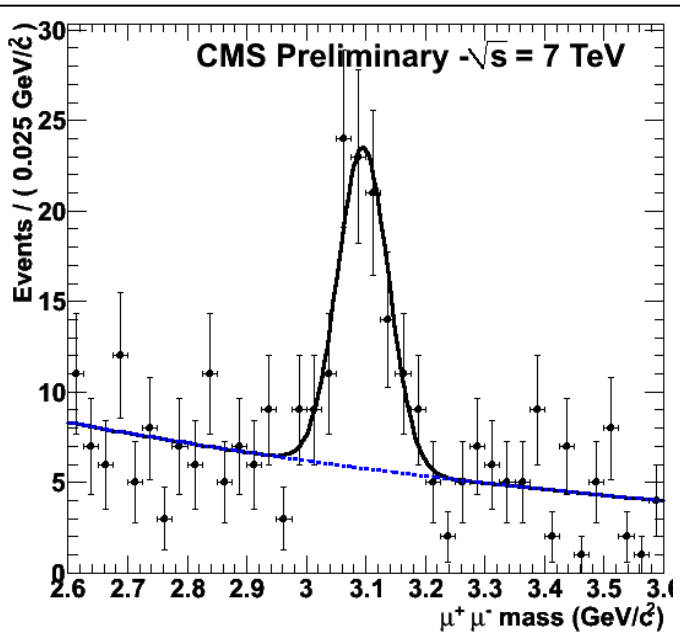
Physics in Less Than a Microsecond

Investigators: D Acosta, I Furic: *University of Florida*

The Large Hadron Collider (LHC) is designed to deliver proton collisions at a rate approaching 1 billion per second, and yet only a tiny fraction can be accepted by the experiments because of the vast volume of data produced by the detectors. Typically no more than 300 collisions per second can be recorded. The Level-1 trigger system is the electronic filter responsible for identifying particles from the collisions in real-time, and selecting only those collisions with features consistent with the most interesting high energy physics processes for which the LHC was designed. The University of Florida designed and built a dozen custom electronic processing cards whose purpose is to reconstruct the trajectories of muons (a particle akin to the electron, and a signature of Higgs boson decays and also possibly also Supersymmetry) in less than ½ microsecond. These "Track-Finder" cards were instrumental in the commissioning of the Compact Muon Solenoid (CMS) experiment with cosmic ray muons over the period 2006-2009. The flexibility of the programmable logic used in the design of the cards allowed us to adapt to the conditions of the start-up of the LHC in 2009. We can efficiently identify nearly every muon that reaches the forward muon system. This allows CMS to collect, for example, sizable samples of J/Psi particles (a bound state of charm quarks) that decay to muons with only minimal luminosity delivered by the LHC. This further enriches the LHC heavy quark physics program.

References: CMS Collaboration, *Journal of Instrumentation* **5** T03002 (2010),



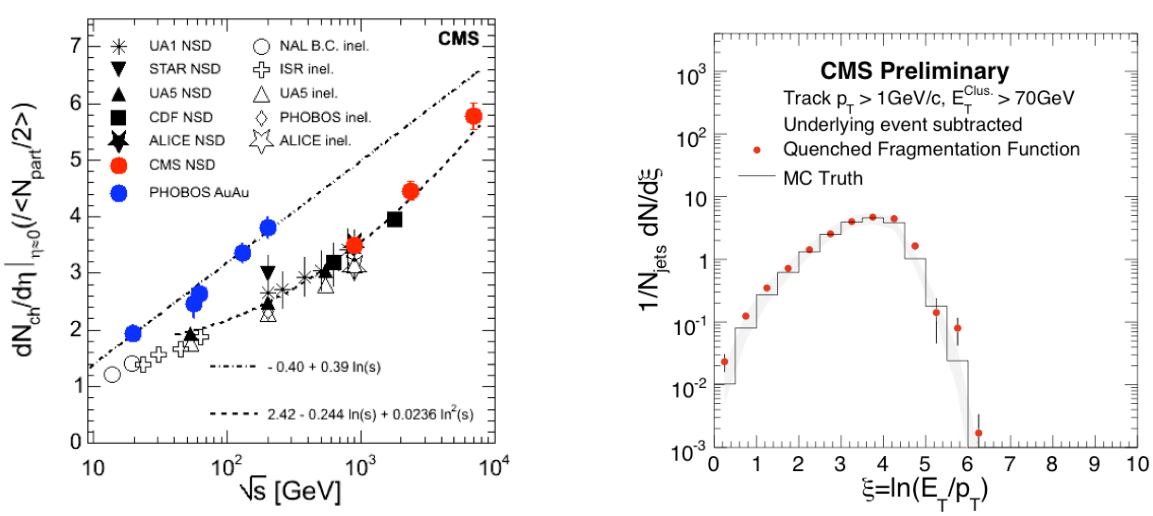
The dimuon mass peak of the J/Psi particle with 1 nb^{-1} of luminosity delivered by the LHC and analyzed by the CMS experiment. The data were mostly collected online using the Track-Finder trigger.

Quark-Gluon Plasma Studies with CMS at the LHC

B. Alver, W. Busza, I. Cali, Y-J. Lee, W. Li, Y. Kim, F. Ma, C. Roland, G. Roland, G.S.F. Stephans, S. Vaurynovich, E. Wenger, B. Wyslouch, Y. Yilmaz, and A. Yoon, *Massachusetts Institute of Technology*

Experiments at RHIC have shown that heavy-ion collisions at the highest energies produce a new state of matter with remarkable properties, the strongly coupled Quark-Gluon Plasma (sQGP). In the sQGP, we observe strong modifications of long range correlations and high p_T particle production due to hydrodynamic flow and jet quenching. With its large acceptance, full coverage calorimetry, high precision tracking and sophisticated trigger, the Compact Muon Solenoid (CMS) experiment is ideally suited to extend these studies to Pb+Pb collisions in the TeV range at the LHC. The MIT group plays a leading role in preparing the CMS heavy-ion program, with first data expected in fall 2010. The first proof for CMS' suitability for heavy-ion studies comes from a series of reference measurements which have been performed by members of our group. These include the first CMS physics paper [1] for p+p collisions at 0.9 and 2.36TeV, the first CMS paper at 7TeV [2] and a recently approved measurement of two-particle correlations at all three energies. The first two papers examined the energy dependence of particle multiplicities (left plot) and transverse momentum distributions, which is essential information for the interpretation of the first heavy-ion data expected later this year. Eventually, the full capabilities of CMS will allow us to study the sQGP properties in great detail. The flagship example is a study of jet quenching combining particle track, jet and photon reconstruction at large transverse energy to measure the modification of fragmentation functions underlying the jet quenching effect (right plot). Such measurements, made possible by the large coverage and resolution of CMS, will provide qualitatively new insights as we collect high statistics heavy ion data sets at LHC.

References: [1] CMS collaboration, *JHEP* (2010) 1002
[2] CMS collaboration, arXiv:1005.3299, *Phys. Rev. Lett.* in press.



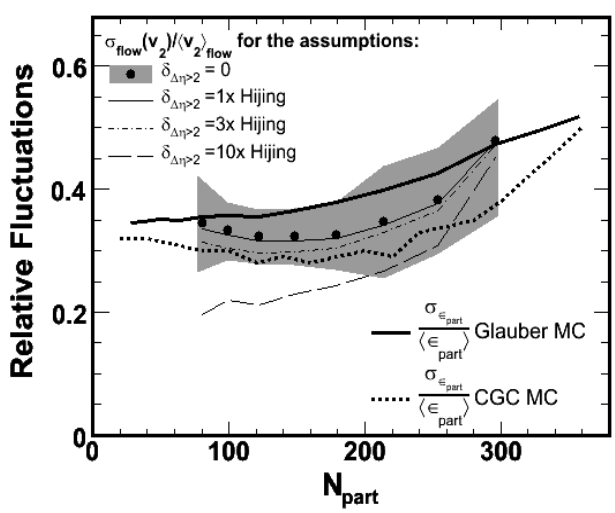
(Left) Energy dependence of dN/dη near midrapidity for inelastic and non-single diffractive p+p collisions. (Right) Effective parton fragmentation function measurement in 5.5 TeV Pb+Pb photon-jet events in a 10^6 sec heavy ion run (HydJet Simulations).

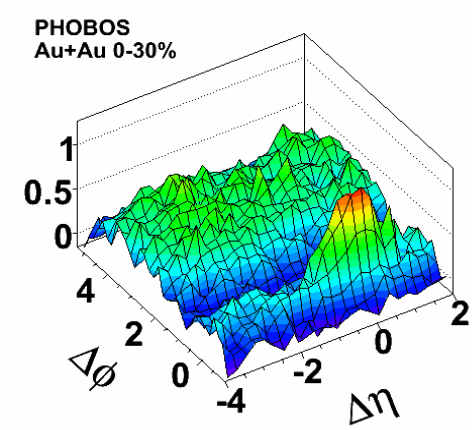
The Quark-Gluon Liquid at RHIC: New results from PHOBOS

B. Alver, W. Busza, I. Cali, Y-J. Lee, W. Li, Y. Kim, F. Ma, C. Roland, G. Roland, G.S.F. Stephans, S. Vaurynovich, E. Wenger, B. Wyslouch, Y. Yilmaz, A. Yoon, *Massachusetts Institute of Technology*

Results from the four RHIC experiments indicate that in heavy-ion collisions at the highest energies a new state of matter is formed, now often referred to as the strongly coupled Quark-Gluon Plasma (sQGP). One of the remarkable properties of the sQGP is its small ratio of shear viscosity to entropy, □/s: in hydrodynamic calculations describing the azimuthal anisotropy of particle production ("elliptic flow"), the allowed range for □/s is close to a lower bound of 1/4□as postulated using methods of string theory. In 2006, the MIT group in the PHOBOS experiment at RHIC embarked on a program to study fluctuations and correlations in particle production over a wide range of rapidity, looking for more detailed insights into the properties of the sQGP. This program has led to three PhD theses, six papers and several remarkable observations. Among the most important are the first measurement of event-by-event fluctuations in azimuthal particle anisotropy [1], shown on the left plot below, and the discovery of very long-range correlations relative to high-momentum particles [2], shown in the right plot. While the first observation is in excellent agreement with the expectations for the hydrodynamic evolution of the sQGP, the long-range nature of the second observation defied many explanation attempts. In a very recent paper [3], however, we showed that the existence of initial state fluctuations, in combination with hydrodynamic flow, naturally explains this observation. This so-called "triangular flow" also explains several other previous measurements and may provide a novel and more sensitive handle in the quantitative determination of the sQGP shear viscosity. These new analysis methods are now being readied for use in heavy-ion studies with the CMS experiment at the LHC.

References: [1] PHOBOS collaboration, *Phys. Rev. Lett.* **104** (2010) 142301
[2] PHOBOS collaboration, *Phys. Rev. Lett.* **104** (2010) 062301
[3] B. Alver, G. Roland, *Phys. Rev.* **C 81** (2010) 054905





(Left) PHOBOS measurement of fluctuations in elliptic flow in Au+Au collisions at 200 GeV, as function of collision centrality. (Right) Two-particle correlation function in 200 GeV Au+Au collisions relative to p_T > 2.5 GeV/c trigger particle after subtraction of elliptic flow.

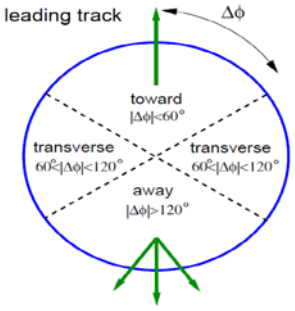
Underlying event measurements in ATLAS

Investigators: S. Chekanov, J. Proudfoot, R. Yoshida, and J. Zhang, *Argonne National Laboratory*

The first measurements of the underlying event with the ATLAS detector using the data delivered by the LHC during 2009 and 2010 at the center of mass energies of 900GeV and 7 TeV have been performed. The Argonne group contributed to the primary analysis as well as performed an independent analysis of these data confirming the results obtained. The studies are done in the transverse region (Figure 1) which is considered to be the most affected by the soft QCD processes responsible for the underlying event. Figure 2 shows the density distributions in the transverse region as a function of the transverse momentum of the leading charged particle for 900 GeV and 7 TeV data. The density distributions indicate an approximately constant "plateau", consistent with the observation of the underlying event which is expected to be independent of the hard scatter. For the 7 TeV data, the average number of charged particles in the transverse region doubles relative to 900 GeV. All Monte Carlo tunes considered show a particle density which is 10–15% lower than the data in the plateau region of the transverse region. This data are used to test and improve Monte Carlo models, in preparation for studies of new physics at the LHC. The underlying event observables are particularly important for constraining the energy evolution of multiple partonic interaction models.

Reference: ATLAS-CONF-2010-029

For more information: ATLAS communication notes: ATL-COM-PHYS-2010-164, ATL-COM-PHYS-2010-237, ATL-COM-PHYS-2010-165, ATL-COM-PHYS-2010-210, ATL-COM-PHYS-2010-293



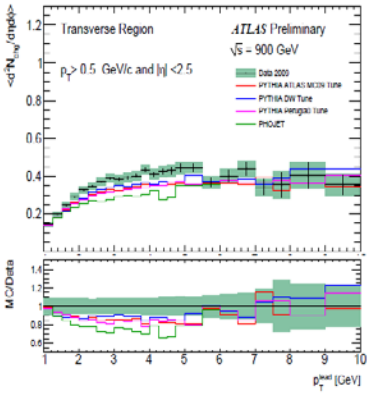


Fig. 1

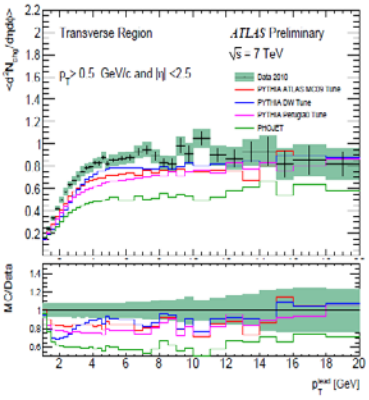


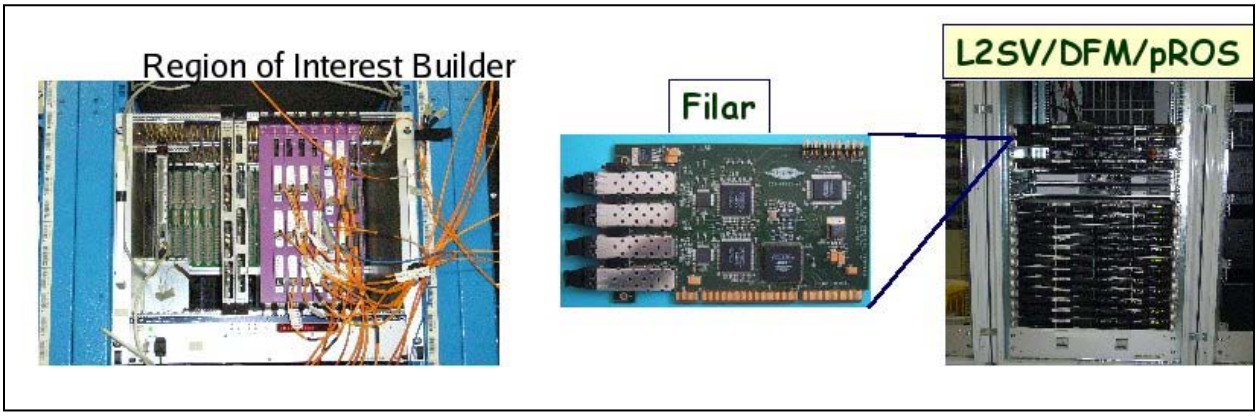
Fig. 2

Triggering the ATLAS Detector – The Region of Interest Builder

Investigators: R. Blair, J. Zhang, and G. Drake, *Argonne National Laboratory*

The ATLAS detector is designed to study proton proton collisions at the center of mass energy of 14 TeV with the bunch crossing rate of 40 MHz. In order to reduce this rate down to the level at which only interesting events will be fully reconstructed, a three-level trigger system has been designed. Argonne is responsible for the Region of Interest Builder (RoIB) and the Level 2 Supervisors. These custom electronics boards take as input Region of Interest (RoI) records from custom trigger electronics which indicate regions in the detector corresponding to particular physics signatures (jets, electrons, muons and taus) and transmit them to the level 2 trigger for further processing. In this processing chain the level 1 (LVL1) trigger is reduced from 75 kHz to ~3.5 kHz. The RoIB has been fully deployed more than three years ago and in this period has continuously supported detector commissioning and operation. It was ready at the first day of the LHC beam and has been running smoothly since then under all circumstances. Its excellent performance is being proved in different run conditions, either with high LVL1 rate requiring fast assembling speed, or with large fragment size requiring flexible latency. Its good scalability and reliability also provide the feasibility for TDAQ system evolutionary improvements in the near future.

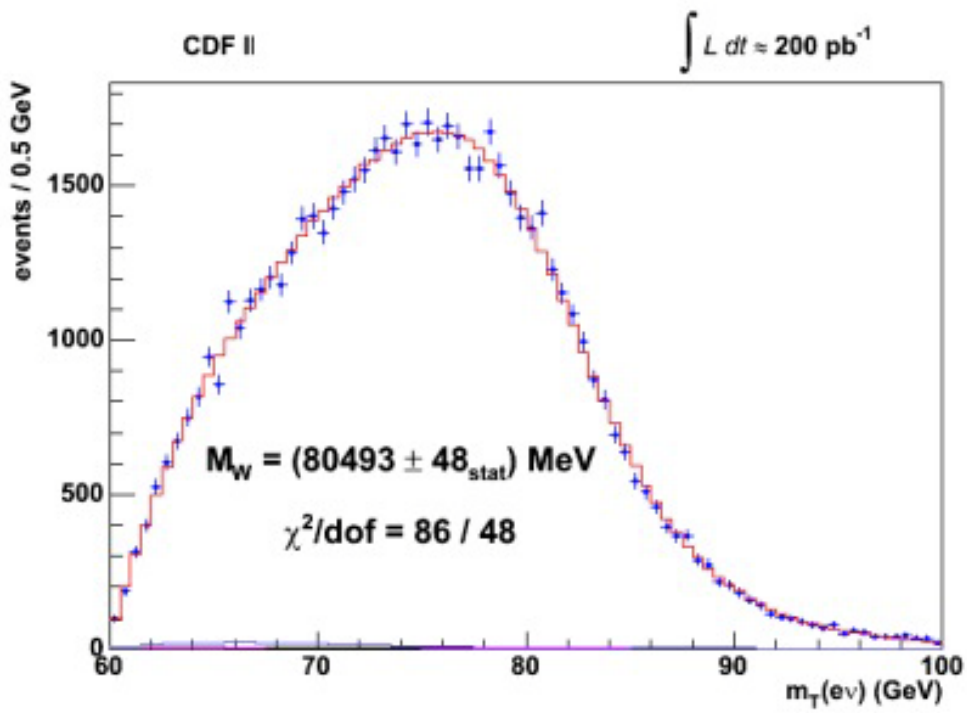
Reference: R. Blair et al, JINST 3 : P04001, 2008, 13pp



Precision Measurement at the Tevatron Squeezes Electroweak Symmetry Breaking

Investigators: C. Hays, A. Kotwal, *Duke University,* O. Stelzer-Chilton, W. Trischuk, I. Vollrath, *Toronto University,* and L. Nodulman, *Argonne National Laboratory*

By 2007, 0.2 fb^{-1} of Tevatron CDF data was used to make a precise (80413 ±48 MeV/c^2) measurement of the W boson mass. Measuring the W boson mass, along with the mass of the top quark, sets important constraints on Electroweak symmetry breaking; if there is a Higgs particle, its mass is more constrained by these mass measurements than by the rest of the combined LEP/SLC precision measurement program. This W mass result is more precise than any LEP experiment, and it has only recently been surpassed in precision by a D0 measurement using 1 fb^{-1}. A CDF W boson mass using 2.3 fb^{-1} is in progress.



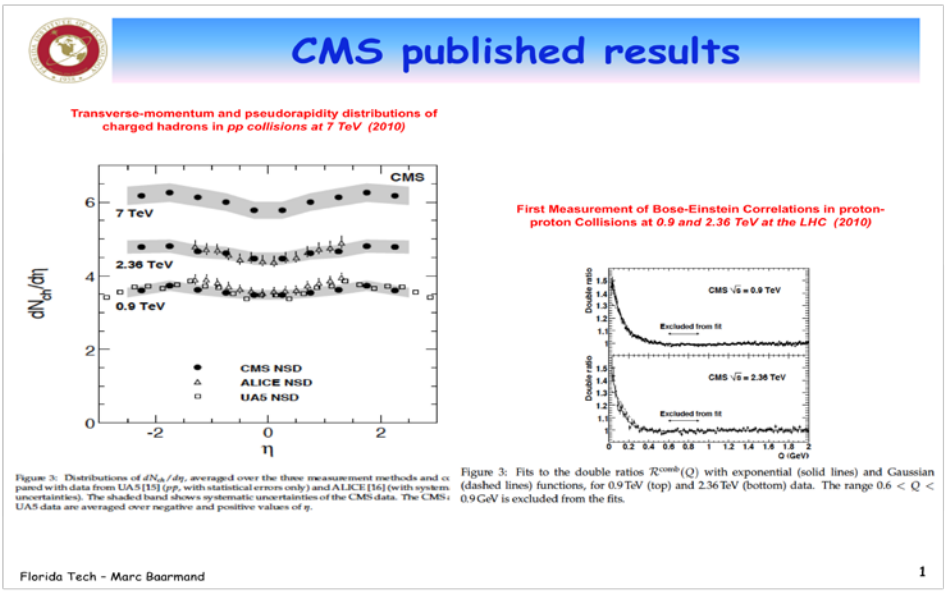
Investigation of proton collisions at LHC with the CMS detector

Investigators: M. Baarmand, M. Hohlmann, and I. Vodopiyanov, *Florida Institute of Technology*

We have been involved with the design and construction of the Compact Muon Solenoid (CMS) detector at the LHC accelerator at CERN for over a decade CMS will investigate physics of elementary particles in proton-proton collisions at the highest ever energy. The origin of mass and the Higgs boson, search for supersymmetric particles, dark matter and extra dimensions are a few examples of LHC physics goals. Our hardware contributions to CMS were in calorimetry and muon detectors, where an optical calibration system for forward hadron calorimeters and an alignment system for forward muon chambers were made. In anticipation of collisions in 2010, we have focused on analysis of early data and tested with simulated data several analyses to measure properties of bottom and top quarks and high mass vector bosons. One analysis measures the angular correlation between two b quarks in their strong production – a test of perturbative QCD. Another analysis measures spin correlation in pair production of top quarks – a test of the Standard Model top quark production and decay. And a third analysis improves the vector boson mass measurement by including the muon system alignment corrections. In all analyses, techniques are developed to use real collision data for estimation of efficiencies and backgrounds.

References: CMS Collaboration, European Physics Journal C53 (2008) 139. CMS Collaboration, JINST **5** T03012 (2010), CMS Collaboration, Journal of High Energy Phys 02 (2010) 041.

For more information: *http://research.fit.edu/hep/*



Into the unknown: From the Tevatron to the LHC

Investigators: H. Band, V. Barger, D. Carlsmith, D. Chung, S. Dasu, L. Everett, T. Han, A. Hashimoto, M. Herndon, R. Loveless, B. Mellado, Y. Pan, F. Petriello, L. Pondrom, G. Shiu, W. H. Smith, S. L. Wu*, University of Wisconsin – Madison.*

Experimenters at the University of Wisconsin – Madison are sifting through the highest energy data from the CDF experiment at the Fermilab Tevatron and the ATLAS and CMS experiments at the newly commissioned CERN LHC to search for the Higgs mechanism of particle mass generation, supersymmetry that links mass particles with force particles, the dark matter making up most of the universe and extra dimensions. Having constructed major parts of these experiments such as the CDF and CMS muon detectors, UW researchers are continuously working on them to assure optimal performance. They constantly tune the LHC filtering systems they developed to select the few hundred interesting collisions out of the billion per second. They analyze the Tevatron and LHC data on UW high-throughput computing facilities. After extracting results, they huddle with the University of Wisconsin theorists peering through the maze of possible new physics to understand the implications of a Higgs discovery for the history and composition of the universe. UW theorists are studying what the new data tells about the landscape of the parallel universe of supersymmetric particles, hints of extra dimensions that will point to a new theory of quantum gravity via string theory, signs of new force-carrying particles such as the Z', insights about dark matter and dark energy and the puzzle of the excess of matter over antimatter in the universe.

References: (1) http://www.news.wisc.edu/on-wisconsin/heart-of-the-matter/

(2) "Particle Accelerator may reveal shape of alternate dimensions", University of Wisconsin News, January 2008: http://www.news.wisc.edu/14678

For more information: http://www.hep.wisc.edu/

.

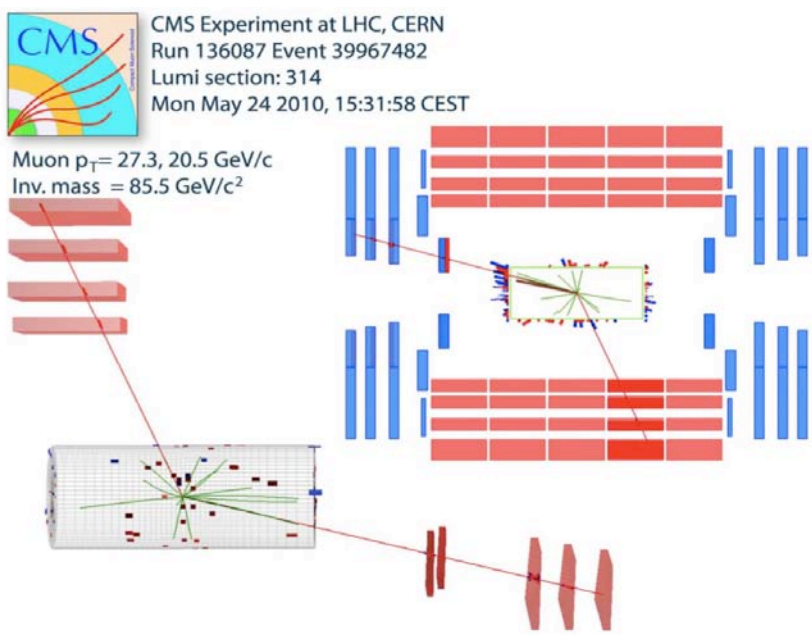


Figure: LHC collision at 7 TeV producing a pair of muons observed in CMS

Weak Bosons and Freshman Physics

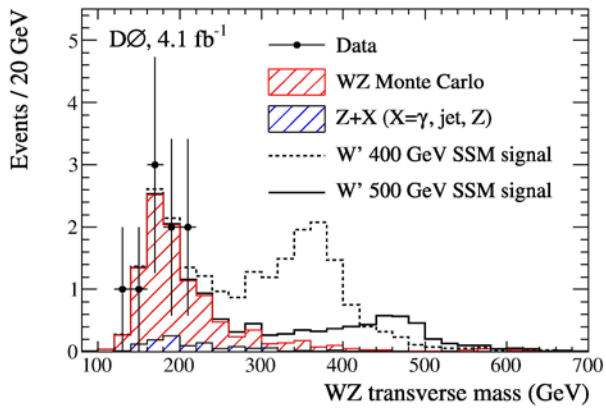
Investigators: A. Barfuss, T. Bolton, I. Chakaberia, A. Ivanov, K. Kaadze, S. Khan, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze, and Z. Wan; *Kansas State University*

Every engineering and physical science major suffers through Newton's second law "F=ma". In the weak nuclear force, the force-carrying W and Z bosons contribute in subtle ways to both the force and inertia sides of this relation. Sorting out the intricacies of W-Z self-interactions constitutes one of the main goals of the Fermilab Tevatron and the CERN Large Hadron Collider programs. K-State physicists working with collaborators on the D0 experiment at the Tevatron have produced two of the most stringent tests to date of the theory of interacting W and Z bosons. The highest statistics sample of collisions producing both a W and a Z confirm for now the predictions of the standard model. Boson pairs are produced at the expected rate and with the expected spectrum of W+Z invariant mass. With only 34 W+Z pairs in the final sample, however, much remains to be learned. This work formed the basis of graduate student Keti Kaadze's PhD thesis under the supervision of KSU's Yurii Maravin, helping Keti to earn a prestigious CERN Fellowship. The W+Z results marked the end of a string of measurements of weak and electromagnetic boson pair production performed at the Tevatron by members of the KSU group and D0 colleagues. These measurements will continue on the Large Hadron Collider with our collaborators on the CMS experiment.

References:

1. Non-technical:http://www.fnal.gov/pub/today/archive_2009/today09-12-17.html, http://www.fnal.gov/pub/today/archive_2010/today10-06-10.html.
2. Technical: D0 Collaboration (V. Abazov *et al.*), Phys. Rev. Lett. **104**, 061801 (2010); D0 Collaboration (V. Abazov *et al.*). FERMILAB-PUB-10-184-E, Jun 2010. 8pp.

For more information: http://www.phys.ksu.edu/hep.



The invariant transverse mass of W-Z boson pairs measured at the Fermilab Tevatron D0 experiment. Points with error bars represent the data. The shaded area denotes the predictions of the standard model, while the dotted and solid curves show predictions of alternative theories.

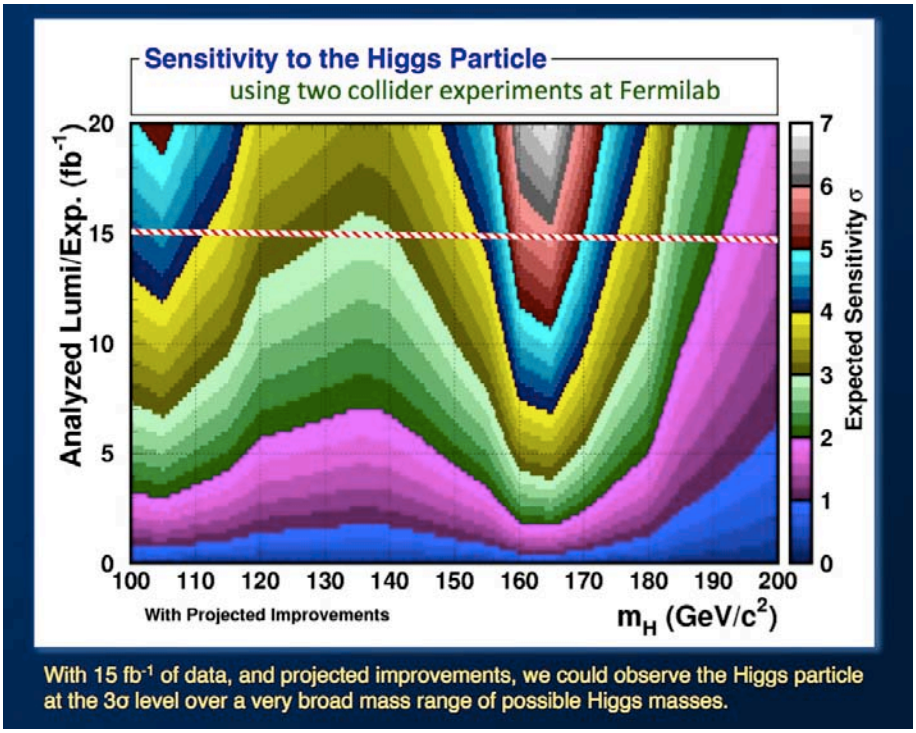
Higgs Hunting at the Tevatron

Investigators: K.R. Bland, J.R. Dittmann, M.J. Frank, A. Kasmi, and Z. Wu, *Baylor University*

Baylor University researchers know exactly *where* to hunt for the elusive Higgs particle – at the center of massive particle detectors like the Collider Detector at Fermilab. The big question is *how*. The Higgs Boson is tied to the mechanism in which all particles acquire mass, yet, ironically, no one knows the exact mass of the Higgs Boson itself. Without this information, it's difficult to pin down the best strategy for discovering it. Researchers at Baylor are therefore playing a leading role in searching for the Higgs Boson using two different strategies: first, through its production in association with a *W* boson, and second, via its decay to two photons. If the Higgs exists, the best chance of discovering it comes from combining as many strategies as possible and collecting as much data as we can. By collecting 15 fb^{-1} of data at Fermilab over the next few years, physicists have a great chance of seeing evidence for the Higgs over a broad range of masses from 100 GeV/c^2 to 182 GeV/c^2.

References: T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. 103, 101802 (2009).

For more information: http://www.baylor.edu/physics



With 15 fb^{-1} of data, and projected improvements, we could observe the Higgs particle at the 3σ level over a very broad mass range of possible Higgs masses.

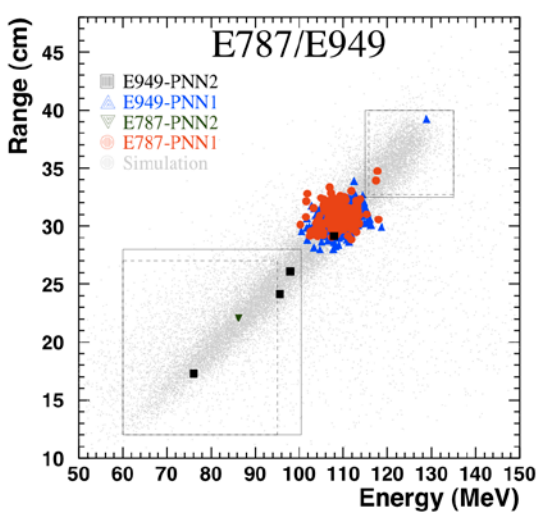
BNL Experiment E949/E787 Measures Extremely Rare Decay Process

Investigators: I-H. Chiang, M.V.Diwan, J.S.Frank, D.E.Jaffe, S.H.Kettell, L.S.Littenberg, G.Redlinger, B.Viren, Zhe Wang, *Brookhaven National Laboratory*

Physicists recently discovered additional evidence for an extremely rare subatomic decay that is very sensitive to new forces not predicted in the Standard Model (SM) of particle physics. The new evidence increases the total number of events to seven that have been observed by BNL experiment E949/E787 since the first evidence in 1997. The disintegration of the K^+ meson into a □ meson and an unobservable neutrino-antineutrino pair ($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) is reliably predicted by the SM to occur once in 12 billion K^+ decays. A highly sensitive, state-of-the-art detector, combined with innovative and sophisticated data analysis techniques, was required to reveal the rare decay. The final result of E949/E787 indicates that $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ occurs once in every 5.8 billion K^+ decays as described in a series of publications in *Physical Review Letters* and *Physical Review* ***D***. Although the E949/E787 results are statistically consistent with the SM prediction, if the current decay rate were confirmed with improved precision by future experiments, it would signal existence of new fundamental physics effects. The success of E949/E787 has inspired a new experiment at CERN that is designed to achieve ten times more sensitivity as well as a proposed experiment at FNAL with even greater sensitivity.

References: S. Adler *et al*., Phys. Rev. Lett. ***101*** 191802 (2008); S. Adler *et al.*, Phys. Rev. ***D77***, 052003 (2008)

For more information: http://www.phy.bnl.gov/e949/



The π^+ kinetic energy vs range of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events that pass all selection criteria. The points represent the data from different E949/E787 data-taking periods. The solid and dashed boxes show the signal region of E949 and E787 analyses, respectively. The collection of points near 108 MeV is due to π^+ from the copious K^+ decay to a charged and neutral pion.

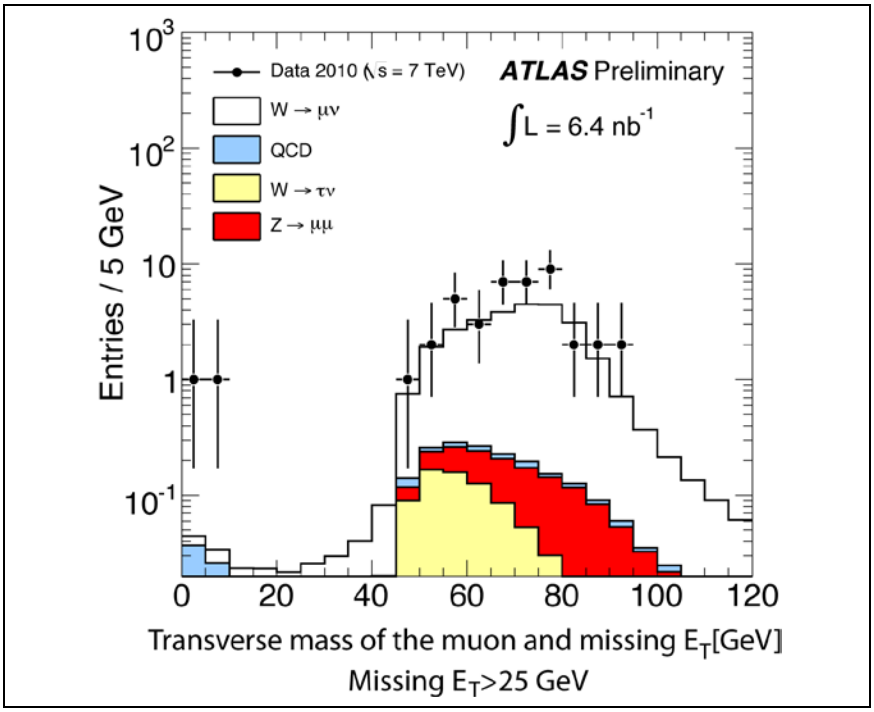
The Giant ATLAS Detector Starts Taking Data

Investigators: D. Adams, K. Assamagan, M. Baker, M. Begel, J. Caballero, H. Chen, P. De Castro Faria Salgado, W. Deng, M. Ernst, T. Gadfort, B. Gibbard, H. Gordon, A. Klimentov, F. Lanni, D. Lissauer, D. Lynn, H. Ma, T. Maeno, S. Majewski, S. Misawa, P. Nevski, K. Nikolopoulos, D. Oliveira Damazio, F. Paige, S. Panitkin, M.-A. Pleier, V. Polychronakos, M. Potekhin, S. Protopopescu, V. Radeka, S. Rajagopalan, G. Redlinger, S. Rescia, Y. Smirnov, S. Snyder, P. Steinberg, H. Takai, F. Tarrade, V. Tcherniatine, A. Undrus, T. Wenaus, S. White and S. Ye: *Brookhaven National Laboratory (BNL)*

On March 30, 2010, the ATLAS Detector at the Large Hadron Collider at CERN started recording proton-proton collisions for an initial physics run at 7 TeV. ATLAS is designed to answer many fundamental questions in particle physics such as “What gives particles their mass?”, “What is the source of dark matter?”, “Is there a whole new family of ‘Supersymmetric’ particles?” and “Does space have more than our familiar three dimensions?” A leading candidate for the source of mass is the conjectured Higgs Boson. BNL is the host for the 44 U.S institutions working on ATLAS, which is about 20% of the ATLAS Collaboration which has about 3000 scientists from 37 countries. The largest Tier 1 computing center in ATLAS is located at BNL and this facilitates physics analysis in the U.S. BNL strongly contributes to the liquid argon calorimeter, the muon spectrometer, the trigger system and the software development. The first physics result has been published and this summer more than 40 physics topics are being presented at international conferences. The figure below shows the preliminary signal for W bosons decaying into muons an analysis to which BNL contributed.

Reference: ATLAS Collaboration, *et al*., Phys. Lett**. B688**, 21 (2010).

For more information: http://www.nytimes.com/info/large-hadron-collider/?scp=1-spot&sq=Large%20Hadron%20Collider&st=cse
https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults



Measuring the W Boson Mass: Is the Standard Model Correct?

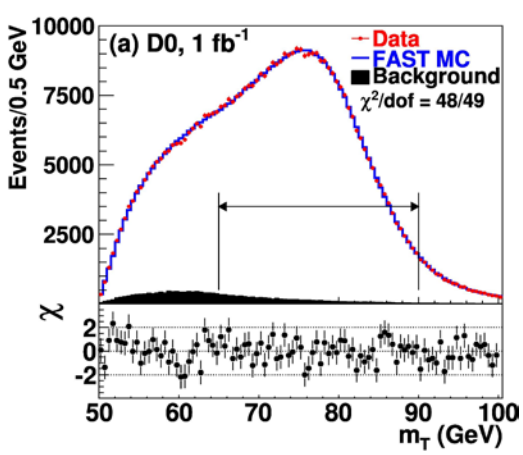
Investigators: D Boline, F Guo, J Hobbs, R Lopes de Sa, and M Rijssenbeek, *SUNY Stony Brook,* and D0 Collaborators

This work reports the first Run II measurement of the W boson mass from the D0 collaboration. The measurement uses a data set with an integrated luminosity of 1 fb^{-1}. The result, M_W = 80.401 +- 0.043 GeV is the most precise single measurement. This measurement tightens the constraint on the mass of the Higgs boson as derived from internal consistency of the Standard Model when compared with a variety of measurements from ALEPH, DELPHI, L3, OPAL, SLD, CDF, D0 and other experiments. The W boson mass precision is now the limiting factor in this constraint. With significantly more data now being analyzed, the uncertainties on the D0 measurement are expected to improve by a factor of two in the coming year.

Reference: V. M. Abazov et al., Phys. Rev. Lett. **103**, 141801 (2009)

For more information: http://www-d0.fnal.gov/Run2Physics/WWW/results/final/EW/E09E/

The transverse mass distribution of reconstructed W boson candidate events from the D0 experiment for data and simulated events.



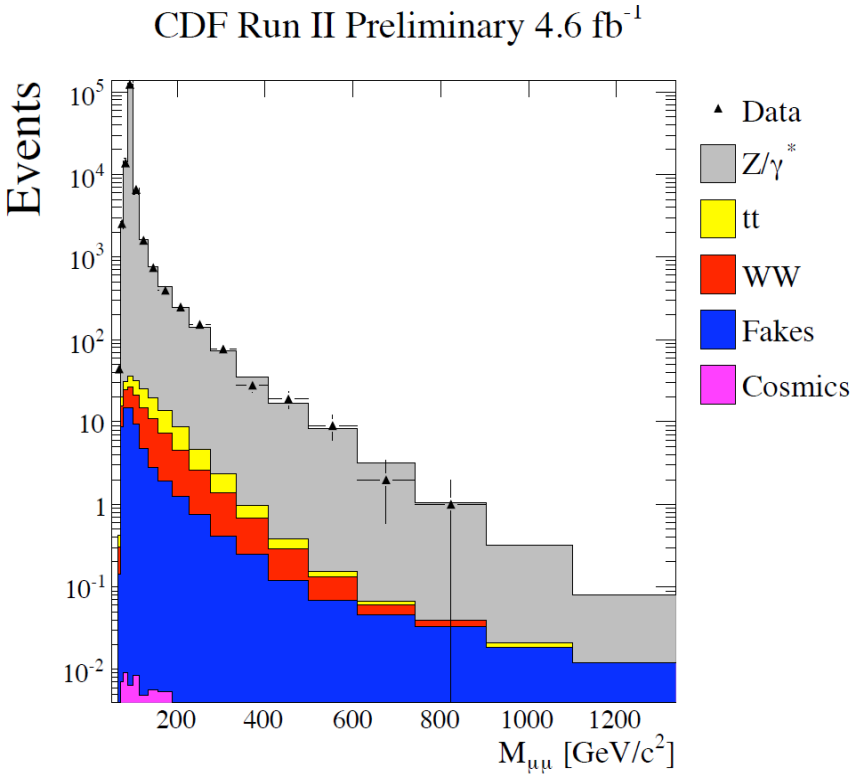
The fit region used to determine the W boson mass is indicated by the arrow.

On the Hunt for New Particles

Investigators: M. Bondioli, J. Deng, Ivo Gough Eschrich, S. Farrell, A. Lankford, H. Okawa, R. Porter, A. Taffard, J. Tatar, B. Toggerson, M. Werth, D. Whiteson, N. Zhou, *University of California--Irvine*

Collisions of high-energy, high-intensity beams give researchers the chance to observe very massive, very rare particles. If discovered, these particles would provide critical clues as to the organization of the fundamental particles and forces, and open a window to a time just after the Big Bang when there was enough energy density for these massive particles to exist. Researchers at the University of California, Irvine are hunting for new particles at the current energy frontier, using the ATLAS detector at CERN's Large Hadron Collider, as well as the in the large dataset collected by the CDF detector at FermiLab's Tevatron collider. Recent work, using data from the Tevatron, has not uncovered evidence of new particles, but has set stringent new limits on possible masses of new particles. The figure below shows the result of a search for a new heavy boson, Z', decaying to a pair of muons, which would have appeared as a bump on this spectrum.

For more information: http://www.fnal.gov/pub/today/archive_2010/today10-06-17.html.



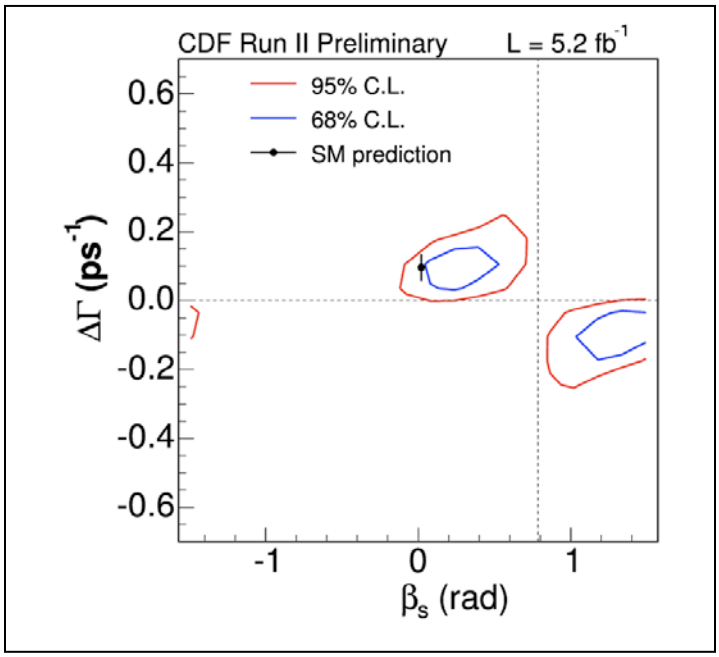
Searching for CP Violation in B^0_s mesons

Investigators: J. Boudreau, K. Gibson, and C. Liu, *University of Pittsburgh*

Physical laws governing the properties of elementary particles show a nearly perfect symmetry between matter and its mirror-image, antimatter. The symmetry is so good that it wasn't until 1964 that researchers discovered a small difference between matter and antimatter, and only in one species of particle known as neutral kaons. In the 21st century, bottom mesons were also found to behave differently from their antiparticles. The source of these small differences (called CP violation) is the Higgs mechanism interacting with the three generations of quark. Researchers at the University of Pittsburgh have extended the search for CP violation to the even more exotic strange bottom mesons, called B^0_s. There is good reason to think that more CP violation is lurking in the interactions of those particles, because our universe, cooling down from the Big Bang, leaned more heavily towards matter and away from antimatter than standard physics explains. The parameter quantifying CP violation in strange bottom mesons is called β_s. The world's most sensitive measurement to β_s comes from a University of Pittsburgh analysis of B^0_s decays at the CDF experiment at the Tevatron. The measured value falls slightly to the right of the prediction from standard physics. As the measurement grows in precision, we may be in for some surprises, including possibly an answer to the question: Why are we here?

References: Phys.Rev.Lett.100:161802,2008; Phys.Rev.Lett.100:121803,2008

For more information: www-cdf.fnal.gov



The Revolution in Computing for Physics Research

Investigators: A. Brandt, K. De, A. Farbin, P. McGuigan, M. Sosebee, A. White, and J. Yu, *University of Texas--Arlington*

The High Energy Experimental group at the University of Texas at Arlington (UTA) has a long history of research using particle colliders at the energy frontier, for example, the D0 experiment at the Tevatron, and the ATLAS experiment at the LHC, to explore the deepest mysteries of nature, such as the origin of mass, energy, and space-time. Of special note are contributions by UTA in hadronic calorimetry, diffractive physics, and computing. With the start of the LHC collisions at 7 TeV in April, 2010, we highlight here the role UTA is playing in distributed computing. One of the largest computing centers used for ATLAS data analysis, the Southwest Tier 2 center (SWT2) is jointly located at UTA and the University of Oklahoma. The SWT2 is part of a grid/cloud of about one hundred computer centers around that world that can work together to analyze data from ATLAS. Thousands of physicists worldwide are connected to and benefit from the computing resources available at UTA. Over one petabyte (1000 terabyte) of storage and 1500 CPU's are available and constantly in use at UTA, to make cutting edge discoveries at the highest energies available. In addition SWT2 serves as a regional computing hub for several other universities in the region, providing both technical support and hosting periodic workshops.

Reference: www-hep.uta.edu

First phase of the ATLAS Tier 2 center at the University of Texas at Arlington

Towards producing Dark Matter in the Laboratory

Investigators: J. Branson, V.Sharma, A.Yagil, and F.Würthwein, *University of California—San Diego*

Astrophysical measurements indicate that close to 30% of the matter/energy in the Universe is due to a new class of particles that interact with ordinary matter primarily via gravity. Beyond being "dark", its fundamental properties are unknown. One of the core goals of the LHC is to try and produce this dark matter in the laboratory so that it can be studied, and its properties understood. The signature of dark matter at the LHC is momentum imbalance transverse to the beam, also called Missing Transverse Energy (MET for Missing E_T). The dominant LHC production mechanism is via strongly interacting "sister particles" that then decay into dark matter plus jets and leptons. For example, in Supersymmetry this would be implemented as gluino-gluino, squark-gluino, or squark-anti-squark production, with the lightest supersymmetric particle in the decay chain being the dark matter. The UCSD group has developed a novel MET reconstruction algorithm for CMS that uses the excellent tracking detector to improve upon the traditional calorimetric MET measurement. We have played a lead role in the commissioning of MET with early CMS data. This included detailed studies of events at large MET using the Fireworks event display developed at UCSD. To understand the origin of the anomalous ECAL deposits, detailed simulations of particle interactions with the avalanche photo diodes used in the ECAL barrel were developed and studied. We have furthermore demonstrated that the sensitivity of a same sign dilepton plus MET plus jets analysis exceeds the Tevatron sensitivity in the mSUGRA parameter space with as little as 0.1-1/fb of CMS data at 7TeV.

References: CMS-PAS-JME-10-002, CMS DPS-2010/14, CMS Note-2010/008

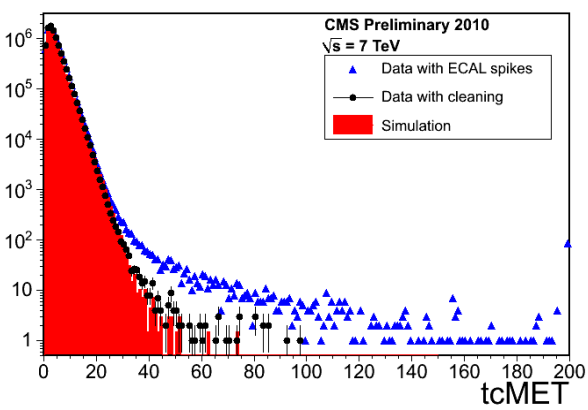


Fig.1: Track-corrected MET before and after anomalous deposits in ECAL are "cleaned up."

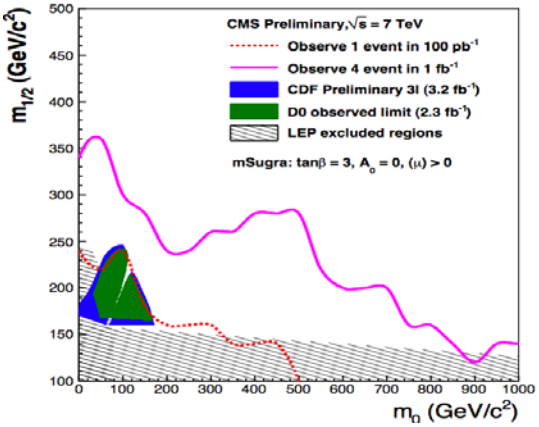


Fig.2: Expected SUSY reach in same sign dilepton final state at 7TeV.

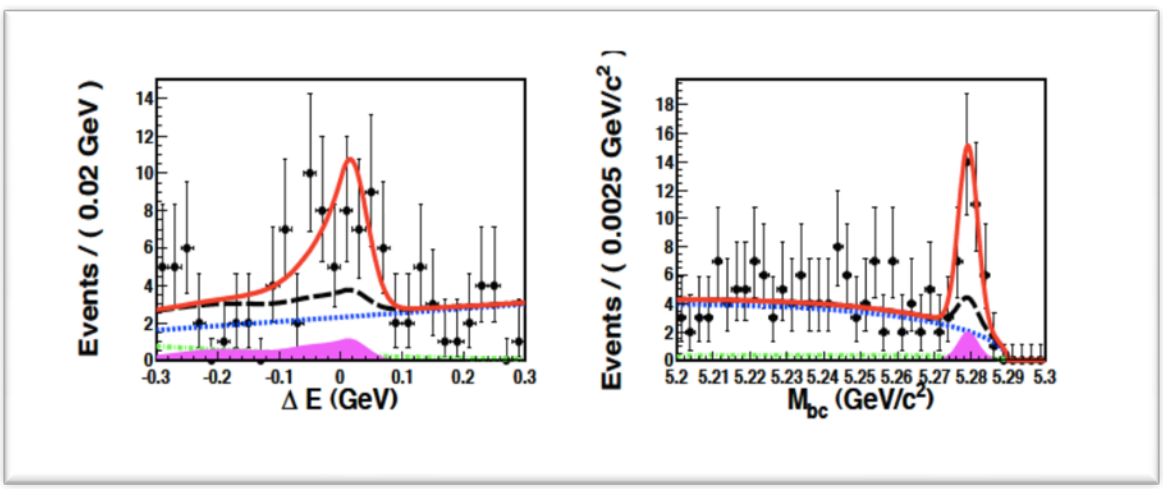
Probing penguins at Belle

Investigators: T. E. Browder and G.S. Varner, *University of Hawaii*

Graduate students, postdocs and faculty members at the University of Hawaii are using the world largest data sample accumulated at the Upsilon(4S) resonance to observe new rare decays of the B meson, a particle containing beauty quarks. A particular class of these rare decays is called "penguins" for historical reasons and because their underlying Feynman diagrams vaguely resemble the Antarctic bird. Hawaii researchers have recently reported the first observation of the radiative penguin $B \rightarrow \varphi K_S \gamma$. This decay is particularly interesting because measurements of its time-dependent CP asymmetry are sensitive to new physics from right-handed currents. Hawaii researchers have also reported the first observation of the inclusive gluonic penguin $B \rightarrow \eta X_S$, where X_S denotes a final state containing a strange quark. Detailed measurements of these decay may help to resolve the enigma of another related penguin, $B \rightarrow \eta' X_S$. The University of Hawaii at Manoa was a founding member of the Belle collaboration located at the KEK laboratory in Tsukuba, Japan. Hawaii faculty members have served as Belle co-spokespersons and analysis coordinators since 1998. Belle's critical measurements of matter-antimatter asymmetry were noted in the 2008 Nobel Prize citation for Kobayashi and Maskawa.

References: H. Sahoo et al., Belle collaboration, arXiv:0911.1779; K. Nishimura et al., Belle collaboration, arXiv: 0910.4751, to be submitted to Physical Review Letters.

For more information email: teb@phys.hawaii.edu



The first signal for the radiative penguin decay $B \rightarrow \varphi K_S \gamma$. This mode may someday be used to unlock the mysteries of right-handed currents from new physics.

Precision Tests of QCD

Investigator: D. N. Brown, *University of Louisville*

Using the large data set of electron-positron collisions collected with the BaBar Detector at the SLAC National Accelerator Laboratory between 2000 and 2008, scientists are performing tests of Quantum Chromodynamics (QCD), the theory of strong nuclear interactions among quarks and the particles made from them. The scientists are using more data than available from previous similar experiments to complete one of the largest particle censuses to date. In addition to testing available theories, the measurements will provide input for scientists working at the energy frontier of the Large Hadron Collider.

For more information: http://www.hep.louisville.edu/

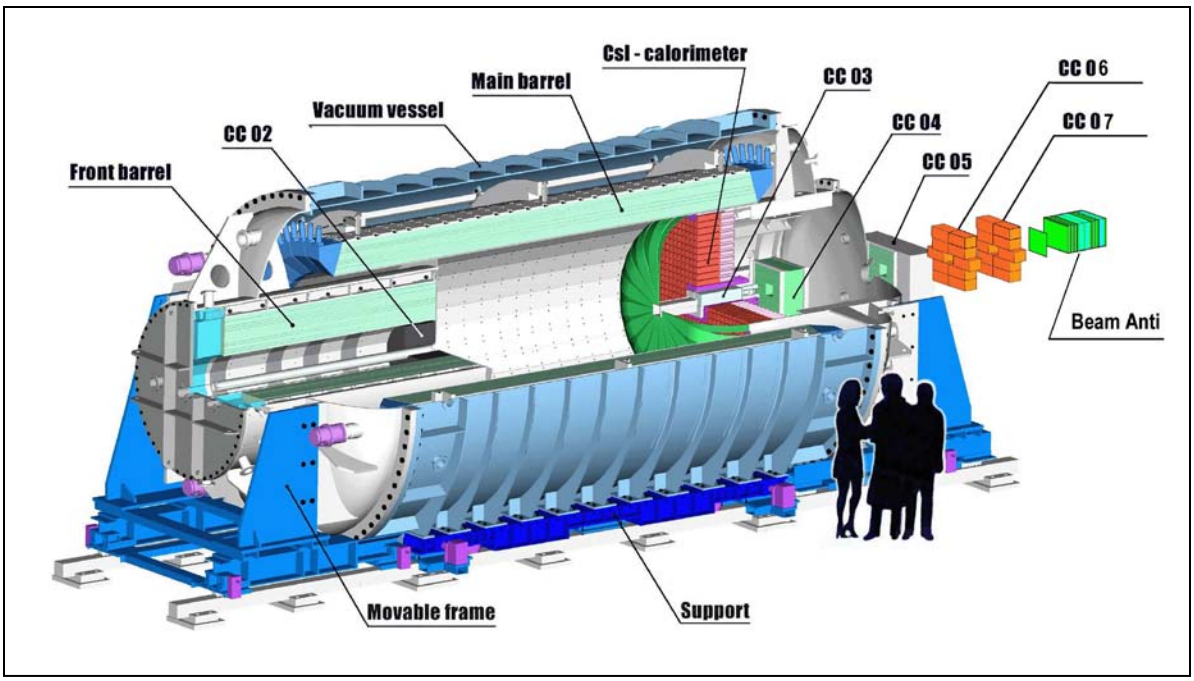
The Intensity Frontier: Rare Kaon Decays

Investigators: Myron Campbell and Monica Tecchio, *University of Michigan;* Joseph Comfort, *Arizona State University;* Yau Wah, *University of Chicago*

The goal of the J-PARC K0TO experiment is to discover and measure the rate of the rare decay $K_L \to \pi^0 \nu \bar{\nu}$. This flavor changing neutral current decay proceeds through second-order weak interactions. Other, as yet undiscovered particles, which can mediate the decay could provide an enhancement to the branching ratio, which in the Standard Model accurately calculated to be about $(2.8 \pm 0.4) \times 10^{-11}$. The experiment is expected to observe 100 events at the Standard Model branching ratio. This decay mode is one of the four 'golden modes' of very rare processes that can be calculated in the standard model and are sensitive to new physical processes which would be obscured in other decays. An observation of a branching fraction which deviates from the standard model could give valuable insight into the realm of physics at much higher energies than is currently accessible, and could shed light on the observed matter – antimatter asymmetry in the universe. The experiment is a follow-up to E391a which operated at the KEK in Japan. The K0TO experiment will operate at the new high intensity accelerator at JPARC, near Tokai Japan. The collaboration has members from the United States, Japan, Taiwan, South Korea and Russia.

References: http://pdg.lbl.gov/2009/reviews/rpp2009-rev-rare-kaon-decays.pdf
http://physicsworld.com/cws/article/news/19255
http://www.lnf.infn.it/wg/vus/content/Krare.html

For more information: http://phys-hep0.physics.lsa.umich.edu/K0TO



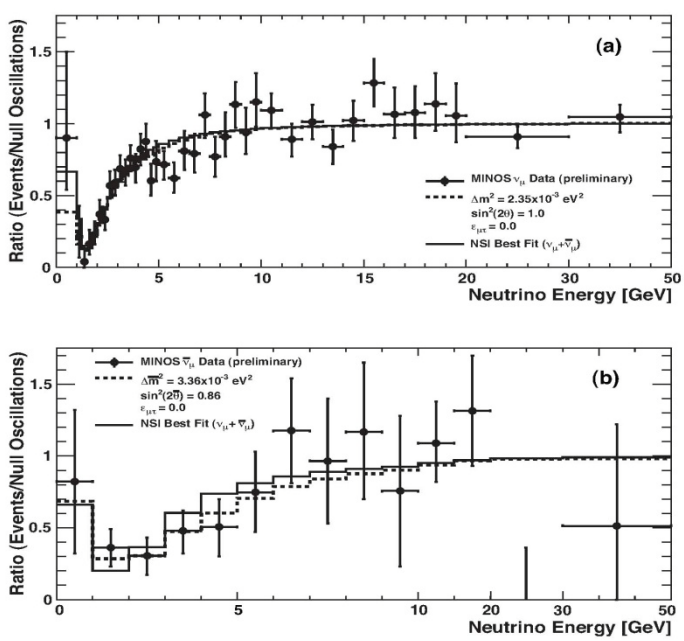
Neutrino and Anti-Neutrino Oscillations at 735 Kilometers

Investigators: D. Cherdack, H. Gallagher, T. Kafka, A. Mann, W. Oliver, and J. Schneps, *Tufts University,* with authors of the MINOS Collaboration

Intense beams of muon-neutrinos created at Fermi National Accelerator Laboratory travel through the earth beneath Illinois and Wisconsin and are detected one-half mile underground at Soudan, Minnesota. During their millisecond transit, the neutrinos oscillate from muon flavor into tau flavor, with the result that a significant depletion of neutrino reactions yielding muons is observed at the Soudan detector as shown in Fig. 1a. The depletion's spectral shape provides fundamental information about the masses and mixing strengths of neutrino states. Newly released measurements show muon anti-neutrino beams also exhibit oscillations with a similar muon-flavor disappearance spectrum observed at 735 km (Fig. 1b) [1]. Intriguingly however, the oscillation pattern measured for anti-neutrinos differs from that for neutrinos. This may be due to statistical limitations or else it may be evidence for a heretofore unknown interaction which distinguishes anti-neutrinos from neutrinos. In a paper just released, Tufts authors point out that neutrinos and anti-neutrinos that travel long distances through normal matter have extraordinary sensitivity for a new type of matter potential, and so the apparent difference between anti-neutrino and neutrino propagation may arise as a cumulative effect of a new class of neutrino interactions [2].

References: [1] P. Vahle, for the MINOS Collaboration, NEUTRINO 2010 plenary talk, June 2010; A. Himmel for the MINOS Collaboration, Joint Experimental-Theoretical Seminar, Fermilab, June 2010.

[2] W.A.Mann, D.Cherdack, W. Musial, T.Kafka, Tufts Univ., paper submitted to PRD and arXiv,



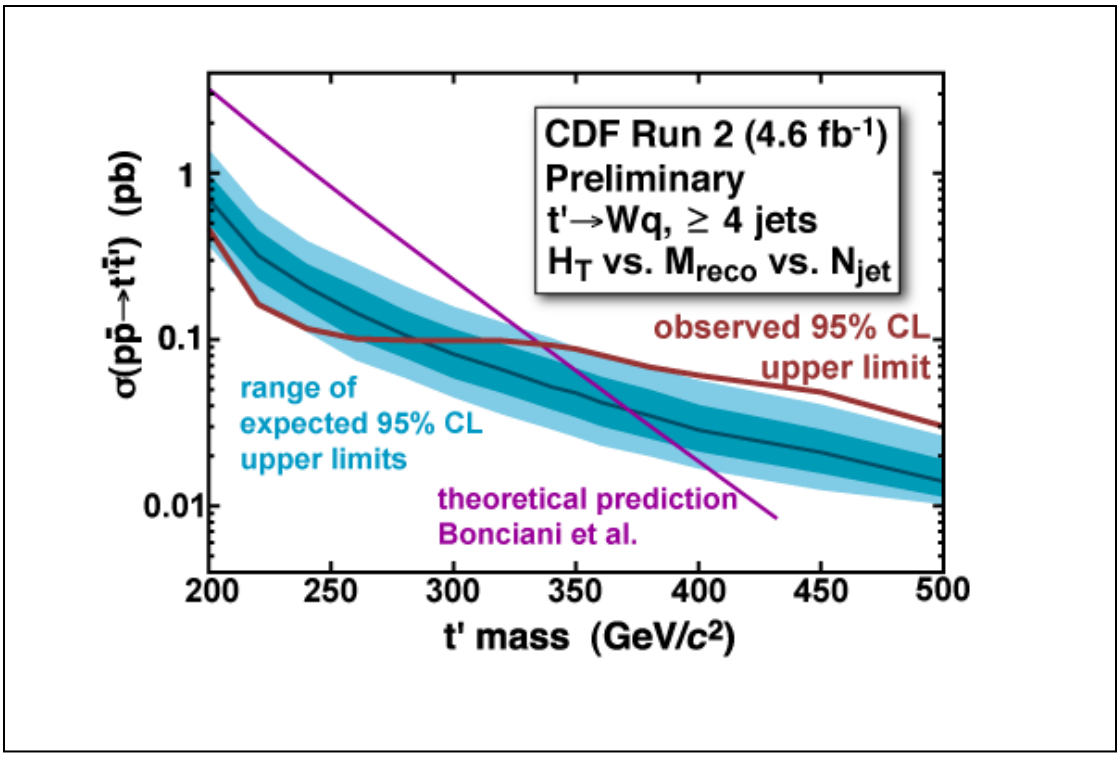
Quarks: the Next Generation

Investigators: J. Conway and R. Erbacher, *University of California--Davis*

Since the discovery of the surprisingly heavy top quark in 1995 at the Tevatron, we have known that there are three generations of quarks and leptons. This immediately begs the question: can there be more generations? A fourth generation of quarks could help explain a number of observations, from the lack of observation of a low-mass Higgs boson to odd behaviors of B mesons. The large data samples collected at the Tevatron in the past decade have allowed a sensitive search to be performed for a new heavy top-like quark, dubbed t', in the Collider Detector at Fermilab (CDF). The search uses exactly the same technique, and indeed the same data sample, as that used to discover and measure the properties of the top quark. Pair production of top quarks is in fact the largest background in the search. With data collected through summer 2009, the lower bound on such a new quark's mass is 337 GeV/c^2. But this bound is less than anticipated, due to a tantalizing excess of events with very high total energy. The analysis of more data from the record amount being recorded at the Tevatron (and soon data from the LHC at CERN) will reveal whether more generations await discovery.

Reference: T. Aaltonen et al., The CDF Collaboration, Phys. Rev. Lett. 100, 161803 (2008).

For more information: http://www-cdf.fnal.gov/physics/new/top/2010/tprop/Tprime_v46_public/public_4.6.html

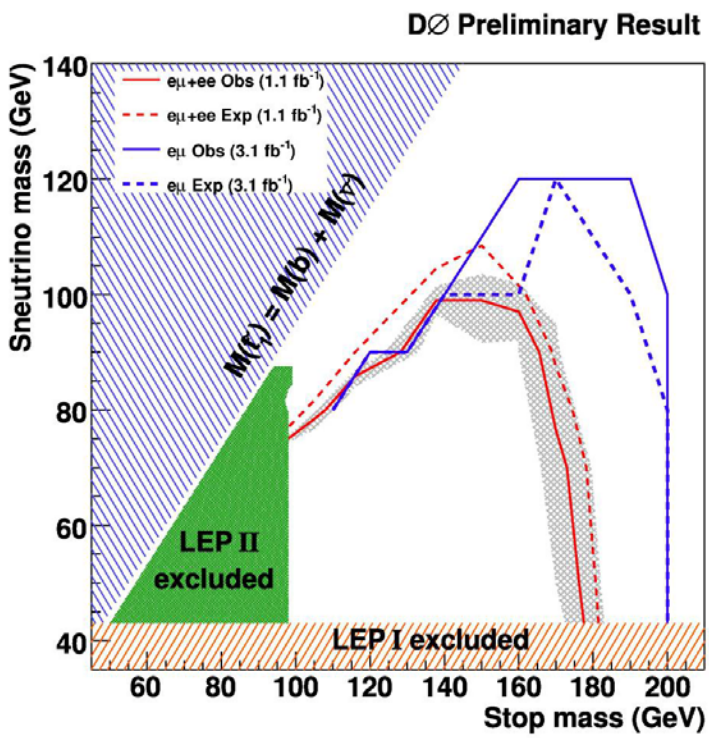


Pushing the limits on the superpartners of the top quark

Investigators: M. Corcoran and D. Mackin, *Rice University*

The standard model of particle physics has been extraordinarily successful in describing phenomena at the subatomic level. However this theory has serious shortcomings, so physicists have been searching for more than 30 years for evidence of physics beyond the standard model. One of the most theoretically complete ideas for physics beyond the standard model is Supersymmetry, which postulates a symmetry between fermions and bosons and predicts a superpartner to all of the currently-known fundamental particles. In the D0 experiment at the Fermilab TeVatron collider, we continue to constrain the masses and properties of the superpartners. We have searched for the supersymmetric partner of the top quark decaying to the final state of two b quarks, an electron, a muon, and two supersymmetric neutrinos which escape the detector unobserved and carry away missing energy. No, we haven't observed the supersymmetric partner of the top quark, but we have significantly improved our knowledge of where the supersymmetric top quark is *not.*

For more information: http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm



Precision Measurements in Electroweak and Hadron Physics

Investigators: L. Cremaldi, V. Eschenburg, R. Kroeger, A. Melnitchouk, L. Perera, B. Quinn, Rahmat, D. Sanders, P. Sonnek, D. Summers, *The University of Mississippi*

Investigators at the University of Mississippi have made several significant contributions to Electroweak, Hadron Collider and Accelerator physics in FY09-10. **1)** In 2009-10 scientists on the BaBar experiment have made the most precise measurement of KM matrix element |Vcb| and the f00 decay constant by partial reconstruction of B→ D* l v decays. The measurement of f00 represents the fraction of Y(4S) decaying in to neutral B mesons [1] at the B-factories and is extremely important in determination of B-meson branching fractions. **2)** In 2009-10 UM researchers on the D0 experiment will measure the W boson mass to unprecedented levels with Run IIb data (Figure 1). The current world average uncertainty on the W mass is 23 MeV. In 2009, D0 published a M(W) measurement using Run IIa data with an uncertainty of 43 MeV, the greatest precision ever from a single experiment (Figure 2). The aim of the D0 Run IIb analysis is to measure M(W) with 25-30 MeV precision, a significant step towards a Tevatron legacy M(W) measurement with a target of 15 MeV uncertainty. Such precision will allow more stringent limits to be placed on the probable Higgs mass range, potentially excluding the Standard Model Higgs boson all the way down to the low mass region already excluded by LEP experiments. **3)** The CMS experiment at the Large Hadron Collider, CERN CH, is well on its way to recording large amounts of high energy collisions at the record high energy of 7 TeV center of mass energy. New physics is expected. UM researchers are investigating extra-dimensional black holes and higgs decays in to jets and leptons. Of special significance is that CMS simulations of these events have been shortened by factors of 100s by implementation of the GFLASH Monte Carlo code by UM scientists and colleagues. **4)** Muon acceleration and shrinking muon bunches (cooling) are the prerequisite for forming high intensity neutrino beams and muon collider storage rings for a future higgs factory. Scientists at UM are one a few universities designing muon acceleration techniques and participating in cooling experiments ultimately aimed at studing new forms of matter [3].

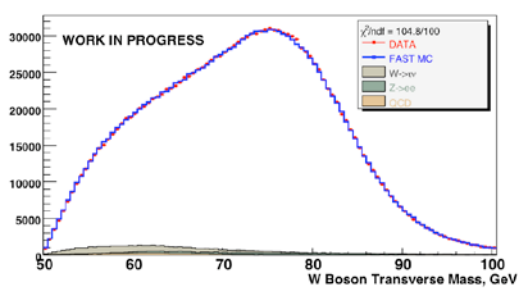


Figure 1: W Boson Mass, D0 Run IIb.

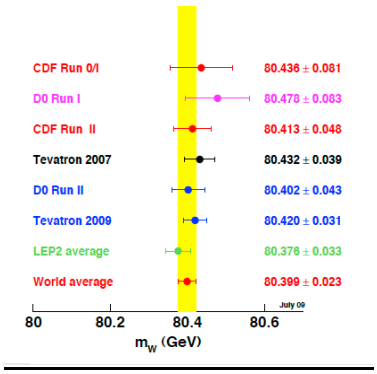


Figure 2: W Boson mass measurements.

References:

[1] " Measurement of the branching fraction of Y(4S) →B0B0bar ", Phys. Rev. Lett. 95:042001, 2009.
[2] " Measurement of the W Boson Mass". D0 Collaboration, Phys. Rev.Lett. 103, 141801 (2009).
[3] "Muon acceleration to 750 GeV in the Tevatron tunnel for a 1.5 TeV mu+ mu- collider," PAC07.

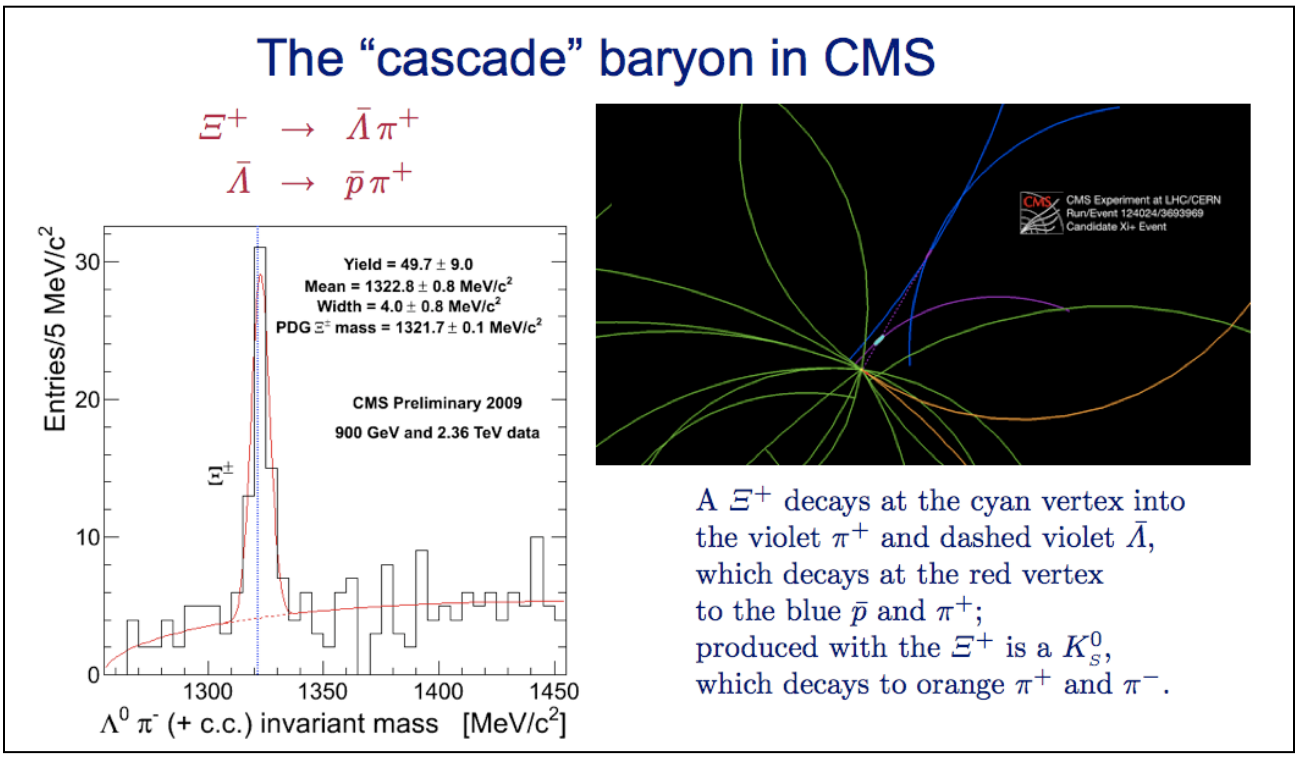
A whole new world of elementary particles?

Investigators: J. P. Cumalat, W. T. Ford, U. Nauenberg, J. G. Smith, K. Stenson, S. R. Wagner, M. Dinardo, A. Gaz, E. Luiggi, K. Ulmer, S. Zang, B. Drell, C. Edelmaier, B. Heyburn, and A. Proulx, *University of Colorado--Boulder*

As proton collisions at a new energy frontier were first achieved at CERN's Large Hadron Collider (LHC) starting late last year, researchers diligently began tuning their methods to search the new data for signs of a conjectured new family of elementary particles. Predicted by SUperSYmmetry theory (SUSY), the new particles would constitute a shadow spectroscopy to the one containing the currently known building blocks of matter. To shake down the new experimental apparatus, participants in the LHC's detector collaborations first concentrated on rediscovering the old spectroscopy. From the first hours of data-taking, physicists from the University of Colorado working with the Compact Muon Solenoid (CMS) detector have pulled from the data signals for neutral K mesons, and the baryons lambda, cascade, and omega-minus. With these samples they are confirming that the detector performs well within its design specifications, and are measuring the rates at which these particles are produced at the new proton collision energies. Others in the group are honing their strategies for the search to come for the new spectroscopy of the SUSY world.

References: http://cms-physics.web.cern.ch/cms-physics/public/TRK-10-001-pas.pdf

For more information: http://www-hep.colorado.edu/



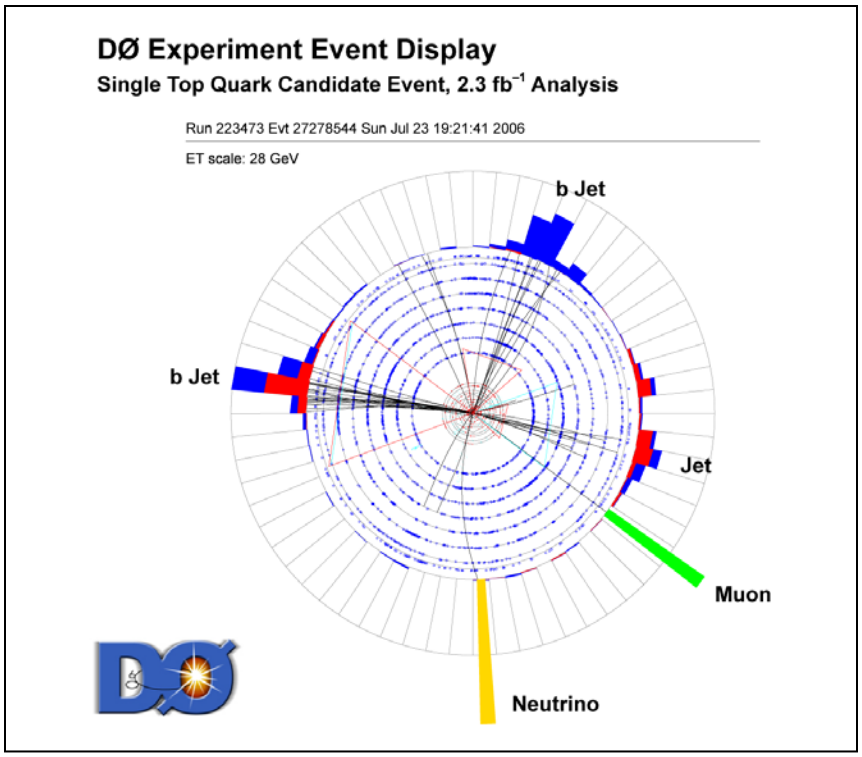
Single tops are all the rage

Investigators: D. Cutts, U. Heintz, M. Narain, and G. Landsberg, *Brown University*

On Monday, March 9, 2009 the CDF and D0 Experiments at Fermilab announced that they had found conclusive evidence that the top quark is produced alone, not accompanied by its antiparticle, in proton-antiproton collisions at high energy. Brown University graduate student Monica Pangilinan, under the guidance of Professor Meenakshi Narain carried out one of the analyses that isolated single top quark production from the overwhelming background of other, less interesting, particle interactions. Having been discovered in 1995 at the Tevatron by the same teams, the top quark is almost old hat, but up to now it had only been observed together with its antiparticle, the anti-top quark. Studying the single production of top quarks gives researchers a way of measuring properties of the top quark such as its lifetime that cannot be determined otherwise. Measuring how often single top quarks are produced gives scientists clues about the existence of additional – as of yet undiscovered – quarks. The discovery of single top quark production is also an important stepping-stone in the search for the Higgs boson. Single top quarks are produced only slightly more often than the elusive Higgs boson and decay to the same final states as Higgs boson events. The discovery of single top quark production proves that such rare processes can be observed.

References: Phys. Rev. Letters, 103:092001,2009; Brown University News, March 9, 2009

For more information:
http://brux.hep.brown.edu/~narain/singletop_observation_BrownU.html



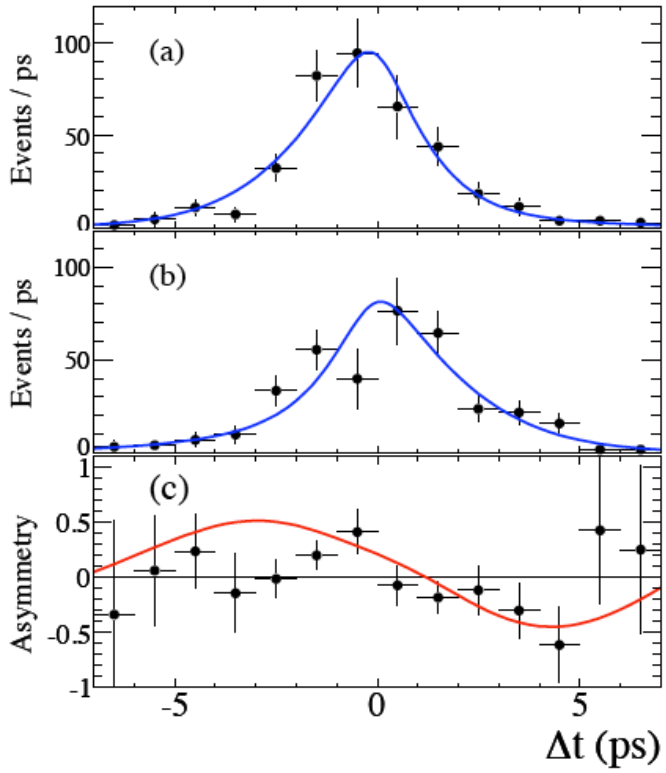
Observation of Matter-antimatter Asymmetry in Rare B Decays

Investigators: C. Dallapiccola and X. Li, *University of Massachusetts--Amherst*

The BaBar experiment operating at the SLAC PEP-II B Factory recorded unprecedented amounts of data to study the asymmetry between matter and antimatter. One of the key measurements is that of the CP-violating angle alpha that can be determined by careful study of rare B $\rightarrow \pi^+\pi^-$ decays. Key measurements were obtained with a sample of 383 million B Bbar events. Of particular note is the first 5-sigma observation of CP violation in B decays involving b $\rightarrow$ u quark transitions (as is relevant in this decay mode). Furthermore, first observation of so-called direct CP violation was obtained in the companion B $\rightarrow K^+\pi^-$ decay. The BaBar analysis working group responsible for this textbook physics result was led by Prof. Dallapiccola, who was one of the founders of the group and led this rare decay analysis for much of the lifetime of the BaBar experiment. Graduate student Li was also instrumental in carrying this latest round of analysis having taken on the primary responsibility for data processing and sophisticated fitting method that resulted in these keystone measurements. The UMass group has made long-standing contributions to the BaBar experiment in the areas of accelerator-detector liaison, Electromagnetic Calorimeter and Cherenkov detectors, as well as physics analysis.

References: B. Aubert et al., BaBar Collaboration, Phys. Rev. Letters 99, 021603 (2007).

For more information: http://people.umass.edu/eppex/



Search for dark forces at *BABAR*

Investigators: B. Echenard, D. Chao, C.H. Cheng, A. Chivukula, D. Doll, D.G. Hitlin, P. Ongmongkolkul, F. Porter, and A. Rakitin, *CalTech*

While the evidence for dark matter is now overwhelming, its precise nature and origin remain elusive. Determining the properties of dark matter is the objective of many current theoretical and experimental investigations. The existence of a dark (*i.e.,* hidden) sector has recently been proposed [1] to explain a variety of new terrestrial and satellite observations. These models introduce "dark forces" mediated by new particles with a mass of the order of a GeV, which interact weakly with photons [3]. As in the Standard Model, the Higgs mechanism generates massive bosons, giving rise to the presence of one or several dark Higgs bosons.

Thanks to their large integrated luminosity, *B* Factory experiments such as ***BABAR*** provide an ideal environment to probe the existence of a dark sector at the GeV scale. Currently, constraints on the existence of weakly-coupled particles in this region are not very stringent (see Figure 1). Our group has taken a leading role in the investigation of dark forces, with the co-convener of the ***BABAR*** Dark Forces Task Force, and in initiating several searches for dark Higgs production. These searches can improve the current limits in the 0.1 to 3.5 GeV region by an order of magnitude [2], or else provide a striking signature of physics beyond the Standard Model. This sensitivity can be increased by a further two orders of magnitude at a Super *B* Factory such as Super*B*.

References:
[1] N. Arkani-Ahmed *et al.*, Phys. Rev. D79 (2009), 015014.
[2] B. Battell *et al.*, Phys. Rev. D79 (2009), 115008.
[3] *A bizarre universe may be lurking in the shadows*, A. Ananthaswamy, New Scientist, **2698,** 28, 4 March 2009. http://www.sott.net/articles/show/178447-A-bizarre-universe-may-be-lurking-in-the-shadows

For more information: http://www.hep.caltech.edu/~echenard/DarkForces.html

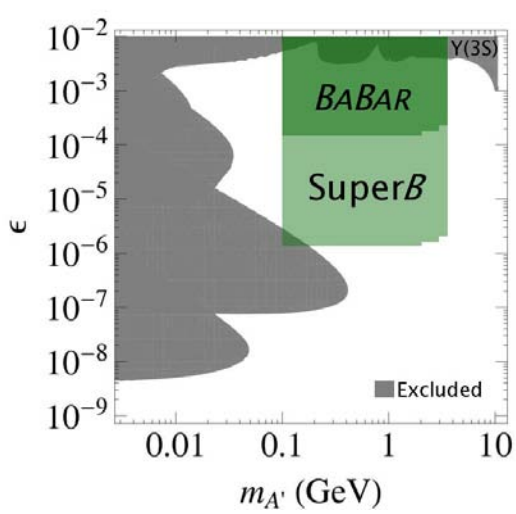


Figure 1. Limits on the mass ($m_{A'}$) of the dark force carrier, in GeV, *vs*. the coupling strength ▱ of the dark photon to the photon. The grey regions are currently excluded. The dark green area outlines the potential exclusion region of the current search at *BABAR*. The light green area shows the additional region that can be investigated at a Super*B* Factory.

A Hidden World at the LHC

Investigators: J. Ernst, T. Qian, and J. Saland, *University at Albany, SUNY*

Our current view of matter comes from observing the interactions among the particles that compose The Standard Model. There may however, be other classes of matter that exist but that interact too weakly with ordinary matter to have been observed. Recent theories suggest that the Higgs Boson may act as a type of connection between the ordinary matter that we can observe directly, and the matter that may lie outside the Standard Model. The ATLAS experiment at the Large Hadron Collider will allow physicists to search for this possible connection. To test the theory, researchers at SUNY Albany have begun developing a strategy that will allow the ATLAS experiment to search for signs of this connection to a still-hidden type of matter.

Reference: http://www.guardian.co.uk/science/2010/jun/21/higgs-boson

An Asymmetry that Matters

Investigators: H.Evans, S.Lammers, R.van Kooten, and D.Zieminska, *Indiana University*

We live in a universe made entirely of matter. This is fortunate for us, but odd because equal amounts of matter and antimatter were produced in the Big Bang. Sakharov famously proposed three conditions that allow matter to become dominant as the universe evolves. Research from the D0 experiment operating at Fermilab's Tevatron Collider has recently shed light on one of these conditions – *CP* symmetry violation. *CP* is shorthand for an operation that changes a particle to its antiparticle and inverts the particle's spatial coordinates. The violation of *CP* symmetry, which was first observed in 1964, is explained in our current theory of particle physics, the Standard Model (SM). But the level of *CP* violation predicted by the theory is far too small to explain the preponderance of matter in our universe. Indiana University scientists have played an important role in several new measurements of *CP* violation by D0 involving *b*-quarks . These measurements, which make use of B_s mesons, particles containing an anti-*b* and an *s* quark, show a significantly larger level of *CP* violation than expected in the SM. They could pave the way to a new understanding of the matter-antimatter asymmetry of the universe.

Reference: *"A New Clue to Explain Existence"*, Dennis Overbye, New York Times, May 17, 2010

For more information:
http://www-d0.fnal.gov/Run2Physics/top/public/CP_violation_evidence_DZero.html

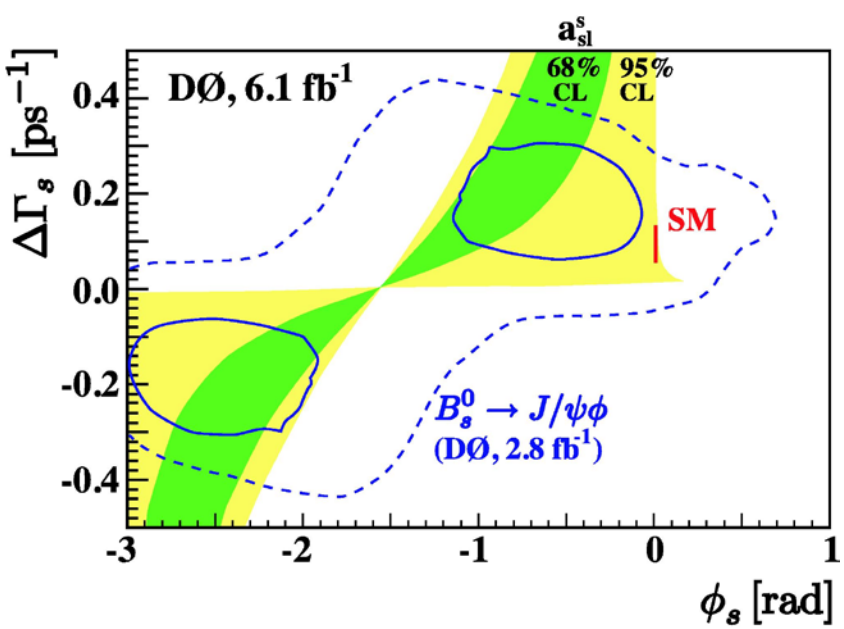


Illustration 1: The horizontal axis is a CP-violation parameter for the B_s system that is predicted to be close to zero for the Standard Model. Preferred regions for two separate D0 analyses are shown.

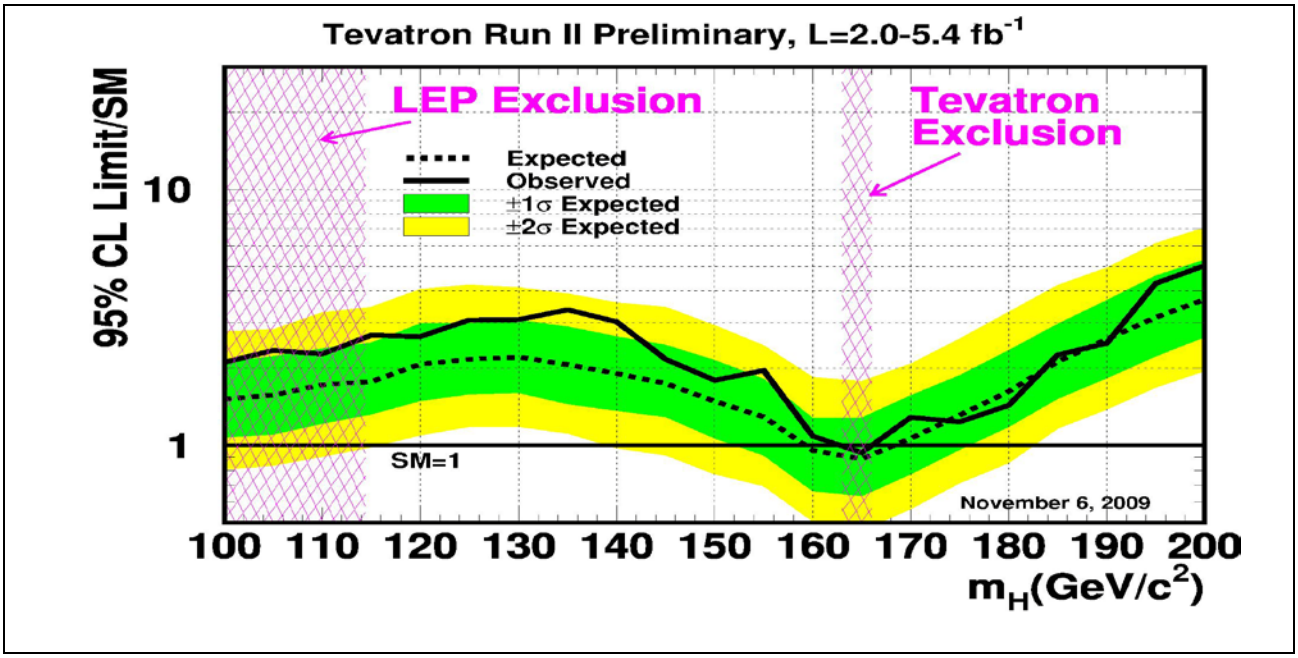
The Energy Frontier: The Hunt for the Higgs Boson

Investigators: CDF and DZero Collaborations

The Higgs boson, predicted by the Standard Model, is thought to interact with other particles to give them mass. The mechanism by which particles acquire different mass values is unknown, and finding evidence for the existence of the Higgs boson would address this fundamental mystery of nature. The Tevatron accelerator at the U.S. Department of Energy's Fermilab is the only place where scientists have a chance to see the Higgs over the next few years thanks to record-breaking levels of luminosity. Moreover, by continually improving their experimental techniques, physicists on the CDF and DZero experiments have been able to boost their sensitivity to the Higgs and other phenomena by more than the margin afforded by the increased data alone. Scientists from the CDF and DZero collaborations recently combined Tevatron data from the two experiments to advance the quest for the long-sought Higgs boson. Their results indicate that Fermilab researchers have excluded, with 95 percent probability, a mass range for the Higgs of 163-166 GeV/c2. This result not only restricts the possible masses where the Higgs might lie, but it also demonstrates that the Tevatron experiments are sensitive to potential Higgs signal and will be able to find evidence of its existence or exclude it over all allowed mass ranges. The next combination of the results from the two experiments is planned for late summer 2010. The Tevatron physics program is extremely successful . In the past year alone, the two experiments have produced 60 Ph.D.s and 100 publications on a wide range of studies that advance the state of our knowledge across the span of particle physics at the energy frontier.

Reference: http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H86/

For more information: http://www-d0.fnal.gov/Run2Physics/WWW/results.htm, http://www cdf.fnal.gov/physics/physics.html



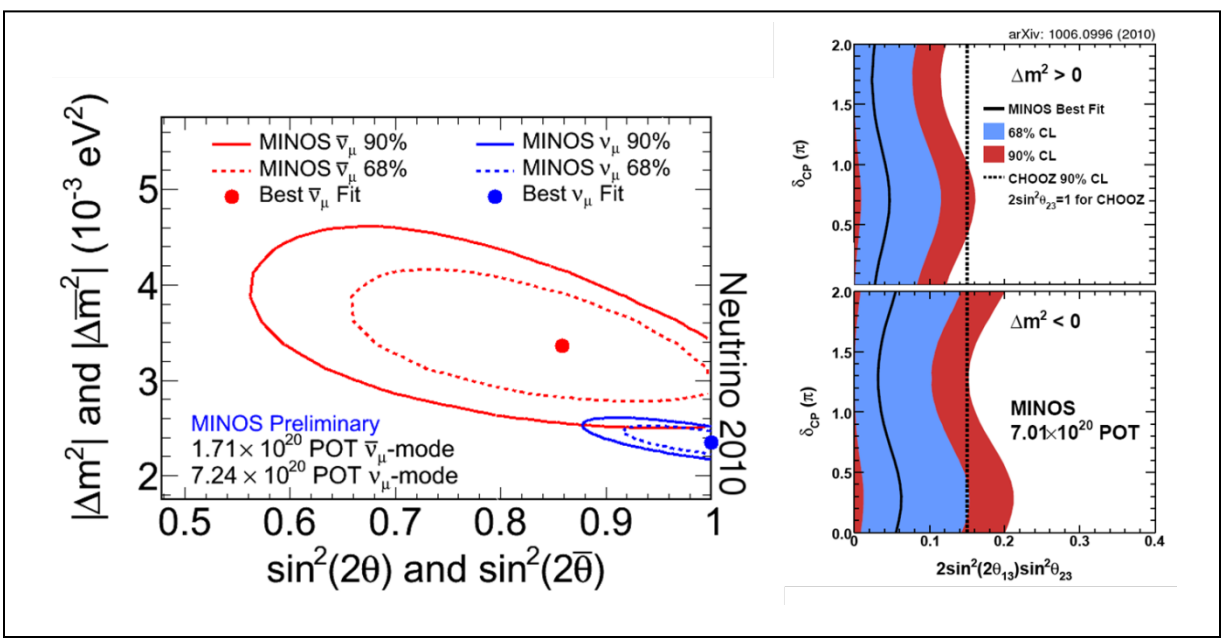
Precision Neutrino Physics at Long Range

Investigators: MINOS Collaboration

Using a large sample of neutrinos produced by the NuMI facility at the Fermilab Main Injector, the scientists of the MINOS Collaboration have produced precision results of the phenomenon of neutrino oscillations. In this recently discovered effect, very weakly interacting neutrinos of one of the three known types are produced at Fermilab and sent 450 miles through the earth to a detector in northern Minnesota, where they are found to have become a mixture of types. MINOS measures the number of muon-type neutrinos that have changed type. The oscillations are described by a parameter that gives the amount of the mixing and the masses of neutrino, which used to be thought to be zero. The precision obtained in the difference of the masses (squared) is 4%, the world's best. The MINOS experiment has also searched for the as-yet undetected transformation of muon neutrinos into electron neutrinos. This small effect is influenced by the earth the neutrinos pass through and depends on which type of neutrino is heavier. The MINOS limit is the best from any experiment studying oscillations of muon-type neutrinos and is superior to all current types of searches for one of the cases (called "normal hierarchy"). A smaller sample of antineutrino's has also been collected, and a preliminary analysis of their oscillations has been completed. In this measurement the antineutrino system is best described by parameters that are slightly different from neutrinos. More data is needed to verify the result, but if confirmed the consequences for physical theory will be extremely important.

Reference: arXiv:hep-ex/1006.0006

For more information: http://www-numi.fnal.gov/PublicInfo/forscientists.html



Unprecedented Performance of the Fermilab Accelerator Complex

Investigators: Fermilab Staff of the Accelerator Division, Technical Division, Accelerator Physics Center

In 2010 the Fermilab Accelerator Complex reached unprecedented performance levels, both in support of Tevatron Collider and neutrino operations. This performance has enabled groundbreaking discoveries at both the energy and intensity frontiers. The Tevatron Collider remains to this day the highest luminosity hadron collider ever operated. Luminosity surpassed $4\times10^{32}cm^{-2}sec^{-1}$ for the first time during the spring of 2010 – a factor of 400 beyond the design goal of the original construction. Collider performance is reliant on many breakthroughs and innovations implemented by the Fermilab accelerator staff over the last decade, including: 1) the first (and only) utilization of electron cooling to provide high density hadron beams; 2) the first (and only) utilization of separated helical orbits in a particle collider; 3) the first (and only) utilization of electron beams to manipulate the beam dynamics of individual bunches in a collider; and 4) operation of the highest capacity antiproton production facility ever constructed – capable of producing close to 3×10^{11} antiprotons/hour. Total delivered luminosity through the first nine months of FY2010 is 2.1 fb^{-1}, already exceeding the 1.9 fb-1 delivered in all of FY2009. The neutrino complex operates at levels unmatched anywhere in the world, simultaneous with collider operations. The average beam power delivered at 120 GeV is approximately 300 kW while operating simultaneously with antiproton production for the Collider, and has approached 400 kW in a dedicated mode. Major innovations that have enabled this level of performance including: 1) the only operational system in the world for longitudinal slip-stacking of proton beams; and 2) implementation of advanced collimation systems. Total protons delivered to the neutrino production target in FY2010 are 2.9×10^{20} , exceeding the 2.2×10^{11} antiprotons delivered in all of FY2009.

For more information: http://tomato.fnal.gov/ops/records.php http://www-bd.fnal.gov/pplot/today/DataSummaryTables.html

The Fermilab Accelerator Complex consists of nine distinct accelerators, all working in parallel, to support simultaneous operations of the Tevatron (2 TeV) proton-antiproton Collider, the Main Injector (120 GeV) based neutrino program, and the Booster (8 GeV) based neutrino program.

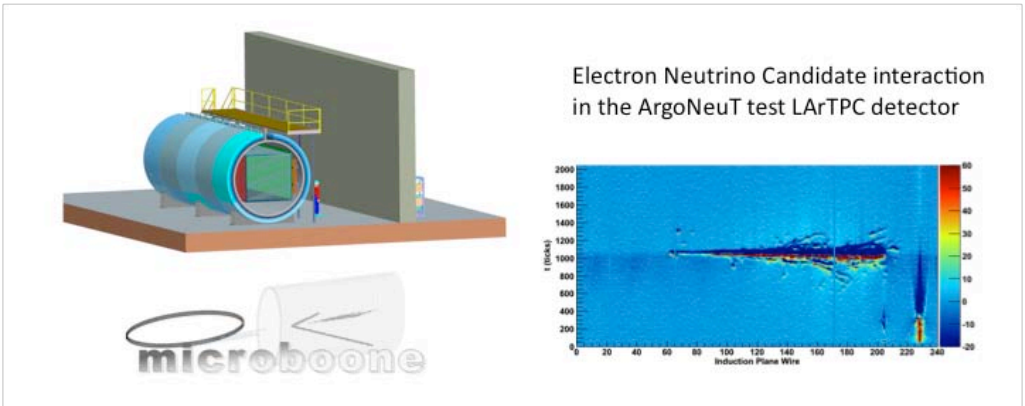
The Intensity Frontier: Exploring low energy neutrino phenomena with the MicroBooNE experiment

Investigators: *Brookhaven:* H. Chen, J. Farrell, F. Lanni, D. Lissauer, D. Makowiecki, J. Mead, V. Radeka, S. Rescia, J. Sondericker, C. Thorn, B. Yu. Columbia: L. Camilieri, C. Mariani, B. Seligman, M. Shaevitz, B. Willis. Fermilab: B. Baller, C. James, H. Jostlein, S. Pordes, G. Rameika, B. Rebel, R. Schmitt, D. Schmitz, J. Wu, G. Zeller. *Kansas State:* T. Bolton, D. McKee, G. Horton Smith. Los Alamos Lab: G. Garvey, J. Gonzales, B. Louis, C. Mauger, G. Mills, Z. Pavlovic, R. Van de Water, H. White. *MIT:* W. Barletta, L. Bugel, J. Conrad, G. Karagiorgi, T. Katori, H. Tanaka. Michigan State: C. Bromberg, D. Edmunds. *Princeton:* K. McDonald, C. Lu, Q. He. St. Marys: P. Nienaber. *UCLA:* H. Wang, *University of Cinncinnati:* R. Johnson, A. Wickremasinghe. *University of Texas at Austin:* S. Kopp, K. Lang. *Yale:* C. Anderson, B. Fleming, R. Guenette, K. Partyka, S. Linden, M. Soderberg, J. Sptiz

The MicroBooNE experiment will use a 150-ton liquid argon time projection chamber, LArTPC, to measure low energy neutrino phenomena. MicroBooNE will observe neutrinos on-axis from the Booster Neutrino Beamline and off-axis from the NuMI beam at Fermilab. The experiment will explore the low energy neutrino phenomena observed by the MiniBooNE experiment, and will measure a suite of low energy neutrino cross sections. MicroBooNE's fine grained precision detection technique makes it ideal for these neutrino physics measurements and for electron neutrino appearance searches beyond. It serves as the next necessary step in development of LArTPCs towards multi-kiloton scale detectors for the Long Baseline Neutrino Experiment Program (LBNE). Coupling these neutrino detectors with high intensity neutrino beams within the LBNE program, the final unknowns of neutrino oscillation phenomena, including the possibility of CP violation in the neutrino sector, will be explored.

References: "Proposal for a New Experiment Using the Booster and NuMI Neutrino Beamlines: MicroBooNE", the MicroBooNE Collaboration, Fermilab Proposal 0974

For more information: www-microboone.fnal.gov



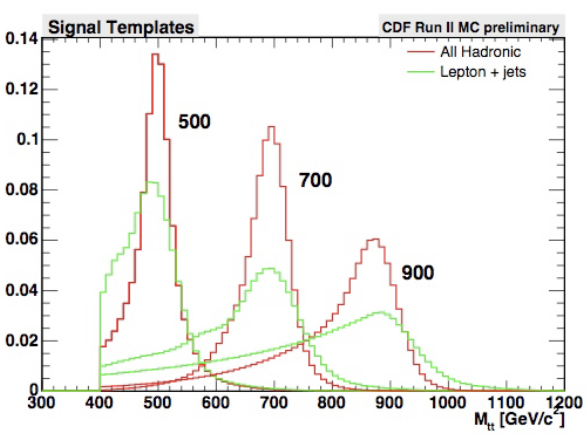
The Top Quark as a Window to New Physics

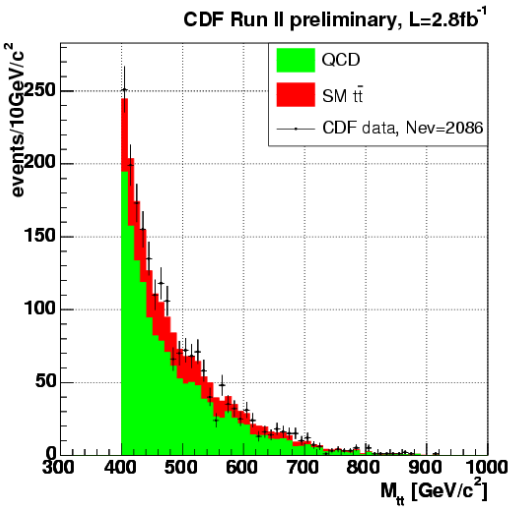
Investigators: N. Goldschmidt, J. Konigsberg, Y. Oksuzian, and A. Sukhanov, *Univ. of Florida*

The copious matter anti-matter collisions at the Fermilab'sTevatron collider provide a unique environment to test for the production of new, non-Standard Model particles. A particularly promising exploration is the production of top quark pairs. New theories [1,2] predict the existence of new particles that could appear in the proton anti-proton collisions that also produce top quark pairs. Scientists from the University of Florida (UF) are studying the CDF collision data to find these new phenomena. To do so, they identify collisions that produce top quark pairs and then reconstruct the total energy and momentum of the pair. New particles that produce top quark pairs will distort the invariant mass spectrum predicted by standard model processes. If new particles are produced in these collisions, the reconstructed invariant mass spectrum will show a peak at the mass value of the new particle as shown in the left hand figure. The UF team studied for the first time the "all-hadronic" final state. In this case each top quark decays to three-jets, and the invariant mass reconstruction is relatively straightforward. However, very copious QCD backgrounds make the search very difficult. This was overcome by using complex multivariate analysis techniques to both reduce the background level and to properly reconstruct the invariant mass distribution. With this analysis new physics contributions at the level of a few percent could be observed. The resulting distribution is shown on the right hand figure. No significant bumps are evident. The team was able to place very stringent limits on the mass of new particles that would produce top quark pairs, and invariant masses of the order of 1 TeV can now be explored at the Tevatron.

References: [1] C.T. Hill, Phys. Lett. **B266** (1991); [2] 419. R. Frederix, F. Maltoni JHEP 0901:047, 2009

For more information:
wwwcdf.fnal.gov/physics/new/top/confNotes/cdf9844_AllHadMtt_pub.pdf





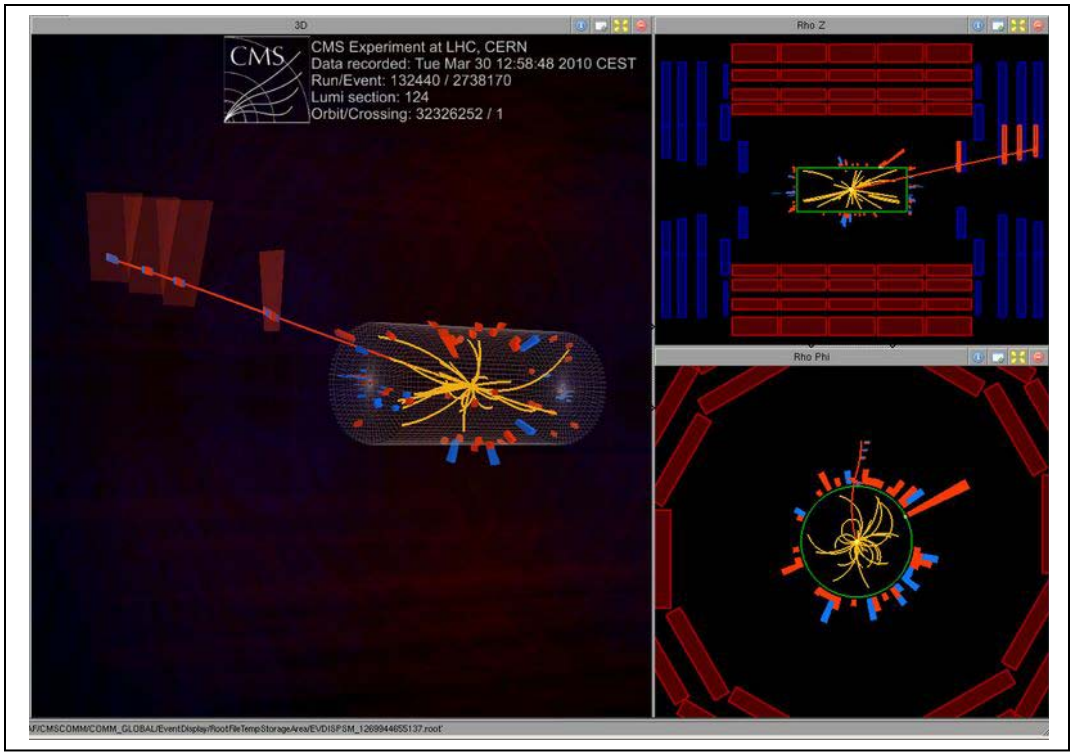
Novel "Muon Microscope" is a Big Success at the LHC

Investigators: S. Gollapinni, R. Harr, P. Karchin, M. Mattson, and A. Sakharov, *Wayne State*

Like a giant version of an electron microscope, the end-cap muon detector system of the Compact Muon Solenoid Experiment at the Large Hadron Collider, measures muon particles (which are a type of heavy electron) emerging from collisions produced by the world's highest energy particle accelerator at the European Center for Nuclear Research in Geneva, Switzerland. The muons carry key information about the structure of the colliding protons and the new types of particles that may be produced. It is a challenge to design a detector capable of accurately measuring the speed and direction of the muons because of the high radiation environment surrounding the colliding beams. To solve this problem, specially built cathode strip chambers are assembled in six-layer "sandwiches". Even if one or two of the layers are affected by the radiation, the combination of all six layers can identify the path of a muon which passed through the sandwich. The event display below shows an example of a muon (red line) produced on March 30, 2010 in a 7 TeV collision. The muon is clearly detected by four sandwiches of detectors, each having a trapezoidal shape. Scientists from Wayne State University in Detroit help operate the complex detector system and wrote key software to process the data produced by the cathode strip chambers.

Reference: CMS Collaboration, Journal of Instrumentation, Vol. 5, T030018 (2010)

For more information: http://cms.web.cern.ch/cms/Detector/Muons/index.html



The strong coupling constant from hadronic tau-lepton decays

Investigator: Maarten Golterman, *San Francisco State University*

Hadronic decays of the tau lepton provide one of the most precise determinations of the strong coupling constant. However, while the main strong-interaction effect is well described by perturbative QCD, there are various small, but significant nonperturbative effects that have to be taken into account, given the increasing precision of experimental data. One of these effects is due to the fact that the data is better described in terms of hadronic resonances, instead of in terms of the perturbative picture of quarks and gluons. This leads to a violation of the assumption of "quark-hadron duality," which stipulates that the description in terms of hadrons and the perturbative description in terms of quarks and gluons are interchangeable. At present little or no quantitative information is available about the size of dualtity violations, and it is not known how to derive a systematic description of this effect from the theory of strong interactions. In order to make progress, one has to resort to a model. Using a heuristic, but sensible model, we have demonstrated that this effect cannot be ignored. We are currently using our model in order to reassess the value of the strong coupling constant from tau decays, expecting to present a completely new analysis of the data in the near future.

Reference: O. Cata, M. Golterman and S. Peris, Physi, Rev. D79 (2009) 053002

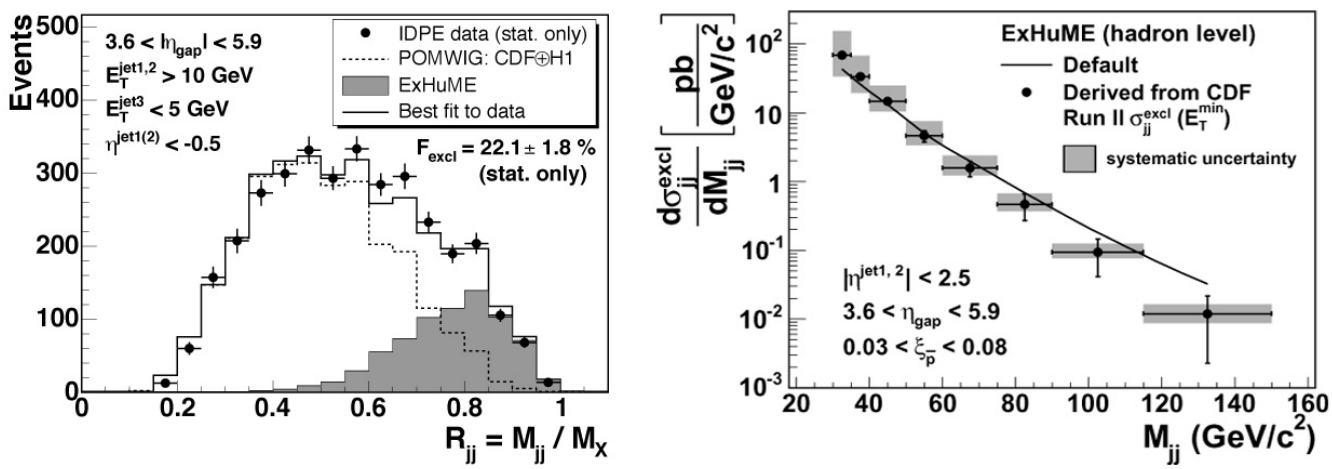
A New Tool in the Search for the Higgs Boson

Investigators: K. Goulianos, A. Bhatti, L. Demortier, C. Mesropian, R. Ciesielski, G. Lungu, and S. Malik, *The Rockefeller University*

One of the top priorities for experiments conducted at the Large Hadron Collider (LHC) is to clarify whether or not the Higgs boson exists. An important advance toward this goal was recently made possible at the Fermilab Tevatron thanks to the observation of exclusive dijet events. These are events in which a proton collides with an antiproton, both particles escape intact except for a small momentum loss, and two collimated jets of particles (the "dijet") are produced in the center of the detector. Such events had never before been observed, and their discovery has extraordinary implications for the search for the Higgs boson at the LHC. Indeed, it indicates that if this boson exists, it can also be produced "exclusively", that is, with only the Higgs decay products and the surviving beam protons appearing in the detector. This will allow us to determine the Higgs mass and quantum numbers by measuring the momenta and angular correlations of the escaping protons, and then use this information to identify unambiguously the Higgs boson.

Reference: T. Aaltonen et al. (CDF Collaboration), Phys. Rev. D77, *052004* (2008).

For more information: http://physics.rockefeller.edu/



The figure below on the left shows data from the CDF experiment (black dots) superimposed on expectations from theory. The shaded area is the contribution from exclusive dijet events. The plot on the right shows the dijet invariant mass spectrum for these events. This spectrum extends well into the mass region that is relevant for the Higgs search (above 115 GeV/c^2), indicating that a Higgs discovery in this channel is indeed possible.

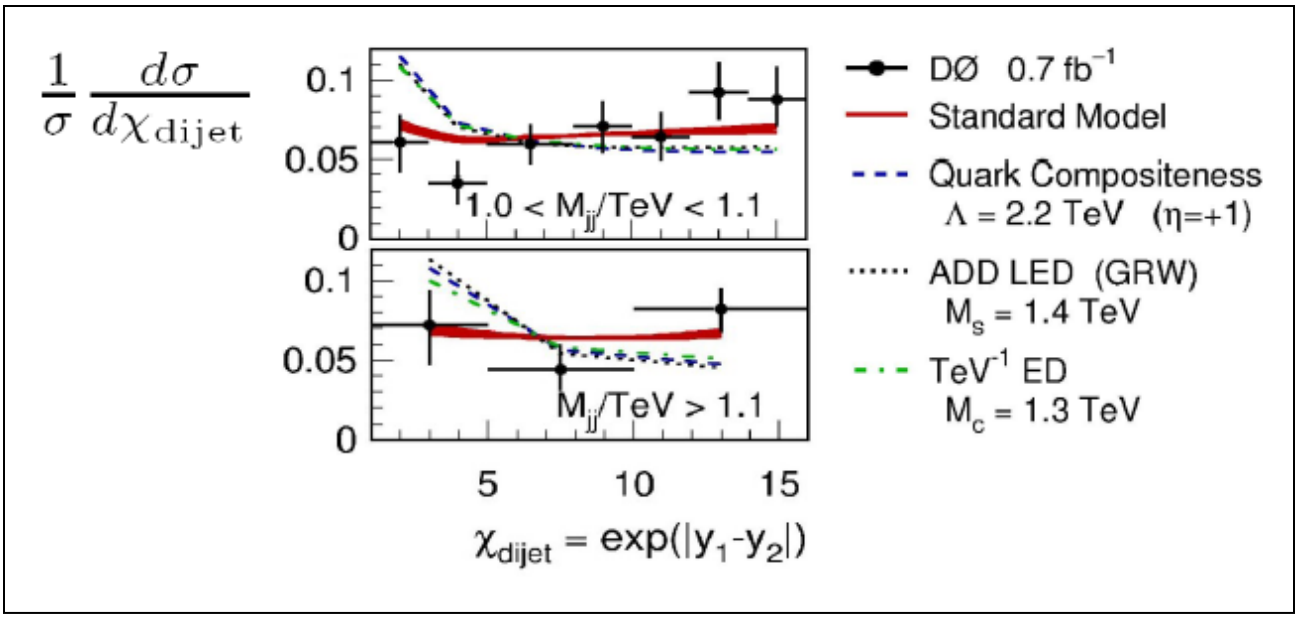
Probing the Structure of Matter and Spacetime

Investigators: D. Greenwood, L. Sawyer, and M. Wobisch, *Louisiana Tech University*

Researchers on the D0 experiment at the Fermilab Tevatron Collider have used angular distributions of dijets to probe the structure of matter at energies up to and above 1000 times the mass of the proton. At these energies, dijet production has the largest cross section of all processes at a hadron collider and therefore the highest sensitivity to test predictions of the Standard Model at previously unexplored small distance scales. Deviations from these predictions could reveal the presence of a new layer of particles inside the quarks ("quark compositeness") or point to the existence of additional compactified spatial dimensions ("extra dimensions"). Based on the measurements of dijet angular distributions, the D0 collaboration has set upper limits on the possible size of the quarks inside the proton and on the maximum size of possible extra spatial dimensions. These results constitute the strongest limits on the above mentioned New Physics models to date. Researchers from Louisiana Tech University have been leading the analysis efforts which have produced these results.

Reference: D0 Collaboration, V.M. Abazov et al., Physical Review Letters **103**, 191803 (2009).

For more information: http://prl.aps.org/abstract/PRL/v103/i19/e191803



Large Hadron Collider: Big Science, Huge Questions

Investigators: V. Halyo, D. Marlow, J. Olsen, C. Tully, D. Stickland, N. Adam, and D. Lopes-Pegna, *Princeton University*

On March 30, 2010, physicists "flipped the switch" on the world's highest-energy particle accelerator, the Large Hadron Collider (LHC), a 27km circular track buried 100 meters below the French-Swiss border. Scientists are now poised to exploit this new energy frontier in search of the elusive Higgs boson, which is thought to give mass to the fundamental particles, and for evidence of particles and interactions that go beyond our current understanding of matter and forces, including the mysterious “dark matter” that pervades the Universe. Researchers at Princeton University are playing a lead role in the commissioning of the Compact Muon Solenoid, one of the massive particle detectors installed in the LHC tunnel that is designed to record the aftermath of proton collisions with energies reminiscent of the Big Bang. Princeton is responsible for measuring the collision rate, or “luminosity” delivered by the LHC, which is critical not only to understand the physics data recorded by the CMS experiment, but also as continuous feedback to the LHC operators in their continuing effort to improve the performance of this new machine. Group members are also analyzing the first data collected by CMS in order to better understand the detector, including using the decays of charm quarks to measure the performance of the charged-particle tracking system, and using “jet data” to tune the performance of the hadron calorimeter, which is a key system in the search for new particles that are detectable only through their ability to carry away “missing energy” (see below).

Reference: “European Collider Begins Its Subatomic Exploration,” New York Times, March 30, 2010

For more information: http://public.web.cern.ch/public/en/LHC/CMS-en.html

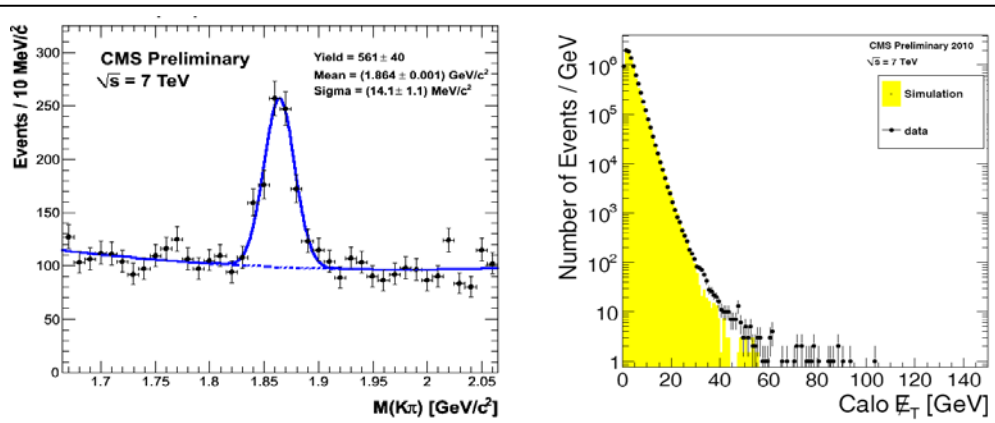


Figure: Physicists at Princeton are using particles produced in the decay of charm quarks (left) to study the performance of the CMS tracking system, and are playing a leading role in the commissioning of the hadron calorimeter, which is a key component in the search for “supersymmetric” particles through their signature of “missing energy” in the detector (right).

What Will We Discover First?

Investigators: G. Hanson, G.-Y. Jeng, H. Liu, and R. Stringer, *University of California--Riverside*

The Large Hadron Collider (LHC) at CERN near Geneva, Switzerland, is now the world's highest energy collider with proton-proton collisions at a center-of-mass energy of 7 TeV, three and half times the energy of the Tevatron collider at Fermilab, near Chicago. Now we can begin our program of physics, which will undoubtedly lead to discoveries that will increase our understanding of the Universe. We will be able to find out whether the Higgs mechanism is the correct explanation for the masses of elementary particles. Dark Matter, which accounts for most of mass of the Universe, may be explained by the discovery of supersymmetric particles, the lightest of which can decay invisibly. There may be extra dimensions, as predicted by string-theory based models. The only question is what will we discover first? The Compact Muon Solenoid (CMS) Tracker Group at the University of California, Riverside, has spent many years building and commissioning the largest silicon tracker ever built. We are working on the measurement of the cross section for the production of a pair of top quarks, the heaviest quark, which will help us to understand the performance of the detector and backgrounds that can mask the new physics. We are working on gauge-mediated supersymmetry breaking, which, if it exists, should provide a signal during our first year of data taking. We are also searching for the Higgs boson, which we expect will require the larger LHC collision energy that will be available around 2013.

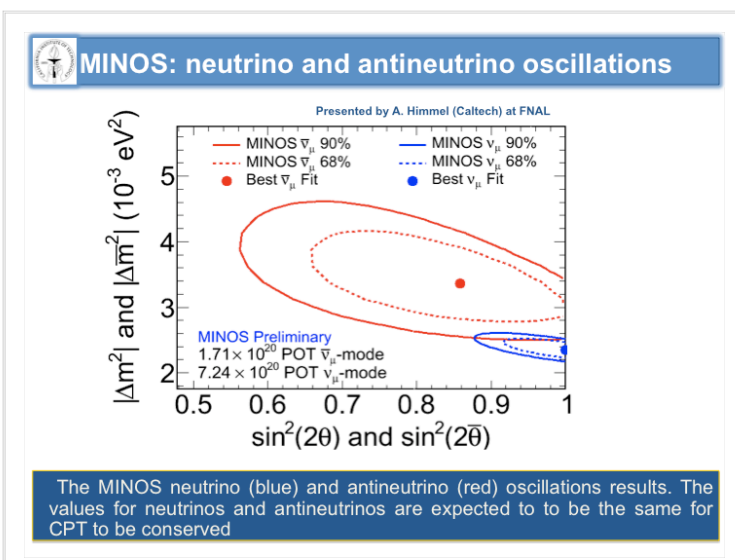
Reference: Searching for the Higgs, G. G. Hanson, invited article, Physics **2**, 106 (2009), http://physics.aps.org/articles/v2/106 and references therein

Breaking new ground at the Intensity Frontier with Neutrinos at MINOS and NOνA

Investigators: A. Himmel, L. Mualem, H. Newman, J.P. Ochoa, M. Orchanian, and R. Patterson, *Caltech*

Neutrinos are the most elusive particles yet discovered. Their tiny masses and peculiar habit of oscillating from one neutrino type to another may be the key to the origin of matter in the universe and a unified understanding of particles and forces in the Big Bang. The Caltech group at MINOS has had leading roles in the most sensitive search yet for oscillations from muon-type to electron-type neutrinos as the neutrinos fly from Fermilab over 735 km to the Soudan mine in Minnesota. These results yield the most precise bounds ever on the key angle θ_{13}, which characterizes the mixing between the first and third neutrino generations [1]. Caltech has also driven the first MINOS running optimized to detect oscillations of muon antineutrinos, confirming that muon antineutrinos oscillate and producing the most precise antineutrino mass splitting measurement [2]. Comparing with the corresponding neutrino mass splitting provides a new fundamental test of the relation between matter and antimatter, and could even provide hints of new kinds of exotic neutrinos. These investigations continue with greater precision as MINOS continues to collect data through the end of 2011, and with much greater precision at NOvA in the coming years. If θ_{13} is large enough, NOvA also could determine the mass-ordering of neutrino types, and measure an asymmetry in the oscillations of neutrinos and antineutrinos that could explain the predominance of matter over antimatter in our universe.

References: [1] http://www.symmetrymagazine.org/breaking/2010/04/13/minos-continues-the-race/ ;[2] http://www.interactions.org/cms/?pid=1029542

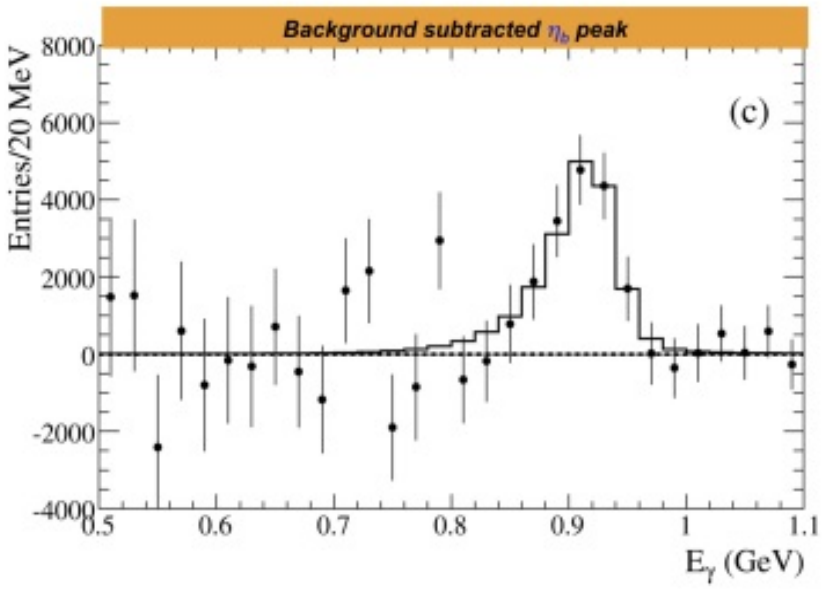


Discovery of the η_b

Investigators: A. Jawahery, D. Roberts, J. Tuggle, J. Anderson, G. Simi, R.Cenci, E. Behn, B. Hamilton, *University of Maryland,* and BaBar collaboration

In 2008, collaborators on the BaBar experiment, at the U.S. Department of Energy (DOE) supported Stanford Linear Accelerator Center (SLAC), have detected and measured the lowest energy bound state of the "bottomonium" family: η_b. This is the first observation of the ground state of a b and anti-b quark pair. This state has been anticipated but has gone unobserved for quite a long time. Failure to observe it has led many particle physicists to speculate that it may be interfering with a light CP-odd Higgs state, which masks its signature. The η_b observation at BaBar provides a key element of our understanding of the physics of the b/anti-b system, and allows probing the role of spin in the strong interactions. The BaBar collaboration consists of 459 physicists and 74 institutions in 10 countries and was led by Professor Hassan Jawahery from the University of Maryland during 2006-2009. Professor Jawahery championed the idea of running on the upsilon resonances which was essential to the discovery of this new particle, with the goal of discovering this and other new states during the last few months of operation of the Babar detector.

References: Babar Collaboration, Phys.Rev.Lett.101:071801,2008; Erratum-ddddddibid.102:029901,2009



Research at BABAR and CMS

Investigators: Romulus Godang and C. M. Jenkins, *University of South Alabama*

The Experimental High Energy Physics Group at the University of South Alabama consists of two faculty members and several undergraduate students. The faculty members in this group are Dr. Romulus Godang who is a member of the BABAR collaboration and CMS (via the University of Mississippi) and Dr. C. M. Jenkins who is a member of CMS (via the Florida State University). Before joining the University of South Alabama, Dr. Godang played a key role in the BABAR analysis of the Upsilon(4S) to B^0 anti-B^0 branching fraction using a partial reconstruction technique that results in about a factor of 20 in statistical gain compared to the full reconstruction technique. Dr. Godang is improving the precision of this measurement at the University of South Alabama with a factor of five increase in data. This precise measurement is an important input to many B-meson measurements at B-factory machines and can be a significant contribution to enhance our knowledge of the isospin violation in the Upsilon (4S) decays. The project is conducted using a very large BB-pairs data sample produced by PEP-II electron-positron collider and collected by BABAR detector at the SLAC National Accelerator Laboratory in California.Dr. Jenkins is working on including the CATFISH microscopic blackhole Monte Carlo program, developed at the University of Mississippi, into the CMSSW analysis framework for CMS.

Reference: BABAR Collaboration, B. Aubert et al., “Measurement of the Absolute Branching Fraction of $D^0 \rightarrow K^- \square^+$”, Phys. Rev. Lett. 100, 051802 (2008).

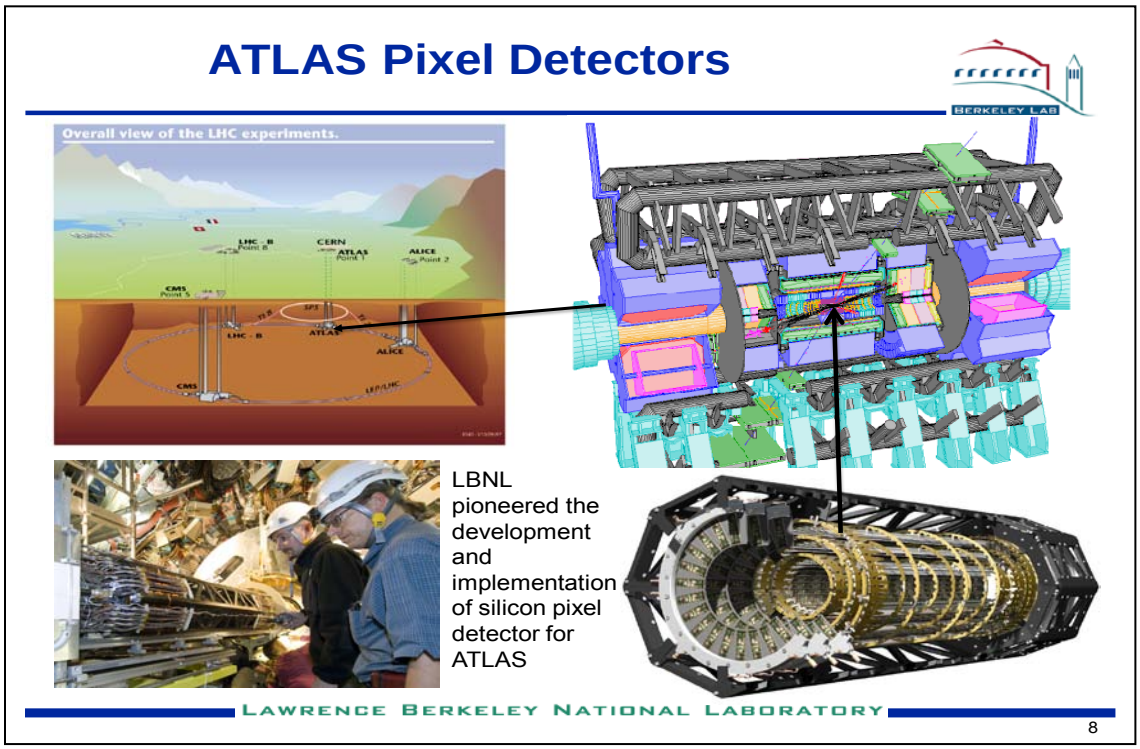
Berkeley Lab Pixel Detector Plays Vital Role in First ATLAS LHC Publication

Investigators: The ATLAS Collaboration

The first physics results from the ATLAS experiment, reporting proton-proton collisions at energy of 0.9 TeV (almost a trillion electron volts) in late 2009, were published in the journal *Physics Letters B* on April 26, 2010. Vital to these results was the pixel tracking detector, a key component of ATLAS located closest to the interaction point. Berkeley Lab researchers played a critical role in the design and construction of the pixel detector, which measures the momentum of charged particles emerging from proton-proton collisions. After 20 years of effort by more than 3,000 scientists, engineers, and technical staff, the first results demonstrated that the mammoth ATLAS detector (seven stories tall and twice as long) works almost flawlessly. That a 7,000-tonne detector with 3,000 kilometers of cables and close to 100 million channels of read-out electronics successfully measured particle tracks with a precision of 0.001 centimeters so quickly is a great achievement. The first paper is based on data taken with the experiment's "trigger" set to accept almost all events and reports results for the number of charged particles per collision and its dependence on several variables such as the particles' momentum perpendicular to the beam. In later stages, ATLAS will focus on rare events, filtering out the less interesting ones. ATLAS's first paper with physics results demonstrates the experiment's enormous potential for making major discoveries in the years ahead.

References: ATLAS Collaboration (G. Aad *et al.*), Phys.Lett.B688:21-42,2010.

For more information: http://www-atlas.lbl.gov/pixel/



Berkeley Lab's Laser Accelerators of the Future

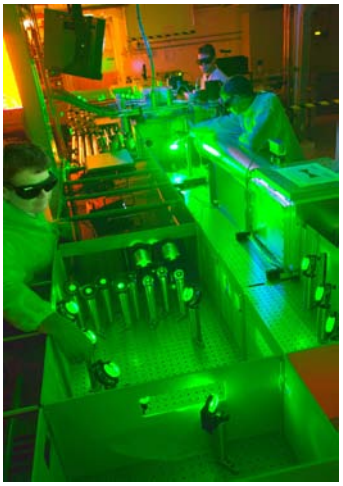
Investigators: Wim Leemans, Eric Esarey, Cameron Geddes, Anthony Gonsalves, Nicholas Matlis, Carl Schroeder, Csaba Tóth, and Jeroen van Tilburg, *Lawrence Berkeley National Laboratory (LBL)*

In 2004 the LBL Laser Optics and Accelerator Systems Integrated Studies (LOASIS) group made the cover of *Nature* with an early demonstration that laser-plasma acceleration might be practical after all. Two years later LOASIS stunned the world by accelerating high-quality electron beams to energies of a billion electron volts (1 GeV) in a mere 3.3 centimeters, instead of the hundreds of meters required by a conventional radio-frequency accelerator. Now the LOASIS team is poised to achieve energies an order of magnitude higher still, zapping electron beams to energies exceeding 10 GeV in just one meter with the BErkeley Lab Laser Accelerator (BELLA). BELLA's 10-GeV module will provide intense electron beams with pulses as short as a femtosecond for research in materials science, life sciences, physics, and chemistry—and that's just the beginning. If both the accelerator technology and the lasers that drive them continue to mature and reach higher average power, it may one day be possible to build high energy particle colliders. By stringing a hundred or so BELLA modules together, colliding beams of electrons and positrons could reach 1 TeV, a trillion electron volts, twice the energy of a conventional collider 30 kilometers long, in just a few hundred meters. That's potentially an enormous savings in money, a significant reduction in environmental impact, and a doorway to the high-energy physics of the future.

References: *Nature Physics* vol . 2, 696, Oct 2006, *Nature* vol. 431, 538, 30 Sep 2004

For more information:
http://www.lbl.gov/publicinfo/newscenter/features/2008/apr/assets/docs/NCFBELLA.pdf

Compact Particle Accelerators



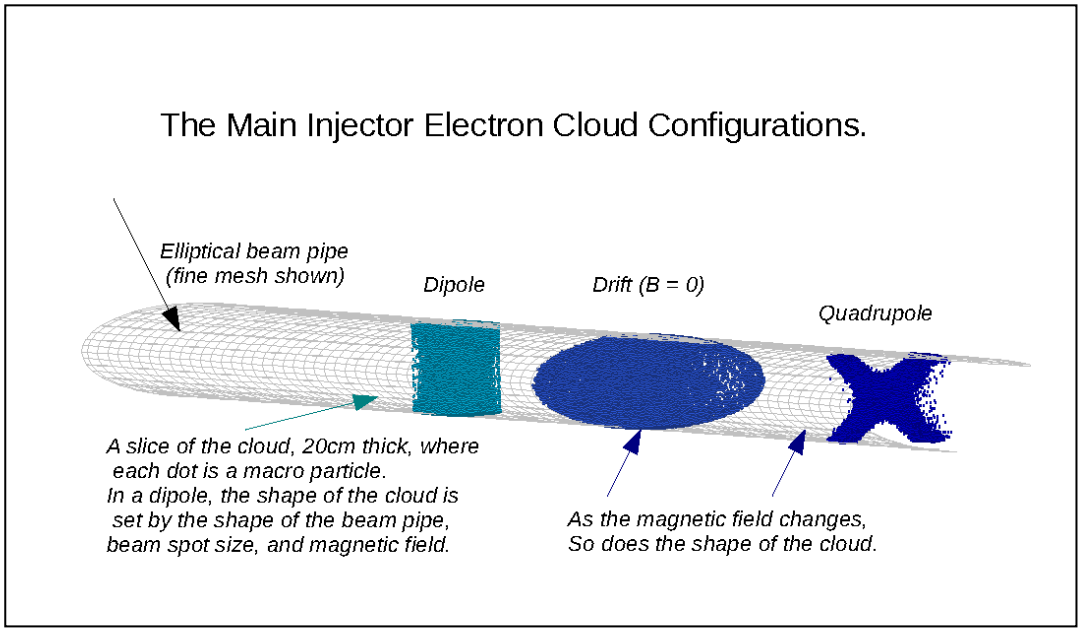
High Performance Computing Helps Project X Define Design Configurations

Investigators: P. Lebrun and P. Spentzouris, *FNAL*; J. Cary, P. Stoltz, and S. Veitzer, *Tech-X*

ComPASS SciDAC researchers are using High-Performance Computing to help Project X designers reduce the buildup of electron clouds, which are thought to be a major limiting factor for the next-generation of high-brightness proton accelerators. Electron clouds are non-neutral plasmas caused by ionization of small amounts of gas in an accelerator, and further increased through the production of electron by collisions between particles and beam pipe walls. Electron clouds can interfere with proton beams, severely limiting the performance of the accelerator. Utilizing high-performance computing facilities (The BlueGene/P system at the Argonne Leadership Computing Facility) and specialized parallel software (Tech-X's plasma simulation code VORPAL), numerical simulations were performed on hundreds of computers simultaneously in order to accurately model the buildup of electron clouds in a 15 meter section of the Fermilab Main Injector accelerator with different magnetic field configurations and different wall properties. With these simulations, ComPASS researchers were able to determine the requirements on material properties of the accelerating cavity walls and magnetic configurations for suppressing the formation of electron clouds. These simulations have shown that negative electron cloud effects can potentially be controlled in future high-brightness proton accelerators, thereby increasing performance and cost efficiency.

References: S A Veitzer *et al* 2009 *J. Phys.: Conf. Ser.* **180** 012007

For more information: www.compass.fnal.gov



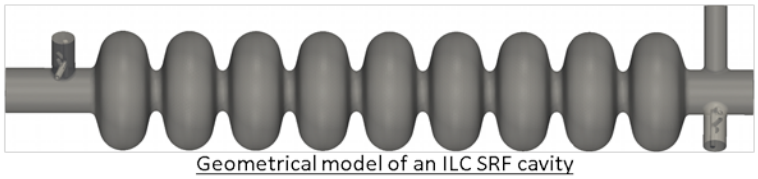
End-to-End Electromagnetic Simulation of ILC Cryomodule

Investigators: L.-Q. Lee, K. Ko, Z. Li, C.-K. Ng, and L. Xiao, *SLAC;* E. Ng, *LBNL*

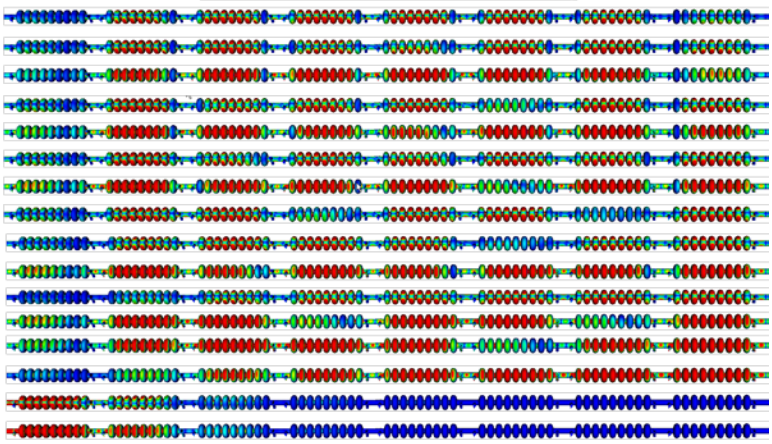
With the support of SciDAC initiative for the past decade, SLAC has developed a comprehensive suite of electromagnetic simulation codes ACE3P based on the higher-order finite-element method. One of ACE3P's codes, the eigensolver Omega3P, has increased its computational capability by 5 orders of magnitude, thanks to advances in computational science research. Under ComPASS, Omega3P was applied to end-to-end simulation of the ILC cryomodule consisting of 8 connected superconducting (SRF) cavities. The first-ever calculations of higher-order-modes (HOM) were carried out and provided direct comparison with data measured at the FLASH facility at DESY. The sixteen modes arising from a dipole pair in a single cavity exhibit complicated electromagnetic field couplings between the cavities in the cryomodule. In particular, the twisting of the field polarization along the cryomodule indicates a strong coupling for beam dynamics in the horizontal and vertical directions. Detailed analysis of measured data also showed that the damping factors of HOMs varied among the cavities in the cryomodule due to cavity imperfection. Using measured cavity parameters as inputs, the deformed cavity shape was recovered by solving the inverse problem through an optimization method. The same method was later used to identify the cause of beam breakup in the CEBAF 12-GeV upgrade prototype cryomodule. The applicability of the simulation tools across DOE accelerator complex has exemplified HEP stewardship in accelerator science R&D.

References: C. Yang, W. Gao, Z. Bai, X. Li, L.-Q. Lee, P. Husbands, E. Ng, Siam J. Sci. Comput., **27**, 873 (2005); V. Akcelik, K. Ko, L.-Q. Lee, Z. Li, C.-K. Ng, L. Xiao, J. Comput. Phys., **227**, 1722 (2008).

For more information: www.compass.fnal.gov



Geometrical model of an ILC SRF cavity



HOMs in an ILC cryomodule

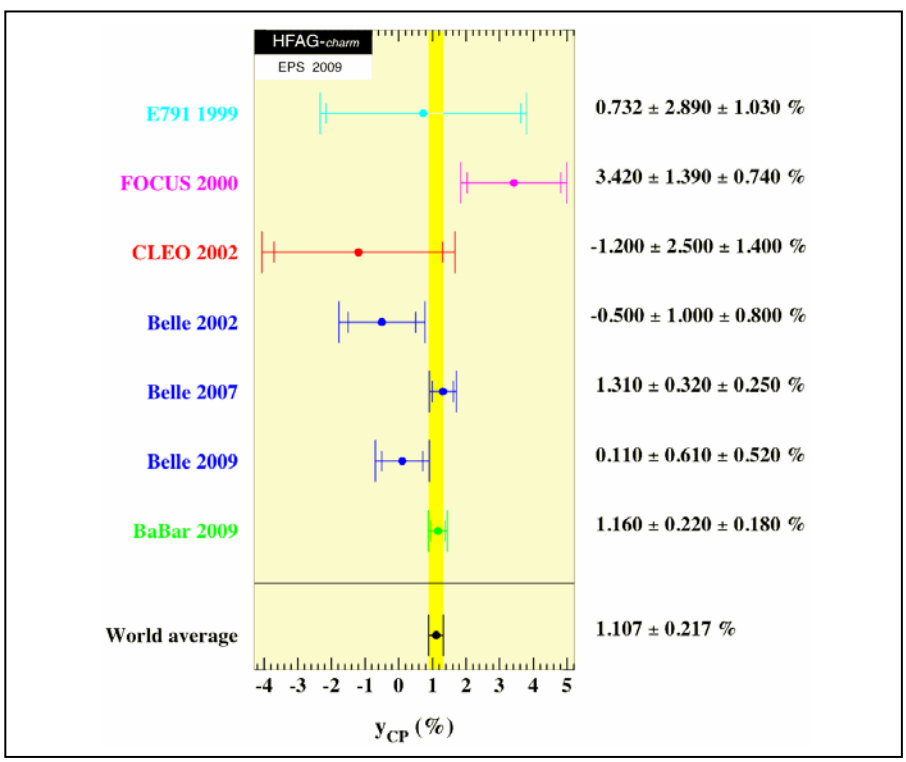
D^0-D^0 Mixing

Investigators: William Lockman and Abraham Seiden, *UCSC-SCIPP*

Unlike the situation in the *K*- and *B* systems where mixing is well-established, $D^0 - \bar{D}^0$ mixing mediated by Standard Model amplitudes is expected to be small, at the level of 1% or less in the mixing parameters, x and y. Thus, observation of charm mixing at the 1% level could indicate New Physics. The first evidence for charm mixing (3.9σ) was obtained by the BaBar experiment [1], which measured $x'^2 = [-0.22 \pm 0.30\ (stat) \pm 0.21\ (\text{syst})] \times 10^{-3}$ and $y' = [9.7 \pm 4.4(stat) \pm 3.1(syst)] \times 10^{-3}$ using wrong-sign $D^0 \to K^+\pi^-$. The observables x' and y' are related to x and y through a rotation transformation involving an unmeasured strong phase angle, $\delta_{K\pi}$. Recently, BaBar has focused on measurements of $D^0 - \bar{D}^0$ mixing parameters using self-conjugate D^0 decay modes which do not involve the strong phase. Currently, BaBar's 4.1σ measurement of y_{CP} (y assuming CP conservation) = [1.16 ± 0.22 (stat) ± 0.18 (syst)]%, obtained from lifetime measurements of $D^0 \to h^- h^+$, *h=K or* $\square$ relative to $D^0 \to K^-\pi^+$ [2] from 384 fb^{-1}, is the world's most precise determination of this quantity to date. The full BaBar dataset, 535 fb^{-1}, re-analyzed with improved tracking and particle identification algorithms and re-optimized selection criteria, will be used to significantly improve the precision of the y_{CP} measurement.

References:

1. B. Aubert et al., Phys. Rev. Lett. **98**, 211802 (2007).
2. B. Aubert et al., Phys. Rev D **80**, 071103(R) (2009).



An Improved Particle Experiment at the Energy Frontier

Investigators: A. Lopez, H. Mendez, J.E. Ramirez, and A. Zatserklyaniy, *U. of Puerto Rico-- Mayaguez*

Although new discoveries from the data presently being collected at the highest energy accelerator in the world, the Large Hadron Collider (LHC), are still in the future, plans are already underway to make improvements both to the accelerator itself as well as to the experiments. The general aim is a dramatic increase (tenfold) in the collision rate. The resulting increase in the number of interesting events studied will lead to more precise information about the new phenomena discovered which will be crucial to our understanding.

Researchers at the Univ. of Puerto Rico at Mayaguez are participating in the research and development of an improved pixel detector for the Compact Muon Solenoid (CMS) experiment at the LHC. The pixel detector is the closest to the collision point and carries out the most precise measurements of the particle trajectories.

This work involves both the computerized simulation of new detector geometries as well as experimental tests of prototype detector components. An important aspect of the improved detector is a reduction in the amount of auxiliary material, such as mechanical infrastructure and electrical connections, which are necessary but can affect the particle trajectories. Recent tests by our group have demonstrated the viability of using microtwisted pair cables for the pixel connections thereby greatly reducing the cable material.

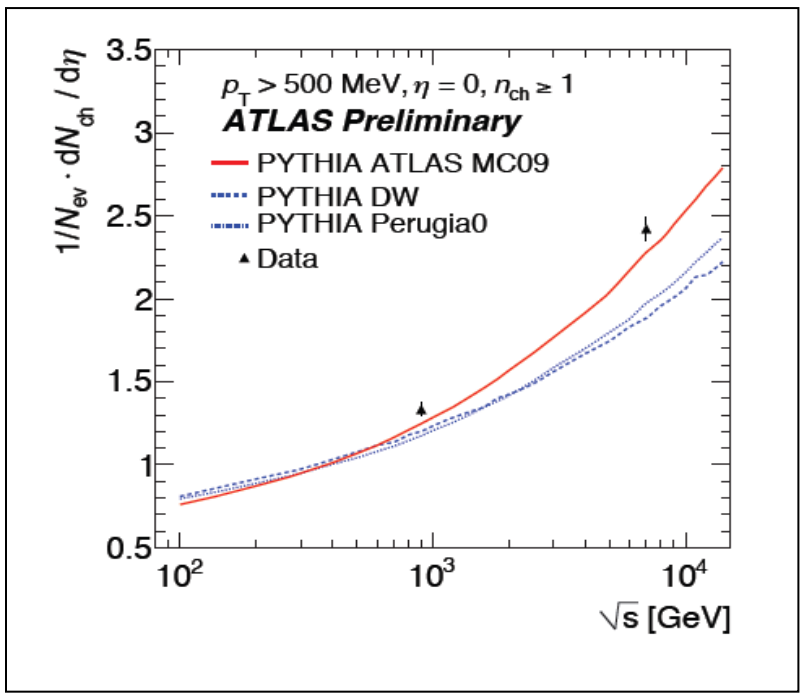
A baby step toward the understanding of unification of forces

Investigators: P.Behera, U.Mallik, Y.Meurice,J.Nachtman, C.Newsom, Y.Onel, and M.H.Reno, *University of Iowa*

The physicists at Iowa are involved in the quest to solve the puzzle of how the seeds of our current day universe were planted, trying to uncover physics beyond the Standard Model. The Large Hadron Collider was constructed with this goal in mind; we are actively engaged in both the ATLAS and CMS collaborations and are poised to make discoveries. The LHC started operation at the end of 2009, and is now working at a total energy of 7 TeV with a rapid increase in data rate. The CMS group has been responsible for the construction, calibration and maintenance of the very forward hadron calorimeter. LHC physicists are now measuring the Standard Model processes, trying to understand the detector performance and the energy scale. This year the ATLAS part of the Iowa group has been pivotal in the very first physics publication on Minimum Bias events in the first data collected at 900 GeV. Their efforts were central in tracking, vertexing, and getting all of the data from collisions and from Monte Carlo simulation processed in GRID; they were also responsible for designing, coding and debugging the Data Summary framework which is now used throughout the ATLAS collaboration. They continued in their central role for the 2.36 and 7 TeV data to be presented at ICHEP 2010 and followed by another publication.

Reference: Phys Lett B **688**, Issue 1, 21-42, by ATLAS Collaboration

For more information:
http://indico.cern.ch/getFile.py/access?contribId=165&sessionId=6&resId=0&materialId=slides&confId=86184 (DIS 2010), ICHEP 2010 (Conference Note and talk by ATLAS Collaboration)



dN/dη$_{\eta=0}$: 1.333±0.003 (stat.)±0.040 (syst.) (900 GeV
dN/dη$_{\eta=0}$: 2.418 ±0.004 (stat)±0.076 (syst) (7TeV)

Charged particle multiplicity **underestimated** by 10-30% depending on the model

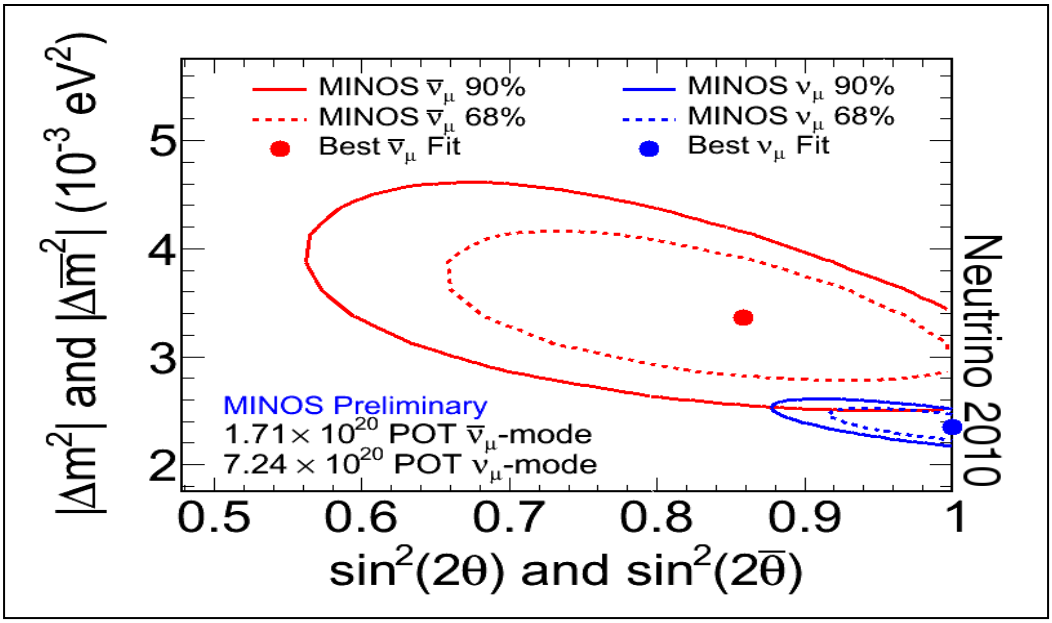
New Results on Neutrino Oscillations from the MINOS Experiment

Investigators: MINOS Collaboration (including D. Cronin-Hennessy, K. Heller and M. L. Marshak, *University of Minnesota*)

The MINOS Experiment has reported interesting new results on the study of neutrino oscillations at the biennial Neutrino 2010 Conference in Athens, Greece. Neutrino oscillations are a process in which neutrinos of one type spontaneously transform in neutrinos of a different type. Measurements of neutrino oscillations provide a means to study the fundamental interactions in the Universe and, possibly, to understand why our present day Universe contains very different amounts of matter and antimatter. The new MINOS measurements provide the world's more precise values of the parameters that relate to oscillations from muon neutrinos to tau neutrinos (blue lines in the diagram below). A perhaps even more interesting result is that MINOS measures possibly different parameters for muon antineutrino to tau antineutrino oscillations (red lines). There is currently no theoretical framework to explain such an effect. MINOS also reported other new results at the same conference, including some evidence for muon neutrino to electron neutrino oscillation, a process that has not been previously been observed, as well as new results on oscillations into so-called "sterile" neutrinos and new measurements of neutrino cross-sections. The University of Minnesota is a founding participant in the MINOS Collaboration. The University's unique underground laboratory at Soudan MN houses the MINOS Far Detector and is the target for the 730 km long Fermilab-to-Soudan NuMI Long Baseline Neutrino beam.

References: Phys. Rev. Lett. **101**, 131802 (2008).

For more information: http://www.fnal.gov/pub/presspass/press_releases/minos-antineutrinos-20100614.html



First exclusion of Standard Model Higgs boson at mass near 165 GeV

Investigators: A. Khanov and F. Rizatdinova, *Oklahoma State University*

One of the most exciting mysteries of modern high energy physics is the origin of mass. While the exact mechanism that gives rise to masses of elementary particles remains to be uncovered, the common belief is that masses arise via spontaneous symmetry breaking, which predicts the existence of the hypothetical particle named Higgs boson. A quest for this fundamental particle constitutes the core of the physics program at modern large collider experiments. The Standard Model (SM) Higgs boson production limits have been improved significantly during the last two years due to successful physics program running at the Tevatron accelerator at Fermi National Laboratory. The OSU physicists contributed to this search as members of one the two large Tevatron experiments, D∅. They proposed a new channel $WH \rightarrow WWW \rightarrow l^{\pm}l^{\pm}+X$, where the final state is characterized by two high momentum charged leptons of the same charge. This is very distinct signature which makes this channel very clean. The results of this search were combined with other searches performed at the D∅ experiment. Using the total amount of up to 5.4 fb^{-1} of integrated luminosity of data, the D∅ experiment in a combination with the CDF experiment for the first time since the LEP era has been able to exclude a new range of Higgs masses from 162 to 166 GeV at 95% C.L.

Reference: Phys. Rev. Lett. 104, 061802 (2010), 11 pp.

New mechanism for neutrino mass generation and triply charged Higgs bosons at the LHC

Investigators: K.S. Babu, S. Nandi, and Z. Tavartkiladze, *Oklahoma State University*

We proposed a new mechanism for generating small neutrino masses which predicts the relation $m_\nu \sim v^4/M^3$, where v is the electroweak scale, rather than the conventional seesaw formula $m_\nu \sim v^2/M$. Such a mass relation is obtained via effective dimension seven operators $LLHH(H\dagger H)/M^3$, which arise when an isospin 3/2 Higgs multiplet Φ is introduced along with iso-triplet leptons. The masses of these particles are naturally in the TeV scale. The neutral member of Φ acquires an induced vacuum expectation value and generates neutrino masses, while its triply charged partner provides the smoking gun signal of this scenario. These triply charged bosons can be pair produced at the LHC and the Tevatron, with Φ^{+++} decaying into $W^+\ell^+\ell^+$ or $W^+W^+W^+$, possibly with displaced vertices. The leptonic decays of Φ^{+++} will help discriminate between normal and inverted hierarchies of neutrino masses. This scenario also allows for raising the standard Higgs boson mass to values in excess of 500 GeV. This proposal links the neutrino physics with the high energy collider physics.

Reference: Phys. Rev. D80, 071702 (2009), 5 pp.

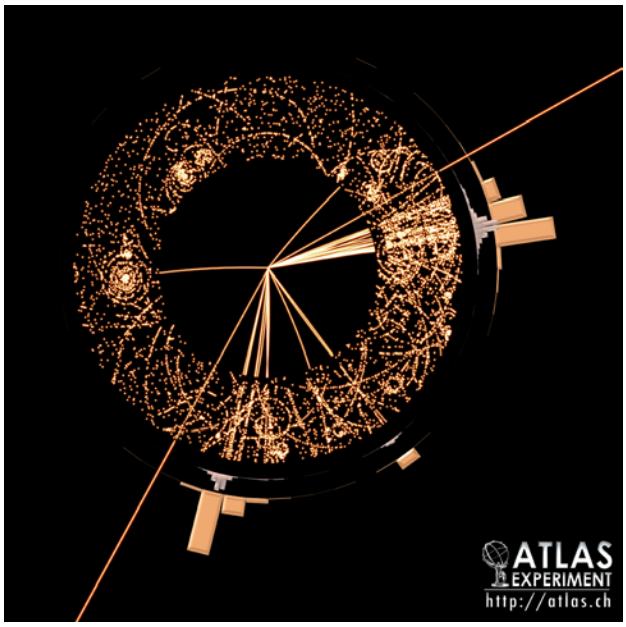
COLLISIONS AT LAST! The ATLAS experiment on the Large Hadron Collider at CERN

Investigator: J Nielsen, *UCSC-SCIPP*

When the high-energy proton beams of the Large Hadron Collider collided for the first time in 2009, there were cheers from physicists working on the ATLAS experiment, one of the general purpose detectors at the LHC. A group from the University of California, Santa Cruz was one of the first in the U.S. to begin working on the experiment in 1994. Researchers at the Santa Cruz Institute for Particle Physics (SCIPP) helped develop the complex silicon tracker that intercepts particles spraying from the collision and measures their directions with micron-level precision. They also wrote and tested algorithms for identifying high-energy photons produced in collisions, even if the photons convert to an electron-positron pair. Recent measurements show that the experiment is performing well and collecting high-quality data. Scientists are now in the hunt for signs of new physics in the form of new forces or new particles. Theories of supersymmetry predict new particles that may be found in the ATLAS experiment and may be the "dark matter" known to comprise more than 75% of the universe. The SCIPP physicists have developed techniques that could find new particles in the data from the current run.

Reference: "Large Hadron Collider Set to Unveil a New World of Particle Physics," Science Daily

For more information:
http://www.sciencedaily.com/releases/2008/08/080820163243.htm



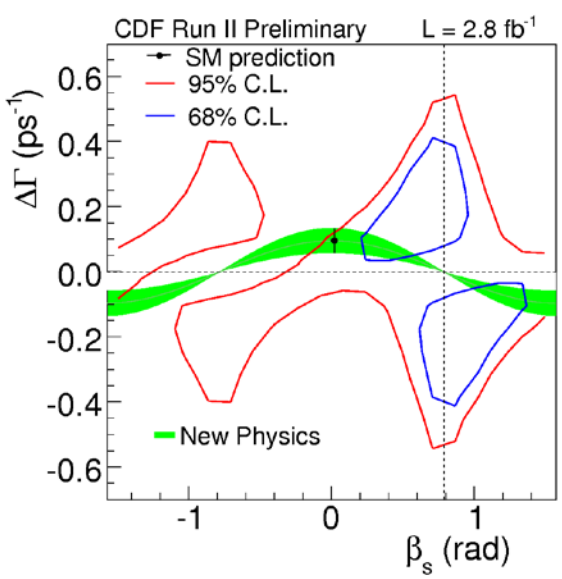
Measurement of the CP Violation Phase sin(2β_s) in B_s Decays into J/ψ φ with CDF

Investigators: M. Paulini and E. Pueschel, *Carnegie Mellon University*

The fact that all antimatter in the universe has disappeared and the remainder is made only of matter particles can be linked to a small difference between the rate of decay of particles and antiparticles. This effect, called CP violation, was first discovered in the decay of K mesons. CP violation is also expected to occur in strange B_s mesons containing both a strange and a beauty quark. However, the Standard Model predicts the effect to be very small in the decay of B_s mesons into a J/ψ and φ meson. If a large CP violation is measured in B_s mesons, this must be due to a contribution from physics beyond the Standard Model. Physicists from Carnegie Mellon University working on the CDF experiment at Fermilab played a significant role in the measurement of the matter-antimatter symmetry in B_s decays. They find that the value of the CP violation parameter favored by the Standard Model is outside the one-standard-deviation region allowed by the original measurement indicating that CP violation in the B_s system is only in marginal agreement with the Standard Model prediction. The first measurement from 2008 has recently been updated with more data, but still more statistics is needed for a final answer to this intriguing subject.

Reference: T. Aaltonen et al. [CDF Collaboration], Phys. Rev. Lett. 100, 1616802

For more information: http://www-cdf.fnal.gov/physics/new/bottom/080724.blessed-tagged_BsJPsiPhi_update_prelim/



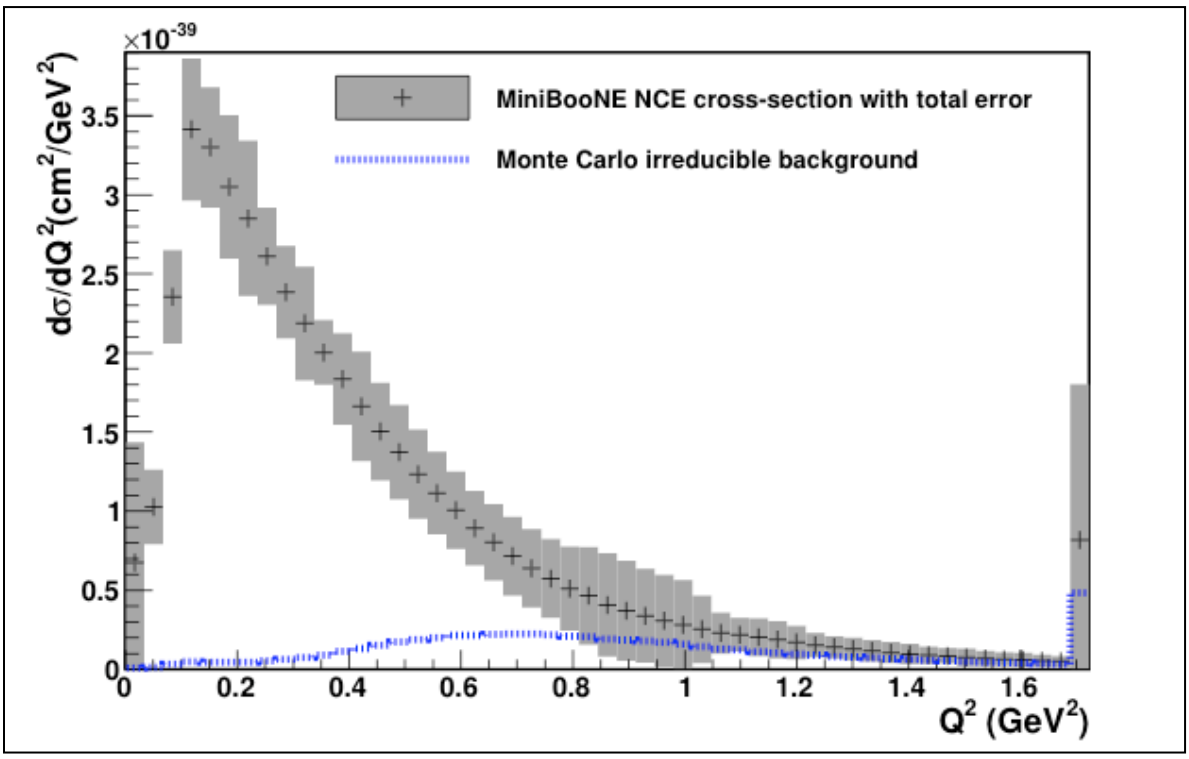
Allowed range for the CP violation parameter 2 β_s and the decay rate difference ΔΓ from the CDF analysis.

Neutrino-Nucleon Neutral Current Elastic Scattering in MiniBooNE

Investigators: D. Perevalov and I. Stancu, *University of Alabama*

MiniBooNE has used a high-statistics sample of neutral current elastic (NCE) interactions to measure the neutrino-nucleon NCE scattering flux-averaged differential cross-section, plotted below. Unlike charged current quasi-elastic (CCQE) scattering, the neutral current is sensitive to the nucleon's isoscalar weak current, of which the isoscalar axial weak current is of particular interest. The differential cross-section distribution has been fit with fixed nucleon form factors apart from an axial mass, M_A, and provides the best fit for M_A = 1.39 +/- 0.11 GeV. This higher value of M_A (as compared to the largely accepted value of M_A = 1.02 GeV) is in agreement with the results from other recent experiments for muon neutrino CCQE scattering of carbon, oxygen and iron. In addition, for energies above Cherenkov threshold, a sample of NCE proton-enriched events was obtained, which was used for the ratio measurement of neutrino-proton to neutrino-nucleon events, which in turn is sensitive to \Delta s, the strange quark contribution to the nucleon spin. A value of \Delta s = 0.08 +/- 0.26 has been extracted, in agreement with the results from the BNL E-734 experiment.

References: To be submitted to Physical Review D

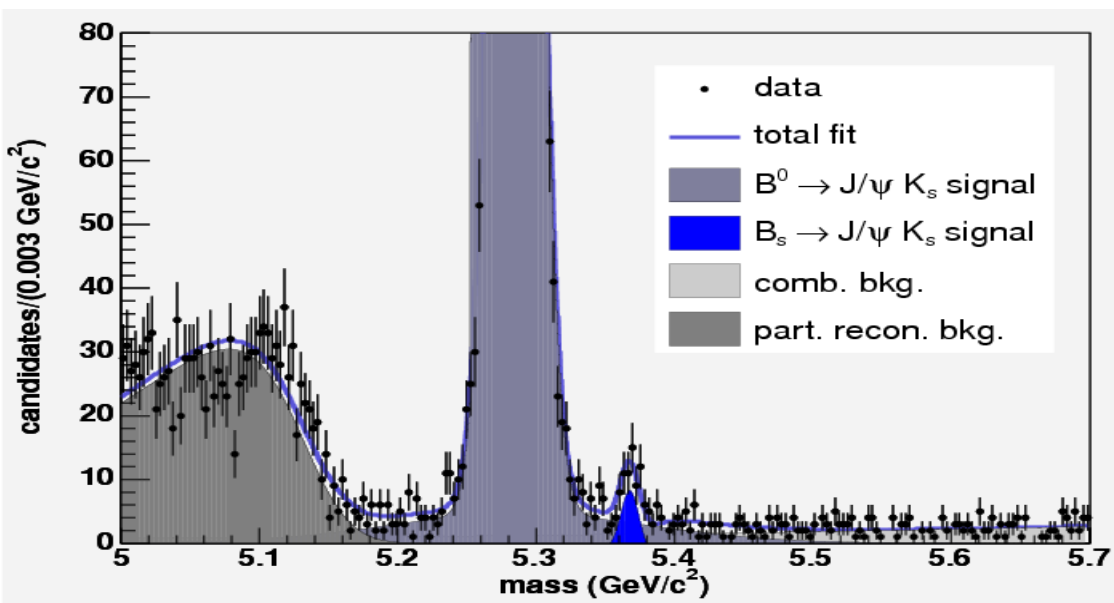


New ways to decay

Investigators: K. Pitts, O. Norniella, and B. Carls, *University of Illinois--Urbana-Champaign*

Early in the history of the universe we believe there were equal amounts of matter and antimatter. Now, 14 billion years after the Big Bang, the universe has lots of matter, but no antimatter. The search for effects that might have caused this asymmetry between matter and antimatter has led us to the study of B_s (b-sub-s) mesons, a bound state of a bottom and strange quark. By studying how these particles behave, we hope to gain insight into how our universe came to be matter-dominated, and why we exist! Recently, using the CDF detector operating at the Fermilab Tevatron, we have identified two new ways in which the B_s meson can decay. Each of these new decay modes is rather rare, less than 1 in every 50,000 B_s mesons will decay in these newly identified ways. The figure below shows a very large peak at a mass of 5.28 GeV/c^2, which is a decay of the B^0 (b-zero) meson, a bound state of a bottom and down quark, that has been measured precisely by a number of experiments. The small blue peak at 5.36 GeV/c^2 represents about 60 events in one of these newly observed B_s decay modes. Although the observation of these decays does not yet shed light on the matter-antimatter asymmetry, the properties of these decay modes will help us to further understand the nature of antimatter.

For more information: www-cdf.fnal.gov



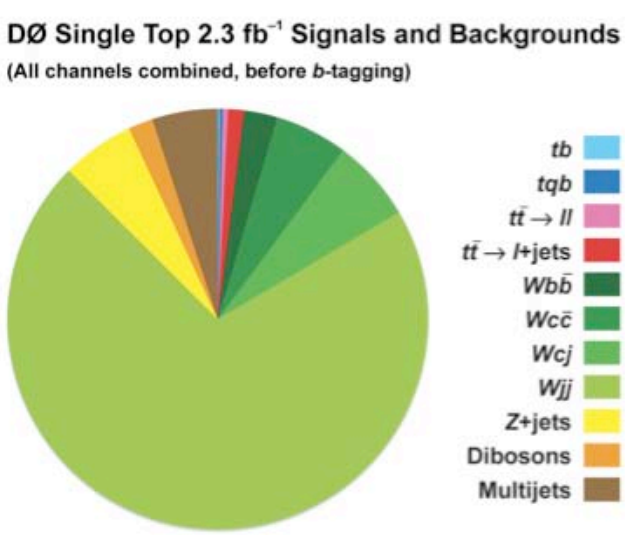
Reaching for the Top

Investigators: Members of the DØ Collaboration and T Adams, A Askew, S Blessing, S Hagopian, J Owens, H Prosper, L Reina, and H Wahl, *Florida State University*

In 2009, after a veritable *tour de force* lasting fourteen years, a fundamental prediction of the Standard Model of particle physics was confirmed at Fermilab: that in energetic proton antiproton collisions, a top quark can be created without its antiparticle. The rarity of this reaction is illustrated in the pie chart below. It shows the relative strength of the single top quark signal as a thin blue line. Finding this reaction was critical. Had it been shown not to exist, at approximately the predicted rate, the Standard Model would have been dealt a serious blow. But now that we know that such reactions exist, the current interest is to use them as a probe of new physics by measuring the cross section of these reactions as accurately as possible. Members of the Florida State University group made key contributions to these measurements – either as active participants in the DØ Collaboration or through the work of its theoretical physicists. One important contribution of the Florida State University group was its introduction and development of Bayesian neural networks (BNN), a mathematical method that, in part, made it possible to measure the rare single top quark signal in a convincing manner.

Reference: Science Daily, http://www.sciencedaily.com/releases/2009/03/090309131725.htm

For more information: http://www-d0.fnal.gov/Run2Physics/top/singletop_observation



PRL 103, 092001 (2009) PHYSICAL REVIEW LETTERS week ending 28 AUGUST 2009

Observation of Single Top-Quark Production

0031-9007/09/103(9)/092001(7) 092001-1 © 2009 The American Physical Society

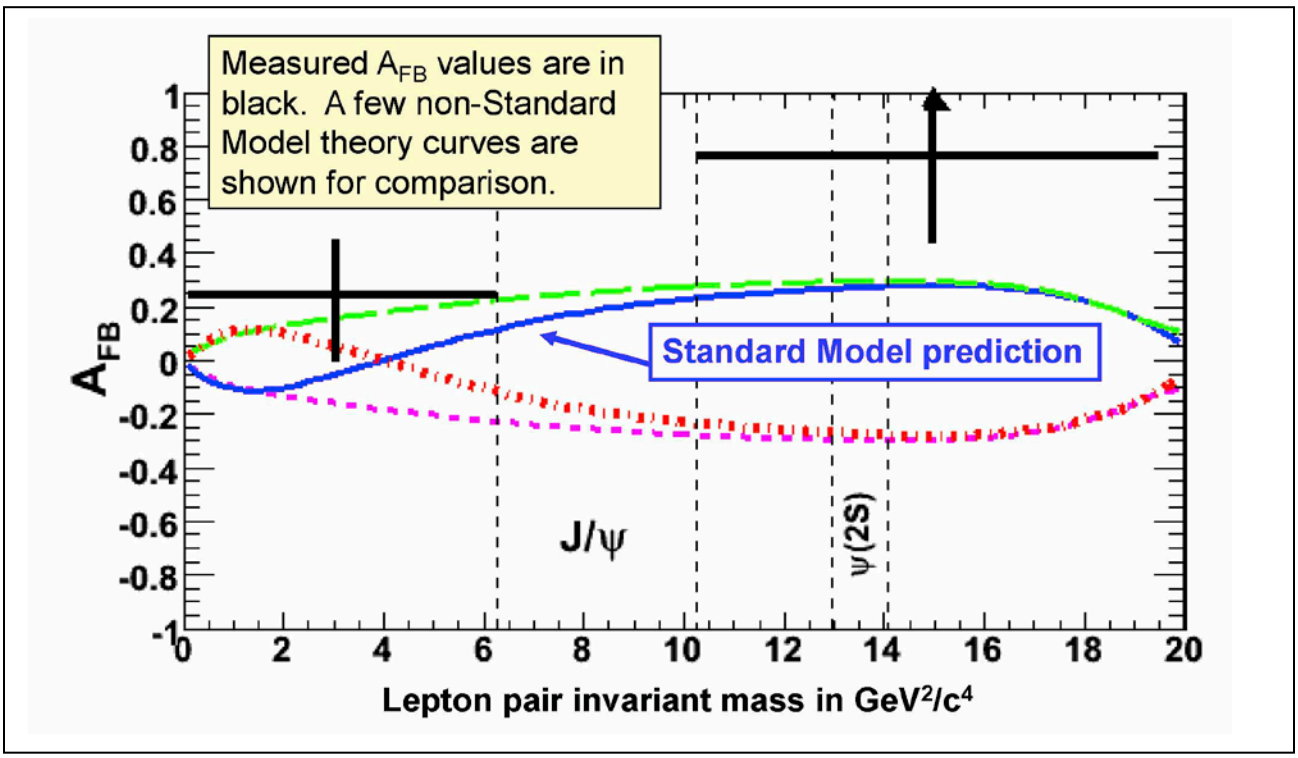
Probing for New Physics in Rare *B*-meson Decays

Investigators: Jack L. Ritchie and Christopher J. Schilling, *University of Texas at Austin*

The BaBar experiment at the SLAC PEP-II *B*-factory has many ways to search for deviations from the Standard Model that would reveal the presence of yet unknown physics processes. One of the most promising of these is the study of decays of the type $B \rightarrow K^* l^+ l^-$, where the l represents an electron or muon. This rare decay occurs only once in about a million *B* decays. A particularly incisive probe for new physics is a measurement of the lepton forward-backward asymmetry (A_{FB}) in this decay; it is determined from the angular distribution of the leptons. Theoretical physicists can precisely predict its value as a function of the invariant mass of the lepton pair in the Standard Model and in a wide variety of new physics scenarios. A_{FB} for $B \rightarrow K^* l^+ l^-$ is difficult to measure, but working with colleagues on BaBar, we completed a new measurement in 2008. Work is now underway to update this measurement by including the final BaBar data, which will add about 25% more events to our sample. Our result (shown in the accompanying figure) hints at the presence of physics beyond the Standard Model, but it is statistically limited so that a firm conclusion is currently not possible. The Belle experiment in Japan has made a similar measurement with consistent results. To fully exploit the potential of a measurement of A_{FB} in $B \rightarrow K^* l^+ l^-$, significantly larger samples of these decays will be required, but we have demonstrated that the measurement is feasible and will not be limited by systematic errors.

Reference: B. Aubert *et al*. (BABAR collaboration), Physical Review D, 79(R), 031102 (2008)

For more information: http://www-public.slac.stanford.edu/babar



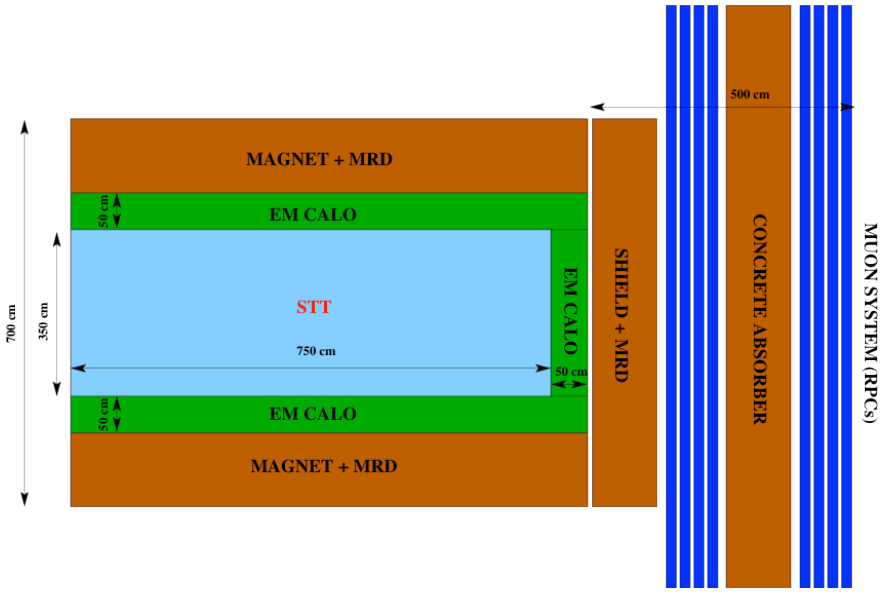
Precise Characterization of Neutrino Events and Neutrino Beams

Investigators: S.R. Mishra, R. Petti, and C. Rosenfeld, *University of South Carolina*

The last decade saw the discoveries of atmospheric and solar neutrino oscillations. The HEP community now faces the task to measure all the parameters that govern neutrino oscillation.[1] An important contributor will be an experiment in which an intense muon neutrino beam, generated at Fermilab, propagates to a “far detector” 1200 kilometers away in DUSEL, a new underground lab in South Dakota. On the journey, some of the muon neutrinos will change flavor to electron or tau neutrinos. Making sense of the far detector data requires that the flux and flavor composition of the beam as well as the rates for various types of neutrino interactions in the far detector be known with high precision. A “near detector” makes this possible. The neutrino group at the University of South Carolina has created the conceptual design for a near detector, "HiResMnu,"[2] that takes its inspiration from CERN's NOMAD detector. Its centerpiece is a fine-grained, low-density 120 m3 charged particle tracker, which also serves as the neutrino target. The tracker and a surrounding fine-grained electromagnetic calorimeter are embedded in a magnetic field. The tracker also functions as a transition radiation detector facilitating high fidelity electron identification. A muon identifier rounds out the complement of instrumentation. The design is capable of distinguishing an incident neutrino from its anti-particle as well as determining the incoming flavor and energy. The unprecedented competence of this detector together with the extraordinary intensity of the next-generation neutrino beams will considerably enhance the precision of Standard Model neutrino phenomenology as well as oscillation physics.

References:

1. http://cupp.oulu.fi/neutrino/, http://neutrinooscillation.org/, http://www.nu.to.infn.it/.
2. “A high resolution neutrino experiment in a dipole-magnetic field in Project-X,” S.R. Mishra *et al*. (Feb. 18, 2008), http://www.fnal.gov/directorate/Longrange/Steering_Public/files/LOI-08-02-18_HiResMnu.pdf.



Legend

STT: Straw Tube Tracker

EM CALO: Electromagnetic Calorimeter

MRD: Muon Range Detector

RPC: Resistive Plate Chamber

The highest energies probe the smallest constituents of matter

Investigators: E.Cheu, K.Dienes, K.Johns, J.Rutherfoord, I.Sarcevic, M.Shupe, S.Su, D.Toussaint, and E.Varnes, *University of Arizona*

To discover what the universe is made of and how it works is the goal of elementary particle physics. High energies are required to "see" ever smaller features of the quantum world. This world, surprisingly, seems inextricably linked to the structure and history of the universe. These nine faculty in the University of Arizona Physics Department are dedicated to unraveling the mysteries of the smallest constituents of matter and their interactions and to finding new forms of matter and energy, and perhaps additional dimensions of space. The theorists in the group focus on various theoretical and phenomenological aspects of physics both within and beyond the so-called Standard Model of elementary particle physics. New theories which might resolve current puzzles with satisfying self-consistency are the holy grail. Predictions within reach of upcoming experiments are particularly important for progress. The experimentalists collaborate on large scale experiments carried out at two international accelerator labs: The DØ experiment at Fermilab and the ATLAS experiment at CERN. A part of the group's effort goes into innovative instrumentation to allow major new capabilities for the next generation of experiments. The group hopes to find examples of the elementary particles behaving in unanticipated ways, leading to a new understanding of how nature works at the smallest distances.

Reference: C.Quigg, Scientific American, Feb 2008, p46.

For more information: atlas.physics.arizona.edu

Completed module, part of the ATLAS Forward Calorimeter with the Arizona construction team in the clean room

Understanding Jets at the Large Hadron Collider

Investigator: Matthew D. Schwartz, *Harvard University*

The Large Hadron Collider (LHC) at CERN is now taking data at the highest energies ever recorded. While the LHC promises to give us glimpses into the fundamental nature of matter, understanding its output will be an extremely challenging enterprise. In order to better understand what it going on, having more accurate theoretical calculations will be an invaluable tool. Researchers in the theoretical high energy physics group at Harvard University are currently investigating numerous approaches which may help us unravel the LHC data. As an example, consider the production of high energy photons. Because photon energies can be measured very accurately, this process is an extremely important benchmark for calibrating the accuracy of our theoretical predictions. In recent work, Schwartz's research group produced an extremely accurate prediction of the photon's transverse momentum (pT) distribution. Shown in Figure 1 is the photon pT spectrum at the Tevatron, comparing previous work (left) to their new results (right), performed using Soft-Collinear Effective Theory (SCET). As the figure shows, the SCET calculation both improves the agreement with data (black data points are closer to the center of the uncertainty band) and has reduced theoretical uncertainty at large pT (size of the band) as compared to previous work. One application of this work is to better measure the parton distribution functions at the Tevatron and the LHC. This is possible only because the theory uncertainty (green band) is now smaller than the PDF uncertainty (blue lines). Comparisons of the SCET predictions to early LHC data should be available soon. Work is also in progress on improved theoretical predictions for the related processes W and Z boson production at high pT, which the experimental high energy physics group at Harvard is currently measuring at the LHC.

References: T. Becher and M. D. Schwartz, "Direct photon production with effective field theory" JHEP 0911:0681 (2010).

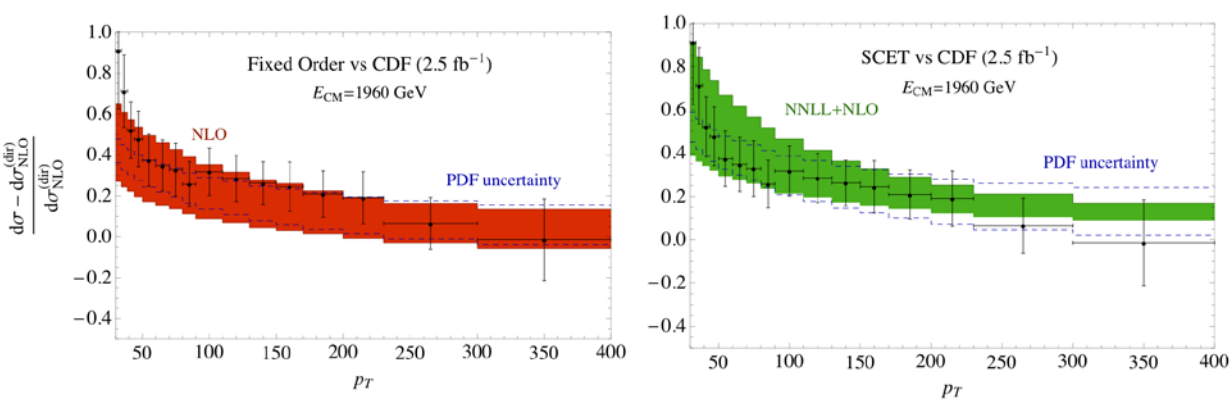


Figure 1: Direct photon pT distribution – previous work (left) is improved with SCET (right). Black points are Tevatron data from CDF.

Light Higgs Boson and New Fermions at the LHC

Investigators: I. Gogoladze, B. He, and Q. Shafi, *University of Delaware*

Unification at high energies of the three Standard Model (SM) gauge couplings can be achieved, without supersymmetry, by introducing a pair of vectorlike fermions carrying SM charges. We recently performed some calculations in this framework and find that the preferred mass range for the new fermions is around 400 GeV - 1 TeV, which therefore makes them accessible to LHC searches. Furthermore, we have shown that these new fermions can significantly modify some well known bounds on the mass of the SM Higgs boson. For instance, the requirement that the SM vacuum is stable in these models, all the way from today's energies to the Planck or GUT scale, leads to a lower bound of around 115 GeV on the Higgs boson mass. This should be compared with the lower bound of about 128 GeV obtained in the absence of the new vectorlike fermions. Thus, the discovery of a relatively light Higgs boson with mass around 115-125 GeV could signal the presence of new vectorlike fermions that are about three to six times heavier than the top quark.

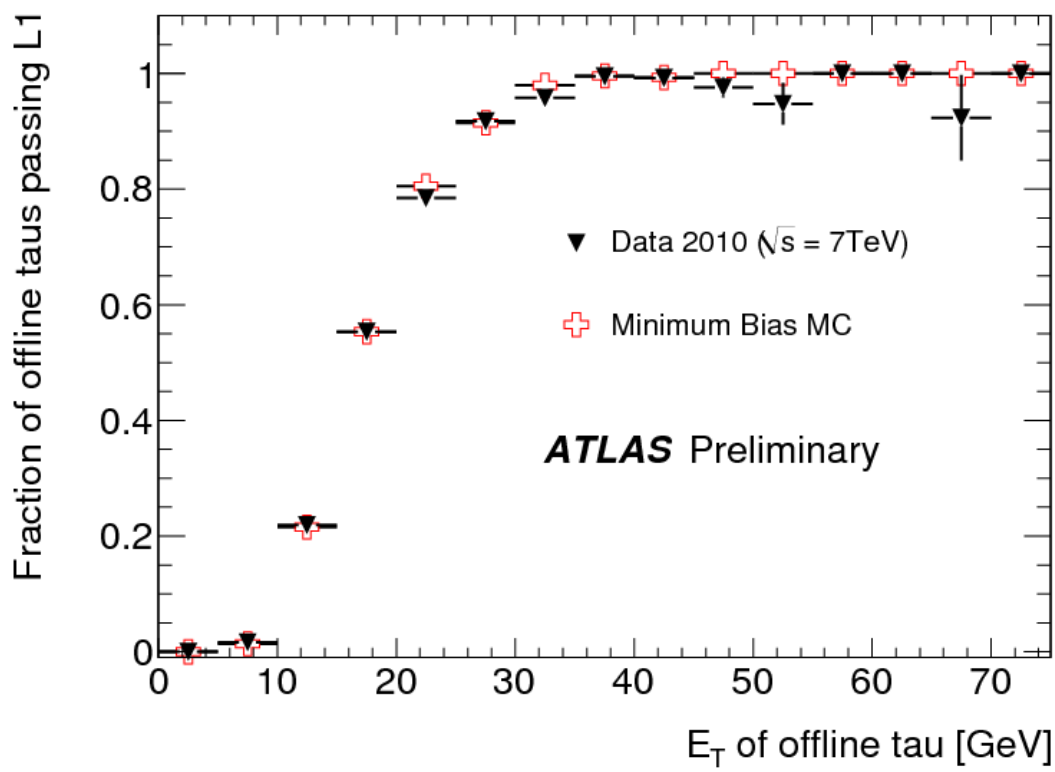
Reference: arxiv: 1004.4217 (hep-ph)

Tau Triggering on New Physics at the LHC

Investigators: M. Shamim, E. Torrence, D. Strom, *Univ. of Oregon*

In many models of new physics at the Energy Frontier, the tau lepton is a common signature. These include Higgs bosons, supersymmetric particles, and new heavy bosons. A tau trigger selecting hadronic decays has been developed for the ATLAS detector. At level one the trigger has common features with the electron/photon trigger, using EM and HAD calorimeter clusters to define regions of interest. At level two, track information is introduced, with track multiplicity, narrowness, and isolation employed to purify the selection of tau events. The tau trigger performance was optimized and evaluated with simulated data, and was commissioned in 2008 with cosmic ray data. It has been validated with 7 TeV data (see below). The tau trigger parameters will be adjusted as the LHC luminosity increases in order to optimize purity and efficiency. At 10 10^{31} cm^{-2} s^{-1} missing transverse energy and electron and muon triggers will complement the tau trigger. An enriched sample of W → tau nu will be collected. At 10^{33} cm^{-2} s^{-1} the triggers will be tightened, with an increased transverse energy threshold, and jet and lepton triggers will be used. Sensitivity to new physics will be achieved, including charged and neutral Higgs, Z', and supersymmetric particles.

For more information: http://www.uoregon.edu/~mshamim/DOE/ATL-DAQ-SLIDE-2009-294.pdf



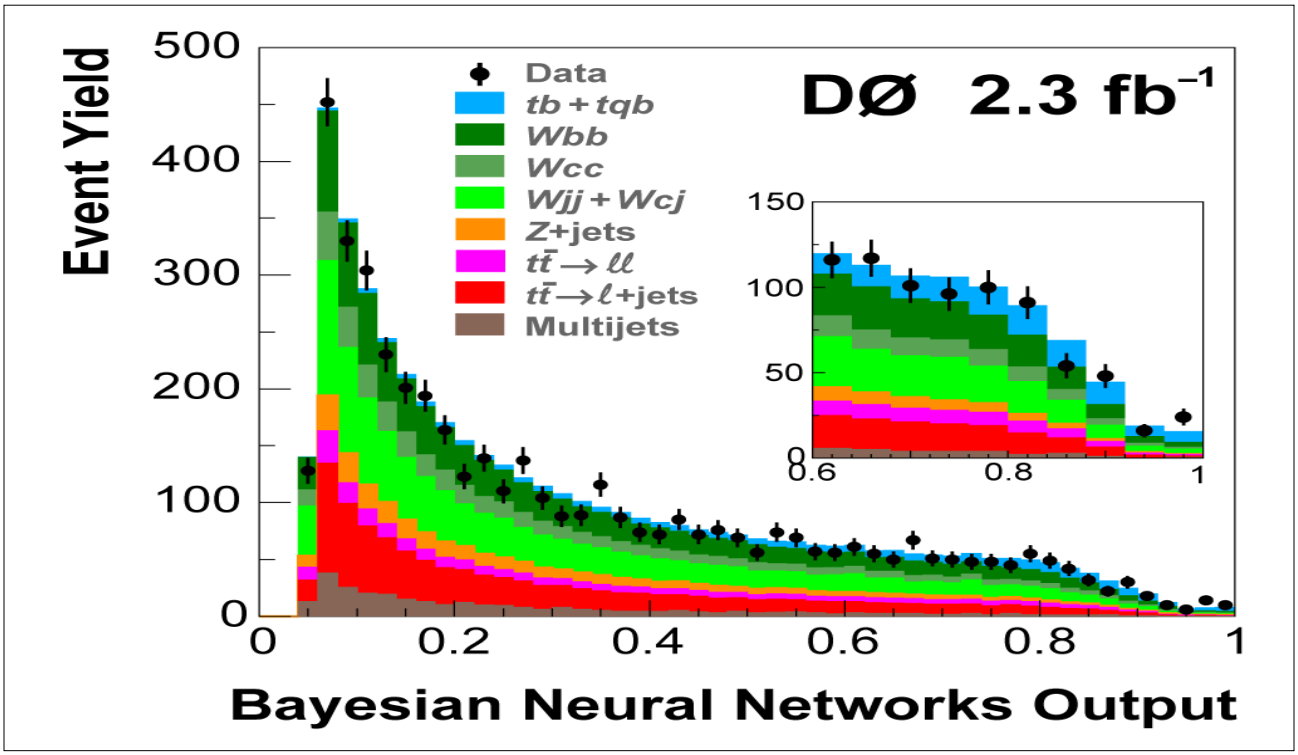
Discovery of Single Top

Investigators: B. Abbott, P. Gutierrez, S. Jain, P. Skubic, and M. Strauss, *University of Oklahoma*

The top quark was first observed through pair production at the Fermilab Tevatron in 1995. Pair production occurs through the strong interaction. In addition, the top quark can also be produced through the weak interaction, in which case the top quark is produced singly. Single top quark production allows for the direct measurement of the decay probability to other quarks and indirectly to non-standard model particles. This along with the measurement of the top quark polarization provides information on the weak interaction properties of the top quark. Because of the large physics backgrounds to this process, the observation of single-top production is far more challenging to observe than pair production, therefore requiring the use and development of more sophisticated analysis techniques. Three such techniques were employed in this analysis: the matrix element, the boosted decision tree, and the Bayesian neural network (BNN) methods. The three results were combined using the BNN method leading to a measured cross section of 3.94±0.88 pb, which is consistent with the theory prediction of 3.46 pb. The University of Oklahoma group was a key contributor on the Bayesian neural network method, where much effort went into the selection of the input variables to the network. These techniques will be useful for search of new particles at the Large Hadron Collider at CERN.

References: Phys. Rev. Lett. 103, 092001 (2009); NPR Science Friday March

For more information: http://www-d0.fnal.gov/Run2Physics/top/singletop_observation/



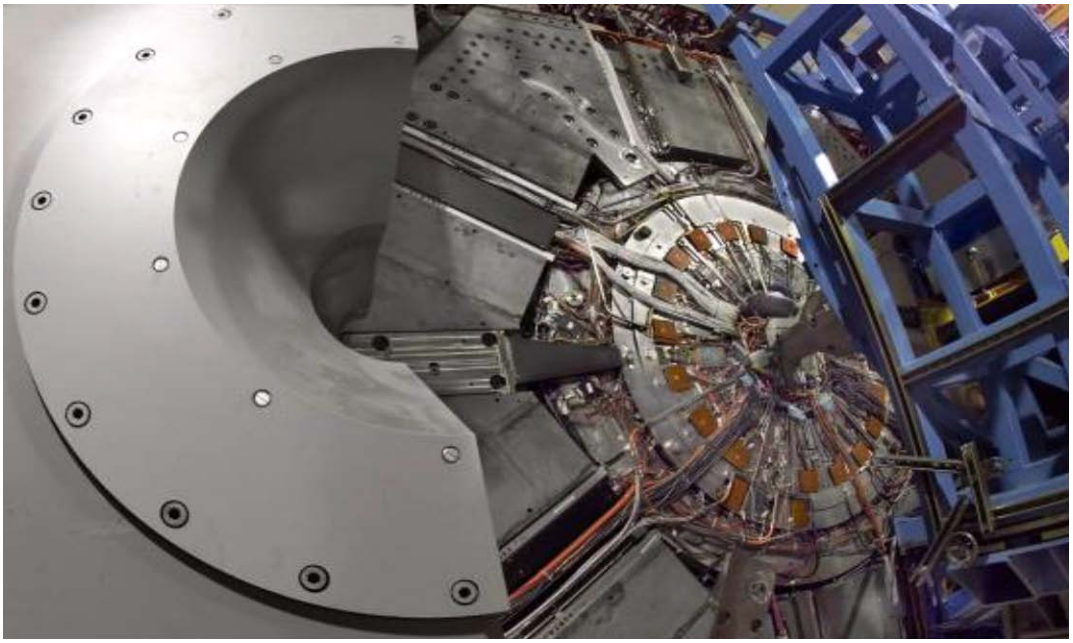
BaBar Hunts for a Low Mass Higgs

Investigators: BaBar Collaboration (Analysis teams for these analyses: A. Gabareen H. Kim, and A. Snyder, *SLAC*; Y. Kolomensky and E. Petrigura, *LBNL*)

In the standard model (SM), fundamental particles acquire mass by interacting with the Higgs field permeating space and the SM predicts the existence of one new particle called the Higgs boson. Experiments constrain its mass to be roughly 100-200 GeV/c^2 (the mass of a proton is 0.9 GeV/c^2) and finding it is one *raison d'etre* of the LHC. But many theories that extend the SM predict multiple Higgs particles with some theories calling for one of the Higgs particles to have a much lower mass. In 2008 the SLAC B-factory collided electrons and positrons at an energy just high enough to produce a b-quark and anti-b-quark pair bound in a particle called the Upsilon(3S) and the BaBar experiment, with the world's largest sample of Upsilon(3S) particles, became the ideal lab for searching for a light Higgs. In a pair of papers published in the top-tier physics journal Physical Review Letters, BaBar reported the results of its hunt for the light Higgs which is predicted to be produced ubiquitously in radiative decays of the Upsilon(3S). The Higgs would then decay, depending on its mass, to either a pair of oppositely charged muons or tau leptons. BaBar found no evidence for such light Higgs decays having a mass between 0.21 GeV/c^2 and 10 GeV/c^2 and succeeded in ruling out those theories predicting them. BaBar continues to hunt for other types of light Higgs decays and other manifestations of new physics in its very rich dataset.

References: Phys.Rev.Lett. 103, 081803(2009);Phys.Rev.Lett. 103, 181801 (2009)

For more information:
http://www.slac.stanford.edu/BFROOT/www/pubs/babarpubs.html



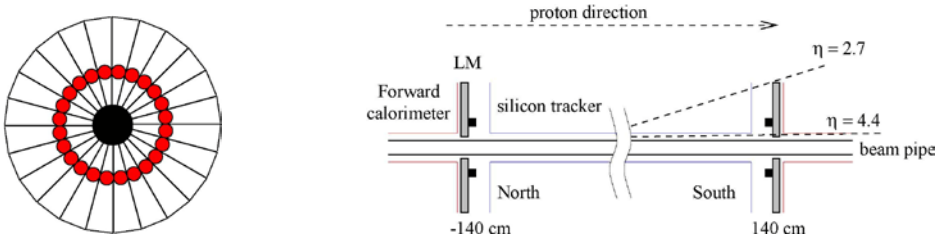
DZERO's record-setting luminosity

Investigators: G. Snow, I. Katsanos, and K. Devaughan, *University of Nebraska--Lincoln*

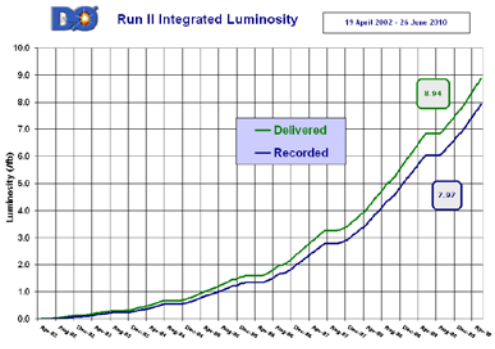
Supported by an award from the DOE/EPSCoR National Laboratory Partnership Program, a subgroup of the University of Nebraska-Lincoln (UNL) high energy physics group leads the Luminosity Working Group in the DZERO experiment at Fermilab's Tevatron Collider. Collaborators from UNL, Rice University, Michigan State University, Brown University, and Fermilab work together to make the measurement of the integrated luminosity using the detector system, shown below, which employs wedges of scintillation counters located close to the particle beams on each side of the proton-antiproton interaction region. The luminosity measurement is an essential ingredient in the calculation of any cross section quoted by the experiment for the large range of physics processes studied. Hence, the luminosity measurement is woven into publications on electroweak physics, top quark production, B physics, processes governed by Quantum Chromodynamics (QCD) such as inclusive jet and di-jet production, searches for the Higgs boson, and searches for physics beyond the Standard Model of particle interactions. As shown in the figure below, by the end of June 2010 the DZERO experiment has recorded an integrated luminosity approaching 8.0 inverse femtobarns at a center-of-mass energy of 1.96 TeV, representing an unprecedented number of proton-antiproton collisions available for physics analysis and searches for rarely occurring new phenomena.

References: T. Andeen, G. Snow, *et al*., FERMILAB-TM-2365 (2007).

For more information: http://www-d0.fnal.gov



The Luminosity Monitor System for the DZERO Experiment at Fermilab's Tevatron Collider



Delivered, recorded luminosity as of 6/26/2010

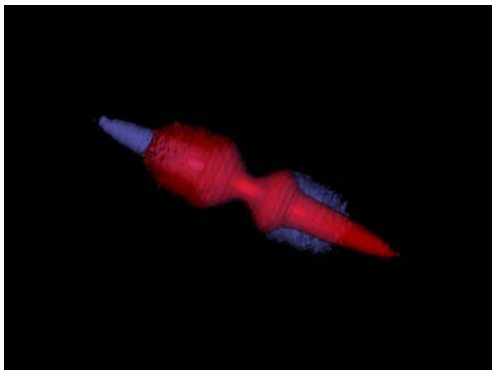
Improving the FNAL Tevatron luminosity

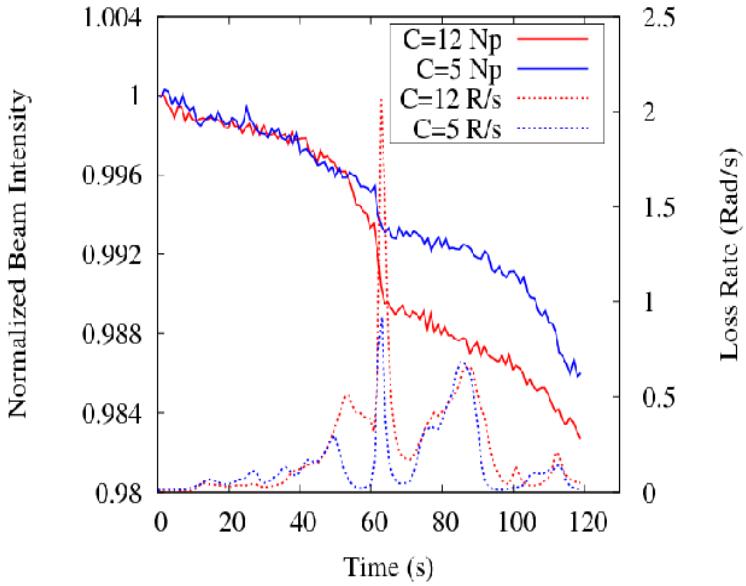
Investigators: E.G. Stern and P. Spentzouris, *FNAL*; J. Qiang and R. Ryne, *LBNL*

For the past 20 years the Fermilab Tevatron has been the energy frontier discovery machine for HEP. A lot of the successes of its physics program have relied on increased luminosity and reliable operation. Simulations of the machine by researchers of the ComPASS project were used to optimize its operational parameters resulting in reduction of beam losses and increase in beam luminosity, thus enhancing the reach of the physics program. The realistic inclusion of multiple beam dynamics processes in the simulation enabled the investigation and optimization of many parameters and effects that complicate the running of such a large accelerator. The application used the BeamBeam3D code developed under the SciDAC accelerator modeling projects. The results improved the safety and reliability of the machine and increased the physics discovery potential of the facility, enabling the lab to achieve the mission of scientific discovery in a shorter amount of time at reduced cost. Reduced beam losses lower the radiation exposure to personnel and radioactive activation and damage to the equipment. As shown in the picture below, the optimized parameters enabled operation at higher intensities without exceeding radiation limits, thus providing higher rate of proton-antiproton collisions for scientific study.

References: J. Qiang, M.A. Furman, R.D. Ryne, Phys. Rev. ST AB, **5** (2002); J. Qiang, M.A. Furman, R.D. Ryne, J.Comp.Phys., **198** (2004); E. Stern, J. Amundson, P. Spentzouris, A. Valishev, Phys. Rev. ST AB, **13** (2010)

For more information: www.compass.fnal.gov





Origin of Particle Mass

Investigators: R. Kehoe, R. Stroynowski, and J. Ye, *Southern Methodist University*

ATLAS, the largest and most complex particle detector ever built operates at the Large Hadron Collider at CERN. This experiment searches for the Higgs and new phenomena that may show up in particle collisions approximating state of the matter immediately after the Big Bang. The mass of the Higgs is unknown, but can be predicted from precise measurement of the top quark mass. The SMU group built a substantial part of the electronics of the electromagnetic calorimeter, one of the crucial components of the ATLAS detector. The search for the Higgs has begun. Future studies of the Higgs properties will need additional improvements of the ATLAS detector. For this, SMU Optoelectronics Laboratory developed a new, fastest of its kind integrated chip to serialize data obtained in the experiment. It uses ultra-thin Silicon-on-Sapphire technology to transmit 5.8 billion data bits per second over optical fibers. This step is crucial in the development of the desired 150 terabits data transmission system. Additional constraints on the Higgs mass come from precision measurements of the top quark mass. Researchers from SMU have been studying the top quark with the D0 detector at the Tevatron. Using state-of-the-art analysis techniques, they have measured the mass of this particle in a rare class of events with two leptons. The measurement is twice as precise as the previous results and favors a low value of the Higgs mass.

References:

1) *The ATLAS Experiment at the CERN Large Hadron Collider*, G. Aad et al, 2008 JINST 3 S08004.
2) *Measurement of the top quark mass in final state with two leptons*, V. Abazov et al., Phys.Rev. D80,092006(2009).

For more information: http://www.physics.smu.edu/web/

Opening New Channels to Find the Higgs Boson

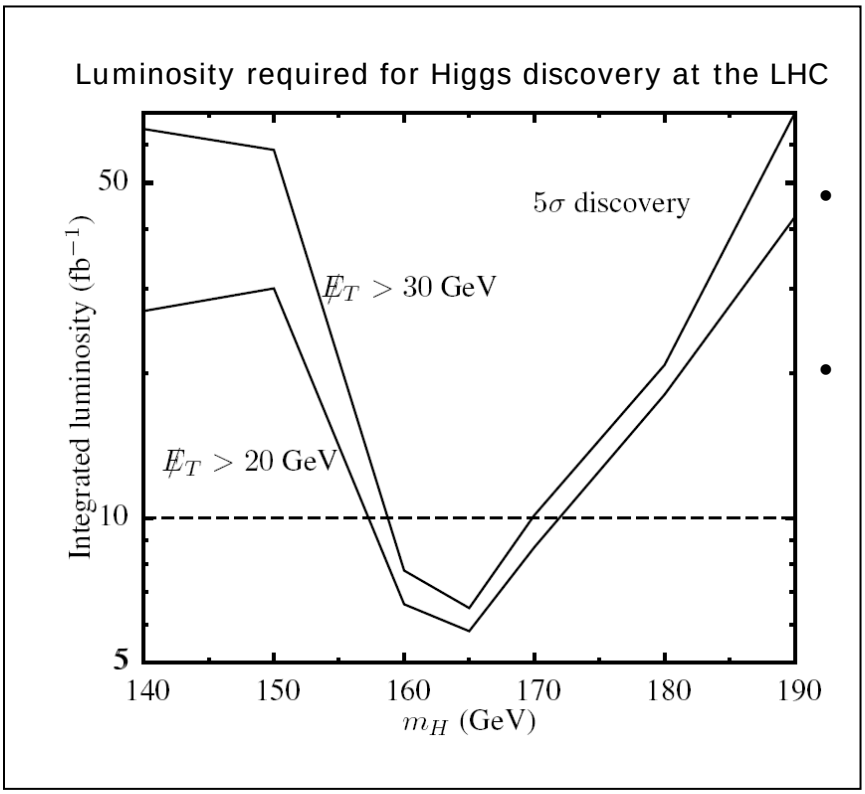
Investigator: Z. Sullivan, *Illinois Institute of Technology*

At the Illinois Institute of Technology we are demonstrating the use of a new channel for the discovery of a Higgs boson of mass 150 – 190 GeV.[1] This previously overlooked channel involves the decay of a Higgs boson to a pair of W bosons, with one W decaying into a charged lepton plus a neutrino (l+□) while the other W boson decays into a charm quark and a jet (c+j). Until now, the favored channel for observing a Higgs involved both W bosons decaying into a charged lepton plus neutrino, otherwise known as the dilepton channel. We have shown that the WW -> l+□ c+j channel may be superior to the dilepton channel in that the invariant mass of the Higgs can be directly measured, and we avoid a large, recently discovered QCD background processes[2] that severely obscures the dilepton channel. We expect that this new channel will significantly enhance the Higgs discovery potential at the LHC, and will improve existing Fermilab Tevatron searches.

References: [1]A. Menon and Z. Sullivan, arXiv:1006:1078, submitted to Phys. Rev. Lett.

[2]Z. Sullivan and E.L. Berger, arXiv:1003:4997, to appear in Phys. Rev. D.

For more information: http://www.hep.anl.gov/zack/home.html.



- Motivates development of dedicated charm tagging at ATLAS and CMS
- Plot assumes charm efficiency of ε_c ~ 50-60% (current ε_c ~15%)

First Data with ATLAS Muon System at 7 TeV

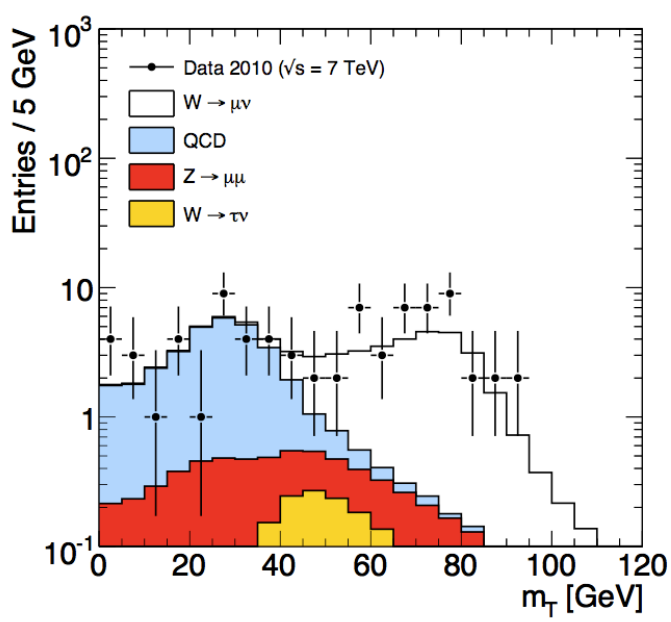
Investigator: F. Taylor, *Massachusetts Institute of Technology*

In many instances final states comprised of leptons have indicated 'new physics' and provided incisive tests of theories. Hence, a significant element of the LHC ATLAS physics program is based on the exploration of leptonic final states. To date, ATLAS has accumulated only 30 nb^{-1} of data. Nevertheless, with this early sample it was possible to perform a measurement of the $W^{\pm}$ gauge bosons production and to observe the Z^0 gauge bosons in 7 TeV p-p collisions for the first time. In the lower dilepton mass region, the J/ψ vector meson decaying to two muons also has been observed. These measurements verify that the ATLAS muon system is providing good data and has the capability to explore these important physics channels when more statistics are accumulated. This early physics program is a prelude for searches for physics beyond the standard model

The MIT ATLAS group played a leading role in the construction of the endcap muon system.

For more information: *Physics at the LHC*, *DESY, (7-12 June 2010)*: http://plhc2010.desy.de/

ATLAS Preliminary (6.7 nb^{-1})



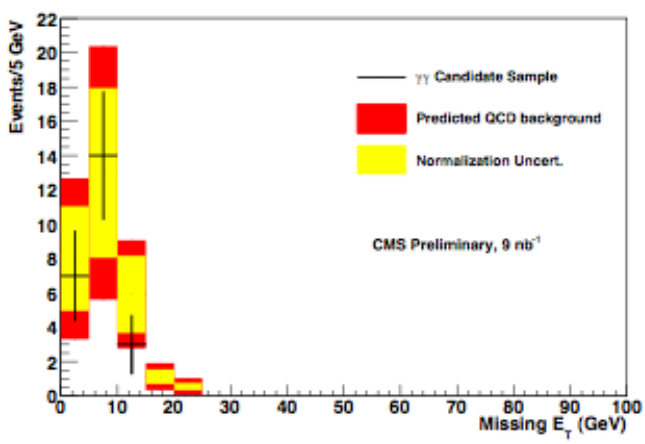
The reconstructed transverse mass m_T of high transverse momentum muons in p-p collisions at 7 TeV observed in the ATLAS detector. The bump at ~80 GeV originates from $W^{\pm} \rightarrow \mu^{\pm} \nu$ decays and the superimposed histograms show various expected contributions to the spectrum. The plot is based on ~6.7 nb^{-1}.

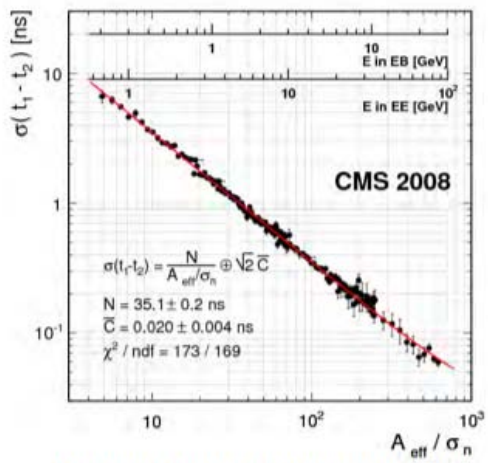
CMS: University of Virginia Contributions

M. Arenton, M. Balazs, S. Boutle, S. Conetti, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood, R. Yohay, *University of Virginia*

The University of Virginia is heavily involved in the construction, installation, commissioning, and operation of the CMS (ECAL) detector at the LHC. Our research group has produced an LED system that provides for stabilization and calibration of the ECAL endcaps and have prepared an off-line test bed for long term testing of vacuum phototriodes (VPT) in a 3.8T magnetic field provided by a large aperture a 4.7T super conducting solenoid in our UVa laboratory. We have also been involved in many other aspects of ECAL. A major accomplishment of the UVa group (Ledovskoy) has been to develop a method[1] for extracting timing of the ECAL lead tungstate crystals better than 1 ns. We have several upgrade projects under way including development of GaAs rad hard Geiger mode pixelated photodetector for use in calorimetry. We also are involved in the development of a high intensity solid state light source to back up the laser for ECAL barrel and µTCA readout architecture for ECAL and HCAL. We have several physics interests with members of the group interest in gauge mediated SUSY[2] . Other members are working to measure the ttbar cross section and as an aspect of this, deeply involved in the bbar tagging. Finally, some of us are studying QCD via photon-jet final states.

References: (1.) Time Reconstruction and Performance of the CMS Electromagnetic Calorimeter, JINST 5 T3011, 2010.
(2.) Understanding Missing Transverse Energy in Di-Photon Events for SUSY Searches, CMS AN 2010-168.





Measured time resolution as a function of energy using electrons in test beam

Left hand plot: Agreement of missing ET (MET) from di-photon events (which should contain SUSY events eventually when more data is available) with a control sample of QCD events from 9.03 nb^{-1} of 7 TeV data. SUSY will appear as a disagreement of the di-photon spectrum with the expected QCD (and EW)backgrounds at high MET.

Right hand plot: Timing resolution expected from the "ratio" method developed by A.Ledovskoy.

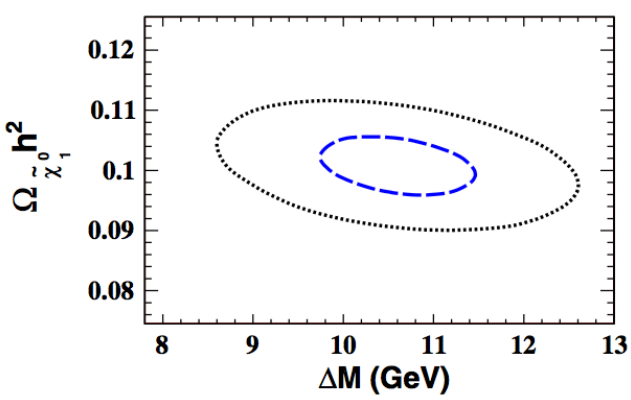
Connecting the Higgs, Supersymmetry, and the Cosmos at the LHC.

Investigators: R. Eusebi, T. Kamon, A. Safonov, and D. Toback. *Texas A&M University*

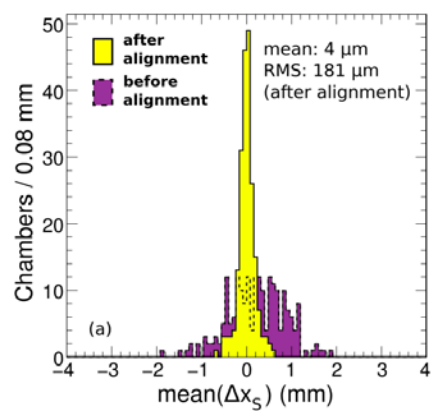
The Texas A&M group has a synergetic Supersymmetry (SUSY) and Higgs programs at the LHC. The SUSY program is focused on searches for signals of models that both provide a candidate for the cold dark matter and a cosmologically consistent explanation of the early Universe that predicts the astronomical measurements of cosmic microwave background. Events with tau (τ) leptons or top (t) quarks have been suggested to be a key probe of these types of SUSY models. At the same time, these third generation particles are a central part of our Higgs discovery program that focuses on the $H \rightarrow \tau\bar{\tau}$ channel in the early data and then on measurements of Higgs mass and couplings both in the framework of Standard Model and SUSY at high luminosity. Since the identification of tops and taus, often through their decay into muons, are keys to both programs, we have created a highly synergetic program to work on the muon systems, as well as hadronic tau identification and triggering. For the early discovery programs we focus on the identification of τ leptons from the $Z \rightarrow \tau\bar{\tau}$ and $t\bar{t}$ processes in the muon + hadronic-tau channel. In the long term we are playing a lead role in upgrading the CMS detectors and trigger with the aim of allowing improved measurements of the parameters of the theories. Our SUSY-phenomenological calculations indicate that we should have a determination of the dark matter content ($\tau h^2 \sim 0.1$) at a level of 10% using the expected performance of the tau identification (left figure) and the achieved alignment of the muon detector at the 200 mm level (right figure).

References: Phys. Rev. Letters **100**, 231802 (2008); JINST **5**, T03020 (2010).

For more information: http://physics.tamu.edu/research/list-high_energy.html



Left: Relationship between the cosmological parameter and the difference between the stau and neutralino masses. The ellipses are the expected 1 sigma uncertainties obtained with 10 fb^{-1}(dashed) and 50 fb^{-1} (dotted).



Right: Distribution of muon chamber residuals for muon tracks before and after chamber alignment at CMS.

High-precision hadron detection

Investigators: R. Wigmans, N. Akchurin, and I. Volobouev, *Texas Tech University*

A new technique we proposed to measure the properties of high-energy hadrons with much better precision than previously possible has turned out to work spectacularly well in practice. By measuring simultaneously the Cherenkov light and the scintillation light produced in the absorption of these particles in a calorimeter, the dominating source of fluctuations which tend to spoil the measurement precision could be eliminated. This (dual-readout) method has been demonstrated to work both for sampling calorimeters (in which the two types of light are detected in separate media) as for crystals in which the two types of light can be separated, e.g. bismuth germanate or lead tungstate.

References: R. Wigmans, Nucl. Instr. and Meth. A617 (2010) 129

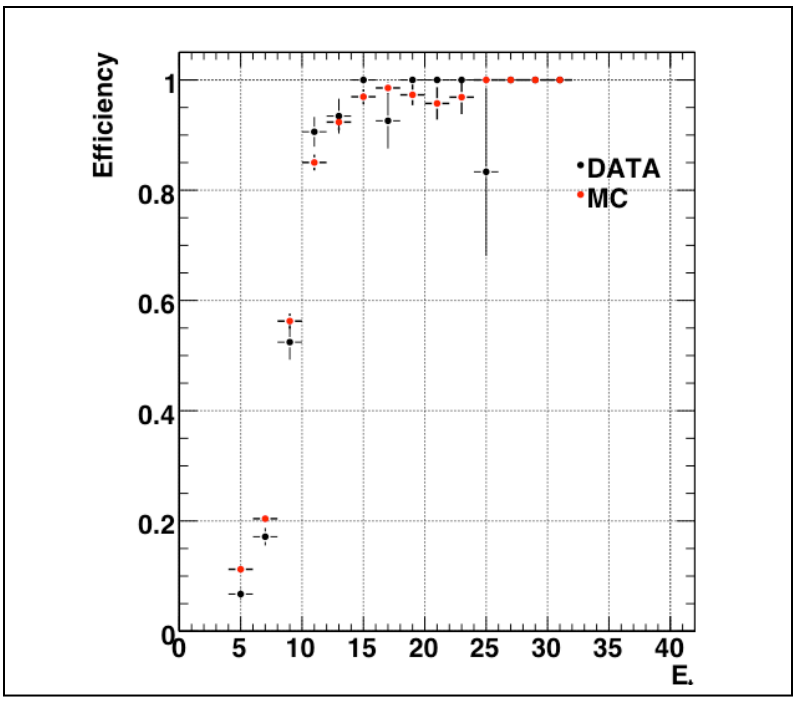
Charting new frontiers at the highest energies ever achieved

Investigator: P. Wittich, *Cornell University*

Cornell works on the biggest science experiment ever built, the CERN LHC. The LHC recreates the conditions a ten billionth of a second after the big bang to answer fundamental questions such as, Why do the particles have the masses they do? and why is there a matter-antimatter asymmetry in the universe? The Cornell group works on the CMS trigger. Though we will collide particles 40 million times a second, only few of them harbor evidence for the questions posed above. The trigger is the first step in that selection, rejecting 99.99975% of the events within seconds of the data being collected. We work on understanding, characterizing and monitoring the trigger. We have just started taking with the CMS experiment, and below shows a first comparison of the expected performance with the actual performance of this very sophisticated tool. The plot shows the response of the trigger to high-energy photons as a function of the energy of the photon. The red curve shows the expected behavior based on simulations, while the black curve shows the measured performance. They agree with one another. These plots were made using tools developed by the Cornell group. Since we know how it performs, we can confidently tailor its selection to save just those few events that will answer the big questions the LHC was designed for.

Reference: S.~Chatrchyan et al (CMS Collaboration), JINST **5** T03005

For more information: http://www.lepp.cornell.edu/Research/EPP/CMS/



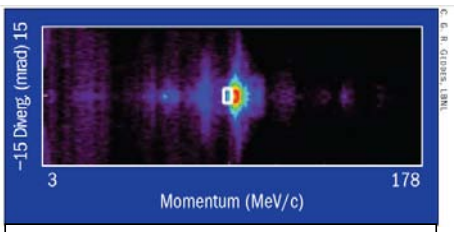
Simulations support GeV/cm lepton acceleration in the lab

Investigators: An W. (UCLA), Bruhwiler D.L., Cary J.R., Cormier-Michel E., Cowan B.M. (Tech-X), Decyk V. (UCLA), Esarey E., Geddes C.G.R. (LBNL), Huang C. (LANL), Lu W. (UCLA), Messmer P. (Tech-X), Mori W.B. (UCLA)

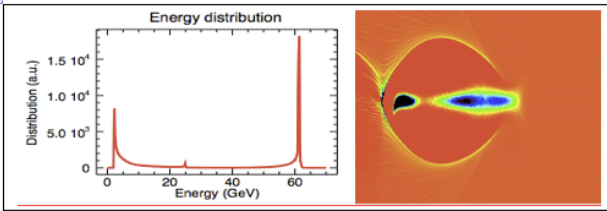
Accelerating gradients in plasma can be orders of magnitude higher than those in evacuated metal structures, holding promise for future high-energy lepton colliders with dramatically smaller footprint cost. Laser-plasma experiments have demonstrated GeV electron beams with percent level energy spread in cm-scale plasmas. Beam-driven plasma experiments have demonstrated energy gain of nearly 50 GeV in m-scale plasmas. Algorithms and software developed and continually improved by the SciDAC project ComPASS and run on massively parallel computers made important contributions to these advances. The subtle 3D dynamics of particle trapping and acceleration that forms high quality bunches has been carefully explored through simulations in a manner not accessible to experiment. Characterization of highly-nonlinear plasma bubbles and shaping of the plasma density resulted in better understanding and subsequent optimization of the worldwide experimental efforts. The simulation tools used to design and interpret experiments using control of driver shape and particle injection methods to improve beams for applications (left) and optimize efficiency (right), in preparation for the BELLA and FACET facilities, which will each target 10 GeV level high quality beams from laser and beam drivers respectively.

References: I. Bloomenfeld et al. Nature 445, 741-744 (2007); Leemans *et al.,* Nature Physics 2006 (exp.); N. Hafz *et al*., Nature Photonics **2**, 571 (2008). C. Huang et al., Journal of Physics: Conference series 180, 012005 (2009).

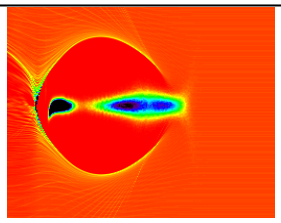
For more information: www.compass.fnal.gov



VORPAL simulated electrons show narrow divergence, similar to white overlain circle showing the experimental beam envelope.



QuickPIC simulation of a plasma wakefield accelerator stage showing high efficiency while maintaining a small energy spread.



100MV/m of Gradient and 50MW rf Pulse Achieved with Superior High Current Beam at AWA Facility

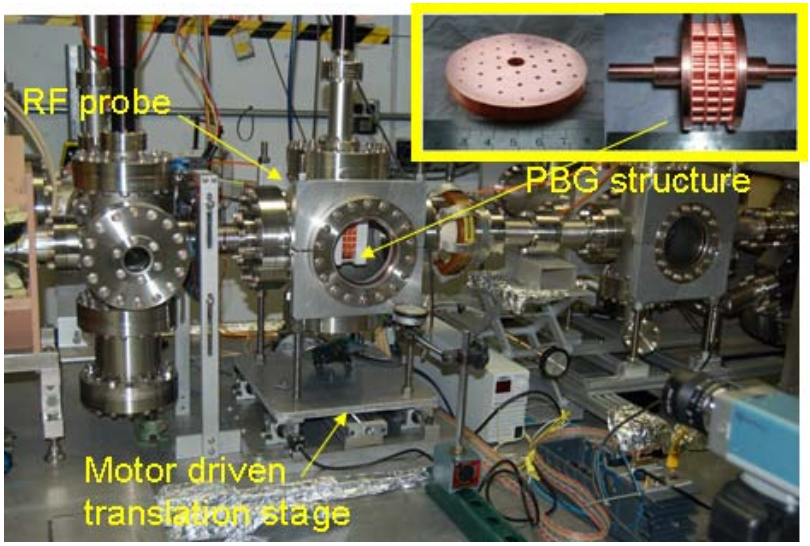
Investigators: M. Conde, S. Doran, W. Gai, W. Liu, J. Power, R. Konecny, and Z. Yusof, *Argonne National Laboratory*

The Accelerator Research group of the High Energy Physics Division at Argonne National Laboratory focuses on the physics and technology of advanced accelerator methods, mainly the high gradient dielectric wakefield accelerator to generate rf power at the GW level, and accelerate electrons to the TeV level. The group is also responsible for the Argonne Wakefield Accelerator (AWA) facility, which has a unique capability of providing high quality, world record high charge beams (>100nC, single bunch), with short bunch length (<2mm) using a 1.3 GHz photoinjector RF gun. In collaboration with Euclid Techlabs LLC, NRL, and SLAC, a series of proof-of-principle experiments have been performed: 1) 100MV/m was achieved in a wakefield Dielectric Loaded Accelerator (DLA) without dielectric breakdowns; 2) 50MW C-band and 30MW Ku-band high power rf pulse have been generated in two dielectric based wakefield power extractors respectively; 3) Successfully performed the first ever experiment to enhance the wakefield transformer ratio over 2, a limitation in having high efficiency collinear wakefield acceleration; 4) first ever experimental characterization of the damped dipole modes in photonic band gap accelerator.

References:

1. C. Jing, *et al, Phys. Rev. Lett.* **98** (2007) 144801.
2. F. Gao, *et al, IEEE, Nuclear Science*, **56**, 1492-1497, 2009

For more information: www.hep.anl.gov/awa



The recent experiment of Photonic Band Gap (PBG) accelerating structure at AWA reveals that the quality factor Q of the dipole modes is ~10 times smaller than that of the accelerating mode, which demonstrates a significant advantage of the PBG structure over others.

Validation of the Digital Hadron Calorimeter Concept

Investigators: E May, J Repond, D Underwood, L Xia, and Q Zhang, *Argonne National Laboratory*

A novel type of calorimeter for the measurement of the energy of hadronic particles utilizes Resistive Plate Chambers (RPCs) as active elements together with a very finely segmented electronic readout. The latter applies a simple threshold to each channel, hence the designation of Digital Hadron Calorimeter (DHCAL), and the energy is reconstructed to first order as the sum of readout pads above threshold. The group built a small prototype calorimeter with up to 10 layers and 2560 readout channels. The calorimeter was exposed to cosmic rays and particles at the Fermilab test beam facility. Using pions at the test beam hadronic showers were detected and measured in this novel calorimeter, thus providing a first validation of the DHCAL concept. The results agreed well with Monte Carlo simulations of the set-up. A larger prototype with a total of 400,000 channels is currently being assembled. The construction is expected to be completed by early summer, to be followed by several test beam runs at the Fermilab test beam facility.

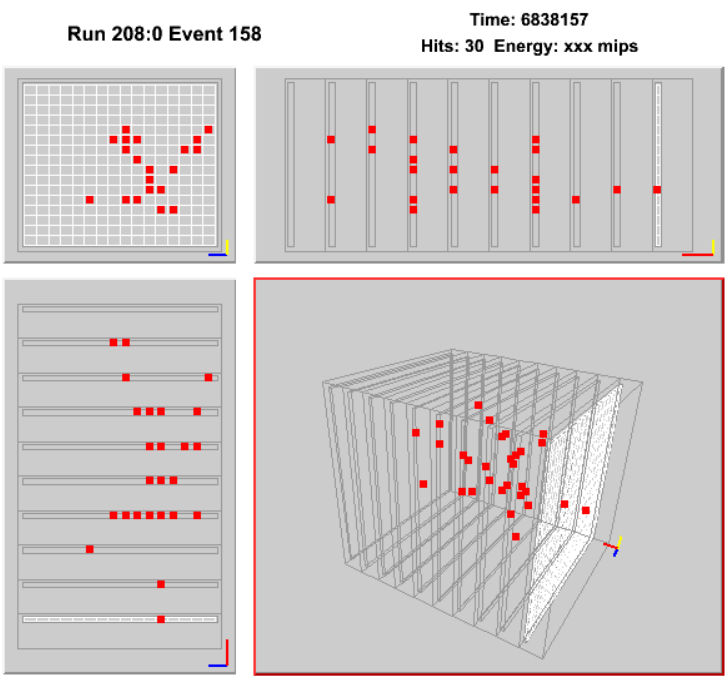
References:

'Hadron Showers in a Digital Hadron Calorimeter', B.Bilki et al., arXiv:0908.4236. 2009 JINST 4 P10008.

'Environmental Dependence of the Performance of Resistive Plate Chambers', Q.Zhang et al., arXiv:0911.1351. 2010 JINST 5 P02007.

'Measurement of Positron Showers in a Digital Hadron Calorimeter', B.Bilki et al., arXiv:0902.1699. 2009 JINST 4 P04006.

For more information: www.hep.anl.gov/repond/DHCAL_US.html



Event display of a 8 GeV π^+ interacting in the small Digital Hadron Calorimeter prototype. Each red square corresponds to a pad with a charge above threshold. The branching out of secondary particles following the first nuclear interaction is clearly visible.

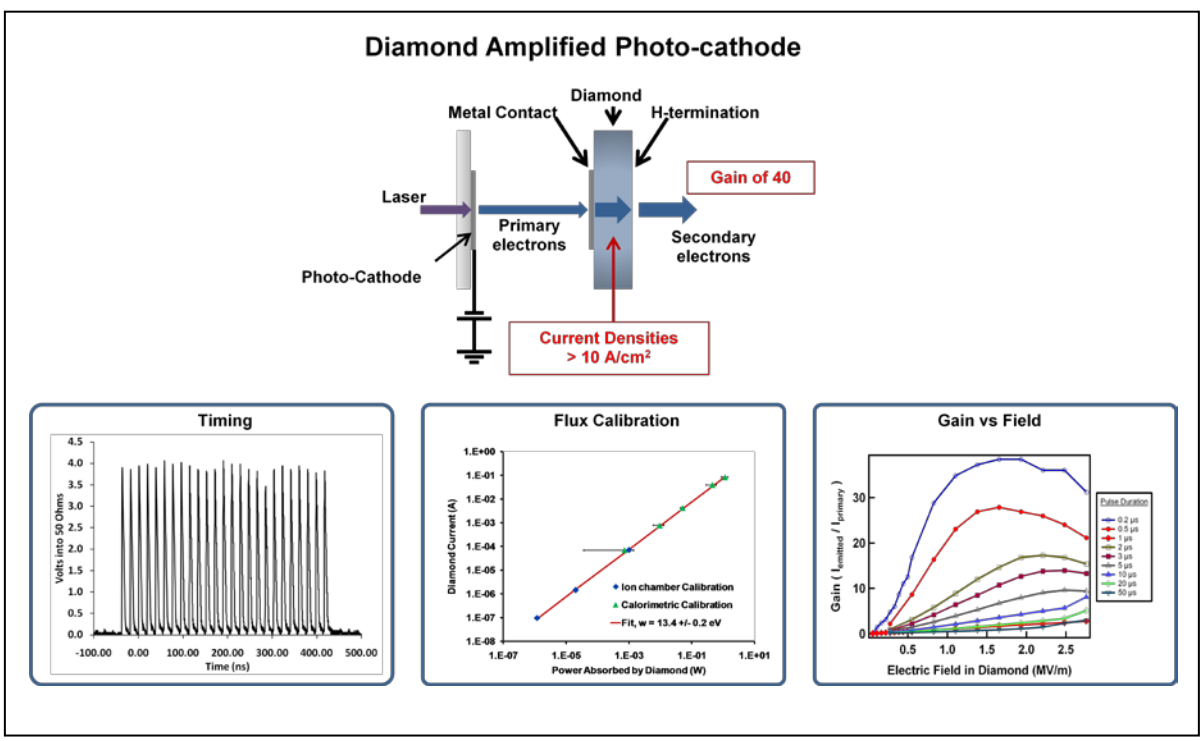
Diamond Amplified Photocathode

Investigators: I Ben-Zvi, E Muller, *Stony Brook University;* J Smedley, *Brookhaven National Laboratory*

Researchers at Stony Brook University and Brookhaven National Laboratory are investigating diamond amplified photocathodes (DAP) for use as high-brightness, high-average-current electron sources. With a potential gain of up to 300 in electron current, the DAP has the potential to revolutionize photoinjector design and cathode development. To date, a gain of 40 for electron generated carriers has been demonstrated, very high average current densities (>10A/cm^2) have been transported through diamond material using X-ray generated carriers, and the energy required to create an electron-hole pair has been measured. The origin of charge trapping in diamond has also been investigated for both bulk and surface trapping. We propose to continue this effort along three lines of investigation: (1) to understand the diffusion and loss of carriers at the incident surface, and incorporate these effects into our modeling of charge transport; (2) to continue our investigation of charge transport in the material bulk, with the goal of discovering the ultimate current density limits, the intrinsic pulse spreading, and further investigating the role of crystalline defects in charge trapping; (3) to improve electron emission from the diamond surface, including identifying sources of charge accumulation and studying the impact of the hydrogenation method on the emitted electron energy spectrum. The response of diamond to nanosecond X-ray pulses has also been measured.

References: Mater Res Soc Symp Proc, **1203** (2010), 1203-J17-19, 1203-J19-03, 1203-J17-21, 1203-J17-43.
J. Keister and J. Smedley. Nucl Instrum Meth A. **(606)**. 774-779.

For more information: https://pubweb.bnl.gov/~emuller/DiamondPublications.html



Generation of Monoenergetic Ion Beams by Laser Radiation Pressure Acceleration from Gas Jets

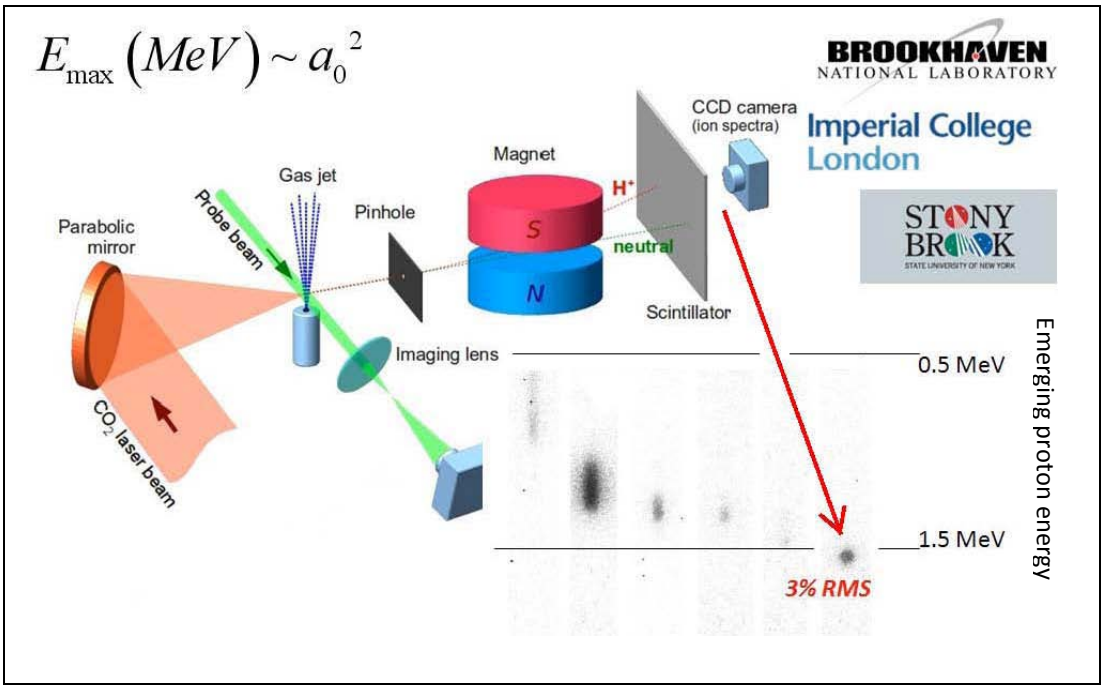
Investigators: I. [1]Pogorelsky[1], M. Babzien[1], M. N. Polyanskiy, V. Yakimenko[1], P. Shkolnikov[2], M. Ispiriyan[2], Charlotte A. J. Palmer[3], N. P. Dover[3], Z. Najmudin[3]

1. *Accelerator Test Facility, Brookhaven National Laboratory*
2. *Stony Brook University, Stony Brook*
3. *The Blackett Laboratory, Imperial College London*

High energy ion beams generated by intense laser pulses promise to be viable alternatives to conventional ion beam sources due to their unique properties such as high charge, low emittance, compactness and ease of beam delivery. Typically the acceleration is due to the rapid expansion of a laser heated solid foil, but this usually leads to ion beams with large energy spread. Radiation pressure acceleration (RPA) provides an alternative route to producing laser-driven monoenergetic ion beams. In this work, conducted at Brookhaven Accelerator Test Facility, we experimentally observed that the interaction of an intense infrared laser with a gaseous hydrogen target can produce proton spectra of small energy spread (~3%), and low background [1]. The possibility of obtaining critical plasma density in a gas jet target and the unprecedented diagnostic efficacy of the visible-light probe laser are among the advantages associated with the use of a long wave-length primary laser. These are the first high-contrast monoenergetic beams that have been theorized from RPA and which are highly desirable for numerous ion beam applications. This work is an experimental confirmation of the new laser ion acceleration scheme previously predicted by theory and simulations. Linear proton beam energy scaling with laser intensity is associated with RPA, in contrast to the less favorable scaling associated with laser-foil interactions. This result opens the path to practical medical applications of compact laser-based ion sources.

Reference: [1] C.A.J. Palmer *et. al.*, submitted for publication (2010)

For more information: http://www.bnl.gov/atf/



The mini-TimeCube Project

Investigators: J. G. Learned, *University of Hawaii,* with National Geospatial Intelligence Agency/Measurement and Signal Intelligence

Idea: build easily portable 2 liter scintillating detector with 1656 fast (<200 ps) pixels to waveform record and reconstruct electron anti-neutrino events.

Virtues:

- small size avoids gammas which smear resolution
- use photon recording to reconstruct with medical imaging techniques
- fast processing of waveforms rejects background in real time
- no shielding needed
- get incoming neutrino directionality to few degrees

Rate: ~10 clean events/day near San Onofre power reactor.

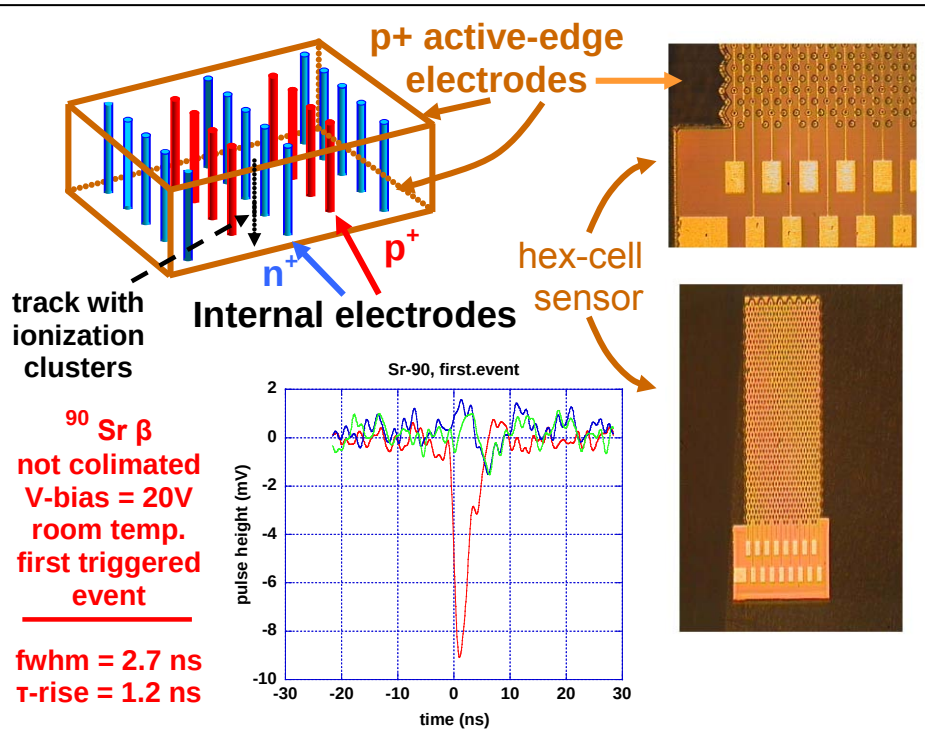
Status: Under construction at UH, testing in early 2011.

Silicon Radiation Detectors with 3D Electrodes: Active Edges, Extreme Radiation Hardness / Speed

Investigators: S. Parker, *U. of Hawaii with 3DC Collaboration: 18 institutions, 5 processing labs.* Key members include C. Kenney, *SLAC* and C. Da Via, *Manchester U.*

1. Silicon sensors with electrodes penetrating into the substrate, forming a 3D array, rather than being confined to the top and bottom surfaces, were proposed in 1995 by S. Parker.
2. They are made by etching deep electrode holes with F^- ions where etching is alternated with side-wall protection. The holes are then filled with conformal, doped, polycrystalline silicon.
3. The electrodes separation is small compared to the sensor thickness giving low bias voltages, short collection distances, and low capture probability, thus radiation hardness and speed.
4. Irradiated with 8.8×10^{15} equivalent 1 MeV neutrons per cm^2 (an amount greater than expected for 10 years at the sLHC) and read out by un-irradiated ATLAS FEI-3 readout chips, 2, 3, and 4 electrode per pixel sensors still have signal to noise ratios of 30, 31, and 38 to 1.
5. Ionization clusters in planar sensors are collected sequentially, giving uneven pulse leading edges. With 3D, they all collected at almost the same time, giving a smooth pulse leading edge, further increasing time resolution to a fraction of the rise time.
6. Active edge electrodes, made from border trenches parallel to the holes, were proposed in 1997 by C. Kenney. They provide sensitivity to within 2 µm of the edges (compared with about 1 mm for ATLAS and CMS pixel sensors). They are particularly useful when large area coverage with little dead space is important and for forward physics at colliders, where detectors must be sensitive as close as possible to the circulating beams.

For more information email: sher@slac.stanford.edu



3D Publications

1. NIM **A395** (1997) 328
2. APS Mtg. **2** (1998) 1342-5
3. IEEE TNS **46** (1999) 1224
4. IEEE TNS **48** (2001) 189
5. IEEE TNS **48** (2001) 1629
6. IEEE TNS **48** (2001) 2405
7. Proc. SPIE **4784** (2002) 365
8. CERN Cour. **43** (01.2003) 23
9. NIM **A509** (2003) 86
10. NIM **A524** (2004) 236
11. NIM **A549** (2005) 122
12. NIM **A560** (2006) 127
13. NIM **A565** (2006) 272
14. IEEE TNS **53** (2006) 1676
15. NIM **A576** (2007) 32
16. NIM **A582** (2007) 178
17. NIM **A587** (2008) 243
18. NIM **A594** (2008) 7
19. NIM **A594** (2008) 332
20. IEEE TNS **55** (2008) 3731
21. IEEE TNS **56** (2009) 505
22. NIM **A604** (2009) 505

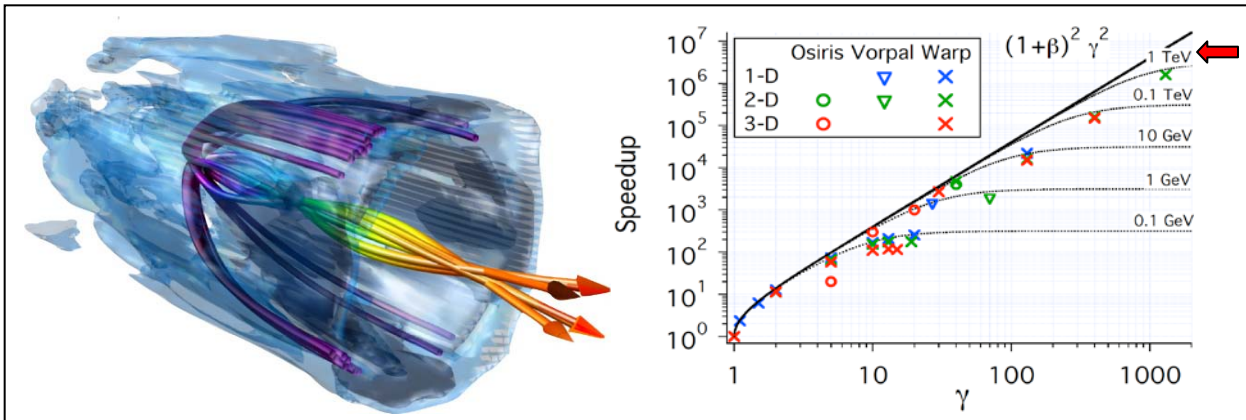
"Boosting" plasma accelerator simulations

Investigators: Bruhwiler D.L., Cary J.R., Cormier-Michel E., Cowan B.M. (Tech-X), Fonseca, R.A. (IST, Portugal), Geddes C.G.R. (LBNL), Lu W. (UCLA), Martins, S.F. (IST, Portugal), Mori, W.B. (UCLA), Silva, L.O. (IST, Portugal), Tsung, F.S., (UCLA), Vay, J.-L. (LBNL)

Simulation tools developed by the SciDAC Compass project are using a technique exploiting Einstein's theory of special relativity to speed up some calculations dramatically. The project develops and maintains a suite of simulation tools that are optimized for modeling compact accelerator stages using plasma wave 'wakefields' driven by lasers or particle beams, which provide accelerating gradients more than 1000 times higher than current technology. These simulation tools now run efficiently on over 100,000 processors on national leadership class facilities, and are used to explore accelerator designs for future experiments not yet feasible in laboratories. Such simulations were at or beyond the capacity of even the present world's largest computers until it was demonstrated recently that dramatic speed ups were possible by carrying out the simulations in a Lorentz boosted frame, a frame moving with a velocity near or at that of the wakefield which accelerates the particles. A numerical instability which limited previous speed ups has been controlled recently, allowing speed ups in the 10^2 to 10^6 range under appropriate condition. This novel technique is being used to optimize the laser and plasma conditions for 10 GeV and beyond class laser wakefield stages.

References: J.-L. Vay, *Phys. Rev. Lett.* **98** (2007); S. F. Martins et al, *Nature Phys.* **6** (2010); D. Bruhwiler et al, AIP Proc. (2008); J.-L. Vay et al, *submitted to J. Comput. Phys.*

For more information: www.compass.fnal.gov



(left) Three-dimensional rendering from an Osiris simulation of a laser wakefield accelerator stage in a Lorentz boosted frame with self-trapping (arrows); (right) Examples of speed ups including a 1 million times speed up for a 1 TeV stage with no self-trapping.

Disordered Photonic Crystal accelerator cavity with only a single mode discovered

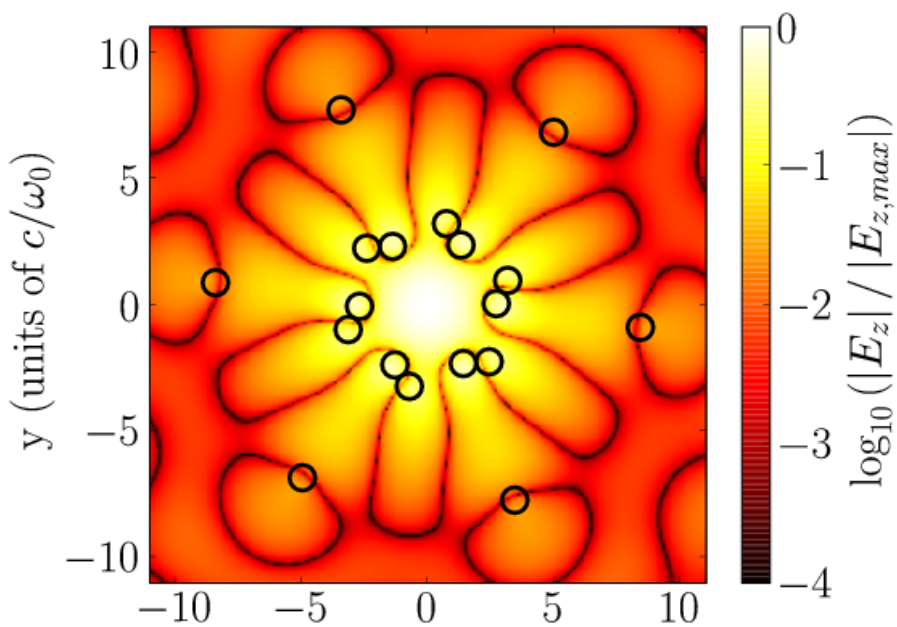
Investigators: C. A. Bauer, J. R. Cary, and G. R. Werner, *University of Colorado*

An irregular configuration of 18 sapphire rods has been precisely tailored by researchers at the University of Colorado to confine a single electromagnetic resonant mode. Using the high performance computation framework VORPAL to simulate electromagnetic waves, the positions and sizes of the rods were optimized to improve the mode confinement by an order of magnitude compared to a regular crystal structure with twice as many dielectric elements. Wake-field calculations subsequently demonstrated the suppression of the deleterious higher order modes found in traditional cavities intended to confine electromagnetic radiation. Single mode cavities will allow particle accelerators to accelerate more particles to higher energies before instabilities develop, furthering the energy frontier for high energy physics as well as benefiting biological and materials research conducted at accelerator-driven light sources.

References C. A. Bauer, G. R. Werner, and J. R. Cary, J. Appl. Phys. 104 (2008), 053107; G. R. Werner, C. A. Bauer, and J. R. Cary, Phys. rev. spec. top., Accel. beams 12 (2009), 071301.

For more information: http://cips.colorado.edu/groups/beams/research.htm

The single trapped mode in a disordered photonic crystal cavity. Image chosen for the 2010 calender of the American Physical Society.



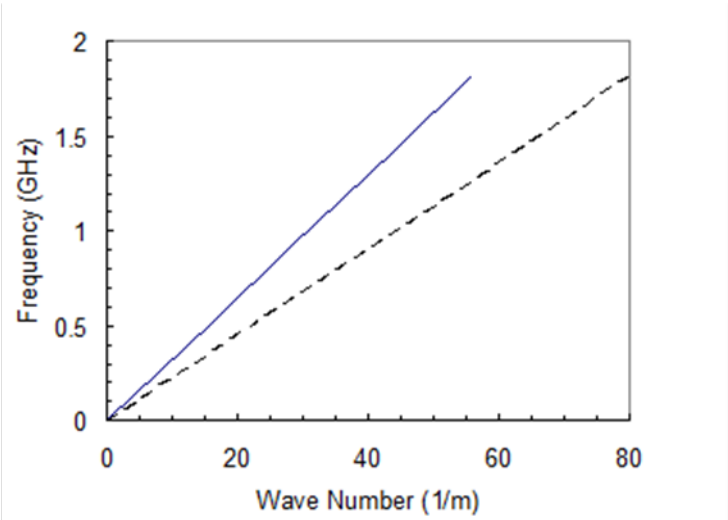
Theoretical and Computational Investigation of Periodically Focused Intense Charged-Particle Beams

Investigator: Chiping Chen, *Plasma Science and Fusion Center, Massachusetts Institute of Technology*

One important application of periodically focused intense charged-particle beams is in the development of an innovative elliptic-beam or sheet-beam klystron. Compared with conventional circular-beam klystrons, elliptic-beam or sheet-beam klystrons have the potential for radio-frequency (rf) radiation generation at higher efficiency, higher output power, and lower voltage. A fundamental beam physics problem in the research and development of elliptic-beam or sheet-beam klystrons is the excitations of space-charge waves on elliptic electron beams. A theory of space-charge waves on an elliptic electron beam has been established. In particular, a dispersion relation for the space-charge waves has been derived analytically. A computer code, Elliptic-Beam Small Signal (EBSS), has been developed and applied in the studies of the dispersion characteristics of fast- and slow-space-charge waves in relativistic elliptic electron beams. The theory can be used to predict the spacings of rf cavities in elliptic-beam klystrons such as a 10 MW 1.3 GHz elliptic-beam klystron for the International Linear Collider (ILC).

Reference: A.E. Brainerd, C. Chen, and J. Zhou, "Space-charge waves on relativistic elliptic electron beams," J. Appl. Phys. **106**, 023310 (2009).

For further information: Contact Chiping Chen at chenc@psfc.mit.edu



Dispersion characteristics of fast- and slow-space waves on a relativistic elliptic beam with an aspect ratio of 6:1.

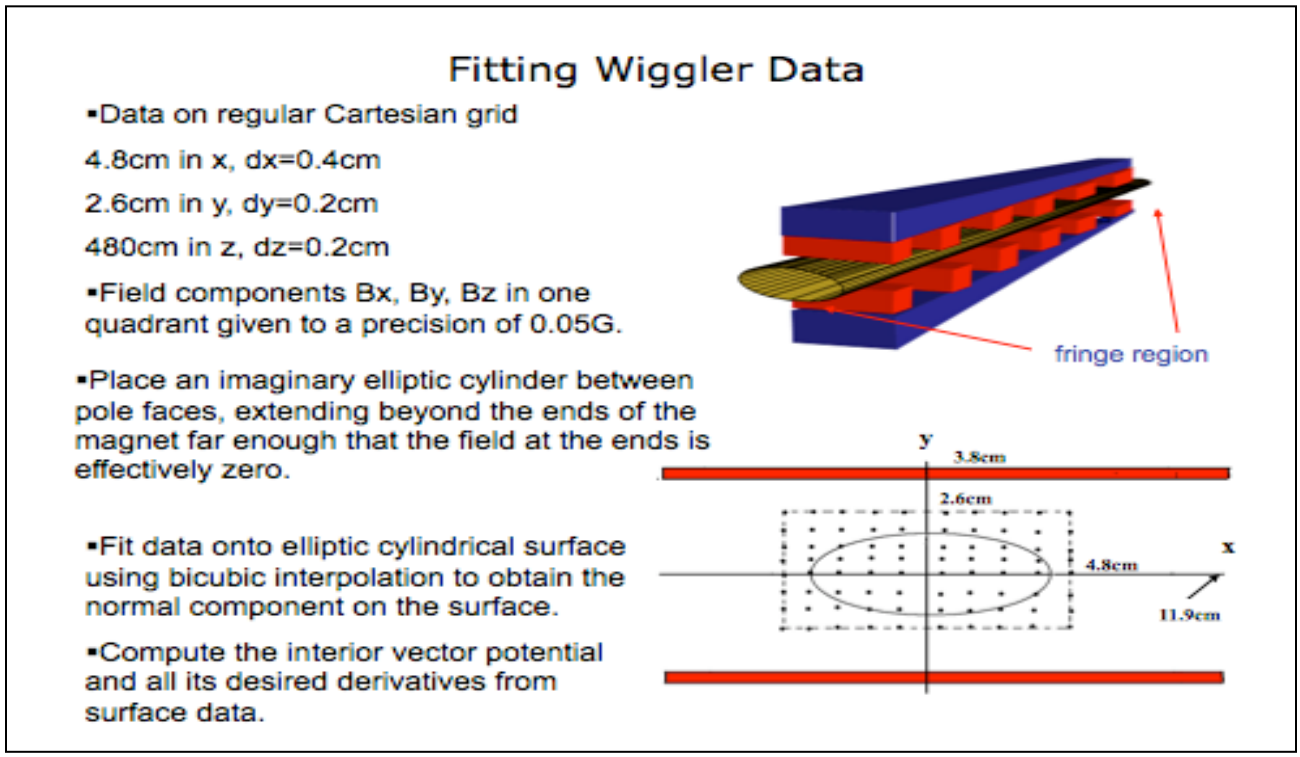
Realistic Accelerator Modeling/Design

Investigators: A. Dragt and C. Mitchell, *University of Maryland*

The behavior of orbits in charged-particle beam transport systems, including both linear and circular accelerators as well as final focus sections and spectrometers, can depend sensitively on nonlinear fringe-field and high-order-multipole effects in the various beam-line elements. The inclusion of these effects requires a detailed and realistic model of the interior and fringe fields, including their high spatial derivatives. A collection of surface fitting methods has been developed for extracting this information accurately from 3-dimensional field data on a grid, as provided by various 3-dimensional finite-element field codes. Based on these realistic field models, Lie or other methods may be used to compute accurate design orbits and accurate transfer maps about these orbits. Thus, it is now possible, for the first time, to compute realistic transfer maps for real magnets including all fringe and high-order multipole field effects. The figure below, for example, shows the surface of an imaginary elliptical cylinder used to compute realistic transfer maps for a proposed ILC damping ring wiggler.

Reference: C. Mitchell and A. Dragt, Phys. Rev. ST Accel. Beams 13, 064001 (2010)

For more information: http://www.physics.umd.edu/dsat/



A Vlasov-Maxwell Approach to Collective Effects in Accelerators

Investigator: James A. Ellison, *University of New Mexico*

The subject of collective beam instabilities is one of the main issues facing high performance particle accelerators. In most cases the mean field Vlasov-Maxwell system (VMS) is valid. Our goal is the development of efficient algorithms for the accurate numerical integration of this system in important applications. Numerical integration of the VSM is computationally intensive, thus a combination of high level analytical and computational work is necessary. We have made excellent progress in the case of a sheet bunch represented by a random sample of N simulation points in 4D phase space. The self field is computed from Maxwell's equations in a lab system and the particles are tracked in a beam centered system. This requires a transformation of densities between the two systems and we have discovered the exact expression (Ref.1). Our evolution algorithm samples the 4D phase space density of the beam by means of the N simulation points and applies density estimation methods from Nonparametric Statistics to accurately compute the smooth charge/current density and the field in a self-consistent manner. Our state-of-the-art algorithm and parallel code has been successfully applied to the CSR micro-bunching instability in bunch compressors (Ref.2). This is important in e.g. free electron lasers such as the LCLS at SLAC. Extension to the more difficult Klimontovich-Maxwell system, which includes shot noise, is in progress.

References: G. Bassi et al., to be publ. in PRST-AB; G. Bassi et al., PRST-AB **12**, 080704 (2009).

For more information: www.math.unm.edu/~ellison

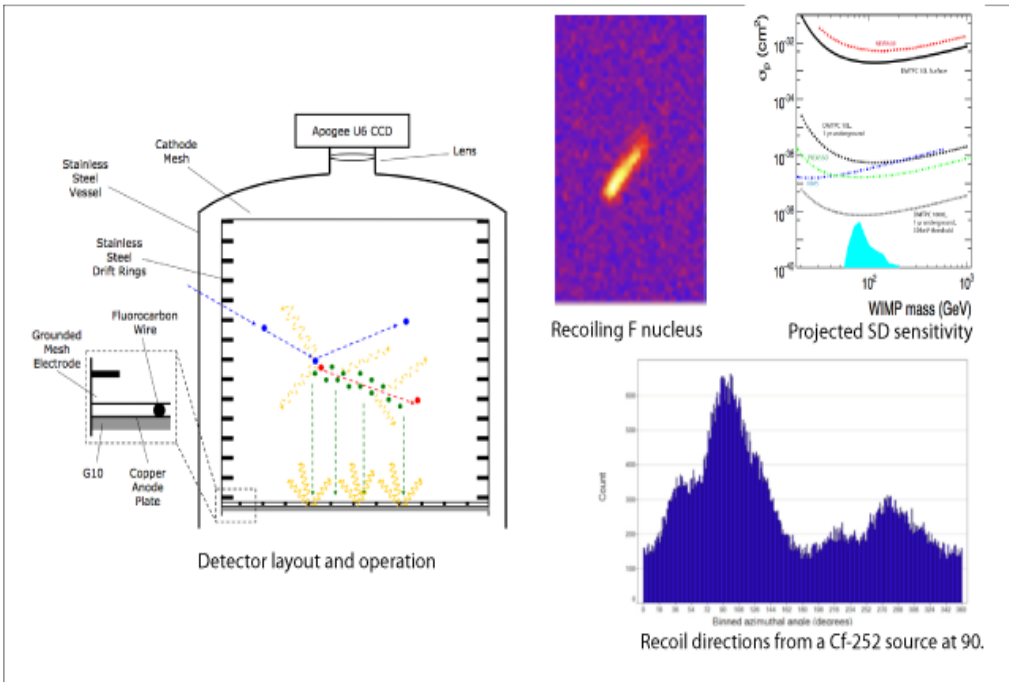
A Low Pressure TPC for detecting dark matter and neutrons with directional sensitivity

Investigators: P. Fisher, J. Monroe, and G. Sciolla, *MIT,* S. Ahlen, *Boston University,* H. Wellenstein*, Brandeis*

We have constructed several low pressure Time Project Chambers (TPCs) based on CF_4-He gas mixes. The principle of operation is shown below: the use of CF_4 allows the detection of scintillation light in the amplification gap, allowing all the readout electronics to be located outside the gas vessel. For dark matter detection, this makes very low backgrounds possible by minimizing the amount and type of material in the gas volume. For dark matter detection, which uses only CF_4 at around 80 torr, fluorine gives high sensitivity to spin-dependent type interactions. The low pressure allows the detection of the direction of the recoiling fluorine. We have operated a 10L detector on the surface (right figure) and are in the process of locating a larger detector underground at WIPP. We are beginning to design a 1000L detector for underground operation. For neutron detection, we add 500-700 torr of ^{4}He to the gas and observe the recoiling alpha. ^{4}He has a very high neutron elastic scattering cross section around 1 MeV, which makes this detector sensitive to neutrons from fissile materials and cosmic rays. The directional sensitivity makes determination of the source direction possible with a few events in the presence of backgrounds and the measurement of the energy of the incident neutrons. We have demonstrated detection of neutrons from cosmic rays and ^{252}Cf and are constructing a larger detector for use at reactor neutrino and neutrino beam experiments. We are also actively developing this technology for use in cargo screening.

References: S. Ahlen *et al*., rXiv:1006.2928, A. Rocarro *et al.*, *Nucl. Instr.* **A608** (2009)305-9.

For more information: http://dmtpc.mit.edu



Accelerators of the Future: Neutrino Factories and Muon Colliders

Investigators: G. Hanson and P. Snopok, *University of California--Riverside*

Colliding beams of positively- and negatively-charged muons in a Muon Collider will provide an energy frontier machine to explore new physics. A Muon Collider will be the best way to study the Higgs bosons associated with supersymmetric theories and may be necessary to discover them. A Neutrino Factory will provide an intense, well controlled, well characterized, narrow beam of muon neutrinos and electron antineutrinos from the decay of muons in a storage ring, which will advance neutrino physics beyond the current round of approved and proposed experiments using conventional neutrino beams and will allow the exciting possibility of a measurement of *CP* violation in the leptonic sector. Our group at the University of California, Riverside, is focusing on methods to reduce the emittance, or phase space, of the muon beam using ionization cooling. Muon beam cooling is necessary to allow the muon beam, which is broad at production from pion decay, to fit within the acceptance of downstream accelerator components. We are simulating six-dimensional cooling in the Guggenheim channel, which is considered to be one of the most promising candidates for cooling for the Muon Collider. We are also participating in the international Muon Ionization Cooling Experiment (MICE), which will demonstrate muon ionization cooling. In particular, we are leading an effort to demonstrate emittance exchange in MICE using a wedge absorber in the muon beam.

References: R&D Proposal for the National Muon Accelerator Program, FERMILAB-TM-2459-APC, https://mctf.fnal.gov/mapproposal.pdf/view and references therein

An International Muon Ionization Cooling Experiment (MICE), Proposal to the Rutherford Appleton Laboratory, MICE Note 021, January 10, 2003, available from http://hep04.phys.iit.edu/cooldemo/micenotes/public/pdf/MICE0021/MICE0021.pdf

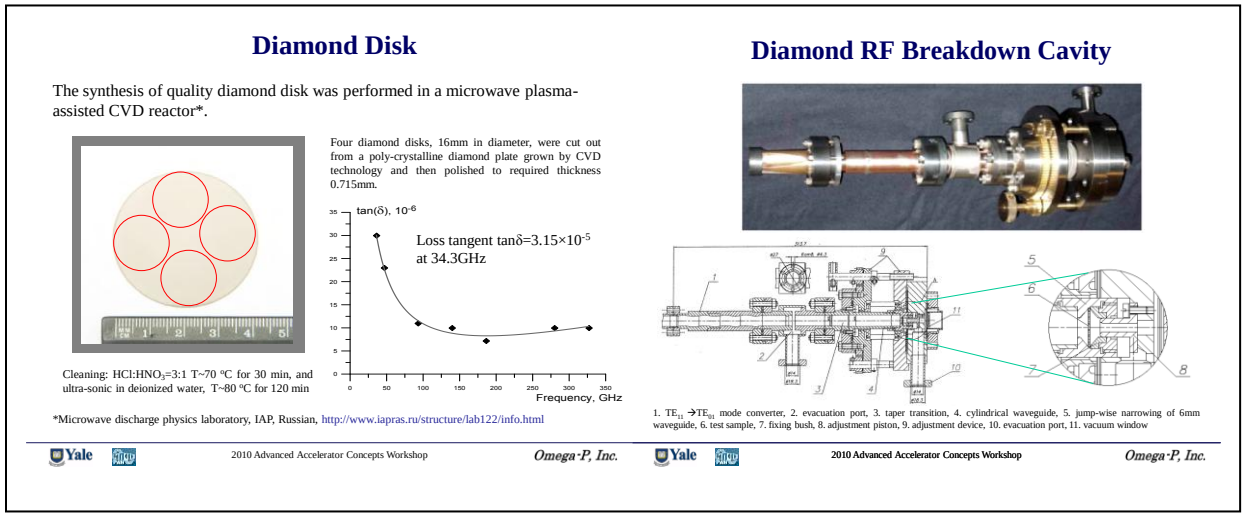
RF BREAKDOWN TESTS ON CVD DIAMOND

Investigator(s): Y. Jiang, Yale University; M. LaPointe, Yale University; A. Vikharev, Institute of Applied Physics, RAS, Nizhny Novgorod, Russia; V. Yakovlev, FNAL; S. Kazakov, FNAL; J. Hirshfield, Yale University (PI).

Interest arises in use of Chemical Vapor Deposition (CVD) artificial diamond as an element in advanced accelerator structures. This interest is part of a growth in studies of dielectric accelerator structures that might sustain higher accelerator gradients than conventional copper structures, with acceptably low breakdown rates. CVD diamond is probably the most attractive dielectric for this application, on account of its moderate dielectric constant, low dielectric losses, high thermal conductivity, and supposed high threshold for RF breakdown. That high threshold (in the GV/m range) is so far only inferred from DC breakdown measurements, since RF breakdown measurements have heretofore not existed. Such measurements have begun at 34.3 GHz using the multi-MW magnicon RF amplifier at the Yale Beam Physics Lab Ka-band Test Facility. These measurements rest upon two critical achievements, namely production of appropriate CVD diamond test samples, and design of a suitable RF test cavity. Photos of each of these are shown below. Four 14-mm diameter, 0.7 mm thick CVD diamond samples were cut from a larger disk as shown in the photo, and are processed to exhibit both high and low secondary electron emission coefficients. The test cavity is capable of imposing >500 MV/m tangential RF electric fields on the samples, when 5 MW of RF power is fed to the cavity. So far, with about 0.5 MW of RF power, fields >150 MV/m have been imposed for over 10^5, 0.5 µs pulses, without any evidence of RF breakdown.

Reference(s): Y. Jiang, *et al* "Breakdown tests on CVD diamond," AAC2010, to be published.

For more information: http://www.iapras.ru/structure/lab122/info.html (CVD diamond production)



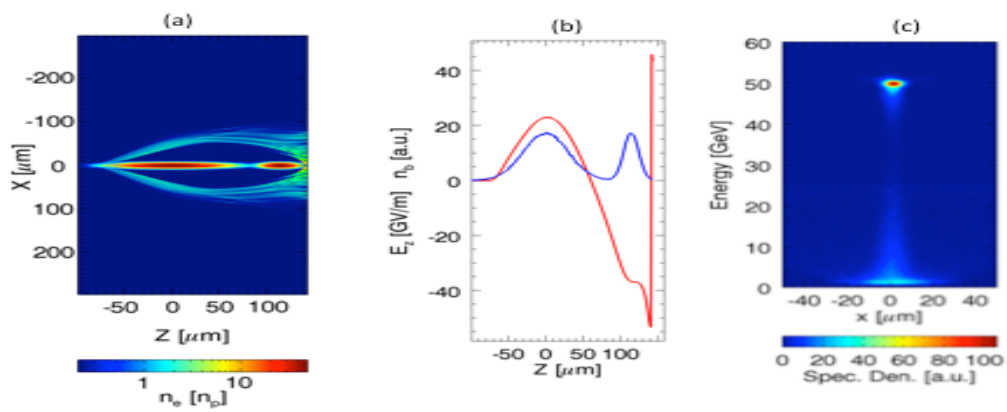
Plasma Wakefield Acceleration on FACET

Investigators: C.Joshi, W.B. Mori and C.E.Clayton, *University of California--Los Angeles*

FACET --Facilities for Accelerator Science and Experimental Test Beams – now under construction at SLAC will provide high energy density electron and positron beams well suited for next generation experiments on the Plasma Wakefield Accelerator. The main goal of these experiments is to demonstrate a significant energy gain for electron and positron bunches containing a substantial charge in a single meter scale plasma acceleration stage while preserving the beam emittance and energy spread. The UCLA Plasma Acceleration Group will play a significant role in these experiments that are expected to begin in Summer 2011. In preparations for this experiment the UCLA group has been working on making suitable plasma sources and developing computer codes that will rapidly and accurately enable us to design the experiments and analyze the results.

Reference: M.Hogan et al., New Journal of Physics, vol. 12, 055030 (2010)

For more information: http://www.ee.ucla.edu/~plasma/



Figures shown above depict the wake produced in a plasma by the drive and witness bunch expected to be generated at FACET (a). The longitudinal wakefield which slows down the drive bunch but accelerate the witness bunch is shown in (b). After propagating through a roughly one meter long plasma the drive beam has nearly lost all its energy to the wake whereas the witness beam has doubled it's energy from initial 23 GeV to about 50 GeV while maintaining a better than 5% energy spread (c).

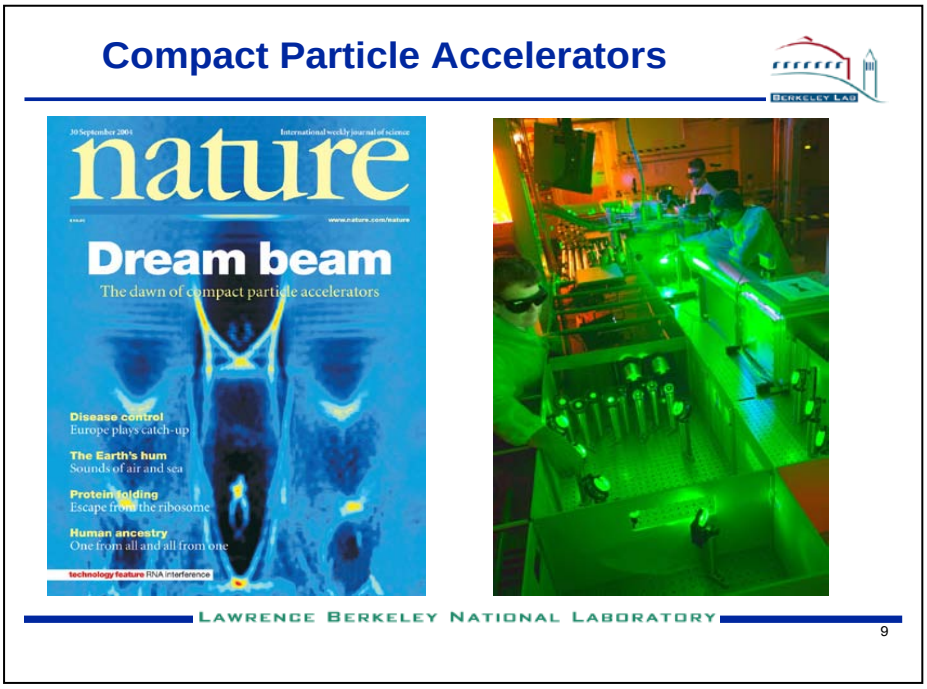
Berkeley Lab's Laser Accelerators of the Future

Investigators: Wim Leemans, Eric Esarey, Cameron Geddes, Anthony Gonsalves, Nicholas Matlis, Carl Schroeder, Csaba Tóth, and Jeroen van Tilburg, *Lawrence Berkeley National Laboratory (LBL)*

In 2004 the LBL Laser Optics and Accelerator Systems Integrated Studies (LOASIS) group made the cover of *Nature* with an early demonstration that laser-plasma acceleration might be practical after all. Two years later LOASIS stunned the world by accelerating high-quality electron beams to energies of a billion electron volts (1 GeV) in a mere 3.3 centimeters, instead of the hundreds of meters required by a conventional radio-frequency accelerator. Now the LOASIS team is poised to achieve energies an order of magnitude higher still, zapping electron beams to energies exceeding 10 GeV in just one meter with the BErkeley Lab Laser Accelerator (BELLA). BELLA's 10-GeV module will provide intense electron beams with pulses as short as a femtosecond for research in materials science, life sciences, physics, and chemistry—and that's just the beginning. If both the accelerator technology and the lasers that drive them continue to mature and reach higher average power, it may one day be possible to build high energy particle colliders. By stringing a hundred or so BELLA modules together, colliding beams of electrons and positrons could reach 1 TeV, a trillion electron volts, twice the energy of a conventional collider 30 kilometers long, in just a few hundred meters. That's potentially an enormous savings in money, a significant reduction in environmental impact, and a doorway to the high-energy physics of the future.

References: *Nature Physics* vol . 2, 696, Oct 2006, *Nature* vol. 431, 538, 30 Sep 2004

For more information:
http://www.lbl.gov/publicinfo/newscenter/features/2008/apr/assets/docs/NCFBELLA.pdf



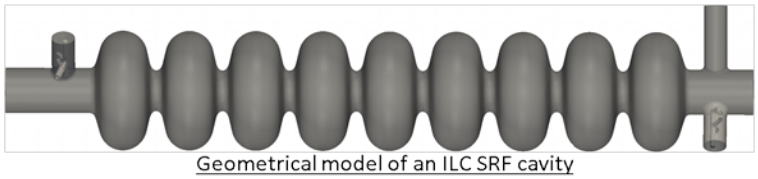
End-to-End Electromagnetic Simulation of ILC Cryomodule

Investigators: L.-Q. Lee, K. Ko, Z. Li, C.-K. Ng, and L. Xiao, *SLAC;* E. Ng, *LBNL*

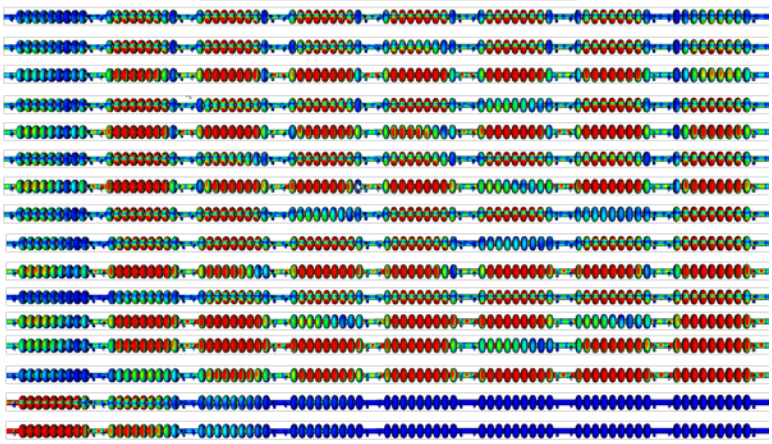
With the support of SciDAC initiative for the past decade, SLAC has developed a comprehensive suite of electromagnetic simulation codes ACE3P based on the higher-order finite-element method. One of ACE3P's codes, the eigensolver Omega3P, has increased its computational capability by 5 orders of magnitude, thanks to advances in computational science research. Under ComPASS, Omega3P was applied to end-to-end simulation of the ILC cryomodule consisting of 8 connected superconducting (SRF) cavities. The first-ever calculations of higher-order-modes (HOM) were carried out and provided direct comparison with data measured at the FLASH facility at DESY. The sixteen modes arising from a dipole pair in a single cavity exhibit complicated electromagnetic field couplings between the cavities in the cryomodule. In particular, the twisting of the field polarization along the cryomodule indicates a strong coupling for beam dynamics in the horizontal and vertical directions. Detailed analysis of measured data also showed that the damping factors of HOMs varied among the cavities in the cryomodule due to cavity imperfection. Using measured cavity parameters as inputs, the deformed cavity shape was recovered by solving the inverse problem through an optimization method. The same method was later used to identify the cause of beam breakup in the CEBAF 12-GeV upgrade prototype cryomodule. The applicability of the simulation tools across DOE accelerator complex has exemplified HEP stewardship in accelerator science R&D.

References: C. Yang, W. Gao, Z. Bai, X. Li, L.-Q. Lee, P. Husbands, E. Ng, Siam J. Sci. Comput., **27**, 873 (2005); V. Akcelik, K. Ko, L.-Q. Lee, Z. Li, C.-K. Ng, L. Xiao, J. Comput. Phys., **227**, 1722 (2008).

For more information: www.compass.fnal.gov



Geometrical model of an ILC SRF cavity



HOMs in an ILC cryomodule

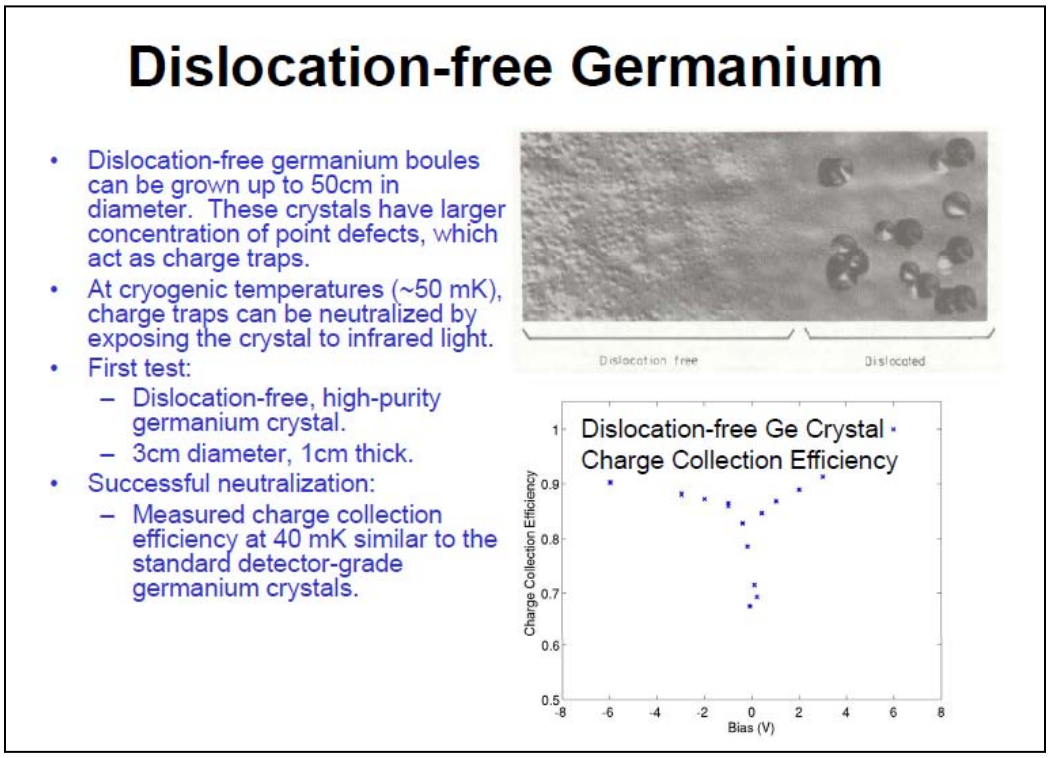
Large Germanium Dark Matter Detectors

Investigator: V. Mandic, *University of Minnesota*

Germanium-based detectors have been on the forefront of the direct dark matter search over the past decade. Moreover, their full potential has not been reached yet. Future dark matter search experiments will require substantially larger targets, reaching the total detector mass of the ton-scale or beyond. Our group has made significant strides toward developing large germanium-based dark matter detectors, of 4”-6” diameter. We have built a new facility on the University of Minnesota campus, centered around a dilution cryostat capable of hosting and operating a germanium detector of up to 6” diameter. This facility is now operational and we are currently making preparations to run first 4” diameter germanium crystals. We are also working with vendors of germanium crystals to develop a new commercial line of high-purity, dislocation-free, 6”-diameter germanium crystals that could be used for direct dark matter searches. In addition to dark matter searches, large germanium detectors can also be used in X-ray and Gamma-ray spectroscopy, medical imaging, and homeland security applications. Finally, our group has contributed to the data analysis that led to the most recent results of the Cryogenic Dark Matter Search experiment, which was recently published in the *Science* magazine.

Reference: Z. Ahmed et al (CDMS Collaboration), *Dark Matter Search Results from the CDMS II Experiment*, Science **327**, 1619 (2010).

For more information: http://www.hep.umn.edu/cdms/



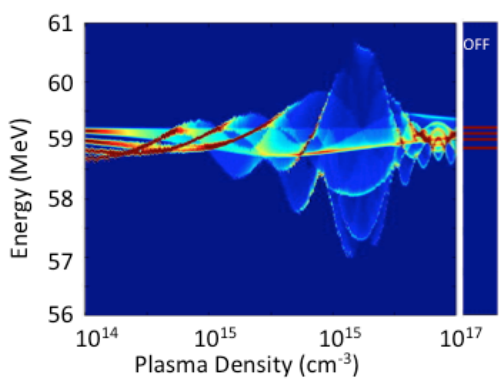
Plasma-based Particle Accelerators and Astrophysics

Investigator: Patric Muggli, *University of Southern California, Los Angeles*

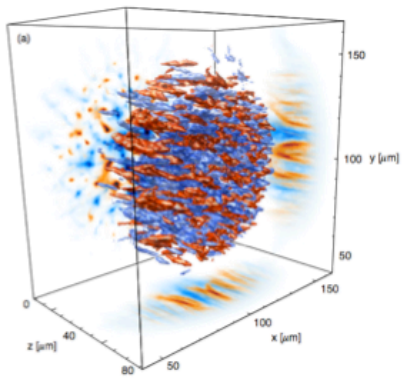
Plasma-based accelerators are the rockets of particle accelerators. They take electrons and positrons to high energies in short distances, much shorter than today's radio-frequency accelerators[1]. Resonantly driving wakefields with multiple particle bunches and accelerating a trailing witness bunch will produce high quality beams at the energy frontier with high efficiency. These bunches will enable new particle physics discoveries with a future plasma-based electron/positron collider. The acceleration process is now tested with low energy beams at the Brookhaven National Laboratory Accelerator Test Facility in order to understand the physics at play and determine the optimum experimental parameters. The resonant excitation of the wakefields and the expected physics have been observed in initial experiments. Accelerator beams propagating in plasmas can also yield information relevant to astrophysics and inertial confinement fusion. Under certain conditions, these beams are subject to instabilities that also occur when plasmas or particle jets are expelled into space and collide with the ambient interstellar plasma, as during supernovae and gamma ray bursts. Relativistic flows are subject to the transverse current filamentation instability that breaks up the flow into transverse current filaments. These large currents generate magnetic fields and synchrotron radiation that can be observed from Earth. Plasma astrophysics can therefore be studied in the laboratory with electron and positron beams and scaled to relevant parameters.

Reference: [1]P. Muggli and M.J. Hogan, Comptes Rendus Physique, 10(2-3),

For more information: http://www-rcf.usc.edu/~muggli/index.html



Calculated energy spectrum of a train of three drive bunches and one witness bunch after propagating through a 2cm-long plasma of various densities. The resonant excitation of wakefield leading to large energy loss and gain is observed a density of near $2x10^{15}cm^{-3}$.



Density of an initially neutral electron (blue) positron (red) "fireball" beam after propagation in a 10cm-long $2.7x10^{17}cm^{-3}$ plasma. The simulation shows that the CFI has broken the beam into small transverse current filaments and large magnetic fields have been generated.

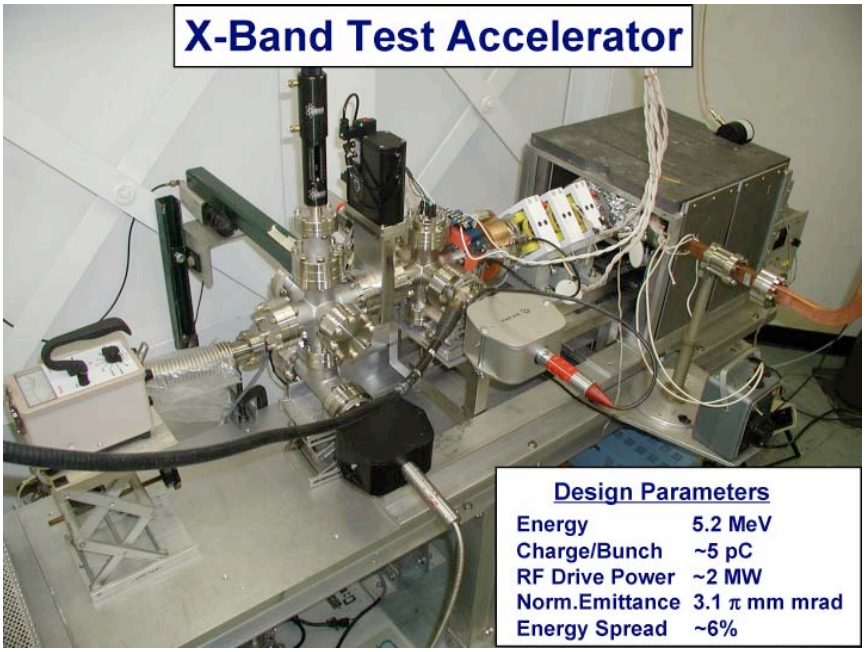
High Gradient Accelerator Science and Technology

Investigator: S.H. Gold, *Naval Research Laboratory*

The Magnicon Facility at the Naval Research Laboratory (NRL) provides 20 MW of X-band power for experiments carried out as part of the DoE High Gradient Collaboration. A collaboration with the High Energy Physics group at Argonne National Laboratory (ANL) and with Euclid Techlabs LLC is studying externally driven dielectric-loaded accelerating (DLA) structures to determine their suitability as a replacement for metal disk-loaded accelerating structures, with a focus on multipactor and rf breakdown phenomena. A variety of quartz, alumina, and magnesium calcium titanate dielectric-lined metal structures have been tested at gradients up to 15 MV/m, and higher gradient structures and special structures designed to minimize multipactor effects are being designed. Also, as part of the collaboration with ANL, a 5-MeV X-band test accelerator has been set up at NRL. A collaboration with Omega-P, Inc. is focused on active microwave pulse compressors for use in a future linear collider. A two-channel, dual-mode pulse compressor experiment using plasma switch tubes, carried out in collaboration with scientists from Omega-P, Inc. and the Institute of Applied Physics of the Russian Academy of Science, has demonstrated 70 MW output pulses with 8x power multiplication, and a new series of experiments employing ferroelectric switching technology will begin in 2010. The interim goal is to generate 100 MW pulses at 10 times power multiplication from a 10 MW, 1-μs drive pulse. Also, a second new series of experiments employing cavities switched by an electron beam will begin in 2011.

References: C. Jing *et al*., *IEEE Trans. Plasma Sci*. **38**, 1354 (2010).

A. L. Vikharev *et al*., *Phys. Rev. ST Accel. Beams* **12**, 062003 (2009).



UMER: A Storage Ring with Extreme Space Charge

Investigators: P.G. O'Shea, R.A. Kishek, S. Bernal, I. Haber, M. Reiser, B. Beaudoin, M. Cornacchia, D. Feldman, R. Fiorito, K. Fiuza, T. Koeth, D. Sutter, E. Voorhies, H. Zhang, *University of Maryland, College Park*

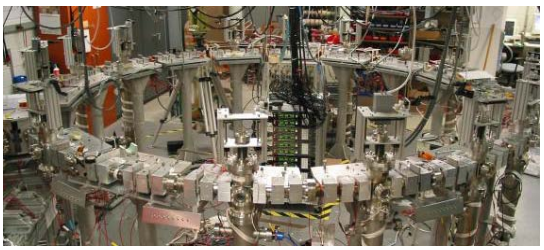
Our recent research on the University of Maryland Electron Ring (UMER) suggests the possibility of operating storage rings with significantly higher space charge intensities than previously thought. UMER is a scaled experiment using low-energy electrons at 10 keV to emulate and explore the basic physics of high-intensity beams. Examples of such applications include high-luminosity colliders, spallation neutron sources, X-ray and other free electron light sources, and future heavy ion-driven inertial fusion concepts. We have recently lengthened the propagation distance of the UMER beam by introducing longitudinal focusing and optimizing the beam transport. Our lowest-current beam, at 0.55 mA, has a tune shift resulting from space charge of the order of 1.0, which is several times larger than the standard tune shift limit for storage rings. We have successfully propagated that beam over 1000 turns, or 11.5 km. Research is ongoing on the topics of beam halo and emittance growth, ring resonances, and longitudinal physics. We plan to add an acceleration stage to UMER, so that we can perform experiments on the dynamics of resonance crossing. Finally, work on UMER has led to the development of several novel beam diagnostics including phase-space tomography, dynamic core-masking for halo studies, and multi-turn measurements by rf beam excitation.

References: S. Bernal, *et al.,* Proc. PAC '09, paper ID FR5PFP059 (2010).
R.A. Kishek, et al., Proc. PAC '07, p. 820 (2007).

For more information: *http://www.umer.umd.edu/*

Goal: To study space charge physics and verify models → preservation of beam quality

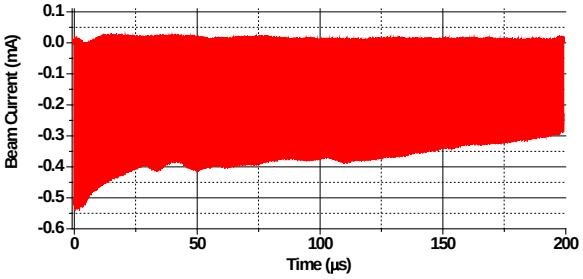
Status: Recently exceeded 1000 turns for a beam with tune shift of 1.0 using longitudinal focusing



Recent and Ongoing Work:

- Longitudinal: Focusing / Edge Erosion / Waves / Solitary Waves
- Transverse: Beam Halo / Ring Resonances / Lattice Function Measurements
- Novel Diagnostics: Tomography / Halo Core-masking / DC Beam detection

0.6 mA beam,
Tune Shift > 1.0
>1000 Turns



A general technique for producing relativistic electron bunches with arbitrary current profiles

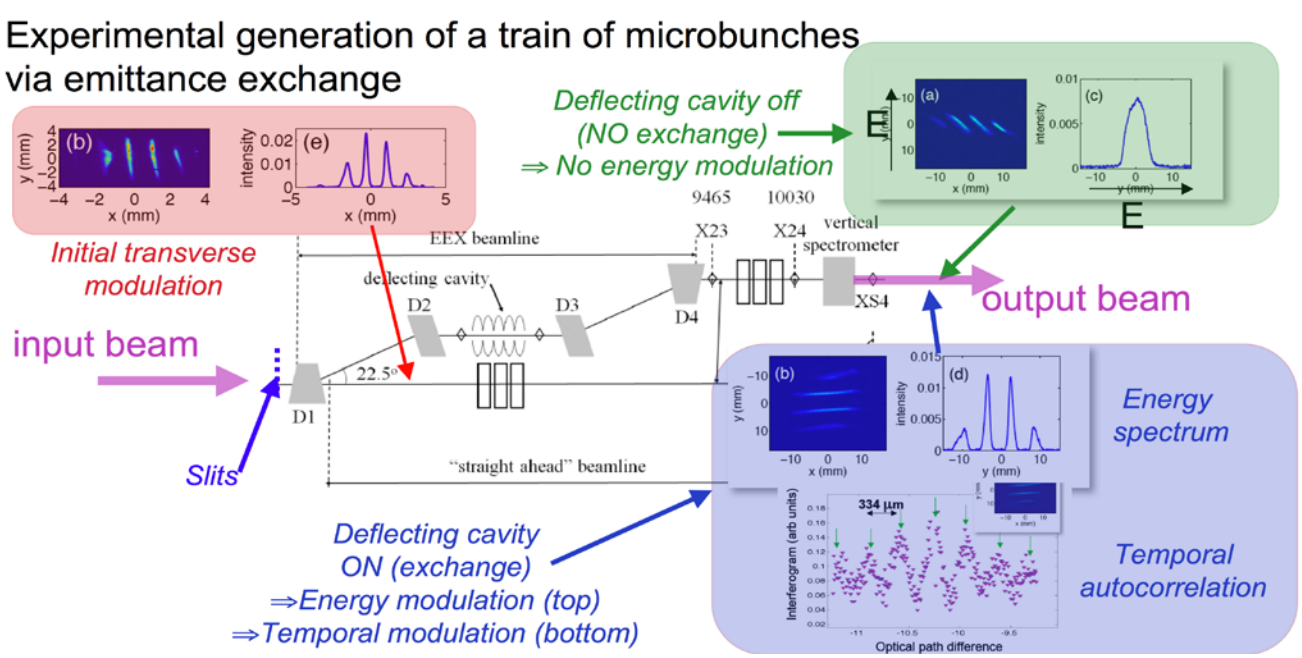
Investigators: P. Piot, *Northern Illinois University & Fermilab,* M. M. Rihaoui, *Northern Illinois University,* and Y.-E Sun, *Fermilab*

A novel technique to arbitrarily and precisely control the current profile of an electron bunch was proposed and experimentally demonstrated at the Fermilab's A0 photoinjector. The technique relies on a transverse-to-longitudinal phase space exchange beamline that can swap the emittances associated to the horizontal and longitudinal degrees of freedom. By properly shaping the horizontal profile of the beam upstream of this "emittance exchange" beamline, one can produce *any* current profile downstream of the beamline. The ability to tailor the current profile of sub-picosecond electron bunches has important applications such as the enhancement of transformer ratio in collinear beam-driven wakefield acceleration techniques or the production of super-radiant radiation. An experiment carried at Fermilab's A0 photoinjector confirmed the viability of the technique. In the experiment a train of sub-picosecond bunches separated by 1 ps was produced and diagnosed. The bunch train was generated by converting a set of transversely-separated beamlets using the emittance exchange beamline.

References: P. Piot, Y.-E Sun and M. M. Rihaoui, AIP Conf. Proc. 1086, 677 (2009).

Y.-E Sun, P. Piot et al, http://arxiv.org/abs/1003.3126v1 (2009).

For more information: www.nicadd.niu.edu

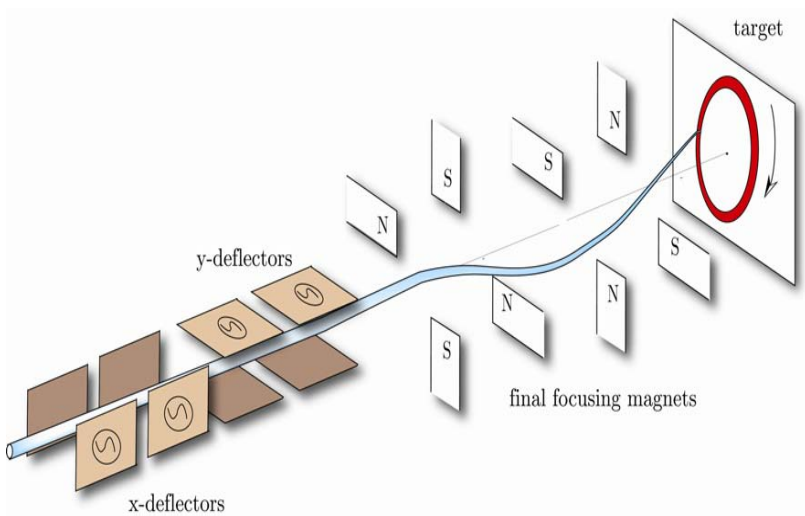


Centroid and envelope dynamics of high-intensity charged particle beams in an external focusing lattice and oscillating wobbler

Investigators: Hong Qin and Ronald C. Davidson, *Princeton Plasma Physics Laboratory,* and B. Grant Logan, *Lawrence Berkeley National Laboratory*

Intense beam dynamics is often studied in terms of envelope and centroid motions. However, the dynamics of the beam centroid have not been extensively explored for practical applications. Recently, the dynamics of the beam centroid has been investigated as a possible beam smoothing technique to achieve a uniform illumination over a suitably chosen region of the target. The basic idea is to induce an oscillatory motion of the centroid for each transverse slice of the beam such that the centroids of different slices strike different locations on the target. The motion of the centroid projected onto the target is designed to follow a smooth pattern in order to achieve the desired uniform illumination over a suitably chosen region, e.g., an annular region, for significantly improved stability properties. The centroid dynamics is actively controlled by the deflection force imposed by a set of biased electrical plates, which are called "wobblers", because of the wobbling motion that they induce in the beam centroid motion. The bias voltage on the wobbler plates oscillates with time in order to deliver different beam slices to different locations on the target. The wobbler system is designed to ensure that different slices are uniformly distributed onto a desirable pattern on the target. The beam then passes through the final focusing magnets located downstream from the wobbler plates, to reach a small focal spot size on the target.

Reference: H. Qin, R. C. Davidson, and B. Grant Logan, Phys. Rev. Lett. **104**, in press (2010).



Schematic of wobbler deflection system and final focusing magnet system.

Accelerating Particles with Light

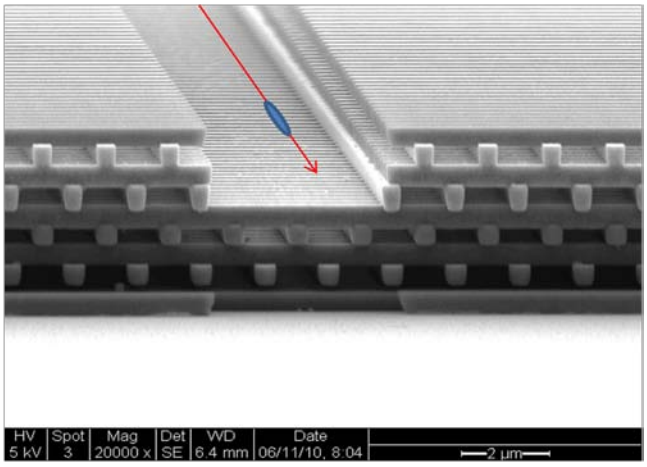
Investigators: Eric R. Colby, Joel England, Johnny Ng, Bob Noble, Ken Soong, Jim Spencer, Dieter Walz, *SLAC;* Robert L. Byer, Chris McGuinness, Edgar Peralta, *Stanford University;* Tomas Plettner, *KLA-Tencor*

Researchers at SLAC National Accelerator Laboratory and Stanford University are working to develop the first entirely solid-state accelerator using semiconductor manufacturing technologies. Making accelerators more compact, more economic, and extending their capabilities into the ultrafast attosecond domain are the goals of this research. Using techniques pioneered by the chip manufacturing industry, accelerators built from damage-resistant dielectric and semiconductor materials are being realized (see figure below) and will be tested in the harsh environment of a working accelerator. Utilizing artificial optical materials called photonic band gap crystals to confine the laser light has allowed researchers to tailor the coupling of the laser light to the particles while allowing control of brightness-degrading effects of wakefields. Materials available today should permit accelerators to reach GeV-scale energies of interest for both electron and photon sciences in just a few meters, bringing this capability into university- and smaller industrial-scale laboratories. Researchers have already produced and accelerated trains of some of the world's shortest electron bunches (410 as) and are on track to demonstrate the first engineered microaccelerator this year.

References: C. McGuinness, "Fabrication and Characterization of Woodpile Structures for Direct Laser Acceleration", in *Proc. Adv. Accel. Conc. Wkshp*, June 13-19, Baltimore, MD, (2010).

R. Byer, T. Plettner, "Building a Pocket-Size Electron Accelerator", *Photonics Spectra*, July 2008, p. 64ff.

For more information:
https://slacportal.slac.stanford.edu/sites/ard_public/aard/dla/Pages/Default.aspx



The lower half of a silicon "woodpile" photonic band gap accelerator designed to accelerate particles with 3.9 µm light.

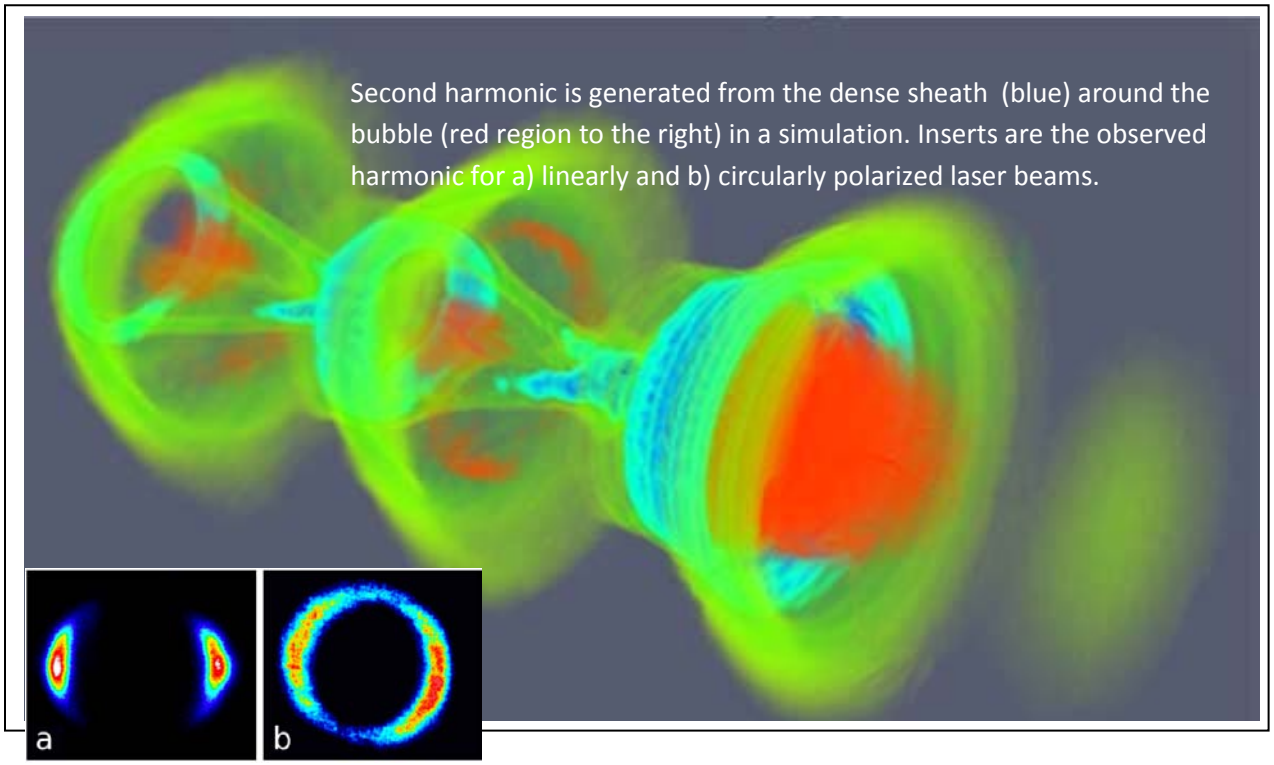
Discover the Plasma Bubble

Investigators: D. Kaganovich, M. Helle, D. Gordon, A. Ting and P. Sprangle, *Naval Research Laboratory*

In the laser wakefield accelerator, a laser pulse propagating through a plasma produces a large amplitude plasma wave that moves with the laser pulse and can accelerate electrons. For high enough laser power or plasma density, the ponderomotive force of the laser is strong enough to form a plasma “bubble” (electron cavitation). Theoretical studies predict the strong electric field inside the bubble can trap and accelerate plasma electrons and eventually produce quasi-monoenergetic high energy electron beams over a very short distance. Numerous experimental groups have since demonstrated production of quasi-monoenergetic electrons, however not until very recently has there been any experimental attempt to observe the bubble formation. Researchers from the Naval Research Laboratory theoretically predicted and experimentally confirmed that the interaction of the intense laser field within the high density sheath of the plasma bubble is generating conically emitted (Cerenkov-like) second harmonic radiation. This conically emitted radiation looks like a blue ring in experimental studies. The way this blue ring evolves was used as the first practical diagnostic tool for laser wakefield accelerators operating in the bubble regime.

References: D. F. Gordon, B. Hafizi, D. Kaganovich, and A. Ting, PRL **101**, 045004 (2008).

D. F. Gordon, A. Ting, M. H. Helle, D. Kaganovich, B. Hafizi, New J. Phys. **12** 045026 (2010).



Second harmonic is generated from the dense sheath (blue) around the bubble (red region to the right) in a simulation. Inserts are the observed harmonic for a) linearly and b) circularly polarized laser beams.

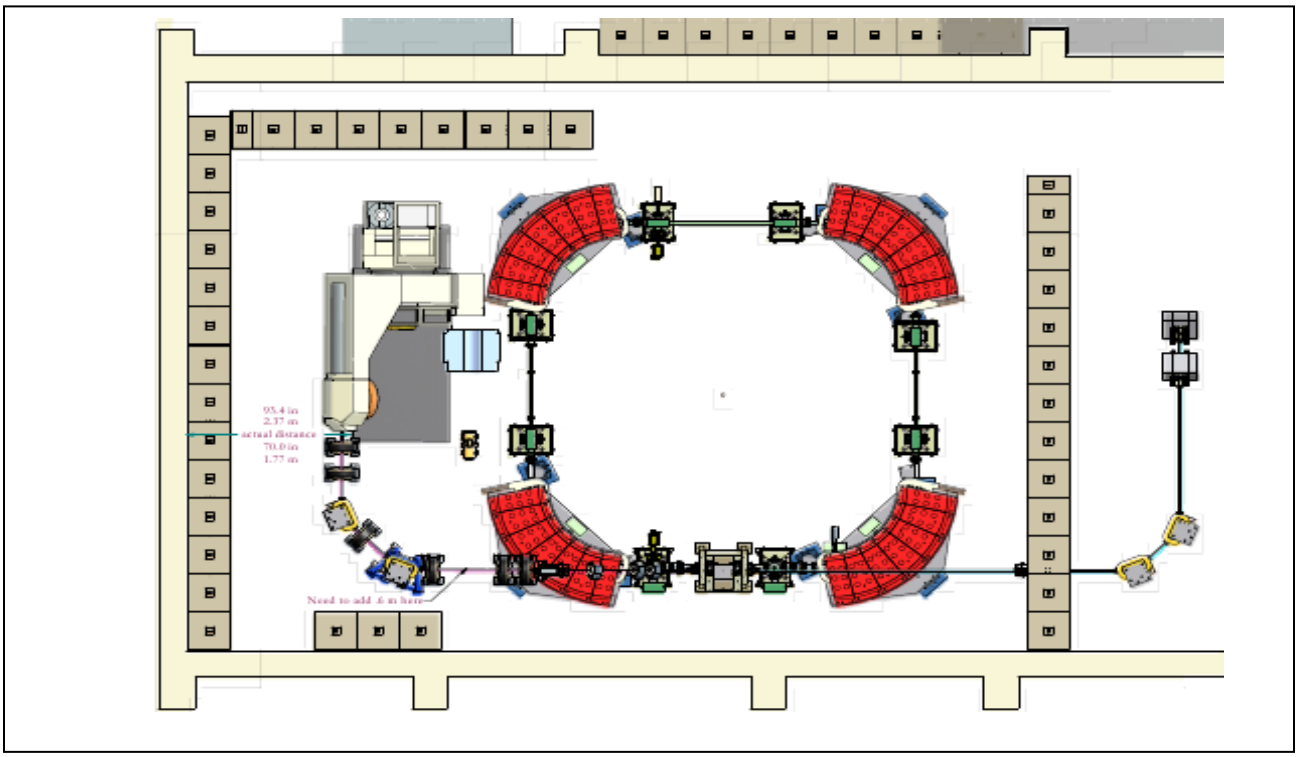
Construction of a high intensity electron storage ring (ALPHA)

Investigators: J. Doskow, G. East, R. Ellis, Y. Jing, Y. Kim, S.Y. Lee, T. Luo, P. McChesney, X. Pang, T. Rinckel, C. Romel, and P. Sokol, *Indiana University*

The Advanced eLectron and PHoton fAcility (ALPHA) project at Indiana University Center for Exploration of Energy and Matter (IU CEEM) includes a 50 MeV linac, 100 MeV electron synchrotron ring of 20 m circumference, and a radiation effect experimental area for the external beam line. The ring is composed of 4 dipoles (2 m long each with 12º edge angle), 2 sets of gradient damping wigglers with field gradient B_1/B_0=1.9 m^{-1}. The horizontal and vertical betatron tunes are 1.75 and 0.75 respectively. By changing the field strength of the wigglers, one can vary the momentum compaction factors from 0.5 to –0.5. At large compaction factor, the ring is a debuncher for RF linac beams. At compaction factor near 0, we can study the beam dynamics of isochronous storage ring by simply changing a single parameter of wiggler field. Such an isochronous accelerator can be valuable to future muon colliders. The ring can also store beam bunches for inverse Compton X-ray source.

References: J. Doskow, G. East, R. Ellis, Y. Jing, Y. Kim, S.Y. Lee, T. Luo, P. McChesney, X. Pang, T. Rinckel, C. Romel, P. Sokol, IPAC2010 proceedings (2010).
S. Y. Lee, J. Kolski, Z. Liu, X. Pang, C. Park, W. Tam, and F. Wang, REVIEW OF SCIENTIFIC INSTRUMENTS **78**, 075107 (2007).

For more information: http://www.indiana.edu/~estor/



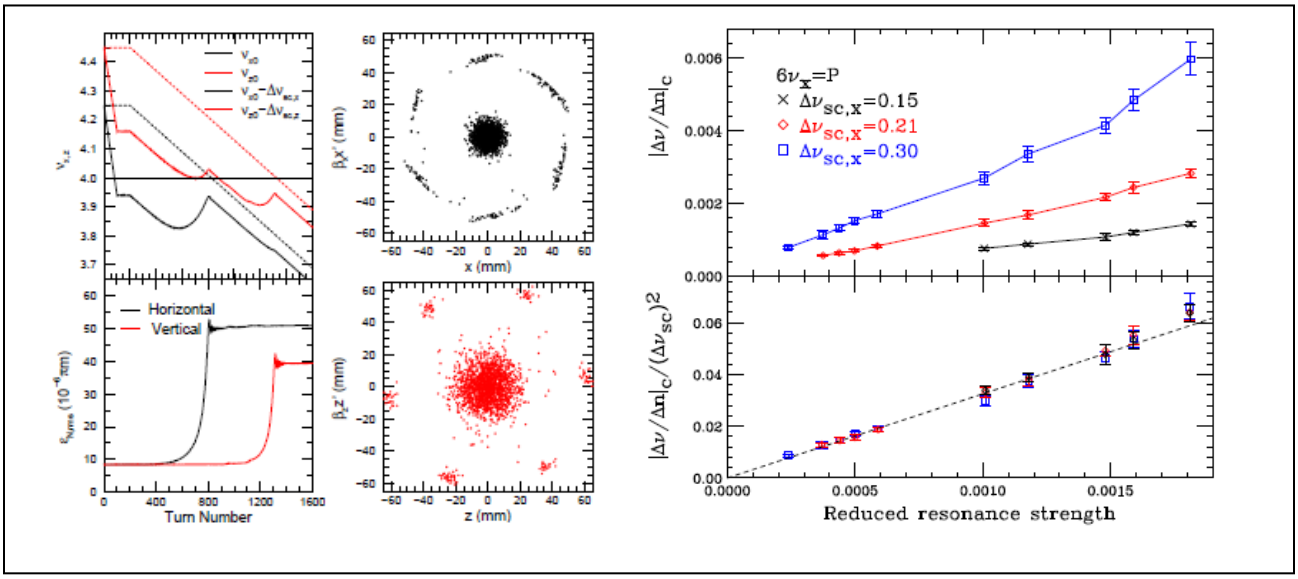
Emittance growth in High Intensity Accelerators

Investigators: Y. Jing, S.Y. Lee, T. Luo, K.Y. Ng, X. Pang, F. Wang, and X. Wang, *Indiana University*

The emittance growth, when high intensity beams ramp through systematic space charge resonances, obeys simple scaling laws. Scaling laws of the emittance growth factor (EGF) for a beam crossing the 4th and the 6th order systematic space-charge resonances are obtained by numerical multi-particle simulations. These scaling laws can be used in setting the minimum acceleration rate, and the maximum tolerable resonance strength for the design of non-scaling fixed-field alternating gradient (FFAG) accelerators. An example of the 6th order resonance is shown below, where the left plot shows the phase space distribution after passing through the resonance, and the right plot shows the EGF scaling law.

References: Phys. Rev. Letters, 97, 104801 (2006);
Proceedings of Hadron Beam 2008, Nashville, Tennessee, USA. P.118 (2008);
New Journal of Physics, 8, 291 (2006)

For more information: http://ceem.indiana.edu/accelphysics.shtml



Photonic Structures Push the Limits of Accelerator Gradient

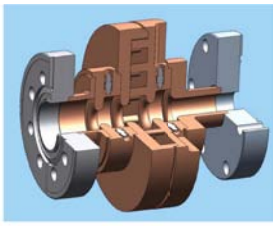
Investigators: A. Cook, I. Mastovsky, B. Munroe, M. Shapiro, and R. Temkin *MIT;* J. Haimson, *Haimson Research Corp.;* R. Marsh, *LLNL*; E. Smirnova, *LANL;* V. Dolgashev and S. Tantawi, *SLAC*

Progress in High Energy Physics requires the study of particles at ever increasing particle energy. To complement the results of the LHC, it is desirable to build an electron – positron collider in the TeV energy range. The cost, size and complexity of such an accelerator would be greatly reduced by operation at higher gradient. A high gradient accelerator structure must contain some form of damping in order to limit wakefields caused by particles passing through the structure. Photonic bandgap (PBG) cavities are ideal damped accelerator structures because they can support a single accelerating mode while suppressing all higher order mode wakefields. A PBG cavity is formed by a triangular array of metal or dielectric rods with a single rod removed at the center. First tests of such a metal structure were conducted at MIT at 17 GHz to a gradient of 35 MV/m. Recently, the first tests of a PBG structure at 60 Hz repetition rate and 100 MV/m gradient were conducted on an 11.4 GHz structure at SLAC. The results showed that the PBG structure operated without any damage arising from surface electric fields exceeding 200 MV/m. However, the high RF magnetic fields on the rods caused high surface temperature increases resulting in damage. Future research will include use of elliptical rods to reduce surface heating and testing to achieve higher gradients at low breakdown rates.

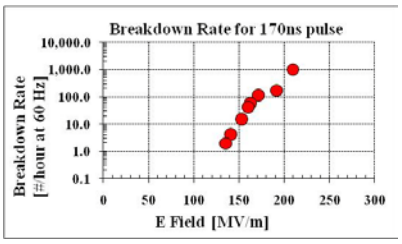
References: E. I. Smirnova et al., Phys. Rev. Lett. **95** 074801 (2005);
R. A. Marsh et al., Proc. Part. Accel. Conf. PAC09, Paper TH4GBC06 (2009).

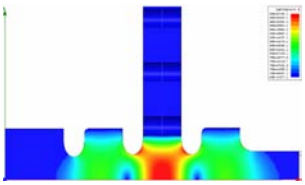
For more information: http://www.psfc.mit.edu/research/wab/

Photonic Structure Test at SLAC



Photonic Structure





E-Field Distribution

- **Photonic structure is a single cell between two coupling cells**
- **Peak electric field occurs at the iris**
- **Tests at 11.4 GHz in pulses of 170 ns exceeded 200 MV/m at the surface, 100 MV/m gradient**

Superfluid Helium Cryogenics: an Enabling Technology for Future Accelerators

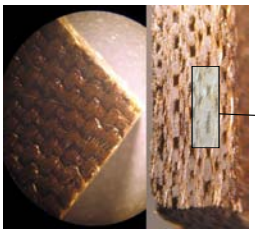
Investigators: S. Van Sciver and S. Fuzier, D. Celik, *National High Magnetic Field Laboratory, Florida State University*

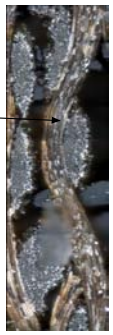
The Florida State University Cryogenics group is pursuing the fundamental issues associated with using superfluid helium for cooling high field superconducting magnets and RF cavities in future accelerators. Two main projects have recently been completed. First, the cooling of high current density superconducting magnets may be significantly enhanced by using porous insulation between conductor turns. This insulation allows the superfluid helium to permeate the coil windings and thus be in direct contact with the conductor turns. In this context, experiments have been performed at FSU to quantify the transient and steady heat conduction through superfluid helium contained in prototype porous insulating materials for magnets. The basic physical models used to understand superfluid helium heat transport are then used to interpret the data with the purpose of developing tools to assist with superconducting magnet design. The second project involves the study of superfluid helium flow through components used in accelerator cooling systems. This work currently is studying the flow of superfluid helium through orifice plates most commonly used to monitor flow rate. A combination of experiments and analytical modeling are similarly being used to interpret the data. Close collaboration with US-DOE high energy physics laboratories provides valuable insight to focus the R&D on accelerator relevant work.

For more information: www.eng.fsu.edu/cryolab

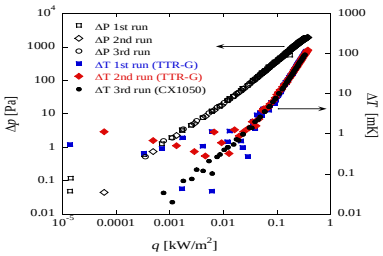
Porous insulation for high field Nb_3Sn dipole magnets

Cooling of high field dipole magnets can be enhanced by use of porous insulation and superfluid helium cooling.

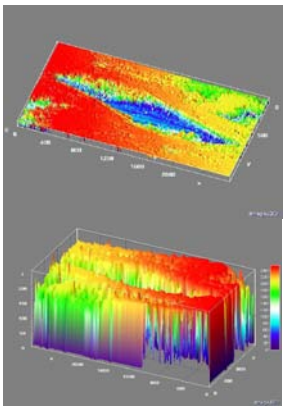




Sample micrograph showing porous structure



Temperature and pressure difference across porous media containing superfluid helium



Laser confocal microscope image of porous media

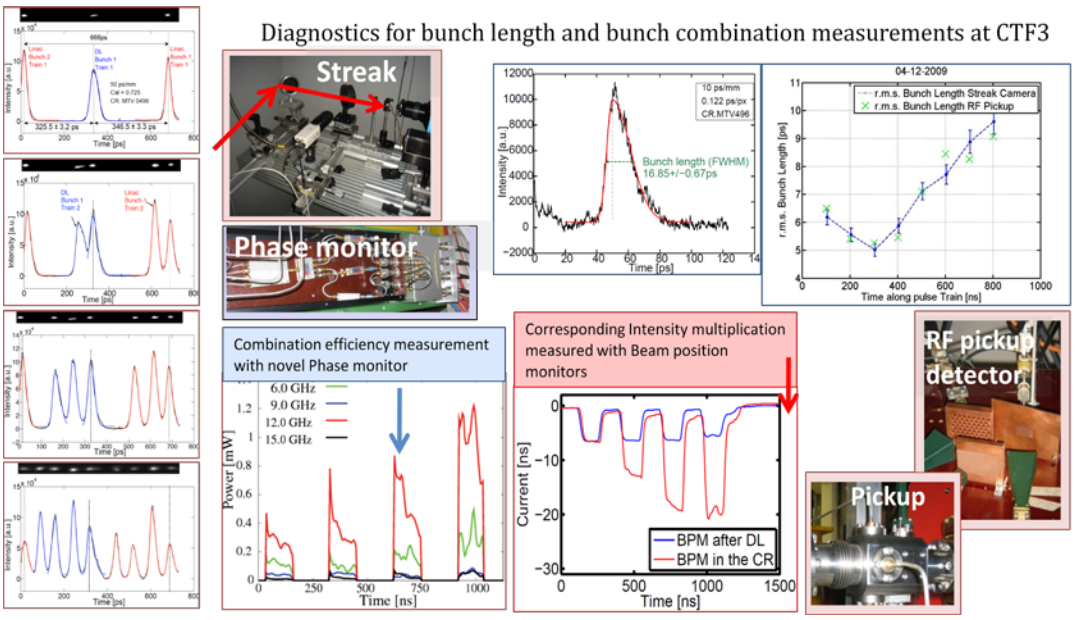
Development of Beam Instrumentation for Future e+e- Machines

Investigators: M. M. Velasco, *Northwestern University,* A. E. Dabrowski, *CERN*

This work focuses on the design of novel beam diagnostics for charged particle accelerators required to monitor and tune the performance of next-generation linear electron and positron colliders and 4th generation light sources. Our main interest is in non-invasive techniques to measure the longitudinal phase space of an electron beam, including the beam energy, phase (bunch spacing) and bunch length. This work is done at the 3rd CLIC Test Facility at CERN, which has been built in order to prove the feasibility of some of the main technological challenges of the "two beam acceleration scheme". 2009 was a milestone year for the CTF3 project, demonstrating for the first time the production of a 12 GHz combined 28 Amp beam from an initial 1.5 GHz 4 Amp beam. Streak camera measurements and our novel phase monitor diagnostics have measured and monitored this bunch spacing gymnastics. The novel "RF pickup" microwave detector has been calibrated with the Streak Camera for bunch lengths of 2-10ps for reliable bunch length measurements. During 2010 design work will continue to push the envelope in this microwave spectroscopy technique, with the goal of an r.m.s. bunch length resolution of 300 femtoseconds. A new detector is currently being designed and foreseen for installation in the CTF3 CLIC Experimental Area (CLEX) at the end of 2010.

Reference: A. Dabrowski, Proceedings, 1st International accelerator conference, Kyoto, Japan

For more information: http://accelconf.web.cern.ch/AccelConf/IPAC10/papers/mope058.pdf



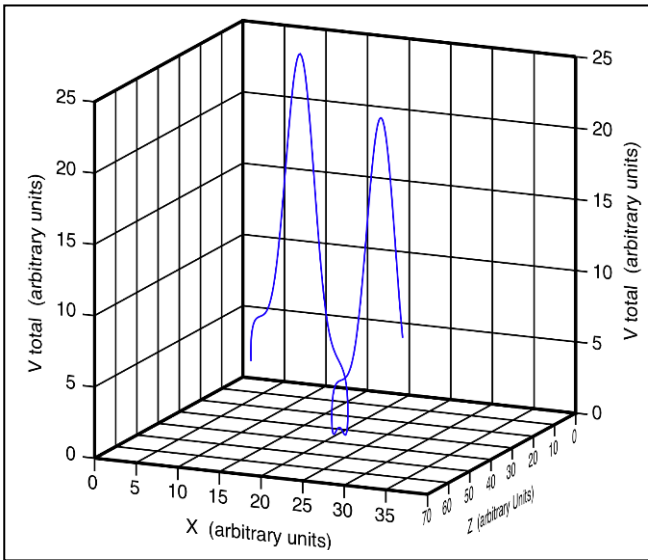
Electron Beam Transport in Advanced Plasma Wave Accelerators

Investigators: R. Williams and A. Bowman, *Florida A. & M. University*

Laser-generated plasma waves may lead to a future generation of compact high energy particle accelerators for scientific research and to compact lower energy particle accelerators for industrial, environmental, energy, and medical applications. Charged particles (such as electrons) can gain large amounts of energy over short distances by being trapped and riding along with fast moving waves created in plasmas. Progress has been made in developing a technique to measure the plasma wave's accelerating electrostatic fields by injecting a low-energy electron beam perpendicular to the plasma wave and observing how this electron beam is distorted by the plasma waves. Recently, numerical simulations have been performed that show the complex trajectories and energy changes of diagnostic electrons as they travel perpendicularly across both the plasma wave's electrostatic fields and the laser beam's electromagnetic fields as well as the effect of electron injection angles. Ongoing studies include the effects of the diagnostic beam's emittance and energy spread and the use of a low power laser beam as a diagnostic of the electron beam. A new flexible interaction chamber has been built so that experiments can be performed to demonstrate these diagnostic techniques in the laboratory.

References: A. L. Bowman and R. L. Williams, "Analysis of Trajectories and Multi-dimensional Phase Space Diagrams for Electrons Injected Orthogonal to Plasma Waves, and Laser and Scattered Radiation", 49th Annual Meeting of Division of Plasma Physics, APS, November 2007, Orlando, FL: Bull. A.P.S., Vol. 52, No. 16, (2007) p.36.

For more information: ronald.williams@famu.edu.



Sample 3-D lab frame phase space diagram for an electron propagating across overlapping laser beam (electromagnetic field) and plasma wave (electrostatic field): (total velocity versus x and z).

Technology Identification and Integrated Circuit Developments of Next Generation High Speed Optical Link Systems for Future HEP Detectors and Experiments

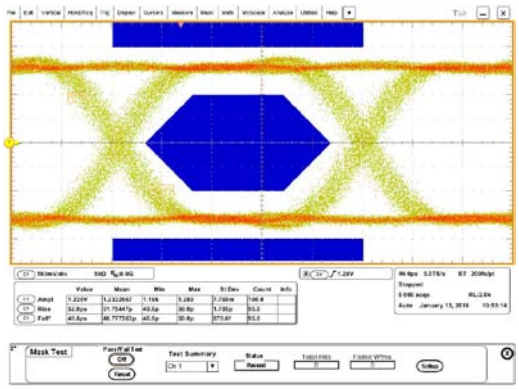
Investigator: Jingbo Ye, *Southern Methodist University*

High reliability radiation tolerant optical links are used in experiments at the Tevatron and the LHC to meet data transmission requirements in high energy physics (HEP). Detector developments such as the digital hadron calorimeter and upgrades for the sLHC all demand much higher data bandwidth, lower power consumption, and often higher radiation tolerance than the present data links. To meet these requirements, we are currently evaluating a commercial silicon-on-sapphire (SOS) CMOS technology for Application Specific Integrated Circuit (ASIC) developments for HEP detector front-end electronics readout. We have also developed a 5 Gb/s serializer, the highest speed ever reached in serializer ASICs developed for HEP applications. On the technology identification front, we have successfully tested this SOS technology with the 5 Gb/s serializer as well as other test structures. These test results are of interest to a broad community of end users and not just for HEP applications. Finally, for the first time we are testing and proposing an optical link inside liquid argon for the Long Base Line Neutrino Experiment at Fermi Lab and DUSEL.

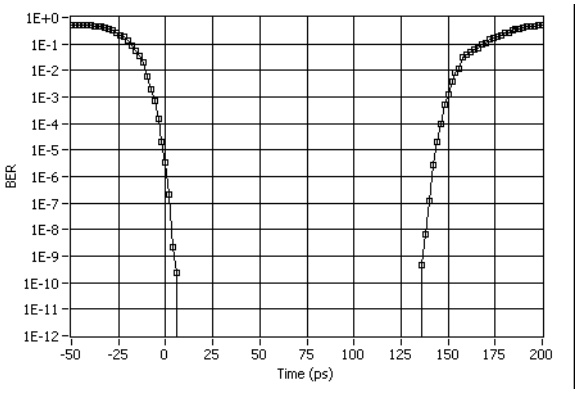
Reference: J.Ye on behalf of the ATLAS LAr Calorimeter Collaboration, 'A Serializer ASIC at 5 Gbps for Detector Front-end Electronics Readout'. Calor201, Beijing 5/10-14, 2010.

For more information:
http://blog.smu.edu/research/2010/04/new_highspeed_integrated_circu.html#more and http://nsf.gov/news/news_summ.jsp?cntn_id=116778&org=NSF&from=news

The 5 Gb/s Serializer LOCs1:



Eye mask test at 5 Gb/s.

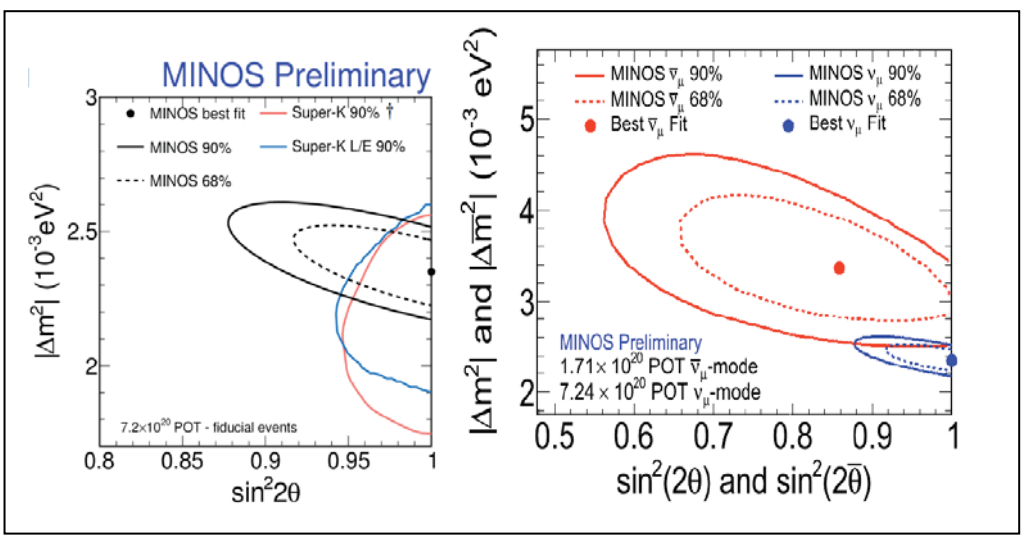


Bathtub scan at 5 Gb/s

MINOS Experiment: Unraveling the Mysteries of the Elusive Neutrino

Investigators: Sarah Budd, Maury Goodman, Xiaobo Huang, Jonathan Paley, Richard Talaga, *Argonne National Laboratory*

The Main Injector Neutrino Oscillation Search (MINOS) Experiment collects data when an intense beam of neutrinos, generated at Fermi National Laboratory, passes through two massive detectors separated by 460 miles. During their flight between the two detectors, the neutrinos of one type convert to a different type of neutrino. These oscillations indicate that neutrinos have mass, a fact that does not fit into the Standard Model of Particle Physics. Strong evidence exists that there are only three types of neutrinos (electron-neutrinos, muon-neutrinos and tau-neutrinos) that interact via the Weak force, and MINOS has made the most precise measurement yet of the difference in masses between the muon- and tau-neutrino types (see bottom-left figure). MINOS has also produced the best limit on the as-yet unobserved oscillation between the muon-neutrino and electron-neutrino; such oscillations are the goal of future neutrino experiments, such as NOvA (in which ANL plays a critical role), since such a discovery could eventually yield an explanation of why the universe is dominated by matter and not anti-matter. Finally, MINOS has completed an analysis of a data set collected when the neutrino beam was running in a “reversed” mode and thus observed mostly antineutrinos, a form of anti-matter. The results shown in the bottom-right plot agree rather poorly with the results shown in the bottom-left (where the beam was run in “normal” mode). More antineutrino data is needed to make a compelling case, and MINOS hopes to be able to collect more in the next year.



Left: MINOS results (in black) of the oscillation parameters compared to the Super-K experiment. Right: MINOS results of the oscillation parameters in two neutrino beam configurations. The results shown in blue are those shown in black in the plot on the left. The results shown in red are those from a mostly anti-neutrino beam. The Standard Model of Particle Physics predicts that the oscillation parameters for neutrinos and anti-neutrinos be exactly the same.

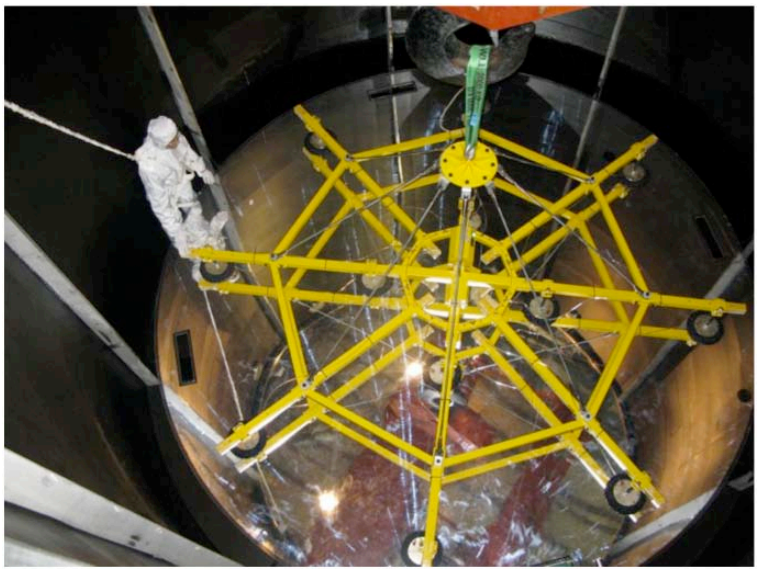
Following the mysterious neutrino on the trail of missing antimatter

A. B. Balantekin, V. Barger, H. Band, L. Everett, K. Heeger, T. Han, and T. Wise,
Physics Department, University of Wisconsin – Madison.

University of Wisconsin – Madison researchers are investigating effects of new physics in neutrino interactions as probed by precision measurements of neutrino oscillations in accelerator and reactor experiments. The discovery of neutrino mass and the conversion from one type of neutrino to another provided clues about the disappearance of antimatter. The multifaceted UW neutrino physics research program will lead to a greater understanding of these mysterious particles. On the theoretical side, UW researchers are studying the implications of neutrino oscillation data for a variety of fundamental questions, including the origin of the excess of matter-antimatter asymmetry in the Universe and the implications for theories of quark-lepton unification. UW theorists are also devising ways to test theories of neutrino mass generation at collider experiments such as the Large Hadron Collider. On the experimental side, UW scientists and a technical team from Wisconsin play a lead role in constructing detectors for the US-China Daya Bay project which will search for the disappearance of electron antineutrinos from a nuclear power plant near Hong Kong. The experiment broke ground in 2007 and the first results in 2012 will measure the last unknown parameter characterizing neutrino mixing. The results from Daya Bay will also set the stage for a proposed neutrino beam from Fermilab to a planned deep underground lab in South Dakota for future precision studies of neutrino oscillations.

References: *Celebrating the Neutrino*, Los Alamos Science, http://la-science.lanl.gov/lascience25.shtml

Detecting Massive Neutrinos, Scientific American, August 1999



Assembly of the antineutrino detectors for the US-China Daya Bay experiment near Hong Kong.

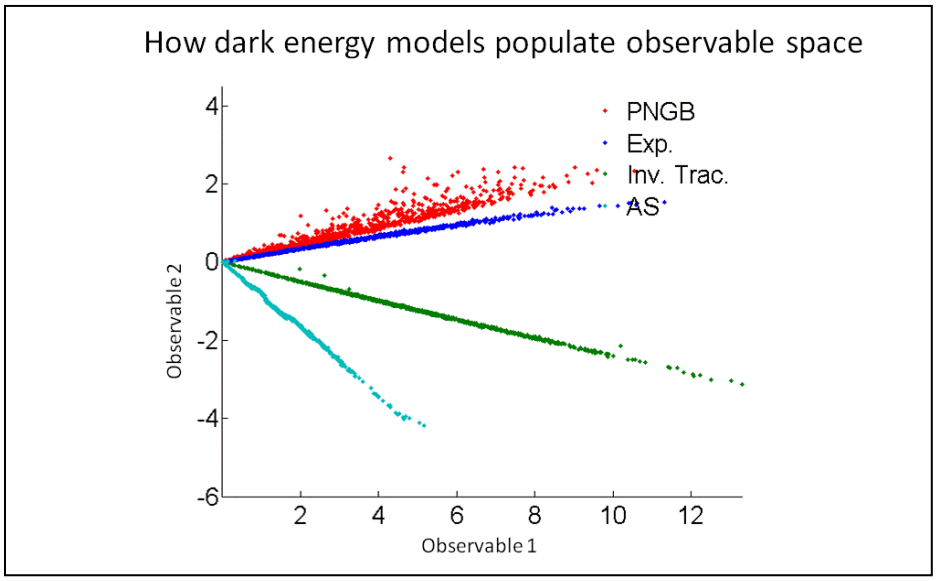
Pinning down the elusive Dark Energy

Investigators: M. Barnard and B. Bozek, *Johns Hopkins;* A. Abrahamse and A. Albrecht, *University of California--Davis;* M. Yashar, *University of Illinois—Urbana-Champaign*

Named the top science problem by *Science* magazine, there is a global effort to build the next generation of telescopes to pin down the nature of the Dark Energy. Dark Energy is hypothesized in order to explain the acceleration of the Universe. To do so it must comprise 70% of the Universe, yet the Dark Energy is poorly understood. Our uncertainty about Dark Energy is one reason the topic is exciting, but that also makes it hard to forecast the impact of proposed experiments. In light of the uncertainties, most forecasts use simple heuristic descriptions of Dark Energy that do not commit to a specific theoretical model. But what *will* the impact of new experiments be on existing published models? One might worry that with their diversity of adjustable parameters, any theoretical model could mimic any future observation, preventing serious progress in the field. The Barnard collaboration projected models into the specific observable space of proposed experiments, allowing the theoretical parameters to range freely. As illustrated in the figure, these models occupy different regions of observable space, despite the free parameters. A nonzero signal in the observable quantities could rule out some or even all of these models. While the mystery of the dark energy is yet unsolved, this work shows new ways that future experiments will have a great impact, and thus further advances the case for building the next generation of telescopes in pursuit of the Dark Energy.

Reference: Barnard et al., Phys. Rev. D **78**, 043528 (2008)

For more information: http://www.physics.ucdavis.edu/Cosmology/albrecht/
(especially under "Dark Energy Task Force and followup work")



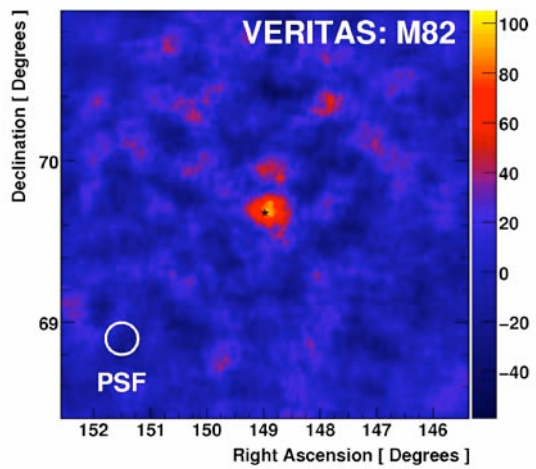
VERITAS Helps Solve 100-Year-Old Mystery of Cosmic-Ray Origin

Investigators: W. Benbow, T.C. Weekes, J.S. Perkins, N. Galante, K. Gibbs, V. Acciari and M. Theiling, *Smithsonian Astrophysical Observatory*

In 2009, researchers working with the Very Energetic Radiation Imaging Telescope Array System (VERITAS) reported the discovery of very high energy gamma rays from the starburst galaxy Messier 82 (M82). The observed gamma rays have energies more than a trillion times higher than the energy of visible light, and are believed to be produced by cosmic rays in M82, created by the galaxy's unusually numerous massive stars, interacting with its interstellar gas and radiation. Cosmic rays are particles hitting the Earth's atmosphere and are produced in violent processes in our own Galaxy and beyond. Although they were discovered in 1912, definitive evidence for the origin of cosmic rays has remained elusive for nearly a century. The VERITAS discovery clearly links the acceleration of cosmic rays in M82 to the processes that enable stars to form, and it indicates that the cosmic-ray density in M82 is approximately 500 times the average density in our Galaxy, the Milky Way. These VERITAS observations also strongly support the long-held theory that supernovae and massive star winds are the dominant accelerators of cosmic-ray particles. Dr. Wystan Benbow coordinated this project for the VERITAS collaboration, an international group of almost 100 scientists.

References: V. Acciari et al., Nature, **462** (2009), 770

For more information: http://www.cfa.harvard.edu/news/2009/pr200921.html & http://veritas.sao.arizona.edu/~benbow/M82-VERITAS-PressRelease.pdf



This representative-color figure shows the very-high-energy gamma-ray emission observed by VERITAS coming from Messier 82. The black star is the location of the active starburst region. The emission from M82 is effectively point-like for VERITAS. The white circle indicates the size of a simulated point source. The entire galaxy would be contained within the circle.

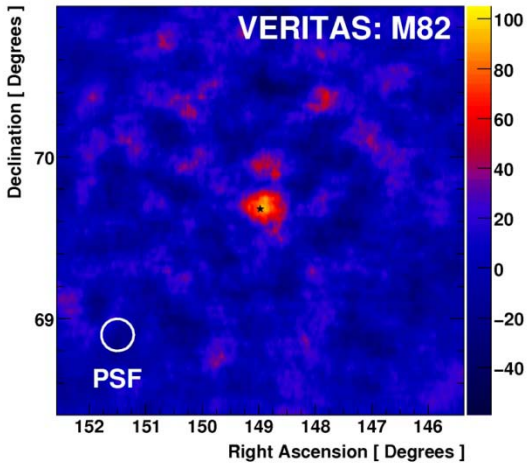
Discovery of High Energy Gamma-Ray Emission from the Starburst Galaxy M82

Investigators: J. Buckley, H. Krawczynski, M. Beilicke, S. Bugayev, R. Dickherber, S. McArthur, and S.Thibadeau, *Washington University,* and the VERITAS collaboration

The VERITAS collaboration discovered very high-energy gamma-ray emission from the nearby starburst galaxy M82 and established together with the Fermi and H.E.S.S. gamma-ray observatories starburst galaxies as a new class of gamma-ray bright objects. The discovery gives strong support to the hypothesis that the remnants of exploded stars in our galaxy and in other galaxies (like M 82) accelerate atomic nuclei to very high energies, and are the likely sites of Cosmic Rays acceleration. Victor Hess discovered Cosmic Rays in 1912, and the origin of Cosmic Rays has been one of the longstanding riddles of modern astrophysics. The Washington University group was centrally involved in planning the observations and in the analysis of the VERITAS data. The VERITAS gamma-ray observatory consists of four 12 m diameter Cherenkov Telescopes located at Mt. Hopkins, AZ. The experiment started operation in April 2007 and is used to study the origin of Cosmic Rays, to search for dark matter gamma-ray annihilation radiation, and to explore how supermassive black holes grow by swallowing matter.

Reference: Acciari, V. A., Aliu, E., Arlen, T., et al. 2009, Nature, **462**, 770-772

For more information: http://news.wustl.edu/news/Pages/15193.aspx



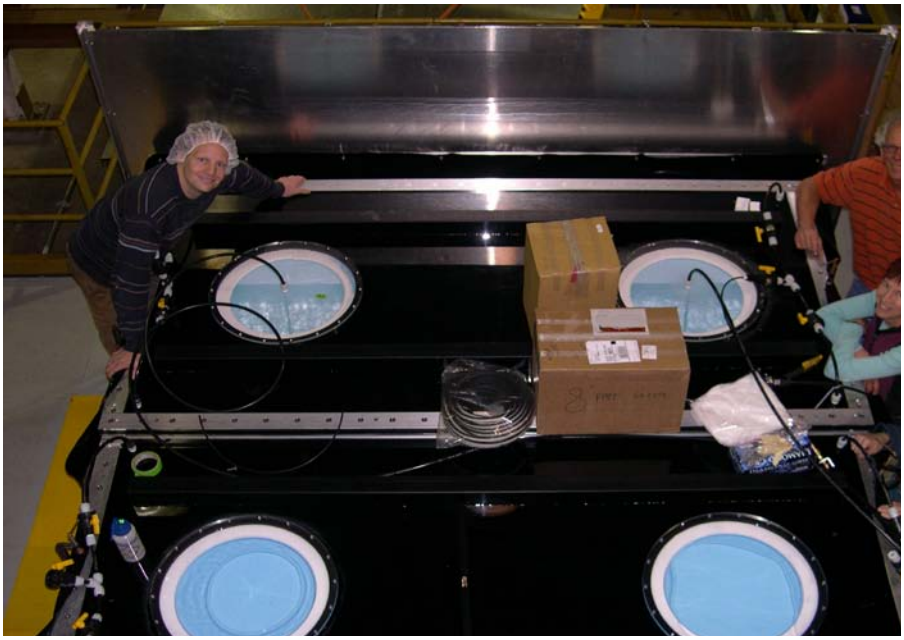
Dark Matter and Deep Underground High Energy Neutrons

Investigators: Burke, S., Kyre, S., Lanza, R., Nelson, H., Nielsen, C., Olmedo, M., Quinlan C., Sander, J., and White, D. *University of California—Santa Barbara;* Akerib, D., Dragowsky, M., Hennings-Yeoman, R., and Lee, C., *Case Western;* Sweaney, M. and Tripathi, M., *University of California—Davis*

Most matter in the universe is dark matter, as deduced from its gravitational pull on normal atoms and from studies of the cosmic background radiation. Data indicate that 5/6 of matter in the universe is dark matter which doesn't feel the electromagnetic or strong nuclear forces. Many searches are underway worldwide to determine if the dark matter can interact with normal matter via the remaining force – the weak interaction, by seeking recoils of nuclei without an apparent source. The deduced cause would be a type of dark matter called `Weakly Interacting Massive Particles' or WIMPs. Fast neutrons also cause nuclei to recoil, and fake the signal expected from WIMPs. The fast neutron flux at the Earth's surface is large, and so WIMP detectors are operated deep underground. Estimates of the fast neutron flux deep underground have large uncertainties, so the detector pictured was fabricated at UCSB and deployed in Minnesota's Soudan Laboratory to measure that flux. The detector has two large area water tanks atop a pedestal of lead. Fast neutrons interact in the lead and liberate slower neutrons, which thermalize and are captured on gadolinium added to the water, causing emission of gamma rays, which hit electrons in the water. The electrons emit Cherenkov radiation, detected by the Kamland-type 20" diameter photomultiplier tubes placed over the four holes.

References: Hennings-Yeomans and Akerib, NIM A 574 (2007) 89; CDMS Collaboration, Science 327 (2010) 1619.

For more information: http://neutron.physics.ucsb.edu/



Core-Collapse Supernova Explosions

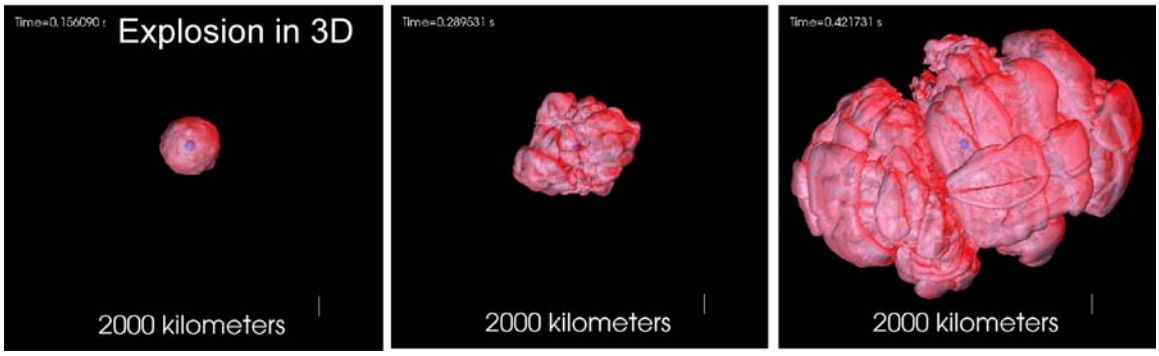
Investigators: A. Burrows and J. Nordhaus, *Princeton;* A. Almgren and J. Bell, *LBNL;* L. Howell, *LLNL*

We have developed a 3D AMR, multi-grid Radiation-Hydrodynamical code CASTRO with block-structured grids, subcycling in time, and a general Poisson gravity solver and are applying it to the study of a central astrophysical problem - the mechanism of core-collapse supernova explosions. Using CASTRO, we have discovered that the viability of the neutrino-driven model of explosion is strongly dependent on dimension and that 3D simulations are essential to cracking this puzzle. We find that the efficiency of explosion is a monotonic function of dimension, with 3D being (in some measures) roughly twice as prone to explosion as 1D. The next step is 3D models of the full explosion including multi-group neutrino transport. We hope to achieve this by the end of 2010.

CASTRO - 3D AMR, Multi-Group Radiation-Hydrodynamic Supernova Code : Near-term Code Development Plans for CASTRO (Neutrino) Transport: By July of 2010: Finish implementing 1D conservative version of mixed-frame method of Hubeny & Burrows (2007), with v/c terms and inelastic scattering. Summer of 2010: Finish implementing 2D/3D version using scalable linear solvers (e.g., hypre) with high-performance preconditioners featuring parallel multi-grid and Krylov-based iterative methods. Goal in 2010: To demonstrate scaling of transport module to 32,000 cores. (Hydro already at > 200,000 cores.)

References: J. Murphy & A. Burrows, Astrophys. J., 688, 1159 (2008); J. Nordhaus et al., submitted to Ap.J. (2010); A. Almgren et al., submitted to Ap.J. (2010); I. Hubeny & A. Burrows , Ap.J., 658, 1095 (2007)

For more information: http://www.astro.princeton.edu/~burrows/sn.3d/



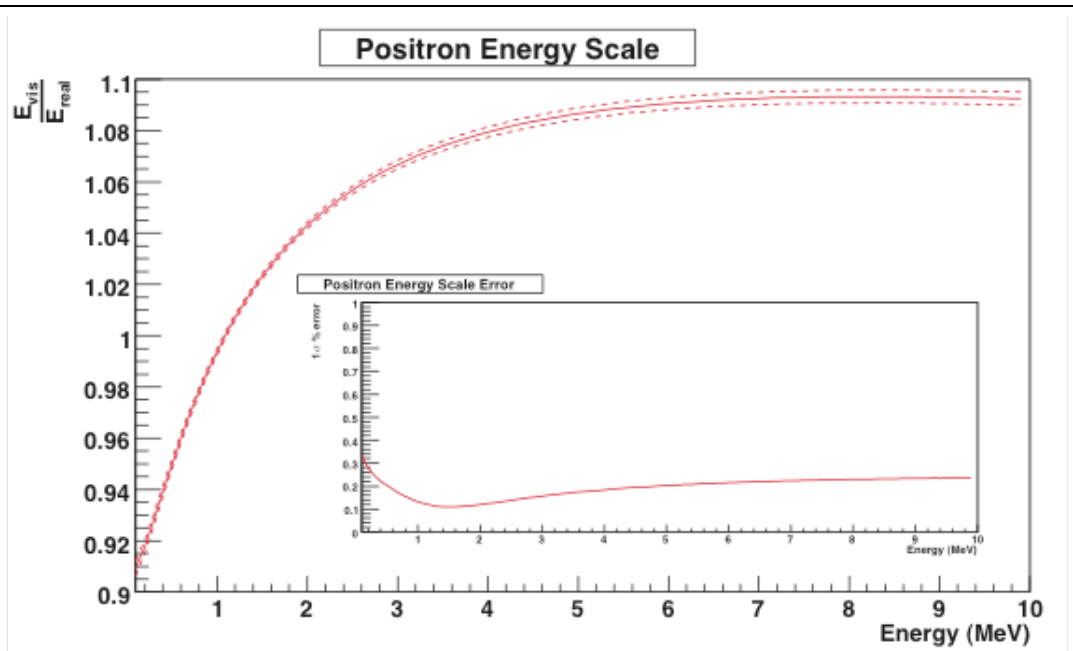
Time sequence of a 3D explosion on the same spatial scale.

Precise Measurement of the KamLAND Energy Scale Using Gamma Sources

Investigators: J. Busenitz and T. Classen, *University of Alabama*

The KamLAND experiment is designed to precisely measure the energy of reactor antineutrinos inducing inverse beta decay and the energy loss of solar neutrinos by electron scattering. This requires the precise measurement of the energies of positrons (inverse beta decay) and electrons (electron scattering) in the final state. Ideally, one would calibrate the energy scale using sources which emit the same particles as being produced in the reaction and would deploy these sources at a full set of representative positions throughout the detector. In the KamLAND experiment, full-volume deployment was largely achieved but owing to the difficulty of fabricating and deploying beta and positron sources which are well--understood at the percent level, only gamma sources and neutron sources producing gammas through (n,gamma) reactions were deployed. By using gamma sources spanning a wide range in energy, carefully correcting for the effects of energy losses in the capsule, light shadowing by the capsule and deployment system, and detector noise, and building a detailed model for the energy scale and fitting it to the corrected gamma source data, the energy scale for electrons and positrons was determined to within 0.4% over the energy range 0.3-10 MeV. The following plot shows the ratio of the visible energy to actual energy determined for positrons; the dashed lines indicate the band of uncertainty and the inset plot shows the estimated uncertainty as a function of positron energy.

References: being prepared for publication in Nuclear Instruments and Methods

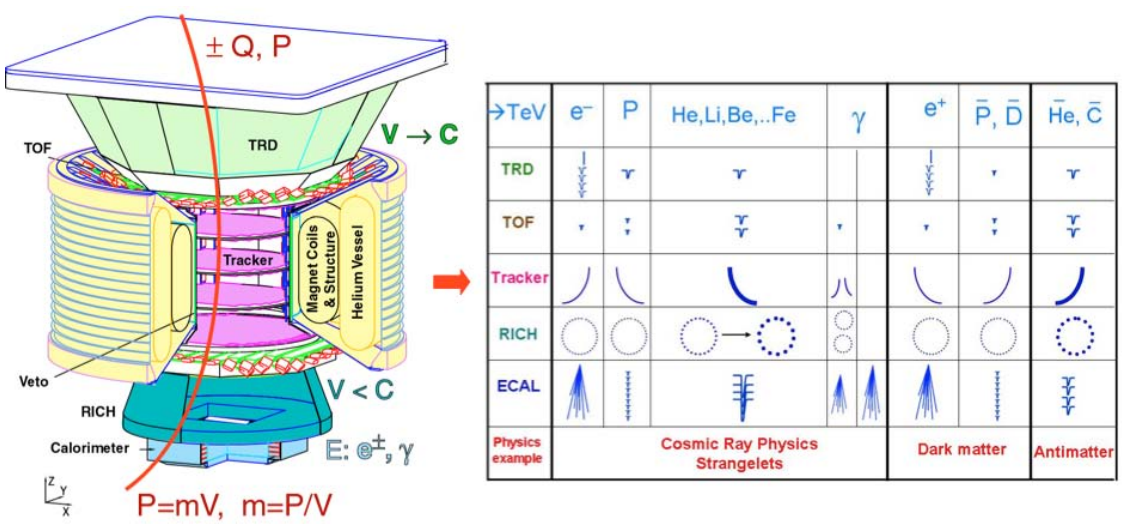


AMS in Space – Testing the Strange Quark Matter Hypothesis

Investigators: A. Chikanian, E. Finch, R. Majka, and J. Sandweiss, *Yale University*

Twelve years after the successful prototype flight of AMS in 1998, the full detector will be launched and placed on the International Space Station via the last shuttle flight, at the end of 2010 or early in 2011. This powerful detector will measure cosmic charged particles and high energy photons with unprecedented accuracy and acceptance. The focus of the Yale group will be the search for stable strange quark particles with mass number (AMU) up to 2000. Because a precise determination of the cosmic ray spectrum (particle by particle) must be done to identify a "strangelet", a measurement will also be made of the chemical composition of the cosmic rays with much greater accuracy than hitherto possible. In 1984 Professor E. Witten (1) hypothesized that nuclei with an arbitrarily large number of quarks might be stable if they contained an approximately equal number of up, down, and strange quarks (hence the name strange quark matter, SQM). Accelerator experiments cannot produce SQM because the coalescence rate of the quarks is too low. However, if the SQM hypothesis is correct, all compact stars are SQM stars and not neutron stars. It is not possible to distinguish them from earth. Calculations indicate that binary collisions with SQM stars will produce a sufficient rate of SQM particles to essentially test the hypothesis with AMS. If SQM exists, there will be a number of fascinating physical and technological potentialities.

Reference: (1) E. Witten, Phys. Rev. D **30**, 272 (1984)



Do Neutrinos Violate Matter/Anti-matter Symmetry?

Investigators: T. Classen, J.F elde, P. Gupta, C. Henson, and R. Svoboda, *University of California-- Davis*

The last fifteen years have been ones of extraordinary progress in understanding the nature of the neutrino. Once thought massless, neutrinos have now been shown to have a tiny mass, less than one-millionth that of the electron. In addition, two of the three neutrino mixing angles have been measured (Θ_{12} and Θ_{23}), and the third (Θ_{13}) has been shown to be small ($\sin^2 2\Theta_{13} < 0.12$). If this third angle is not *too* small, then there is the intriguing possibility of testing if neutrinos violate CP symmetry – a key ingredient of the *Leptogenesis Model*, which ascribes the preponderance of matter over anti-matter in the universe to CP violation in the neutrino sector of a "see saw" doublet. Motivated by this, the Double Chooz reactor experiment will attempt to make the first measurement of Θ_{13}. Reactors are very powerful (8.5 GW for the Chooz B power plant) sources of electron anti-neutrinos. A non-zero Θ_{13} would manifest itself as a departure from the $1/r^2$ distance law between the calculated reactor flux and a Near and Far detector due to neutrino oscillations. Currently, the Far detector has been completed at the Chooz complex, and filling is scheduled to start July 15. UC Davis is one of the founding institutions of the experiment and helped to design and build the 200-ton detector. UC Davis researchers are taking place in filling operations (in charge of shifts) and will install calibration deployment hardware this Fall, bringing the Far detector facility into full operation. Shown below are physicists installing the mumetal shielded photomultipliers inside the 15-cm thick iron shield and oil buffer vessel. This key experiment will be the first experiment to run that was built explicitly to measure Θ_{13}.

Reference: I.Gil-Botella, et al. arXiv:0905.3693

For more information: www.dchooz.org

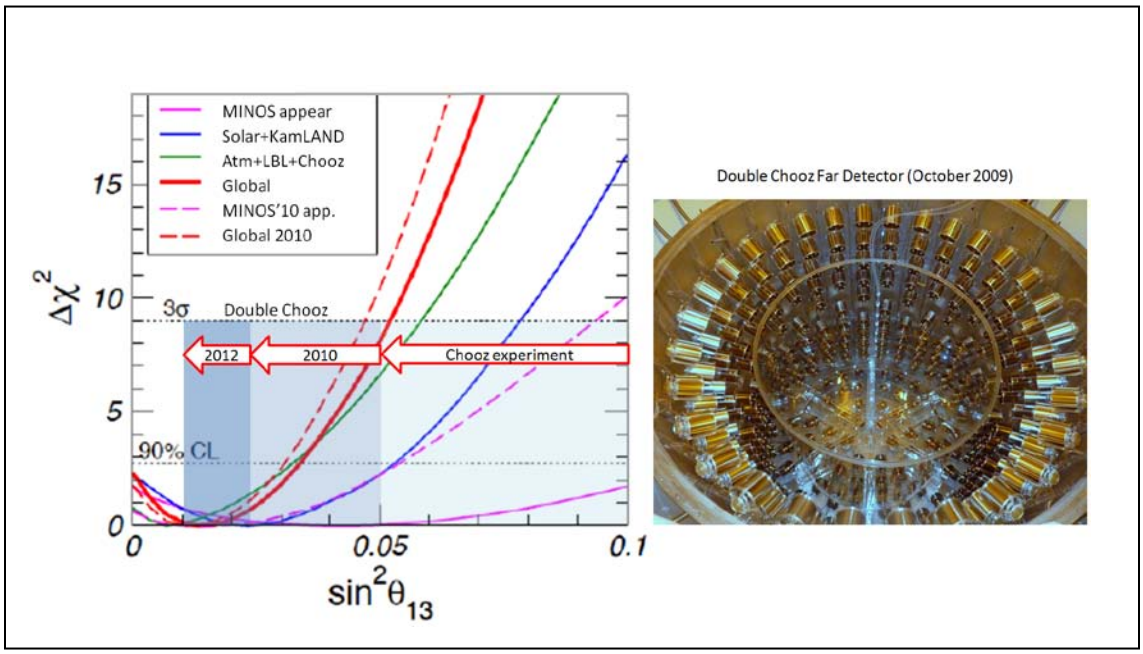
Measurement of Neutrino Mixing Angle θ_{13}

Investigators: members of Double Chooz Collaboration Y. Efremenko, A. Hatzikoutelis, Y. Kamyshkov, A. Osborn, and B. White, *University of Tennessee*

Recent neutrino experiments Super-K, SNO, KamLAND, and MINOS clearly demonstrated phenomenon of neutrino oscillations. The neutrino mixing matrix is defined by 3 angles between mass and flavor eigenstates and a complex phase that is responsible for CP violation in the neutrino sector. Two of the mixing angles are well determined by the above mentioned neutrino experiments but the third angle θ_{13} is only limited by the Chooz-1999 experiment to <13°. The value of θ_{13} angle is coupled with CP-violation phase which in case of finite θ_{13} can be measured in the future long-baseline accelerator-based neutrino experiments. Future observations of CP violation in neutrino sector will be an important step towards testing the hypothesis of leptogenesis and the explanation of matter-antimatter asymmetry of the universe. Combined analysis of all existing neutrino data indicates the possibility that θ_{13} has a finite magnitude that can be measured by Double Chooz experiment. Double Chooz will use antineutrinos produced by two nuclear power reactors in France and will detect them by two detectors thus eliminating major systematic uncertainty of the neutrino flux. FAR Double Chooz detector will produce first data by the end of 2010; with the NEAR detector commissioned in 2012 sensitivity will be considerably improved. In this precision experiment UT group is responsible for the reconstruction of neutrino energy through the detailed studies of non-linearity of liquid scintillator response.

Reference: F. Ardellier et al., Double Chooz Collaboration, Proposal, arXiv: hep-ex-

For more information: http://doublechooz.in2p3.fr/



Ba tagging for EXO ^{136}Xe double beta decay

Investigator: W. Fairbank, *Colorado State University*

To eliminate all backgrounds and reach the ~10meV level of neutrino mass sensitivity, it is desired for the next generation EXO neutrinoless double beta decay experiment to be able to identify the ^{136}Ba daughter nucleus. Several Ba tagging methods involving laser-induced fluorescence of the Ba daughter are being explored. One technique in development at CSU involves freezing the Ba^+ ion and a small amount of surrounding Xe on a cold tip and looking for the characteristic fluorescence of Ba^+ or Ba in the solid xenon (Fig. 1). Spectra of Ba atoms in solid xenon are shown in Fig. 2. The current sensitivity is about 10^4 Ba atoms on a cooled window. Single dye molecule sensitivity has been demonstrated with a fiber setup (Fig. 1). This method is expected to work for single Ba detection in a similar manner. Spectroscopy for comparable measurements with Ba^+ ions is in progress. CSU also has a role in the installation and commissioning of EXO-200.

For further information: http://www.physics.colostate.edu/groups/exo/. http://www-project.slac.stanford.edu/exo/

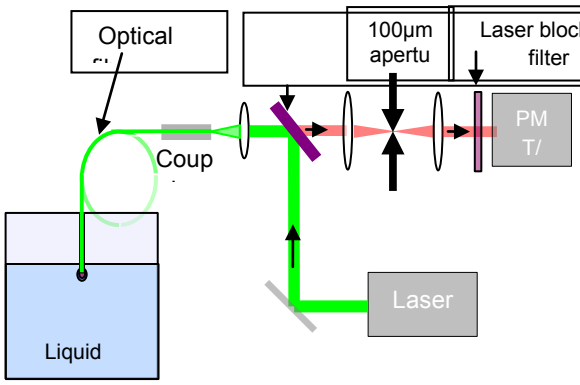


Fig. 1. Fiber scheme for Ba tagging.

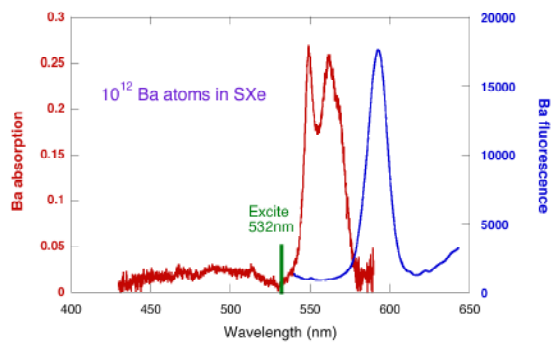


Fig. 2. Spectra of Ba atoms in solid Xe.

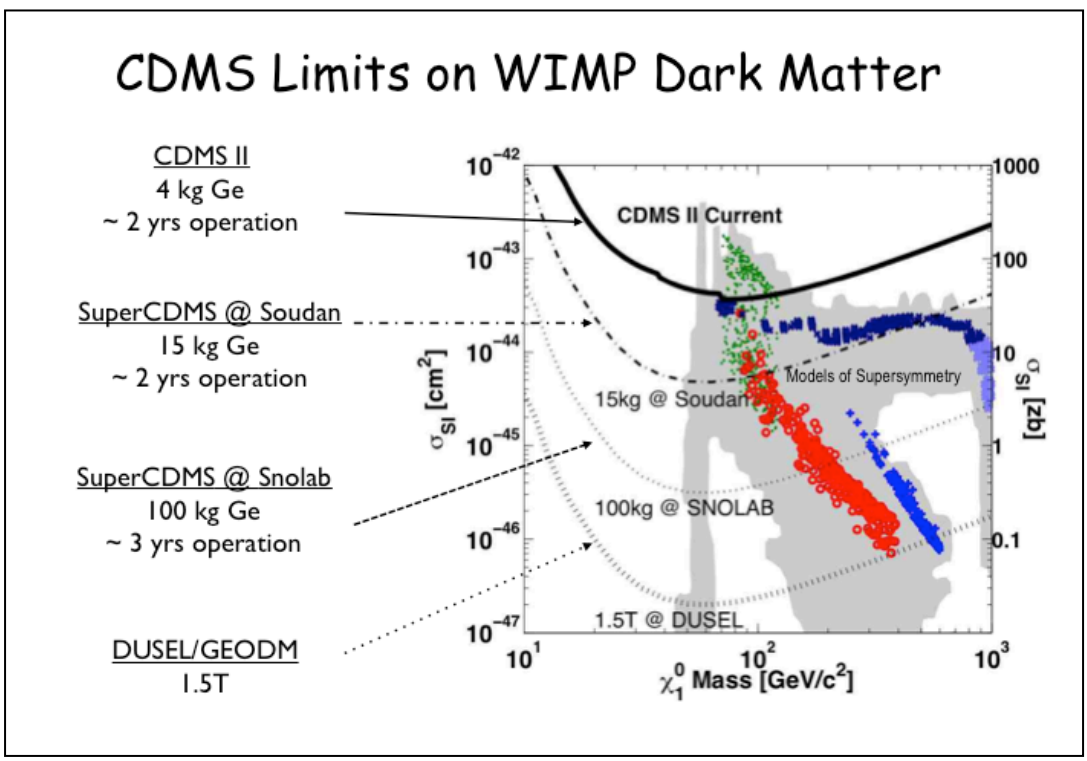
The Cosmic Frontier: Search for Dark Matter

Investigators: D. Bauer, F. DeJongh, J. Hall, L. Hsu, E. Ramberg, and J. Yoo, *Fermilab*

Astronomical observations have led scientists to believe that most of the matter in the universe neither emits nor absorbs light. Particle physics theories suggest that this dark matter may be composed of Weakly Interacting Massive Particles (WIMPs). Although such WIMPs would rarely interact with normal matter, they could occasionally scatter from an atomic nucleus like billiard balls, leaving a small amount of energy that might be detectable under the right conditions. The Cryogenic Dark Matter Search (CDMS) experiment, located a half-mile underground at the Soudan mine in northern Minnesota, uses special germanium detectors, cooled to temperatures very near absolute zero, to search for these WIMPS. In December 2009, Fermilab scientists announced that the result of several years of searching was two events with the characteristics expected of WIMPs. While this sample was too small to claim discovery of dark matter, it did provide world-leading limits on the rate of interaction of WIMPs with normal matter. The experimenters plan to continue the search for dark matter over the next few years with larger detectors at Soudan, and in the SuperCDMS experiment planned for SNOLAB, in Canada. The figure below shows the expected reach in WIMP cross-section (interaction rate) with normal matter versus WIMP mass for each of these experiments, compared with predictions from a particle physics model called Supersymmetry.

Reference: *Science,* 26 March 2010: Vol. 327. no. 5973, pp. 1619-1621

For more information: http://www.fnal.gov/pub/today/Special_Edition121709.html



Nearby Supernova Rates from the Lick Observatory Supernova Search

Investigators: R. Chornock, A. V. Filippenko, M. Ganeshalingam, J. Leaman, W. Li, D. Poznanski, and X. Wang, *University of California--Berkeley*

We present new measurements of the observed rates of supernovae (SNe) in the local Universe, determined from 726 SNe in the Lick Observatory Supernova Search. This is the largest and most homogeneous set of nearby SNe ever assembled for this purpose, and ours is the first local SN rate analysis based on CCD imaging and modern image-subtraction techniques. A complete SN sample is constructed, and the observed (uncorrected for host-galaxy extinction) luminosity functions of SNe are derived. A comparison between our SN rates and the published measurements shows that they are consistent with each other to within the uncertainties when the calculations are done in the same manner. Nevertheless, our data demonstrate that the SN rates cannot be adequately described by a single parameter using either galaxy Hubble types or B-K colors. A secondary parameter in galaxy "size," expressed by luminosity or stellar mass, is necessary as part of a rate-size relation: the galaxies of smaller sizes have higher SN rates per unit mass or per unit luminosity. Physically, the rate-size relation for core-collapse SNe is probably linked to the correlation between the specific star-formation rate and the galaxy size, but it is not clear whether the same link can be established for SNe Ia. We discuss the two-component ("tardy" and "prompt") model for SN Ia rates, and find that the SN Ia rates in young stellar populations might have a strong correlation with the core-collapse SN rates.

References: J. Leaman, et al. (2010), MNRAS, submitted (arXiv:1006.4611); W. Li, et al. (2010a), MNRAS, submitted (arXiv:1006.4612); W. Li, et al. (2010b), MNRAS, submitted (arXiv:1006.4613).

Core-Collapse Supernova Rates and Implications for Massive Star Evolution

Investigators: R. Chornock, A. V. Filippenko, W. Li, and N. Smith, U*niversity of California--Berkeley*

We analyze the observed fractions of core-collapse supernova (SN) types from the Lick Observatory Supernova Search, and we discuss the corresponding implications for massive star evolution. For a standard initial mass function, observed fractions of SN types cannot be reconciled with the expectations of single-star evolution. The mass range of Wolf-Rayet (WR) stars that shed their hydrogen envelopes via their own mass loss accounts for less than half of the observed fraction of Type Ibc supernovae. The true progenitors of SNe Ibc must extend to a much lower range of initial masses than classical WR stars, and we argue that most SN Ibc and SN IIb progenitors must arise from binary Roche-lobe overflow. In this scenario, SNe Ic would still trace higher initial mass and metallicity, because line-driven winds in the WR stage remove the helium layer and propel the transition from SN Ib to Ic. Less massive progenitors of SNe Ib and IIb may not be classical WR stars; they may be under luminous with weak winds, possibly hidden by overluminous mass-gainer companions that could appear as B[e] supergiants or related objects having a spherical circumstellar material. The remaining SN types (II-P, II-L, and IIn) need to be redistributed across the full range of initial masses, so that even some very massive single stars retain H envelopes until explosion. We consider the possibility of direct collapse to black holes without visible SNe, but find this hypothesis difficult to accommodate in most scenarios.

Reference: N. Smith, et al. (2010), MNRAS, in press (arXiv:1006.3899).

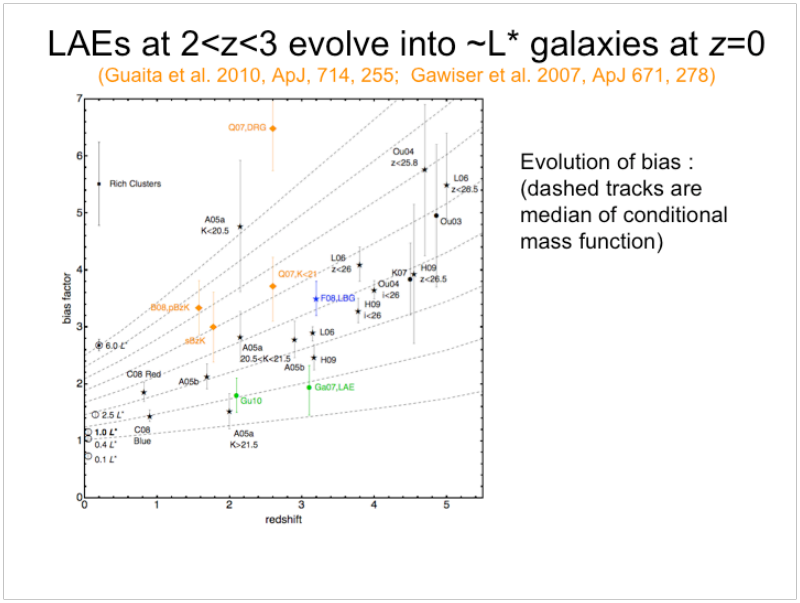
Lyα Emitting Galaxies at 2 < z < 3: Towards a Calibrated Probe of Dark Energy

Investigators: V. Acquaviva, M. Berry, E. Gawiser, N. Bond, J. Walker-Soler, *Rutgers;* R. Ciardullo, C. Gronwall, A. Matkovic, S. Sinawa, C. Wolf, *PSU;* J. Feldmeier, *YSU;* L. Guaita, *P.U. Catolica & Rutgers;* H. Francke, *P.U. Catolica;* G. Kanarek, *Columbia & Rutgers*

The Hobby-Eberly Dark Energy Experiment (HETDEX) aims to measure the expansion history of the universe over the redshift range of z=2 to 4 to 1% precision. It begins taking data in Spring 2012. To achieve this goal, it will perform a spectroscopic survey of ~800,000 Lyα emitting galaxies (LAEs) over an area of ~400 sq. degrees. Because of their strong emission-line, LAEs are easy to detect and provide an ideal probe of the large-scale structure of the universe over a broad range of redshifts. Until recently little was known about the physical properties of LAEs. In particular, the clustering properties (bias) and number density of LAEs at these redshifts are crucial inputs into the HETDEX experimental design. We have followed up our successful narrow-band survey for LAEs at z=3.1 with a second survey at z=2.1 in order to measure the evolution in the properties of LAEs from z=3.1 to 2.1. Guaita et al. (2010) presents the results of this survey. Our sample of 250 LAEs implies that the observed number density of LAEs at z=2.1 is consistent with no evolution since z=3.1 and that the bias factor of z=2.1 LAEs is 1.8 +/- 0.3. This implies that LAEs at z=2.1 will evolve into L^* (Milky Way) type galaxies today (see figure.) We are currently expanding our narrow-band surveys at z=2.1 and 3.1 to additional fields in order to assess the effects of cosmic variance on the bias and number density of LAEs.

Reference: Guaita, L., et al. 2010, ApJ, 714, 255

For more information: http://www.physics.rutgers.edu/~gawiser/MUSYC/



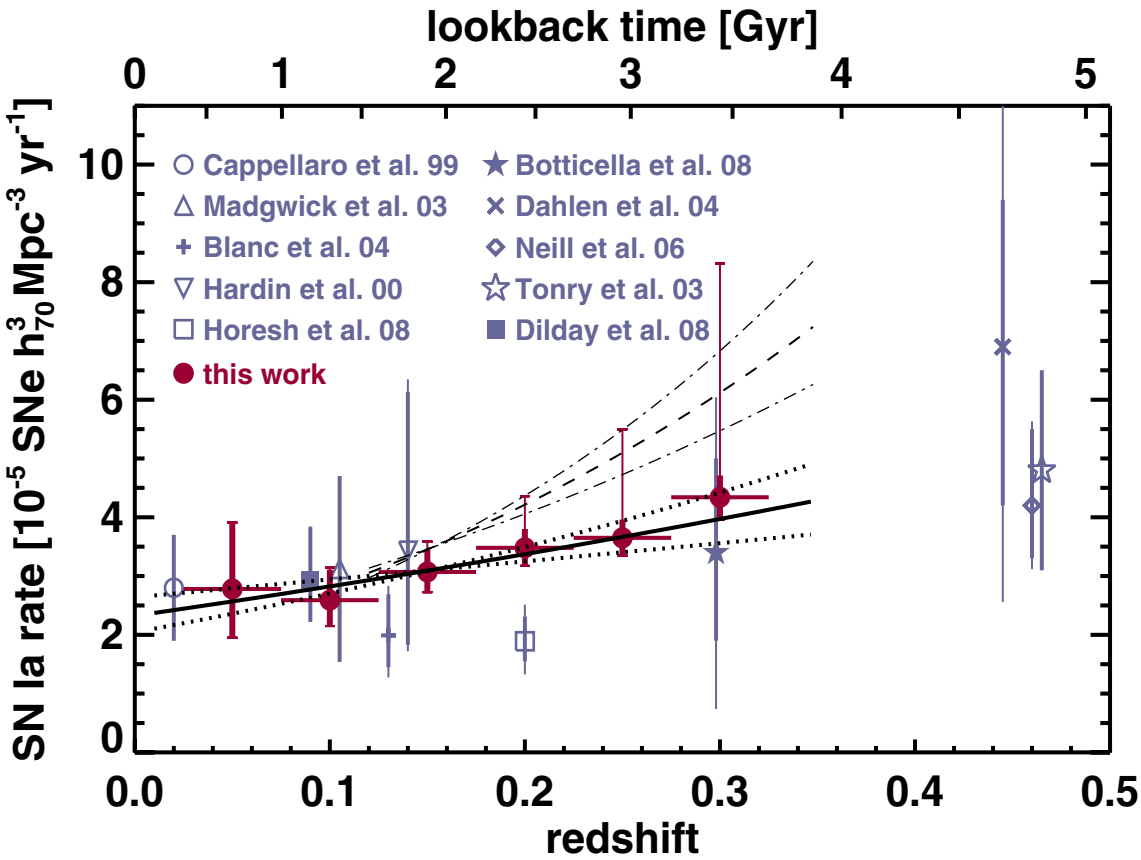
Supernova Explosions Through Cosmic Time

Investigator(s): S Jha, Rutgers the State University of New Jersey

Prof. Saurabh W. Jha and Dr. Benjamin Dilday of Rutgers University, along with collaborators from the Sloan Supernova Survey, have shown that the rate of Type Ia supernovae in the Universe has been decreasing over the past few billion years. Type Ia supernovae (SN Ia) are thought to be explosions of white dwarf stars . Being very bright and very homogeneous, SN Ia make excellent cosmological *standard candles* with which to survey the Universe. Indeed, precise measurements of SN Ia in distant galaxies revolutionized cosmology – the expansion of our Universe is *accelerating*, driven by mysterious *dark energy*. Understanding dark energy is at the forefront of modern cosmology research. To make best use of SN Ia we need to know which white dwarfs explode: what are their progenitor stars? Answering that question requires an accurate census: how many SN Ia have been exploding throughout the history of the Universe? As part of the Sloan Supernova Survey, we have measured the SN Ia rate in the Universe over the last few billion years (see figure below, from Dilday et al. 2010). We find that the SN Ia rate was *higher* in the past than it is today, and our results imply that at least some SN Ia come from relatively massive progenitors, without a long delay between the birth of the star and its explosive death.

Reference(s): Dilday, B., et al.,*The Astrophysical Journal*, **713**, (2010), pp. 1026-1036

For more information: SDSS SN Survey, http://www.sdss.org/supernova/aboutsupernova.html



Cigar galaxy: The Origin of Cosmic Particles

Investigators: A. Imran, F. Krennrich, M. Pohl, M. Schroedter, and T. Nagai, *Iowa State University*

For the first time a starburst galaxy has been shown to play a major role in the acceleration of cosmic particles, thereby providing the key to solving a century old problem in particle astrophysics. The origin of cosmic rays, which consist of speedily moving atomic nuclei, is finally being revealed. As founding members of the VERITAS consortium, scientists at Iowa State University designed and built the focal plane instruments for the VERITAS γ-ray telescopes in southern Arizona and contributed to the finding of TeV γ rays (trillion times the energy of visible photons) from the Cigar galaxy. VERITAS uses large light collectors in conjunction with high-speed imaging cameras to identify the faint bluish glow from a particle shower that is started by a cosmic γ ray at the top of the earth's atmosphere. The Cigar galaxy exhibits a high stellar birth and death rate and thus harbors a large number of supernova remnants, which have long been suspected to accelerate cosmic particles that in turn collide with surrounding gas to produce TeV γ rays. The understanding of the origin of cosmic particles is critical and could also shed light on the question of a mysterious but ubiquitous substance that pervades astrophysical space: dark matter. Further observations with current generation γ-ray telescopes, but most likely future large arrays of ground-based VERITAS-like instruments will be critical to unveil the origin of the faintest γ-ray sources thought by theorists to be clumps of dark matter.

Reference: V.A. Acciari et al. (VERITAS Collaboration), Nature, **462, 770** (2009).

For more information: http://veritas.sao.arizona.edu/

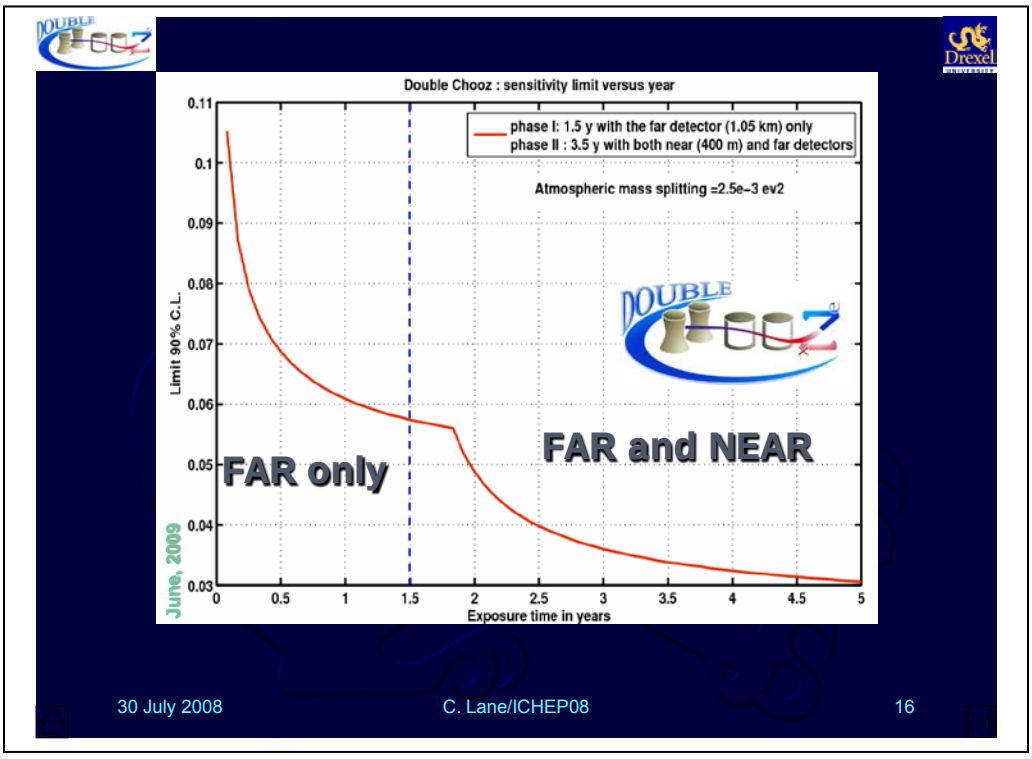
Where Neutrino Oscillation leads us

Investigators: C. Lane and J. Maricic, *Drexel University*

Neutrino oscillation has been a very effective tool for experimentally determining such neutrino properties as mass differences and mixing angles. The neutrino mixing still has some unknown parameters, of which the θ_{13} mixing angle and the CP violating phase δ are particularly interesting. Measurement of CP violation in the neutrinos sector may contribute to the understanding of matter dominance in the universe. The neutrino oscillation terms that contain a contribution from CP violation occur in combination with θ_{13}, motivating experiments to determine θ_{13}, as a prelude to the more ambitious CP violation measurement. The Drexel group has involvement in KamLAND, the Double Chooz θ_{13} experiment, and the LBNE effort to measure neutrino CP violation and neutrino mass hierarchy, with various contributions to electronics, calibration hardware, and PMT systems. While KamLAND is a mature experiment, the first Double Chooz detector is turning on very soon, with Drexel-provided Inner Veto PMTs and bases and Front-End electronics. LBNE is much further in the future, but Drexel is contributing effort in PMT testing, light collector design, and calibration systems.

References: S. Abe *et al*, PRL **10**0 221803 (2008).
J. Maricic, J. Phys. Conf. Ser. **203**:012095, (2010)

For more information: http://www.dchooz.org



Counting Neutrinos at Daya Bay

Investigators: K. Lau, L. Lebanowski, S. Lin, B. Mayes, C. Newsom, L. Pinsky, and G. Xu, *University of Houston*

Some 200 scientists and engineers from the US, China, and Europe are gathering in Daya Bay, China to install an experiment to count neutrinos from nearby nuclear reactors. A 2-km tunnel was evacuated in a neighboring mountain to house eight 20-ton detectors inside. These detectors will catch a small fraction of neutrinos flying by, order 1 in a trillion trillion. The experiment was conceived in the wake of surprisingly large oscillations observed in neutrinos from reactors and other sources (see reference below). These unexpected discoveries not only explained the apparent deficit of neutrinos from the Sun and other neutrino anomalies; they also provided first evidence that the standard model of particle physics is incomplete. By counting the total number of neutrinos interacted in the detectors in 3 years, the experimenters will find out how small the remaining neutrino mixing angle Θ_{13} is. A large Θ_{13} makes it easier to pin-point the possible neutrino connection to the dominance of matter over antimatter in the universe. The University of Houston group has participated in the construction of the muon veto system, including work on the quality assurance of Resistive Plate Chambers (RPCs), detectors for identifying muons.

Reference: X. Guo et al. (Daya Bay Collaboration), hep-ex/0701029, BNL-77369-2006-IR, Jan 2007. 156pp. e-Print: **hep-ex/0701029**
By Daya-Bay Collaboration (Xinheng Guo *et al.*). BNL-77369-2006-IR, Jan 2007. 156pp. e-Print: **hep-ex/0701029**

For more information: http://dayabay.ihep.ac.cn

A picture of the Daya Bay Power Plant complex. The Daya Bay Power Plant is in the foreground. The Ling Ao Power Plant is in the background. The experimental halls will be located underneath the hills on the left.

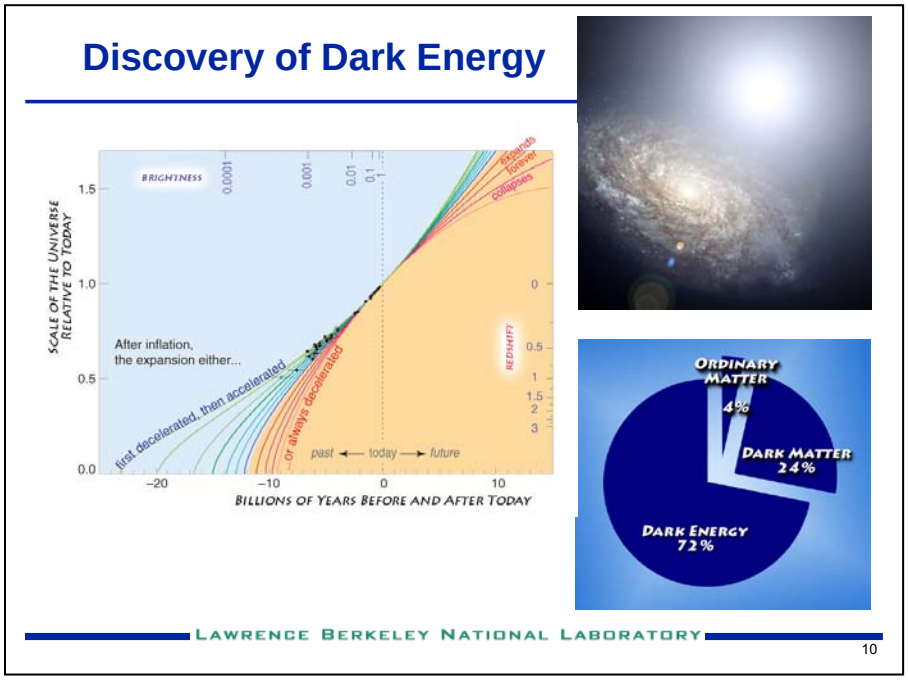
Supernova Cosmology Project Leads Dark Energy Discovery

Investigators: Saul Perlmutter, Greg Aldering, Lorenzo Faccioli, Gerson Goldhaber,Eric Hsiao, Xiaosheng Huang, Peter Nugent, Pascal Ripoche, Tony Spadafora, Mark Strovink, Nao Suzuki, and Lifan Wang, *Lawrence Berkeley National Lab*

In the 1980s, the Berkeley-Lab-based Supernova Cosmology Project (SCP) launched the use of bright Type Ia supernovae as standard candles to measure the expanding universe, proving they could find numerous Type Ia supernovae "on demand." Early in 1998, the SCP and a rival supernova search team announced a startling discovery: expansion is accelerating. Dubbed the "breakthrough of the year" by *Science* magazine, the news was followed by a flood of books, articles, and programs. The cause of runaway expansion, soon dubbed dark energy, constitutes three-quarters of our universe. To this day no one knows what it is; it has been called "the most fundamentally mysterious thing in basic science." Berkeley Lab's Nearby Supernova Factory and the Computational Cosmology Center have pioneered better measurements and new supernova physics to insure that the mystery of dark energy will be solved. As early as 1999 SCP researchers proposed SNAP, the SuperNova Acceleration Probe, a space-borne experiment to investigate dark energy's nature, strongly supported by DOE. In 2004 DOE joined forces with NASA in the Joint Dark Energy Mission; in 2010 JDEM published fresh ideas for combining research techniques to sort through competing theories. Comparing the brightness and redshifts of Type Ia supernovae remains the best-tested of all.

References: *New York Times*, 3 June 2008; *New York Times Magazine*, 11 March 2007; *Physics Today*, April 2003; *Science*, 30 January 1998

For more information: http://www.lbl.gov/ScienceArticles/Archive/sabl/2007/Nov/darkenergy1.html



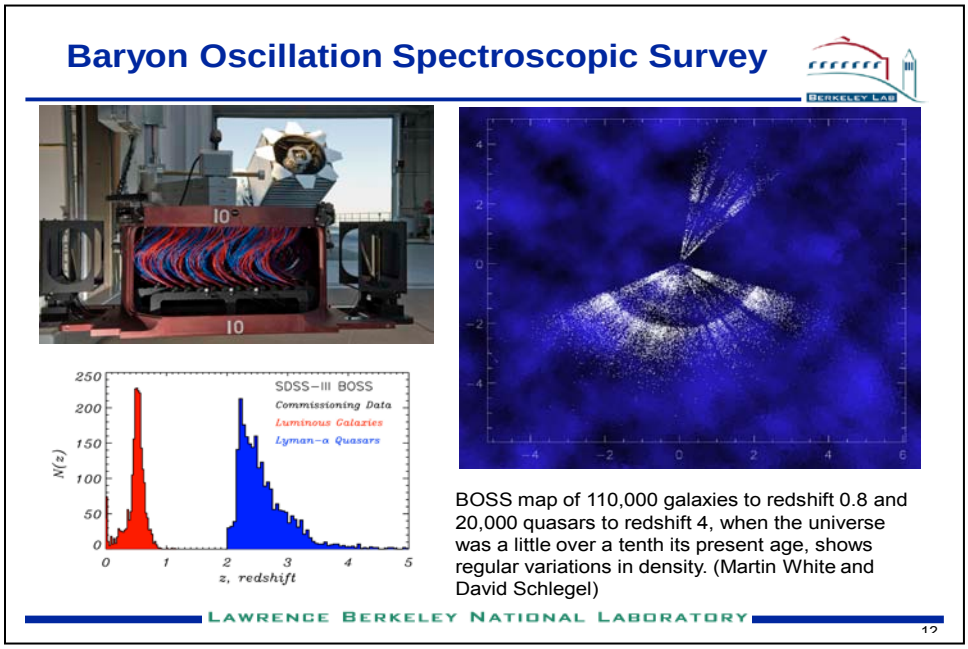
BOSS Maps the Universe

Investigators: BOSS consists of 160 investigators from 42 institutions. Berkeley Lab participants include David Schlegel, *principal investigator*; Natalie Roe, *instrument scientist*; Martin White, *survey scientist*; and others.

The Baryon Oscillation Spectroscopic Survey (BOSS) is the largest program in the Sloan Digital Sky Survey III (SDSS-III) and the most ambitious attempt yet to map the expansion history of the universe using the technique known as baryon acoustic oscillation (BAO). BAO is a fast-maturing method for measuring dark energy in a way complementary to the proven techniques of supernova cosmology. Baryon oscillations began as pressure waves propagating through the hot plasma of the early universe, creating regions of varying density that can be read today as temperature variations in the cosmic microwave background. As the universe evolved these density variations also left their mark in the periodic clustering of visible matter such as galaxies and quasars and the clumping of invisible dark matter. Comparing the scales at different eras makes it possible to trace the details of universal expansion and distinguish among competing theories of dark energy. BOSS began survey operations on December 5, 2009, and by June 2010 had acquired 200,000 survey-quality spectra. By the survey's end in June 2014, the researchers anticipate recording two million spectra as well as variations in the density of intergalactic hydrogen gas. Although millions of galaxies represent only a small fraction of the universe, BOSS's galaxy maps will be the best ever made.

References: *EarthSky*, 1 Feb. 2010; *Sky & Telescope*, February 2009; *Wired*, October 2009

For more information: [http://newscenter.lbl.gov/ news-releases/2009/10/01/first-light-boss/](http://newscenter.lbl.gov/news-releases/2009/10/01/first-light-boss/)

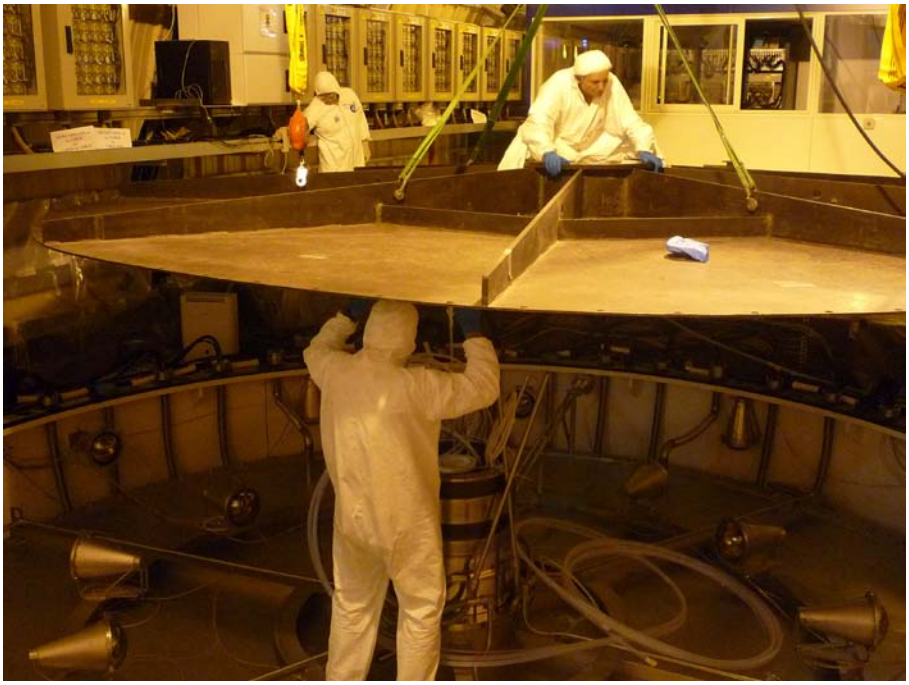


Major Milestone in the Search for the Neutrino Mixing Angle Θ_{13}.

Investigator: John LoSecco, *University of Notre Dame*

The Double Chooz experiment at the Chooz nuclear power station in northern France has just completed the sealing of its detector. Operation, the detection of neutrinos from the nuclear reactors located about 1 km away will commence in a few months. Photographs of the closing are below. Sealing of the detector is a major milestone for the project indicating the completion of the phototube, mechanical, electronics and substantial parts of the calibration system. All that is needed to detect neutrinos is the addition of hydrogen in the form of various mineral oils, which is currently underway. Full operation is expected in a few months. The Double Chooz project is a sensitive search for distortions of the neutrino spectrum and flux as the neutrinos propagate from their source in the nuclear reactors. A side benefit of such a precise measurement will be to study the use of the neutrino spectrum as a non proliferation safeguard for the diversion of plutonium for weapons. The neutrino spectrum is sensitive to the reactor fuel mix, as well as to neutrino oscillations. Double Chooz is an international effort with groups from France, Germany, Japan, Spain, Brazil, Russia and the US.

For more information: http://www.hep.nd.edu/Dchooz-ND.html
http://doublechooz.in2p3.fr/Public/public.php
http://www.physics.drexel.edu/~wkushner/index.php



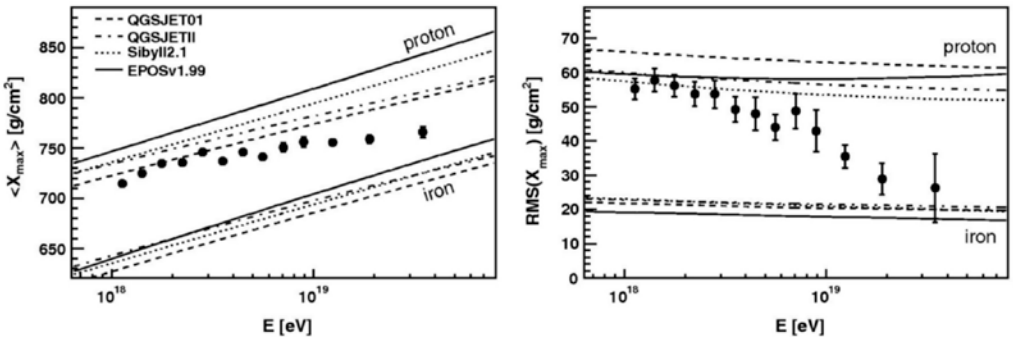
Puzzling Features of the Highest Energy Cosmic Rays

Investigators: J. Chirinos, B. Fick and D. Nitz, *Michigan Technological University*

The nature of the highest energy cosmic rays is becoming more puzzling. New results from the Pierre Auger Observatory challenge what had become conventional wisdom. Previous observations reported by the Auger Collaboration of anisotropy in the distribution of the highest energy cosmic rays lent support to the idea that the highest energy cosmic rays should be protons. However, the new results on the distribution of the extensive air shower development in the atmosphere appear to be at odds with this picture. Above 10^{19}eV, the showers are observed to develop in a shorter distance with fewer shower to shower fluctuations than expected for protons, implying a higher than expected interaction cross section. Compounding the puzzle are the lower energy cosmic rays (at a few times 10^{18}eV), which behave as expected for protons. Are the highest energy cosmic rays protons, and these results perhaps indicate the onset of new physics? Or are they heavier nuclei (Iron, for example) which somehow preserve an imprint of their source in traveling through the direction scrambling inter-galactic and galactic magnetic fields? One thing is clear: The energies involved are far beyond the reach of CERN's Large Hadron Collider, so the answer must come from further studies of cosmic rays. Researchers at Michigan Technological University played key roles in the development of the trigger systems for the detector and in the monitoring of the atmosphere.

References: J. Abraham et al. (Auger Collaboration), *Phys. Rev. Lett.* **104** 091101 (2010)
Physics Today, May 2010, p15.

For more information: www.auger.org



The average depth of maximum shower development $\langle X_{max} \rangle$ and the fluctuations in the depth rms(X_{max}) compared with air shower simulations using different hadronic Interaction models.

Fermi Gamma-ray Space Telescope Launches, Delivering Great Science

Investigator: S Ritz, *University of California at Santa Cruz-SCIPP*

The Large Area Telescope (LAT) is the principal scientific instrument on the Fermi Gamma Ray Space Telescope spacecraft. It has been operating very smoothly, delivering a large number of great science results, with more than 70 publications by the Large Area Telescope (LAT) team alone. The first LAT paper, published in Science, surprised the world with the first detection of a gamma-ray only pulsar, a remnant of a stellar explosion that has a magnetic field a trillion times that of the earth and a mass density of about a billion tons per cubic centimeter. The detection was only possible because of a novel algorithm, invented and developed at UCSC. Since then, 24 gamma-ray only pulsars have been detected (see August 14, 2009, cover from Science Magazine below), transforming our understanding of these cosmic accelerators. The search for particle Dark Matter throughout the Universe has also been a main focus of the space telescope. Even with the early data gathered thus far, there have been significant limits set. The LAT has also made the most precise measurement, by far, of the high-energy cosmic electron+positron flux, all with leadership and analyses provided by UCSC personnel. With its huge leaps in key capabilities the Fermi Gamma-ray Space Telescope is a great success, and it is likely that the best is yet to come.

For further information: http://www-glast.stanford.edu

References

W.B. Atwood, M. Ziegler, R.P. Johnson, B.M. Baughman, “A Time Differencing Technique for Detecting Radio-Quiet Gamma-Ray Pulsars,” Ap.J. 652, L49, 2006.

Abdo, A. A. et al., “Observations of Milky Way Dwarf Spheroidal galaxies with the Fermi-LAT detector and constraints on Dark Matter models”, ApJ 712, 147, 2010.

Popular article, "Window on the Extreme Universe", by W.B. Atwood, P.F. Michelson, and S. Ritz, Scientific American, December 2007. Science Cover attached.

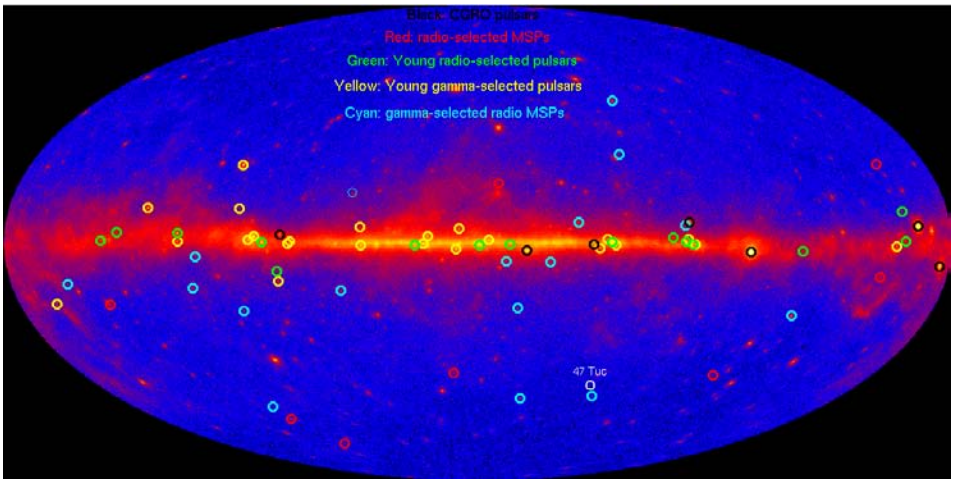
Fermi LAT discovery of new pulsars stimulates fundamental science

Investigators: Fermi Observatory Large Area Telescope collaboration (SLAC)

The Fermi LAT has discovered, in collaboration with a global network of radio astronomers, a large number of nearby and energetic yet formerly unknown pulsars. Those are rotating neutrons stars, which are unique laboratories for fundamental physics and are important as a potential background for dark matter searches. Extremely valuable are the 17 new millisecond pulsars, which can be used to search for gravitational waves at wavelengths inaccessible for other detectors. While known for over 40 years, until recently nearly all pulsars were discovered via their radio emission, which represents a minuscule fraction of their emitted power. The LAT, in contrast, detects pulsars in MeV and GeV gamma-rays that dominate the power output and trace directly the energetic particles. Understanding how pulsars work has become necessary as they are used to perform increasingly precise fundamental physics measurements for testing general relativity and Lorentz invariance, to measure the equation of state of cold nuclear matter and to study quantum electrodynamical effects in super-critical *B* fields. Finally, the origin of energetic (GeV) *electrons* measured by many instruments (including Fermi) is under intensive debate. Among the most popular interpretations for their origin are pulsars (capable of accelerating particles to TeV energies), or a signal from the annihilation or decay of dark matter particles into electrons and positrons: understanding pulsars is essential to resolve this debate, and the LAT is providing the essential data.

References: A. Abdo et al., *Science,* **325,** (2009), pp. 848-852; A. Abdo et al., *Science,* **325,** (2009), pp. 840-844

For more information: http://www.sciencemag.org/cgi/reprint/325/5942/848.pdf



Fermi LAT 1-year gamma-ray sky with the positions of the LAT-discovered pulsars. Black are gamma-ray pulsars known before the launch of the LAT. Red and green are known pulsars seen for the first time in gamma-rays. Yellow and cyan are newly discovered pulsars based on Fermi LAT observations.

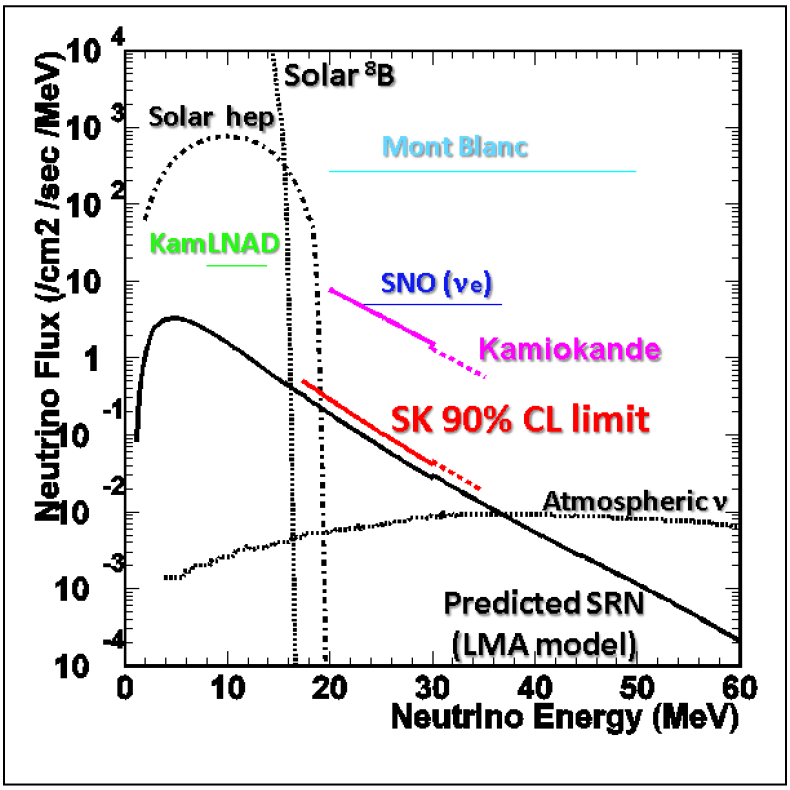
Supernova Relic Neutrinos

Investigators: H. Sobel, K. Bays, W. Kropp, M. Smy, and M. Vagins, *U.C. Irvine*

Core collapse supernovae (SN) release an enormous amount of energy (~10^{44} J), ~99% of which is released in the form of a ten second long neutrino burst. Unfortunately, due to the small neutrino cross section, even such massive neutrino bursts can only be detected when they occur in our own galactic neighborhood. In 1987, twenty detected neutrino interactions resulting from the explosion of a supernova in the Large Magellanic Cloud provided rich information. Super-Kamiokande would detect thousands of neutrino interactions from a SN within our galaxy, providing important information about the time evolution and dynamics of the explosion. The rate of such galactic core collapse supernovas is estimated to be just a few per century. However, SK can do more than simply wait for an explosion in our own galaxy: the neutrinos emitted by all past core collapse SN throughout the universe form a diffuse, isotropic background of SN 'relic' neutrinos. This as-yet-unobserved signal is also of immense interest, as the spectrum and rate of SN relic neutrinos would provide important information about the history of SN explosions and consequently the star formation rate in the universe. The UCI group has been extending and continues to extend SK's sensitivity to both rate and spectrum by reducing backgrounds from nuclear spallation and solar neutrinos as well as improving signal selection efficiency.

Reference: arXiv:hep-ex/0209028, Phys.Rev.Lett.90:061101, 2003

For more information: http://www.ps.uci.edu/~superk/



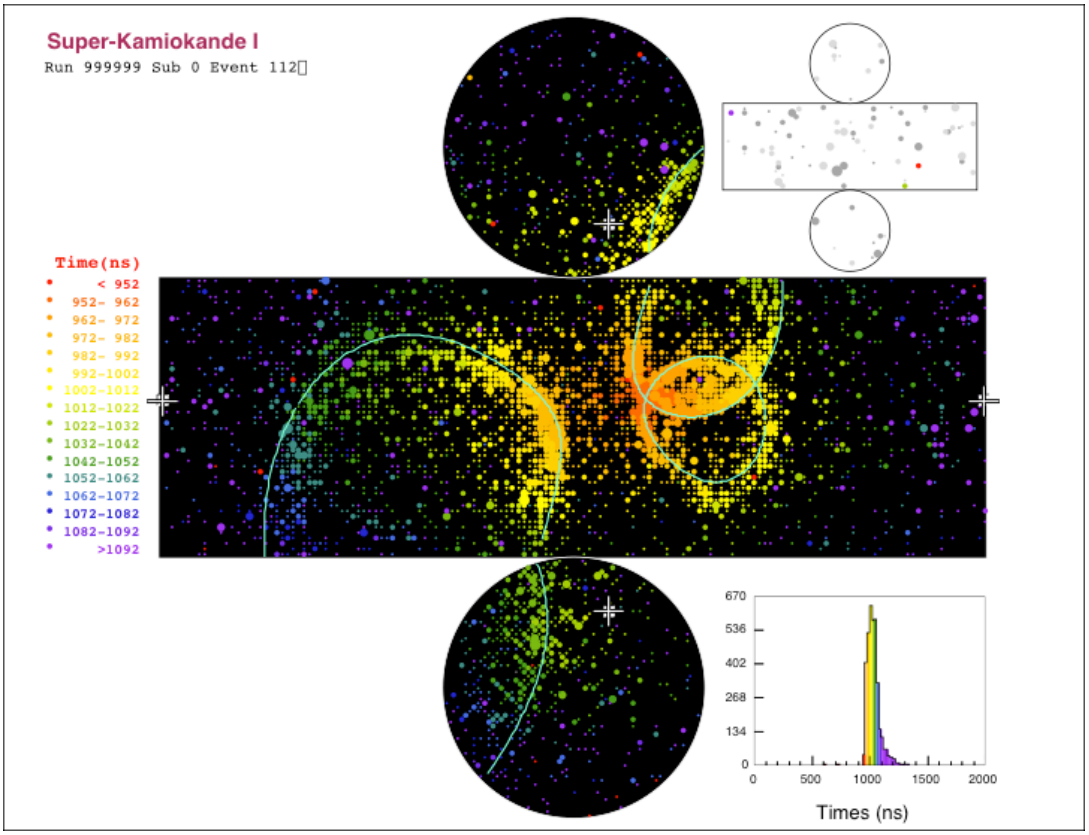
A Milestone in the Stability of Matter

Investigators: U.S. Co-spokespersons: H. Sobel, *U.C. Irvine*; J. Stone, *Boston University*; Duke University, Stony Brook University, University of Hawaii, University of Washington, California State Dominguez Hills.

The Super-Kamiokande experiment, a large water Cherenkov detector located underground in Japan, has searched over a 12-year period for the decay of the proton into a positron and neutral pion. Such decays must not be commonplace, or else matter as we know it would not persist. However, rare occurrences of this decay process are one of the hallmarks of Grand Unified Theories that connect leptons to quarks through new extremely massive force carrying particles. The absence of any sign of this decay increasingly constrains the theoretical options for unifying the forces of nature. With an exposure of 173 kiloton-years, no candidate proton decay events have been seen, resulting in a lower limit on the lifetime that now exceeds10^{34} years. A graphical event display of a simulated event is shown. The Super-Kamiokande experiment is a joint effort between the U.S., Japan, and several other countries. University groups from the U.S. have contributed to the outer detector system, electronics, data reduction and reconstruction software, calibration, and analysis. Several Ph.D. theses have resulted from the studies of this proton decay mode and many others.

Reference: H. Nishino, S. Clark, *et al*., "Search for Proton Decay via $p \rightarrow e^+ p^0$ and $p \rightarrow m^+ p^0$ in a Large Water Cherenkov Detector", Phys. Rev. Lett. **102**, 141801 (2009)

For further information: http://www-sk.icrr.u-tokyo.ac.jp/whatsnew/new-20091125-e.html



Addressing the Dark Energy Crisis

Investigator: Christopher Stubbs, *Harvard University*

The observation that the expansion of the Universe is accelerating, driven by gravitational repulsion of the empty space between galaxies, constitutes a crisis for fundamental physics. In many respects this "Dark Energy" problem is analogous to the challenge of understanding blackbody radiation prior to the advent of quantum mechanics, and may well lead to a revolution in our understanding of the interplay between quantum mechanics and gravity. Using astrophysical observations to discriminate between different Dark Energy scenarios will require improved calibration techniques and more refined measurements. The Harvard group plays a leading role in developing methodologies (such as using tunable lasers to calibrate instrumental sensitivity vs. wavelength, and measuring directly the optical transmission of the atmosphere) that will enable next-generation projects to reach new levels of precision and accuracy.

References:

"Toward More Precise Survey Photometry for PanSTARRS and LSST: Measuring Directly the Optical Transmission Spectrum of the Atmosphere" C. Stubbs et al, PASP 119, 1163S (2007)

"Toward 1% Photometry: End-to-End Calibration of Astronomical Telescopes and Detectors", ApJ 646, 1436 (2006).

For further information:
http://physics.harvard.edu/~stubbs/Stubbs_Group/Home.html

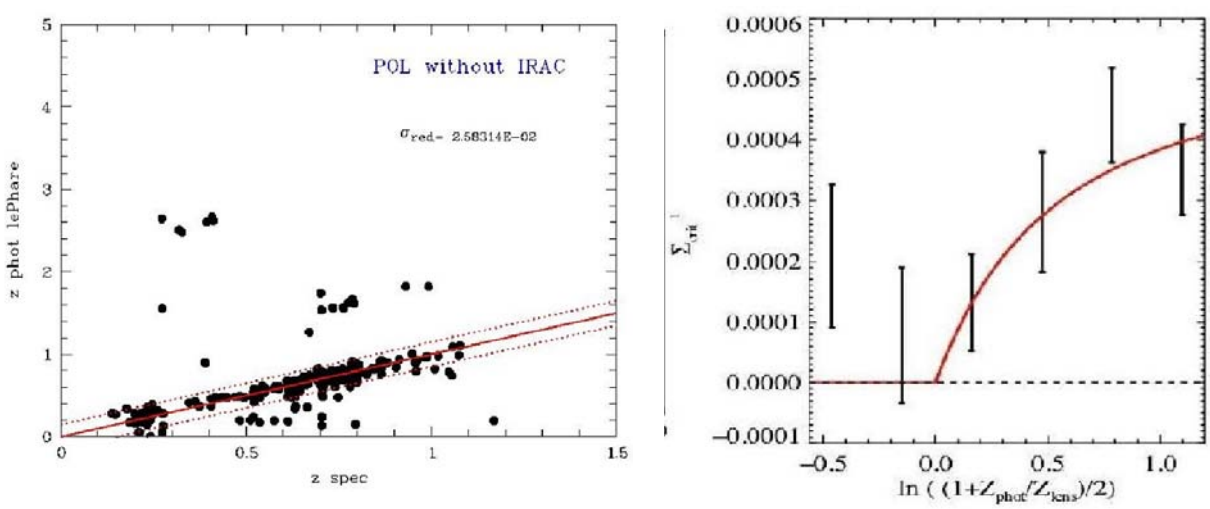
Weak Lensing Tomography to Study the Nature of Dark Energy: First Steps

Investigators: L. Guenou [1,2], C. Adami[1], M. P. Ulmer [2,1]
[1]*Laboratoire d'Astrophysique de Marseille* [2]*Northwestern University*

We report the early results obtained from the American French collaboration called the Dark energy American French Team/French American DArk energy Team (DAFT/FADA). The goal of the DAFT/FADA collaboration is to carry out a weak lensing tomography survey of z = 0.4-0.9 rich clusters of galaxies. The reason for analyzing observations in the direction of clusters is that the shear signal is enhanced by about 10 over the field. Our work will eventually contain results based on 91 rich clusters from the HST archive combined with ground based work to obtain photo-zs. Unlike supernovae or other methods such as cluster of galaxy counts, weak lensing tomography in the direction of clusters is purely based on geometry and does not depend on knowledge of the physics of the objects used as distance indicators. A crucial first step in carrying out this work is to determine the photo-zs of all the sheared background galaxy images. Weak lensing tomography carried out with these photo-zs is in preparation as is a through basis of the theoretical underpinning of this process by D. Johnston et al.

References: L. Guennou et al to be submitted to Astronomy and Astrophysics, 2010; K. Murphy et al. in preparation 2010; D. Johnston et al. in preparation 2010

For more information: contact m-ulmer2@northwestern.edu



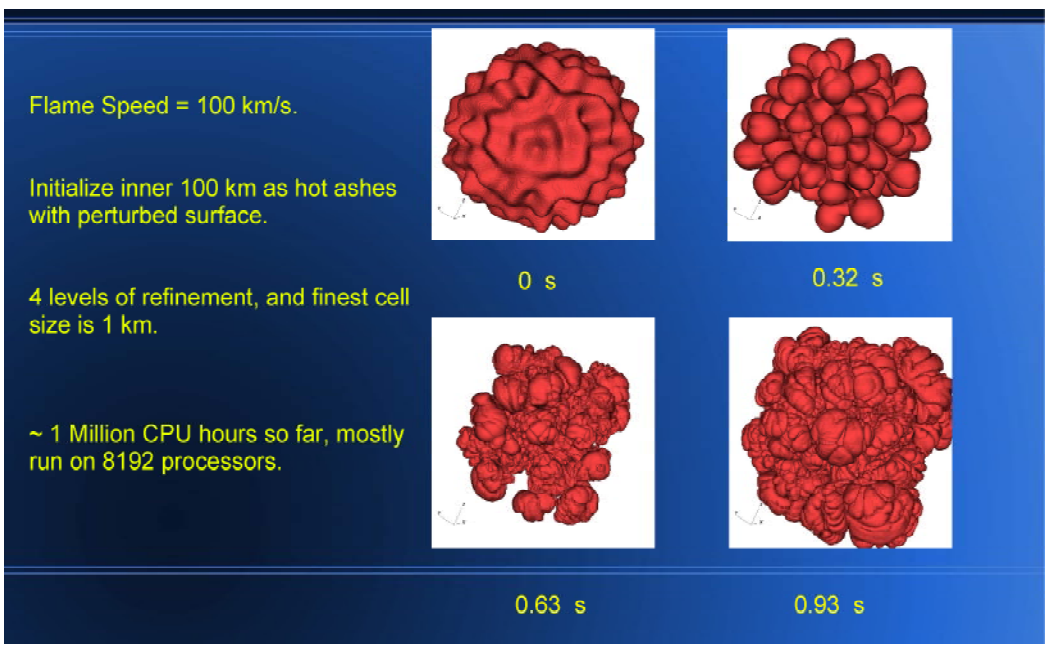
Caption: Left, spectroscopic redshifts versus photo-zs. Right, Inverse shear versus redshift based on just 7 clusters

3D Explosion Models of Type Ia Supernovae using CASTRO

Investigators: H. Ma, M. Zingale, S. Woosley, *UC Santa Cruz;* A. Aspden, J. Bell, A. Almgren and A. Nonaka, *LBNL*

As an example of the power of the new CASTRO code, and because of their interest to dark energy experiments, we are exploring first principles models for the explosion of Type Ia supernovae. The model below is our first publishable result. This is the first time, outside of Germany, that the calculation of a centrally ignited, carbon-oxygen white dwarf has followed through the deflagration stage in three dimensions. The calculation, which is still running on Franklin at NERSC, has already produced over 0.6 solar masses of iron and radioactive ^{56}Ni and will definitely explode violently. High resolution is important here to resolve the turbulent flow in the vicinity of the flame. The efficiency of the turbulent combustion determines the brightness and kinetic energy of the supernova. The study here used approximately 1 billion zones running on 8000 CPU, but more realistic studies will require about 20 billion zones running on over 100,000 CPU. So far our results show increased burning beyond what was reported by the Munich group and will give a brighter more typical supernova.

Reference: Ma, H. et al., *Astrophysical Journal*, in preparation, (2010)



Thermonuclear explosion of a Chandrasekhar mass of carbon and oxygen ignited near its center. Hot ash beneath cold fuel is Rayleigh-Taylor unstable and floatation leads to turbulence that reacts back on the burning. The frame size here ranges here from 250 km (t = 0) to 6000 km (0.93 s).

Hunting for Dark-Matter Axions with ADMX

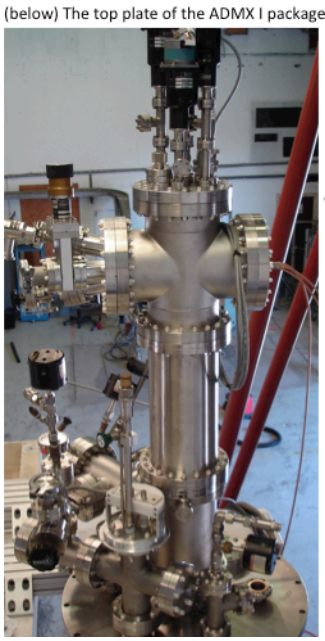
Investigators: M. Hotz, D. Lyasputin, L. Rosenberg, G. Rybka, and A. Wagner,
University of Washington

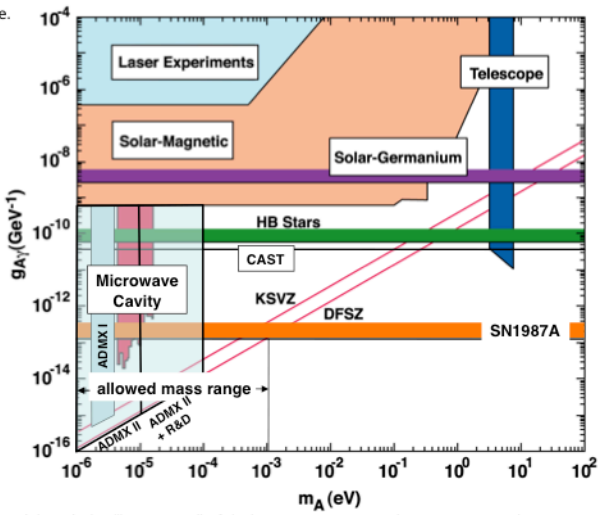
Decades of research in astronomy, astrophysics, general relativity and particle physics have converged to an astounding conclusion: (1) All ordinary matter together accounts for only a tiny fraction of the mass in the universe; and (2) The majority of matter, the "dark matter", is likely some new, exotic particle species left over from the big bang. This is indeed truly astounding, yet the evidence is overwhelming; what constitutes this dark matter is one of the most important scientific questions of our time. Particle physics provides several compelling dark-matter candidates: for one candidate, the axion, people and technologies are poised for a definitive search. The axion is a hypothetical elementary particle that arose in a simple and elegant extension to the Standard Model of particle physics. Light axions have properties that make them an ideal dark-matter candidate. Even though such axions would surround us, they have extraordinarily weak couplings to normal matter and radiation and are therefore very hard to detect. However, if a microwave RF cavity is immersed in a large magnetic field, nearby axions having total energy near the cavity resonant frequency convert into microwave power within the cavity. The Axion Dark-Matter experiment (ADMX) is such a detector. Its RF cavity is the size of an oil drum and is cooled with liquid helium and is able to detect an axion's microwave power of less than a yoctoWatt (10^{-24} Watts). It is the only detector sensitive to dark-matter axions, and ADMX II is poised to detect them.

Reference: L. Rosenberg et al.,"Searches for Invisible Axions," *Physics Reports*, **325** (2000).

For more information: http://www.phys.washington.edu/groups/admx/home.html

(below) The top plate of the ADMX I package.





(above) The "big picture" of dark-matter axion searches. Axes: $g_{A\gamma}$ is the strength of an axion's interactions and m_A its mass. Theory restricts axions to lie between the diagonal red lines. Further, axions lie below "1987A "and have mass above a μeV. Only ADMX, a "Microwave Cavity" detector, has achieved this sensitivity at these masses. ADMX I has published results and ADMX II is under construction. Other, considerably less sensitive searches, are also shown.

Non-Accelerator

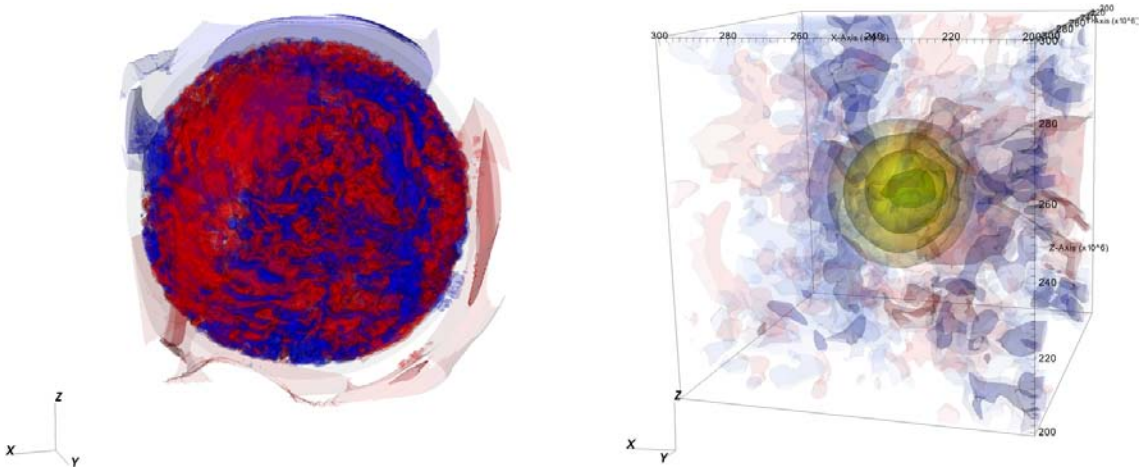
Ignition in Type Ia Supernovae using MAESTRO

Investigators: M. Zingale, *SUNY Stony Brook;* A. Almgren, J. Bell, and A. Nonaka, *LBNL*

The standard model for a Type Ia supernova is the thermonuclear explosion of a carbon/oxygen white dwarf in a binary system. As the white dwarf grows to the Chandrasekhar mass (the maximum possible mass), carbon fusion reactions in the center drive convection throughout the interior of the star. This convective phase can last for centuries, and is characterized by highly subsonic flows. Eventually, as the star continues to heat up, the reactions will proceed so quickly that a burning plume of fluid cannot cool via expansion as it is carried away from the center by the convective flow, and a flame is *ignited*. This flame subsequently burns through the star in seconds, converting most of the carbon and oxygen into iron-group and intermediate mass elements, and unbinds the star.
The details of the ignition process is important, as the location and number of the first flames has an enormous impact on the subsequent explosion process. Using our low Mach number hydrodynamics code, MAESTRO, we modeled the final hours of convection, leading up to the ignition of the first flame. By running a suite of such calculations in the future, we will be able to map out the distribution of allowed ignition locations. This provides important details of the initial conditions for subsequent explosion studies.

References: Zingale et al., Astrophysical Journal, 2009, **704**, 196.
Zingale et al., Astrophysical Journal, *in preparation.*

For more information: http://www.astro.sunysb.edu/mzingale



Radial velocity (red=outflow; blue=inflow) and nuclear energy generation rate (yellow to green contours) seconds before the ignition of the first flame. The image on the right shows only the inner 1000 km.

MZ was supported by a DOE/Office of Nuclear Physics OJI award, grant No. DE-FG02-06ER41448 to Stony Brook. The work at LBNL was supported by the SciDAC Program of the DOE Office of Mathematics, Information, and Computational Sciences under the U.S. Department of Energy under contract No. DE-AC02-05CH11231. Computer time for the main calculation in this paper was provided through a DOE INCITE award at the Oak Ridge Leadership Computational Facility (OLCF).

Michigan Center for Theoretical Physics

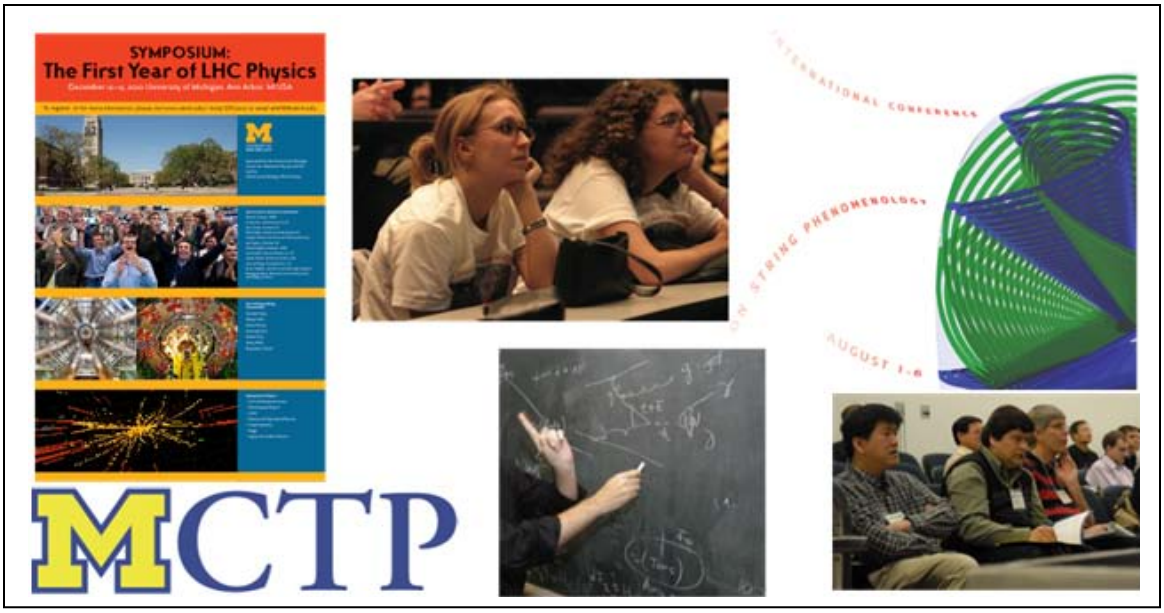
Investigators: R. Akhoury, K. Freese, G. Kane, F. Larsen, J. Liu, L. Pando Zayas, A.Pierce, J. Wells, *University of Michigan*

The Michigan Center for Theoretical Physics (MCTP) is a nexus for exploration and collaboration on the frontiers of particle theory, supporting the entire U.S community of particle physicists. This center, supported by the U.S. Department of Energy and the University of Michigan, has brought over 2400 scientists to the U-M campus since its founding in 2000. During the last year, the center hosted eight workshops attracting scientists from all over the world to discuss cutting-edge questions in High Energy Physics and to develop plans for attacking these problems: What challenges remain in developing optimal search strategies for the Higgs boson at the Tevatron and the LHC? Did Dark Matter power the first generation of stars? If so, what were the properties of these mysterious objects? What connections can be drawn between string theory and on-going experimental efforts?

The particle theory group at Michigan, supported in part by this center, has made an impact on these questions and others. Informed by data from satellites, colliders, and underground experiments, theorists at Michigan are working to form a coherent theoretical picture of the Dark Matter and its place in the universe. Other theorists are working to illuminate the structure of string theory. Tools developed while studying string theory are also being used to study superconductors and strongly coupled field theories.

Reference: C.Choi. *Scientific American,* **302** (2010) 22-24.

For more information: http://www.umich.edu/~mctp/



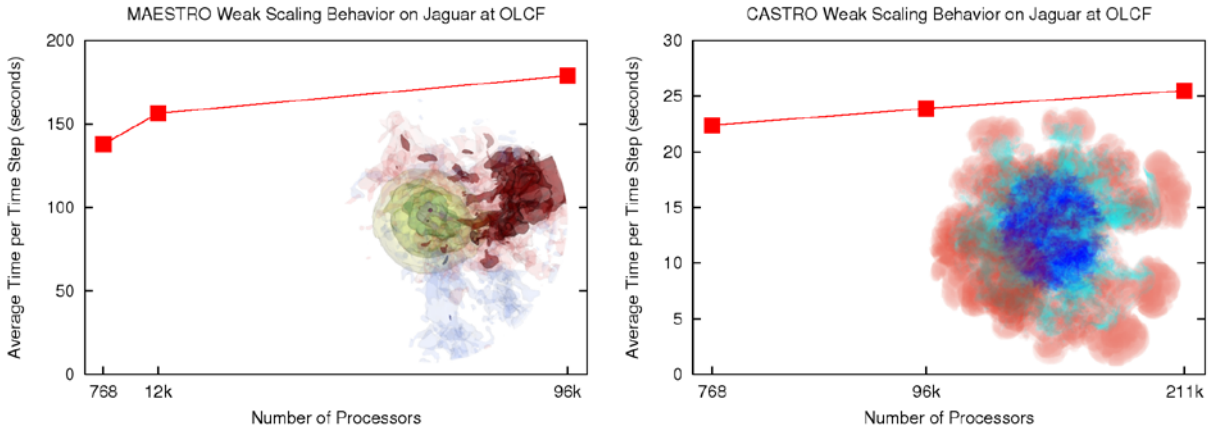
SciDAC Astrophysics Code Scales to Over 200K Processors

Investigators: A. Almgren, J. Bell, A. Nonaka, *LBNL;* M. Zingale, *SUNY--Stony Brook*

Performing high-resolution, high-fidelity, three-dimensional simulations of Type Ia supernovae (SNe Ia), the largest thermonuclear explosions in the universe, requires not only algorithms that accurately represent the correct physics, but also codes that effectively harness the resources of the most powerful supercomputers. Two SciDAC do just that. MAESTRO, a low Mach number code for studying the pre-ignition phase of SNe Ia supernovae, as well as other stellar convective phenomena, has just been demonstrated to scale to almost 100,000 processors on Jaguar at OLCF. CASTRO, a general compressible astrophysics radiation/hydrodynamics code which handles the explosion itself, now scales to over 200,000 processors. Like many other structured grid AMR codes, CASTRO and MAESTRO use a nested hierarchy of rectangular grids. This grid structure lends itself naturally to a hybrid OpenMP/MPI parallelization strategy. At each time step the grid patches are distributed to nodes, and MPI is used to communicate between the nodes. OpenMP is used to allow multiple cores on a node to work on the same patch of data. A dynamic load-balancing technique is used to adjust the load. Soon, scientists will be able to initialize a CASTRO simulation with data mapped from a MAESTRO simulation, thus enabling them to study SNe Ia from "end-to-end", taking advantage of the accuracy and efficiency of each approach as appropriate.

References: Almgren et al., Astrophysical Journal, **715** (2010) 1221; Nonaka et al, Astrophysical Journal Supplement, **188** (2010), 358.

For more information: https://ccse.lbl.gov/



(Left) MAESTRO scaling results and image of convection in a white dwarf preceding a SN Ia. Shown are contours of radial velocity (red=outward, blue=inward) and nuclear energy generation. (Right) CASTRO scaling results and image of nucleosynthesis during the explosion phase of a SN Ia. Shown are nuclear burning products (orange=iron, light blue=silicon and calcium, dark blue=helium).

Theoretical explorations of BSM physics

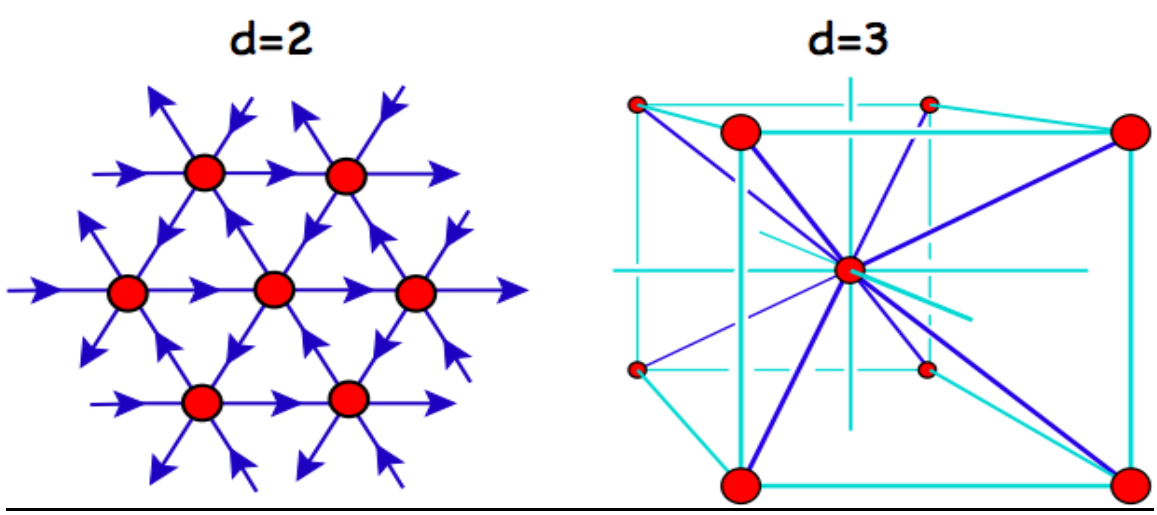
Investigators: A. Balachandran, S. Catterall, J. Hubisz and J. Schechter, *Syracuse University*

The high energy theory group at Syracuse University is focused on a wide range of theoretical extensions of the so-called Standard Model of particle physics. The list of topics includes formal studies of non-commutative Planck scale geometry, the search for viable Technicolor and composite Higgs theories using lattice gauge theory, lattice supersymmetry, the exploration of models with large warped extra dimensions, little Higgs models, and effective field theories. The work on non-commutative geometry has revealed the possible existence of a twisted form of Poincare invariance with the consequence that such theories may violate the Pauli Exclusion Principle. The study of new types of strongly interacting gauge theory using techniques borrowed from lattice QCD may help to reveal new mechanisms for dynamically breaking the electroweak symmetry without a Higgs. New lattice theories have been constructed which are exactly invariant under supersymmetry, offering new ways to calculate the properties of strongly coupled supersymmetric theories, making contact with string theory dualities and shedding light on dynamical supersymmetry breaking. The group's expertise in model building and collider physics at the TeV scale is complementary to such numerical approaches to physics beyond the Standard model. Extra dimensions have offered new ways in which to view effective field theories arising from confining strong dynamics, providing insights and direction in the study of strongly coupled electroweak symmetry breaking.

References: S. Catterall, D. Kaplan and M. Unsal, Physics Reports 484:71-130,2009; A. Balachandran, P. Padmanabhan, JHEP 0909:120,2009**;** D. Bunk J. Hubisz Phys Rev D. 81.125009, 2010

For more information: http://physics.syr.edu/FTGPeople.htm

Examples of supersymmetric lattices



Spectra of Astrophysical Jets

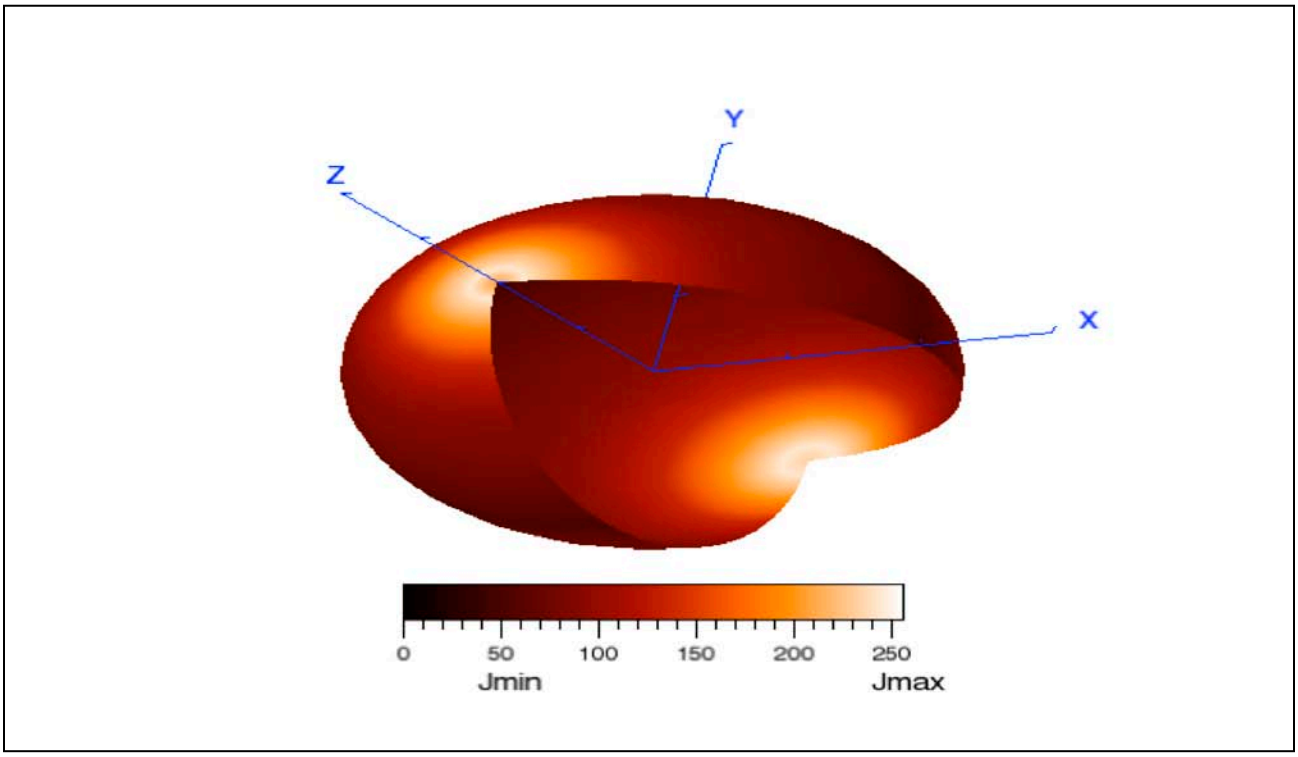
Investigators: E. Baron, *University of Oklahoma*

The PHOENIX team (Eddie Baron, Bin Chen, OU; Peter Hauschildt, Sebastian Knop; Hamburg) have developed a novel method to calculate the interaction of photons with matter in three dimensions, when the matter is moving at arbitrary velocities. This work is important throughout astrophysics, from studies of the Sun to supernovae and active galactic nuclei. Computationally this problem is one of the most intensive in science due to the high dimensionality (3 spatial dimensions and 3 angles which specify the direction of the motion of the radiation) and its non-locality. The code exhibits excellent weak scaling up to 16,000 processors. The figure below shows the mean intensity (brightness) of the surface of a star with a jet-like velocity field, which is ubiquitous in astrophysics.

References: B. Chen et al., MNRAS, 2007, 380:104

E. Baron et al, 2010 in preparation

For more information: http://nhn.ou.edu/~baron



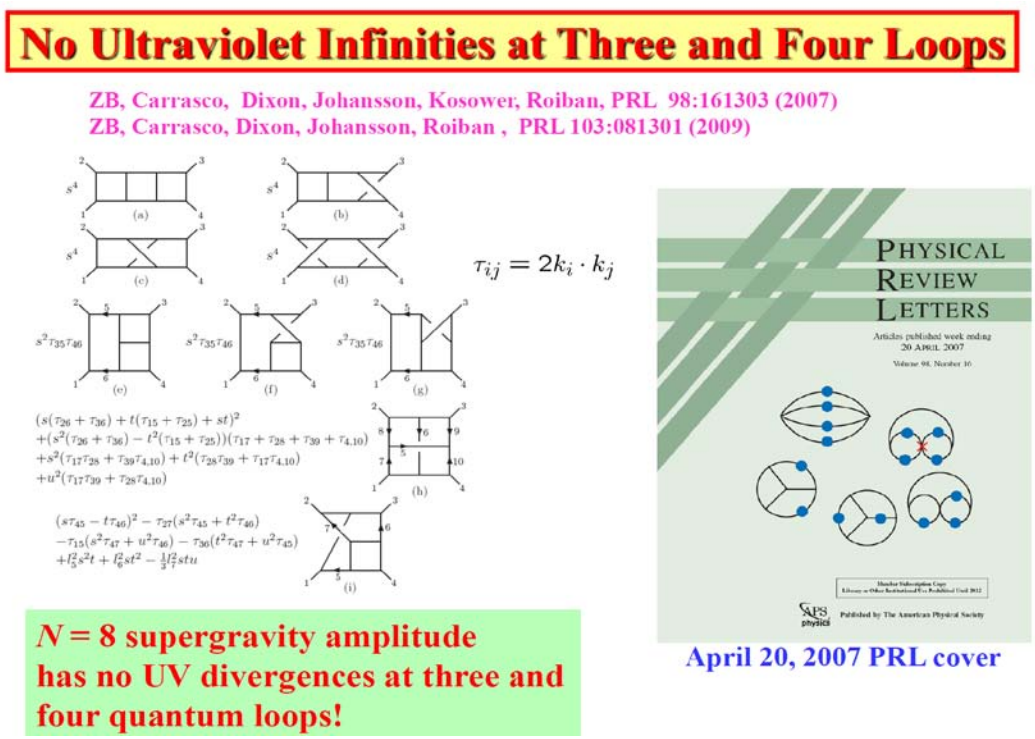
Is Gravity Compatible with Quantum Mechanics?

Investigators: Z. Bern, *UCLA;* J.J. Carrasco, *UCLA;* L. Dixon, *SLAC;* H. Johansson, *Saclay* and R. Roiban, *Penn State*

For over 30 years physicists have believed it to be impossible to construct a point-like quantum theory of gravity. A basic difficulty is the non-renormalizable nature of gravity, inevitably leading to untamed infinities. A version of gravity widely studied in the late 70's and early 80's as a candidate theory, known as *N*=8 supergravity, was abandoned because no mechanism could be identified for cancelling the potential infinities. The first of these was expected at the third order in the quantum corrections. Are these infinites really inevitable? Calculations needed to demonstrate this were considered impossibly difficult to carry out at the time, so the question languished as undecidable. Recently, because of new evidence demonstrating the existence of non-trivial ultraviolet cancellations to *all* quantum loop orders [1], we decided to carry out the necessary calculations, using modern ideas. The results are rather startling: not only is there no divergence at the expected third order, they are not present at the four order as well [2]. A striking outcome of these investigations is a new conjecture that to all quantum orders, gravity is given as a double copy of much more well behaved gauge theories [3]. This may very well hold the key for finding point-like theories of quantum gravity which are sensible.

References: [1] Z. Bern, L.J. Dixon and R. Roiban, *Phys. Lett.* B **664**, 265 (2007)
[2] Z. Bern, J. J. Carrasco, L. J. Dixon, H. Johansson and R. Roiban, Phys. Rev. Lett. **103,** 081301 (2009)
[3] Z. Bern, J. J. Carrasco, and H. Johansson, arXiv: 1004.0476, to appear in Phys. Rev. Lett.

Further Reading: H. Nicolia, Physics 2, 70 (2009)



Precision Tests of QCD

Investigators: D. N. Brown, University of Louisville

Using the large data set of electron-positron collisions collected with the BaBar Detector at the SLAC National Accelerator Laboratory between 2000 and 2008, scientists are performing tests of Quantum Chromodynamics (QCD), the theory of strong nuclear interactions among quarks and the particles made from them. The scientists are using more data than available from previous similar experiments to complete one of the largest particle censuses to date. In addition to testing available theories, the measurements will provide input for scientists working at the energy frontier of the Large Hadron Collider.

For more information: http://www.hep.louisville.edu/

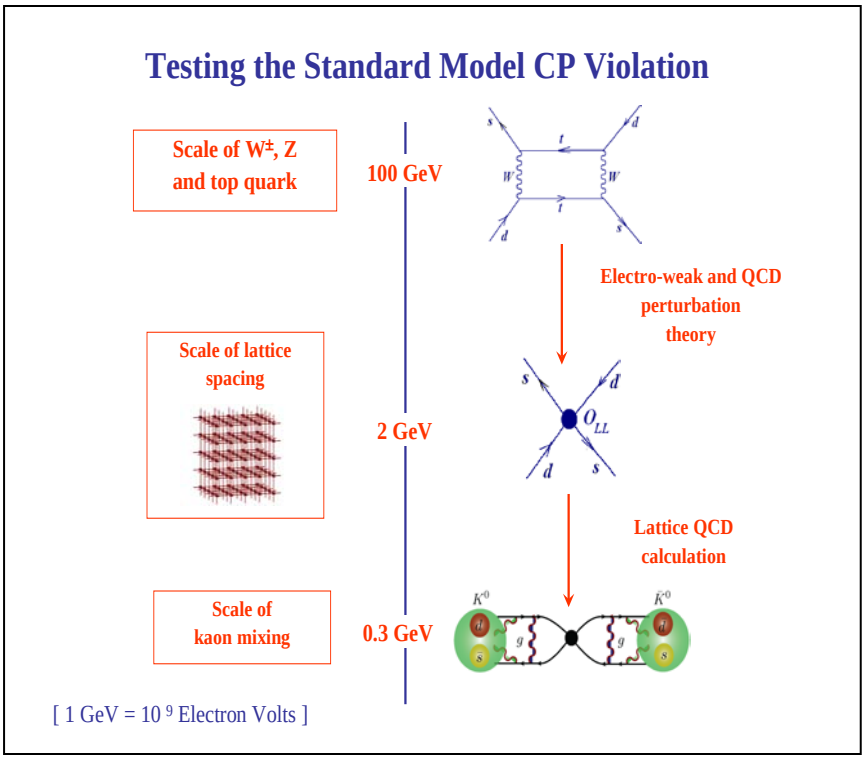
Testing the Standard Model of CP Violation

Investigators: Norman H. Christ and Robert D. Mawhinney, *Columbia University*

Major discoveries over the past 45 years have established small asymmetries between particles and anti-particles if right and left is simultaneously exchanged. These effects, known as CP violation, appear in the decays of both strange and bottom quarks. In the standard model both are caused by a single complex amplitude coupling the quarks and the $W^{\pm}$ bosons. Is this theory (for which the 2009 Nobel Prize was awarded) correct or are there other sources of CP violation? At the heart of these CP violations is the massive top quark whose existence was predicted because of its role in CP violation. These top quark effects at the 100 GeV scale can be extrapolated down to 2 GeV by expanding in the small electro-weak and QCD couplings. However, calculation of the decays themselves must include the strong binding of the quarks, which is only possible using lattice QCD. Recent work of the Columbia group as part of the RBC and UKQCD collaborations using the Argonne Leadership Class Facility has dramatically refined these calculations. Specifically, the error on the parameter B_K, which relates the CP violation in B and K meson decays, has been reduced from 15% to 4%. The preliminary result B_K =0.546(23) was presented in June at the Lattice 2010 Symposium. So far the standard model has withstood this substantial increase in precision. However, a two-standard deviation disagreement between theory and experiment can now be recognized so further improvements in all parts of the calculation are being vigorously being pursued.

Reference: D. J. Antonio, et al., Phys Rev Lett, **100**, (2008) 032001.

For more information: http://rbc.phys.columbia.edu/USQCD/KaonPhysics/index.html



Innovations in connecting QCD to experiment

Investigators*:* J Collins, *Pennsylvania State University*

Although QCD is sufficiently well-established to be considered the correct theory of the strong interactions of hadrons, there are many areas in which it is very difficult to extract reliable predictions from QCD to compare with experiment. Even with established methods (notably hard-scattering factorization), there are considerable conceptual complications. The Penn State group led by John Collins is recognized for its leadership in deepening the concepts used with QCD, and for developing innovative methods to extend the reach of its predictions. Particularly notable results have concerned the effects of parton and hadron spin. The theoretical discoveries of new parton densities and fragmentation functions have uncovered a whole set of previously unexpected phenomena, and have greatly contributed to establishing new fields of experimental investigation. This particularly concerns work by the HERMES, COMPASS, Belle, BABAR collaborations, and the polarized proton program at RHIC. These methods also lead to new probes of the nature of the structure of the proton, a fundamental issue in QCD. This work has led to a much deeper understanding of QCD dynamics. A textbook, "The Foundations of Perturbative QCD", has been completed by J Collins and will soon be published; it gives a pedagogical and detailed account of the subject.

References: J.C. Collins, "Leading-twist Single-transverse-spin asymmetries: Drell-Yan and Deep-Inelastic Scattering", Phys. Lett. B536, 43-48 (2002).

J Collins and J-W Qiu, "Factorization is violated in production of high-transverse-momentum particles in hadron-hadron collisions", Phys. Rev. D75, 114014 (2007).

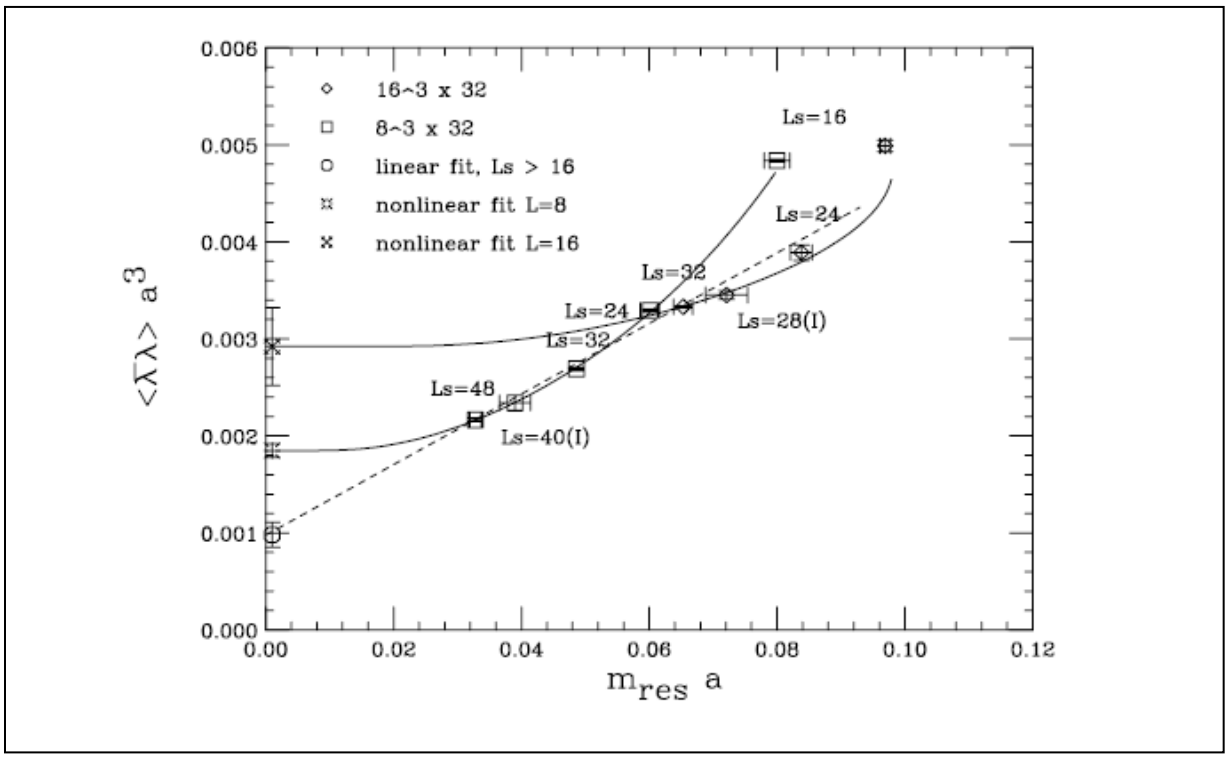
Supersymmetric Yang-Mills with Domain Wall Fermions

Investigator: J. Giedt, *Rensselaer Polytechnic Institute*

If new particles and interactions are discovered at the Large Hadron Collider, there is a good chance that they will consist of a supersymmetric extension of the standard model of particle physics. In that case it is probable that the masses of these new particles will be determined by the size of the "gluino condensate" formed in a hidden sector of the theory. Recently, Rensselaer Polytechnic Institute led an effort to numerically compute this gluino condensate that is supposed to occur in supersymmetric Yang-Mills. This hidden sector theory has, in addition to a "gluon," a massless fermion, the "gluino". It has been known for some time that adding a fictitious fifth dimension to lattice gauge theory allows for massless fermions to be represented in a rigorous manner, and RPI researcher Giedt and collaborators have produced their gluino condensate results using this domain wall fermion approach. They have found that indeed gluino condensation occurs in supersymmetric Yang-Mills, so that supersymmetric particle physics that relies on this mechanism is a viable candidate for discovery at the Large Hadron Collider.

Reference: J. Giedt, R. Brower, S. Catterall, G.T. Fleming and P. Vranas, Phys. Rev. D 79 (2009) 025015.

For more information: http://www.rpi.edu/~giedtj/



Supersymmetric Yang-Mills with Domain Wall Fermions

Investigator: J. Giedt, *Rensselaer Polytechnic Institute*

If new particles and interactions are discovered at the Large Hadron Collider, there is a good chance that they will consist of a supersymmetric extension of the standard model of particle physics. In that case it is probable that the masses of these new particles will be determined by the size of the "gluino condensate" formed in a hidden sector of the theory. Recently, Rensselaer Polytechnic Institute led an effort to numerically compute this gluino condensate that is supposed to occur in supersymmetric Yang-Mills. This hidden sector theory has, in addition to a "gluon," a massless fermion, the "gluino". It has been known for some time that adding a fictitious fifth dimension to lattice gauge theory allows for massless fermions to be represented in a rigorous manner, and RPI researcher Giedt and collaborators have produced their gluino condensate results using this domain wall fermion approach. They have found that indeed gluino condensation occurs in supersymmetric Yang-Mills, so that supersymmetric particle physics that relies on this mechanism is a viable candidate for discovery at the Large Hadron Collider.

Reference: J. Giedt, R. Brower, S. Catterall, G.T. Fleming and P. Vranas, Phys. Rev. D 79 (2009) 025015

For more information: http://www.rpi.edu/~giedtj/

The Yang-Mills vacuum wavefunctional in 2+1 dimensions

Investigator: J. Greensite, *San Francisco State University*

Casimir scaling of the string tensions of color charges in higher color group representations is one of the most striking and characteristic features of the gauge theories at large distance scales, and it cries out for an explanation. The simplest explanation is that the vacuum wavefunctional of a pure non-abelian gauge theory approximates, at large scales, the exponential of the action in one lower dimension. Recently we have proposed a vacuum wavefunction which has both the dimensional reduction property at large scales and the proper perturbative form at high frequencies, and we have devised a method for simulating this wavefunctional numerically in 2+1 dimensions. We have found that the mass gap, the Coulomb ghost propagator, and the color Coulomb potential derived from our proposed vacuum state all agree with the corresponding quantities extracted by standard lattice Monte Carlo methods. In work in progress we have developed a numerical method for computing the relative amplitudes of the true Yang-Mills vacuum wavefunctional in any finite set of configurations, and these can be compared to the theoretical values. Using sets of non-abelian constant lattices, and abelian plane wave lattices, excellent agreement has been found.

References: J. Greensite and S. Olejnik, Phys. Rev. D**81,** 074504 (2010)

J. Greensite and S. Olejnik, Phys. Rev. D**77,** 065003 (2008)

J. Greensite and S. Olejnik, M. Quandt, H. Reinhardt, A. Szczepaniak

work in progress

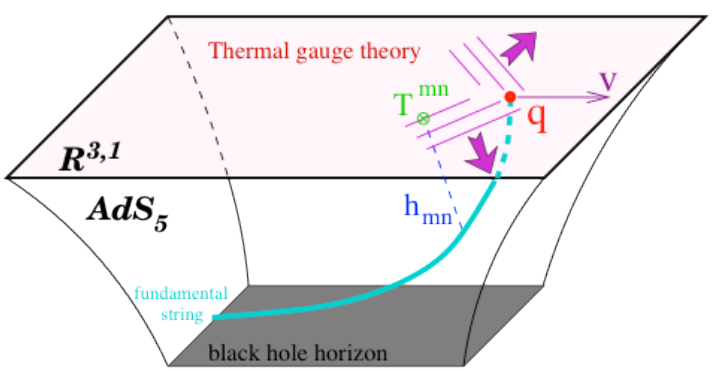
String Theory Connects with Experiment

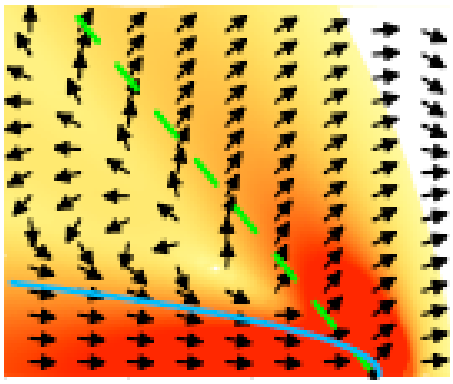
Investigator: Steven S. Gubser, *Princeton University*

High-energy collisions of gold nuclei at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) produce a plasma of quarks and gluons. Techniques from string theory based on the gauge-string duality, which Gubser helped pioneer, have in the past several years become a useful tool to understand strong coupling aspects of the quark-gluon plasma. Insights from the string theory approach complement those from perturbative Quantum Chromodynamics and lattice gauge theory. Gubser's contributions to this growing field stretch back to his work with I. Klebanov and A. Peet, arguing that thermal states of four-dimensional gauge theories can be represented as black hole horizons in a higher-dimensional geometry. Many subsequent calculations hinge on this picture. Among them are Gubser's estimate of the drag force on energetic heavy quarks and his studies with J. Friess, G. Michalogiorgakis, S. Pufu, and A. Yarom of the spatial pattern of energy emission from those quarks. The drag force estimate leads correctly to the conclusion that charm quarks equilibrate with the thermal medium in RHIC collisions. The energy emission studies have been interpreted by B. Betz, M. Gyulassy, J. Noronha, and G. Torrieri as indicating that high-angle emissions observed in experiment may originate from a non-hydrodynamical region close to the quark. Gubser received a Blavatnik Award in 2008 and a Guggenheim Fellowship in 2009 based on his work on string theory and heavy ion collisions.

References: S. Gubser, "Drag force in AdS/CFT," Phys. Rev. D74 (2006) 126005; S. Gubser, S. Pufu, and A. Yarom, "Sonic booms and diffusion wakes generated by a heavy quark in thermal AdS/CFT," Phys. Rev. Lett. 100 (2008) 012301.

For more information: https://www.princeton.edu/physics/research/high-energy-theory/gubser-group/





Left: A heavy quark can be described in the gauge-string duality as the endpoint of a string which trails into a black hole horizon in a five-dimensional curved geometry. Graviton emission from the string can be related to the energy emission from the quark.

Right: The spatial pattern of energy emission from the quark, from calculations based on the trailing string. A sonic boom and diffusion wake are visible at the scale shown---roughly 4 femtometers across.

First-principles calculation of the electron's magnetic moment

Investigators: S. Chabysheva and J. Hiller, *University of Minnesota-Duluth*

Researchers at the University of Minnesota-Duluth have recently completed a major milestone in their program of developing methods to solve quantum chromodynamics, the theory of the strong nuclear interactions. A promising candidate for such a method has been successfully applied to the simpler yet related theory of quantum electrodynamics, and used to compute the shift in the electron's magnetic moment caused by the emission and absorption of virtual photons. Perturbative methods can do this calculation very accurately, but for a nonperturbative method intended for a strongly interacting system, the calculation becomes a nontrivial test. The computer code developed to complete the calculation required over 100 gigabytes of RAM and several weeks of cpu time on machines operated by the Minnesota Supercomputing Institute.

Reference: S.S. Chabysheva and J.R. Hiller, Physical Review D **81**, 074030 (2010).

Superstrings and Quantum Superfields

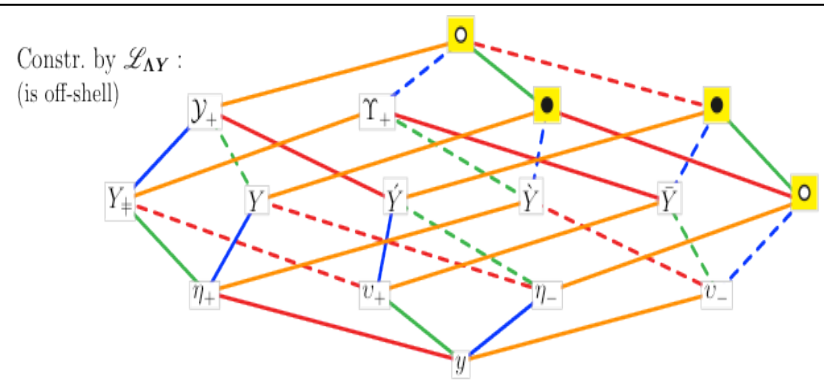
Investigator: Tristan Hubsch, *Howard University*

Superymmetric quantum field theories—including the worldsheet field theories underlying (super)string theory—require the use of off-shell supermultiplets and/or superfields. A recent study [1] shows that such superfields on the worldline are many orders of magnitude more abundant than previously known, and classifies them using graph theory and doubly even binary error-correcting codes. These results show that this abundance in fact indicates a vast, hierarchical generalization of the superspace known so far [2], one that is big enough for many surprises. In turn, even with standard superfield methods, we construct novel world-sheet models the target spaces of which (as in superstring theory) are highly nontrivial algebraic varieties, allowing for couplings to external fluxes of the kind used in superstring, *M*- and *F*-theory models [3].

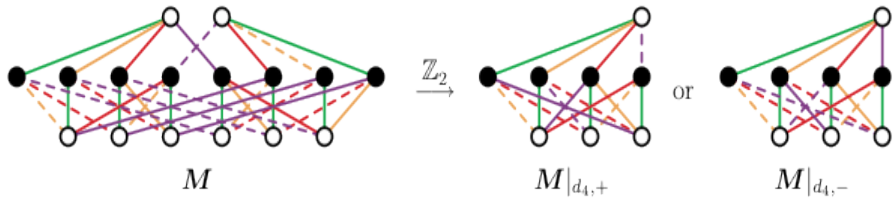
References:

1. C.F. Doran, M.G. Faux, S.J. Gates, Jr., T. Hübsch, K.M. Iga and G.D. Landweber: *Int. J. Mod. Phys*. **A24** (2009) pp. 5681-5695, and refs therein.
2. T. Hübsch: in *Geometric Analysis: Present and Future*, eds. L. Ji et al., (Intl. Press & H. Ed. Press, 2010), http://arxiv.org/abs/0901.2136.

For more information: http://homepage.mac.com/thubsch/



A novel off-shell world-sheet superfield [2] (above), and one of the supermultiplets projections that are classified by doubly even binary error-correcting codes [1] (below).



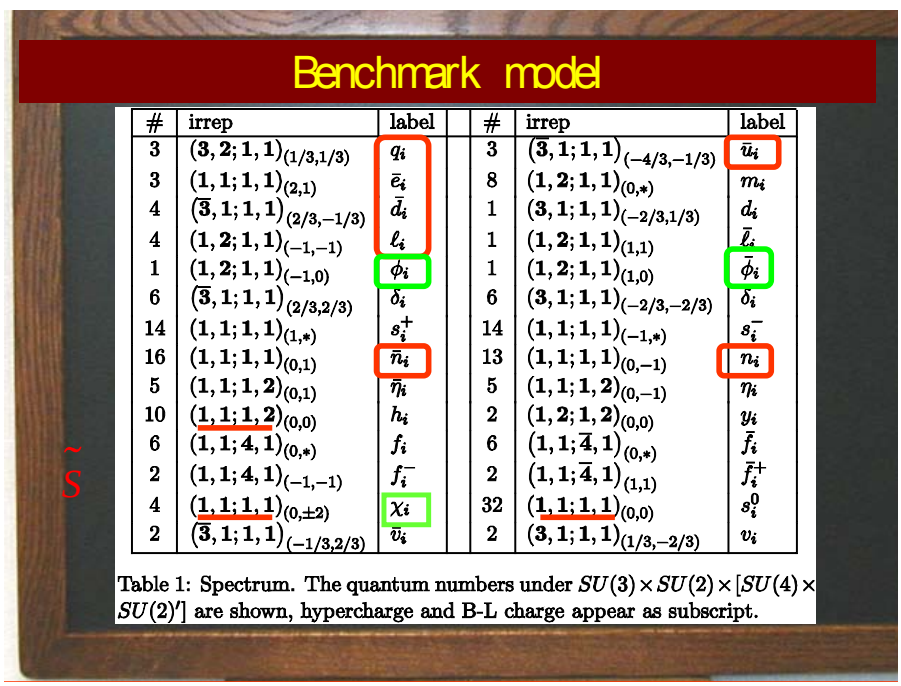
The Heterotic Road to the MSSM with R parity

Investigators: O. Lebedev, *CERN;* H.P. Nilles, S. Ramos-Sanchez and P. Vaudrevange, *U. Bonn;* S. Raby and A. Wingerter, *Ohio State University;* and M. Ratz, *TUM Munich*

In a previous paper, referred to as a "Mini-Landscape" search, we explored a "fertile patch" of the heterotic landscape based on a Z6-II orbifold with SO(10) and E6 local GUT structures. In the present paper we extend this analysis. We find many models with the minimal supersymmetric standard model spectra and an exact R parity. In all of these models, the vector-like exotics decouple along D flat directions. We present two "benchmark" models which satisfy many of the constraints of a realistic supersymmetric model, including non-trivial Yukawa matrices for 3 families of quarks and leptons and Majorana neutrino masses for right-handed neutrinos with non-trivial See-Saw masses for the 3 light neutrinos.

References: O. Lebedev, Phys. Rev. D77, 046013 (2008)

For more information: http:// www.physics.ohio-state.edu/~raby



Benchmark model

#	irrep	label	#	irrep	label
3	$(\mathbf{3},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/3,1/3)}$	q_i	3	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-4/3,-1/3)}$	$\bar{u}_i$
3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(2,1)}$	$\bar{e}_i$	8	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(0,*)}$	m_i
4	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(2/3,-1/3)}$	$\bar{d}_i$	1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,1/3)}$	d_i
4	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,1)}$	$\bar{\ell}_i$
1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,0)}$	ϕ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,0)}$	$\bar{\phi}_i$
6	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(2/3,2/3)}$	δ_i	6	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,-2/3)}$	δ_i
14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1,*)}$	s_i^+	14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1,*)}$	s_i^-
16	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,1)}$	$\bar{n}_i$	13	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,-1)}$	n_i
5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,1)}$	$\bar{\eta}_i$	5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,-1)}$	η_i
10	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,0)}$	h_i	2	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{2})_{(0,0)}$	y_i
6	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(0,*)}$	f_i	6	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(0,*)}$	$\bar{f}_i$
2	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(-1,-1)}$	f_i^-	2	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(1,1)}$	$\bar{f}_i^+$
4	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,\pm 2)}$	χ_i	32	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,0)}$	s_i^0
2	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,2/3)}$	$\bar{v}_i$	2	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,-2/3)}$	v_i

Table 1: Spectrum. The quantum numbers under $SU(3)\times SU(2)\times[SU(4)\times SU(2)']$ are shown, hypercharge and B-L charge appear as subscript.

$\tilde{S}$

/

Making Light of Dark Matter

Investigator: Danny Marfatia, *University of Kansas*

Dark matter is needed to explain the shape and formation of galaxies, galaxy clusters, and even the whole Universe after the Big Bang. Thus far it has not been directly observed. New work by Danny Marfatia of the University of Kansas and his collaborators finds that dark matter, the mysterious stuff observed so far only by its gravitational effects, may soon be seen. Marfatia and collaborators propose that *dark matter* may be the same as *dark antimatter*. This is which is exotic, but violates no principles. If correct, dark matter particles should annihilate and release energy when they meet at random in interstellar space. Marfatia's research group believes that seeing a large flux of photons at the correct energy and position on the sky will be a unique signal of dark matter. The work predicts high energy photons in a narrow energy range will be observed in our galaxy. Atmospheric Cherenkov telescopes, including the new VERITAS observatory, may soon discover the signal. The Fermi Gamma-ray Space Telescope may also see a hint of the same effects at higher energies. Galactic gamma rays are already sought by the VERITAS experiment under construction in Arizona.

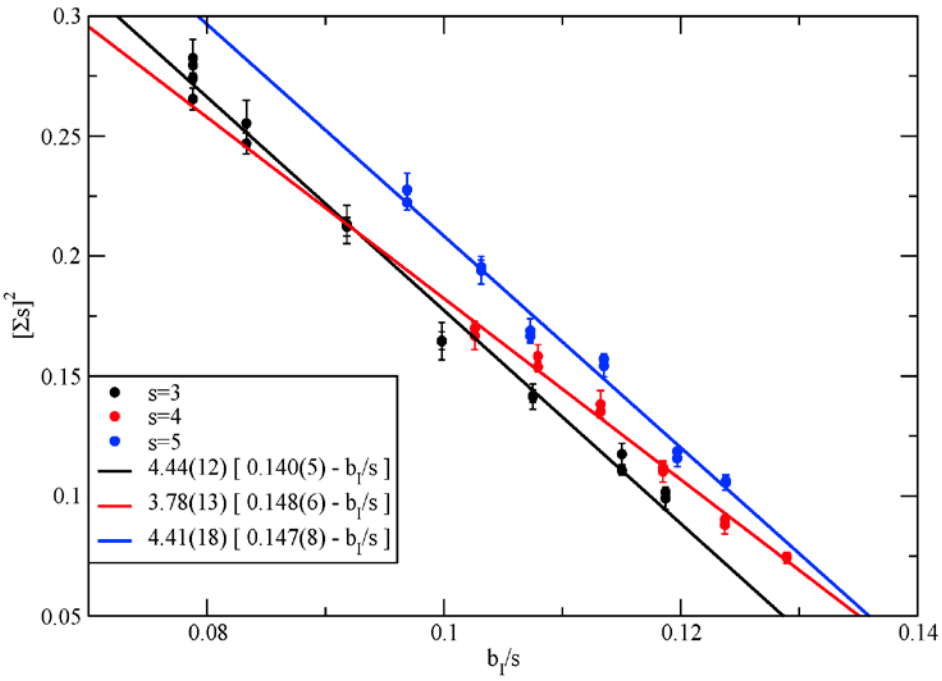
Reference: *Generic dark matter signature for gamma-ray telescopes*, V. Barger, Y. Gao, (Wisconsin U., Madison) , Wai Yee Keung, (Illinois U., Chicago) , D. Marfatia, (Kansas U.) , Jun 2009. (Published Sep 15, 2009). 9pp. Published in Phys. Rev. **D80,** 063537 (2009)

Bridging long and short scales

Investigator: Herbert Neuberger, *Rutgers University*

In Quantum Chromodynamics, forces at short distances are weaker than electromagnetic ones but become so strong at long distances that they permanently confine quarks. The crossover from short- to long-distance behavior occurs over a short range. Working in 2+1 dimensions and at an infinite number of colors, we have shown that the crossover collapses into a point where an operator-dependent phase transition occurs. For quarks constrained to move on a square of side x the transition occurs at a critical value of x given by 1.4(1) in units of the inverse of the square root of the string tension. This is the first example of such a phenomenon with no dependence on extra parameters. In the figure we see the vanishing of the appropriate order parameter, plotted along the y-axis as a function of size, plotted along the x-axis, for several values of the lattice spacing used in the Monte-Carlo simulation.

Reference: R. Narayanan, H. Neuberger, JHEP, to appear [arXiv: 1005.0576].



Birth of Our Universe from the Multiverse

Investigator: Laura Mersini-Houghton, *University of North Carolina--Chapel Hill*

"Why did we start with this universe?" is one of the most fascinating and crucial questions in physics. In recent years, Laura Mersini-Houghton of the University of North Carolina at Chapel Hill has addressed this question by showing how the Big Bang arises within the landscape multiverse scenario of string theory. (At different stages of her work, she was joined by various collaborators including, in particular, Richard Holman of Carnegie Mellon University.) The mechanism involved is driven by the out-of-equilibrium quantum dynamics of the initial states. Mersini-Houghton used the 'no information loss' principle as a handle to test her theory and estimated the strength of the superhorizon entanglement of our universe with other initial patches at the earliest times. Her theory, a natural Copernican extension of the standard model of cosmology, predicts (1) the existence of a giant void; (2) the existence of a dark flow of galaxies; and (3) a suppressed amplitude of cosmic microwave background fluctuations. All three predictions, unique to the theory, have so far been succesfully tested. Her theory also predicts a higher supersymmetry breaking scale, which can be tested at the Large Hadron Collider.

References:

New Scientist, 24 Nov 2007 issue, cover story by M. Chown (http://www.newscientist.com/article/mg19626311.400).

Bild der Wissenschaft, 18.12.2007 issue, cover story (http://www.focus.de/wissen/wissenschaft/bdw/tid-8337/entropie_aid_229970.html).

"The Many Worlds of Hugh Everett III" by P.Byrne (Oxford University Press, 2010), Epilogue.

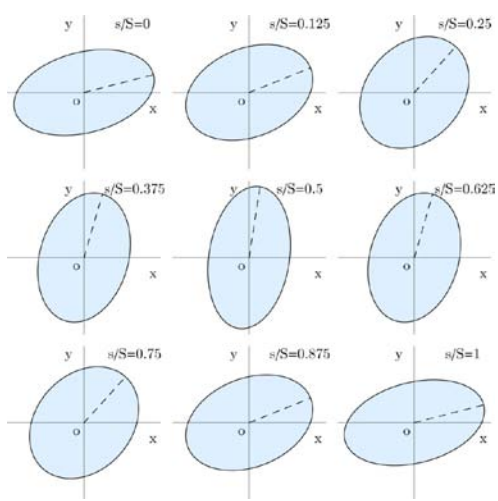
For more information: http://www.physics.unc.edu/research/theory/gchep/

Generalized Courant-Snyder Theory and Kapchinskij-Vladimirskij Distribution for coupled transverse dynamics of charged particles in electromagnetic focusing lattices

Investigators: Hong Qin and Ronald C. Davidson, *Princeton Plasma Physics Laboratory,* and Moses Chung, *Fermilab*

Courant-Snyder theory gives a complete description of the uncoupled transverse dynamics of charged particles in electromagnetic focusing lattices. The Courant-Snyder theory has been generalized to the case of coupled transverse dynamics with two degrees of freedom. In the generalized theory, the envelope function is generalized into an envelope matrix, and the envelope equation becomes a matrix envelope equation with matrix operations that are non-commutative. In an uncoupled lattice, the Kapchinskij-Vladimirskij distribution function first analyzed in 1959 is the only known exact solution of the nonlinear Vlasov-Maxwell equations for high-intensity beams including self-field effects in a fully self-consistent manner. Using the generalized Courant-Snyder theory, the Kapchinskij-Vladimirskij solution has been generalized to describe high-intensity beams in a coupled transverse lattice. This solution projects to a rotating, pulsating elliptical beam in transverse configuration space, determined from the generalized matrix envelope equation. Modern accelerator designs are often based on the original Courant-Snyder theory and Kapchinskij-Vladimirskij distribution function for uncoupled transverse dynamics. Unavoidable coupling and resonances between the two degrees of freedom in the transverse plane always have deleterious effects on the beam quality. The generalized Courant-Snyder theory and Kapchinskij-Vladimirskij distribution function developed here establish the theoretical foundations for designing new types of accelerators where the transverse dynamics are strongly coupled, and immune to the conventional deleterious effects induced by unstable coupling and resonances.

References: H. Qin, M. Chung, and R. C. Davidson, Phys. Rev. Lett. **103**, 224802 (2009); H. Qin and R. C. Davidson, Physical Review Special Topics – Accelerators and Beams **12**, 064001 (2009)



A matched-beam solution of the nonlinear Vlasov-Maxwell equations for a high-intensity beam propagating through a coupled quadrupole focusing lattice.

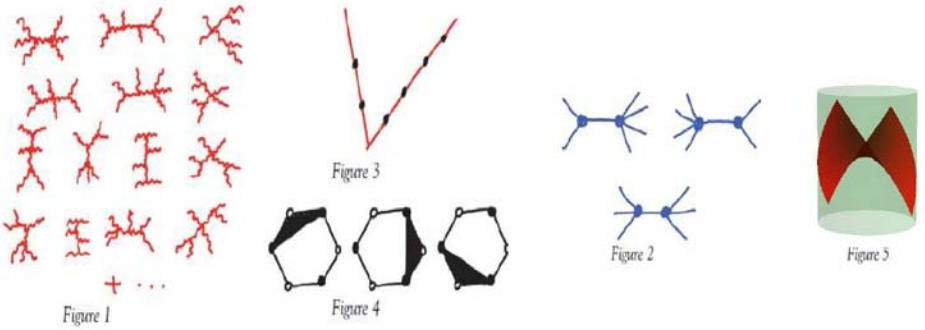
Understanding the glue that binds us

Investigators: L. Alday, N. Arkani-Hamed, S. Caron-Hout, H. Elvang, D. Gaiotto, J. Maldacena, and D. O' Connell, *Institute for Advanced Study*

Quantum Chromodynamics (QCD) plays a central role in understanding the strong interactions that hold the nucleus together. The high-energy collisions between two protons at the Large Hadron Collider are so fast that the quarks and gluons inside the proton collide head-on and produce complex showers of particles. While in principle QCD predicts how these collisions proceed, extracting precise results is difficult and has required extensive computations. We have developed new methods to simplify the computations. These methods use novel insights into the structure of gauge theories, which have many remarkable properties. For example, some computations are simpler in theories that have a higher degree of symmetry than others. In particular, a supersymmetric version of QCD displays a hidden symmetry that can be used to simplify the computations in QCD. In these computations one skips the ordinary Feynman diagram expansion and examines the physical scattering amplitude as a whole, exploiting its analytic properties, which are fixed by simple physical requirements. The supersymmetric version of QCD has a limit where the coupling is strong. In this limit the computation of amplitudes is related to a simple geometric problem involving minimal surfaces in a five dimensional space. This geometric picture is useful for discovering the hidden symmetries of the amplitudes. Some of these methods can also be extended to theories of gravity, where they are expected to have far reaching consequences.

Reference: N. Arkani-Hamed, F. Cachazo, C. Cheung, J. Kaplan; JHEP 1003:020,

For more information: http://www.sns.ias.edu/~malda/FeynmanDiagrams.pdf



In 1) we see a small fraction of the diagrams we would need to sum to come to the six gluon scattering amplitude. In 2,3,4) we see the smaller set of diagrams which is necessary to compute the amplitude using our new methods. In 5) we see a sketch of the geometric problem we need to solve when the coupling is strong.

Inflation and the hunt for Gravity Waves

Investigators: M. Rehman, Q. Shafi, and J. Wickman, *University of Delaware*

While many properties of the epoch of cosmic inflation have been constrained, the exact mechanism remains a mystery. For instance, inflation is expected to produce primordial gravitational waves, but the strength of such waves is not yet known. The amplitude of gravity waves, parameterized by the so-called tensor-to-scalar ratio r, has been constrained, via their impact on the cosmic microwave background, by the Wilkinson Microwave Anisotropy Probe (WMAP). Using more sensitive equipment and techniques, the Planck satellite now in orbit will be able to detect gravitational waves if $r > 0.03$ (in contrast to $r > 0.2$ from WMAP). We have recently examined models of inflation which produce gravity wave amplitudes that are possible for Planck to detect. By including corrections arising from interactions with additional quantum fields, we were able to show that non-supersymmetric inflation models involving a Higgs potential predict $r > 0.02$, allowing a wide range in which Planck can discover these gravity waves. In supersymmetric models on the contrary, exceedingly small r-values are usually expected; however, by considering a more general supersymmetric framework, our recent calculations have found r values as large as 0.05, able to be verified by Planck. With gravity waves we are able to look back at the very early universe when it was a mere 10^{-36} seconds old!

References: arxiv: 1003.5915 (astro-ph.CO), and paper in preparation.

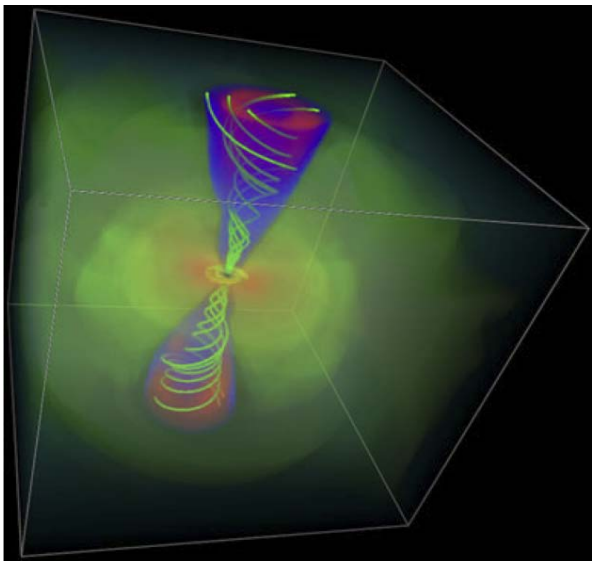
Numerical Simulations of Extraction of Energy from a Spinning Black Hole

Investigators: Jonathan McKinney and Roger Blandford, *SLAC / KIPAC*

Fermi Observatory has detected almost a thousand celestial gamma-ray sources with radiation arising in a powerful relativistic jet, where the radiating particles must be accelerated to enormous (multi-GeV) energies. Such jets are likely to be formed and collimated by strong magnetic fields anchored in the vicinity of spinning black holes: their power can be "tapped" from the black hole's spin, which in turn couples to the electromagnetic field generated by the surrounding plasma. Detailed understanding of the formation of those jets is difficult, since the magneto-hydrodynamical equations governing the dynamics of jets are highly non-linear: this requires detailed and complex numerical simulations, but those are increasingly more successful in reproducing observations. The snapshot illustrated below, from a 3D simulation run on thousands of multi-core systems, shows the black hole (black at the center) and surrounding accretion disk (yellow, orange, and green volume) and magnetic field lines (green) generating an extremely powerful electromagnetic jet (blue and red) driven by the rotational energy of the black hole. Besides being among the most energetic sources in the Universe, such jets are known to control the fate of most galaxies and their production of stars. In some systems, as much energy is released as in all the stars in the entire galaxy that hosts the super-massive black hole at its center. The Fermi telescope gamma ray data, together with detailed numerical simulations, are leading a new revolution in understanding how black hole energy extraction really works.

References: J . McKinney, and R. Blandford, *Mon. Not. Royal Astr. Soc*., **394**, (2009), pp. L126-L130

For more information: http://arxiv.org/abs/0812.1060

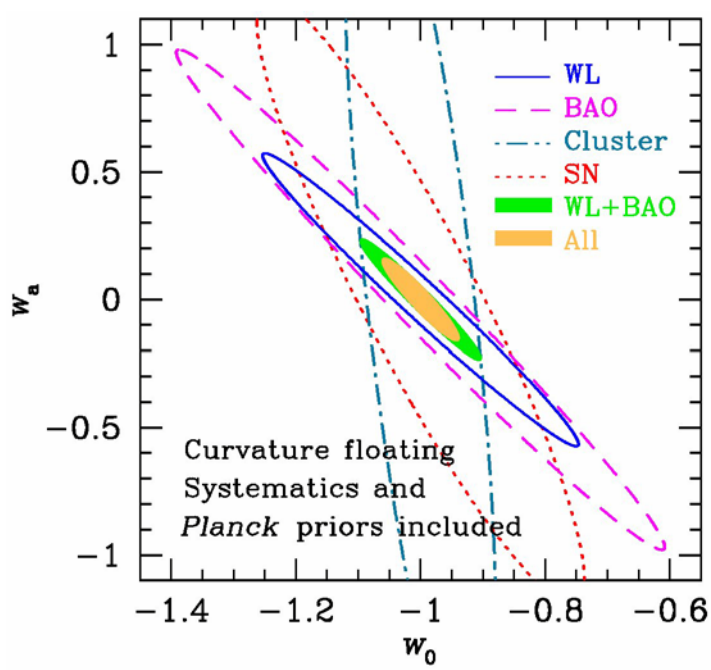


Was Einstein Right?

Investigators: J. Thaler, Mats Selen, W. Hanlon, and I Karliner, *University of Illinois--Urbana-Champaign*

According to Gamow (*My World Line*, 1970), Einstein said that the cosmological constant was his biggest blunder. However, we now observe that the expansion of the universe is accelerating, and the natural explanation is that there really is a cosmological constant, or something similar. The study of dark energy (DE), as this effect is called, has become a major focus of cosmological research. Lacking any compelling theory, it is imperative we measure the properties of the DE more precisely. The equation of state, $P = w\rho$, where P is pressure and ρ is energy density, is particularly important, because the cosmological constant has $w = -1$, not varying with time. Negative pressure is needed for an accelerated expansion. The value of w and its time dependence (w_a in the figure) can be measured by observing the history of the expansion rate of the universe and of the formation of cosmological structure. Two new projects, the Dark Energy Survey (DES, first light in 2011) and the Large Synoptic Survey Telescope (LSST, first light in 2016) will lead to a reduction by more than a factor of ten of the area of the error ellipse ($\sigma_w \sim 0.016$ and $\sigma_{wa} \sim 0.16$). These measurements may tell us whether or not Einstein was right after all, and will help guide us to a more encompassing cosmological theory.

For more information: http://www.lsst.org



New Approach to Parton Showers in Precision QCD for LHC

Investigator: B.F.L. Ward, *Baylor University*

For the first time in the history of parton shower Monte Carlo (MC) event generators, the infrared (IR) singularities in the famous Dokshitzer-Gribov-Lipatov-Altarelli-Parisi-Callan-Symanzik kernels have been resummed so that their integrals are finite. The result is that the arbitrary infrared cut-off that is standard in such calculations is now no longer needed and the description of the showers in the infrared regime should be more closely matched to real data. Recent publications [1, 2] by Ward at Baylor and his research team show that, with their new MC realization of such IR-improved showers in the new MC Herwiri1.031 in the Herwig6.5 environment, this is already evident in comparisons with the soft transverse momentum distribution of single Z production at D0 in FNAL and with the soft aspects of the rapidity distribution of the same process at CDF, as we illustrate in Fig. 1. Such IR-improved parton showers open a new era in precision QCD theory for LHC physics via MC event generators for both signal and background processes, where 1% precision on the theory obtains.

References: 1. S. Joseph, S. Majhi, B.F.L. Ward, S.A. Yost, Phys. Rev. D**81**, 076008 (2010).

2. S. Joseph, S. Majhi, B.F.L. Ward, S.A. Yost, Phys. Lett. B**685**, 283 (2010).

For more information: http://prd.aps.org/abstract/PRD/v81i7/e076008.

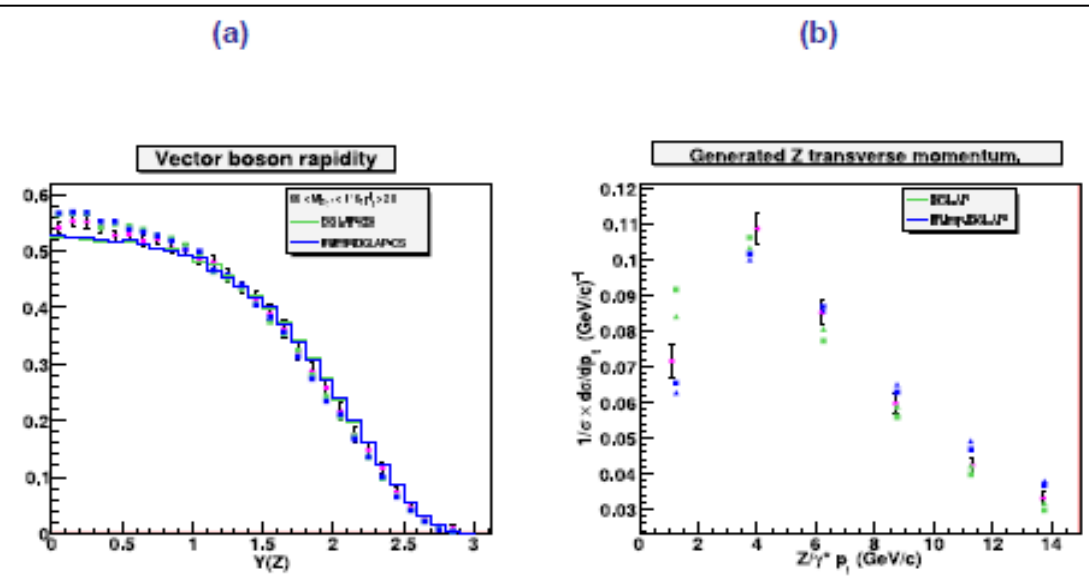


Figure 1: Comparison with FNAL data: (a), CDF rapidity data on ($Z\ /\gamma^*$) production to e^+e^- pairs, the circular dots are the data, the green(blue) lines are HERWIG6.510(HERWIRI1.031); (b), D0 p_T spectrum data on (Z/γ^*) production to e^+e^- pairs, the circular dots are the data, the blue triangles are HERWIRI1.031, the green triangles are HERWIG6.510 – in both (a) and (b) the blue squares are MC@NLO/HERWIRI1.031, and the green squares are MC@NLO/HERWIG6.510. These are untuned theoretical results.