U.S. DEPARTMENT OF ENERGY | Office of Science

# Transforming Geant4 for the Future

Ceren Susut
Advanced Scientific Computing Research
Ceren.Susut-Bennett@science.doe.gov
March 5th, 2013

# Outline

Geant4 and its importance to High Energy Physics

The “Transforming Geant4 for the Future” workshop

Findings and Path Forward

# The Energy Frontier

**The Large Hadron Collider is the world's largest particle accelerator.**

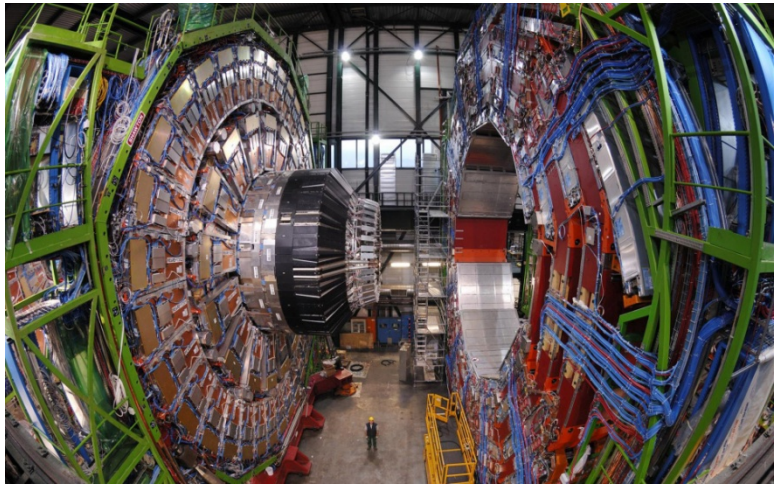
- **It collides beams of protons at 8 TeV.**
- **Possibly the largest machine of any kind.**

**There are four large experiments there:**

- **ATLAS & CMS (general purpose)**
- **ALICE & LHCb (specialized)**

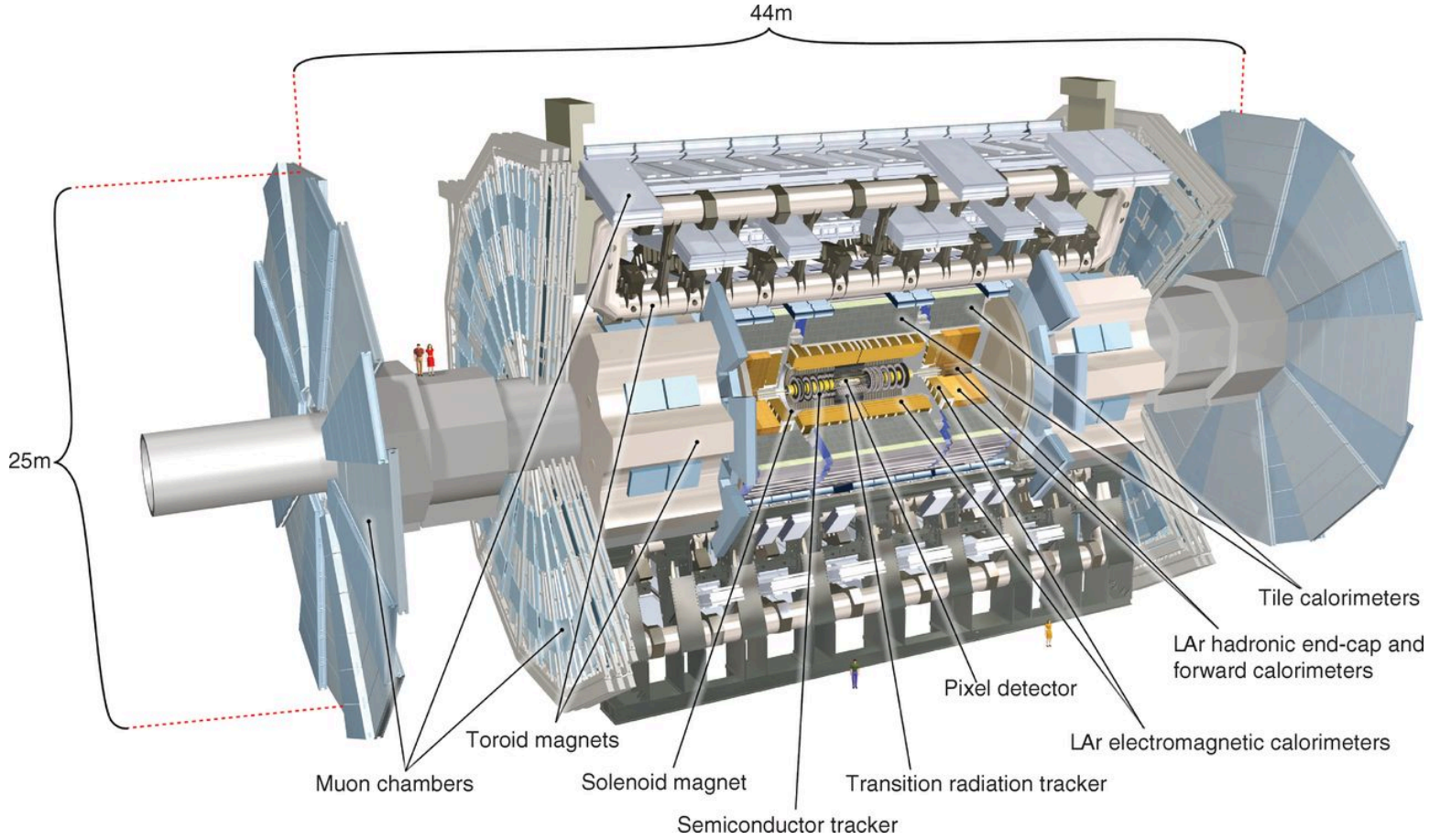
**The experiments intend to shed light on several fundamental questions:**

- **Why is the weak nuclear force so weak? The "Higgs mechanism" is one answer to this.**
- **What is the Dark Matter (80% of the universe?)**
- **Why is the universe made out of matter, not antimatter?**
- **Why is gravity so much weaker than the other forces?**



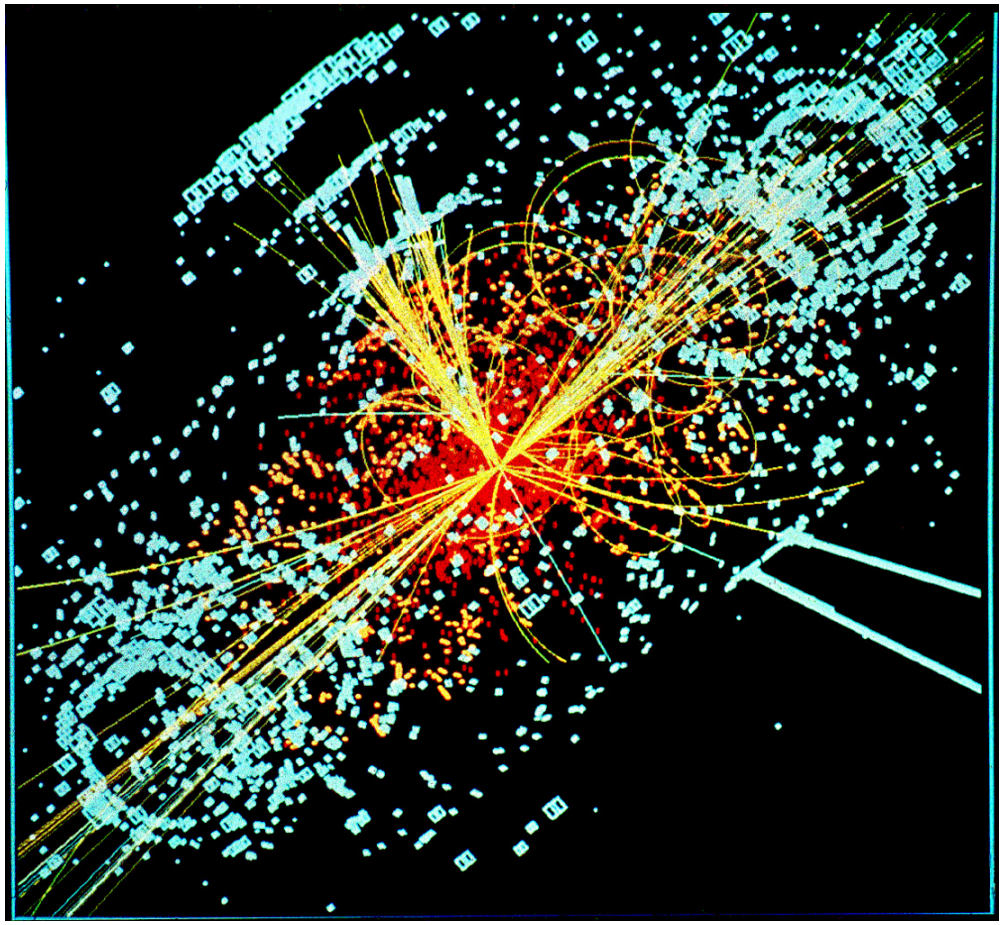
# The ATLAS Detector

## It takes a lot of “stuff” to detect particles!




*Science*, Vol. 338, No. 6114, December 2012.

# Simulated Higgs Event in CMS



# Geant4 (GEometry ANd Tracking)

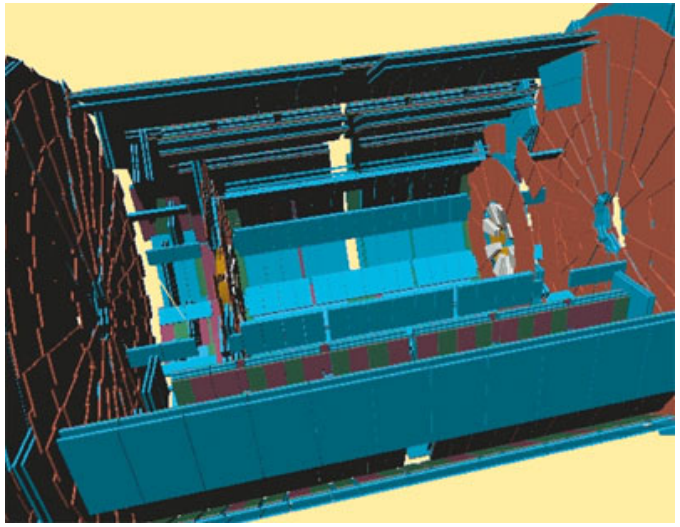
Geant4 is a C++ tool kit that tracks particles through matter, breaking the particle motion into small segments, applying appropriate physical processes and probabilities at each segment.

- These processes can destroy old particles, modify state or create new ones.
- Processes include atomic processes like ionization and excitation, decay processes, photonic transitions, secondary emission, etc.
- The wide coverage of physical processes comes from mixture of theory-driven, parameterization, and empirical formulae.
- Successor to Geant3, the Geant4 Project began in 1994 with the first public release in 1998.

# Geant4 is Unique

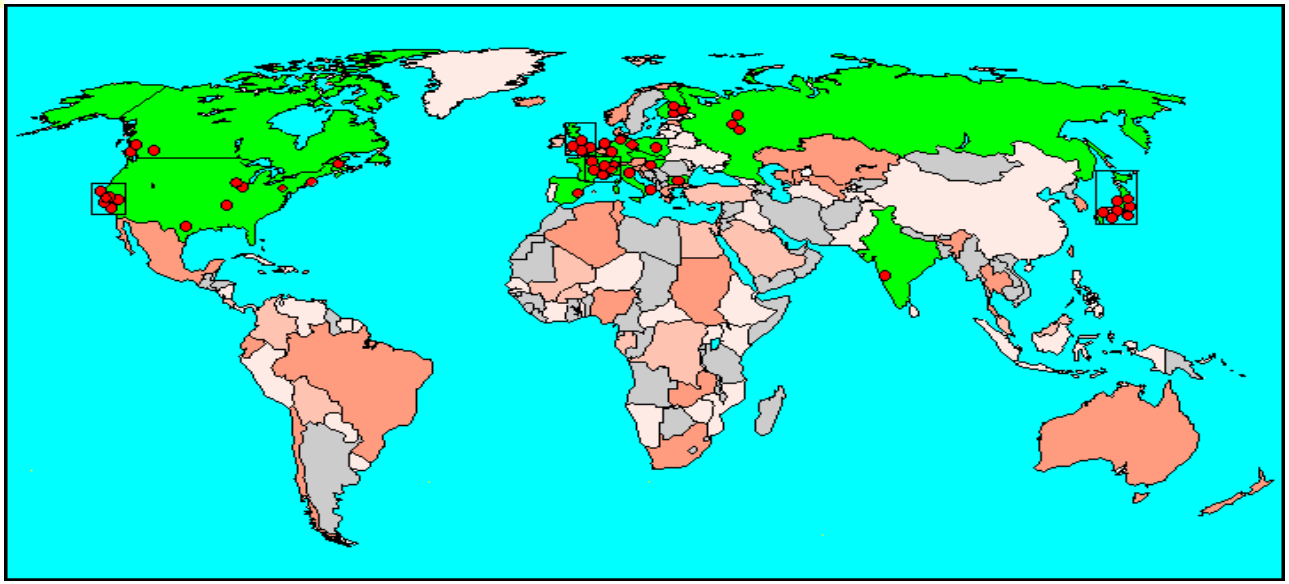
Geant4 is distinguished from other Monte Carlo Particle Transport codes by

- The comprehensive suite of physics processes and particle types.
- The complexity of geometrical descriptions leads to realistic representations.
- A collaborative open source model leveraging international expertise.



Enables the user to select physics processes/models and choice of GUI, visualization, persistency, and histogramming technologies.

# Geant4 is an International Collaboration



TRIUMF

Lebedev

J.W.Goethe Universität

Collaborators also from non-member institutions, including
Budker Inst. of Physics
IHEP Protvino
MEPHI Moscow
Pittsburg University

# Geant4 is Big

Computation

- Large ensembles of sequential jobs
- Runs on a worldwide Grid of processors
- Significant Computing Hardware investment worldwide in order to satisfy demand

Data

- HEP has more simulated than collected data
- LHC data is currently ~100 PB and rapidly increasing

# Challenges for Geant4's Future

Geant4 is a sequential C++ toolkit

- MC runs are ensembles dispatched to the Grid
- It can take months to simulate a billion particles
- Code as it stands now is extremely "serial"

CPU capability has plateaued

- Dennard scaling has ended

Potential to constrain progress in HEP if we don't react

# Joint ASCR/HEP Workshop

***"Transforming Geant4 for the Future"*** workshop was held in Rockville, MD on May 8th-9th 2012.

Website: http://www.orau.gov/transformwkshop2012/

Goals:

- Review status, successes and limits of Geant4
- Determine challenges posed by emerging architectures
- Consider opportunities in algorithms and optimization
- Ascertain research for robust, sustainable code
- Create foundation among ASCR and HEP investigators
- Understand and not duplicate international efforts
- Explore transformative advances via HEP-ASCR collaboration.

# Participants

- Co-chaired by Bob Lucas (USC) and Rob Roser (Fermilab)
- 50 participants from HEP and ASCR communities
- Ceren Susut (ASCR) and Lali Chatterjee (HEP)

| | | |
|---|---|---|
| David | Asner | Pacific Northwest National Laboratory |
| Amber | Boehnlein | SLAC National Accelerator Laboratory |
| Richard | Brower | Boston University |
| Paolo | Calafiura | Lawrence Berkeley National Laboratory |
| Philippe | Canal | Fermi National Accelerator Laboratory |
| Lali | Chatterjee | DOE Office of High Energy Physics |
| Gene | Cooperman | Northeastern University |
| Terence | Critchlow | Pacific Northwest National Laboratory |
| Pedro | Diniz | University of Southern California |
| V. Daniel | Elvira | Fermi National Accelerator Laboratory |
| Michael | Ernst | Brookhaven National Laboratory |
| Robert | Fowler | University of North Carolina |
| Salman | Habib | Argonne National Laboratory |
| Andrew | Hanushevsky | SLAC National Accelerator Laboratory |
| Jim | Kowalkowski | Fermi National Accelerator Laboratory |
| David | Lange | Lawrence Livermore National Laboratory |
| Randall | Laviolette | DOE Office of Advanced Scientific Computing Research |
| Thomas | LeCompte | Argonne National Laboratory |
| Steven | Lee | DOE Office of Advanced Scientific Computing Research |
| Qing | Liu | Oak Ridge National Laboratory |
| Bob | Lucas | University of Southern California |
| David | Malon | Argonne National Laboratory |
| Gabriel | Marin | Oak Ridge National Laboratory |
| John | Mellor-Crummey | Rice University |
| Richard | Mount | SLAC National Accelerator Laboratory |
| Esmond | Ng | Lawrence Berkeley National Laboratory |
| Boyana | Norris | Argonne National Laboratory |
| Lucy | Nowell | DOE Office of Advanced Scientific Computing Research |
| Bruce | Palmer | Pacific Northwest National Laboratory |
| Karen | Pao | DOE Office of Advanced Scientific Computing Research |
| Marc | Paterno | Fermi National Accelerator Laboratory |
| Joseph | Perl | SLAC National Accelerator Laboratory |
| Allan | Porterfield | University of North Carolina |
| Lawrence | Price | DOE Office of High Energy Physics |
| Michael | Procario | DOE Office of High Energy Physics |
| Kenneth | Roche | Pacific Northwest National Laboratory |
| Rob | Roser | Fermi National Accelerator Laboratory |
| Paul | Ruth | University of North Carolina |
| Allen | Sanderson | University of Utah |
| Elizabeth | Sexton-Kennedy | Fermi National Accelerator Laboratory |
| Panagiotis | Spentzouris | Fermi National Accelerator Laboratory |
| Ceren | Susut | DOE Office of Advanced Scientific Computing Research |
| Timothy | Tautges | Argonne National Lab |
| Craig | Tull | Lawrence Berkeley National Laboratory |
| Brian | Van Straalen | Lawrence Berkeley National Laboratory |
| Torre | Wenaus | Brookhaven National Laboratory |
| Dennis | Wright | SLAC National Accelerator Laboratory |
| John | Wu | Lawrence Berkeley National Laboratory |

# Agenda

**May 8**

| | | |
|---|---|---|
| 8:00-8:30 am | Registration Open<br>Continental Breakfast | |
| 8:30-9:00 am | Welcome and Goals<br>ASCR and HEP | Dan Hitchcock, ASCR<br>Jim Siegrist, HEP |
| | Conference Chairs | Bob Lucas, USC<br>Rob Roser, FNAL |
| 9:00-9:30 am | Geant4 overview | Amber Boehnlein, SLAC |
| 9:30-9:45 am | Geant4 Collaboration and History | Makoto Asai, SLAC |
| 9:45-10:15 am | Physics uses of Geant4 | Tom LeCompte, ANL |
| 10:15-10:45 am | Break | |
| 10:45-11:15 am | Trends in multi-core architecture and optimization opportunities | Rob Fowler, UNC |
| 11:15-11:45 am | Exploiting concurrency in Geant4 | Jim Kowalkowski, FNAL |
| 11:45 – 12:15 pm | Scientific data management and analysis challenges | Rob Ross, ANL |
| 12:15-12:30 pm | Charge to Workshop Participants | Bob Lucas, USC<br>Rob Roser, FNAL |
| 12:30-1:45 pm | Lunch on your own | |
| 1:45-3:15 pm | Parallel Sessions<br>Multi-core Optimization<br>Scientific Data Handling and Analysis | |
| 3:15-3:30 pm | Break | |
| 3:30-5:00 pm | Resume sessions | |
| 5:00 – 5:30 pm | Report of Parallel Session progress | |
| 5:30 pm | Adjourn for the day | |

**May 9**

| | |
|---|---|
| 8:00-8:30 am | Continental Breakfast |
| 8:30-10:30 am | Resume breakout discussions |
| 10:30-11:00 am | Break |
| 11:00-12:00 pm | Plenary reports from discussions |
| 12:00-12:15 pm | Closing remarks and path forward |
| 12:15-1:30 pm | Workshop adjourn<br>Working lunch for organizers and chairs |
| 1:30 pm | Report preparation |

## Multi-core Optimization

Daniel Elvira, (FNAL)
Robert Fowler, (UNC)

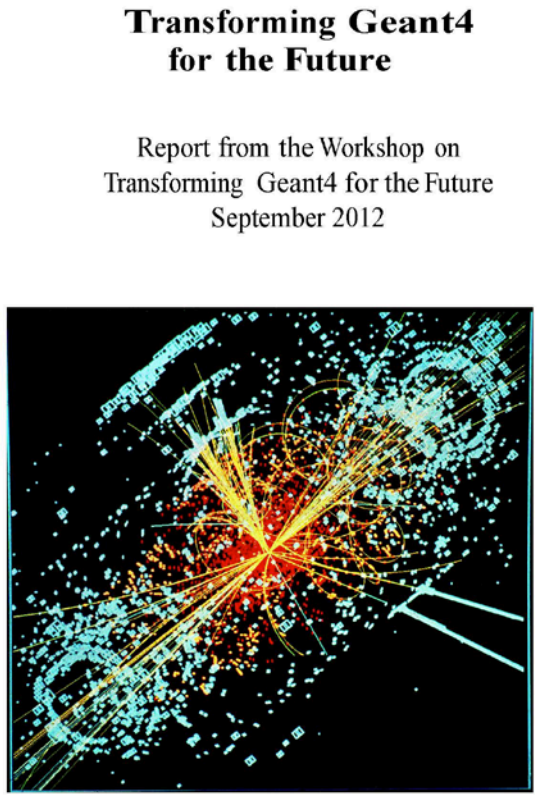
## Scientific Data Handling and Analysis

Gene Cooperman, (Northeastern University)
Rob Ross (ANL)

# Report

An ASCR/HEP joint program in SciDAC model to:

- Explore existing tools
- Strengthen US efforts to refactor/rearchitect
- Plan and implement necessary validation and testing processes
- Develop efficient I/O strategies
- Explore the possibility of using higher-level abstraction
- Explore how to handle petabyte-to-exabyte scale data with much lower human effort




http://science.energy.gov/~/media/ascr/pdf/research/scidac/GEANT4-final.pdf

# Path Forward

- **Optimizations Within the Geant4's Current Framework**
- **Refactoring Demonstrations and Prototypes**

2-year joint ASCR/HEP pilot study is underway.
HEP effort is led by Rob Roser (Fermilab and SLAC).
ASCR effort is led by Bob Lucas (USC, ANL and UNC from SUPER SciDAC Institute).

# THANK YOU!

Special thanks to Rob Roser and Bob Lucas for help with these slides and Lali Chatterjee for helpful discussions.