The Echo-7 Program at SLAC

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for Echo-7 team:

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Motivation

- Goal: Seeding to generate transform limited x-ray pulses
- Many approaches:
  - High Harmonic Generation (HHG)
  - High Gain Harmonic Generation (HGHG)
  - Various Self-seeding techniques (HXRSS and SXRSS)
  - Echo-Enabled Harmonic Generation (EEHG)
- Various degrees of demonstration
- Echo is a new approach where laser challenges are traded for beam manipulation challenges
  - Has feature in that bunching is weak function of harmonic number
- Echo (EEHG) demonstration to benchmark critical accelerator physics
Echo Enabled Harmonic Generation
Features and Challenges of Echo

**Features**
- Excellent frequency up-conversion efficiency
- Generate high harmonics from small energy modulation
- Both bunching and gain at short wavelengths
- UV laser can be used to seed soft x-rays in single stage

**Challenges**
- Must preserve small correlations in phase space
- Sensitive to unwanted x-z coupling; higher-order effects
- Sensitive to incoherent synchrotron radiation and IBS
- Requires excellent laser stability
Echo Demonstration at SLAC

- Used existing NLC Test Accelerator for demonstration
  - Rf gun, high gradient rf and multiple laser systems pre-installed
  - Added 60 MeV acceleration, 3 chicanes (C0-C2), 3 undulators, and lots of diagnostics in 2010
  - Subsequently installed two TCAVs, VUV spectrometer and upgraded energy spectrometer
Hardware Fabricated for Echo

C1     TCAV1     X2     TCAV2

U1     U2     spectrometer
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-08</td>
<td>Concept proposed</td>
</tr>
<tr>
<td>03-09</td>
<td>First studies of demo</td>
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<tr>
<td>06-09</td>
<td>Initial funding from LDRD</td>
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<tr>
<td>08-09</td>
<td>Undulators ordered</td>
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<tr>
<td>09-09</td>
<td>BES R&amp;D funds received</td>
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<tr>
<td>11-09</td>
<td>H75 X-band structure inst.</td>
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<tr>
<td>12-09</td>
<td>120 MeV beam achieved</td>
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<tr>
<td>02-10</td>
<td>First undulator installed</td>
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<tr>
<td>04-10</td>
<td>Initial beamline complete</td>
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<tr>
<td>05-10</td>
<td>First harmonics seen</td>
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<tr>
<td>07-10</td>
<td>Clear evidence of 3\textsuperscript{rd} and 4\textsuperscript{th} harmonics due to EEHG</td>
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<tr>
<td>09-10</td>
<td>Began fabrication of TCAVs and upgrade of spectrometer</td>
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<tr>
<td>12-10</td>
<td>Energy spectrometer inst.</td>
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<tr>
<td>02-11</td>
<td>VUV spectrometer install</td>
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<tr>
<td>03-11</td>
<td>Two TCAVs installed for diagnostic and energy modulation</td>
</tr>
<tr>
<td>05-11</td>
<td>Measured 7\textsuperscript{th} harmonic with large energy modulation</td>
</tr>
<tr>
<td>07-11</td>
<td>Measured 7\textsuperscript{th} harmonic with small energy modulation</td>
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</table>
Echo Results (2010)

Observation of 4\textsuperscript{th} harmonic due to EEHG confirmed by varying chirp

FIG. 5: Radiation wavelength vs beam energy chirp for the echo signal E2 (red), E3 (magenta) and that from the 795 nm laser alone H2 (blue).
Goals for Echo Experiment
(Benchmarking EEHG Simulations)

- Confirm the high up-frequency conversion efficiency with $\Delta E \sim \sigma_E$
- Varying beam, laser and chicane parameters to benchmark EEHG theory
- Measure bunching for various harmonic numbers to confirm the slow decaying of the bunching

$b_7$ for various laser modulations

$b_7$ for various chicane strength
Large Energy Spread Results
(Intensity at 227 nm)

A Laser modulation is ~ 15 keV.

Fit to decay of HGHG bunching $\Rightarrow \sigma_{\Delta E} \sim 4$ keV.

FIG. 4: Spectrum of the radiation for various TCAV1 voltage:
(a) $V=0$; (b) $V=85$ kV; (c) $V=170$ kV; (d) $V=255$ kV.
(a)-(d) are the case when only the 1590 nm laser is on and (e) is at $V=255$ kV with both lasers on.
Echo Experiment Status

- Extensive theory and simulations of EEHG and variants
- Measured 7th harmonic with energy spread comparable to laser modulation
  - Have data on optics sensitivities and on slice emittance
- Developed diagnostic techniques for longitudinal phase space
- Need to analyze July data further
  - Inconsistencies in slice energy spread between different measurement techniques
  - Parameterize decay of EEHG bunching versus TCAV1
  - Parameterize EEHG versus slice emittance
- Limited by NLCTA injector system and beam timing jitter
Publications
(11 Journal articles; 9 conference Proceedings)

**Journal Articles:**

**Conference Proceedings:**
2. Commissioning the Echo-Seeding Experiment Echo-7 at SLAC. FEL’10, SLAC-PUB-14450. (2011).
Future Plans

• Complete Echo-7 benchmarking
  – Need to understand beam parameters and fully analyze July data
  – Projected emittance appears much than larger slice emittance
  – Verify decay of 7th EEHG harmonic with energy spread

• Beginning studies of laser phase stabilization (critical for EEHG and HGHG) and upgrade NLCTA injector systems
  – Purchasing new laser system for phase stabilization studies
  – Re-align capture structures and bypass chicane for cleaner phase space and reduced timing jitter and installing LLRF upgrade

• Use upgrades injector to study 15th harmonic and benchmark collective effects as well as phase space limitations

• Study microbunching and new diagnostic techniques as well
Support

- Work has been supported by the BES Accelerator and Detector R&D program
- The NLCTA was originally constructed as part of the HEP linear collider R&D program and currently supports the Echo-7 (BES) program as well as the High Gradient RF (HEP) program and the Direct Laser Acceleration (HEP) experiment
- This experiment has been possible due to the great team at SLAC and the Test Facilities Department operating the NLCTA