The Echo-7 Program at SLAC

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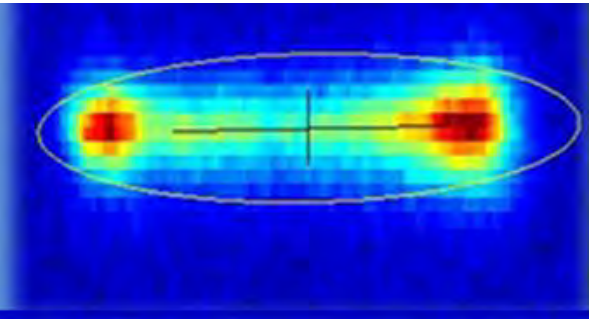
SLAC National Accelerator Laboratory

Accelerator and Detector Research and Development Program Principal Investigators' Meeting

August 22-23, 2011
The Westin, Annapolis, MD



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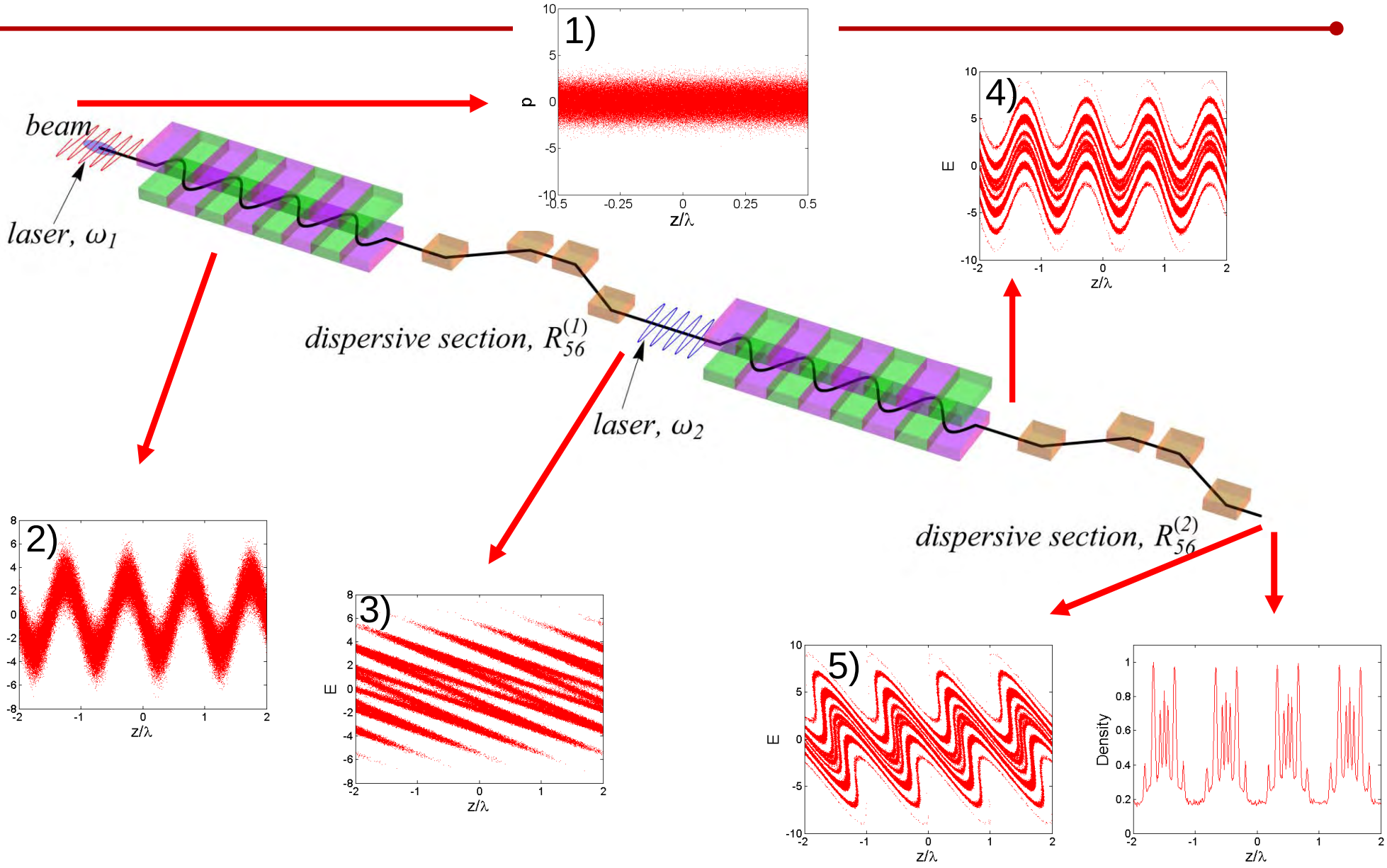
Motivation

- 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

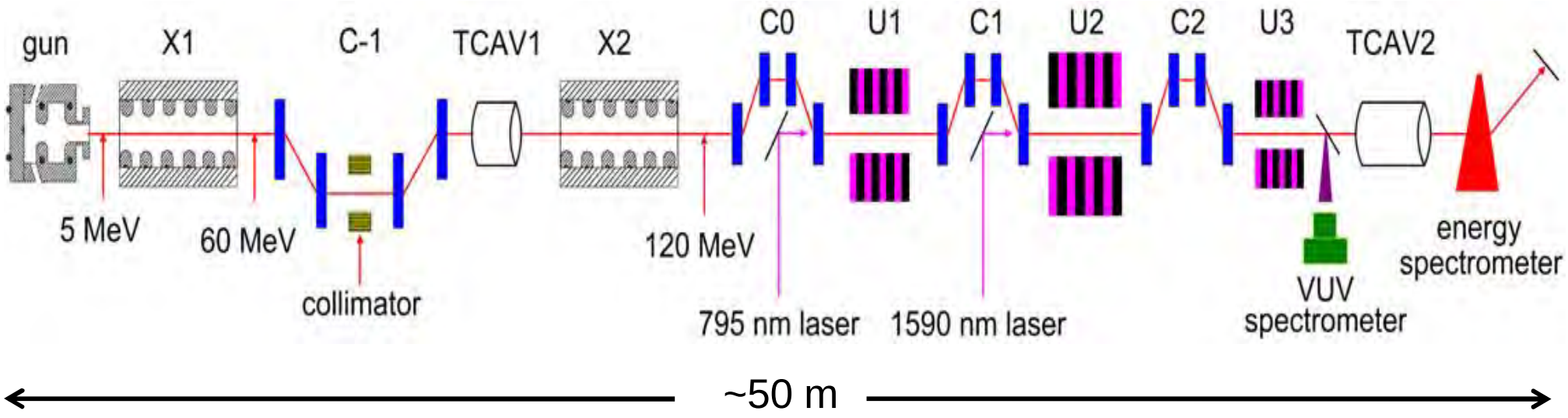
- ✓ Excellent frequency up-conversion efficiency
- ✓ Generate high harmonics from small energy modulation
- ✓ Both bunching and gain at short wavelengths
- ✓ UV laser can be used to seed soft x-rays in single stage

Challenges

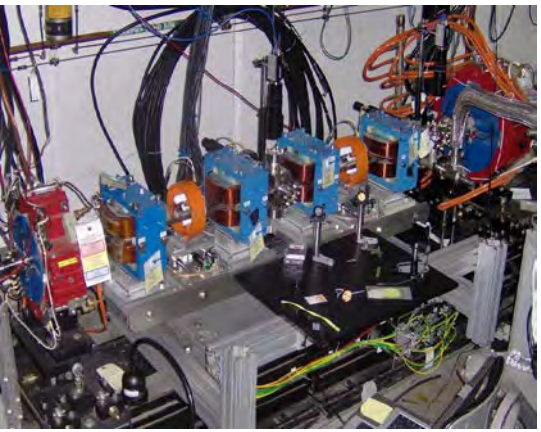
- Must preserve small correlations in phase space
- Sensitive to unwanted x-z coupling; higher-order effects
- Sensitive to incoherent synchrotron radiation and IBS
- Requires excellent laser stability

Echo Demonstration at SLAC

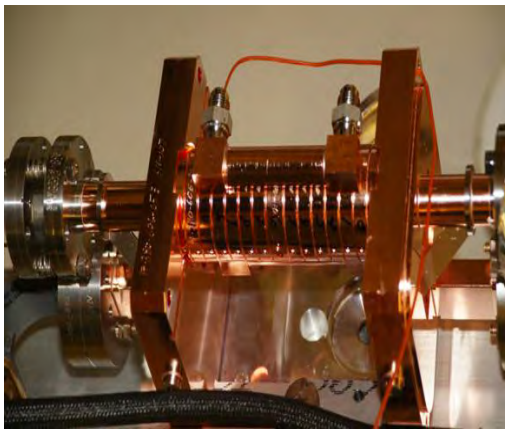
- Used existing NLC Test Accelerator for demonstration
  - Rf gun, high gradient rf and multiple laser systems pre-installed
  - Added 60 MeV acceleration, 3 chicanes (C0-C2), 3 undulators, and lots of diagnostics in 2010
  - Subsequently installed two TCAVs, VUV spectrometer and upgraded energy spectrometer



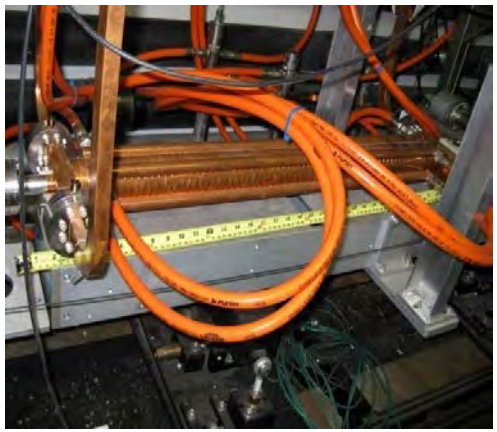
Hardware Fabricated for Echo



C1

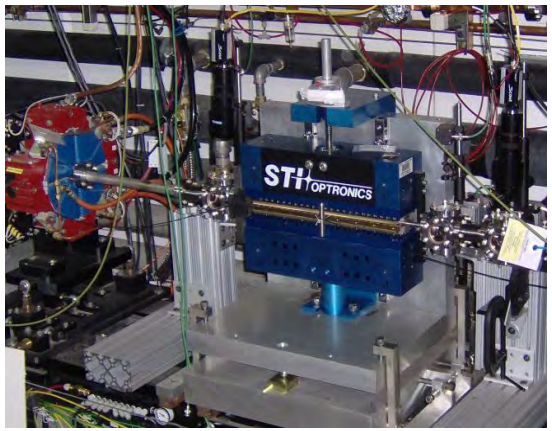


TCAV1



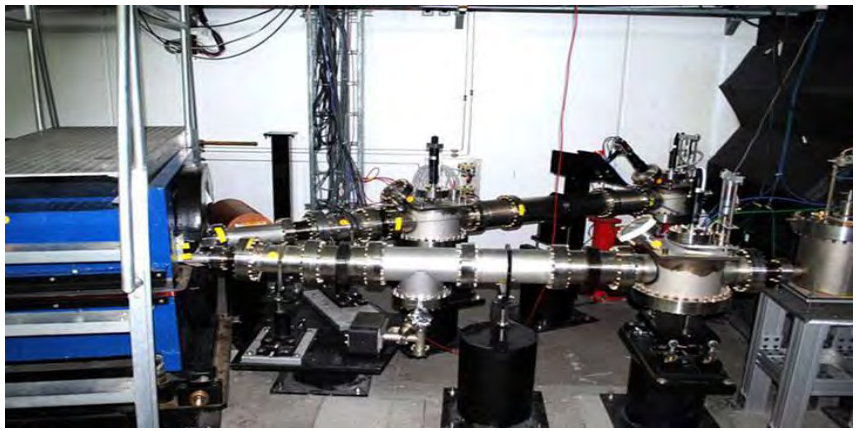
X2

TCAV2



U1

U2



spectrometer

Timeline for Echo Demonstration

10-08 Concept proposed

03-09 First studies of demo

06-09 Initial funding from LDRD

08-09 Undulators ordered

09-09 BES R&D funds received

11-09 H75 X-band structure inst.

12-09 120 MeV beam achieved

02-10 First undulator installed

04-10 Initial beamline complete

05-10 First harmonics seen

07-10 Clear evidence of 3rd and 4th harmonics due to EEHG

09-10 Began fabrication of TCAVs and upgrade of spectrometer

12-10 Energy spectrometer inst.

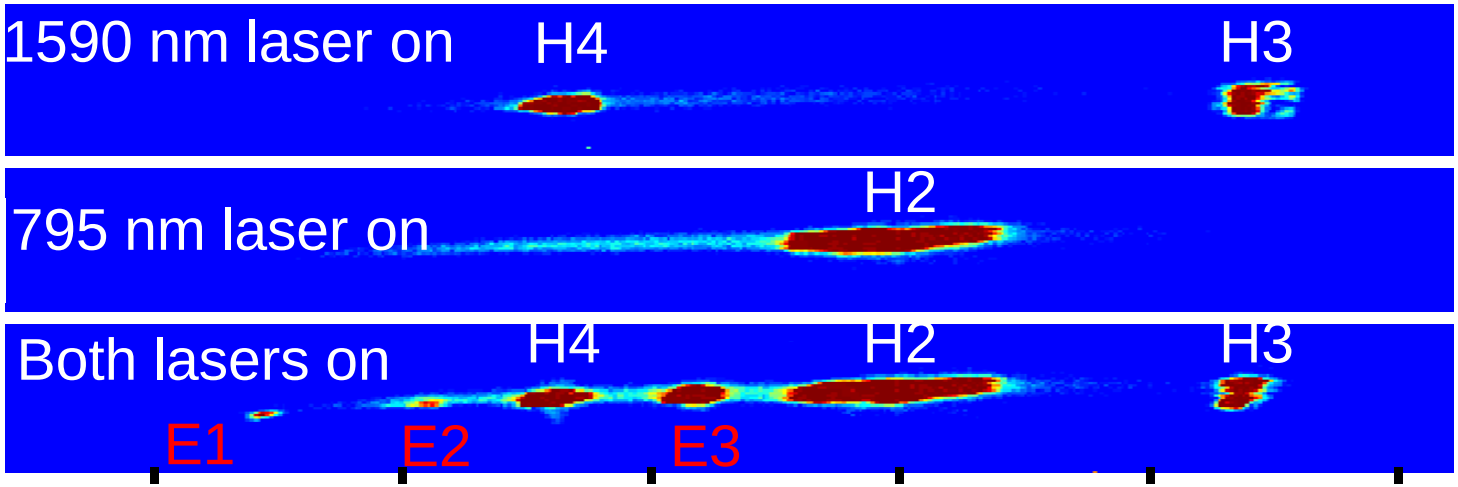
02-11 VUV spectrometer install.

03-11 Two TCAVs installed for diagnostic and energy modulation

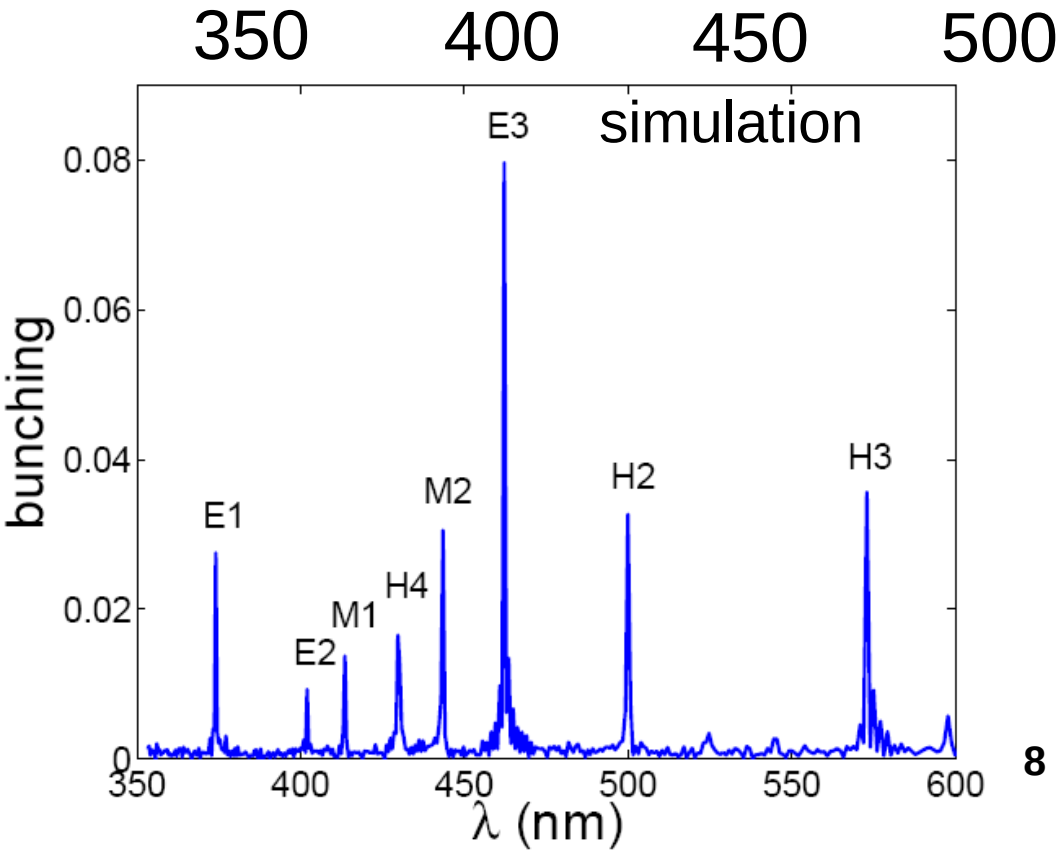
05-11 Measured 7th harmonic with large energy modulation

07-11 Measured 7th harmonic with small energy modulation

Echo Results (2010)



Observation of 4th harmonic due to EEHG confirmed by varying chirp



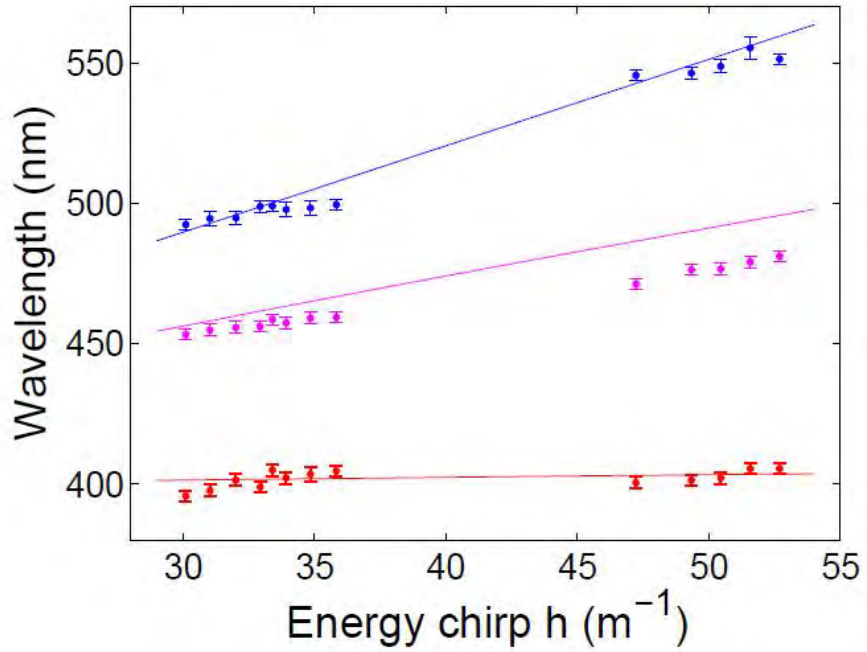
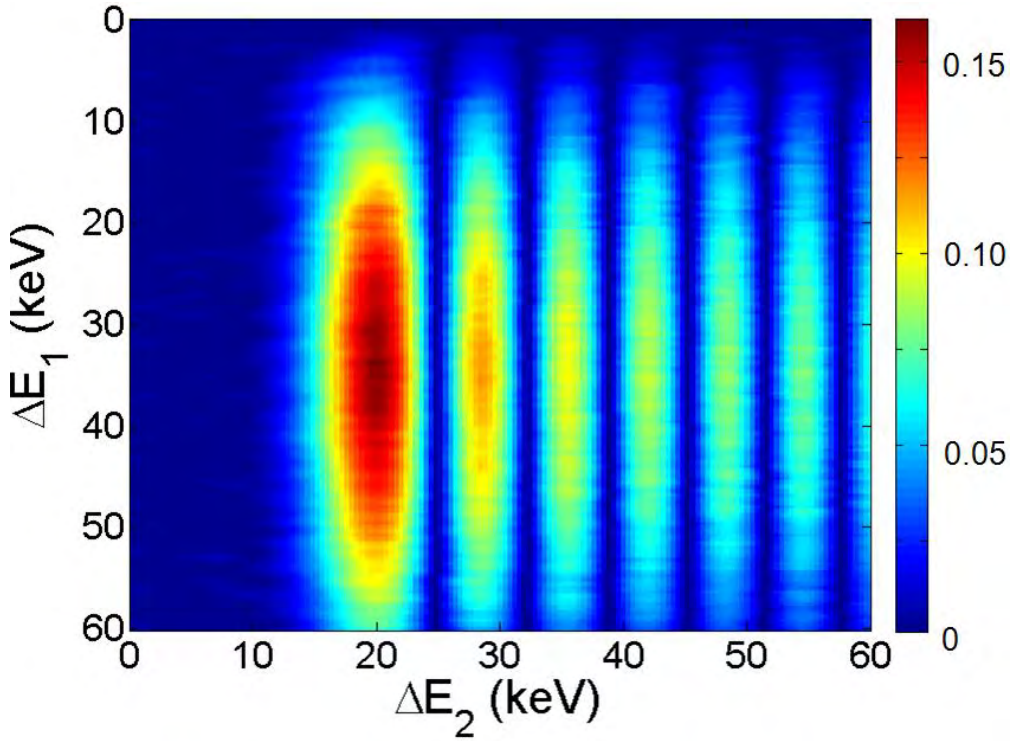


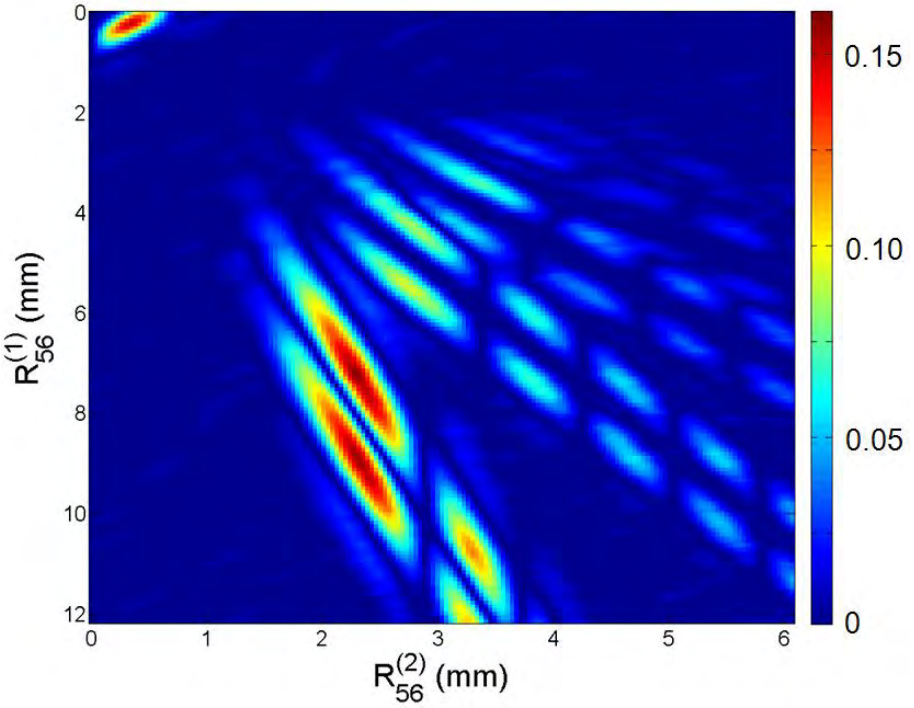
FIG. 5: Radiation wavelength vs beam energy chirp for the echo signal E2 (red), E3 (magenta) and that from the 795 nm laser alone H2 (blue).

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

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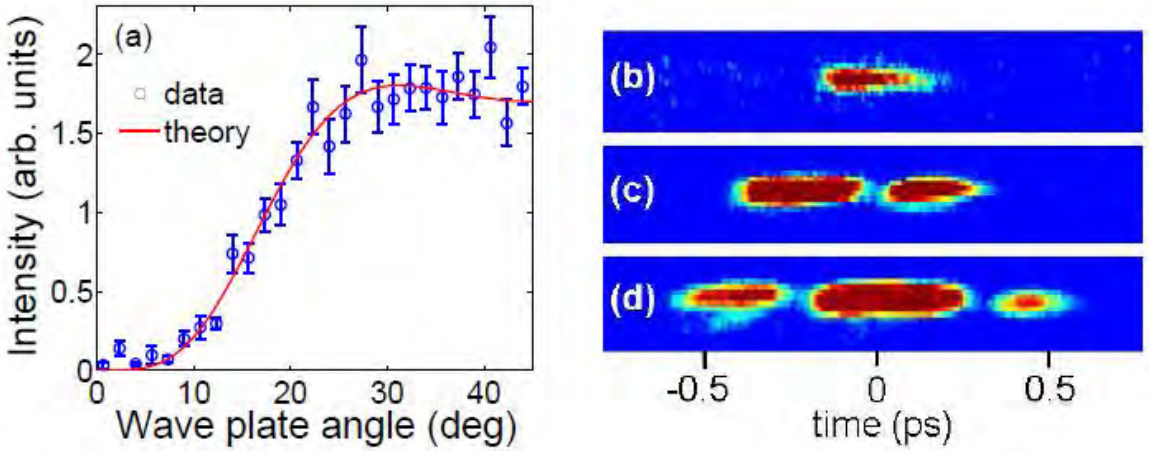
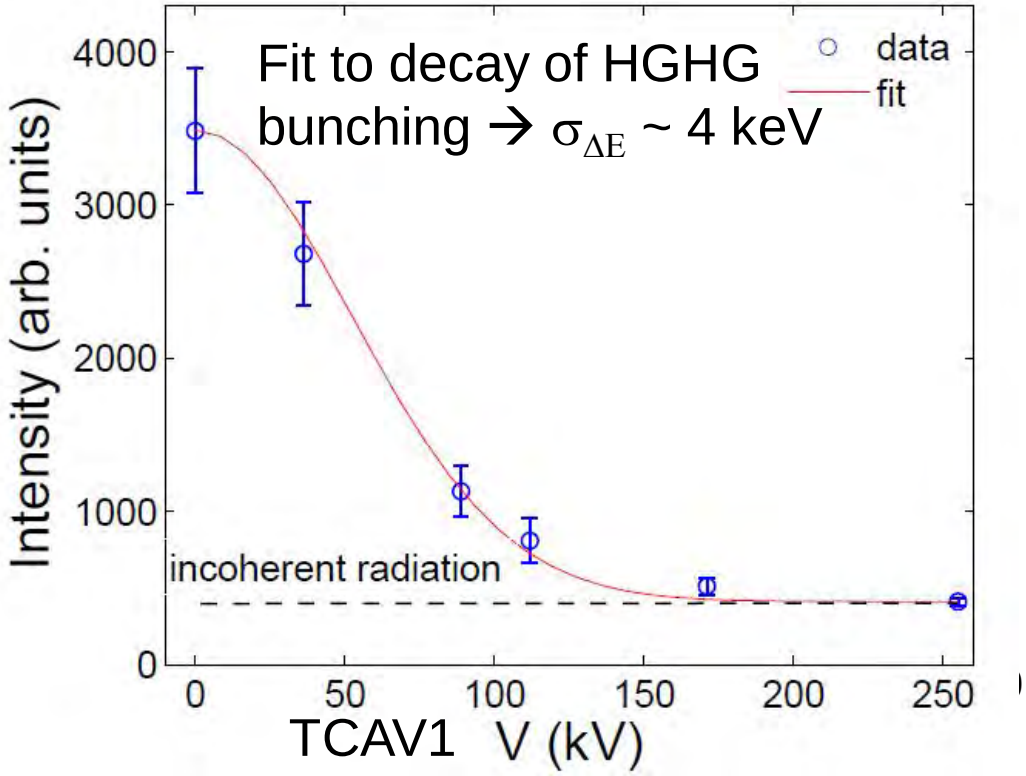
Large Energy Spread Results
(Intensity at 227 nm)

Laser modulation ~ 15 keV





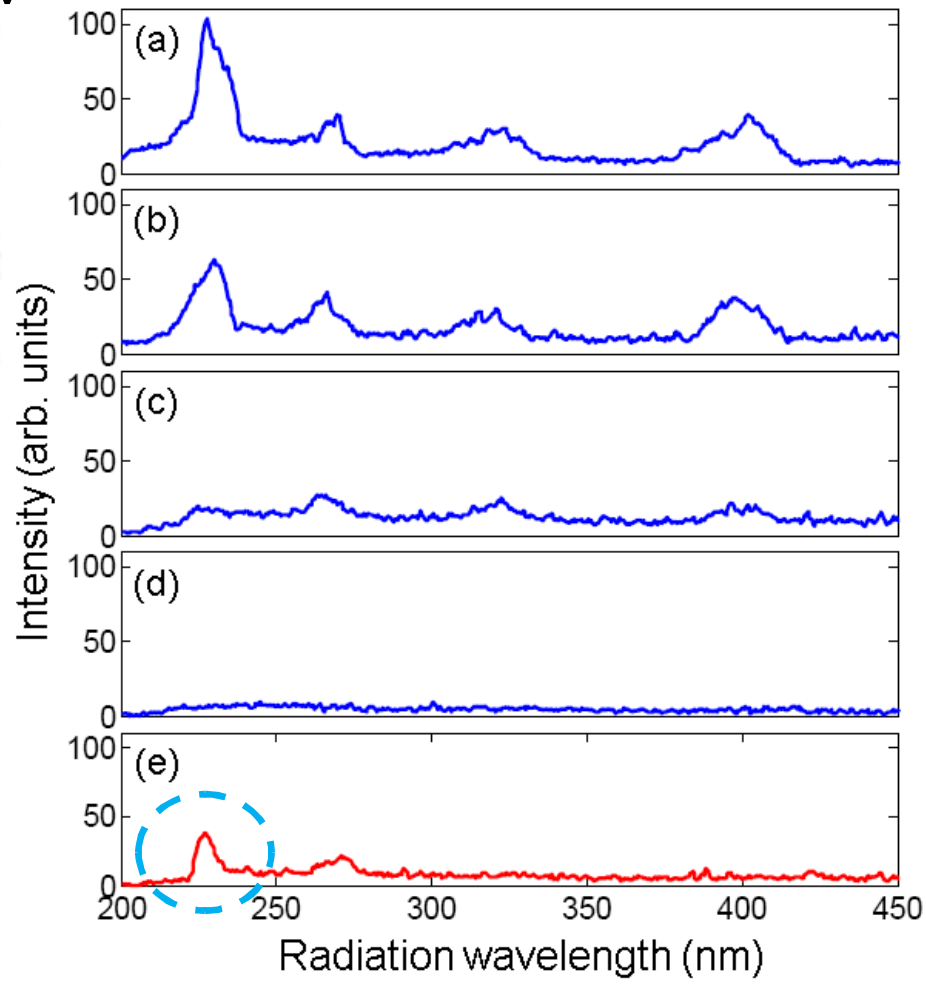


FIG. 4: Spectrum of the radiation for various TCAV1 voltage:(a) V=0; (b) V=85 kV; (c) V=170 kV; (d) V=255 kV. (a)-(d) are the case when only the 1590 nm laser is on and (e) is at V=255 kV with both lasers on.

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:

1. Evidence of High Harmonics from Echo-Enabled Harmonic Generation for Seeding X-ray Free Electron Lasers, **in preparation (2011).**
2. A novel diagnostic for measuring the laser modulation of the longitudinal phase space, **in preparation (2011).**
3. Triple modulator-chicane scheme for seeding sub-nanometer x-Ray free electron lasers.**Submitted to: New Journal of Physics (2011).**
4. Laser assisted emittance transfer for storage ring lasing. **Submitted to:** P**hys. Rev. ST Accel.B eams (2011).**
5. Longitudinal profile diagnostic scheme with subfemtosecond resolution for high-brightness electron beams. P**hys. Rev. ST Accel.B eams 14 (2011) 072802.**
6. Demonstration of the Echo-Enabled Harmonic Generation Technique for Short-Wavelength Seeded Free Electron Lasers. **Phys. Rev. Lett. 105 (2010) 114801.**
7. Longitudinal-to-transverse mapping for femtosecond electron bunch length measurement. **Phys. Rev. ST Accel. Beams 13 (2010) 094001.**
8. Laser Assisted Emittance Exchange: Downsizing the X-ray Free Electron Laser. **Phys.Rev.ST Accel. Beams 13 (2010) 010701.**
9. Generation of intense attosecond x-ray pulses using ultraviolet laser induced microbunching in electron beams. **Phys .Rev. ST Accel. Beams 12 (2009) 060701.**
10. Enhanced tunable narrow-band THz emission from laser-modulated electron beams. **Phys. Rev. ST Accel. Beams 12 (2009) 080701.**
11. Echo-enabled Harmonic Generation Free Electron Laser. **Phys.Rev.ST Accel. Beams 12 (2009) 030702.**

Conference Proceedings:

1. Observation and Characterization of Coherent Optical Radiation and Microbunching Instability in the SLAC Next Linear Collider Test Accelerator. PAC'11, SLAC-PUB-14451. (2011).
2. Commissioning the Echo-Seeding Experiment Echo-7 at SLAC. FEL'10, SLAC-PUB-14450. (2011).
3. Laser assisted emittance exchange. AIP Conf.Proc. 1299, 620-625 (2010).
4. Echo-Enabled Harmonic Generation. IPAC'10, SLAC-PUB-14438 (2010).
5. A Proof-of-principle Echo-enabled Harmonic Generation FEL Experiment at SLAC. IPAC'10, SLAC-PUB-14448, (2010).
6. Preliminary results of the echo-seeding experiment ECHO-7 at SLAC. IPAC'10, SLAC-PUB-14450, (2010).
7. Effects of energy chirp on echo-enabled harmonic generation free-electron lasers. SLAC-PUB-13547. (2009).
8. Tolerance Study for the Echo-Enabled Harmonic Generation Free Electron Laser. SLAC-PUB-13644. (2009).
9. Feasibility study for a seeded hard x-ray source based on a two-stage echo-enabled harmonic generation FEL. SLAC-PUB-13818. (2009).

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 7^{th} 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 15^{th} 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