Commissioning the Echo-Seeding Experiment ECHO-7 at NLCTA

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for the
ECHO-7 team

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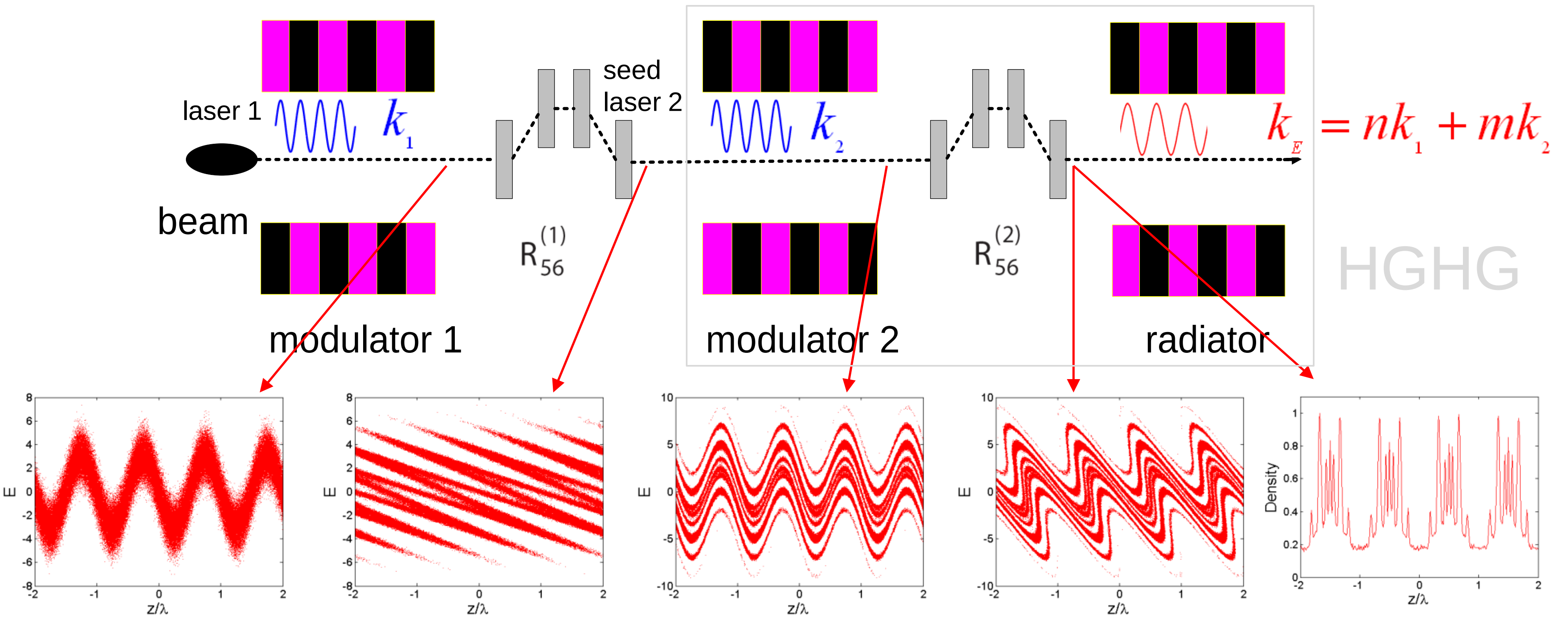
Outline

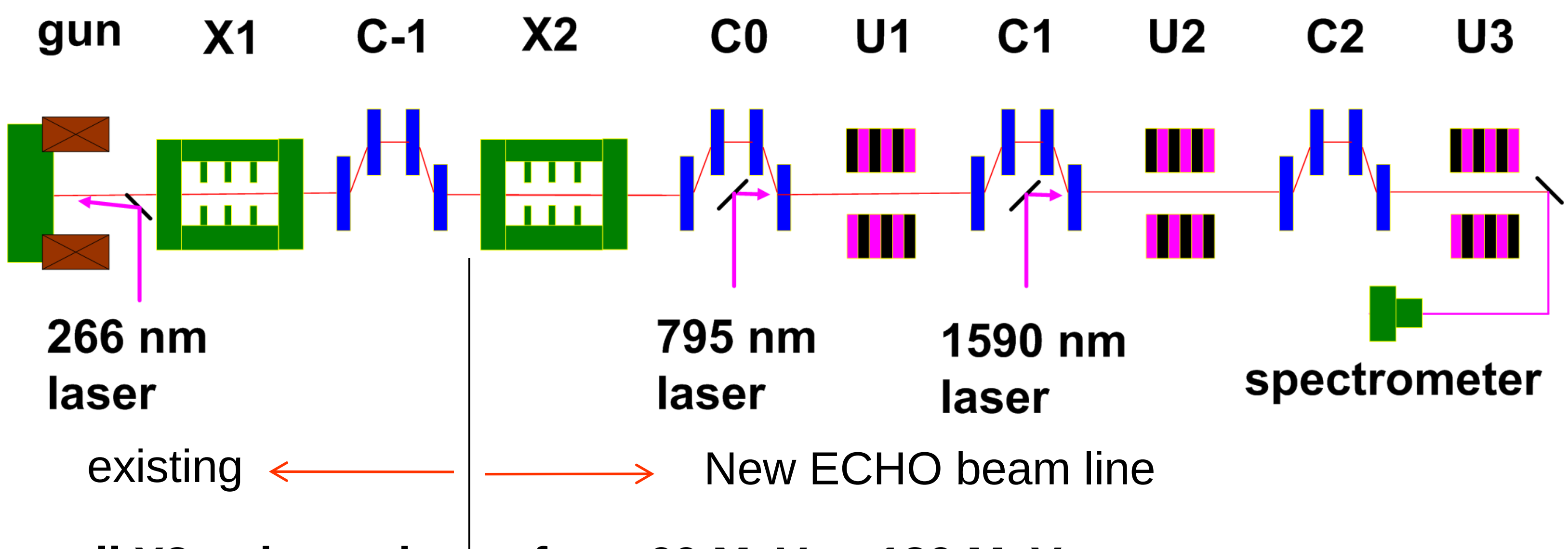
- The echo enabled harmonic generation (EEHG or echo) FEL: extends the high gain high harmonic (HGHG) concept
- Commissioning milestones for the Echo-7 experiment at the Next Linear Collider Test Accelerator (NLCTA) at low harmonics n<5
- Echo-7 first results
- Conclusion and outlook

Echo enhanced harmonic generation (EEHG)



- First laser to generate energy modulation in electron beam
- First strong chicane to split the phase space
- Second laser to imprint certain correlations
- Second chicane to convert correlations into density modulation
- Experimental challenge: preserve phase space topology

ECHO-7 at NLCTA



- Install X2 to boost beam from 60 MeV to 120 MeV
- Laser transport
- Construction of three undulators, three chicanes
- Add new or move existing quadrupoles, correctors, etc.
- New power supplies
- New diagnostics: OTRs, YAGs, cameras, movers, spectrometer, DAQ

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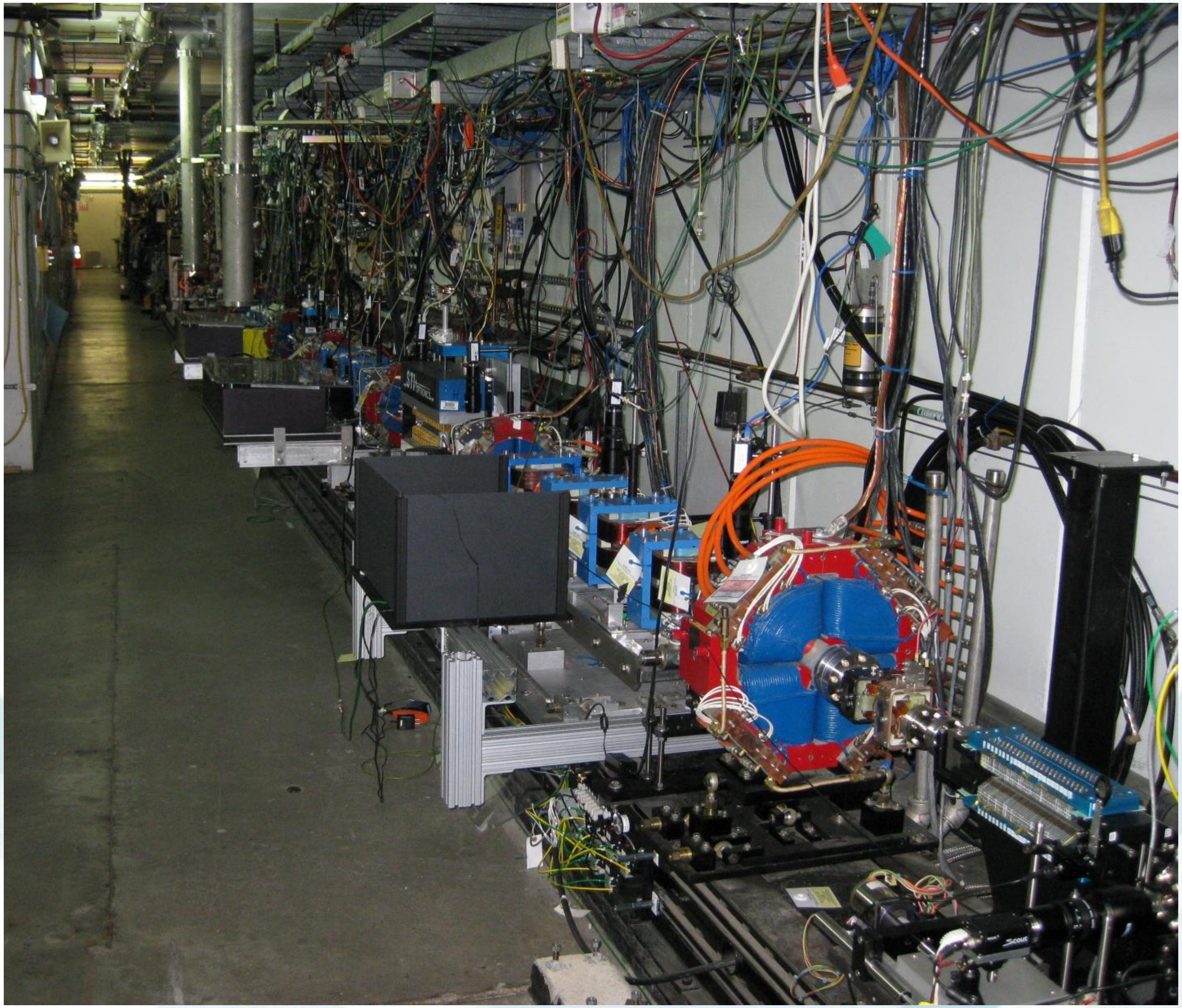
Upstream view



ECHO-7 at NLCTA

- **Milestones**
  - **03-2009: First planning meeting**
  - **06-2009: LDRD funded**
  - **08-2009: Undulators ordered**
  - **09-2009: BES Funding arrived / First chicane installed**
  - **12-2009: 120 MeV beam achieved**
  - **02-2010: First undulator installed**
  - **04-2010: 795 nm laser-electron interaction achieved**
  - **05-2010: 1590 nm laser-electron interaction achieved**
  - **05-2010: First harmonic radiation observed**
  - **7-2-2010: First echo signal**

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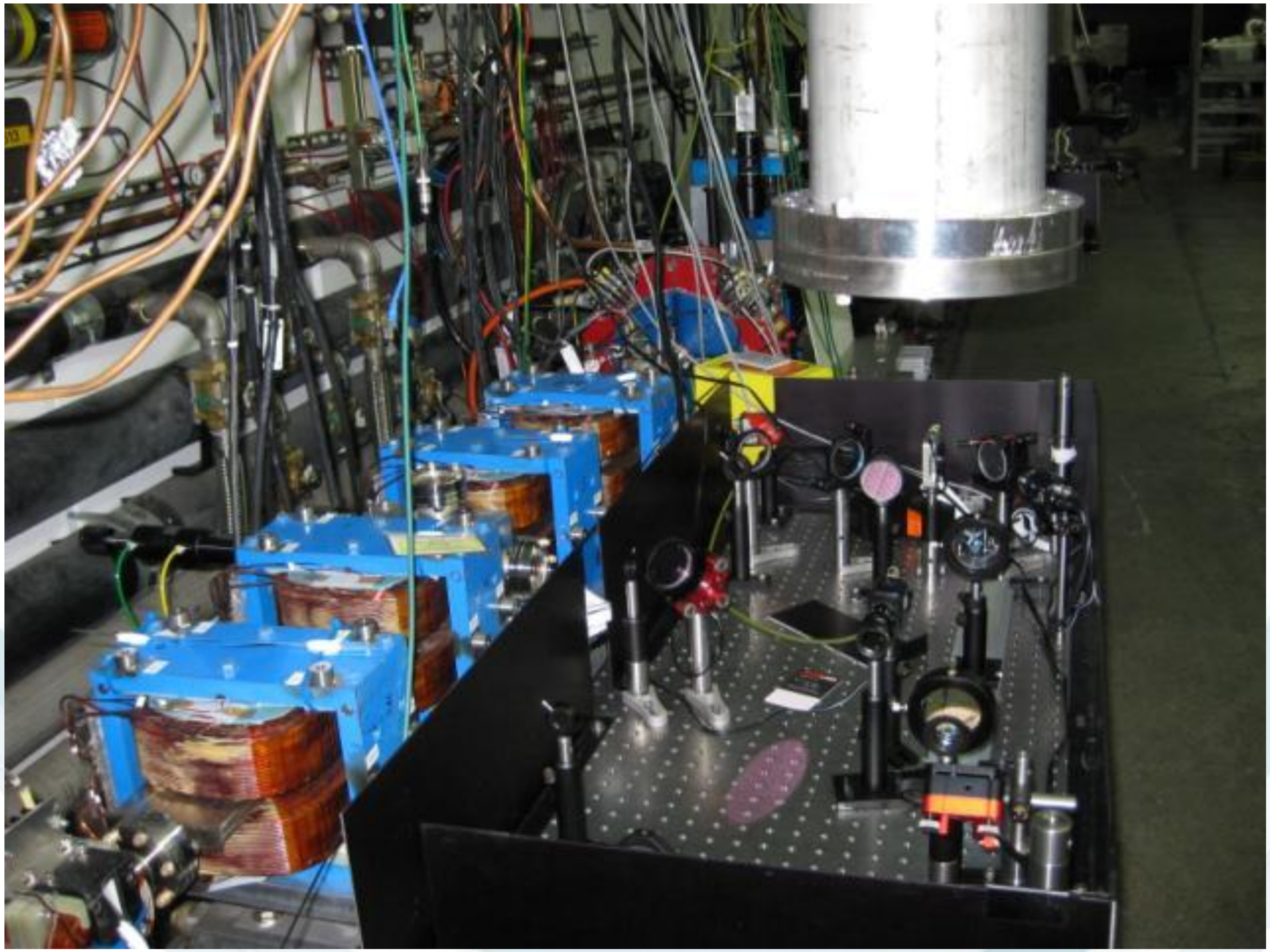
ECHO-7 at NLCTA

- **Milestones**-2-2010: First echo signal



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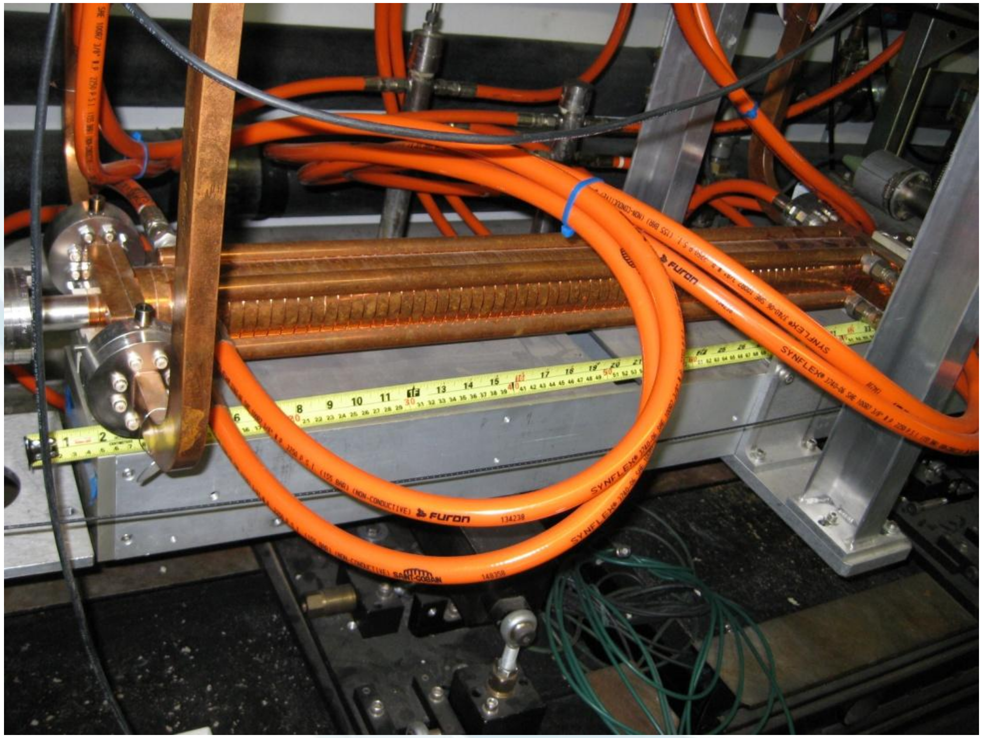
- **Milestones**



X2 X-band
Length: 75 cm
Operating gradient: 80 MV/m
Max gradient: 100 MV/m

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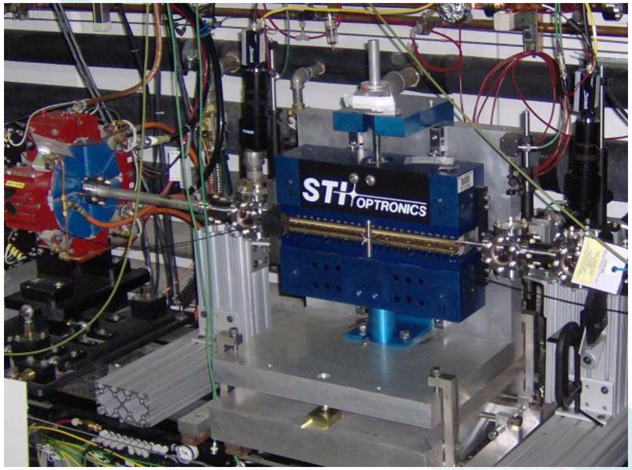
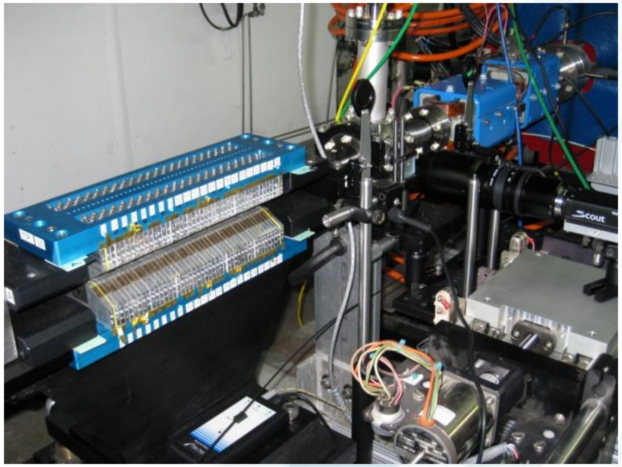
- Milestones
  - U1, U2 STI Optronics
  - U3 LBL with adjustable gap
  - Pneumatically actuated OTR profile monitors





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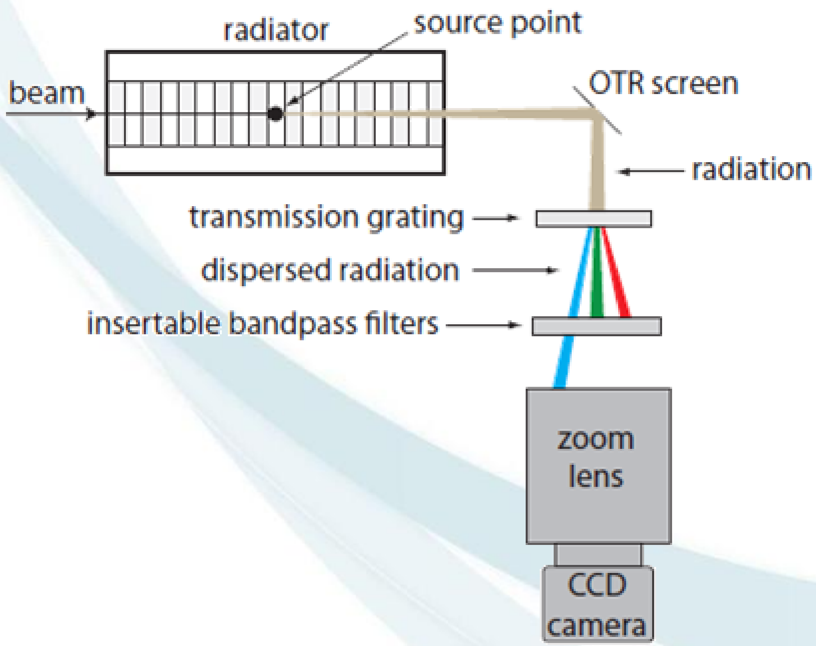
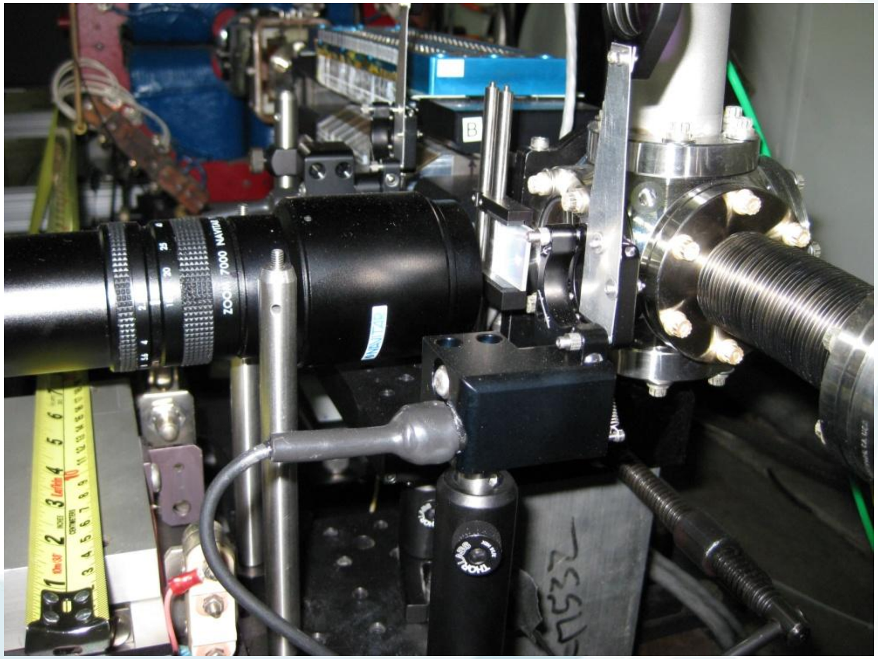
Parameters of ECHO-5 (July 2010)

Beam Energy	120 MeV	
Bunch length	0.5 -2.5 ps	
Normalized Emittance	8 mm-mrad	
Bunch charge	20-40 pC	
Laser wavelength in U1	795 nm	NIR
Laser wavelength in U2 (seed)	1590 nm	IR
Slice energy spread	~ 1 keV	
$N_p \times \lambda_u$ for U1	10 x 3.3 cm	K=1.82
$N_p \times \lambda_u$ for U2	10 x 5.5 cm	K=2.09
$N_p \times \lambda_u$ for U3	10 x 2 cm	K=1.23
Peak energy modulation in U1 and U2	10-40 keV	
R_{56} for C1 and C2	1.0 ~ 9.0 mm	
Radiation wavelength in radiator	>318 nm	ECHO-5

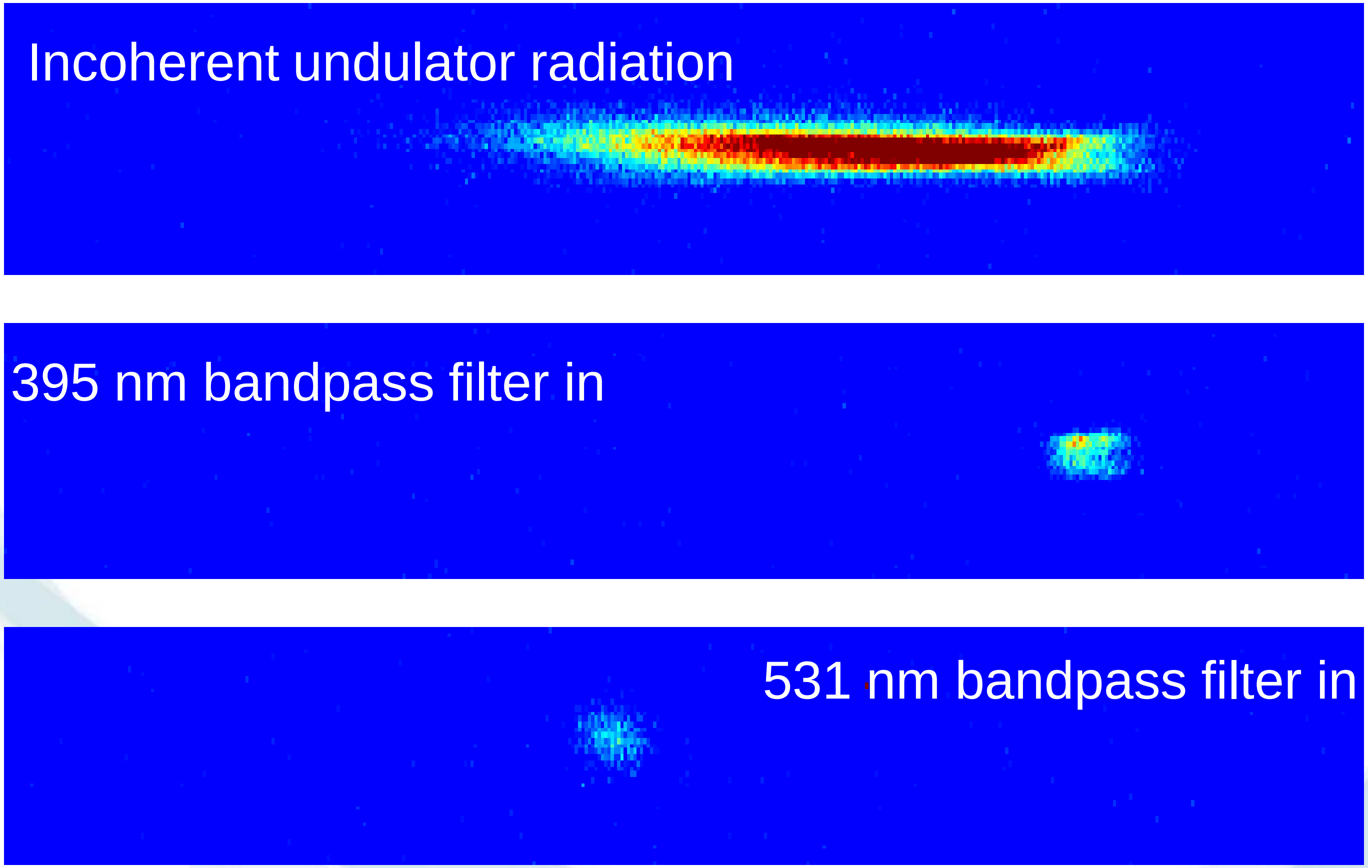
Radiator Spectrum

- Undulator radiation /OTR with UV window
- Transmission grating: 300 lines/mm
- Insertable bandpass filters 395 and 531 nm, 11 nm BW
- CCD camera





Wavelength calibration



The radiation spectrum [350, 600] nm can be measured in a single shot

HGHG/EEHG predictions 350-600 nm

	795	1590	Radiator (nm)	
HGHG	n=2		397	observed
HGHG		n=3	530	observed
HGHG		n=4	397	observed
EEHG	n=-1	m=5	530	?
EEHG	n=-1	m=6	397	?

- **Difficult to distinguish HGHG from EEHG for this range**
- **Somehow need to kill the 1590 nm HGHG contribution to 530 nm radiation**
- **795 laser does not have harmonic content at 530 nm**

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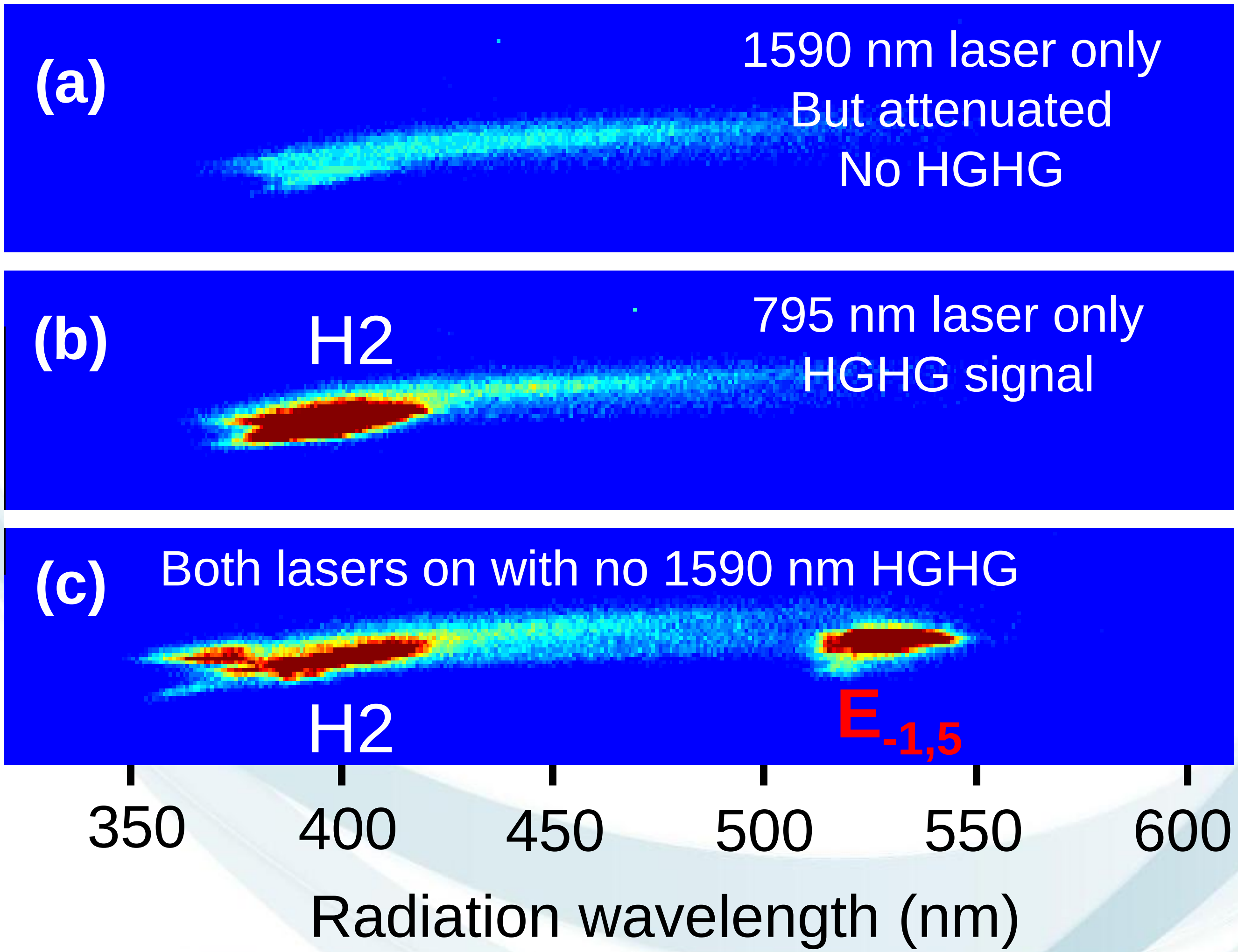
Experimental strategy

	795	1590	Radiator (nm)	
HGHG	n=2		397	
~~HGHG~~		~~n=3~~	~~530~~	
HGHG		n=4	397	
EEHG	n=-1	m=5	530	observed!
EEHG	n=-1	m=6	397	?

- **Establish the HGHG 1590 nm setup**
- **Reduce 1590 modulation strength until HGHG signal disappears @ 530**
- **Turn on 795 nm interaction and see if 530 nm reappears**

First ECHO signal!



Separating EEHG from HGHG

- **Theory predicts spectra shift differently for HGHG and EEHG in the presence of an energy chirp*** $h = d\delta/dz$

HGHG

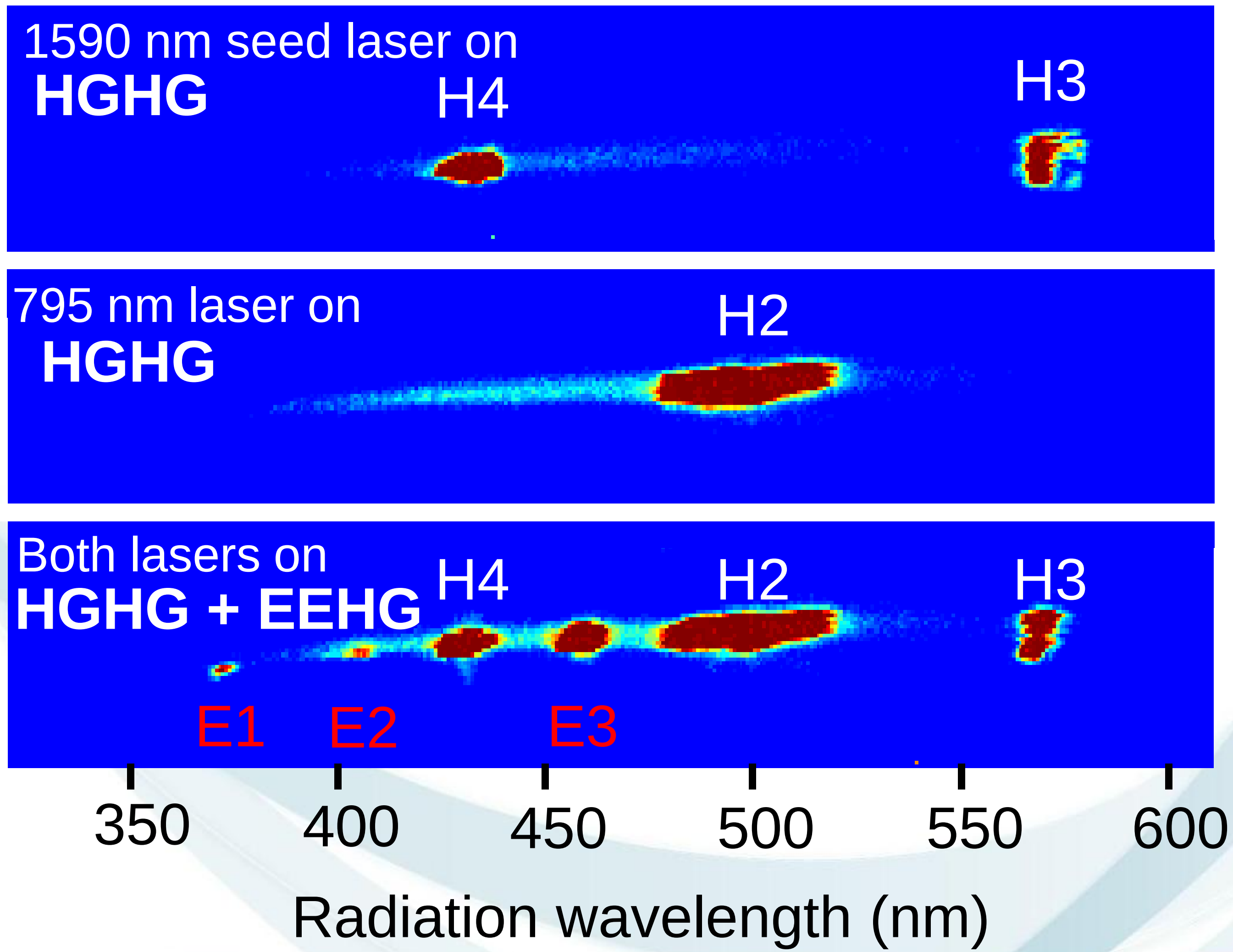
$$k_H = k_0 C \qquad C = 1/(1 + hR_{56})$$

EEHG

$$k_E(h) = \frac{nk_1 + (1 + hR_{56}^{(1)})mk_2}{1 + h(R_{56}^{(1)} + R_{56}^{(2)})}$$

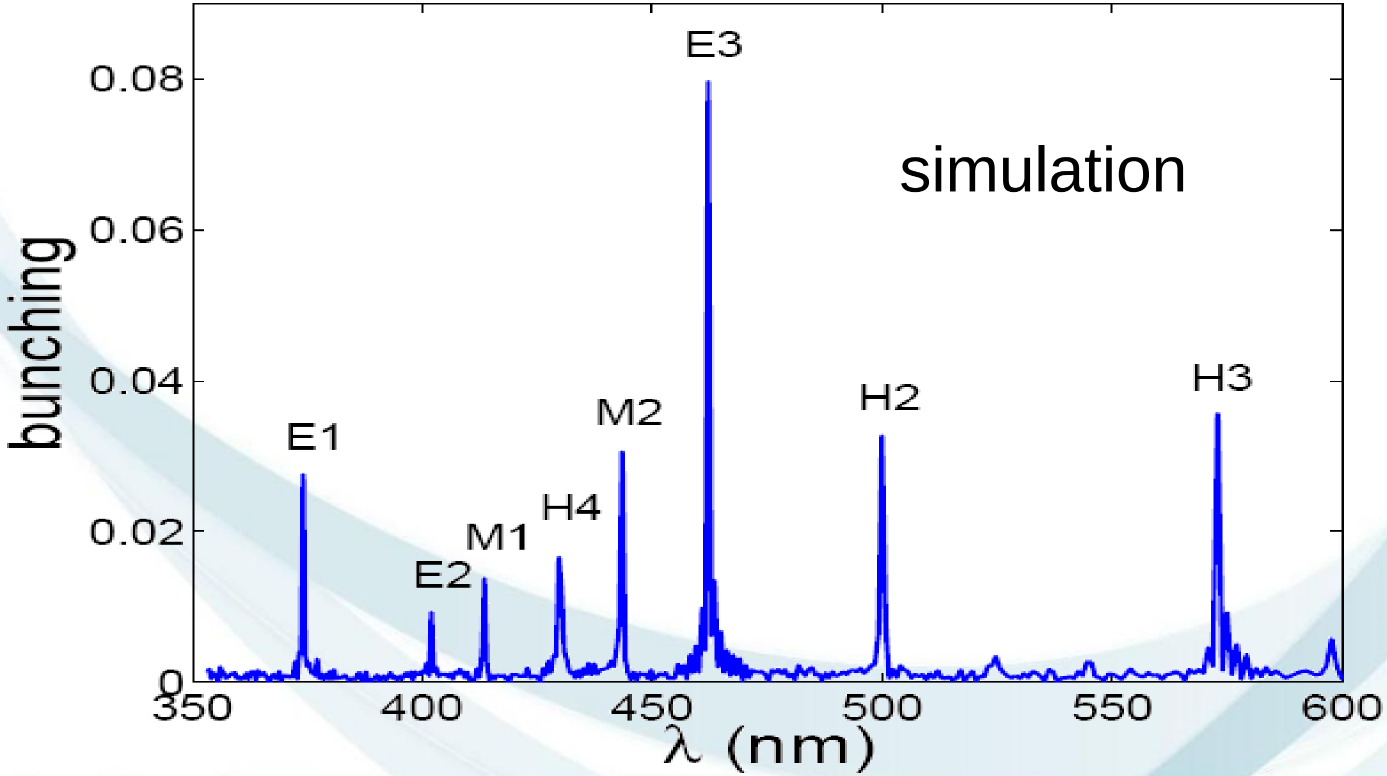
* Z. Huang et al., FEL09

ECHO signals when beam has an energy chirp

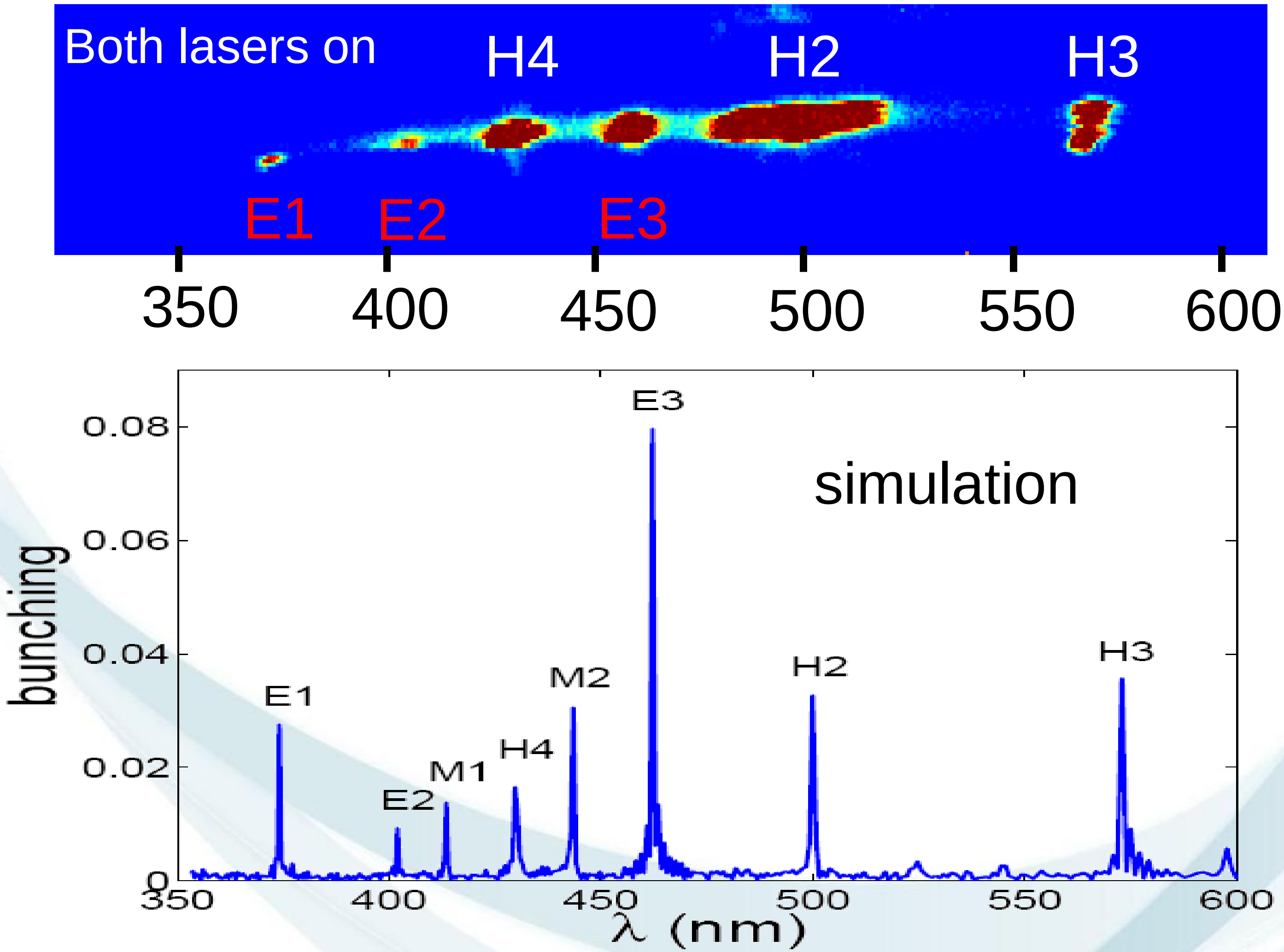


Separating EEHG from HGHG: simulation

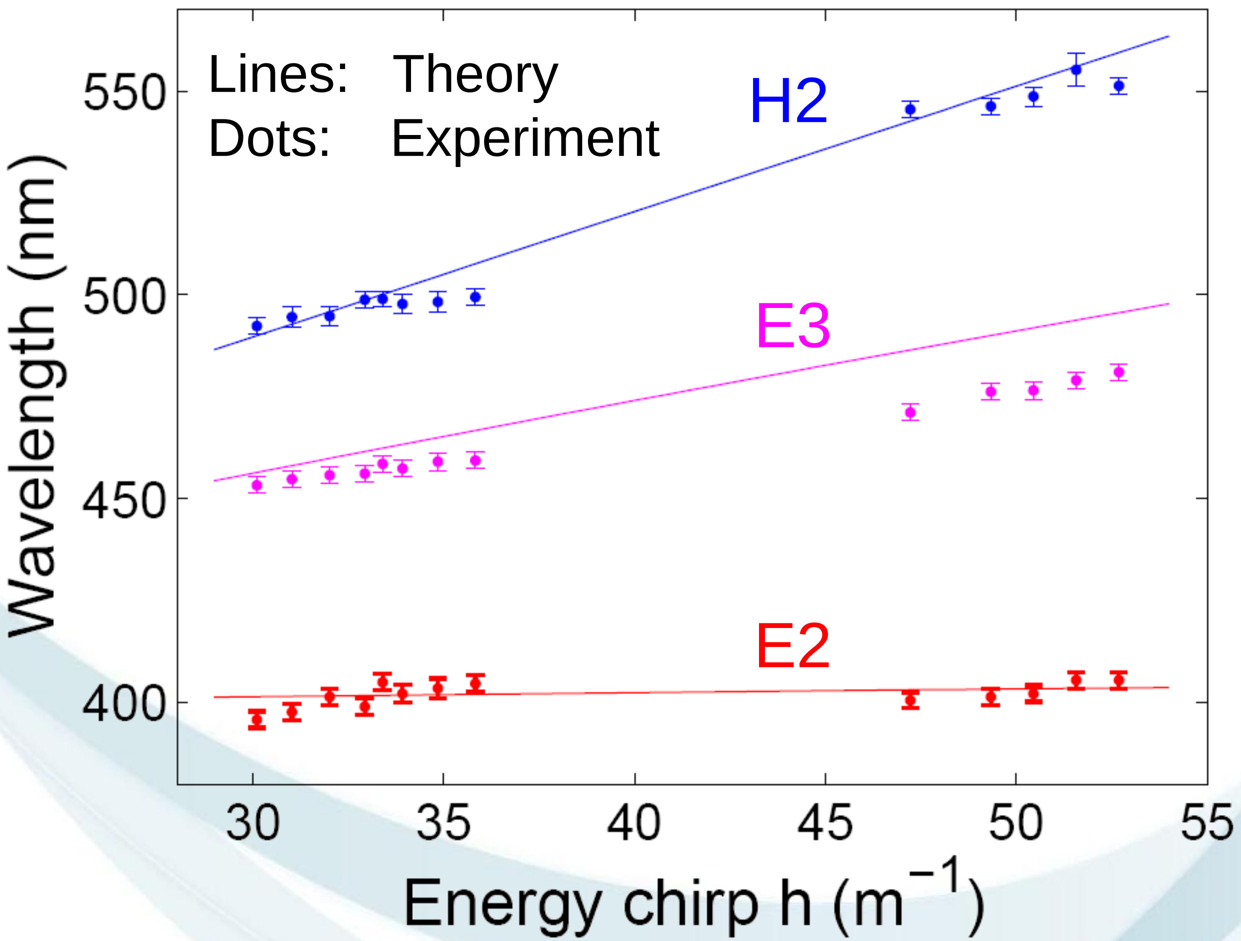
- For a chirp $h \sim 33.4\ \mathrm{m}^{-1}$ the HGHG (H) and EEHG (E) simulation shows signals become distinct. (M) are 'mystery echo peaks'
- Such a chirp is applied by moving X2 phase by ~10 degrees



ECHO signals when beam has an energy chirp



Radiation wavelength vs. beam energy chirp



Conclusion and outlook

- **Experimental verification of the EEHG scheme n<5**
  - **About one year from inception to execution**
  - **Some basic physics verified for lower harmonics**
    - **HGHG overwhelms echo signal at low harmonics**
    - **Phase space correlations are preserved**
    - **Energy chirp prediction confirmed**
- **Upgrades and diagnostics aimed at demonstrating the EEHG concept at n = 7~15 AND benchmark the codes so that we can predict performance at much higher harmonic number.**
  - **UV optics**
  - **New RF gun cathode and laser**
  - **Improve and characterize beam quality**
  - **Transverse deflecting cavity**

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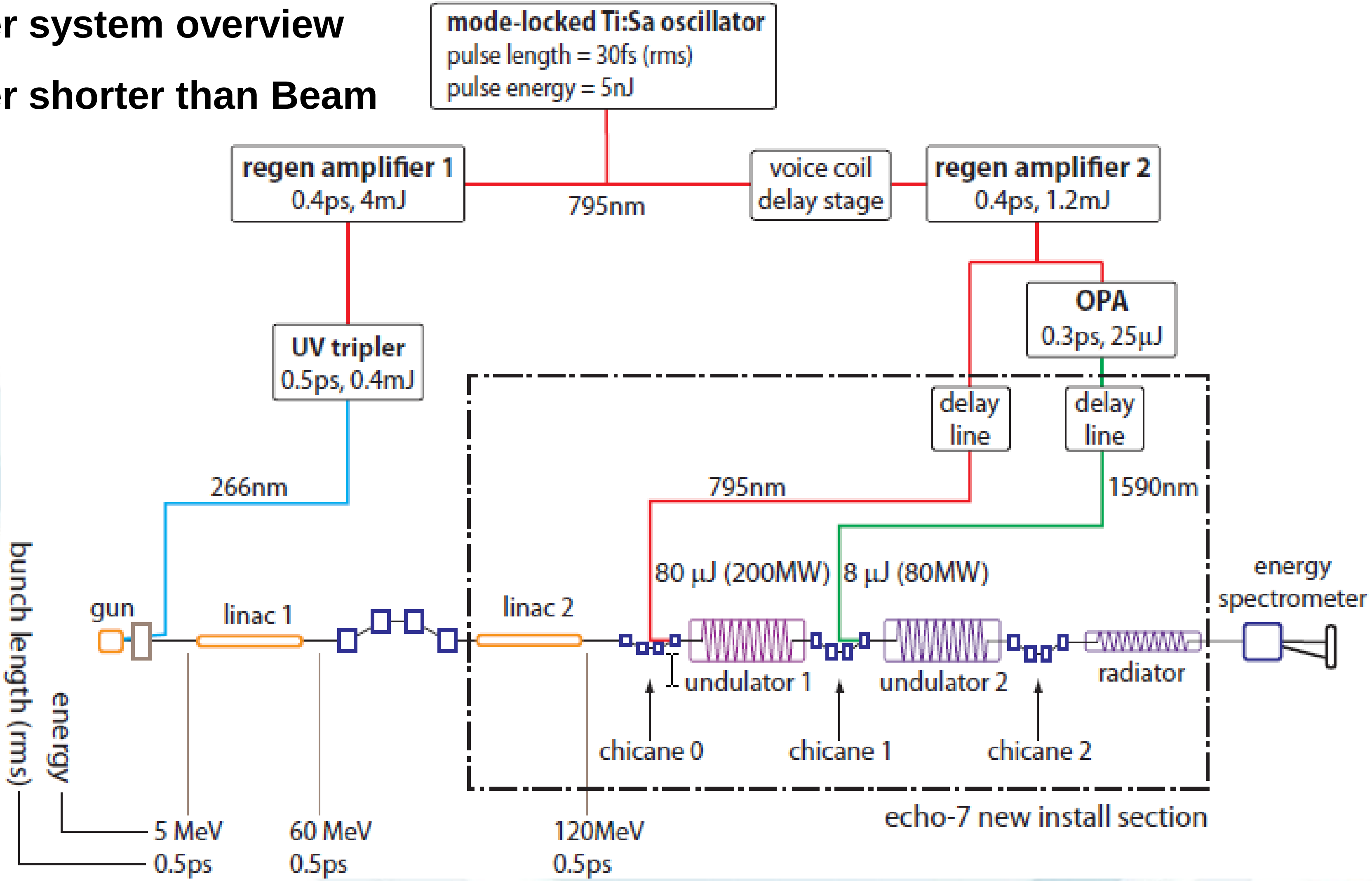
- Laser system overview
- Laser shorter than Beam



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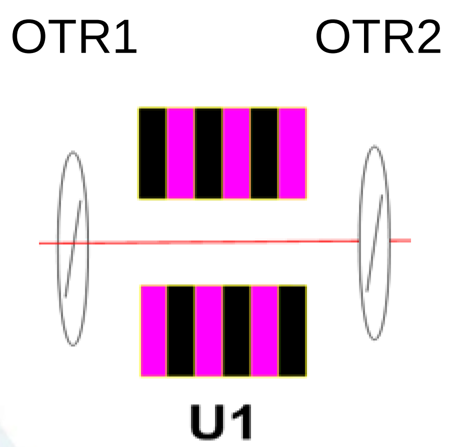
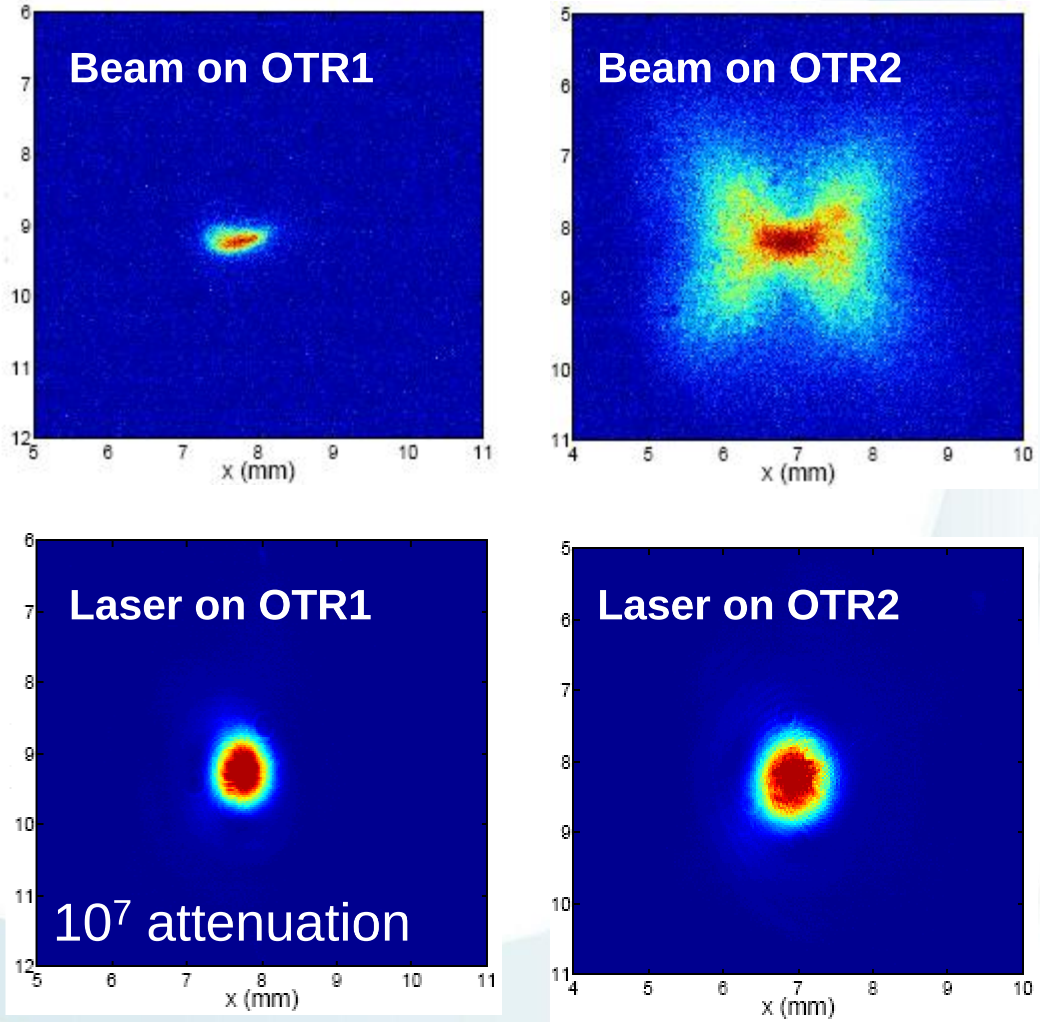
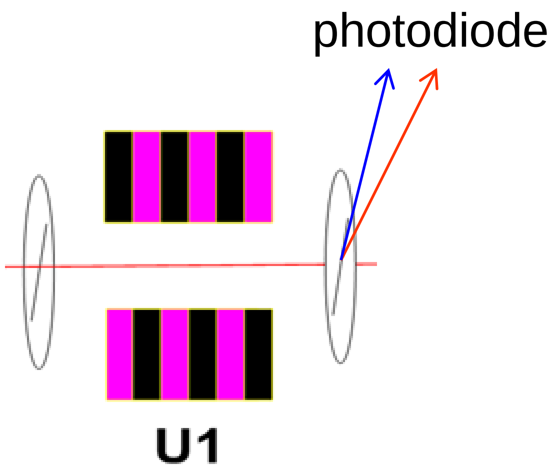
Spatial overlap



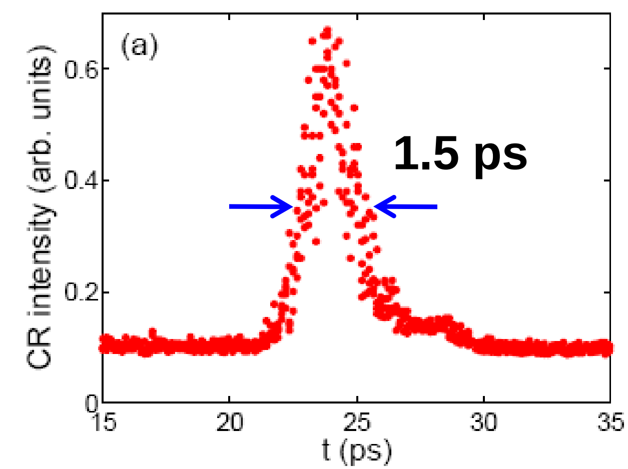
The spatial overlap is achieved by steering the laser to the same position as the electron beam on the OTR screens upstream and downstream of the undulators



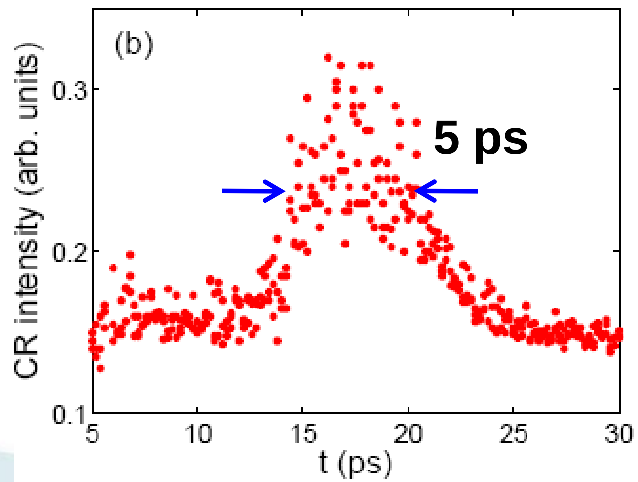
Temporal overlap



- The laser and undulator radiation are reflected out by the OTR screen and detected by a fast photodiode.
- Scan delay stage to finely adjust the laser timing until the COTR enhancement is observed.



Beam on crest in X1



Beam off crest in X1