Evidence of High Harmonics from Echo-Enabled Harmonic Generation for Seeding X-ray FELs

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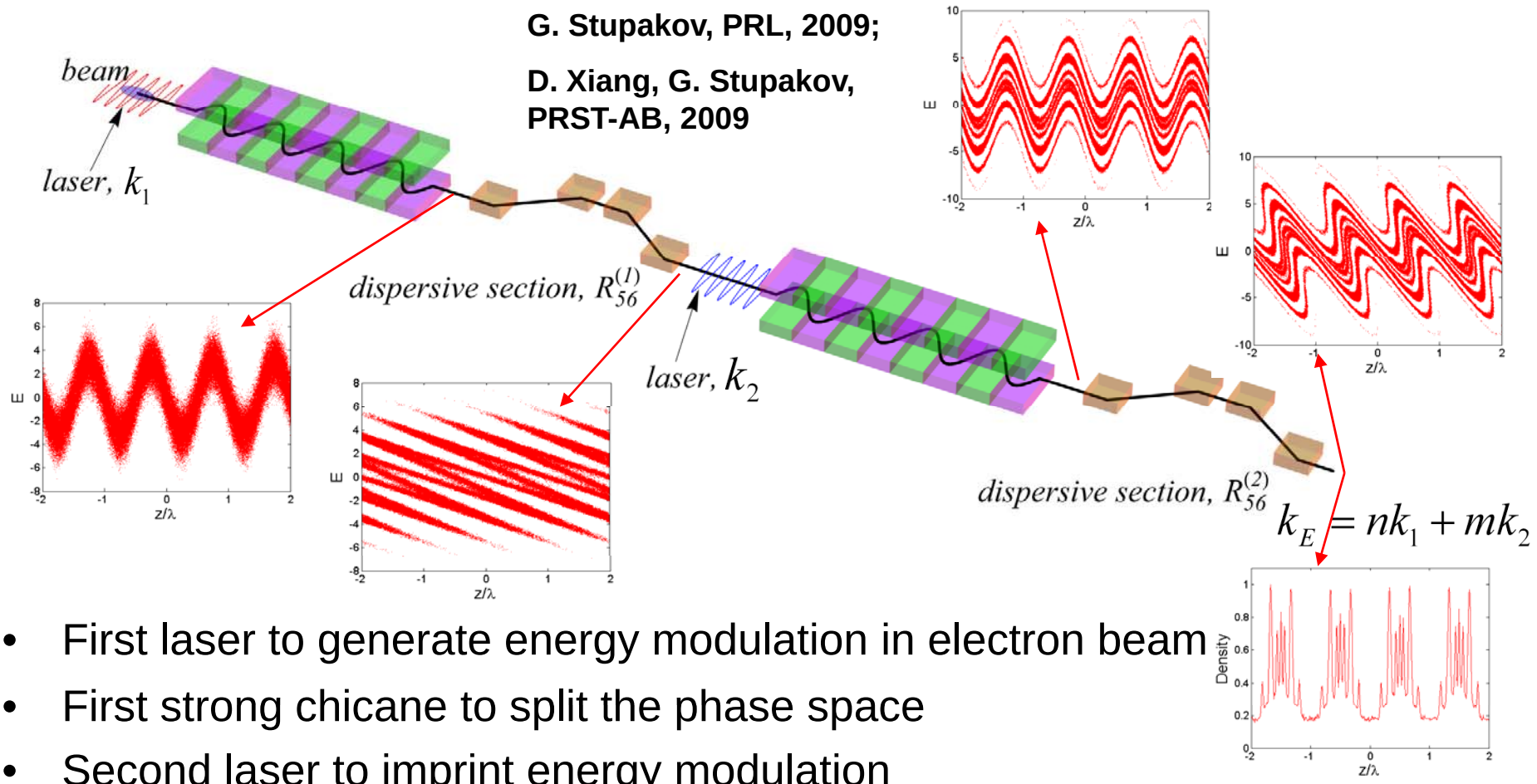
Echo-Enabled Harmonic Generation (EEHG)

G. Stupakov, PRL, 2009;

D. Xiang, G. Stupakov, PRST-AB, 2009

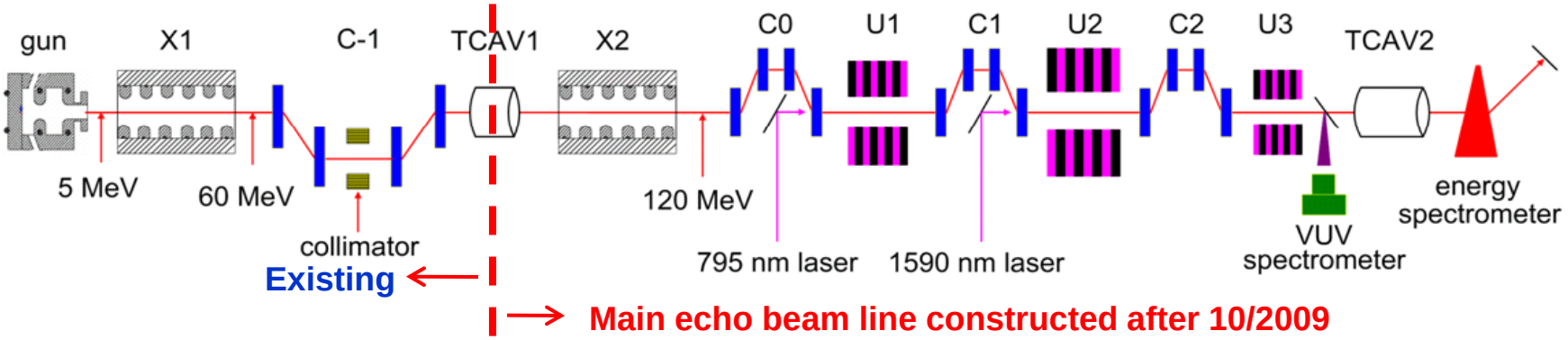


- First laser to generate energy modulation in electron beam
- First strong chicane to split the phase space
- Second laser to imprint energy modulation
- Second chicane to convert energy modulation into density modulation

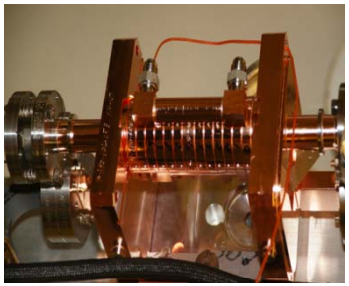
EEHG FEL: Promises and Challenges

- **Promises**
  - **High frequency up-conversion efficiency: $b_n \sim n^{-1/3}$**
  - **High harmonics from small energy modulation**
  - **UV laser -> soft x-rays in a single stage**
  - **Wide interest: China / France / Italy / Switzerland / UK / USA**
- **Challenges**
  - **Preservation of long-term (~ns) memory of phase space correlations**
  - **CSR/ISR in chicanes**
  - **Intra-beam scattering**
  - **2nd order effect**

Echo-7 experiment at NLCTA



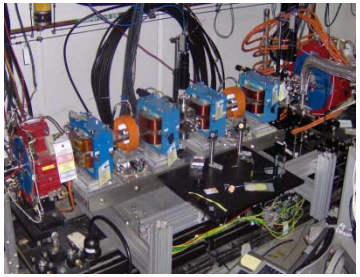
C-1



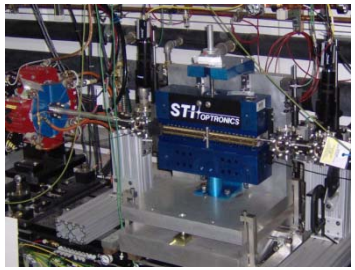
TCAV1

X2

TCAV2

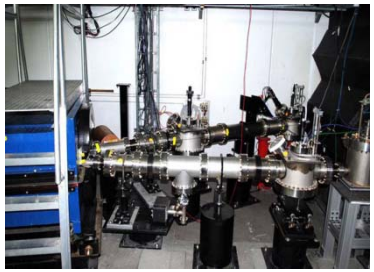


C1



U1

U2



spectrometer

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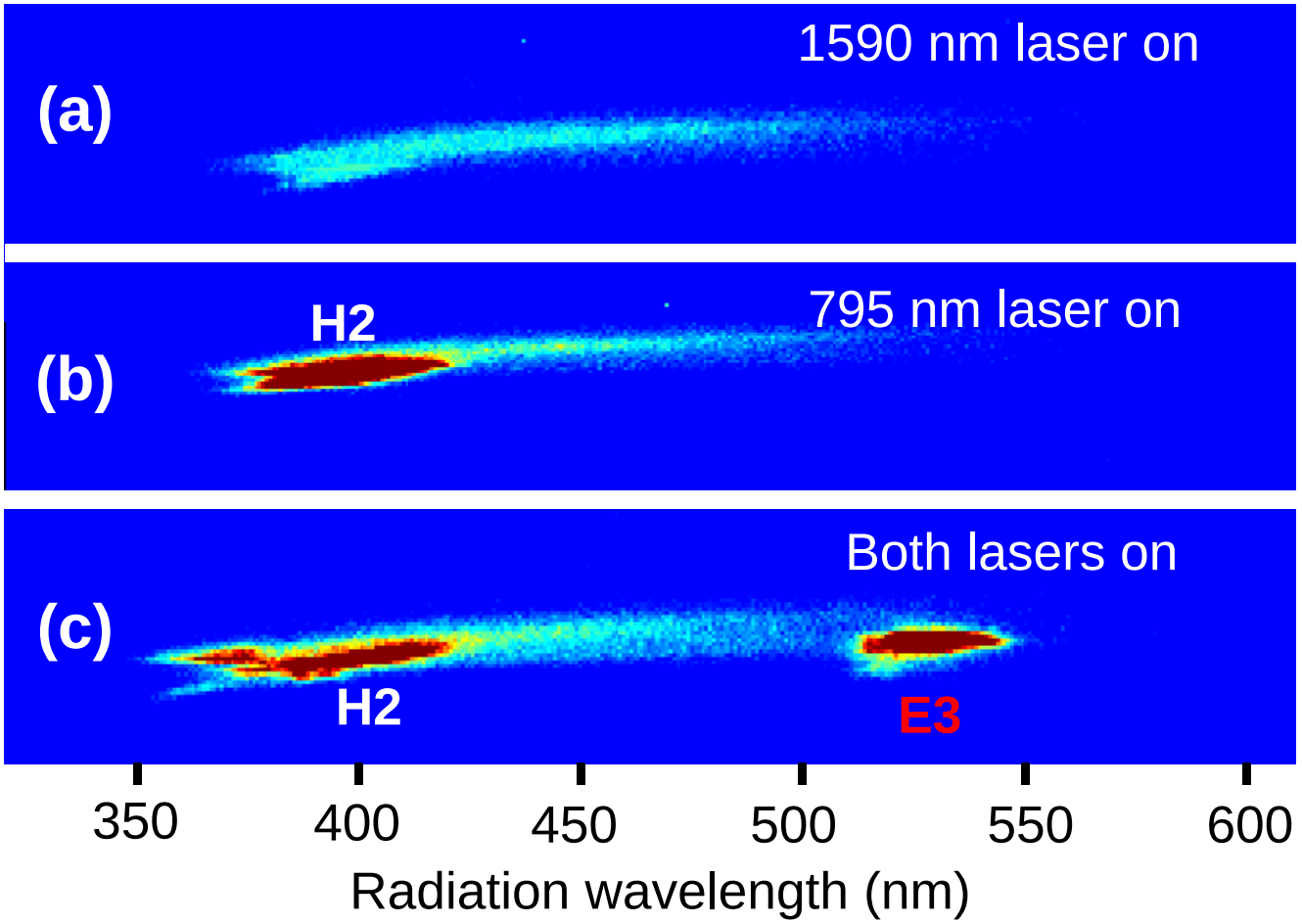
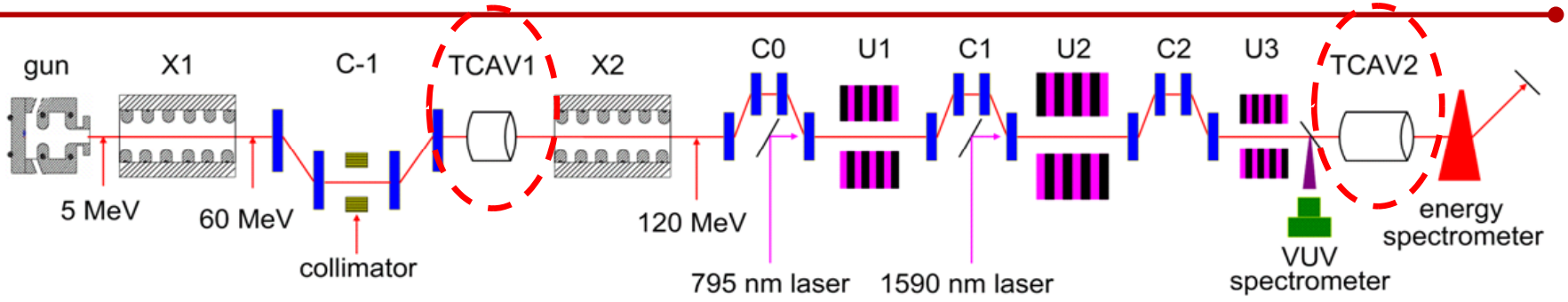
First unambiguous Echo signal

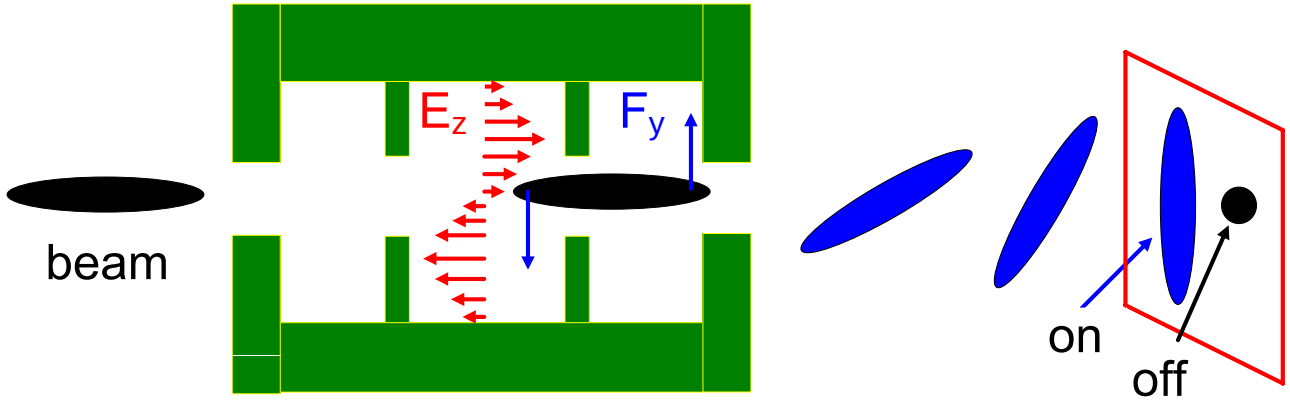


D. Xiang *et al.*, PRL, 2010; Featured in Nature Photonics "News & Views"

EEHG in the realistic scenario



- Typically a 'laser heater' is used to increase beam slice energy spread
- RF transverse cavity used to increase slice energy spread



$$\delta = k\sigma_x$$

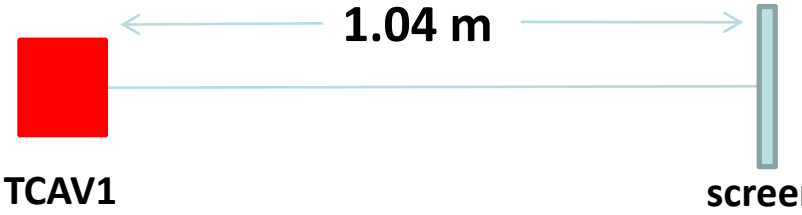
$$k = \frac{2\pi eV}{\lambda_{RF} E}$$

WEPB15, C. Behrens, Z. Huang and D. Xiang, 'Reversible heater based on TCAV'

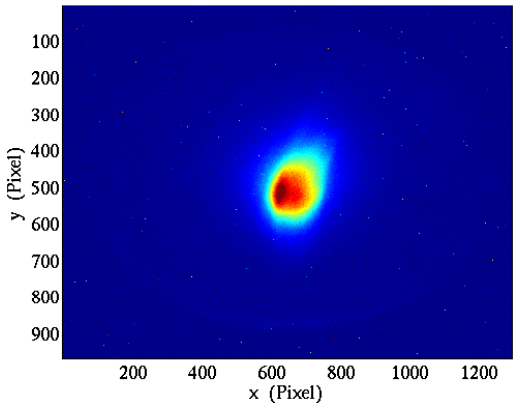
Measuring slice energy spread

Slice energy spread growth $\delta = k\sigma_x$

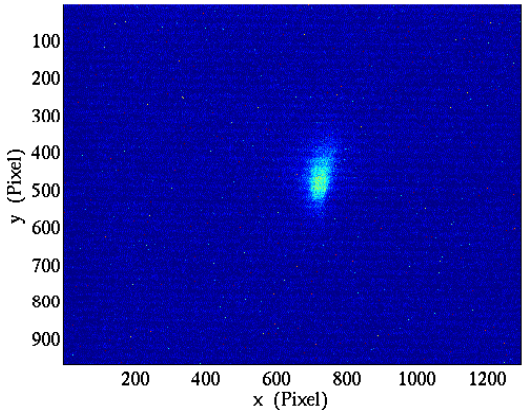
- **Measure kick strength by operating beam at on-crest phase**



- **Measure slice beam size with a collimator in chicane C-1**



Projected beam size



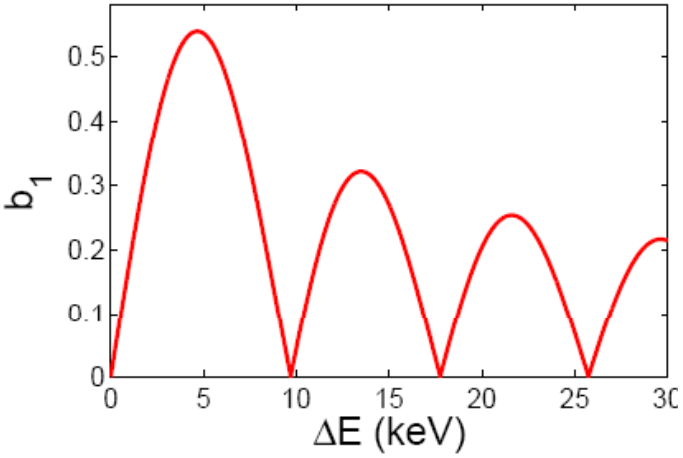
Slice beam size

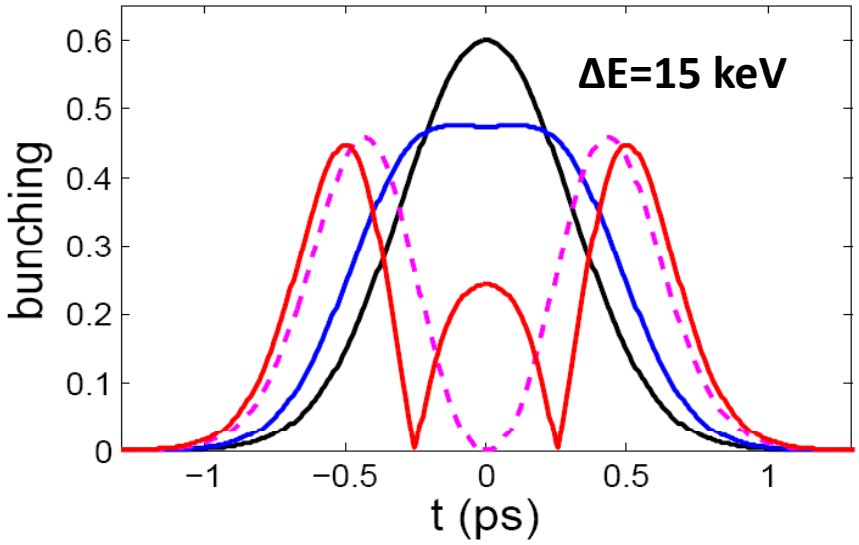
Measuring energy modulation

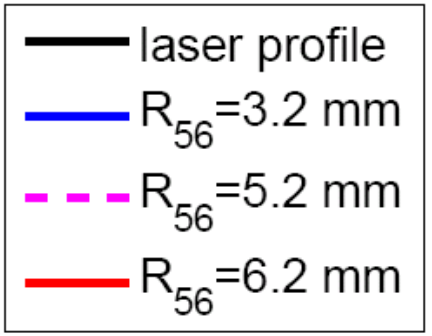
$$b = |J_1(kR_{56}\Delta E/E)|e^{-\frac{1}{2}k^2R_{56}^2\sigma_E^2/E^2}$$

E=120 MeV, λ=795 nm,

R_{56}=6mm, σ_E=1 keV

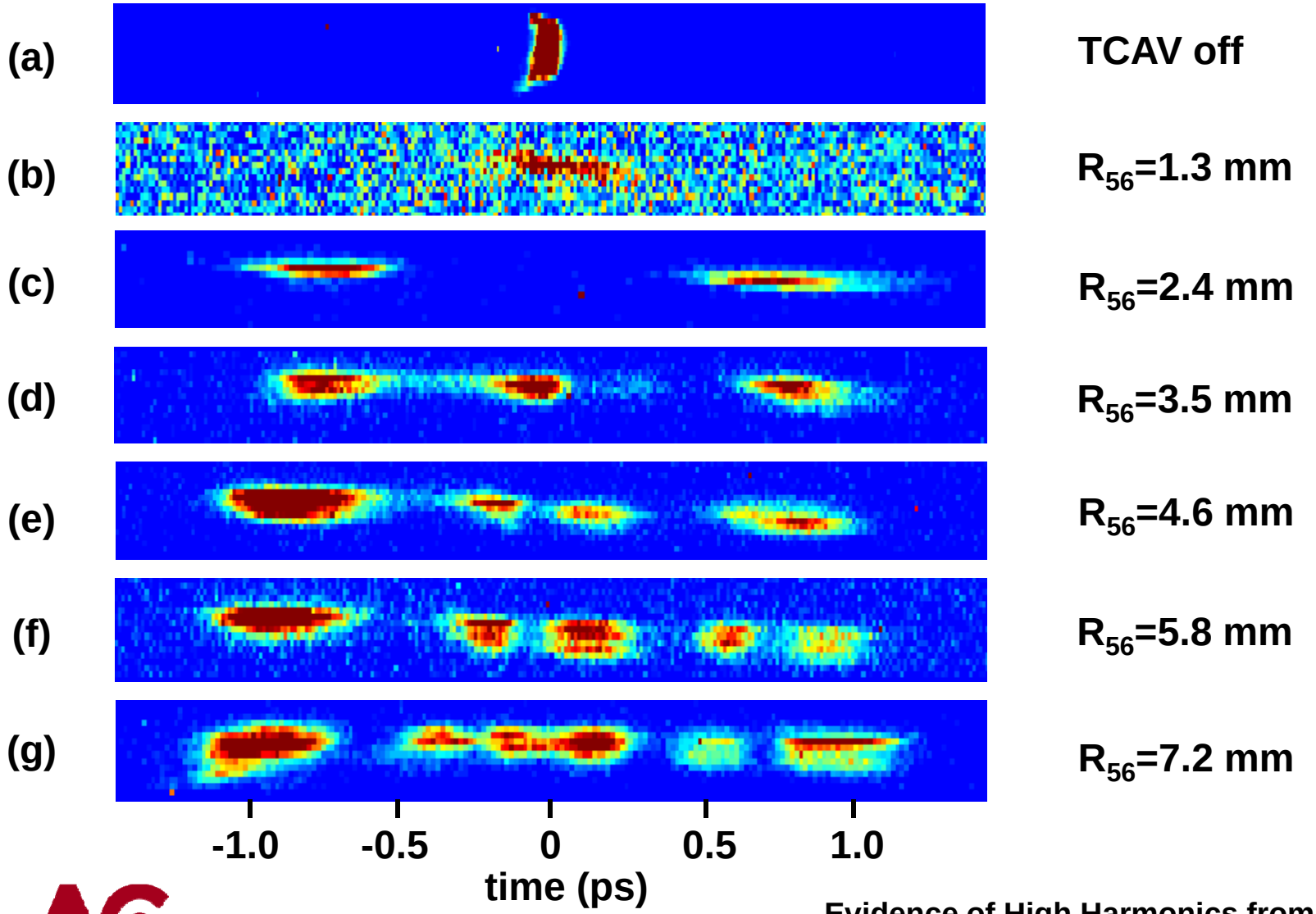






Time-dependent bunching for various R_{56}

Measuring energy modulation



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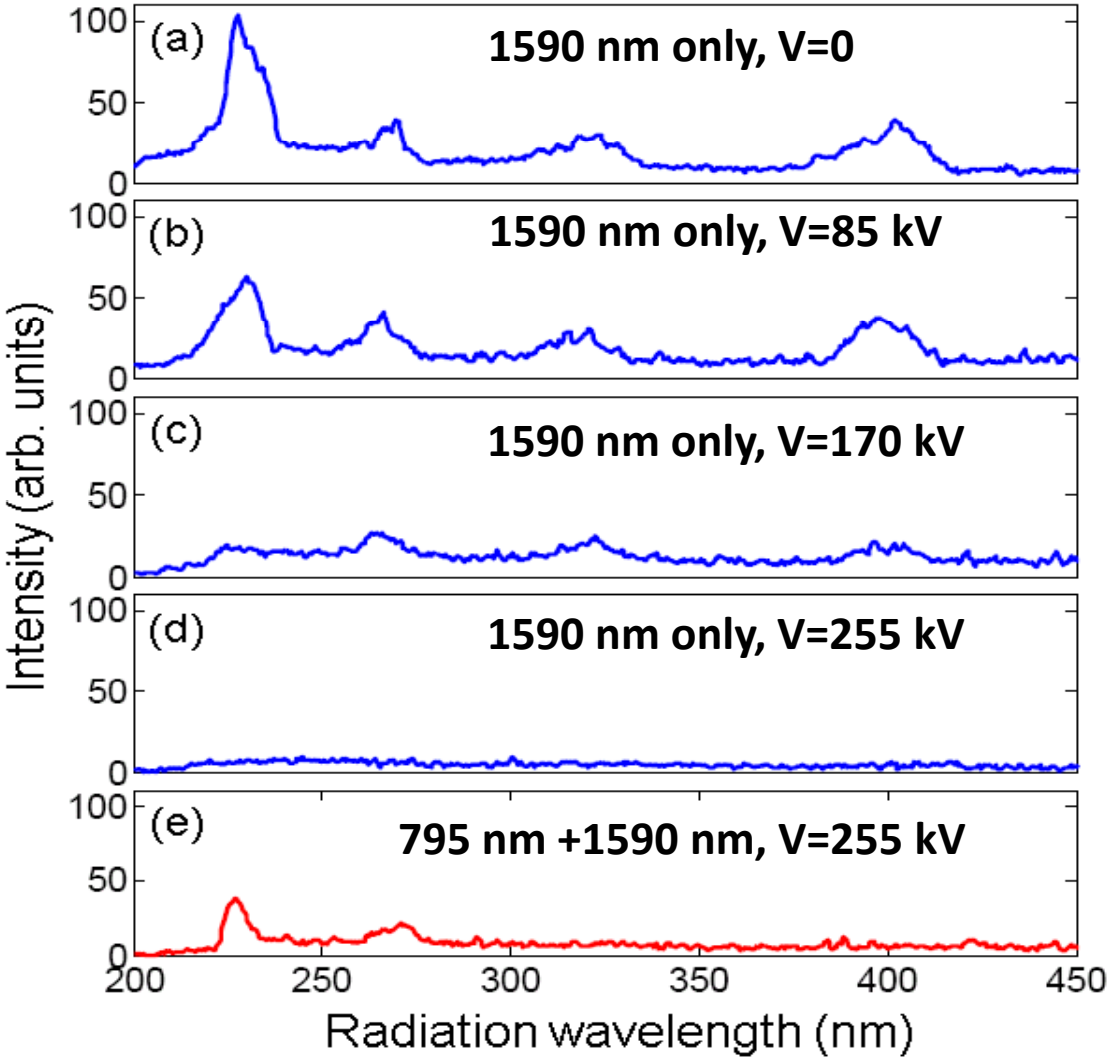
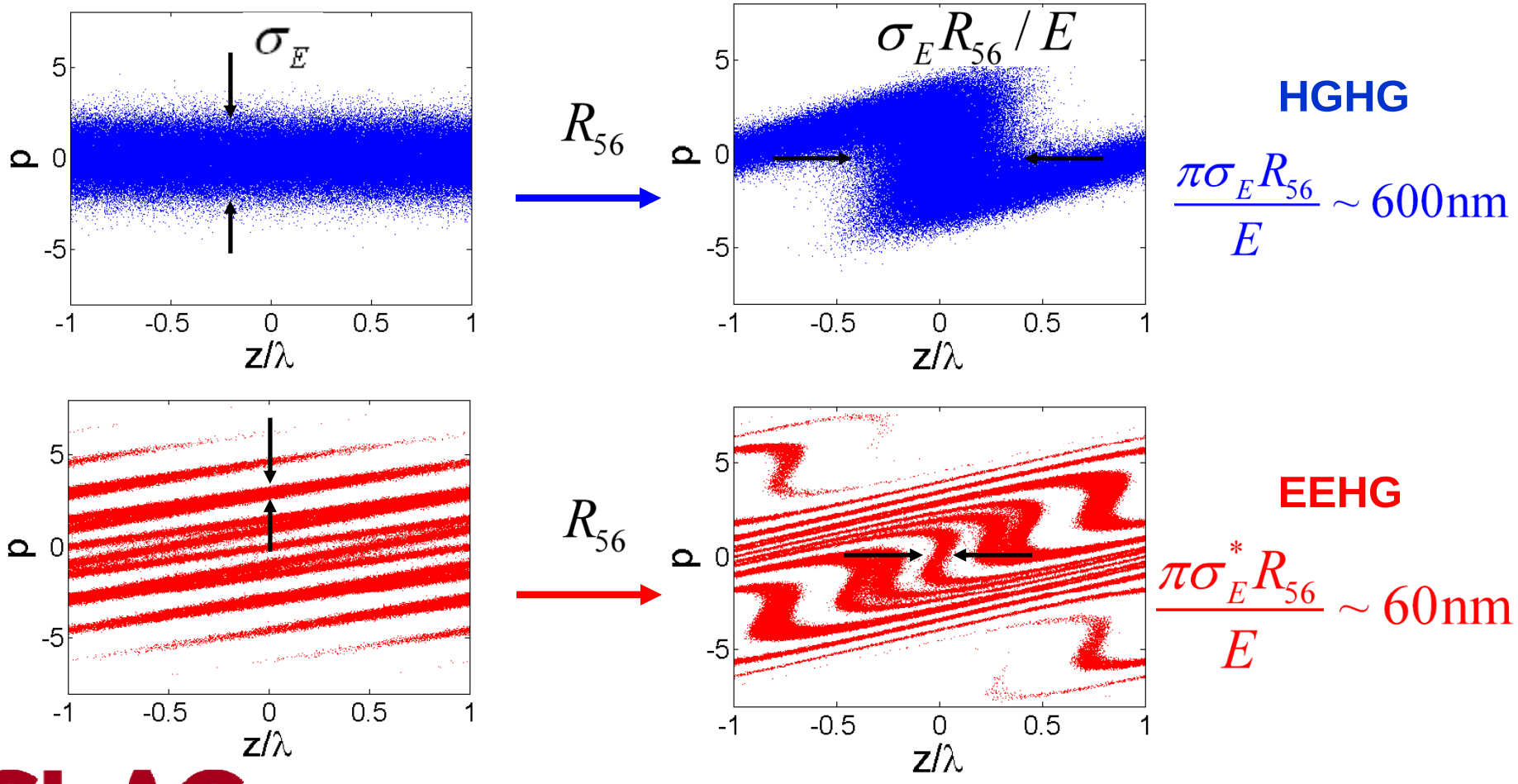
Evidence of high harmonics from EEHG



- 4th to 7th harmonics from HGHG suppressed with increased beam slice energy spread
- 7th harmonic reappear with the first laser on, like an echo
- 7th harmonic generated when energy modulation is about 2~3 times the beam slice energy spread

Evidence of high harmonics from EEHG

- **Suppression of high harmonics in frequency domain can be understood as smearing of fine structures in time domain**



Summary

- **EEHG is a very promising scheme to generate fully coherent soft x-rays directly from UV lasers in a single stage**

- **The supreme frequency up-conversion efficiency has been demonstratred at SLAC's NLCTA**

Many thanks to the Echo-7 team and a lot of other people for helpful discussions and commissioning assistance.

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Thanks!