FEL Overcompression in the LCLS

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Special thanks to Yuantao Ding for his leadership and for much of the analysis in this presentation, and thanks to the program committee for allowing us to present these studies.

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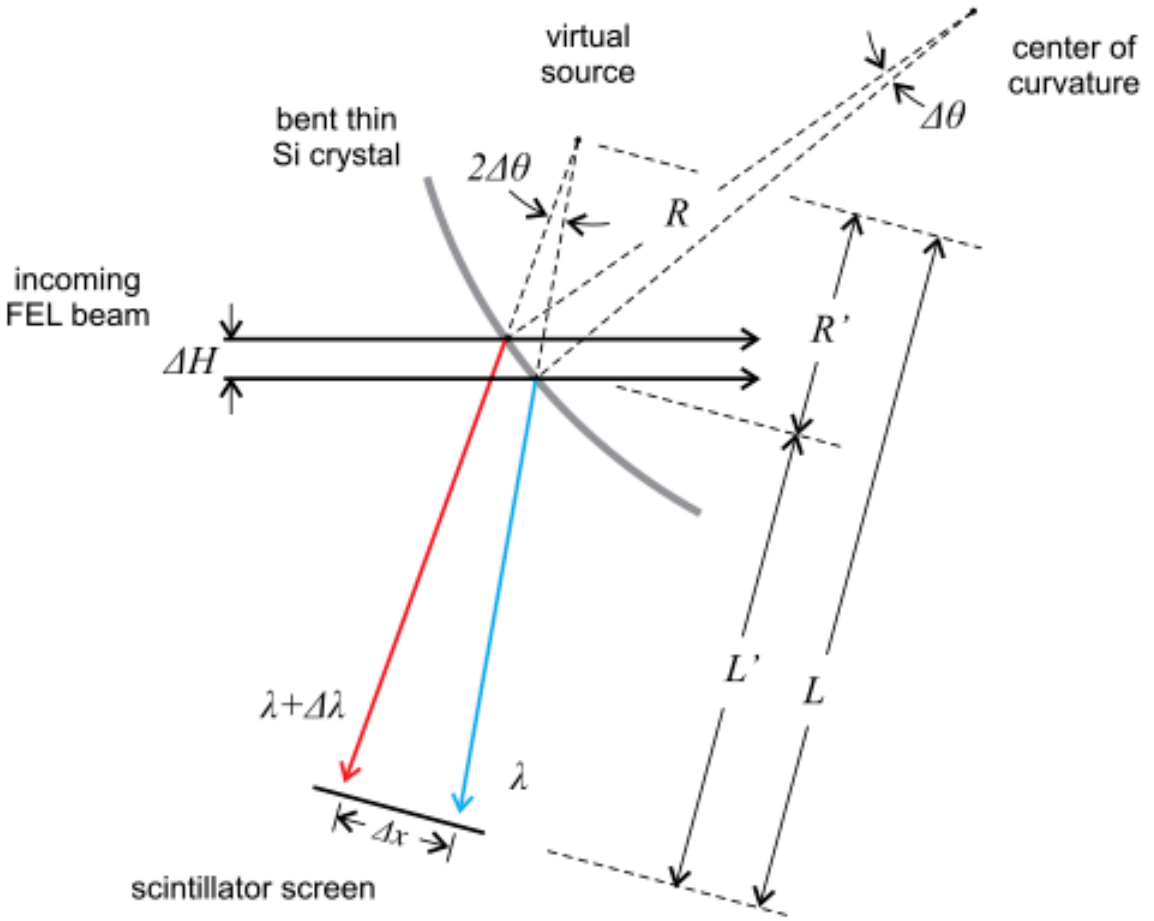
Overcompression in LCLS

- Motivation:
  - Some experiments need broad bandwidth
  - Simulation shows high peak current is attainable when beam “horns” are cut.
- Team members in these studies:
  - F.-J. Decker, Y. Ding, Z. Huang, R. Iverson, J. Krzywinski, H. Loos, A. Lutman, A. Marinelli, T. Maxwell, H.-D. Nuhn, D. Ratner, T. Smith, J.L. Turner, J. Welch, F. Zhou
- Diagnostics:
  - Bent Si crystal spectrometer (HXSSS) “A single-shot transmissive spectrometer for hard x-ray free electron lasers” D. Zhu, et al., URL http://scitation.aip.org/content/aip/journal/apl/101/3/10.1063/1.4736725.
  - X-band Transverse Cavity (XTCAV) “Few-femtosecond time-resolved measurements of X-ray free-electron lasers”, C. Behrens, et al., http://www.nature.com/ncomms/2014/140430/ncomms4762/abs/ncomms4762.html

Bent Crystal Si Spectrometer

X-ray beam comes in from the left, is dispersed by different energies having different Bragg angles from the bent Si crystal.



dispersion geometry

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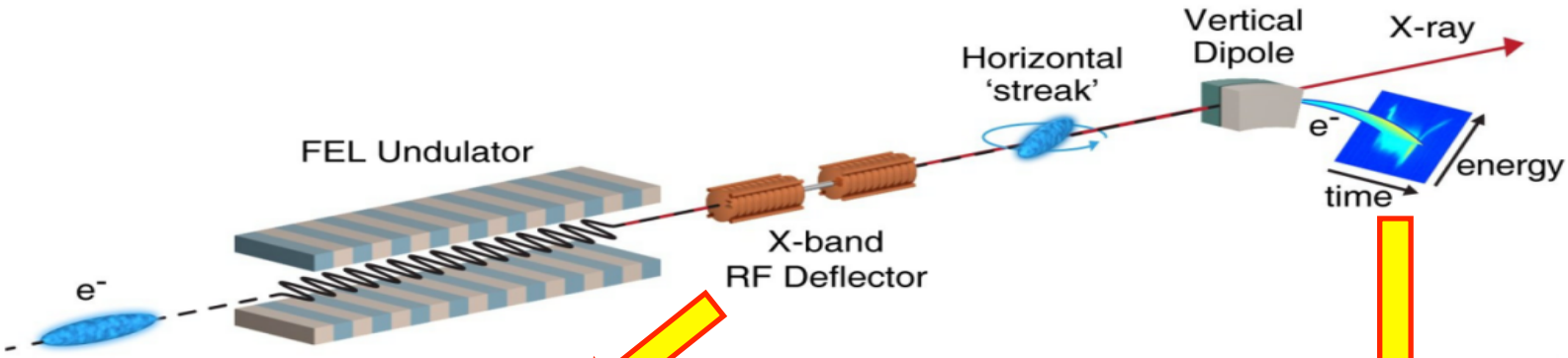
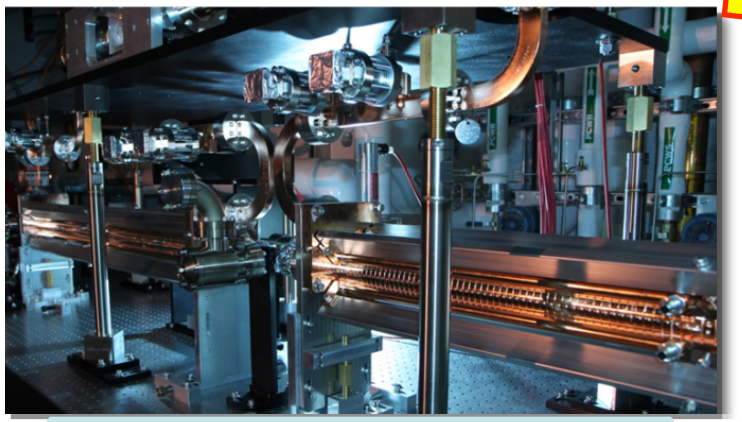
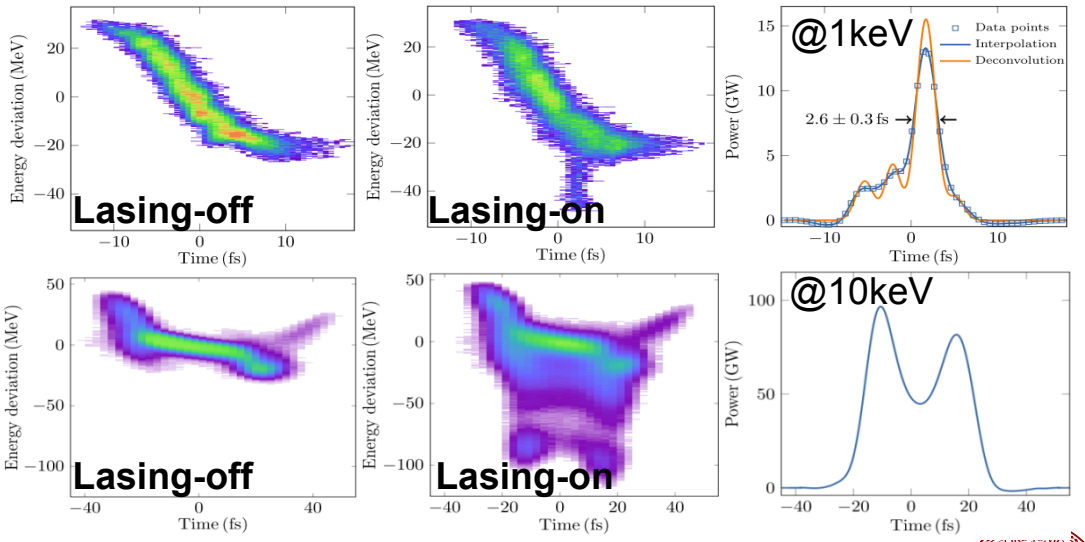
XTCAV: online electron bunch and X-ray pulse length diagnostic with femtosecond resolution





- ✓ High resolution, ~ few fs;
- ✓ Single shot;
- ✓ Noninvasive to operation;
- ✓ Both e-beam and x-ray profiles.
- ✓ Applicable to all FEL wavelength;

Reconstructed X-ray profile



C. Behrens et al., *Nat. Commun.* 5:3762 (2014).

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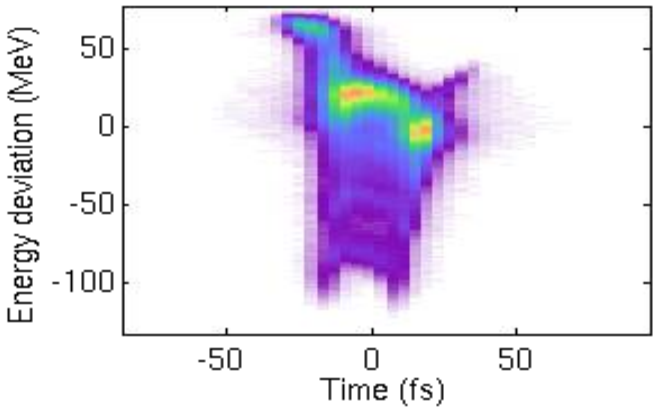
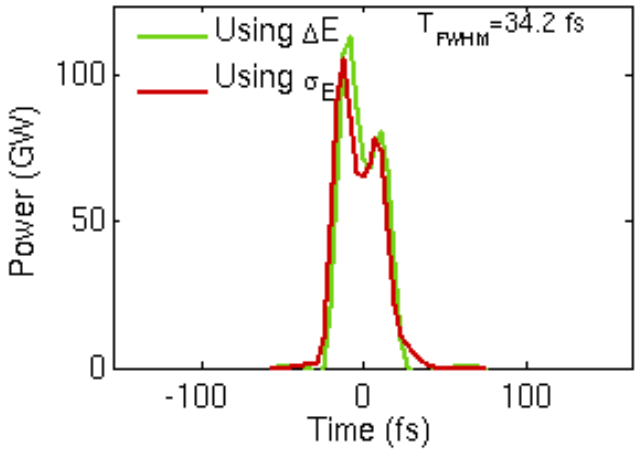
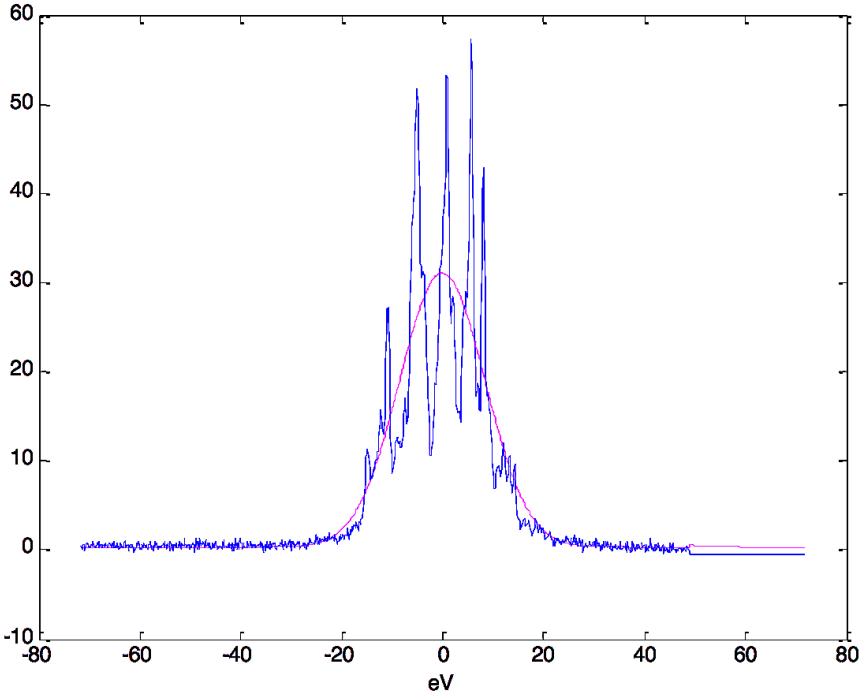
Overcompression in LCLS

- Cases studied (all at 8.3 keV):
  - 180 pC undercompressed (Nominal)
  - 250 pC overcompressed
  - 250 pC truncated to 170 pC undercompressed
  - 250 pC truncated to 170 pC overcompressed

180 pC, 8.3 keV, Under-compression







Fitted FWHM = 20.0 eV

FWHM Bandwidth about 20 eV
From XTCAV left and HXSSS above (Spectrometer).

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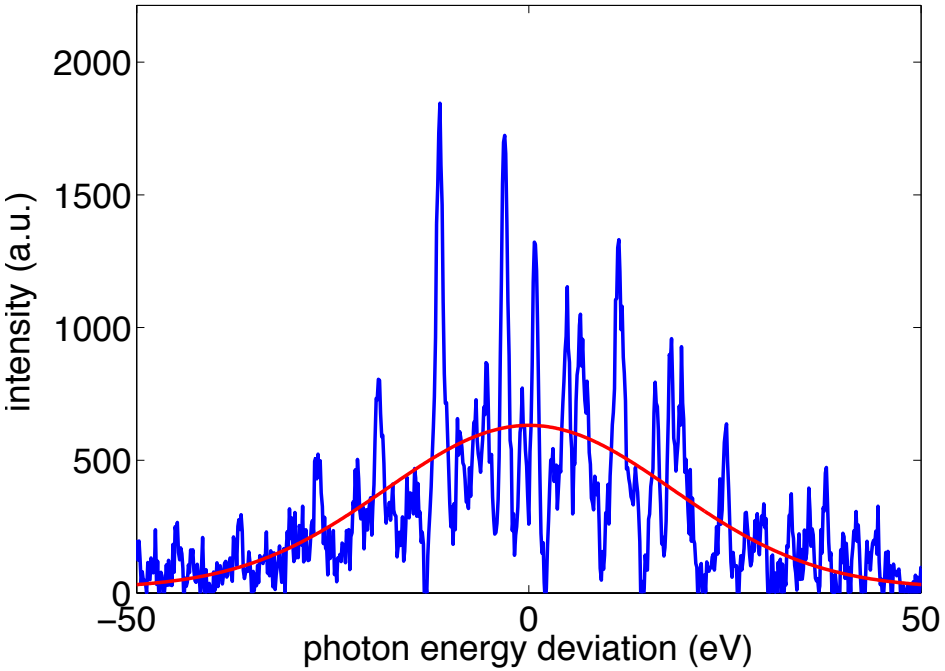
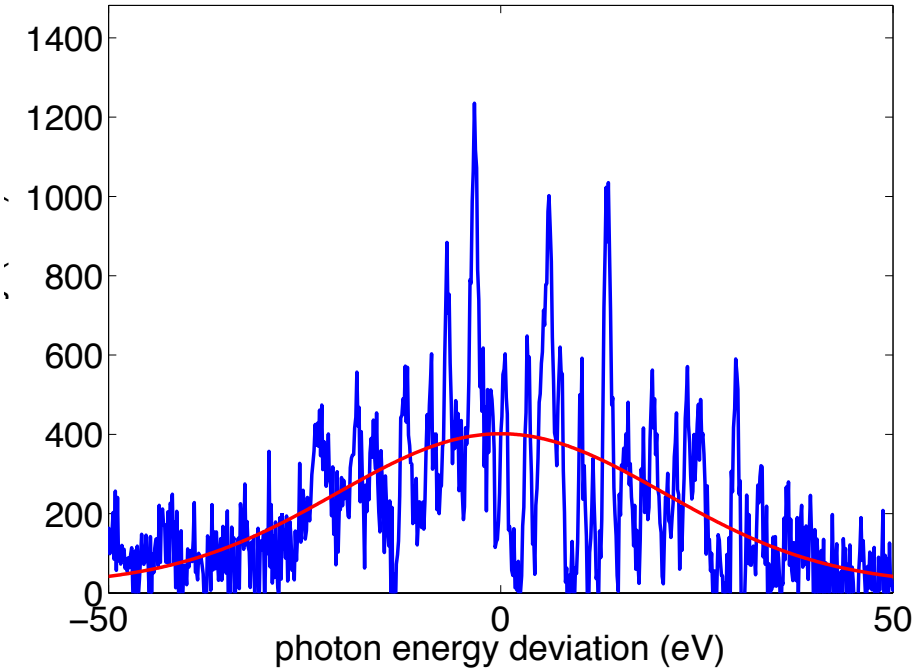
250 pC, 8.3 keV, Overcompression



Fitted FWHM = 44 eV



Fitted FWHM = 51 eV

The bandwidth of each shot is calculated by gaussian fit.

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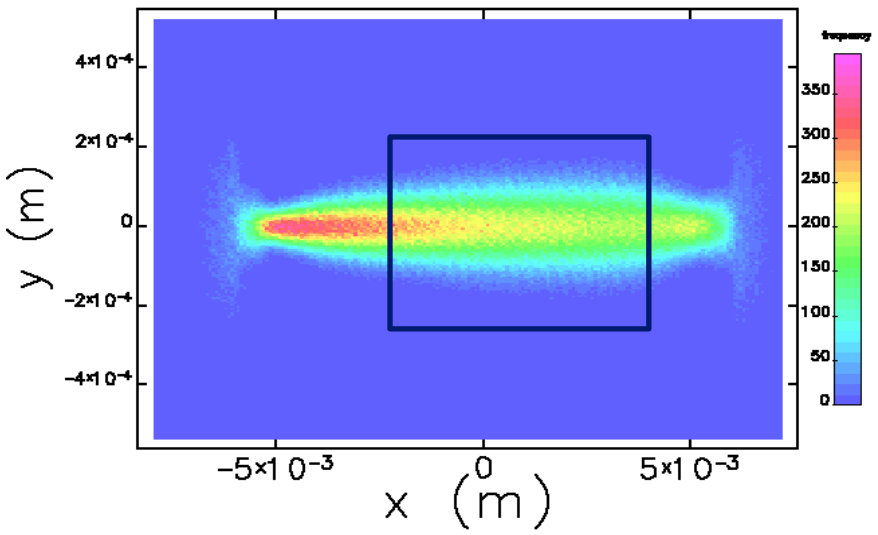
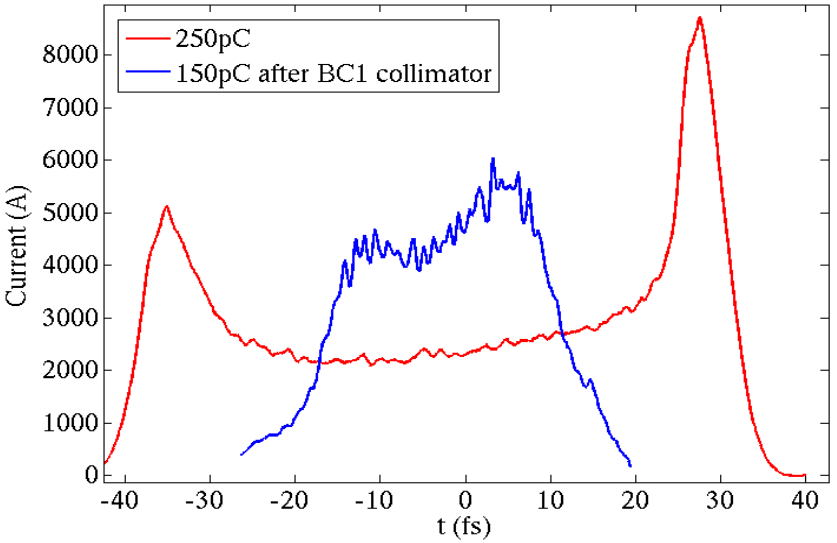
Simulation, cutting from 250pC to 150pC



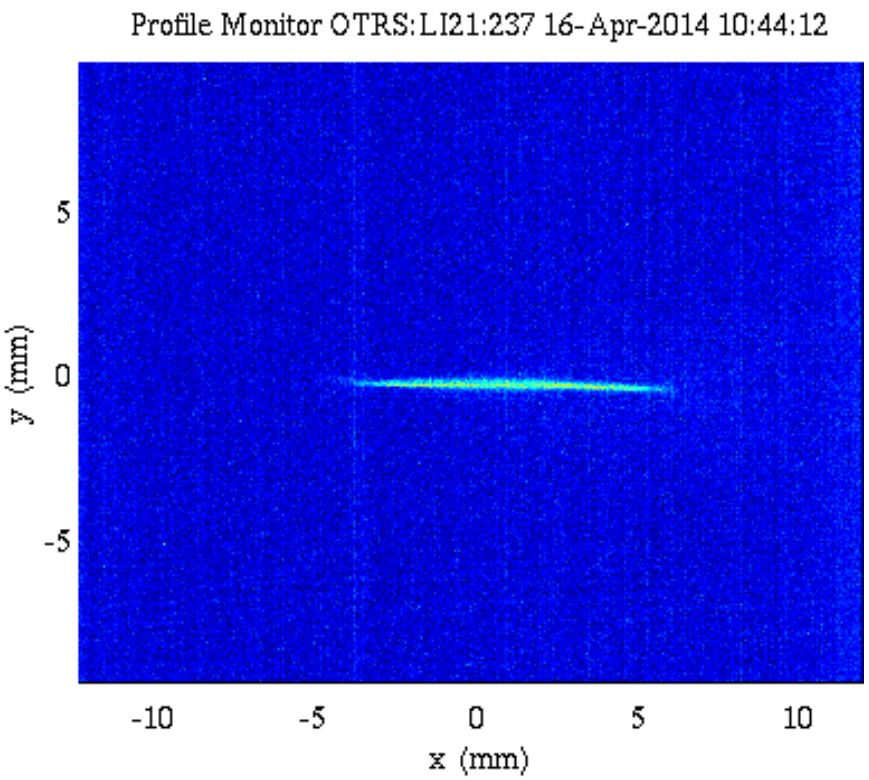


Simulation at BC1 of the cut to achieve the simulated 5kA. This is an asymmetric cut of 6.4 mm offset by +1mm.

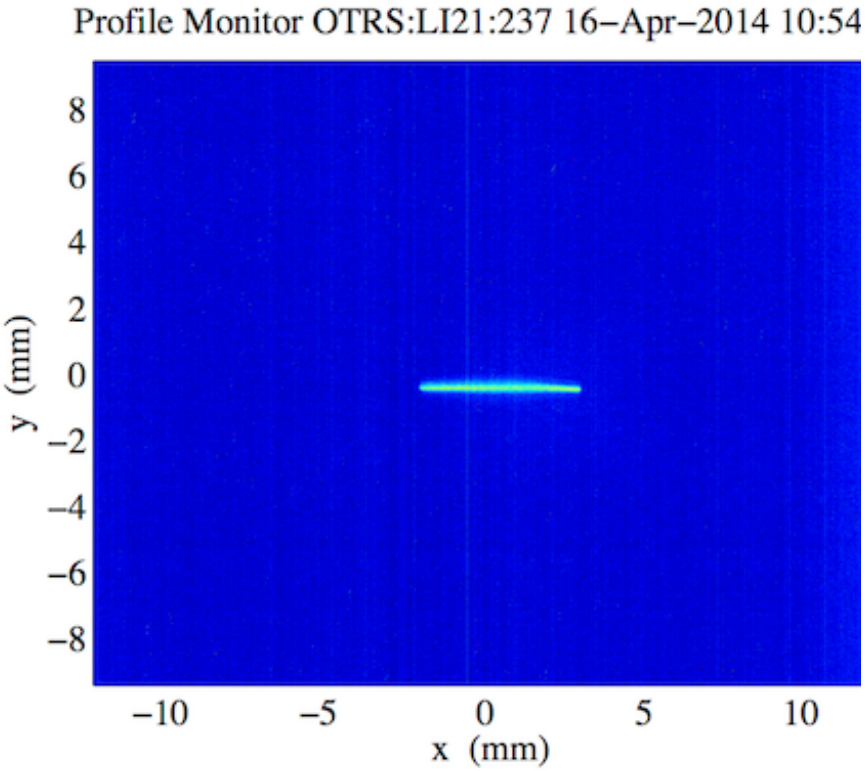
5kA is anticipated in the cut core at 13.6 GeV, 8.3 keV.

Simulation in 2011 by Yuantao Ding shows that cutting the “horns” of the temporal distribution will lead to higher peak current in the core of the beam. The cut is by collimation in the first bunch compressor (BC1).

Experiment: Cutting from 250 pC to 170 pC



Beam at BC1 before collimation



Beam at BC1 after collimation

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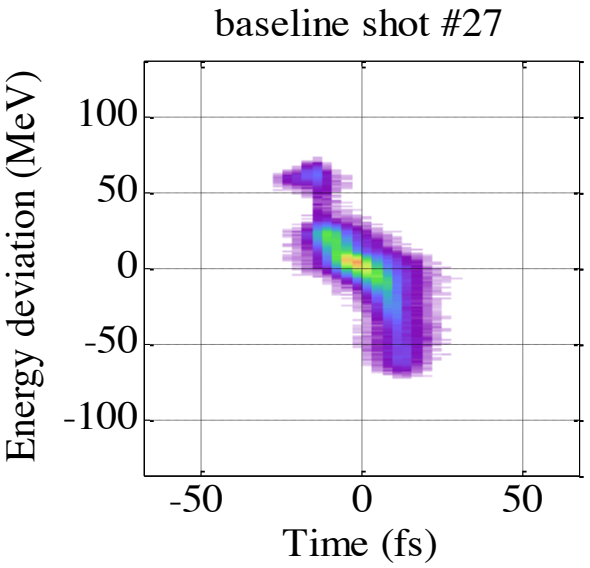
250 pC cut to 170 pC Under-compressed

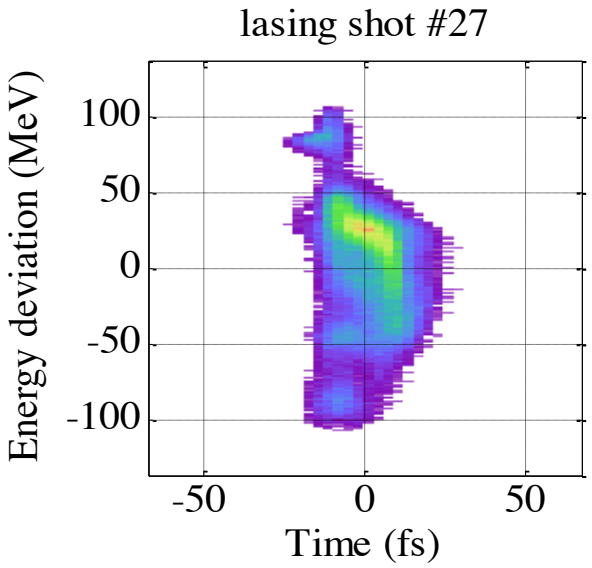
XTCAV single shot data showing baseline non-lasing left top. Lasing right top.

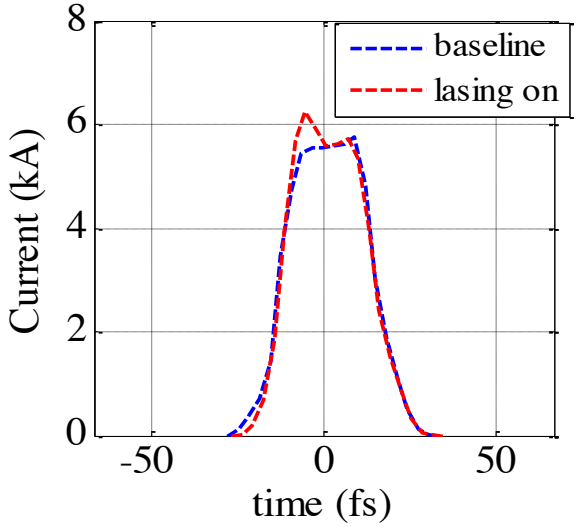
Bottom left is peak current temporal profile, and right is peak power.

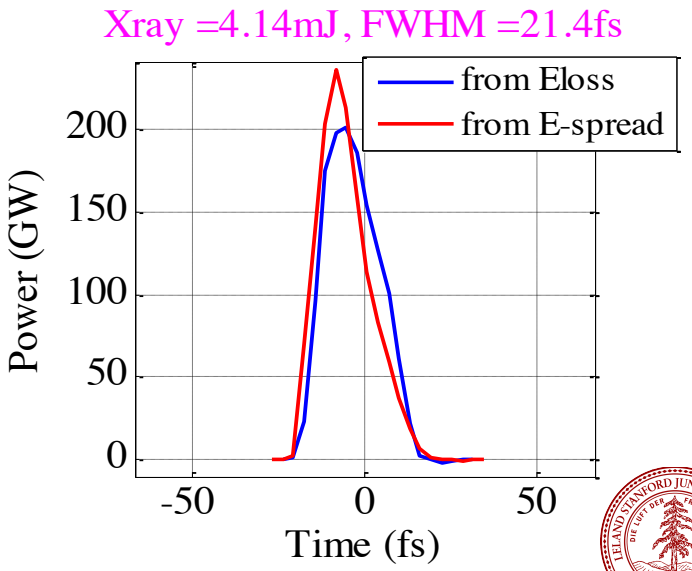
4 mJ in 21 fs -> ~200 GW!

2014/04/16: 161538









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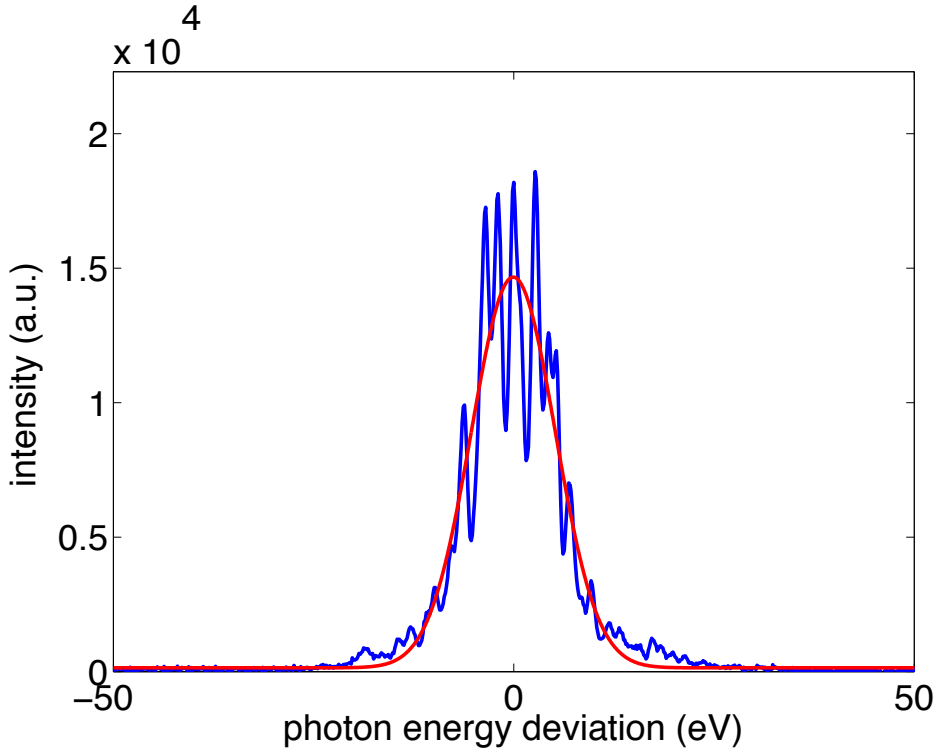
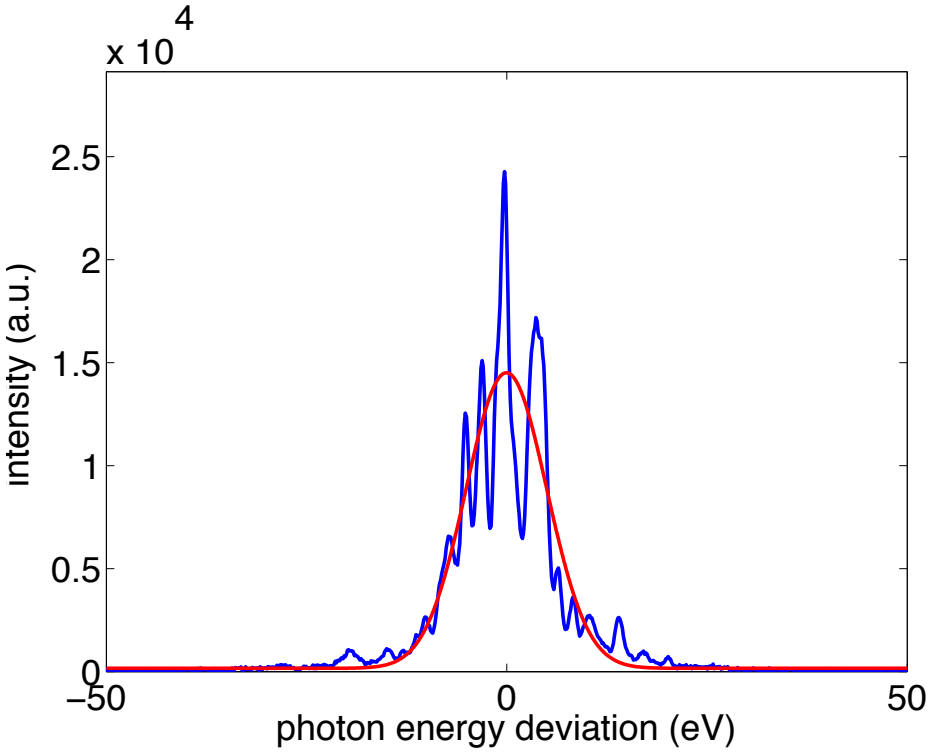
250 pC cut to 170 pC Under-compressed





Single shots FWHM Bandwidth = 11.9 eV at 4.1 mJ (right)
And 12.3 eV at 3.7 mJ (left)

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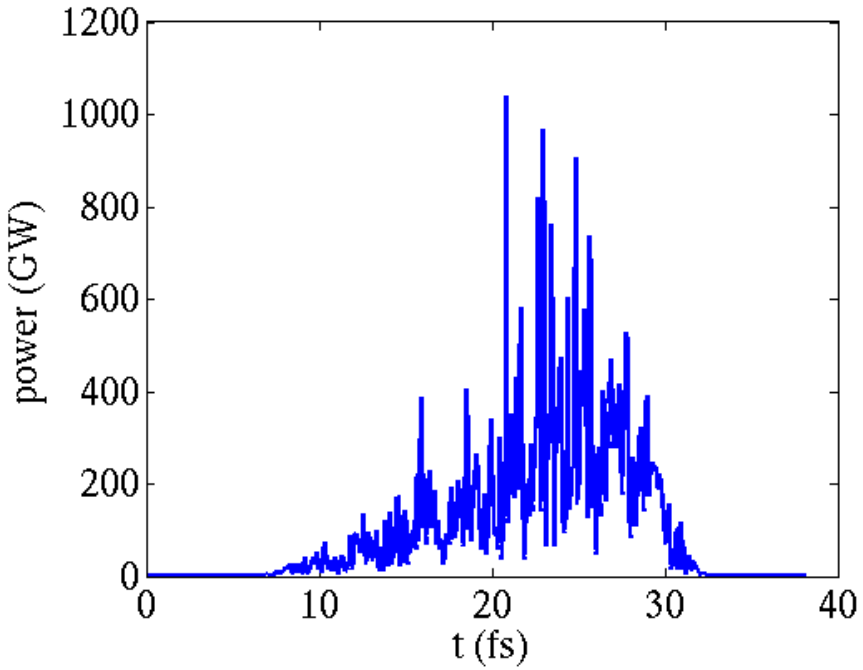
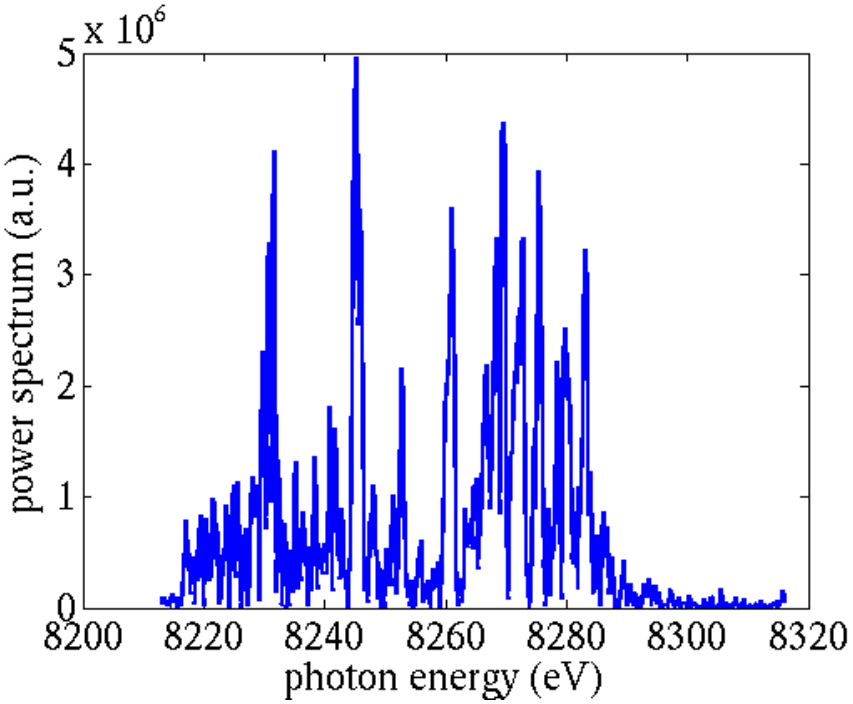
Simulation 250 pC cut to 170 pC Overcompressed





Simulation -Roughly the peak mean power about 300 GW (left), bandwidth is about 50 eV (right). The current is about 7 kA.

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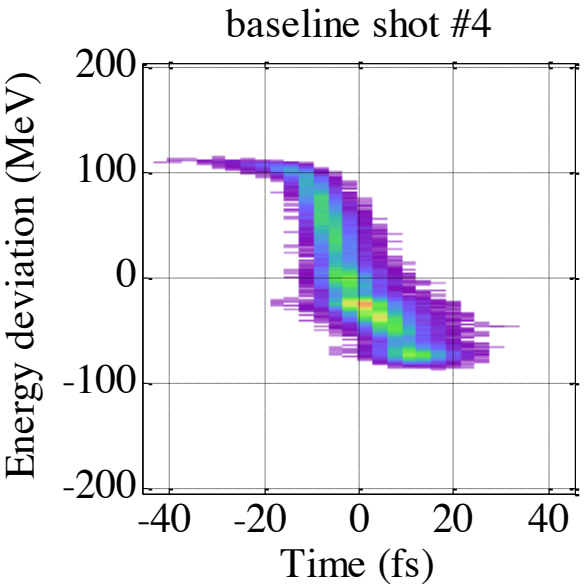
250 pC cut to 170 pC Overcompressed

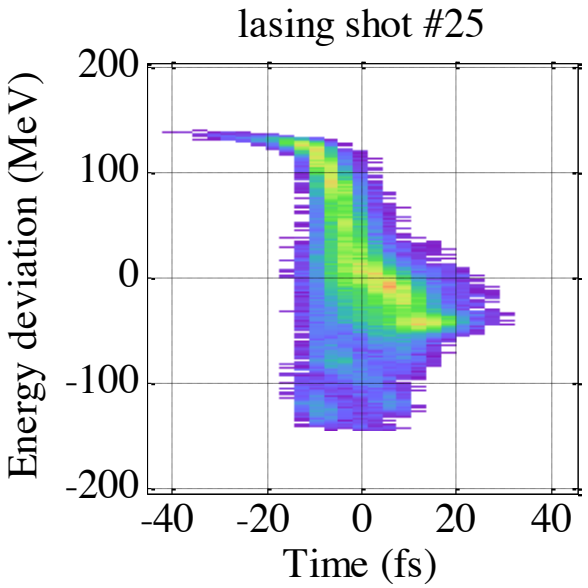
XTCAV single shot data showing baseline non-lasing left top. Lasing right top.

Bottom left is peak current temporal profile, and right is peak power.

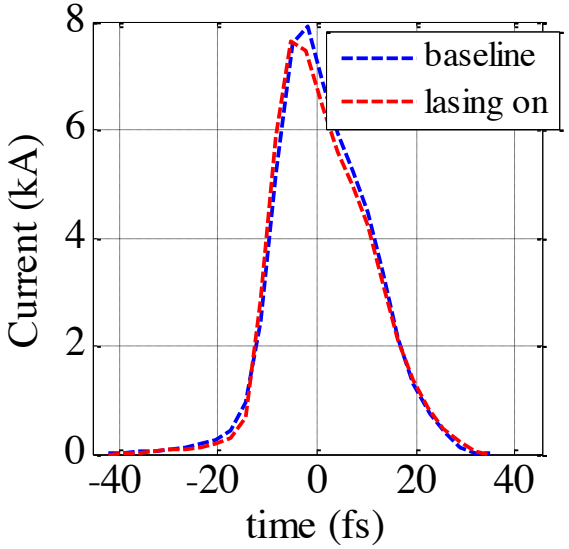
5.36 mJ in 13.8 fs -> ~350 GW!

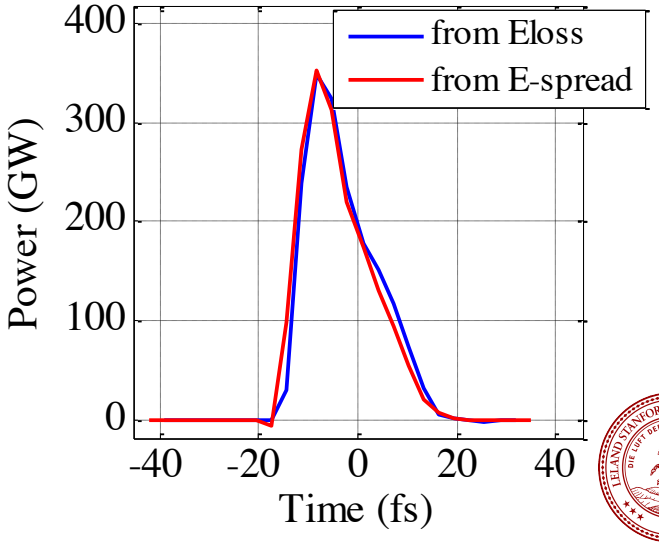
2014/04/16: 165200





Xray =5.36mJ, FWHM =13.8fs





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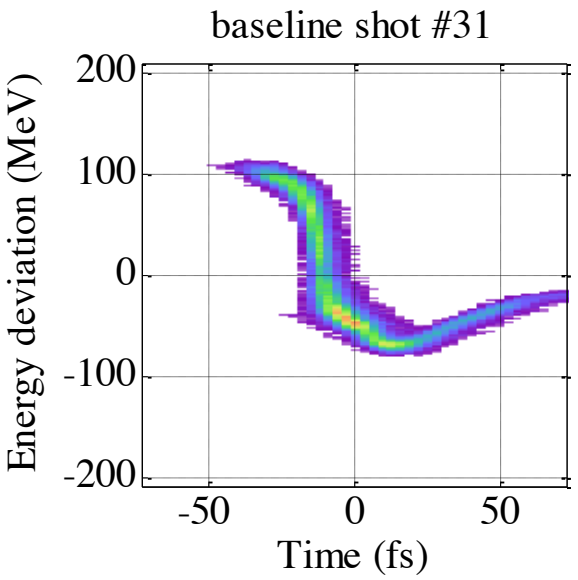
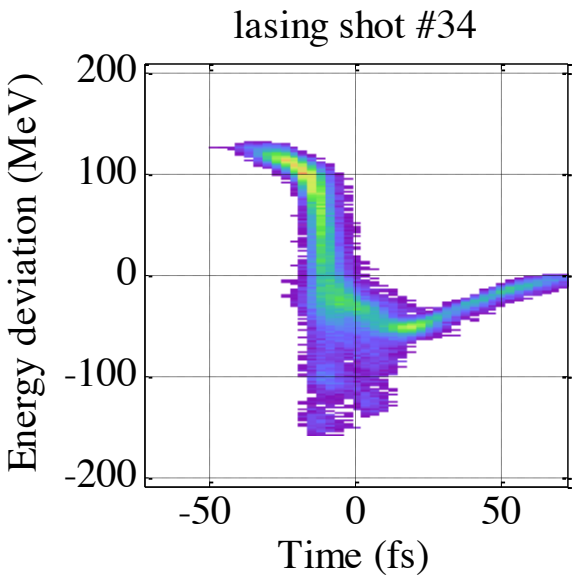
Full 250 pC, Overcompressed

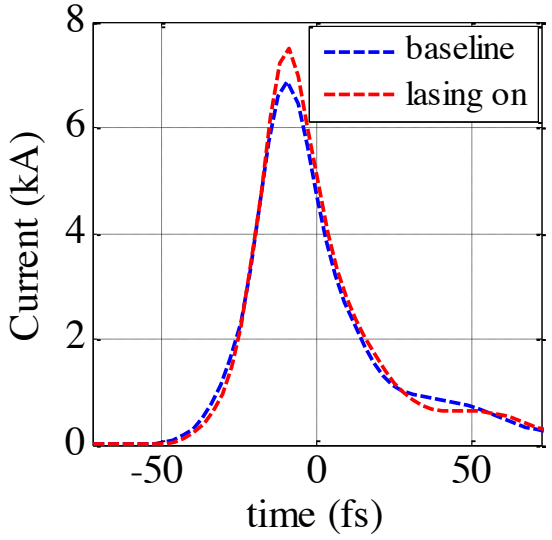
XTCAV single shot data showing baseline non-lasing left top. Lasing right top.

Bottom left is peak current temporal profile, and right is peak power.

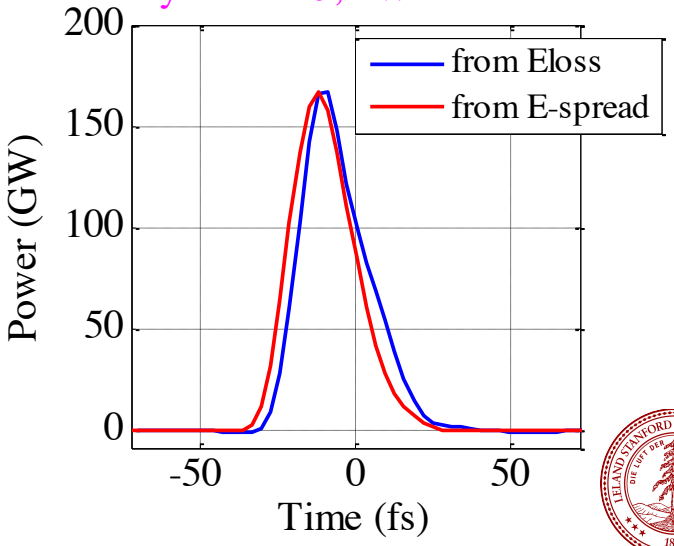
4.16 mJ in 22.9 fs -> ~170 GW







Xray =4.16mJ, FWHM =22.9fs



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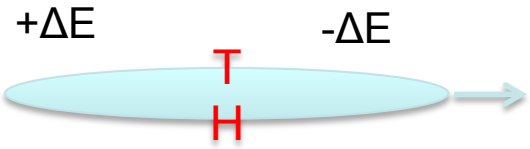
Summary

- Overcompression has great potential, but repeatability issues. Because of the large projected energy spread: dispersion after BC2, any downstream chromaticity, and divergence correction at B4 in BC2 are issues for further study.

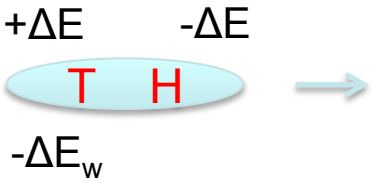
Backup Slides

Compression, Wakefields, & Energy Spread

Normal Compression



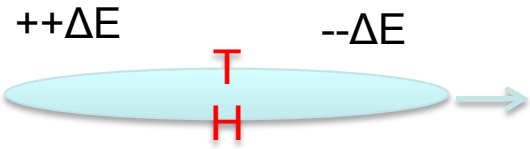
Applied chirp makes Head take a longer path in the chicane and slip toward the Tail



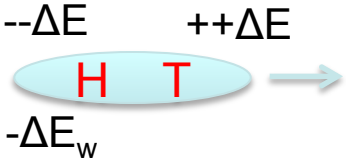
wakefield chirp is partially canceled

Subsequent wakefields in L3 lower Tail energy

Over-Compression



More applied chirp can force Head to slip **past** the Tail



wakefield chirp is reinforced

Subsequent wakefields in L3 lower Tail energy

<u>Should see a step increase in energy spread (~ 2 ΔE) going from normal to over-compression</u>

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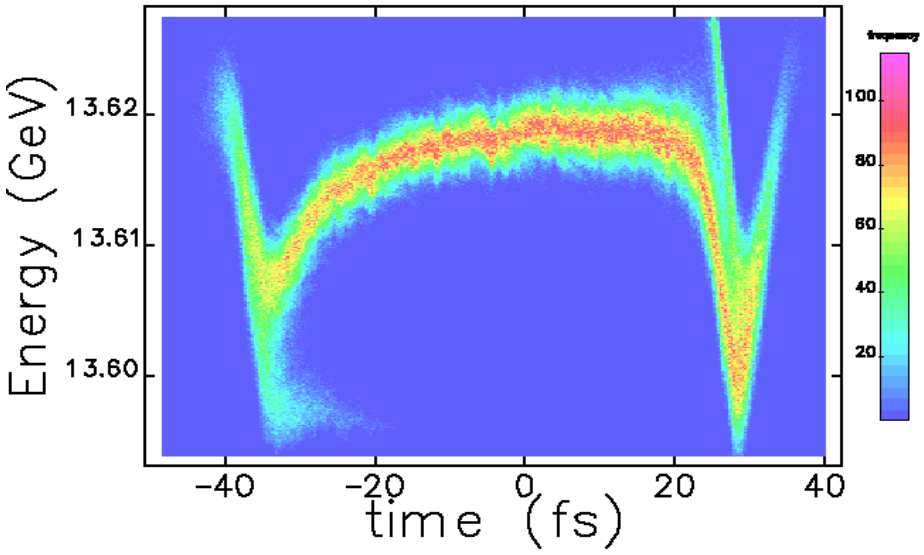
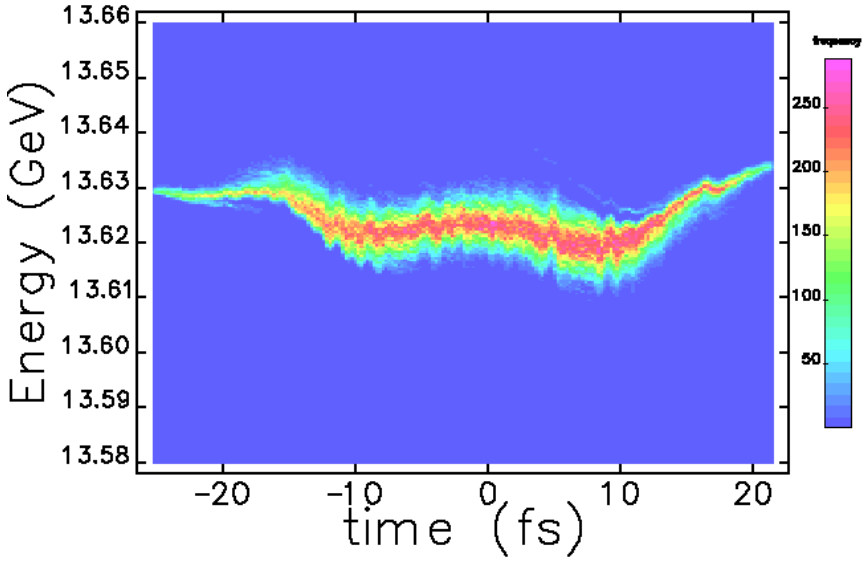
Thanks to Jim Welch. Presented at FEL 2011, Shanghai, China, Aug. 22-26, 2011

Simulation, cutting from 250pC to 150pC



Uncut 250 pC with L2 = -36 degrees



Cut to 150 pC at BC1 collimator, L2 = -38 degrees

Simulation in 2011 by Yuantao Ding shows that cutting the “horns” of the temporal distribution will lead to higher peak current in the core of the beam. The cut is by collimation in the first bunch compressor (BC1).

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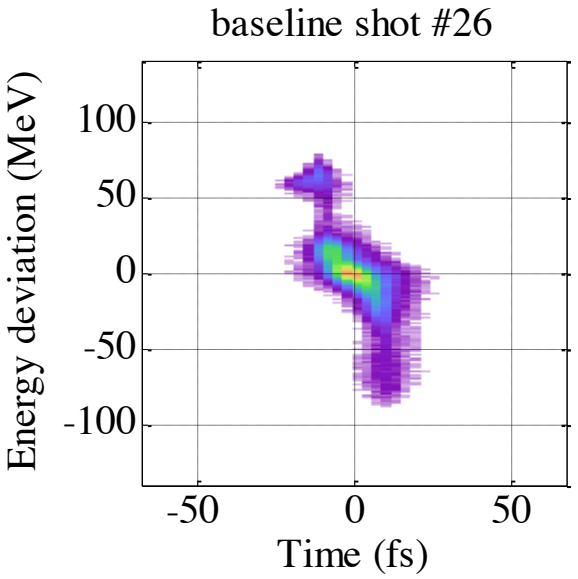
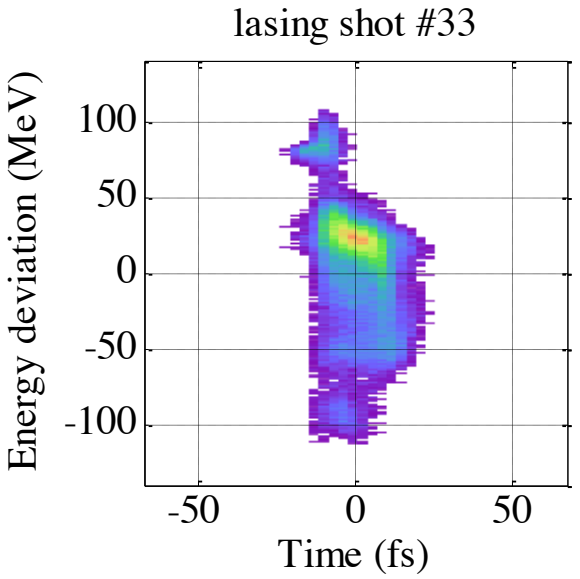
250 pC cut to 170 pC Under-compressed

XTCAV single shot data showing baseline non-lasing left top. Lasing right top.

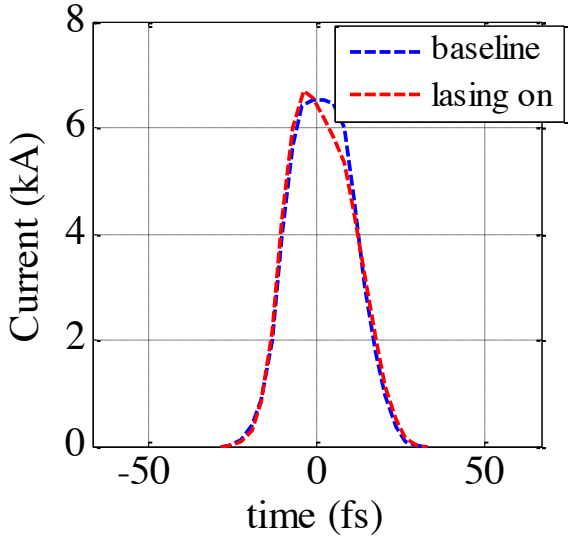
Bottom left is peak current temporal profile, and right is peak power.

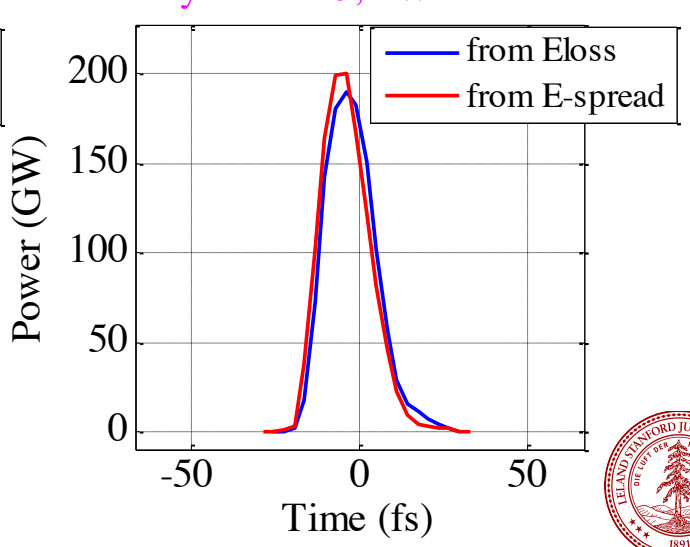
3.6 mJ in 18 fs -> ~180 GW!





Xray =3.61mJ, FWHM =18fs





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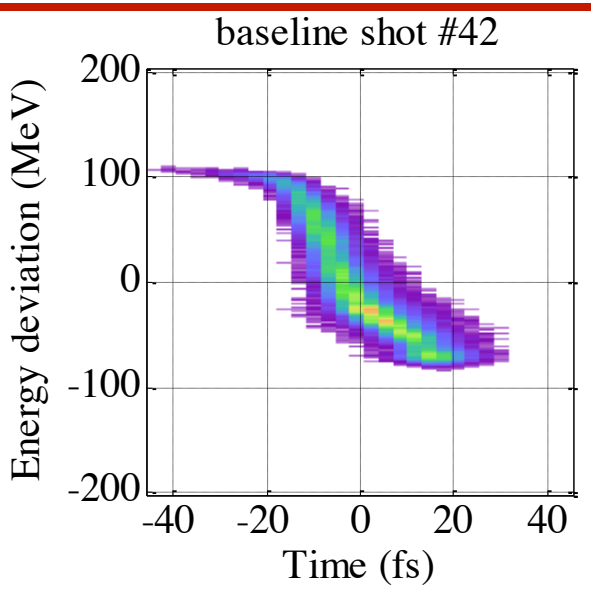
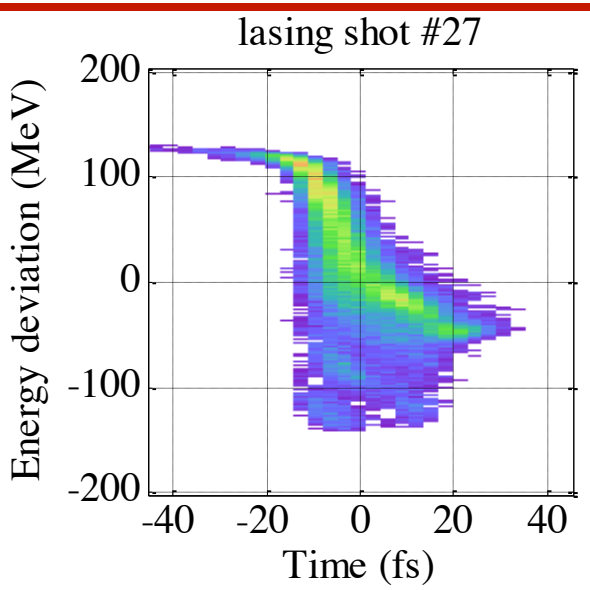
250 pC cut to 170 pC Overcompressed

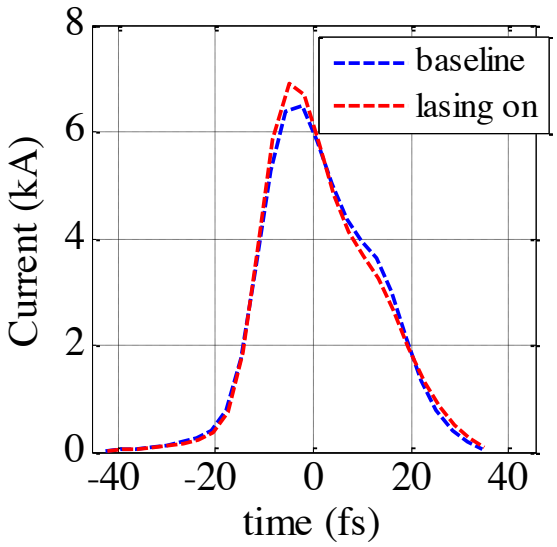
XTCAV single shot data showing baseline non-lasing left top. Lasing right top.

Bottom left is peak current temporal profile, and right is peak power.

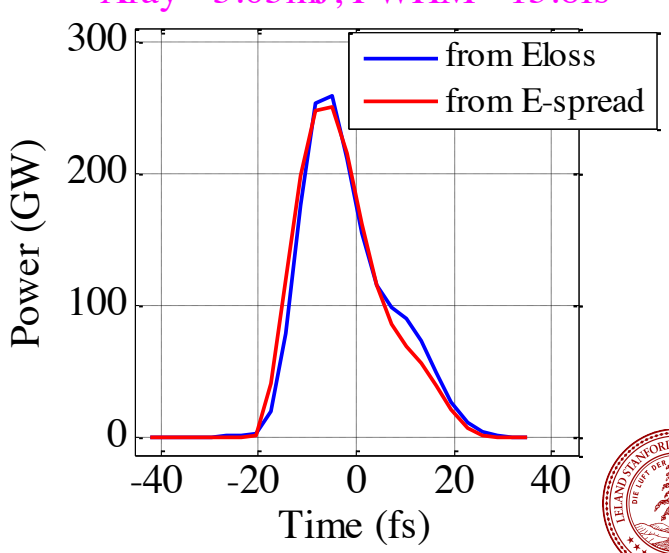
5.05 mJ in 15.8 fs -> ~250 GW







Xray =5.05mJ, FWHM =15.8fs



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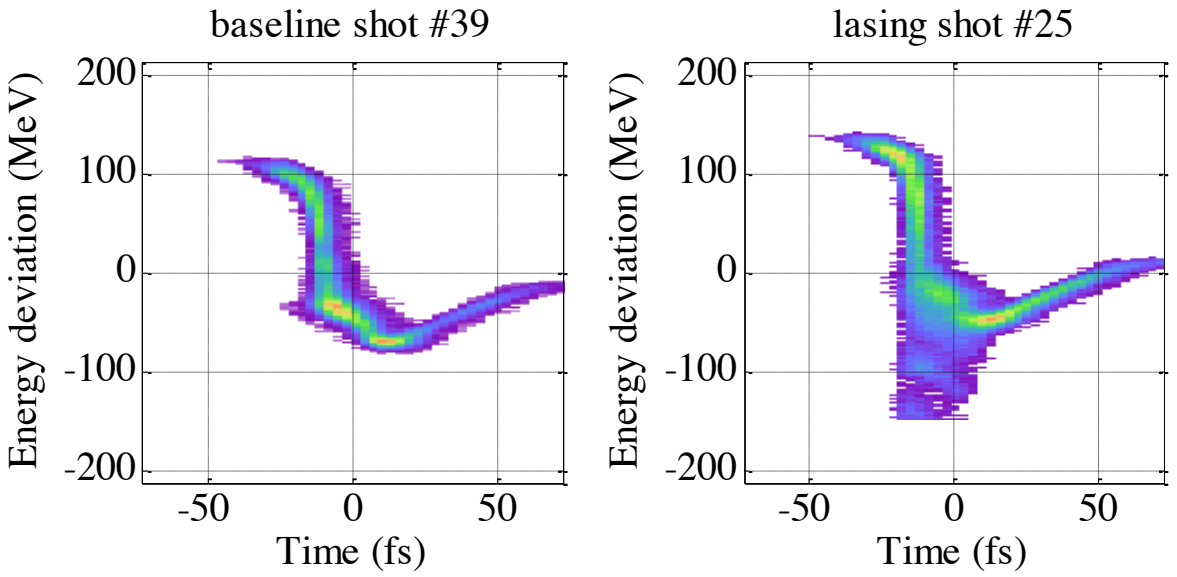
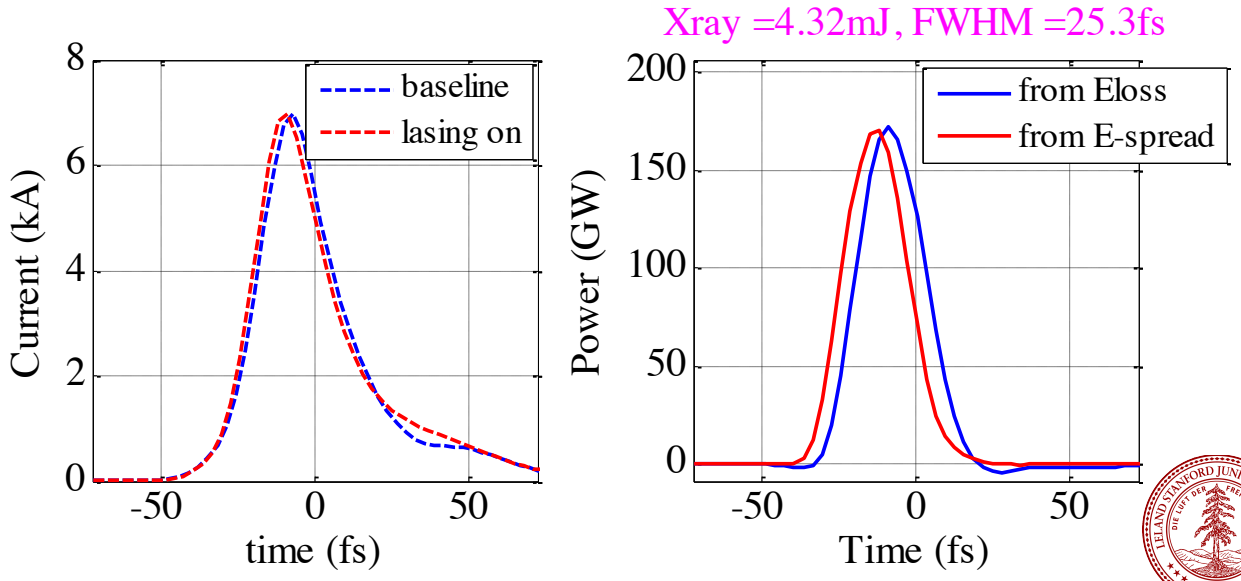
Full 250 pC, post saturation taper, Overcompressed

XTCAV single shot data showing baseline non-lasing left top. Lasing right top.

Bottom left is peak current temporal profile, and right is peak power.

4.32 mJ in 25.3 fs -> ~170 GW





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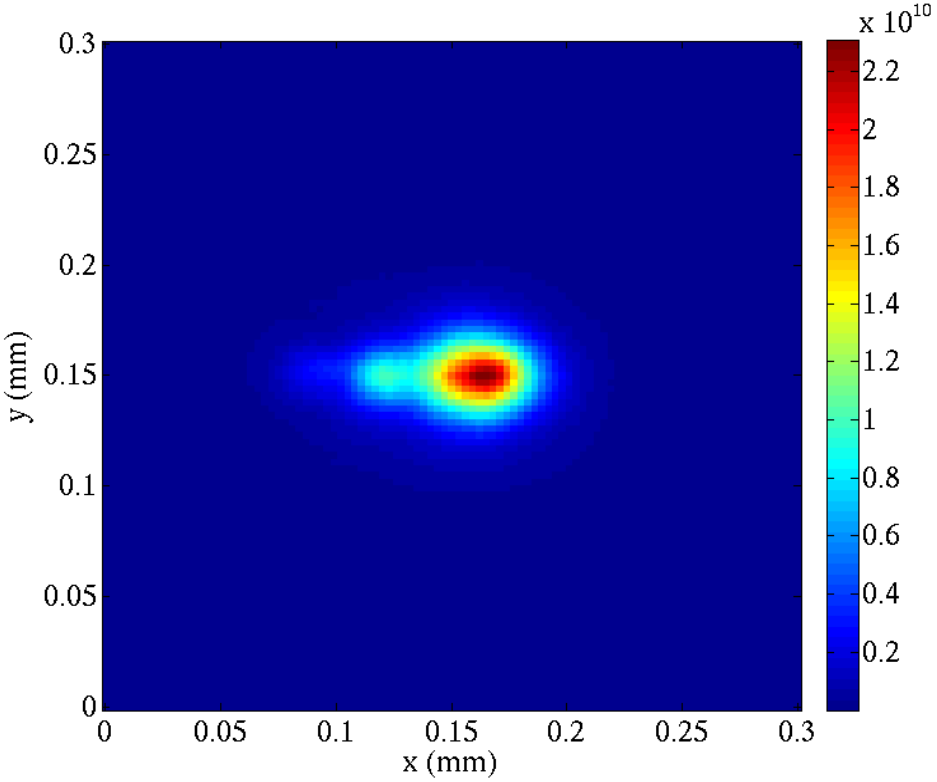
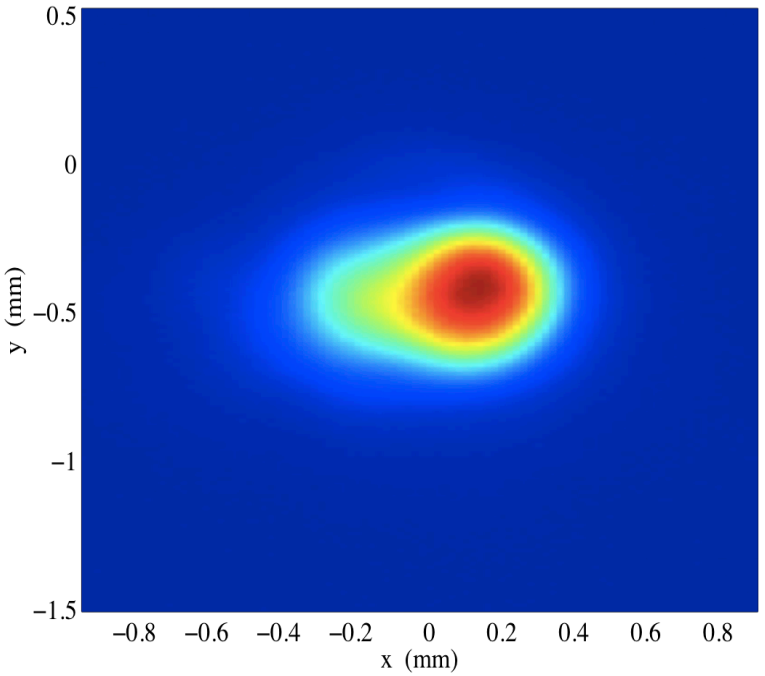
Simulation and Measurement



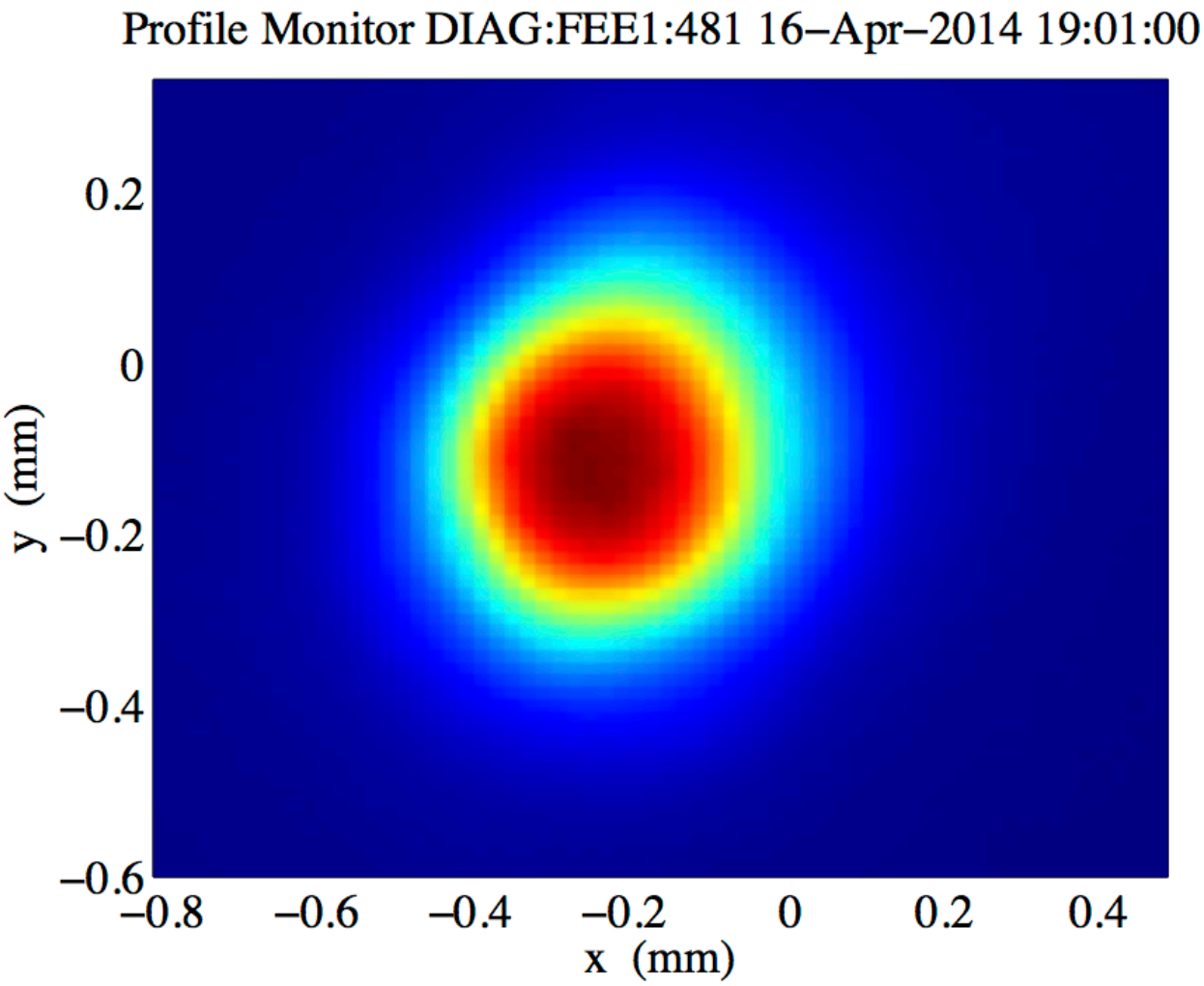


Xrays from 250pC electron bunch (laser heater on and aligned)

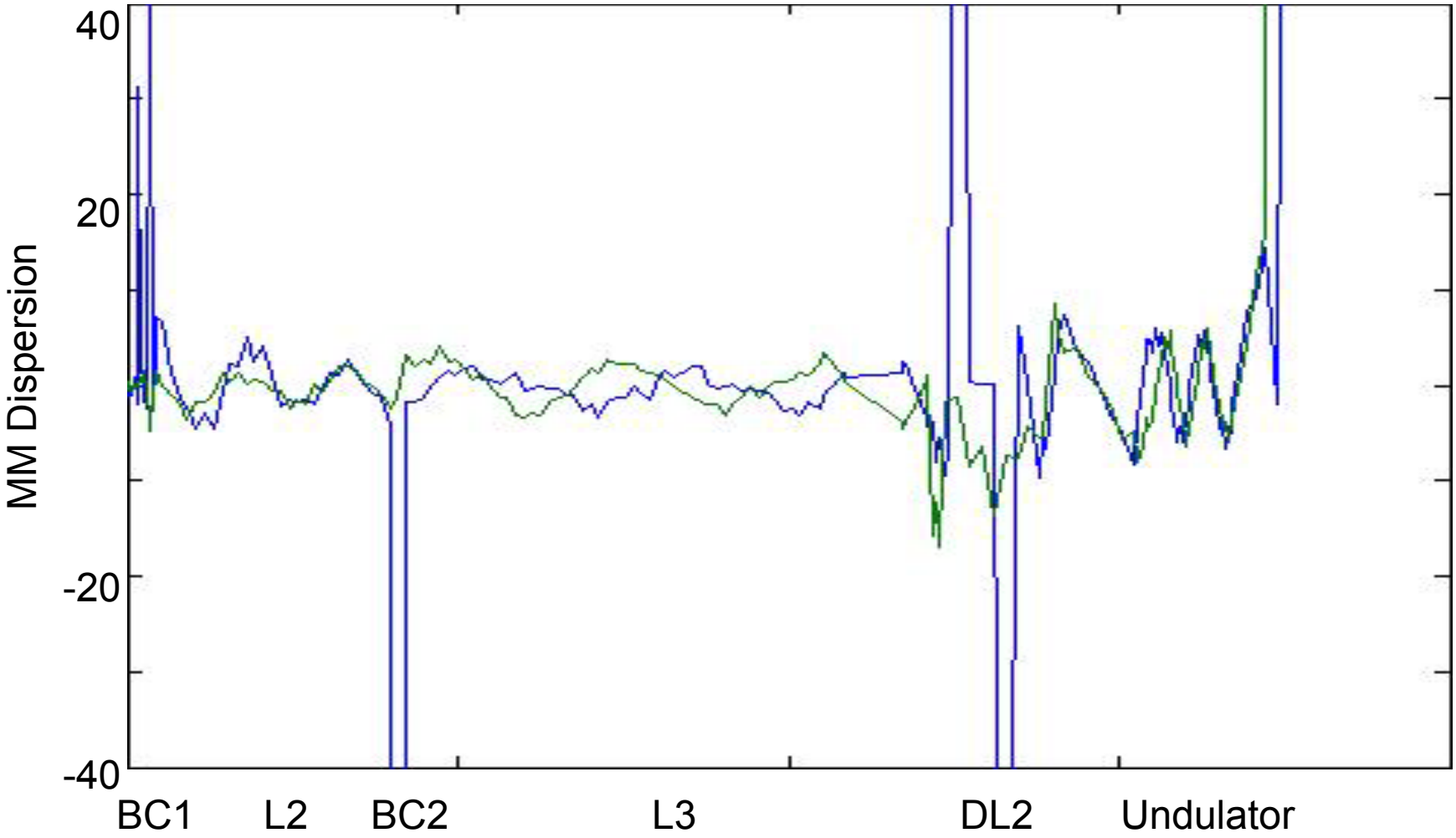
8.3 keV xray distribution, 3 kA Left is Genesis simulation at end of undulator. Right is measurement at ~+90 m. So, simulation is near field and measurement is far field. At ~1 kA both are round (not shown).

250 pC, 8.3 keV, Overcompression

After tuning only on the core, the transverse distribution in overcompression is gaussian at 250 pC.



Dispersion along LCLS



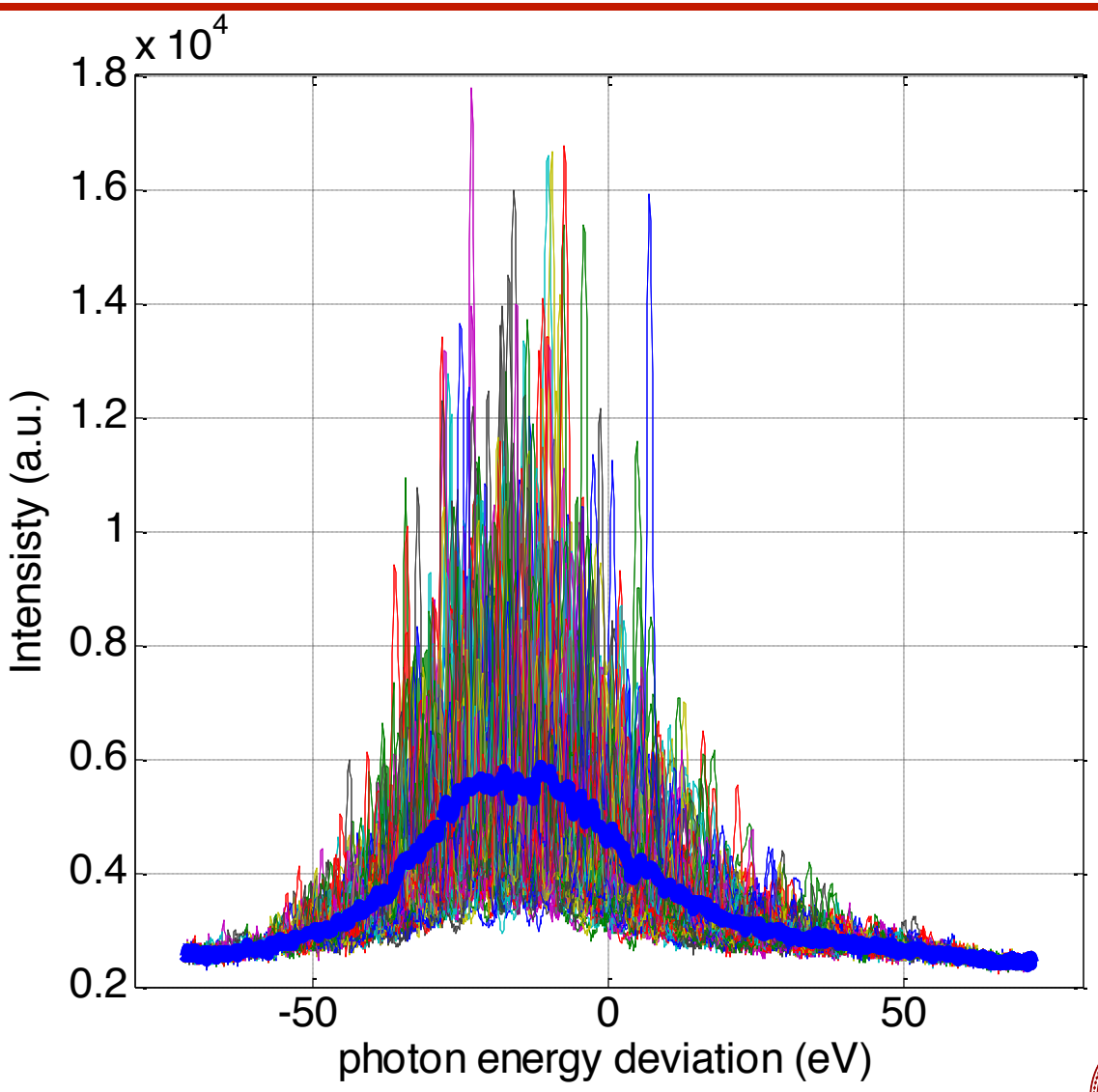
Thanks to William Colocho and Franz-Josef Decker

250 pC cut to 170 pC Overcompressed

Post saturation Taper.

The bandwidth of each shot is calculated, then 100 shots are averaged

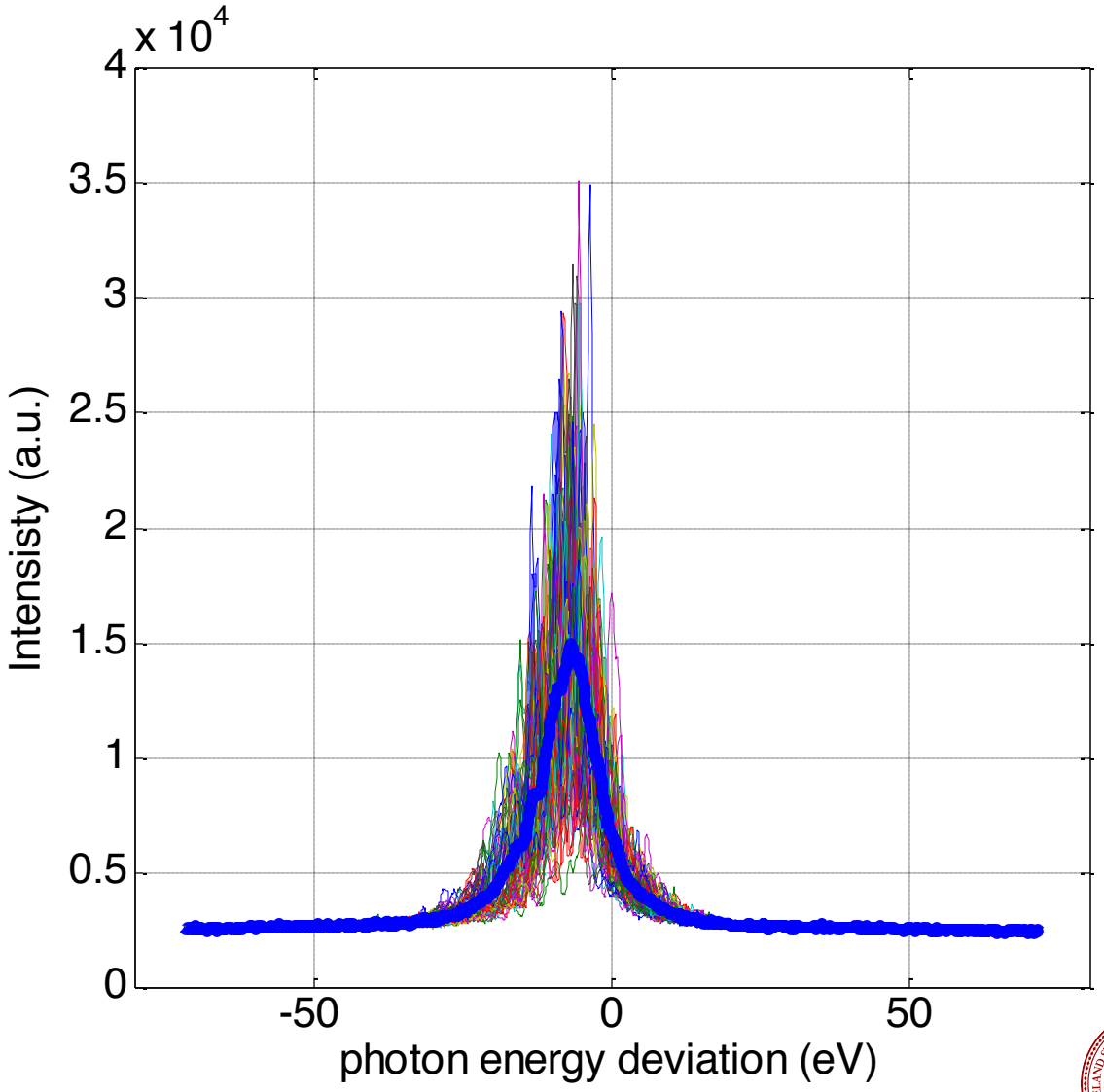
FWHM bandwidth = 36.7+-7.3 eV



250 pC cut to 170 pC Under-compressed

FEE Spectrometer average spectrum.

FWHM Bandwidth = 12.0+-2.3 eV

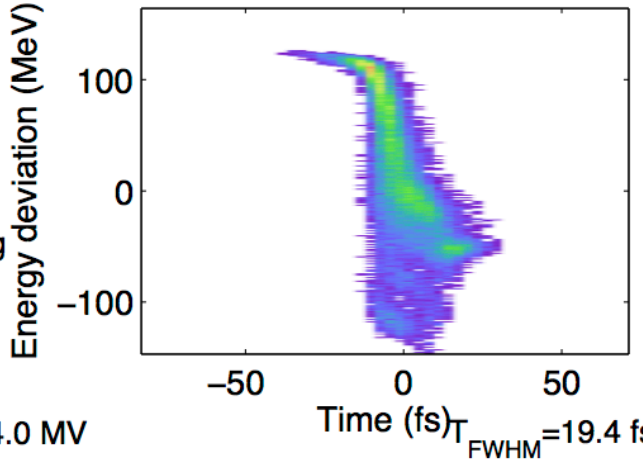


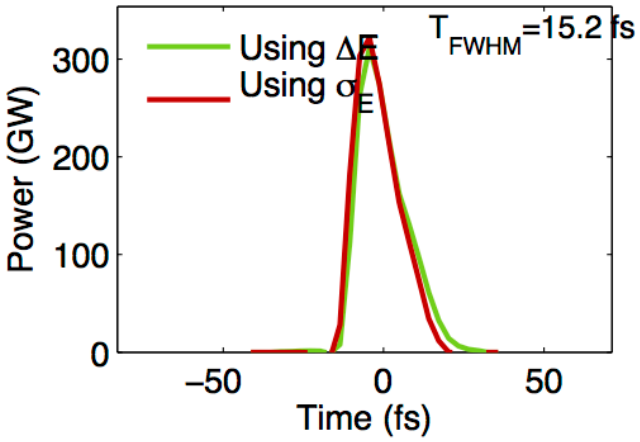
Overcompressed 250 pC cut to 170 pC

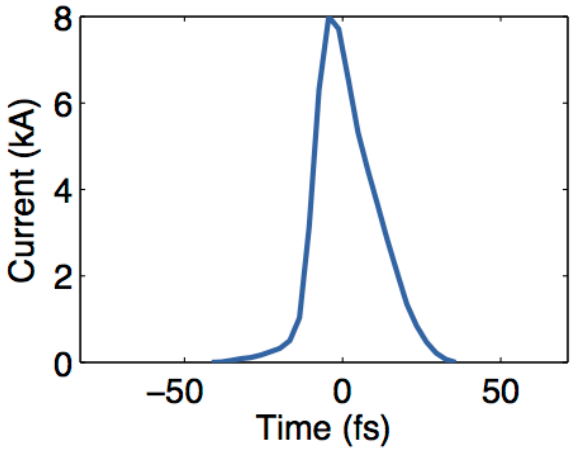
XTCAV single shot data. Here's what you see live. (thanks to Chris Behrens) Bottom right is peak current temporal profile, and left is peak power.

5.24 mJ in 19.4 fs -> ~300 GW

Date and time: 2014–04–16–164705
Shot number: 1
Synchronized data: yes
Background from file: yes
Electron beam energy:13467 MeV
Bunch charge: 171 pC
Bunch current (BC1, BC2): 203 A, 3598 A
X–ray pulse energy: 5.24 mJ
Effective. Streak (init. streak): 2.80 (0.00) mm/deg
Dispersion: 0.433 m
Applied slice width and number: 1.0 and 26
Applied cut level: 4
Actual slice width: 1.0
XTCAV phase and amplitude (DES): 86.4 deg, 44.0 MV







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