Femtosecond Electron and X-ray Beam Diagnostics Using an X-band Transverse Deflector at the LCLS

Yuantao Ding on behalf of

C. Behrens, F.-J. Decker, J. Frisch, Z. Huang, P. Krejcik, H. Loos, T. Maxwell, J. Turner, J. Wang, M.-H. Wang, J. Welch

SLAC National Accelerator Laboratory

SLAC NATIONAL ACCELERATOR LABORATORY

Outline

- Motivation/background
- Principle and design
- Implementation at LCLS
- Recent experimental measurements

Motivation

- X-ray FELs, such as LCLS, provide x-ray pulses typically from 100s femtoseconds (fs) to 10s fs;
- At LCLS, two short-pulse operation modes – low-charge and slotted-foil – have been established to generate <10-fs x-rays;
- The pulses of <10fs are too short to be measured by the present diagnostics at LCLS;
- Developing new schemes for temporal diagnostics with fs-resolution is critical and challenging.
- It would be also helpful to understand the FEL process, and to improve the operation performance.

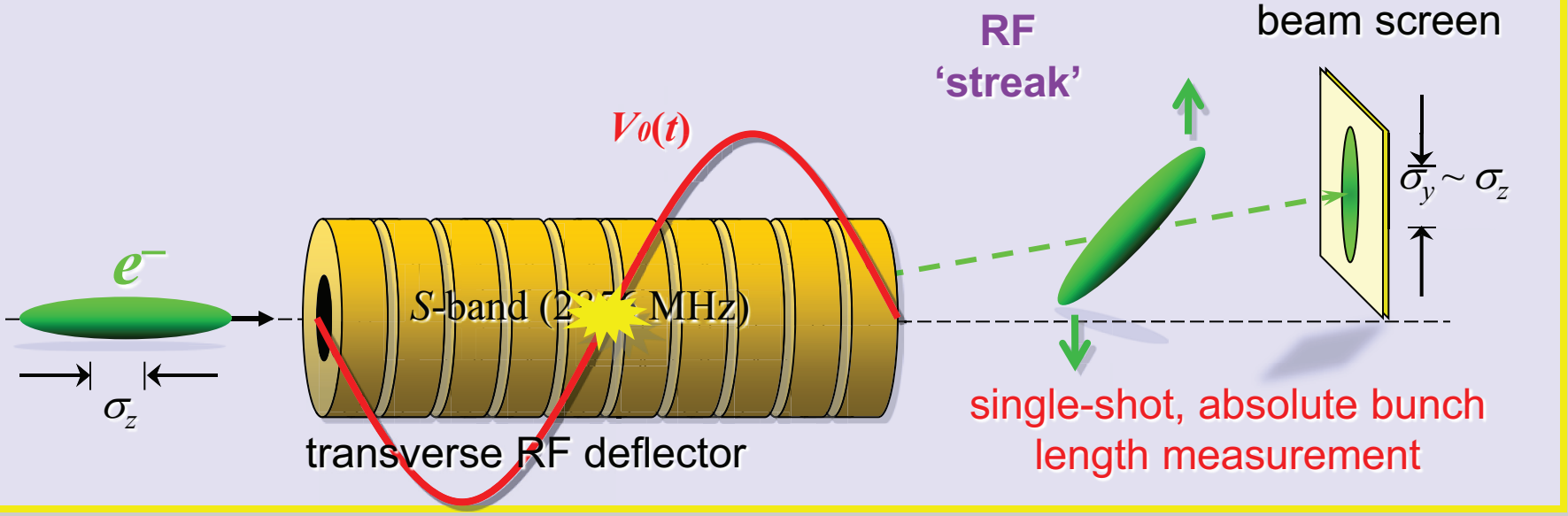
Recent developments at LCLS

- e-beam
  - Longitudinal mapping (Huang et al, PRSTAB2010)
  - Prism-based Mid-IR spectrometer (Maxwell et al, TUOANO03, FEL13)
- x-rays
  - Cross-correlation (Ding et al., PRL2012)
  - Statistical spectral (Lutman et al., PRSTAB2012)
  - THz-streaking (A. Cavalieri et al.)
- **X-band transverse deflector (XTCAV)**

  (Ding et al., PRSTAB2011)

  → to measure e-beam and x-rays simultaneously, single-shot.

TCAV: an RF "streak" camera for e-beam



X-band TCAV:	
Frequency	11.424 GHz
Maximum kick	48 MV@40MW

Temp. resol.

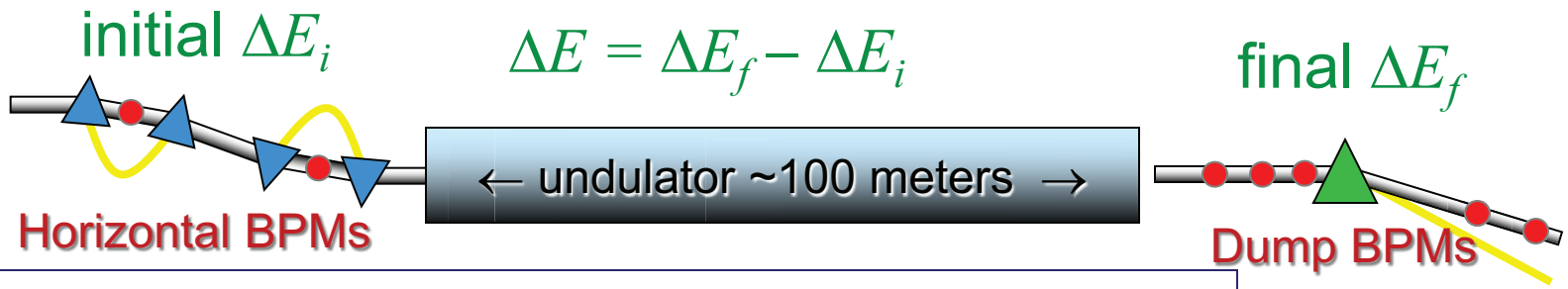
$$\sigma_{t,R} \propto \frac{\lambda_{rf}}{V_0}\sqrt{E\frac{\varepsilon_{N,x}}{\beta_x(s_0)}}$$

HXR: *(14GeV)*	***SXR:*** *(4.3GeV)*
Calib.factor =42, $\sigma_{t,R} \sim$ ***3 fs;***	*Calib. factor =136,* $\sigma_{t,R} \sim$ ***1 fs;***

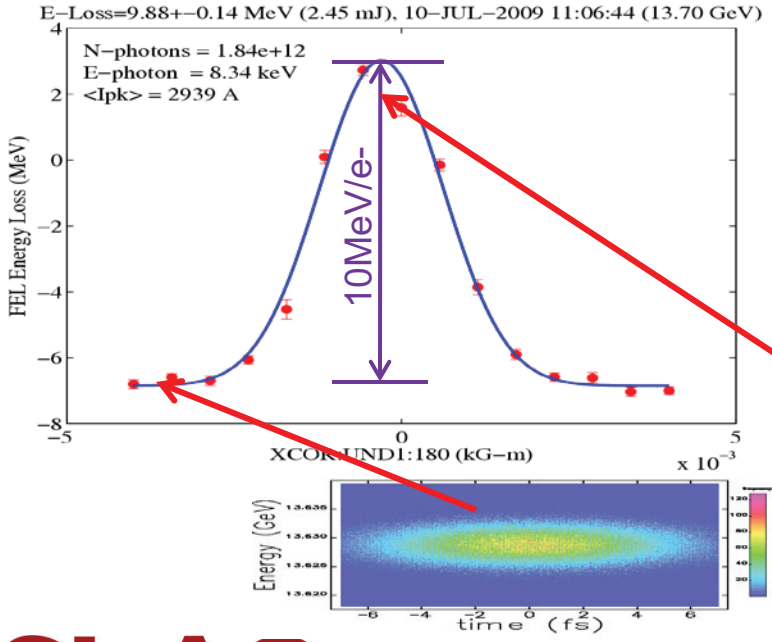
SLAC NATIONAL ACCELERATOR LABORATORY

How to retrieve x-ray temporal profile?

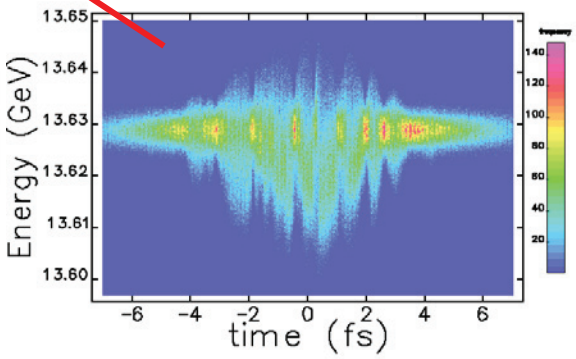
- The E-loss scan for measuring x-ray pulse energy:

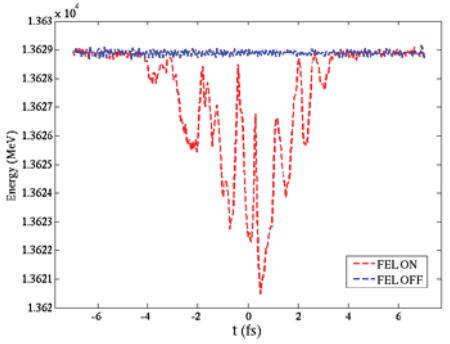


vary FEL power with oscillations & record e^- energy loss

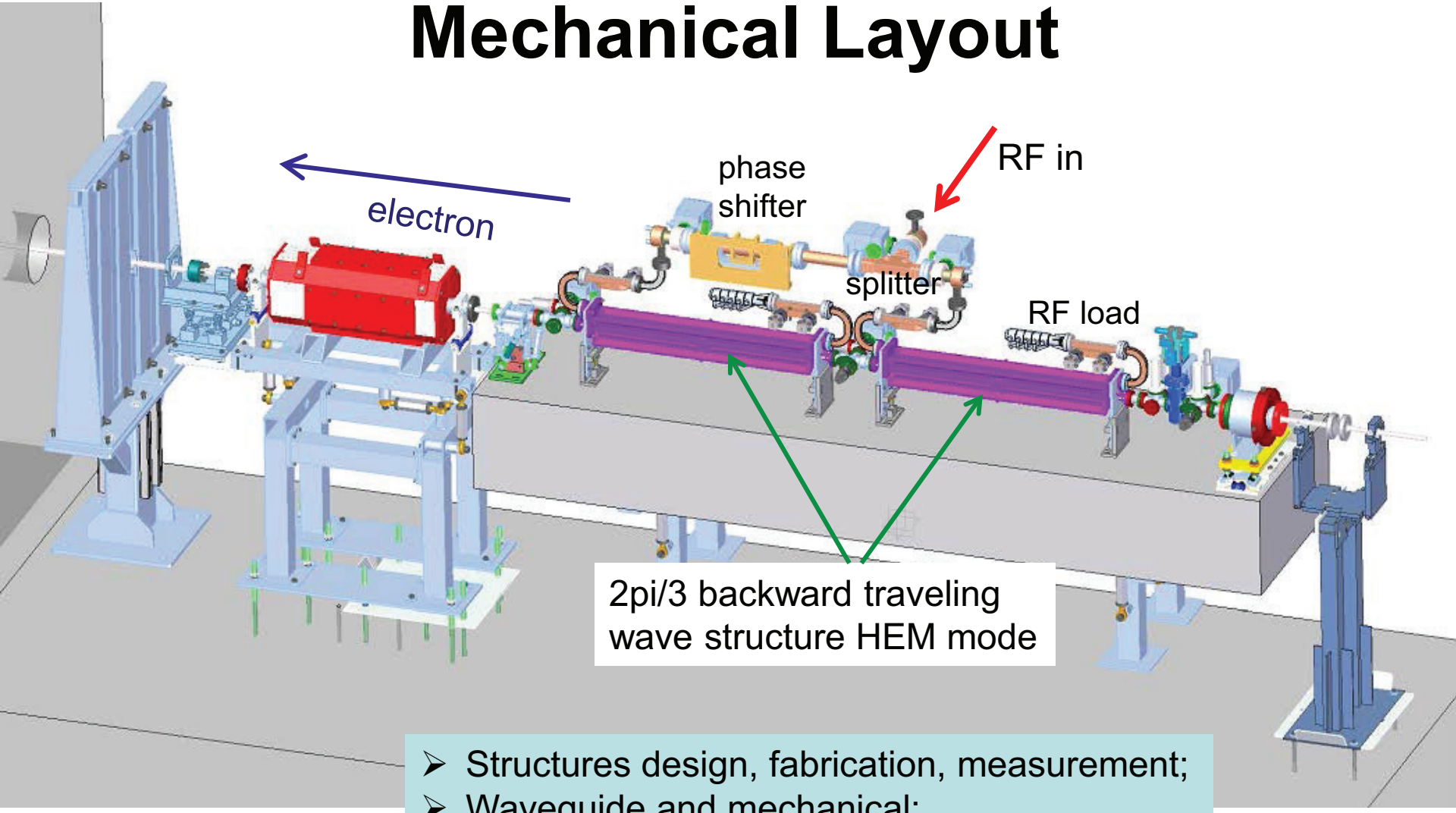


→ to measure the ***time-resolved*** energy loss or energy spread, after the undulator. (**Ding et al., PRSTAB2011**)





Mechanical Layout

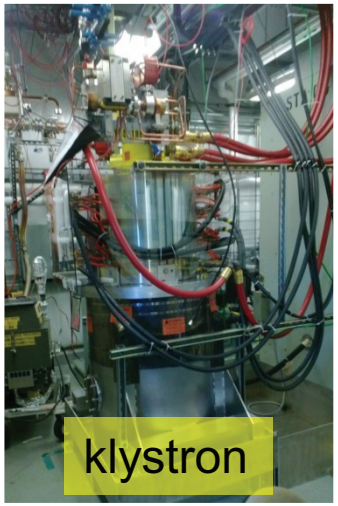


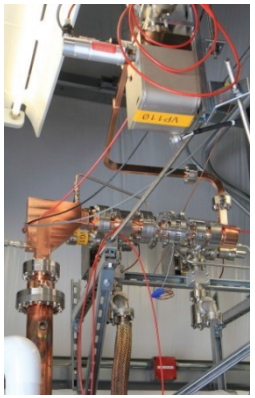
(Courtesy of Eric Bong)

- Structures design, fabrication, measurement;
- Waveguide and mechanical;
- Klystron and modulator;
- LLRF and controls;
- Safety and protection;
- Electrical AC power and cooling.
- etc.

SLAC NATIONAL ACCELERATOR LABORATORY

The whole system is ready in April 2013, commissioning started in May.

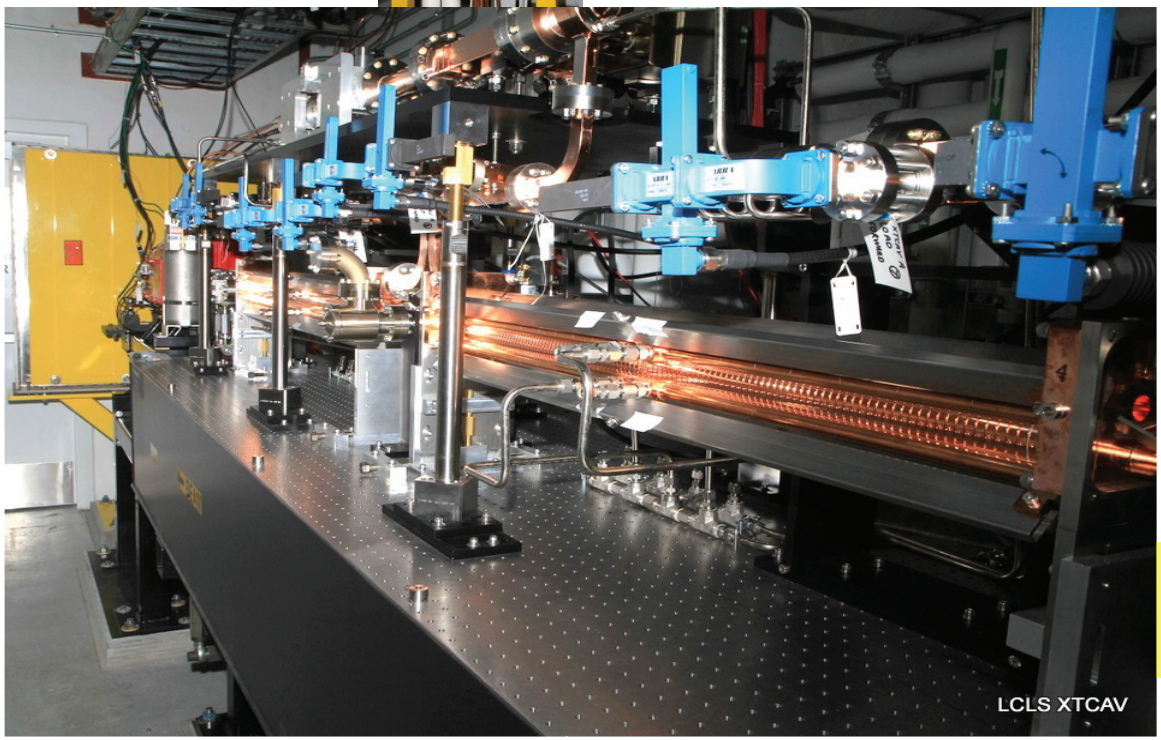

klystron




waveguide


PAC, PADS, MKSU-II


modulator



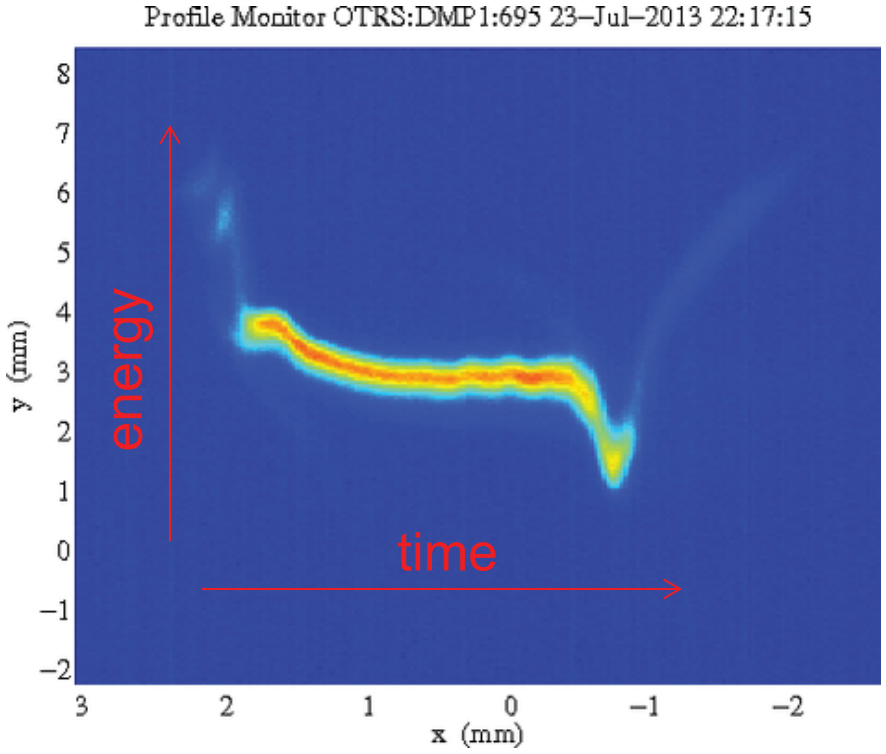

TWTA, klystron mag. Suppl.

SLAC NATIONAL ACCELERATOR LABORATORY

(Pictures courtesy of P. Krejcik)

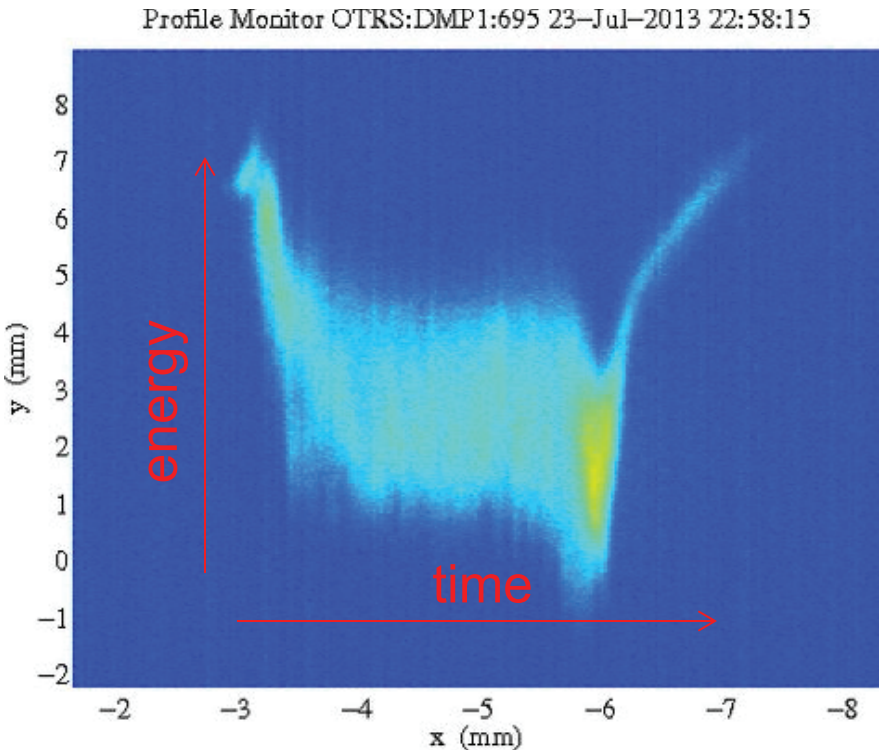
Measurement examples: 4.7GeV, 150pC (raw images)

Bunch head on the left



FEL-OFF

(baseline)

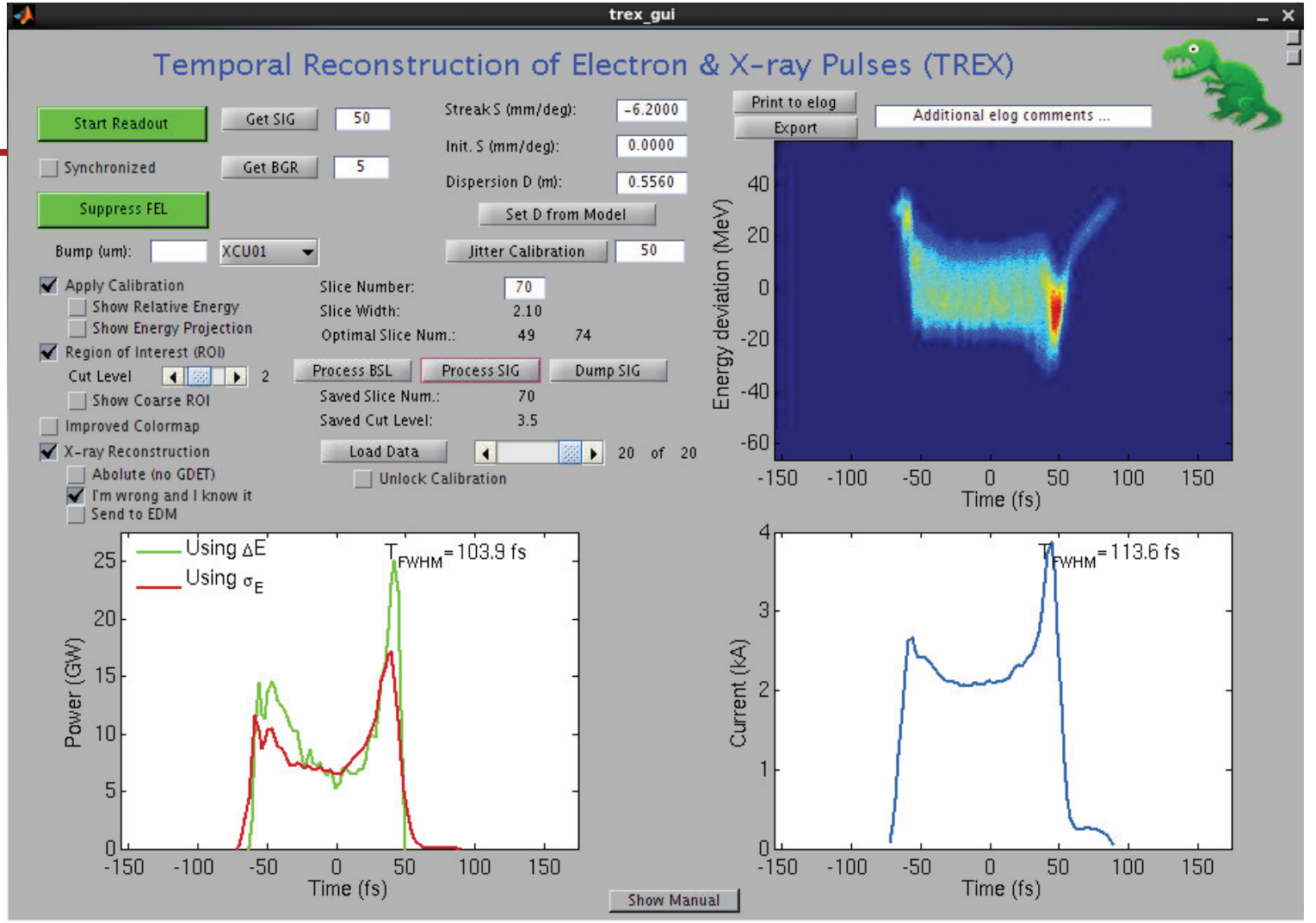


FEL-ON

(~1mJ pulse energy in this example).

SLAC NATIONAL ACCELERATOR LABORATORY

Data processing

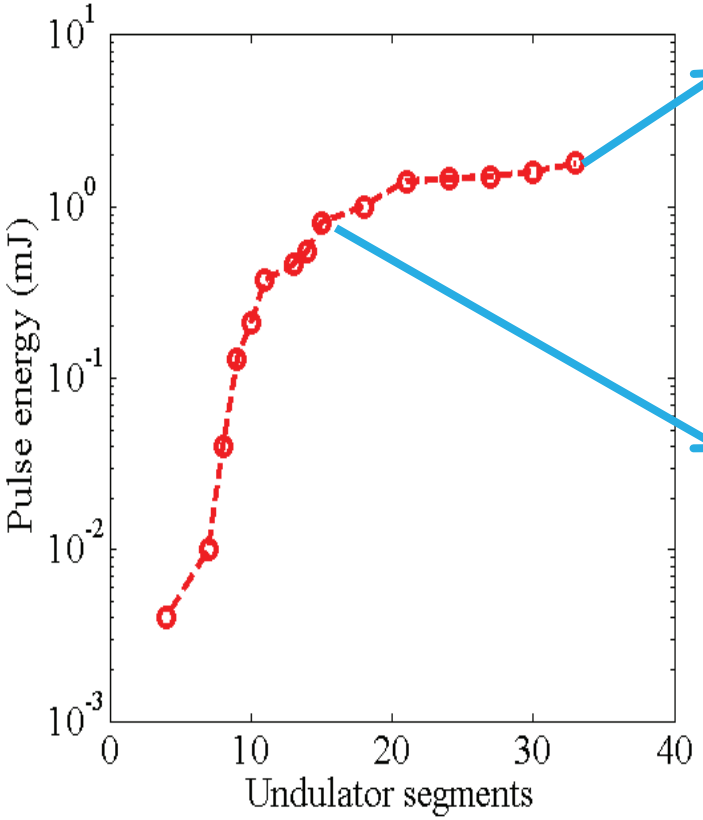


- Calibration (time and energy); (C. Behrens)
- Record baseline images (FEL-off);
- Image processing, slicing and averaging baseline data;
- Take single-short image (FEL-on) and other beam parameters;
- Reconstruct electron and x-ray temporal profile.

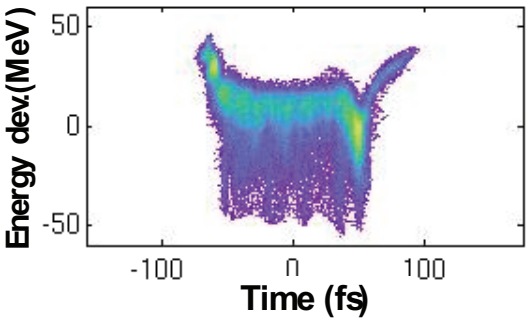
SLAC NATIONAL ACCELERATOR LABORATORY

SXR Examples at 4.7GeV, 150pC (1keV)

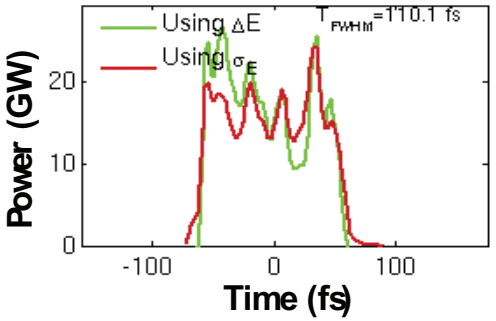
FEL power gain curve



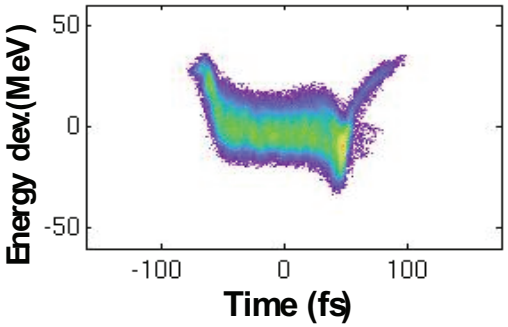
At U33: 2 mJ



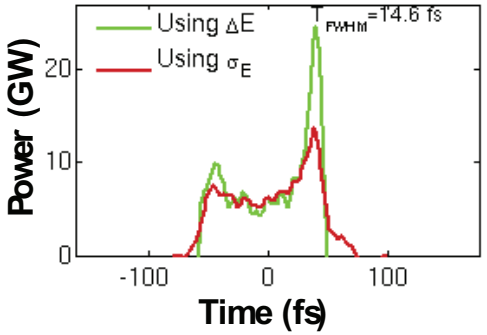
X-ray temp. profile



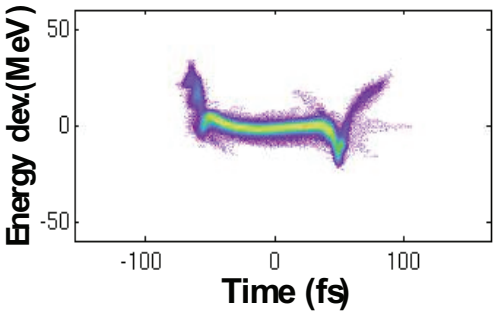
At U15: 0.8 mJ



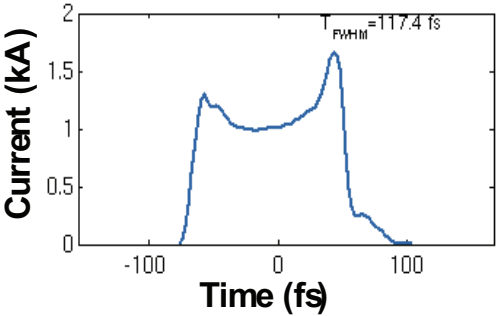
X-ray temp. profile



Lasing-off

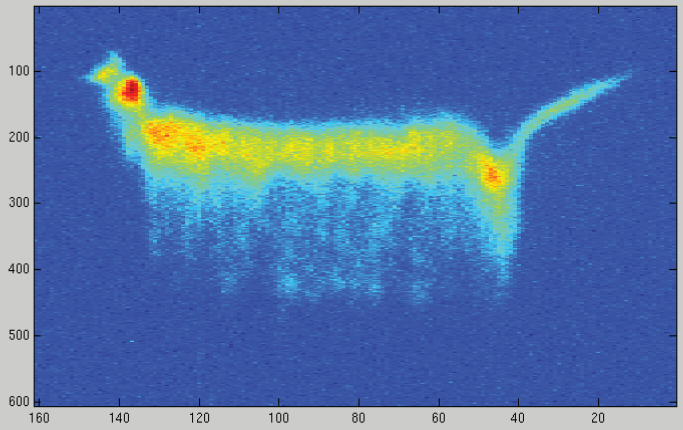


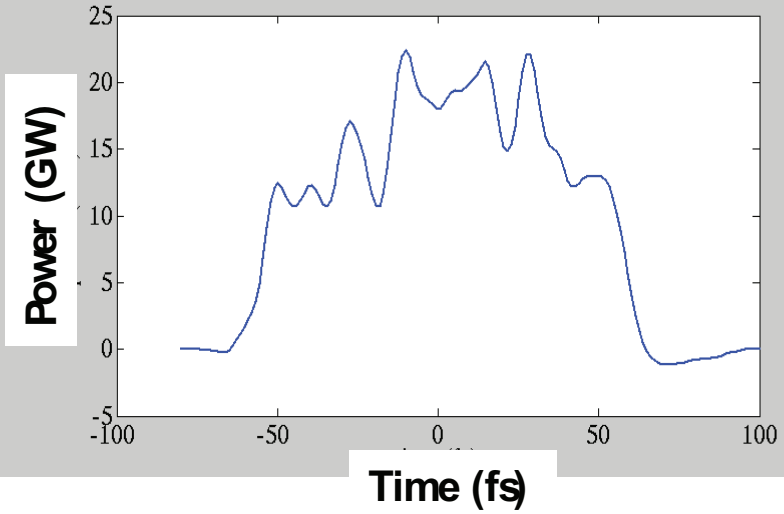
e-beam temp. profile



SLAC NATIONAL ACCELERATOR LABORATORY

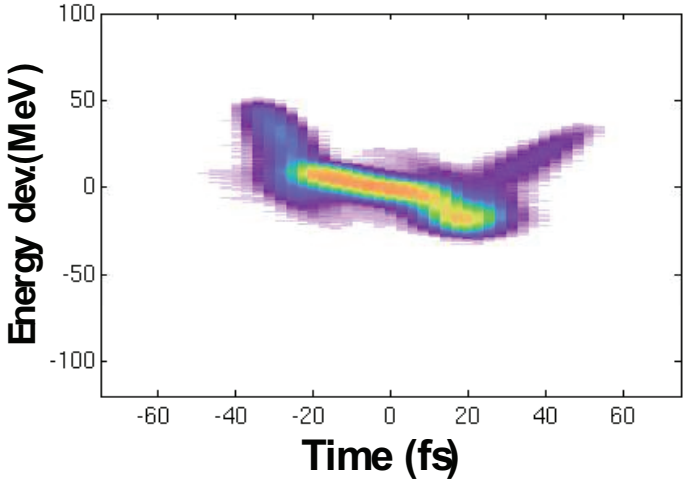
10 consecutive shots (150pC, 1keV)



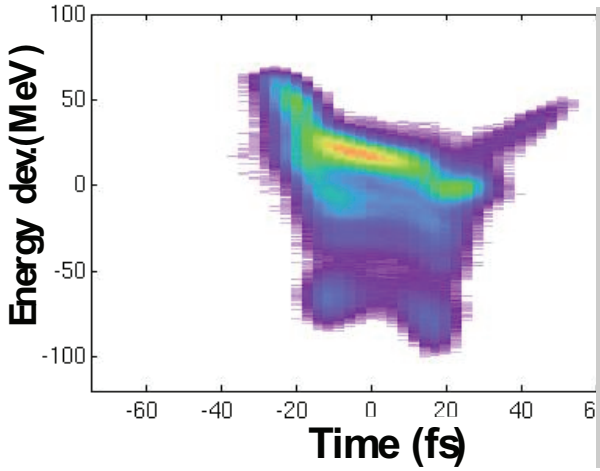


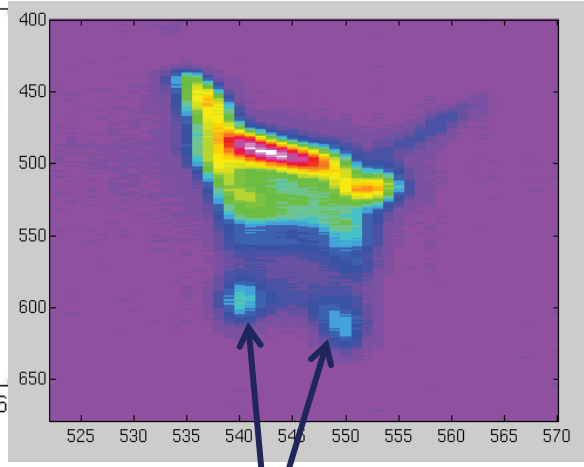
HXR examples at 15.2GeV, 150pC, 10.2keV

Lasing off

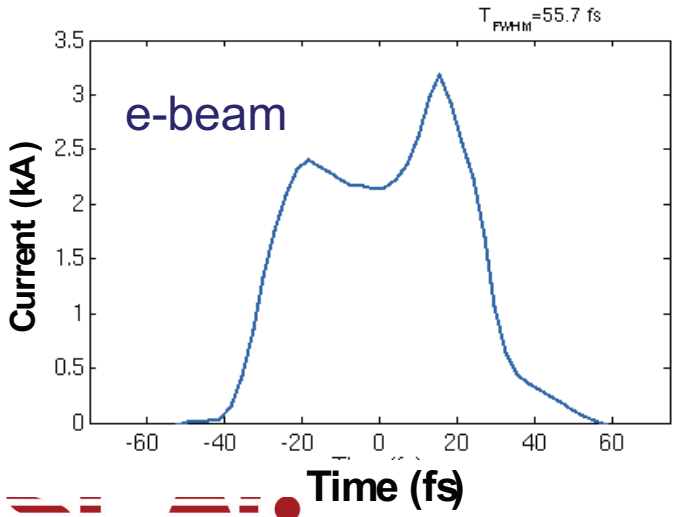


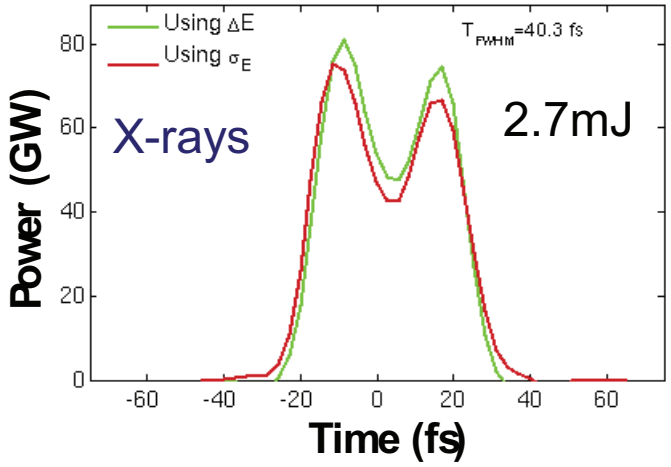
Full lasing





Trapped electrons after saturation.



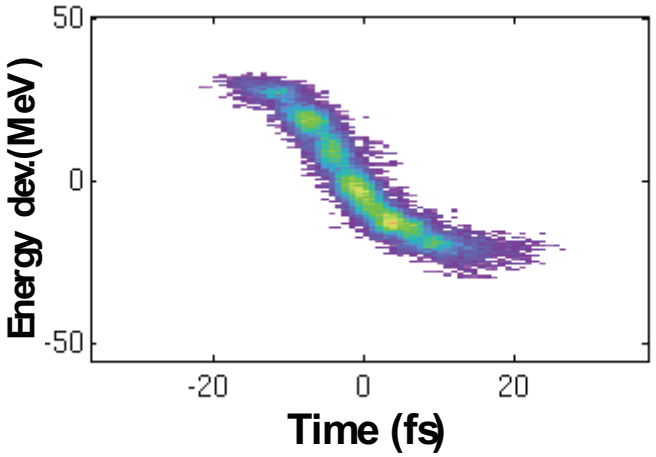


SLAC NATIONAL ACCELERATOR LABORATORY

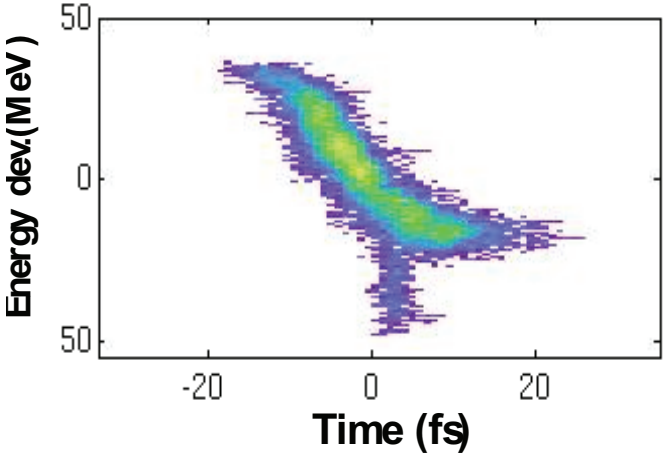
LELAND STANFORD JUNIOR UNIVERSITY

20pC, 1keV examples

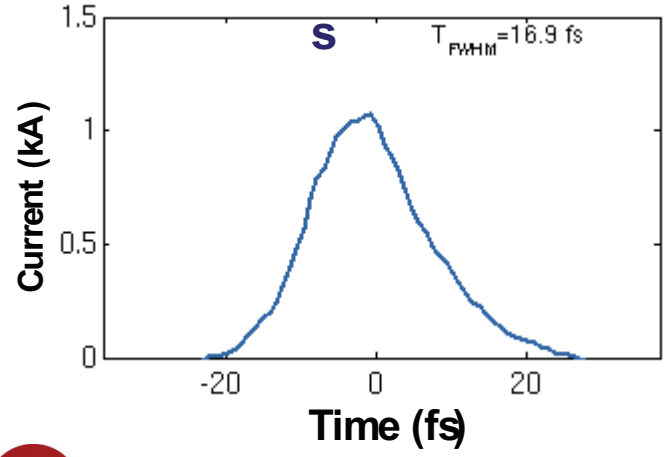
Lasing off



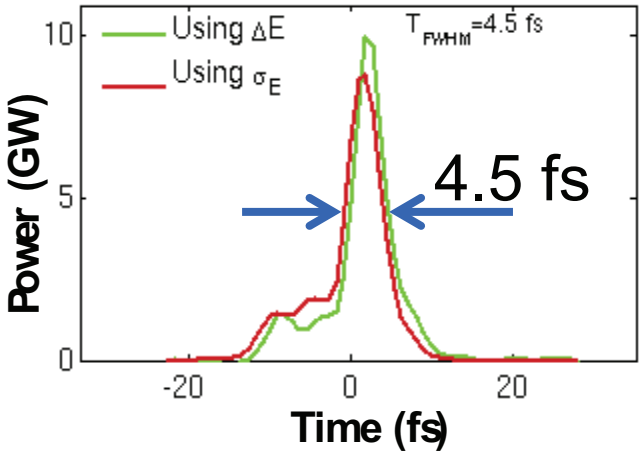
Lasing on



Electron s



X-rays

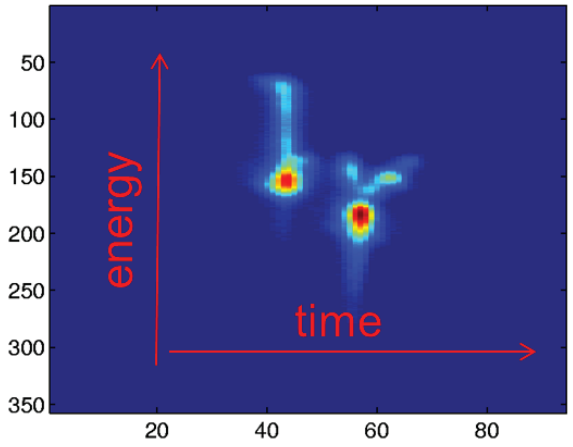


Further data analysis is on-going…

SLAC NATIONAL ACCELERATOR LABORATORY

Summary and outlook

- Demonstrated single-shot, non-invasive x-ray temporal diagnostics with fs resolution using XTCAV;
- It will provide x-ray pulse length and profile for user experiments for each shot at 120Hz.
- XTCAV provides a useful tool for FEL R&D studies: self-seeding, pulse shape control, micro-bunching, multi-pulse mode, collimation and slotted foil, wake fields, energy spread, etc.
- More fun is coming….



Marinelli et al., MOPSO12

Acknowledgements

- we are indebted to the SLAC community for their contributions:

- P. Emma for his contributions and earlier work on TCAV systems
- P. Krejcik for project management and coordination.
- J. Wang, V. Dolgashev and G. Bowden for concept and design of the X-band structures
- Engineering: R. Akre, E. Bong, M. Boyes, S. Condamoor, J.P. Eichner, G. Gassner, A. Haase, B. Hong, A. Khalid, J. Lewandowski, B. Morris, J. Olsen, D. Sprehn, A. Wu
- SLAC engineering, controls, operations, safety, and RF groups for their dedicated support.
- And thanks to all of the XTCAV commissioning team!

Thank you!

SLAC NATIONAL ACCELERATOR LABORATORY