Results from the LCLS X-band transverse deflector with femtosecond temporal resolution

Yuantao Ding

On behalf of

C. Behrens, F.-J. Decker, Y. Ding, V. A. Dolgashev, J. Frisch, Z. Huang, P. Krejcik, H. Loos, A. Lutman, A. Marinelli, T. J. Maxwell, D. Ratner, J. Turner, J. Wang, M.-H. Wang, J. Welch, and J. Wu

SLAC National Accelerator Laboratory

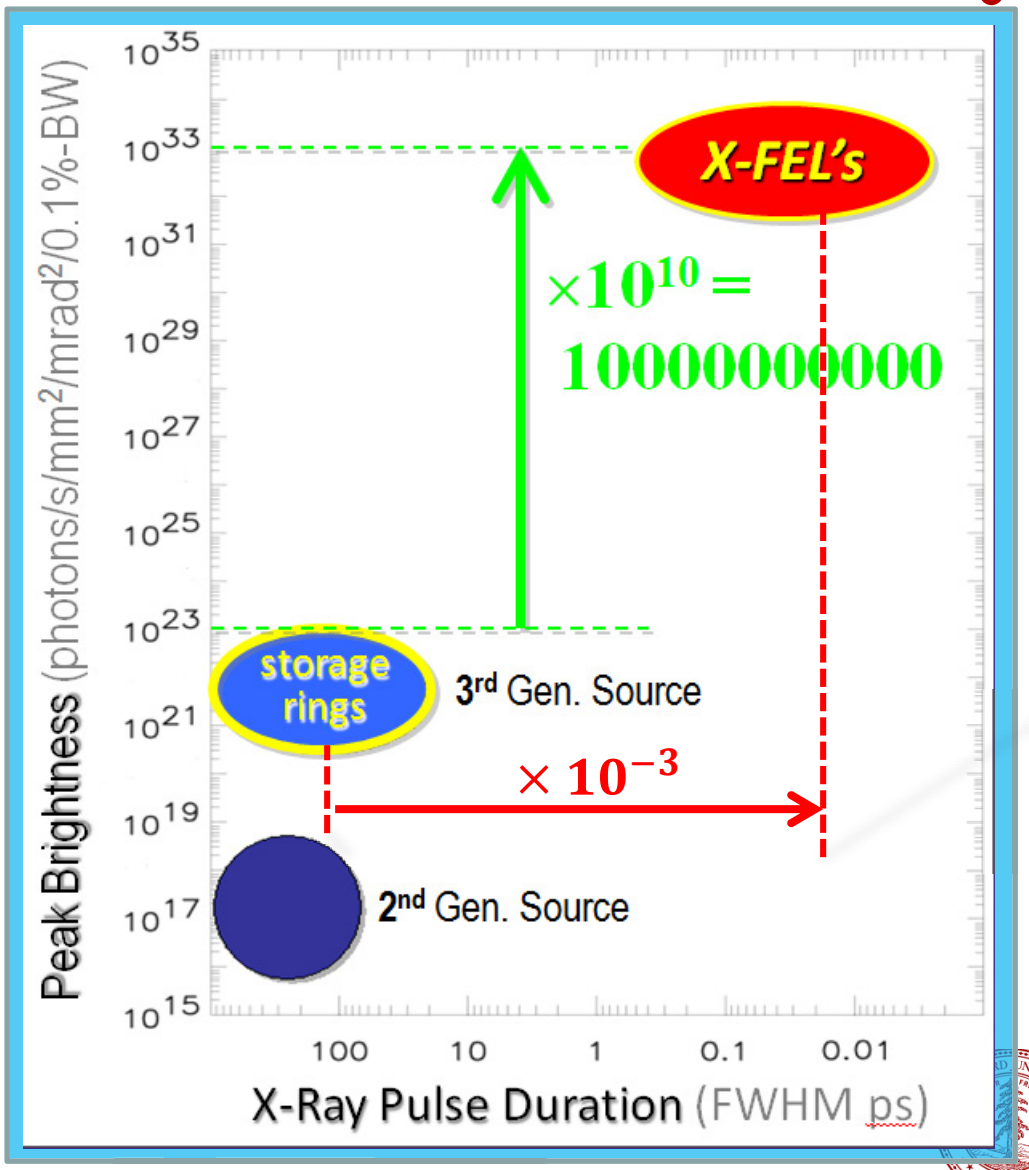
X-band transverse deflector (XTCAV) at LCLS

- Background/motivation of the project
- Principle, design and realization
- **Recent experimental results**
- Discussion

Reference: **C. Behrens et al., *Nature Communications,* 5:3762 (2014).**

XFELs: the 4th generation light source

- ~10 orders higher peak brightness and ~3 orders shorter pulse duration.
- X-ray FELs: probe of the ultra-small and ultra-fast worlds;
- Temporal diagnostics are very challenging.



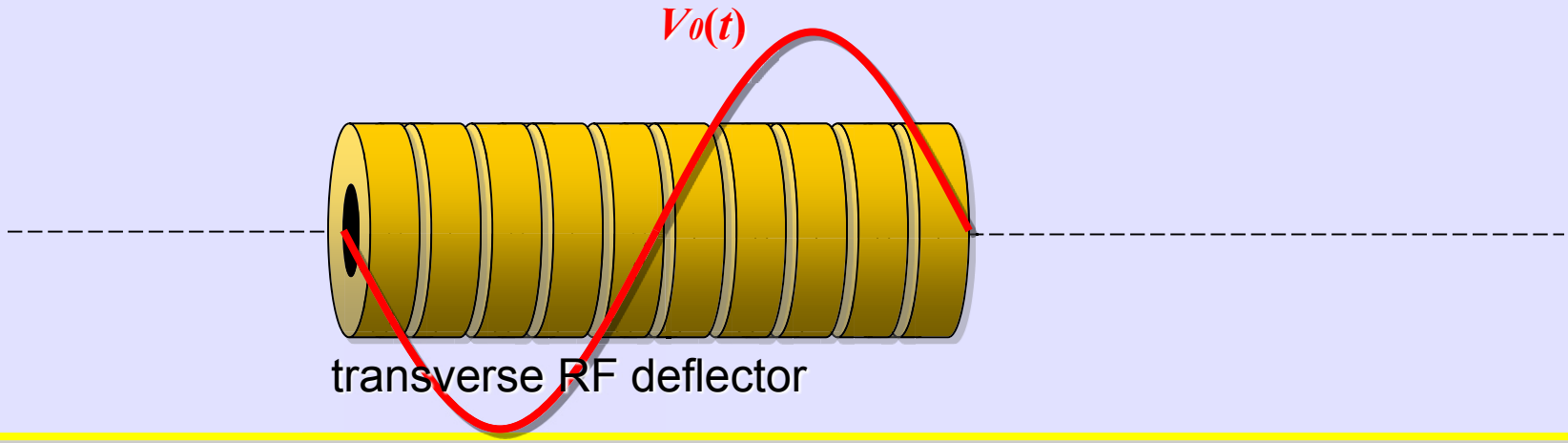
H.-D. Nuhn, H. Winick

Motivation / Goal

- **Measure X-ray pulse duration and temporal shape;**
- **Resolution: ~fs, shorter is better…**
- **Single-shot, non-invasive to operation, large dynamic range.**
- Other methods have been studied: THz streaking, statistical (spectral) analysis, correlation…
- We proposed to measure the lasing effect on the electron bunch with a transverse deflector in 2011.

  (***Ding et al., PRSTAB 14, 120701***)
- This device was commissioned in 2013 summer, and now it is operational.

TCAV: an RF “streak” camera for e-beam



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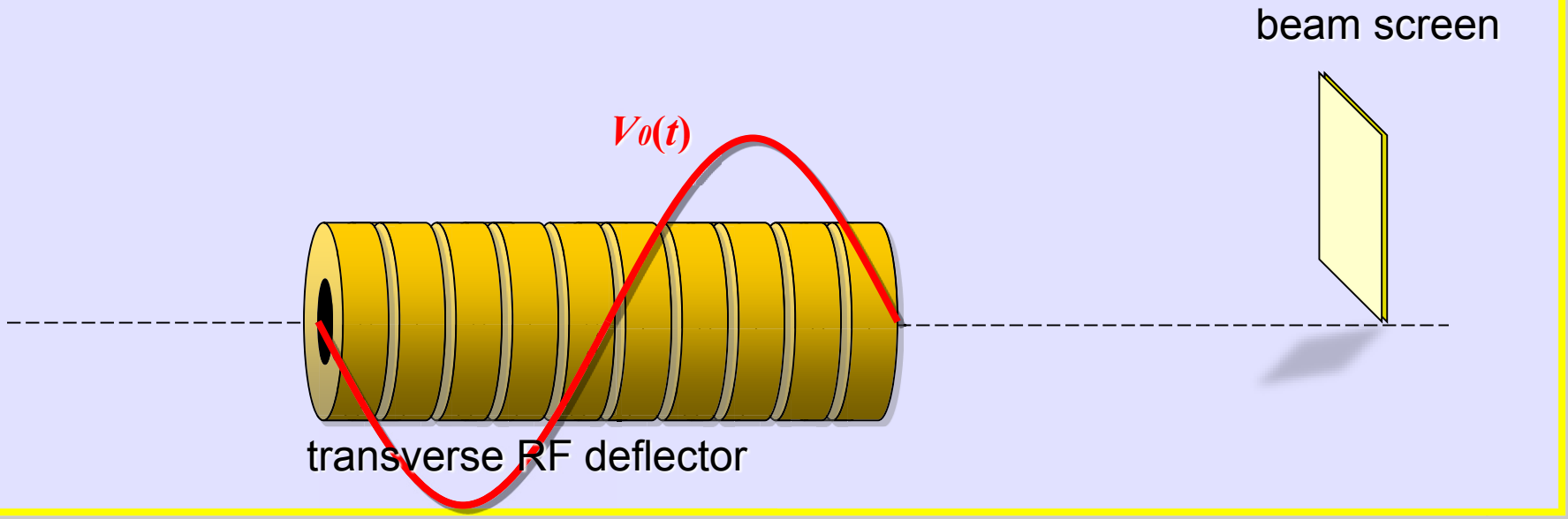

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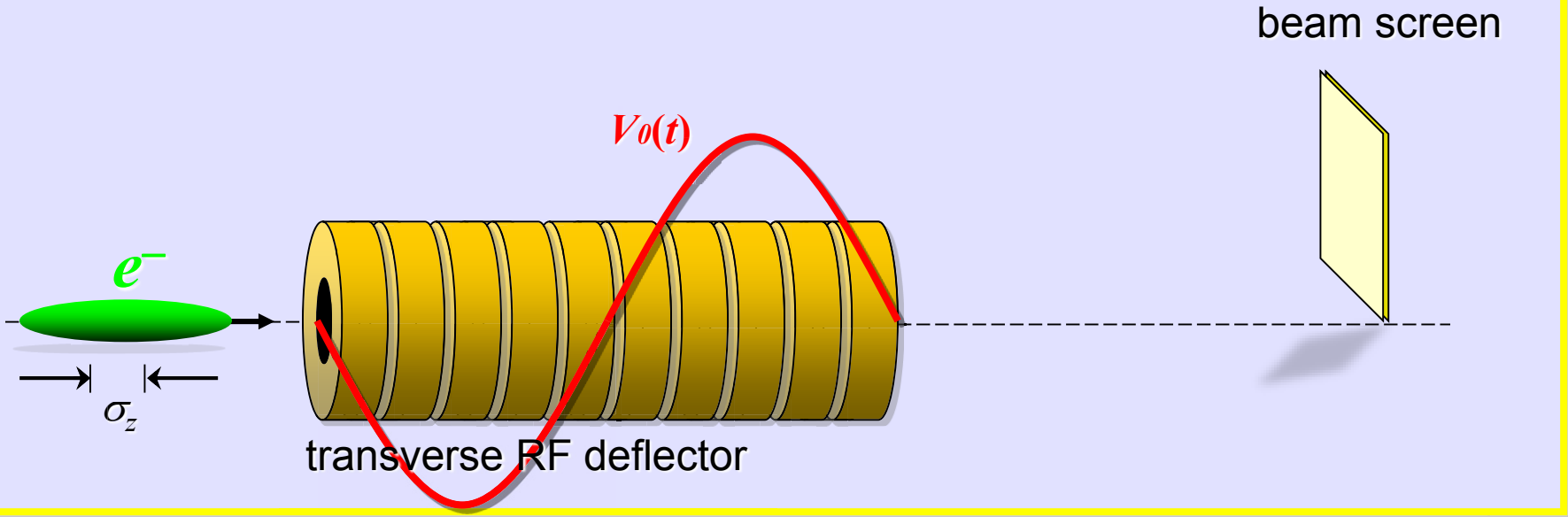

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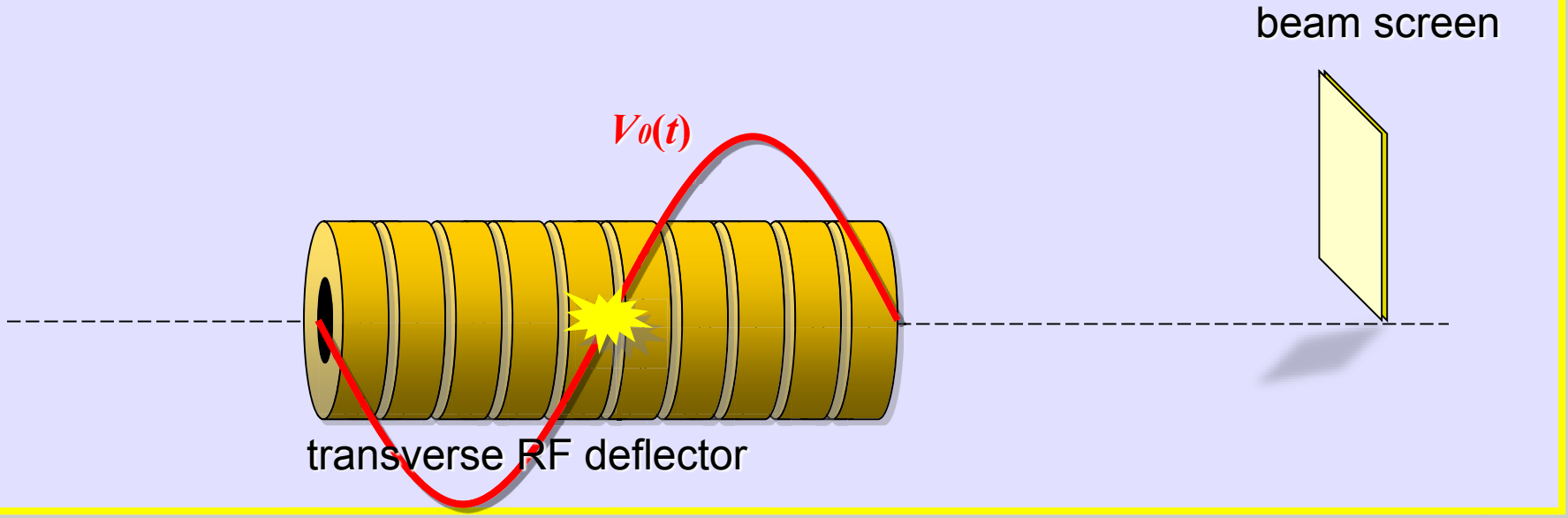

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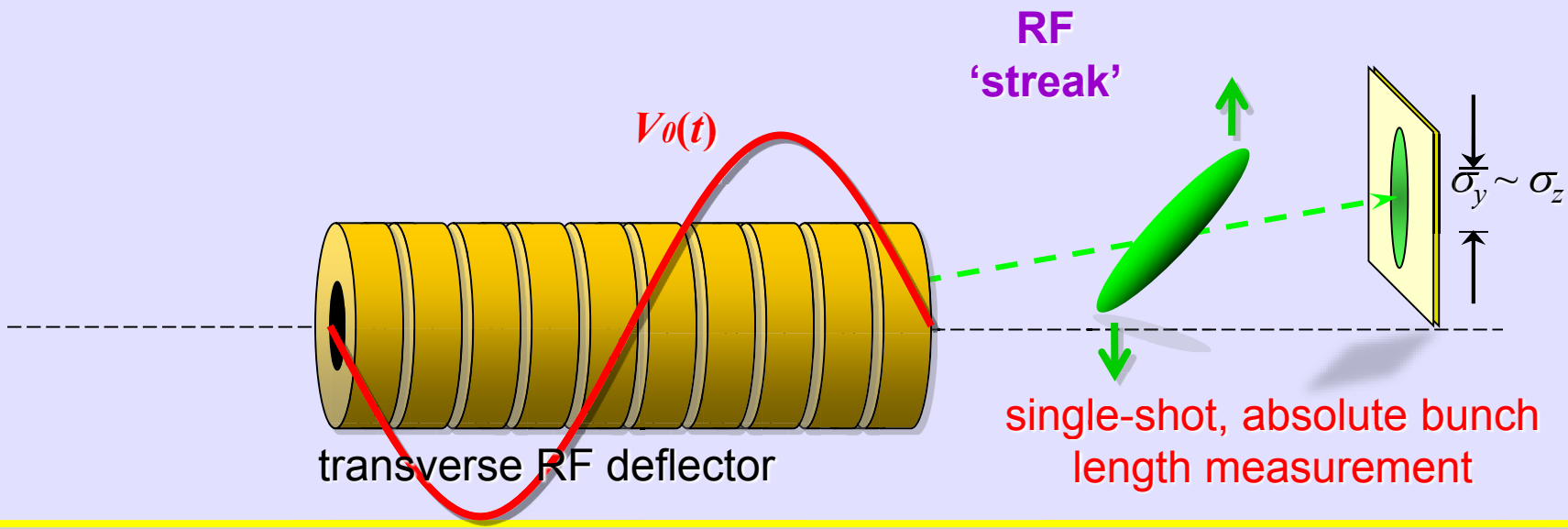

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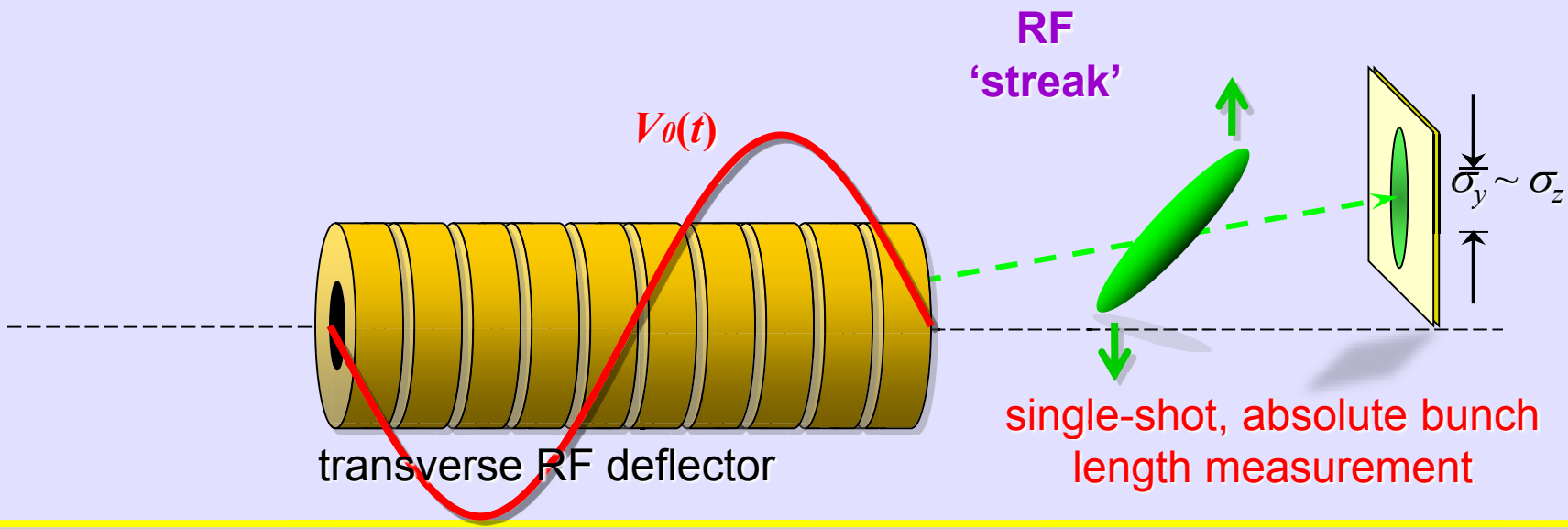

X-band TCAV:	
Frequency	11.424 GHz
Maximum kick	44 MV@35MW

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 ~40, $\sigma_{t,R} \sim$ ***3 fs;***	*Calib. factor ~120,* $\sigma_{t,R} \sim$ ***1 fs;***

How to retrieve x-ray temporal profile?

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

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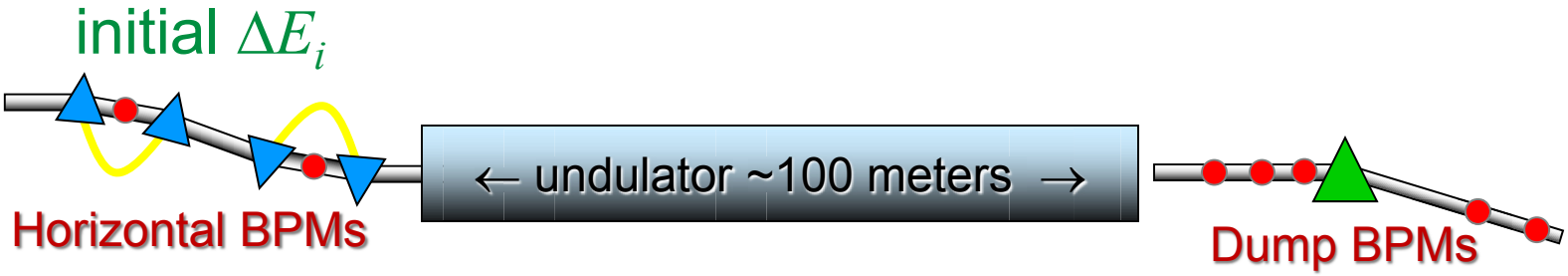

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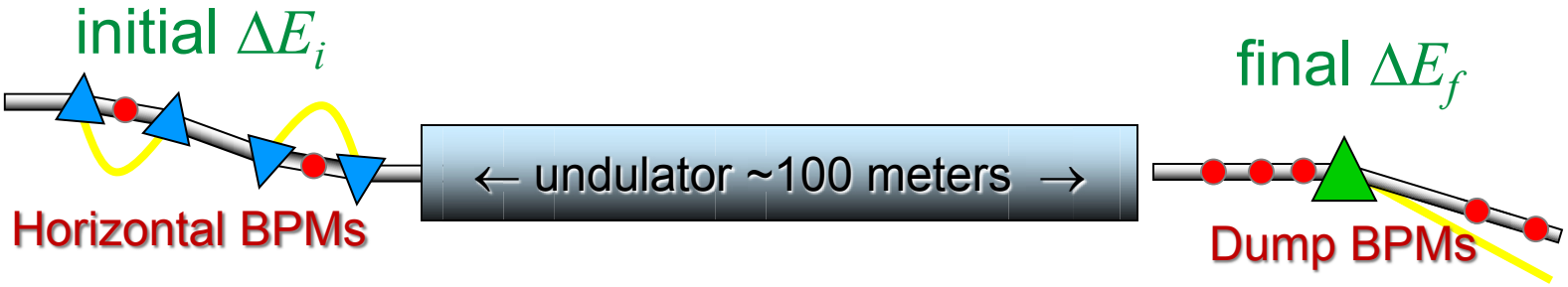

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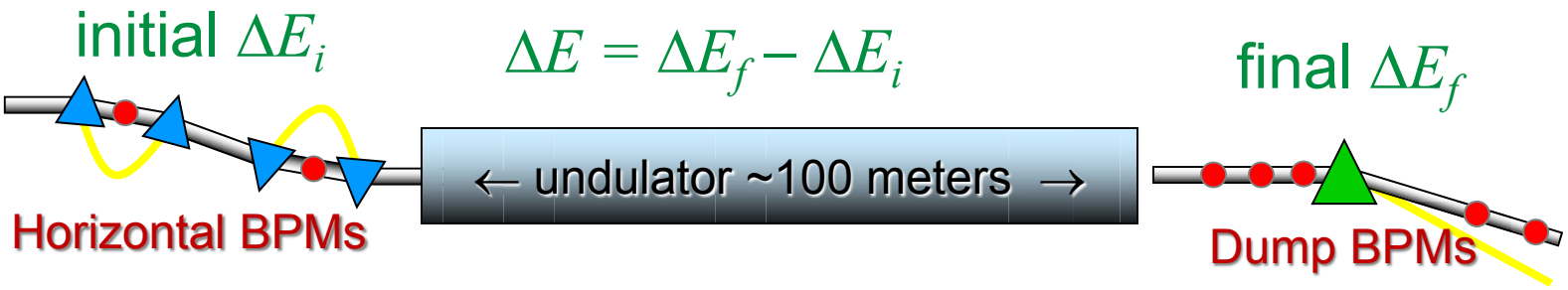

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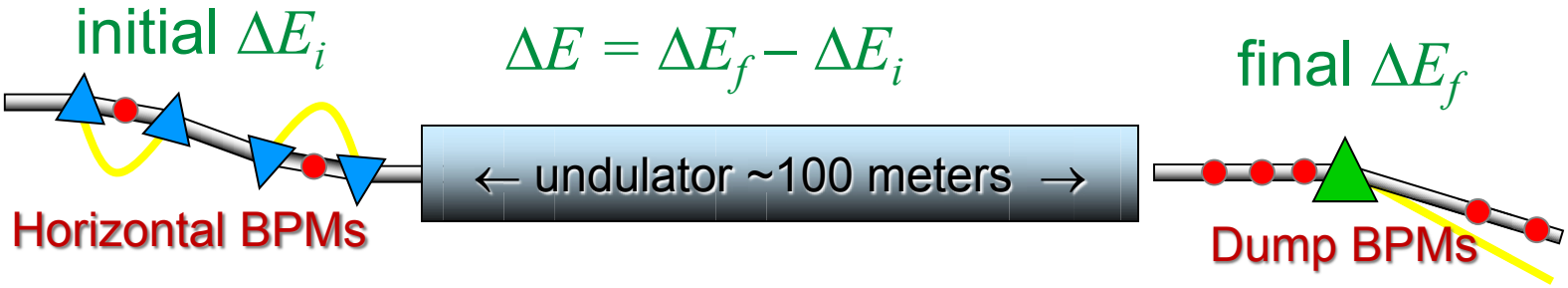
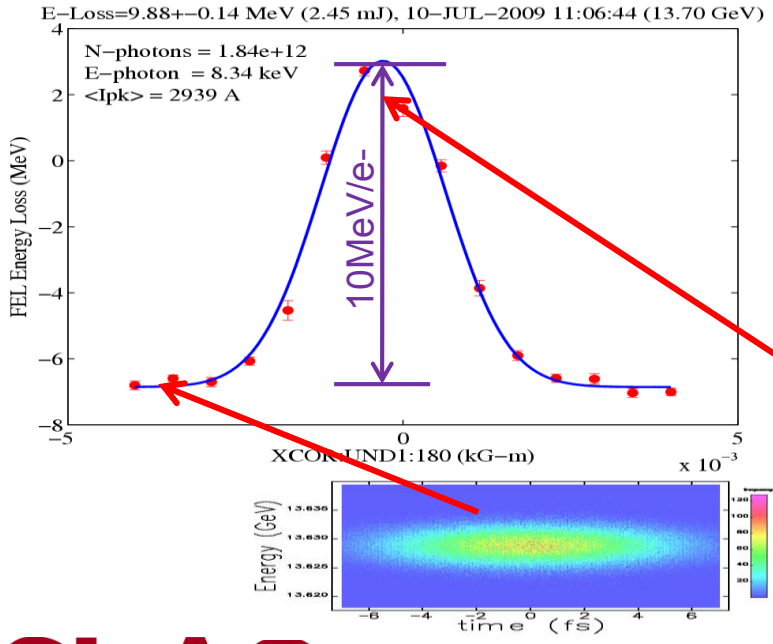
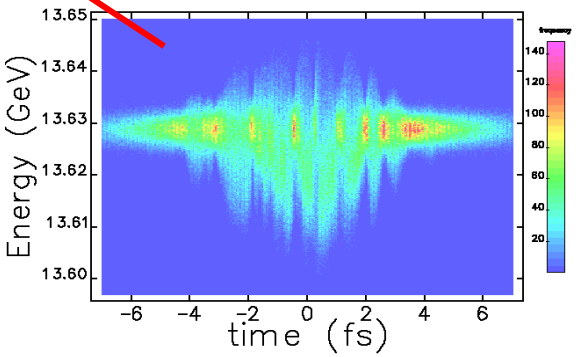
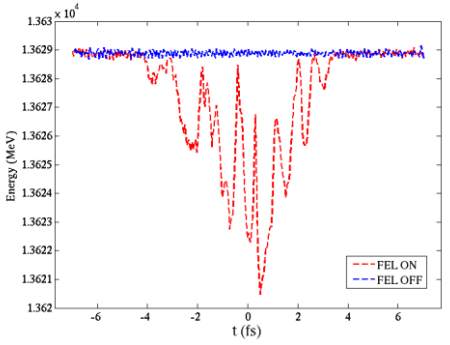




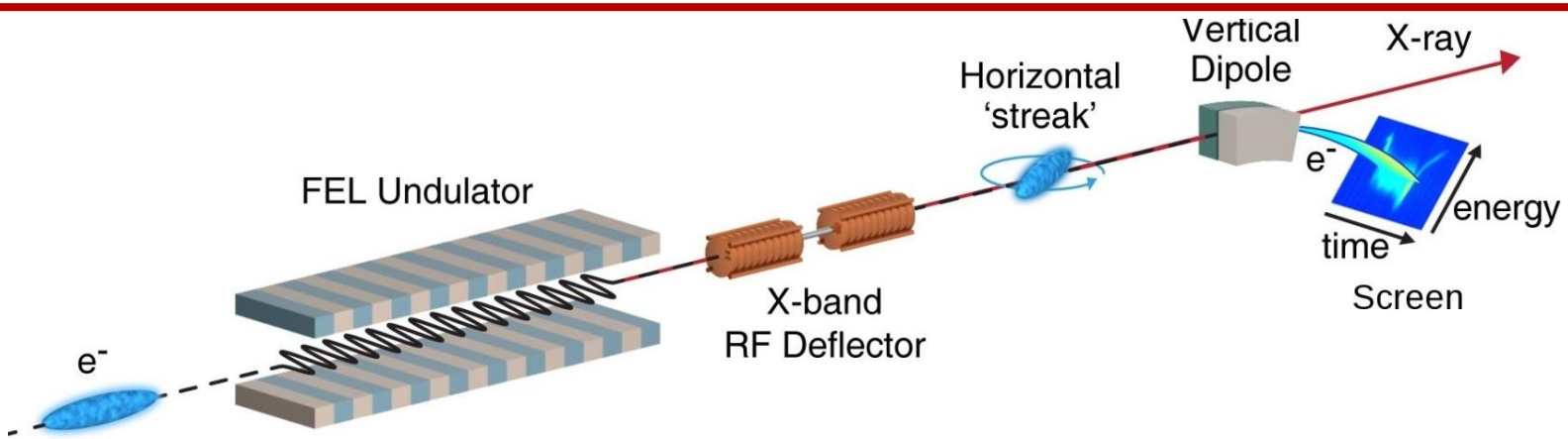
→ to measure the ***time-resolved*** lasing effect ("footprint") left on the electron bunch.

(***Ding et al., PRSTAB 14, 120701***)





XTCAV at LCLS



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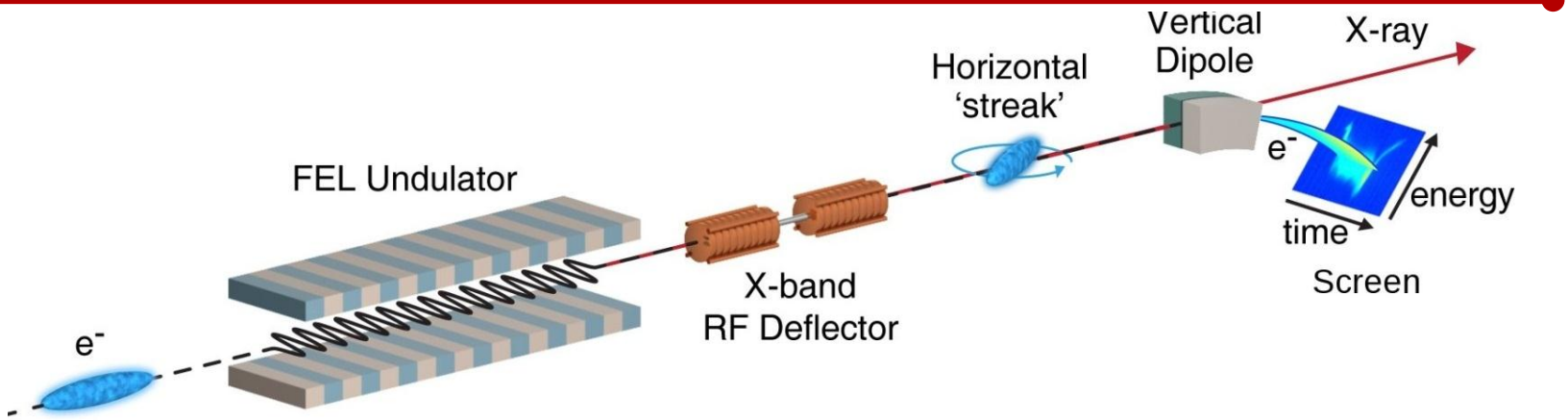
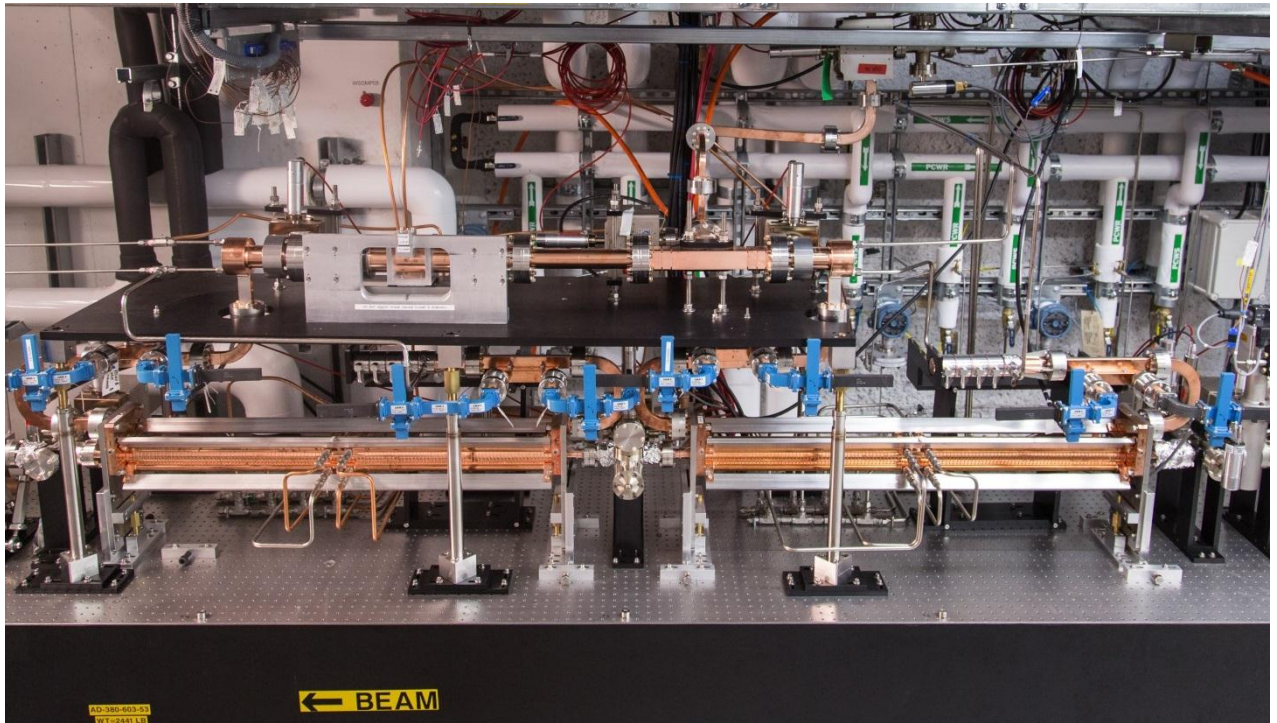
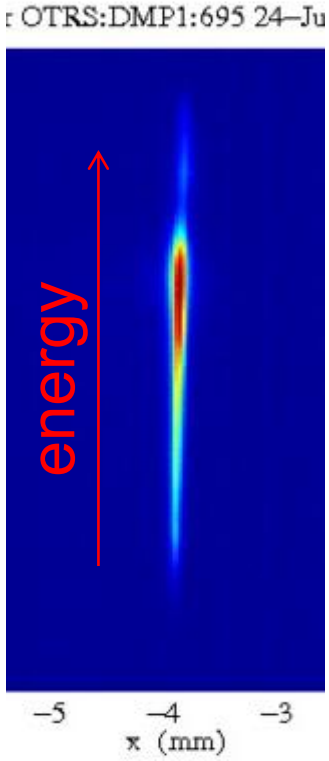


Installed at the LCLS beamline (May 2013)

Structure design and tuning
(J. Wang, V. Dolgashev et al.)



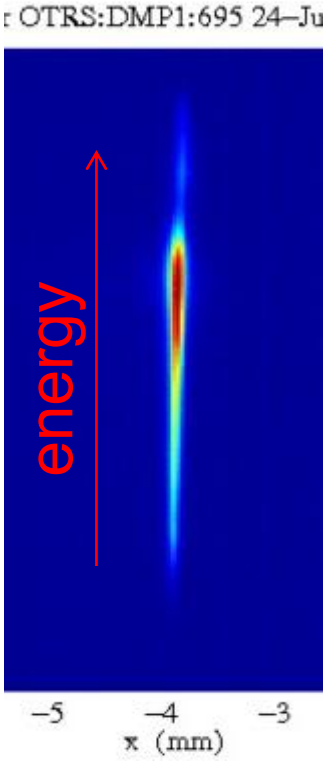
Measurement examples: 4.7GeV, 150pC (raw images)



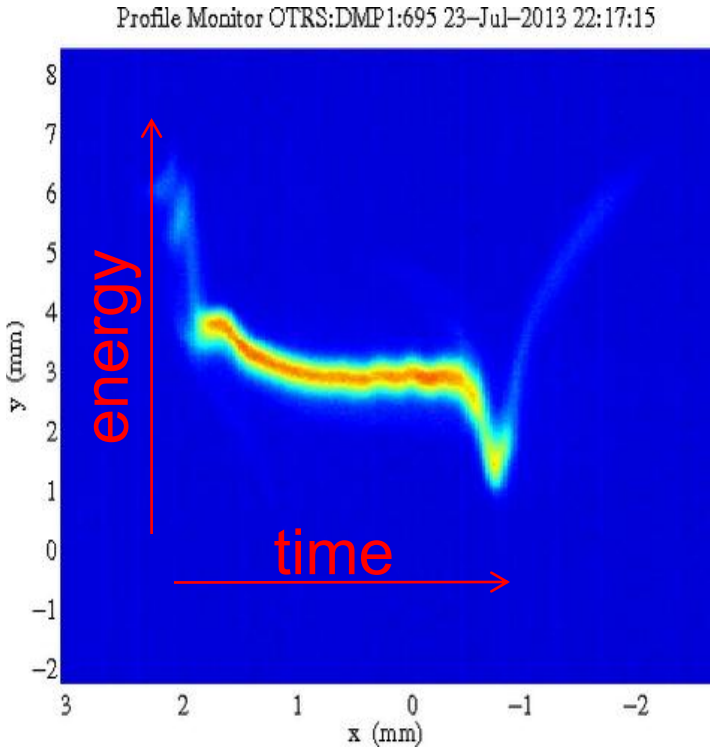
XTCAV OFF

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

Bunch head on the left



XTCAV OFF



XTCAV ON, FEL-OFF

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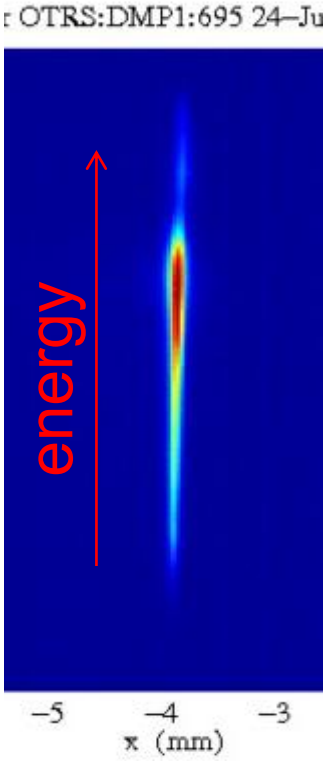
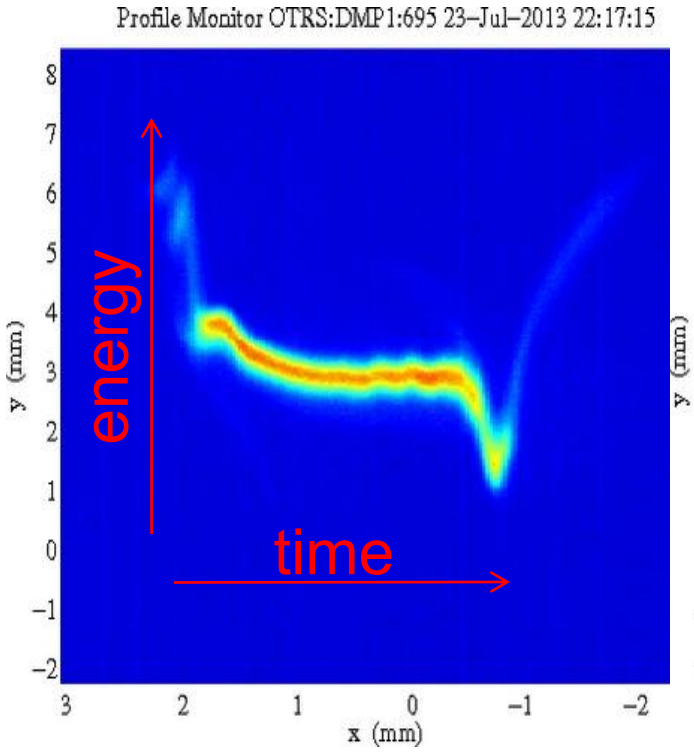
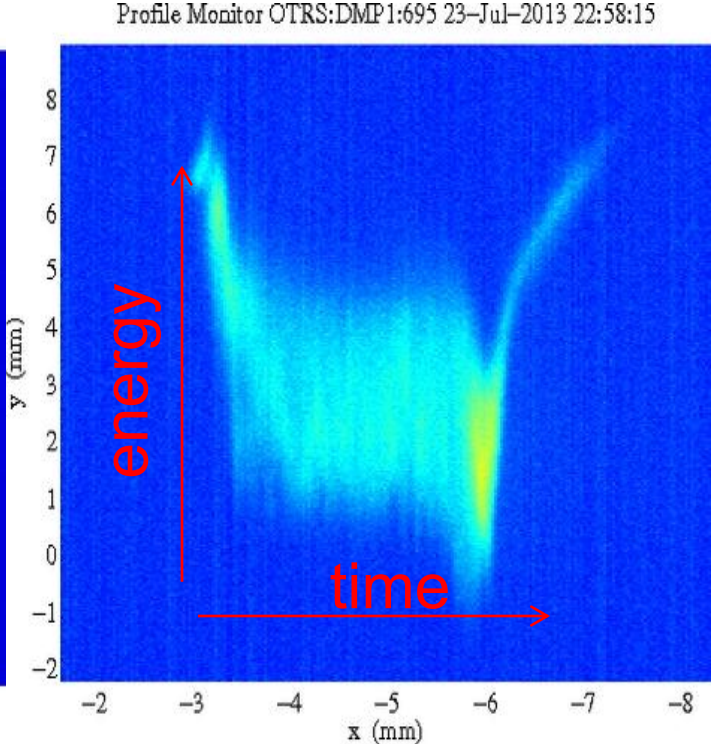


XTCAV OFF



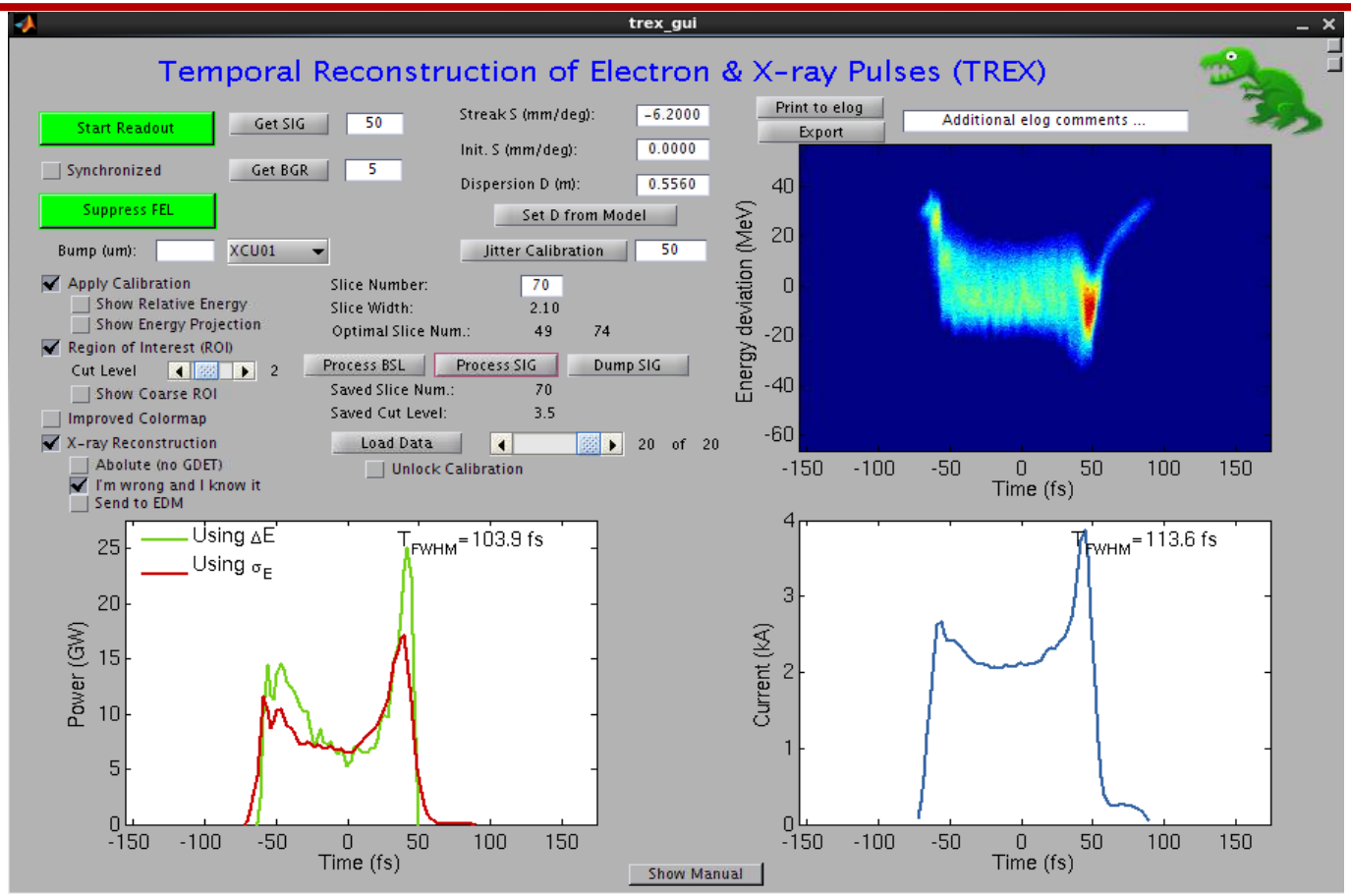
XTCAV ON, FEL-OFF



XTCAV ON, FEL-ON

(~1mJ pulse energy in this example).

Data processing



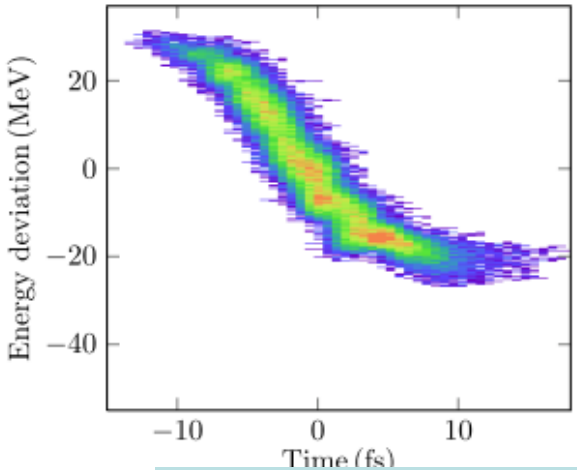
(C. Behrens)

- Calibration in time and energy;
- 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.

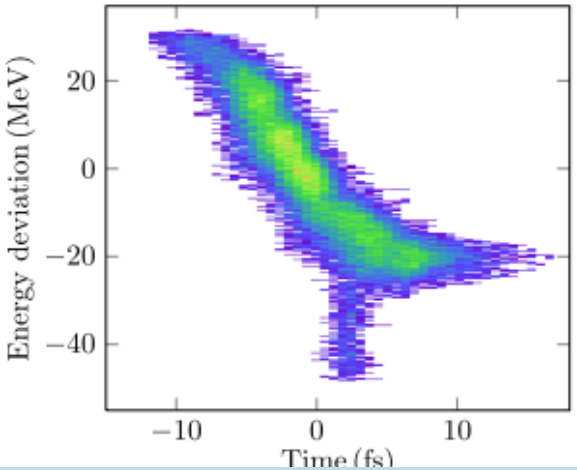
Recent experimental results

- X-ray pulse length reconstruction
- FEL lasing characterization
- Lasing control with slotted foil
- Two-bunch two-color lasing
- Micro-bunching studies
- ….

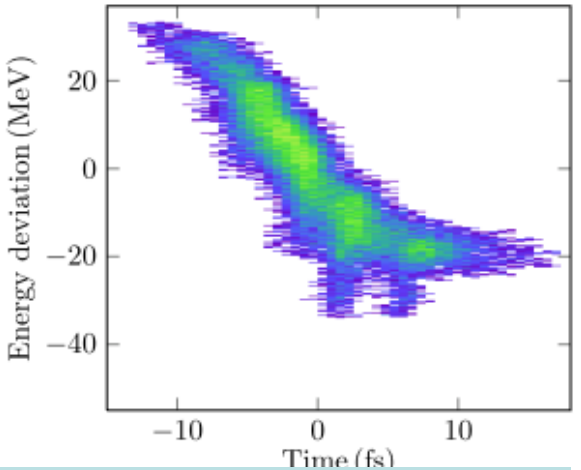
Short pulse: 20pC, 1keV examples



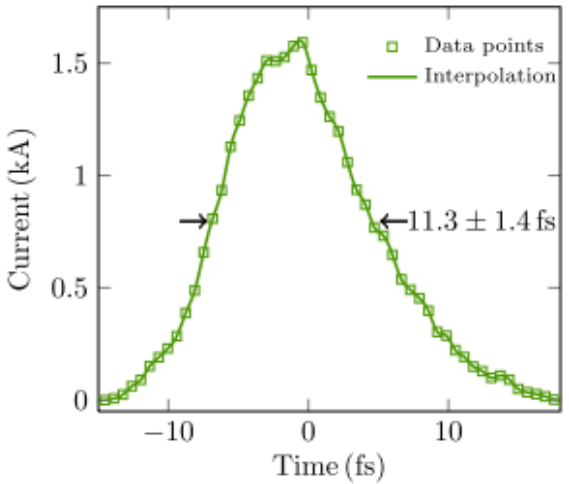
Lasing OFF



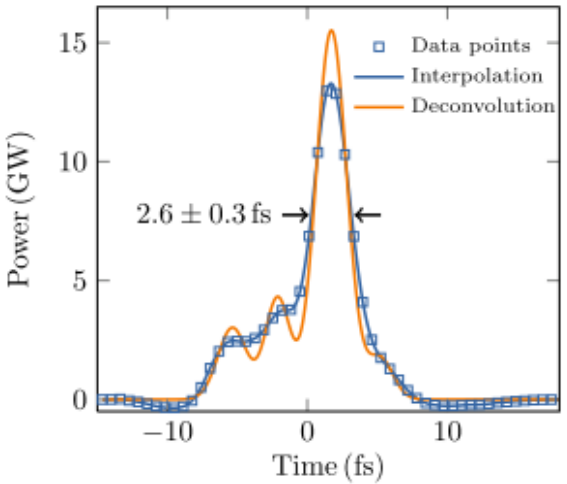
Lasing ON, shot-1



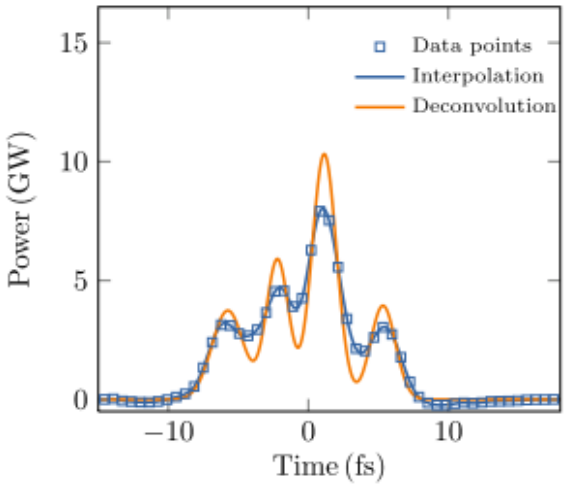
Lasing ON, shot-2



Current profile

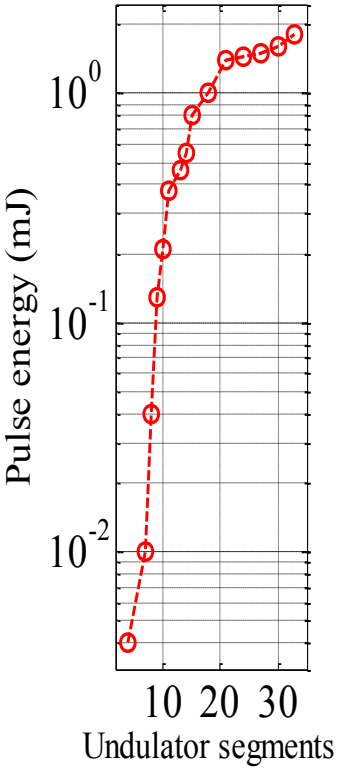


X-ray profile, shot-1



X-ray profile, shot-2

SXR, 150pC, 1keV, Lasing evolution.



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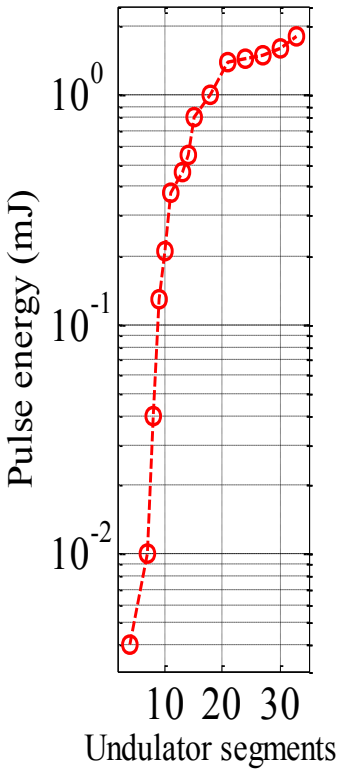

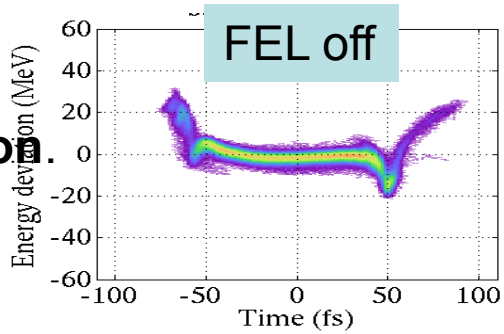

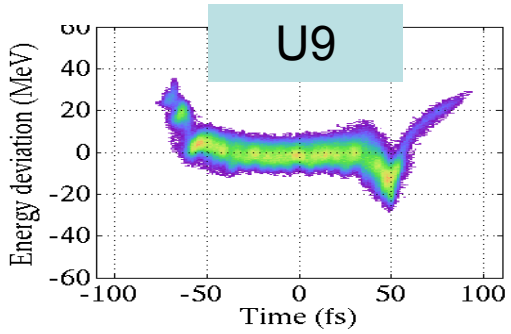

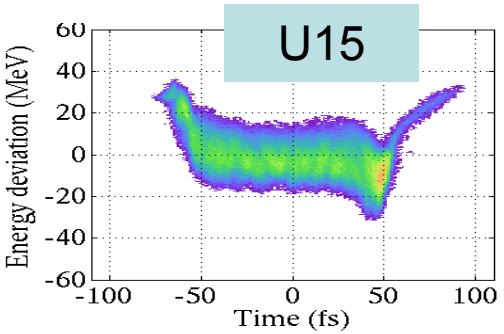

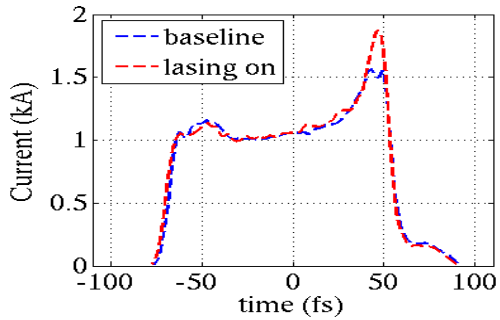

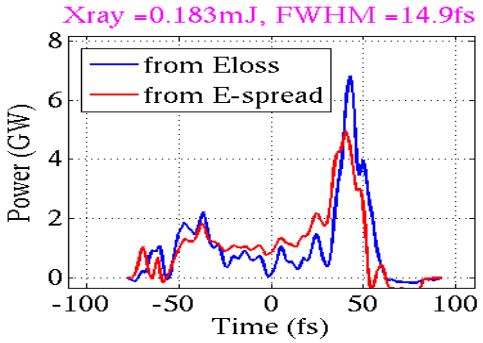

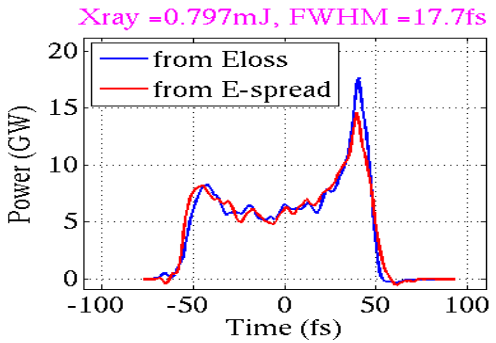

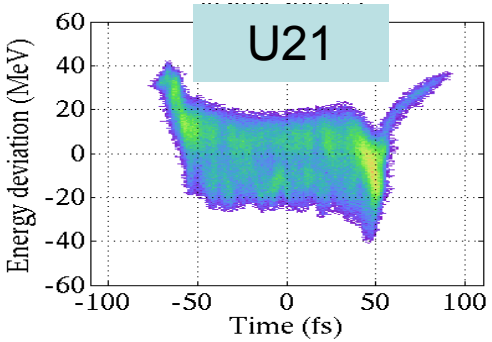

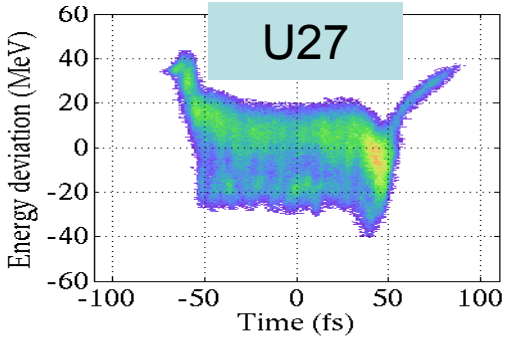

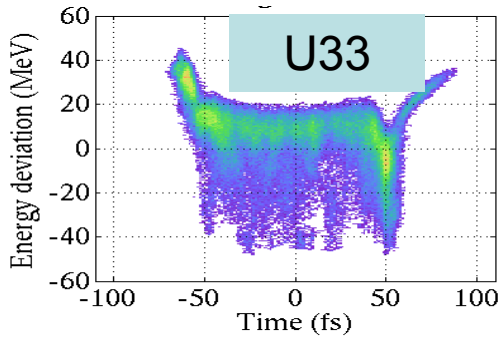

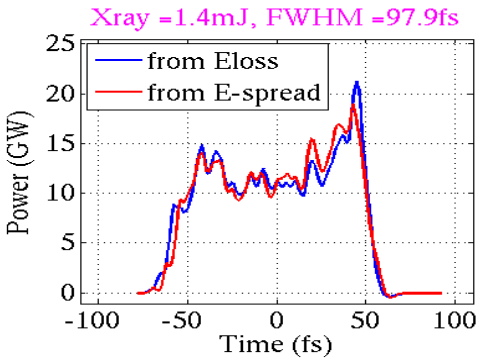

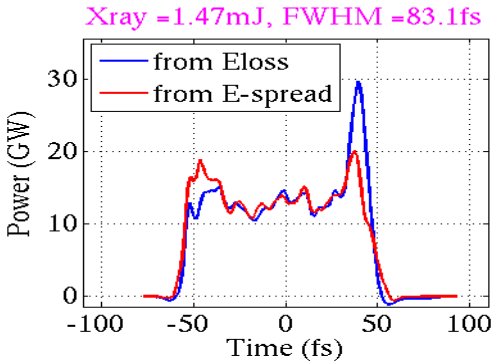

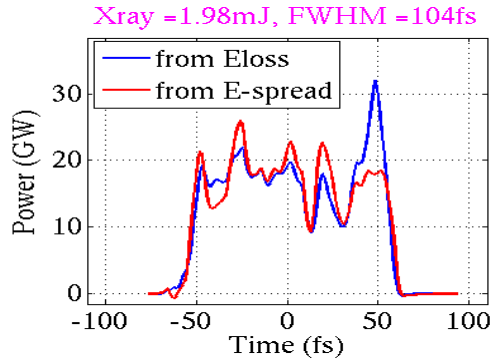

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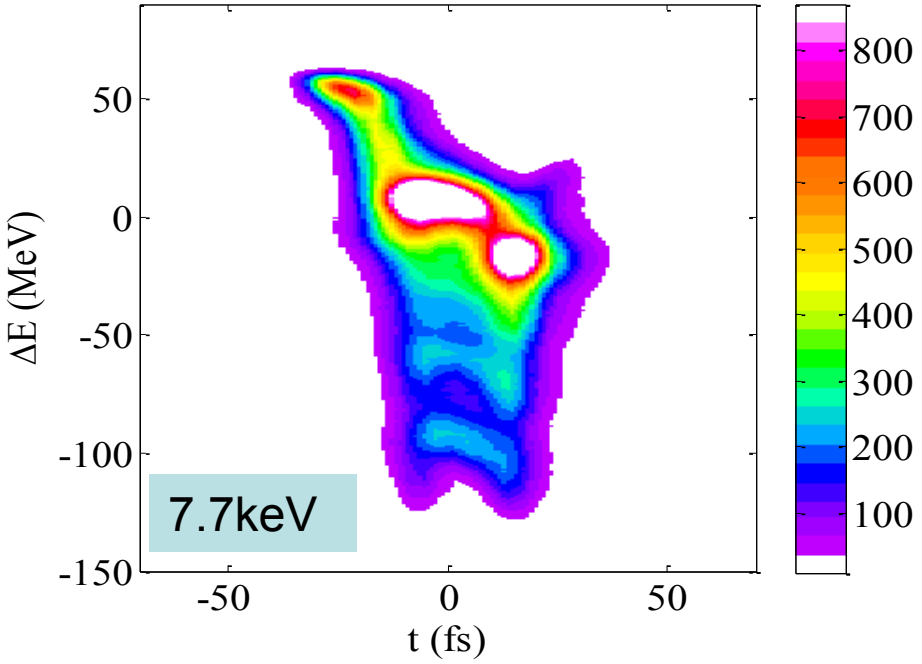
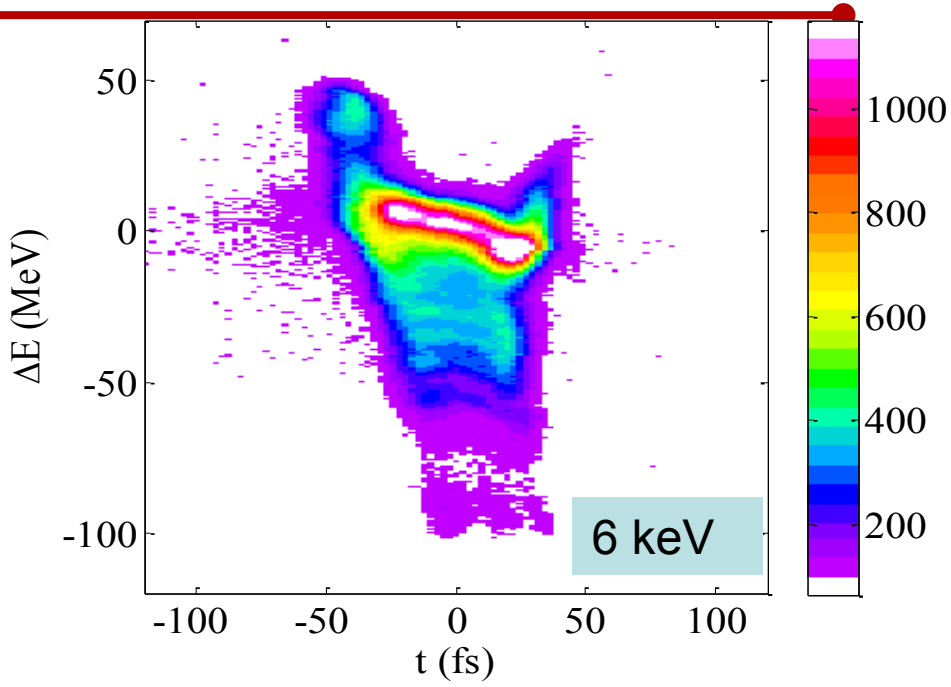
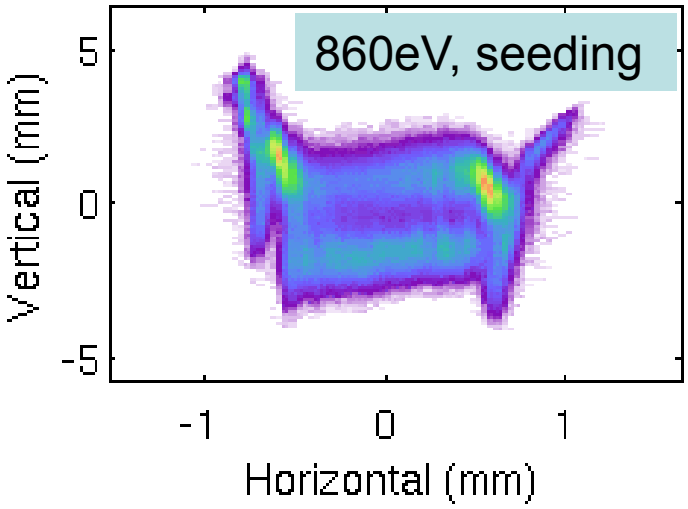
Observed particle trapping at deep saturation







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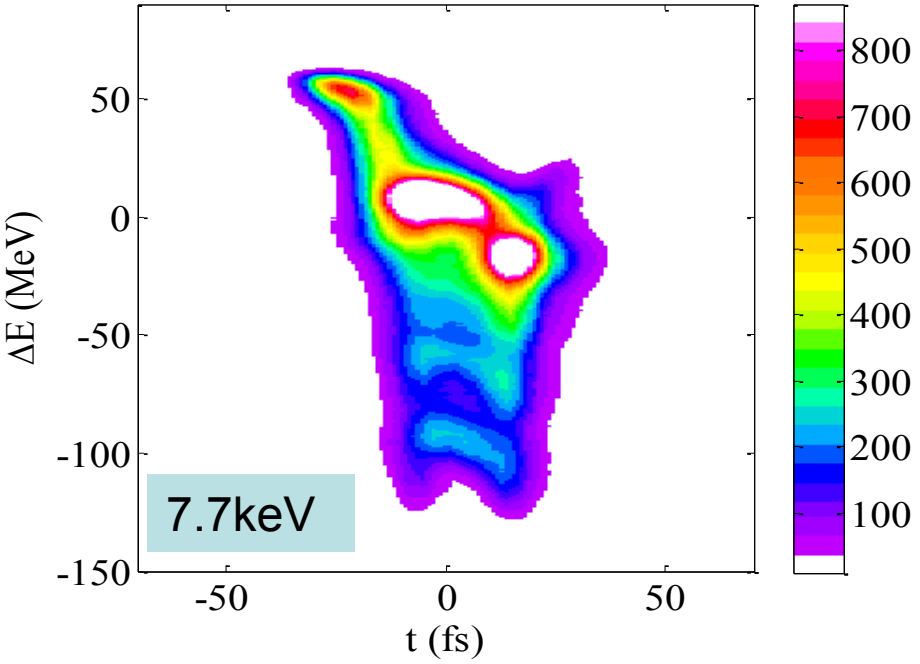
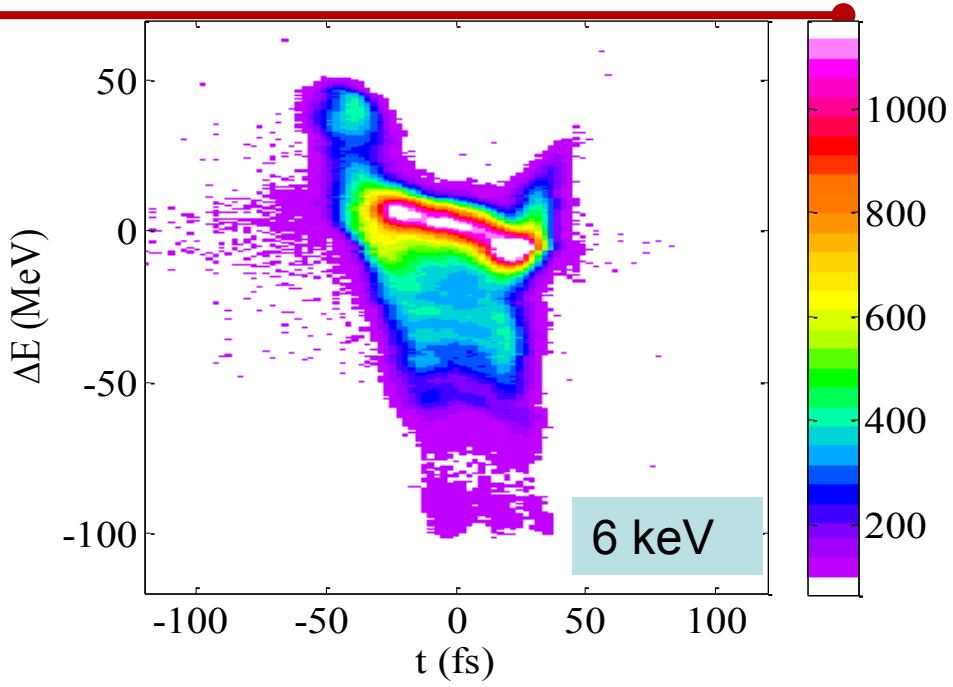
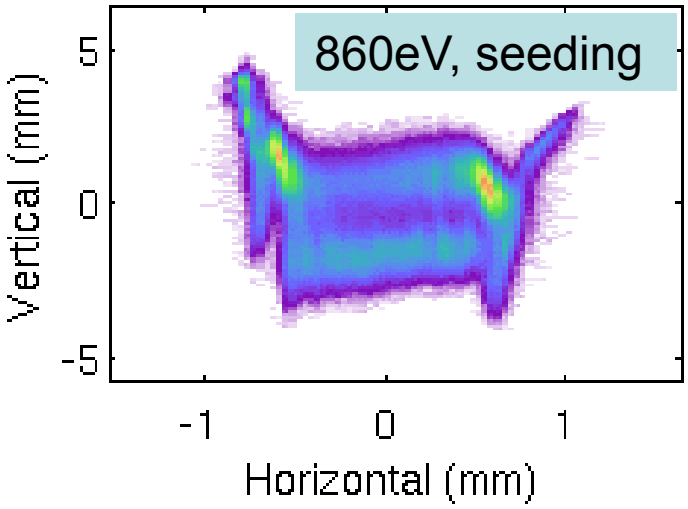
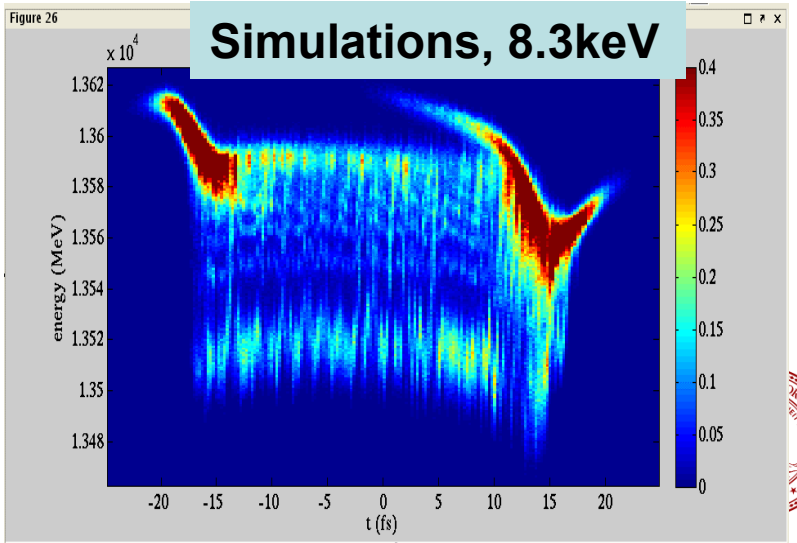


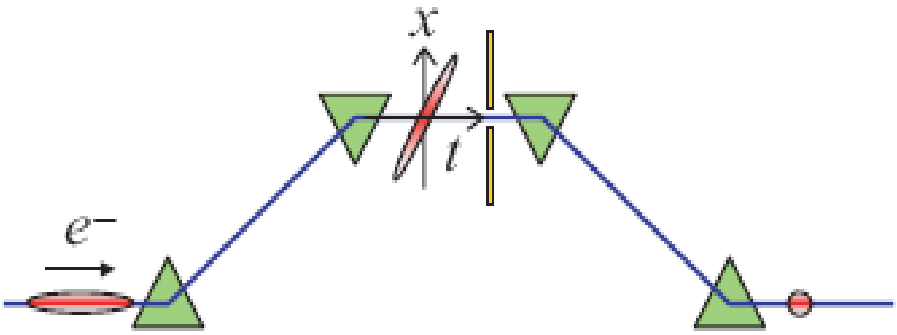


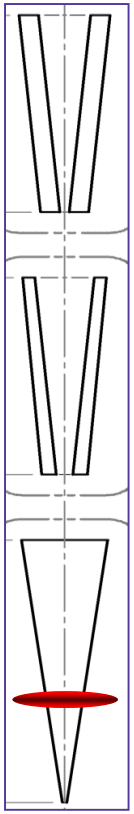




Lasing control with slotted foil

1. Emittance-spoiling foil inserted in compressor chicane



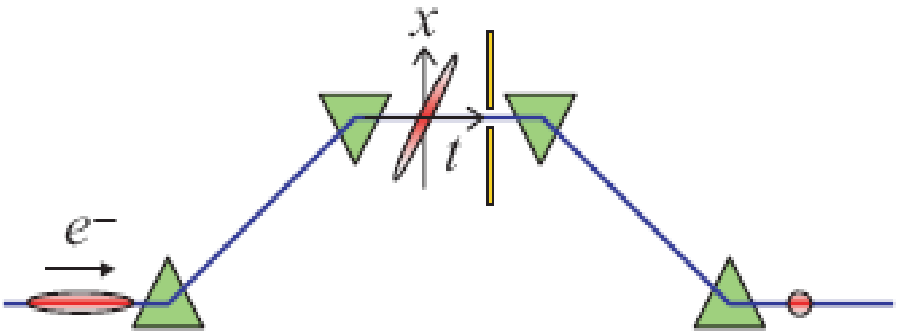


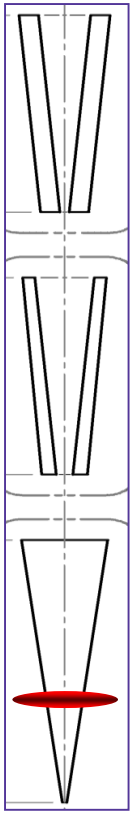
2. E selection correlated with t

P. Emma, *et al*, PRL **92**, 074801 (2004) & Y. Ding, *et al*, PRL (2012)
Slide courtesy P. Emma

Lasing control with slotted foil

1. Emittance-spoiling foil inserted in compressor chicane





2. E selection correlated with t

3. Generate ultrashort single or double e-bunches for FEL

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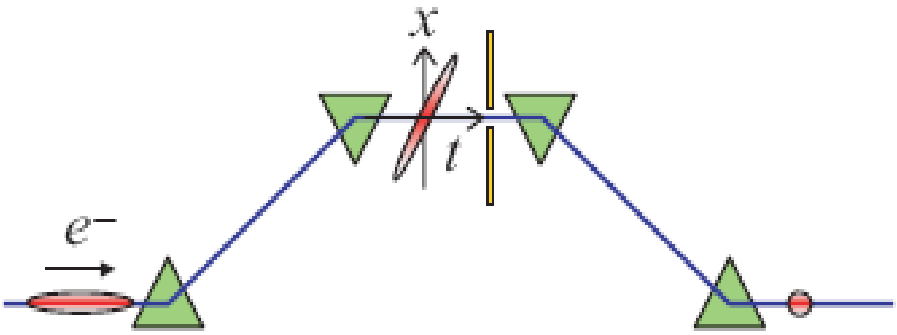

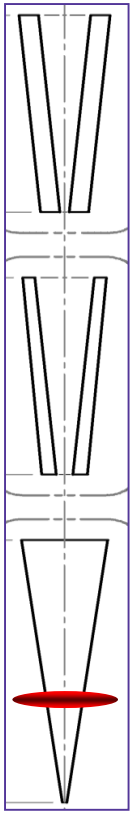

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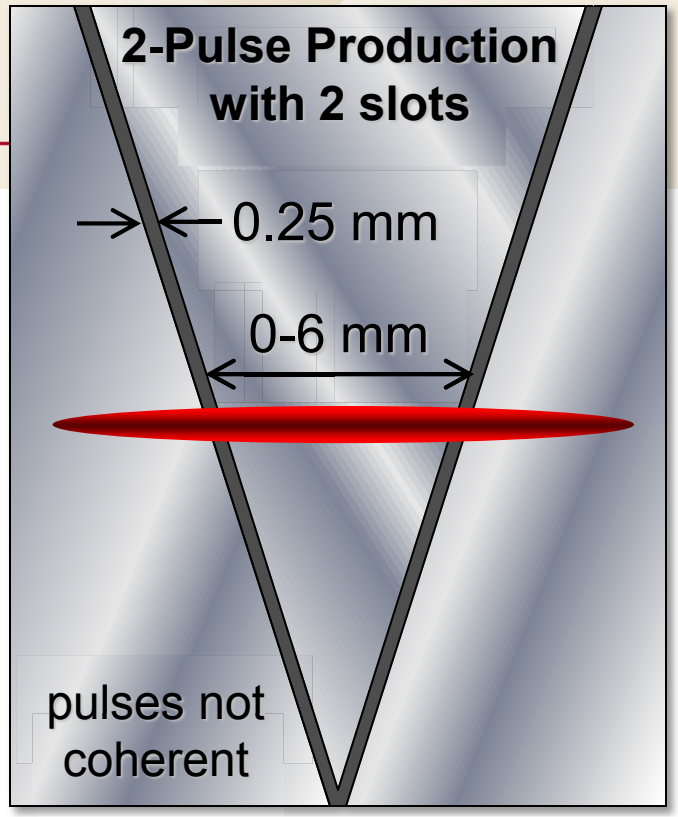

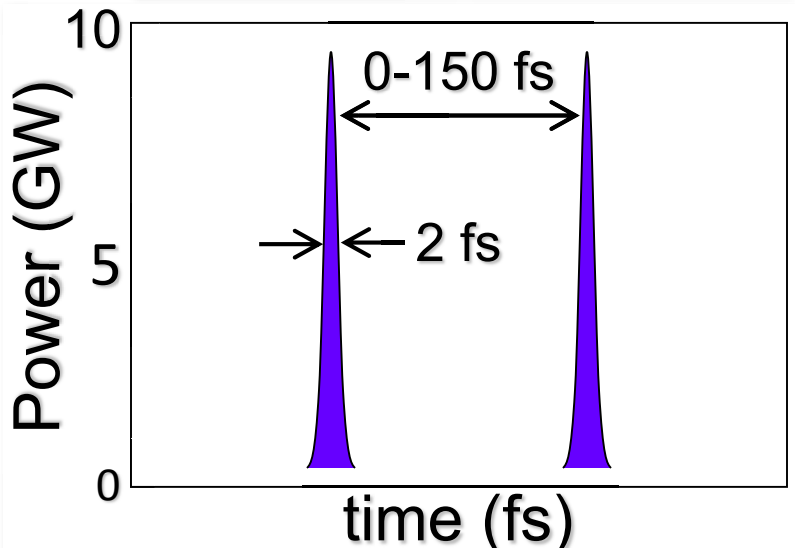

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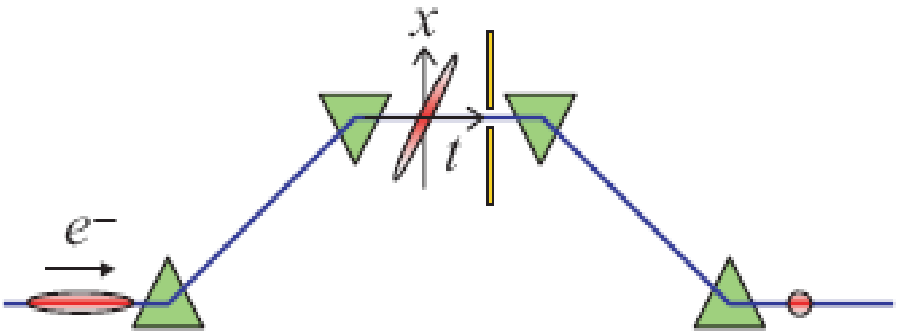

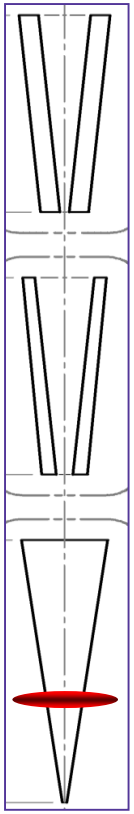

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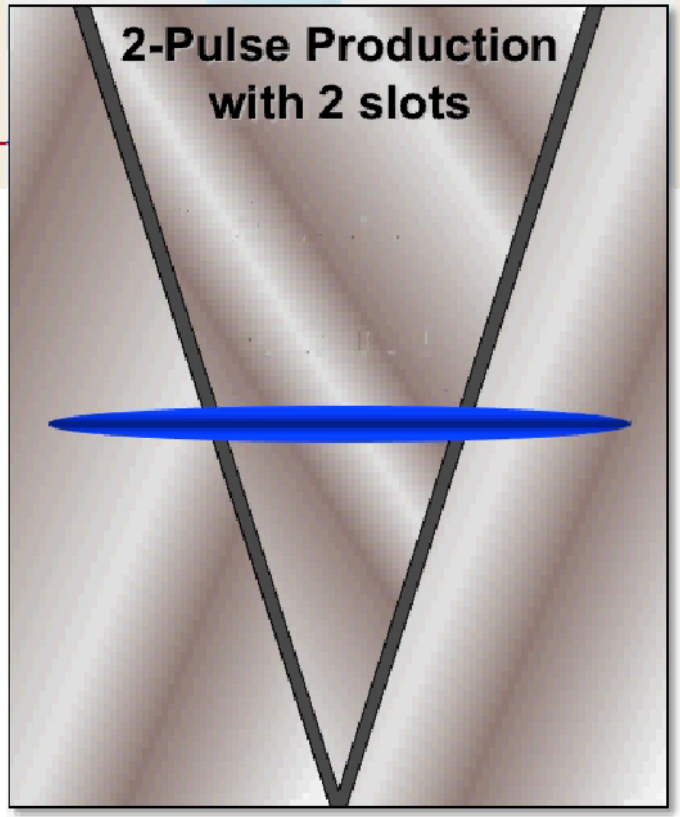
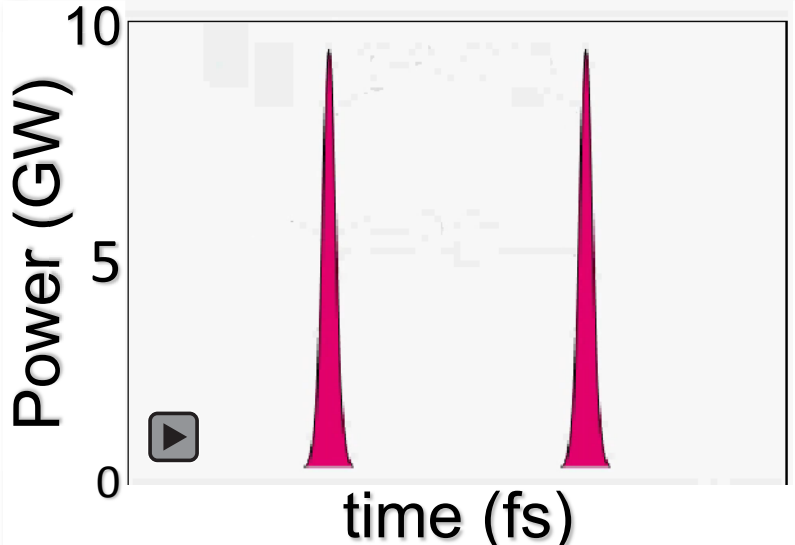
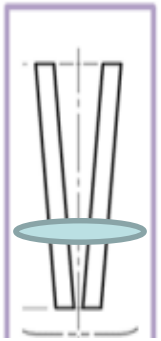


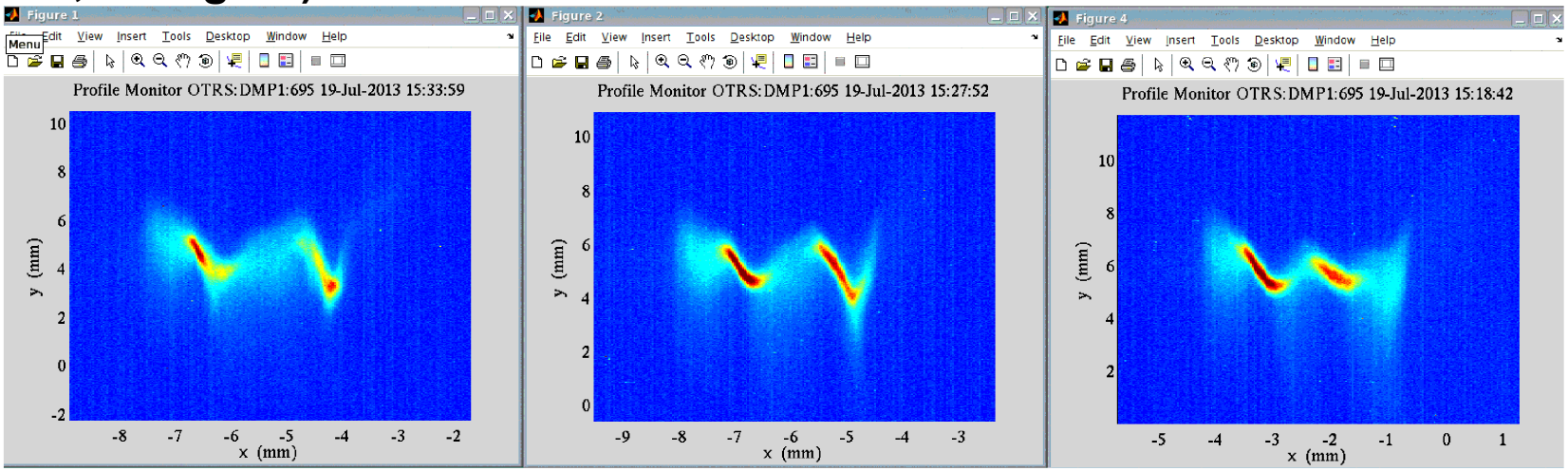


P. Emma, *et al*, PRL **92**, 074801 (2004) & Y. Ding, *et al*, PRL (2012)
Slide courtesy P. Emma

Slotted-foil measured examples

(double-slot, lasing off)





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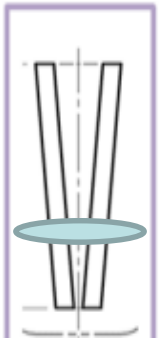
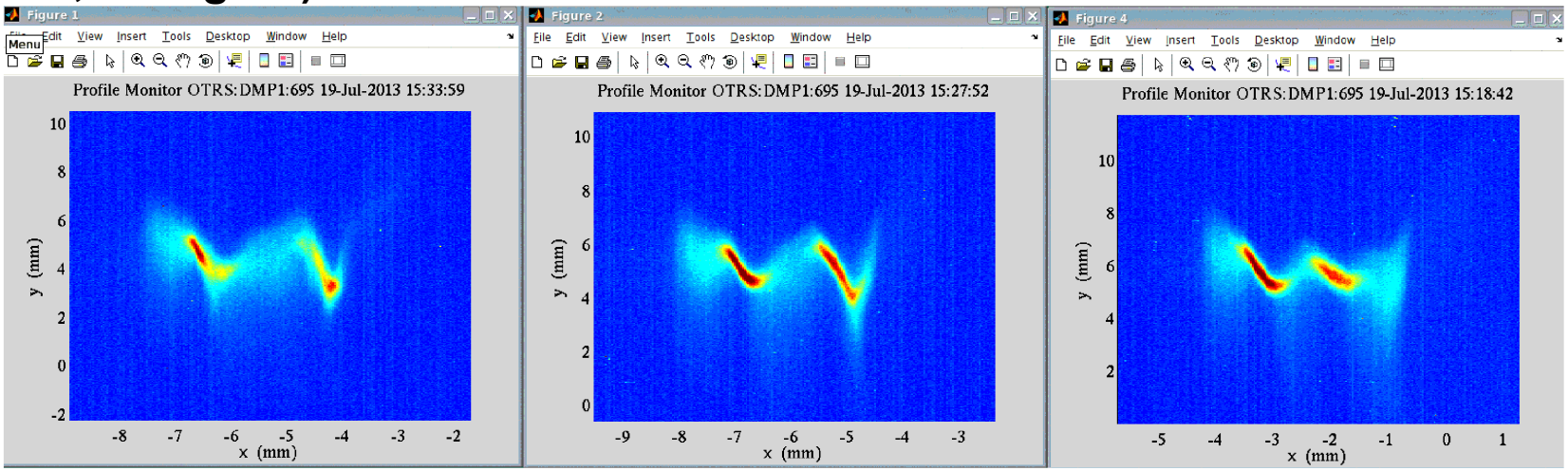
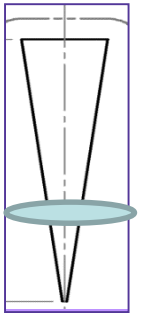
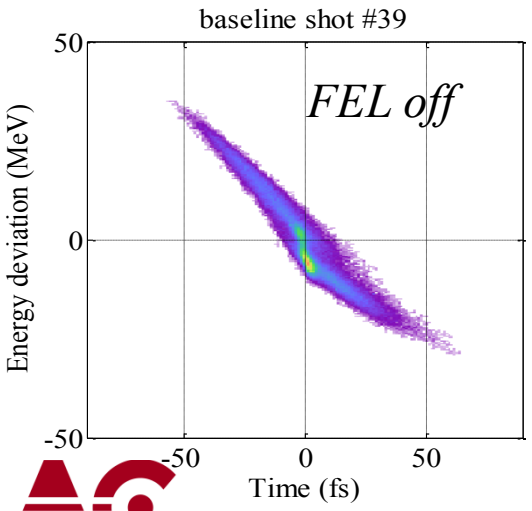
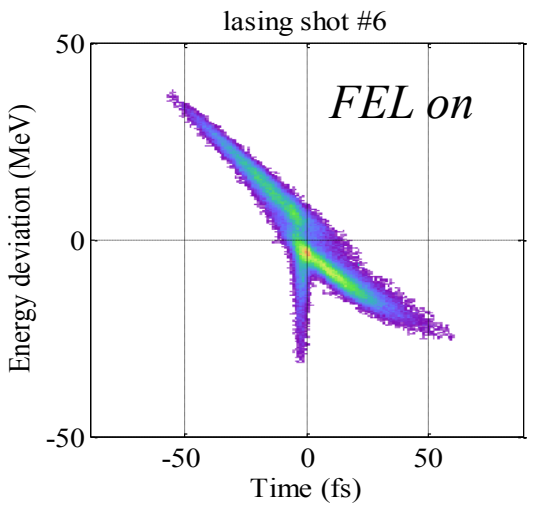


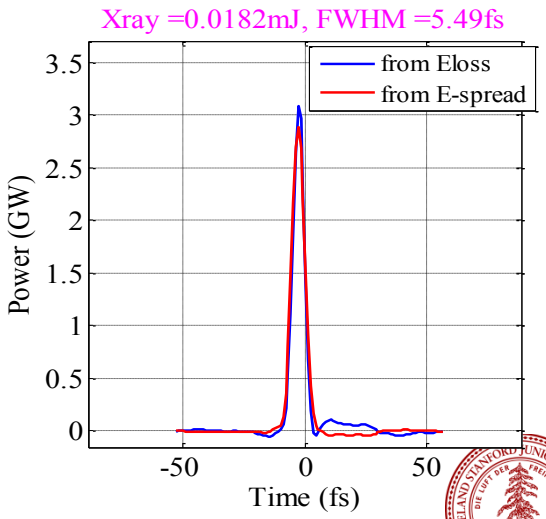


(single-slot, 1keV)

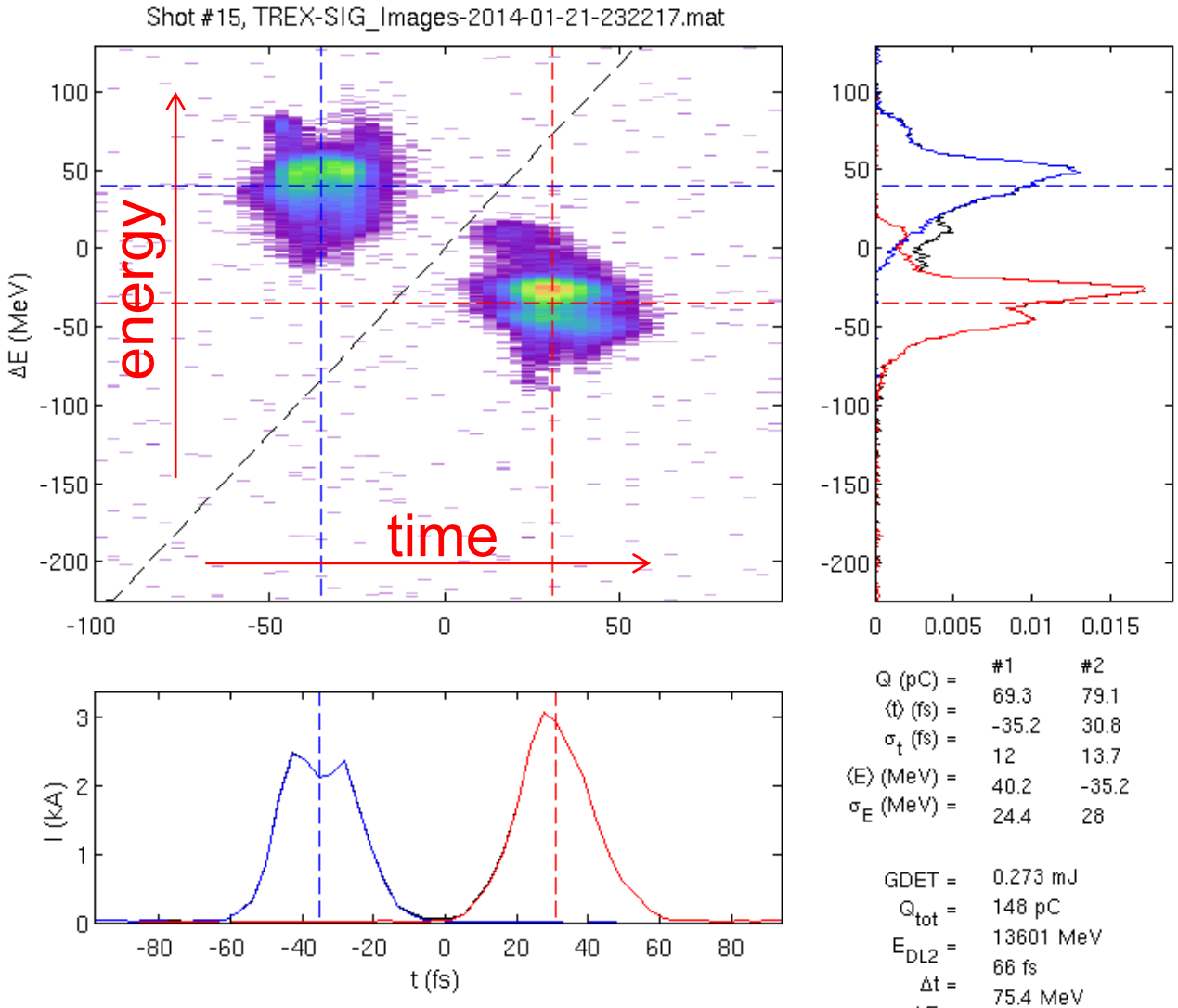








Double-bunch (two-color) example

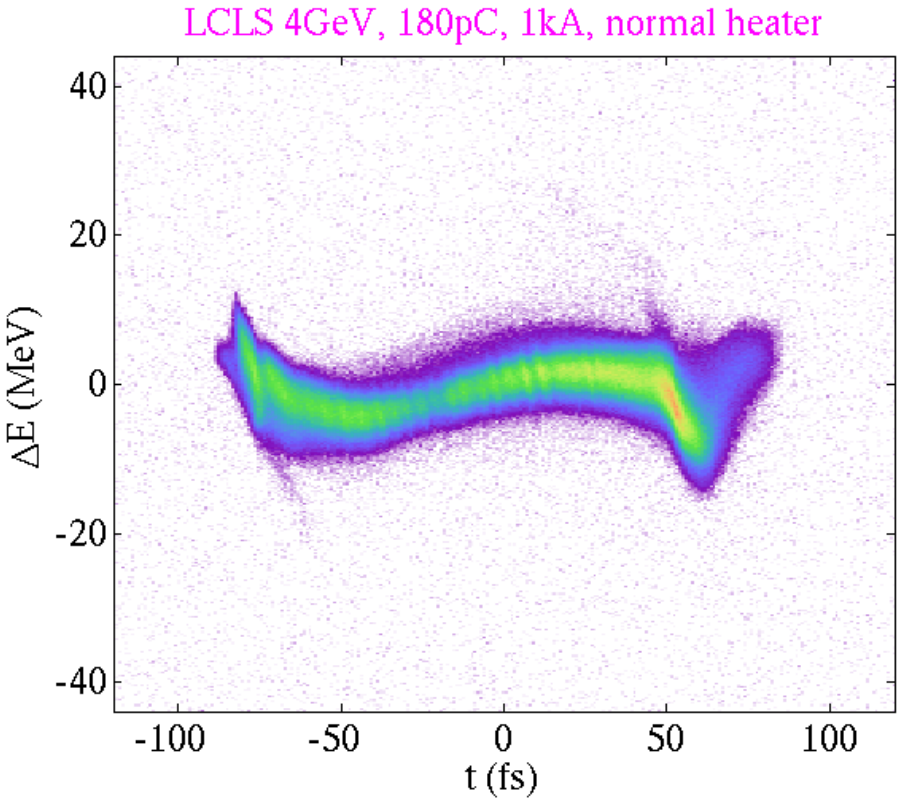


	#1	#2
Q (pC) =	69.3	79.1
⟨t⟩ (fs) =	-35.2	30.8
σ_t (fs) =	12	13.7
⟨E⟩ (MeV) =	40.2	-35.2
σ_E (MeV) =	24.4	28

GDET =	0.273 mJ
Q_{tot} =	148 pC
E_{DL2} =	13601 MeV
Δt =	66 fs
ΔE =	75.4 MeV

(A. Marineli)

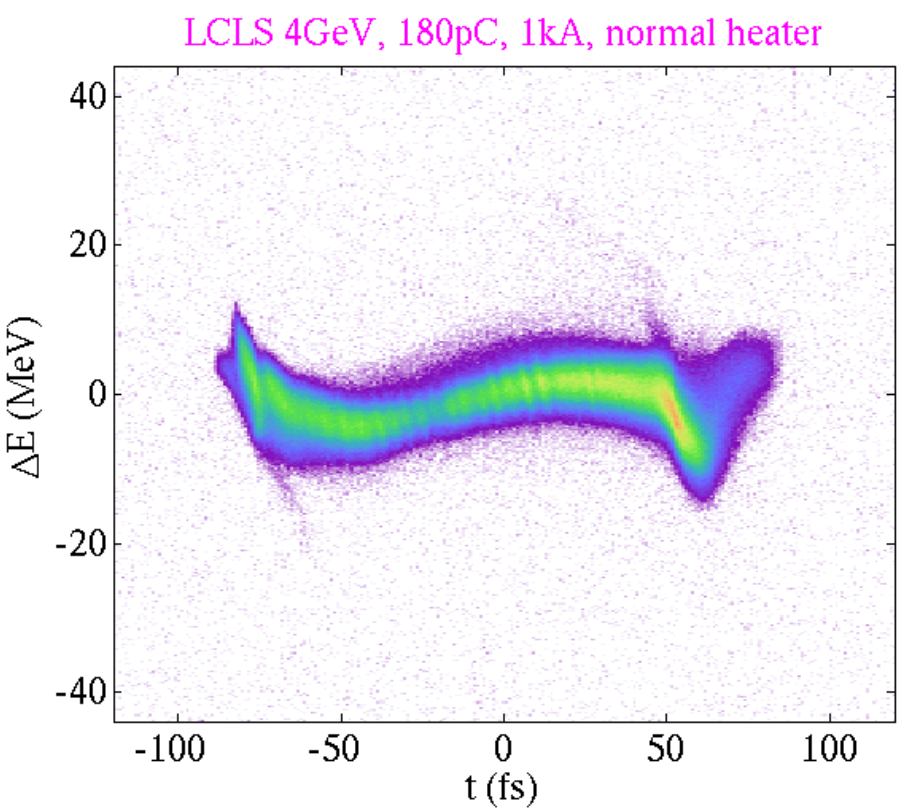
Direct & quantitative study of micro-bunching

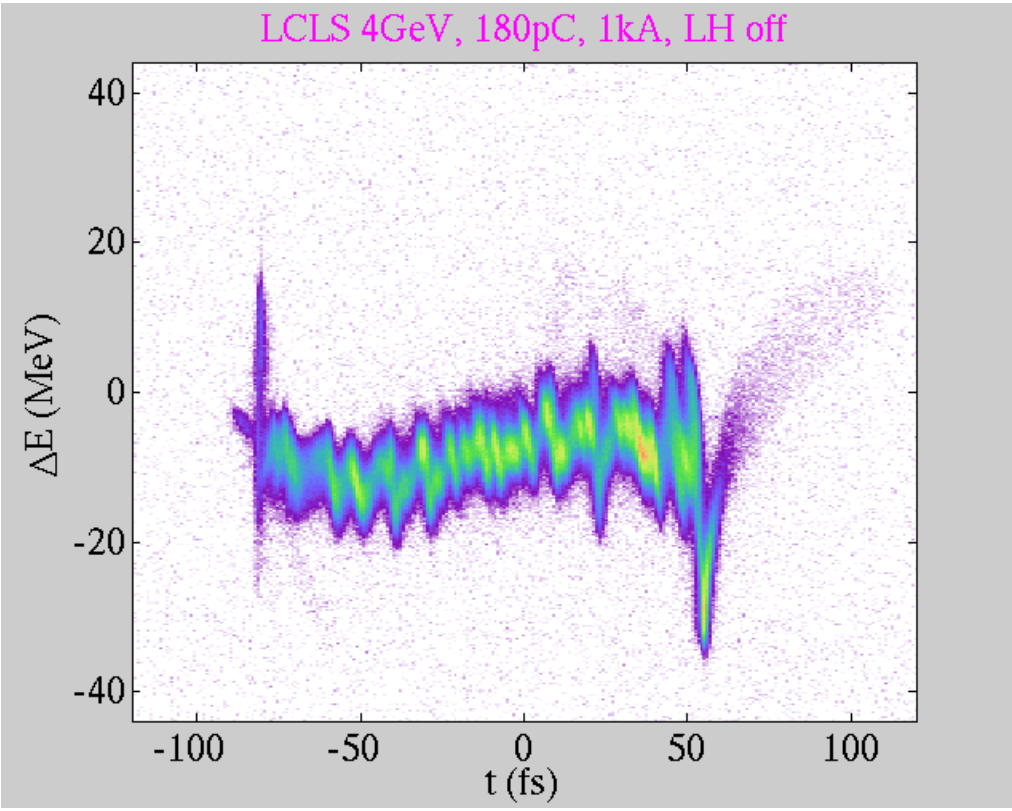


Laser Heater 22uJ
(nominal setting)

(D. Ratner et al.)

Direct & quantitative study of micro-bunching





Laser Heater 22uJ
(nominal setting)

Laser Heater OFF

(D. Ratner et al.)

Discussion

- Demonstrated single-shot, non-invasive x-ray temporal diagnostics with fs resolution using XTCAV;
- Best resolution achieved is about 1 fs rms @ SXR, and 4 fs rms @ HXR.
- An upgrade to double the deflecting voltage using SLED technology is ongoing (**J. Wang et al. poster: THPP125**).

Acknowledgements

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

- Thanks all the co-authors for their contributions;
- Thanks to A. Brachmann, G. Bowden, W. Colocho, P. Emma, W. Fawley, Y. Feng, J. Hastings, J. Lewandowski and S. Tantawi for their support and interest in this work.
- Special thanks to P. Krejcik (project manager).
- Great support from the SLAC engineering groups.
- Thanks for the interest from the photon scientists and the DOE BES support.

Thank you!