XTCAV for electron beam and lasing temporal diagnostics at the LCLS

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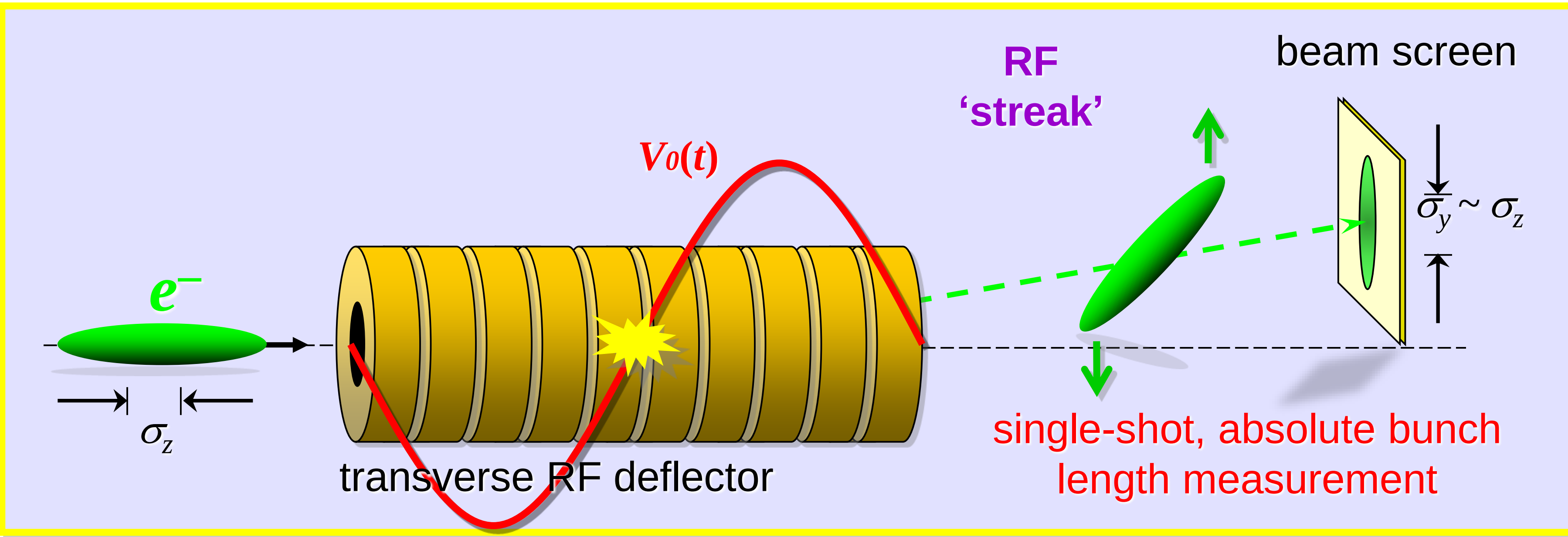
SLAC National Accelerator Laboratory

Hard X-ray Collaboration Meeting, PAL

Outline

- Introduction
- Recent SLED upgrade
- XTCAV applications
- Summary

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



X-band TCAV: (before SLED)	
Frequency	11.424 GHz
Maximum kick	45 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)*

Calib.factor ~40,

$\sigma_{t,R} \sim$ ***4 fs****;*

SXR: *(4.3GeV)*

Calib. factor ~120,

$\sigma_{t,R} \sim$ ***1 fs****;*

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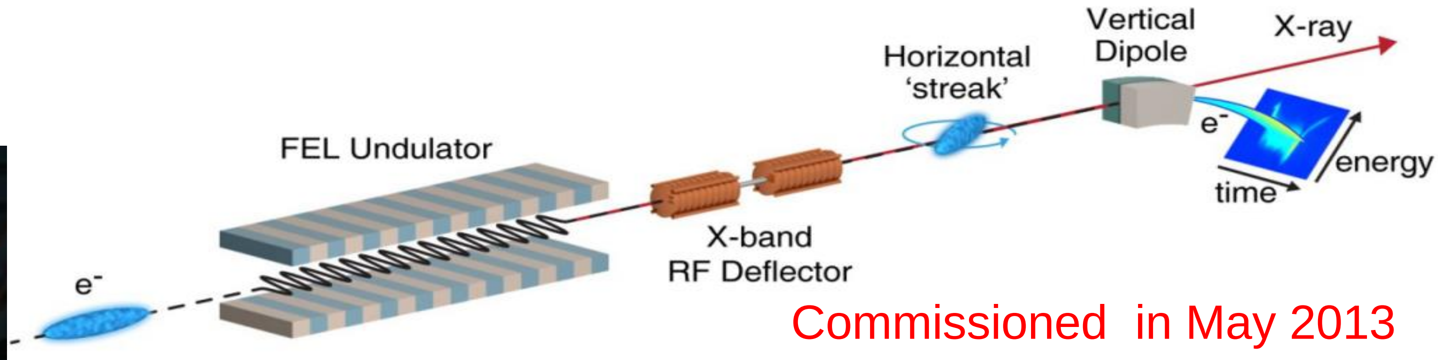
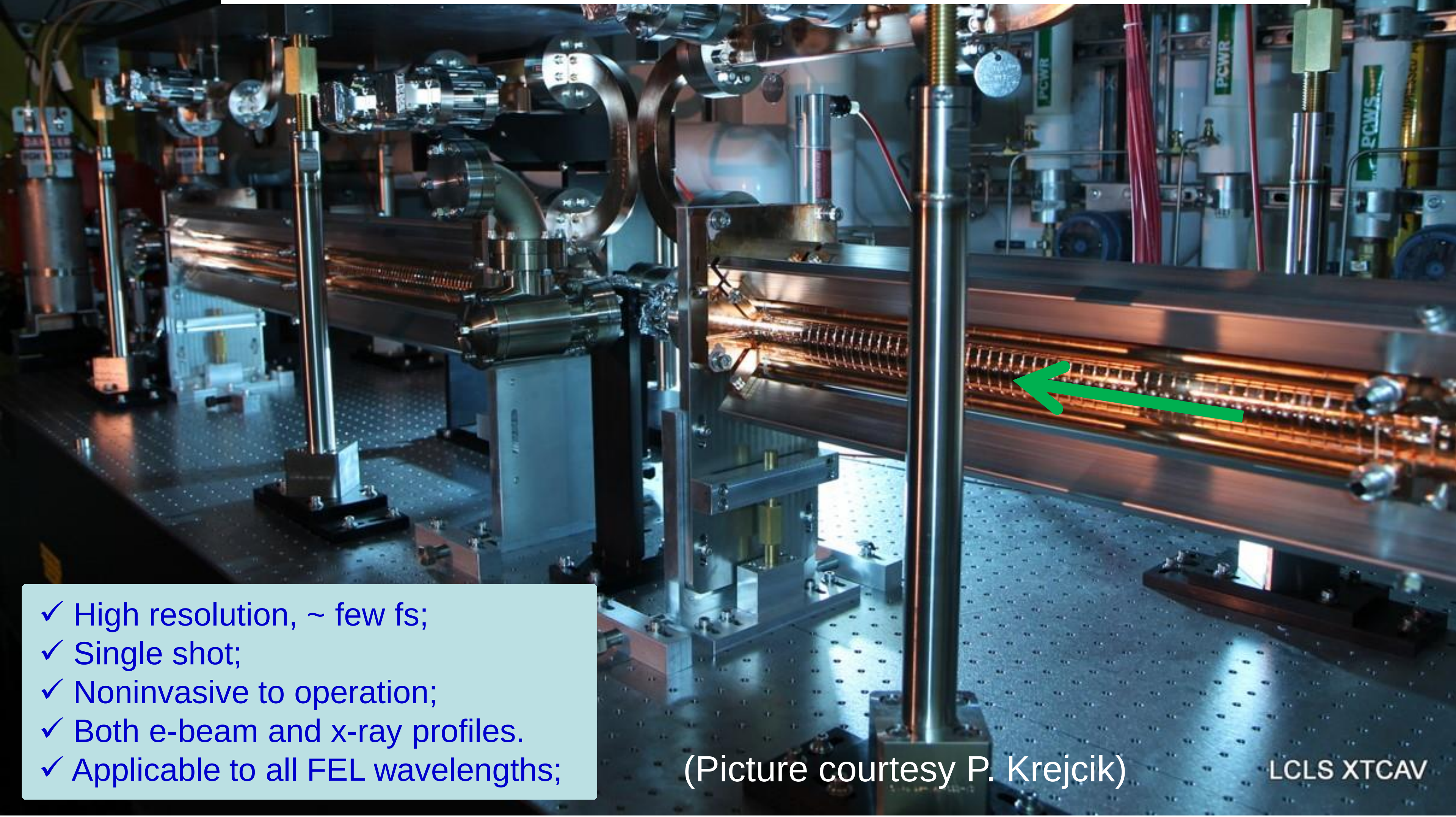


Commissioned in May 2013



(Picture courtesy P. Krejcik)

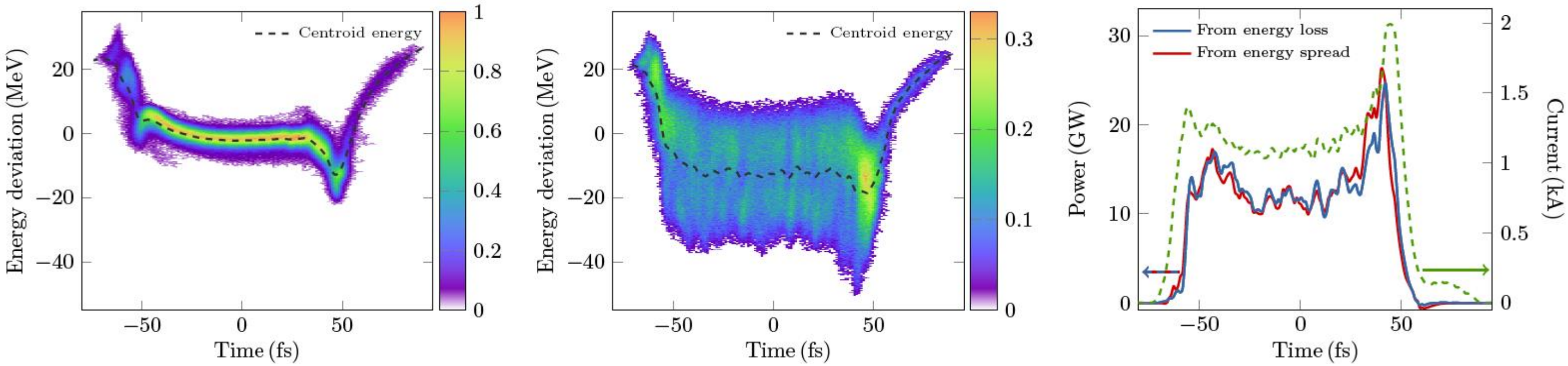
- ✓ High resolution, ~ few fs;
- ✓ Single shot;
- ✓ Noninvasive to operation;
- ✓ Both e-beam and x-ray profiles.
- ✓ Applicable to all FEL wavelengths;

X-ray power profile reconstruction

- **Two formulas compute profiles***

$$P_{\mathrm{FEL}}(t) = \left[\langle E\rangle_{\mathrm{FEL\ off}}(t) - \langle E\rangle_{\mathrm{FEL\ on}}(t)\right] \times I(t)$$

$$P_{\mathrm{FEL}}(t) \propto \left[\sigma^2_{E,\mathrm{FEL\ on}}(t) - \sigma^2_{E,\mathrm{FEL\ off}}(t)\right] \times I^{2/3}(t)$$

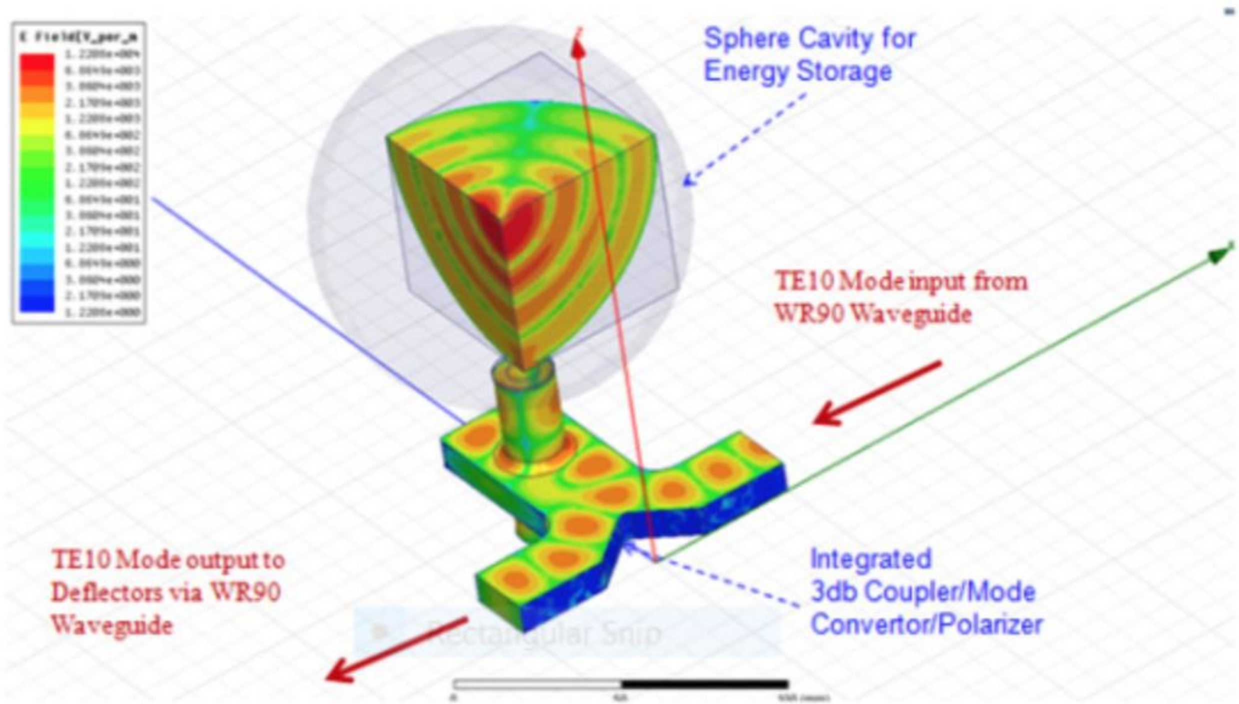


- Typ. disagree due if…
  - Poor SNR (filters, camera settings)
  - Bad image processing
  - Glitchy moment calculation
- **Comparison is free "consistency check"**

C. Behrens et al., Nat. Commun. 5:3762 (2014).
Y. Ding et al., PRSTAB 14, 120701 (2011).

*** T. Maxwell, *Proc. SPIE 9210*, X-Ray Free-Electron Lasers: Beam Diagnostics, Beamline Instrumentation, and Applications II, 92100J (2014).**

X-band SLED Cavity & Coupler Assembly
- Designed by Juwen Wang



Sphere diameter < 12 cm

Final Brazed Assembly

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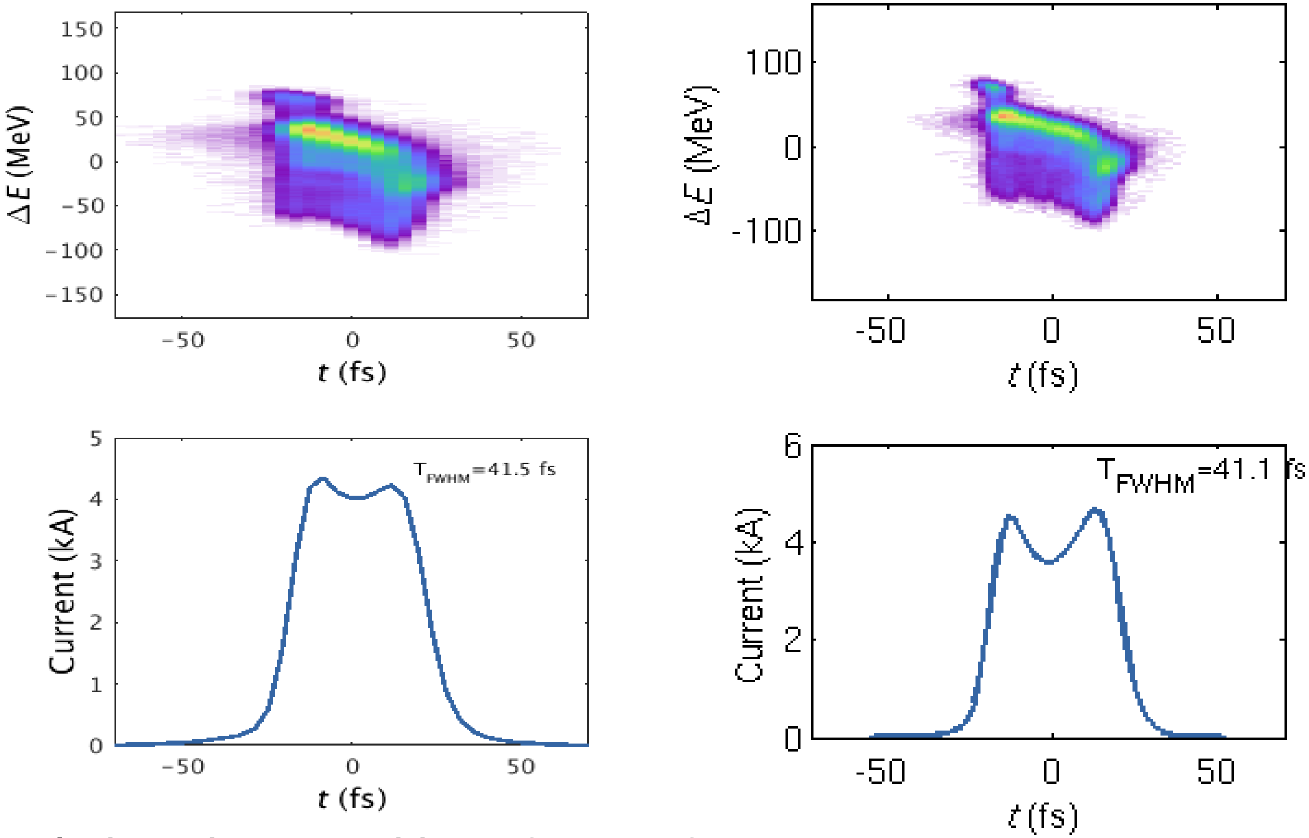
J. Wang et al., "R&D of a Super-compact SLED System at SLAC", IPAC'16, MOOCA01.

Beam Streaking enhancement with SLED mode

45 MV Non-SLED | **85 MV SLED**



Resolutions improved by a factor of 2!
For soft x-rays, we could get sub-fs resolution now.

P. Krejcik et al., Sub-fs Resolution with the Enhanced Operation of the X-band Transverse Deflecting Cavity using an RF pulse Compression SLED Cavity, WEPG77, IBIC 2016.

Application Examples

XTCAV provides e-beam/x-ray temporal characterization:

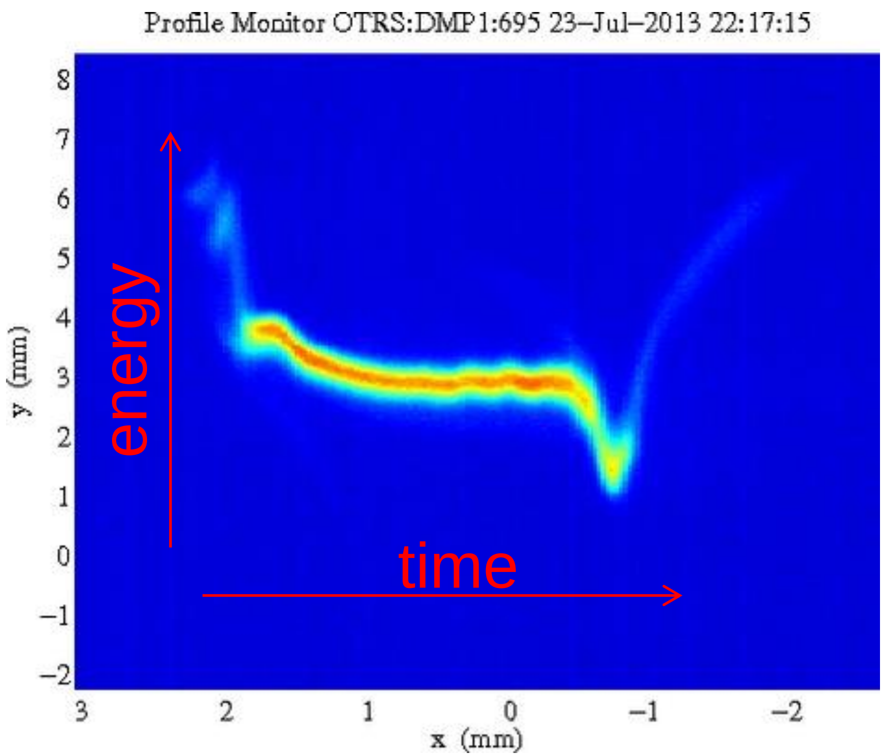
- e-beam/x-ray profile;
- slotted foil;
- microbunching benchmark;

XTCAV enables new operating mode development:

- shaping/collimation mode;
- twin-bunch setup;
- fresh-slice lasing;

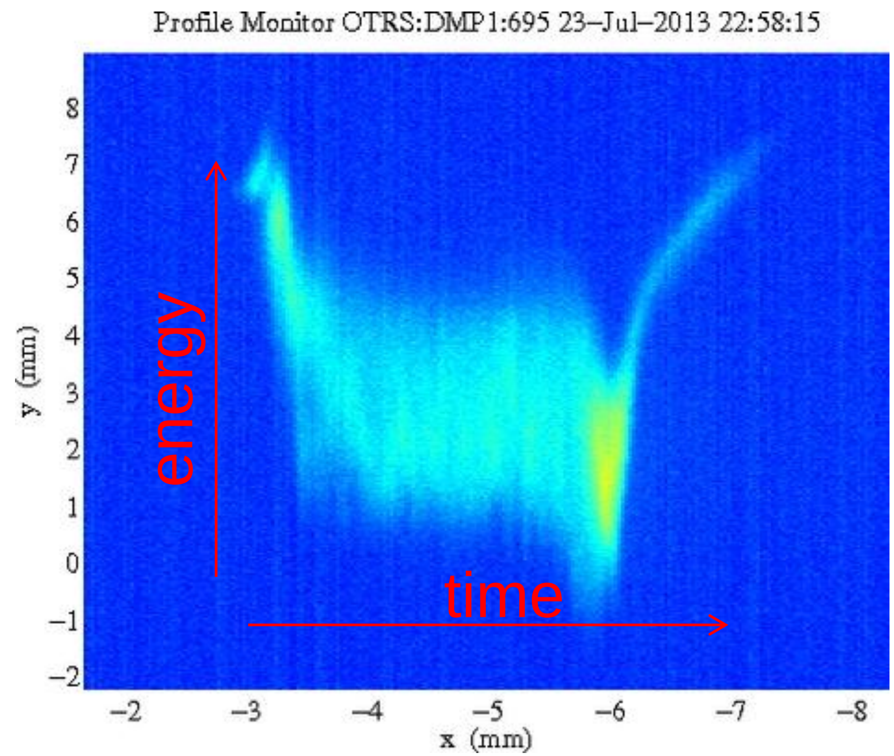
Lasing characterization

Bunch head on the left



FEL-OFF

(baseline)



FEL-ON

(~1mJ pulse energy in this example).

4.7GeV, 150pC (raw images)

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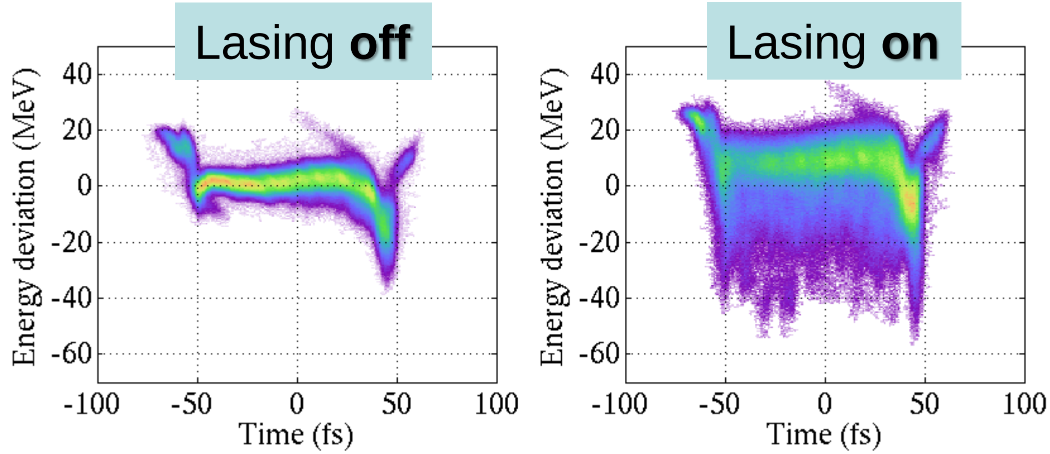
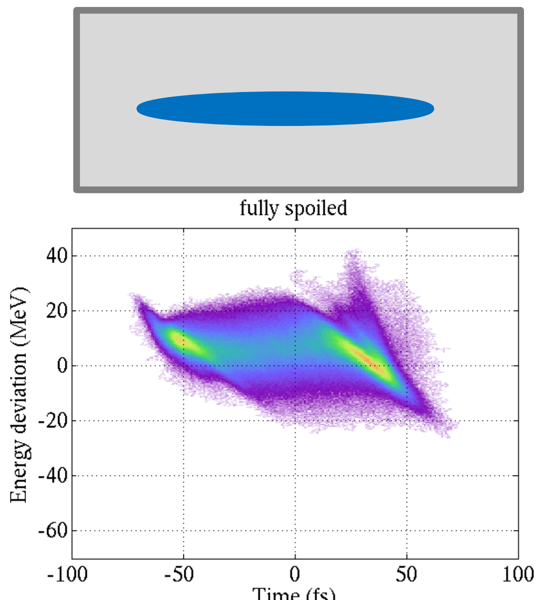
XTCAV measures the lasing, and spoiling

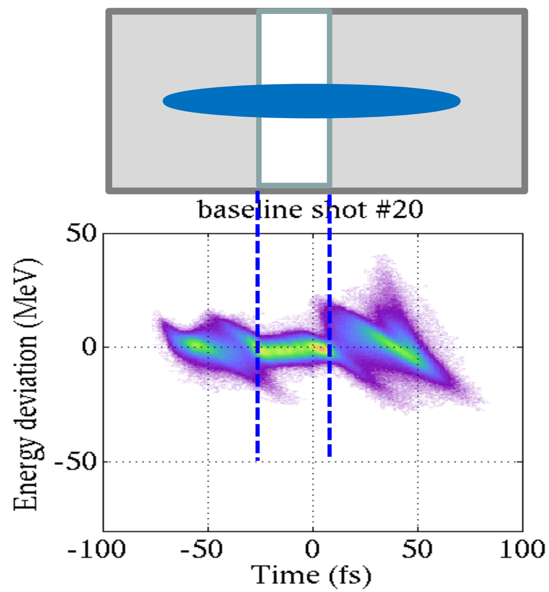
Regular SASE,
Without foil



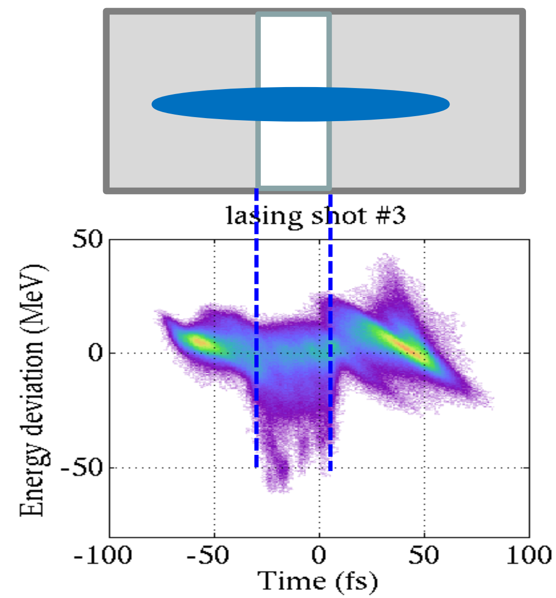
With foil



fully spoiled, no slot



Lasing **off**, single slot



Lasing **on**, single slot

Y. Ding et al., APL 107, 191104 (2015)

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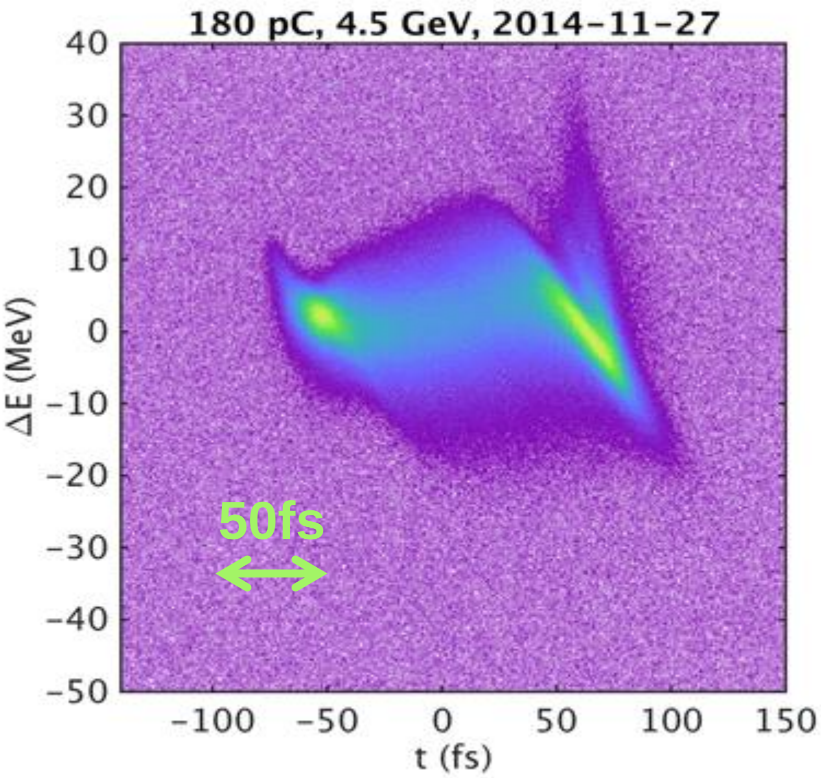
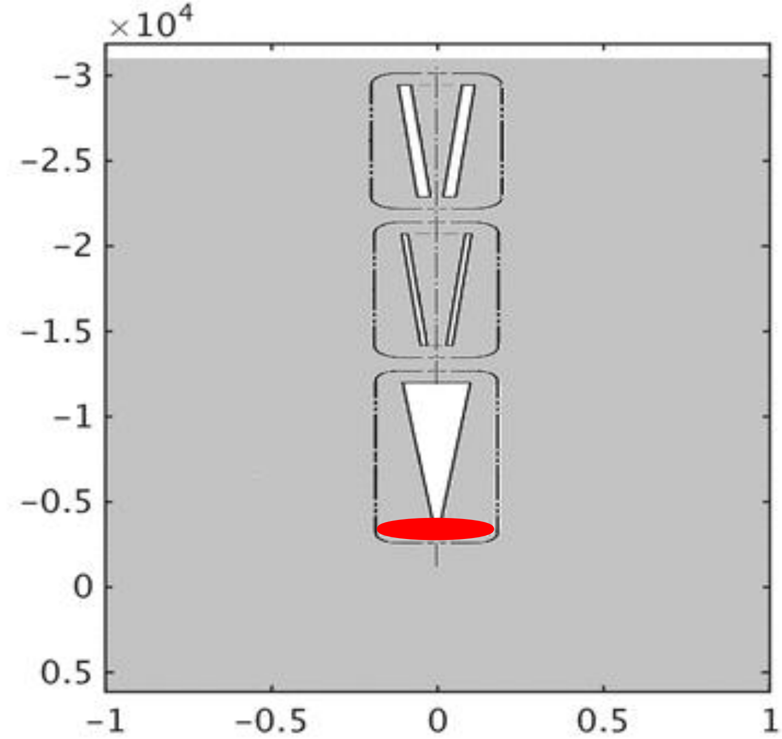
Measurements with foil-scan at LCLS





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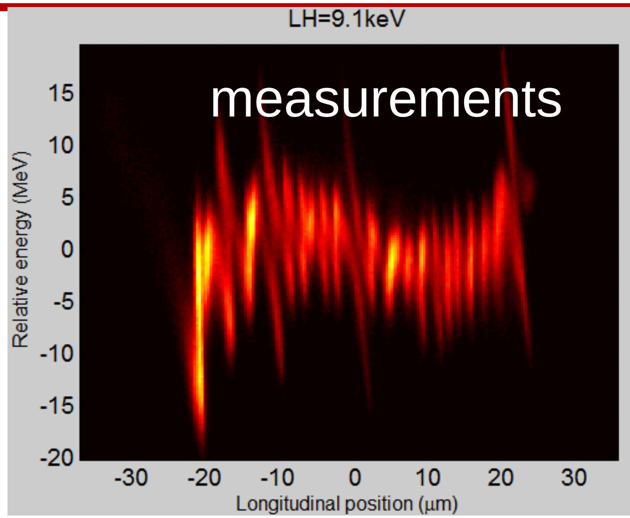
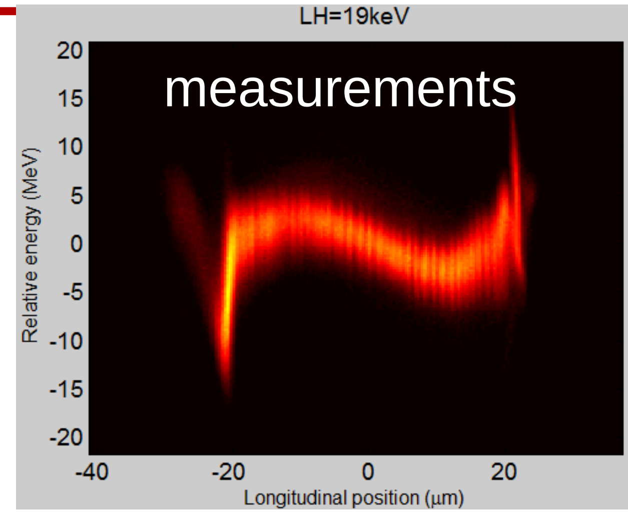
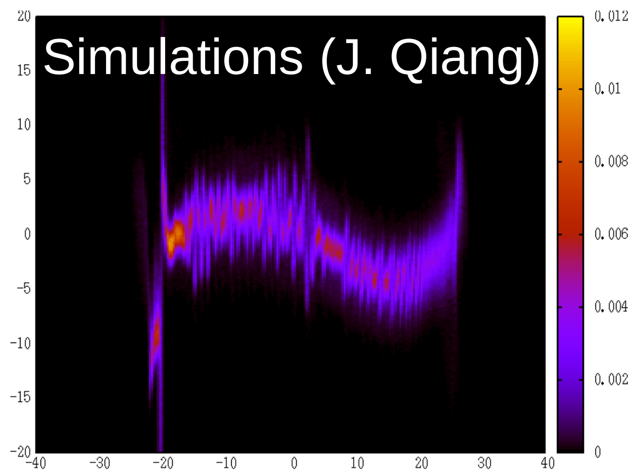
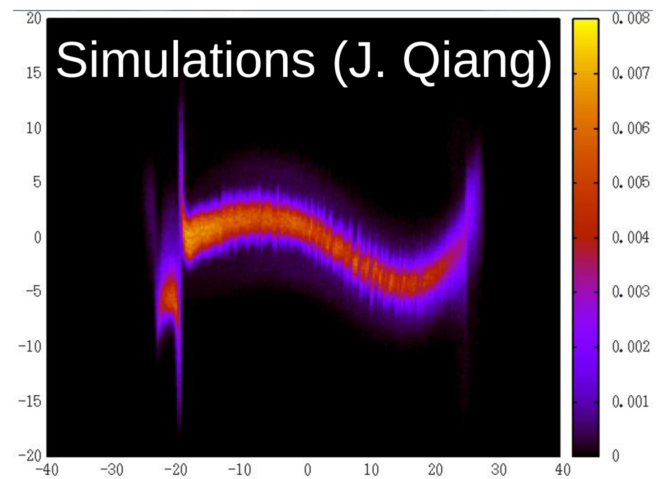
Microbunching benchmark



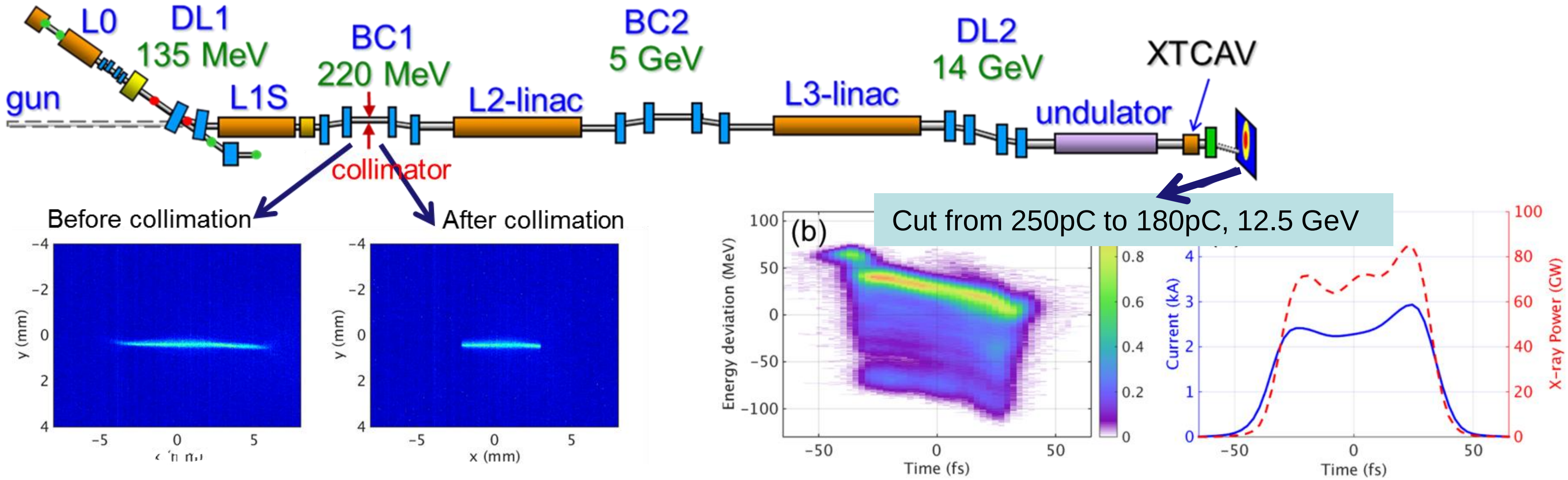






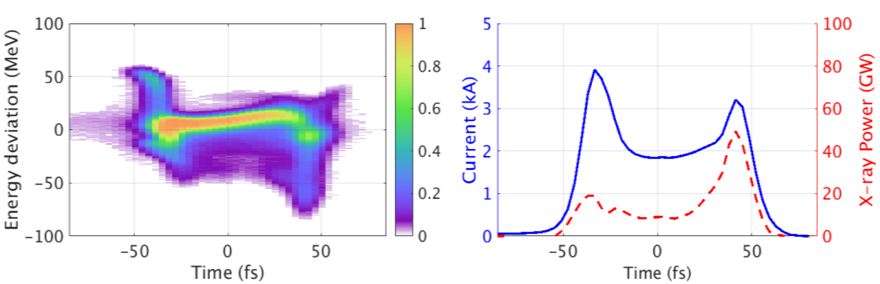
D. Ratner et al., PRSTAB 18, 030704 (2015);
J. Qiang et al., NaPAC 2016.

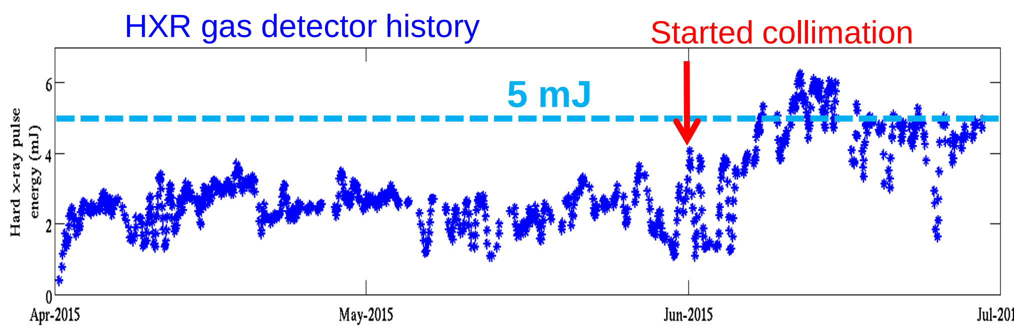
Beam shaping with horn-collimation mode



- Electron bunch head and tail are truncated in BC1 by a transverse collimator, typically from 250pC to 180pC.
- This shapes the electron beam longitudinal phase space and achieves a uniform current profile, which reduces CSR problem and helps transverse matching, tapering efficiency and bandwidth control.
- Horn-collimation has been developed as a routine operating mode at the LCLS, delivering over 4-mJ SASE FEL pulses and also benefiting self-seeding performance.

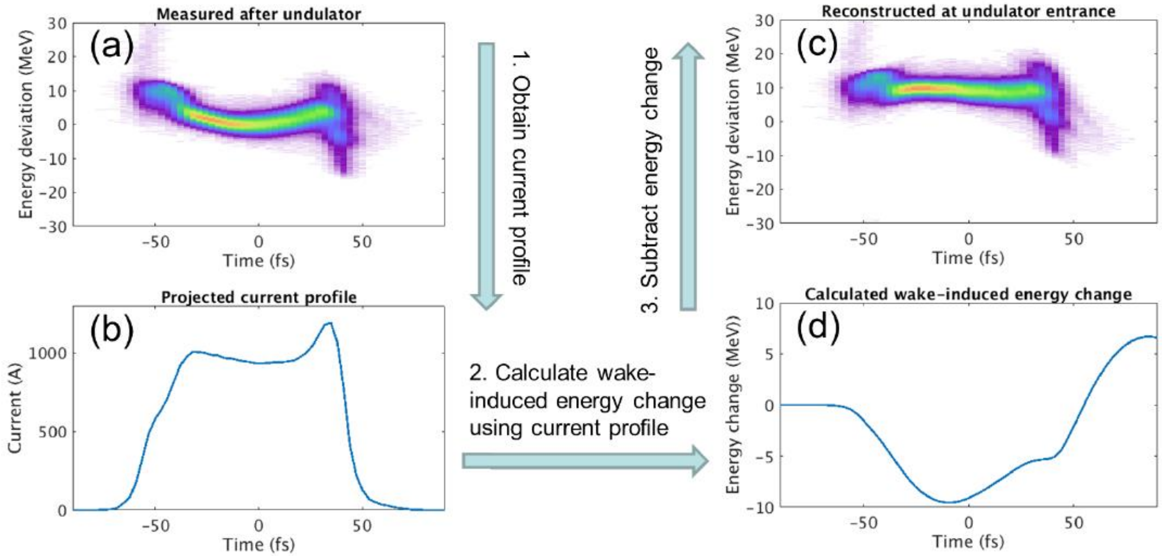
Measured **non-collimation** example: 250pC, 13.5 GeV



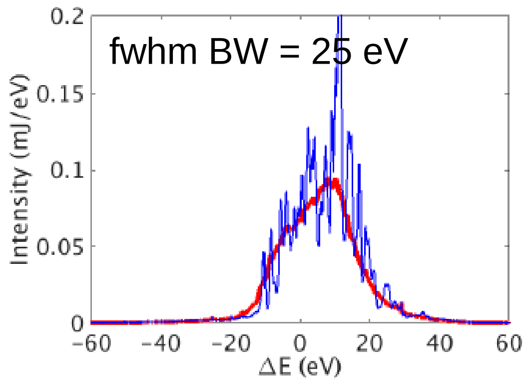


Y. Ding et al., PRAB, 2016.

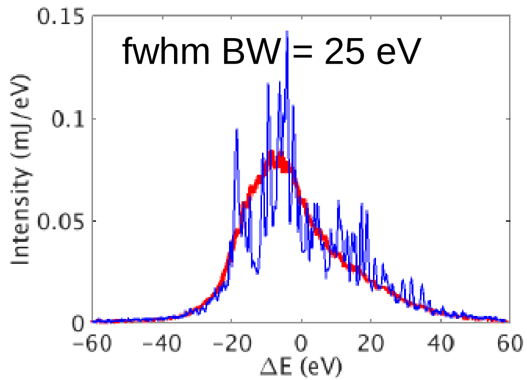
Horn-collimation improves bandwidth



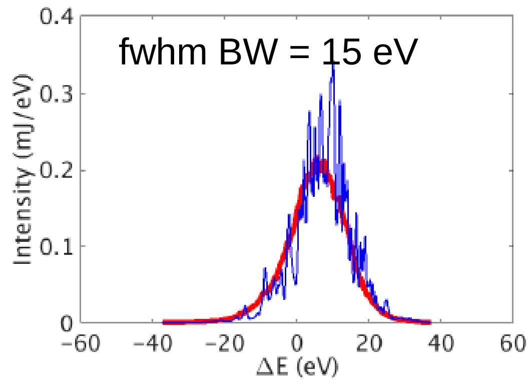
Flat the final chirp for seeding and narrow-BW SASE operation.



(a)150 pC, without collimation, 7 keV



(b)150 pC, without collimation, 9.3 keV



(c)Collimation mode,180 pC, 7.9 keV

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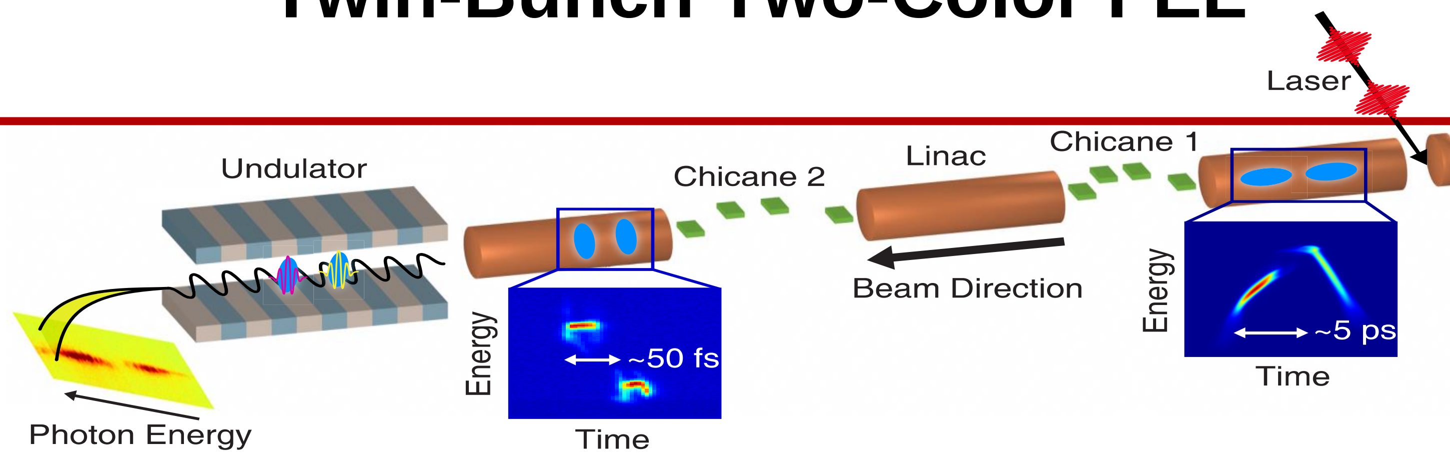
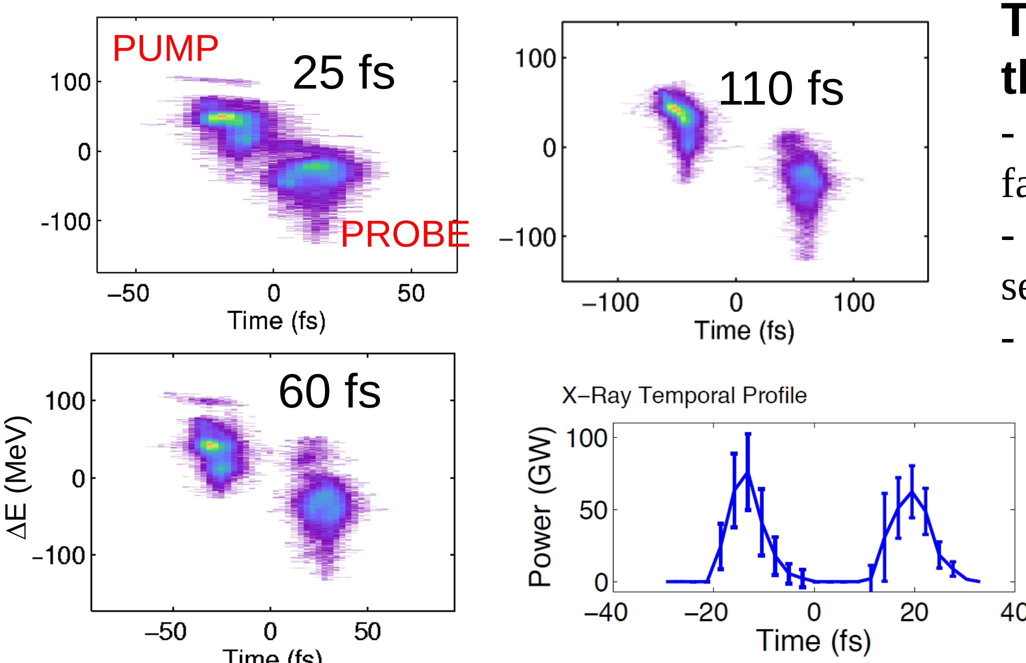
Y. Ding et al., PRAB, 2016.

Twin-Bunch Two-Color FEL





Twin-bunch takes full advantage of the XTCAV capability.

- Improve the peak power of 2-color SASE by a factor 20 at hard x-rays
- Allow 2 color self-seeding with large separation
- Allow x-ray pump/x-ray probe at high tensities

✓ **~10 fs pulse duration, over 1mJ pulse energy, pulse delay up to 150 fs.**

✓ **Up to 1% energy separation at HXR.**

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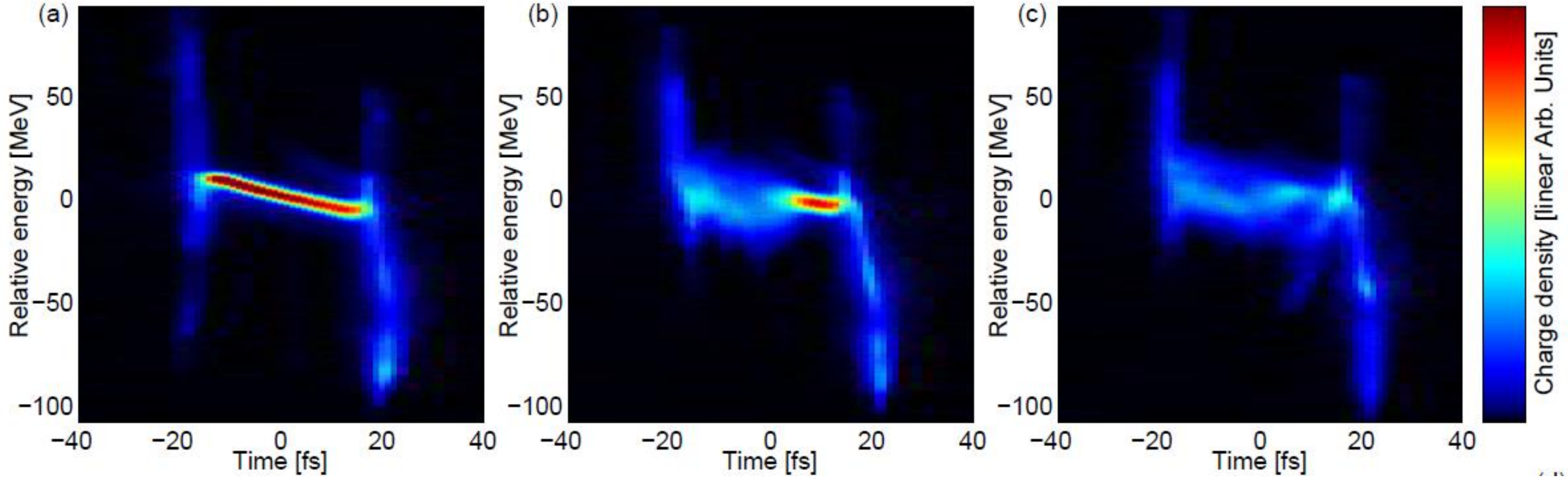
(*A. Marinelli et al., Nature Commun. 6, 6369, 2015*)

Fresh-slice lasing mode



(See A. Lutman's talk)

Summary

- XTCAV has been available for routine operations and synchronized data recording at the experimental hutch.
- It is critical for some special modes (twin-bunch, selfseeding, collimation etc.) setup.

- *We thank the support from the SLAC community for the XTCAV project. Special thanks to P. Krejcik, J. Wang, T. Maxwell and C. Behrens.*

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