Generation and characterization of ultrashort e-beams for X-ray FELs

DOE Early-Career Program (starting from 04/2010)

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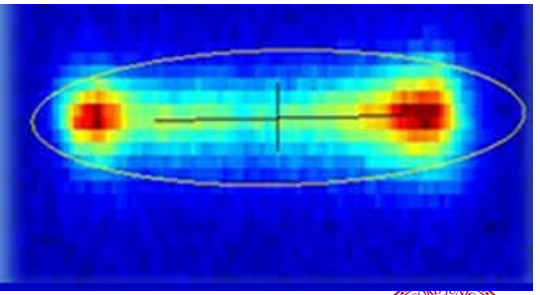
Main collaborators: Z. Huang, P. Krejcik, A. Lutman, H. Merdji, L. Wang

SLAC National Accelerator Laboratory

Accelerator and Detector Research and Development
Program Principal Investigators' Meeting

August 22-23, 2011
The Westin, Annapolis, MD



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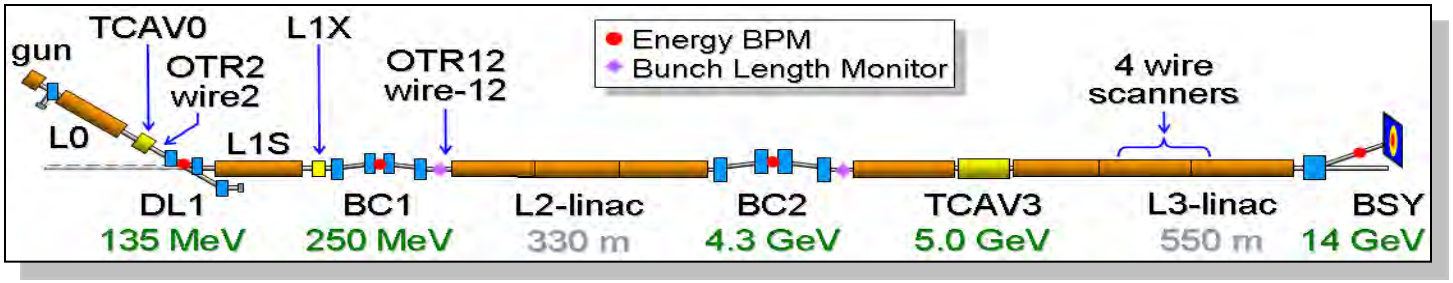
Motivation/background

- The successful operation of the LCLS has opened vast opportunities for ultrashort studies. For nominal operation with 250 pC:
  - ✓ x-ray pulses 70fs - 300fs, ~2 orders shorter than SR;
  - ✓ Peak brightness, ~10 orders higher than SR;
- A low charge (~20 pC) operation mode has also been established, expected to produce a few fs e-beam. However, no direct diagnostic tools available at LCLS to measure the electron-bunch length.
- Also, the x-ray users are interested to have even shorter x-ray pulses, fs to sub-fs, for dynamic studies.
- The characterization on the x-ray temporal duration is also a challenging problem, even for a few hundred fs pulses.

We proposed…

- To study new methods and physics of generation ultrashort (fs) e-beams:
  - ✓ Low charge optimization?
  - ✓ Slotted-foil?
- To develop new techniques for characterization of the ultrashort pulses:
  - ✓ Higher RF frequency deflecting?
  - ✓ Optical streaking?
  - ✓ Frequency domain methods?

Generation of ultrashort beams



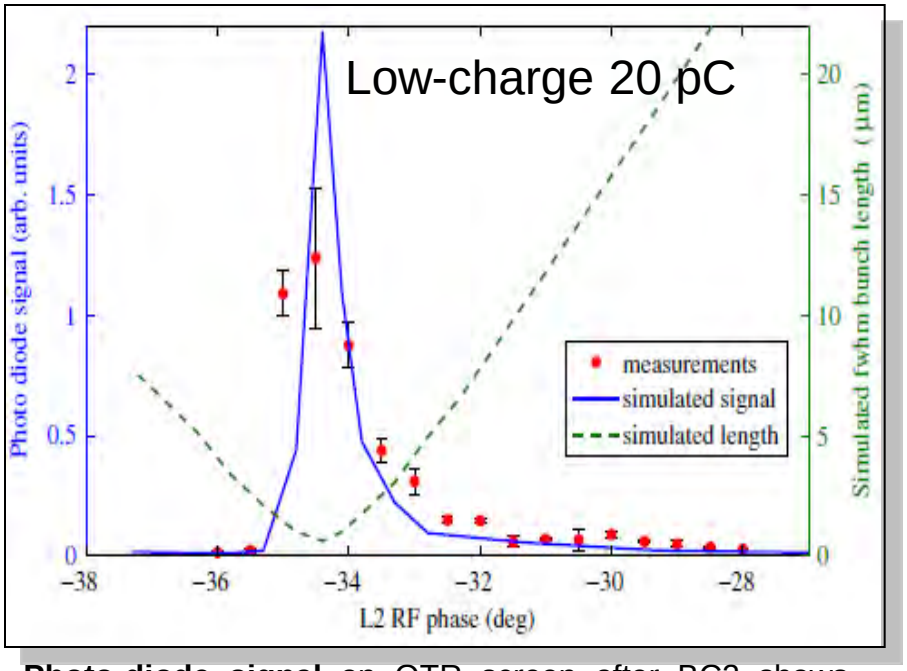
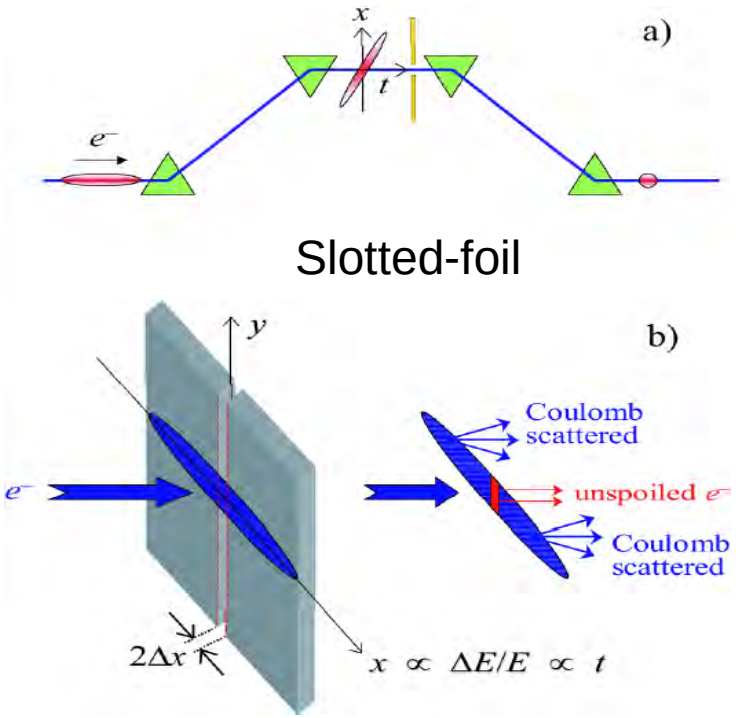


Photo-diode signal on OTR screen after BC2 shows minimum compression at L2-linac phase of -34.5 deg.

Y. Ding et. al, PRL 2009

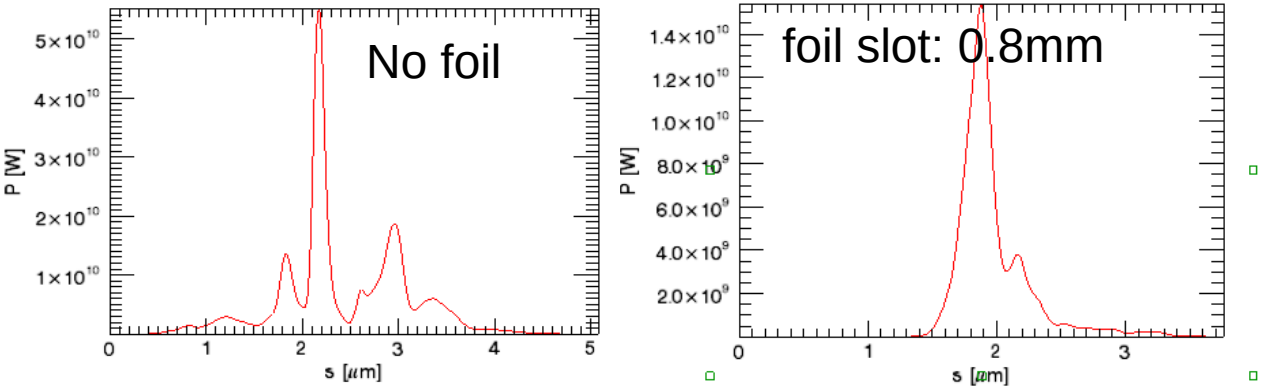


P. Emma et. al, PRL 2004

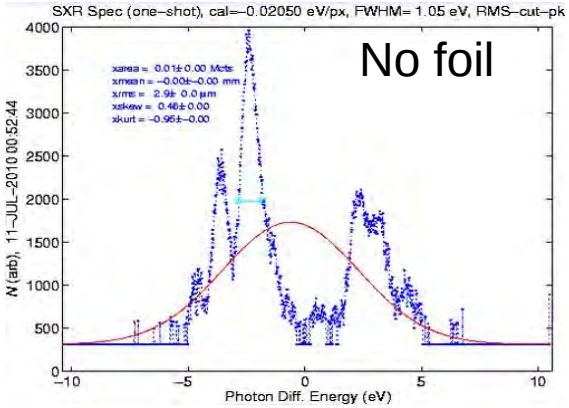
Optimization studies: low charge +foil/taper

Soft x-ray 1.5nm, over-compression

Genesis simulations

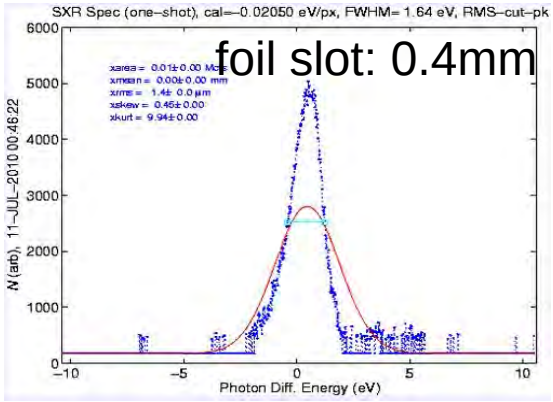


Spectrum measurements



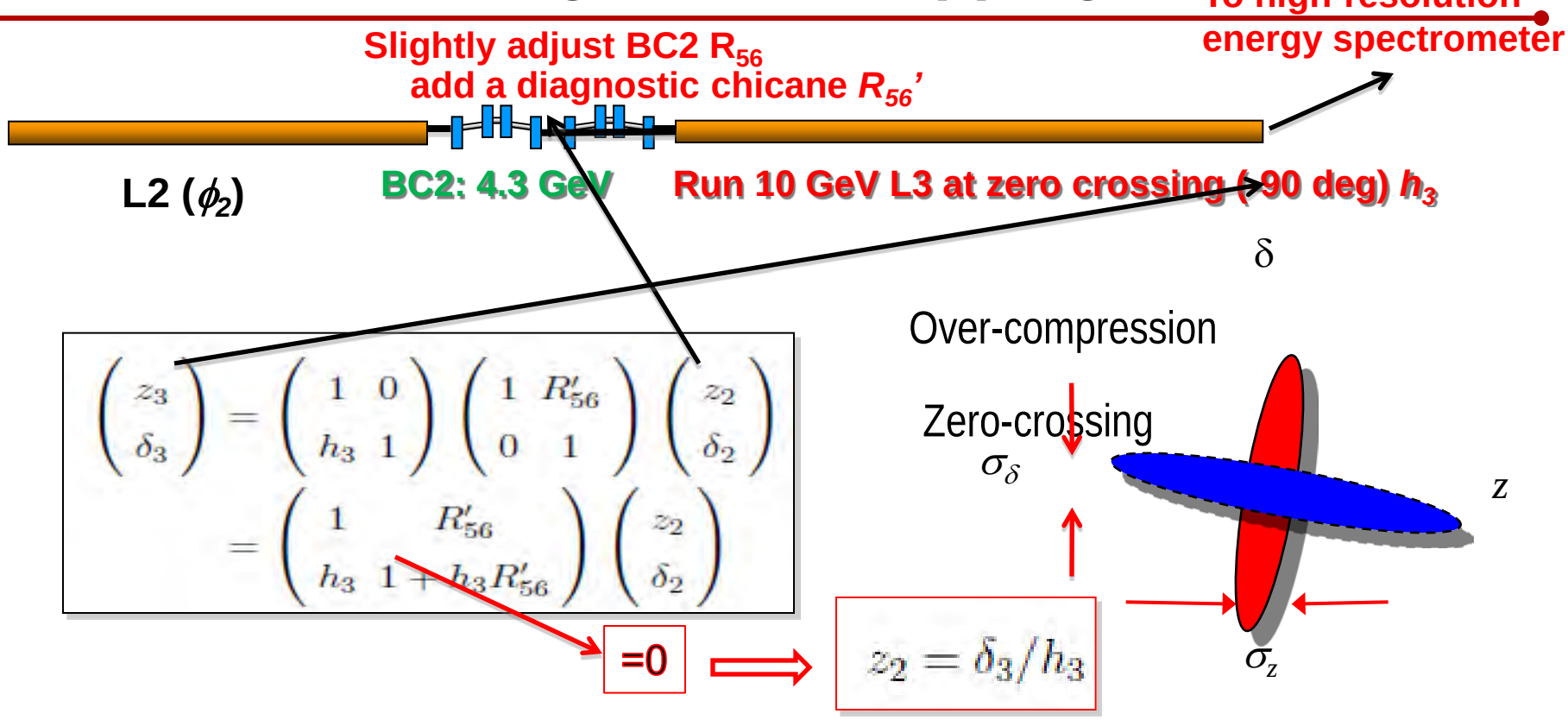
We explored methods to generate single-spike x-ray pulses mainly based on simulations:*

- At soft x-ray, may combine low-charge and slotted-foil or undulator taper;
- At hard x-ray, may obtain sub-fs x-ray pulses at full-compression by adjusting L1 rf phase;
- *Experimental studies are hard to perform due to the absence of diagnostic tools.*



L. Wang et al., to present at IPAC11

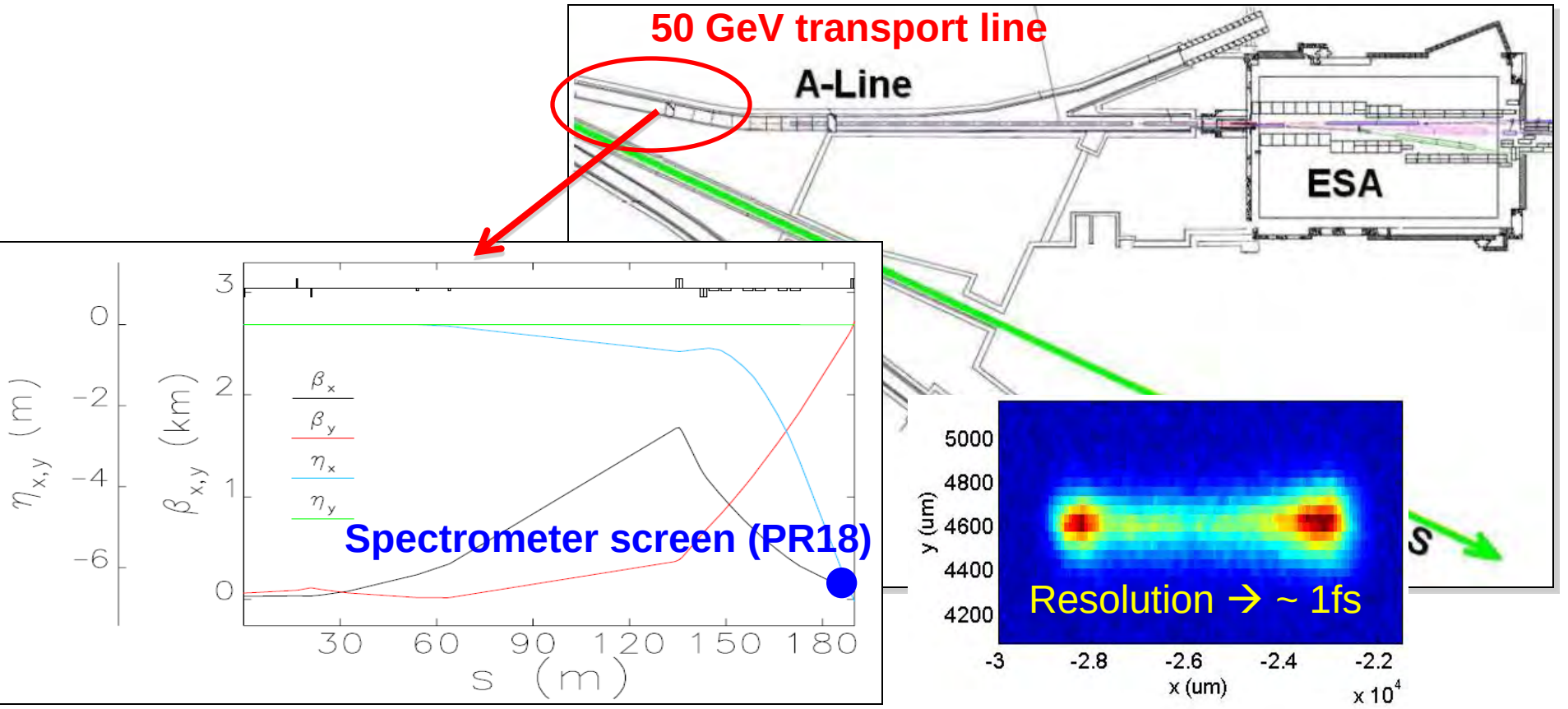
A single-shot method to measure fs bunch length by longitudinal mapping*



- Final energy spread/profile corresponds to compressed bunch length/profile.
- Wake fields from L3 has to be compensated.

** Z. Huang, K. Bane, Y. Ding, P. Emma (PRST, 2010); based on a technique by T. Smith (2000)*

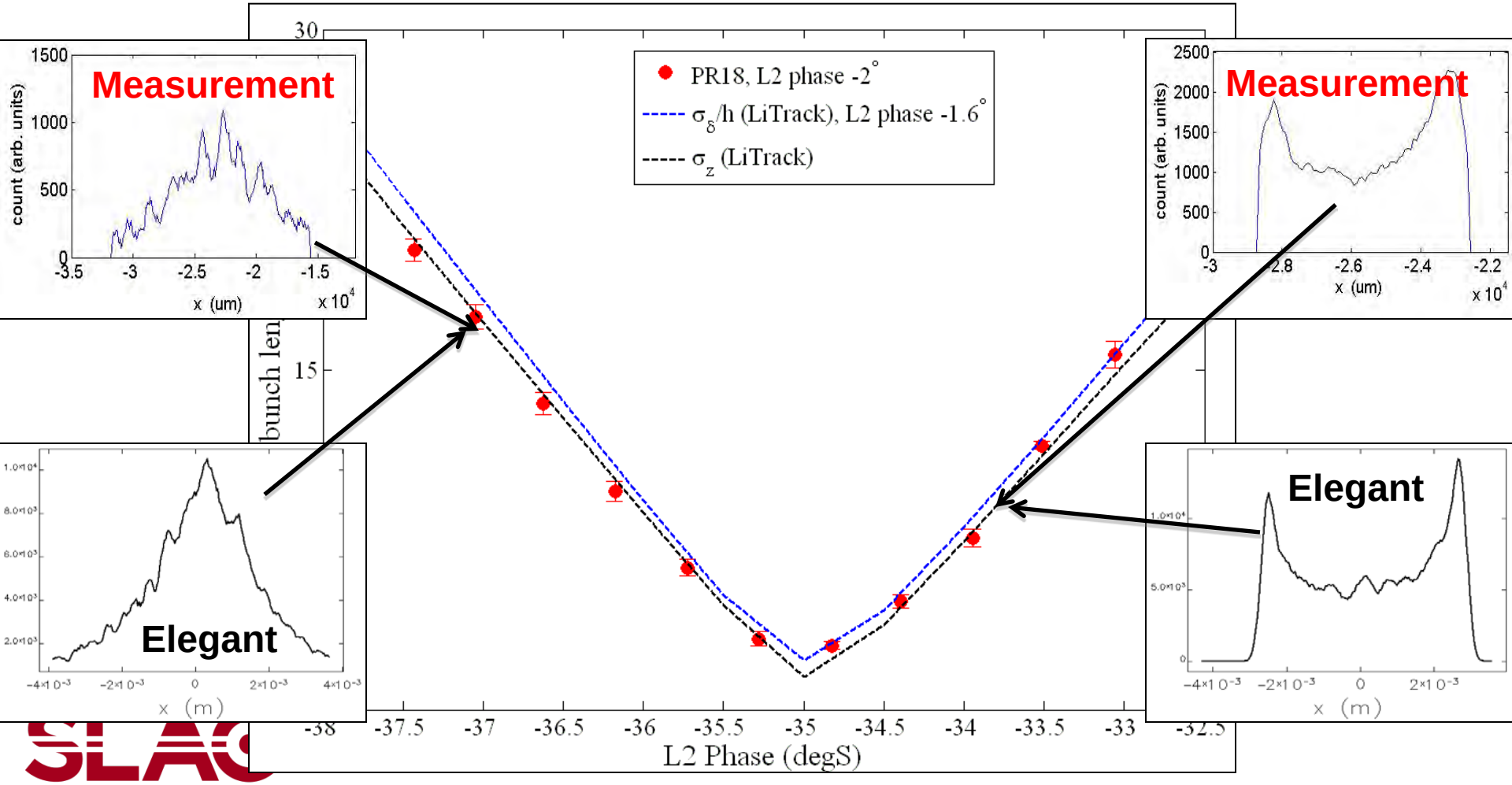
A-line as a high-resolution spectrometer



A-line restart and instrumental upgrades are supported from the early-career program.

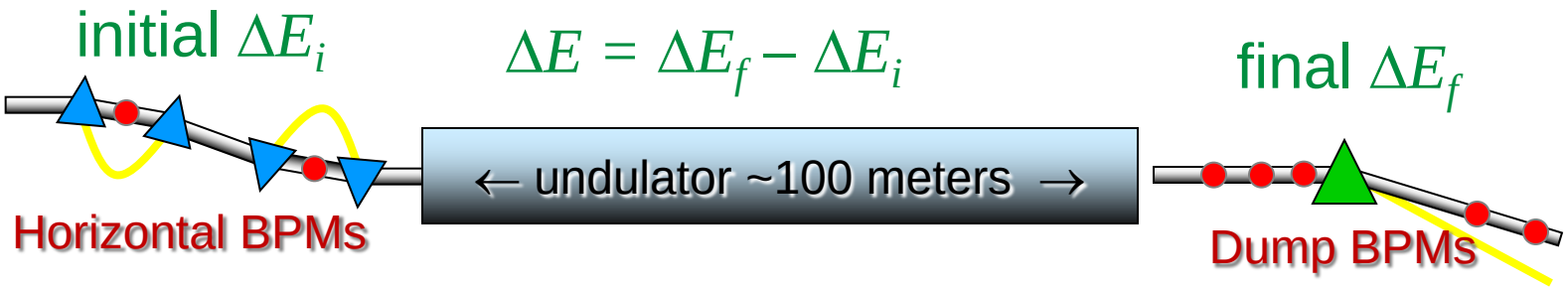
Measurement vs. simulation (40 pC)

- BC2 R56=-24.7mm to get σ_z, and R56=-35 mm and L3 -90 deg to get σ_δ
- Shifted L2 phase to compare measurement with simulations (5% cut area)

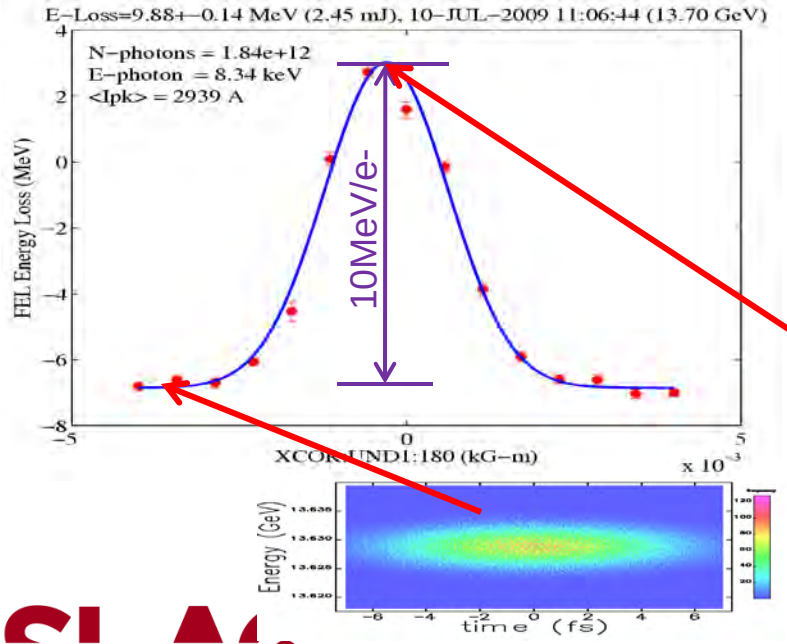


X-band transverse deflector: principle

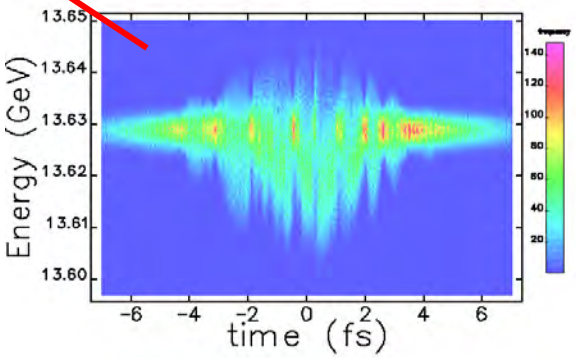
- The E-loss scan for measuring x-ray pulse energy:

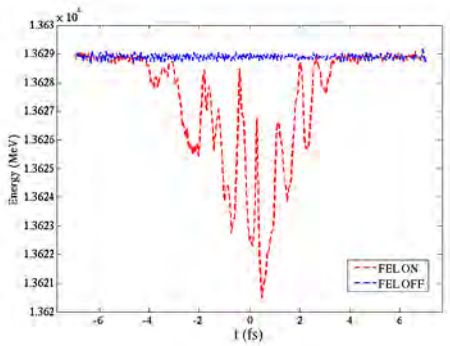


vary FEL power with oscillations & record e^- energy loss



We propose to streak the beam using a transverse deflector in time to measure the ***time-resolved*** energy loss, or energy spread, where the x-ray profile has been imprinted in the e-beam time-energy phase space.





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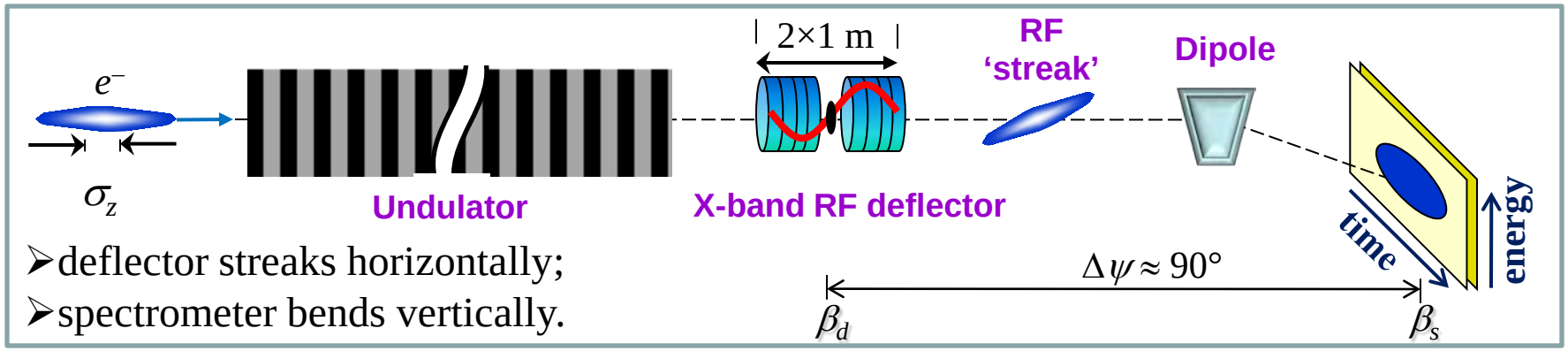
X-band deflector: both e-beams and x-ray pulses*

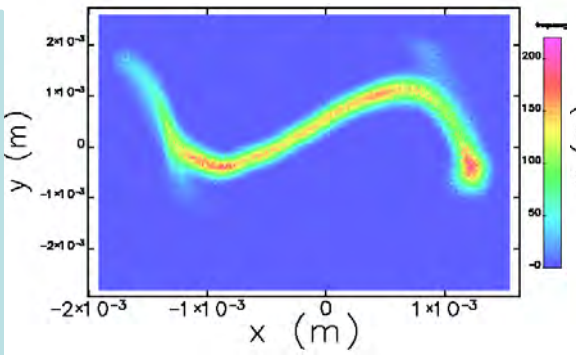


- deflector streaks horizontally;
- spectrometer bends vertically.

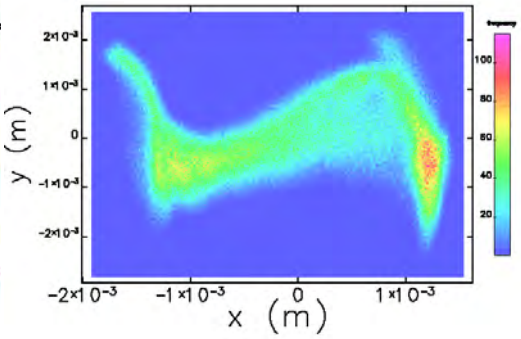
Advantages:

- ✓ High resolution, ~ few fs;
- ✓ Single-short, any wavelength;
- ✓ Wide range, ~ 1 fs to ~100s fs;
- ✓ No interruption with operation;
- ✓ Both e-beam and x-ray profiles.

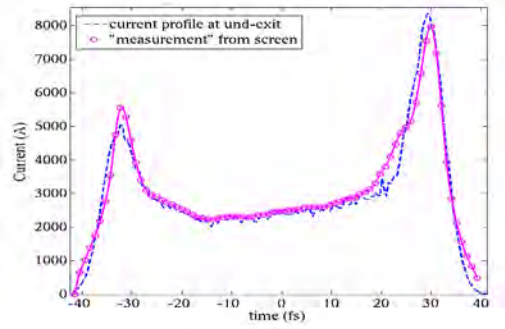
Screen, FEL OFF



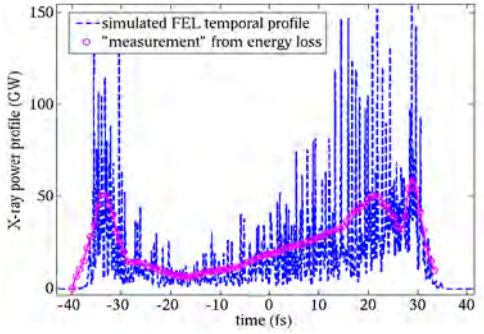
Screen, FEL ON



Reconstruction e-beam



Reconstruction x-ray profile



Y. Ding et al., SLAC-PUB-14534, submitted to PRSTAB.

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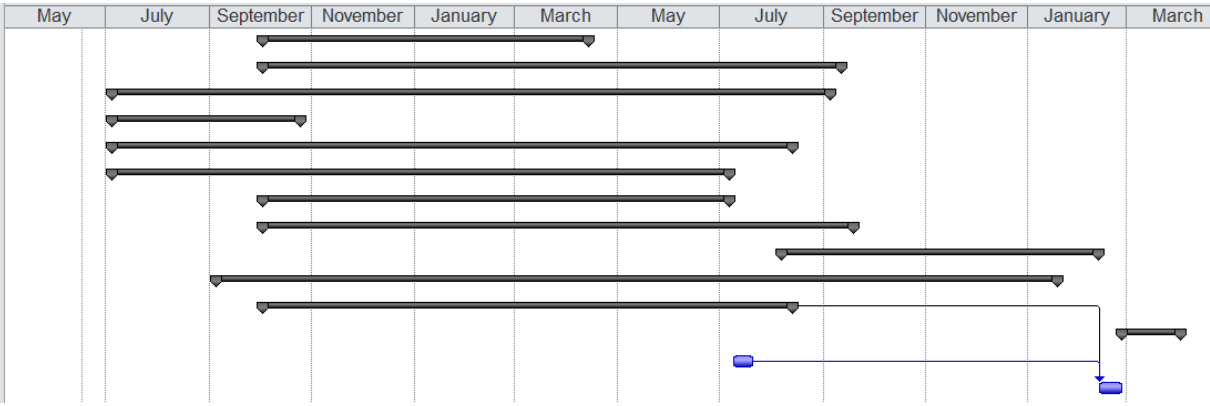
XTCAV progress and schedule

- ✓ This deflector proposal has been categorized into the “must-do” list during the LCLS Scientific Advisory Committee review in this spring;
- ✓ We get supports from LCLS on the hardware and engineering;
- ✓ Early-career program supports physicists’ time;
- ✓ **Has started from this July. To be ready in two years**.

	Task Name	Cost	Duration	Start
1	structure 2	$190,000.00	140 days	Mon 10/3/11
4	klystron	$690,000.00	247 days	Mon 10/3/11
9	modulator	$1,015,000.00	306 days?	Tue 7/5/11
29	AC Power	$168,000.00	80 days	Tue 7/5/11
32	Cooling systems	$157,000.00	290 days	Tue 7/5/11
39	Beam line	$390,000.00	264 days	Tue 7/5/11
43	wave guide	$508,000.00	200 days	Mon 10/3/11
48	LLRF driver	$334,000.00	252 days	Mon 10/3/11
54	Klystron/modulator ctrls	$0.00	135 days	Tue 8/7/12
60	LLRF controls	$505,000.00	360 days	Mon 9/5/11
66	Safety systems	$150,000.00	226 days	Mon 10/3/11
77	Profile Monitor	$50,000.00	25 days	Tue 2/26/13
80	Final Installation	$0.00	10 days	Mon 7/9/12
81	Commissioning	$0.00	10 days	Tue 2/12/13



With this diagnostic tool, we will further study low-charge optimization and new methods for generation of ultrashort x-ray pulses.

Other related work on ultrashort measurements

- ✓ Optical streaking using a Ti:Sa laser;

  Y. Ding et al., to present at FEL11

- ✓ Optical streaking on ionized low-energy beams

  L. Wang et al., to present at IPAC11

- ✓ Longitudinal mapping

  D. Xiang and Y. Ding, PRSTAB 13, 094001 (2010)

- ✓ Statistical analysis from spectral correlation function

  A. Lutman et al., to present at FEL11

- ✓ ***Y. Ding, invited talk at FEL11 on the ultrashort topic.***

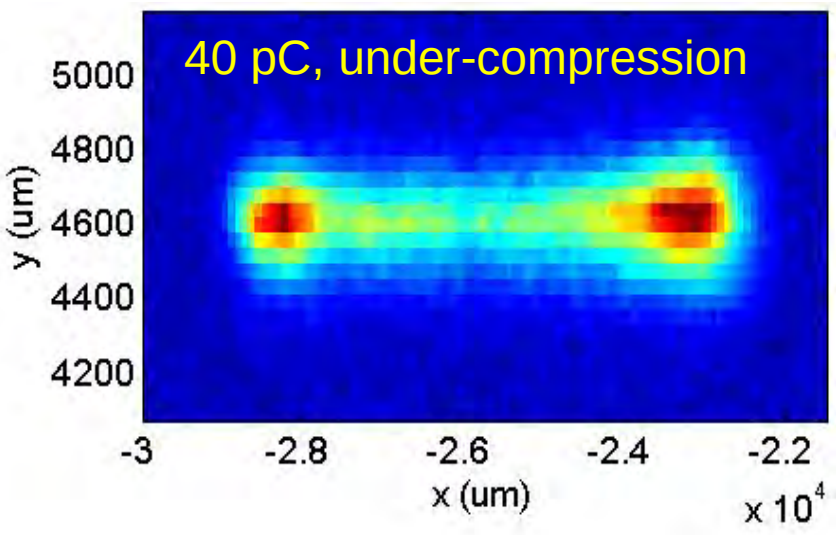
Future plans

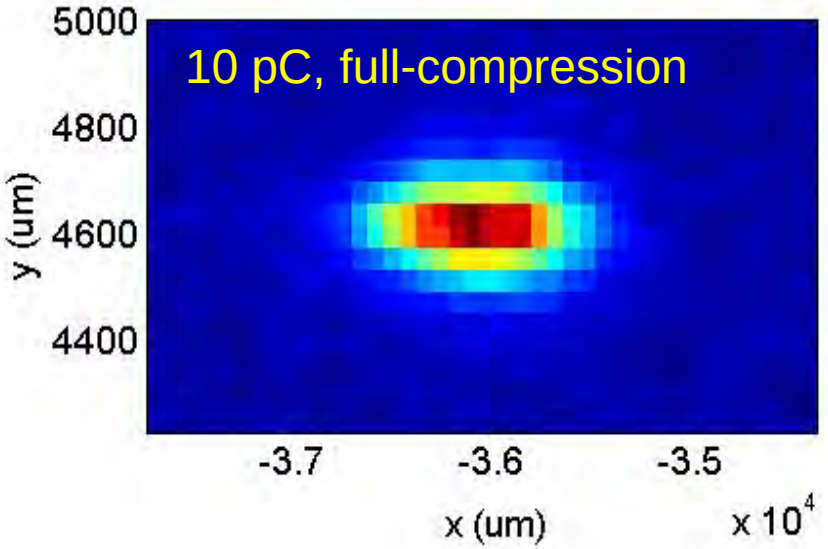
- We will converge and focus on the X-band transverse deflector program to develop a reliable diagnostic tool for ultrashort e-beam and x-ray pulse temporal measurements in the coming two years;
- With the new diagnostic tool, we plan to study low-charge optimization based on both simulations and experiments, and further explore new schemes for ultrashort generation;
- Continue on study of the optical and frequency domain methods.

- Thanks the DOE Early-career program support
- Thanks the great team and SLAC/LCLS support

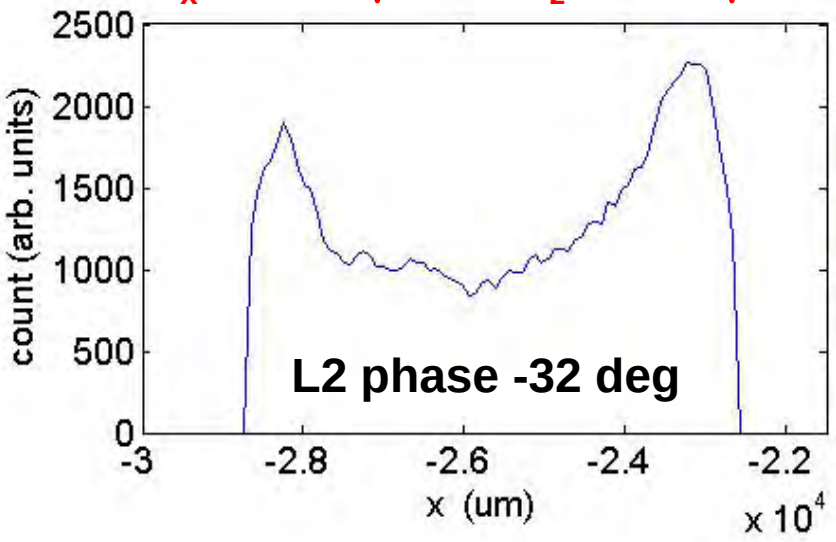
THANK YOU

Measurement examples on PR18

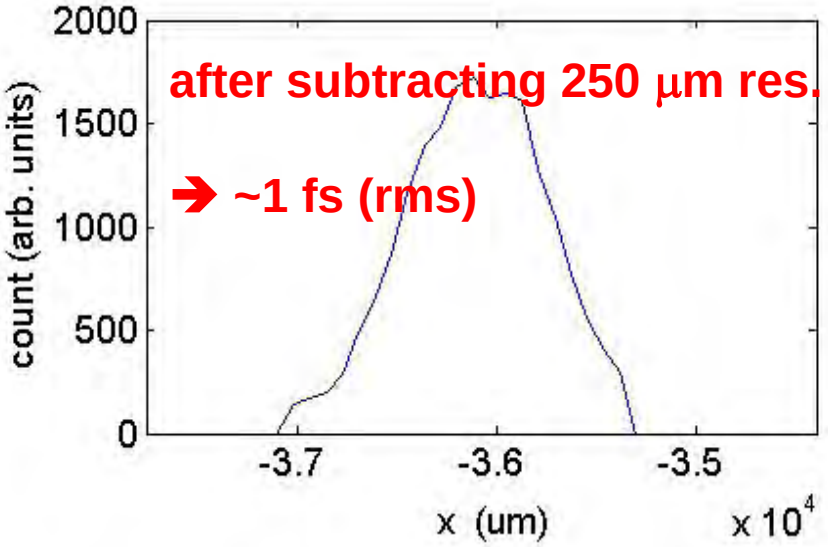




σ_x = 1908 μm ➔ σ_z = 2.47 μm



σ_x = 327 μm ➔ σ_z = 0.27 μm



(Z. Huang et al.,PAC11, THP183)