Femtosecond X-ray Pulse Characterization in Free-electron Lasers using a Cross-Correlation Technique

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On behalf of
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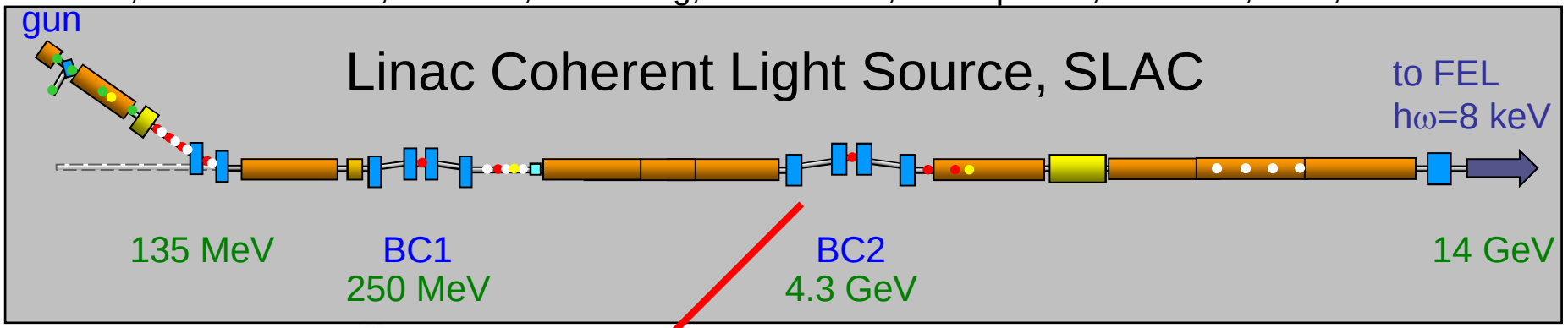
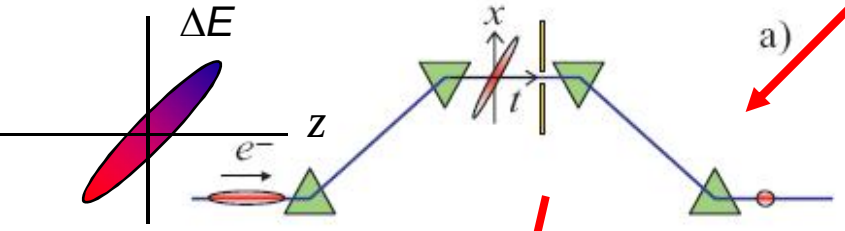
Outline

- Ultrashort x-rays generation with a slotted foil
- Characterization of the pulse separation and duration using a cross-correlation method
- Generation of fs 2-color FEL pulses
- Discussions

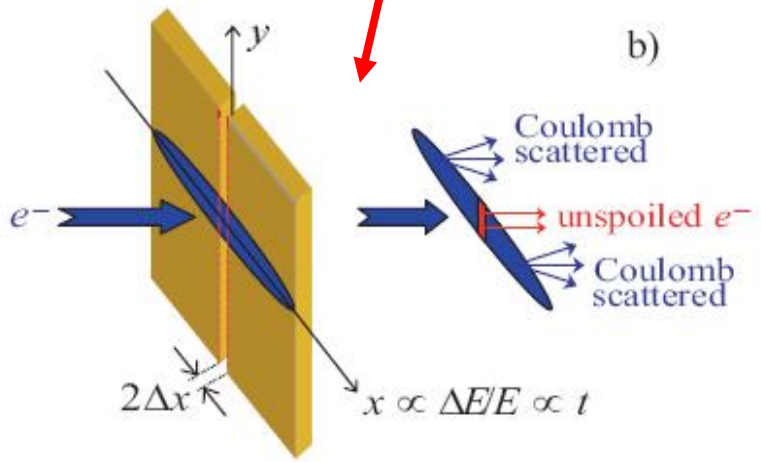
SUB-FEMTOSECOND X-RAY PULSES USING THE SLOTTED FOIL METHOD

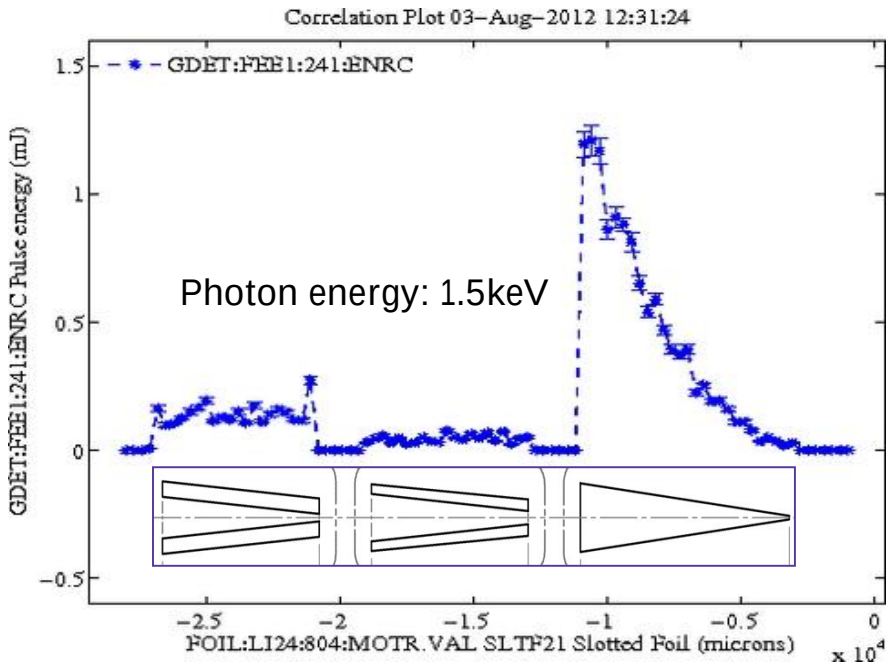
P. Emma, M. Cornacchia, K. Bane, Z. Huang, H. Schlarb ,G. Stupakov, D. Walz , PRL, 2004





energy chirp





Measured x-ray pulse energy vs foil vertical position

Courtesy P. Emma

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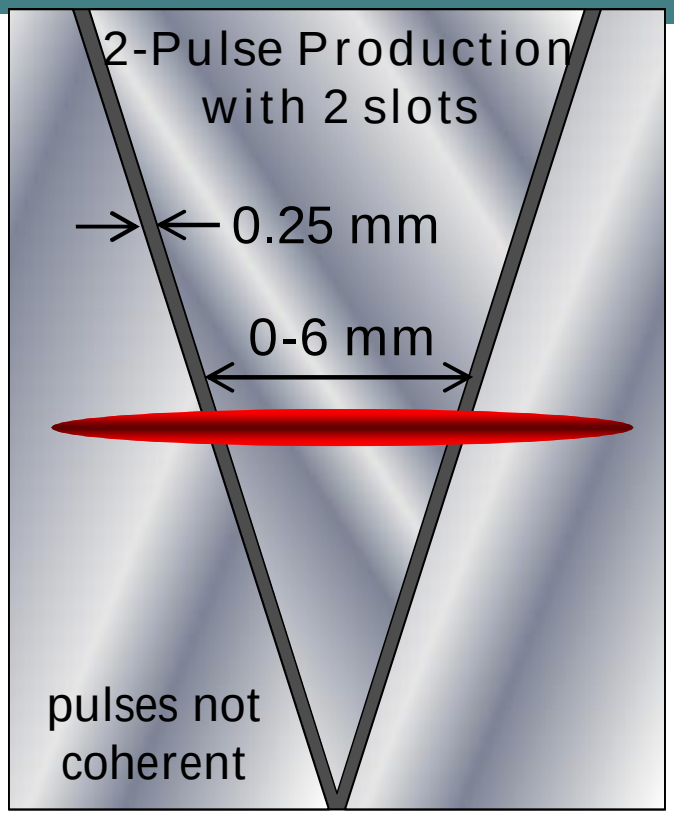
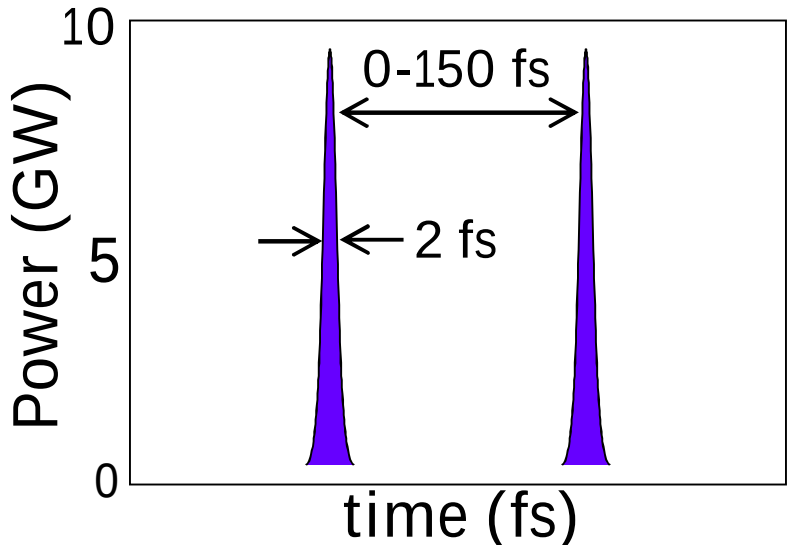
Double X-Ray Pulses from a Double-Slotted Foil



FEMTOSECOND X-RAY PULSES IN THE LCLS USING THE SLOTTED FOIL METHOD



Precise controlled time delay between x-ray pump and x-ray probe pulses

Courtesy P. Emma

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Simple calculations

- to calculate the pulse separation from double-slotted foil:

$$\Delta t = \frac{\Delta x}{\eta h C c}, \quad (1)$$

Δx is the slot separation, C is compression factor, h is the energy-time chirp, η is the dispersion,

- In operation, we have the bunch length information before and after the compression. The chirp can be calculated:

$$h = \frac{1 - \sqrt{{\sigma_{z2}}^2 - {R_{56}}^2 {\sigma_{\delta 0}}^2} / \sigma_{z1}}{|R_{56}|} \quad (2)$$

- To calculate the pulse duration, we have to include the un-correlated energy spread and betatron beam size effects. (P. Emma et al., FEL2004)

$$\Delta\tau \approx \frac{2.35}{|\eta h| c} \sqrt{\eta^2 \sigma_{\delta_0}^2 + (1 + h R_{56})^2 \left[\Delta x^2/3 + \epsilon\beta\right]} \quad (3)$$

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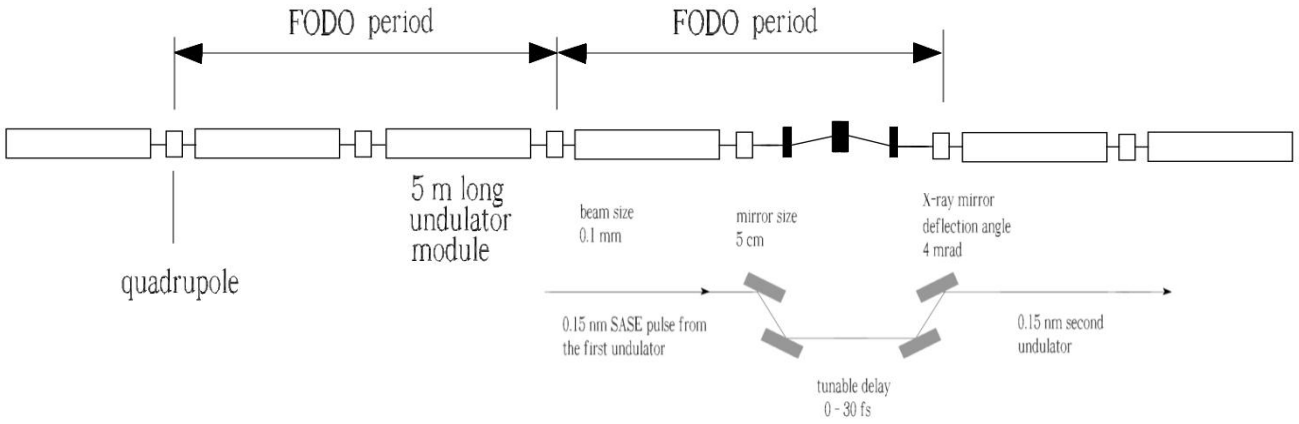
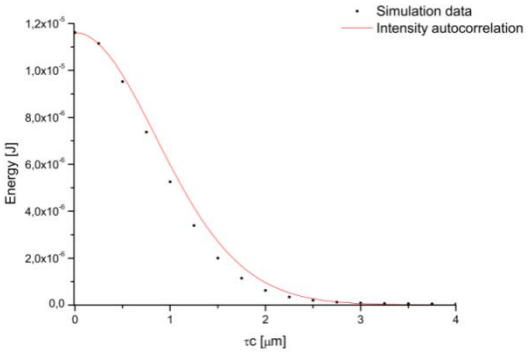
It is *challenging* for x-ray diagnostics

- The expected x-ray pulse duration is about a few fs, and can be shorter. Pulse duration and delay.
- Geloni et al. proposed an autocorrelation method recently with "fresh bunch" technique. [DESY10-008]





- Chicane is to wash out microbunching and to make an offset for installation of x-ray delay line. Scan x-ray delay line in measurements.
- It is possible to use a chicane only, but points near zero delay are missing.
- We like to call it *cross-correlation*, since x-rays overlaps with "fresh bunch" in the second part undulator.

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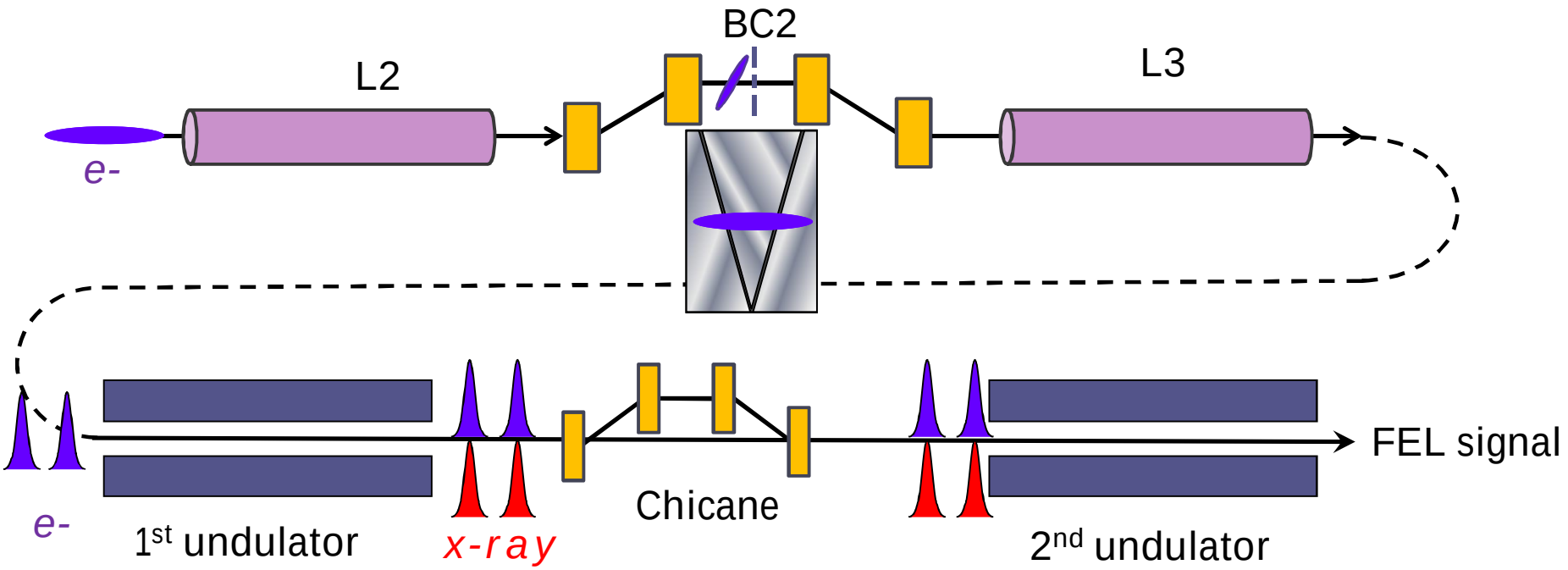
We applied the *cross-correlation* measurements for slotted-foil case use a chicane only.



- For double-pulse mode, we can measure the pulse separation (delay) and also the pulse duration in one scan;
- The pulse delay should not matter the system is in exponential gain regime or saturation regime.
- We also carried out correlation measurements for single-bunch mode.

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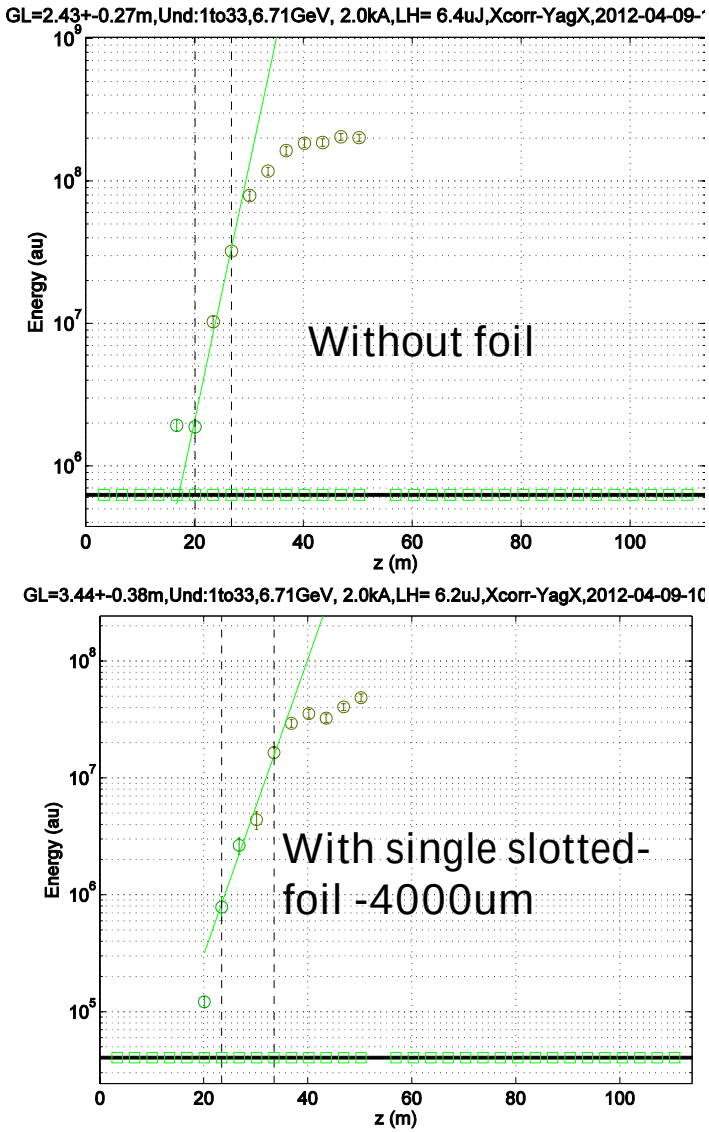
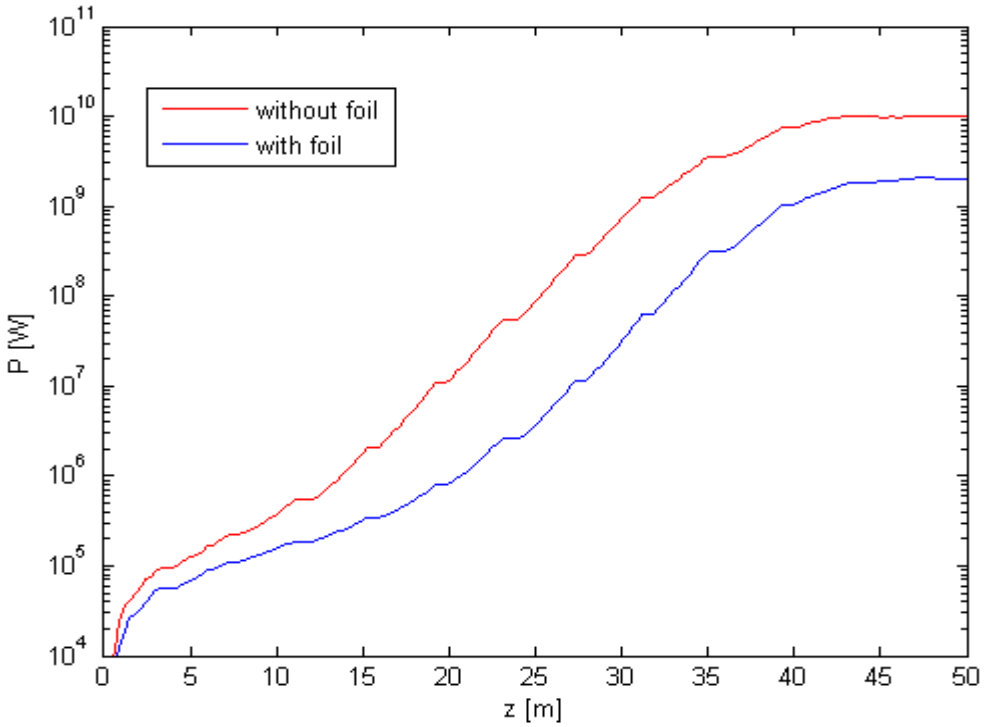
2kA, 2keV FEL gain length measurements





Simulation gain curves fit very well with measurements. Saturation lengths are nearly the same (~40m).

We setup the measurements in exponential gain regime.

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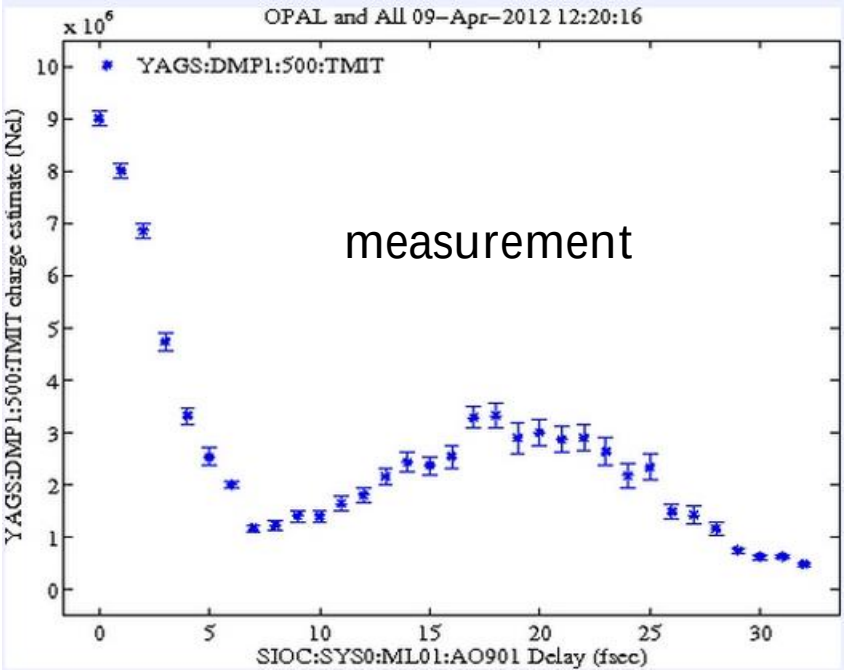
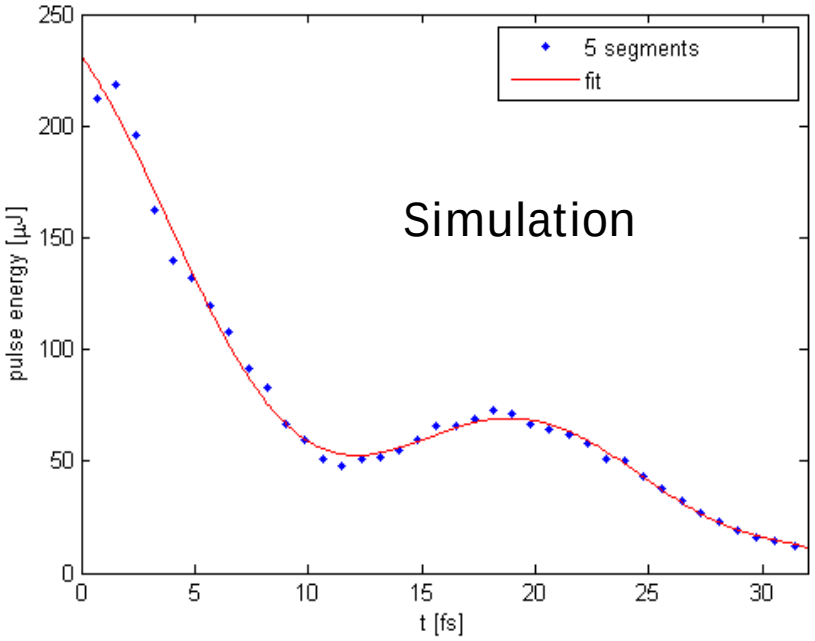
Double-pulse mode, full scan curve (2keV, 2kA)





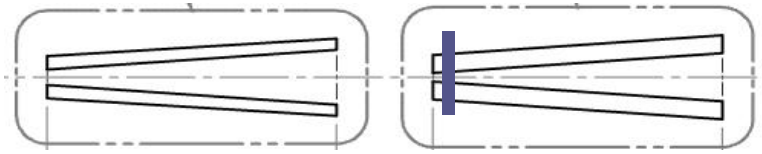
Foil at -21500um (690um separation) , 2kA, 2keV.

First part x-ray correlates with the same e-beam;

Second part the delayed first e-beam correlates with the second x-ray pulse;

The peak at ~18fs gives the delay of the two pulses.

The peak width gives the pulse duration info.



-21500 um

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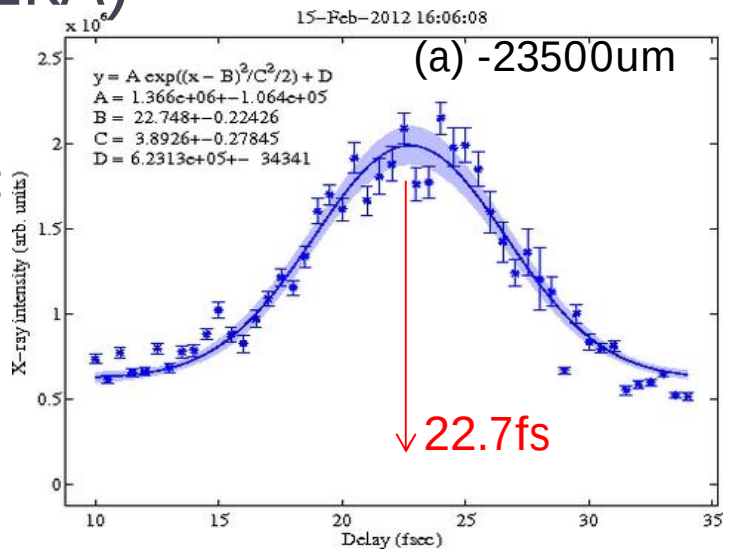
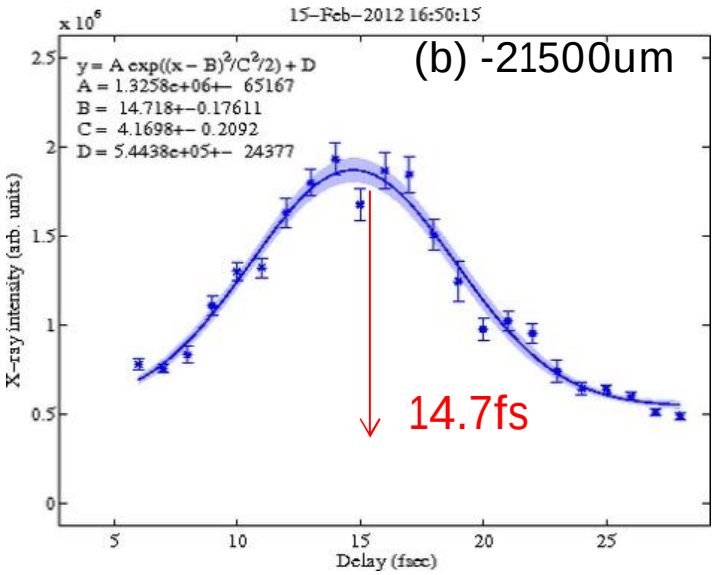
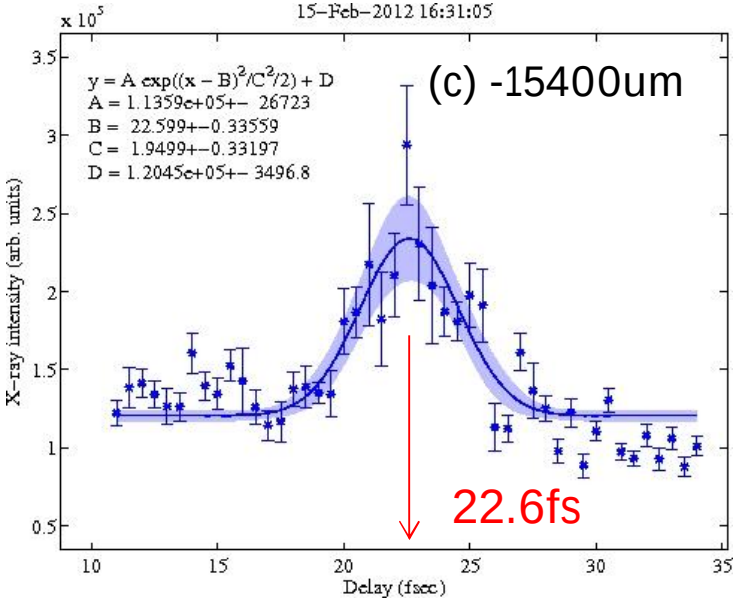
Different slot separation and different slot width (2keV, 2kA)

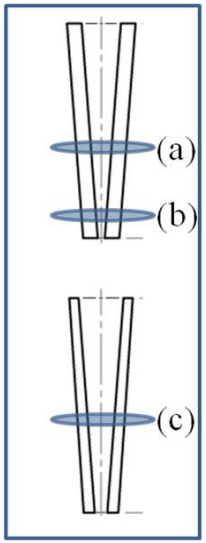
Meas. fwhm:
(a)=6.1fs;
(b)=6.5fs.





Meas. fwhm:
(c)=3fs.





Calculation of delay with the equation:
23.5fs
16.5fs.

(PRL 109, 254802 (2012).)

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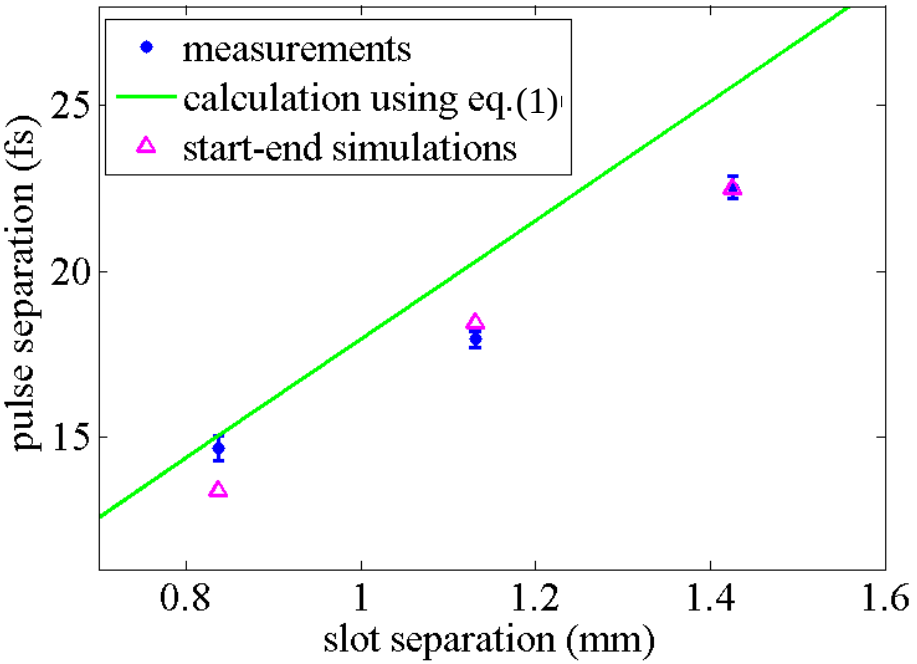
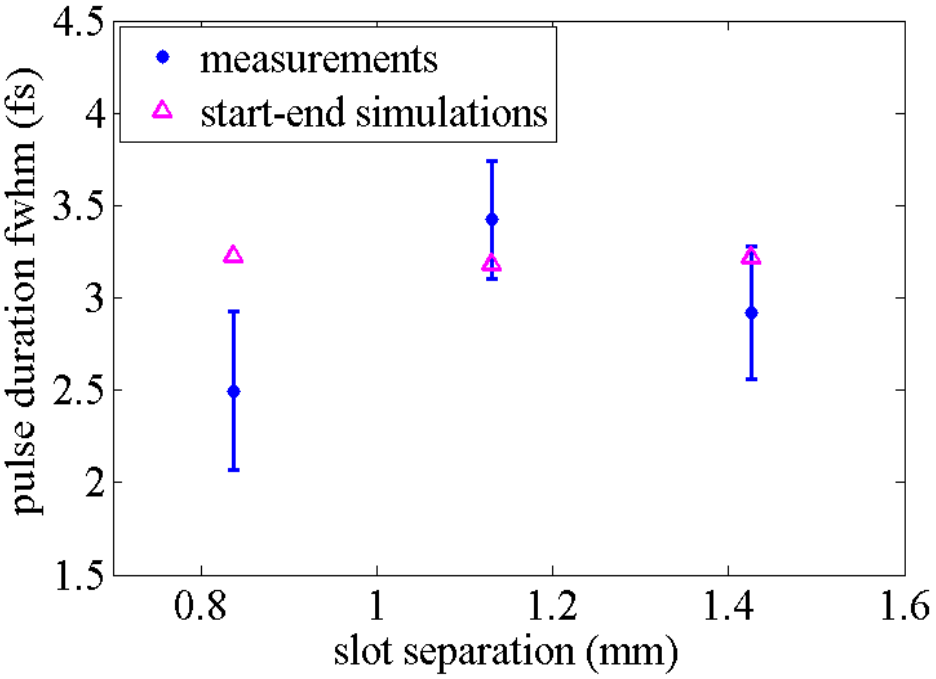
Cross-correlation measurements with Double-slotted foil, HXR 8.2keV, 2.6kA, 7/4/2012





The measured pulse delay is slightly smaller than simple calculations.

The discrepancy gets larger with a bigger slot separation.

The local compression is nonlinear due to a nonlinear chirp, from which a double-horn shape is formed, and the pulse delay at larger separation is smaller due to a larger local compression factor.

(PRL 109, 254802 (2012).)

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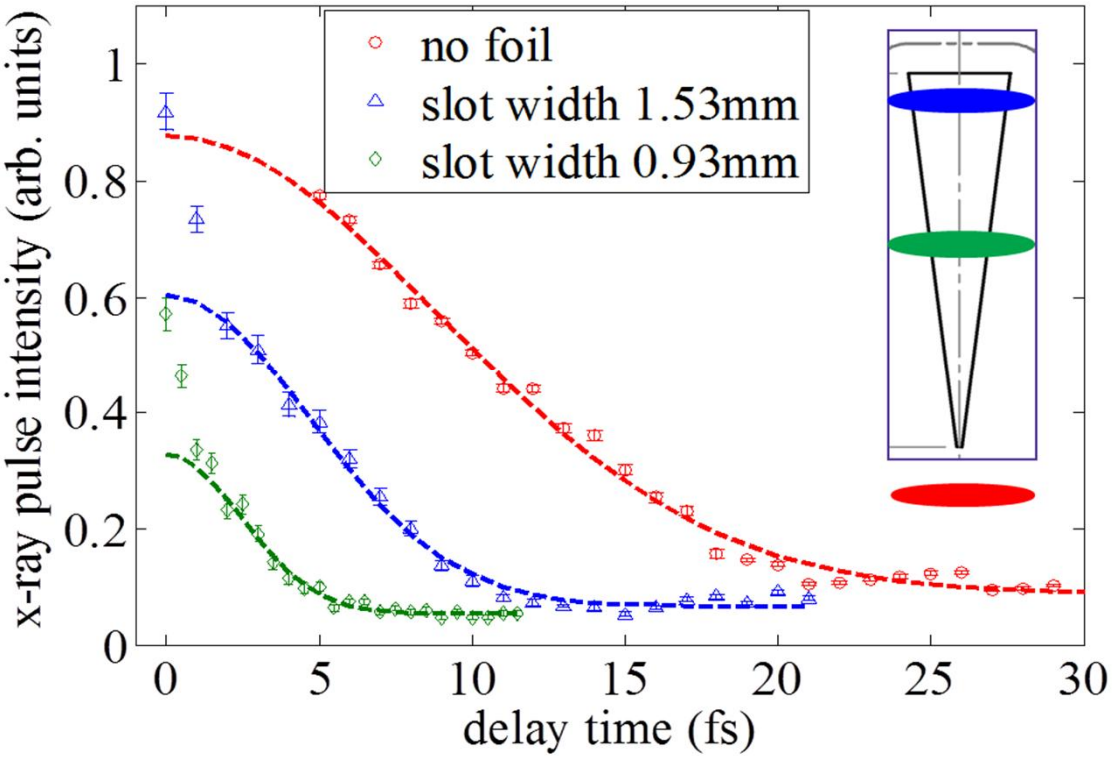
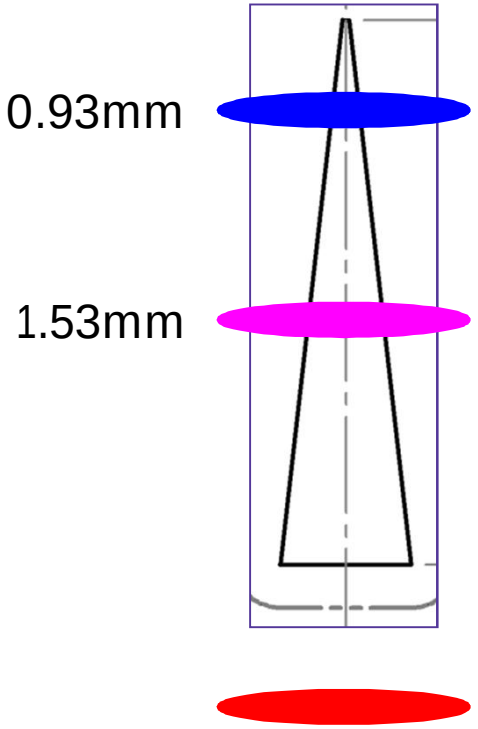
Cross-correlation measurement for a single bunch: 150pC, 3.2kA, HXR 8.3keV





The fitting rms widths are: 8.98fs, 4.67fs, 2.44fs.
Divided by the deconvolution factor 1.5, and go to fwhm by 2.355,
we get pulse duration (fwhm): 14.1fs, 7.3fs, 3.8fs.

(PRL 109, 254802 (2012).)

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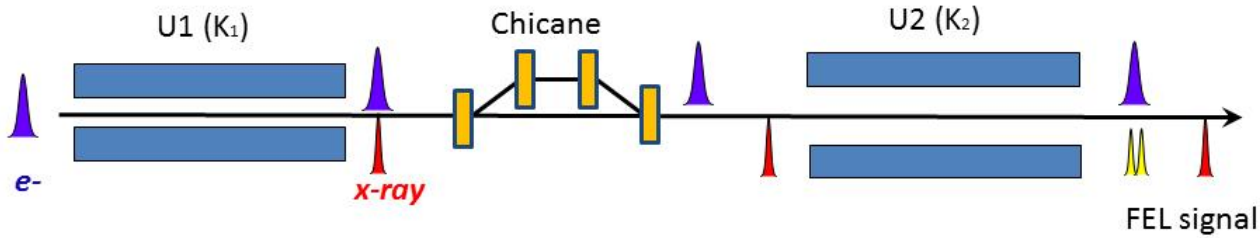
Generating fs x-ray pulses with different colors

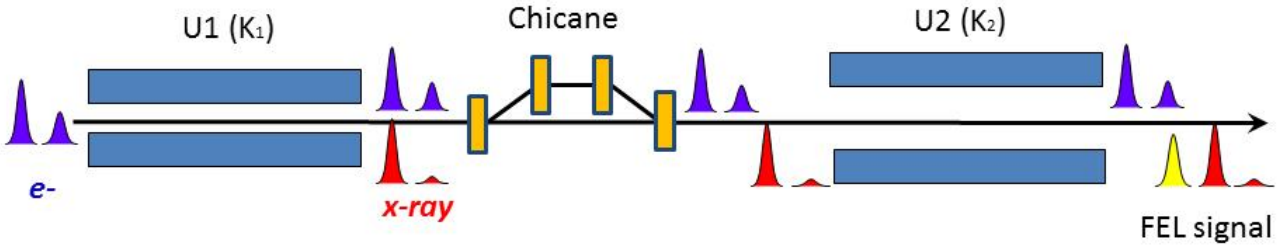
- We used foil to shorten x-rays to fs.
- different colors can be generated by the e-beam energy difference of the two pulses, OR by the difference of undulator K setup.
- we take the advantage the seeding chicane in the middle of the undulator to further control the pulse delay between the two colors.

Three 2-color schemes proposed and tested

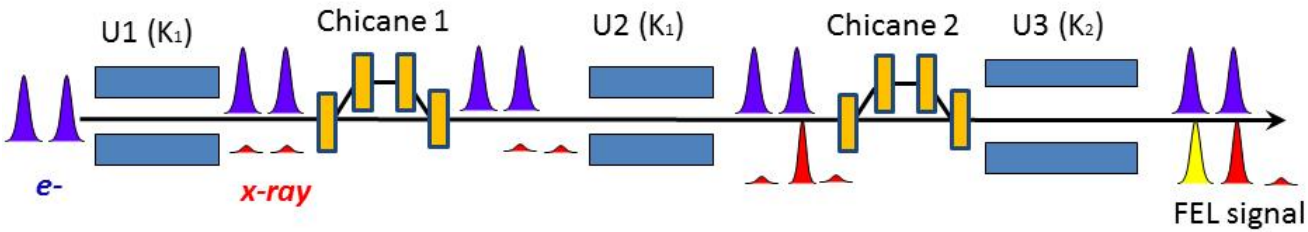
(A)



(B)



(C)



C. Feng et al., FEL12, THPD56

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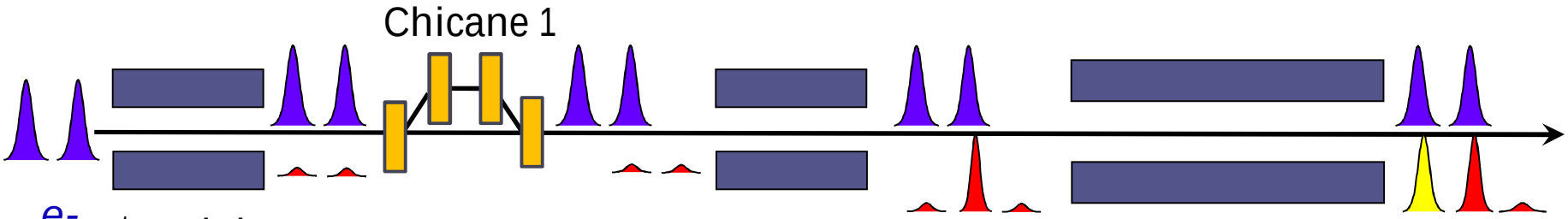
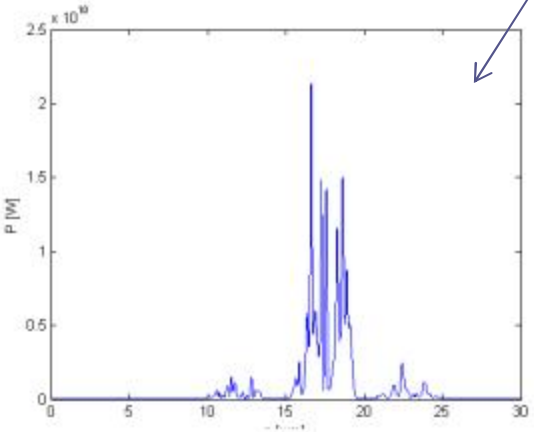
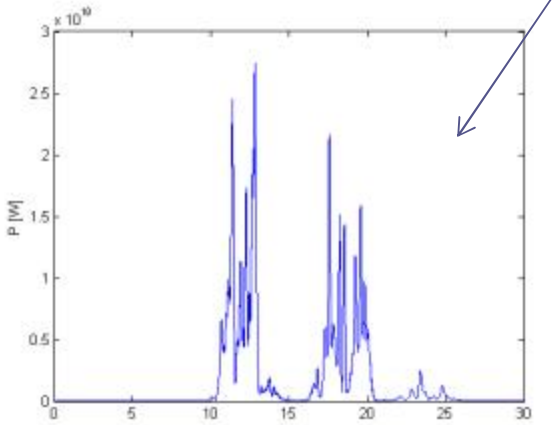
Cross-correlation for two-color generation (scheme 3)

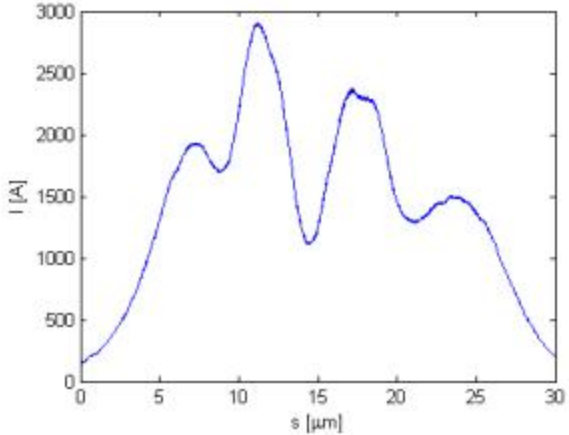


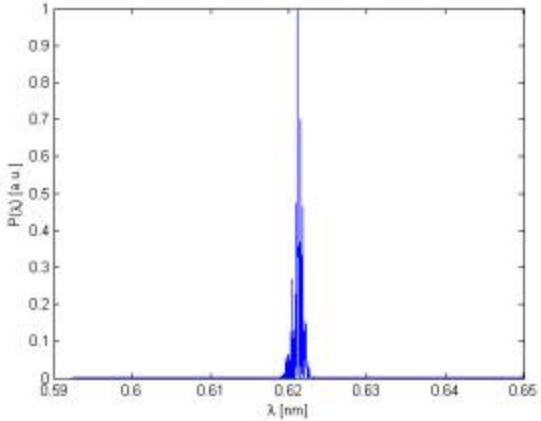
Double slots
Width: 0.8mm
Separation: 1mm
Beam energy: 6.7GeV

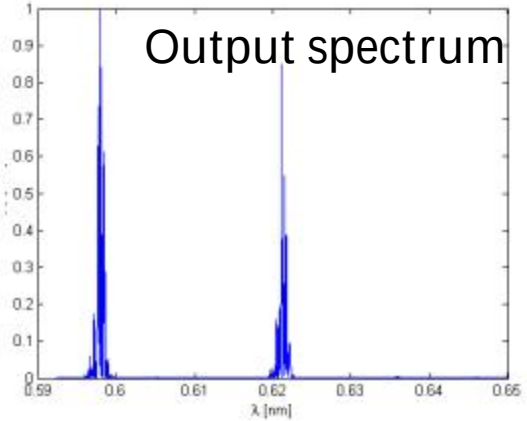
1st undulator: 8 segments
2nd undulator: 6 segments
3rd undulator: 12 segments











Discussions

- Slotted foil works well for generating shorter x-ray pulses;
- Characterization is still a challenging topic;
- Auto/cross-correlation measurements have been made using the selfseeding chicane in the middle of the undulator.
- The measured pulse delay gives important information for pump-probe experiments.

THANKS!!!

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