Measuring the LCLS few-fs xray pulse length

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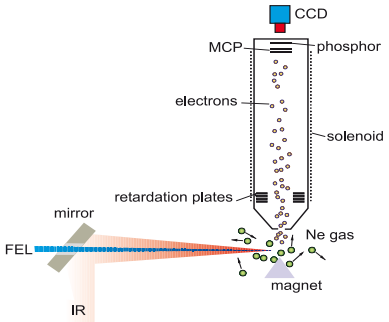
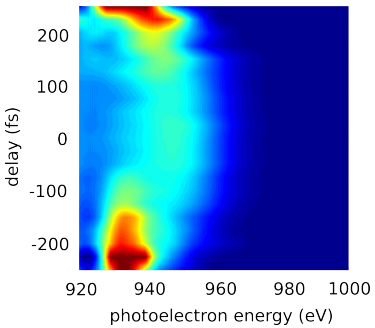
LMU[1] / TU[2] / MPQ[3] / CFEL[4]/ DESY[5] / XFEL[6] / OSU[7] / ANL[8] / SLAC[9] / DCU[10]

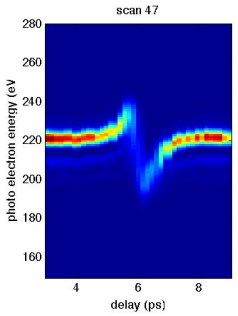
1. Measurement Method



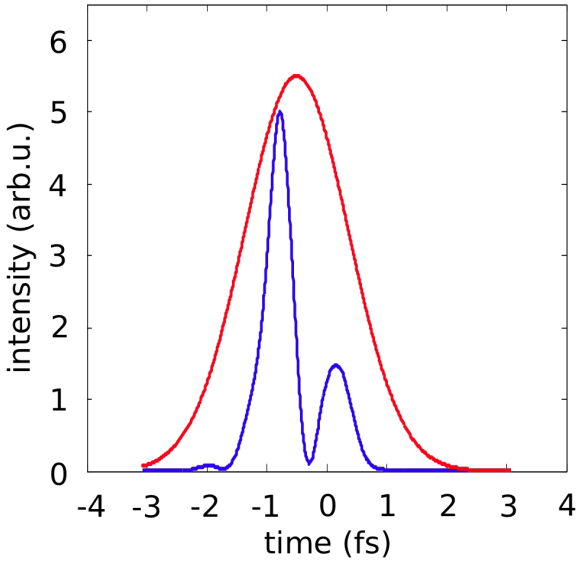
2. Fighting the Jitter Problem



3. Single-Cylce THz Streaking



The Mission



GENESIS simulation of LCLS low-charge mode, 2fs FEL pulse (blue) and gaussian envelope (red). pulse close at saturation.

- LCLS is a pretty cool machine delivering tunable hard xray pulses
- we want to measure the actual pulse lenght
- for non-linear processes we need exact temporal pulse profile

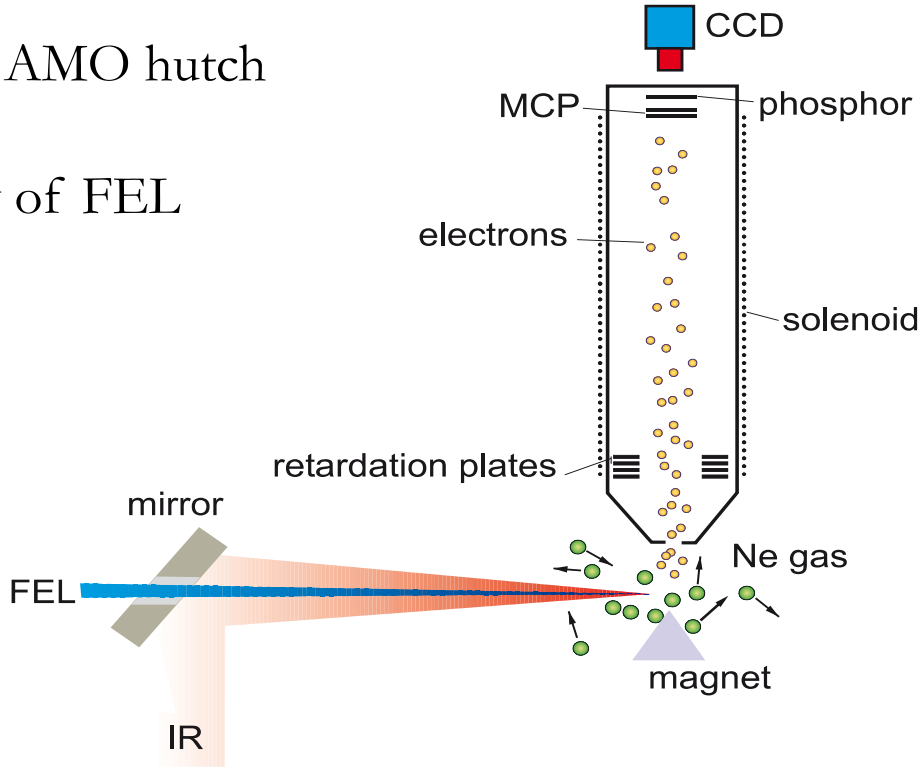
required diagnostic:

- single-shot
- non-invasive
- ~fs resolution

➔ optical streak camera

Experimental Setup

- Experiment summer 2010 at LCLS AMO hutch
- high transmission of FEL pulse
- photoelectron pulse is a direct copy of FEL pulse profile

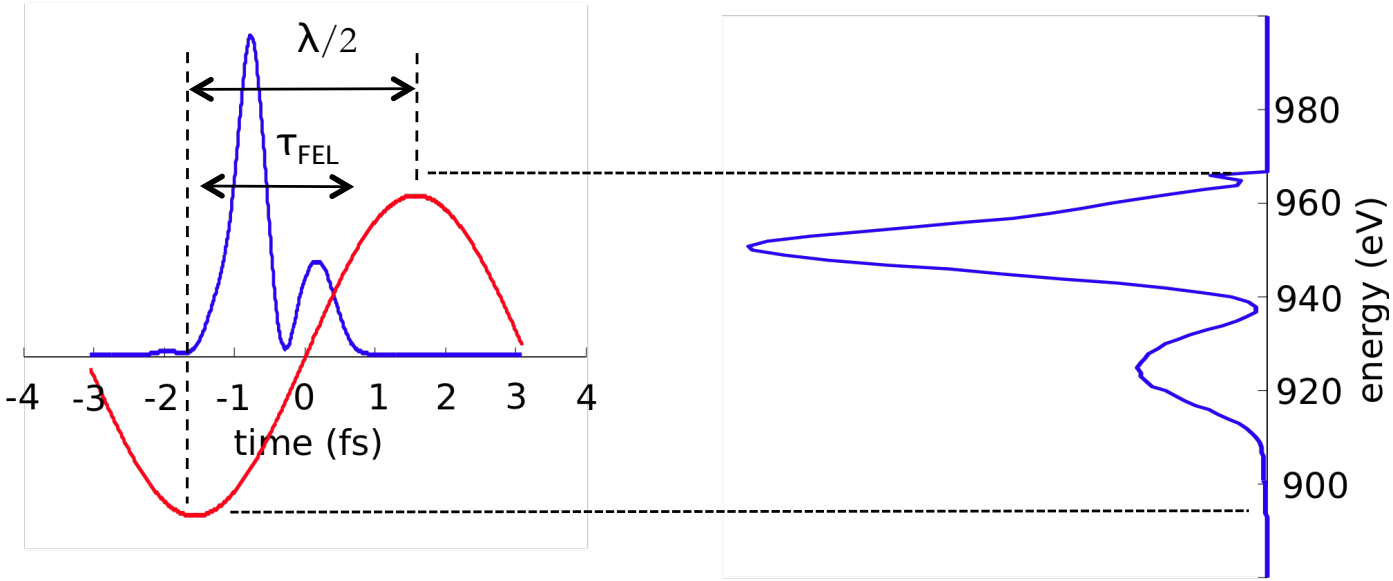


LCLS FEL pulse
1keV - 2keV,
few-fs pulse duration

IR laser
2 – 2.4 micron wavelength

figure: P. Radcliffe

Mapping time to energy



energy shift: $\Delta E \approx - p_e A(t)$

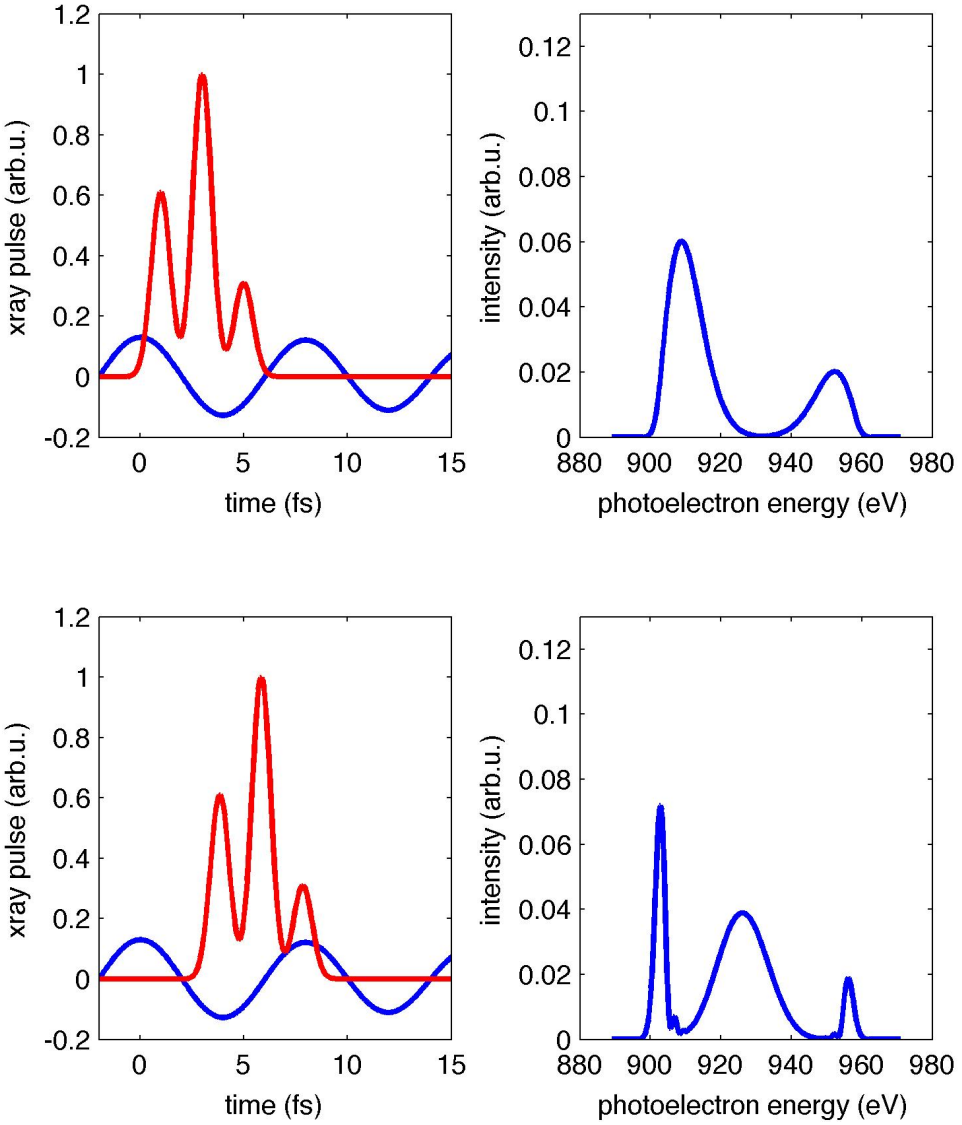
almost linear mapping from time to energy

2 micron IR laser, A=0.13 (red), GENESIS simulated 2keV 2fs FEL pulse (blue)
E_0 = 930 eV, initial photo electron kinetic energy, p_e: photo electron momentum, A(t): instantaneous vector potential

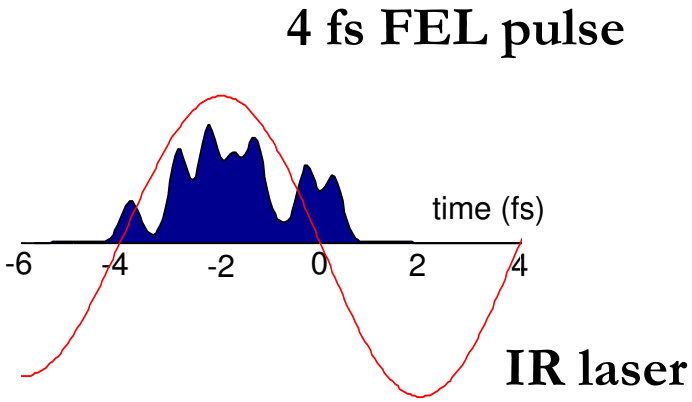
A. K. Kazansky, I. P. Sazhina, and N. M. Kabachnik: PRA 82, 033420 (2010)
V. Yakovlev, J. Gagnon, N. Karpowicz, and F. Krausz: PRL 105, 073001, (2010)

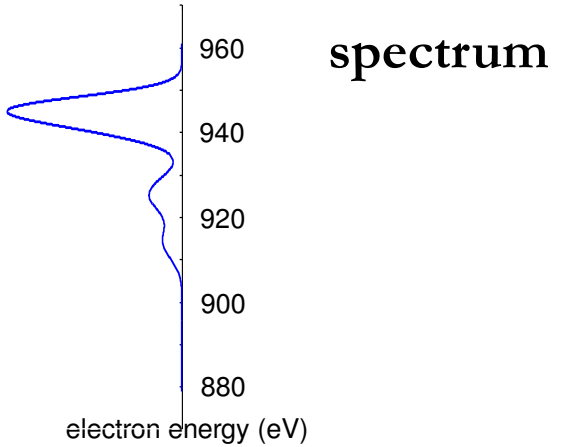
Things are not that easy...

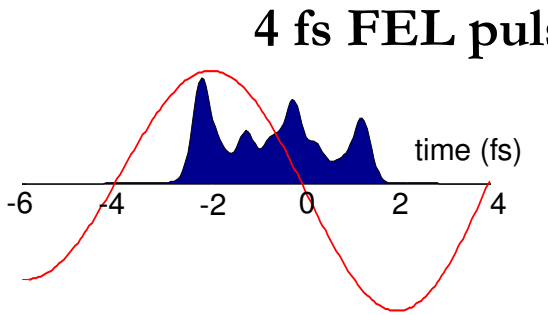
- summer 2010: only limited wavelength available: 2.4 μm – 8 fs
- synchronization jiter FEL – IR laser ~ 30-60 fs rms
- not single-shot analysis (yet)
- derive only typical pulse lengths

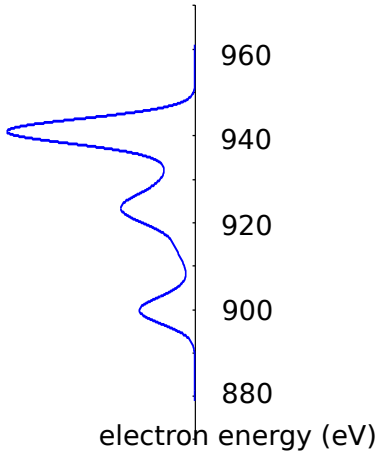


Analysis – The basic idea



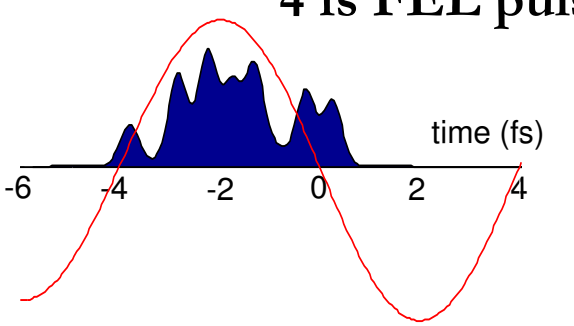


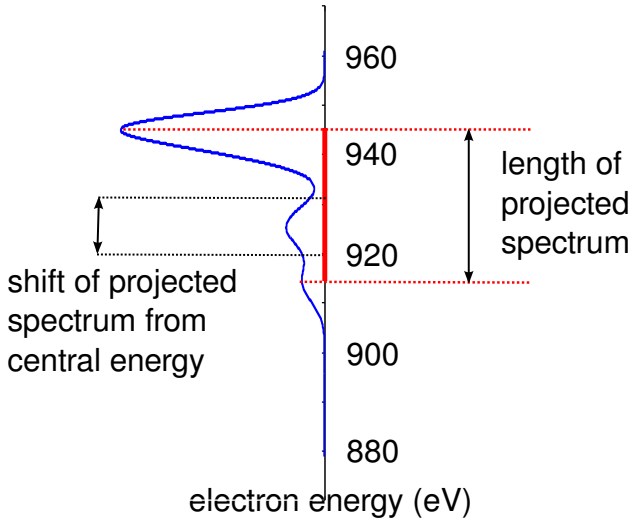


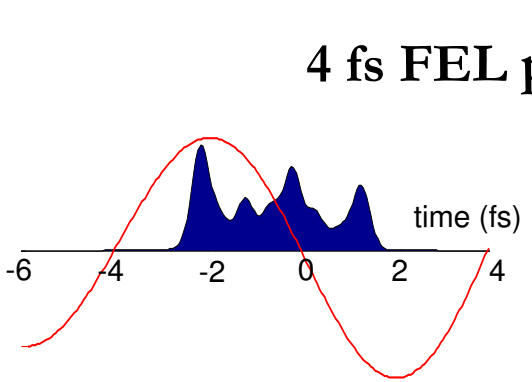


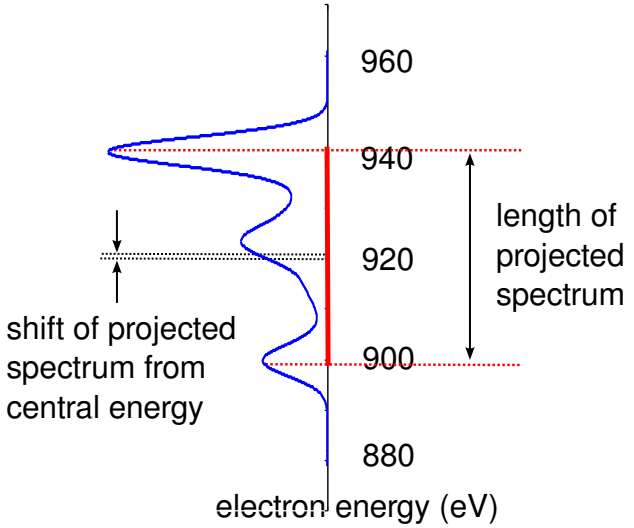
4fs FEL pulse constructed from subspikes. central energy = 920 eV, λ = 2.4 μm, A_{max} = .13 a.u. IR laser. 50 fs fwhm IR pulse length.

Analysis – The basic idea



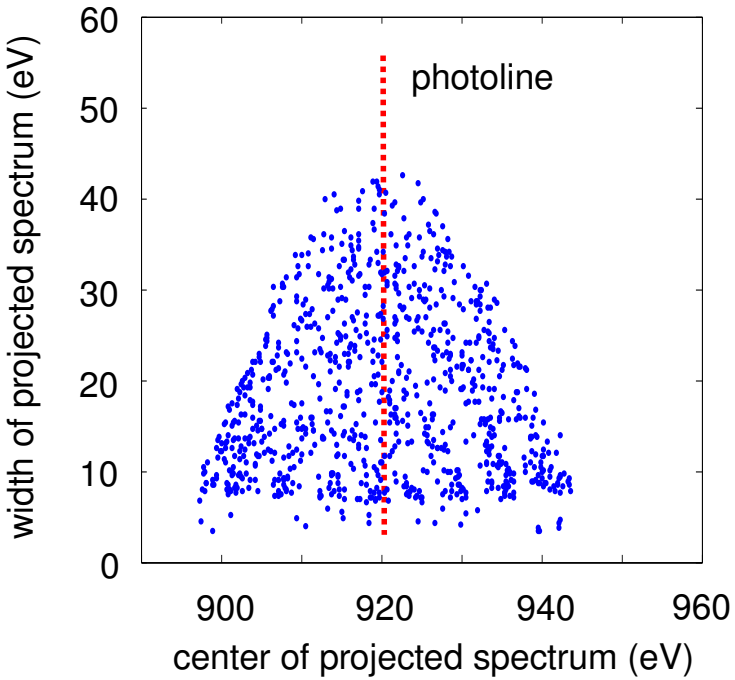




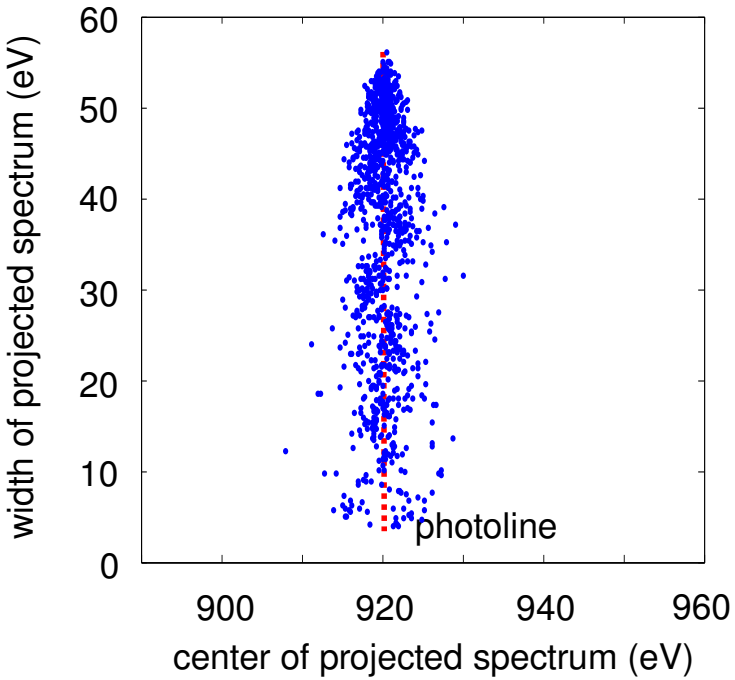


Analysis – The basic idea

- correlate projected spectrum length and shift
- assumes pulse lengths of 2 fs and 10 fs

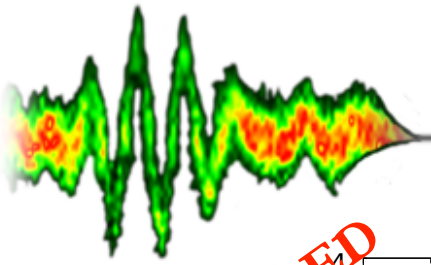


2fs pulse



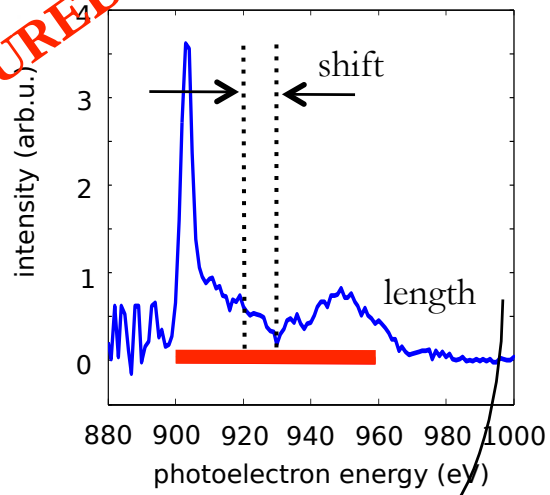
10fs pulse

central energy = 920 eV / λ = 2.4 μm / A_{max} = .13 a.u. / 20 fs rms jitter about the center of the 50 fs fwhm IR pulse



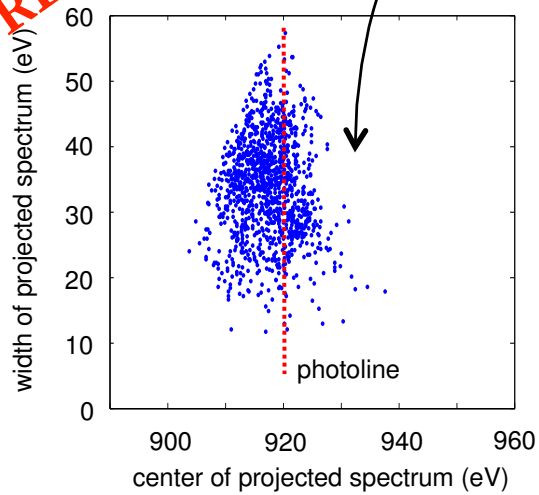
Somewhere around 4 fs fwhm

MEASURED



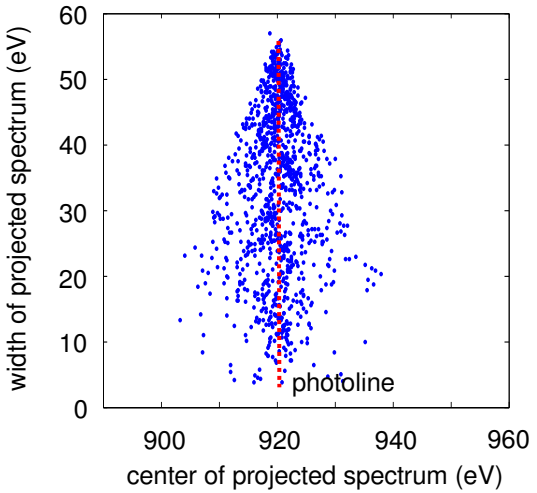
EXPERIMENTAL DATA
analyze

MEASURED



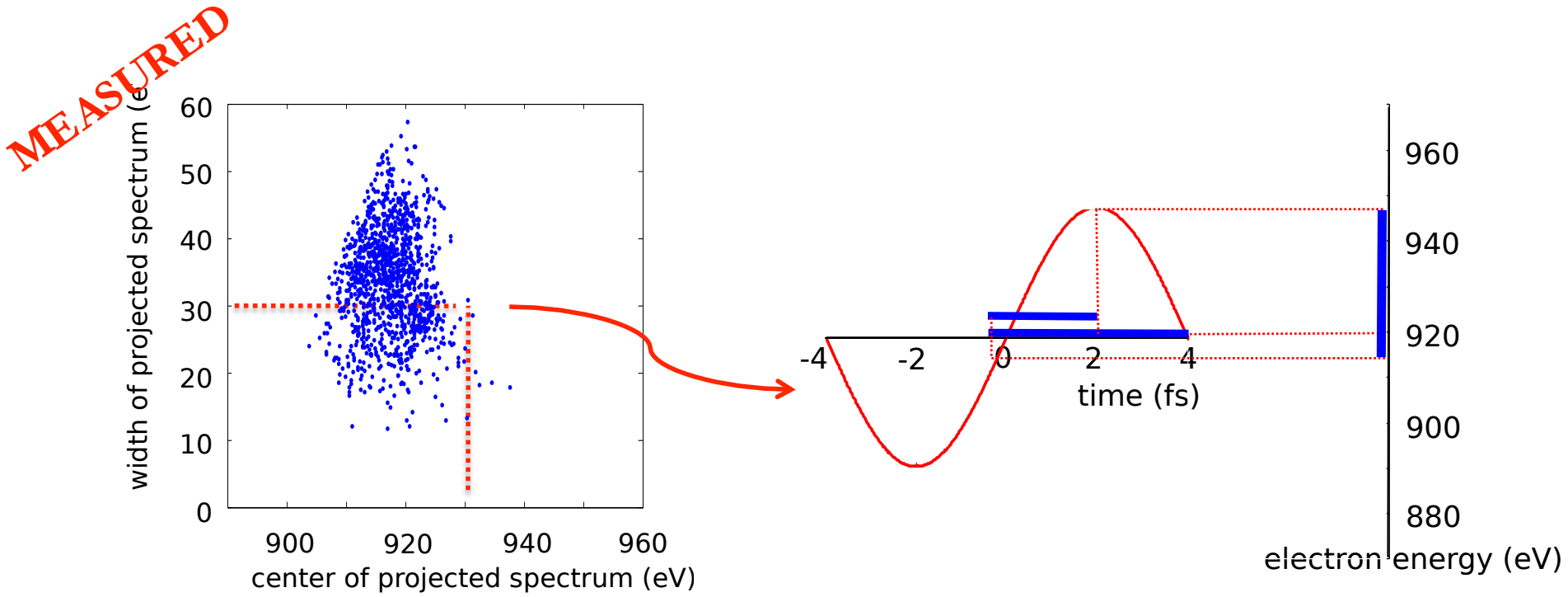
compare
correlation

SIMULATION
4fs fwhm pulse

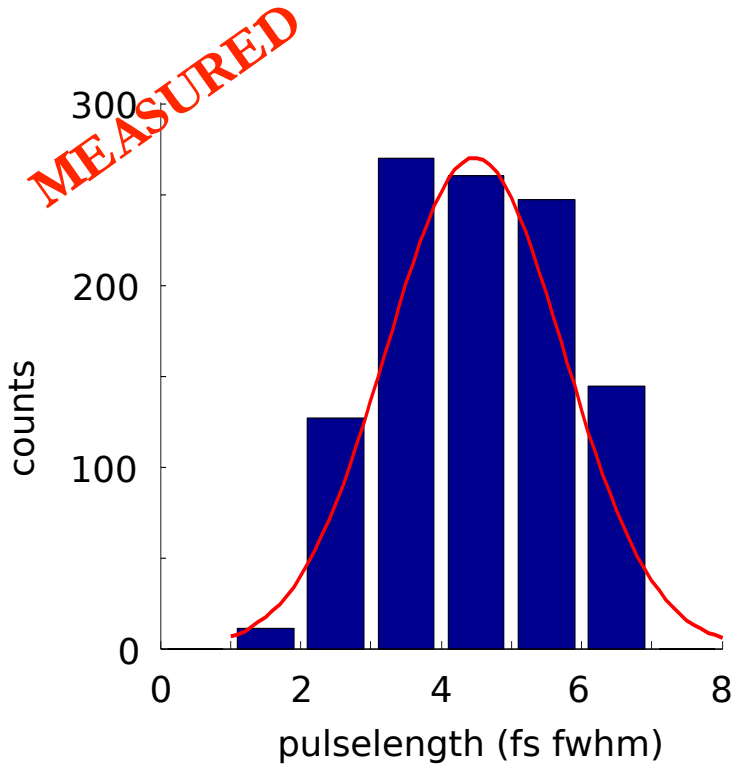


Quantitative Analysis

- for every point in the correlation calculate all possible pulse lengths
- due to the unknown phase (jitter) pulse lengths are not unique



4 fs fwhm xray pulses



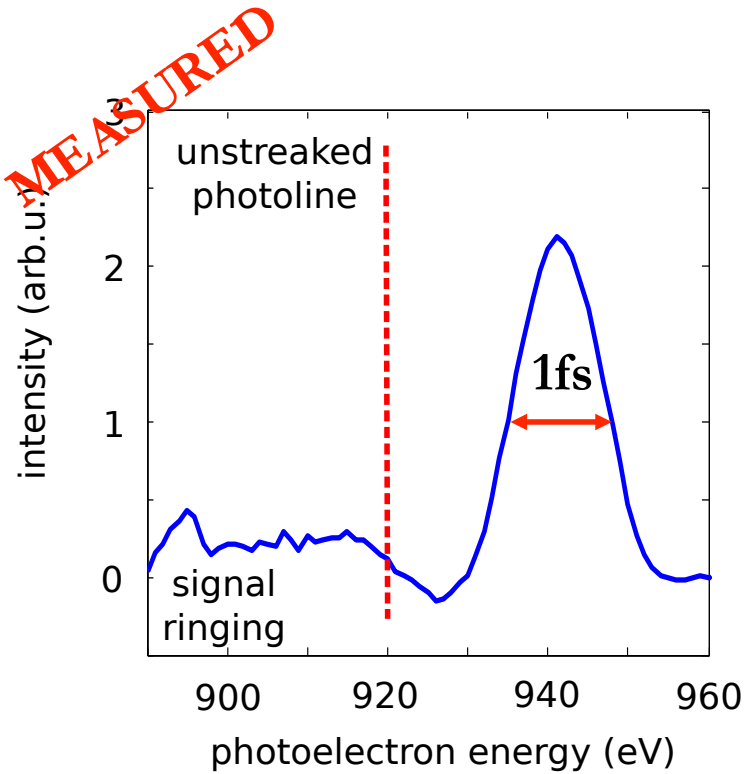
MEASURED:

Sort all possible pulse lengths calculate from measured spectra into histogram to get the typical pulse length.

This pulse length is an upper limit.

4.4 ± 1.3 fs pulse width (fwhm)

Single-Spike, Single-fs Pulses

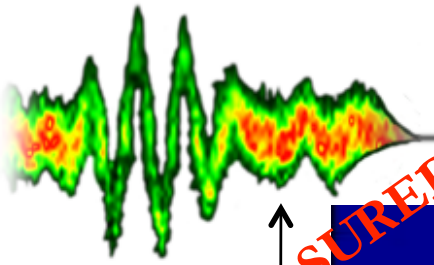


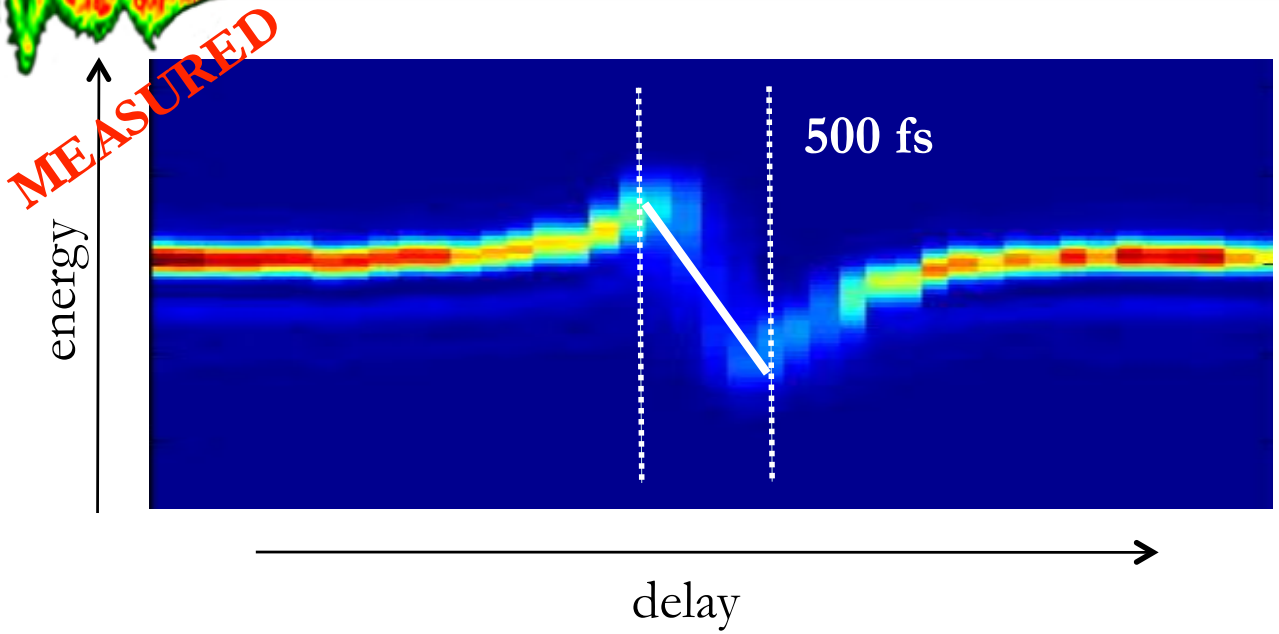
- Some spectra show single spikes.
- Corresponds to coherent single spike FEL pulses.

Back-of-the-envelope calculation:

- 4 fs mapped to 45 eV
- peak is 1 fs fwhm

Single-Cycle THz streaking





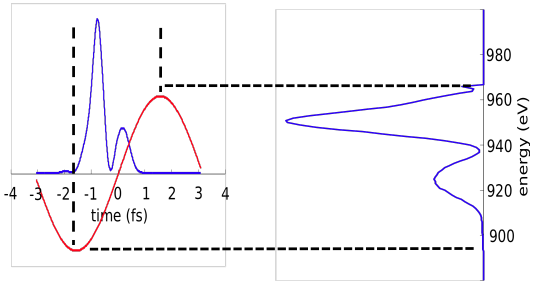
cross-correlation FEL with single-cycle THz pulse

Recent Experiment at FLASH (06/2011) by Adrian Cavalieri

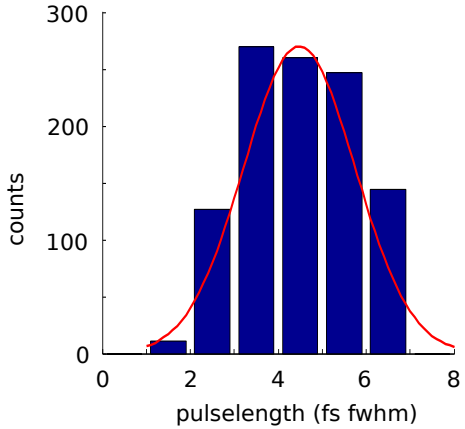
- single-cycle THz pulse
- 300-500 fs rising edge

- shift of peak is time-of-arrival
- width of peak is pulse length
- limited by detector resolution
- independent of xray energy
- non-invasive

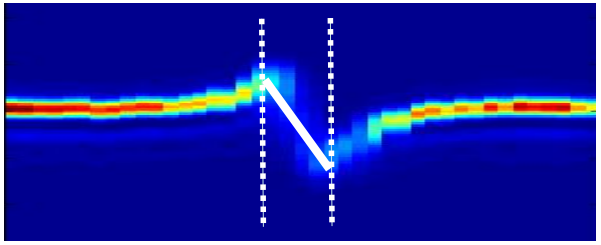
Summary



Pulse length measurement with optical streak camera.

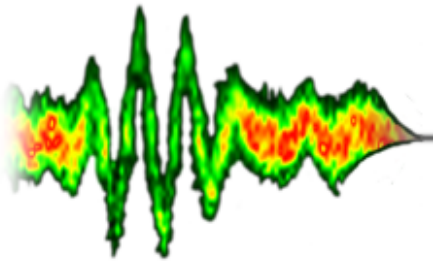


- 4 fs Pulses
- Shortest Xray pulses measured so far.
- Not yet single shot.



500 fs

Single-shot measurement is possible.



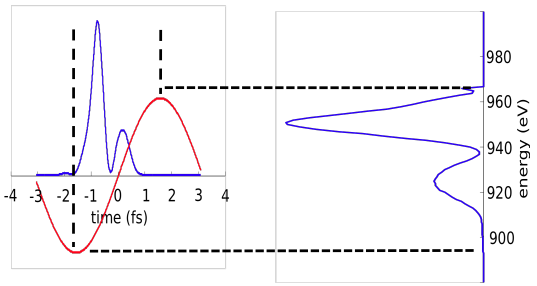
Acknowledgment

Wolfi Helml and Paul Radcliffe for great help during data analysis.

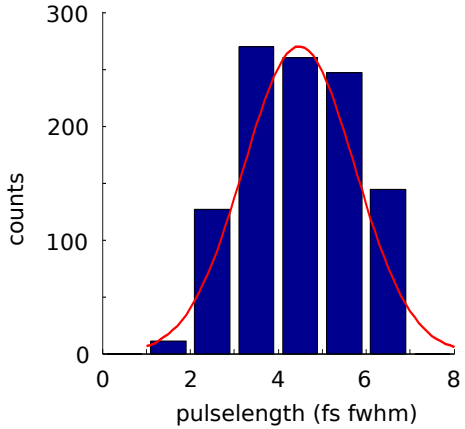
Sven Reiche and Yuantao Ding for help with simulations and many discussions.

The whole LCLS team for support and that wonderful machine.

Summary



Pulse length measurement with optical streak camera.



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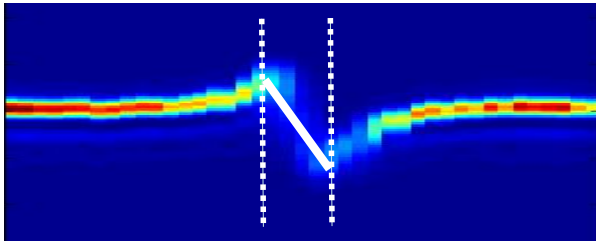

500 fs

Single-shot measurement is possible.

Thanks for your attention.