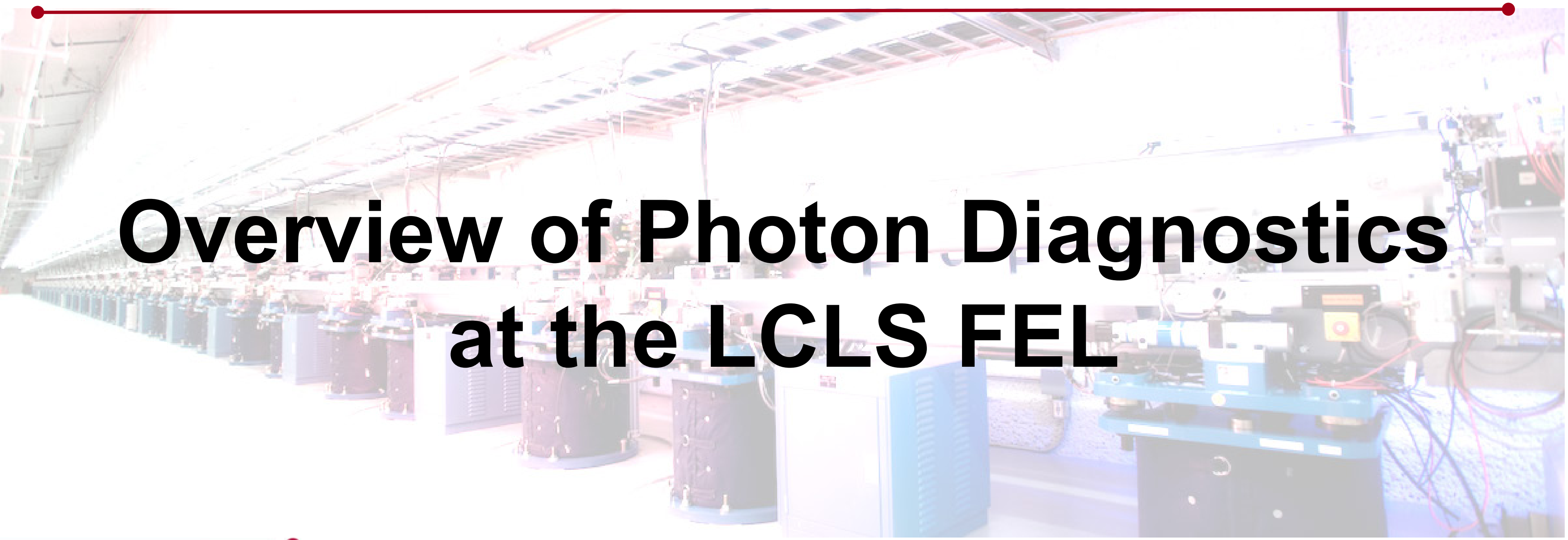


Overview of Photon Diagnostics at the LCLS FEL

David Fritz (on behalf of the LCLS team)
SLAC National Accelerator Laboratory

Acknowledgments

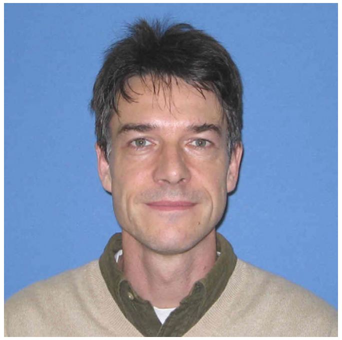
- The IBIC Organizers
- DOE Office of Science
- The LCLS Team

- Special thanks to:

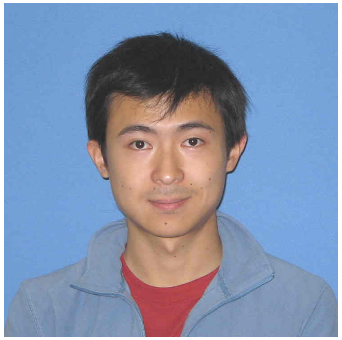
Ryan Coffee

Yiping Feng

Henrik Lemke

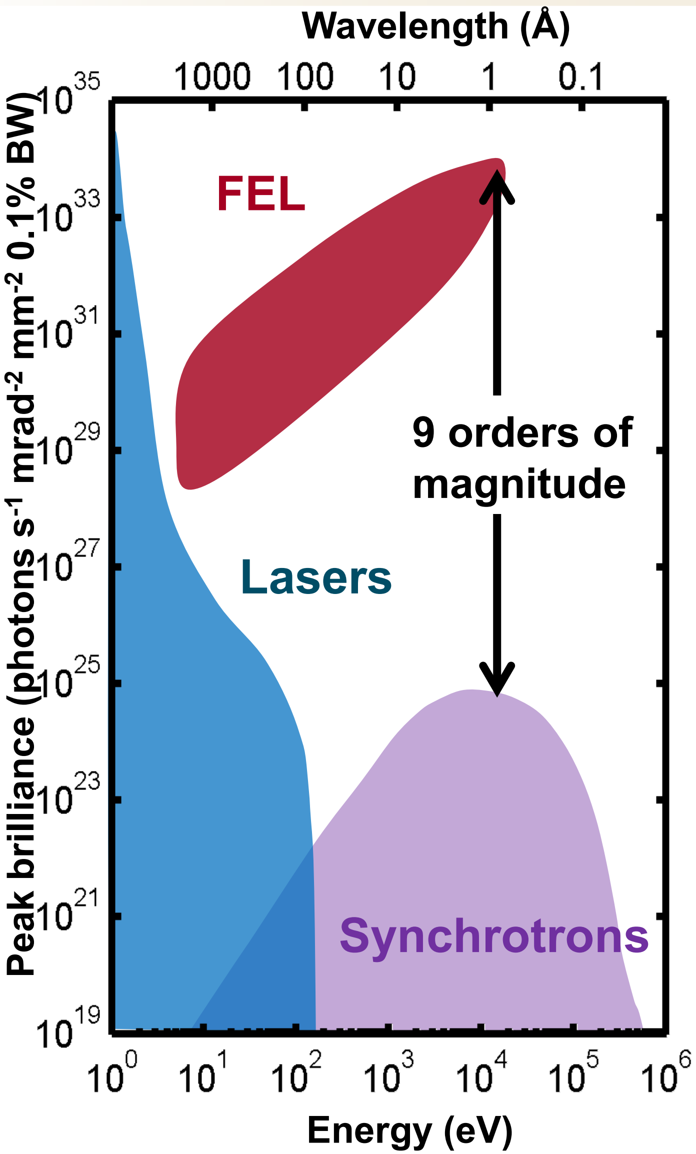


Stefan Moeller



Diling Zhu

X-ray FELs promise revolutionary capabilities



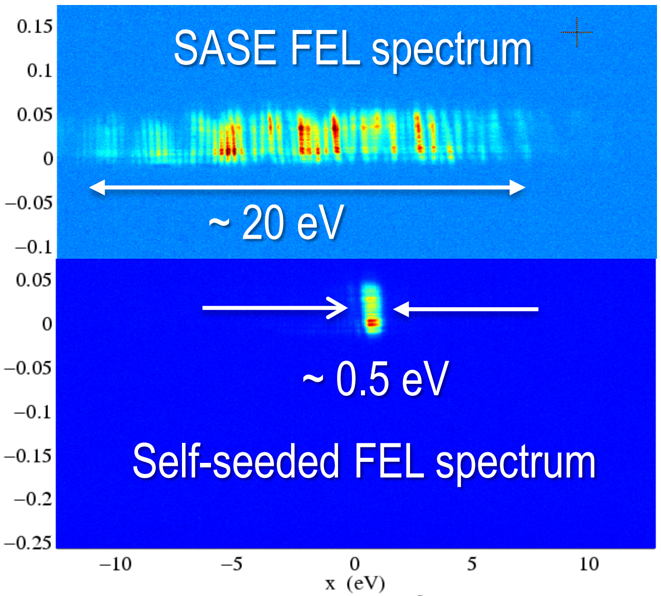
Exploiting the 9 orders of magnitude increase in x-ray peak brilliance

- **Pulse energy**
- **Pulse length**
- **Pulse coherence**
- **Spectral brightness**

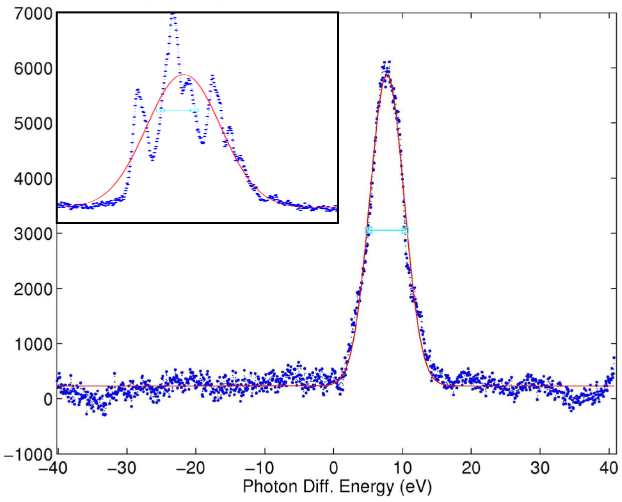
These properties enable us to measure DYNAMCIS on the atomic length and time scale!

LCLS performance parameters

	Current performance
Photon energy range	280 to 11,500 eV
FEL pulse length	< 5 – 500 fs
FEL pulse energy	~ 4 mJ (2.5 * 10^{12} @ 10 keV)
FEL coherence	SASE, Seeding (hard x-ray)
Repetition Rate	120 Hz



Hard X-ray self-seeding

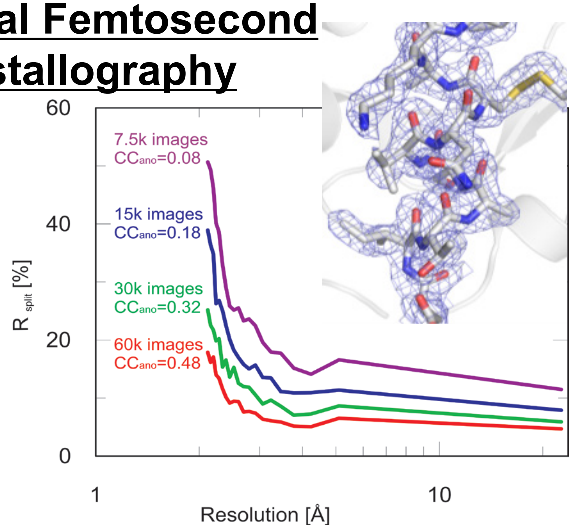


Near transform limited soft x-ray pulses

What LCLS does: a few examples

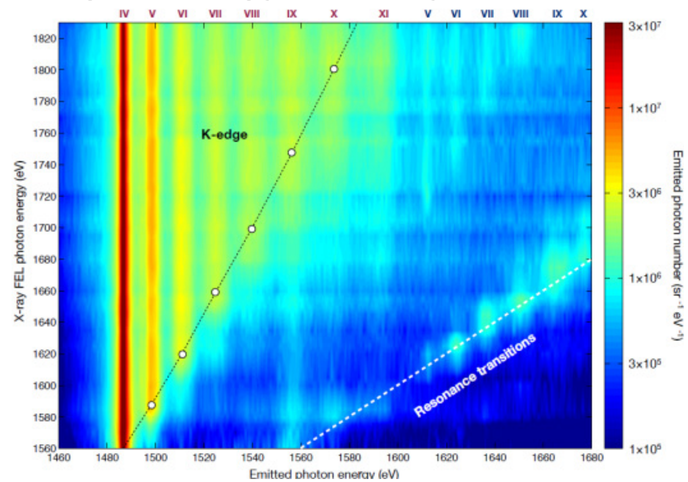
SLAC

Serial Femtosecond Crystallography



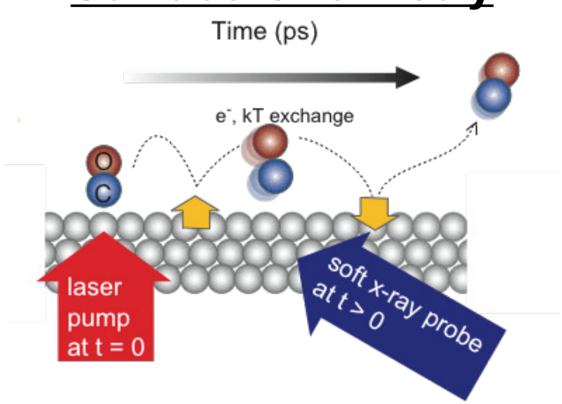
Barends *et al.*, *Nature,* **505**, 244-247 (2014)

High Energy Density Science



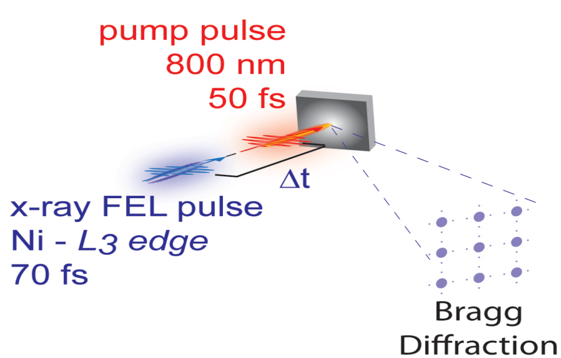
Vinko *et al.*, *Nature,* **482**, 59-62 (2012).

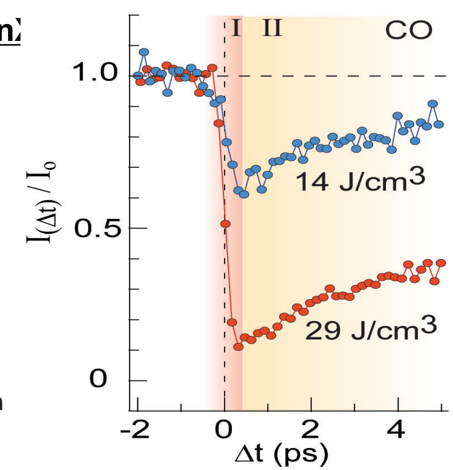
Surface Chemistry



Dell'Angela *et al.*, *Science*, **339**, 6125 (2013)

Time-resolved Resonant Diffraction



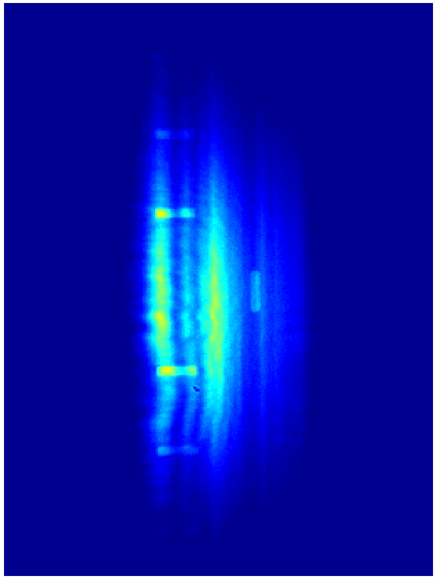


Lee *et al.*, *Nature Communications*, **3**, 838 (2012)
Chuang *et al.*, *Phys. Rev. Lett.*, **110**, 127404 (2013).

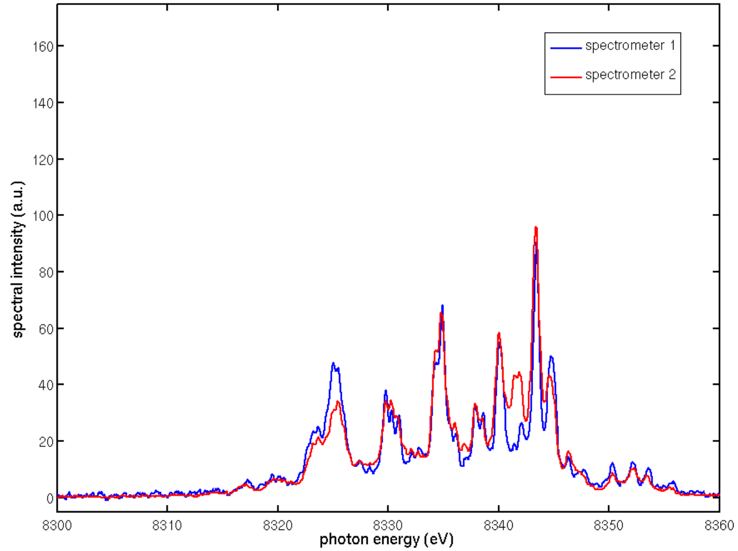
LCLS (FELs) – the ideal x-ray source?

LCLS source fluctuations

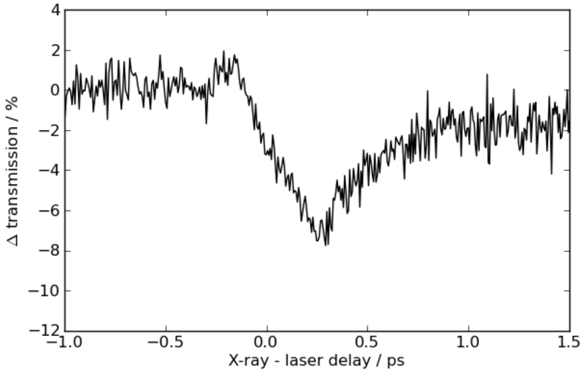
Spatial



Spectral



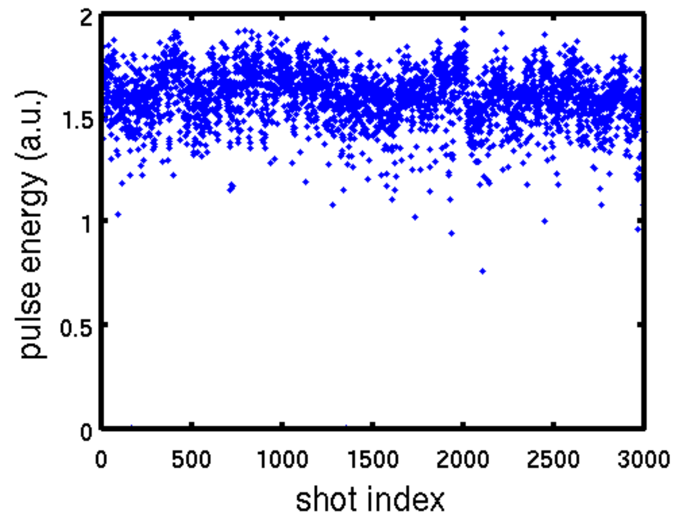
Temporal

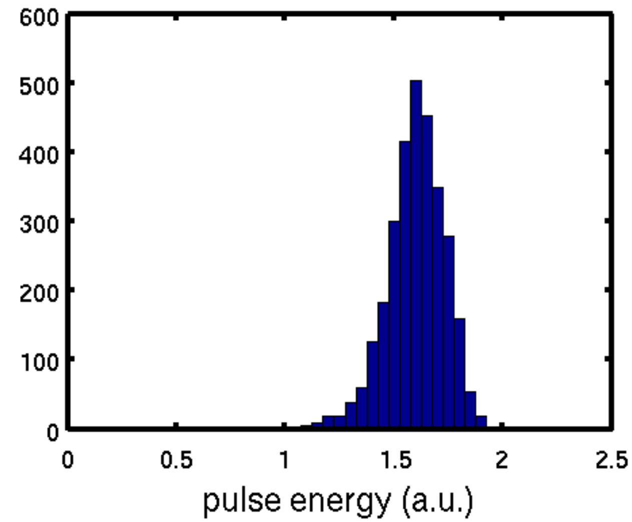


- Every pulse is different and must be diagnosed individually

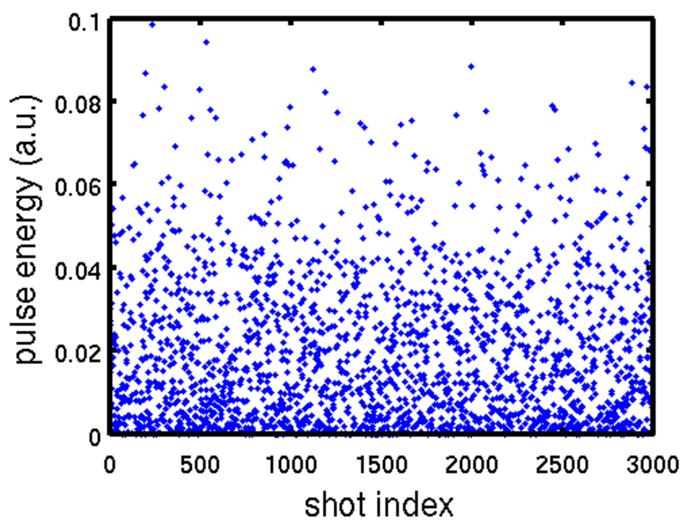
LCLS – intensity fluctuations

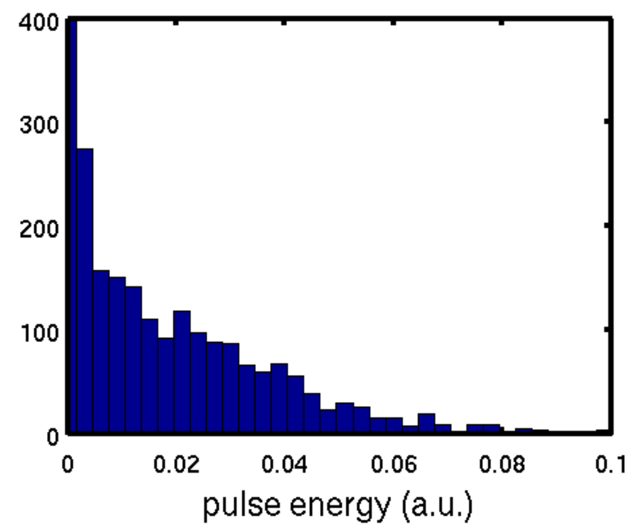
Pink Beam





Mono Beam
Si (111)





Spatial Diagnostics
Intensity Diagnostics
Spectral Diagnostics
Temporal Diagnostics

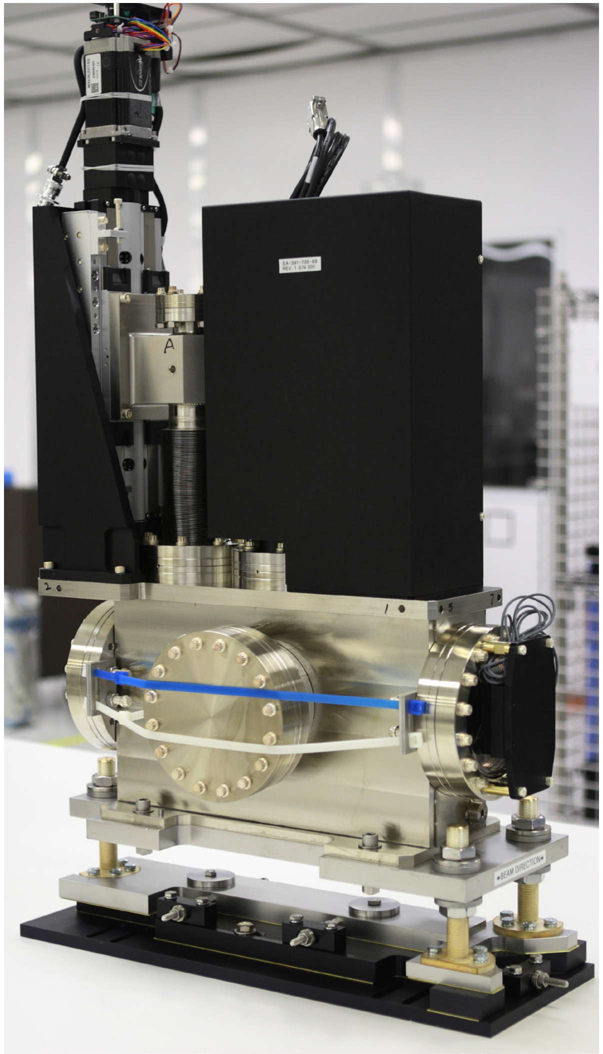
Spatial Diagnostics

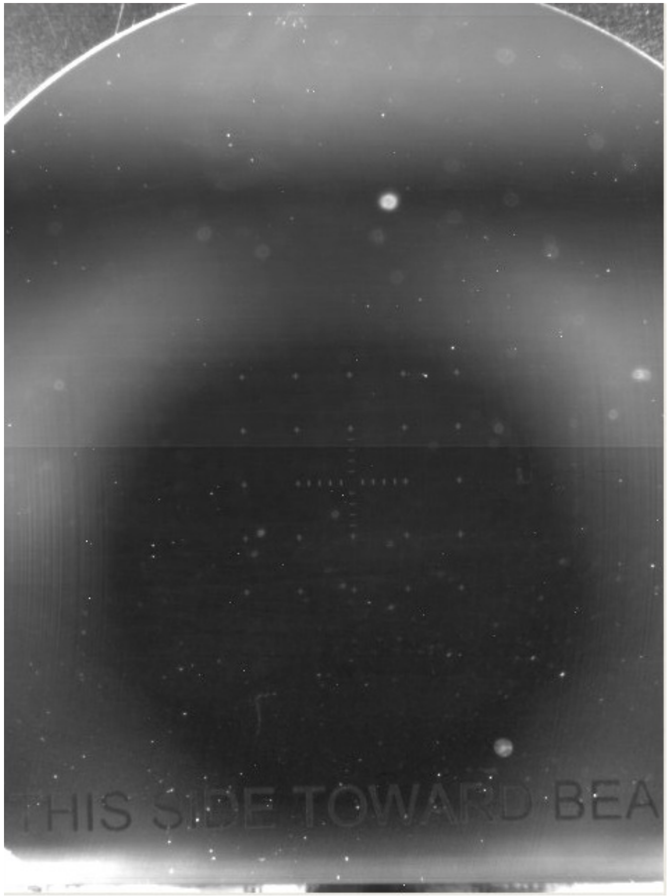
Intensity Diagnostics

Spectral Diagnostics

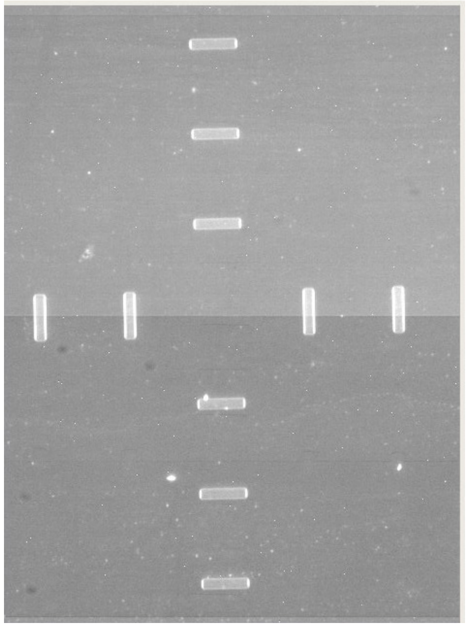
Temporal Diagnostics

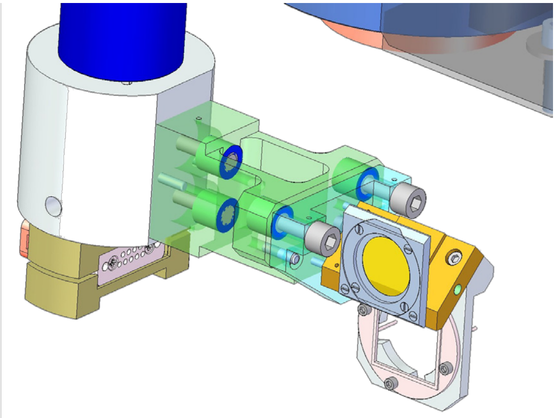
LCLS beam profile monitor



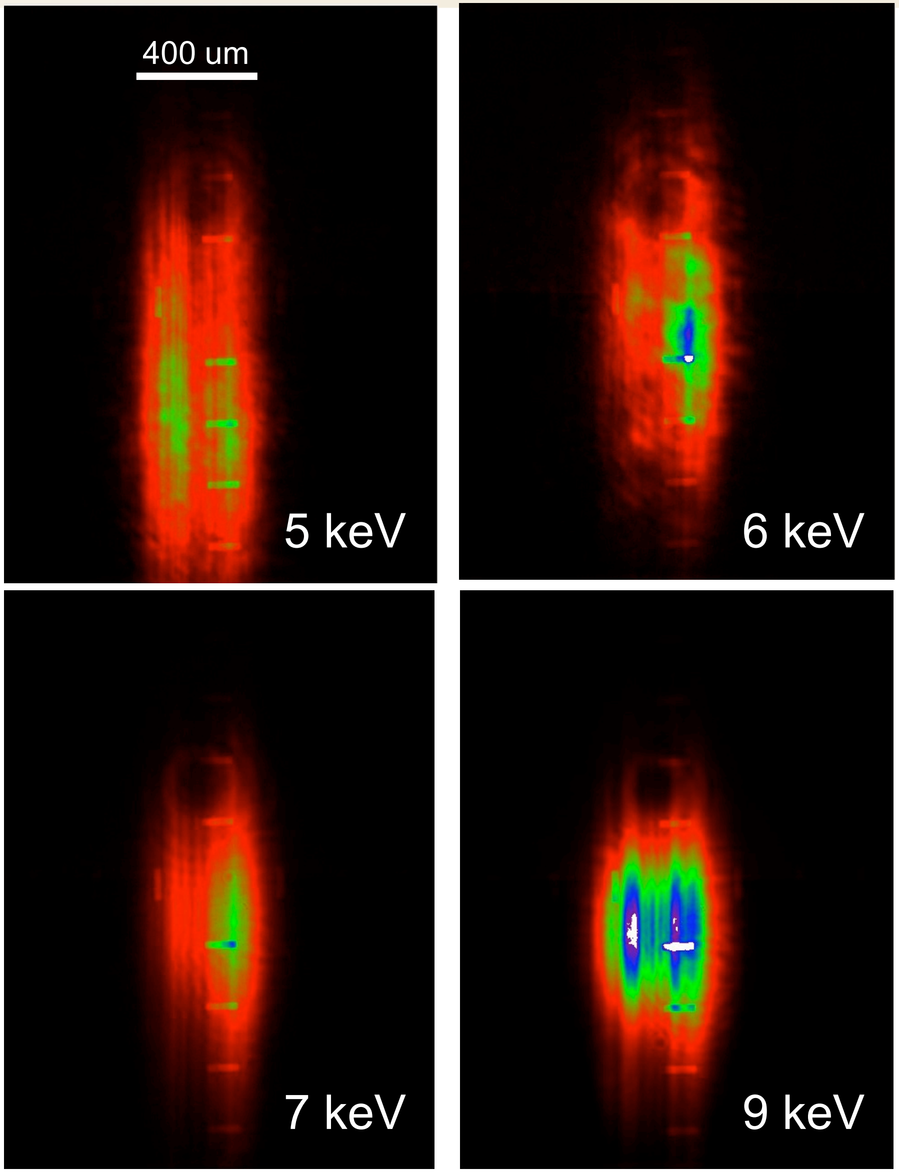


YAG:Ce

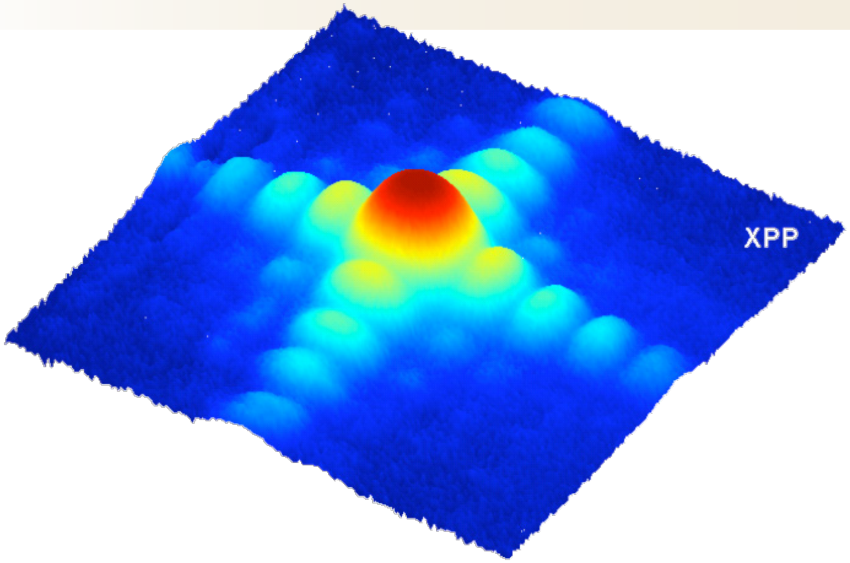


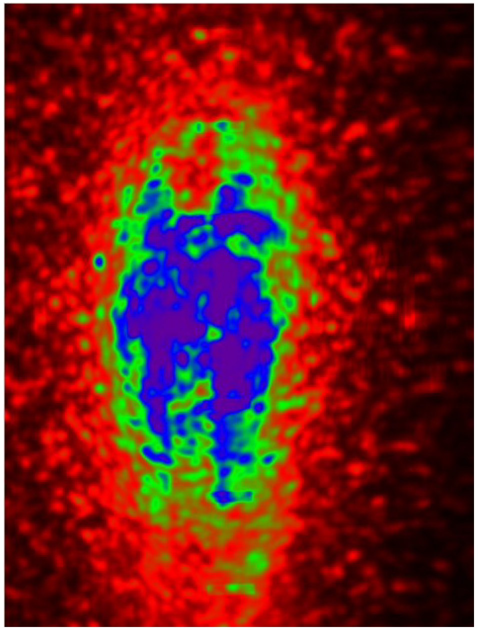


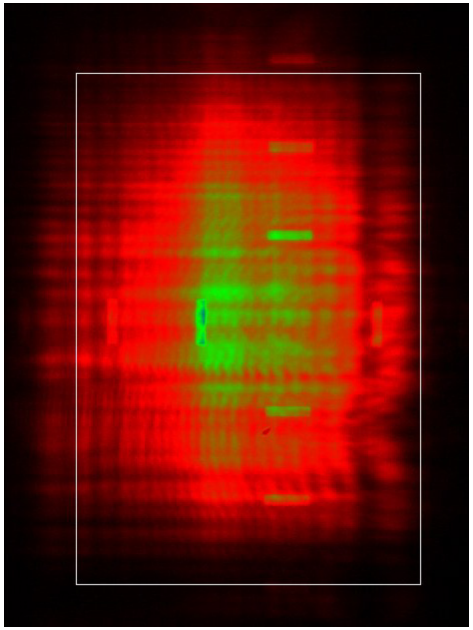
LCLS beam profile measurements

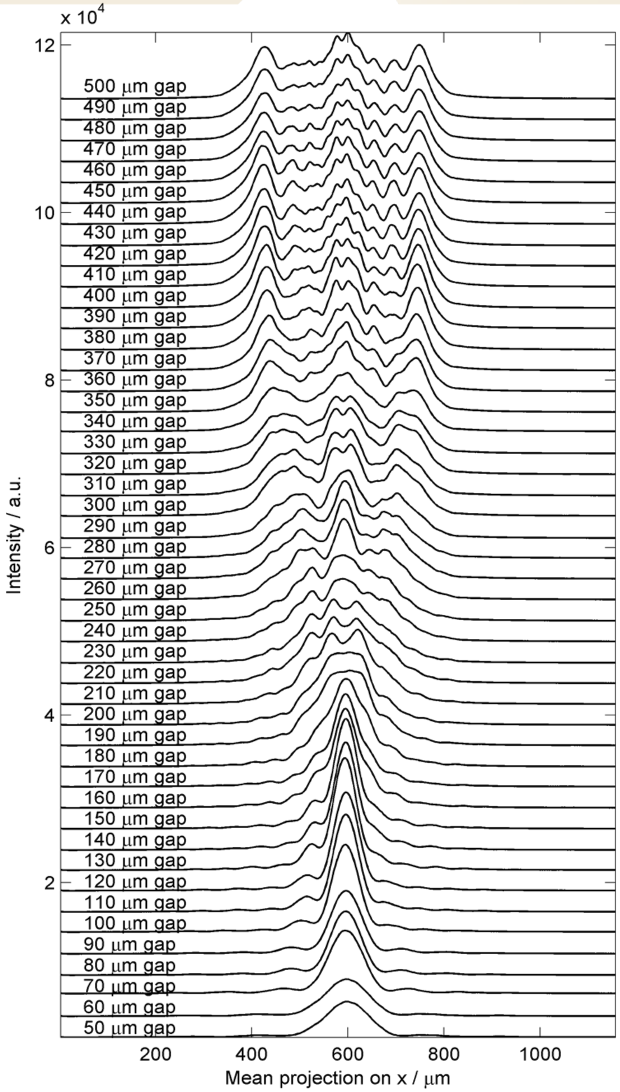


Transverse coherence effects









Spatial Diagnostics

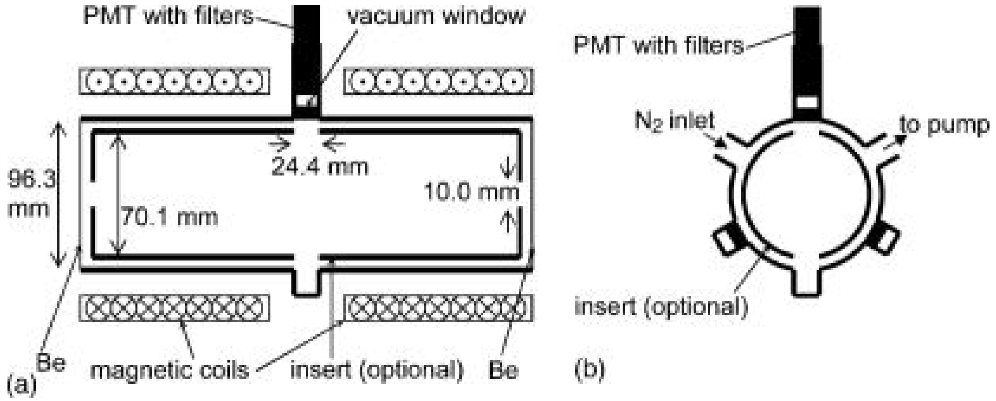
Intensity Diagnostics

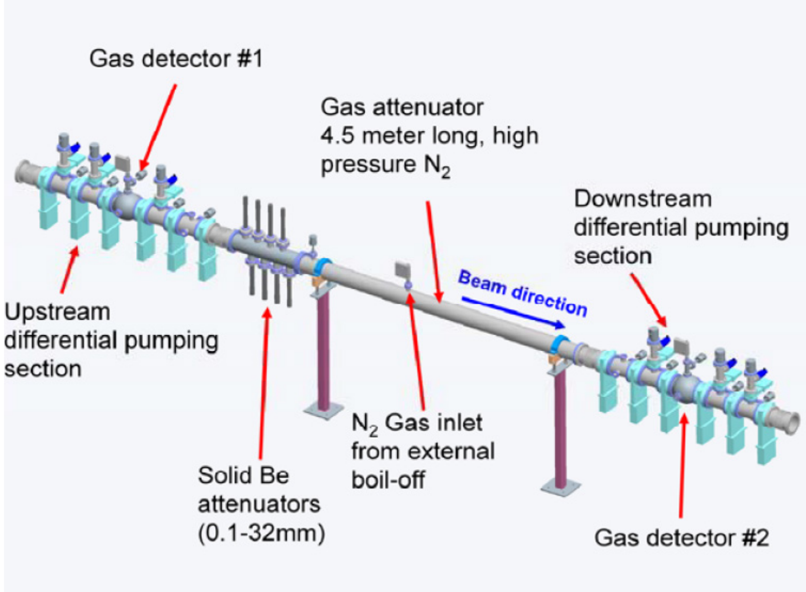
Spectral Diagnostics

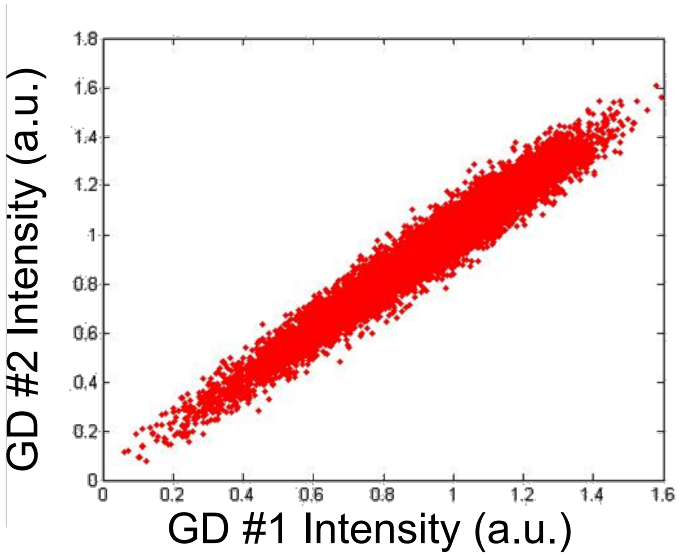
Temporal Diagnostics

LCLS front end gas detectors

S. Hau_Riege et al., J. Appl. Phys. **103** 053306 (2008).

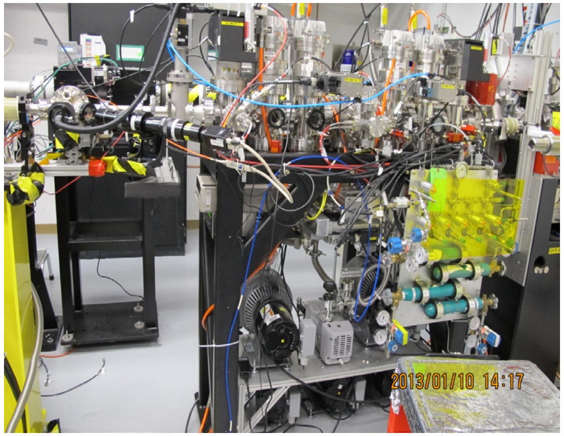


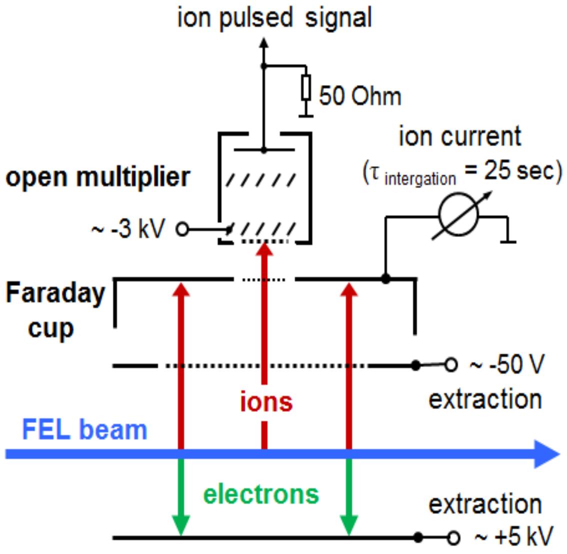




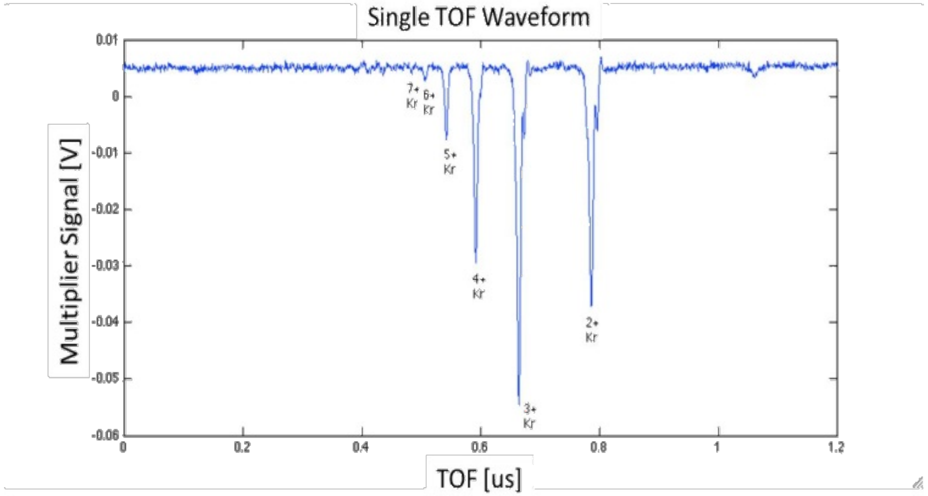
DESY/PTB Gas monitor detector deployed at LCLS

K. Tiedtke et al., J. Appl. Phys. **103** 094511 (2008).





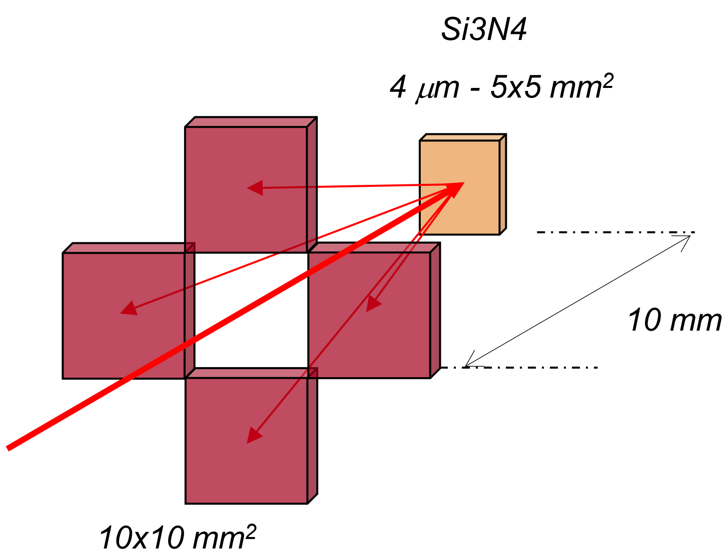
GMD schematic:
Ions are measured as average ion current and pulse resolved multiplier waveforms.



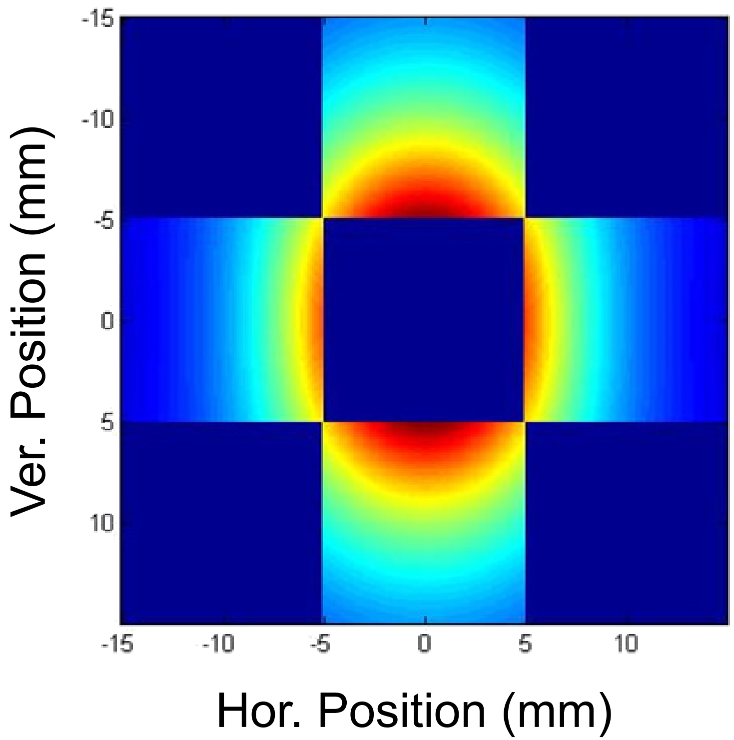
Typical time of flight ion charge spectrum for a single pulse using krypton as a target gas.

Relative intensity monitor

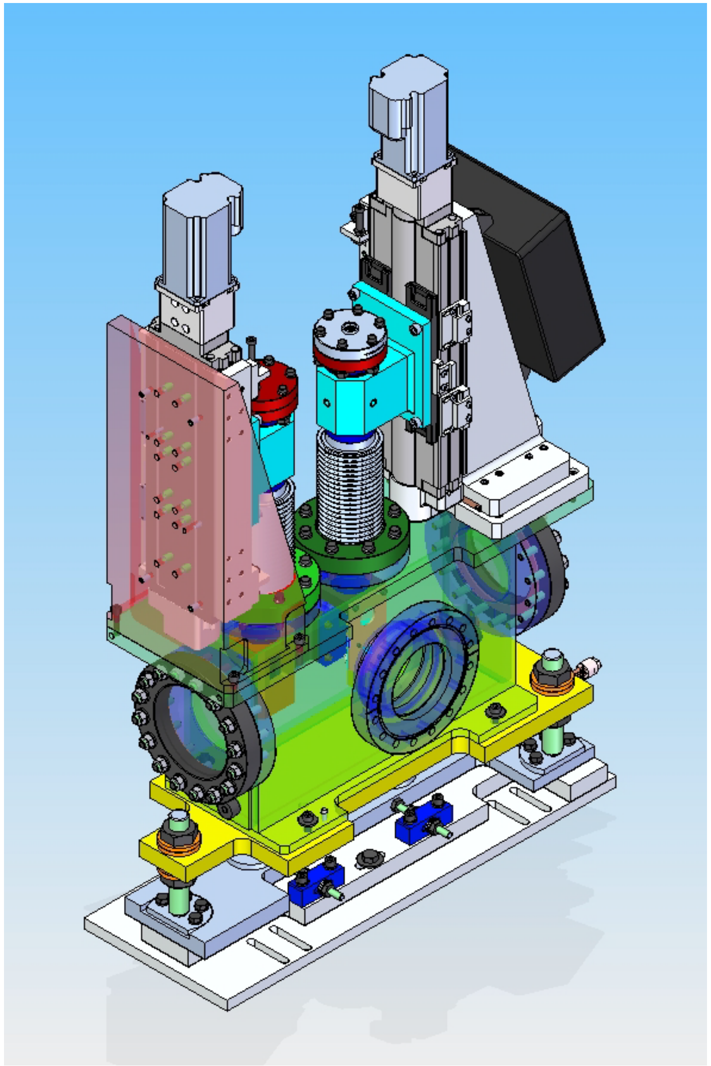
Tono et al., Rev. Sci. Intsr. **98,** 023108 (2011).

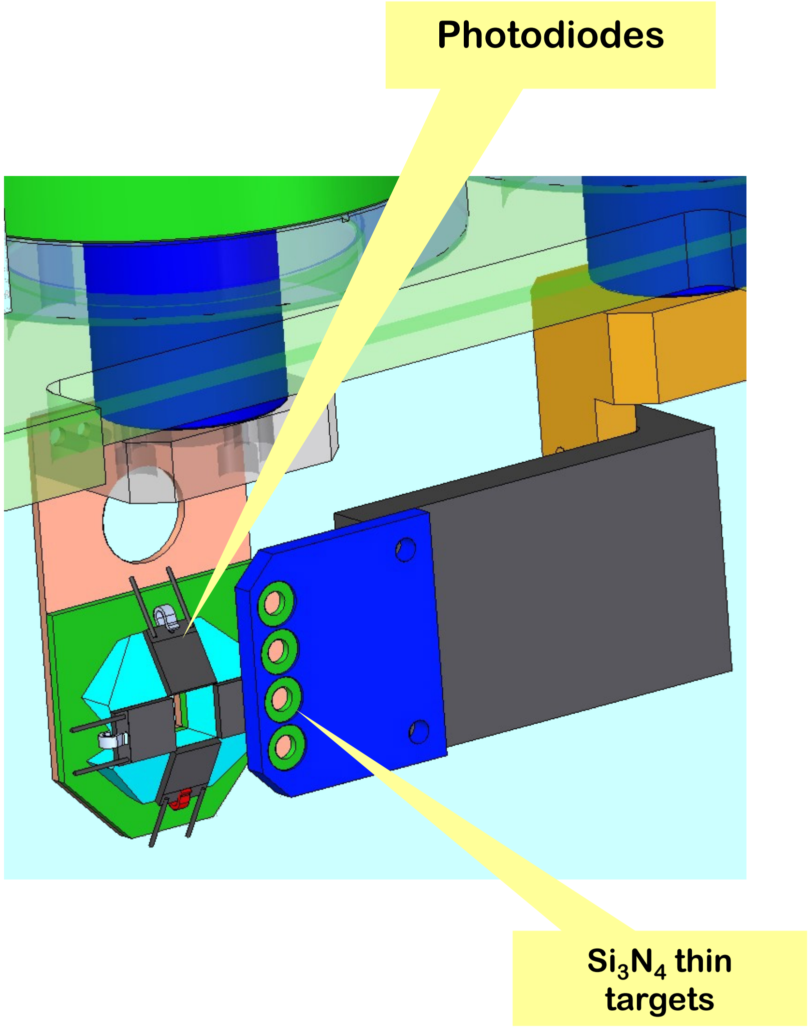


Calculated Scattering Pattern



Relative intensity monitor



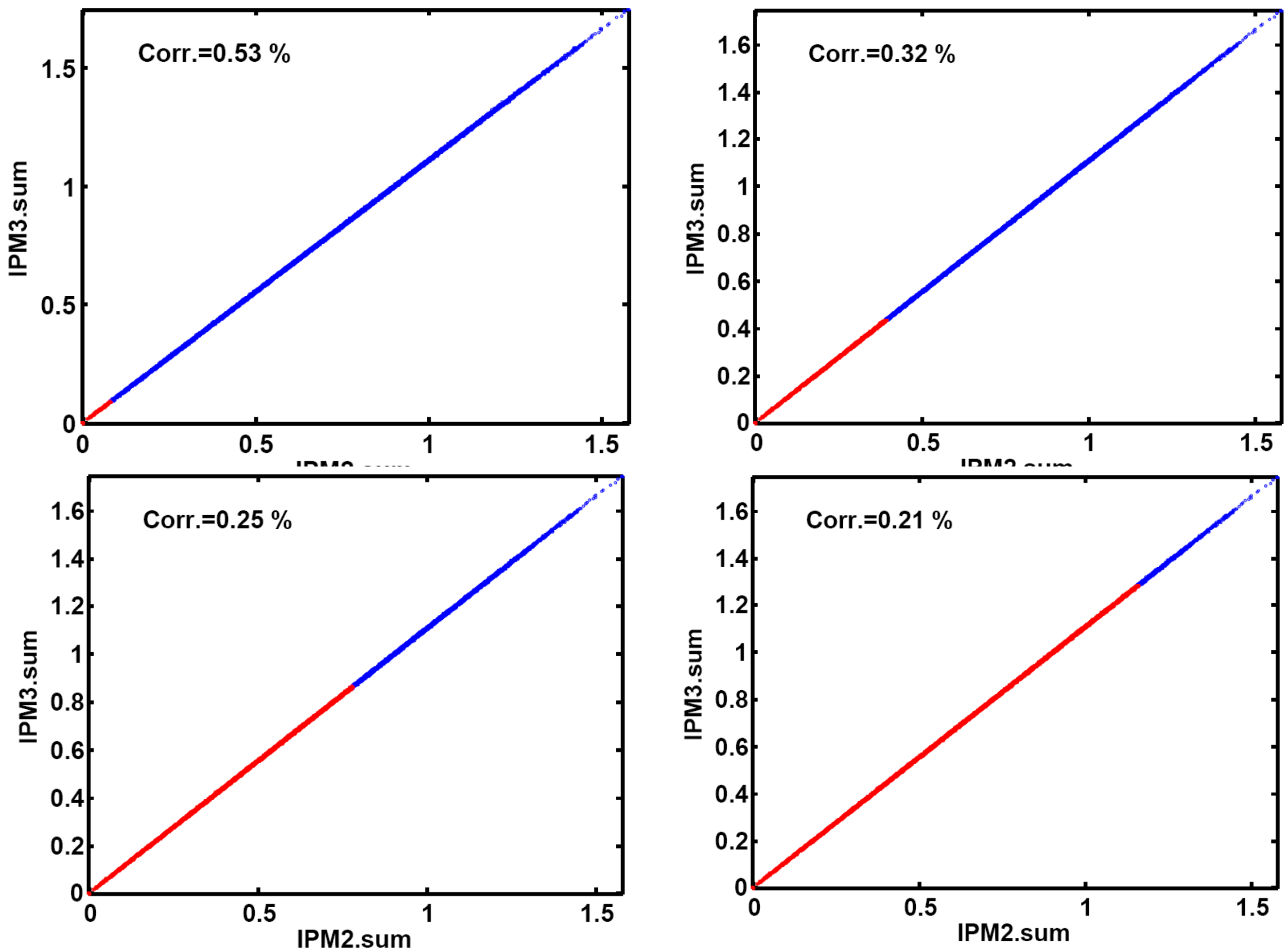


Photon statistics limited relative accuracy

SLAC

estimate
0.38%

estimate
0.23%

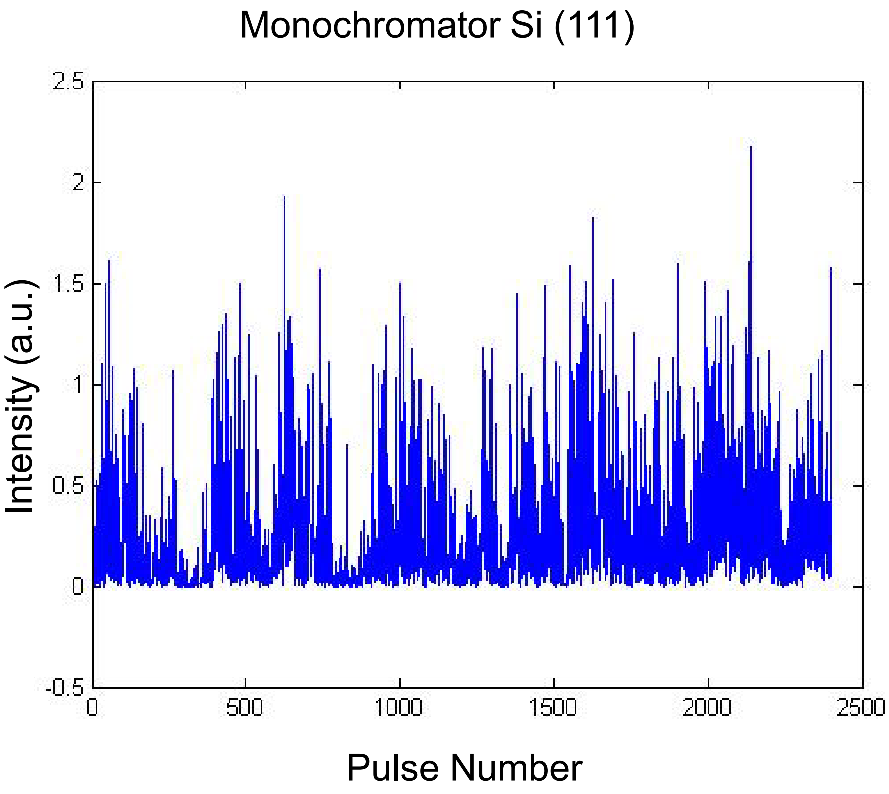


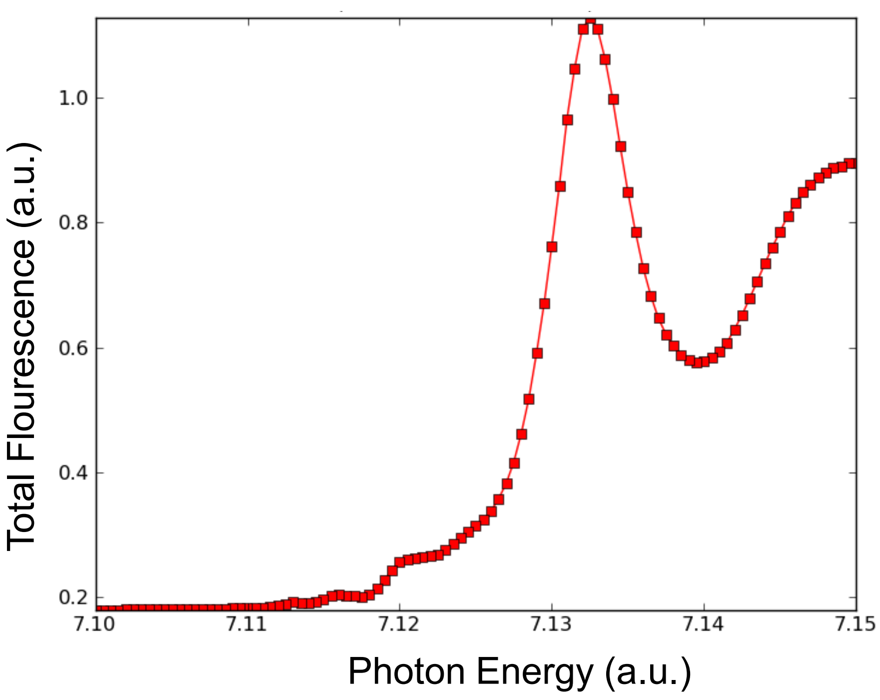
estimate
0.18%

estimate
0.15 %

Atomic absorption edge measurement

Iron absorption edge





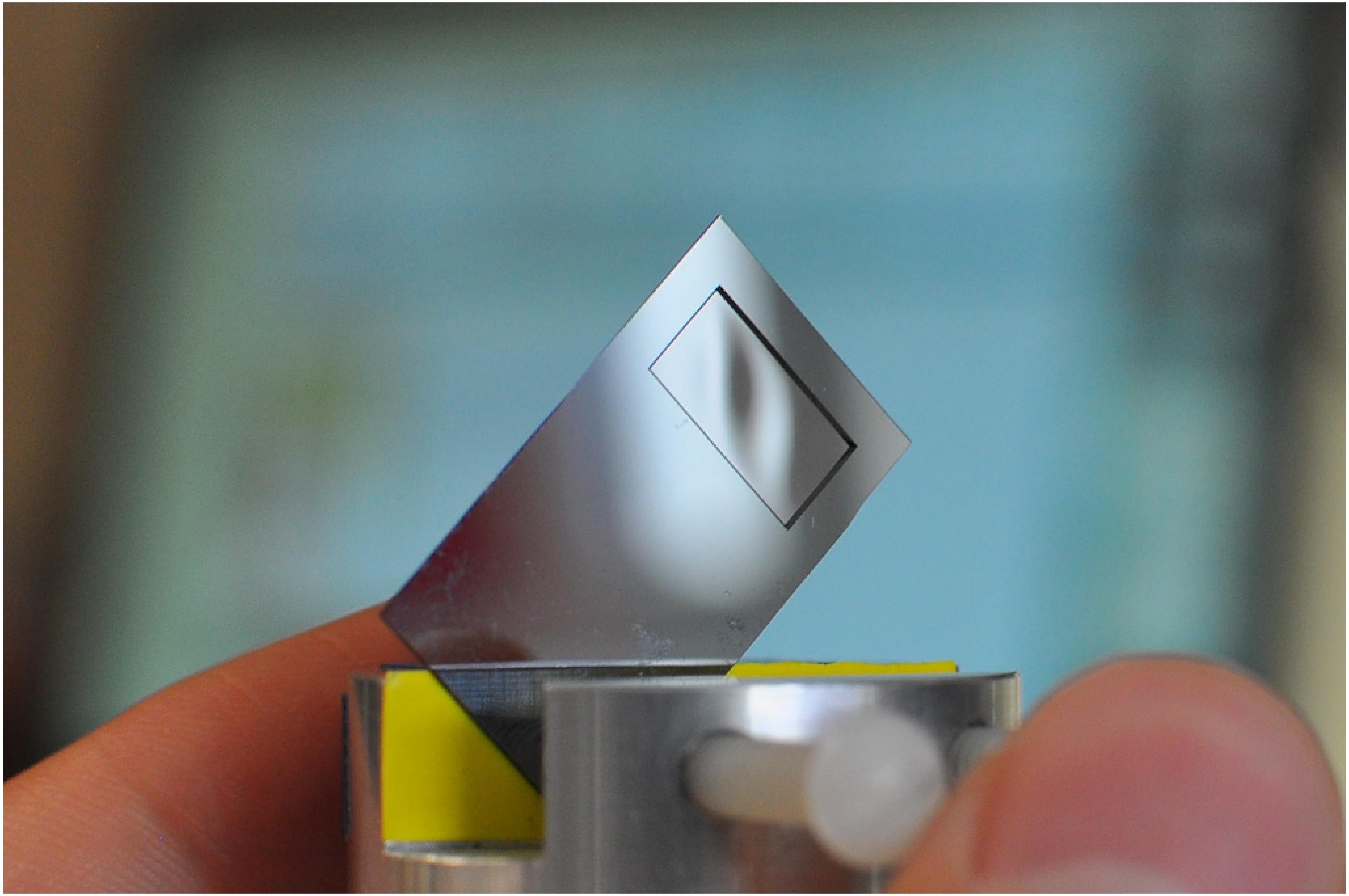
Spatial Diagnostics

Intensity Diagnostics

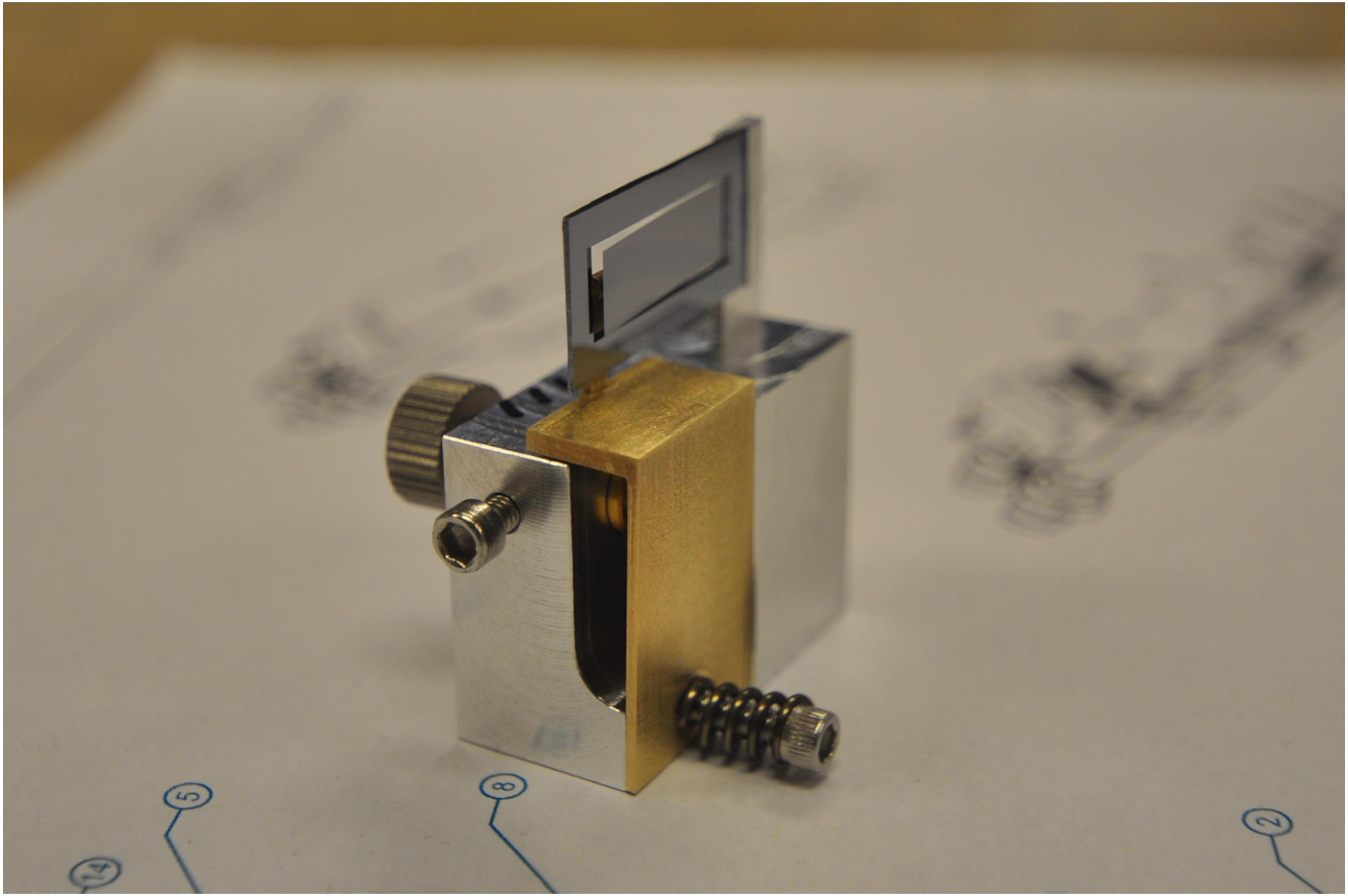
Spectral Diagnostics

Temporal Diagnostics

One man's trash is another man's treasure!

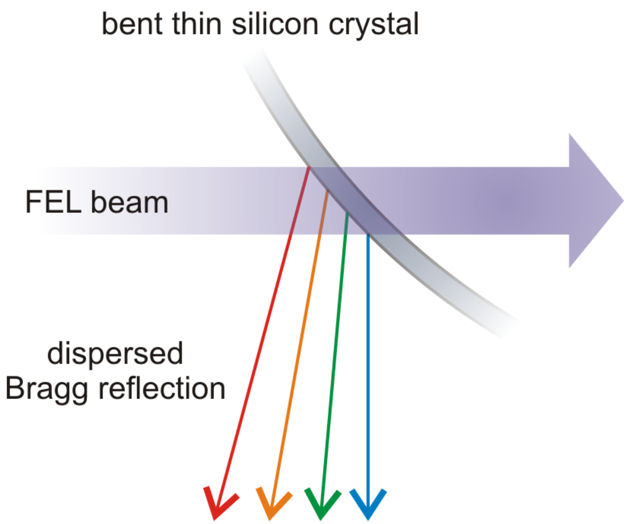


One man’s trash is another man’s treasure!



The bent crystal concept

$$2d \sin \theta_B = \lambda$$



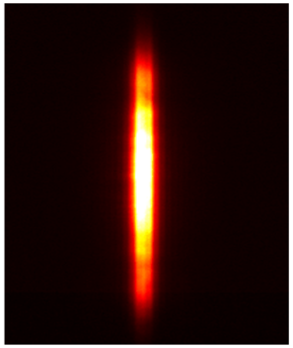
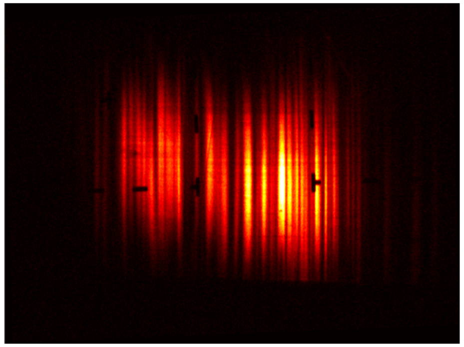
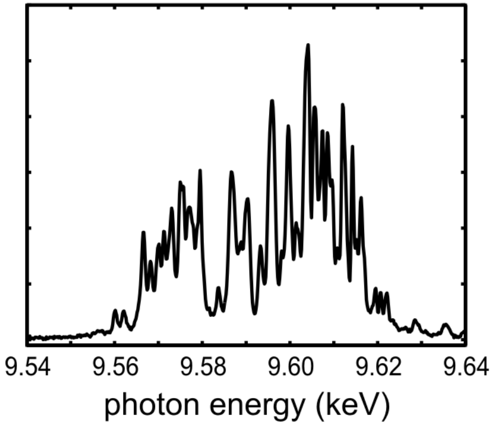


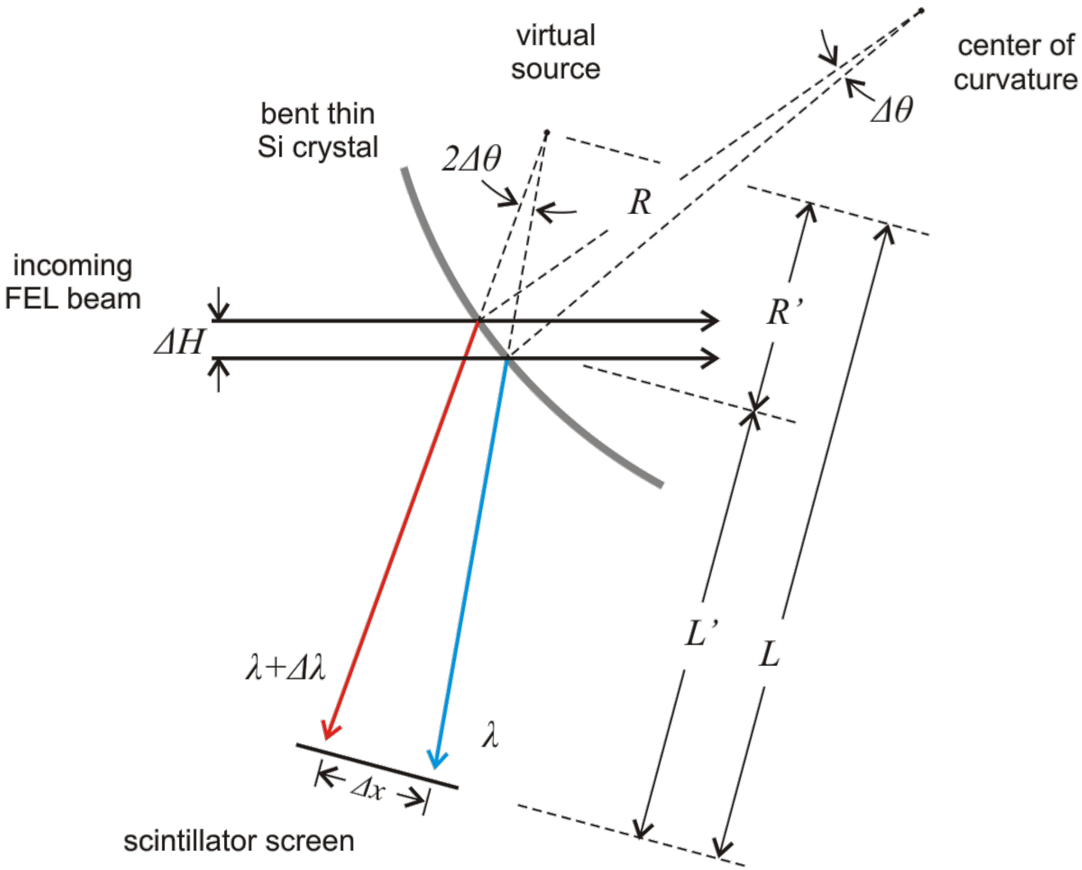
image of the through beam



2-D spectrograph



The bent crystal concept



Flexible knobs

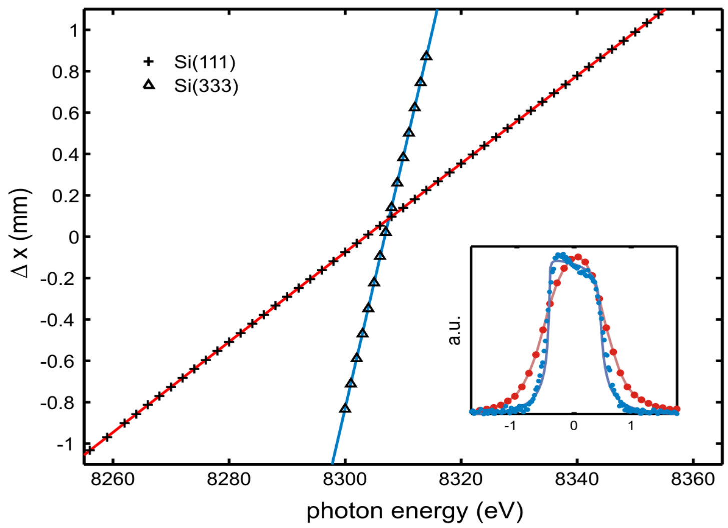
- crystal orientation
- radius of the thin crystal
- distance of the detector
- magnification of the imaging system

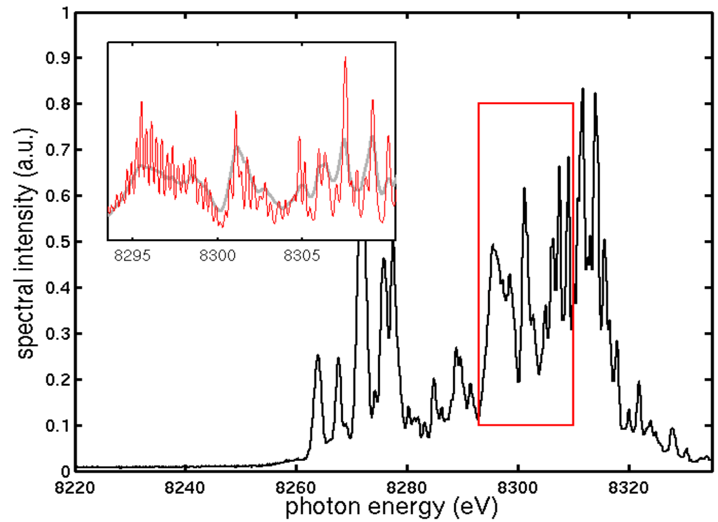
Range: $$\frac{\Delta E_{\max}}{E} = \cot\theta_B \frac{H}{R\sin\theta_B}$$

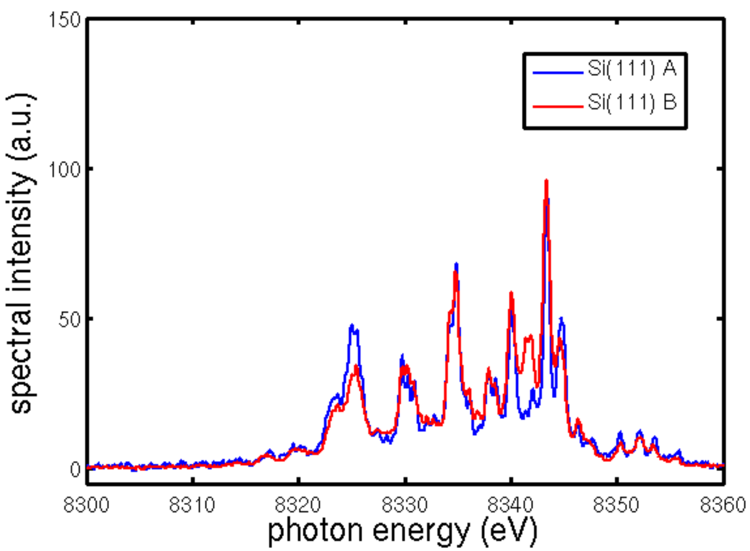
Dispersion relation: $$\Delta x = 2\tan\theta_B \left(\frac{R\sin\theta_B}{2} + L'\right)\frac{\Delta E}{E}$$

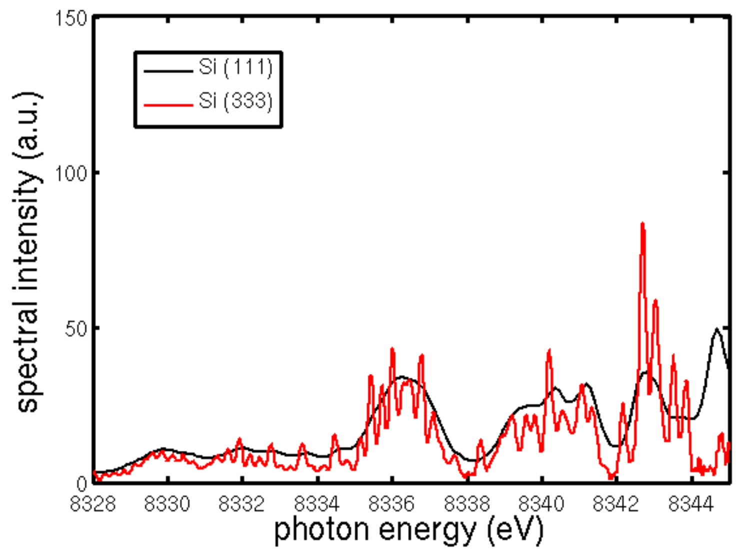
D. Zhu *et al.*, APL. **101** 034103 (2012)

Spectrometer performance

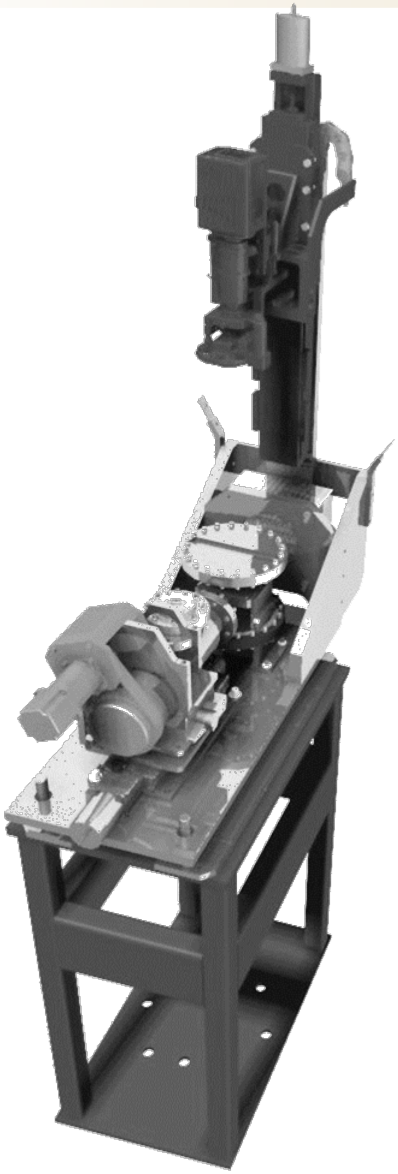








The next generation – variable energy design



- energy range: 4-20 keV
- bandwidth: > 1%
- resolution: < $3x10^{-5}$
- dynamic range: > 10^4
- transmission: > 50%
- sensitivity: < 1 micro Joule

- Three crystals cover all the possible photon energies with good overlap, for high/low resolution options.

Spatial Diagnostics

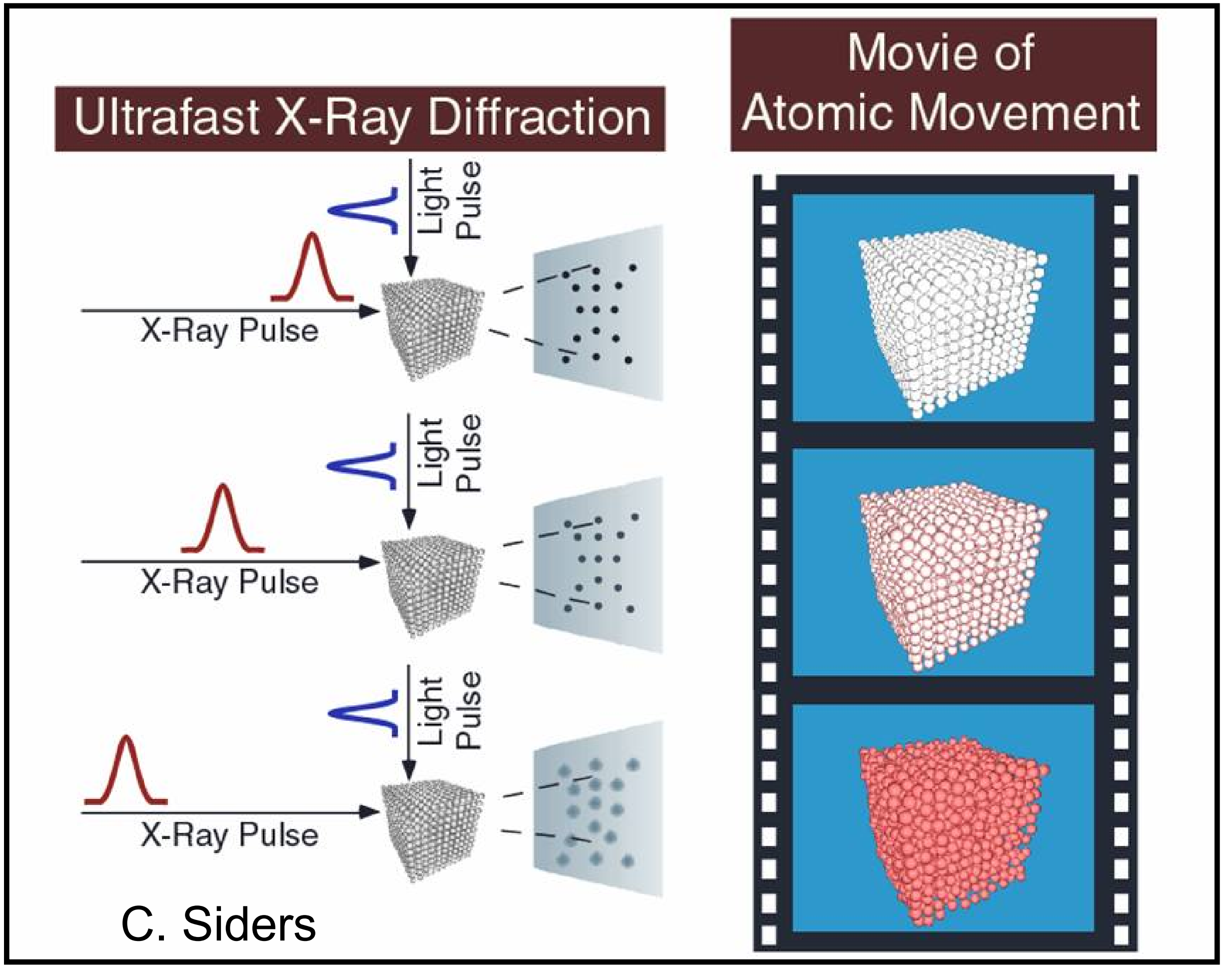
Intensity Diagnostics

Spectral Diagnostics

Temporal Diagnostics

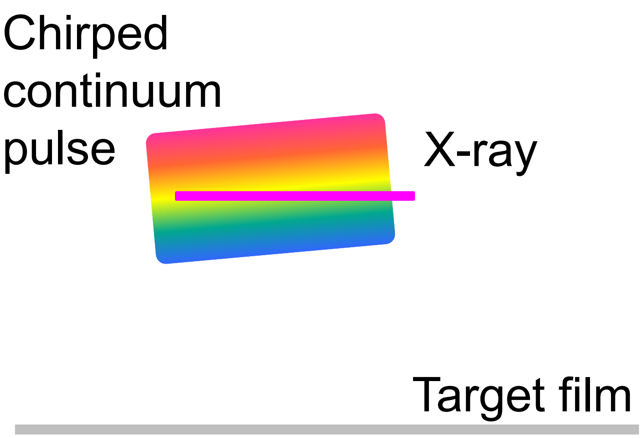
- **Arrival Time**
- **Pulse Structure**

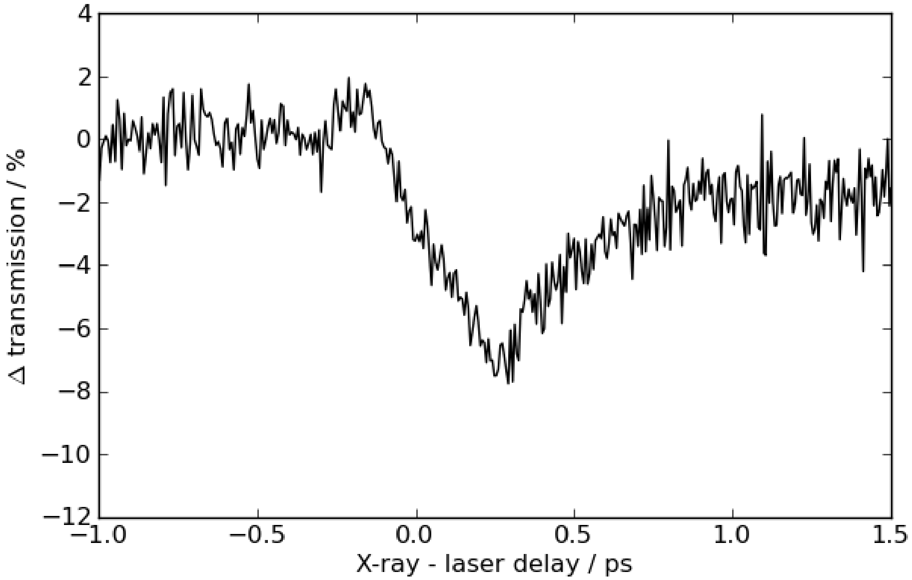
Pump-Probe Experiments



Relative pump laser/FEL arrival time monitor

Spectral dispersion



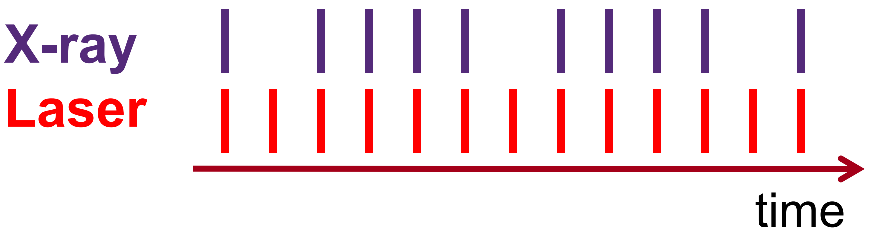


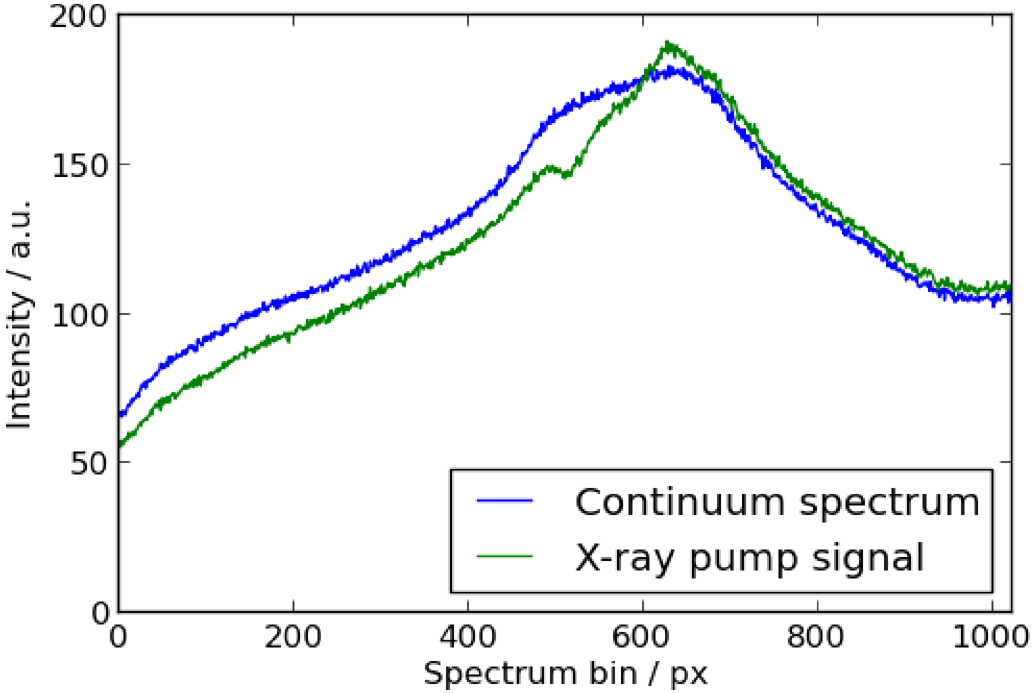
- Collinear configuration
- Time window controlled by probe pulse chirp

Bionta et al. (2011), Optics express, 19(22), 21855-65.
Harmand et al. (2013). Nature Photonics, 7(3), 215–218.
Lemke et al. Proc. SPIE 8778 87780S (2013)

H. Lemke

Spectral normalization

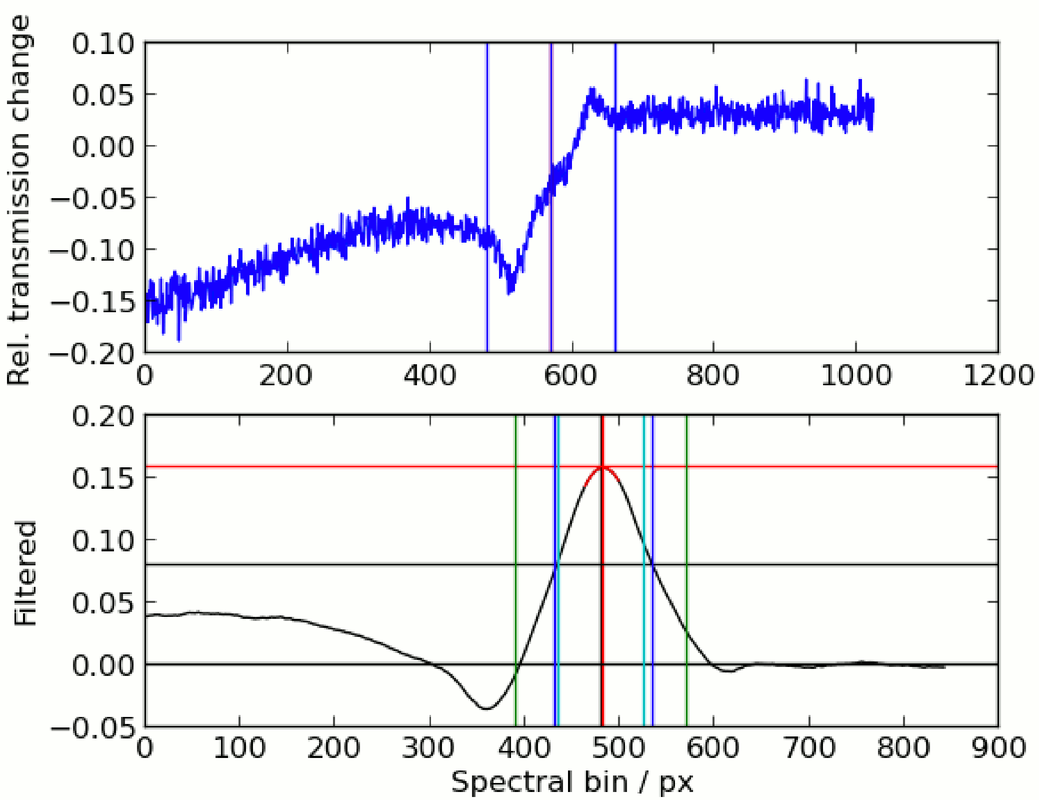




Reference spectra are taken regularly to correct for continuum spectrum fluctuations

Data reduction example: Step finding

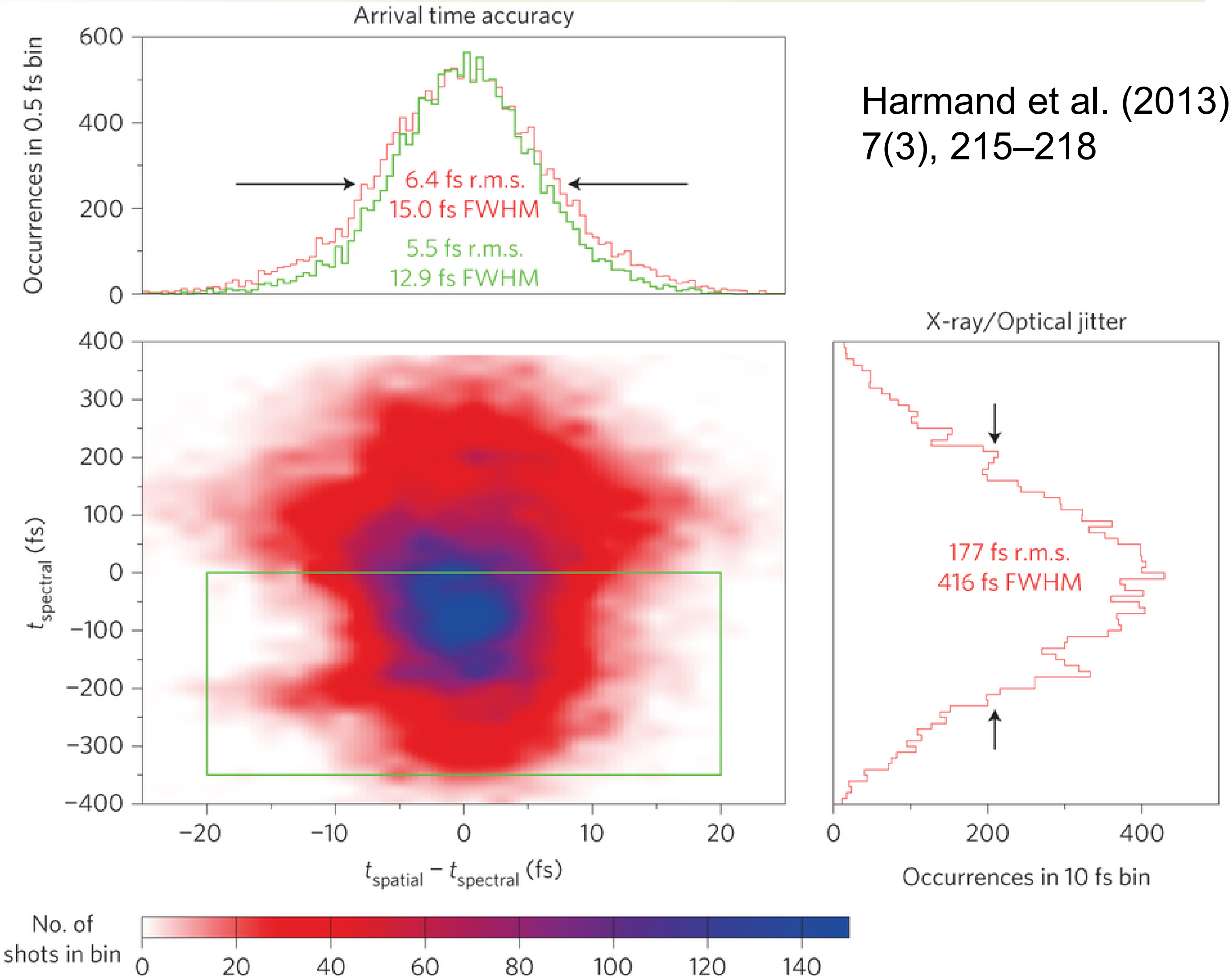
Relative spectral change



Reduction of data array to few numbers (i.e. few “point detectors”)

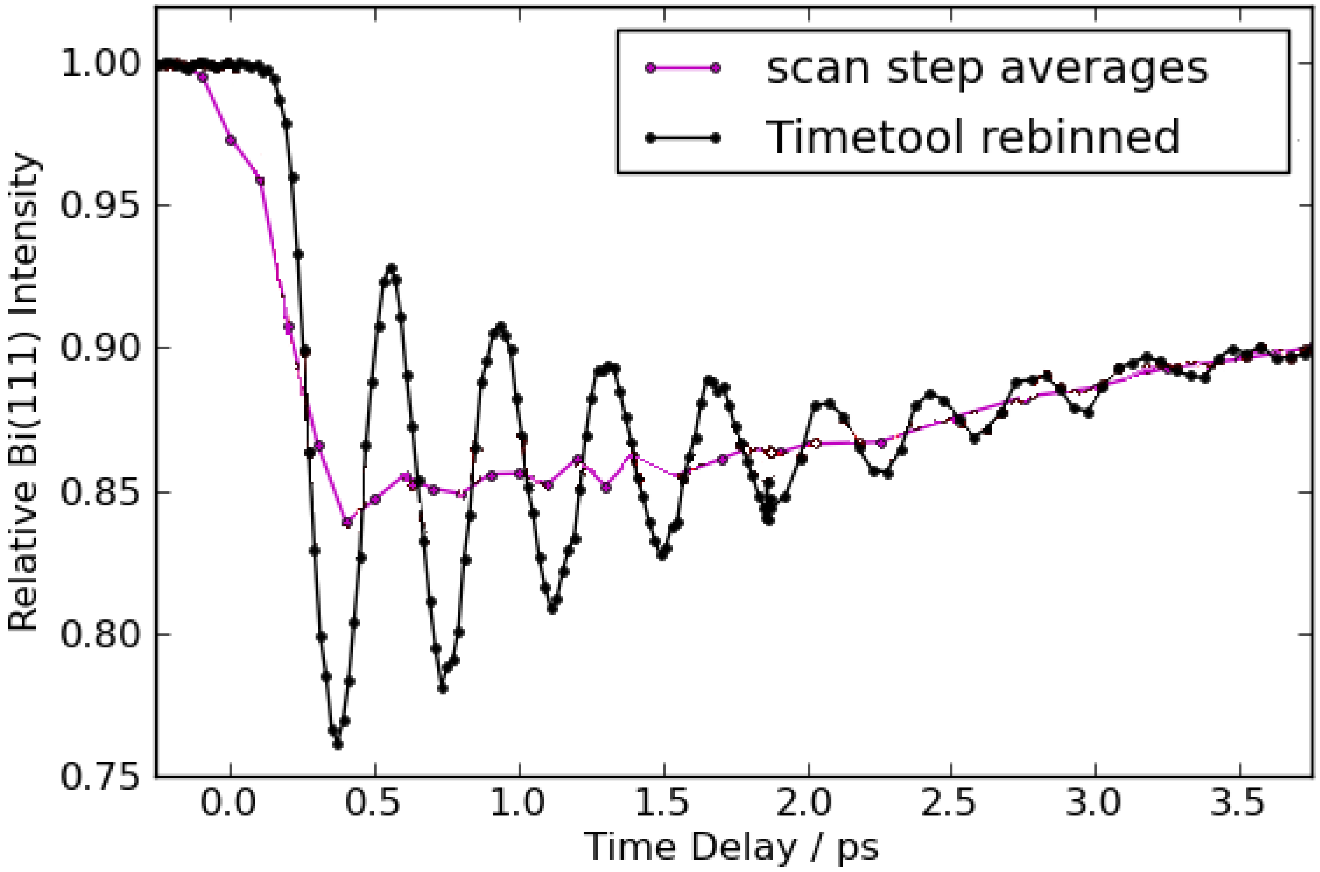
Digital filter edge recognition: Matt Weaver

Correlating two time tools



Harmand et al. (2013). Nature Photonics, 7(3), 215–218

Sorting Data is Essential to "See" Effects



Spatial Diagnostics

Intensity Diagnostics

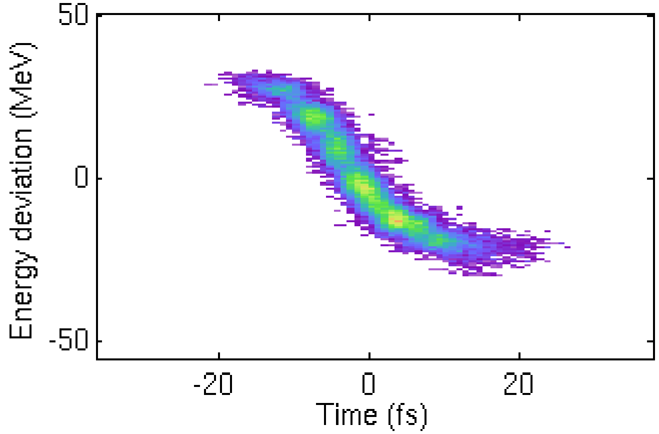
Spectral Diagnostics

Temporal Diagnostics

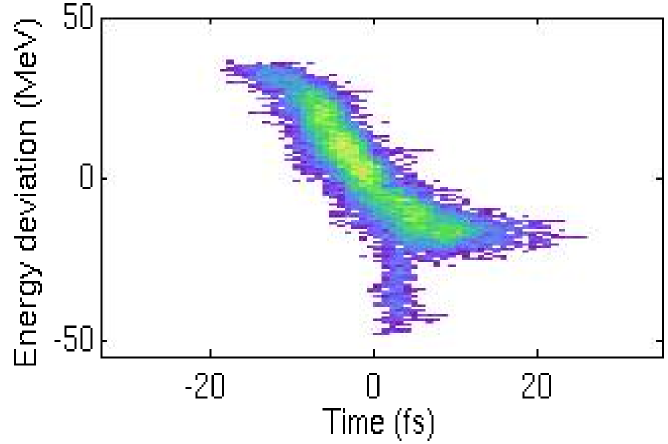
- **Arrival Time**
- **Pulse Structure**

X-band Transverse Cavity

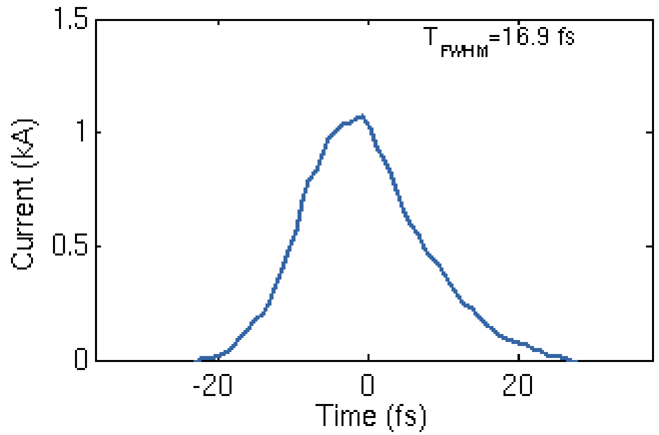
Lasing off



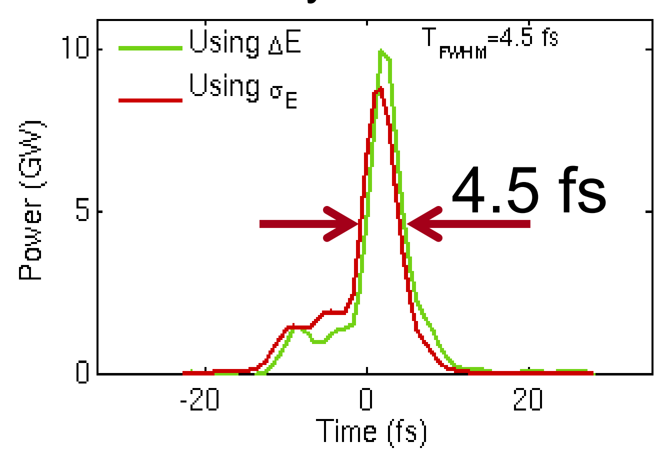
Lasing on



electrons



X-rays



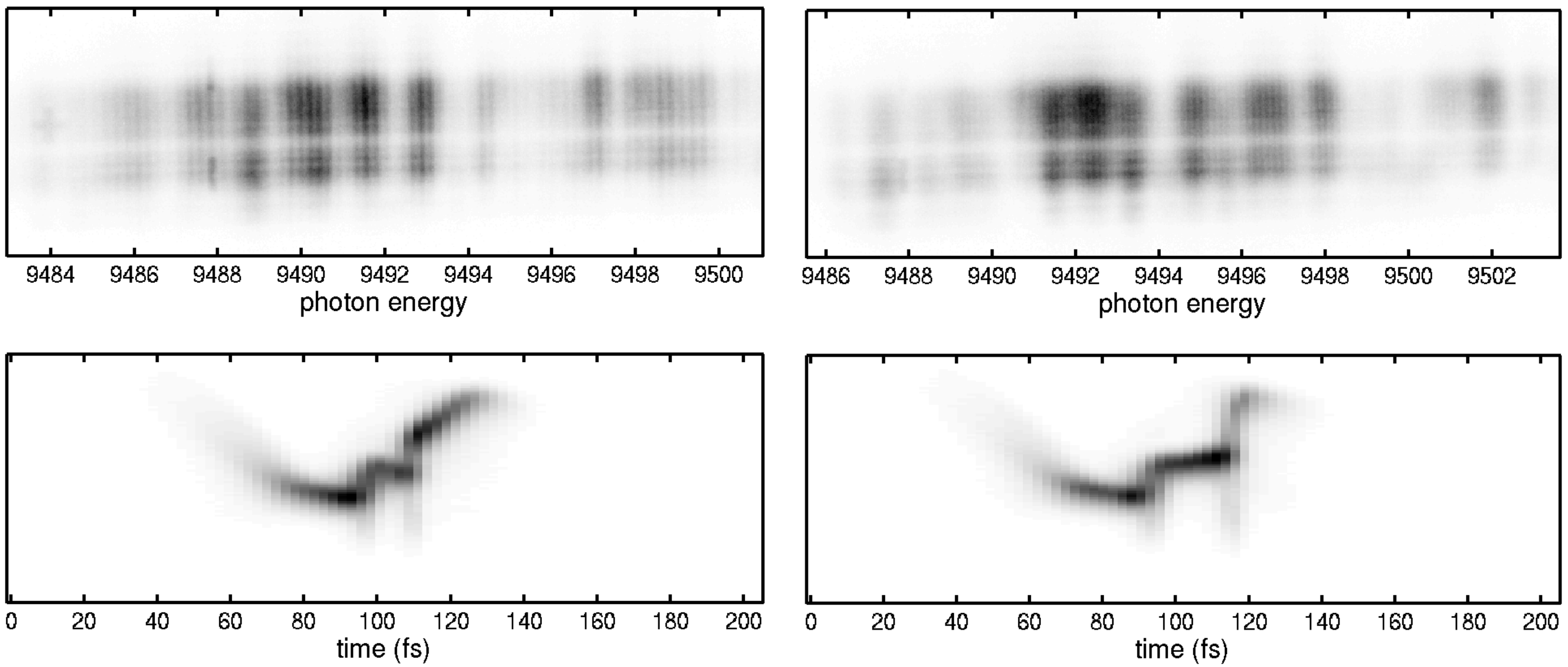
Y. Ding, P. Krejcik et al.

Resolution corrected 2.6 fs FWHM

Spectrum can be used to characterize double pulse

Photon Spectrum

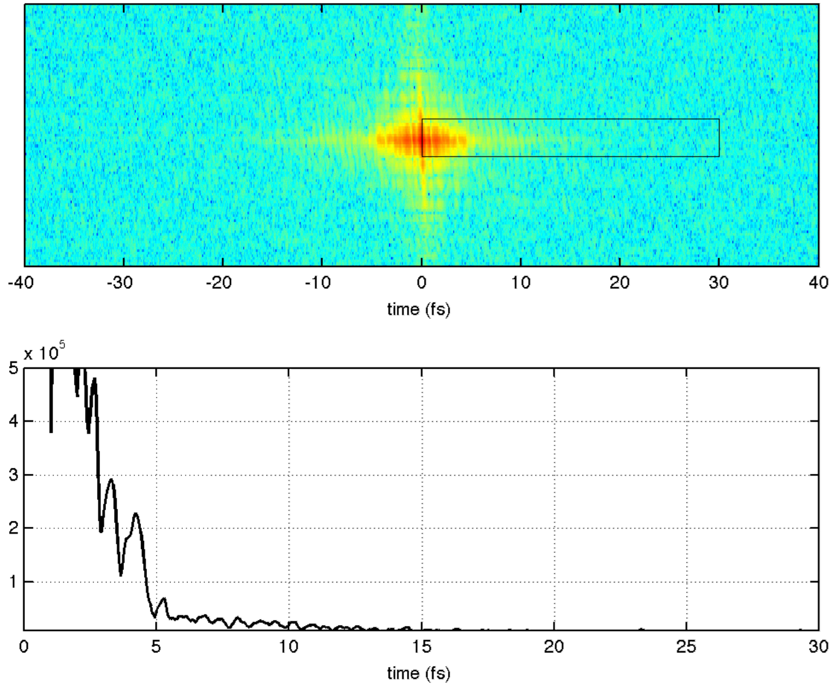
XTCAV



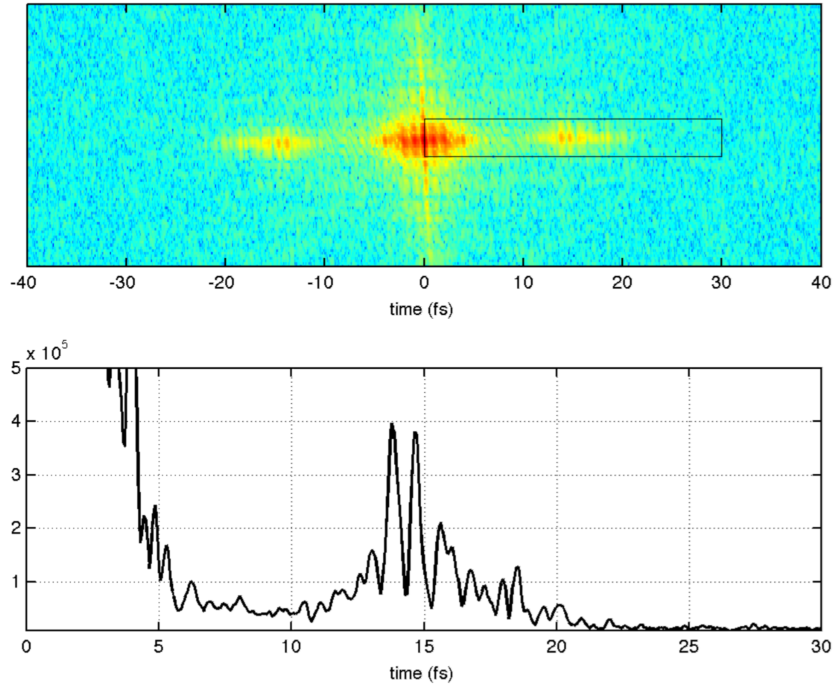
D. Zhu

Spectrum can be used to characterize double pulse

Double slotted foil at 14 fs:
only one slot lasing

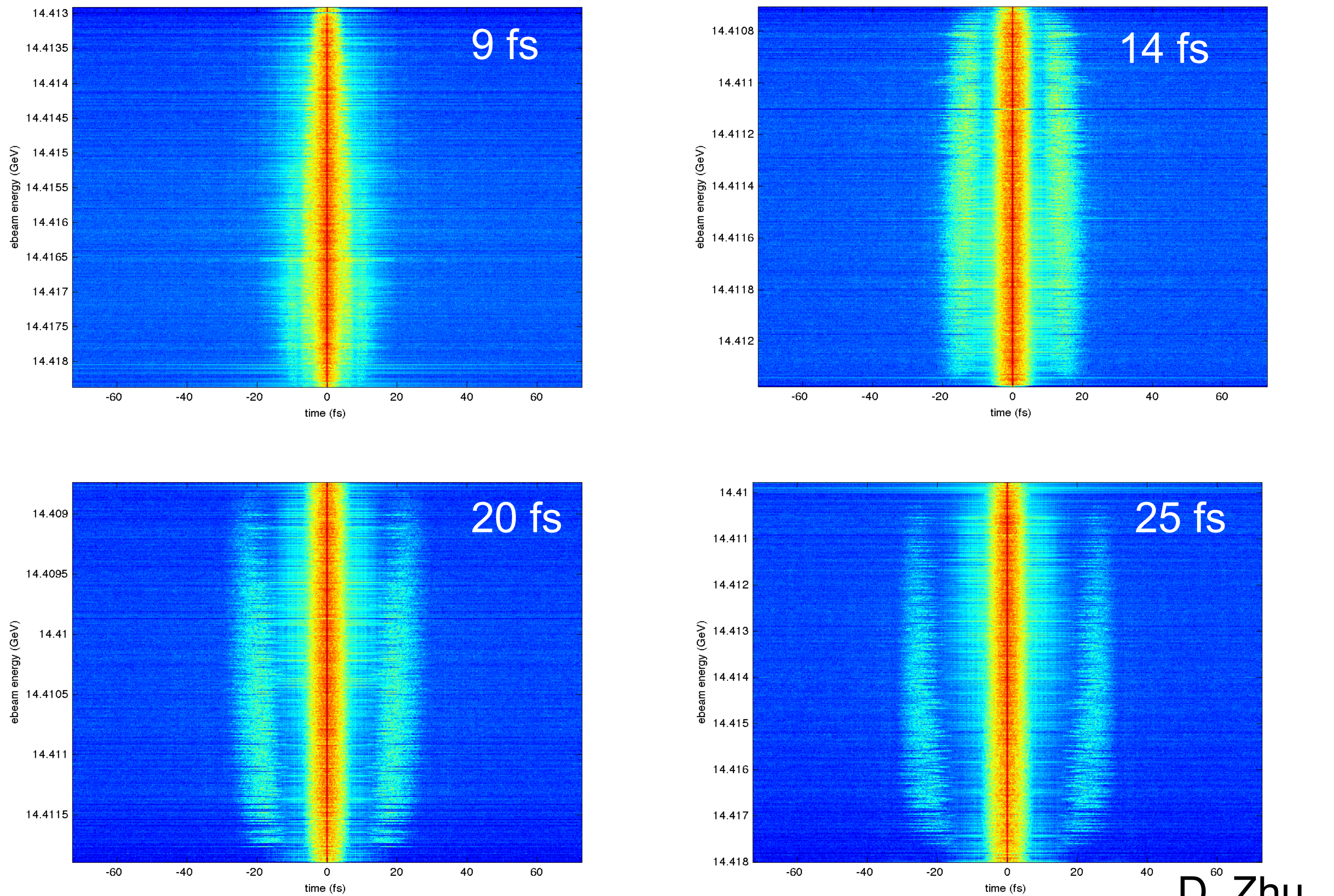


Double slotted foil at 14 fs:
both lasing



D. Zhu

Spectrum can be used to characterize double pulse



D. Zhu

Summary

- X-ray free electron lasers provides revolutionary capabilities but present significant challenges
  - Uniqueness of each pulse, and in some cases sample, drive the need to diagnose each x-ray pulse
- Sophisticated diagnostics are needed to optimize the use of these sources
- Diagnostics are now implemented at LCLS to measure various properties of the beam
  - Spectrum, arrival time, intensity, …
- Our ability to conduct more precise experiments requires advances in our beam diagnostics