Diagnostics for Measuring and Mitigating Femtosecond Microbunches at the LCLS

6th Microbunching Workshop,
6-8 October 2014, Trieste, Italy

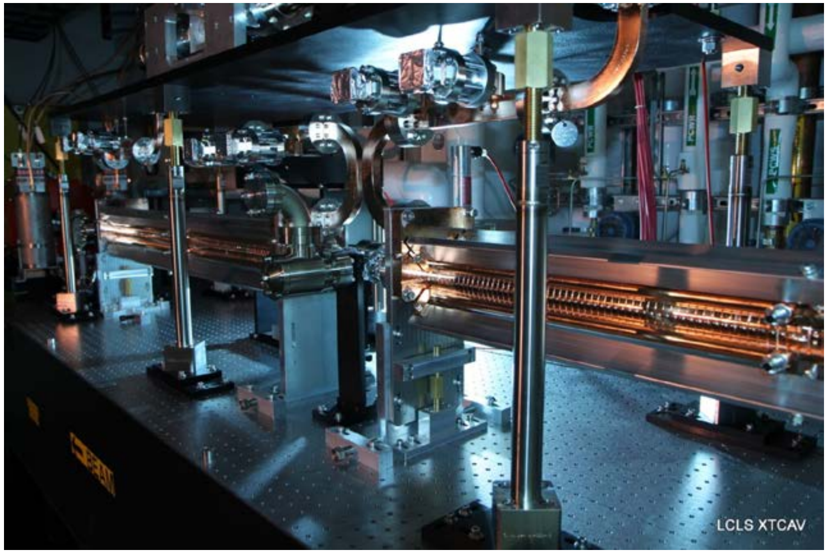
Patrick Krejcik, Christopher Behrens, Yuantao Ding, Zhirong Huang,, Agostino Marinelli, Timothy J. Maxwell Luciano Piccoli and Daniel Ratner
Rasmus Ischebeck (PSI), Minjie Yan (DESY)

October 8, 2014

Outline

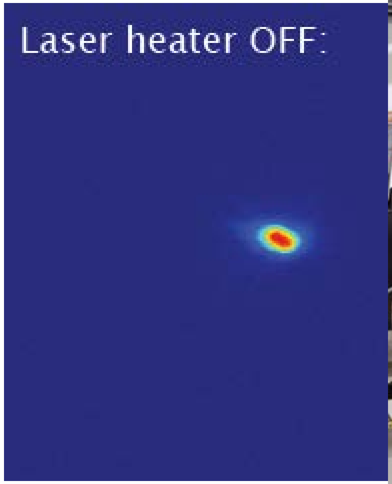
Temporal Diagnostics:

- X-band transverse deflection structure for streaking the beam with femtosecond resolution.
- Dispersion downstream of XTCAV allows observation of full longitudinal phase space
- *Location downstream of undulator for reconstruction of x-ray emission*



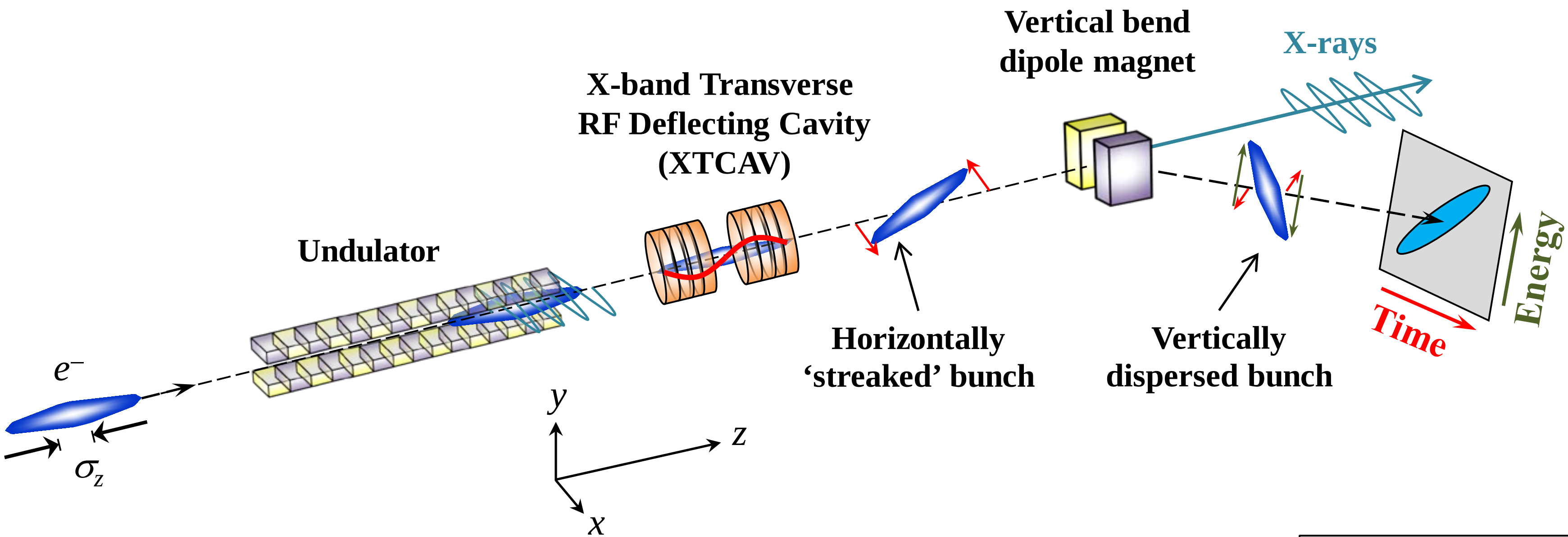
Suppression of COTR in Profile Measurements

- SLAC test measurements with PSI profile monitor
- Sensitivity to bunch length
- Sensitivity to laser heater



Temporal Diagnostic Measurement Layout

XTCAV: Resolving the e-bunch *t-E* phase space



$$\sigma_t = \frac{1}{2\pi\, f_{\mathrm{rf}}} \frac{E_e}{eV_{\mathrm{rf}}} \sqrt{\frac{\varepsilon_x}{\gamma\beta_x}} \qquad \propto \sqrt{E_e} \qquad \propto \frac{1}{f_{\mathrm{rf}}}$$

Time resolution

High-*E* FEL

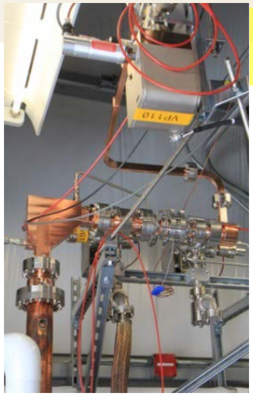
x8 improvement with SLAC X-band @ 11.4 GHz

Result:
1 fs rms @ SXR
3 fs rms @ HXR

Installation in the LCLS Undulator Hall

A powerful, but not inexpensive diagnostic

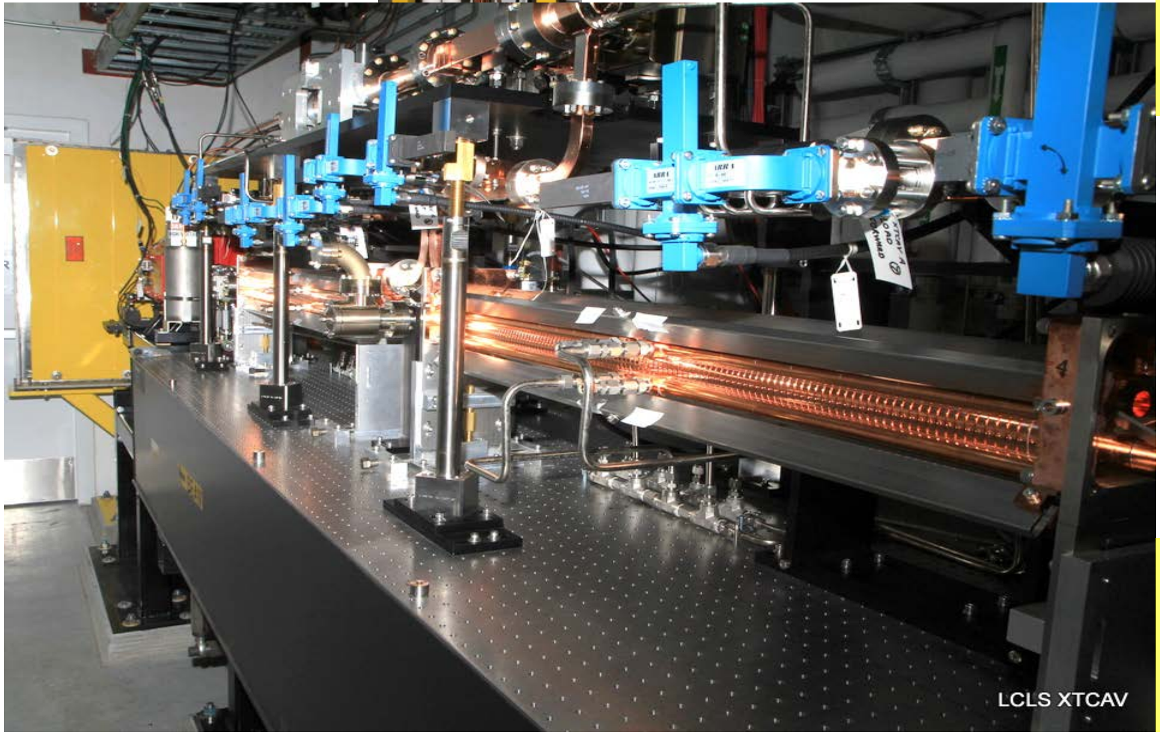
50 MW klystron



waveguide

Controls:
PAC, PADS,

430 kV modulator

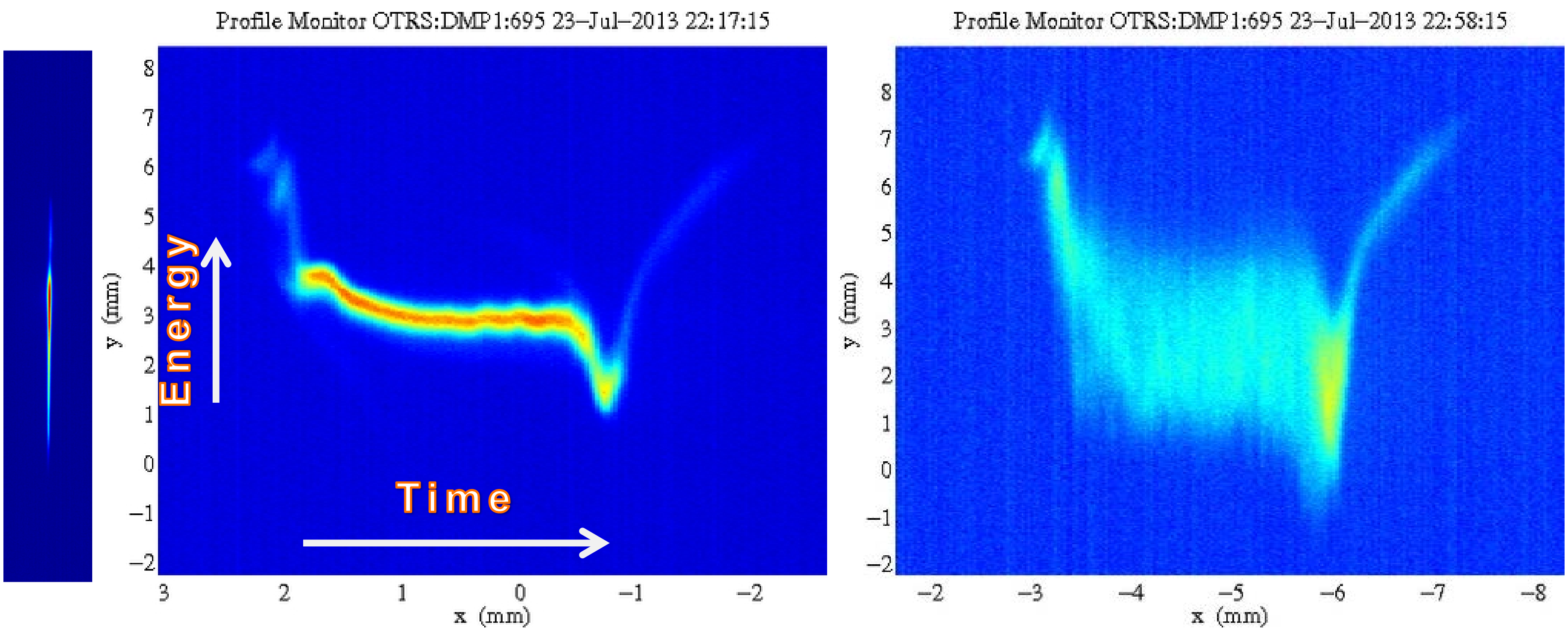


LLRF Drive:
TWTA, klystron
Mag. Suppl.

Measurement examples: 4.7GeV, 150pC (1keV)

SLAC

Three Images at the e-dump spectrometer screen

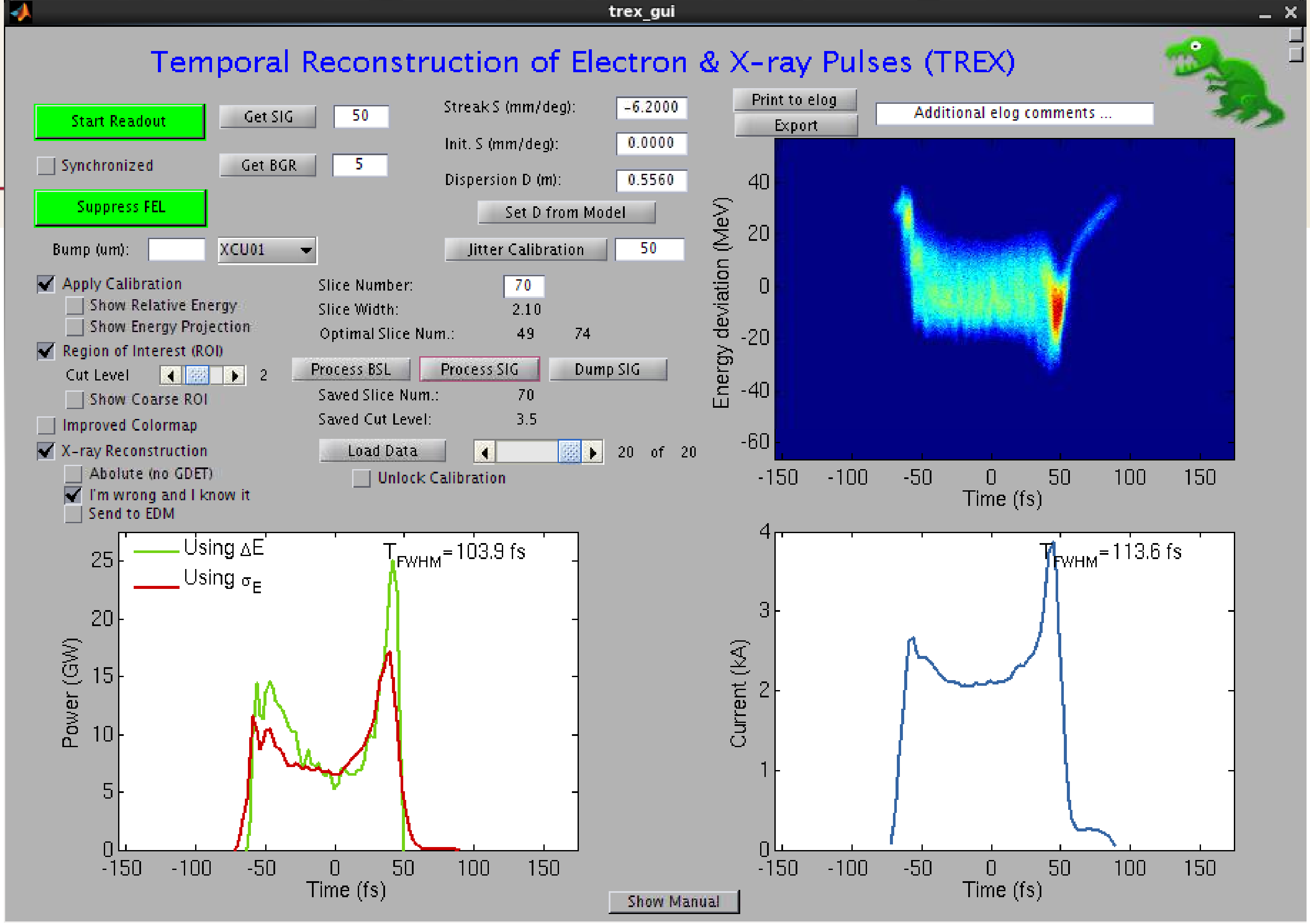


XTCAV Off

XTCAV On
FEL Supressed
(baseline)

XTCAV On
FEL On
~1mJ FEL pulse energy

Real-Time data analysis



C. Behrens et al

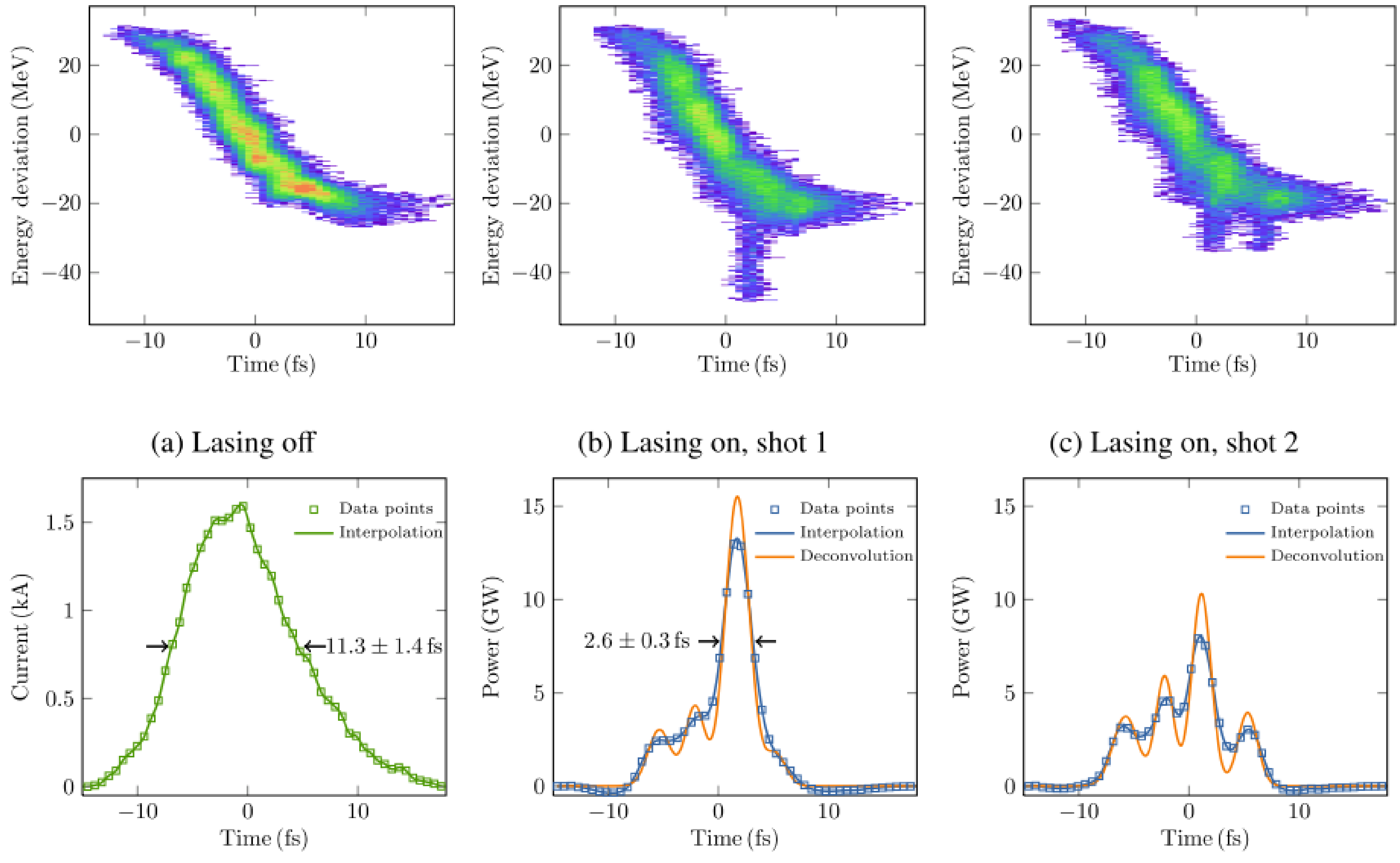
- Analyze energy difference between FEL On and FEL Off images

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

- Alternative analysis based on change in energy spread

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

Able to resolve individual features -- 20pC, 1keV examples



(a) Lasing off
(b) Lasing on, shot 1
(c) Lasing on, shot 2
(d) Electron current
(e) X-ray power, shot 1
(f) X-ray power, shot 2

Is it a suitable diagnostic for Microbunch Instabilities

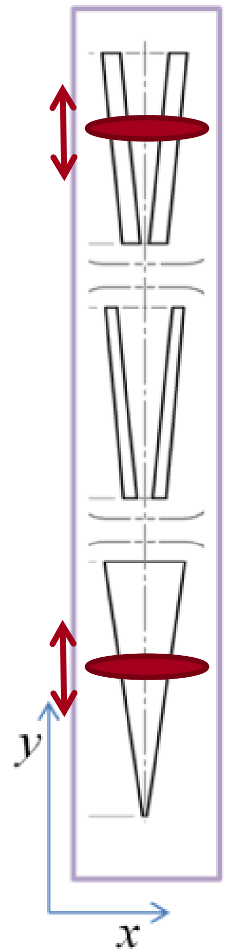
- Previous slide demonstrated that temporal resolution is adequate
- Next question is whether features on the beam that are generated upstream in the bunch compressor are preserved all the way through to the measurement screen.
- Test this by generating temporal features using a pair of slits in the bunch compressor chicane

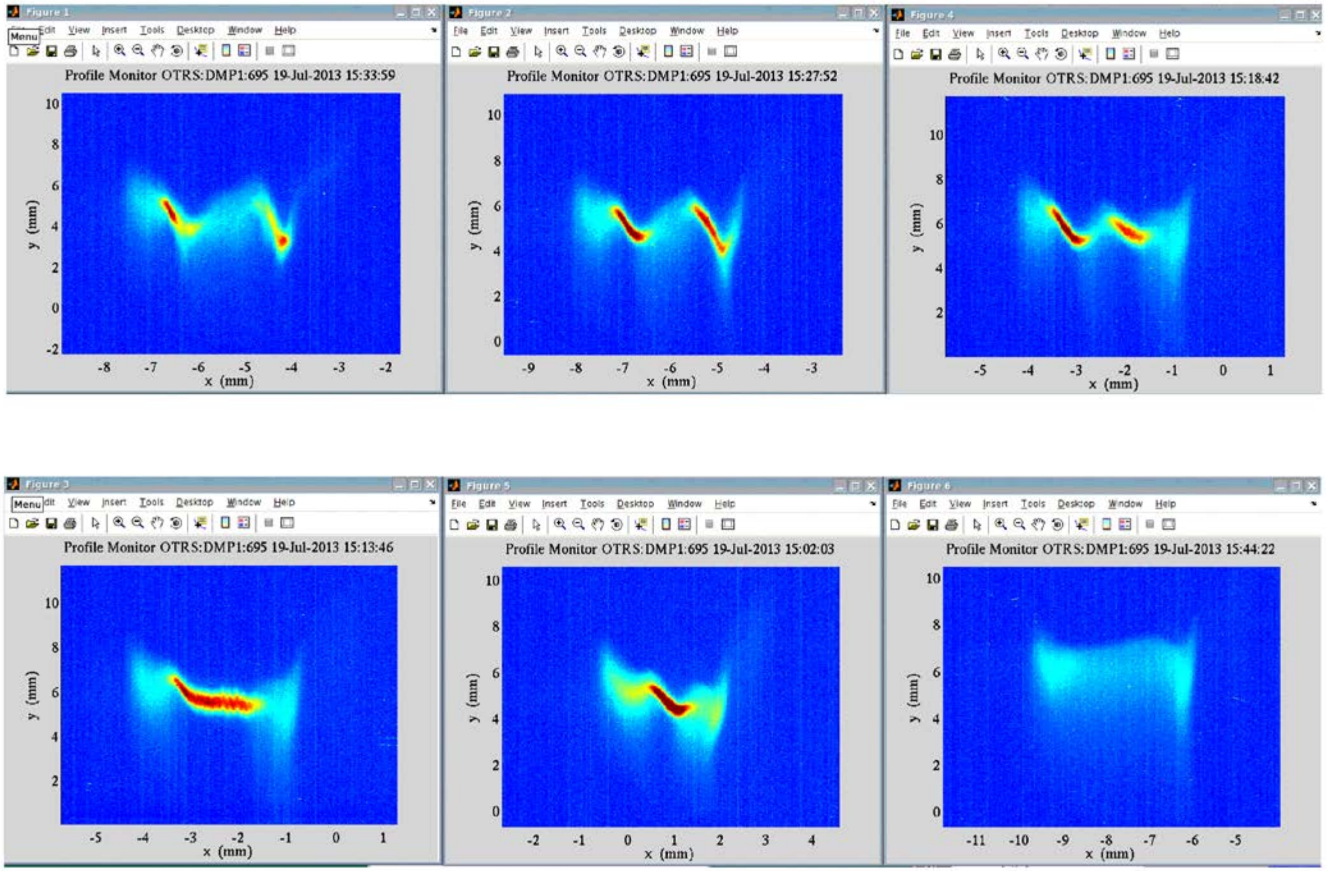
Features introduced upstream at BC are preserved
Slotted-foil examples (lasing off)

shows clearly the unspoiled beam region

Double Slit

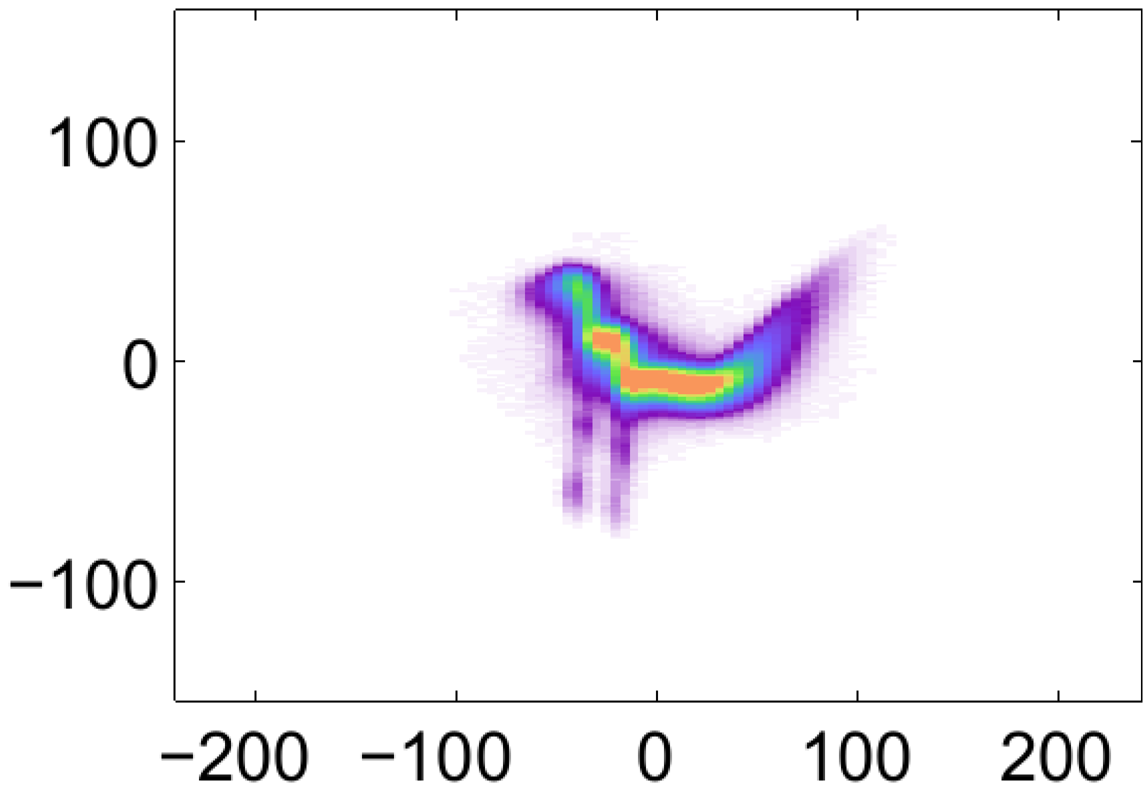
Single Slit





4.7GeV, 150 pC

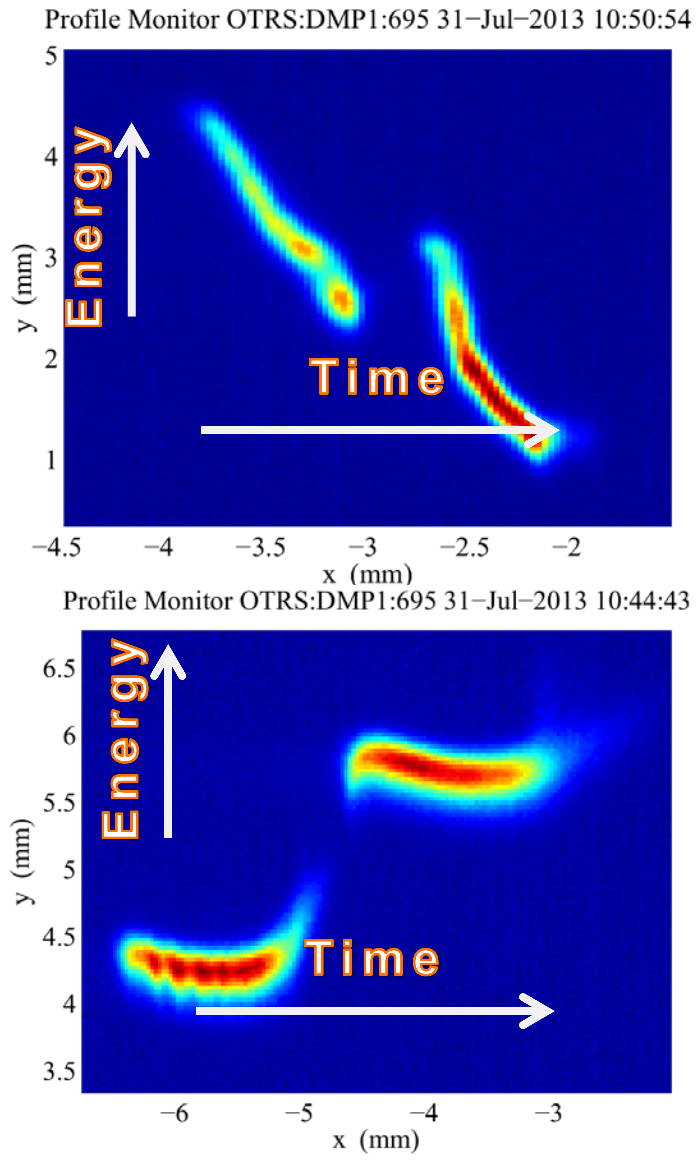
Lasing with double-slotted foil



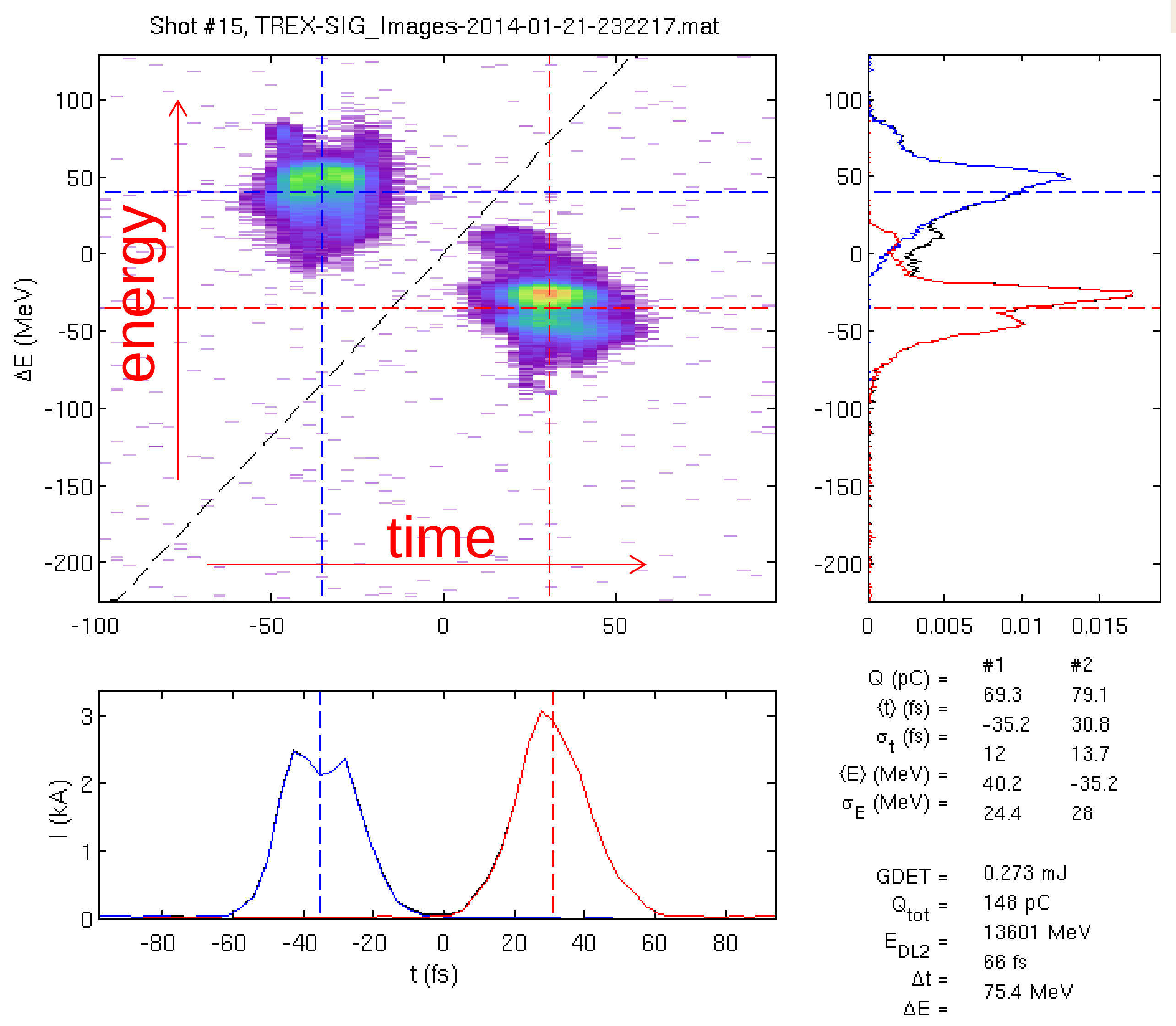
Second example with pulse stacking

Laser pulses are stacked at the LCLS photo-Injector to produce multiple electron bunches within one RF bucket **A Marinelli**

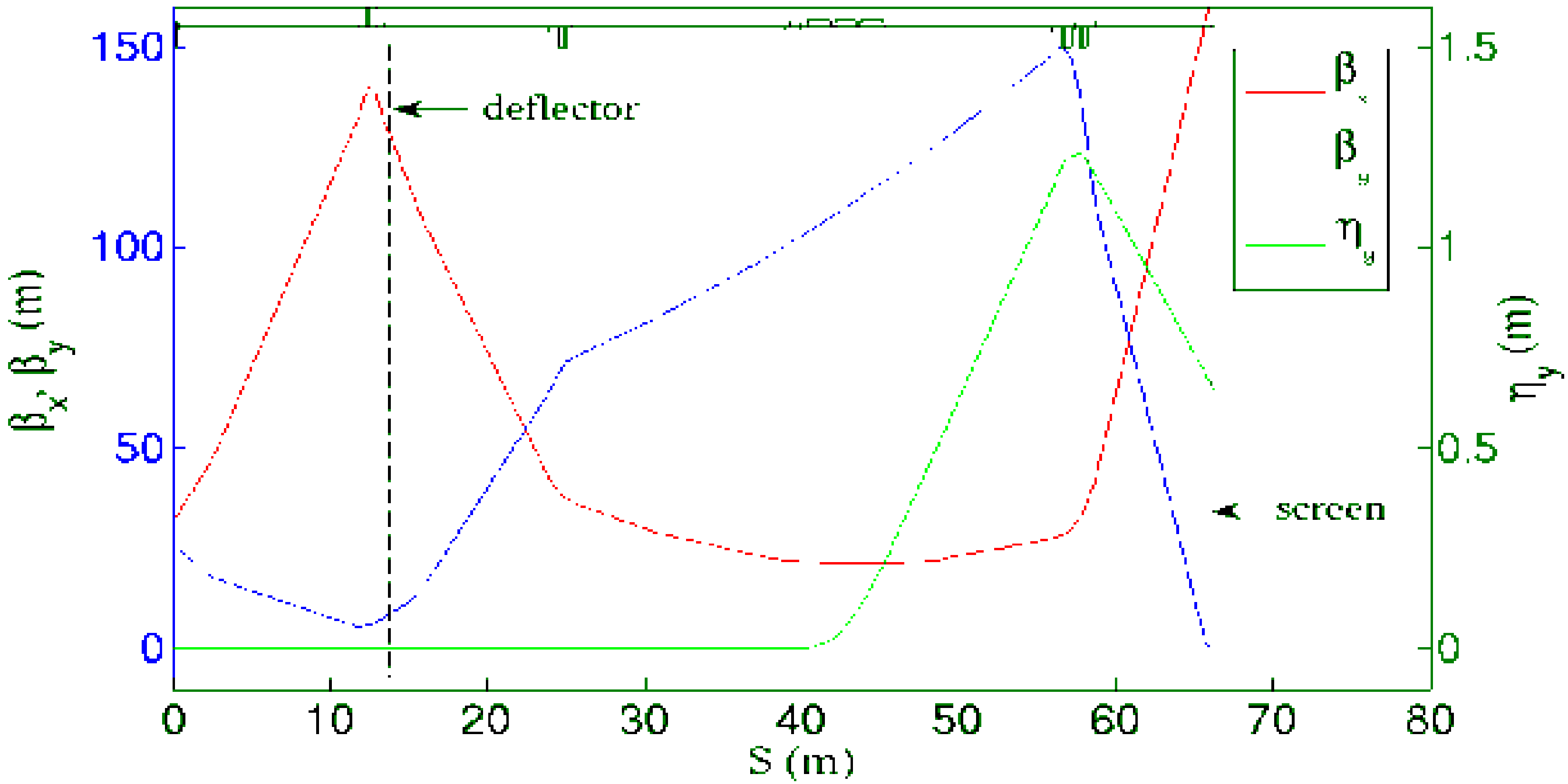
XTCAV gives clear view of bunch separation and orientation in longitudinal phase space



Double-bunch (two-color) example - A. Marineli



Beam Line Optics

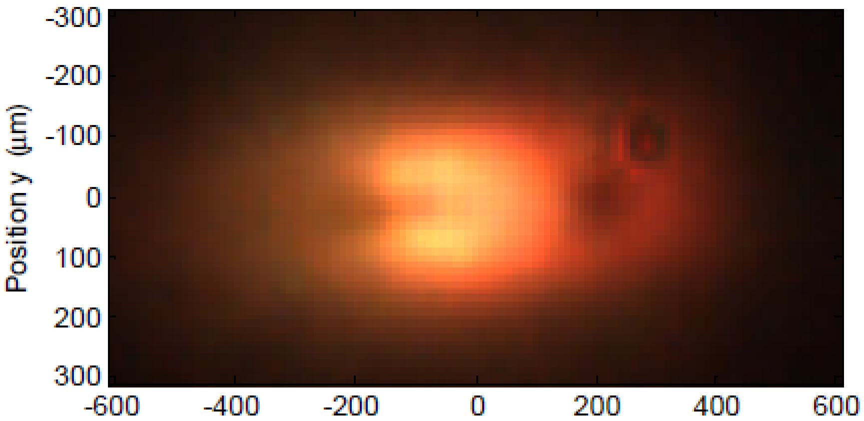


Summary (1)

- The LCLS XTCAV system has been implemented as a powerful diagnostic tool
- Can distinguish temporal microstructures in the beam down to 1 fs resolution
- Slice energy spread can also be resolved with keV resolution
- Examples of microbunching instability shown in Tim Maxwell's talk.

2. Beam Profile Measurements and MBI induced COTR

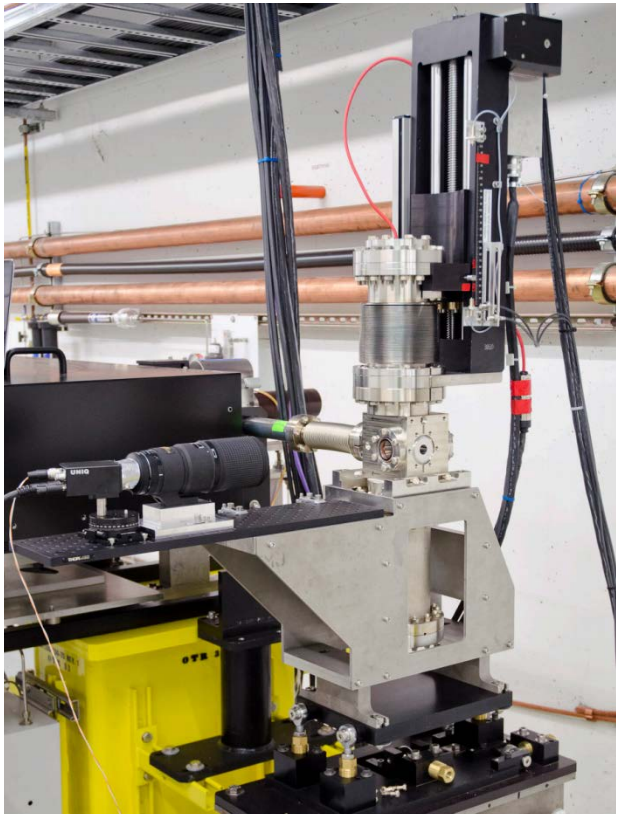
- OTR foil screens unusable for beam size measurement downstream of BC at LCLS
- 10^5 intensity enhancement
- With large variations



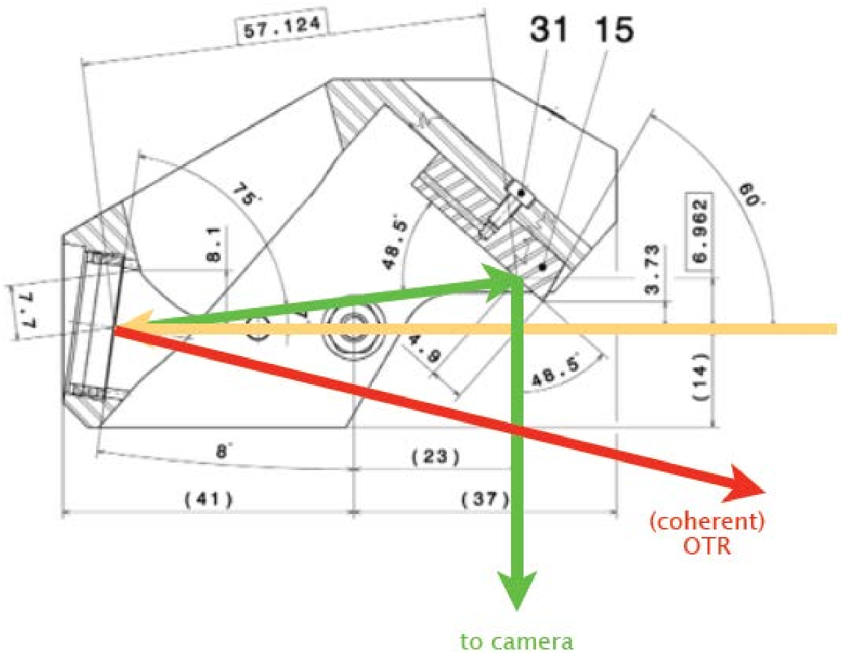
- Resorted to wire scanners for beam profiling
- Motivated to study COTR suppression with fluorescent screens

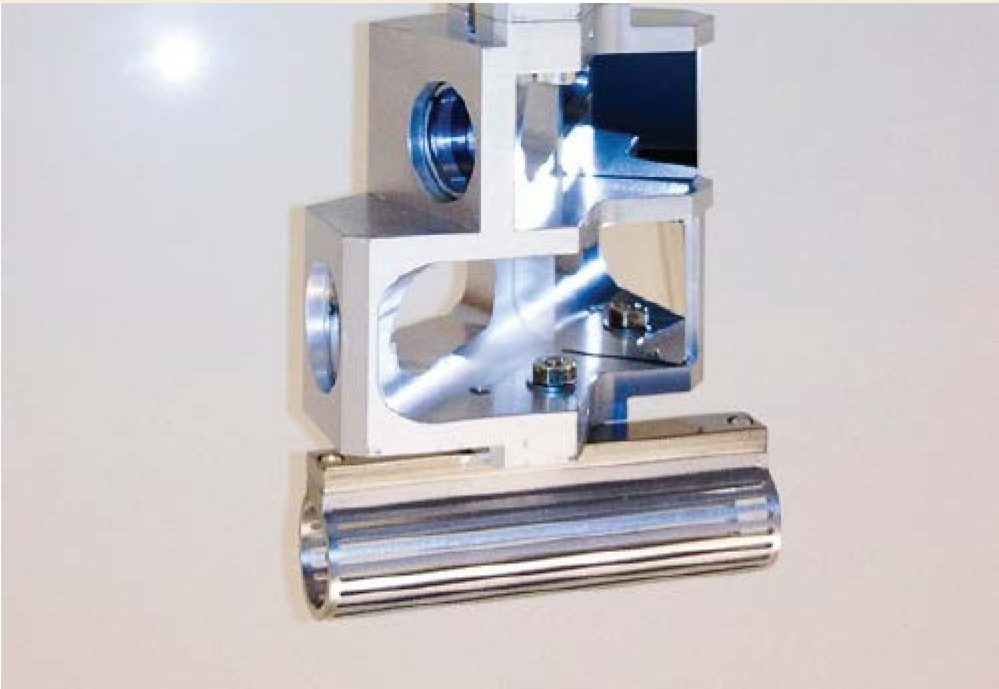
PSI Profile Monitor Tests at LCLS

- YAG screen monitor designed by Rasmus Ischebeck built at PSI was installed in the LCLS LTU beamline
- 30 micron thick crystal
- Beam loss is still significant
- Max rep rate of 10 Hz
- Undulator stopper must be in



Unique target geometry – R. Ischebeck



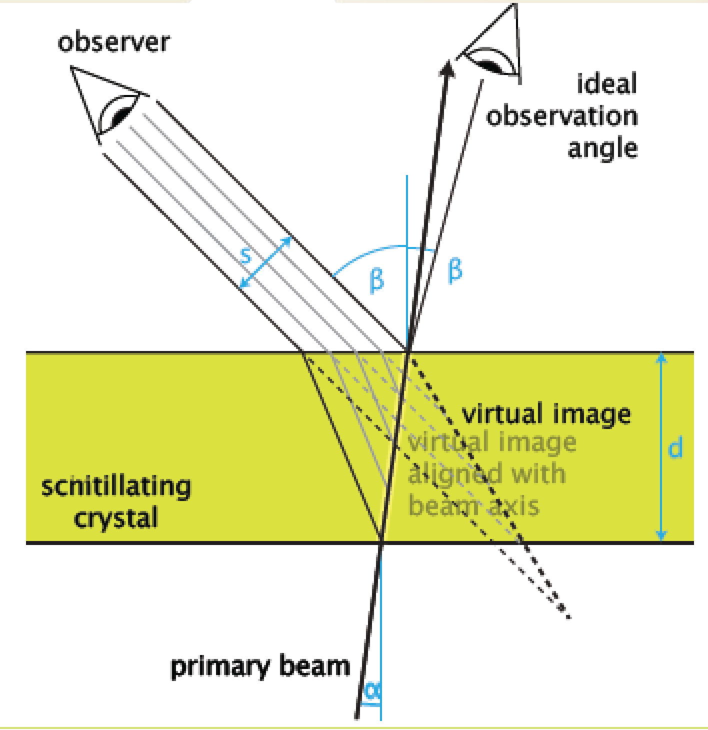


- COTR light is directed away from camera
- Requires use of Scheimpflug optics and Snell observation angle

Unique target geometry – R. Ischebeck

- Observe the screen at the correct angle for Snells law so that beam sizes smaller than the screen thickness are imaged

- Camera image plane is also tilted to preserve depth of field across tilted crystal (Scheimpflug optics)



Beam tests at LCLS (together with M. Yan, DESY)

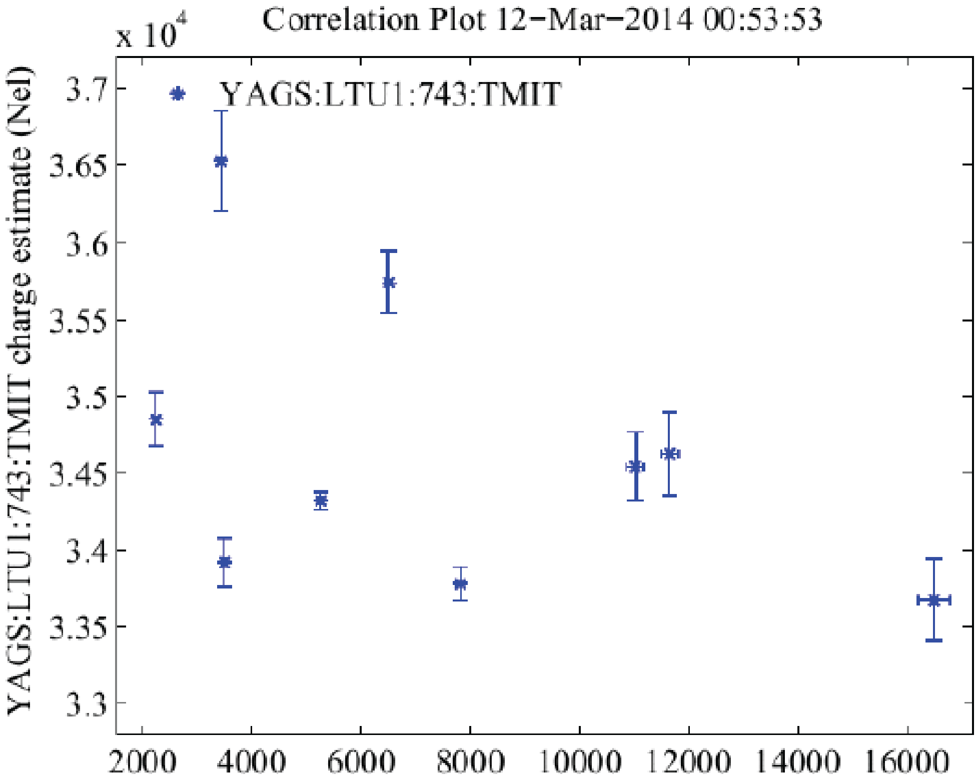
- Concern is that screen may still be illuminated by upstream COTR
- And, that COTR may be short enough wavelength to fluoresce in the YAG crystal
- Measure image intensity as a function of:
  - Beam size
  - Bunch charge
  - Peak current (bunch length)
  - Laser heater power

Screen intensity during beam size scan almost constant

Plot camera intensity vs beam area $\sigma_x * \sigma_y$

Laser heater ON; Nominal under compression

Camera Intensity

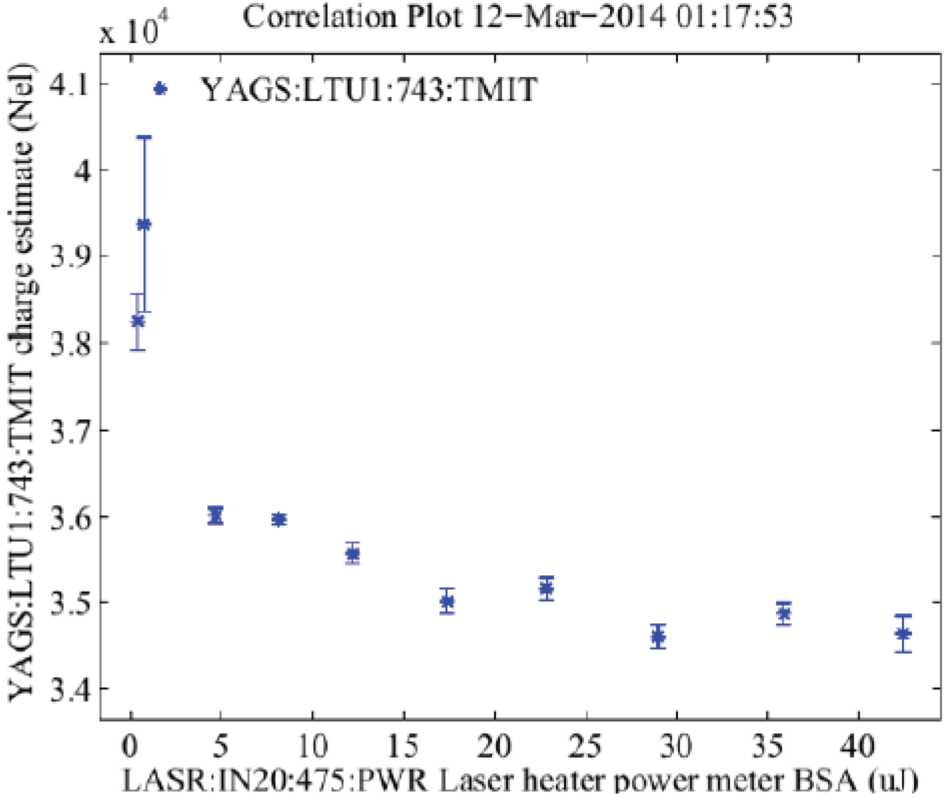


Beam Area

Screen intensity versus laser heater power

Fixed spot size

10% light intensitv increase with laser heater OFF



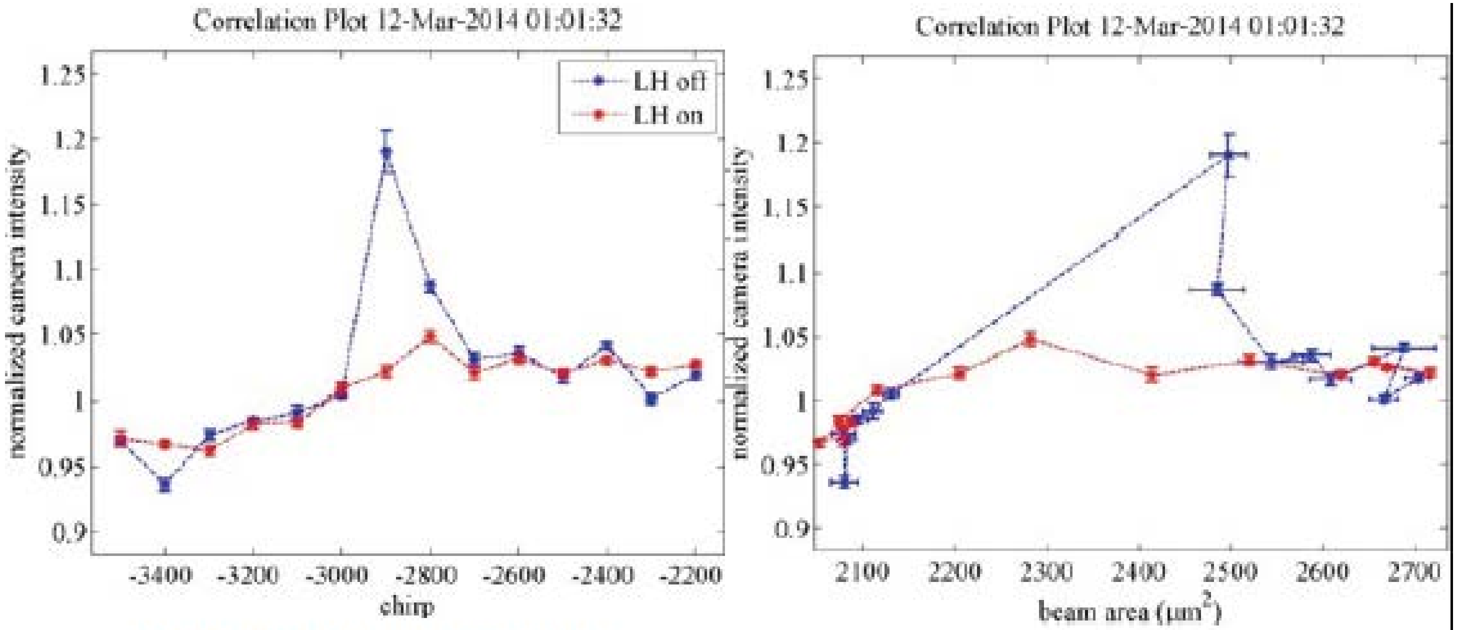
Bunch length scan

SLAC

20 pC bunch charge at 13.1 GeV

Compare Laser Heater On/Off

Worst case, factor 1.2 enhancement



Normalized to mean(Icamera)

Normalized to mean(Icamera)

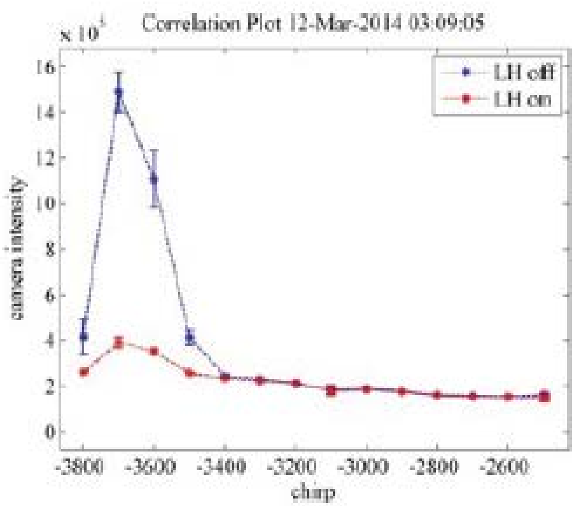
Analysis Minjie Yan

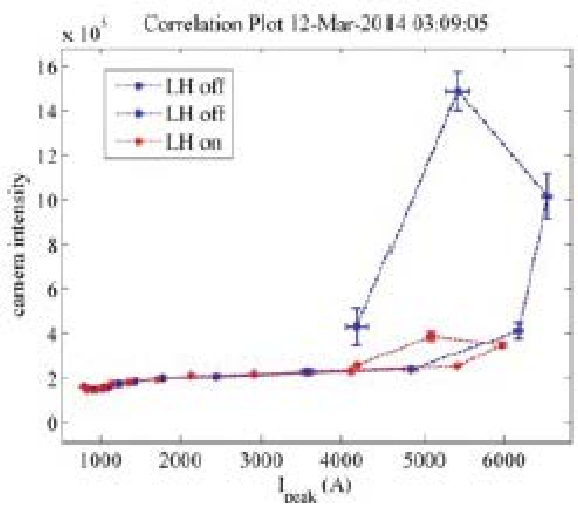
Bunch length scan

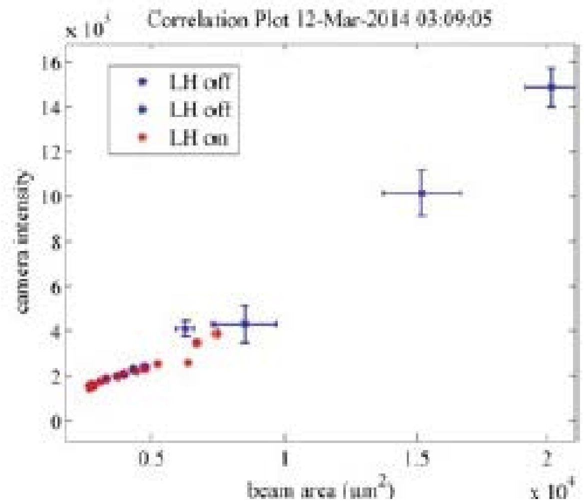
150 pC bunch charge at 13.1 GeV

Compare Laser Heater On/Off

Worst case, factor 2 - 7 enhancement







Analysis Minjie Yan

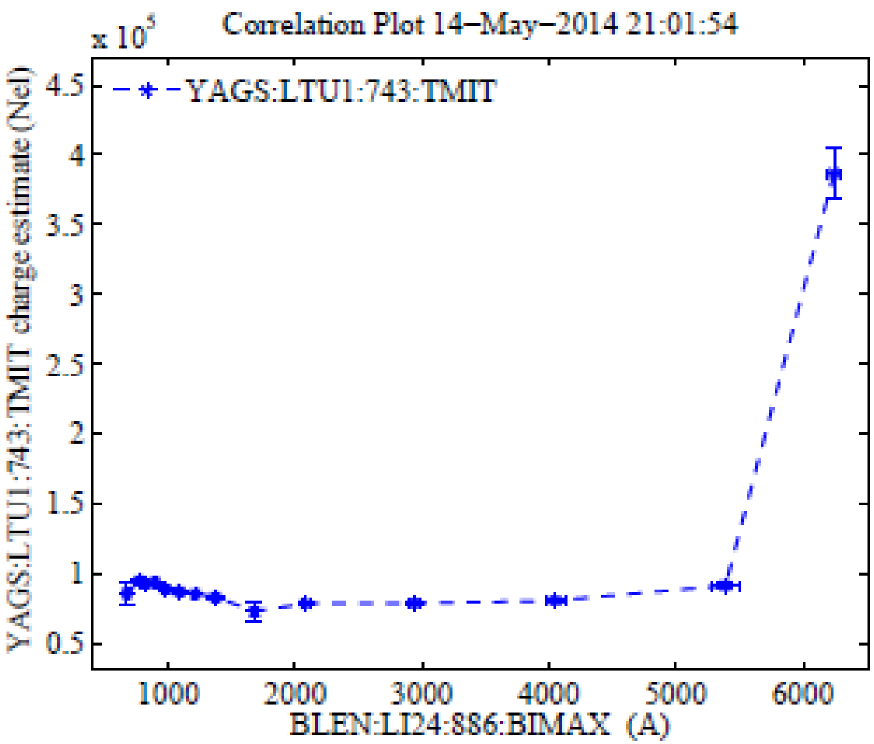
More recent result

Add a narrow band yellow filter to the camera

150 pC bunch charge at 13.1 GeV

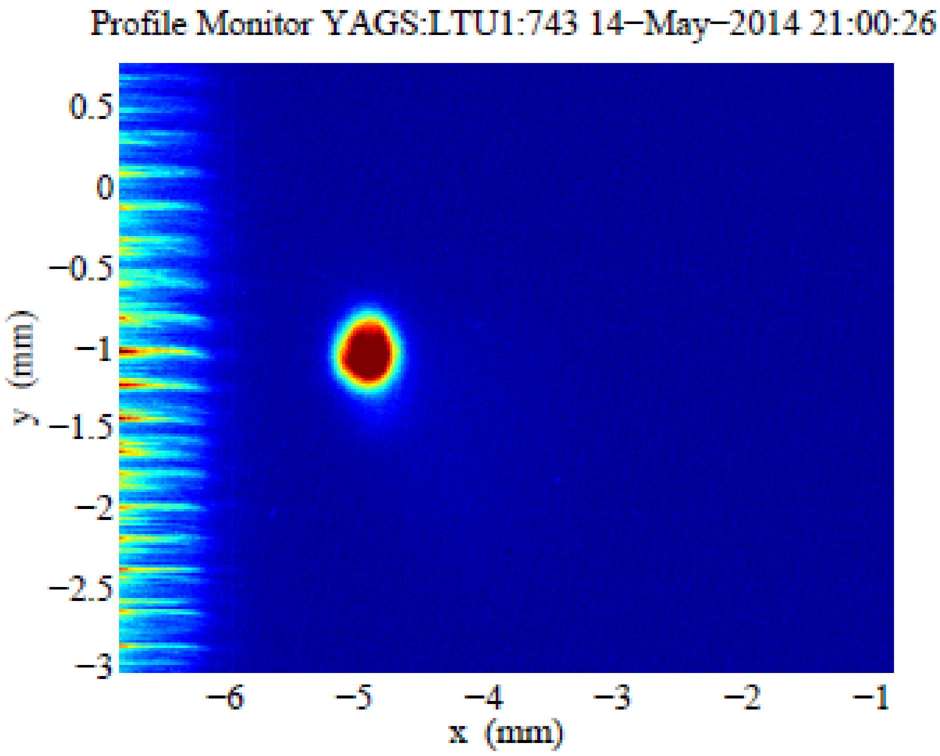
Compare Laser Heater Off

Worst case, factor 4 enhancement



CDR visible on the edge of the screen

In the peak compression case, with LH off, we see coherent diffraction radiation at the edge of the screen (Probably generated from the edge of the mirror)



Summary (2)

- The PSI design effectively suppresses COTR
- Can be used for single shot transverse beam size measurements
- Only in the worst cases (6 kA) of beam operation in the LCLS when the laser heater is off do we see factor ~4 light intensity enhancement
- But, this has been reduced from 10^5 enhancement!

Thank you!