LCLS Beam Diagnostics

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Office of Science
SLAC NATIONAL ACCELERATOR LABORATORY

Outline

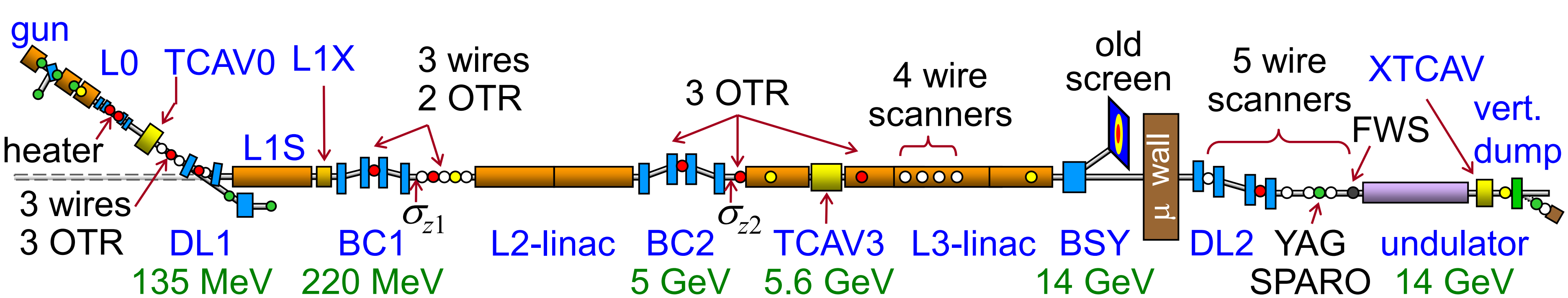
- Overview
- LCLS accelerator diagnostics
- LCLS-II
- Charge and beam position
- Beam profile measurement
- Bunch length diagnostics
- Summary

LCLS and LCLS-II Beam Parameters

	LCLS		LCLS-II	Unit
	Baseline	Operation	SC	Unit
RF frequency	2856		1300	MHz
Repetition rate	120	1 – 120	10^6	Hz
Electron energy	4.3 - 13.6	2.4 – 15.4	4	GeV
Bunch charge	200 & 1000	20 – 250	10 – 100	pC
Bunch length	20	< 2 – 50	8	µm (rms)
Emittance norm.	1.2	0.13 – 0.5	0.4	µm
X-ray energy	0.83 – 8.3	0.25 – 10.5	0.2 – 5	keV
X-ray pulse energy	< 2	< 4.7	< 2.2	mJ
X-ray pulse length	230	< 5 – 500	60	fs (FWHM)

LCLS Diagnostics Development

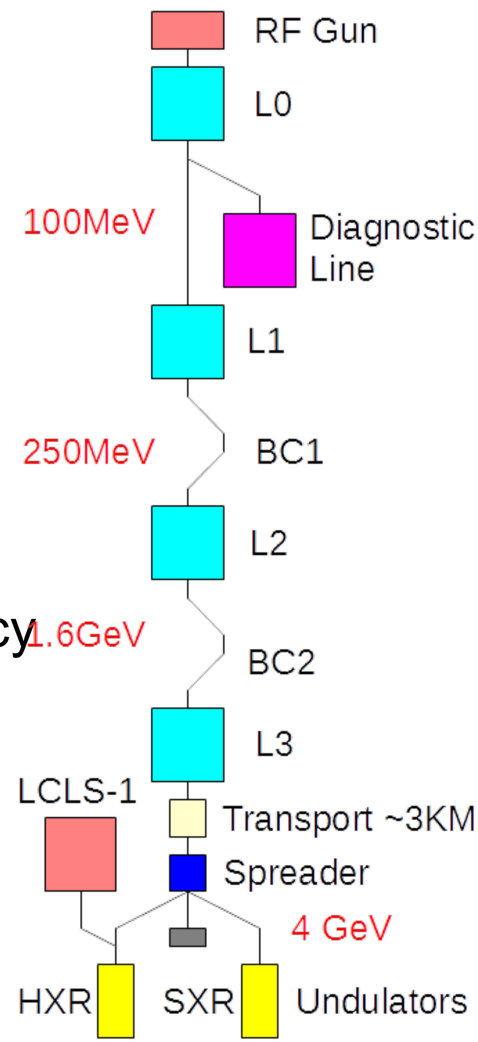
- Machine tuning optimization
  - Fast wire scanner
- High brightness beam issues
  - YAG screen (PSI)
- New capabilities
  - SXRSS, overlap diagnostics
- Extended machine parameters
  - Low charge mode
  - Mid IR spectrometer
  - XTCAV
- LCLS-II
  - BPM µTCA receiver
  - RF-BPM (PAL)



LCLS-II Diagnostic Challenges

SLAC

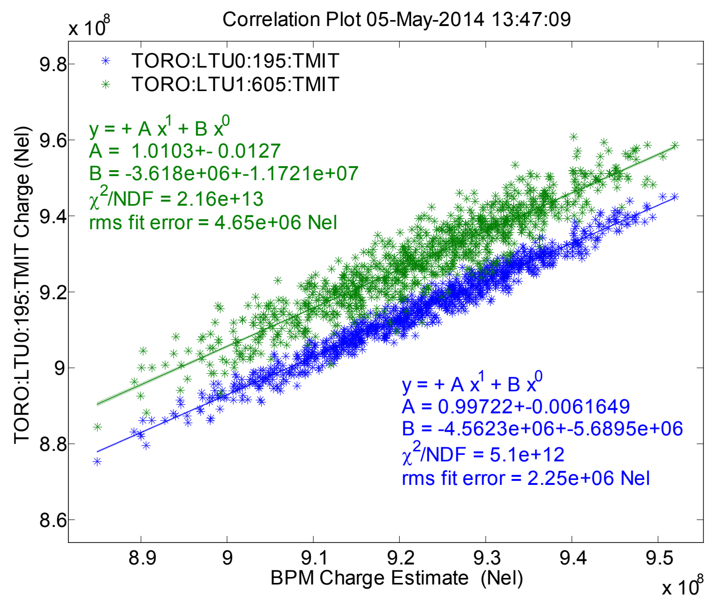
- Single bunch properties like LCLS-I
- High beam power
  - Put (almost) nothing into the full rate beam
  - Low rate (diagnostic) or variable rate (post-spreader) lines for most invasive diagnostics
- High beam rate
  - Fast DAQ needed, FPGA processing, low latency networks for feedback, MPS, etc.
  - Single shot detector signals
- Low charge mode
  - BPM & R-BLM sensitivity



Courtesy J. Frisch

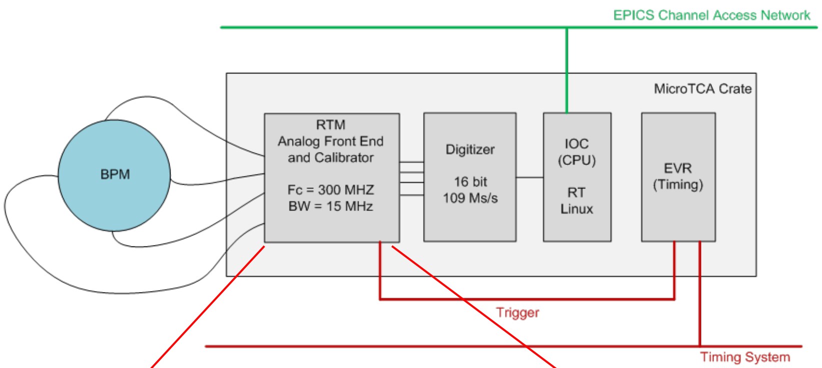
Charge Measurement Upgrade

- Existing toroid electronics issues
  - only local calibration
  - up to 15% read-back variation
  - Up to 4% noise at 150 pC from up to 500' cable run (BPMs give 0.05%)
- New electronics and DAQ
  - Add remote calibrator to in-tunnel amp
  - Use differential cable
  - Gated charge amplifier CAEN QDCV965A already used for PMTs
- Get ~1% agreement for absolute charge between two toroids
- Noise of 0.2% to 0.5%
- LCLS-II requires high dynamic range average current measurement, use commercial solution (Bergoz Turbo-ICT)

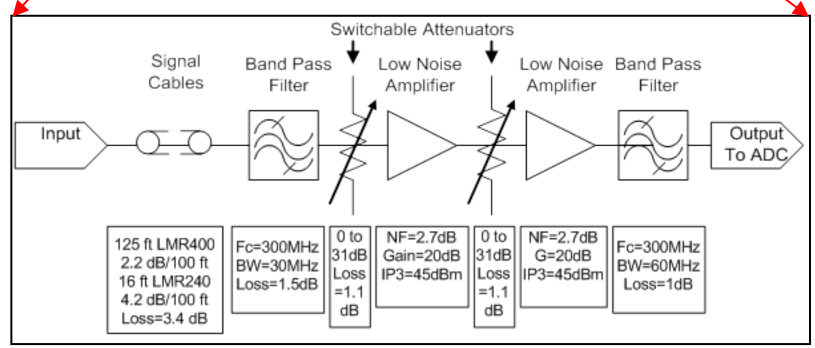


µTCA Strip-line BPM Electronics

- Part of SLAC µTCA development
  - Initiated for NC LCLS-II project
- New AFE, use 300 MHz rather than 140 MHz, also higher BW
- Uses SIS8300 16 bit ADC at 109 MHz
- Up to 8 BPMs per crate possible



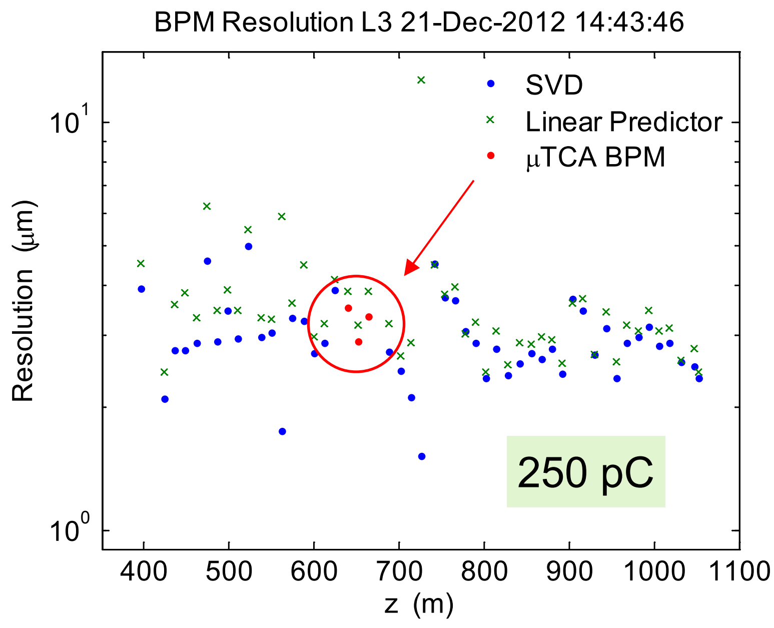
Courtesy S. Hoobler

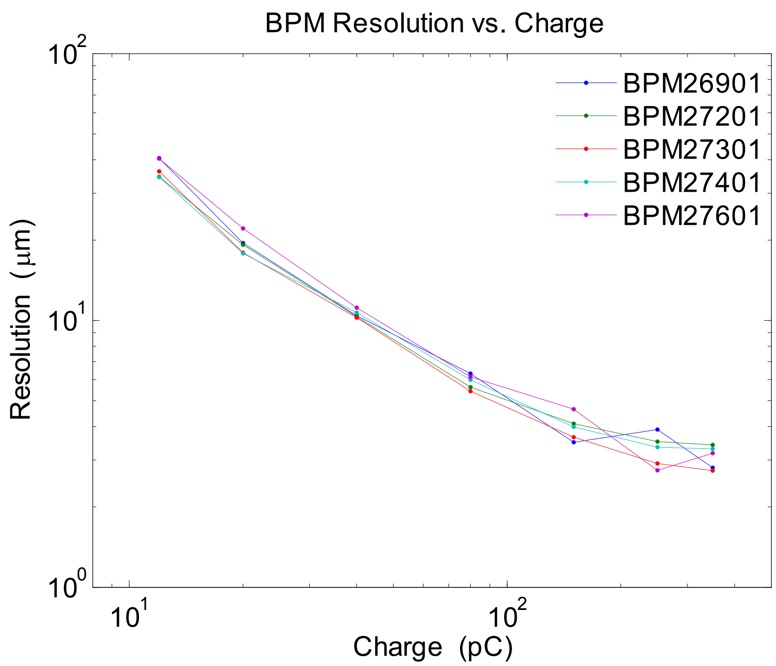


Poster C. Xu, WEPD17

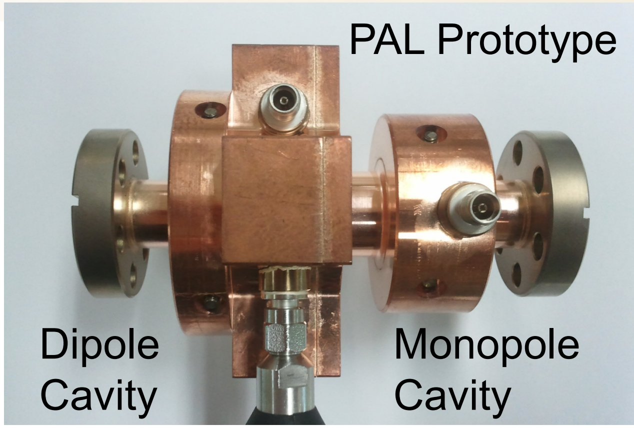
LCLS Test Installation

- Implemented for 4 strip-line BPMs in L3 linac
- Operational for almost 2 years without issues
- Achieve same resolution as from existing electronics

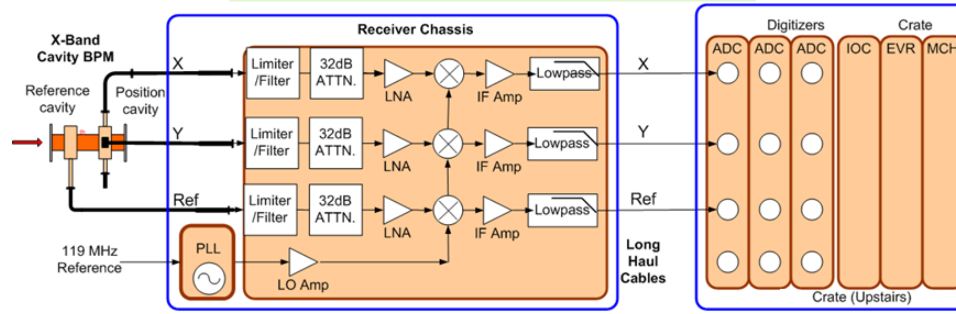




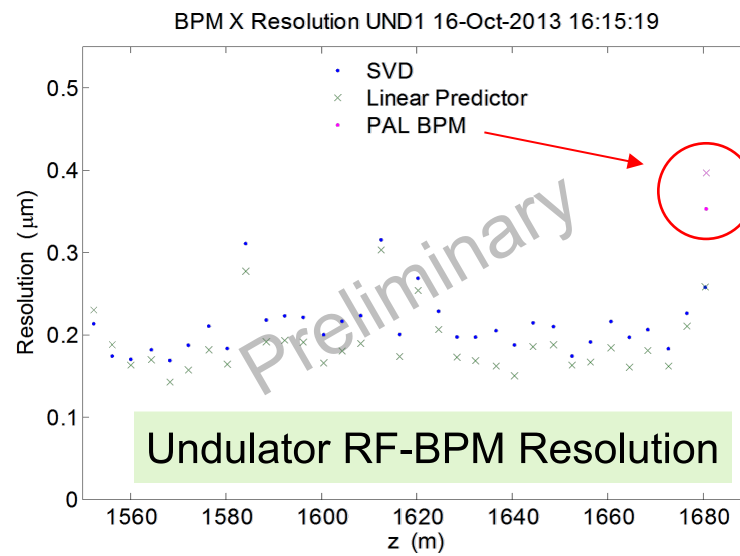
X-Band RF Cavity BPM



SLAC Receiver Schematic



- PAL-SLAC collaboration
- 11.424 GHz (4x S-band) for flexible bunch pattern
- New receiver with coax input and μTCA
- Test BPM next to ANL undulator RF-BPM
- Preliminary results already meet <1 μm LCLS-II requirement
- Noise issue with power supply resolved, awaiting beam test

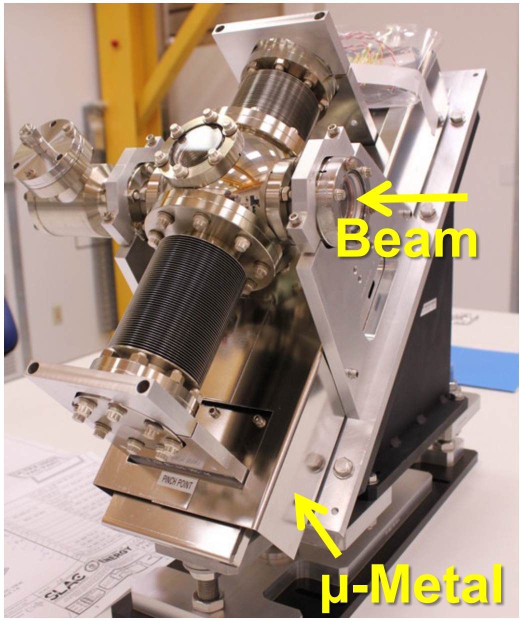


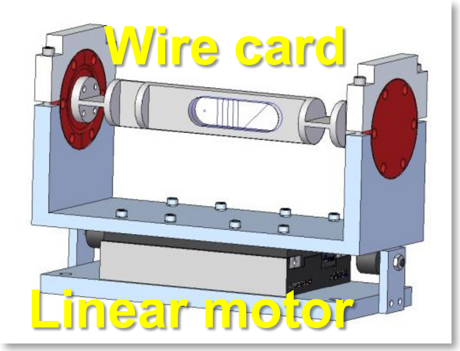
LCLS-II BPMs

- Most critical performance at 10 pC low charge limit
- Strip-line BPMs (30 μm) for most of beam transport
- RF cavity BPMs in special locations, X, S, or L band
  - Energy measurement
  - Orbit for fast feedback
  - Wire scanner jitter correction
  - Undulators
- Cold button BPMs inside cryo-modules (100 μm)

Fast Wire Scanner

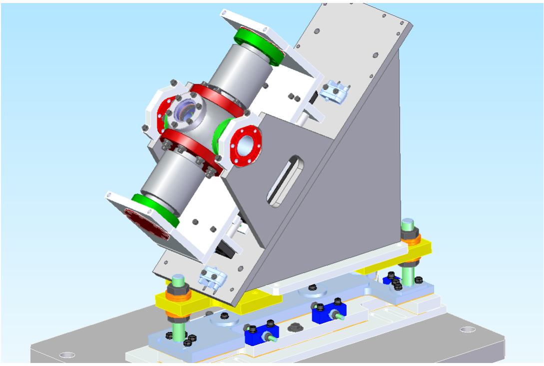
- COTR makes WS critical for LCLS beam tuning
- LCLS uses existing SLC design
  - Stepper motor driven, mm/s speed
  - Vibrations from wire card support on single side and stepper motor
  - 45° actuator with 3 wires for x, y, u plane
- Fast wire scanner development
  - Linear motor, up to m/s speed possible
  - 2 bellows to cancel vacuum forces
  - Also 45° scan orientation, 2” stroke for 3 wires
  - Encoder with sub-µm resolution



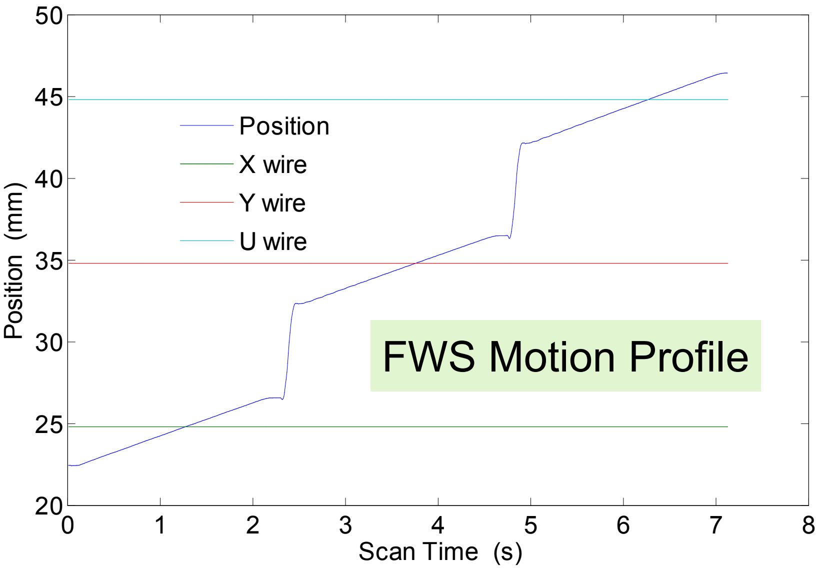


FWS Motion Profile

- Motion profile to minimize scan time
- Beam synchronous data acquisition of encoder position and beam loss signal
- Makes motion stability not critical

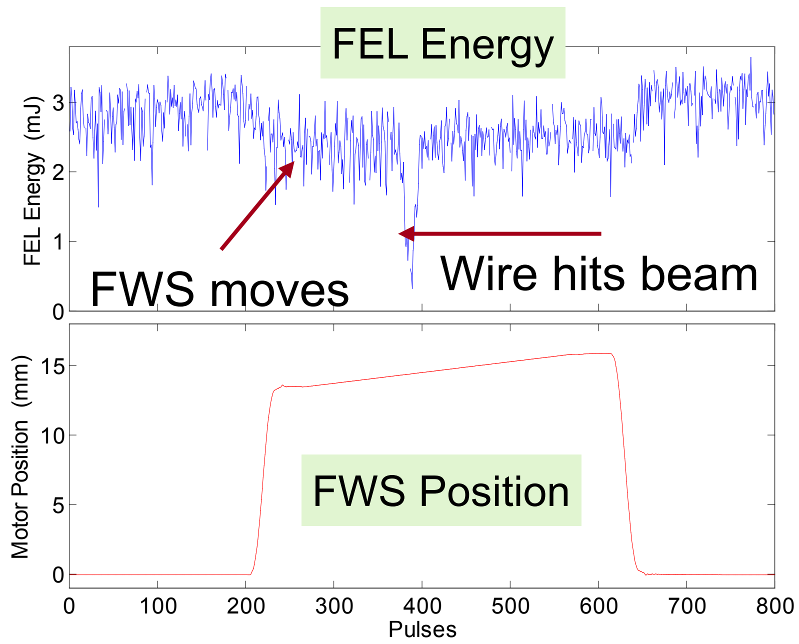


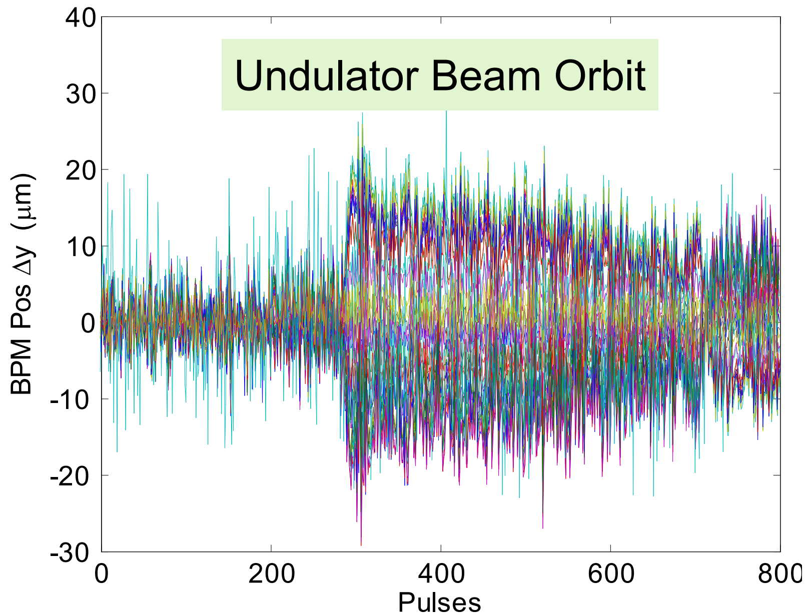
- SLC-style 4 location emittance measurement for x, y, and coupling takes 8 min
- Expect < 30 sec with FWS
- Upgrade project started for LCLS



FWS Magnetic Shielding

- First prototype installed upstream of undulators
- Observed significant drop in FEL during scan
- Related to ~20 μTm magnetic field from linear motor

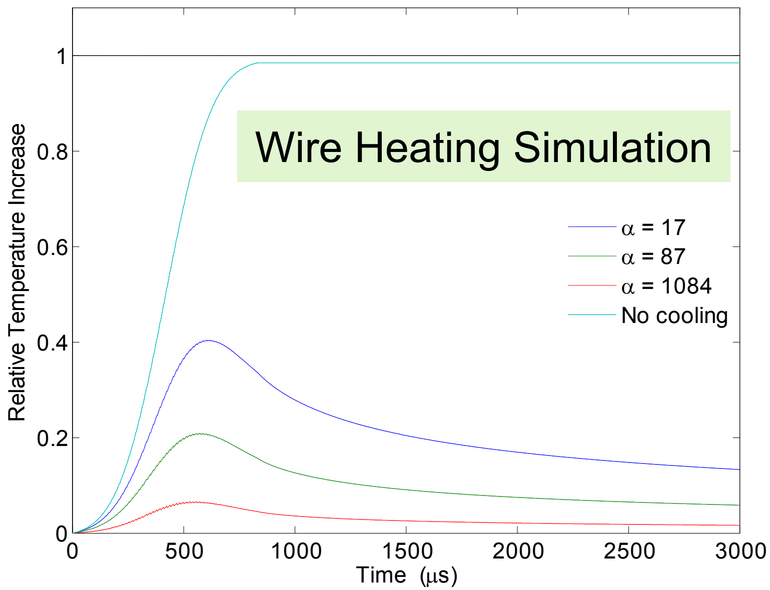


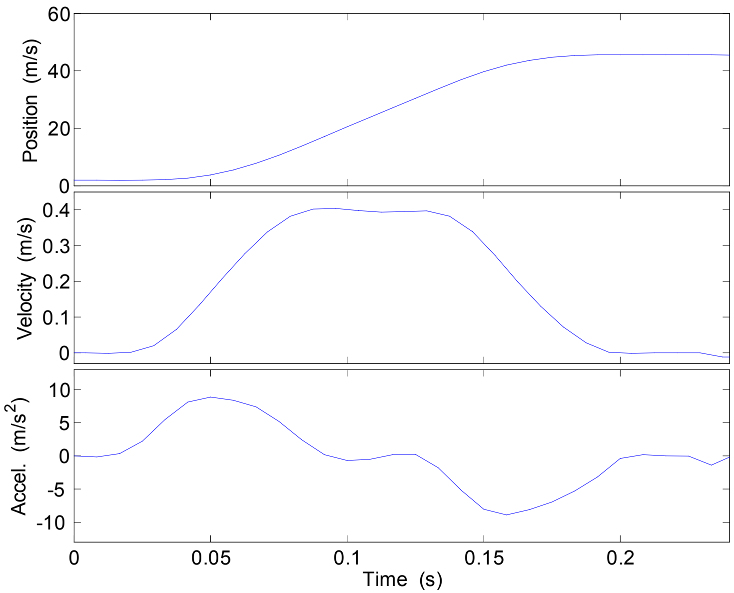


- μ-metal shielding was added
- Now reduced to ~1 μTm
- Tolerance limit for LCLS & LCLS-II

LCLS-II FWS

- MW beam power
- Carbon wire for least beam loss
- Scan simulation with typical beam parameters of wire heating
- Stays below safe fluence studies established for SLC

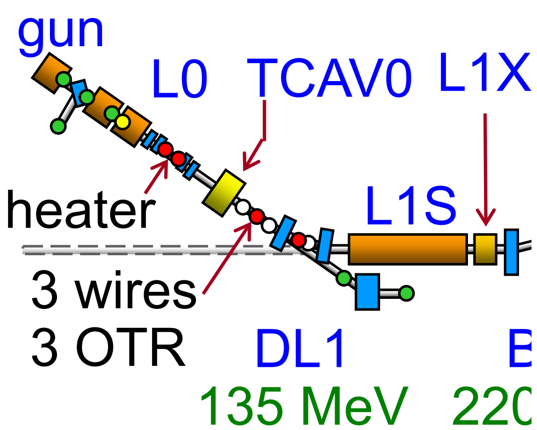


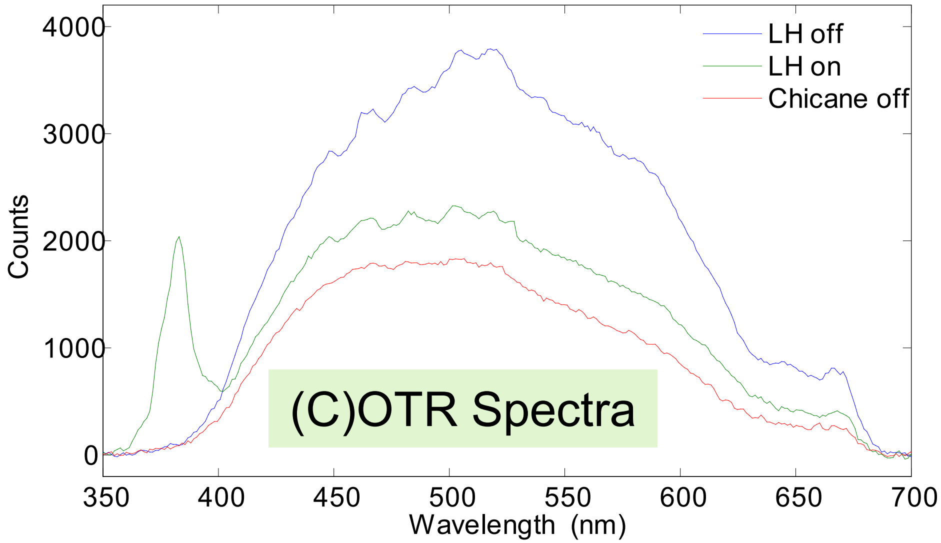


- Speed of 400 mm/s already demonstrated with FWS
- Higher speed requires longer stage
- May add thick wire for beam halo measurement

Injector OTR Measurements

- Straight beam path, no COTR affect on beam size
  - OTR and wire scanner emittance agree
- Laser heater chicane
  - introduces small R56, see 2x COTR enhancement, emittance 25% too small
  - Energy modulation from laser interaction in undulator
    Enhancement reduced to 20%
  - See laser 2. harmonic
  - Emittance still underestimated
- Even small enhancements of COTR can affect emittance measurements

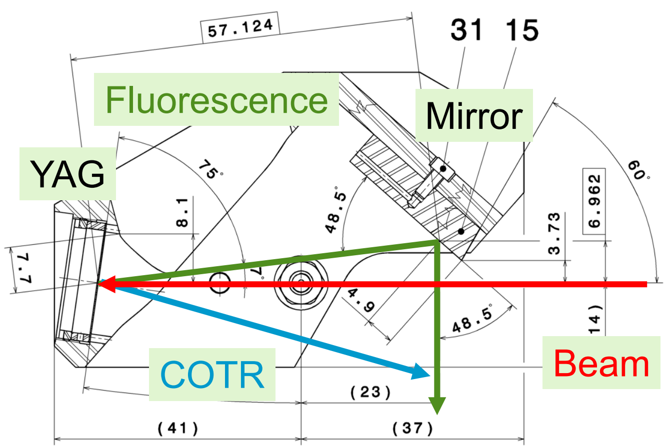


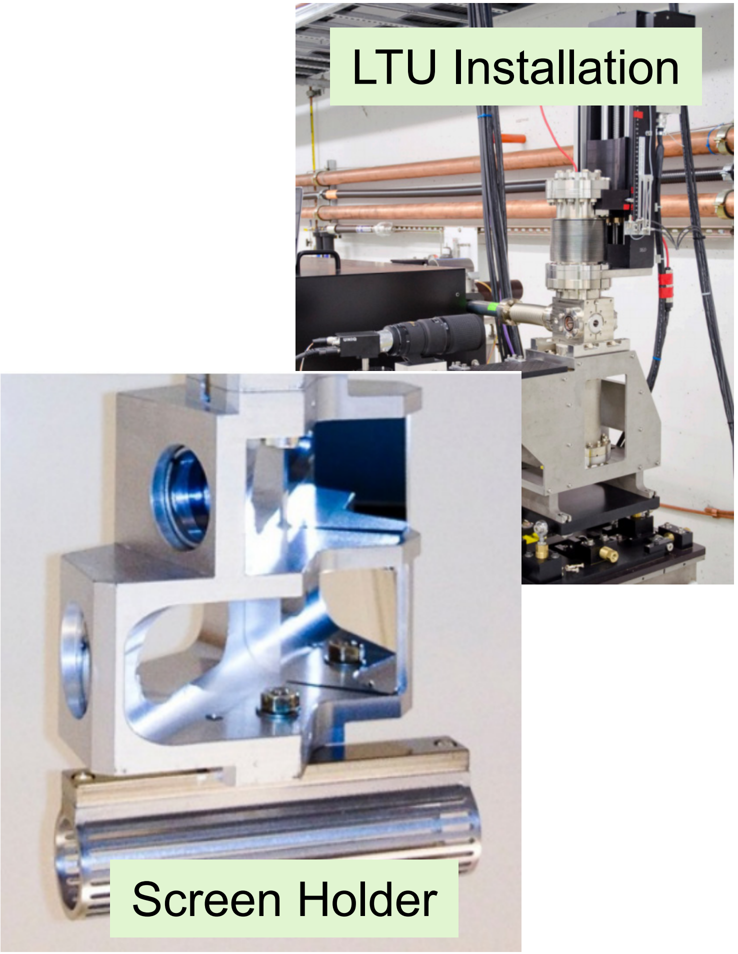


see also F. Zhou et al., FEL14, THP031

SwissFEL Profile Monitor

- PSI development
- Installed at SLAC for GeV beam test at factor 10^5 COTR location
- YAG viewing geometry
  - Smallest spot size
  - COTR reflected away from CCD
  - Tilted focal plane needs tilted CCD

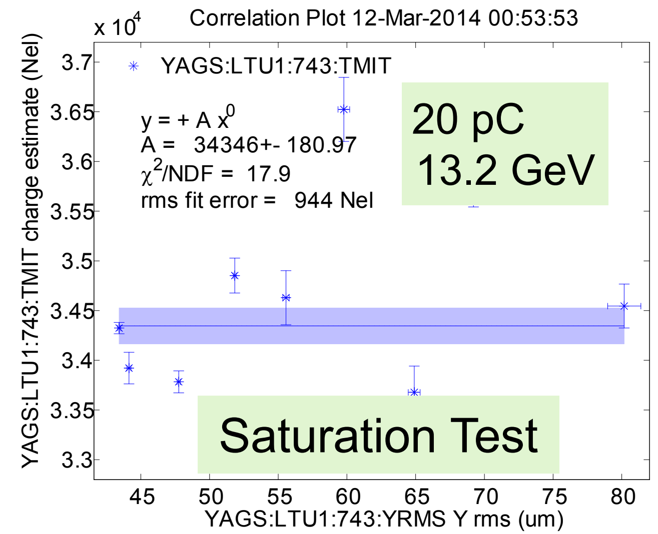


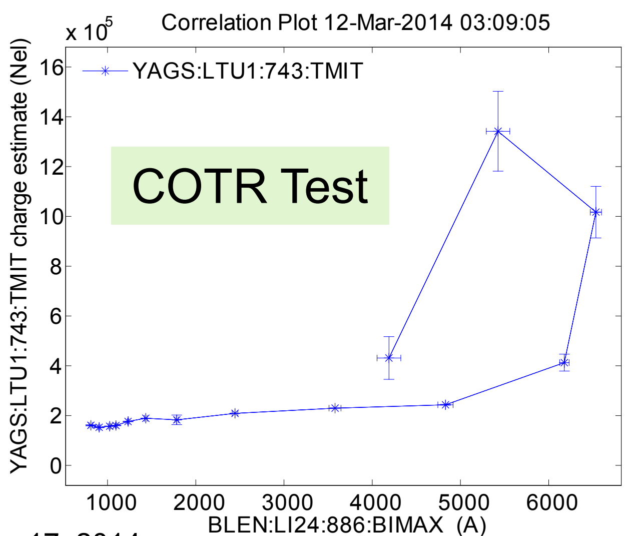


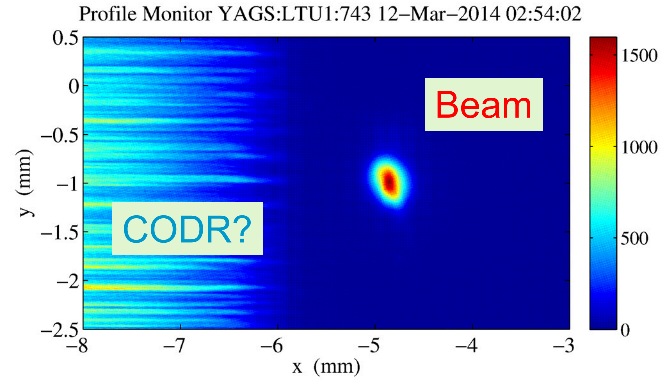
Talk R. Ischebeck, TUCYB3

Commissioning Results

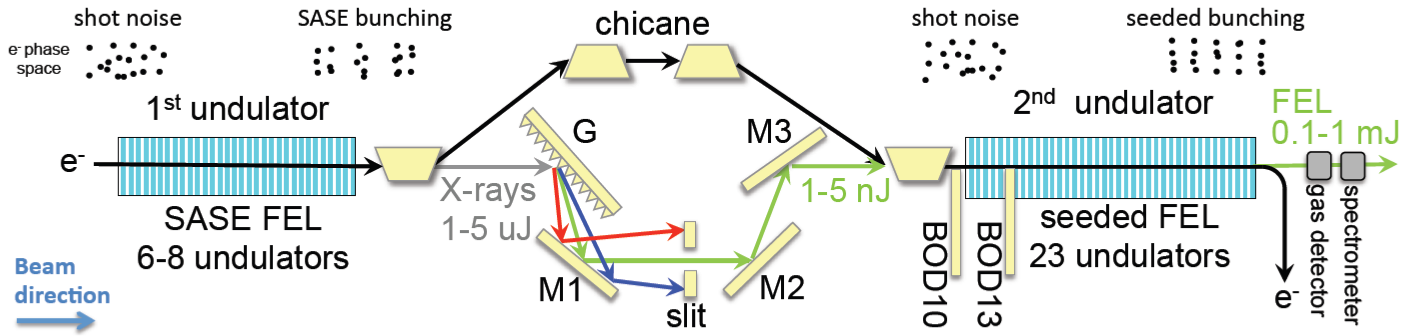
- Saturation of YAG tested
  - None at 20 pC, indication at 180 pC
- Test for coherent enhancement
  - Scan RF phase to change bunch length
  - COTR enhancement reduced from 10^5 to small factor at full compression or 10's of percent in normal setup



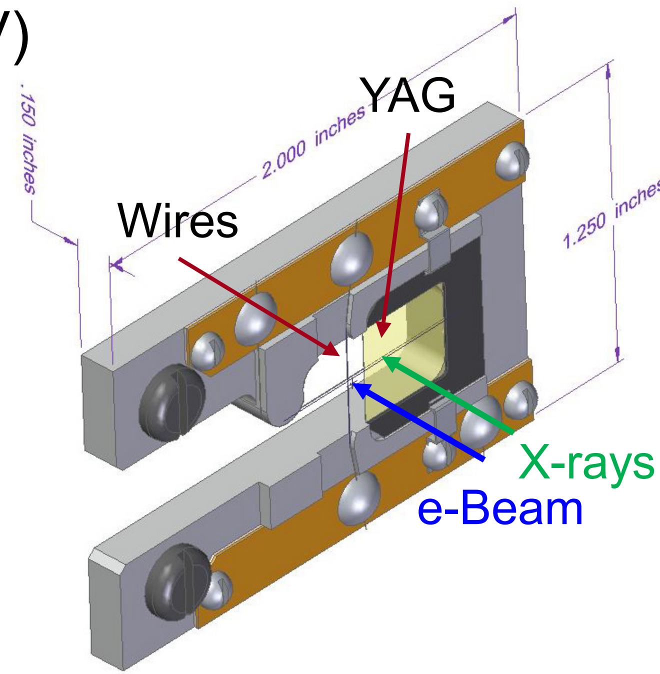




SXRSS Beam Overlap Diagnostics



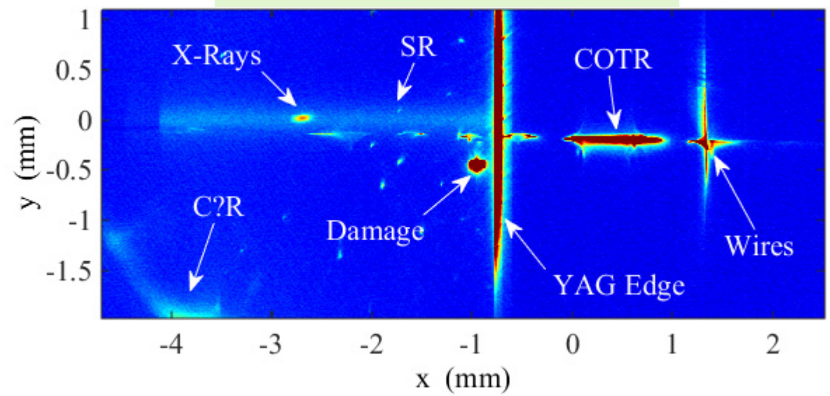
- Soft X-Ray Self Seeding (500 – 1000 eV)
- Both beams diverted by chicanes
- Need diagnostics to measure both
- Combine wire scanner and YAG screen
- Wire 40 μm carbon, YAG 20 μm thick
- View both with CCD camera
- ~10 μm position measurement needed

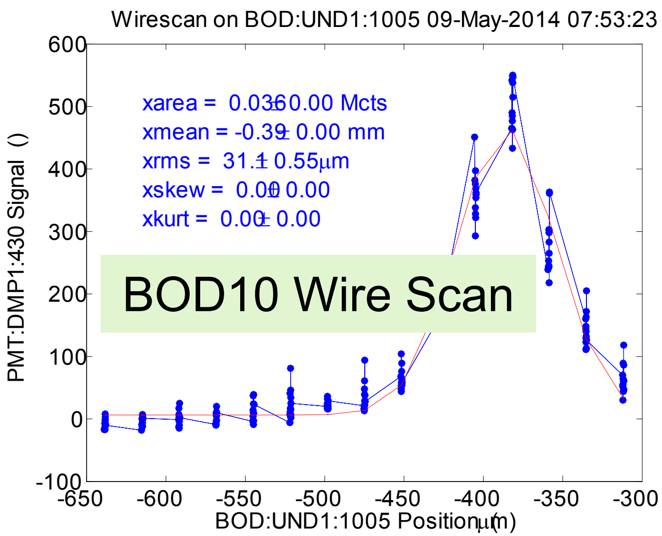


Overlap Diagnostics Performance

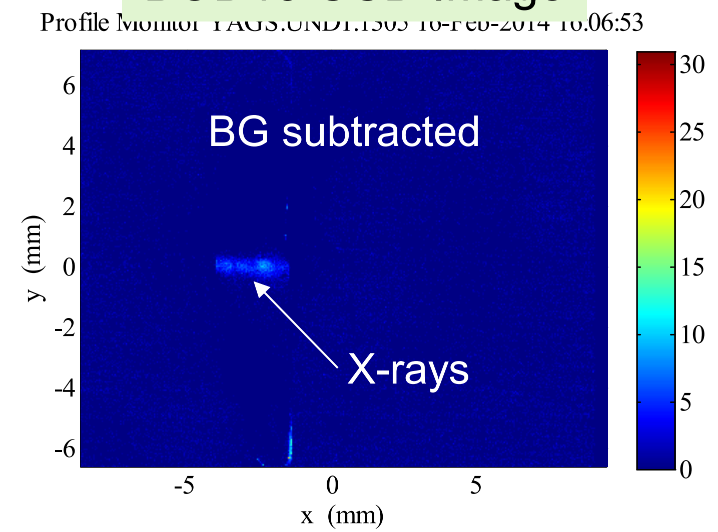
- Move supporting girder to scan wire and find e-beam position
- Move x-ray mirror to steer x-rays onto YAG, find position
- Use mirror response matrix to overlap beam, get seeding
- CR effects are serious issue

BOD10 CCD Image





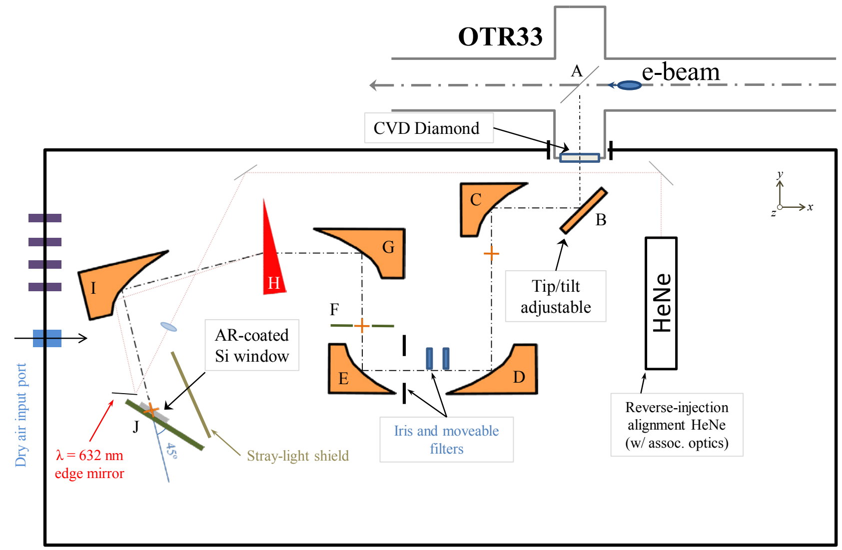
BOD13 CCD Image

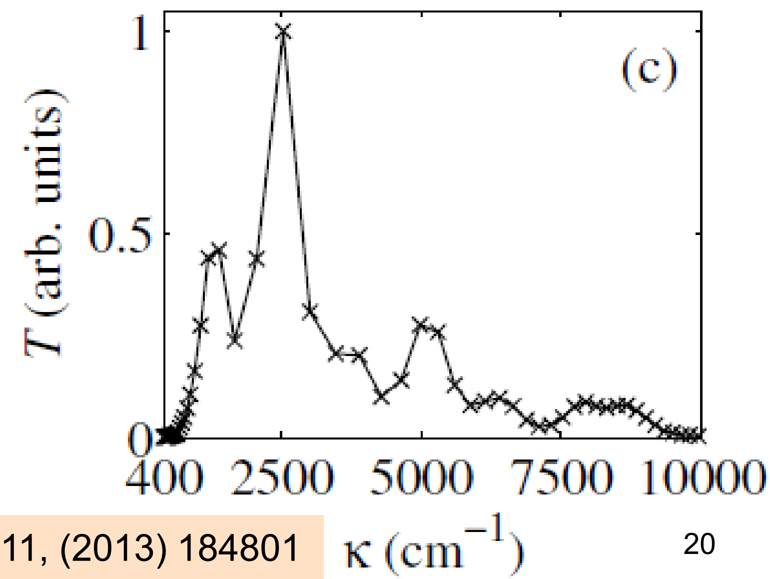


Mid-IR Spectrometer

- C*R based bunch length measurement of LCLS um and sub-um beams needs 1-20 µm
- Single shot preferred
- KRS-5 prism based spectrometer developed
- Images OTR from foil onto 128 element pyroelectric line array

- Transfer function determined by fitting spectra at different bunch lengths to simulated bunch spectra

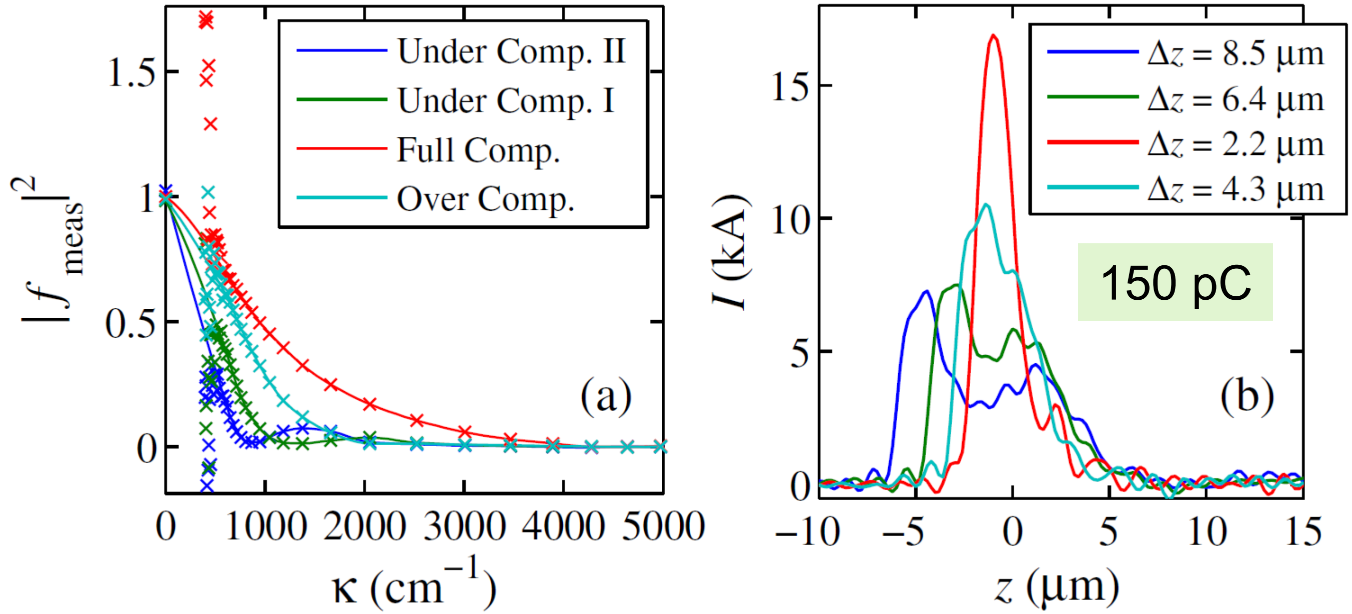




T. Maxwell et al., PRL 111, (2013) 184801

MIR Spectrometer Results

- Form-factor extrapolation for λ > 20 µm necessary
- Bunches as short as 0.7 µm rms at 20 pC measured



T. Maxwell et al., PRL 111, (2013) 184801

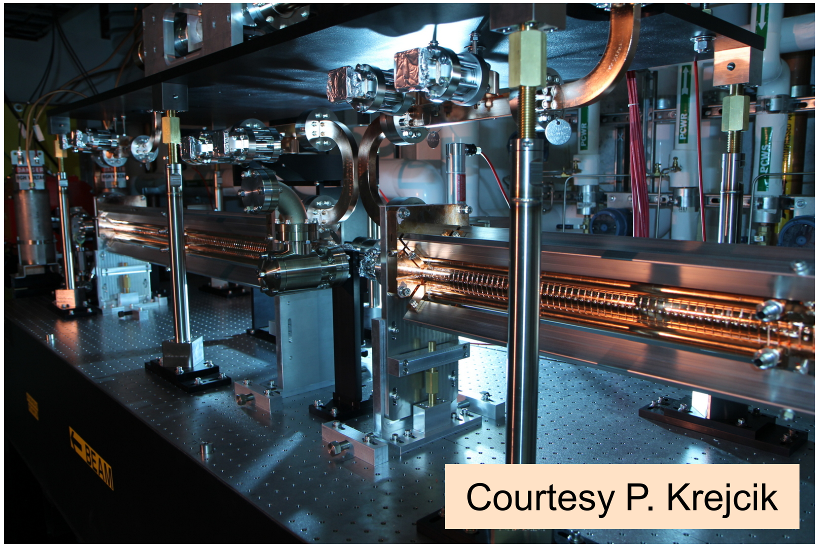
- Non-invasive version possible using CER from DL2 bends

LCLS-II Bunch Length Monitors

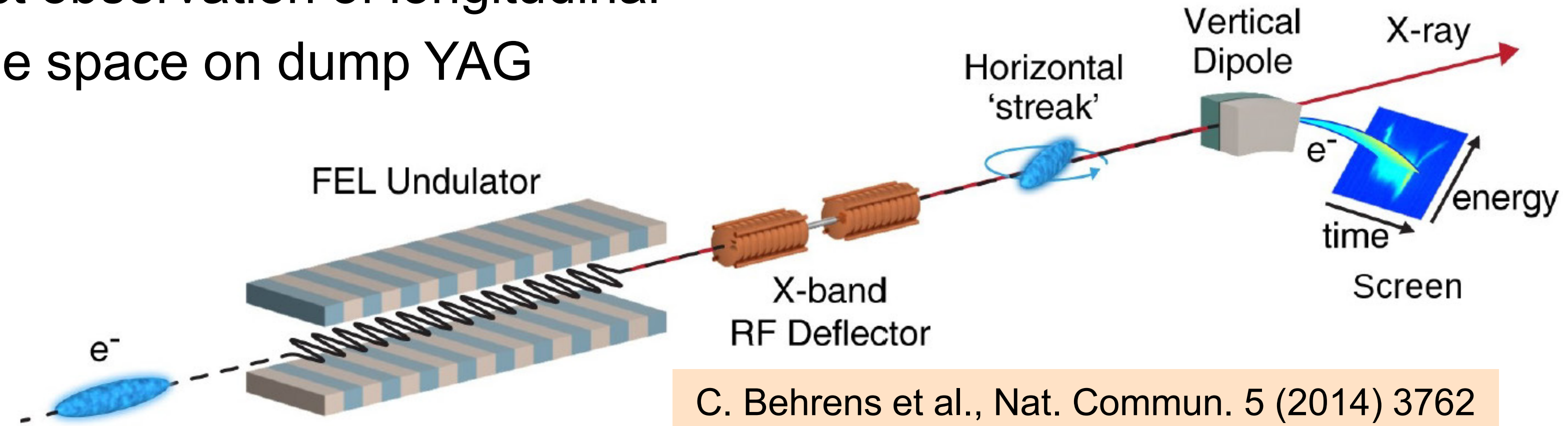
- Relative BLMs similar to LCLS-I detecting edge radiation
- R-BLMs at full beam rate for feedback system
- Average THz radiation power at few W level becomes issue
  - Required attenuation leaves insufficient single shot energy
  - Cooled pyroelectric detectors being investigated
- High dynamic range from wide charge and length range
  - Use of Schottky diodes at few 100 GHz with much higher sensitivity
- Fast detector response for MHz rate

X-Band Deflecting Cavity

- Existing S-band deflecting structure about 5 μm resolution
- X-band provide ~10x better
  - 4x higher frequency
  - 2.5x higher gradient
- Installation post-undulator in main dump beam line
  - Non-invasive for FEL users
- Direct observation of longitudinal phase space on dump YAG



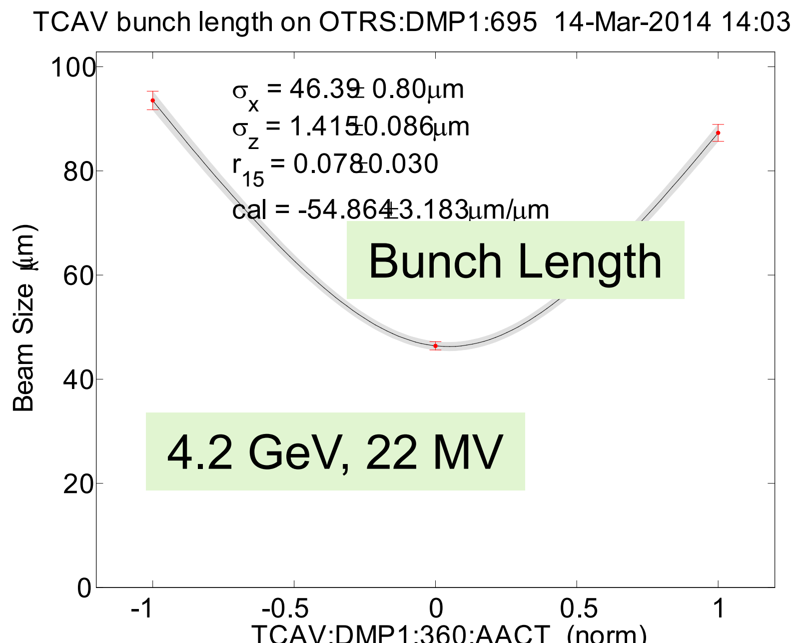
Courtesy P. Krejcik

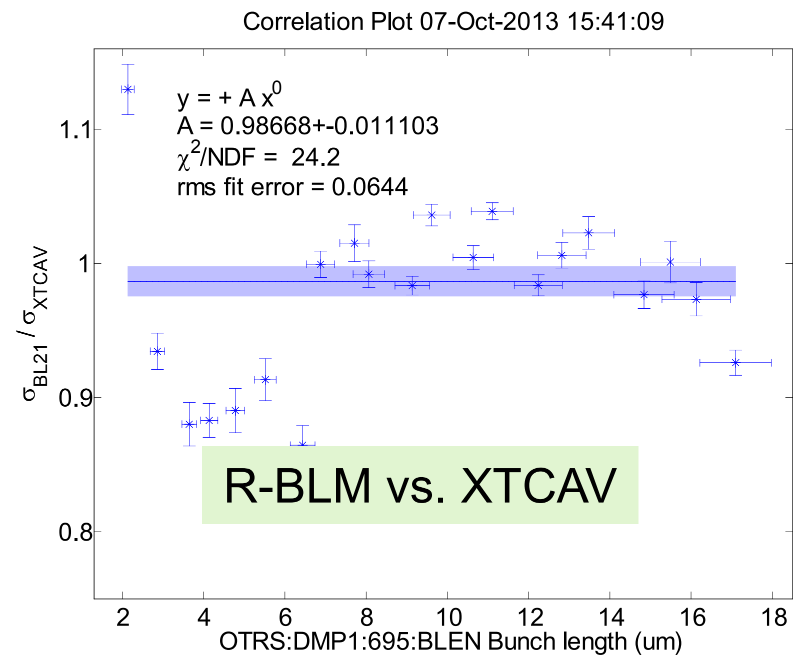


C. Behrens et al., Nat. Commun. 5 (2014) 3762

XTCAV Bunch Length Measurement

- Simple calibration with phase sweep
- Bunch length with fit to off and ±90°
- Achieved resolution
  - 1 fs (4 GeV)
  - 4 fs (14 GeV)
- Doubling plan using SLED

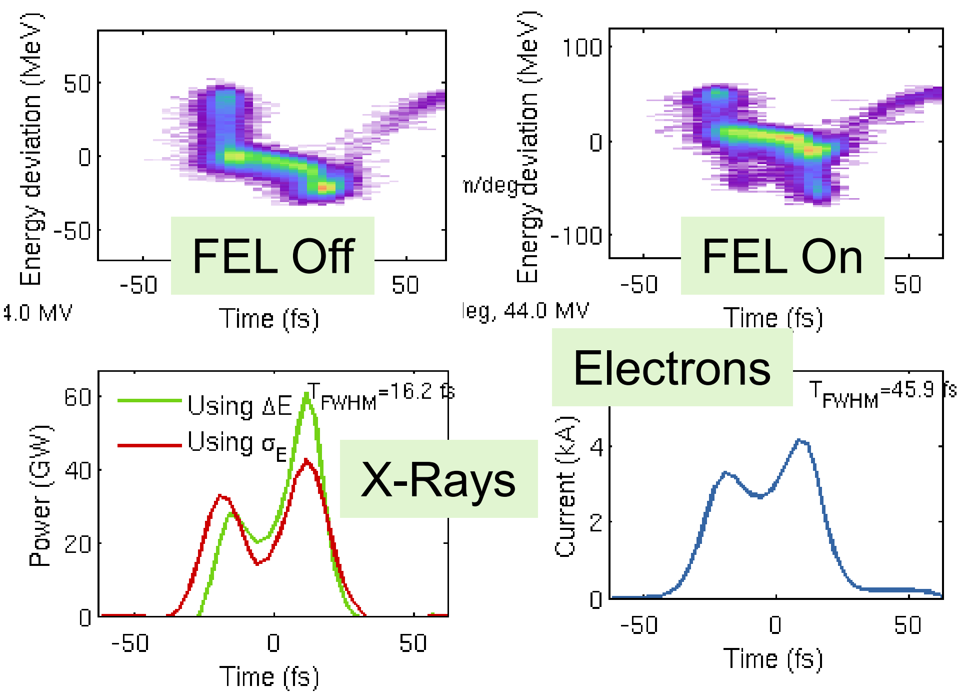


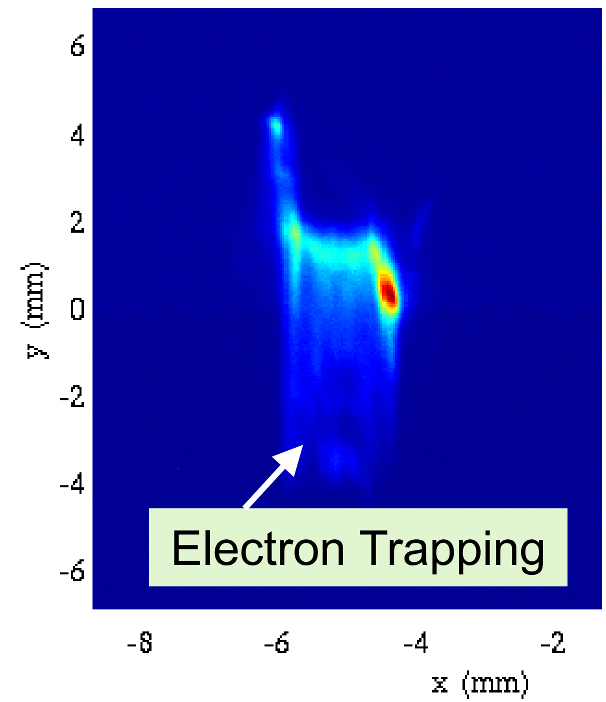


- Checked R-BLM calibration
- 5% average deviation to XTCAV
- R-BLM not sensitive below 2 μm

XTCAV as FEL and X-Ray Diagnostics

- X-ray pulse reconstruction
  - Compare FEL off and on
  - Measure time resolved energy loss
  - Energy spread increase also used





- Longitudinal bunch manipulations
  - Slotted foil emittance spoiler
  - Double bunch setup

Summary

- Diagnostics was sufficient for first LCLS operation
- New developments driven by enhancements in beam parameter range and capability, and also operational needs
- LCLS-II diagnostics benefits greatly from existing projects, but still many challenges remain

Acknowledgements

Thank you for your attention!

Special thanks to the diagnostics teams for

Toroids: D. Brown, S. Condamoor, R. Larsen

PAL RF-BPM: S. Babel, C. Kim, S. Hoobler, P. Krejcik, A. Young, C. Xu

Fast Wire Scanner: S. Anderson, M. Campell, A. Cedillos, M. D’Ewart, P. Krejcik, R. Iverson, Z. Oven