Operational Experience at LCLS

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for the LCLS Commissioning Team

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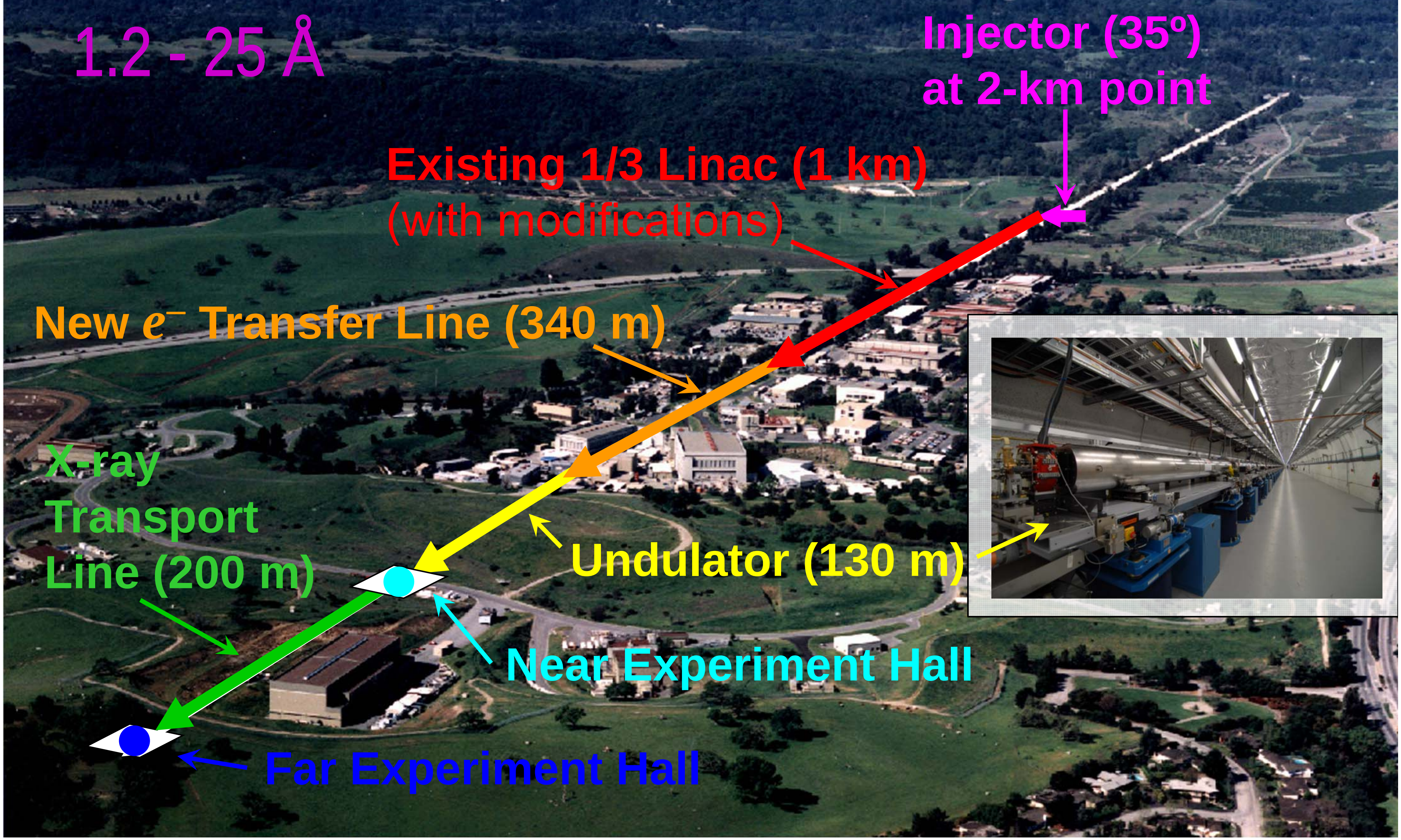
Aug. 22 - 26, 2011

Linac Coherent Light Source at *SLAC*

X-FEL based on last 1-km of existing linac



1.2 - 25 Å

Injector (35º)
at 2-km point

Existing 1/3 Linac (1 km)
(with modifications)

New *e*⁻ Transfer Line (340 m)

X-ray Transport Line (200 m)

Undulator (130 m)

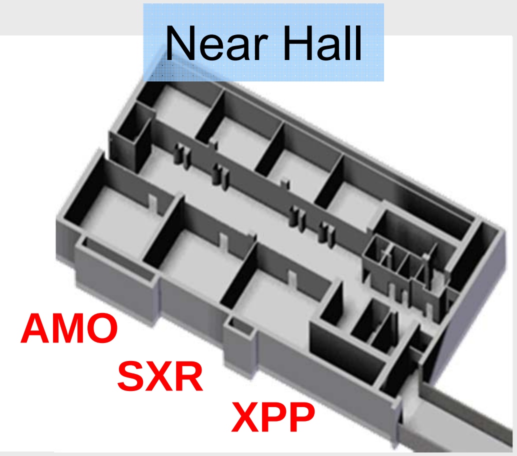
Near Experiment Hall

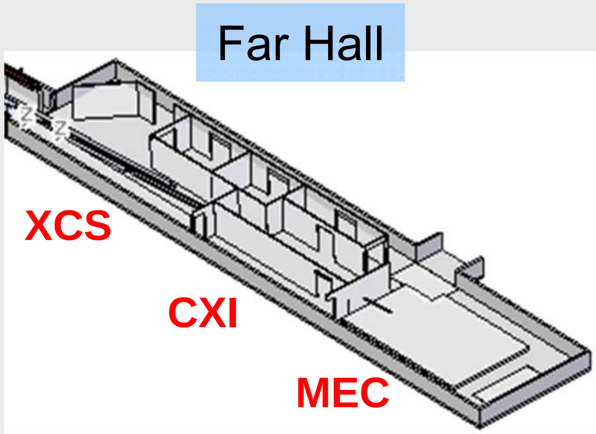
Far Experiment Hall

LCLS Parameter Table

	Baseline	Achieved	
Electron energy	4.3 – 13.6	3.3 – 15.4	GeV
Bunch charge	200 & 1,000	20 - 250	pC
Emittance	1.2	0.13 – 0.5	μm (norm.)
FEL energy	830 – 8,300	480 – 10,500	eV
FEL pulse energy	< 2	< 4.7	mJ
FEL pulse length	230	< 5 – 500	fs (FWHM)
Repetition rate	120	120	Hz

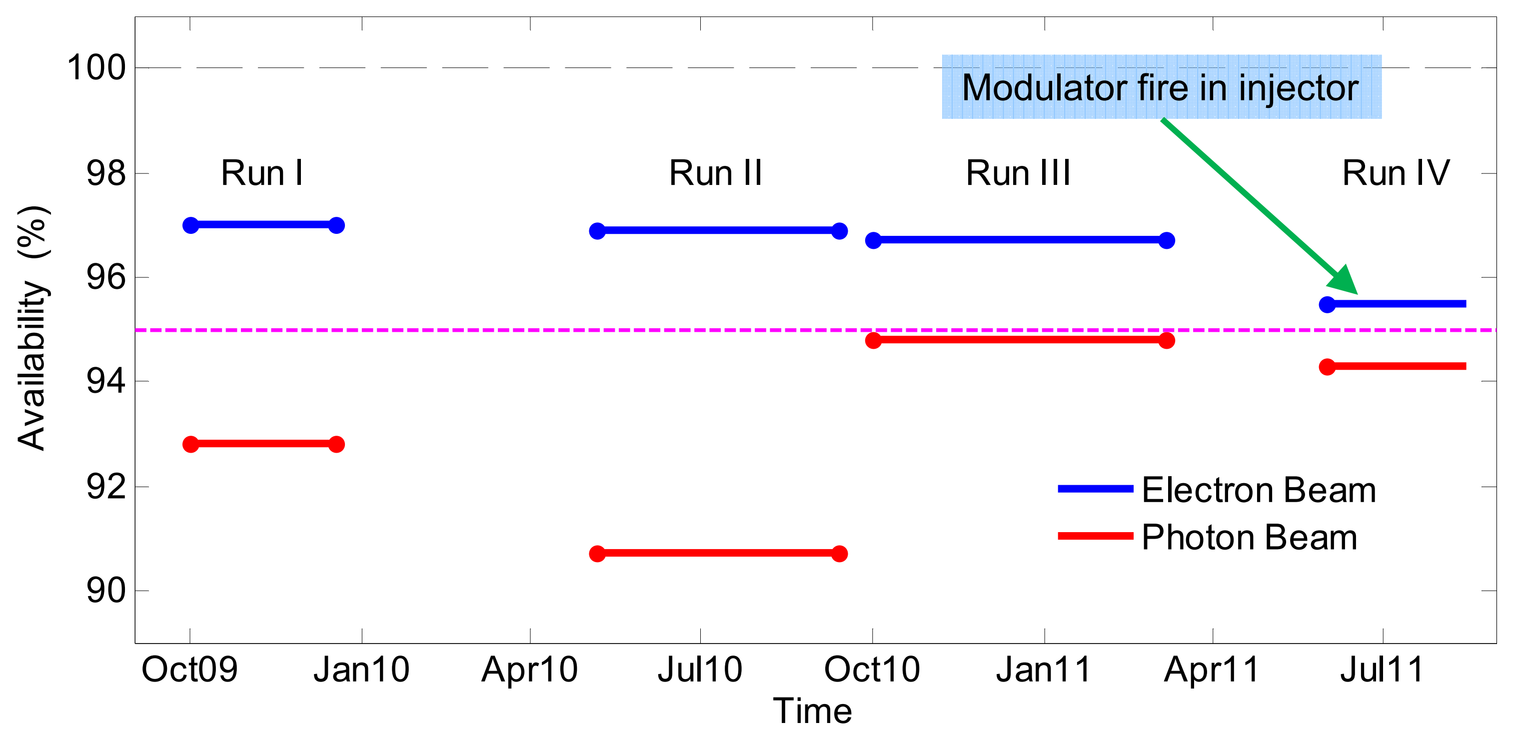
- 6 user experiments
  - 4 operational
  - 1 in commissioning (XCS)
  - 1 in construction (MEC)





LCLS Availability

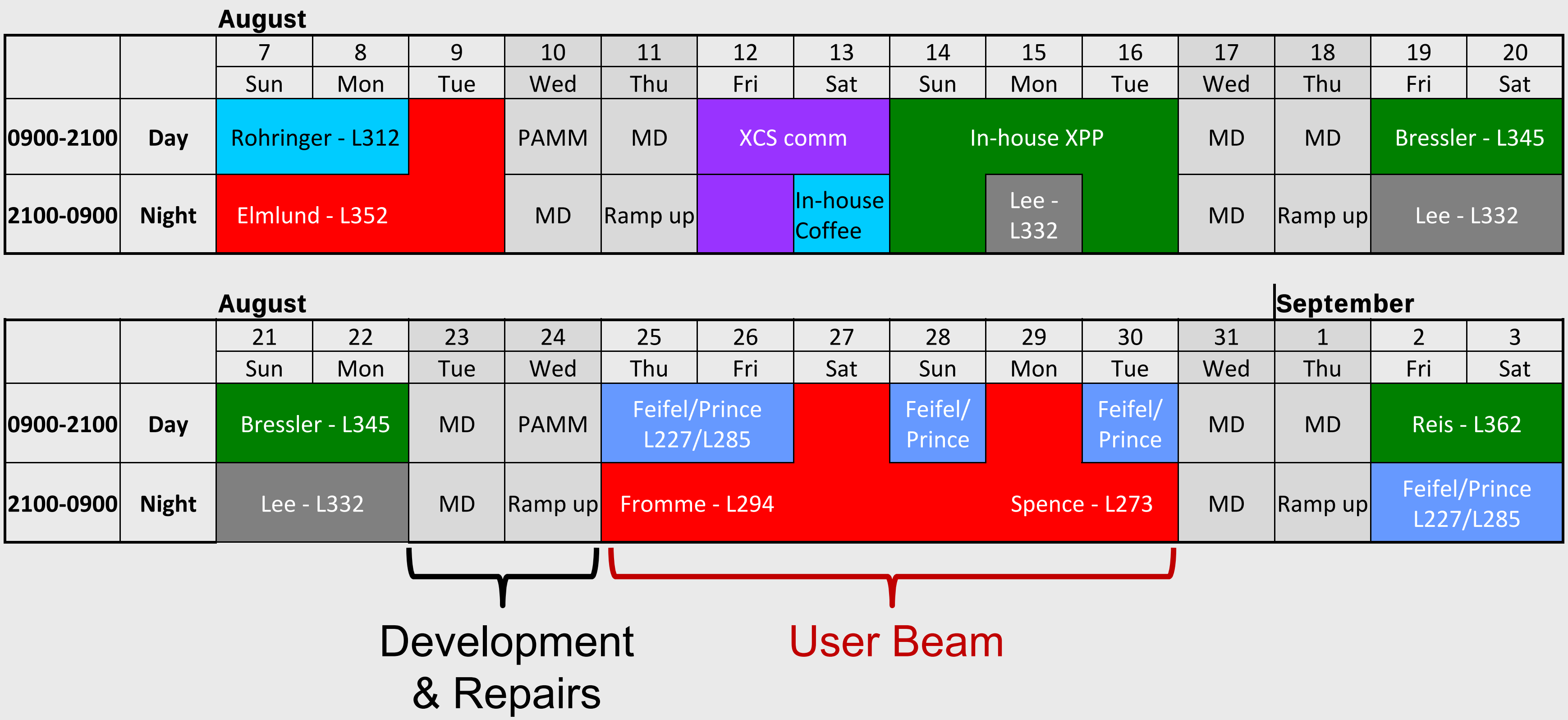
- Steady 97% availability of electron beam throughout past user runs
- Availability of photons is getting close to goal of 95%



W. Colocho

LCLS Schedule User Beam/MD

- Weekly: 5 days user, 2 days machine development and/or maintenance



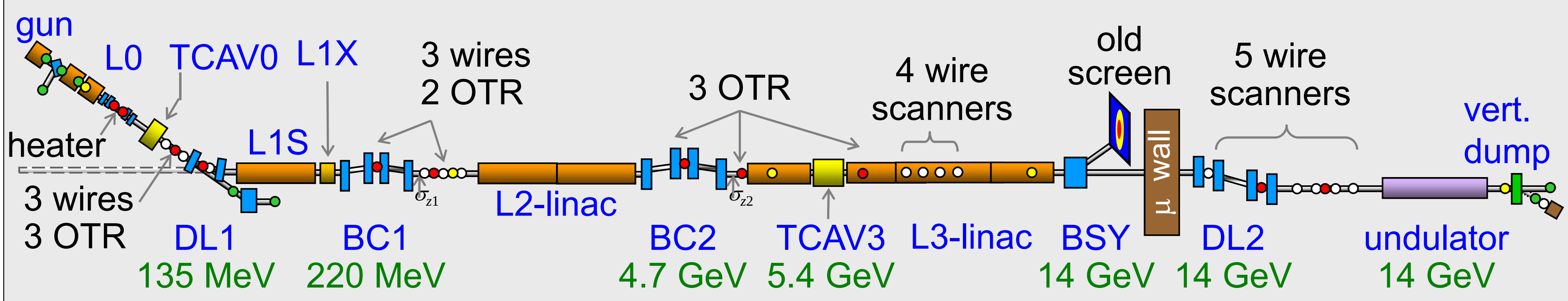
		August													
		7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0900-2100	**Day**	Rohringer - L312			PAMM	MD	XCS comm		In-house XPP			MD	MD	Bressler - L345	
2100-0900	**Night**	Elmlund - L352			MD	Ramp up		In-house Coffee		Lee - L332		MD	Ramp up	Lee - L332	

		August											September		
		21	22	23	24	25	26	27	28	29	30	31	1	2	3
		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat
0900-2100	**Day**	Bressler - L345		MD	PAMM	Feifel/Prince L227/L285			Feifel/ Prince		Feifel/ Prince	MD	MD	Reis - L362	
2100-0900	**Night**	Lee - L332		MD	Ramp up	Fromme - L294				Spence - L273		MD	Ramp up	Feifel/Prince L227/L285	

Development & Repairs

User Beam

LCLS Layout/Diagnostics

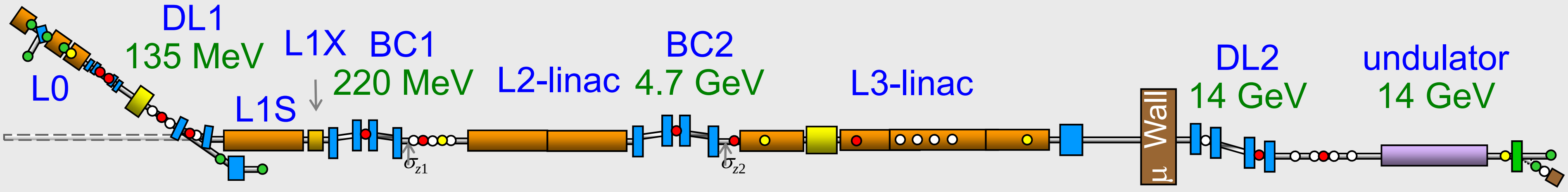


- 2 Transverse RF cavities (135 MeV & 5 GeV)
- 180 BPMs and 13 toroids
- 7 YAG screens (at *E* ≤135 MeV, one at 14 GeV)
- 13 OTR screens at *E* ≥ 135 MeV
- 17 wire scanners (each with x & y wires)
- CSR/CER pyroelectric bunch length monitors at BC1 & BC2
- 5 beam phase monitors (2856 – 51 MHz)
- Gun spectrometer line + injector spectrometer line

● YAG screens
● OTR screens
● Wire scanners
● Phase monitors

LCLS Operation Modes

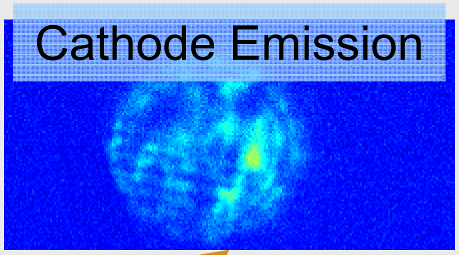
- Photon energy
  - 480 eV – 10.5 keV (3.3 – 15.4 GeV)
  - Change beam energy in last accelerator (L3)
- Photon pulse length
  - 50 – 500 fs (FWHM)
  - Change peak current set point in feedback (L2)
- High/low charge mode
  - 150, 250 pC for normal length range
  - 20, 40 pC for ultra short <5 fs pulses
  - Retune mostly injector, some linac tuning



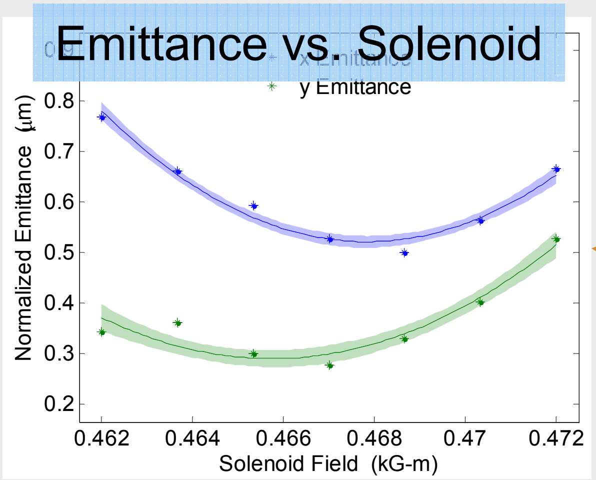
Machine Tuning for User Modes

- Wide parameter range from user requests
- Changes in injector input conditions (laser profile, cathode)
- Procedures required to reproduce machine conditions
- Use small subset of parameters for FEL optimization
- Operate feedbacks loops and feed-forwards to decouple accelerator parameters for tuning
- Automate measurements/setup procedures

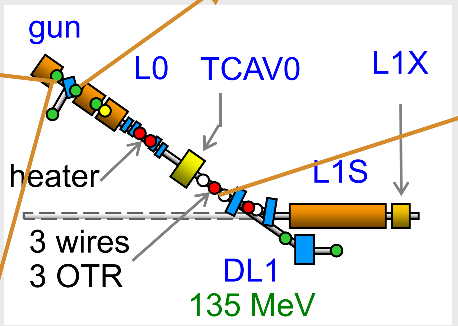
Injector Emittance Tuning

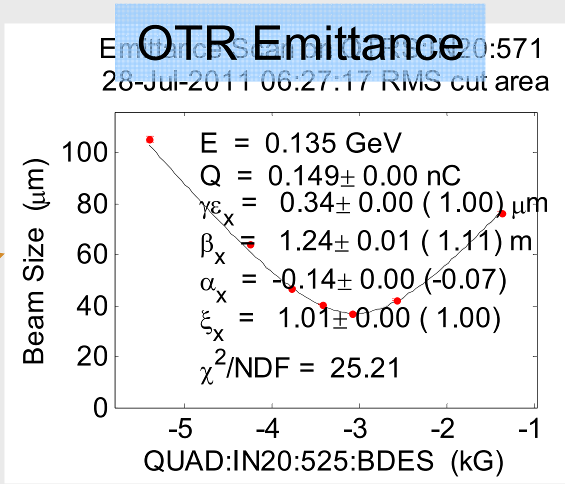


Cathode Emission

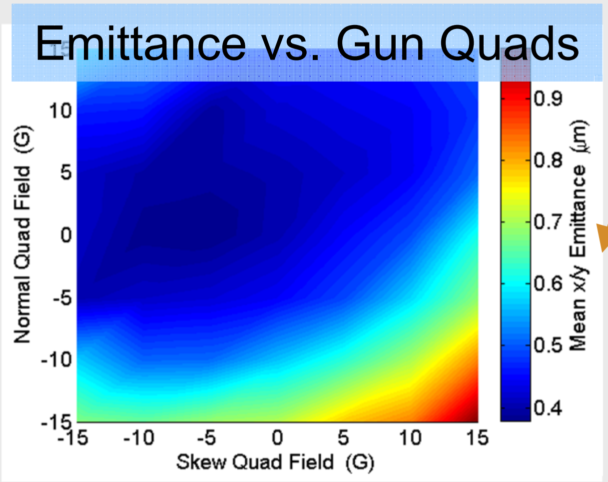


Emittance vs. Solenoid





OTR Emittance



Emittance vs. Gun Quads

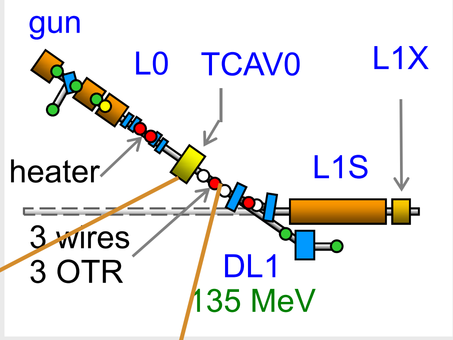
A. Brachmann, F. Zhou

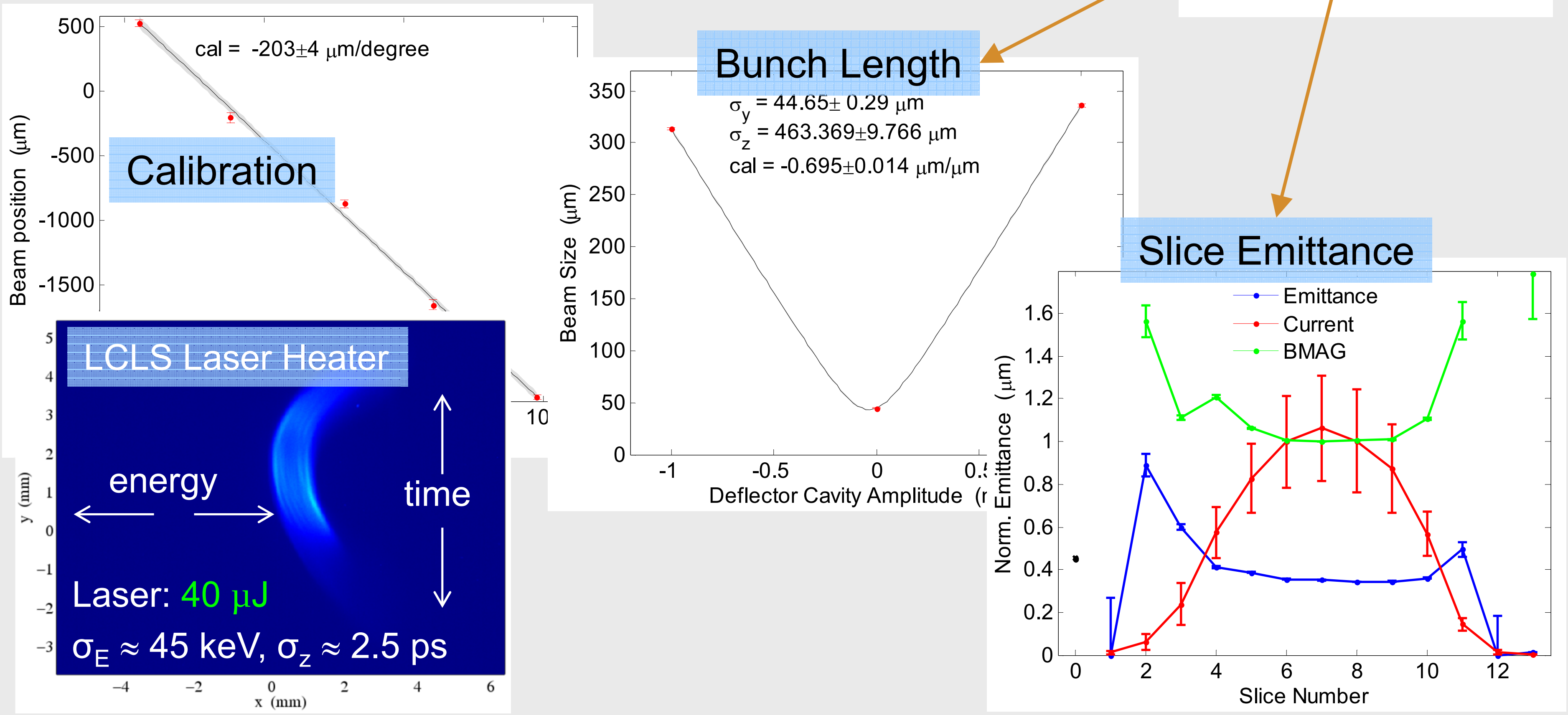
- Varying laser profile and cathode emission pattern requires tuning of injector emittance
- Automated software for emittance quad scan
- High level software to correlate emittance with any other accelerator parameter
- Optimize emittance with solenoid, normal & skew quads in gun

More on injector emittance see WEPA06

More Injector Tuning

- Transverse deflector measurements
- Use calibration and bunch length software script
- Measure slice emittance to check uniform match
- Set timing of laser heater by observing energy spread




Calibration

Bunch Length

Slice Emittance

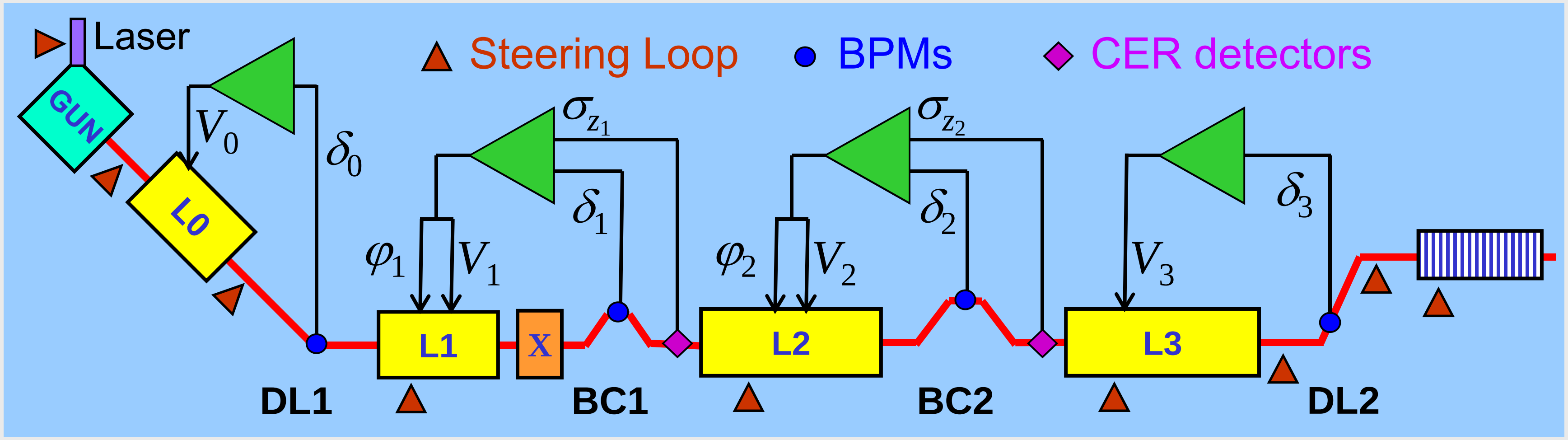
LCLS Laser Heater

Laser: 40 μJ

$\sigma_E \approx 45$ keV, $\sigma_z \approx 2.5$ ps

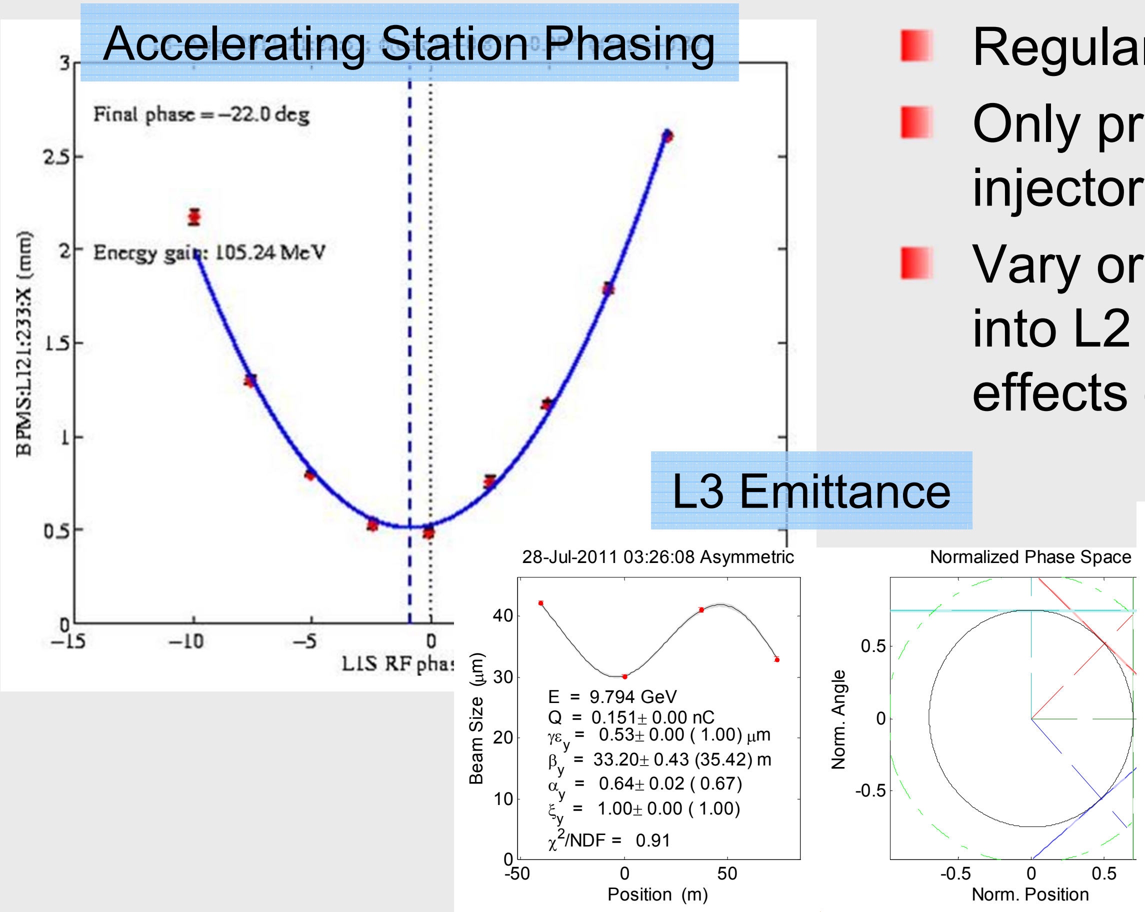
LCLS Feedback Loops

- Transverse Feedbacks
  - Independent feedback loops
  - Decoupled by different response time
- Longitudinal Feedback
  - Orthogonal actuators for energy gain & chirp
  - Separate loops for both 60 Hz power line cycles at 120 Hz
- FB set points varied by high level software for FEL optimization



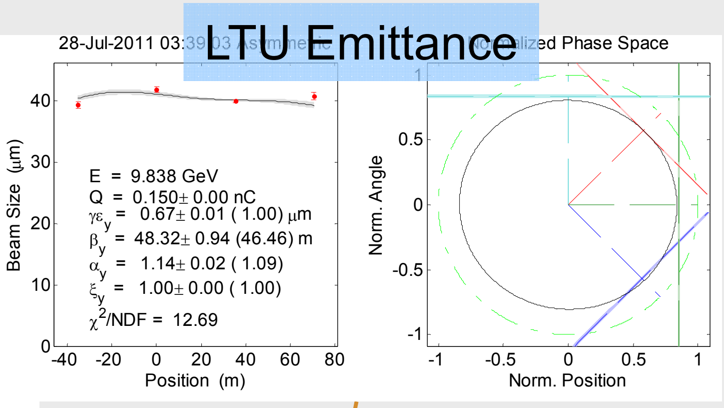
Linac Phasing and Tuning

- Regularly do beam-based phasing
- Only projected emittance after injector using wire scanners
- Vary orbit launch through L1X & into L2 to minimize wakefield effects on emittance

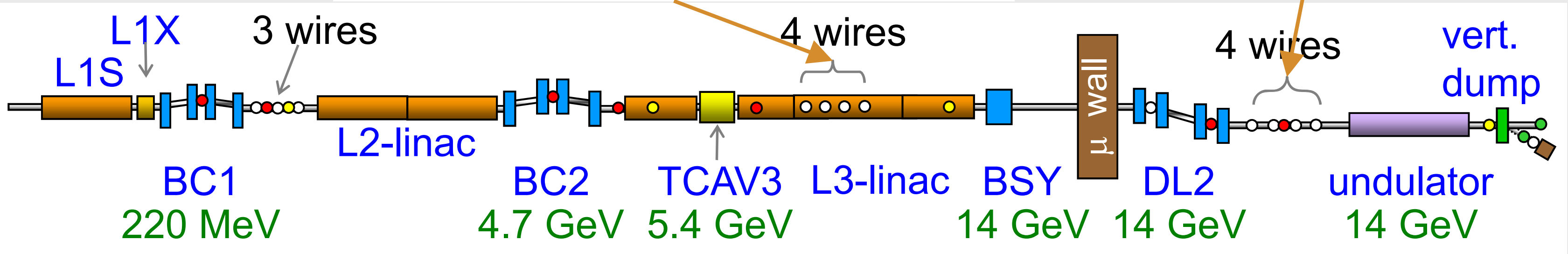


Accelerating Station Phasing

L3 Emittance



LTU Emittance

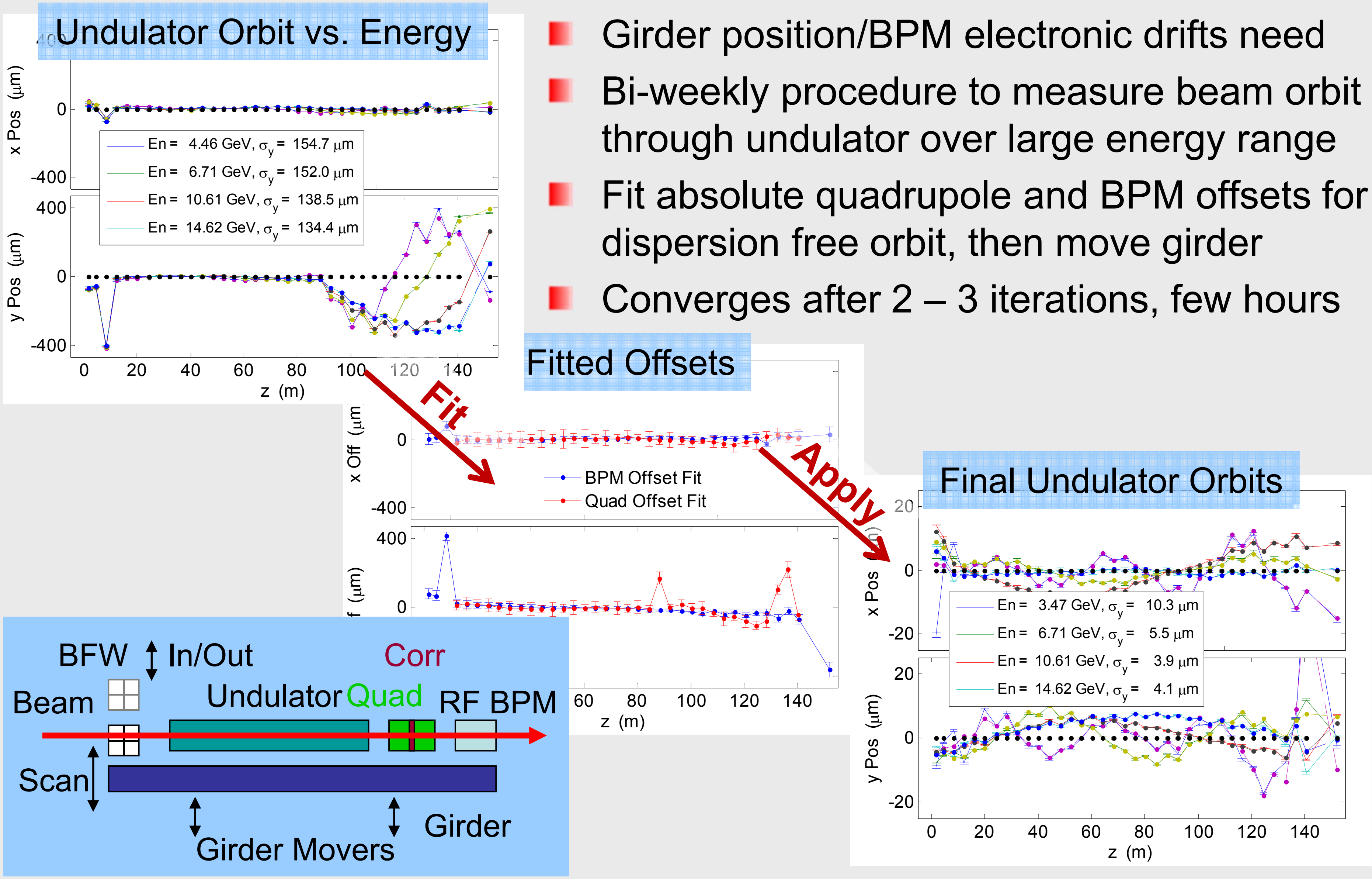


Undulator Operation

- Orbit straightness requirement ~few um
- Beam-based alignment procedure to setup and maintain straight undulators and orbit
- Alignment diagnostic system to monitor
  (see poster WEPB04)
- Automatic taper setting based on few parameters
- Feed-forward to keep orbit while changing taper configuration
- Enables fast taper tuning & optimization

Routine Undulator BBA

- Girder position/BPM electronic drifts need
- Bi-weekly procedure to measure beam orbit through undulator over large energy range
- Fit absolute quadrupole and BPM offsets for dispersion free orbit, then move girder
- Converges after 2 – 3 iterations, few hours



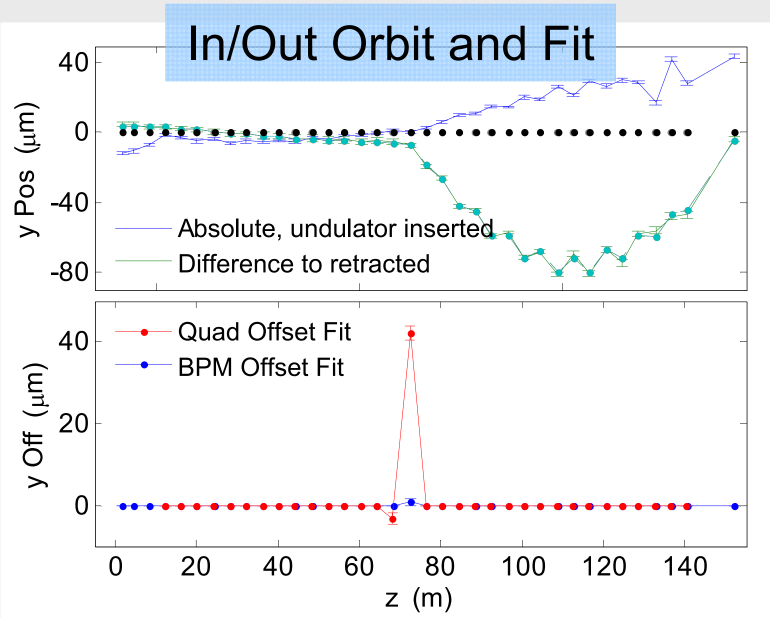
Undulator Orbit vs. Energy

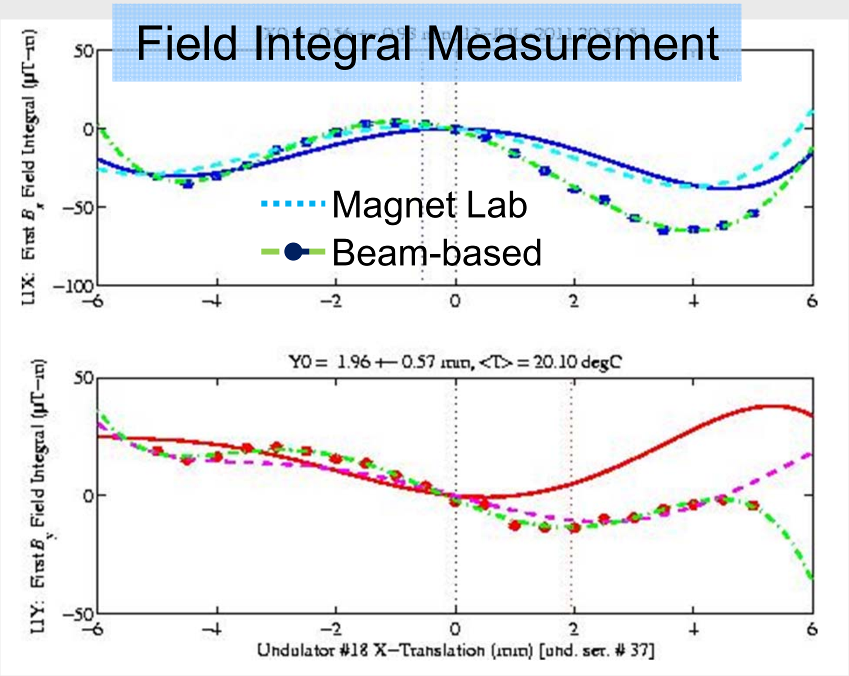
Fitted Offsets

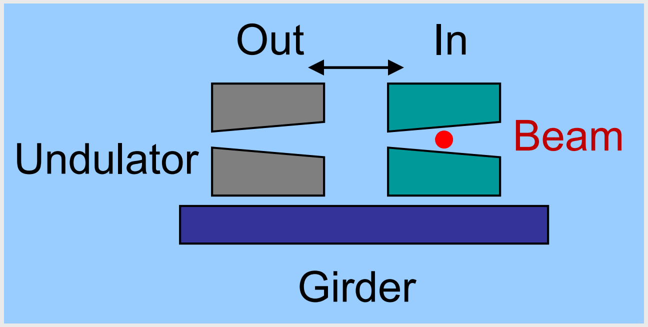
Final Undulator Orbits

Field Integral Measurements

- Adjustable undulator K from wedged poles
- Software for beam-based field integral measurement vs. undulator position
- Beam-based measurement of kick from extracted undulator
- Effect from weight shift and earth field

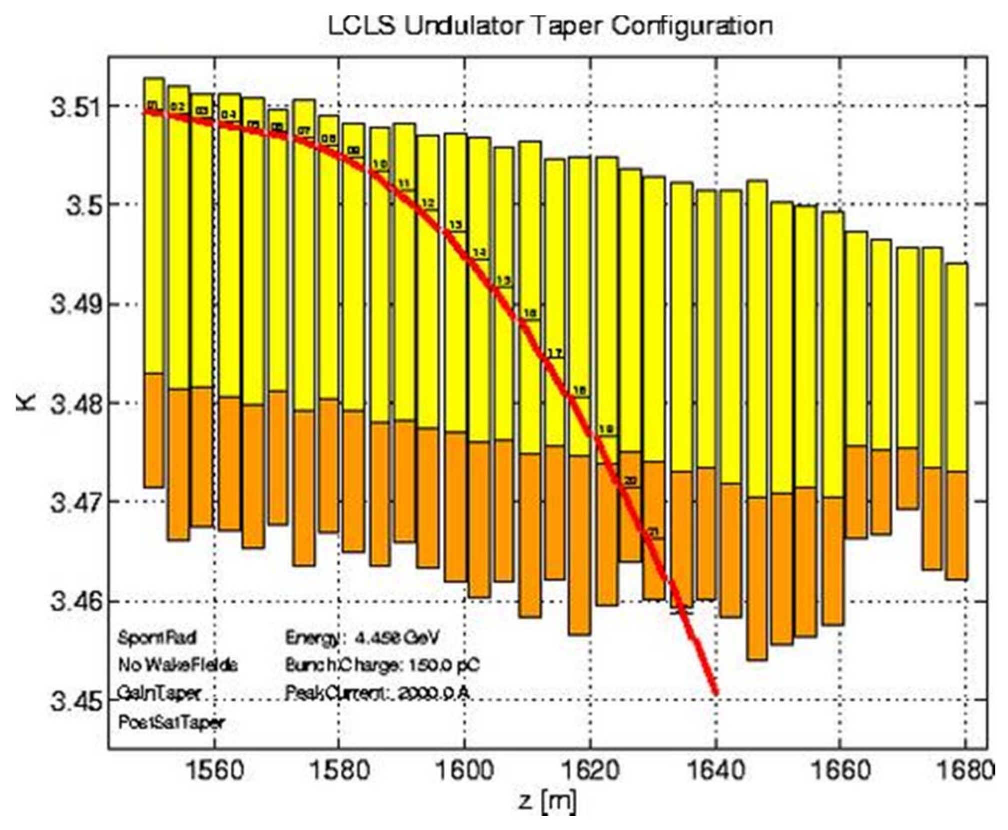

In/Out Orbit and Fit


Field Integral Measurement



Undulator Taper Control

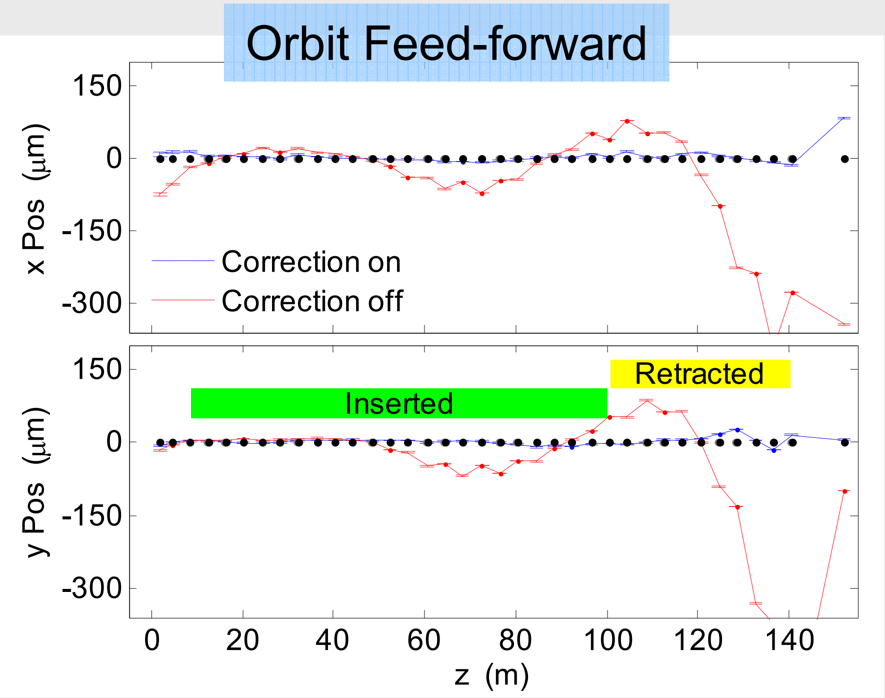
- Undulator taper for each segment preset for wakefield and spontaneous loss
- High level software to set taper
  - linear (gain)
  - Exponential (saturation)
- Programmable set points
- Automatic adjustment to enable FEL optimization

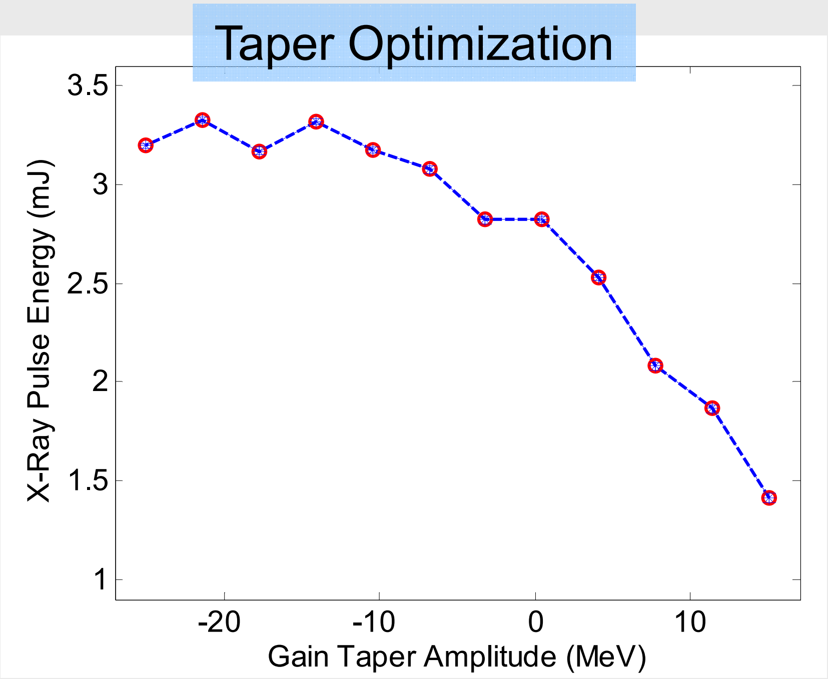


H.-D. Nuhn

Undulator Orbit Corrections

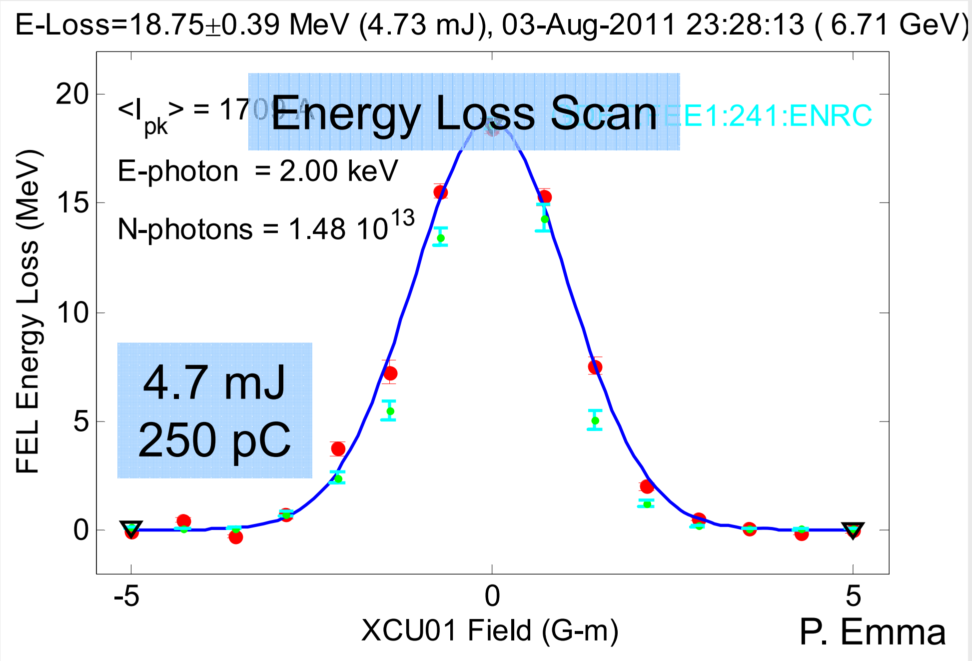
- Significant orbit distortions (~100 µm) from taper and undulator configuration change
- Automatic correction done by control system
- Enables FEL optimization through taper variation





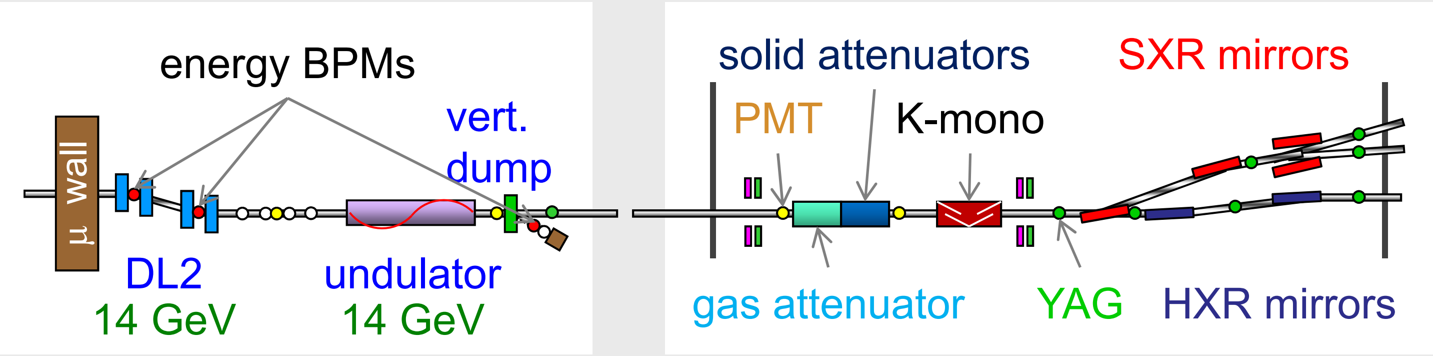
X-Ray Pulse Energy Measurement

- Absolute X-ray energy from electron beam energy loss
- Orbit oscillation in undulator for baseline loss from SR, wake fields
- Calibrate gas detectors
- Routine measurement after wavelength change
- Thermal & thermo-acoustic measurement in commissioning (see WEPA02)



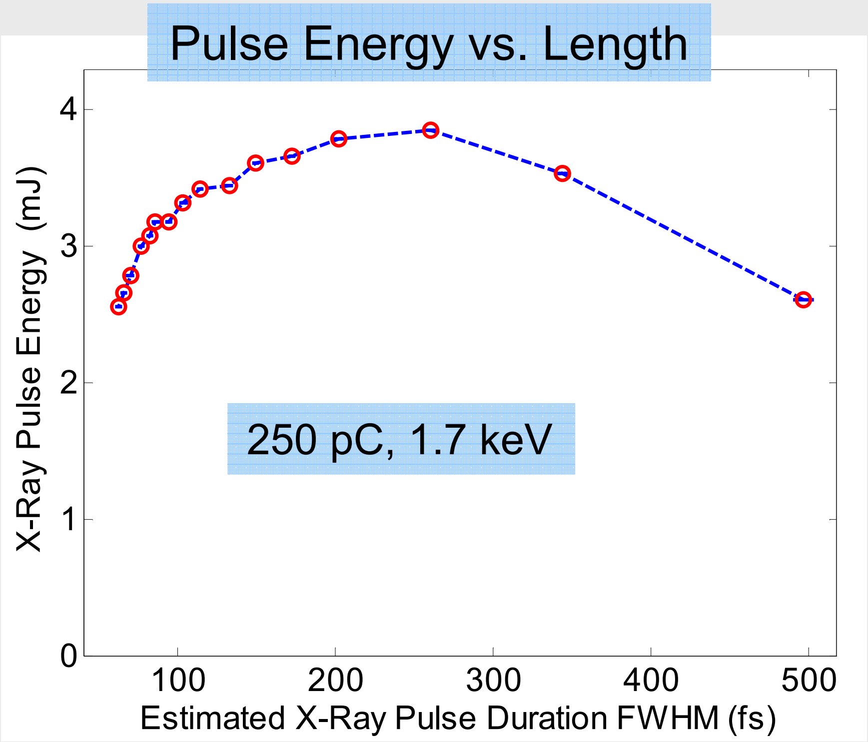
P. Emma

X-ray distribution see THOC4



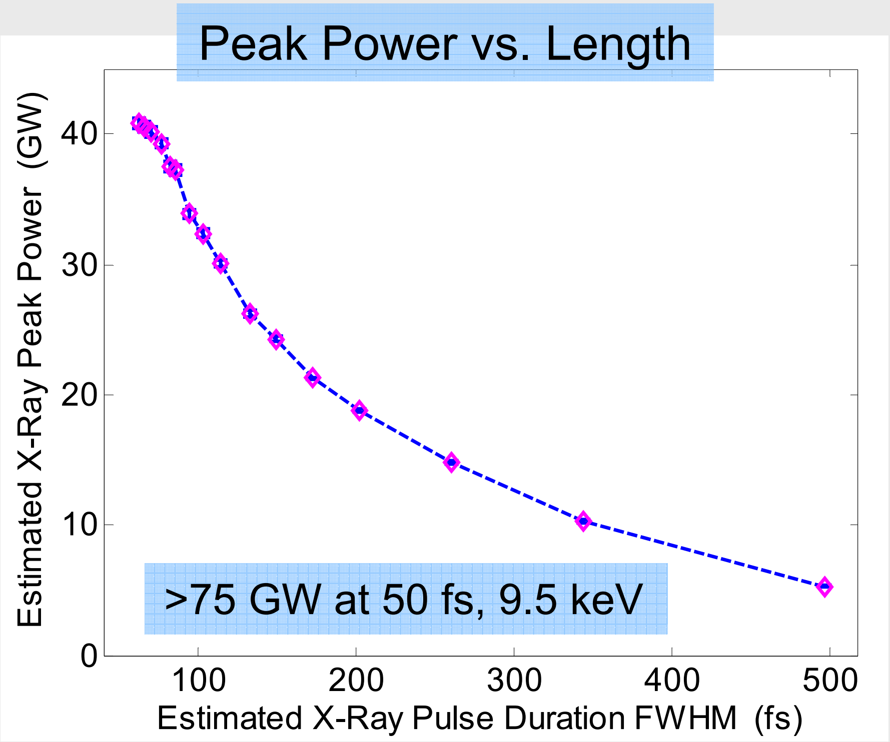
FEL Pulse Length Range

- Large pulse length tuning range 60 – 500 fs FWHM (soft X-ray)
- Takes ~1 min to rescale lattice from linac phase change
- Hard X-rays 60 – 100 fs
- X-Ray pulse length estimated from electron bunch length



Pulse Energy vs. Length

250 pC, 1.7 keV



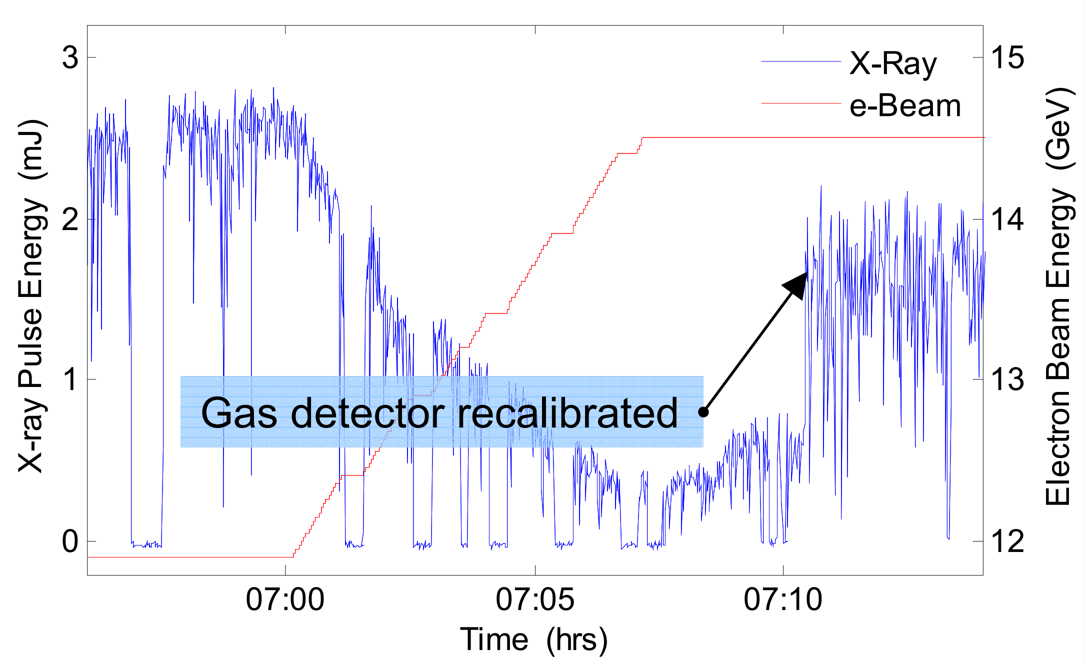
Peak Power vs. Length

>75 GW at 50 fs, 9.5 keV

P. Emma, H.-D. Nuhn

FEL Wavelength Change

- Small: Energy vernier in longitudinal feedback
- Medium: Automatic script to ramp beam energy
- Large: Semi-automatic, manual tuning required
- Example: Automatic energy change from 12 – 14.5 GeV with only 30% X-ray energy loss takes few minutes



N. Lipkowitz

Summary

- Reliable X-ray beam delivery to 4+ experiment stations
- Parameter range far exceeds original design and is fully exploited by user requests
- Large number of feedback systems and mature high level software enables stable FEL operation, quick machine configuration changes, and systematic machine setup and tuning

Acknowledgements

- Thanks to my colleagues at SLAC and our collaborators at ANL and LBNL
- Special thanks to Paul Emma for leading the meticulous design and thorough commissioning that enabled LCLS to operate so successfully