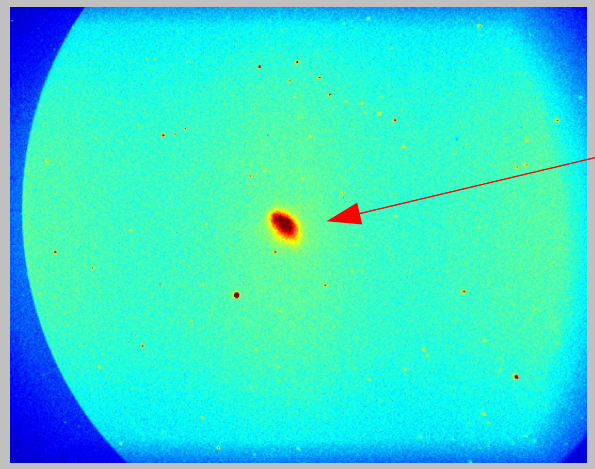
Short Pulse, Low charge Operation of the LCLS

Josef Frisch for the LCLS Commissioning Team

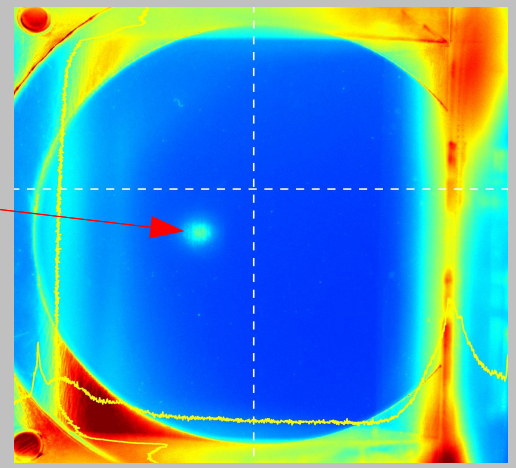
Normal LCLS Parameters



First Lasing in April 10, 2009

Beam to AMO experiment August 18 2009.

Expect first user experiments Oct 1, 2009



Normal Operating Parameters at 250 pC Bunch Charge

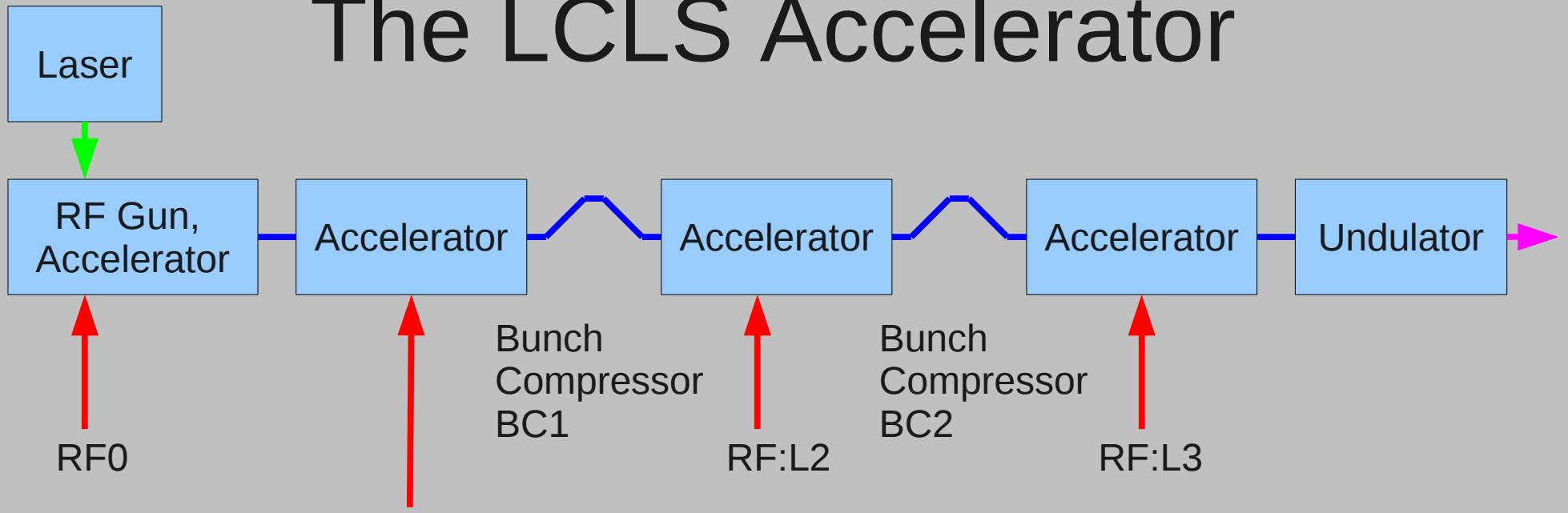
X-ray energy	780 eV to 9 KeV
Pulse energy	2 mJ (typical)
Pulse Length	~60 femtoseconds FWHM
Peak power	~30 GW
X ray average line-width	~ 3×10^{-3}

Possible LCLS Upgrades

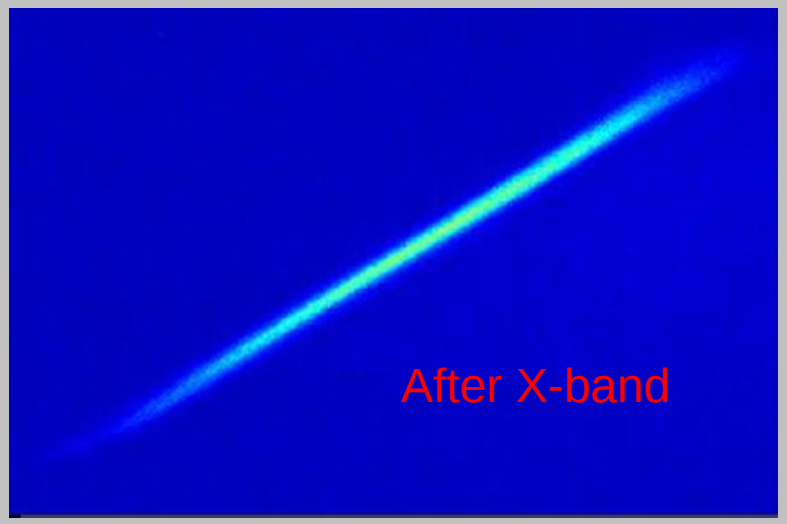
Users won't stay happy for long

- Wider wavelength range: New undulator
- Narrower Linewidth: Seeding
- Higher pulse energy: Increase bunch charge
- Higher repetition rate :30 -> 120 Hz
- Shorter Pulses
  - **Femtosecond** ← THIS TALK
  - Attosecond

The LCLS Accelerator



RF: S-band and X-band to linearize energy vs. time



Typical parameters at 250 pC

Laser: 2.5 ps RMS

Gun: 2 ps, 6 MeV

Preaccelerator: 2 ps, 135 MeV

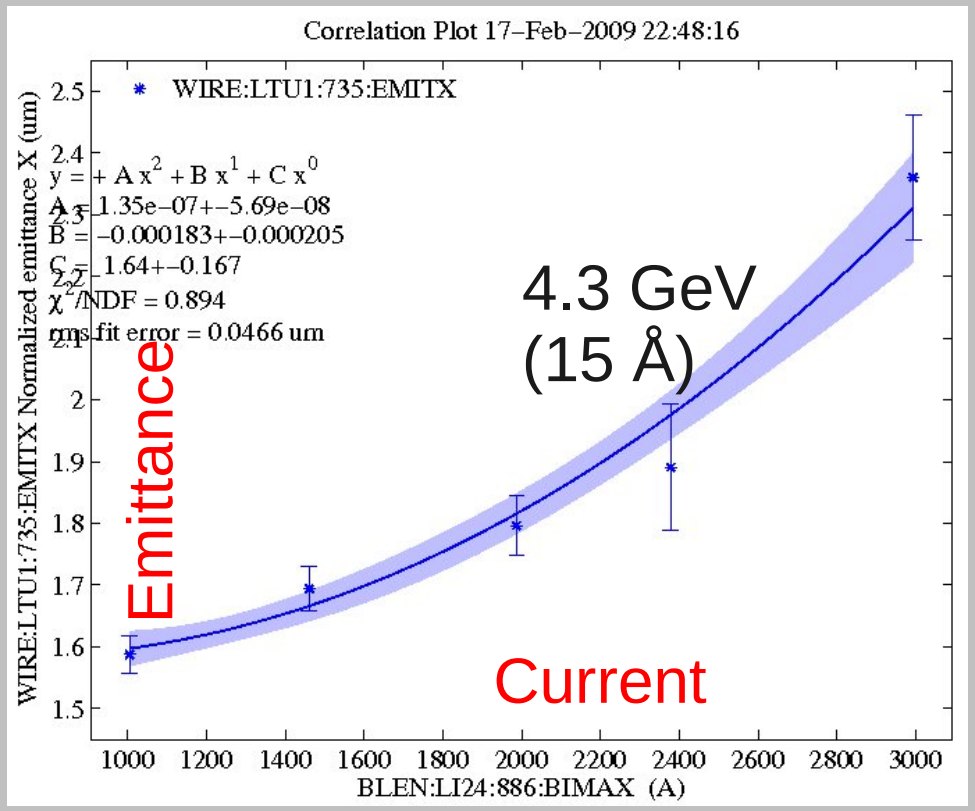
Bunch Compressor 1: 300 fs, 250 MeV

Bunch Compressor 2: 25 fs, 4.3 GeV

Undulator: 25 fs, 4.3-14 GeV

Peak Current Limitation

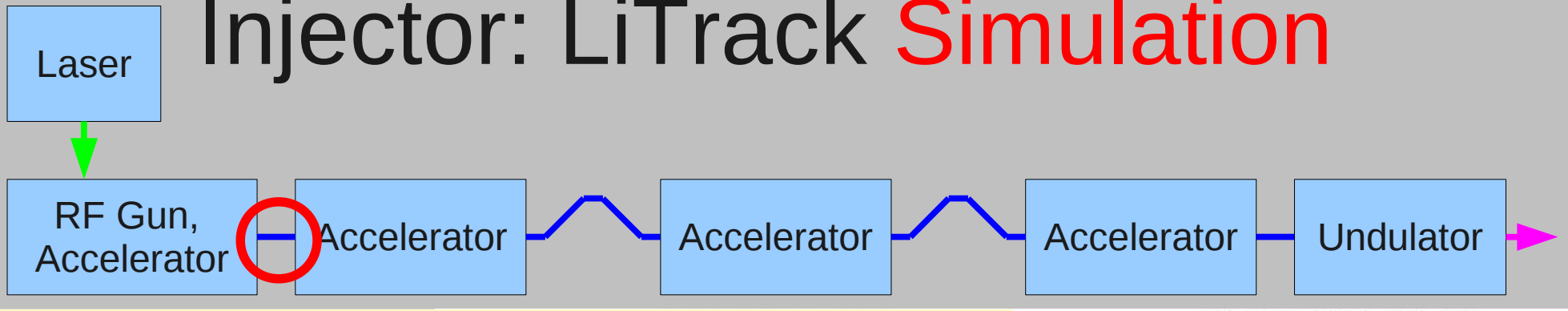
- CSR breakup increases beam emittance as current increases
- Practical limit for LCLS is ~3000 Amps for good FEL operation
- **For short bunch need low charge**
- Tested at 20pC



Emittance at undulator changes from 1.6 to 2.4 mm-rad For 1000 to 3000 A peak current

Low charge / short pulse / low emittance FELs suggested by C Pellegrini, J Rosenzweig

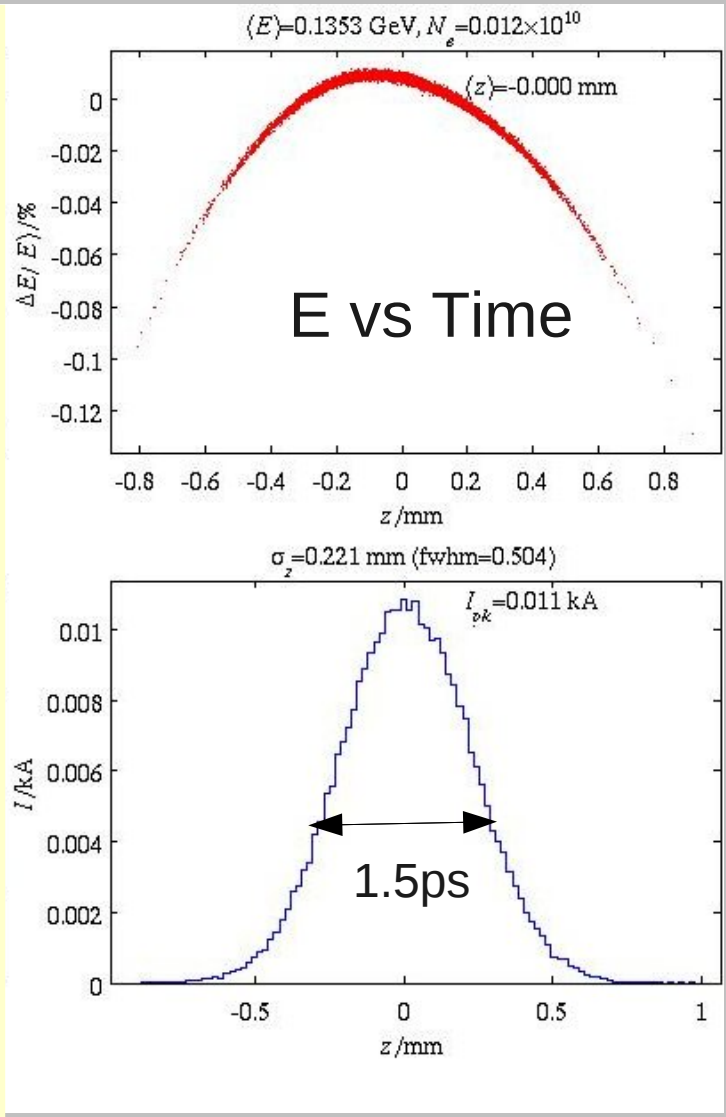
Injector: LiTrack Simulation



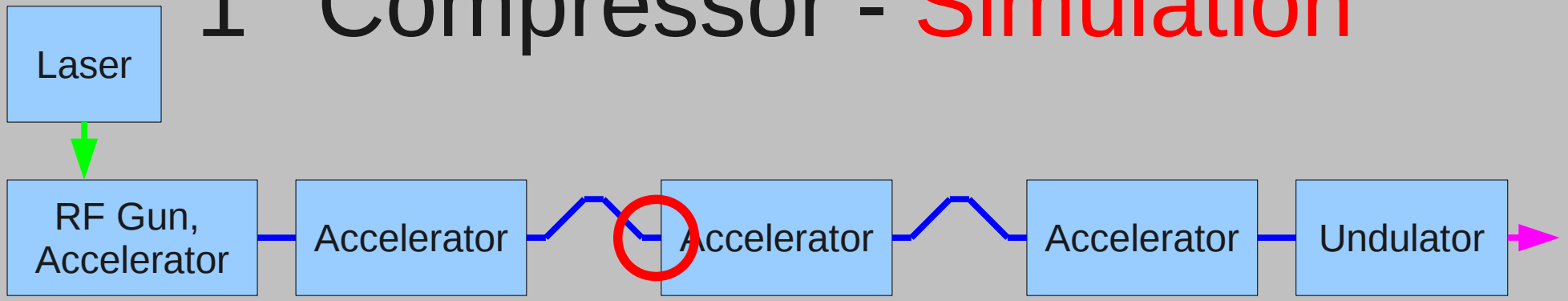
1-d Simulation at 20pC

135 MeV Injector
1.5ps FWHM
No correlated energy spread

Note: Laser heater was off for most short-bunch tests



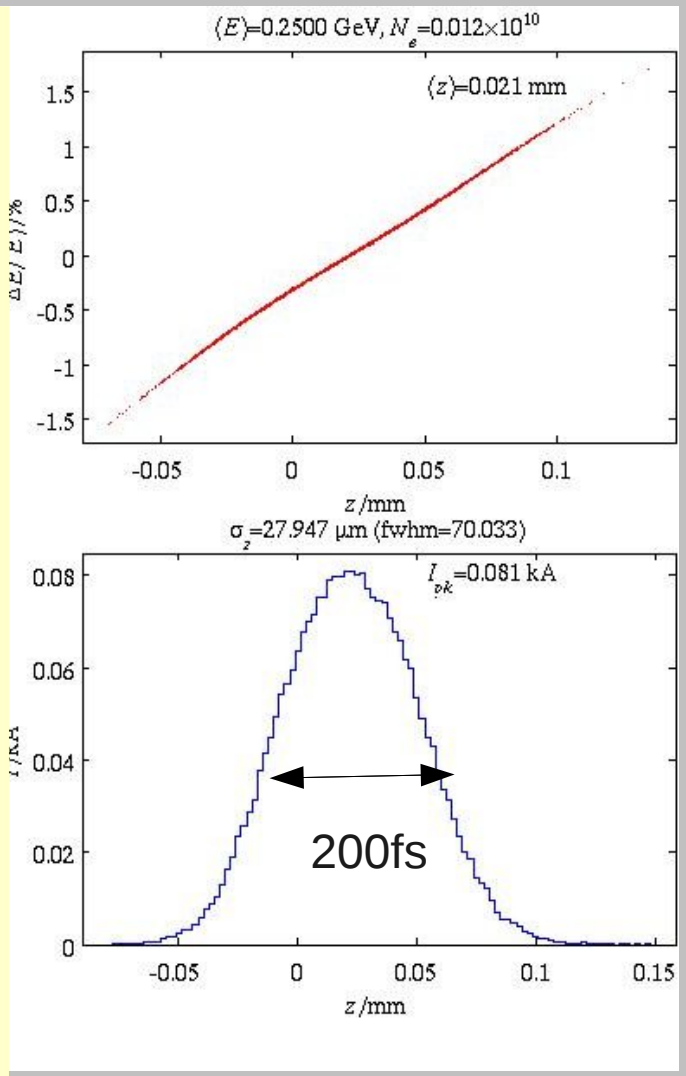
1st Compressor - Simulation



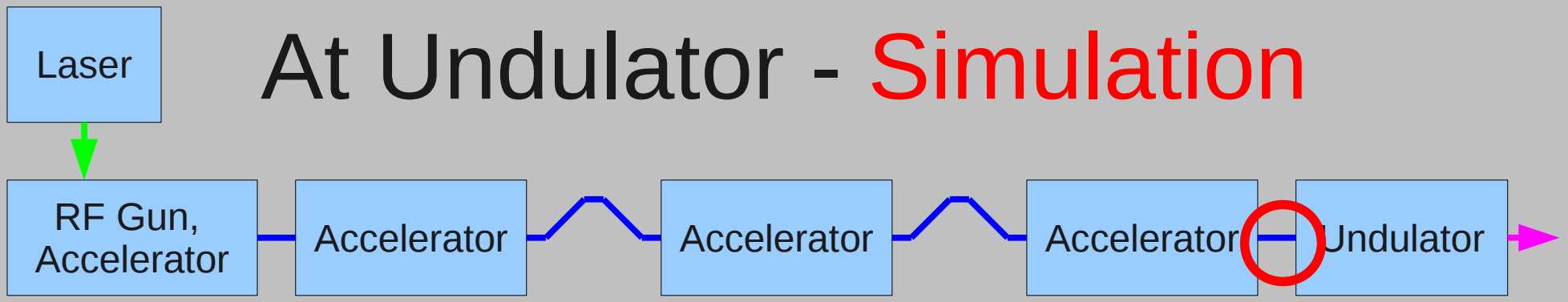
S-band structure (L1) operated off crest to provide energy / time correlation.

Bunch not fully compressed

250 MeV
200 Femtosecond FWHM



At Undulator - Simulation

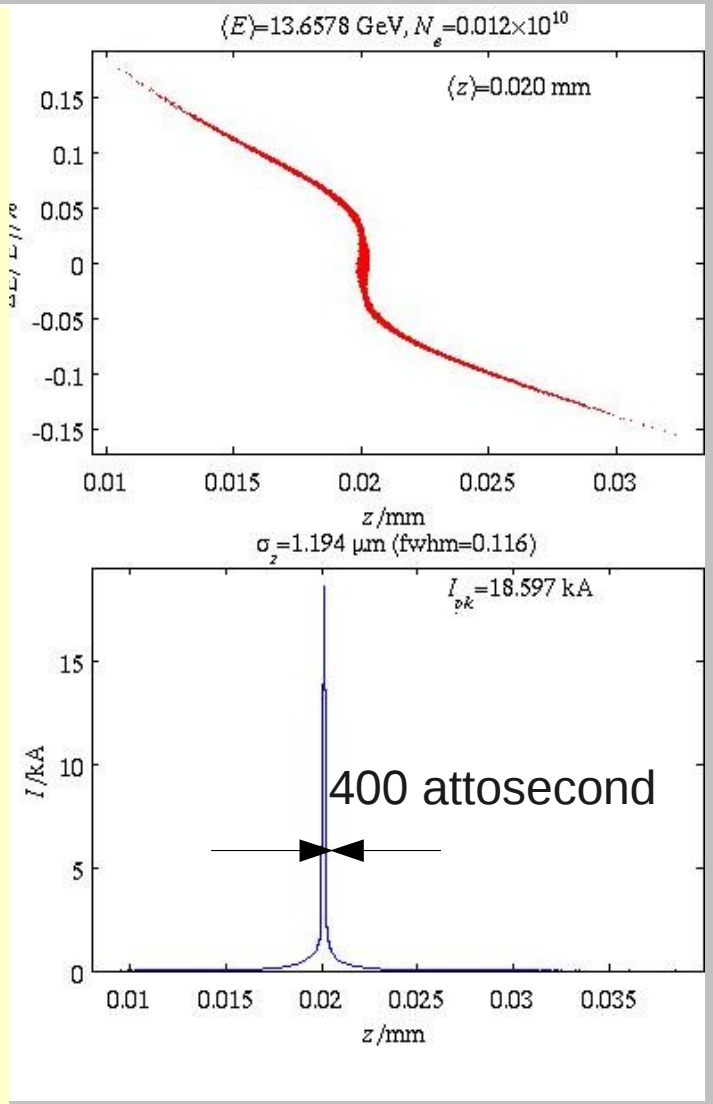


L2 structure operated off crest

Beam compressed in BC2

Wakefields in L3 linac cancel energy chirp (14 GeV)

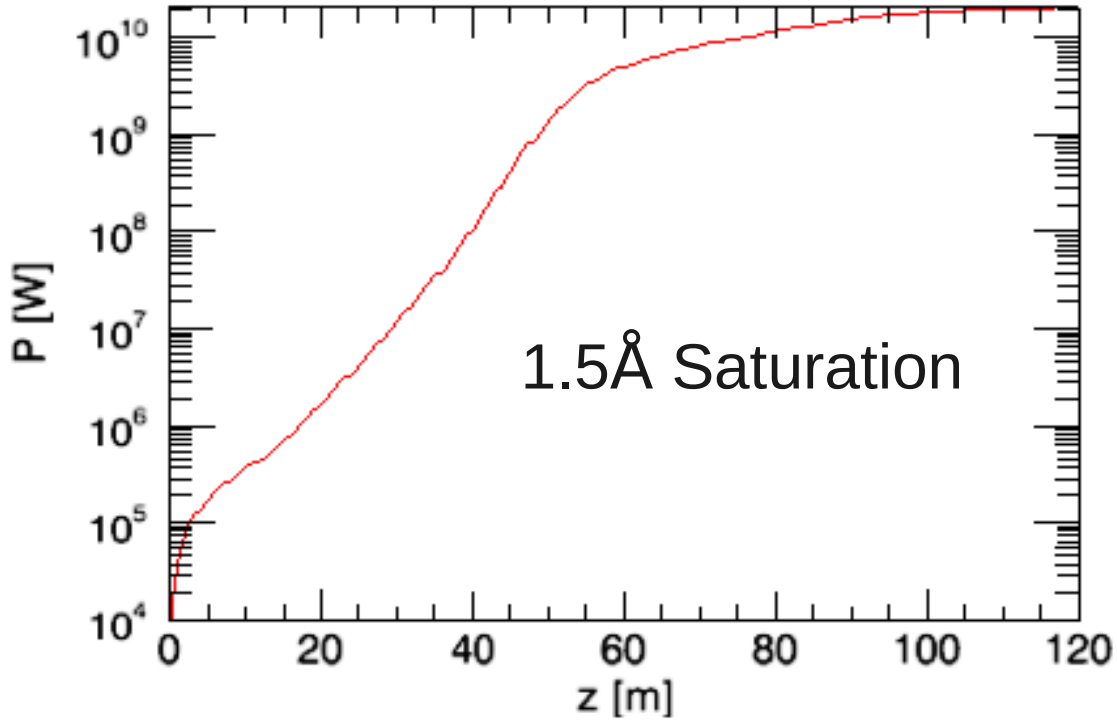
400 attosecond FWHM
(1-d simulation: Don't believe this!!!)

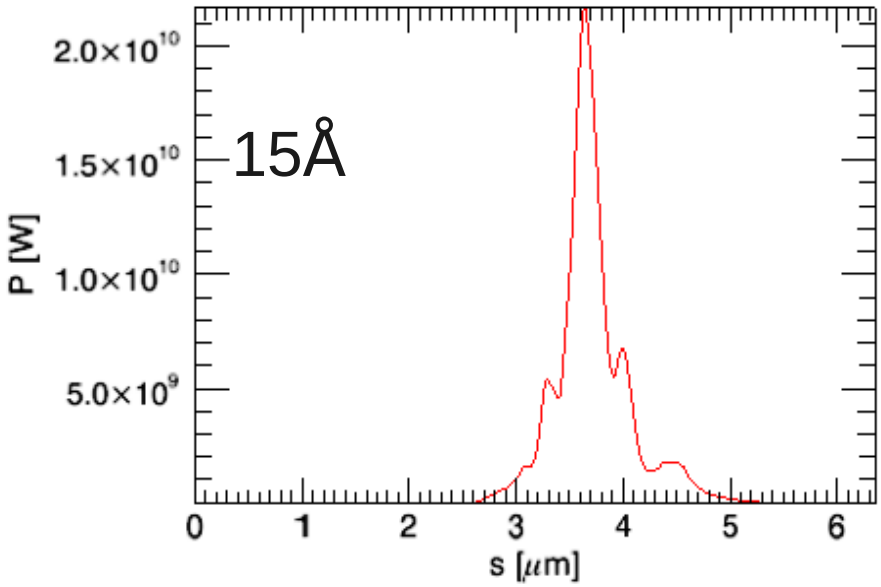


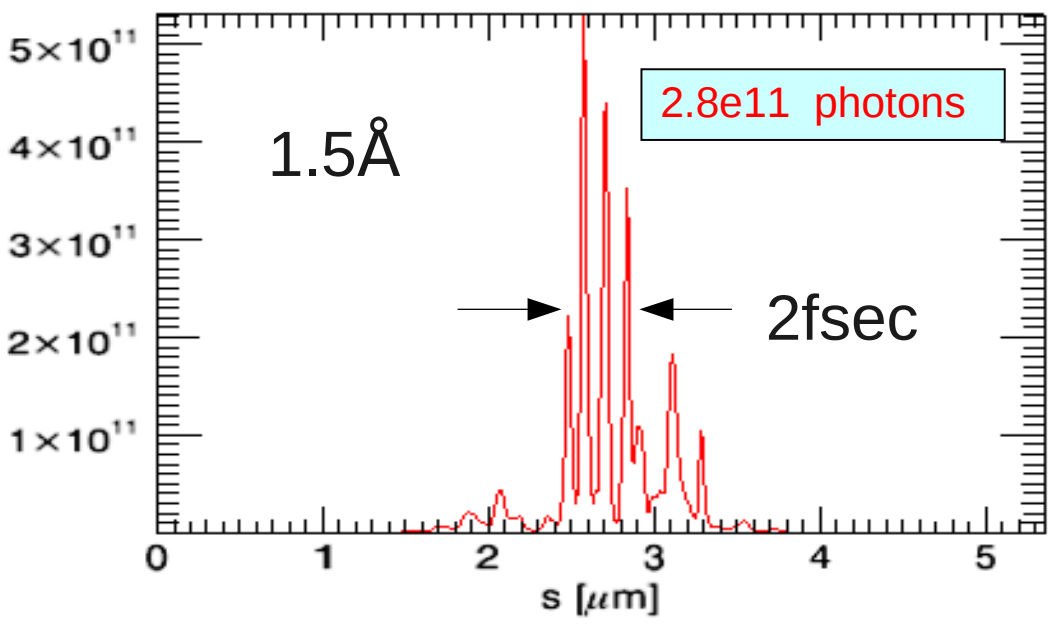
20pC Simulations

2 femtosecond FWHM
Peak power > 300 GW

At 15Å predict pulse that is 3X transform limit

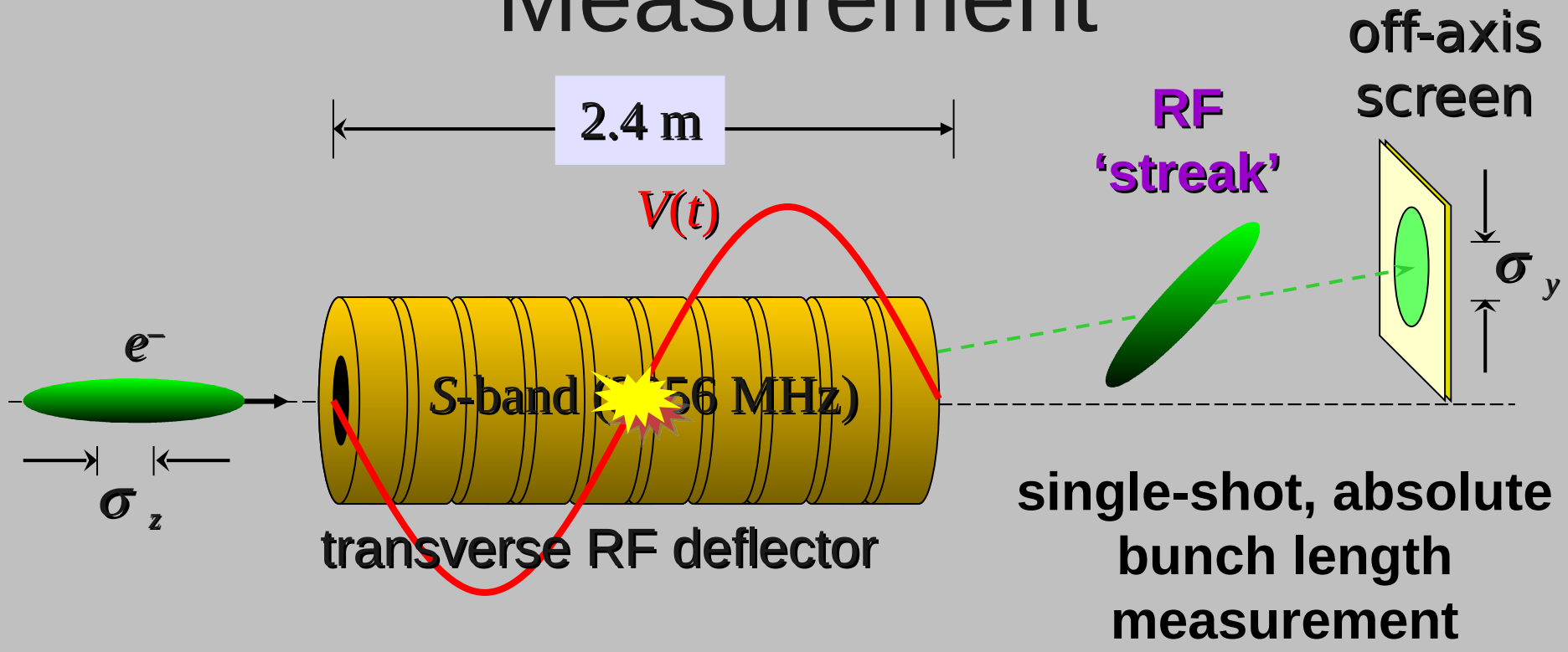






Yuantao Ding

Transverse Cavity Bunch Length Measurement

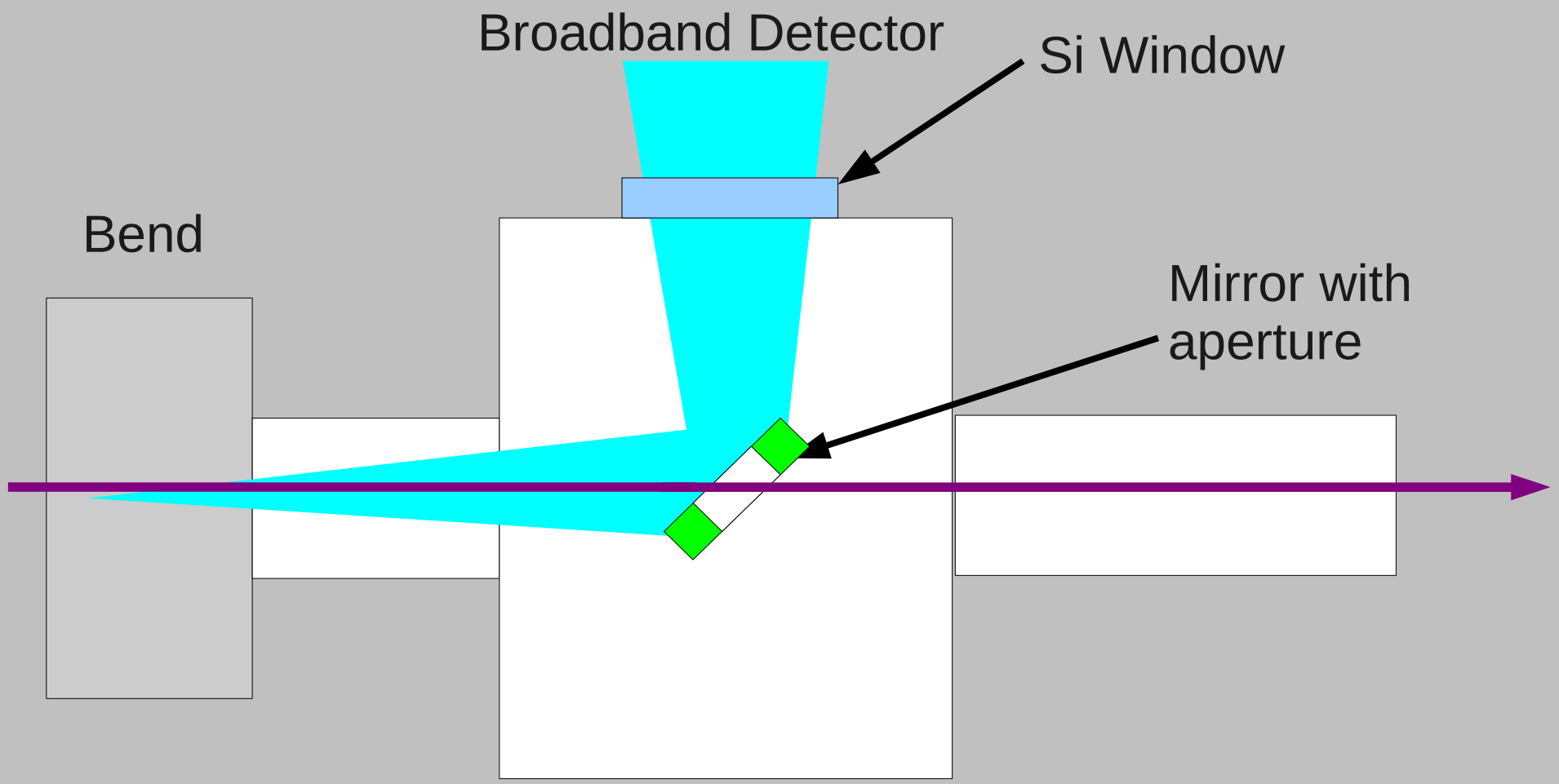


Transverse cavity provides only absolute calibrated bunch length measurement

Available RF power and emittance limit resolution to ~ 10 femtoseconds. **Cannot resolve ultra-short bunches**

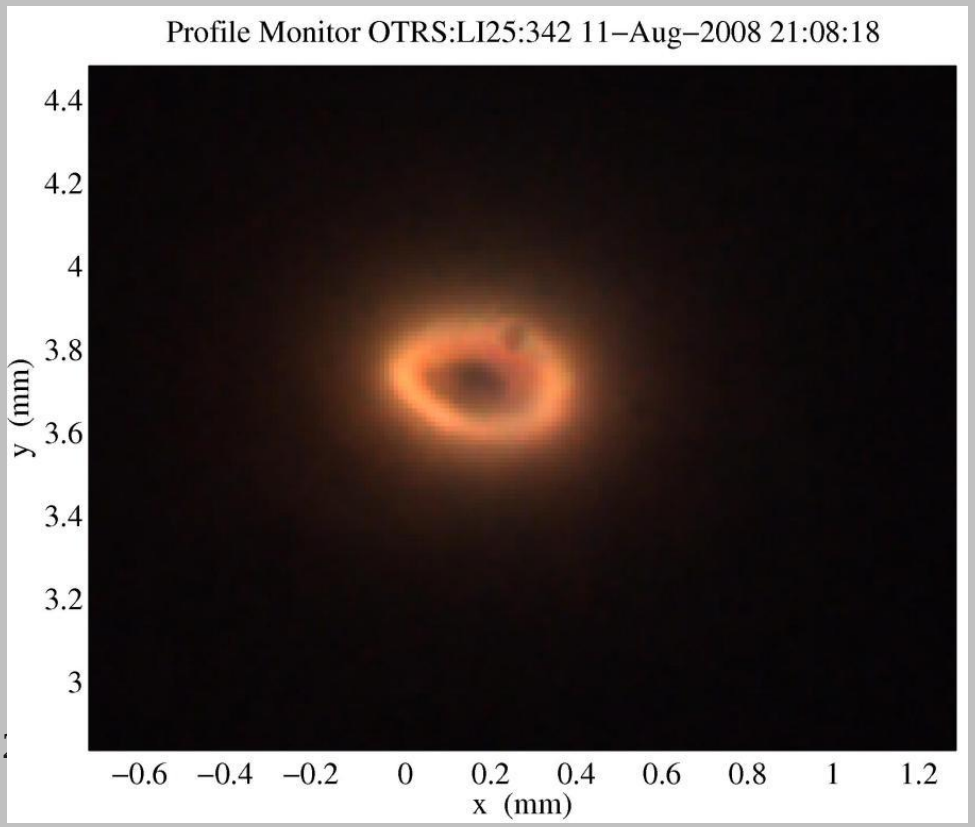
Relative Bunch Length Monitor

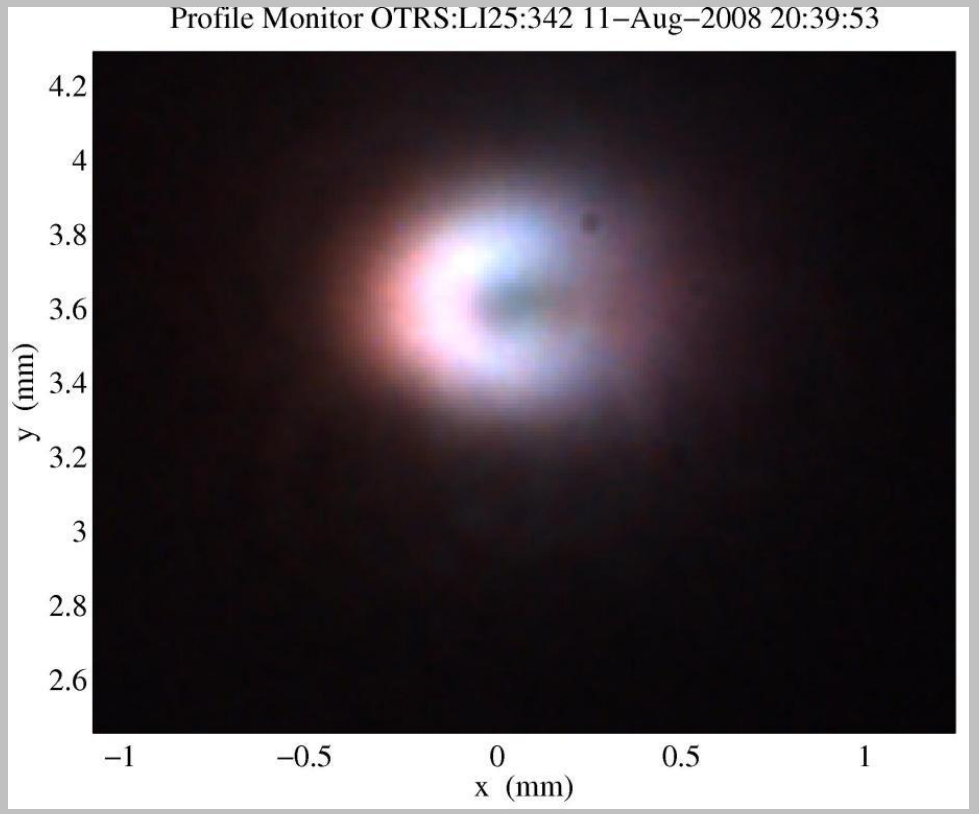
Measures integrated power from 1 to ~100 microns
Sensitive down to ~1 femtosecond FWHM
Cannot distinguish spikes from bunch length



COTR Bunch Length Monitor

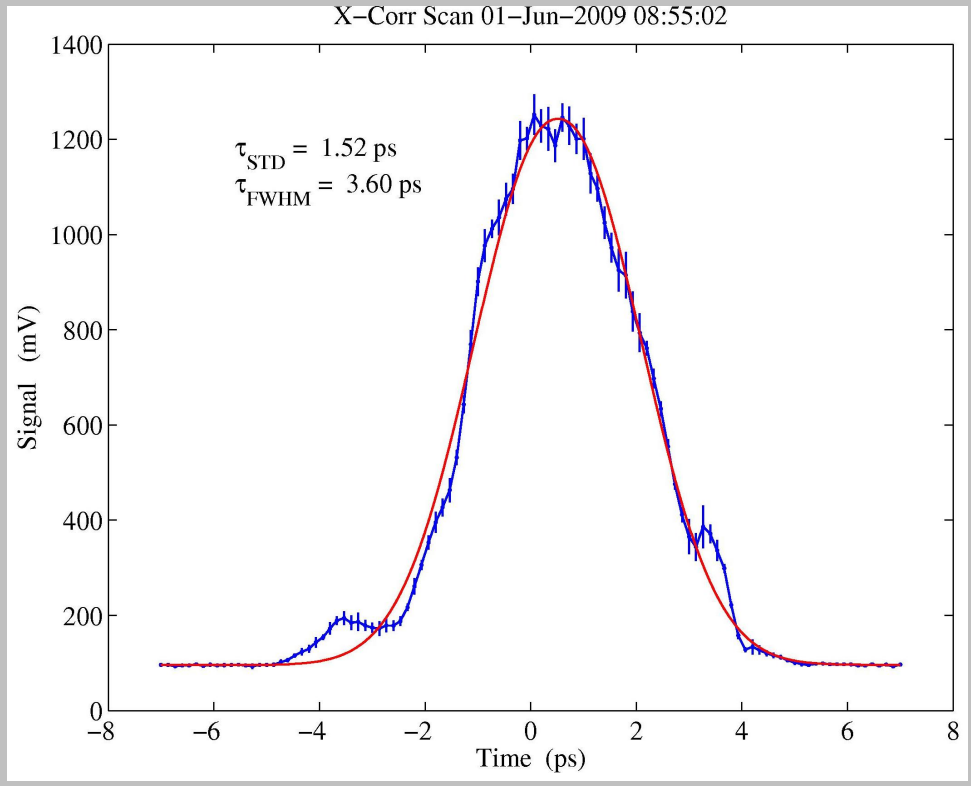
- Coherent Optical Transition Radiation
  - Sensitive from 300 – 800nm wavelength
  - **Cannot distinguish spikes from short bunch**
  - Enhancement 10^5 over incoherent





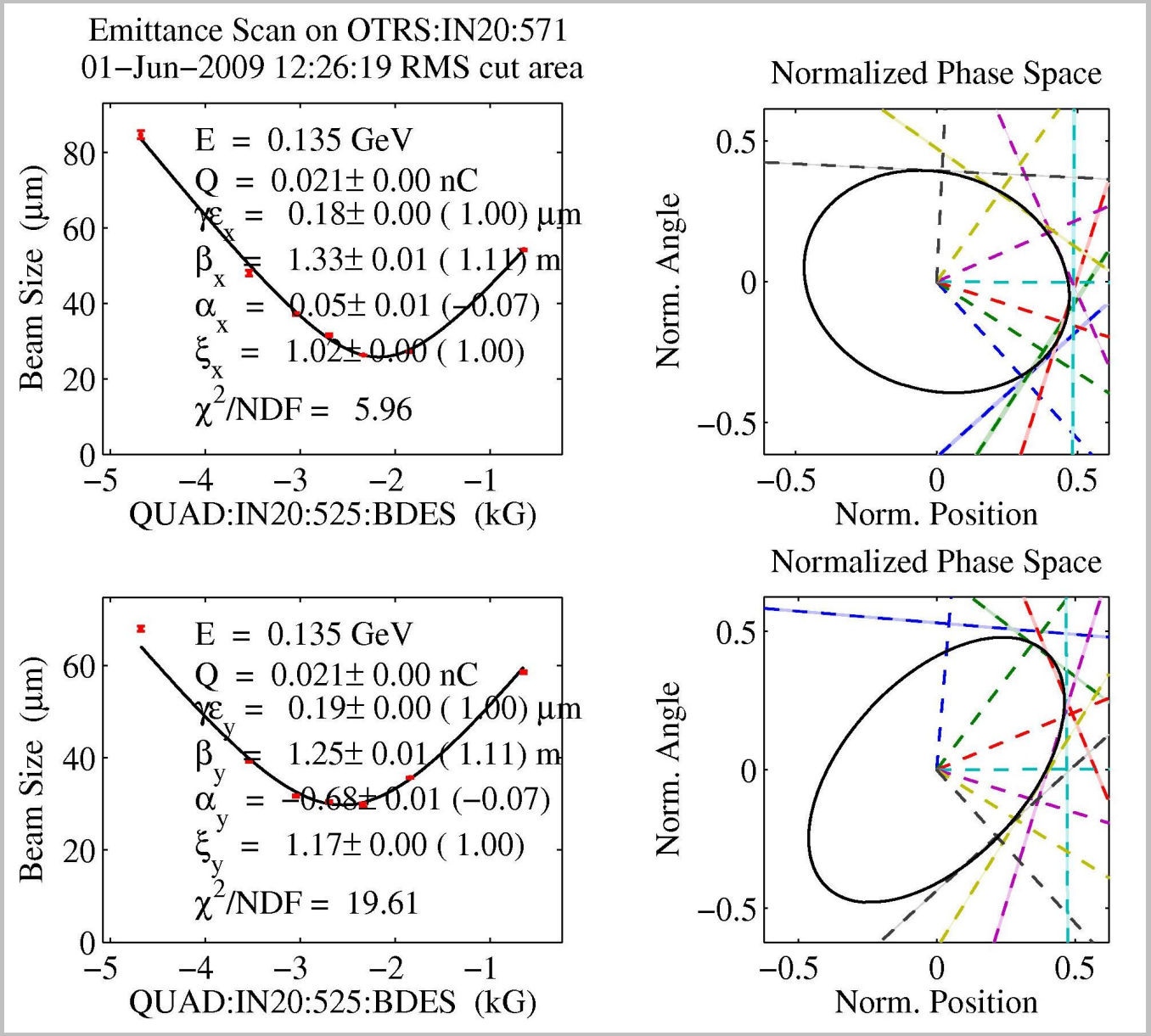
20pC Operating Conditions

- Spot size on cathode 0.6 mm diameter.
- Bunch compressors unchanged
- Set RF phases and amplitudes to (approximately) match Simulation

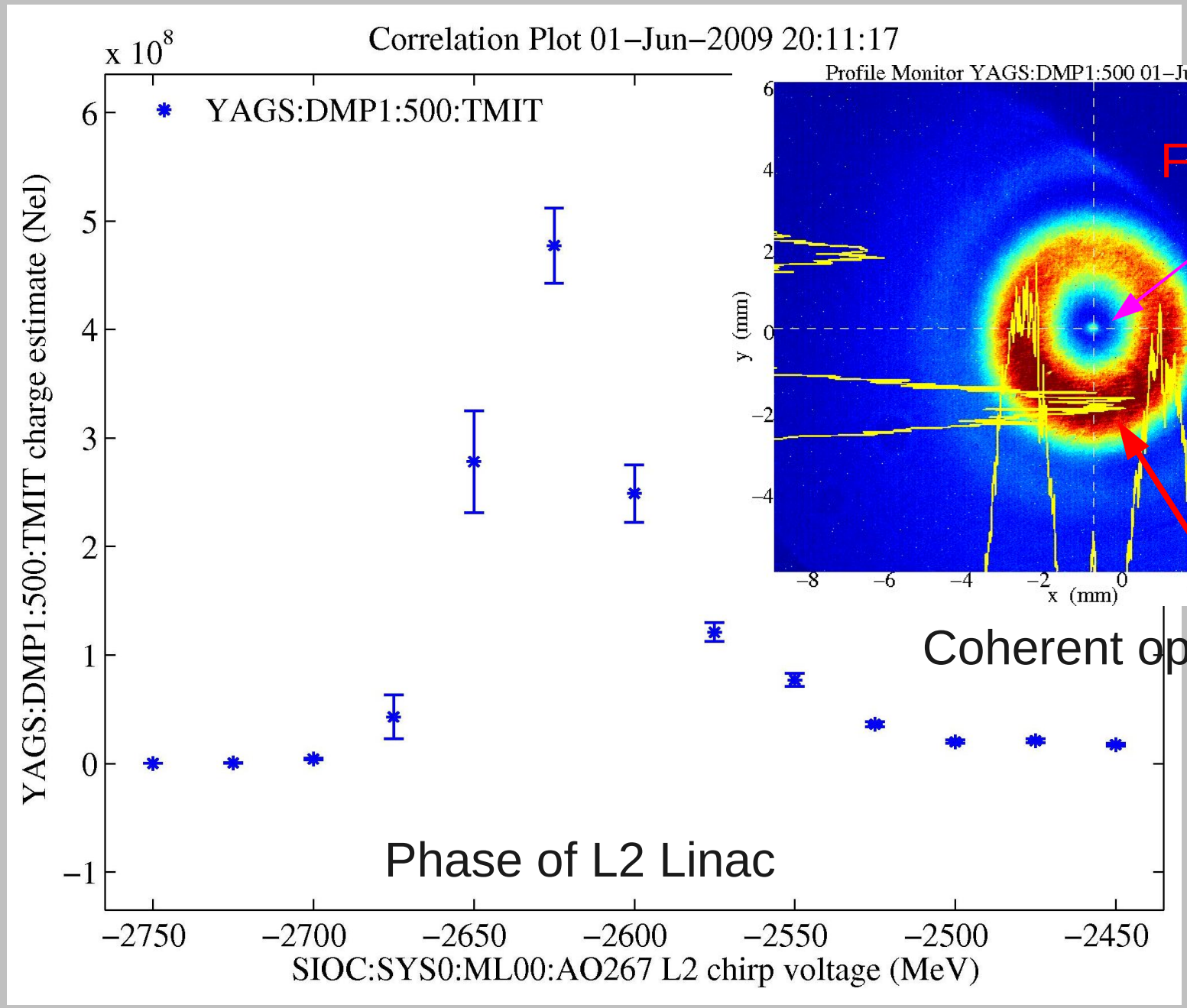


Laser Pulse
1.5 ps RMS

Injector Projected Emittance at 20pC: 0.18 X 0.19 microns RMS



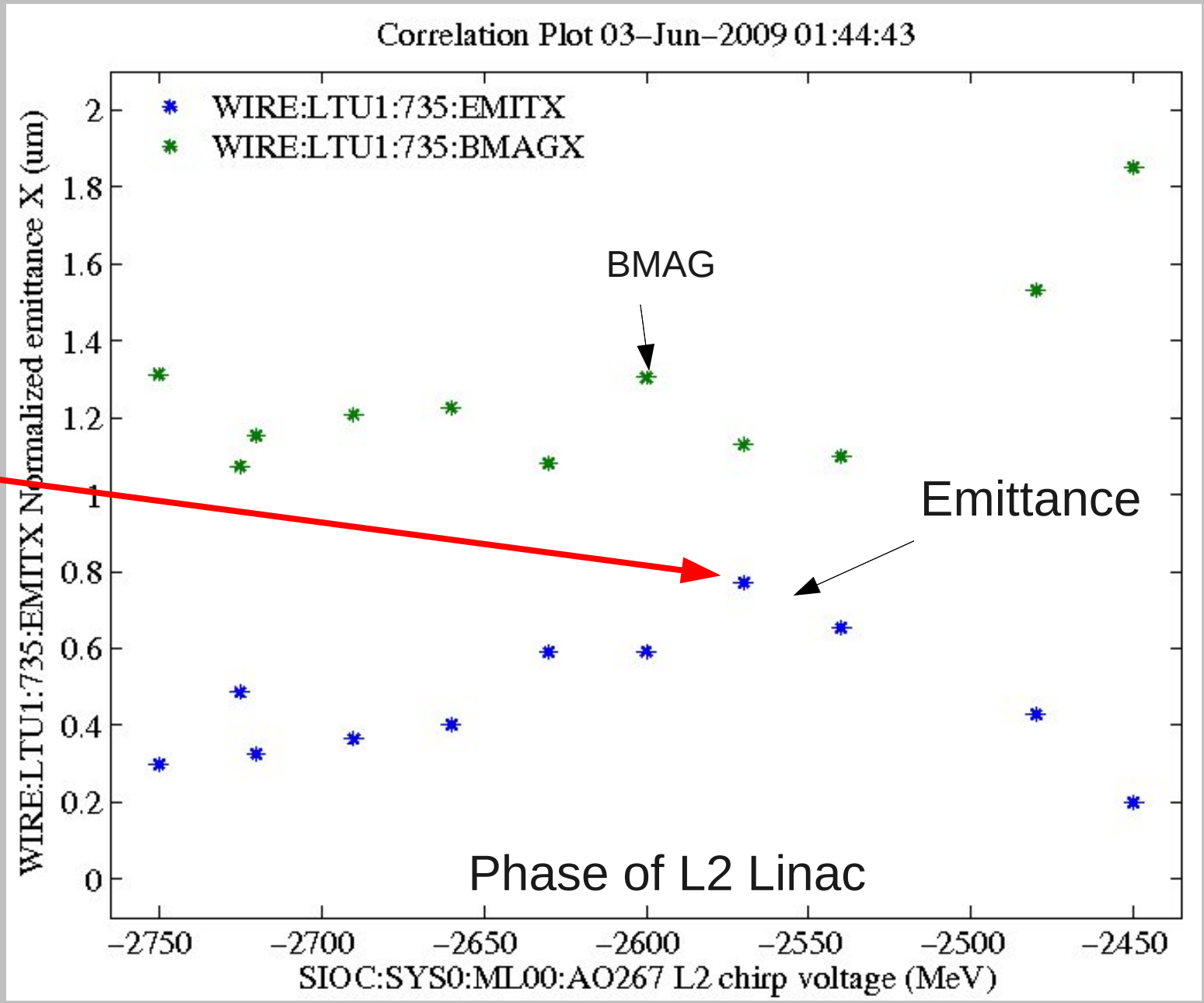
Cohrent Edge Radiation vs L2 phase



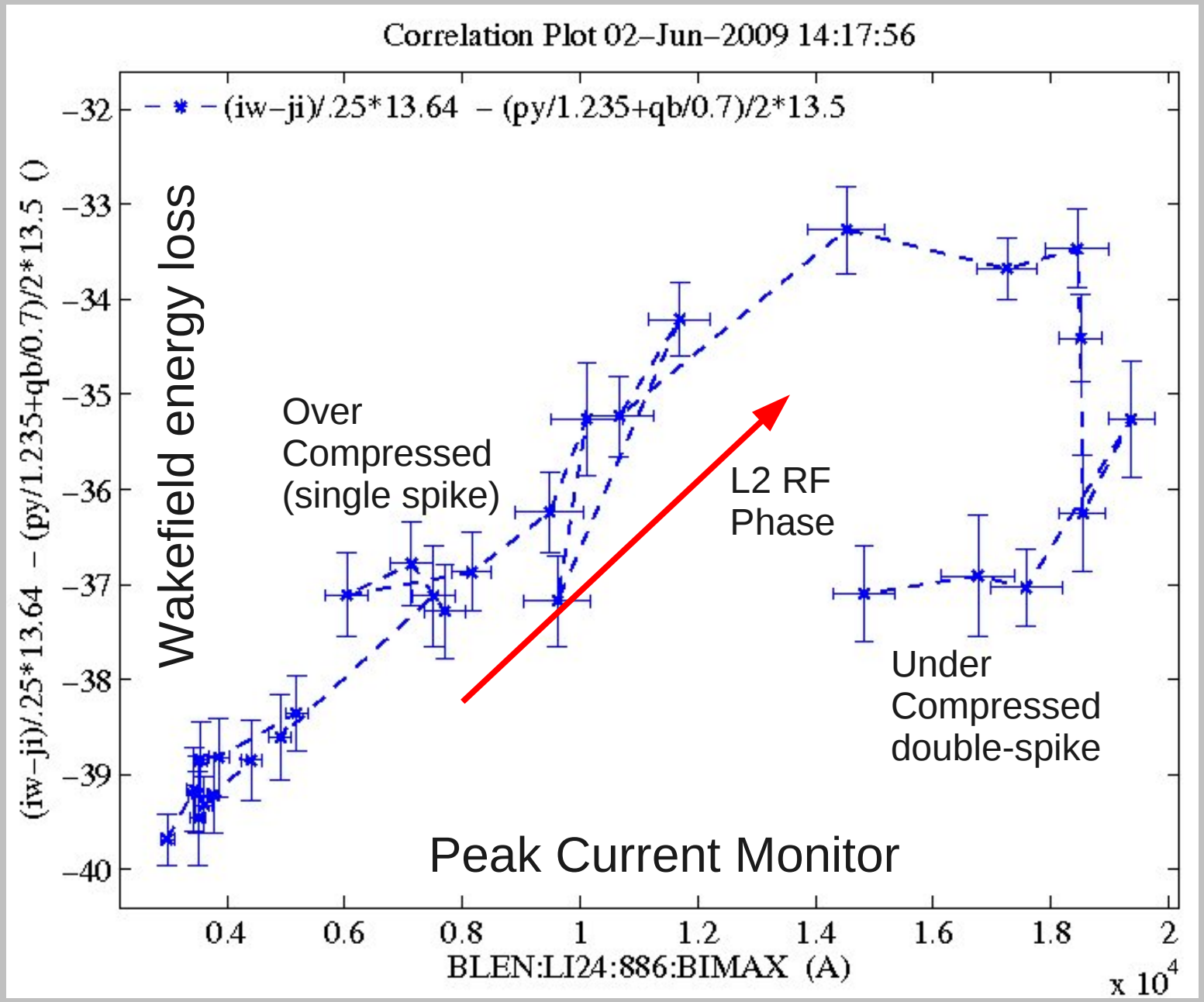
Coherent optical ring

X Emittance vs. L2 Phase

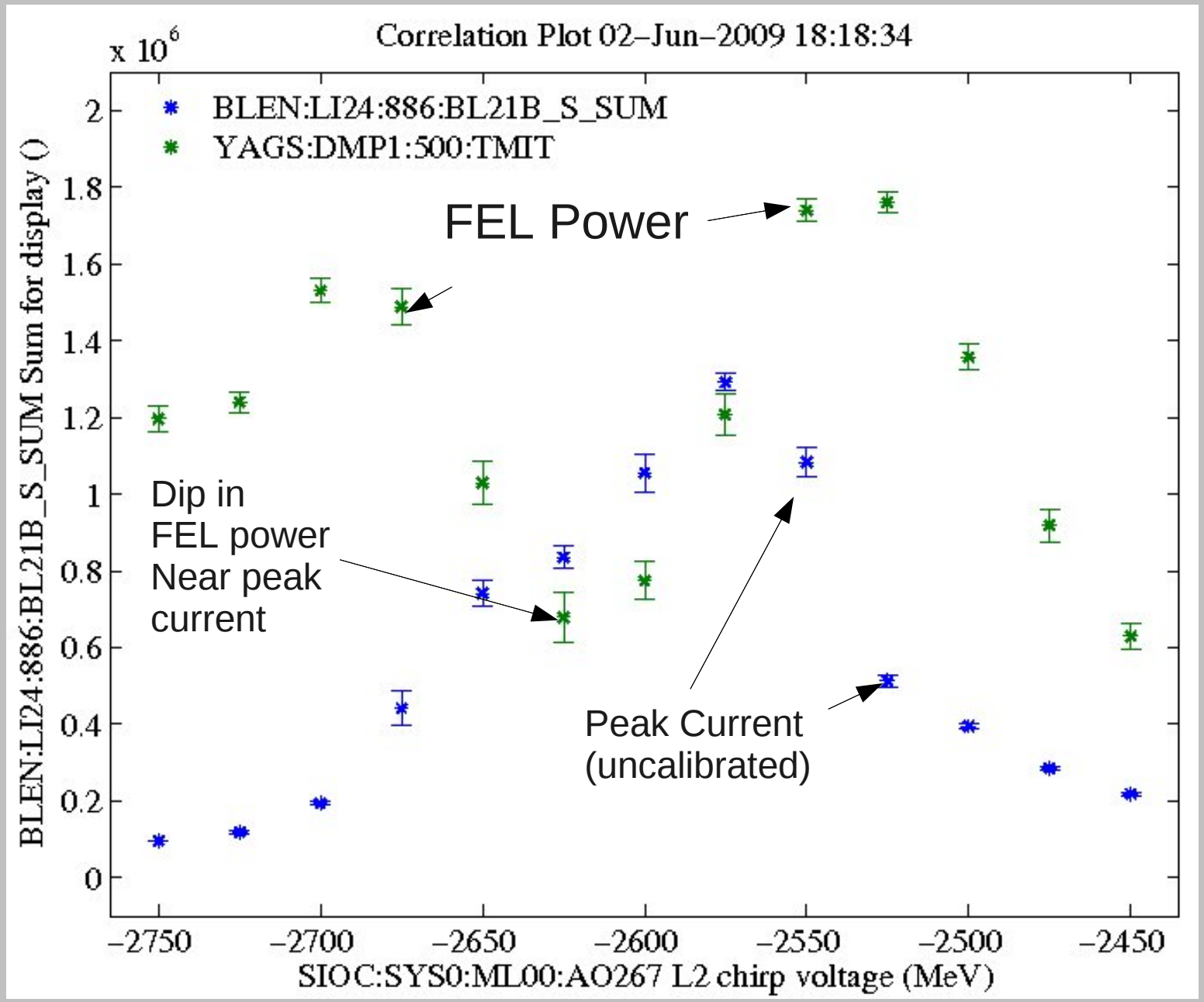
Max emittance
0.75 mm-mr
OK for FEL



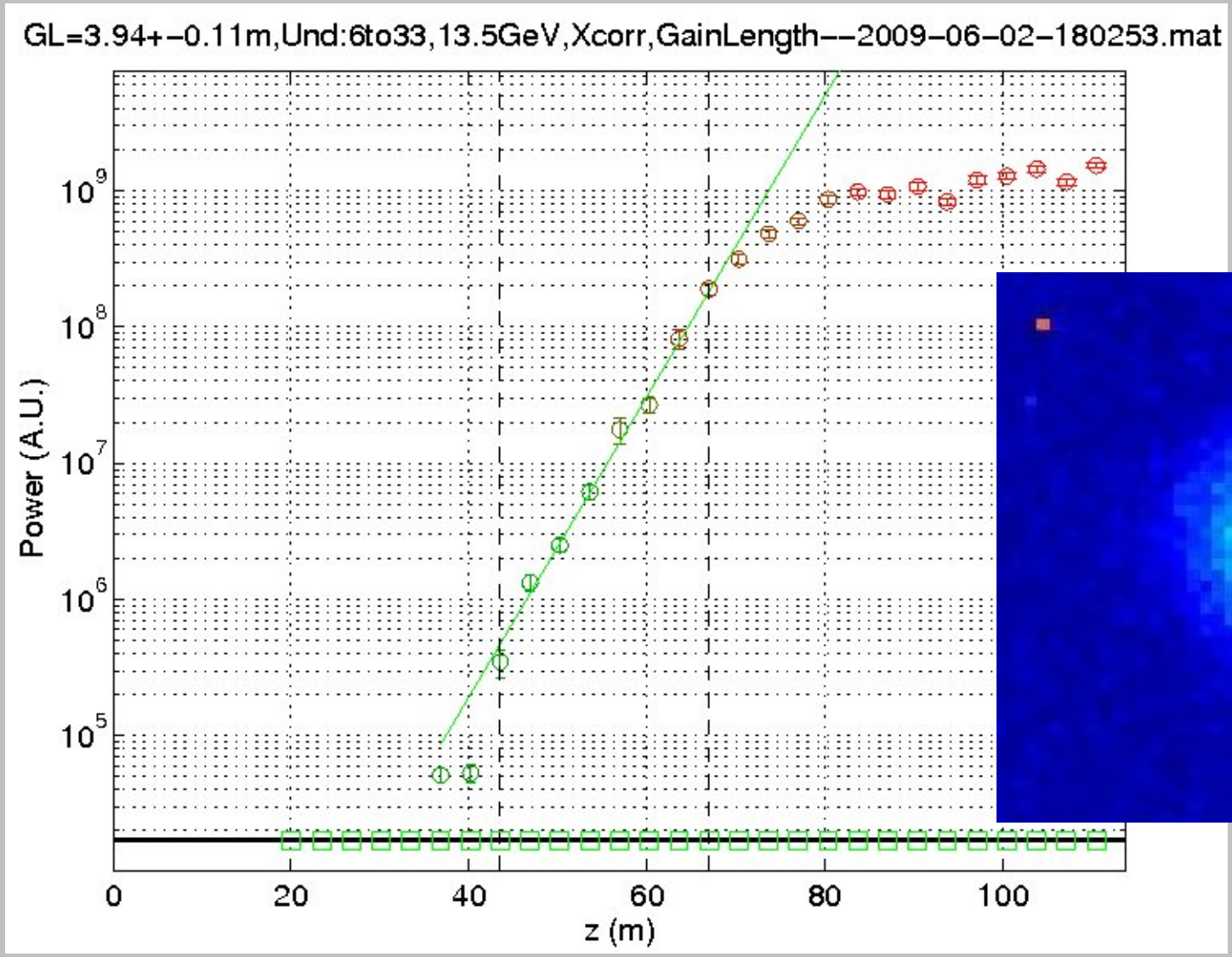
Wakefield Loss vs Compresion



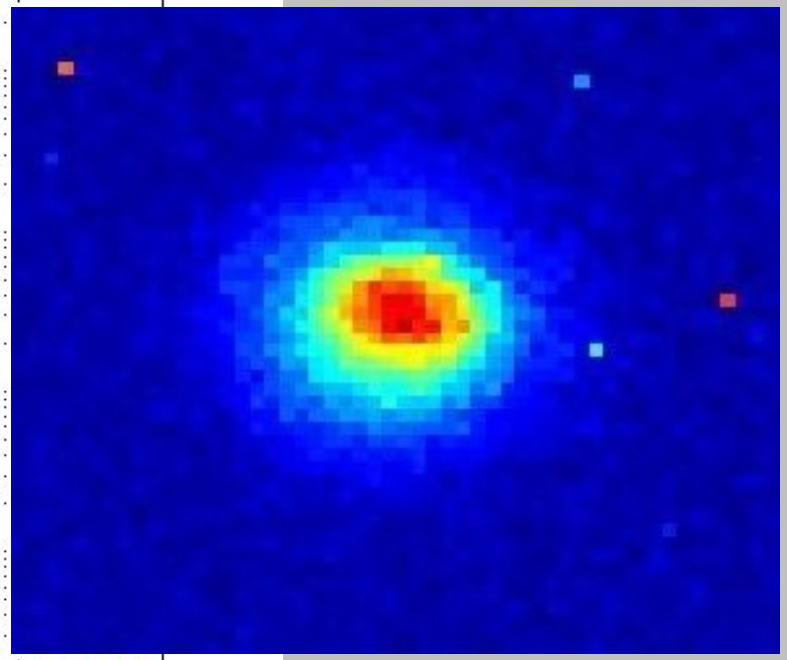
Power vs. Compression 1.5Å



FEL at 20pC, 1.5Å

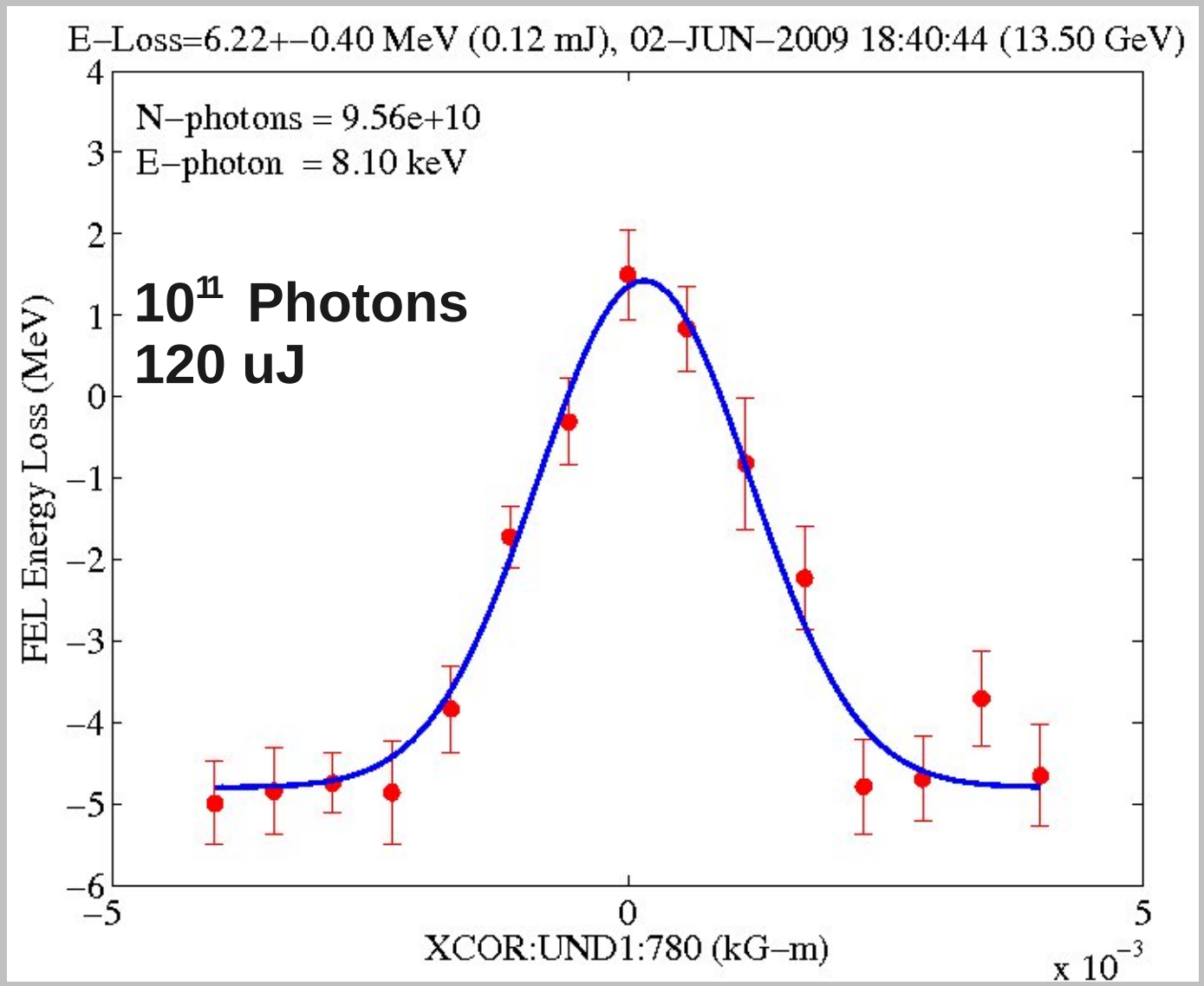


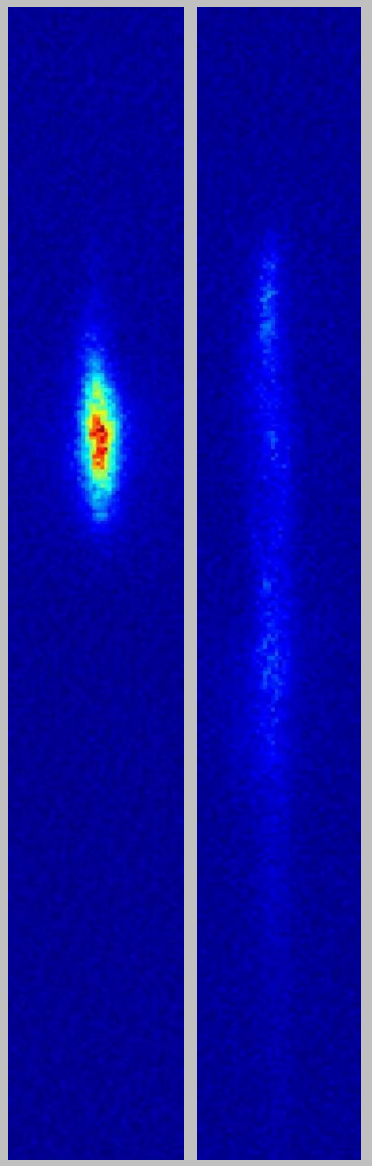
FEL power vs undulator length
3.9 Meter Gain Length



FEL image on YAG screen

Output Power - 20pC





Dump Electron Spectrometer

Energy loss scan at full compression

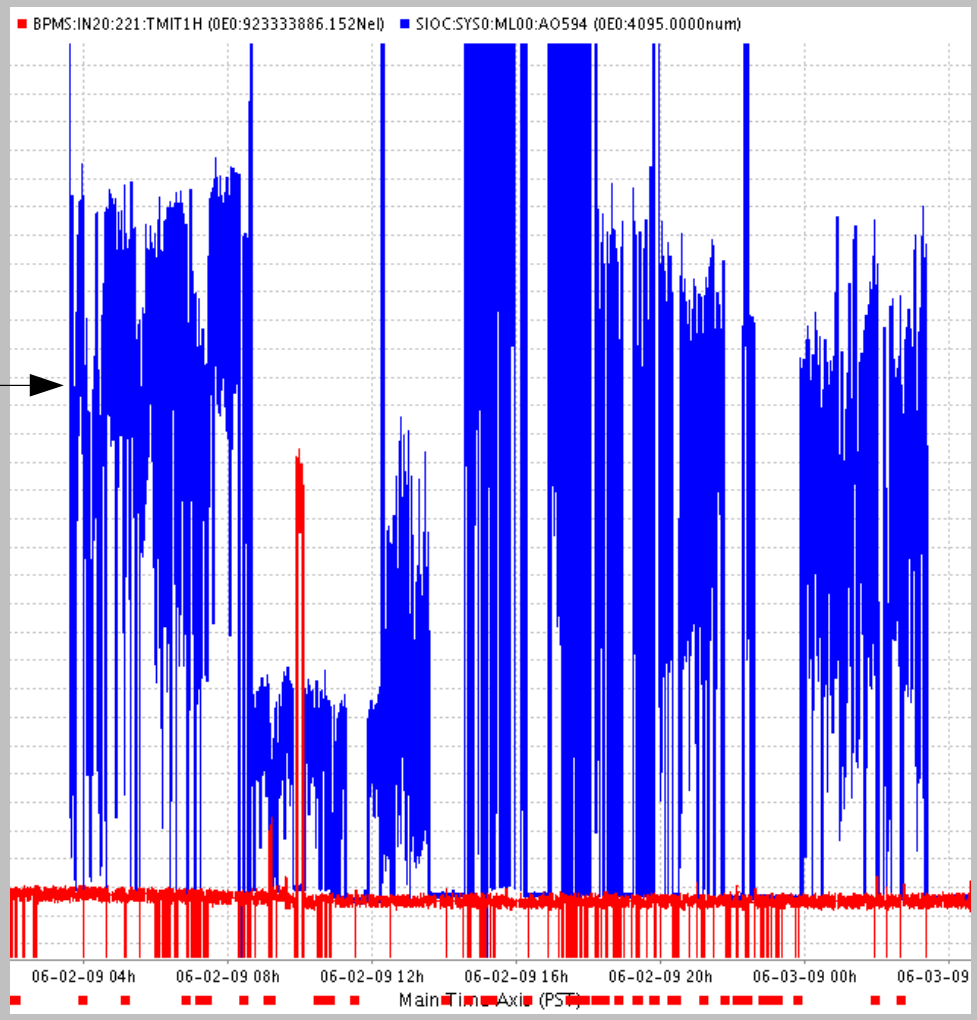
Bunch Length Feedback

- For 20 pC short-bunch operation used "dither" feedback for L2 phase to keep BC2 bunch length signal maximized.

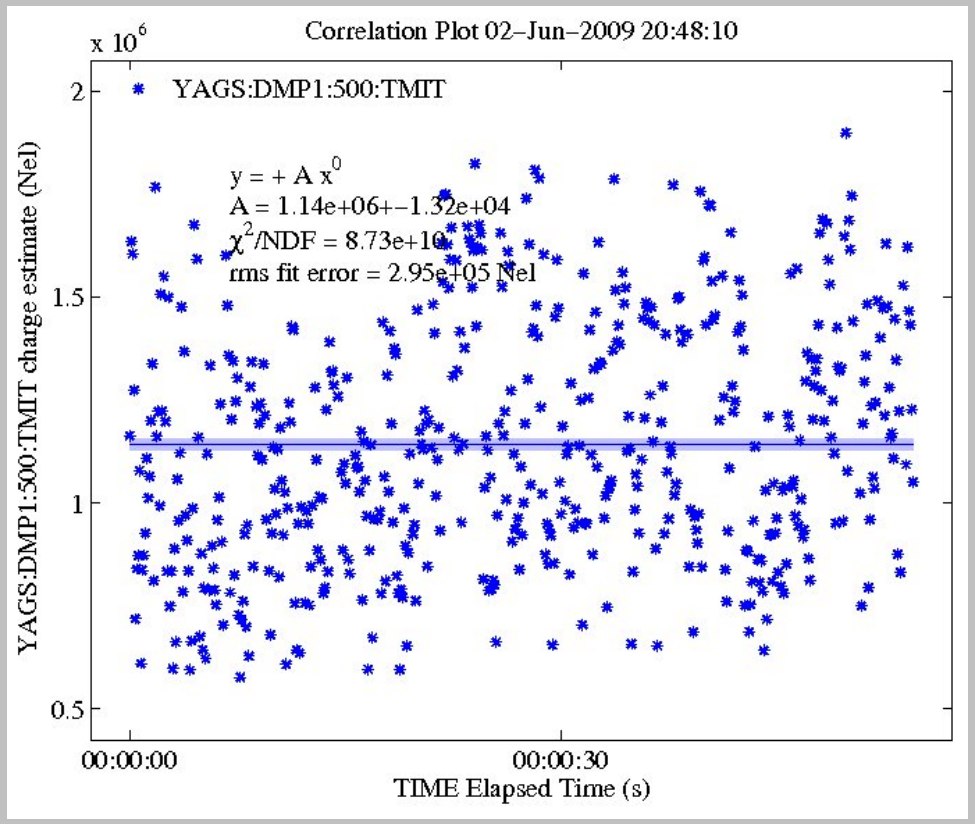
FEL power (arbitrary units)

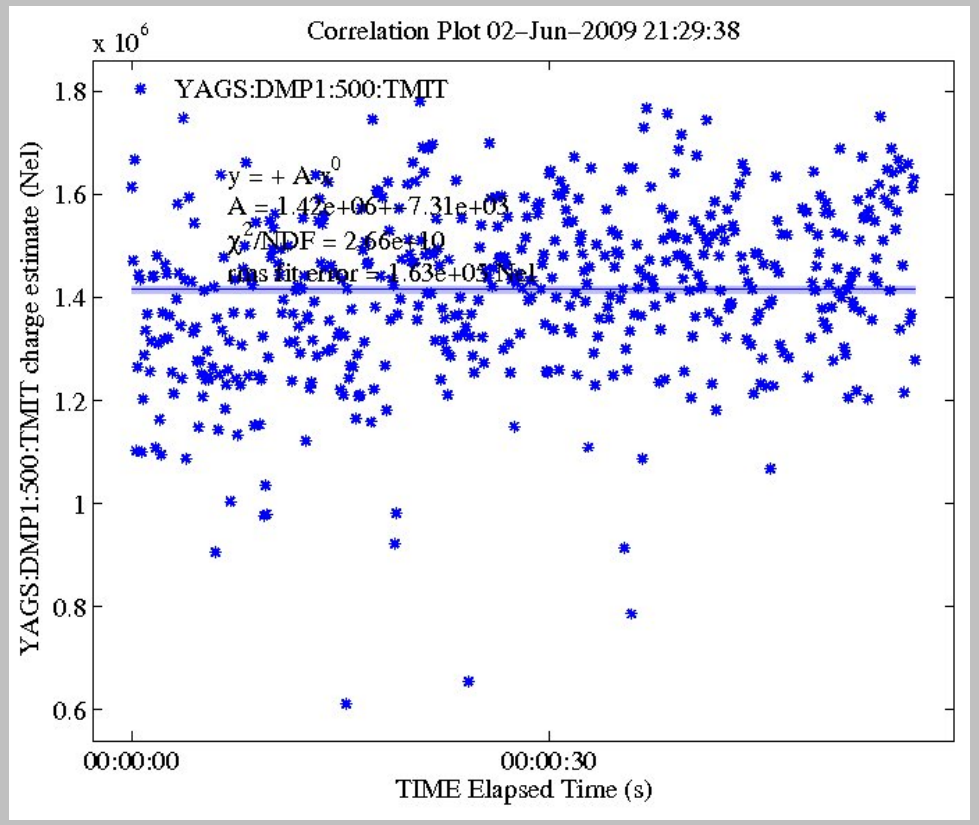
24 Hour operation at 20pC

Beam current (20 pC nominal)



Jitter



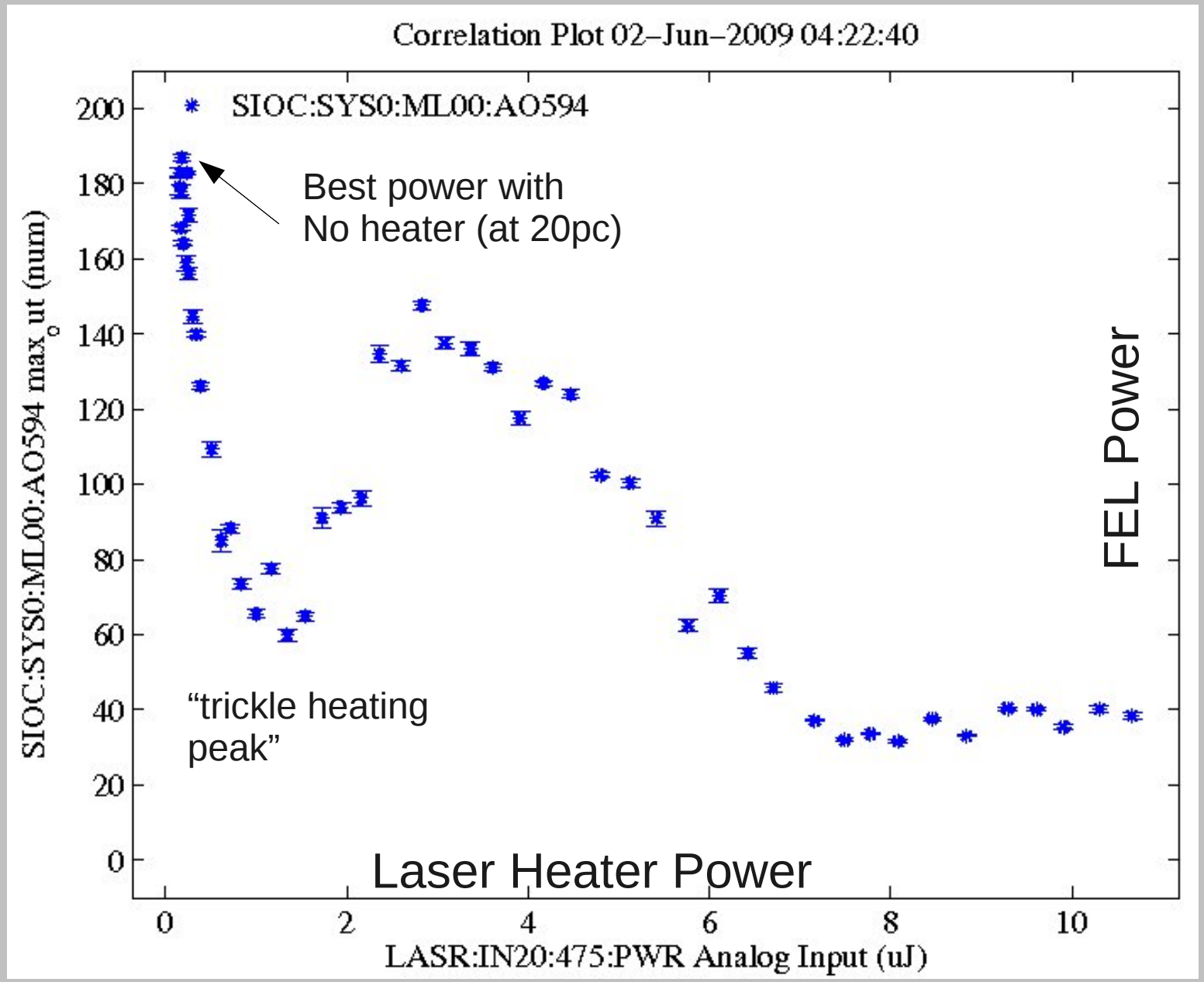


26% RMS jitter at full compression (1 minute)

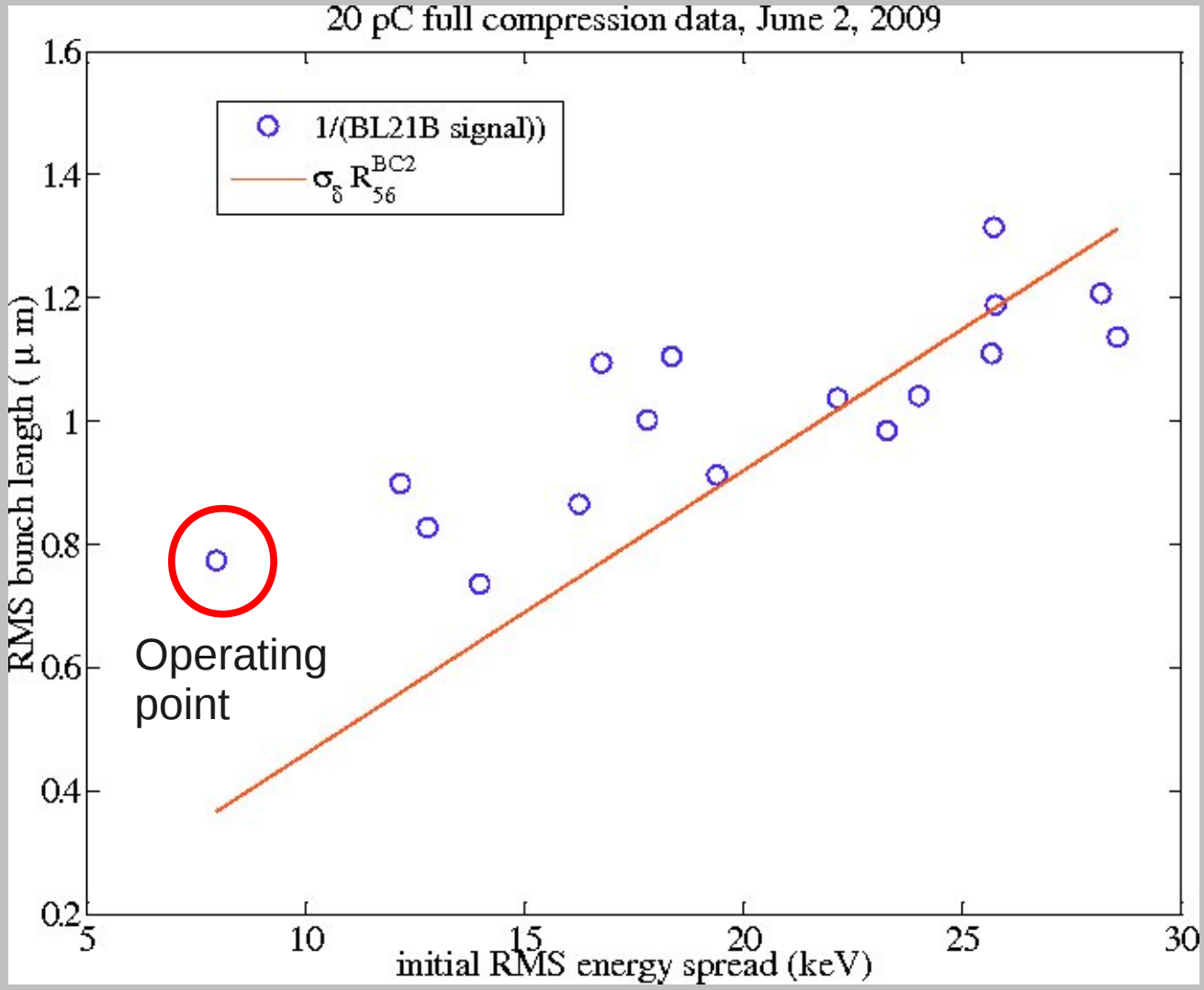
12% RMS Jitter undercompressed

Higher jitter at short bunch - small number of spikes?

Laser Heater Effect

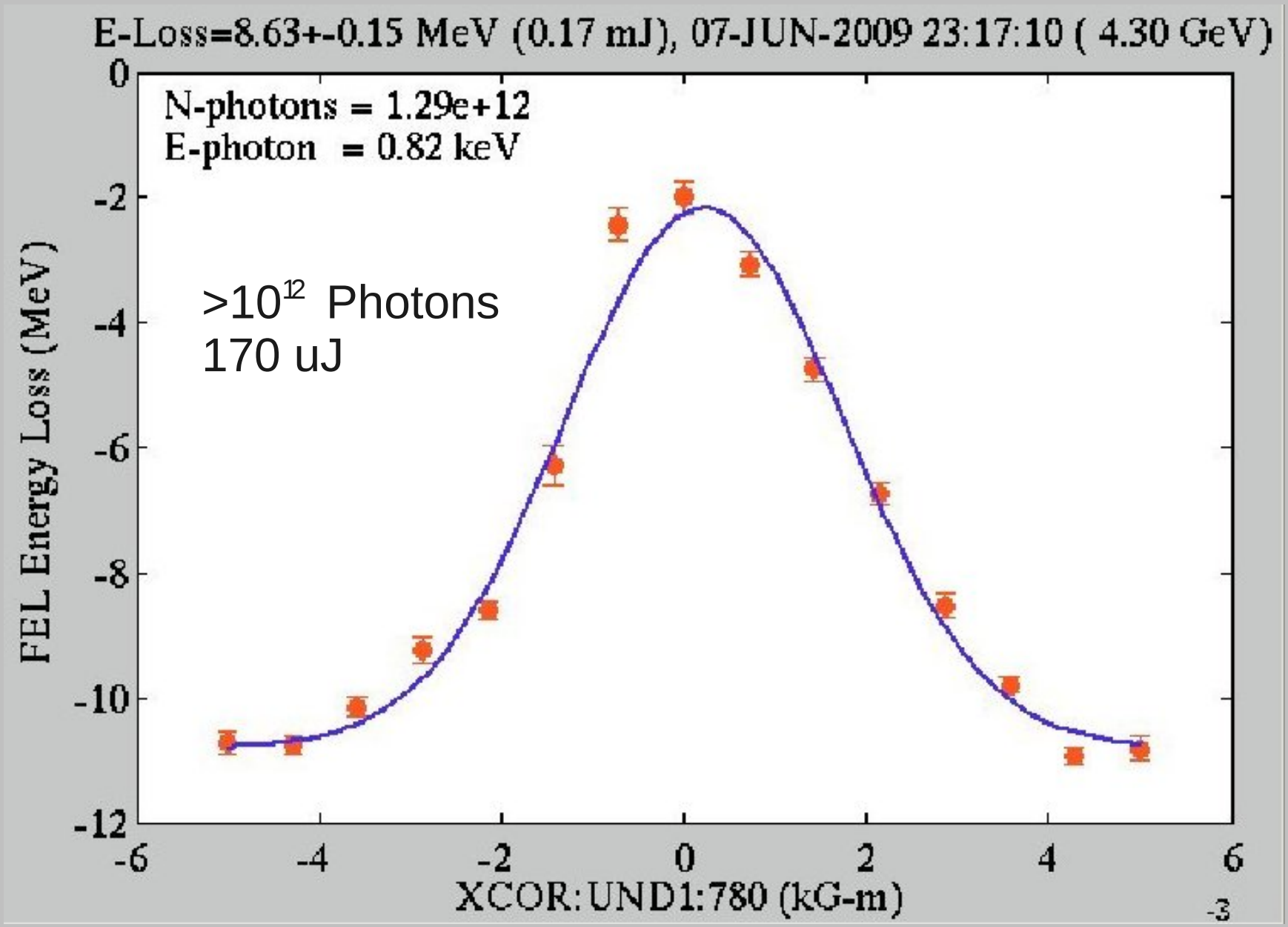


Estimate bunch length from heater

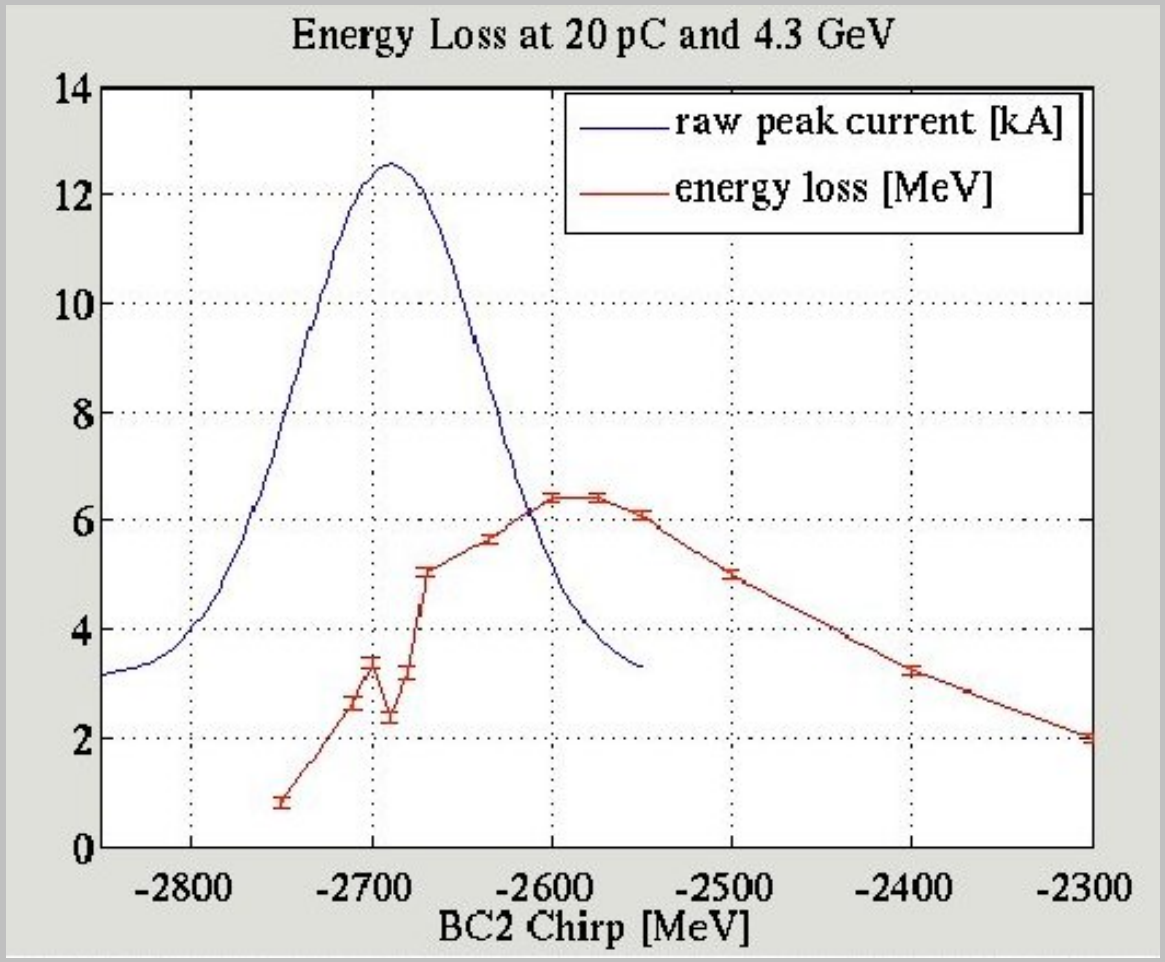


Vary heater, look at (uncalibrated) bunch length monitor
Indicates **2.5fs** RMS bunch length

FEL power at 15Å



Power vs compression at 15Å



Note: Taper was not adjusted during this scan

Peak current measured before dogleg bend

FEL does not operate at full compression at 20pC 4.3 GeV Possibly slippage limit?

How to Measure Bunch Length?

- X-band transverse cavity
  - Straightforward but expenisve
  - Difficult to resolve < ~5fsec FWHM
- Statistical measurement on X-ray spectrum
  - Could measure very short pulses
  - CSR can produce sub-micron modulation on the beam: migth be difficult to interpret the statistics.
- Optical TCAV
  - Great if we can figure out how to do it
- Just ask the experimenters
  - Make it someone else's problem!

Short Bunch Operation Status

- LCLS runs well over full wavelength range with 20pC bunches: **Can deliver to users if they want.**
  - Cannot run at 15Å with full compression
- Bunch length is probably short (<10fs FWHM) but cannot measure directly
  - Decreased power, increased jitter at full compression: Slippage effect
  - Reduced power with laser heater
  - Strong visible COTR emission 10^5 enhancement
- Need a bunch length monitor!