Short Pulse Operation

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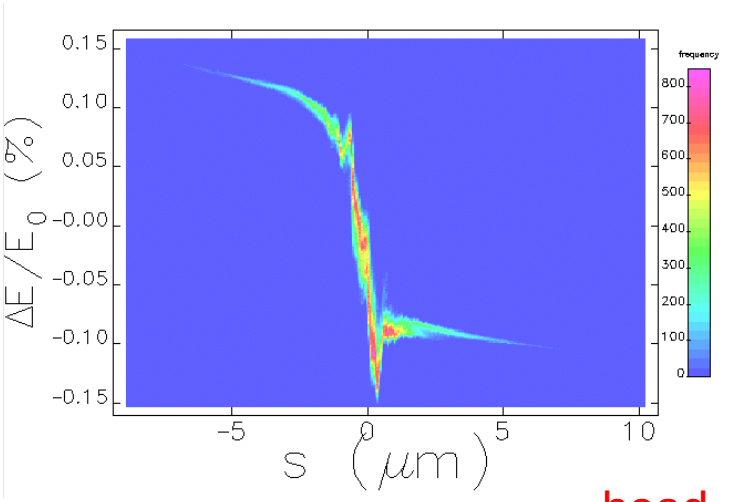
for the LCLS Commissioning Team

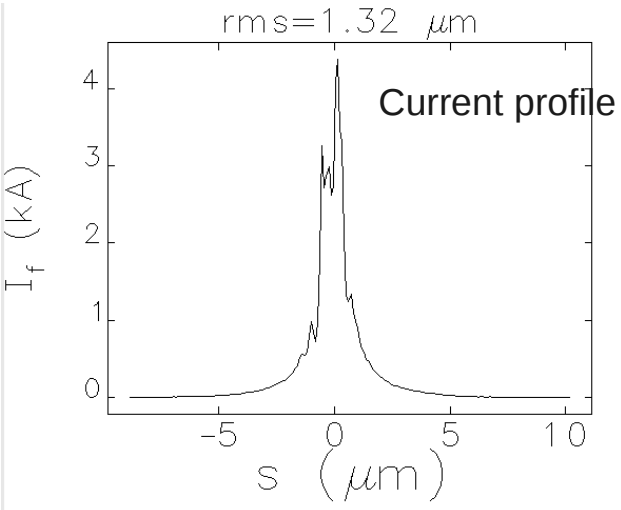
Short Pulse Operation

- **Low Charge**:
  - 20pC expect ~7 fs pulses
  - Lower charge gives better emittance
  - LCLS has operated at 20pc from 15Å to 1.5Å.
- **Emittance spoiling** (slotted foil)
  - Spoil of all but a small part of the electron bunch
  - Foil in second bunch compressor
- **Laser manipulation:** See A. Zholents talk

1.5Å 20pC Simulations

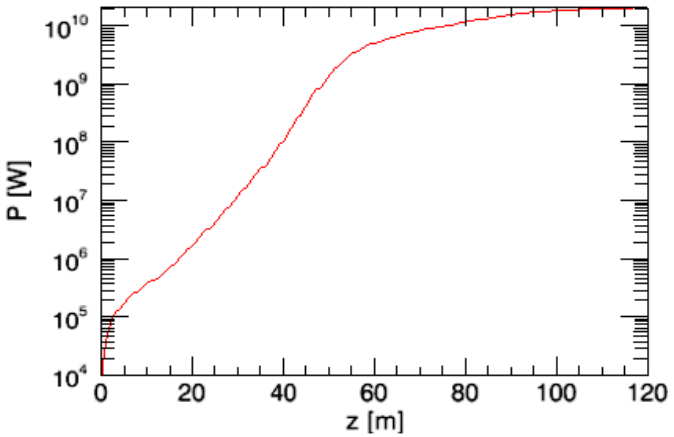
Longitudinal phase space



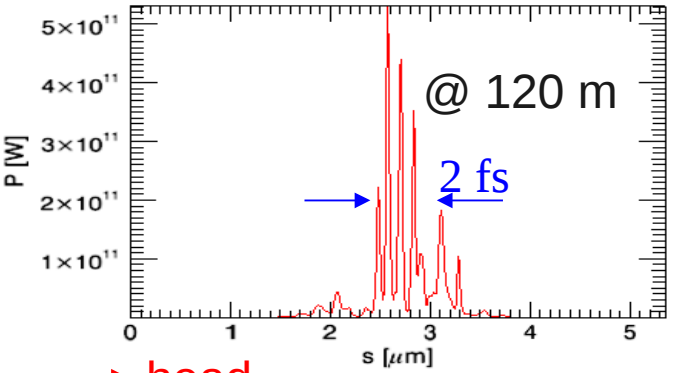


head

Average FEL power along undulator



X-ray FEL power profile



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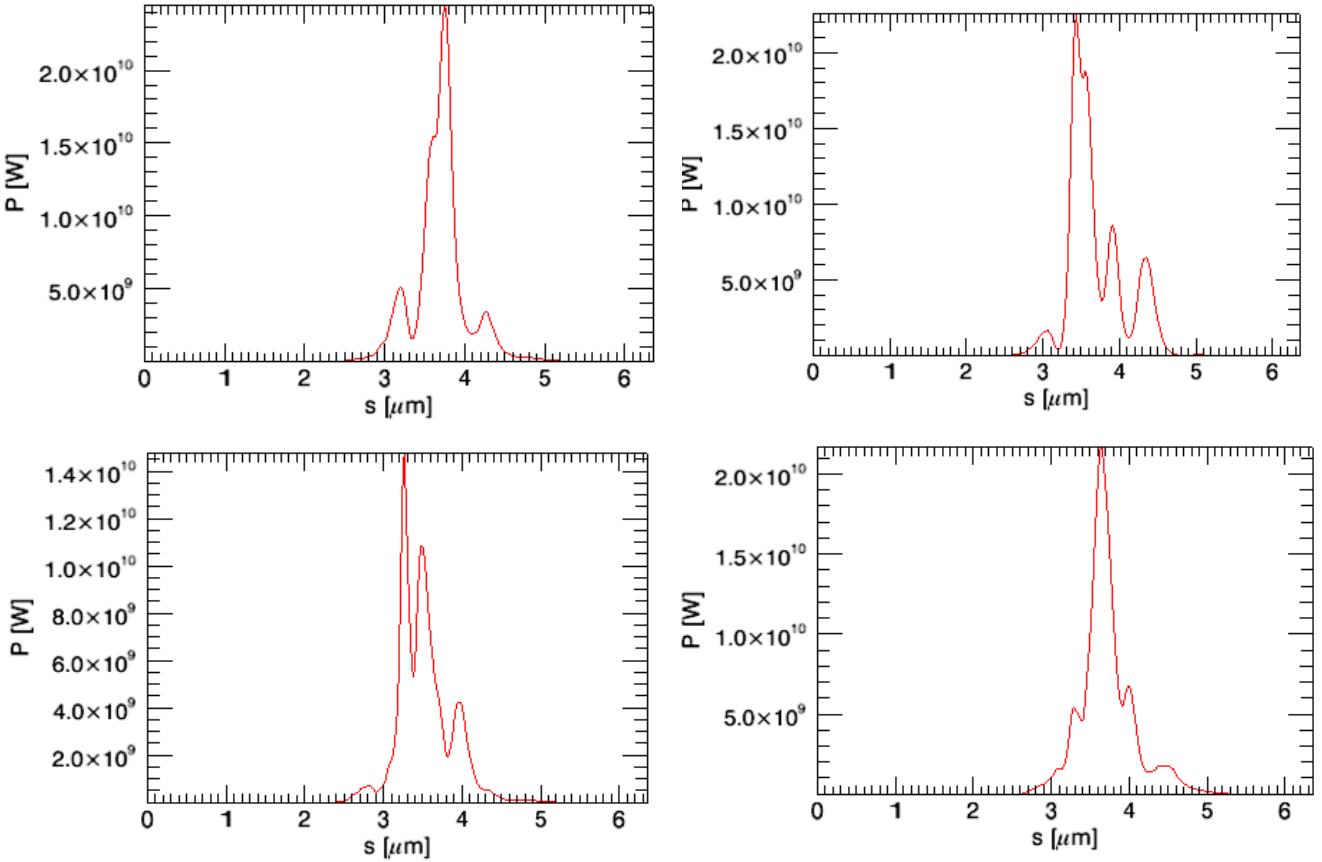
2.8e11 photons

Yuantao Ding

15 Å Simulations



Examples of 4 shots.

Average photon number: 2.4x10^{11} , with 20% fluctuation.
Estimated time-bandwidth product ~ 3 times Fourier-transform limit.

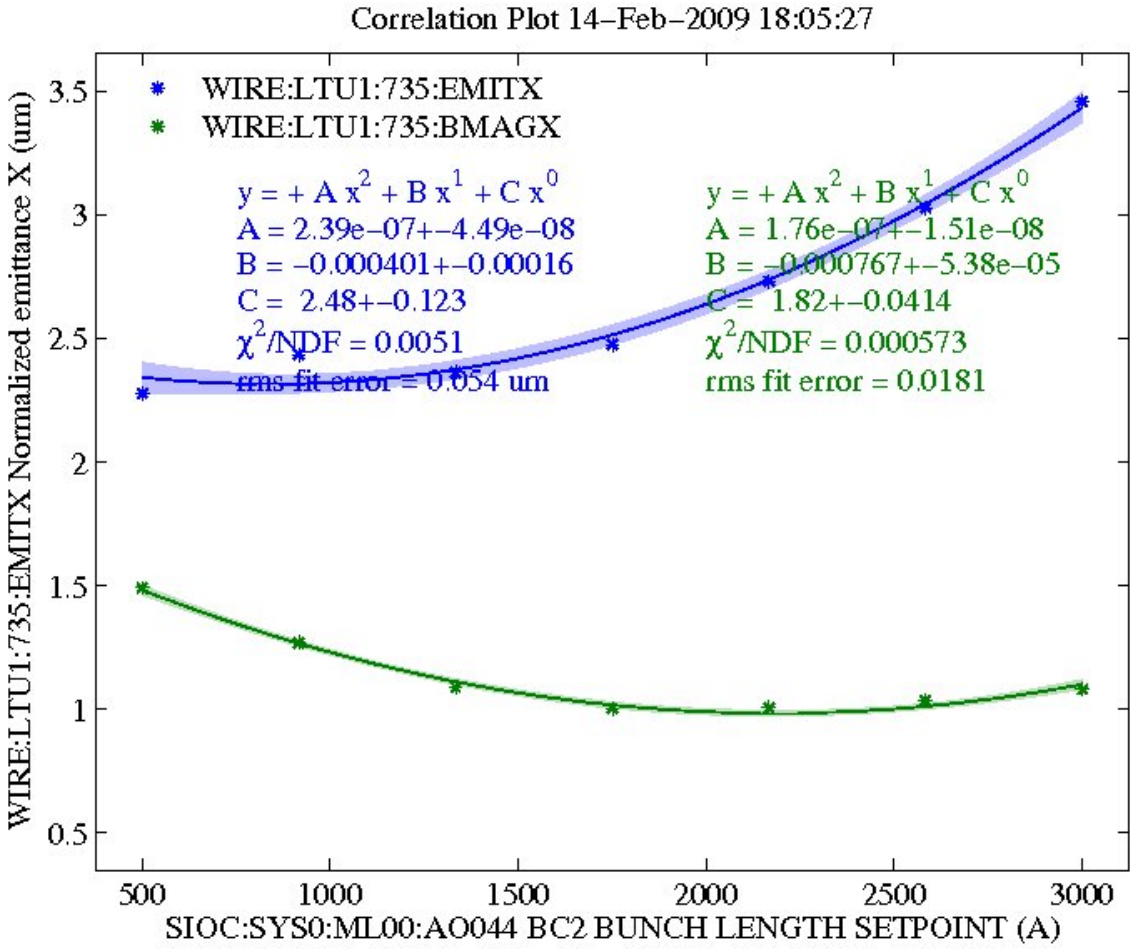
Peak Current Limit

- At high peak beam currents above CSR beam breakup degrades the emittance of the LCLS beam.

Limit depends somewhat on beam charge and energy but the FEL does not operate well above 2000-3000 Amps

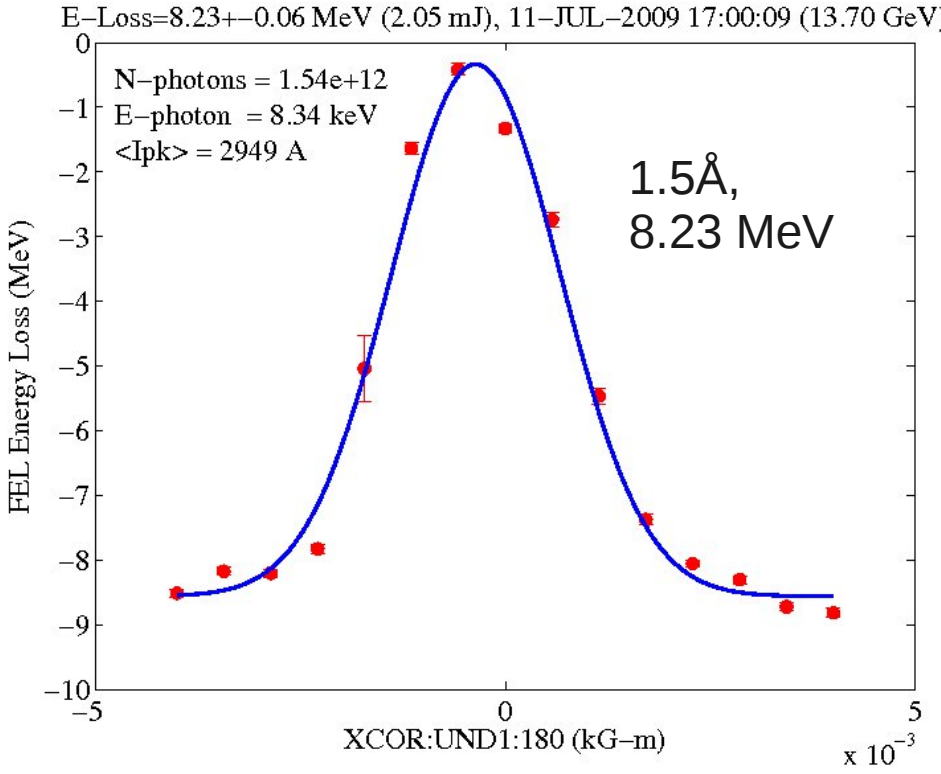
This example is at 4.3 GeV 250pC

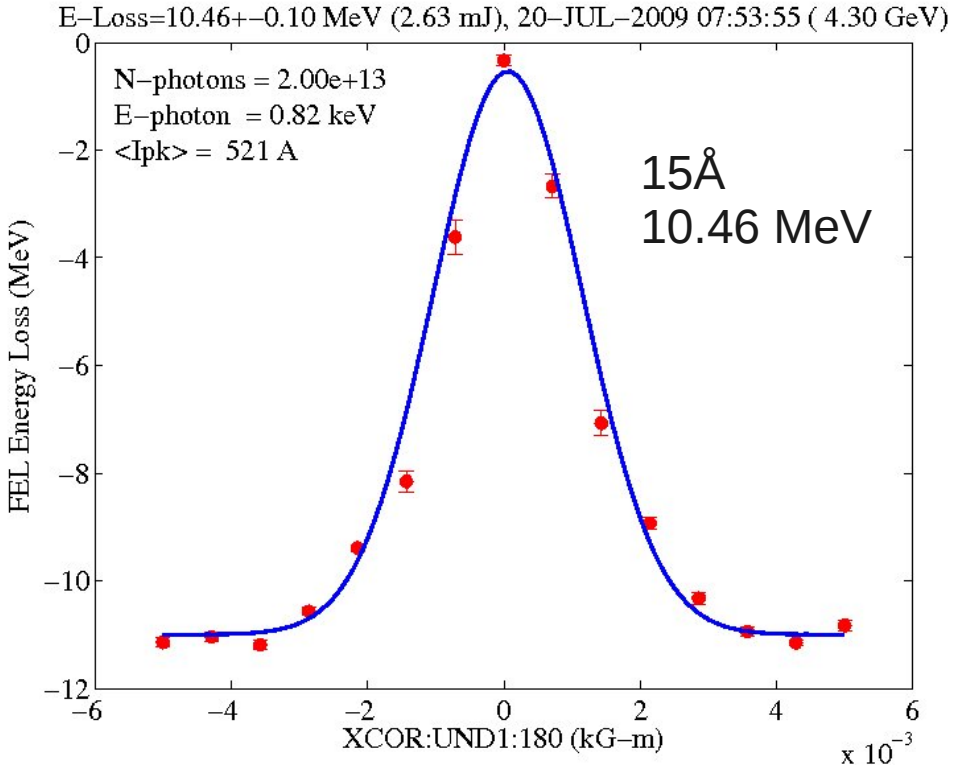
LCLS bunch compressors already optimized for maximum peak current without beam breakup – not a lot to gain here without new accelerator physics ideas.



Energy Extraction Limit

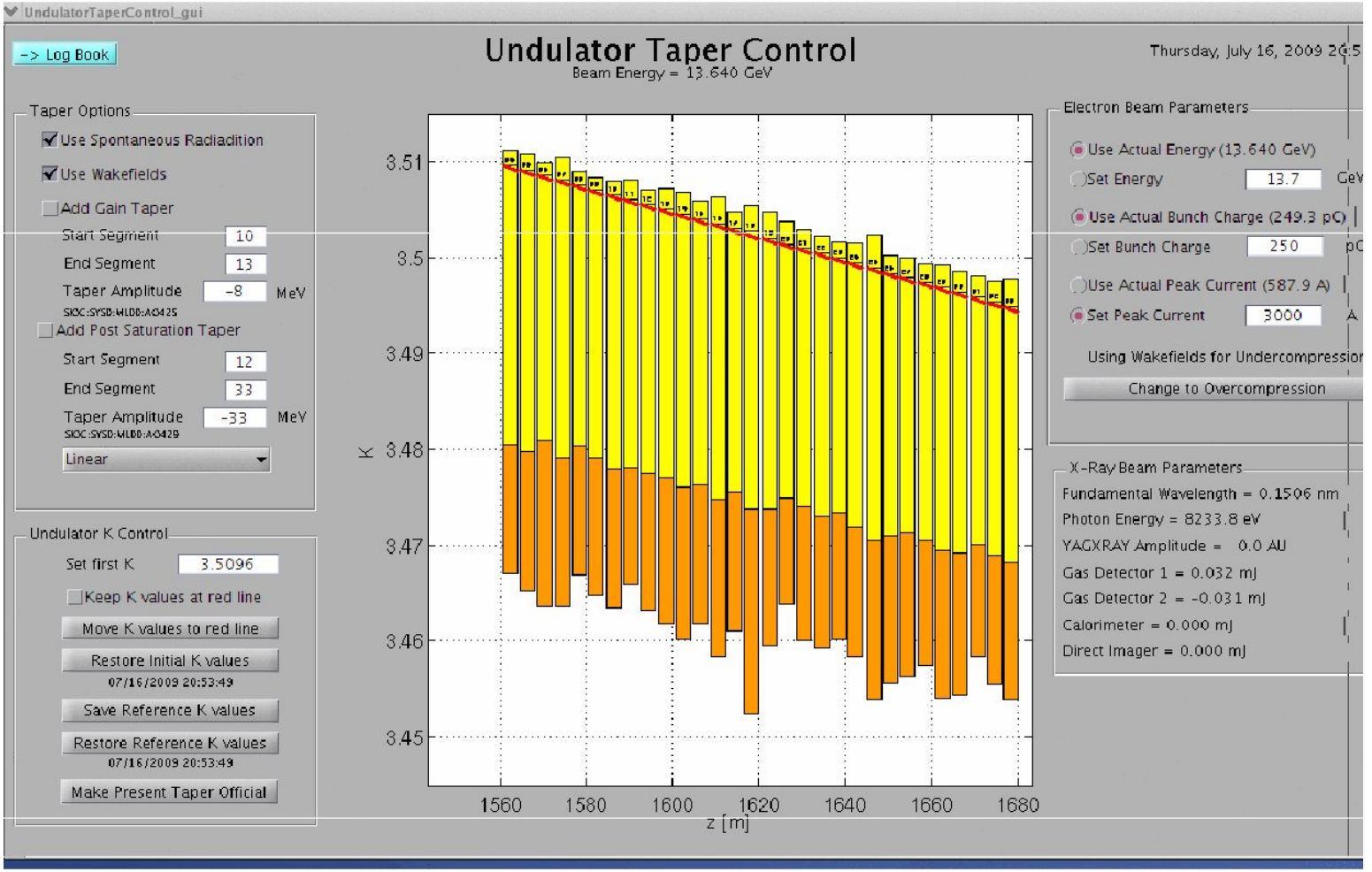
- At LCLS we see a maximum energy extraction of about 10 MeV. (at 250pC and 20pC)





Undulator Taper

Taper for spontaneous and wakefields shown



Undulator taper range from K = 3.51 to K = 3.47: Will stay in phase for a 1% energy extraction.

Approximately ½ of that range needed for spontaneous radiation energy loss and wakefield energy loss

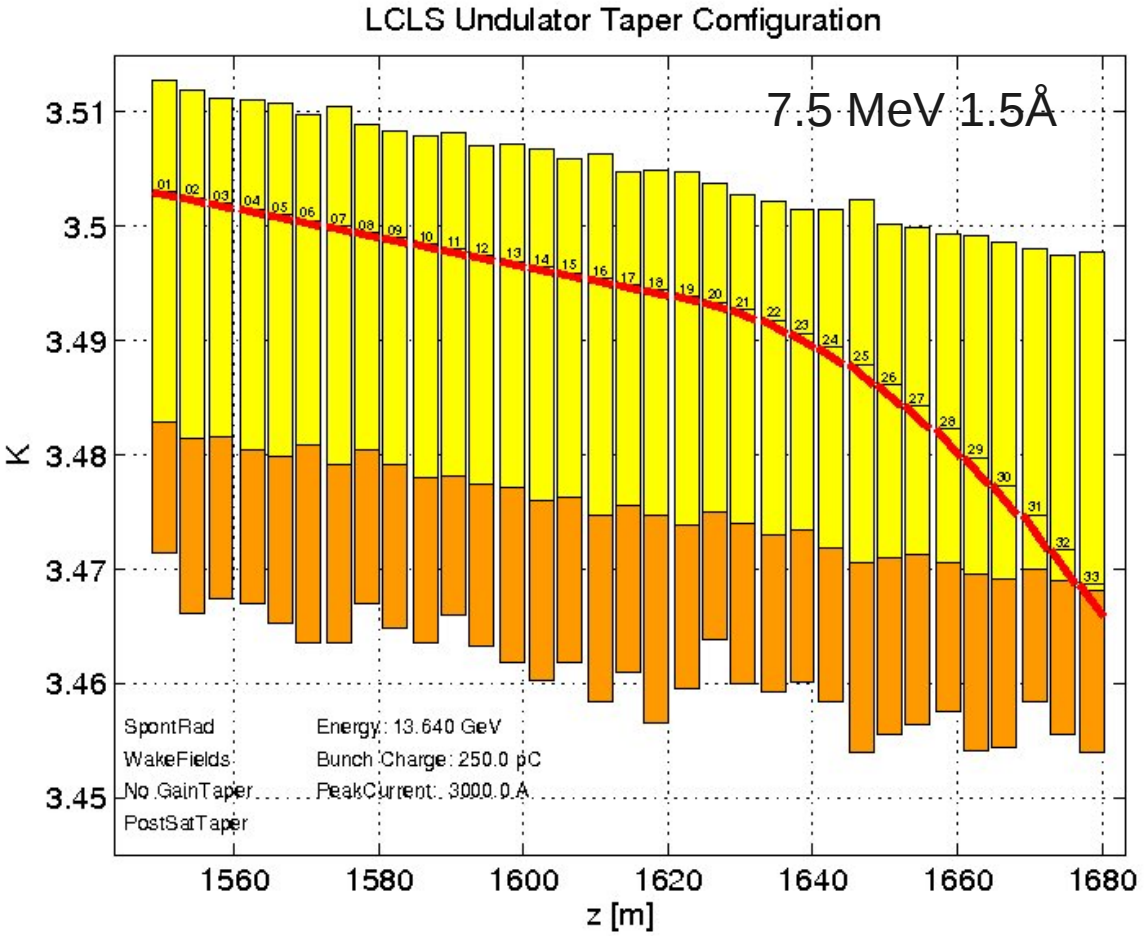
Energy Extraction Taper

Generally see maximum FEL power when taper is adjusted to make full use of range of K.

This should give ~0.5% extraction
20 MeV at 15Å
70 MeV at 1.5Å

Actual maximum extraction ~10MeV

No all electrons are loosing full energy.

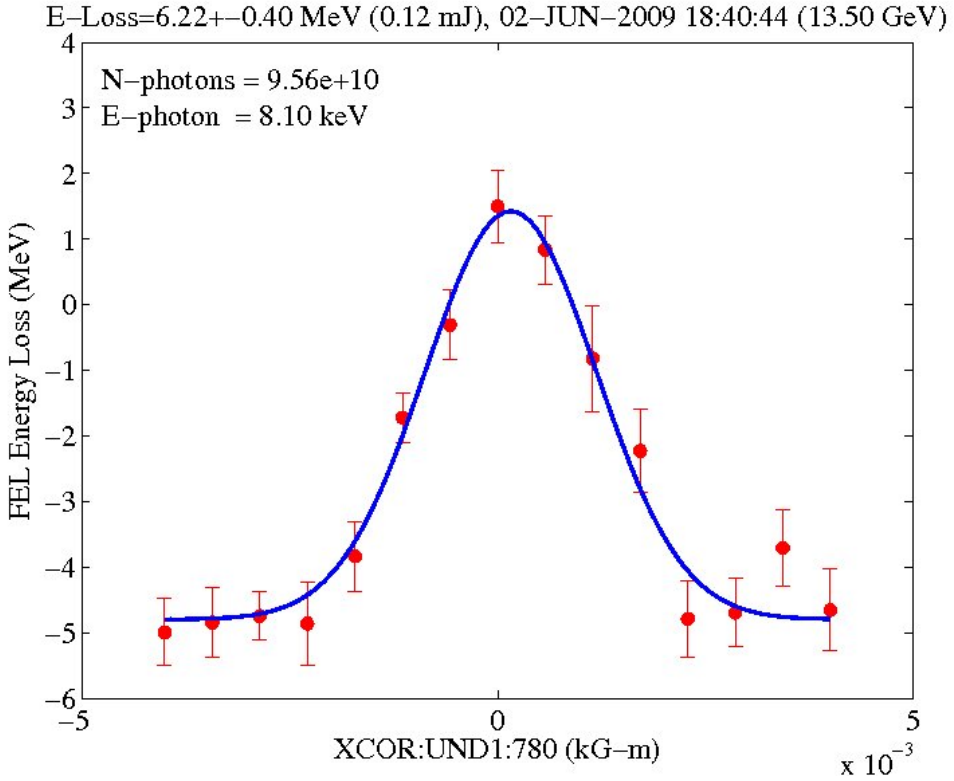


It appears that our maximum peak power is limited by (peak_current) X (energy_extraction) ~ 30GW (assuming X-ray pulse length is similar to the electron pulse length)

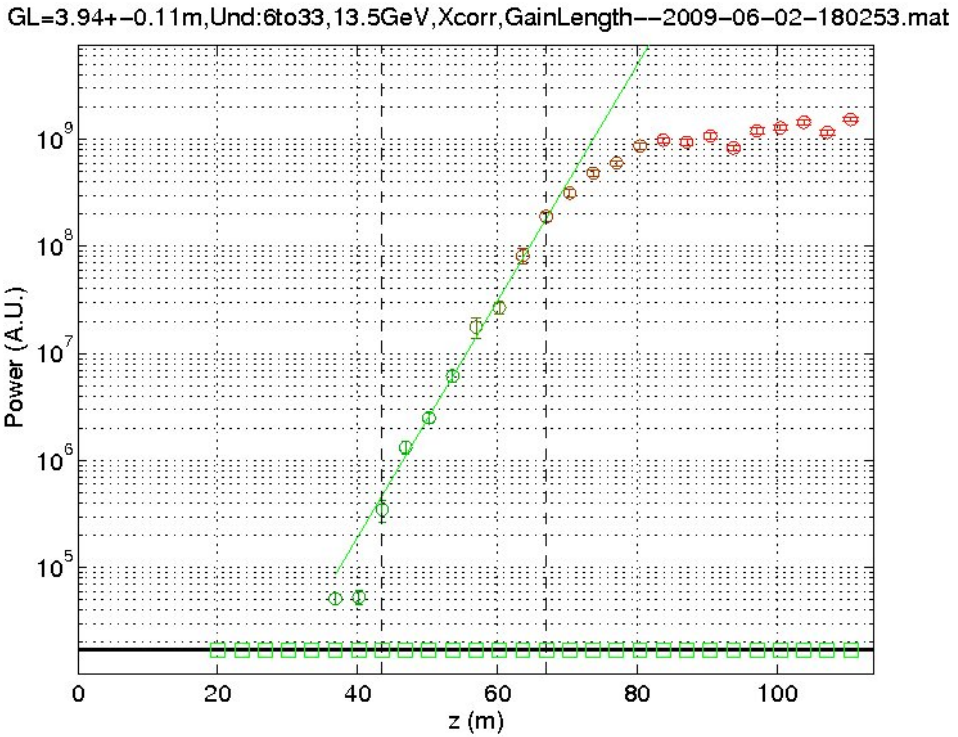
Short Pulse Diagnostics Issues

- Beam position monitors only work reliably for charges >20pC
- Transverse cavity bunch length monitor resolution limited to ~10 femtoseconds RMS.
- Peak current monitor uncalibrated for short bunches
- We can measure the X-ray pulse energy but not the pulse length!

20pC operation - 1.5Å

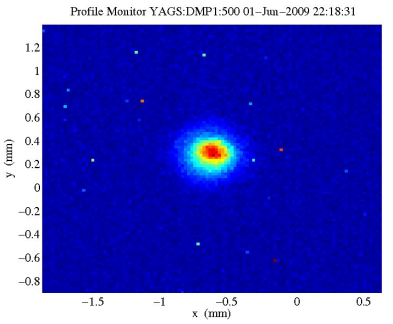


6.7 MeV energy loss with beam at maximum compression
120 uJ, 9x10^{10} photons. (3x lower than simulation)



Good gain length (~4M) implies high peak current and short bunch, but no direct measurement

Good FEL Spot



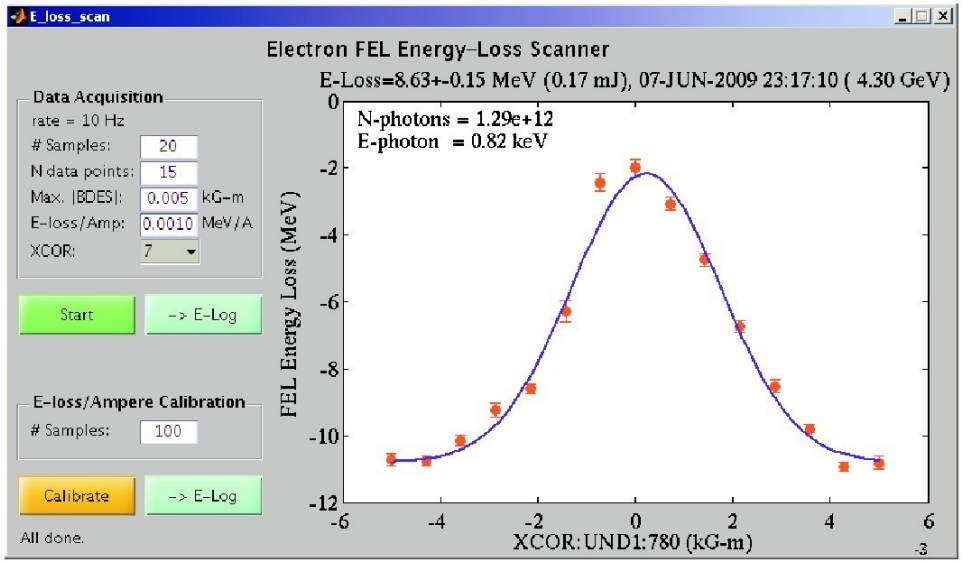
20pC operation at 15Å

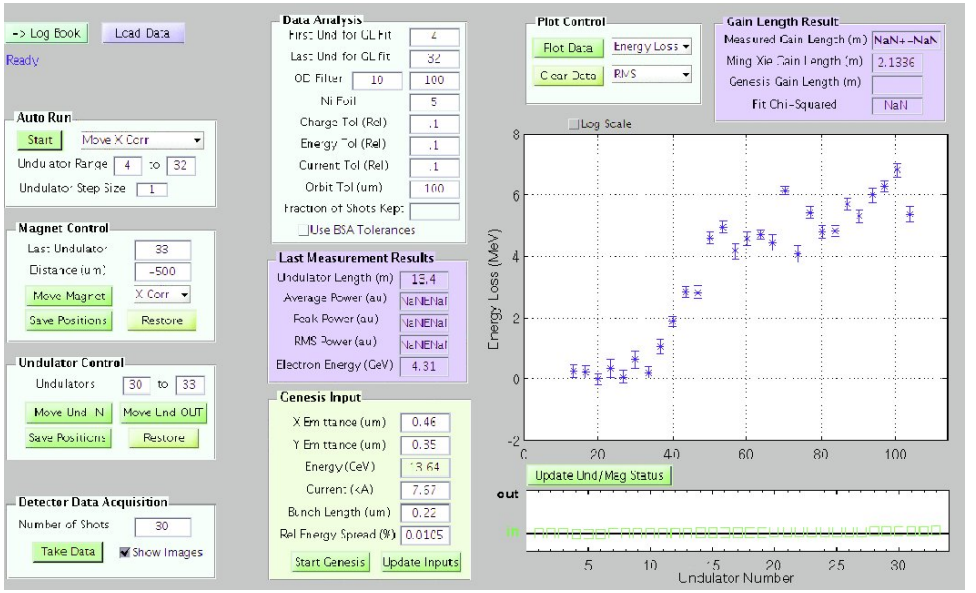
FEL did not operate at maximum compression, actual pulse length not known.

Energy loss 8.63 Mev (170uJ)
1.3×10^{12} photons
This is 4X higher than in simulation

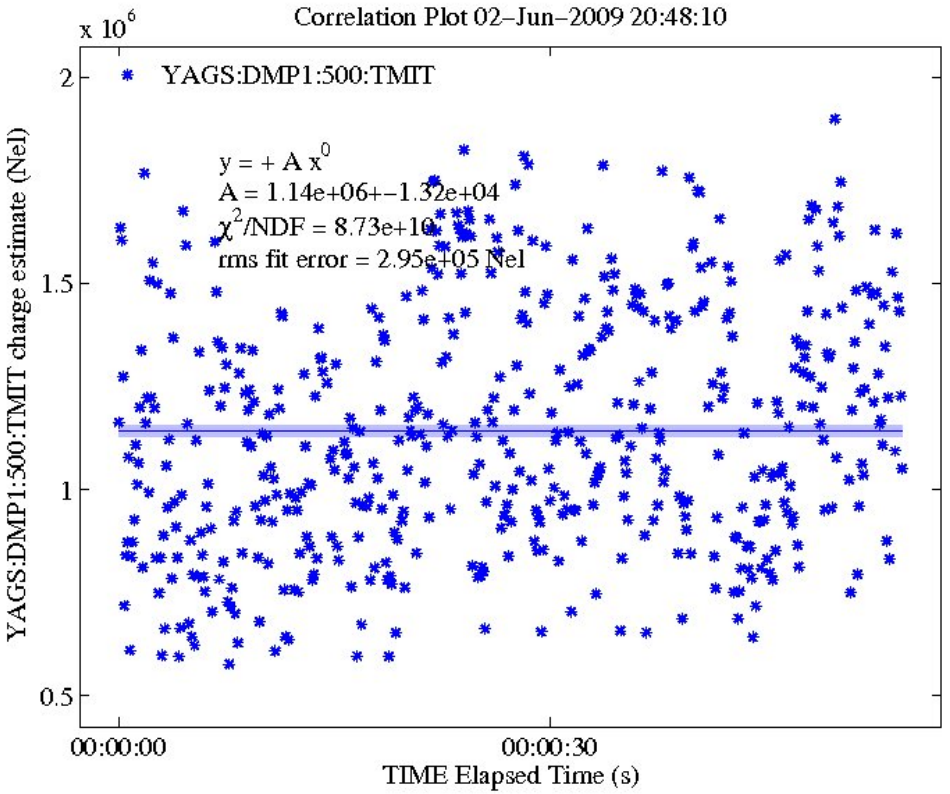
Simulation does not include taper
Pulse probably longer than in simulation

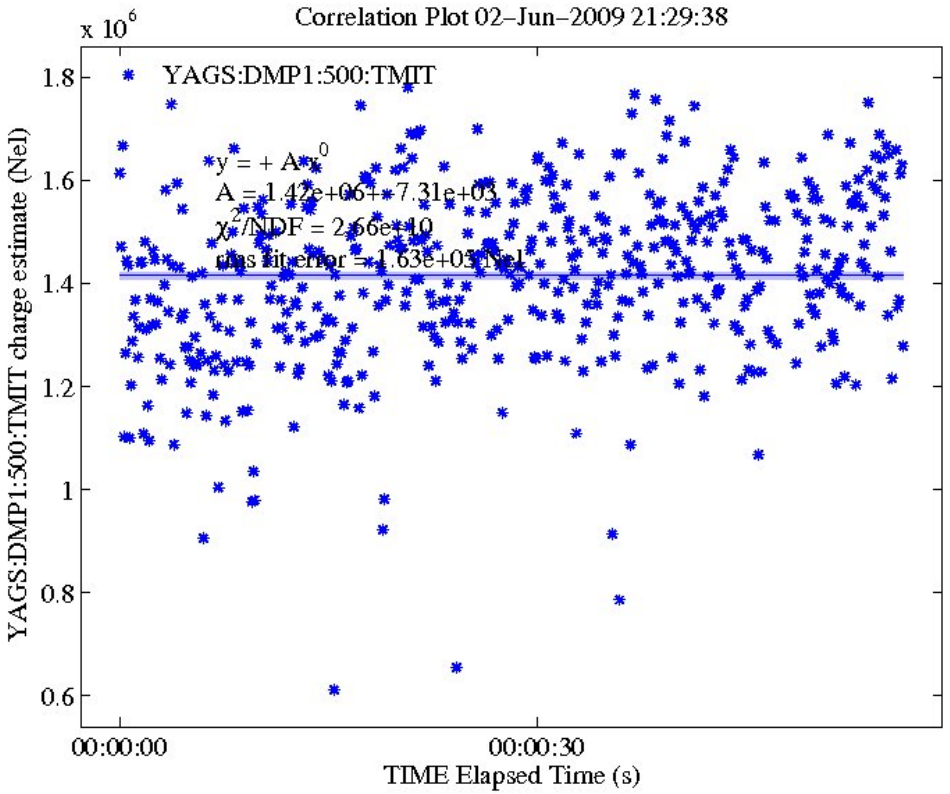
High gain suggests pulse is short





Stability



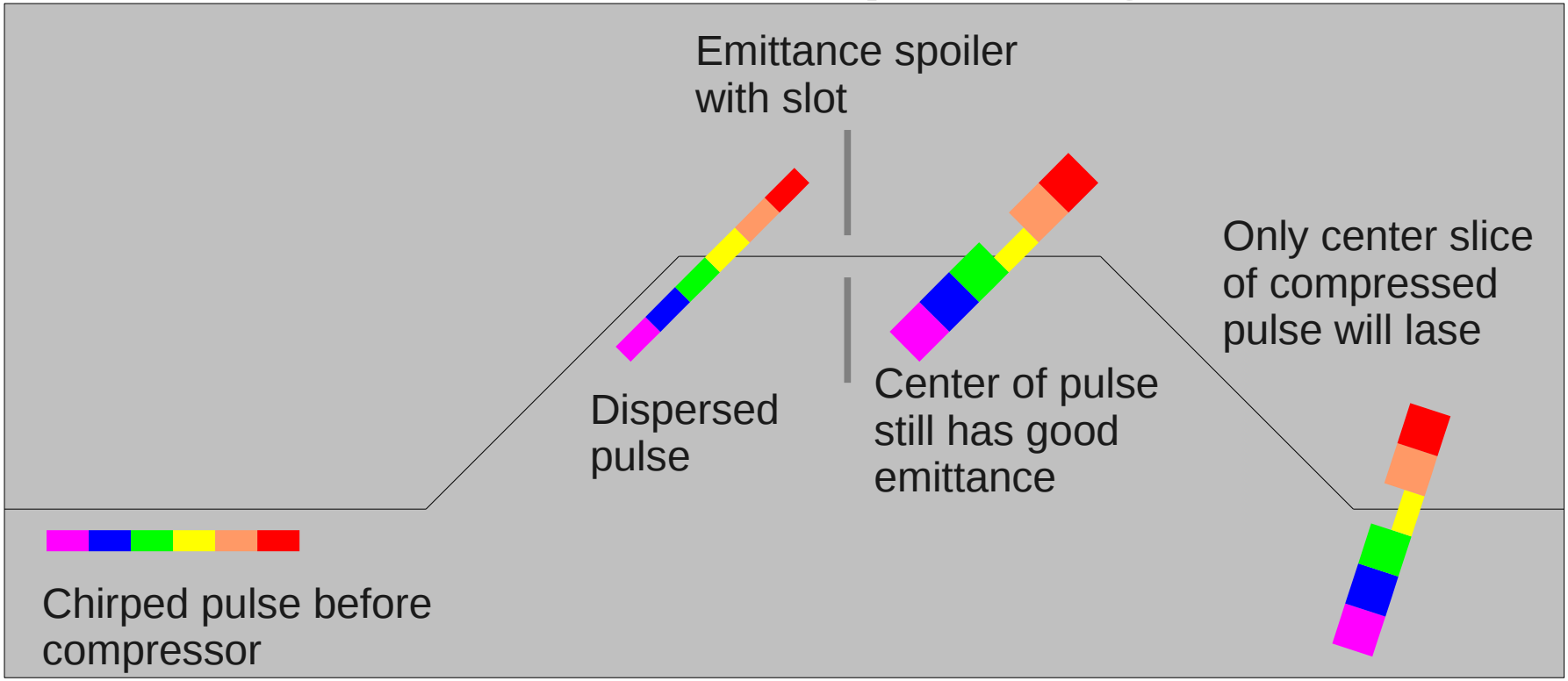


Intensity jitter at full compression 1.5Å
20pC = 25% RMS

Intensity jitter overcompressed 1.5Å
20pC = 11% RMS

With beam feedbacks on, machine would run for hours without operator tuning

Emittance Spoiling foil



Operate accelerator in normal 250pc mode, but only a small part of the bunch will lase

Advantages:

better stability as klystron phases change (smaller compression ratio)
May work with even shorter bunches – not limited by diagnostics

Disadvantages:

Does not make use of low emittances from low charge operation, peak power probably lower

Beam Timing

- LCLS accelerator has ~50 femtosecond RMS jitter relative to a “perfect” clock
- Expect to provide beam synchronous timing data relative to the experimenter lasers
  - Specification is <50 femtoseconds
  - Hope to do better
  - Few femtoseconds probably is the limit for RF technology.
- For ultra-short bunches need direct laser to X-ray measurements.

Short Bunch Developments

- Need bunch length diagnostics!
  - Advanced TCAV or FIR / mm-wave spectrometer could measure electron beam.
  - X-ray beam may have a different bunch length than electrons
- If this mode is interesting to users, need more operating experience / machine tuning and feedbacks
- No clear path to peak powers above 10s of GW.