Reducing LCLS injector emittance

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SLAC

8th 5-way Hard x-ray collaboration meeting
Pohang, October 24-26

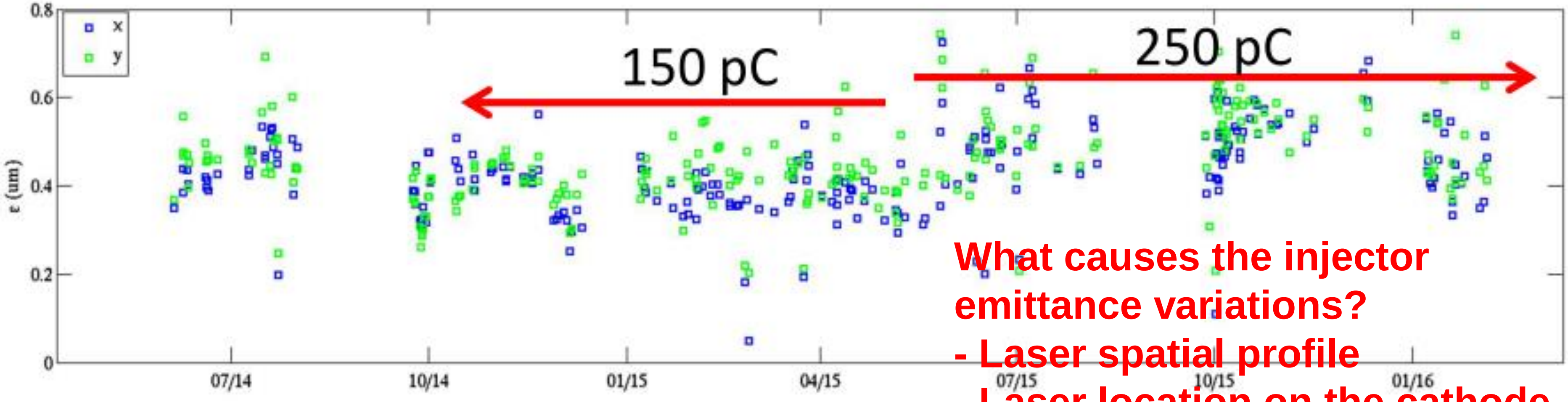
Studies for LCLS injector emittance reduction

- Controlling drive laser spatial profile and optimizing laser location on the cathode
- Lengthening photocathode drive laser pulse
- Circularly collimating e-beam in the injector area
- Multi-parameter optimization

Photocathode laser spatial profile

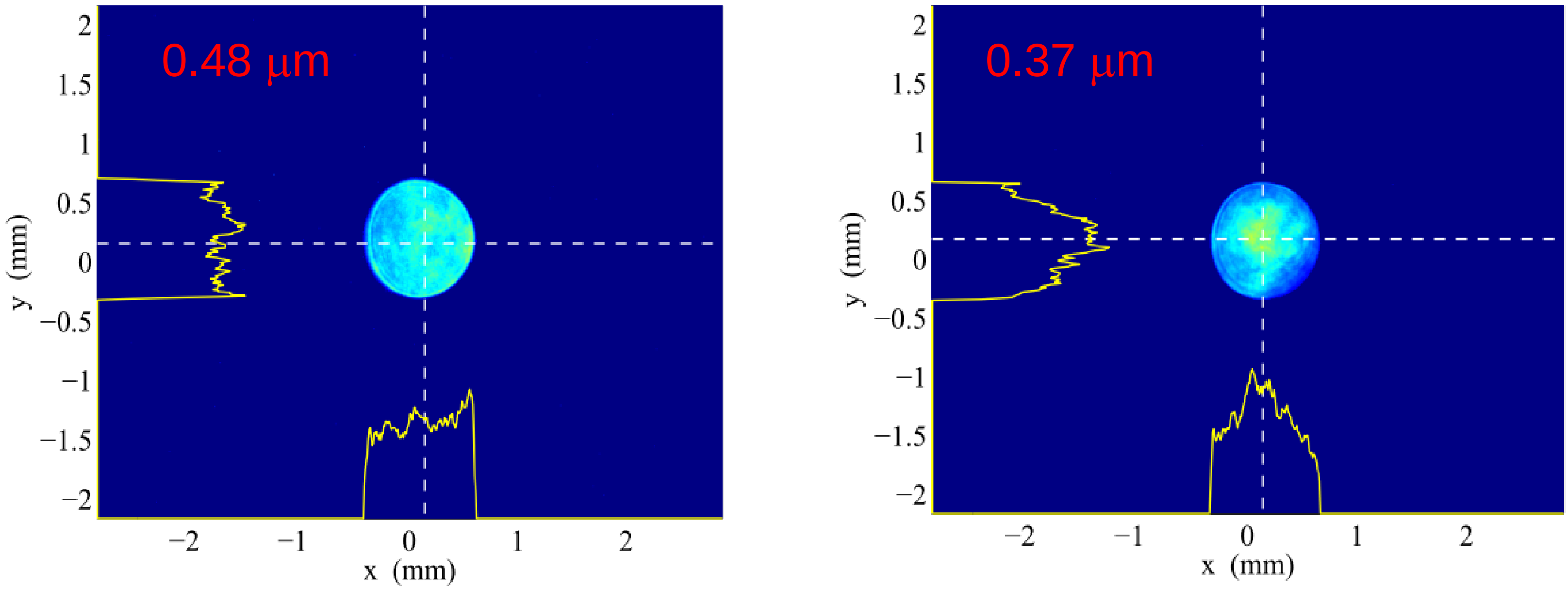
What we learned from LCLS operation:

- Soft XFEL performance is insensitive to photocathode laser profile variation and laser location on the cathode
- Hard XFEL performance is sensitive to spatial laser profile variation and laser location on the cathode



What causes the injector emittance variations?
- Laser spatial profile
- Laser location on the cathode

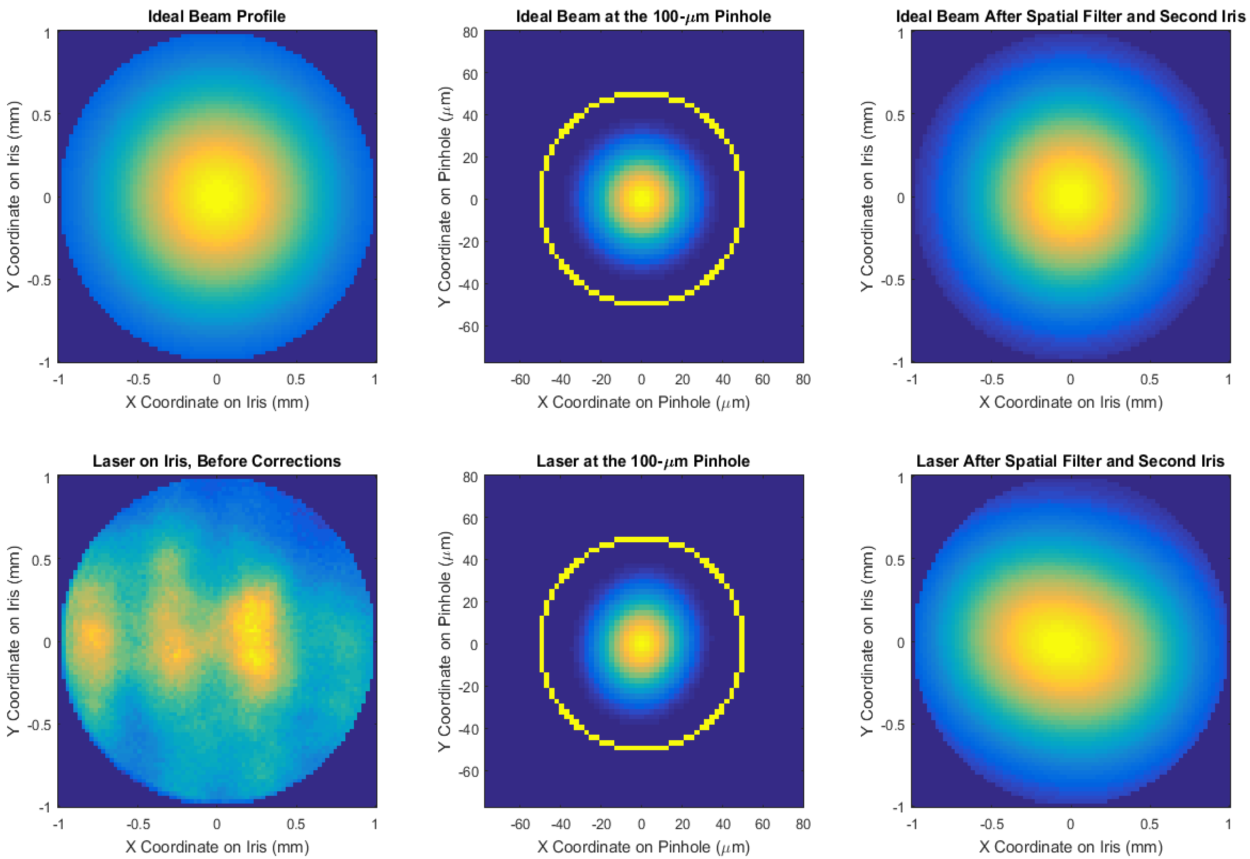
Example: impact of spatial laser profile variation



- Challenge is to reproduce/control the truncated-Gaussian laser profile through weeks of operation and/or after necessary laser maintenance work.

Control of photocathode spatial laser profile

- Deformed mirror device (Li/Ratner *et al*., NA-PAC16)
- Laser spatial filter



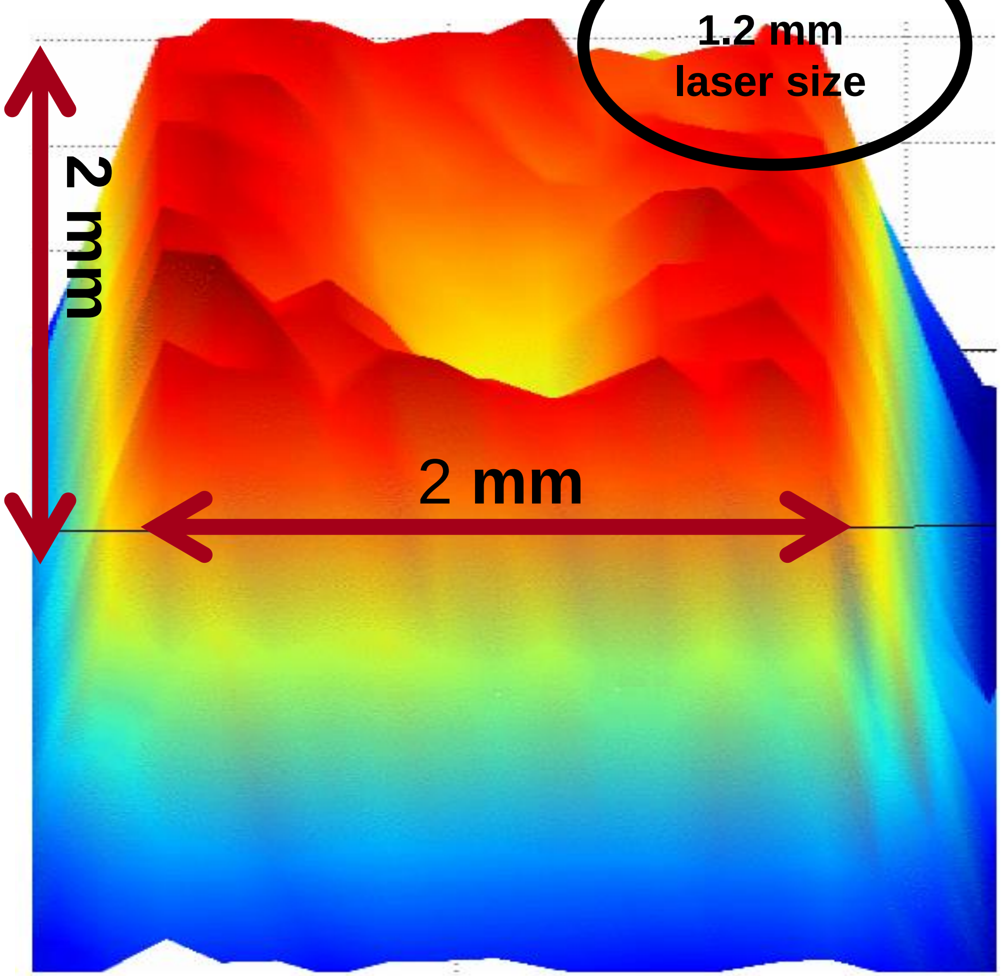
Spatial filter under test at LCLS for issues:

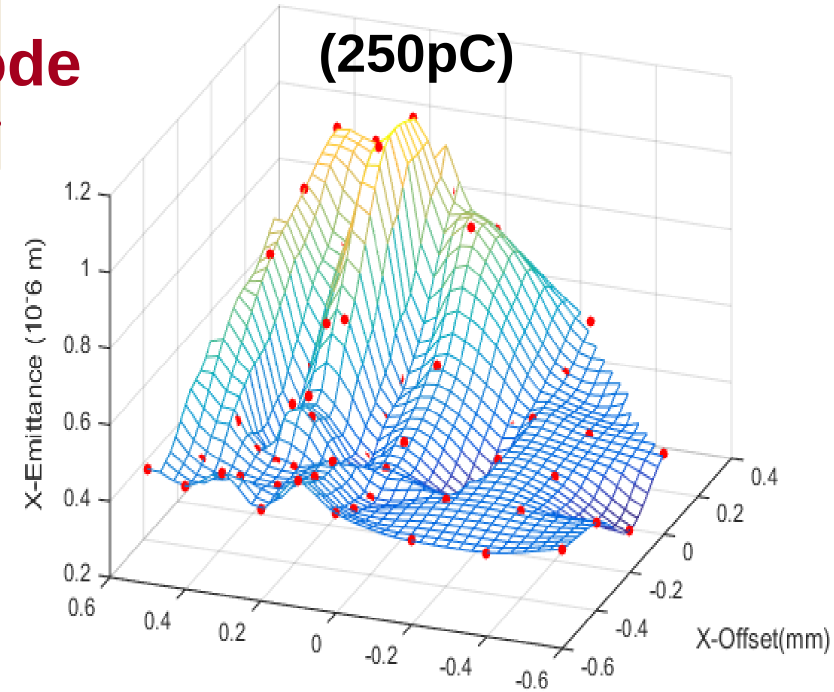
- Damage issues
- Beam loss
- Pointing stability
- Reliability

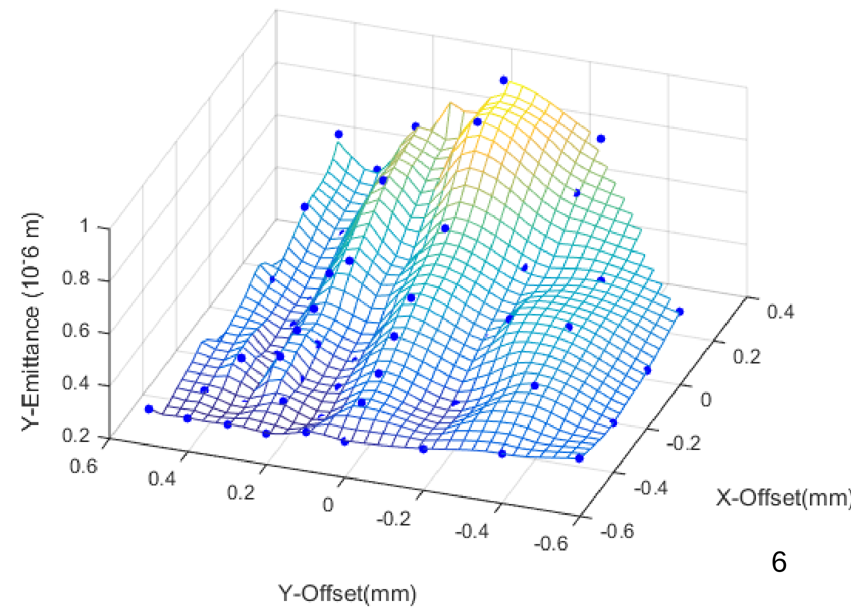
Alan Fisher

Impact of laser location on cathode

After 5.5 years operation







Impact of laser location on cathode (grain)

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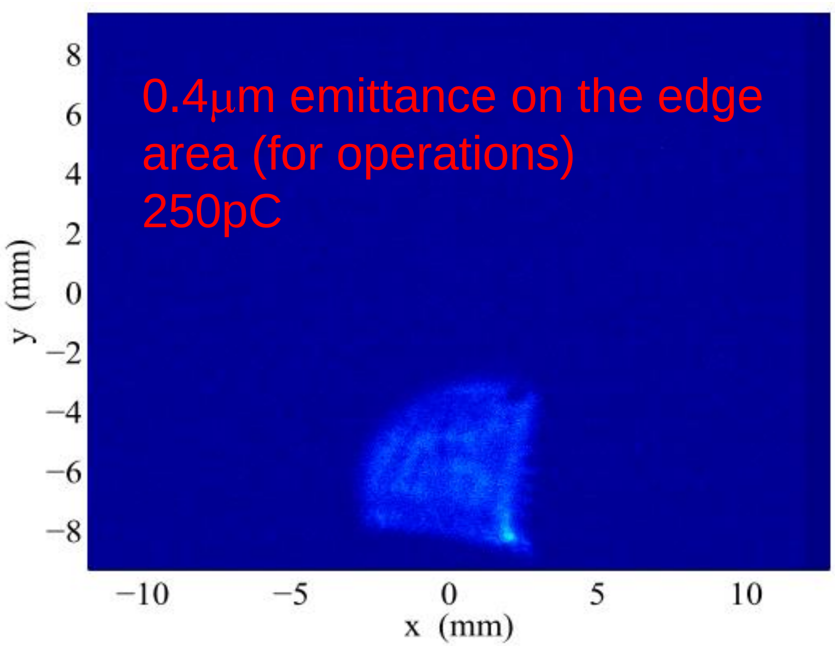
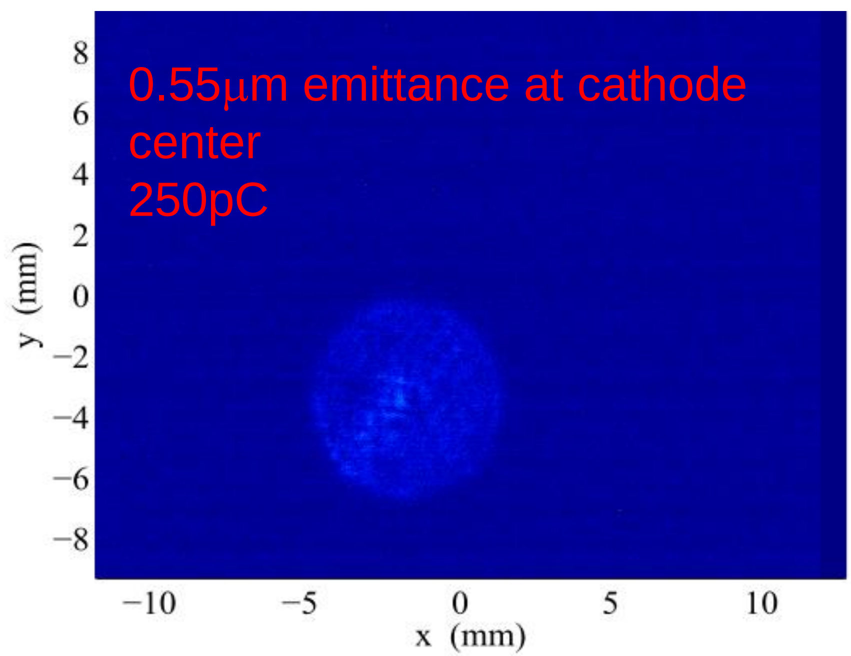
Simulation (but without including cathode grain quality info) shows the emittance of the electron emission is >0.7μm

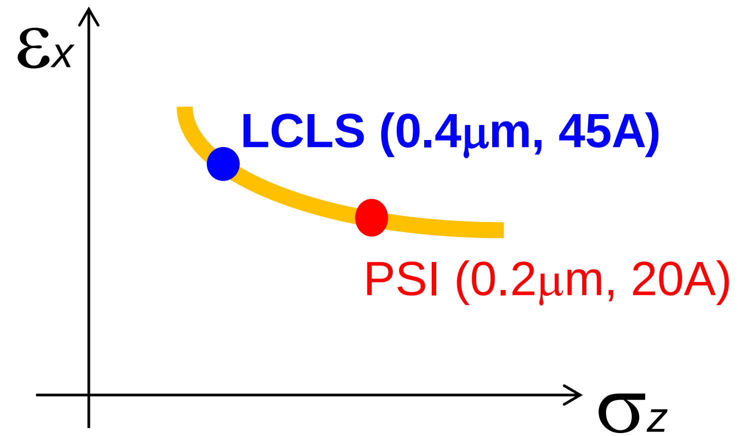
- But the actual measured emittance is great, only 0.4μm
- Does the grain quality dominate the emittance?



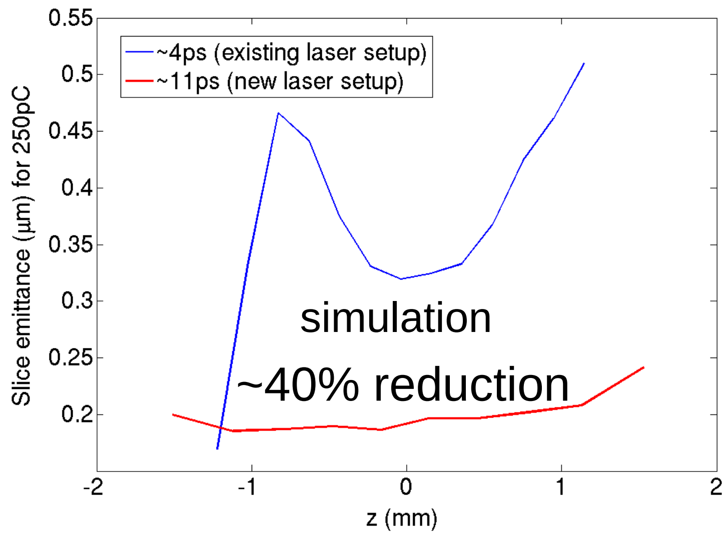


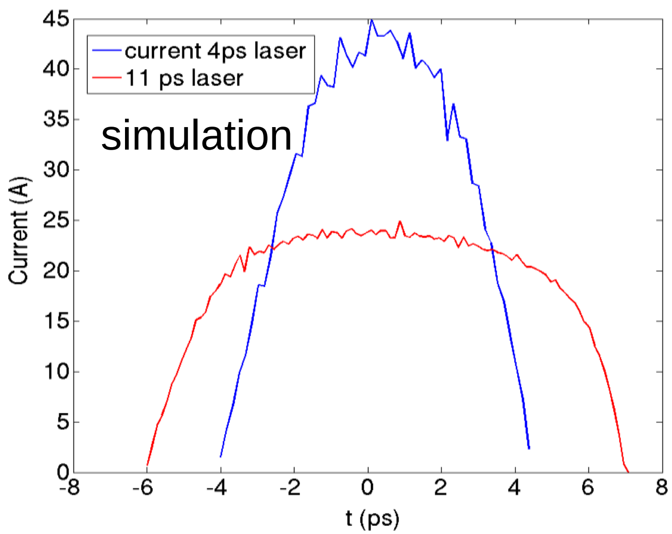
Lengthening drive laser pulse – I_{peak} reduction

- Typical Pareto Front (ε_x vs. σ_z)
- Simulations show that the LCLS emittance can be reduced from 0.4 μm to 0.2 μm with 11ps FWHM laser for 250 pC without change of beamline layout.

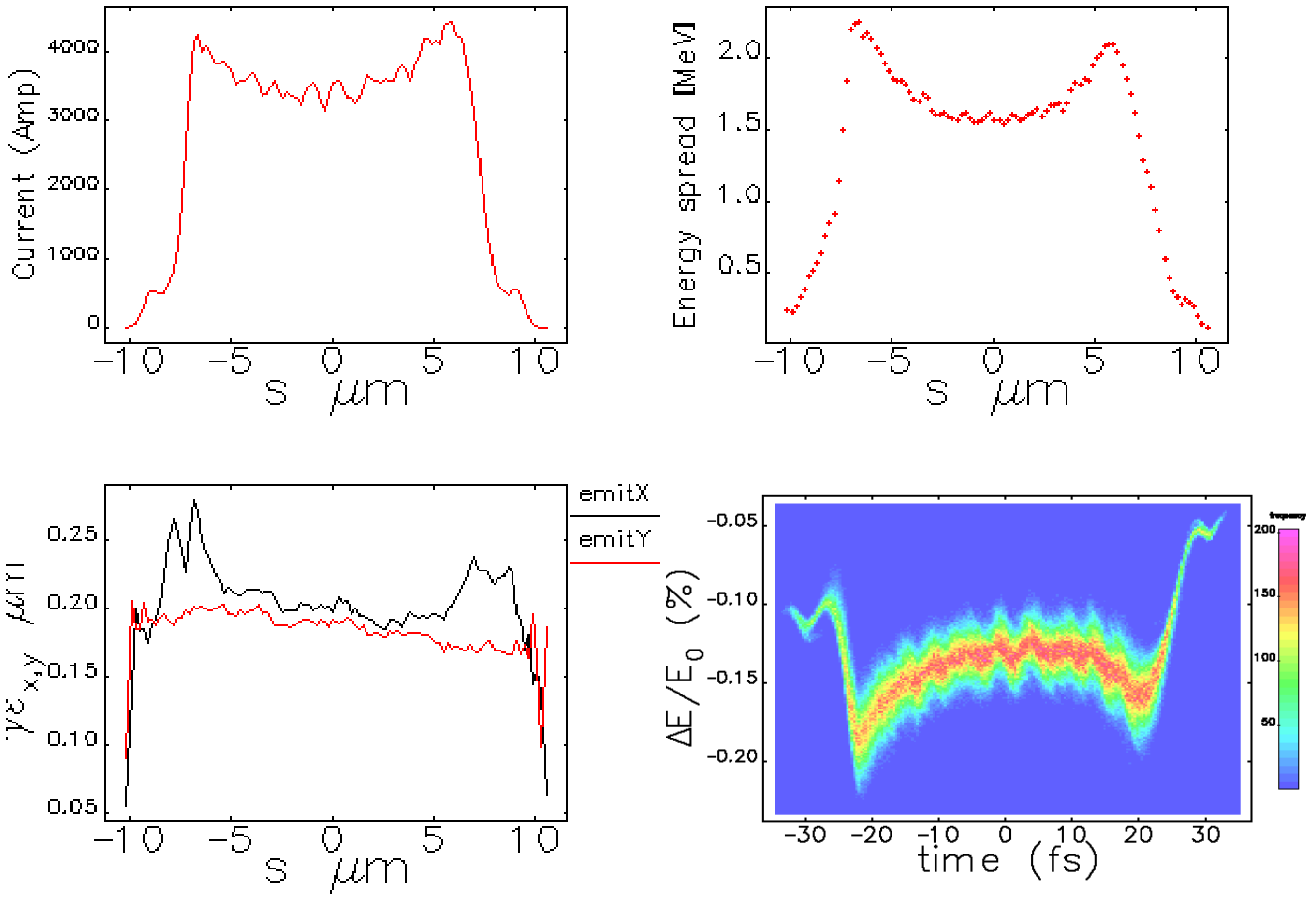


Typical Pareto Front





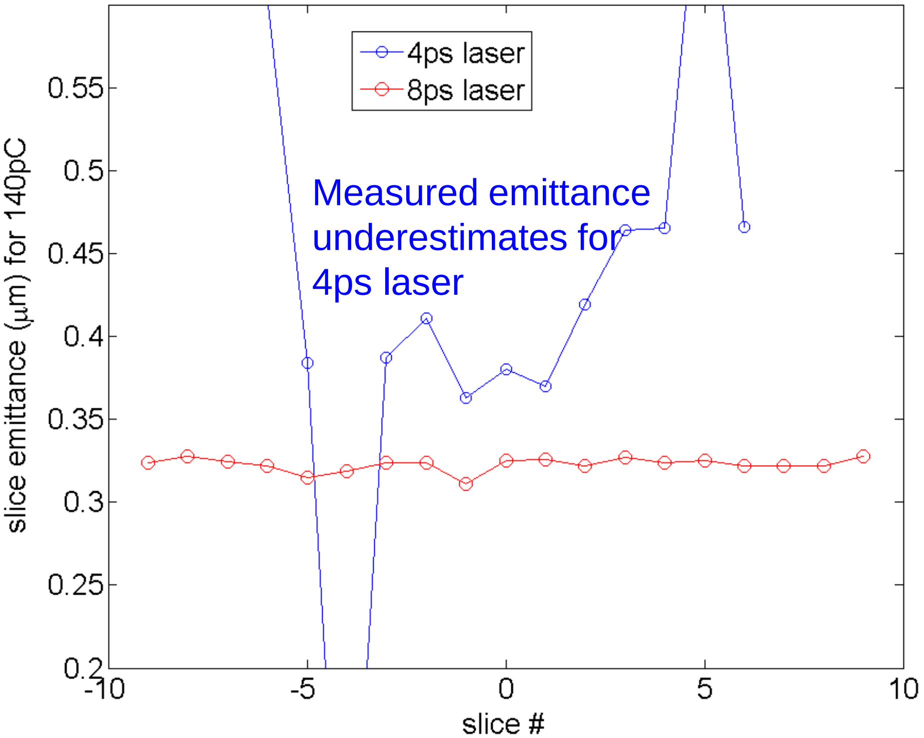
S2E simulation to undulator with 0.2μm injector beam



Y. Ding

Preliminary experimental result at LCLS (140pC)

- Measured OTR projected and sliced emittances reduced >25%
  - OTR emittance for the shorter bunch (4ps laser) underestimates due to COTR effect (Zhou *et al,* PRST-AB May 2015)
- To further improve emittance with smaller laser size, ~10ps laser, and better spatial laser profile
- FEL related studies: gain length and FEL performance



Preliminary LCLS data measured on September 6, 2016

Zhou, Hering, Gilevich, and Ding

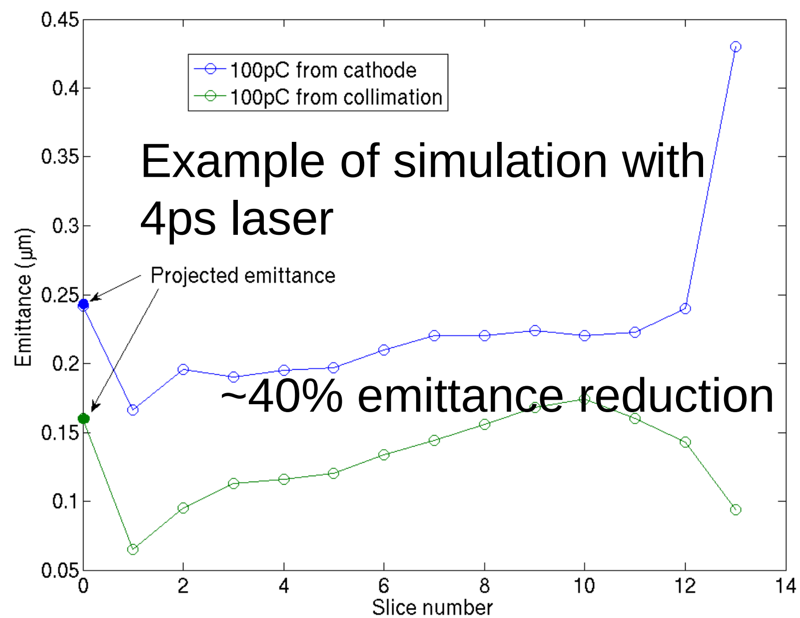
Circular collimation for the injector e-beam

- With flat jaws, a quad wake can be generated even with the beam on axis
- With circular collimator for round-like beam:
  - No quad wake
  - Dipole wake is negligible with half mm aperture and ~50μm transverse offset:

$$\frac{\Delta\epsilon_y}{\epsilon_{y0}} \approx \frac{1}{2}\left(\frac{eQ\varkappa_y y_0}{E\sigma_{y'}}\right)^2$$

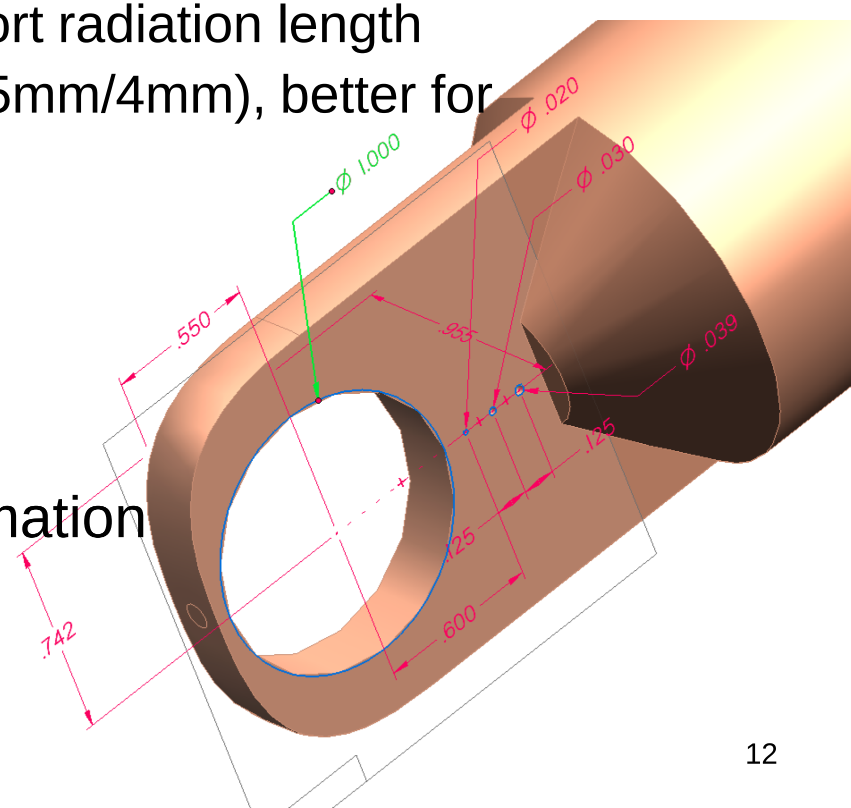
$$\varkappa_y \approx (0.3)\frac{1}{2\sqrt{\pi}}Z_0 c\frac{1}{a\sigma_z}$$

Q bunch charge; y0 is transverse offset
E is energy; *a* is aperture
σ_z is bunch length; $\sigma_{y'}$ beam divergence



To be tested at LCLS injector

- The circular collimator will be installed in the next Spring; the collimator locates at 65 MeV after one s-band structure where the beam is close to round.
- Physics design for the collimator:
  - Material is tungsten/Tantalum for short radiation length
  - Thin thickness 1 radiation length (3.5mm/4mm), better for pitch/yaw alignment
  - Angular alignment tolerance
  - Minimum 0.5mm aperture
  - Power loss is <0.2W for 20pC loss
    - No additional rad protection needed
- Beam studies for circular beam collimation expected in the next Summer.

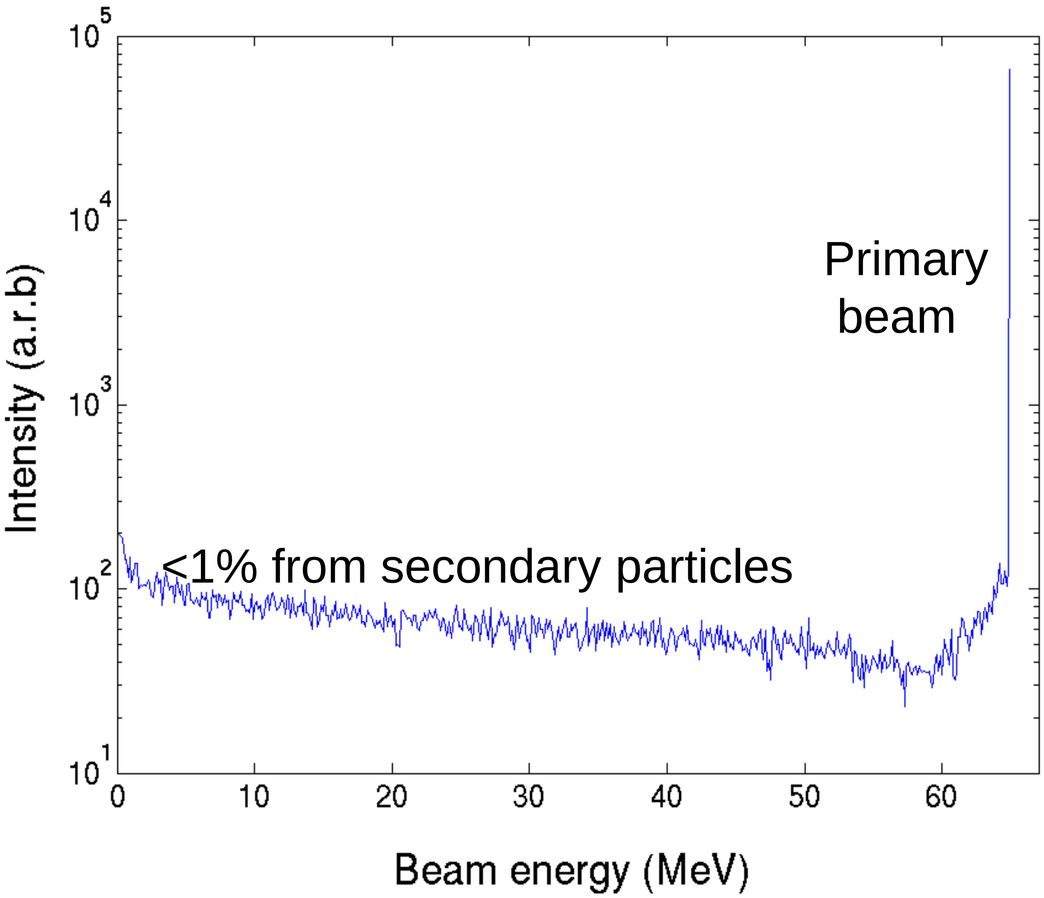


Zhou, Sheppard, Ding, and Grouev

Simulation of energy distribution through collimator

With tungsten collimator:

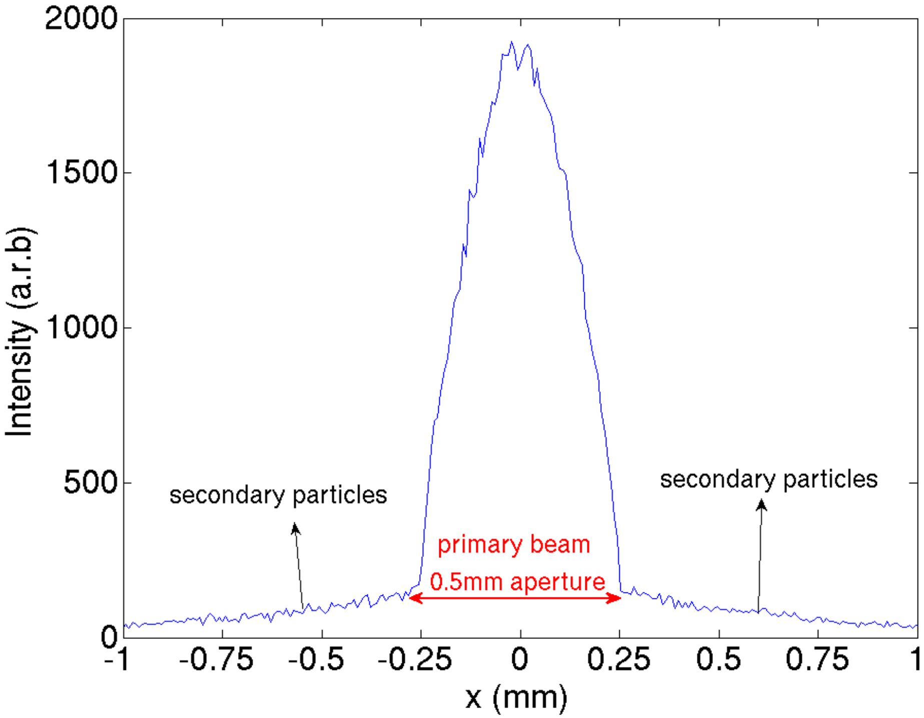
- 0.5 mm aperture
- 1 radiation-length thickness
- Primary + secondary particles distribution
  - Second particles only occupies <0.5%, which will be lost through laser heater chicane and dogleg and BC1



Does the secondary particles affect emittance measurement?

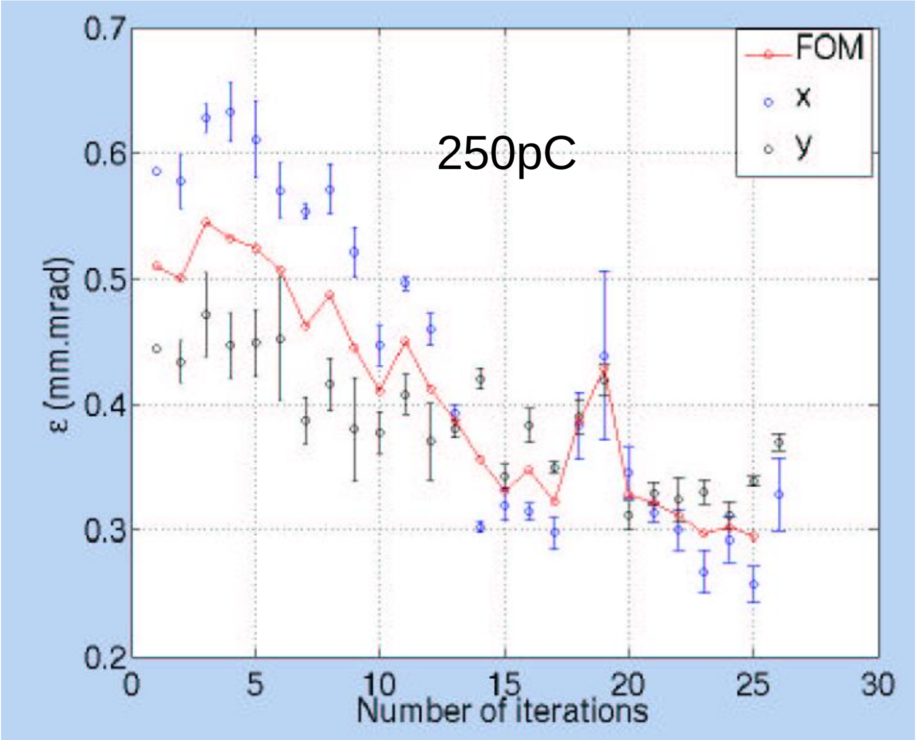
Secondary particles through the collimator only occupy 0.3% beam area:

- Much smaller than 5% background cutting for image processing for emittance measurement
- Have no impact for the emittance measurement
- Tails will be lost in the downstream bends



Online injector emittance optimizer

- In collaboration with the PSI colleague (Simona Bettoni), we made online emittance optimizer working at LCLS injector.
- Converged injector emittance through simultaneously optimizing multi-variables (i.e., simplex method) within 25 minutes, improving emittance.
- More beam tests are underway



LCLS data measured on Aug 23, 2016
Zhou, Bettoni (PSI)

Summary

We are evaluating solutions for the LCLS injector emittance reduction:

- Control of laser spatial => maintain optimal emittance and save significant amount of time for FEL recovery due to laser work
- Optimized laser locations on the cathode for optimum emittance
- Lengthening laser pulse already achieved >25% emittance reduction; further emittance reduction and FEL performance optimization is underway
- Circular collimation of the e-beam for emittance reduction planned
- Multi-variable emittance optimization works well at the LCLS