Measurements of the LCLS Laser Heater and its impact on the LCLS FEL Performance

Z. Huang for the LCLS commissioning team

Outline

- *Introduction*
- *LCLS setup and measurements*
- *Effects on FEL performance*
- *Anomalous heating effects (next talk)*

- **Results are published as PRSTAB 13, 020703 (2010).**
- **Sorry for many repeating slides from FEL2009.**

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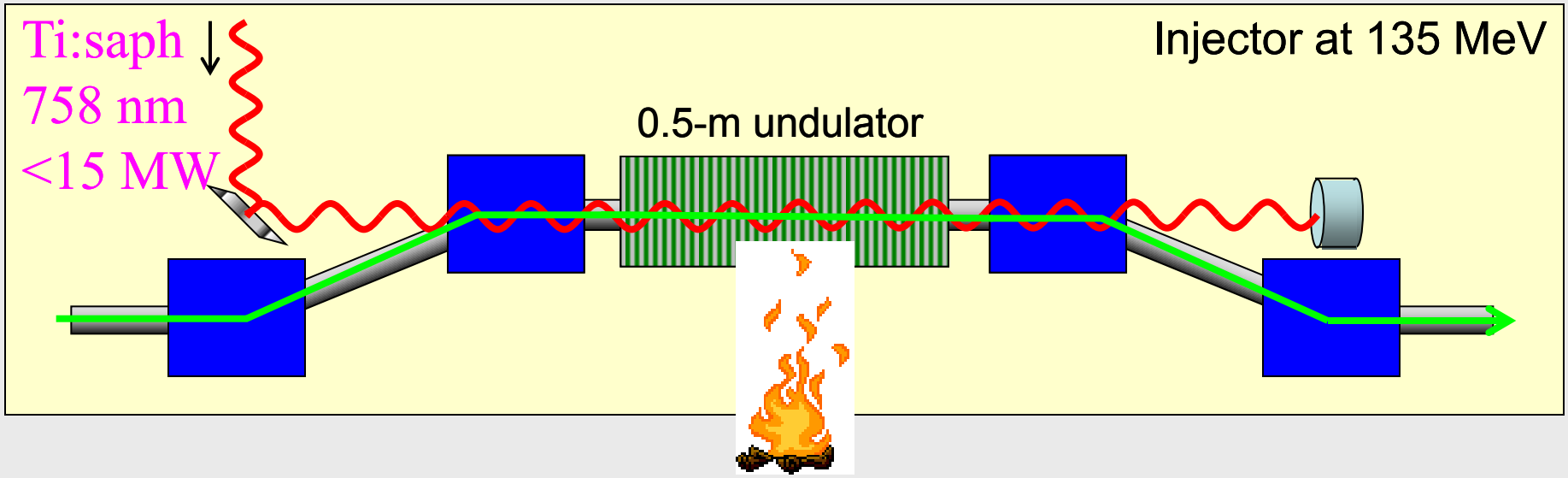
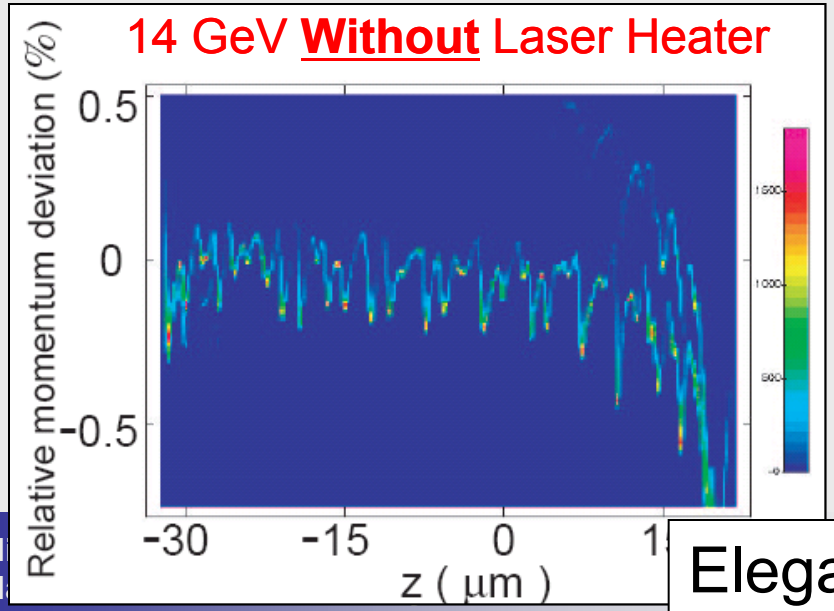
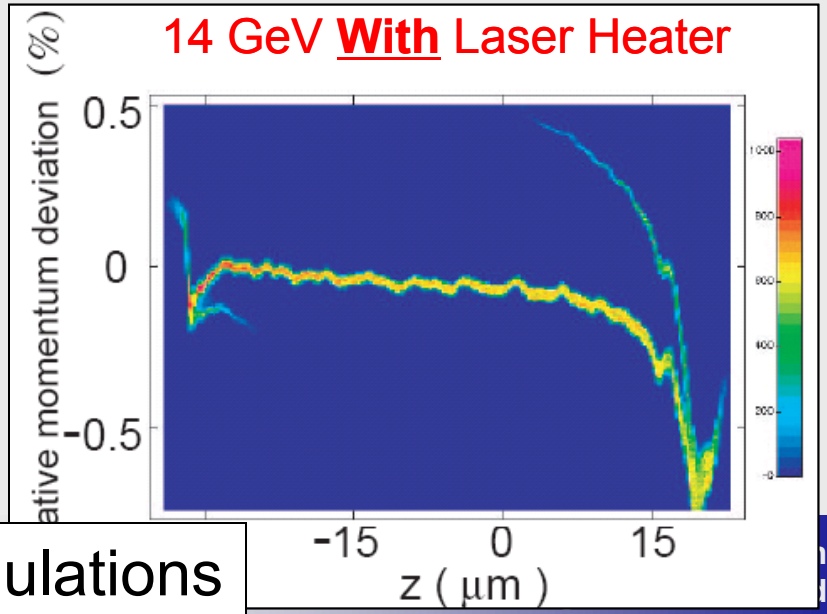
μ-Bunching Landau Damped by Laser Heater



'Laser heater' suggested by Saldin et al., NIMA, 2004; independently by J. Galayda

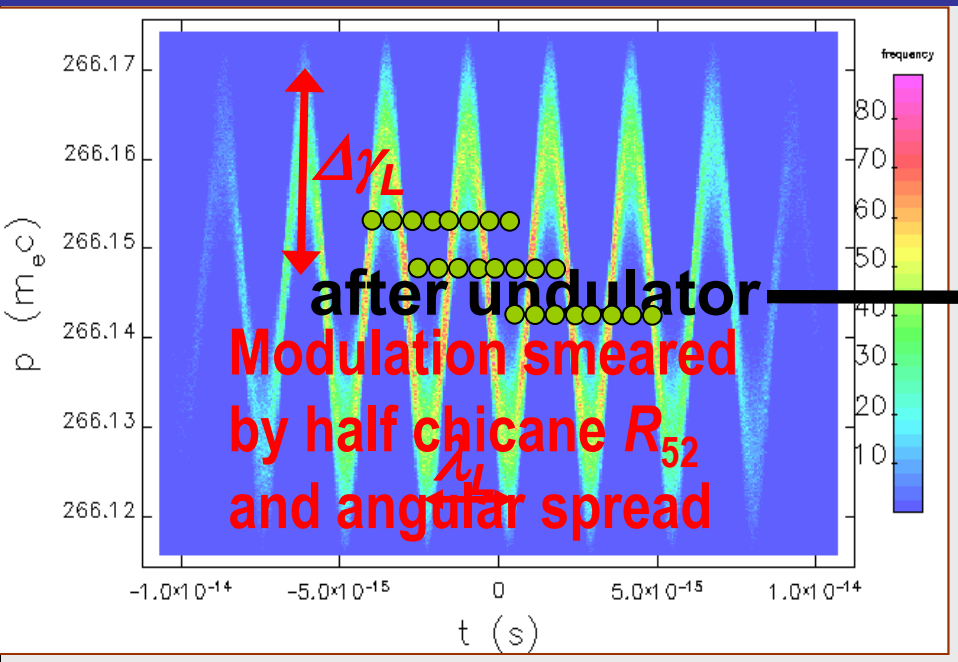
LCLS design study: Z. Huang et al., PRST 2004 (chicane suggested by T. Smith)

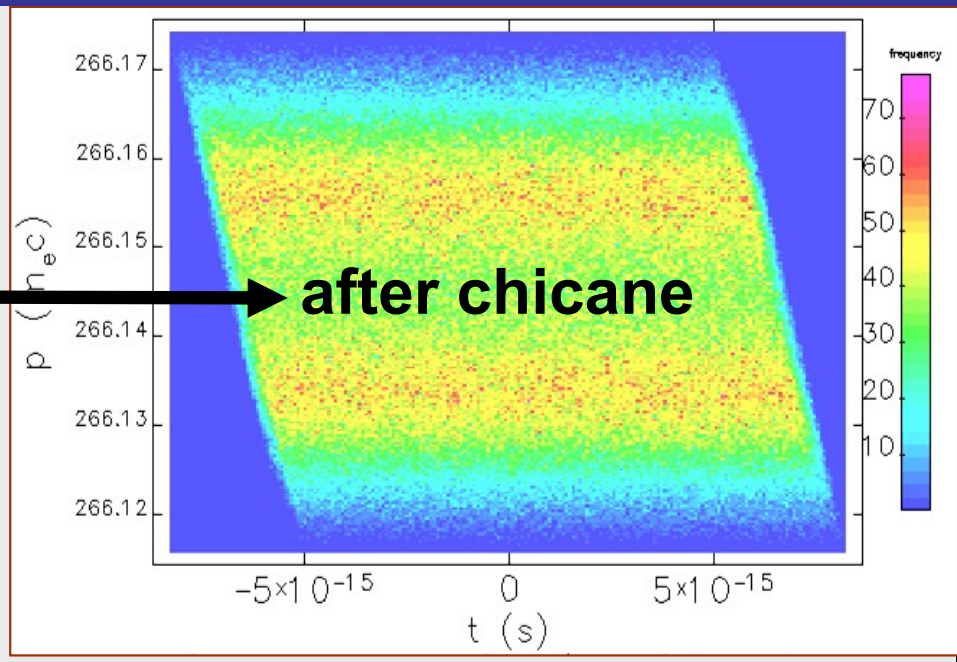




Elegant simulations

How does a laser heater work?





$$\Delta\gamma_L(r) = \sqrt{\frac{P_L}{P_0}}\frac{KL_u}{\gamma_0\sigma_r}[\mathrm{JJ}]\exp\left(-\frac{r^2}{4\sigma_r^2}\right)$$

laser peak power

laser rms spot size

- The last half chicane time-smears the energy modulation leaving an effective "thermal" energy spread increase

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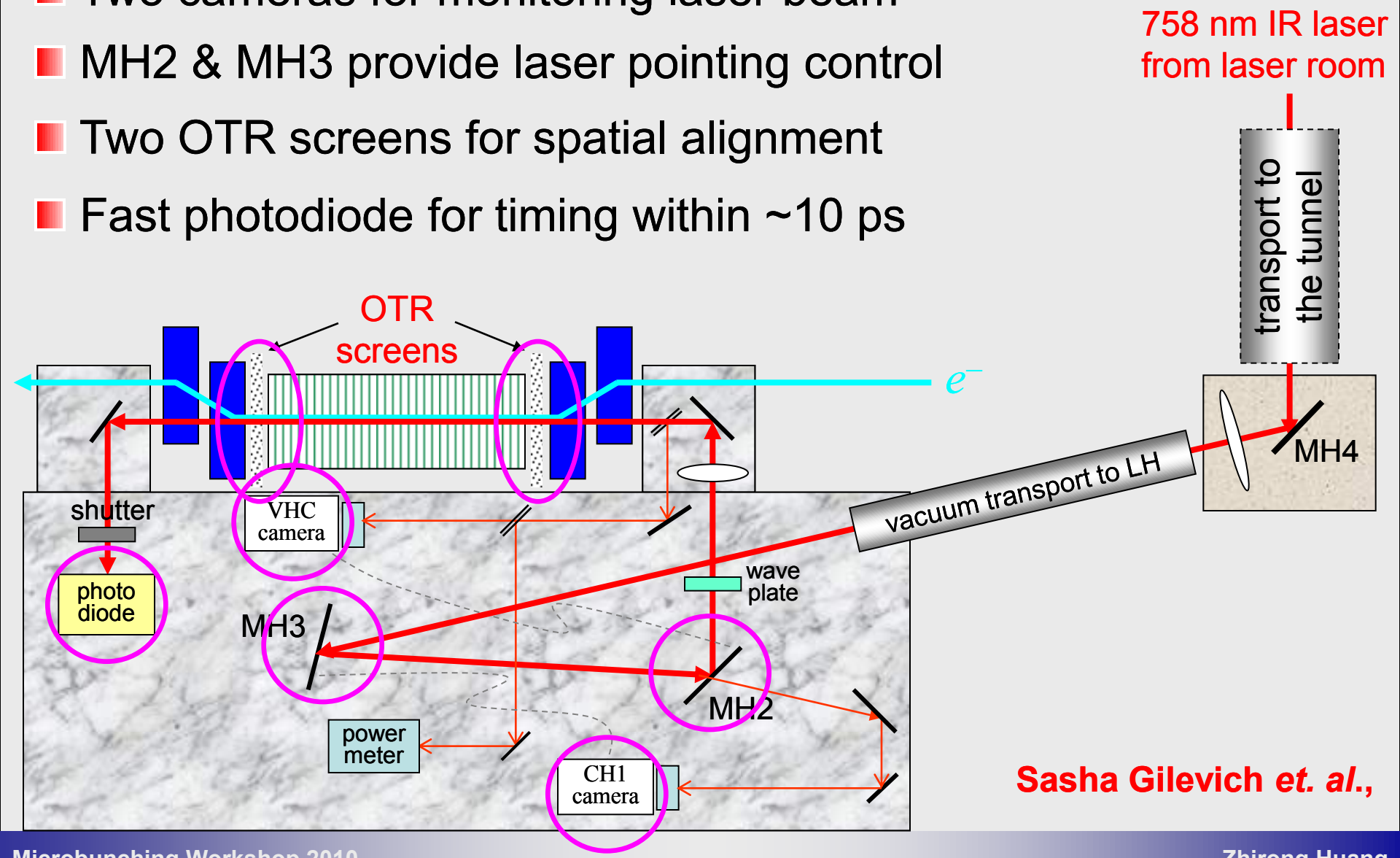
Layout of the Laser Heater Optics

- Two cameras for monitoring laser beam
- MH2 & MH3 provide laser pointing control
- Two OTR screens for spatial alignment
- Fast photodiode for timing within ~10 ps



Sasha Gilevich *et. al.*,

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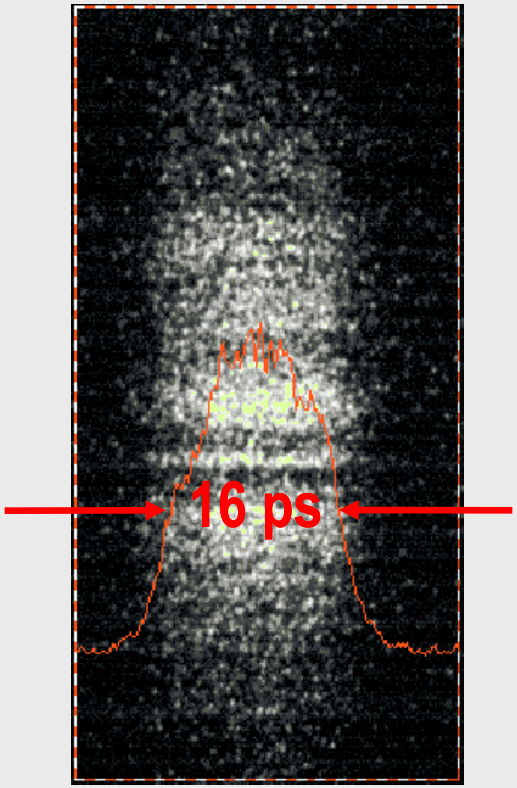
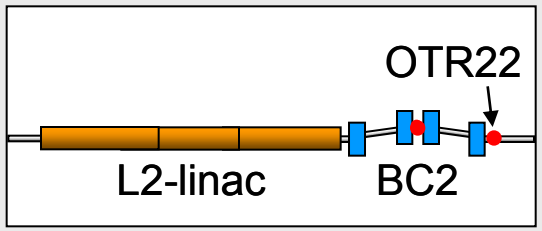
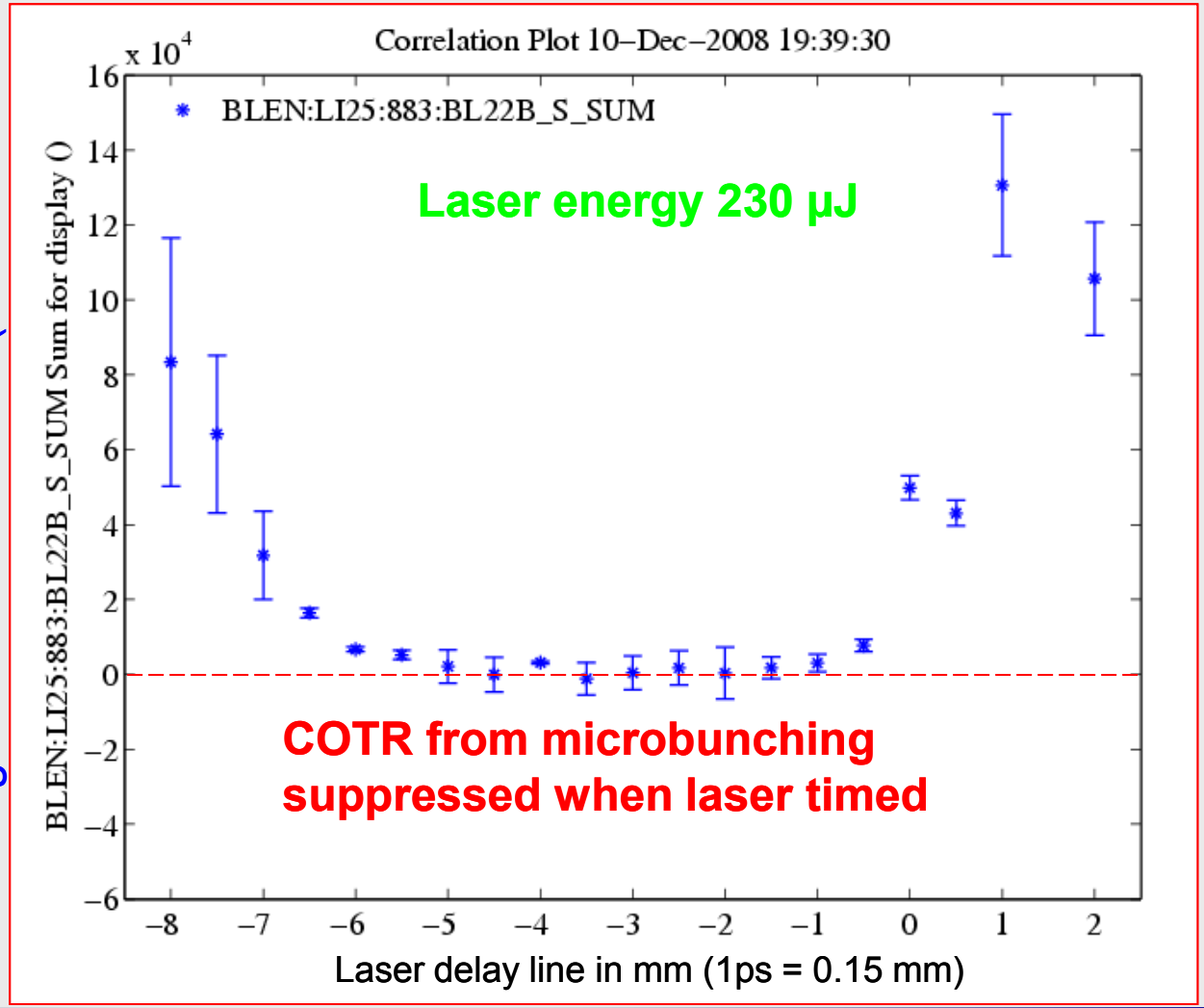
Laser Heater Temporal Overlap

- Laser pulse 10-20 ps, electron bunch 5-7 ps
- Laser timing done by minimizing the **COTR** signal after BC2





COTR signal after BC2 bends (OTR22 inserted)



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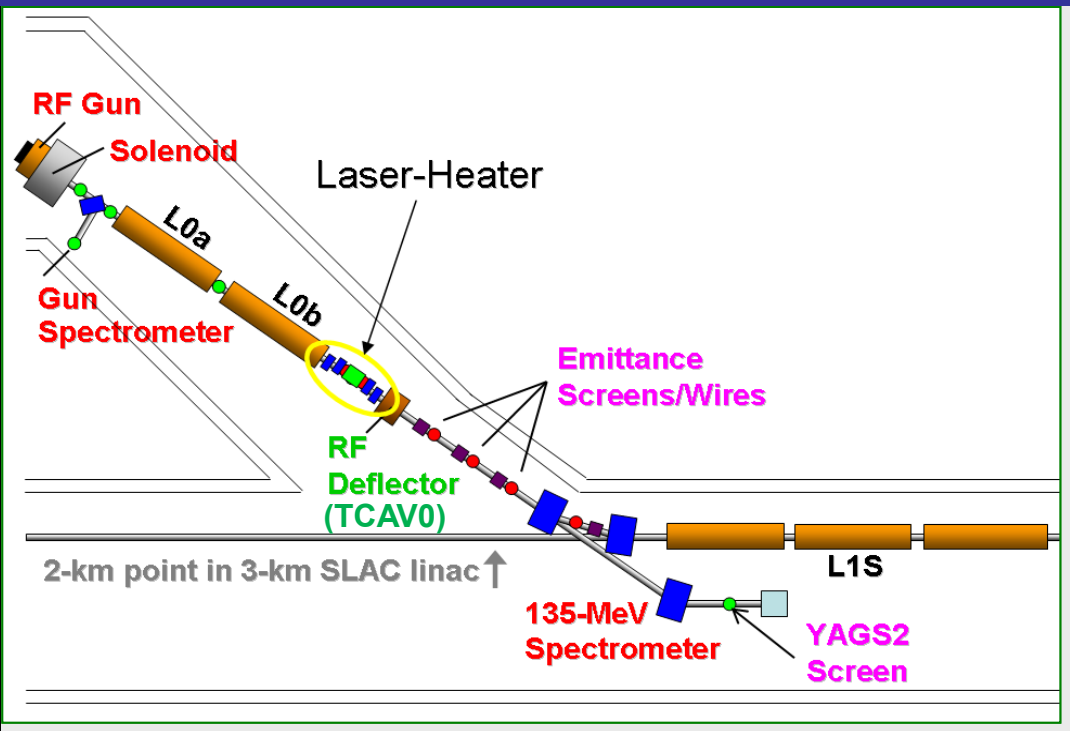
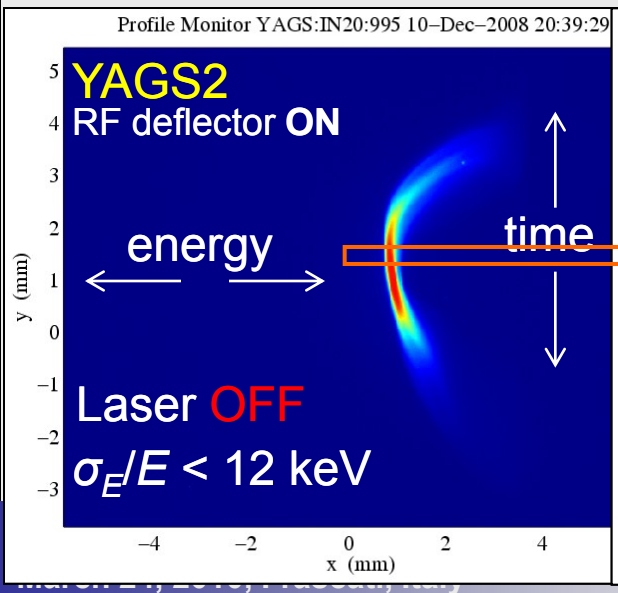
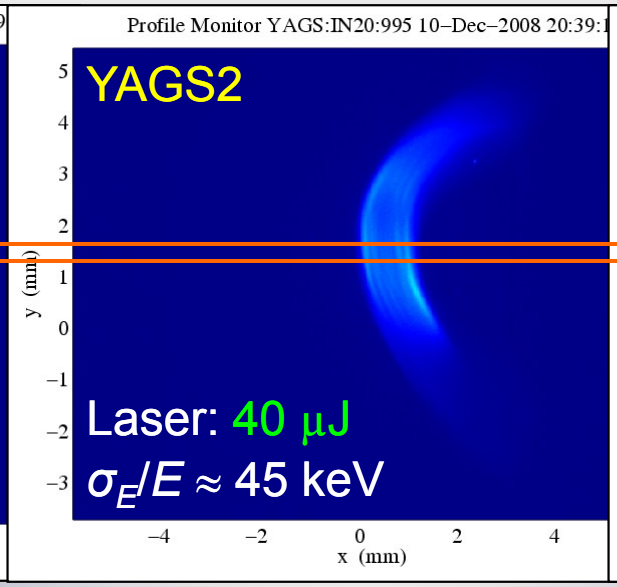
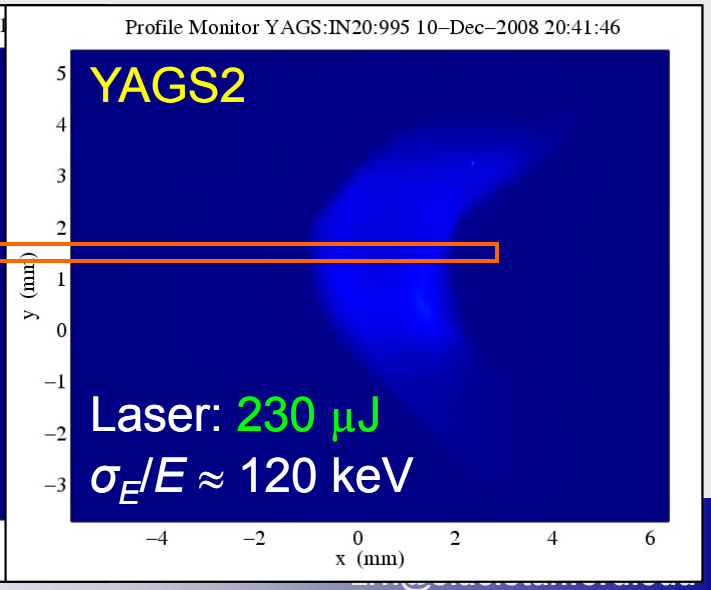
Heating Measurements

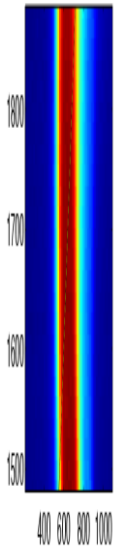


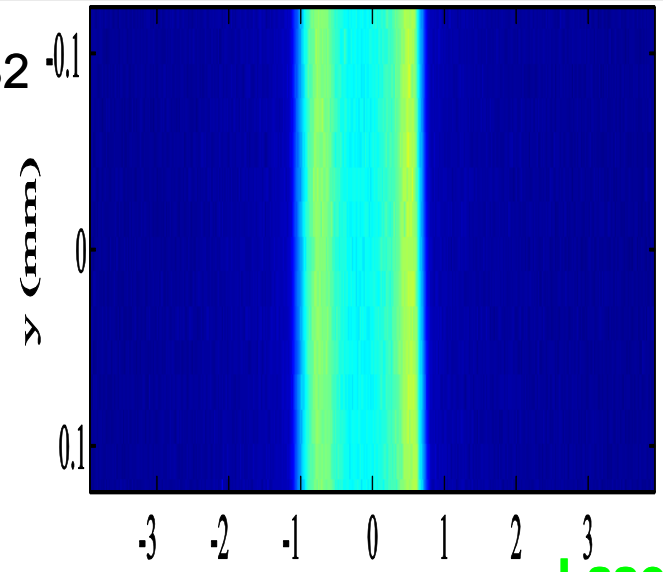


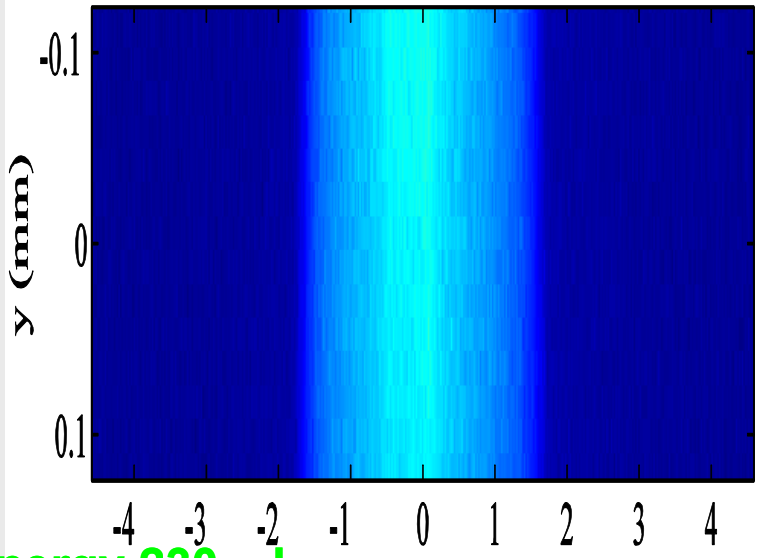




Slice Energy Spread

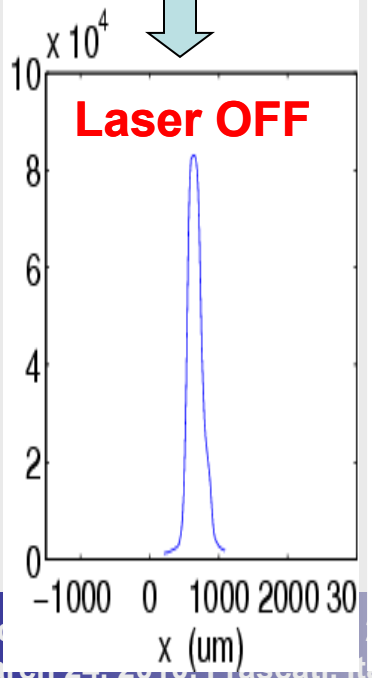


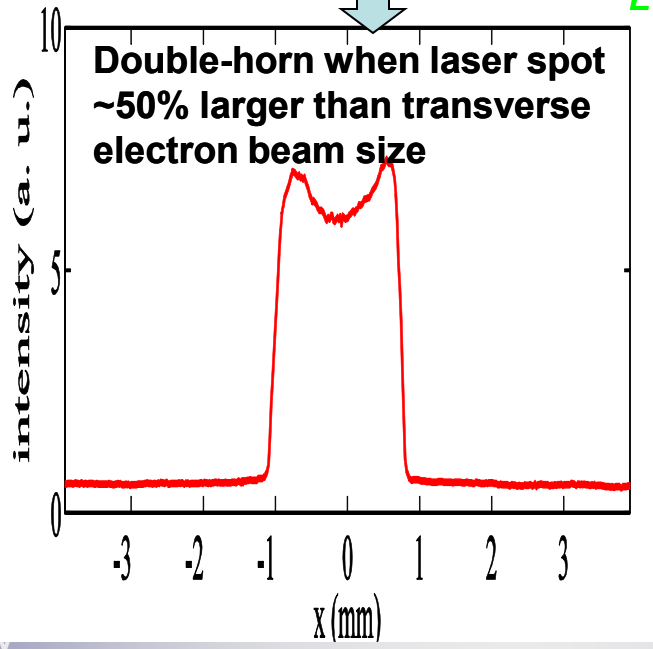


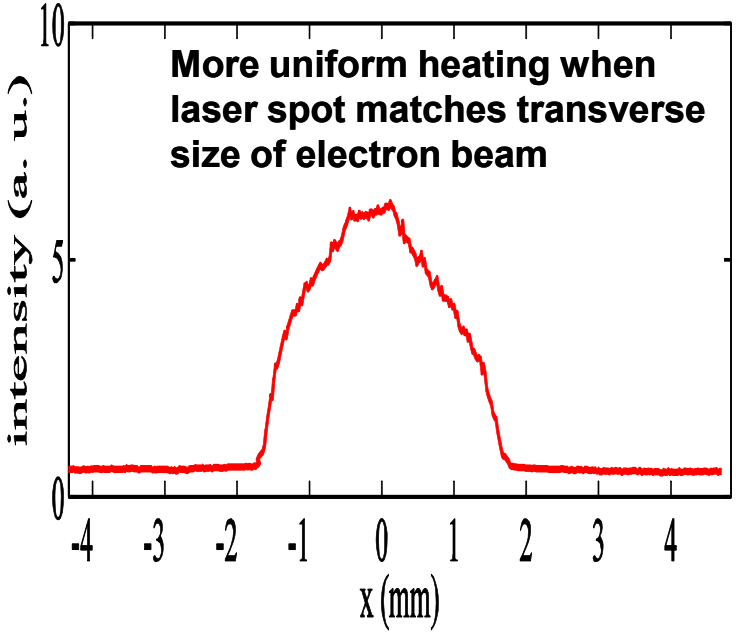


Laser energy 230 μJ

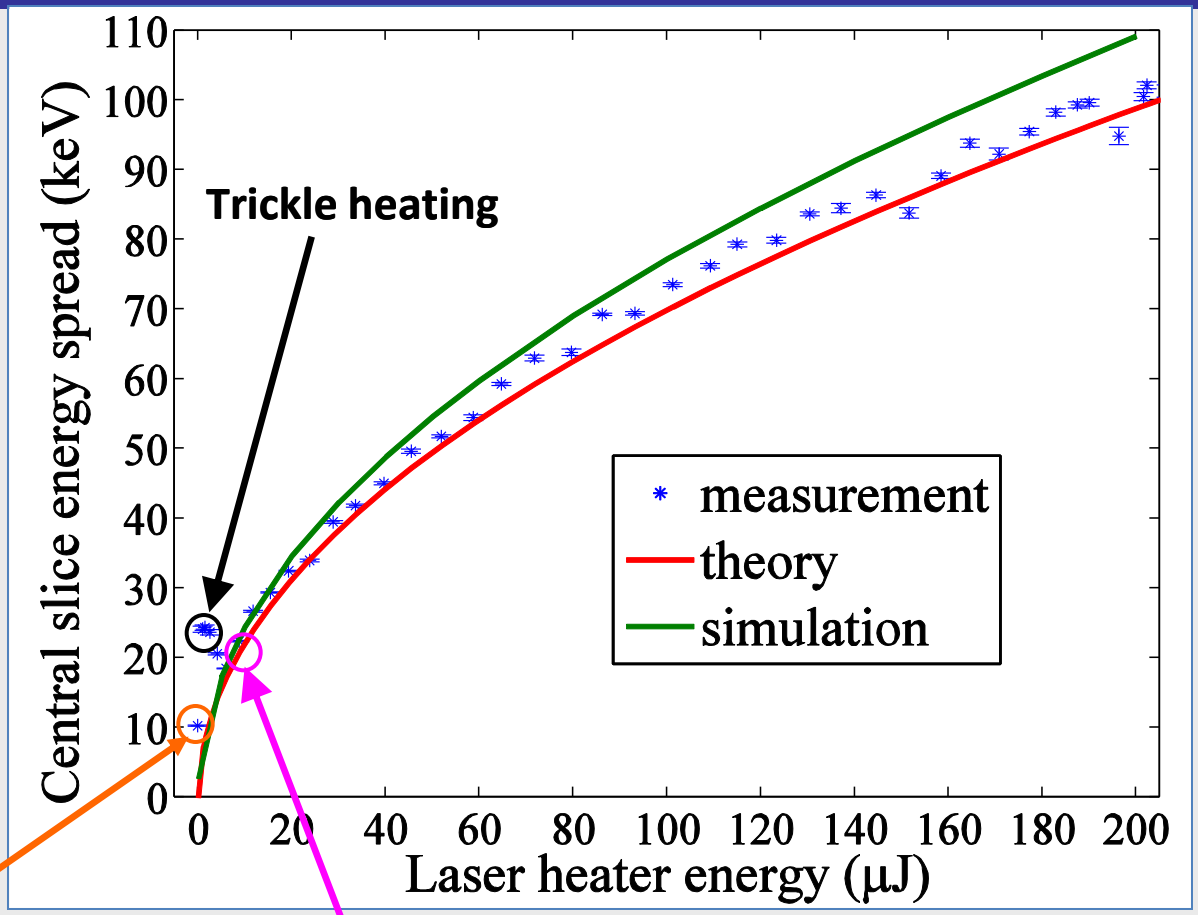
$\sigma_E/E \approx 120$ keV



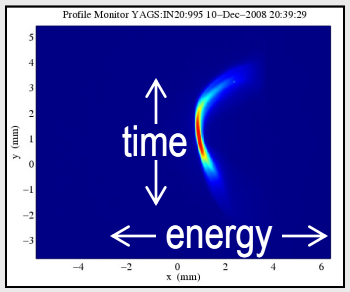




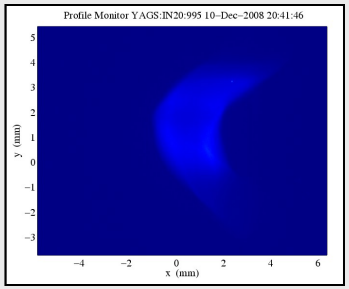
Slice-E Spread vs. Laser Energy



no heating



good heating



No heating 8-10 keV (limited by resolution?)

Operating point (~7 uJ)
20 keV × compression ratio 90/14GeV = 1.3×10^{-4}

- TCAV has an off-axis acceleration field which can increase slice energy spread on YAGS2 (thanks to D. Filippetto!)

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Slice E-spread from Transverse Cavity

- This effect can be derived from PW theorem (e.g., S.Korepanov et al., DIPAC07, p144)

$$dp_z = \frac{dE}{E} = \frac{\omega}{c} \cdot \frac{V_{y\max}}{E/e} \cdot y_0$$

$$\sigma_E = \sqrt{\sigma_E^{'2} - \left[\frac{\omega}{c} V_{y\max} \cos(\omega t)\right]^2 \sigma_y^2}$$

- Take V_{ymax} = 1 MV (S-band), $\gamma\varepsilon_y$=0.5 μm, β_y=7 m, E=135 MeV, TCAV0 contributes to 7 keV slice energy spread

- Plan to measure TCAV off-axis acceleration soon

- Need to subtract TCAV0 effect in quadrature to determine slice E-spread (yet to be done)

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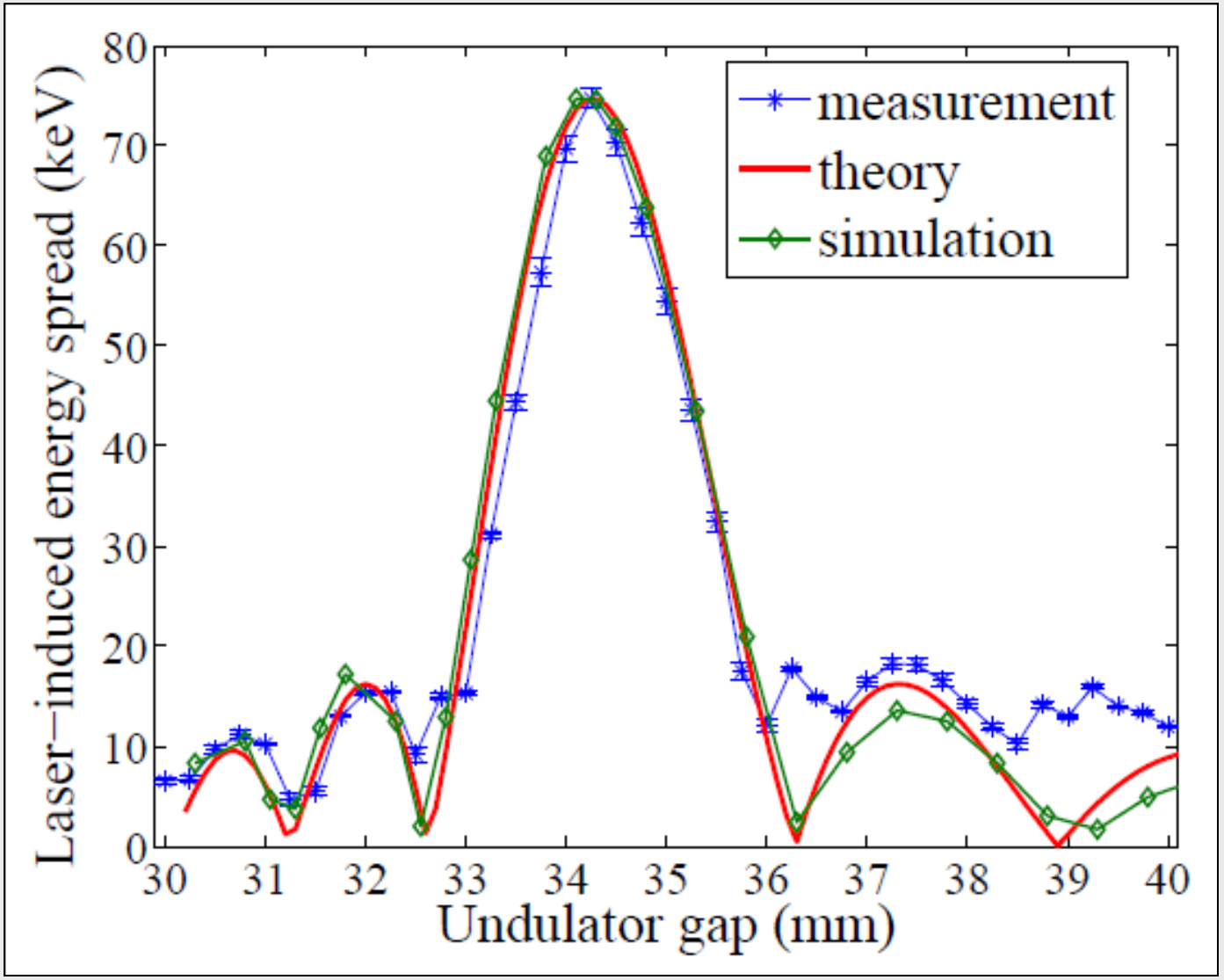
E-spread vs. Undulator Gap

- Scan undulator gap, subtract LH-off energy spread in quadrature



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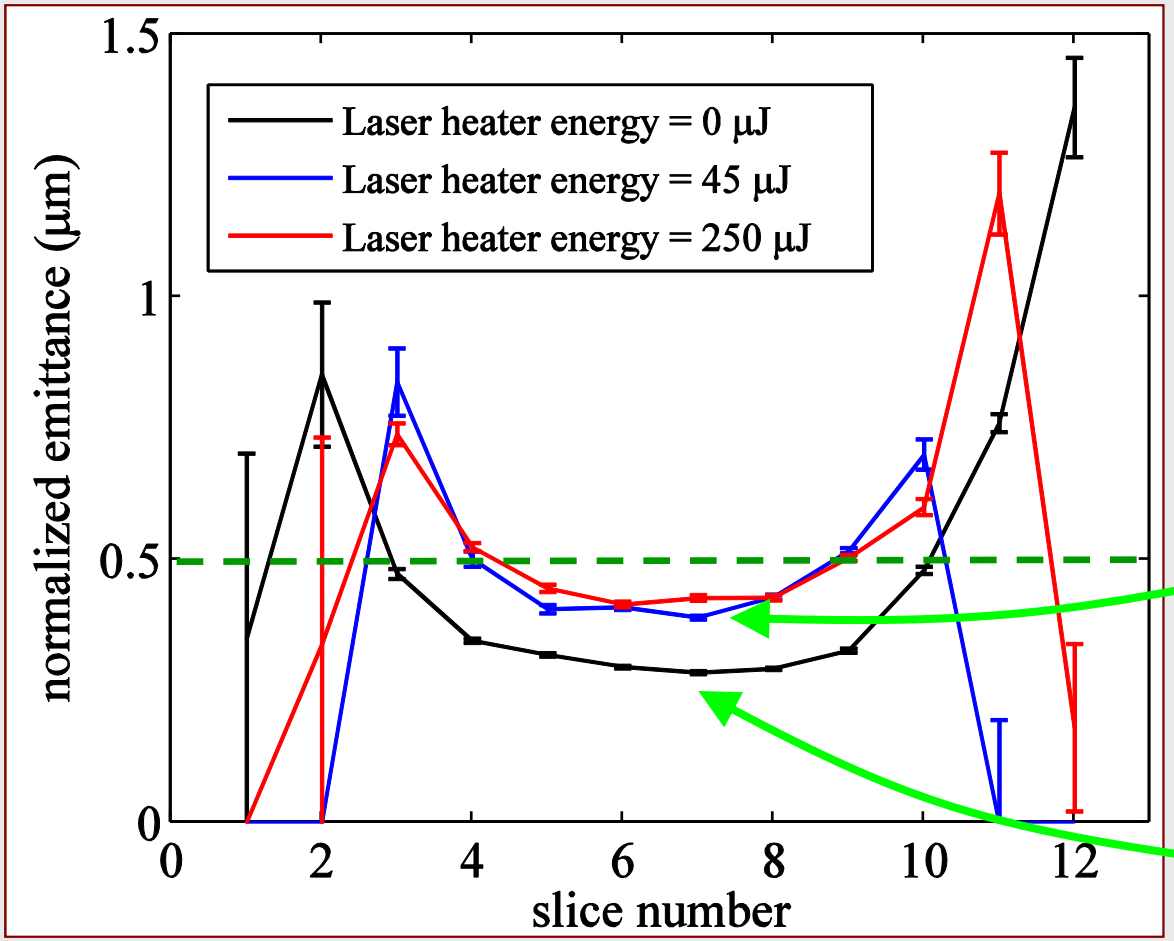
No Emittance Growth from Heating

- Laser-induced E-spread in chicane does not introduce emittance growth (< 2%)

$$\frac{\Delta\epsilon_x}{\epsilon_x} \approx \frac{1}{2}\left(\frac{\sigma_{\gamma_L}\eta}{\gamma_0\sigma_x}\right)^2$$



Heater from 45 μJ to 250 μJ, no change in slice emittance

Heater off, COTR after LH chicane biases emittance results

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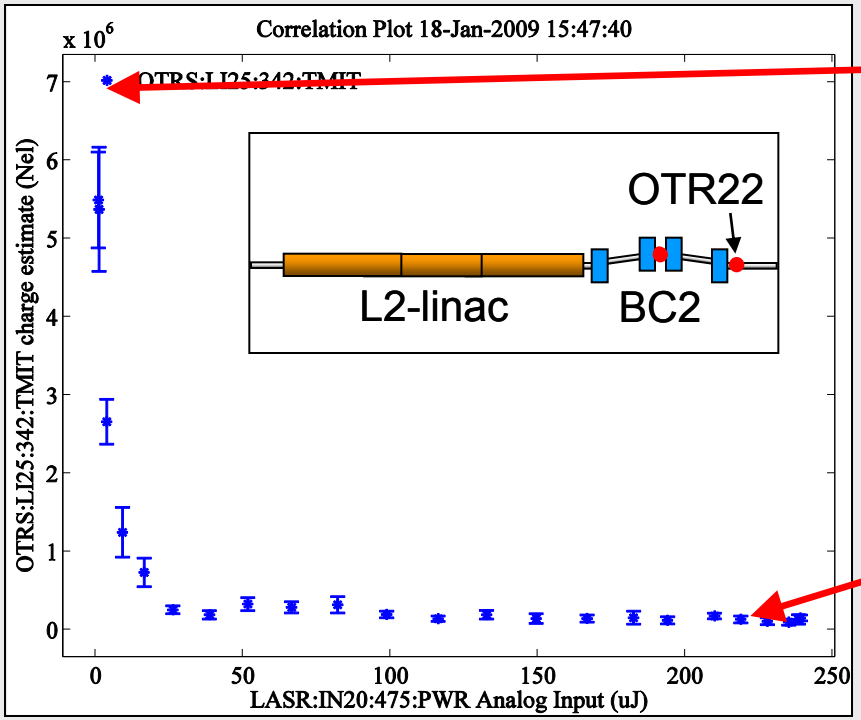
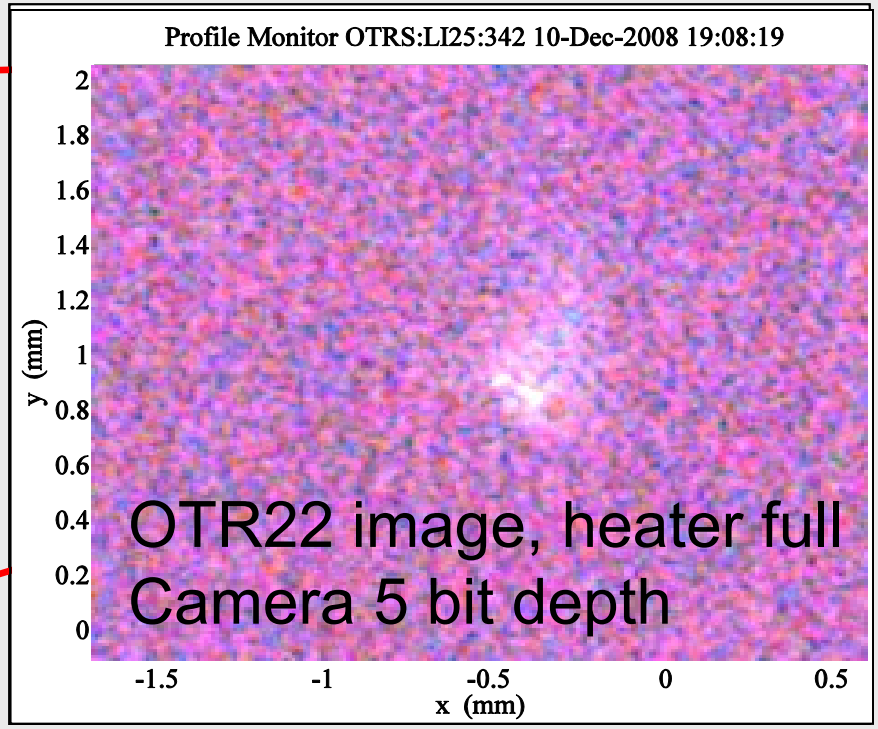
Effects on COTR

- Modulated e-beam current from microbunching leads to many COTR problems in LCLS
- Laser heater suppresses COTR but not to incoherent level (small part of beam escaped heating, laser-heated energy profile non-Gaussian?)





- COTR can restart from shot noise in the downstream linac + bend
- Alternative diagnostics (wires) used for beam profiles after compressors

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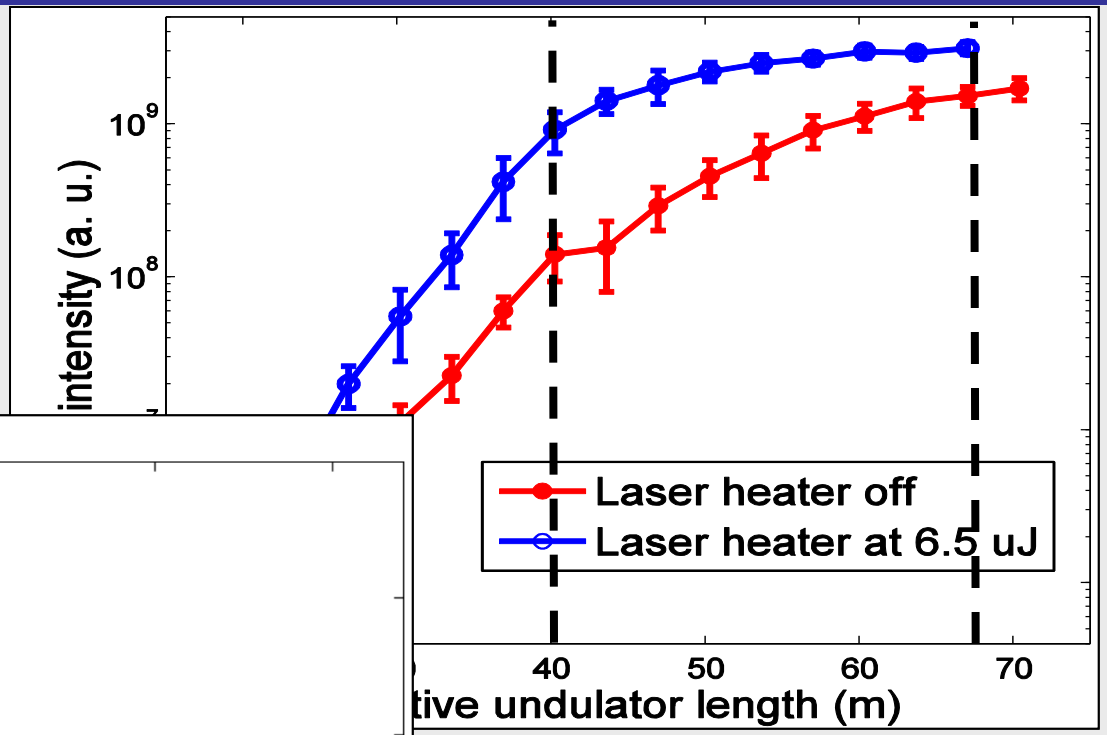
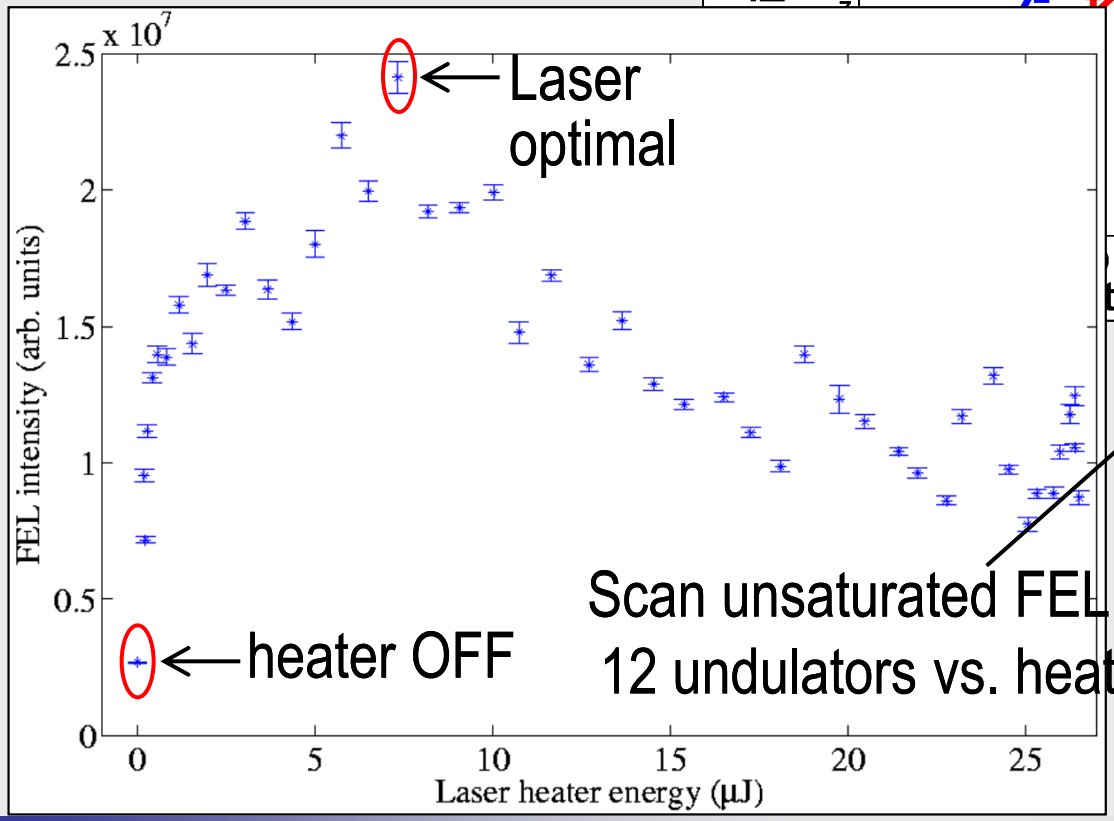
Laser Heater Improves FEL Power

250 pC, 3 kA, 1.5 Å FEL





Scan unsaturated FEL w/ 12 undulators vs. heater

FEL saturation power improves 2X w/ heater

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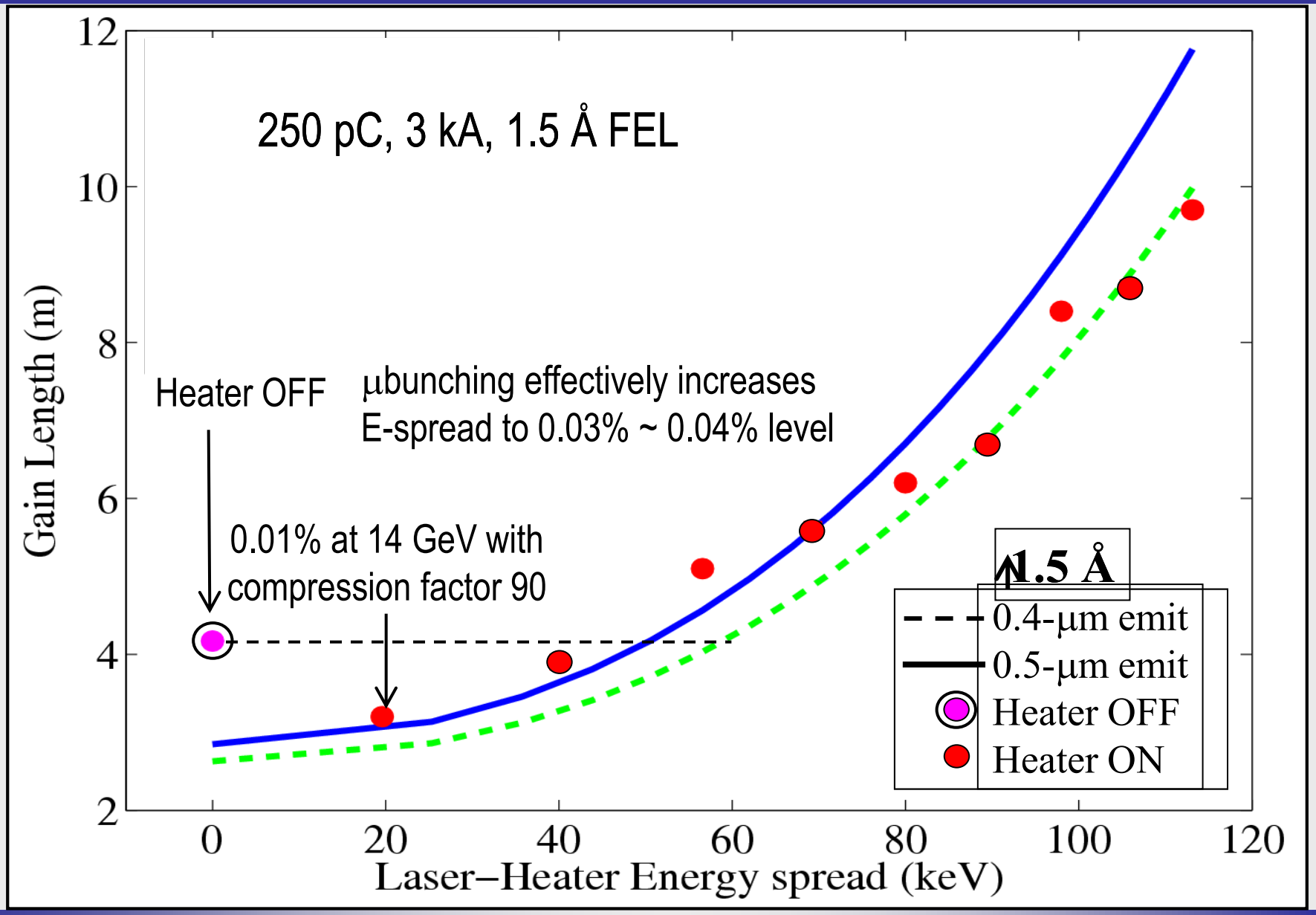
FEL Gain Length vs. Laser Heater



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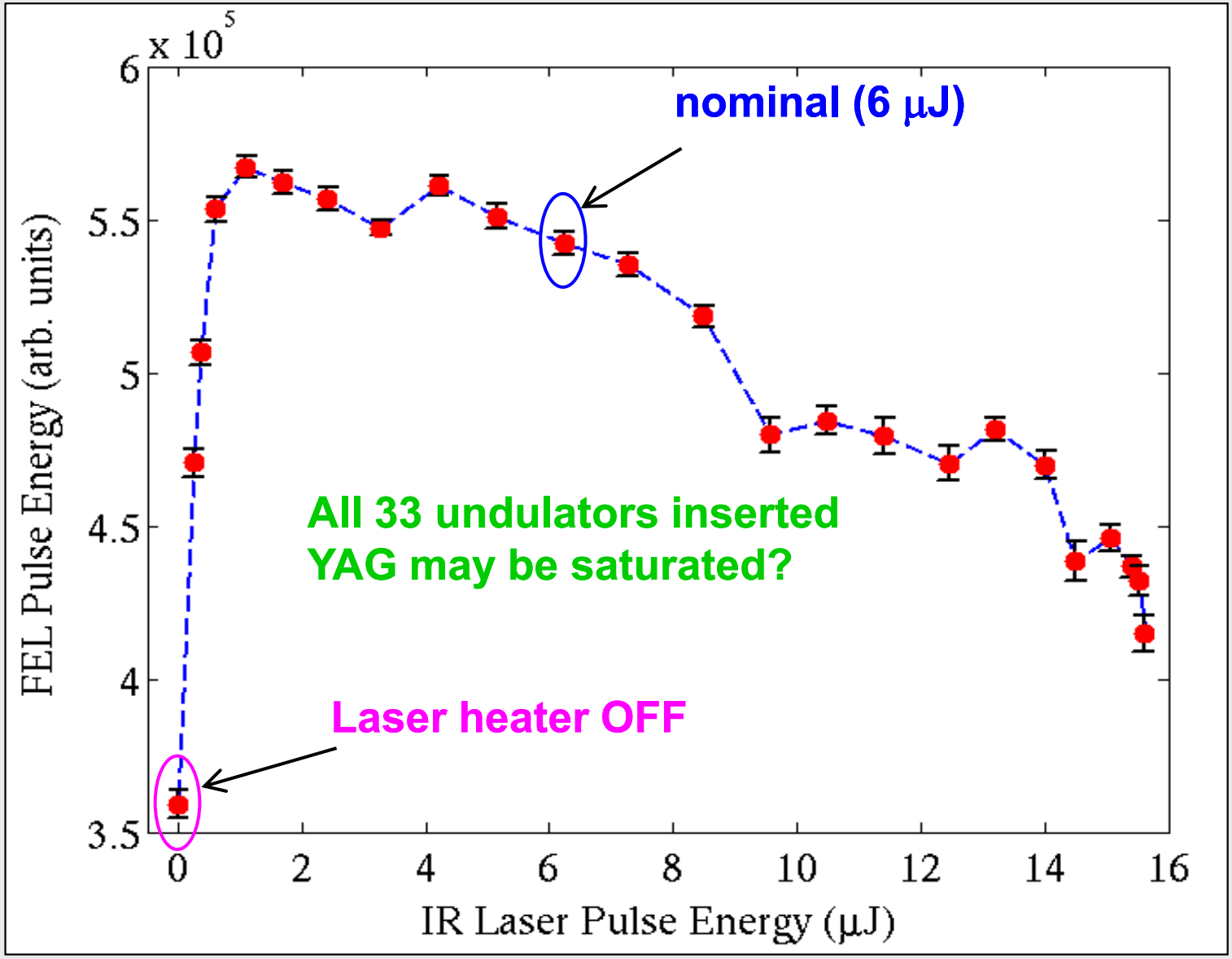
FEL Power vs. LH after saturation



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Summary

- Microbunching is a generic problem for high-brightness beams (brighter beams become a bigger problem)
- LCLS laser heater works well to control microbunching and to improve x-ray FEL performance.
- Microbunching is suppressed but not all COTR is gone
  ➔ alternative diagnostics necessary for bright beams

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