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Experimental characterization of the laser heater effects on a seeded FEL

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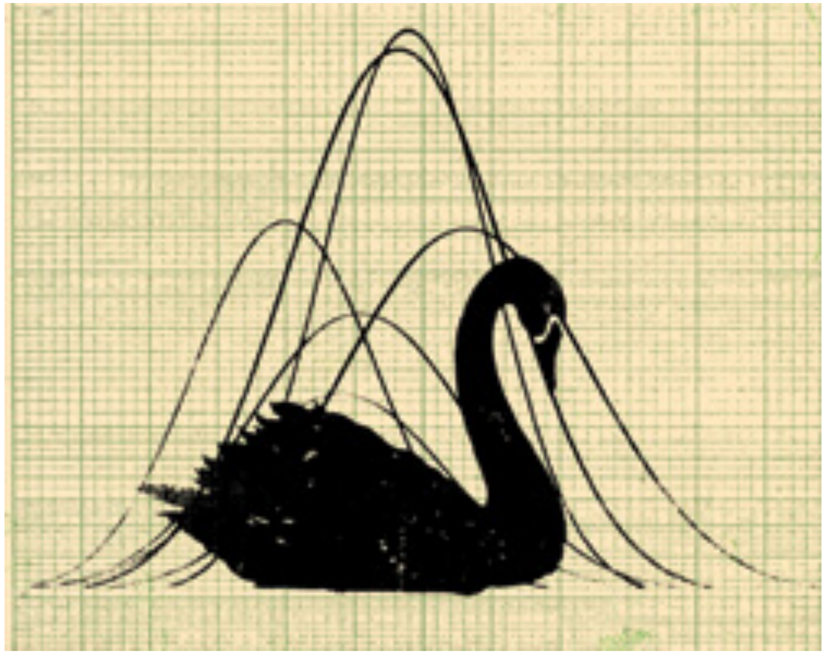
3. ENEA C.R. Frascati
4. SLAC National Accelerator Laboratory

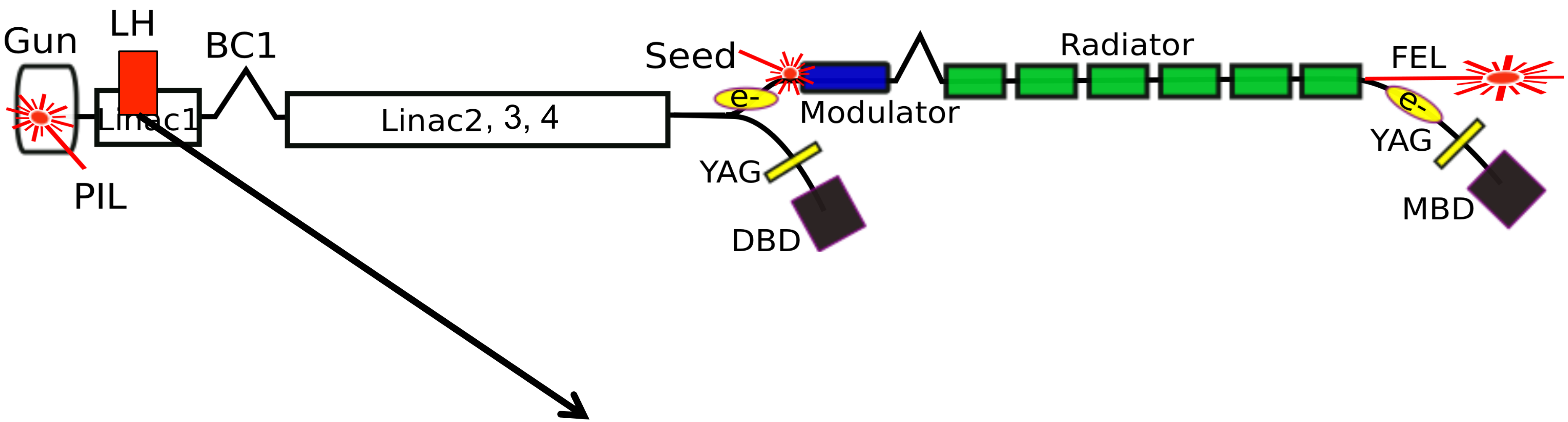
Outline

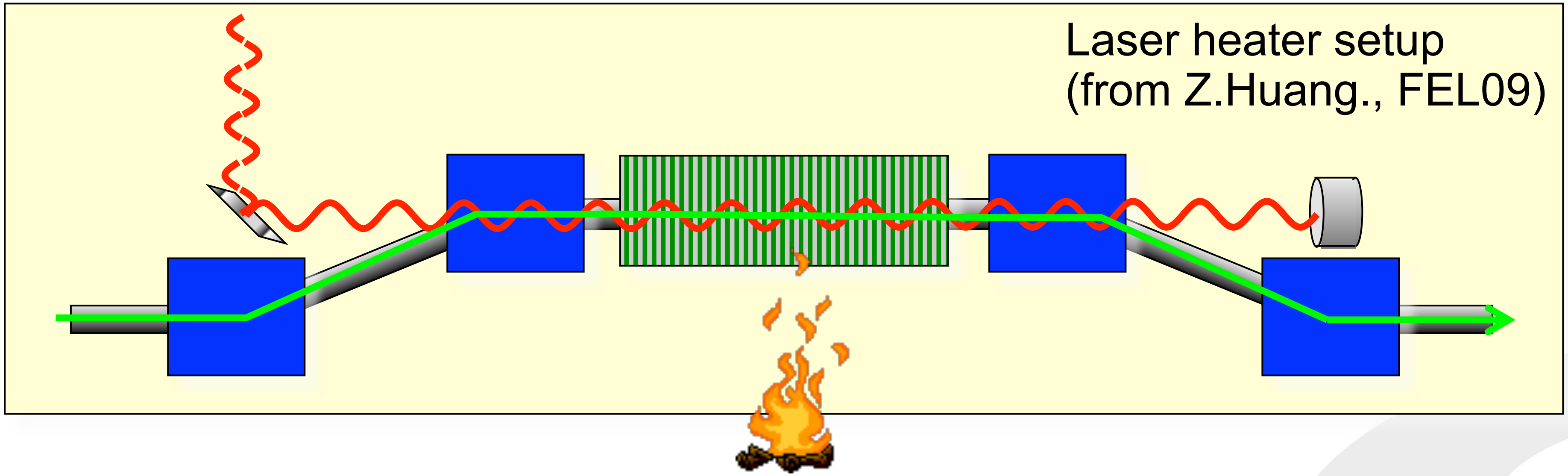
- ★ Fermi experimental setup
- ★ Impact of the laser heater on seeded FEL
- ★ Non-Gaussian effects



Experimental setup

Fermi scheme





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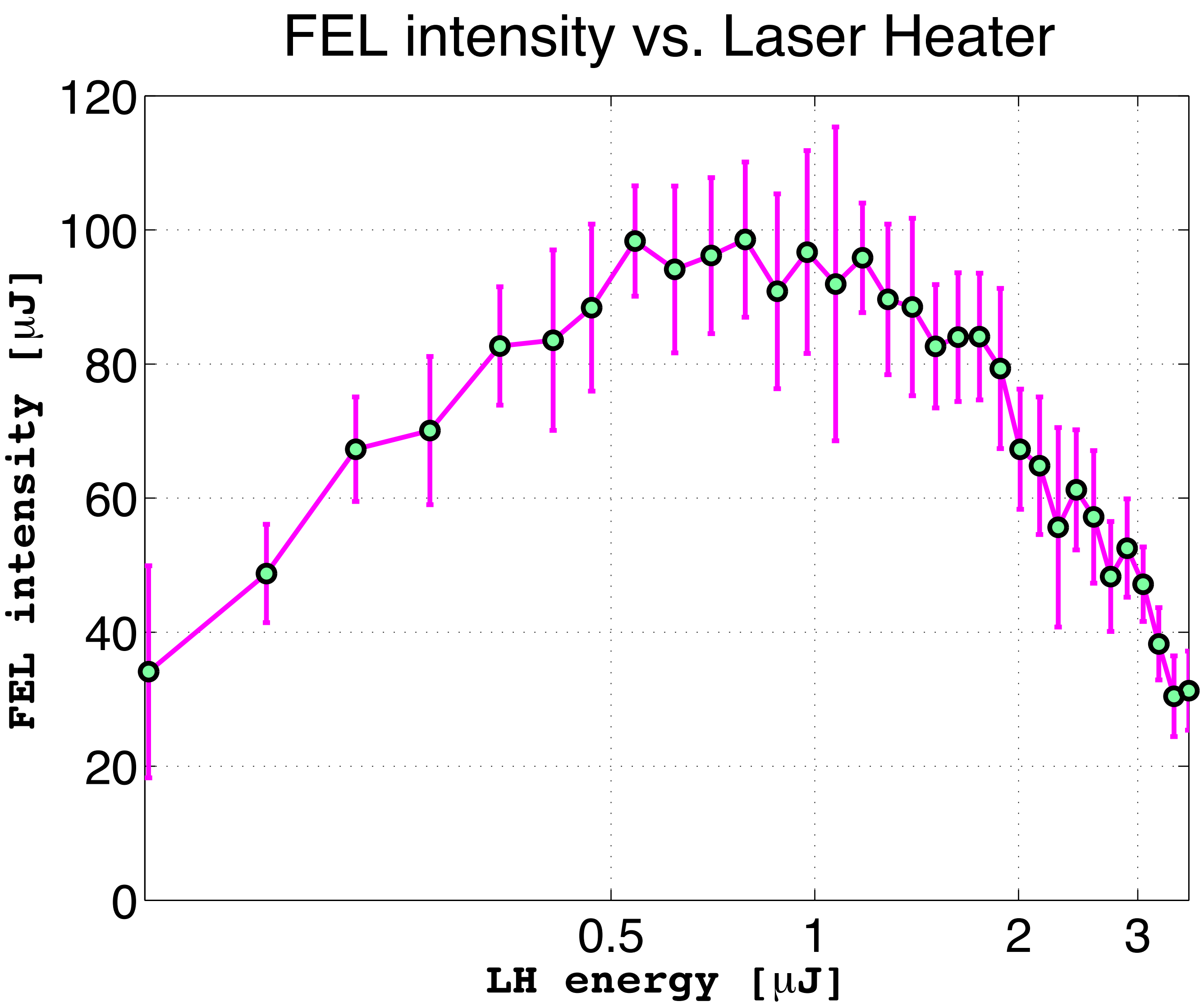
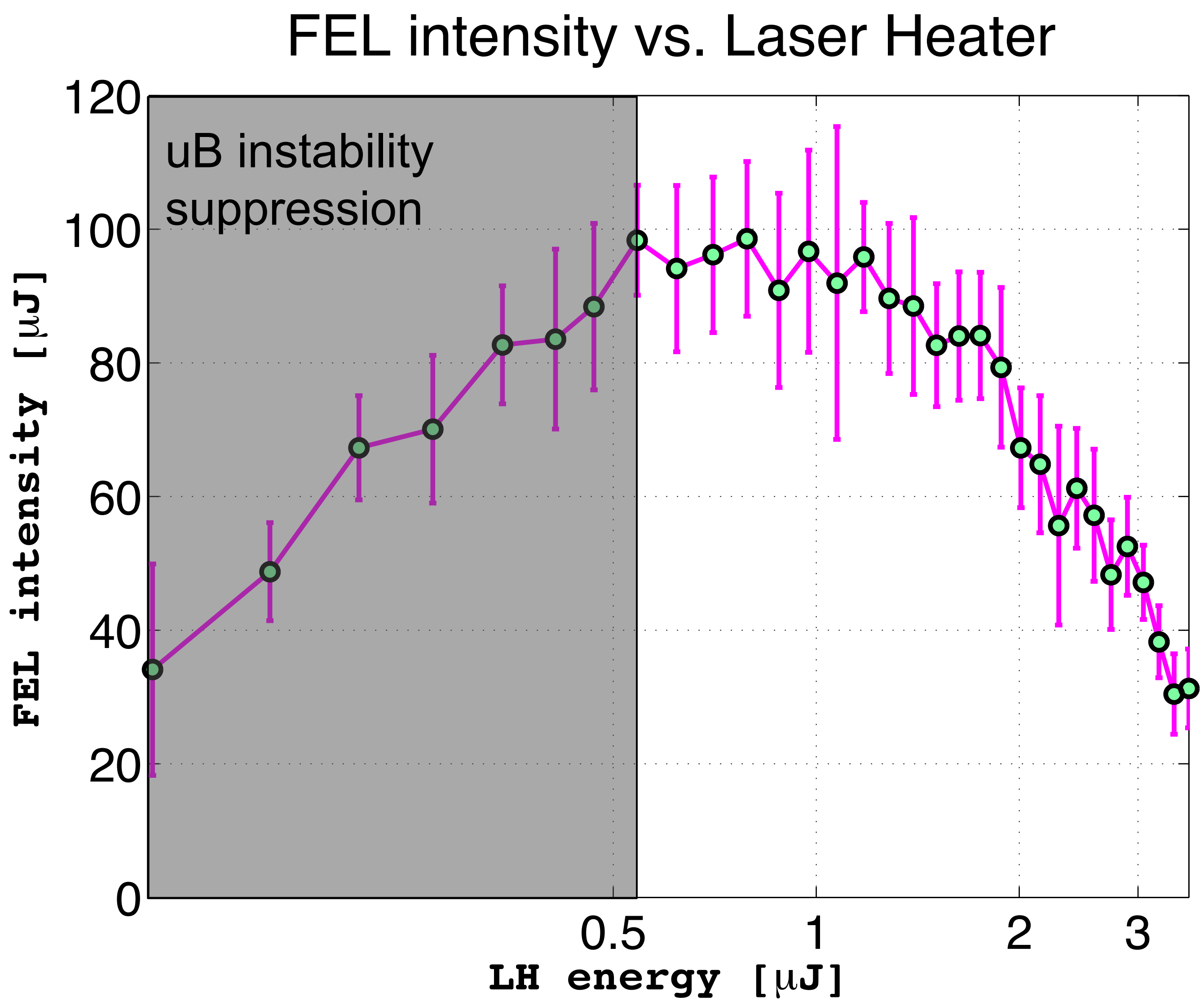
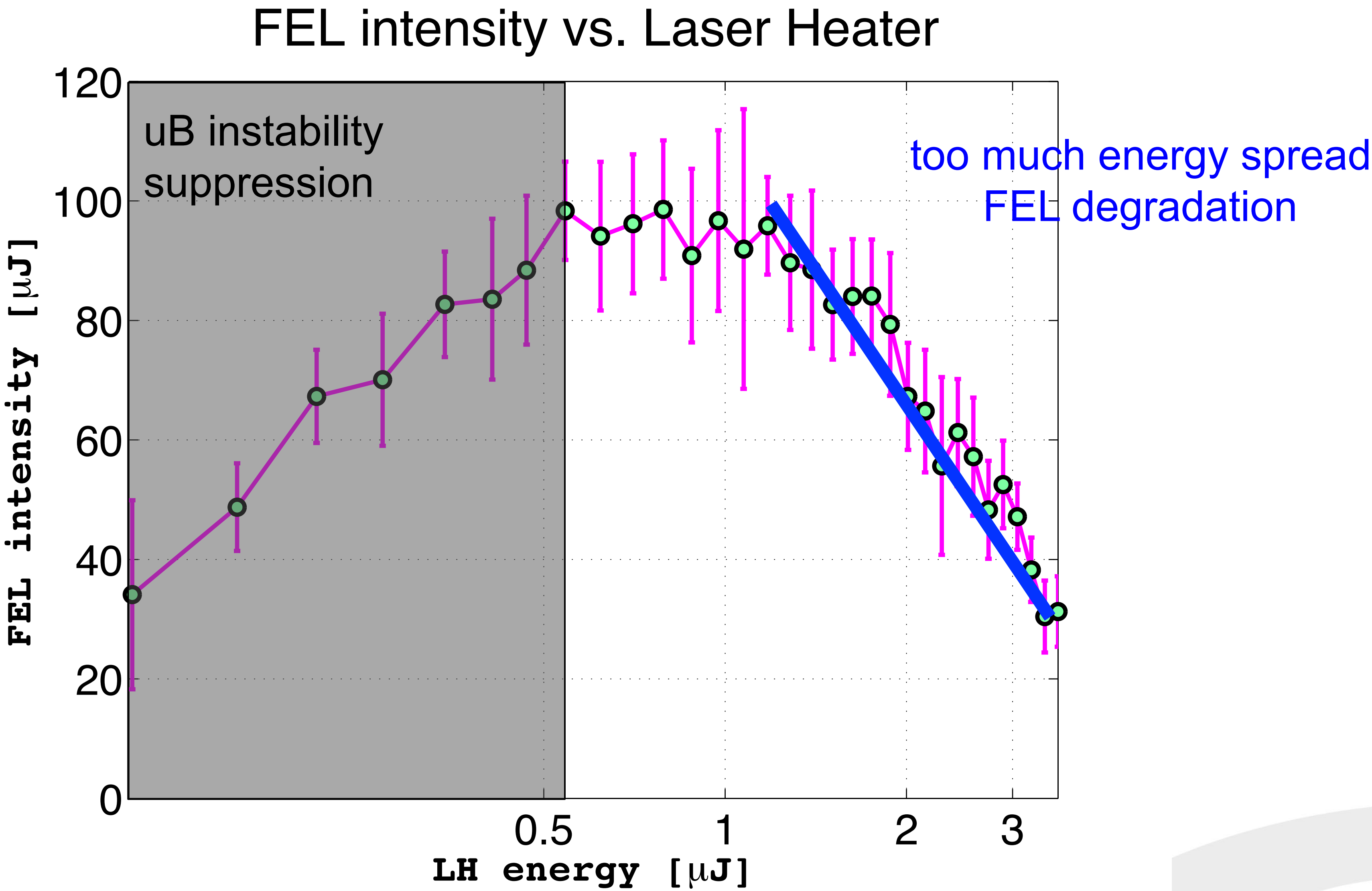
Laser heater – FEL intensity



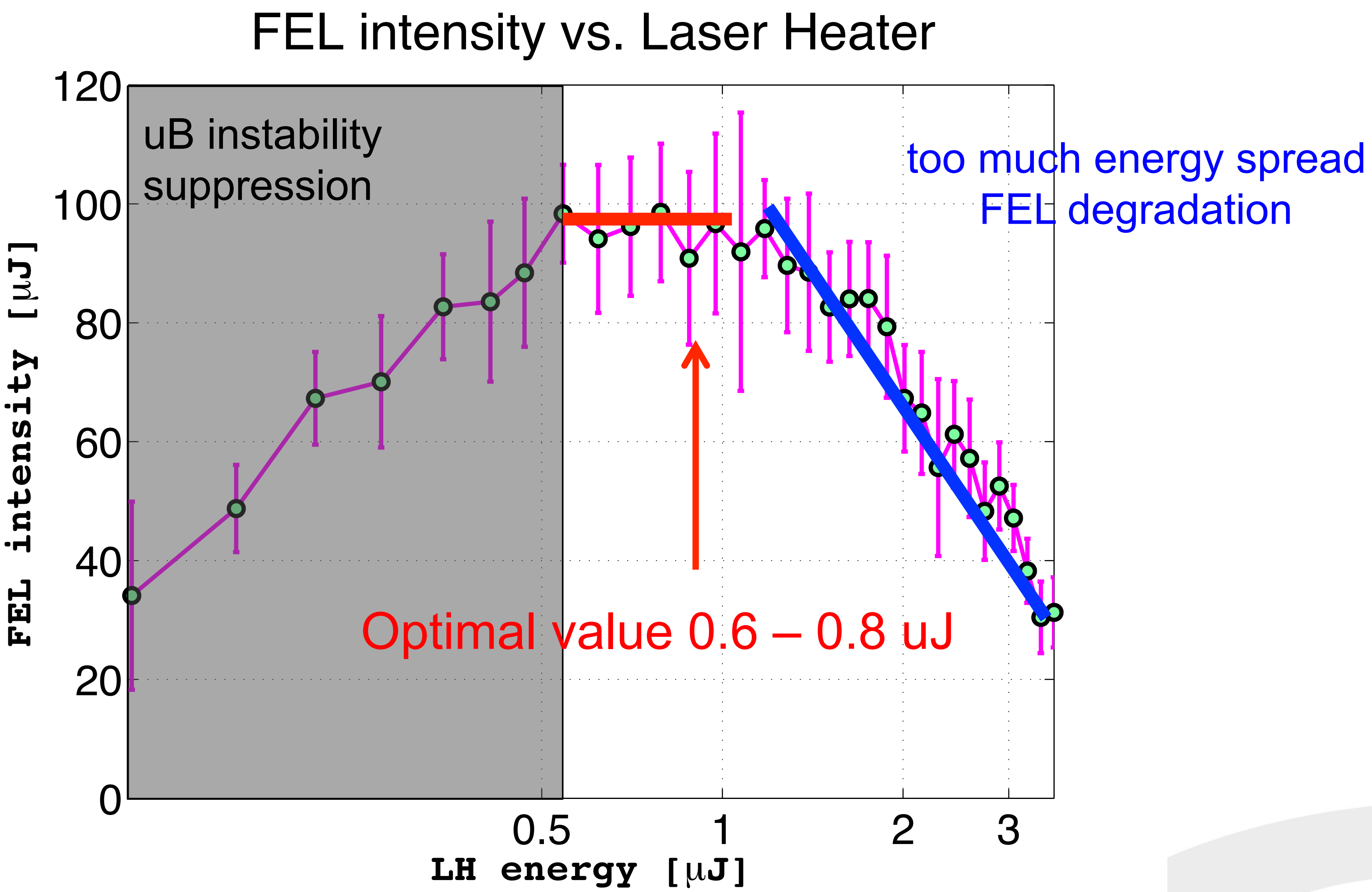
Laser heater – FEL intensity



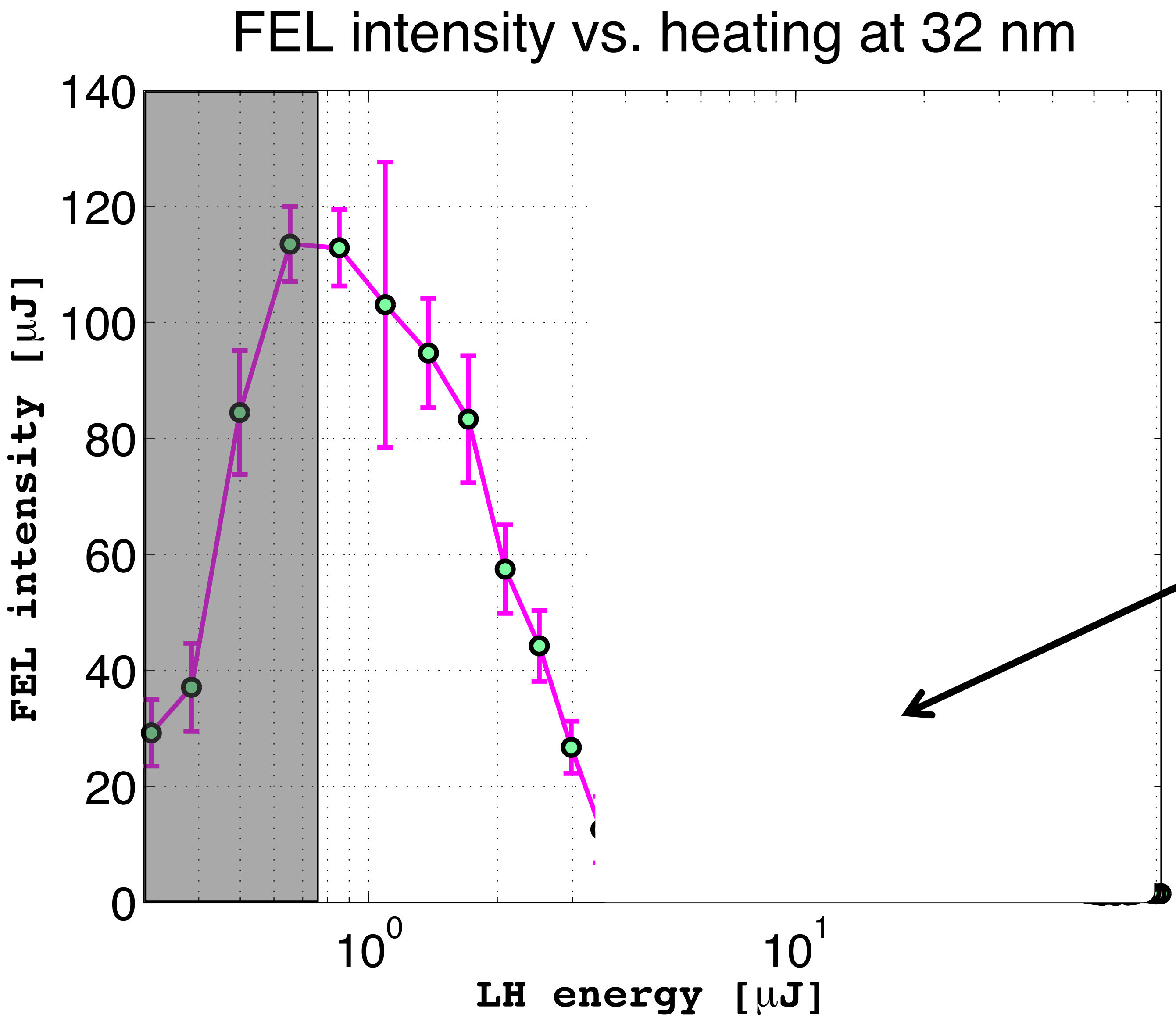
Laser heater – FEL intensity



Laser heater – FEL intensity



But if we enlarge the scan range…



Appearence of local maxima at large heating (x10 with respect to optimal)

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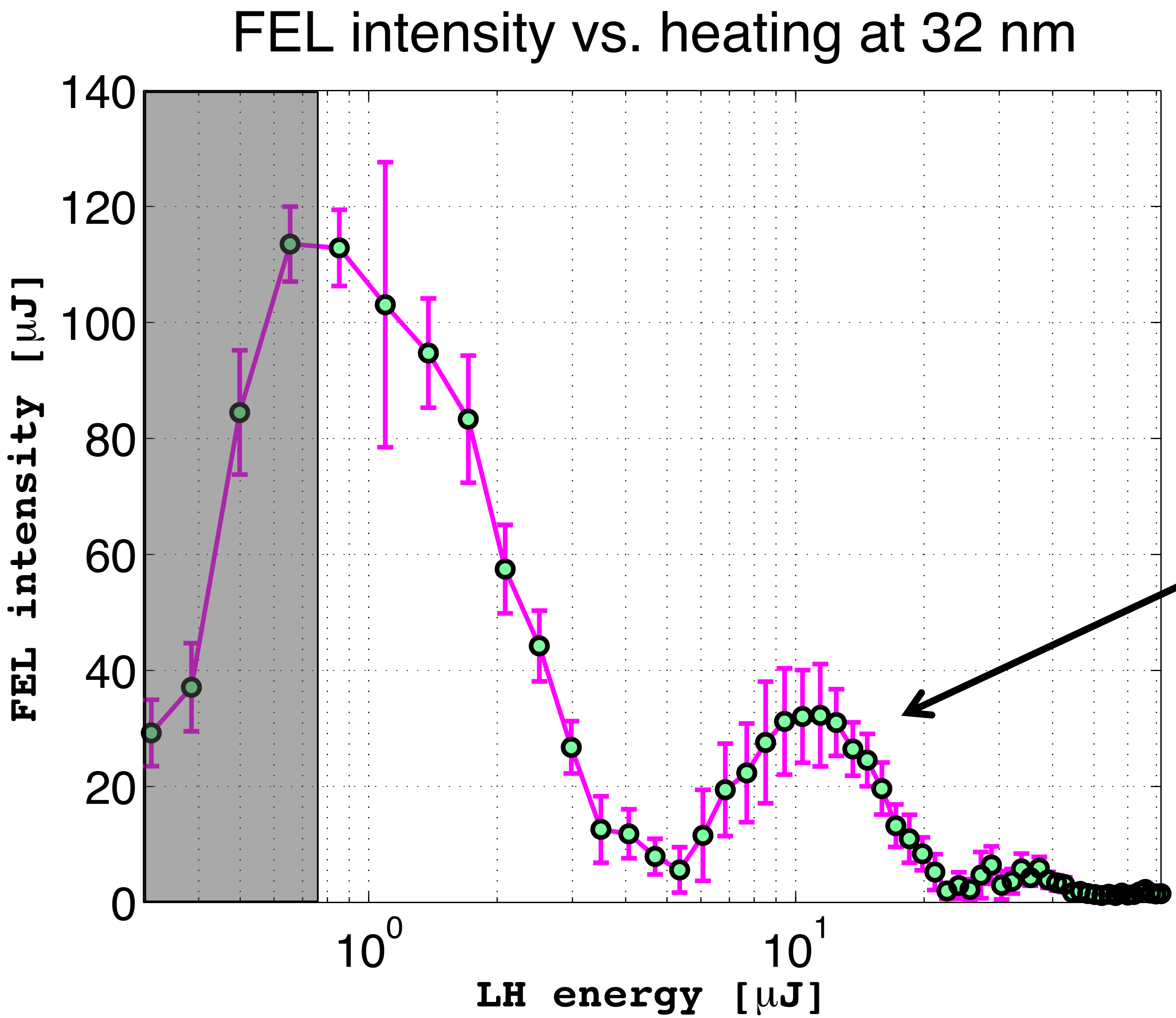
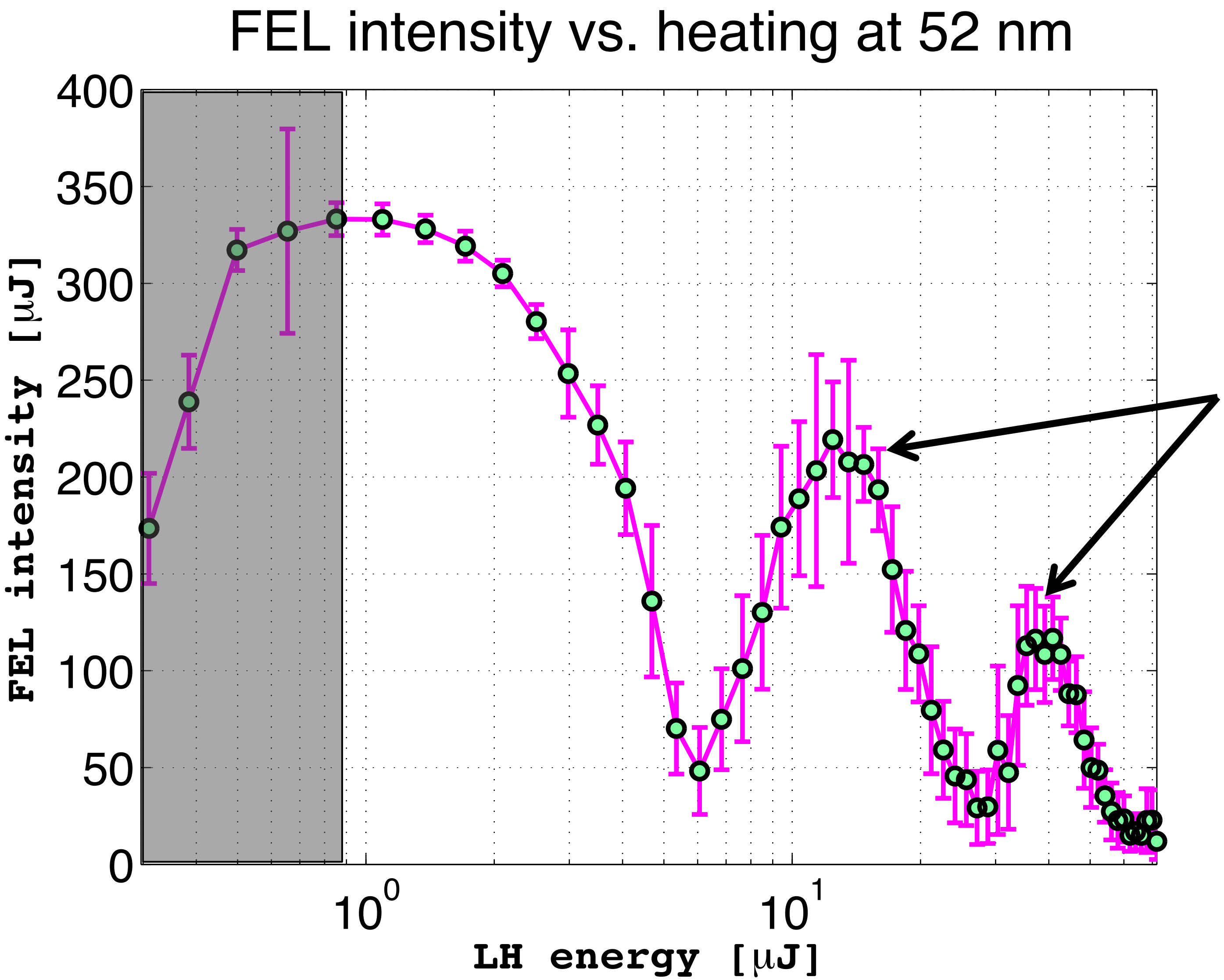


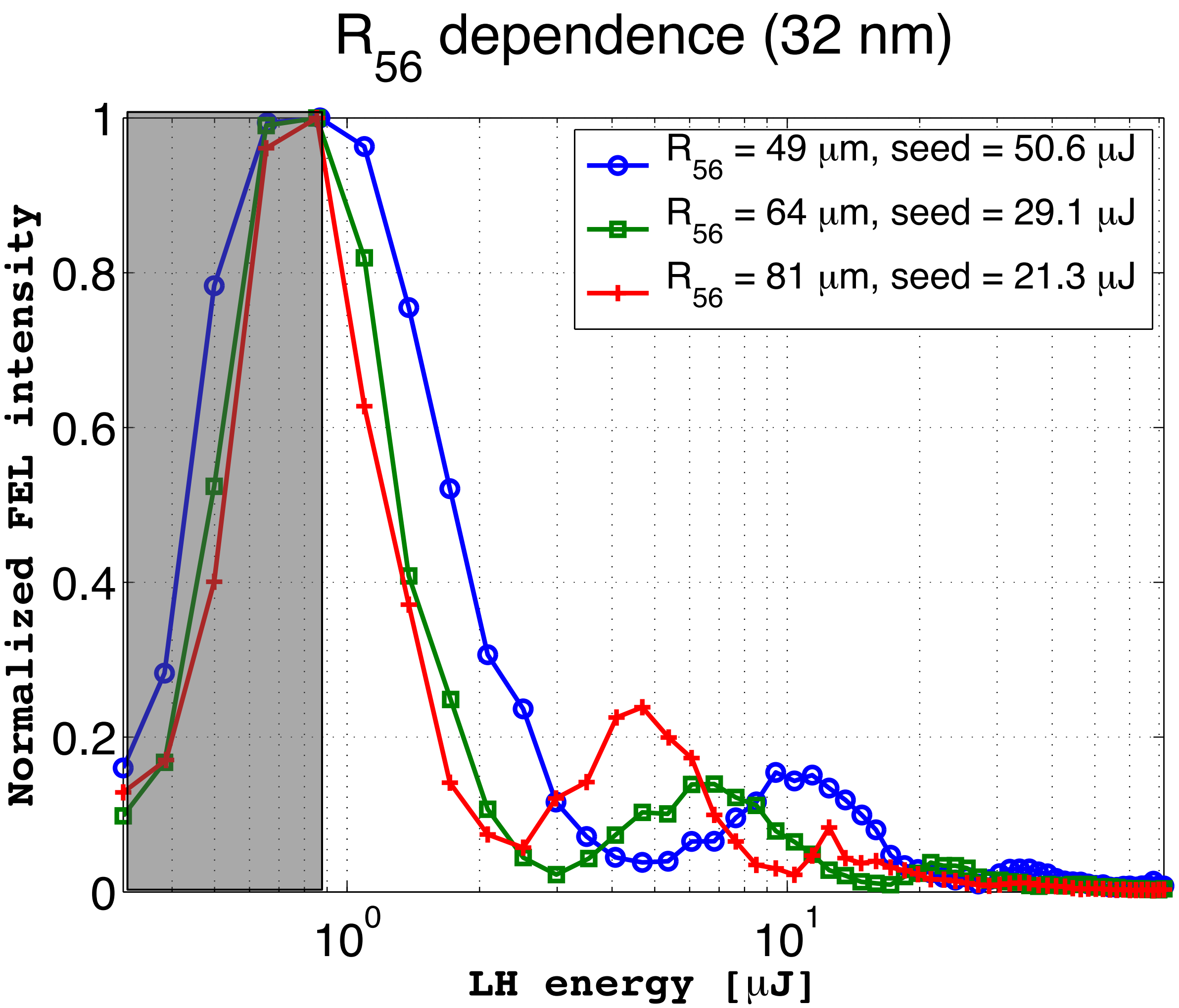
Appearence of local maxima at large heating (x10 with respect to optimal)

The effect can be dramatic!

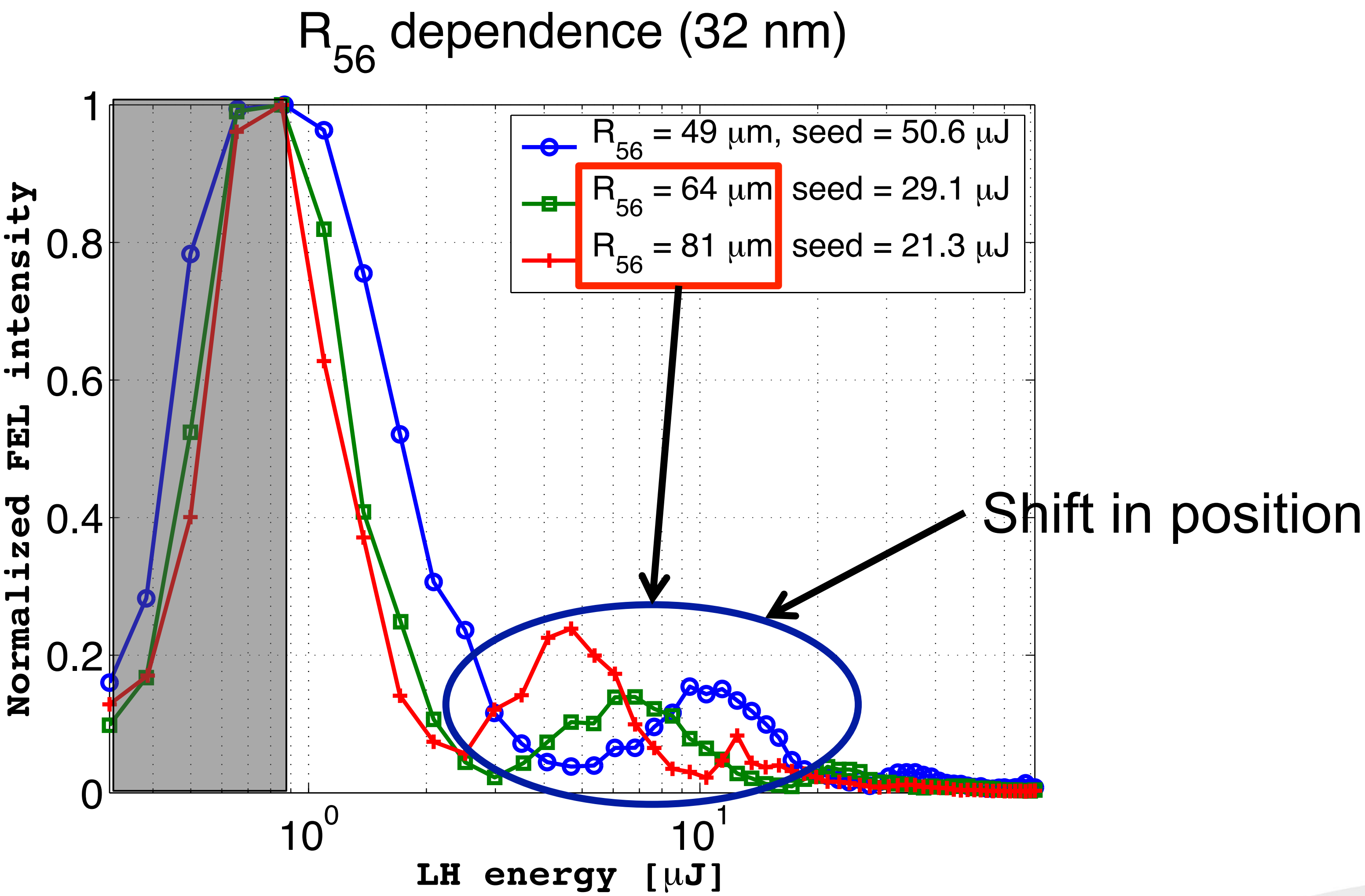


Many multiple peaks with decreasing intensity

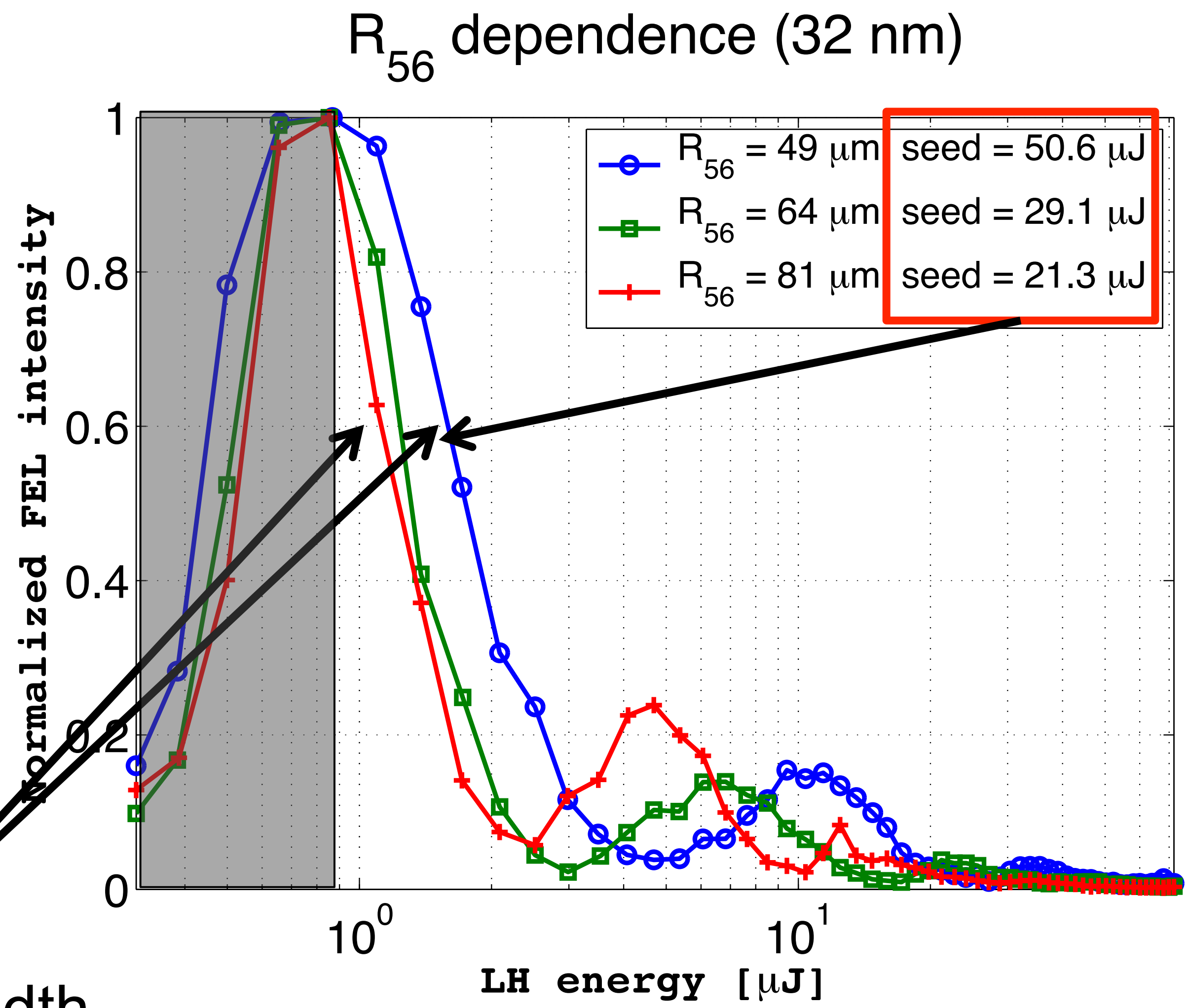
Dependence on R56 and seed



Dependence on R56 and seed

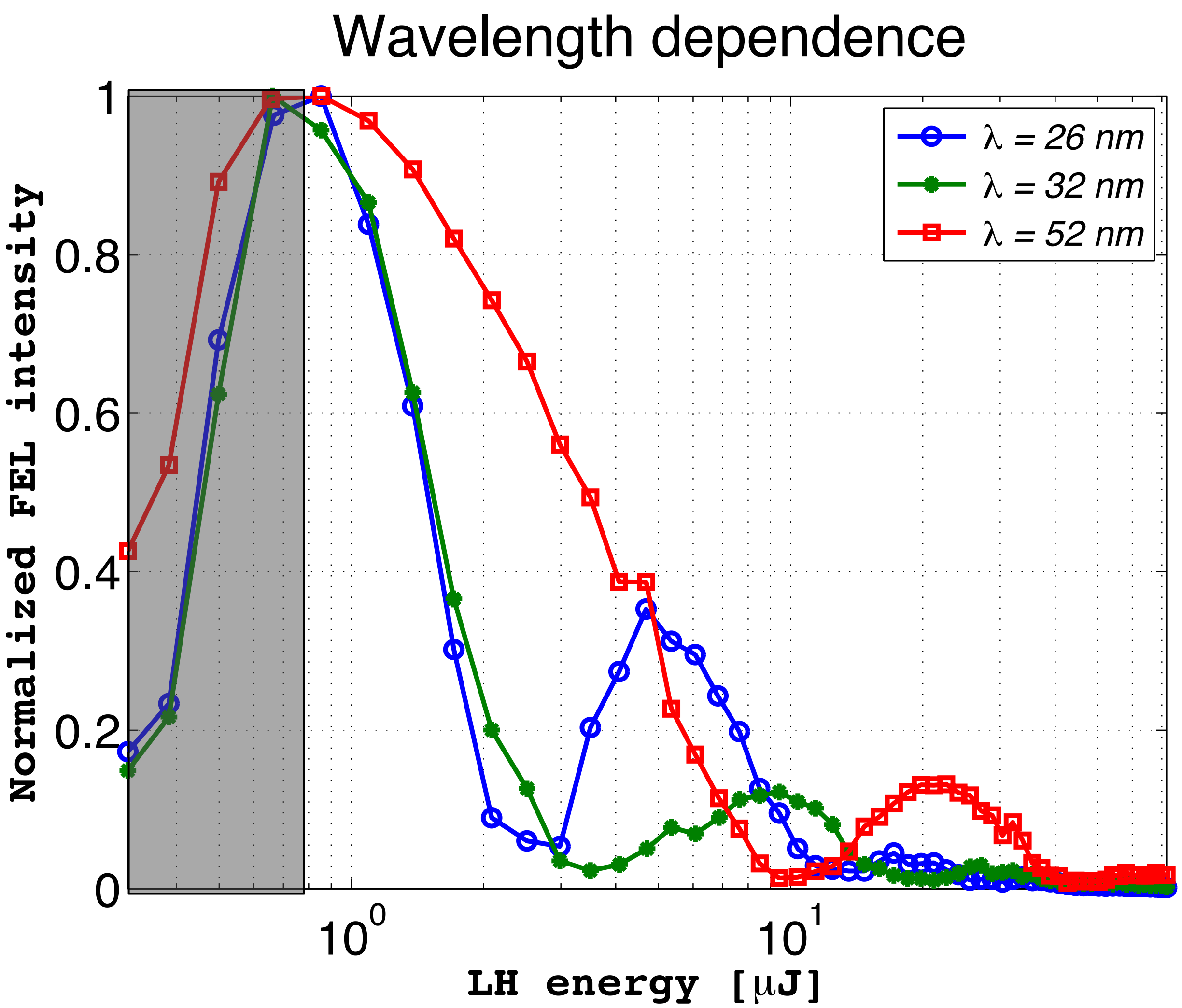


Dependence on R56 and seed



Change in width

Dependence on FEL wavelength



The number, position and relative intensity of secondary peaks can be tuned

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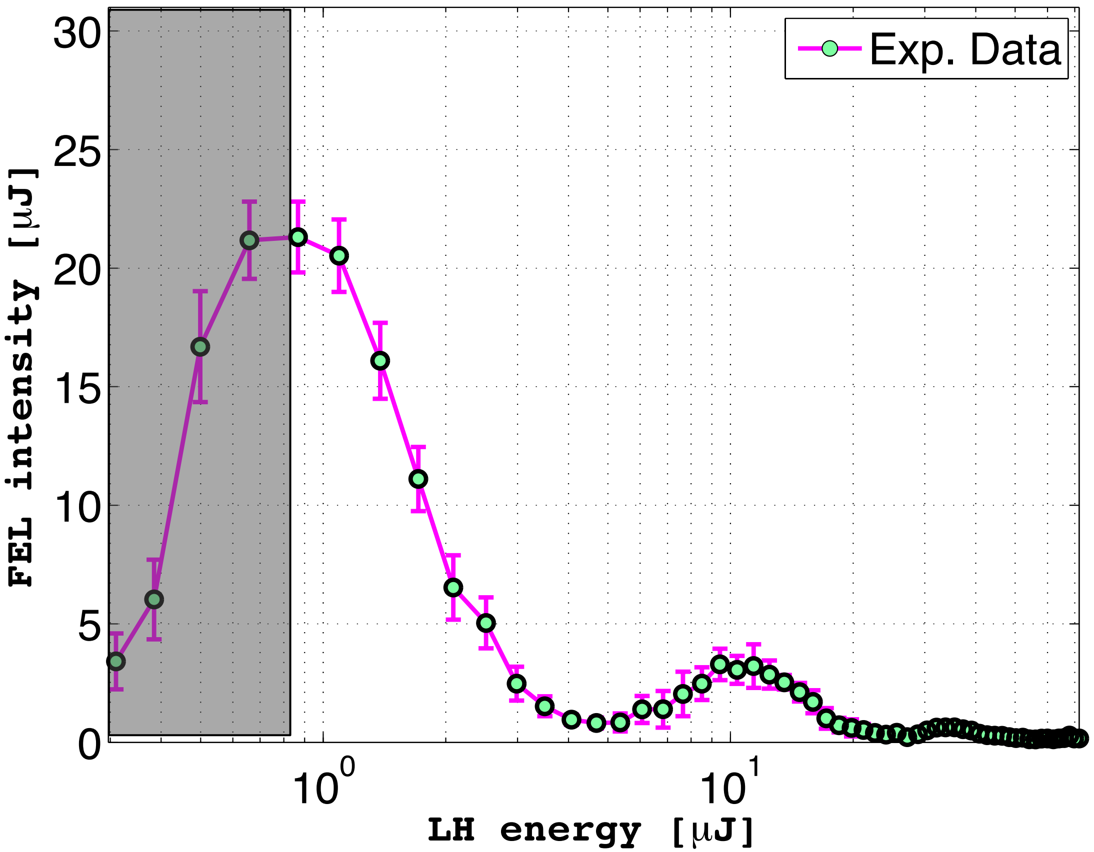
How to explain this behaviour?

FEL vs. LH - Without gain

Without gain, the FEL intensity is almost proportional to the square of the bunching b_m

FEL intensity vs. heating (no gain, 32 nm)

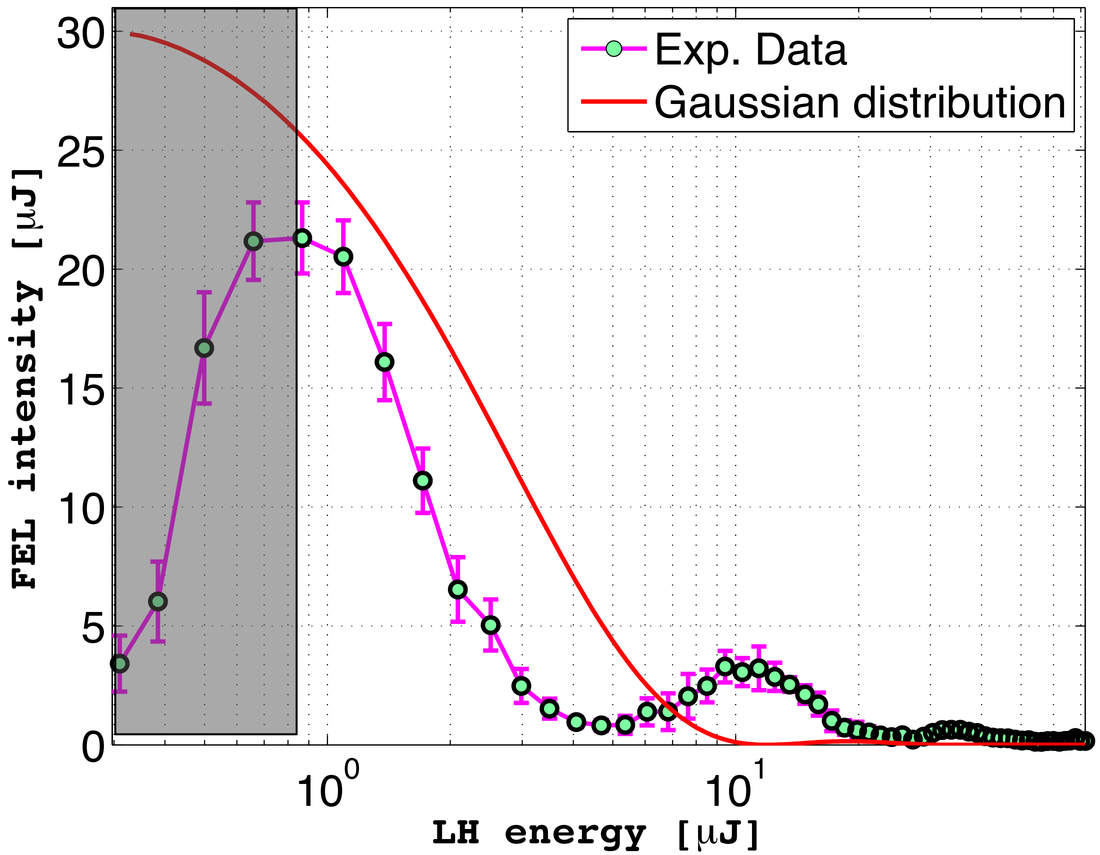


Coherent emission from three radiators only

Bunching

(1) $$\mathbf{b_m} = \exp(-\frac{1}{2}\mathbf{m^2D^2}\sigma_\gamma^2)\mathbf{J_m}(\mathbf{mD}\Delta\gamma)$$

FEL intensity vs. heating (no gain, 32 nm)



$$\mathbf{D} = \frac{2\pi \mathbf{R_{56}}}{\gamma_0\lambda}$$ Dispersion

R_{56} Momentum compaction

γ_0 e⁻ energy

λ FEL wavelength

$\mathbf{m}$ Harmonic number

σ_γ Energy spread (rms)

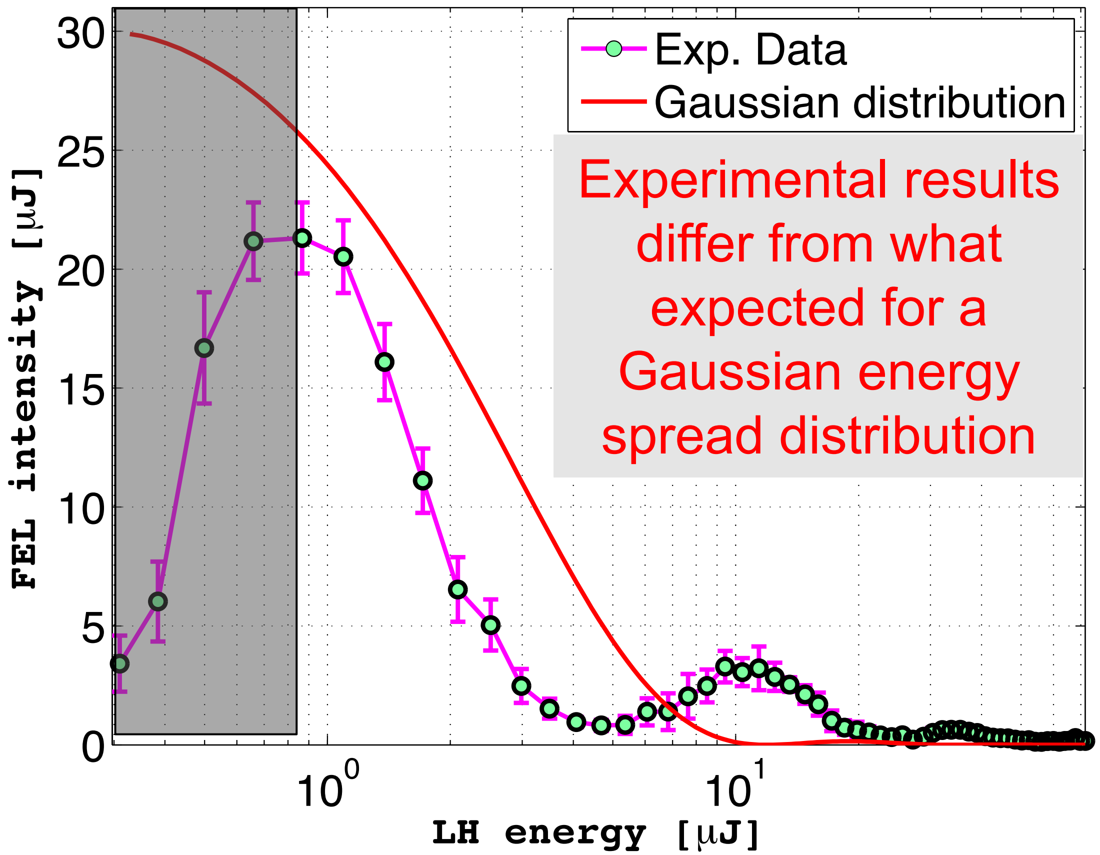
$\mathbf{J_m}$ m-th order Bessel

$\Delta\gamma$ FEL energy modulation

Bunching

(1) $$b_m = \exp(-\frac{1}{2}m^2D^2\sigma_\gamma^2)J_m(mD\Delta\gamma)$$

FEL intensity vs. heating (no gain, 32 nm)



$D = \frac{2\pi R_{56}}{\gamma_0\lambda}$ Dispersion

R_{56} Momentum compaction

γ_0 e^- energy

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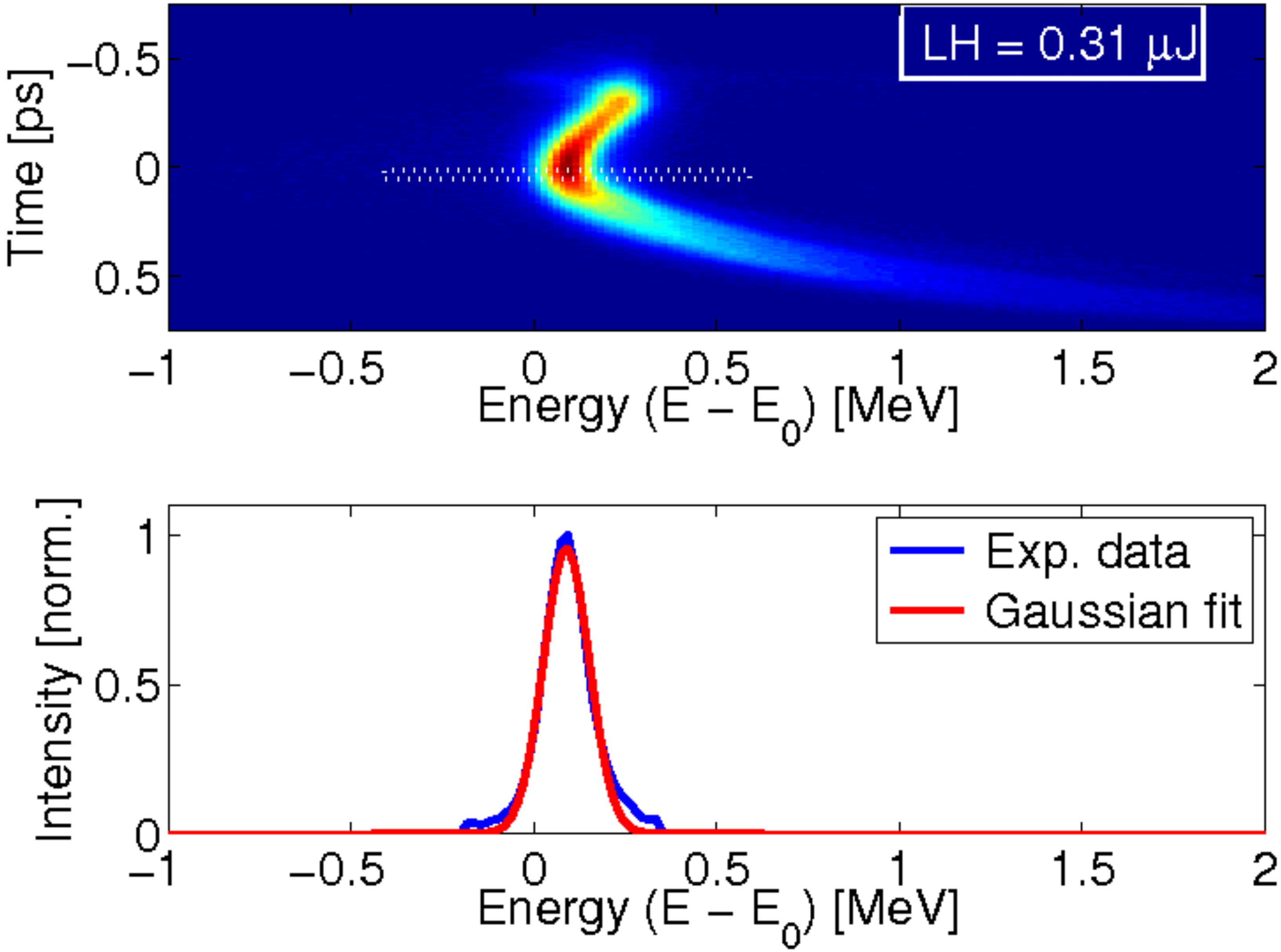
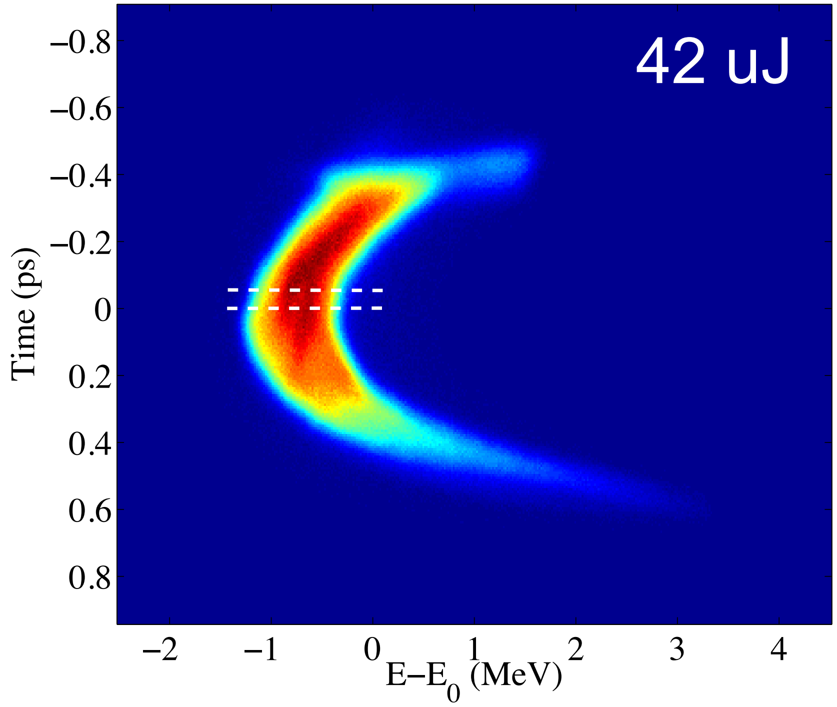
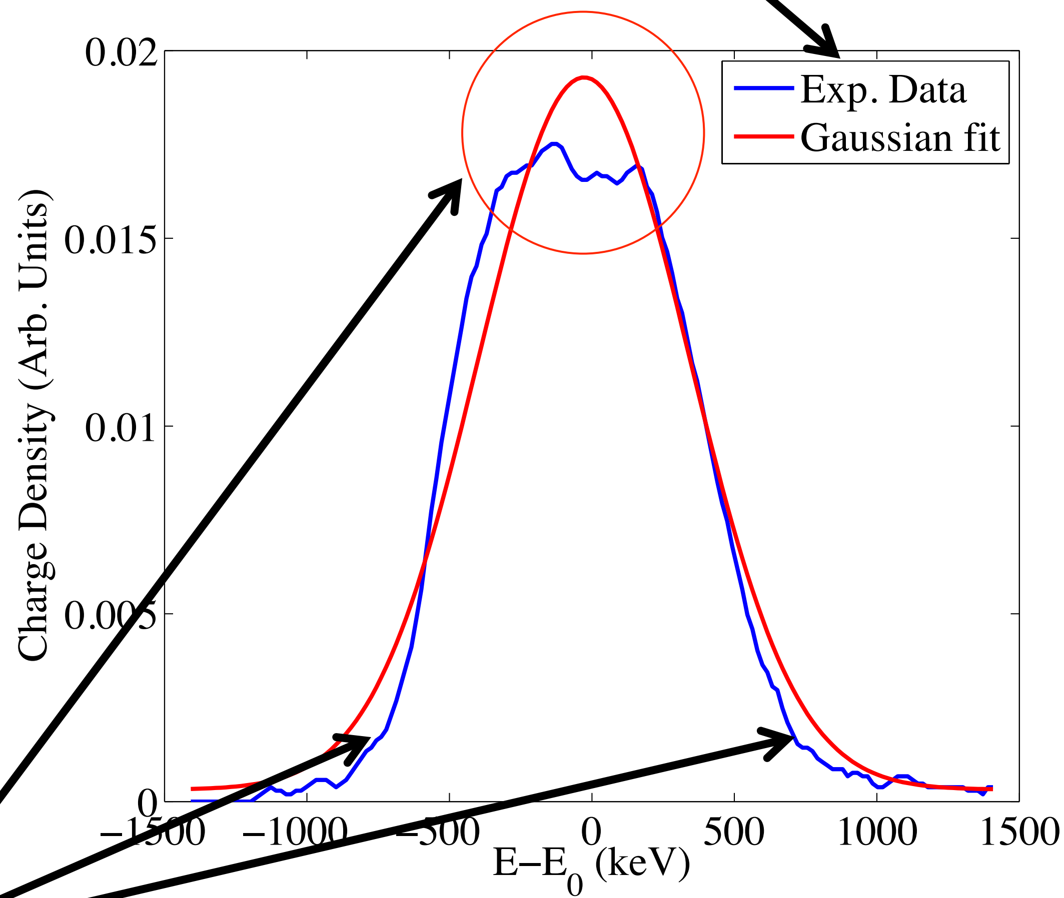
Longitudinal Phase Space and heating



Non-Gaussian energy spread

Same area and same second moment





Significant differences

Bunching with non-Gaussian energy spread

(2) $$\mathbf{b_m} = \exp(-\frac{\mathbf{1}}{\mathbf{2}}\mathbf{m}^2\mathbf{D}^2\sigma_\gamma^2)\mathbf{J_m}(\mathbf{mD}\boldsymbol{\Delta}\gamma)\mathbf{S_L}(\mathbf{mD}\boldsymbol{\Delta}\gamma, \frac{\sigma_\mathbf{r}}{\sigma_\mathbf{x}})$$

Z. Huang, PRSTAB 7, 074401 (2004)

$$\mathbf{S_L}(\mathbf{A},\mathbf{B}) = \int \mathbf{RdR}\exp\left(-\frac{\mathbf{R}^2}{\mathbf{2}}\right)\mathbf{J_0}\left[\mathbf{A}\exp\left(-\frac{\mathbf{R}^2}{\mathbf{4B}^2}\right)\right]$$

bunching suppression factor

$$\mathbf{D} = \frac{\mathbf{2}\pi\mathbf{R_{56}}}{\gamma_0\lambda}$$

$$\mathbf{S_L}(\mathbf{A},\mathbf{B}) = \begin{cases} J_0(A), & \text{if } B \gg 1 \\ \frac{2J_1(A)}{A}, & \text{if } B = 1 \end{cases}$$

$\mathbf{m}$ Harmonic number

σ_γ Energy spread (rms)

$\mathbf{J_m}$ m-th order Bessel

$\boldsymbol{\Delta}\gamma$ FEL energy modulation

$\sigma_\mathbf{r}$ laser spot size (in LH)

$\sigma_\mathbf{x}$ e^- spot size (in LH)

Bunching with non-Gaussian energy spread

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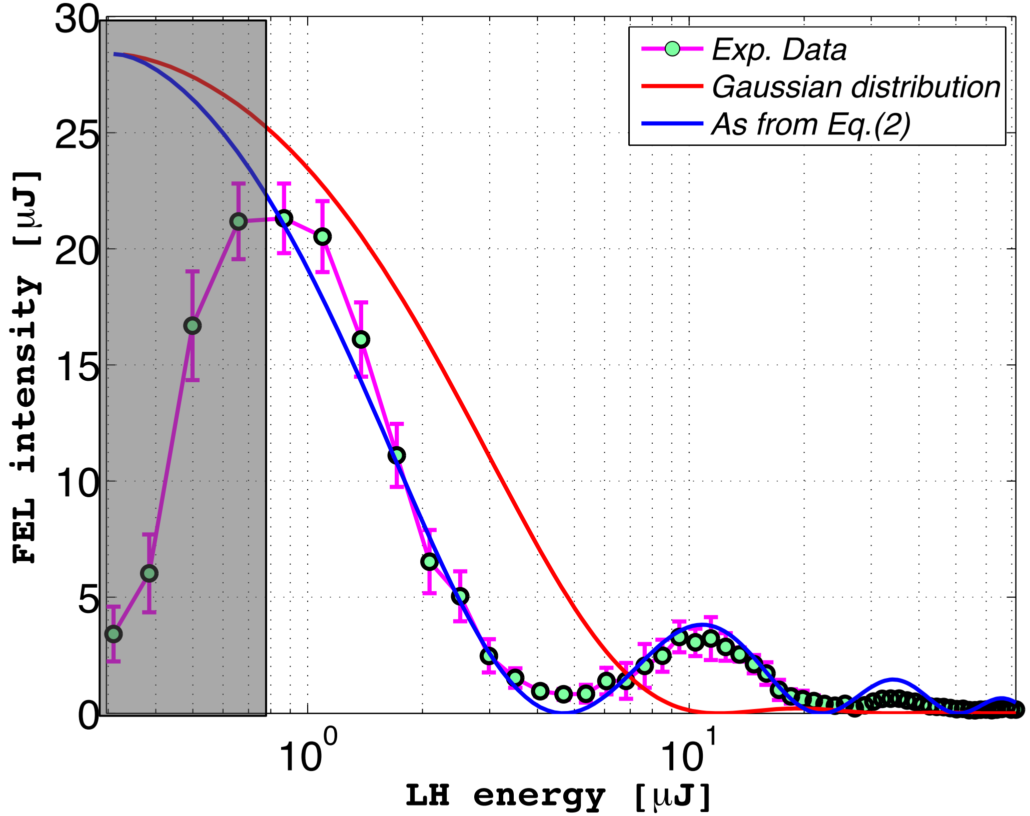
Z. Huang, PRSTAB 7, 074401 (2004)

FEL intensity vs. heating (no gain, 32 nm)



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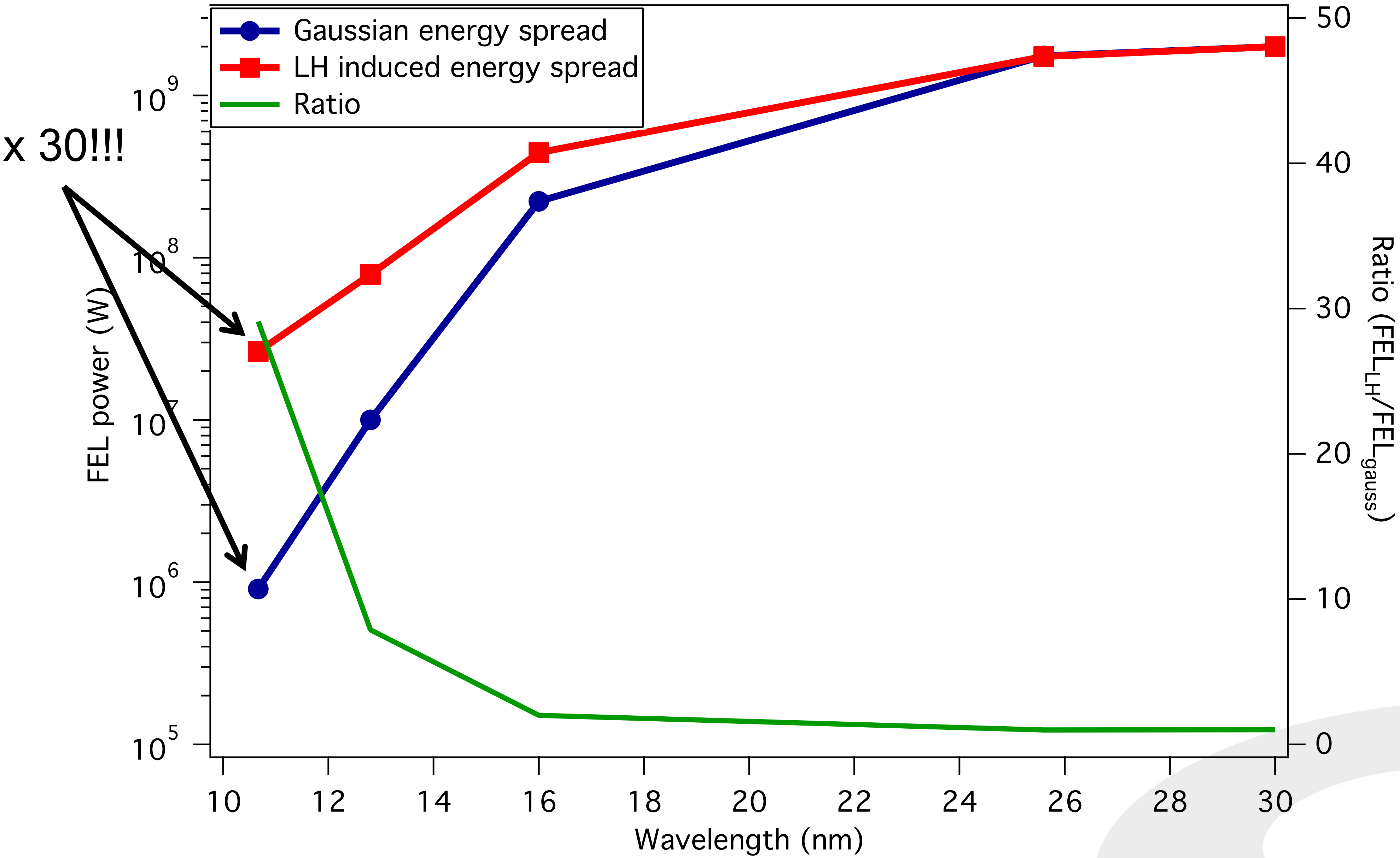
$\sigma_\mathbf{r}$ laser spot size (in LH)

$\sigma_\mathbf{x}$ e[-] spot size (in LH)

Simulated impact on high-harmonic emission



Summary

- ★ A Laser Heater is routinely used in FEL operations at FERMI.
- ★ The non-Gaussian distribution of the energy spread induced by the Laser Heater has been shown to be preserved up to the linac end and the undulators.
- ★ The shape of the slice energy spread distribution has a significant impact on FEL intensity, as it ultimately determines the bunching.
- ★ In particular, several FEL local maxima as a function of LH intensity have been observed, and can be controlled by tuning the machine parameters.
- ★ The unexpected behavior is well reproduced by previously developed LH theory.

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Perspectives

★ Preliminary numerical simulations show that the non-Gaussian energy spread can increase the FEL power at high harmonic (i.e. shorter wavelength) in a HGHG FEL.

★ The significant increase in emission power could potentially extend the operation range of the single cascade HGHG scheme.

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We acknowledge the support of the
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Thanks for your attention!