Elettra Sincrotrone Trieste

6th Microbunching Instability Workshop

Trieste, Italy / 6 - 8 October 2014

Benefits of the laser heater induced energy spread for high harmonic conversion in HGHG FEL

E. Ferrari[1,2], G. Penco[1], E. Allaria[1], S. Spampinati[1], L. Giannessi[1,3], W. Fawley[1], Z. Huang[4]

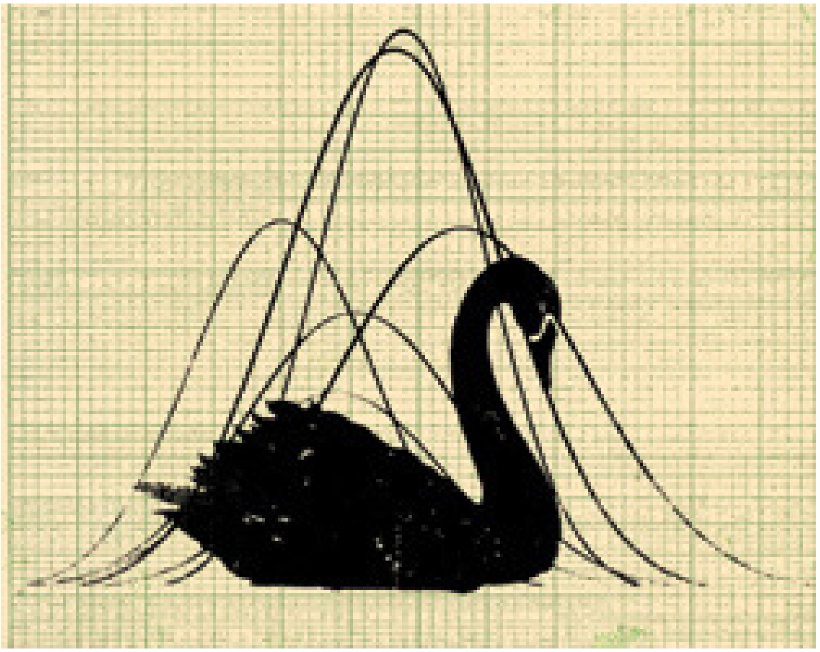
1. Elettra - Sincrotrone Trieste;
2. Universita' degli Studi di Trieste;
3. ENEA C.R. Frascati
4. SLAC National Accelerator Laboratory

Outline

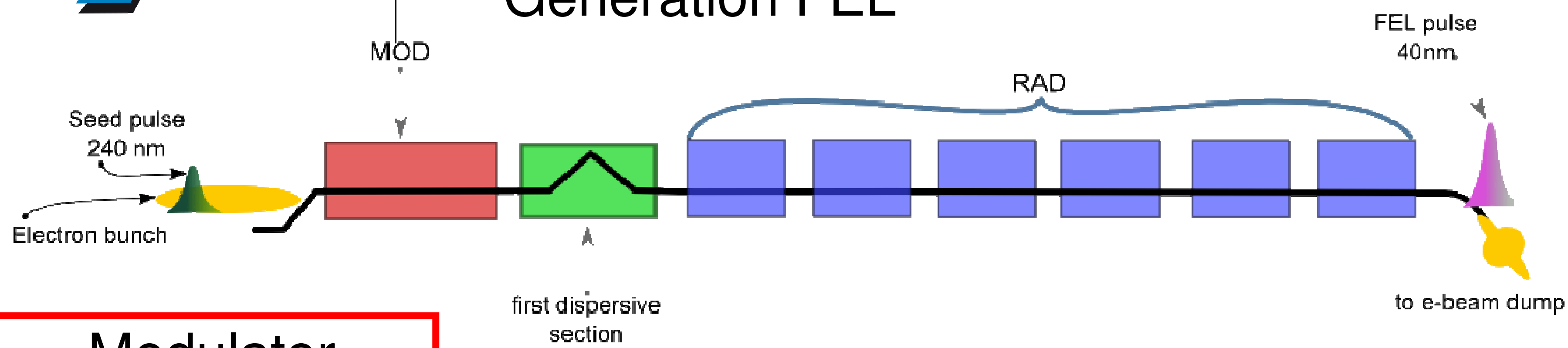
★ Fermi experimental setup

★ Impact of the laser heater on seeded FEL

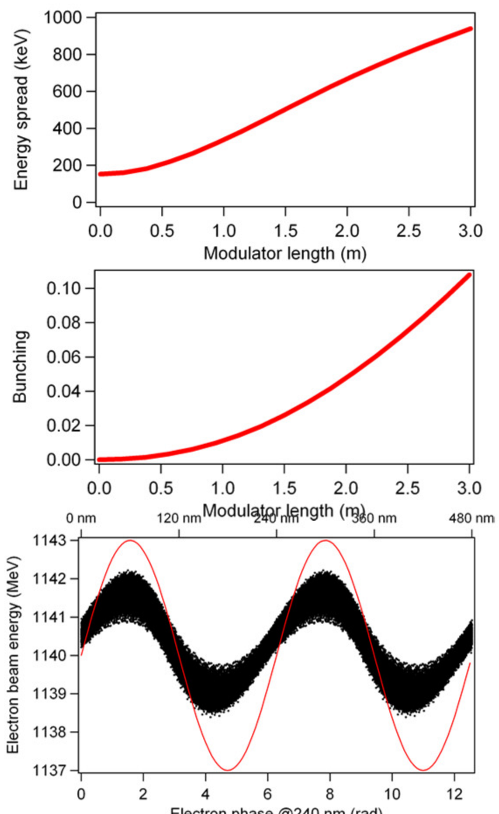
★ Non-Gaussian effects



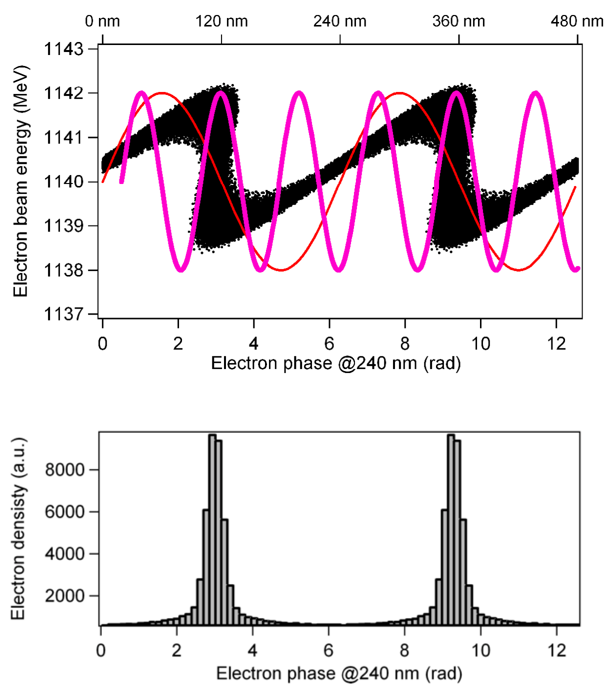
FERMI: a Seeded High Gain Harmonic Generation FEL



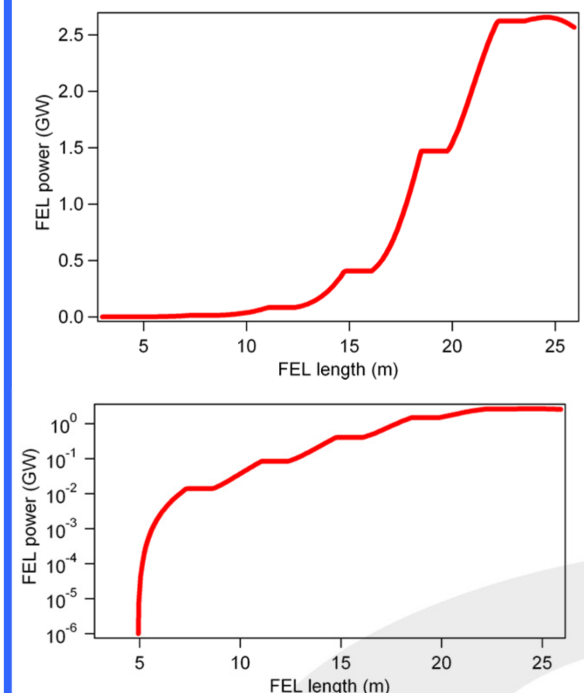
Modulator



Dispersive section



Radiator



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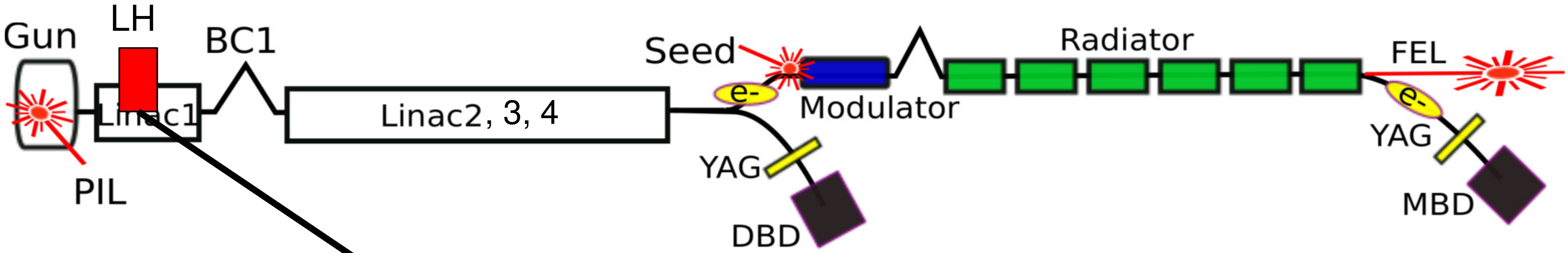
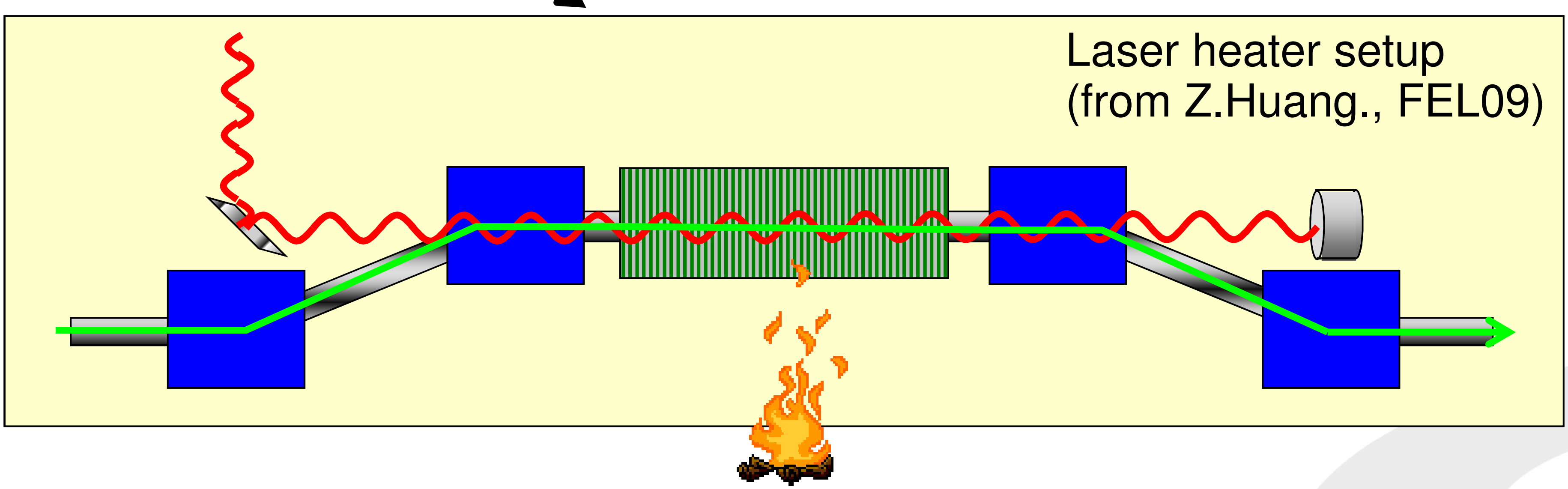
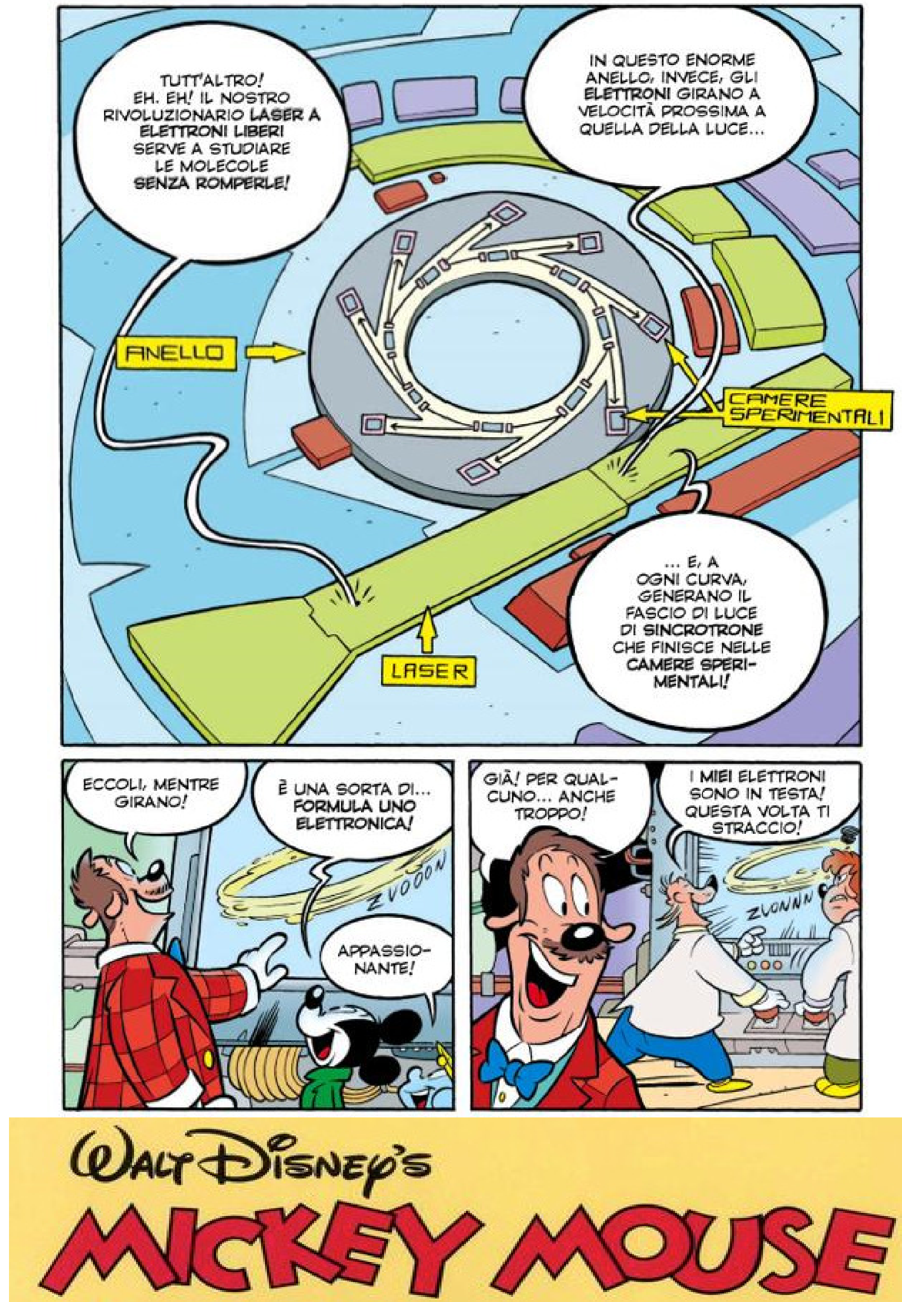
Experimental setup

Fermi scheme

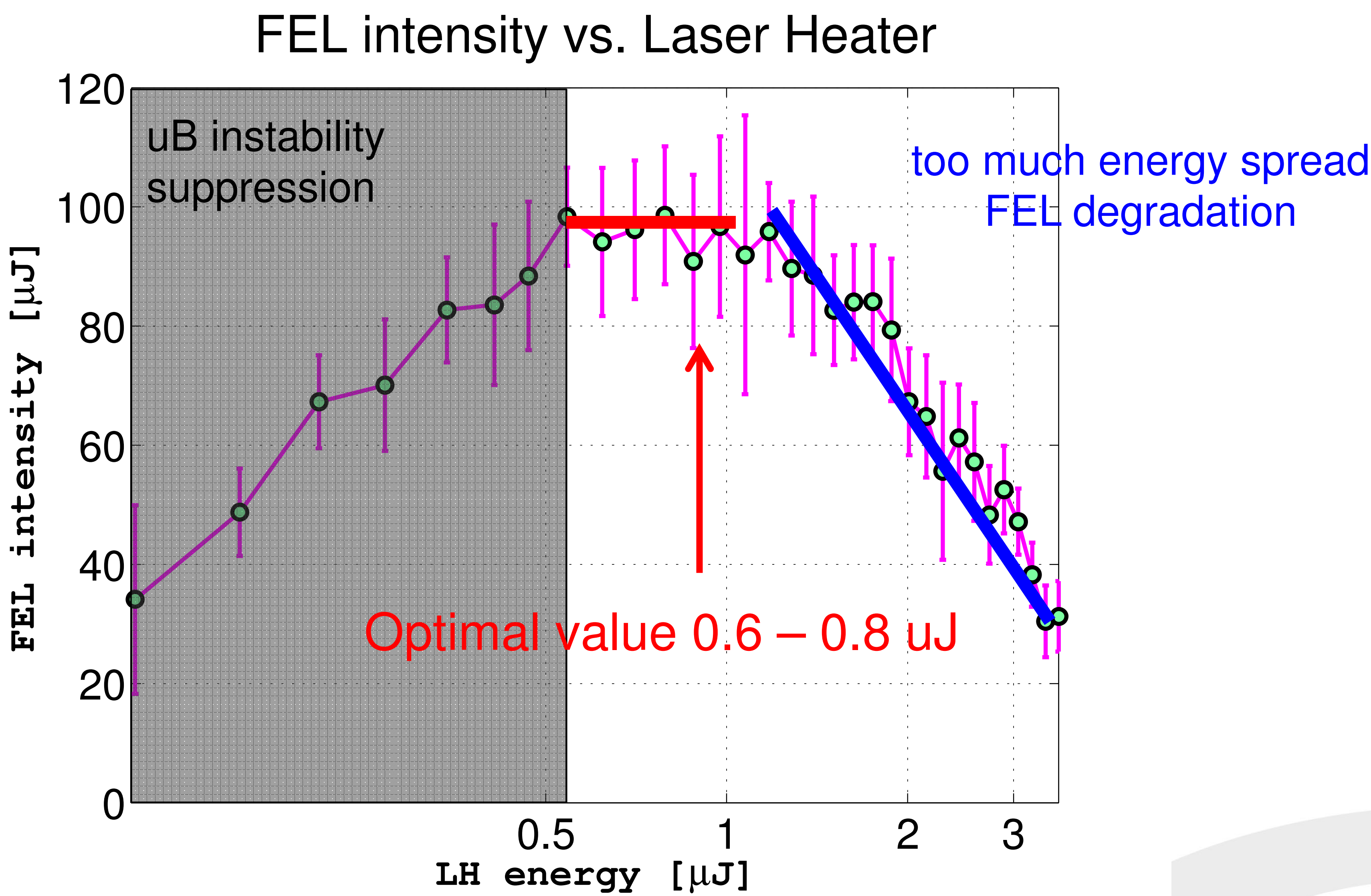




For more details on the FERMI scheme

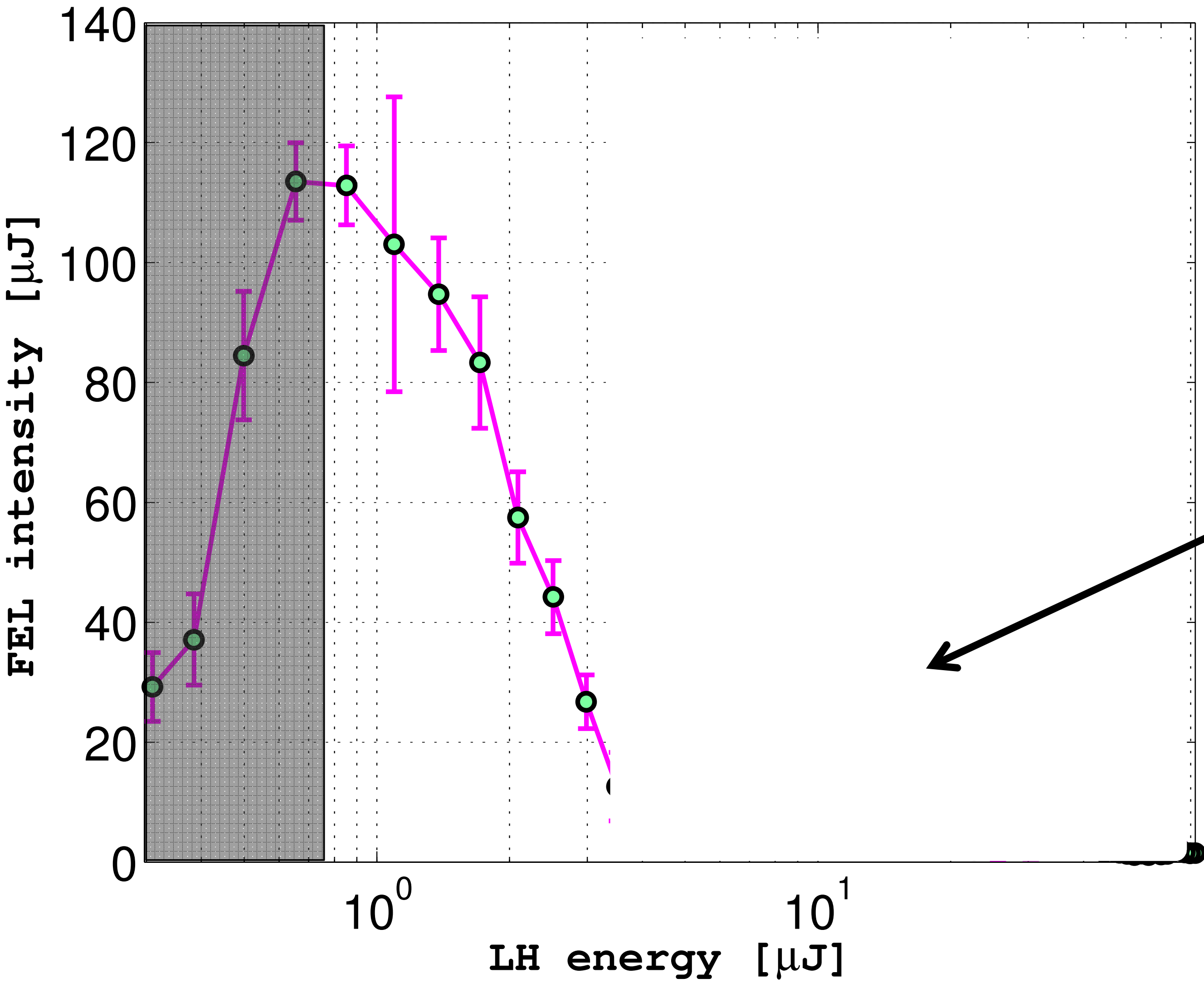


Laser heater – FEL intensity



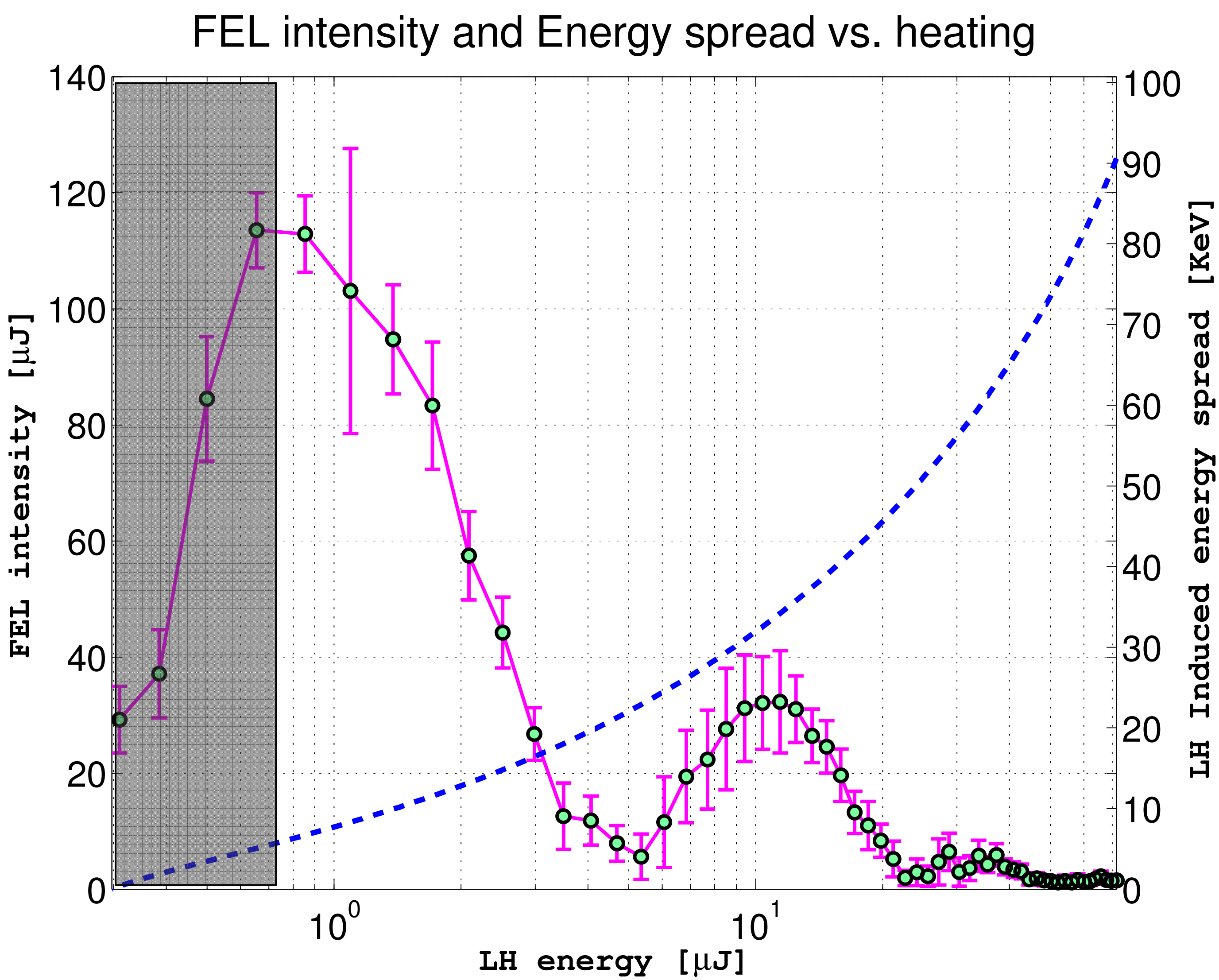
But if we enlarge the scan range…

FEL intensity vs. heating at 32 nm



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

The induced energy spread is monotonic



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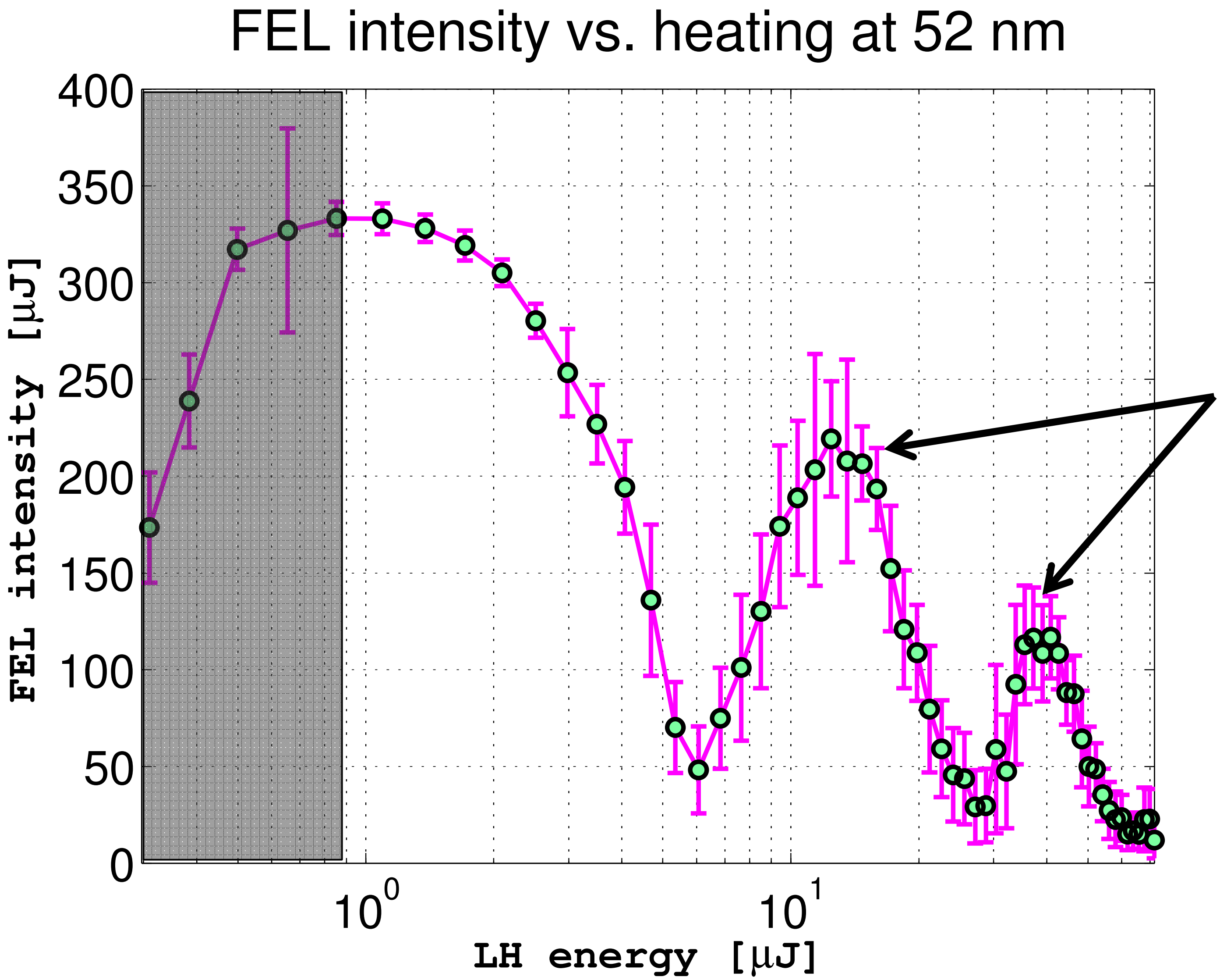
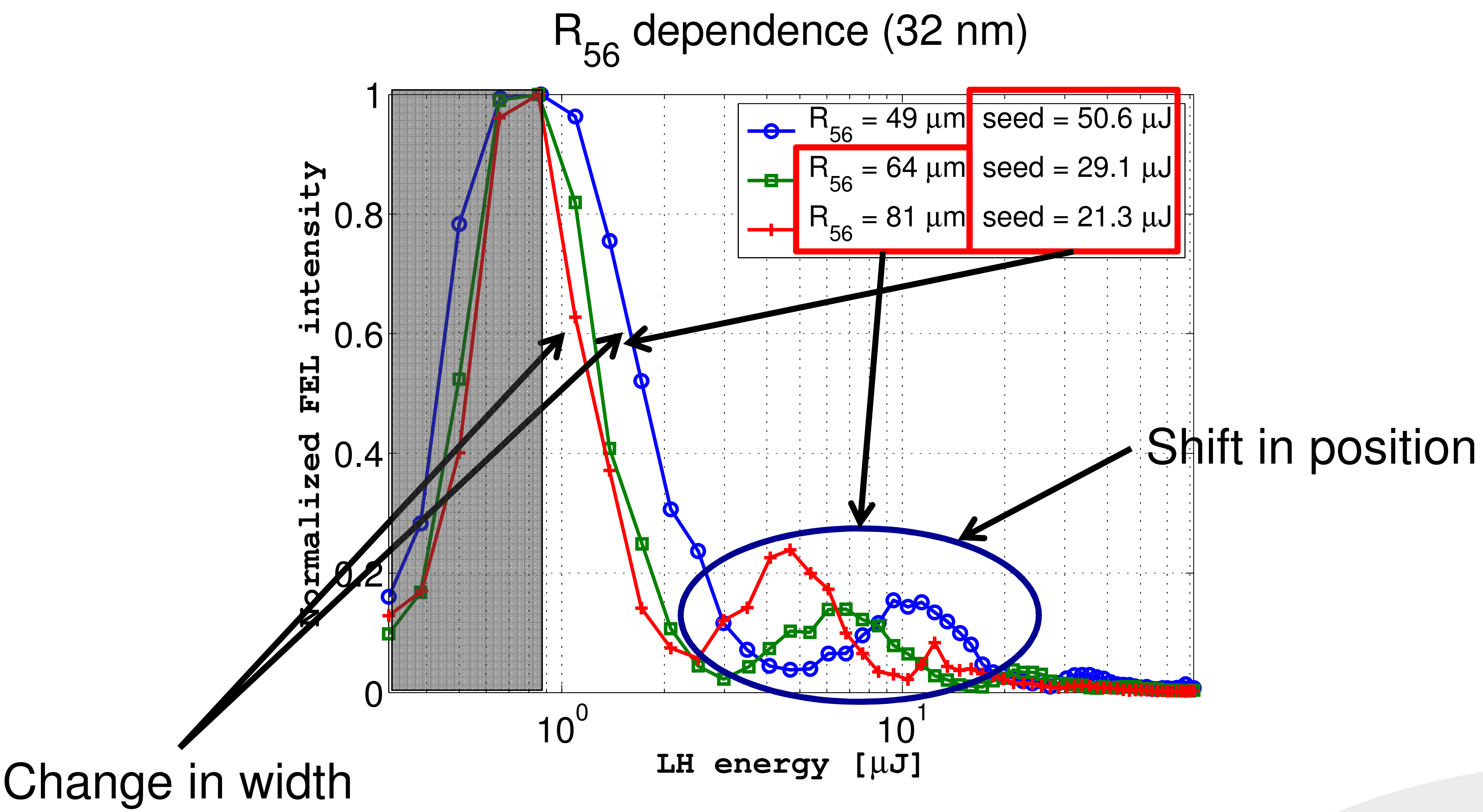
The effect can be dramatic!

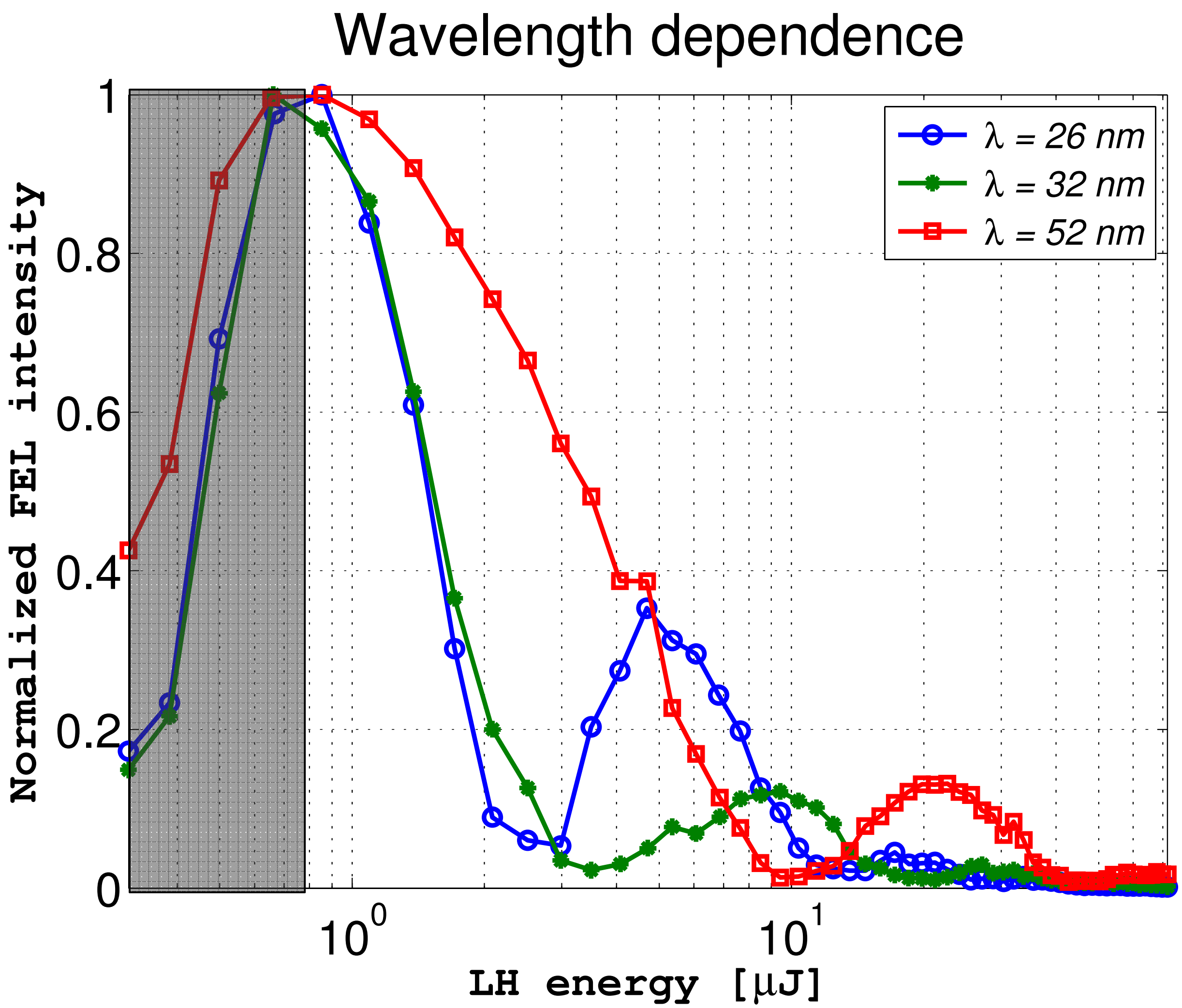


Many multiple peaks with decreasing intensity

Dependence on R56 and seed



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?

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Impact of Non-Gaussian Electron Energy Heating upon the Performance of a Seeded Free-Electron Laser

E. Ferrari,[1,2,*] E. Allaria,[1] W. Fawley,[1,3] L. Giannessi,[1,4] Z. Huang,[3] G. Penco,[1] and S. Spampinati[1,5,6,7]

[1]*Elettra-Sincrotrone Trieste S.C.p.A. di interesse nazionale, Strada Statale 14-km 163,5 in AREA Science Park, 34149 Basovizza, Trieste, Italy*

[2]*Università degli Studi di Trieste, Dipartimento di Fisica, Piazzale Europa 1, 34127 Trieste, Italy*

[3]*SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*

[4]*Enea, via Enrico Fermi 45, 00044 Frascati, Roma, Italy*

[5]*Laboratory of Quantum Optics, University of Nova Gorica, 5000 Nova Gorica, Slovenia*

[6]*Department of Physics, University of Liverpool, Oxford Street L69 7ZE, Liverpool, United Kingdom*

[7]*Cockcroft Institute, Sci-Tech Daresbury, Keckwick Lane WA4 4AD, Daresbury, Warrington, United Kingdom*

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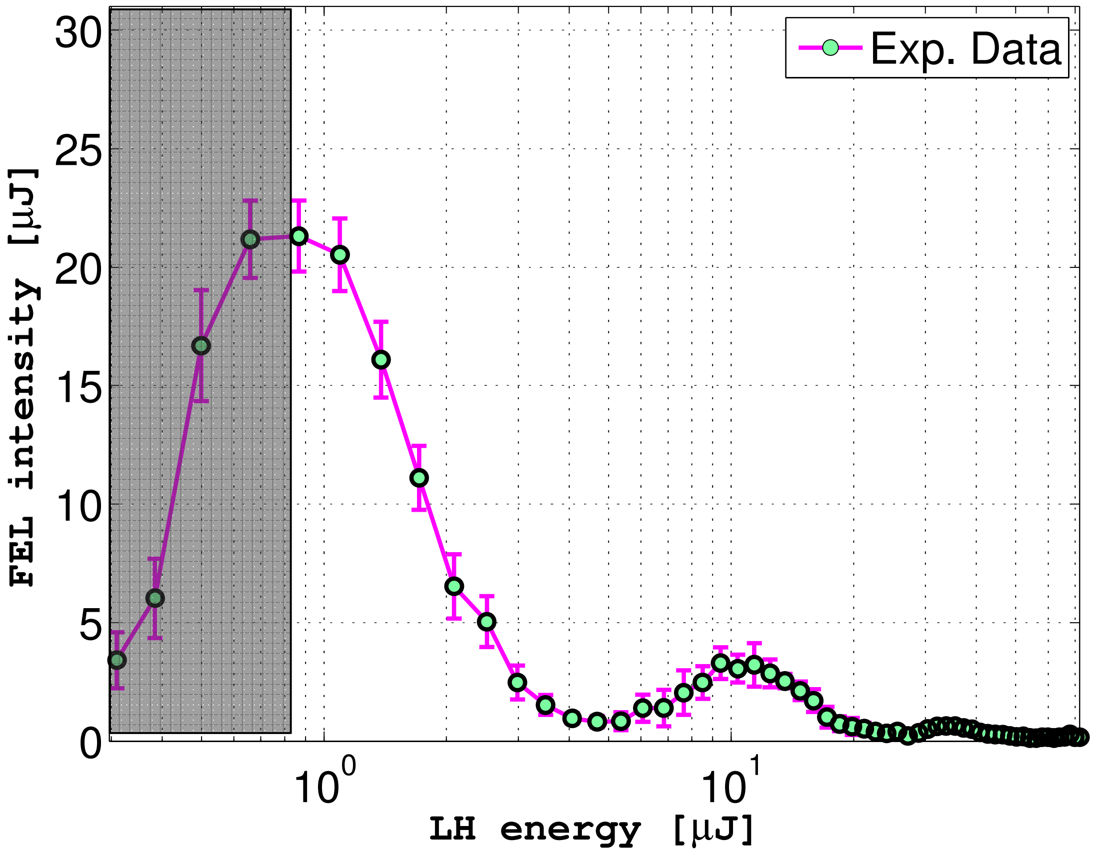
FEL vs. LH - Without gain

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

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

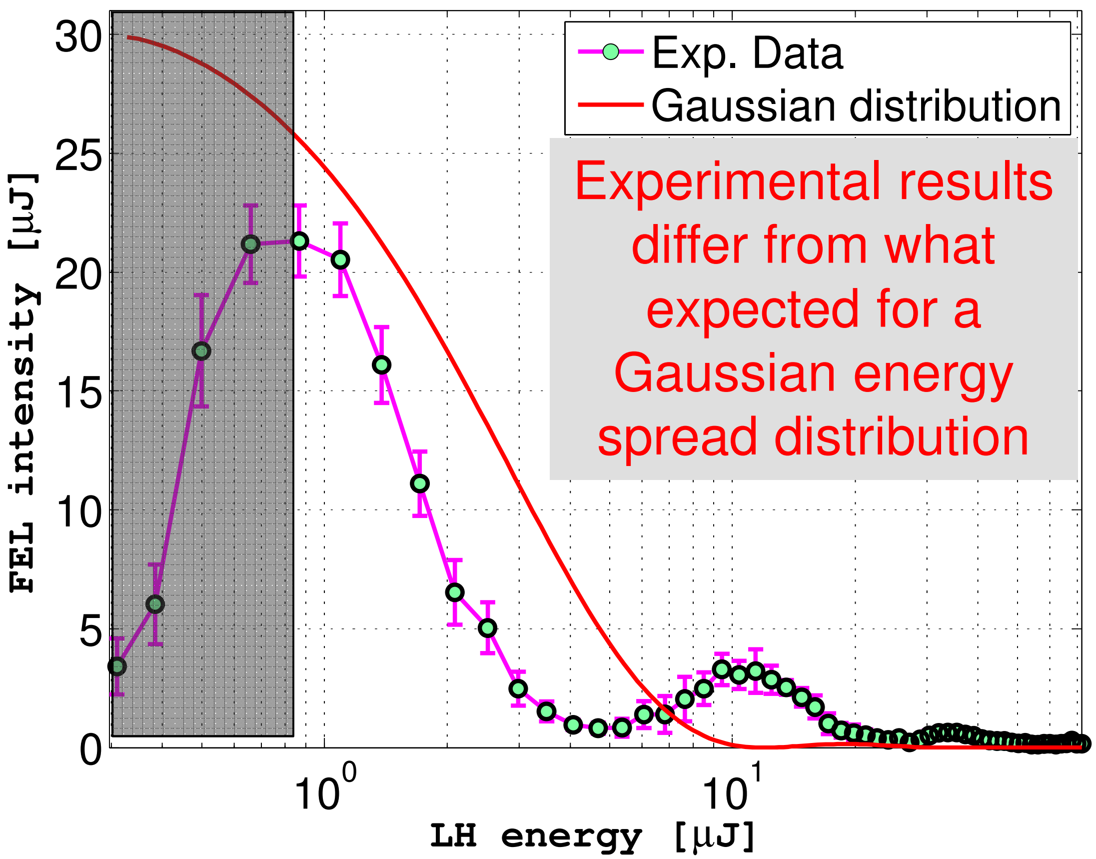


Coherent emission from three radiators only

Bunching

(1) $$\mathbf{b_m} = \exp\left(-\frac{1}{2}\mathbf{m}^2\mathbf{D}^2\sigma_\gamma^2\right)\mathbf{J_m}(\mathbf{mD}\Delta\gamma)$$ L. H. Yu

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

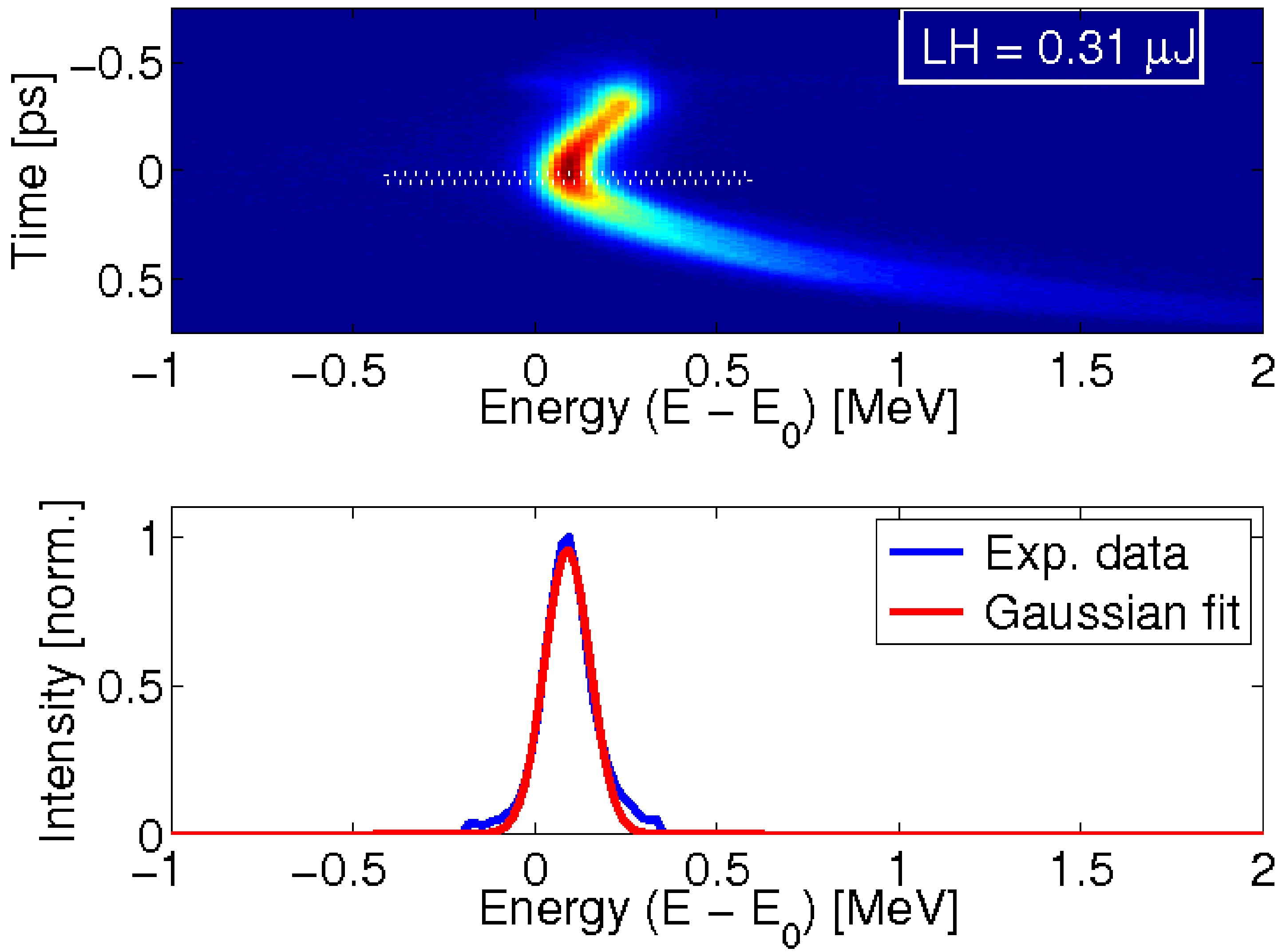
$\mathbf{m}$ Harmonic number

σ_γ Energy spread (rms)

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

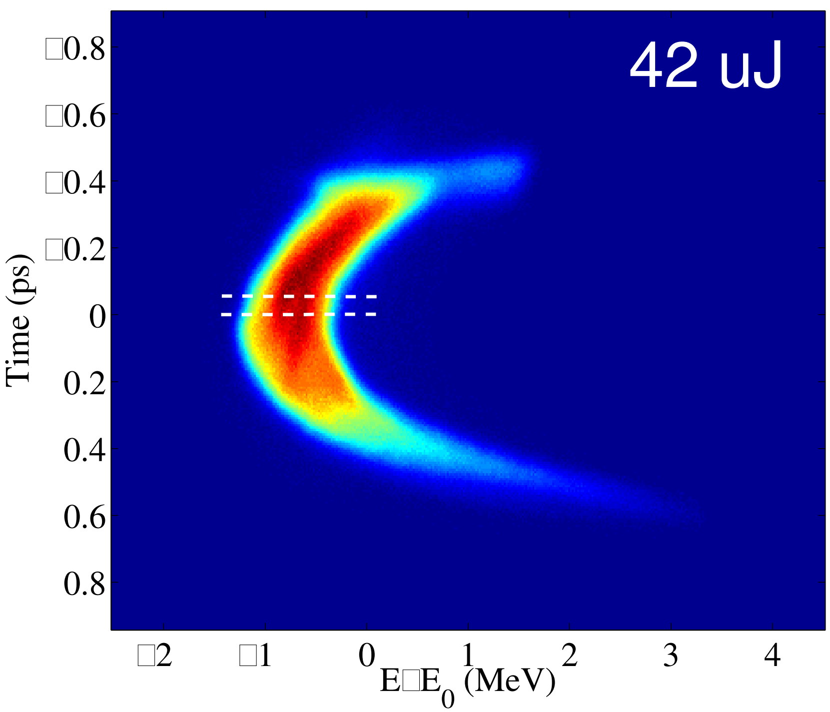
$\Delta\gamma$ FEL energy modulation

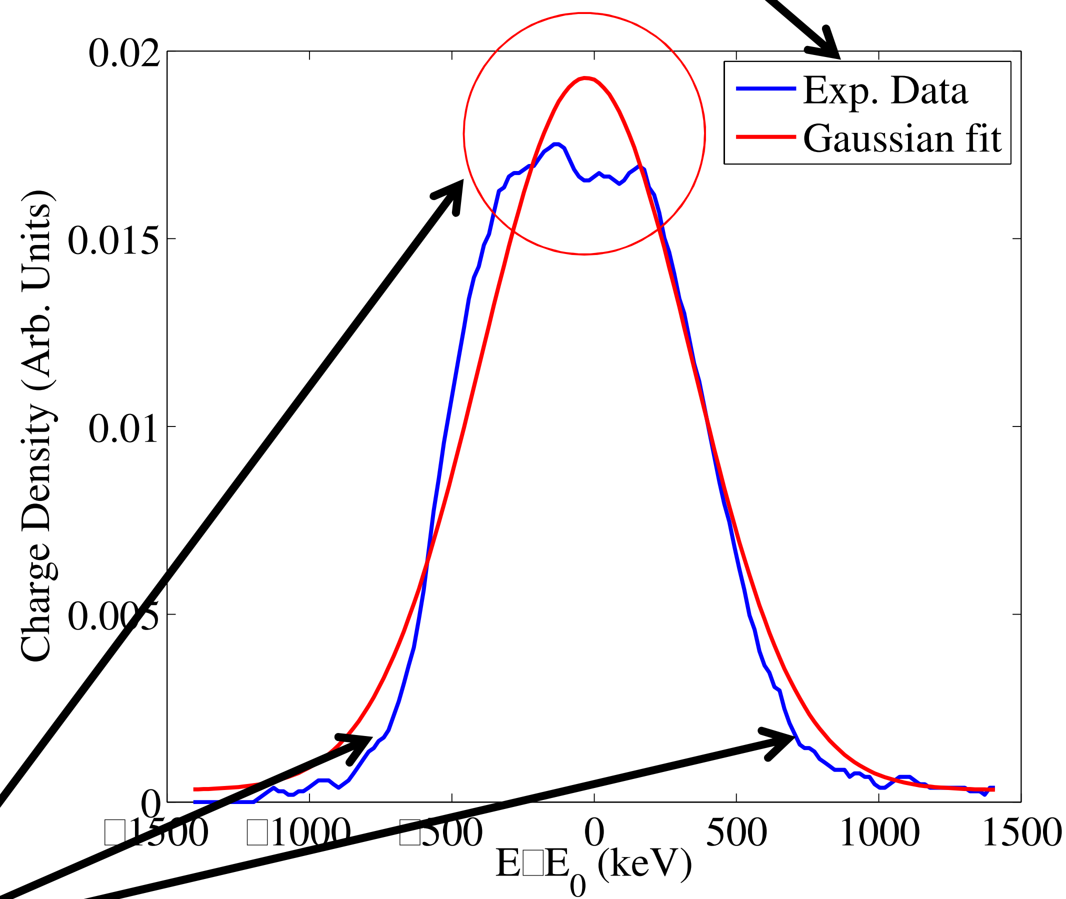
Longitudinal Phase Space and heating



Non-Gaussian energy spread

Same area and same second moment

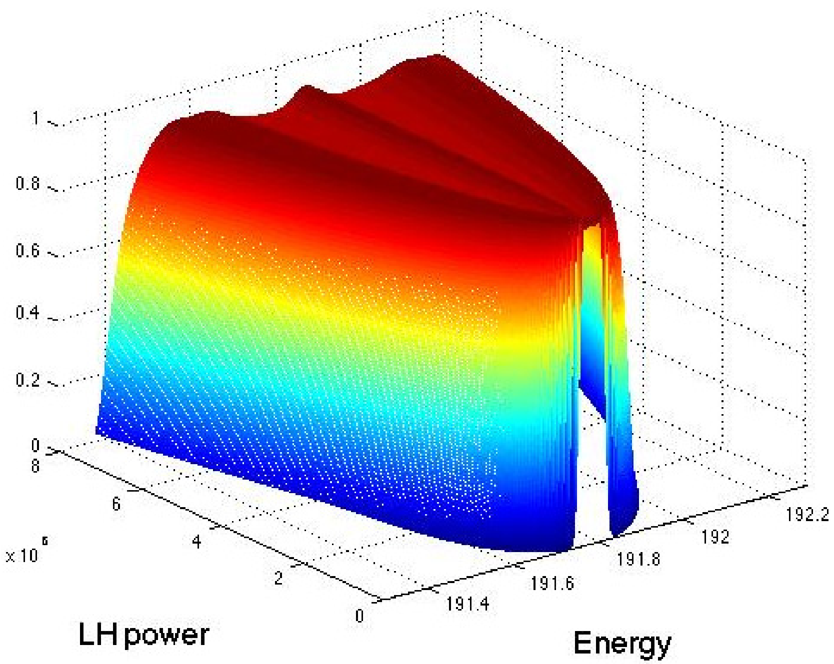




Significant differences

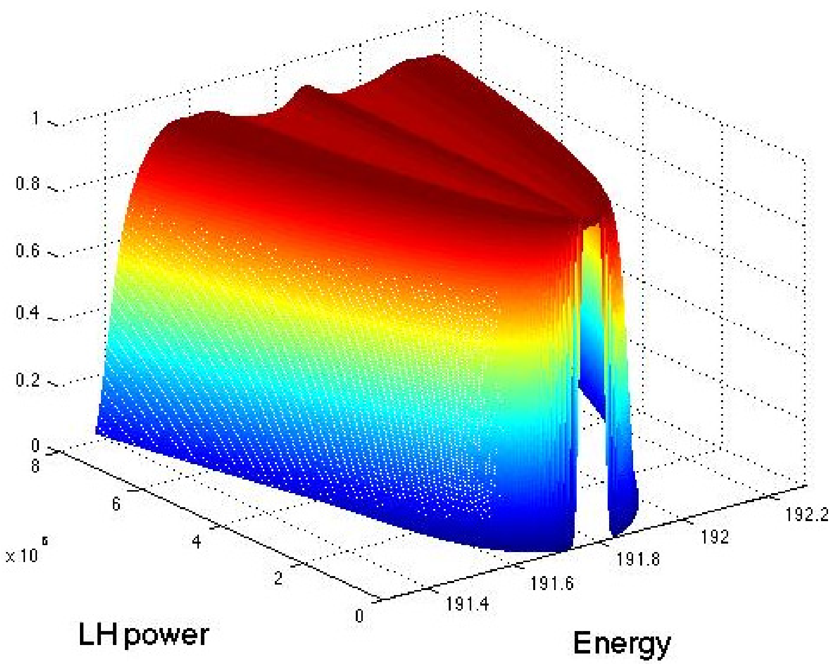
Energy distribution and heating

Simulated energy profile

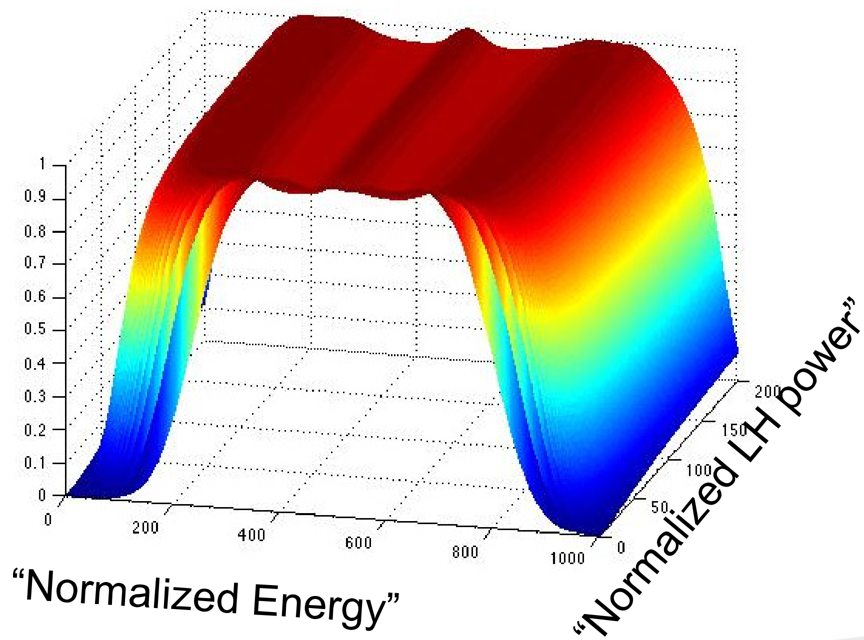


Energy distribution and heating

Simulated energy profile

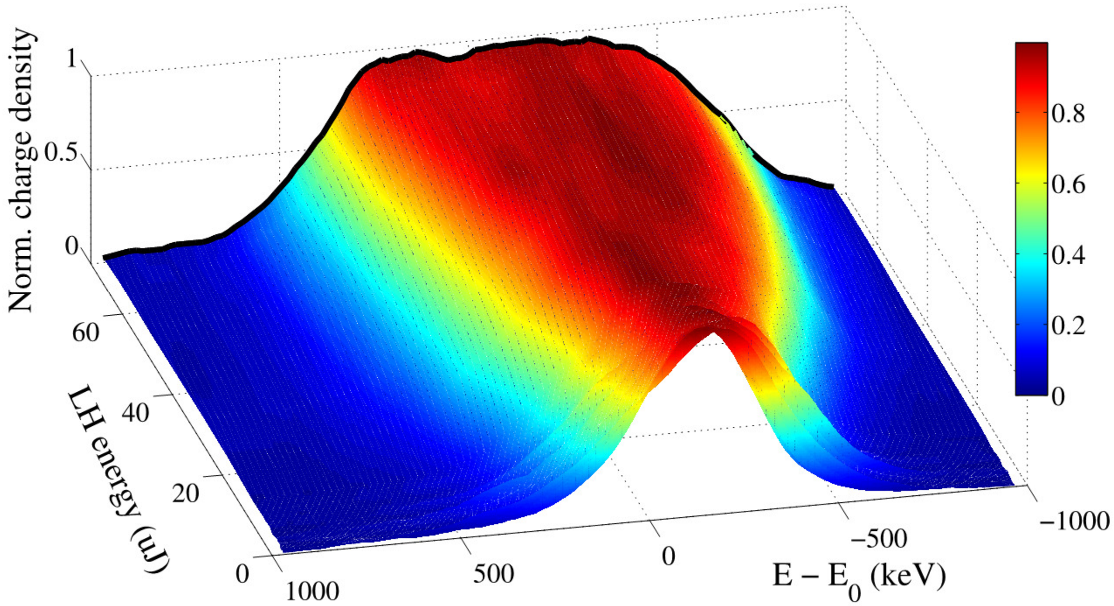


Normalized sim. energy profile

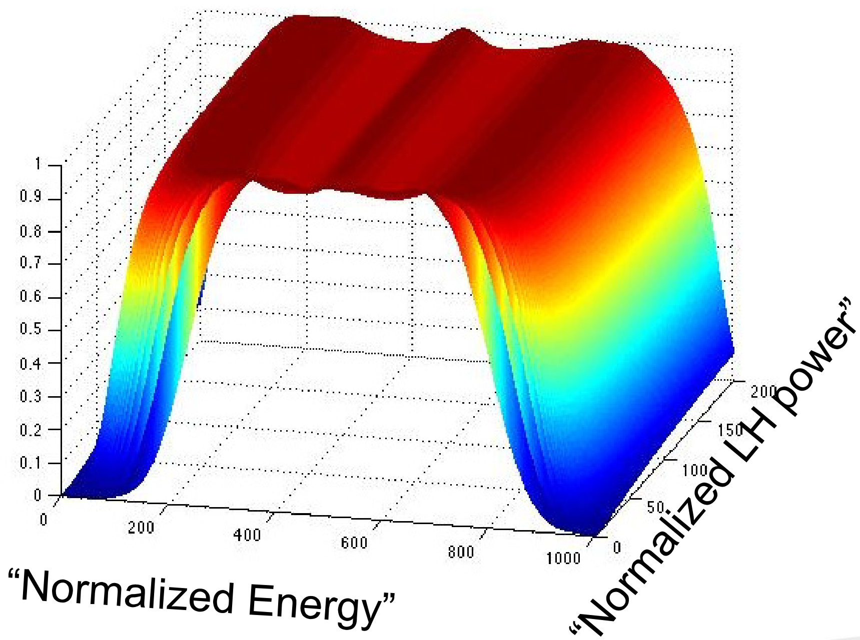


Energy distribution and heating

Measured energy profile



Normalized sim. energy profile



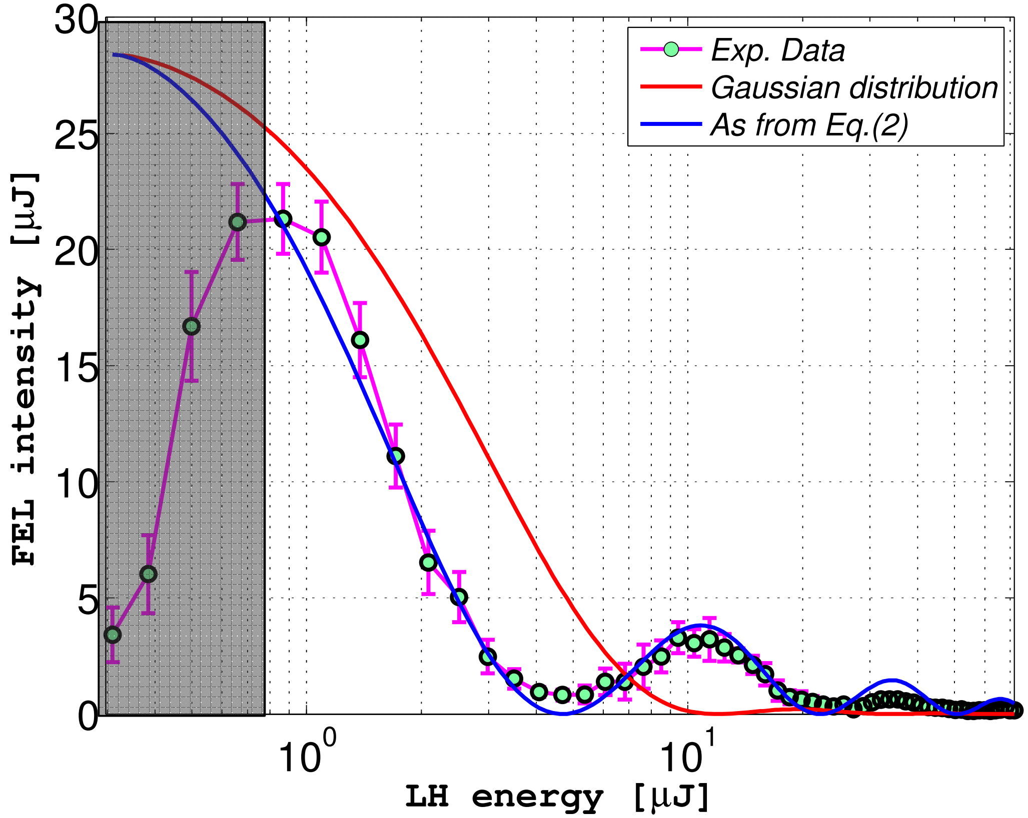
The shape of the energy distribution is, as expected, independent on the heater power

Bunching with non-Gaussian energy spread

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

Z. Huang, PRSTAB 7, 074401 (2004)

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



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

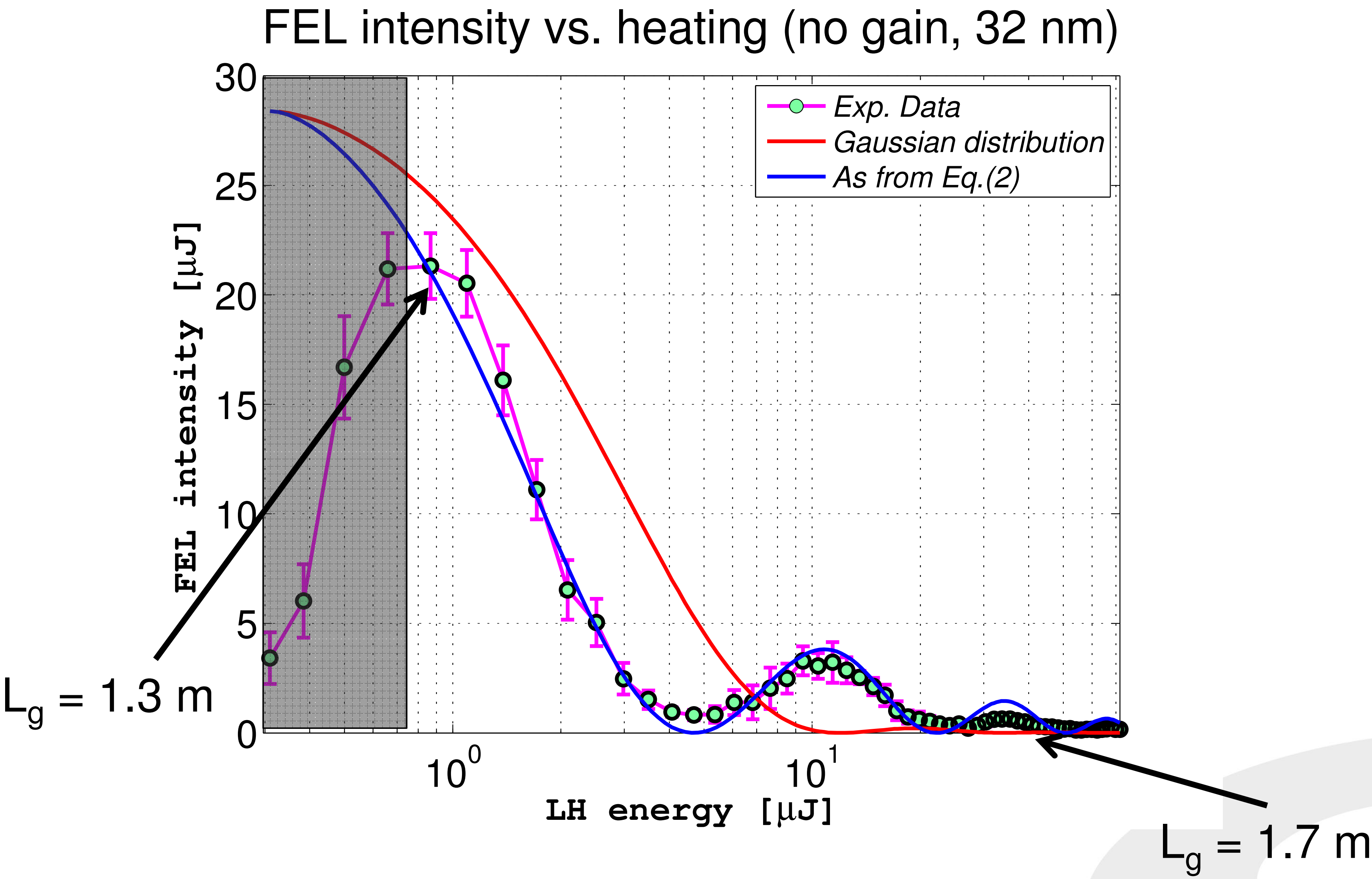
bunching suppression factor

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

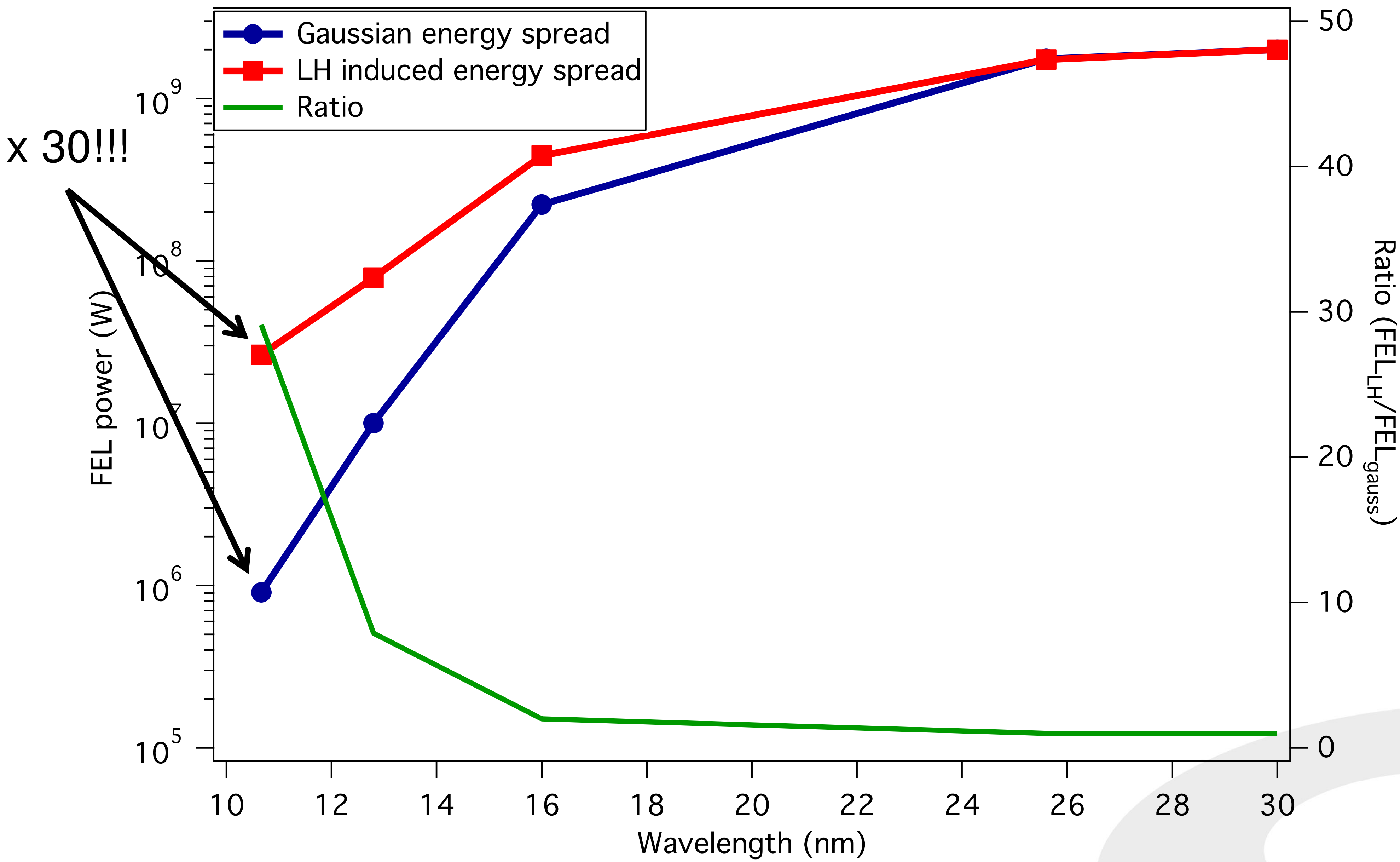
$\sigma_\mathbf{r}$ laser spot size (in LH)

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

(Almost) no gain…



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.

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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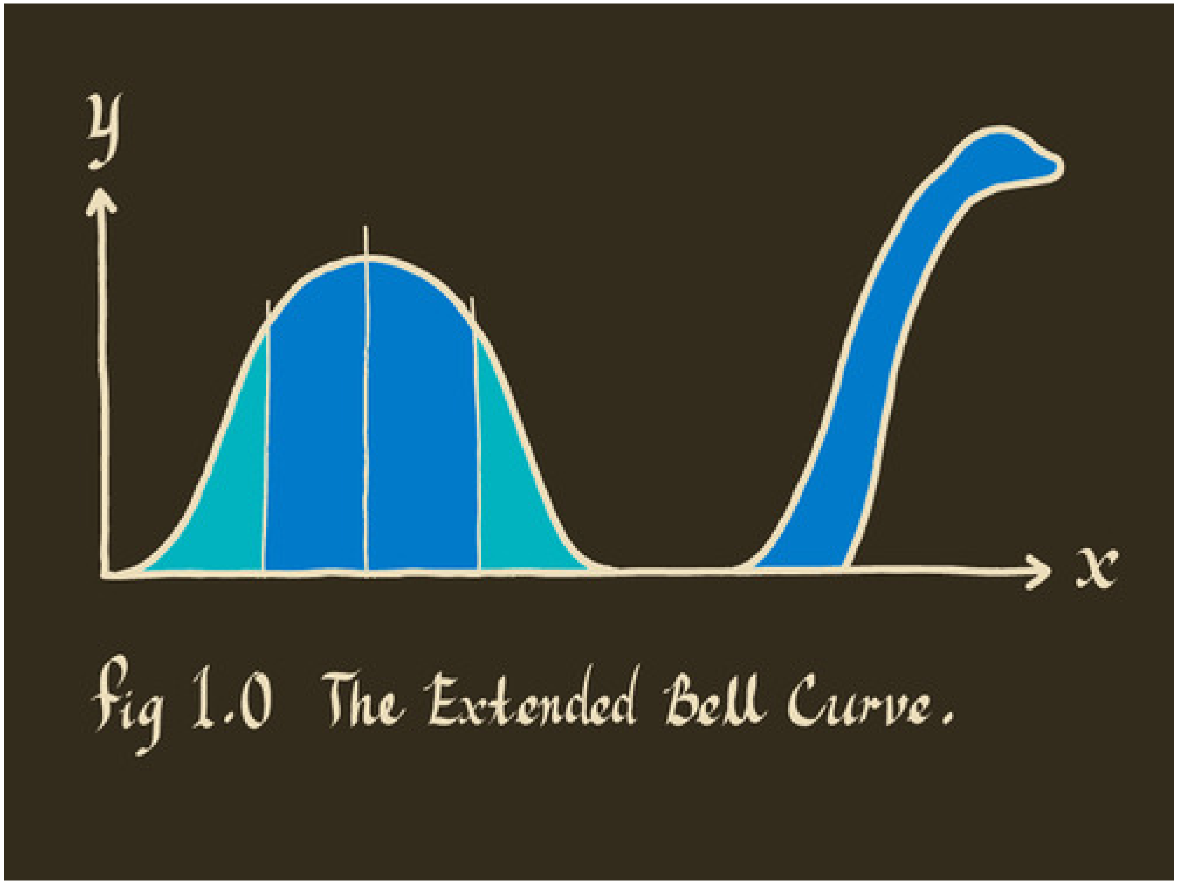
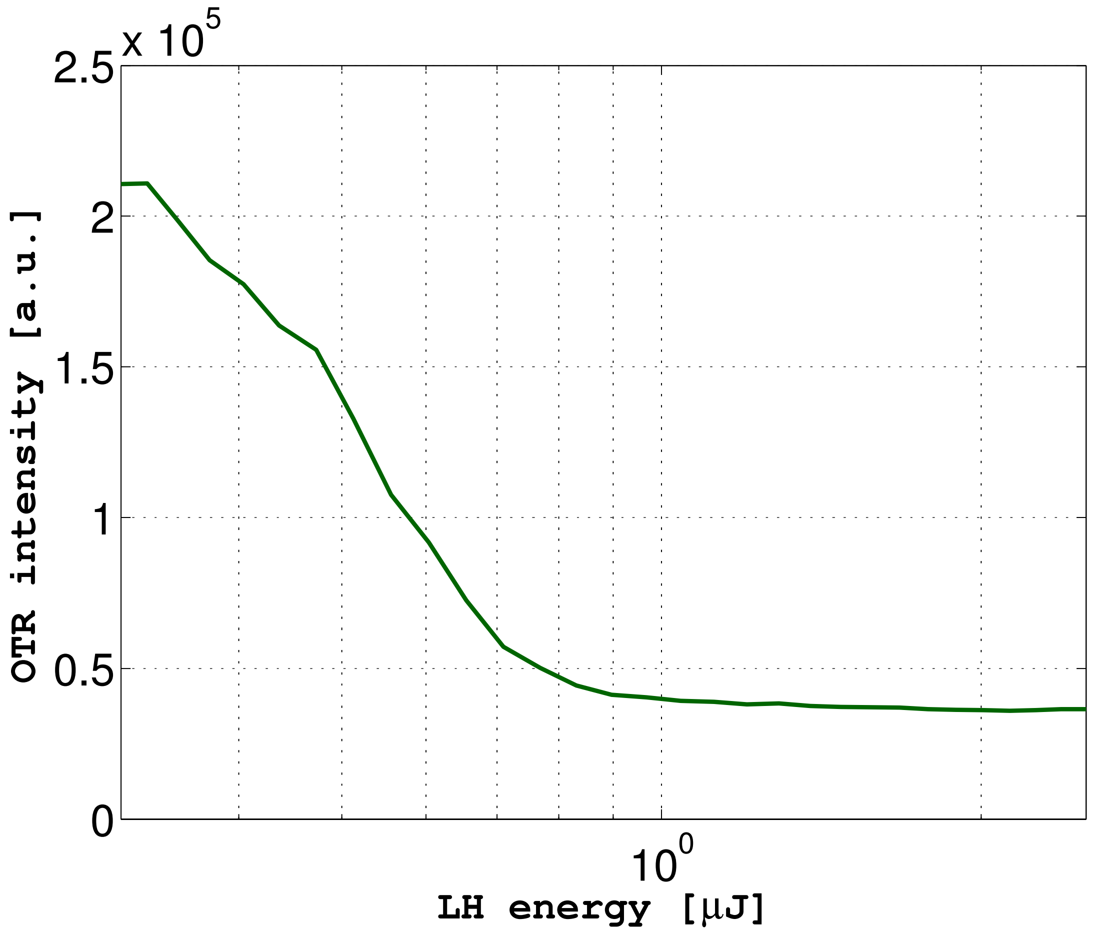
Thanks for your attention!



Laser heater - COTR



As already observed, a small amount of heating is sufficient to dump the COTR at screens downstream the bunch compressor