Self-seeding at 1.5 Å and Harmonic Generation

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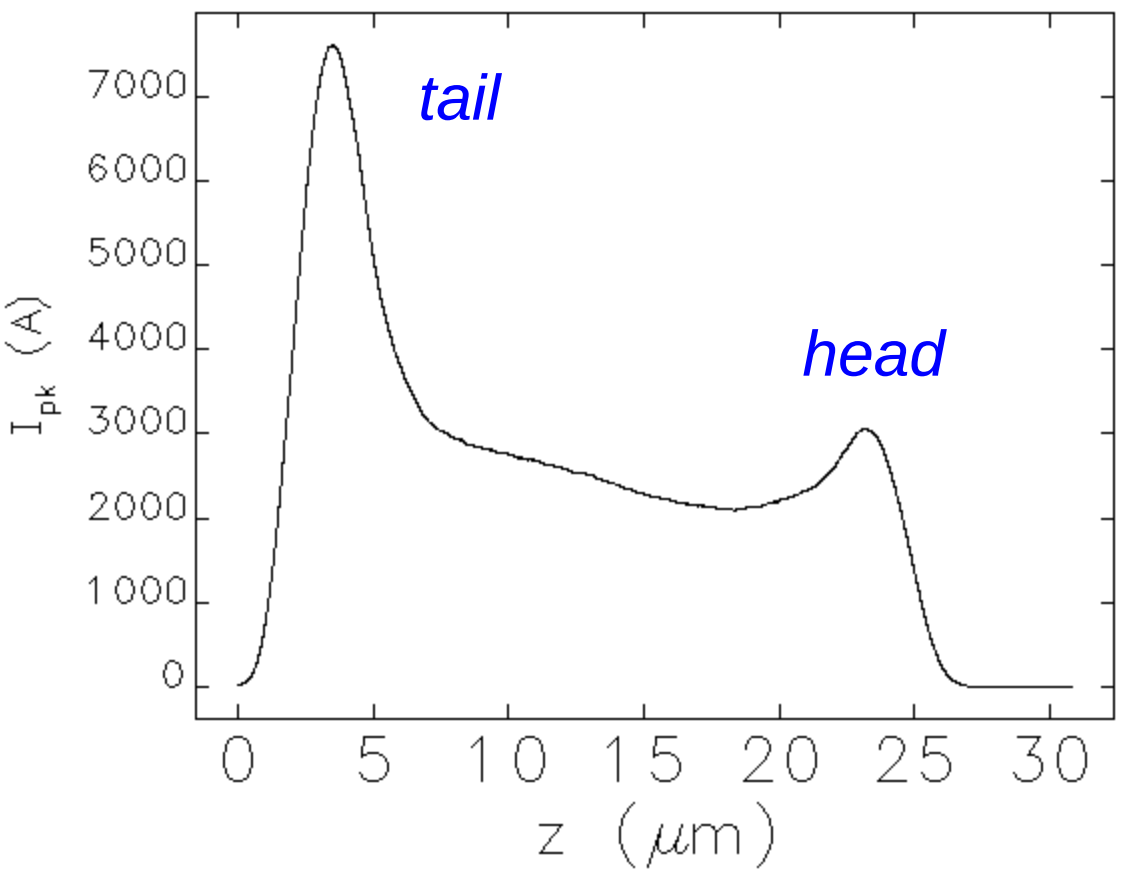
Outline

- *Two-stage self-seeding to reduce the FEL bandwidth*
  - *Details of LCLS electron bunch and FEL*
  - *Comparison of single undulator case with the two-stage case*
- *Energy chirped electron bunch can possibly generate ultra-short FEL pulse in this configuration*
- *Possible third harmonic at 0.5 Å as one of the extension of this configuration*

LCLS SASE FEL Parameters

- *Electron current profile entering the undulator*



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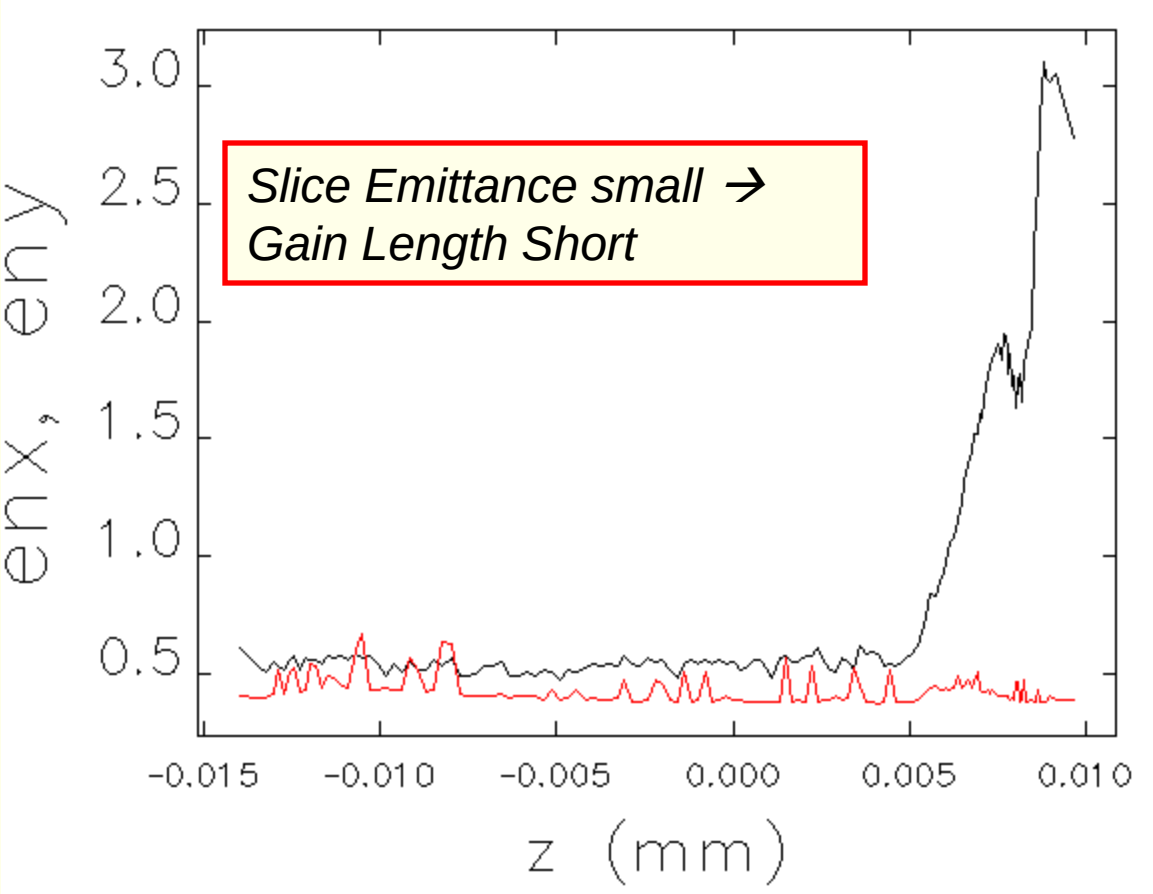
LCLS SASE FEL Parameters

- *Slice emittance entering the undulator*



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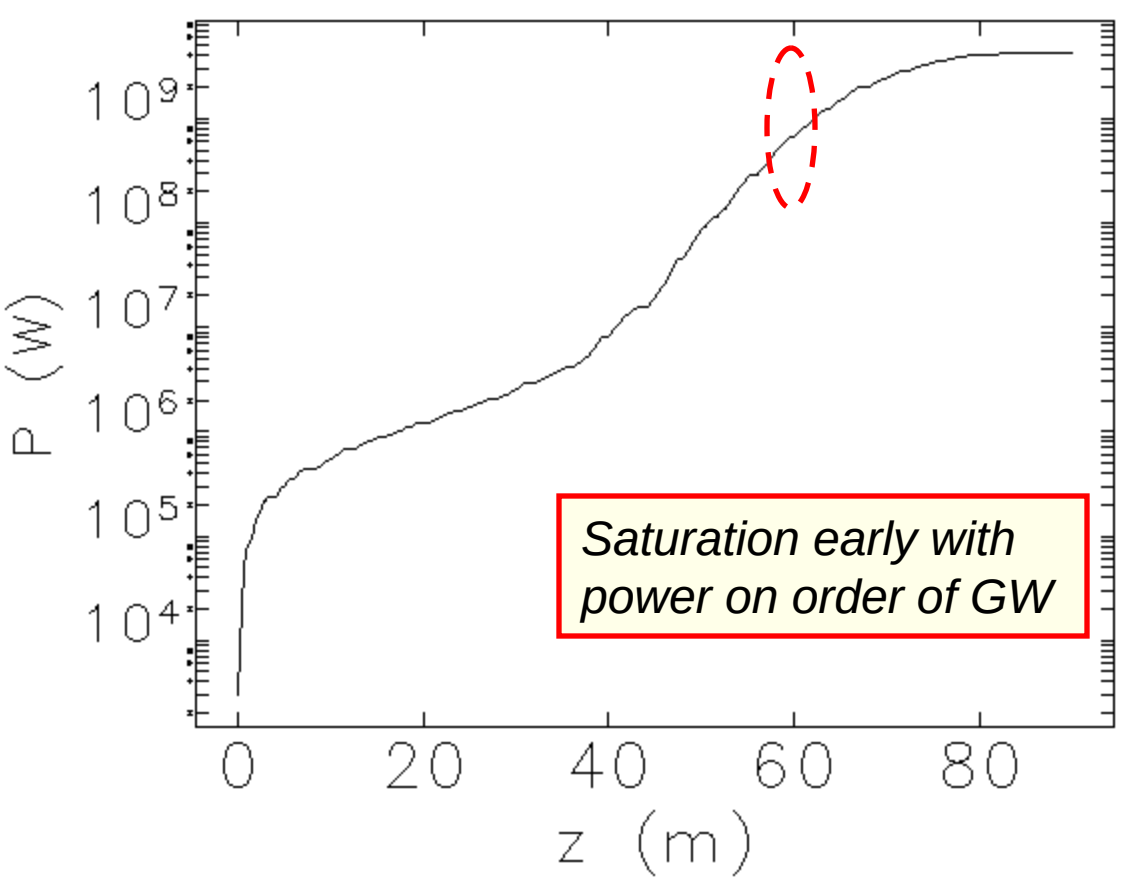
LCLS SASE FEL Parameters

- *FEL power along the undulator*



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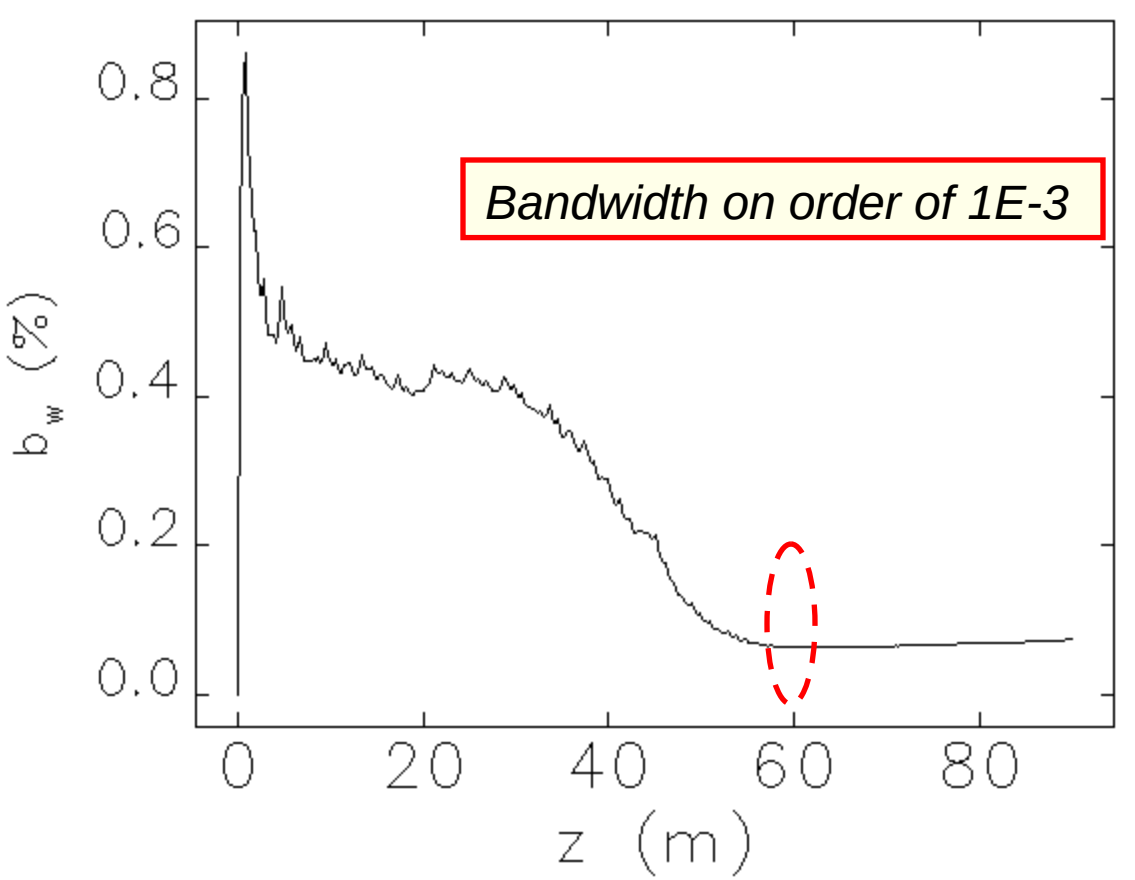
LCLS SASE FEL Parameters

- *FEL bandwidth along the undulator*



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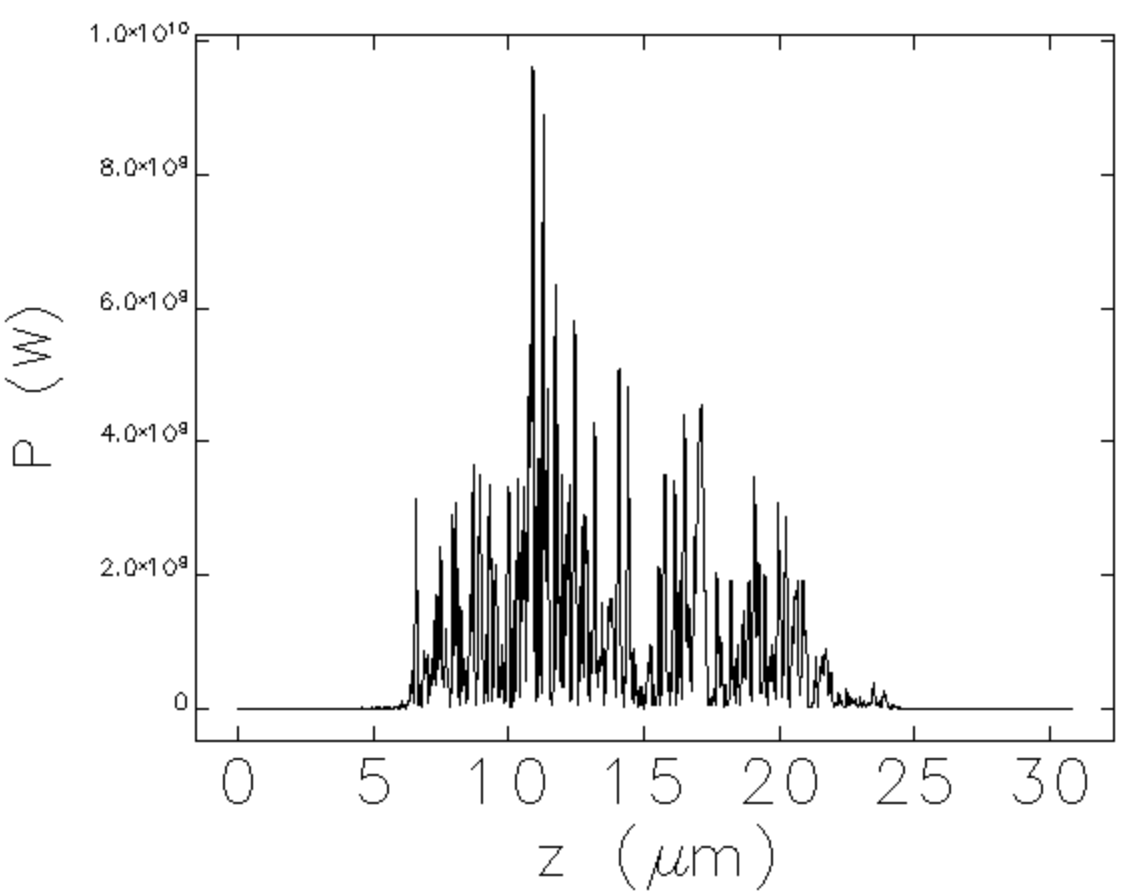
LCLS SASE FEL Parameters

- *FEL temporal profile at 60 m*



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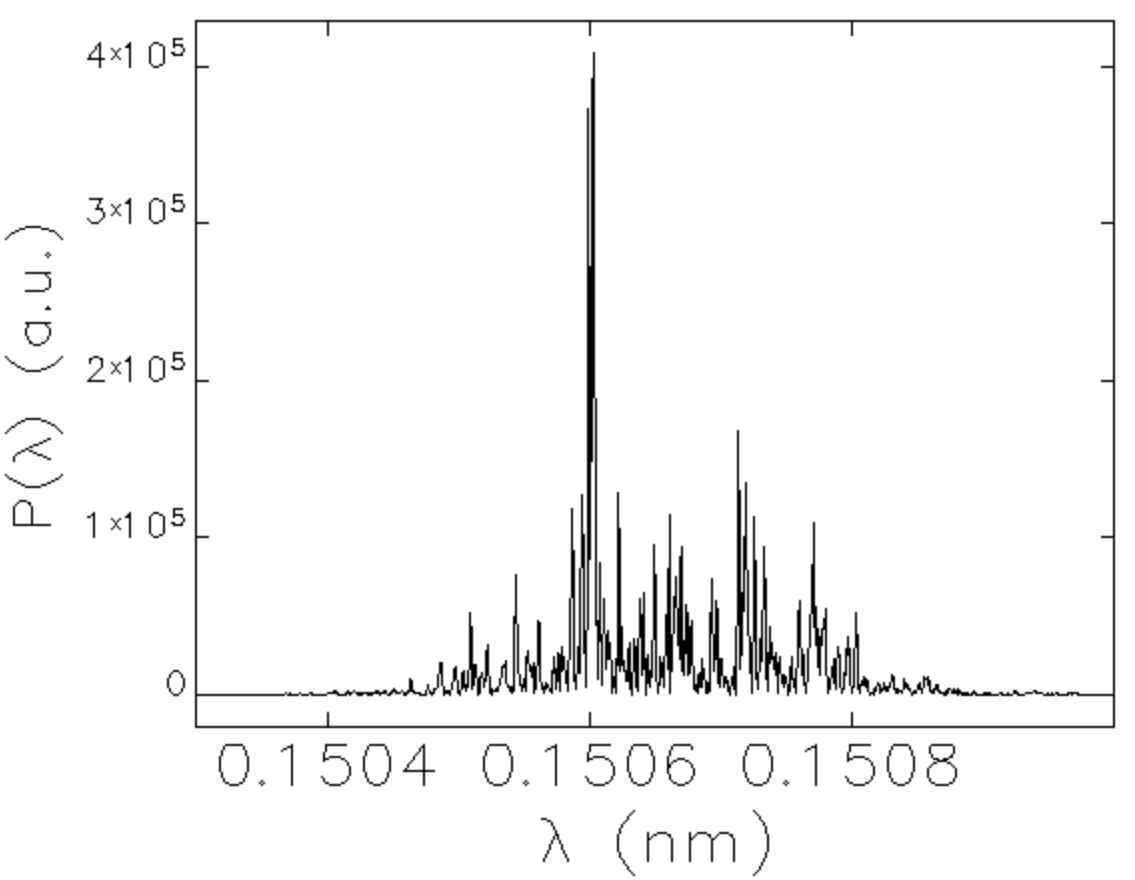
LCLS SASE FEL Parameters

- *FEL spectrum at 60 m*



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Transform limited

- *For a Gaussian photon beam*

$$\sigma_\omega = 1/\left(2\sigma_t\right)$$

  - *LCLS electron bunch flat top, σ_z ~ 10 μm*
  - *Transform limited σ_ω / ω_0 ~ 2E-06*

- *Room to improve the coherence → bandwidth reduces by 2 order of magnitude (?)*

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Two-stage FEL with monochromator

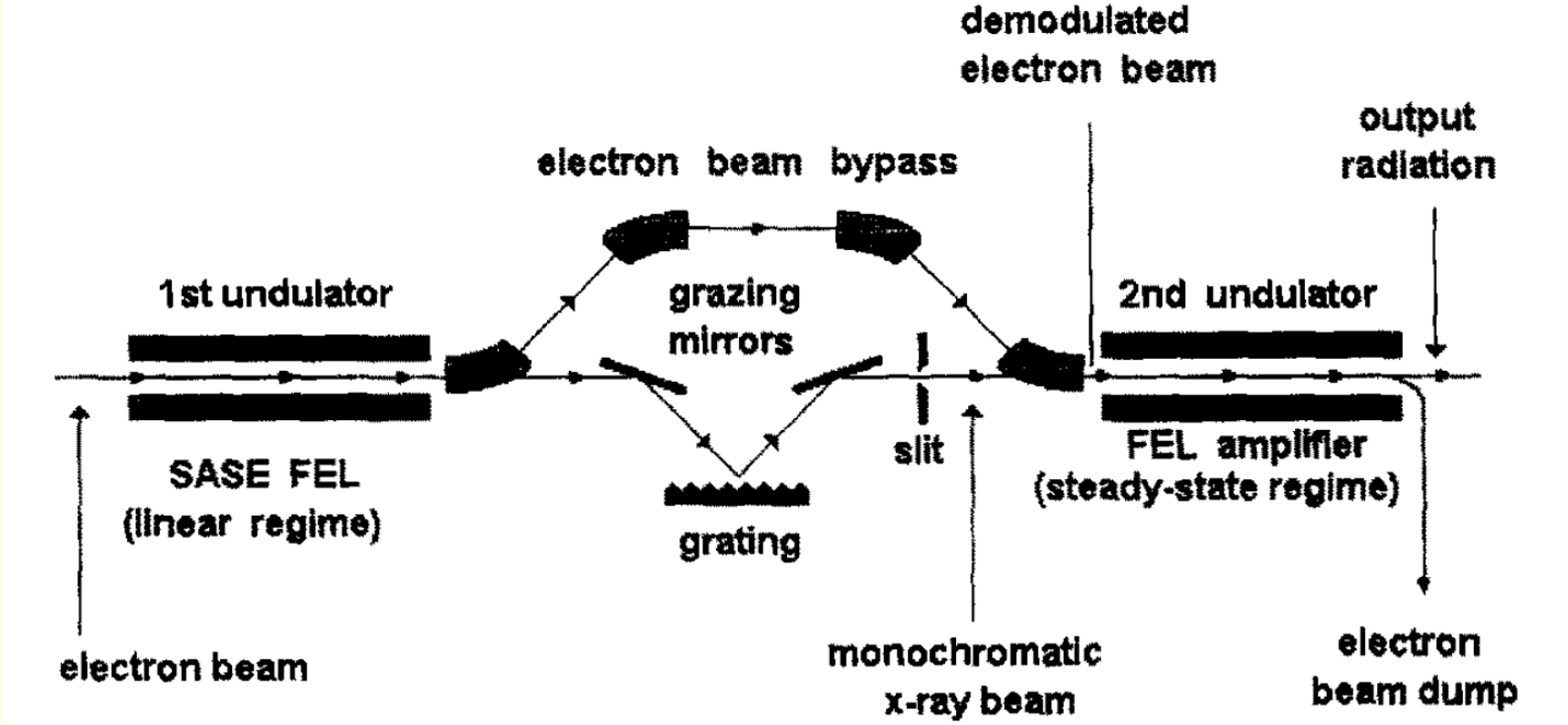

Fig. 3. The principal scheme of a single-pass two-stage SASE X-ray FEL with monochromator.

J. Feldhaus, E.L. Saldin, J.R. Schneider, E.A. Schneidmiller, M.V. Yurkov, "*Possible application of X-ray optical elements for reducing the spectral bandwidth of an X-ray SASE FEL*", Optics Communications, V.140, p341 (1997) .

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Two-stage FEL with monochromator

- *Seeding the second undulator vs. single undulator followed by x-ray optics*
  - *Power loss in the monochromator is recovered in the second undulator (FEL amplifier)*
  - *The shot-to-shot FEL intensity fluctuation reduced due to the nonlinear regime of the FEL amplifier*
  - *The peak power after the first undulator is less than the saturation power, the damage to the optical elements is reduced*

J. Feldhaus, E.L. Saldin, J.R. Schneider, E.A. Schneidmiller, M.V. Yurkov, "*Possible application of X-ray optical elements for reducing the spectral bandwidth of an X-ray SASE FEL*", Optics Communications, V.140, p341 (1997) .

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Possible Monochromator

- *J. Hastings suggested monochromators as Si(111), Si(220), and Si(444)*
  - *Si(111) path length difference (PLD) 3 mm, bandwidth 10^{-4}*
  - *Si(220) PLD 4.7 mm, bandwidth $5X10^{-5}$*
  - *Si(444) PLD 12 mm*
- *Assume FEL (self-seed) into the second part of the undulators*
  - *Peak power only 10 MW*
  - *Light pulse longer than the electron pulse*

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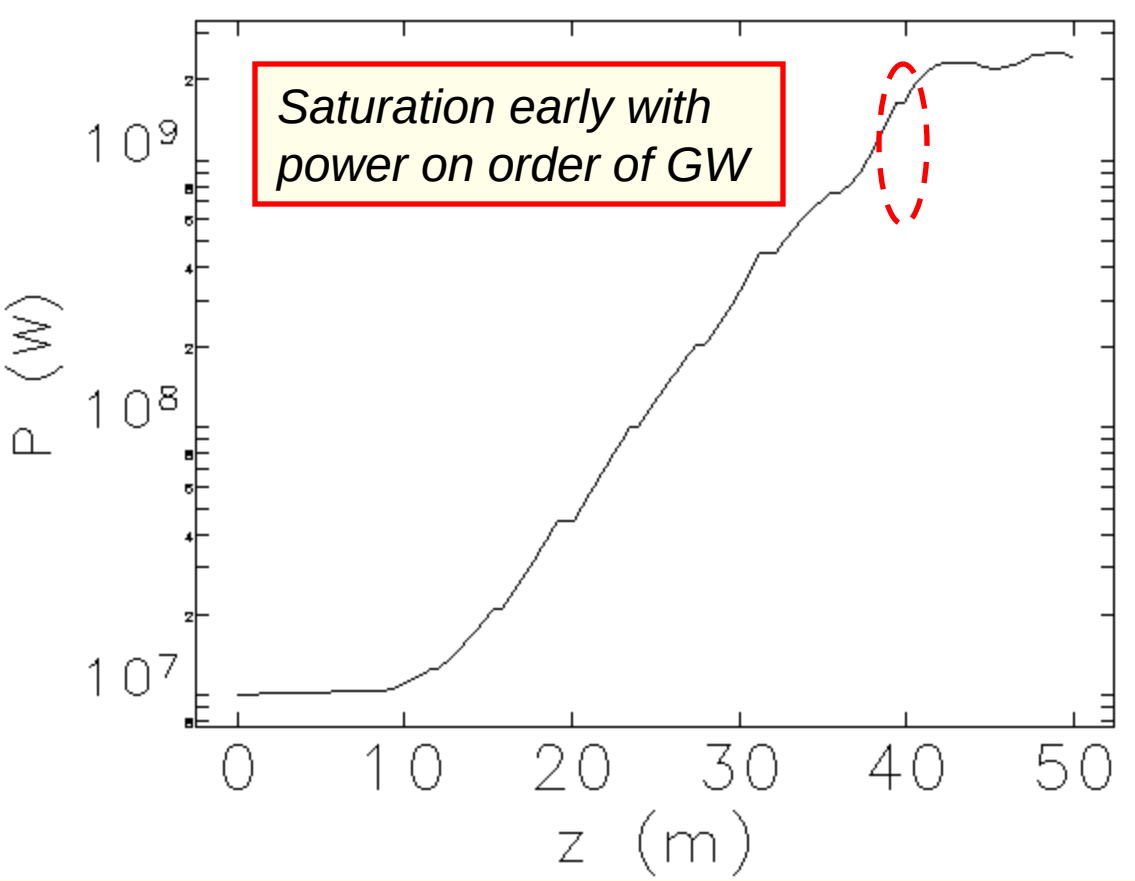
LCLS SASE FEL Parameters

- *FEL power along the undulator*



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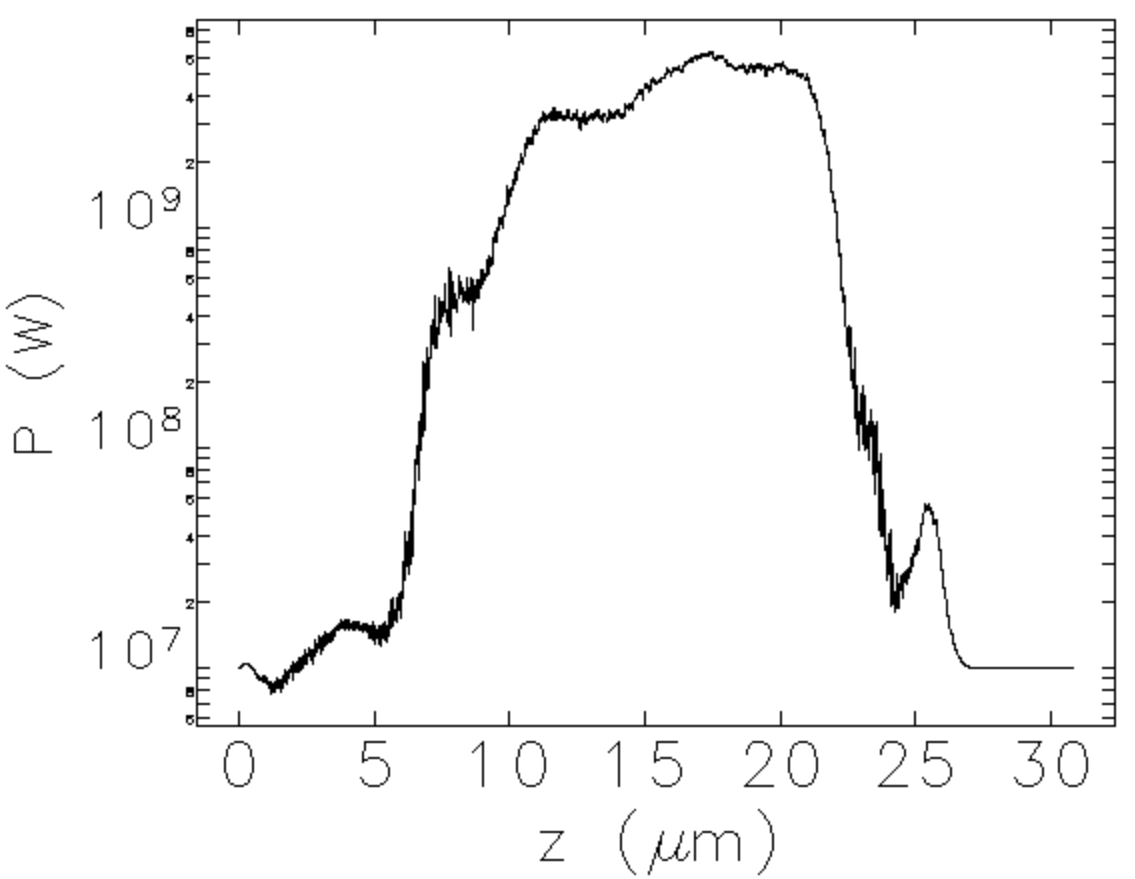
LCLS SASE FEL Parameters

- *FEL temporal profile at 40 m*



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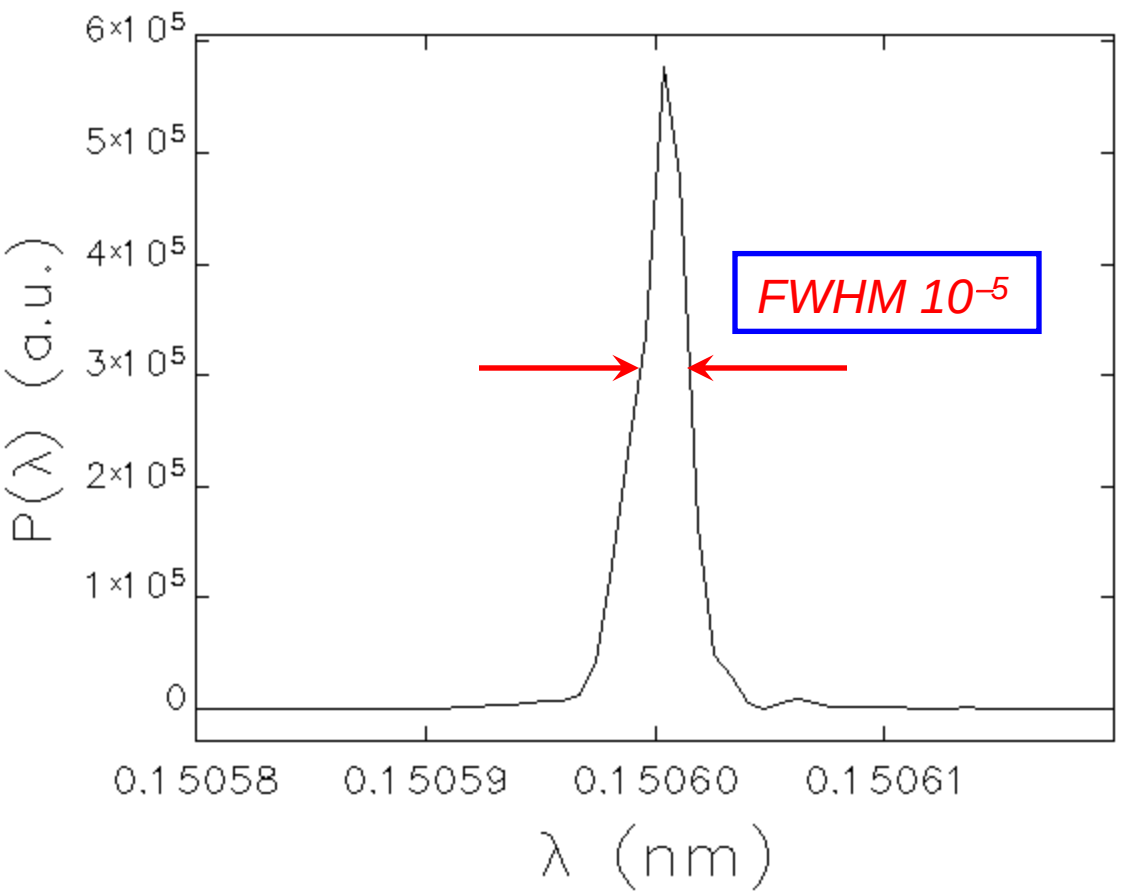
LCLS SASE FEL Parameters

- *FEL spectrum at 40 m*



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Two-stage chirp FEL

- *Energy chirped electron bunch → FEL from the first undulator will be frequency chirped*
- *Through the monochromator, only part of the FEL will propagate through due to the time-frequency correlation*
  - *Control of the radiation-pulse duration*
  - *Stabilize the shot-to-shot fluctuation of the central wavelength*

C.B. Schroeder, C. Pellegrini, S. Reiche, J. Arthur and P. Emma, "*Chirped-beam two-stage free-electron laser for high-power femtosecond x-ray pulse generation*", J. Opt. Soc. Am. B. V. 19, p. 1782 (2002).

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Two-stage chirp FEL

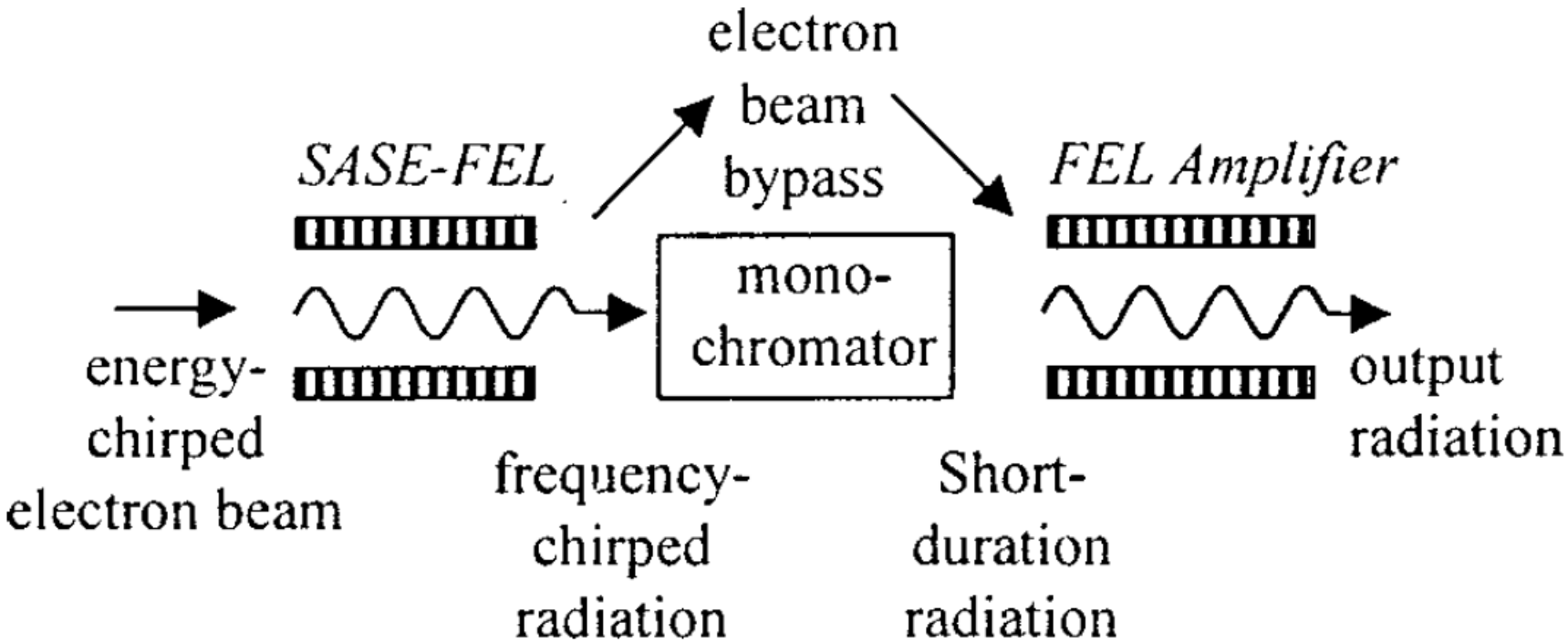

Fig. 1. Schematic of chirped-beam two-stage FEL for short-duration x-ray generation.

C.B. Schroeder, C. Pellegrini, S. Reiche, J. Arthur and P. Emma, "*Chirped-beam two-stage free-electron laser for high-power femtosecond x-ray pulse generation*", J. Opt. Soc. Am. B. V. 19, p. 1782 (2002).

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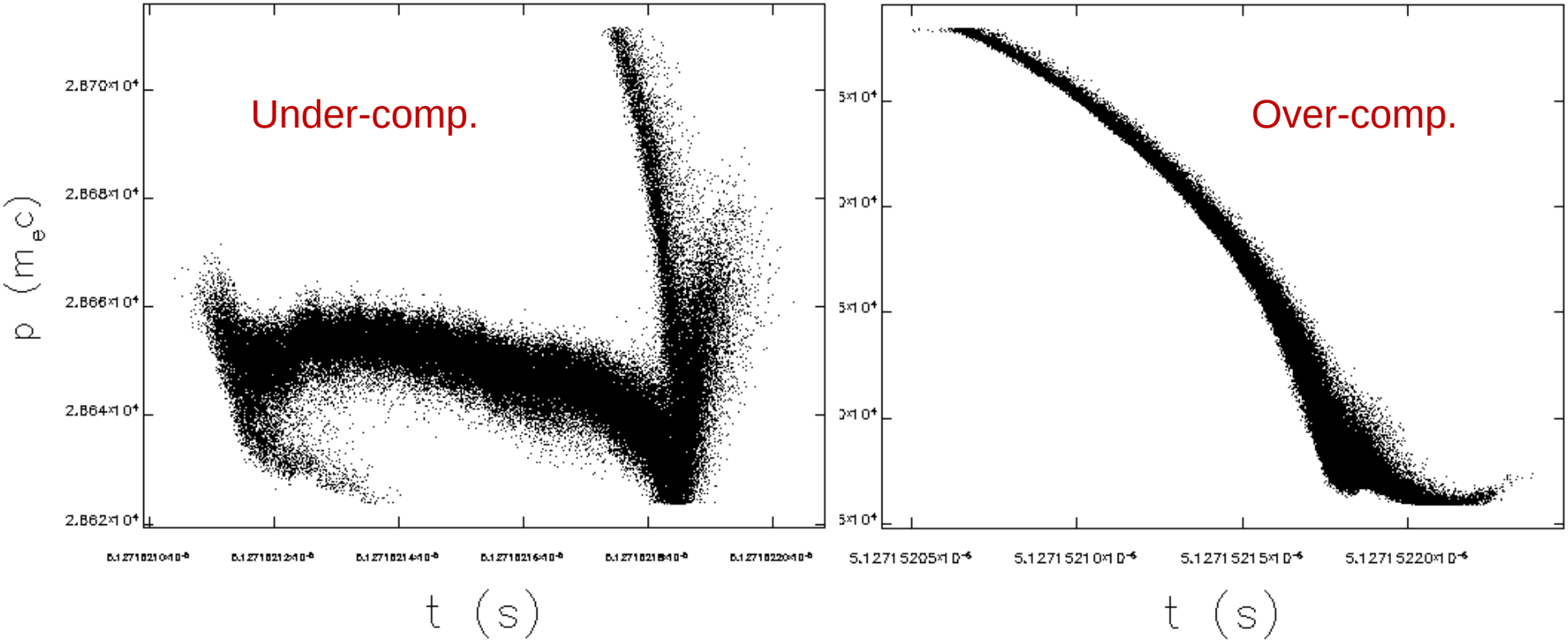
Under- and Over-compression

- *Phase space*
  - Under-compressed case — central part is flat
  - Over-compressed case — central part is quite steep



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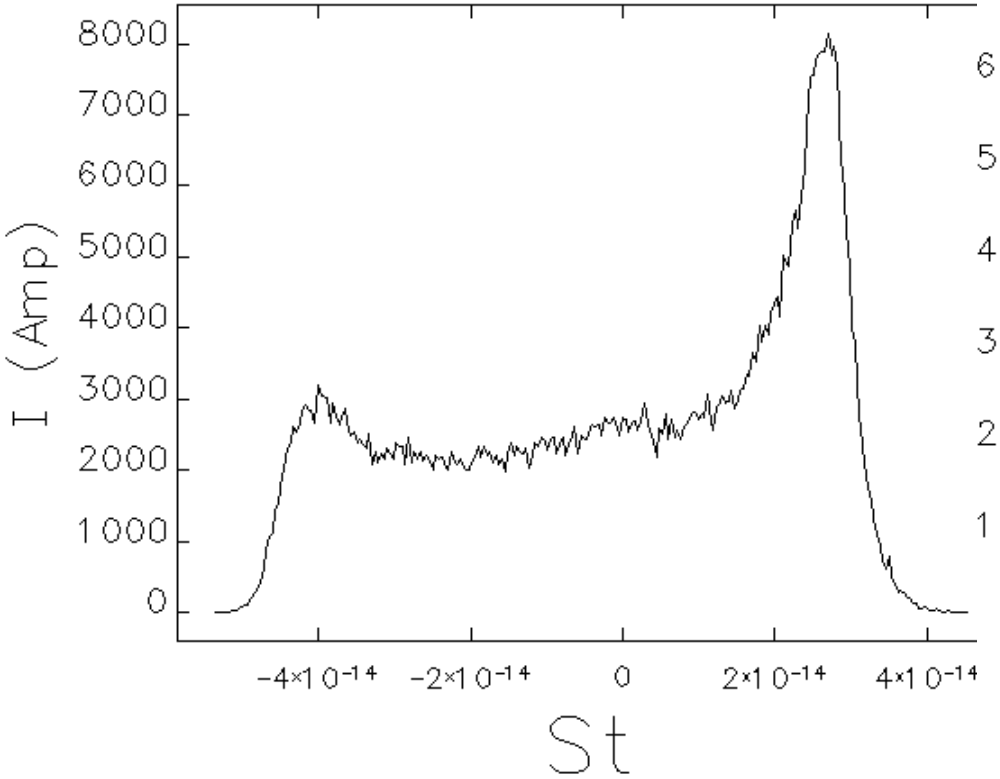
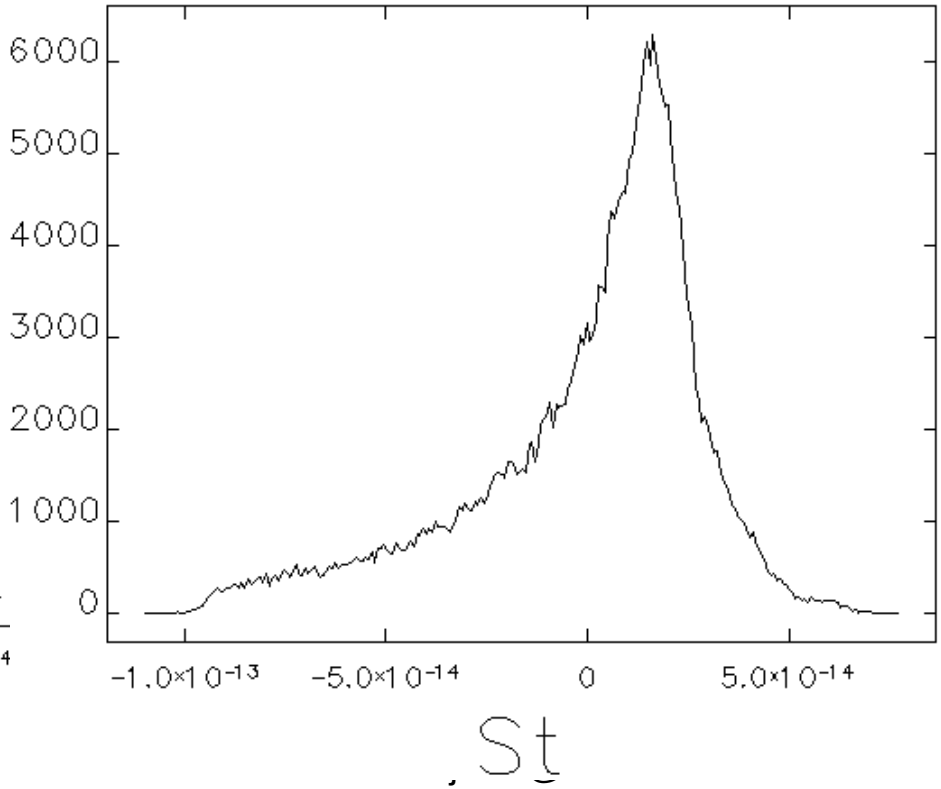
Under- and Over-compression

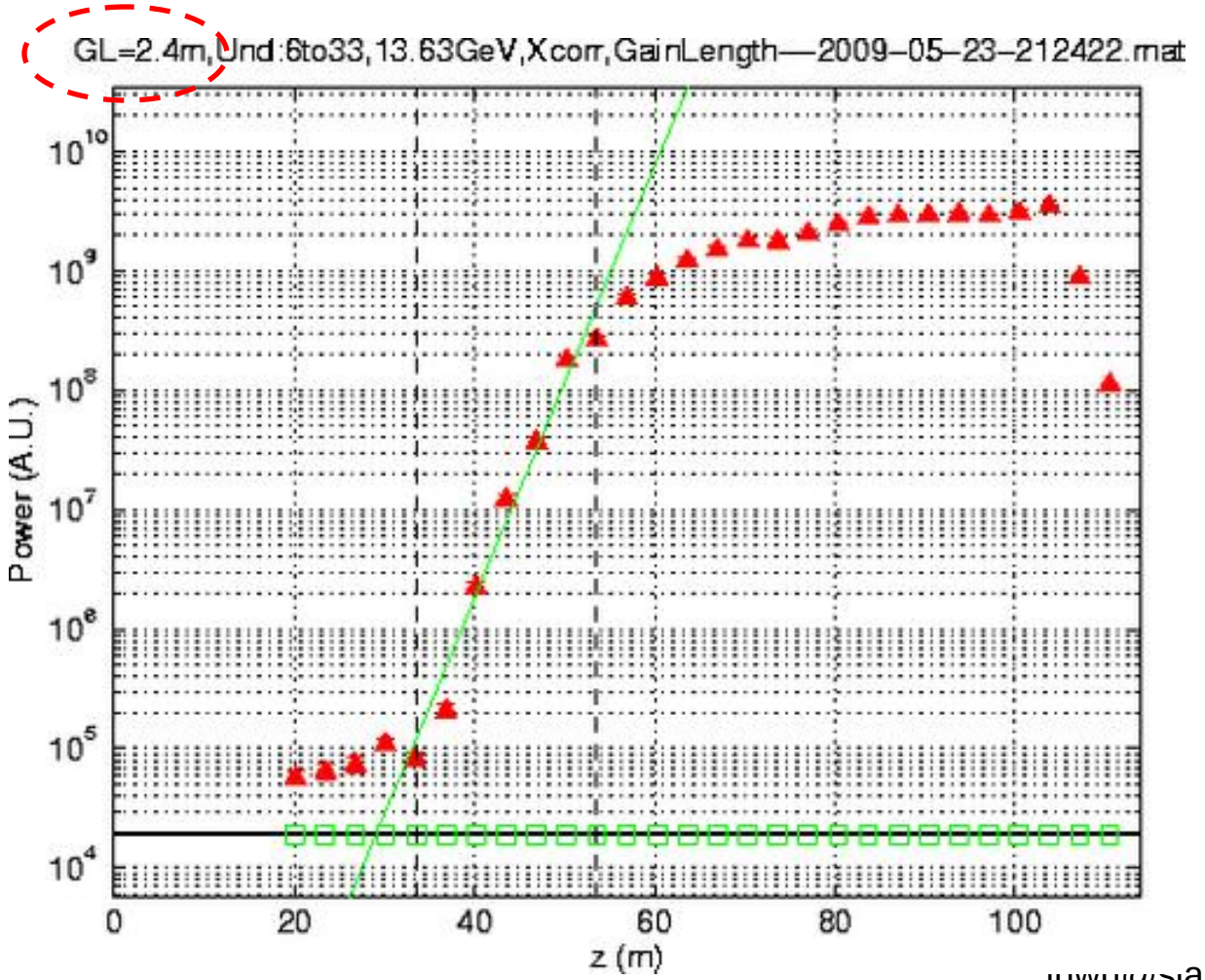
- *Current profile*
  - *Under-compressed case — double-horn — horns: **high** peak current, **high** emittance, **high** energy spread*
  - *Over-compressed case — more or less Gaussian — central part: **high** peak current, **low** emittance, **low** energy spread*





Under- and Over-compression

- *Example: over-compress with 2.5 kA*



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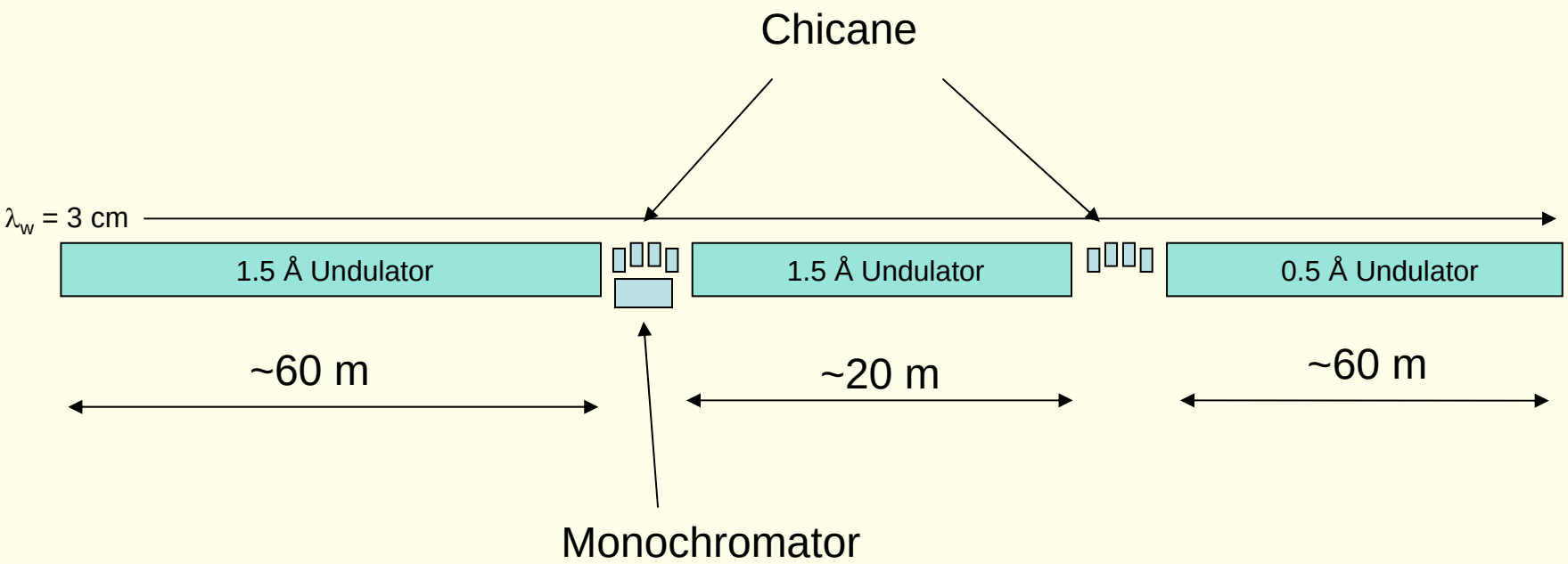
Harmonic Generation

- *With a Self-seeding cleaned up 1.5 FEL, one can consider Harmonic Generation*
  - *Open gap for harmonic generation*
  - *Same LCLS measured electron parameters*



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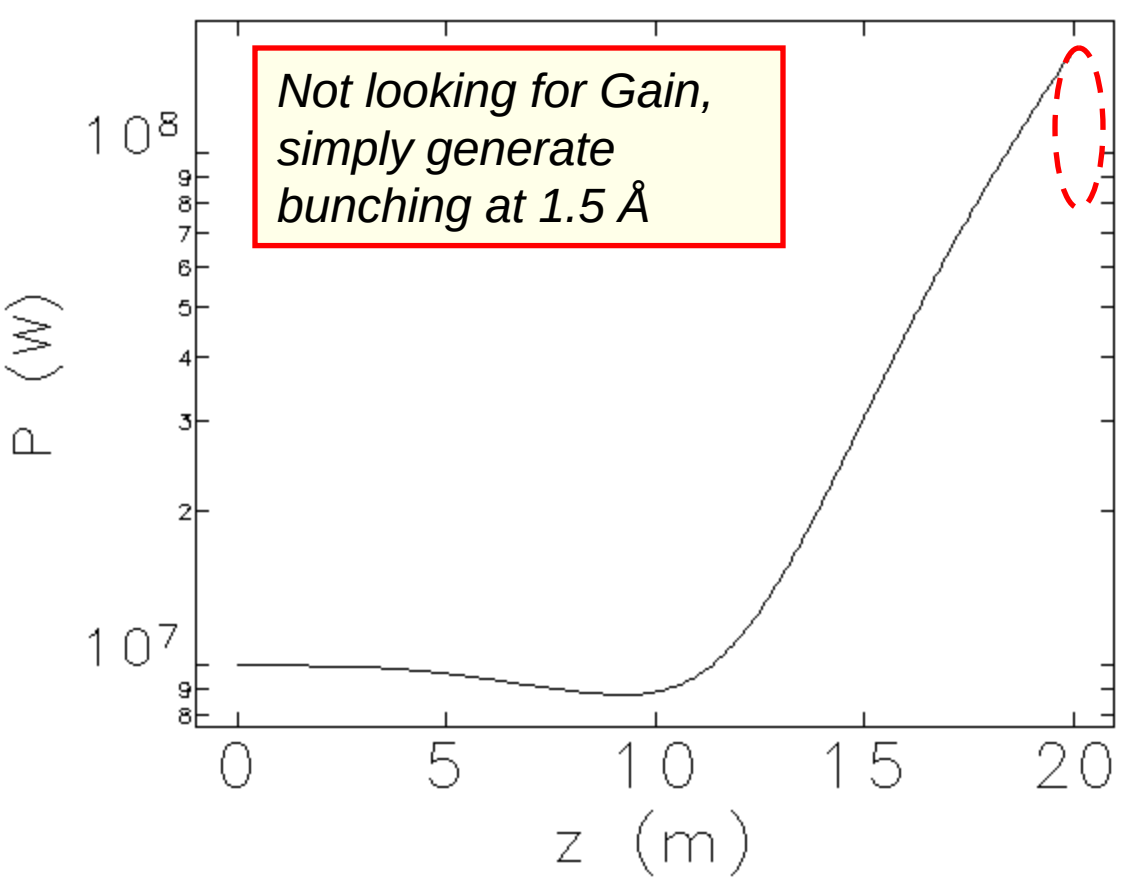
LCLS SASE FEL Parameters

- *FEL power along the second 1.5 Å undulator*



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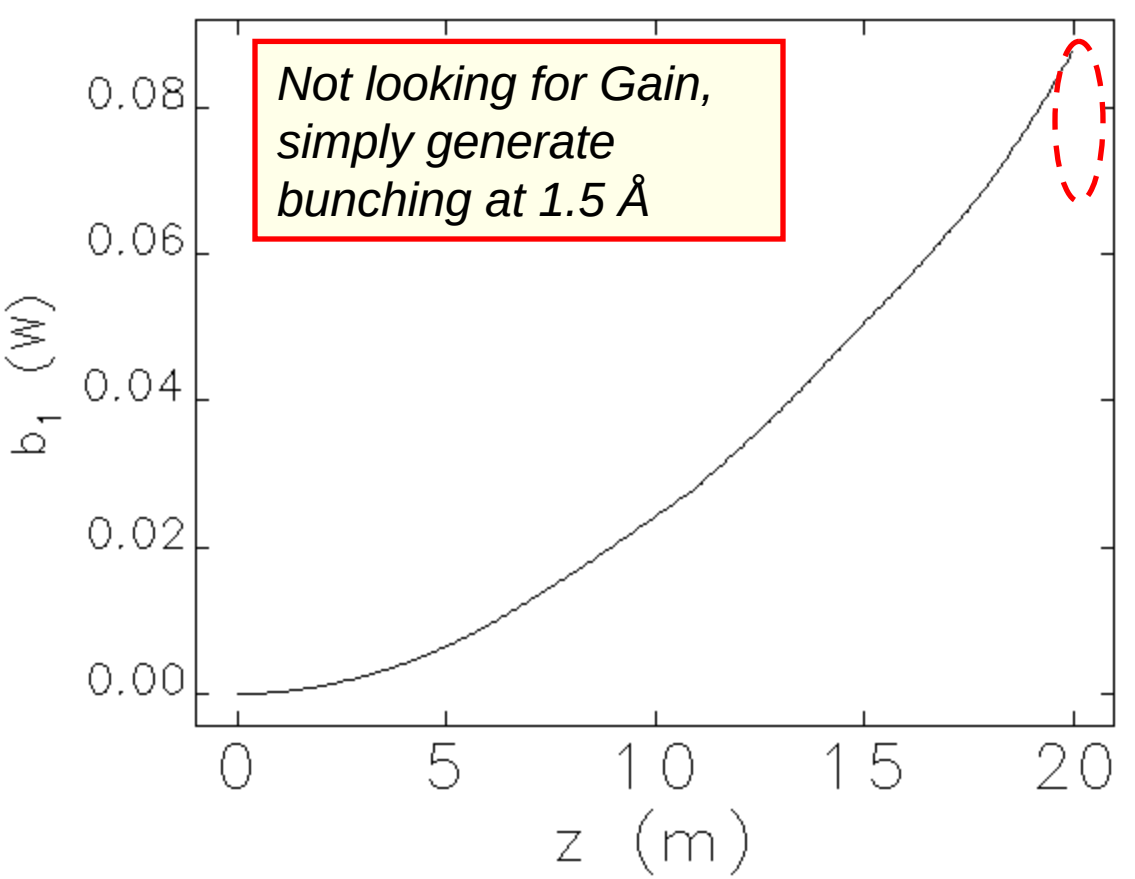
LCLS SASE FEL Parameters

- *Bunching factor along the second 1.5 Å undulator*



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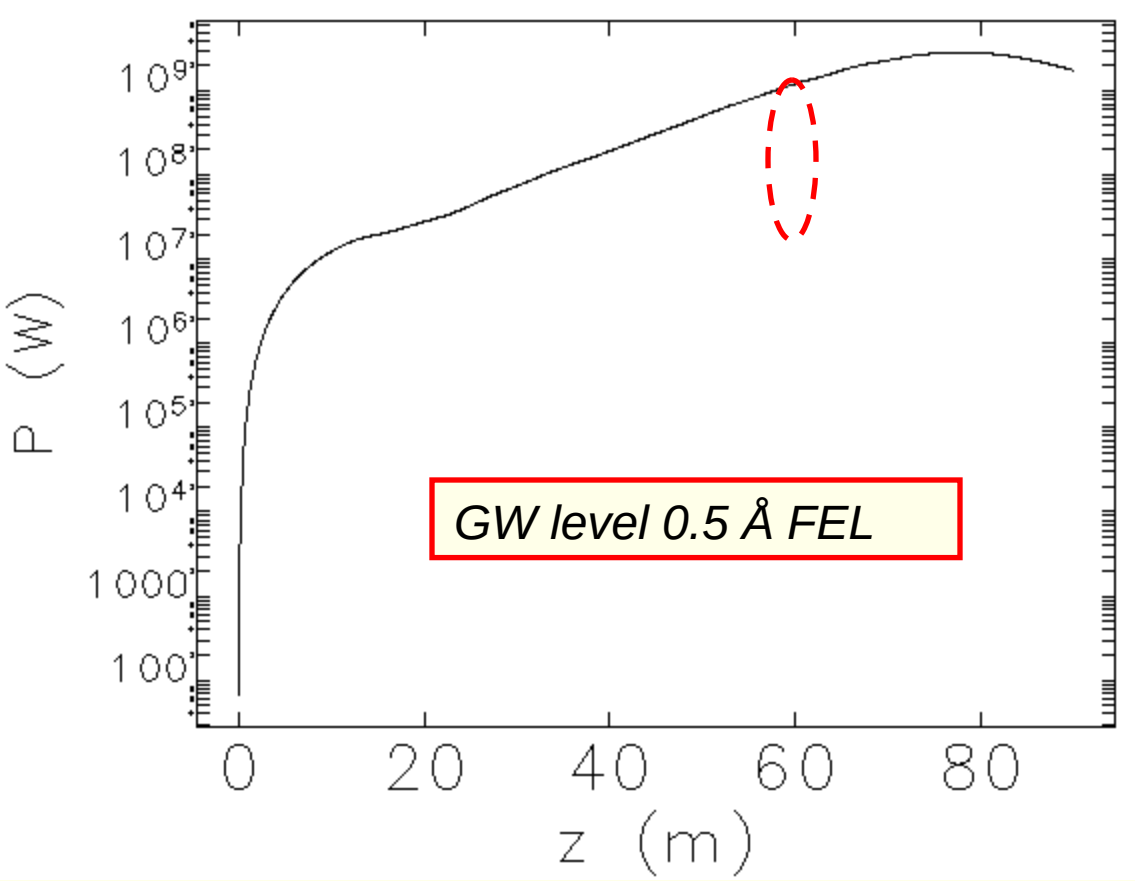
LCLS SASE FEL Parameters

- *FEL power along the 0.5 Å undulator*



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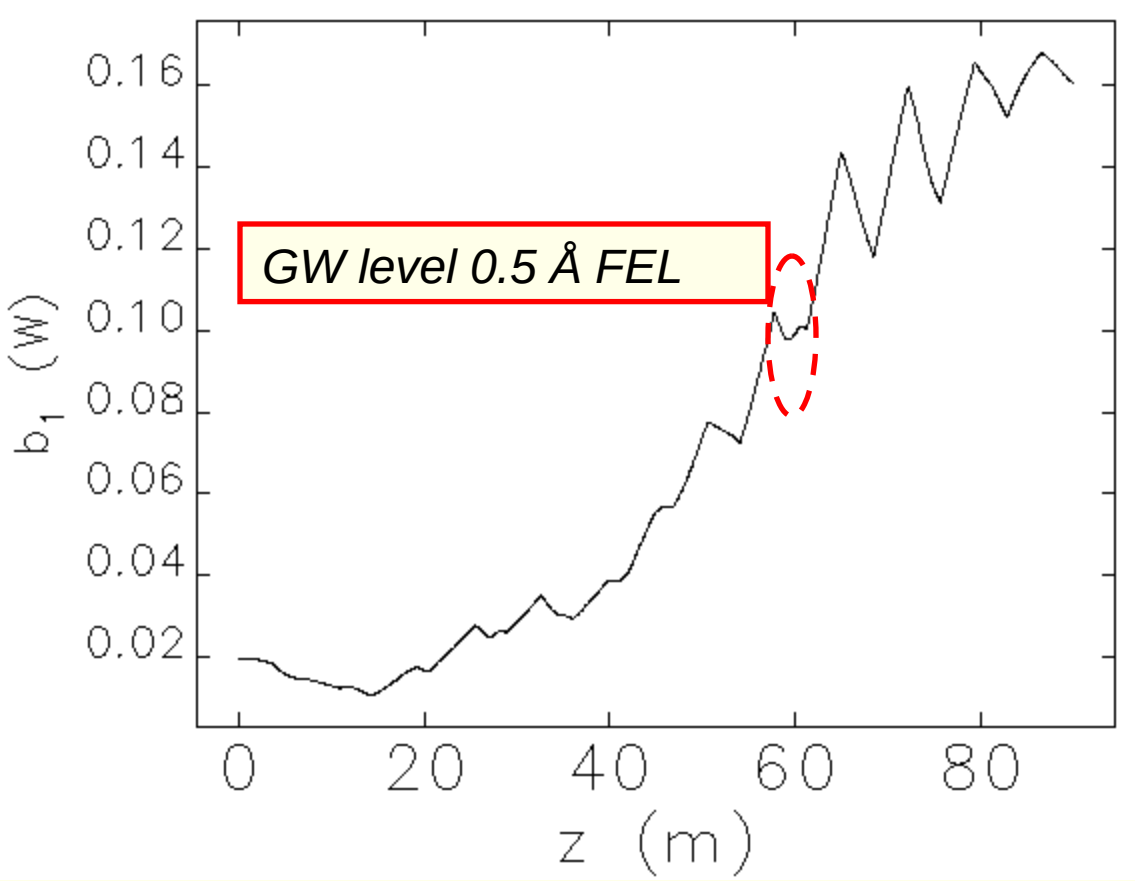
LCLS SASE FEL Parameters

- *Bunching along the 0.5 Å undulator*



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Summary

- *LCLS excellent electron beam quality leads to short gain length, early saturation. This makes possible to add more functions*
- *Two-stage FEL with monochrator reduce the bandwidth from 1E-3 to a few 1E-5 with similar peak power → increase the brightness*
- *With energy chirped electron beam, it is possible to select part of the pulse → ultra short FEL down to femtosecond or even attosecond*
- *Also possible to get third harmonic at 0.5 Å.*

Thanks for your attention!

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