Self-seeding at 1.5 Å and Harmonic Generation

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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

![Graph showing electron current profile](image-url)
Slice emittance entering the undulator

Slice Emittance small $\rightarrow$
Gain Length Short
LCLS SASE FEL Parameters

**FEL power along the undulator**

Saturation early with power on order of GW
LCLS SASE FEL Parameters

FEL bandwidth along the undulator

Bandwidth on order of $1E-3$
LCLS SASE FEL Parameters

FEL temporal profile at 60 m

![Graph showing FEL temporal profile at 60 m]
LCLS SASE FEL Parameters

FEL spectrum at 60 m

![Graph showing FEL spectrum at 60 m]
**Transform limited**

For a Gaussian photon beam

\[ \sigma_\omega = \frac{1}{(2\sigma_t)} \]

- LCLS electron bunch flat top, \( \sigma_z \sim 10 \, \mu m \)
- Transform limited \( \sigma_\omega / \omega_0 \sim 2E-06 \)

Room to improve the coherence \( \rightarrow \) bandwidth reduces by 2 order of magnitude (?)
Two-stage FEL with monochromator

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

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

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 $5 \times 10^{-5}$
  - 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
FEL power along the undulator

Saturation early with power on order of GW
LCLS SASE FEL Parameters

FEL temporal profile at 40 m
LCLS SASE FEL Parameters

**FEL spectrum at 40 m**

![Graph of FEL spectrum at 40 m with FWHM 10^-5 highlighted]
Two-stage chirp FEL

- Energy chirped electron bunch $\rightarrow$ 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

Two-stage chirp FEL

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

Under- and Over-compression

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

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

FEL power along the second 1.5 Å undulator

Not looking for Gain, simply generate bunching at 1.5 Å
LCLS SASE FEL Parameters

Bunching factor along the second 1.5 Å undulator

Not looking for Gain, simply generate bunching at 1.5 Å
LCLS SASE FEL Parameters

FEL power along the 0.5 Å undulator

GW level 0.5 Å FEL
LCLS SASE FEL Parameters

Bunching along the 0.5 Å undulator

![Graph showing bunching along the 0.5 Å undulator with a GW level 0.5 Å FEL annotation.

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LCLS Upgrades Science Drivers
Juhao Wu, LCLS Physics
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 $1 \times 10^{-3}$ to a few $1 \times 10^{-5}$ with similar peak power $\rightarrow$ increase the brightness.
- With energy chirped electron beam, it is possible to select part of the pulse $\rightarrow$ 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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