Two-bunch self-seeding for narrow-bandwidth hard x-ray FELs

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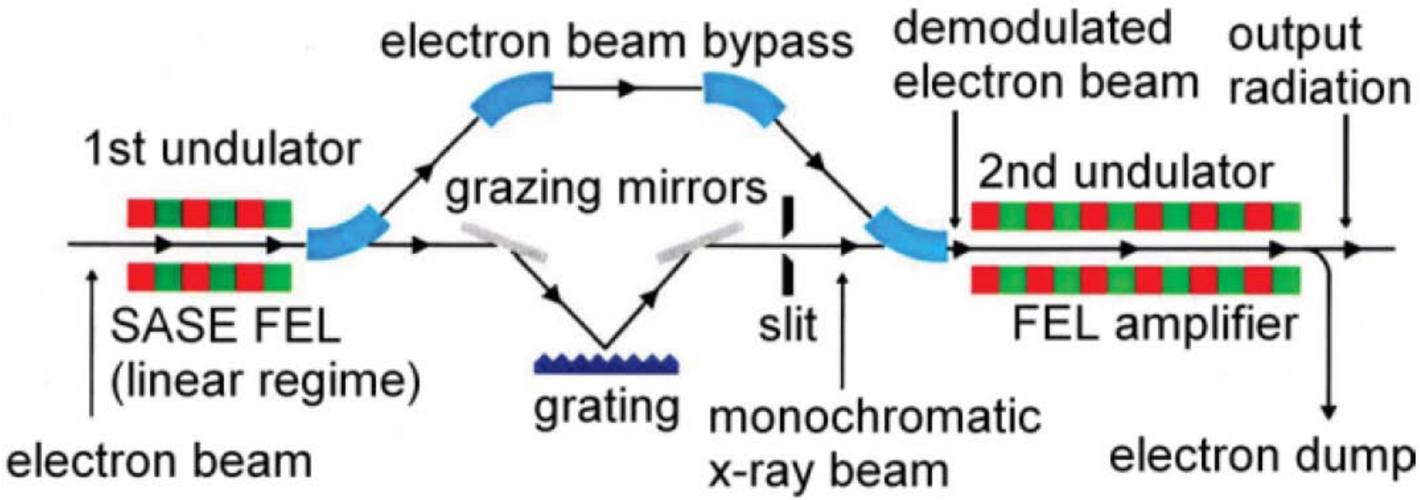
Outline

- **Hard** x-ray FEL self-seeding
- The two-bunch self-seeding scheme
- Accelerator setup and wake fields
- Undulator setup and simulation examples
- Summary

Self-seeding scheme

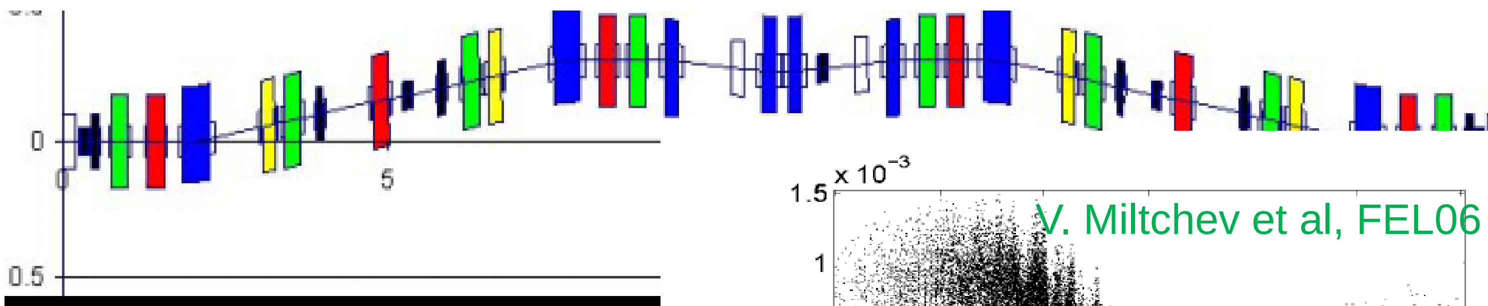
J. Feldhaus et al. / Optics Communications 140 (1997) 341-352



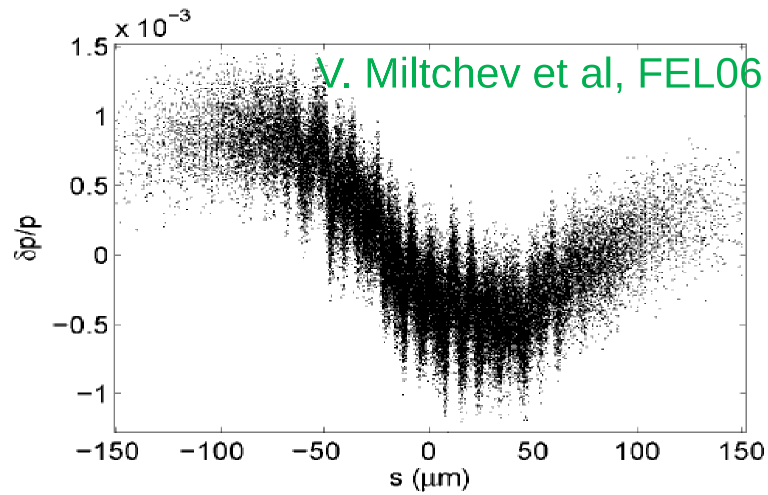
- Two undulators with a bypass and an x-ray monochromator;
- Second stage is an FEL amplifier, to produce narrow bandwidth x-ray FELs.

For **hard** x-ray self-seeding…

- A large magnetic chicane is required to match the x-ray optics delay, ~ 40 m in length; (Saldin et al. NIMA 2001, Schroeder et al, J. Opt. Soc. Am. B 2002)
- Such a chicane takes lots of space. An example of the chicane design studied by Miltchev et al for FLASH.



- Also CSR effect may degrade th

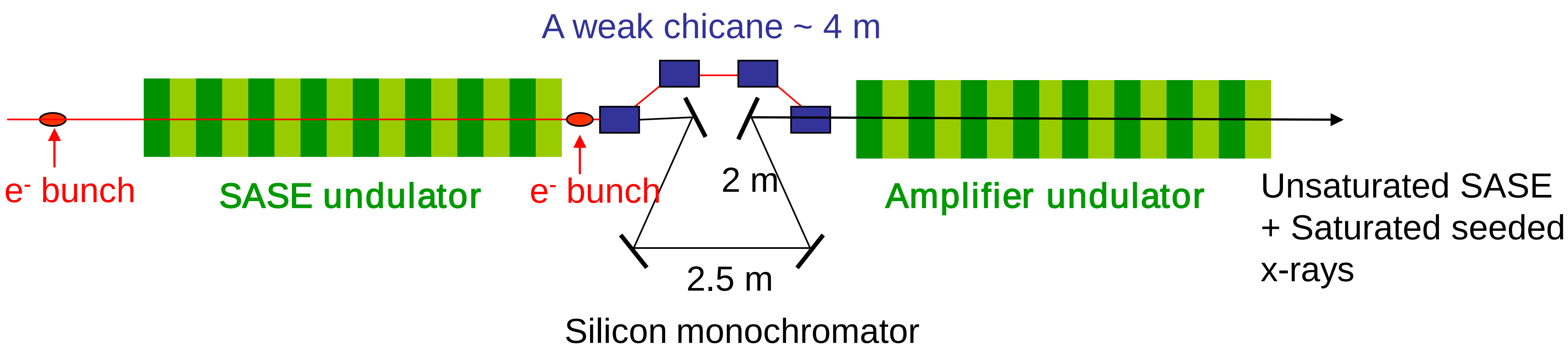


V. Miltchev et al, FEL06

Figure 8: Distortion of the longitudinal phase space due to synchrotron radiation produced in the bypass dipoles.

Two-Bunch Self-Seeding for **hard** x-rays

Using two bunches to match the x-ray delay.

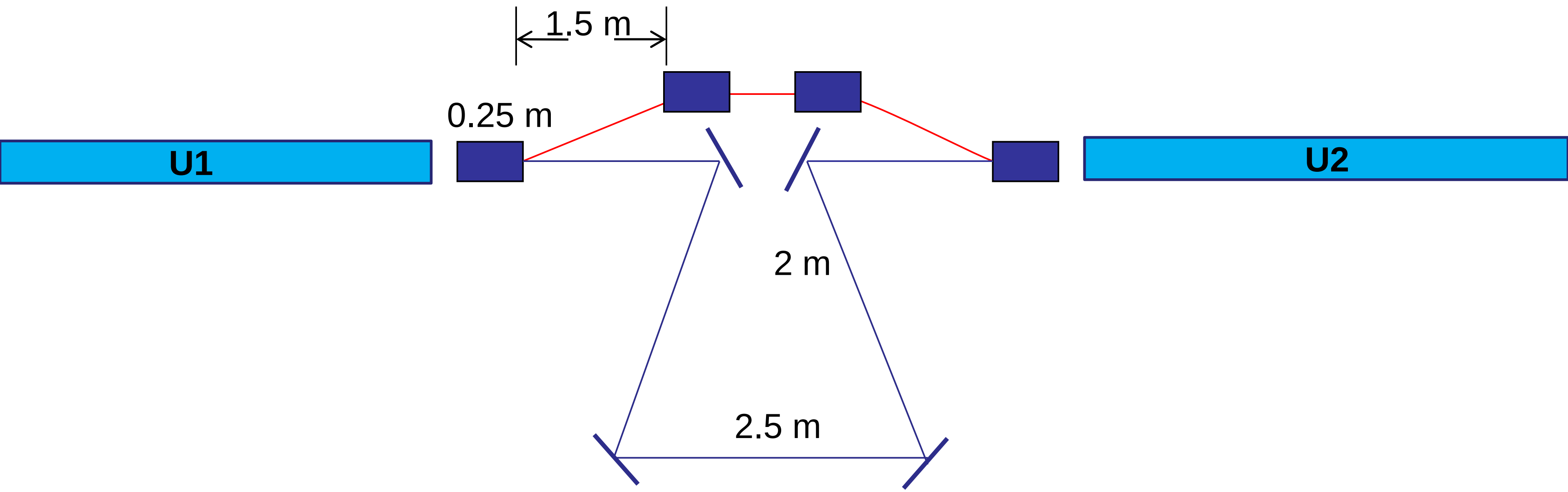


- Two bunches are properly separated (~20 ns) to match the x-ray delay of the monochromator;
- A small chicane serves to avoid the x-ray optics and to wash out the microbunching structures generated in U1;
- This small chicane is only ~ 4m (one undulator segment for LCLS).
- Good timing is required for second electron bunch and the x-rays from the first bunch.

Two-Bunch mode in SLAC Linac

- Two-bunch mode was used in the SLAC linac to accelerate the e^+ and e^- for collisions at the SLC.
  - Routine operation with ~ 6 nC per bunch, 60 ns spacing
- Requirements for the linac RF:
  - Beam loading < 10^{-3} => flat field amplitude;
  - Need same RF phase for the two electron bunches.
  - Precise relative phase adjustment
- The estimated long-range wake-field effects are very small for LCLS operating parameters.
  - Careful simulation required.
  - Two-bunch diagnostics
- The two bunch mode is also useful for other purposes, like the two-pulse two-color FEL.

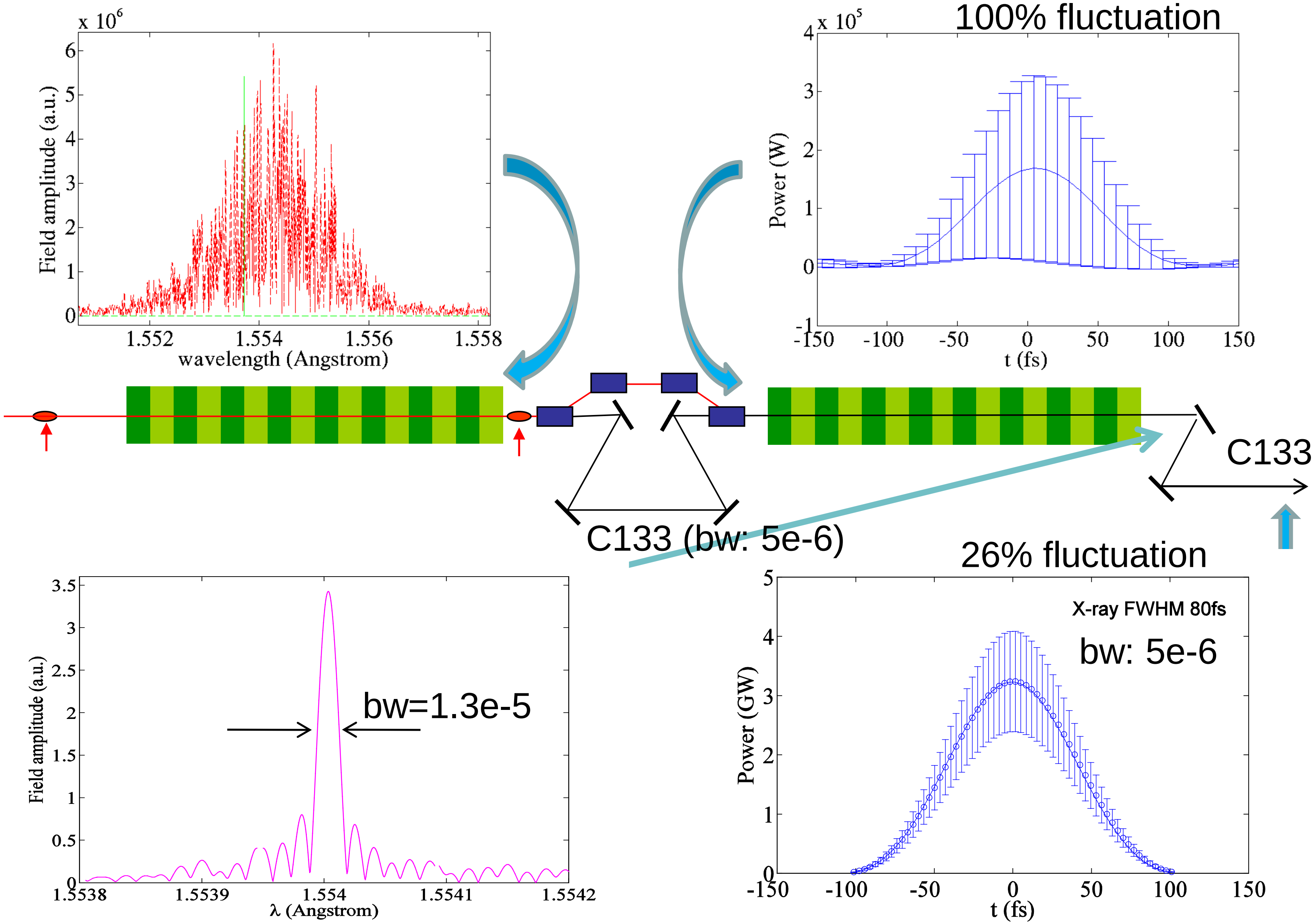
Undulator setup and electron parameters



U1 length (ideal beam)	52m
(LCLS beam)	60 m
U2 length (ideal beam)	70m
(LCLS beam)	70m
Chicane length	~4 m
Chicane R56	150 um
Monochromator (ideal beam)	C133
Monochromator (LCLS beam)	Si113

Energy	13.64 GeV
Charge	250 pC
Peak current	3 kA
Slice energy spread	1.4 MeV
Slice emittance	~ 0.4 um
Bunch length (fwhm)	80 fs

Simulations: ideal beam



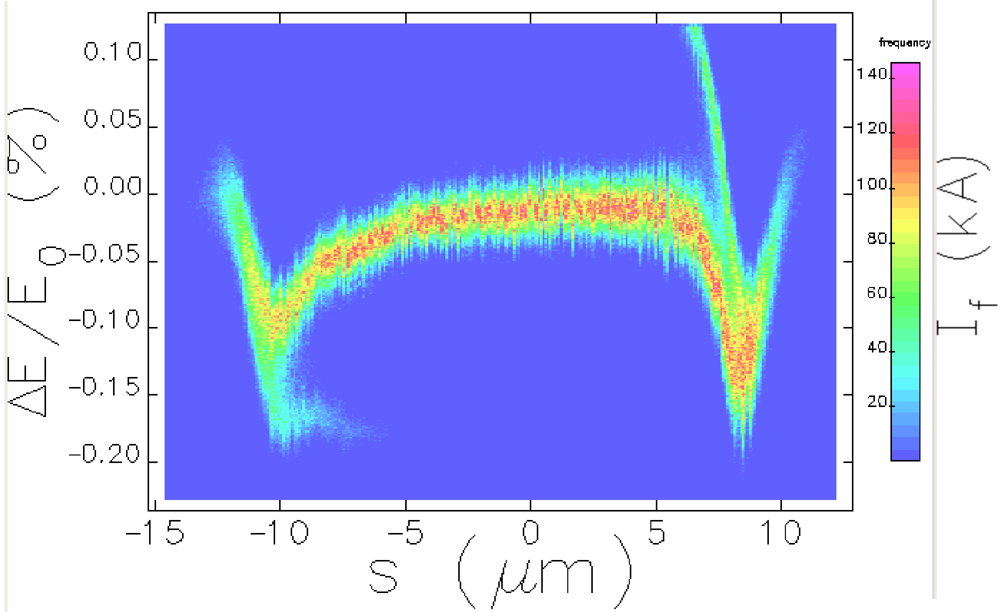
Apply to the LCLS beam

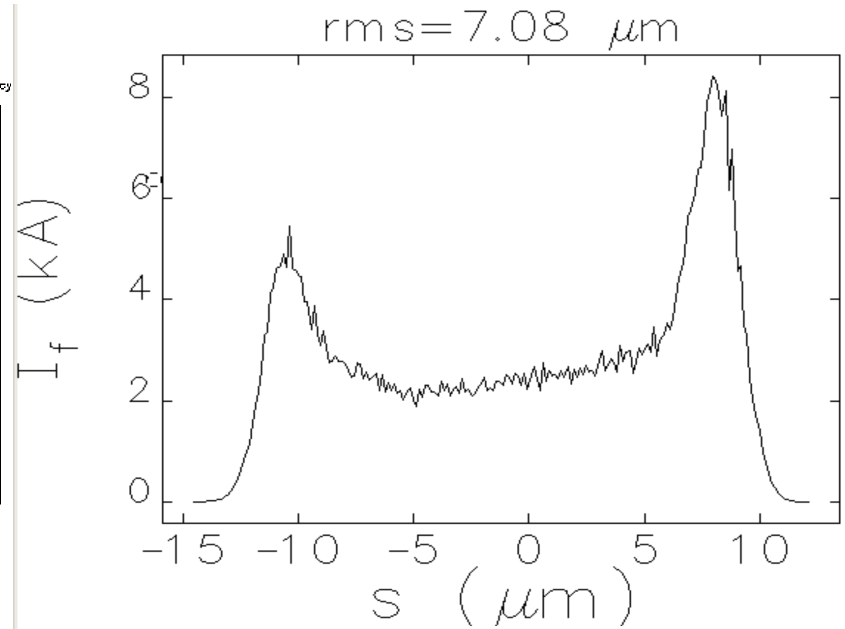
- ❖ Two-bunch self-seeding with an Ideal beam can obtain very narrow bandwidth fully coherent x-ray pulse.

- ❖ But for the LCLS beam:
  - -- double-horn current profile;
  - -- microstructures and chirp;
  - -- wake field effects in the undulator chamber;

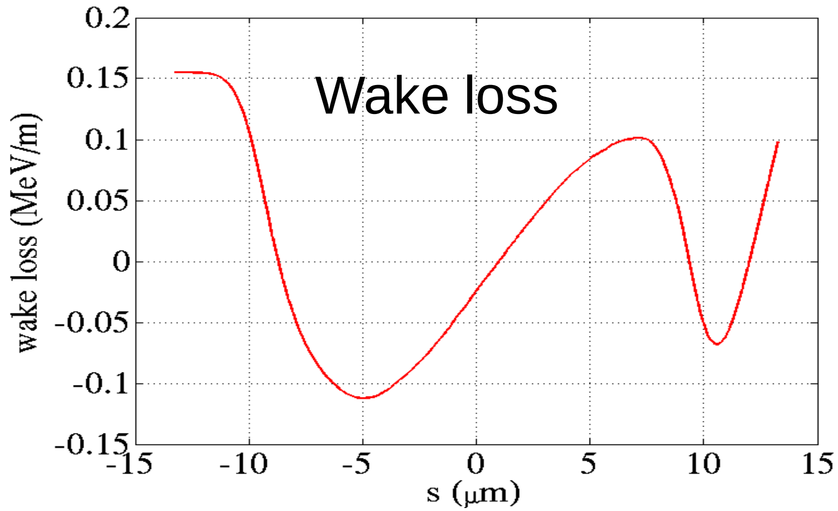
- ❖ We show simulation results in the following slides:
  - -- based on start-end LCLS beam;
  - -- including wake field in the undulator chamber.

Simulations: LCLS beam (1)



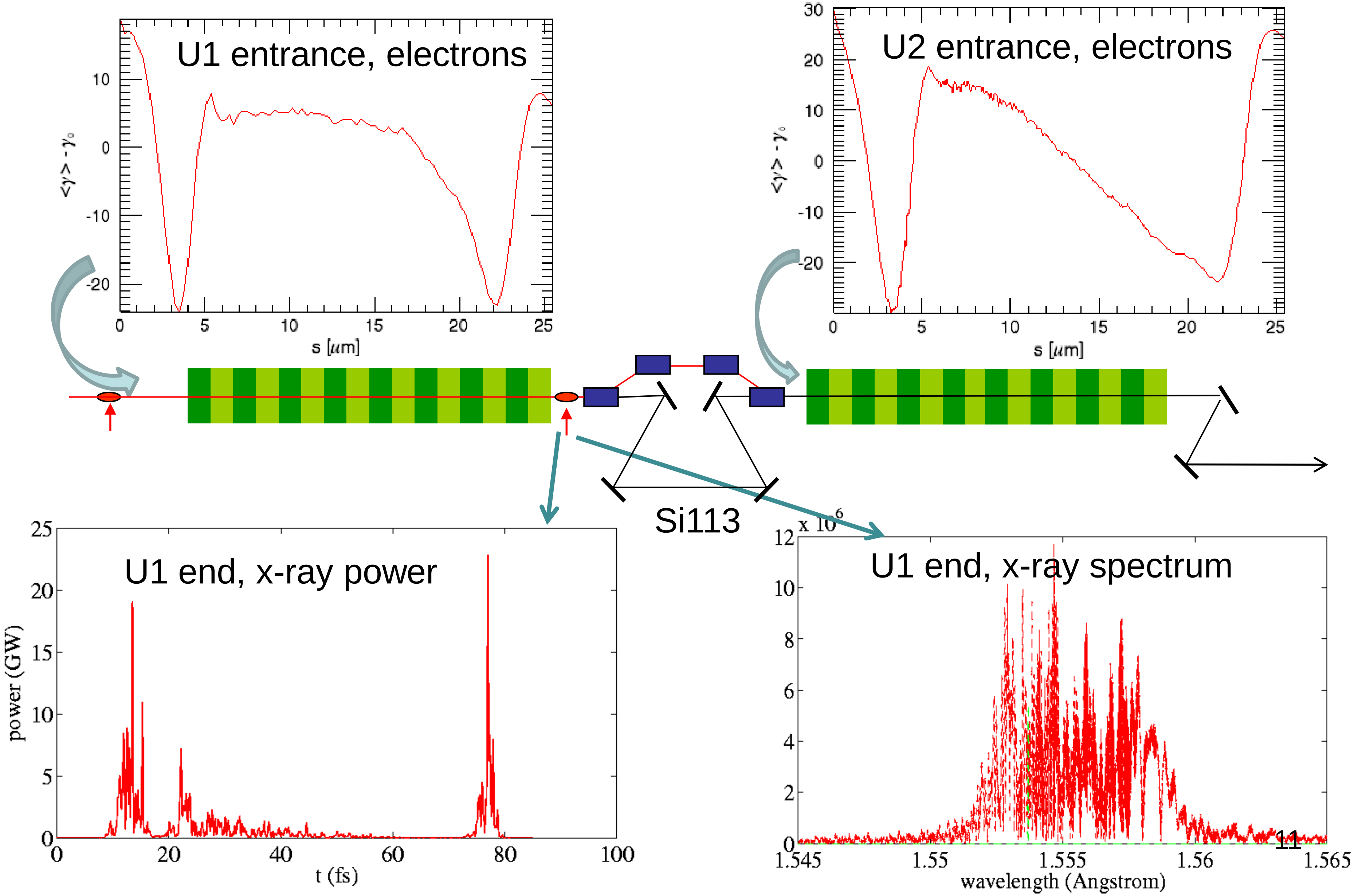


head ←



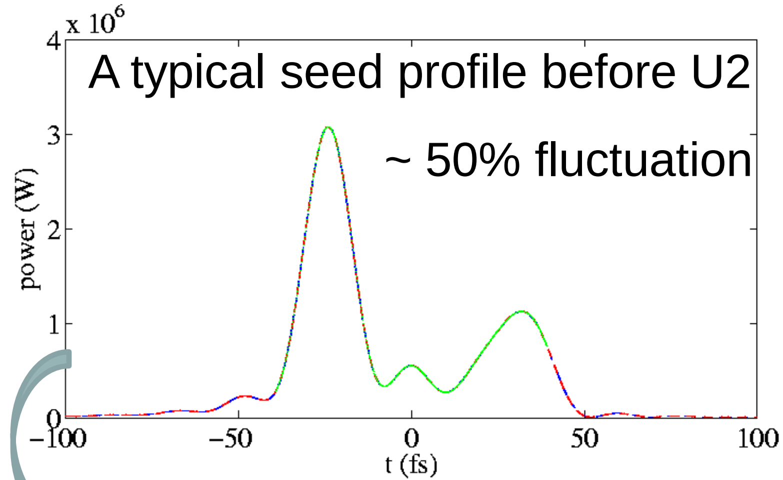
- Double-horn current profile at under-compression;
- Wake loss introduces additional energy modulation.

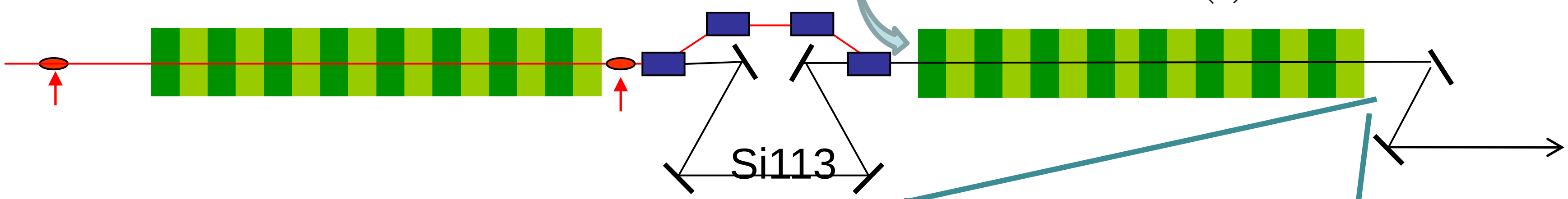
Simulations: LCLS beam (2)

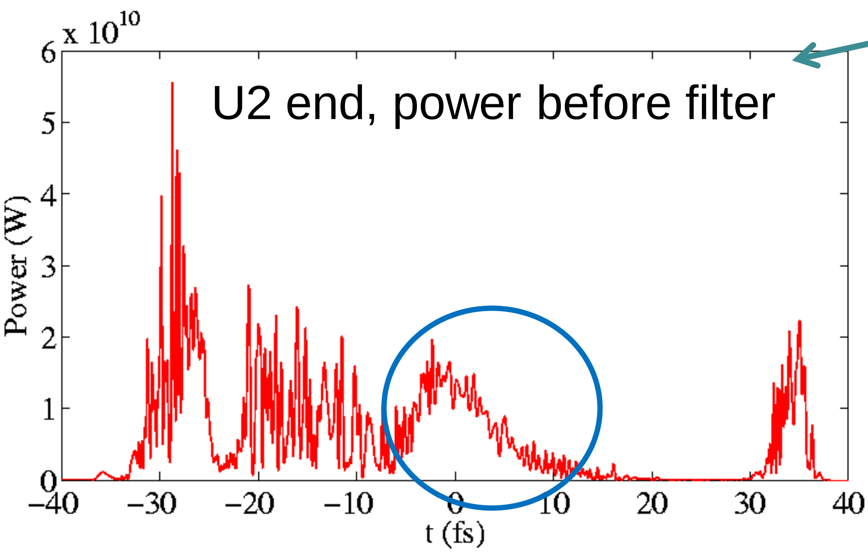


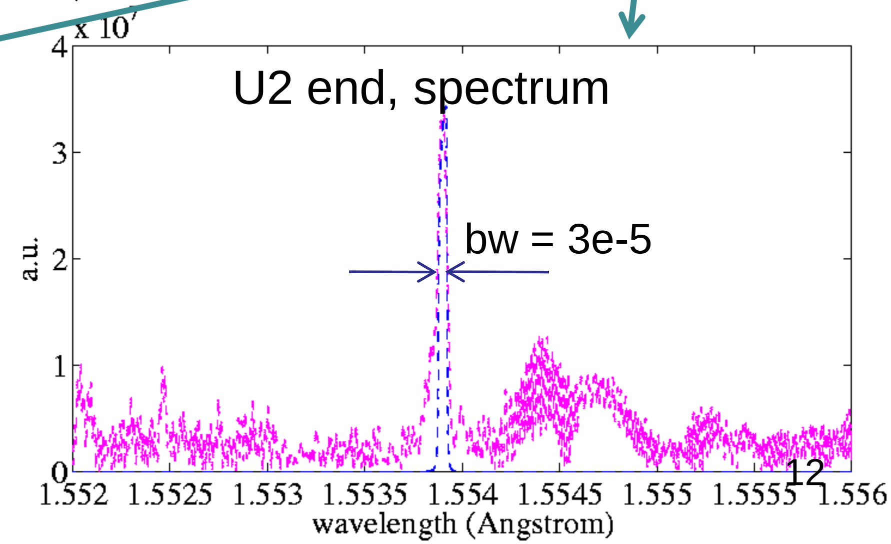
Simulations: LCLS beam (3)

Si113: bw = 3e-5 at 8 keV.

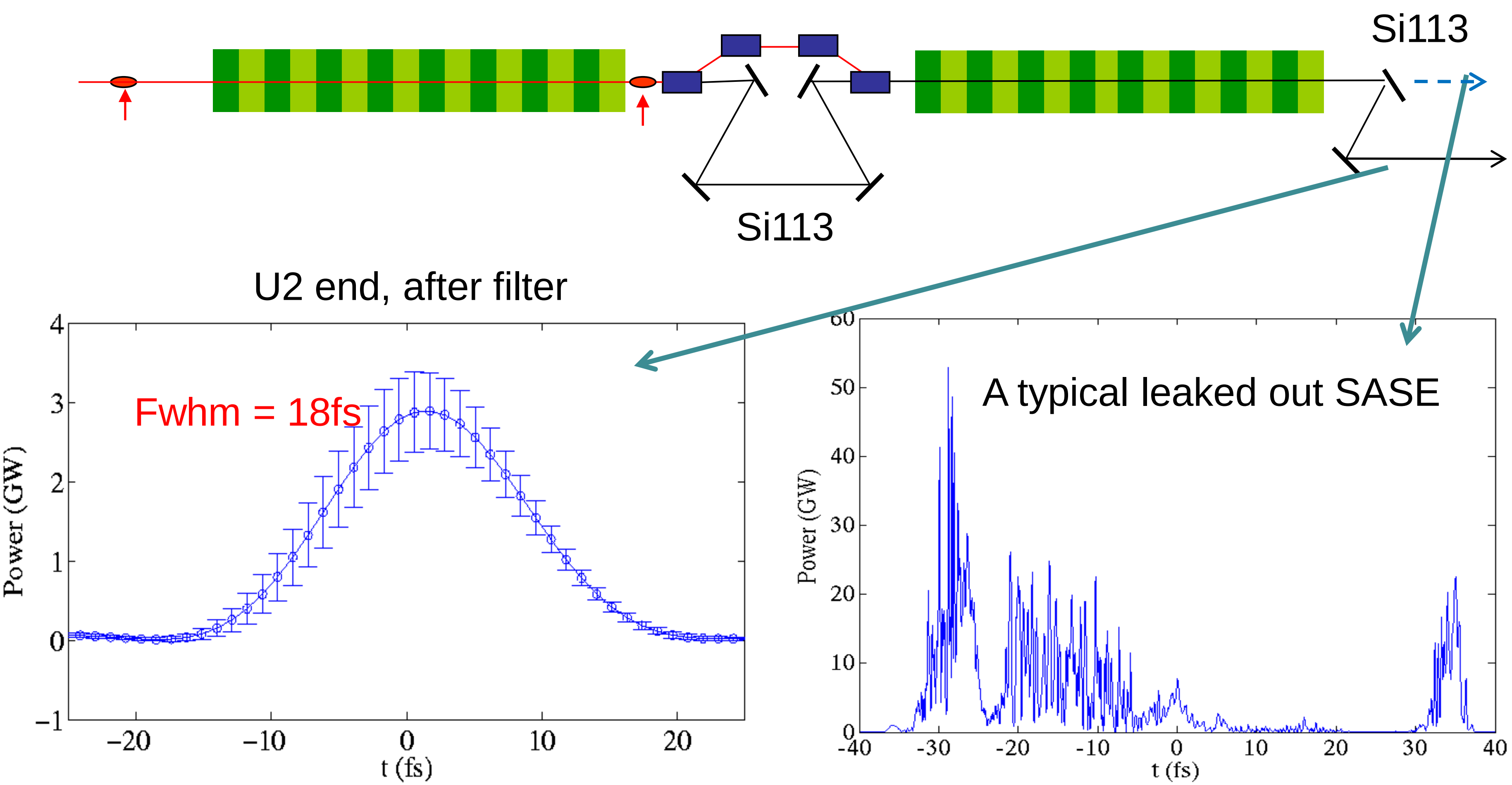








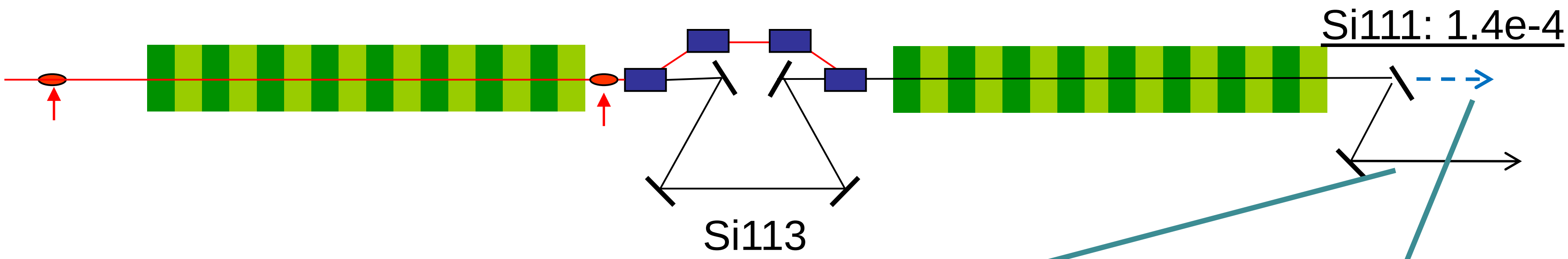
Simulations: LCLS beam (4)



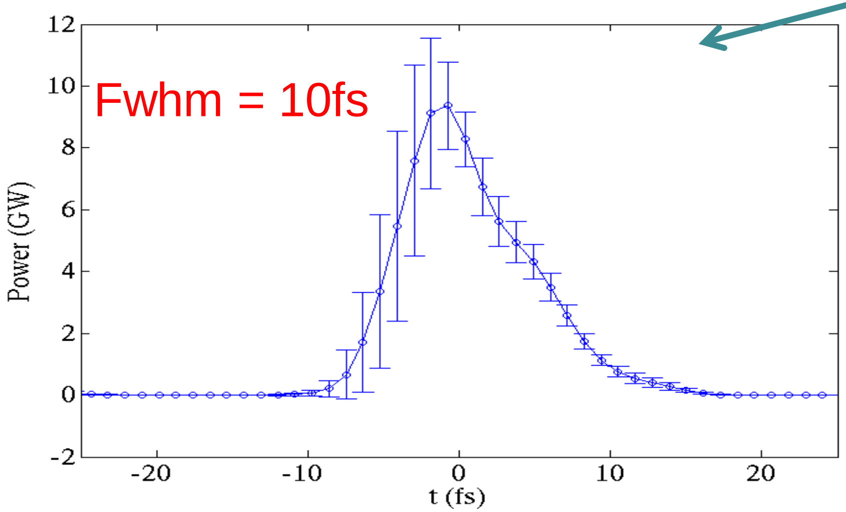
Bandwidth = 3e-5;

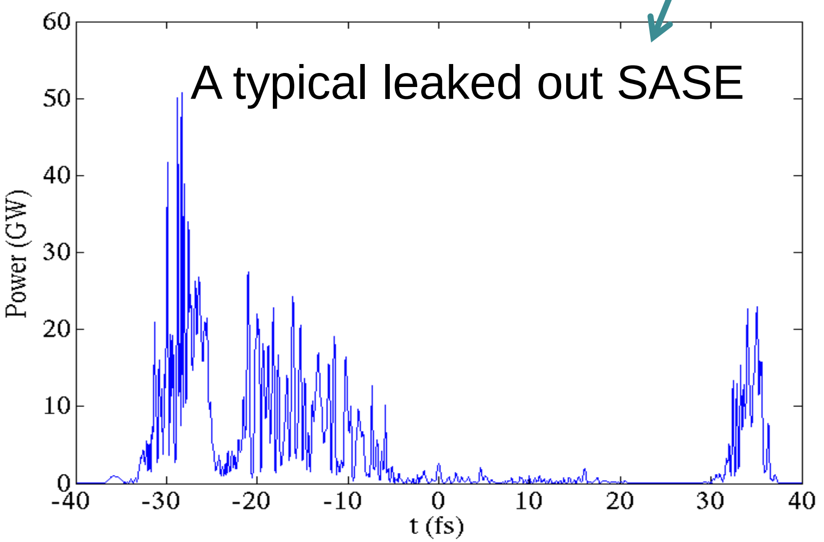
Energy fluctuation: ~15%.

Simulations: LCLS beam (5)



U2 end, after filter





Bandwidth = 1.4e-4;

Energy fluctuation: ~15%.

Summary

- Two-bunch mode for hard x-ray self-seeding appears to be very promising:
  - This method avoids a long, complex chicane.
  - May be relatively straight forward to implement.
- Based on LCLS start-end beam:
  - The narrow-band hard x-ray pulse has a fwhm of 18fs, with the bandwidth of $3*10^{-5}$ using Si113.
  - The broad-band filter yields a fwhm of 10 fs, with a bandwidth of $1.4*10^{-4}$, and peak power of 10 GW.
  - We also have two additional SASE x-ray pulses.

Thanks