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

- 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...


- 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
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 \(~ 6 \text{ nC per bunch, 60 ns spacing}\)

• Requirements for the linac RF:
  – Beam loading \(< 10^{-3} \Rightarrow\) 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>13.64 GeV</td>
</tr>
<tr>
<td>Charge</td>
<td>250 pC</td>
</tr>
<tr>
<td>Peak current</td>
<td>3 kA</td>
</tr>
<tr>
<td>Slice energy spread</td>
<td>1.4 MeV</td>
</tr>
<tr>
<td>Slice emittance</td>
<td>~ 0.4 um</td>
</tr>
<tr>
<td>Bunch length (fwhm)</td>
<td>80 fs</td>
</tr>
<tr>
<td>U1 length (ideal beam)</td>
<td>52m</td>
</tr>
<tr>
<td>(LCLS beam)</td>
<td>60 m</td>
</tr>
<tr>
<td>U2 length (ideal beam)</td>
<td>70m</td>
</tr>
<tr>
<td>(LCLS beam)</td>
<td>70m</td>
</tr>
<tr>
<td>Chicane length</td>
<td>~4 m</td>
</tr>
<tr>
<td>Chicane R56</td>
<td>150 um</td>
</tr>
<tr>
<td>Monochromator (ideal beam)</td>
<td>C133</td>
</tr>
<tr>
<td>Monochromator (LCLS beam)</td>
<td>Si113</td>
</tr>
</tbody>
</table>
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)

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

Wake loss

rms = 7.08 μm
Simulations: LCLS beam (2)

U1 entrance, electrons

U2 entrance, electrons

U1 end, x-ray power

U1 end, x-ray spectrum

Si113
Simulations: LCLS beam (3)

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

A typical seed profile before U2

~ 50% fluctuation

U2 end, power before filter

U2 end, spectrum

$bw = 3e-5$
Simulations: LCLS beam (4)

U2 end, after filter

- Fwhm = 18fs
- Bandwidth = 3e-5;
- Energy fluctuation: ~15%.
Simulations: LCLS beam (5)

Si111: $1.4\times 10^{-4}$

U2 end, after filter

Fwhm = 10fs

Bandwidth = $1.4\times 10^{-4}$;

Energy fluctuation: $\sim 15\%$.
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 straightforward to implement.
- Based on LCLS start-end beam:
  - The narrow-band hard x-ray pulse has a fwhm of 18 fs, with the bandwidth of $3 \times 10^{-5}$ using Si113.
  - The broad-band filter yields a fwhm of 10 fs, with a bandwidth of $1.4 \times 10^{-4}$, and peak power of 10 GW.
  - We also have two additional SASE x-ray pulses.

Thanks