Intro: **The LCLS Beamline**

- Operational 2009
- World’s first X-ray FEL
- 1.6 cell S-band photoinjector
- 2 bunch compressors
- 100 m undulator

http://www-srl.slac.stanford.edu/lcls/
**Intro: The LCLS**

**Relevant Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1.0 nC</th>
<th>0.2 nC</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal electron energy, BC1</td>
<td>0.25</td>
<td>0.25</td>
<td>GeV</td>
</tr>
<tr>
<td>Nominal electron energy, BC2</td>
<td>4.3</td>
<td>4.3</td>
<td>GeV</td>
</tr>
<tr>
<td>Peak current</td>
<td>3400</td>
<td>2500</td>
<td>A</td>
</tr>
<tr>
<td>Nominal RMS bunch length, BC1</td>
<td>200</td>
<td>60</td>
<td>µm</td>
</tr>
<tr>
<td>Nominal RMS bunch length, BC2</td>
<td>20</td>
<td>8</td>
<td>µm</td>
</tr>
<tr>
<td>Nominal RMS bunch duration, BC1</td>
<td>667</td>
<td>200</td>
<td>fs</td>
</tr>
<tr>
<td>Nominal RMS bunch duration, BC2</td>
<td>67</td>
<td>27</td>
<td>fs</td>
</tr>
<tr>
<td>Max single bunch repetition rate</td>
<td>120</td>
<td>120</td>
<td>Hz</td>
</tr>
</tbody>
</table>
Intro: The Problem

- High-quality lasing: tight beam parameters
  - Longitudinal feedback systems needed (along with other diagnostics and feedback systems)
  - Bunch length
  - Energy
- PBPL to build bunch length monitor system
  - System will consist of two grating polychromators, one at each bunch compressor (explained later)
Intro: Possible Solutions

- Streak Camera
- Interferometer
- Electro-Optic Techniques
- RF Deflecting Cavity
- Polychromator (Spectrometer)
(more later)
Intro: *System Requirements*

- Only relative bunch length is needed - not absolute bunch length
- Need two bunch length monitors - one at each bunch compressor [1]
- Single-shot
- Non-invasive
- Maintenance free for several days
- Possibility to run at 120 Hz
- Single-shot measurement resolution: 1-2% of nominal bunch length
- Long term signal drift: <2% over ~24 hours

Intro: Phase Feedback

Observables
- Bunch length $\sigma_z$
- Energy $E$

Controllables
- Linac voltage $V_{rf}$
- Linac phase $\phi_{rf}$

- LCLS longitudinal feedback: 2 bunch length loops
  - BC1 bunch length $\rightarrow$ Linac 1 RF phase
  - BC2 bunch length $\rightarrow$ Linac 2 RF phase

Possible Solutions

• Streak Cameras
  + Single-shot
  + Wide dynamic range
  - Limited by temporal resolution (~200 fs at best)
  - Trigger jitter

Hamamatsu "FESCA-200" (Femtosecond Streak Camera).
Temporal resolution: 200 fs.
Possible Solutions

- Interferometers
  - Can be single-shot
  - High temporal (frequency) resolution
  - Compact
  - Narrow dynamic range
  - Complex

RadiaBeam Technologies BLIS (Bunch Length Interferometer System)
http://www.radiabeam.com/products/diagnostics/blis.html
Possible Solutions

• **Electro-Optic Methods**
  + Single-shot
  + Non-invasive (?)
  + Temporal resolution
  - Not yet mature
  - Require expensive femtosecond lasers

P. Bolton et al., SLAC-PUB-9529. Transverse probe geometry produces a spatial image of the bunch. Also see: http://www.rijnh.nl/users/berden/ebunch.html
Possible Solutions

- **RF Deflecting Cavities**
  - Single shot
  - Femtosecond resolution
  - May require separate RF system
  - Invasive (destroy measured shot)

Possible Solutions

- Polychromators
  - Single-shot
  - Temporal resolution
  - Robust
  - Require relatively expensive detector & vacuum system
## Possible Solutions

### Summary

<table>
<thead>
<tr>
<th></th>
<th>Single-shot</th>
<th>Non-Invasive</th>
<th>Good Temporal Resolution</th>
<th>Maintenance Free</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Streak Camera</strong></td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Interferometer</strong></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td><strong>Electro-Optic</strong></td>
<td>Y</td>
<td>Y (?)</td>
<td>Y</td>
<td>Y (?)</td>
</tr>
<tr>
<td><strong>RF Deflector</strong></td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td><strong>Polychromator</strong></td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>
Single-Shot Spectrometer

*Bunch length monitor locations*

- After 4\textsuperscript{th} chicane magnet of BC1, BC2
Single-Shot Spectrometer Design

- Use CSR/CER from bunch compressor chicane magnets
  - Vacuum port window
  - Focusing/turning mirror
  - Entrance slit
  - Grating
  - Off-axis parabola (line focus)
  - Multichannel detector (linear array of cryogenically cooled bolometers)
Single-Shot Spectrometer

*Bunch Distributions*

- **BC1**
  - Smooth parabolic distribution
  - Simple CSR spectrum
  - $\sigma = 0.197 \text{ mm}$

- **BC2**
  - Wake-induced double-horn
  - Complicated CSR spectrum
  - $\sigma = 20.338 \text{ \mu m}$
Single-Shot Spectrometer

Challenge: BC2 CSR Spectrum

CSR energy spectrum after BC2.
Black curve: double-horn distribution
Blue curve: Gaussian distribution
Red curve: step function


• Double-horn distribution complicates CSR spectrum
  - Similar to Gaussian below 4 THz
  - Stay below 4 THz
Single-Shot Spectrometer

Challenge: Detectors

**BC1**
- Frequency range: 150-500 GHz
- ~ 20 channels
- Easy, but big
  - large vacuum chamber
  - large optics
- InSb hot electron bolometers

**BC2**
- Frequency range: 1-4 THz
- ~ 20 channels
- More challenging than BC1
- Needs special filtering
- Thermal composite bolometers?
- Need to research more
Single-Shot Spectrometer
Challenge: Beamline Integration

- Low-loss vacuum port window over desired frequency range (Diamond?)
- Cryostats: liquid helium & nitrogen
  - Helium hold time (weeks?)
  - Closed-cycle nitrogen system (Sterling Engine?)
- Windowless enclosure for detector system
Single-Shot Spectrometer

**BC1 Detector Assembly**

- InSb hot-electron bolometers
- 10 liter cryostat
- Helium hold time: 4-6 weeks!

20-channel linear array of InSb hot-electron bolometers, courtesy QMC Instruments.
Conclusion

Some work done so far...

Brookhaven CER work

UCLA built ATF compressor.

Simulated CSR spectrum from FieldEye, a post-processor of TREDI.

Ref: G. Andonian, this workshop.
Conclusion

Workplan

• Simulate CR exiting vacuum ports of BC1, BC2 & arriving at detector
  – TREDI/FieldEye simulations
• Choose detector type
  – Finalize bolometer evaluations
  – SLAC to purchase
• Continue to study system
  – Windowless vacuum enclosure
  – Dynamic range (grating, *in situ* tuning)
  – Calibration methods
• Mechanical design & beamline integration with SLAC
  – CAD design work
  – Finalized by SLAC
• Test system (SPPS or APS Linac)