LCLS Single-Shot Relative Bunch Length Monitor System

-An Overview-

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October 11, 2005

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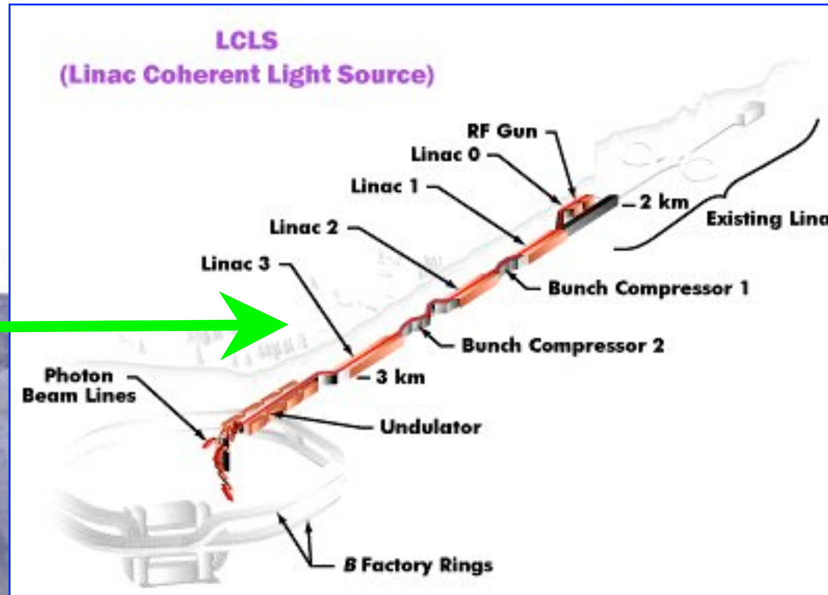
Intro: *The LCLS*

Beamline

LCLS Linac Coherent Light Source — Stanford Linear Accelerator Center — Stanford Synchrotron Radiation Laboratory

http://www-srl.slac.stanford.edu/lcls/

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



Intro: *The LCLS*

Relevant Parameters

	1.0 nC	0.2 nC	
Nominal electron energy, BC1	0.25	0.25	GeV
Nominal electron energy, BC2	4.3	4.3	GeV
Peak current	3400	2500	A
Nominal RMS bunch length, BC1	200	60	µm
Nominal RMS bunch length, BC2	20	8	µm
Nominal RMS bunch duration, BC1	667	200	fs
Nominal RMS bunch duration, BC2	67	27	fs
Max single bunch repetition rate	120	120	Hz

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)

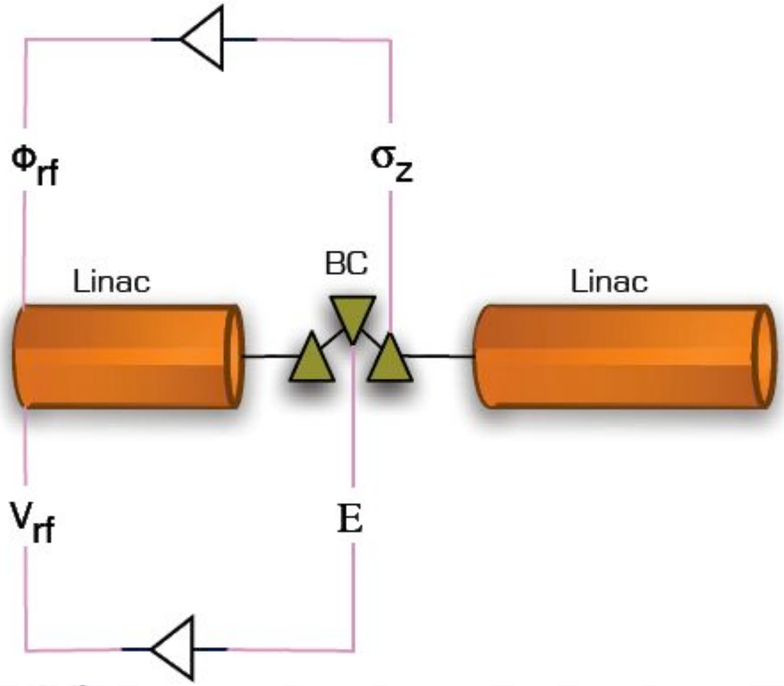
  (more later)

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

[1] J. Wu et al., SLAC-PUB-11276, May 2005.

Intro: *Phase Feedback*



<u>Observables</u>

- Bunch length σ_z
- Energy E

<u>Controllables</u>

- Linac voltage V_{rf}
- Linac phase ϕ_{rf}

- LCLS longitudinal feedback: 2 bunch length loops
  - BC1 bunch length → Linac 1 RF phase
  - BC2 bunch length → Linac 2 RF phase

Feedback model studied by Wu, et al., SLAC-PUB-11276, May 2005.

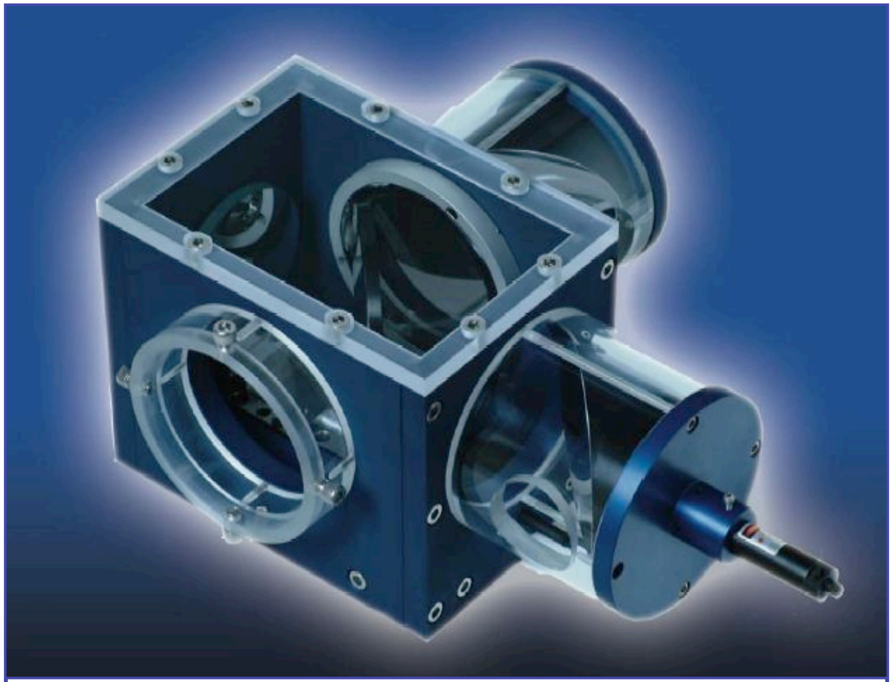
Possible Solutions

- **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

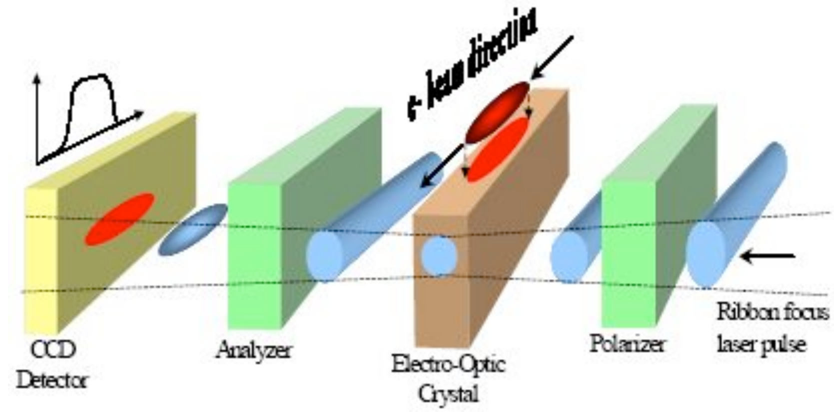


RadiaBeam Technologies BLIS (Bunch Length Interferometer System)

http://www.radiabeam.com/products/diagnostics/blis.html

Possible Solutions

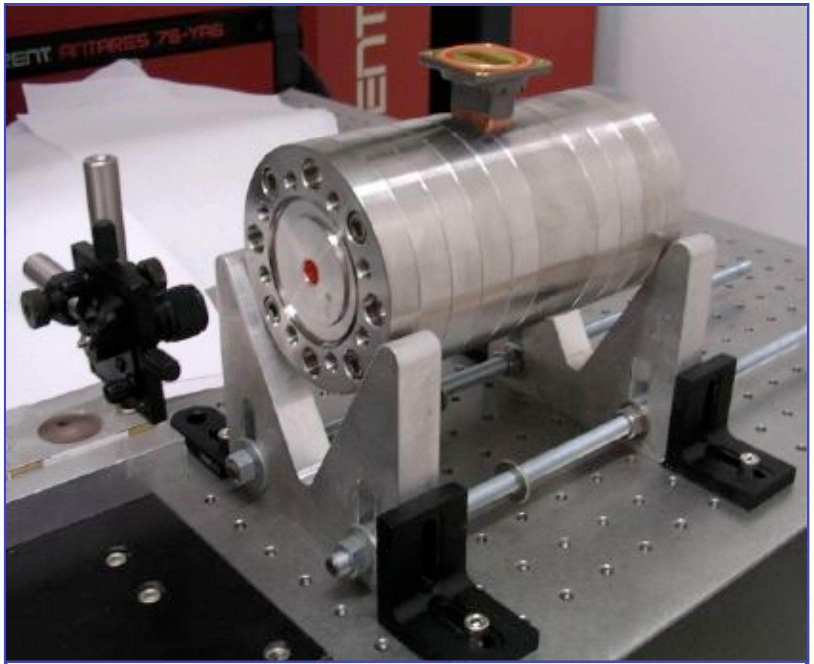
- Electro-Optic Methods
  - + Single-shot
  - + Non-invasive (?)
  - + Temporal resolution
  - - Not yet mature
  - - Require expensive femtosecond lasers



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)



The UCLA 9-cell X-band standing wave deflecting cavity. Courtesy Joel England.

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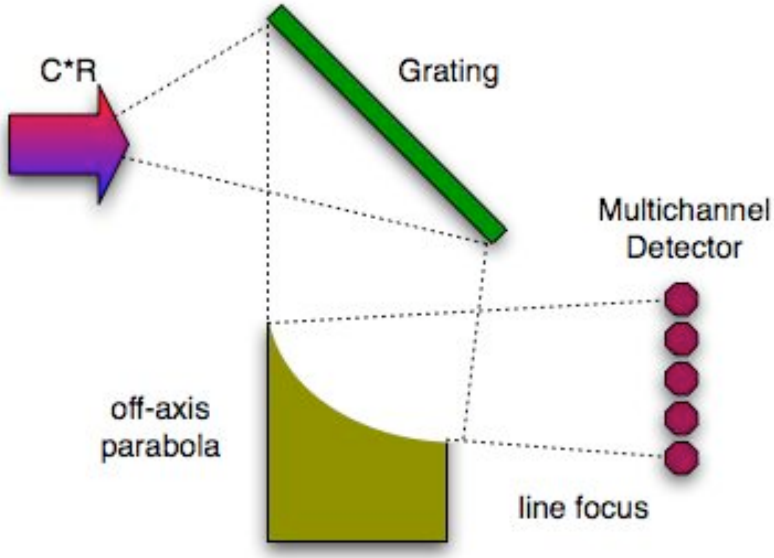
Possible Solutions

- Polychromators
  - + Single-shot
  - + Temporal resolution
  - + Robust
  - - Require relatively expensive detector & vacuum system



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Possible Solutions
Summary

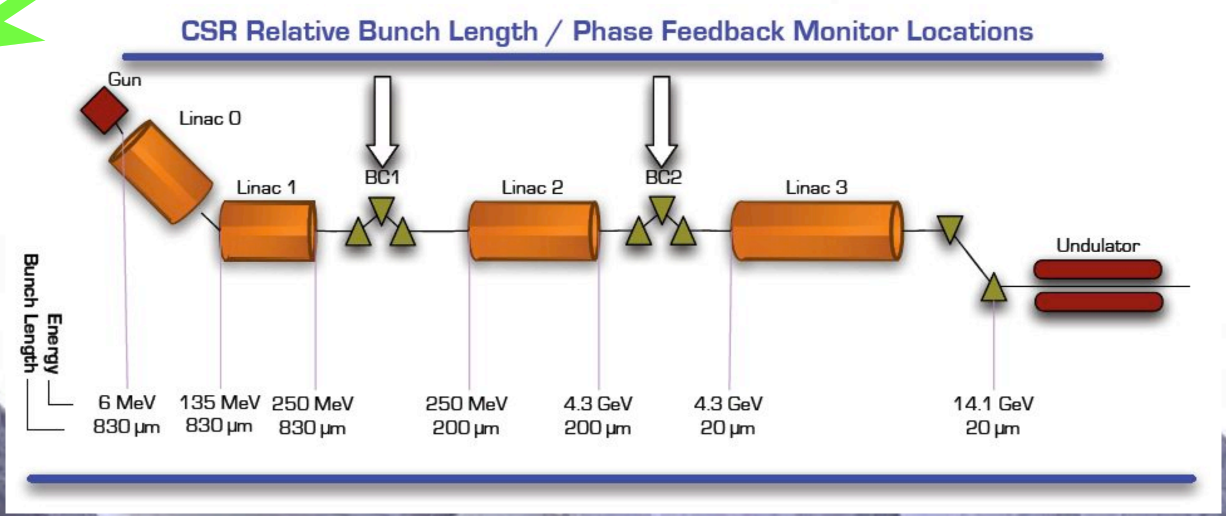
	Single-shot	Non-Invasive	Good Temporal Resolution	Maintenance Free
Streak Camera	Y	Y	N	Y
Interferometer	Y	Y	Y	N
Electro-Optic	Y	Y (?)	Y	Y (?)
RF Deflector	Y	N	Y	N
Polychromator	Y	Y	Y	Y

Single-Shot Spectrometer

Bunch length monitor locations

- After 4th chicane magnet of BC1, BC2

BC1



Single-Shot Spectrometer
Design

• Use CSR/CER from bunch compressor chicane magnets

→ Vacuum port window

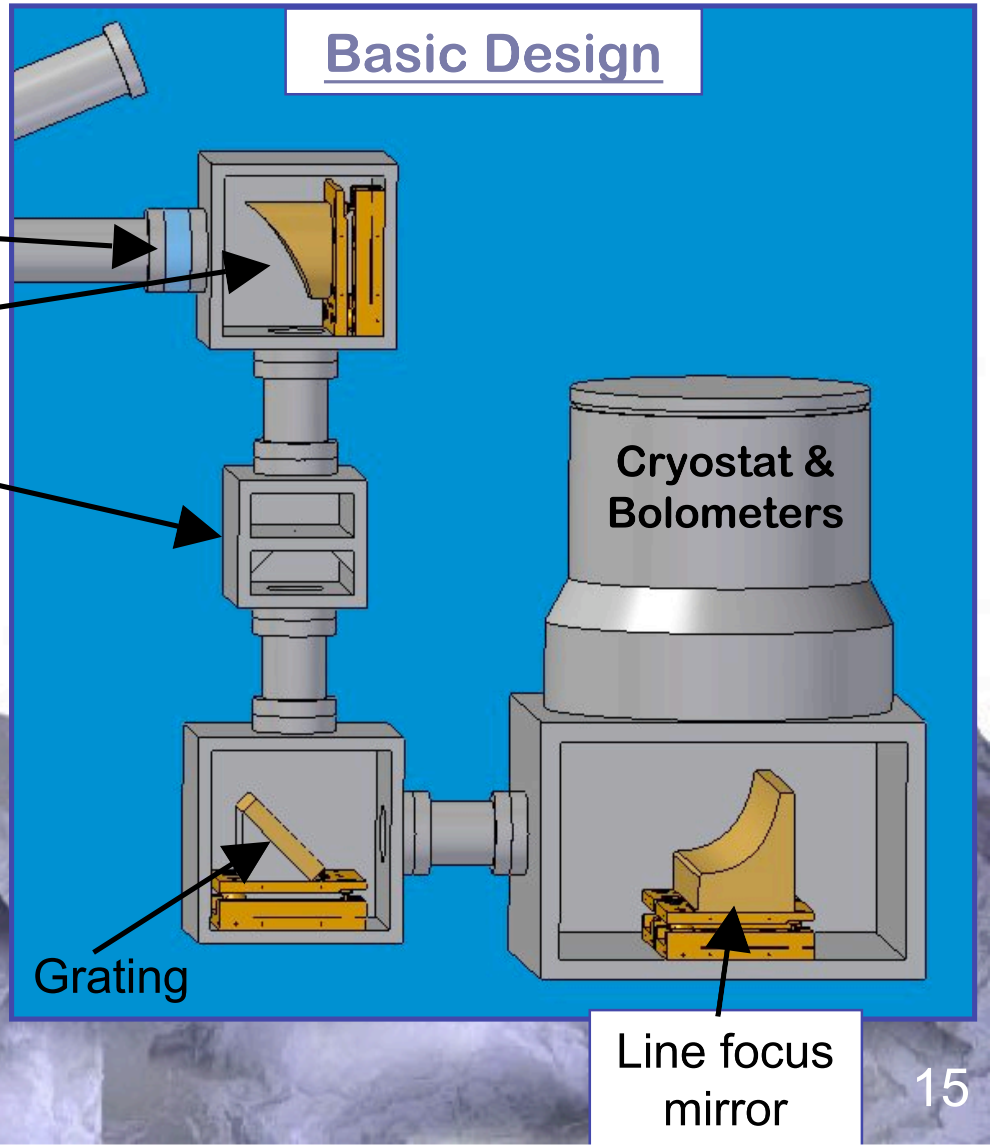
→ Focusing/turning mirror

→ Entrance slit

→ Grating

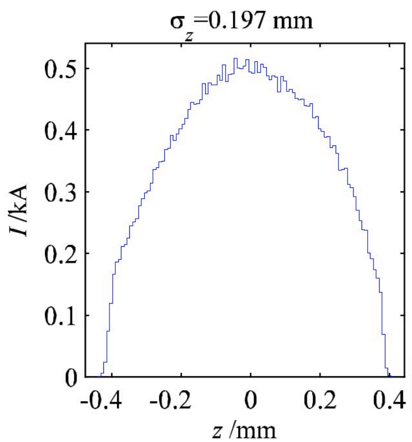
→ Off-axis parabola (line focus)

→ Multichannel detector (linear array of cryogenically cooled bolometers)

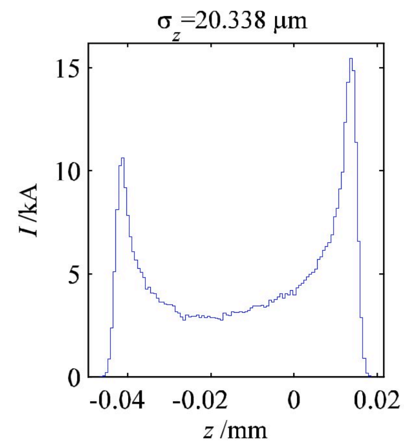


Single-Shot Spectrometer
Bunch Distributions

BC1



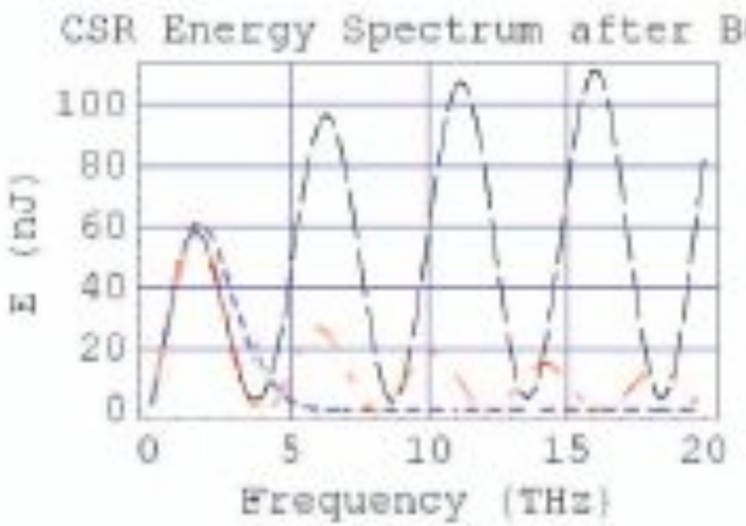
BC2



- Smooth parabolic distribution
  + Simple CSR spectrum
- Wake-induced double-horn
  - Complicated CSR spectrum

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

From J. Wu, et al., SLAC-PUB-11275, May 2005.

- 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

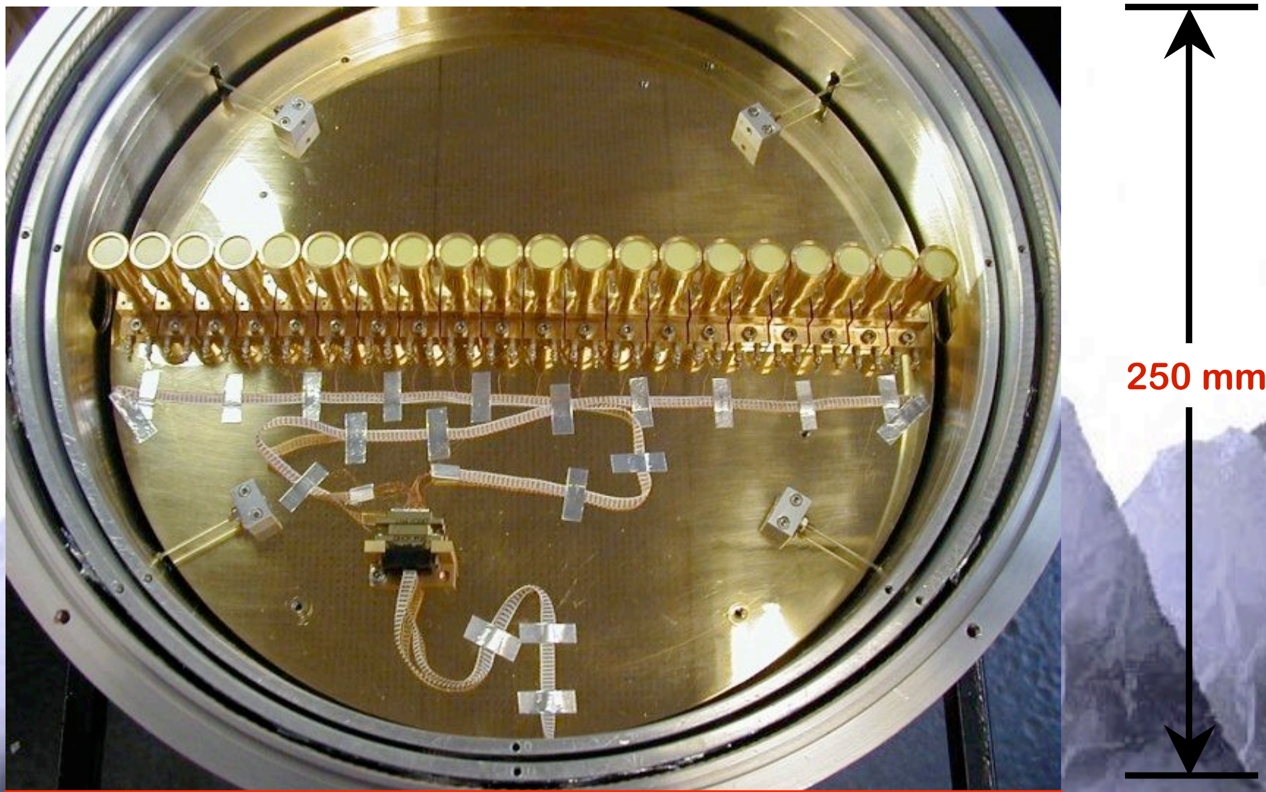
Single-Shot Spectrometer
Challenge: Beamline Integration

- 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.

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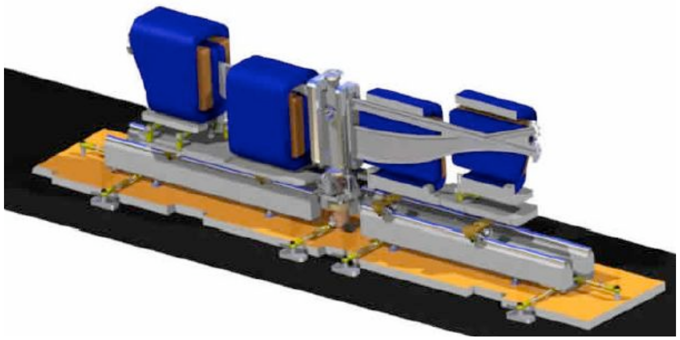
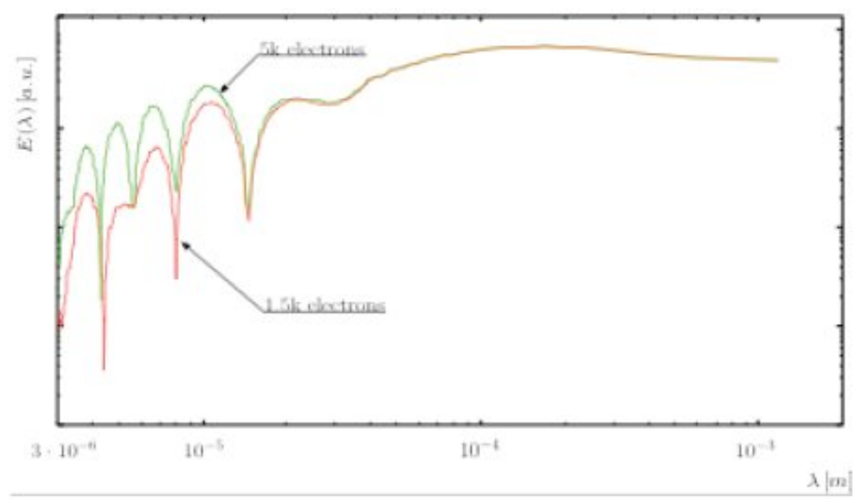
Conclusion

Some work done so far…

Brookhaven CER work



UCLA built ATF compressor.



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

Brookhaven Si Bolometer for CER detection.[1]

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)