FLS 2010

Working Group 2 – Storage Rings

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Photon Source and Optics Considerations

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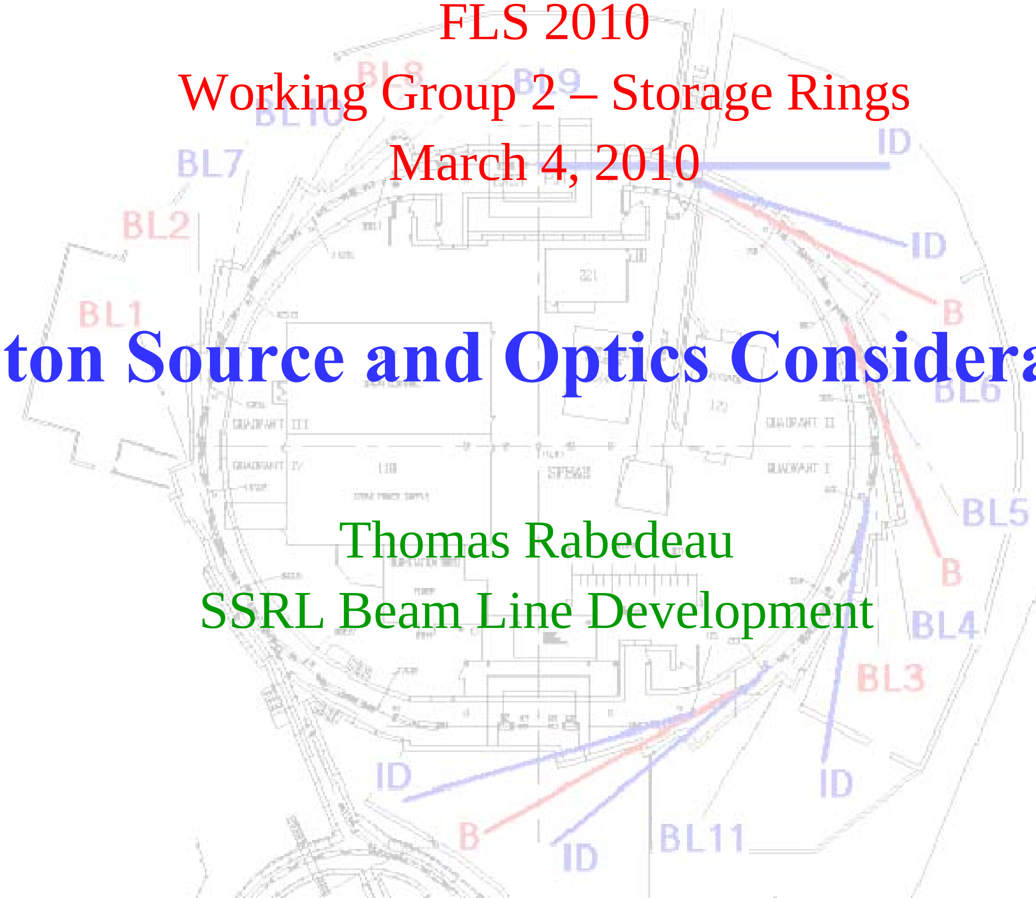
SSRL Beam Line Development



Source Characteristics & Sample Requirements
Two Sides of the Same Coin?

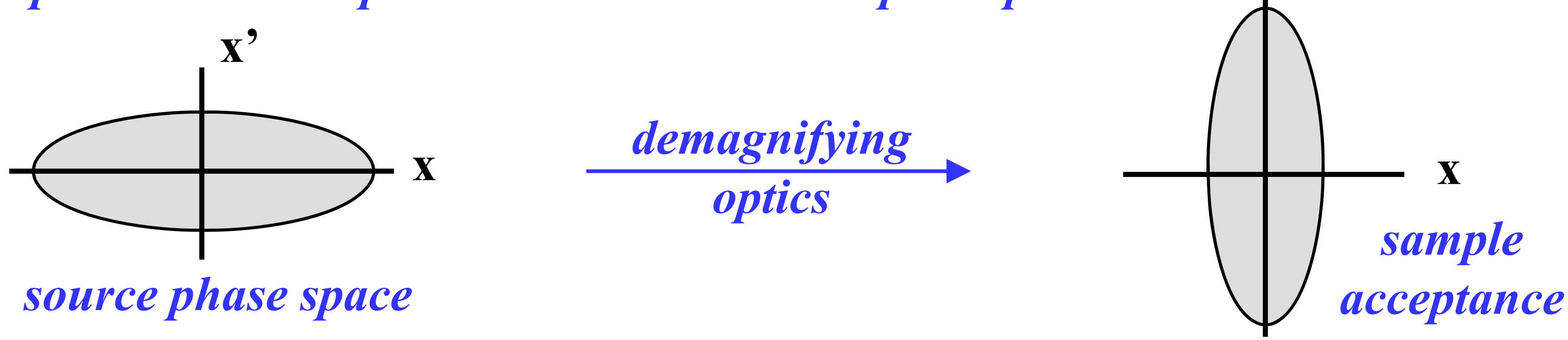
source (beam) characteristics:

- ***size (x, y)***
- ***angular divergence (x', y')***
- ***energy content***
- ***time domain***
- ***polarization***
- ***coherence***
- ***stability***

sample (beam) requirements:

- ***focus size (x, y)***
- ***angular convergence (x', y')***
- ***energy content***
- ***time domain***
- ***polarization***
- ***coherence***
- ***stability***

The job of x-ray optics is to transform the source beam characteristics to provide the best possible match to the sample requirements.



Source Figures of Merit?

Does it make any sense to discuss source figures of merit without considering sample acceptance and impact of optics?

> ***Question – Is an 0.008nm*rad emittance source 10x better than an 0.08nm*rad source if the sample acceptance is 1nm*rad?***
>
> ***Question – Is extraordinary brightness obtained through ultra small vertical coupling relevant if the optics can't preserve the vertical emittance?***

Conclusion - The operative performance figure of merit is technique and sample specific and must include <u>optics transmission function effects</u>.

Corollary - There is no one size fits all performance figure of merit.

X-ray Optics – Design Ingredients

Beam line optics design on storage ring sources involves several major ingredients/challenges:

- ***power management***
- ***emittance/coherence preservation***
- ***beam stability***
- ***optics tailored to manipulate beam properties to the needs of the individual scientific program***

The last of these ingredients often involves "boutique" optics (e.g., micro-focus optics, ultra-small bandpass monos, etc.) operating in concert with more generic optical elements.

It is difficult to address the plethora of boutique optics in this format, so for the remainder of the talk let's focus on the first three challenges and opportunities for associated optics improvements.

PEP-X BL Example

Consider a PEP-X (gedanken) beam line as a vehicle for discussing BL optics, power management, emittance preservation, and stability.

- *150 period undulator on 4.5GeV/1.5A/140pmrad/8pmrad ring*
- *75kW radiated power with 1MW/mrad^2 peak power density*

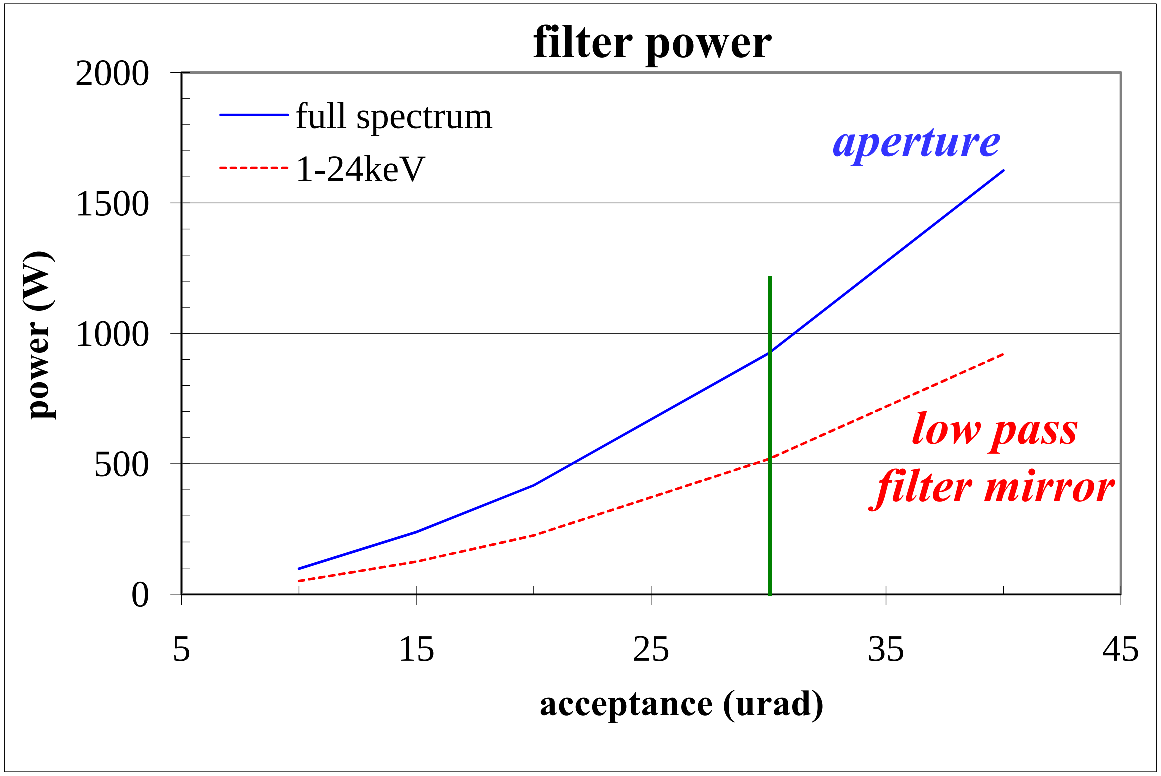
Primary job of optics upstream of the monochromator is to limit power incident on the mono to a manageable level. Tools available include:

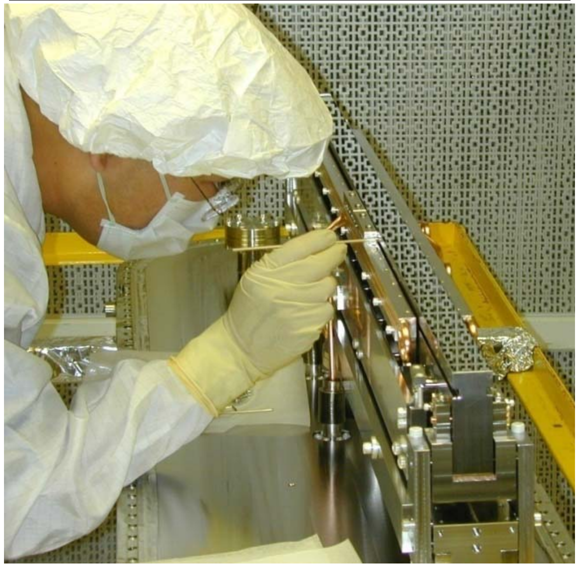
- *apertures - power management can lead to expensive designs*
- *high pass filters (e.g., graphite, Be, etc.) – can introduce structure in beam and may not survive power loading*
- *low pass filters (e.g., mirrors) – grazing incidence so thermal performance generally ok but can introduce beam structure and instability (more on this shortly)*

PEP-X BL Example
Pre-Mono Power Management

- *Absorb >98% on appropriately sized aperture(s)*
- *Introduce horizontally deflecting mirror with fixed energy cutoff to reject additional 2x power.*

E (keV)	$3\sigma_{x'\_eff}$ x $3\sigma_{y'\_eff}$
5.0	27.9 x 25.5
10.0	21.6 x 18.0
20.0	17.4 x 12.9
40.0	15.0 x 9.3

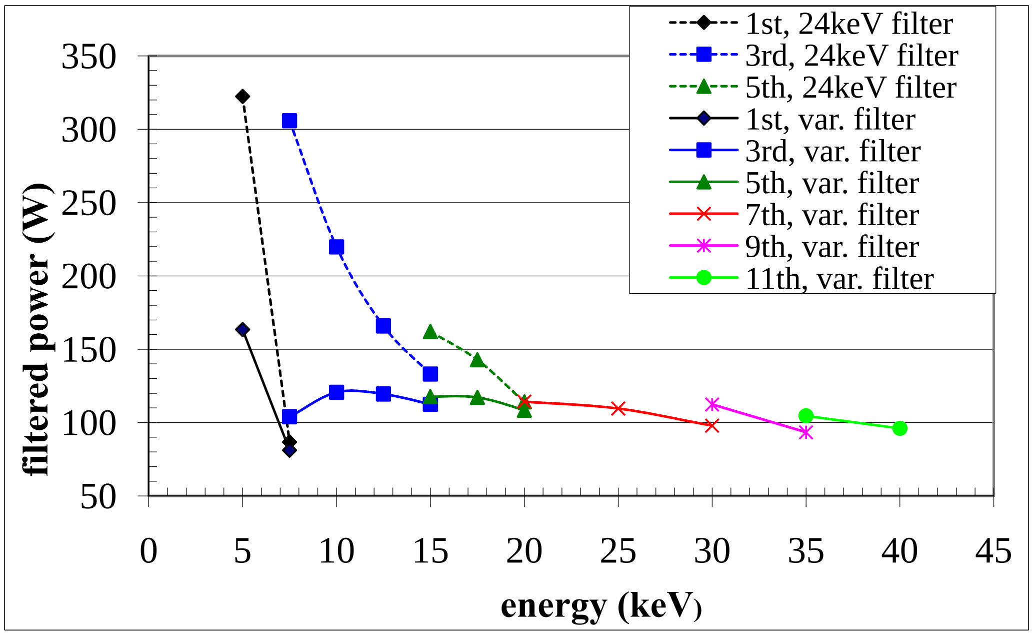




PEP-X BL Example
Variable Cut Off Mirror System

500W power transmitted by 30urad x 30urad pinhole and 24keV cutoff mirror exceeds acceptable mono power loading without significant emittance degradation.

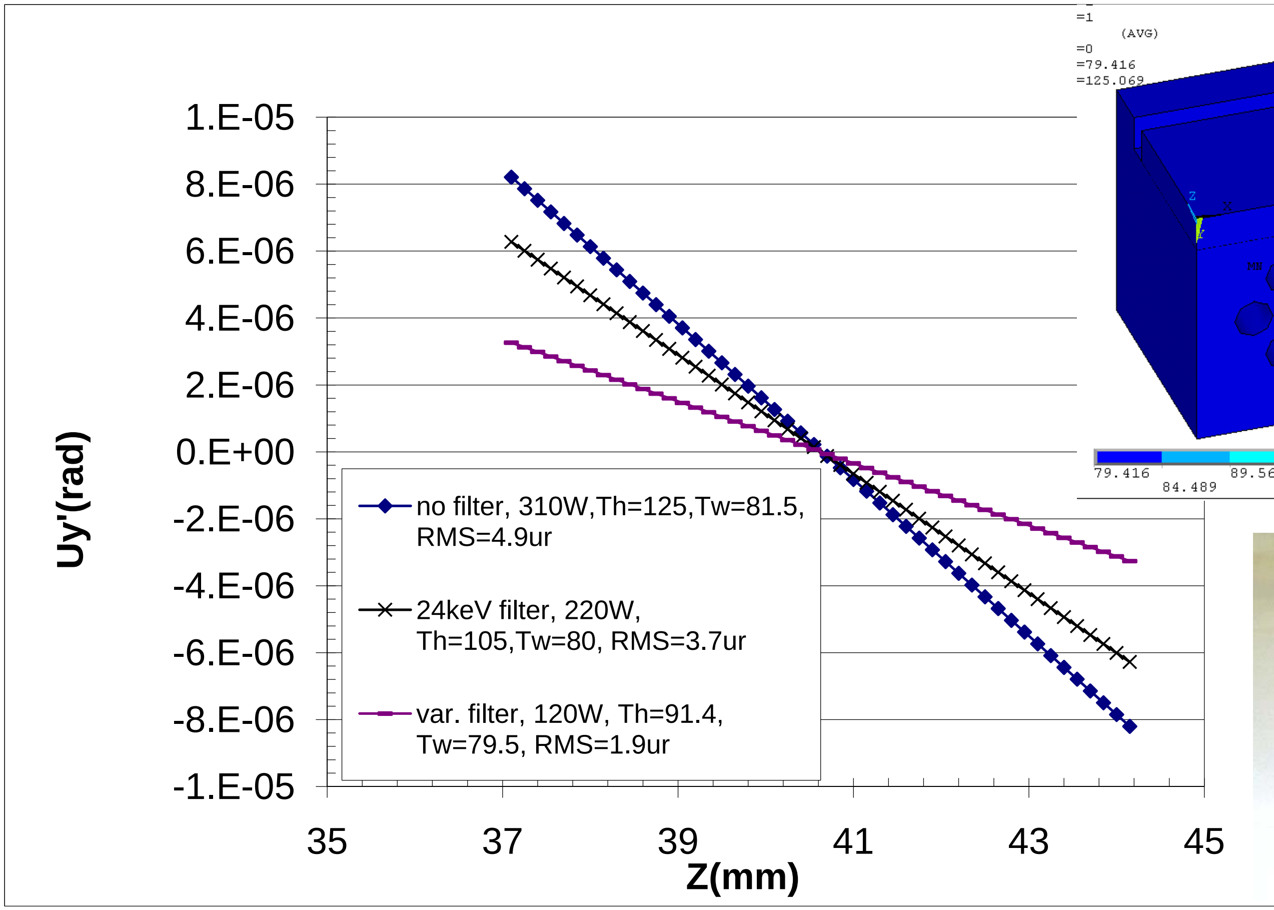
Replace fixed aperture and cut off mirror with 3σ_x' by 3σ_y' variable aperture and anti-parallel pair of mirrors allowing for variable cut off and more effective power filtering.

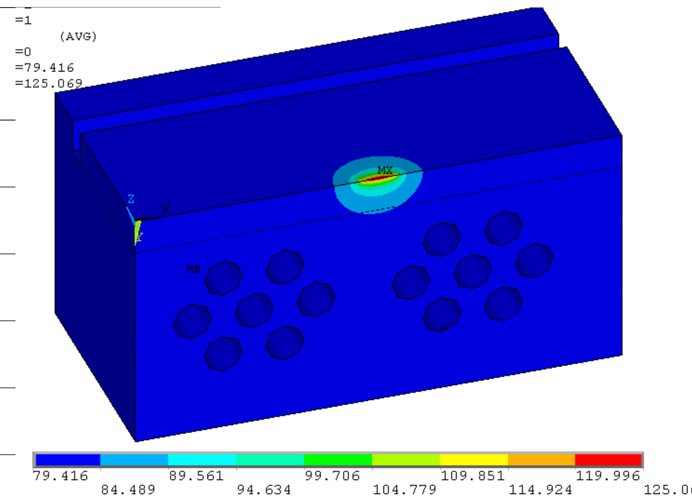


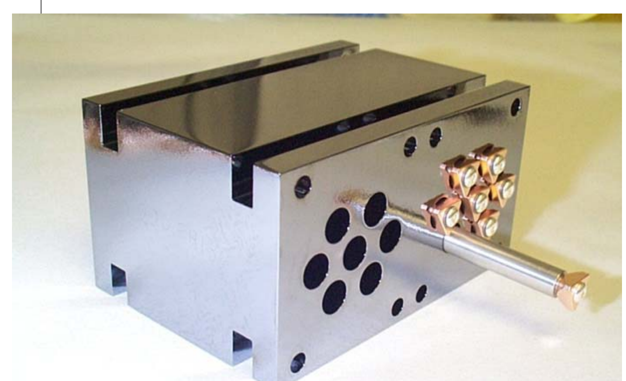
PEP-X BL Example
LN-Cooled Mono Performance

SSRL

Use FEA to examine thermal deformation of internally LN-cooled Si(111) at 10keV for various power filter configurations (A. Ringwall).



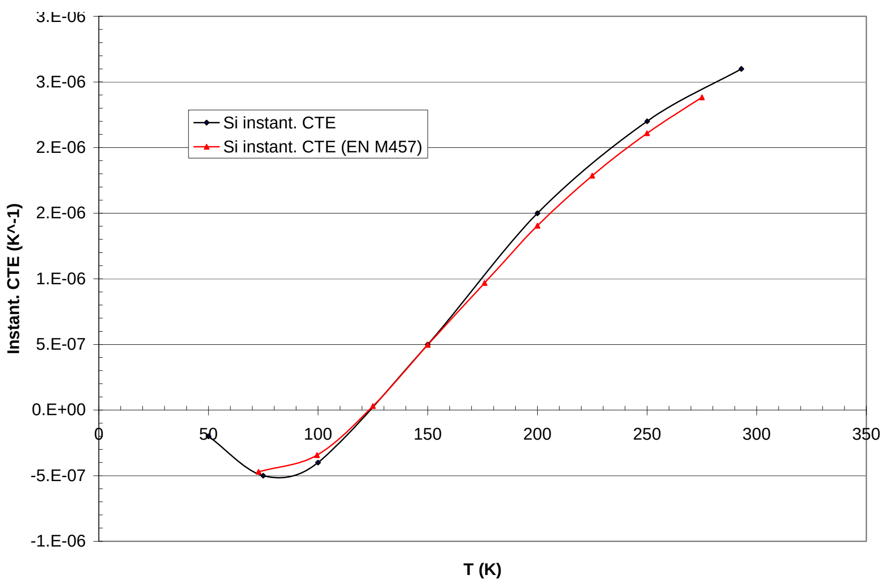


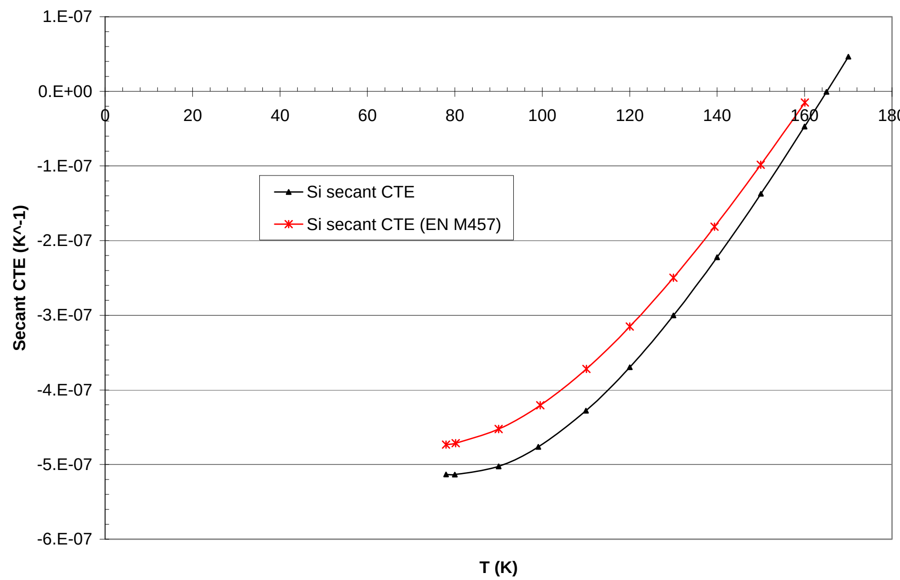


PEP-X BL Example
LN-Cooled Mono Performance

Can we improve LN-cooled Si mono performance?

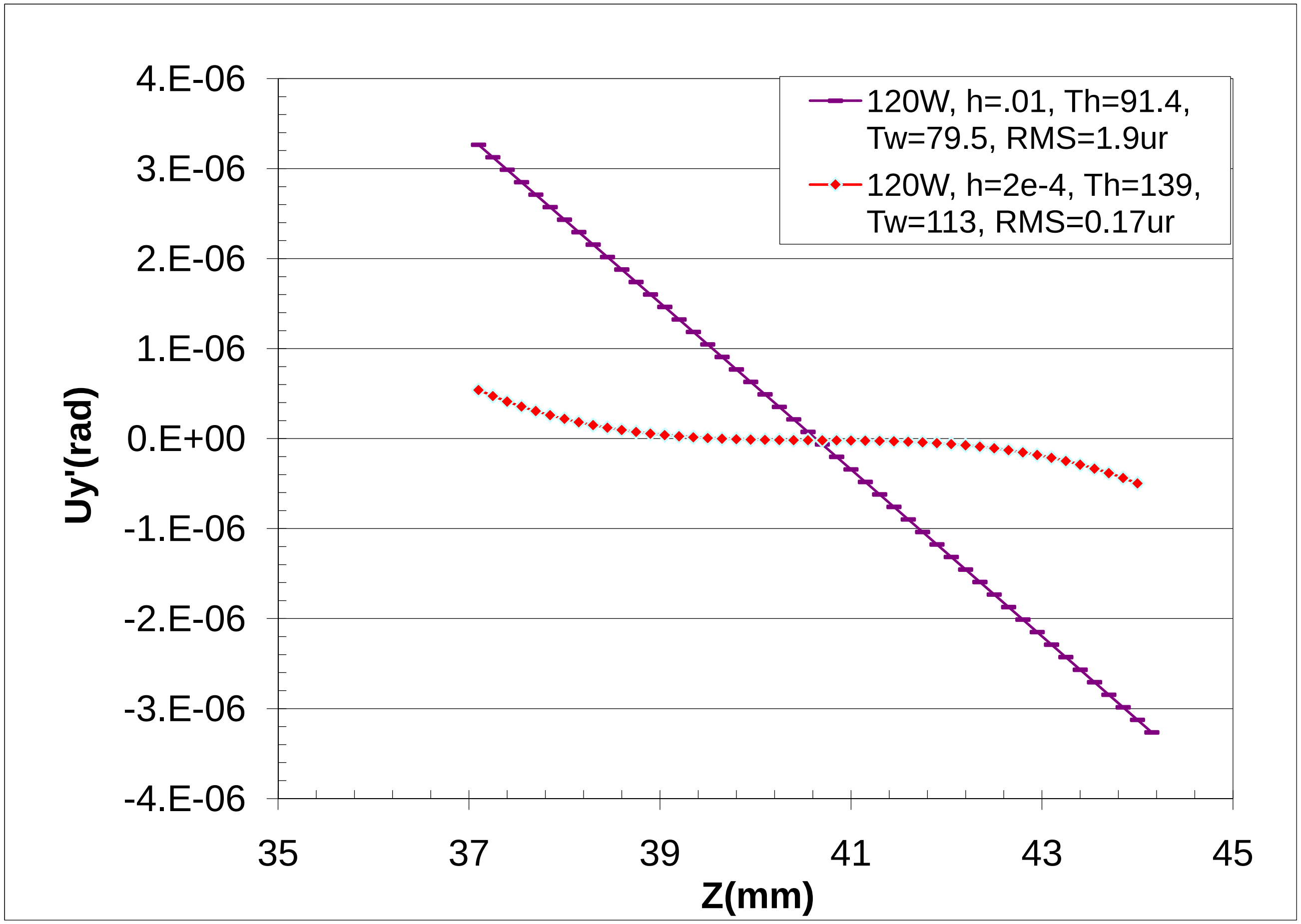
As noted by Zhang, et al (J. Synch. Rad. 10, p313, 2003) operating the mono closer to the zero of Si thermal expansion provides better thermal performance.





PEP-X BL Example
LN-Cooled Mono Performance

Reduce the wet wall heat transfer coefficient to operate the mono crystal at elevated temperature (i.e., reduce LN flow)… 1.9μr → 0.17μr rms!



A. Ringwall

Mono Performance Enhancement Strategies

Cryogenically-cooled Si monochromators:

- ***LN-cooling with servo loop feedback on crystal surface temperature … LN pressure ~20bar to avoid boiling at wet wall in example shown***
- ***employ alternative cryogen such as Ar (87K at 1bar), methane (!, 111K at 1bar), Kr ($, 120K at 1bar)***
- ***utilize crystal geometry (e.g., thin crystal with carefully modeled heat sink to LN) to reduce thermal strain in diffraction volume***

Employ alternative materials such as diamond, etc

Mirror Degradation of Beam Emittance

Let's return to the filter mirror(s) and consider their impact on the beam emittance/coherence…

What specifications will vendors bid (and deliver!) today? Experience with ion beam milling/profiling has moved vendor comfort zone for mirror specification at least 2x in the past few years. Based on recent LCLS/LUSI experience, vendors with ion beam milling technology are willing to bid a specification with 0.25µrad rms slope error and 1nm rms height deviation (i.e., shorter wavelength deviations from ideal figure).

- ***For the example used earlier, two anti-parallel mirrors with uncorrelated 0.25µrad rms figure errors would degrade the 0.14nmrad horizontal emittance about 2x.***
- ***1nm rms short wavelength height deviations creates wavefront variations of ~0.08λ rms (λ=0.1nm, 2.7mrad mirror angle) which results in ~20% intensity loss at focus.***

Metrology needs to keep pace with polish technology to ensure continued improvement. For example, V. Yaschuk (LBNL) is presently organizing a national consortium to develop the next generation Long Trace Profiler.

Mirror Pointing Stability

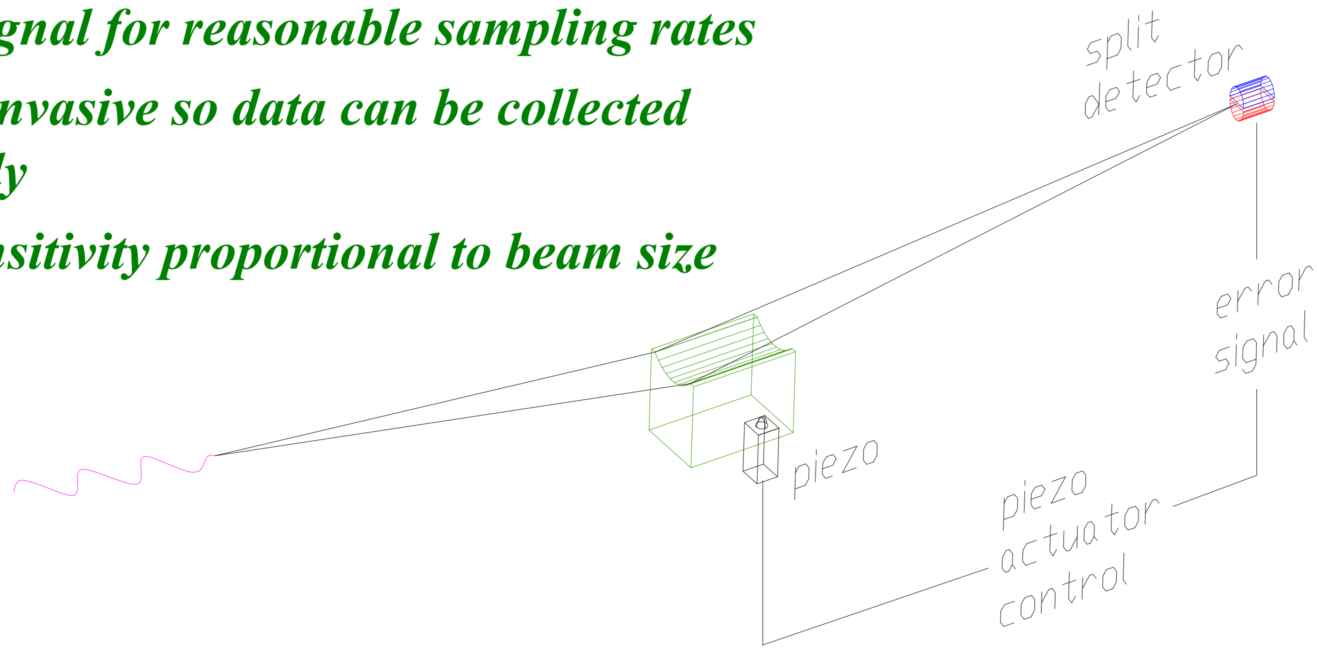
Set the stage…

- ***0.01µm (~0.02µrad) differential motion of a mirror support with a 50m throw from the mirror to focus will translate the beam ~2µm.***
- ***0.01µm differential motion is obtained from a 0.1ºC temperature change acting on a mirror support structure where 20mm of carbon steel in one leg is substituted with stainless steel.***

Mirror Pointing Feedback

Servo loop control of mirror pointing is conceptually trivial. The trick is the photon position sensitive detector …

- ***reliable and stable measurement of beam center of mass independent of beam energy, polarization, etc.***
- ***adequate signal for reasonable sampling rates***
- ***minimally invasive so data can be collected concurrently***
- ***position sensitivity proportional to beam size***

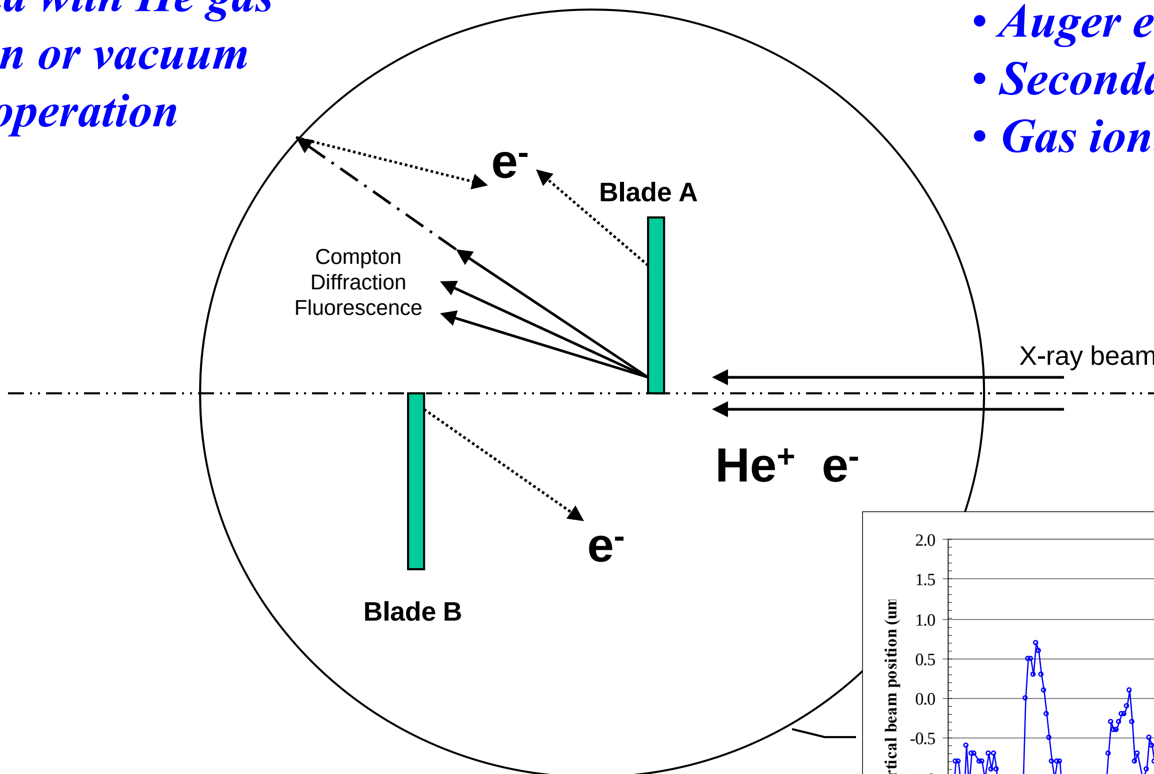


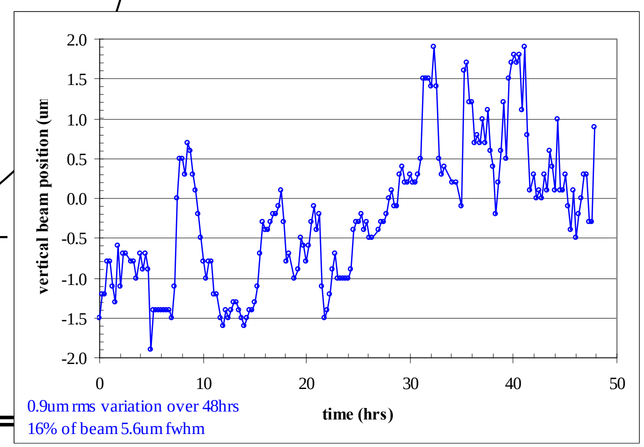
Mirror Pointing Feedback
Electron Yield Detection

- ***Be blades with Ti/Al coatings***
- ***electron yield with He gas amplification or vacuum compatible operation***

Electron Processes

- ***Photoelectrons***
- ***Auger electrons***
- ***Secondary electrons***
- ***Gas ionization***





D. Van Campen, et al