High-Energy X-Ray Optics Development at

SRI-CAT Sec. 1

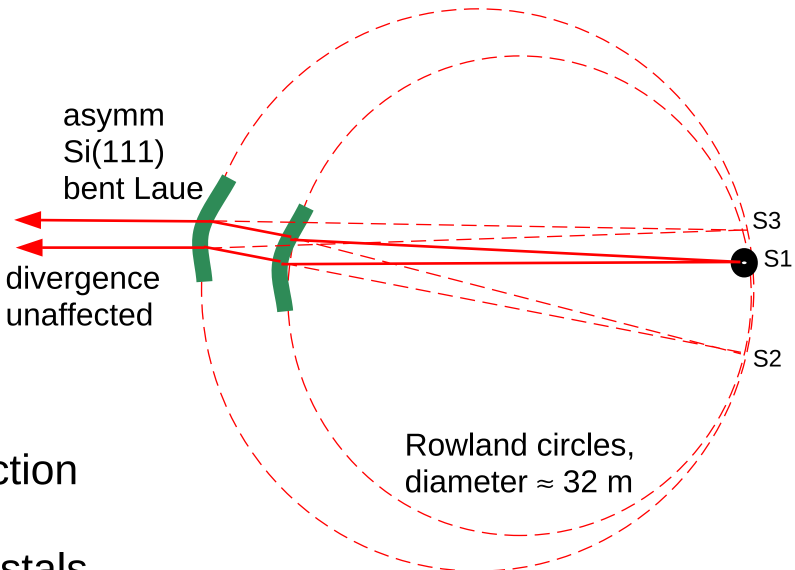
S. D. Shastri

X-Ray Physics Group
APS - XFD

- bent double-Laue monochromator (50 - 200 keV)
- high-resolution post-monochromatization with CRLs
  and flat crystals

Advanced Photon Source

Cryogenically-Cooled Bent Double-Laue Monochromator for High Energies (50 - 200 keV)



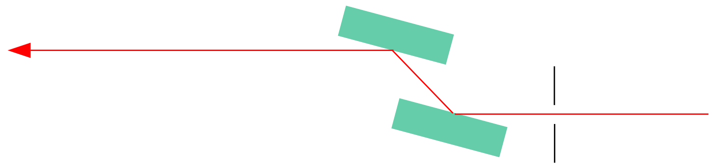
Properties:
- cryo-cooling, no filtration-induced flux sacrifice at closed ID gap
- high flux, e.g., $>10^{12}$ ph/s in 1x1mm aperture at 60 m at 80 keV
- brilliance preserving (unlike mosaic monochromators)
- fully tunable (unlike single-reflection schemes)
- in-line, fixed exit (unlike single-reflection schemes)
- over 10 times more flux than flat crystals, but **without increased energy spread** ($\Delta E/E=10^{-3}$)

Need for Higher Energy Resolution

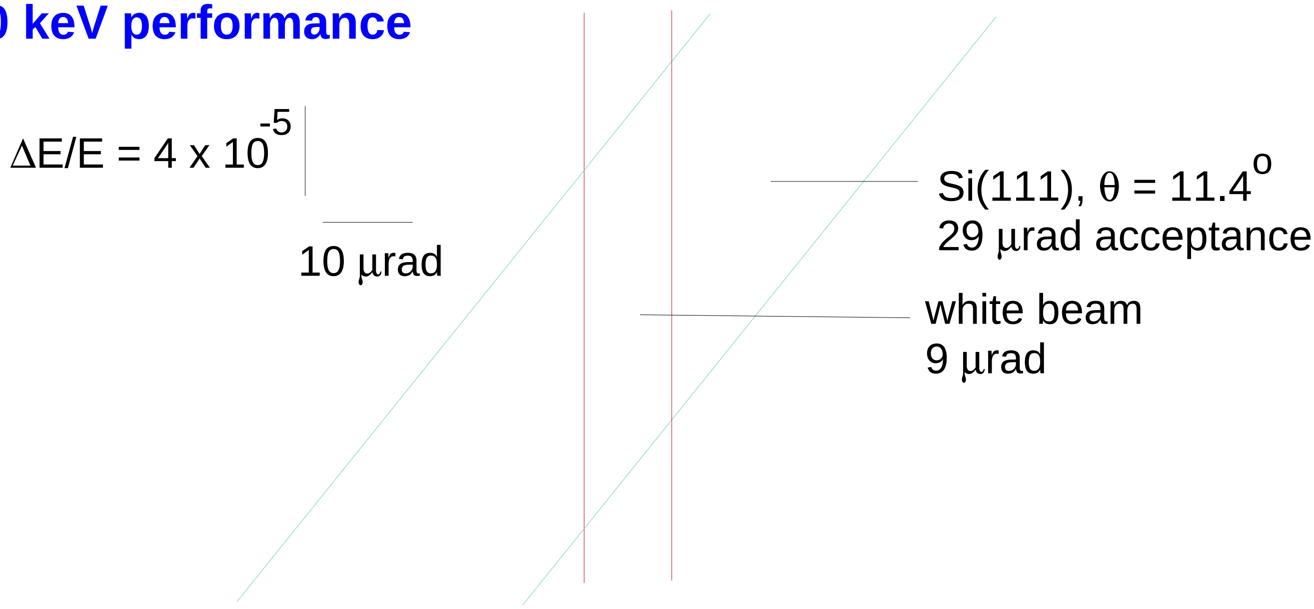
Modest resolution of above scheme is sufficient for numerous high-energy x-ray applications:
- powder diffraction
- stress/strain determination
- fluorescence
- pair distribution function measurements

However, a narrower energy window ($\Delta E/E=10^{-4}$ or better) would benefit:
- high-resolution powder diffraction and stress/strain measurements (i.e., lineshape analysis)
- anomalous scattering
- excitation of nuclear resonances (e.g., nuclear lighthouse effect)
- high-resolution spectroscopy (e.g., Compton scattering, atomic physics)
- improved stability (in post-monochromatization approach)

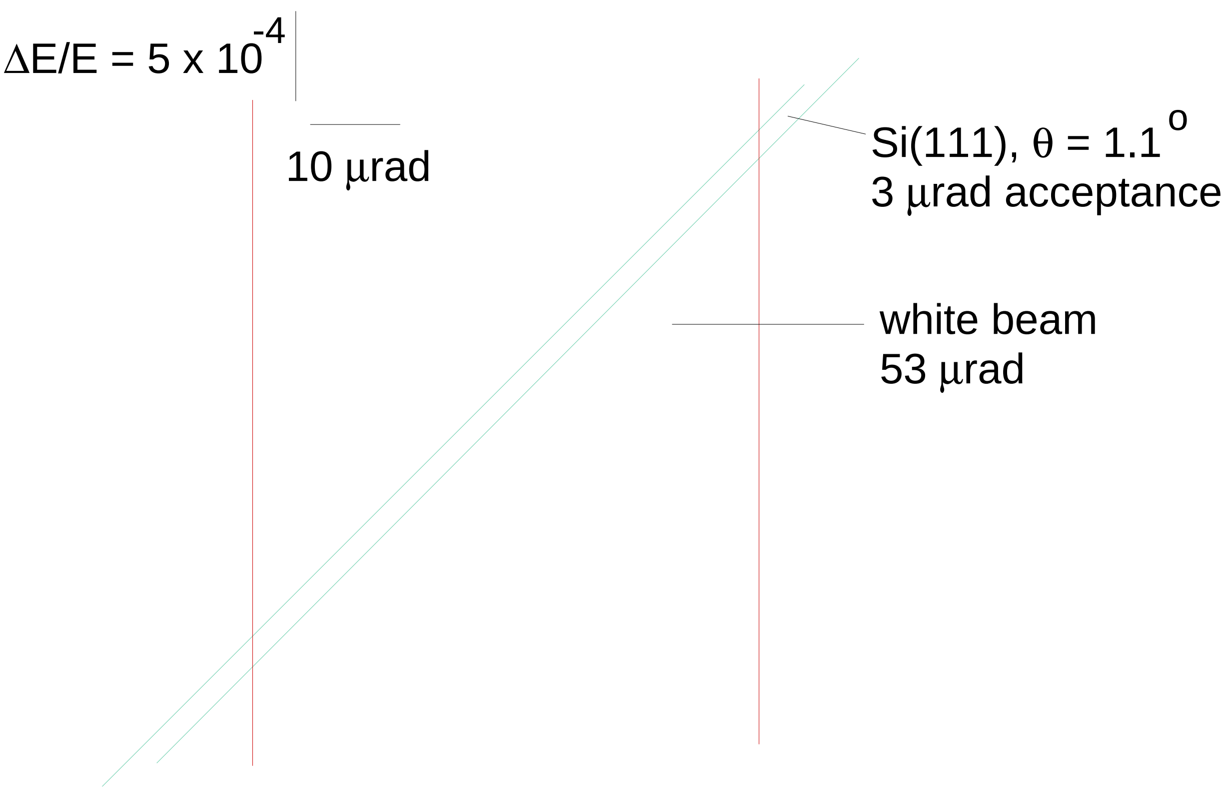
Flat, Perfect Si(111) Monochromator in APS Undulator A Beam



10 keV performance

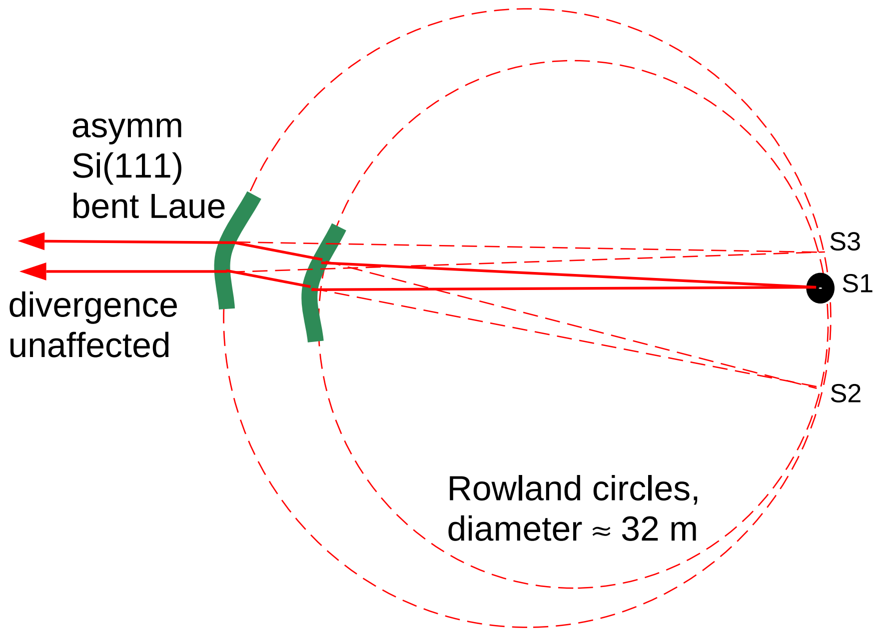


100 keV performance

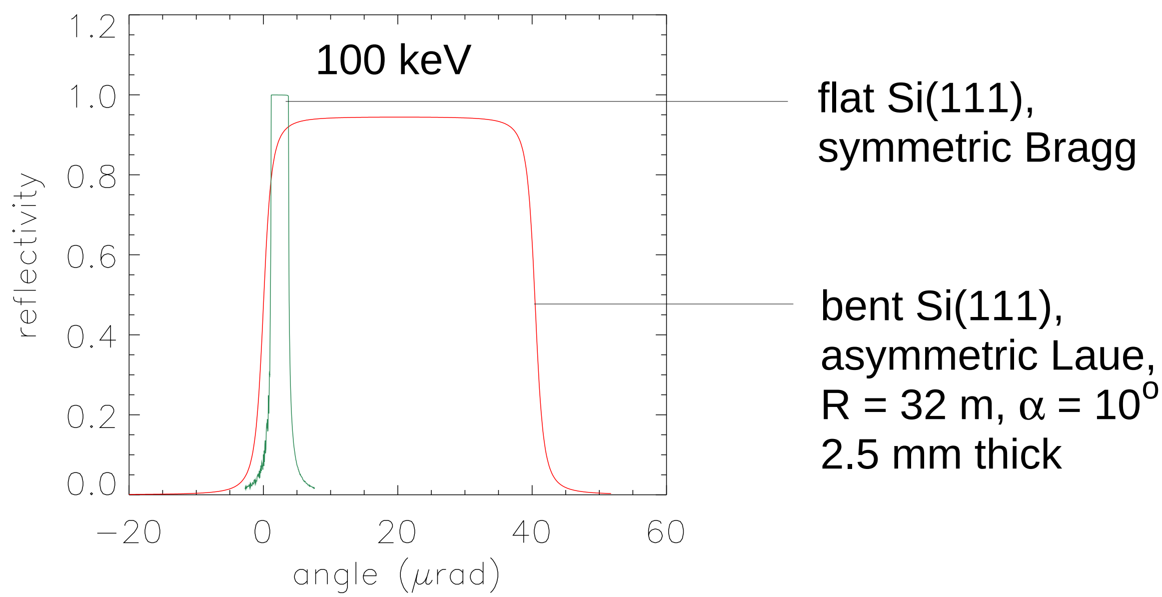


Bent Double-Laue Monochromator for High Energies

Geometry



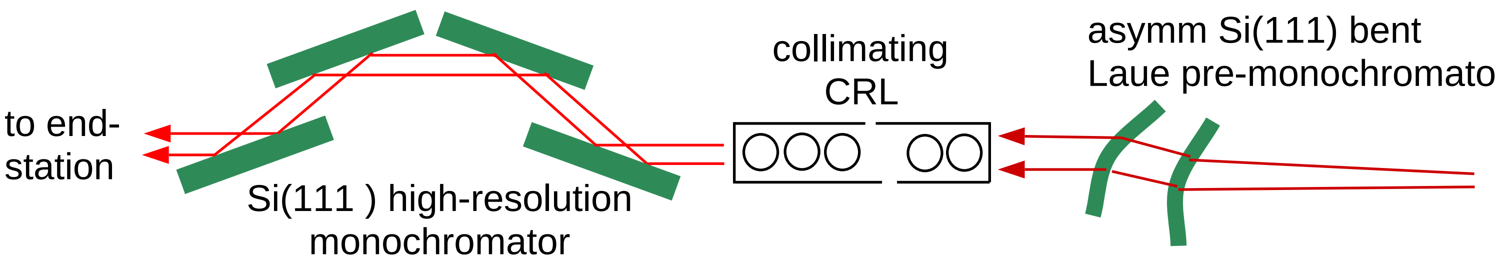
Over 10 Times Flux, but Energy Width Unchanged



$$\Delta E/E = \cot\theta \sqrt{\Delta\Theta_{inc}^2 + \Delta\Theta_{acc}^2}$$

- $\Delta E/E$: 2.5×10^{-3} → 2.0×10^{-3}
- $\Delta\Theta_{inc}$: 53 μrad → 1.6 μrad
- $\Delta\Theta_{acc}$: 2.8 μrad → 40 μrad

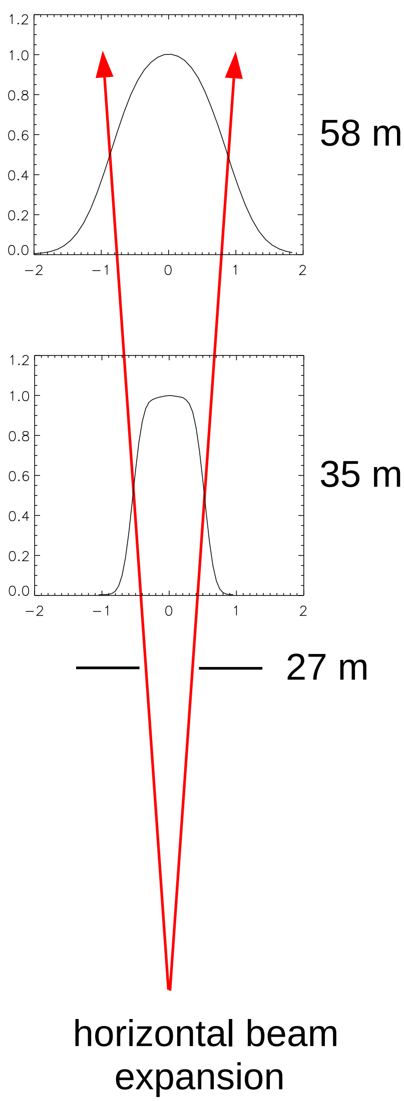
Post-Monochromatization Approach for Higher Energy Resolution: Using Compound Refractive Lenses (CRLs) and Flat Crystals



Why not:
- alter Laue premono parameters?
- or use flat crystal mono and slit down?
- or use flat crystal mono and CRL in white beam?

Is the Pre-Mono Really Brilliance-Preserving ? A Simple Test

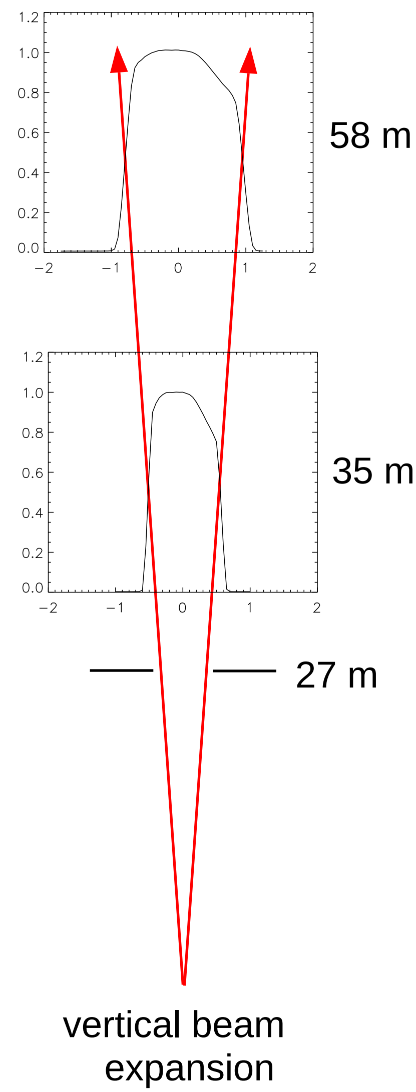
Mono set to 81 keV, location 32 m



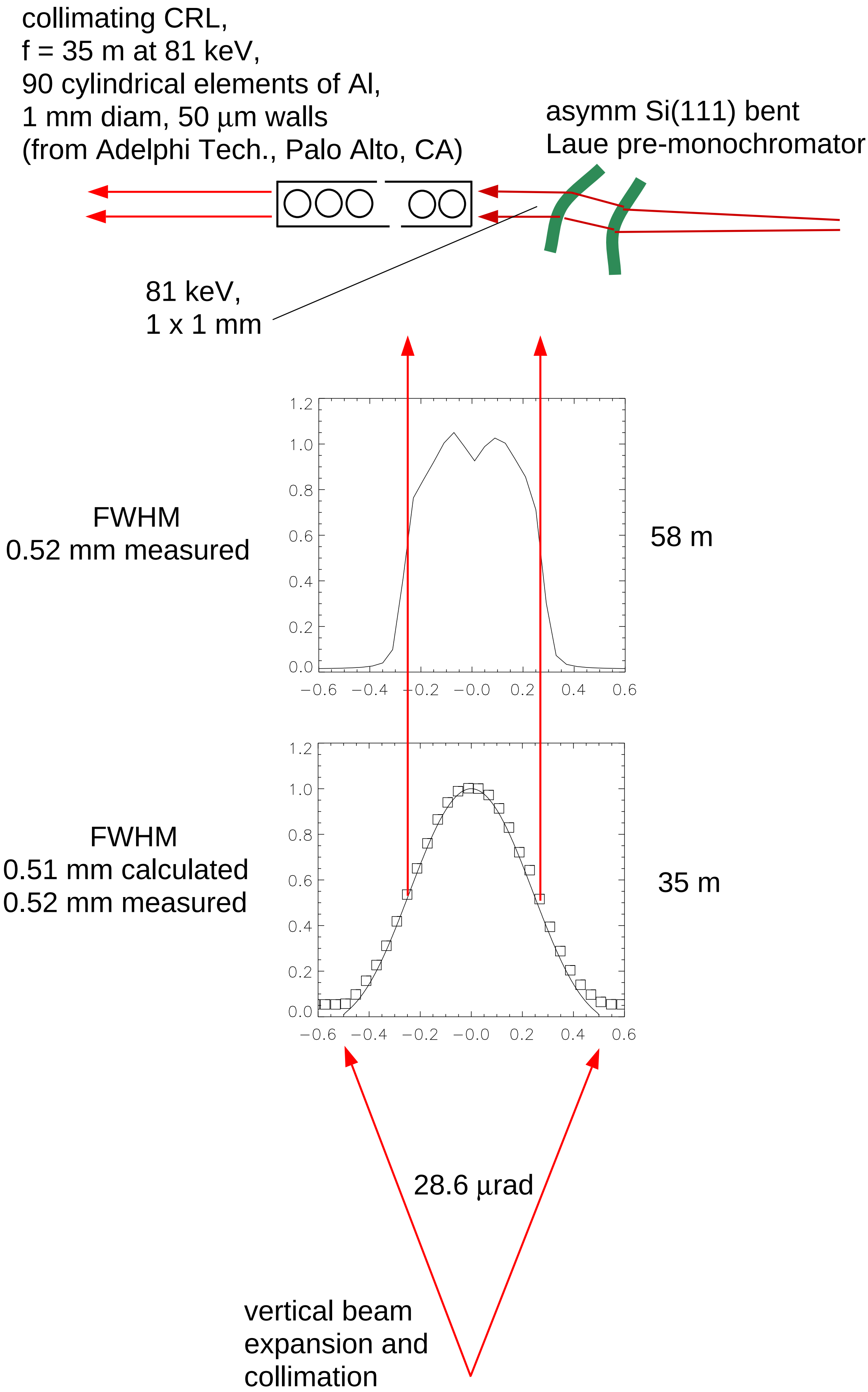
FWHM
1.72 x 1.72 mm calculated
1.74 x 1.72 mm measured

FWHM
1.04 x 1.04 mm calculated
1.06 x 1.07 mm measured

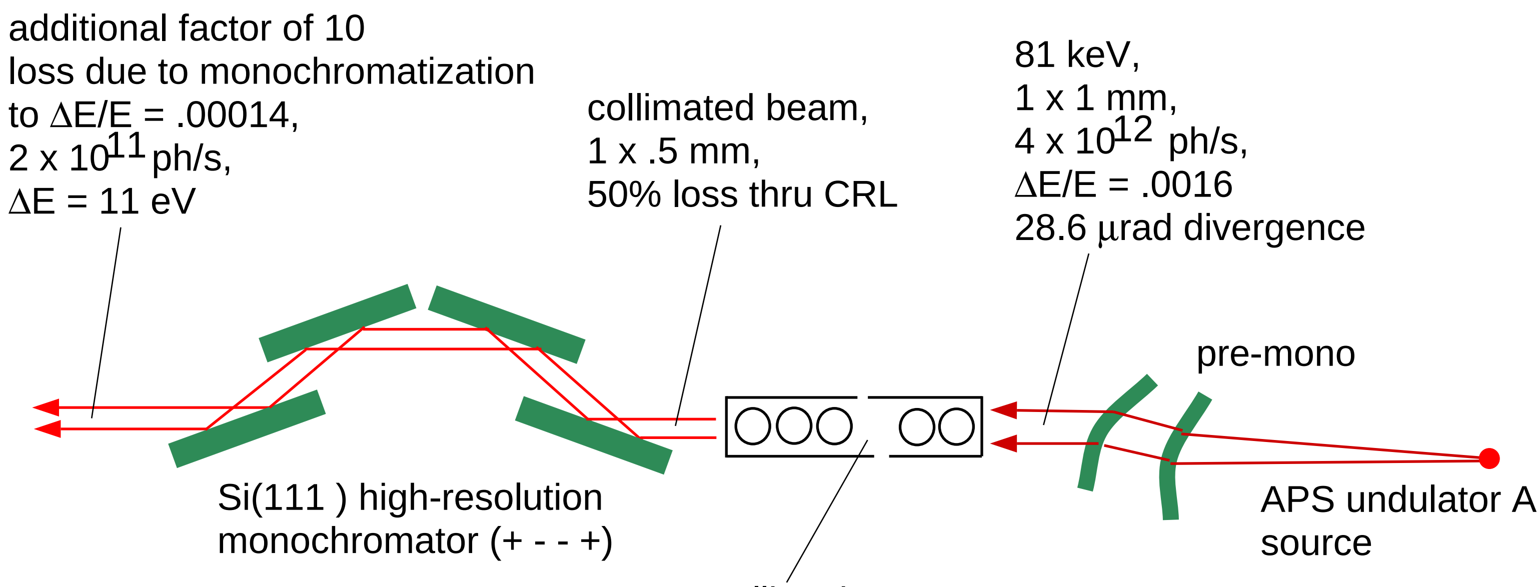
white beam slits
0.8 x 0.8 mm



Is the CRL Collimating ?



Setup and Expected Performance



$$\frac{\text{flux (high-res mono)}}{\text{flux (pre-mono)}} = 1 / 23$$

$$\frac{\text{flux out (CRL in)}}{\text{flux out (CRL out)}} = 8.3$$

source-to-CRL distance: 35 m

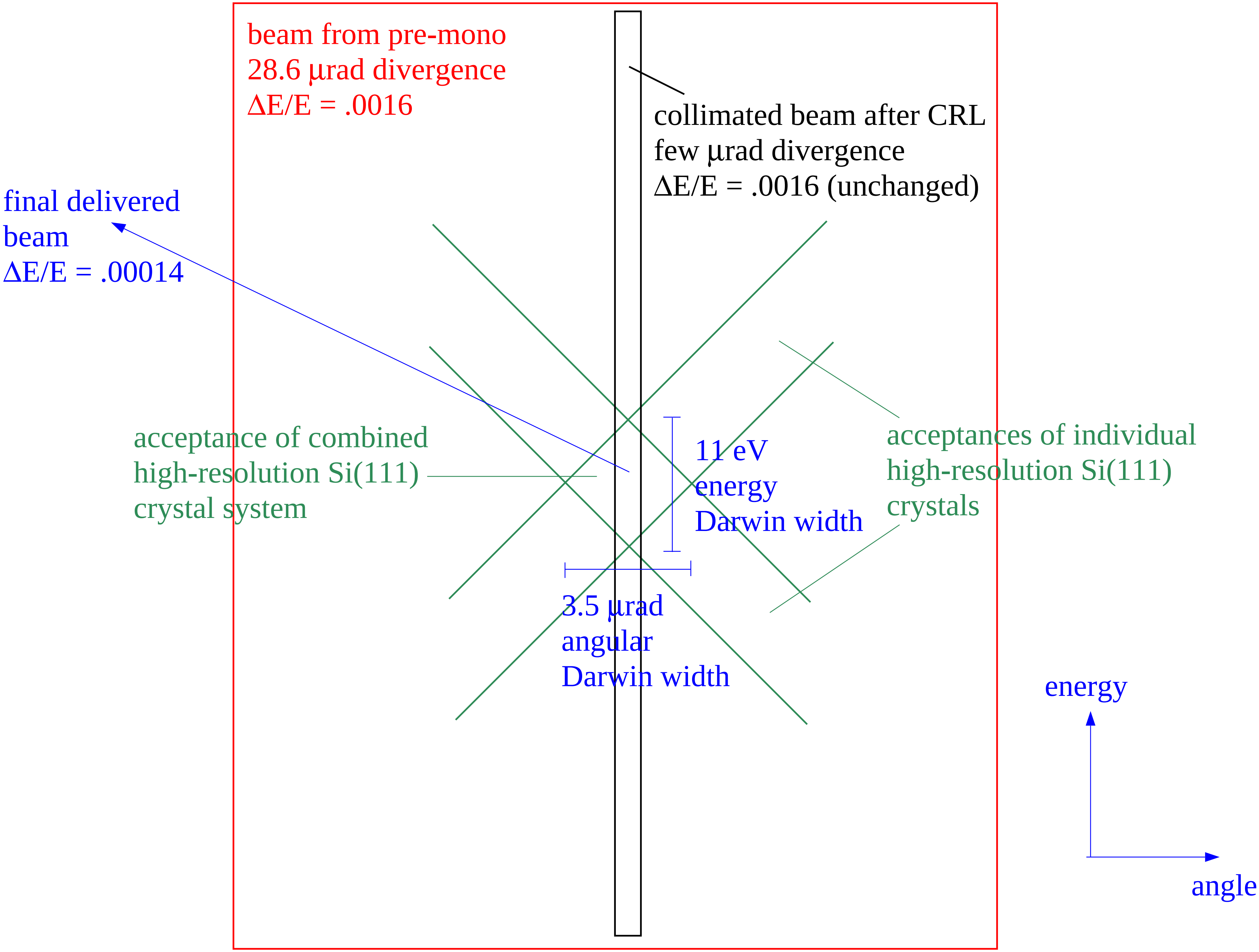
Measured Performance

$$\frac{\text{Flux (high-res mono)}}{\text{Flux (pre-mono)}} = 1 / 52 \quad \text{(discrepancy factor 2.3)}$$

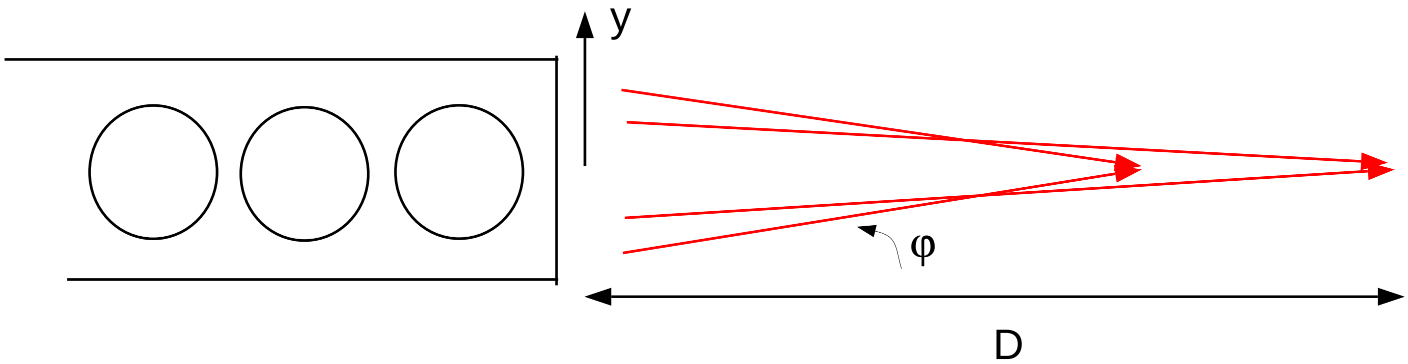
$$\frac{\text{flux out (CRL in)}}{\text{flux out (CRL out)}} = 4.0 \quad \text{(discrepancy factor 2.1)}$$

$\Delta E = 7$ eV

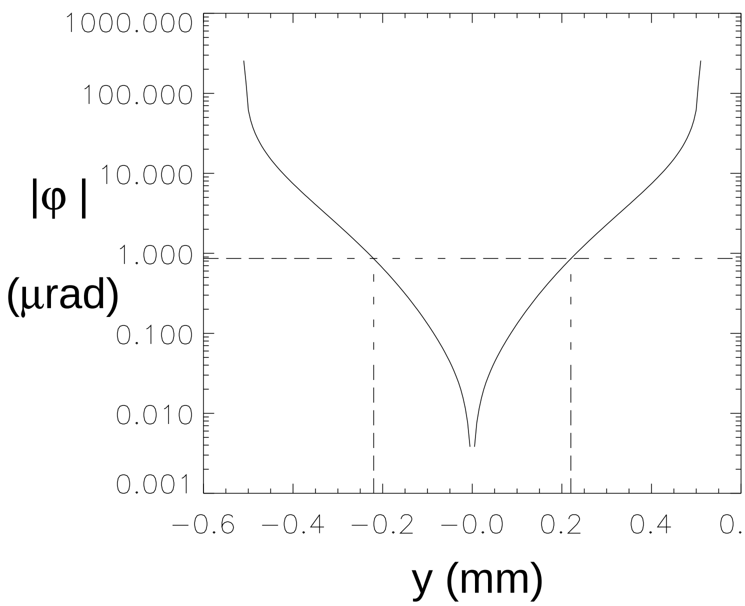
DuMond Representation of Optics (to scale)

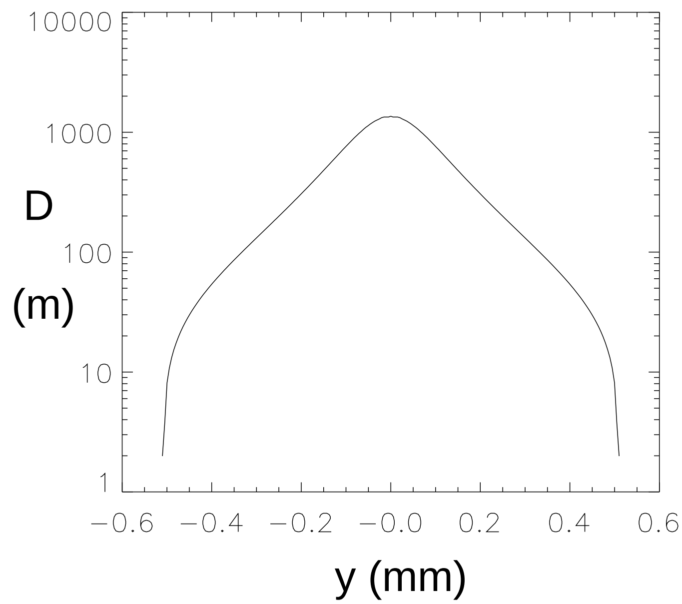


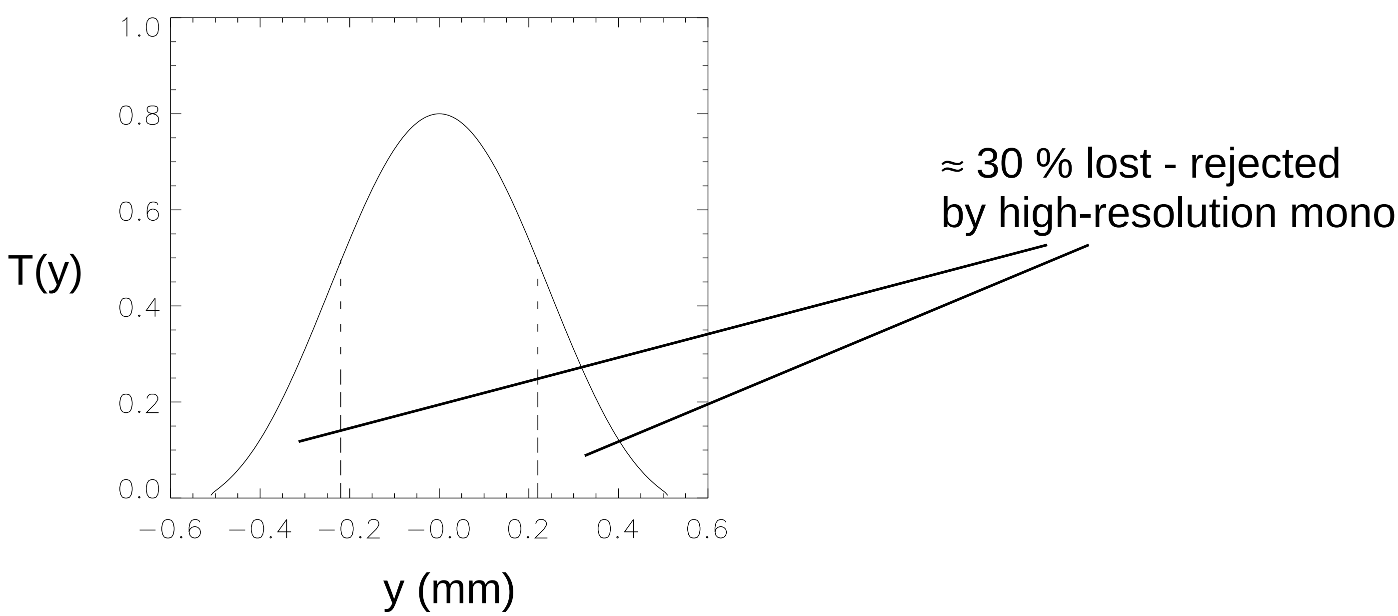
Influence of Cylindrical Aberrations on Collimation



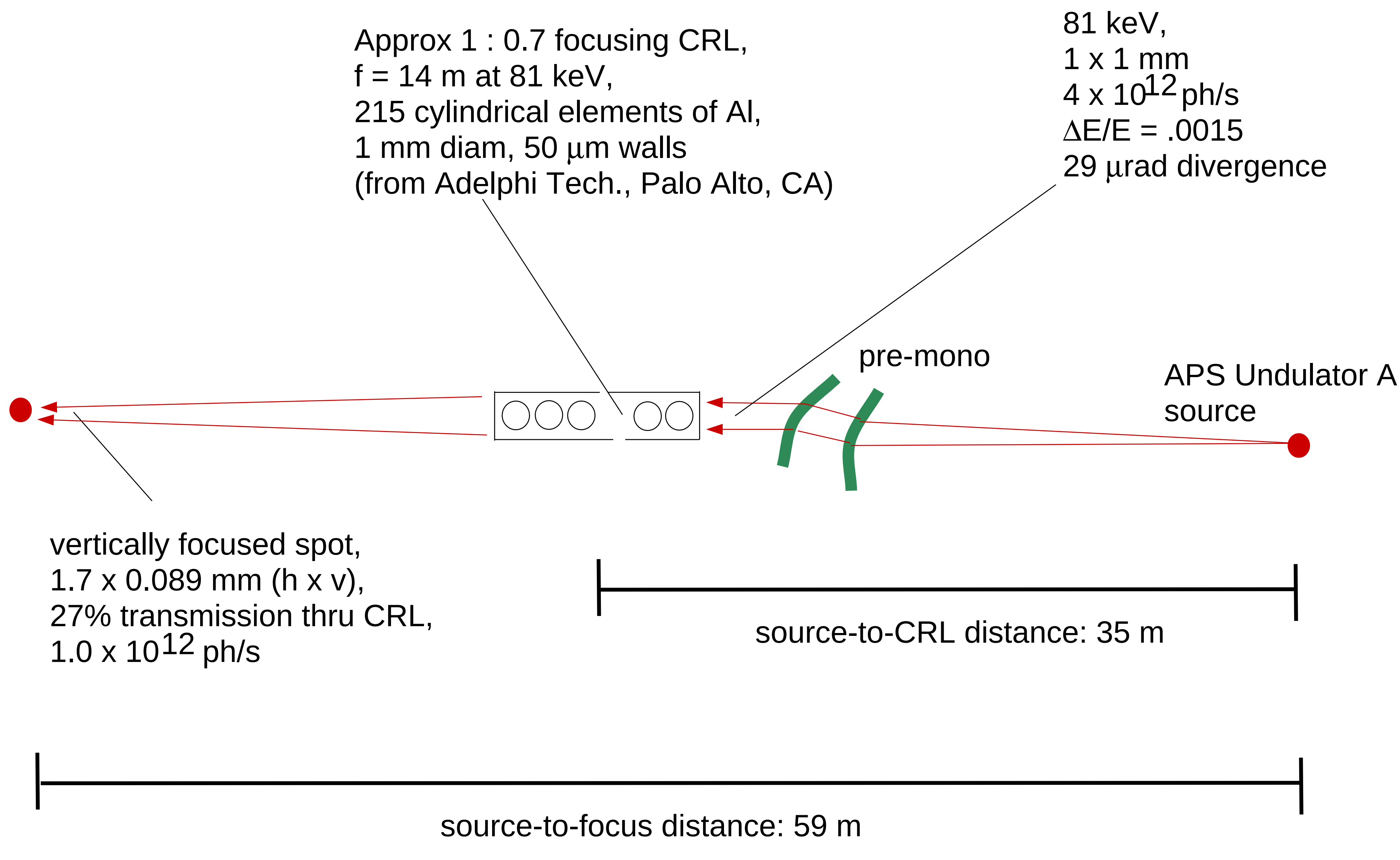
90 elements, diam=1.02 mm, 35 m from source



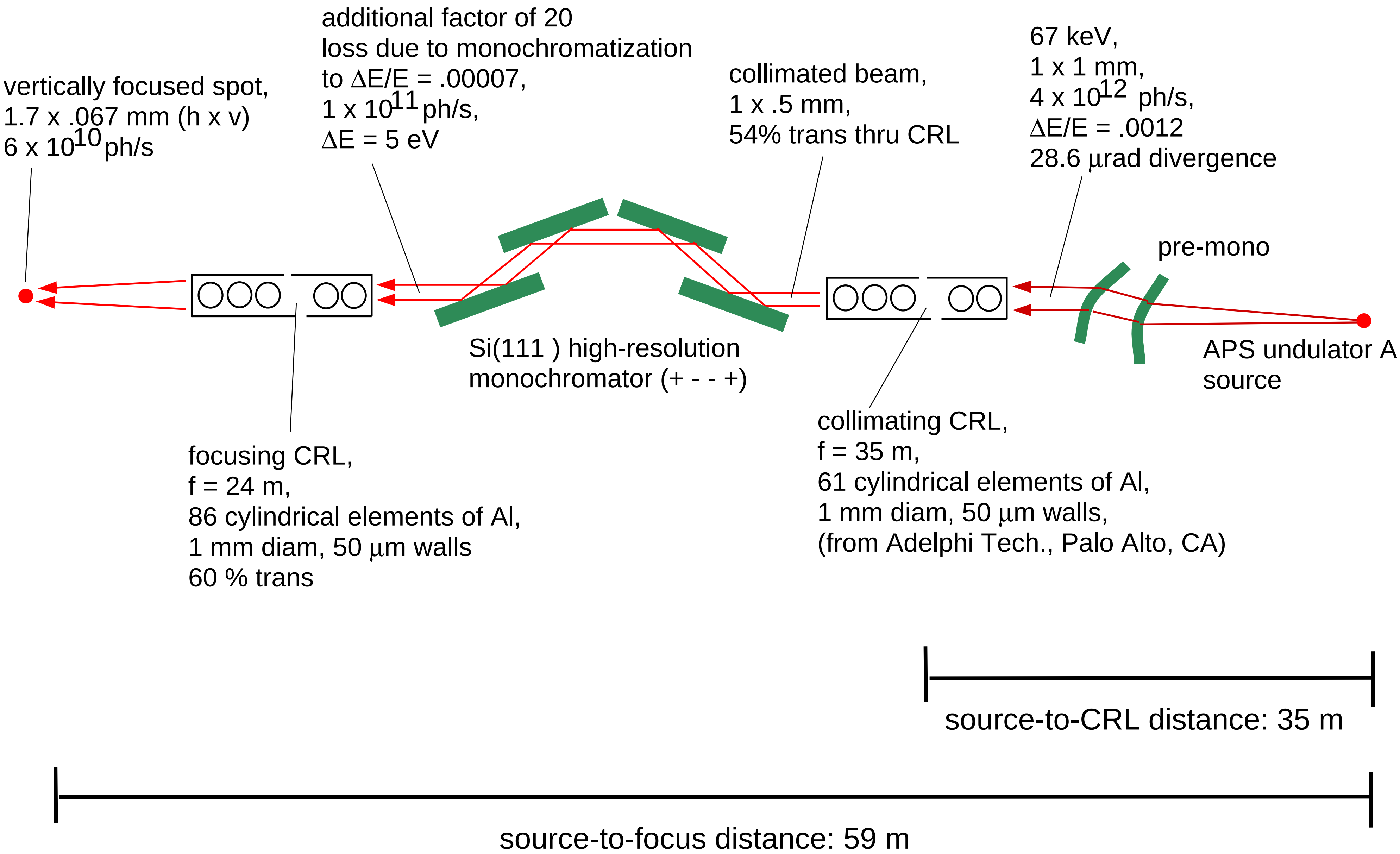




1 : 0.7 Focusing of 81 keV X-Rays

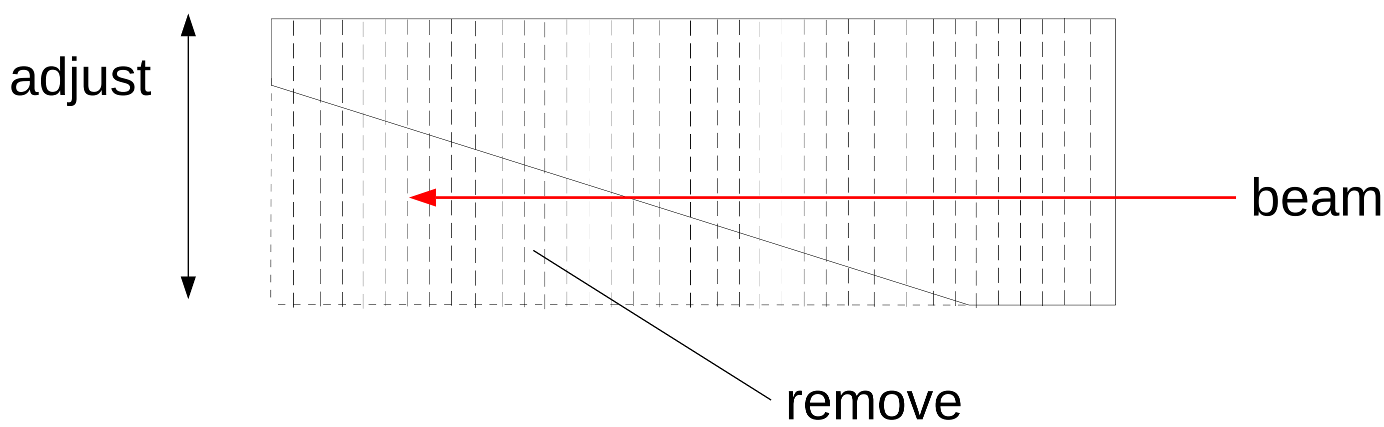


Combining All: Collimation, High Energy Resolution, Focusing at 67.4 keV



Improvements

- Eliminate cylindrical aberrations with parabolic CRLs.
- Optimize high-res mono (reflection order, asymmetries)
- For μrad control, need easily variable number of elements to compensate for unknowns:
  - CRL profile errors
  - distance uncertainties
  - refractive index (density, composition) uncertainty
  - pre-mono uncertainties
- A. Khounsary (APS-XFD) has developed a parabolic, variable focus lens using extrusion fabrication:



Acknowledgements

A. Mashayekhi - SRI-CAT Sec. 1, X-Ray Physics Group
R. Beguiristain - Aledphi Technology, Inc., Palo Alto, CA

Use of the APS is supported by US-DOE, BES, Office of Science, under Contract No. W-31-109-Eng-38.