A Novel Hybrid X-Ray Focusing Scheme

Bernhard W. Adams[1]

[1]Advanced Photon Source
Argonne National Laboratory

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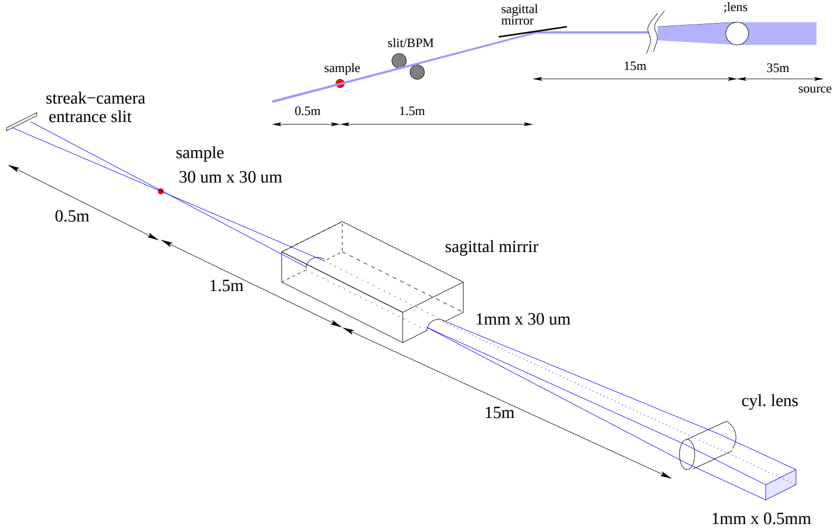
Overview



sagittal
mirror
;lens
slit/BPM
sample
15m
35m
source
0.5m
1.5m
streak−camera
entrance slit
sample
30 um x 30 um
0.5m
1.5m
sagittal mirrir
1mm x 30 um
15m
cyl. lens
1mm x 0.5mm

Why hybrid focusing

Constraints of streak-camera (SC) operation:

Entrance slit small in one dimension (25μm vertical)

larger in other dimension (3 mm horizontal)

laser focus at sample $\rightarrow$ tight focus at sample

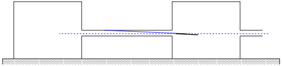
SC vacuum vessel and sample environment

$\rightarrow$ min. separation 50 cm

avoid broadening of diffraction rocking curves

long vertical focal length ($>$ 10m), short horizontal focal length

long-focal mirror challenging due to beam deflection $\rightarrow$ lens



short-focal lens absorbs strongly $\rightarrow$ mirror

also: lens does not suppress harmonics in this geometry

3 Main Components

X-ray lens with continuously variable focal length

to adjust focus onto sample and correct for dispersion in energy sca

long focal length $\rightarrow$ only 2 holes (3 walls)

can't vary number of holes $N \rightarrow N + 1$ for focal adjustment

Short sagittal mirror

focusing x-ray mirrors are typically expensive

not this one, vertical focus makes for short footprint

Slit and beam-position monitor/stabilizer

Variable Lens

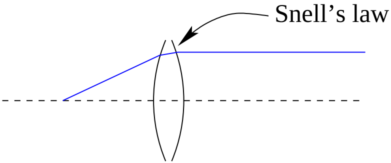
how does an x-ray lens work?

x-ray refractive index:

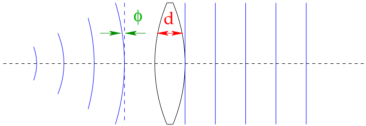
$$n = 1 - \frac{r_e \lambda^2 \rho}{4\pi}, \qquad r_e = 2.8 \cdot 10^{-15}\text{m}, \ \rho \text{ is electron density}$$

$n \approx 1 - 10^{-5}$, strong dispersion $\sim \lambda^2$

$$\varphi = (1 - n)d$$



ray optics



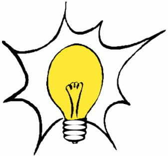
wave optics

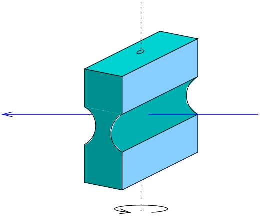
weak refraction → many (N) lenses (compound refractive lens)
vary f through choice of N

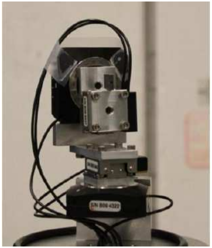
Variable Lens

Long focal length $\rightarrow$ small N, here $N = 2, 3$

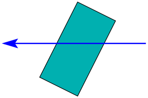
Steps $N \rightarrow N + 1$ are too coarse







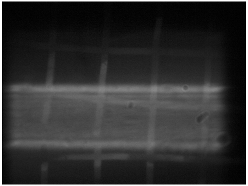
rotation scales all paths through material by same factor $1/\cos\chi$



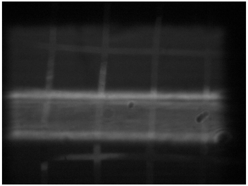
$\rightarrow$ continuous N

Variable Lens

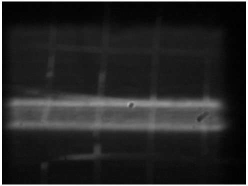
Example: 1-hole lens (2 walls), f=12 m at 5.465 keV (V K edge)



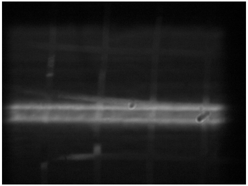
$\chi = 0°$



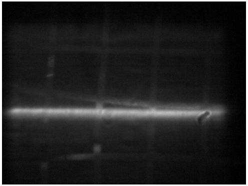
$\chi = 20°$



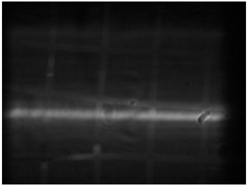
$\chi = 30°$



$\chi = 35°$



$\chi = 40°$



$\chi = 45°$

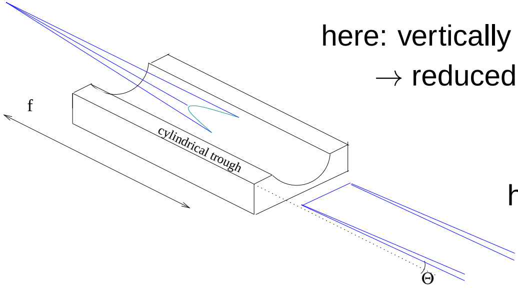
grid: 200lpi Ni mesh   vert focus 35 μm ($\sim$ 0.5 demagnified source)

Small Sagittal Mirror what is a sagittal mirror?

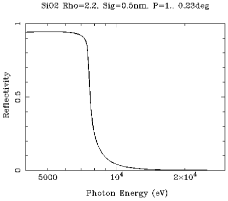
often: grazing incidence $\rightarrow$ long mirror - expensive

here: vertically small beam (focused)

$\rightarrow$ reduced mirror length



harmonic suppression:



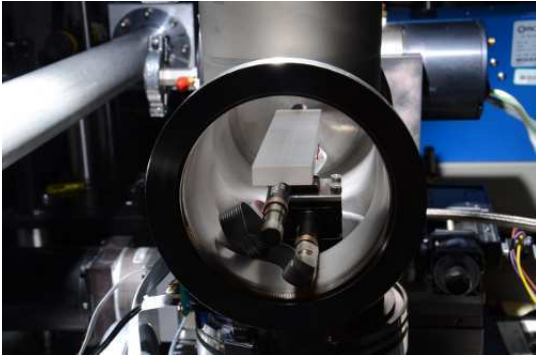
vary f through reflection angle Θ

Small Sagittal Mirror

first attempt: use a high-quality cylindrical lens from CVI laser

but still insufficient surface quality ($\lambda/4$, 20-10 scratch-dig))

then, got x-ray-polished part: 4mm ROC, 150 mm long, 4250 dollars

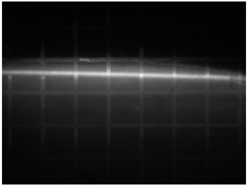


only 20..25 mm

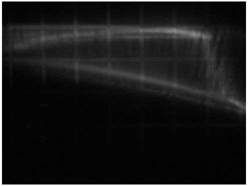
x-ray footprint

will cut in 3..5 pc.

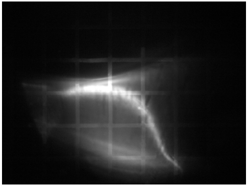
Small Sagittal Mirror



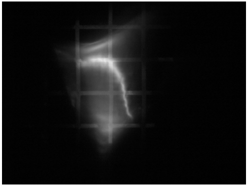
$\Theta = 0^\circ$



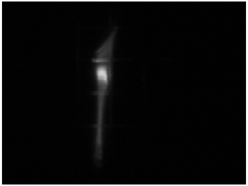
$\Theta = 0.05^\circ$



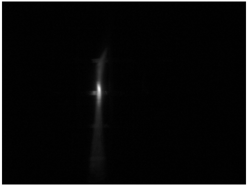
$\Theta = 0.15^\circ$



$\Theta = 0.2^\circ$



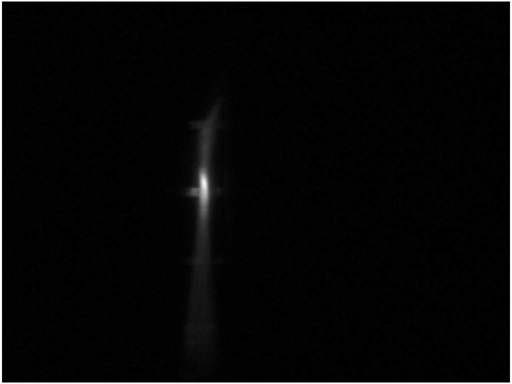
$\Theta = 0.225^\circ$



$\Theta = 0.23^\circ$

grid: 200lpi Ni mesh   focus: 70 μm V by 30 μm (H)

Small Sagittal Mirror



30μm (H) $\times$ 70 μm (V)

slit down to 30 $\times$ 30

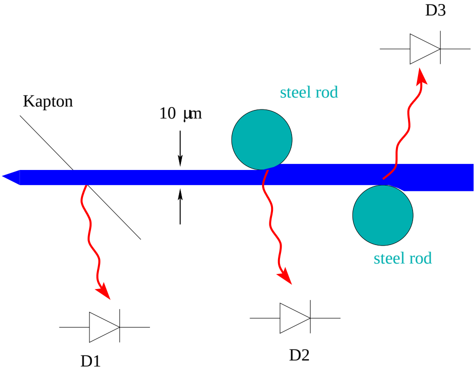
future improvement: aberration corrector (to be patented)

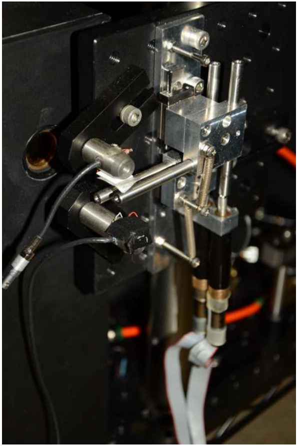
Beam-position Stabilizer (MOSTAB)

We need to keep the focus within 10% of its size, but

beamline BPM has μm resolution, but not long-term stability

High-resolution slit/BPM:





Beam-position Stabilizer (MOSTAB)

due to the slit, no off-target x-rays can reach the streak camera

Problems:

the beamline PID loop works only in a very limited range (in-slit)

solution: MOSTAB instead of simple PID loop

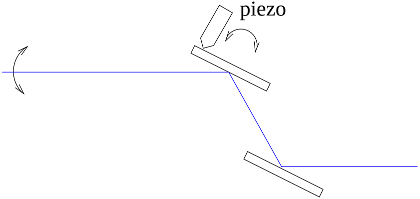
due to focusing optics, complicated position(piezo-V)

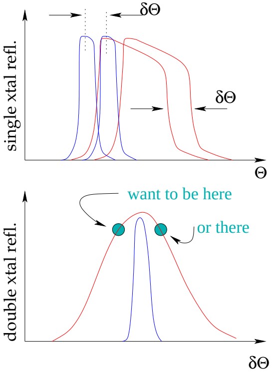
single-parameter feedback loop does not work well

multi-point beam stabilizer (future)

Monochromator

Double-crystal monochromators typically have a piezo on the 2nd crystal to adjust parallelity
motion of the piezo affects throughput and beam position





Often want to detune a bit to suppress harmonics

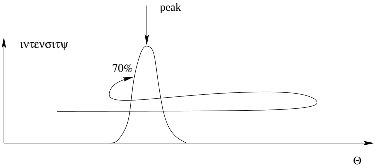
what is a MOSTAB

Monochromator Stabilizer

Feedback loop to maintain constant detuning or beam position

Scans monochromator piezo, then returns to:

- left shoulder of peak at typ. 70 %
- right shoulder of peak at typ. 70 %
- constant position



or, with more advanced programming . . .

- top of peak
- more complex criteria – this talk

MOSTAB

history

MOSTAB (Monochromator Stabilizer) originally developed at DESY

1. generation: all analog Materlik et al., NIM **219**, 430 (1984)

2. generation: digital, no longer available

`http://www.struck.de/dmostab.htm`

new MOSTAB (this talk)

up to 8 analog inputs (12 bit res.)

up to 4 analog outputs (12 bit res.)

up to 4 digital inputs, 4 outputs (counters, veto, gate, etc.)

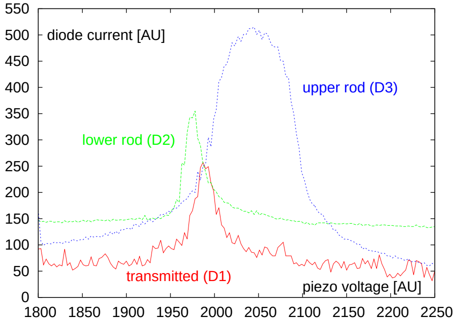
based on Propeller microcontroller and a few extra components

prototype cost ca. $ 150

program easy to modify

MOSTAB

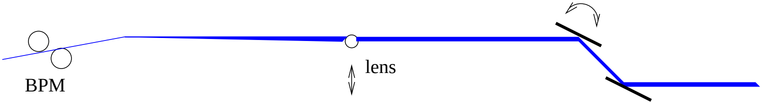
MOSTAB that scans for peak in 1 signal (transmitted, D1),
then stabilizes on on other signals (normalized rod signals, D3-D2)



scan piezo (DAC output), acquire 3 signals on ADC inputs (D1 .. D3)
find peak in transm. signal, rod signals at peak (d2, d3 to normalize
stabilize on D3/d3-D2/d2

MOSTAB

future extension: multipoint stabilizer



runs a program in the MOSTAB to control the monochromator piezo

and moves the lens to keep the monochromator tuned up

first tests Oct. 2012, use Dec. 2012

Summary

- Why long and short focal lengths
- why hybrid lens/mirror
- focusing to 30 by 70 microns (BPM slits to 30 by 30)
- slit/BPM and MOSTAB to keep beam on target