Design and Performance of GSECARS Large KB Focusing Optics

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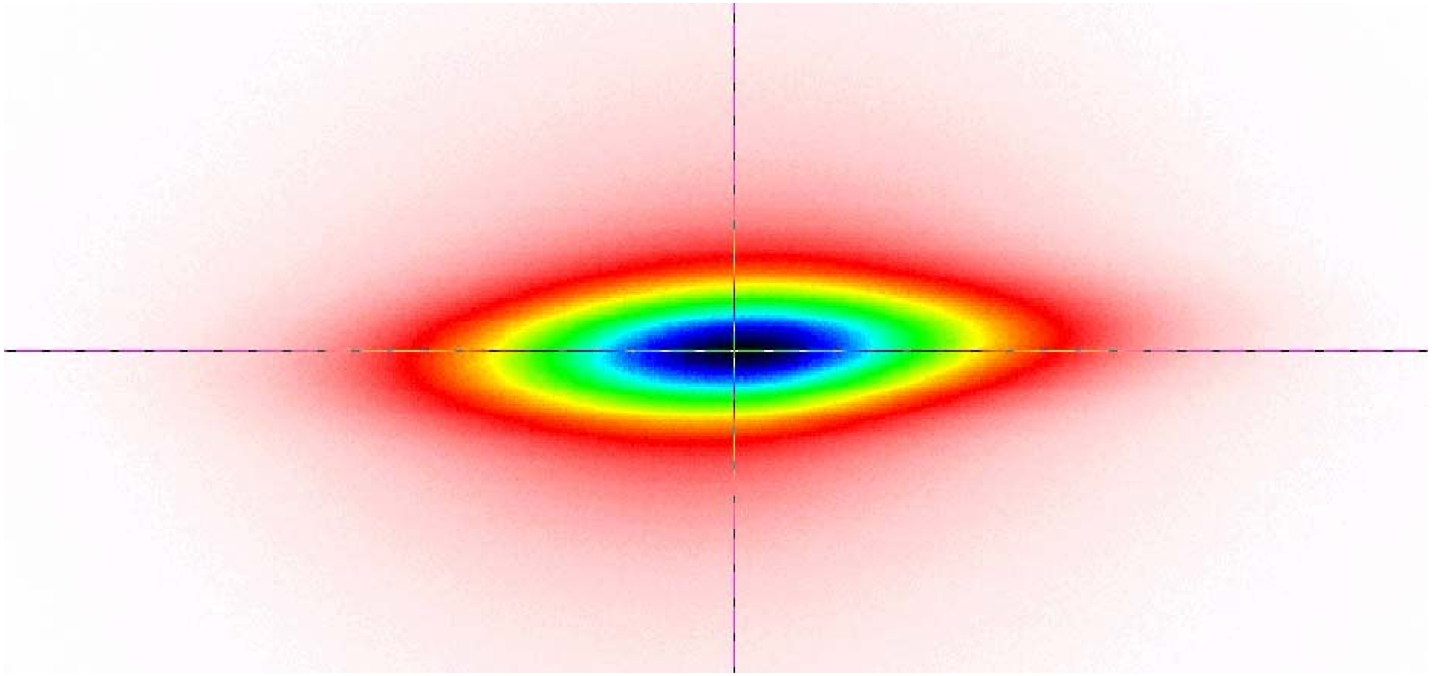
University of Chicago

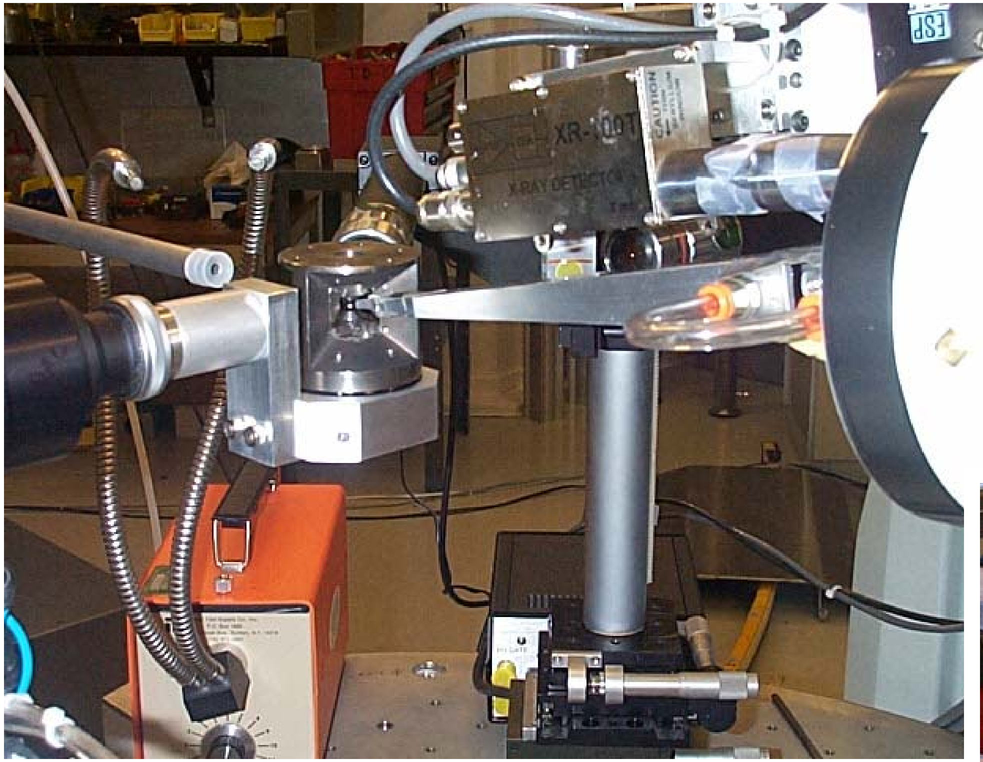


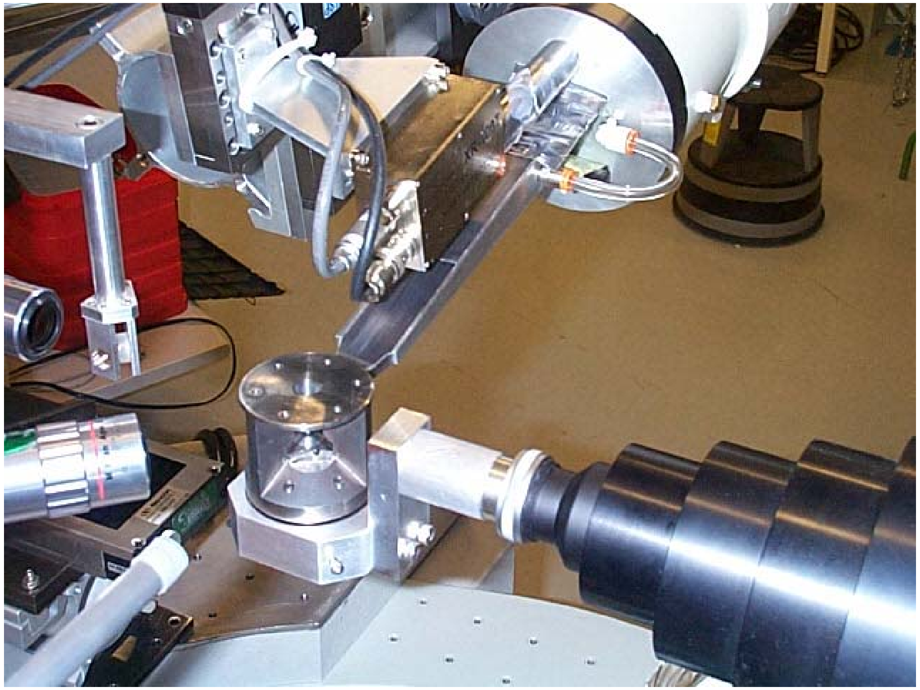
Introduction - Scientific Requirements

- Many earth science problems involve heterogeneous systems on length scales ranging from 500µm to 0.5µm.
- The high brilliance of the APS undulater allows us to strongly focus the beam while keep the divergence to levels acceptable to most of our measurements.
- Achromatic focusing needed to support spectroscopy, and multi wave length scattering experiments.

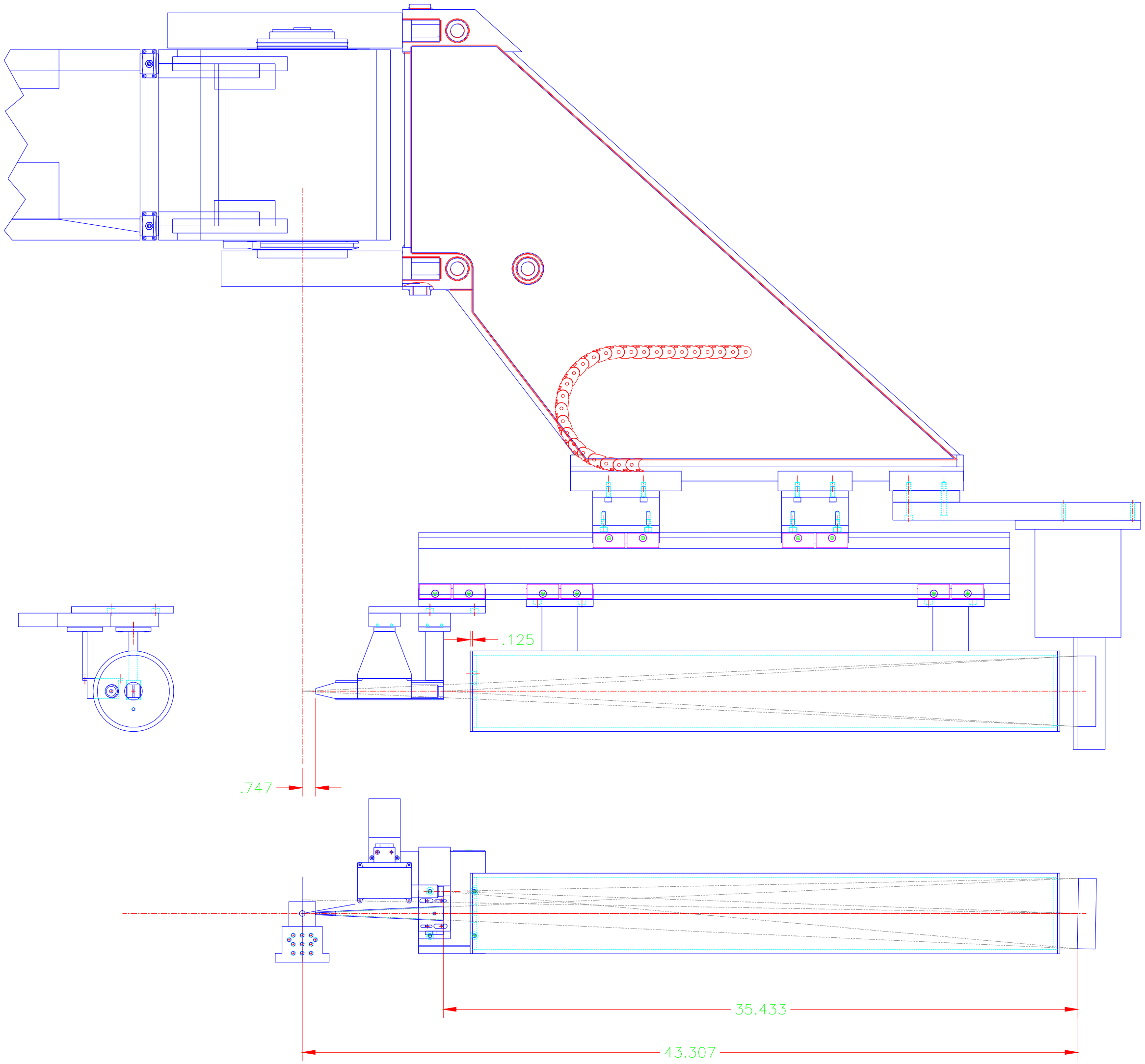
- Techniques:
  - Micro-crystal diffraction
    - Ambient conditions mounted on tapered glass fiber
    - DAC single crystals up to 20Gpa
  - Surface Scattering
    - CTR
    - Reflectivity
  - Surface Spectroscopy
  - Micro-Probe
    - Elemental mapping
    - Spectroscopy
    - Tomography
  - Q-dependent inelastic scattering

Recent Science – Inelastic Scattering in DAC



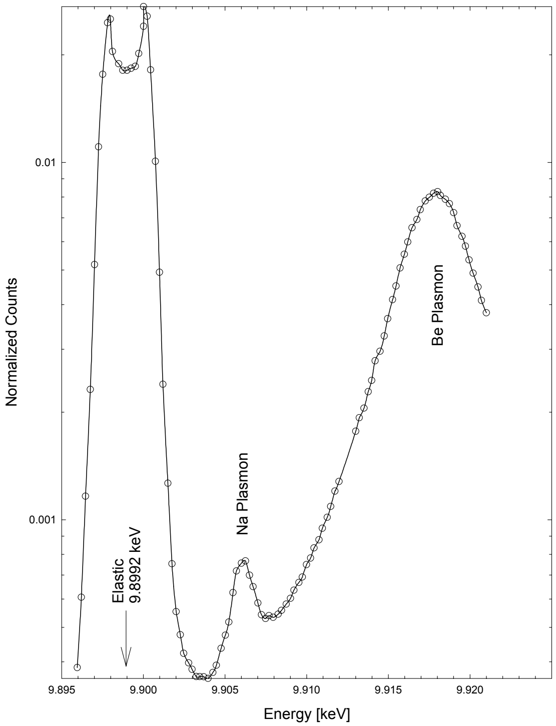


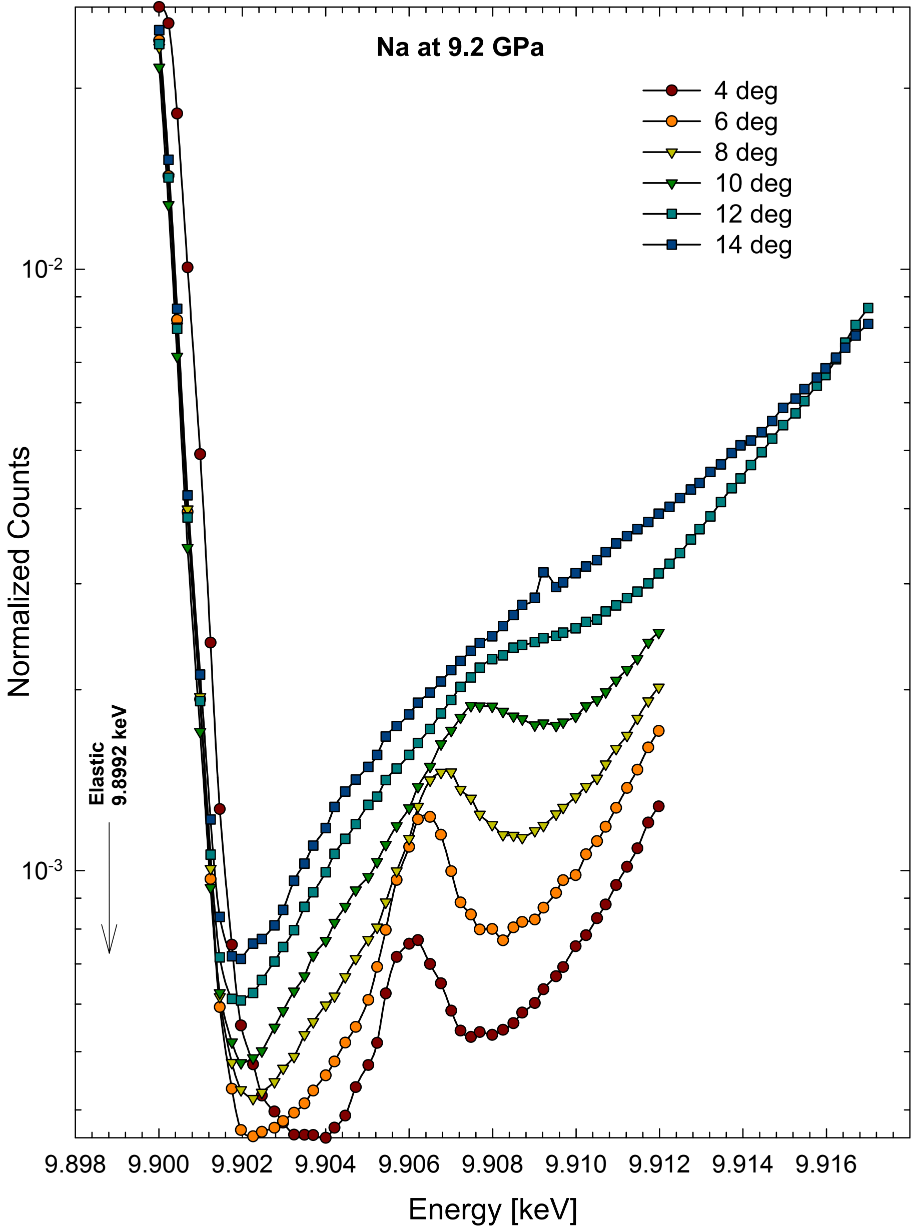
Recent Science – Inelastic Scattering Analyzer



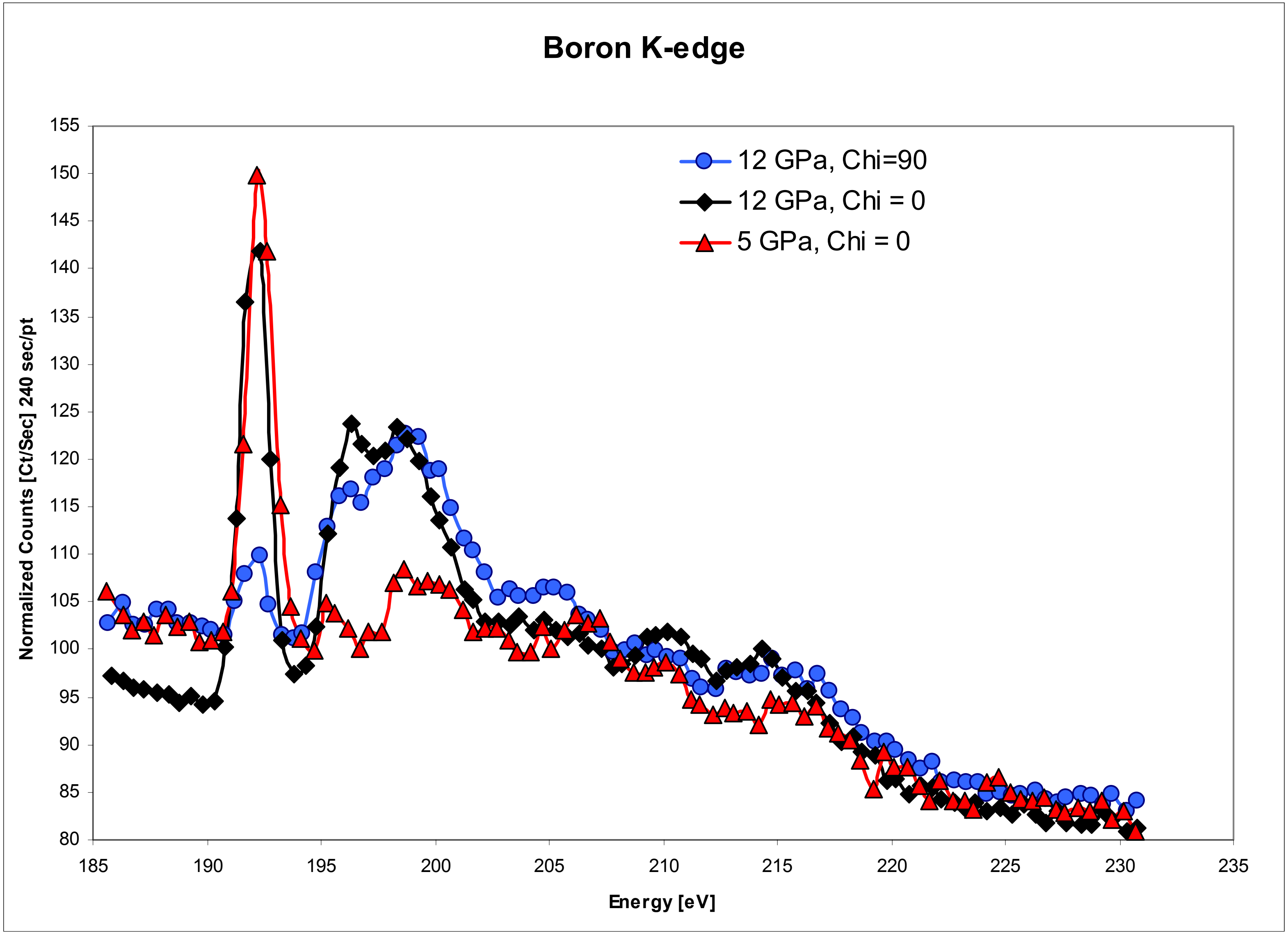
Recent Science – Inelastic Scattering in DAC

- Inelastic scattering at high pressure:
  - Na plasmon
  - Boron Nitride: Boron K-edge, Nitrogen K-edge
  - Water plasmon and oxygen K-edge

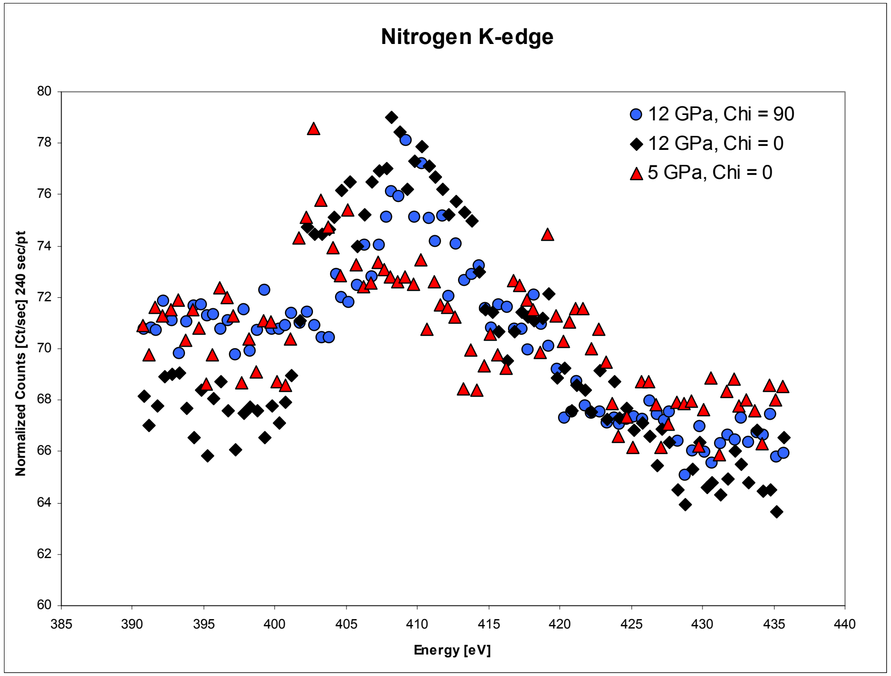


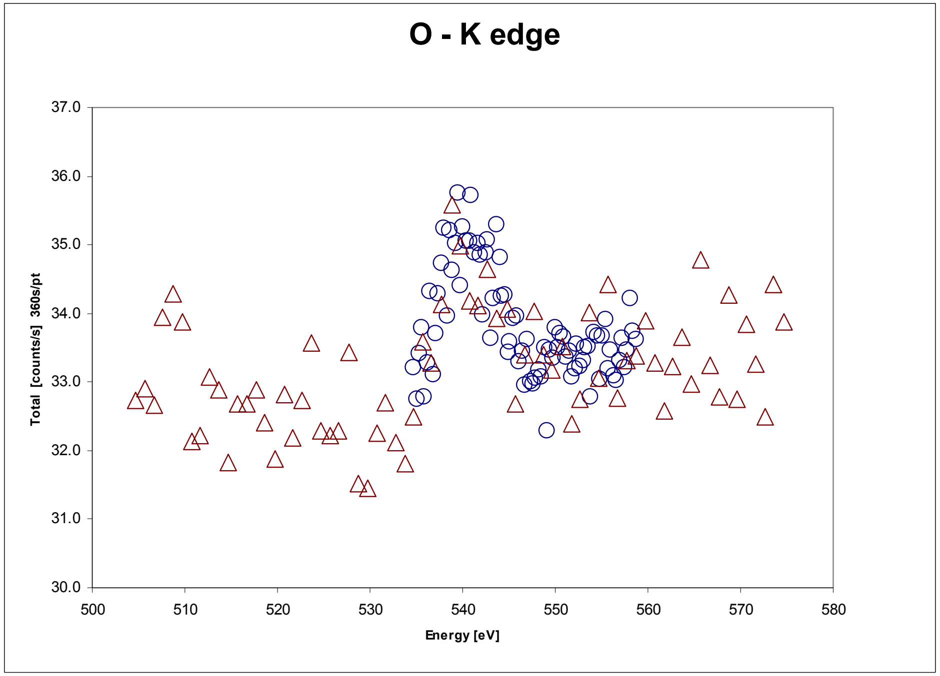


Recent Science – Inelastic Scattering in DAC

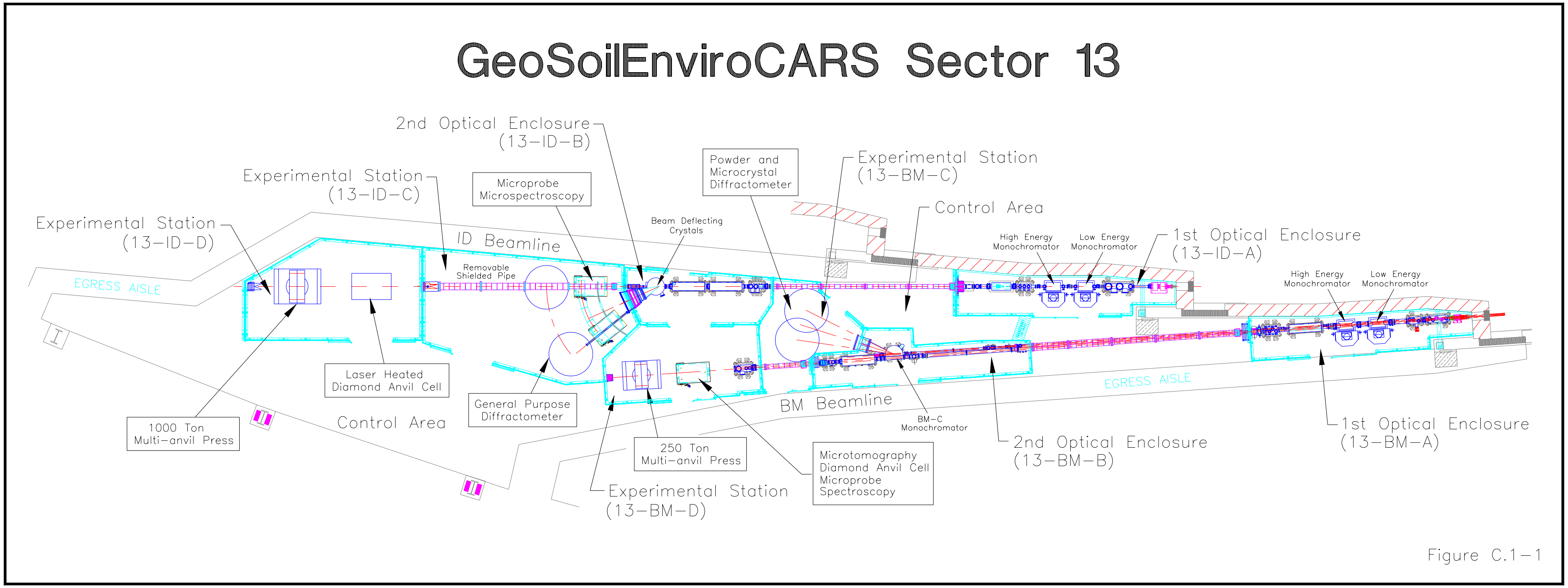


Recent Science – Inelastic Scattering in DAC





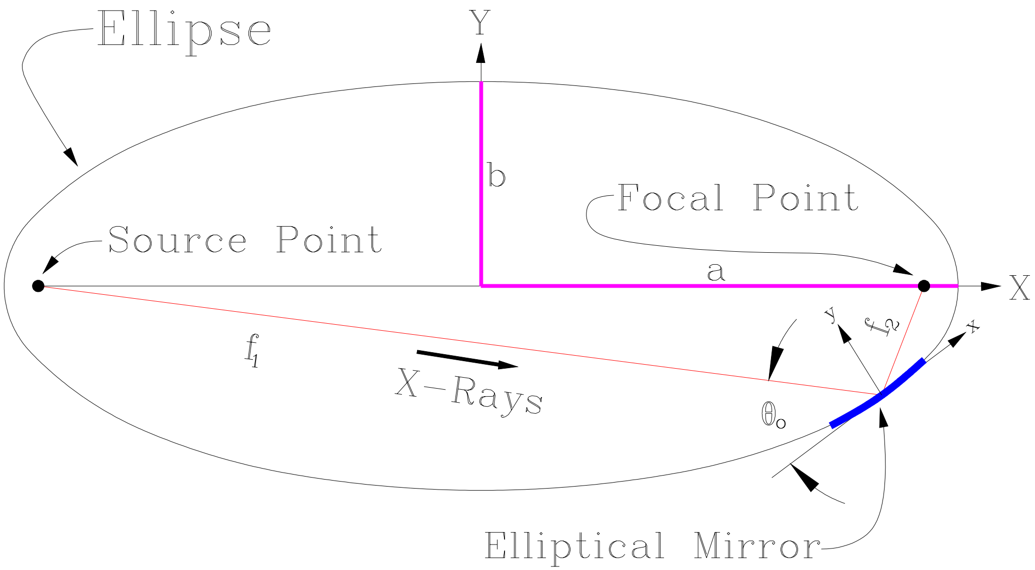
Design Philosophy - Beamline layout & Optics Location

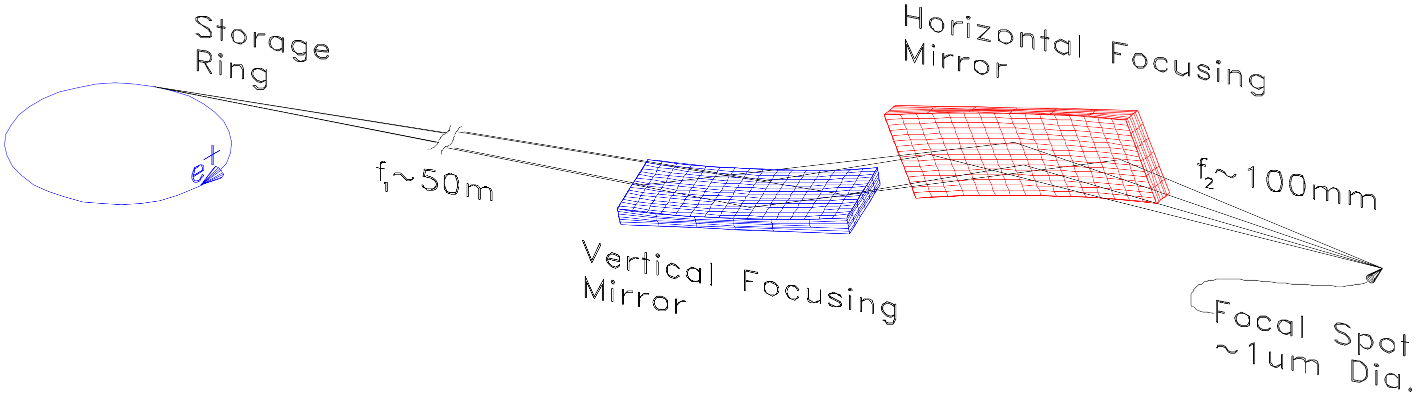


GeoSoilEnviroCARS Sector 13

Figure C.1–1

Design Philosophy - Geometry

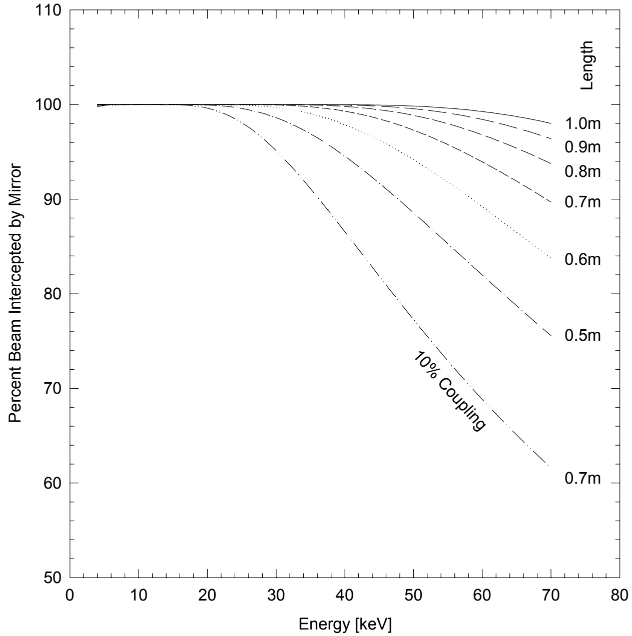




Design Philosophy - Mirror Dimensions

- Length
  - Fraction of the beam intercepted over the desired energy range.

$$F = erf\left[\frac{\sqrt{2}\cdot 0.9\cdot \alpha \cdot L}{4\cdot \Sigma'_y}\right]$$

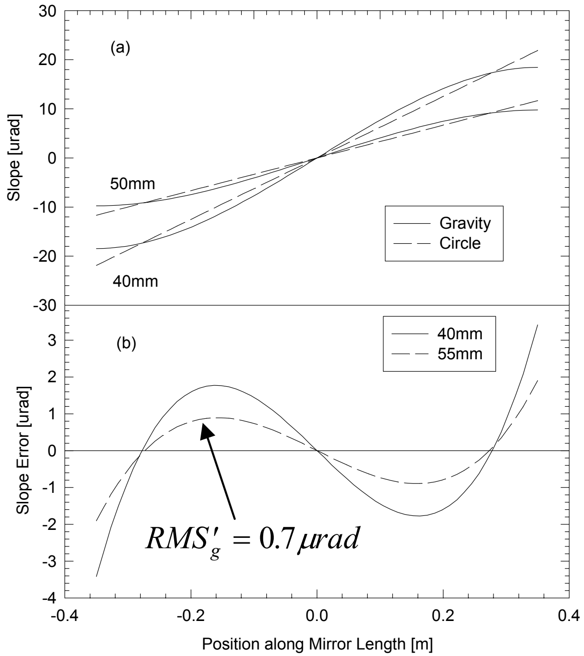


- Thickness
  - Maximal allowable figure error due to gravitational sag.
  - Maximal safe Bending stress

$$RMS'_g = \left(\frac{1}{\sqrt{L}}\right)\sqrt{\int_{-L/2}^{L/2}\left(Slope\_Gravity(x) - Slope\_Circle(x)\right)^2 dx}$$

$$RMS'_g[\mu rad] = 6.5\cdot 10^{-6}\,\frac{\left(L[mm]\right)^3}{\left(c[mm]\right)^2}$$

← For Si



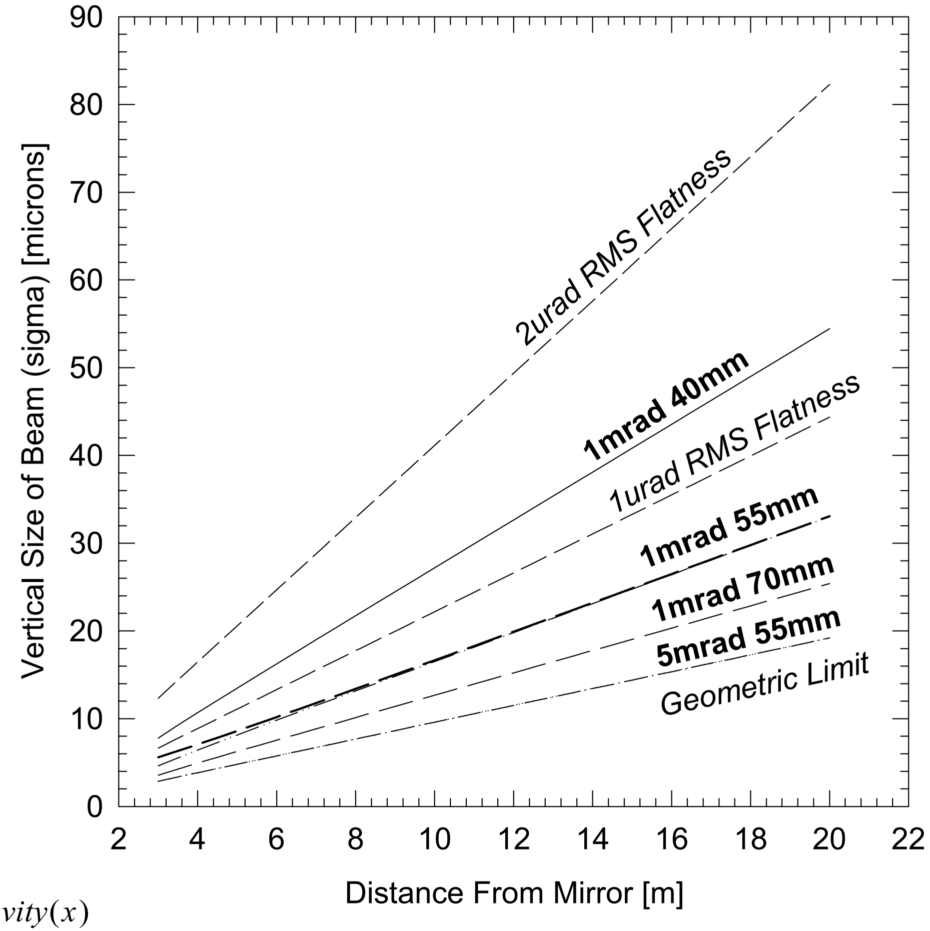
$RMS'_g = 0.7\,\mu rad$

Design Philosophy - Mirror Dimensions – Predicted Performance

We Compute RMS slope error of the mirror by performing a non-linear LSQ fit to an ideal ellipse of the beam weighted two moment slope function and gravitational sag.

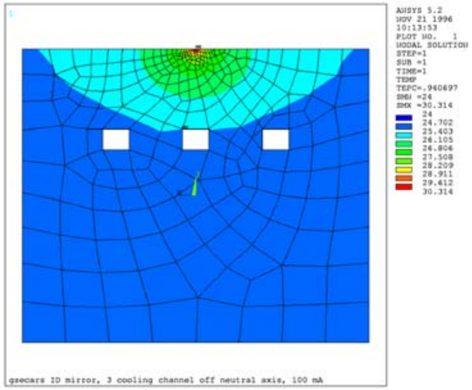
$$W(x) = \frac{\sin(\theta_o)\cdot e^{-\frac{1}{2}\left(\frac{x\cdot\sin(\theta_o)}{\Sigma'_y\cdot S}\right)}}{\sqrt{2\pi}\cdot\Sigma'_y\cdot S\cdot erf\left(\frac{\sqrt{2}}{4}\frac{\sin(\theta_o)\cdot L}{\Sigma'_y\cdot S}\right)}$$

$$Slope\_Mirror(x,K,\eta) = Slope\_Bender(x,K,\eta) - Slope\_Gravity(x)$$

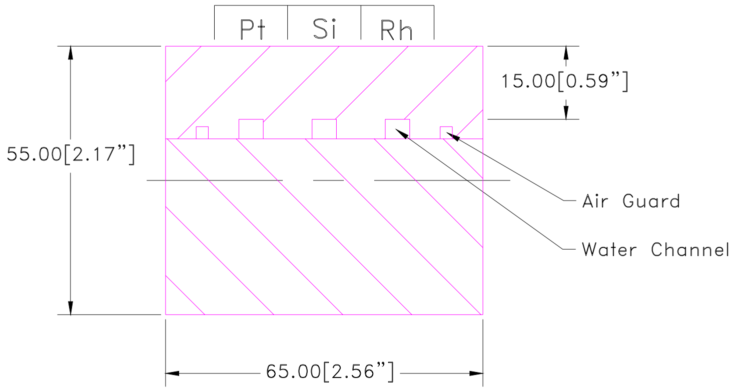


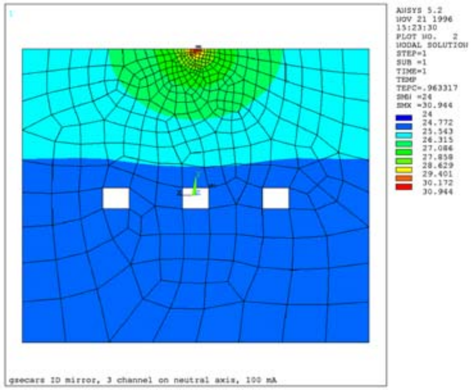
Design Philosophy - Thermal Analysis

- White beam operation
  - Limited to 100W with a power limiting aperture.
  - For the modeling we used a foot print at 5mrad of 1.5 mm wide by 180 mm long resulting in a worst case power density of 0.4 W/mm^2.
- Mirror is internally water cooled.

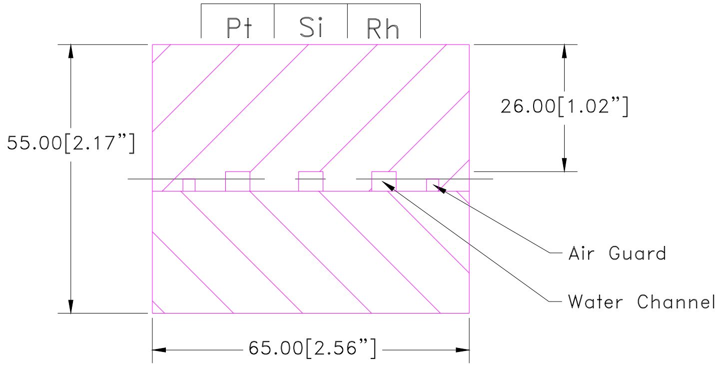


(a) Off Axis



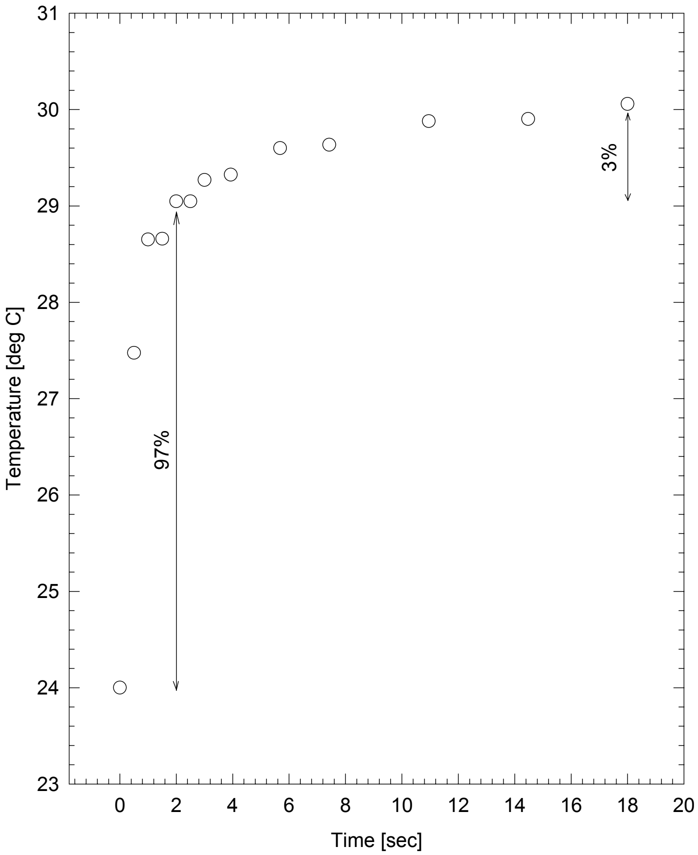


(b) On Axis

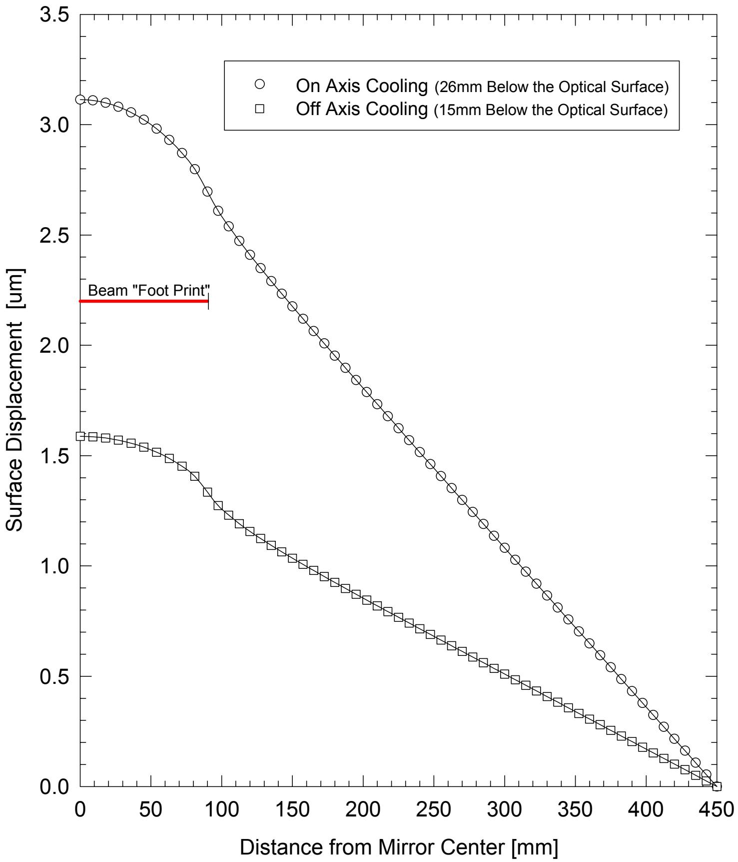


Design Philosophy - Thermal Analysis – Thermal Transient and Displacement

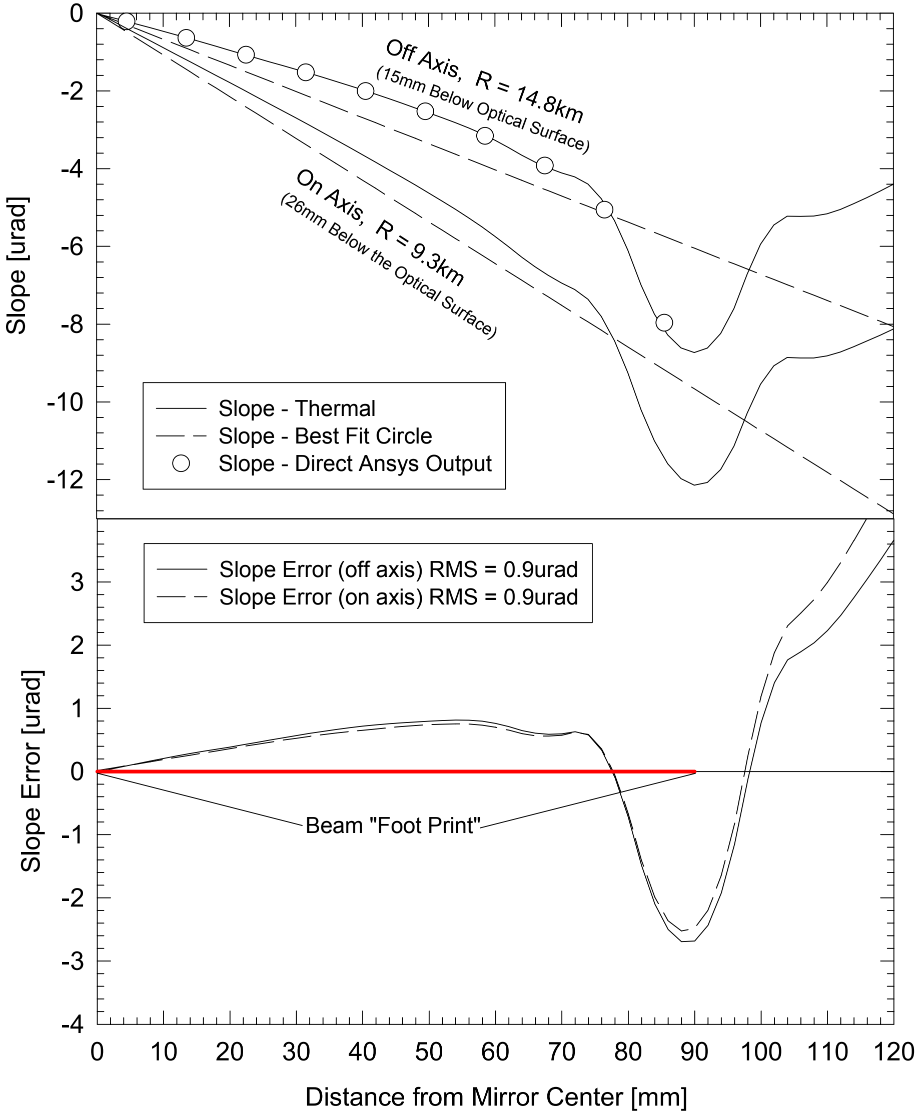
- Thermal Transient
  - Mirror achieves 97% of the max Temperature in 2 sec
  - Achieves steady state in approximately 18 sec



- Thermal Displacement
  - Determined by feeding the thermal results into ANSYS structural package



Design Philosophy - Thermal Analysis – Slope Error and Thermal Stability



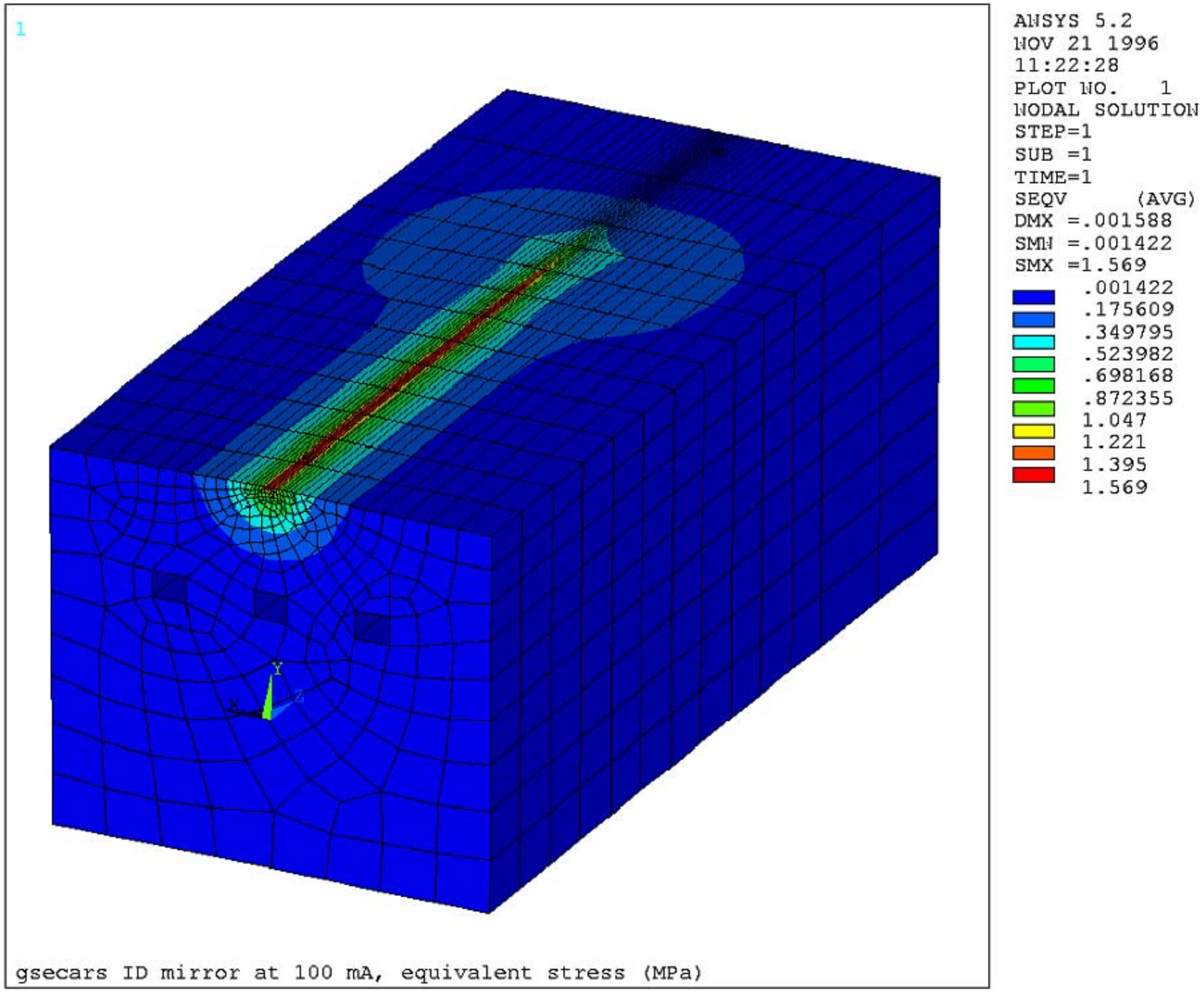
- Slope Error
  - Over the beam foot print the slope error is the same
  - Off axis cooling
    - R = 14.8 km
    - Slope Error = 0.9urad
  - On axis cooling
    - R = 9.3 km
    - Slope Error = 0.9urad
- Thermal Stability
  - For ring current starting at 100ma and dropping to 50ma with an initially corrected thermal bump R and foot print x_o the slope error would increase to:

$$RMS' = \frac{x_o}{4\sqrt{3} \cdot R}$$

  - For the off axis case $RMS' = 1.8\mu rad$
  - Resulting in a increase in focal size by a factor of 4!

Design Philosophy - Thermal Analysis – Thermal Stress

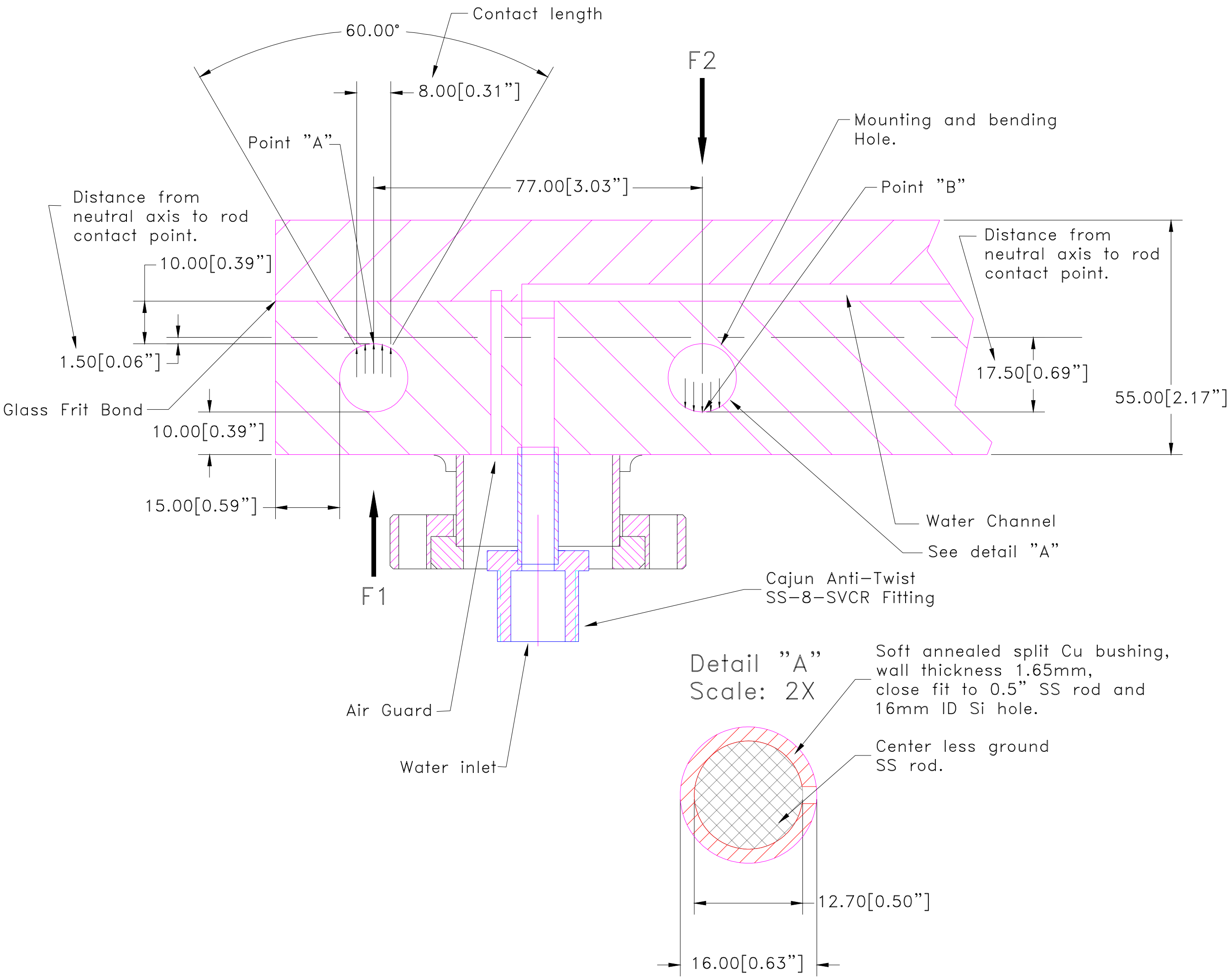
- The maximum thermal equivalent stress for off axis cooling is 1.57 MPa (228 psi) well below the safe limit for Si of 100 psi.



gsecars ID mirror at 100 mA, equivalent stress (MPa)

Design Philosophy - Dynamic Figuring

- Once the length, thickness and cooling geometry are determined, the mirror support and bender interface can be designed.



Design Philosophy - Dynamic Figuring – Mechanical Equivalent Stress

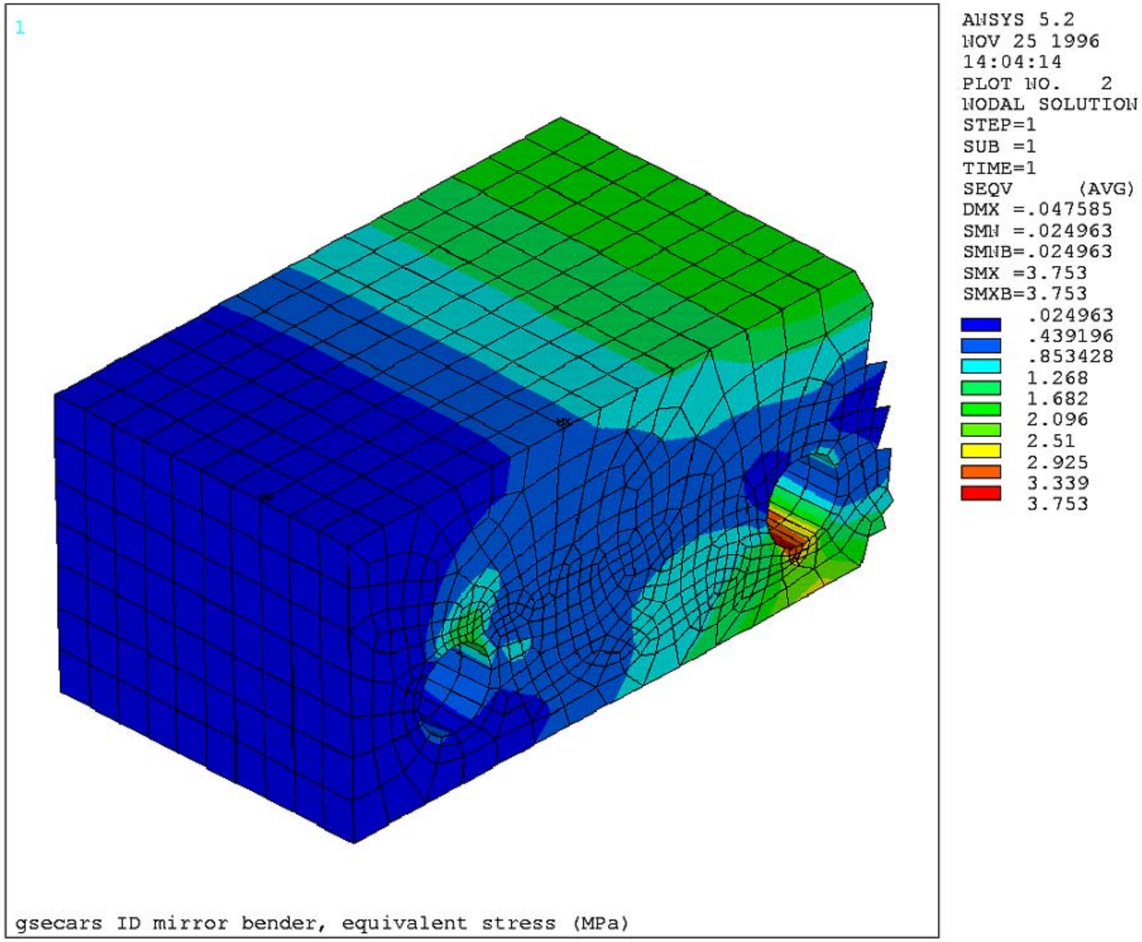
- A simple expression for the maximum contact pressure of the bending rod is:

$$P = \frac{M}{d \cdot Area} = \frac{Y \cdot c^3}{12 \cdot R \cdot d \cdot g}$$

- For our mirror dimensions we find assuming a contact angle of 60deg at maximum curvature (R = 1.8 km) the maximum:
  - contact force is 200 lb
  - pressure 239 psi

Design Philosophy - Dynamic Figuring – Mechanical Equivalent Stress

- Performing ANSYS modeling we find:
  - Maximum equivalent stress to be 3.8 MPa (544 psi) just below the inner bending hole contact point.
  - The stress then drops to 2.9 Mpa (424 psi) on the back surface near the bending hole.



```
ANSYS 5.2
NOV 25 1996
14:04:14
PLOT NO.    2
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
SEQV      (AVG)
DMX =.047585
SMN =.024963
SMNB=.024963
SMX =3.753
SMXB=3.753
```

gsecars ID mirror bender, equivalent stress (MPa)

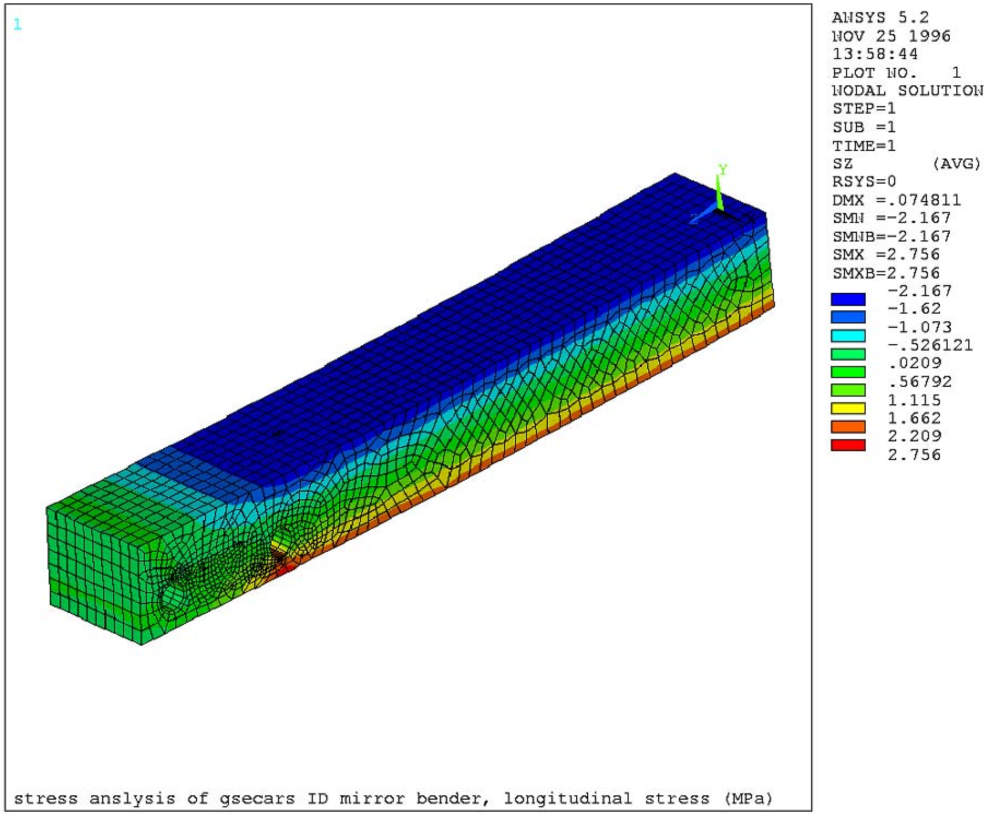
Design Philosophy - Dynamic Figuring – Longitudinal (Bending) Stress

- The longitudinal stress of the bent mirror can estimated using the analytical expression:

$$\sigma_{Bending} = \frac{M \cdot \frac{c}{2}}{I} = \frac{Y \cdot \frac{c}{2}}{R}$$

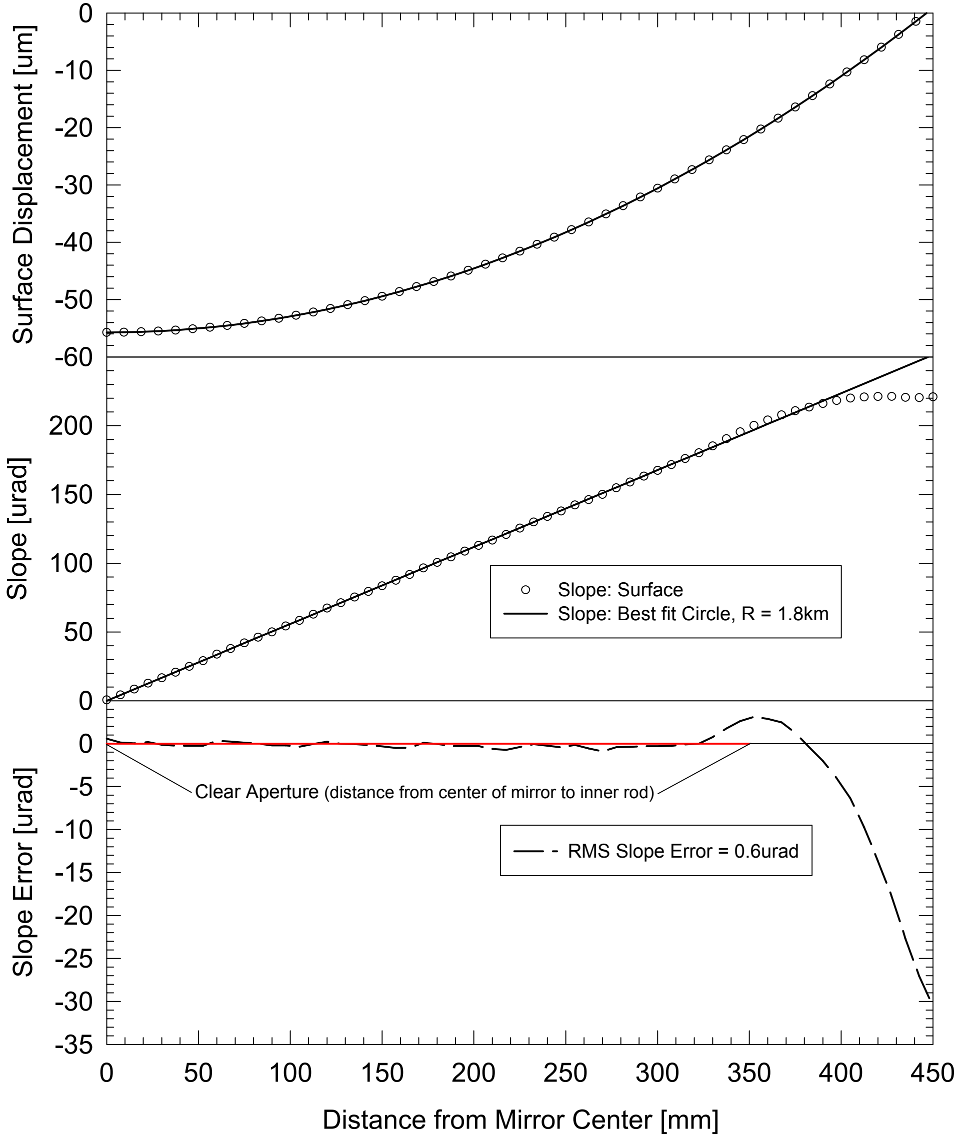
Yielding in our case: $\sigma_{Bending} = 292\,psi = 2\,MPa$

- The analytical result is in good agreement with ANSYS model below resulting in a maximum longitudinal stress component of 2.2MPa



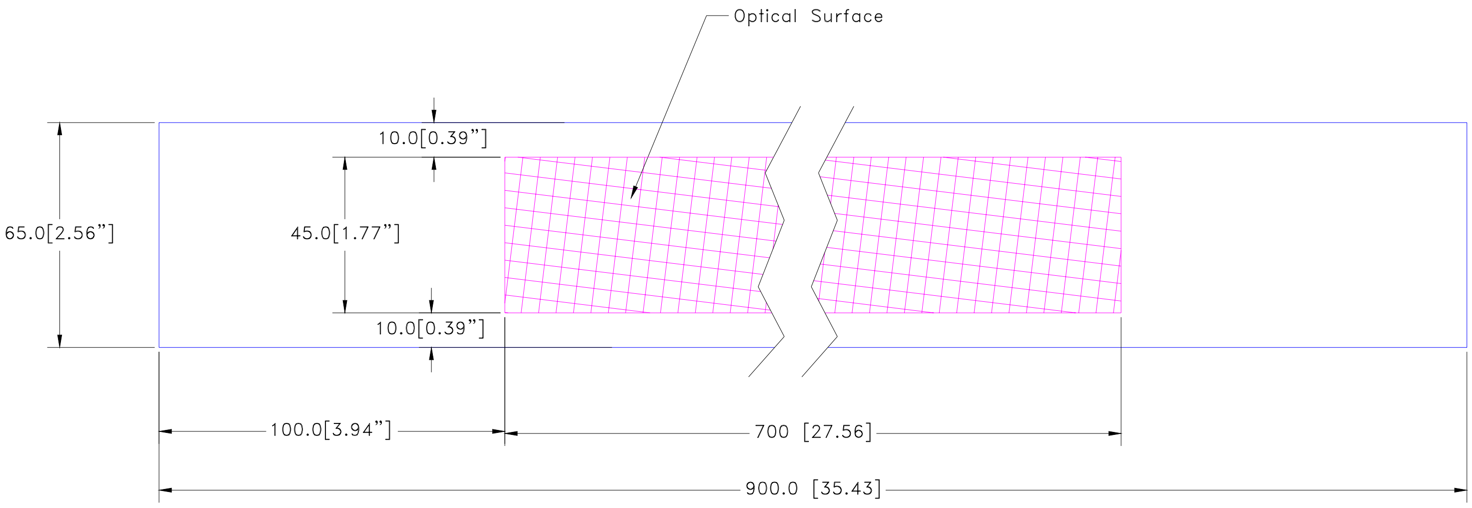
stress anslysis of gsecars ID mirror bender, longitudinal stress (MPa)

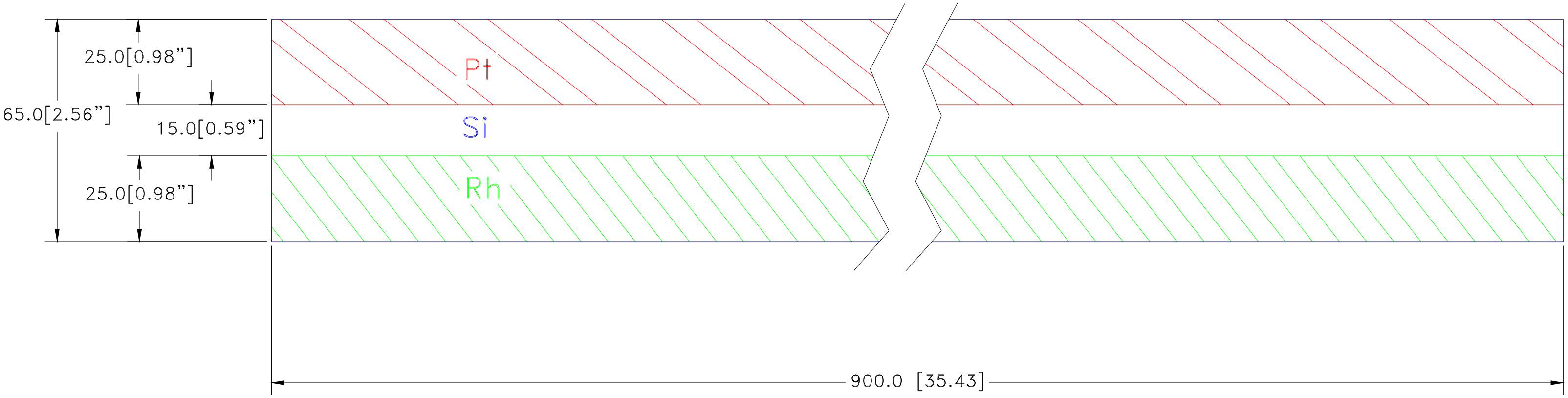
Design Philosophy - Dynamic Figuring – End effects



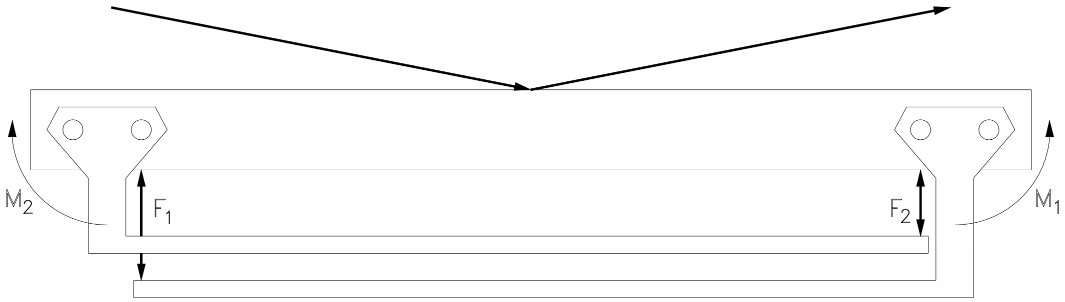
- Optical aperture equal to the distance between the inner bending rods
- Last 25mm contributes about 0.6urad of slope error
- Nearly the full length is a perfect circle.

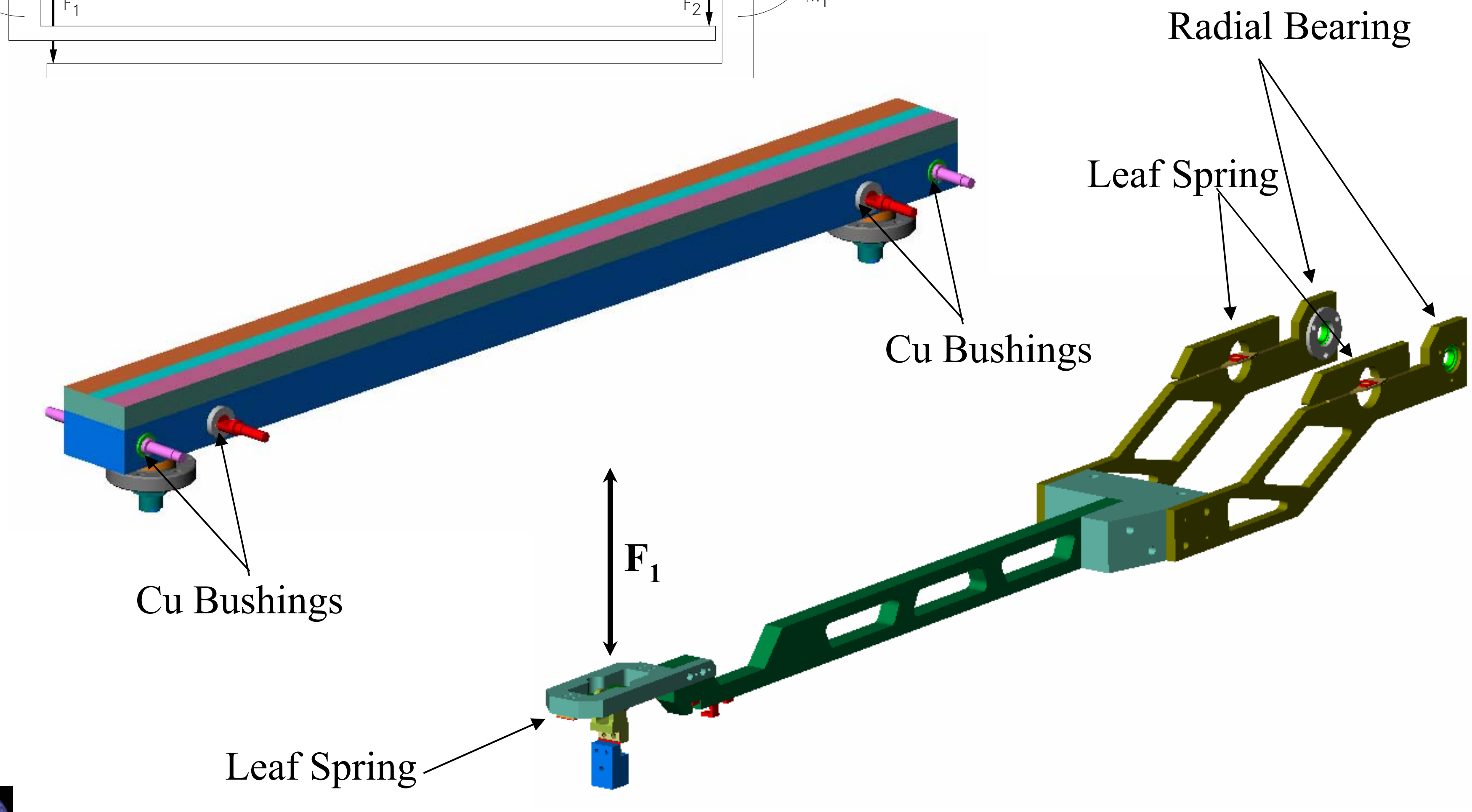
Design Philosophy - Polishing Aperture for and Coatings Arrangementc



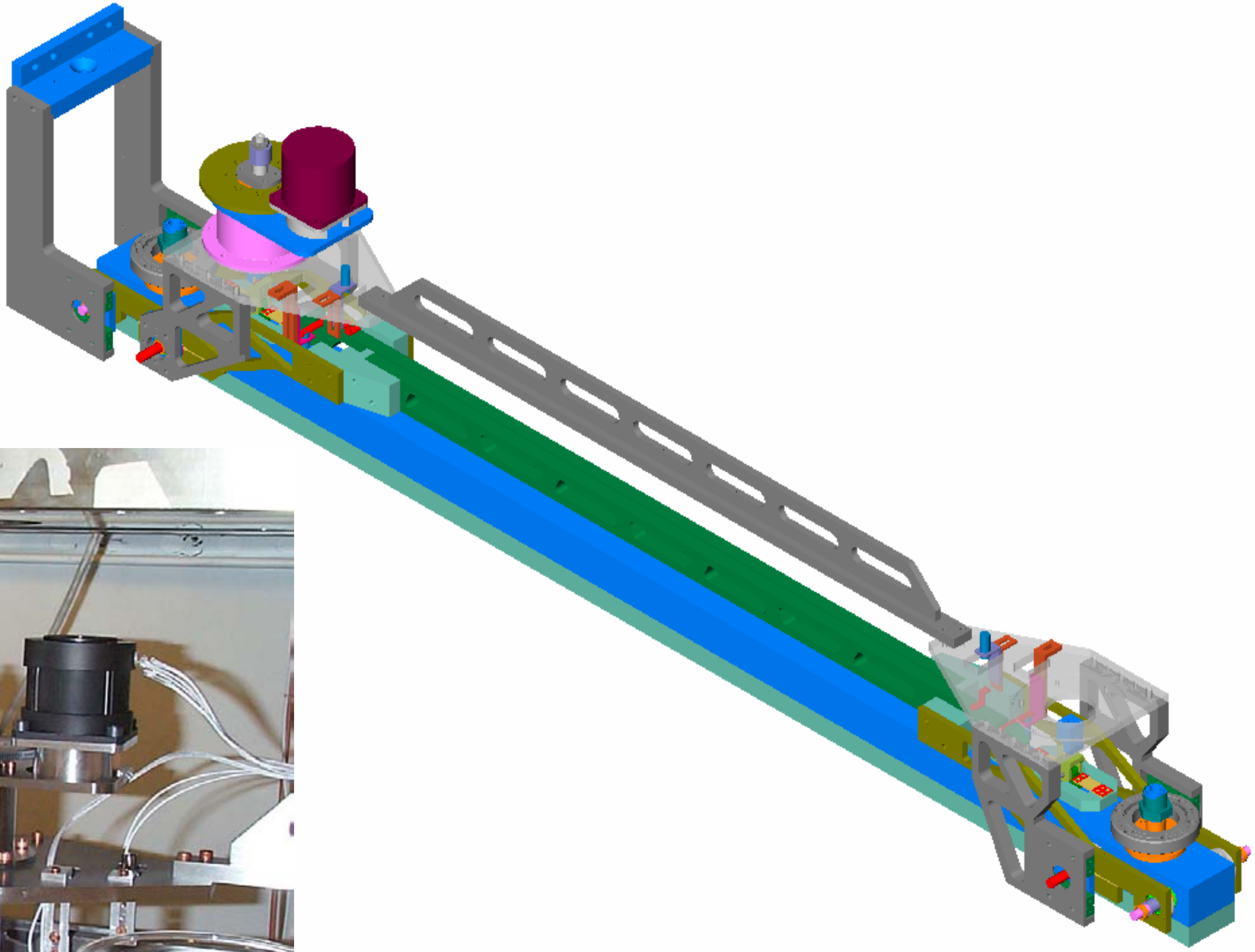


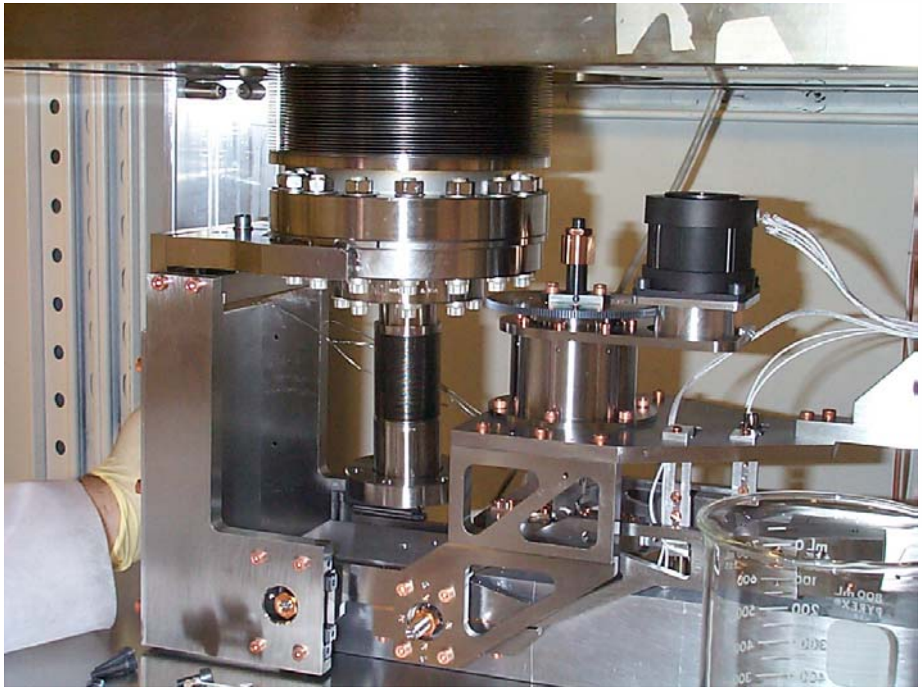
Bender Design – Stable Two Moment Mirror Bender



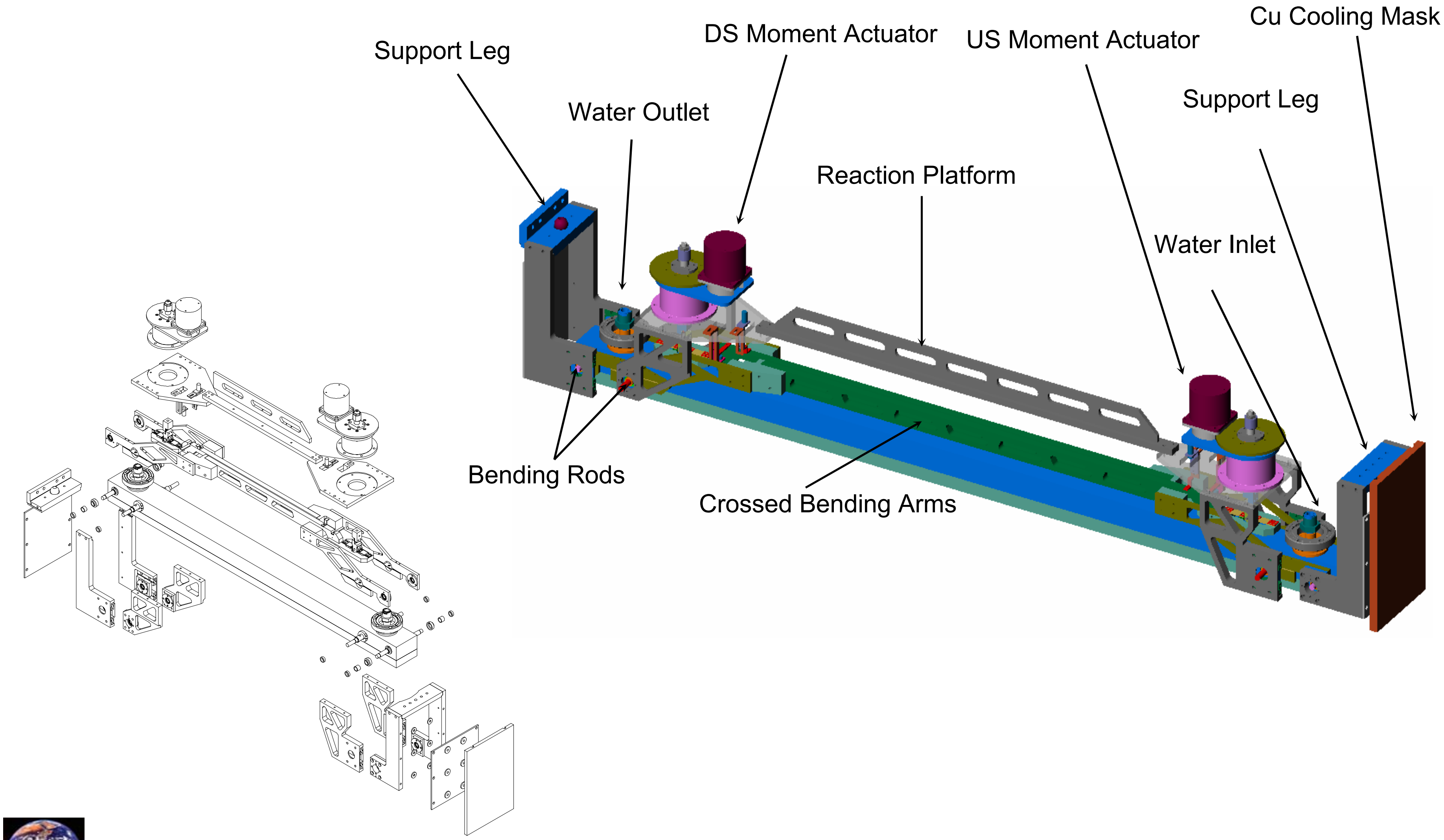


Bender Design – Reaction Platform and In Vacuum Actuator

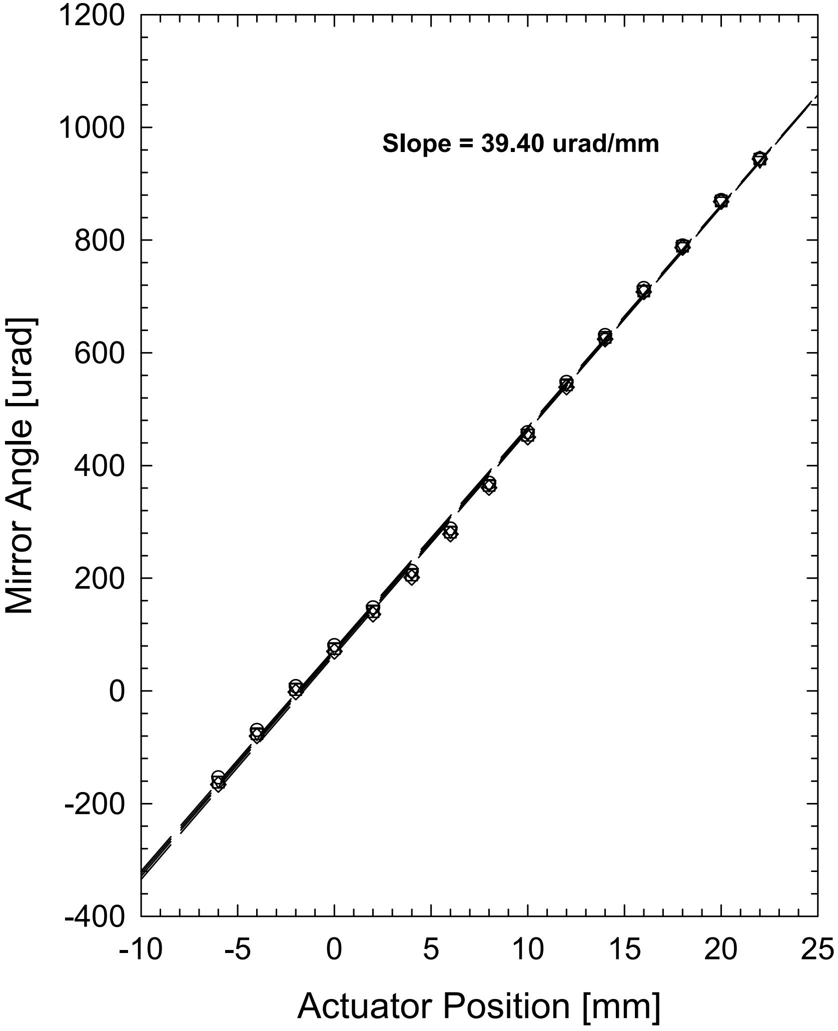




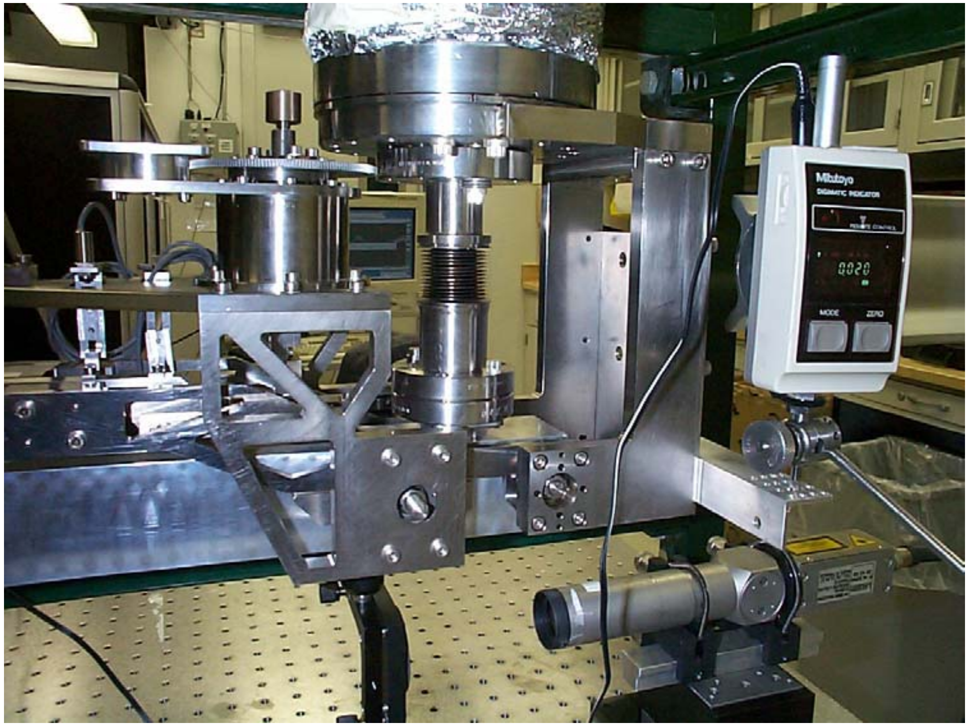
Bender Design – Complete Mirror Bender Subassembly



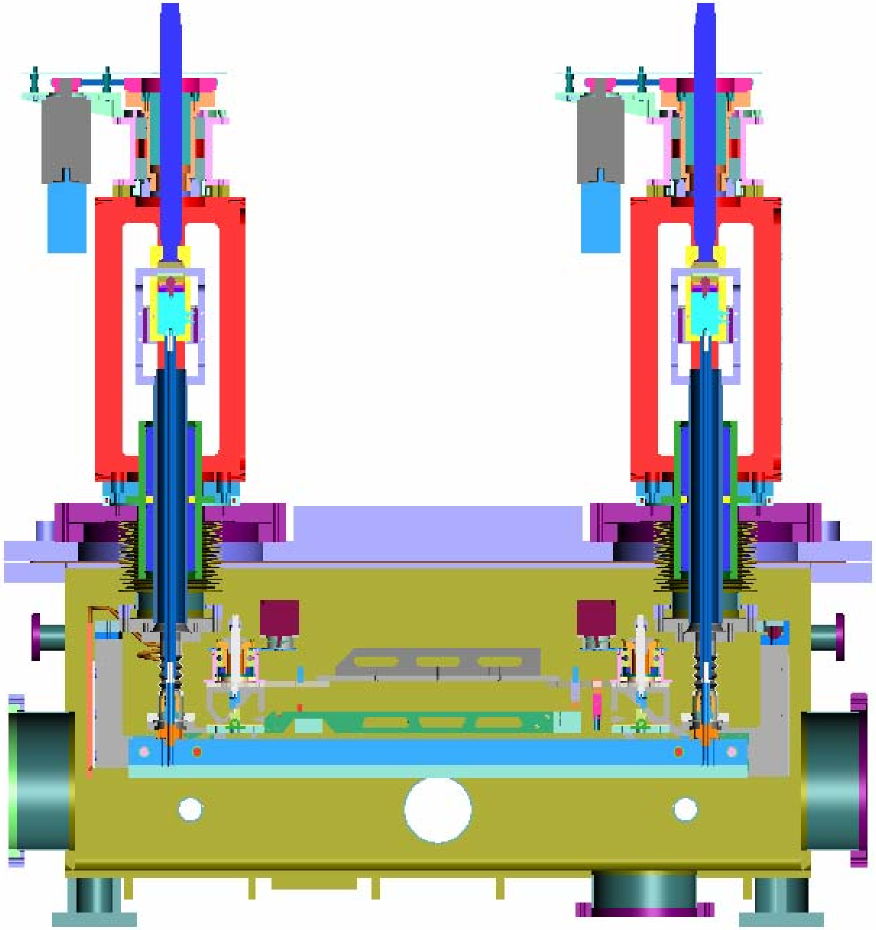
Bender Design – Auto Collimator Test of Mirror Bender



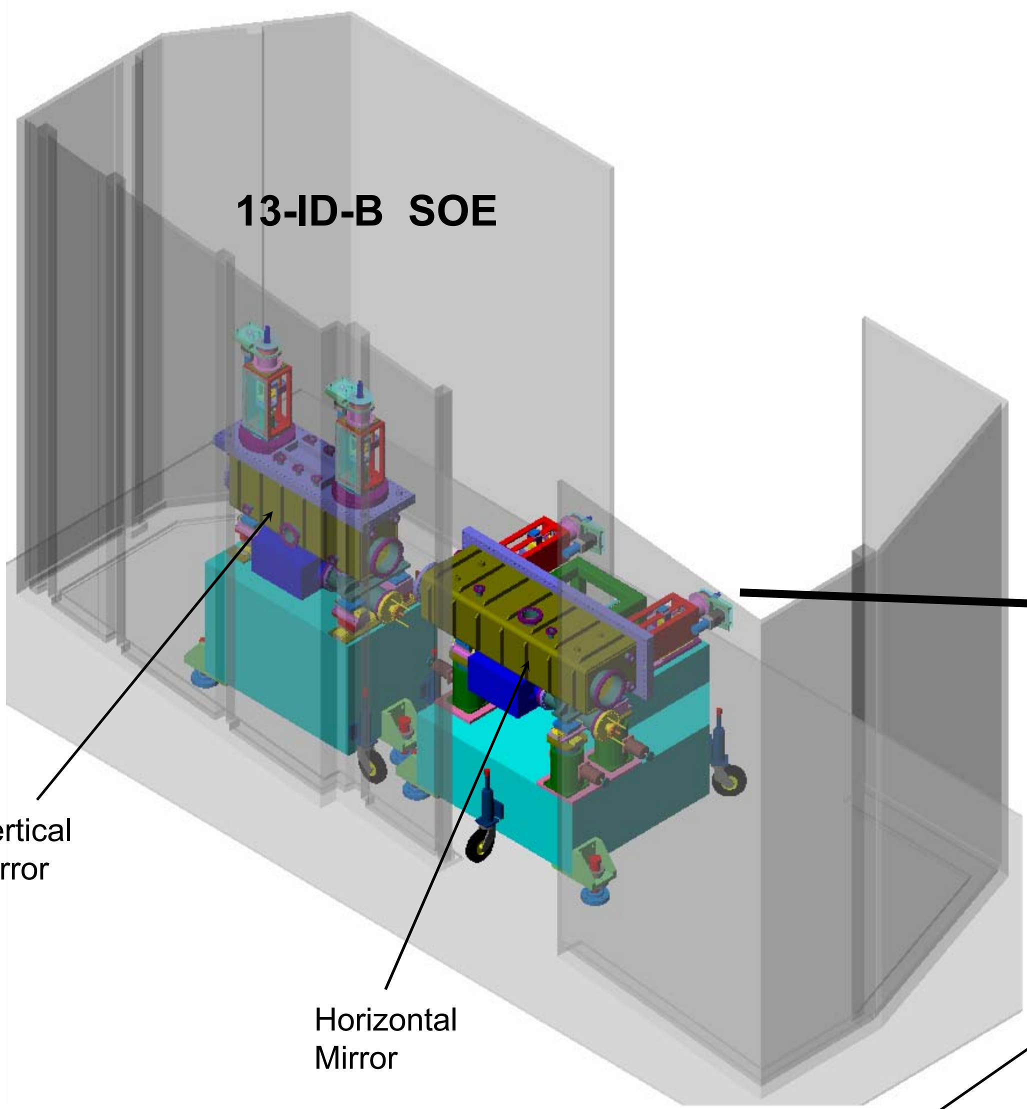
DS = US
Mirror in DS Position



Bender Design – Mirror Bender Mounted on Actuators in Vacuum Tank

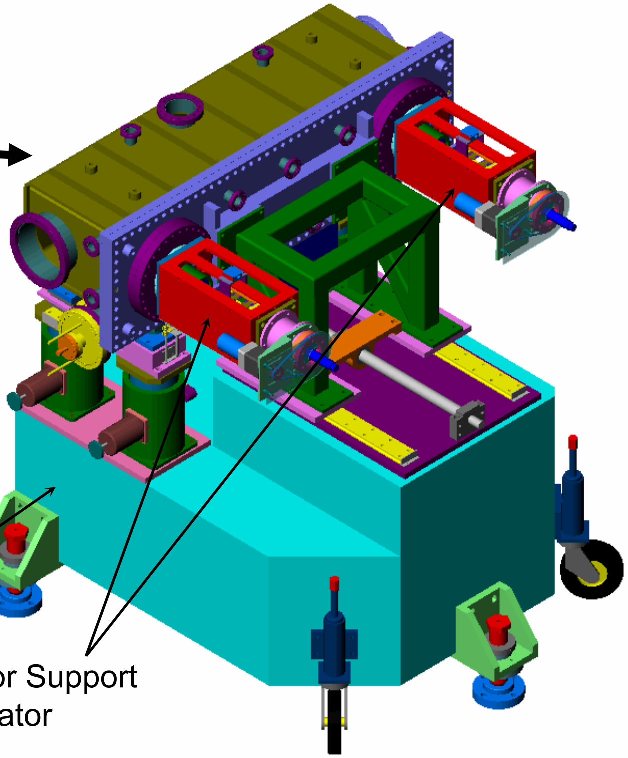


Bender Design – Vertical and Horizontal Mirrors Systems Installed in SOE



Vertical Mirror

Horizontal Mirror

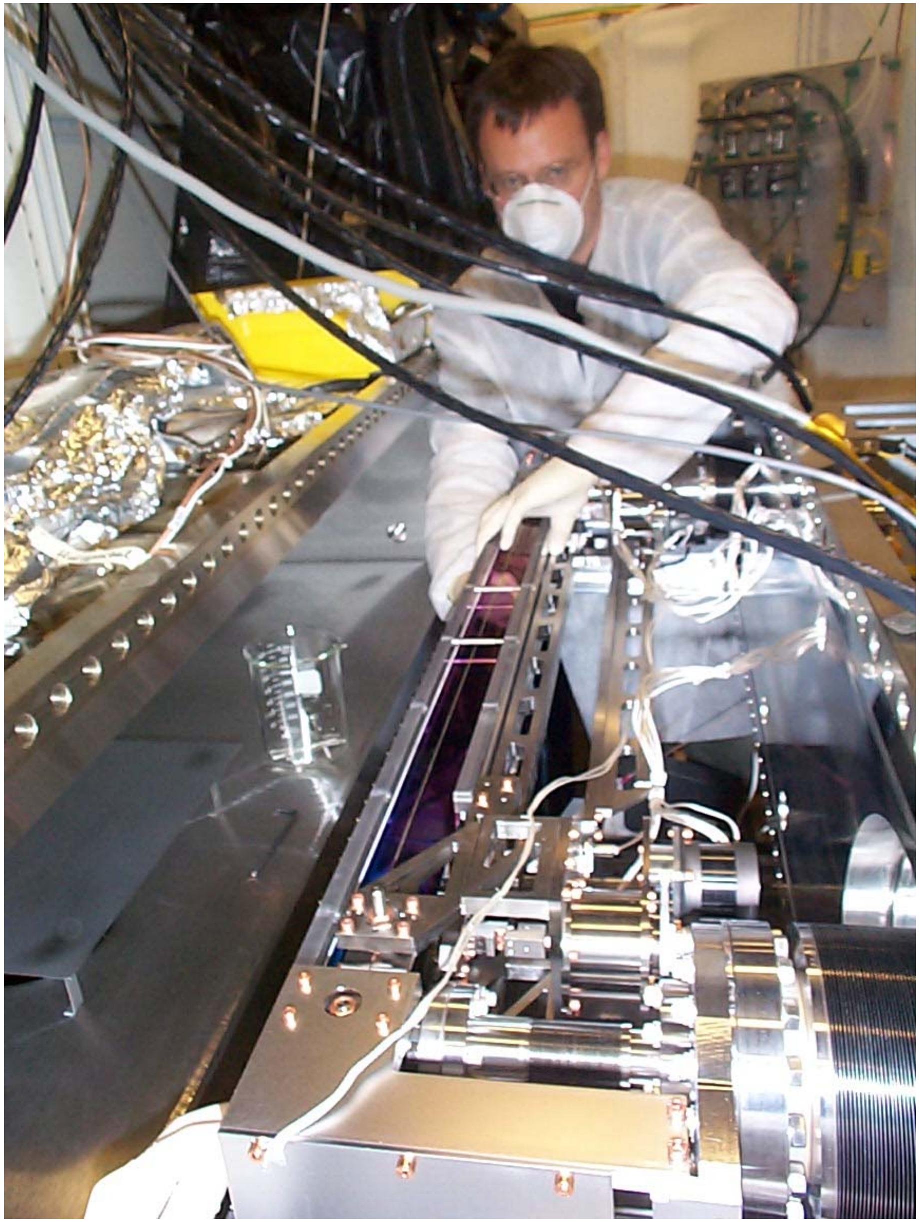


Granite Block

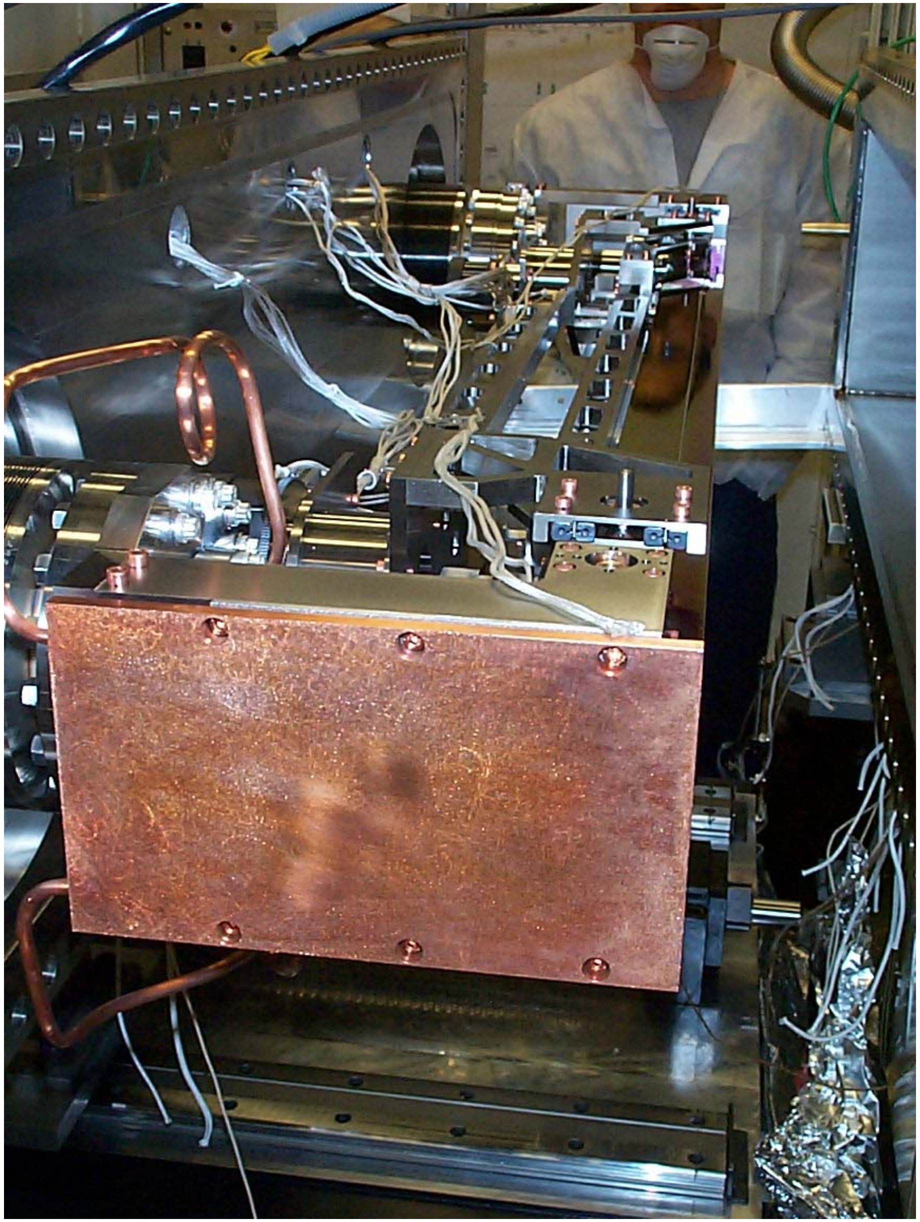
Mirror Support Actuator

Bender Design – Installation of Vertical Mirror

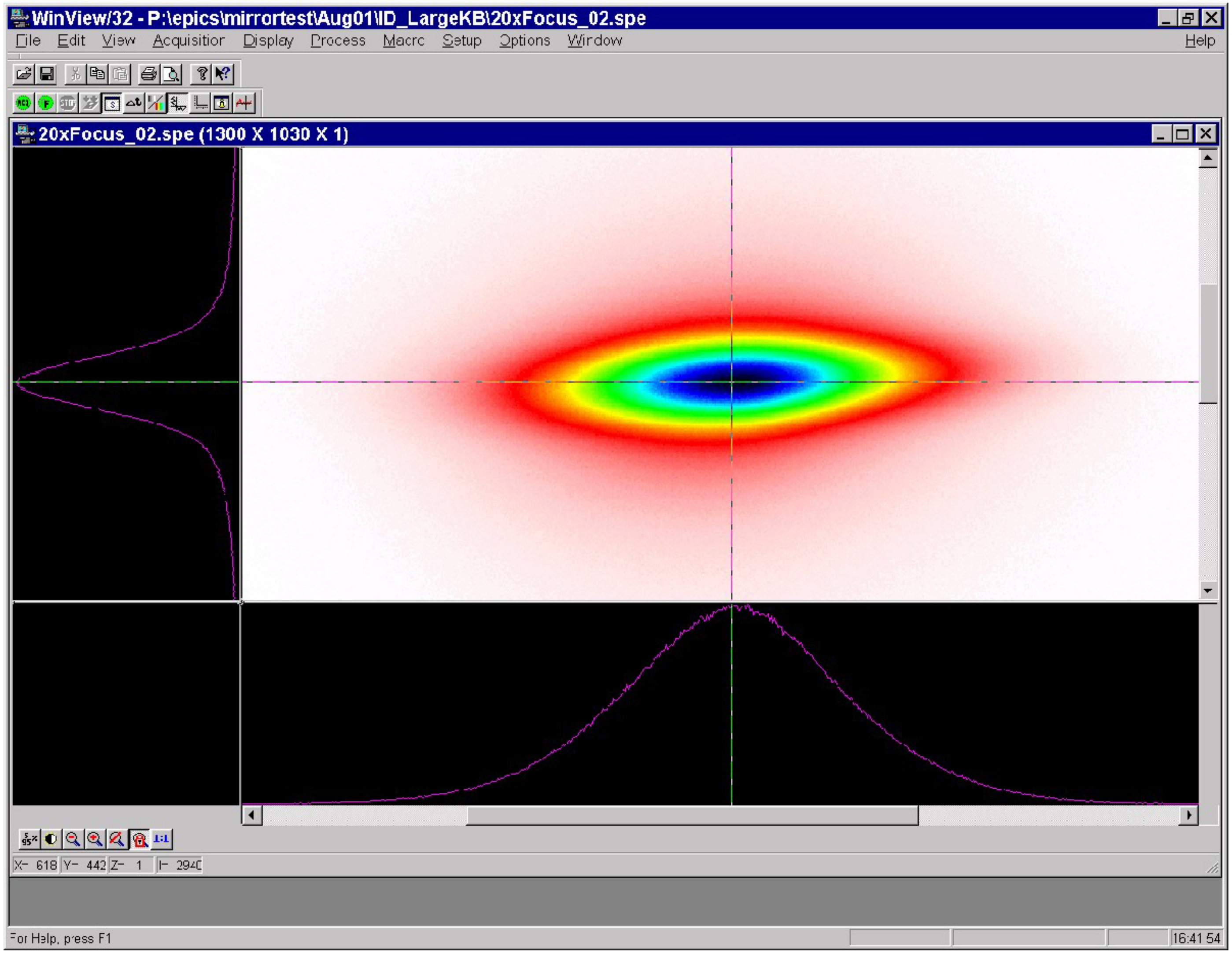
Bender Design – Horizontal Mirrors Removing Protective Cover



Bender Design –Horizontal Mirrors Fully Installed (Ready to Bolt Up Cover)



Performance – CCD Image



WinView/32 - P:\epics\mirrortest\Aug01\ID_LargeKB\20xFocus_02.spe

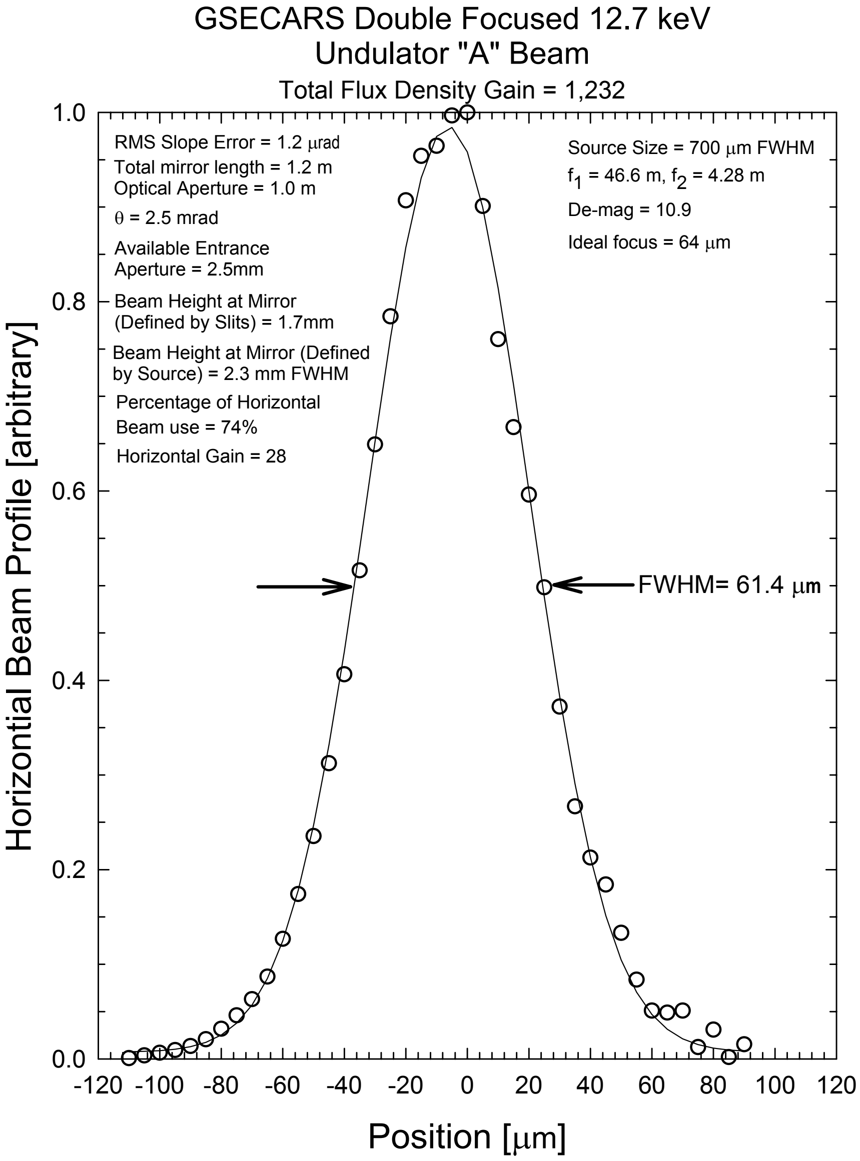
20xFocus_02.spe (1300 X 1030 X 1)

X- 618 Y- 442 Z- 1 I- 2940

The image was produce by focusing the beam onto a thin YAG single crystal producing visible light that is imaged with a 20X objective coupled to 1k x 1k cooled CCD camera.

The effective resolution is about 3 μm.

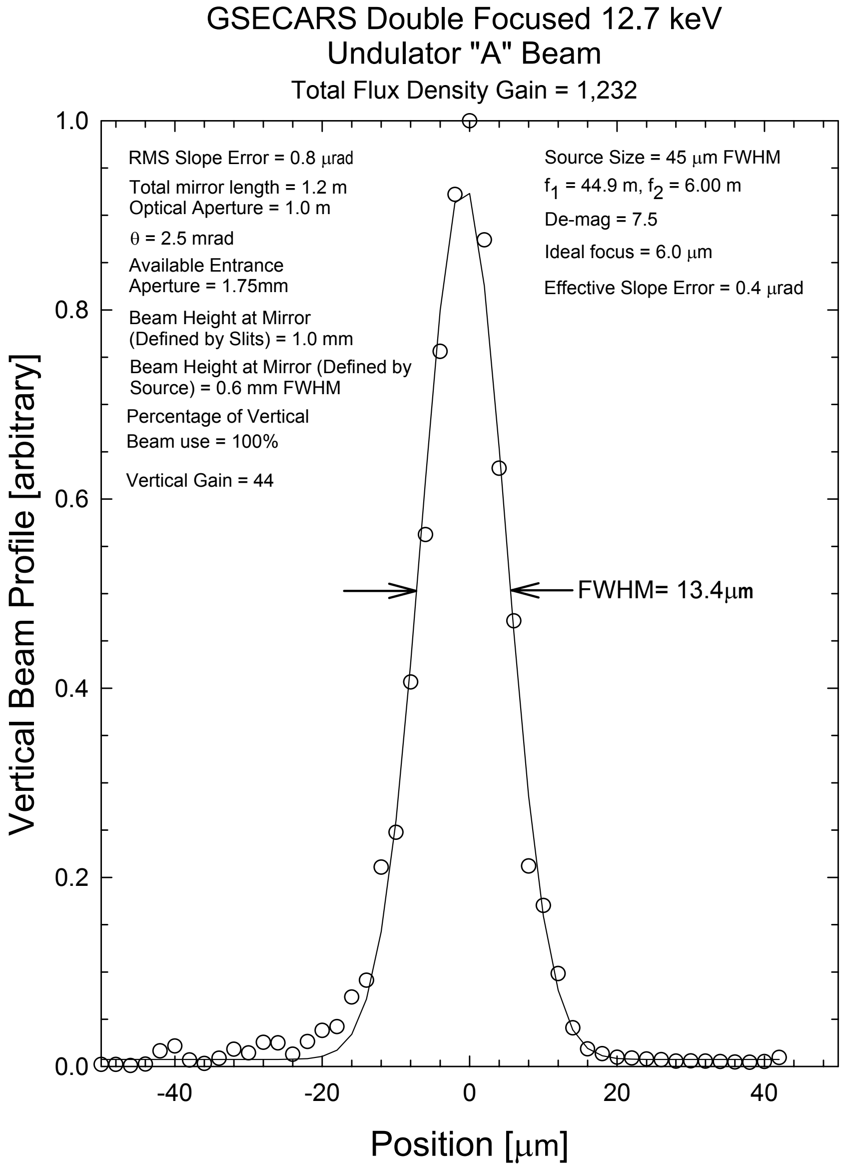
Performance – Knife Edge Scans



GSECARS Double Focused 12.7 keV
Undulator "A" Beam
Total Flux Density Gain = 1,232

RMS Slope Error = 1.2 µrad
Total mirror length = 1.2 m
Optical Aperture = 1.0 m
θ = 2.5 mrad
Available Entrance Aperture = 2.5mm
Beam Height at Mirror (Defined by Slits) = 1.7mm
Beam Height at Mirror (Defined by Source) = 2.3 mm FWHM
Percentage of Horizontal Beam use = 74%
Horizontal Gain = 28

Source Size = 700 µm FWHM
f_1 = 46.6 m, f_2 = 4.28 m
De-mag = 10.9
Ideal focus = 64 µm



GSECARS Double Focused 12.7 keV
Undulator "A" Beam
Total Flux Density Gain = 1,232

RMS Slope Error = 0.8 µrad
Total mirror length = 1.2 m
Optical Aperture = 1.0 m
θ = 2.5 mrad
Available Entrance Aperture = 1.75mm
Beam Height at Mirror (Defined by Slits) = 1.0 mm
Beam Height at Mirror (Defined by Source) = 0.6 mm FWHM
Percentage of Vertical Beam use = 100%
Vertical Gain = 44

Source Size = 45 µm FWHM
f_1 = 44.9 m, f_2 = 6.00 m
De-mag = 7.5
Ideal focus = 6.0 µm
Effective Slope Error = 0.4 µrad

The Team

- Paul Murray
- Clayton Pullins
- Patrick Dell
- Leo Gubenko
- Mike Jagger
- Jim Ciston
- Mathew Newville
- Mark L. Rivers
- Steve Sutton
- Yifei Jaski