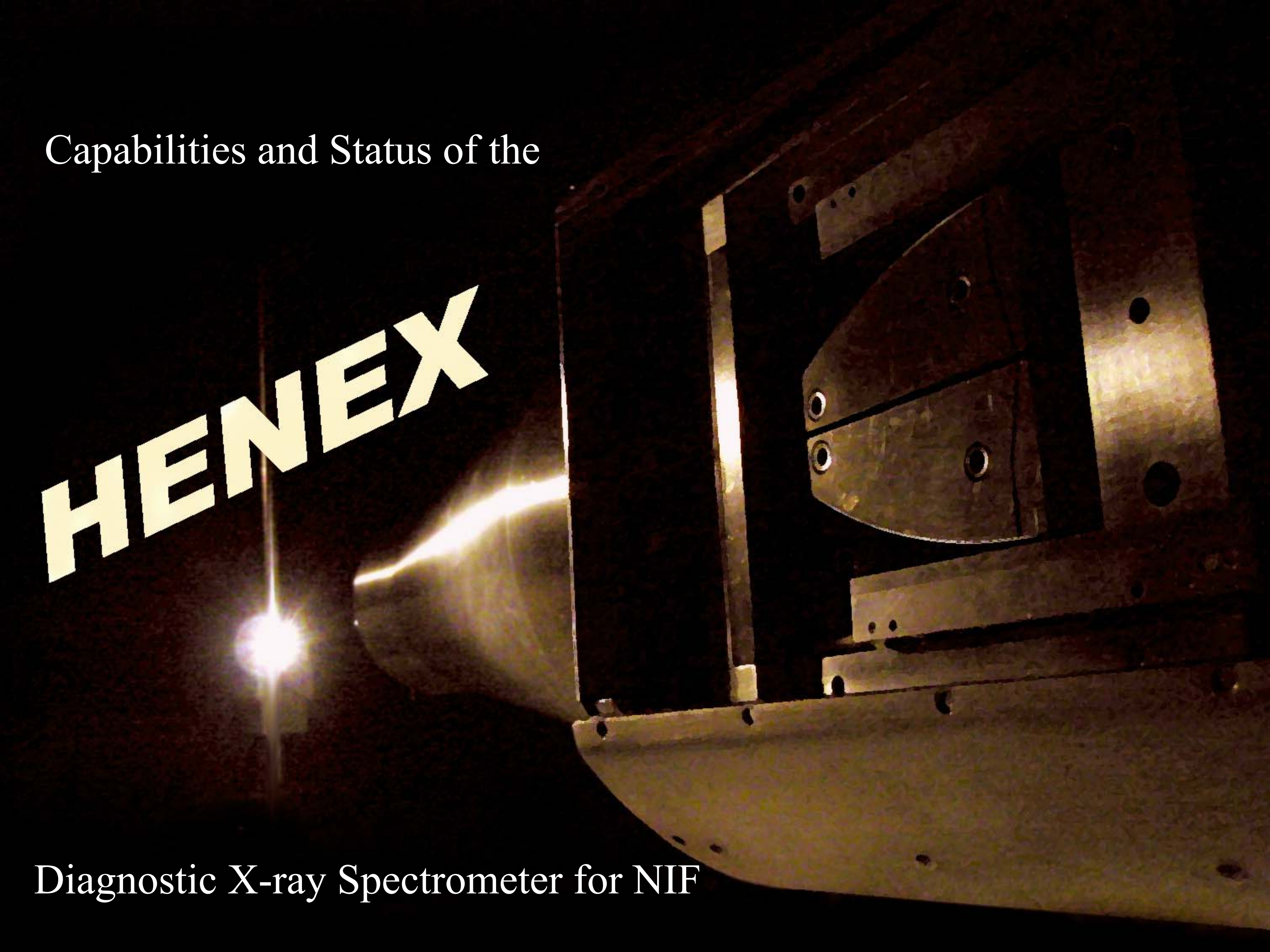
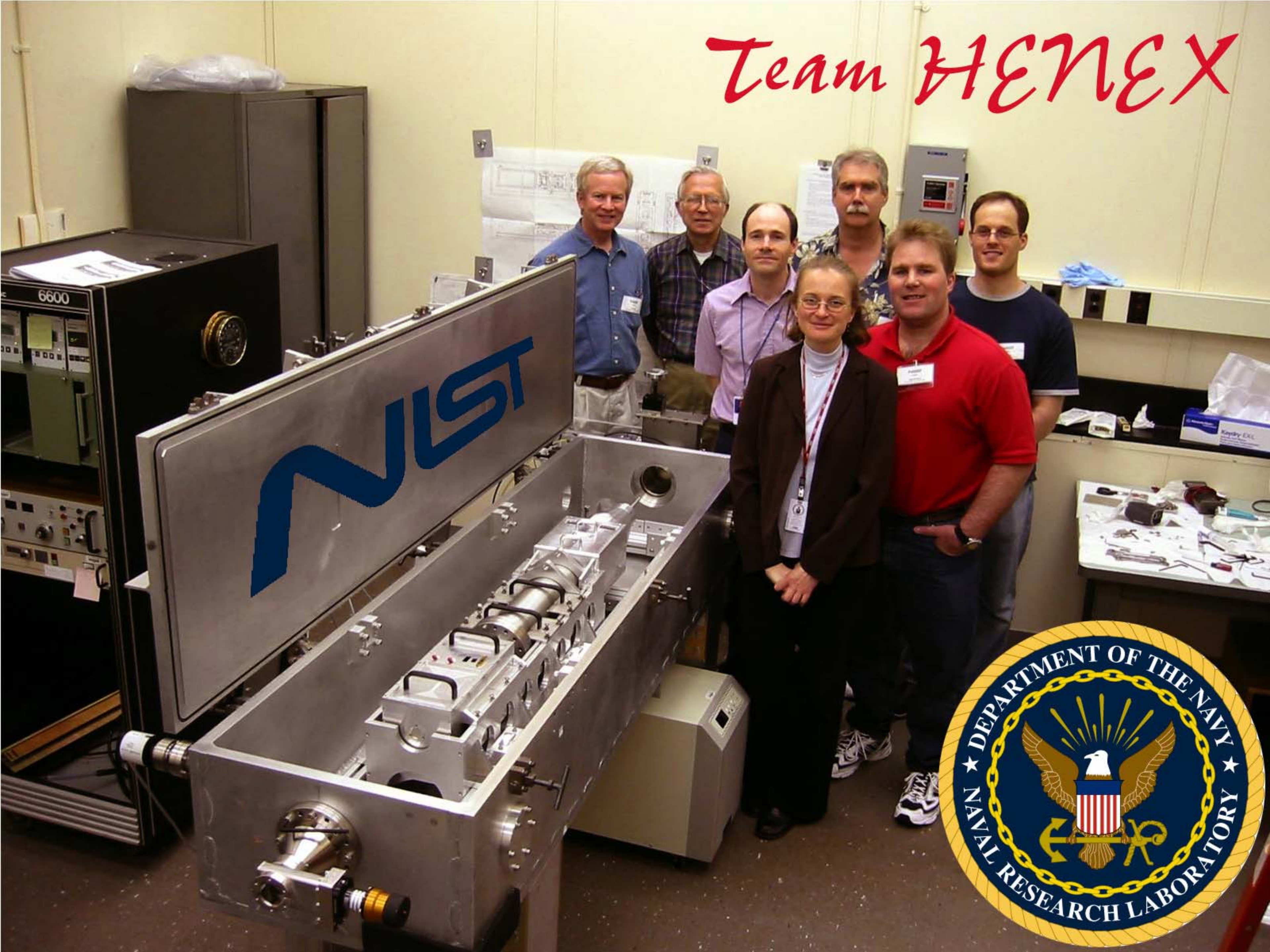
Capabilities and Status of the HENEX Diagnostic X-ray Spectrometer for NIF




Team HENEX
6600
NIST
DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY

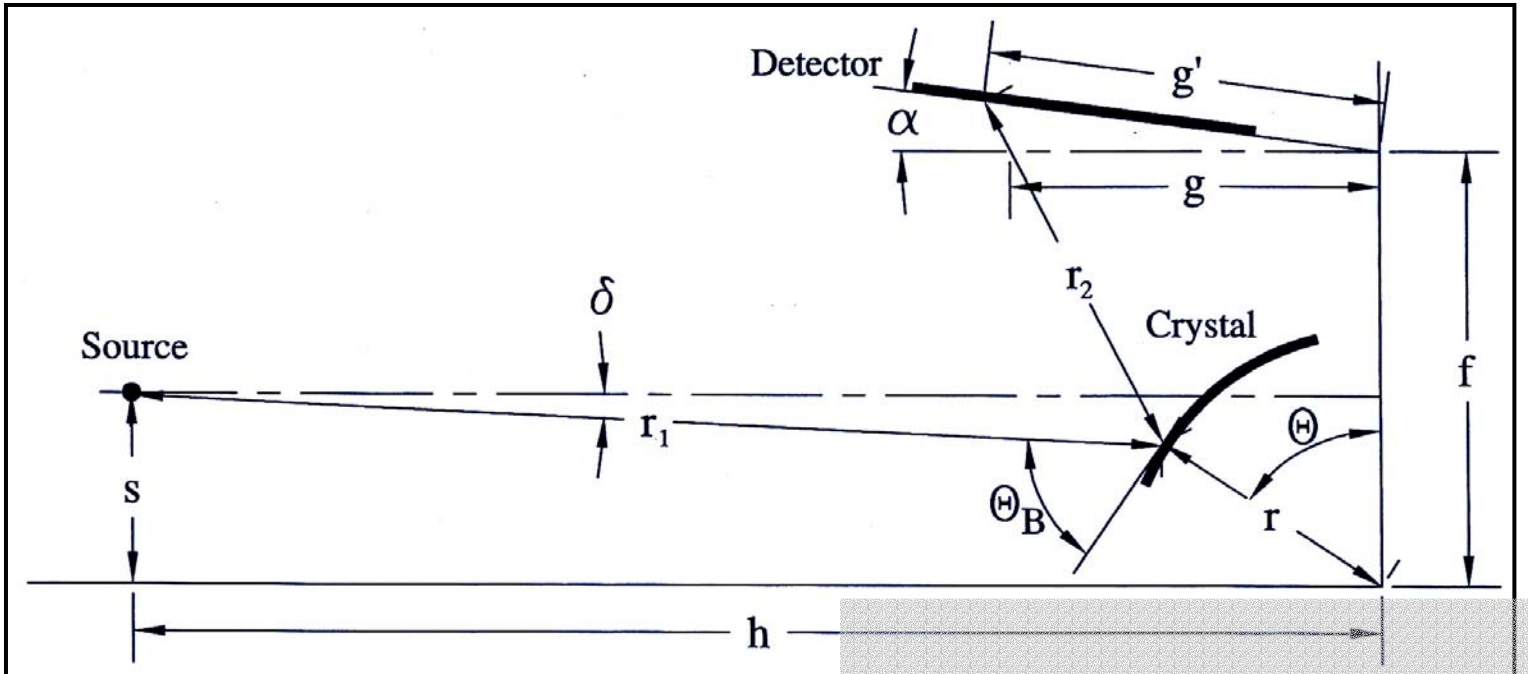
Motivations for the HENEX NIF core-level diagnostic

- X-ray spectroscopic survey meter providing 1 keV to 20 keV registration of x rays from laser-produced plasmas
- Verification of backlighter materials
- A quantitative measure of laser performance; absolute conversion efficiency measurements
- Relative measurements of time-integrated line emissions and bound-free continua
- Basic atomic physics of highly charged ions and plasma interactions

REQUIREMENTS: NIF X-ray crystal spectrometer (HENEX)

As defined by the Expert User Group:

• Energy range of operation	1 keV to 20 keV
• Temporal resolution	time-integrating
• Resolving power $E/\Delta E$	> 300
• Electronic detection	(no film)
• Must fit into a 12 inch insertion module	
• Dynamic range	> 100
• Crystal to TCC	2.2 m
• Signal-to-noise	> 10 for significant spectral lines
• Field-of-view	5 mm
• Detectable fluence	1×10^{-6} J/cm^2
• Data download time	< 10 minutes

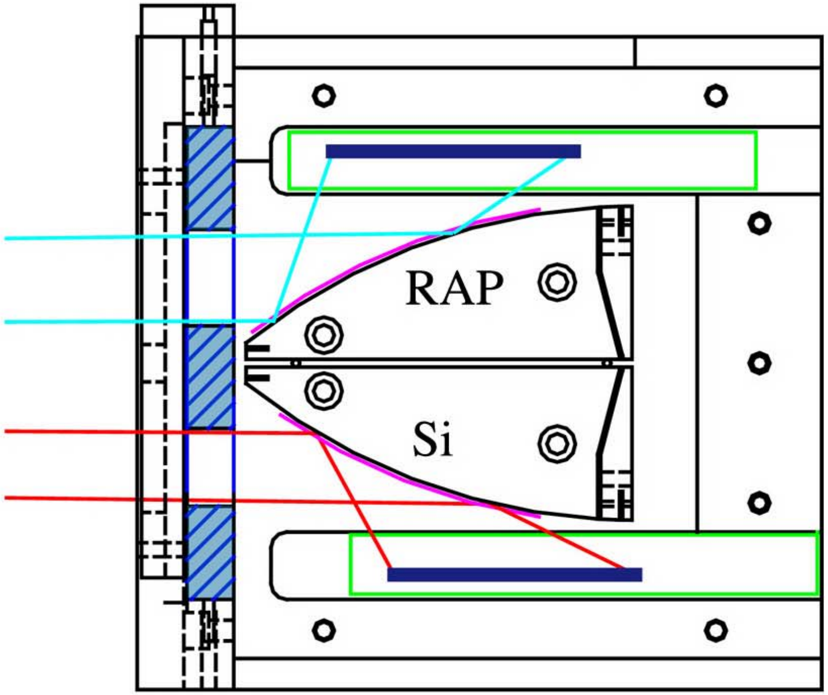


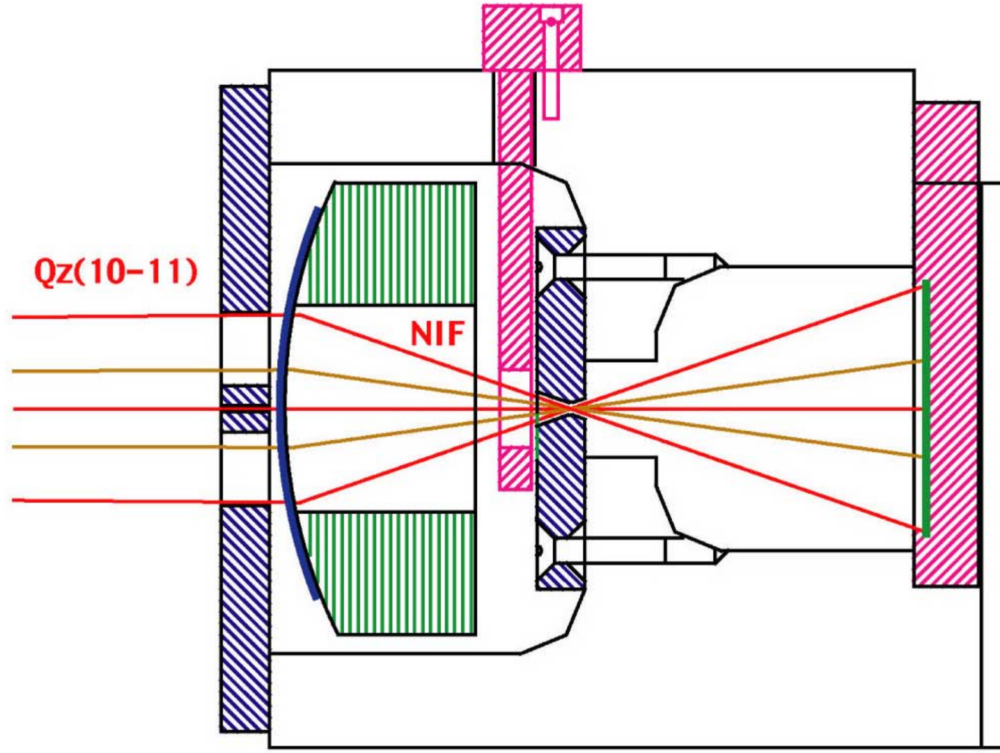
Optical Design

The Bragg diffraction condition:

$$\lambda = 2d \sin \theta$$

side views = plane of dispersion





4 Reflection Channels
Radius of curvature = 5.0 inches

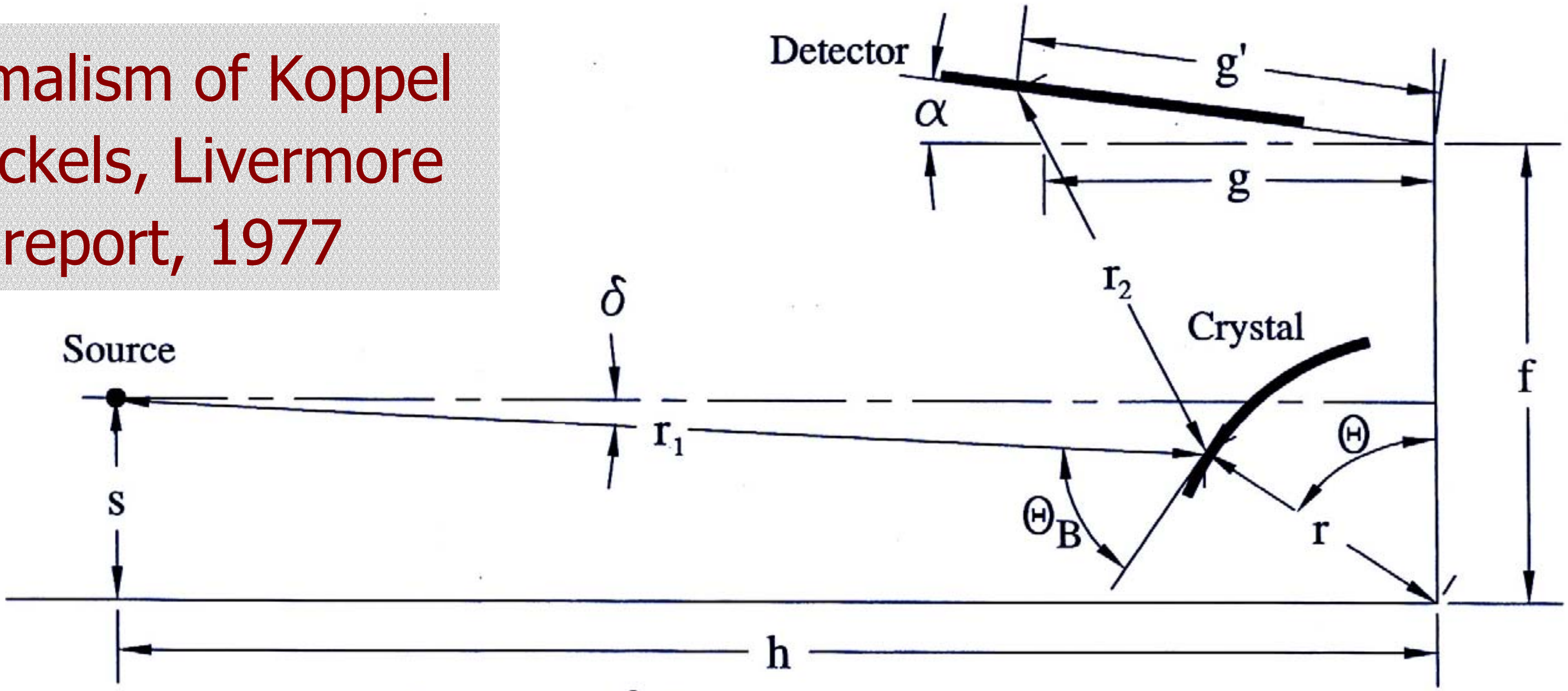
1 Transmission Channel
Radius of curvature = 4.7 inches

- using large-area detector entire 1 keV to 20 keV can be covered with four reflection channels

- low-resolution redundancy
- center-axis pinhole camera
- spectral information above 20 keV

CONVEX CRYSTAL DISPERSION GEOMETRY

Formalism of Koppel & Eckels, Livermore report, 1977



$$\delta = \tan^{-1}\left(\frac{s - r\cdot\cos\Theta}{h - r\cdot\sin\Theta}\right) \qquad \Theta_B = \Theta + \delta$$

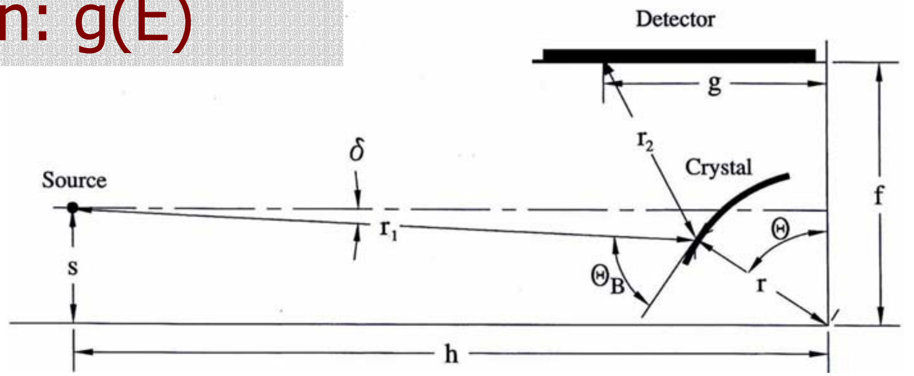
$$g = r\cdot\sin\Theta + (r\cdot\cos\Theta - f)\,/\,\tan\,(2\cdot\Theta + \delta)$$

$$g' = g\cdot\frac{\sin\,(2\cdot\Theta + \delta)}{\sin\,(2\cdot\Theta + \delta + \alpha)} \qquad r_1 = (h - r\cdot\sin\Theta)/\cos\delta$$

$$r_2 = (f - r\cdot\cos\Theta)/\sin\,(2\cdot\Theta + \delta) + g\cdot\frac{\sin\alpha}{\sin\,(2\cdot\Theta + \delta + \alpha)}$$

Convex crystal spectrometer plate function: g(E)

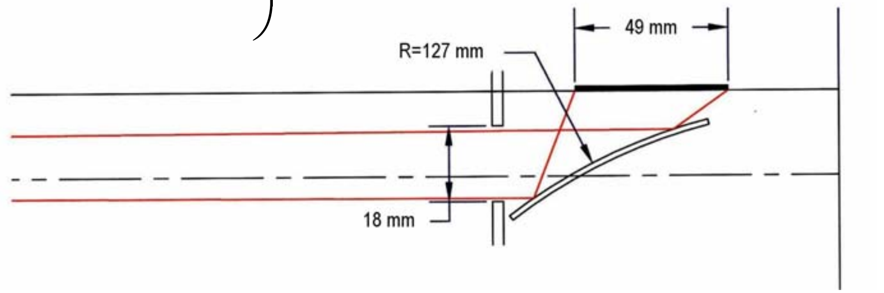
$$g = r \cdot \sin(\theta_B - \delta) + \frac{r \cdot \cos(\theta_B - \delta) - f}{\tan(2\theta_B - \delta)}$$



where

$$\delta = \arcsin\left(\frac{(-r \cdot h \cdot \cos\theta_B) + s \cdot \sqrt{h^2 + s^2 - r^2 \cdot (\cos\theta_B)^2}}{h^2 + s^2}\right)$$

$$\theta_B = \arcsin\left(\frac{12.3984\text{keV} \cdot \text{Å}}{E \cdot 2d}\right)$$

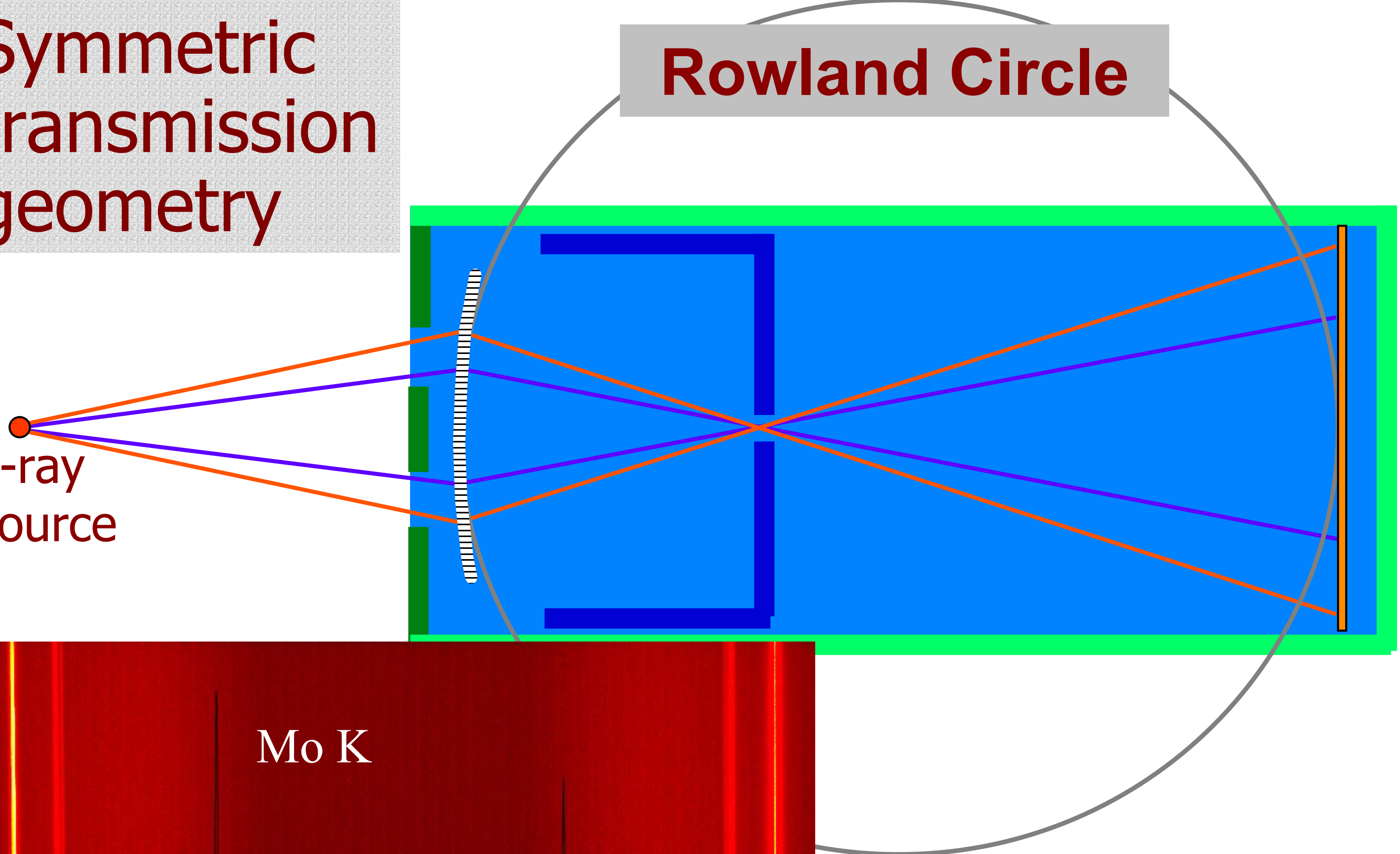


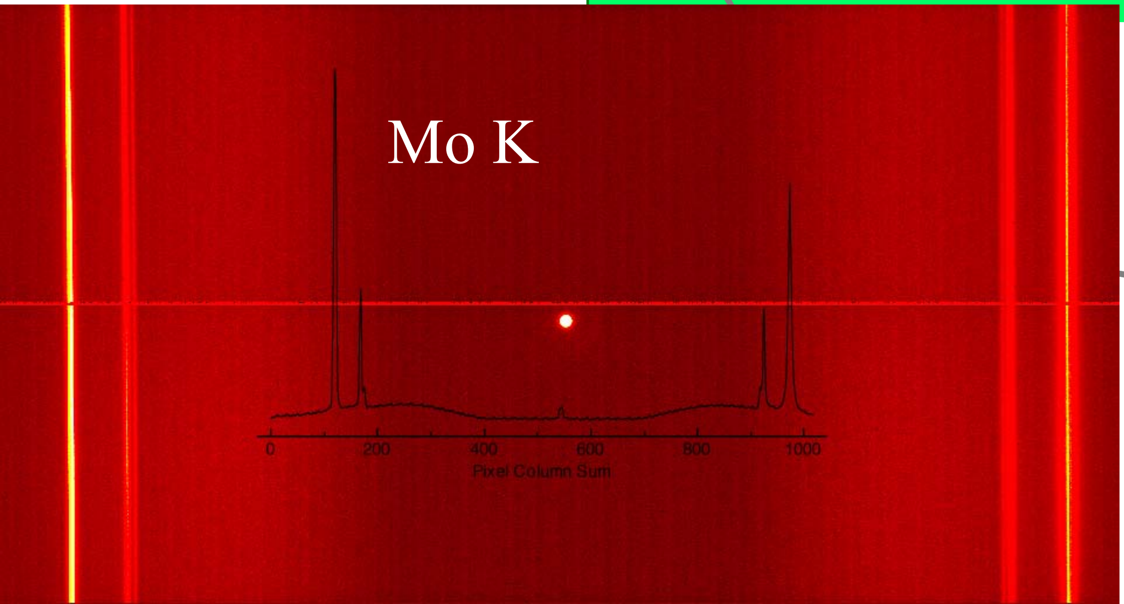
E = x-ray energy
d = crystal lattice spacing
f = 138 mm, height of sensor above origin
r = 127 mm, crystal radius of curvature

at LLE:

h = 584.7 mm, source-to-origin horizontal distance
s = 94.7674 mm, source-to-origin vertical distance

Symmetric transmission geometry

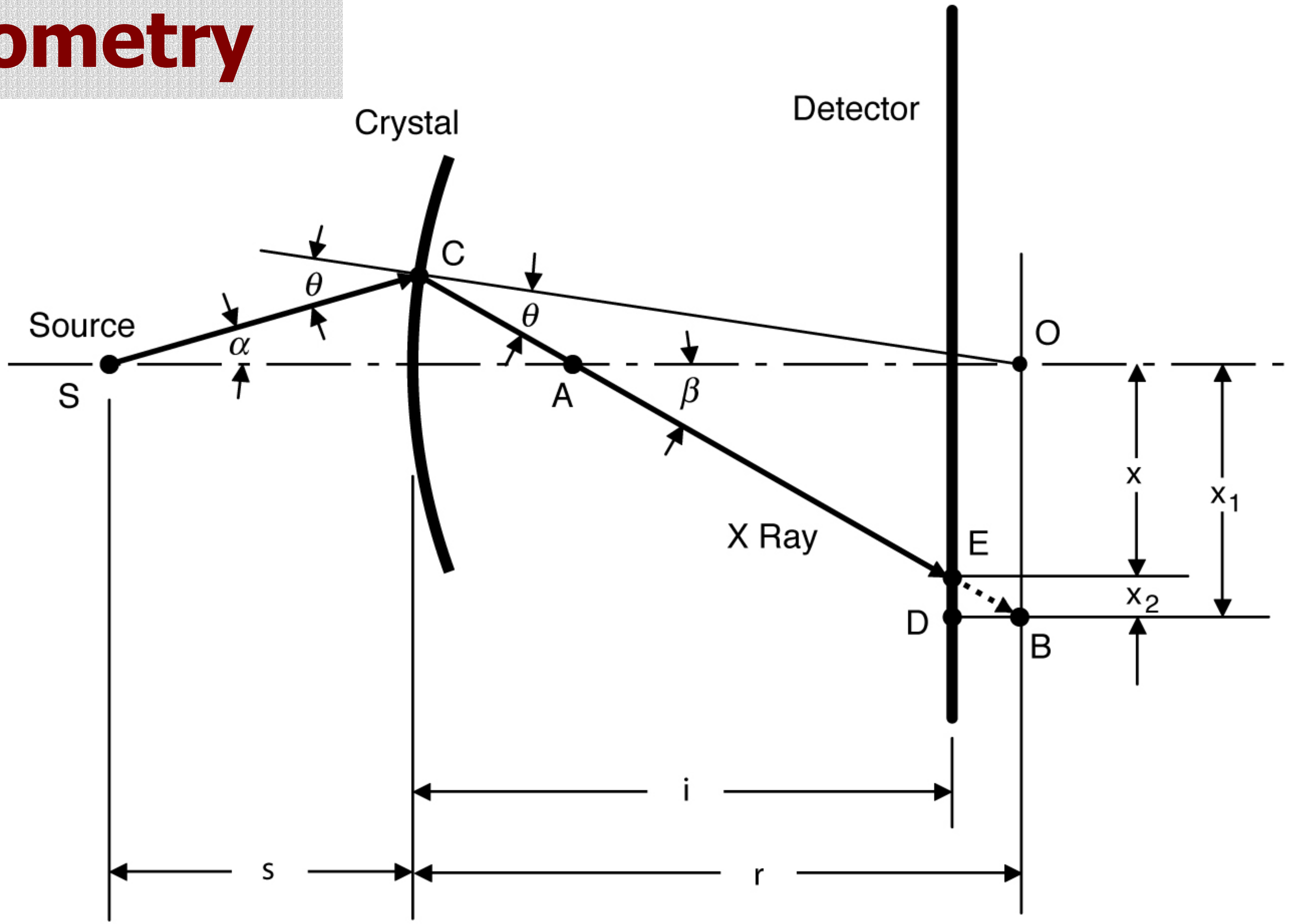




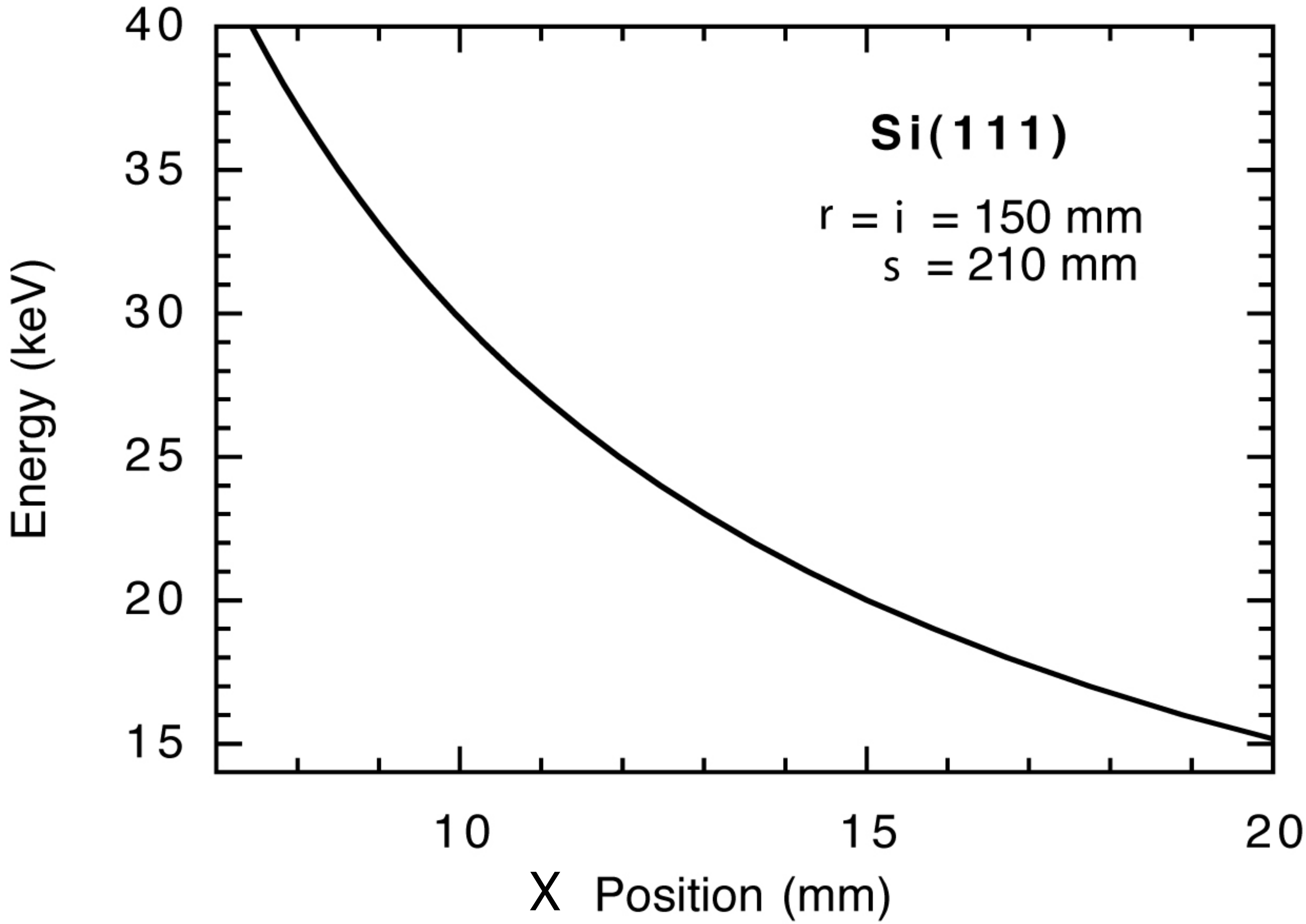
Symmetric Laue spectrometer gives mirror spectra

Laue crystal geometry

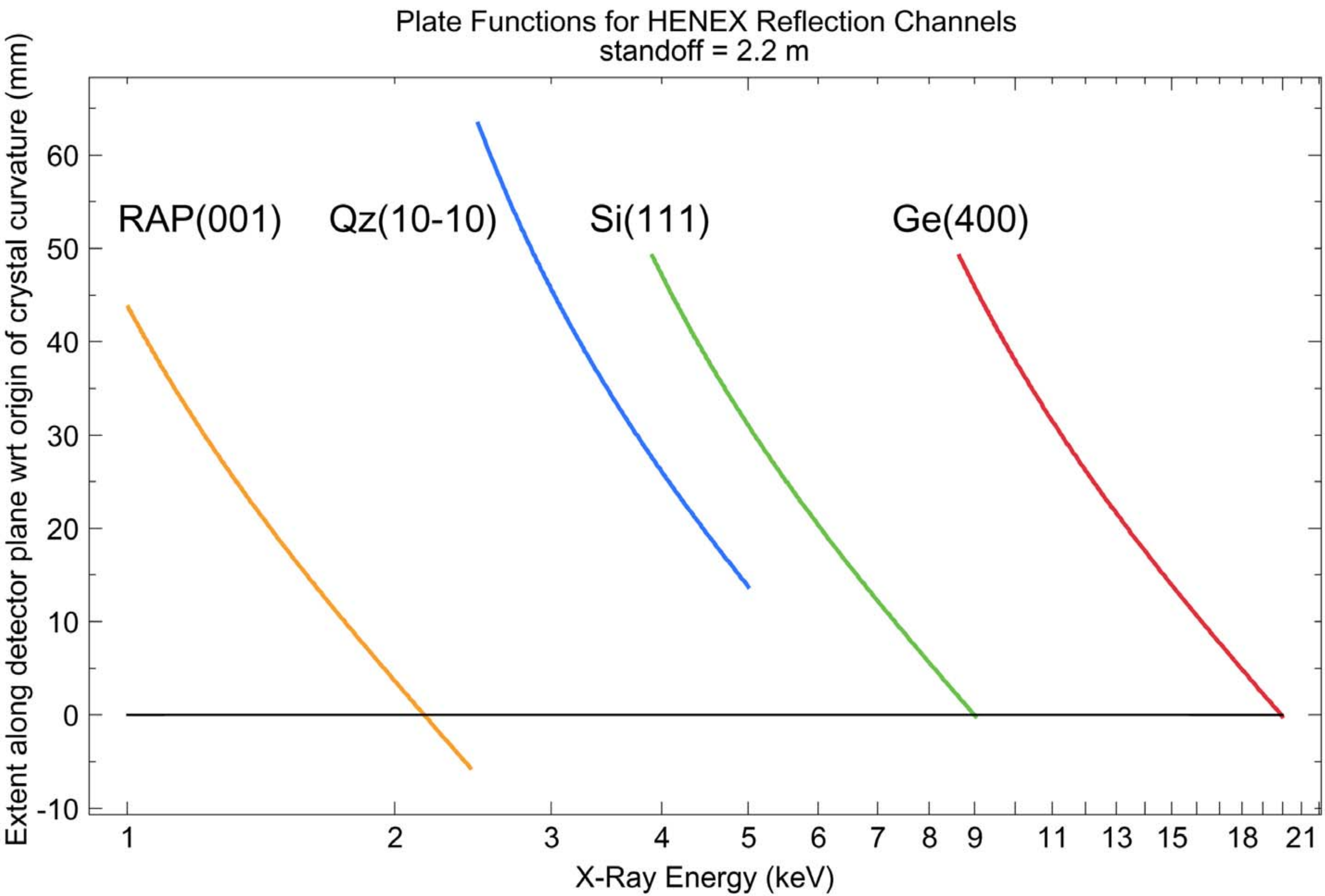
$$E^2 \cong \frac{a}{x^2} + b$$

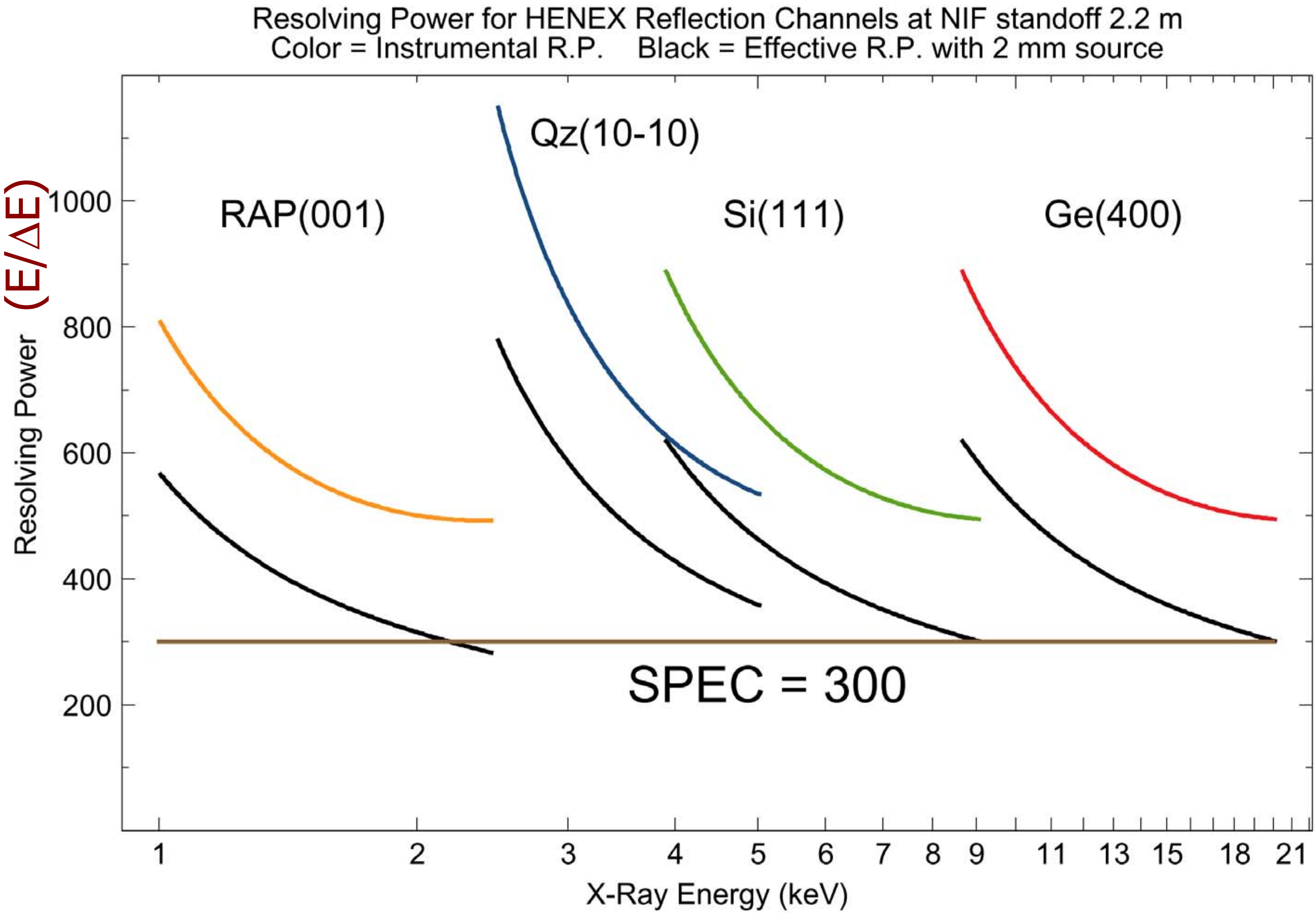


$$E^2 \cong \frac{a}{x^2} + b$$



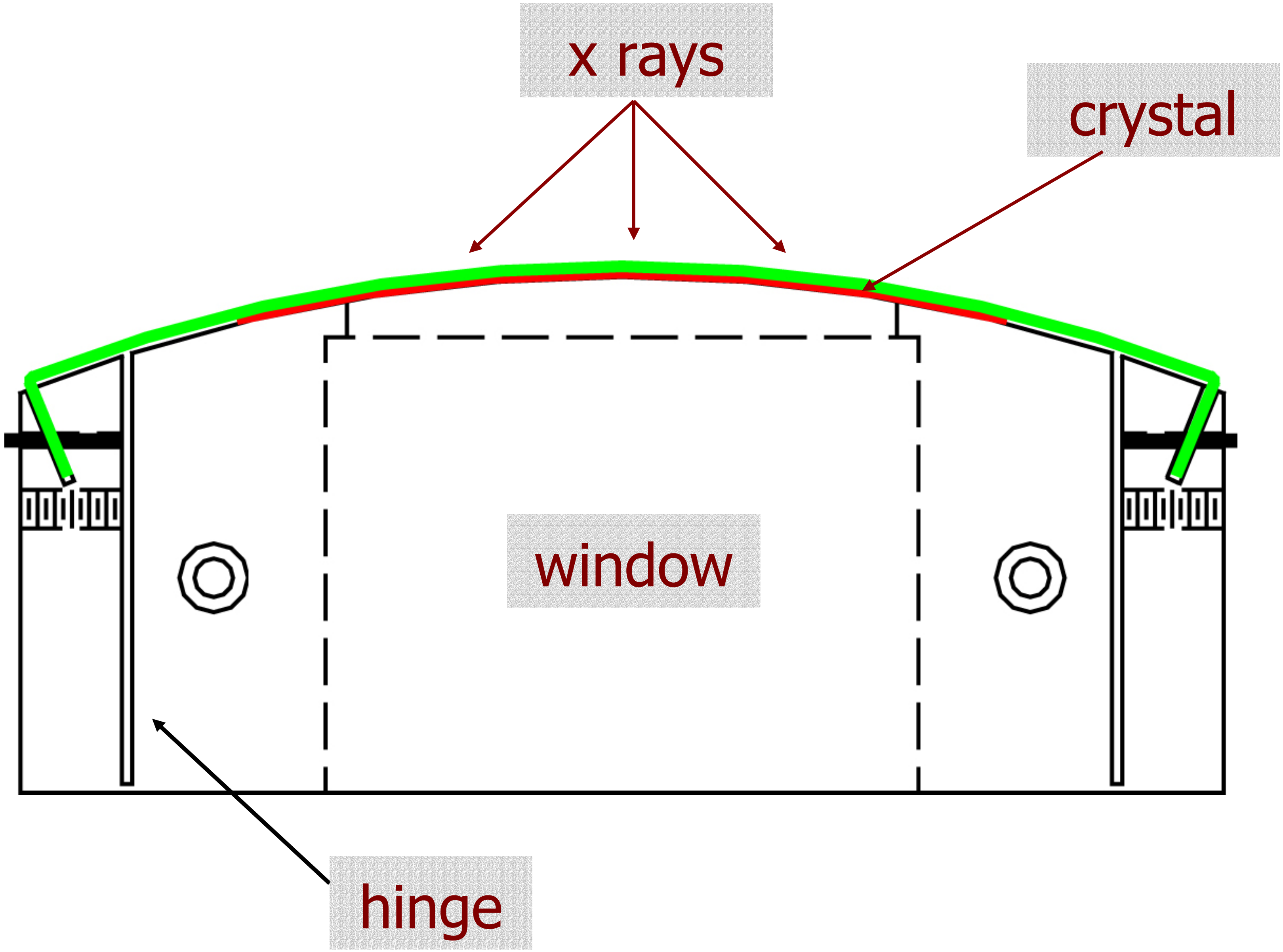
Initial choice of crystals to meet optical design



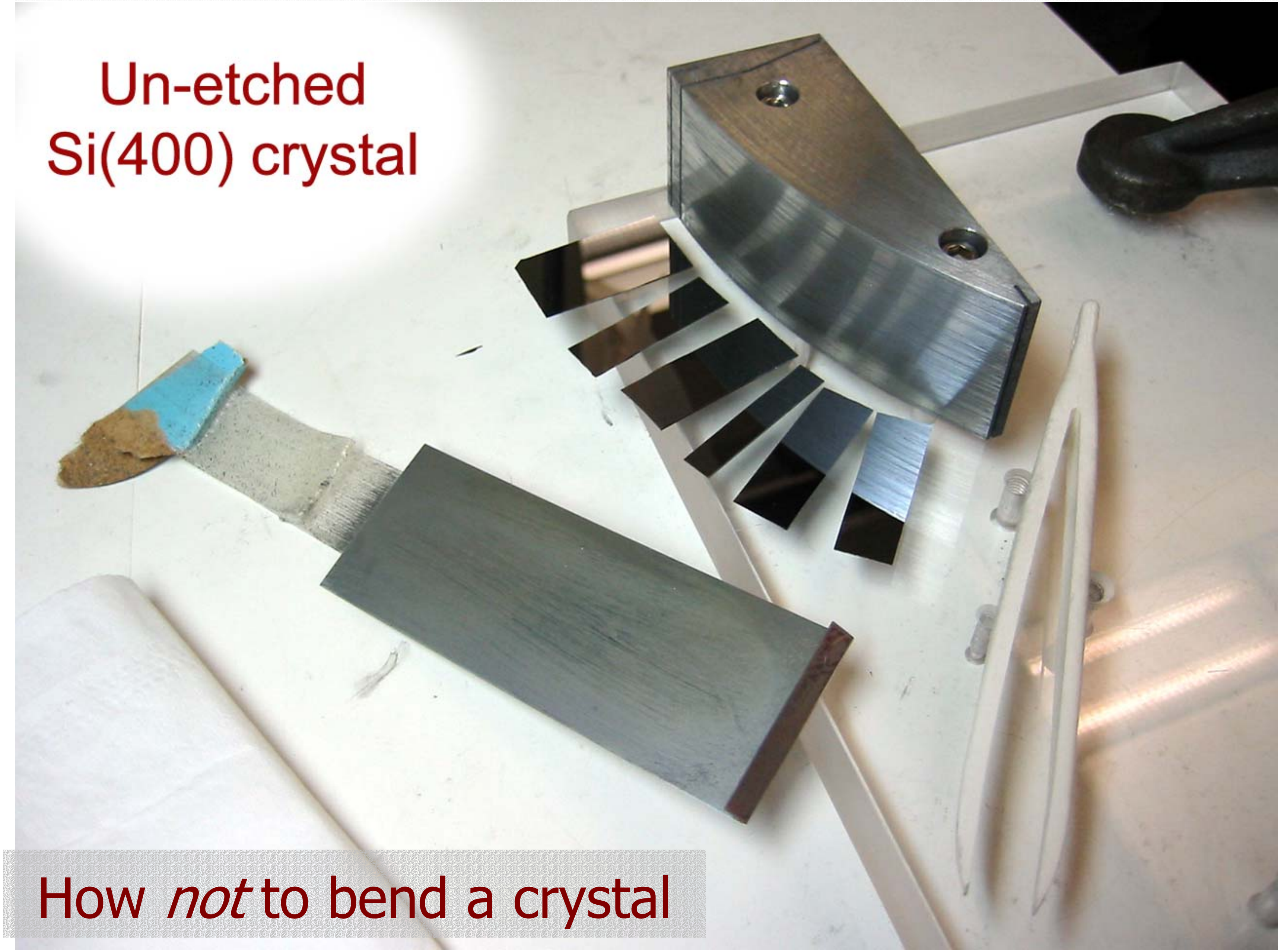

Resolving Power for HENEX Reflection Channels at NIF standoff 2.2 m
Color = Instrumental R.P.   Black = Effective R.P. with 2 mm source
Qz(10-10)
RAP(001)
Si(111)
Ge(400)
SPEC = 300
Resolving Power (E/ΔE)
1000
800
600
400
200
1
2
3
4
5
6
7
8
9
11
13
15
18
21
X-Ray Energy (keV)

The art of crystal bending

Transmission bent-crystal mount

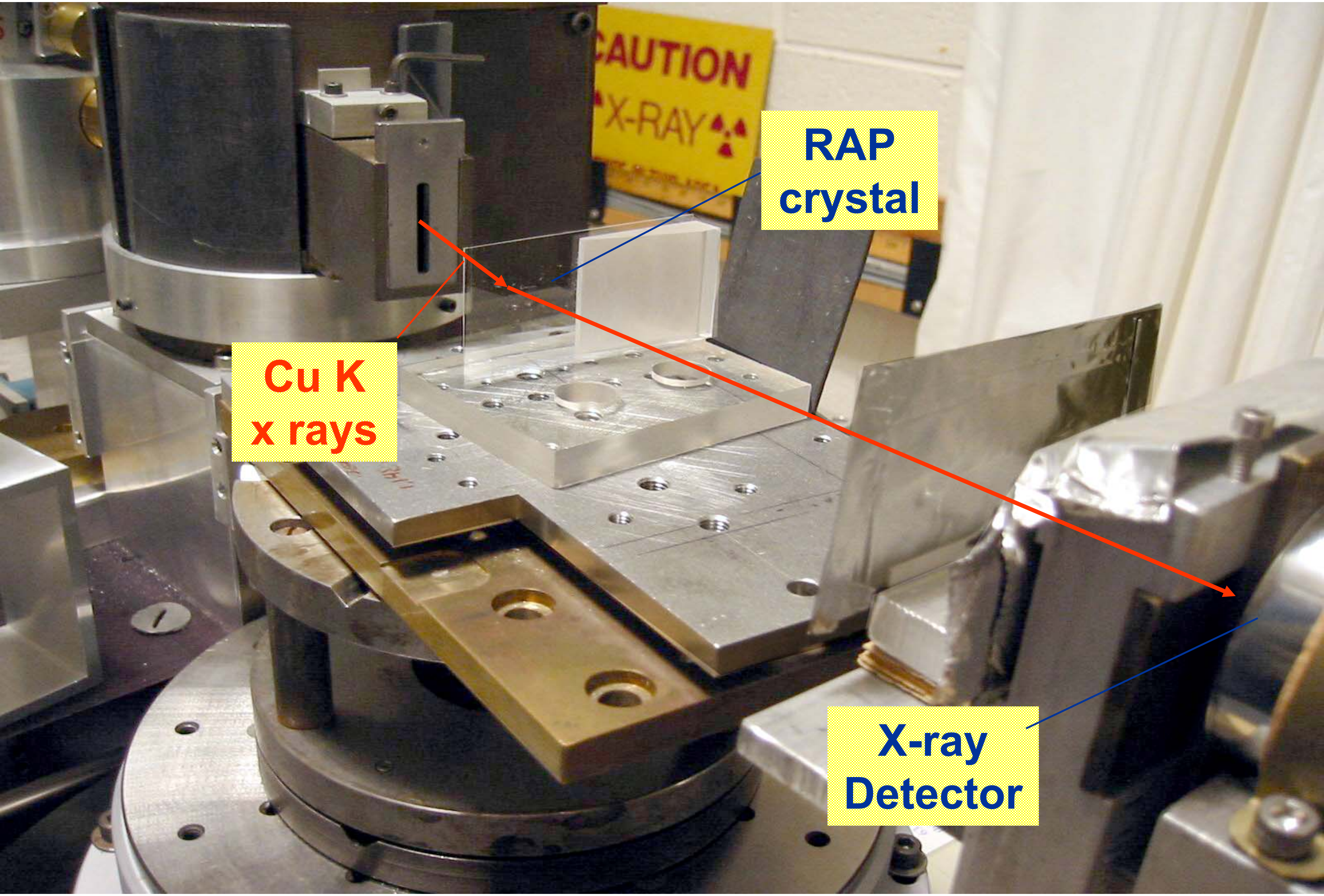


Convex bent-crystal mount



How *not* to bend a crystal

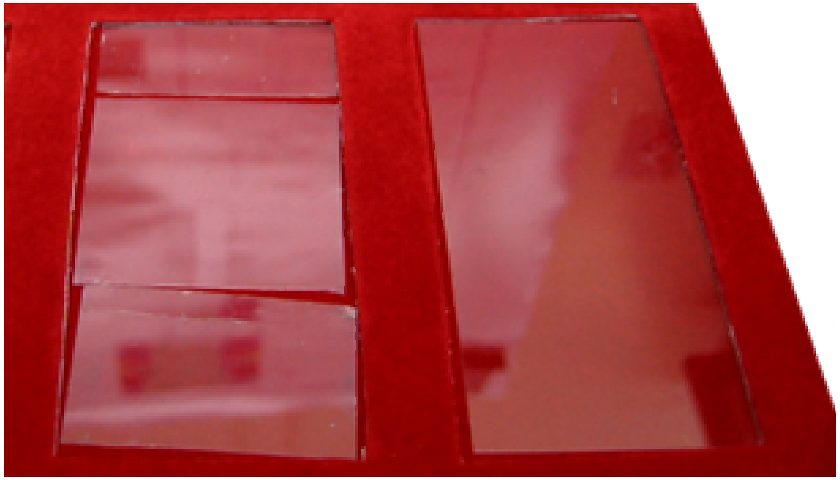
Determine complete 3D orientation

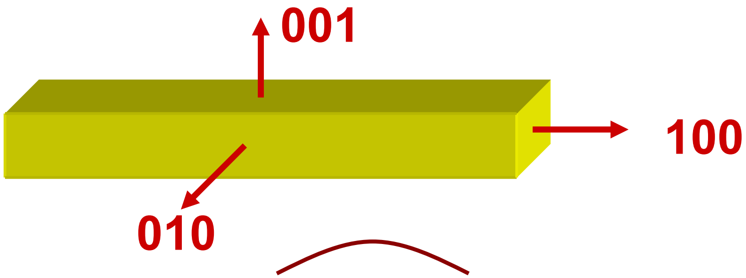


Crystal orientation was determined using these reflection & transmission planes and Cu K x rays

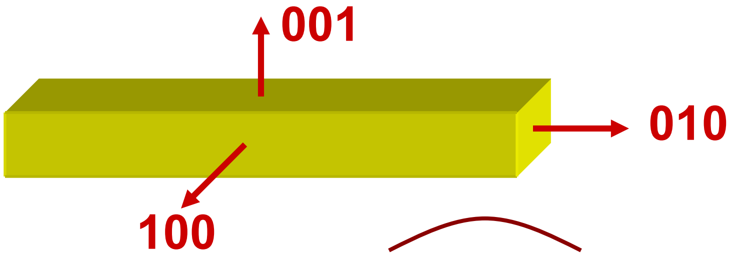
RAP(001)

	lattice spacing (Å)	Bragg angle (deg)
0 0 1	13.06	**3.38**
2 0 0	3.275	**13.60**
0 2 0	5.01	**8.84**

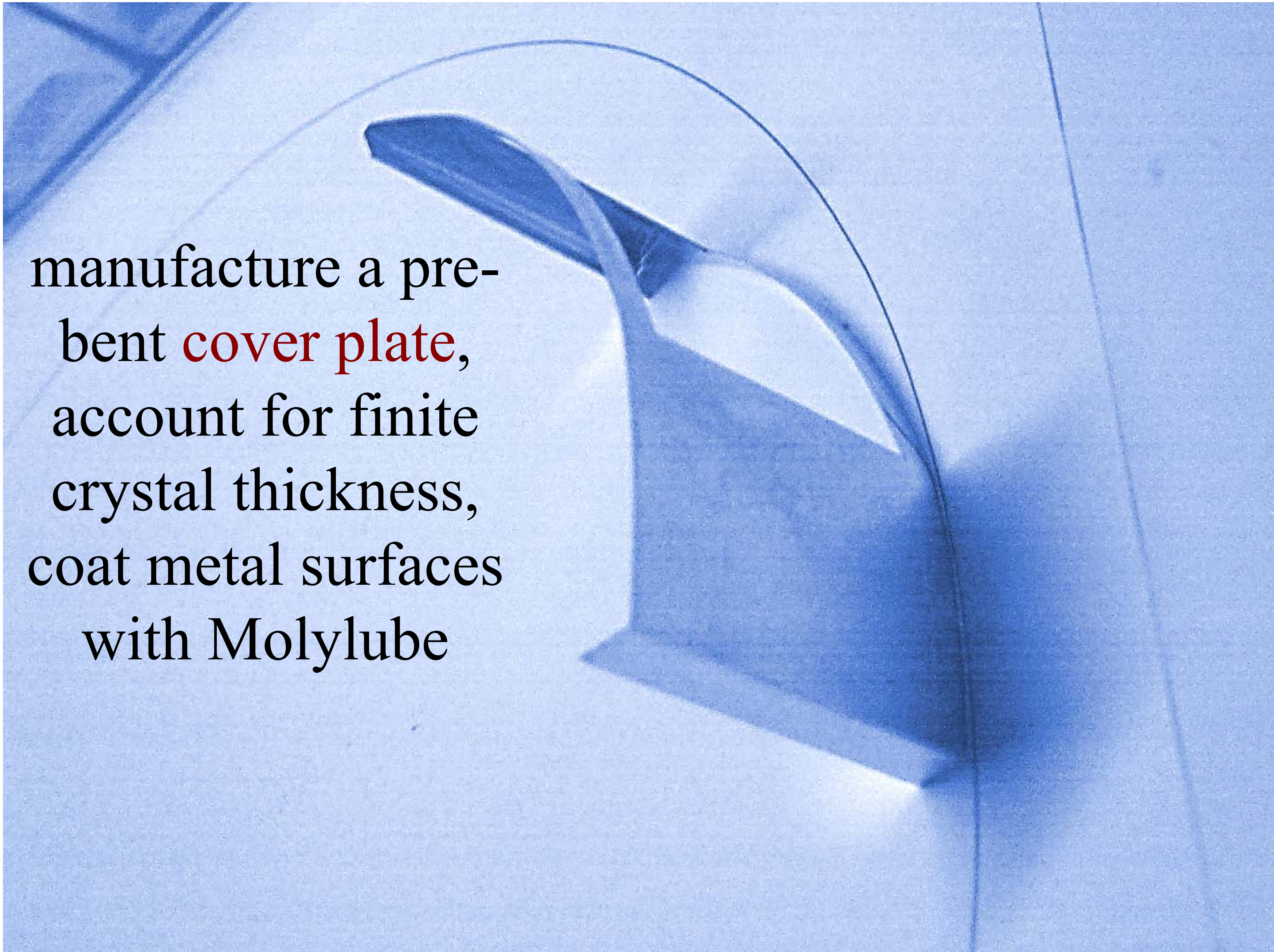


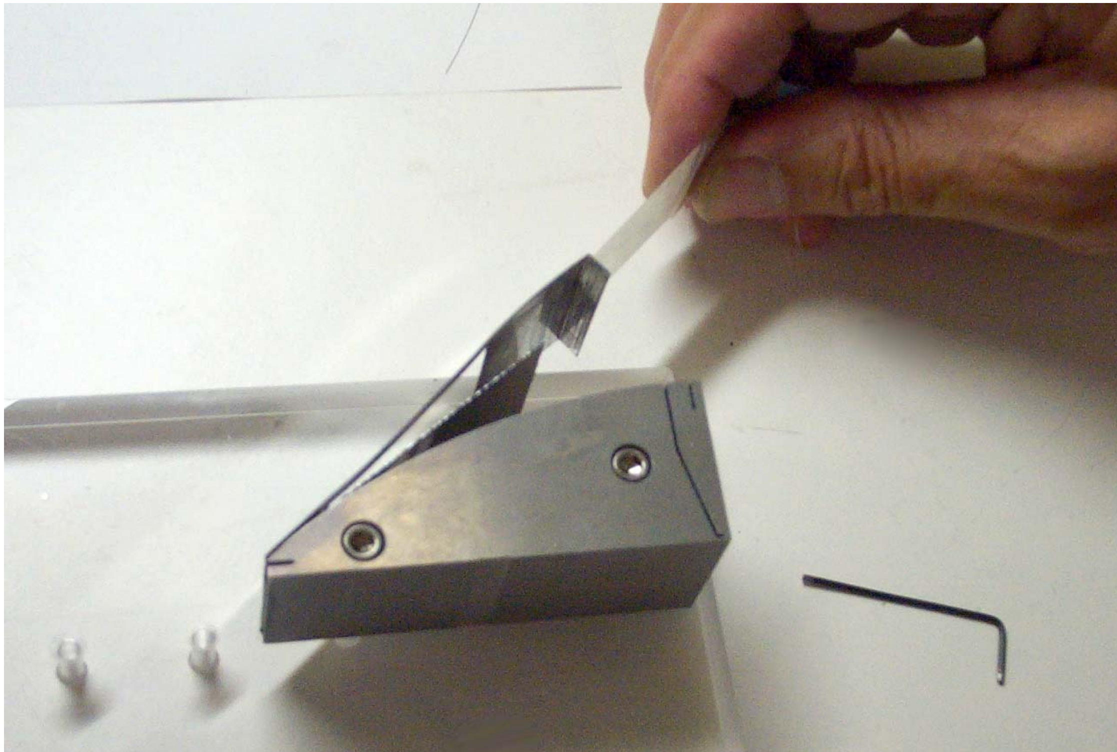


Breaks when bent

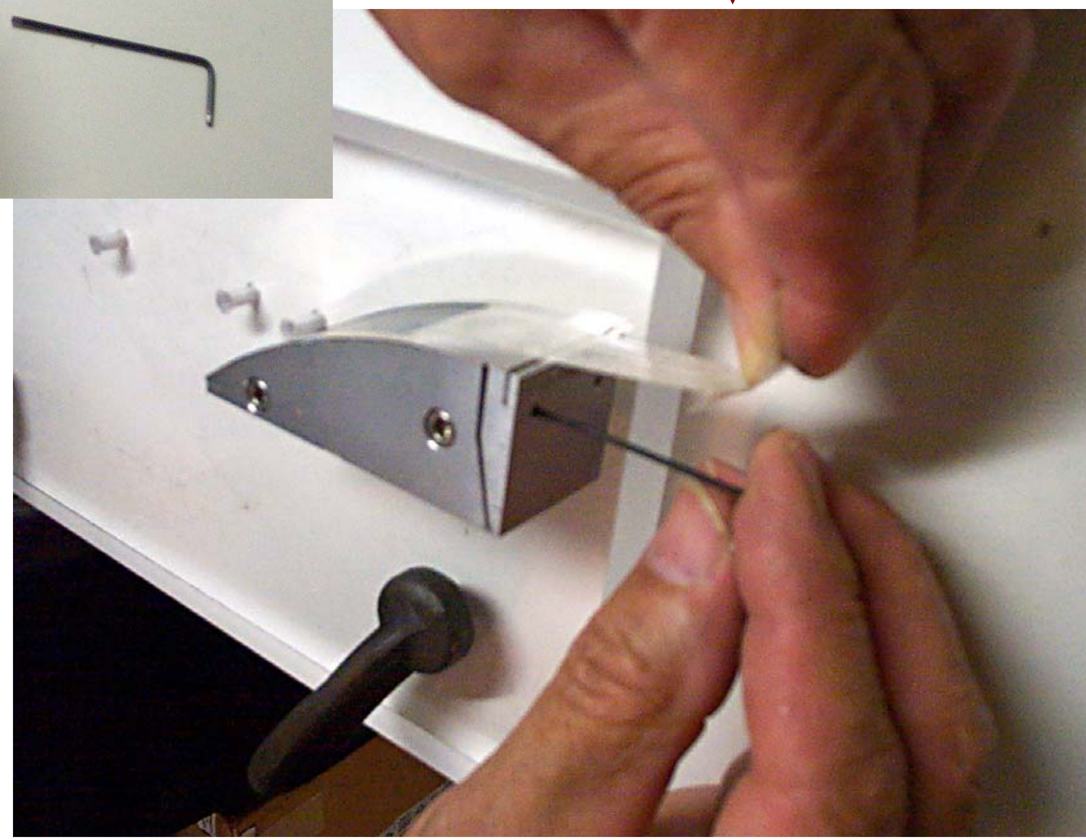


Bends without breaking


manufacture a pre-bent cover plate,
account for finite crystal thickness,
coat metal surfaces with Molylube

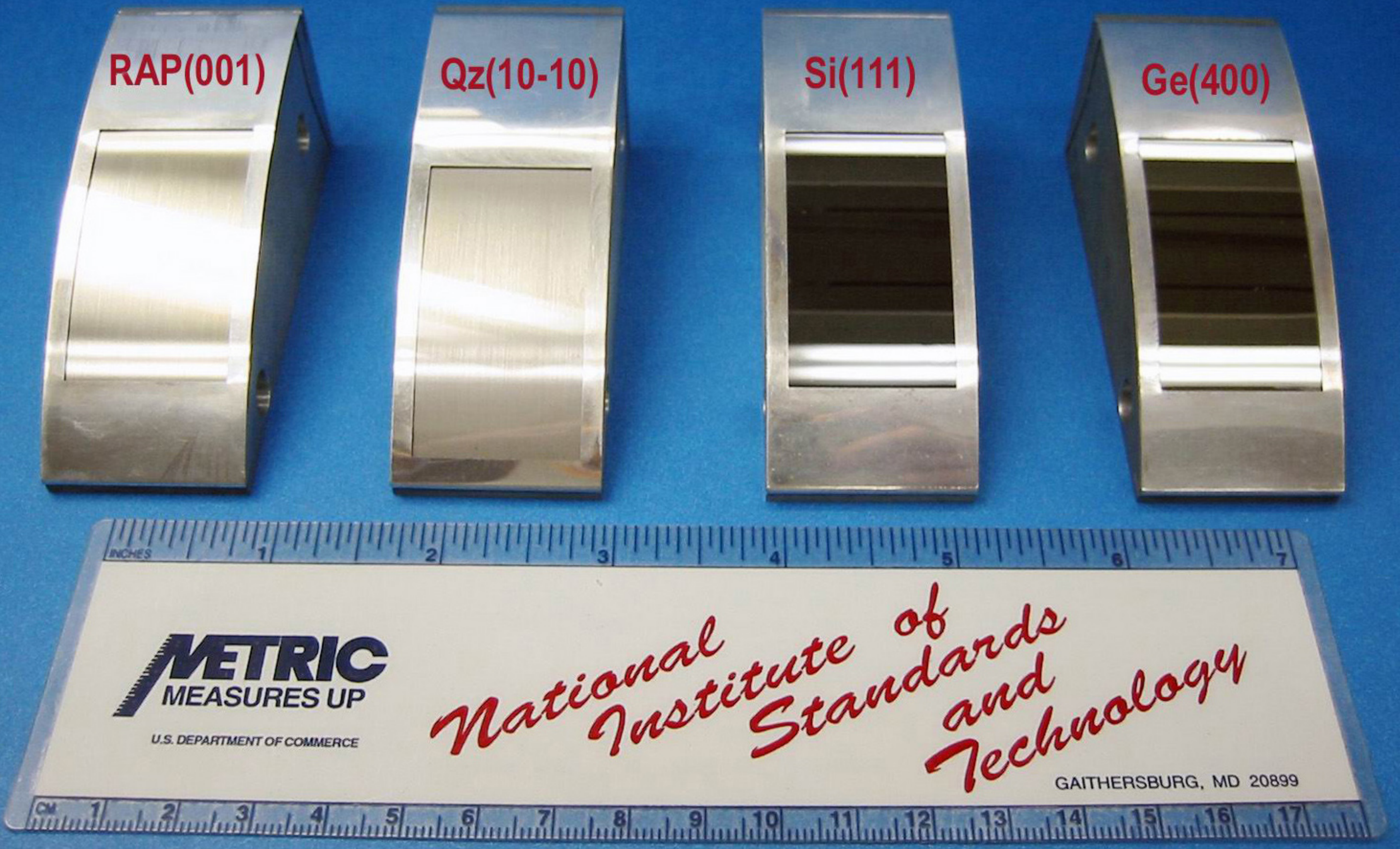


hold breath now!!!

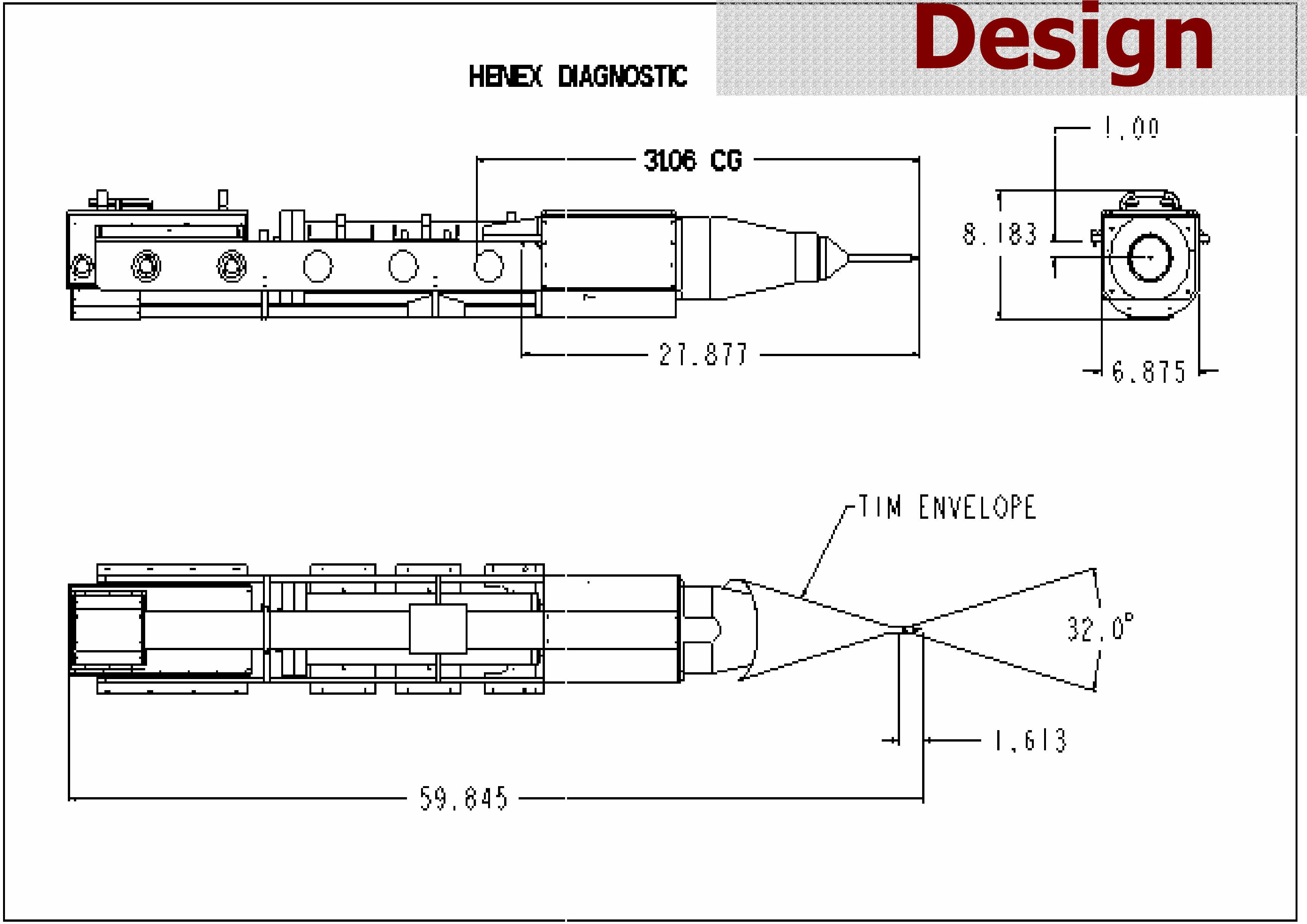


bending a silicon crystal

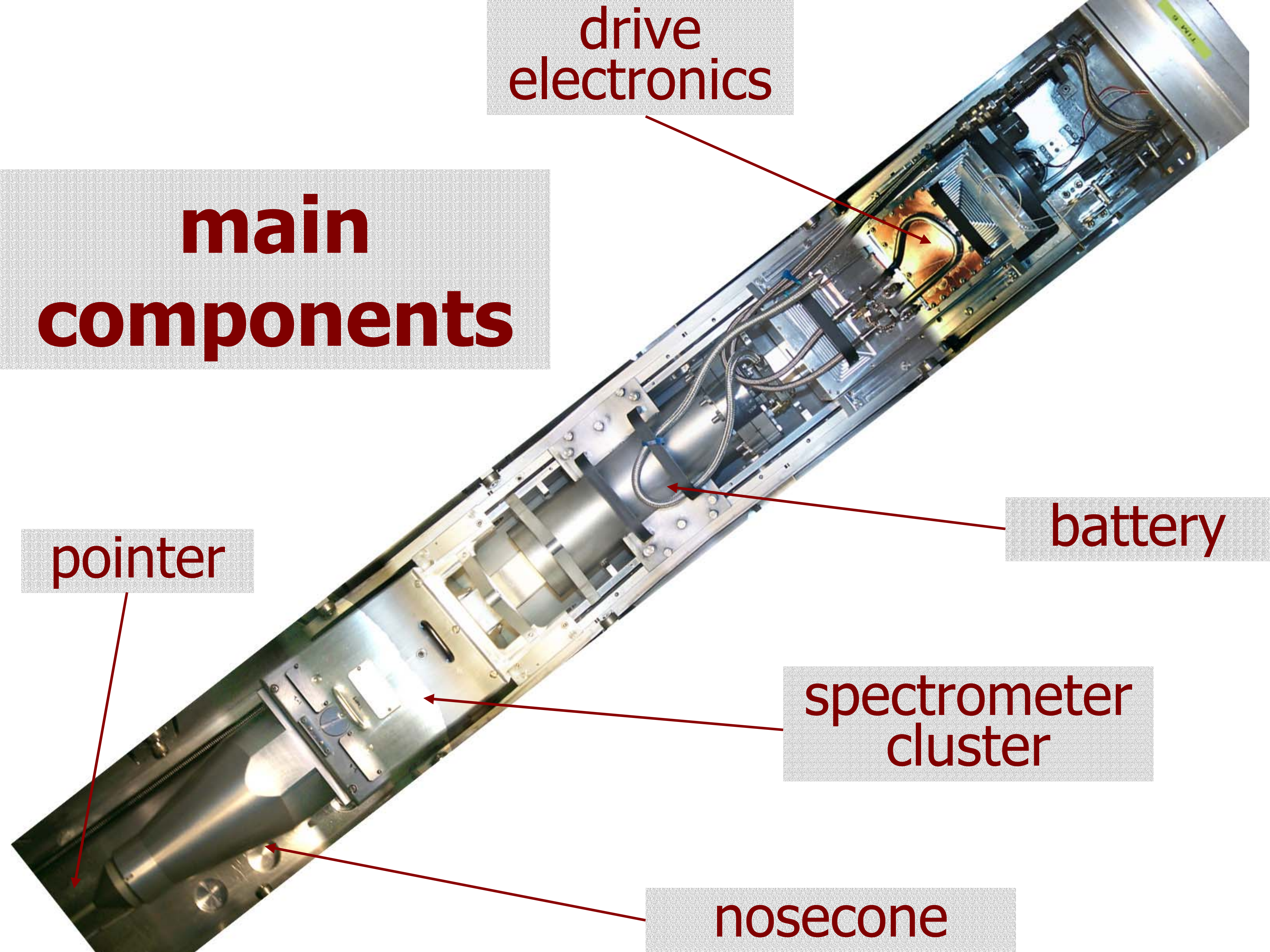
127 mm radius of curvature



Mechanical Design

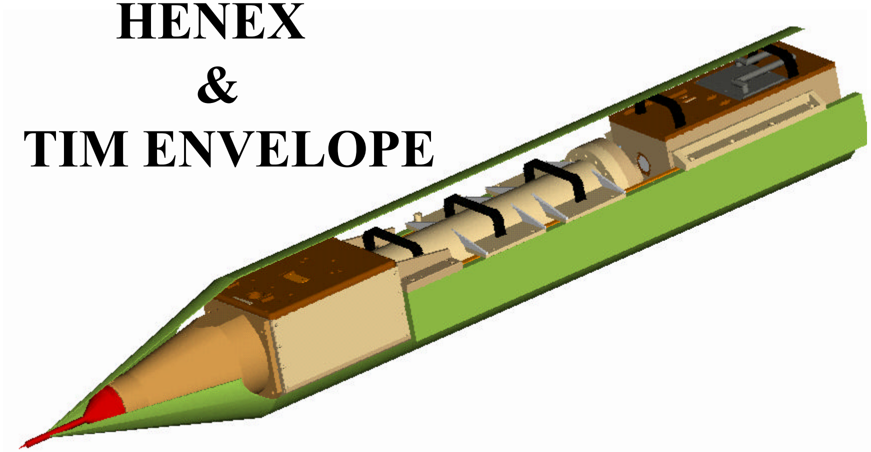


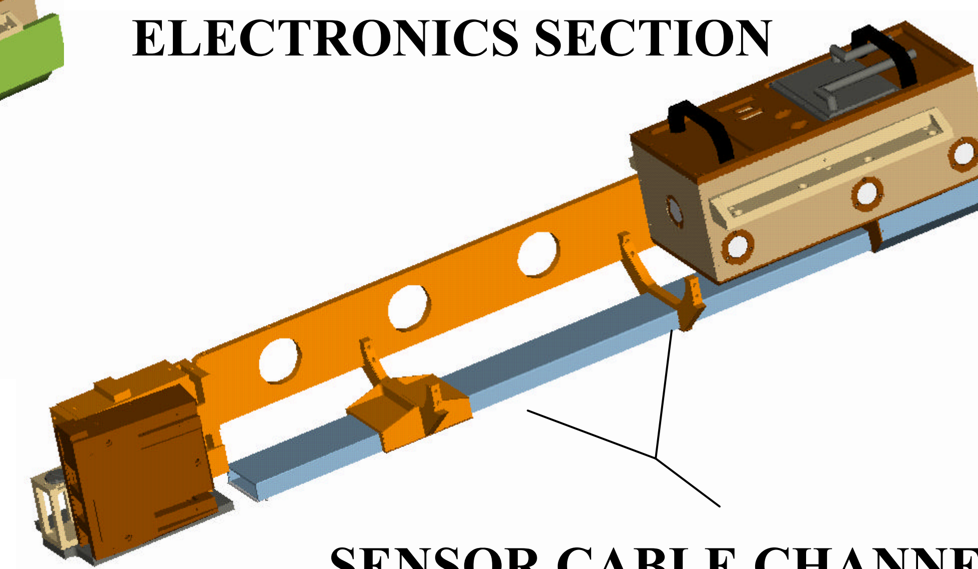
main components

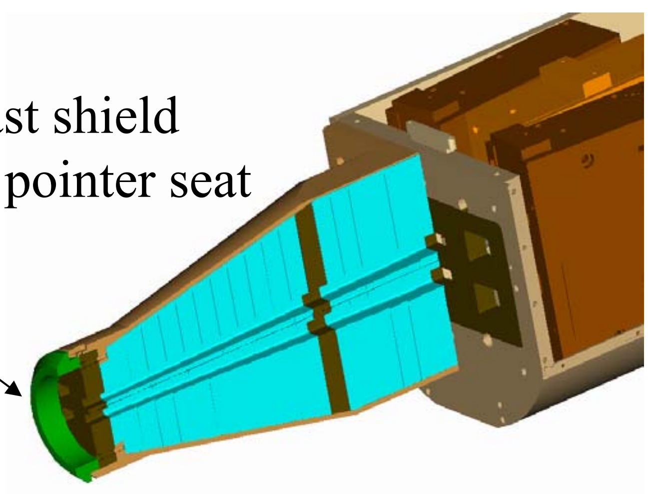


3D view of HENEX

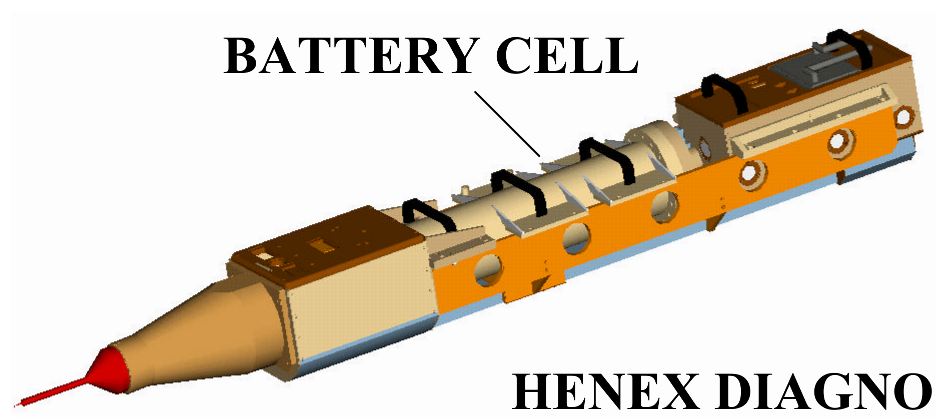
NIF
The National Ignition Facility



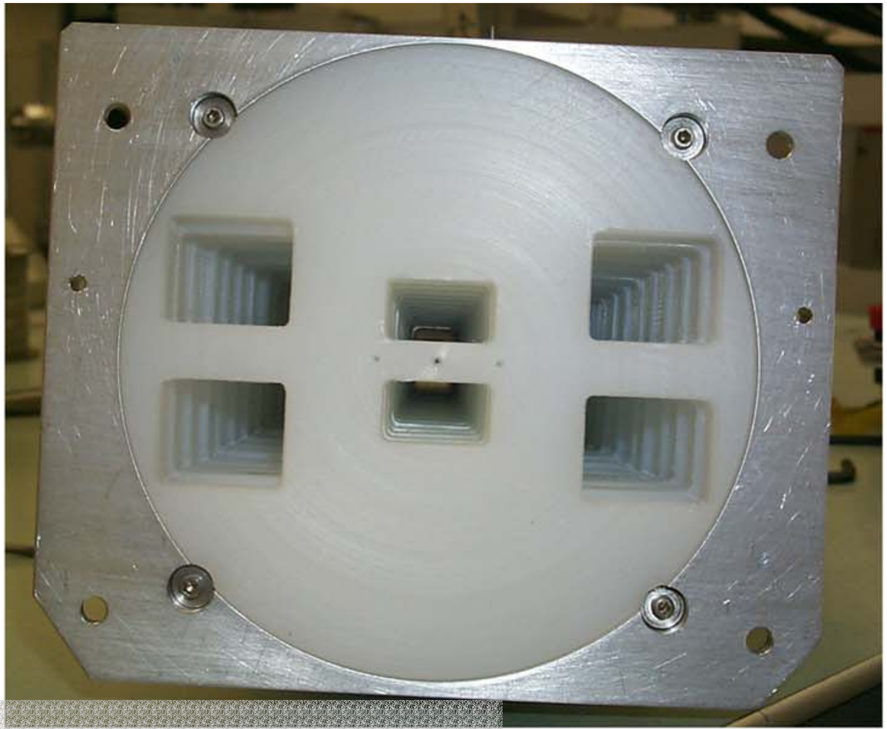




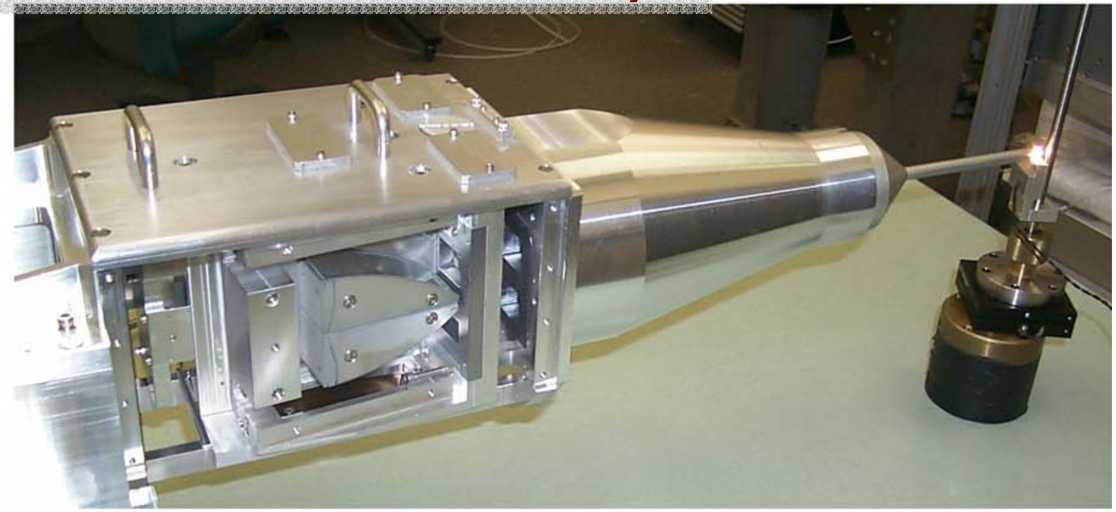
CUTAWAY OF NOSECONE
ATTACHED TO
SPECTROMETER BOX

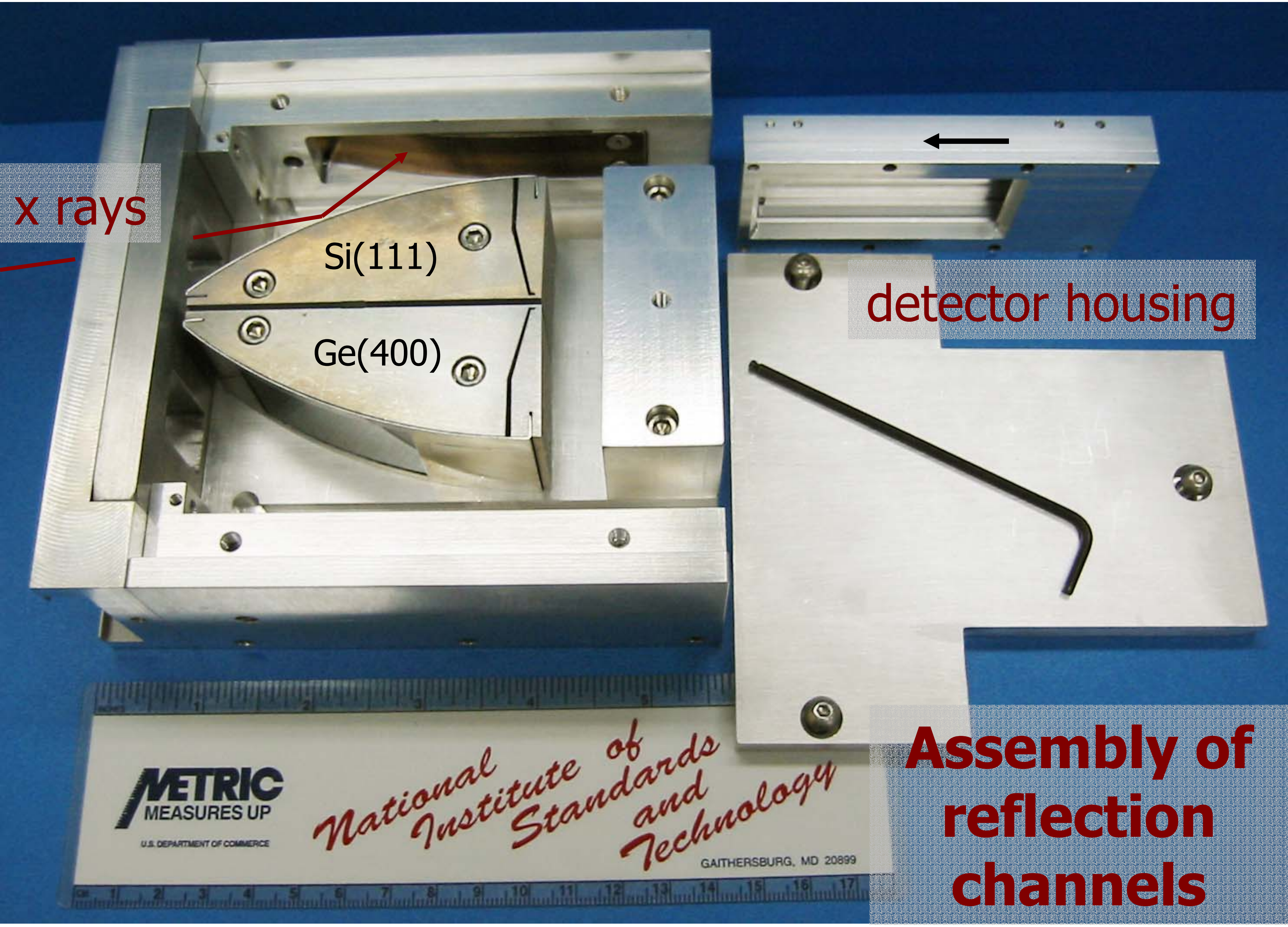


HENEX DIAGNOSTIC
MASS < 100 lb.

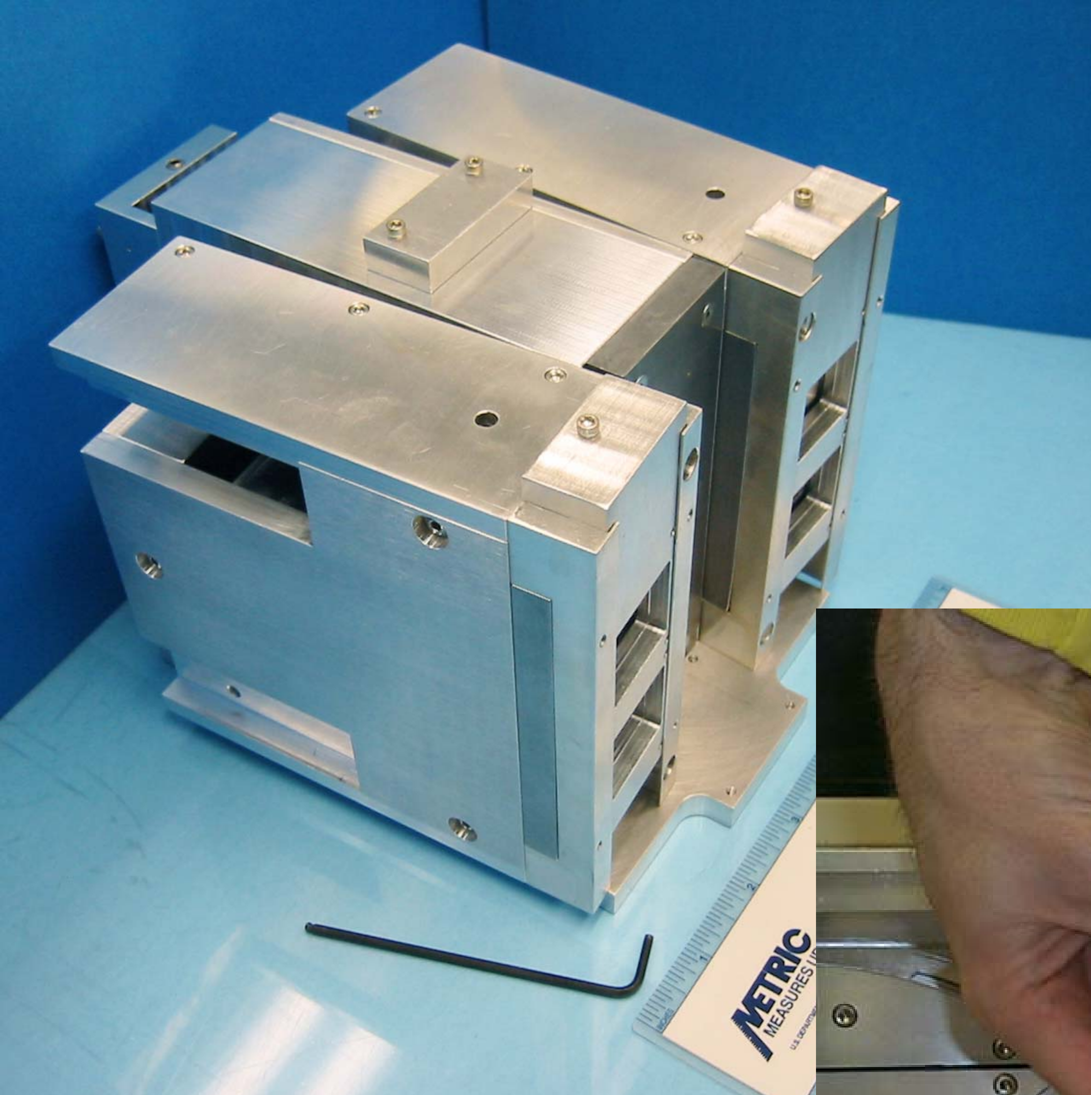


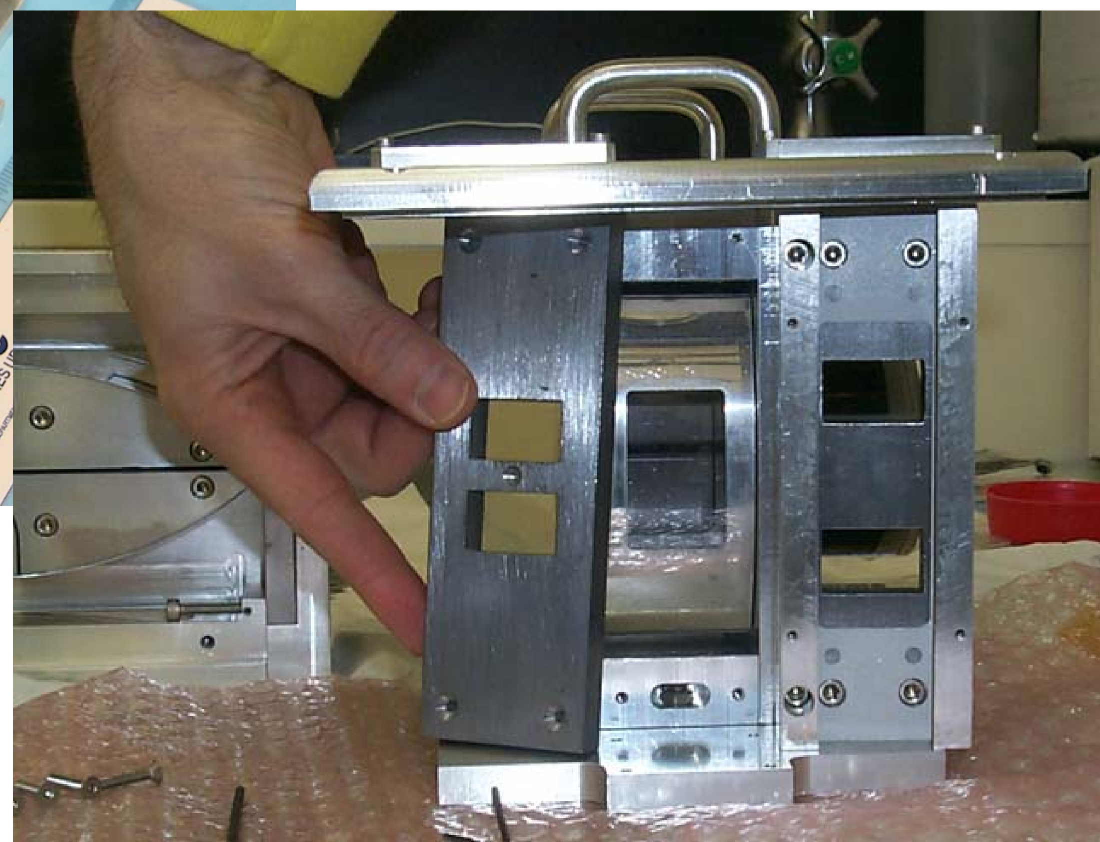
Nosecone assembly

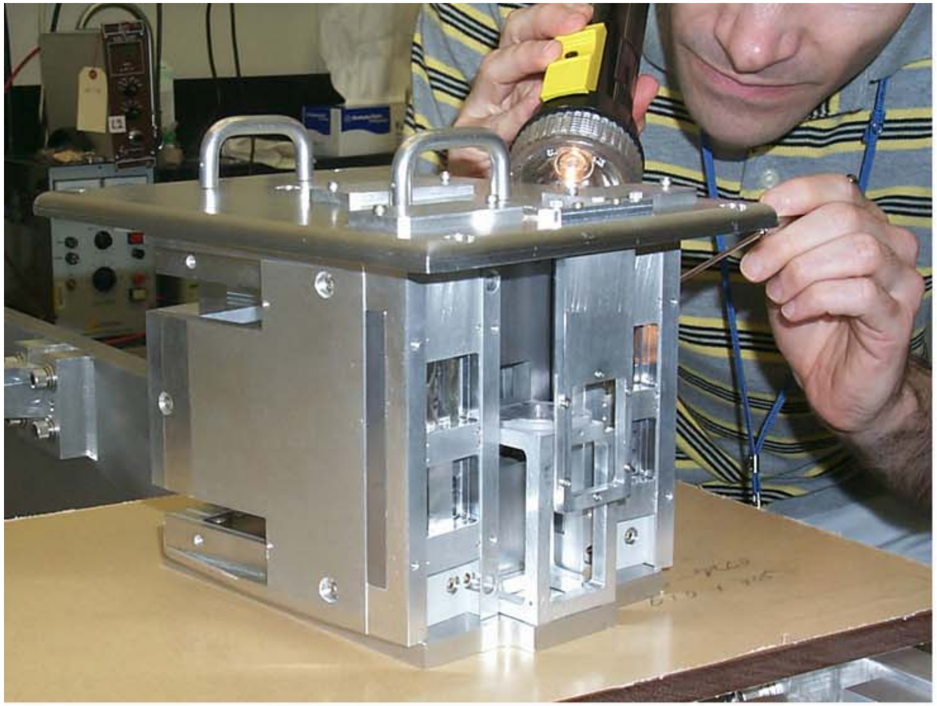



x rays
Si(111)
Ge(400)
detector housing
Assembly of reflection channels
METRIC
MEASURES UP
U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
GAITHERSBURG, MD 20899

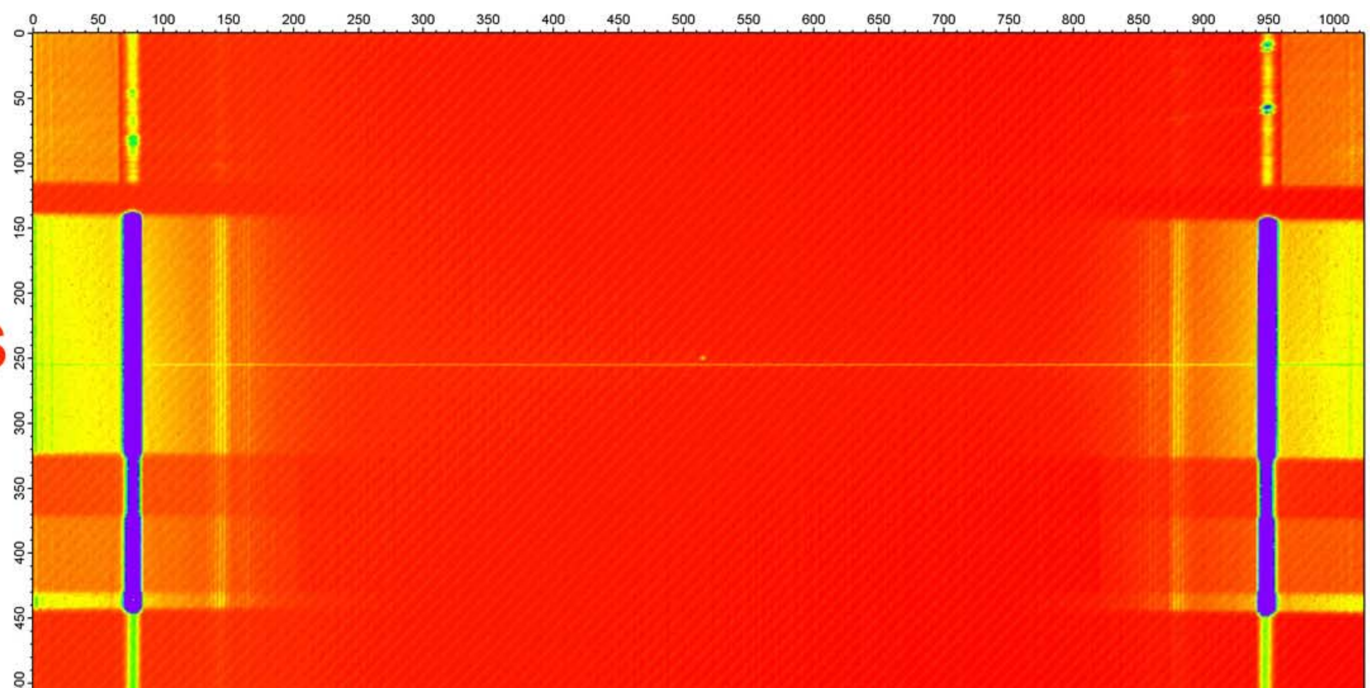
Assembly of the spectrometer cluster



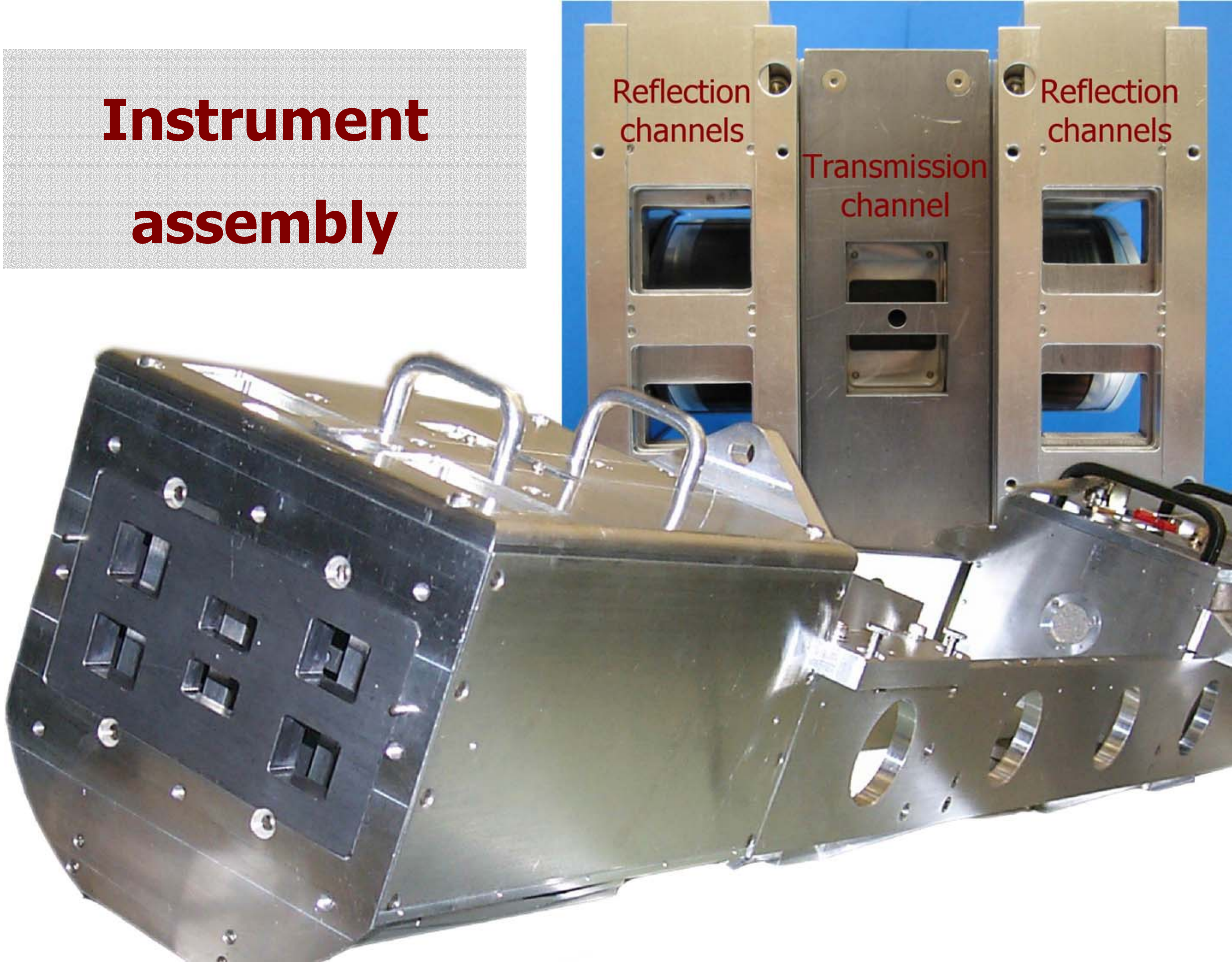




Filter Assemblies



Instrument assembly



If you know how to eat Maryland crabs, then you can make a lithium ion battery array...

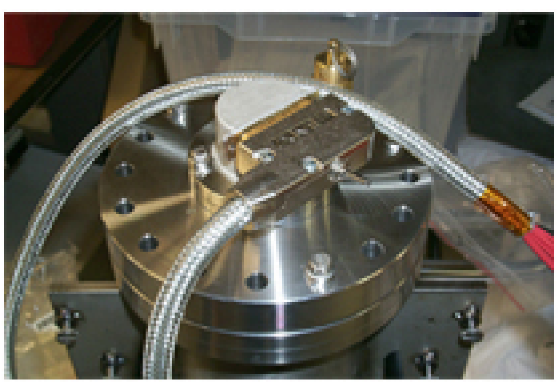
Sony Lithium Ion
NP-F960
7.2VDC, 5400mAh

Maryland Blue Crab

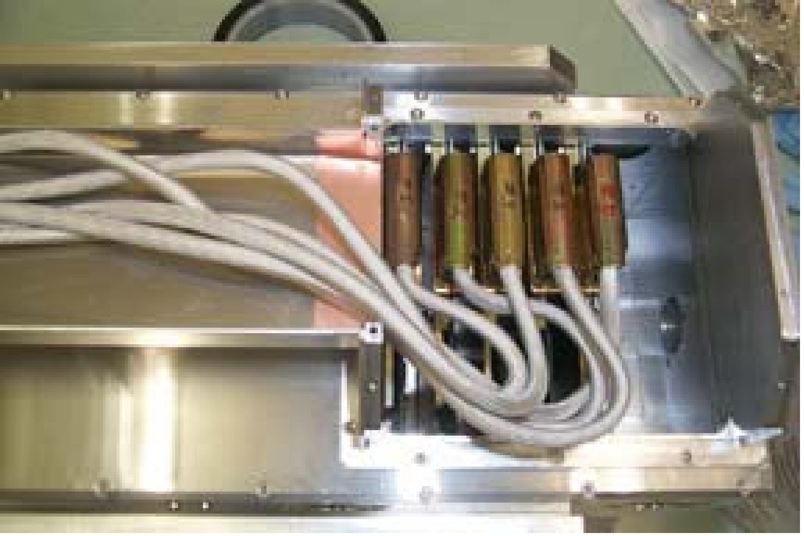
Use a Saw, not a Hammer

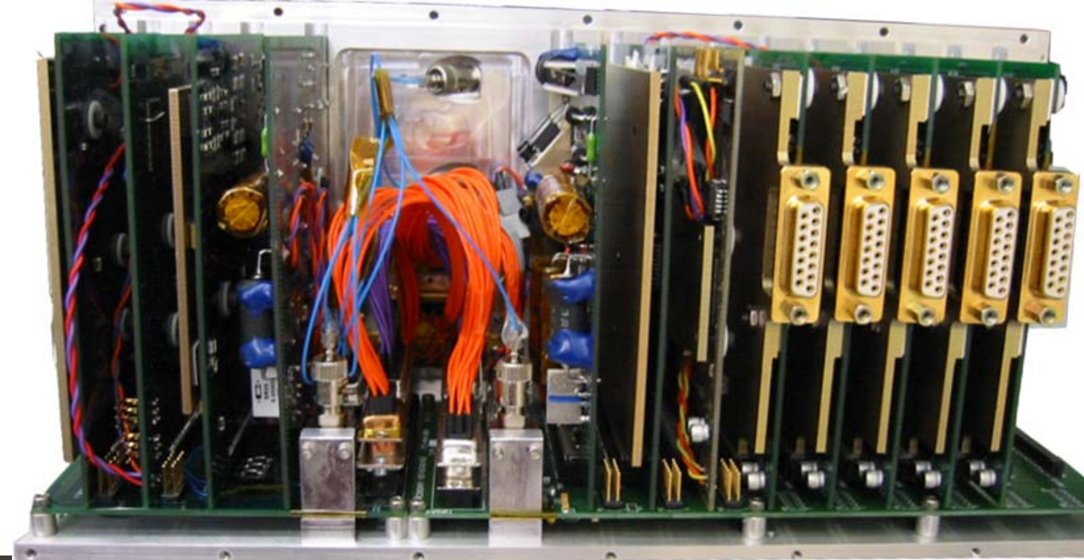
Crack and Peel

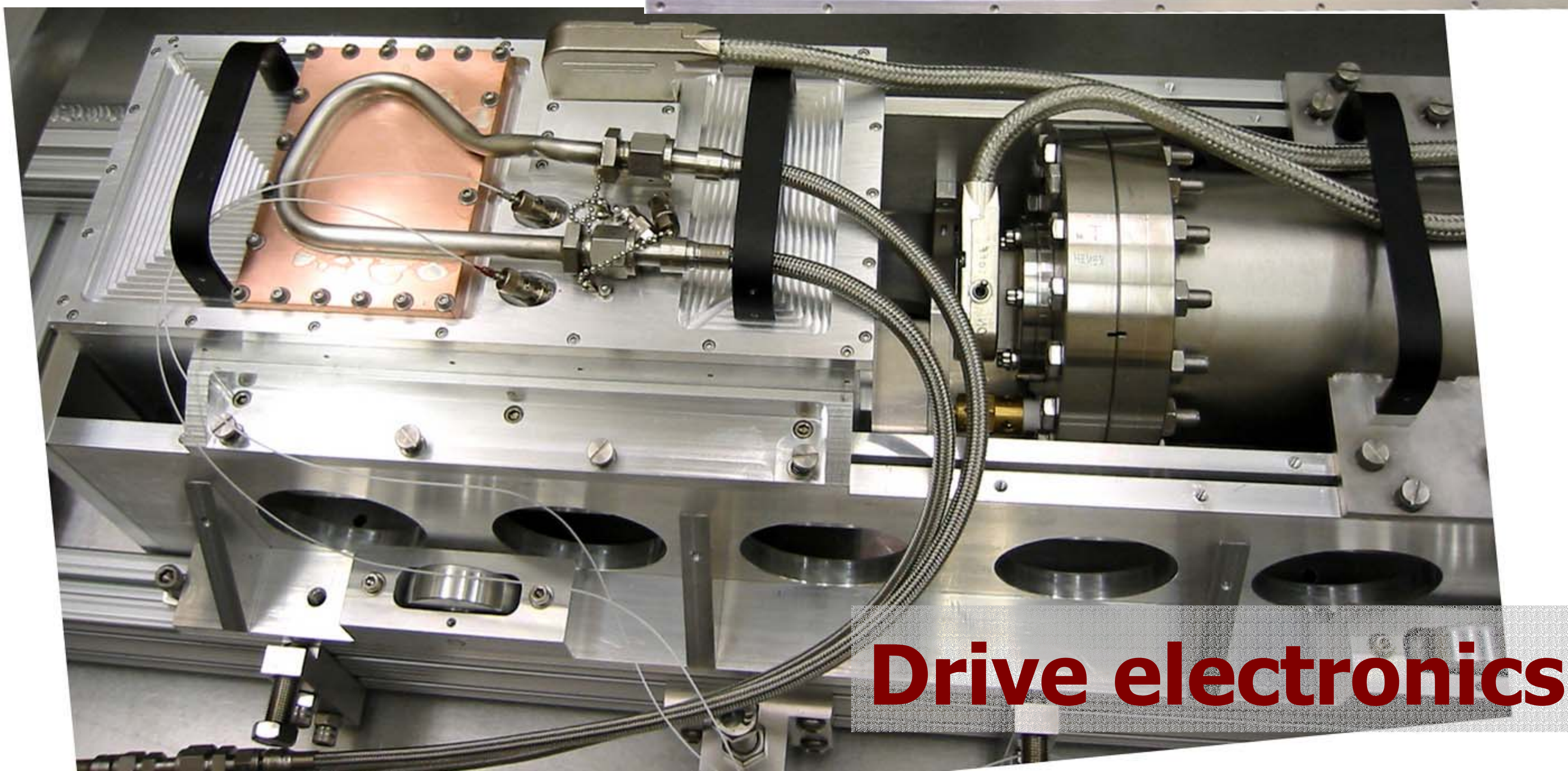
Don't eat the lungs!
Six, 3.6VDC cells 1.800 Ah



re-charger

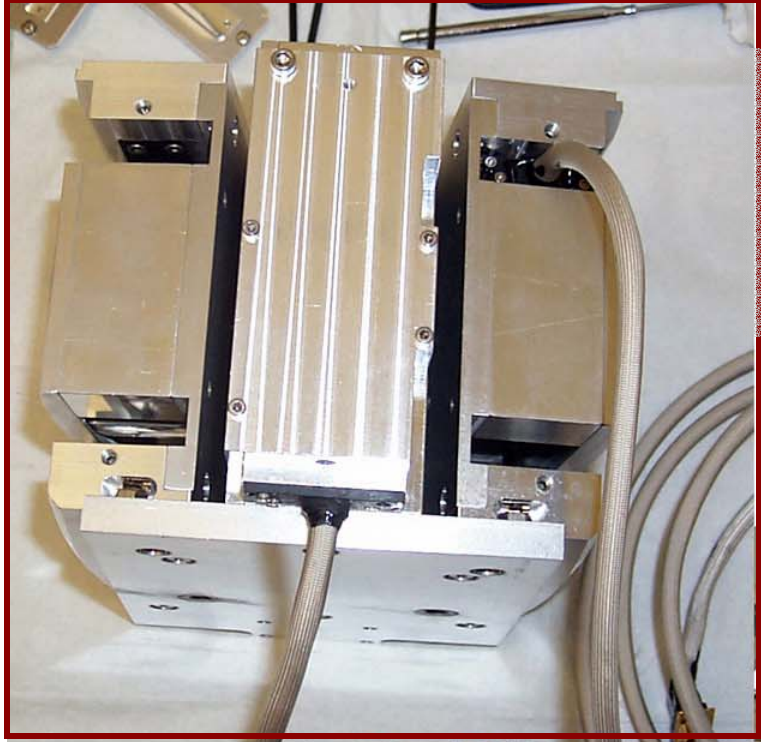


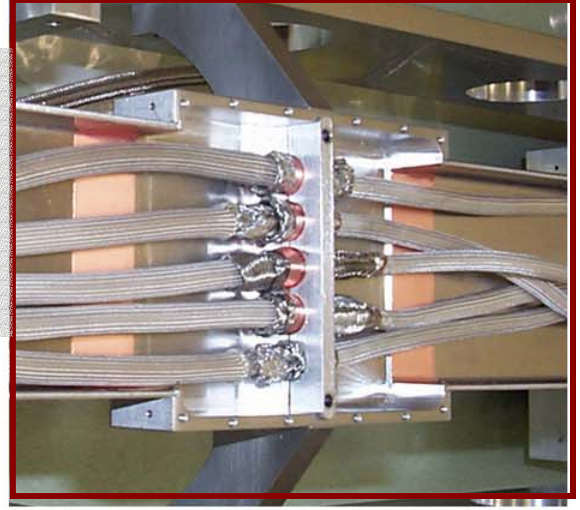


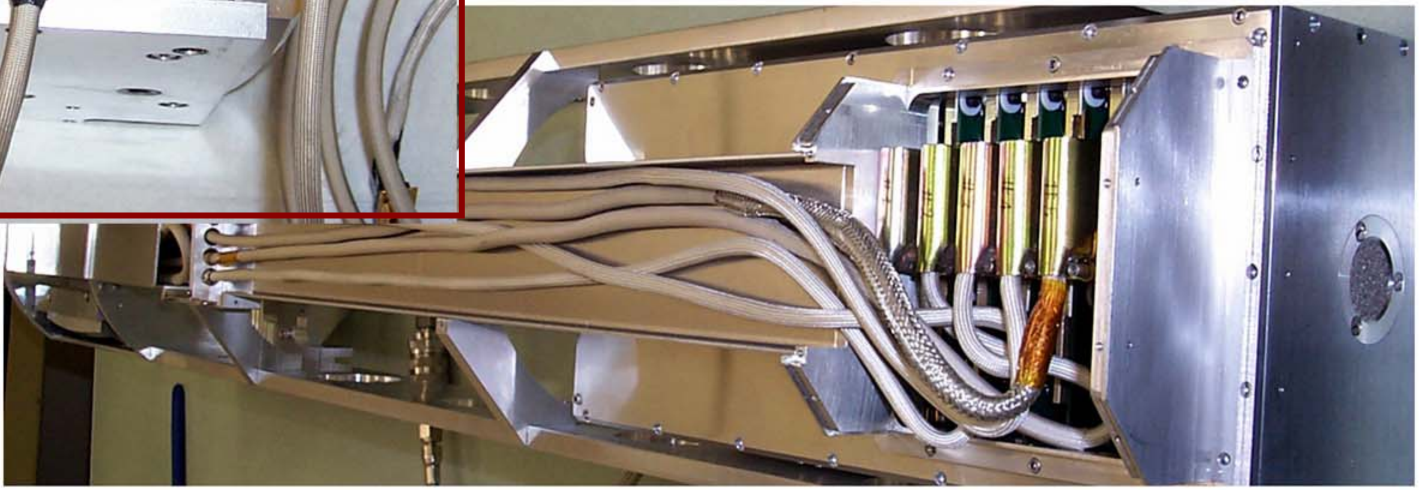


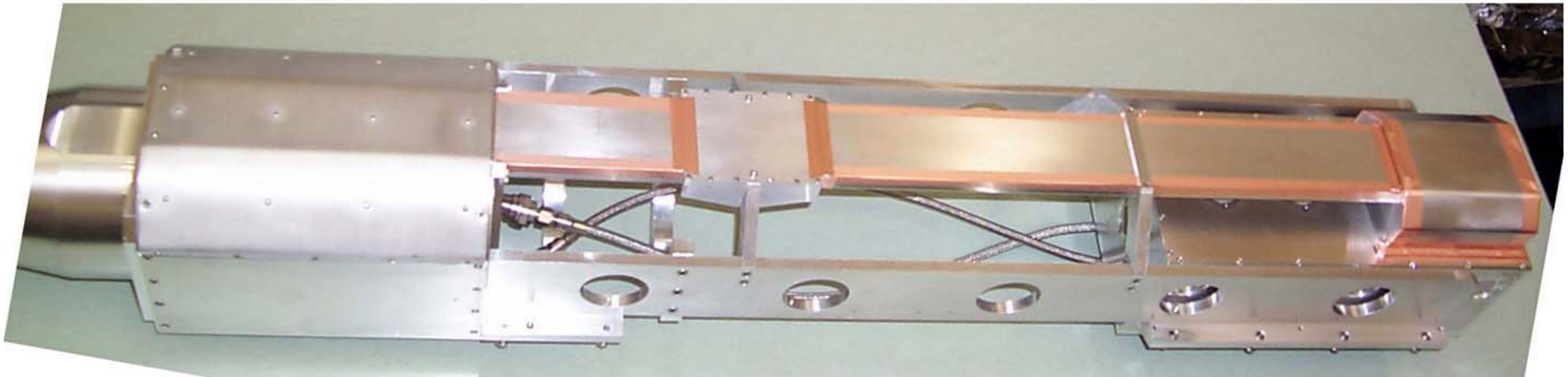
Drive electronics

Faraday cage





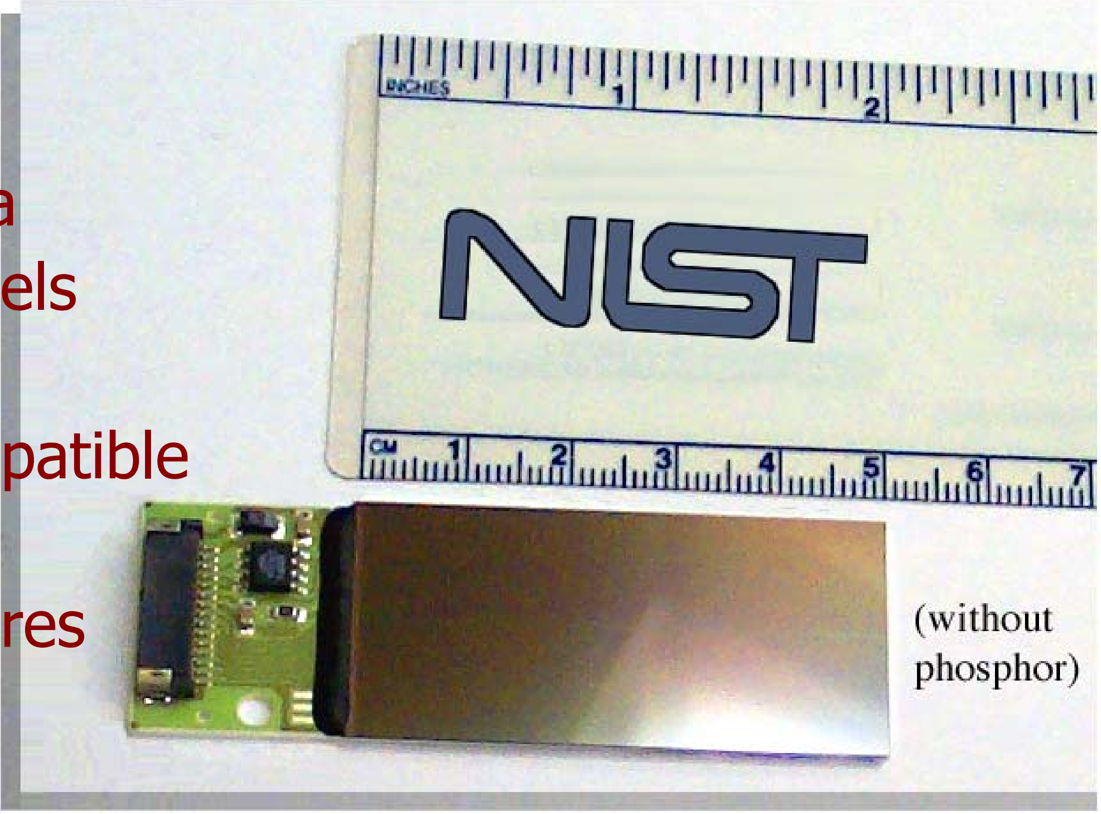




Use of an inexpensive digital sensor

NIF
The National Ignition Facility

Complementary Metal-Oxide Silicon (CMOS)
System on chip (SOC) design
512 x 1022 array imager
48 micron pixels
24.6 x 49 mm active area
95% fill factor, active pixels
Rad-hard to 100K rads
Low power, vacuum compatible
12 bit depth pixels
Within light-tight enclosures
$2k/each



(without phosphor)

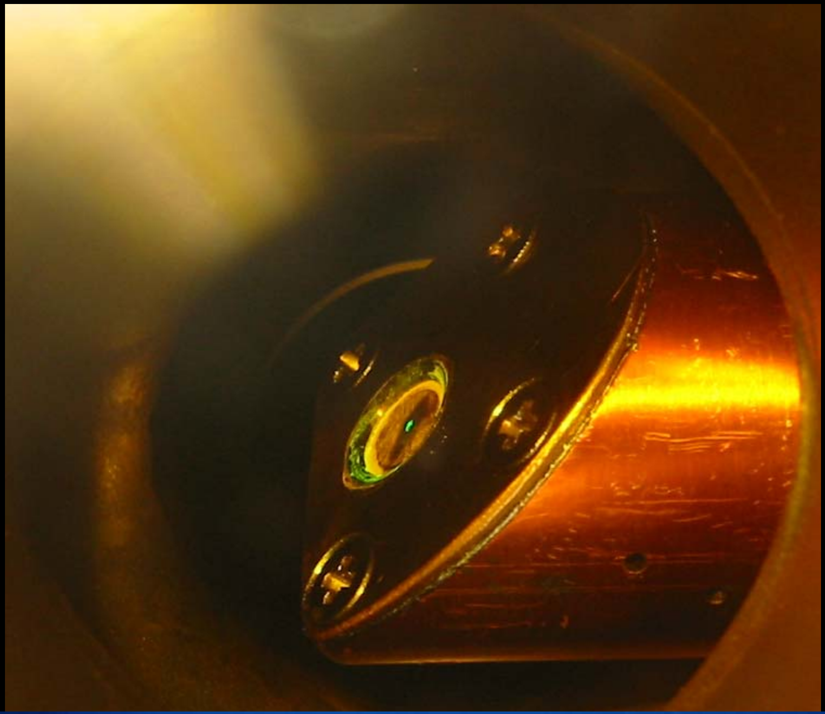

NRL's Scintillator
coating of CMOS
sensor for
HENEX

Calibration of Plate Functions

$$g = r \cdot \sin(\theta_B - \delta) + \frac{r \cdot \cos(\theta_B - \delta) - f}{\tan(2\theta_B - \delta)}$$

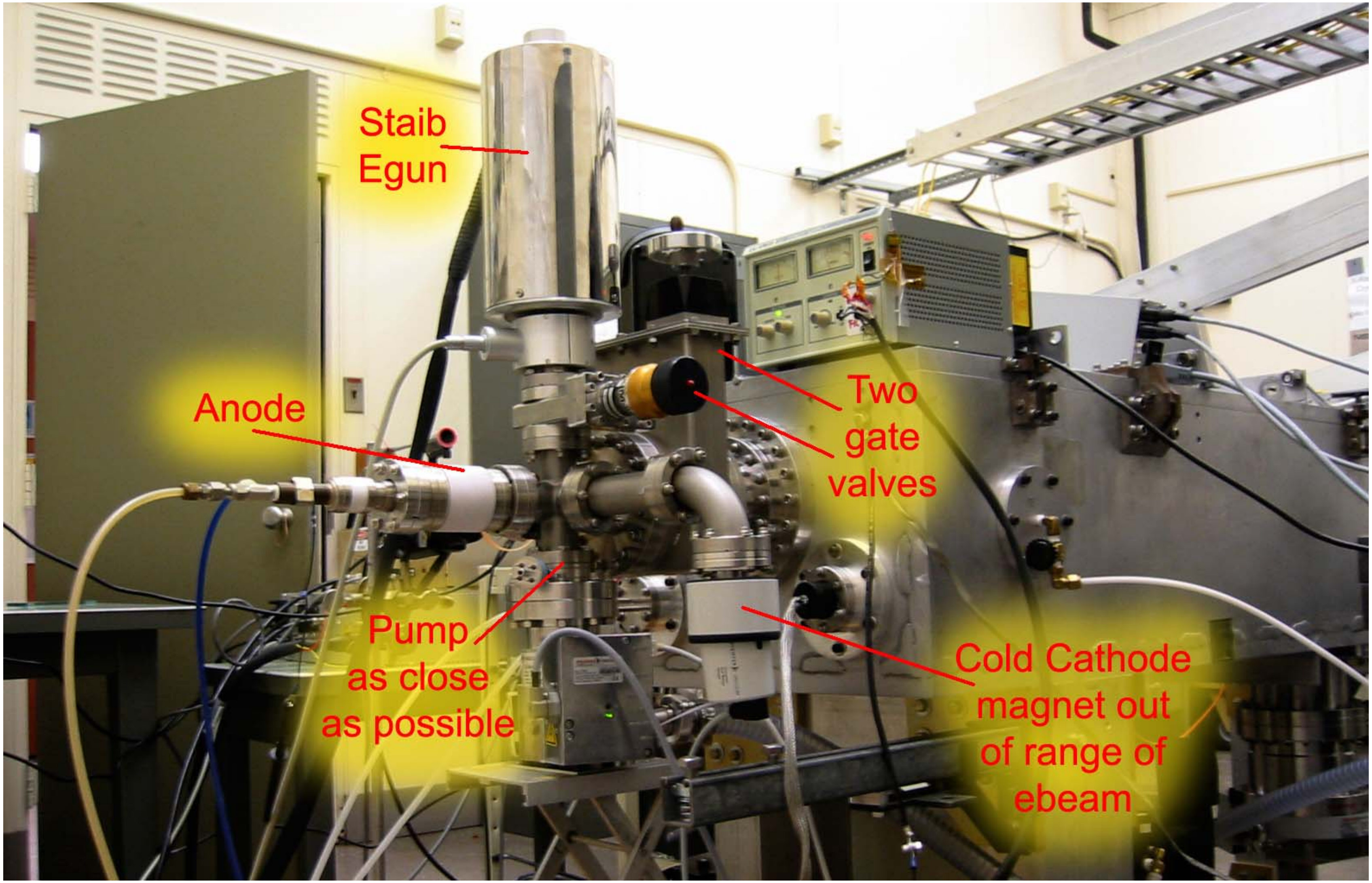
$$E = \sqrt{a + \frac{b}{x^2}}$$

X-ray source & calibration chamber

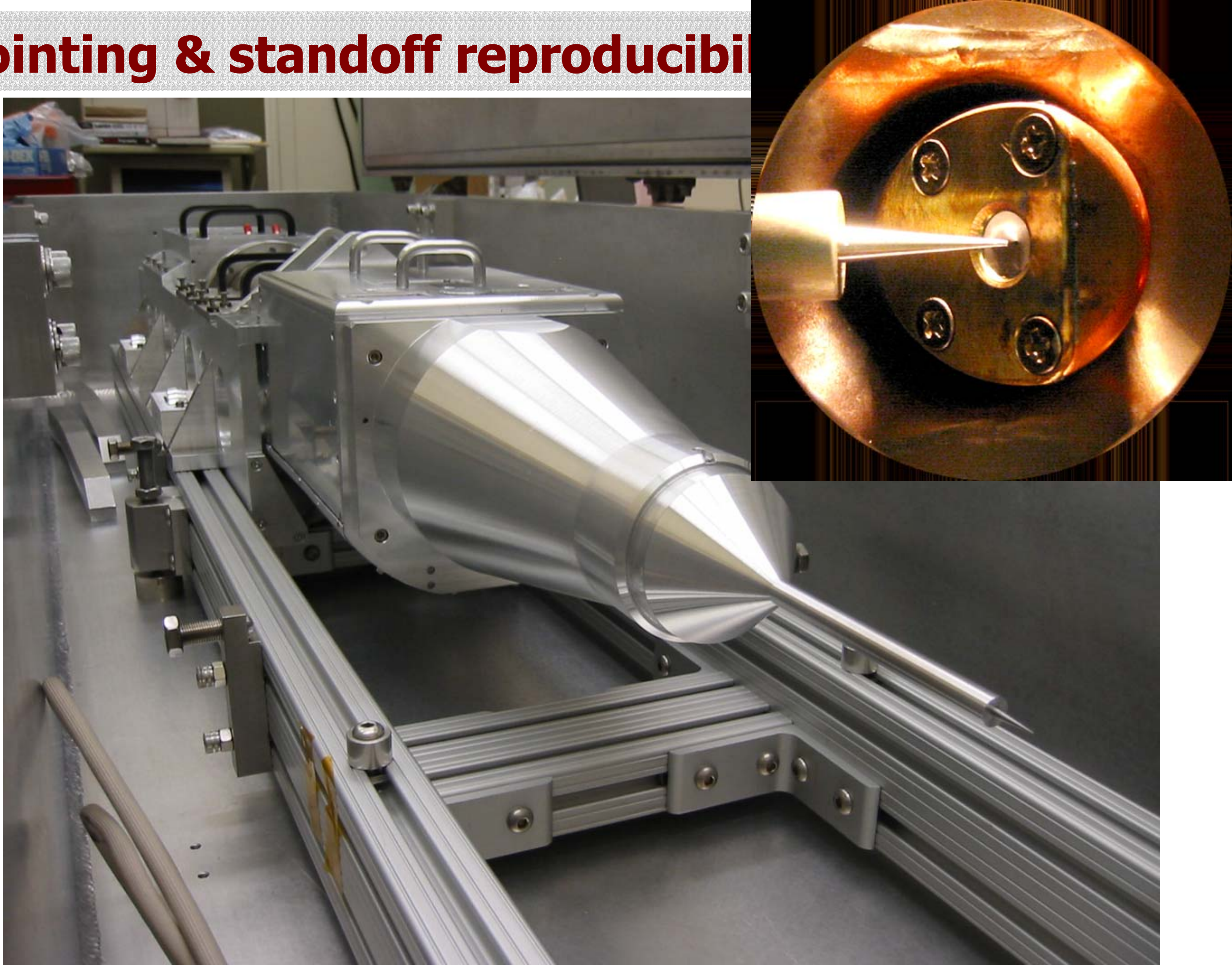


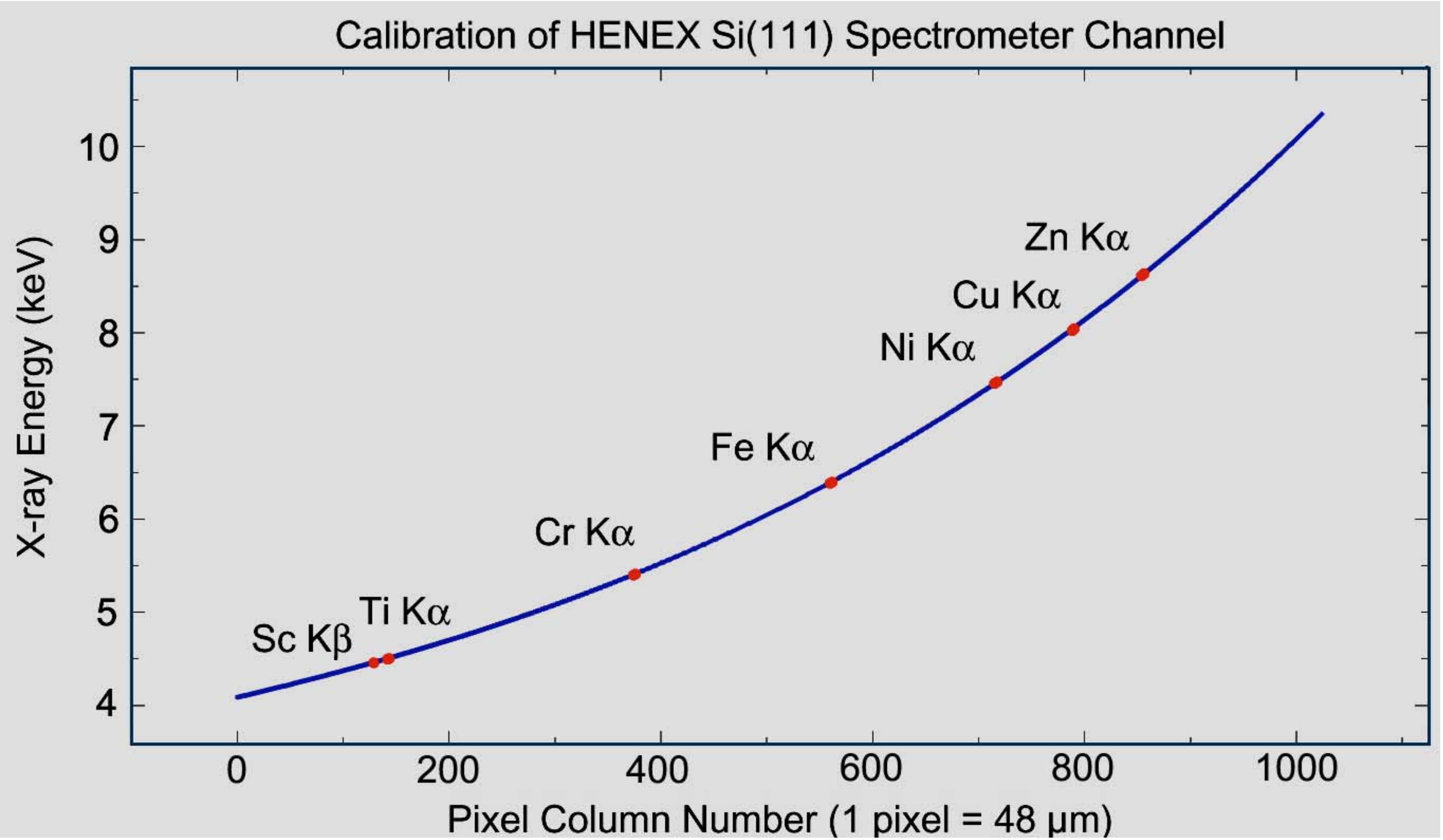
The anode employs user replaceable foils and is actively cooled by a silicone heat transfer fluid

Broadband Calibration Facility X-Ray Source

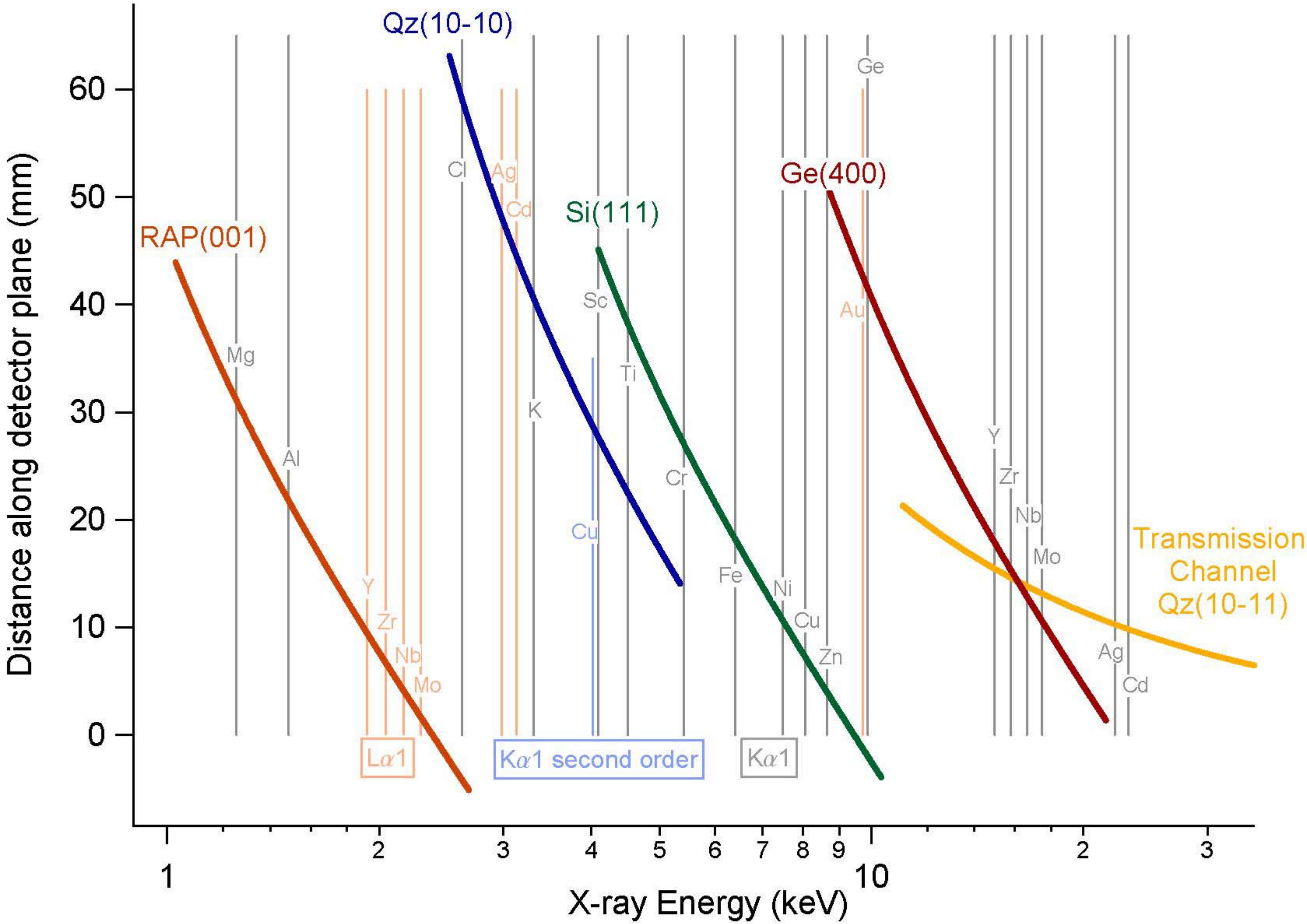


Pointing & standoff reproducibil

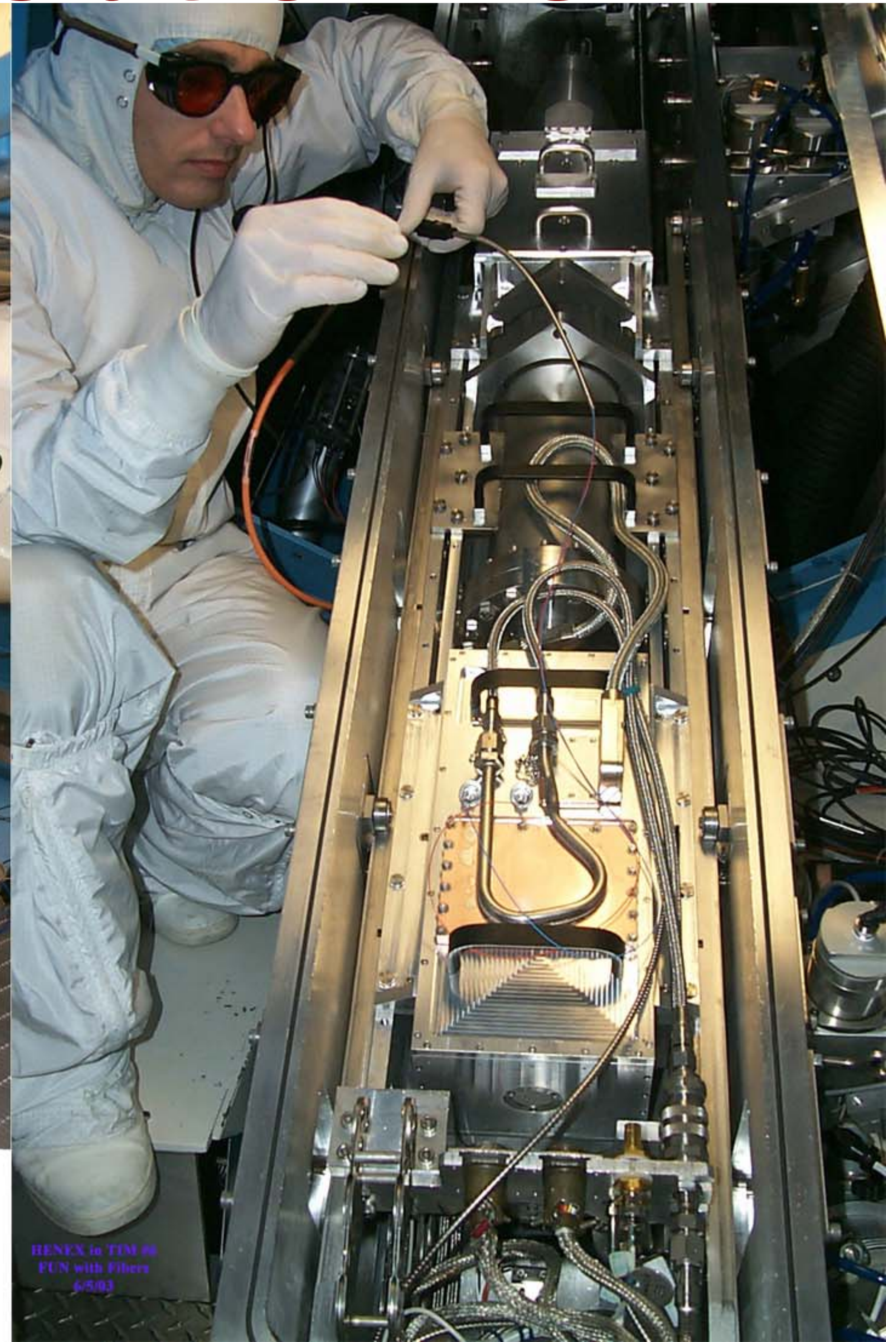


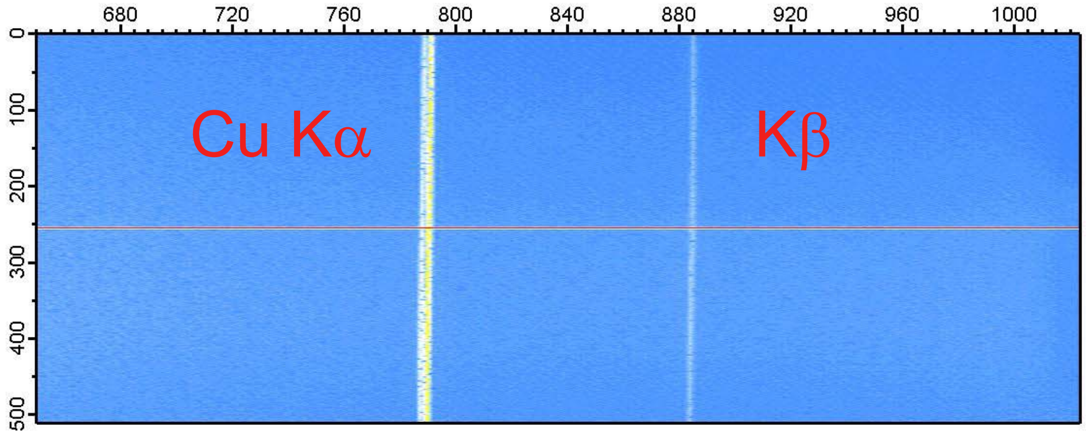

Calibration of HENEX Si(111) Spectrometer Channel
X-ray Energy (keV)
10
9
8
7
6
5
4
0
200
400
600
800
1000
Pixel Column Number (1 pixel = 48 μm)
Zn Kα
Cu Kα
Ni Kα
Fe Kα
Cr Kα
Ti Kα
Sc Kβ

Energy calibration at 0.5 m standoff distance

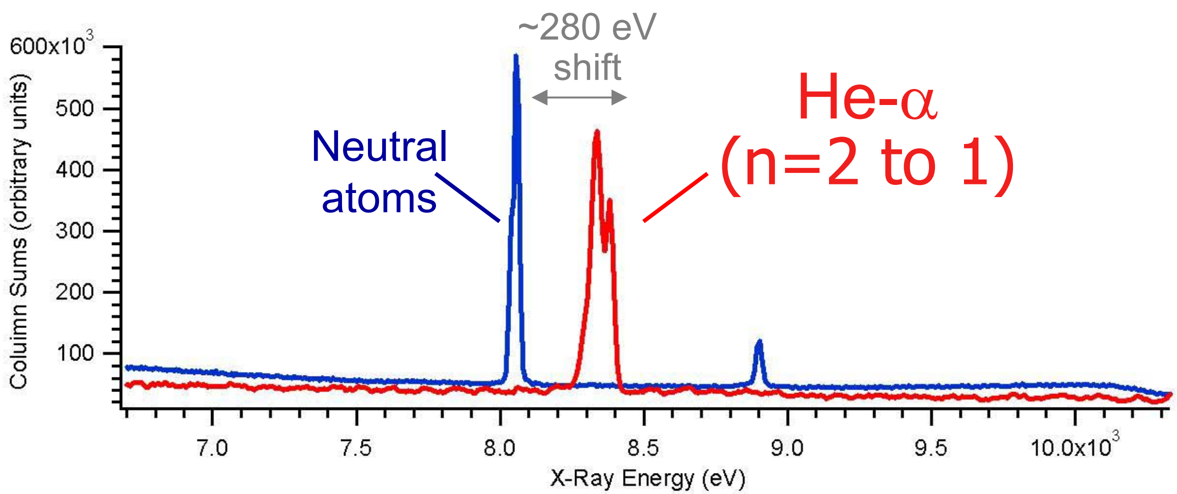


First field tests at OMEGA

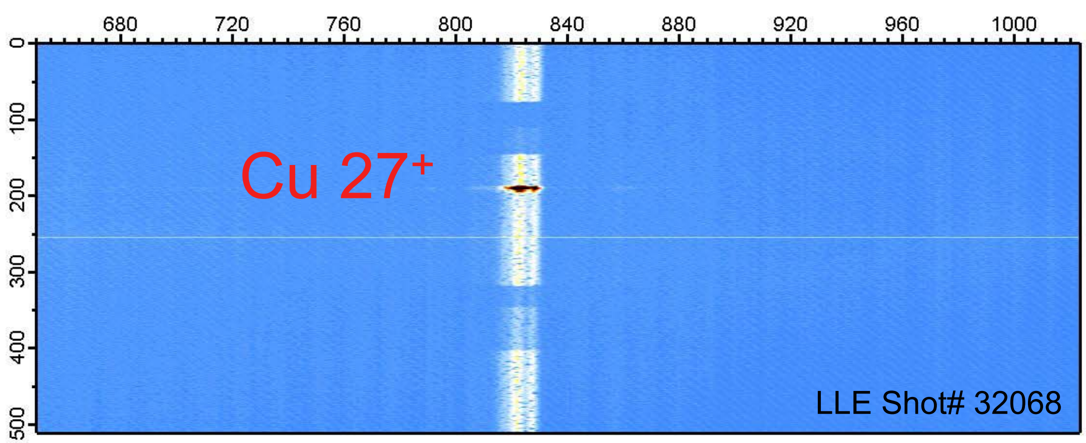




(neutral) Cu calibration source

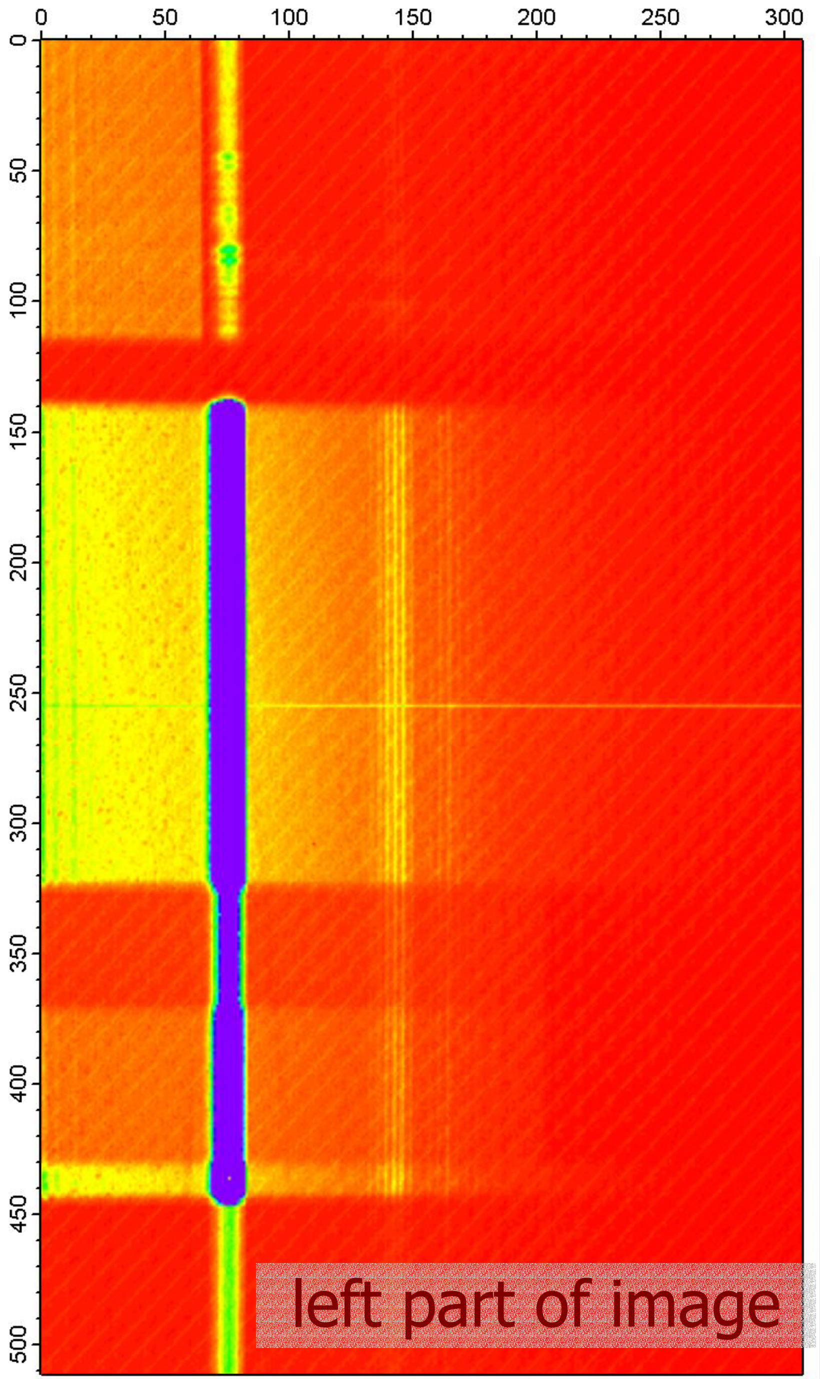


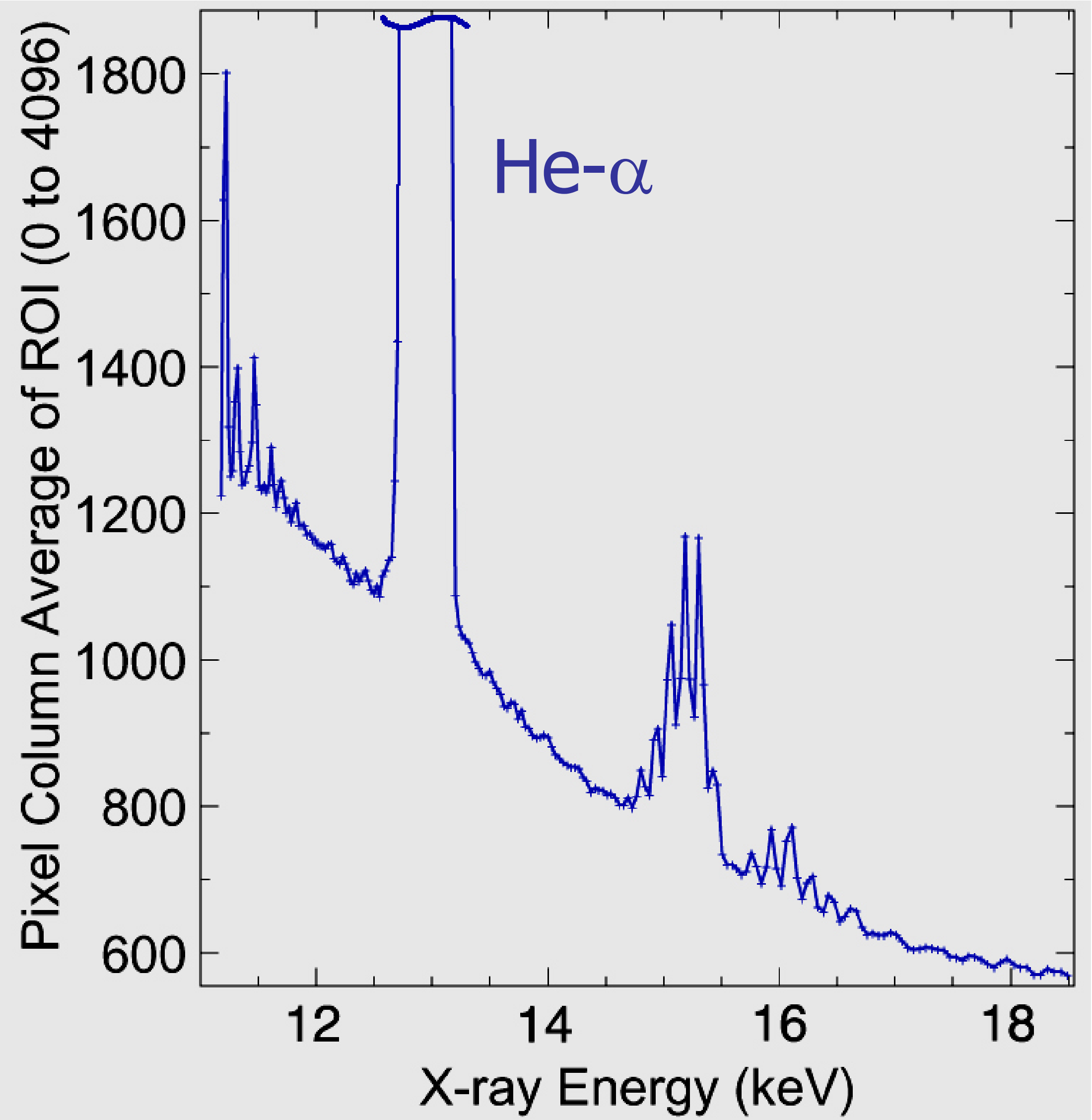
Si(111) channel Cu spectra from calibration source and OMEGA laser



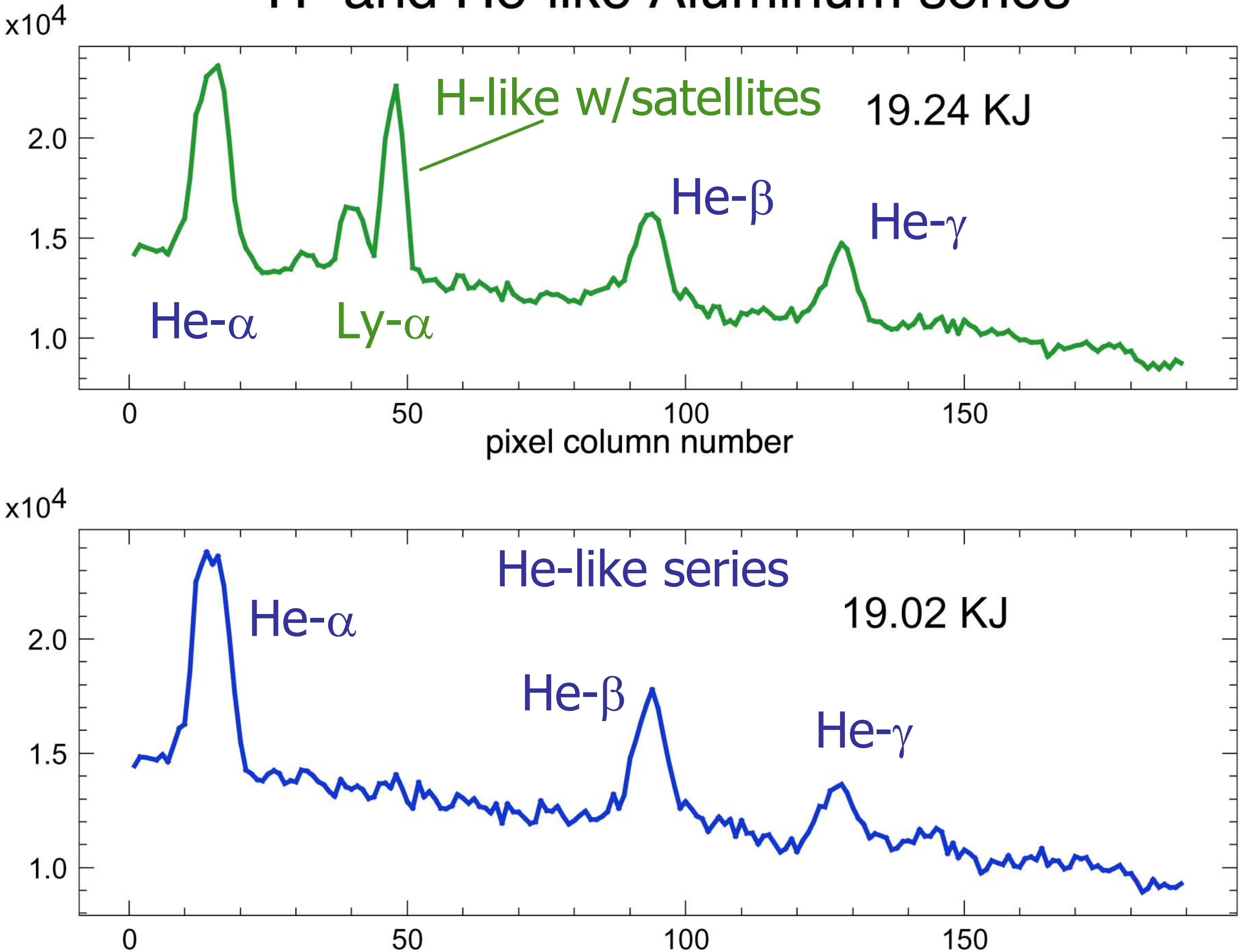
OMEGA laser

Krypton gasbag studies



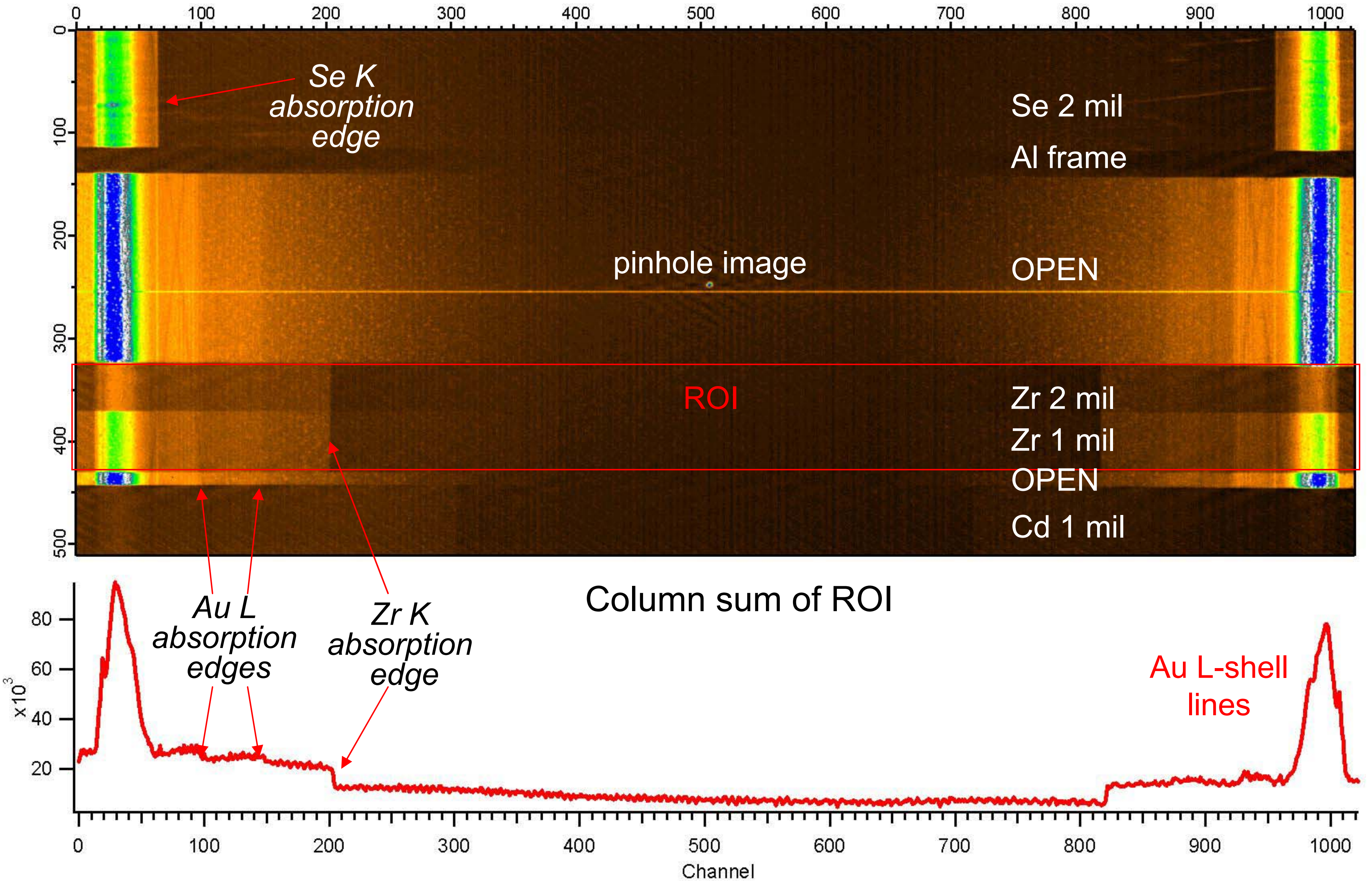


H- and He-like Aluminum series

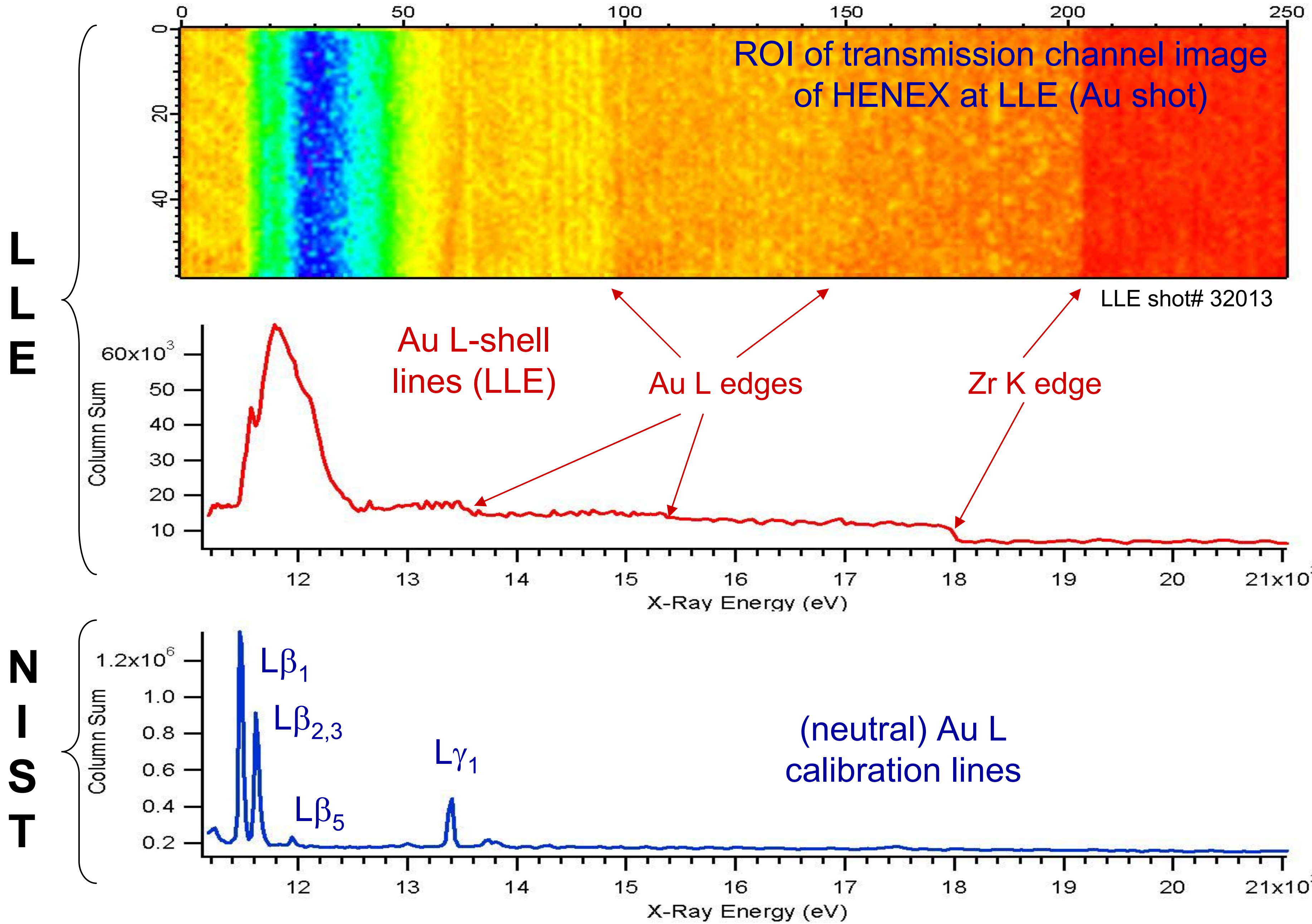


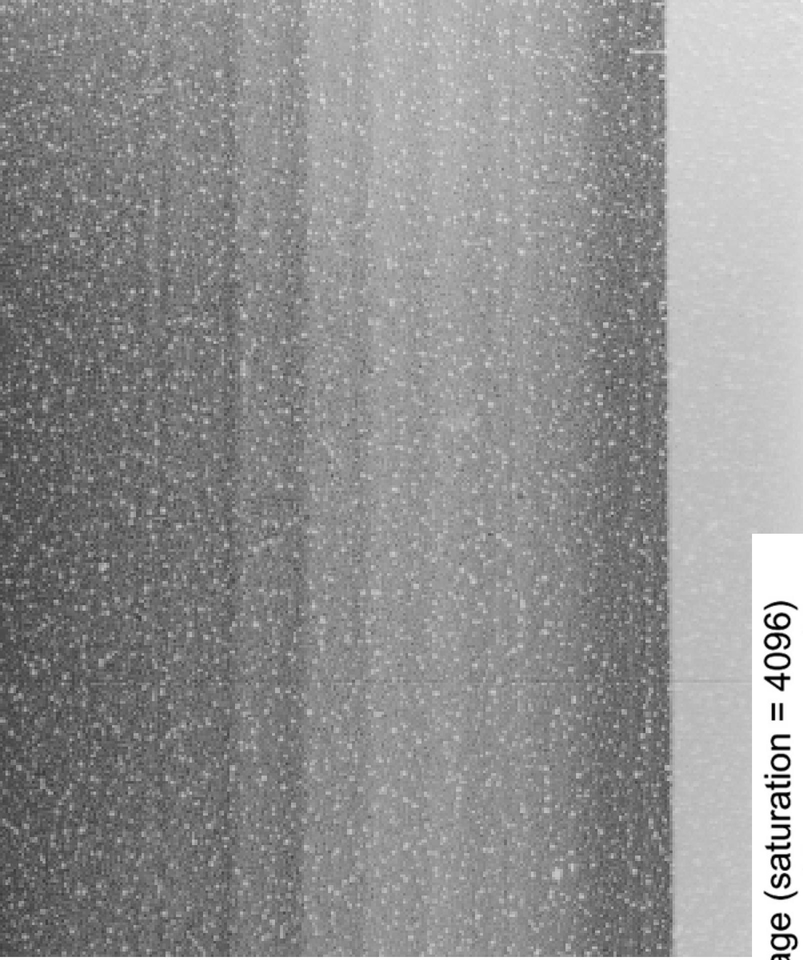
RAP channel

HENEX channel 5 Qz transmission crystal
LLE shot 32013, RID# 13973 (gold target)

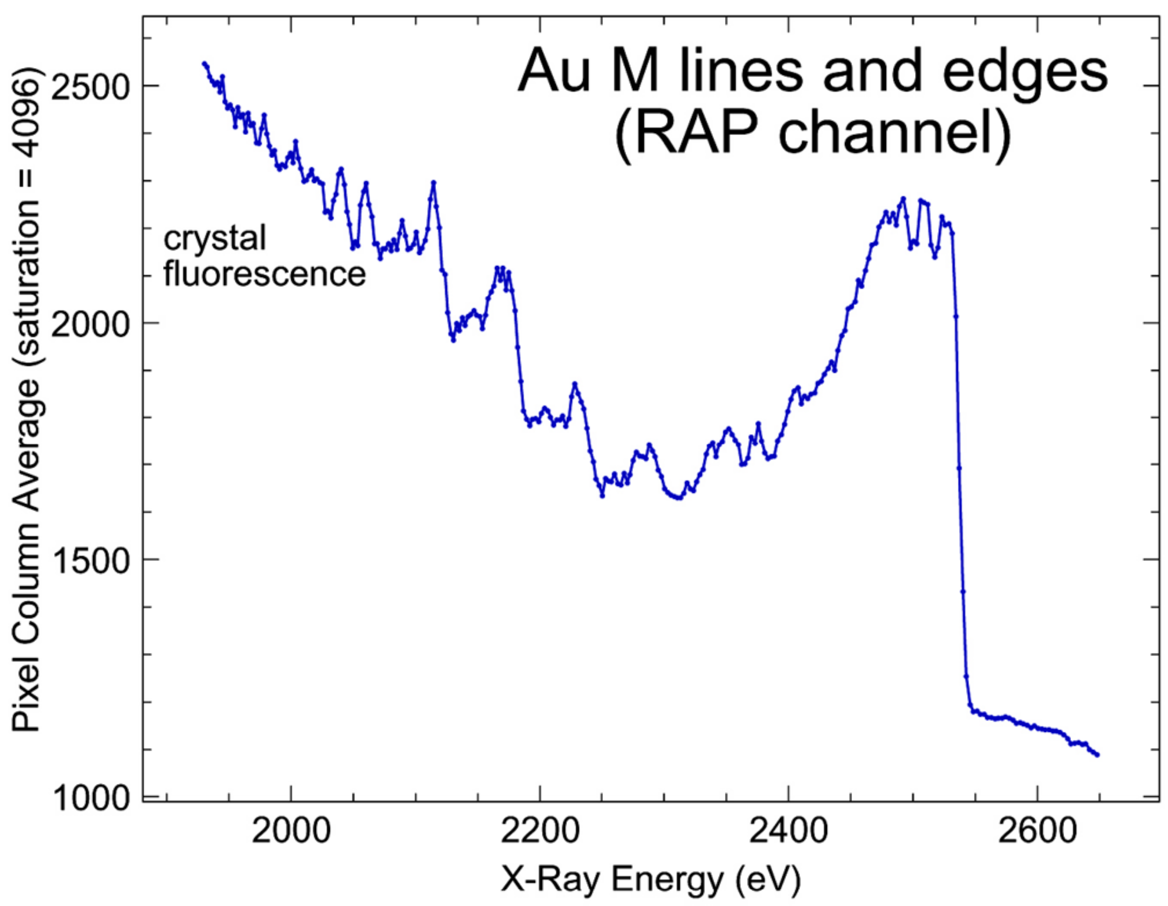


Comparison of LLE and NIST Au L lines





RID# 13948
HENEX channel 1
(RAP crystal)



Extension of HENEX technology to higher energies…

Laue Geometry

Crystal planes = Ge(220)

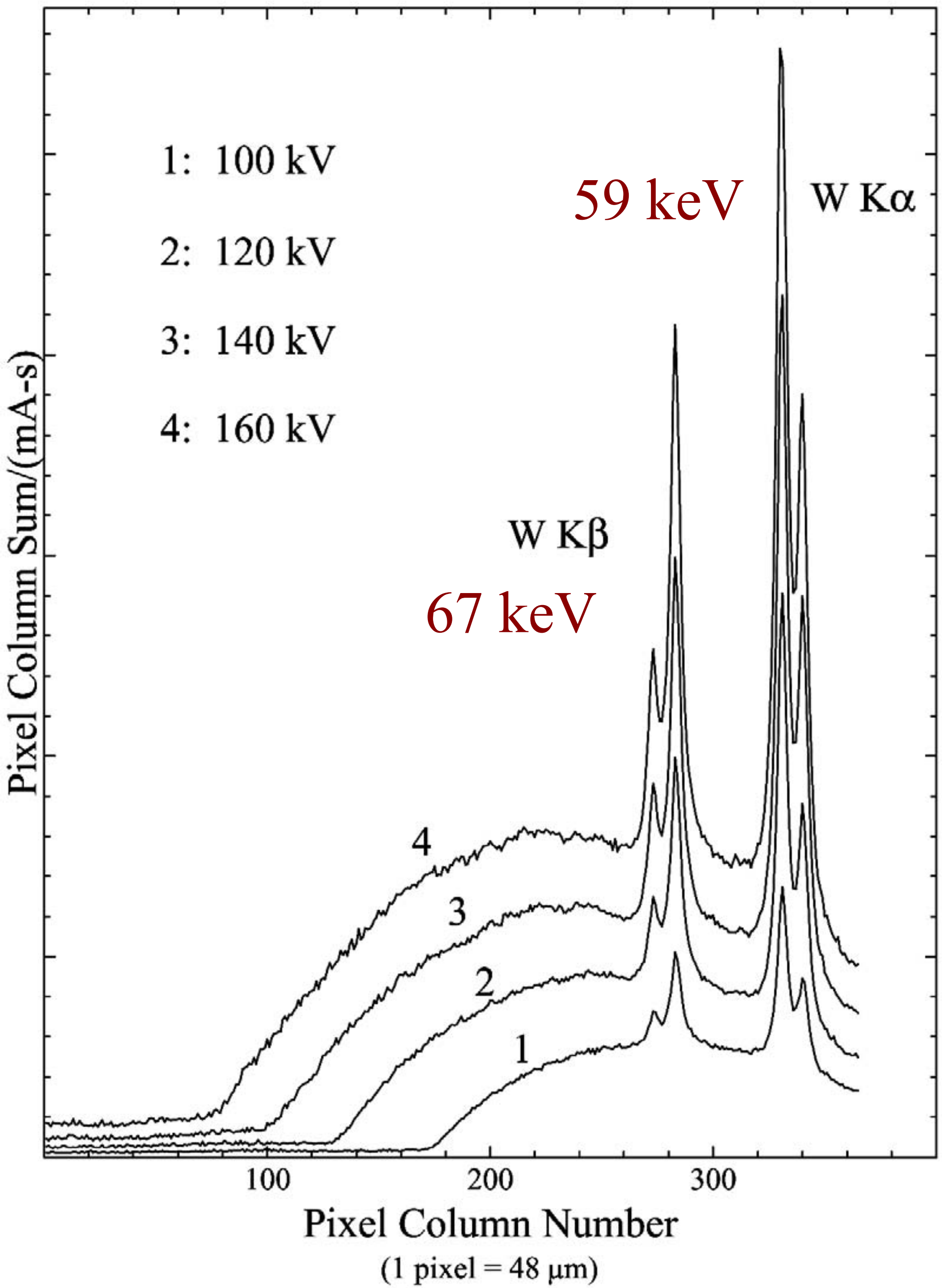
Source to crystal = 1.12 m

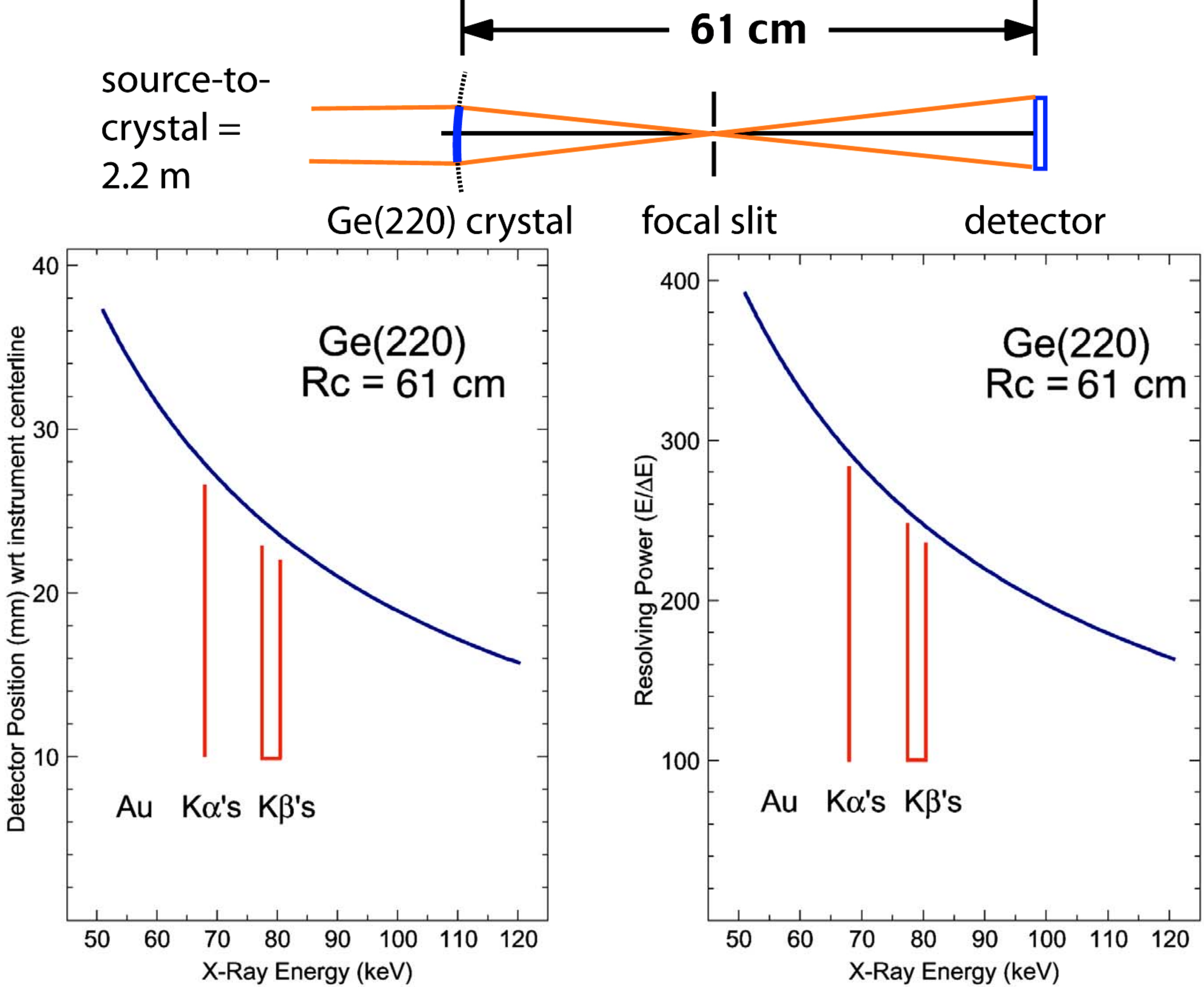
Crystal to detector = 37 cm

Filters = 7 mm of Be and 0.25 mm of Mo

Source I = 10 mA

Integration time = 23 to 65 s



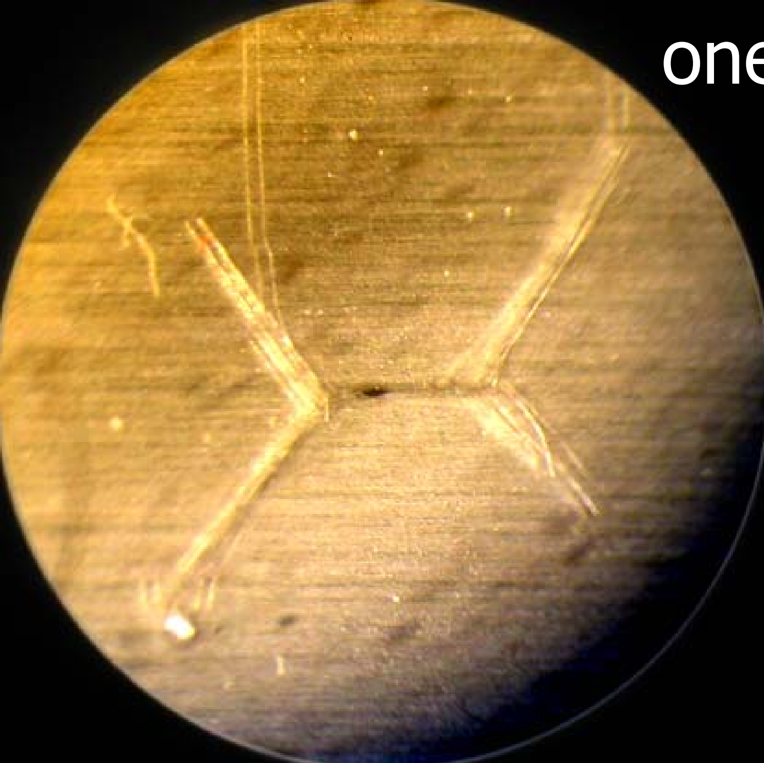

61 cm
source-to-crystal = 2.2 m
Ge(220) crystal
focal slit
detector
Ge(220)
Rc = 61 cm
Detector Position (mm) wrt instrument centerline
Au Kα's Kβ's
X-Ray Energy (keV)
Ge(220)
Rc = 61 cm
Resolving Power (E/ΔE)
Au Kα's Kβ's
X-Ray Energy (keV)

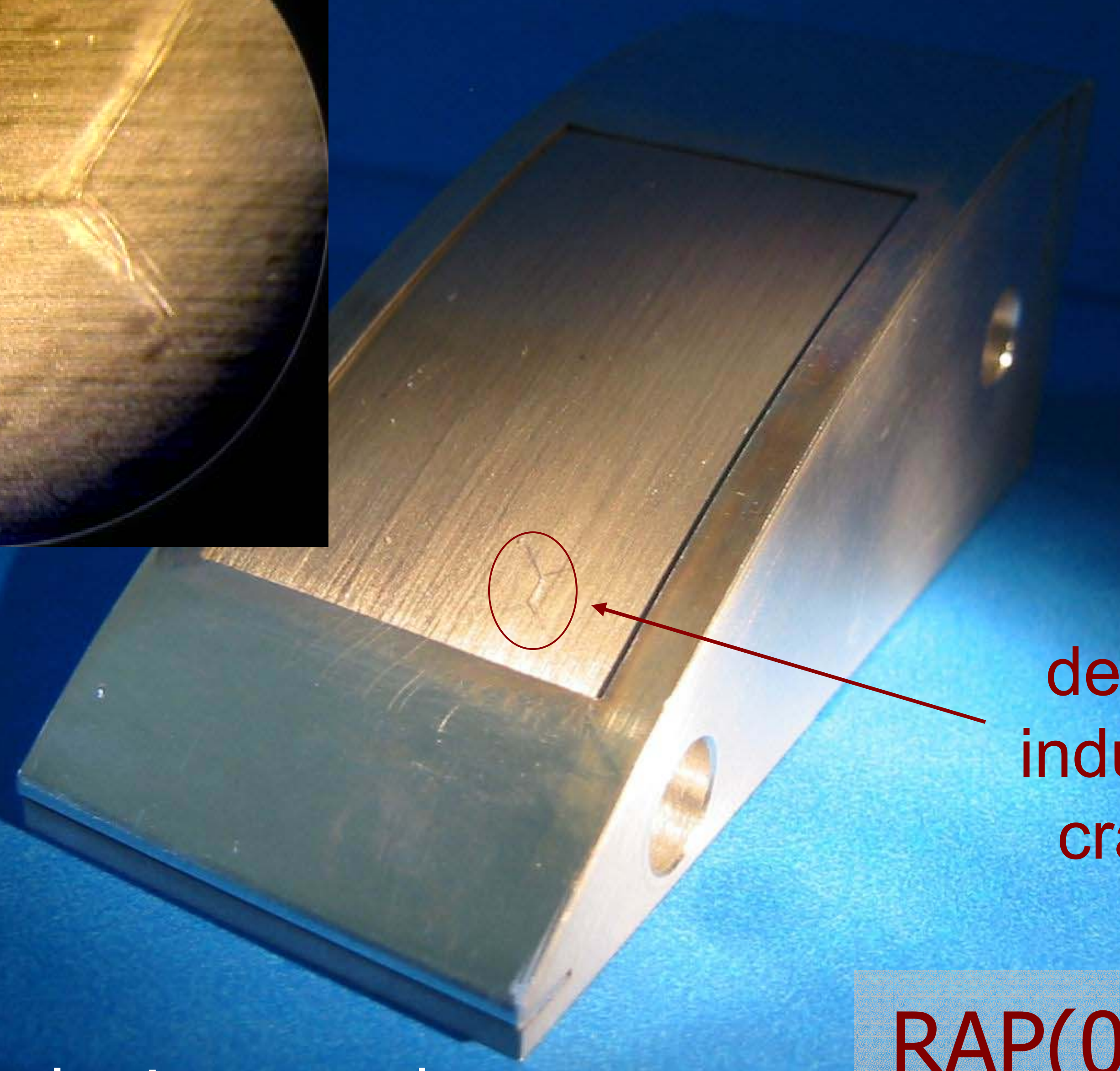
Issues undergoing fine tuning

[1] debris shielding
[2] paraxial spectra
[3] crystal fluorescence

Solutions:
[1] thicker shielding
[2] collimation
[3] filtration, crystal choice, collimation, *etc.*

one incident during a week of shots…





13 µm Be to be increased

Minimizing crystal fluorescence

[1] nosecone

[2] crystal selection

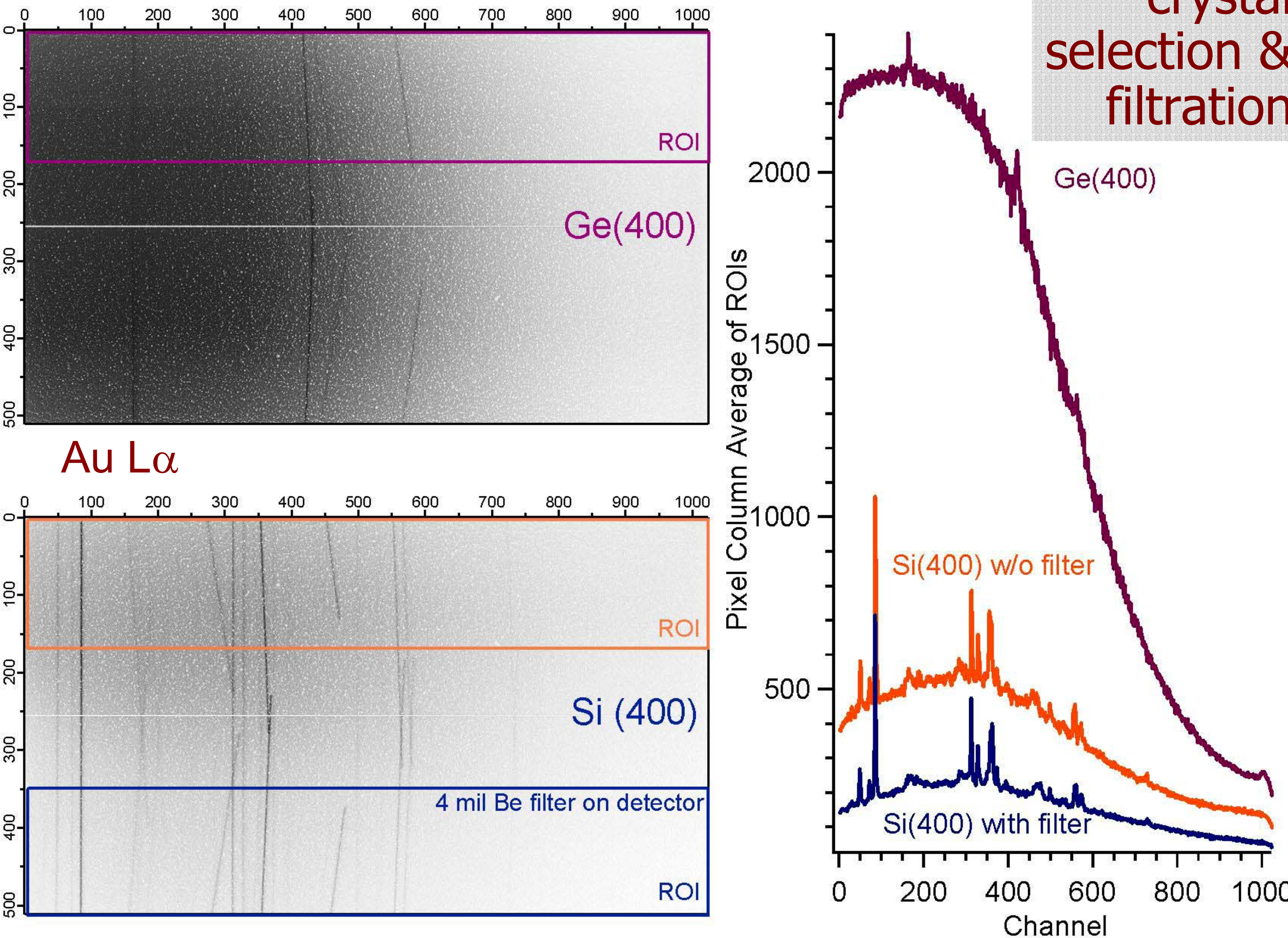
[3] filtration

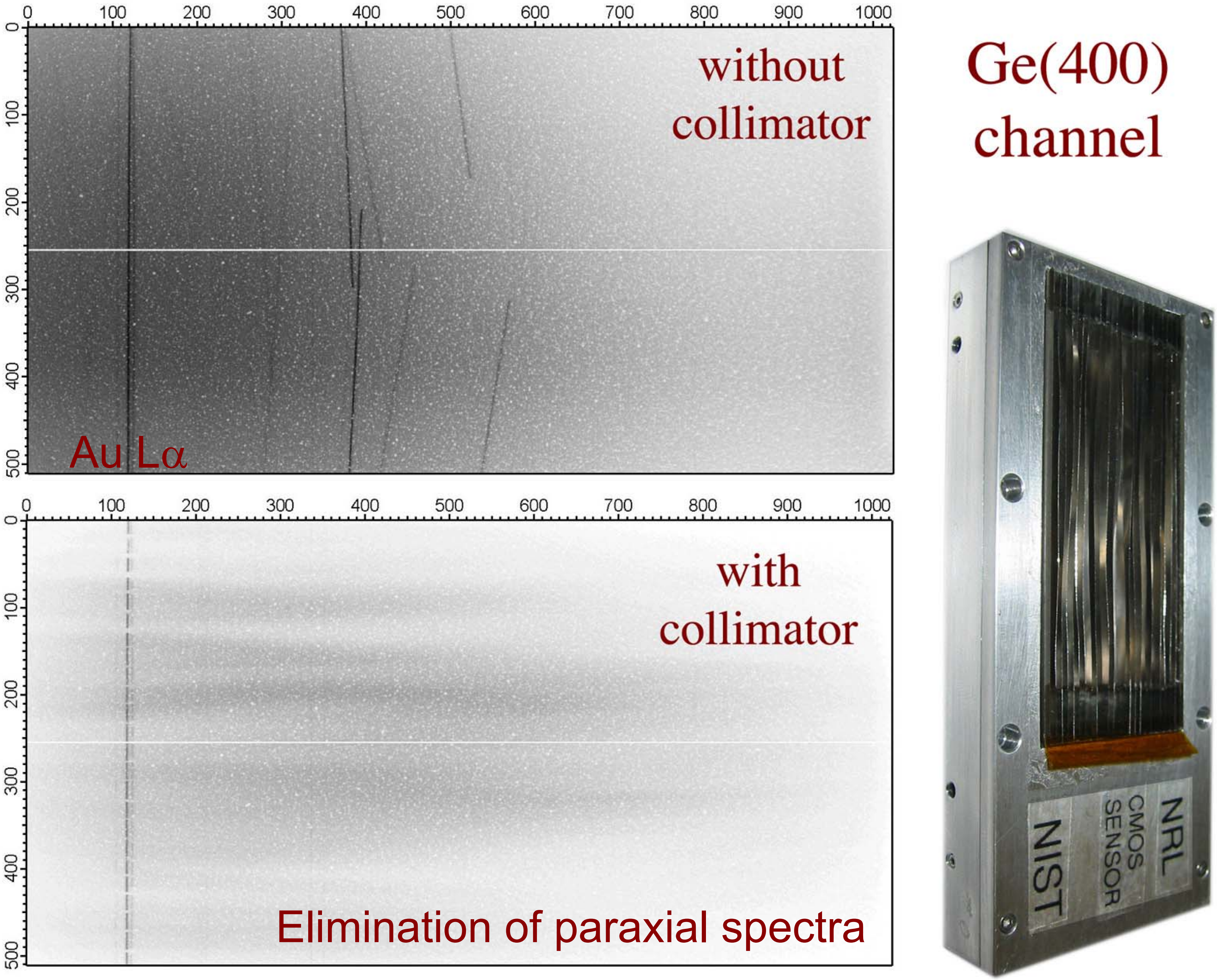
[4] collimation

[5] stand-off distance

[6] increase crystal-to-det distance

crystal selection & filtration




Ge(400)
channel
without
collimator
Au Lα
with
collimator
Elimination of paraxial spectra
NRL
CMOS
SENSOR
NIST

So, we will replace Ge(400)

with

Si(400) + filtration +

collimator + …

Summary of HENEX Status

- HENEX fabrication and laboratory validation testing complete.
- Successfully deployed at LLE, recording x-ray images on all shots; fiber optics and Faraday cage (important for NIF) functioned as expected (no lost data).
- Five-channel energy calibration completed
- October run @ LLE planned to validate upgrades
- Intensity calibrations and preparations for NIF deployment pending funding of HENEX CAP plan.