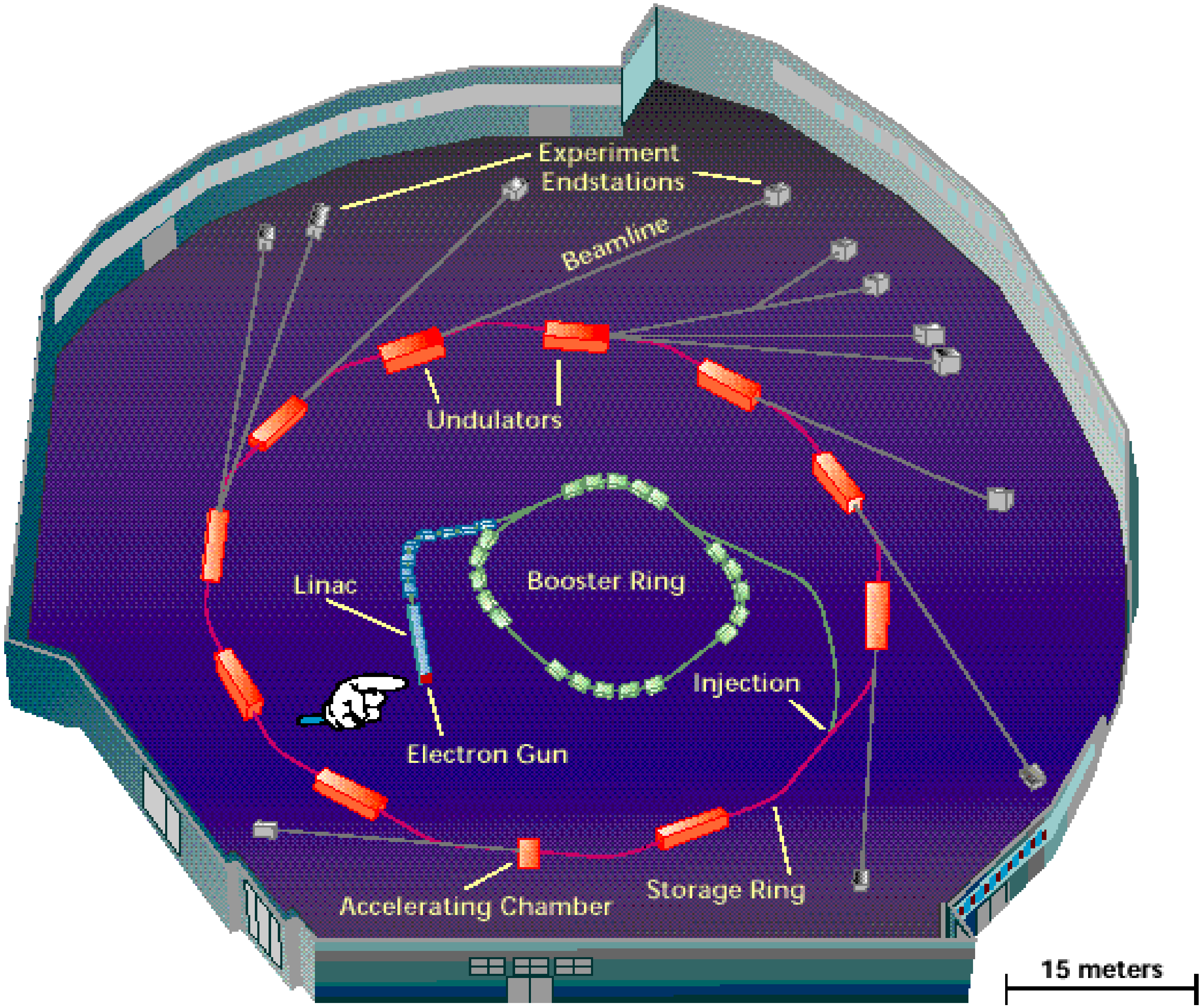
AN INTRODUCTION TO OPTICAL SYSTEMS AT THE ALS

BY MALCOLM HOWELLS

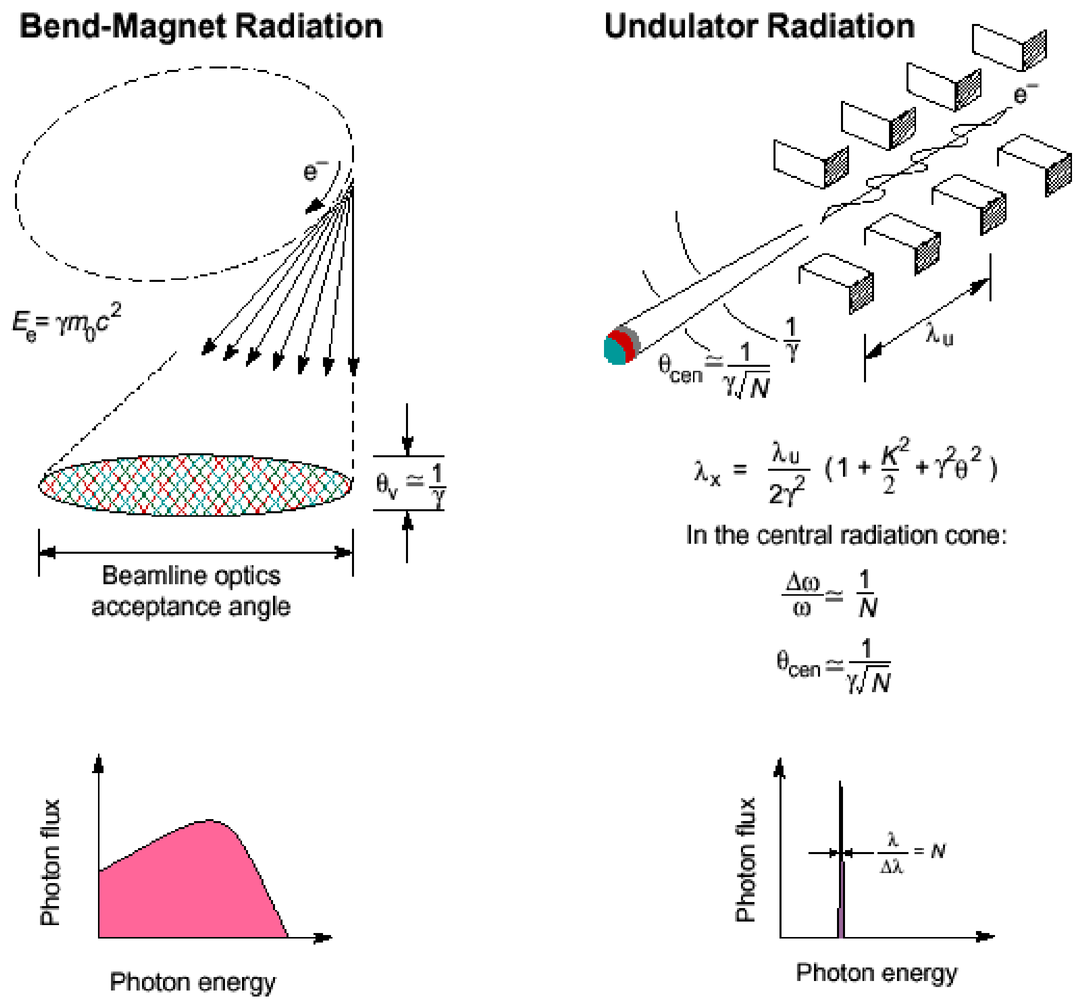
Optical systems for synchrotron radiation: overview

- **What is a beam line?**
- **Optical components**
  - Mirrors
  - Gratings
  - Zone plates
  - The need for cooling
  - The value of deformable optics
- **Optical systems**
  - Monochromators with spherical and plane gratings
  - Microscope condensers
  - Microscopes
- **Whole beam lines**
  - The need for vacuum
  - Paraxial optical design
  - Phase-space matching beam-line optics to experiments
  - The "extras" that make them expensive
- **Introduction to the ALS tour**

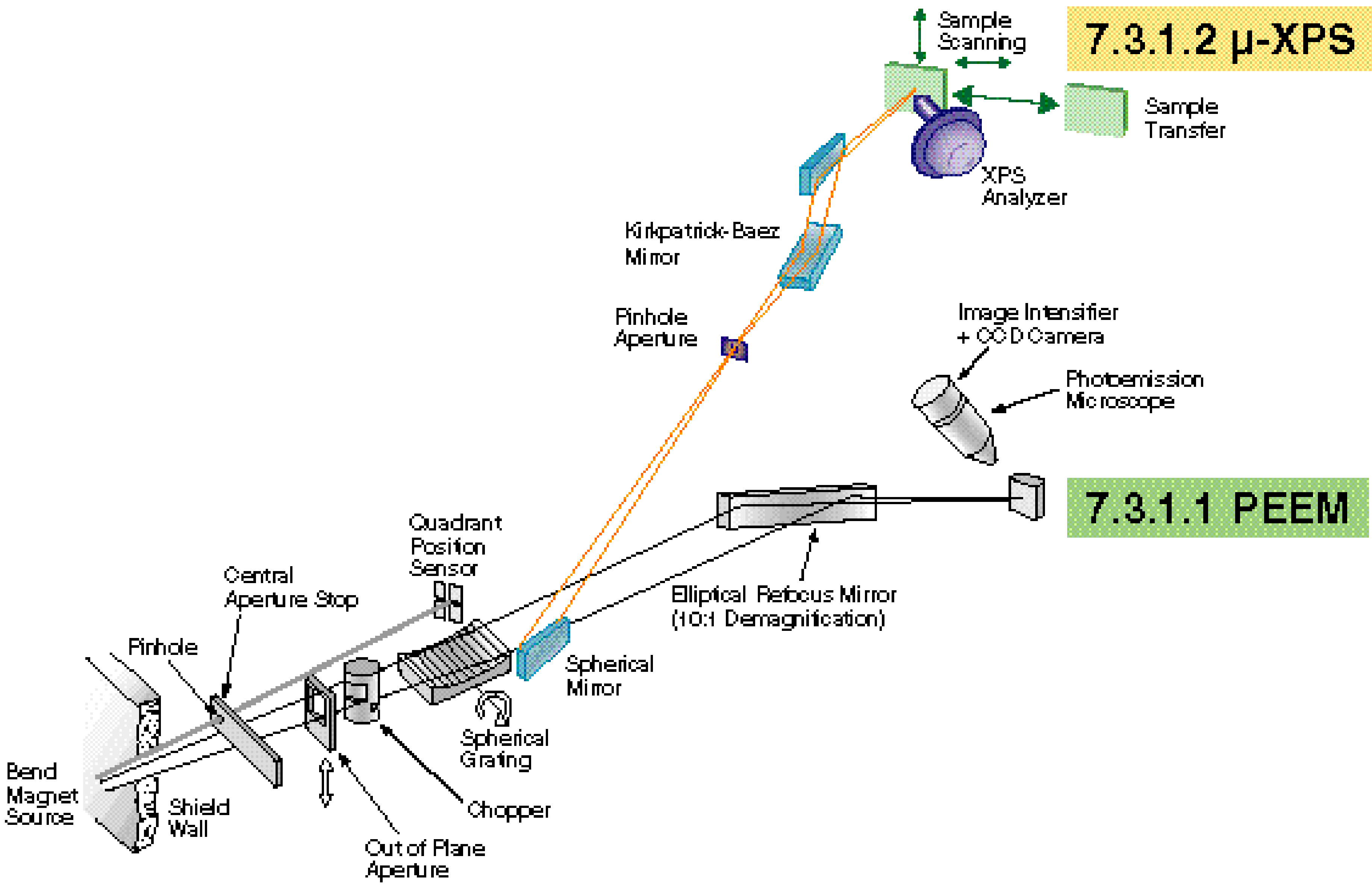
WHAT IS A BEAM LINE?



ALS RADIATION IS PRODUCED BY BENDING MAGNETS AND UNDULATORS



WHAT IS A BEAM LINE?



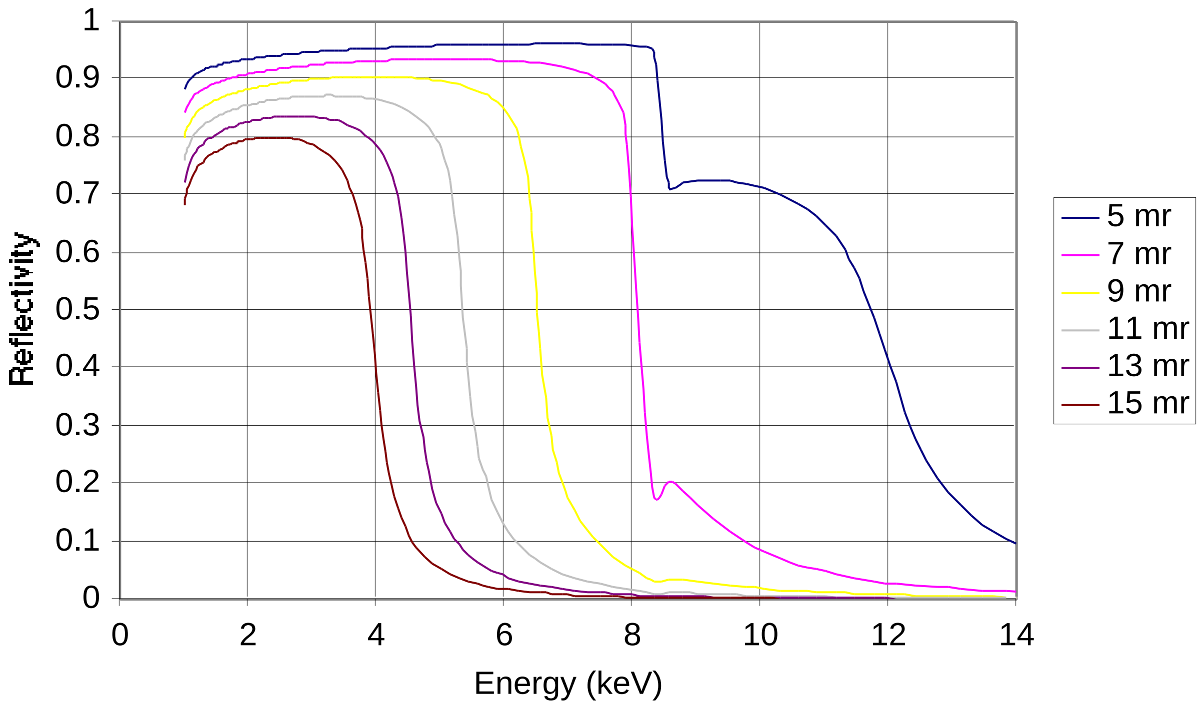
X-RAY MIRRORS

Fresnel equation:

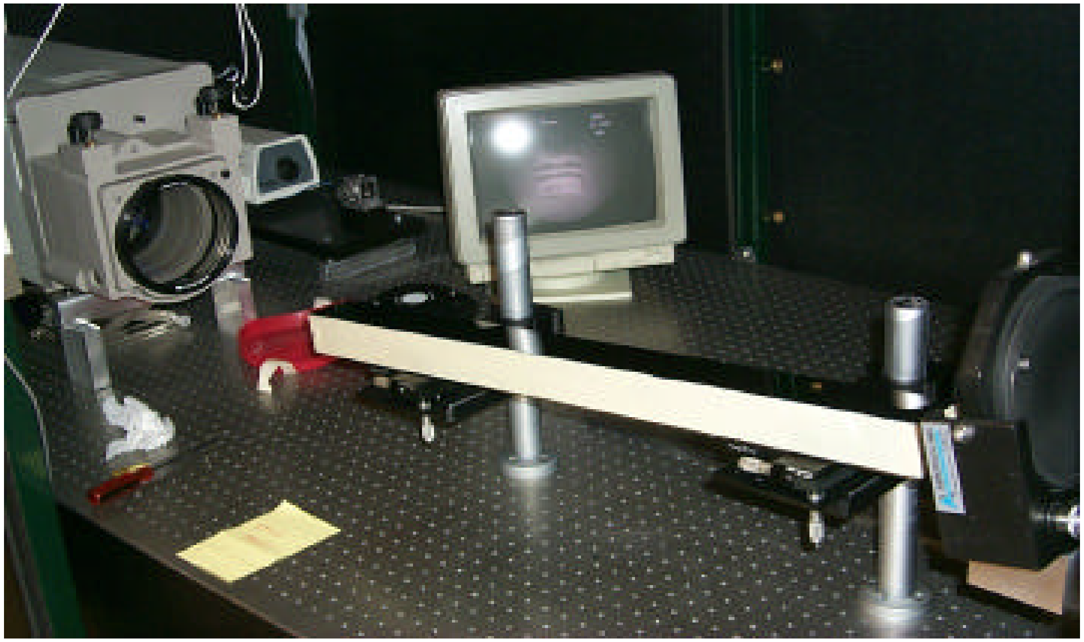
$$R_s(\theta) = \frac{\rho^2(\sin\theta - \rho)^2 + \beta^2}{\rho^2(\sin\theta + \rho)^2 + \beta^2} \qquad \rho^2 = \frac{1}{2}\left\{ \sin^2\theta - 2\delta + \sqrt{\left(\sin^2\theta - 2\delta\right)^2 + 4\beta^2} \right\}$$

Where the refractive index of the mirror is $\tilde{n} = 1 - \delta - i\beta$

Reflectivity of Ni for various grazing angle



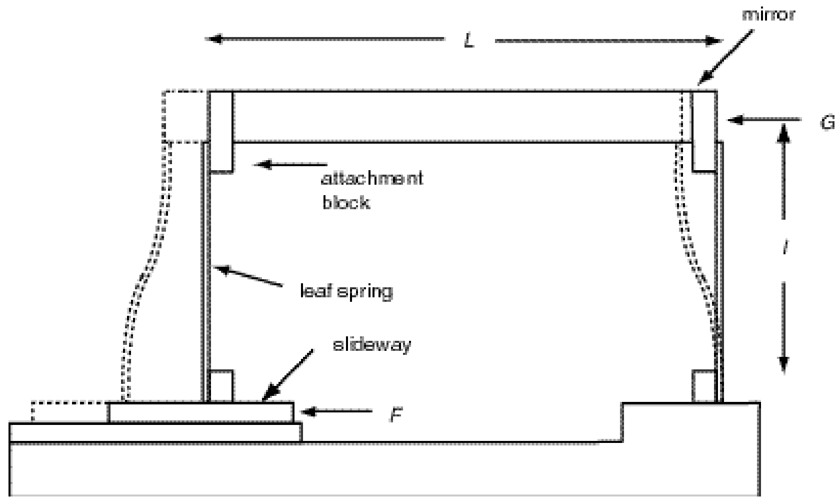
GRAZING INCIDENCE MIRROR UNDER TEST

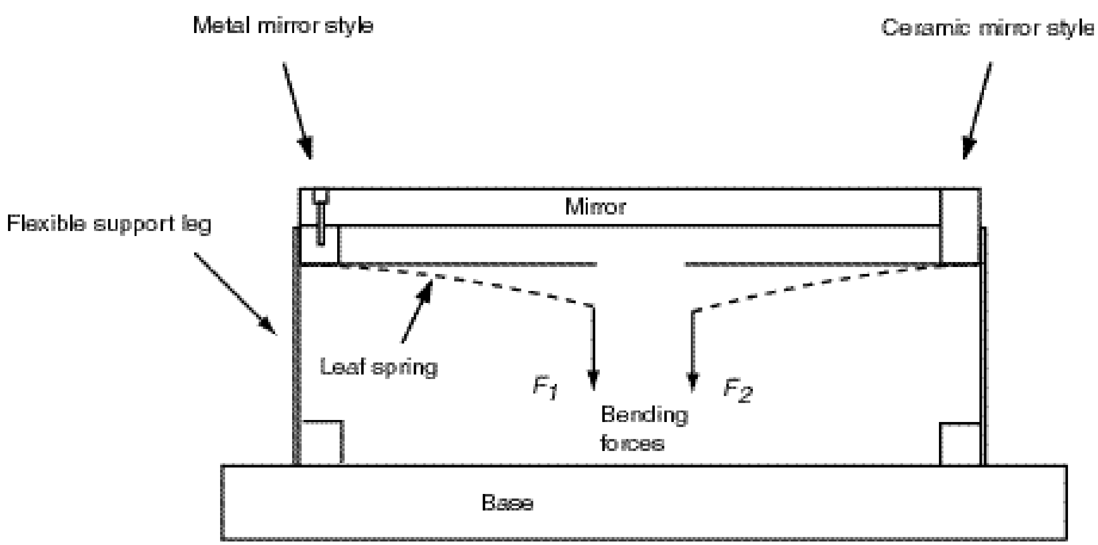


An Invar mirror undergoes interferometric testing for figure accuracy at the ALS Optical Metrology Lab.

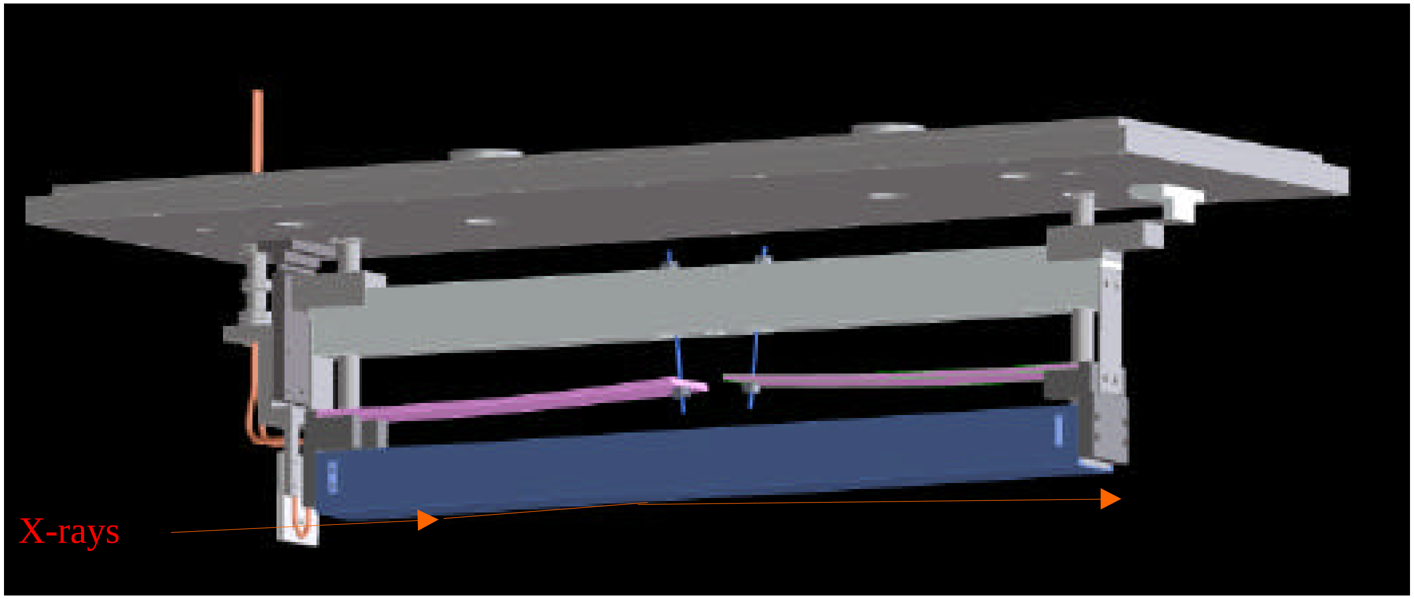
- 1 meter-long grazing-incidence mirrors collimate and focus the x-rays
- Four Nickel-plated Invar mirrors made. These are a new technical development made by the ALS Experimental Systems Group
- Mirror shape is controlled by two bending couples and one point load
- Mirrors are water-cooled via longitudinal gun-drilled holes
- Before bending the mirrors were polished flat within ~ 1.5 µrad RMS by Newport Precision Optics

MIRROR BENDING DEVICES USED AT ALS



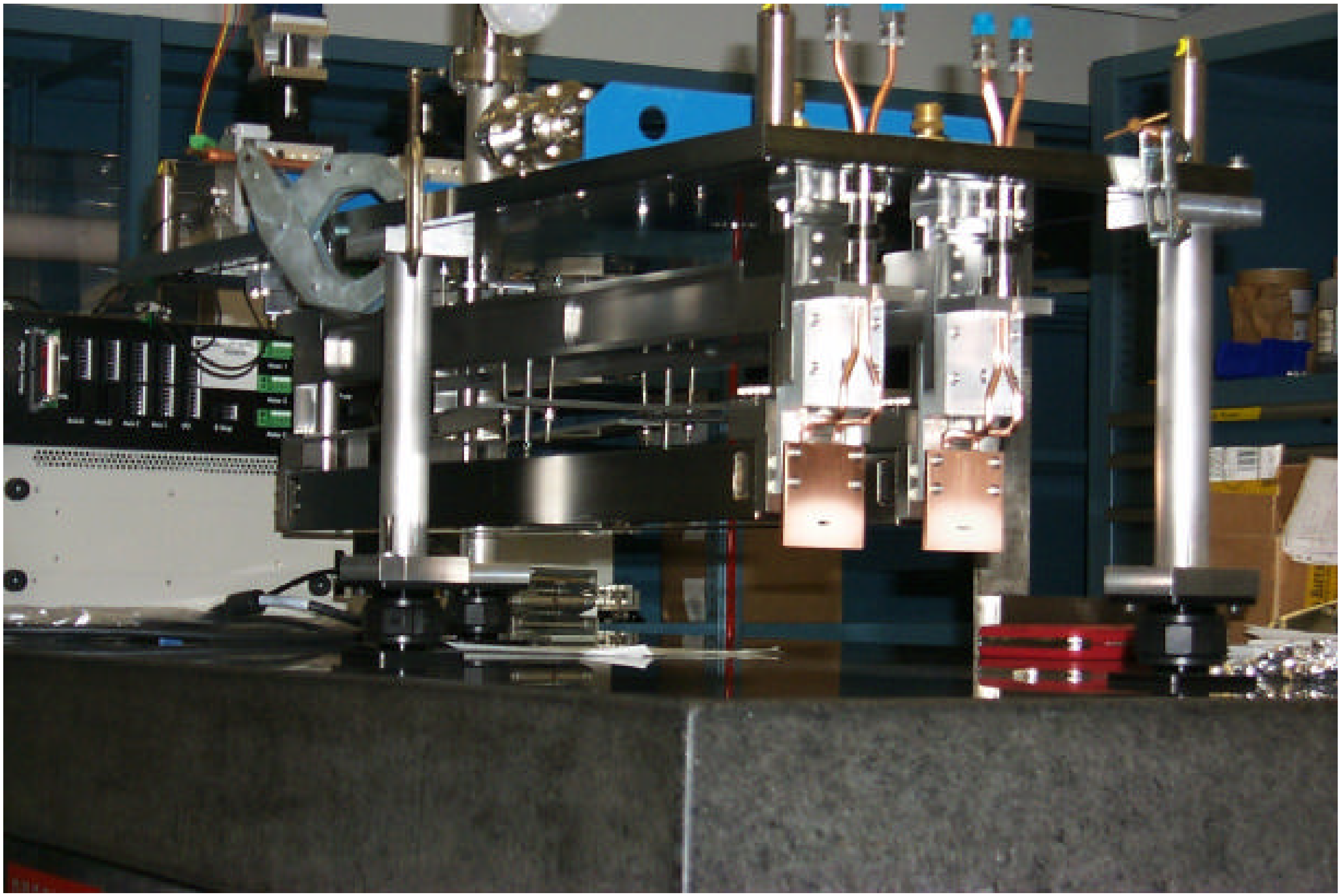


MIRROR SHAPED BY BENDING



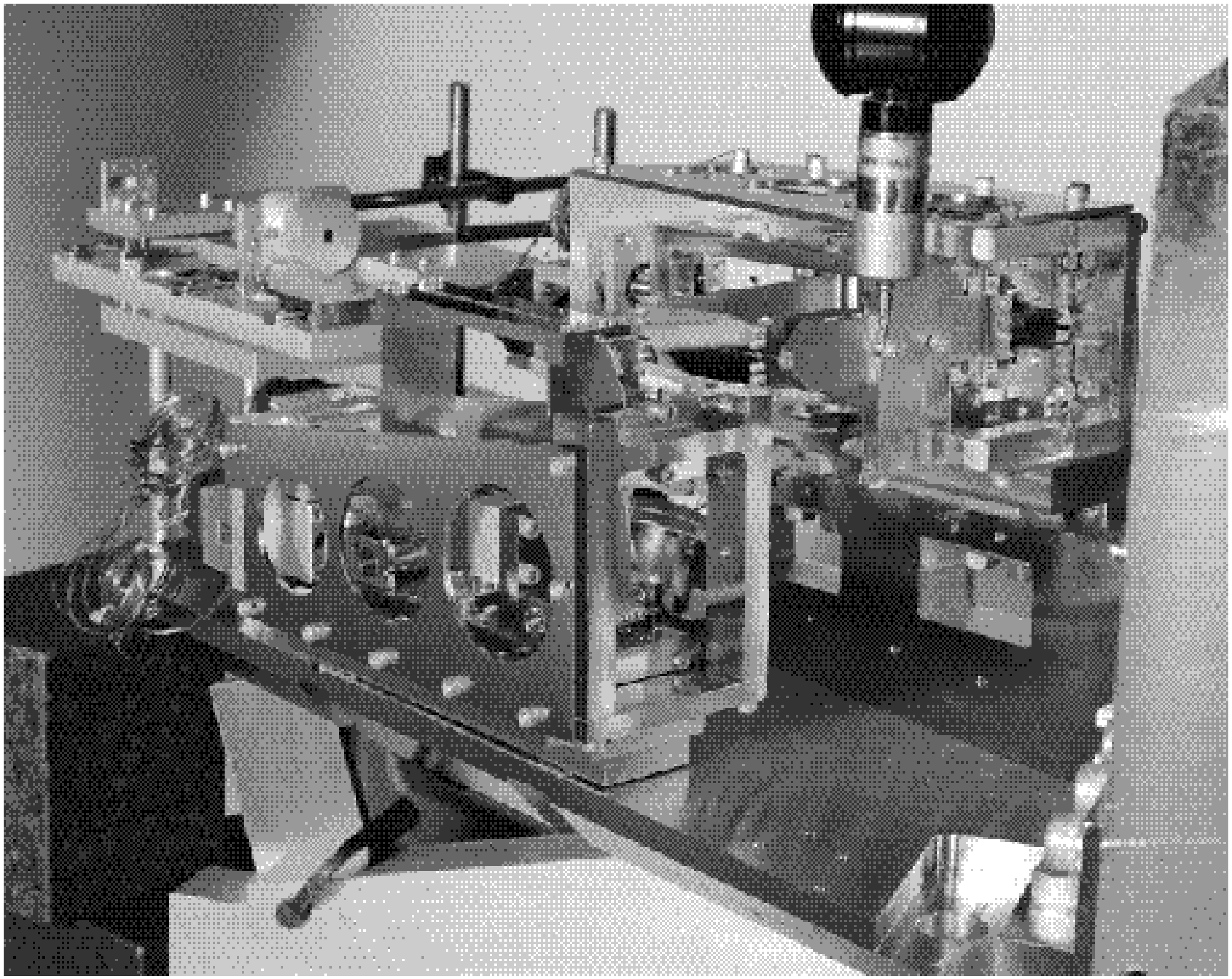
- Reflecting surface faces downward
- Bending forces are applied by adjustable flexible leaf springs
- Mirror shape is a cubic approximation to the ideal parabolic cylinder that collimates the beam for entry into the double crystal monochromator
- Advantages: do *flat* polishing, adaptive, can form “difficult” shapes i. e. not flat or spherical,

TWO MIRRORS READY TO BE INSTALLED

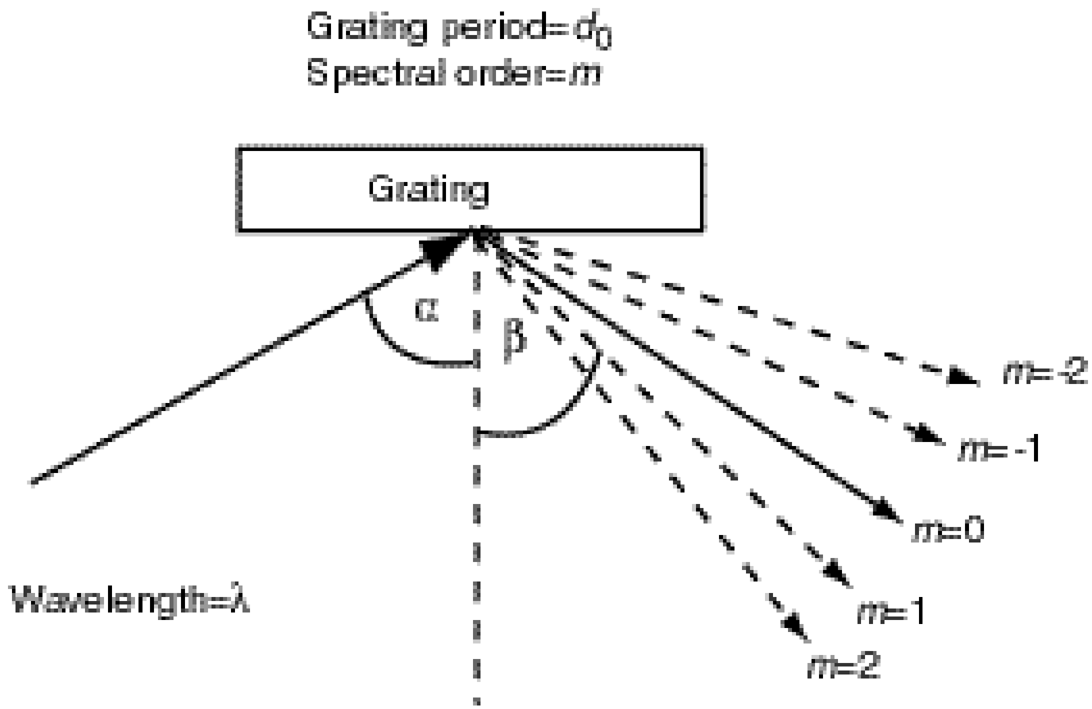


ELLIPTICAL KIRKPATRICK-BAEZ MIRROR PAIR

ALS BEAM LINE 7.3.2 (INTEL)



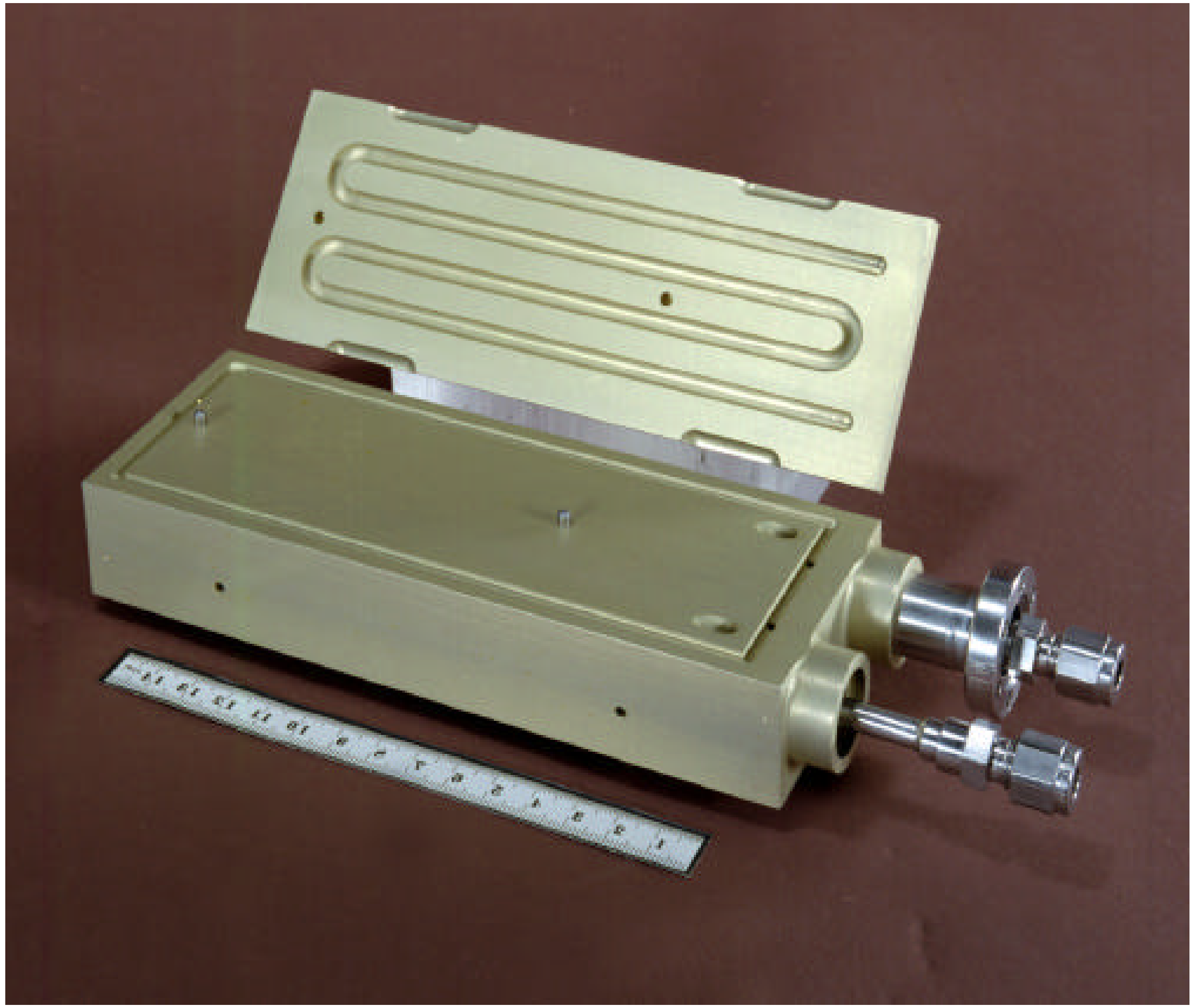
PRINCIPLE OF THE REFLECTION GRATING



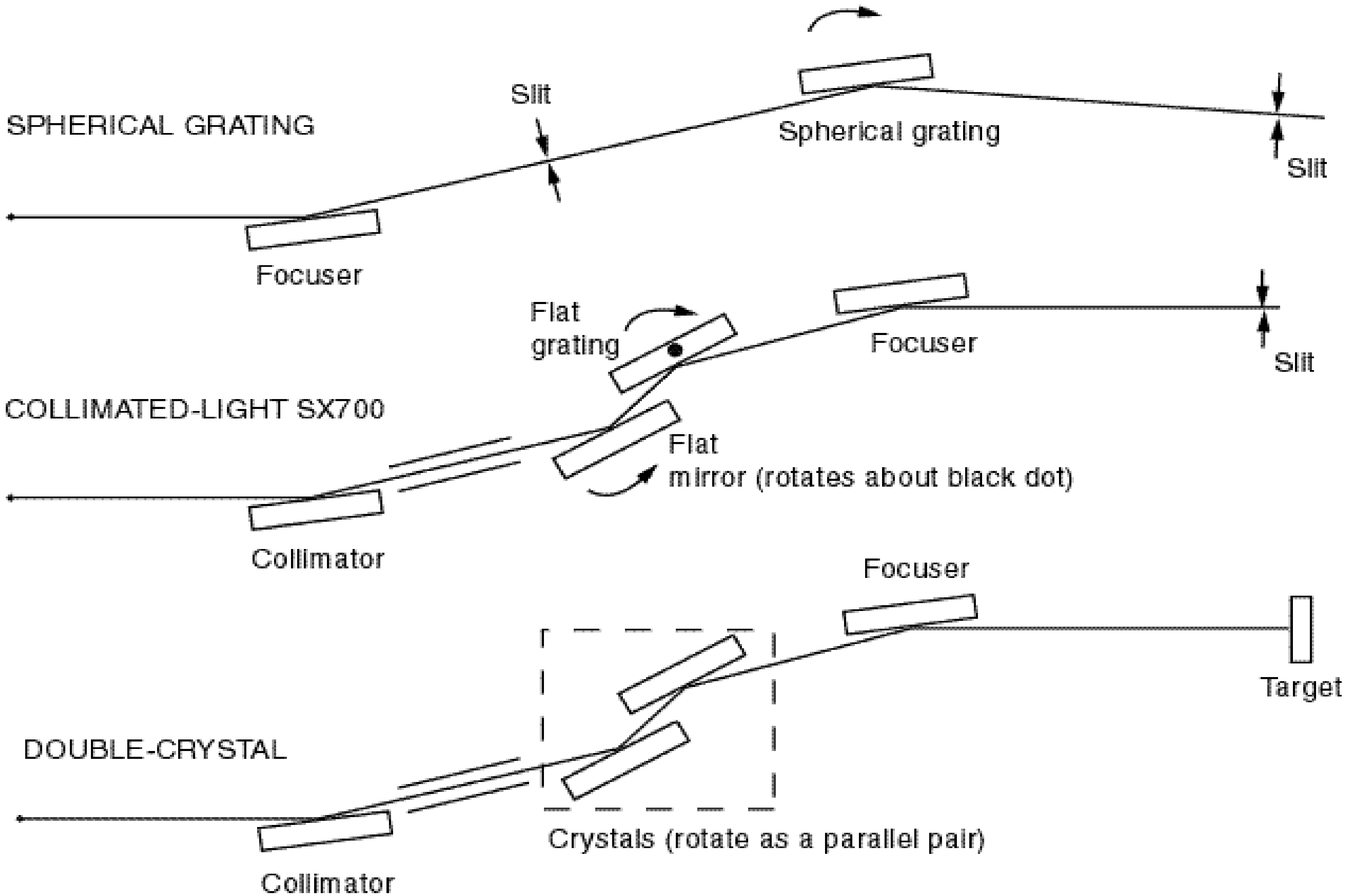
Grating equation: $$m\lambda = d_0\left(\sin\alpha + \sin\beta\right)$$

ALS SPHERICAL REFLECTION GRATINGS

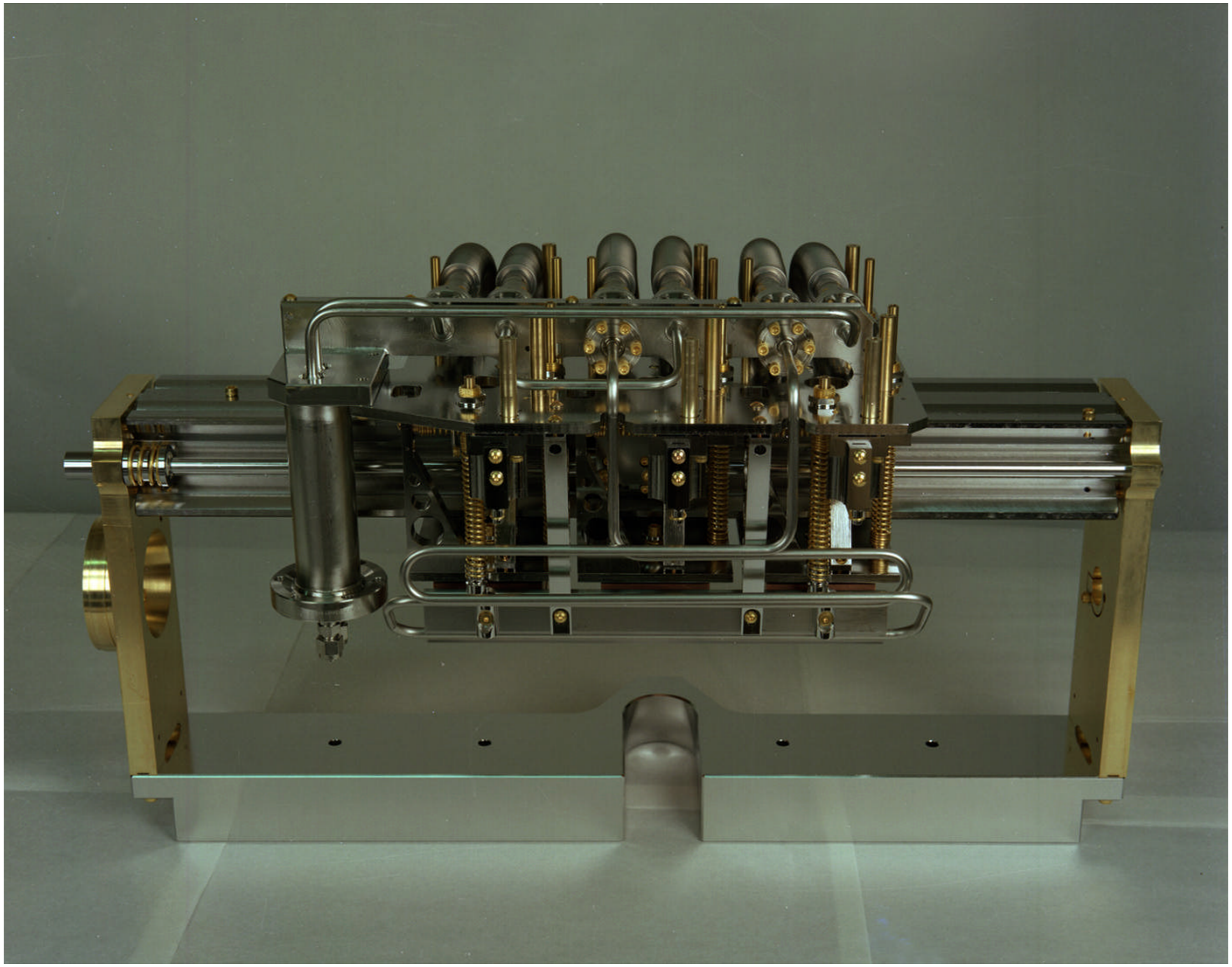
- Polished in electyroless-nickel plated Glidcop
- Conductivity of copper with greater strength and stability
- Double skin water-cooling
- Sub microradian surface accuracy even under heat load
- Record resolving power (65000) in 1995



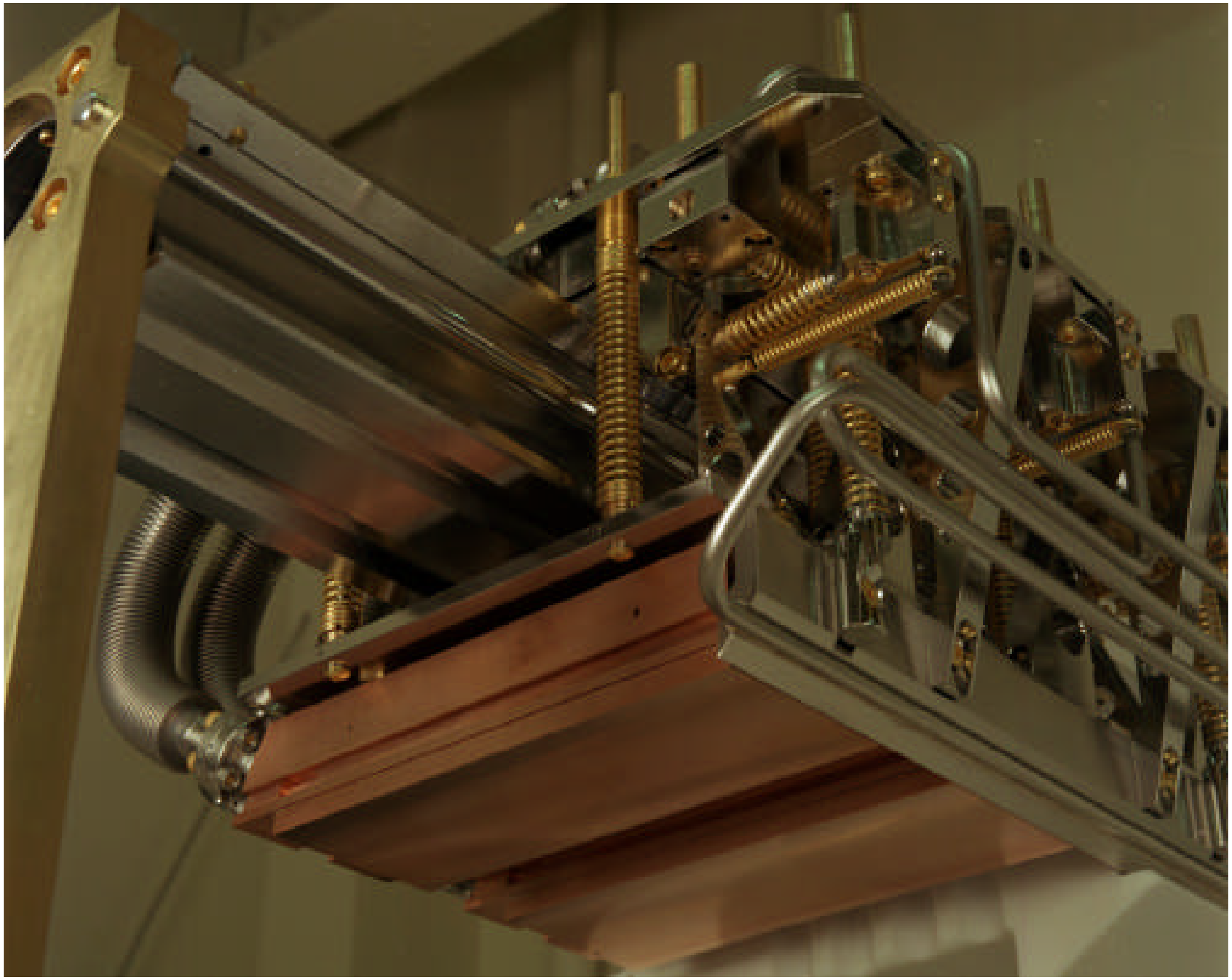
COMMON MONOCHROMATOR TYPES



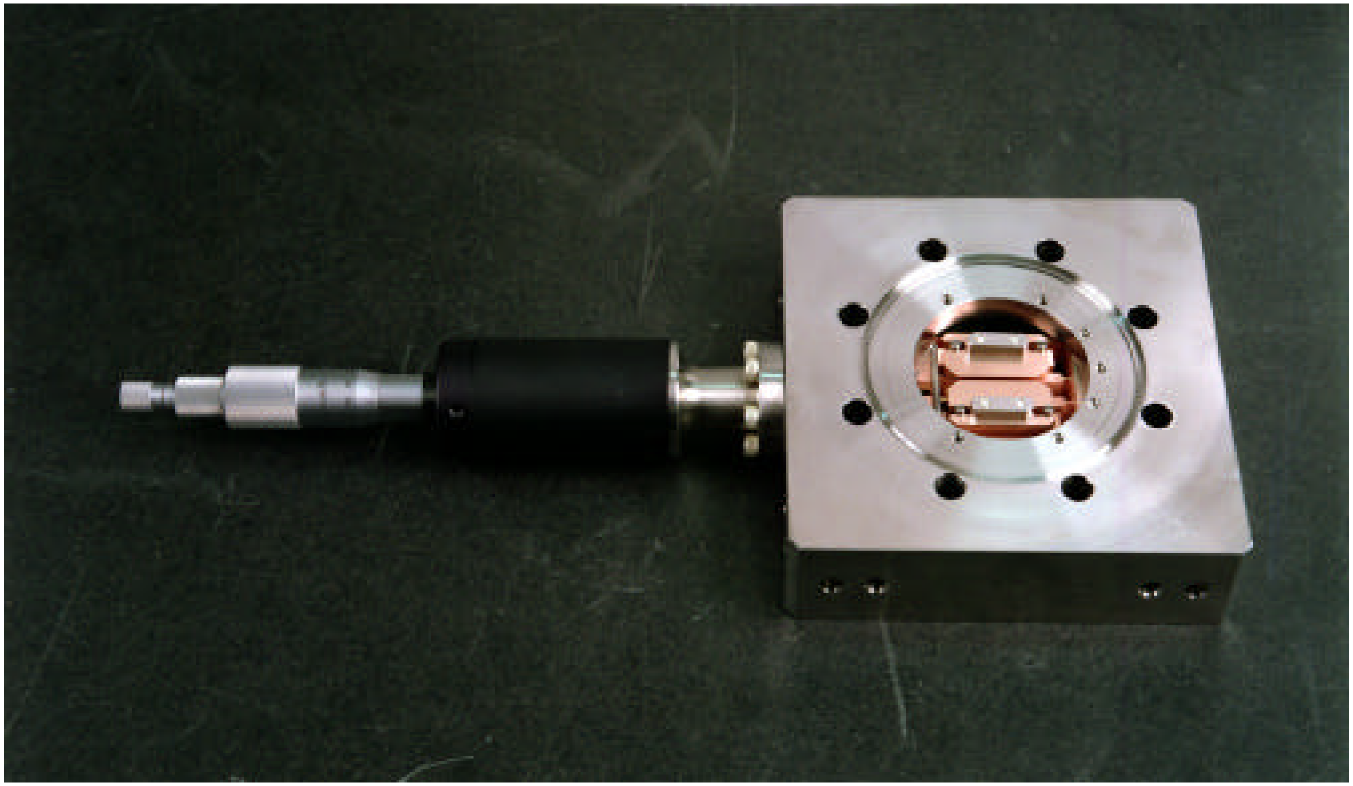
GRATING CARRIAGE OF ALS SPHERICAL GRATING MONOCHROIMATOR (SGM)



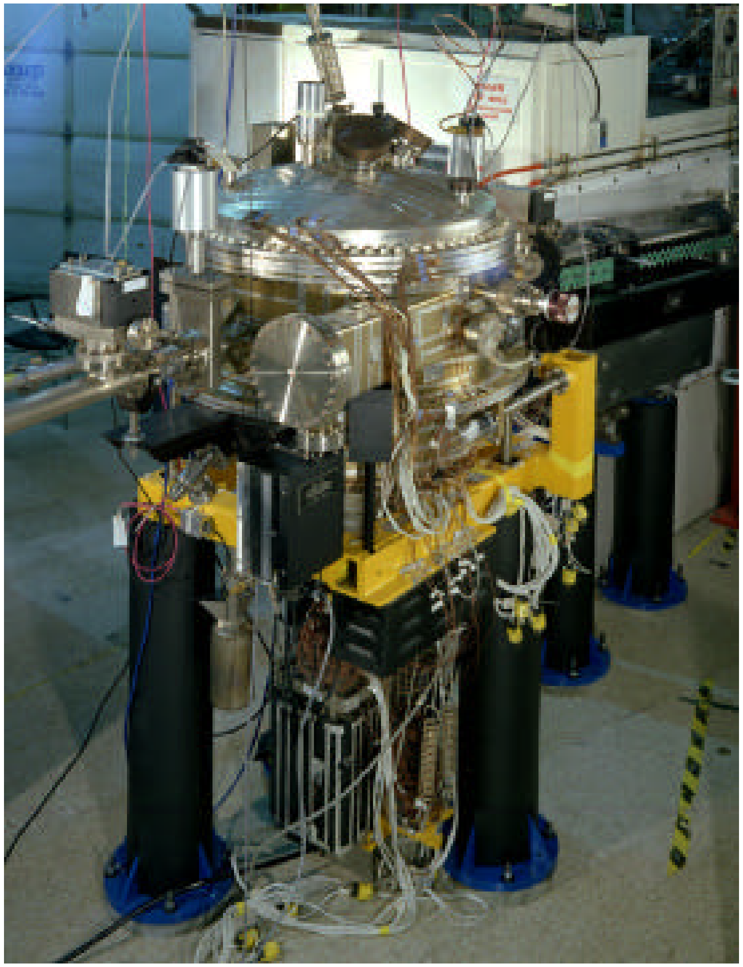
COOLED GRATINGS ON THE ALS SPHERICAL GRATING MONOCHROMATOR



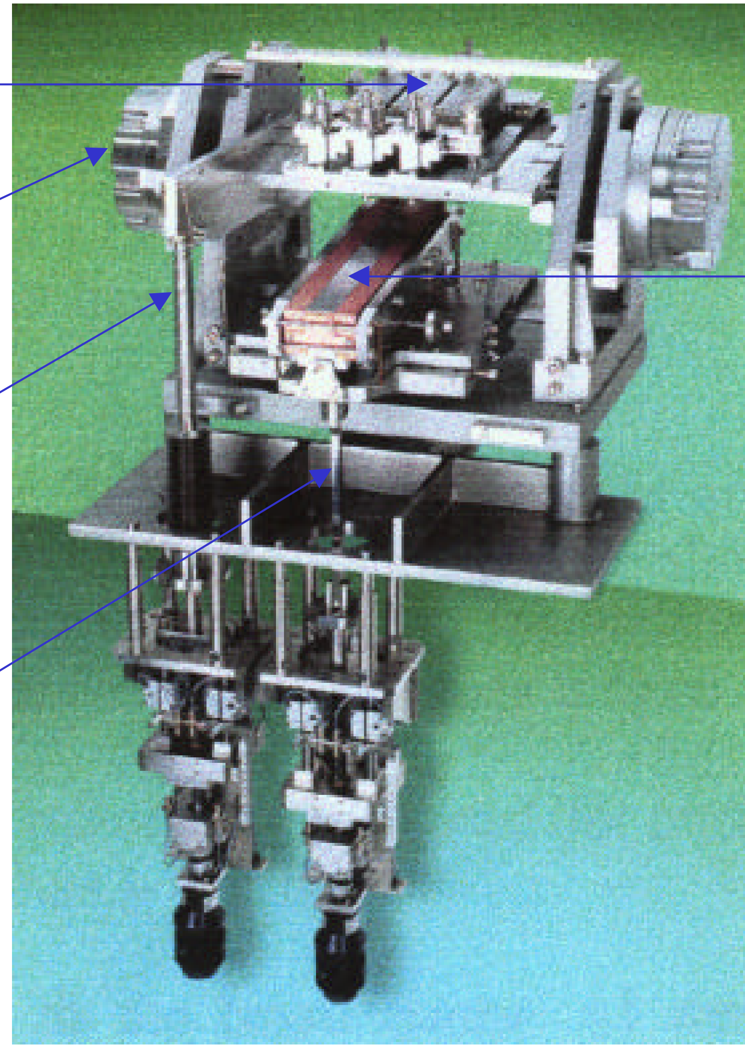
ALS MONOCHROMATOR SLIT



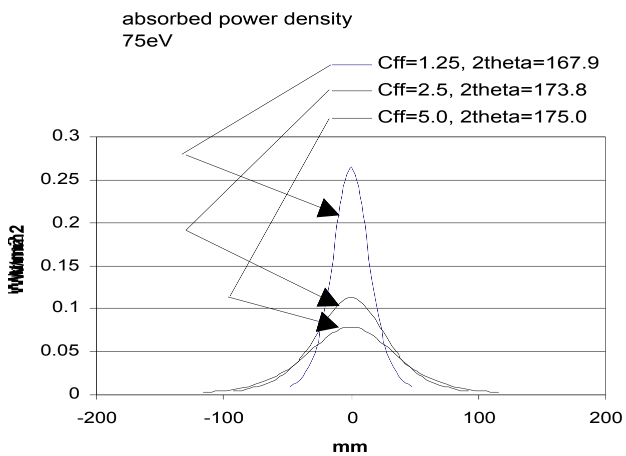
INSTALLED SPHERICAL GRATING MONOCHROMATOR (BL 9.3.2)

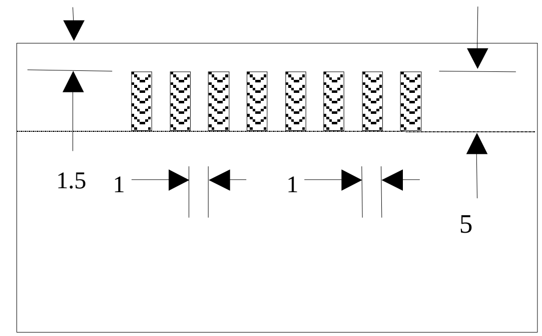


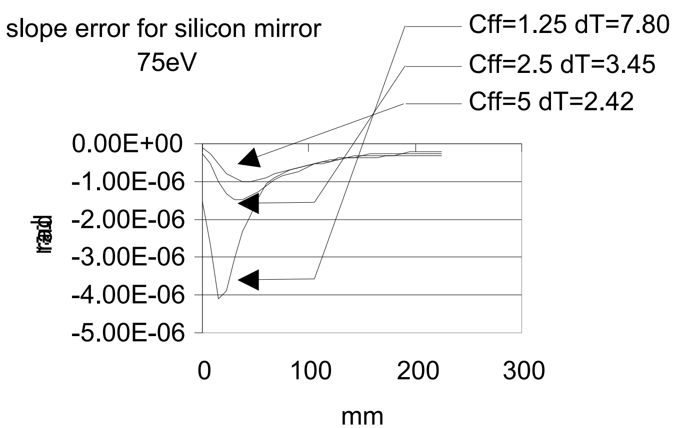
JENOPTIC SX700 MONOCHROMATOR



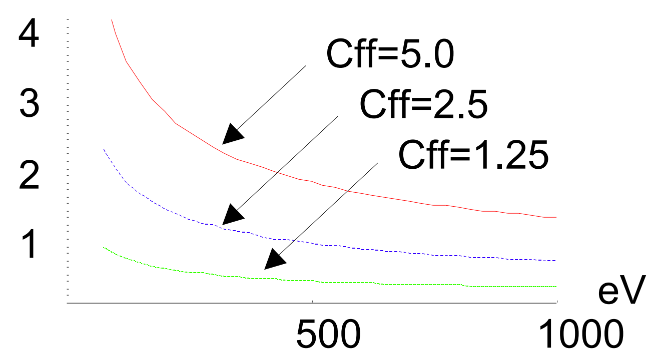
Mirror cooling for high heat load at low energy (75eV)



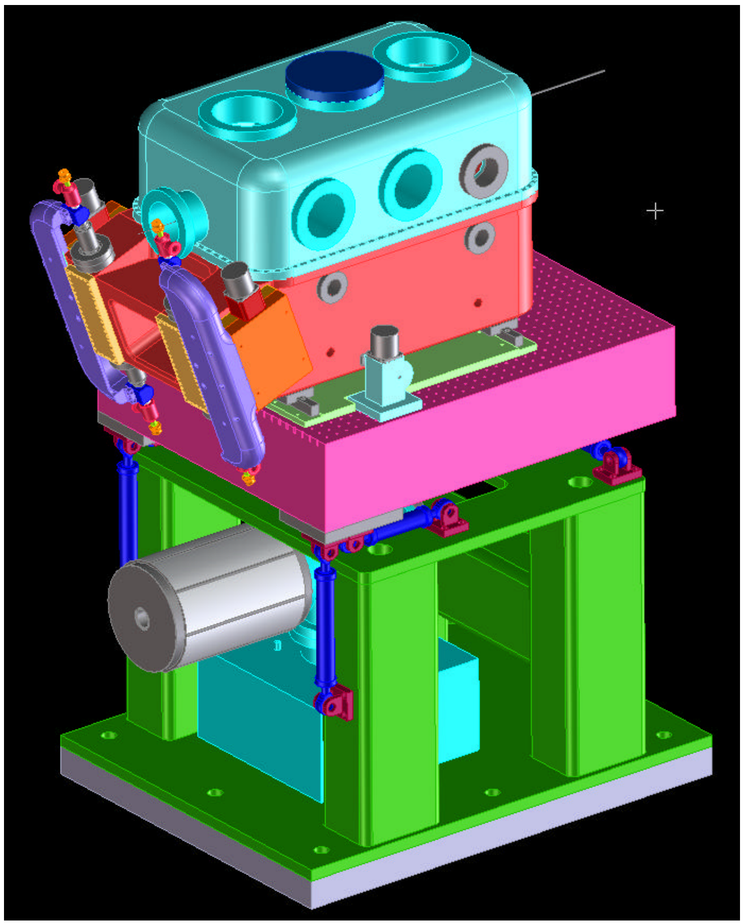


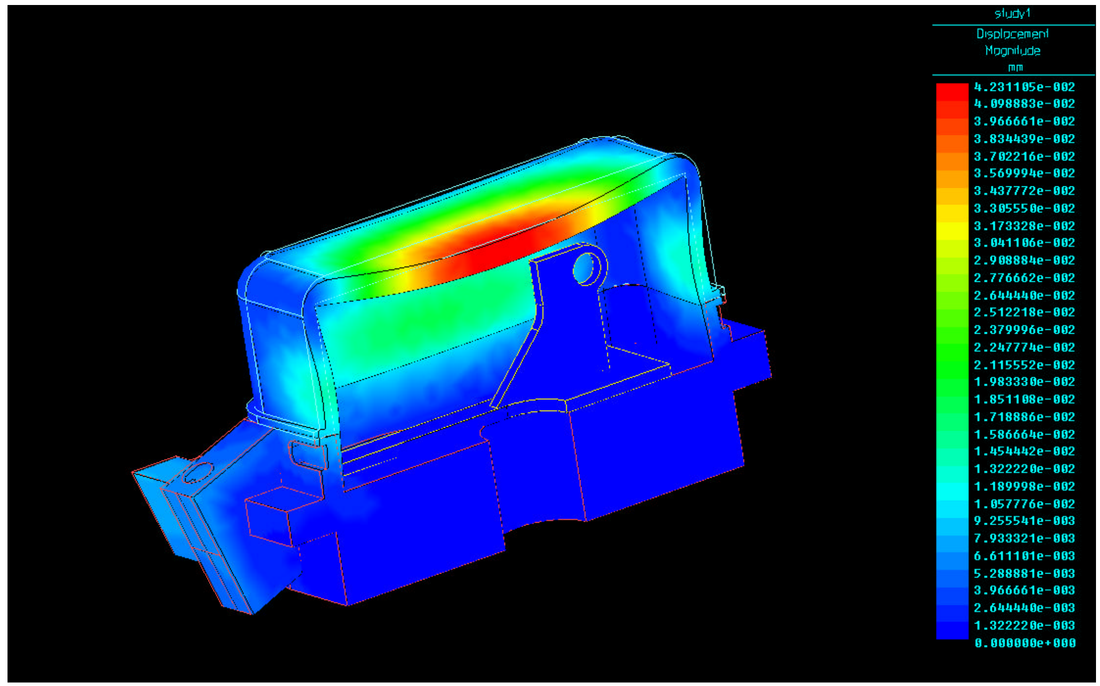


The rms slope error (μrad) of the pre-mirror corresponding to a resolving power R=7500 (FWHM) from the 150l/mm grating.

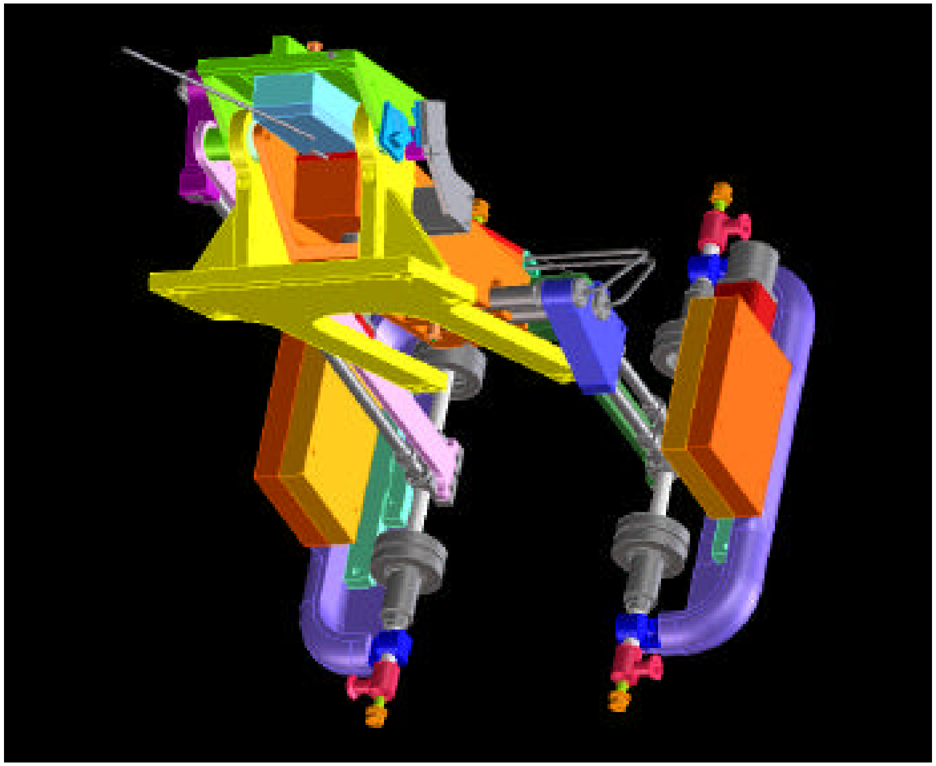


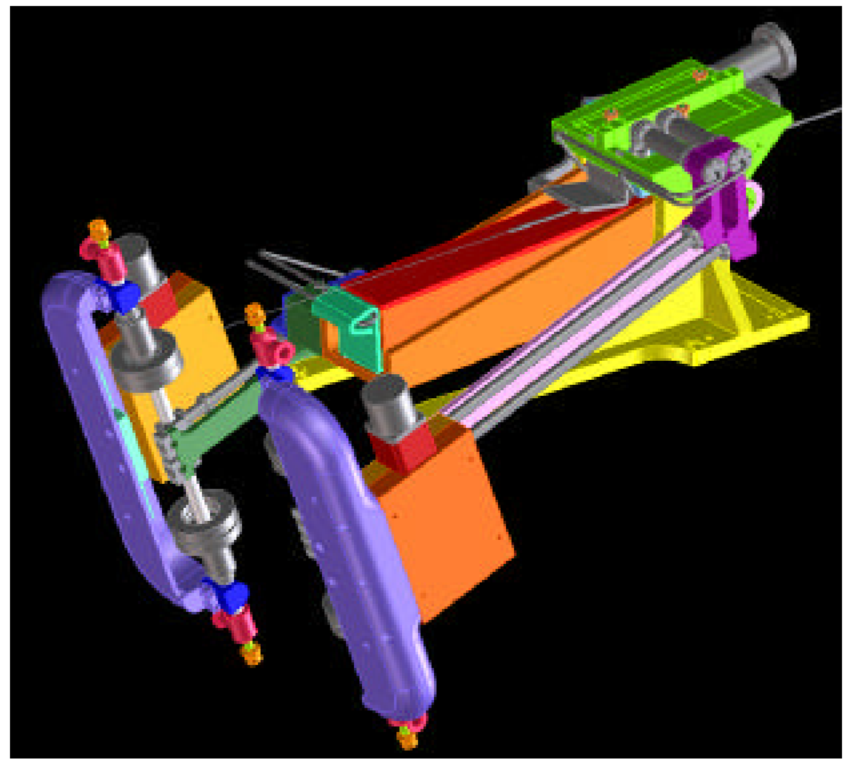
ALS SX700 MONOCHROMATOR: OVERVIEW



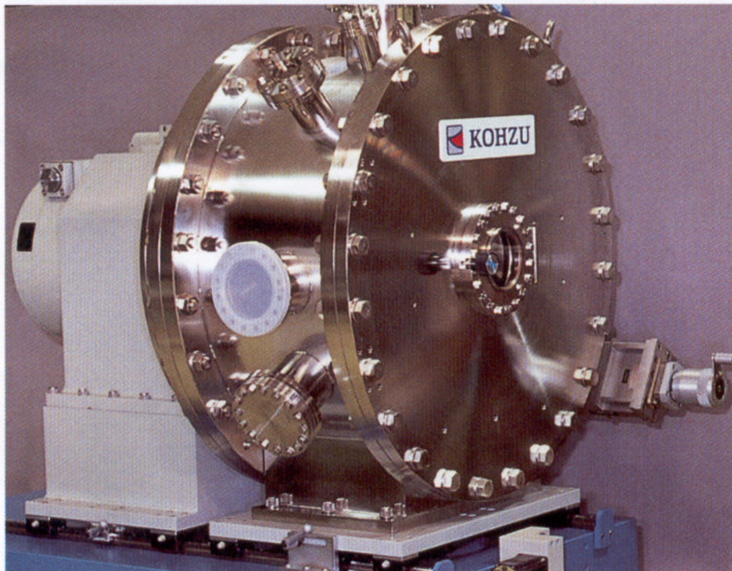


ALS SX700 MECHANICS

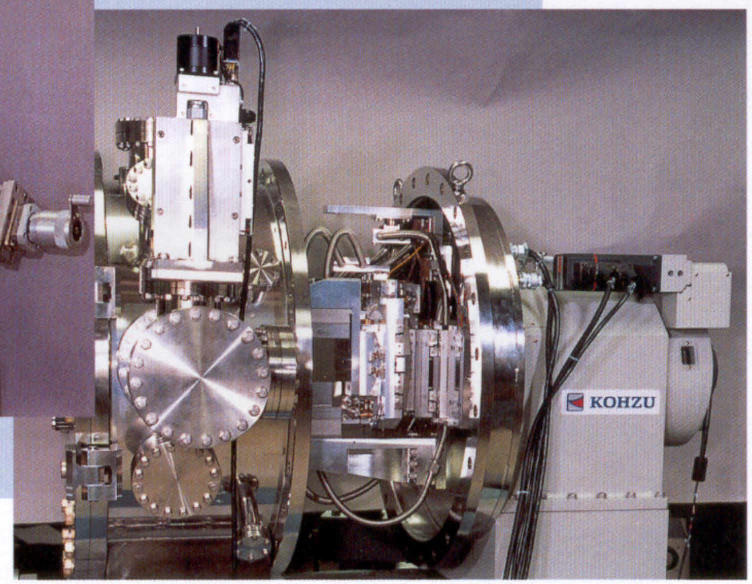




KOHZU DOUBLE-CRYSTAL MONOCHROMATOR



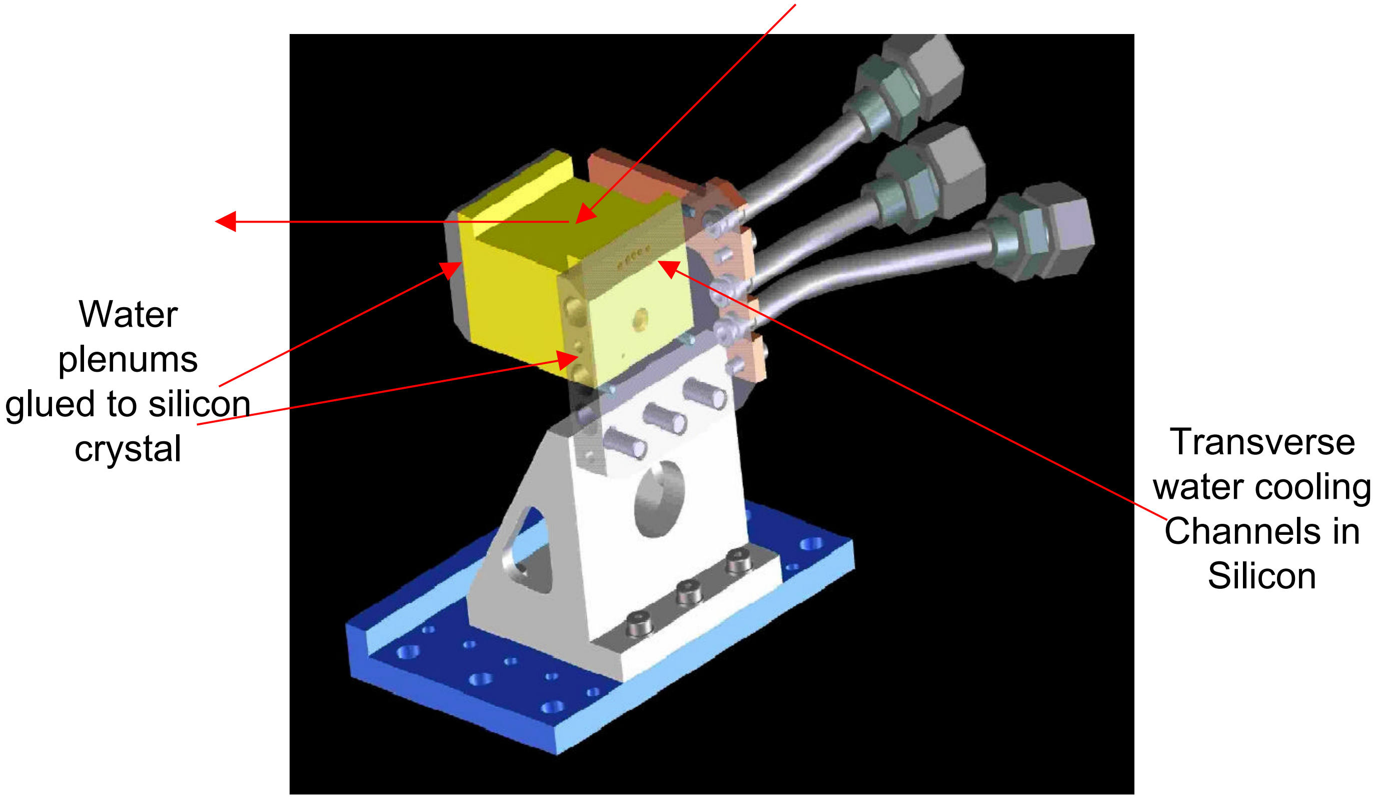
APM-2L"Left-side" monochromator :
a general view.



APM-2L monochromator:crystal adjustment mechanics.

- Commercial double-crystal monochromator type APM2 by Kohzu-Seiki of Japan
- Tunable over 2.3-22.5 KeV photon energy or 5-60 degree Bragg angle
- Cooled silicon 111 crystals providing resolving power E/dE of 7000

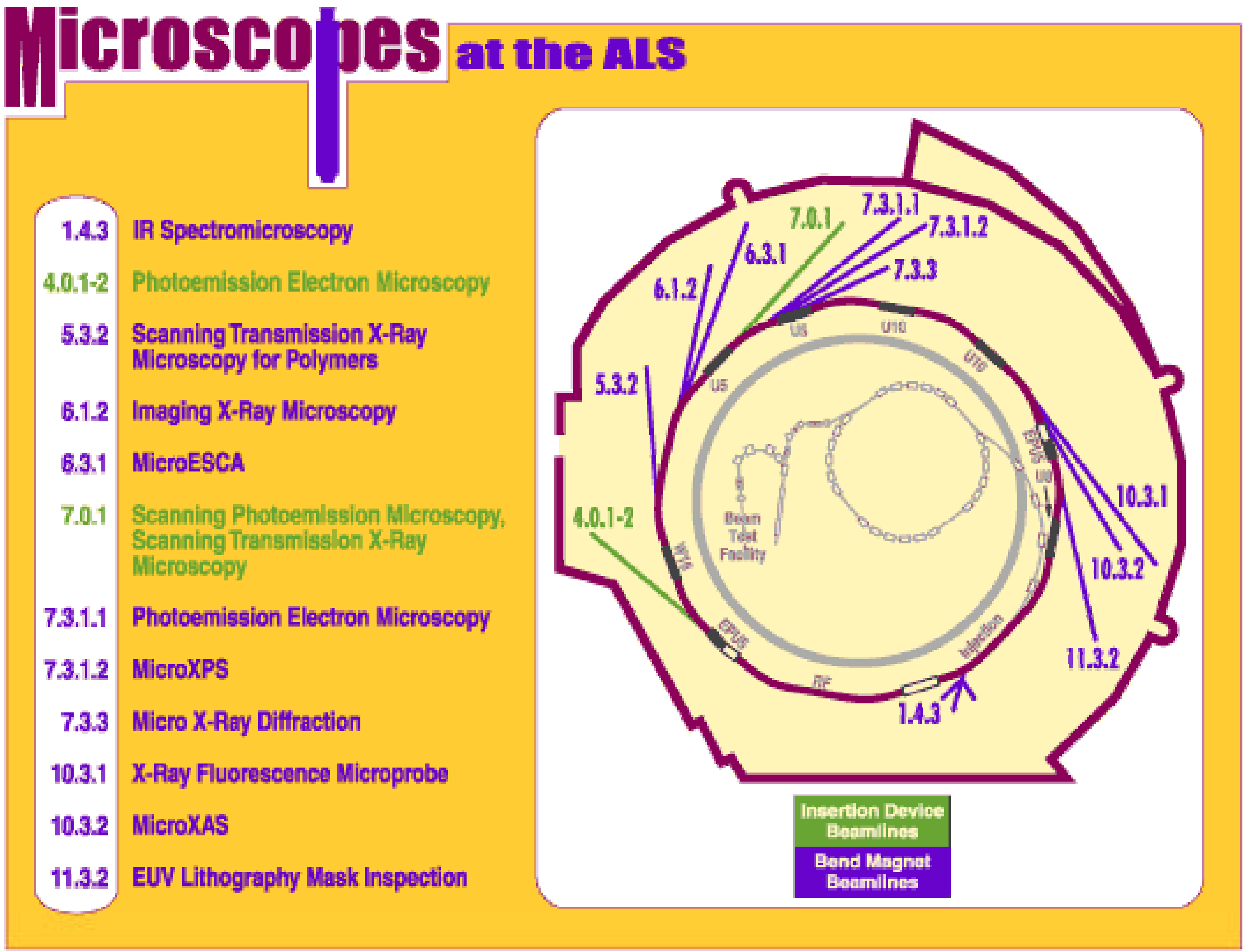
COOLED MONOCHROMATOR CRYSTALS



- First Si (111) crystal is water-cooled via transverse drilled holes: hole-to-surface distance matches power load @ 12.6 keV
- Finite-element analysis indicates slope errors below 0.4 μrad RMS with full thermal load from beam.

X-ray imaging is a major ALS activity

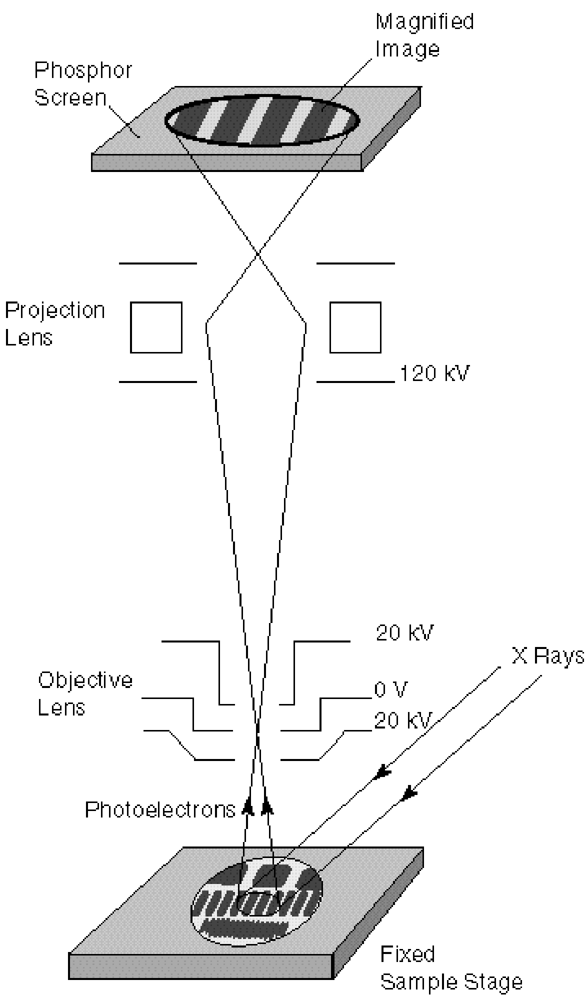
From ALS website (www-als.lbl.gov/als)



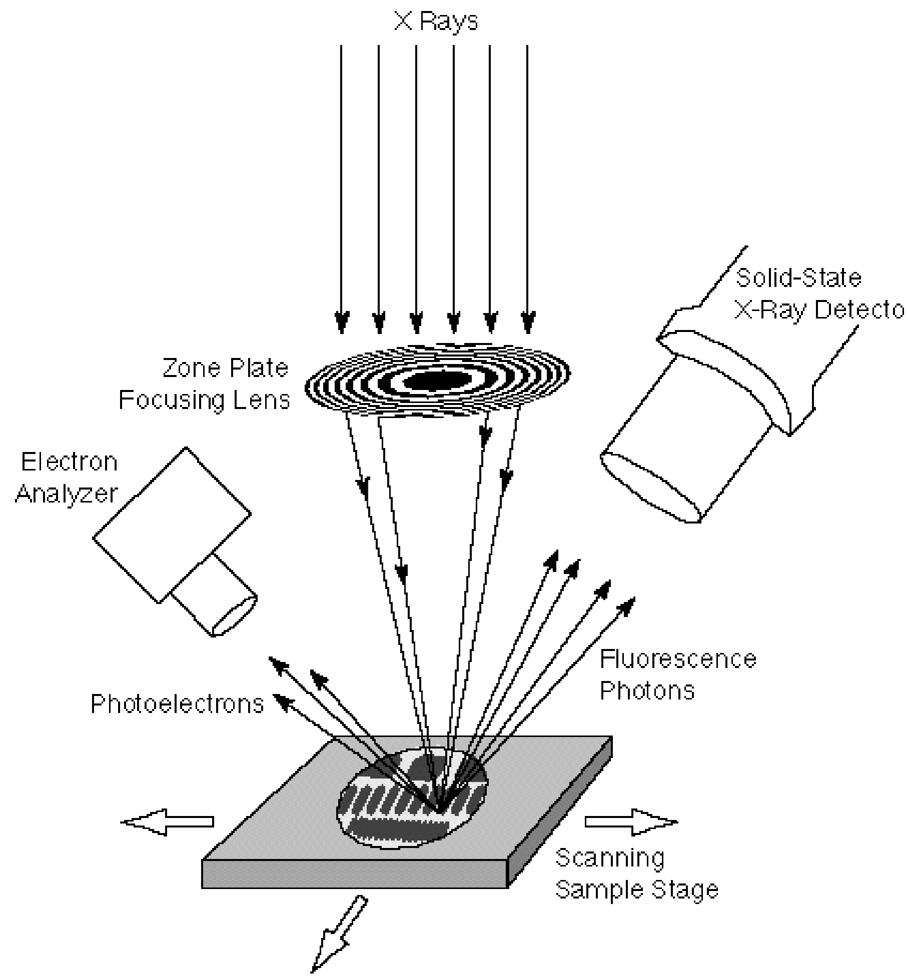
ALS MICROSCOPES

Imaging device	Beam line	Resolution	Mission
Microscopes			
Photoelectrom emission	7.3.1.1	20 nm	Magnetic imaging (SXR)
Scanning transmission zone plate	7.0.1	100 nm	Materials science (SXR)
SPEM	7.0.1	150 nm	Surface science (SXR)
Imaging zone plate	6.1.2	25 nm	Life science (SXR)
Microprobes			
Scanning Kirkpatrick-Baez reflection	7.3.3	420 nm	Microdiffraction (HXR)
Scanning Kirkpatrick-Baez reflection	7.3.1.2	1000 nm	XPS – microcircuit diagnostics (SXR)
Scanning Kirkpatrick-Baez reflection	10.3.1	1000 nm	Scanning XRF (HXR)
Scanning Kirkpatrick-Baez reflection	10.3.2	1000 nm	Small-spot EXAFS (HXR)
Diffractive imaging			
Diffraction/holography	9.0.1	10 nm (projected)	Life science (SXR)

PRINCIPLES OF X-RAY MICROSCOPES FOR EXAMINING SURFCACES

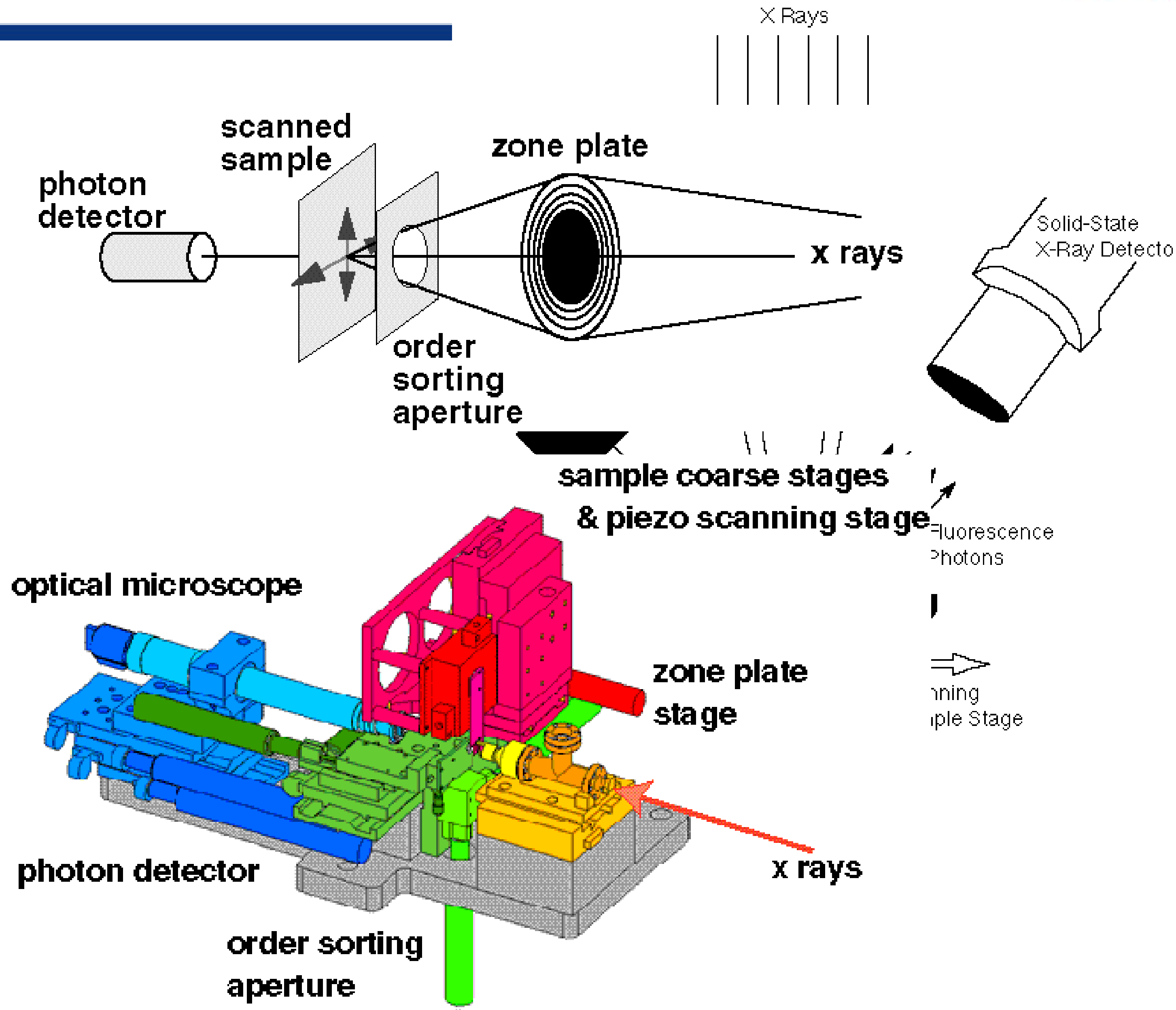


Full-Field Photoemission Microscope

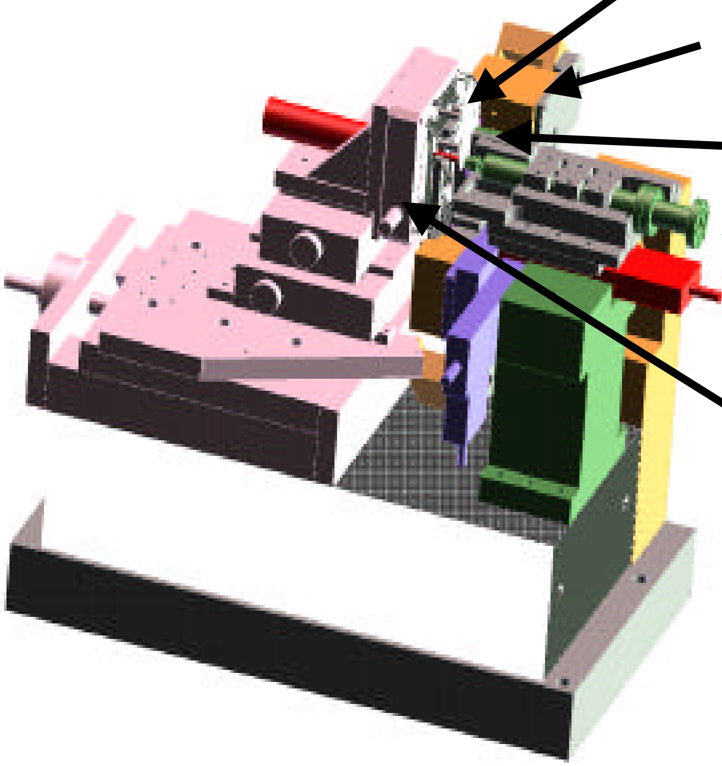


Scanning Zone Plate Microscope

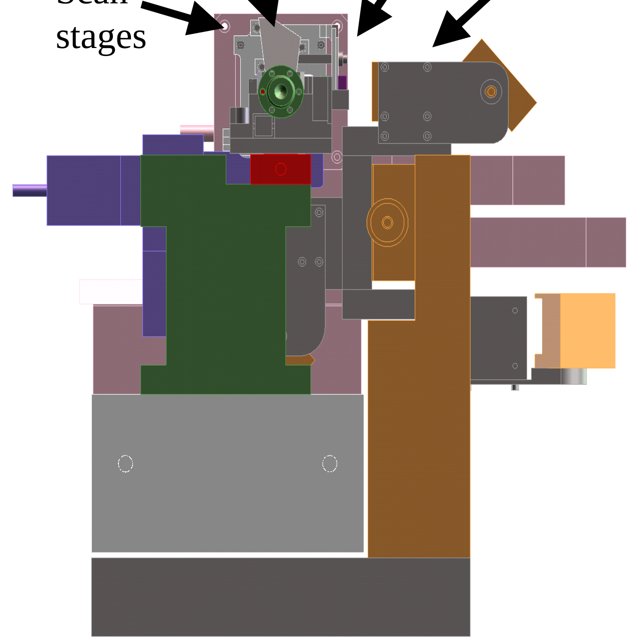
PRINCIPLE OF THE SCANNING ZONE-PLATE MICROSCOPE



The STXM upgrade

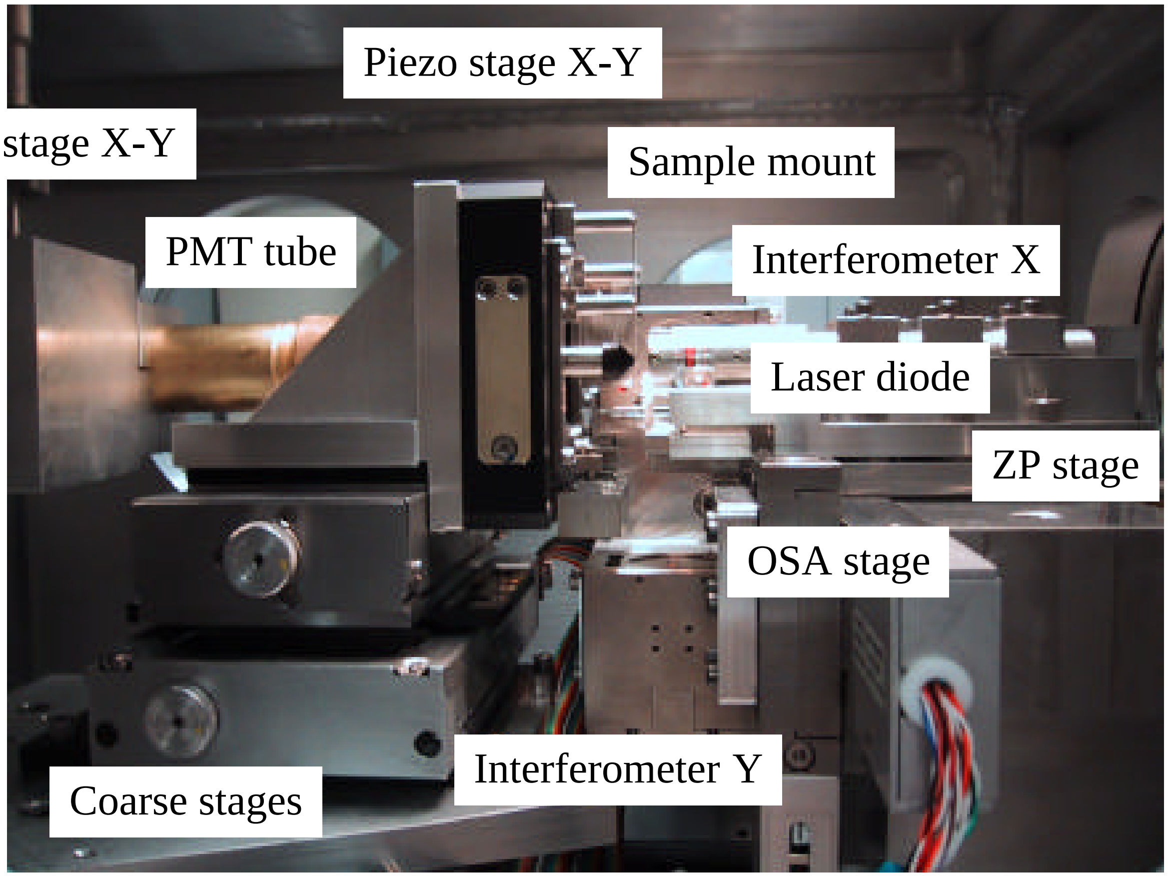


Side view

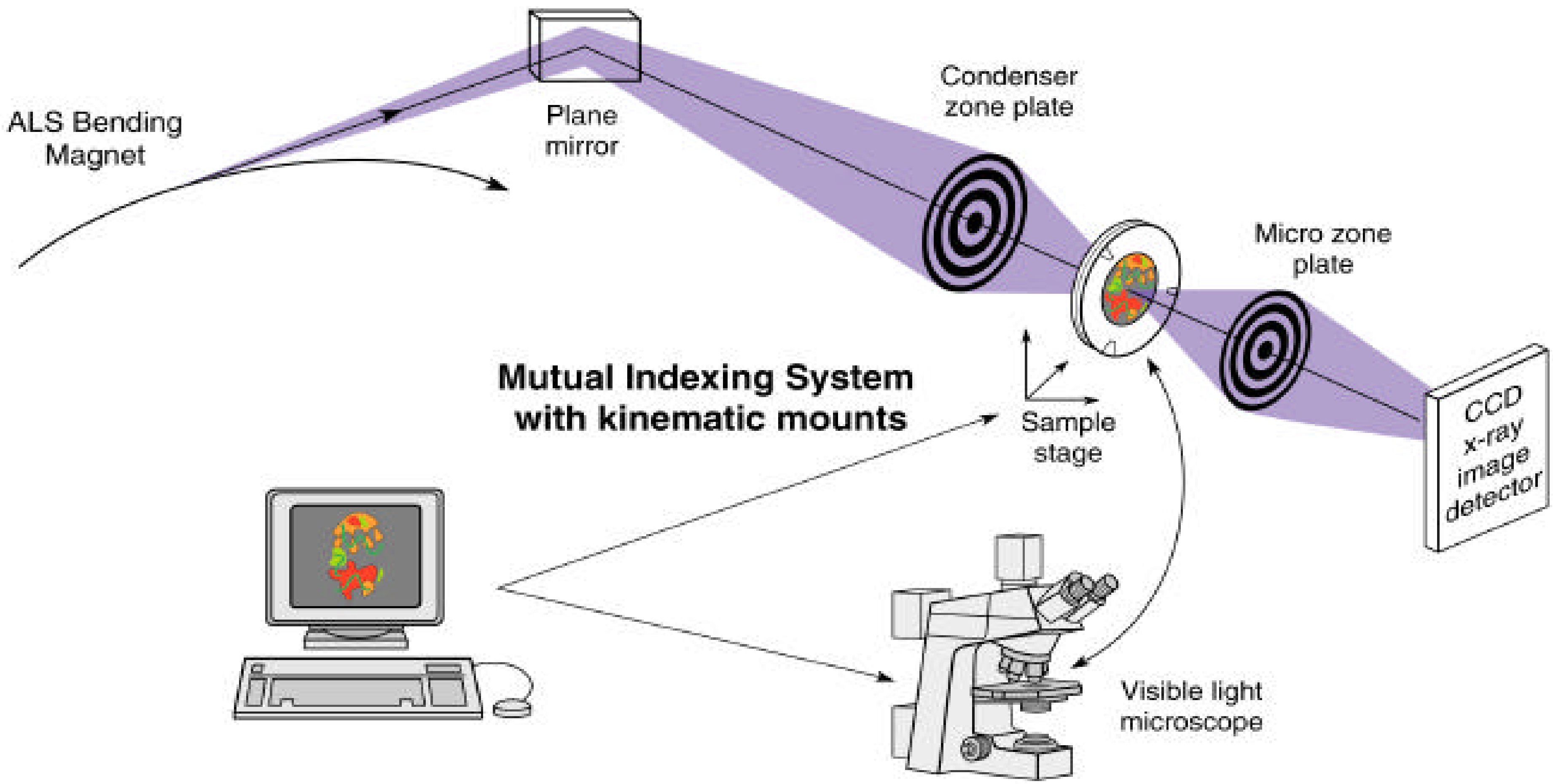


Looking Downstream

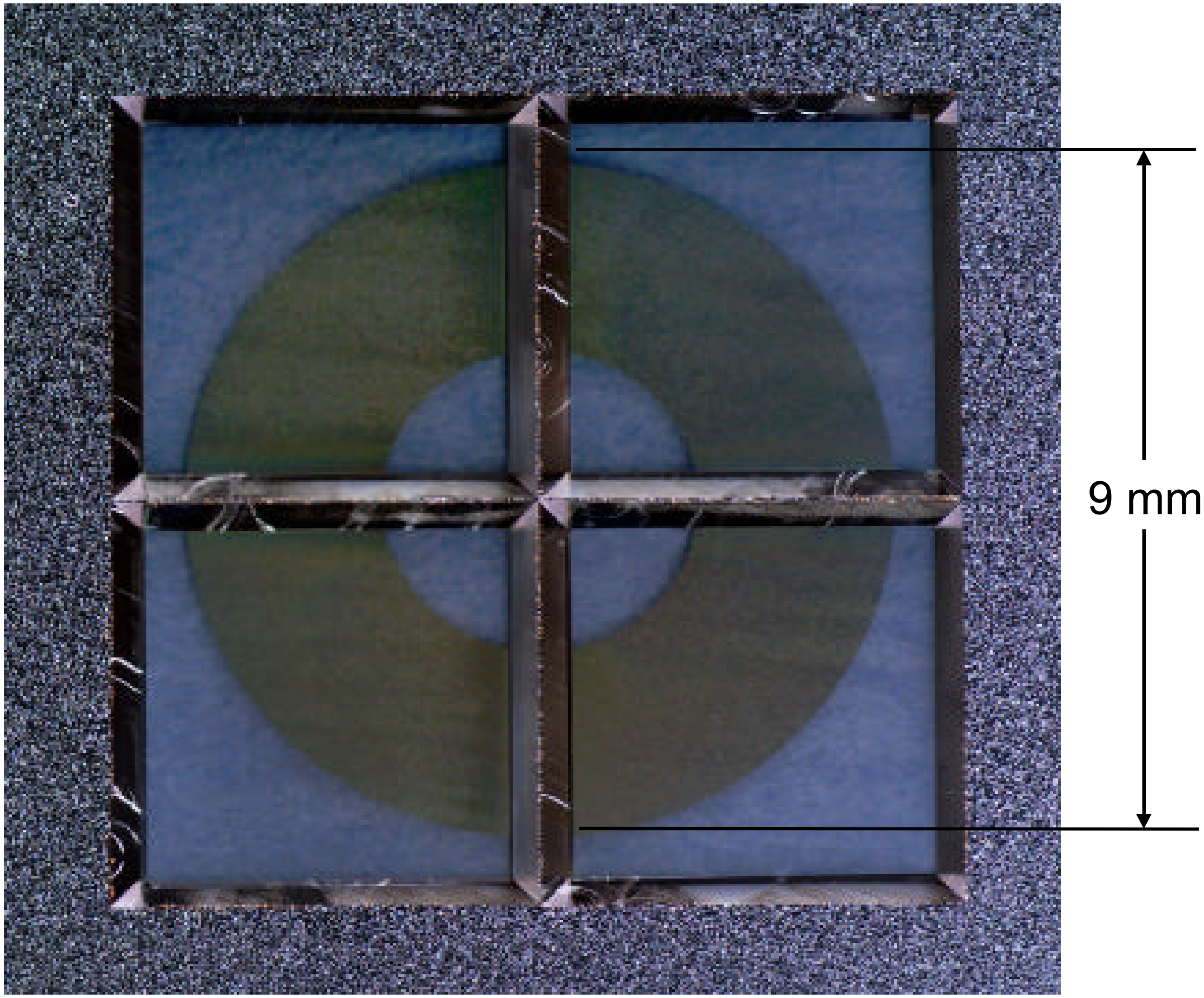
The STXM upgrade



High Resolution Zone-Plate Microscope XM-1 at the ALS



New more efficient Condenser Zone Plate

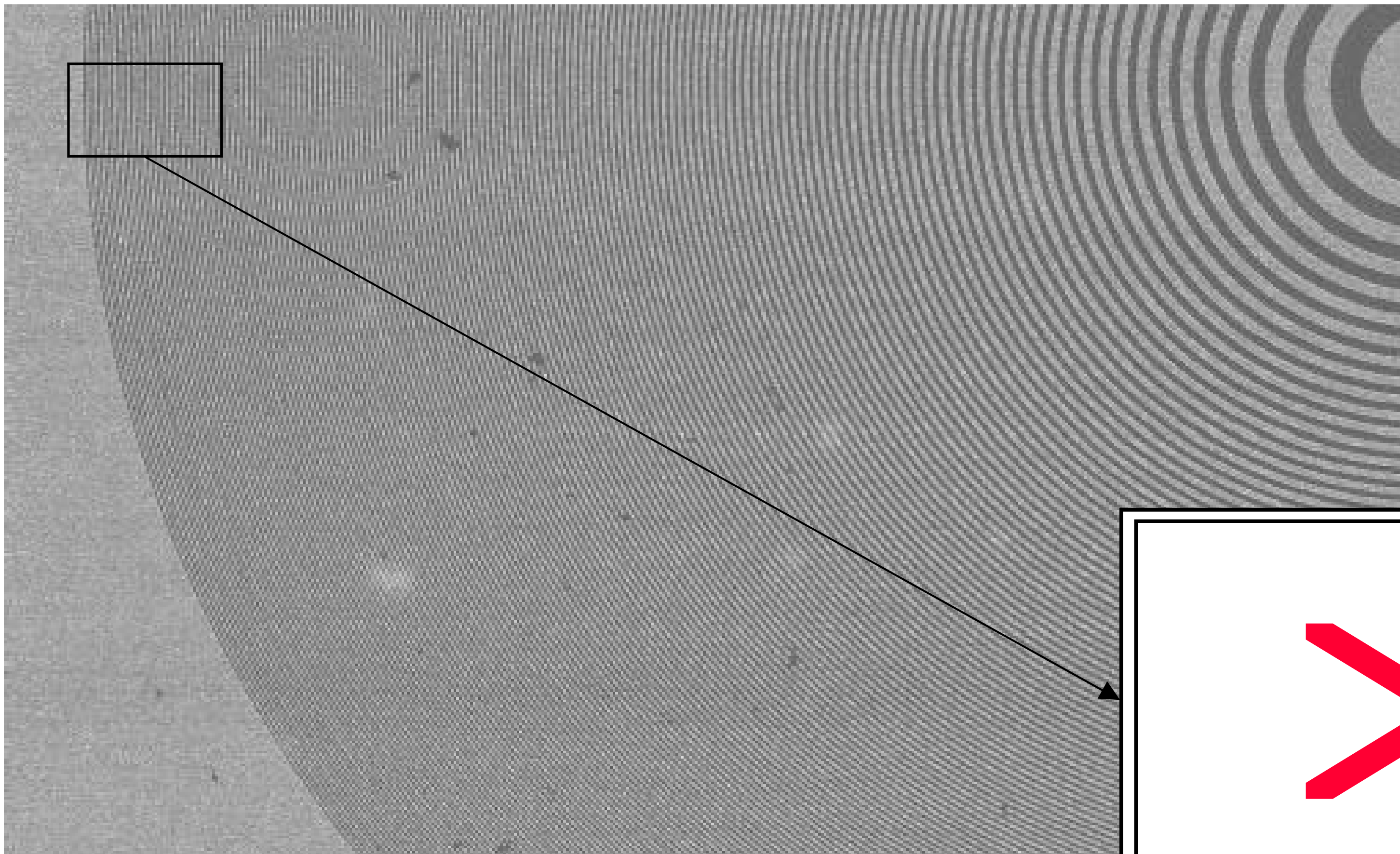


- Δr = 55 nm
- D = 9 mm
- N = 41,000 zones
- f = 207 µm &
  NA = 0.43
  @ λ = 2.4 nm

G. Denbeaux, L. Johnson, A. Lucero, W. Chao, E. Anderson, D. Attwood

New 25 nm Zone Plate

Erik Anderson, Deirdre Olynick and Bruce Harteneck, Zone Plate Fabrication with the Nanowriter.



- Δr = 25 nm
- D = 63 µm
- N = 618 zones
- f = 650 µm &
  NA = 0.05
  @ λ = 2.4 nm

ALS BEAM LINE LAYOUT MAY 2000