Experiences with Phase Retarding Optics in Sector 4

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Beam Polarization

Synchrotron beams are highly linearly polarized

Undulator A ~ P_{lin} 0.999

$$P_{lin}^2 + P_{45}^2 + P_{circ}^2 \leq 1$$

$$P_{lin} = \frac{I^s - I^p}{I^s + I^p} \qquad P_{45} = \frac{2\sqrt{I^s I^p}}{I^s + I^p}\cos d \qquad P_{circ} = \frac{2\sqrt{I^s I^p}}{I^s + I^p}\sin d$$

Phase retarders manipulate the beam polarization by varying the relative phase(δ) between the horizontal (σ) and vertical (π) wave fields

Why mess the polarization?

Magnetic Scattering

$$s_{charge} \approx F(P_{lin})$$

$$s_{magnetic} \approx F(P_{lin}, P_{45}, \underline{P_{circ}})$$

$$s_{magnetic} \approx 10^{(-2 \rightarrow -6)} s_{charge}$$

Look for differences when P_{circ} is reversed

- Polarized EXAFS
- Resonant Charge Scattering
- Horizontal Diffraction

Circularly Polarized X-rays

- Off Axis Bending Magnet
- Special Insertion Devices

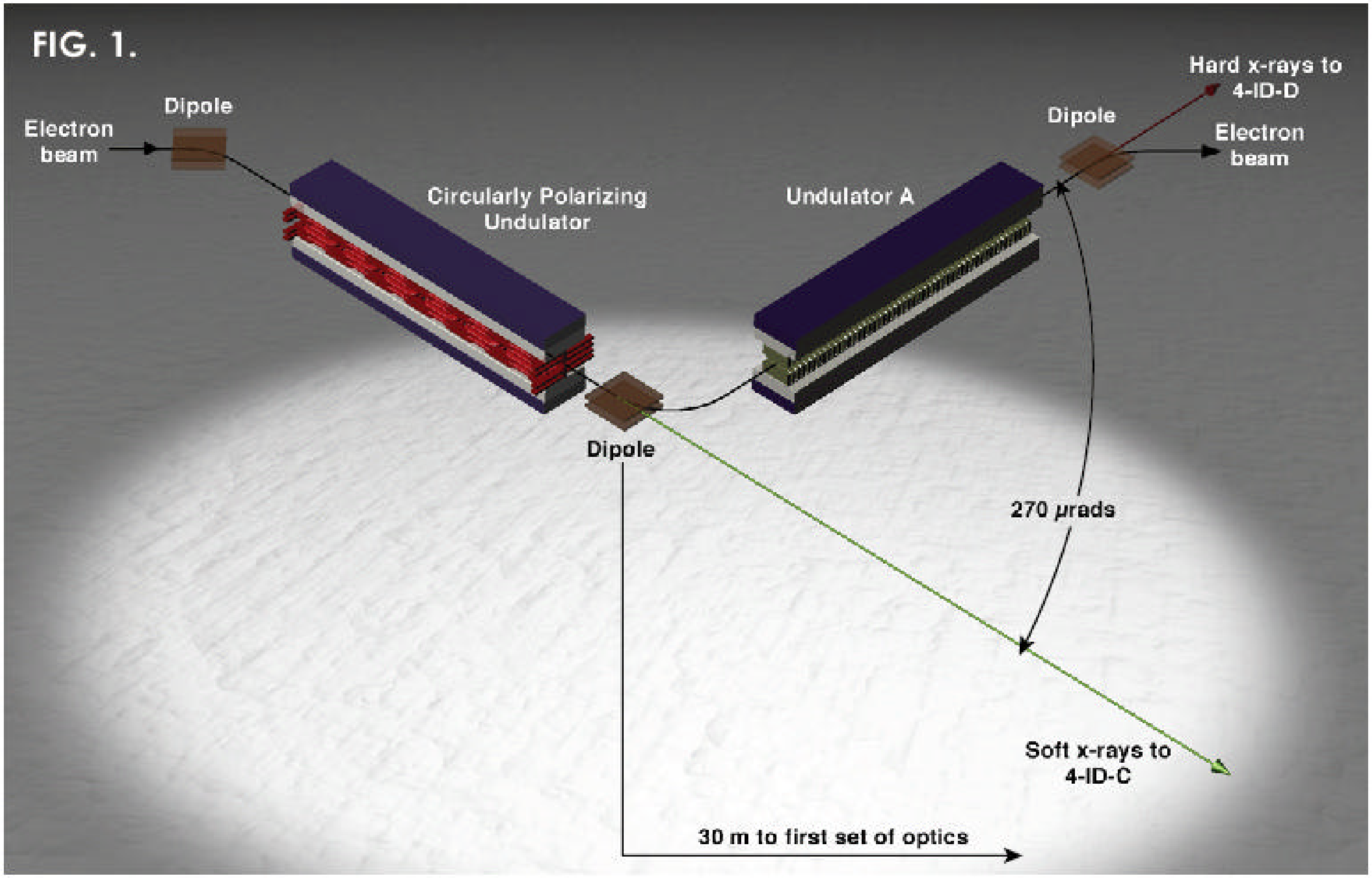
    EMW (*11-ID*), CPU (*4-ID-C*)

- Phase Retarders (Crystal Optics)

    Bragg Diffraction

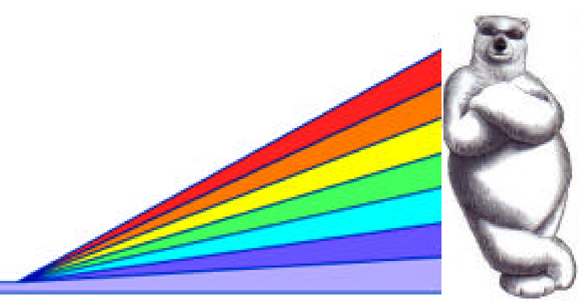
    Thin Crystal Transmission

Sector 4-Canted Undulators



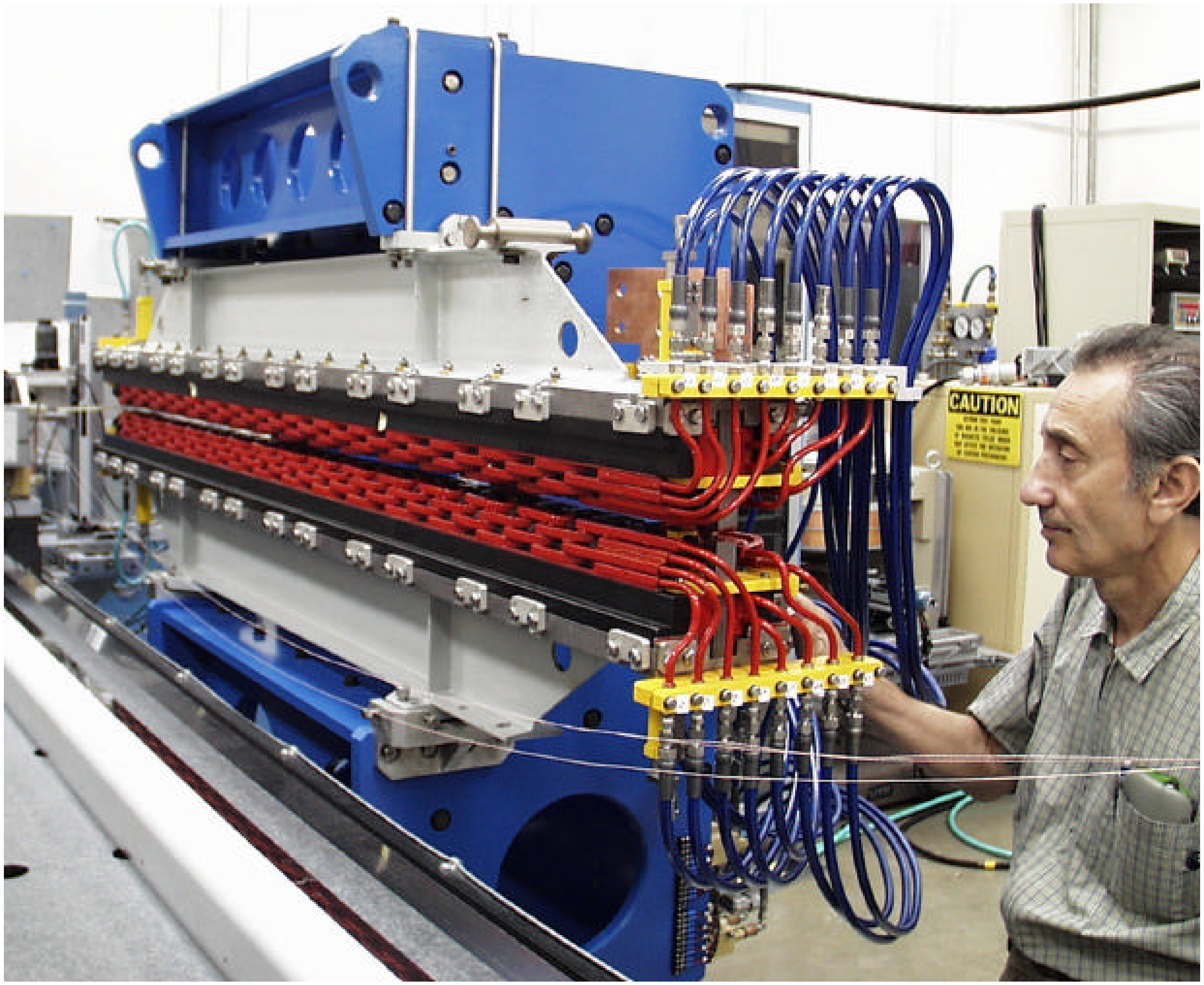
Und A - First Beam May 2000

CPU - First Beam May 2001



Advanced Photon Source-Polarization Studies

Circularly Polarizing Undulator



Fully
Electromagnetic

~1200A DC

~100A AC

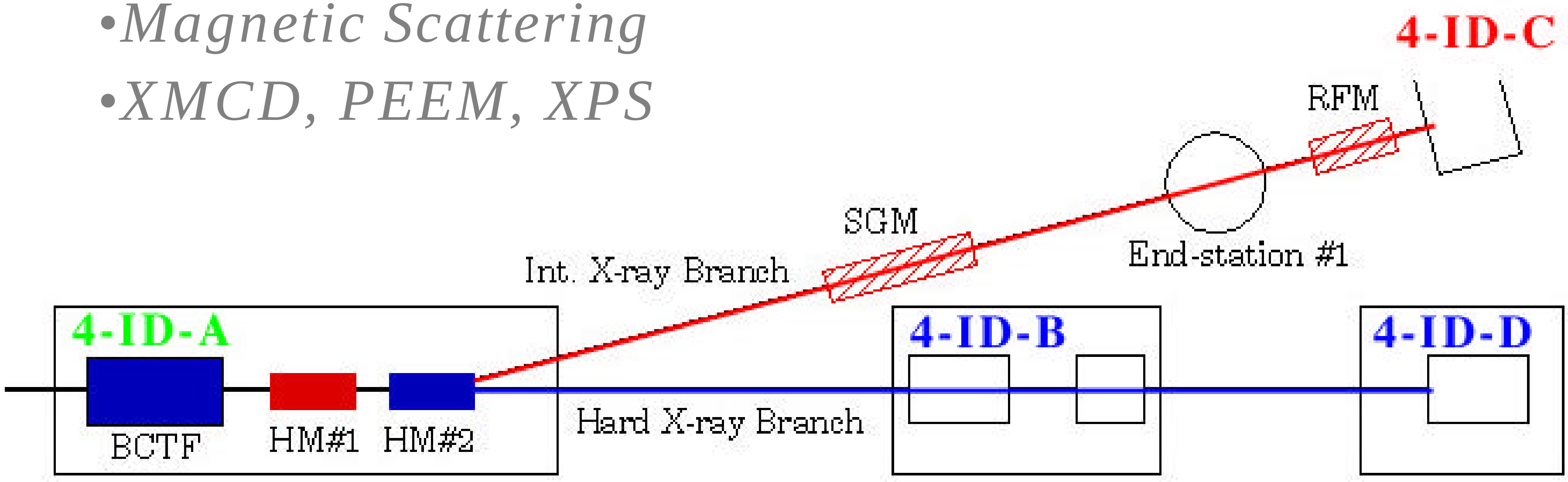
Now: 1/2 Hz.

Future: 10 Hz.

Sector 4 Layout

J. Freeland, Dave Keavney, R. Rosenberg

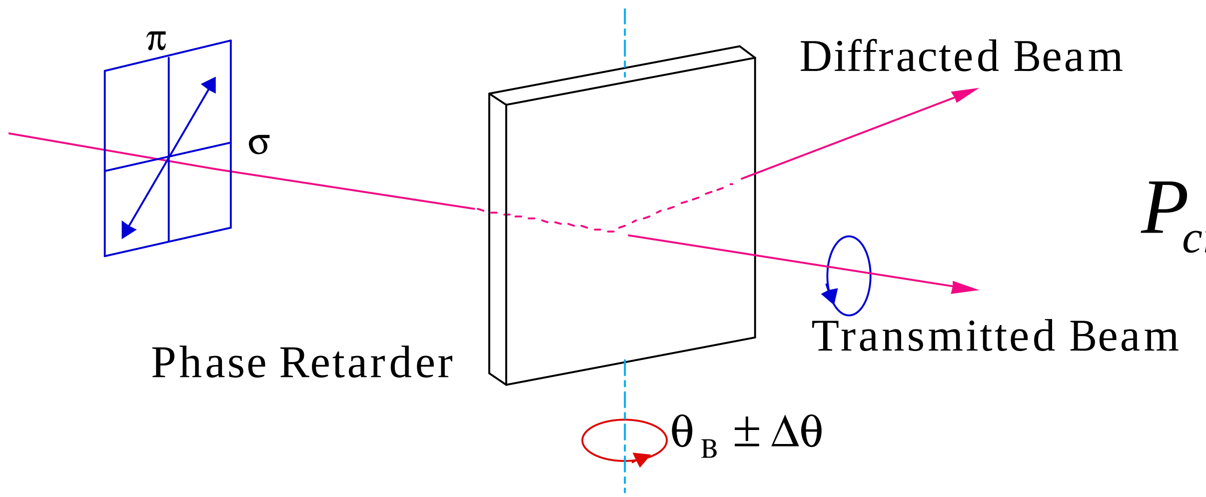
- *Magnetic Scattering*
- *XMCD, PEEM, XPS*



G. Srajer, J. Lang, D. Haskel, Z. Islam

- *Magnetic Scattering/Spectrocopy*
- *Magnetic Microscopy*

Transmission Phase Retarders

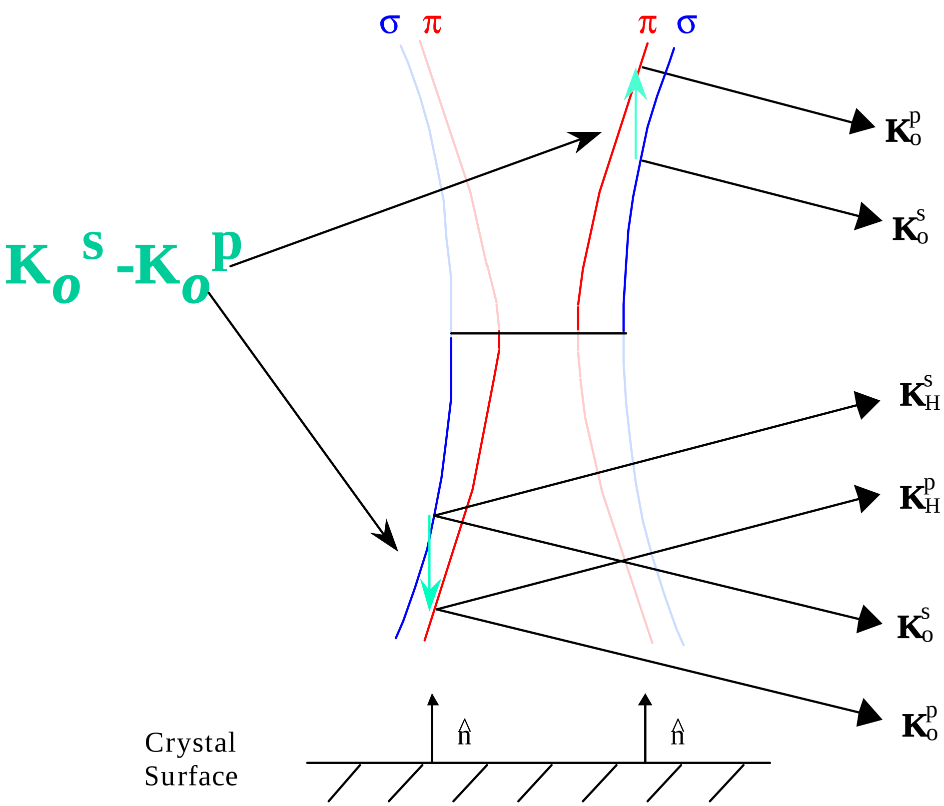


$$P_{circ} = \frac{2\sqrt{I^s\ I^p}}{I^s + I^p}\sin d$$

Diffract @ 45

For x-rays, materials are only birefingent near Bragg reflections

How does it work?



$$\delta = 2\pi \left| K_o^s - K_o^p \right| \cdot t$$

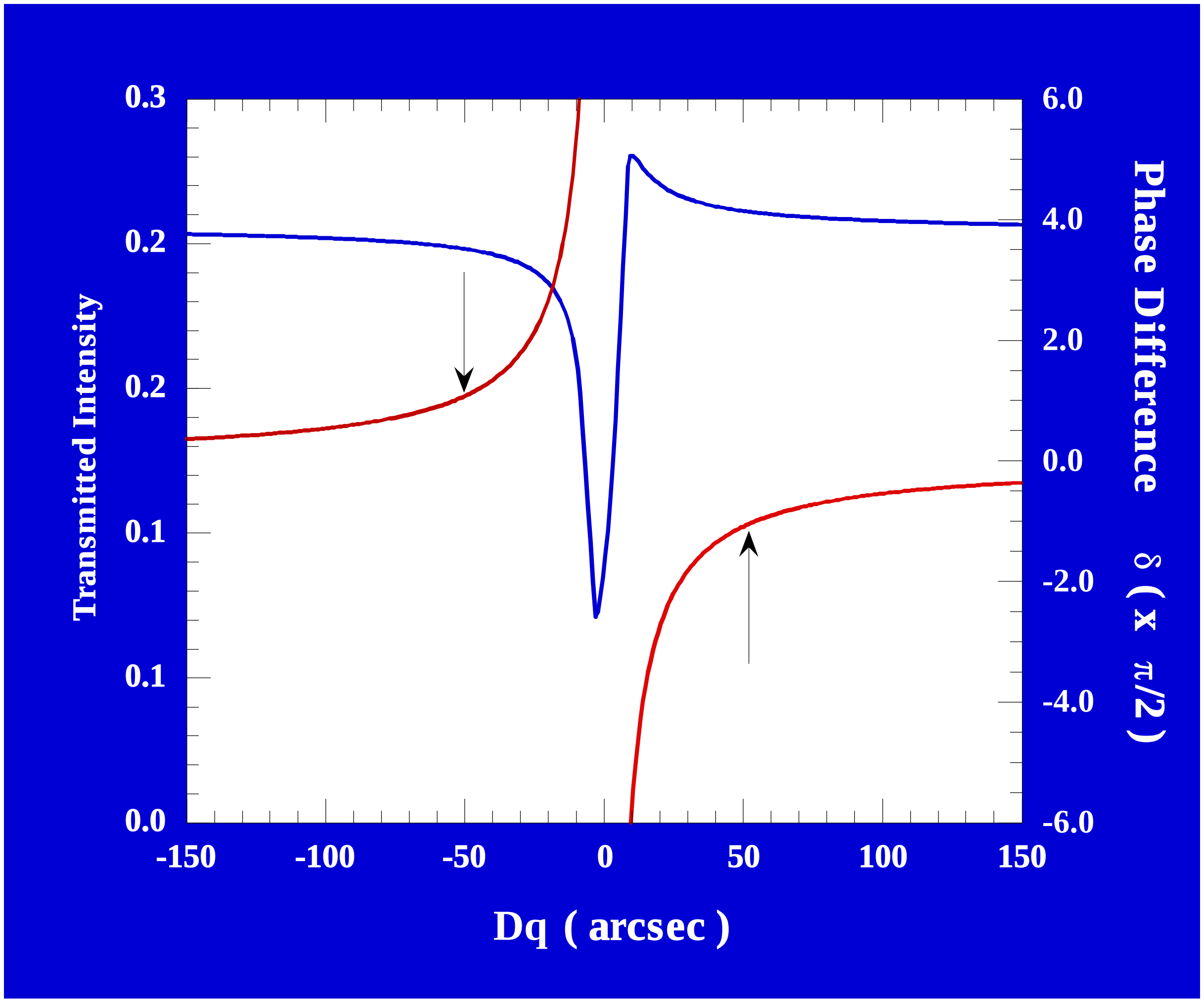
$$\delta = \frac{\pi}{2} \Gamma^2 \frac{t \sin 2\theta_B}{\lambda \, \Delta\theta \, \sin\theta_B} \mathrm{Re}\left(F_H F_{\overline{H}}\right)$$

$$\Gamma = \frac{r_e \lambda^2}{\pi V}$$

Can get δ=π/2 by choosing Δθ for given t and E

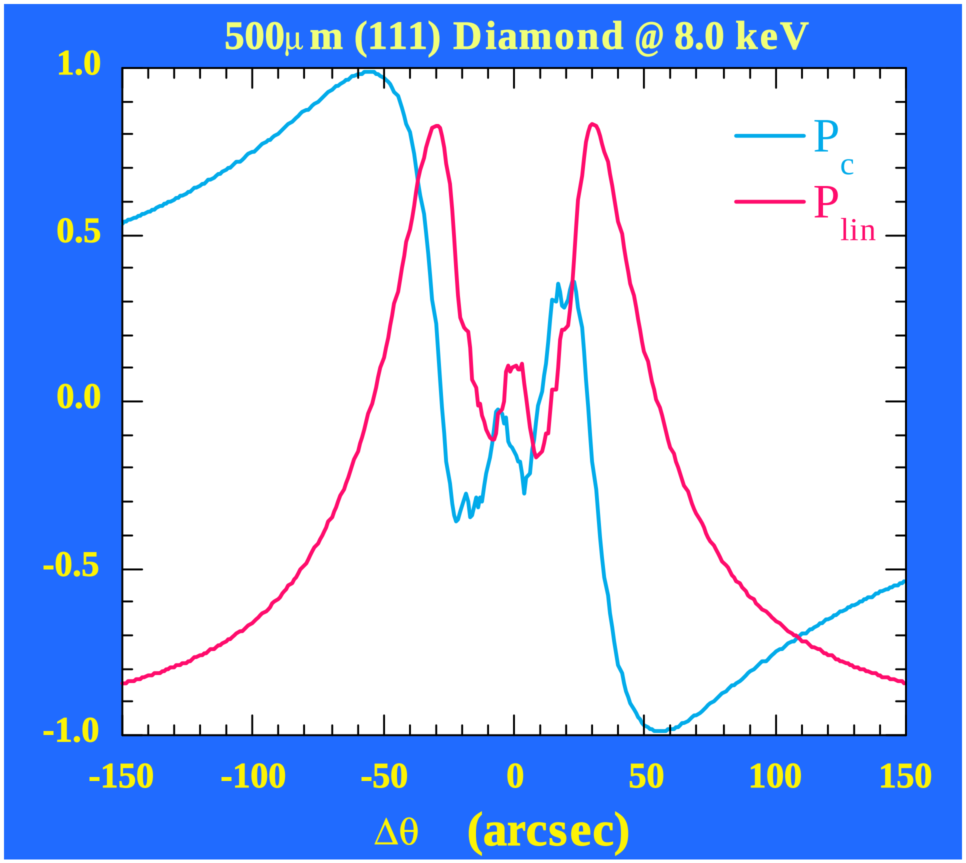
Phase Shift vs. Δθ

500mm Diamond (111)



Phase Shift changes more slowly on the tails of Bragg peak

Transmitted Beam Polarization



- $P_c \sim 0.98$
- Beam direction undeviated
- Best from 5 to 12 keV
- Rapid helicity reversal
- Insensitive to beam divergence
- Can also change P_{lin}

What crystals should you use?

$$d = \frac{p}{2}\Gamma^2 \frac{t \sin 2q_B}{l\,\Delta q\,\sin q_B}\mathrm{Re}(F_H F_{\overline{H}}), \qquad \Gamma = \frac{r_e^{\,2}}{pV}$$

Let δ=π/2 and divide by μ –> figure of merit (Δθ/μt)

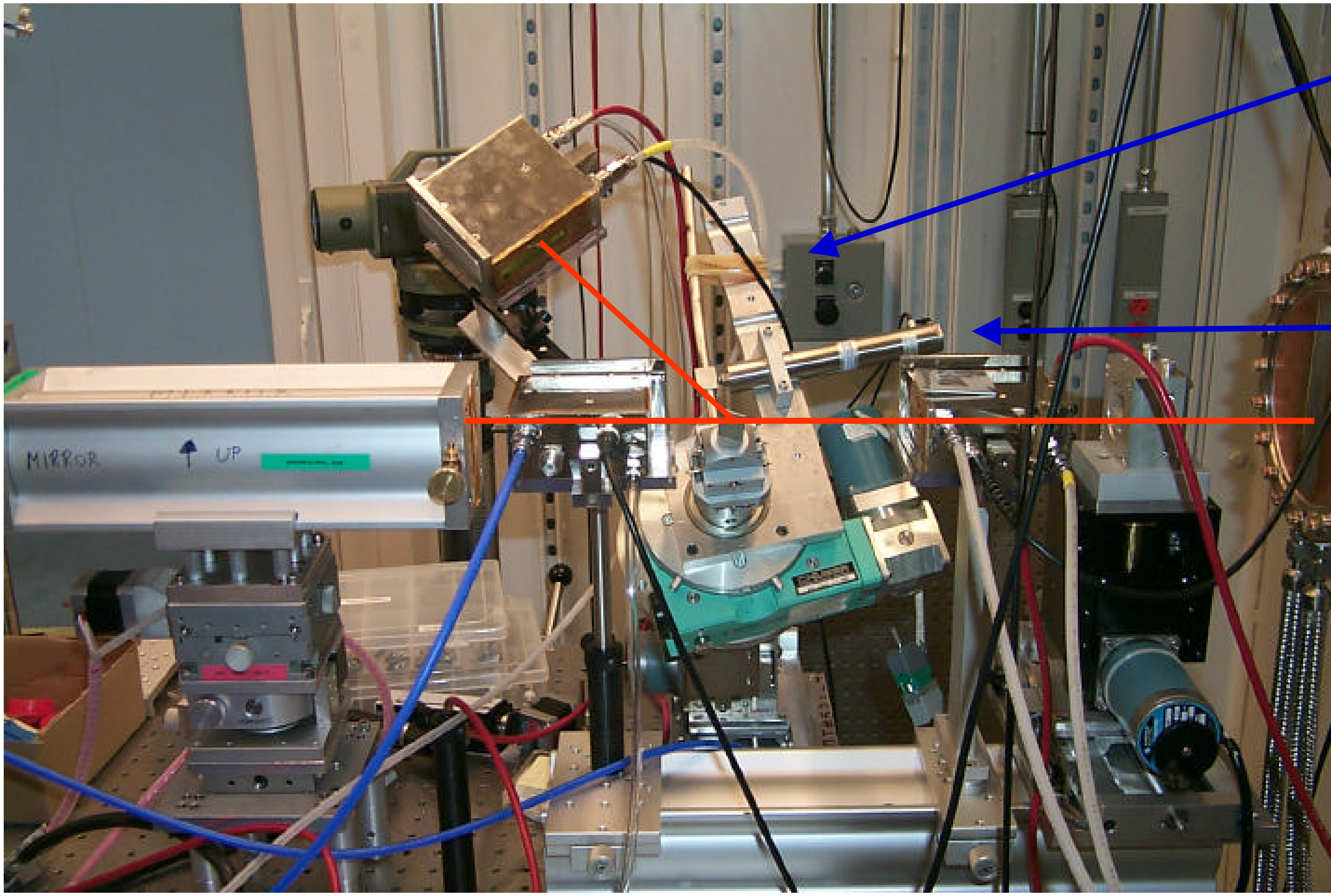
$$\frac{\Delta q}{md} = \frac{r_e^2}{p^2 V^2} l^3 \sin 2q_B \frac{\mathrm{Re}(F_H F_{\overline{H}})}{m}, \quad \mathrm{Re}(F_H F_{\overline{H}}) \sim Z^2, m \sim Z^4$$

$$\therefore \frac{\Delta q}{md} \sim \frac{1}{Z^2}$$

Use low Z crystals such as: Diamond, LiF, Be

Diamond ~x5 better than thin Si

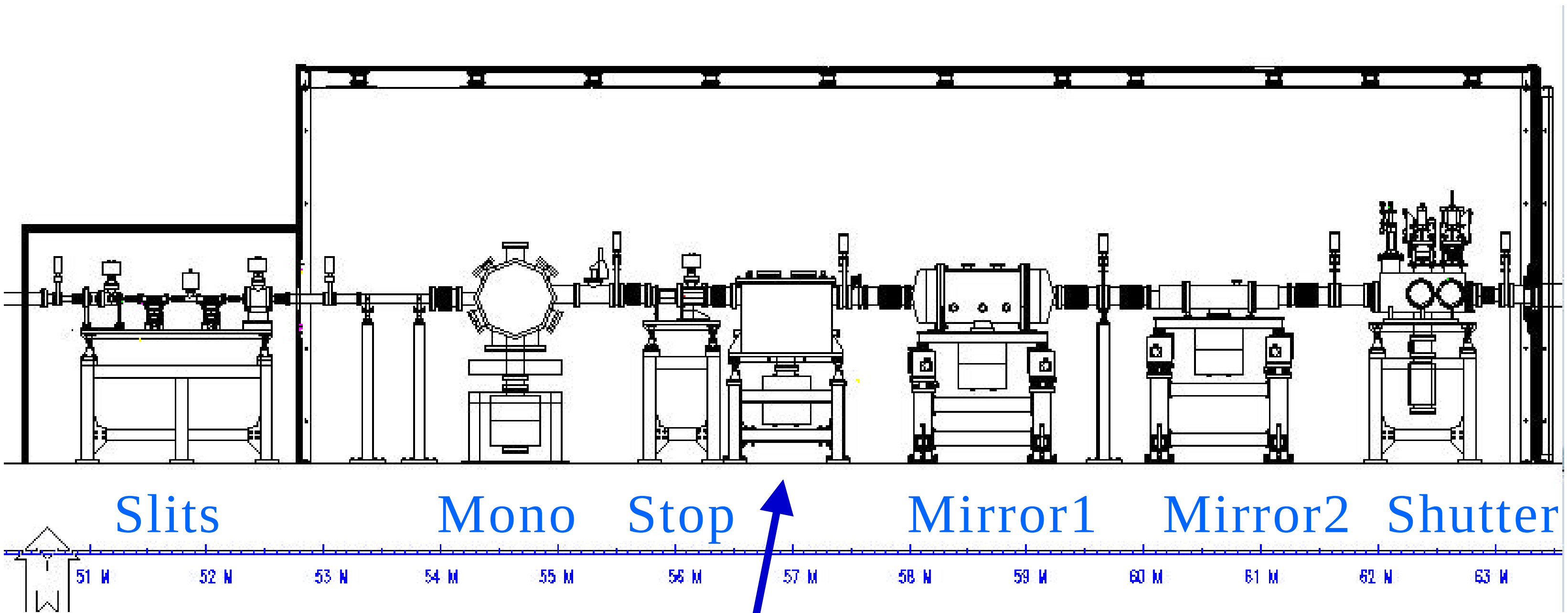
Old Phase Retarder Setup



Rubber Band

PZT

4-ID-B Station

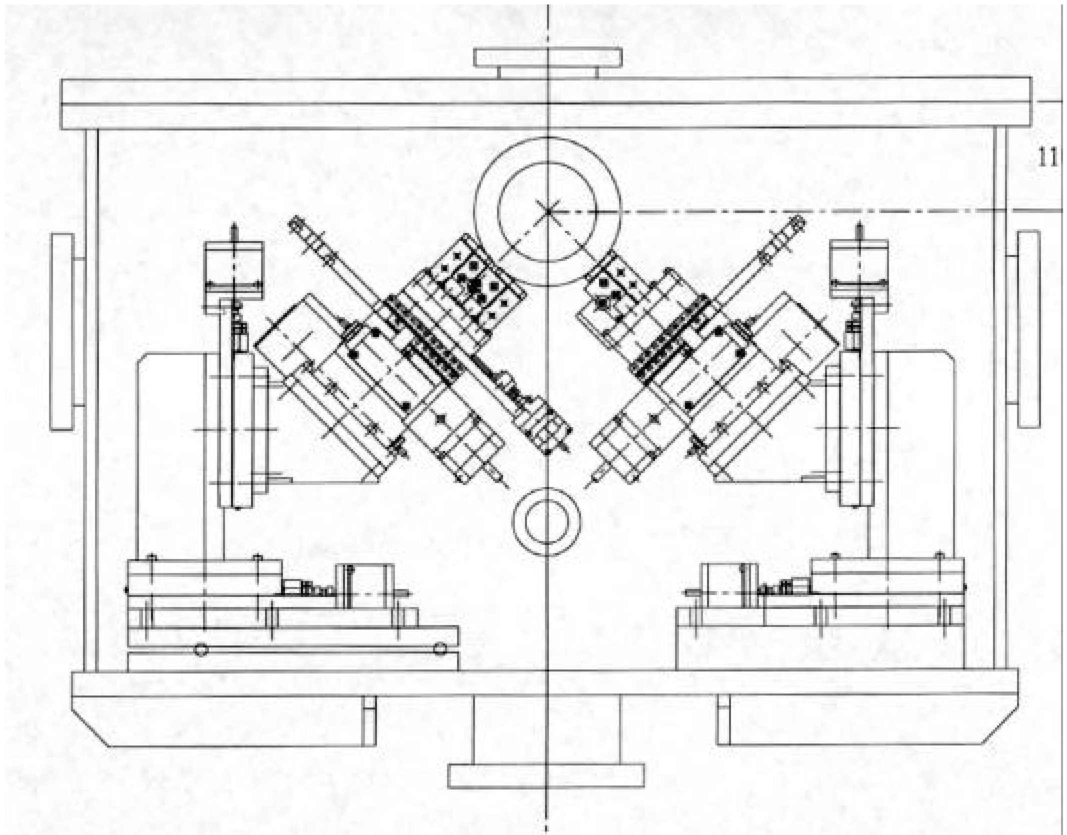


Phase Retarder Chamber

Installed Jan. 2001

In-Vacuum Phase Retarder

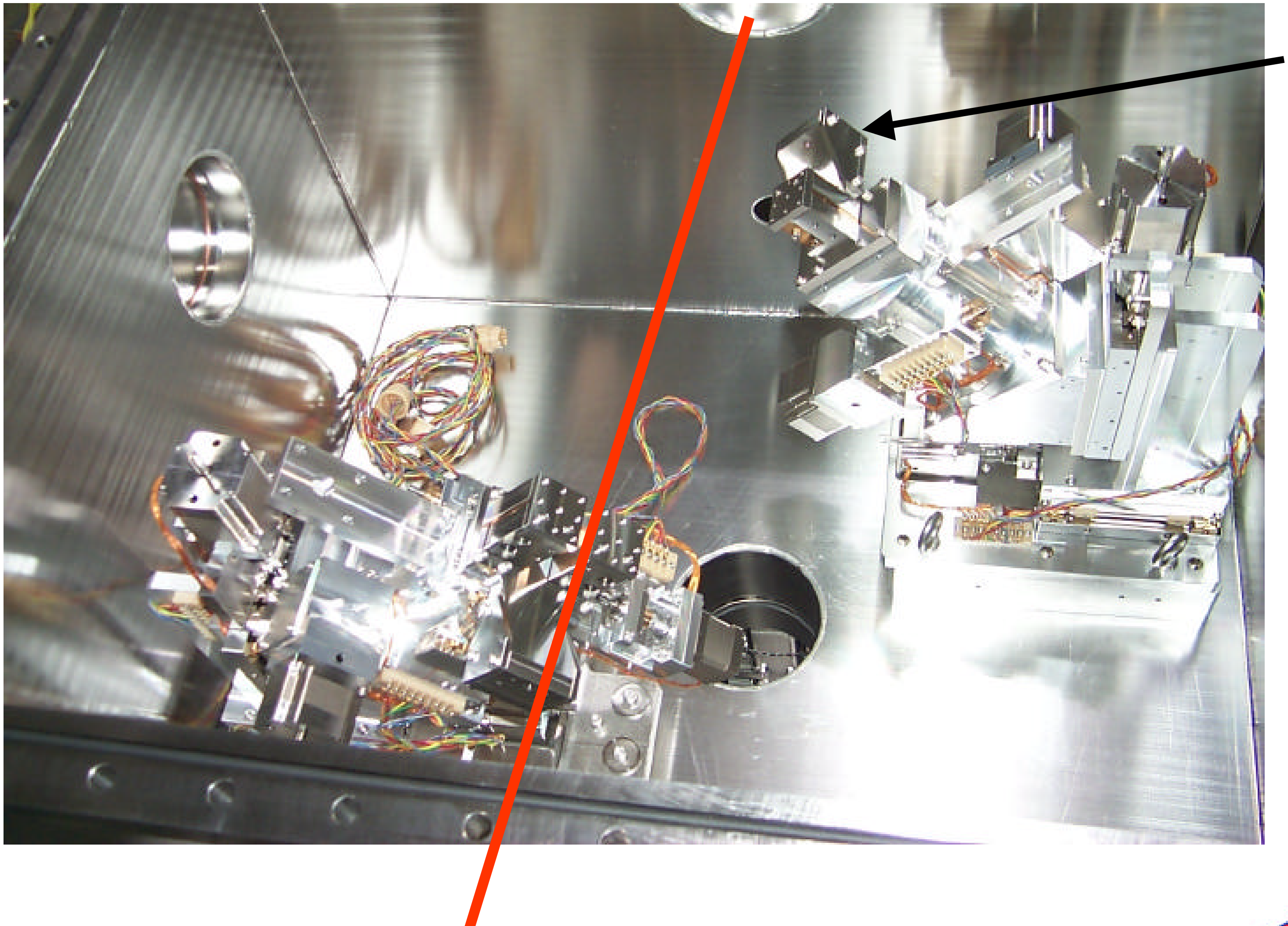
Beam
into page



Multiple
crystals

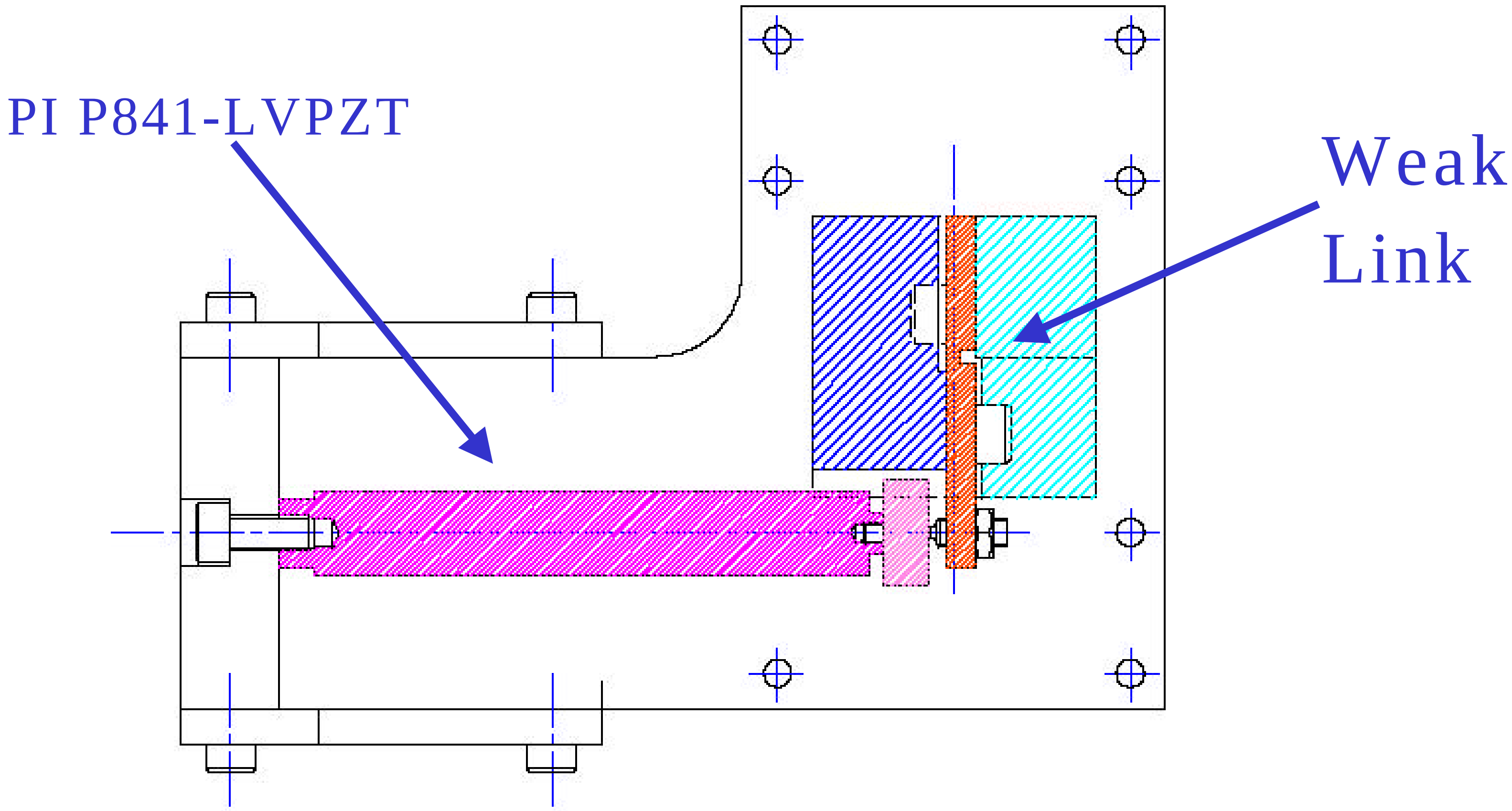
Two X-Y-θ-2θ stages oriented 180 apart
Scattering plane 45 from vertical

In Vacuum Phase Retarder



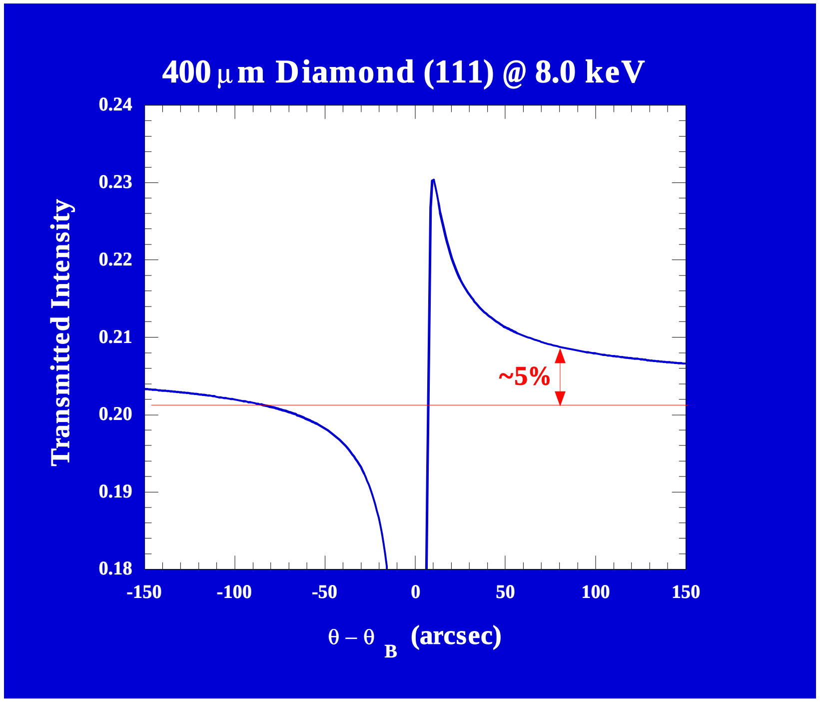
PZT
Stage

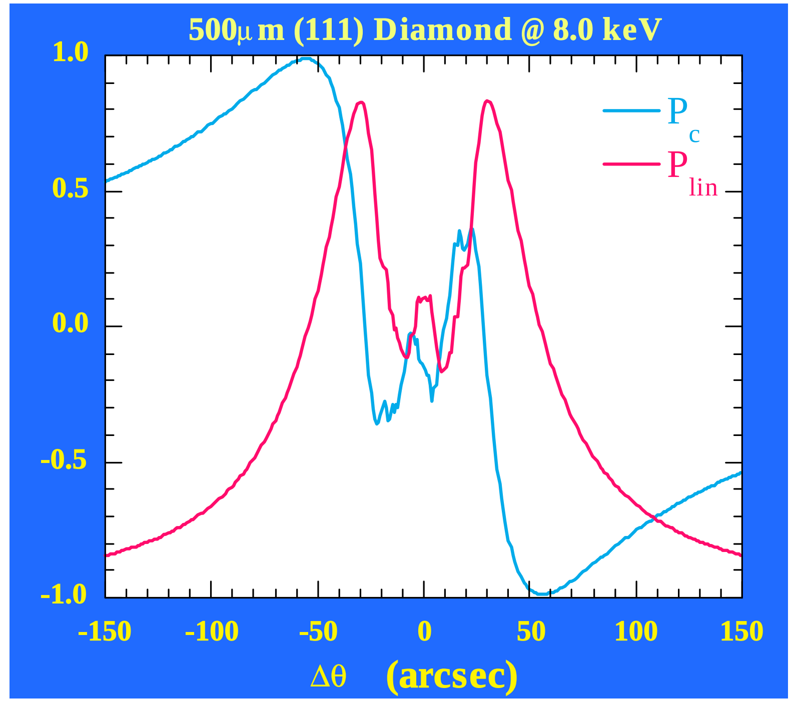
PZT Stages



Dynamic Operation (upto ~50Hz)

Things to watch out for





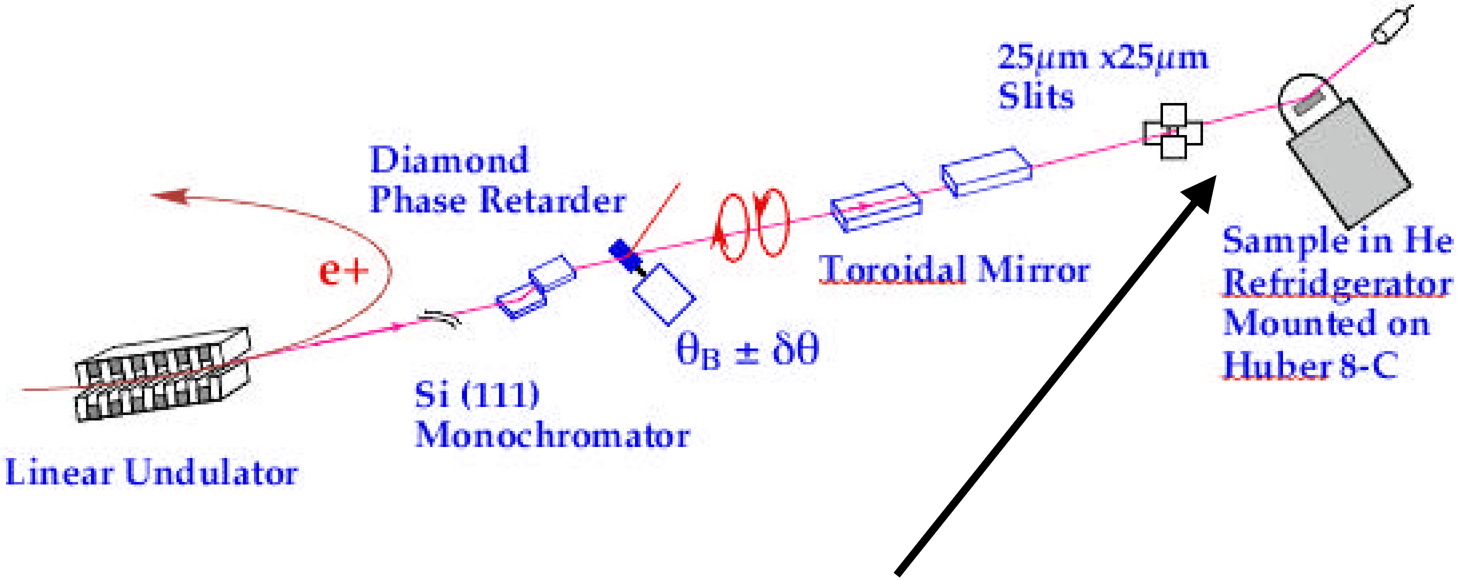
- Asymetric transmitted intensity
- Absolute positioning of phase retarder critical for scattering exps.
- Multiple Scattering

$$\Delta q^{+} - \Delta q^{-} \leq 0.5 arc\sec; P_{lin} \leq 1\%$$

$$I_{charge} \sim \frac{I_o}{2}\left[\left(1+\cos^2 2q\right)+P_{lin}\left(1-\cos^2 2q\right)\right]$$

Advanced Photon Source-Polarization Studies

Experimental Setup 4-ID-D



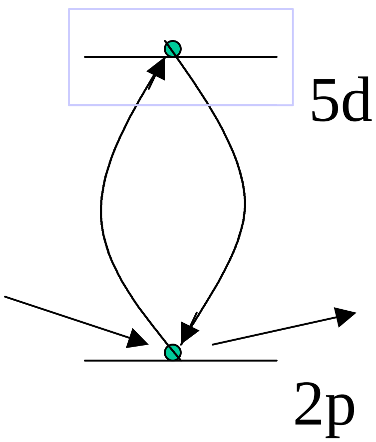
Change setup in end station for different experiments

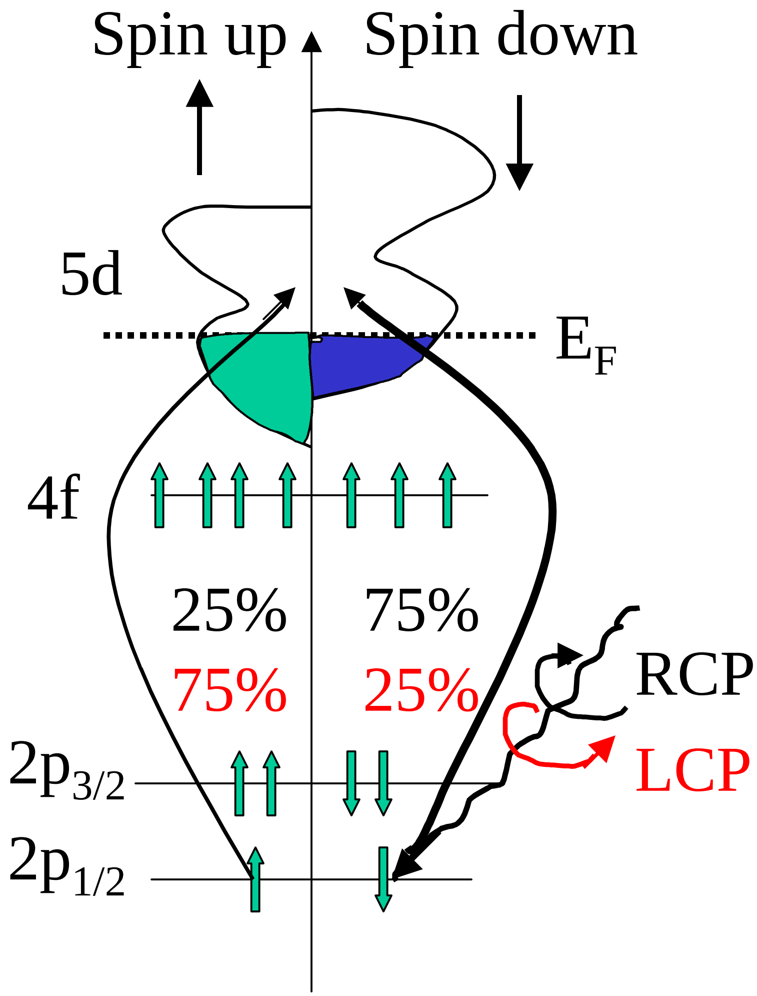
- XMCD, Reflectivity, Diffraction
- Microfocussing (KB or ZP)

X-ray Magnetic Circular Dichroism

XRES

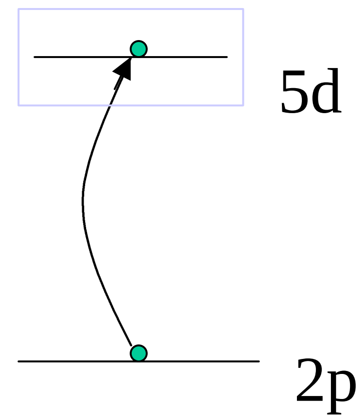
$$I_s = I^L - I^R$$





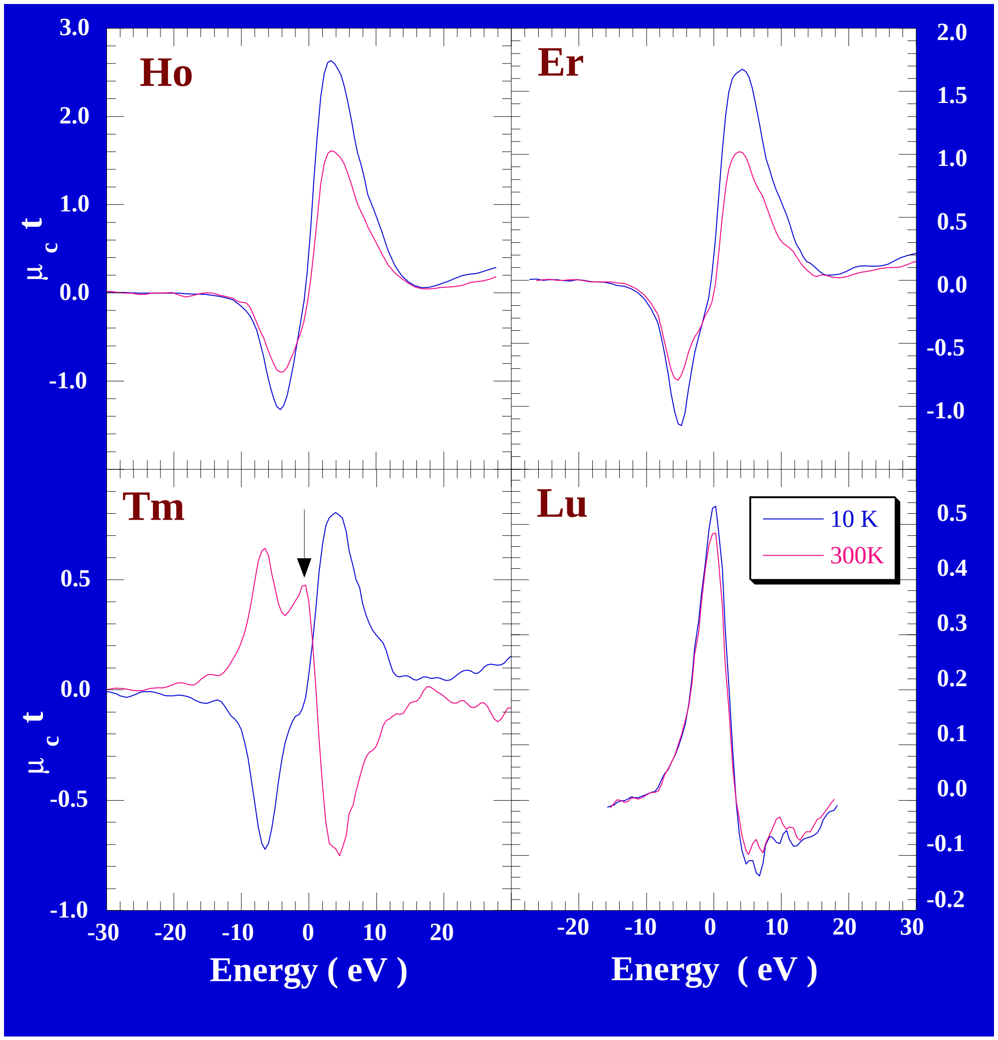
XMCD

$$m_c = m^L - m^R$$



Needs net magnetization → Ferro/Ferri-magnets

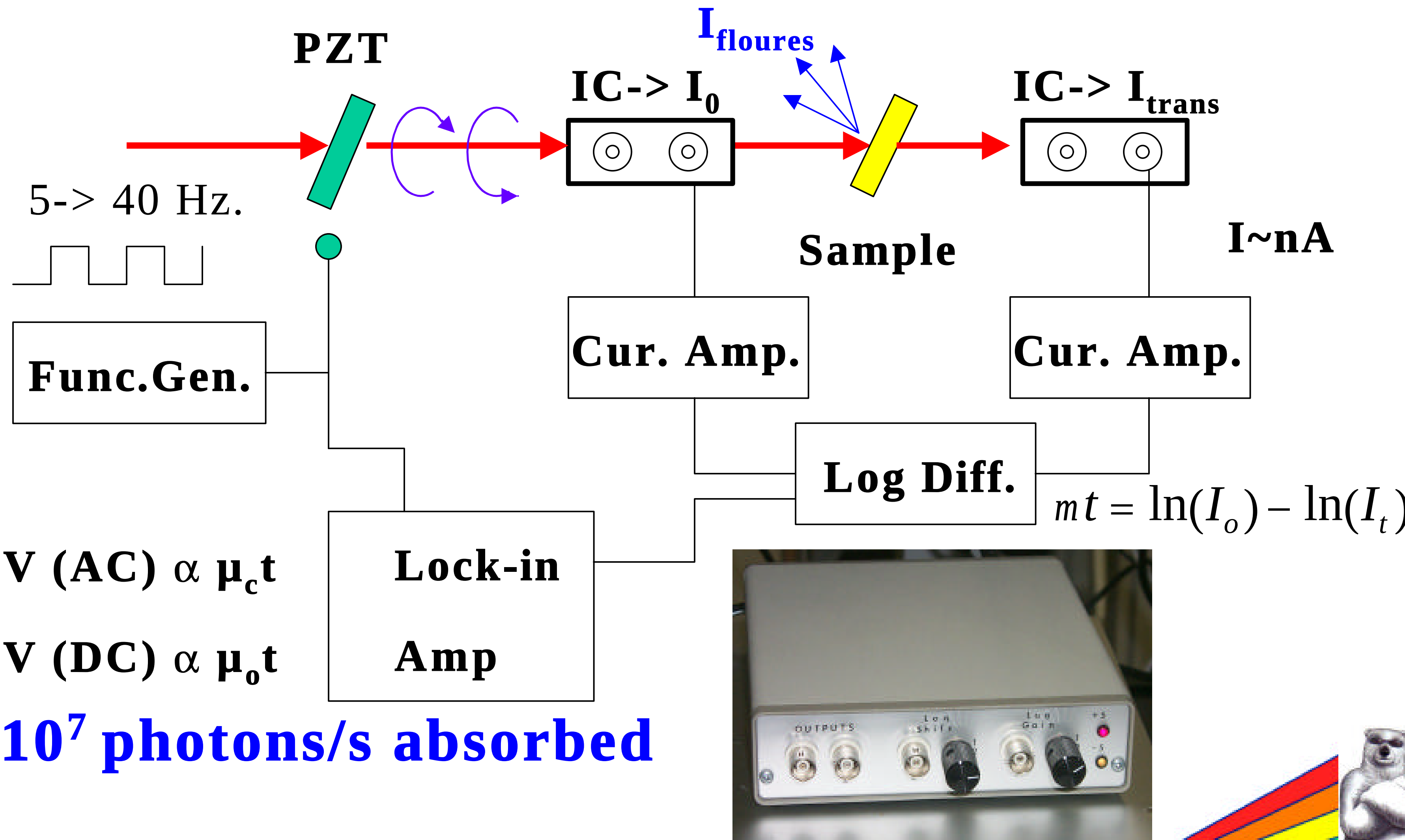
Dichroism in RFe_2



Measure magnetism as a function of temperature.

Near edge rare earth signals are relatively large ~1%

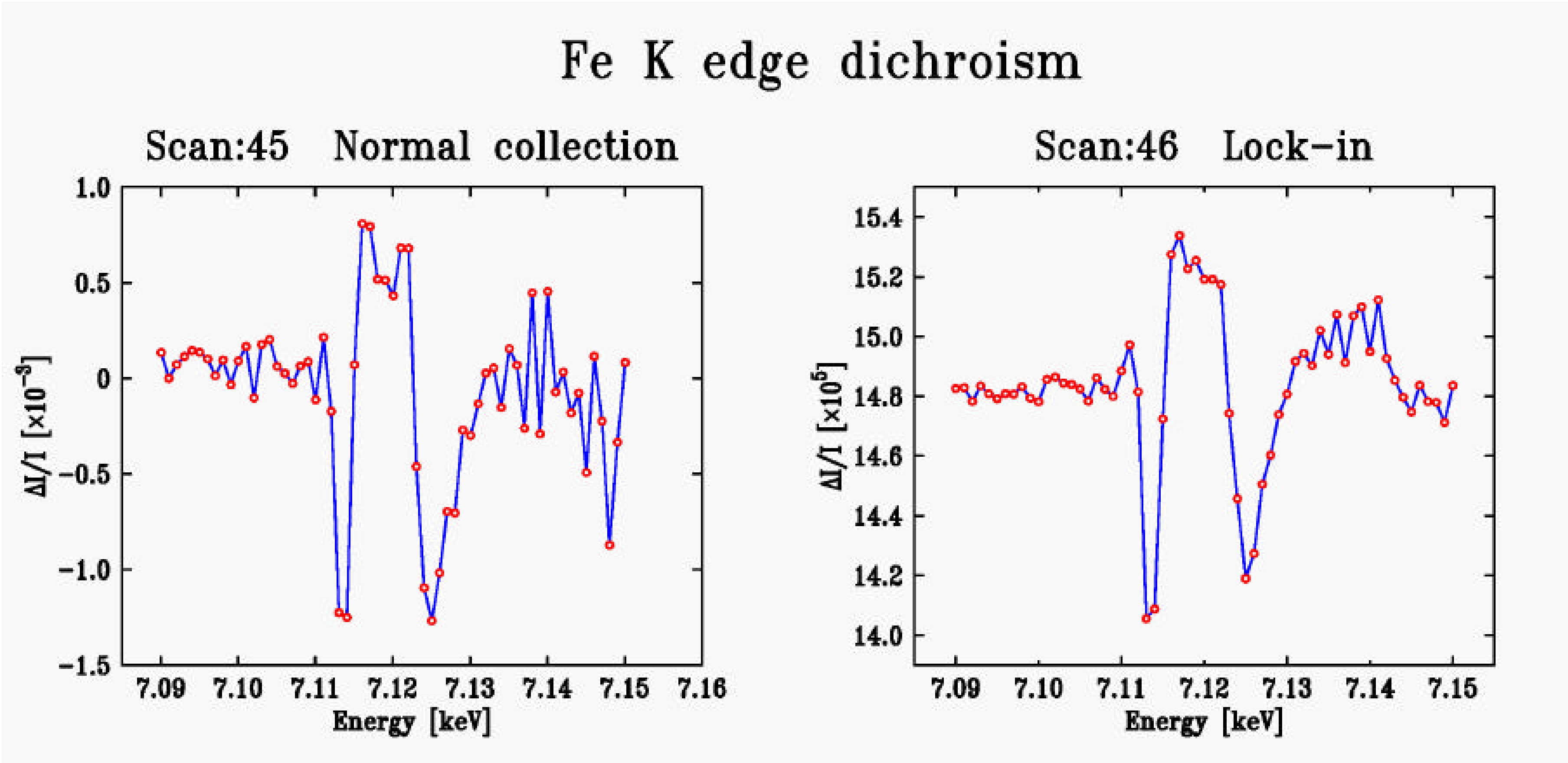
Lock-in Detection



~10^7 photons/s absorbed

-> δs/s ~ 0.03%

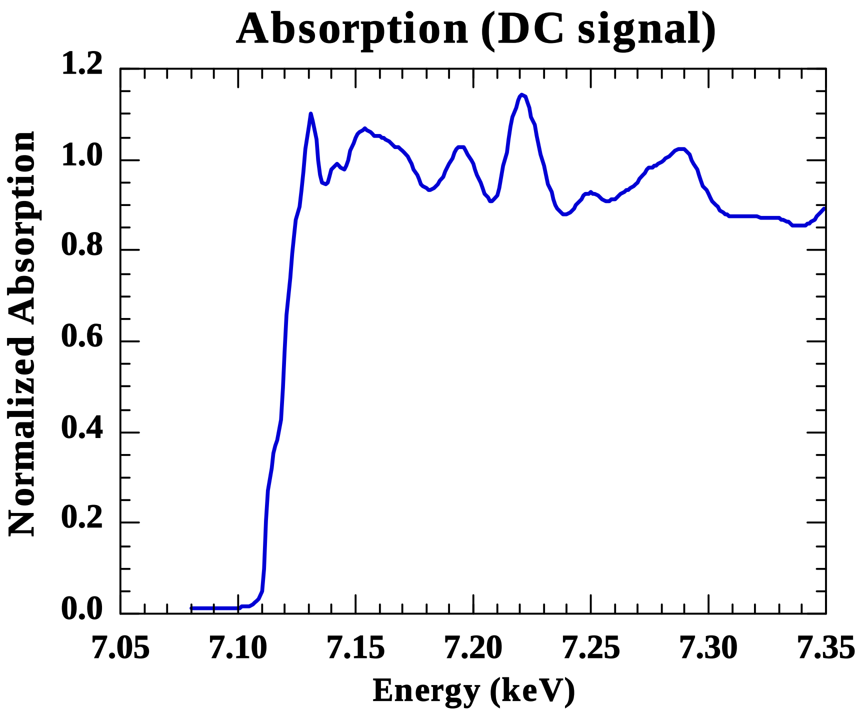
Phase lock for XMCD

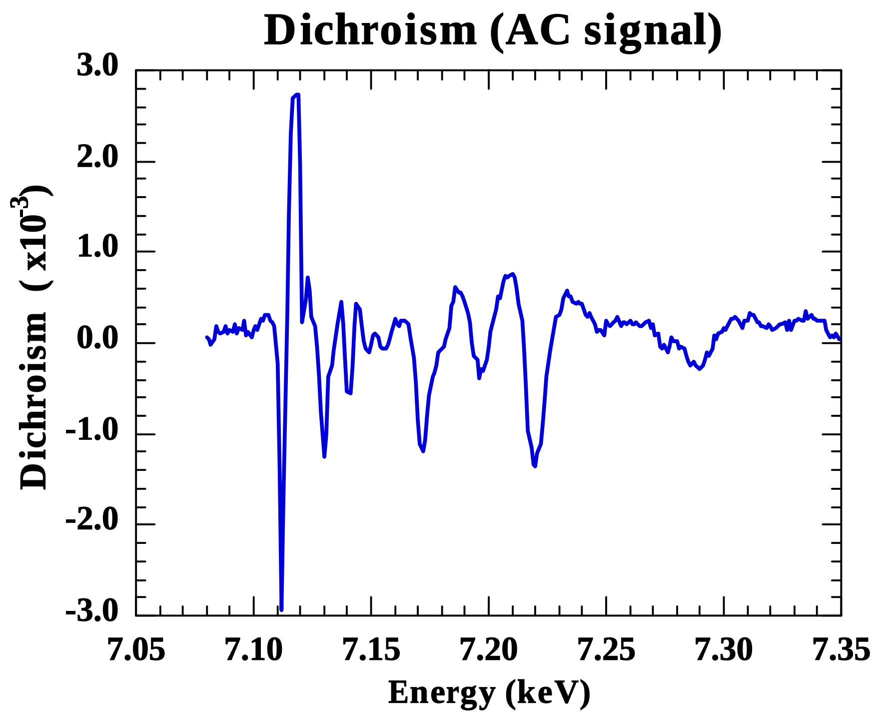


~10 min. ~4 min.

Can easily see differences down to ~5x10^{-5} in spectra taken in only a few minutes

Magnetic EXAFS





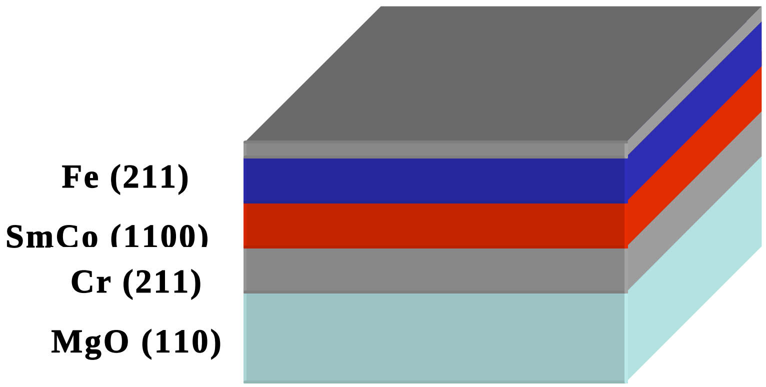
Probes local magnetic structure

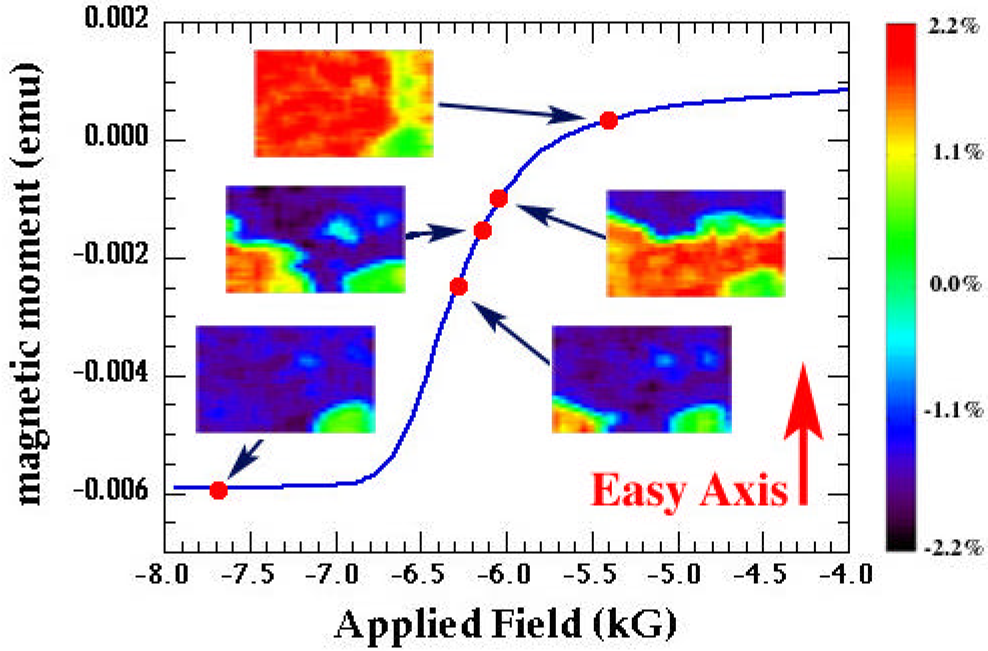
Ferromagnetic Imaging

Absorption-Fluorescence

Sm Domains in
SmCo/Fe bilayer

200Å SmCo

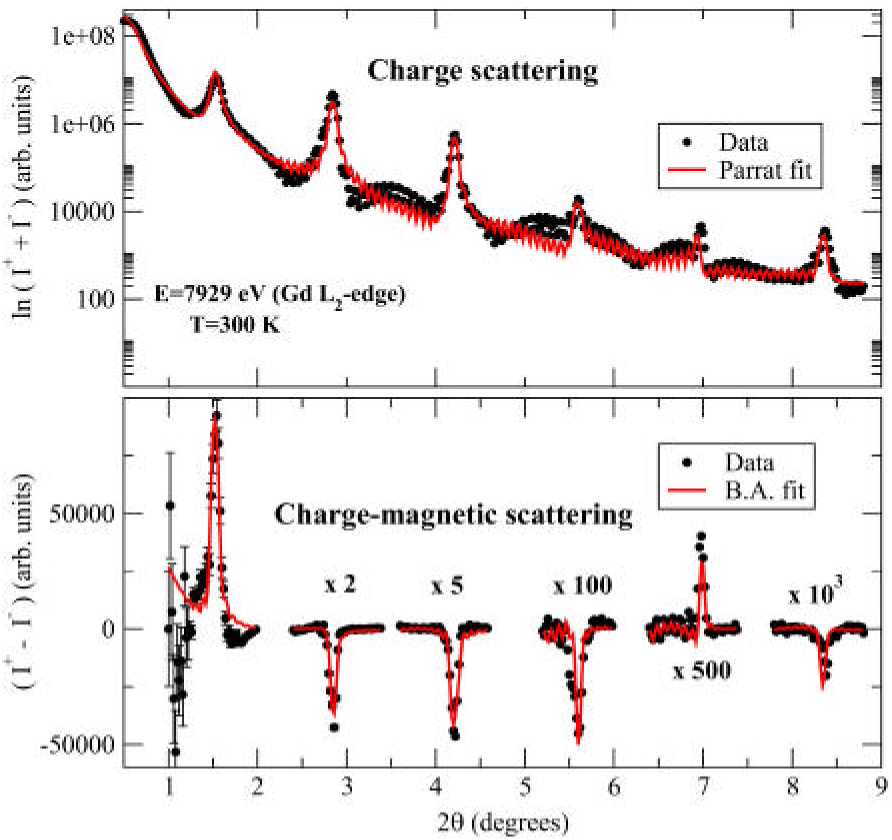


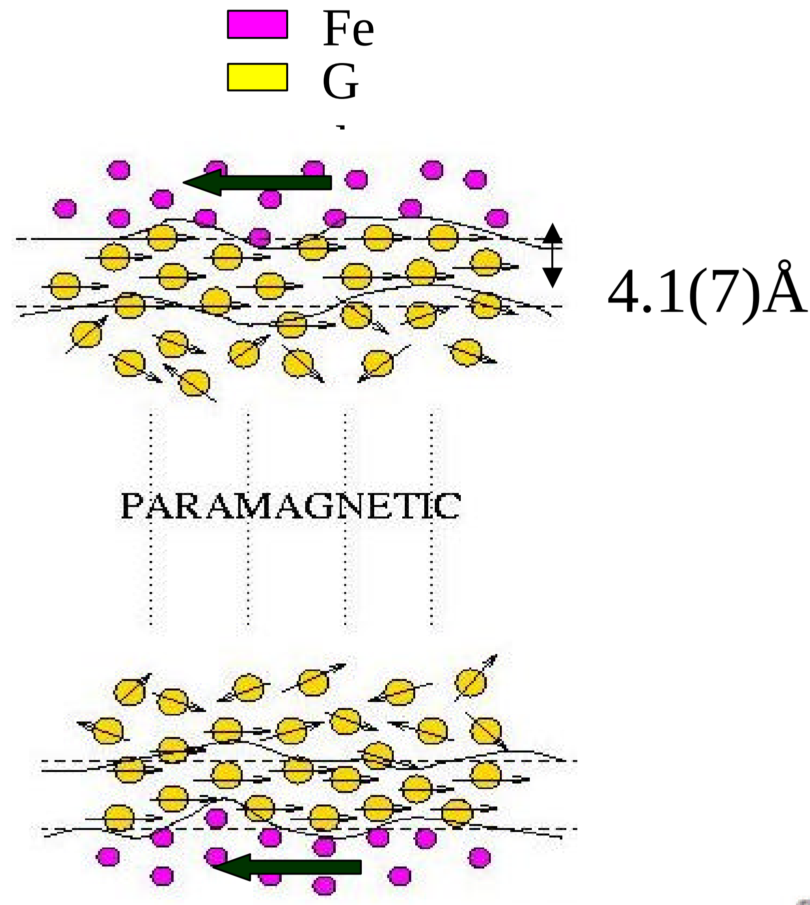


J. Lang, et. al, SPIE **4499** (2001)

Magnetic Reflectivity

[Gd(50Å)Fe(15Å)]$_{15}$



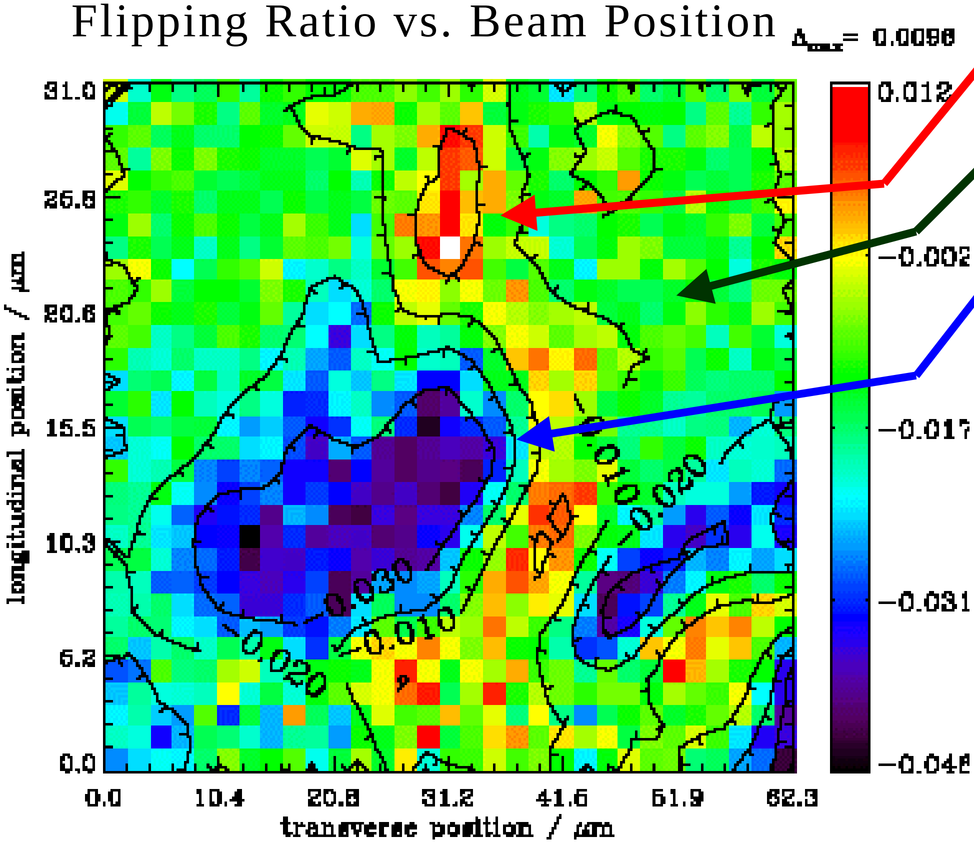


D. Haskel, Phys. Rev. Lett. 87, 207201 (2001)

Microscopic Diffraction in $HoFe_2$

(ferromagnet)

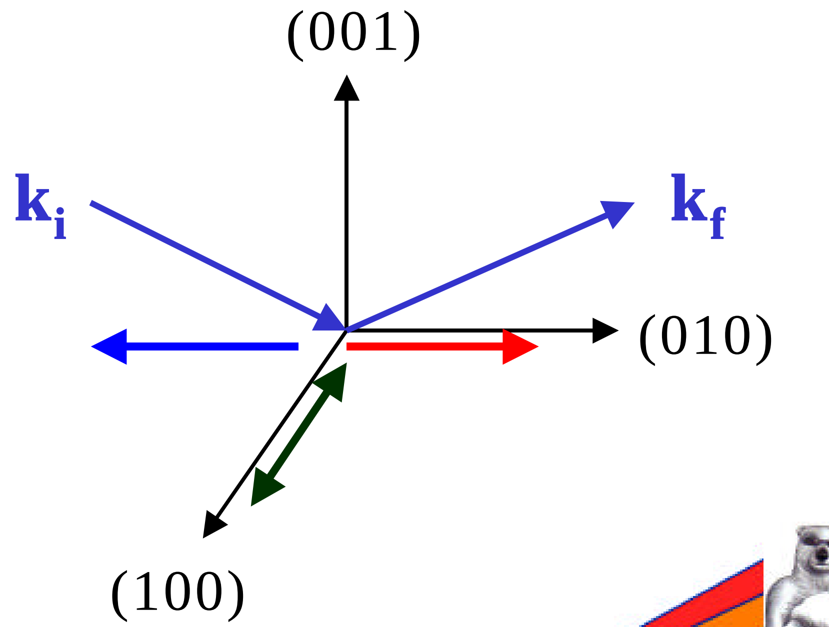
Flipping Ratio vs. Beam Position



Domain Parallel to Beam

Domain Transverse to Beam

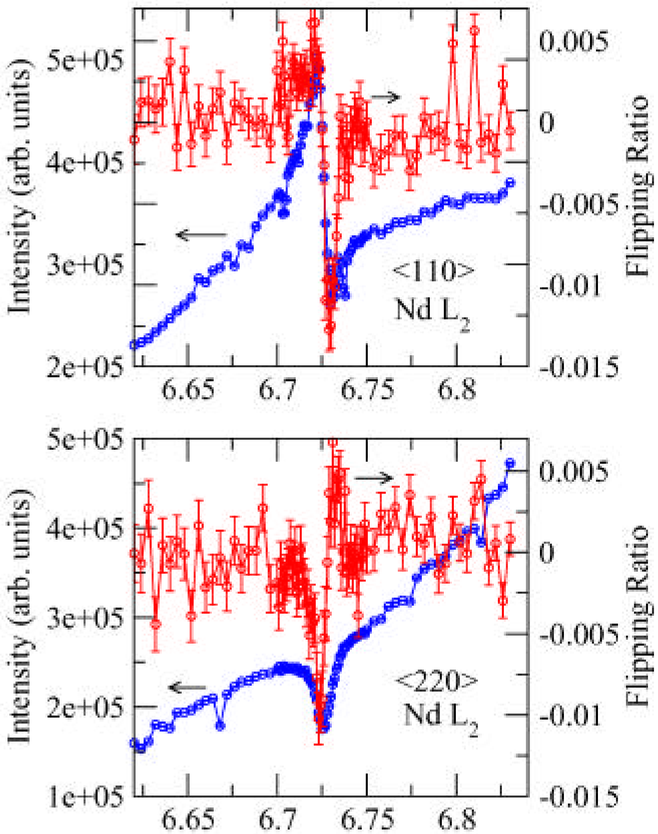
Domain Antiparallel to Beam

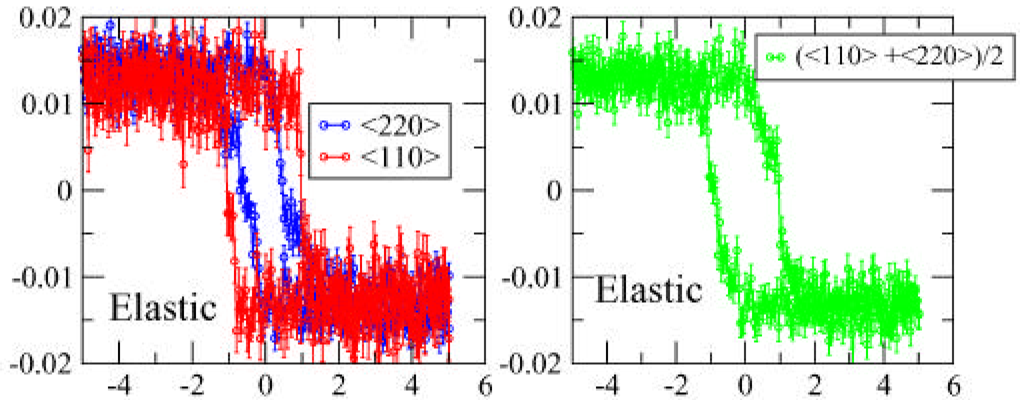


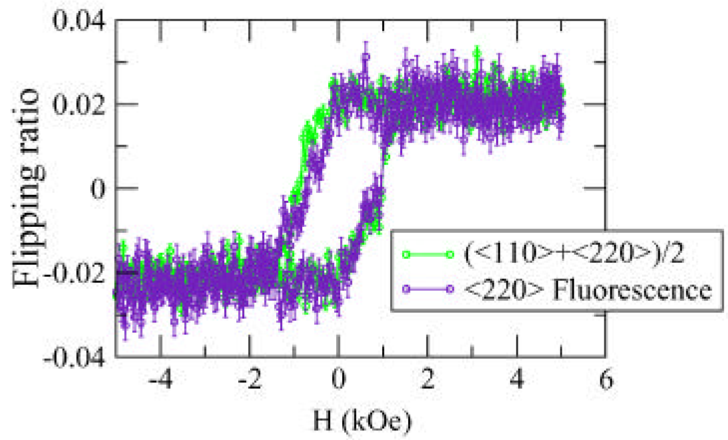
$\Delta I/I \;\alpha\; \cos(\phi)$

Magnetic DAFS

$Nd_2Fe_{14}B$ Single Crystal







Site Specific Magnetism - D. Haskel

Advanced Photon Source-Polarization Studies

Imaging Chiral Domains

Spiral Magnetic Structure of Ho