Opportunities for x-ray POLARization control in APS-U

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Magnetic Materials Group

APS-U forum
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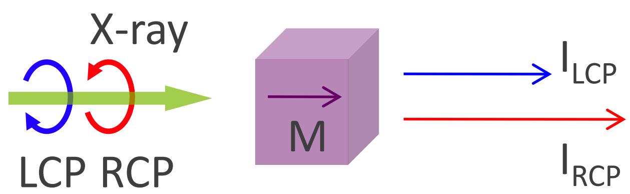
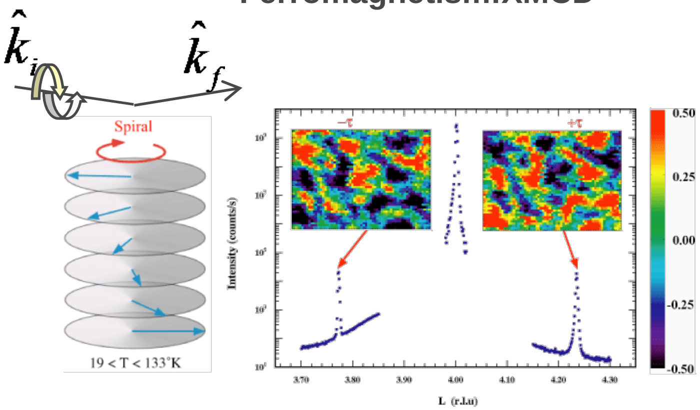
Polarization control is key in probing electronic order, anisotropic structures

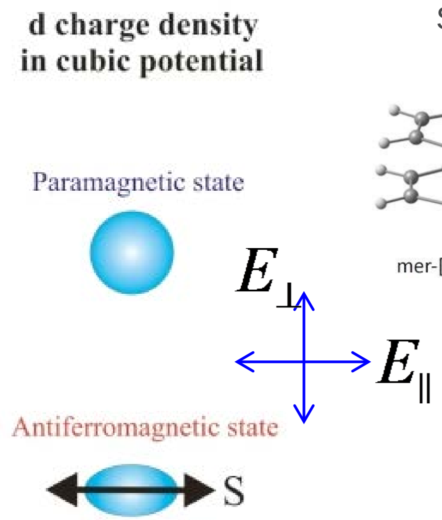


Ferromagnetism:XMCD



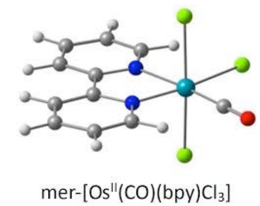
Chiral magnets and structures

Spiral/chiral order in Holmium (Lang et al., 2004)

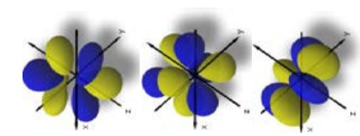


Antiferromagnetism: XMLD

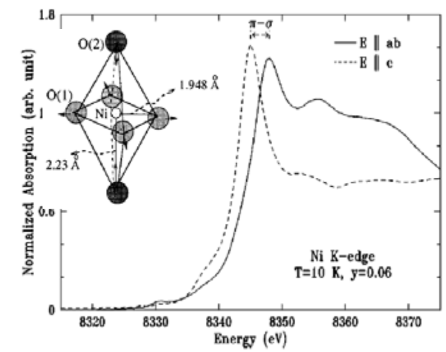
Orbital occupancy
Structural anisotropy



d, f electrons



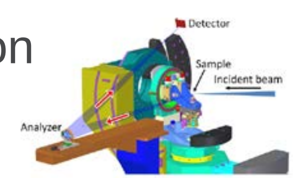
Anisotropy:XLD

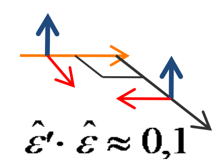


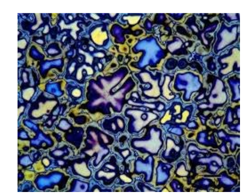
Pol-dependent XANES, XAFS

Lack of polarization control can present limitations (Linear-H at APS)

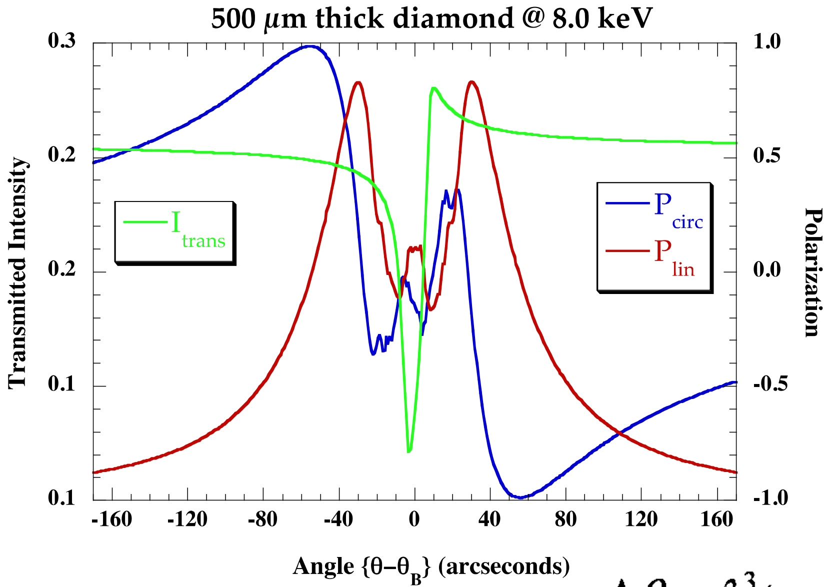
Scattering in horizontal plane: intensity reduction
Micro/Nano probes: phase speciation, valence





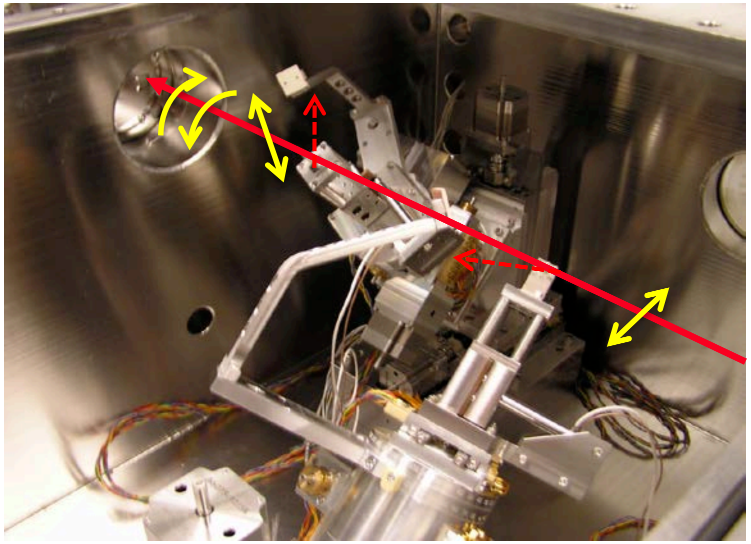


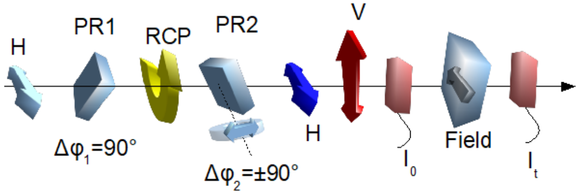
Polarization control at APS (hard x-rays): Phase plates
(softer x-ray beamlines 4-ID-C/29-ID: polarizing EM undulators)



Courtesy JC Lang

$$\Delta\theta \propto \lambda^3 t$$



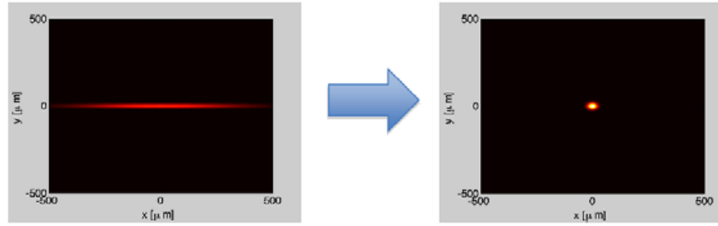


- Large attenuation (x5-30 for 2.8-14 keV)
- Small footprint and angular offset at high E (limited to ~ 14 keV at 4-ID-D)
- Asymmetry between LCP, RCP incident intensity (5-30%)
- Incomplete linear-vertical polarization; improved with tandem plates (but more attenuation)

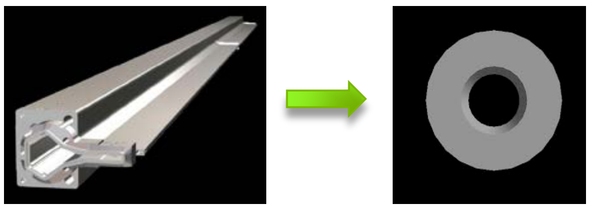
Goal:

Increase flux 2.7-14 keV, enable 14-27 keV range
LCP, RCP, L-H, L-V with high degree of polarization
Preserve fast polarization switching

Opportunity APS-U

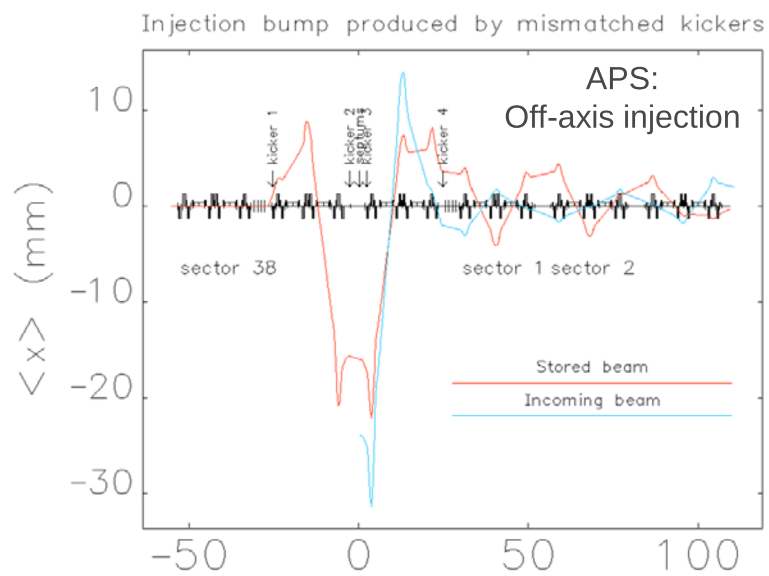


Round ID vacuum chambers

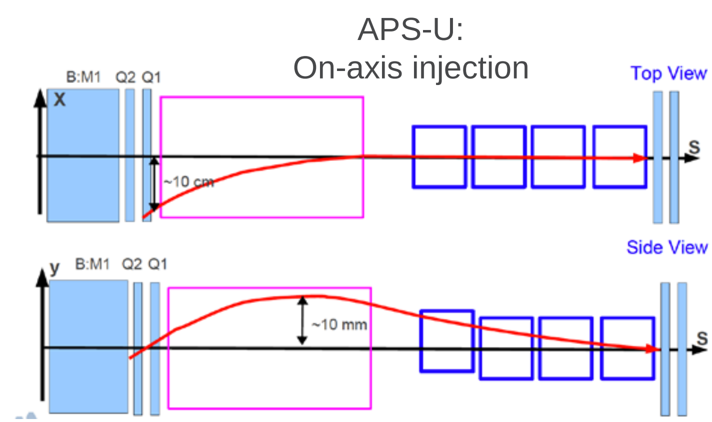


Polarizing superconducting undulators

Overcomes limitations of phase plates
(polarized flux, energy range)

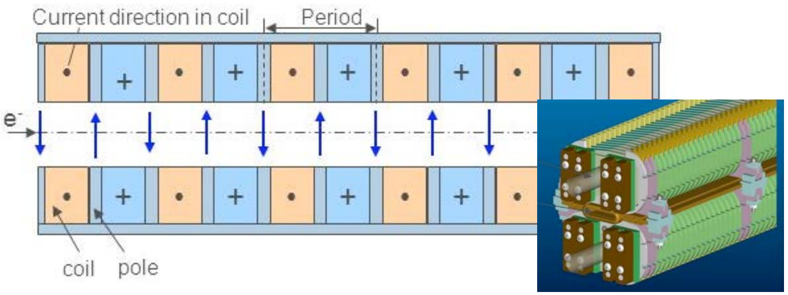


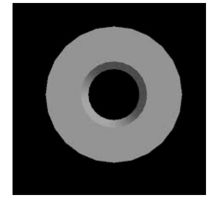
Courtesy L. Emery

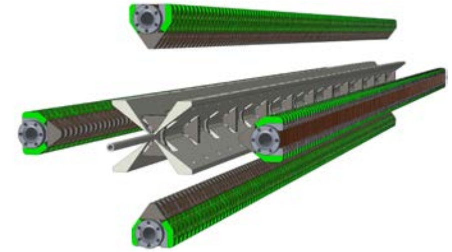


Round ID vacuum chambers: novel SC undulators

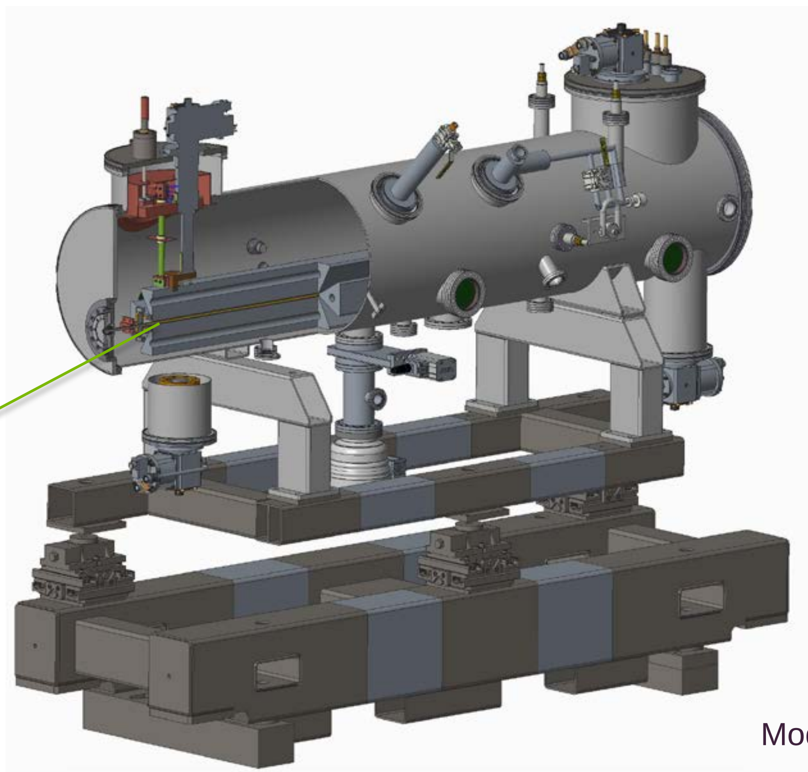
Planar SCU



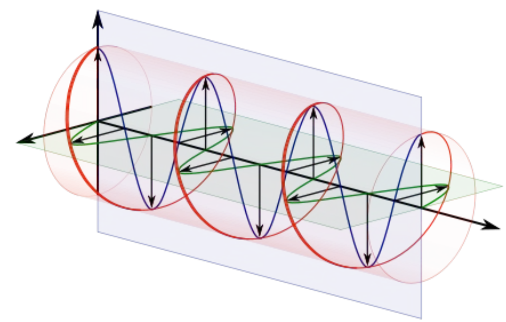




"SCAPE" SCU
L-H, L-V, LCP, RCP
Efim Gluskin, Yury Ivanyushenkov



Round ID vacuum chamber

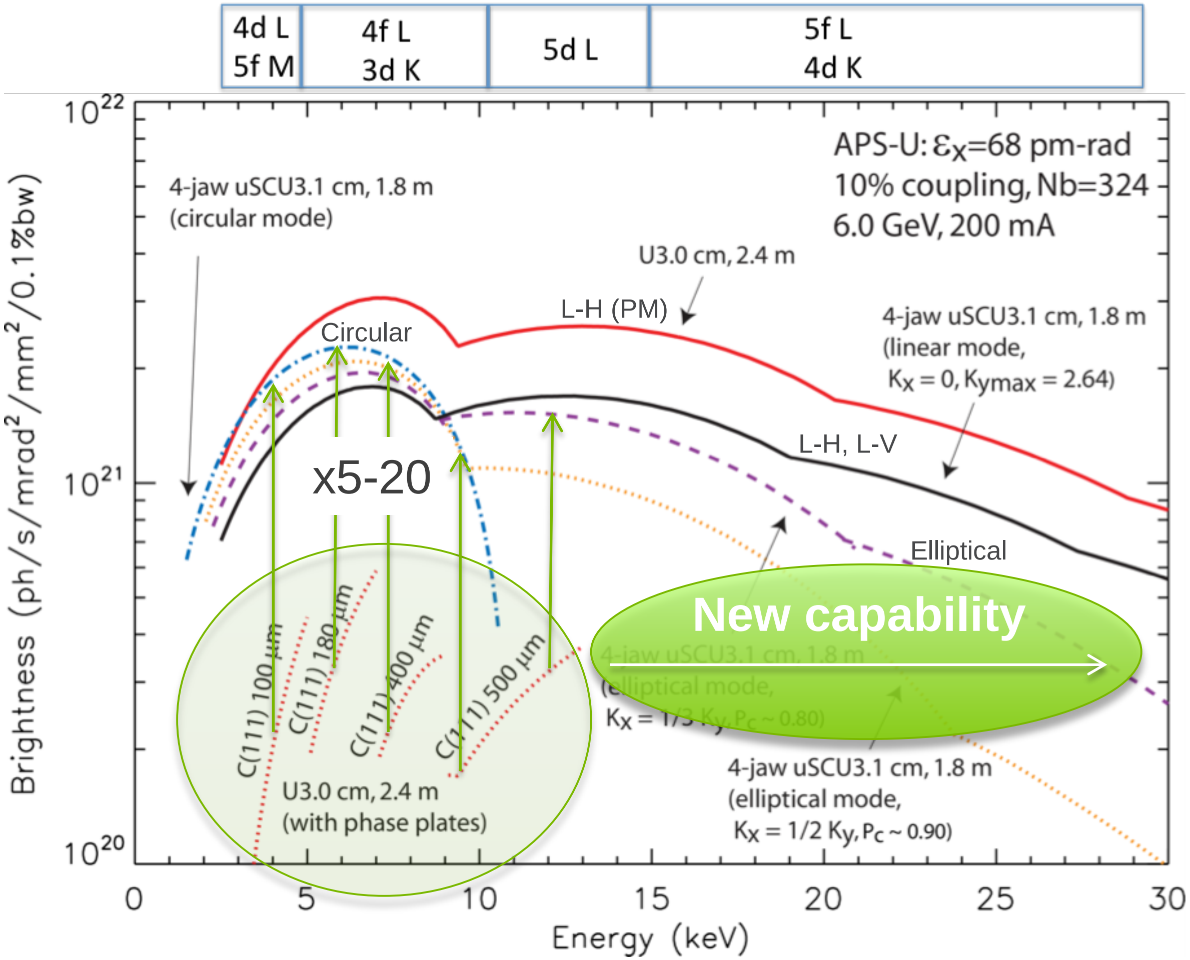


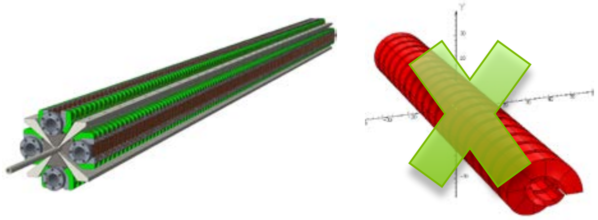
$B_x = B_y$ ($\Phi = 90)^\circ$

Model by Joel Fuerst

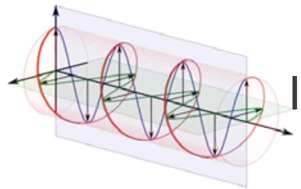
SuperConducting Arbitrarily Polarizing Emitter: "SCAPE"

- Large polarized flux gains 2.7-14 keV; enables 14-27 keV
- LCP, RCP, elliptical, L-H, L-V





How about rapid polarization switching ? (small dichroic signals)

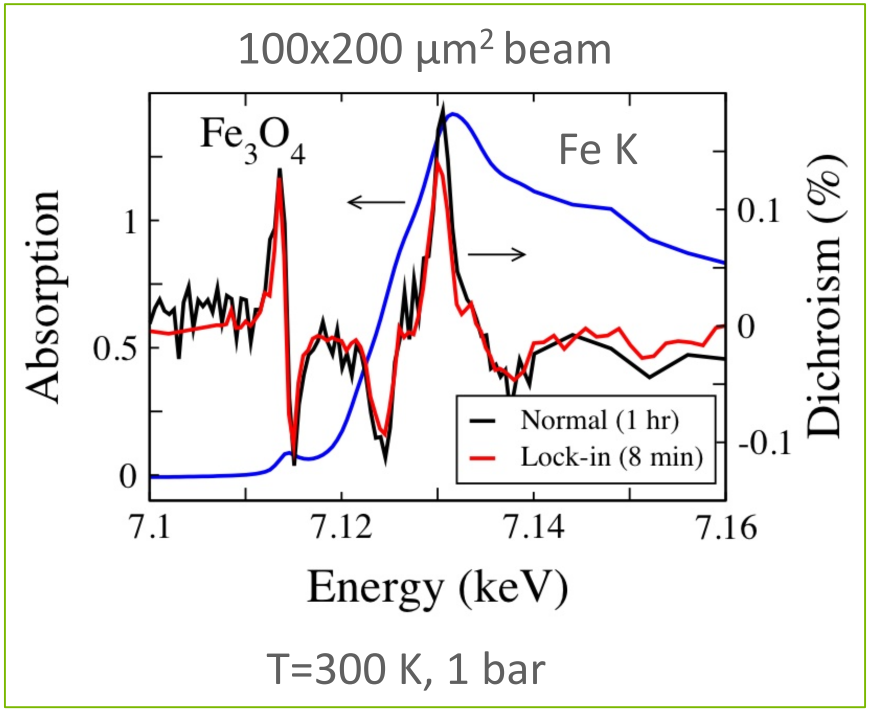


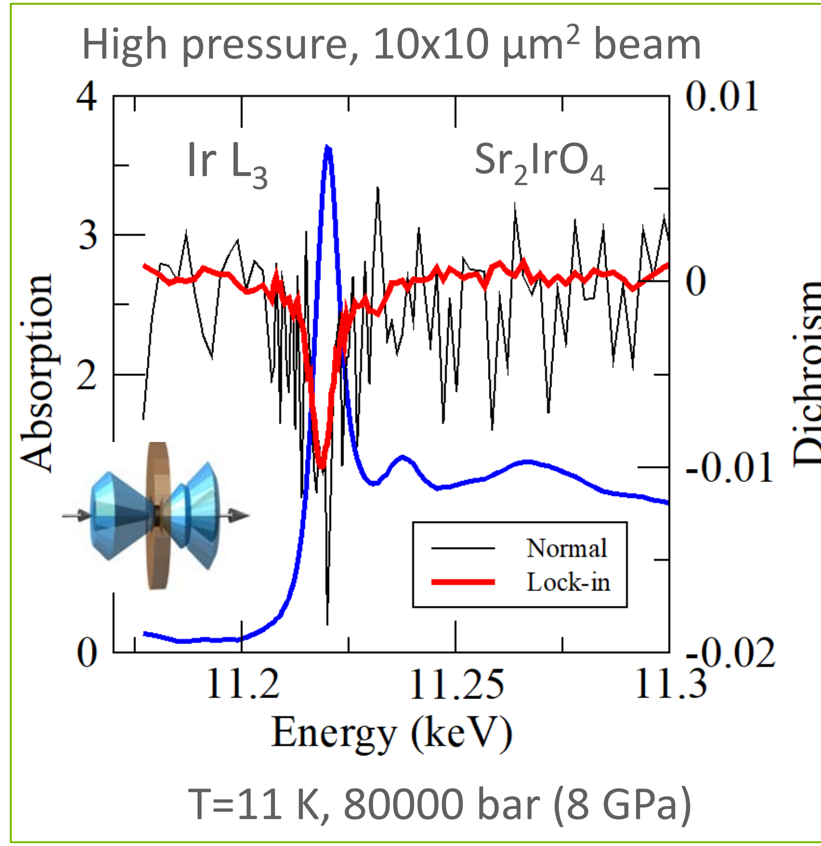
I~ 400 Amps at "closed gap" (K ~ 2.6)

Tuning curves: R. Dejus

Polarization modulation with phase plates (~ 10 Hz) versus slow (several secs) polarization switching

Needs to switch polarization at every energy point in resonant scans

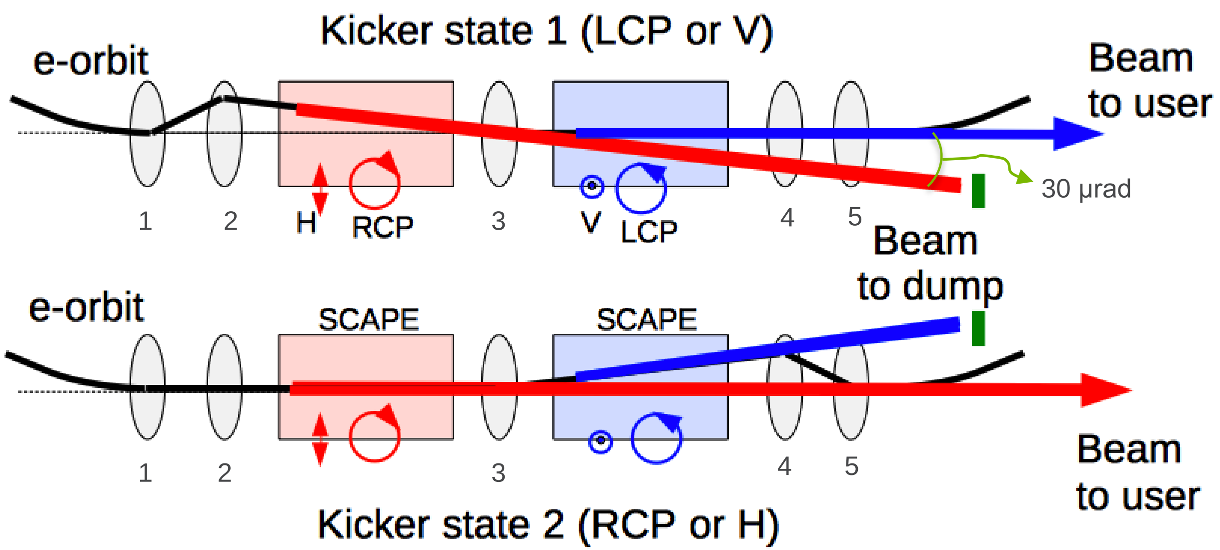


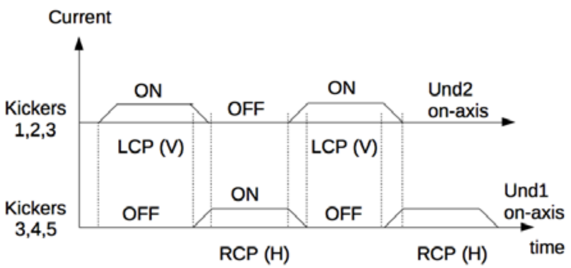


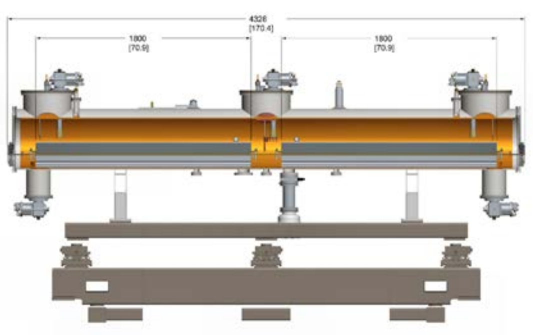
- Polarization switching with single SCAPE device: several minutes
- Goal: Modulate polarization (LCP/RCP or L-H/L-V) at 10 Hz or faster, detect related modulation in absorption coefficient (XMCD, XMLD) with lock-in amplifier

Rapid Polarization Switching: Scheme 1

- Local, alternating electron orbit bumps
- ~ 30 micro-rad bumps sufficient to achieve desired rejection (polarization purity)





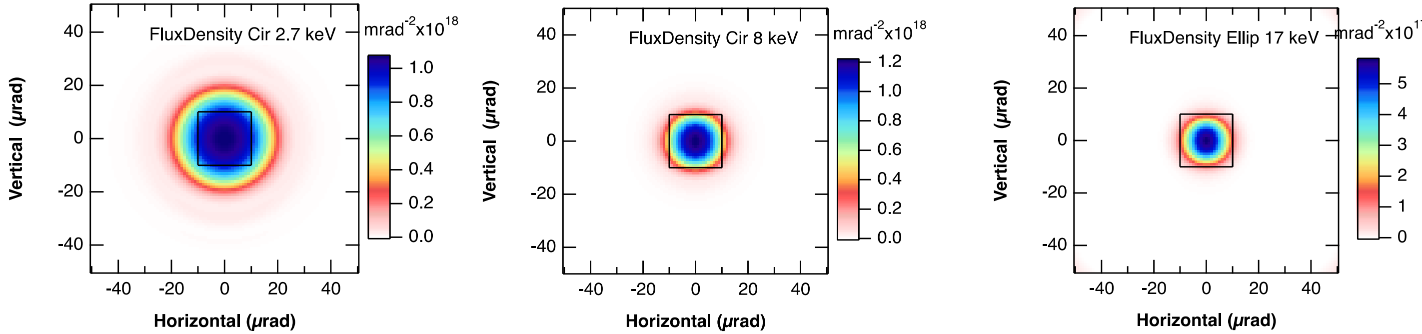


Model Joel Fuerst

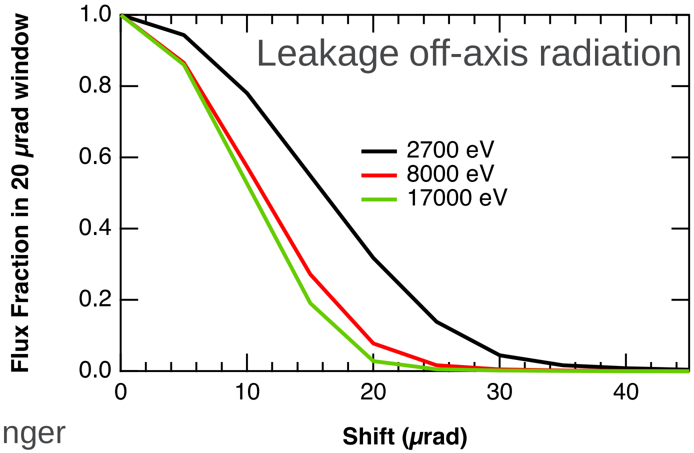
- Operational at two soft x-ray beamlines in Spring-8 (1-10 Hz)
- Commissioned at soft x-ray beamline at DLS (few Hz)
- Both with 200 μrad orbit bumps (beam divergence ~$\sqrt{\lambda}$)

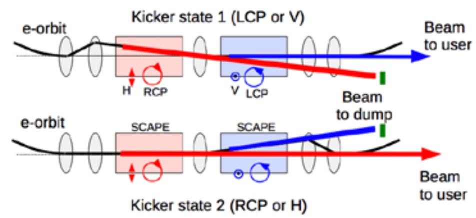
Hara et al, SPRING-8; Steadman et al, DLS

Rapid polarization switching: Scheme 1

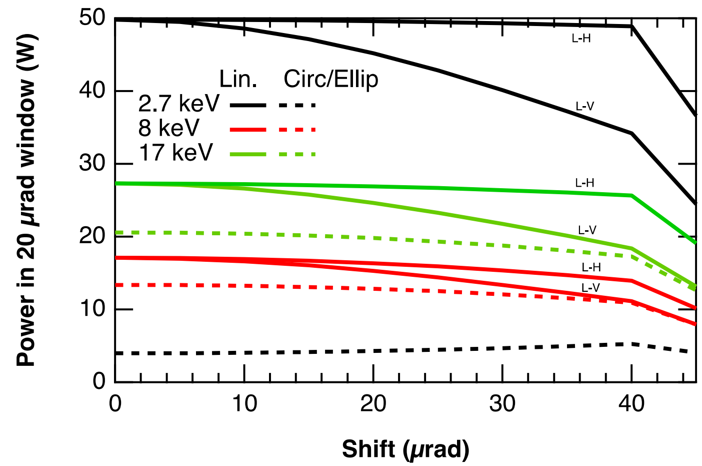


Square box: 0.5x0.5 mm^2 aperture at 25 m (20 μrad)

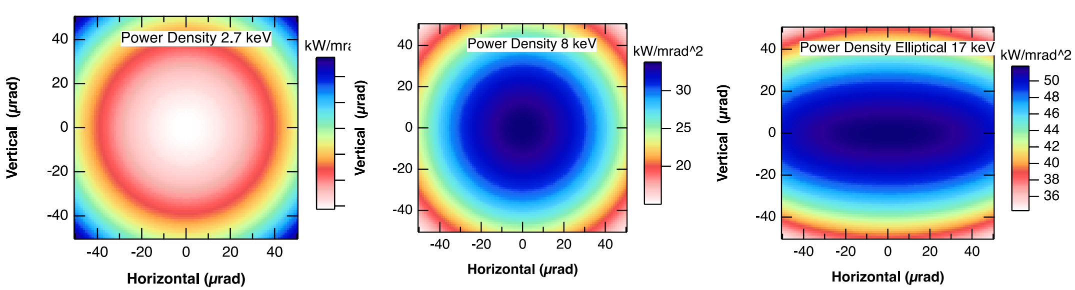




Power on mono

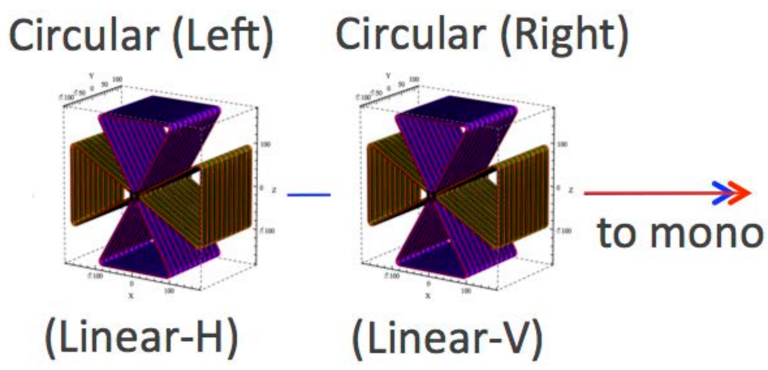


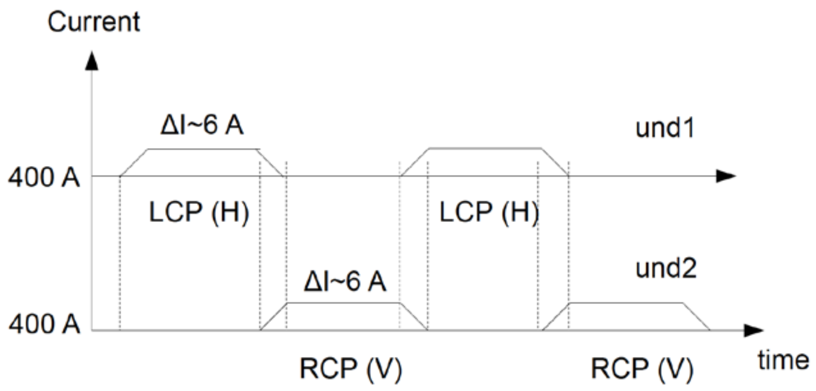
Calculations: R. Reininger

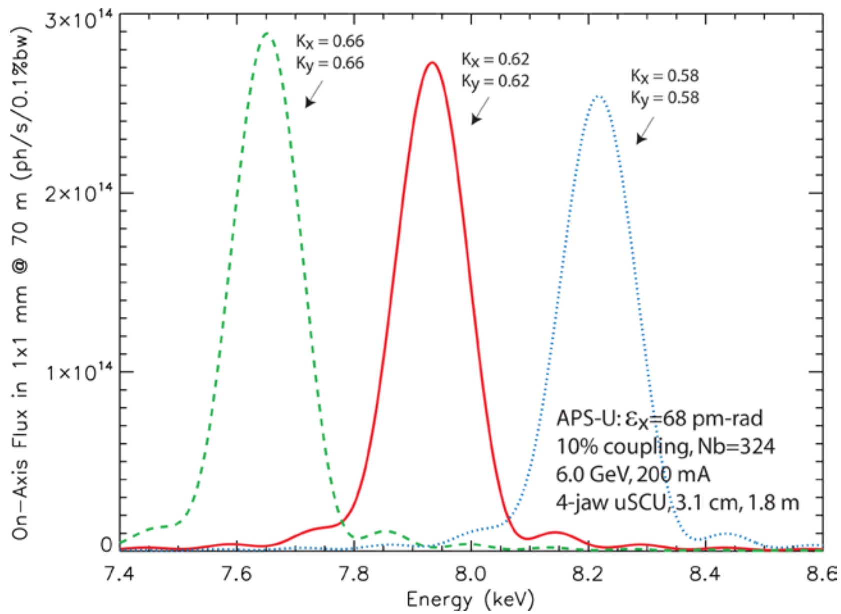


Rapid polarization switching: Scheme 2

- Alternating undulator current bumps shift harmonic energy by BW; monochromator filters
- ~ 5-10 Amps (few % change in K/current value) sufficient to achieve desired rejection

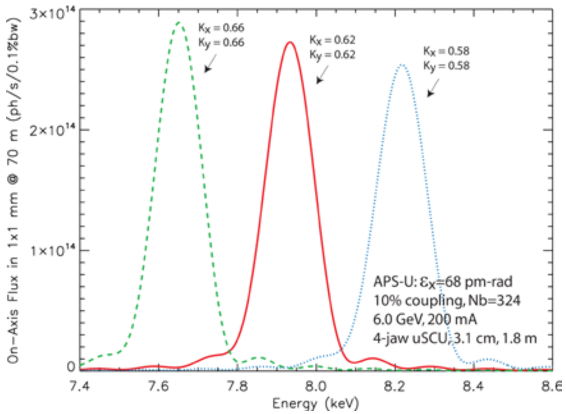




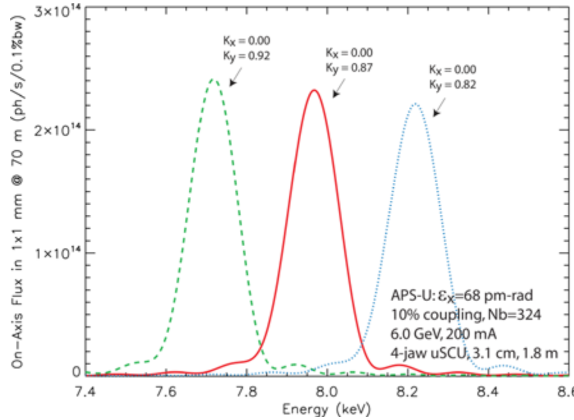


Calculations: R. Dejus

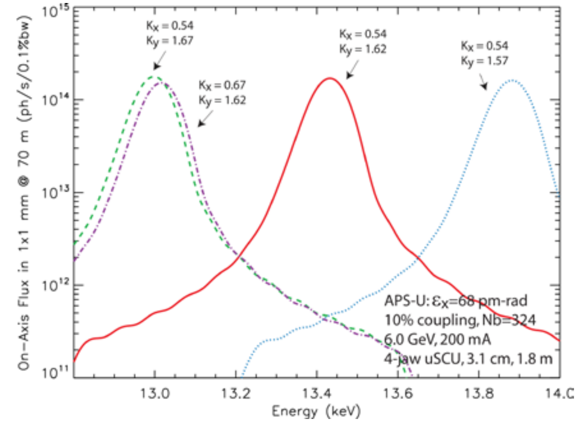
Rapid polarization switching: Scheme 2



8 keV Circular
x100 suppression



8 keV Linear
x50 suppression

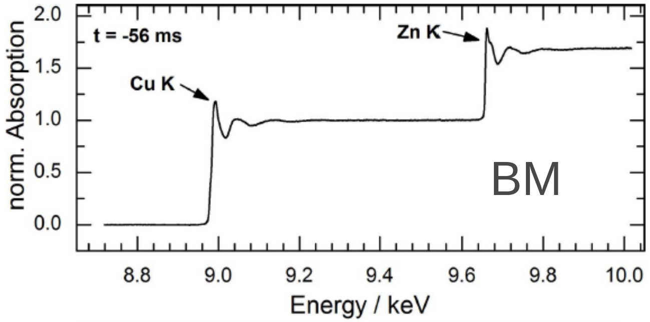


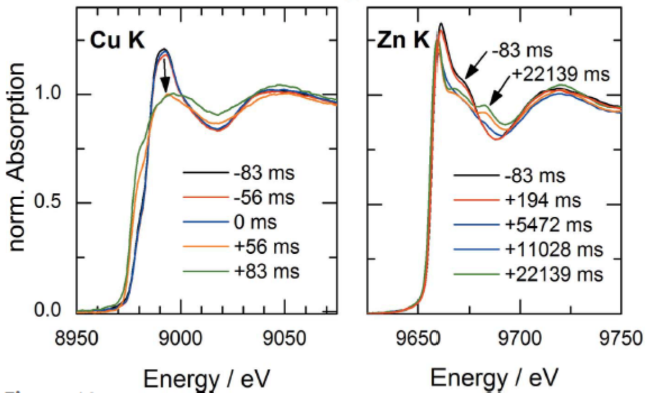
~ 13 keV Elliptical
X400 suppression

- Does not directly perturb electron orbit
- 3-6% change in K value translates to 5-10 Amp current change
- Suppression factors x50-400 means polarization purity 98% or better
- Expects 1 Hz achievable with standard NbTi wire used in planar SC undulators
- Magnetic devices group exploring use of secondary coils made of special “AC friendly” NbTi wire to modulate the small extra current at higher frequencies

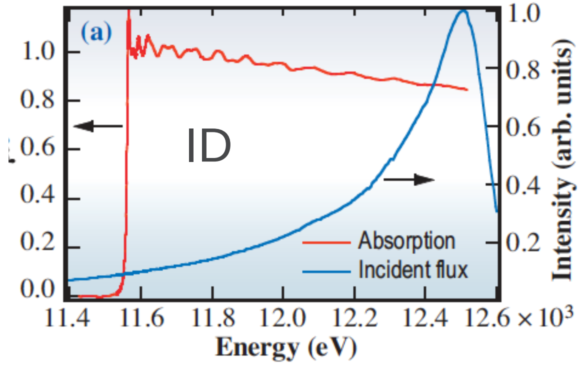
Other applications

Quick XAFS/XAS

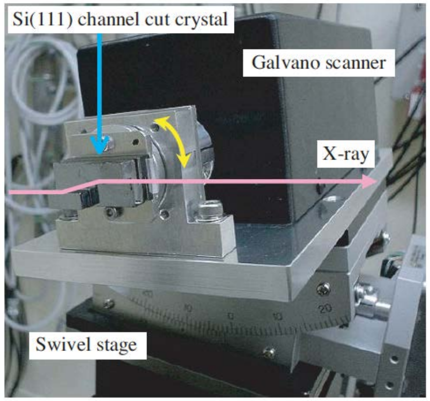




Muller, Frahm (2015)



Uruga, Spring-8



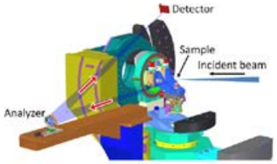
50-100 Hz (10-20 msec)
10 Hz (100 msec)
1 Hz (1 sec)

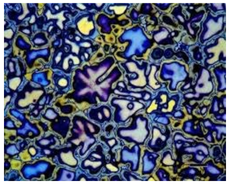
Fast undulator energy scan for Quick-XAFS/XAS

10 Hz: 1 keV/20 Amps/50 msec
1 Hz: 1 keV/20 Amps/500 msec

Nano/micro probes: Polarization-dependent XAS/scattering (can't rotate sample)

Horizontal scattering: flux starved experiments (IXS)





Circular mode: off-axis harmonics, low on-axis power

Wavefront preservation without harmonic rejection mirrors (helical SCU @ 7-ID)

Summary

- Round ID vacuum chambers enabled by on-axis injection in APS-U allow implementation of novel IDs for polarization control (e.g. SCAPE)
- Major improvement relative to phase plates for generation of LCP, RCP, L-V polarization: x10 average flux gains in 3-14 keV, extend to resonances in the 15-27 keV (5f, 4d systems)
- More than one route to fast polarization modulation for detection of small dichroic signals: Electron orbit bumps (implemented at Spring-8&DLS) / undulator current bumps (new, R&D) APS has significant experience with SC undulators and fast switching EM undulators (CPU at 4-ID-C)
- May find applications in other techniques: quick-XAFS, micro/nanoprobes, IXS, wavefront preservation, etc
- POLAR beamline plans to use in-line SCAPE undulators for fast polarization switching

Contributors

- Yury Ivanyushenkov, Efim Gluskin, Ibrahim Kesgin, Joel Fuerst and rest of Magnetic Devices group: “SCAPE” undulator
- Mohan Ramanathan: ID related topics
- Louis Emery: Accelerator Physics
- Ruben Reininger, Xianbo Shi: Optics/Radiation properties/simulations
- Roger Dejus: ID tuning curves
- Joerg Strempfer, Jonathan Lang, Tim Graber: Polarization, phase plates
- MM group members