Magnetic and Atomic Structures Studied by Soft X-ray Spectroscopies

Kenta Amemiya (KEK-PF)

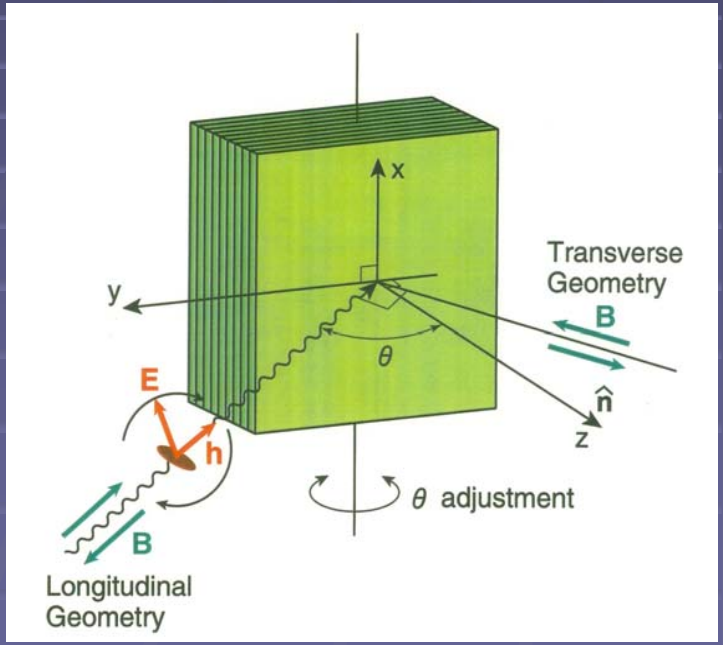
Outline

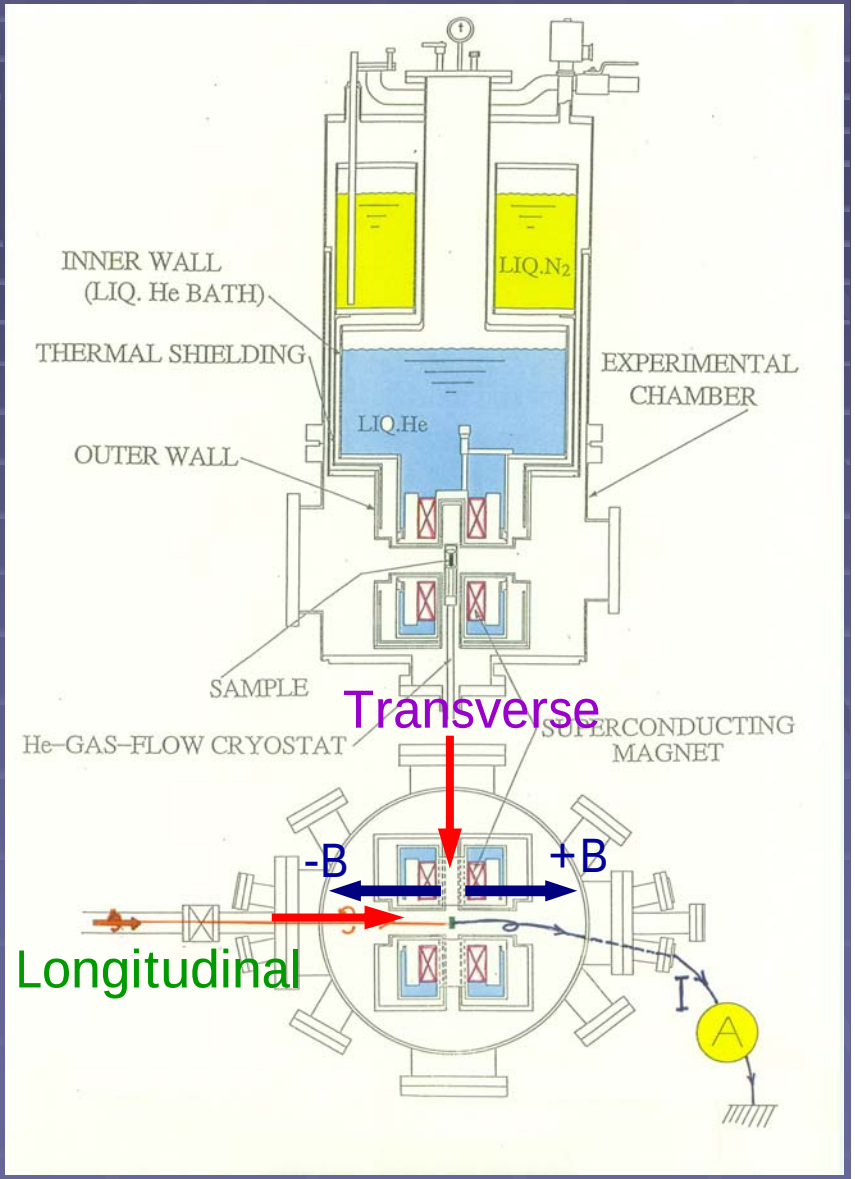
1. Magnetic structure (XMCD)
2. Surface and Interface
   (depth-resolved XAFS)
3. Future plans at a new soft X-ray beamline,
   PF-BL-16A

Magnetic Structures Studied by L/T Geometry Angle-dependent XMCD

XMCD (X-ray Magnetic Circular Dichroism)

- Element selectivity
- Quantitative determination of spin & orbital magnetic moments by using the sum rules





Angle-dependent XMCD

⇒ **Magnetic anisotropy**

Separation of m_s from m_T

T. Koide et al., Rev. Sci. Instrum. **63**, 1462 (1992).

Angle-dependent XMCD in Longitudinal (L) Geometry

T. Koide et al., Phys. Rev. Lett. 87, 257201 (2001)

Au/Co(2 ML)/Au(111)

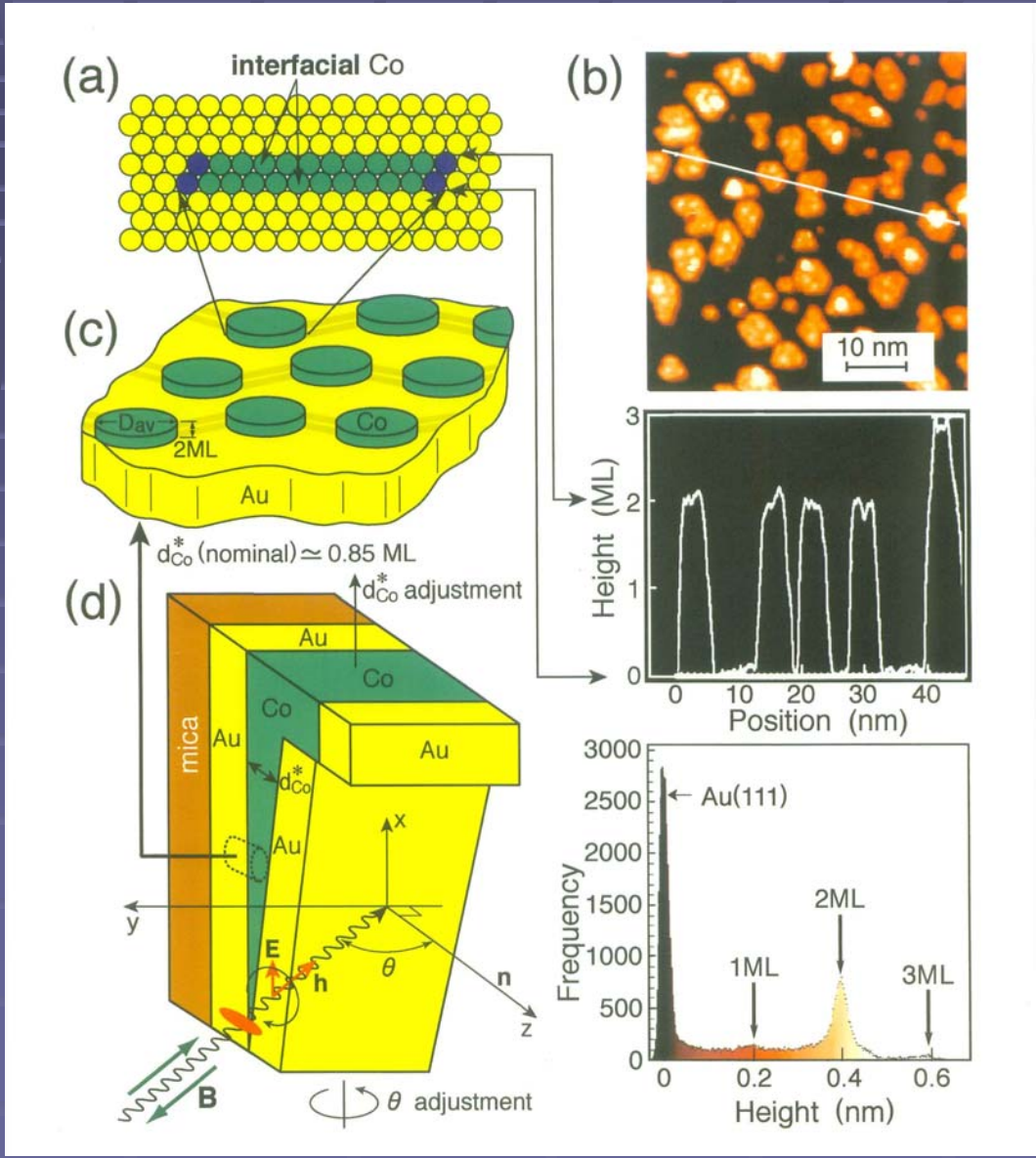
Self-assembled Co islands due to a reconstruction of Au surface

All Co atoms are regarded to "interface" because of 2 ML thickness

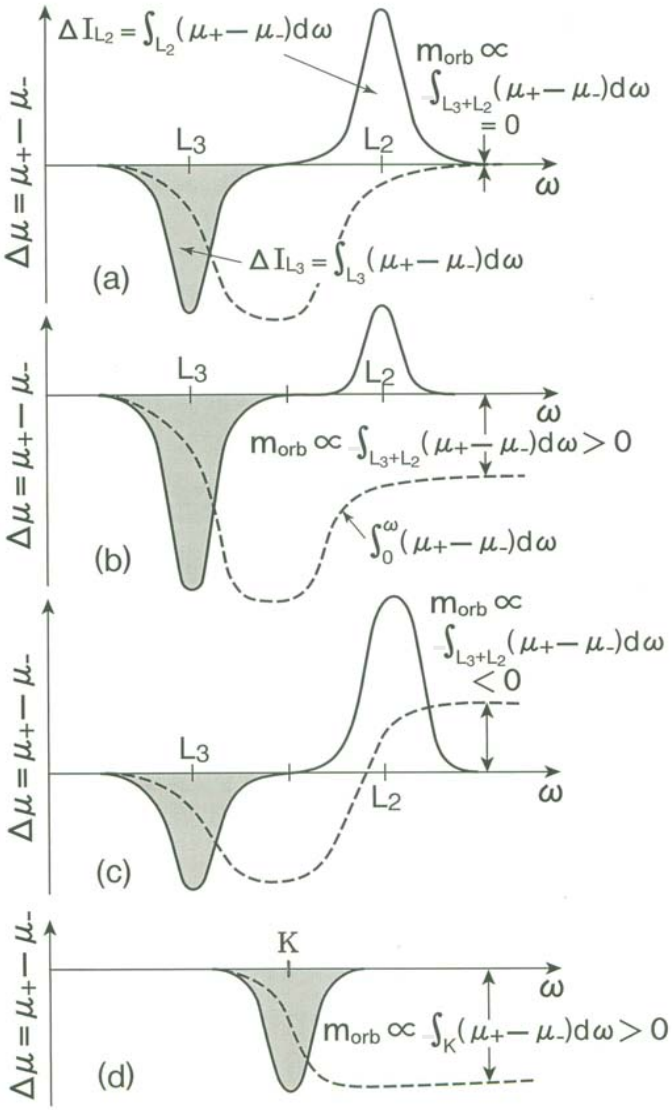
⇒ **Direct observation of interface magnetism**

Angle-dependent XMCD

⇒ **Direct determination** of m_s, $m_l^{//}$, $m_l^{\perp}$, $m_T^{//}$, $m_T^{\perp}$



Sum rules in Longitudinal (L) geometry



Orbital sum rule (L geometry)

$$\frac{[\Delta I_{L_3} + \Delta I_{L_2}]^{\theta}}{I_{L_3} + I_{L_2}} = -\frac{3 \cdot m_{orb}^{\theta}}{4 n_h \cdot \mu_B}$$

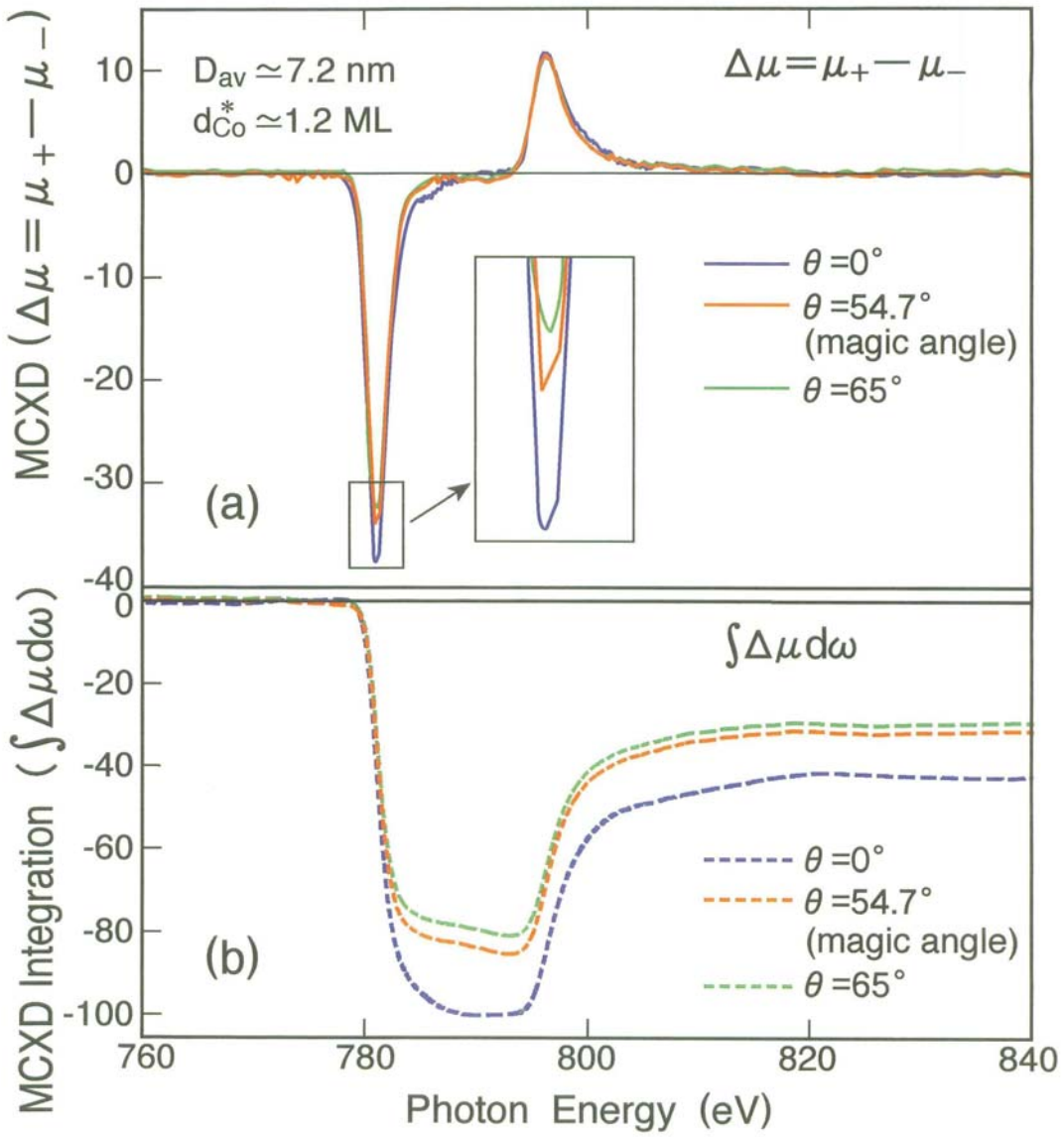
Spin sum rule (L geometry)

$$\frac{[\Delta I_{L_3} - 2 \cdot \Delta I_{L_2}]^{\theta}}{I_{L_3} + I_{L_2}} = -\frac{(m_{spin} + 7 \cdot m_T^{\theta})}{2 n_h \cdot \mu_B}$$

B.T. Thole et al., PRL **68**, 1943 (1992).
P. Carra et al., PRL **70**, 694 (1993).

Angle-dependent XMCD Measurements

T. Koide et al., Phys. Rev. Lett. 87, 257201 (2001)



PF BL-11A

Angle dependence in XMCD
← Anisotropy in m_l, m_T

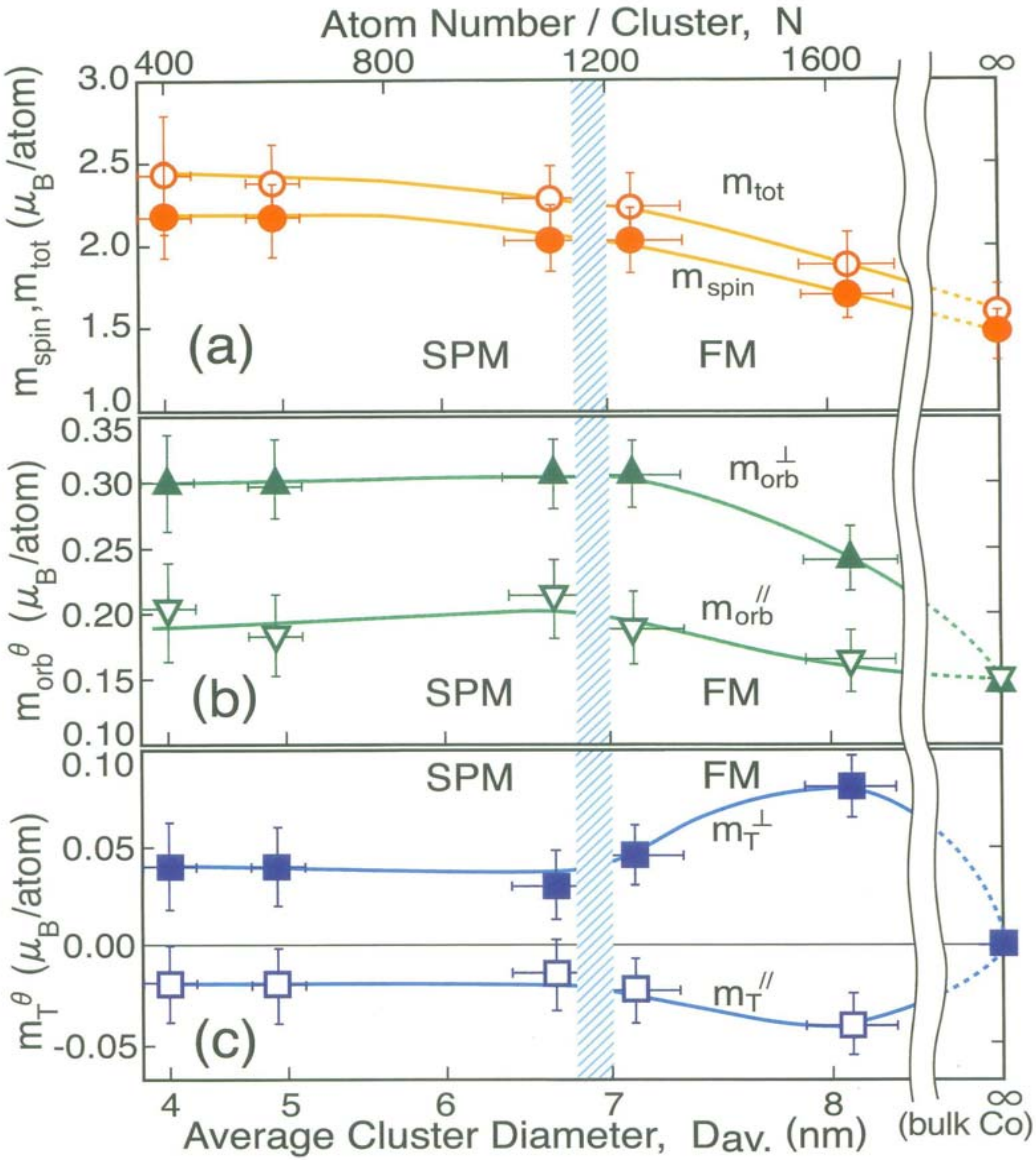
$$m_j^{\theta} = m_j^{\perp}\cos^2\theta + m_j^{//}\sin^2\theta$$
(j = l or T)

$$m_T^{\perp} + 2\, m_T^{//} = 0$$

⇒ Determination of all moments including their anisotropy

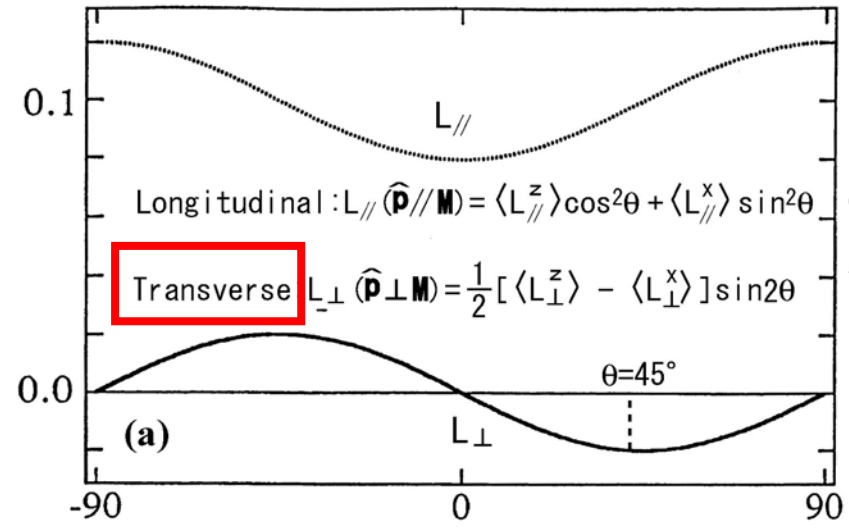
Determined Magnetic Moments

T. Koide et al., Phys. Rev. Lett. 87, 257201 (2001)

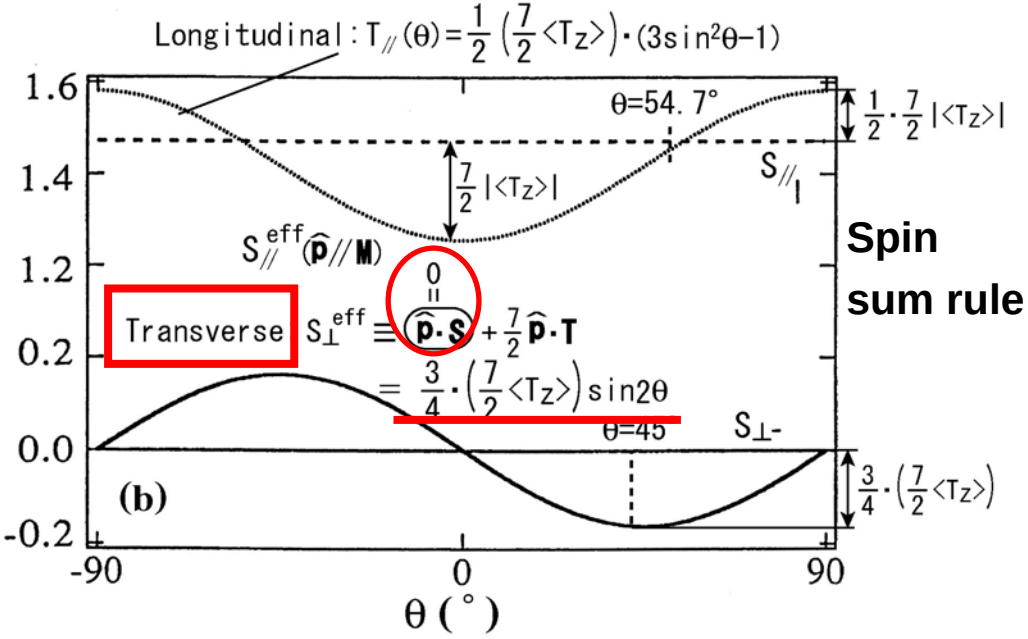


Cluster-size dependent phase transition

Angle-dependent Sum Rules



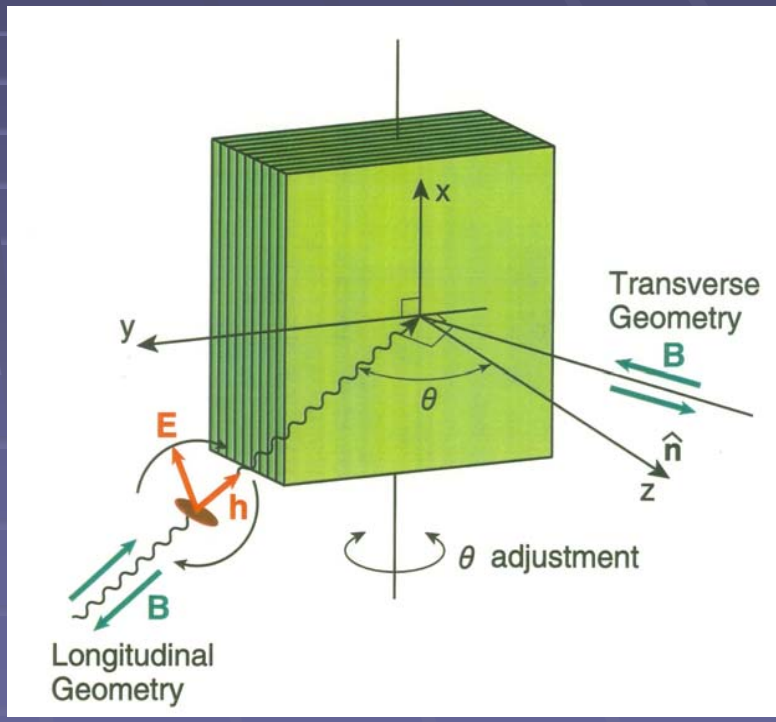
Orbital sum rule



Spin sum rule

// → Longitudinal

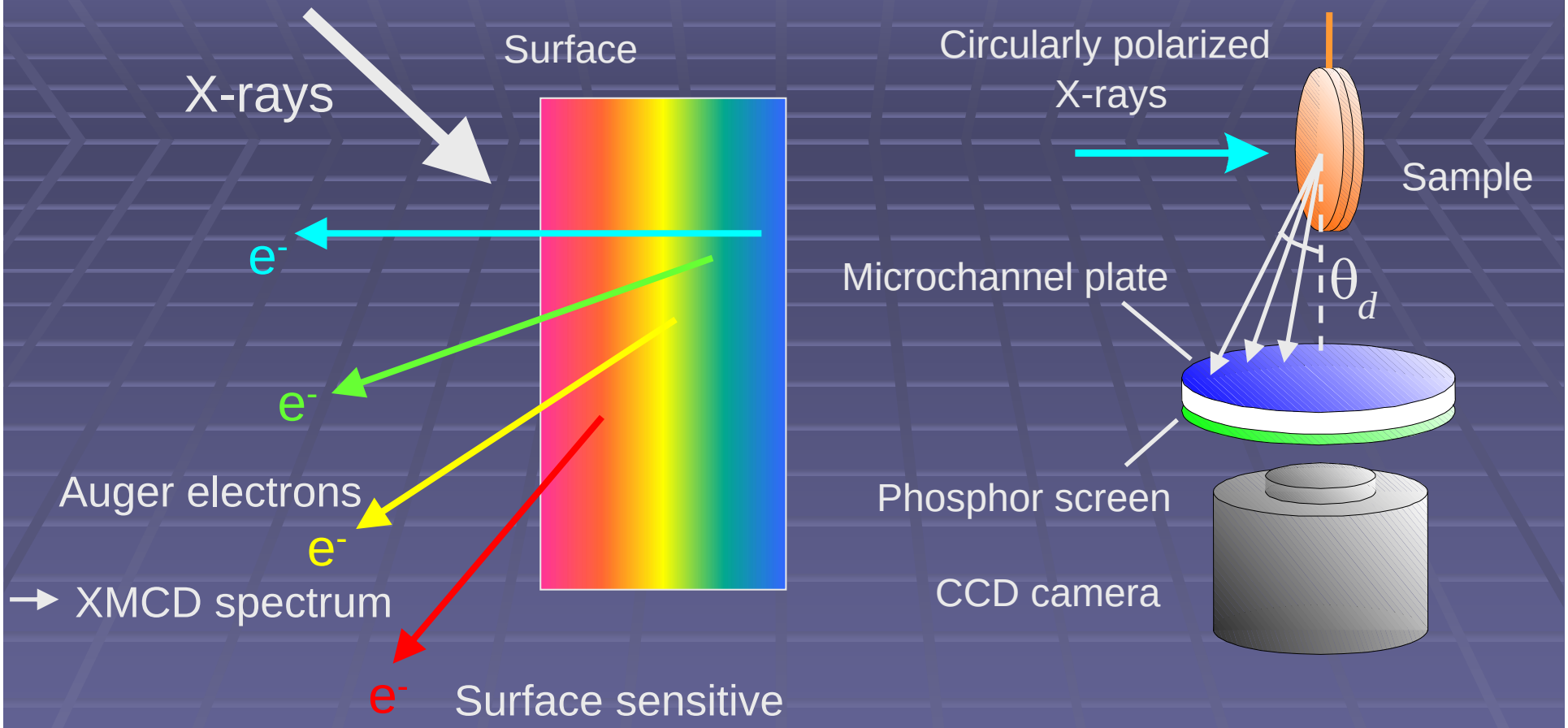
⊥ → Transverse



Outline

1. Magnetic structure (XMCD)
2. Surface and Interface
   (depth-resolved XAFS)
3. Future plans at a new soft X-ray beamline,
   PF-BL-16A

Principle of Depth-resolved XAFS (XMCD)



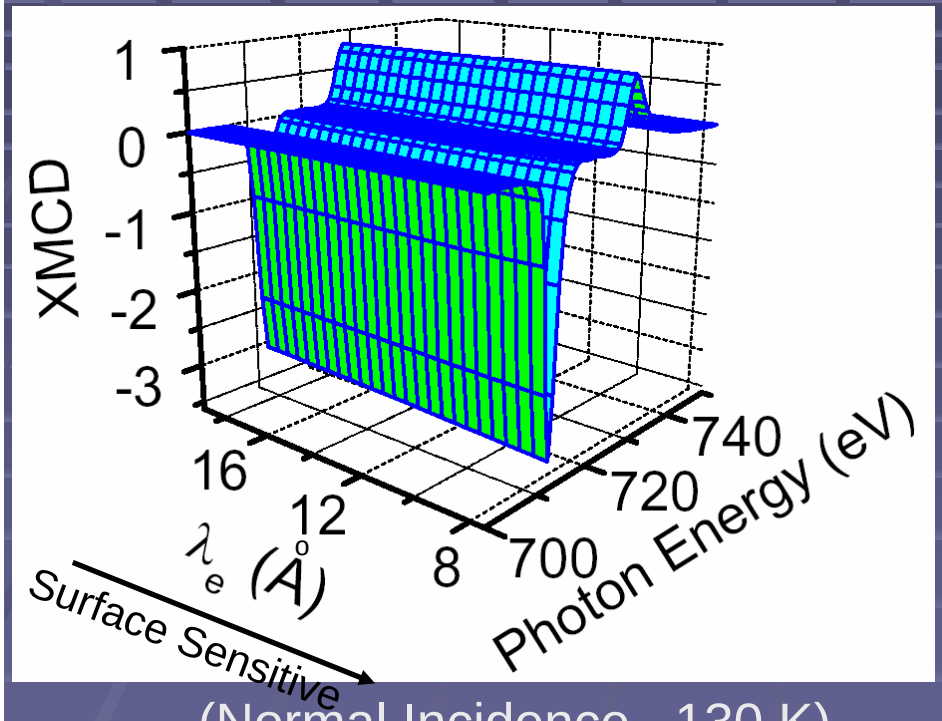
Electron yield XMCD measurements at different detection angles

→ A set of XMCD spectra with different probing depths

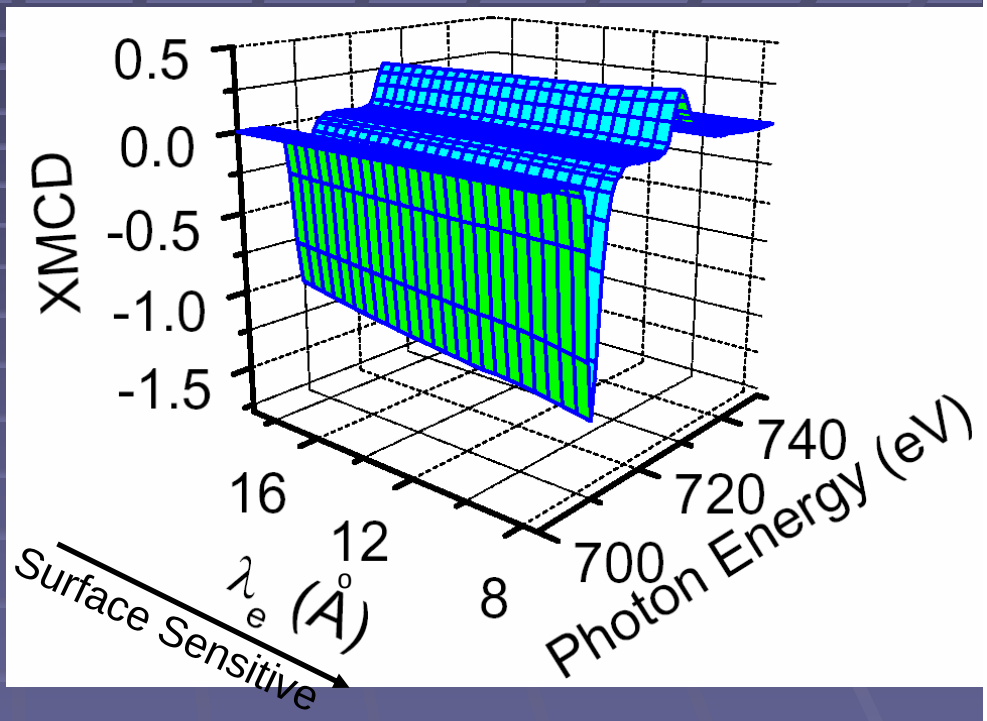
Feasibility Study: Magnetic Depth Profile of Fe/Cu(100)

Amemiya et al., APL 84 (2004) 936.

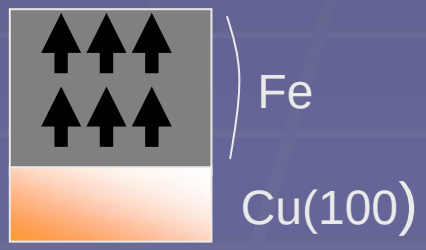
3 ML Fe



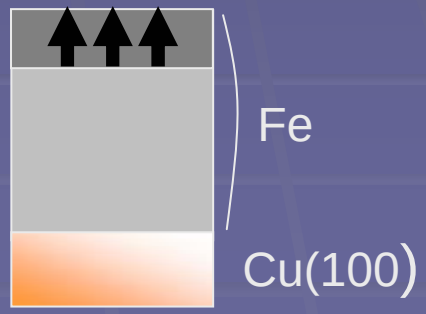
7 ML Fe



(Normal Incidence, 130 K)



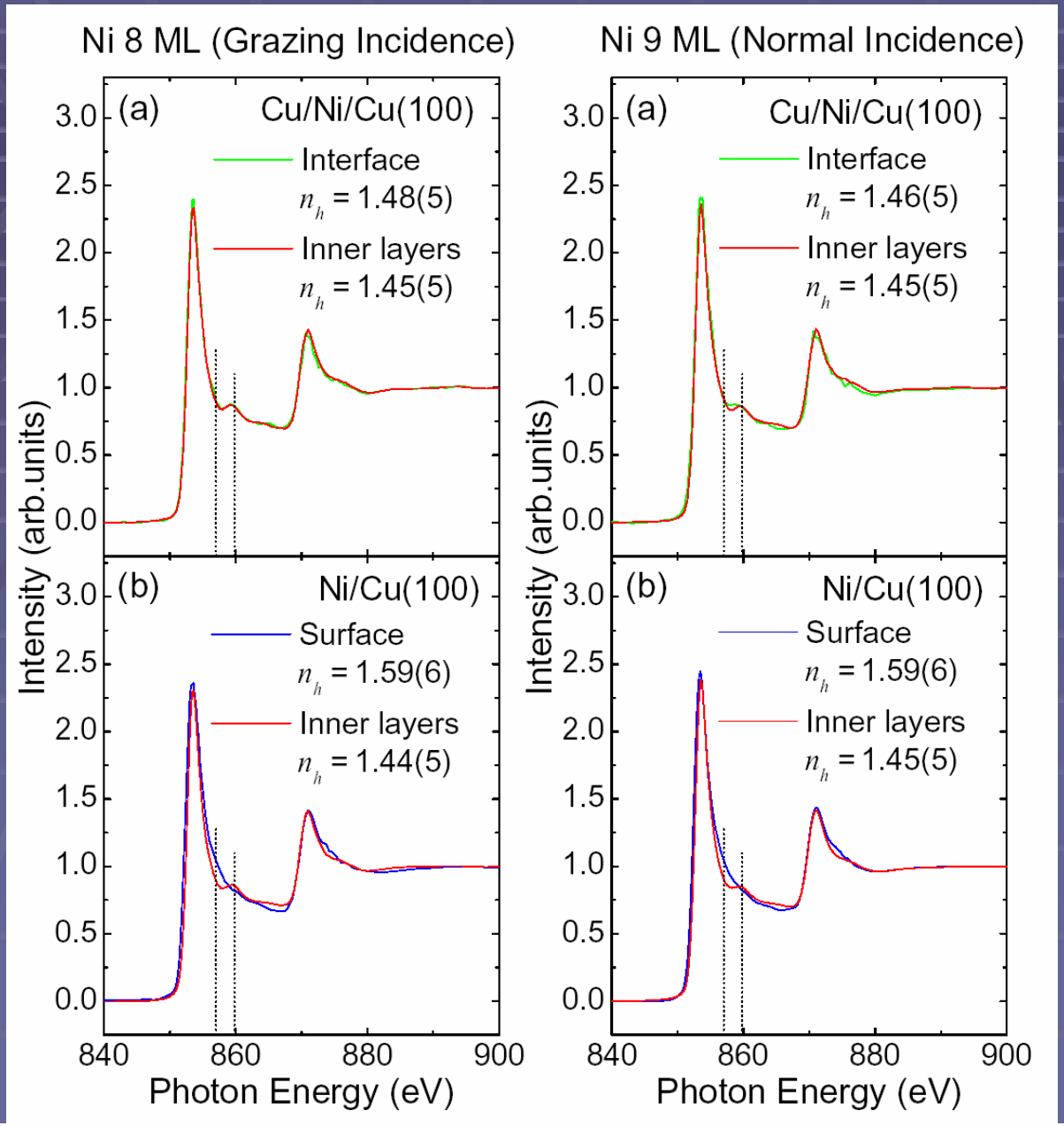
Uniform Magnetization

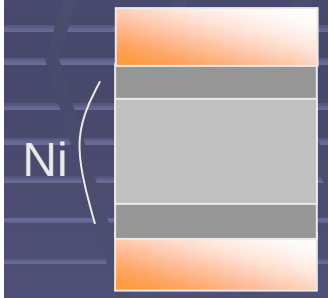


Surface Magnetization

Extraction of Surface and Interface XMCD spectra

Amemiya et al., PRB 72 (2005) 201404(R).





Interface (1 ML)

Inner layers

Interface (1 ML)

Similar spectra for
Interface and inner layers

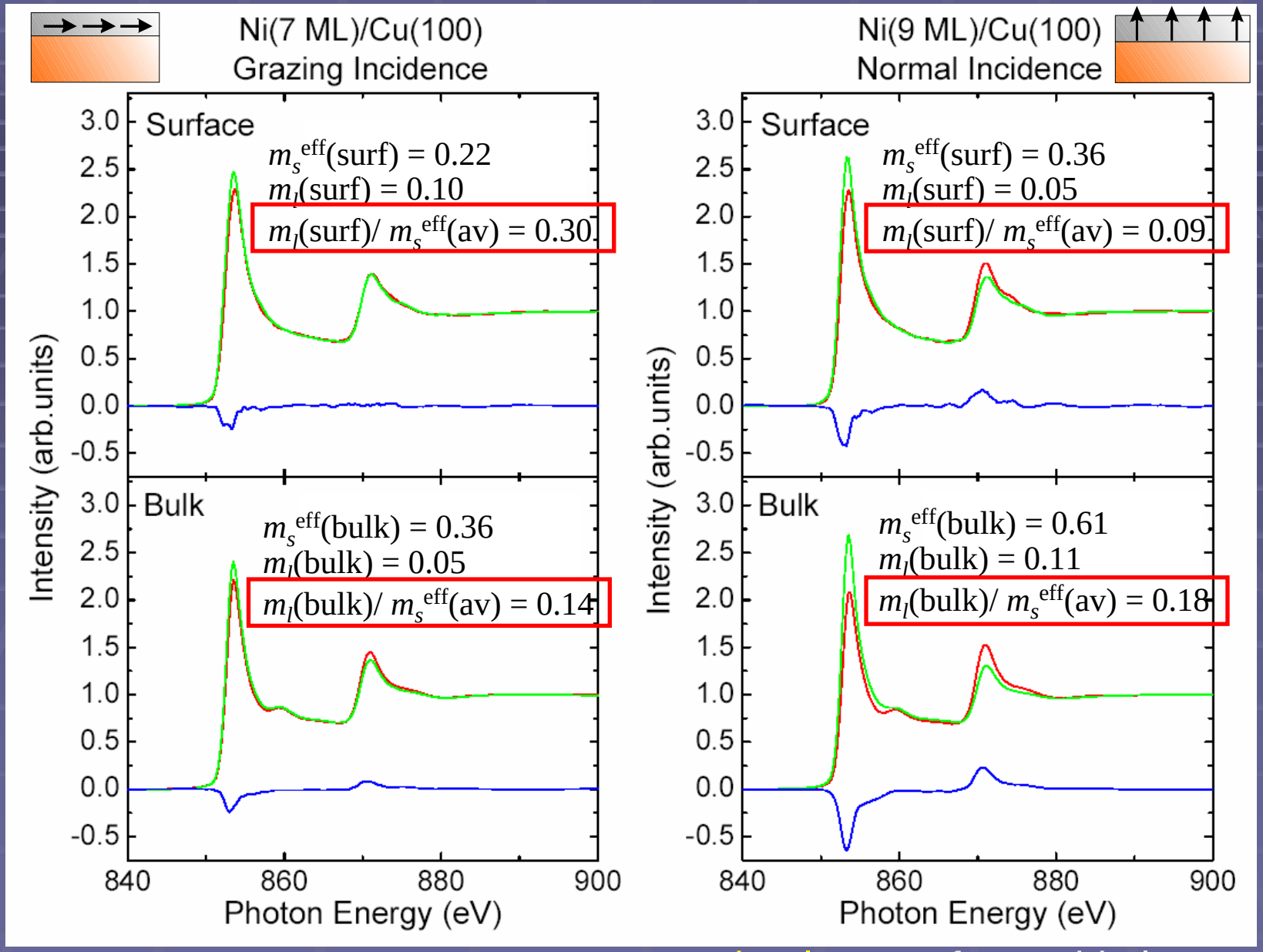
Surface (1 ML)

Inner layers

Surface spectrum is
drastically different

Magnetic Structures at the Surface

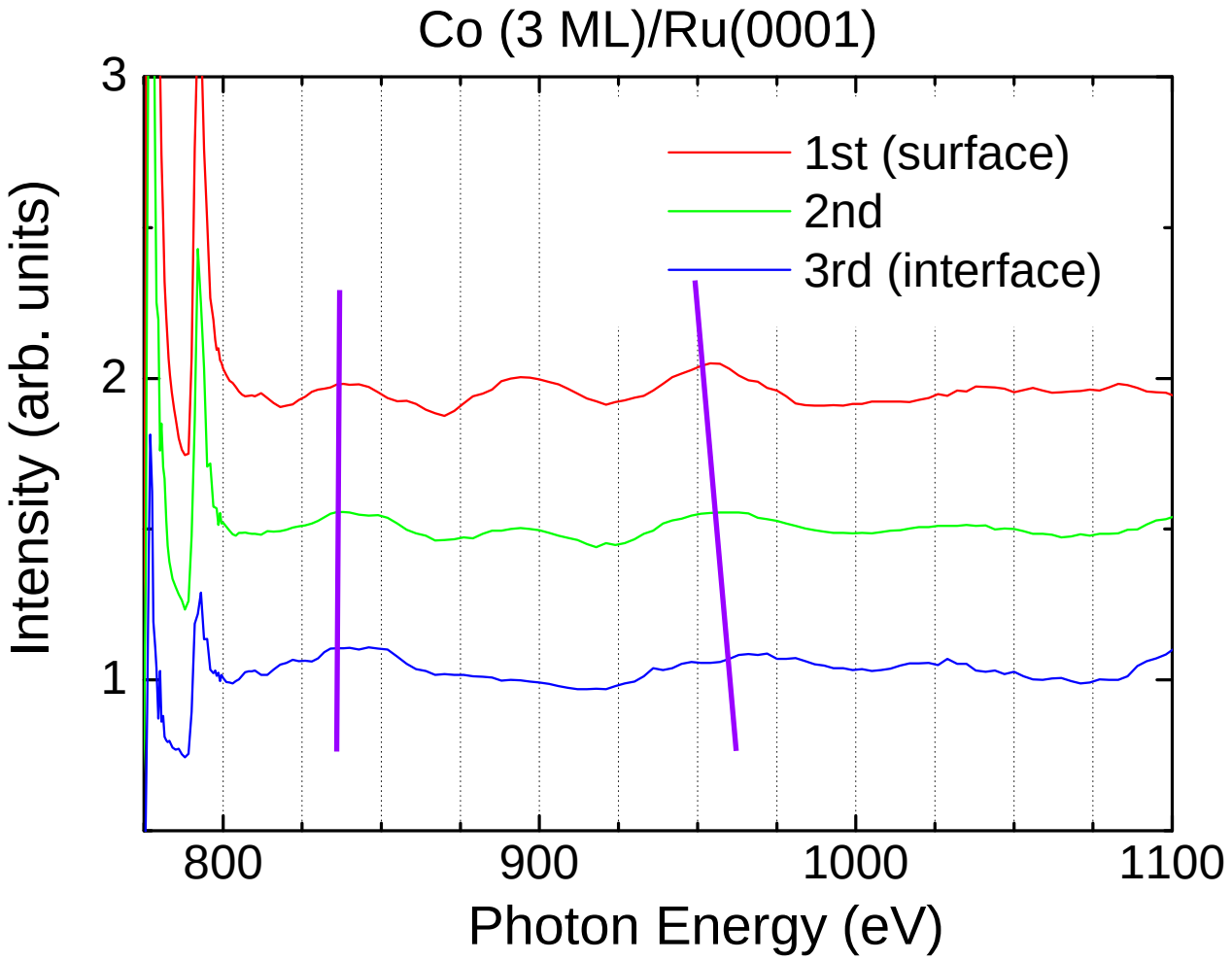
Amemiya et al., PRB 71 (2005) 214420.



Large in-plane surface orbital moment

Depth-resolved Observation of Atomic Structures

Co L-edge EXAFS



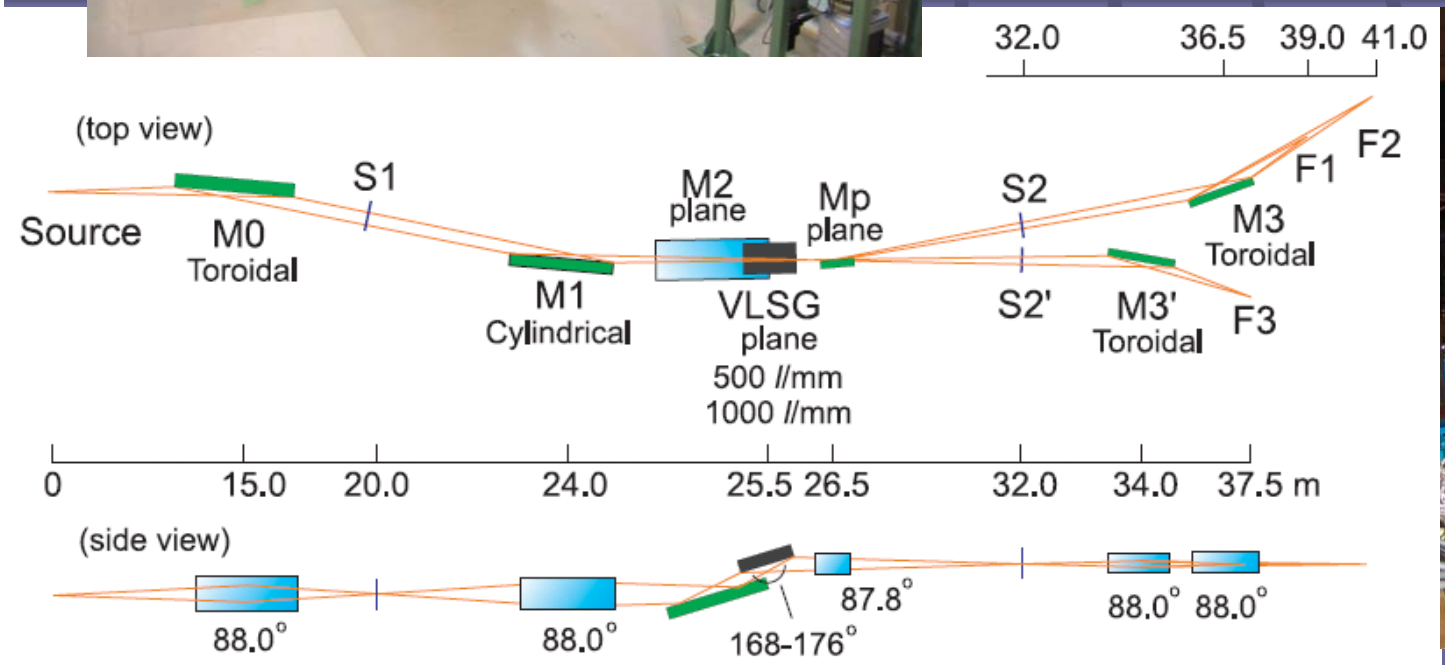
Depth dependence of layer spacing

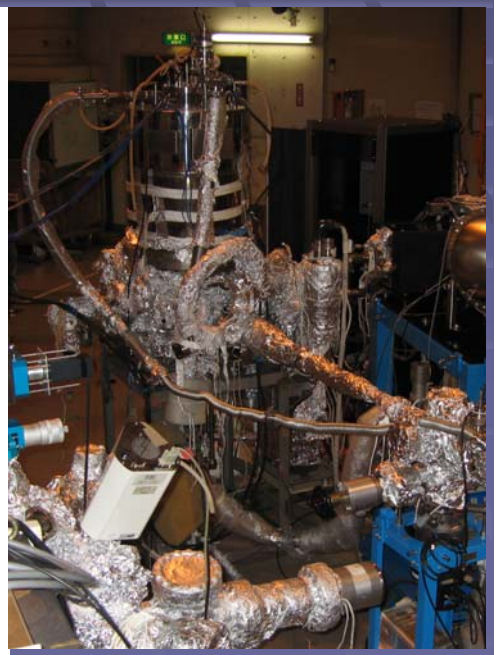
Outline

1. Magnetic structure (XMCD)
2. Surface and Interface
   (depth-resolved XAFS)
3. Future plans at a new soft X-ray beamline,
   PF-BL-16A

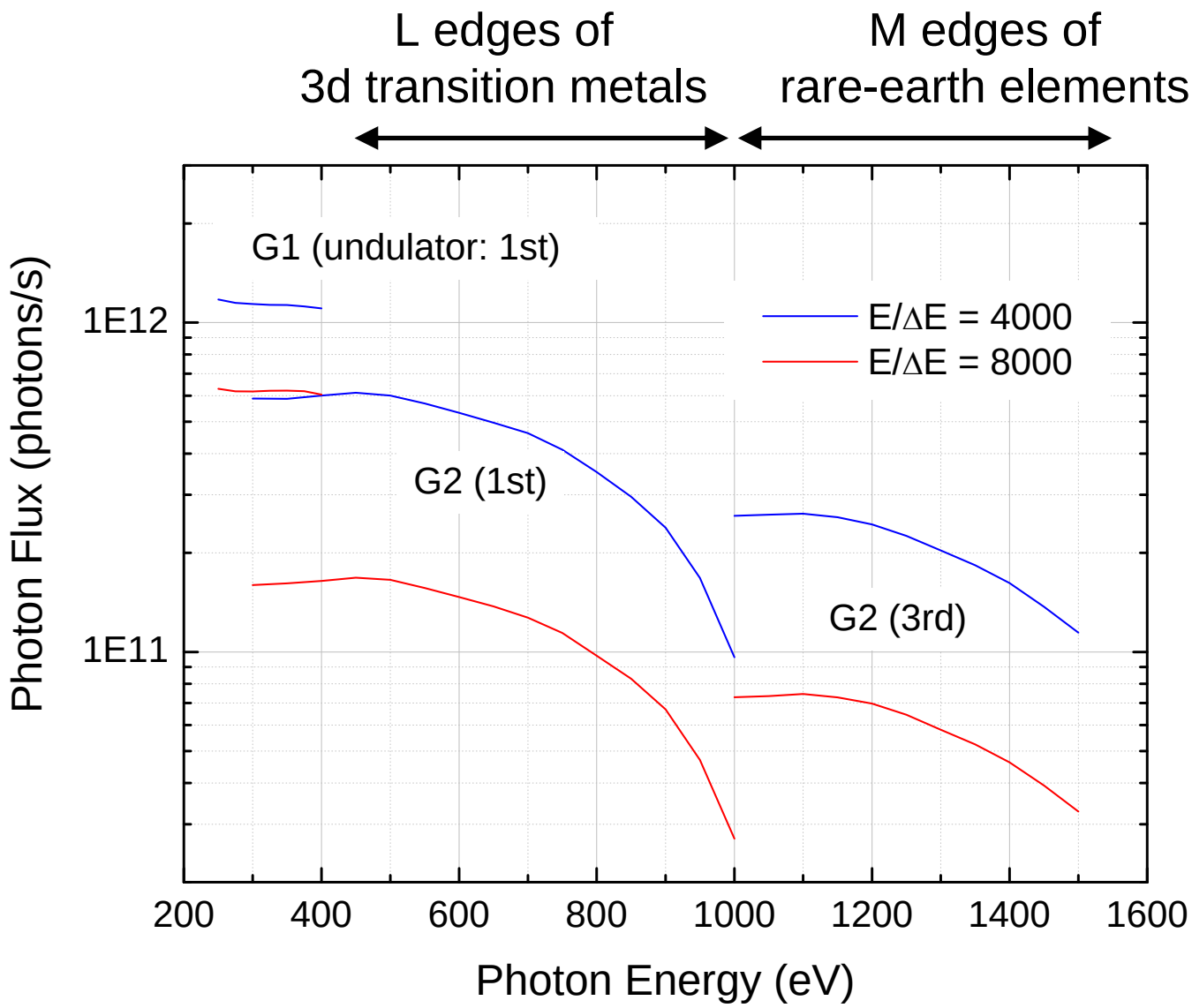
Soft X-ray Beamline BL-16A

Variable Polarization
Circular & Linear (vertical/horizontal)
Construction: Jun.-Oct. 2007
User Experiments: Oct. 2008

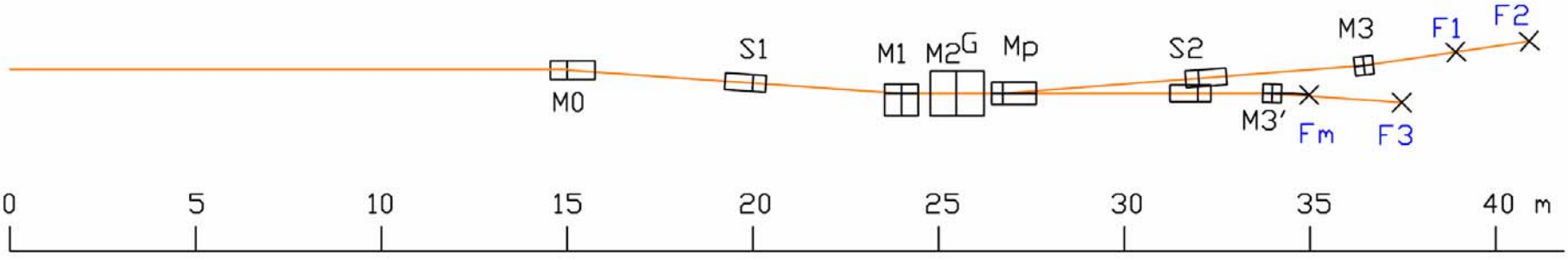




Expected Photon Flux at BL-16A

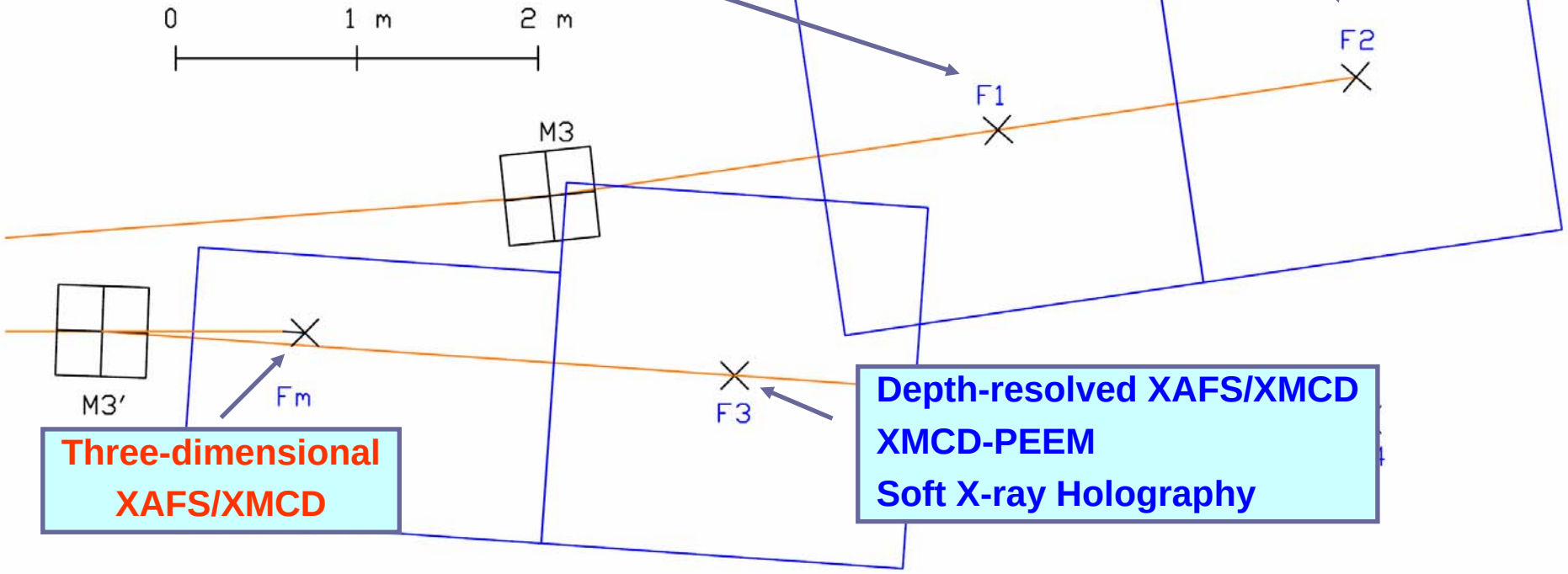


Experimental Facilities



Angle-dependent XMCD
(Superconducting magnet)

X-ray Resonant
Magnetic Scattering



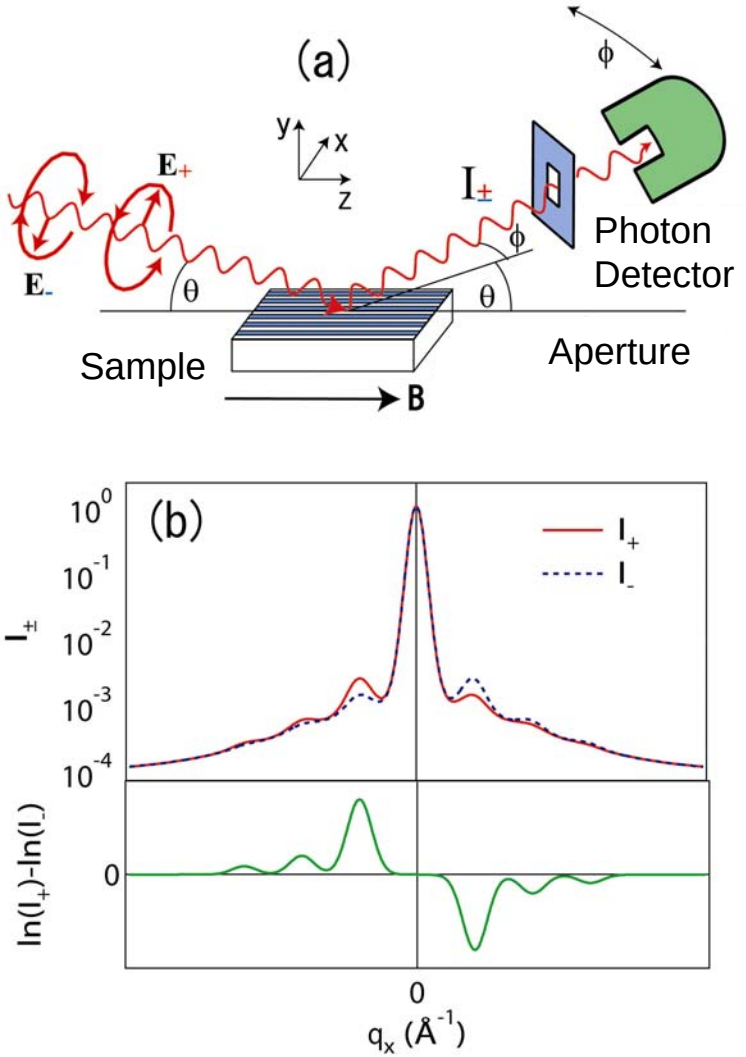
Three-dimensional
XAFS/XMCD

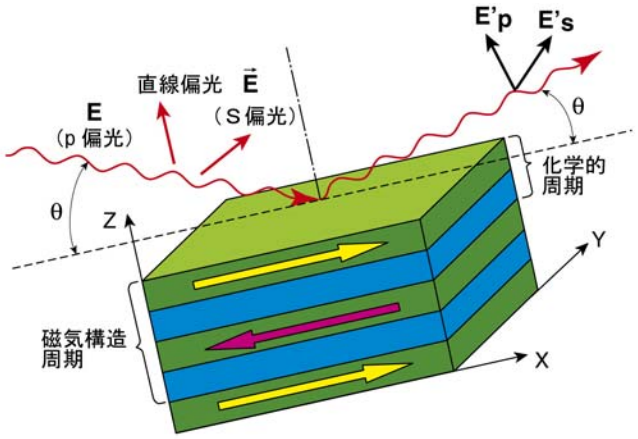
Depth-resolved XAFS/XMCD
XMCD-PEEM
Soft X-ray Holography

Resonant Magnetic Scattering

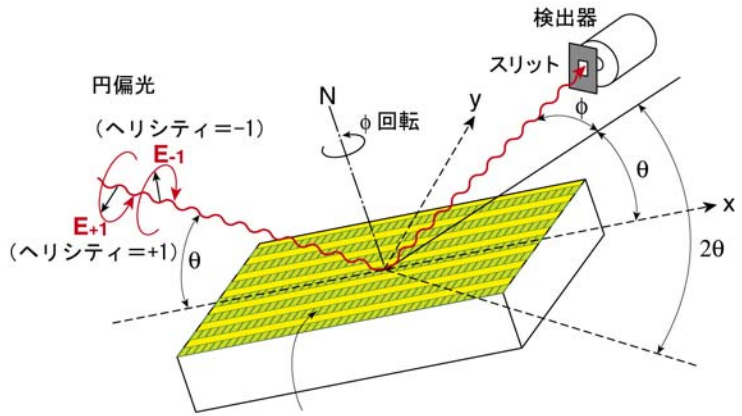
Commissioning from Oct. 2008
(T. Koide et al.)

Observation of periodic structures in nm scale
Simultaneous determination of atomic and magnetic structures





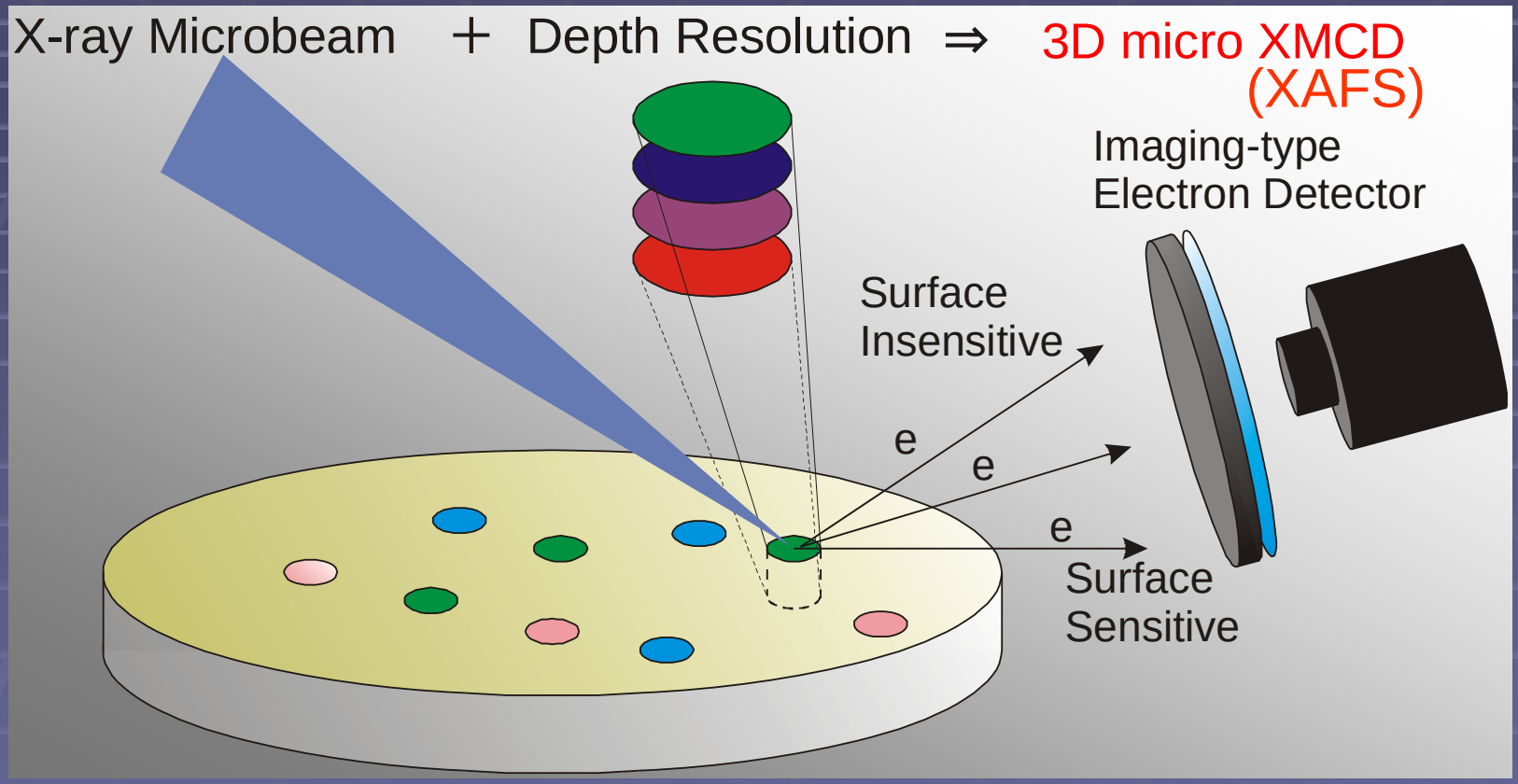
(a) Perpendicular periodic structure



(b) In-plane periodic structure

Three-dimensional XAFS/XMCD

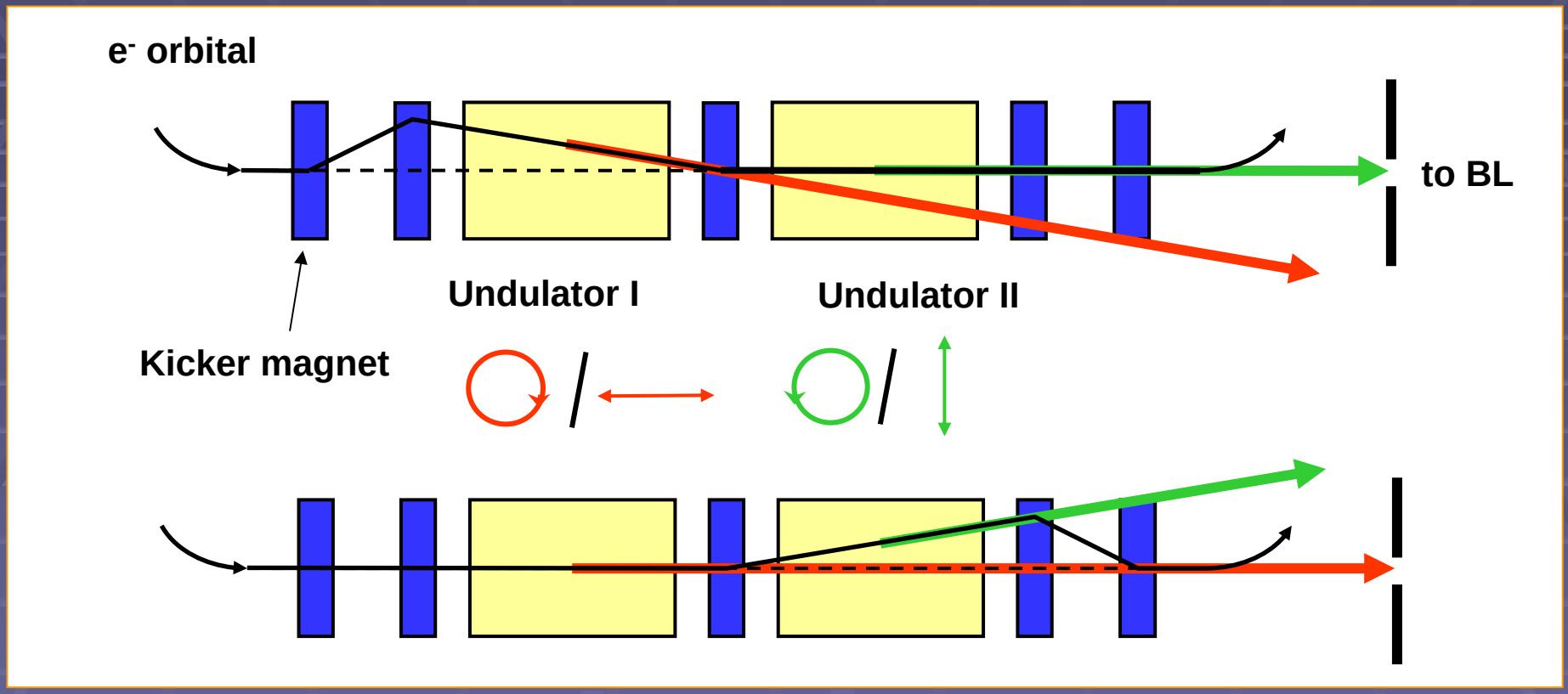
Commissioning from Nov. 2008
(Amemiya et al.)



Three-dimensional information on
- Atomic Structure (EXAFS)
- Electronic Structure (XANES)
- Magnetic Structure (XMCD)

Fast Polarization-Switching Project

Twin APPLE-II type undulators for fast polarization switching (~10 Hz)



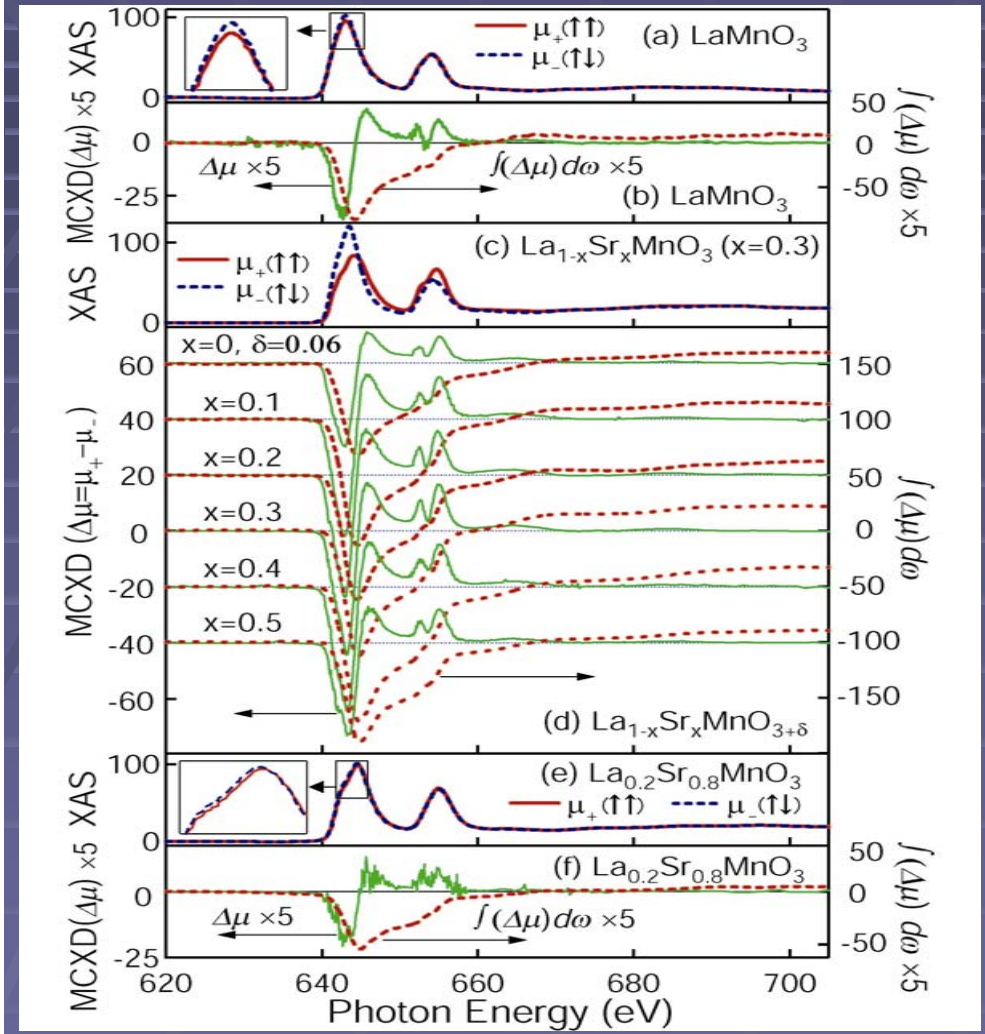
T. Hara et al., J. Synchrotron Rad. **3**, 426 (1998).
Y. Saitoh et al., J. Synchrotron Rad. **5**, 542 (1998).

Lock-in technique ⇒ Observation of small (~10^{-4}) dichroism

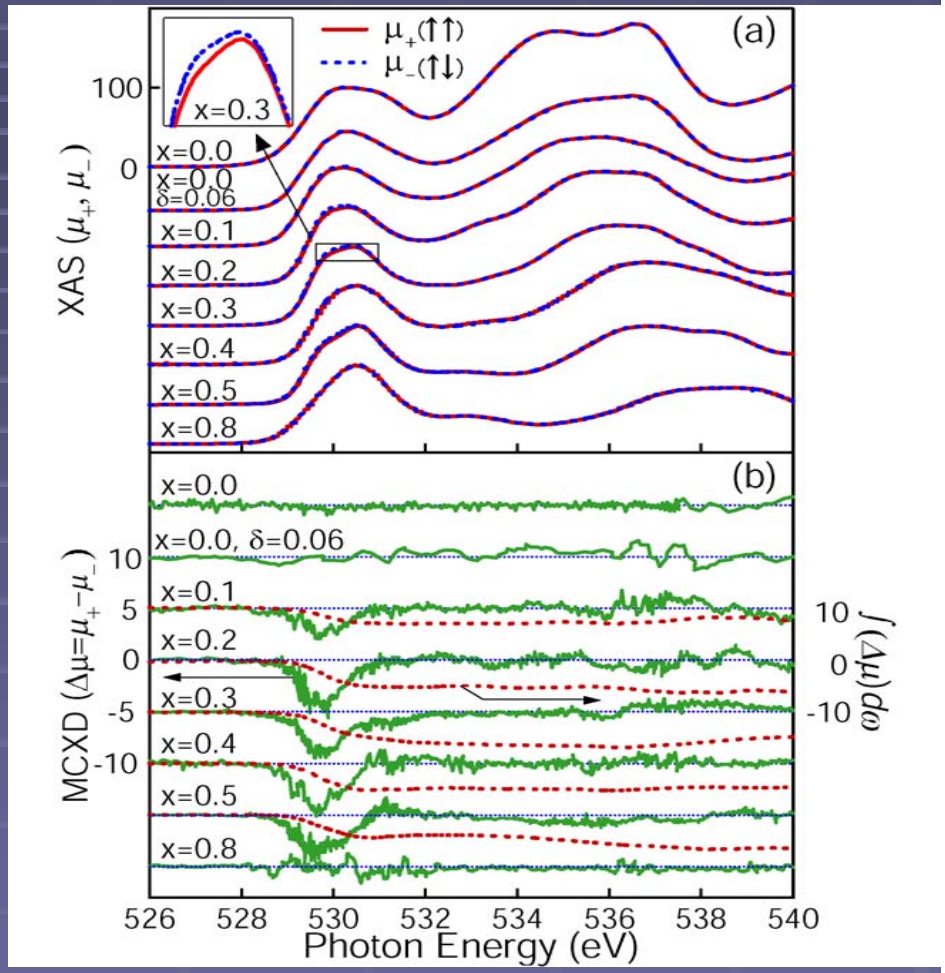
Undulator II will be installed in 2010

Detection of Small XMCD Signals

T. Koide *et al*., Phys. Rev. Lett. 87, 256404 (2001)



Observation of **weak ferromagnetism**

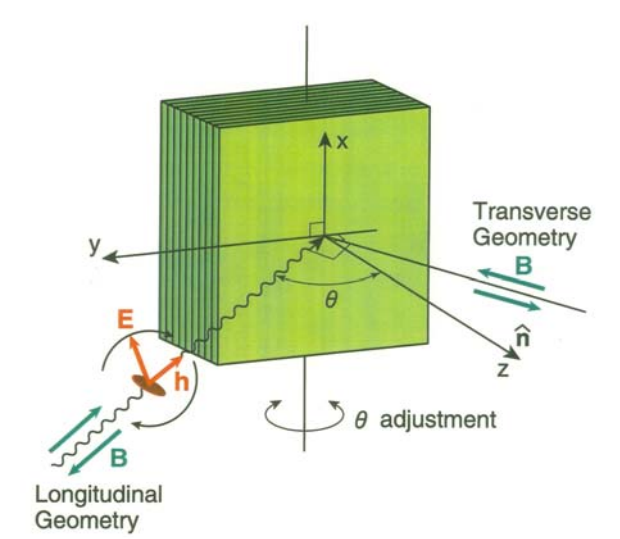


Precise investigation for **phase transition phenomena**

Summary

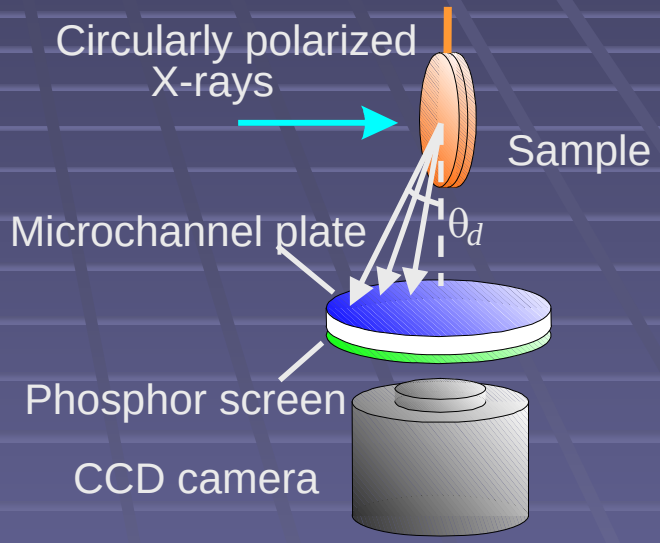
Angle-dependent L/T geometry XMCD

Determination of m_s, m_l and m_T including their **anisotropy**



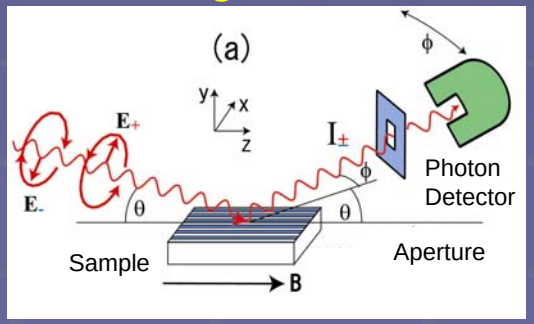
Depth-resolved XAFS/XMCD

Atomic, electronic and magnetic Structures at **surface and interface**

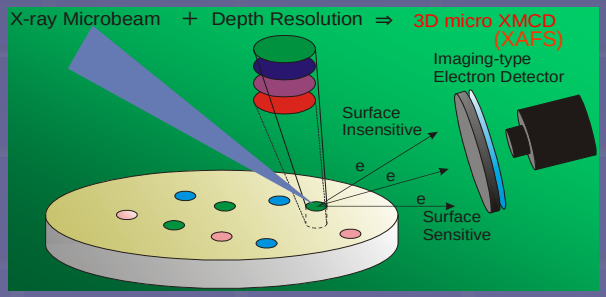


Future plans

Resonant Magnetic Scattering



Three-dimensional XAFS/XMCD



Fast polarization switching