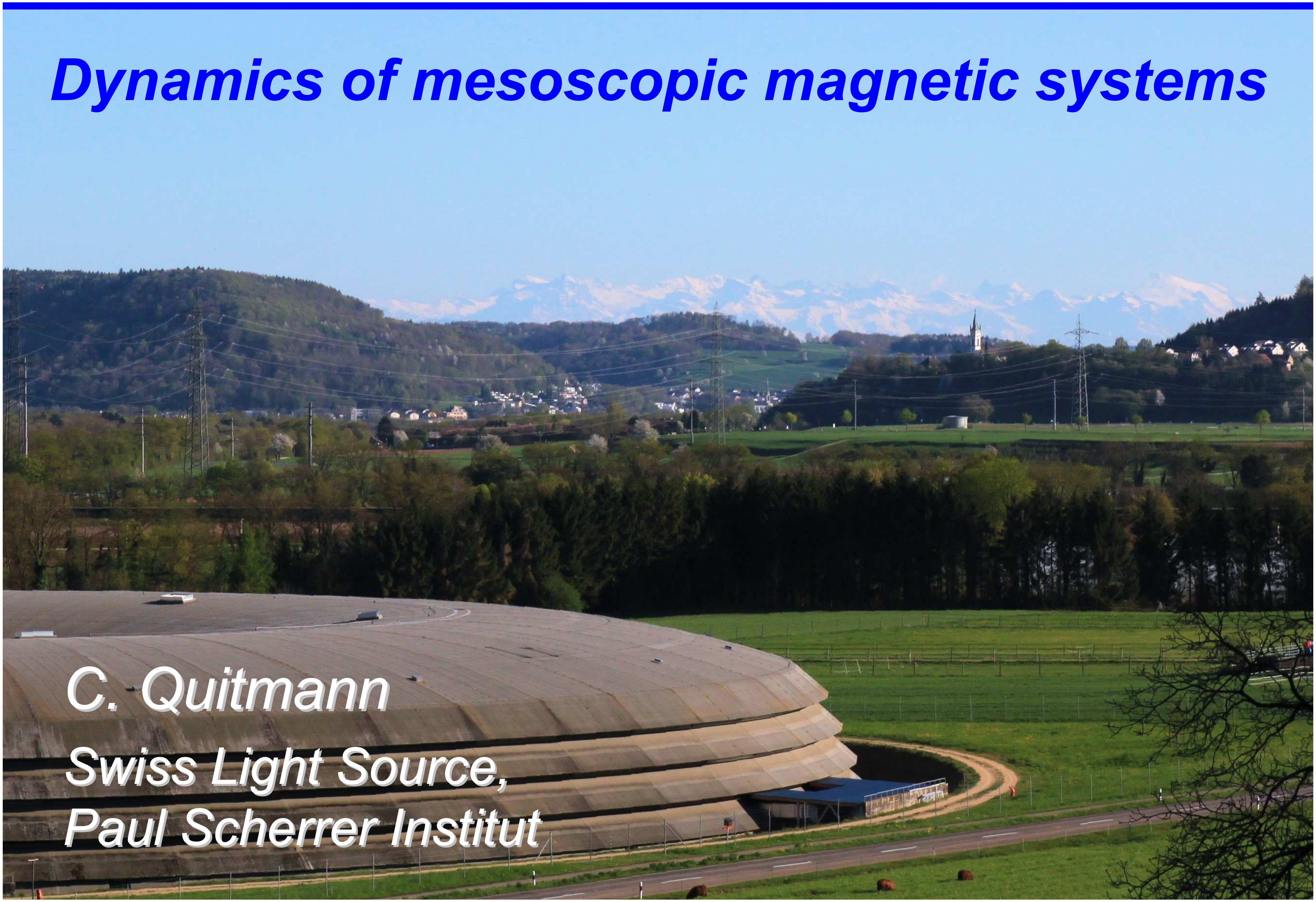
PAUL SCHERRER INSTITUT

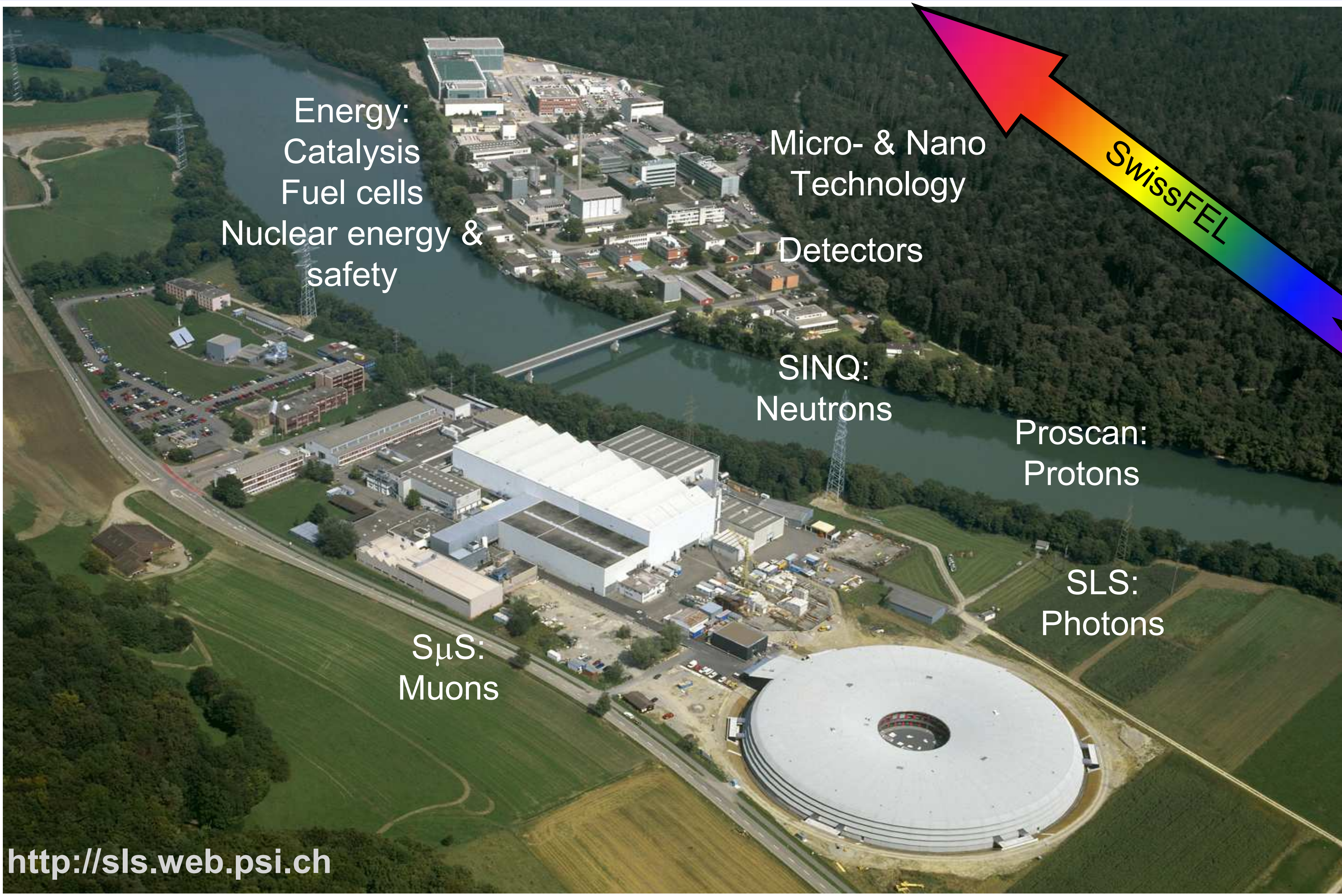
Dynamics of mesoscopic magnetic systems



C. Quitmann

Swiss Light Source,
Paul Scherrer Institut

Paul Scherrer Institut



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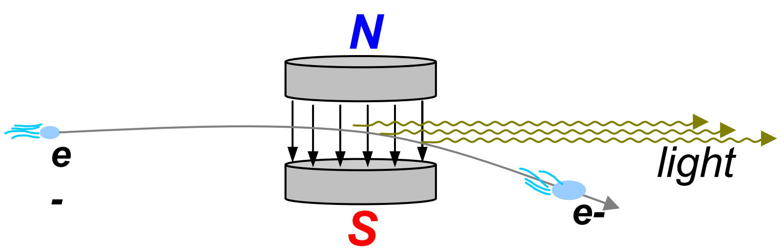
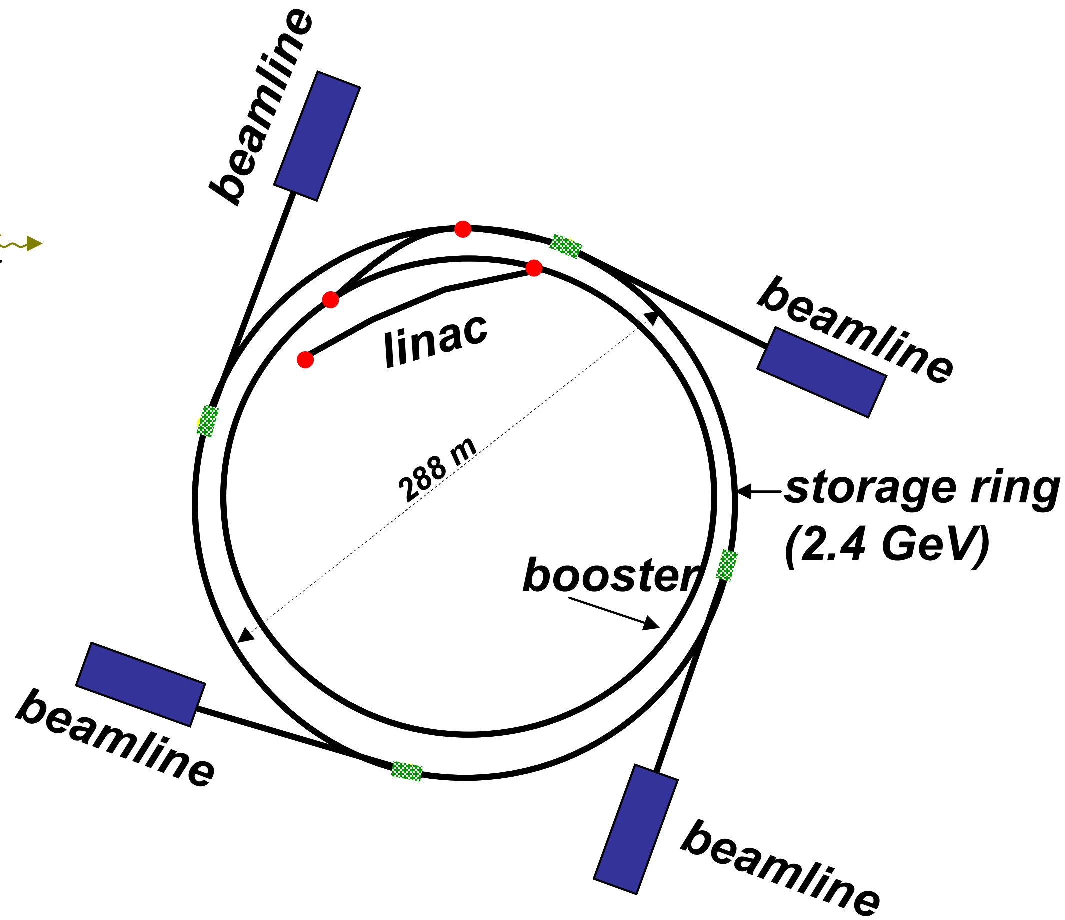
Outline

- Introduction Swiss Light Source
- Scanning Transmission X-Ray Microscopy (STXM)
- Magnetization Dynamics
  – Mesoscopic magnetic objects & magnetization dynamics
  – Topology & static behavior
  – Modified coupling
  – Dynamics in trilayer squares
- Possible collaboration SOLARIS – PSI?

What is a synchrotron?





- Electro-magnetic radiation
  - E ~1meV – 10^1 keV
  - Polarization
  - Brightness

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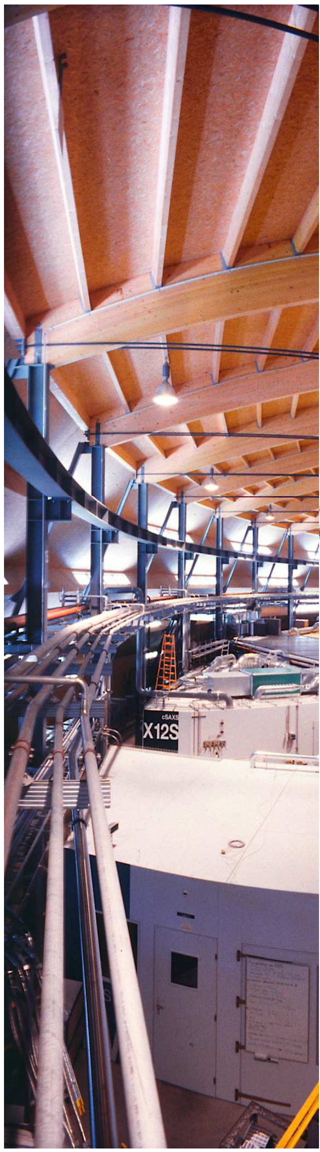
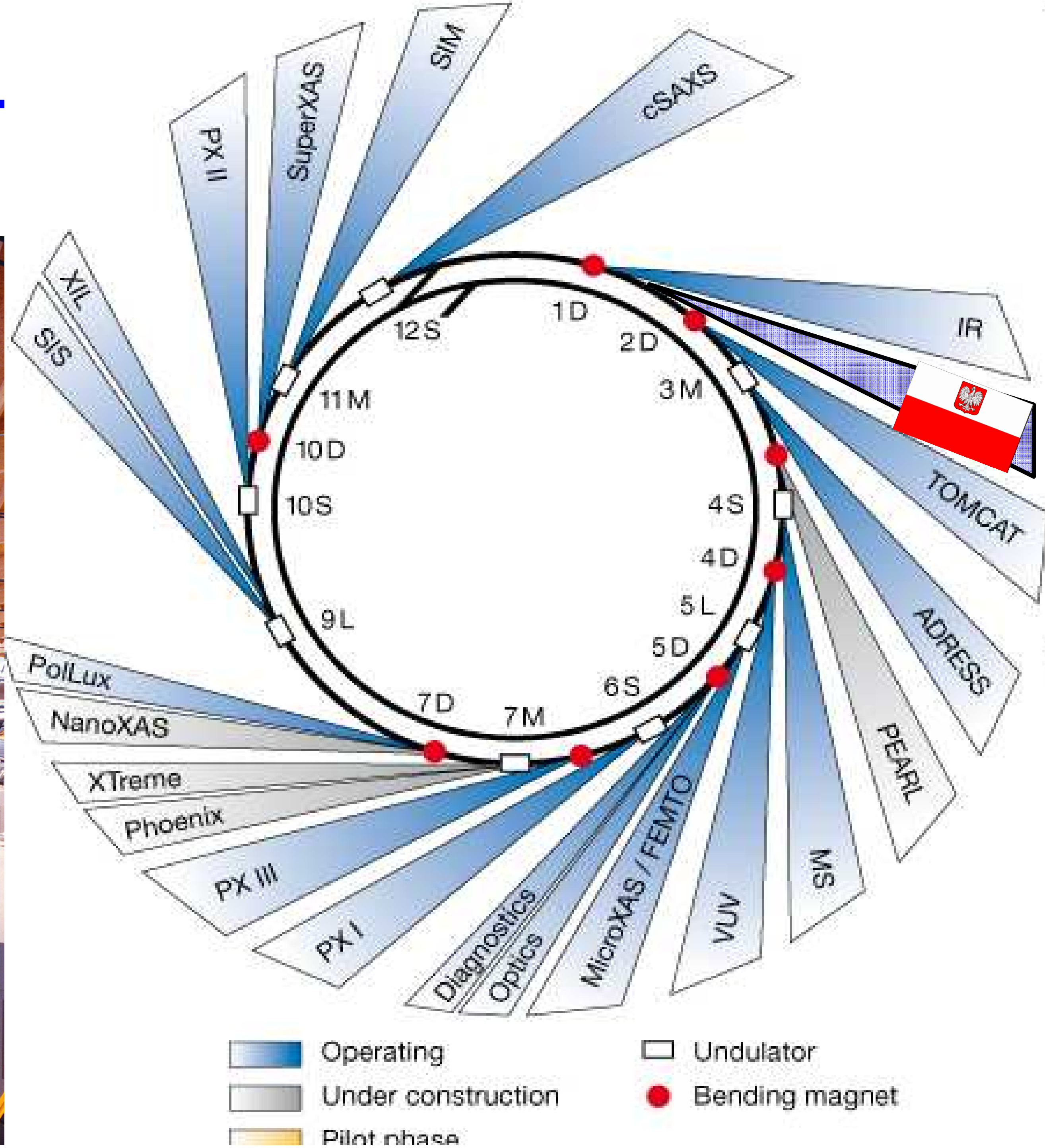
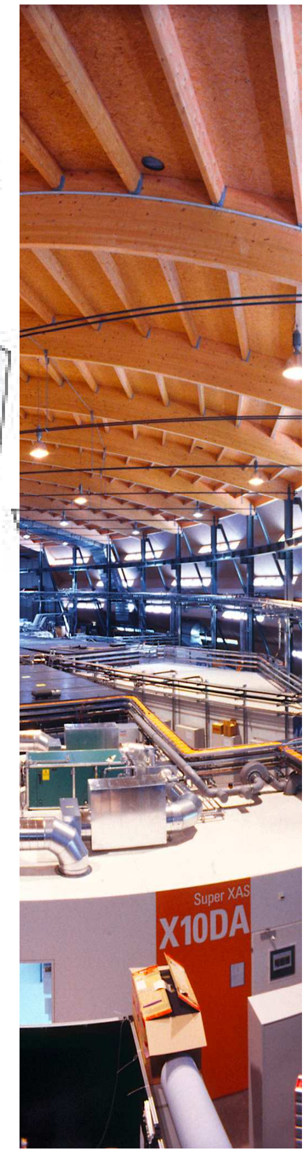
PSI

S







SLS machine – A few facts

- E = 2.4 GeV
- Circumfrence = 288 m
- TBA lattice
  - 12 * 3 dipoles (1.4 Tesla, E_c = 5.5keV)
  - 12 straights (3×11.5 m, 3×7 m, 6×4 m)
  - 1 injection + 1.5 RF
- 3 “Super” bends: H = 3 Tesla (E< 35 keV)
- Emittance
  - H= 5.5 nm rad
  - V = 3 pm rad
- Fast feedback < 200Hz (73 steering magnets)
  - Stability < σ/10

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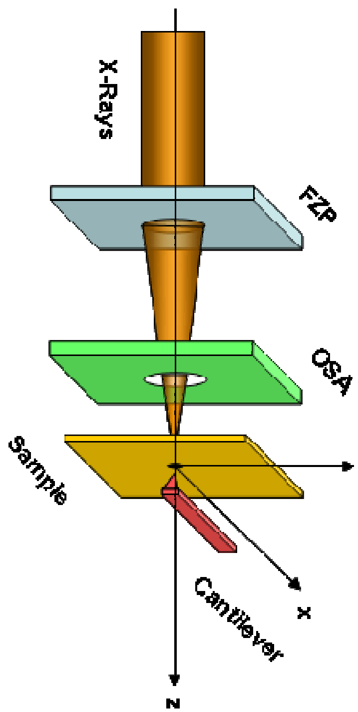
X-Ray Microscopes



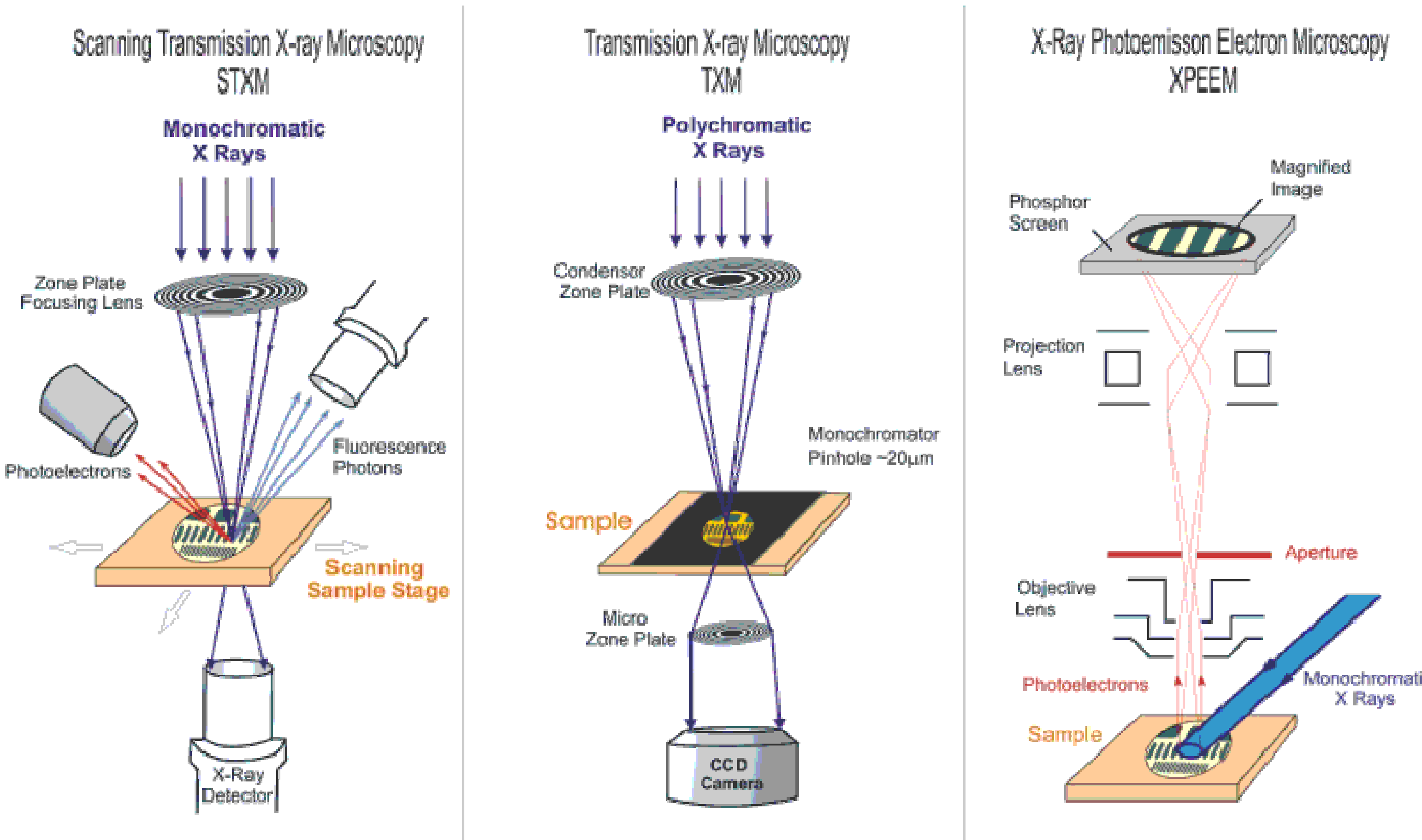


Fig. 1: Three different types of x-ray Microscopes

http://www-ssrl.slac.stanford.edu/dichroism/XDSM/Mic1_large.gif

I. Schmid, Ultramicroscopy 110 (2010) 1267–1272

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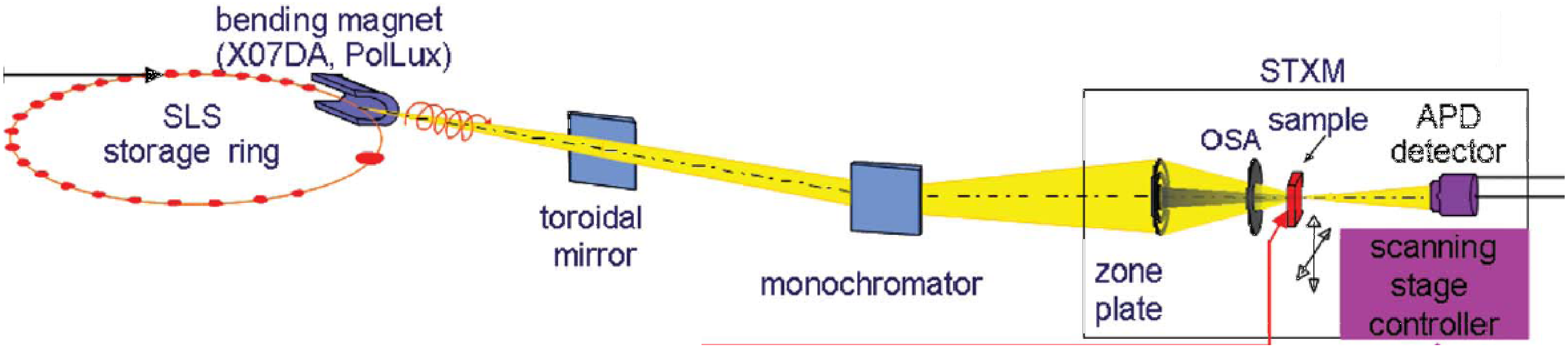
STXM Beamline & Endstation



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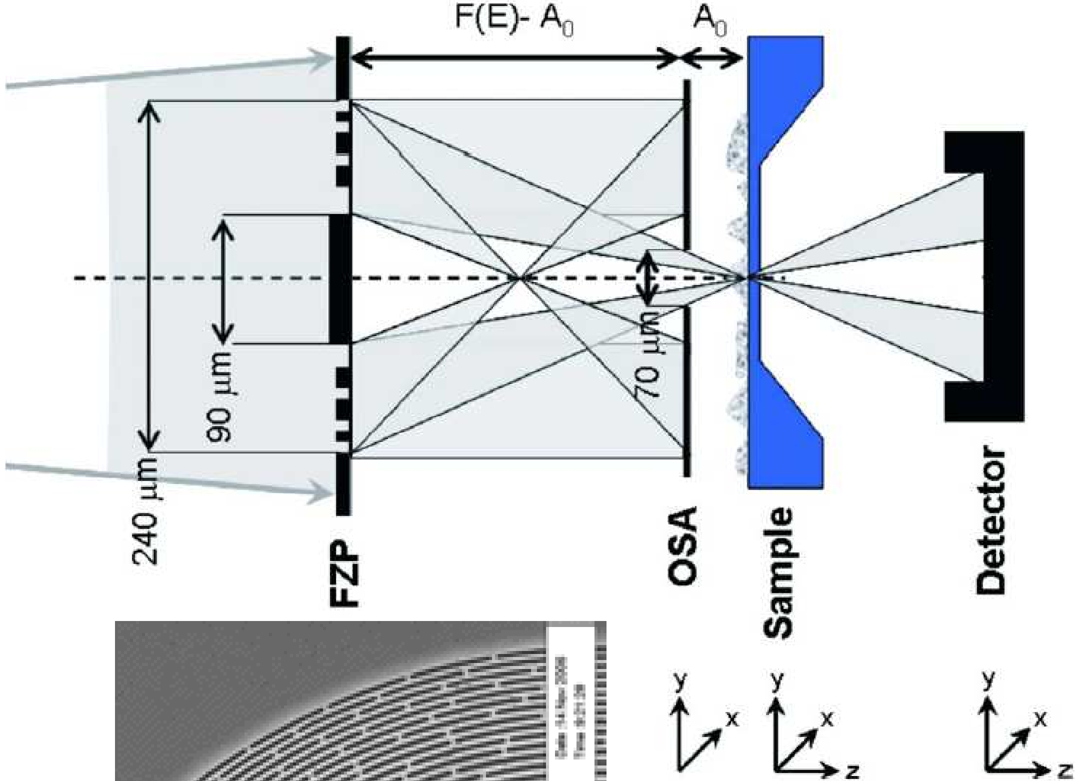
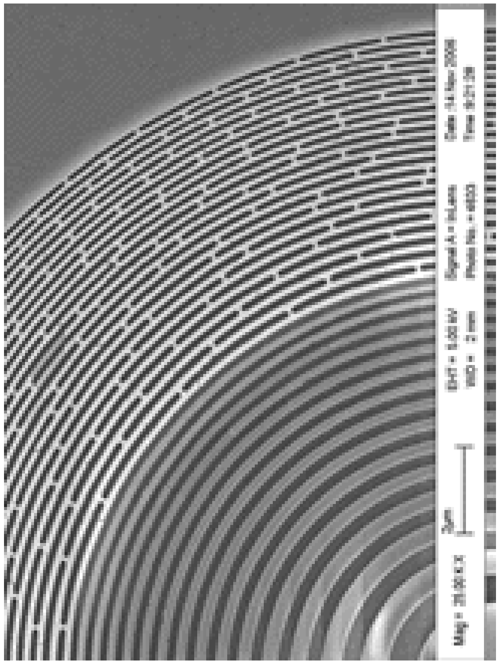
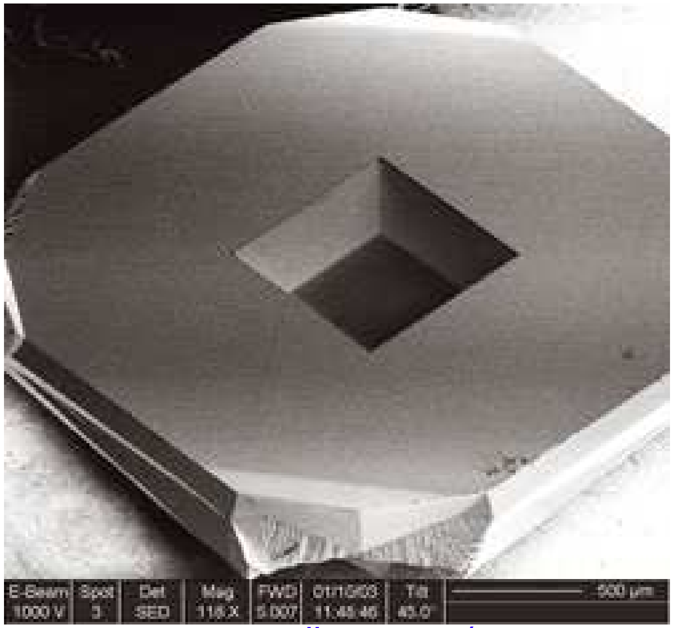
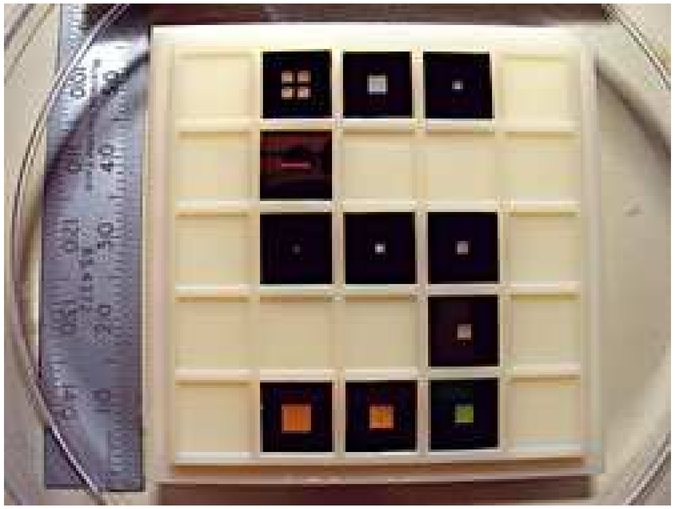
Scanning Transmission X-Ray Microscope







www.silson.com/



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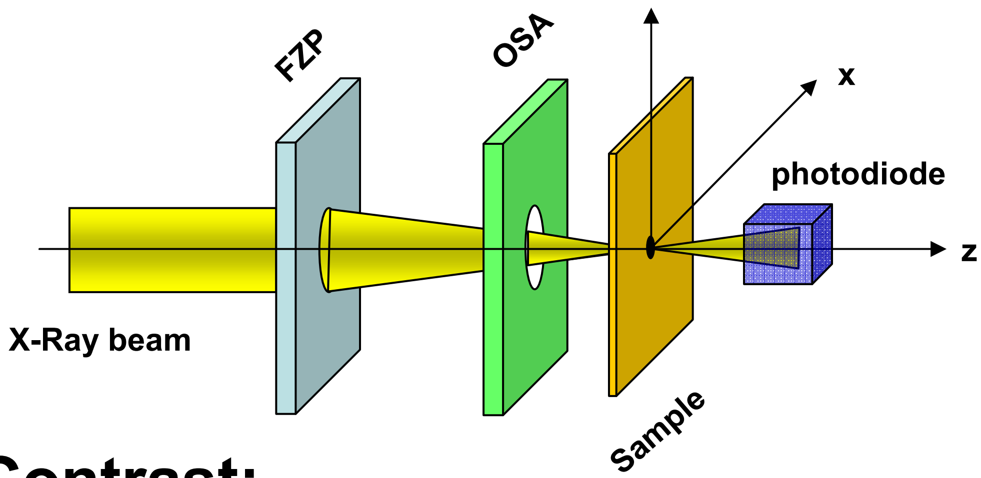
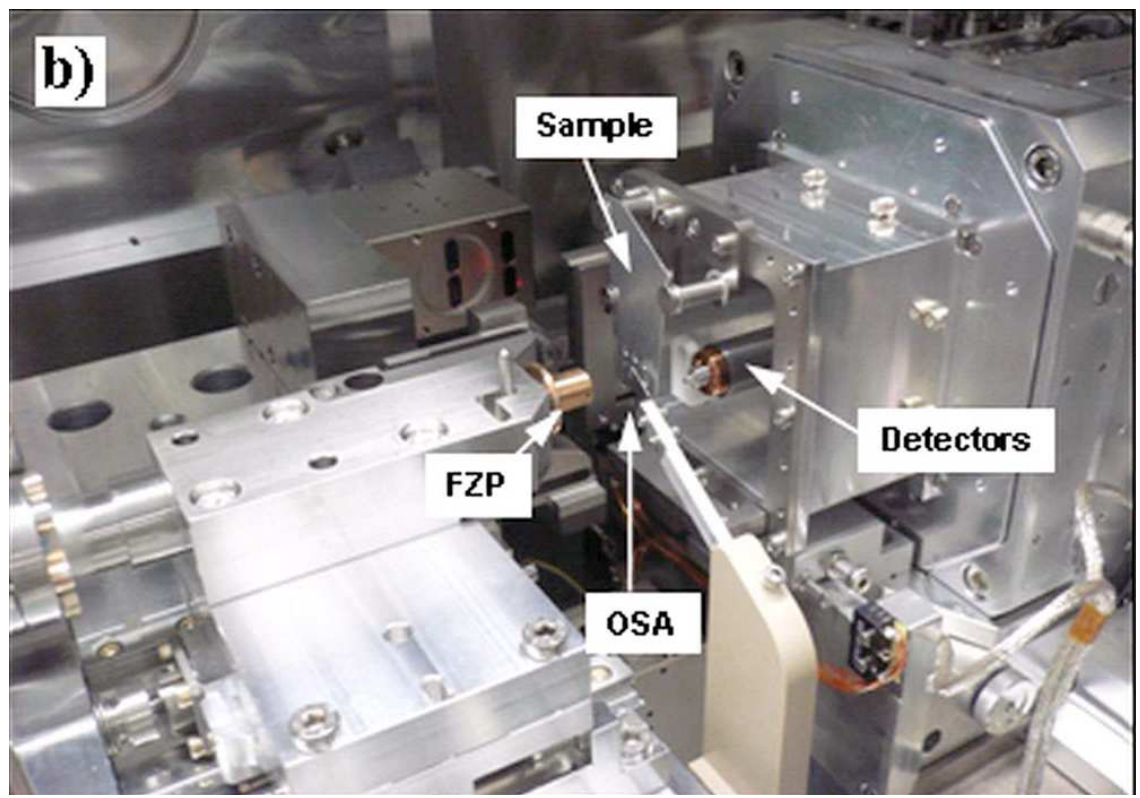
Scanning Transmission X-Ray Microscopy



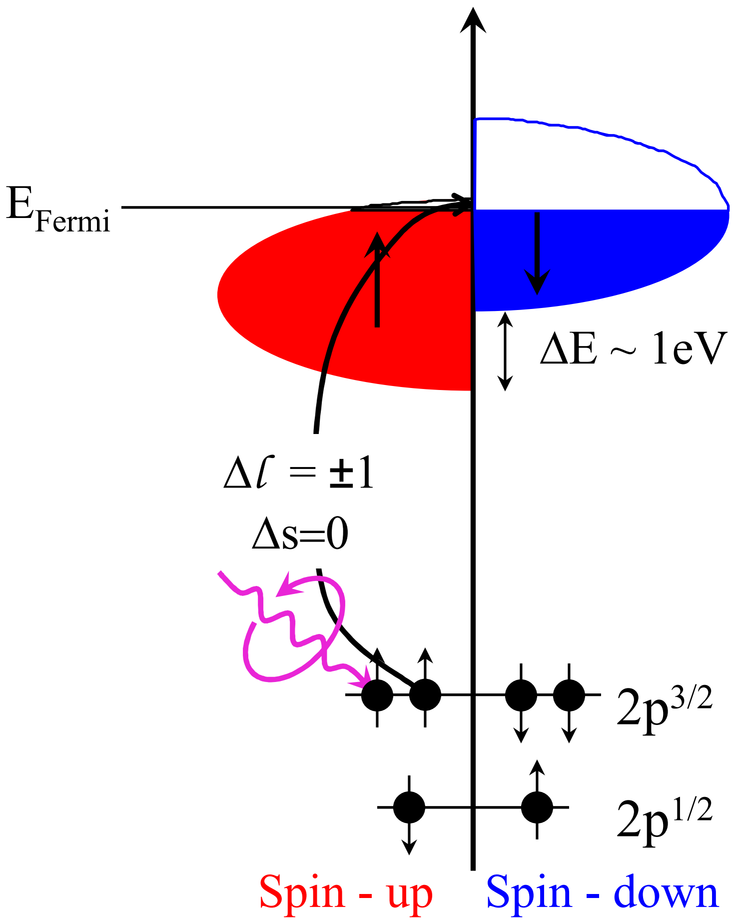
Contrast:

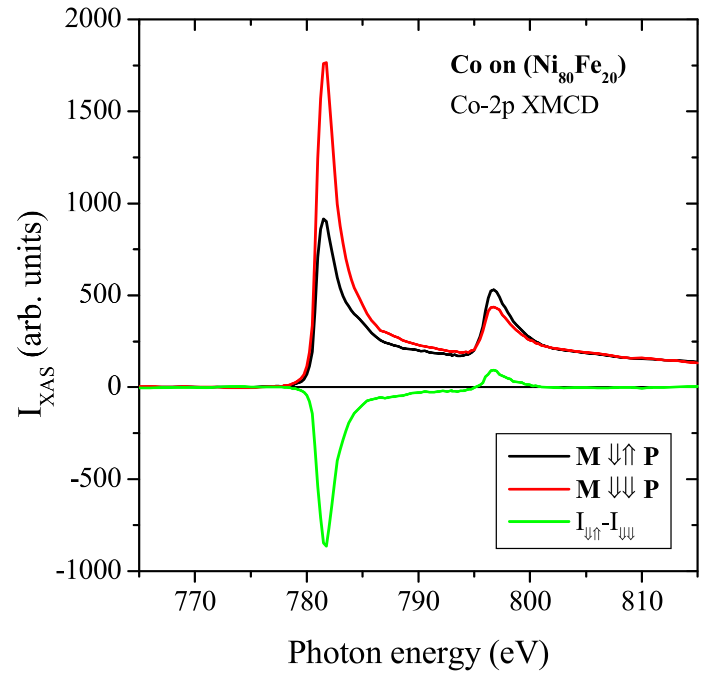
$I_{Trans} = I_0 \exp[-\mu(Z,h\nu)t]$

- Thickness
- Chemical
  - Element (Z)
  - Bonding
- Orientation
- Magnetic
- …



Magnetic absorption spectroscopy: XMCD





$$I_{+,-}(E_{Photon},\sigma) \sim \left| \left\langle f_{3d} \left| \vec{E}_x \cdot \vec{r} \pm i\vec{E}_y \cdot \vec{r} \right| i_{2p} \right\rangle \right|^2 * \rho_f(E_{Fermi},\sigma)$$

Theory: J.L.Erskine et E.A.Stern, Phys.Rev.B 12, 5016 (1975)
Fe K-edge: G.Schütz, W.Wagner, W.Wilhelm, P.Kienle, R.Zeller, R.Frahm, G.Materlik, Phys.Rev.Lett. 58, 737 (1987)
Ni L-edge: C.T.Chen, F.Sette, Y.Ma, et S.Modesti, Phys.Rev.B **42**, 7262 (1990)

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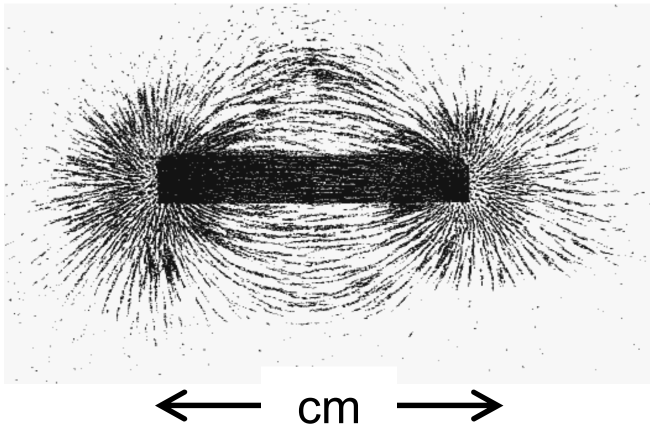
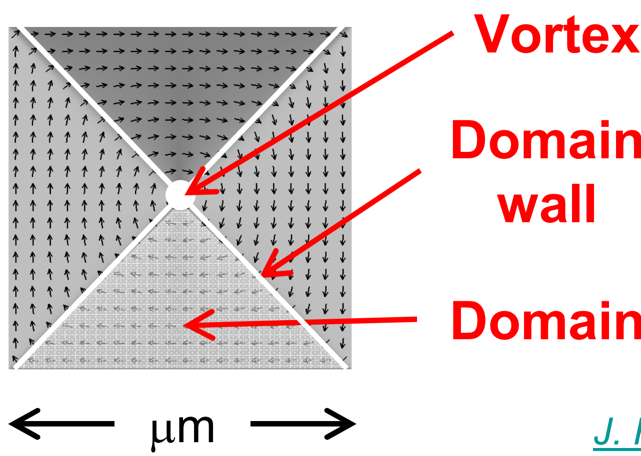
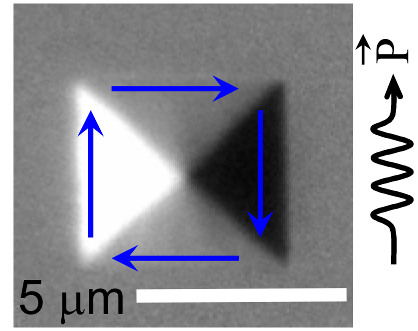
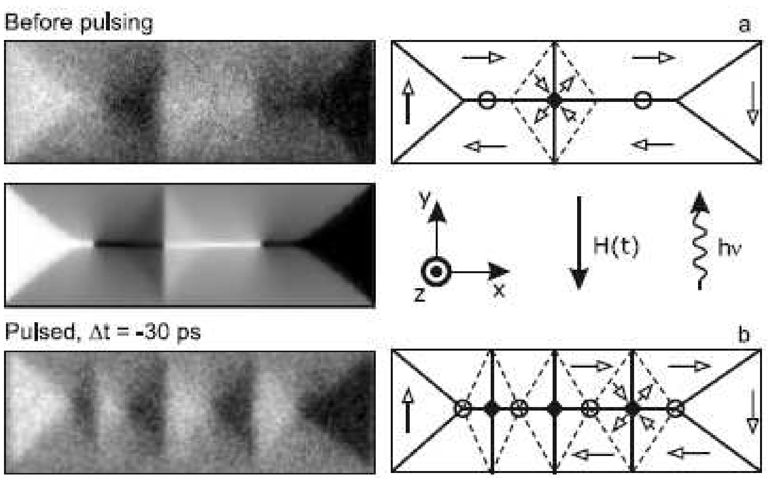
Mesoscopic magnetism



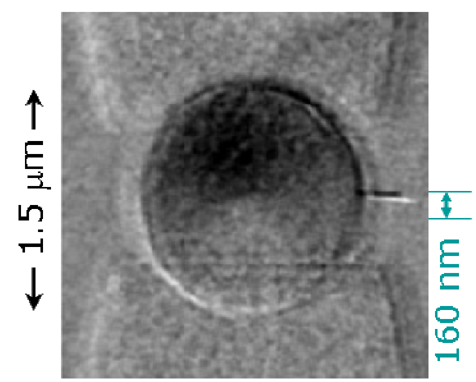




J. Raabe, PRL 94, 217204 (2005)

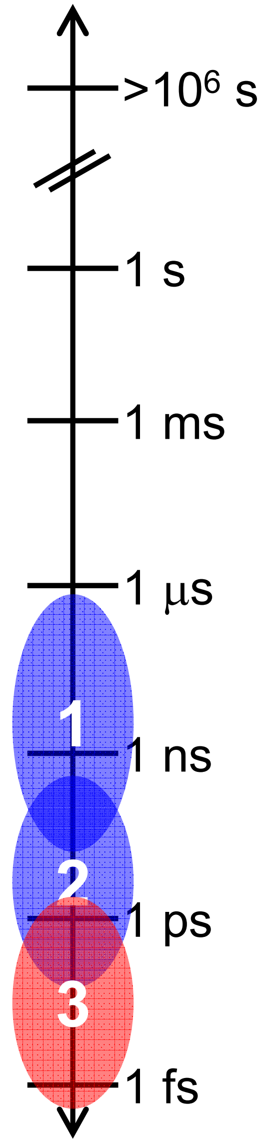


J. Miguel, W. Kuch et al.,
J. Phys.: Cond. Matter (2009)



S. Kasai et al.,
Phys. Rev. Lett. (2008)

Relevant time scales



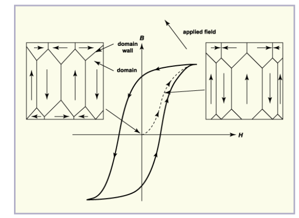
Long term stability

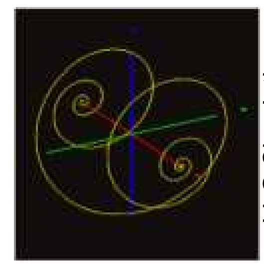
Thermal activation:
domain nucleation &
growth, viscous regime

Precession (γ = 17.6 Mhz/Oe):
precessional switching

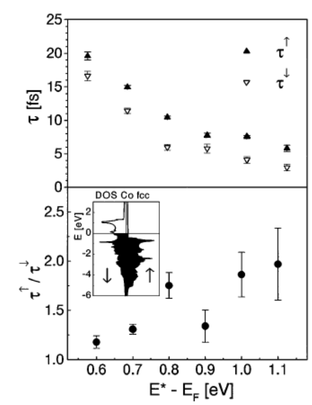
Ultra-fast demagnetization:
Spin-spin & spin-lattice interaction

Atomic physics





LLG Simulation
M. Scheinfein



M. Aeschlimann,
PRL 79, 5158 (1997)

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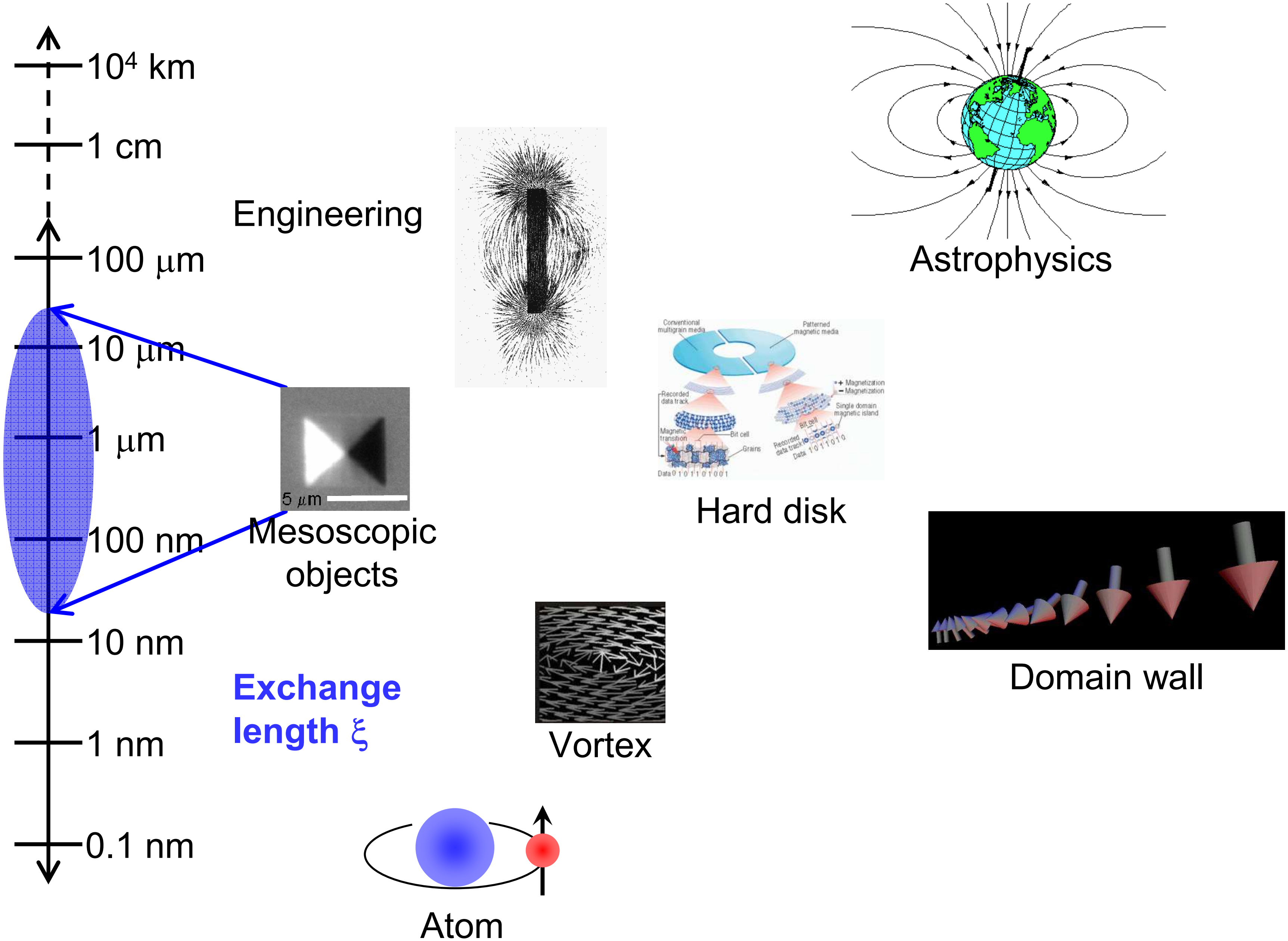
Magnetic length scales



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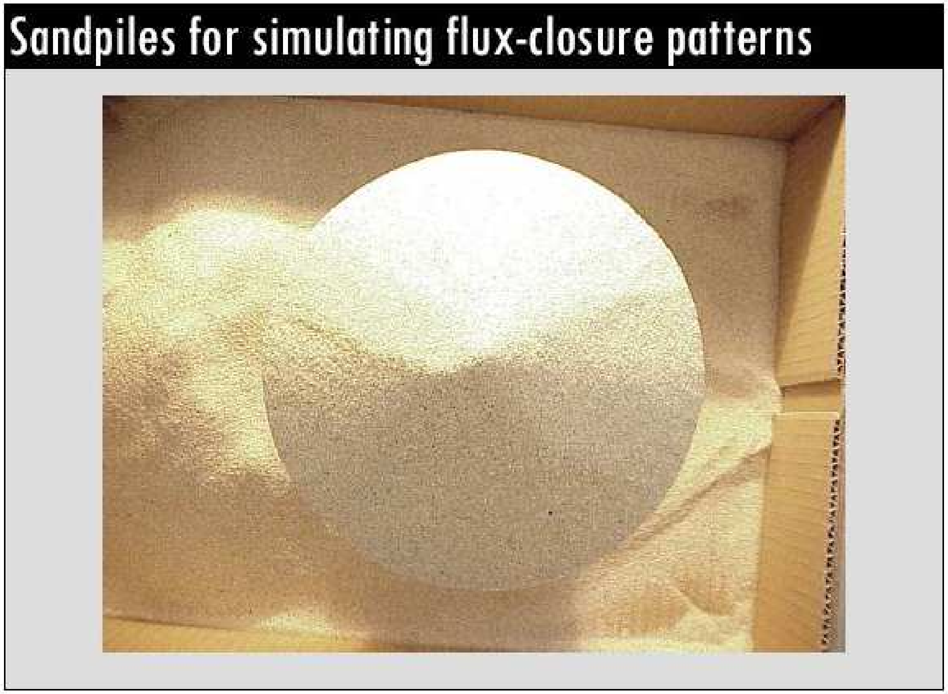
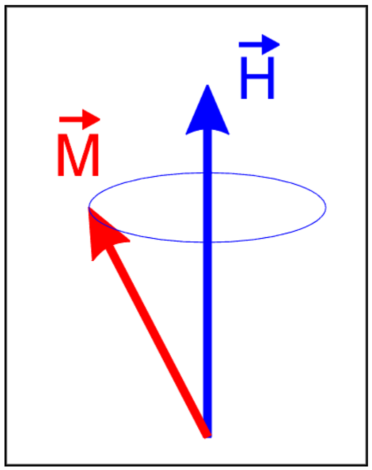
Simulating domain patterns ;-)



Phenomenological Model

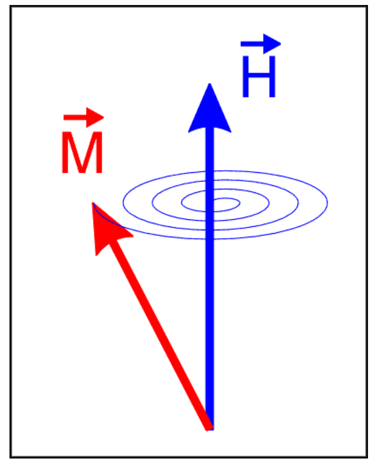
$$\frac{d}{dt}\vec{M} = -\gamma_0 \vec{M} \times \vec{H}_{\text{eff}} + \frac{\alpha}{M}\left(\vec{M} \times \frac{d}{dt}\vec{M}\right)$$



Precession

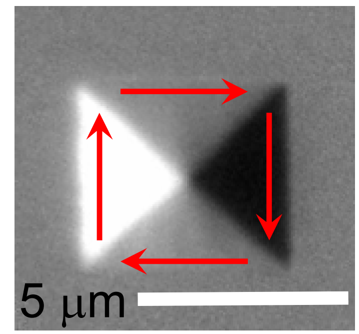
$$\omega_0 = \gamma \cdot H_{eff} = \gamma \cdot \frac{\partial E_{tot}}{\partial \vec{M}}$$

$$\gamma = 17.6 \tfrac{MHz}{Oe}$$



Damping

$$\alpha \approx 0.01 - 1$$



<u>Numerical simulations:</u>

- LLG (M. Scheinfein)
- OOMMF (NIST)
- …

L. D. Landau and E. M. Lifshitz, Phys. Z. Sowjetunion **8**, 153 (1935).

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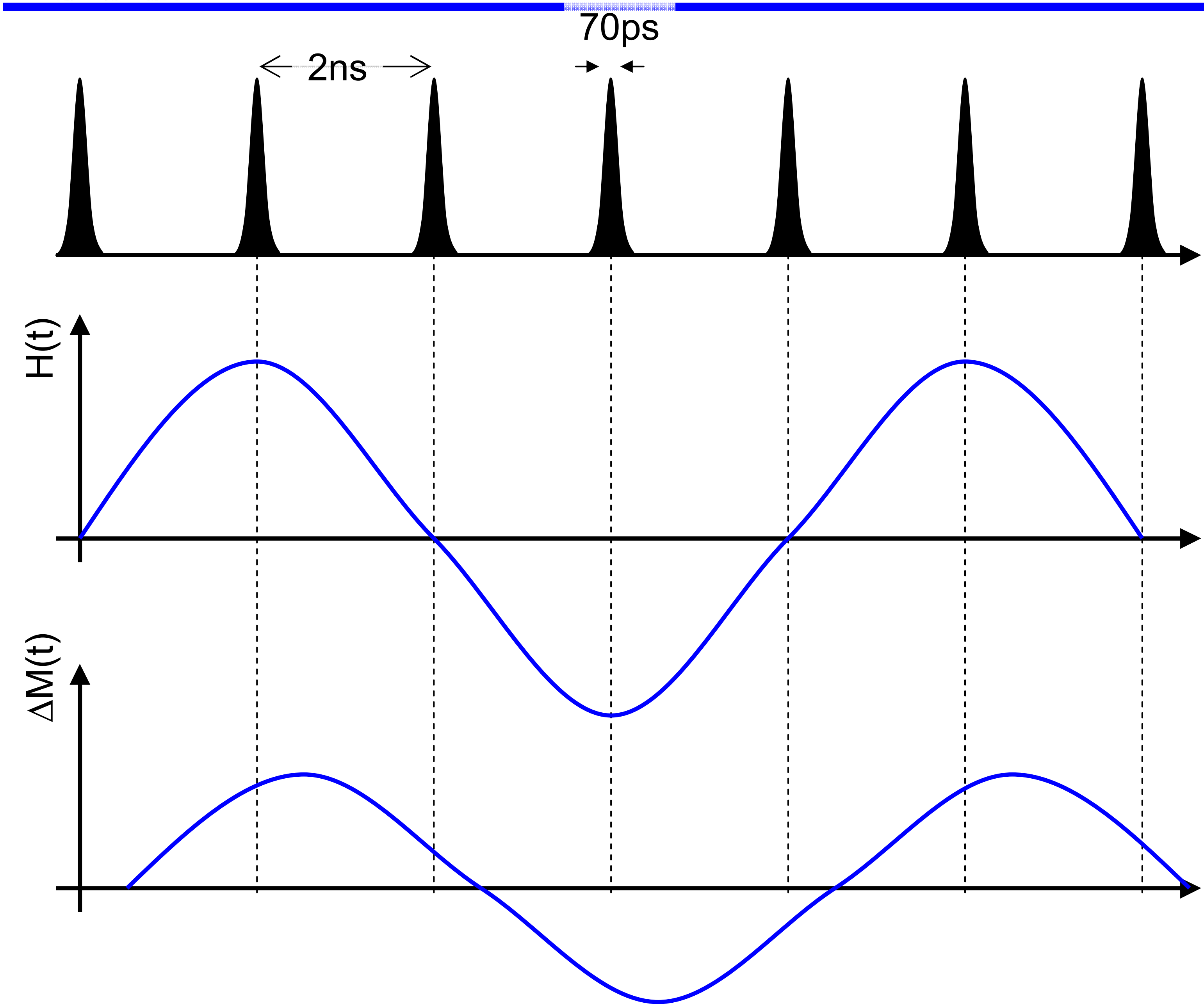
Resonant Pump - Probe



Probe:
500MHz

Pump:
500MHz / n

n = 4:
125 MHz

Measure:
$\Delta M_0(\nu)$,
$\Delta\phi(\nu)$

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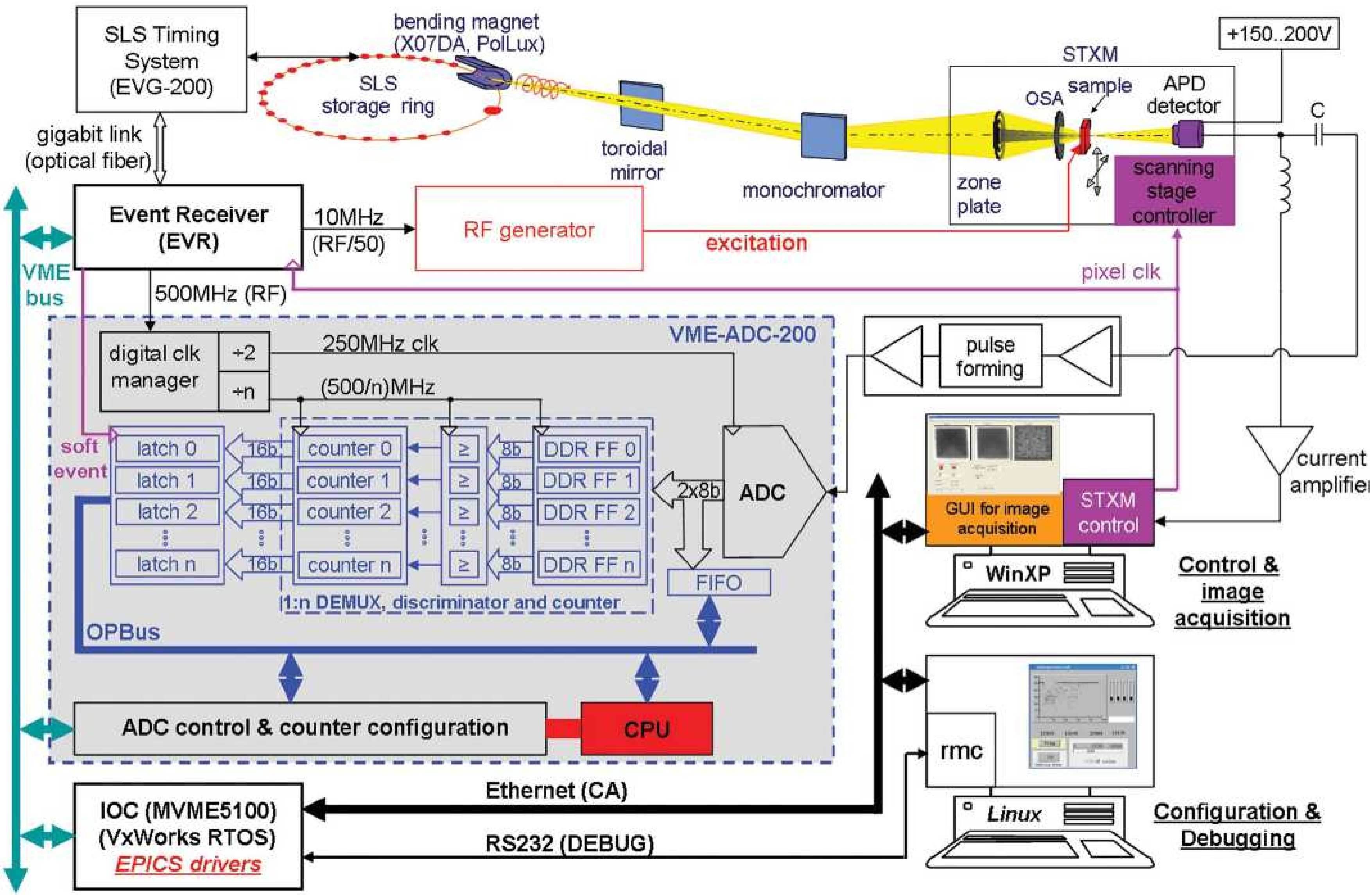
STXM for magnetization dynamics



A. Puzic et al.: Vol. 23, No. 2, 2010, SYNCHROTRON RADIATION NEWS
PSI, FZR-Dresden, MPI-Stuttgart

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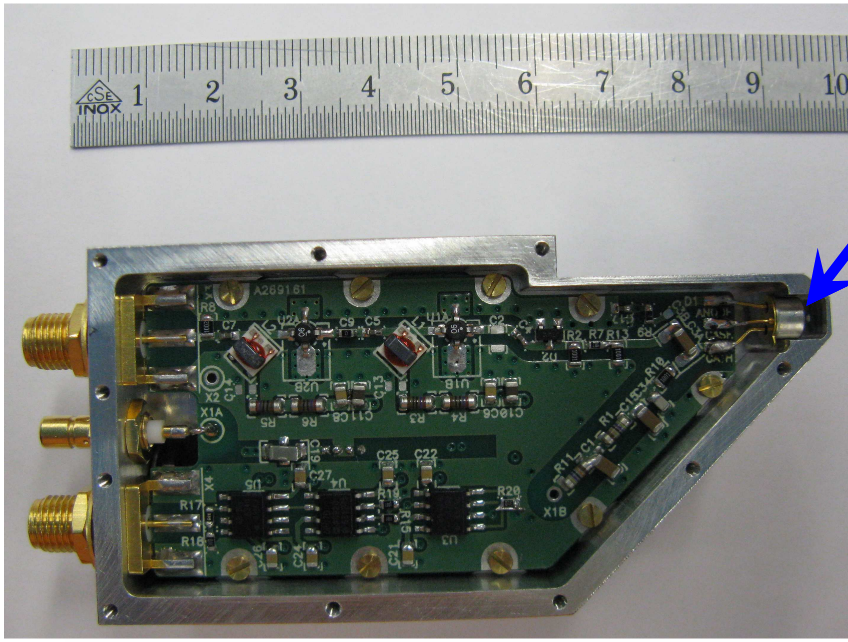
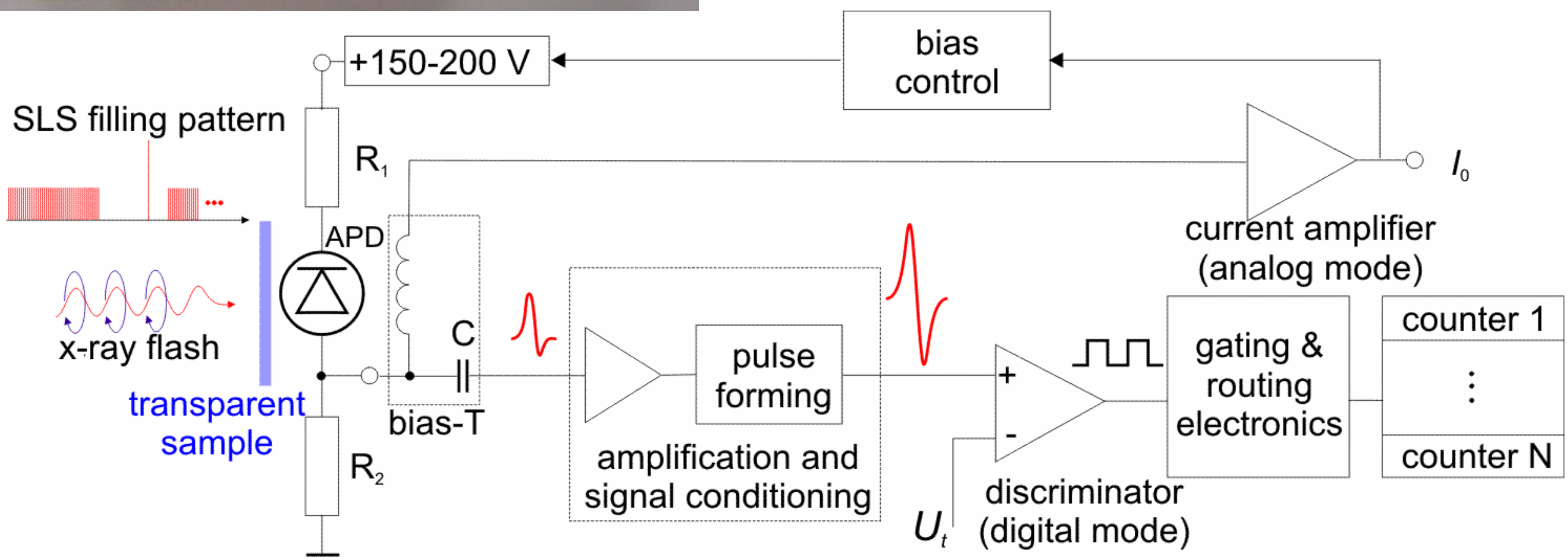
Detector: single photon counting



APD

- Single photon sensitivity: shot noise limited
- Rise time ~10^2 ps: pump-probe experiments



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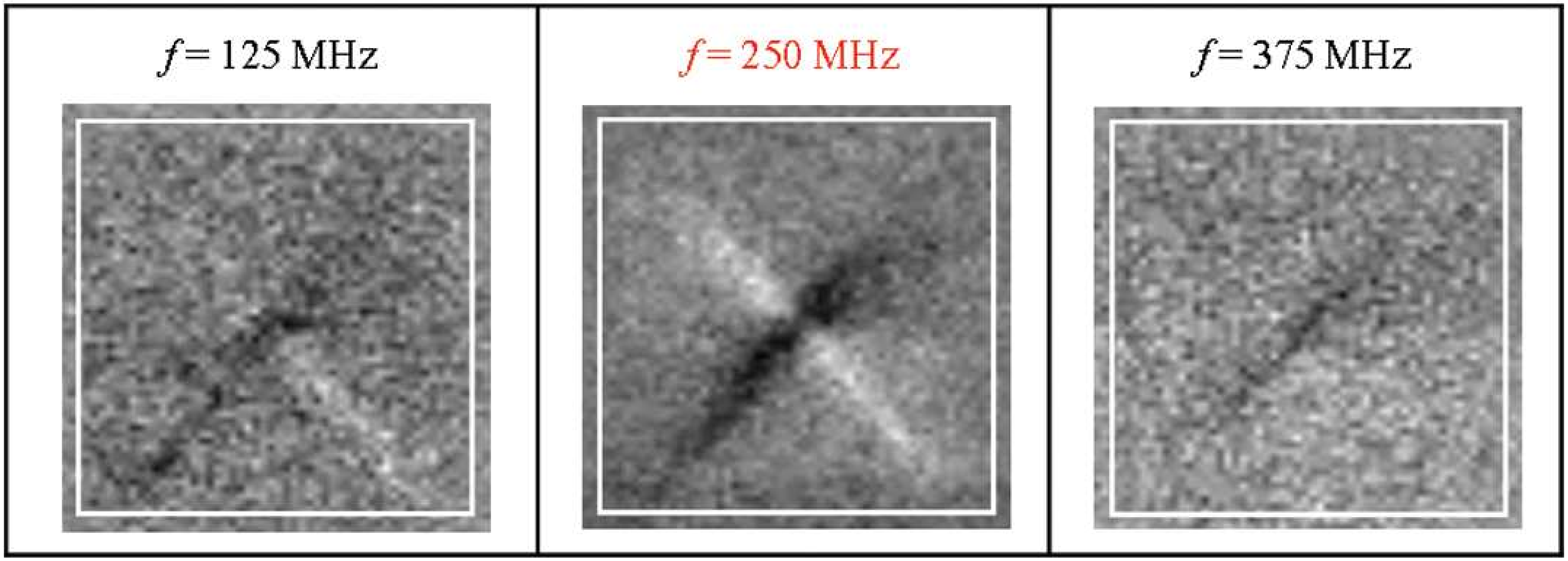
Frequency dependance



- Square: Co, 2 x 2 μm, t= 50 nm
- Vary excitation frequency: 125 / 250 / 375 MHz
- frequency resolution: Δ*f* = 500 MHz/*n*
  n = number of counters (typ.: 4, 8)

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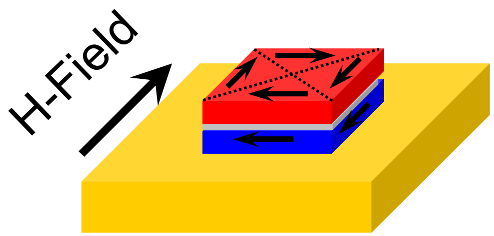
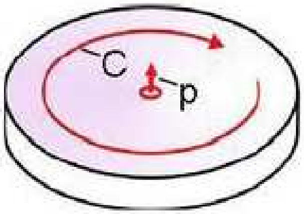
Why magnetic bi-layers

- More complex
  - static
  - dynamics



- Tune coupling
  - Interlayer spacing (IEC – dipolar)
  - Ion beam irradiation
  - Demagnetization
- Goals
  - Understand dynamics
  - Controlled switching
    `Config1` ⇒ **`Config2`** ??

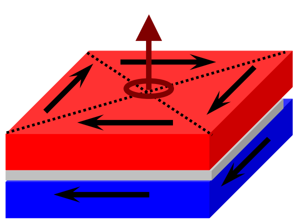
Bi-layer vortex topology

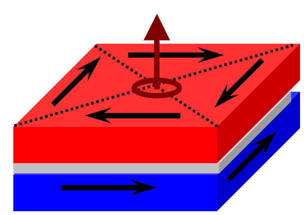


C	in-plane circulation	counterclockwise, clockwise (+1,-1)
p	core polarity	up, down (+1,-1)
$H = C \cdot p$	vortex handedness	right handed, left handed (+1,-1)

FM state					
		$H_{Co} = +1$		$H_{Co} = -1$	
Co	**C**	**+1**	**-1**	**+1**	**-1**
	p	+1	-1	-1	+1
NiFe	**C**	**+1**	**-1**	**+1**	**-1**
	p	±1	±1	±1	±1
		$H_{NiFe} = \pm 1$		$H_{NiFe} = \pm 1$	

AFM state					
		$H_{Co} = +1$		$H_{Co} = -1$	
Co	**C**	**+1**	**-1**	**+1**	**-1**
	p	+1	-1	-1	+1
NiFe	**C**	**-1**	**+1**	**-1**	**+1**
	p	±1	±1	±1	±1
		$H_{NiFe} = \pm 1$		$H_{NiFe} = \pm 1$	





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The PolLux Beamline

An example of what is possible at SLS

Collaboration: *PSI & Solaris?*

Raabe et al., Rev. Sci. Instrum. 79, 113704 2008

U. Flechsig,
"The PolLux Microspectroscopy Beamline at the Swiss Light Source"
Proc. of Ninth International Conference on Synchrotron Radiation Instrumentation 2006, AIP Conference Proceedings 879, Eds Jae-Young Choi and Seungyu Rah, 505 (2006).

S. Henein
"Mechanical Design of a Spherical Grating Monochromator for the Microspectroscopy Beamline PolLux at the Swiss Light Source"
Proc. of Ninth International Conference on Synchrotron Radiation Instrumentation 2006, AIP Conference Proceedings 879, Eds Jae-Young Choi and Seungyu Rah, 643 (2006).

M. Böge
"Fast polarization switching at the SLS microspectroscopy beamline POLLUX"
Proc. EPAC 2006, Edingburgh, United Kingdom, 3610 (2006).

Optical Layout

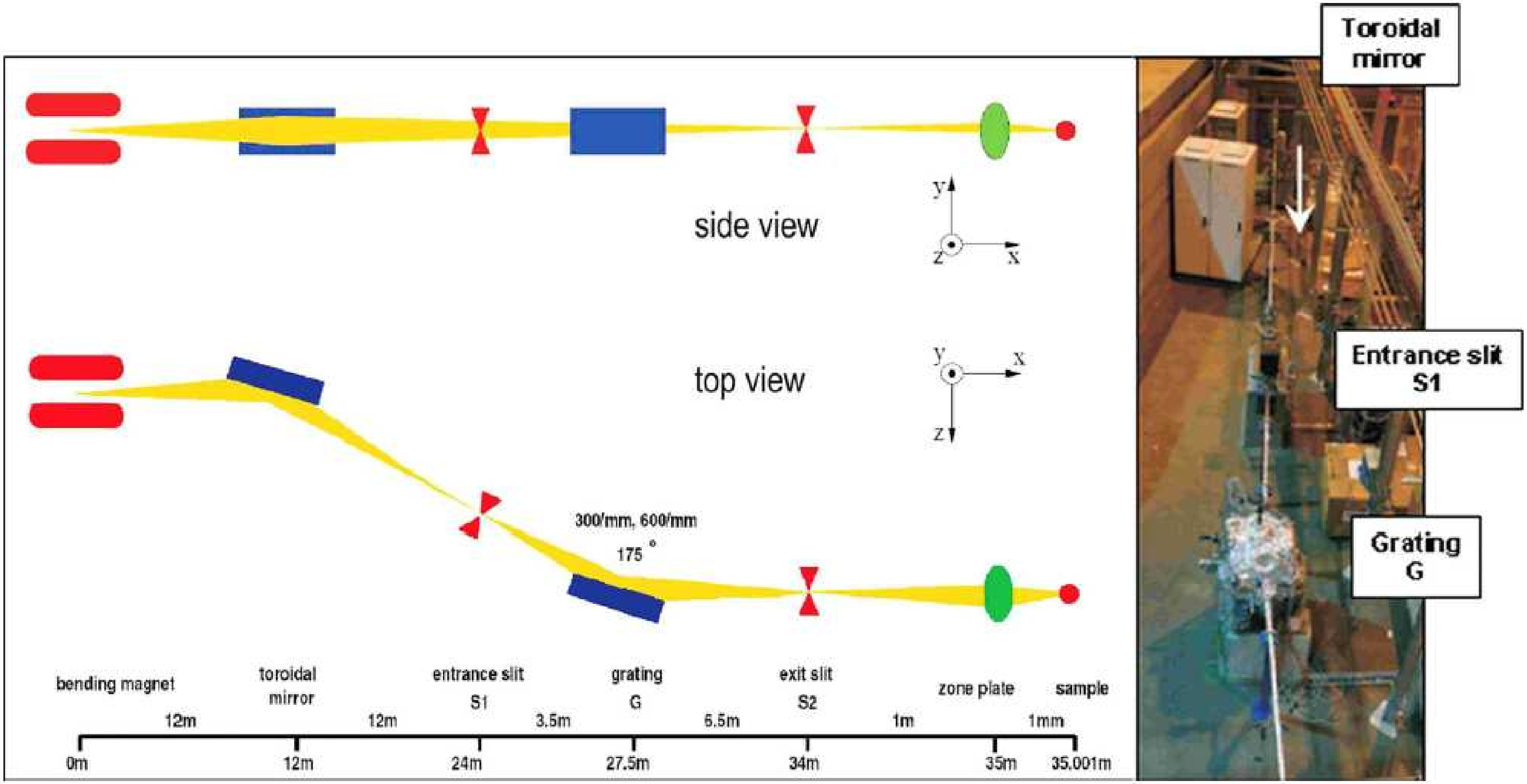

FIG. 1. (Color online) Optical layout of the PolLux beamline (not to scale) showing the bending magnet source followed by the toroidal mirror and the spherical grating monochromator. These create a secondary source at the exit slit (S2) illuminating the FZP which produces the focal spot across which the sample is scanned. The photograph on the right shows several of the beamline components.

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Energy Resolution

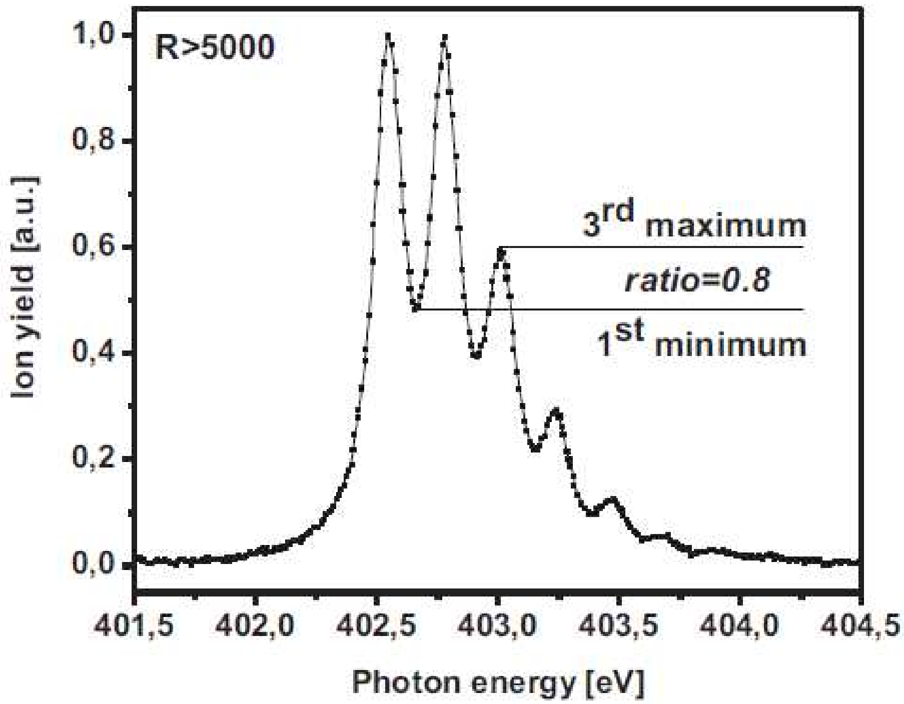


FIG. 2. Measured photoion yield at the nitrogen $1s \rightarrow \pi^*$ transition using the gas cell located between exit slit and FZP of the PolLux beamline (300 lines/mm grating, 10 μm slits). The intensity ratio of the first minimum to the third maximum (0.8) indicates an energy resolution in excess of $E/\Delta E \sim 5000$ (Ref. 23).

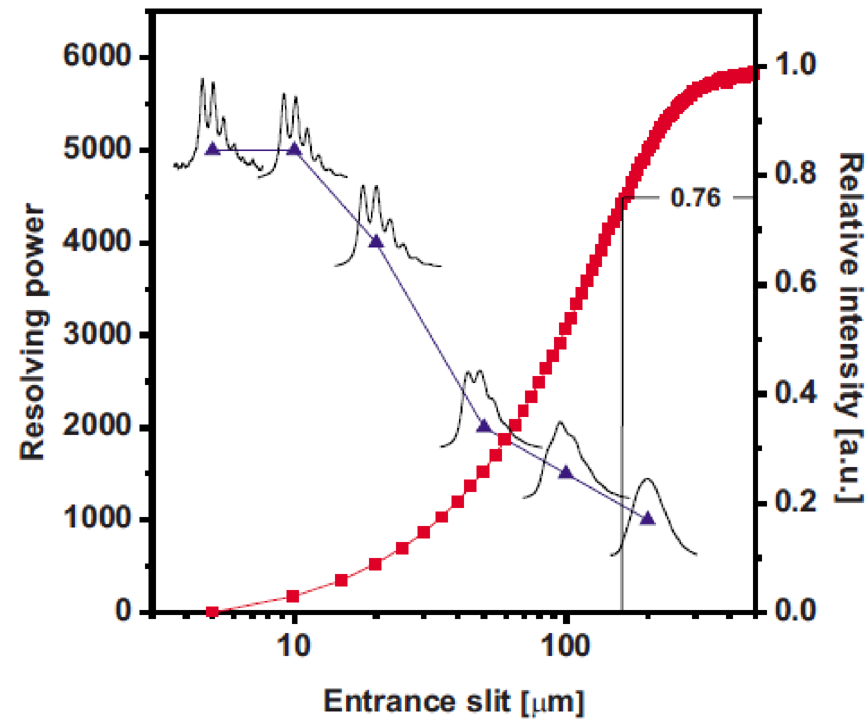
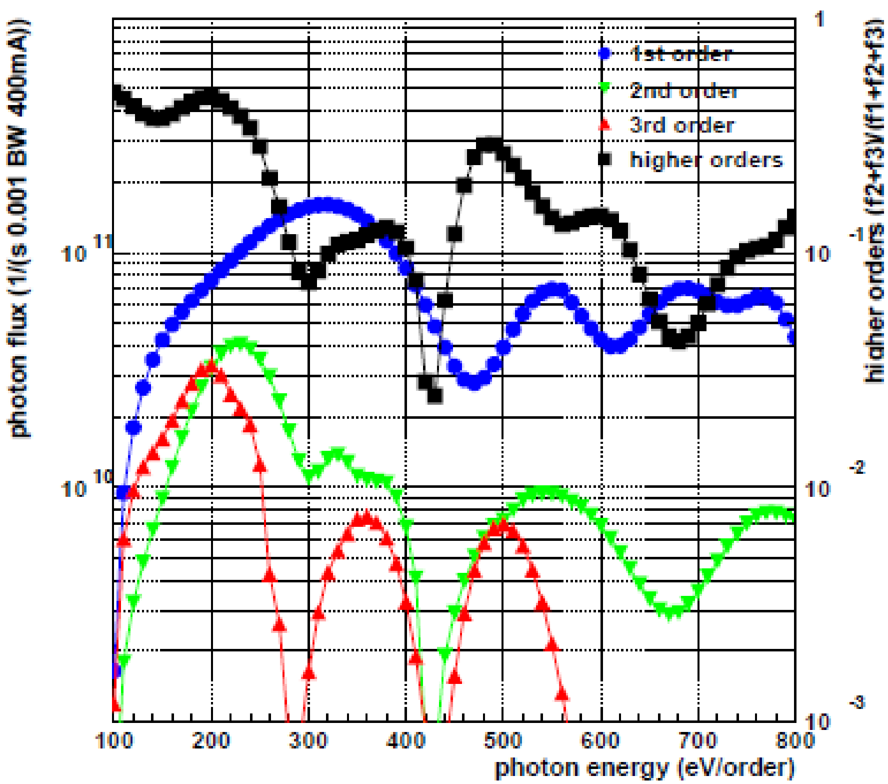


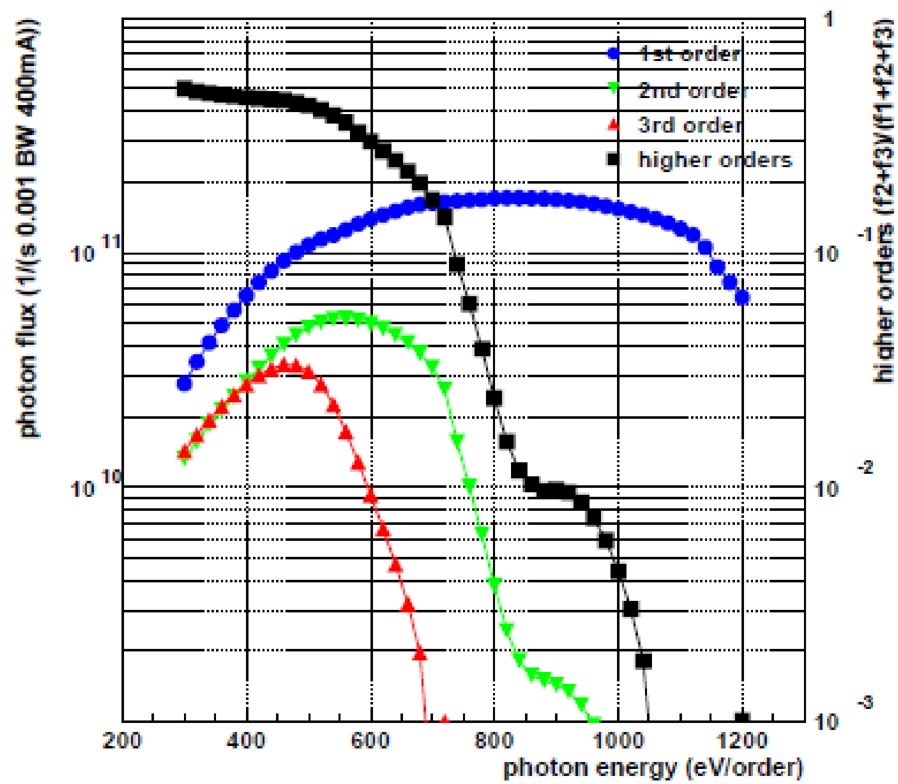
FIG. 3. (Color online) Resolving power (left scale) and relative intensity (right scale) as function of the entrance slit width measured with the 300 lines/mm grating at an exit slit of 50×50 μm^2. The resolving power has been determined from the N_2 spectra shown as insets. The lines indicate the resolving power for equal entrance and exit slits matched to the horizontal focus width at the entrance slit (FWHM=165 μm).

PolLux Flux

300/mm



600/mm



E 3. Predicted relative transmittance in different diffraction orders and higher order content of the beamline. 3
left) and 600/mm grating (right).

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Circular polarization from BM

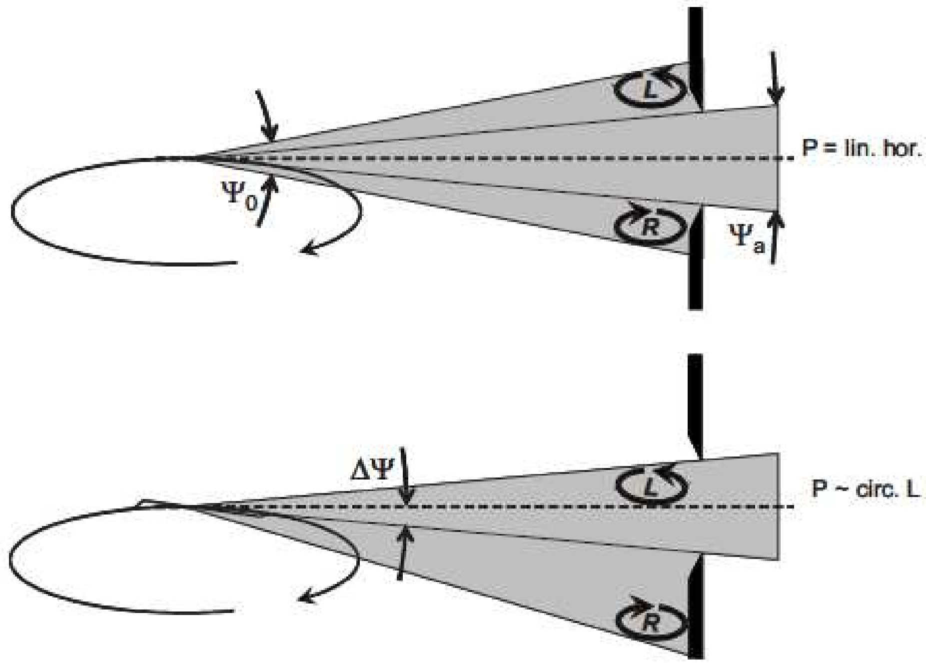

FIG. 6. Scheme showing how circularly polarized light is obtained from a bending magnet by tilting the storage ring orbit relative to the optical axis of the beamline. The beamline acceptance is ψ_A; the tilt angle of the orbit is $\Delta\psi$ ($\leq \pm 300$ μrad).

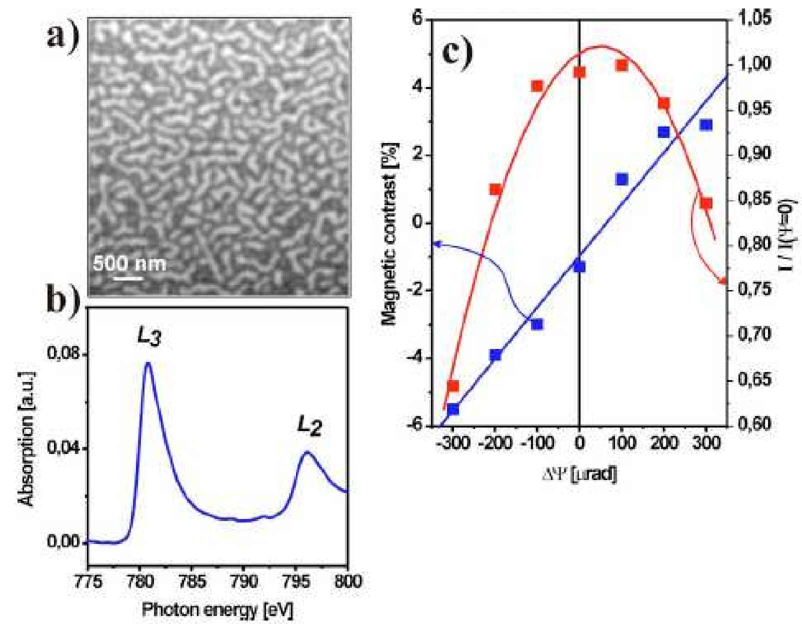

FIG. 9. (Color online) Magnetic imaging of a CoPt/IrMn multilayer sample (total Co thickness=6 nm). The well known worm domains of about 200 nm width are shown in (a), a spectrum taken at the Co L edge in (b), and the magnetic contrast and relative intensity as a function of bump angle $\Delta\psi$ in (c).

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Polish Beamline @ SLS?

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Status of discussion

- Beamline built & financed by SOLARIS
- Design & installation support by SLS
- Operation @ SLS ~3 years
- Endstations:
  - PEEM & XAS
- Transfer to Kracow once SOLARIS is operational

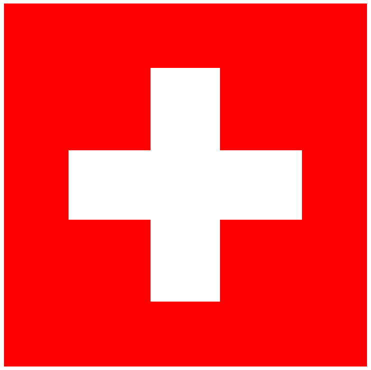
- Pro:
  - Learn how to build & operate BL
  - Good value for money
  - A Polish BL as soon as ~2012
  - Science collaboration PL & CH

- Contra:
  - No undulator
  - Complicated agreement EU – SOLARIS - PSI

The Future?

PSI + SOLARIS:

POLish **A**dvanced **R**esearch **I**nstrument in **S**witzerland



„POLARIS“

C. Quitmann et al. TEAM workshop, 2011

J. Raabe, A. Puzic	**PolLux**
U. Flechsig	
T. Korhonen, B. Kalantari, U. Greuter	PSI
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Thanks for your attention!

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