The Nanospectroscopy Beamline at ELETTRA

S. Heun
Sincrotrone Trieste

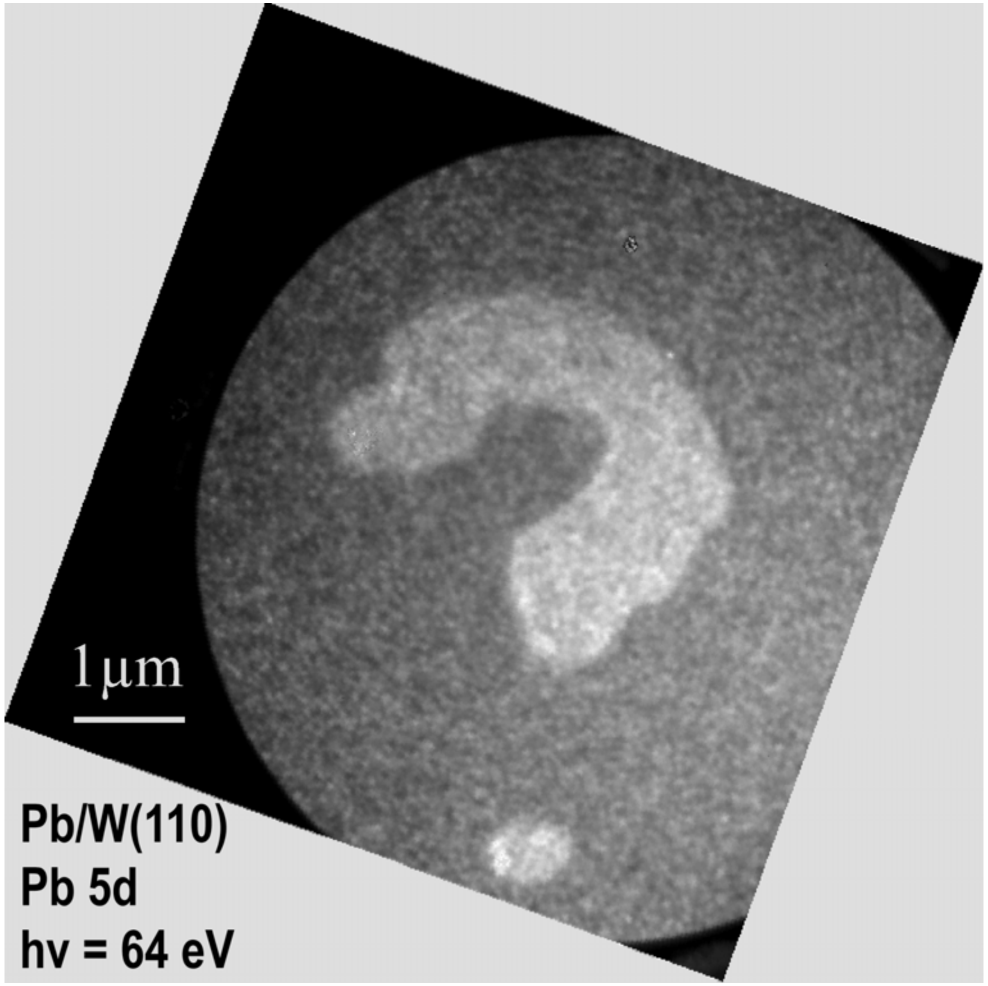
Coworkers

A. Locatelli, S. Cherifi, M. Marsi, and M. Pasqualetto
Nanospectroscopy Group, Sincrotrone Trieste

A. Bianco, G. Sostero, D. Cocco
X-ray Optics Group, Sincrotrone Trieste

E. Bauer
Arizona State University

Motivation



Why spectro-microscopy ?

- (semiconductor) nanostructures
  - lithography
  - self-organization
- devices
- laterally inhomogeneous surfaces
- segregation at defects
- alloying (silicide formation)
- 2-compound growth on surfaces
- XMCD with lateral resolution

Outline

1. Spectromicroscopy at Elettra

2. The SPELEEM microscope

3. The Nanospectroscopy Beamline

4. First Results: MnAs on GaAs

Outline

1. Spectromicroscopy at Elettra

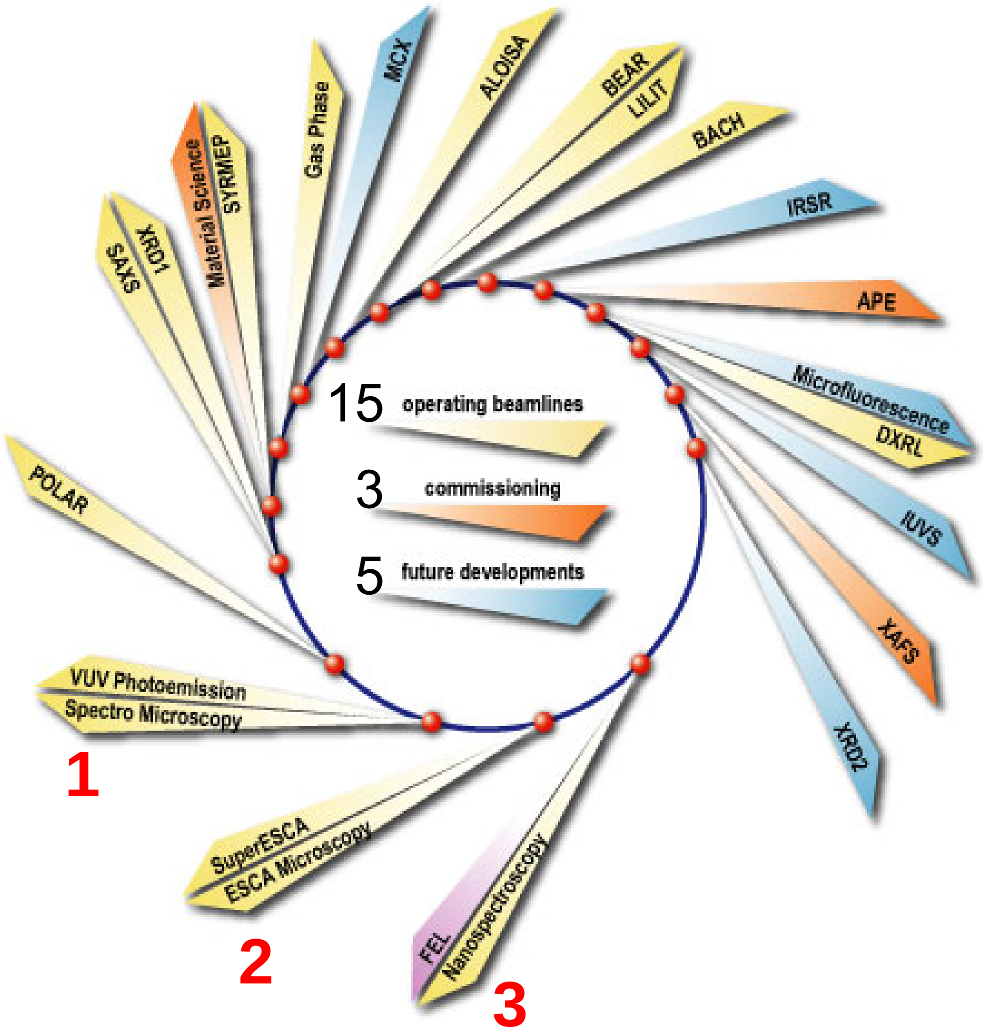
2. The SPELEEM microscope

3. The Nanospectroscopy Beamline

4. First Results: MnAs on GaAs

Location of Elettra

Elettra Beamlines

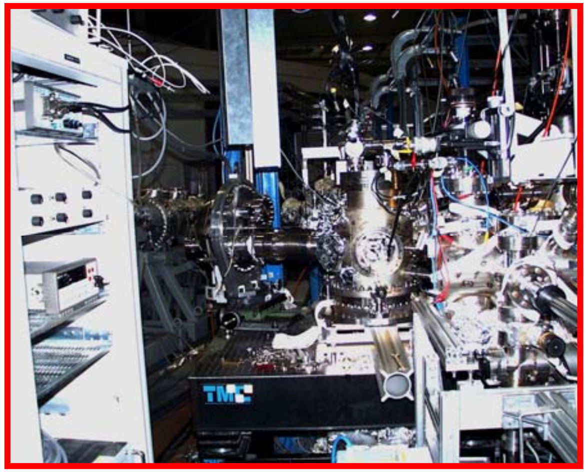


2.0 GeV / 320 mA
2.4 GeV / 140 mA

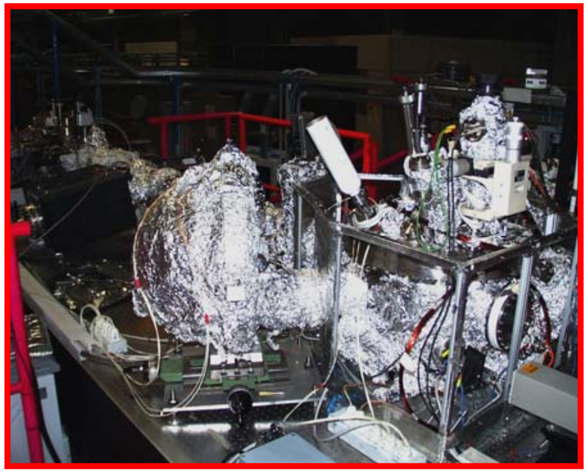
exit	beamline	source
1.2L	Nanospectroscopy *	id
1.2R	FEL (Free-Electron Laser)	-
2.2L	ESCA Microscopy	id
2.2R	SuperESCA	id
3.2L	Spectro Microscopy	id
3.2R	VUV Photoemission	id
4.2	Circularly Polarised Light	id
5.2L	SAXS (Small Angle X-Ray Scattering)	id
5.2R	XRD1 (X-ray Diffraction)	id
6.1L	Material science	bm
6.1R	SYRMEP (SYnchrotron Radiation for MEdical Physics)	bm
6.2R	Gas Phase	id
7.1	MCX (Powder Diffraction Beamline)	bm
7.2	ALOISA (Advanced Line for Overlayer, Interface and Surface Analysis)	id
8.1L	BEAR (Bending magnet for Emission Absorption and Reflectivity) *	bm
8.1R	LILIT (Lab of Interdisciplinary LIThography)	bm
8.2	BACH (Beamline for Advanced DiCHroism) *	id
9.1	IRSR (Infrared Synchrotron Radiaton Microscopy)	bm
9.2	APE (Advanced Photoelectric-effect Experiments) **	id
10.1L	X-ray microfluorescence	bm
10.1R	DXRL (Deep-etch Lithography)	bm
10.2	IUVS (Inelastic Ultra Violet Scattering)	id
11.1	XAFS (X-ray Absorption Fine Structure)	bm
11.2	XRD2 (X-ray Diffraction)	id

Operating Beamlines

U2.2 EscaMicroscopy



U3.2 SpectroMicroscopy

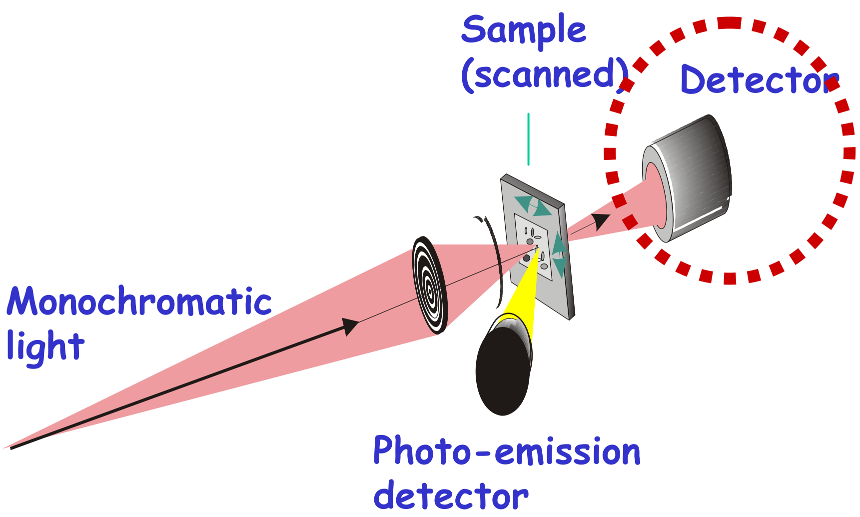


U1.1 Nanospectrocopy

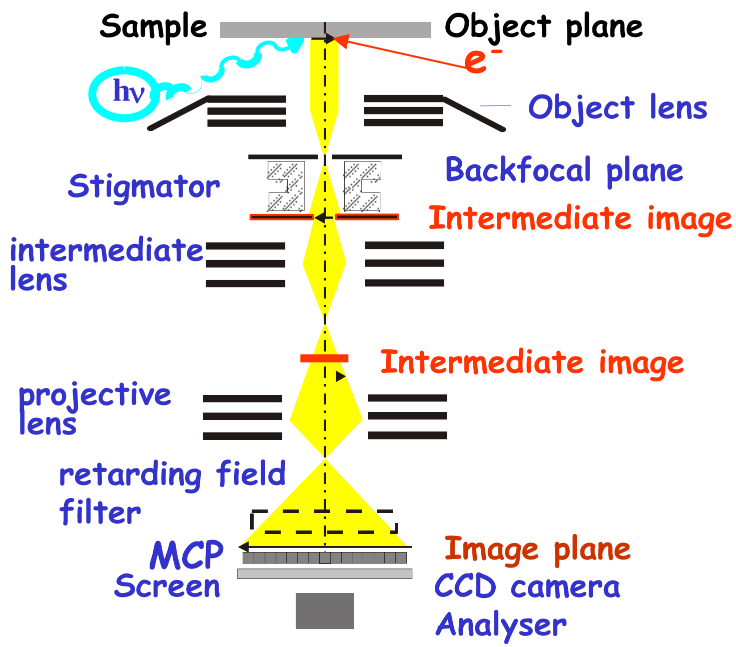
	EM	SM	NS
E (eV):	400-750	20-110	40-1000
SR (nm):	90	500	40 (20)
SR (eV):	0.25	0.07	0.4 (0.25)
Flux (ph/s):	10^9-10^{10}		10^{11}-10^{13}
Methods:	XPS(XAS)	XPS	XPS-XAS
Polarization:	Linear		Linear&circular

Photoemission Microscopy

Scanning (PE&T)



XPEEM



Photon optics is demagnifying the beam:

Scanning Instrument

1. Whole power of XPS in a small spot mode.
2. Flexibility for adding different detectors.
3. Rough surfaces can be measured.
4. Limited use for fast dynamic processes.
5. Lower resolution than imaging instruments.

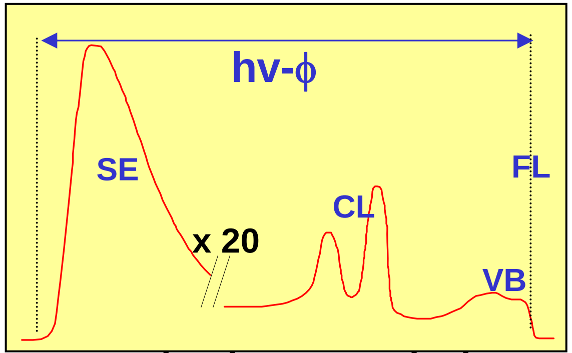
Electron optics to magnify irradiated area:

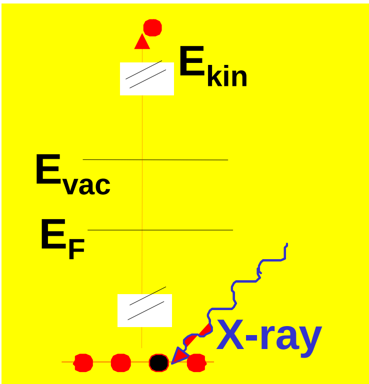
Imaging Instrument

1. High lateral resolution (20 nm).
2. Multi-method instrument (XPEEM/PED).
3. Excellent for monitoring dynamic processes.
4. Poorer spectroscopic ability.
5. Sensitive to rough surfaces.

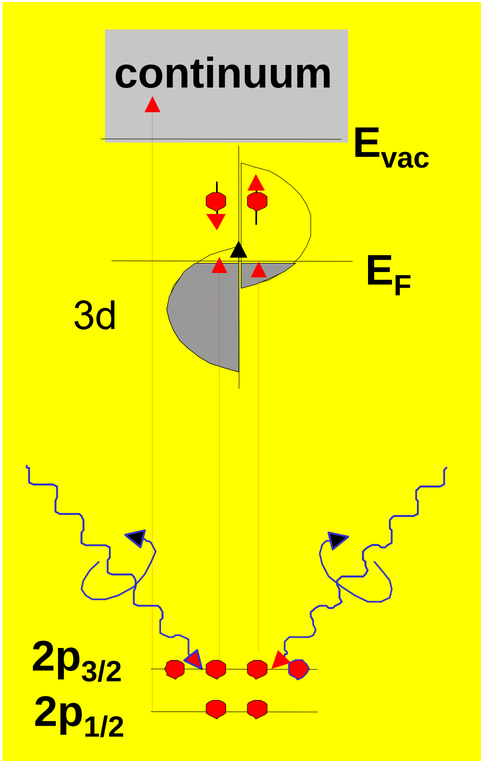
Concepts of Spectromicroscopy

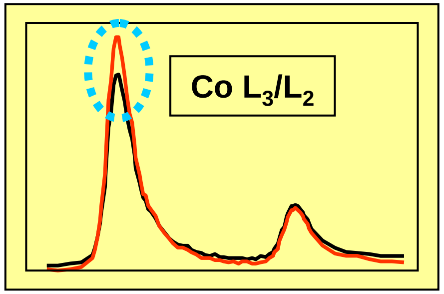
XPS – mode: <u>hv=const</u>
hv in / e⁻ out
+ energy filtering of electrons





XAS – mode: <u>hv scanned</u>
hv in / e⁻ out (TEY)





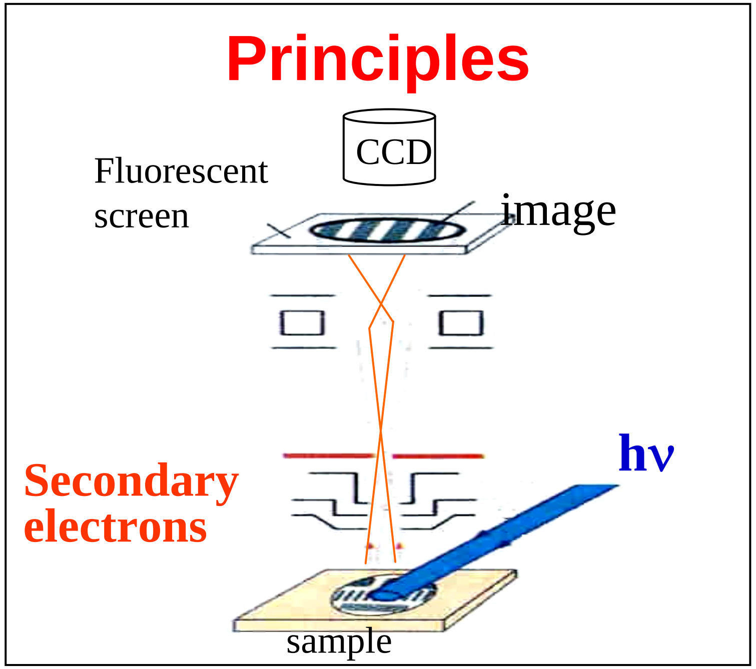
<u>XANES:</u> tuning on molecular orbitals

<u>XMLD:</u> imaging antiferromagnets

<u>XMCD:</u> imaging ferromagnets

Sum rules: Magnetic moment values

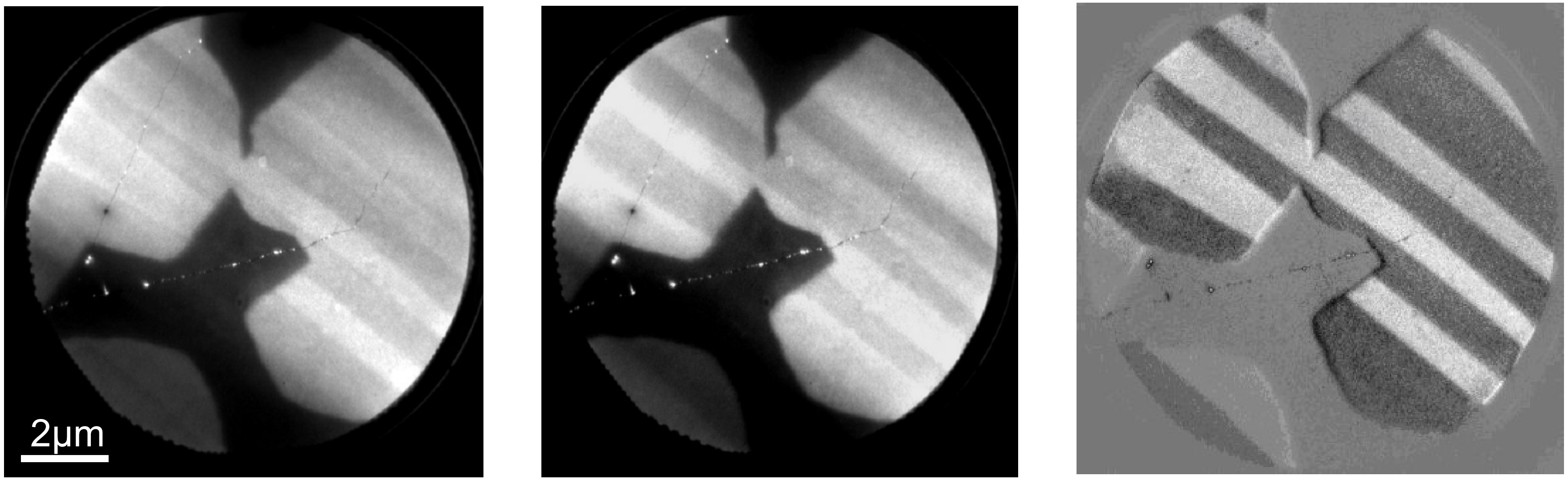
XMCD - PEEM

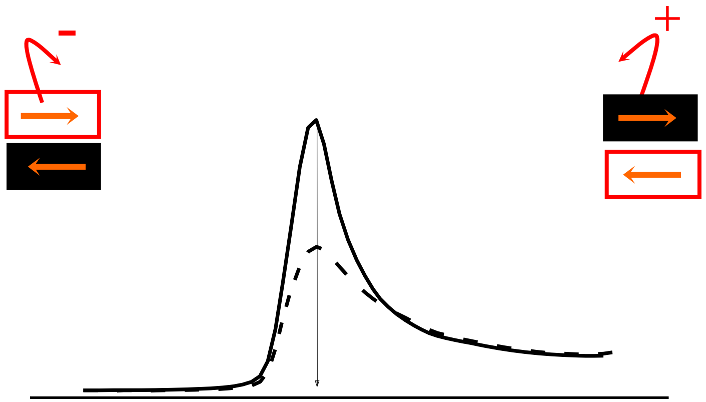


Characteristics

- Elemental resolution
- Lateral resolution
- Magnetic domain imaging
- Magnetic moment values

XMCD-PEEM





I^- max - I^+ max
Magnetic contrast
XMCD- PEEM

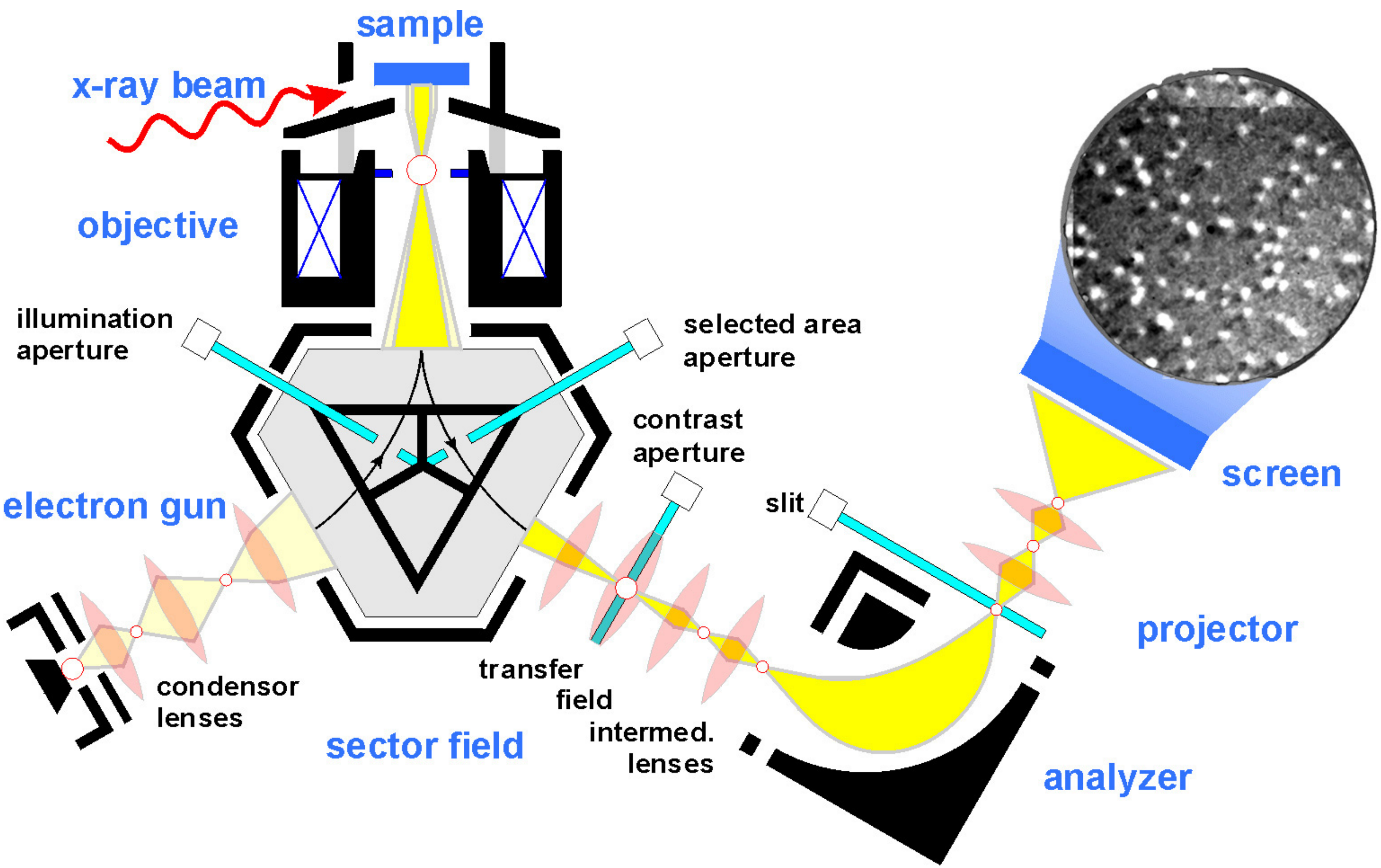
Outline

1. Spectromicroscopy at Elettra
2. The SPELEEM microscope
3. The Nanospectroscopy Beamline
4. First Results: MnAs on GaAs

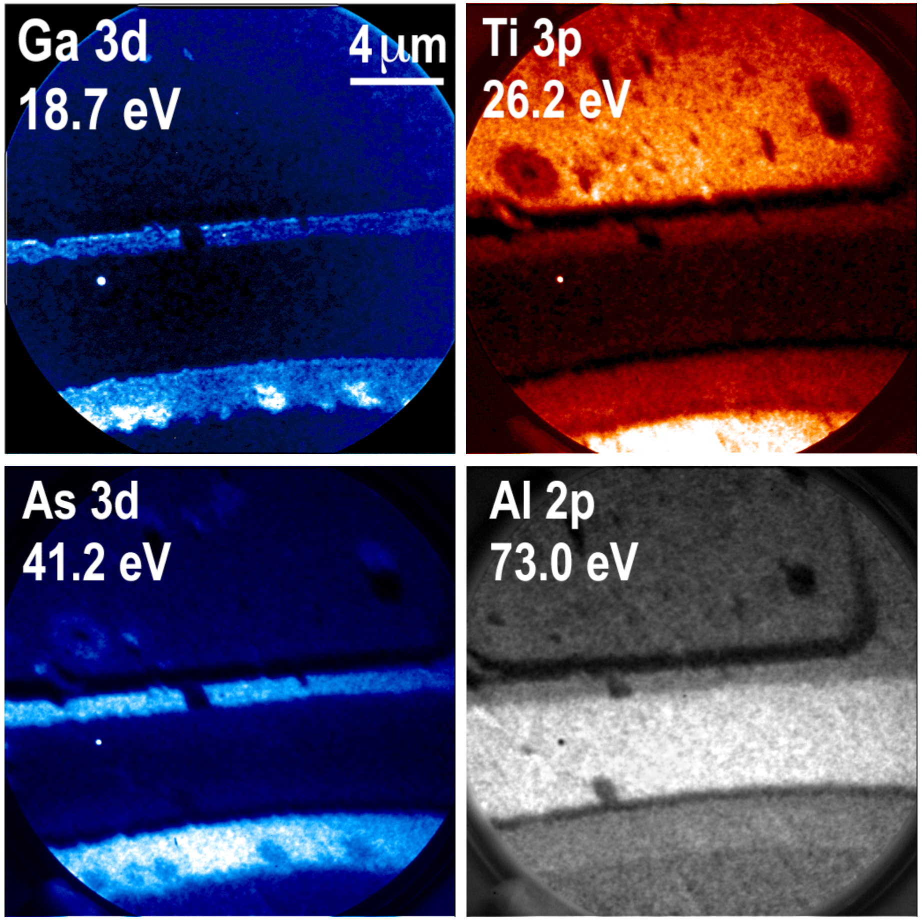
The SPELEEM at ELETTRA

The SPELEEM

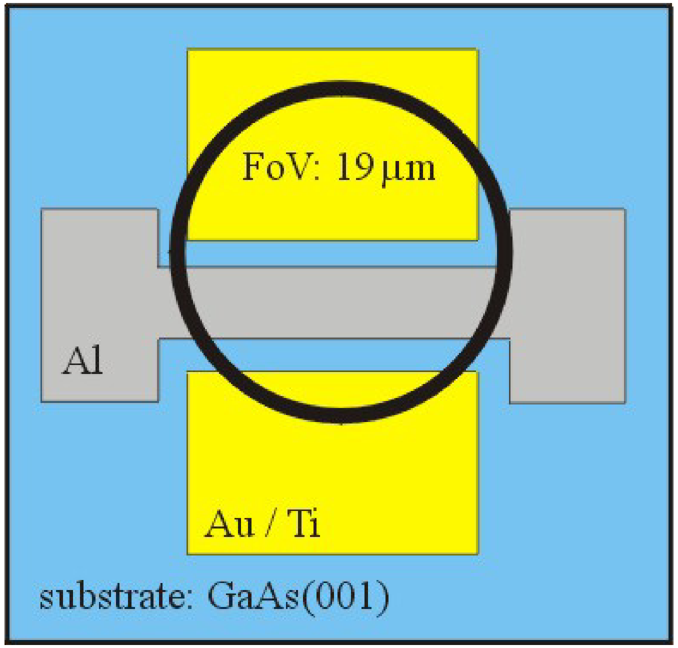
Spectroscopic photoemission and low energy electron microscope



Spectroscopic Microscopy



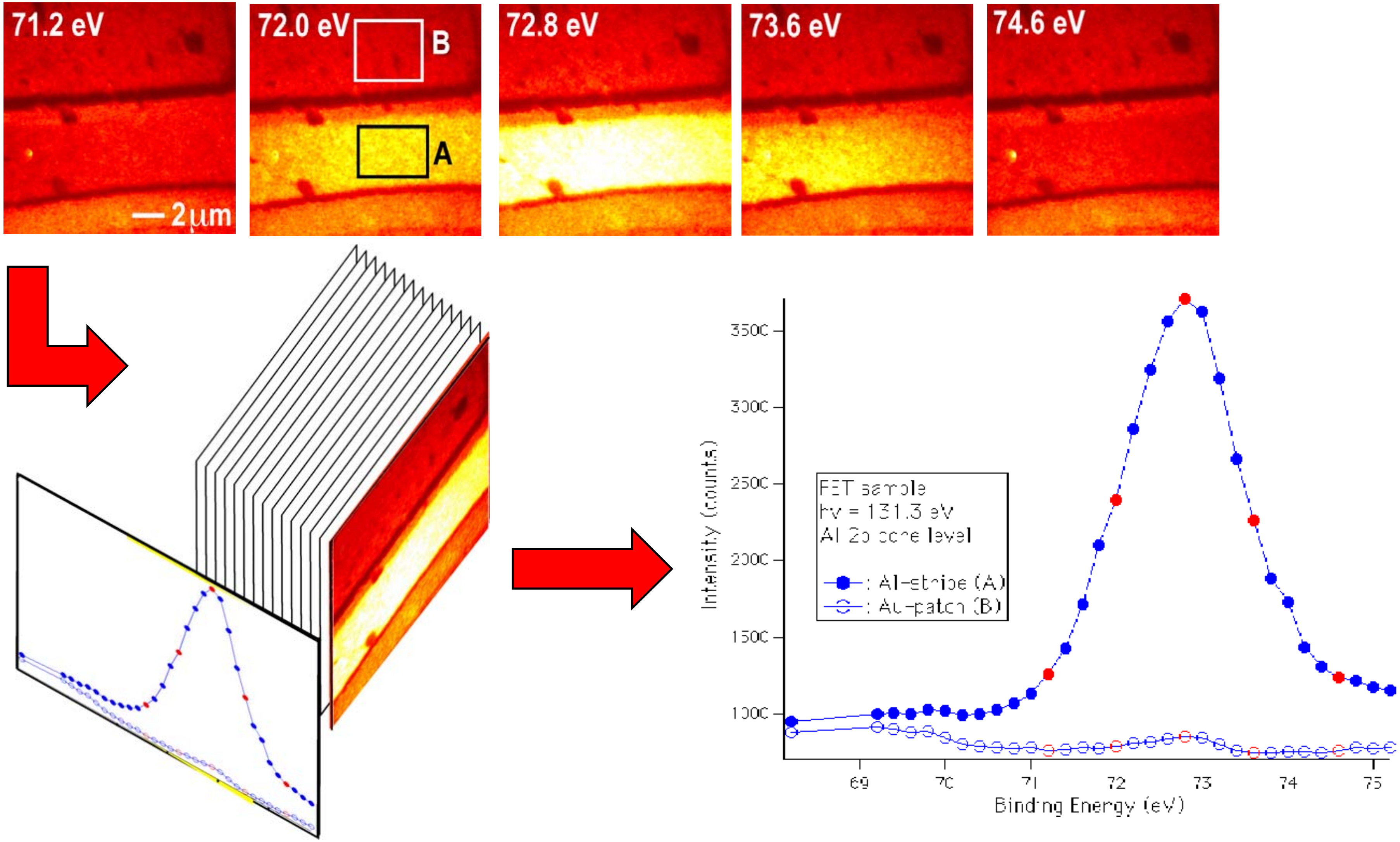
Images from a Field Effect Transistor (FET) at different binding energies. Photon energy hν = 131.3 eV.



Sample from M. Lazzarino, L. Sorba, and F. Beltram, Laboratorio TASC-INFM, Trieste, Italy

S. Heun, Th. Schmidt, B. Ressel, E. Bauer, and K. C. Prince, Sync. Rad. News Vol. 12, No. 5 (1999) 25.

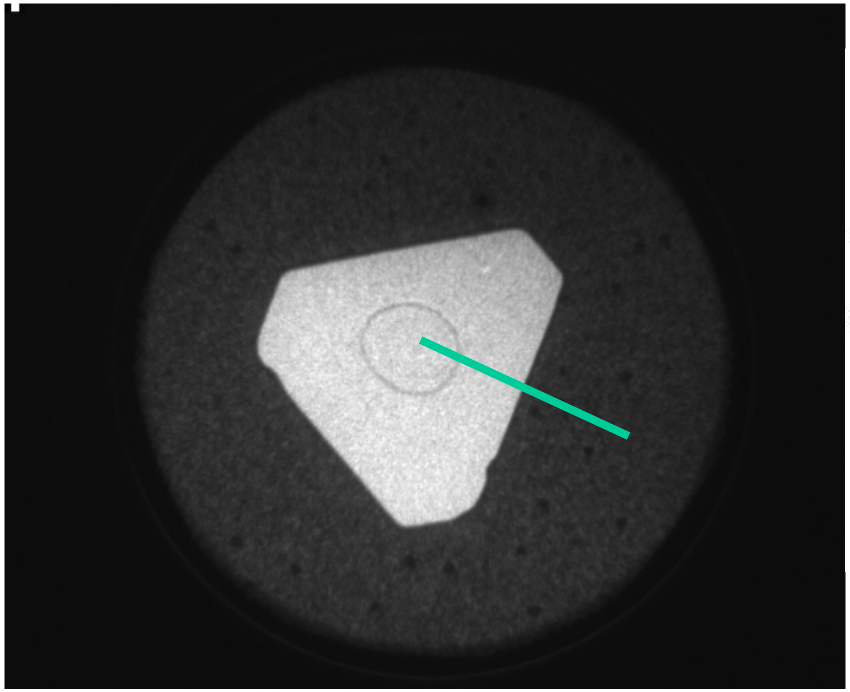
XPEEM



S. Heun, Th. Schmidt, B. Ressel, E. Bauer, and K. C. Prince, Sync. Rad. News Vol. 12, No. 5 (1999) 25.

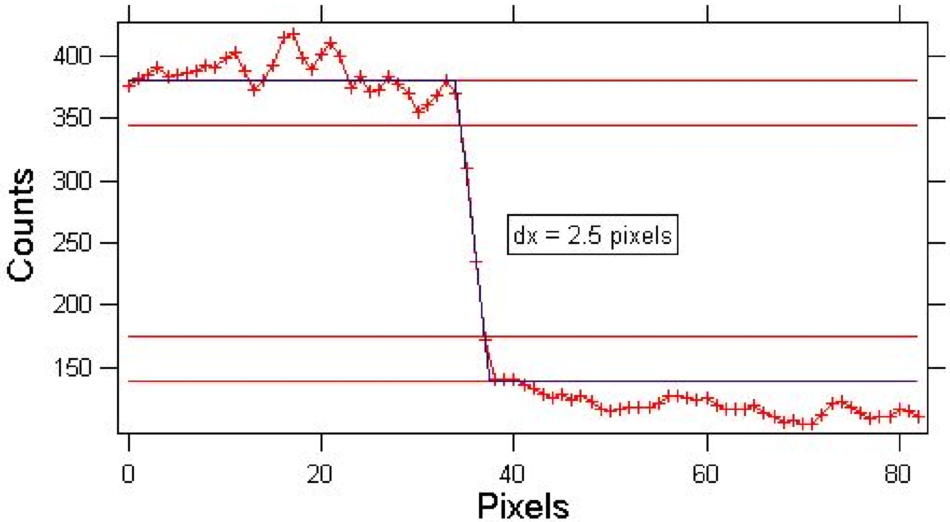
Lateral Resolution of LEEM

FoV = 2.65 µm
STV = 7.5 eV
12.5 µm energy slit
30 µm contrast aperture
100 ms int. time, 2x2 binning



Pb on Si (111)
LEEM – lateral resolution
13/11/2002 image_003

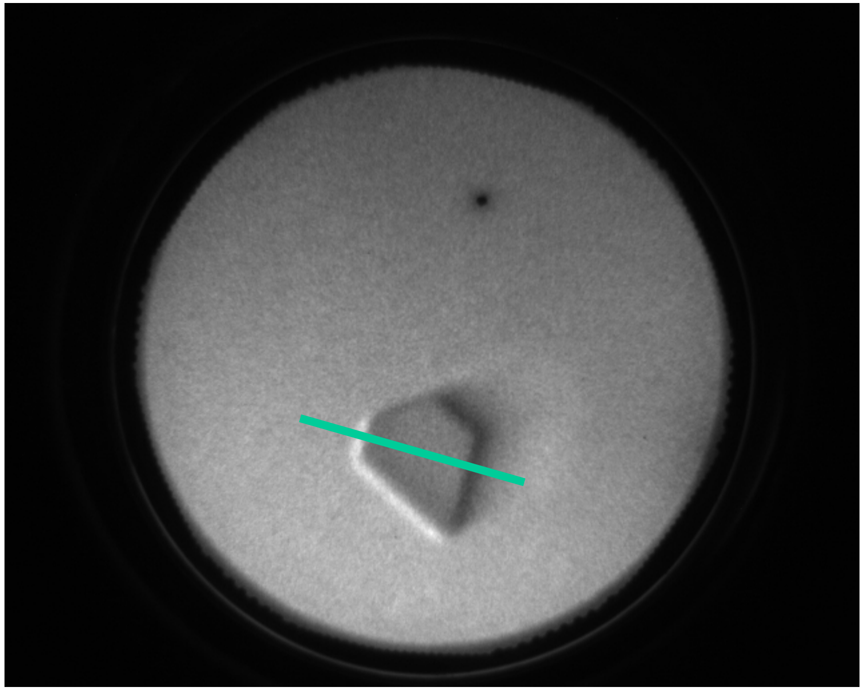
Profile line width = 3 pixels



Spatial resolution is **15 nm**.

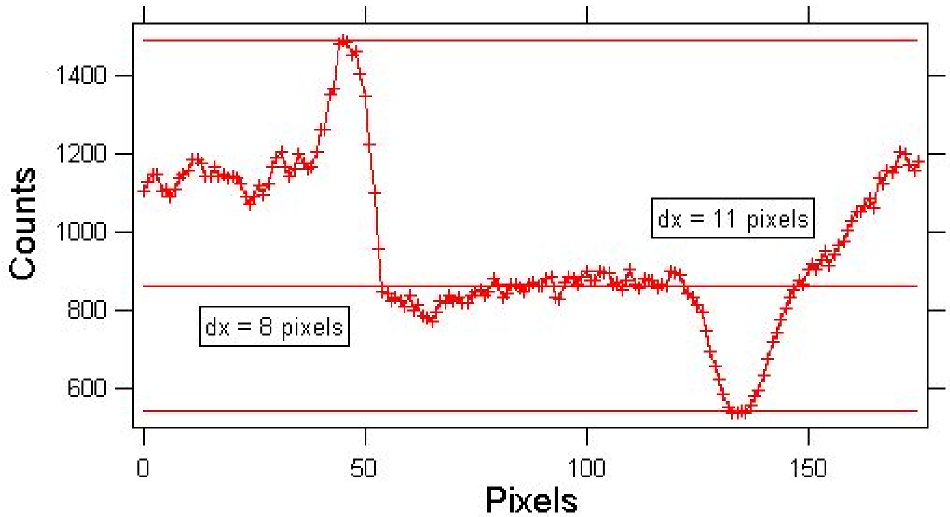
Lateral Resolution of XPEEM

FoV = 2.65 µm
STV = 1.2 eV, hv = 54.5 eV
12.5 µm energy slit
20 µm contrast aperture
15 s int. time, 2x2 binning



Pb on Si (111)
XPEEM – lateral resolution imaging secondaries
12/11/2002 image_025

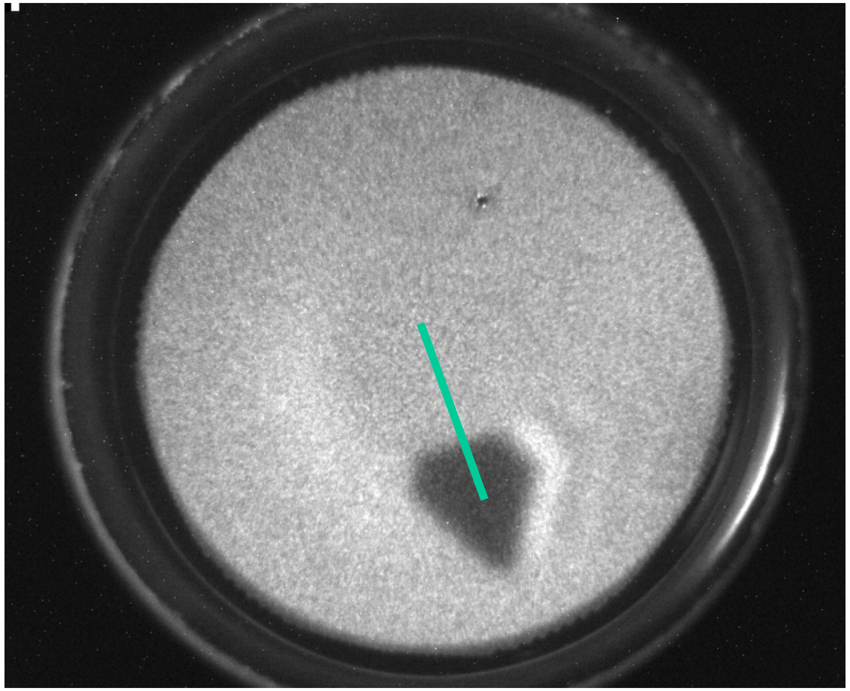
Profile line width = 7 pixels



Spatial resolution is **40 nm**.

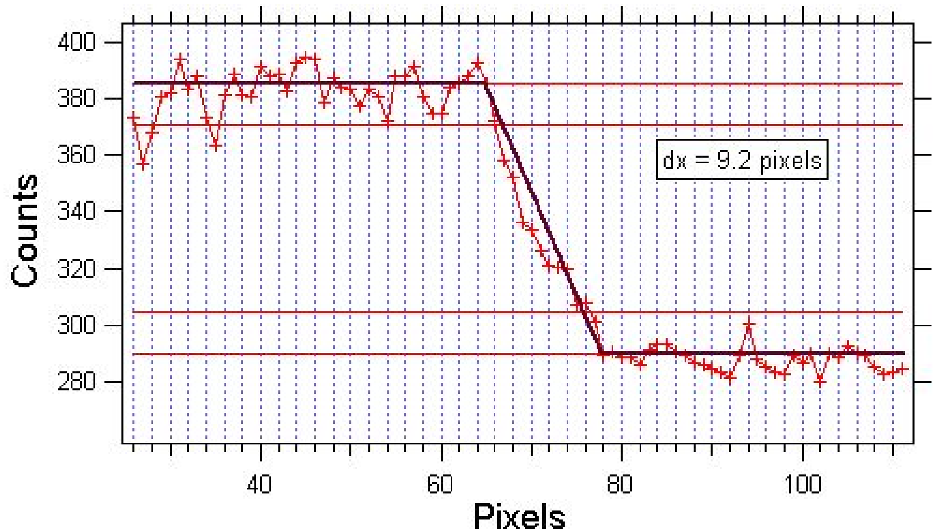
Lateral Resolution of XPEEM

FoV = 2.65 µm
STV = 43.2 eV, hv = 144.0 eV
12.5 µm energy slit
30 µm contrast aperture
240 s int. time, 2x2 binning



Pb on Si (111)
XPEEM – lateral resolution
core level imaging – Si 2p
12/11/2002 image_033

Profile line width = 7 pixels



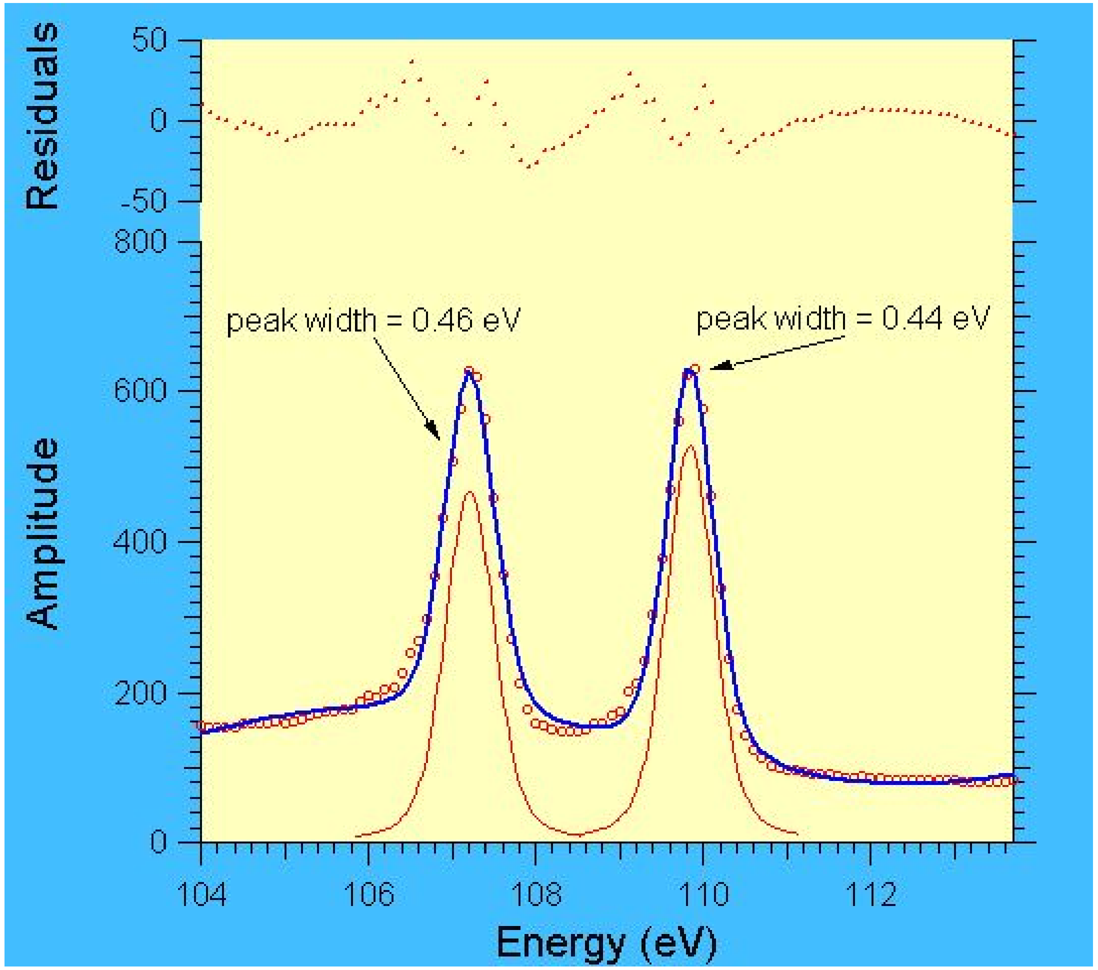
Spatial resolution is **55 nm**.

Energy Resolution of XPEEM

Pb on Si (111)
XPEEM – energy resolution
Pb 5d – Voigt fit
13/11/2002 scan_002

FoV = 2.65 μm
hv = 130.0 eV
12.5 μm energy slit
30 μm contrast aperture
30 s int. time, 4x4 binning

Energy resolution
better than **0.45 eV**.



Outline

1. Spectromicroscopy at Elettra

2. The SPELEEM microscope

3. The Nanospectroscopy Beamline

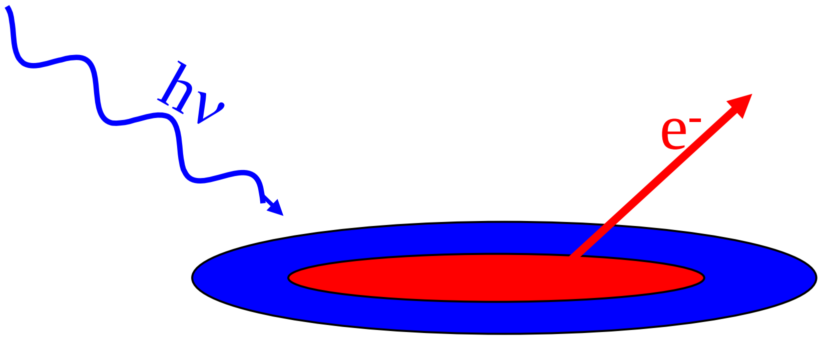
4. First Results: MnAs on GaAs

Requirements

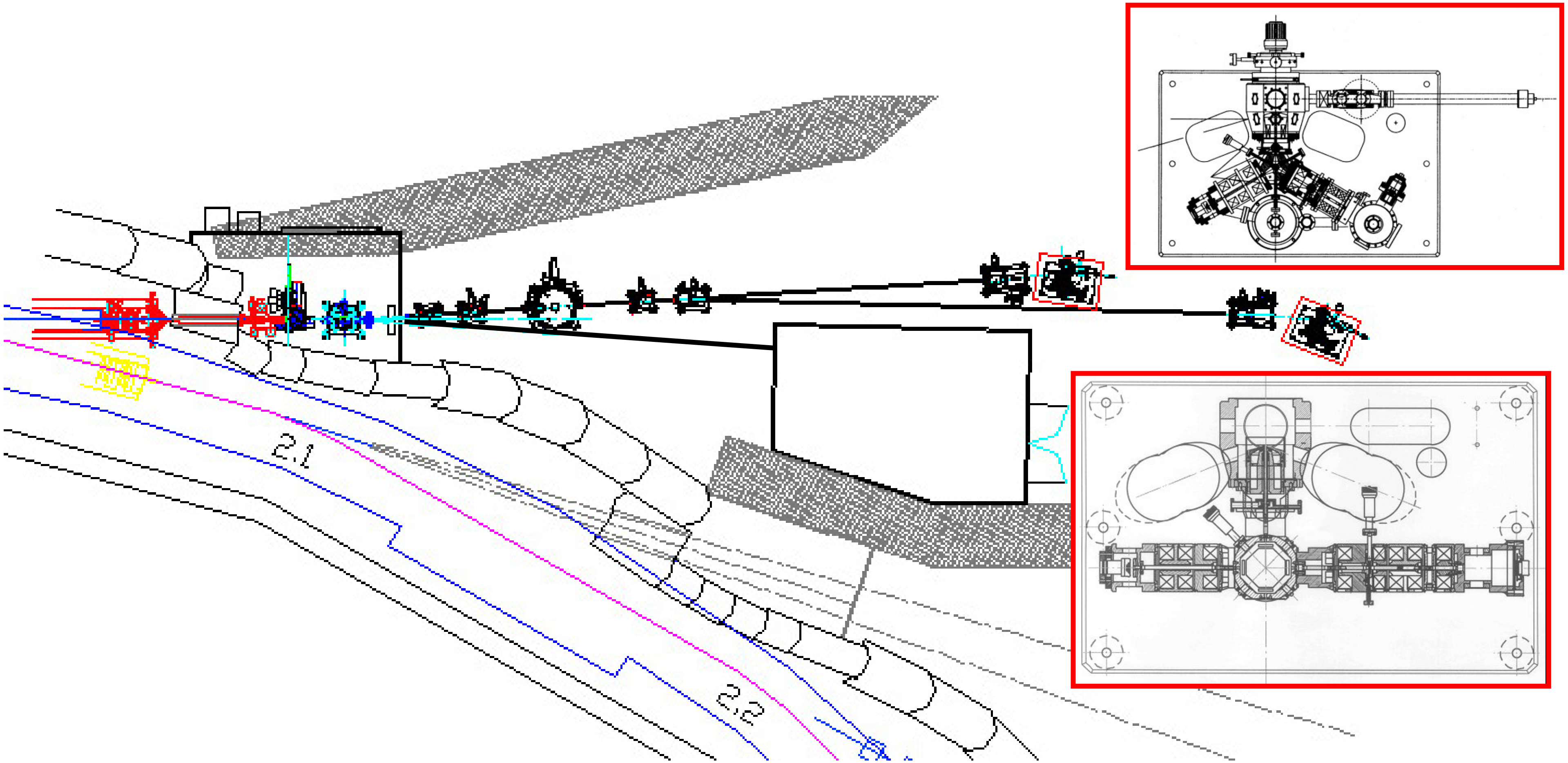
Source: Variable Polarization

Monochromator: Wide spectral range
Medium spectral resolution

Spot: High photon flux density on sample
Small variable spot size (~μm)
Homogeneous illumination



Beamline Layout



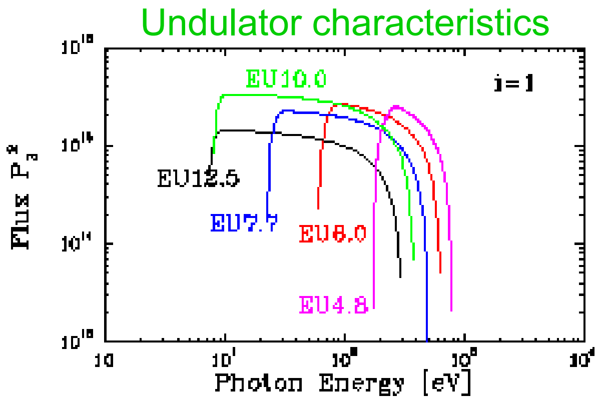
Source Characteristics

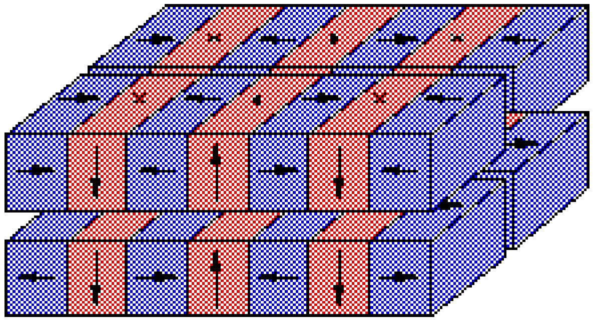
- FEL/Nanospectroscopy undulator
- Sasaki Apple II type undulator

- 2 sections with phase modulation electromagnet
- 2 x 20 periods of length 10 cm

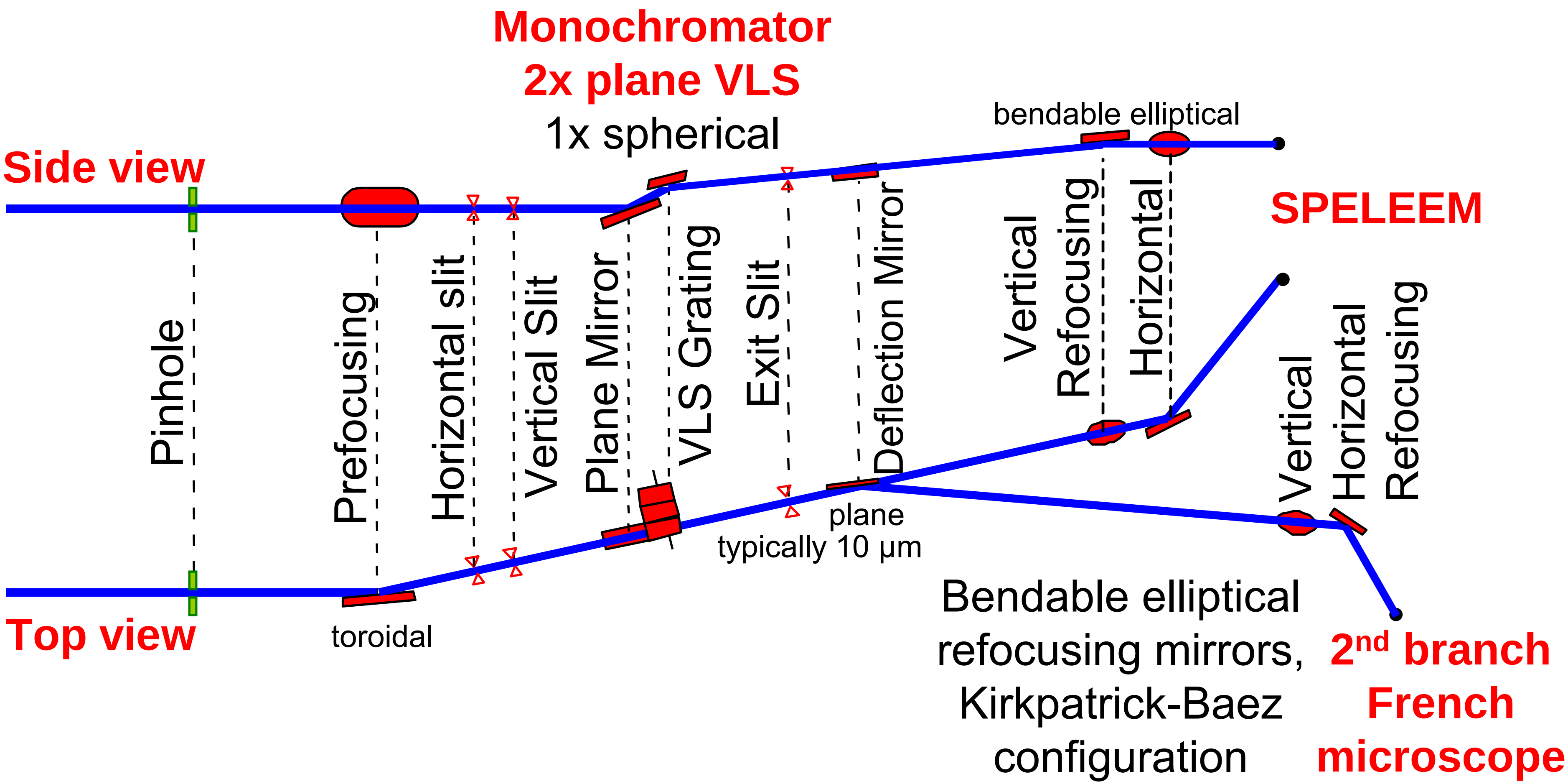
- Polarization: elliptical (horizontal, circular, and vertical)

- Source dim.: 560 μm x 50 μm





Optics



D. Cocco, M. Marsi, M. Kiskinova, K. C. Prince, T. Schmidt, S. Heun, and E. Bauer: Proc. SPIE **3767** (1999) 271.

elettra Synchrotron Light Laboratory

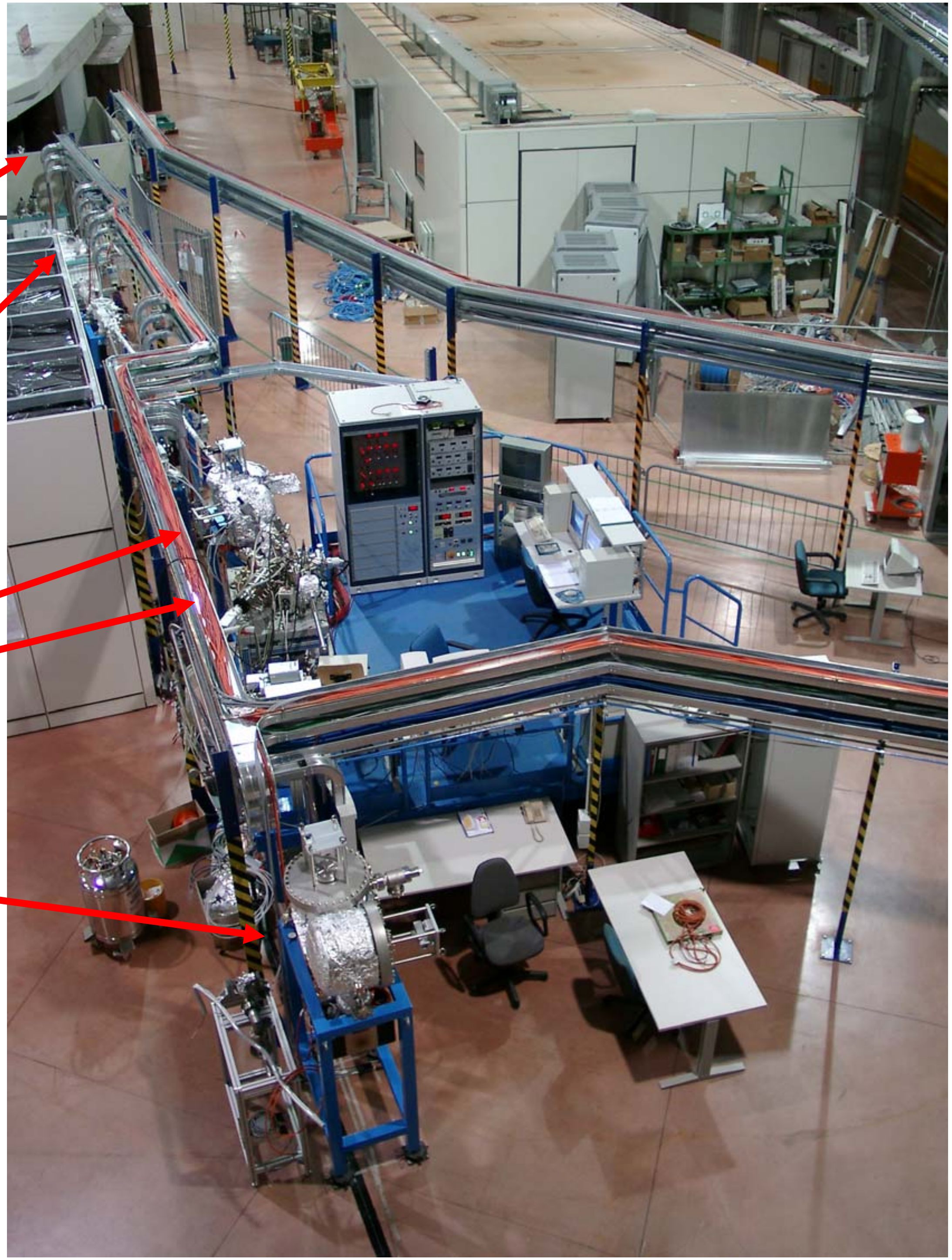
Front End

Monochromator

Refocusing Mirrors

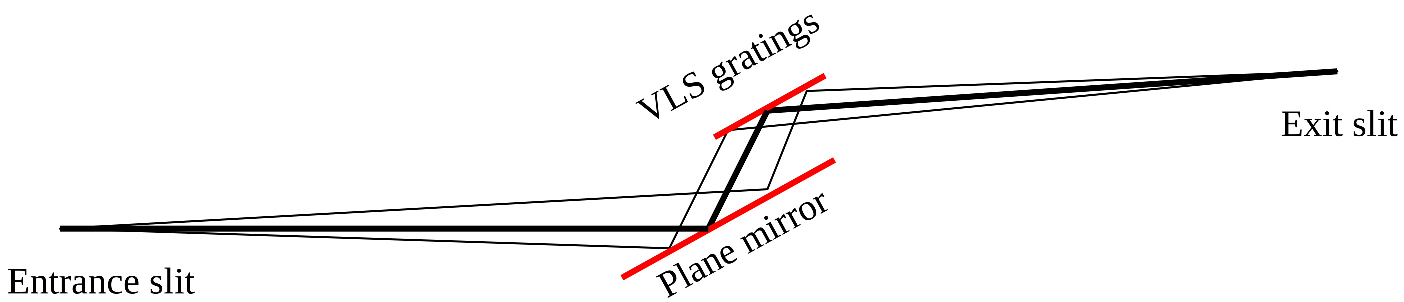
SPELEEM

2nd Branch



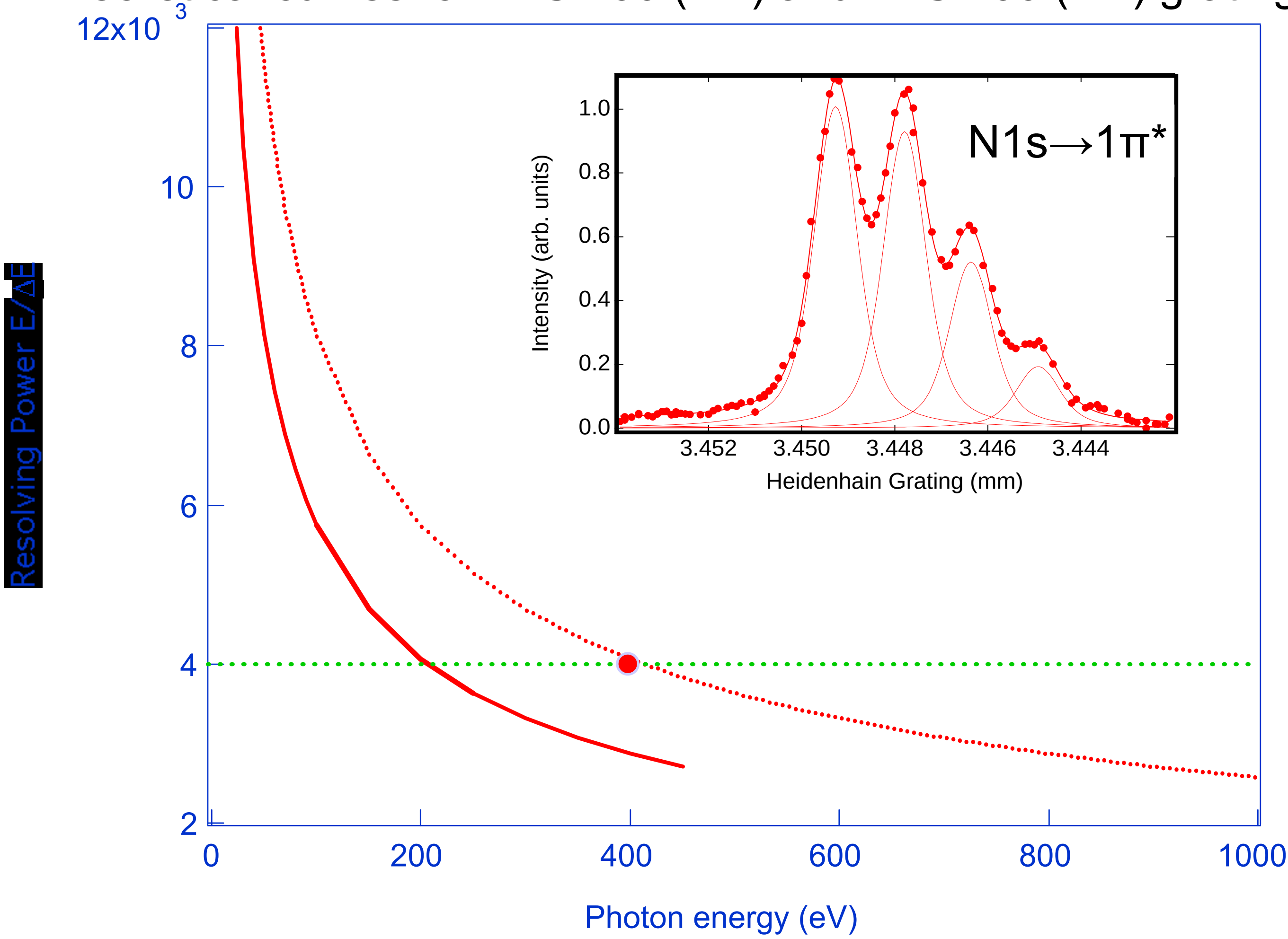
Monochromator

- 2 VLS (variable line spacing) gratings of low groove density
  - 200/mm for 20 - 250 eV
  - 400/mm for 200 - 1000 eV
- 1 spherical grating (5 - 40 eV)



Energy Resolution

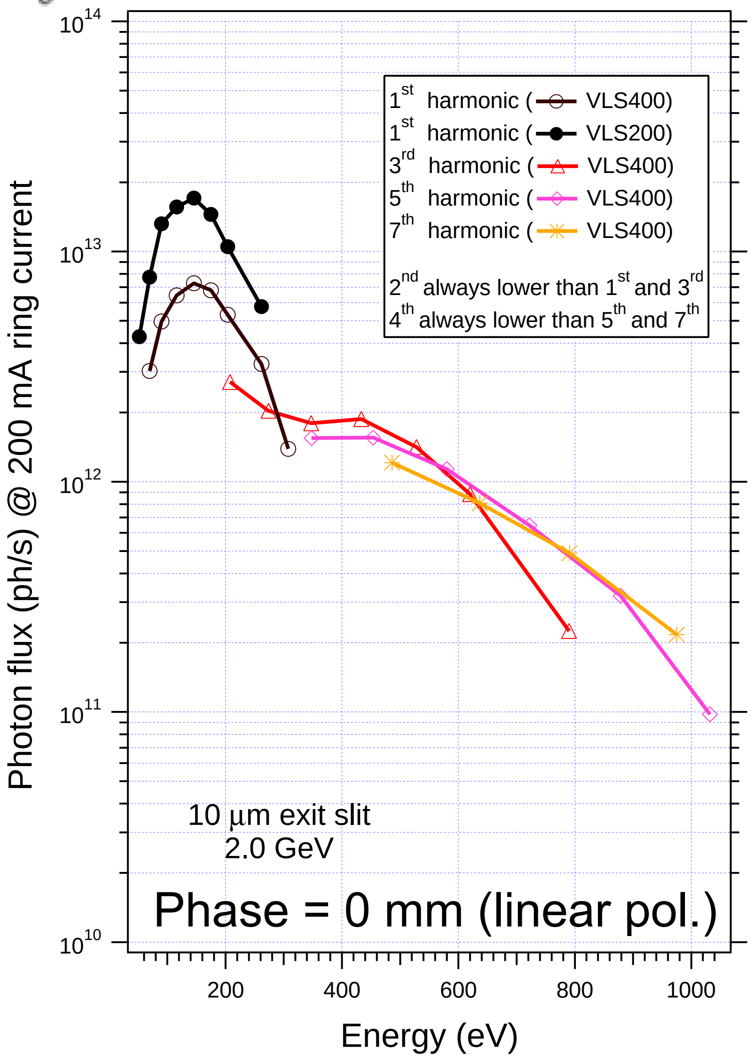
Theoretical curves for VLS 200 (——) and VLS 400 (⋯⋯) gratings

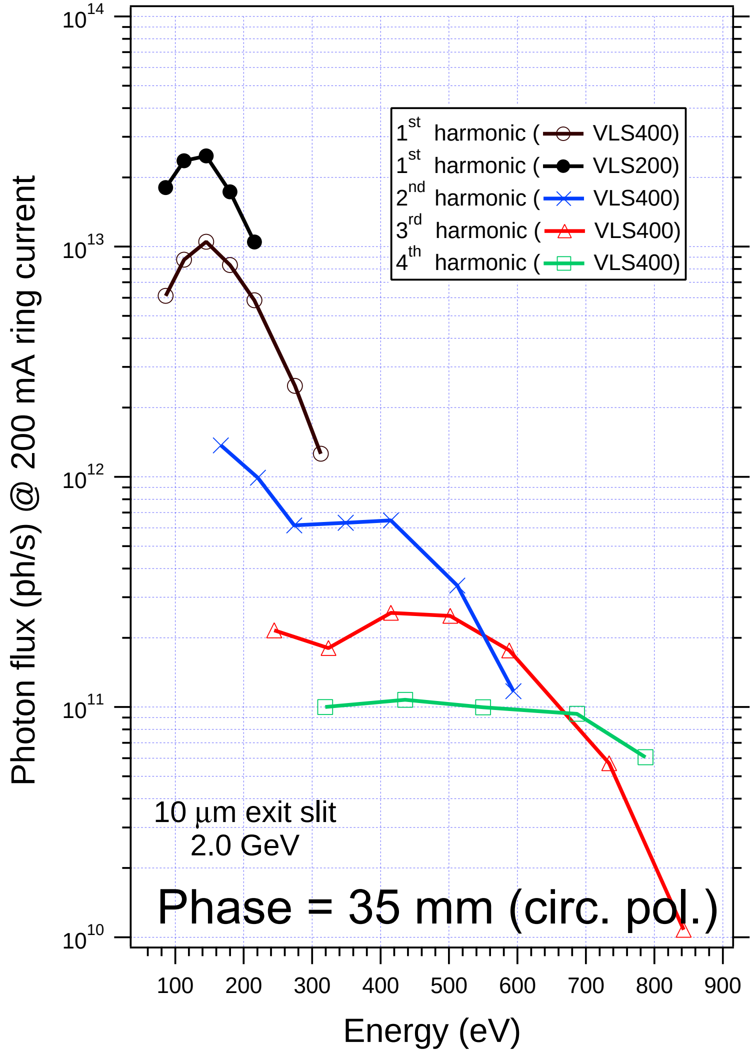


E/ΔE ~ 4000
@ 400.8 eV

A. Locatelli, A. Bianco, D. Cocco, S. Cherifi, S. Heun, M. Marsi, M. Pasqualetto, and E. Bauer: J. de Physique IV, submitted.

Photon Flux



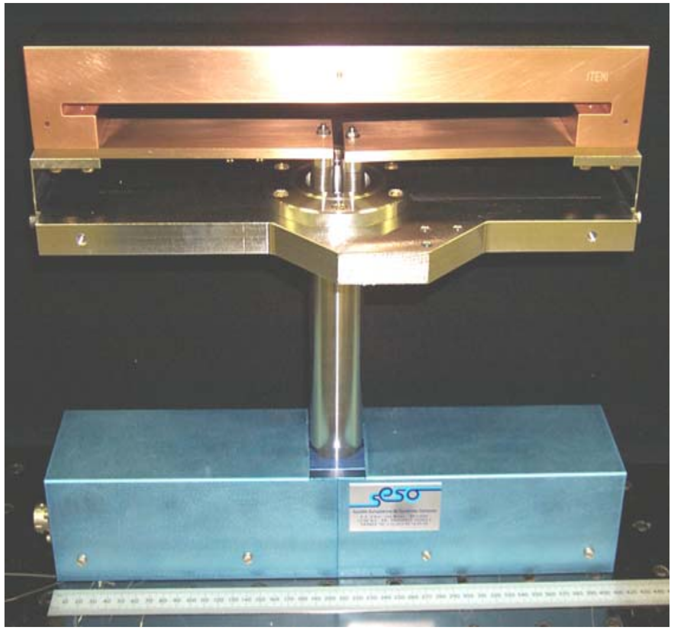


A. Locatelli, A. Bianco, D. Cocco, S. Cherifi, S. Heun, M. Marsi, M. Pasqualetto, and E. Bauer: J. de Physique IV, submitted.

elettra Synchrotron Light Laboratory

Photon Beam Refocusing

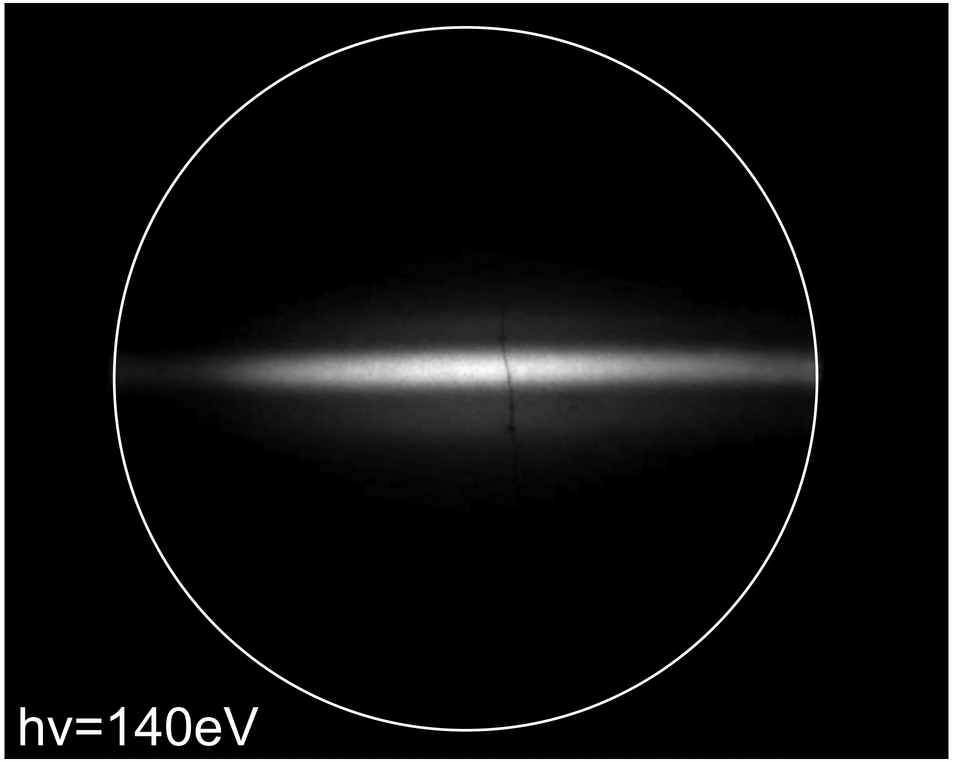
- Need:
  - Homogeneous micro-spot
  - Highest photon flux in the field of view of the microscope
- Two adaptive plane elliptical mirrors («bendable mirrors»)
- Bend by applying unequal moments to their ends
- Kirkpatrick-Baez configuration
- Theoretical spot size:
  1.6 µm (vert) x 6.1 µm (hor)



A. Bianco, G. Sostero, and D. Cocco: Proc. SPIE, submitted.

Best Focus: Spot Size on Sample

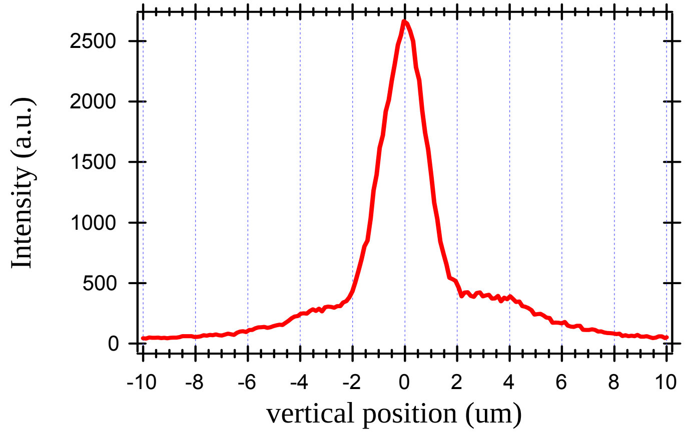
Best Focus



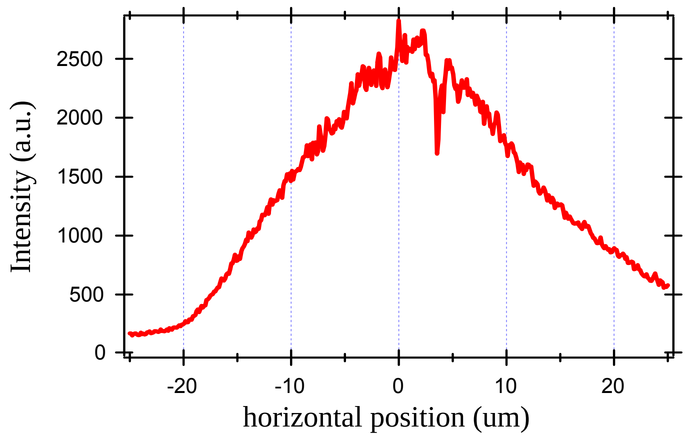
Field of view: 55 μm

A. Bianco, G. Sostero, and D. Cocco: Proc. SPIE, submitted.

vertical line profile (FWHM 2 μm)

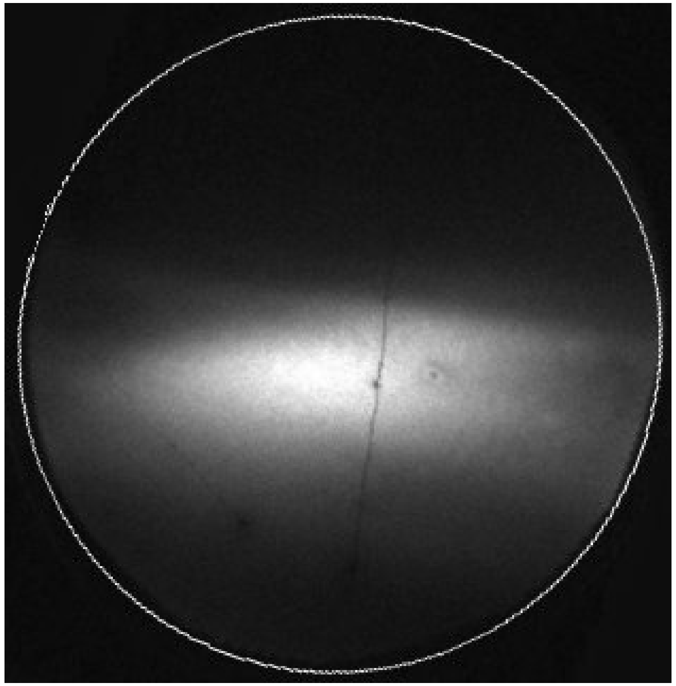


horizontal line profile (FWHM 25 μm)
corrected for grazing incidence: 7 μm

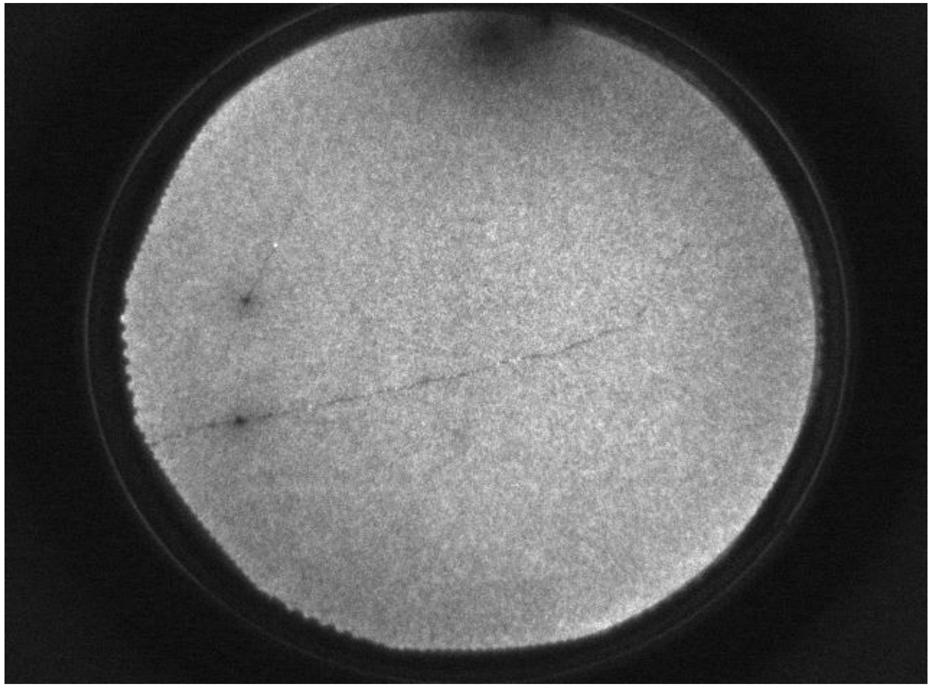


Increased Spot Size

Field of view ~50 μm
HRM roll misalignment (-700 steps)



XPEEM image at 5μm FOV
Homogeneous illumination

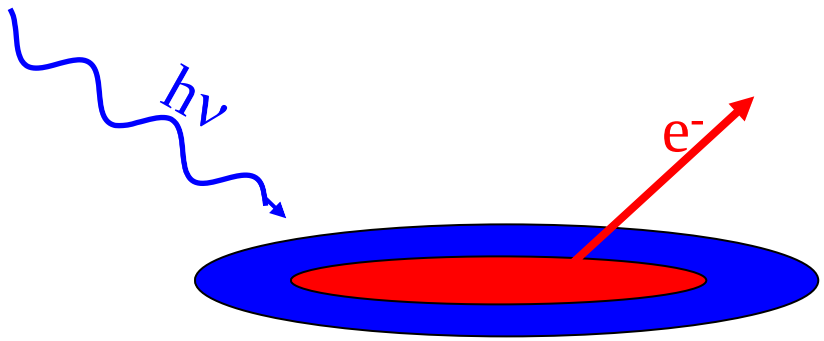


Summary

Source: Sasaki Apple II type undulator
Polarization: circular, elliptical, and linear

Monochromator: Spectral range: 20 - 1000 eV
Spectral resolution: E/ΔE ~ 4000 @ 400 eV

Spot: Flux on sample: 10^{11} - 10^{13} ph/s/200mA
Focused spot size: 2 μm x 7 μm
Vertical spot size from 2 μm to 10 μm



Outline

1. Spectromicroscopy at Elettra

2. The SPELEEM microscope

3. The Nanospectroscopy Beamline

4. First Results: MnAs on GaAs

Structural and Magnetic Phase Transition in MnAs/GaAs epitaxial Films Probed by LEEM and XMCD-PEEM

S. Cherifi, S. Heun, A. Locatelli
Sincrotrone Trieste, Italy

L. Däweritz, M. Kästner
Paul-Drude-Institut, Berlin, Germany

E. Bauer
Arizona State University, Tempe, USA

Epitaxial MnAs on GaAs : Candidate for Spin Injection ?

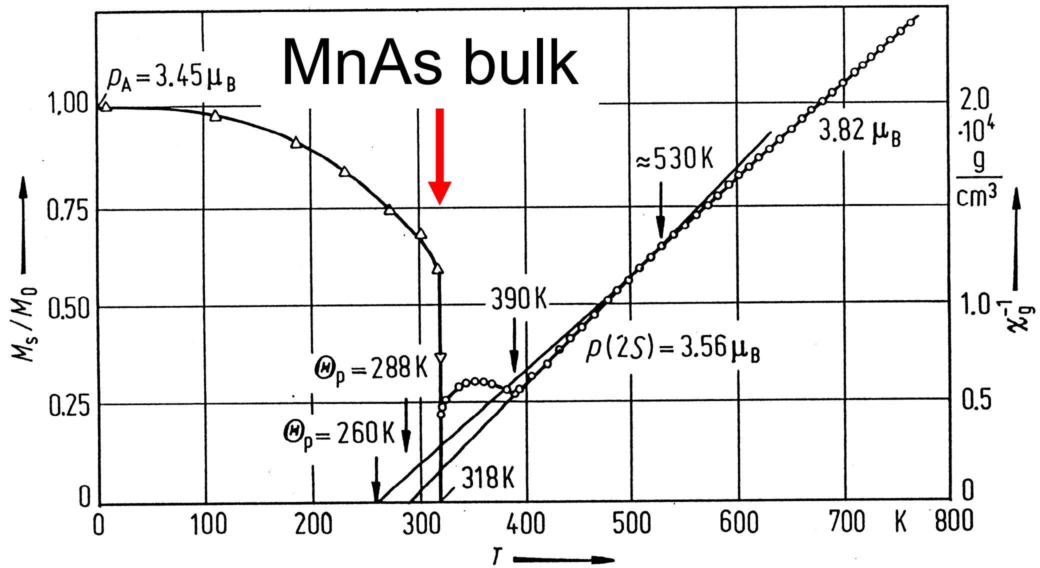
Ferromagnetic epitaxial MnAs films on GaAs:

- combination of ferromagnetic and conventional semiconductor
- spin injection

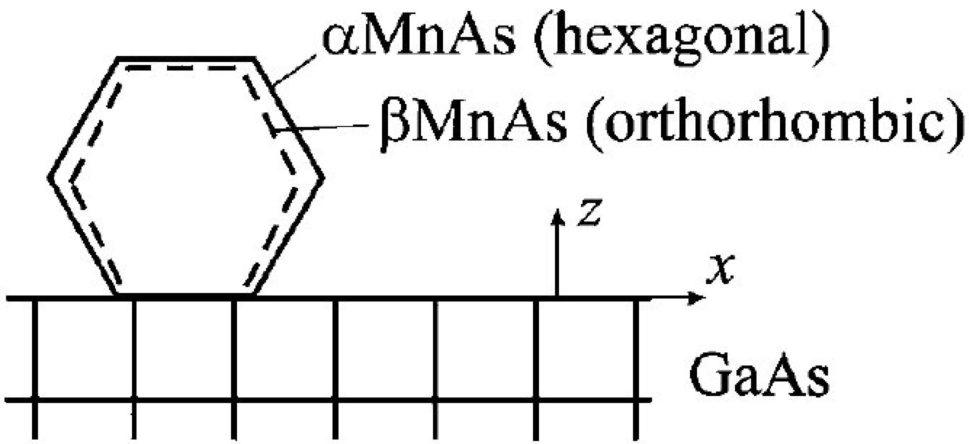
Here: XMCD-PEEM and LEEM study

Magnetic properties vs. structure

Background



First order phase transition from the ferromagnetic hexagonal α phase to the paramagnetic orthorhombic β phase



Large exchange splitting

⇓

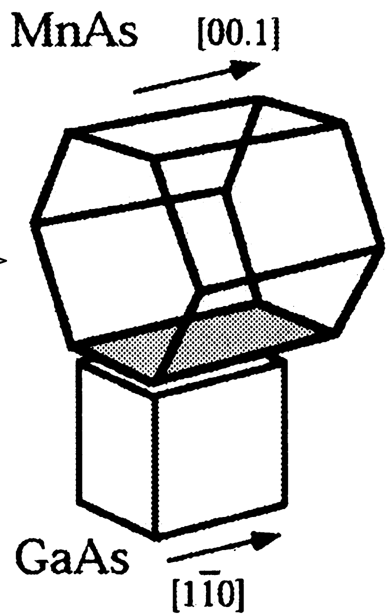
High magnetic moment

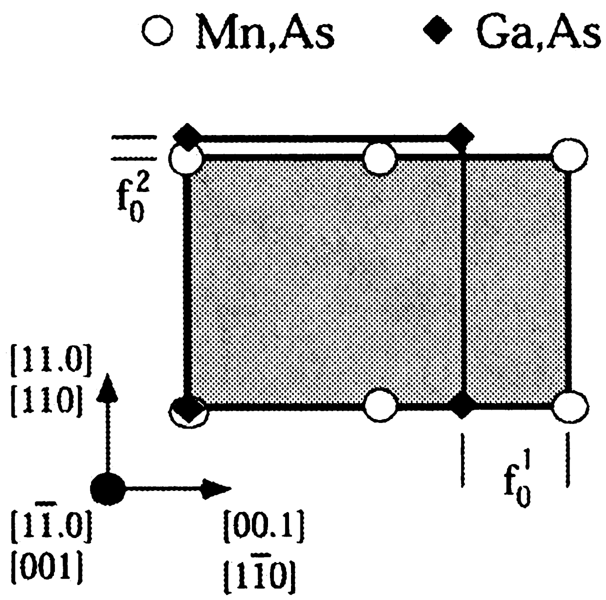
(3.45 μ_B)

V. M. Kaganer, B. Jennichen, F. Schippan, W. Braun, L. Däweritz, and K. H. Ploog: PRL **85** (2000) 341.

Background

Hexagonal MnAs on cubic GaAs epitaxial films



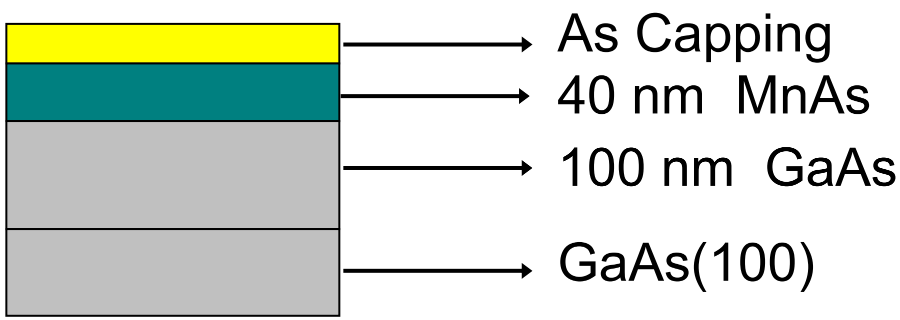


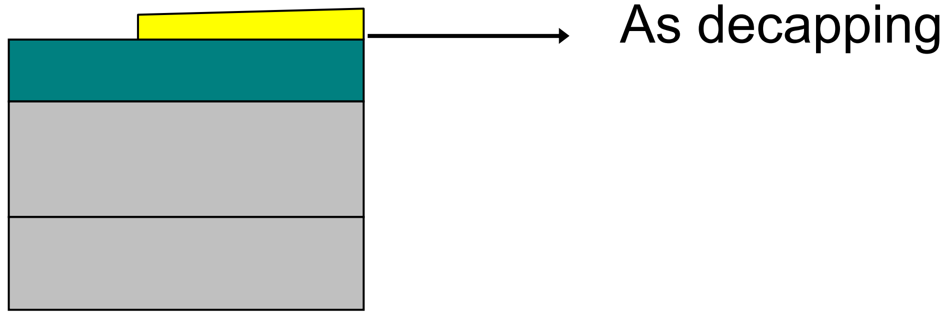
α MnAs(1-100) // GaAs(001)
α MnAs[0001] // GaAs[1-10]

Large lattice misfit
⇓
Large strain

A. Trampert, F. Schippan, L. Däweritz, and K. H. Ploog: Appl. Phys. Lett. **78** (2001) 2461.

Samples





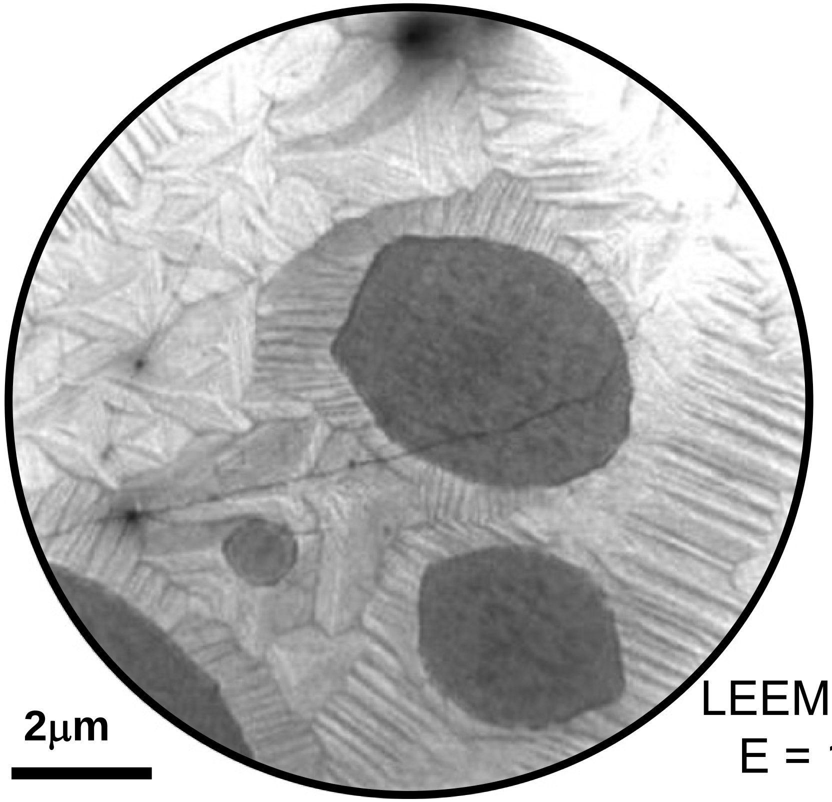
MnAs films:

- grown at 250°C by MBE,
- annealed at 400°C, and
- capped with As before removal from the MBE chamber.

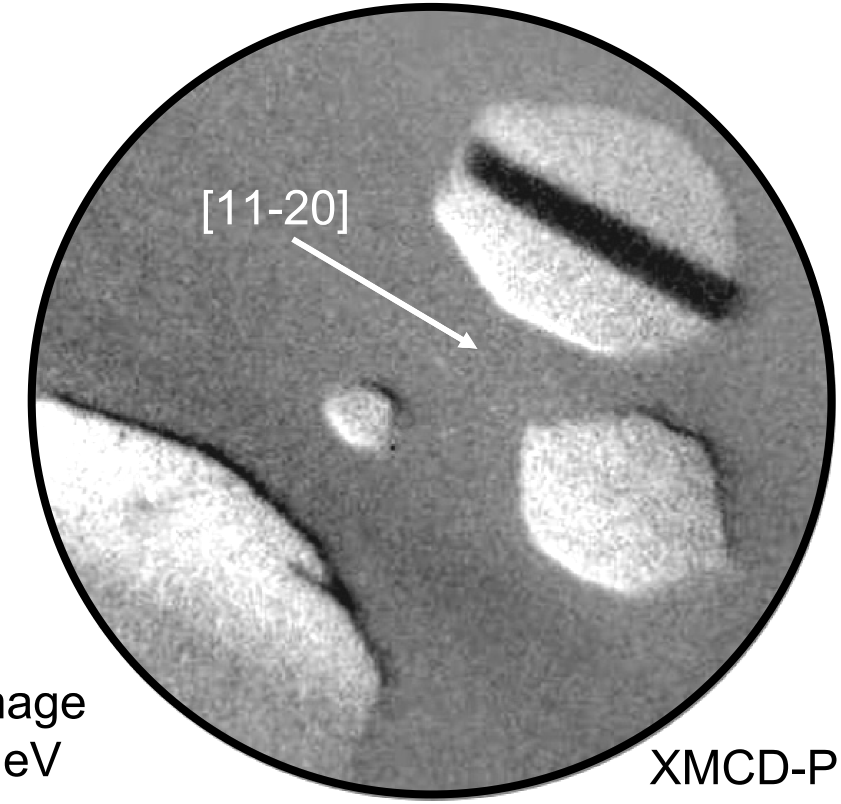
As-decapping at 320°C in the SPELEEM sample preparation chamber

Incompletely decapped MnAs Layer

T < 0°C: Ferromagnetic state



LEEM image
E = 10 eV



XMCD-PEEM

MnAs islands (dark) are surrounded by crystallized As

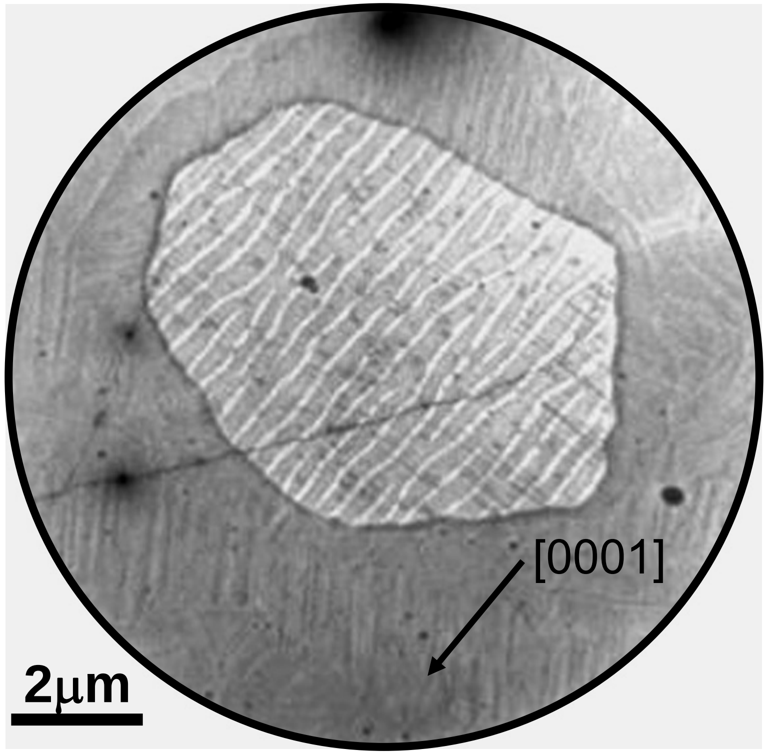
MnAs islands in a completely ferromagnetic state

E. Bauer, S. Cherifi, L. Daeweritz, M. Kaestner, S. Heun, and A. Locatelli: JVST, submitted.

Incompletely decapped MnAs Layer

T = Room temperature

Intermediate ferromagnetic-paramagnetic state



The misfit strain causes coexistence of two phases over a temperature range of about 30°C around room temperature.

LEEM image

electron energy = 4.5 eV

MnAs crystal showing a striped structure with alternating regions of the hexagonal α phase and the orthorhombic β phase.

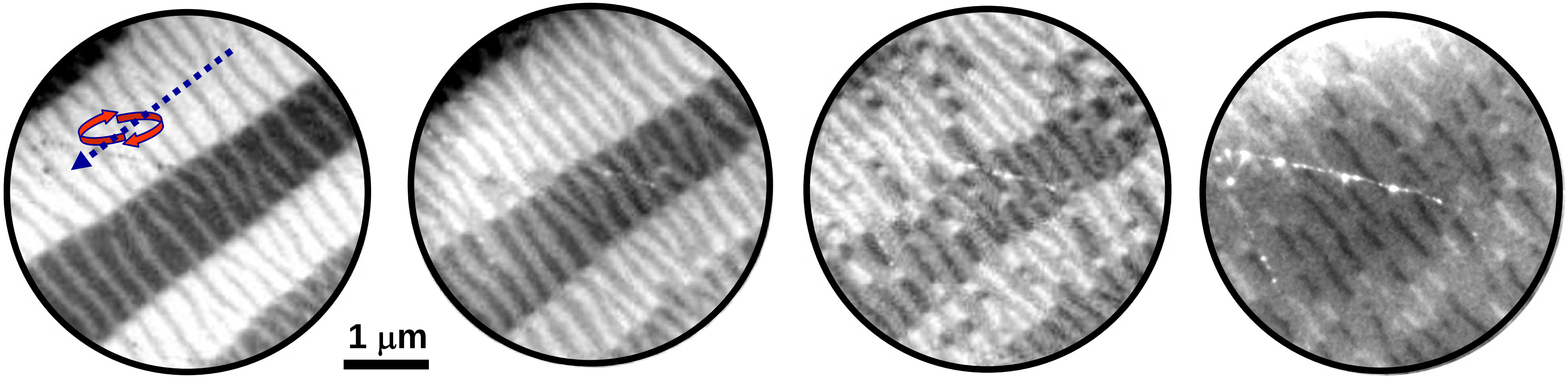
E. Bauer, S. Cherifi, L. Daeweritz, M. Kaestner, S. Heun, and A. Locatelli: JVST, submitted.

Completely decapped MnAs Layer

Magnetic phase transition stage (multi-domain state)

XMCD-PEEM images at the Mn L_3 edge

MnAs[11-20] easy magnetization axis is in the plane of incidence of the photon beam for optimum contrast

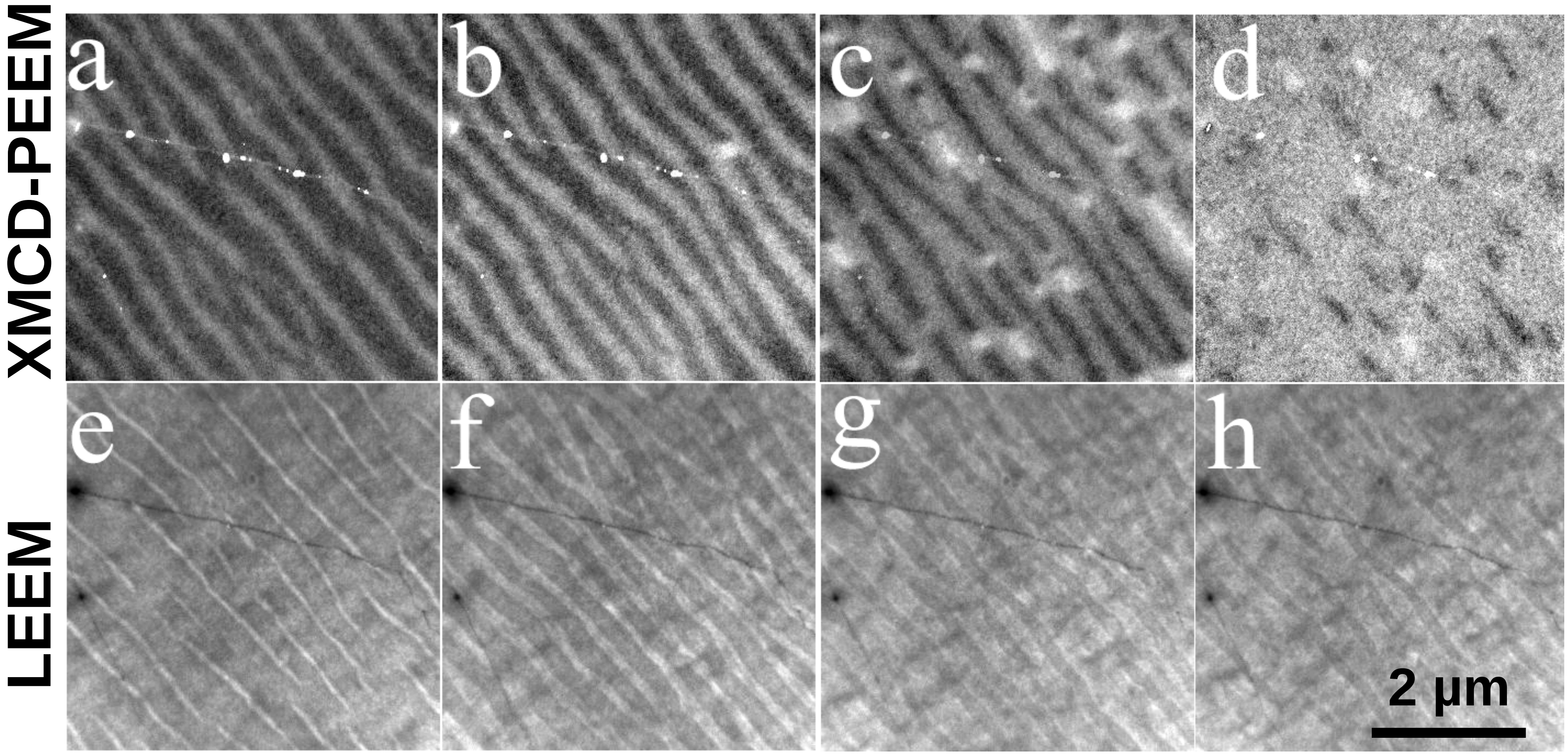


stripe period: 300 ± 10 nm

T: 0 – 40ºC

E. Bauer, S. Cherifi, L. Daeweritz, M. Kaestner, S. Heun, and A. Locatelli: Elettra Highlights 2001-2002.

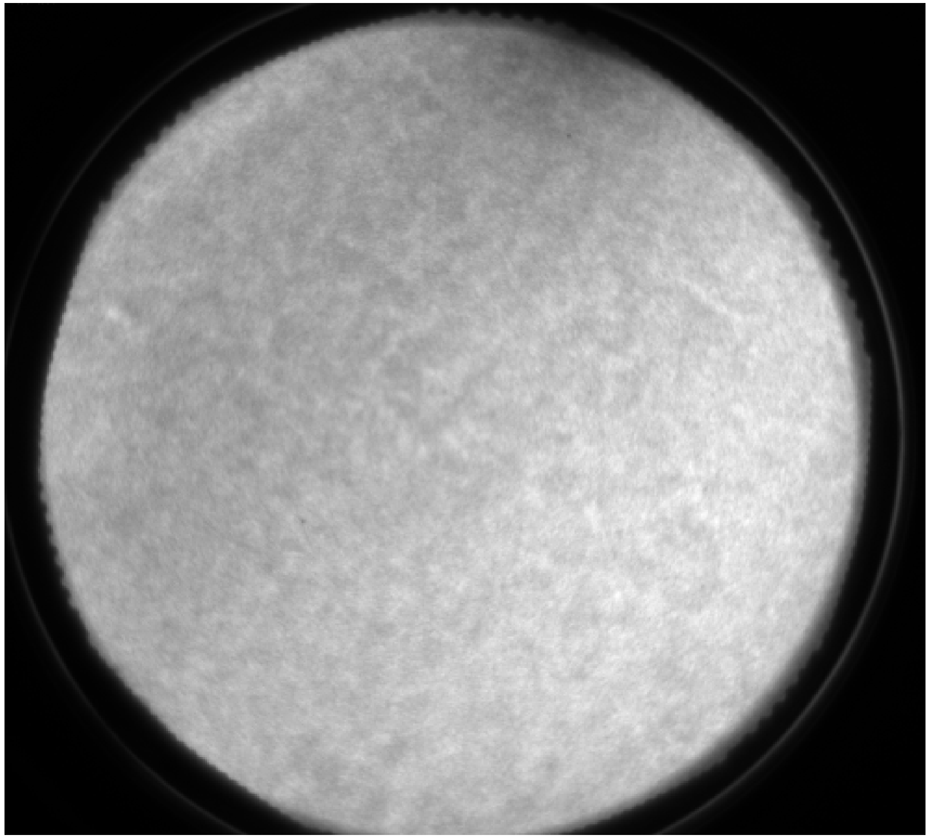
Structural and Magnetic Properties



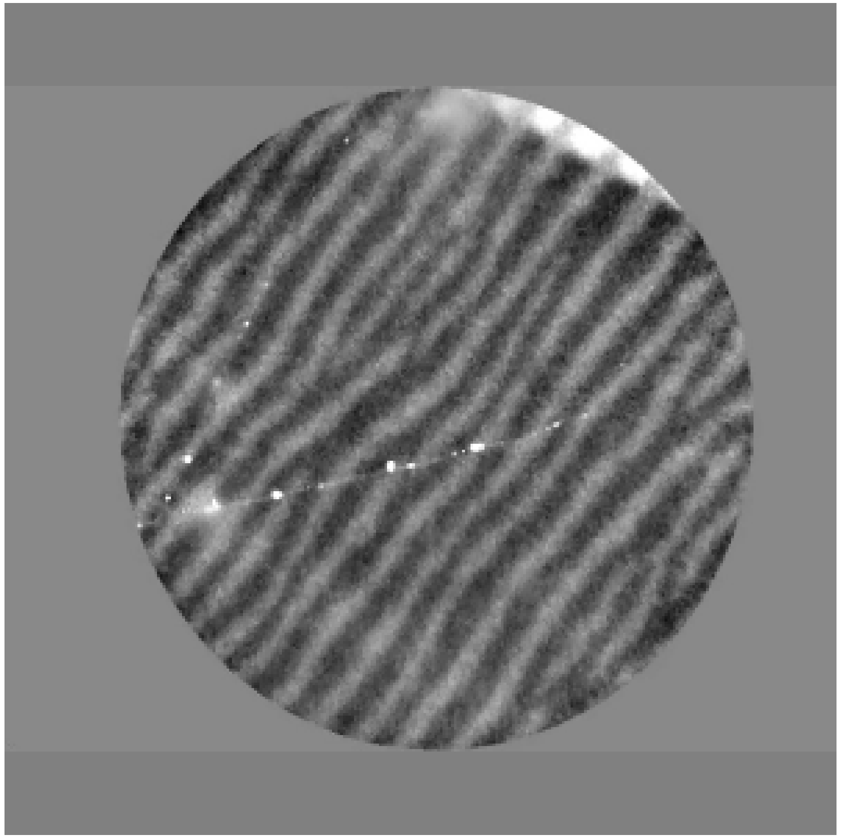
Magnetic and structural phase transition stages during heating

E. Bauer, S. Cherifi, L. Daeweritz, M. Kaestner, S. Heun, and A. Locatelli: http://www.elettra.trieste.it/science/update

Movies

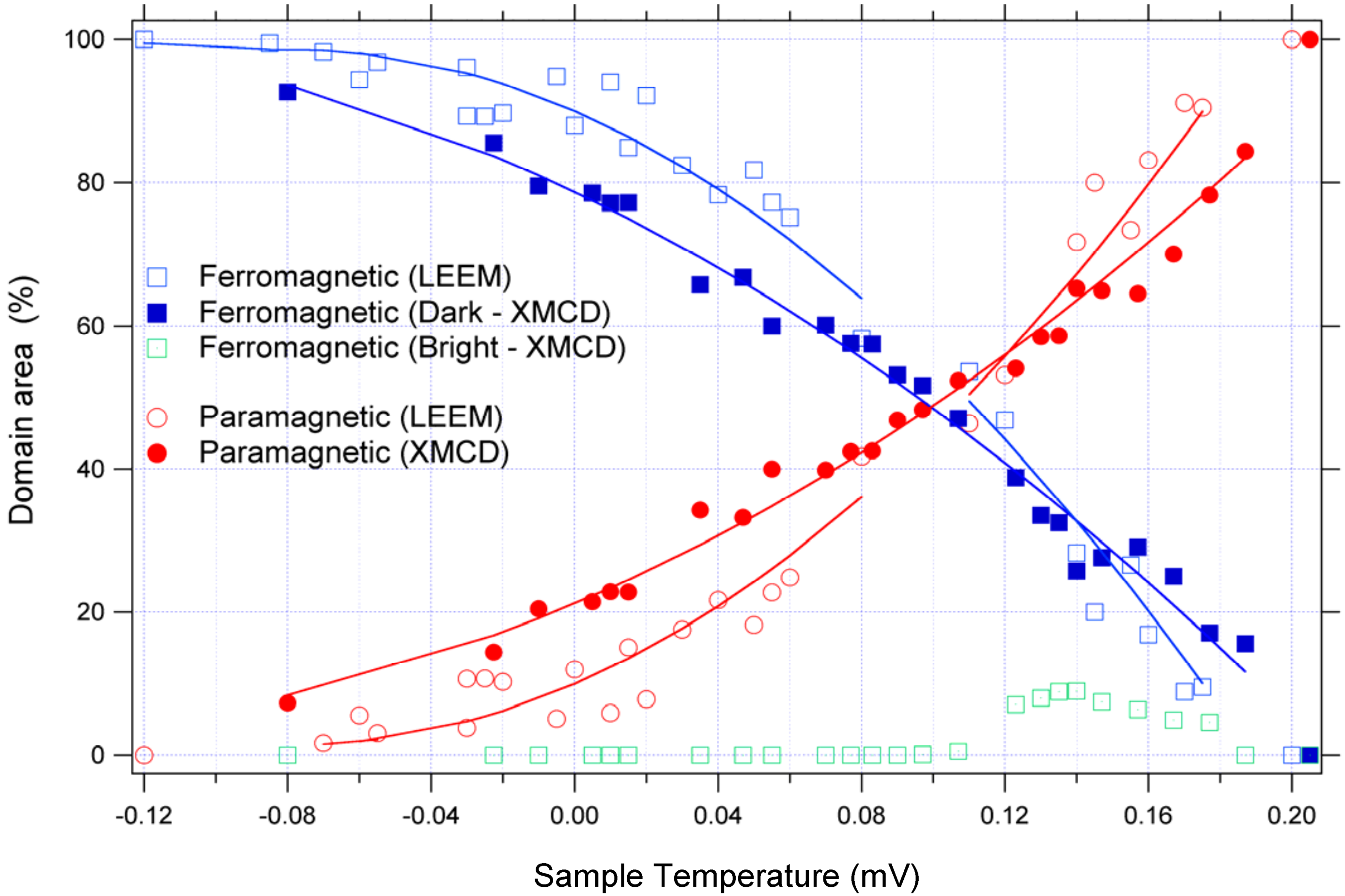


LEEM



XMCD-PEEM

Area Fractions



Evolution of the area fractions of the magnetic phases (ferromagnetic and paramagnetic) and structural phases (α and β) derived from rsp. XMCD-PEEM and LEEM images taken during heating.

elettra
Synchrotron
Light
Laboratory

Summary

- The phase transition of epitaxial MnAs films on GaAs(100) from the ferromagnetic α phase to the paramagnetic β phase occurs via phase separation into a ferromagnetic and paramagnetic striped phase without noticeable decrease of the magnetic moment.
- The stripe period (300 nm) is constant during this transition, causing a continuous decrease of the ferromagnetic stripe width.
- The stripes remain correlated until their distance exceeds a critical value at which they break up into small domains with opposite magnetization.