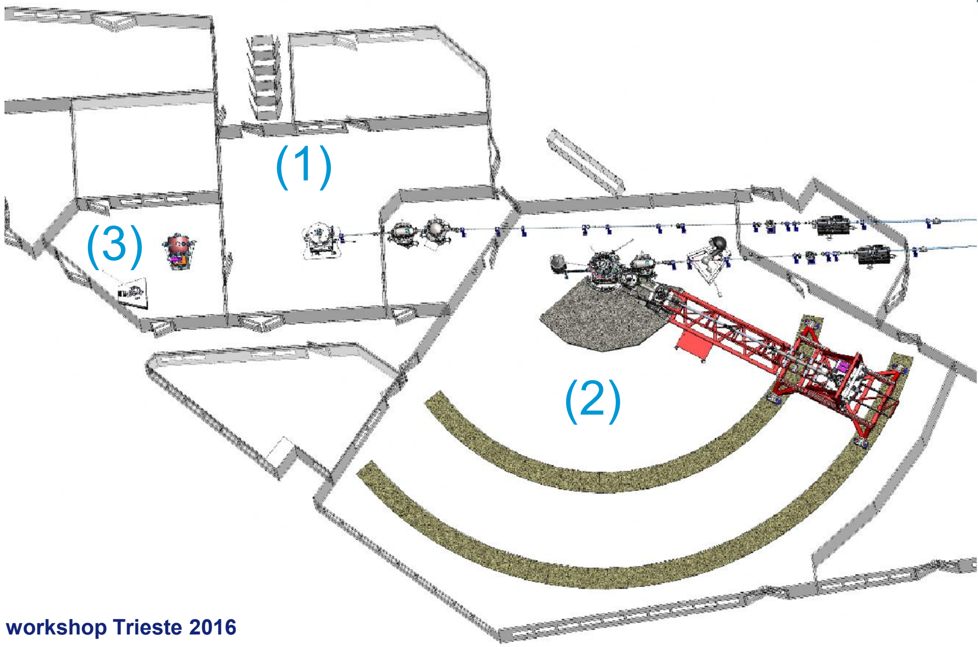
Optical design and performance of the ESRF soft X-ray beamline

Kurt Kummer*, Nick Brookes
ESRF
**kurt.kummer@esrf.fr*

ID32 - THE NEW ESRF SOFT X-RAY BEAMLINE

Soft X-ray beamline for polarisation dependent studies

1) X-ray absorption in high fields, low temperatures (XMCD, XMLD)
2) Resonant inelastic X-ray scattering (RIXS)
3) Open experimental area



ID32 - THE NEW ESRF SOFT X-RAY BEAMLINE

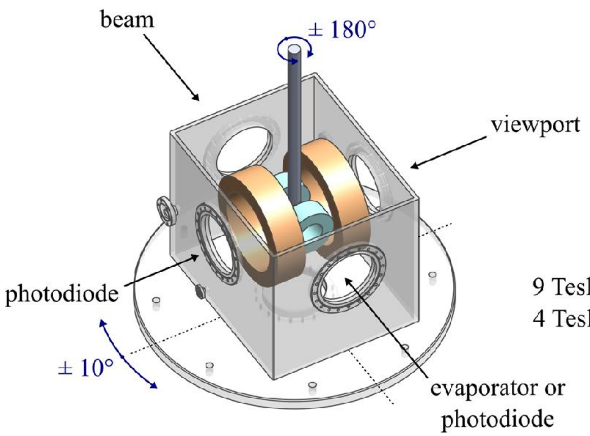
XMCD branch

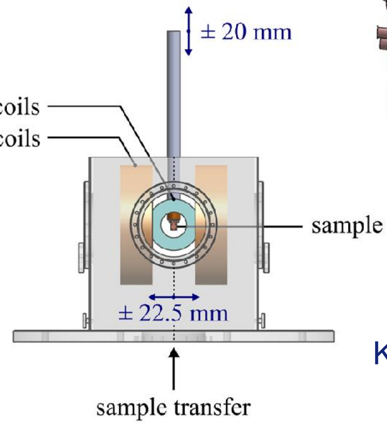
Element specific magnetic characterization with extreme sensitivity

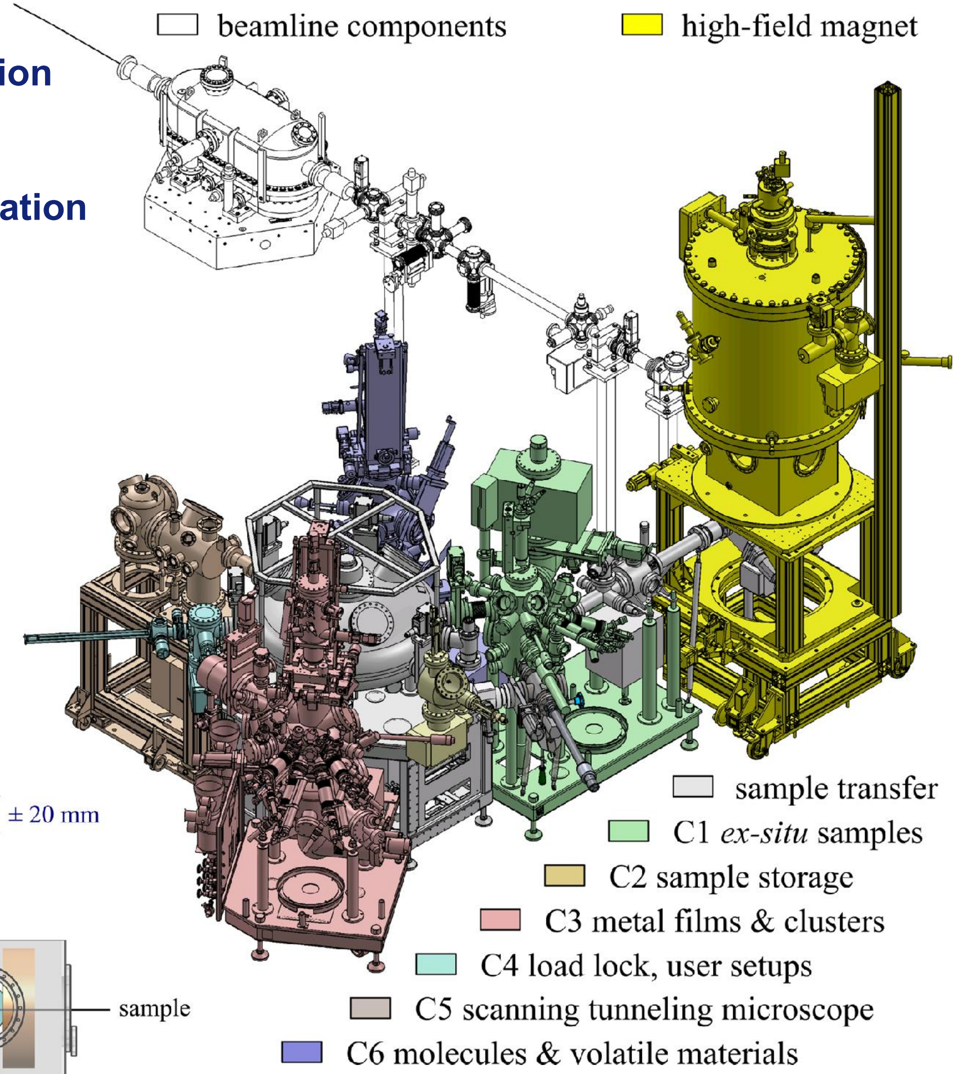
In-situ sample preparation & characterization

Magnetic fields
9T parallel (4T orthogonal) to the beam
high sweep rates of 8T/min (2T/min)

Temperatures
Today 5 K to 325 K, target 3 K to 400 K

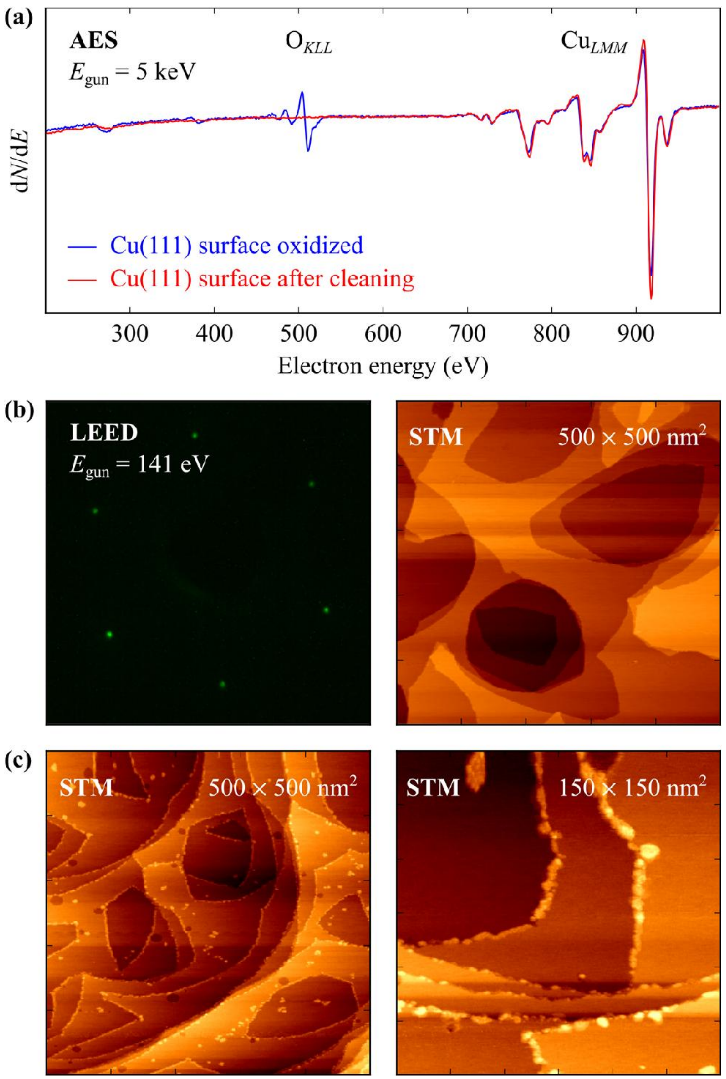




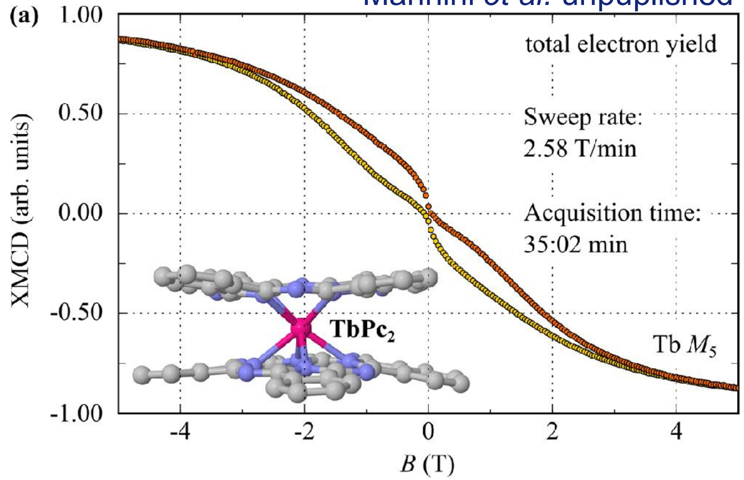


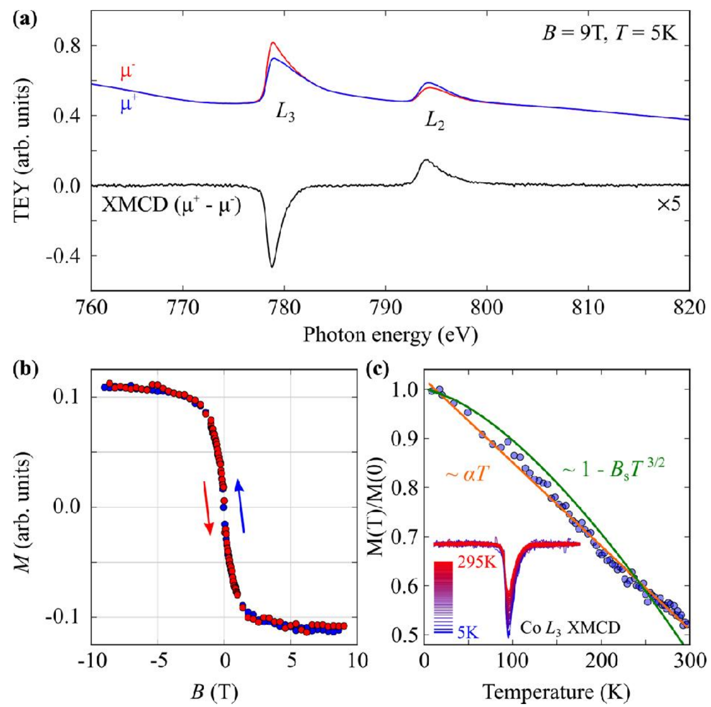
Kummer *et al.* J. Synchr. Rad. **23**, 464 (2016)

XMCD branch



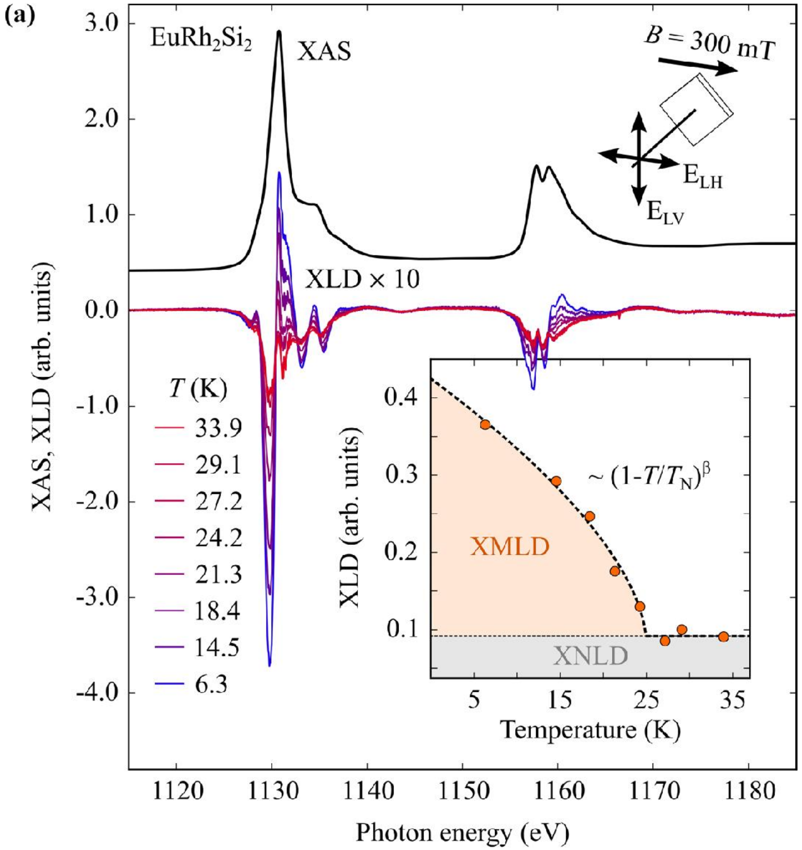
Mannini *et al.* unpuplished





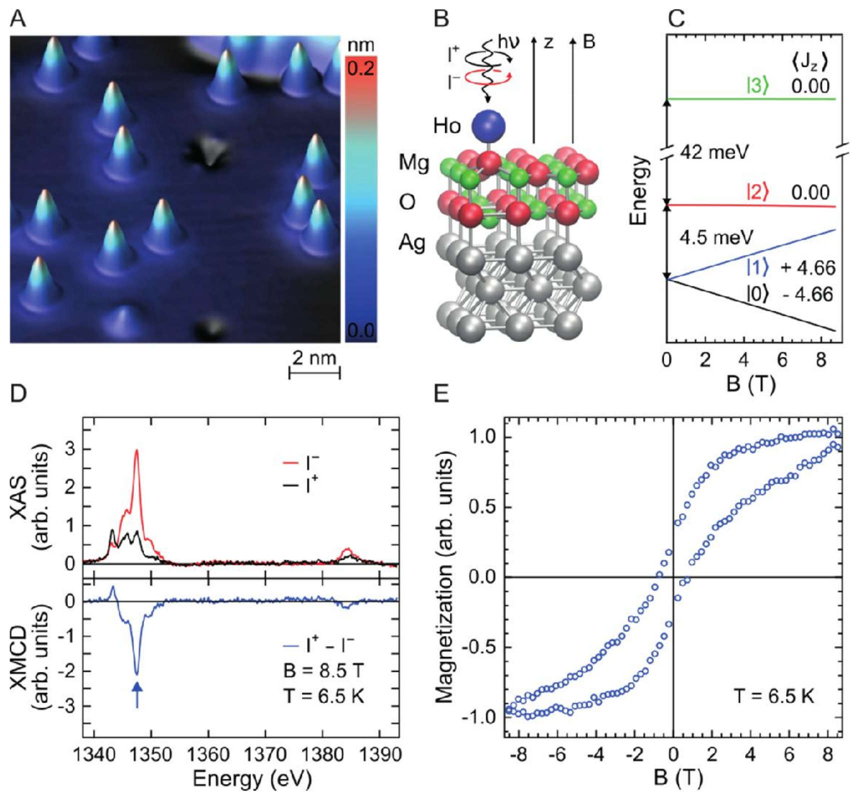
Kummer *et al.* J. Synchr. Rad. **23**, 464 (2016)

XMCD branch



Kummer *et al.* J. Synchr. Rad. **23**, 464 (2016)

Recent highlight

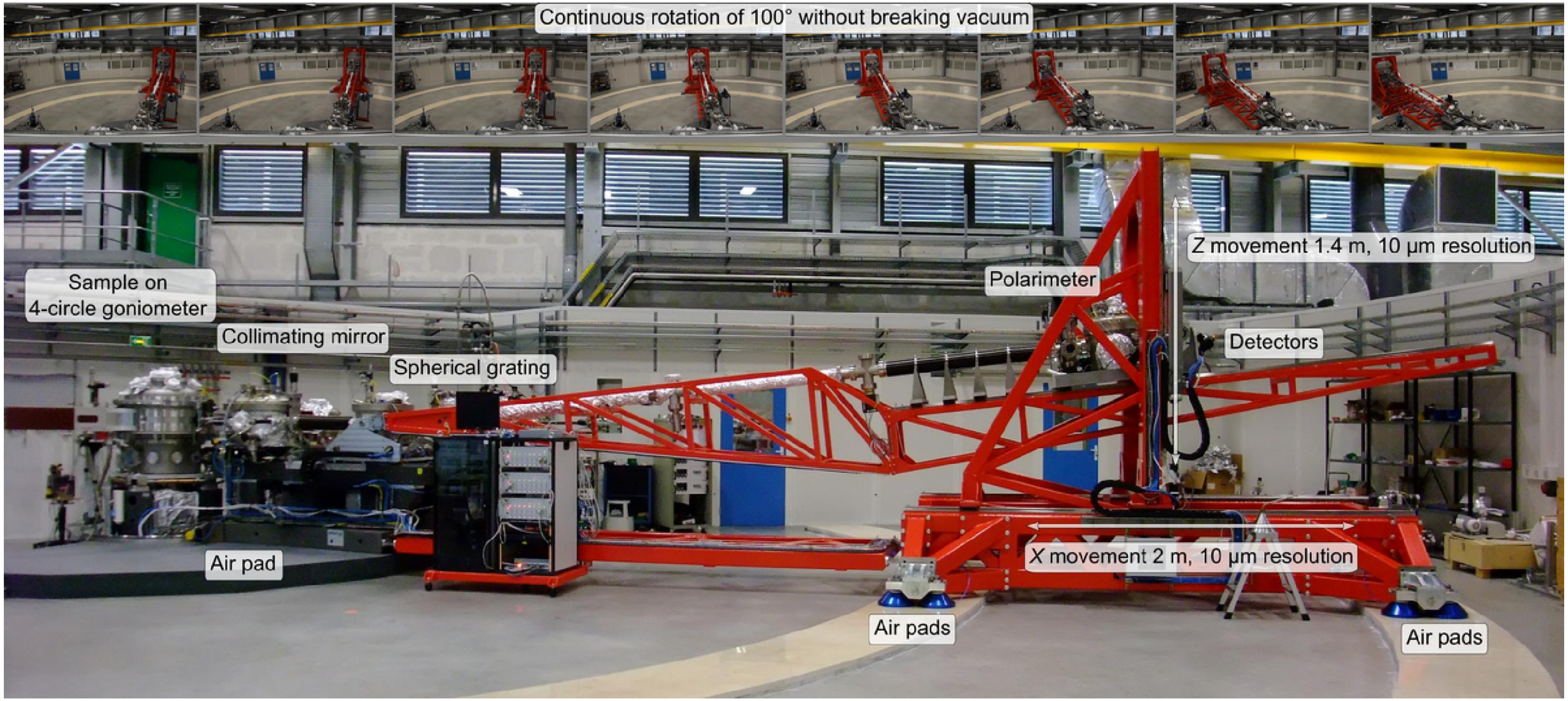


Magnetic remanence in single atoms
F. Donati et al. Science **352** (2016) 318.

RIXS branch

- Resolution
- Flexible scattering geometry, 3D materials
- Polarimetry

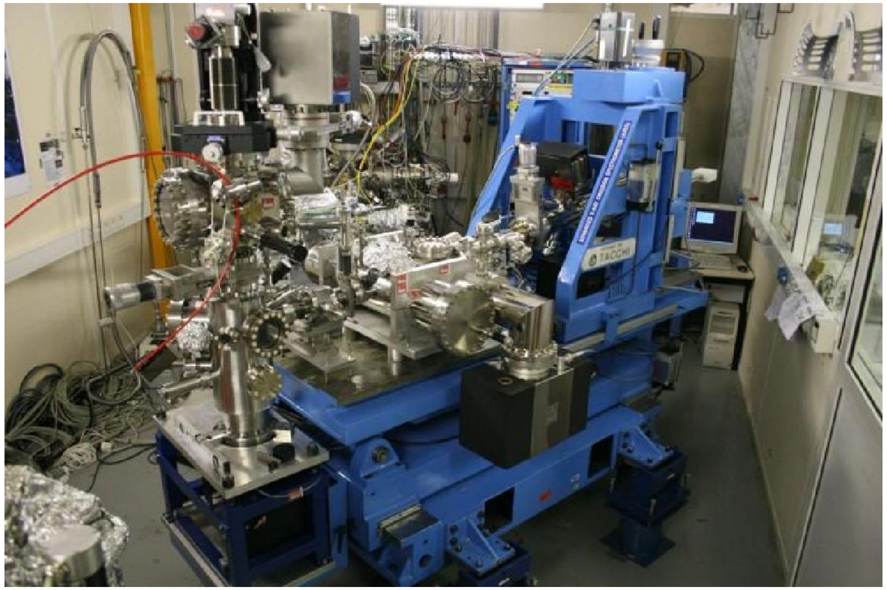
Giacomo Ghiringhelli
Lucio Braicovich



RIXS branch

AXES – ID08 ESRF

In operation 1994-2013
2.2 m scattering arm
Design: E/ΔE = 2,000 at Cu L_3 (930 eV)
2010: E/ΔE = 5,000 at Cu L_3



C. Dallera *et al.* J. Synchrotron Radiat. 3, 231 (1996).
G. Ghiringhelli *et al.*, Rev. Sci. Instrum. 69, 1610 (1998).
M. Dinardo *et al.*, Nucl, Instrum. Meth A 570, 176 (2007

SAXES – ADRESS beamline at PSI-SLS

In operation since 2007
5.0 m scattering arm
Design: E/ΔE = 12,000 at Cu L_3
2008: E/ΔE = 10,000 at Cu L_3

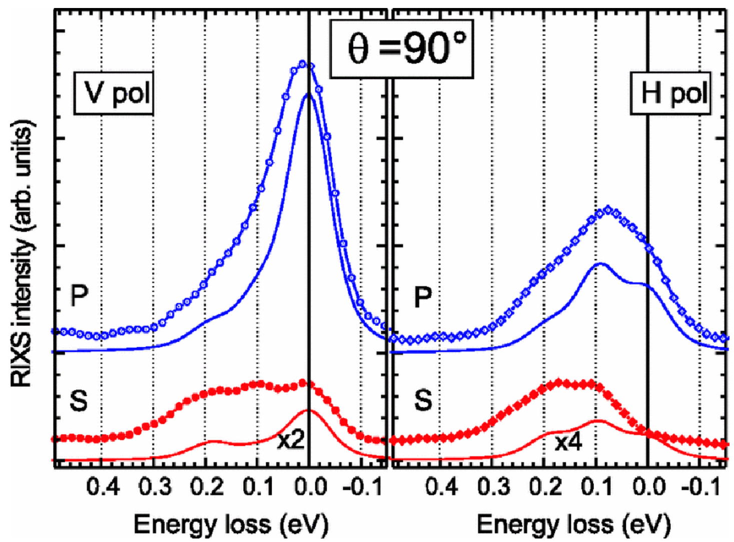
G. Ghiringhelli *et al.,* Rev. Sci. Instrum. 77, 113108 (2006).
V. Strocov *et al.*, J. Synch. Rad., 17, 631 (2010).

Giacomo Ghiringhelli
Lucio Braicovich

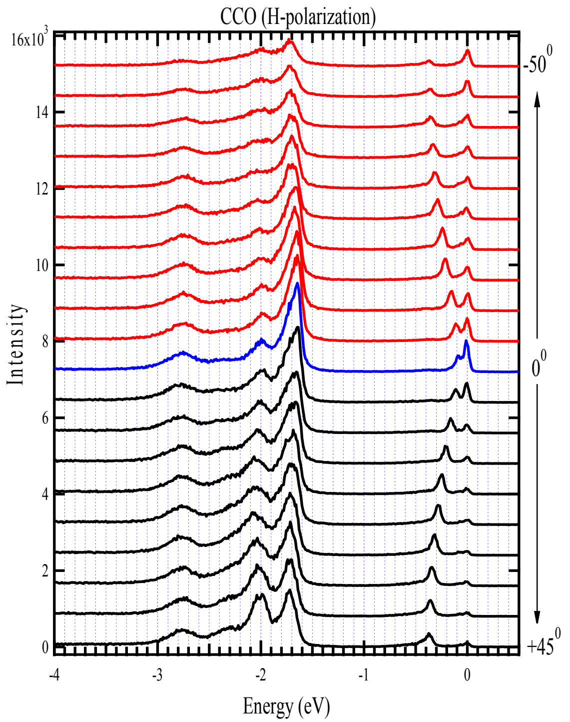
ID32 - THE NEW ESRF SOFT X-RAY BEAMLINE

RIXS branch

ADRESS (PSI-SLS)

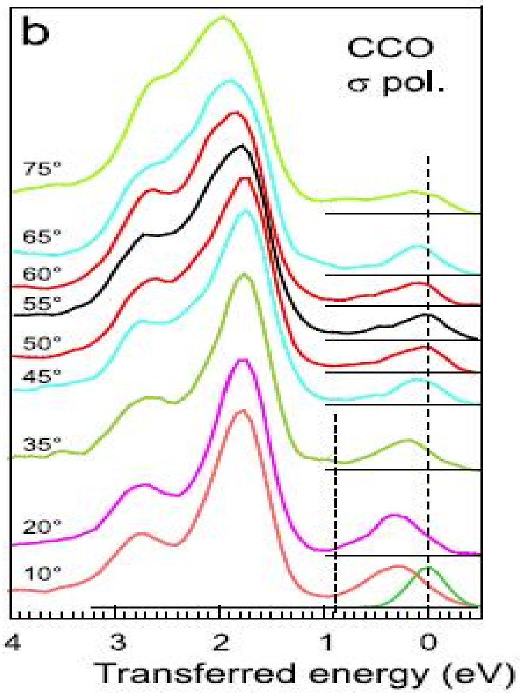


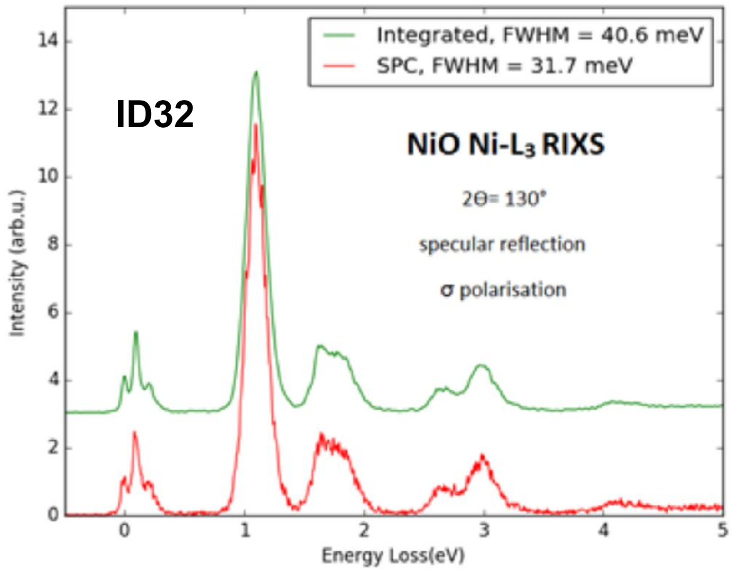
ID32



Ghiringhelli *et al.*

ID08





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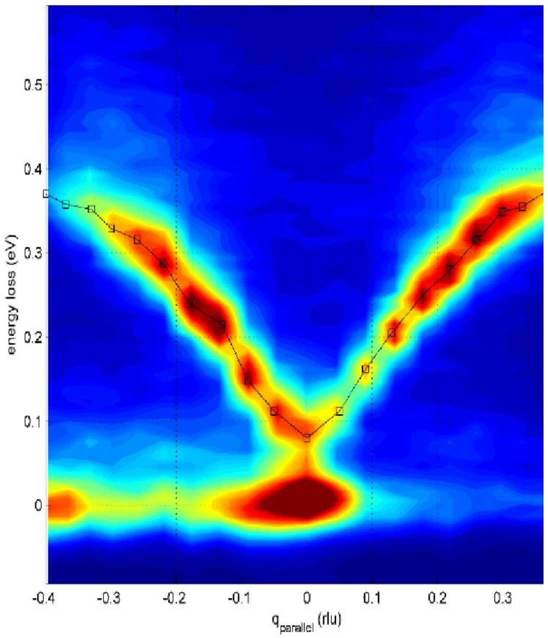
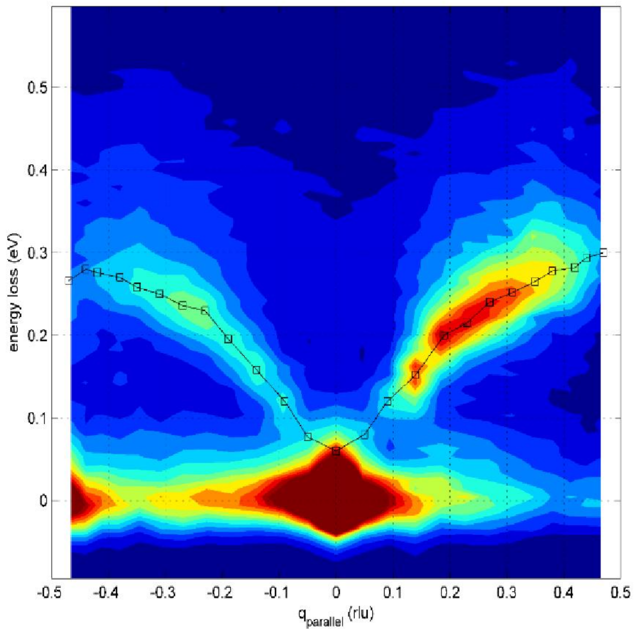
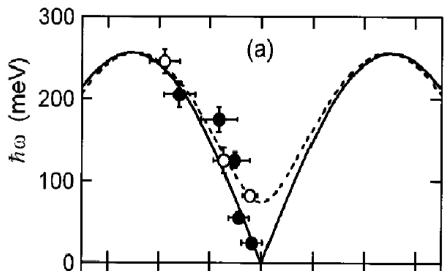
RIXS branch

$CaCuO_2$



$Nd_{1.2}Ba_{1.8}Cu_3O_6$





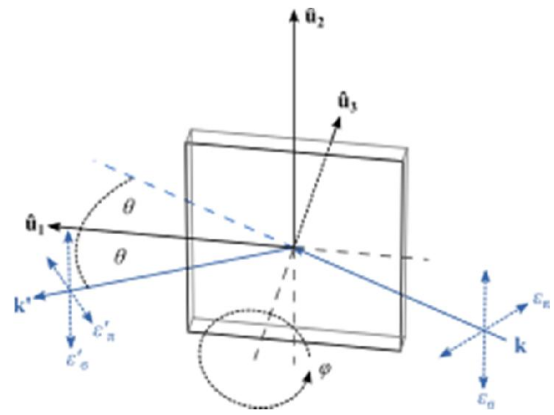
S. M. Hayden et al, PRB **54**, R6905 (1996)

The sample used in INS was a 96g $YBa_2Cu_3O_{6.15}$ single crystal.

Ghiringhelli *et al.* Jul 2015

Giacomo Ghiringhelli
Lucio Braicovich

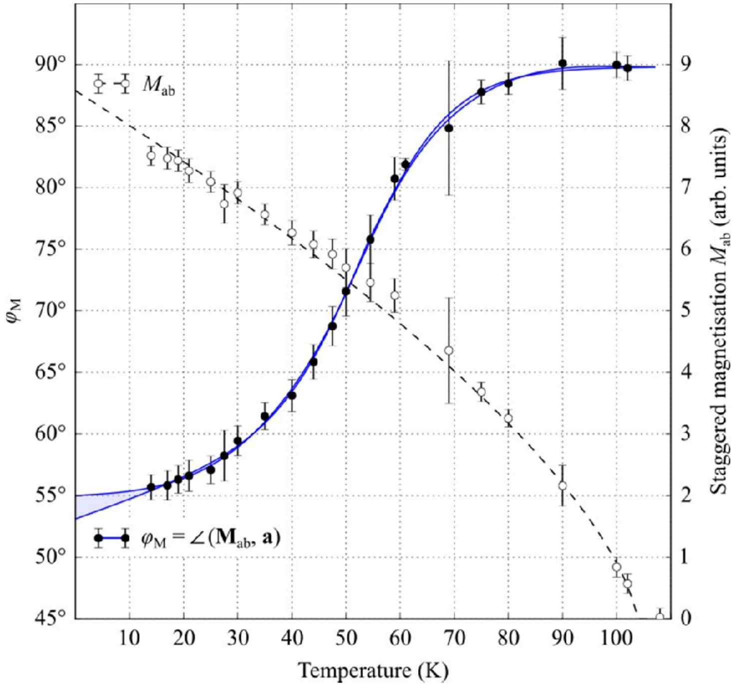
Open for other types of experiments

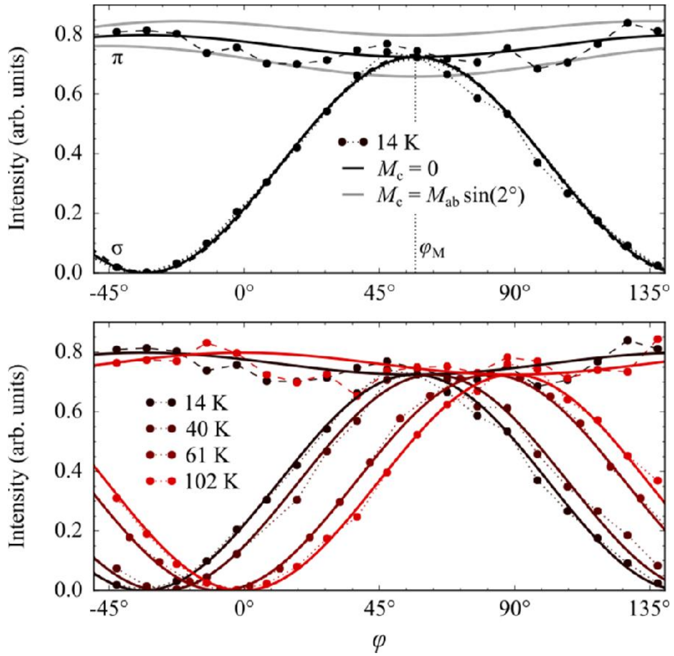


Resonant magnetic X-ray scattering

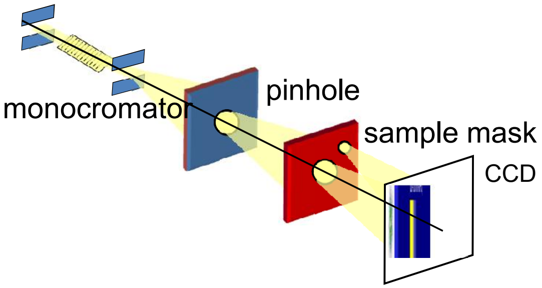
$GdRh_2Si_2$: Strongly T-dependent antiferromagnetic magnetic order in the absence of a crystal field

Kummer *et al.* In preparation.



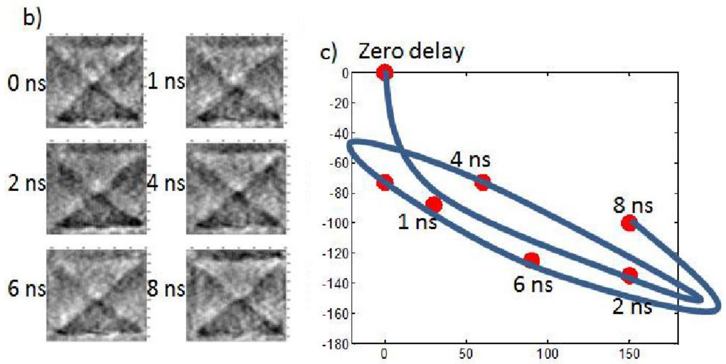


Open for other types of experiments



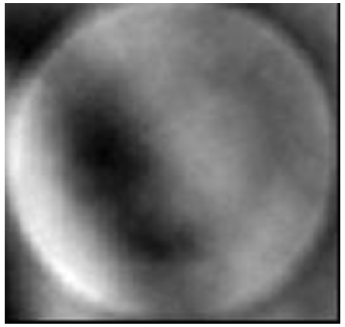
Coherent Imaging

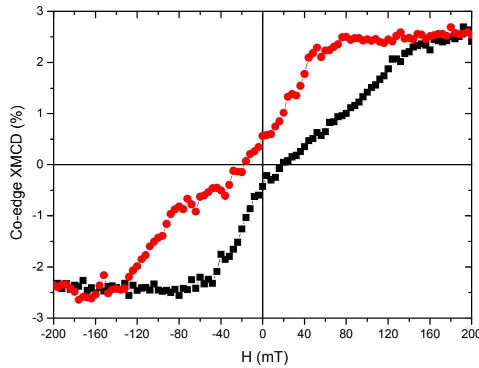
Vortex core gyration in square permalloy elements



Ogrin *et al.* under review at Scientific Reports

Origin of exchange bias: pinning sites and interfacial effects





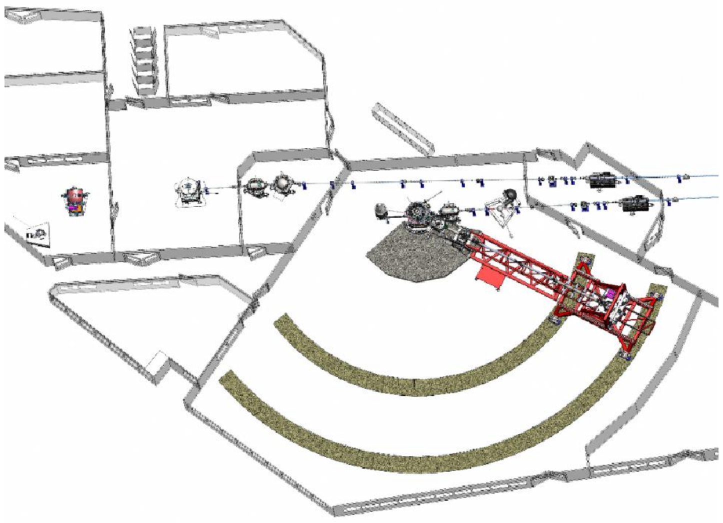
$(PtCo)_{12}Pt_2(NiFe)_4/Al$, signal from 1% of a buried monolayer

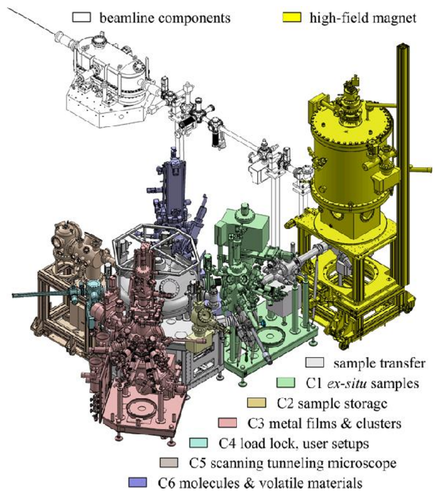
C. Tieg *et al.* Appl. Phys. Lett. **96**, 072503 (2010)
Done at ID08

STARTING POINT FOR THE OPTICAL DESIGN

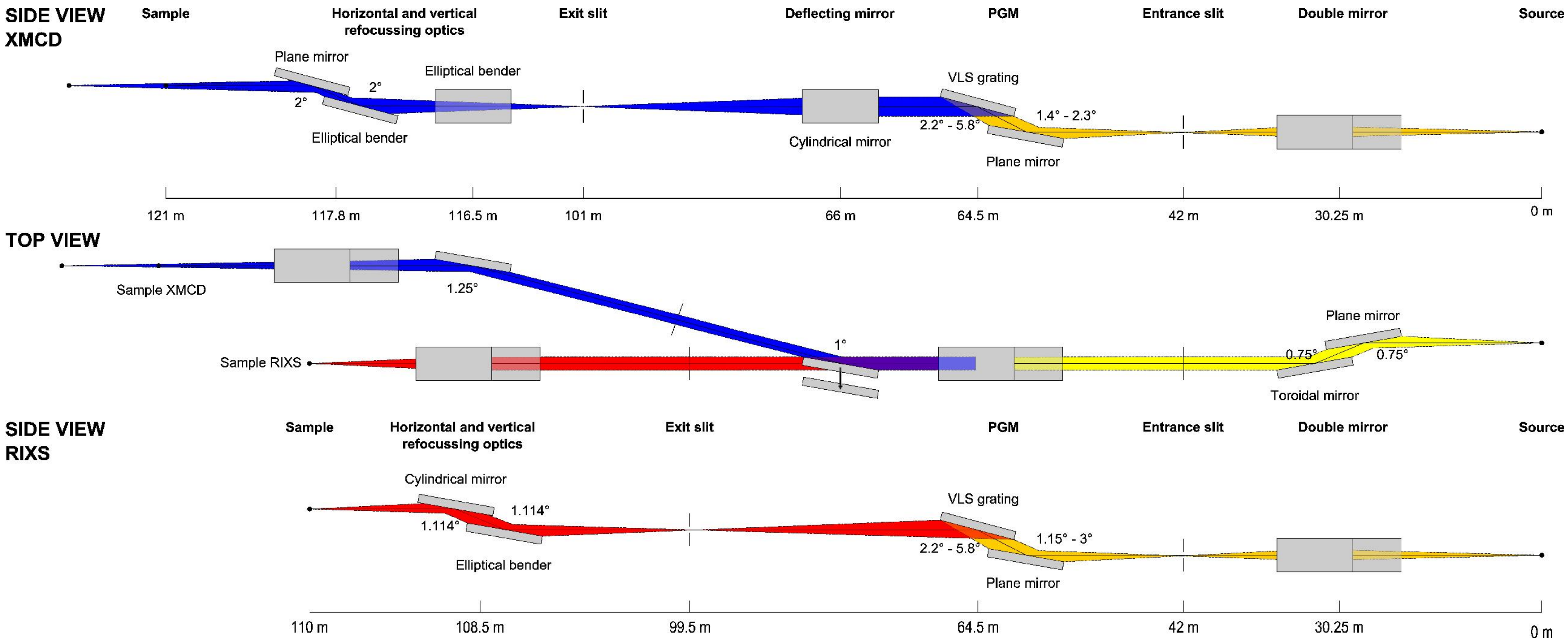
Two branches sharing the same monochromator mechanics

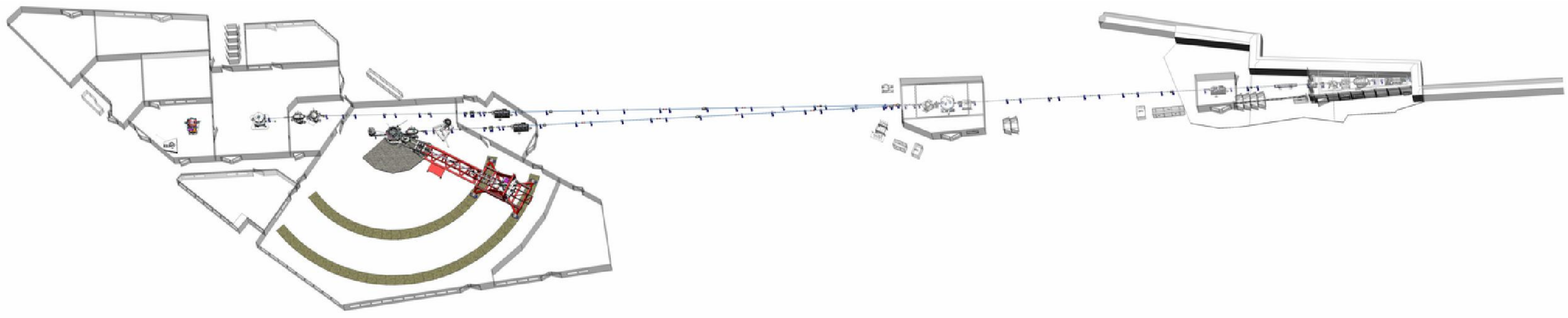
	RIXS branch	XMCD branch
Resolving power (RP) E/δE	~ 50000	~ 5000
Spot size FWHM HxV [μm]	50x4	50x10 (variable)
Fast energy scanning	no	Yes, critical
Wide energy scans at constant (slowly varying) resolution	no	Yes, critical
Photon hungry (high flux / band width unit)	Yes, critical	Less critical
High stability of energy scale	important	critical
Working distance (sample to last mirror)	1 m	3 m





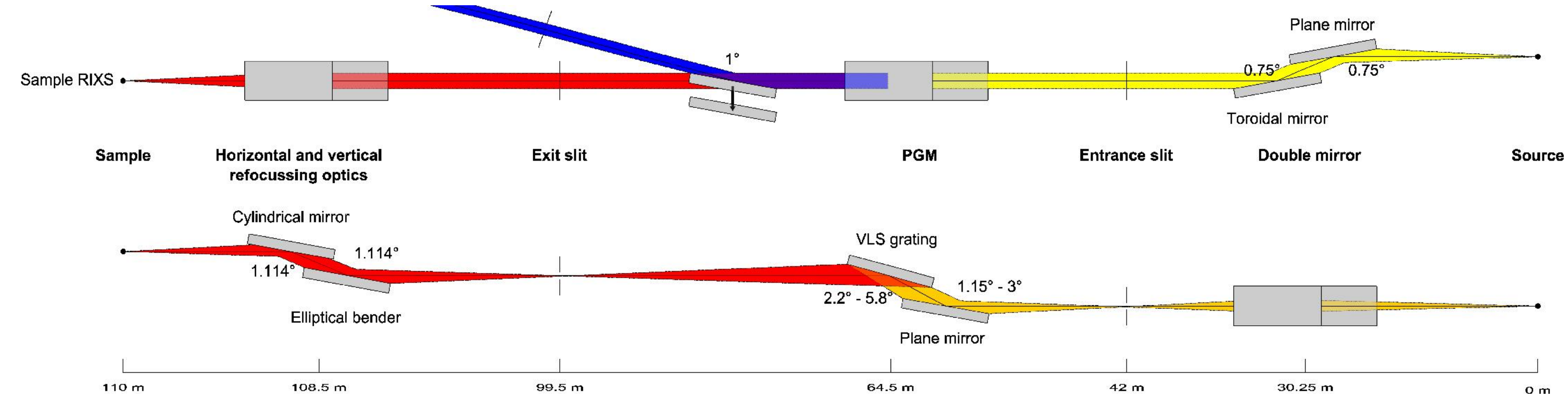
OPTICAL DESIGN





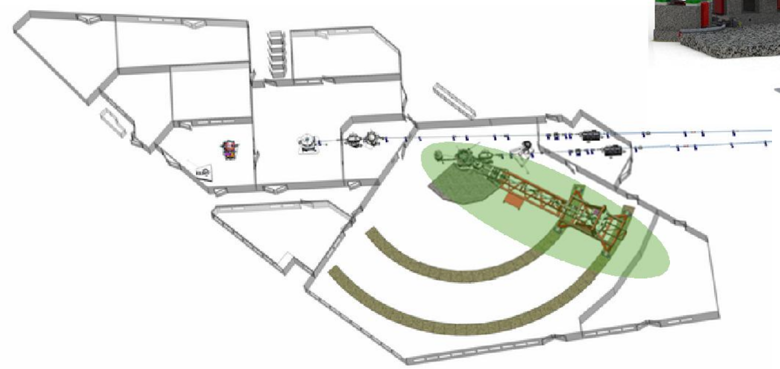
RIXS BRANCH

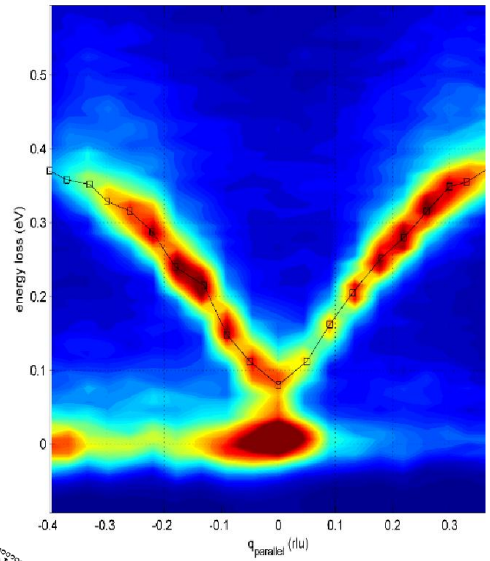
SIDE VIEW
RIXS



Resolving power

Photon flux





Giacomo Ghiringhelli
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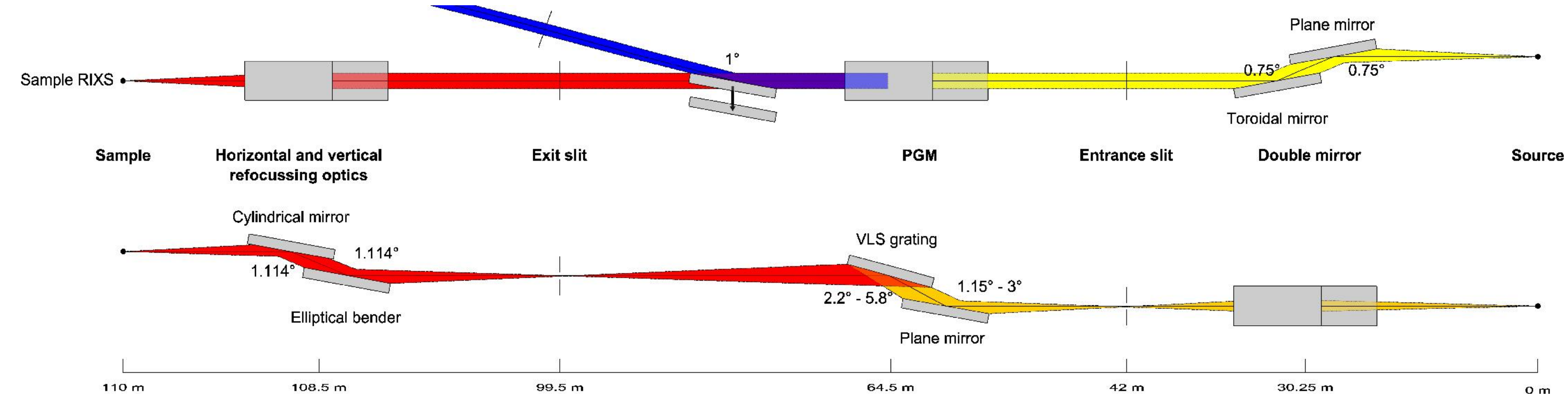
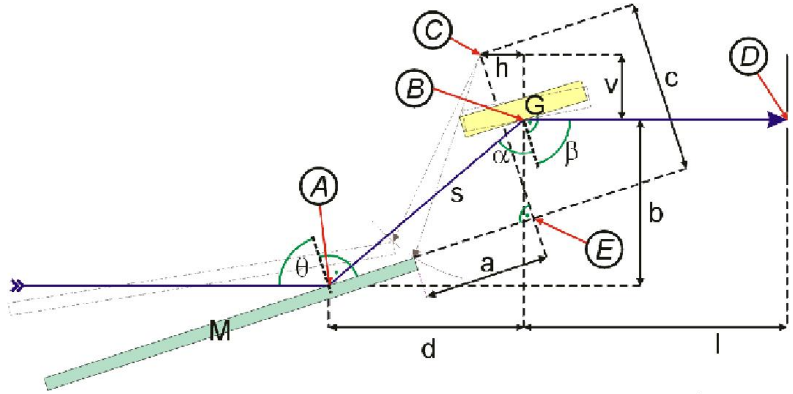
RIXS BRANCH - OPTICAL CONCEPT

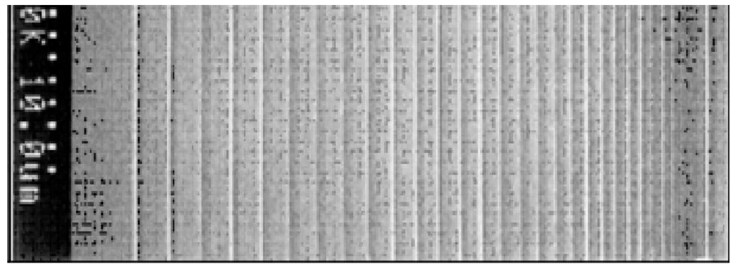
SIDE VIEW RIXS



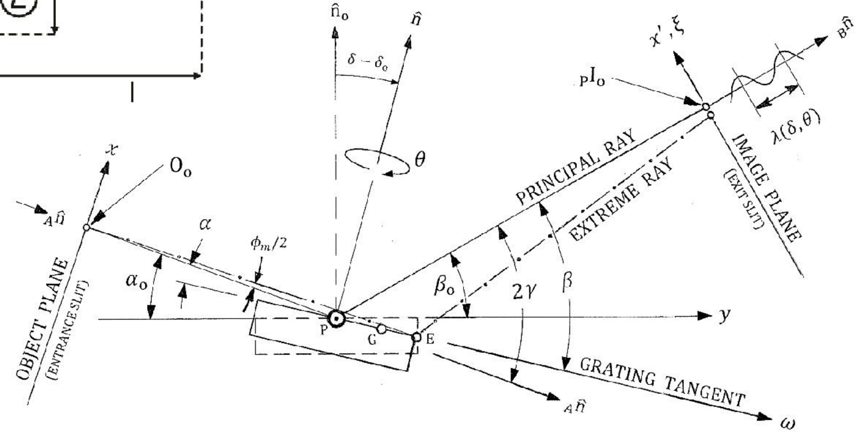
Classic VLS plane-grating monochromator (SX700/Peterson style)



$$D(w) = a_0 + a_1 w + a_2 w^2 + a_3 w^3 \ldots\ldots$$



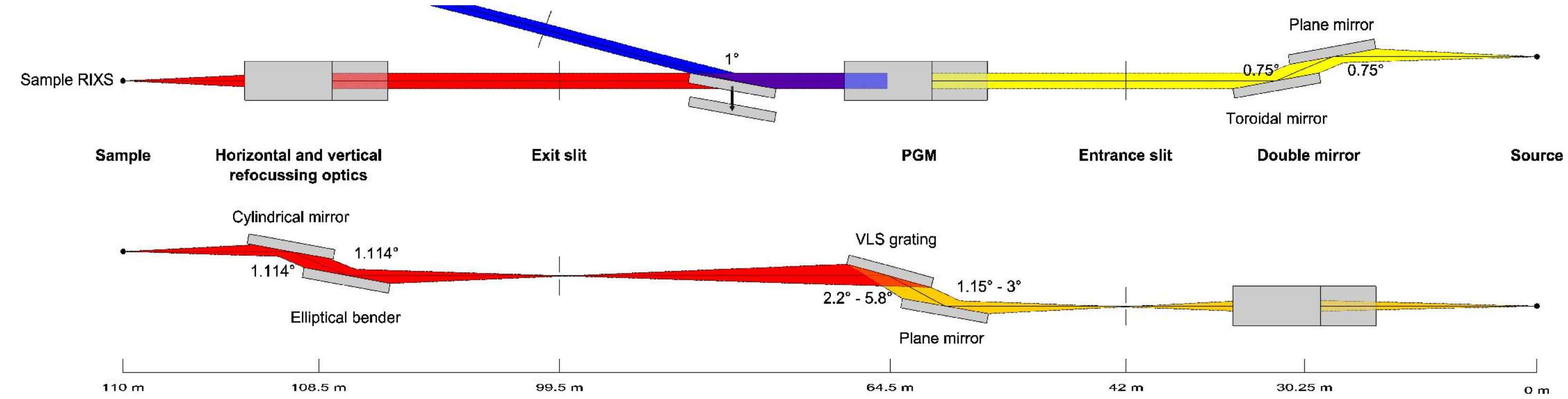
Hitachi



Hettrick. Photonics **3**, 3 (2016)

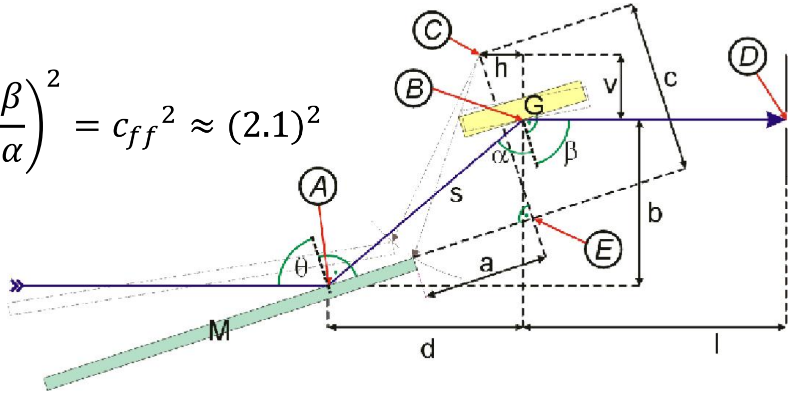
RIXS BRANCH - OPTICAL CONCEPT

SIDE VIEW RIXS



Classic VLS plane-grating monochromator (SX700/Peterson style)

$$-\frac{r'}{r} = \left(\frac{\cos\beta}{\cos\alpha}\right)^2 = c_{ff}^{\,2} \approx (2.1)^2$$



$$\gamma = \frac{\alpha-\beta}{2} - \delta$$

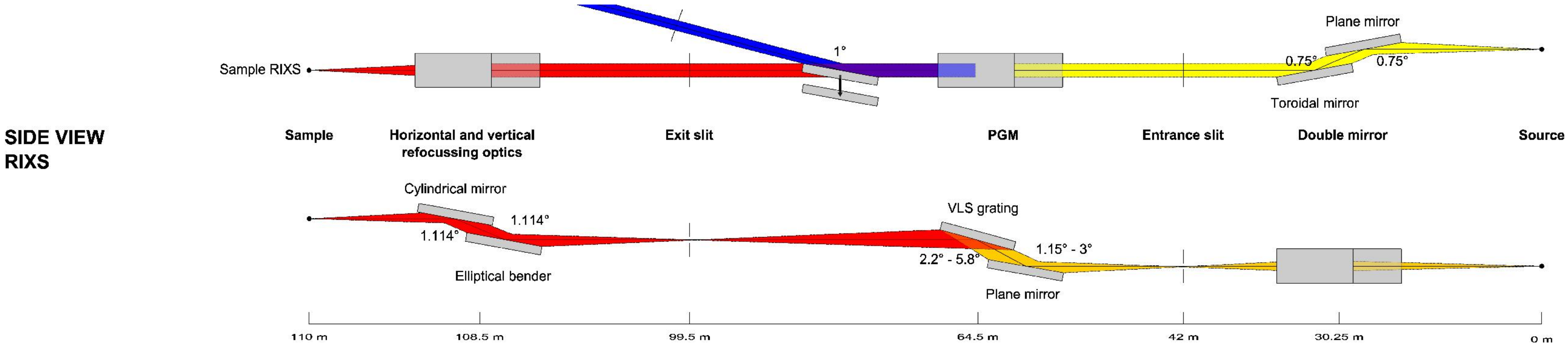
$$D(w) = a_0 + a_1 w + a_2 w^2 + a_3 w^3 \ldots\ldots$$

$$a_1 = \frac{\left(\frac{\cos^2\alpha}{r_1} + \frac{\cos^2\beta}{r_2}\right)}{n\lambda} \qquad a_2 = \frac{3\left(\frac{\sin\alpha\cos^2\alpha}{r_1^{\,2}} + \frac{\sin\beta\cos^2\beta}{r_2^{\,2}}\right)}{2n\lambda}$$

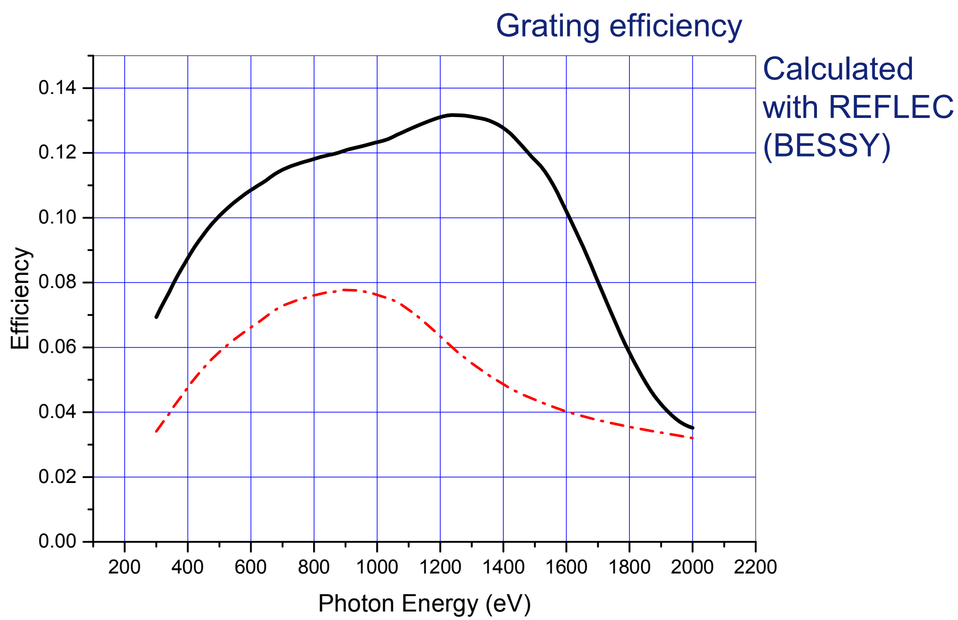
Grating parameters		
l/mm	800	1600
Ruled Area (mm x mm)	180 x 12.5	180 x 12.5
c/a	0.61 / 0.63	0.67 / 0.69
Groove depth (nm)	9.52 / 13.26	5.7 / 8.45
Roughness (nm rms)		
VLS parameters: a0 (l/mm) a1 (l/mm²) a2 (l/mm³)	 799.878 0.058775 1.811×10^{-6} (2.5211×10^{-8})	 1599.746 0.11789 2.9944×10^{-6} (8.4697×10^{-9})
Au coating (nm)	50	50

a1 chosen to zero defocus term if c_{ff} fixed
a2 chosen to zero coma

RIXS BRANCH - OPTICAL CONCEPT



Classic VLS plane-grating monochromator (SX700 style)



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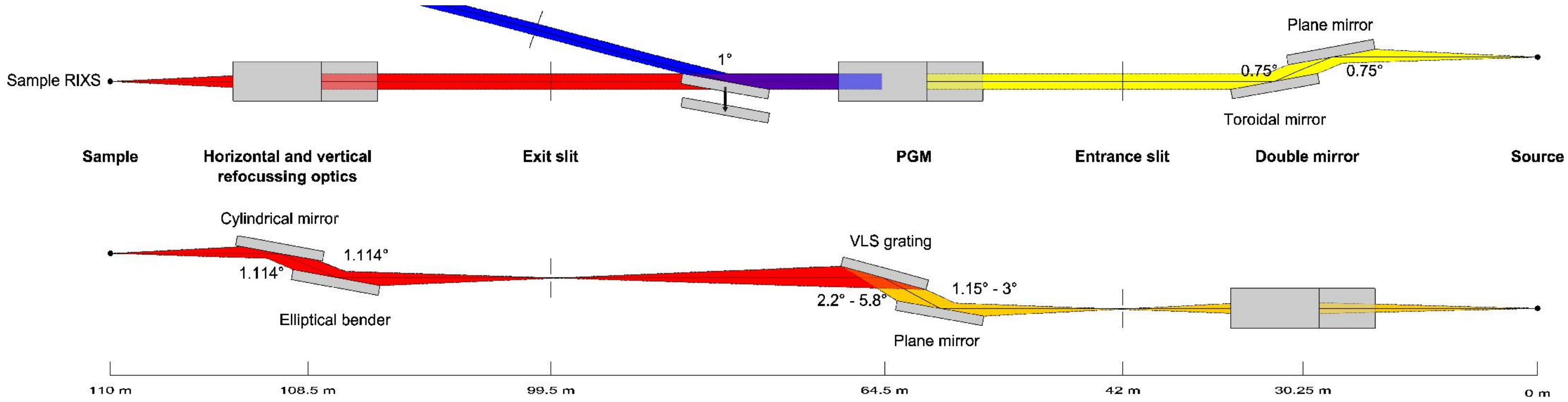
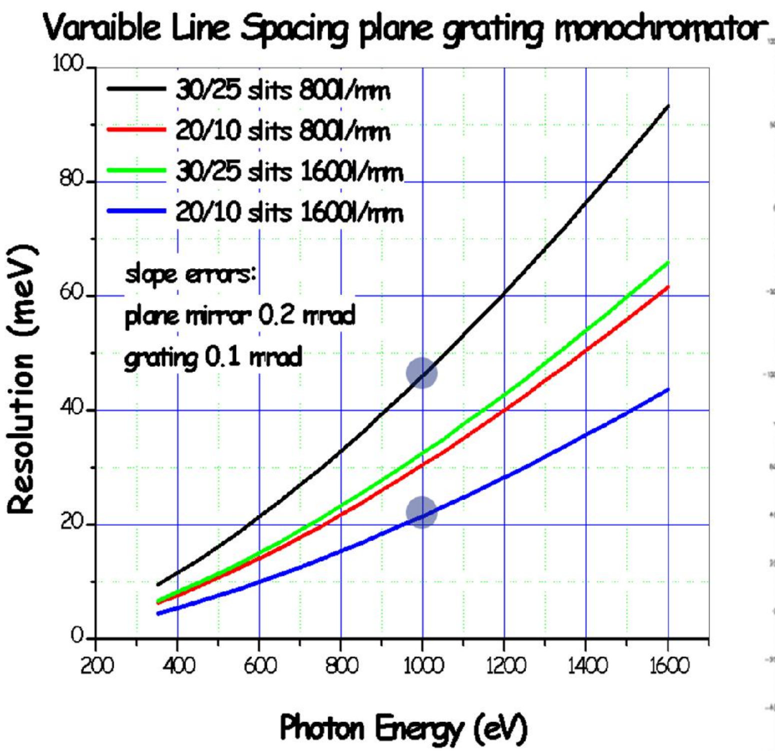
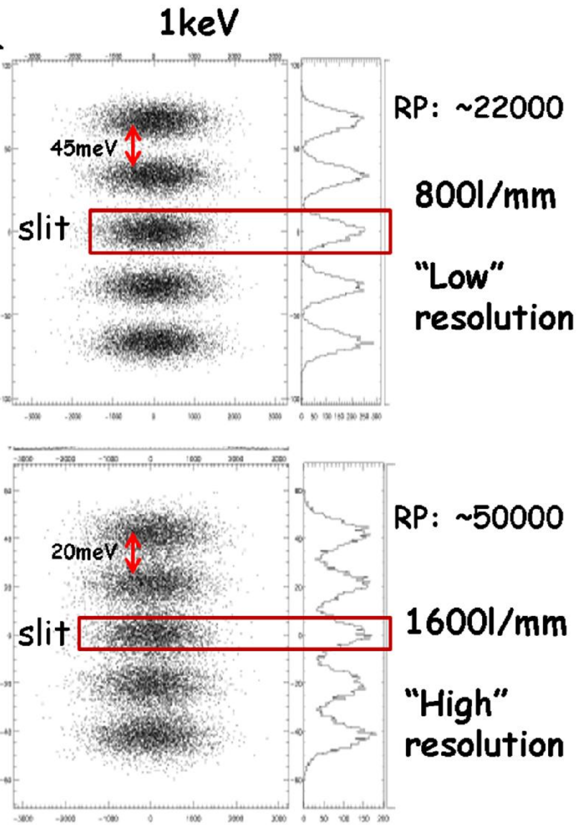
a2 chosen to zero coma

RIXS BRANCH – RESOLUTION

SIDE VIEW
RIXS



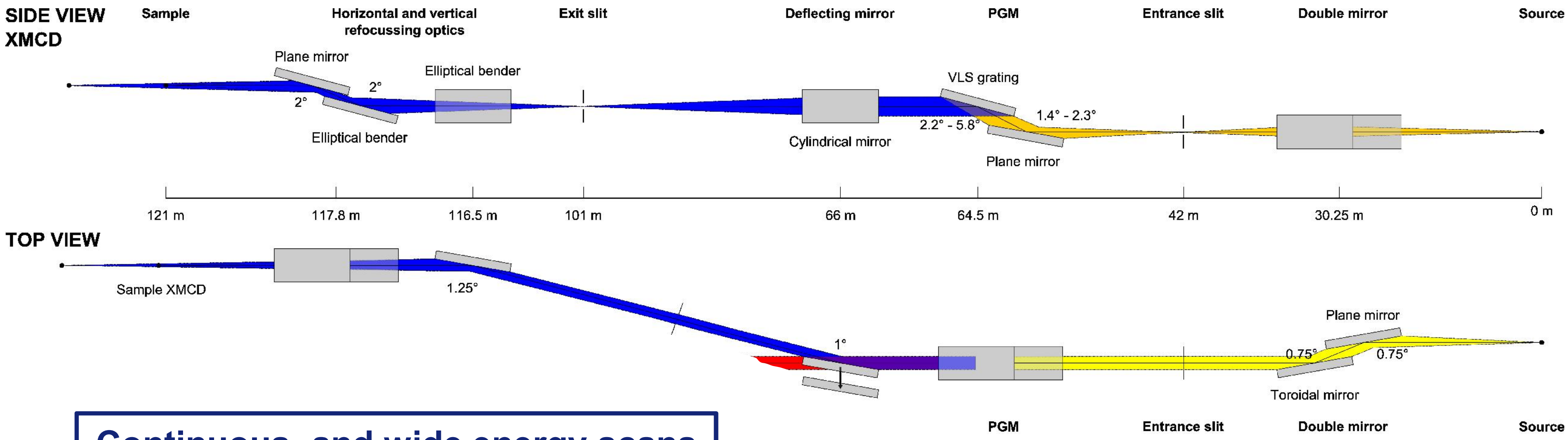




beamline + spectrometer achieve the expected combined resolving power of 30,000

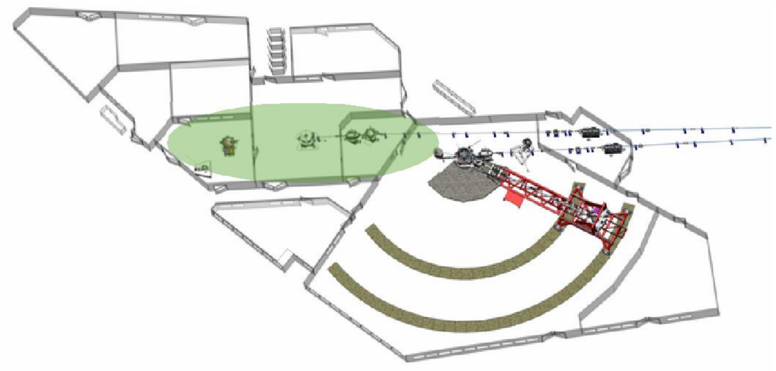
Ray-tracing done with Shadow

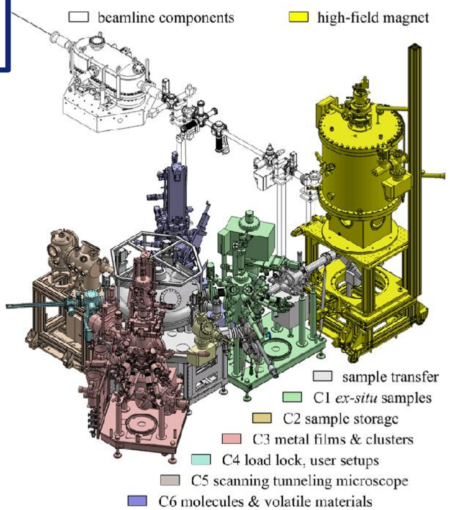
XMCD BRANCH

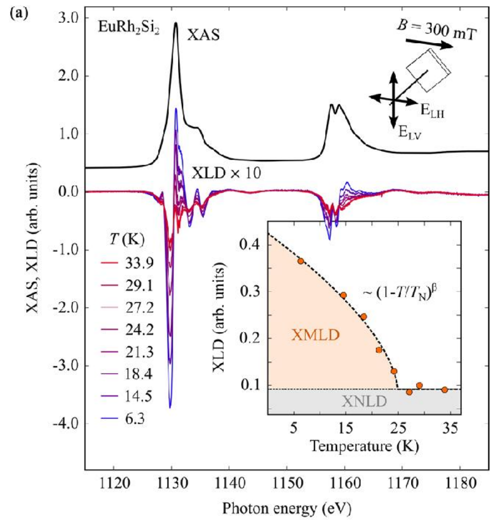


Continuous and wide energy scans at constant resolution

Stability

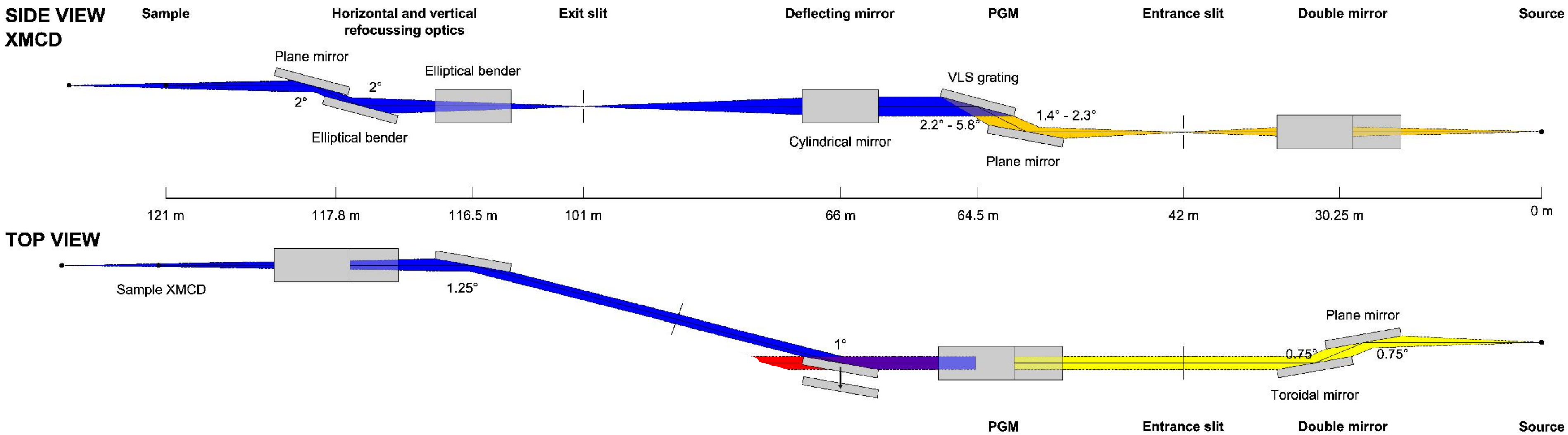






Kummer *et al.* J. Synchr. Rad. **23**, 464 (2016)

XMCD BRANCH – OPTICAL CONCEPT



VLS grating creates a virtual focus at the entrance slit for all energies which is then refocused by the cylindrical mirror on the exit slit. VLS parameters have opposite to usual case!

Optical concept first described by Howells and Staub* and later used at ALBA**. This scheme has not been used for a soft X-ray dichroism beamline.

Several advantages.

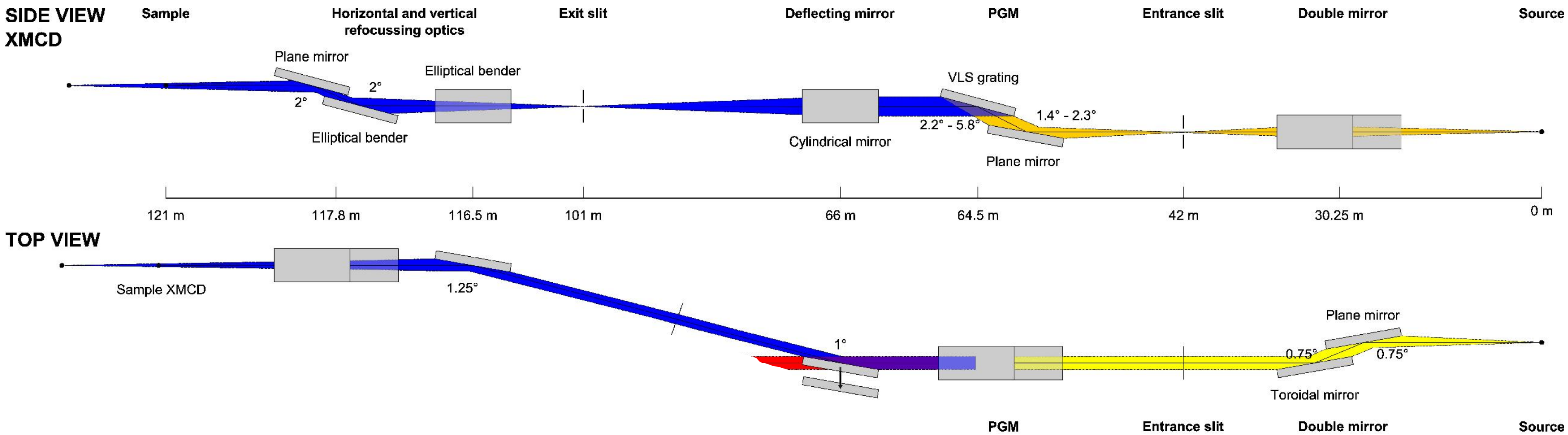
1) Allows continuous scans of the energy by scanning only the grating, pre-mirror angle is fixed.
2) Being able to choose different pre-mirror angles to maximise efficiency or harmonic rejection and still be able to just scan the grating for measurements gives a very flexible set-up.

Grating parameters	
Ruled Area (mm x mm)	170 x 25
Blaze angle (degrees)	0.312+/- 0.02
Anti Blaze angle (degrees)	4.57 +/- 0.64
Roughness (nm rms)	0.42
VLS parameters: a0 (l/mm) a1 (l/mm²) a2 (l/mm³)	 300.02 +/-0.02 -0.0268 +/- 0.00004 $+1.83\times10^{-6}$ +/- 1.3×10^{-6}
Pt coating (nm)	28 +/- 2nm

Exit slit is fixed in position and since the energy resolution varies slowly over an absorption edge the slit opening can also be fixed.

[1] Howells & Staub (1996). PSI report 96–20. [2] Pereiro et al. J. Synchrotron Rad. (2009). 16, 505.

XMCD BRANCH – VLS GRATING PARAMETERS



VLS parameters follow from easy geometric relations

$D(w) = a0(1 - (2/r1)w + (3/(r1*r1))w^2 + ...)$

$= a0 + a1w + a2w^2 + ...$

Howells & Staub (1996).
PSI report 96–20.

Resolving power 5000 is obtained with a 300 l/mm grating and an entrance arm length (r1) of 22456mm → a1, a2

Easy to recalculate for 900 l/mm.

Grating: DIOS/BESSY, mechanically ruled, blazed.

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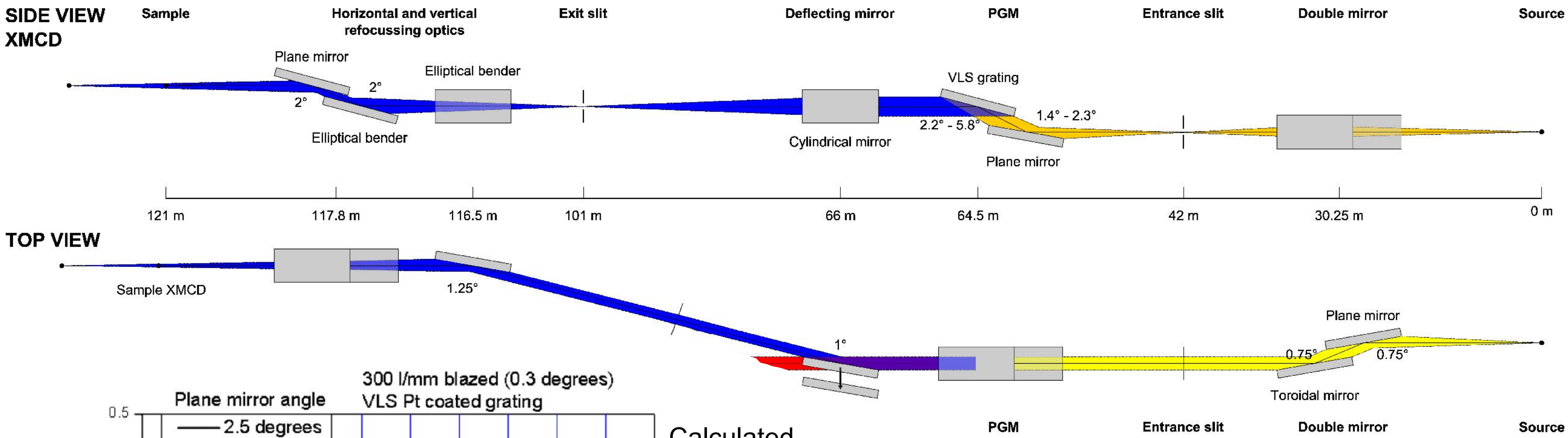
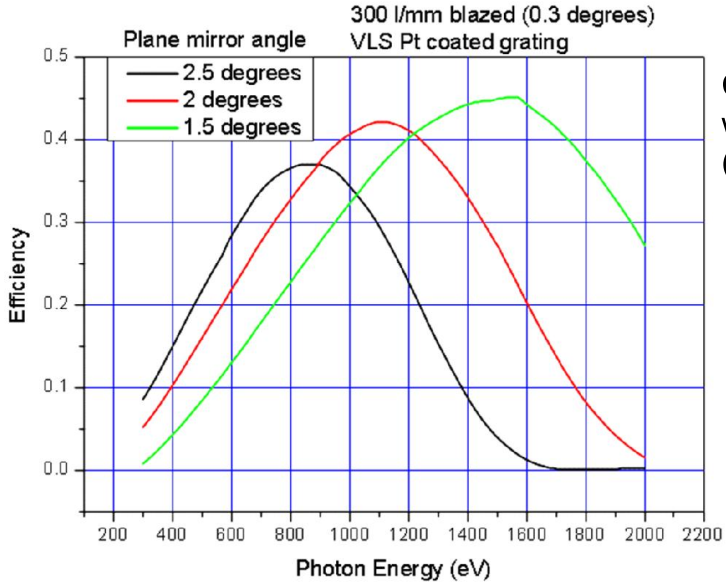
Pt coating (nm)	28 +/- 2nm

Line density varies in the opposite direction to conventional systems!

XMCD BRANCH – VLS GRATING PARAMETERS



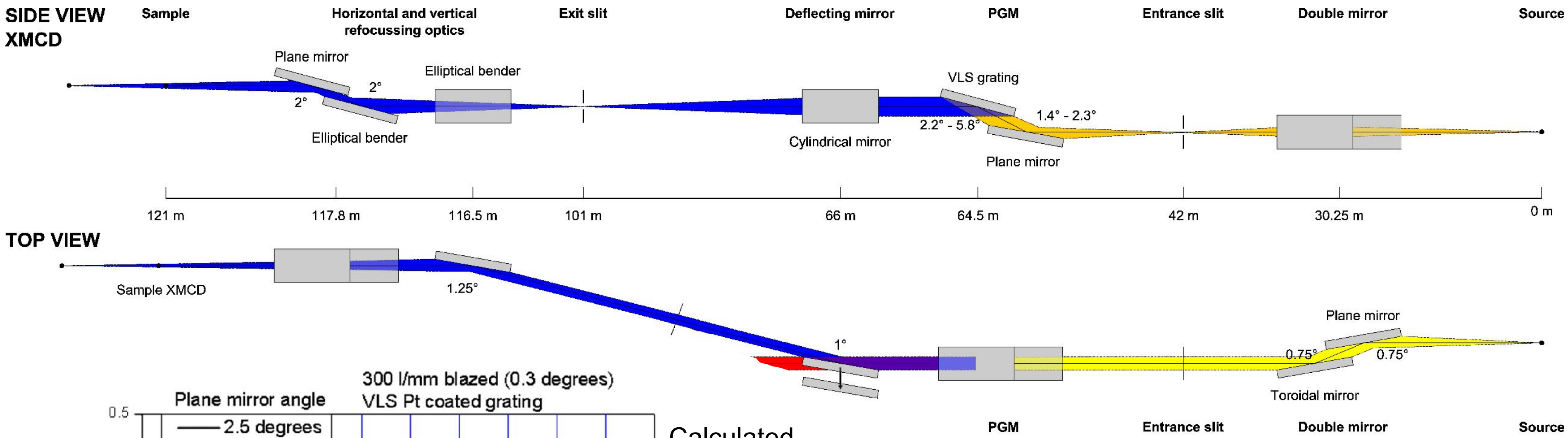


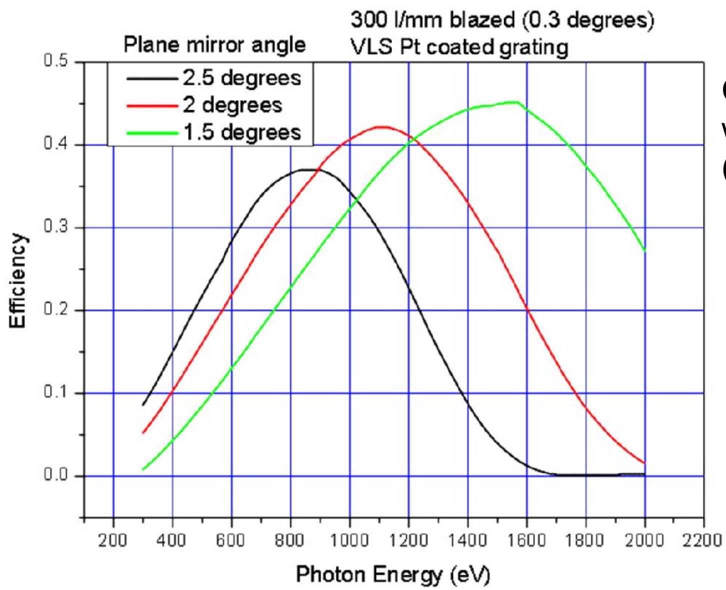
Calculated with REFLEC (BESSY)

A grating peak efficiency of over 40% has been achieved for the XMCD grating by mechanical ruling with a blaze angle of 0.3 deg. The simulations have been confirmed by independent measurements at BESSY.

Grating parameters	
Ruled Area (mm x mm)	170 x 25
Blaze angle (degrees)	0.312+/- 0.02
Anti Blaze angle (degrees)	4.57 +/- 0.64
Roughness (nm rms)	0.42
VLS parameters: a0 (l/mm) a1 (l/mm^2) a2 (l/mm^3)	 300.02 +/-0.02 -0.0268 +/- 0.00004 +1.83x10^{-6} +/- 1.3x10^{-6}
Pt coating (nm)	28 +/- 2nm

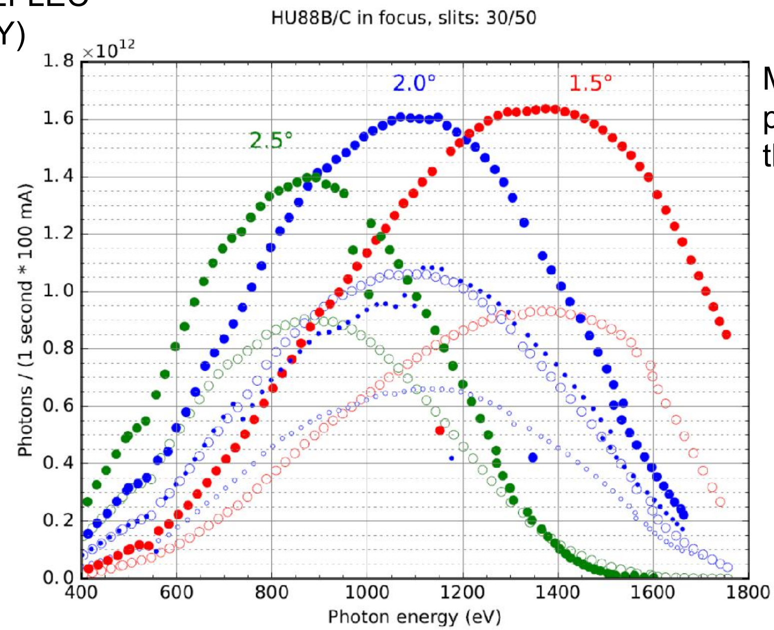
XMCD BRANCH – PHOTON FLUX





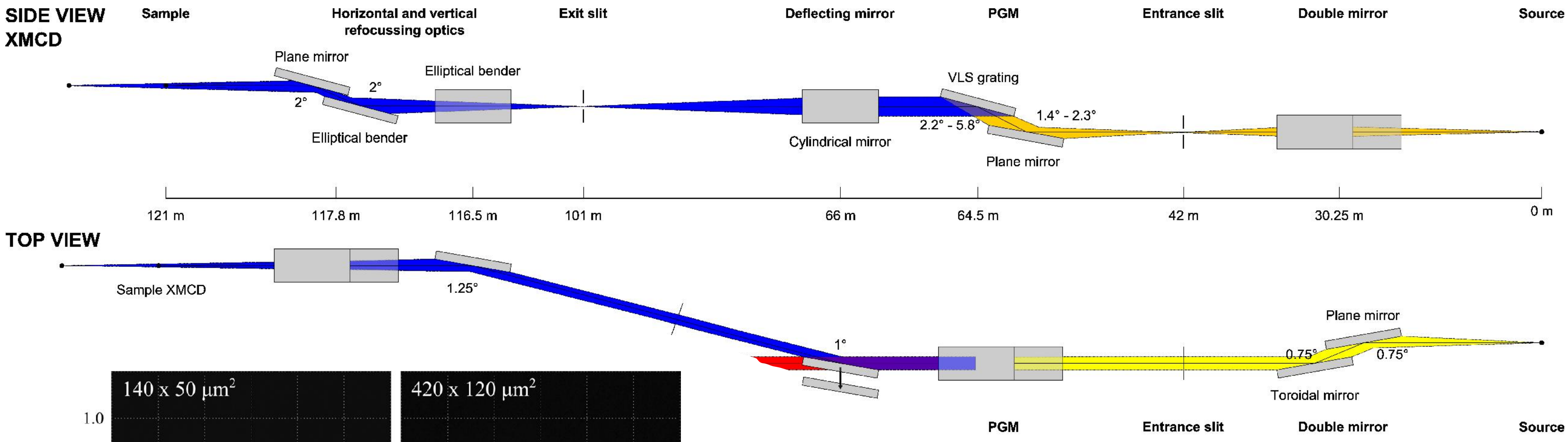
Calculated with REFLEC (BESSY)

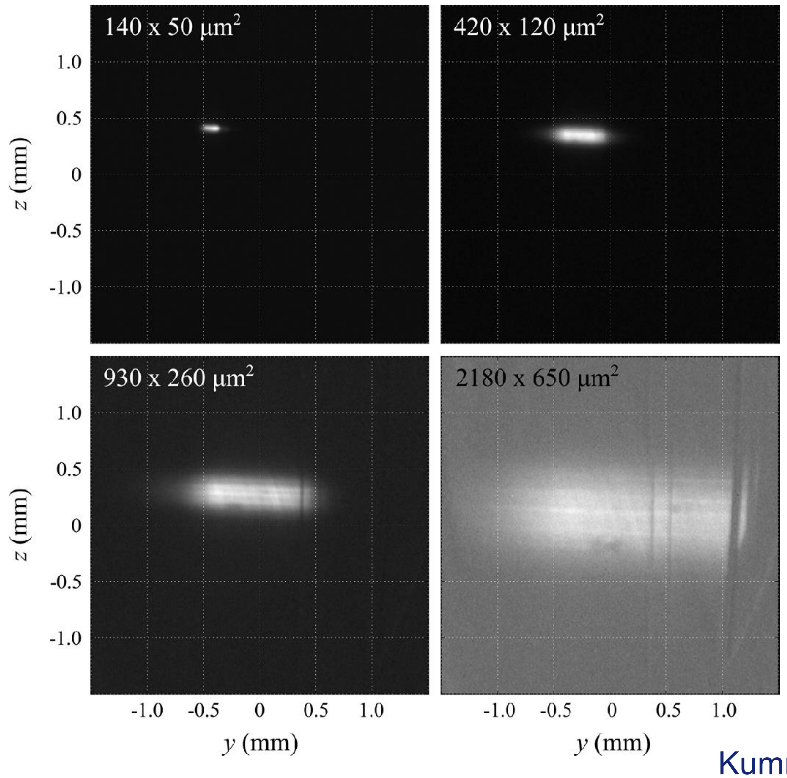
A grating peak efficiency of over 40% has been achieved for the XMCD grating by mechanical ruling with a blaze angle of 0.3 deg. The simulations have been confirmed by independent measurements at BESSY.



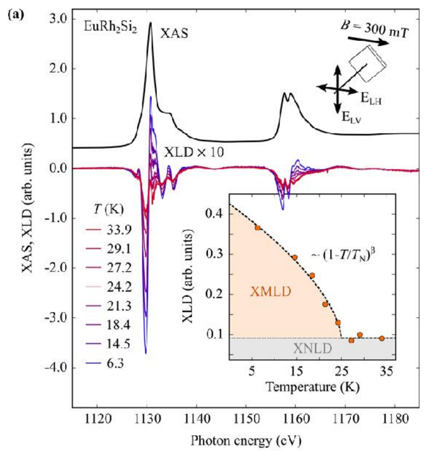
Measured photon flux at the sample

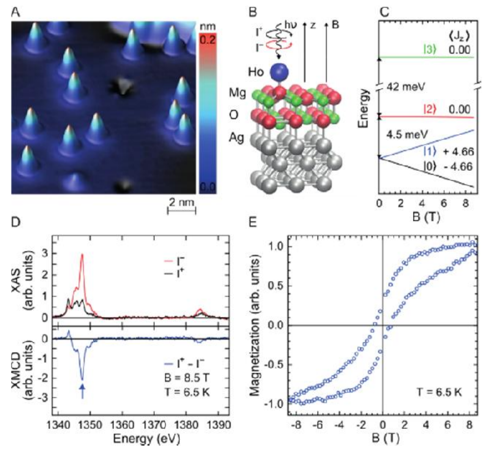
XMCD BRANCH – VARIABLE BEAM SIZE AT THE SAMPLE





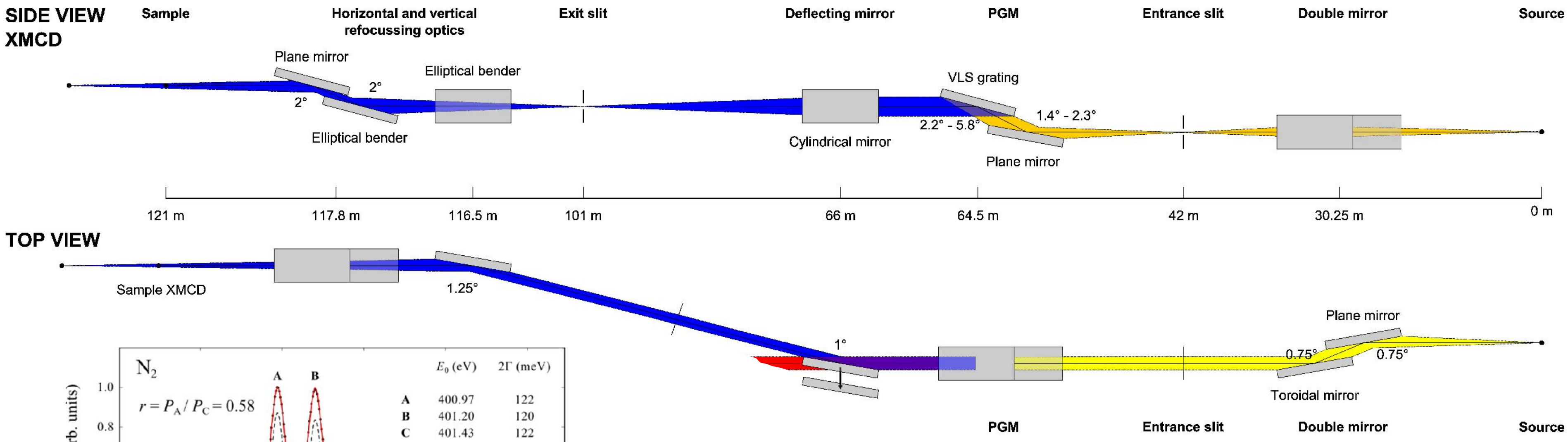
Single crystals vs molecular magnets/atoms

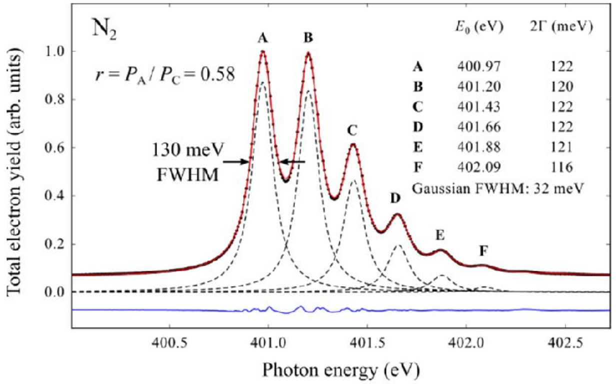


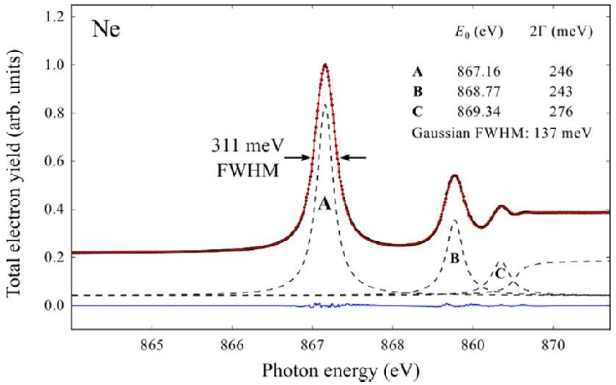


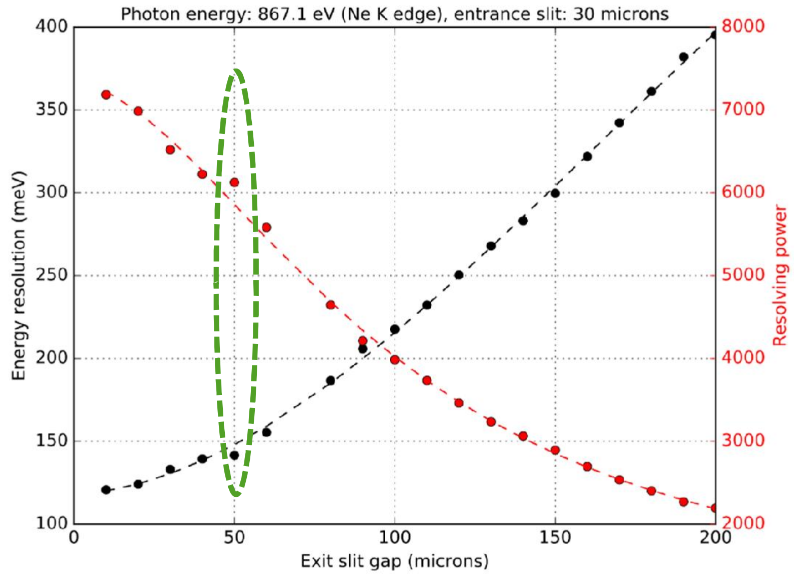
Kummer *et al.* J. Synchr. Rad. **23**, 464 (2016)
Donati el al. Science **352**, 318 (2016)

XMCD BRANCH – RESOLUTION



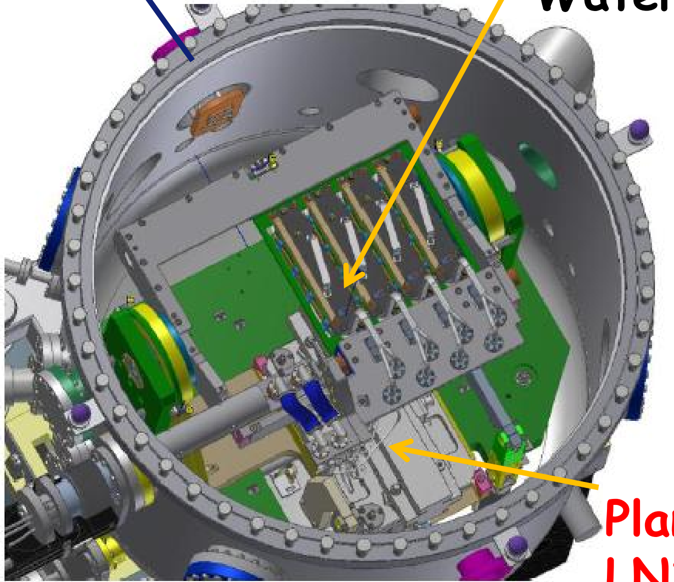


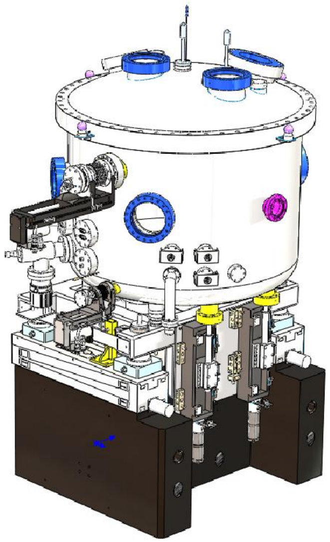


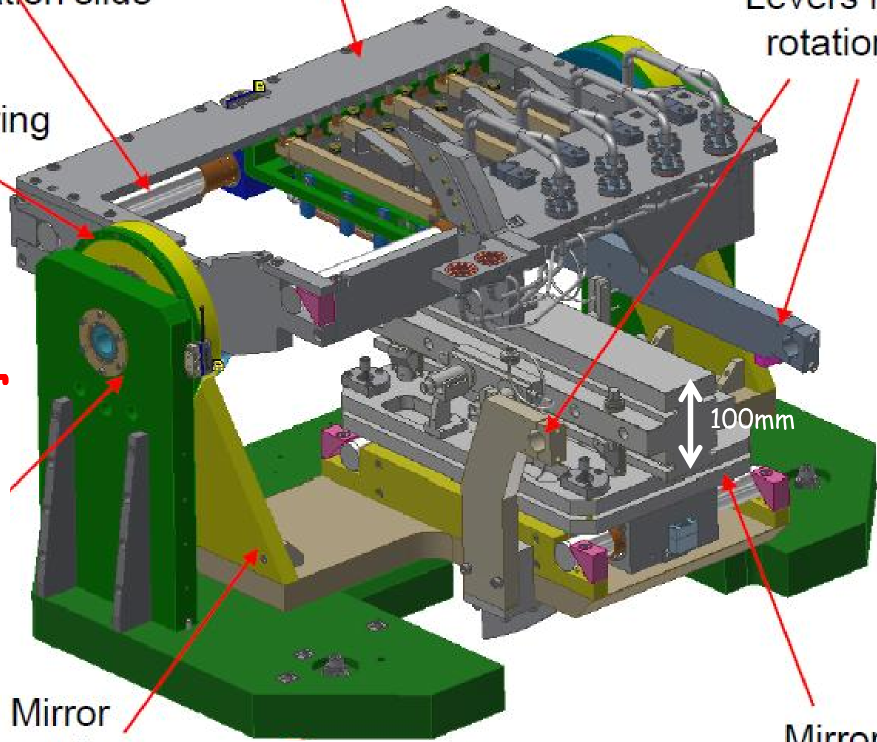


MONOCHROMATOR MECHANICS

BESTEC – Berlin / ESRF



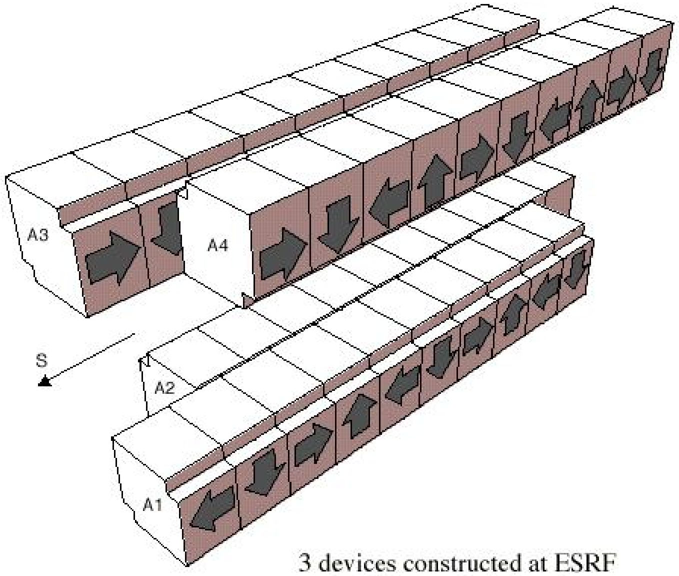




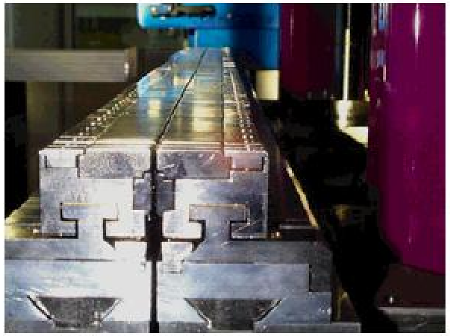
Great care needs to be taken to preserve the optical slope error when mounting the gratings and the cooling.

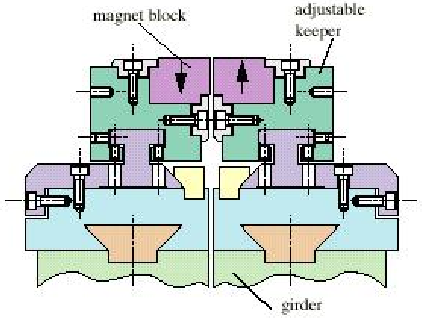
SOURCE

APPLE II STRUCTURE



3 devices constructed at ESRF
period 88 mm (2 devices)
period 38 mm





Insertion Device Group: J. Chavanne

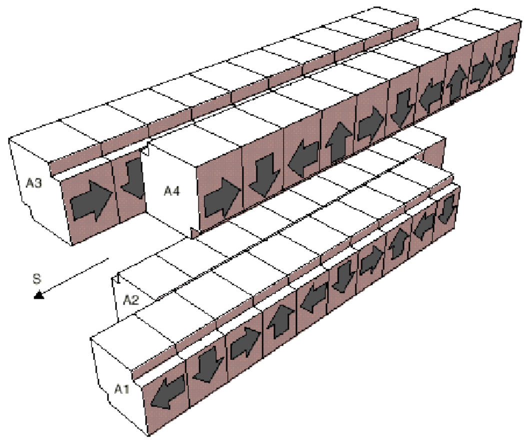
Full polarization control

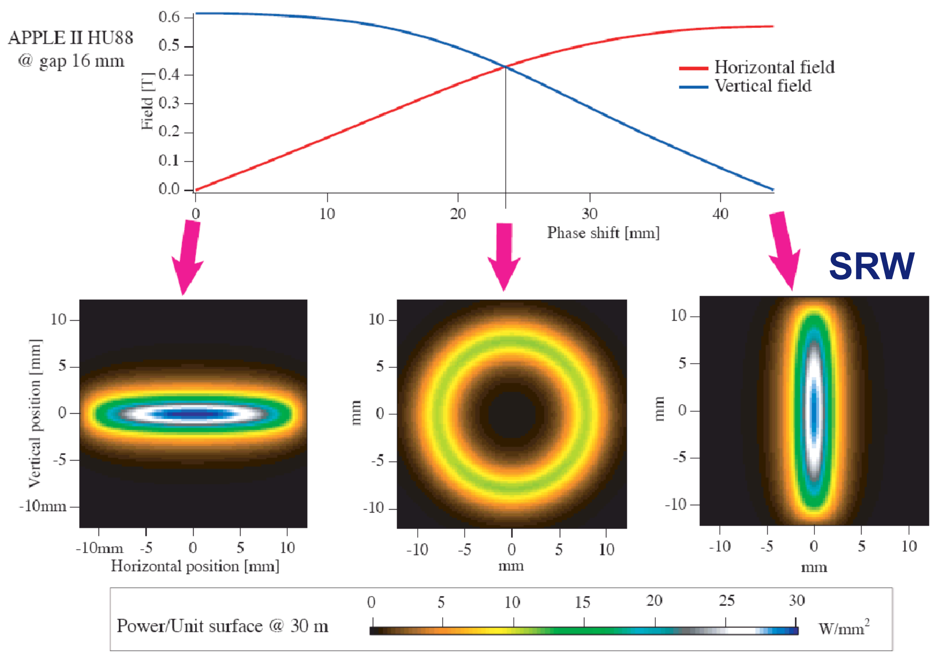
~100% polarised soft X-rays
circular (left and right)
linear (vertical, horizontal, inclined)

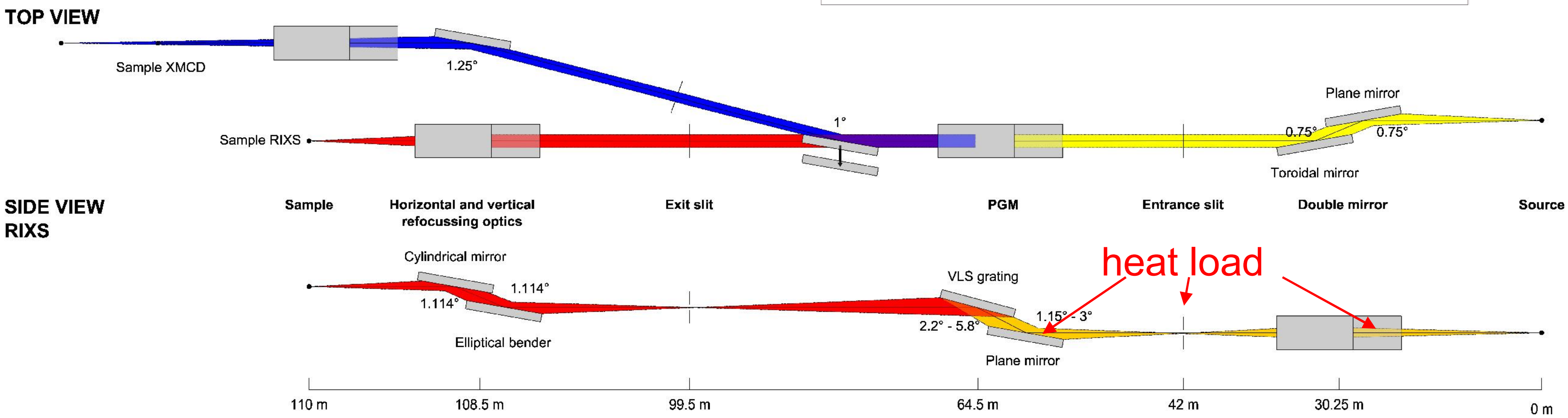
88mm period
three undulators = 1.6m + 2.5m +1.6m

hν=0.3-1.6keV with 1st harmonic
Flux: ~2 x 10^{15} ph/sec/0.1%BW/200mA

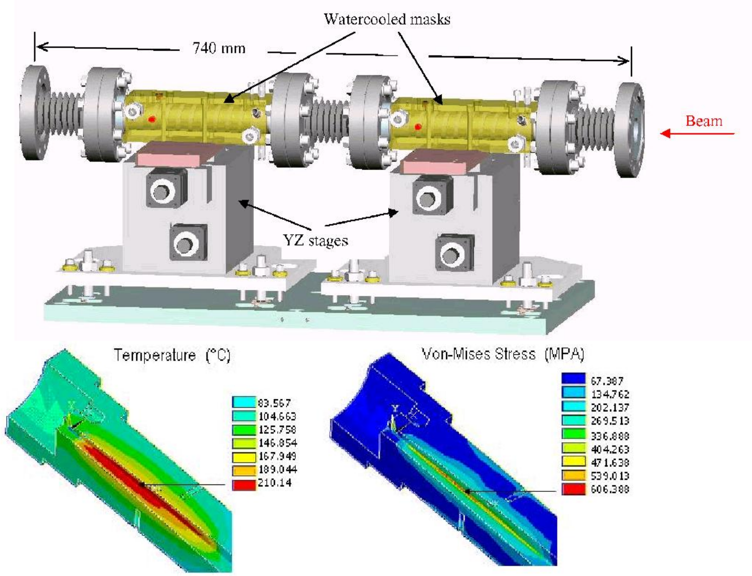
HEAT LOAD MANAGEMENT

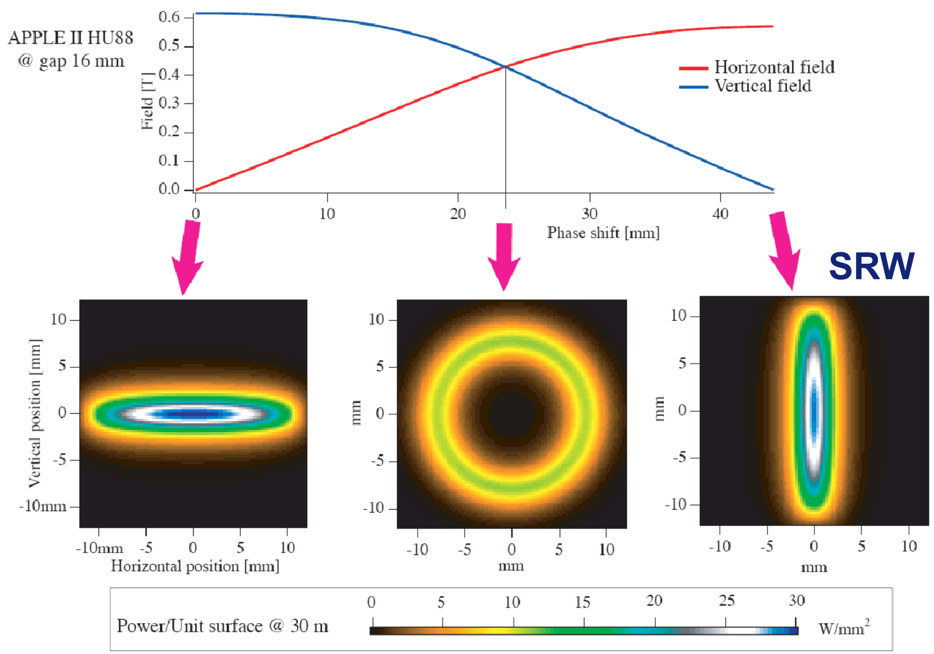






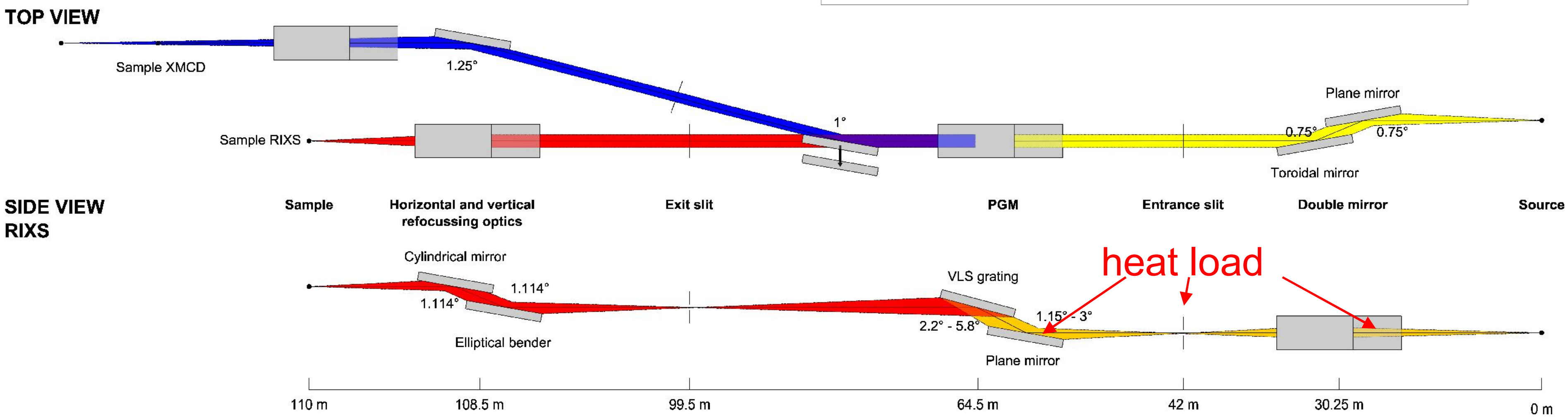
HEAT LOAD MANAGEMENT





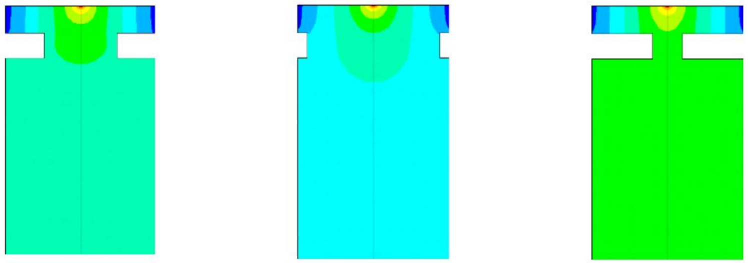
ESRF high power slits

Marion and Zhang, AIP Conf. Proc. **705**, 320 (2004)



HEAT LOAD MANAGEMENT

Heat load analysis of the white beam mirror (L. Zhang)



Profile 1: optimized for both polarisations ("Both") | Profile 2: optimized for horizontal polarisation ("Hopt") | Profile 2: optimized for vertical polarisation ("Vopt")

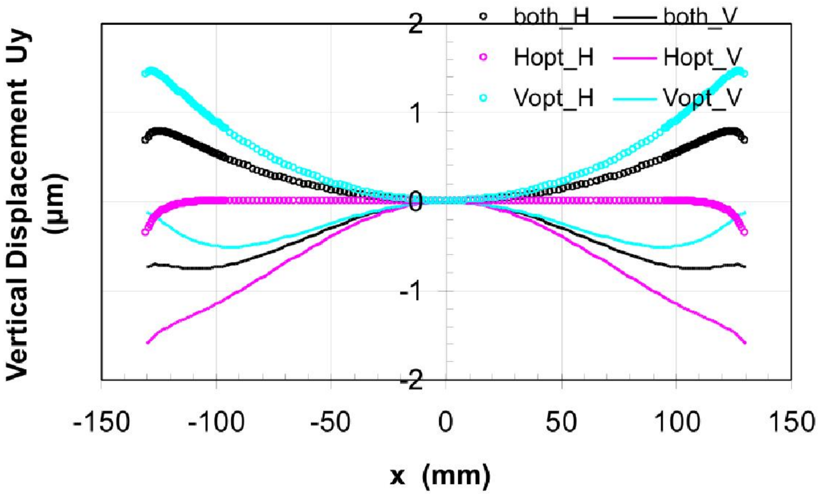
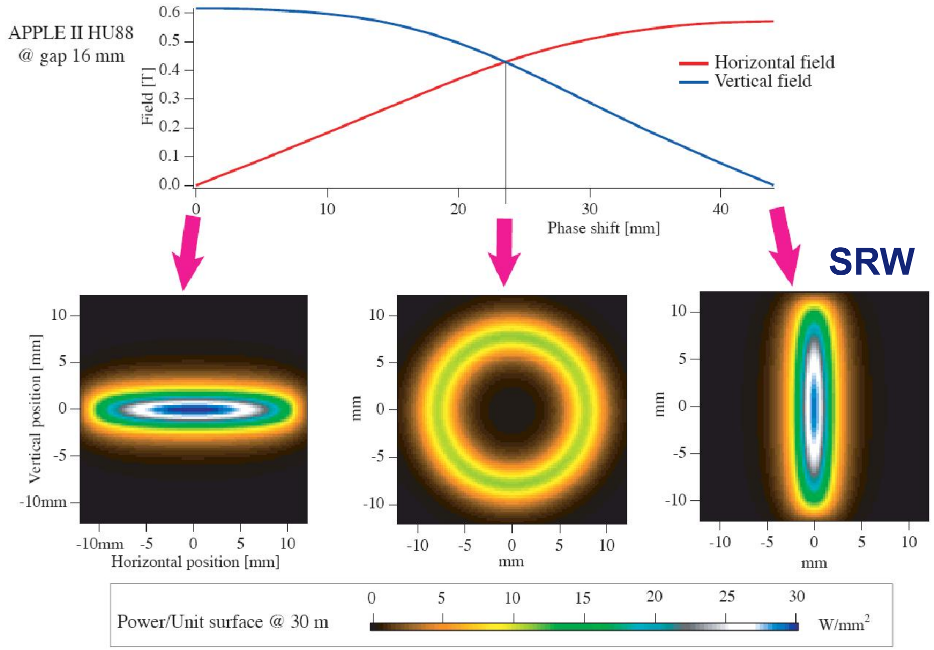
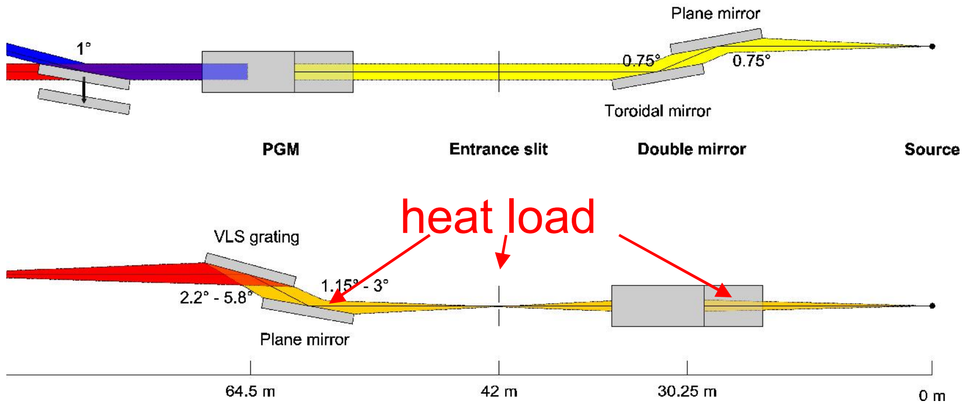


Figure 17: Mirror deformation for different optimisations





HEAT LOAD MANAGEMENT

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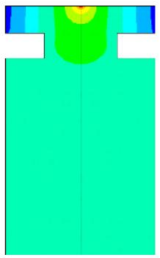
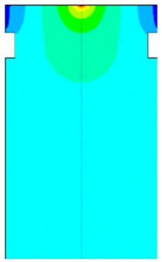
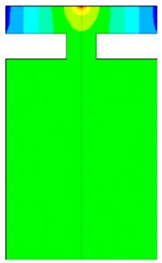


Profile 1: optimized for both polarisations ("Both")



Profile 2: optimized for horizontal polarisation ("Hopt")



Profile 2: optimized for vertical polarisation ("Vopt")

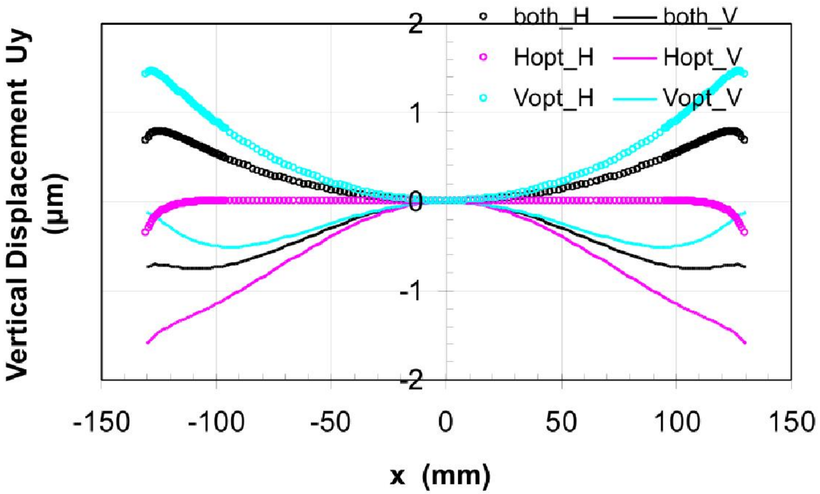
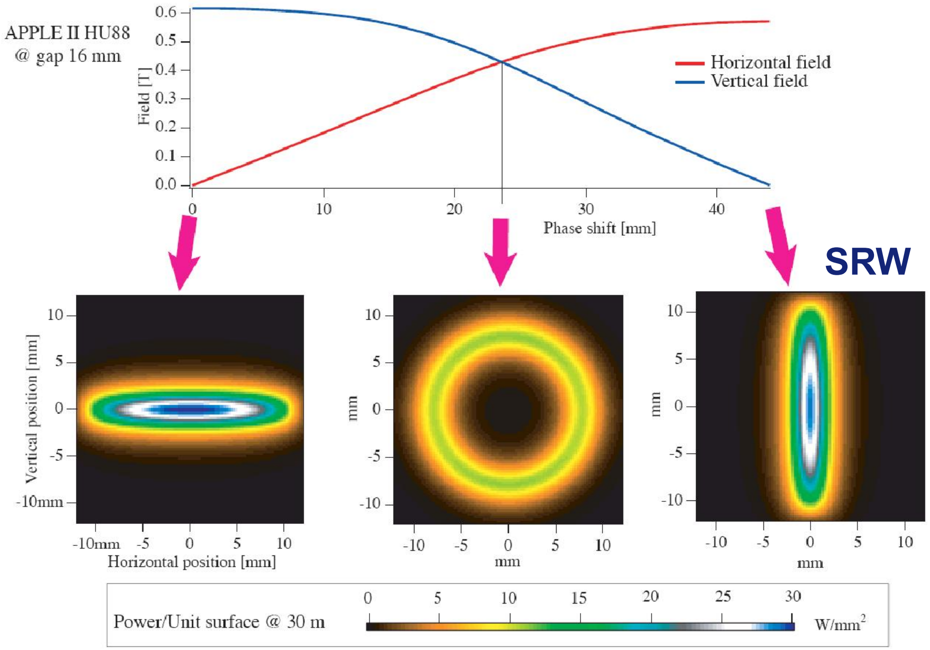
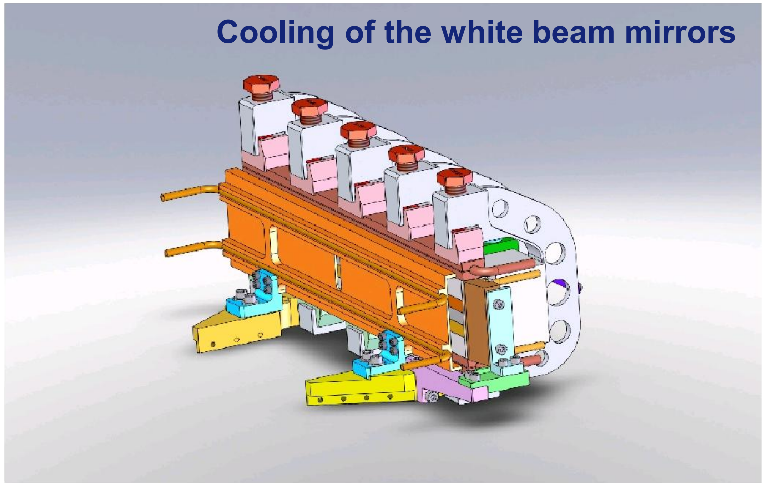


Figure 17: Mirror deformation for different optimisations

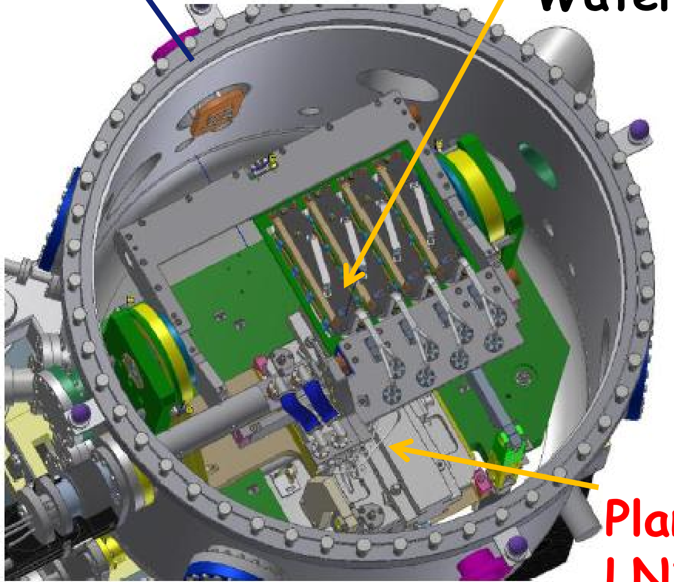




Beam out

Plane VLS grating
Water cooled

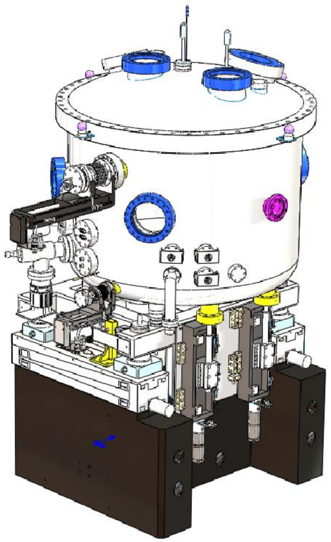
BESTEC – Berlin / ESRF

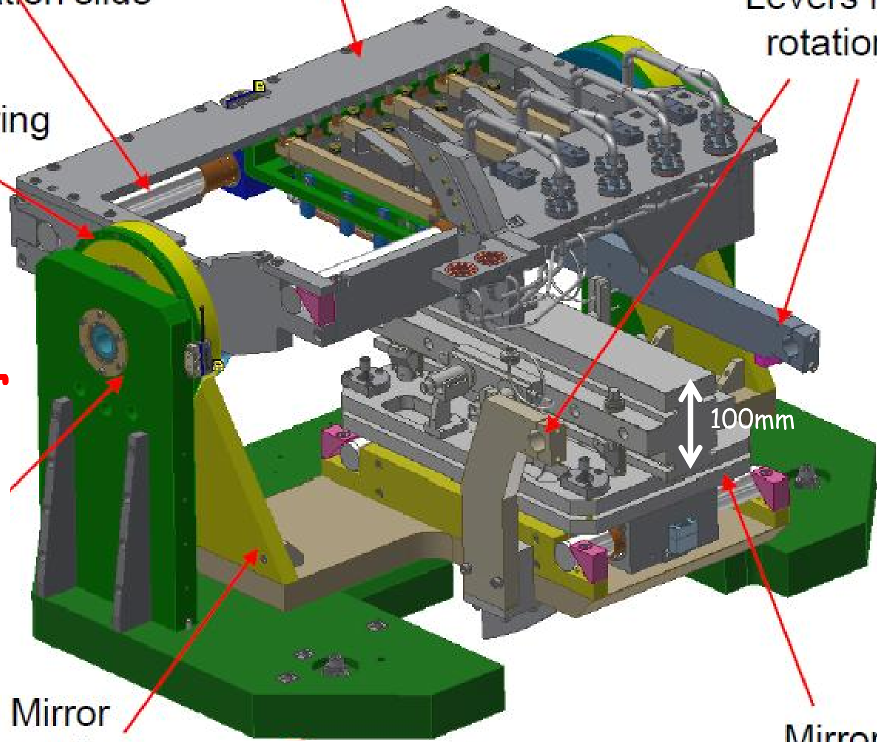


Plane mirror
LN2 cooled

125 K

Beam in

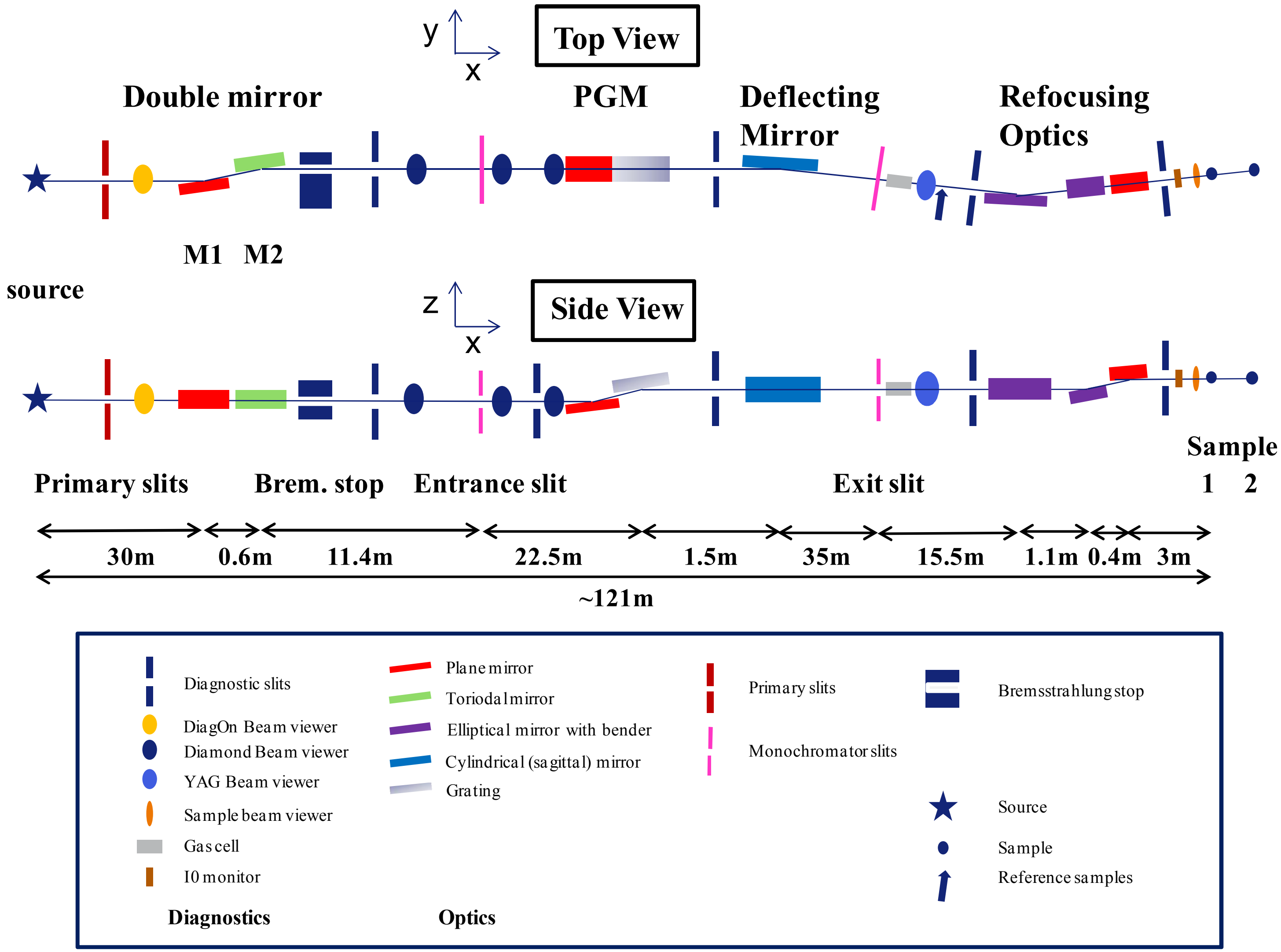




Great care needs to be taken to preserve the optical slope error when mounting the gratings and the cooling.

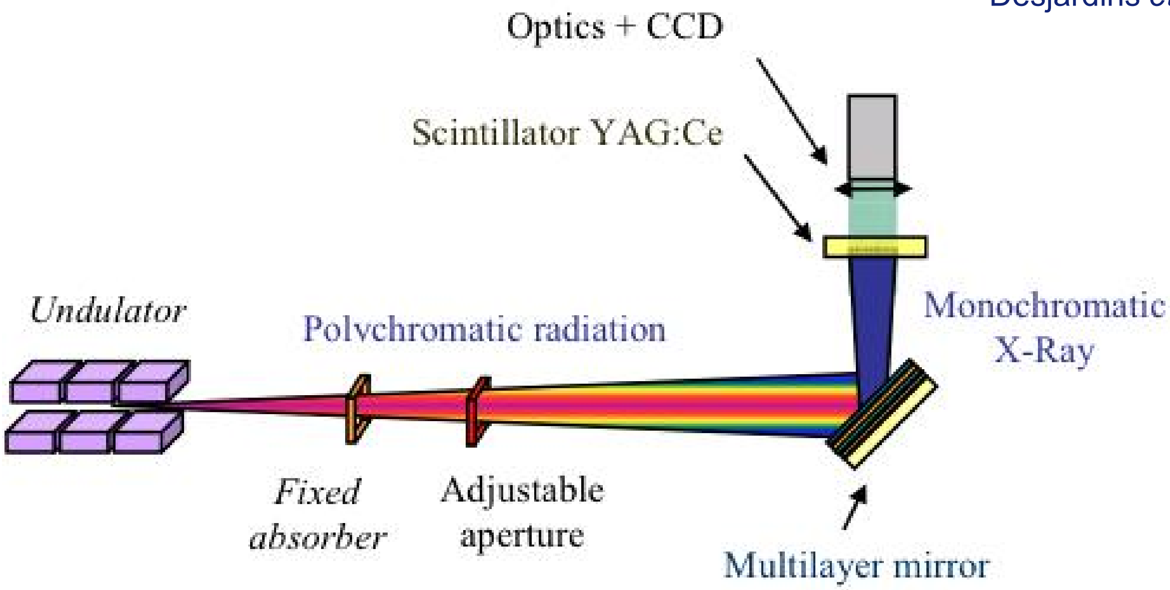
DIAGNOSTICS

Diagnostic tools before and after each optical component were extremely useful during the commissioning

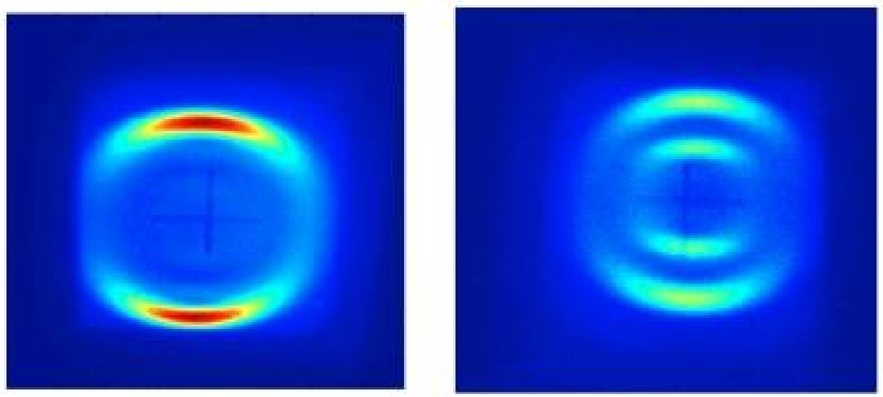


DIAGNOSTICS – UNDULATOR EMISSION

Desjardins *et al.* AIP Conf. Proc. **879**, 1101 (2007)



Schematic layout of a DiagOn device (Soleil)

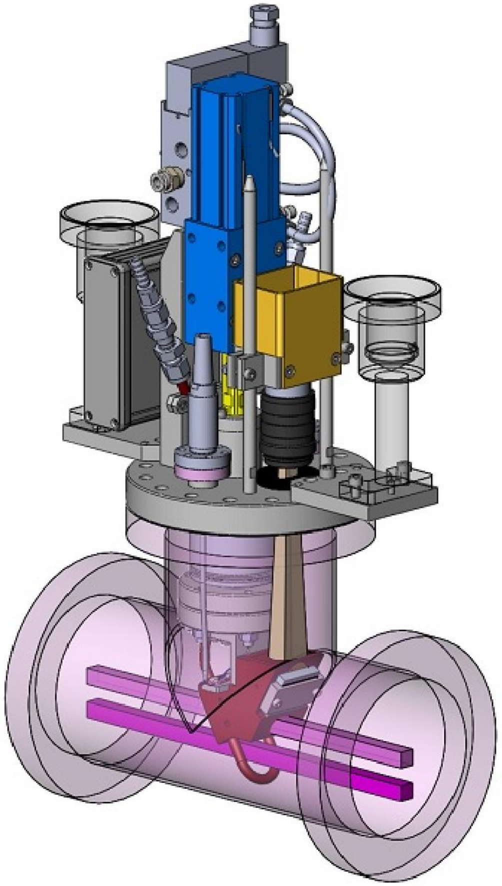


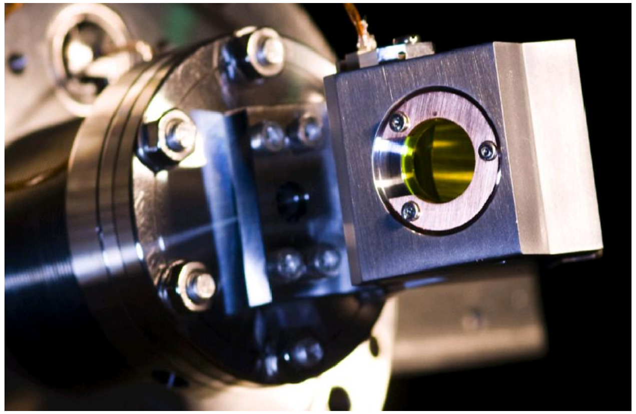
(a) (b)

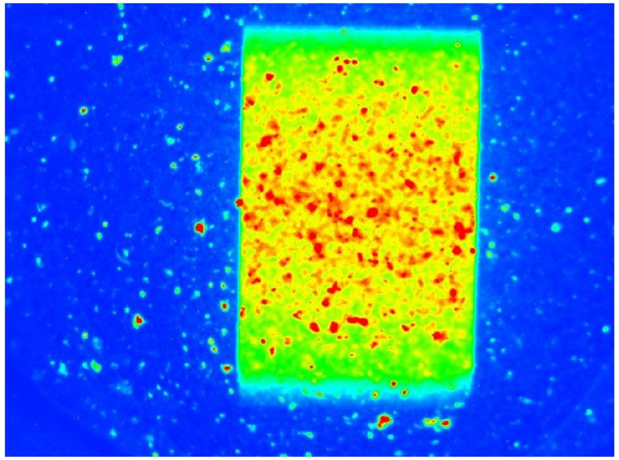
Emission cones of one (a)
or two simultaneous (b) undulators
imaged with DiagOn

DIAGNOSTICS

ESRF white and monochromatic beam viewers







PEOPLE


A. Amorese *PhD student*
N. Brookes *Beamline responsible*
D. Betto *Post-doc*
A. Fondacaro *Technician*
F. Yakhou *Operation manager*
K. Kummer *Beamline scientist*
E. Velez-Fort *Post-doc*
M. Asphury *Trainee*
R. Barret, M. Sanchez del Rio, L. Zhang, A. Vivo
L. Eybert, M. Leme, P. Feder, G. Berruyer, F. Ciancosi, P. Marion
ESRF
R. Reininger
APS
G. Ghiringhelli, L. Braicovich, G. Dellea, Y. Y. Peng, M. Minola
Politecnico di Milano
POLITECNICO
MILANO