A New Reflectometer for At-Wavelength Characterisation of XUV-Reflection Gratings

Reflectometry and more

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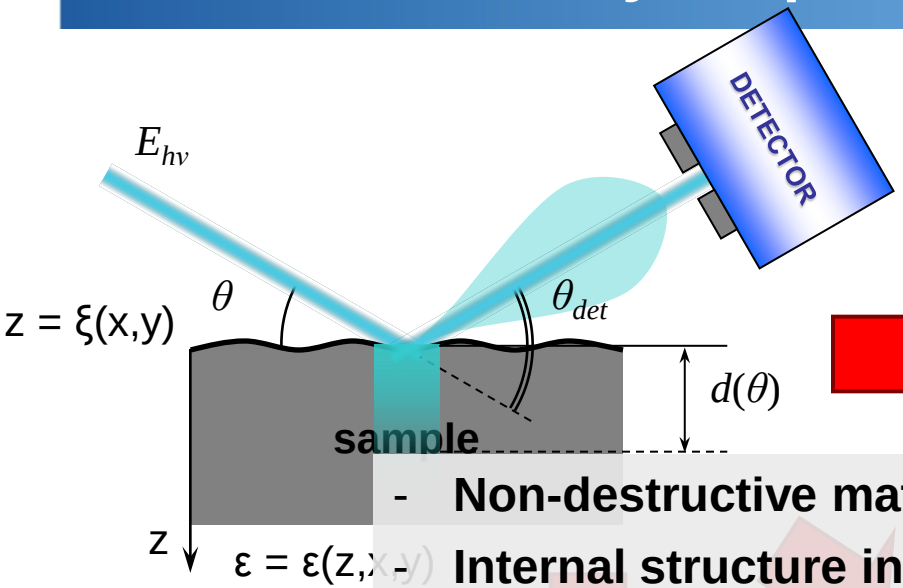
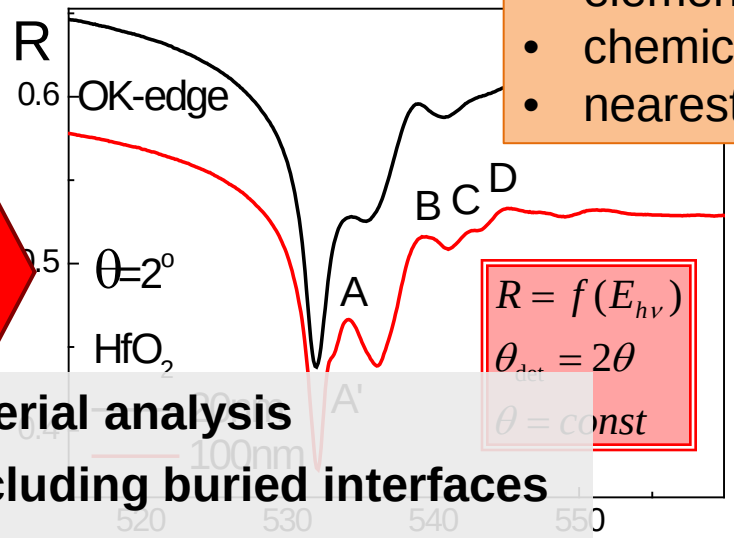
Reflectometry – a powerful technique



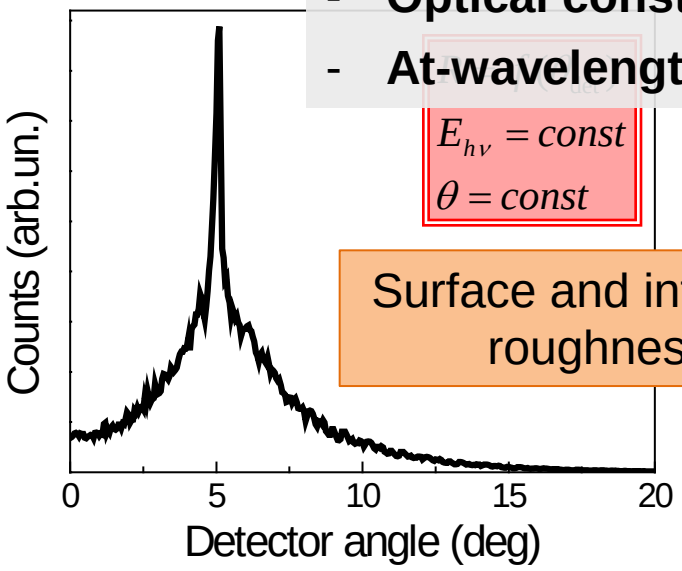


- element specific
- chemical state
- nearest neighbours

$R = f(E_{hv})$
$\theta_{det} = 2\theta$
$\theta = const$

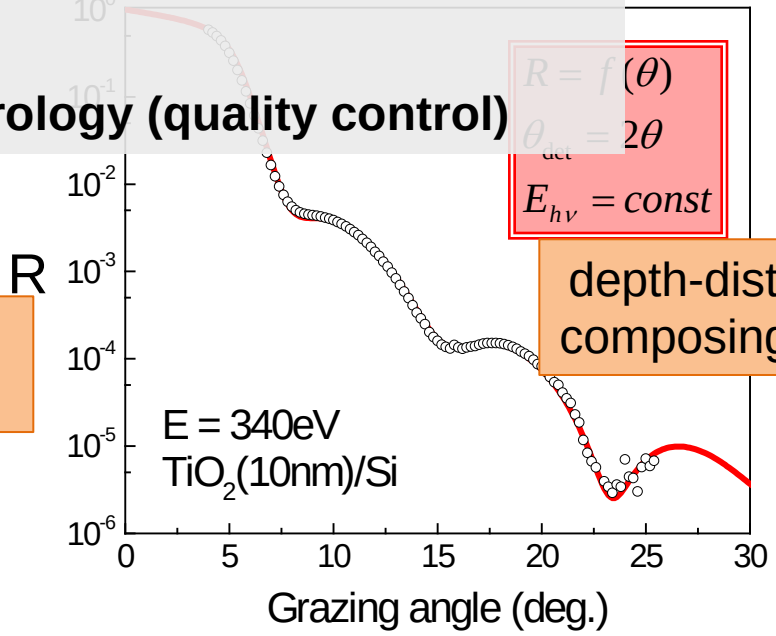
- **Non-destructive material analysis**
- **Internal structure including buried interfaces**
- **Interface quality (compound and roughness)**
- **Optical constants**
- **At-wavelength metrology (quality control)**

Φ(θ,φ) → ξ(x,y)



$E_{hv} = const$
$\theta = const$

Surface and interface roughness

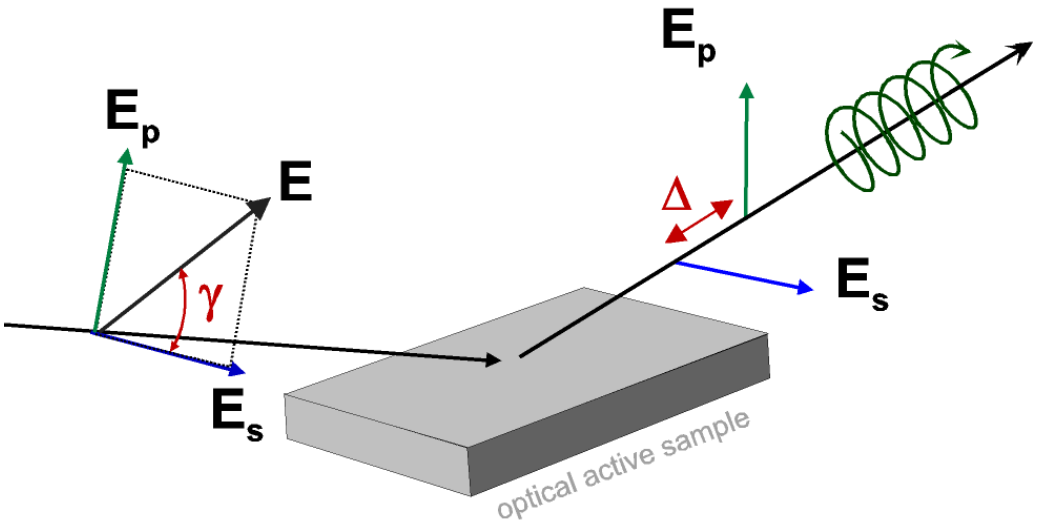


$R = f(\theta)$
$\theta_{det} = 2\theta$
$E_{hv} = const$

depth-distribution of composing elements

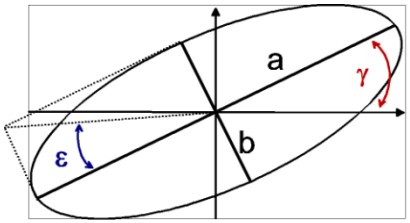
Polarimetry = Ellipsometry = complex Reflectometry

POLARIZED LIGHT

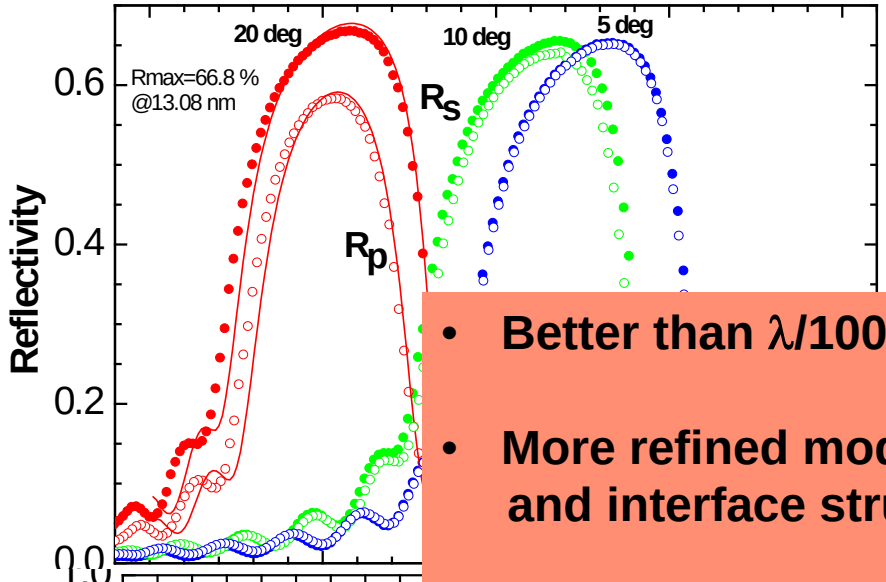


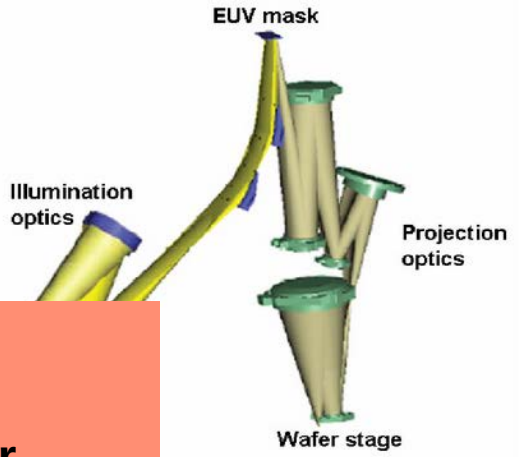
Stokes Parameter:

Intensity	$S_0 = [(E_p)^2 + (E_s)^2]$
Linear polarization	$S_1 = [(E_p)^2 - (E_s)^2]/ S_0$
	$S_2 = 2E_pE_s\cos(\Delta) / S_0$
Circular polarization	$S_3 = -2E_pE_s\sin(\Delta)/ S_0$
Degree of polarization	$P = [S_1^2 + S_2^2 + S_3^2]^{1/2} \leq 1$
Ellipticity	$\sin 2\varepsilon = S_3$
Polarisation ellipse	$\tan 2\gamma = S_2/S_1$

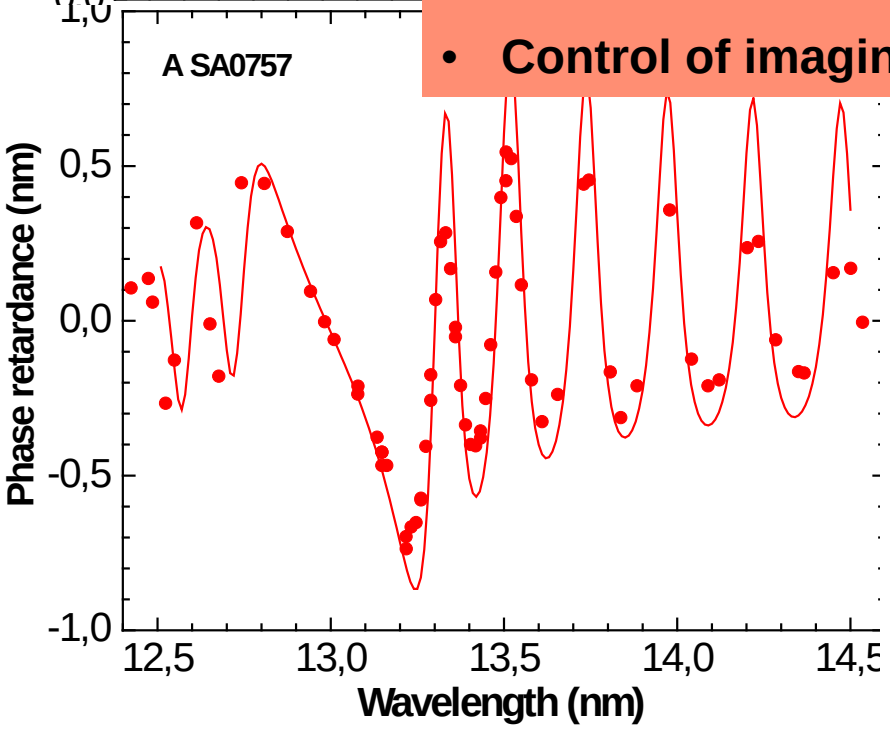


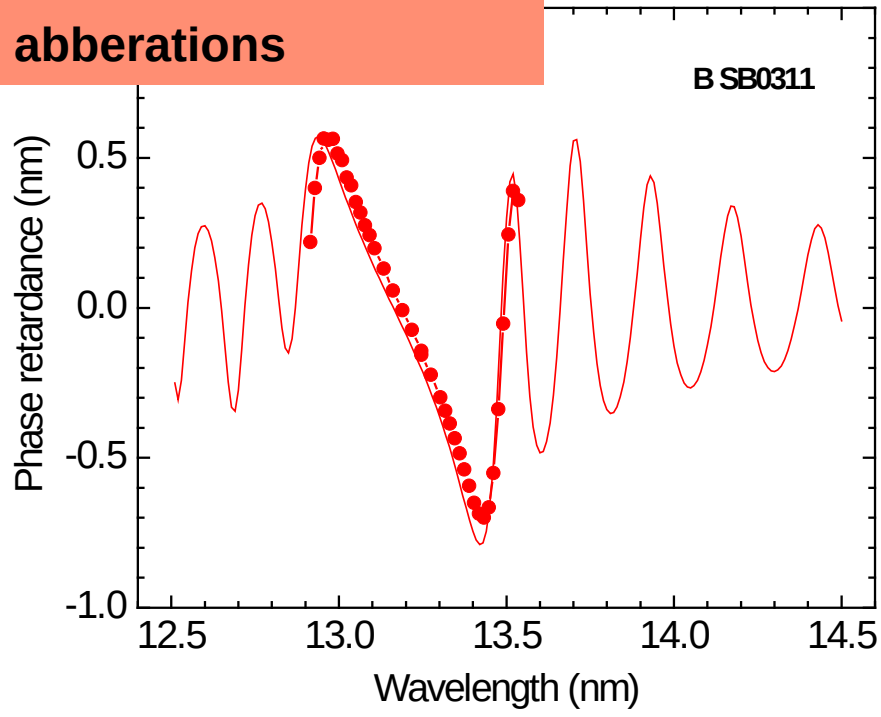
Ellipsometry on EUV optics…



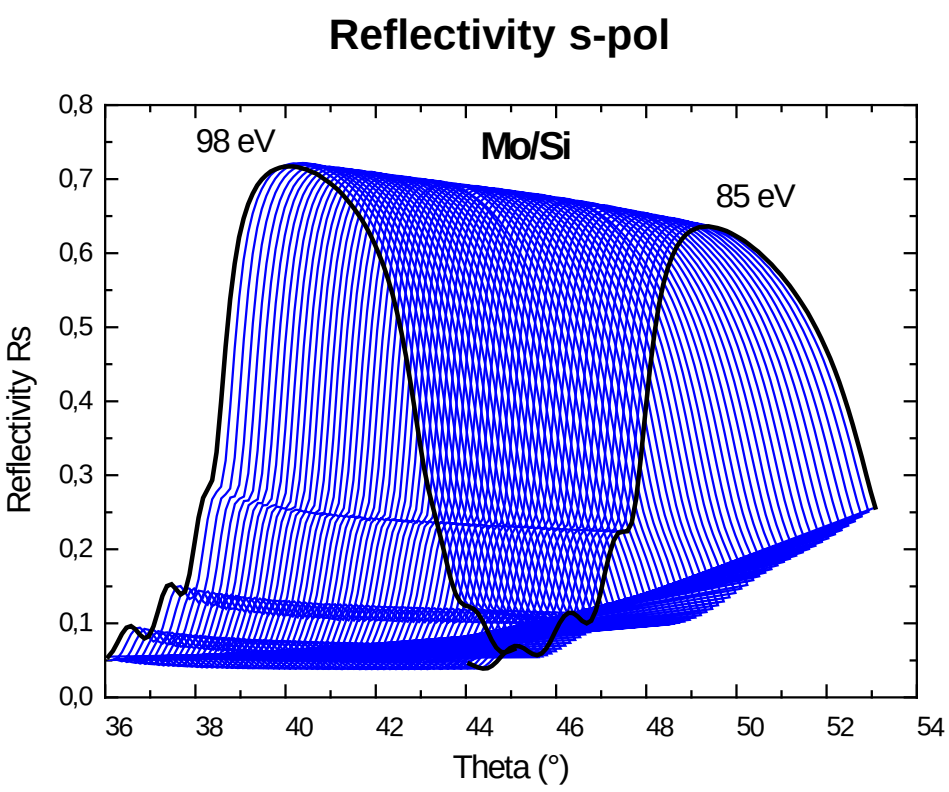


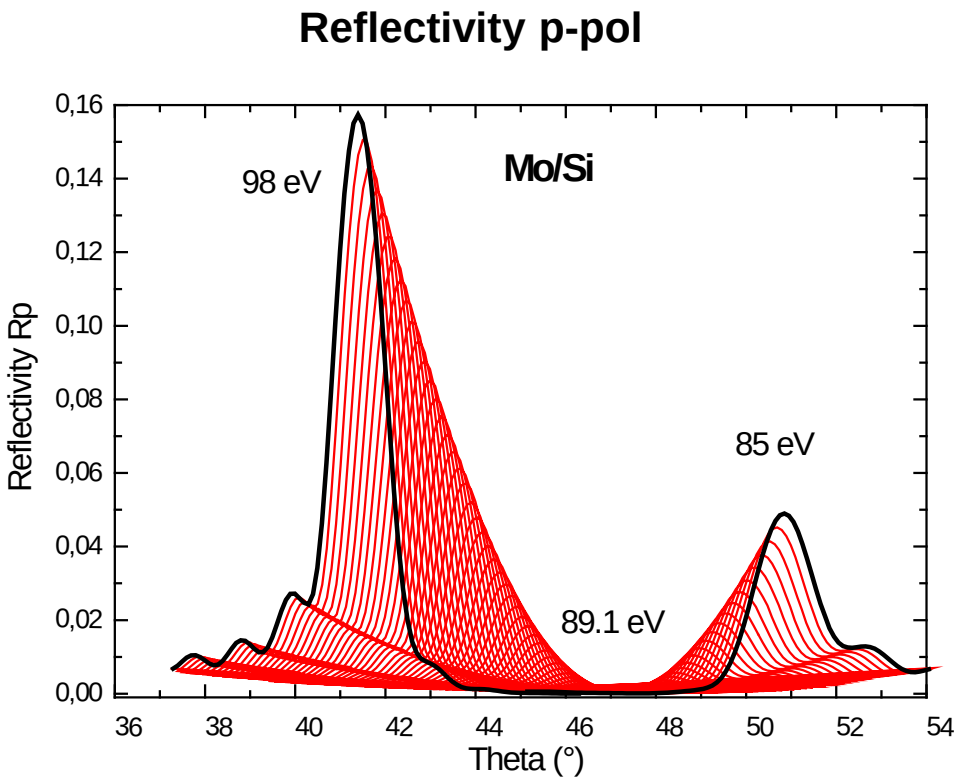
- **Better than λ/100 phase accuracy**
- **More refined modelling of multilayer and interface structures**
- **Control of imaging abberations**





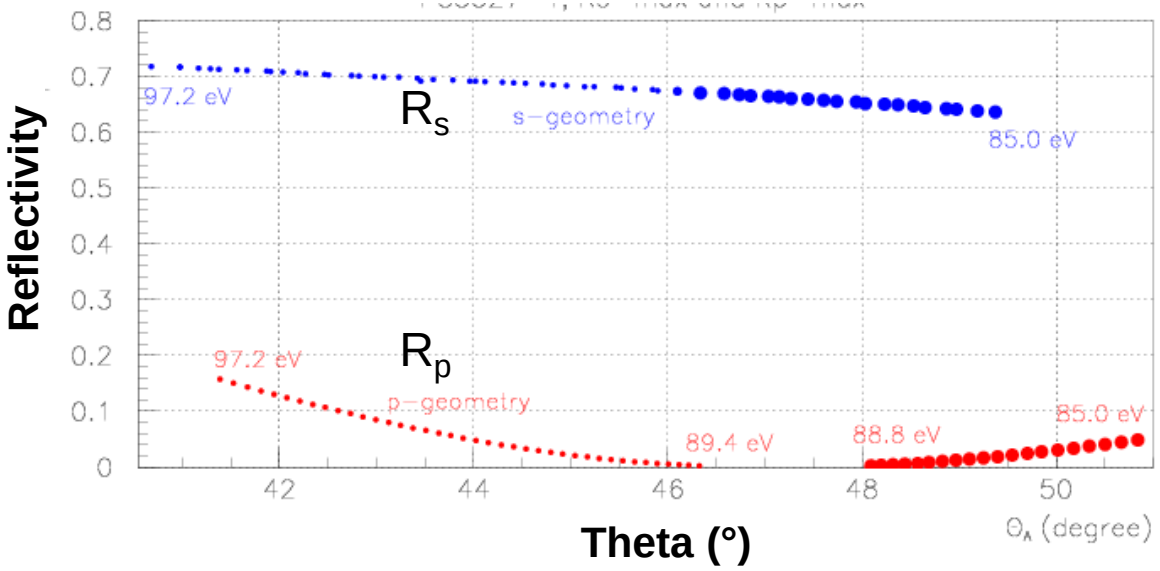
Bragg reflection around Brewster angle

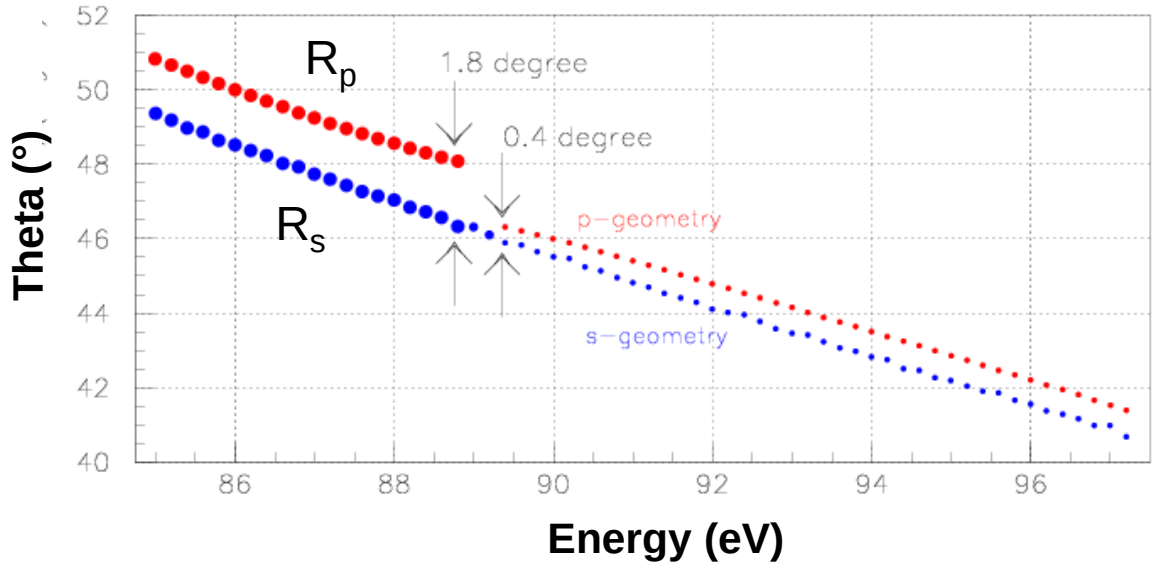




- **Linear polarisation: S1=0.999+/-0.001**
- **Bragg-peaks 4-times wider for s-pol**
- **Polarisance Rs/Rp @89.1 eV = 781**

Polarisation dependent layer thickness?





Bragg equation

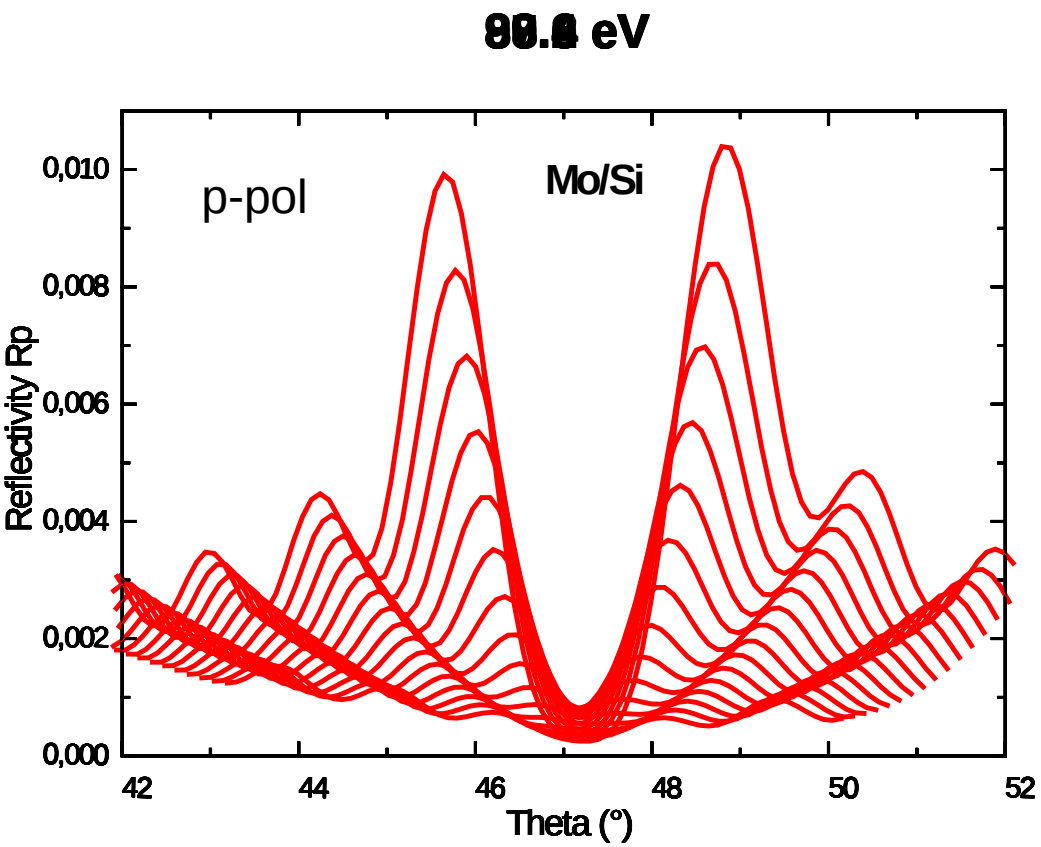
$\lambda = 2\, n_{eff}\, d \sin\theta$

Brewster condition:

$\tan\theta = 1/\, n_{eff}$

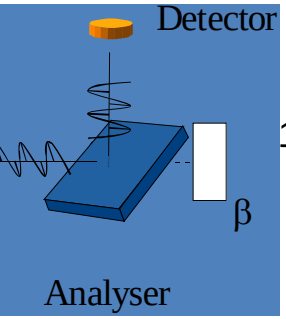
- **effective layer thickness: larger for s-pol**
- **Birefringence?**
- **Phase jump @ Brewster**

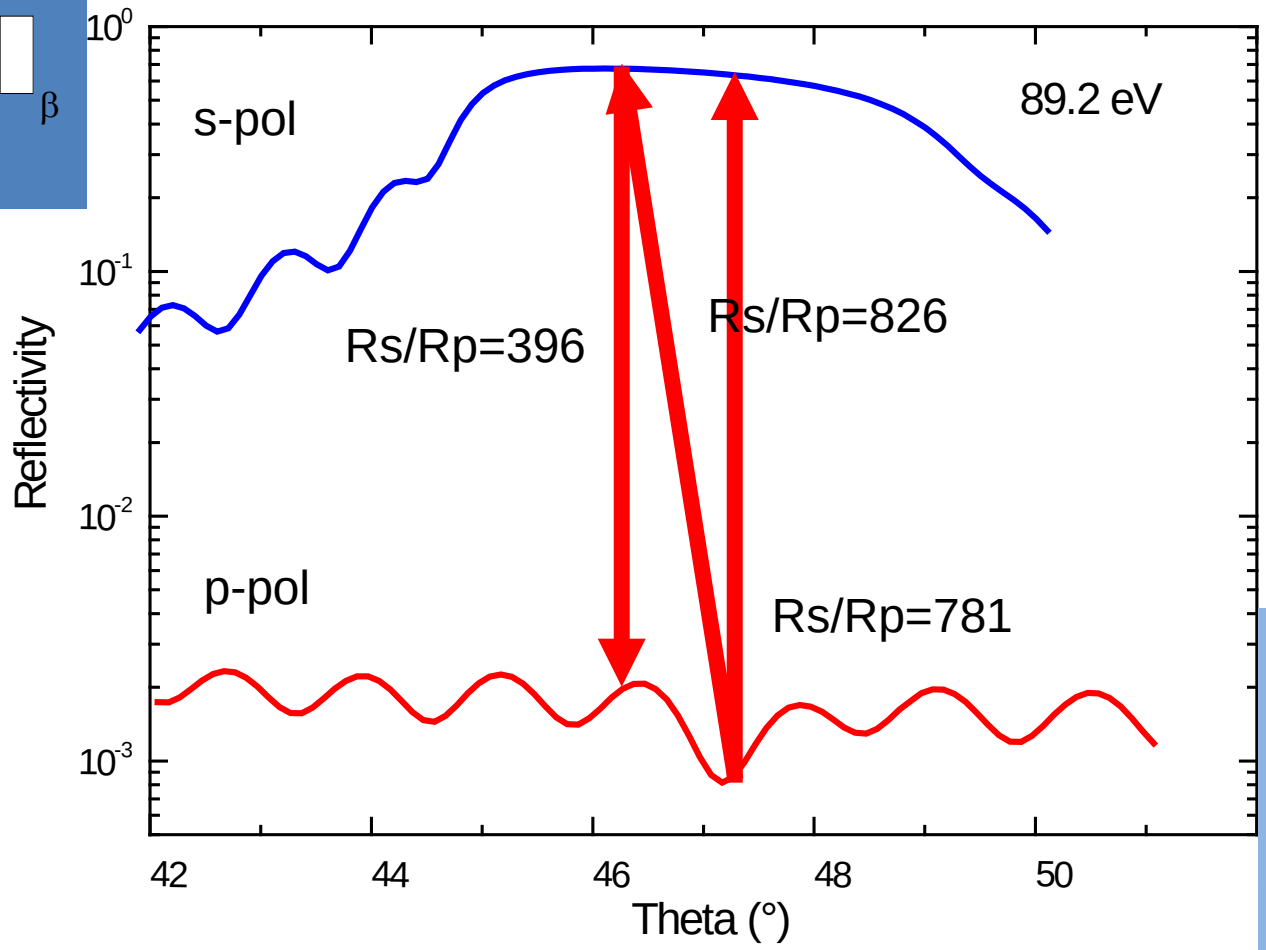
Bragg reflection around Brewster angle



- **Jump of Bragg-peak by 1 Kiessig fringe**
- **Jump dependent on number of layers**
- **Included in Fresnel equations (absorption needed)**

Brewster analyser – Rabinovitch type





Consequences for:

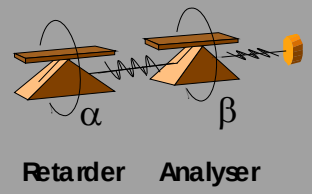
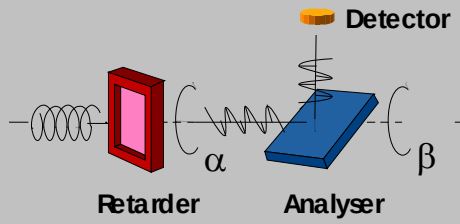
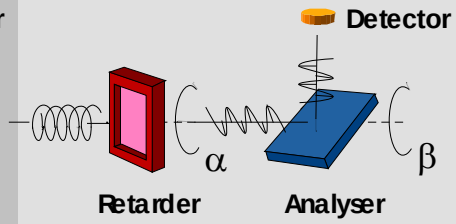
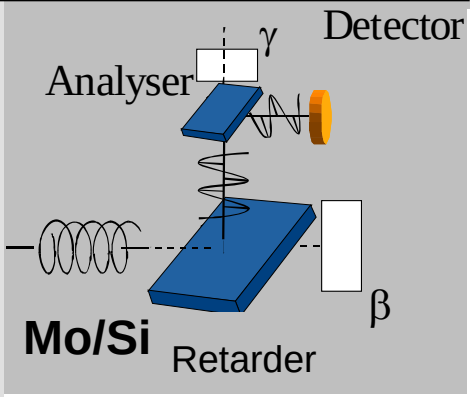
- **polarisation detectors**
- **x-ray scattering**
- **x-ray diffraction**
- **intensity correction**
- **position correction**

- **Polarisance strongly dependent on angle, energy, alignment…**

10 keV: $\sigma/\pi = 2.4\text{x}10^{-10}$

Marx et al. PRL 110, 254801 (2013)

Polarisation Analysis at BESSY

Multiple Reflection Mirrors	Transmission + Reflection Multilayers ((non-)resonant)	Transmission + Reflection Multilayers (non-resonant)	Reflection + Reflection Multilayers
			
Au	**Mo/Si Cr/Sc**	**W/B_4C**	
Triple - Reflection Polarimeter	**Quarter-wave Phase plates (dual-band)**	**Broad-band Phase plates**	
Energy 10	**100 280 400 570**	**700 1000 (eV)**	
Year 1985	**1993 1997 1998**	**2007 2009**	

- **ML-optics for Polarisation Steering and Control**
- **Full control of Stokes vector in XUV-range (<1000 eV)**
- **Complete at-wavelength characterisiton of multilayer optics**
- **Measure complex reflection or transmission coefficients**
- **Polarisation Spectroscopy - Magneto-optics - XMCD…**

Polarimetry, Ellipsometry, Reflectometry ✓

New Reflectometer

The new Optics Beamline at BESSY II

Metrology of in-house produced gratings and more

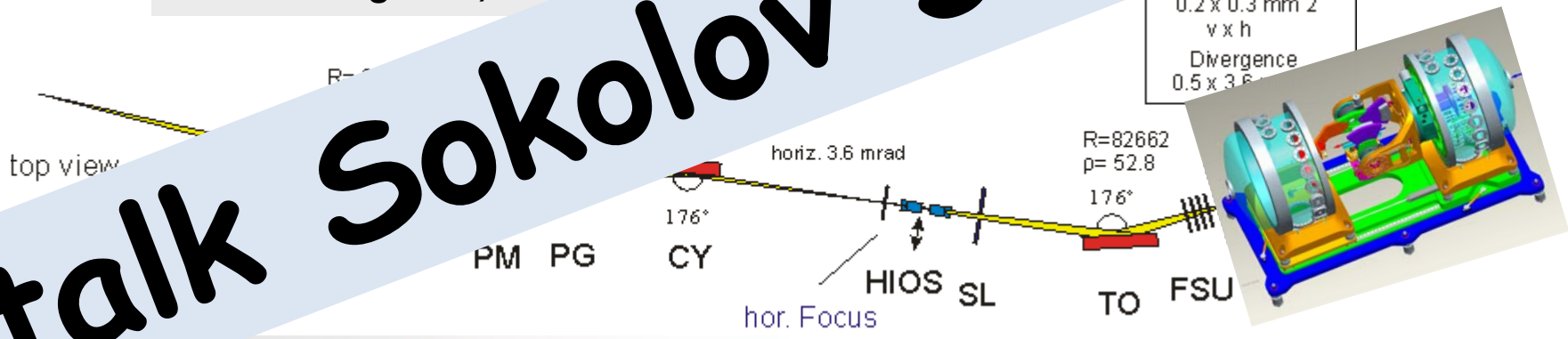
Collimated PGM

- 10 - 2000 eV
- moderate resolution 10.000 (@500 eV)
- polarization linear/elliptical
- higher order light suppressio
- low divergence, small

Reflectometry

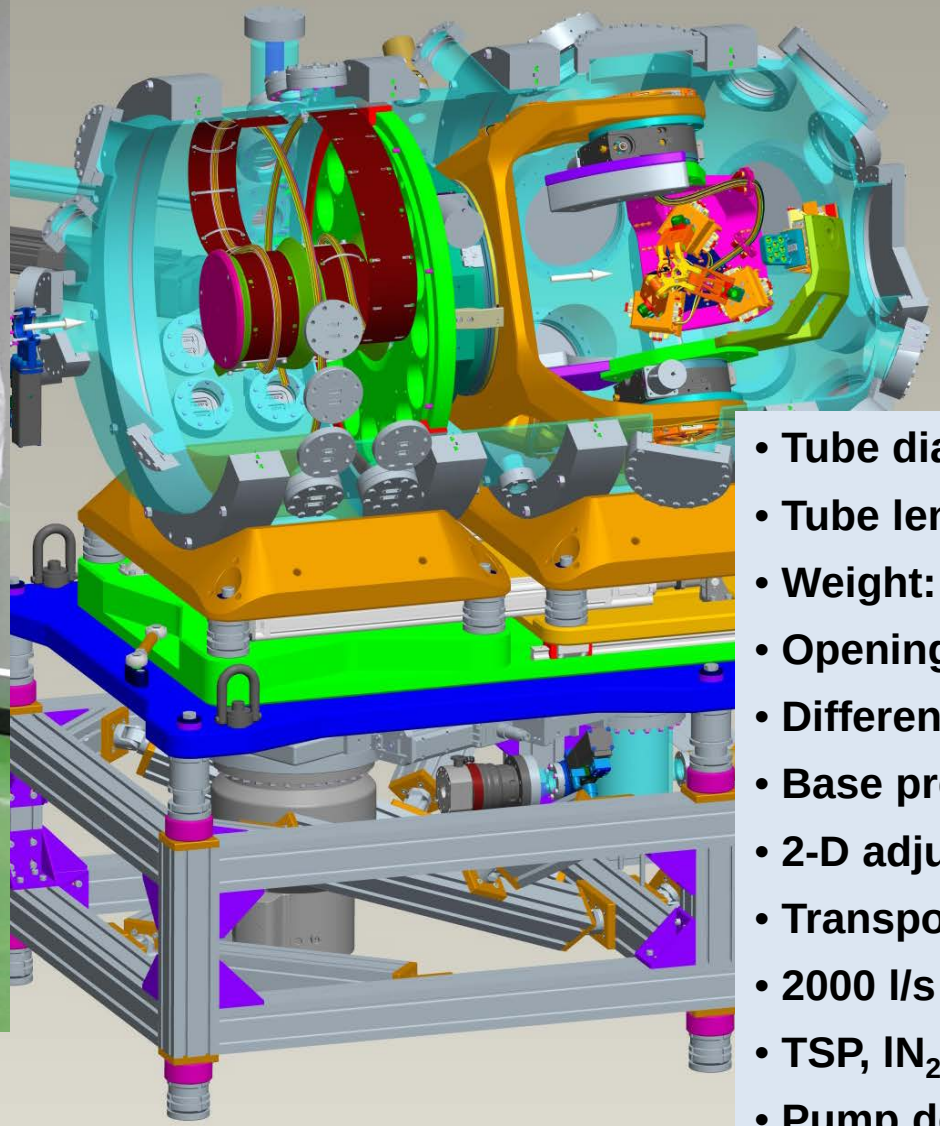
- „at-wavelen
  metr
- access

talk Sokolov 5:00 pm



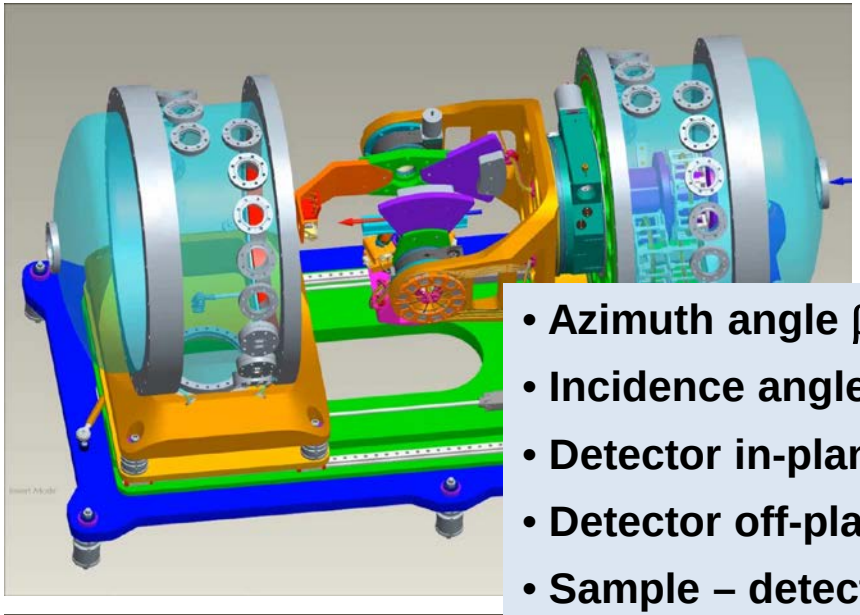
The clean-room hutch for reflectometer

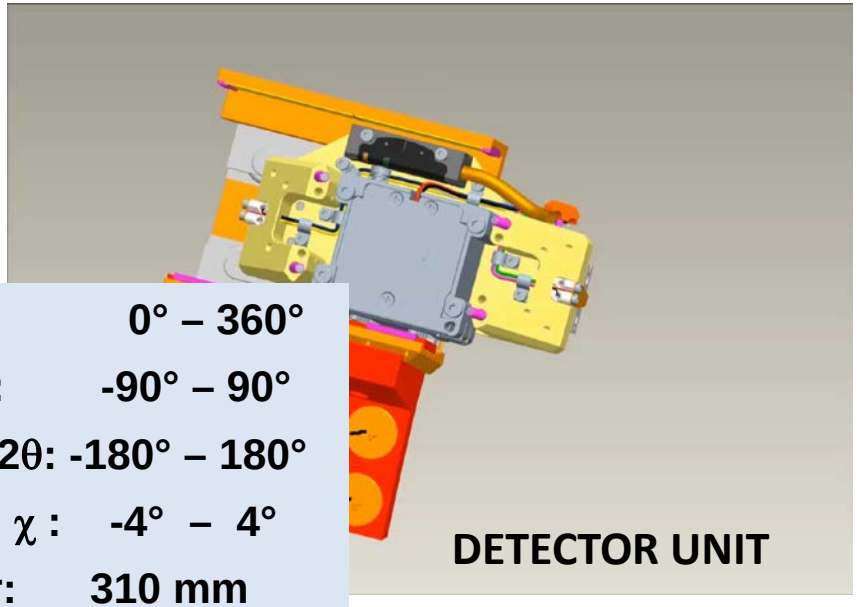
Reflectometer vacuum chamber



- Tube diameter: 0.8 m
- Tube length: 1.5 m
- Weight: 2.1 tons
- Opening by pneumatic guides
- Differentially pumped double O-ring
- Base pressure: $1x10^{-9}$ mbar
- 2-D adjustment on C-coated Al-plate
- Transport on air cushion
- 2000 l/s turbo pump
- TSP, lN_2 cold trap
- Pump down time: 3 h ($1x10^{-7}$ mbar)
- Load-lock in preparation

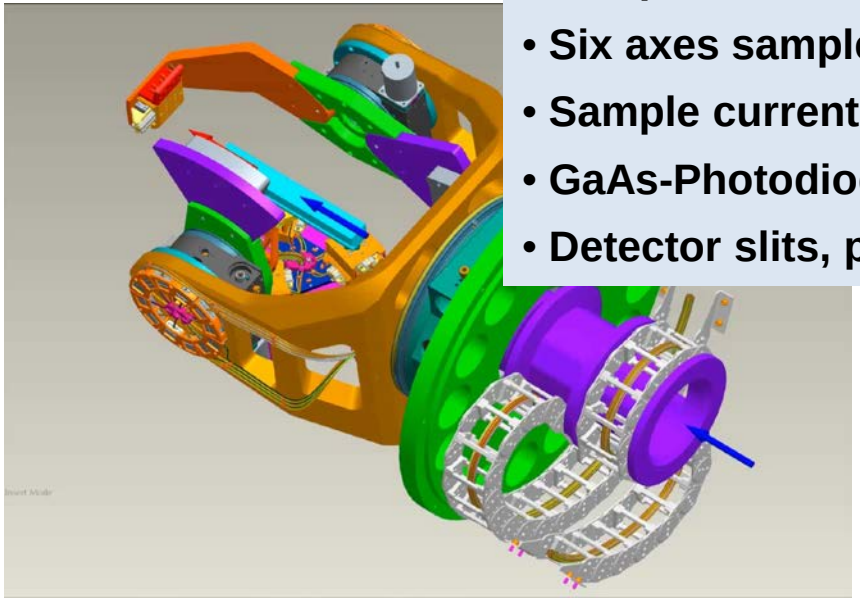
Reflectometer design - four circles – six axes



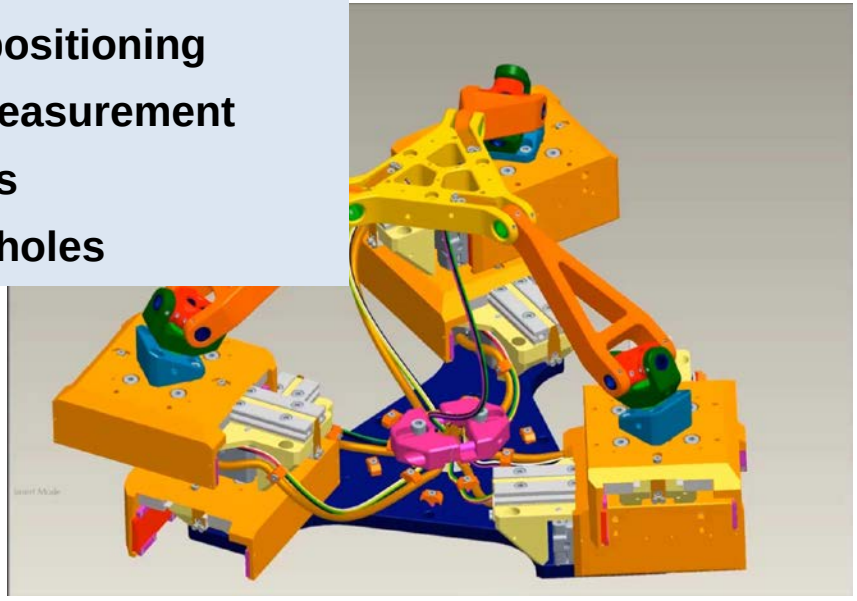


DETECTOR UNIT

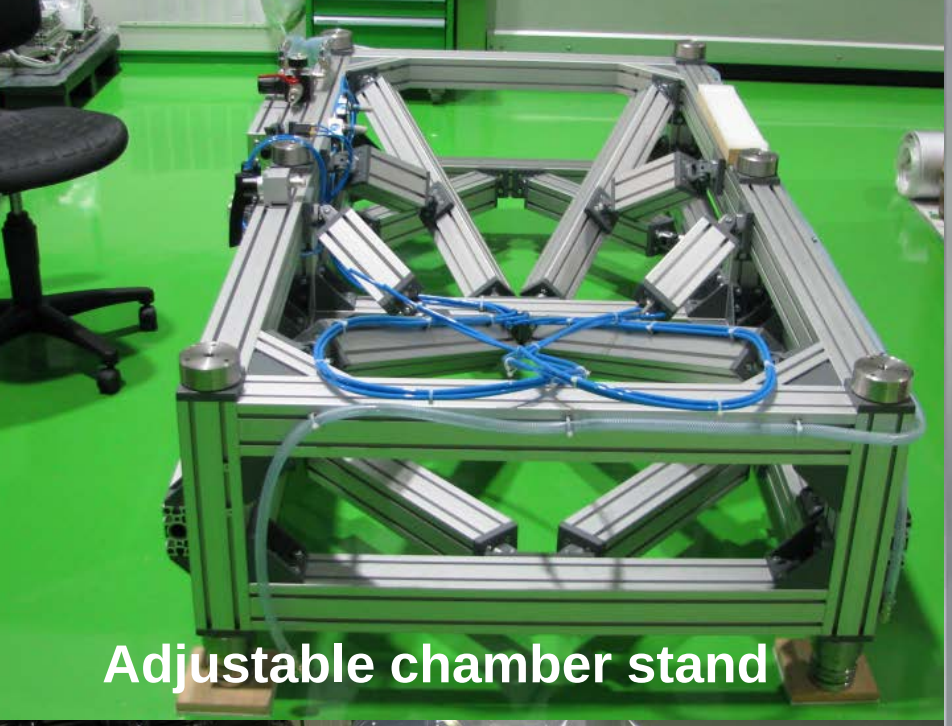
- Azimuth angle β: 0° – 360°
- Incidence angle θ: -90° – 90°
- Detector in-plane 2θ: -180° – 180°
- Detector off-plane χ : -4° – 4°
- Sample – detector: 310 mm
- Six axes sample positioning
- Sample current measurement
- GaAs-Photodiodes
- Detector slits, pinholes



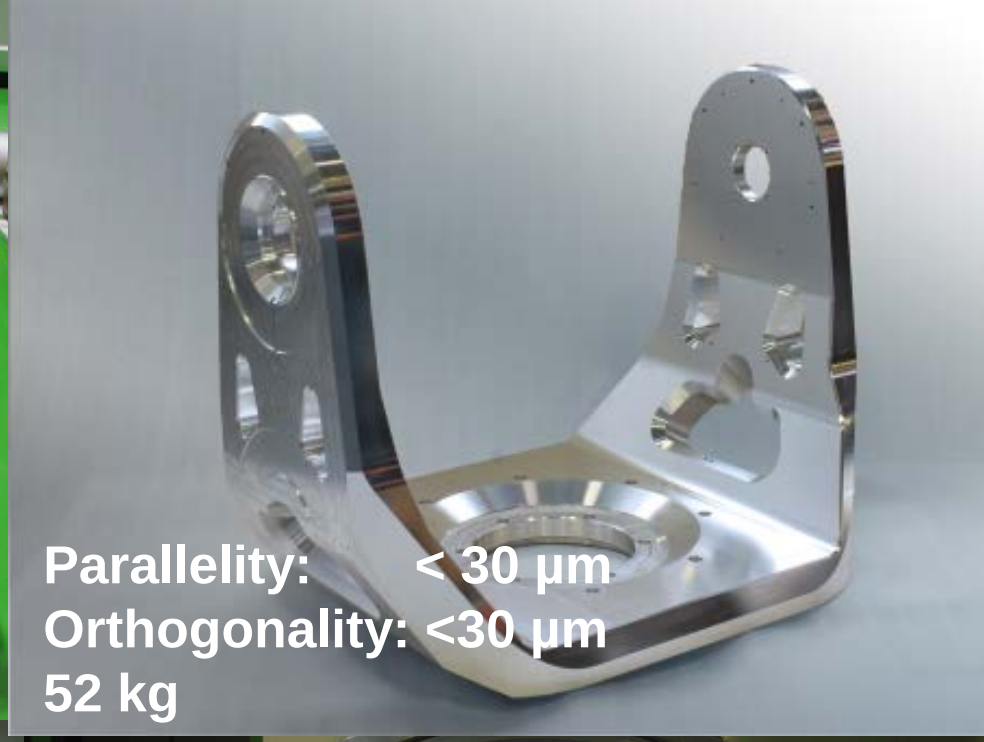
UHV-MECHANIC



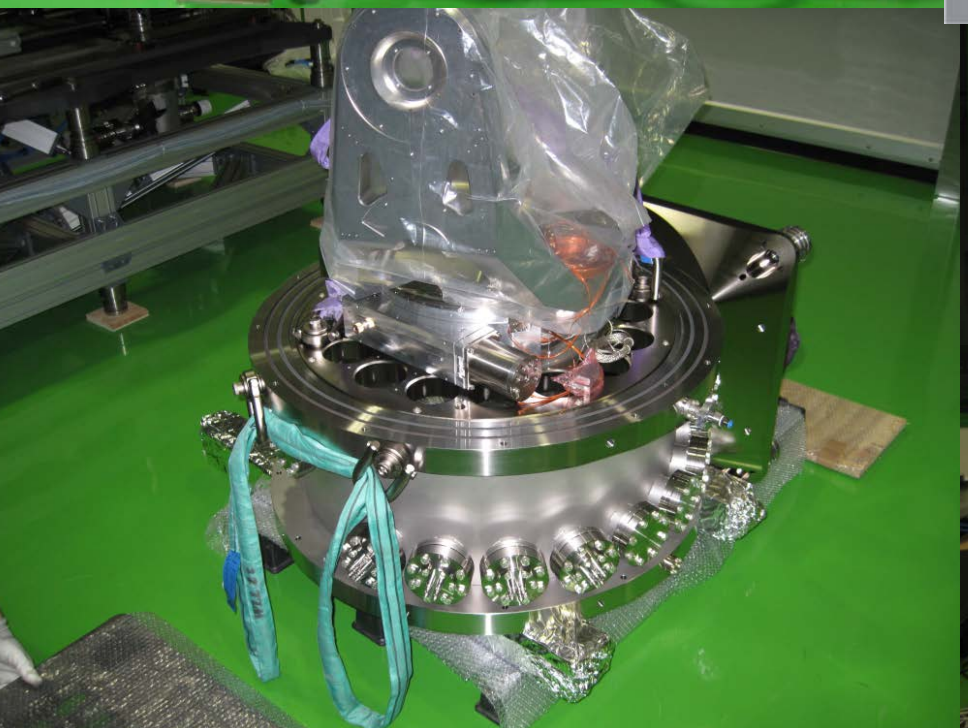
TRIPOD for sample positioning

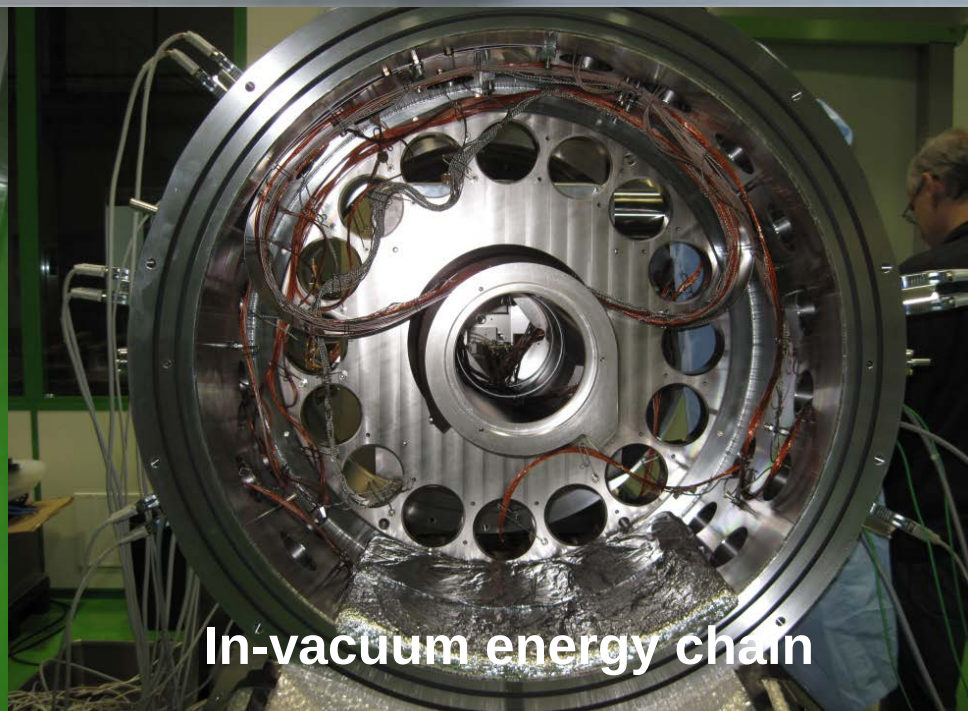


Adjustable chamber stand

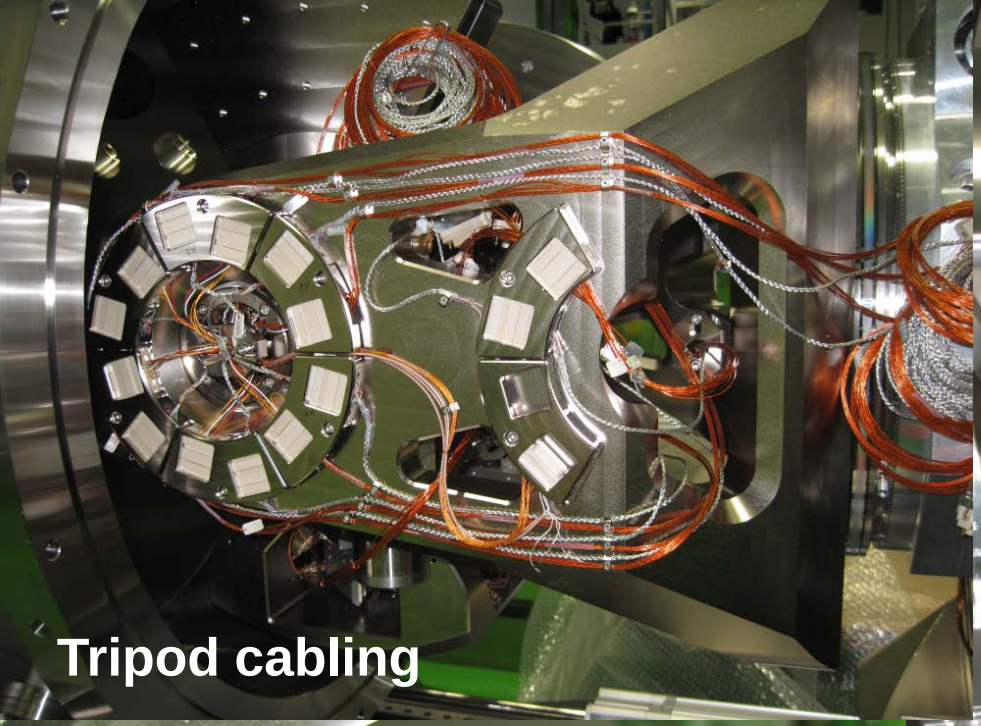


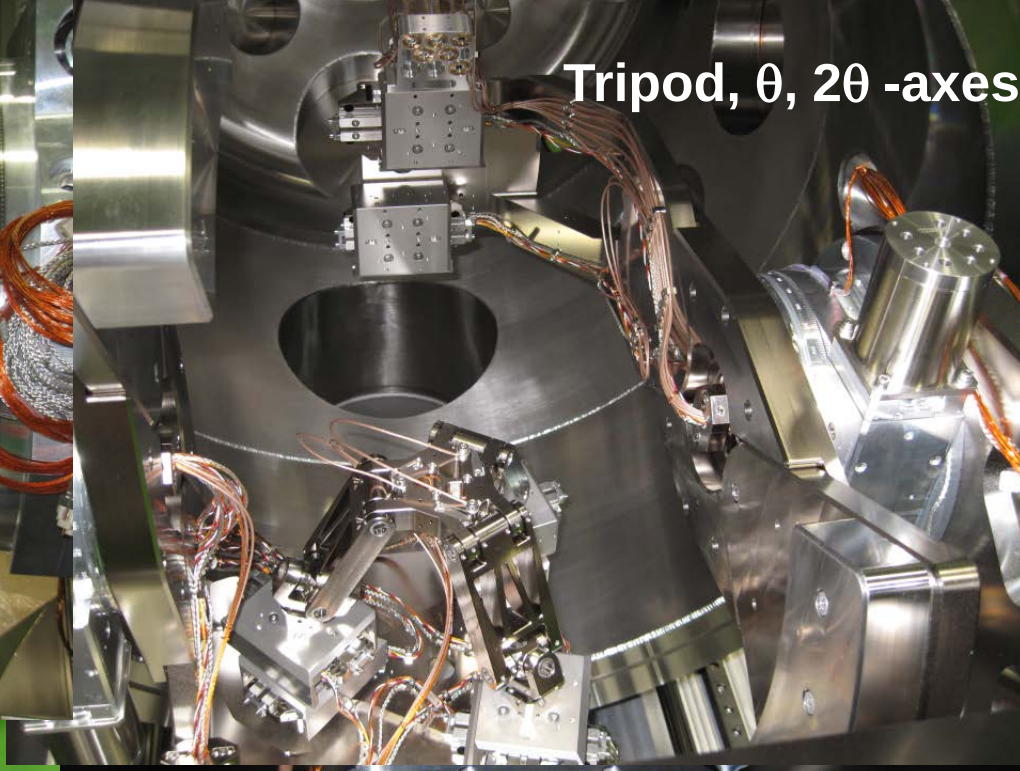
Parallelity: < 30 µm
Orthogonality: <30 µm
52 kg

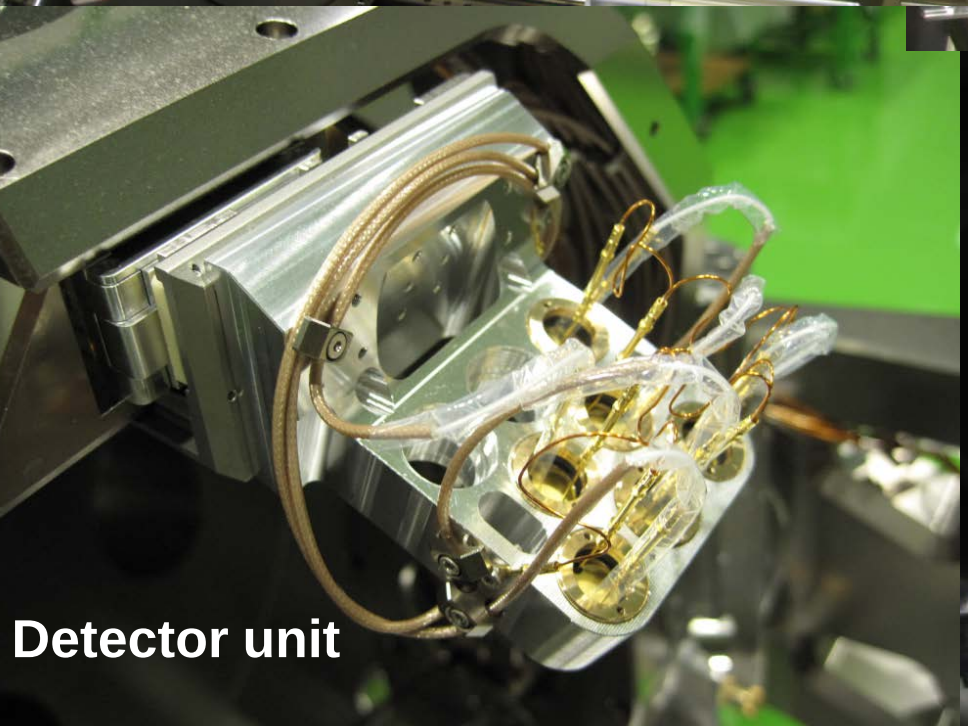




In-vacuum energy chain

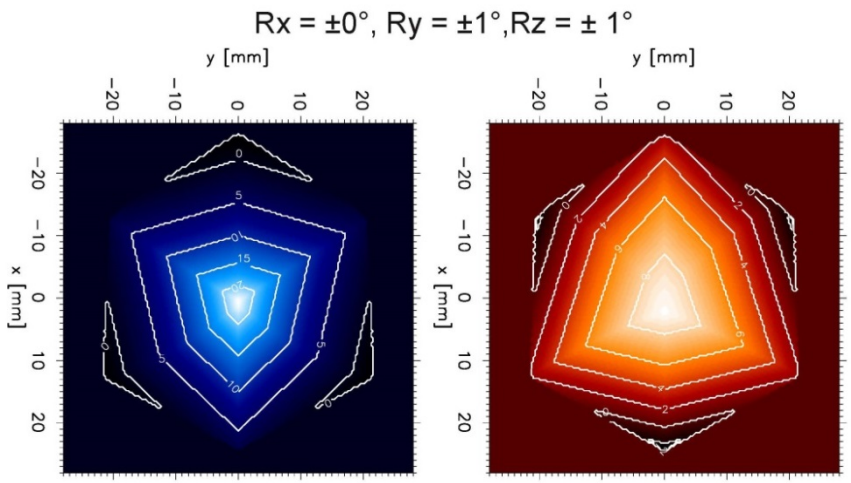

Tripod cabling

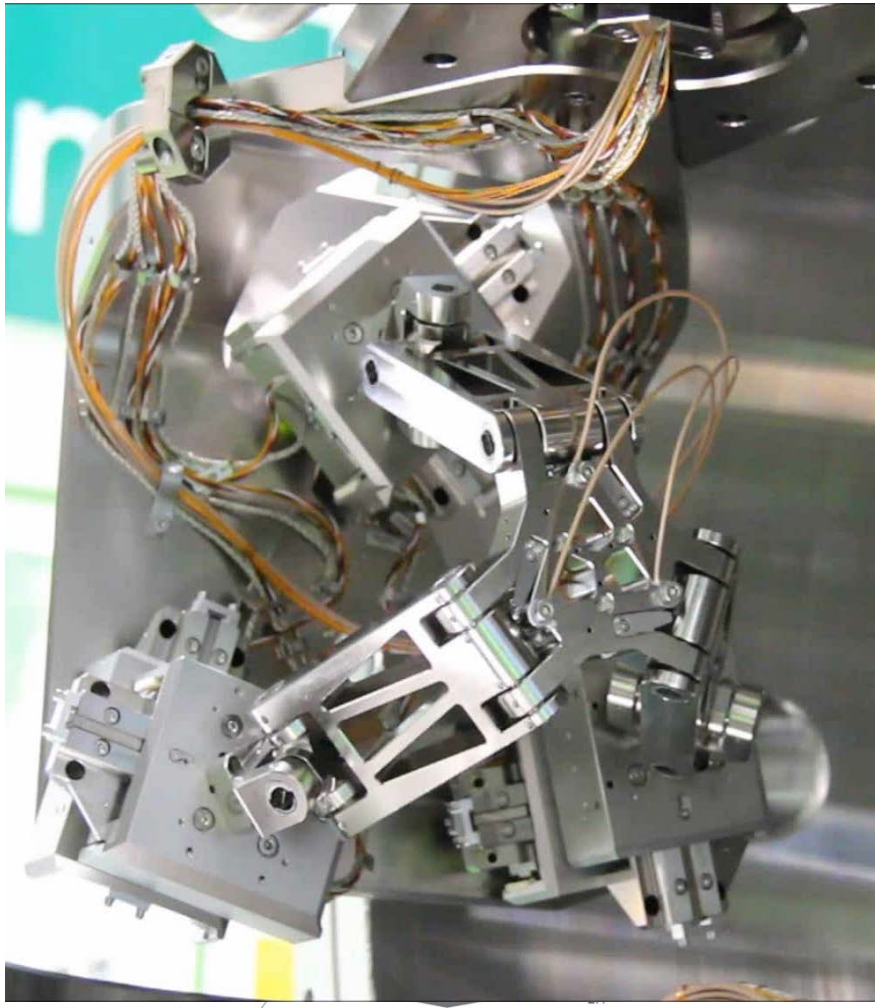

Tripod, θ, 2θ -axes


Detector unit


Detector unit

UHV-Tripod for heavy load

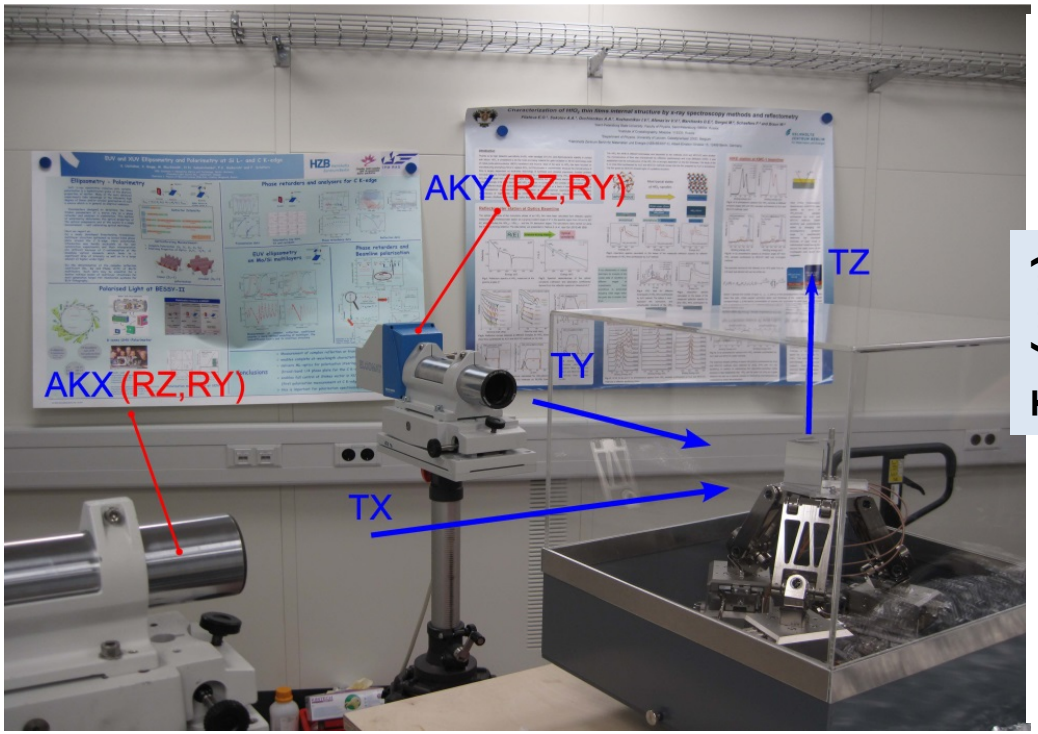


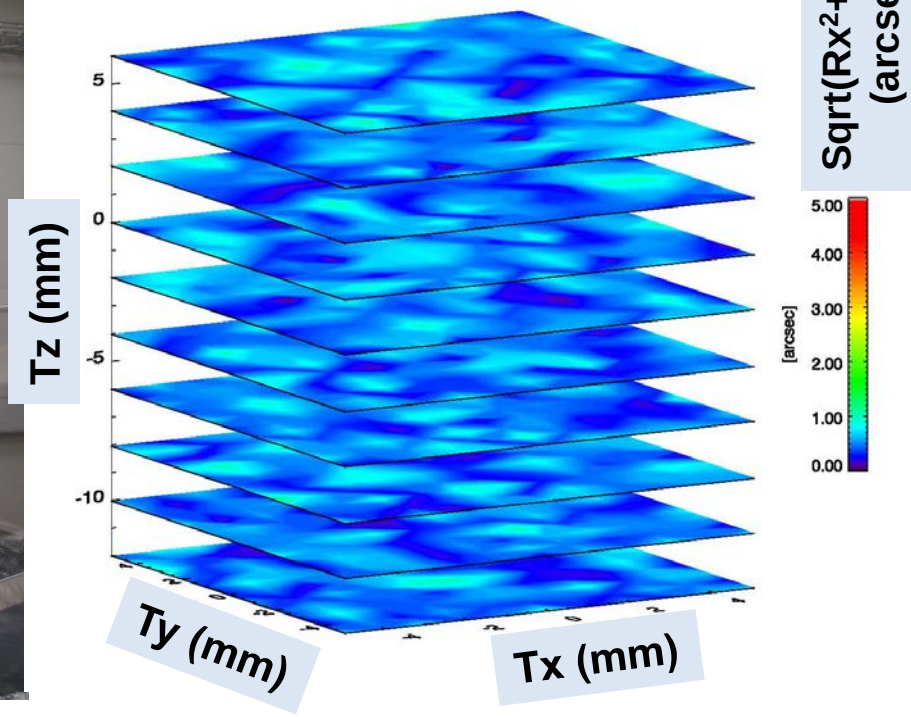


- Six degrees of freedom
- Sample weight: 4 kg
- Sample size: 300 x 60 x 60 mm3
- Max. scan range: +/- 15 mm
- Ceramic motors (Nanomotion)
- Linear encoders (Renishaw)
- Closed loop operation
- 10^{-9} mbar
- Motor resolution: 100 nm / 0.001°

Pointing stability: 10 µm / 0.01°

Tripod characterisation – cross-talk





Open loop deviation	**Rx, Ry, Rz: 500 arcsec**
Open loop deviation corrected	**10 arcsec**
Closed loop deviation (feedback)	**<0.5 arcsec**

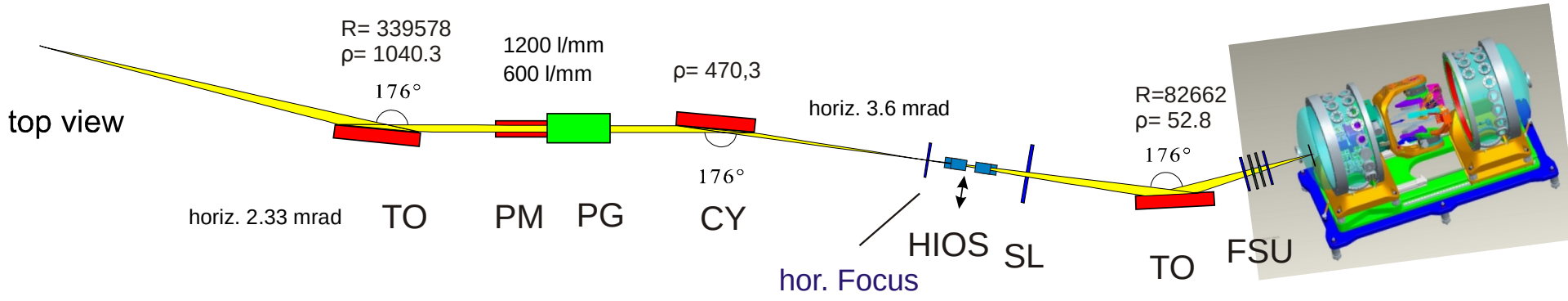
Limited by stop criterion for feedback loop

- **Potential for further improvement**

Conclusion

- **HZB-grating production facility is succesfully operating**
- **New UV / XUV Optics Beamline for at-wavelength metrology & more**
- **Versatile Reflectometer in ‘clean-room’ exp. hutch for large scale samples**
- **4-circles and 6 axes allow for measurement flexibility**
- **High precisicon polarimetry essential to discover / control / compensate beamline contamination/depolarisation effects**
- **High-precision ellipsometry determines λ/100 phase-shift variation**
- **Pol. dependent Bragg-position and intensity around Brewster-angle**

The setup will be open for user operation end of 2014



Acknowledgements

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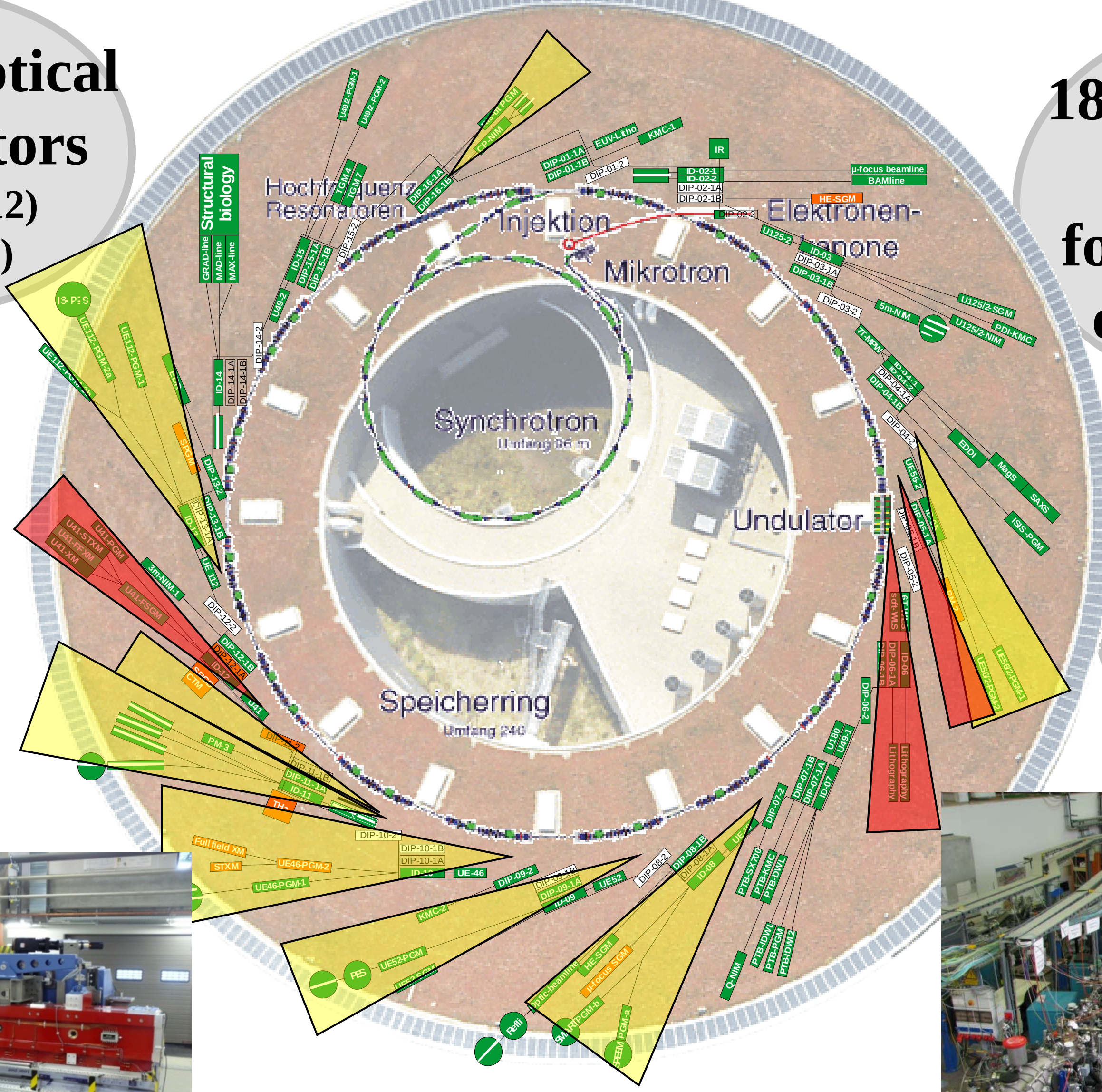
Frank Siewert
Andrey Sokolov
Thomas Zeschke

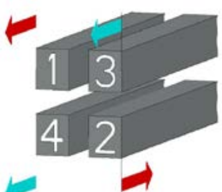
BESSY-II: Polarised Light - our product

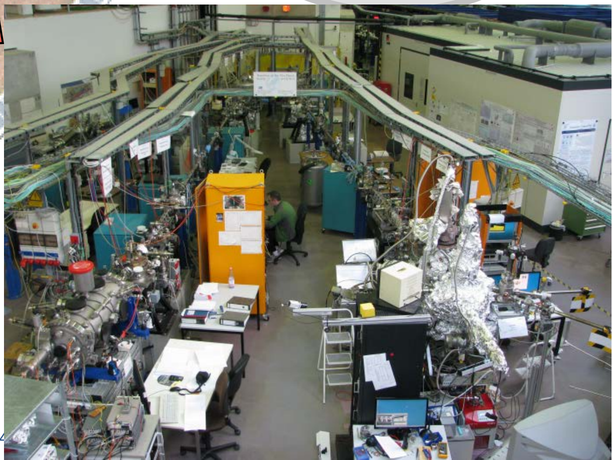
6 (8) elliptical Undulators
(UE46…112)
(out of 10)

18 (22) beamlines out of 50 for polarisation experiments

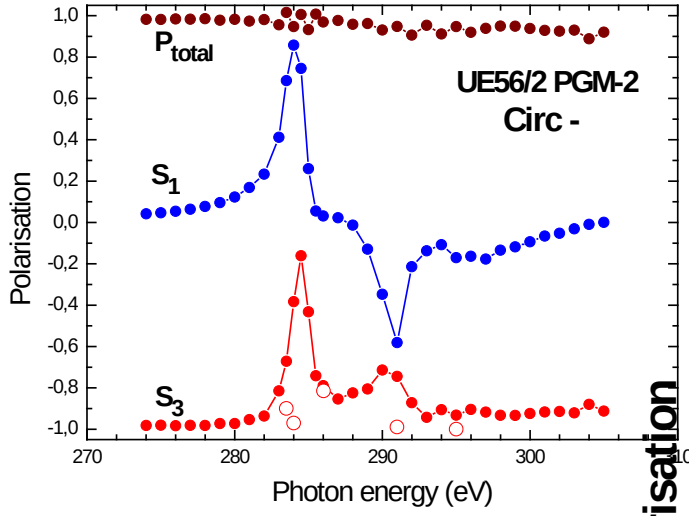
UV >10 eV
EUV 100 eV
XUV <2000 eV

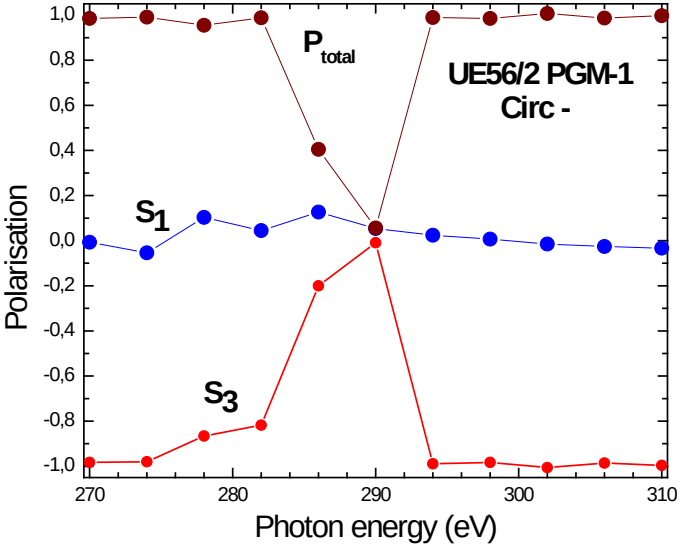


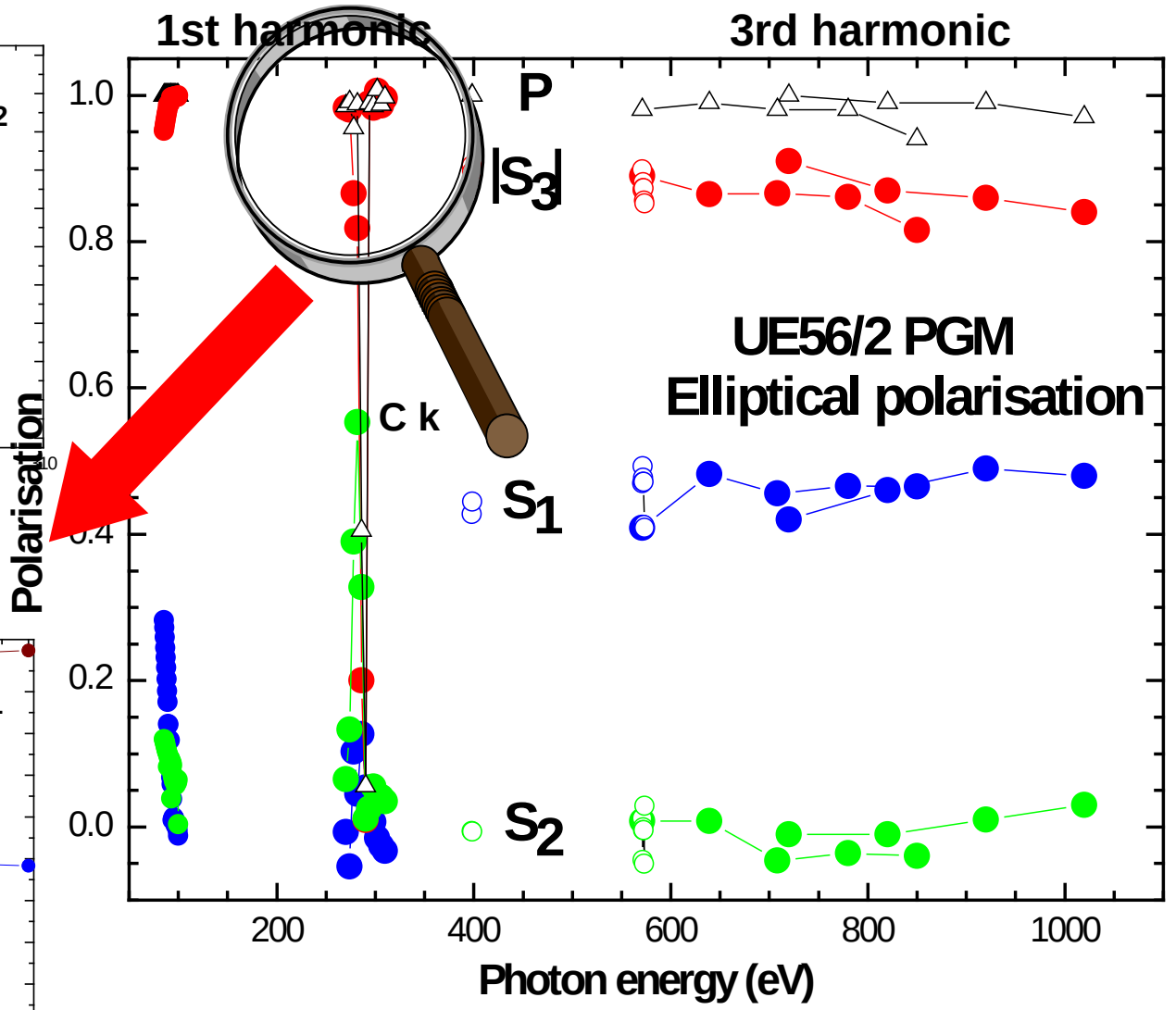




Beamline polarisation



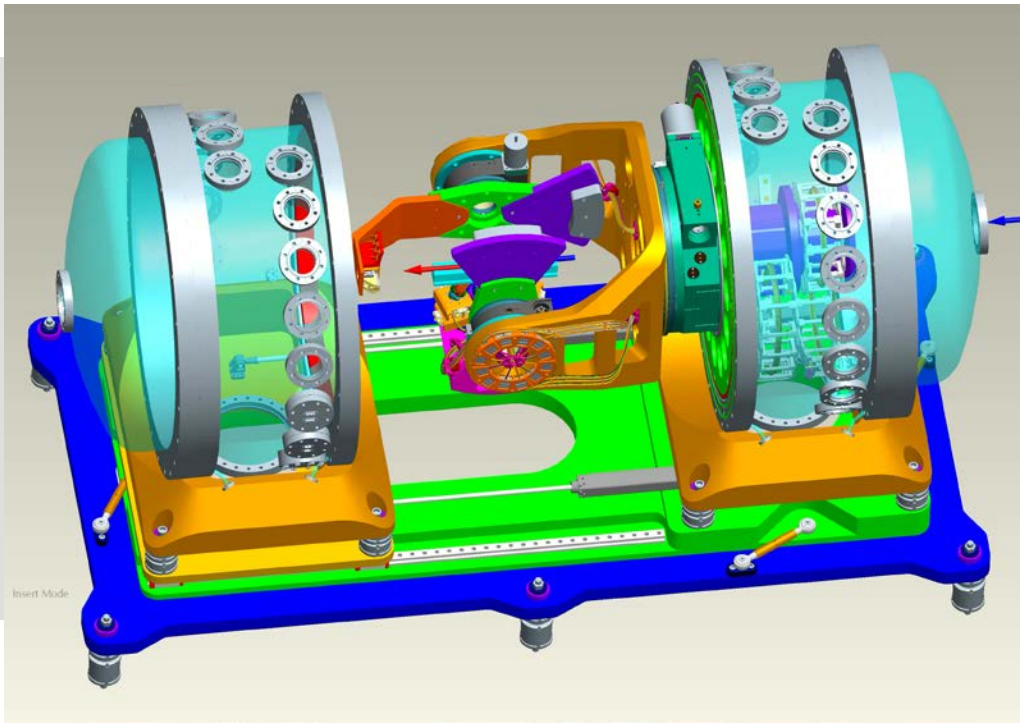




- S3 as expected for 1st and 3rd Undulator harmonic
- high degree of linear polarisation S1 in 3rd harmonic
- C-edge: depolarisation by contamination

Reflectometer workpackages and management

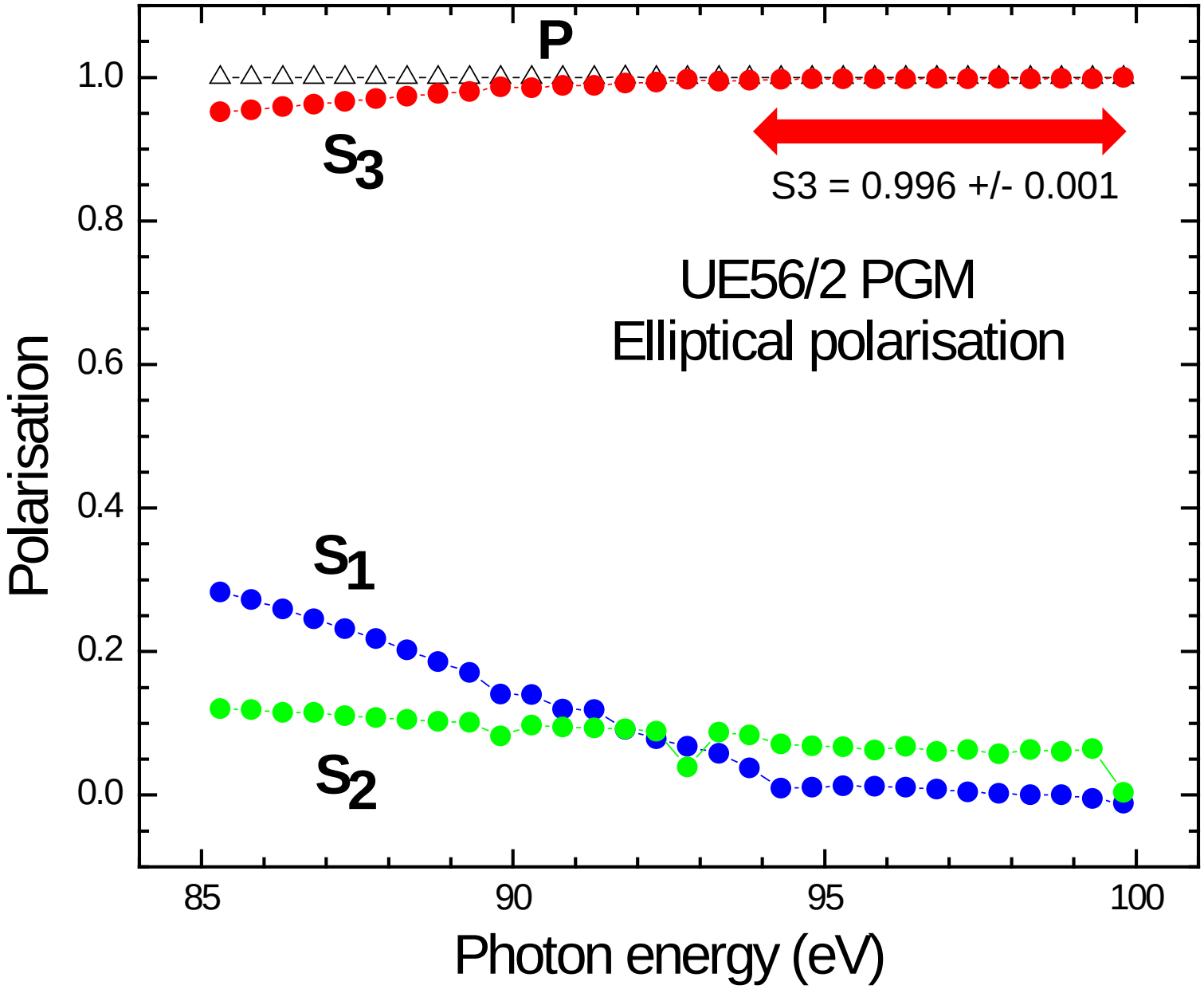
- **Optical bench**
- **Vacuum vessel**
- **Load-lock** (small samples only)
- **Control** (Labview, SPEC)



- **Specs, design and technical drawings made in house**

  (Frank Eggenstein)
- **Order, construction of individual packages separately** (F.E.
- **Mount and setup all parts at contractors site** (F.E.)
- **Develop control software in-house**

Ellipsometry spin-off: Beamline polarisation



Reflection ML as retarder plate

Reflection ML as analyzer