Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

A compact and calibratable von Hamos X-ray Spectrometer based on two full-cylinder HAPG mosaic crystals for high-resolution XES

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Outline

- Introduction
  - Motivation for a novel hard-X-ray high-resolution spectrometer
  - Wavelength-dispersive spectrometer in the von Hamos geometry
- Spectrometer requirements and performance
- Application example
- Conclusion

Motivation

- ➢ Chemical speciation for elements down to 2.3 keV

→ High-resolution X-ray Emission Spectroscopy (XES)

- ➢ Atomic fundamental parameters

Requirements:

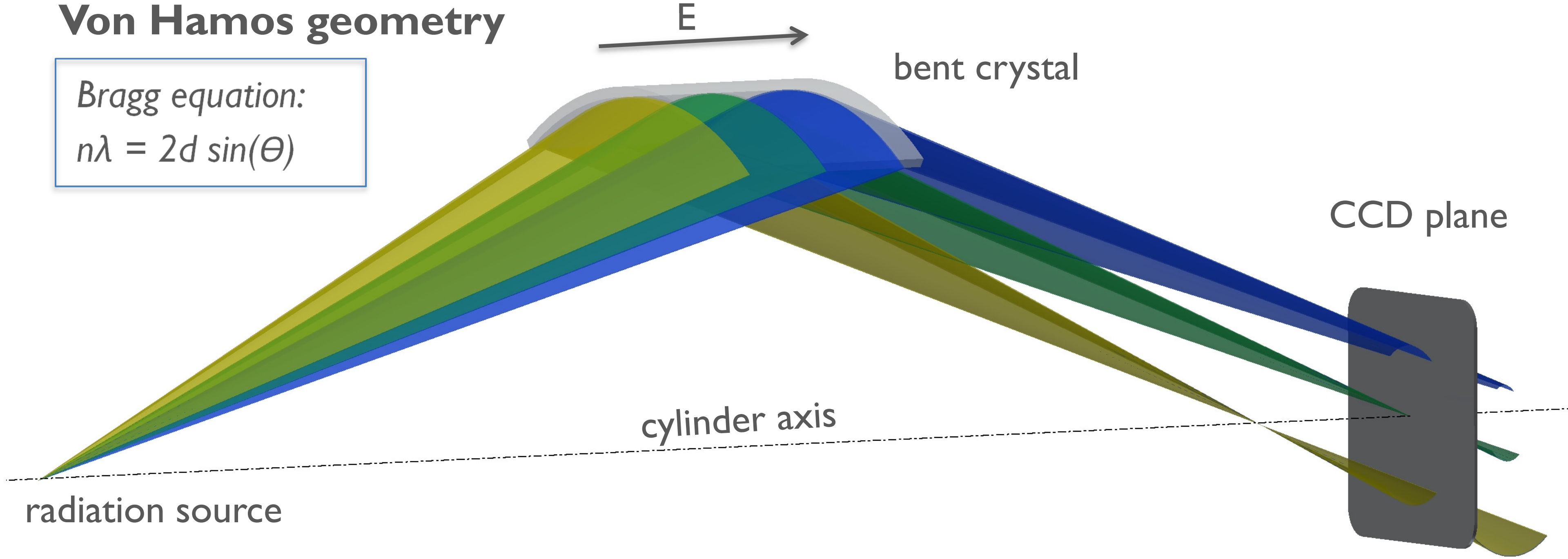
1. Calibratable instrument → **reference-free XRF and XES analysis**
2. Increase of the detection efficiency, thus XRF and XES sensitivity
3. Broad energy range plus fast change of selected photon energy
4. Compactness, reliability, and flexibility
5. Improved spectral resolution

Wavelength-Dispersive Spectrometer (WDS)

Von Hamos geometry

Bragg equation:

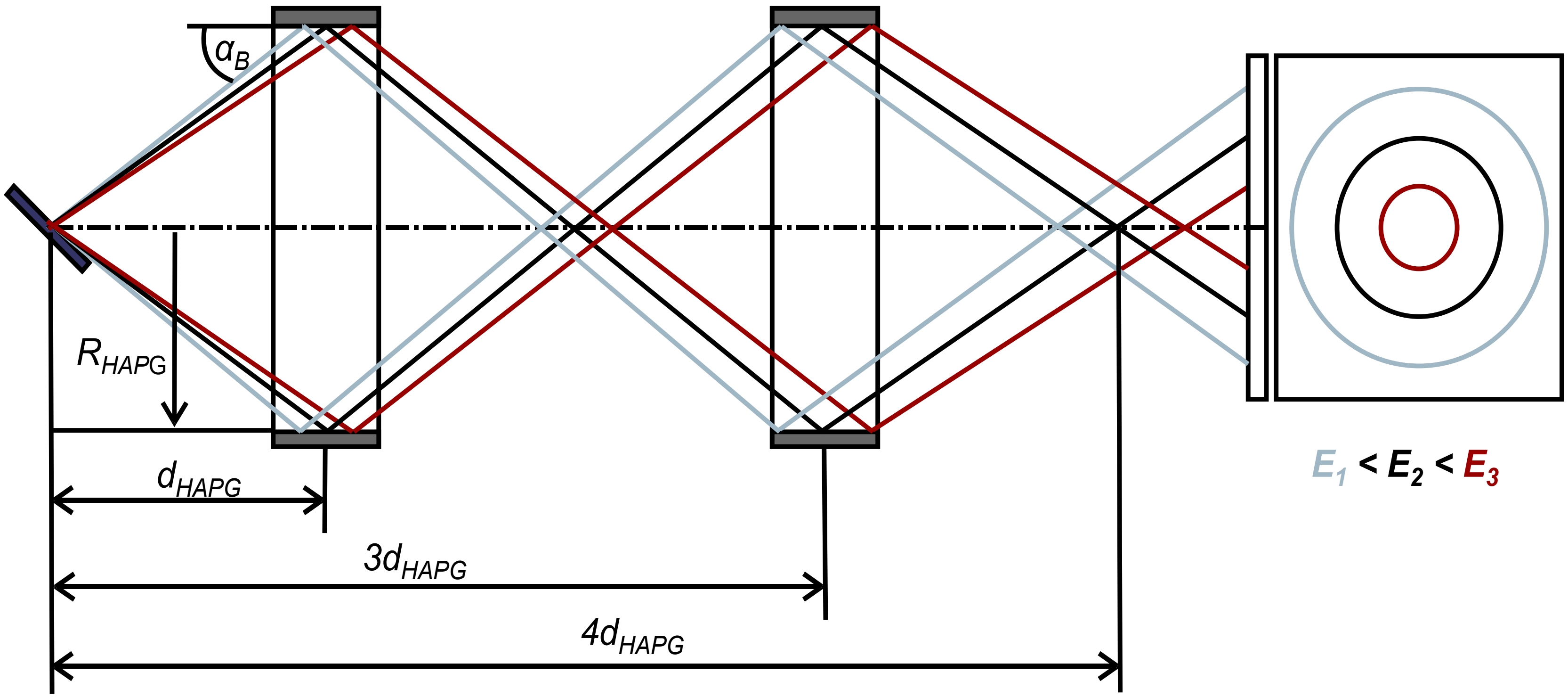
$n\lambda = 2d \sin(\Theta)$



→ **Higher effective solid angle** due to sagittal focussing (up to a factor of 20)

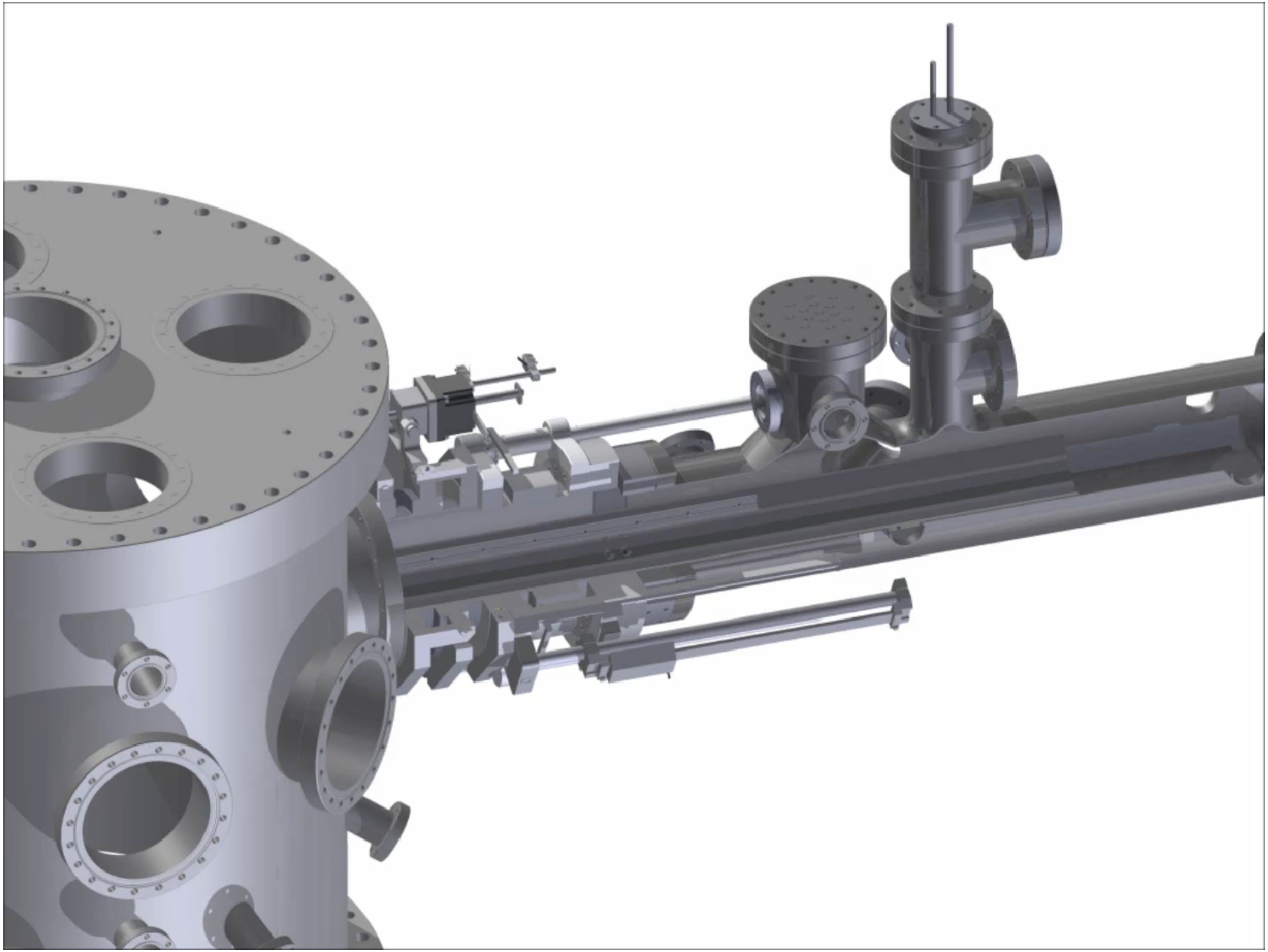
→ **Small bending radius**, down to 50 mm, is achievable when using Highly Annealed Pyrolytic Graphite (HAPG) without any crystal structure impact on the resolution

Double-Bragg-reflection concept



Operation modes:

- One crystal - 1st reflection order
- One crystal - 2nd reflection order
- Two crystals - double Bragg-reflection

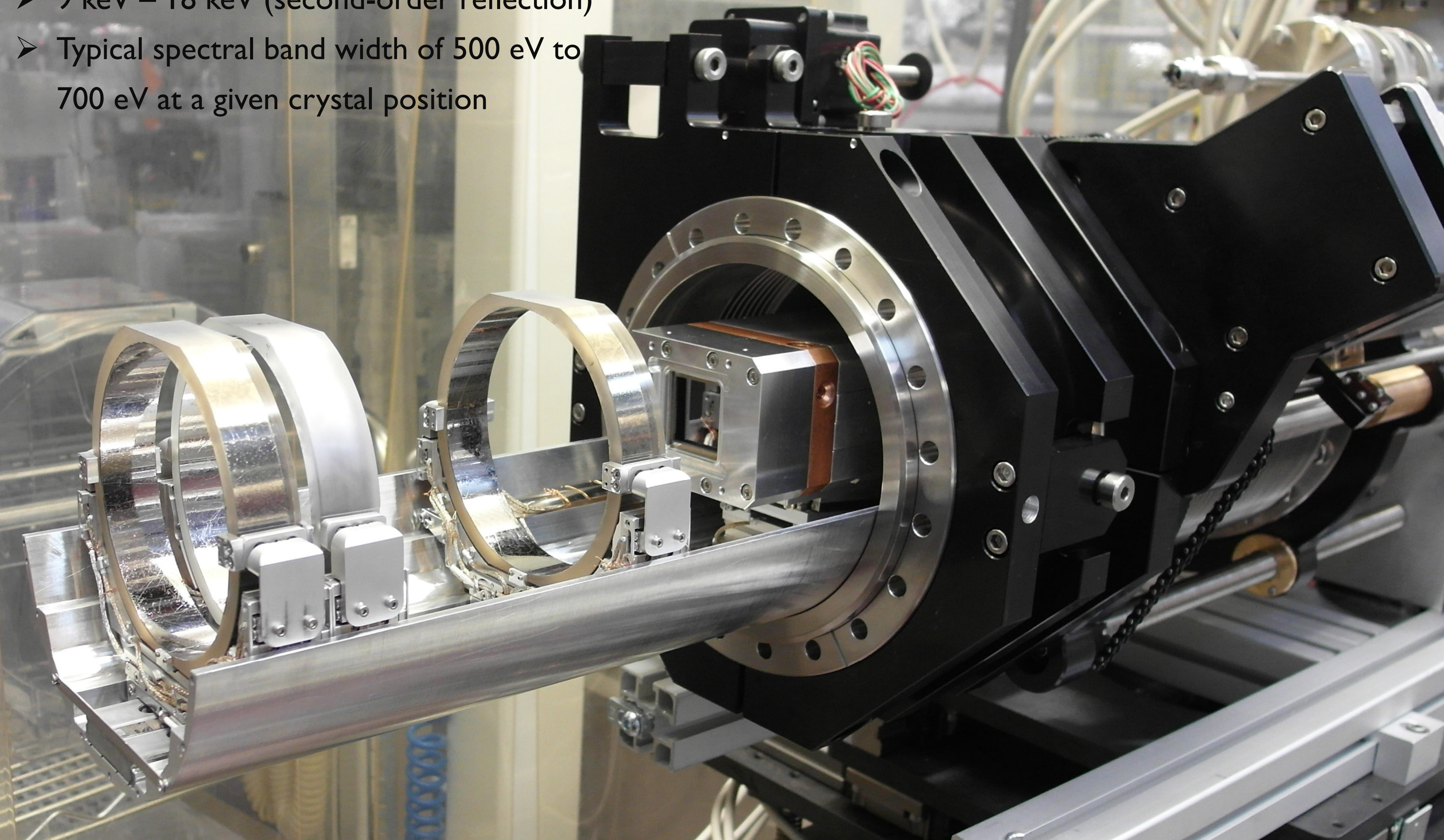


PTB laboratory at BESSY II

SmarAct
PERFECT MOTION

energy range:

- 2.4 keV – 18 keV (single Bragg reflection)
- 2.4 keV – 9 keV (double Bragg reflection)
- 9 keV – 18 keV (second-order reflection)
- Typical spectral band width of 500 eV to 700 eV at a given crystal position



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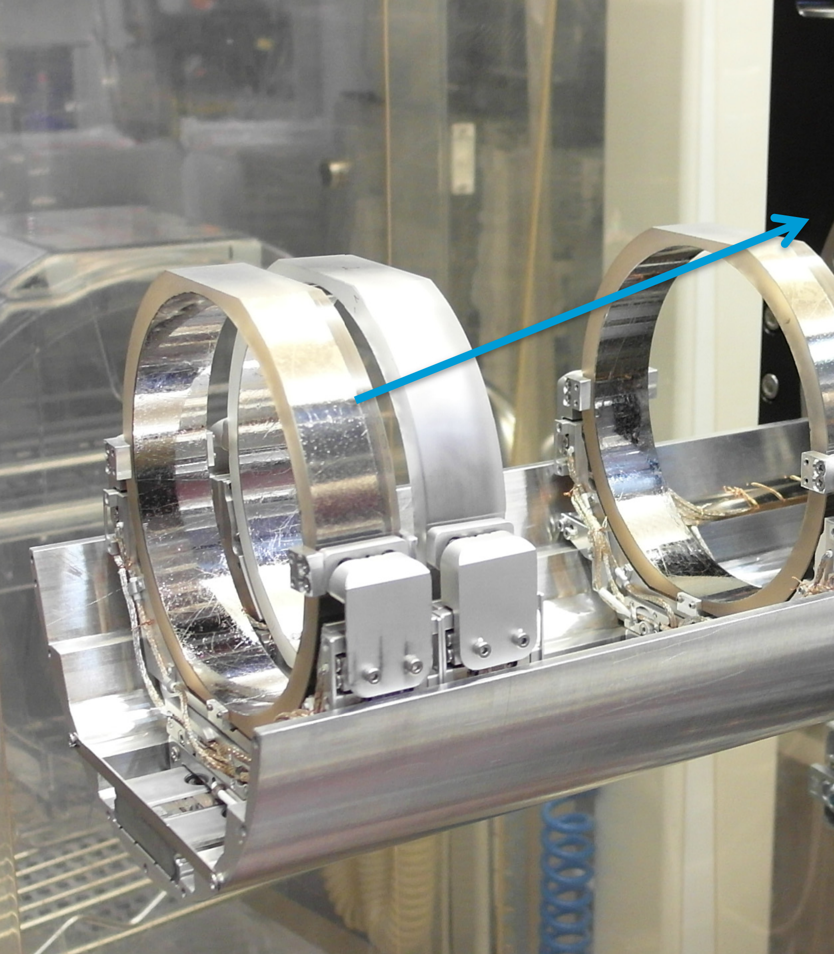
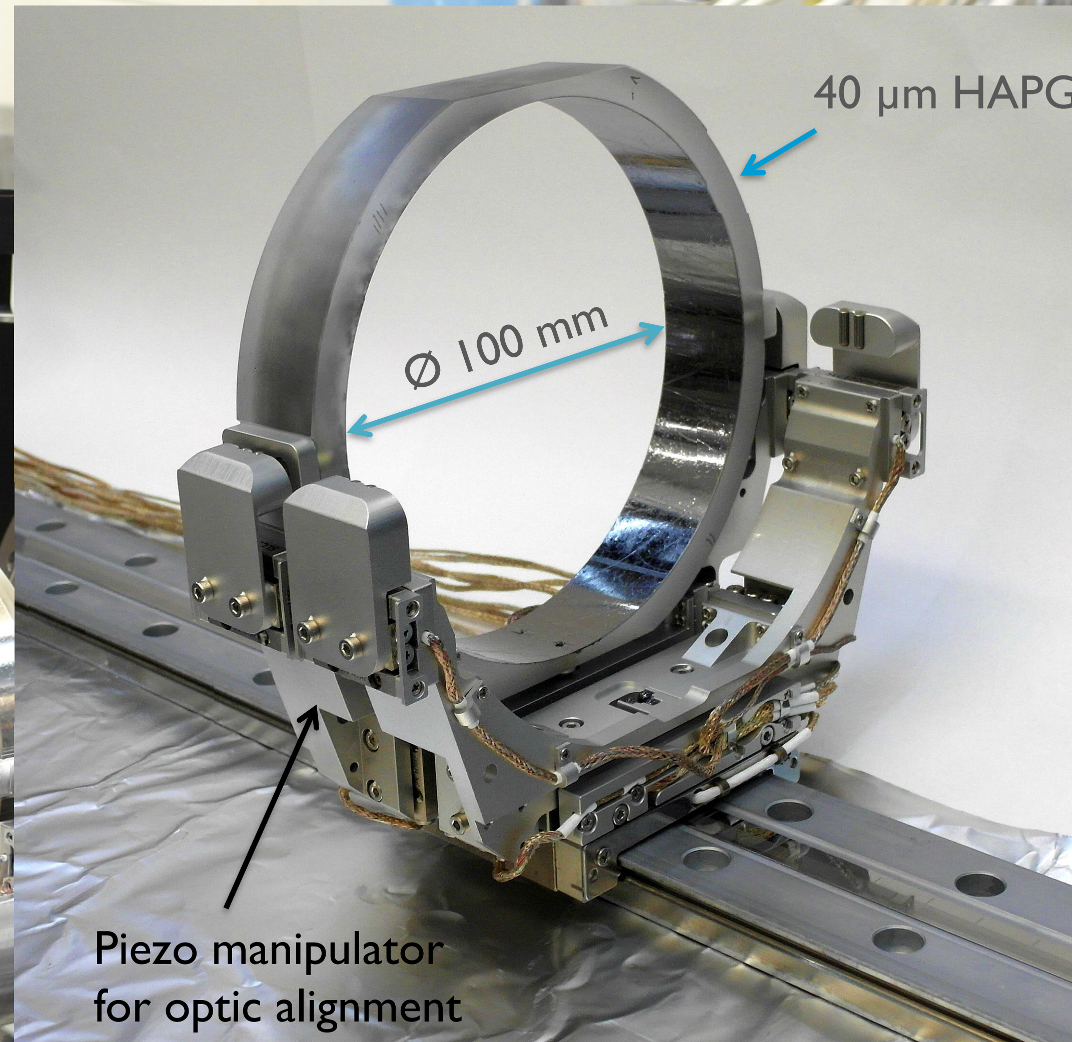
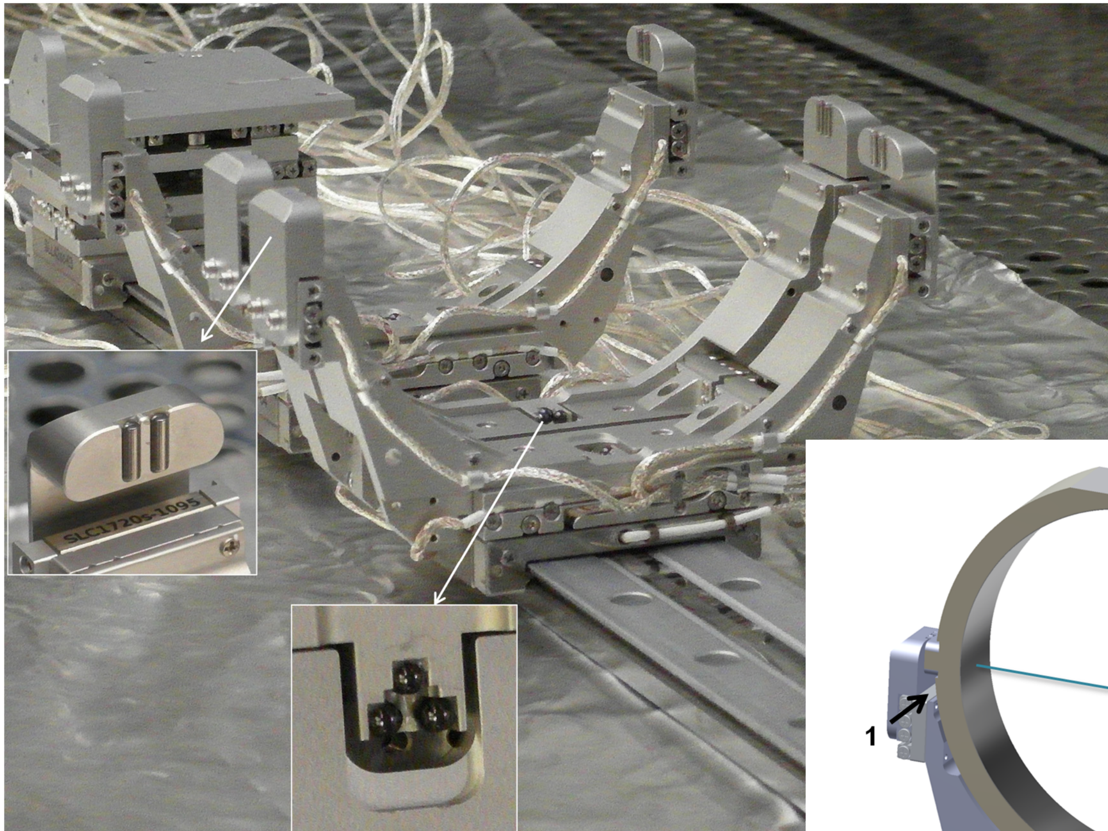
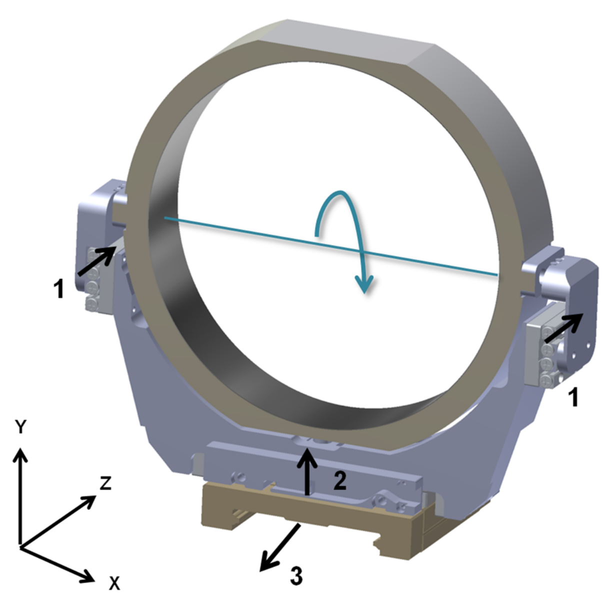
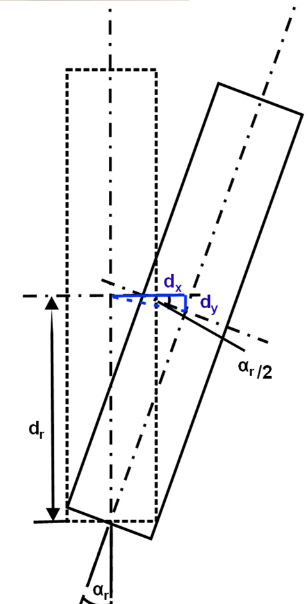




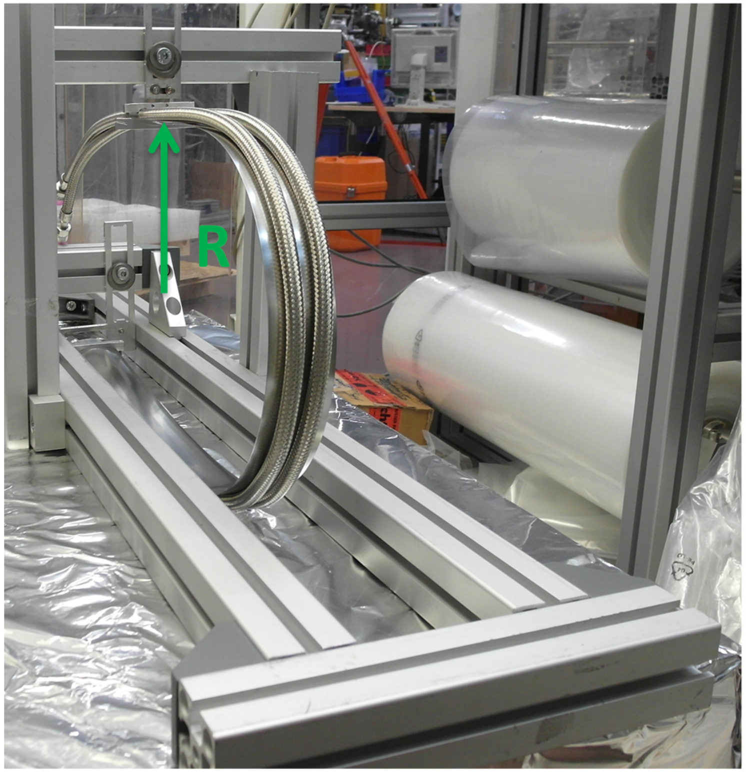
17-axis piezo manipulator

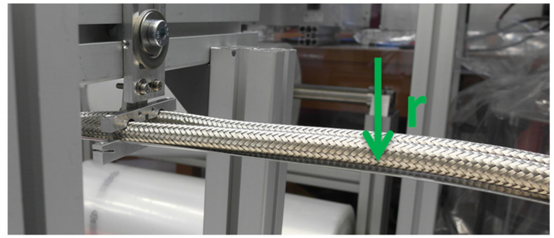


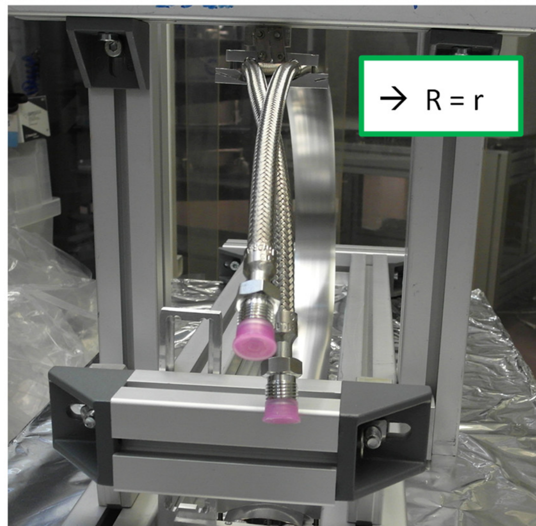


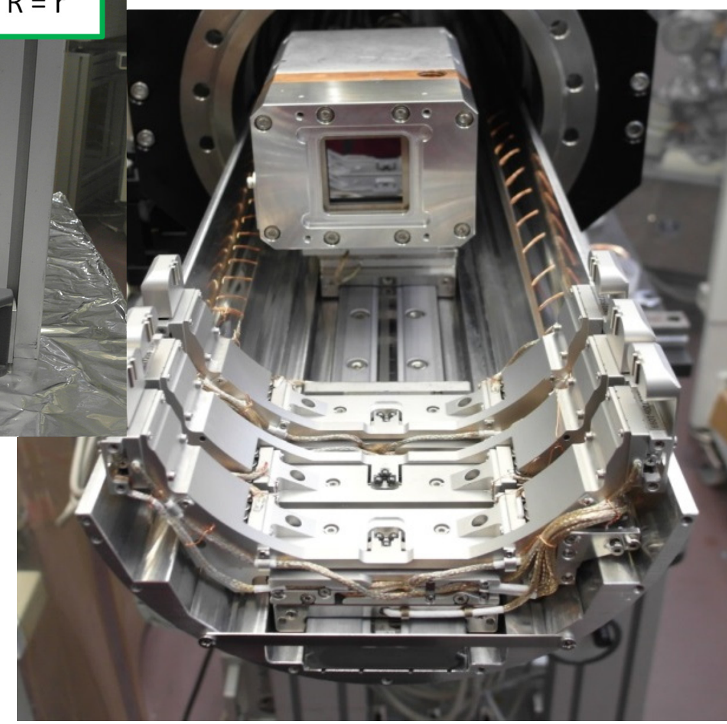


Energy chain





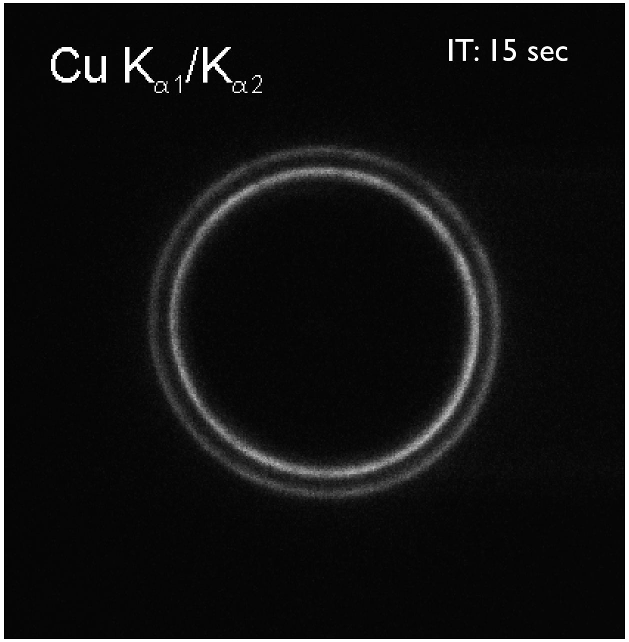




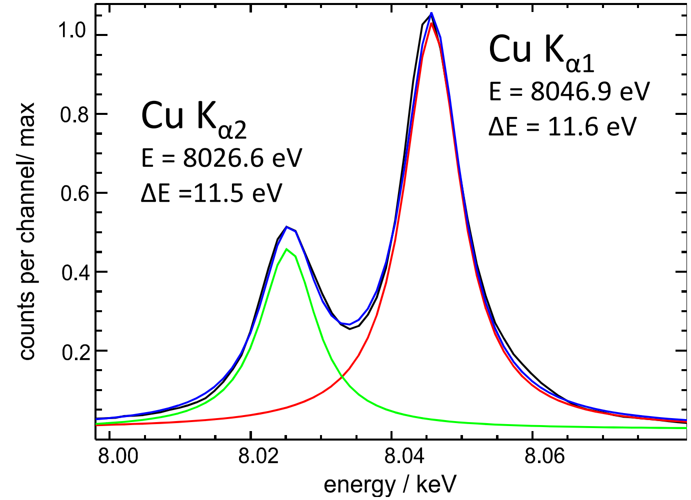
Baecker, H. J., Gaupp, A., Kuhn, C., Noll, T., Wagner, ZT.: In-Vakuum Kabelschlepp.
Interne Dokumentation, 2016.

Comparison of Copper $K_{\alpha 1}$ and $K_{\alpha 2}$ emission lines using one or two crystals

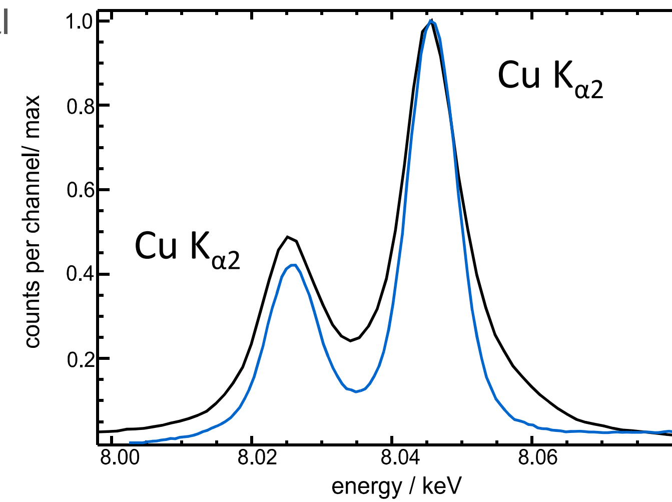
First-order reflection



Copper $K_{\alpha 1}$/ $K_{\alpha 2}$ spectral lines using one crystal

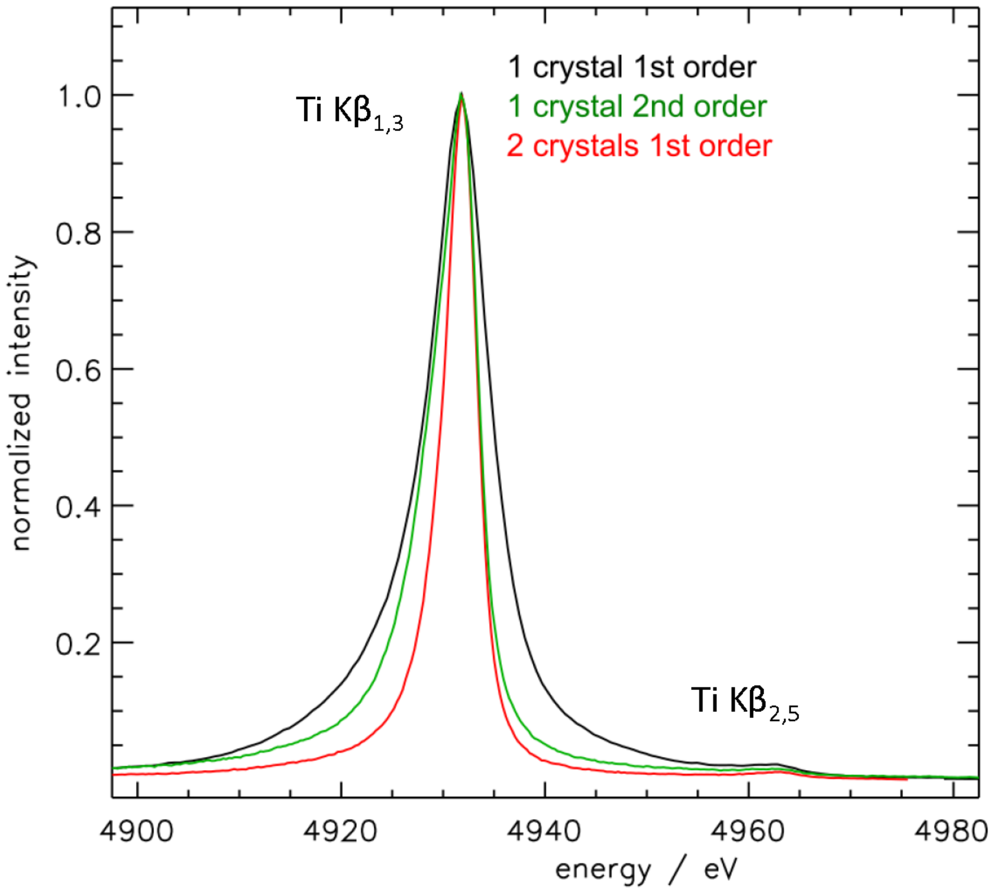


Copper $K_{\alpha 1}$/ $K_{\alpha 2}$ spectral lines using one crystal (black) and two crystals (blue)



Improved tailing and so higher discrimination capability when using two crystals

Spectral resolution - different configurations

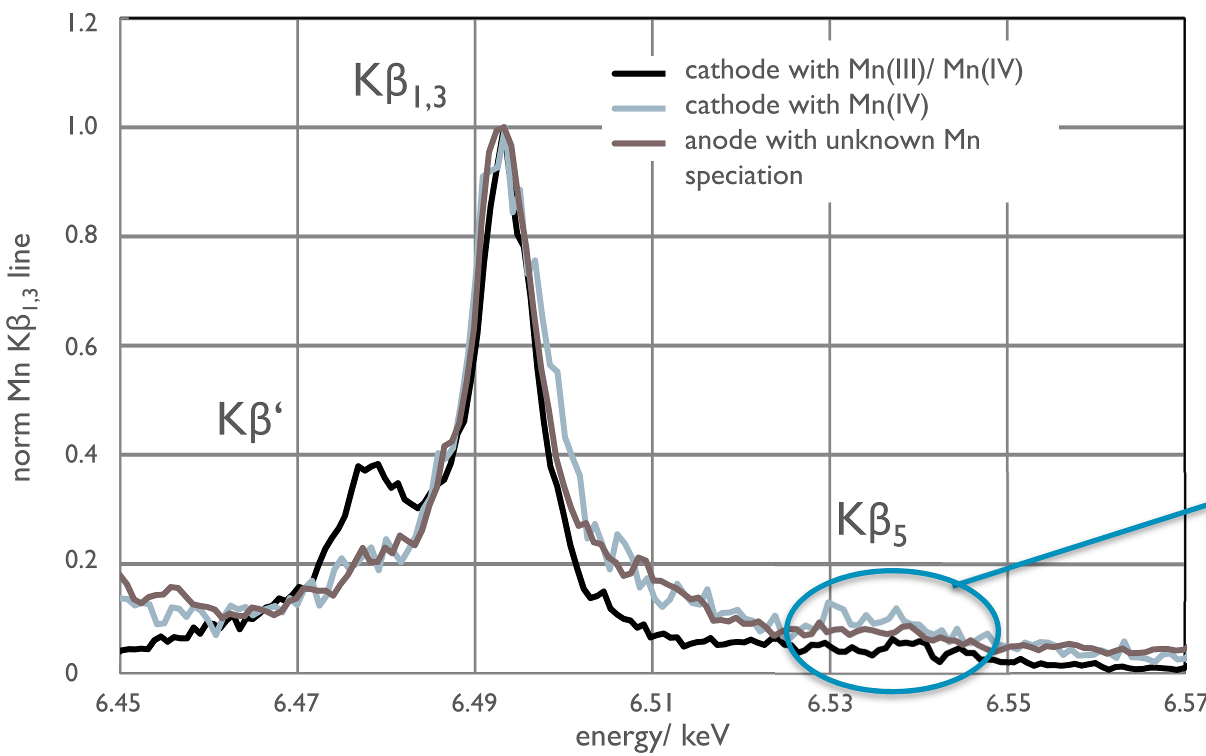


Titanium Kβ	E/ΔE
1 crystal 1st order	850 (5.8 eV)
1 crystal 2nd order	1450 (3.4 eV)
2 crystals 1st order	2800 (1.8 eV)

- Natural line width 1.02 eV
- 40 µm beam size
- 4 µm titanium foil

Wansleben, Malte (2018): Kalibrierabsätze für die hochauflösende XES. Talk. Technical University Berlin: 22.05.2018

Application example - buried Mn nanolayer in a Li-ion battery



Better resolution if using two crystals

Thanks to meet for providing the sample systems

Summary

- Von Hamos spectrometer → **two full-cylinder optics**
- **High detection efficiency** (von Hamos geometry)

  → reduced radiation damage risk and shorter measurement time
- Spectrometer design allows **calibration**

  → reference-free XRF and XES analysis, RIXS
- Compact design and different operation modes
- High resolution spectrometry and tunable response (tailing modification)
- Broad energy range and fast energy setup change

  → **2.4 keV to 18 keV**, spectral band width 500 eV to 700 eV