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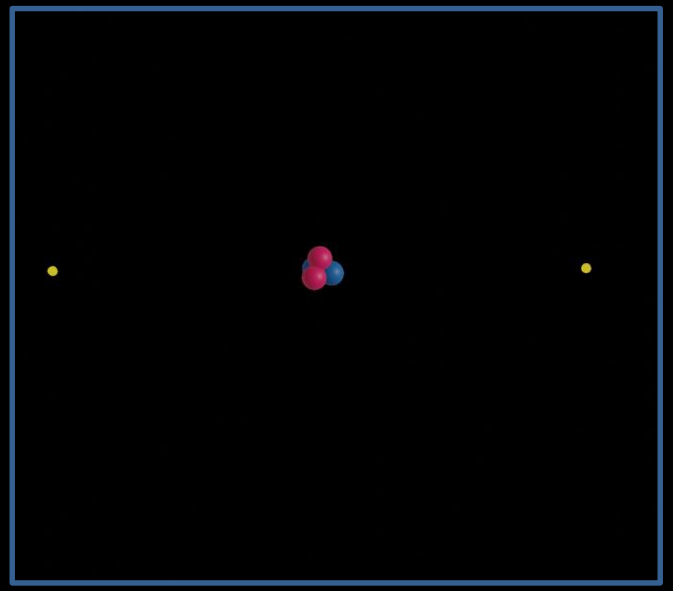
High-Resolution Microcalorimeter Measurement of X-Ray Transitions in He-like Uranium at CRYRING@ESR

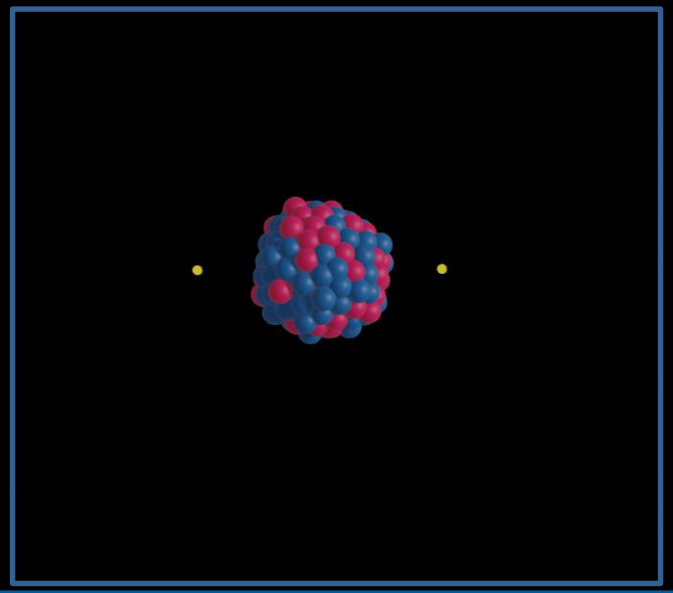
Philip Pfäfflein

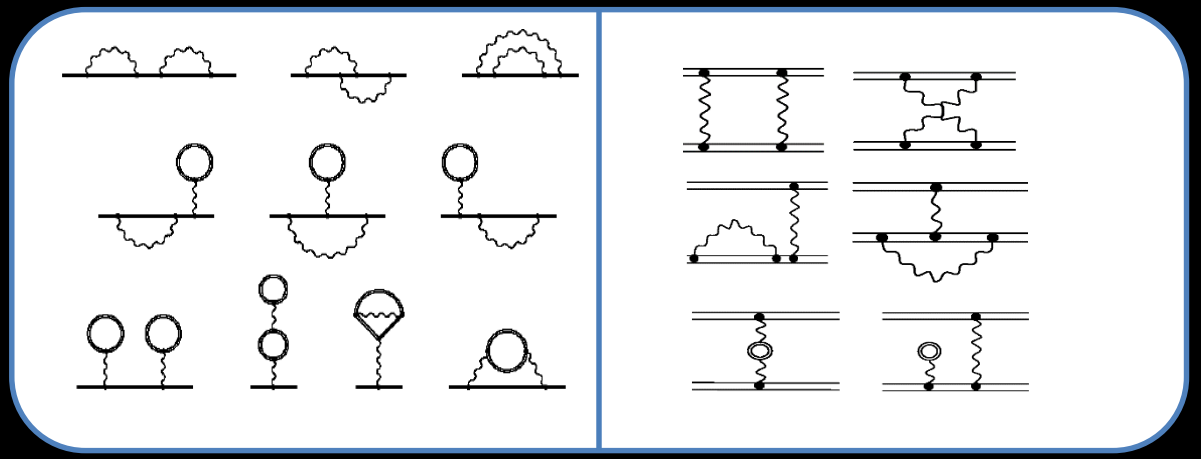
Helmholtz Institute Jena

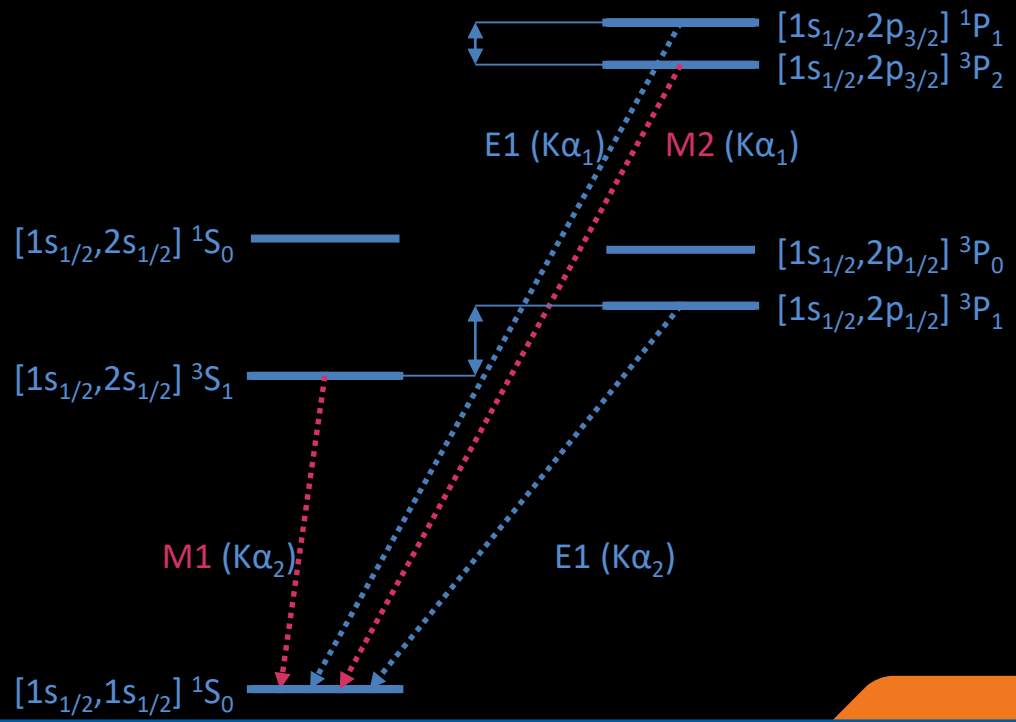
ICNFP, 27.08.2021

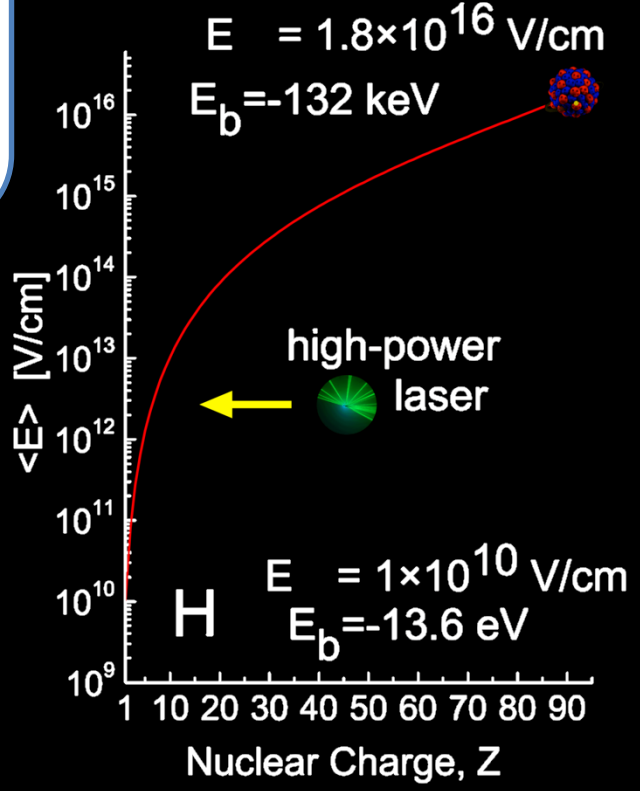
He-Like Atomic/Ionic Systems











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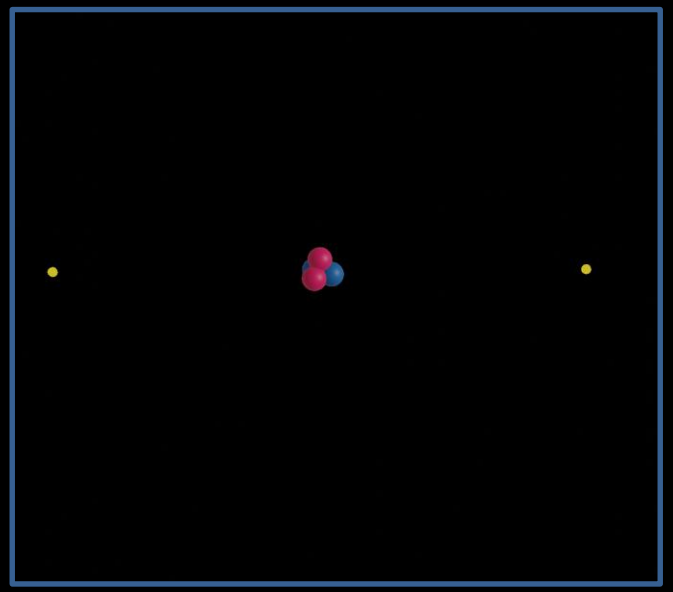
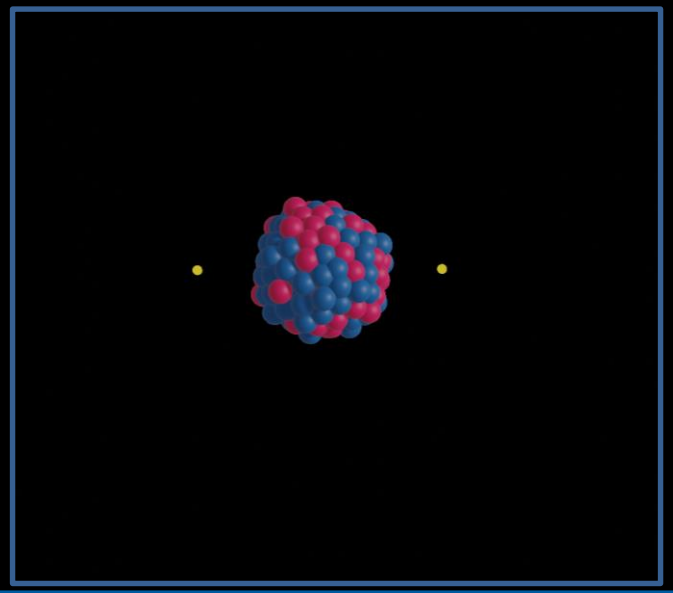
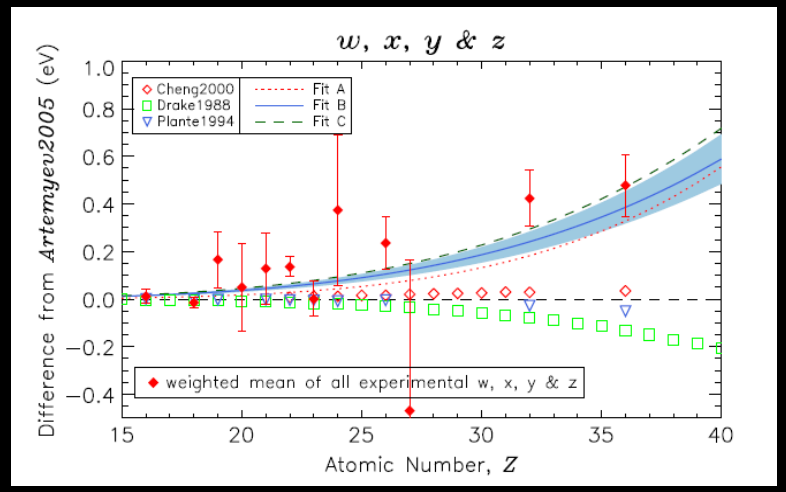
He-Like Atomic/Ionic Systems

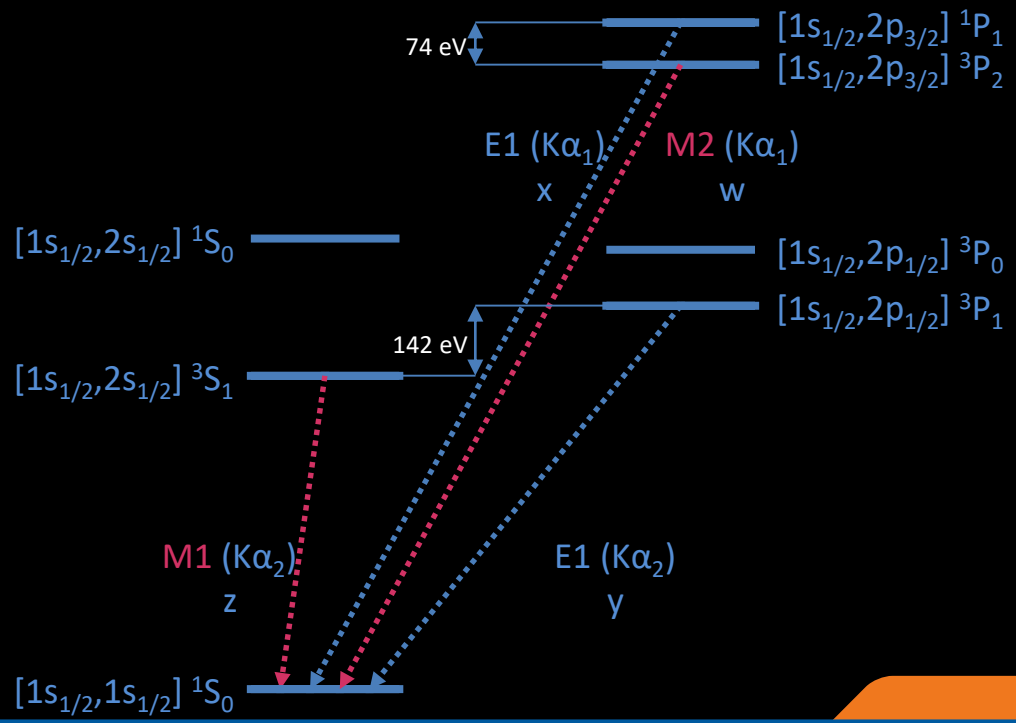


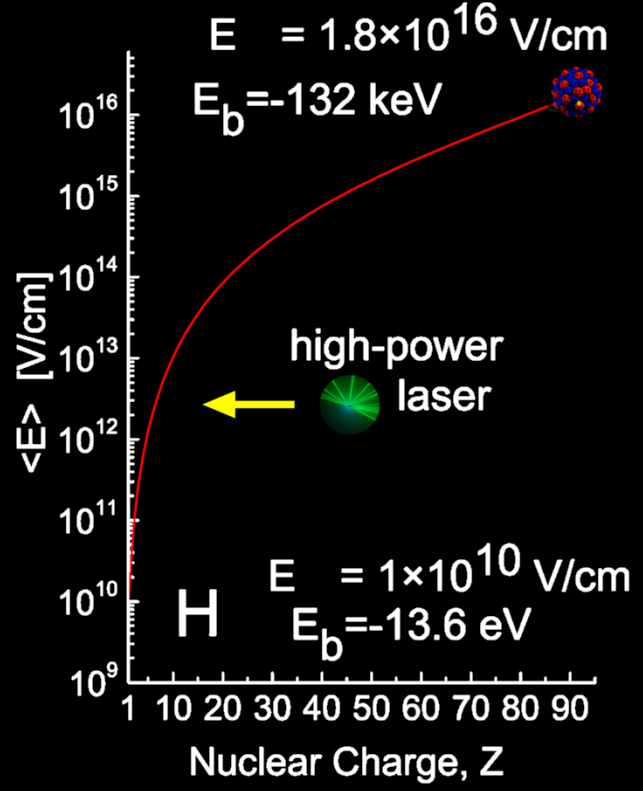




Evidence for a Z-dependent Divergence Between Experiment and Calculation

(C. T. Chantler et al., PRL 109, 153001 (2012))





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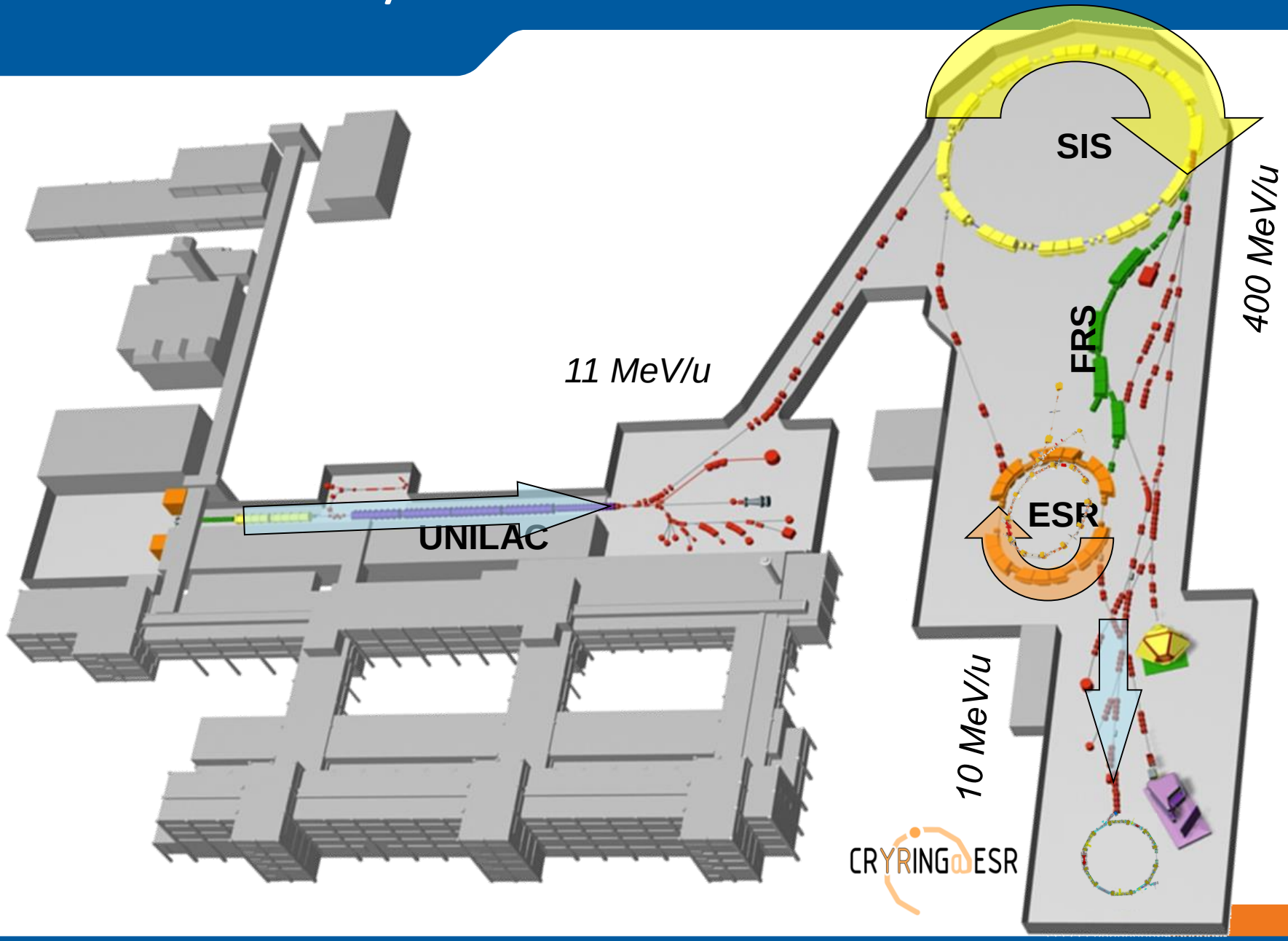
GSI / FAIR: Acceleration & Deceleration of Ions



Ion source U^{7+}

U^{28+} 1.4 MeV/u

UNILAC - Accel

U^{73+} 11.4 MeV/u

SIS 18 - Accel

U^{91+} 400 MeV/u

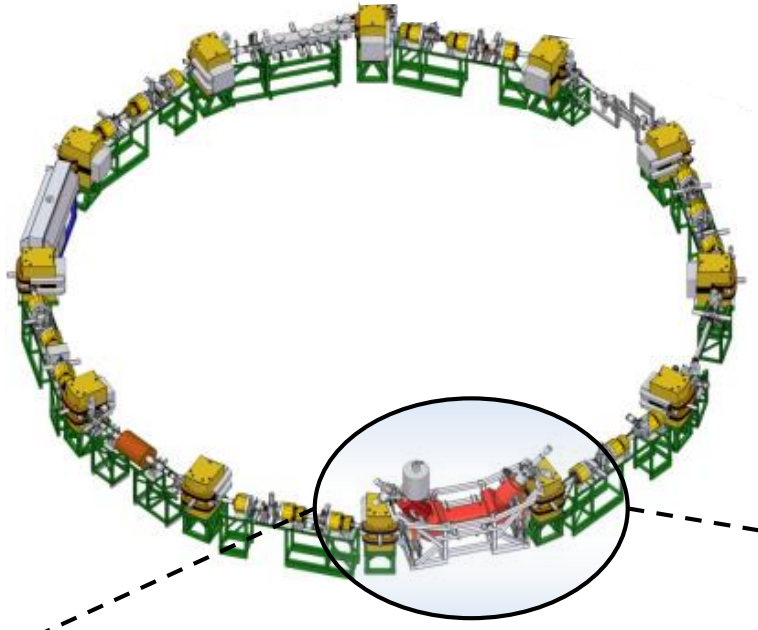
ESR - Decel

U^{91+} 10 MeV/u

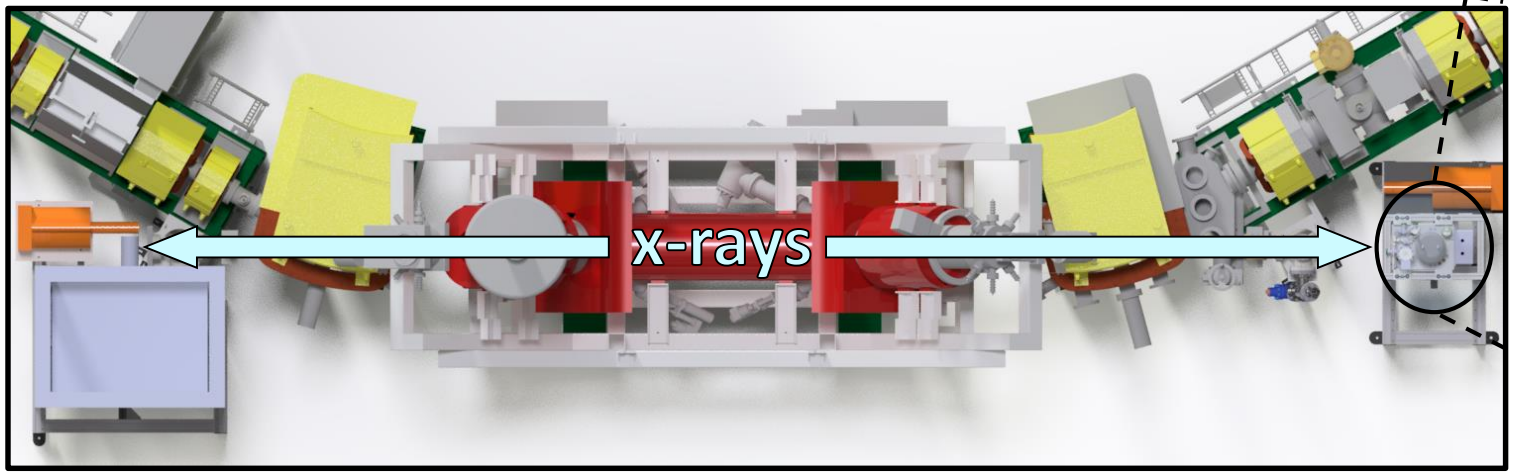
CRYRING@ESR

U^{91+} 10 MeV/u

Spectroscopy of U^{90+} at CRYRING@ESR Electron Cooler

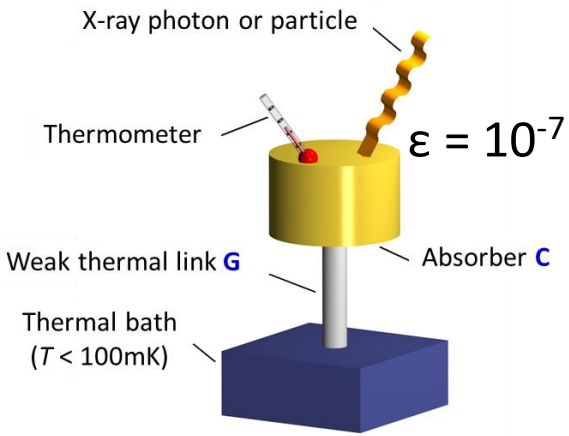


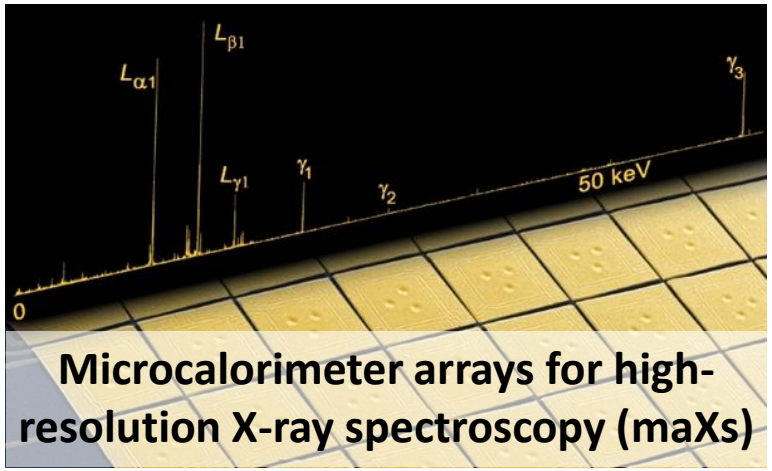
- Adapting the well-proven, successful concept from the ESR cooler to CRYRING@ESR, applying novel high resolution calorimeter detectors.
- **CRYRING@ESR: Factor 4 enhanced luminosity compared to ESR**



Metallic magnetic microcalorimeter

Working principle





Microcalorimeter arrays for high-resolution X-ray spectroscopy (maXs)

The New Experimental Setup at CRYRING@ESR

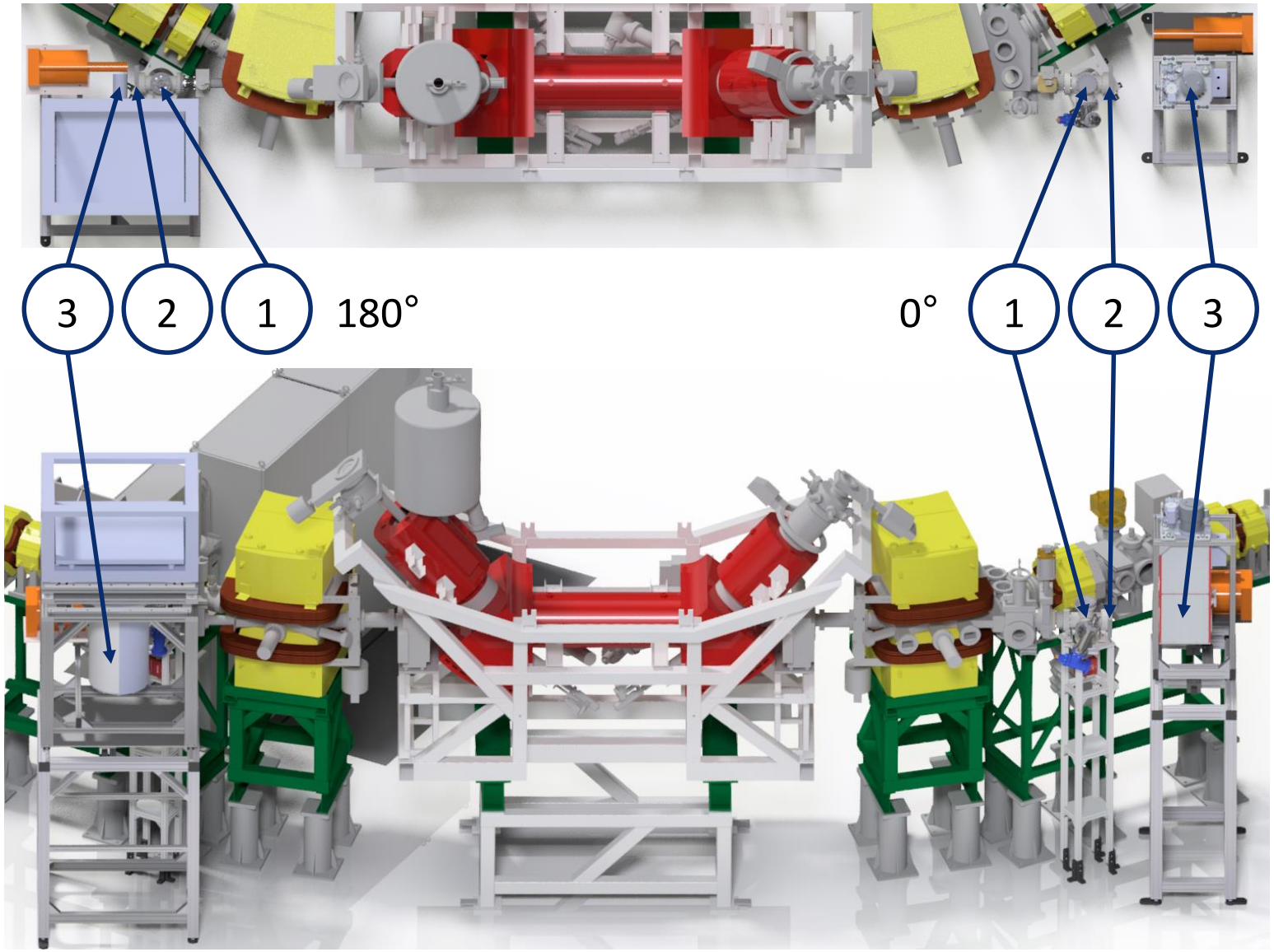
Key features:

0° and 180° observation angles
⇒ Insensitivity to geometrical misalignment

Beryllium windows ①
⇒ High transmission also in the low photon-energy range

Energy calibration ②
⇒ Control of detector response function

High-resolution microcalorimeter detectors ③
⇒ Improved line centroid determination

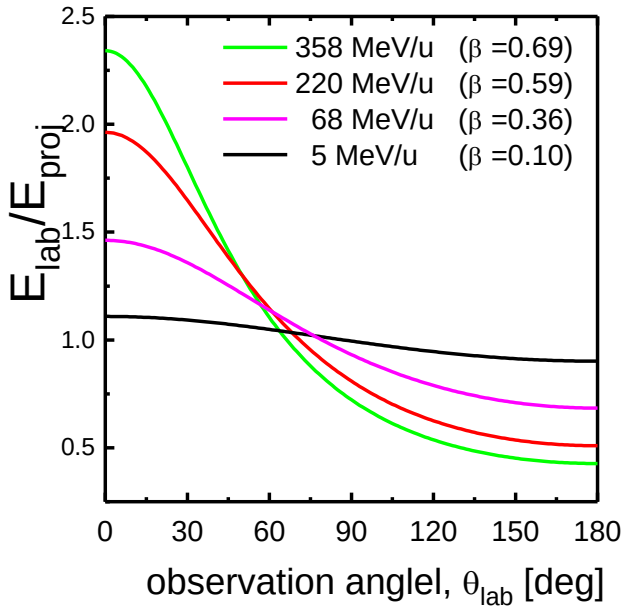


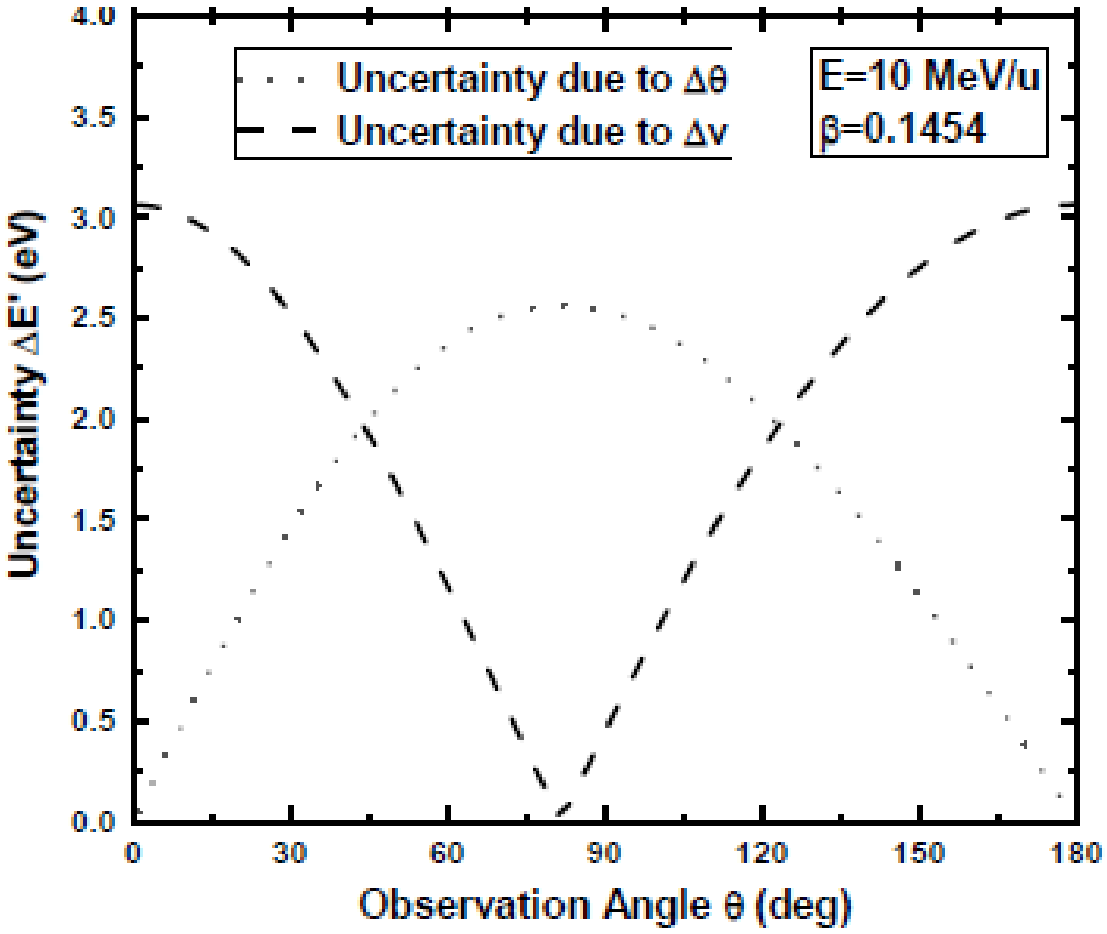
Advantages of the Measurement Positions at CRYRING Electron Cooler

Uncertainties due to relativistic Doppler shift are greatly reduced at a low beam energy and with two detectors at 0° and 180°.

$$E_{lab}(0°) + E_{lab}(180°) = \frac{2 \cdot E_{proj}}{\gamma}$$

E_{lab}: Photon energy in the laboratory system
E_{proj}: Photon energy in the emitter system





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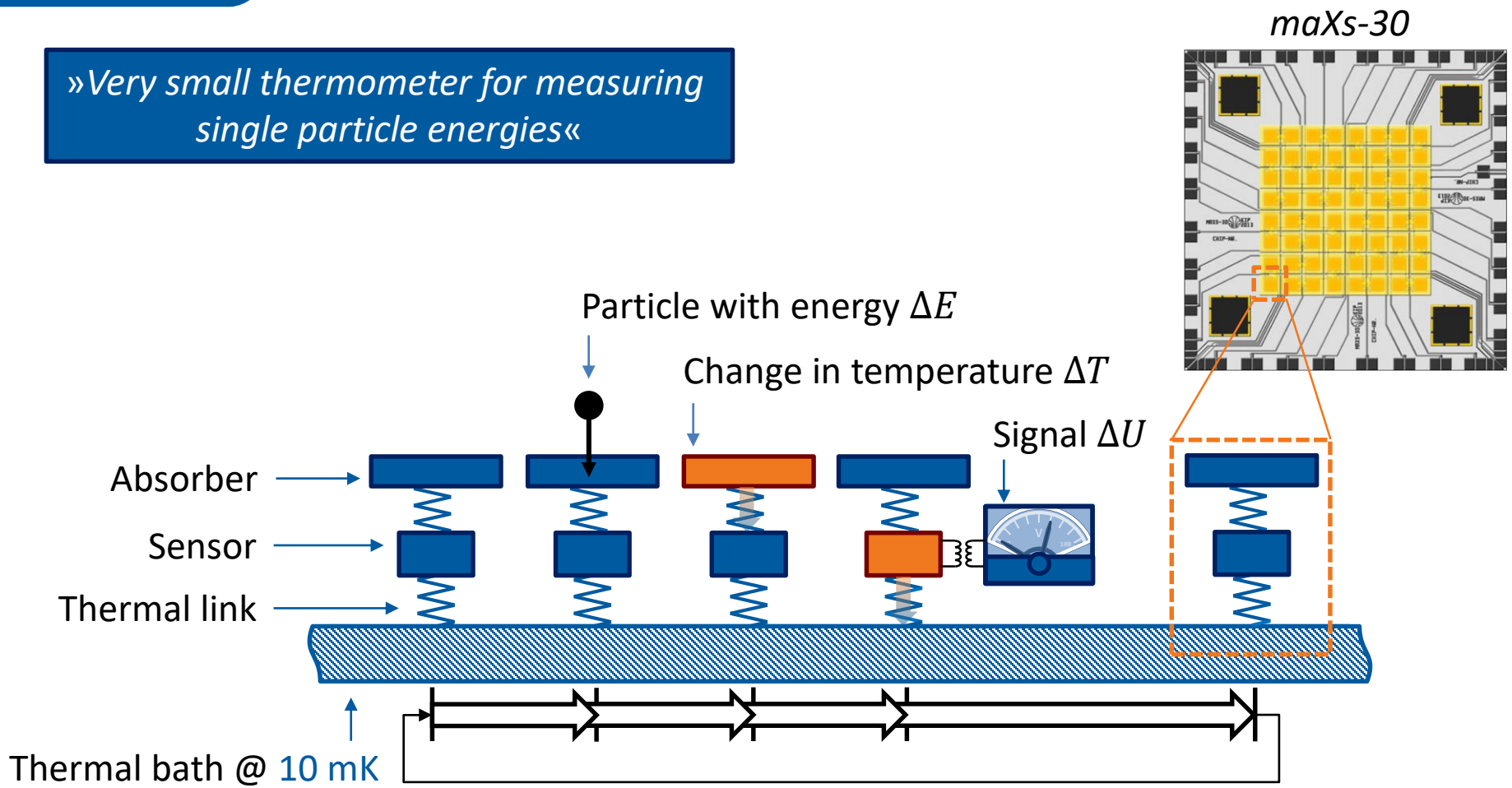
What are Microcalorimeters?

»Very small thermometer for measuring single particle energies«



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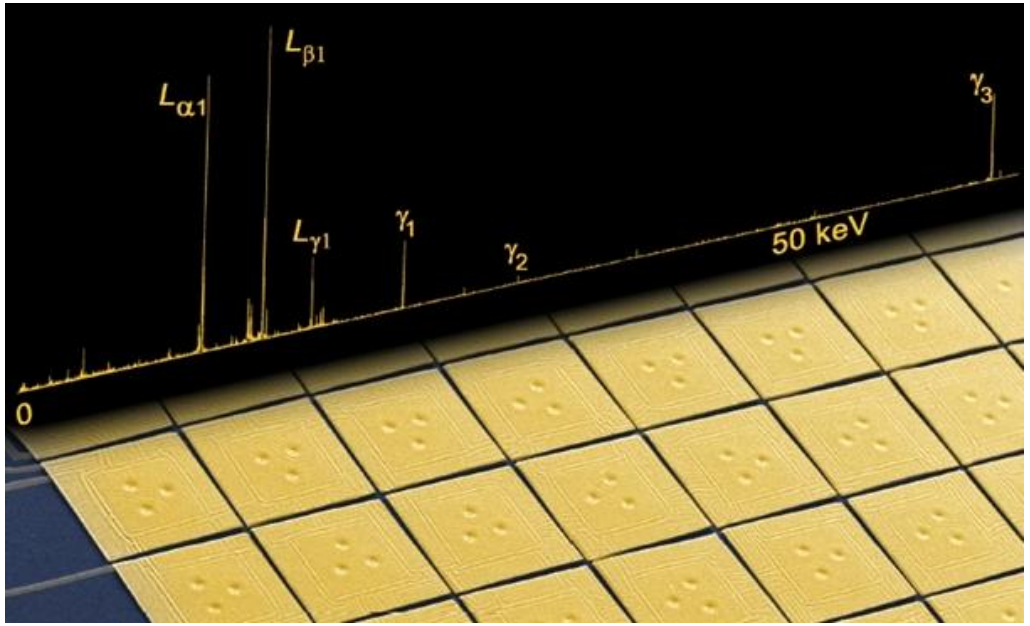
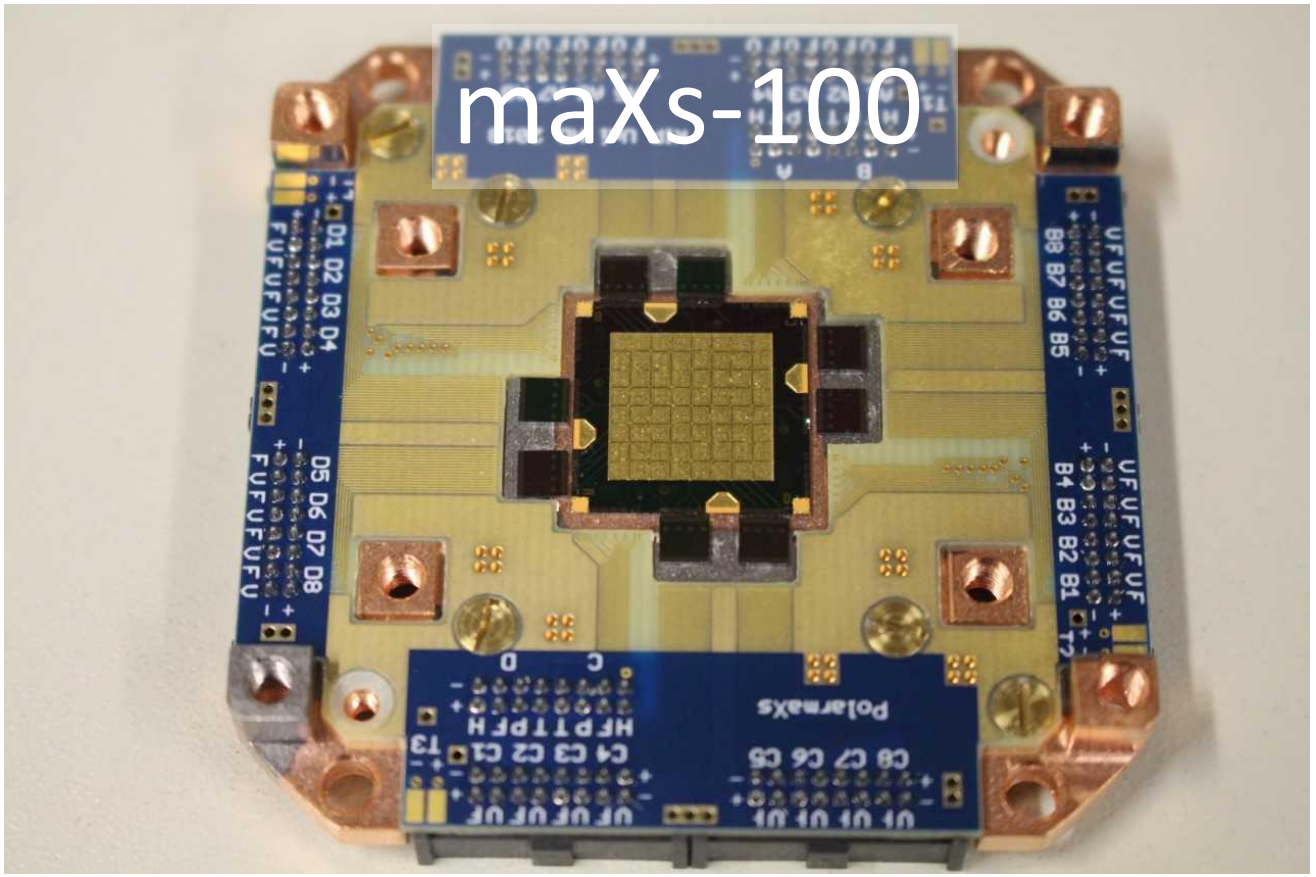
Microcalorimeter Arrays for High-resolution X-ray Spectroscopy - maXs

Detector parameters:	
Active area:	1 cm^2 (64 pixels, with 1.25 x 1.25 mm^2 each)
FWHM at 60 keV:	60 eV
Efficiency (QE) at 100 keV:	> 50%





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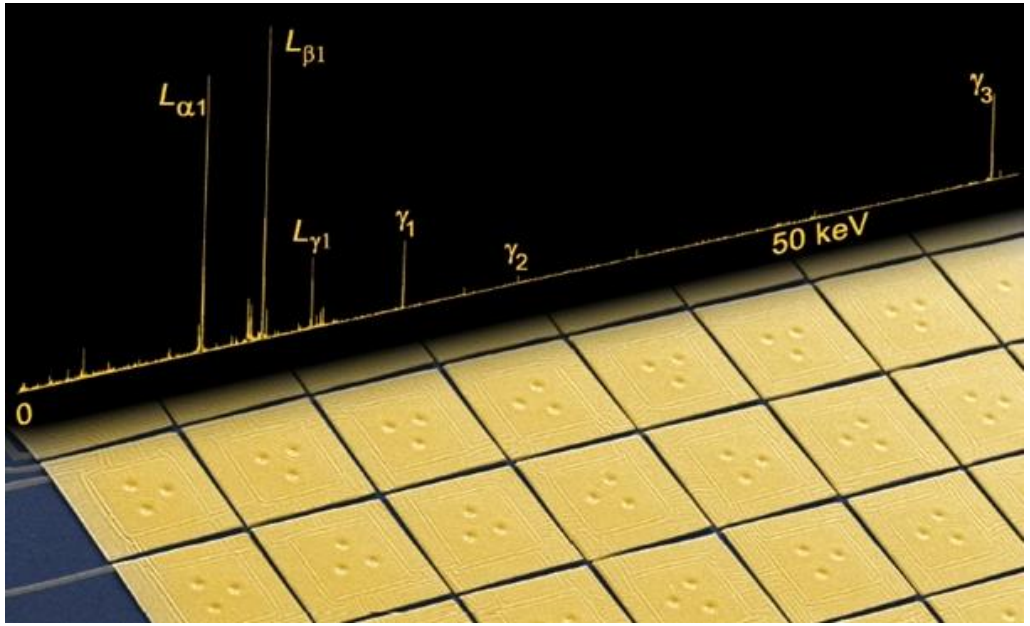

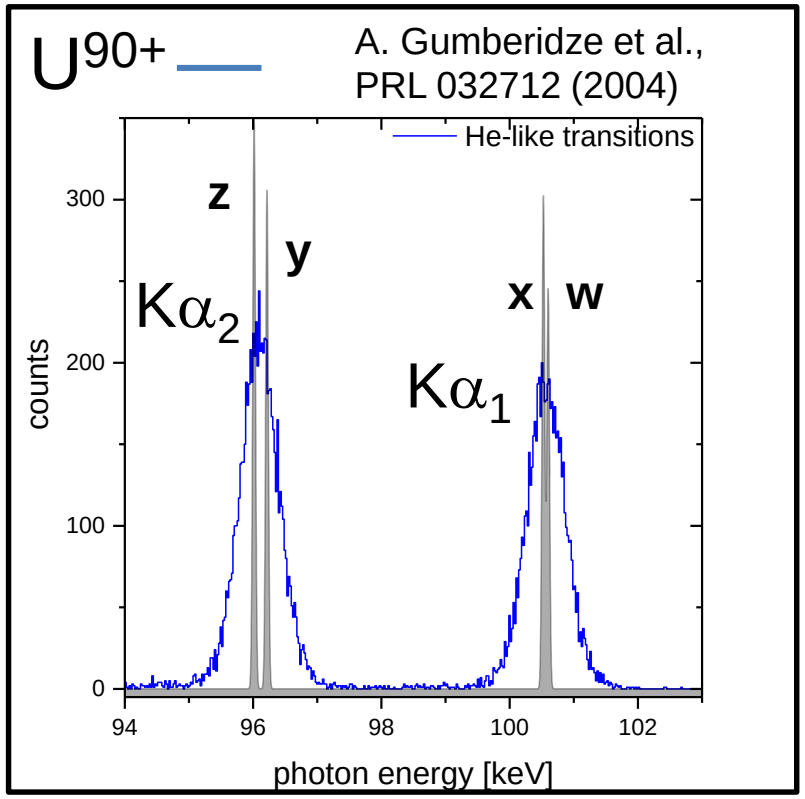

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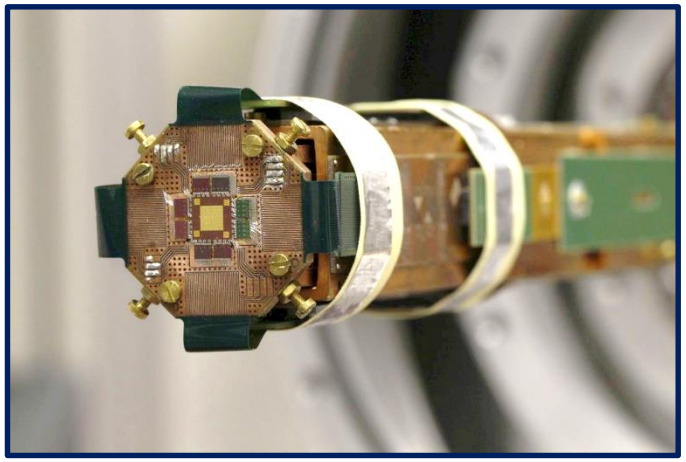
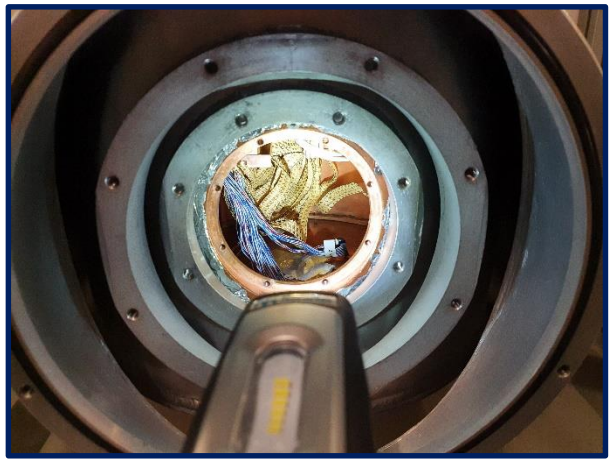
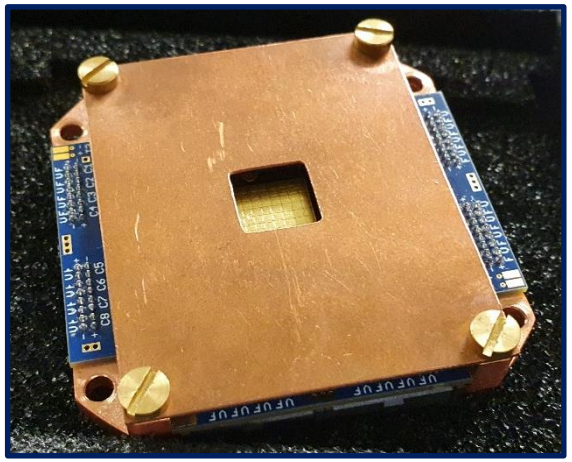
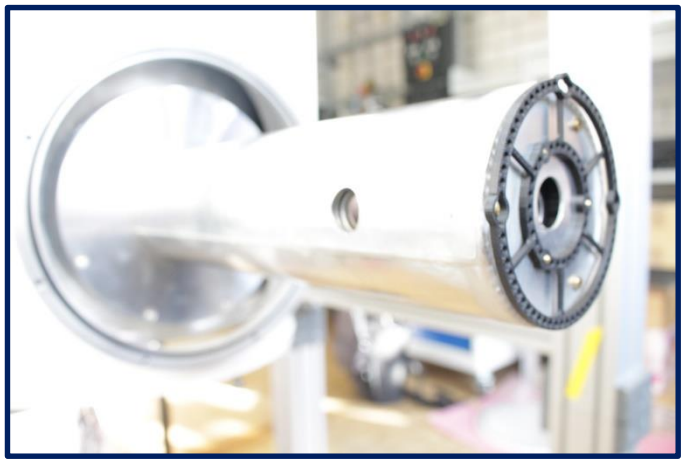
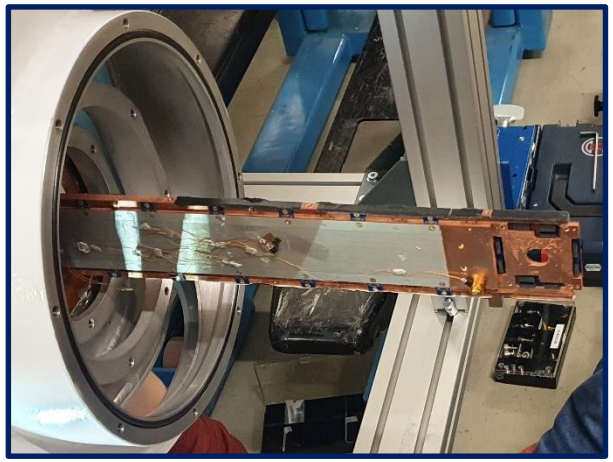
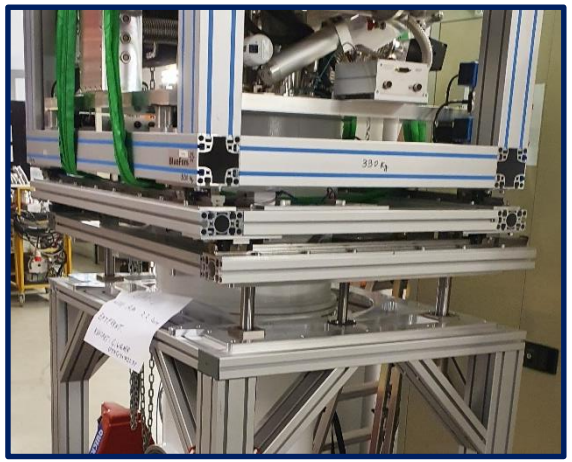
maXs-100 Detector - Optimized for 100 keV

Bluefors-cryostat & maXs-detector for 180°

New detector arm and chip developed at Heidelberg University.

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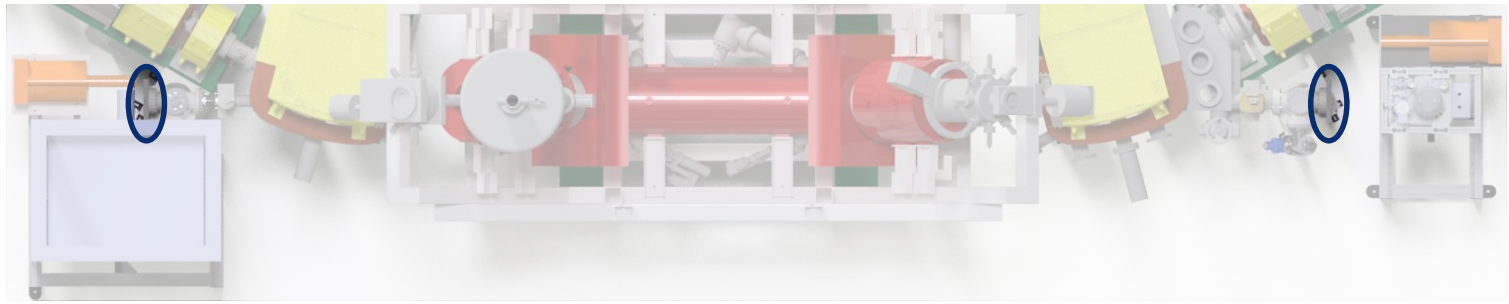
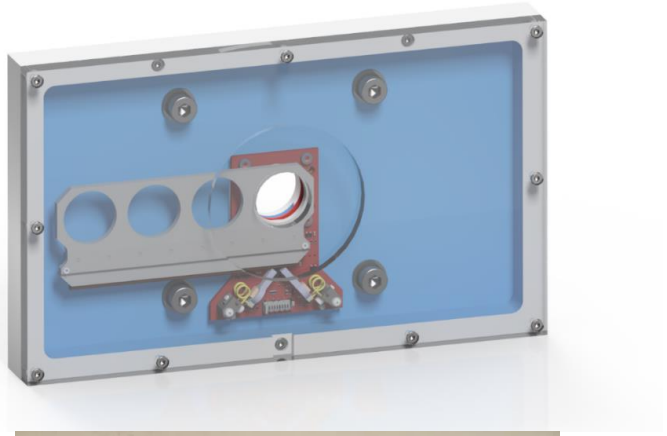
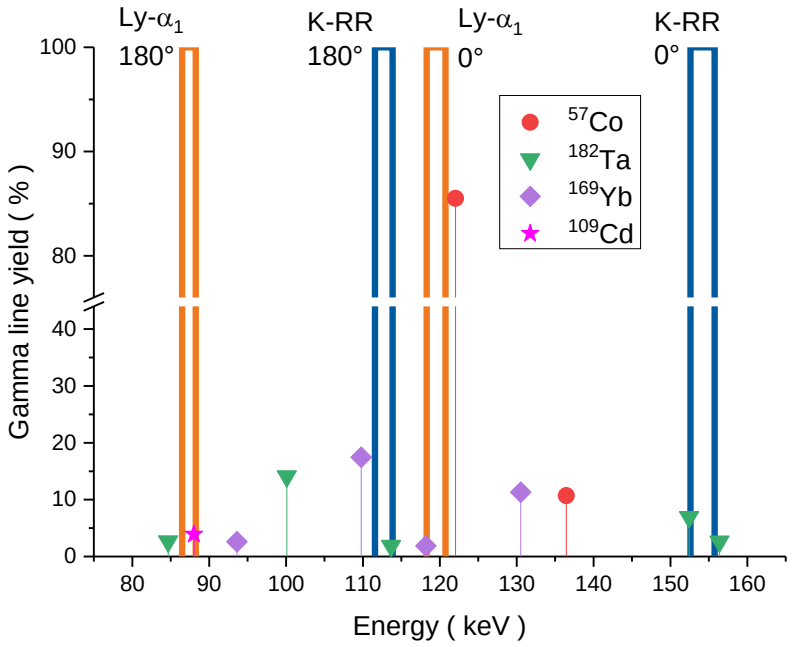
Calibration Source Holder/Manipulator

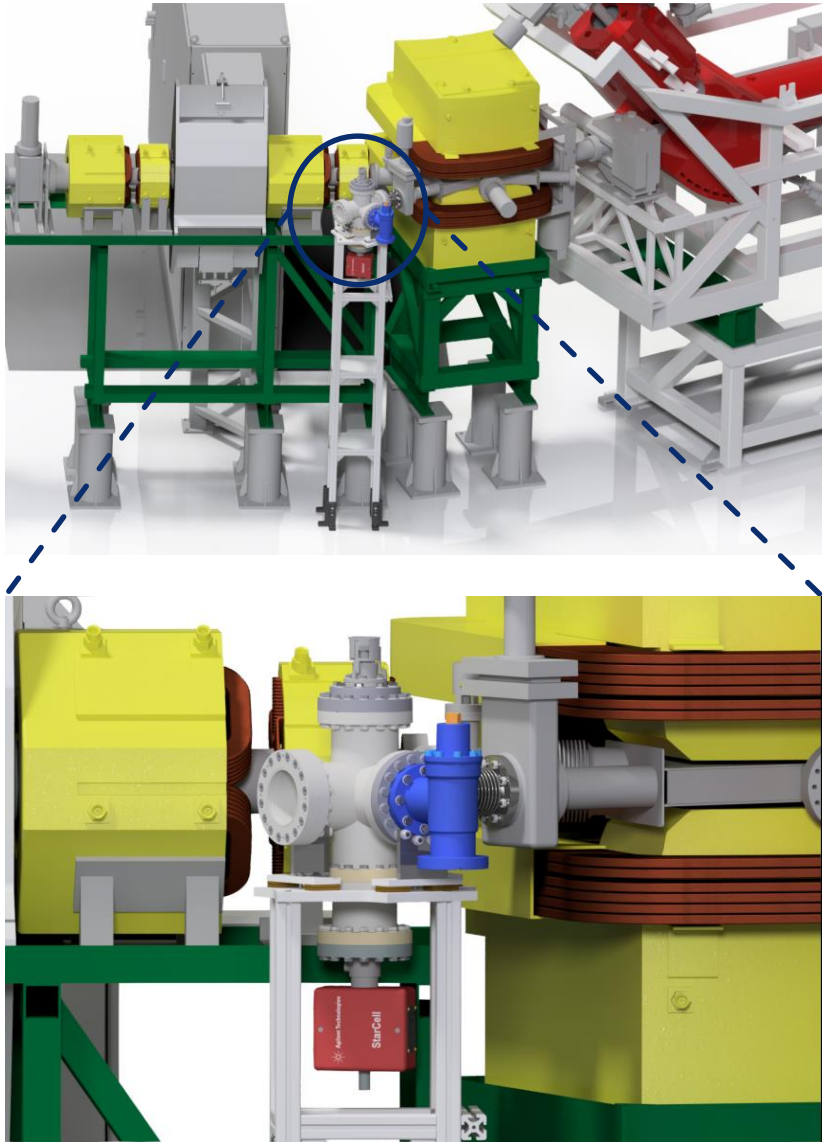


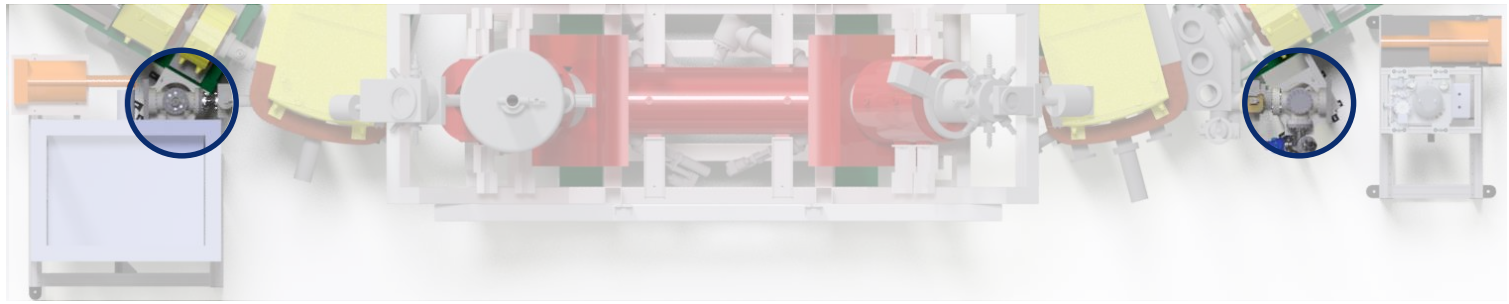




- **Purpose:**
  - mounting and movement of calibration sources
  - shielding the detector from their radiation when parked
- **Features:**
  - controlled motion synchronised with machine status
  - readout of position → source fed into DAQ
  - lead and copper shielding

Beryllium Window Chambers





- **Purpose:** window exchange without breaking CRYRING@ESR vacuum.
- **Features:** self-contained with own vacuum pumps, vacuum sensor and heating jackets.

Were mounted in January/February 2020 as part of the E138 experiment.

⇒ Will stay available for future spectroscopy experiments at the CRYRING@ESR electron cooler.

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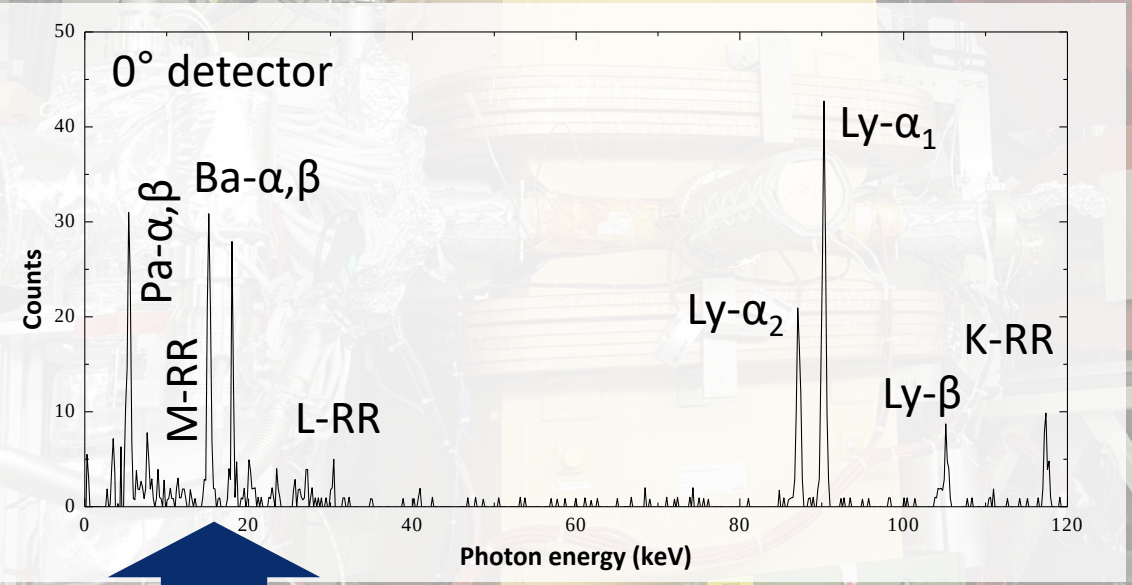
Setup at CRYRING@ESR: Cleaner Spectra + Low Energy Lines

✓ Commissioning CRYRING@ESR (2020)

$$Pb^{82+} + e^- \rightarrow Pb^{81+} + \hbar\omega$$

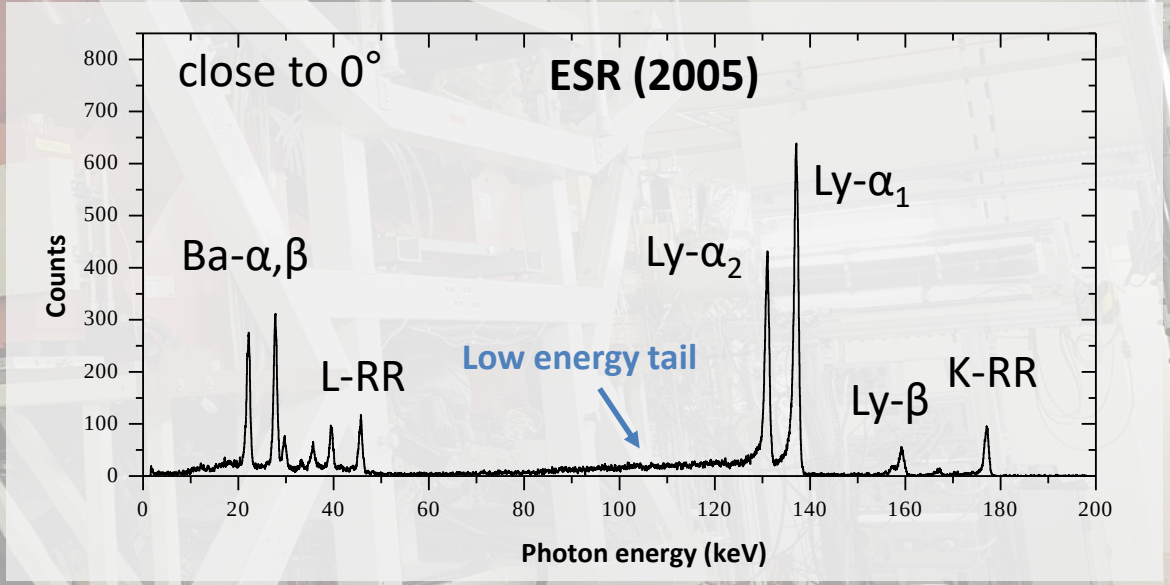
X-rays recorded in coincidence with Pb^{81+}



ESR (2005)

$$U^{92+} + e^- \rightarrow U^{91+} + \hbar\omega$$

X-rays recorded in coincidence with U^{91+}



Low energy transitions, that are virtually unaffected by Lamb shift corrections, will be used for a spectroscopic determination of the Doppler shift.

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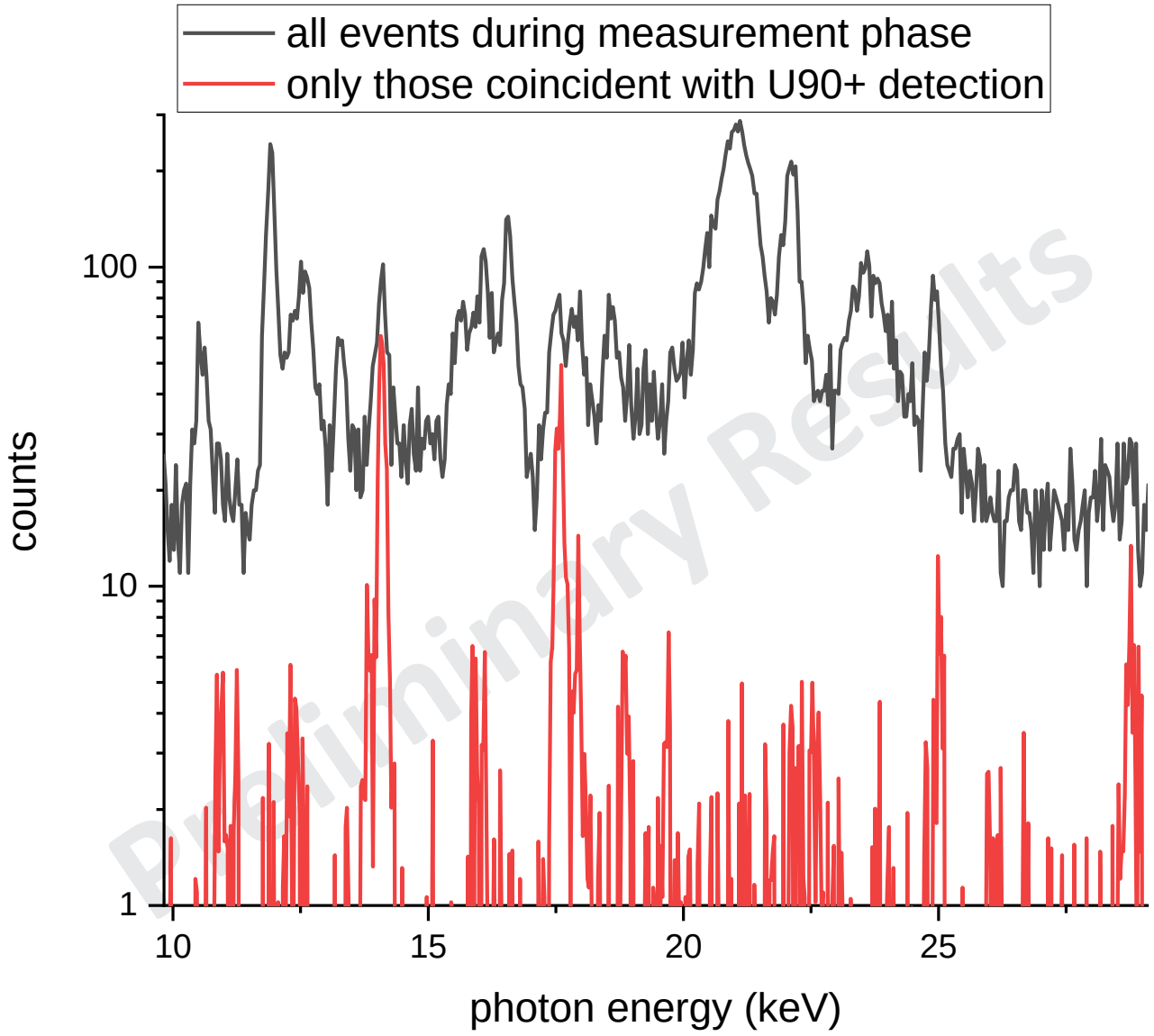
Experimental Run April 2021

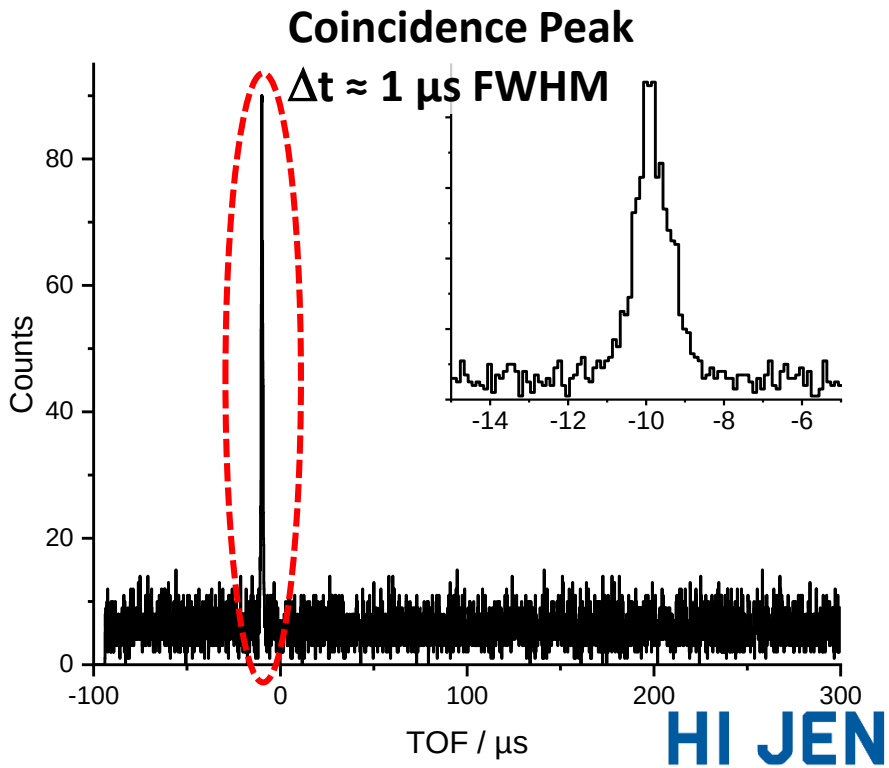
What has been achieved?

- ✓ Uninterrupted operation over several weeks of the novel maXs detectors
- ✓ No effect of the EM enviroment of CRYRING@ESR on the detector performance
- ✓ Positioning of calibration sources in synchronization with the measurement cycle (quasi-continuous calibration)
- ✓ First demonstration and utilization of the time resolution of the maXs detectors

Background Suppression via Coincidences with U^{90+} Ions



We utilized for the first time the time resolution of the maXs detector to suppress the radiation background via a coincidence condition on the detection of down-charged ions.



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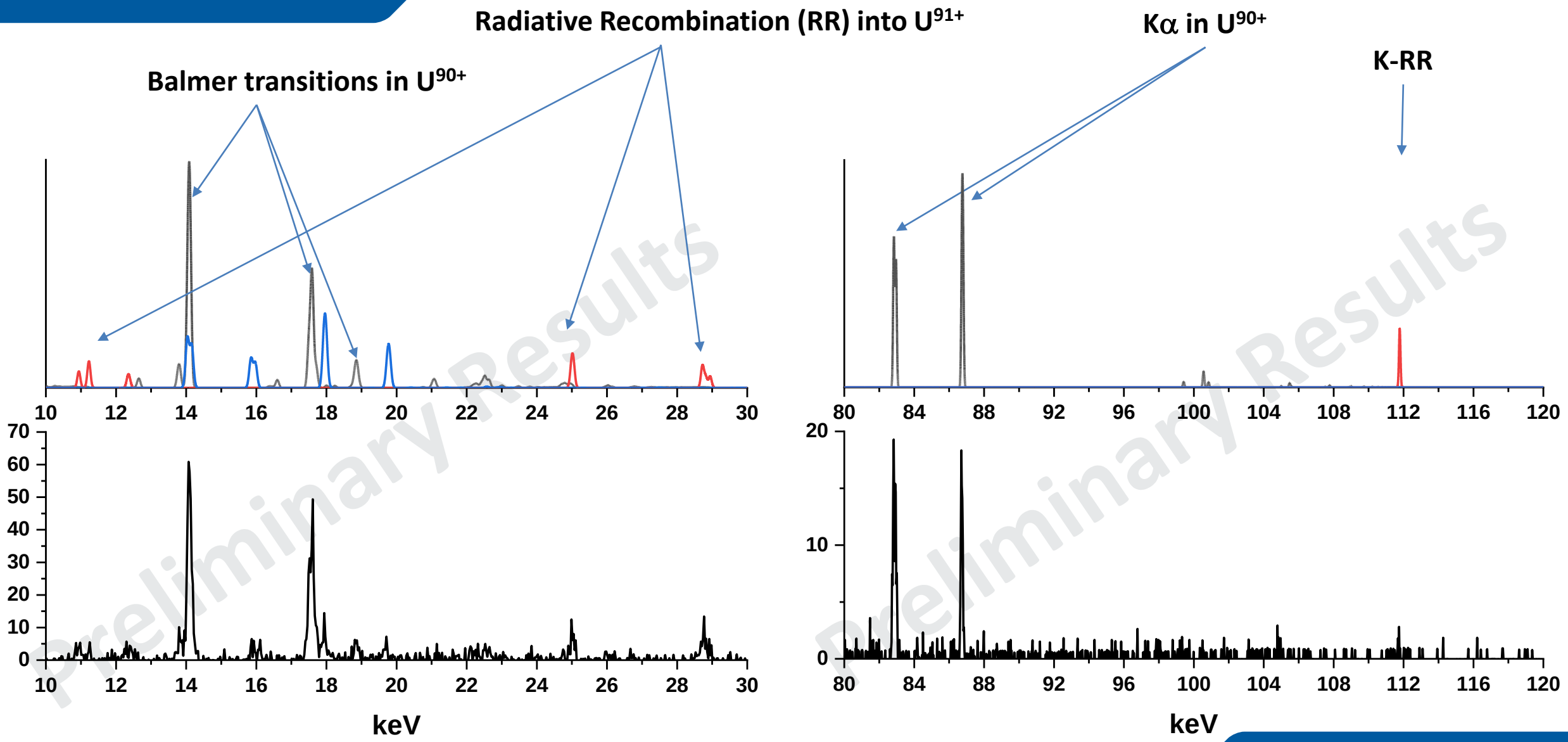
Coincidence Conditions Yield Clear U^{90+} Spectra



A Shoutout to the E138 Collaboration

The Ground-State Lamb Shift in the Heaviest Hydrogen-like Ion (U^{91+}): High Resolution X-ray Spectroscopy at the CRYRING Electron Cooler

G. Weber[1], S. Allgeier[2], P. Amaro[3], D. Banas[4], S. Bernitt[5], H. F. Beyer[6], C. Brandau[6], C. Enss[2], A. Fleischmann[2], O. Forstner[1,5], E. Förster[1,5], M. Friedrich[2], M. Guerra[3], A. Gumberidze[6], S. Hagmann[6], C. Hahn[1,5], D. Hengstler[2], M. O. Herdrich[1,5,6], R. Hess[6], P.-M. Hillenbrand[6], P. Indelicato[7], A. Kalinin[6,8], F. Kröger[1,5], Ch. Kozhuharov[6], S. Kraft-Bermuth[9], P. Kuntz[2], M. Lestinsky[6], Y. Litvinov[6], R. Märtin[1], E. Menz[1,5], T. Over[5], Ph. Pfäfflein[1,5], J. P. Santos[3], S. Schippers[10], V. Shabaev[11], D. Schneider[1], R. Schuch[1], U. Spillmann[6], M. Steck[6], M. Trassinelli[12], S. Trotsenko[1], I. Uschmann[1,5], A. Warczak[13], B. Zhu[1,5], and Th. Stöhlker[1,5,6]

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[2] Kirchhoff-Institut für Physik, Ruprecht Karl University, Heidelberg, Germany
[3] Centro de Física Atómica, Departamento de Física, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
[4] Institute of Physics, Jan Kochanowski University, Kielce, Poland
[5] Institut für Optik und Quantenelektronik, Friedrich Schiller University, Jena, Germany
[6] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
[7] Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-PSL Research University, Collège de France, Paris, France
[8] Institut für Kernphysik, Johann Wolfgang Goethe University, Frankfurt, Germany
[9] Technische Hoschschule Mittelhessen, Gießen, Germany
[10] I. Physikalisches Institut, Justus Liebig University, Gießen, Germany
[11] St. Petersburg State University, St. Petersburg, Russia
[12] Institut des NanoSciences de Paris, CNRS, Sorbonne Université, Paris, France
[13] Institute of Physics, Jagiellonian University, Krakow, Poland

42 shifts (=14 days) of beam time at CRYRING@ESR granted.

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Thank you for your attention

Time for questions