

ErUM-FSP T05

“Aufbau von APPA bei FAIR”

Status and Perspectives

Stefan Schippers

Sprecher des ErUM-FSP T05
Justus-Liebig-Universität Gießen
HFHF Campus Gießen

FACILITY CAPABILITY

Highest Charge States
Relativistic Energies
High Intensities
High Charge at Low Velocity



SCIENTIFIC CAPABILITY

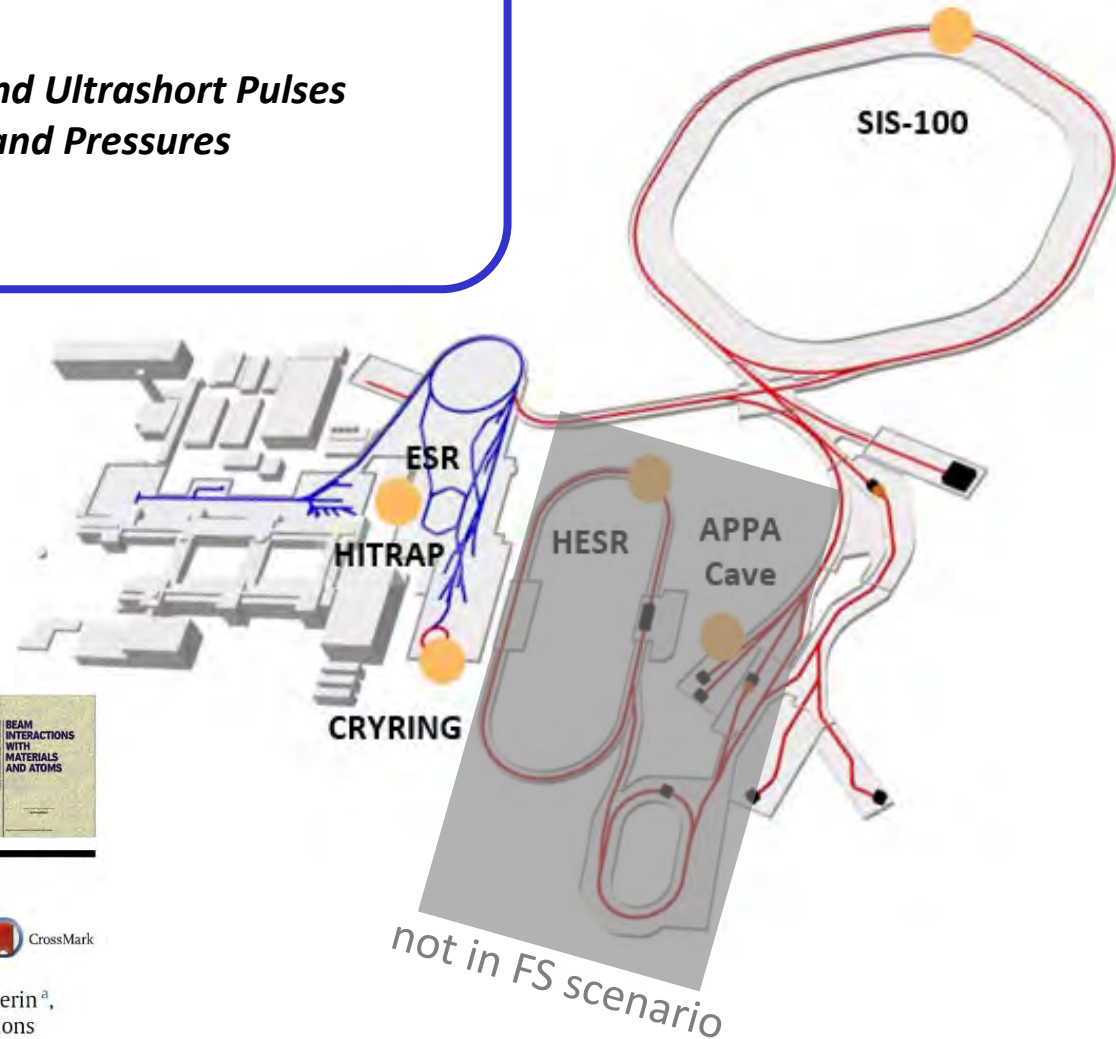
Extreme Static Fields
Extreme Dynamical Fields and Ultrashort Pulses
Very High Energy Densities and Pressures
Large Energy Deposition



Plasma Physics
200 members from 11 countries



Atomic and Fundamental Physics
439 members from 26 countries



Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Nuclear Instruments and Methods in Physics Research B

ELSEVIER

journal homepage: www.elsevier.com/locate/nimb

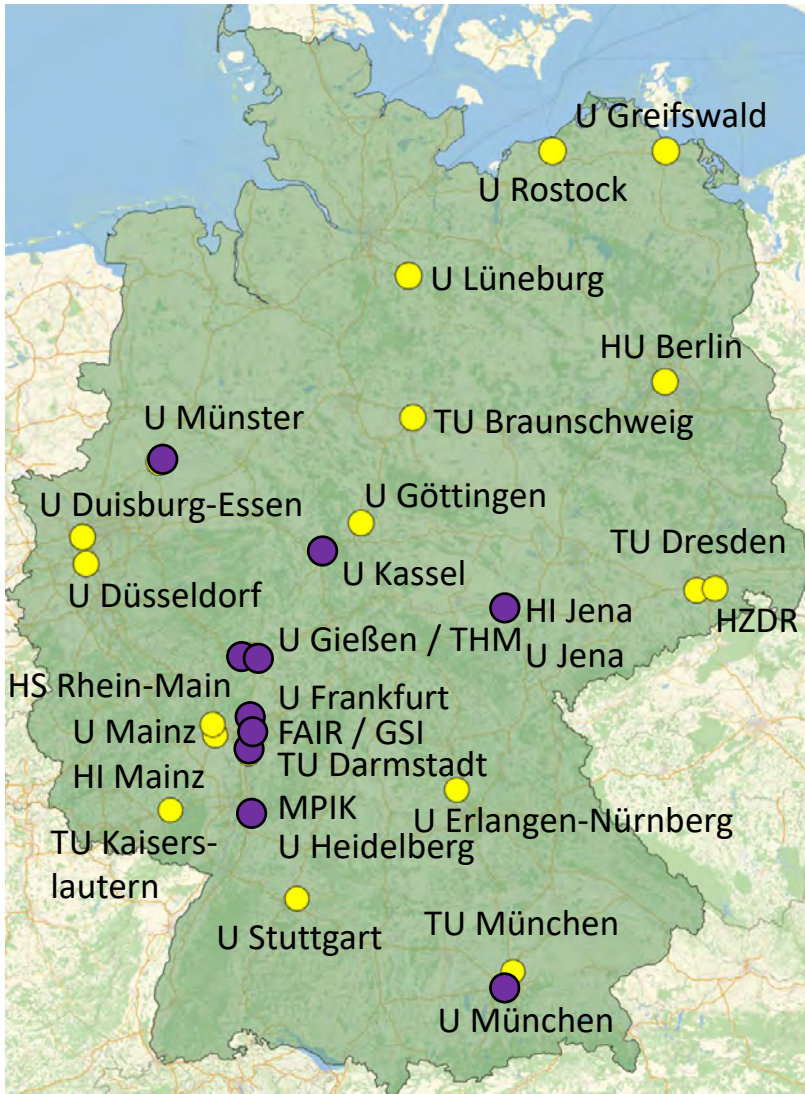
APPA White Paper

NIMB 365 (2015) 680

APPA at FAIR: From fundamental to applied research

Th. Stöhlker^{a,b,c,*}, V. Bagnoud^{a,b}, K. Blaum^d, A. Blazevic^a, A. Bräuning-Demian^{a,e}, M. Durante^a, F. Herfurth^a, M. Lestinsky^a, Y. Litvinov^a, S. Neff^{a,f}, R. Pleskac^a, R. Schuch^g, S. Schippers^h, D. Severin^a, A. Tauschwitz^a, C. Trautmann^{a,f}, D. Varentsov^a, E. Widmannⁱ, on behalf of the APPA Collaborations





not all universities applied for funding

ErUM-FSP APPA: 7.5 M€

SPARC, HED@FAIR (2021-2024)

13 projects (9 SPARC / 4 HED@FAIR)

“Physics of the Smallest Particles”

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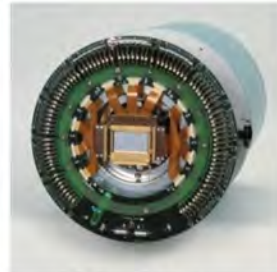
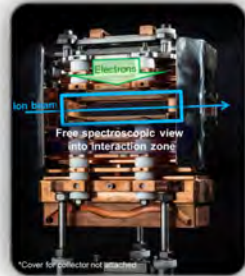
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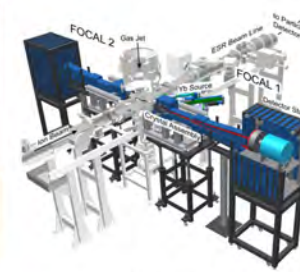
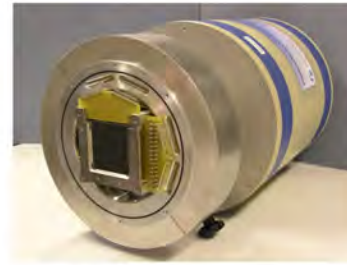
Federal Ministry of Education and Research



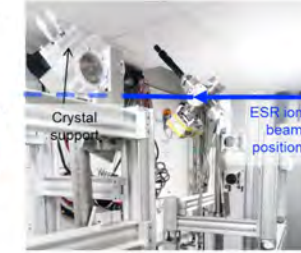
Targets



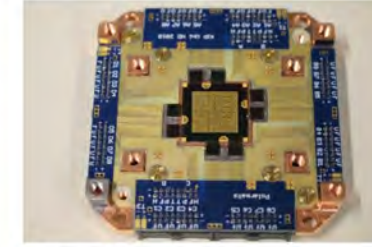
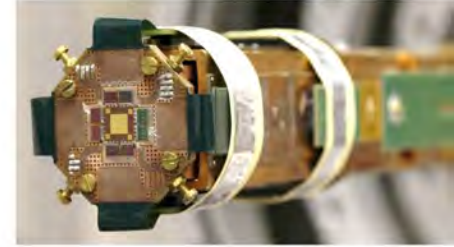
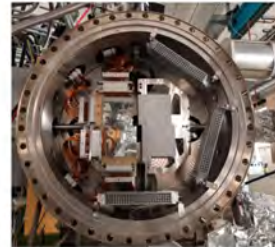
2D micro-strip Ge(i) detectors



crystal spectrometers



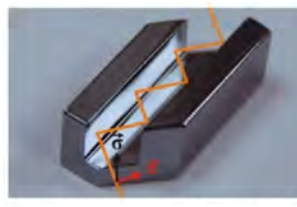
Particle detectors



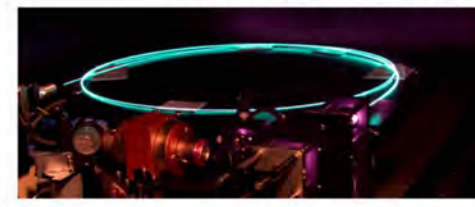
microcalorimeters



Traps



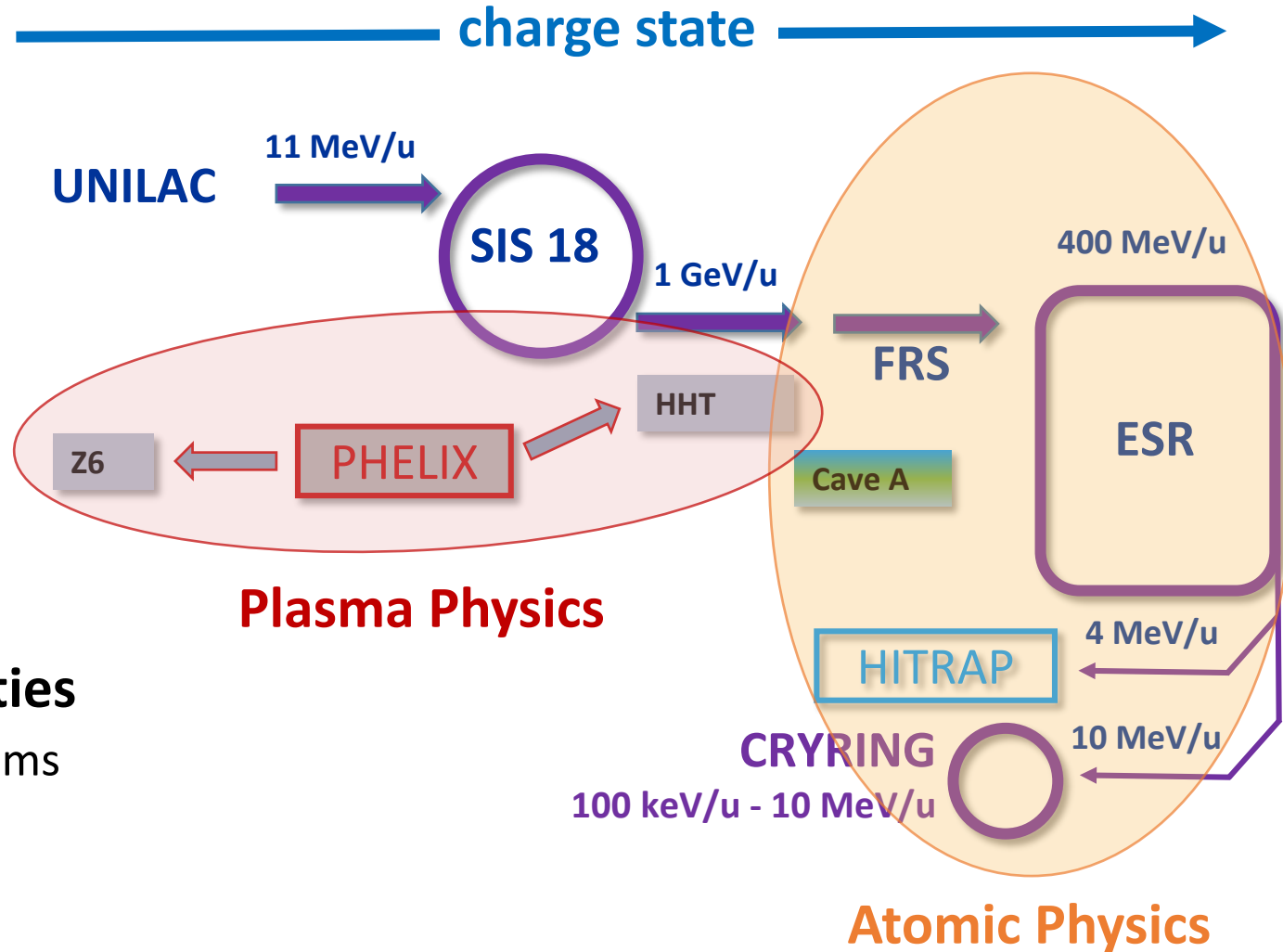
X-ray optics, channel-cut crystals



versatile Laser systems

SPARC/APPA: Besides its facilities, **instrumentation** is of utmost importance. Already the large portfolio of novel FAIR instrumentation guarantees for a rich science research program at the existing facilities HITRAP, CRYRING@ESR, and ESR.

Continuous R&D is required for keeping the instrumentation at the cutting edge.



block diagram of relevant facilities

- **APPA fully involved in FAIR Phase 0**
 - **ESR, CRYRING, HITRAP** are part of FAIR MSV
 - **PRIOR** (proton microscope) and Heavy-Ion Heating setup (**HIHEX**) commissioned at HHT
- **Worldwide unique experimental capabilities**
 - Plasma physics with combined laser and ion beams
 - Atomic physics in rings and traps



ID	Title	Facility	Grade	Shifts
G-22-00025	High-Resolution Electron-Ion Collision Spectroscopy of Berylliumlike Heavy Ions in CRYRING@ESR	ESR-CRYRING	A	45,0
G-22-00028	Indirect measurements of neutron-induced reaction cross sections at storage rings	ESR	A	36,5
G-22-00038	Dielectronic Recombination-assisted laser spectroscopy: A new tool to investigate the hyperfine-puzzle in Bi ^{80+,82+}	ESR	A	41,5
G-22-00047	Absolute rate coefficients from dielectronic recombination for the astrophysically relevant ions Ne ³⁺ and S ³⁺	CRYRING-intern	A	54,0
G-22-00052	Laser Excitation of the ²²⁹ Th Nucleus Using Nuclear Hyperfine Mixing	ESR	A	48,5
G-22-00057	Nanostructuring of monolayer graphene by highly charged ions	ESR-HITRAP	A	45,0
G-22-00058	Ion beam and level population dynamics in Mg ⁺ laser spectroscopy at CRYRING@ESR	CRYRING-intern	A	51,0
G-22-00086	Ultra-high resolution study of the ¹⁵ O(α,α) ¹⁵ O reaction using CARME@CRYRING	CRYRING-intern	A	36,0
G-22-00095	Energy determination of the $1s^2 2s_{1/2} \rightarrow 1s^2 2p_{3/2}$ radiative transition in Li-like uranium ions via resonant coherent excitation	ESR-Cave A	A	35,5
G-22-00134	Precision x-ray spectroscopy of helium-like uranium using metallic magnetic calorimeter detectors	ESR-CRYRING	A	32,0
SPARC research program limited by availability of beamtime				389,5
G-22-00029	X-ray spectroscopy of slow Xe ⁵⁴⁺ + Xe collisions	ESR-CRYRING	A-	36,0
G-22-00037	Atomic Processes in the Wake of Neutron-Star Mergers: Electron-Ion Recombination of Low-Charged Heavy Ions	CRYRING-intern	A-	46,0
G-22-00060	Proton-capture on ⁹¹ Nb - A key to the explosive nucleosynthesis of the p nuclei	FRS-ESR	A-	44,5
G-22-00068	Towards testing three-loop effects of bound-state QED in heliumlike uranium	ESR	A-	38,0
G-22-00070	Dielectronic and trielectronic recombination in sulfur ions	CRYRING-intern	A-	21,0
G-22-00072	Commissioning and First Storage Ring Experiments of the CRYRING Transverse Electron Target	ESR-CRYRING	A-	27,0
G-22-00072	Commissioning and First Storage Ring Experiments of the CRYRING Transverse Electron Target	CRYRING-intern	A-	54,0
G-22-00075	Laser spectroscopy of the $(1s^2 2s2p) ^3P_0 - ^3P_1$ level splitting in Be-like krypton	ESR	A-	27,0
G-22-00087	Astrophysical nuclear reactions between bare ions using FISIC+CARME	CRYRING-intern	A-	18,0
G-22-00093	Influence of hyperfine interaction on the nuclear electron capture decay in ¹¹¹ Sn	FRS-ESR	A-	20,5
G-22-00130	Cooling and precision spectroscopy of ²⁰⁹ Bi ⁸²⁺ ion ensembles with the ARTEMIS and SPECTRAP experiments at the HITRAP facility	ESR-HITRAP	A-	63,0
G-22-00140	High-resolution measurement of the exotic Two-Electron One-Photon decay (TEOP) of the $1s 2s^2$ state in Li-like uranium.	ESR	A-	24,0
G-22-00152	Systematic measurement of electron capture cross sections in the unexplored low collision energy regime	ESR-CRYRING	A-	45,0
G-22-00159	Fast Ion – Slow Ion Collisions @ CRYRING: Exploring quantum dynamics of N-body systems	ESR-CRYRING	A-	71,0
G-22-00165	Heavy Ion Storage Ring Experiments of Nuclear Excitation by Electron Capture (NEEC)	ESR	A-	27,5
G-22-00172	Exploring the limits of bunched beam laser cooling of relativistic stored ions, using 3 laser beams (pulsed and cw)	ESR	A-	39,5

Orange shaded entries: Spearheaded by or with strong participation of groups from the ErUM-FSP APPA



ID	Title	Facility	Grade	Shifts
P-22-00044	Semiconductor doping and annealing with intense ion pulses from laser-plasma acceleration	PHELIX-PTA	A	10
P-22-00048	The enhanced TNSA boosted by the direct laser accelerated electrons	PHELIX-PTA	A	20
P-22-00089	Particle acceleration in a laser-driven magnetized plasma	Z6	A	20
P-22-00125	First compression experiments of carbon with SIS-18beams	HHT-HIHEX	A	18
P-22-00131	Verification and calibration measurements of I-BEAT 3D V2.0 for measuring the energy distribution of laser accelerated protons at the PHELIX facility	PHELIX-PTA	A	6
P-22-00135	Investigation of the fountain field during ion acceleration by intense laser	PHELIX-PTA	A	20
P-22-00137	Detection of ion-beam heating induced melting and graphitization by laser-driven x-ray probing	HHT-HIHEX	A	32
				126
P-22-00035	Time dependent focusing of laser driven proton beams in hemispherical-cone shaped target geometry	PHELIX-PTA	A-	20
P-22-00066	Non-linear Compton scattering from intense laser pulse interactions with expanding foil targets	PHELIX-PTA	A-	20
P-22-00106	Effect of Microstructural Heterogeneities on Material Damage and Failure	HHT-PRIOR	A-	
P-22-00124	Polarization Measurements of Laser-Accelerated 3He Ions from Polarized 3He-Gas Target (Continuation)	PHELIX-PTA	A-	20
P-22-00144	Understanding liquid-liquid phase transformations by temperature-dependent density and viscosity measurements at high pressures using high energy proton microscopy	HHT-PRIOR	A-	

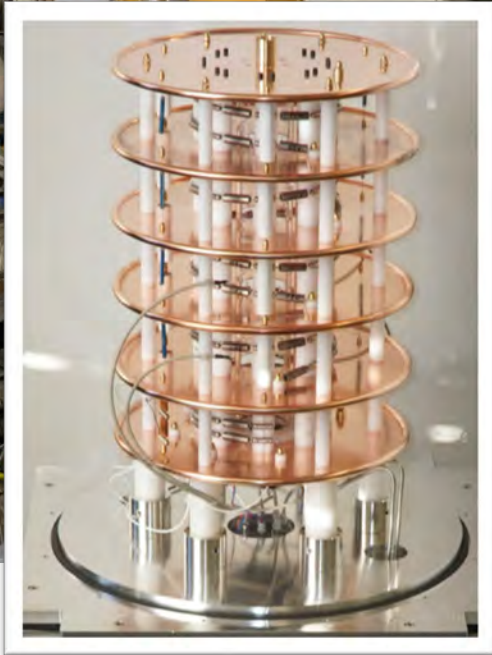
Orange shaded entries: Spearheaded by or with strong participation of groups from the ErUM-FSP APPA

In addition, there are stand-alone PHELIX beam times which are called for on a yearly basis.

Beam time preparation and execution as well as the subsequent data analysis require **manpower** and **support by theory**.

experimental equipment highly integrated into accelerator hardware

CRYRING electron cooler



precise control of electron energy

precision HV divider (10^{-6} accuracy)

particle detector

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Universität
Münster

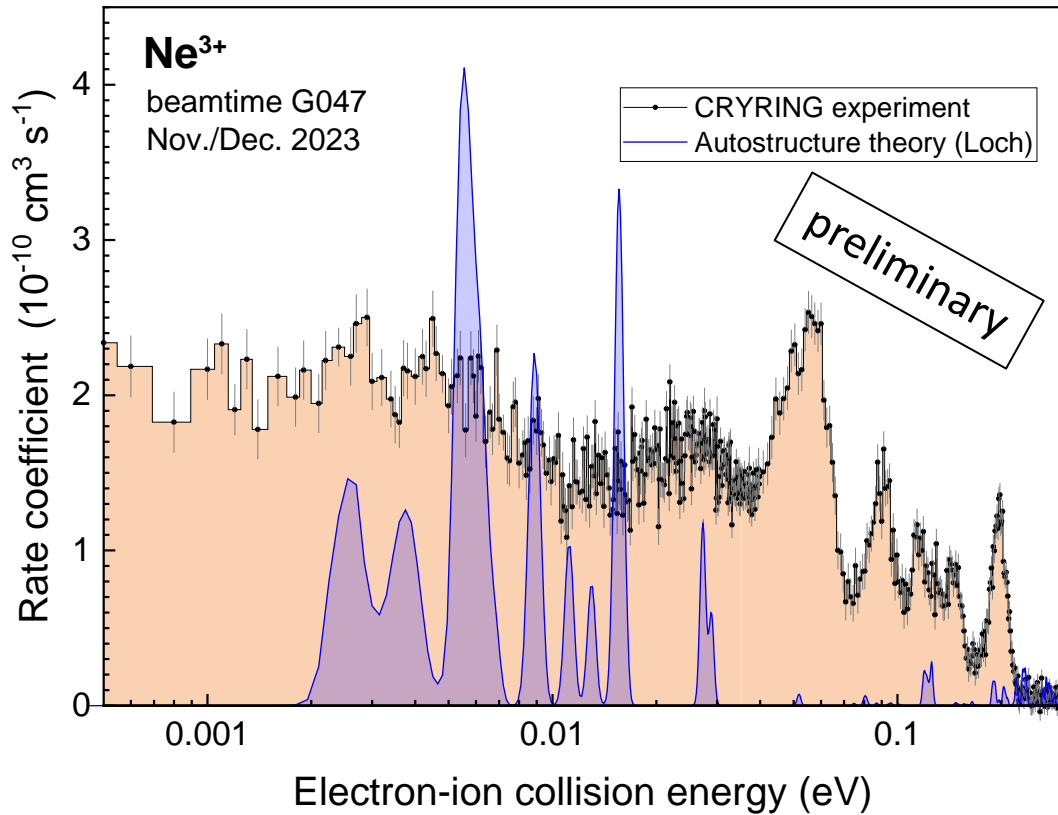
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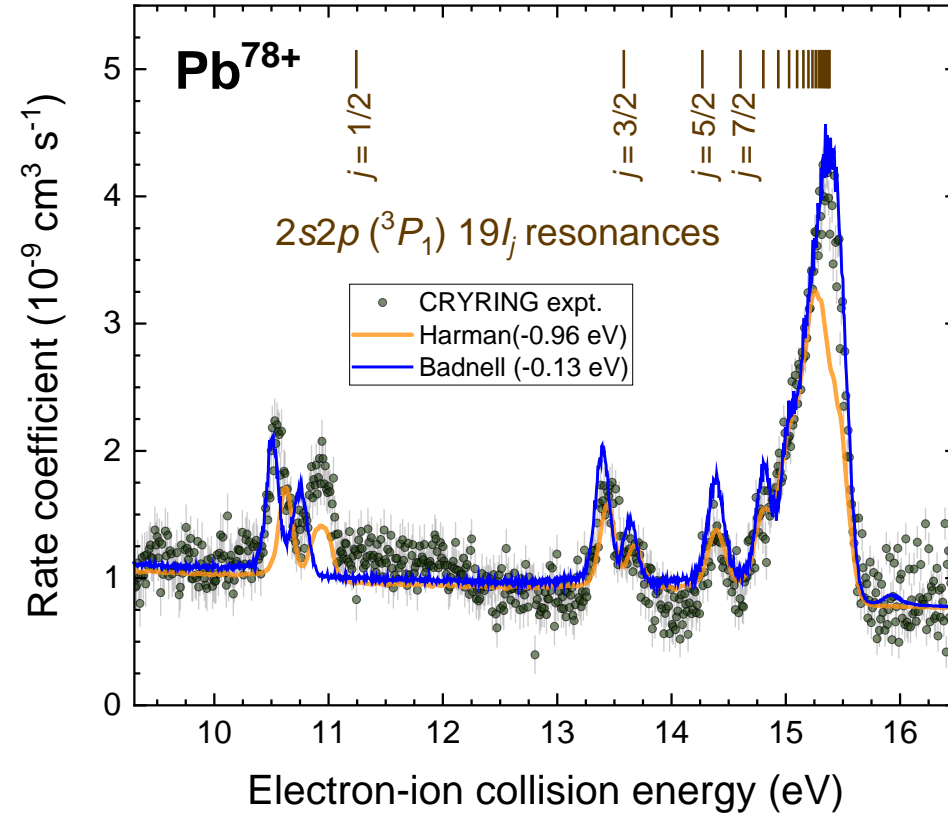
JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

$e^- + 1s^2 2s^2 2p^3 \ ^4S \rightarrow 1s^2 2s^2 2p^3 \ ^2S \ 4\ell$ resonances



ion beam from the CRYRING local injector

beamtime E131



decelerated ions from the ESR

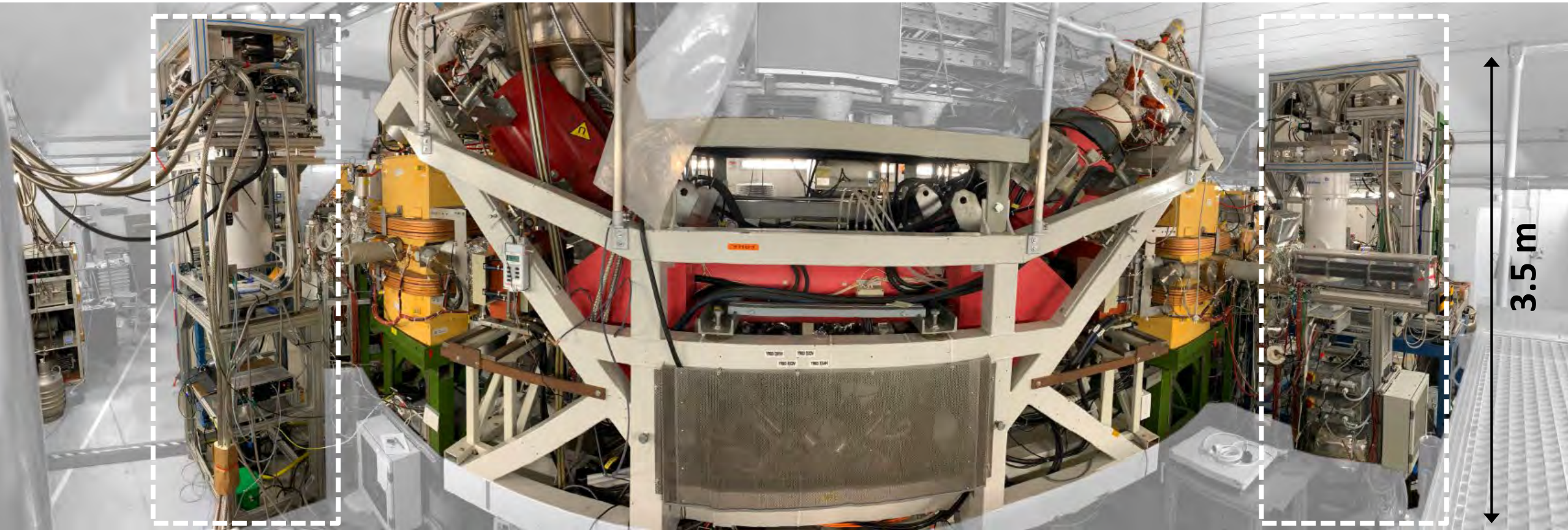
S. Fuchs et al. in preparation

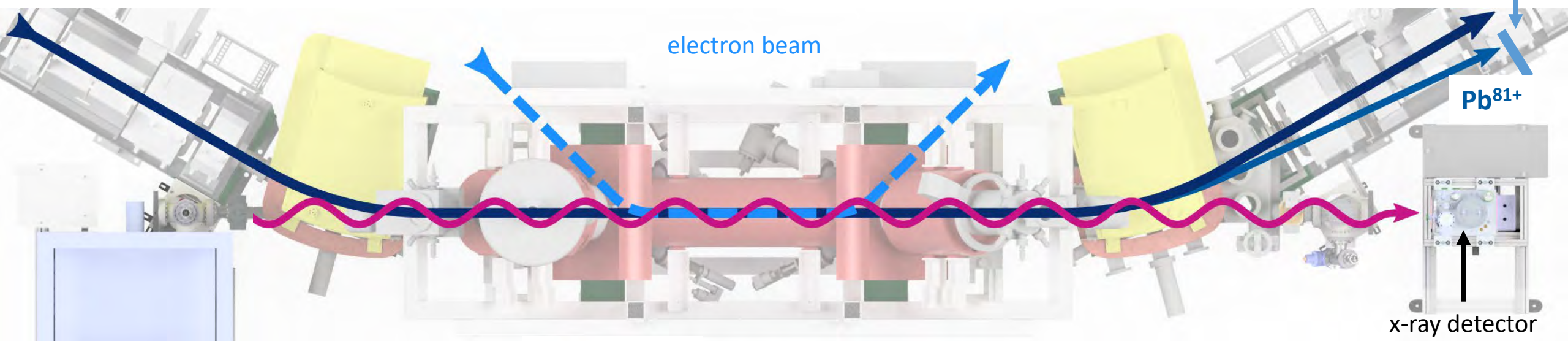
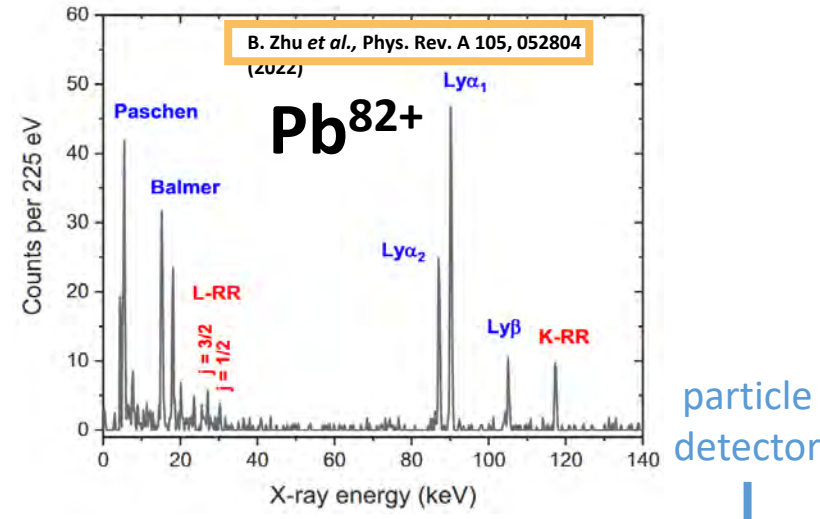
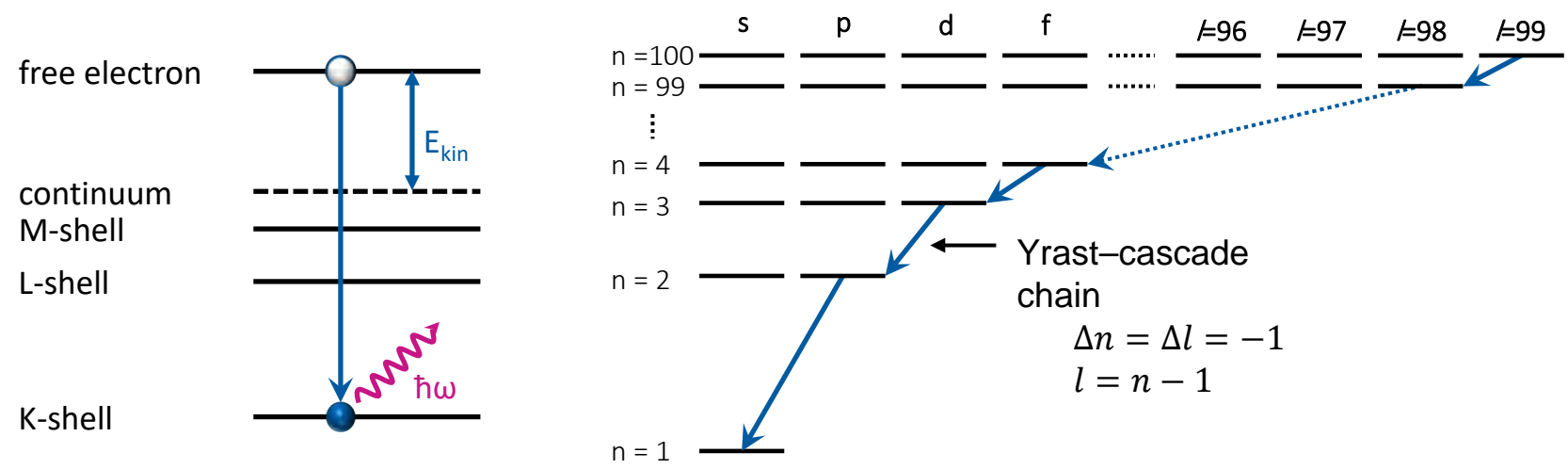
Merged-beams kinematics: Extremely low collision energies are accessible with highest precision

180° x-ray detector

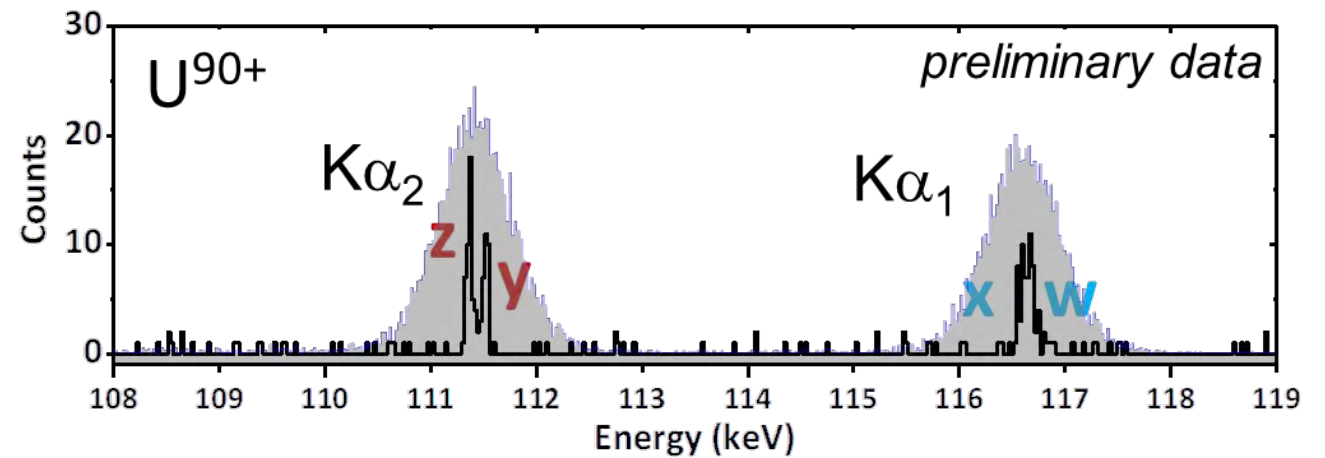
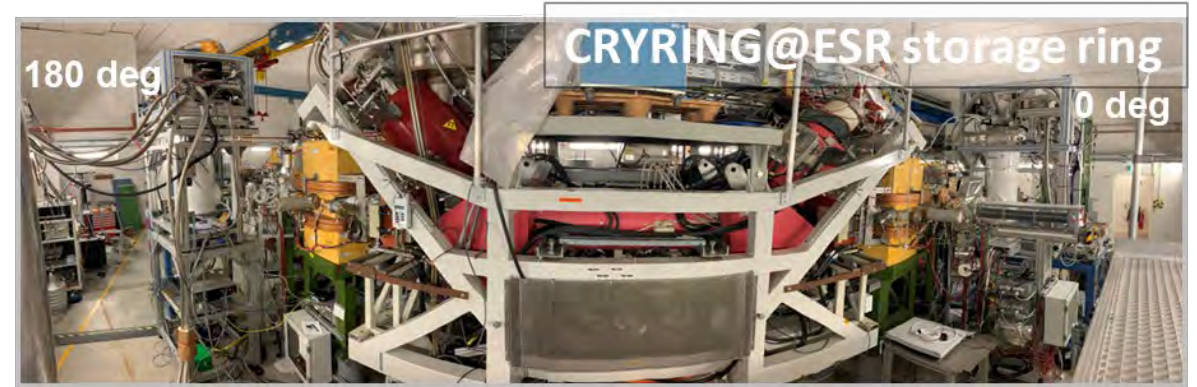
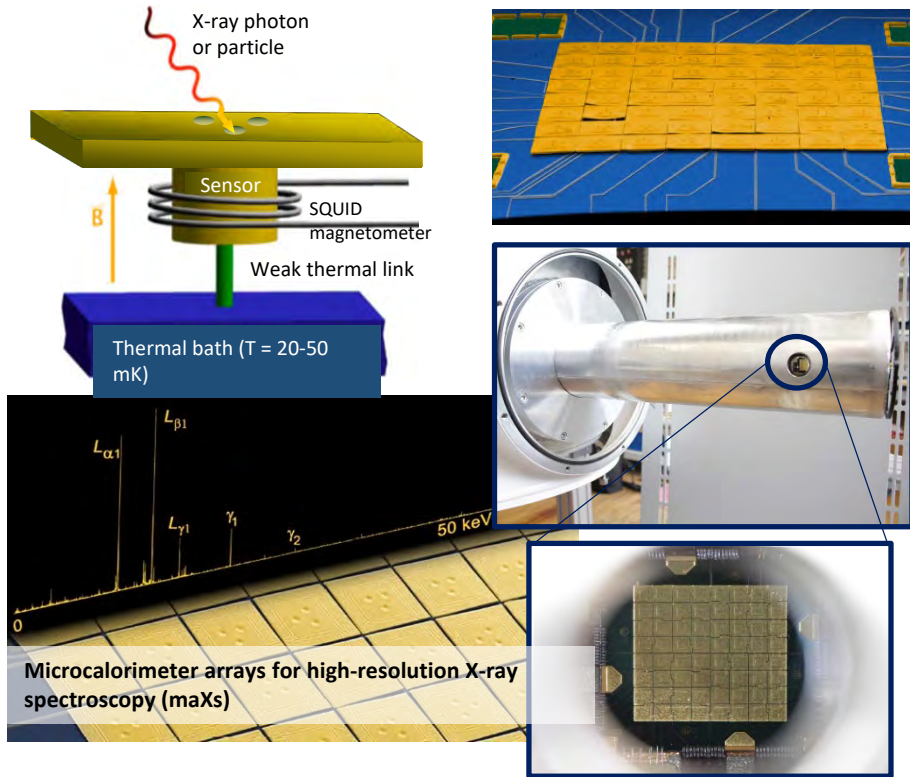
CRYRING electron cooler

0° x-ray detector





Metallic magnetic microcalorimeter

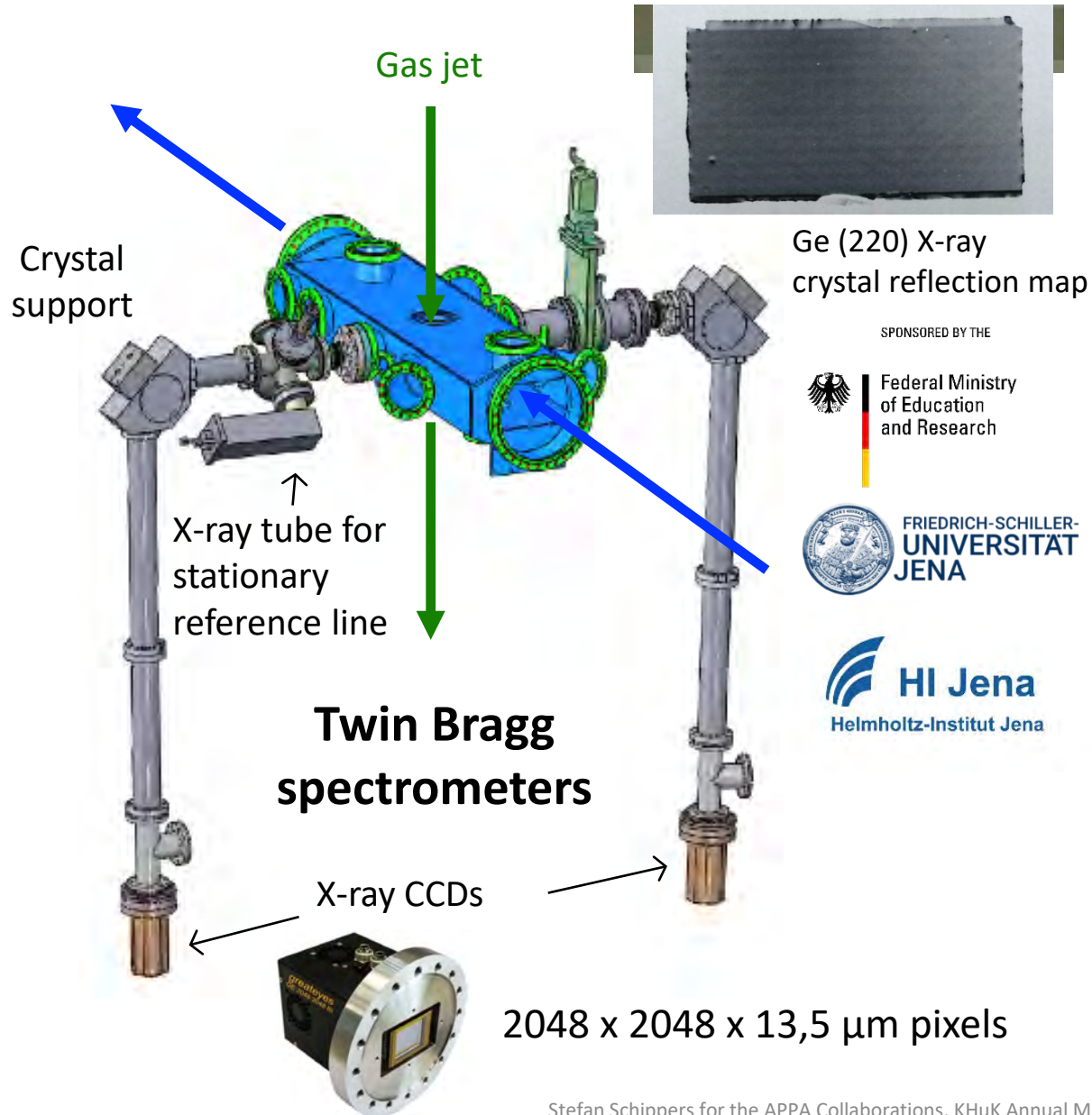


Preliminary data for 0 deg observation (black line) in comparison with scaled data from ESR (shaded area) PRL 032712 (2004)

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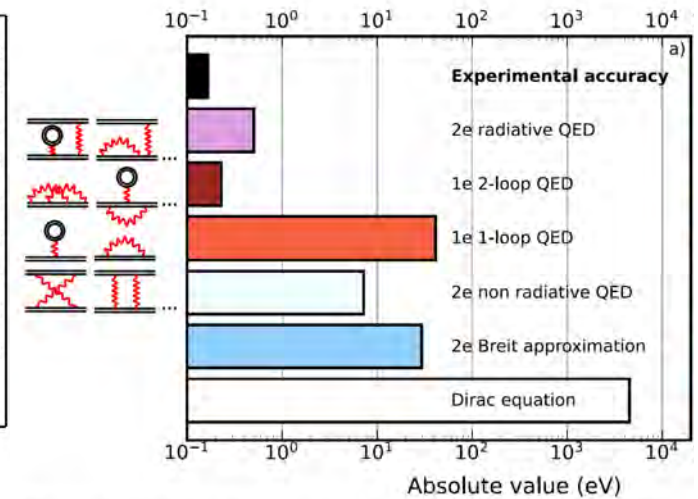
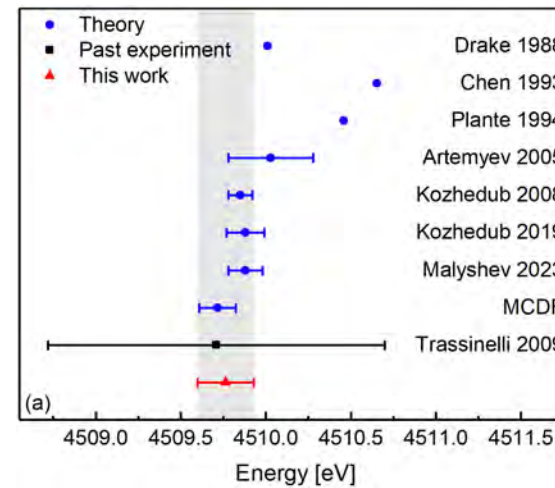
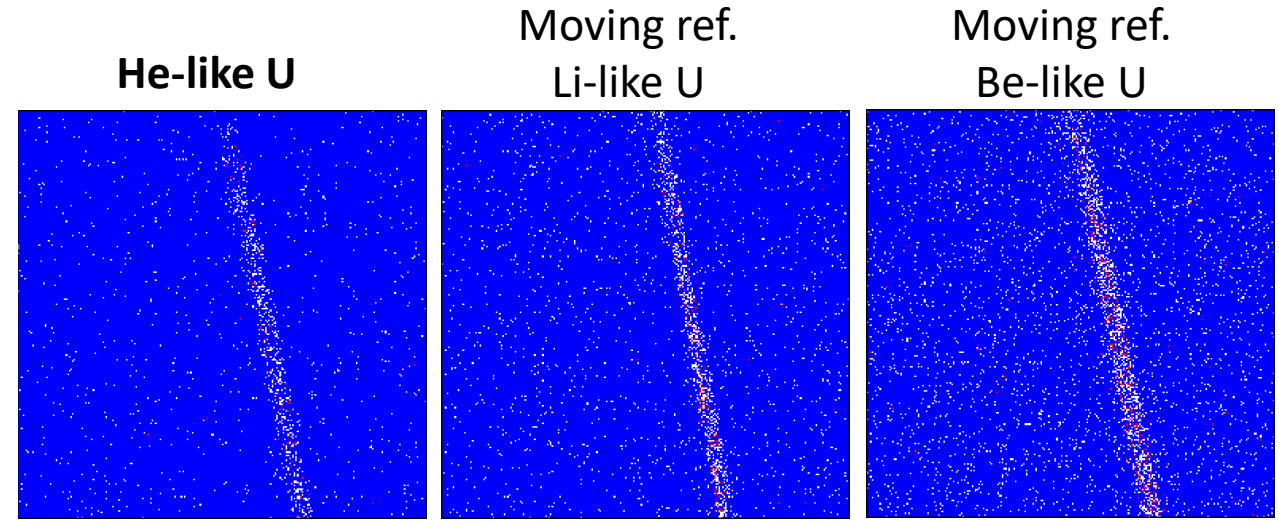
Philip Pfäfflein et al., in preparation



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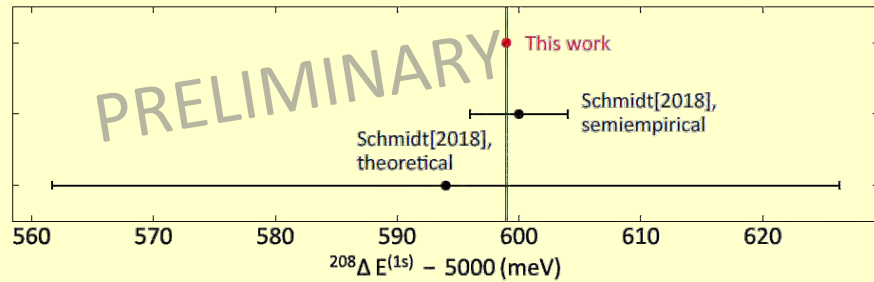
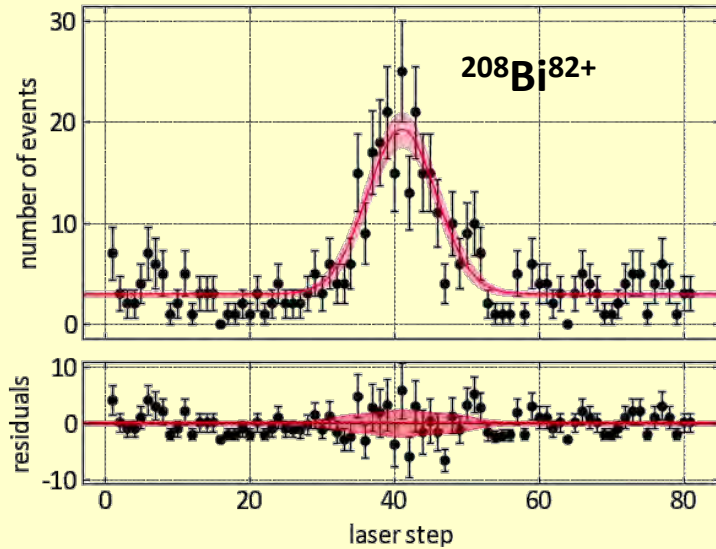
FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

HI Jena
Helmholtz-Institut Jena



R. Loetzsch et al., Nature (accepted)

Laser spectroscopy at the ESR

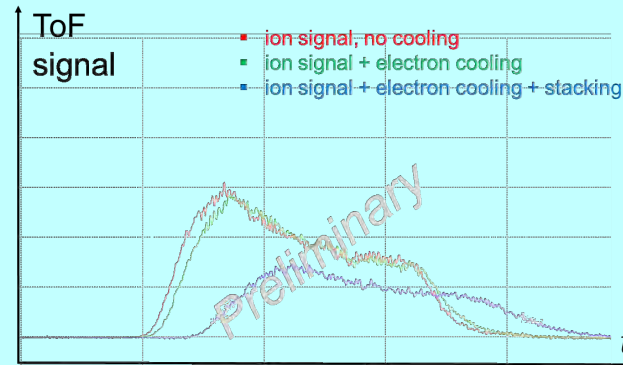
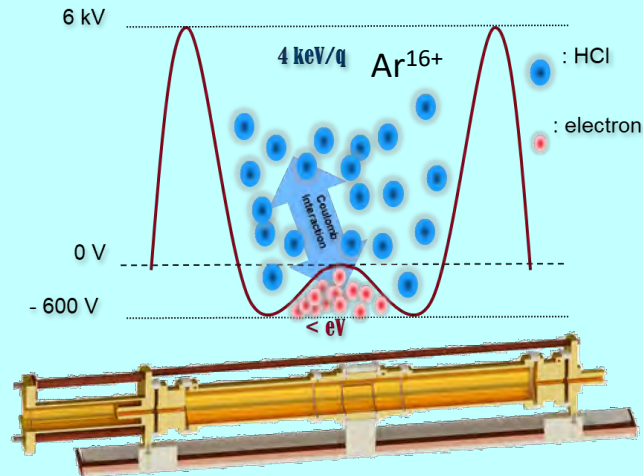


Results from first laser spectroscopy of a
accelerator-produced isotope at a storage ring

Max Horst, Dissertation TU Darmstadt, Nov. 2023, publication in prep.

Beamtimes: ^{229}Th (2024), $^{208}\text{Bi}^{80+}$ (2026)

HITRAP Commissioning

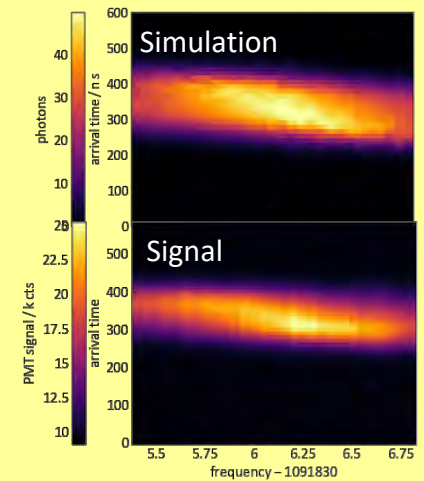


First electron cooling of HCl demonstrated

Simon Rausch, Dissertation, in prep.

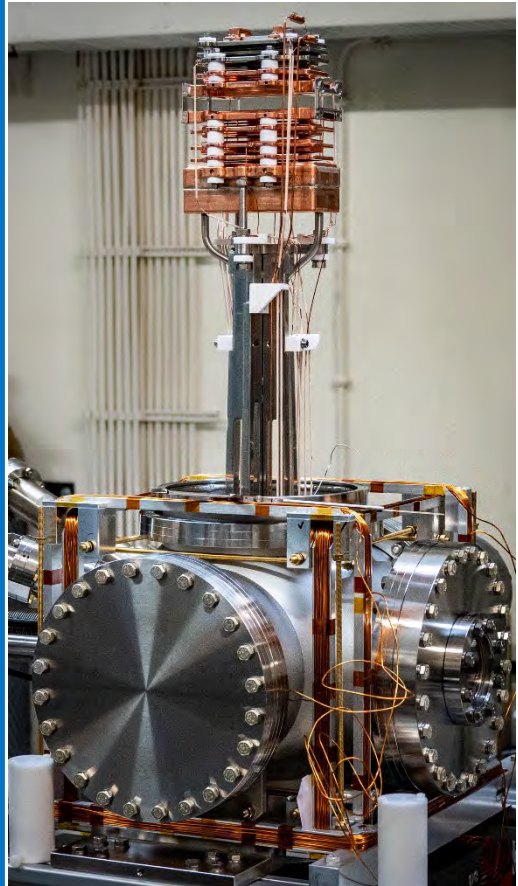
2 Beamtimes in 2024

CRYRING, optical pumping

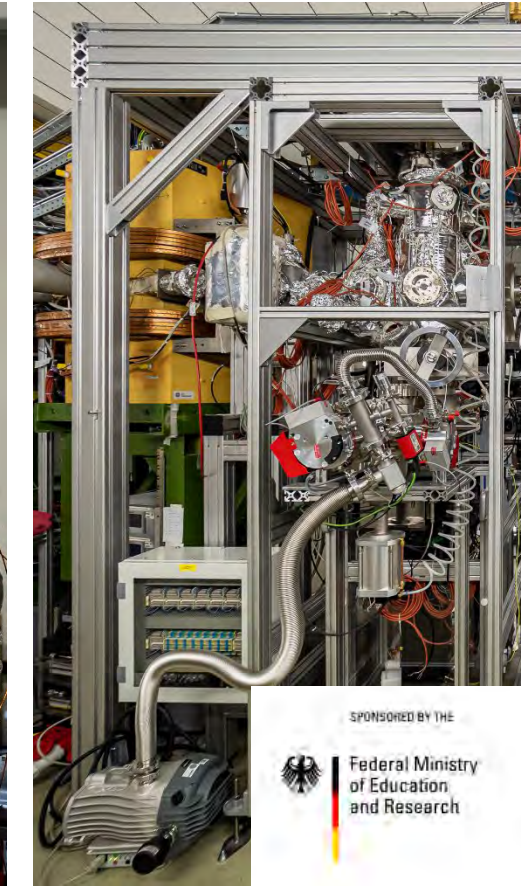


Quantitative understanding
of signal shape and laser-ion
interaction K. Mohr et al. (in prep.)

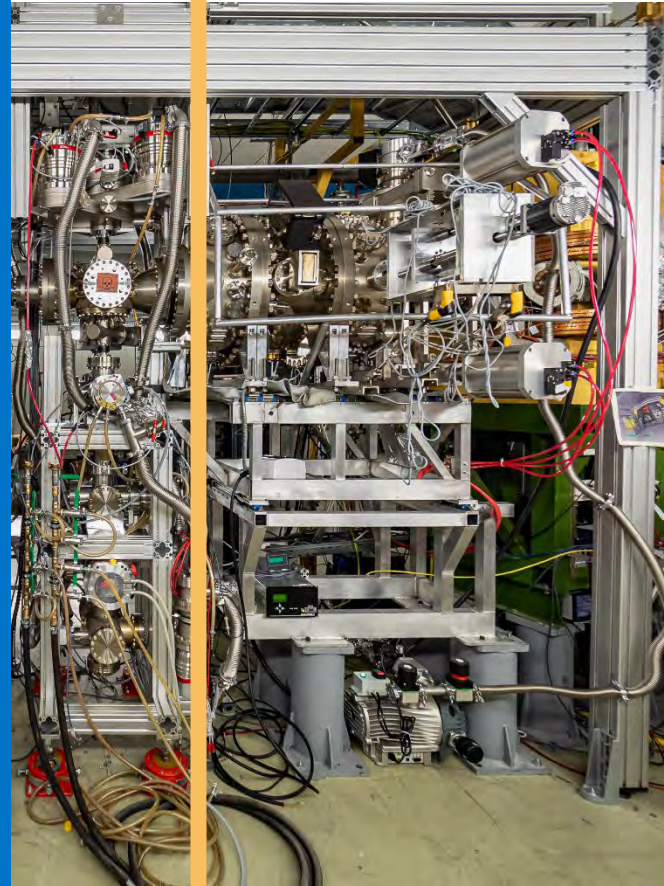
Beamtime ongoing !



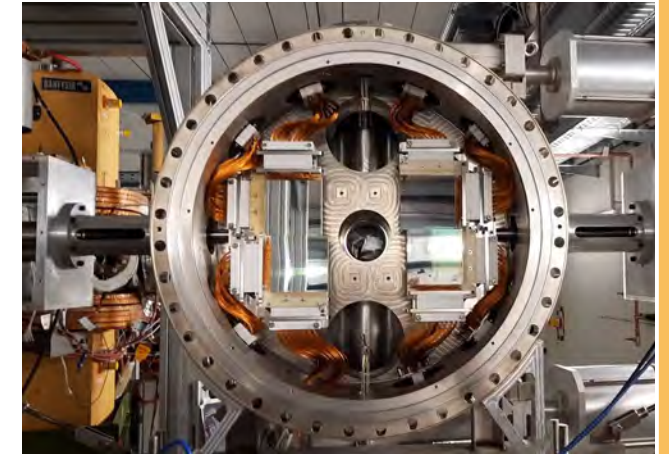
Electron Target



and associated ion detectors and photon detectors



Gas Jet



CARME

CRYRING Array for Reaction Measurements (low-energy nuclear reactions)

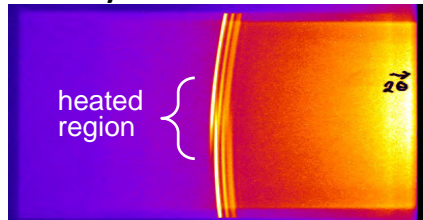


THE UNIVERSITY of EDINBURGH

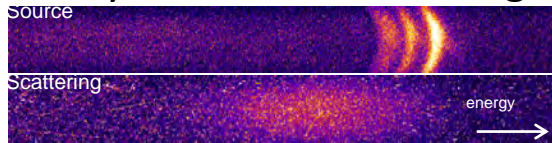


Understanding the temperature evolution during ion- and laser-beam heating at HHT

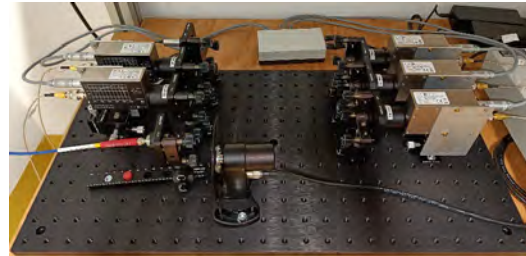
X-Ray Diffraction



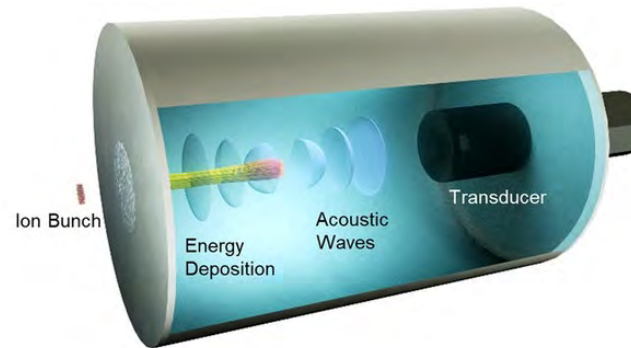
X-Ray Thomson Scattering



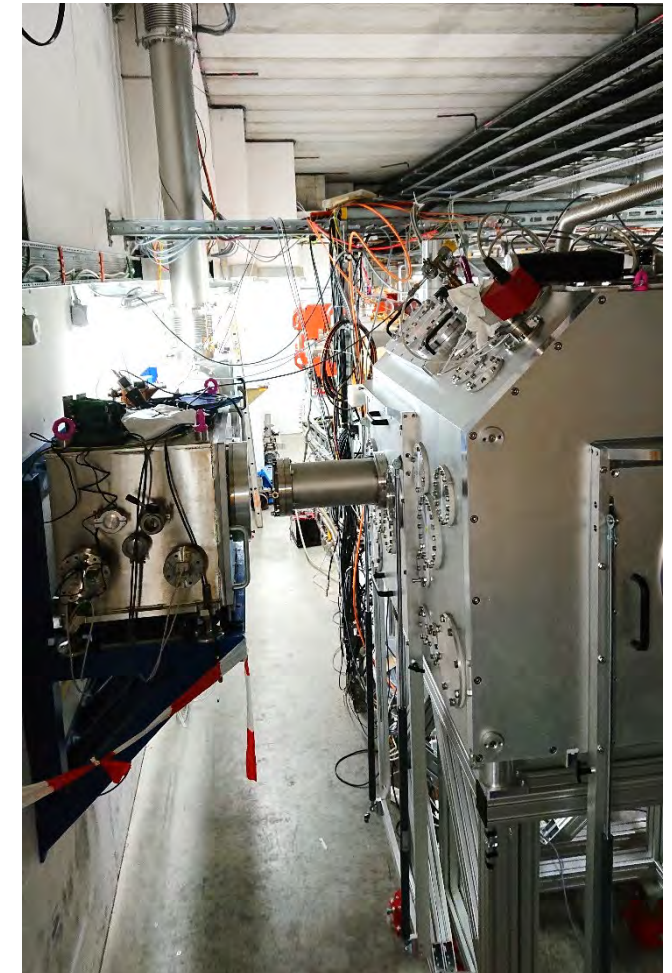
Laser driven X-Ray Diagnostics



Multi-Channel Pyrometer



Ion-Bunch Energy Acoustic Tracing (I-BEAT)



HIHEX target chamber at HHT



- Use the still available **FAIR Core-Invest** (committed by **BMBF**) for the completion of the instrumentation (largest item: **Laser cooling at SIS-100**)
- Carry out the research within **FAIR Phase-0** (granted G/P-PAC beamtimes & supporting theory).
- **R&D** for further advancing the technologies.
- **FSP-Activities**: Outreach (JOO of FAIR & ErUM FSPs, <http://fsp-appa.fair-center.eu>), training of young researchers, scientific meetings.

SPARC & HED@FAIR applications for 2024-2027: 31 projects applied for (14 M€, 31 FTE)



FAIR — Facility for Antiproton and Ion Research in Europe





ErUM-FSP APPA

APPA - Atomic, Plasma Physics and Applications

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- » NUSTAR
- » PANDA (external)

Publications

Related Links

ErUM-FSP APPA - BMBF Collaborative Research Center

The BMBF collaborative research center ErUM-FSP APPA comprises the German university groups who have set out to perform scientific research at the future international accelerator complex FAIR under the umbrella of APPA (Atomic, Plasma Physics and Applications). The FAIR installations are currently under construction at the site of the GSI Helmholtz Center for Heavy Ion Research in Darmstadt, Germany. APPA is one of the four research pillars of FAIR comprising the international research collaborations BIOMAT, FLAIR, HED@FAIR, and SPARC who focus on investigations of (anti)matter under extreme conditions (strong fields, high densities, high pressures, and high temperatures).

The ErUM-FSP APP research center pursues coordinated research projects in the area of accelerator based experiments with heavy ions at the future FAIR-installation. Central issues are:

- Further development of the the experimental infrastructure, in particular, research and development for enhancing the scientific capabilities of the existing installations and of the future accelerator and detector systems including the respective base technologies.
- Set-up of the APPA experiments of the modules 0-3 of the modularized start version of FAIR.

Stefan Schippers for the APPA Collaborations, KHuK Annual Meeting, Bad Honnef, 08 December 2023

fsp-appa.fair-center.eu



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18/19 January 2024

at GSI

https://indico.gsi.de/e/APPA_FSP_2024

Thank you for your attention!