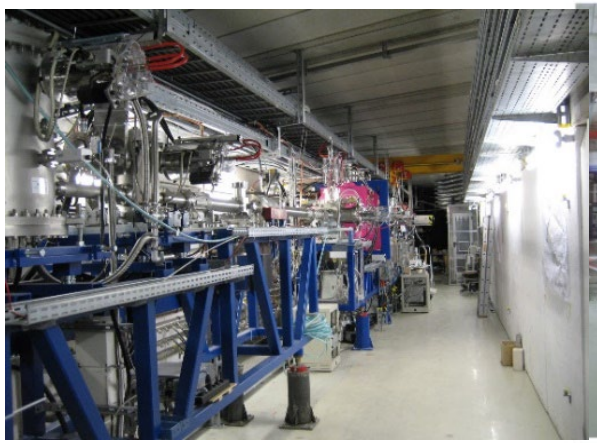
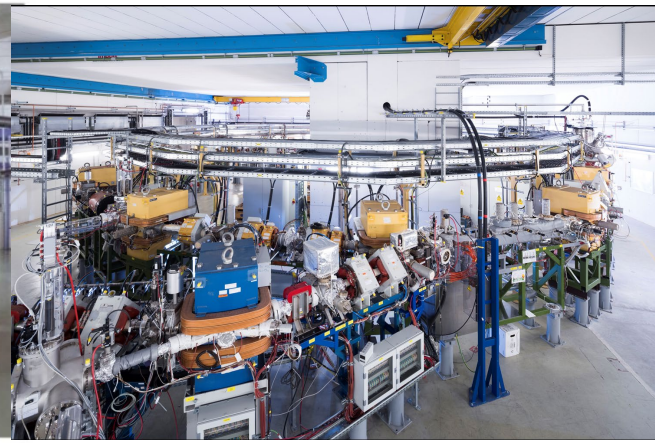
APPA Collaborations
SPARC Progress Report

Storage & Trapping of Cooled Highly Charged, Heavy Ions, and Exotic Nuclei





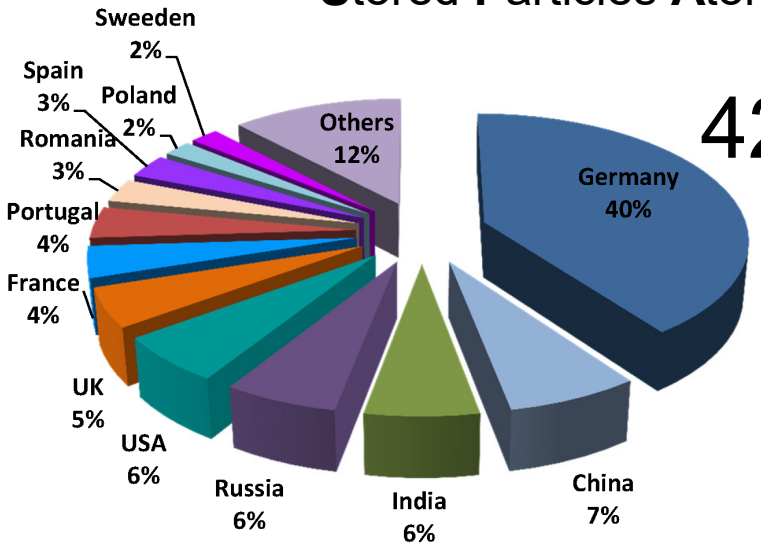
RRB 11, February 22nd & 23rd 2022 (online)

Thomas Stöhlker, Hostlab Liaison
Angela Bräuning-Demian, Technical Coordinator

The SPARC Collaboration

Stored **P**articles **A**tomic Physics **R**esearch **C**ollaboration

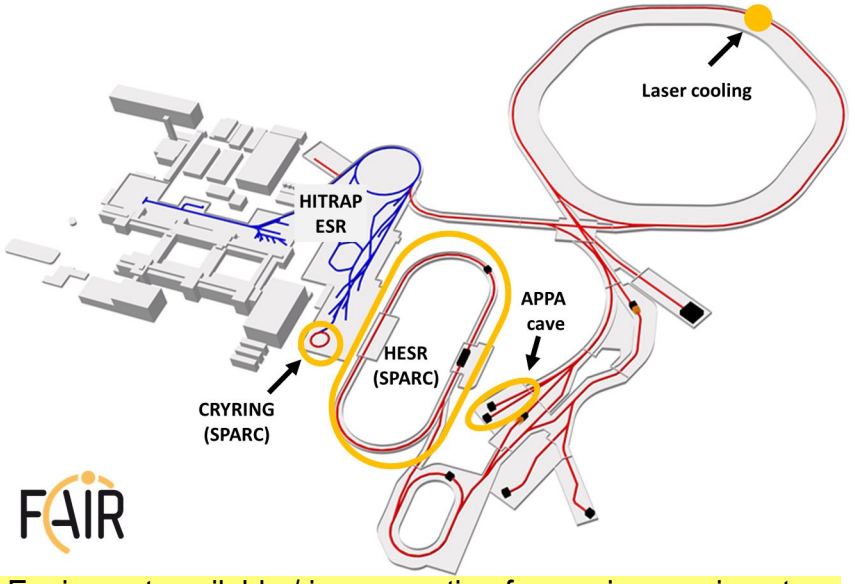
426 members



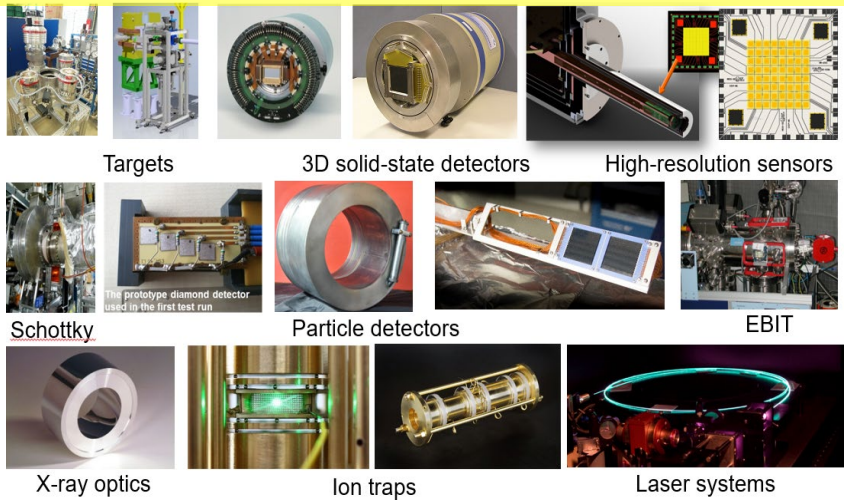
16th SPARC Topical Workshop, Sept. 2019

Spokesperson	Reinhold Schuch	University of Stockholm
Vice Spokesperson	Jose-Paulo Santos	University of Lisbon
Coordinator	Angela Bräuning-Demian	GSI & FAIR
Hostlab Liaison	Thomas Stöhlker	HI Jena & GSI

FACILITIES for SPARC Experiments



Equipment available / in preparation for use in experiments



https://fair-center.de/user/experiments/appa/erum-fsp-appa

2018-2021

SPARC, HED@FAIR

16 applications funded by the program **"Physics of the Smallest Particles"** coordinated by S. Schippers (Giessen)

SPARC 3,8 M€ HED@FAIR 2,5

MAT Users (2010-2022)

2 funded applications **"Condensed Matter"** coordinated by M. Schleberger (Duisburg-Essen)

1,4 M€

2021-2024

SPARC, HED@FAIR

20 applications funded by the program **"Physics of the Smallest Particles"** coordinated by S. Schippers (Giessen)

SPARC 5,1 M€ HED@FAIR 2,4 M€

MAT Users (2022-2025)

"Condensed Matter"

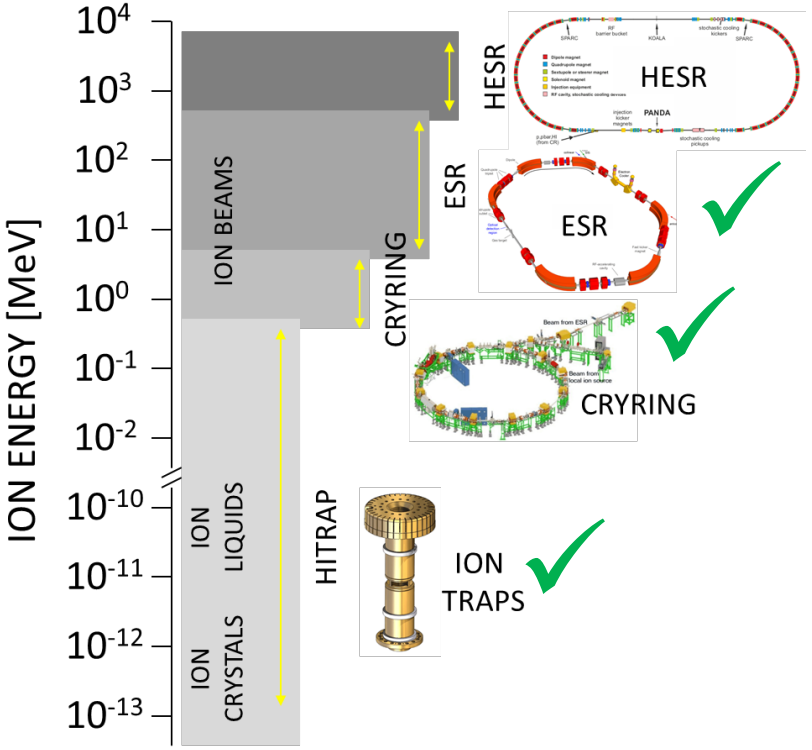
under evaluation

About 60% of the funding is devoted to personnel, mostly PhD students.

Precision Physics, Trapping & Storage
Atomic, Quantum and Fundamental Physics

Worldwide Unique

From Rest to Relativistic Energies (up to 4.9 GeV/u)



HITRAP, CRYRING@ESR, and ESR are part of the MSV

FAIR Phase-0 & Phase 1

- Full exploitation of research opportunities provided by ESR, CRYRING, HITRAP
- Research, employing FAIR instrumentation
- Preparation of laser cooling and laser spectroscopy at SIS100
- Preparation of first experiments at APPA cave with beams from SIS100 at energies above 5 GeV/u
- Preparation of first experiments at HESR cave with cooled relativistic ion beams (2 to 5 GeV/u)

Experiments with Highly-Charged Ions (e.g. U^{92+}) and Exotic Nuclei

In 2020: systematic commissioning of CRYRING and ESR started ! first production runs at ESR.

In 2021, continuation of 2020 with first production runs at CRYRING@ESR

In 2022, reaching the performance parameters of CRYRING in combination with ESR is of high priority.

FAIR Phase-0 (2020/2021)

ESR & CRYRING@ESR

2020 / 2021

Experiments FAIR Phase-0

E125 Δn=0 in He- and Li-like U ✓

E137 Channeling Li-like U **scheduled but postponed / COVID-19**

E128 Hyperfine Spectroscopy (**laser, DR**) **delayed**

E135 Spectroscopy of $^3P_0$ in Be-like Kr (**laser, XUV**) **started**

E132 1s-1s Ioniz. & Charge Transfer (**target, e⁻-spectr.**) ✓

E121 Bound state beta-decay (**Schottky**) ✓

E127 astrophys. p-process (p,γ) (**target**) ✓

E143 Nuclear two-photon decay (Schottky) [in coop. with ILIMA] ✓

Facility Challenges

Commissioning of new FAIR control system, re-establishment of deceleration capability, further commissioning of FAIR control system; improvement of vacuum conditions ✓ ✓

in progress

Experiments FAIR Phase-0 // Beams from ESR

E138 1s Lamb Shift in U^{91+} (**cooler**) **started, to be continued**

E131 Pb^{78+} Spectroscopy of Be-like ions (**DR**) ✓

Experiments FAIR Phase-0 // CRYRING ion souce

E129 Photoionization of C^{1+} (**laser**) **started, to be continued**

E148 A Test of Optical Pumping Mg^+ (**laser**) ✓

E153 O^{6+} Tri-Electronic Recombination (**DR**) ✓

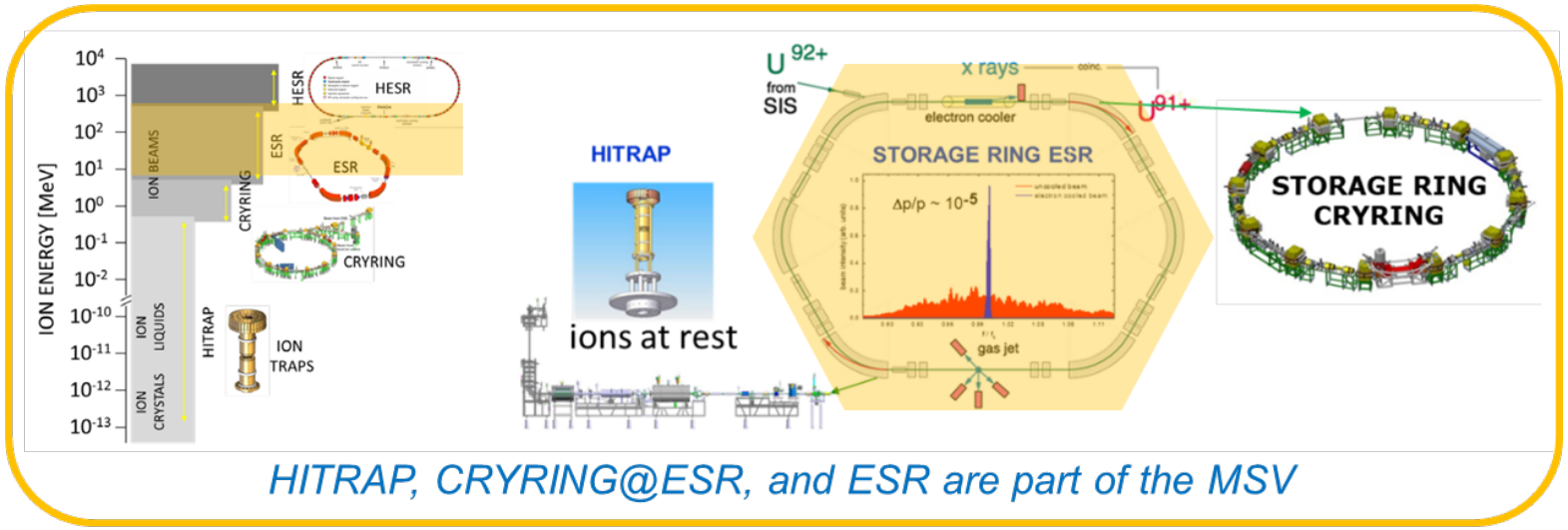
E140 Ne^{2+} Absolute Rate Coefficients (**DR**) ✓

Facility Challenge

electron cooler, commissioning of all ring installations for experiments ✓ ✓

Vacuum, particle detectors, beam transfer from ESR **to be continued**

Experimental Storage Ring (ESR)



HITRAP, CRYRING@ESR, and ESR are part of the MSV

ESR serves as a test bed for:

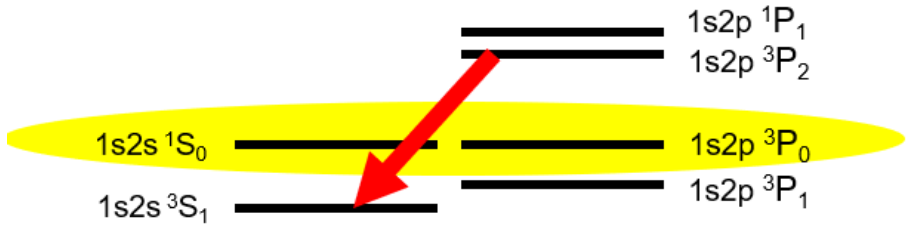
- laser cooling/spectroscopy experiments at SIS100
- ion-crystal interaction (RCE) experiments at APPA Cave using relativistic SIS100 beams

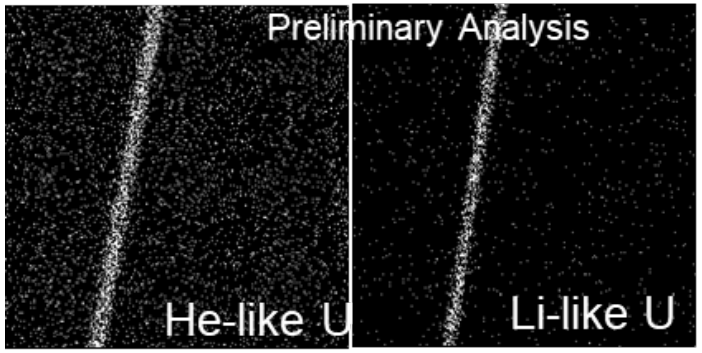
E125 (ESR) First Precision Study Atomic Structure of He-like Uranium

- Benchmarking correlation, relativity and QED in He-like ions in extreme fields
- High-precision x-ray Bragg spectrometry at the internal target of ESR

=> Improved experimental accuracy by one order of magnitude

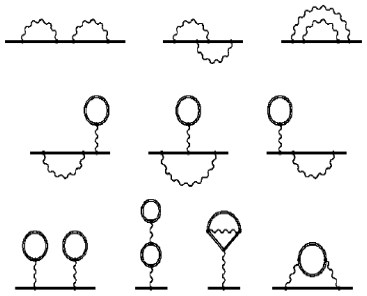
He-like uranium
$1s2p\ ^3P_2$ - $1s2s\ ^3S_1$
transition energy



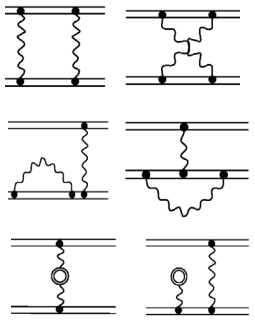


Two-Loop Diagrams

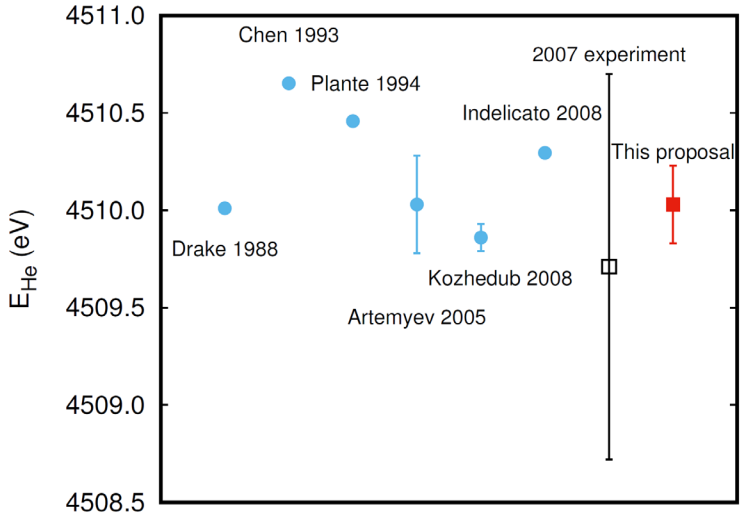
$\Delta E \approx 0.2$ eV



$\Delta E \approx 1.2$ eV



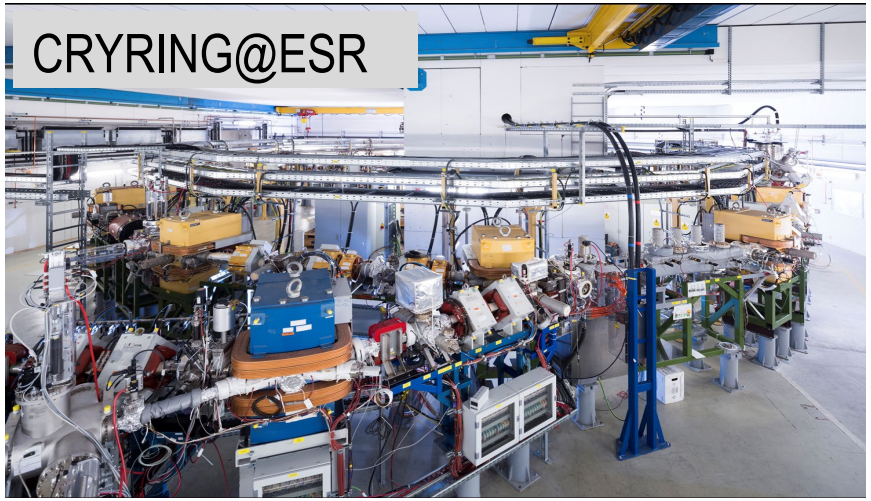
Martino Trassinelli et al.

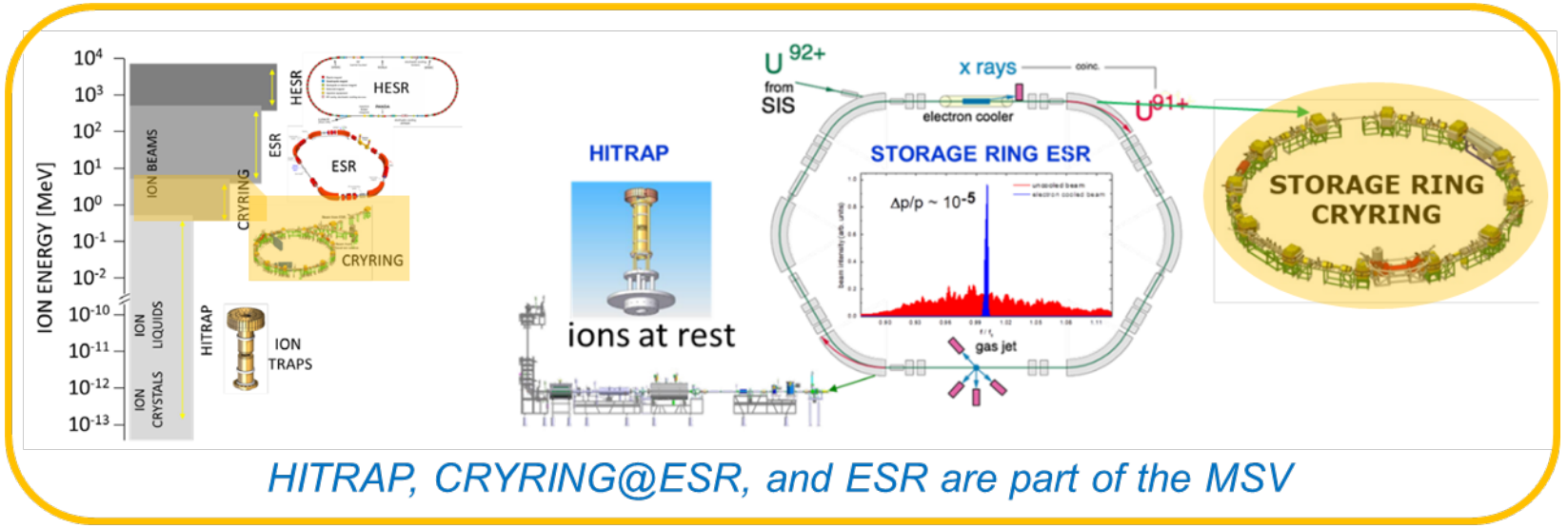


Exp. Accuracy
≈ 0.1 eV
(to be finalized)

benchmarking theory

CRYRING@ESR



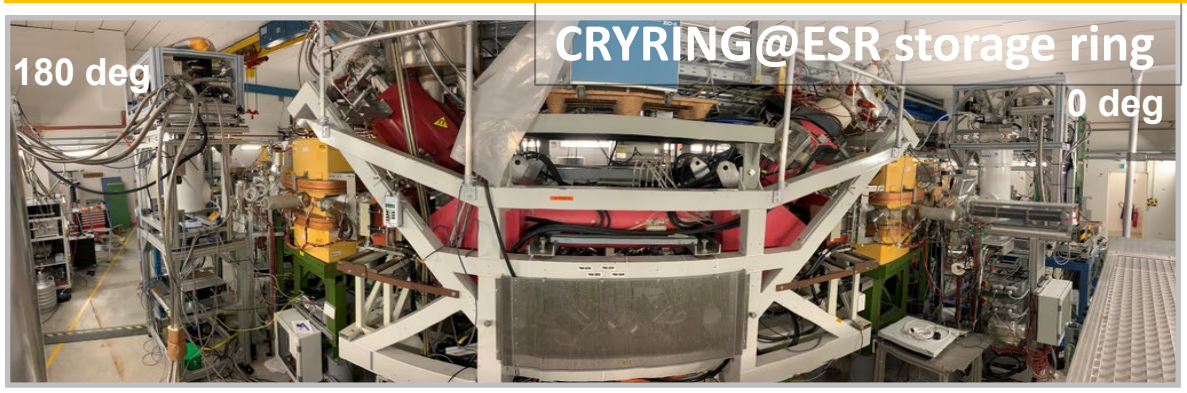


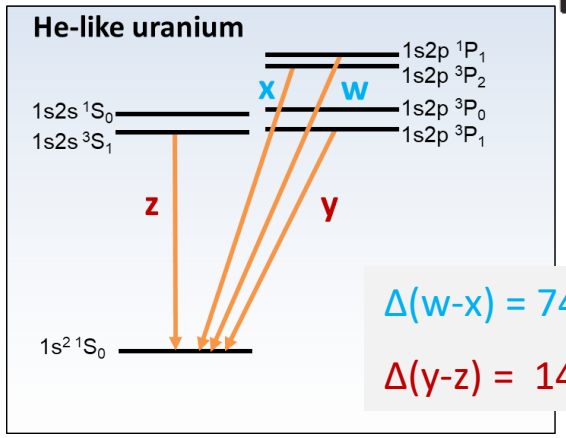
CRYRING@ESR serves as a test bed for:

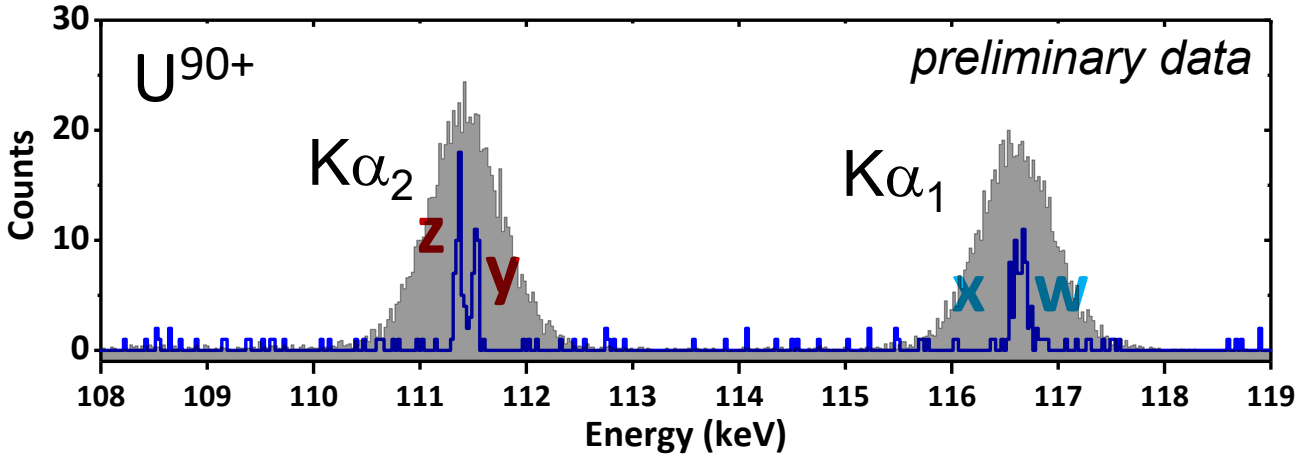
- Recoil ion instrumentation/experiments at HESR
- Attosecond experiments using ultra-intense laser in the XUV to x-ray regime

High-Resolution X-Ray Spectroscopy at CRYRING@ESR (E138)

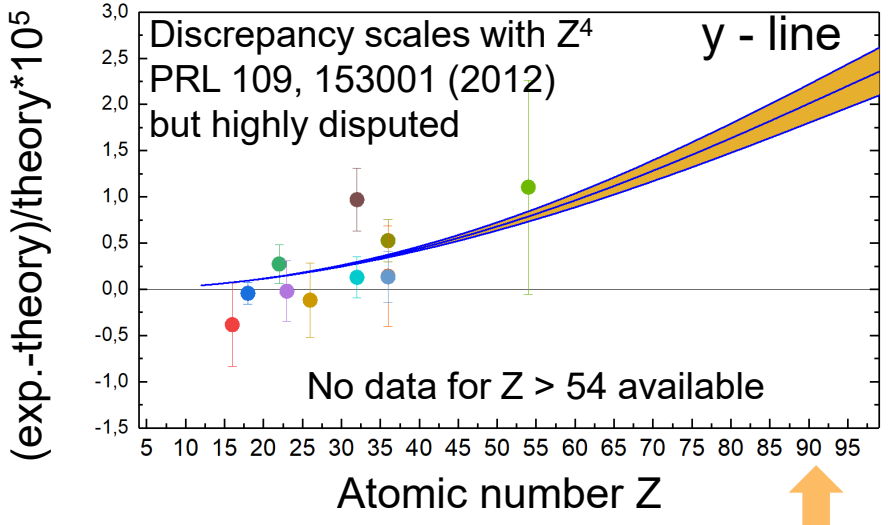
First Fine(sub)structure Resolved Measurement of Groundstate Transitions in He-like Uranium.
Application of Cryogenic Detectors (MMC).







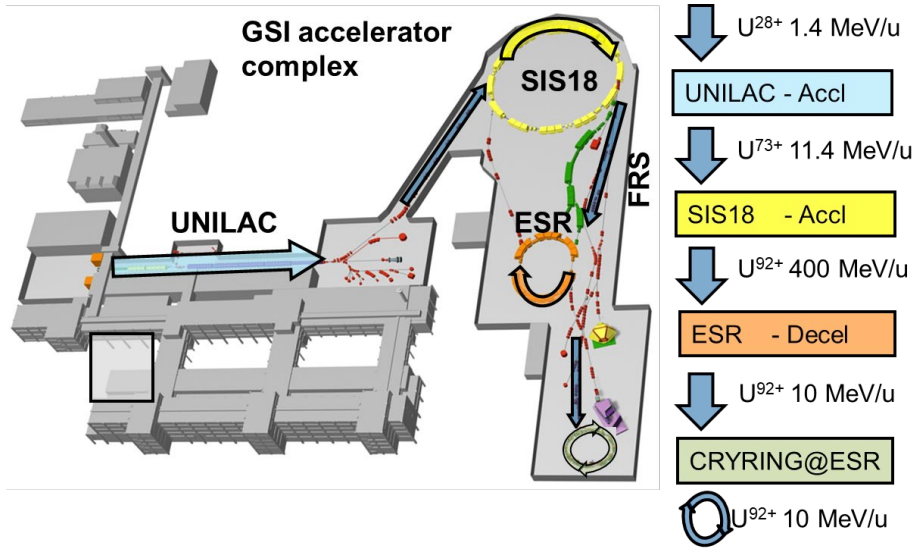
Preliminary data for 0 deg observation (black line) in comparison with scaled data from ESR (shaded area) PRL 032712 (2004)



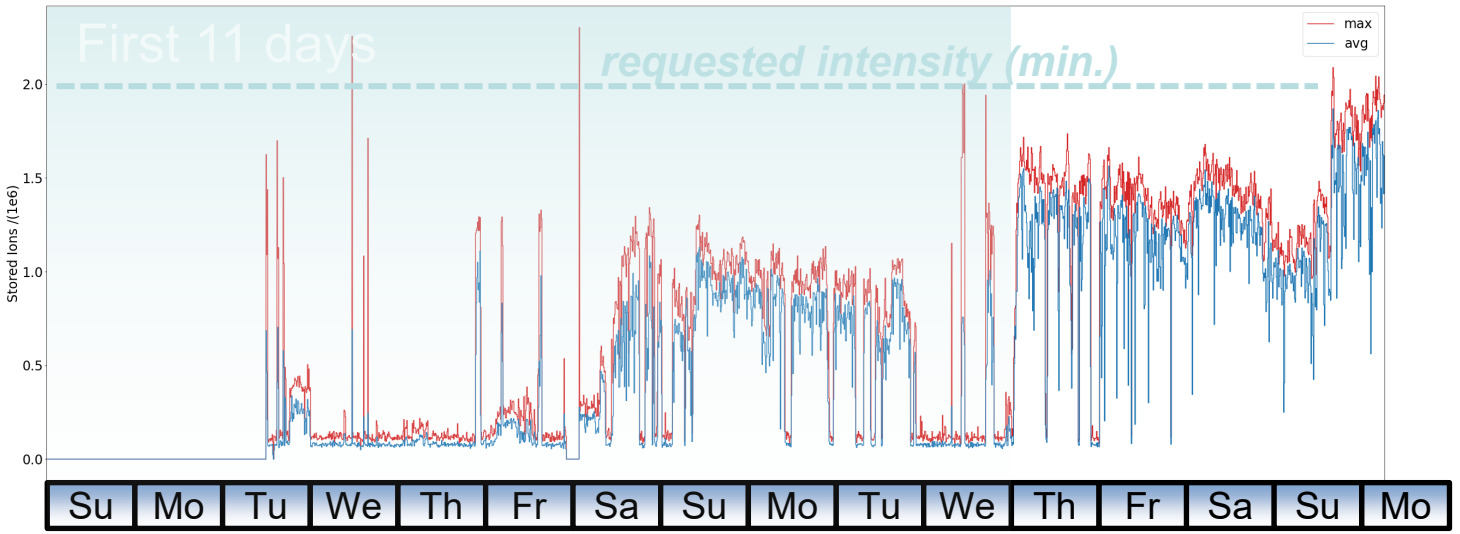
E138

SPONSORED BY THE
Federal Ministry of Education and Research

The Challenge of Deceleration (E138)

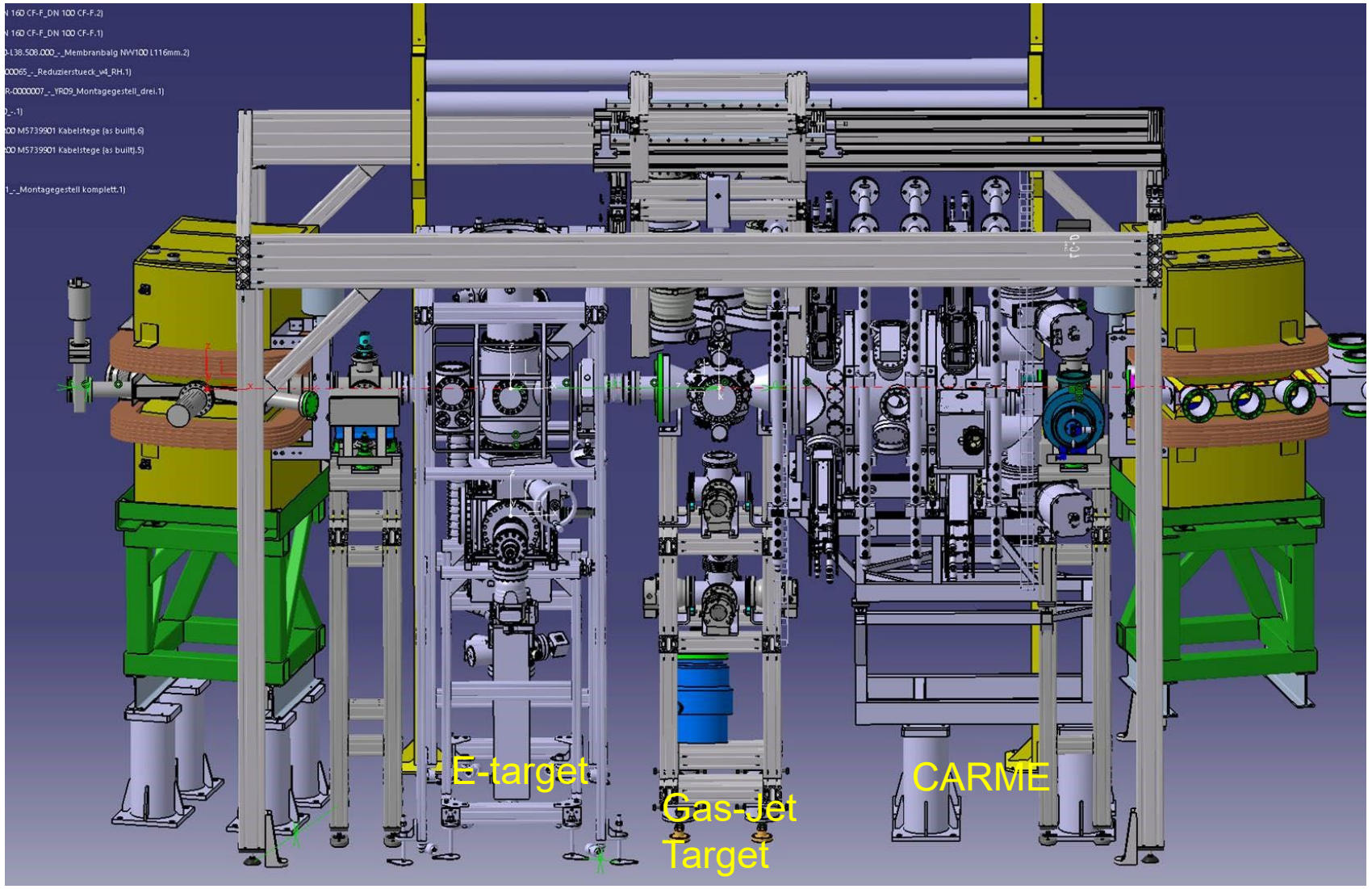


Intensity of H-like uranium beam



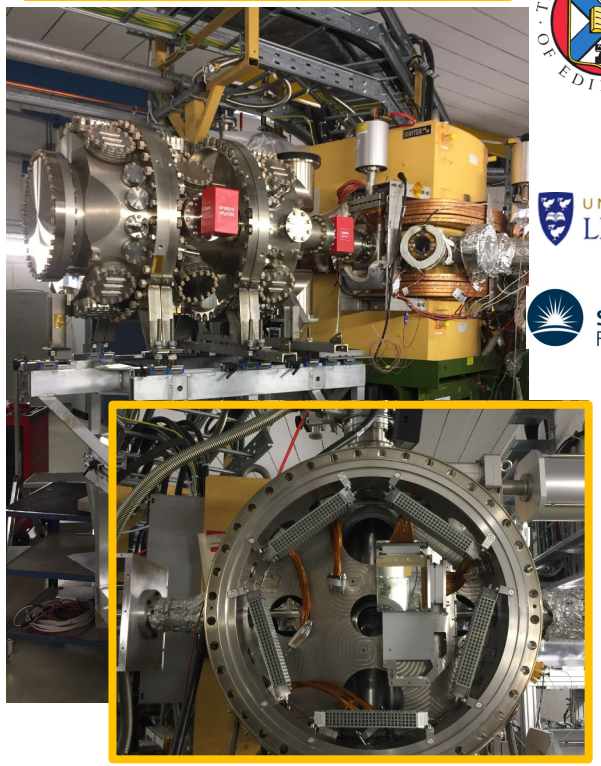
- In 2020 and 2021, substantial progress in commissioning and first experiments at CRYRING@ESR
- Deceleration capability needs to be substantially improved but no principal showstopper!
- Many experiments at CRYRING@ESR rely on >10^7 heavy, highly charged ions stored!
- Main priority: Pushing towards the full (design) performance parameters of CRYRING@ESR, HITRAP and the full deceleration chain.

Section YR09 : setups planed for the beam time 2022



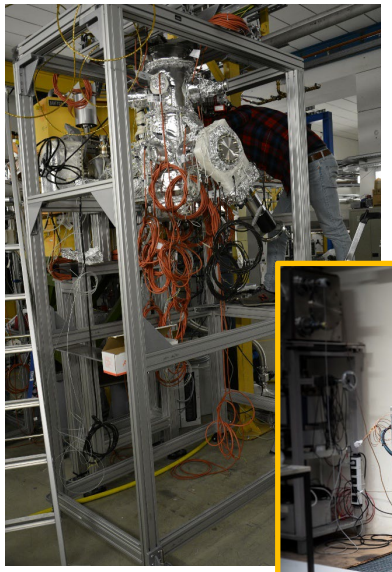
Experiment installation and testing at CRYRING: Status October 2021

CARME spectrometer



- ✓ Installation in ring of the forward part
- ✓ Vacuum test of the chamber with backing concluded: p= 2×10^{-11} mbar
- ✓ Installation of the detectors is ongoing
- ✓ coupling to the target interaction chamber

E- transversal Target

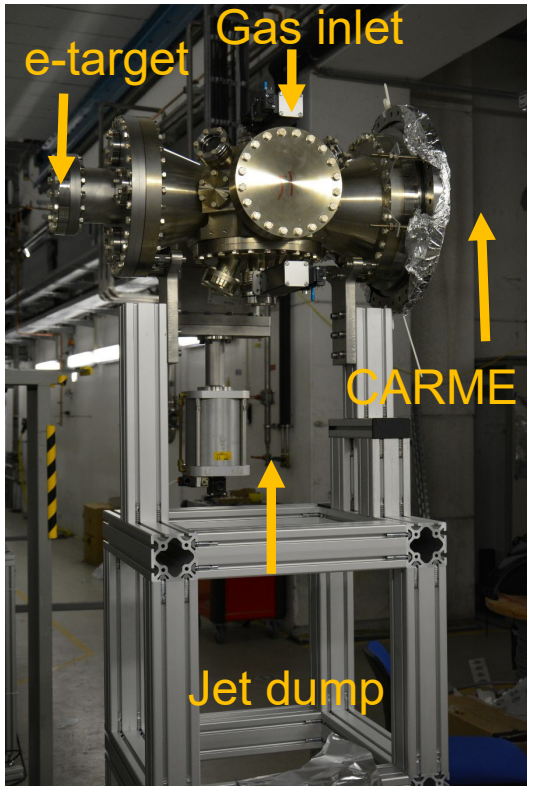


Top interaction Chamber:

Bundesministerium für Bildung und Forschung

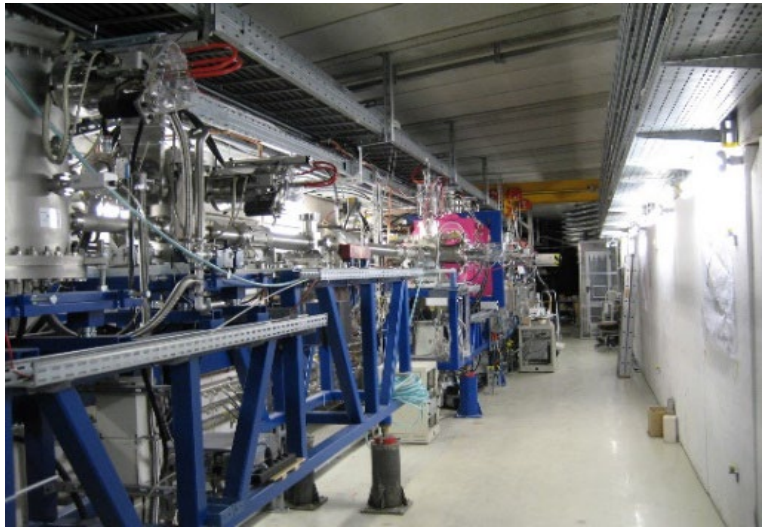
- ✓ The upper part is installed in the ring and ready for backing and vacuum test
- ✓ Optimisation of the electron-gun part is in work
- ✓ Dedicated control system in preparation

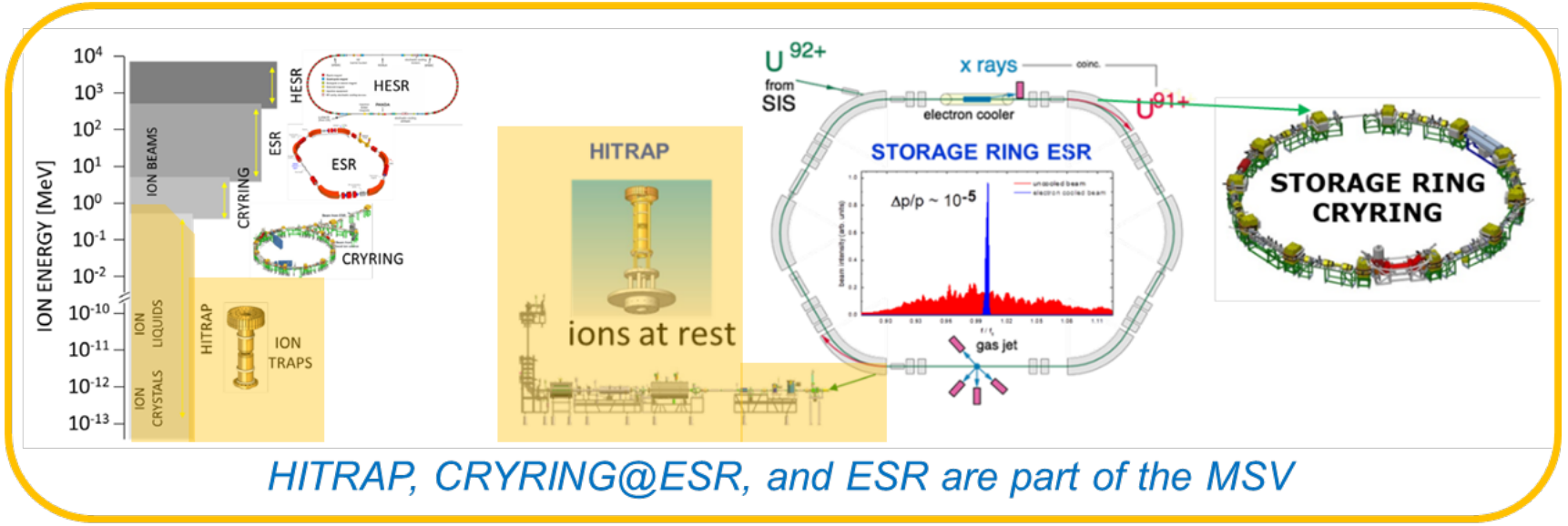
Gas-Jet Target



- ✓ the interaction chamber is ready to be placed in the ring and connected to the other two setups
- ✓ backing and vacuum test are in preparation
- ✓ Inlet and dump will be successively installed at the final place

HITRAP@ESR

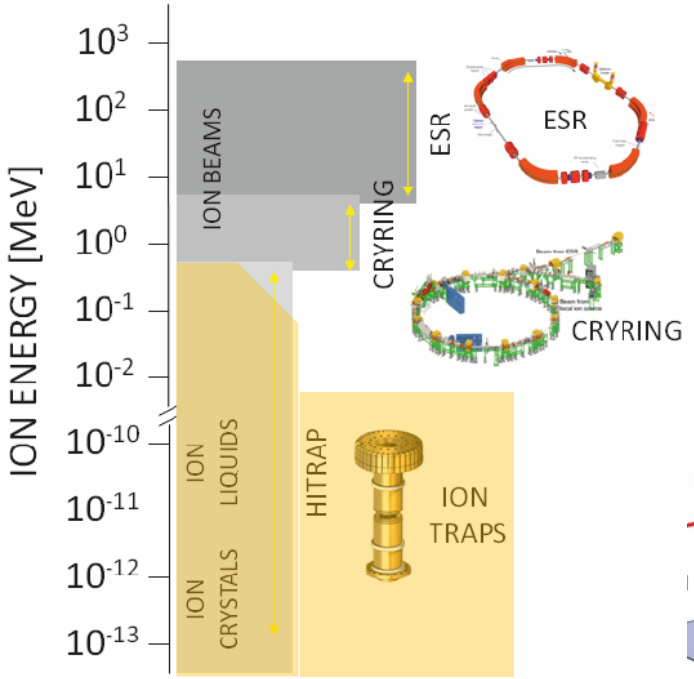


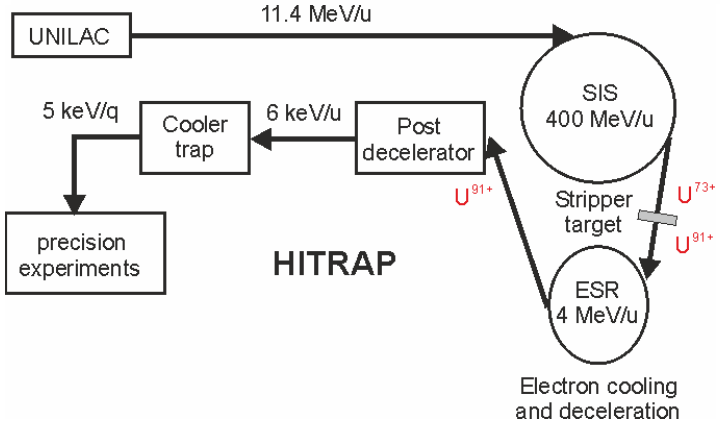


Challenges for 2022

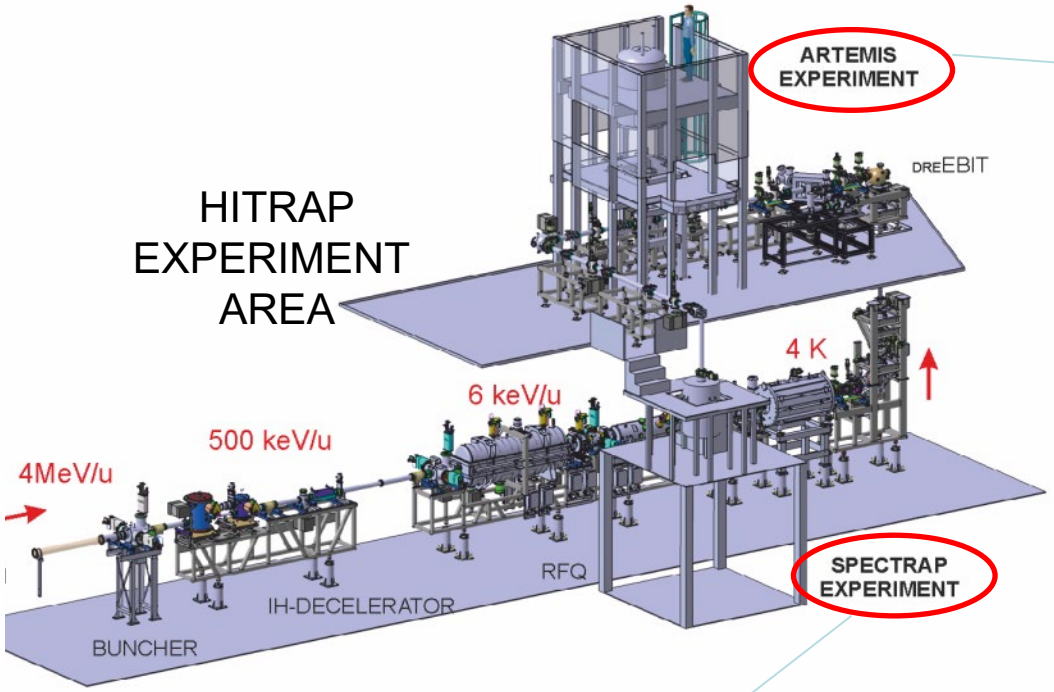
- Re-commissioning of HITRAP decelerator
- Commissioning of the experiment platform

SpecTrap and ARTEMIS@HITRAP





HITRAP EXPERIMENT AREA



CONNECTION TO HITRAP UNDER CONSTRUCTION

NOVEL COLD VALVE

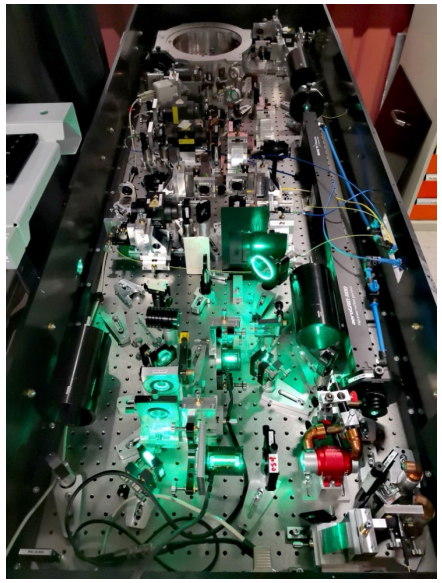
NOVEL NON-DESTRUCTIVE BEAM DIAGNOSTICS

- OLD SC MAGNET RETURNED TO BERKELEY

NEW - NEW SC MAGNET ARRIVED AT GSI (SWEDISH IN-KIND TO FAIR)

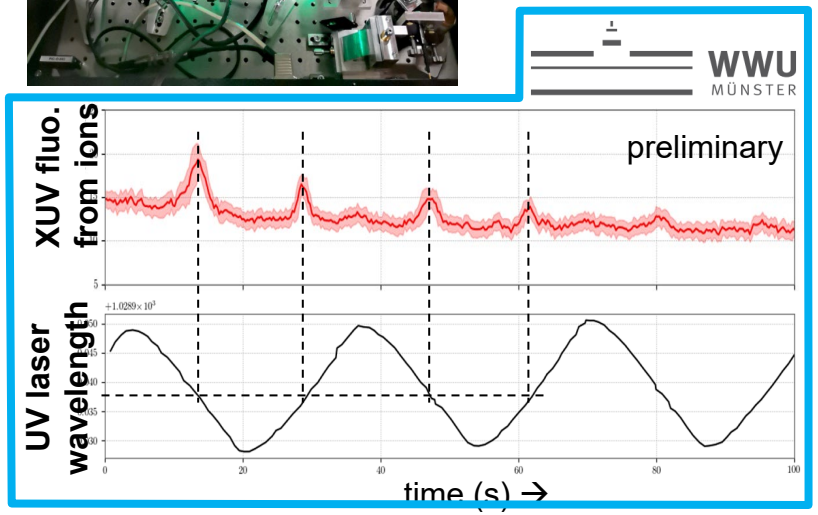
Laser cooling of relativistic C^{3+} ions @ ESR

Proof-of-principle experiment: laser cooling by means of a pulsed laser

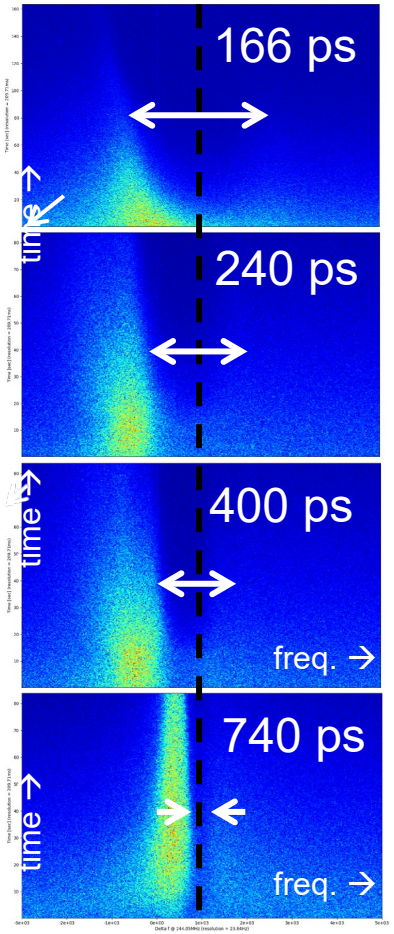


TECHNISCHE UNIVERSITÄT DARMSTADT

← pulsed UV laser
λ = 257 nm
10 MHz rep. rate
70 – 740 ps
>200 mW
prototype for t
he SIS100 setup



D. Winters et al.



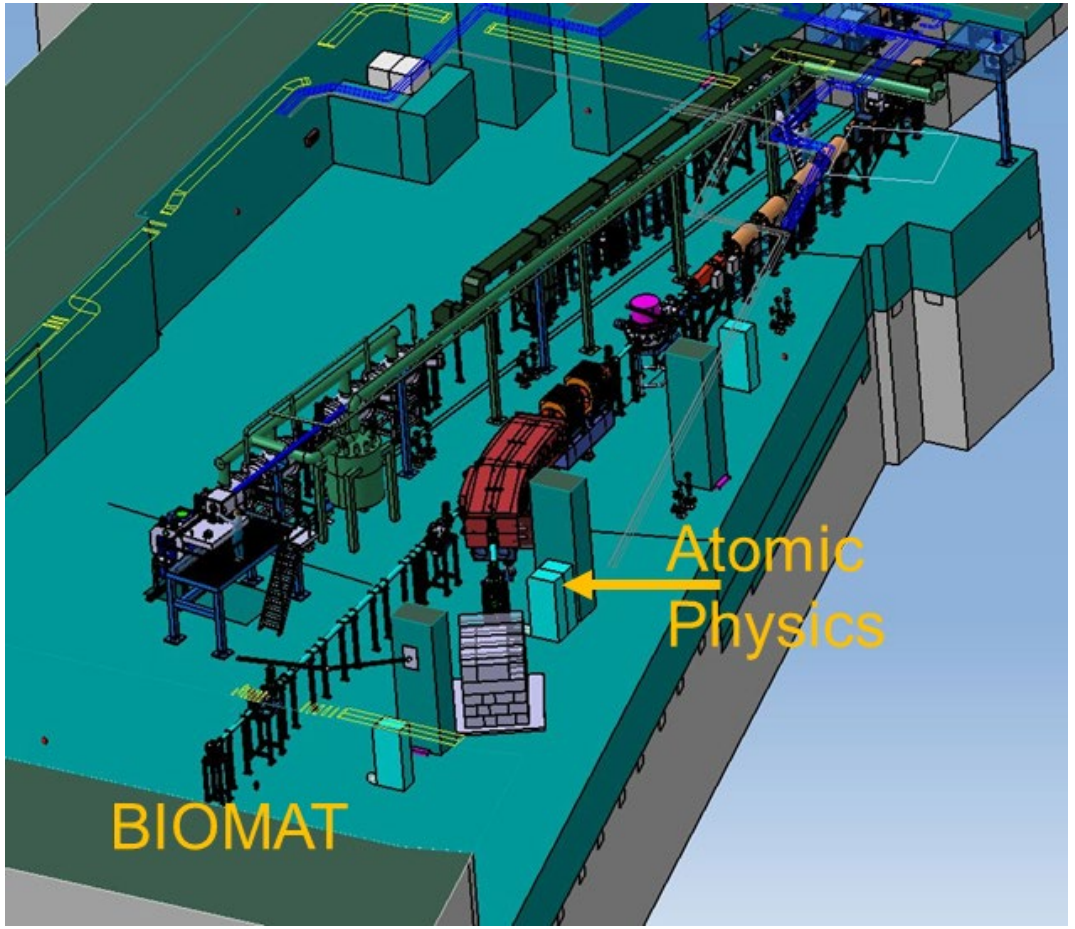
All data are still peliminary

Laser cooling at SIS100

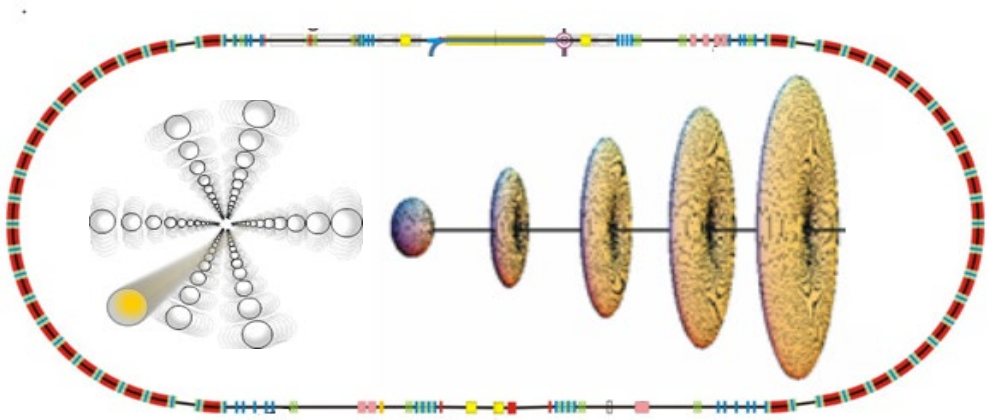
- Funding: ***the German VF funding for the construction of the laser systems was not granted in 2021.*** Therefore the setups will not be ready for installation at SIS100 in 2024 as planed.
- Mitigation: the groups will renew the application in 2024 and will continue the testing and development of the prototypes using the ESR beam in FAIR phase-zero.
- In the frame of the exiting funding, the lab infrastructure at SIS100 will continue to be procured.

SPARC at APPA cave

- SPARC Experiments in APPA cave need the SIS100 beams
- SIS18 beam could be used for commissioning of the setup
- Beam line design is completed: cost re-evaluation is in work
- Start configuration does not include the magnets
- TDR is prepared to be submitted by mid of 2022



SPARC at HESR



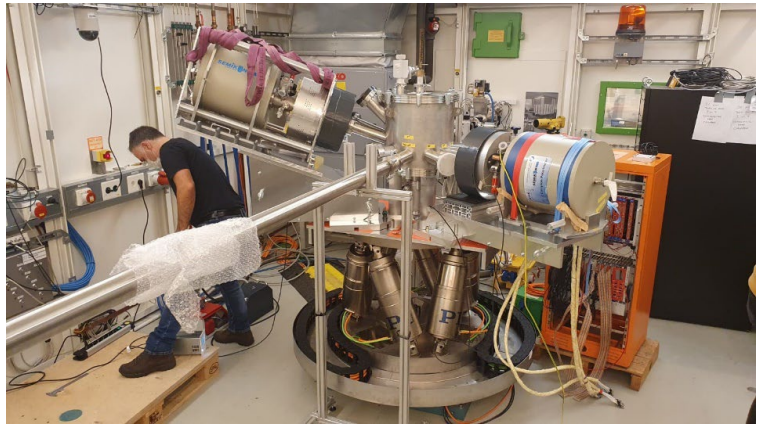
XUV laser setup was tested with beam at CRYING in FAIR Phase –zero

Lepton spectrometer: Funding: part of the German VF was diverted to CRYRING (orange

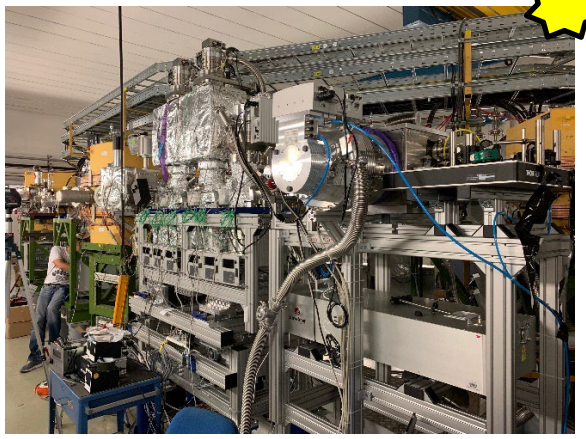
Infrastructure: only partially funded
Risk: cost increase due to delays

Calorimeter 1: Fully funded and used in first experiments at CRYRING

2D Polarimeter: Beam time at DESY, Hamburg performed in October 2020: "Polarisationtransfer in elastic scattering of high energetic photons"



XUV-laser setup: used for exepriments at CRYRING; in the future it will be installed at ESR for a FAIR phase–zero experiments.

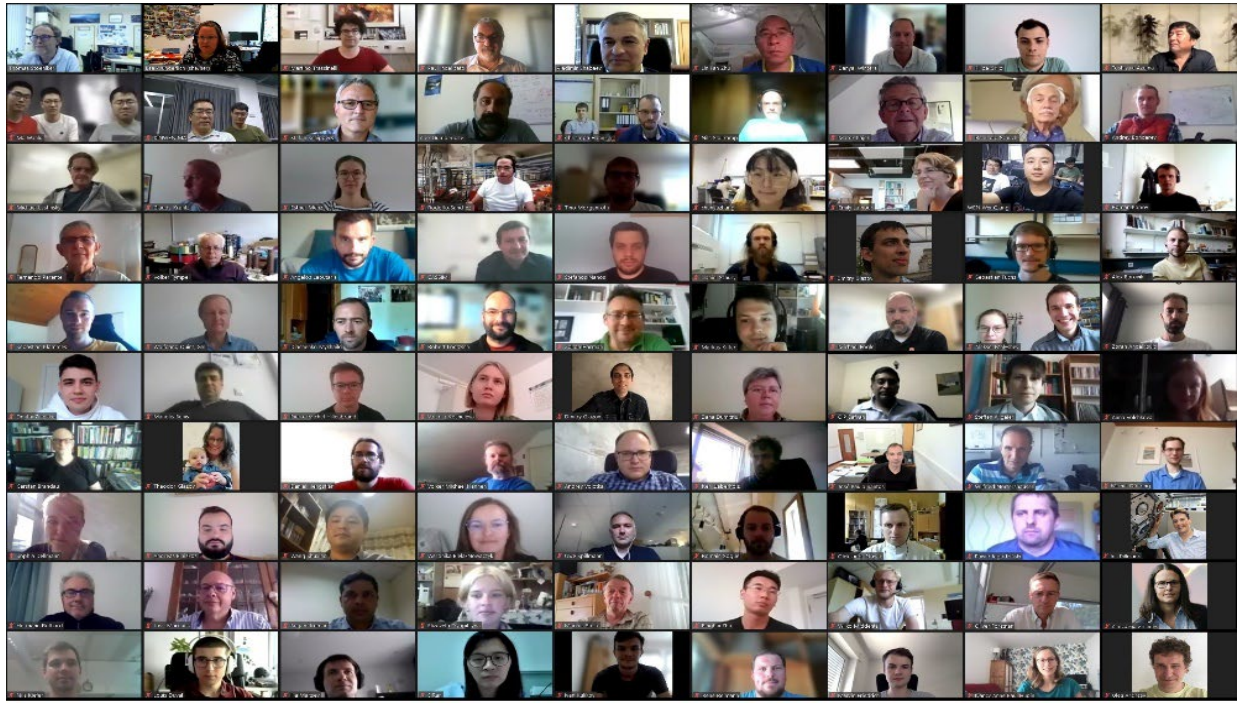


For the moment, the **SPARC activities for the HESR experiments** are reduced to the building and infrastructure planning, as long the situation of the civil construction funding is not clarified (expected for mid of 2022)

In operation at CRYRING@ESR since 2021

Risk: delay in the realization of the HESR building

More than 170 participants from 13 countries



- Atomic Collisions with Highly Charged Ions
- Critical and Super-Critical Fields
- Attosecond Science in the Realm of Extreme Fields
- Fundamental constants
- Cross-link between Atomic and Nuclear Physics
- Astrophysics with Highly Charged Ions
- Novel Instrumentation
- Future Beam times and related SPARC strategy

SPARC PhD Award 2021 for Robert Klas

Friedrich-Schiller University Jena and Helmholtz Institute Jena.

Efficiency Scaling of High Harmonic Generation using Ultrashort Fiber Lasers.

Thank You for Your Attention !

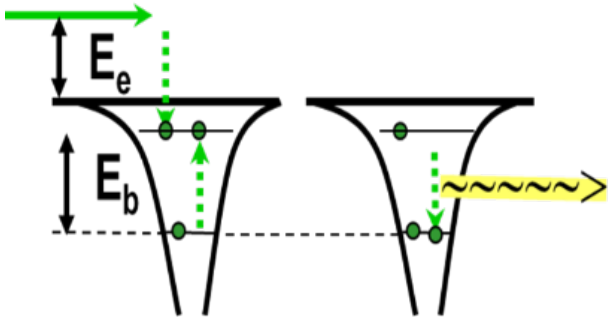
Further Activities

Storage & Trapping of Cooled Highly Charged, Heavy Ions, and Exotic Nuclei

- Detailed planning of component installation at APPA cave started;
- First version of the commissioning plan for APPA cave setup;
- Building and experiment infrastructure integration and installation;
- Beam dump design: discussion with a possible provider are ongoing;
- Coordination design for the SIS100 ion stripper.

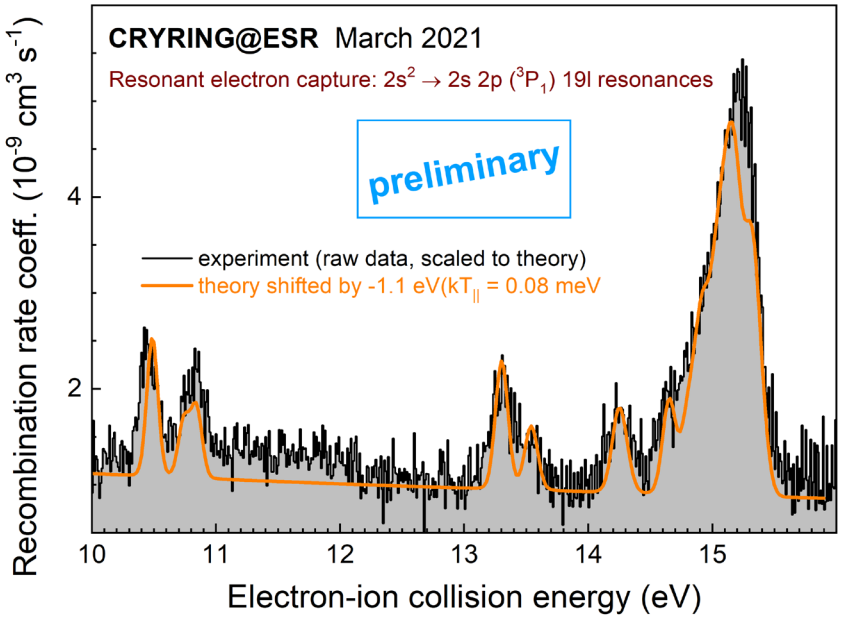
E131: Precision Collision Spectroscopy of $^{208}Pb^{78+}$

High-resolution dielectronic recombination (DR) collision spectroscopy of a heavy Be-like ion at CRYRING@ESR.



Preliminary results of the beam time:

- $5 \cdot 10^6$ Pb^{78+} ions stored in CRYRING.
- Beam lifetime in CRYRING > 30 s.
- Attainable experimental statistical uncertainty limited by CRYRING vacuum.
- High resolution of the electron beam of the CRYRING cooler demonstrated.
- Experimental precision of resonance energies constrains theory.



Stefan Schippers et al.

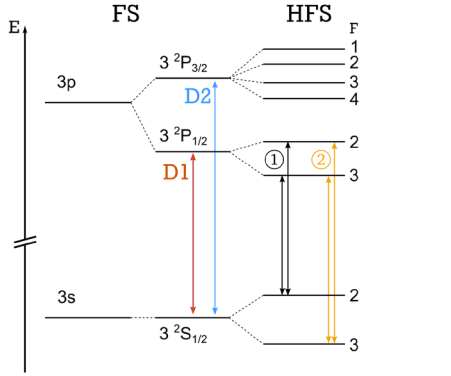
SPONSORED BY THE
Federal Ministry of Education and Research

Experiments with local injector
E148, E140, E153 (March to May 2021)

E148 Mg^{+} @ 170 keV/u

A Test of Optical Pumping

Rodolfo Sánchez Alarcón et al.

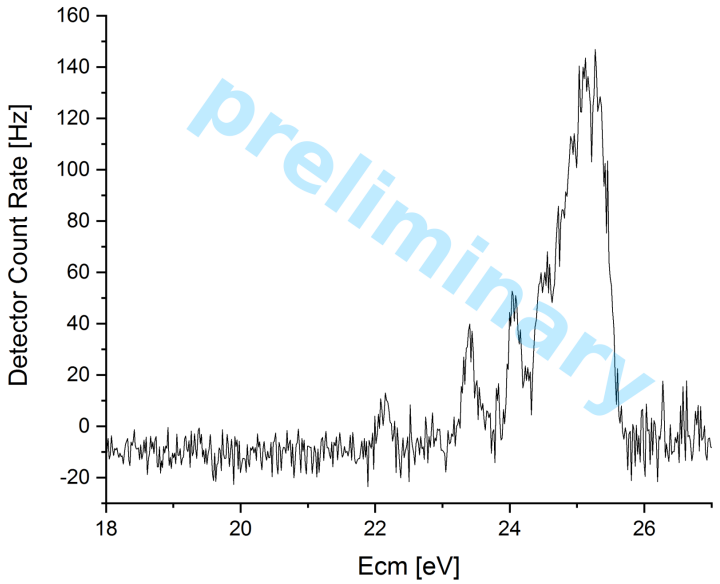


preliminary

E140 Ne^{2+} @ 980 keV/u

Absolute rate coefficients from dielectronic recombination for Astro-physically important ion species

M. Lestinsky et al.

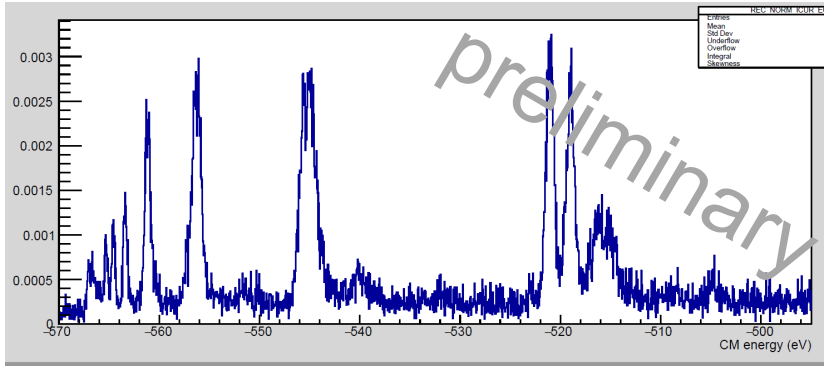


preliminary

O^{6+} @ 10 MeV/u

Multielectron recombination processes in He-like oxygen at the CRYRING@ESR electron cooler

Weronika Biela et al.



preliminary

Data analysis in progress !