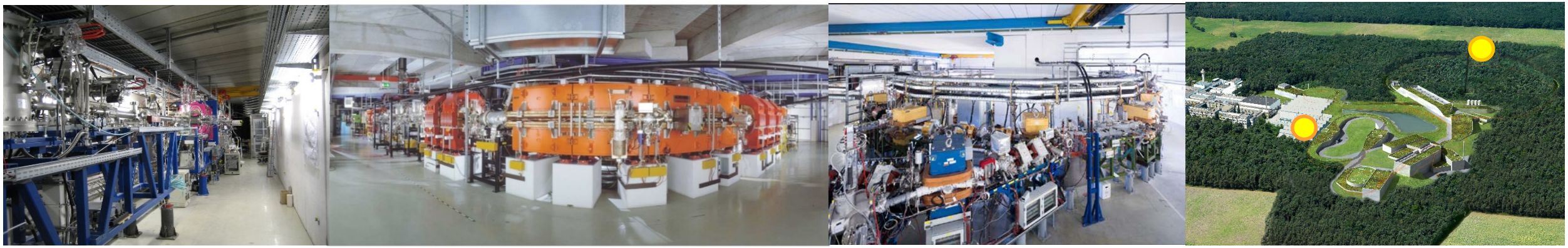
APPA Collaborations
SPARC Progress Report

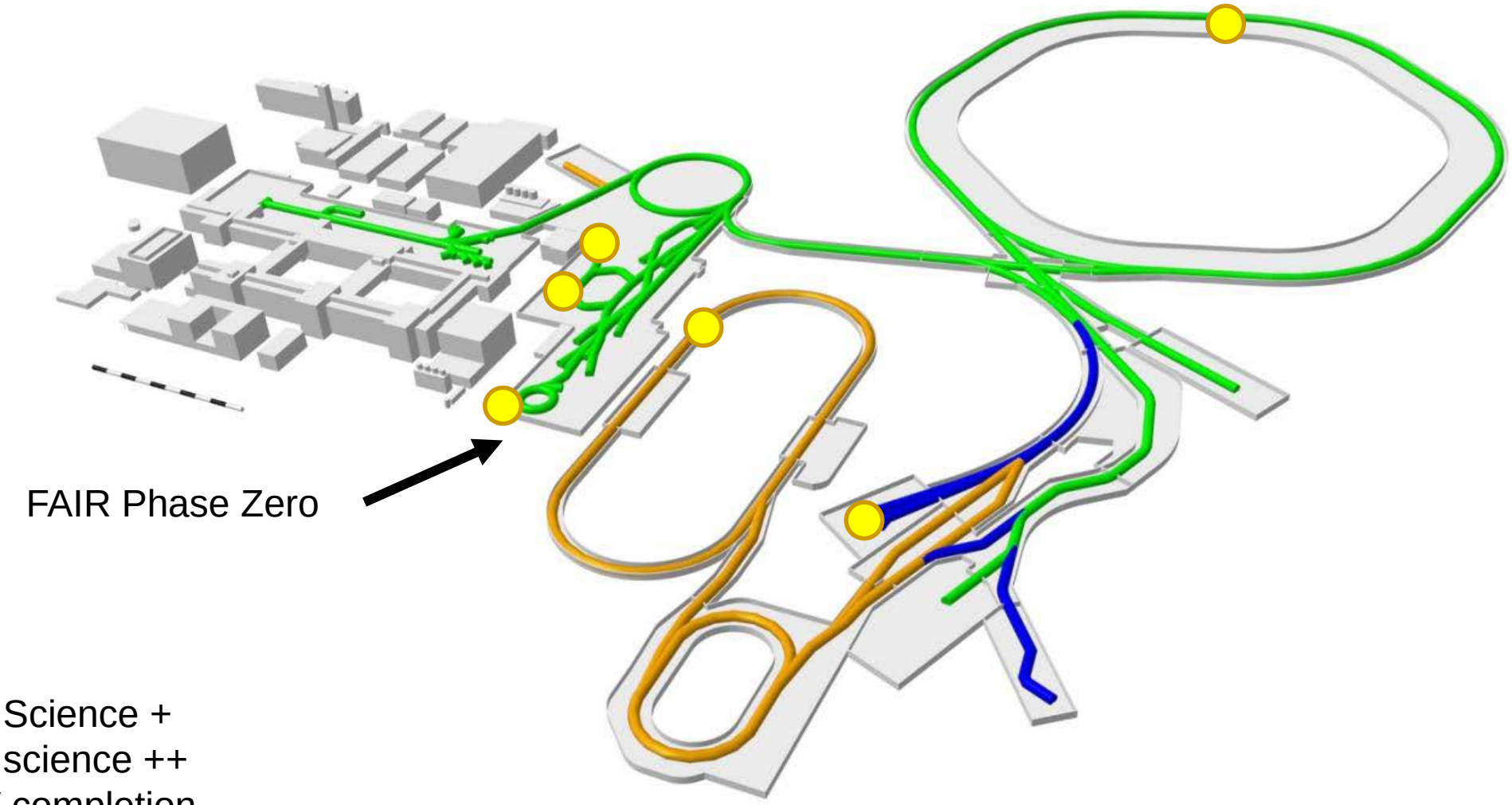
Storage & Trapping of Cooled Highly Charged, Heavy Ions, and Exotic Nuclei



RRB 12, June 05th & 06th 2023

Alexandre Gumberidze
GSI Darmstadt

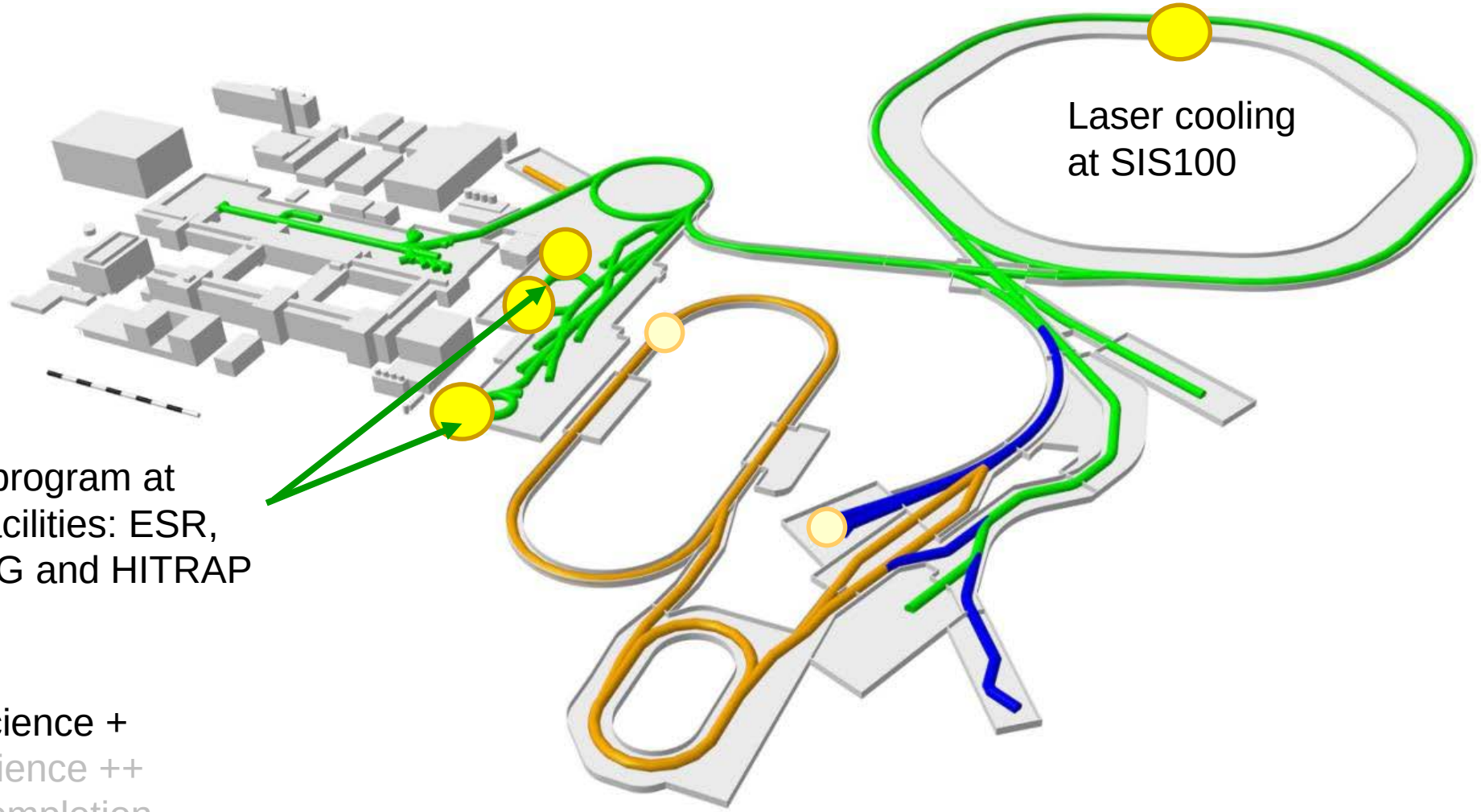
FAIR realisation: the new staging



First Science +
First science ++
MSV completion

SPARC @ FAIR

SPARC at FAIR FS



SPARC program at exiting facilities: ESR, CRYRING and HITRAP

First Science +

First science ++

MSV completion

SPARC@FAIR FS

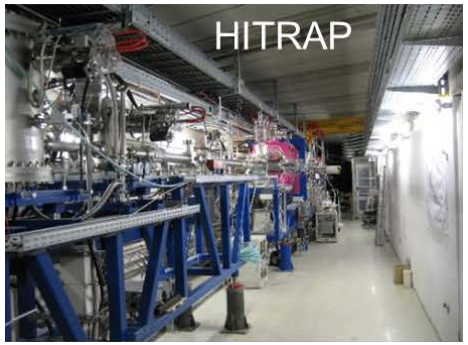
Precision Domain of FAIR: Trapping & Storage of HCI

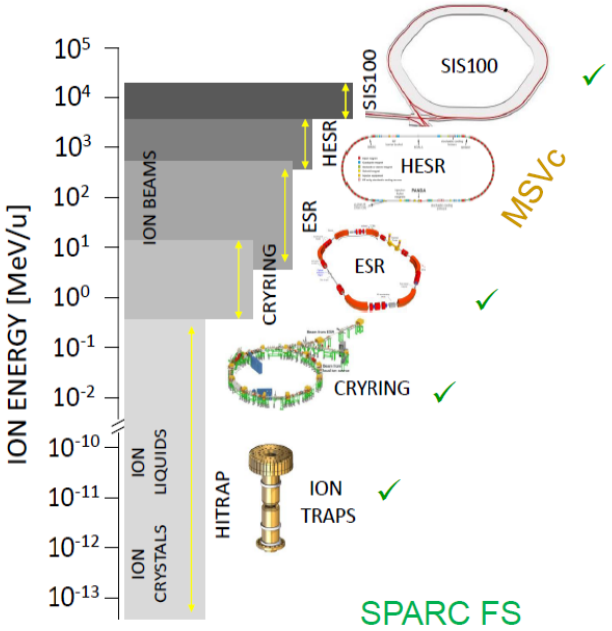
Atomic, Quantum, and Fundamental Physics

HITRAP, CRYRING@ESR, ESR: Existing Facilities of MSV

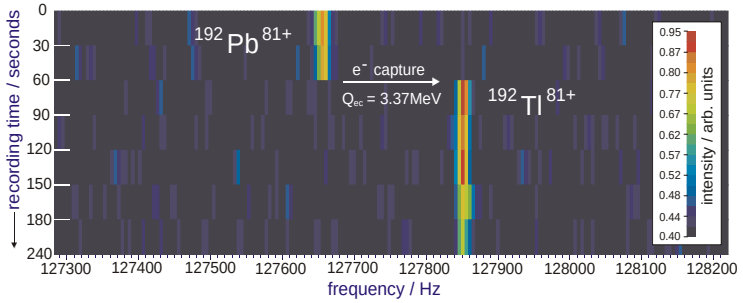
Worldwide Unique !

From rest to relativistic energies (up to 4.9 GeV/u)

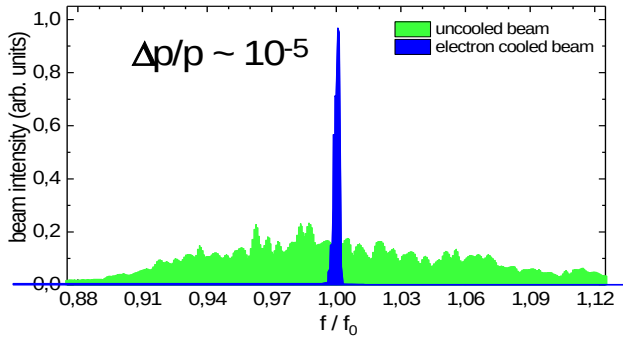




From single ions to highest intensities



Cooling is the key for precision



CRYRING@ESR: Swedish in-kind to FAIR; in operation since 2020

HITRAP: Re-commissioning has started in 2022

Precision Domain of FAIR: Trapping & Storage of HCI

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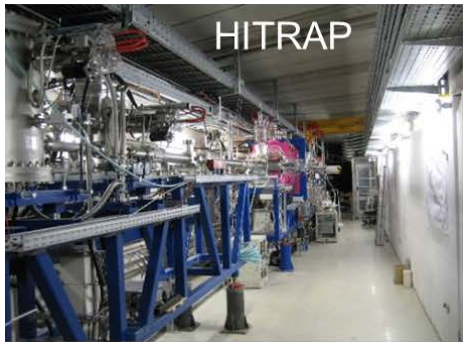
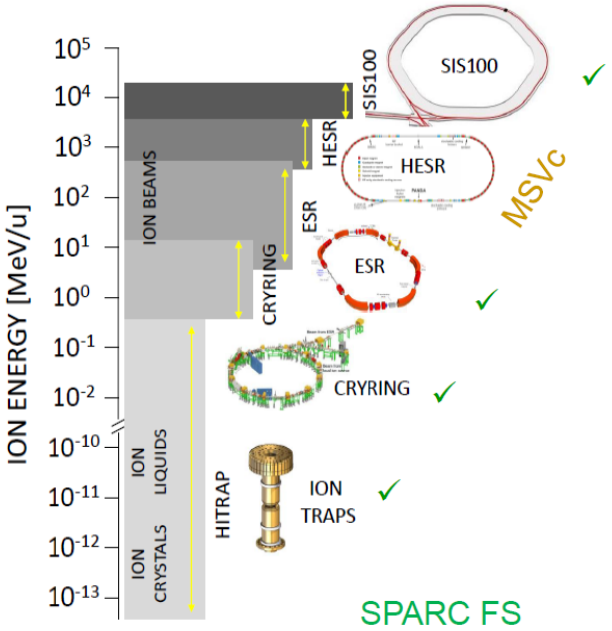
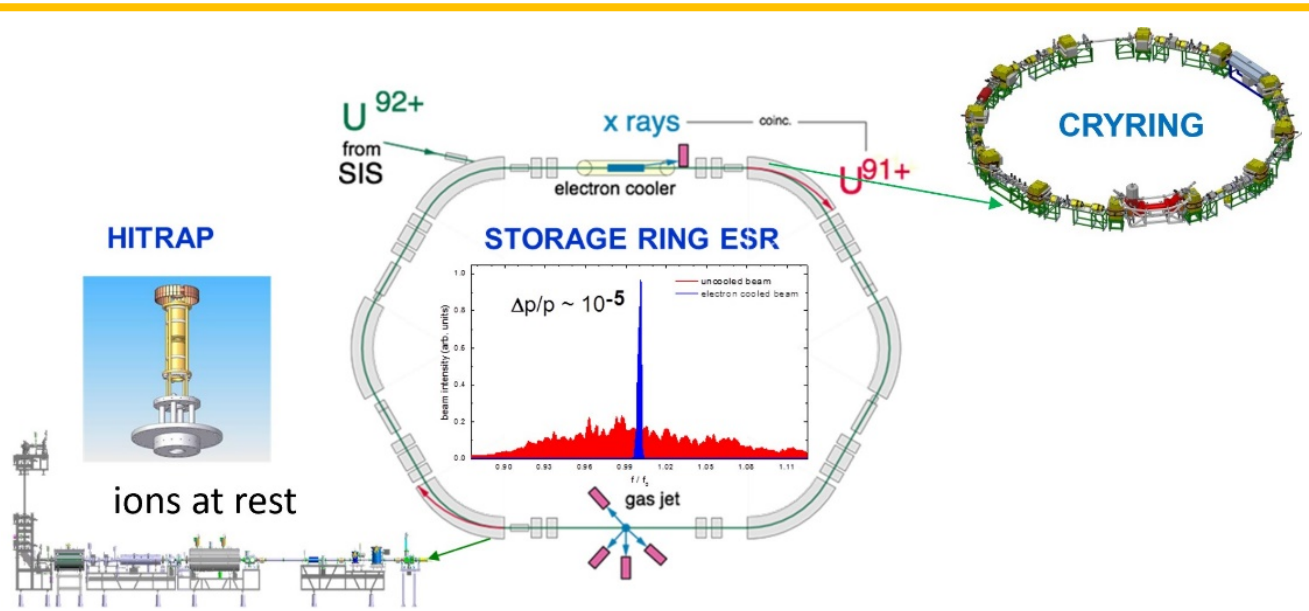
HITRAP, CRYRING@ESR, ESR: Existing Facilities of MSV

From rest to relativistic energies (up to 4.9 GeV/u)







Developments since the RRB11

Contributions and contracts:

- **Funding:**
  - the Giessen university group was awarded additional 47 k€(2005) for the WP *Ion detectors in CRYRING*, as part of the previous application for Collaborative German universities program 2021-2024 (VF).
  - The GSI group secured additional 112 k€ for ultra-high vacuum valves in CRYRING.

- **Contracts**
  - The assignments for *the High Intensity Laser* and *Laser setup at HESR* (Romanian in-kind contribution) and the *Internal Jet target for HESR* (German in-kind contribution) are on hold (not part of the present staging).

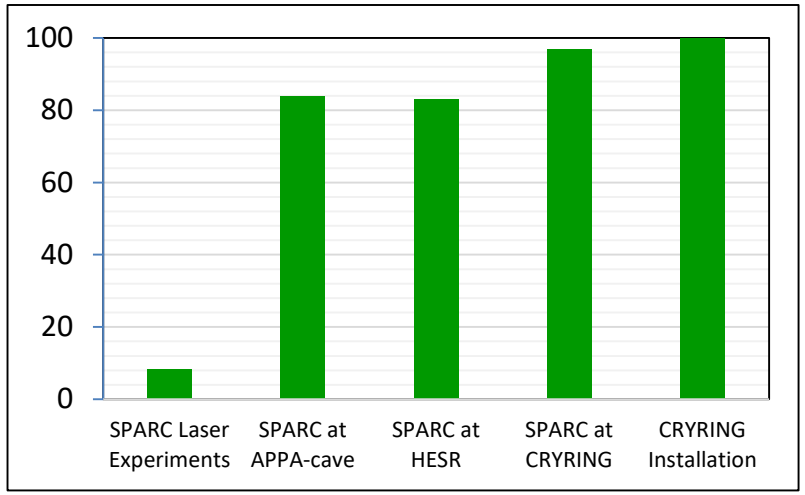
- **TDRs:**
  - The TDR for the SPARC-BIOMAT at APPA cave is on hold until a definite time line for the cave realization is available.
  - The Instrumentation_2@CRYRING (not day-one) was discarded as obsolete.

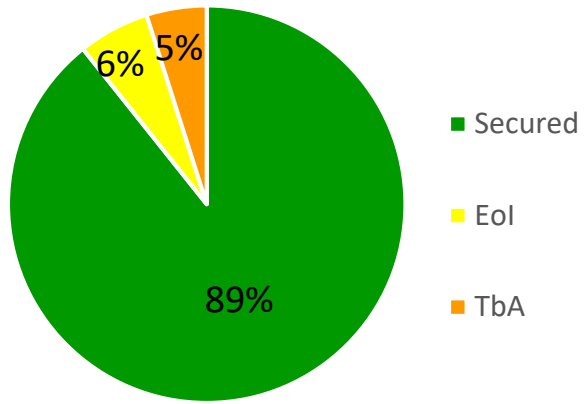
- **FAIR Final Acceptance:**
  - Jagellonian University, Krakow, transferred its in-kind for the CRYRING (*Vacuum system upgrade*) to FAIR GmbH. This WP is closed.
  - The transfer of the *CRYRING Installation* (German in-kind) is in the signing process.
  - The Swedish in-kinds (*Internal Jet target at CRYRING* and *SPECTRAP magnet*) are in preparation.

Funding SPARC experiments Day-one

RRB12 Day-one experiment funding APPA-SPARC						
Experiment	PSP	Total cost [k€, 2005]	Funding [k€, 2005]			Secured [%]
			Secured	EoI	TbA	
SPARC Laser Experiments at SIS100	1.3.1.1	466	39	427	0	8,37
SPARC at APPA-cave	1.3.1.2	931	780,86	0	150	83,87
SPARC at HESR	1.3.1.3	2726,96	2264,46	104,5	358	83,04
SPARC at CRYRING	1.3.1.5	2408,00	2336,50	71,5	0	97,03
CRYRING Installation	1.3.4.2	3801,36	3801,36	0	0	100,00
Grand Total		**10333,32**	**9222,18**	**603**	**508**	**89,25**

- additional 689 k€ 8 2005) are considered secured through the German universities. **Total secured amount: 9911,18 k€**
- the laser setup at SIS100 has now the highest priority, being in Early Science phase.



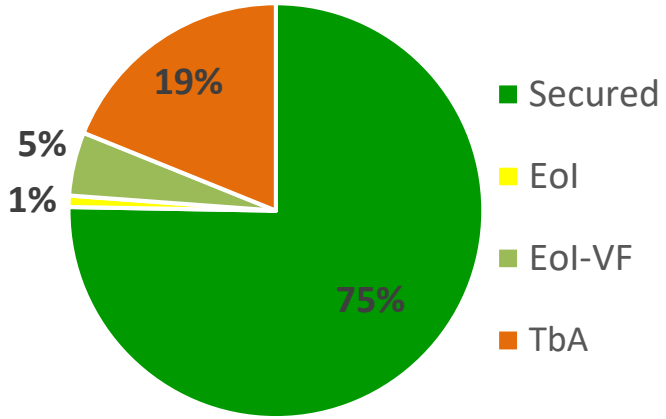


- In the present FAIR staging, SPARC experiments will be carried out at CRYRING, ESR, HITRAP and SIS100.
- CRYRING Day-one is 98% secured. The rest is secured through the German VF program for the universities and Swedish contribution.
- Existing SPARC components planed for FS++ and MSVc will be used at the existing facilities.

Day-one costs: 10,33 M€ (secured 96% with German VF)

Funding SPARC experiments MSV

RRB12 Status experiment funding APPA-SPARC				
Experiment/Project	Prices, K Euro			
	2005 prices			
	Secured amount *	EoI	To be assigned	Total
SPARC Laser Experiments at SIS100	39,00	427	671,62	1137,62
SPARC at APPA cave	780,86	0	360	1140,86
SPARC at HESR	2414,50	191,5	1040	3646
SPARC at CRYRING	3433,50	193,5	554	4181
CRYRING	3801,36	0	0	3801,36
Grand Total	**10469,22**	**812**	**2625,62**	**13906,84**

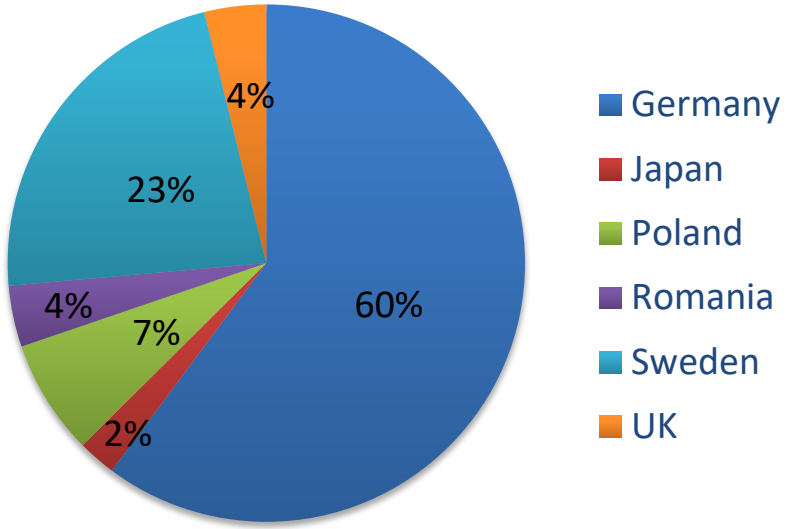


Full MSV cost: 13,9 M€

Total secured funding: 11,158 k€ (80%)

Country Funding for SPARC experiments

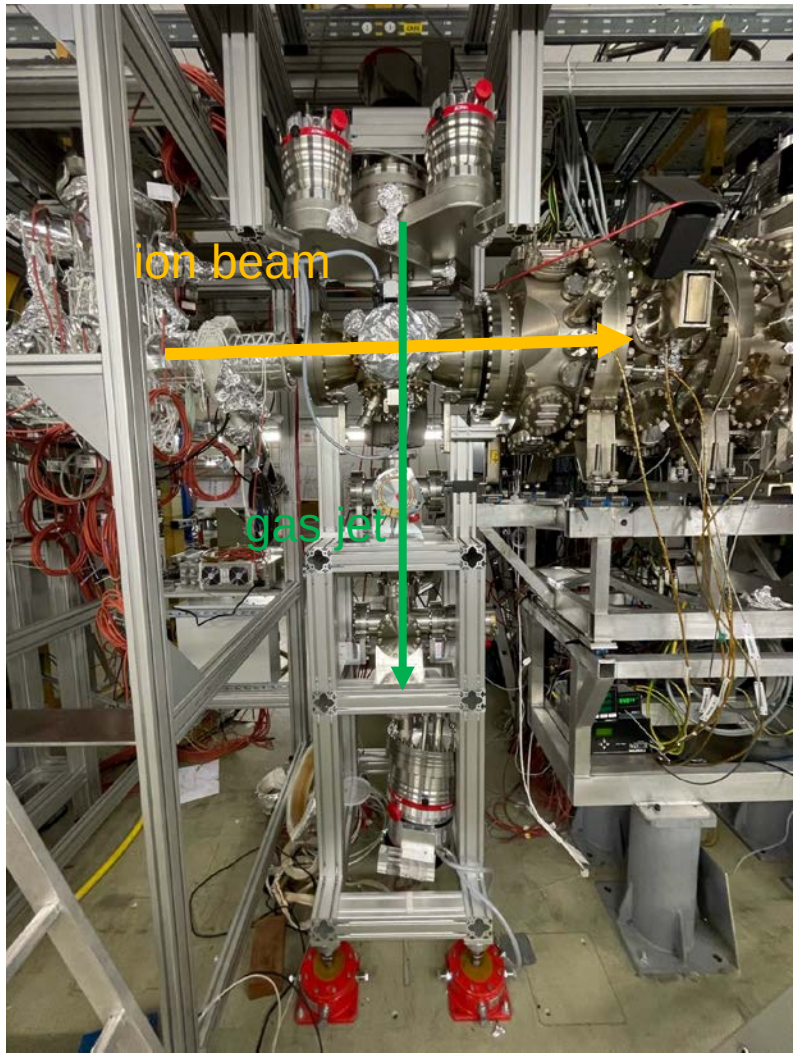
Funding by country : Secured / EoI [k€, 2005 prices]												
SPARC	Germany		Japan		Poland		Romania		Sweden		UK	
	5990	812	263		800		425		2500		492	



Secured: 11,158 M€

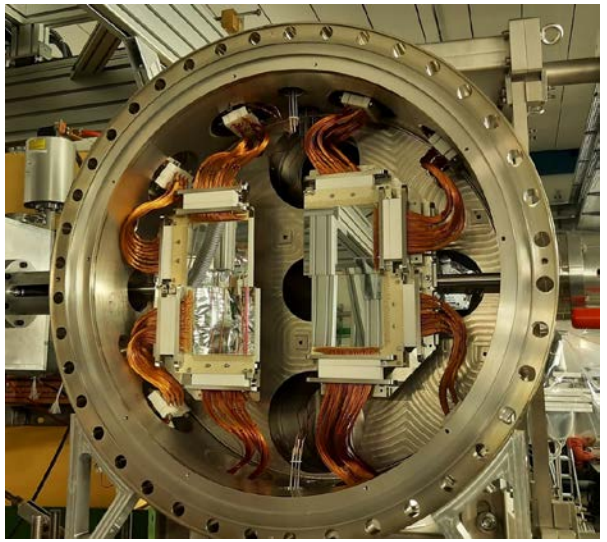
CRYRING@ESR: Internal Jet Target

- Commissioning with beam was done in spring 2022.
- A beam test performed with the internal jet target in May 2022 showed that the target is fully operational.
- Further optimization work, with different gases is requested (He, H_2).
- Gas distribution system for H_2 will be finished in 2023.
- An upgrade of the pumping system for the target sump is in work.
- The target control system must be completed and tested before the beam time in 2024.
- To be able to accommodate new setups close to the target, some rearrangement /reinstallation work is ongoing.



CRYRING@ESR: CARME

- After successful commissioning of CARME in 2022, some maintenance work is needed.
- For servicing CARME, a dolly was built and installed at CRYRING.
- Installation of all the DSSSD detectors (in 2022 only one out of four was installed and was tested with beam).
- Backing (low temperature) system: testing after repair and reinstallation.
- Preparation for a possible beam time in November-December 2023 with local source ^{16}O-beam @1MeV/u on He target (approved proposal).



CRYRING@ESR: Electron Target

- The transversal electron target is a major setup for CRYRING.
- The e-target interaction chamber installed in ring and vacuum tested in 2022.
- All target components are available, and were tested off-line.
- Components transported to GSI in March 2023.

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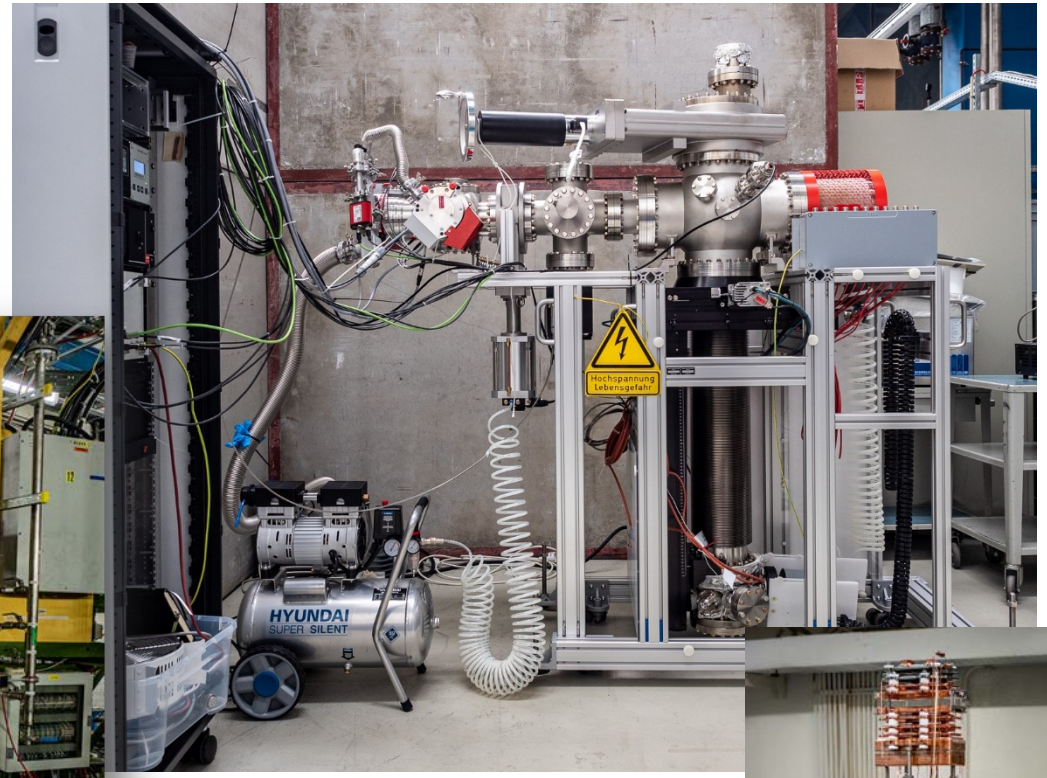
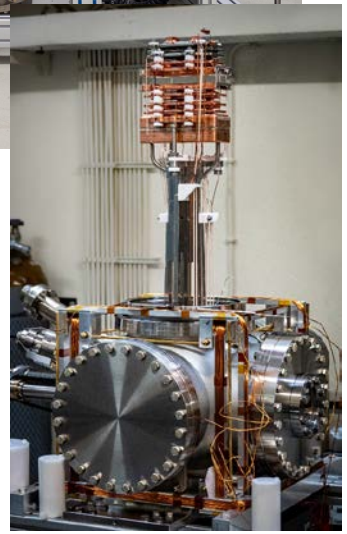
- Conditioning of cathode ongoing: the gun already delivers 35mA electron current at 140 V extraction voltage.
- Gun installation into CRYRING YR09 scheduled for beginning of July 2023.
- The gun control system is presently being programmed.
- Commissioning with beam and first experiments in CRYRING to start in 2024.

Off-ring cathode conditioning at GSI



Int,. chamber in ring



Bundesministerium für Bildung und Forschung

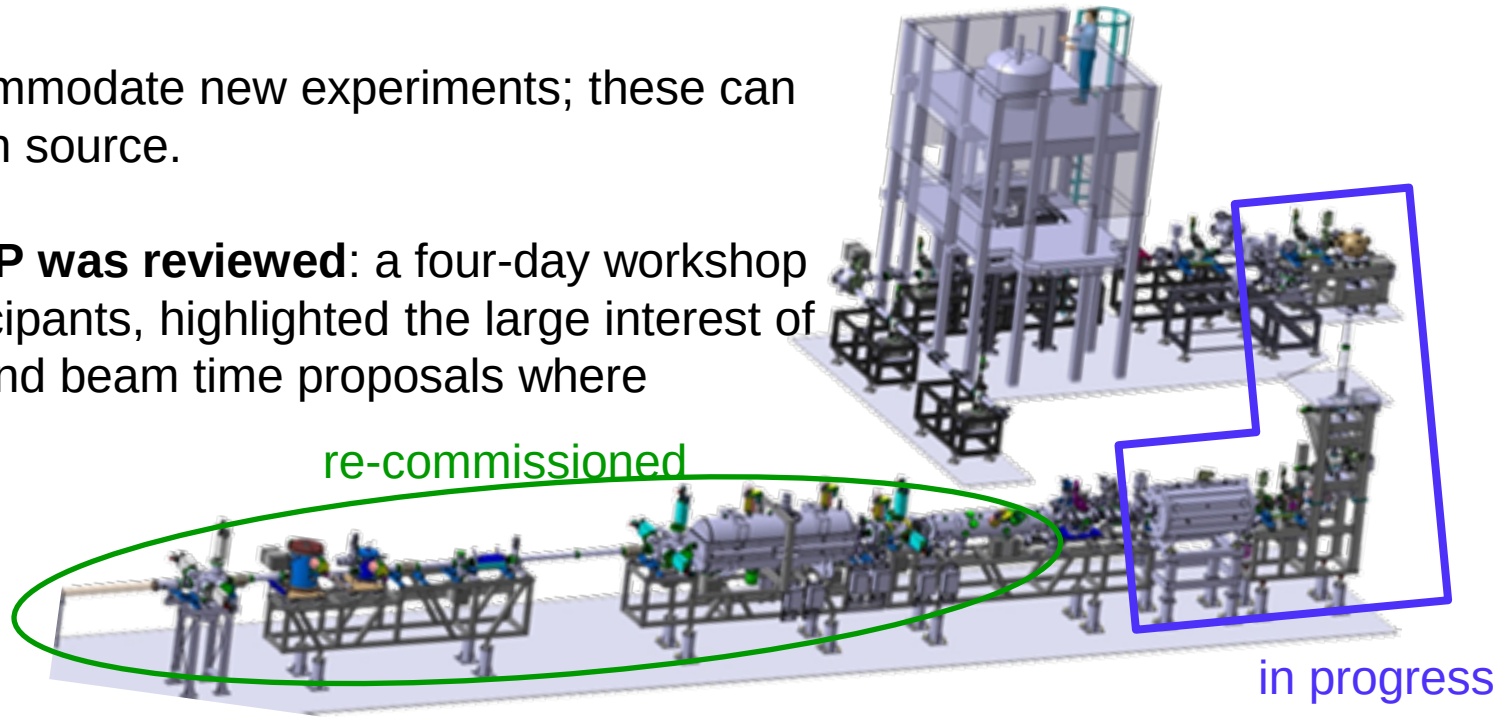
HITRAP re-commissioning

- May 2022: start of the **HITRAP re-commissioning** with the new FAIR control system. The deceleration part up to the cooling trap was successfully put into operation.

- The full scope commissioning includes the cooler trap and the low-energy beam transport line. In work! **Completion time strongly depends on the available beam time.**

- **The experiment platform is ready** to accommodate new experiments; these can be tested off-line with beams from a local ion source.

- In parallel **the physics program for HITRAP was reviewed**: a four-day workshop held in July 2022, attended by over 60 participants, highlighted the large interest of the community for this facility. New setups and beam time proposals where presented.



HITRAP capability today

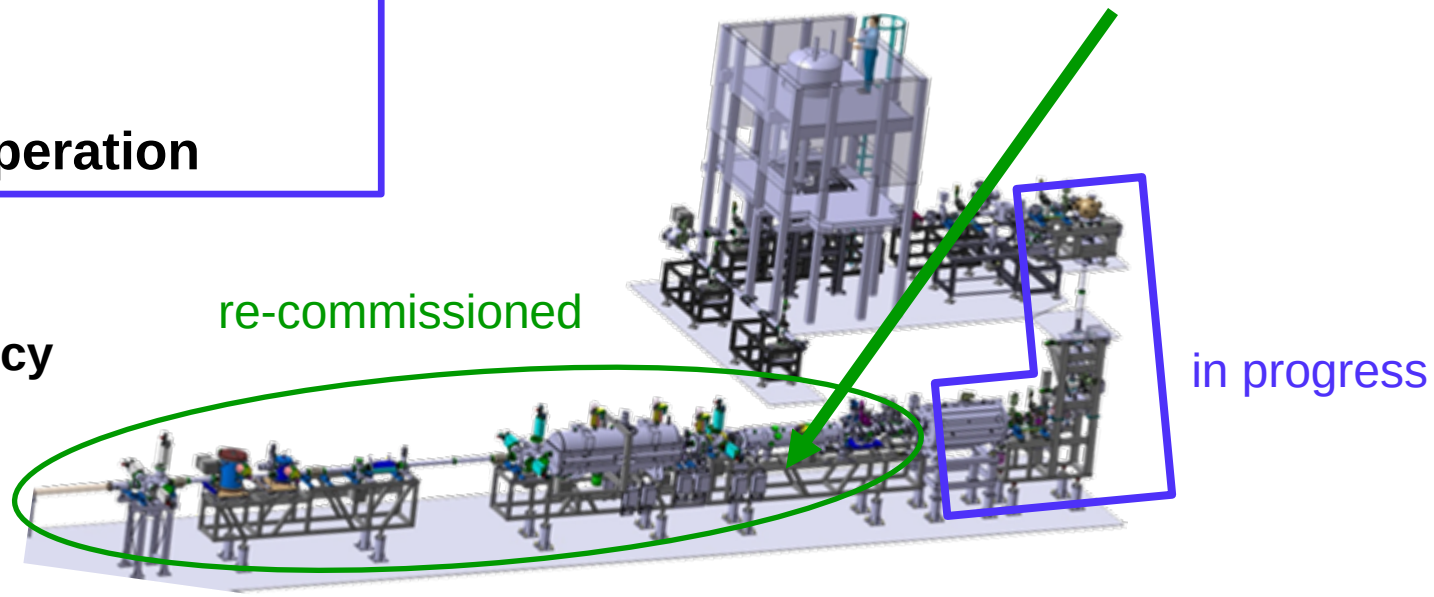
Medium-heavy highly charged ions from EBIT				
charge state	any up to ~ 44+		ion type	gasses, some metals
energy	4 keV/q, adjustable		rep. rate	up to 10 Hz
dispersion	+/- 1 eV/q		focus size	5 mm, adjustable
no. ions	10^4 – 10^5		multi user	two simultaneously

Heavy highly charged ions	
charge state	any up to 92+
energy	5-7 keV/u
dispersion	30% (+/- 1keV/u)
no. ions	1 … 10^4 (estim.)
focus size	< 5 mm
rep. rate	30 sec.
setup time	3-7 days

!!! **Significant resources are still needed:**
- **beam time**
- **man power**

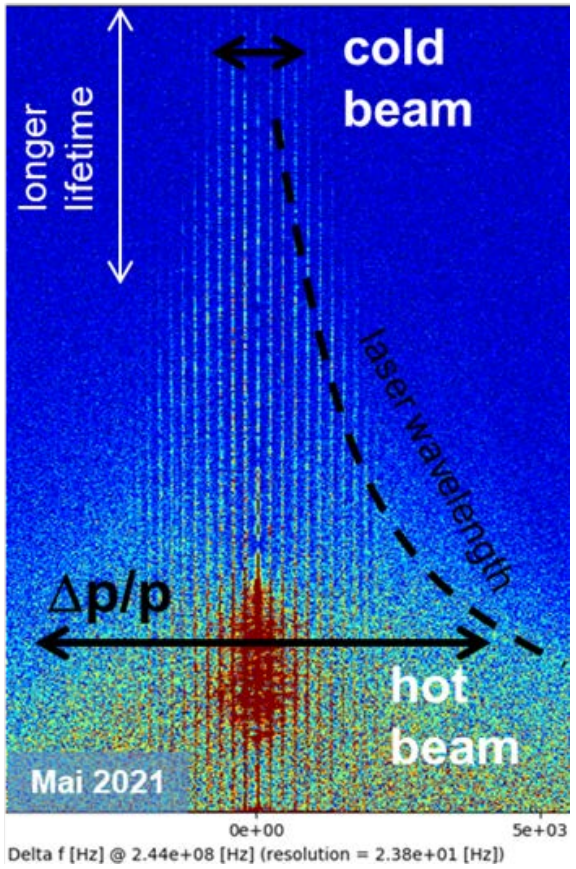
for commissioning and normal operation

New setup at HITRAP: Laser lab for quantum logic spectroscopy for frequency metrology for heavy and simple ions

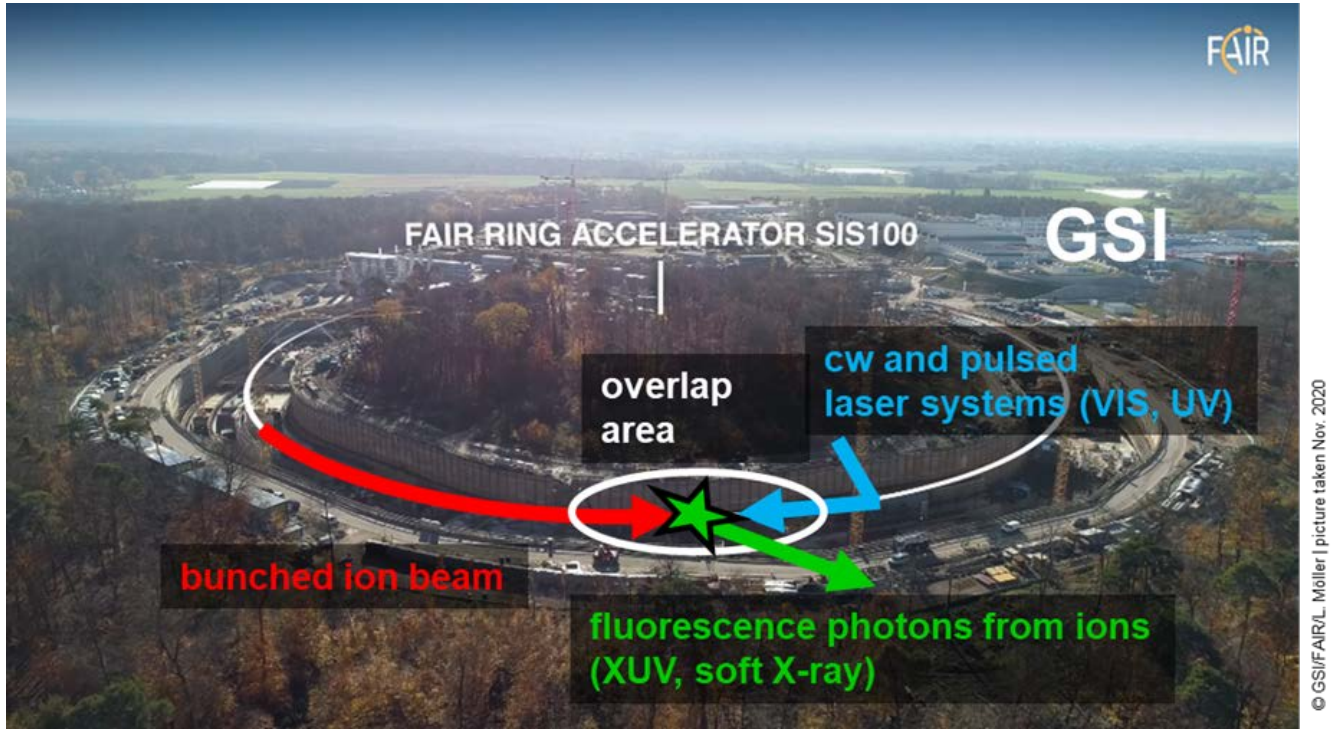


HGF Young Investigator Group 2023-2028, P. Micke, HI Jena

Laser cooling and spectroscopy at SIS100



World-wide unique!



- Laser-cooled relativistic heavy-ion beams (Z = 10 - 60) with γ ~ 12
- Only cooling method at SIS100 energies (Δp/p down to 10^{-7} in a few sec.)
- Extraction of very cold and very short ultra-relativistic ion bunches

– A common project with the SIS100 team
– Part of the experiment infrastructure is available.
– **The laser systems and the detection system will be provided by partners at Darmstadt, Dresden and Münster universities; funding expected via VF, starting with 2024.**

FAIR Phase-0 2024-2025: beam time applications 2022

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 $^{15}O(\alpha,\alpha)^{15}O$ 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-HTA	**A**	35,5
G-22-00134	Precision x-ray spectroscopy of helium-like uranium using metallic magnetic calorimeter detectors	ESR-CRYRING	**A**	32,0

A grade:
10 experiments,
425 shifts

FAIR Phase-0 2024-2025: beam time applications 2022

ID	SPARC research progam limited by availability of beamtime			
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

A- grade:
16 experiments,
592 shifts

Summary and Outlook

- **Focus on FAIR Phase-0 activities at the existing MSV facilities;** ESR, CRYRING@ESR, and HITRAP (Early Science, SPARC low-energy physics program)

- **Sufficient beam time in FAIR Phase-0 as well as third party funding (e.g. BMBF Verbundforschung)** will be essential to keep the scientific community alive. Huge interest of community reflected in numerous submitted proposals at the last G-PAC.

- **Laser cooling and spectroscopy of relativistic heavy ion beams at SIS100**
  German VF funding is of utmost importance.
  (First Science)

- **In the longer term, the APPA cave (First Science++) and HESR (full MSV)**
  (SPARC high-energy physics program)

- The SPARC collaboration will investigate the possibilities to include the members working on setups for FS++ and MSVc facilities in the present program (FAIR Phase-0, ES, FS). The success of this mitigation depends on the financial support these colleagues will get.