

A wireframe model of a particle accelerator complex, including a large circular ring and several smaller sections, is superimposed on a vibrant, multi-colored nebula. The background is filled with numerous bright blue and white stars, creating a deep space atmosphere.

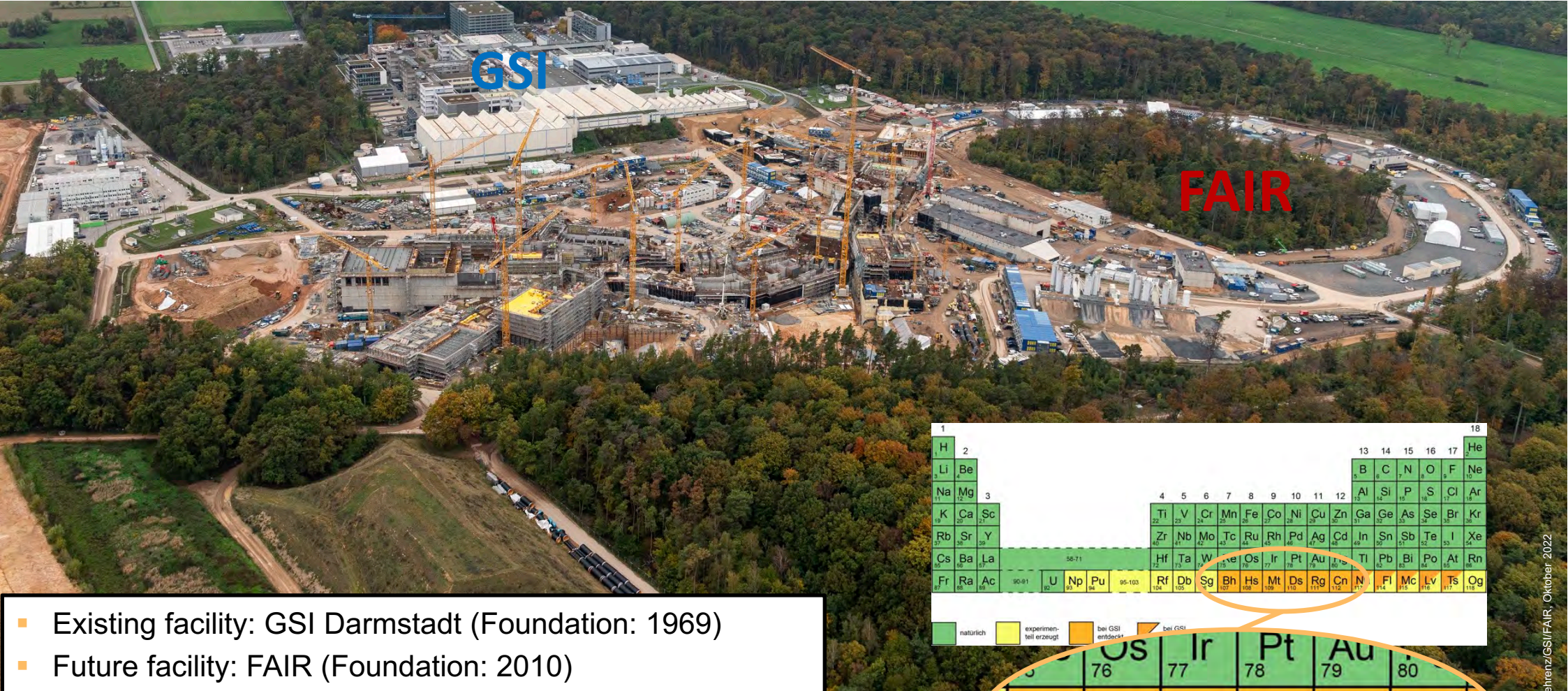
# Status and Plans at GSI/FAIR

Hadron Spectroscopy with Strangeness,  
Glasgow

Inti Lehmann, GSI/FAIR  
3 April 2024



# GSI GmbH – Helmholtzzentrum für Schwerionenforschung FAIR GmbH – Facility for Antiproton and Ion Research



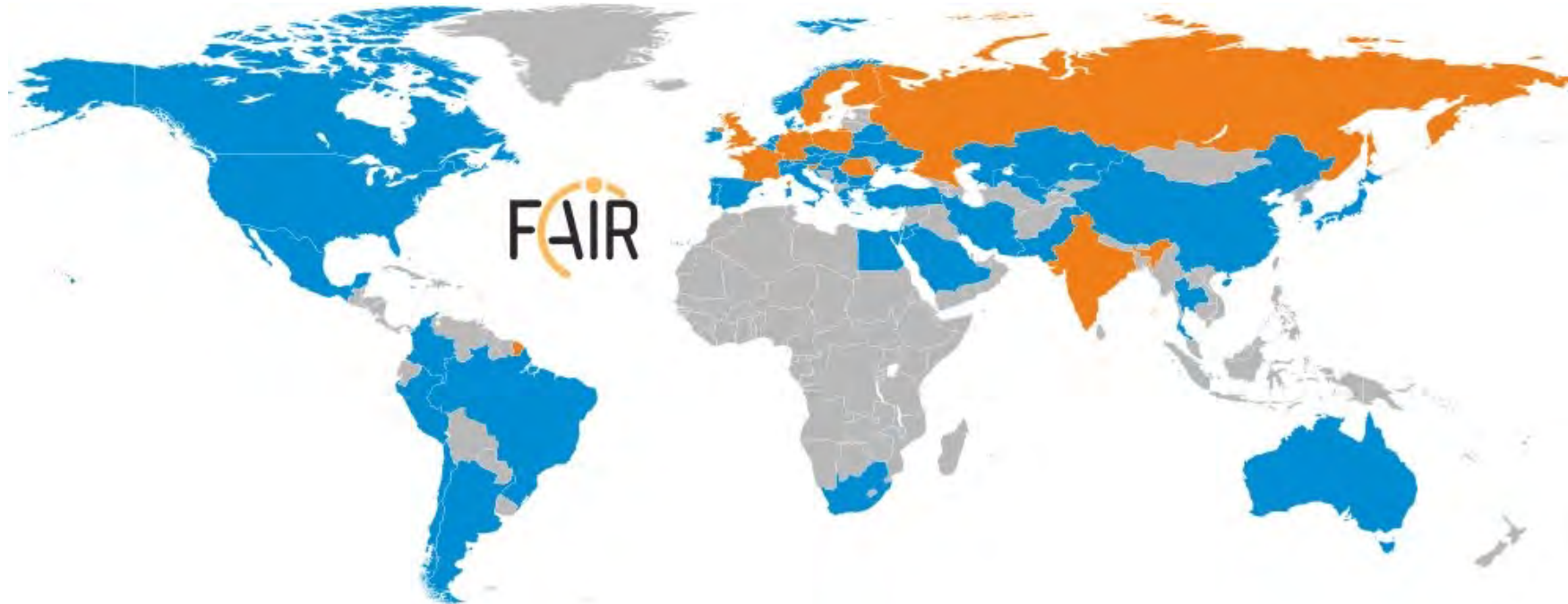
1																	18																						
1	2											13	14	15	16	17	18																						
H	He											B	C	N	O	F	Ne																						
3	4											5	6	7	8	9	10																						
Li	Be											Al	Si	P	S	Cl	Ar																						
11	12	3											13	14	15	16	17	18																					
Na	Mg	Sc											Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr												
19	20	21											22	23	24	25	26	27	28	29	30	31	32	33	34	35	36												
K	Ca	Sc											Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe												
37	38	39											40	41	42	43	44	45	46	47	48	49	50	51	52	53	54												
Rb	Sr	Y											56	57	58-71										72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs	Ba	La											Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn												
55	56	57											72	73	74	75	76	77	78	79	80	81	82	83	84	85	86												
Fr	Ra	Ac	90-103										104	105	106	107	108	109	110	111	112	113	114	115	116	117	118												
87	88	89	90-103										104	105	106	107	108	109	110	111	112	113	114	115	116	117	118												
Fr	Ra	Ac	90-103										Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	N	Fl	Mc	Lv	Ts	Og												

	Os	Ir	Pt	Au	
	76	77	78	79	80
	Bh	Hs	Mt	Ds	Rg
	107	108	109	110	111
	Bohrium	Hassium	Meitnerium	Darmstadtium	Roentgenium
					Copernicium

- Existing facility: GSI Darmstadt (Foundation: 1969)
- Future facility: FAIR (Foundation: 2010)
- Landmark in the European research roadmap (ESFRI)
- Employees on location: approx. 1580



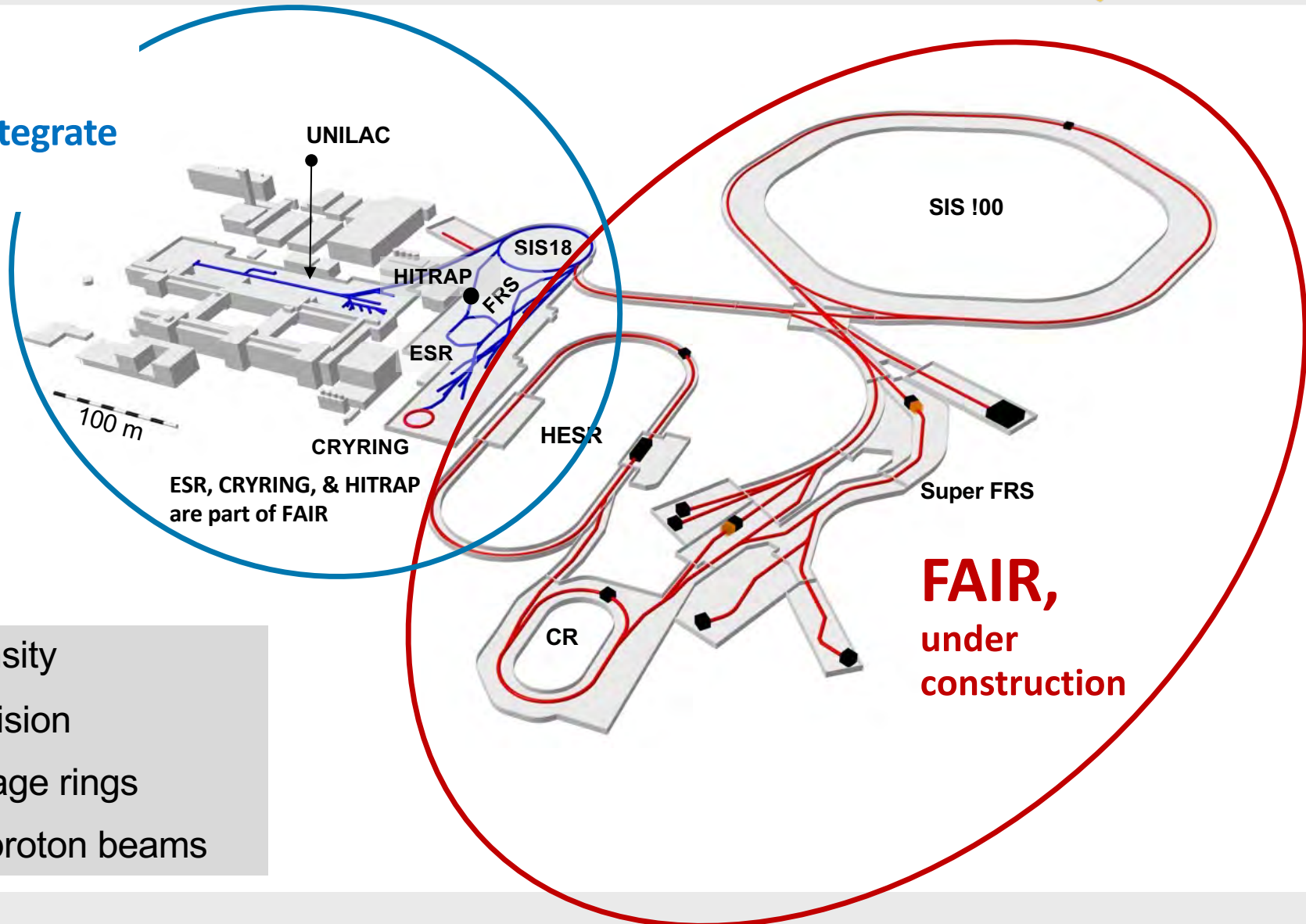
# FAIR: a World-wide project



- FAIR governed by international convention
  - 9 shareholders from:
  - + 1 associated partner:
  - + 1 aspirant partner:
  - Over 3000 Scientists and Engineers from all over the world
- More than 200 institutions from 53 countries are involved with their scientists (orange + blue)

# GSI and FAIR – The Facility

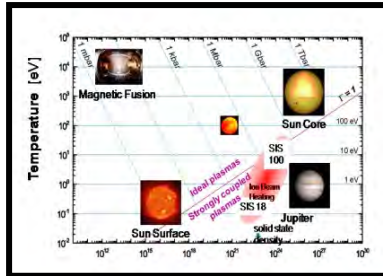
**GSI, existing**  
(upgraded to integrate with FAIR)



- Intensity
- Precision
- Storage rings
- Antiproton beams

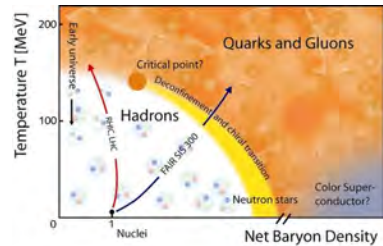
**FAIR,**  
under  
construction

# The FAIR science: four pillars



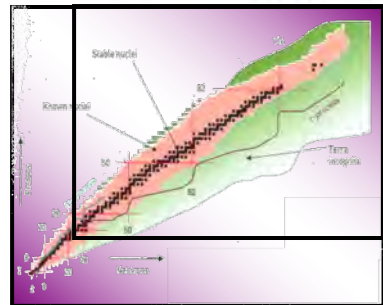
Atomic physics, biophysics,  
plasma physics, material research

**APPA**



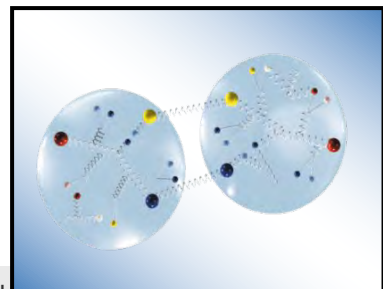
Nuclear- and quark-matter

**CBM**



Nuclear structure and  
nuclear astrophysics

**NUSTAR**



Hadron structure and dynamics

**PANDA**







SIS100

CRYO 2

CBM

S-FRS

NÜSTAR HEB

Movie and more pics via [www.gsi.de](http://www.gsi.de)

2023



# FAIR SIS100 accelerator tunnel





# FAIR SIS 100 supply tunnel

April 2023





# FAIR Area South







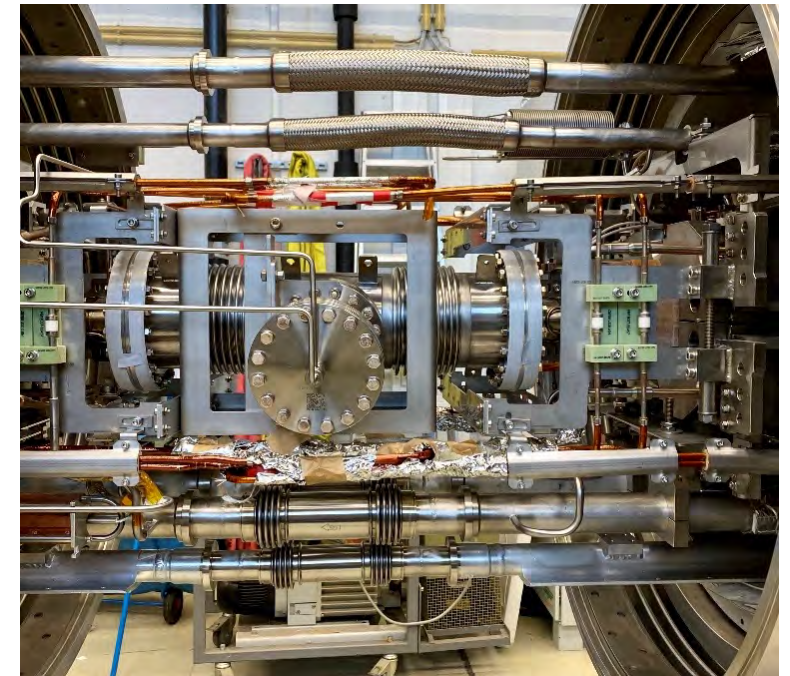
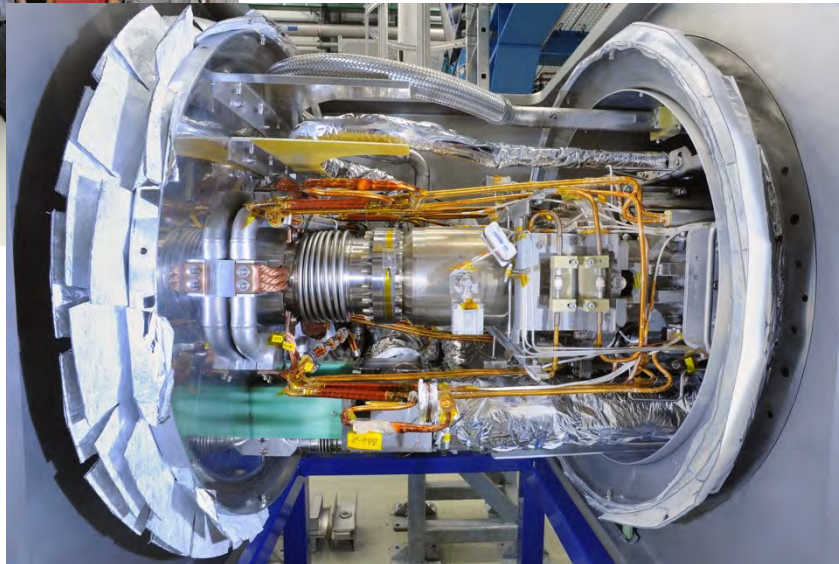
# FAIR CBM Cave



Q2-Q3/2023

String Test SIS100 - installation preparation

Successful completion of welding operations on interconnections  
and pressure test.





# FAIR Highlights- Storage and Logistics

*Completed and delivered high-tech components for accelerator and experiments*



SIS100 Dipoles complete



He-By-pass lines from Poland



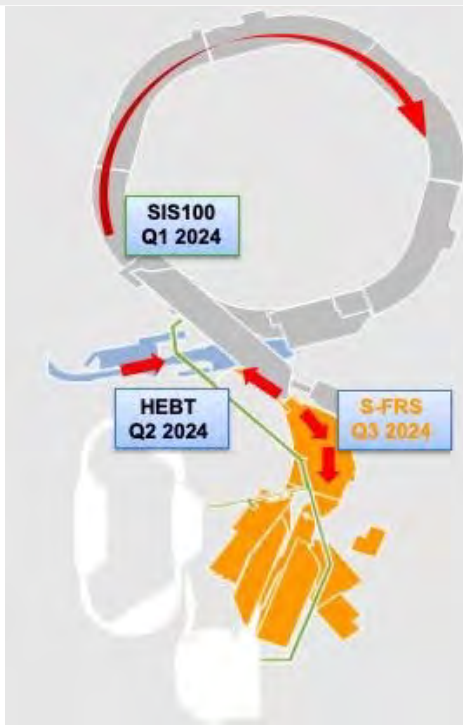
Racks from India

Storage area Weiterstadt: approx. 9.900 m<sup>2</sup>  
4.195 objects (Components, assemblies, boxes)

50% of SIS100 components stored  
90% of HESR components stored

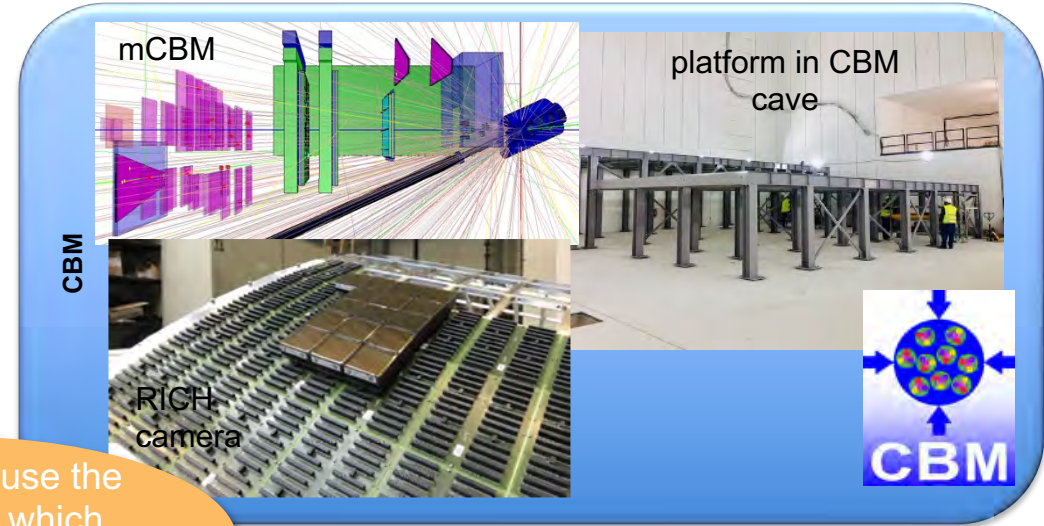
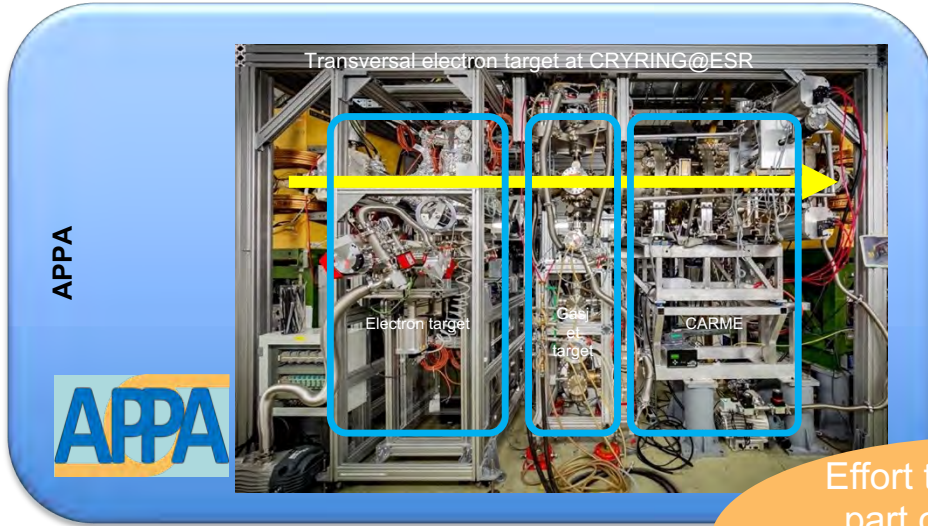


# Installation of components has started

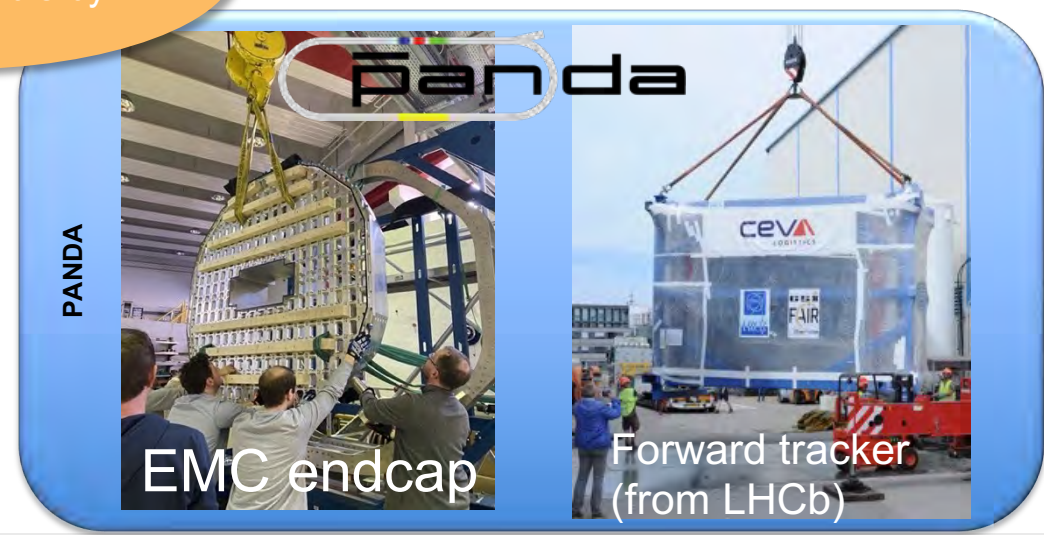




# Experimental highlights



Effort to best use the part of FAIR which will be available by 2028

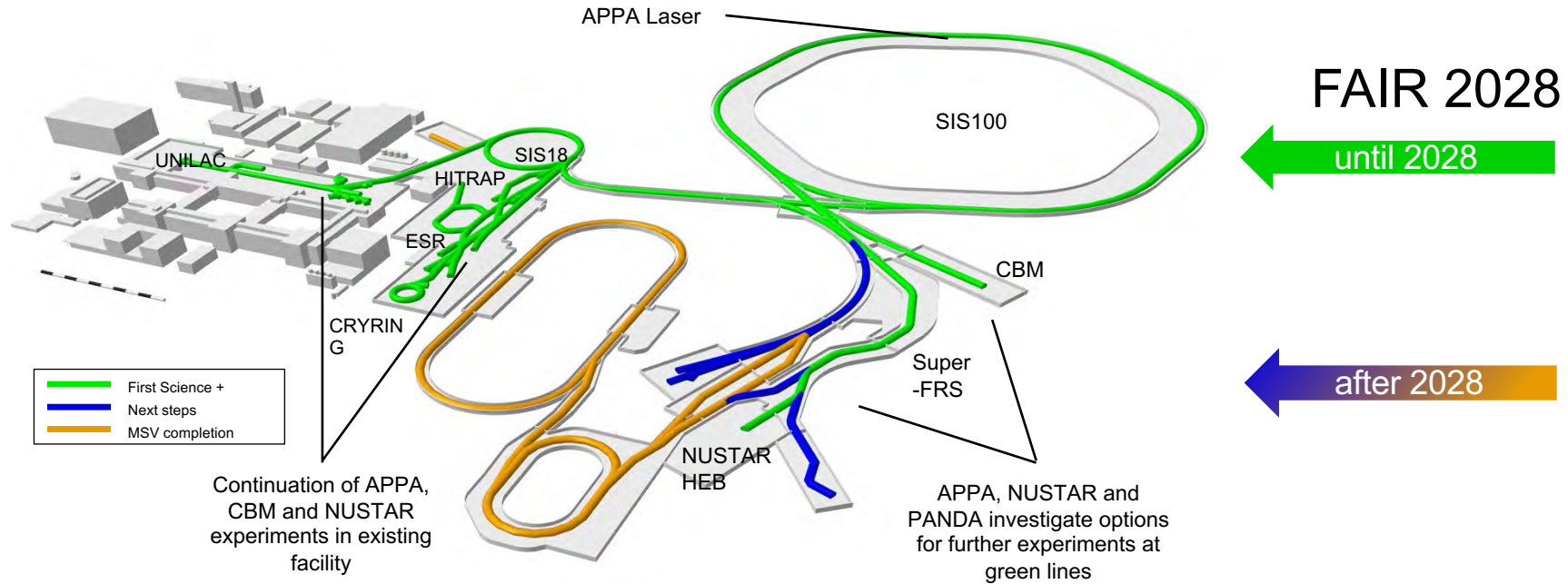




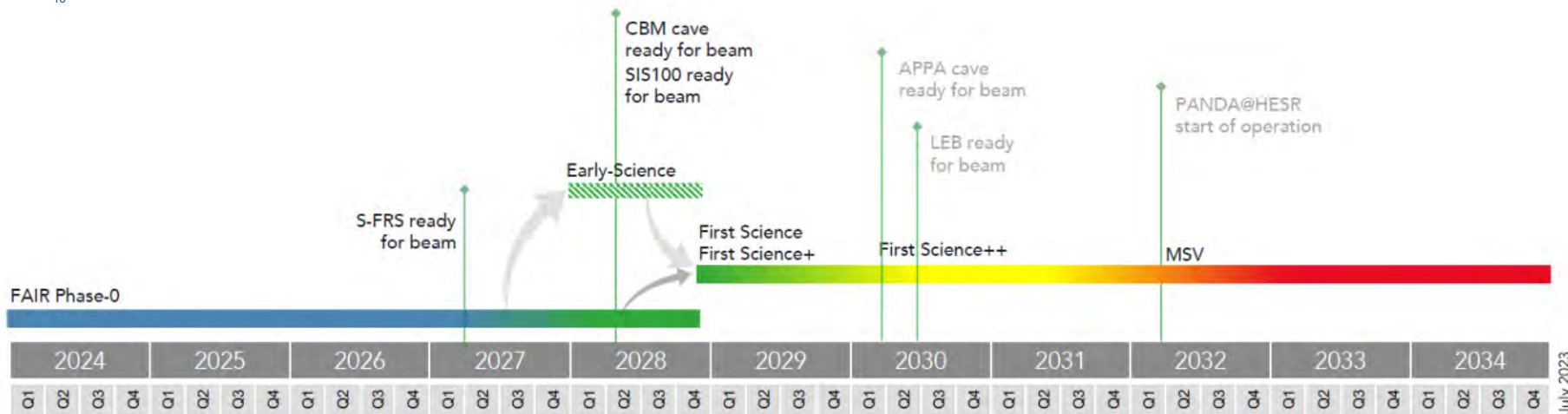
- FAIR in 2028 will feature the most valuable science program which can be hosted in the FS+ infrastructure.
- The „**FAIR 2028**“ science program will include:
  - **APPA** experiments *at the low-energy rings, at SIS100*, at the *caves at SIS18 and UNILAC* with and at *PHELIX* and a limited set of experiments which could be hosted at all the *caves served by SIS100*
  - **NUSTAR** at the *Super FRS with SIS100 beams*, plus *SHE and MATS experiments at UNILAC* and *ILIMA at the low-energy rings*
  - **CBM** at the *new cave with SIS100 beams*, and *HADES at SIS18*
  - **PANDA** is developing a hadron physics program to be carried as bridge towards the program with antiprotons, when possible *using the caves and beams available at GSI/FAIR* and synergies with other experiments.
- Given the limits of financial and human resources, other activities will be downscaled, delayed or even discontinued.



# Current prospects and timeline



16



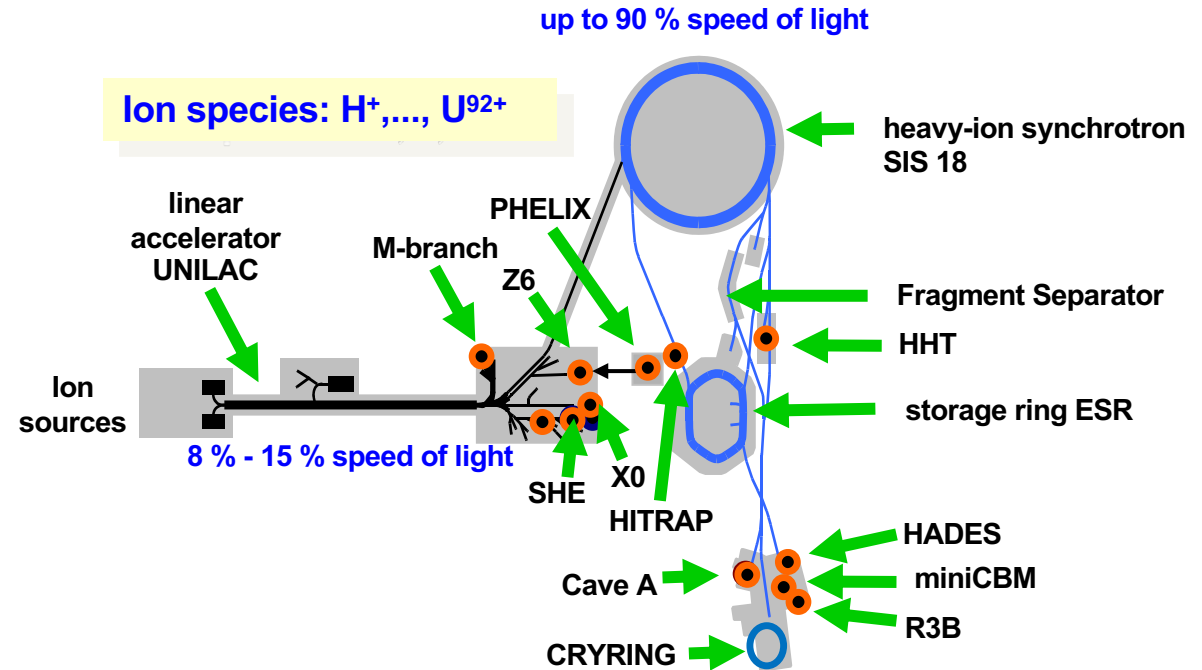
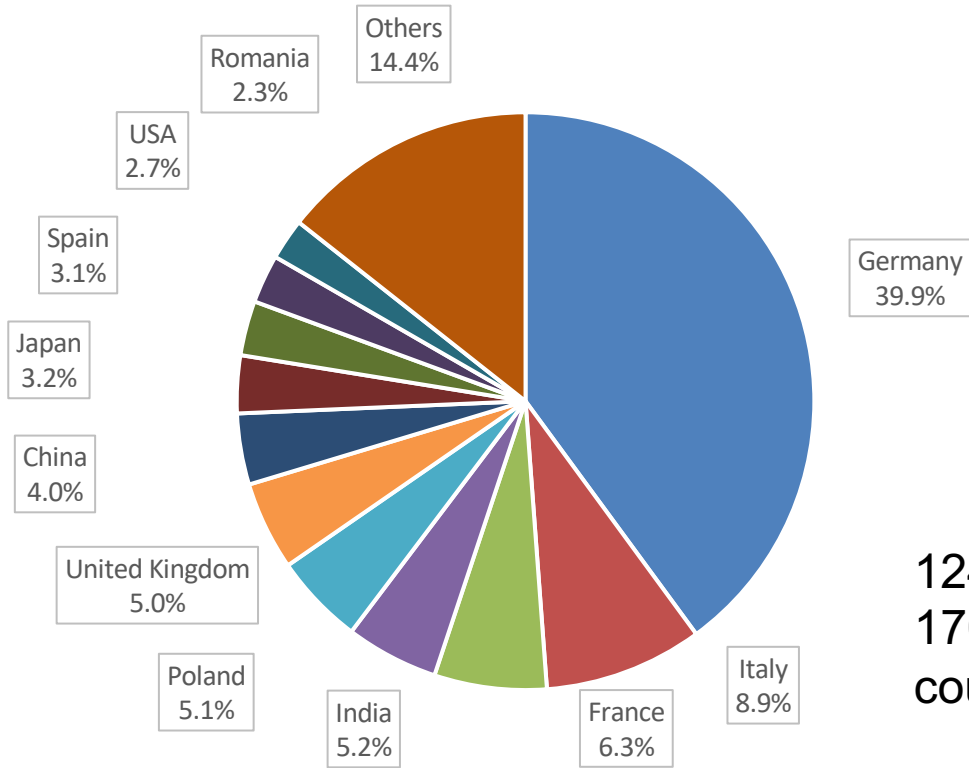


- Up to 2025 we continue with FAIR the annual block of continuous beam time for Phase-0, from 2026 onwards we enter the mixed-mode of Phase-0 with the commissioning of the new beamlines.
- Annual beam time for science will increase progressively, to reach full year operation from 2028 onwards.
- Some experiments at the Super-FRS will start already in 2027 using SIS18 beams („Early Science“)
- We will try to keep a broad research programme on campus, which will also serve the long-term goals of FAIR.



# Ongoing early science program: FAIR Phase-0

- Started in 2019, annual runs of ~110 days until FAIR operation in 2027



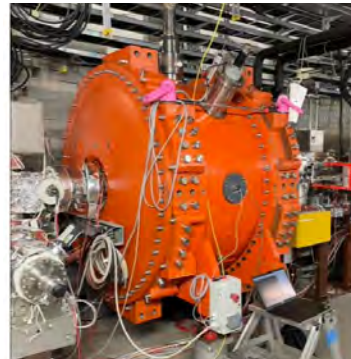
124 proposals with more than 1700 participants from 45 countries received in 2022

Beam time started, very successful to date

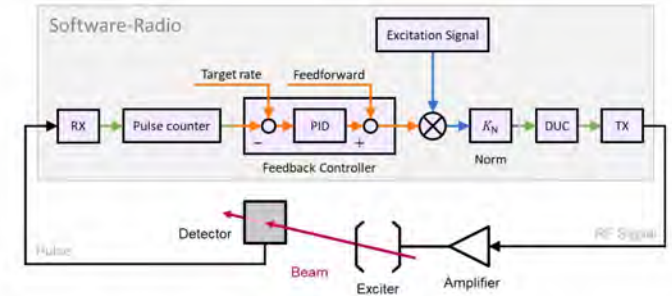


# Some highlights from the engineering run in 2023

- Spill structure improvement
  - feedback system for macro spill structure
  - rf-cavity for micro spill structure



$\mu$ -spill structure cavity



feedback system for KO extraction

- high intensity campaign
  - $N_2$  beam for pion production
  - $U^{28+}$  beam with pulsed gas stripper with  $H_2$



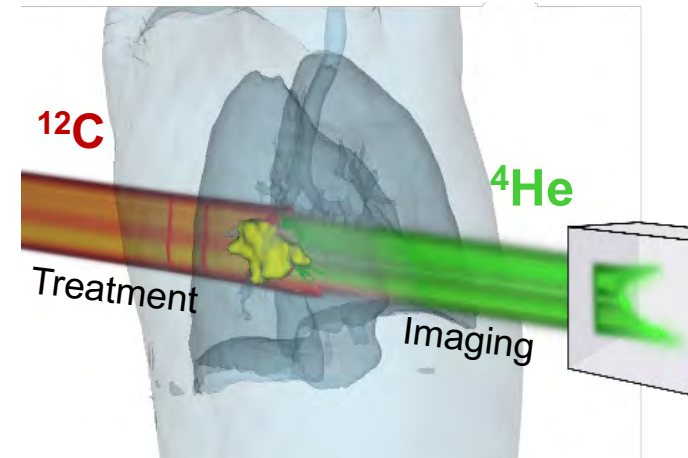
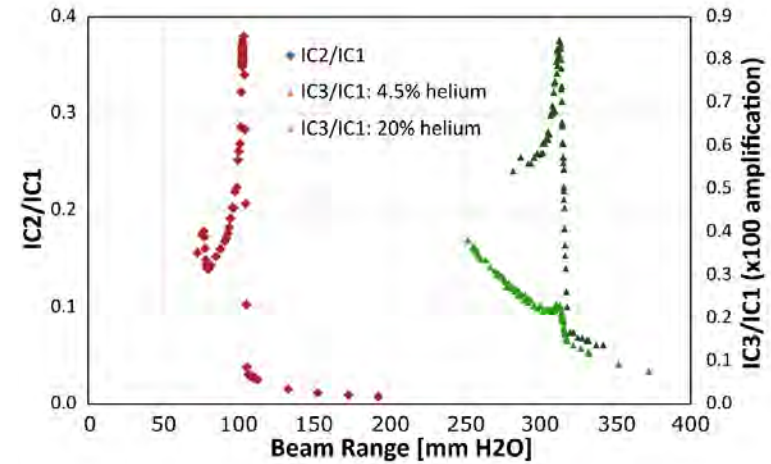
pulsed gas stripper (UNILAC)



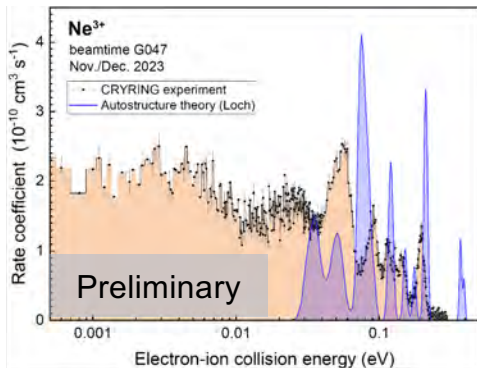
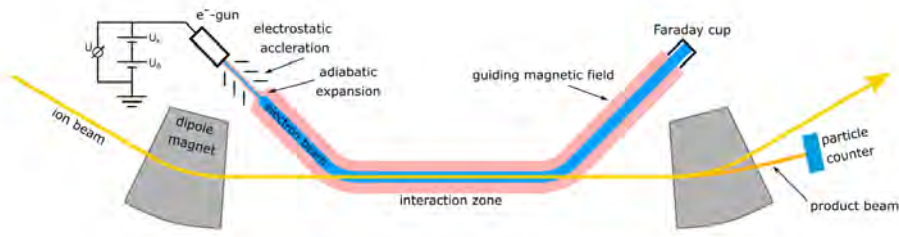
# Some highlights from the engineering run in 2023

## Dual beam

- Two ion species within one bunch ( $^{12}\text{C}^{6+}$  and  $^4\text{He}^{2+}$ ), simultaneously accelerated through the entire accelerator
- Application in cancer therapy, where  $^{12}\text{C}$  is used for tumour treatment and  $^4\text{He}$  for imaging



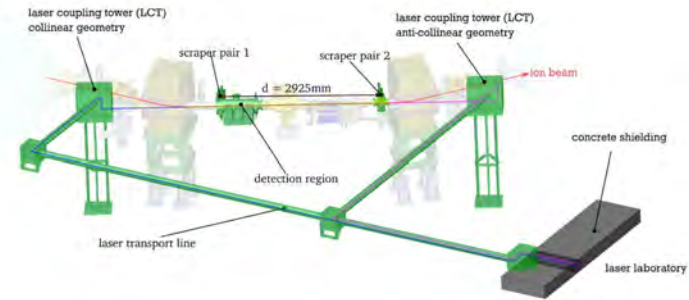
Absolute rate coefficients from dielectronic recombination for the astrophysically relevant ions  $\text{Ne}^{3+}$  and  $\text{S}^{3+}$



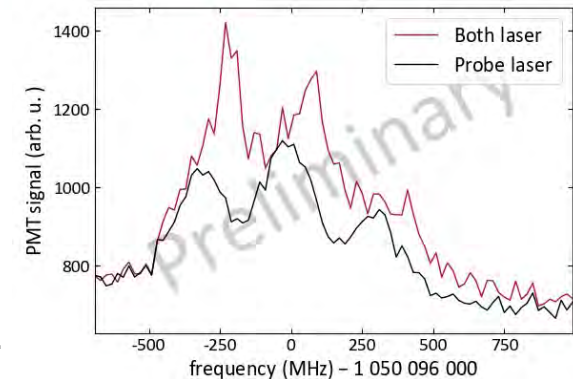
Low-energy theoretical data underpredicts rate coefficient: relevant for low-T charge state distributions, such as e.g. in planetary nebulae, HII regions, AGN...

G-22-00047 M. Lestinsky

Ion beam and level population dynamics in  $\text{Mg}^+$  laser spectroscopy at CRYRING@ESR



Addressing two hyperfine transitions of  $^{25}\text{Mg}^+$  in coasting beam mode with two lasers results in a resolved hyperfine structure. This is the best condition to look for optical pumping.



G-22-00058 R. Sánchez



# Beamtime schedule 2024



JAN	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
IS N																												
IS S																												
ECR																												
MAZ																												
UNILAC																												
UNILAC																												
UNILAC																												
SIS																												
SIS																												
SIS																												
ESR																												
CRY																												

FEB	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
IS N																									
IS S																									
ECR																									
MAZ																									
UNILAC																									
UNILAC																									
SIS																									
SIS																									
ESR																									
CRY																									

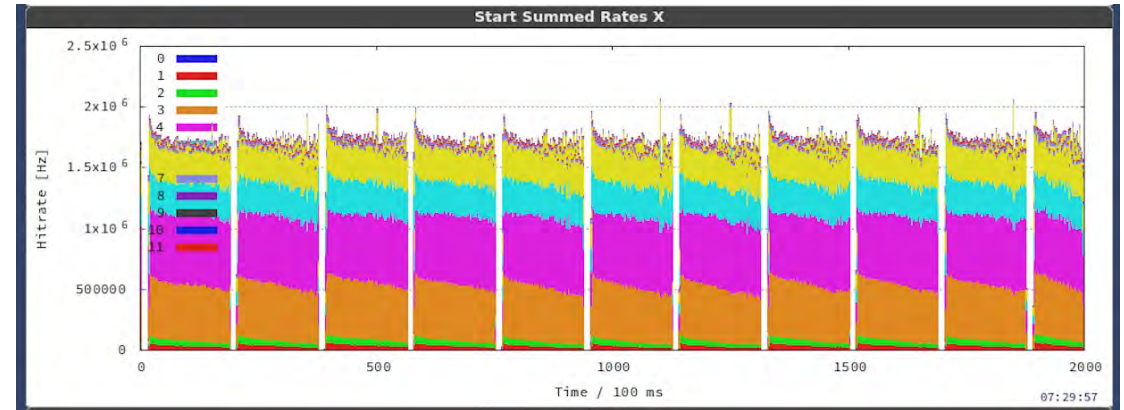
MAR	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
IS N																								
IS S																								
ECR																								
MAZ																								
UNILAC																								
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SIS																								
SIS																								
ESR																								
CRY																								

APR	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	
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IS S																						
ECR																						
MAZ																						
UNILAC																						
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SIS																						
SIS																						
ESR																						
CRY																						

MAY	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	
IS N																				
IS S																				
ECR																				
MAZ																				
UNILAC																				
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SIS																				
SIS																				
ESR																				
CRY																				

JUN	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
IS N																							
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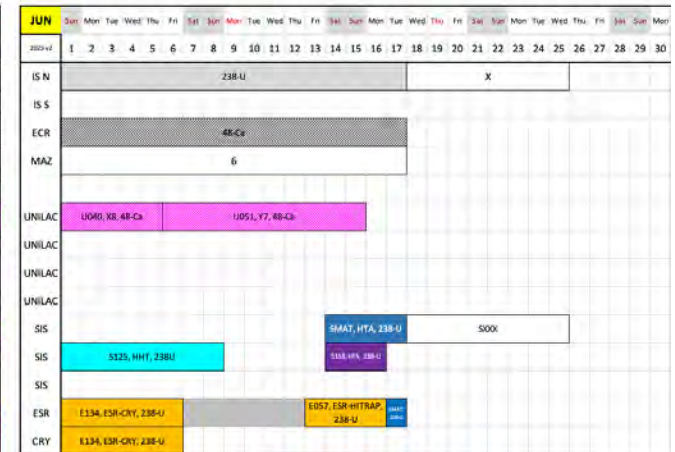
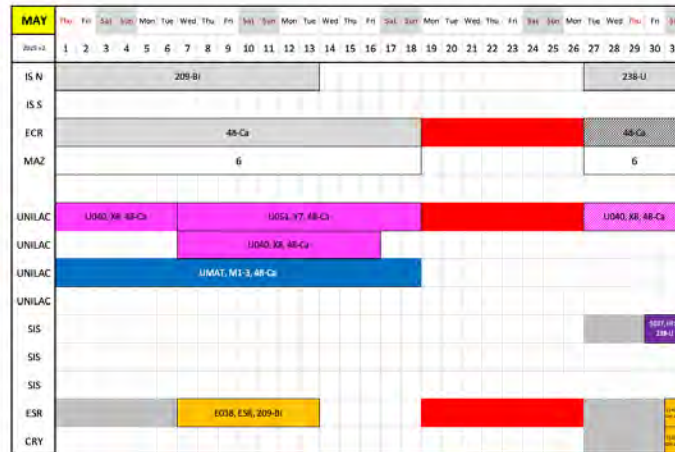
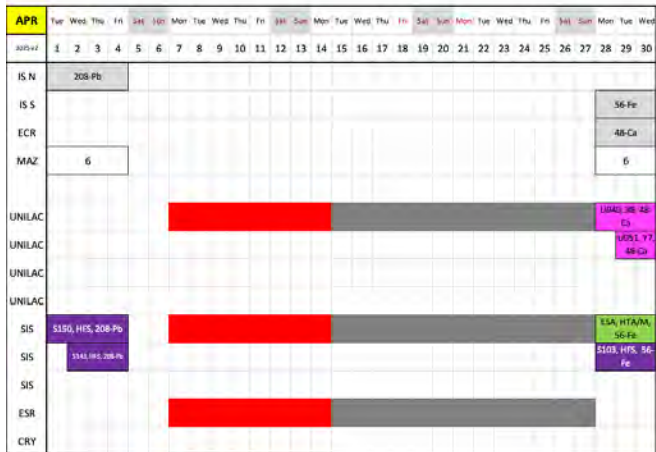
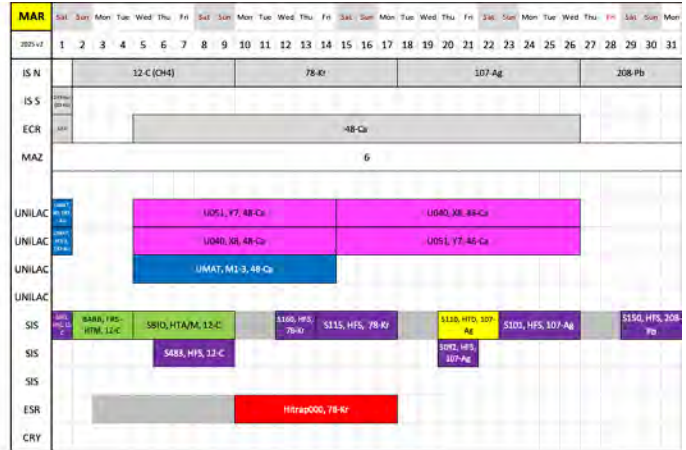
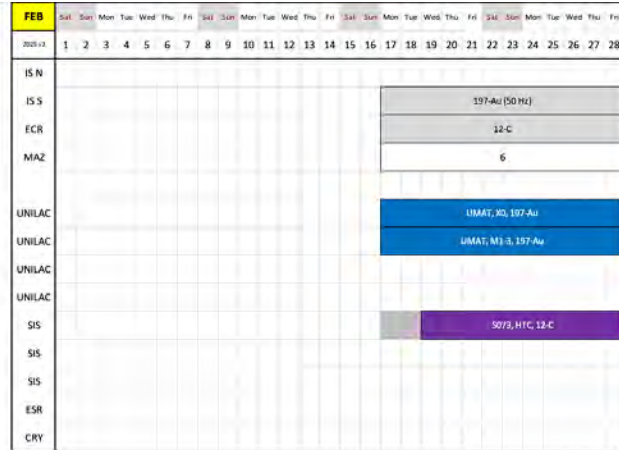
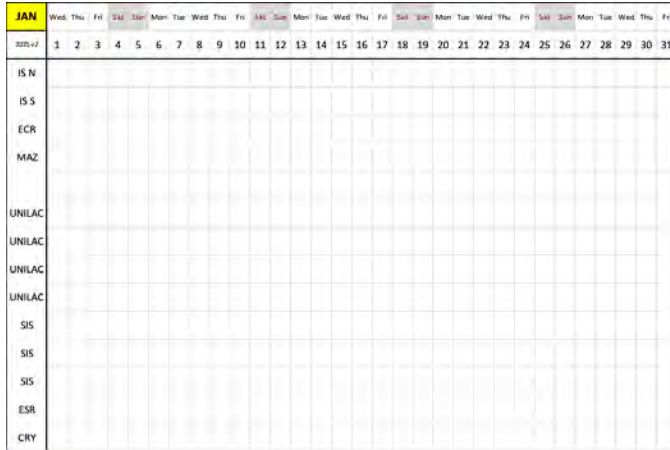
- Successful start of the physics run
  - Fast and smooth machine ramp-up
  - First experiments successful finished
    - e.g. Two-days HADES reference run with 12-C beam with feedback system
    - Test of R3Bs new hydra detector setup (A. Obertelli)



HADES spill structure with new feedback system

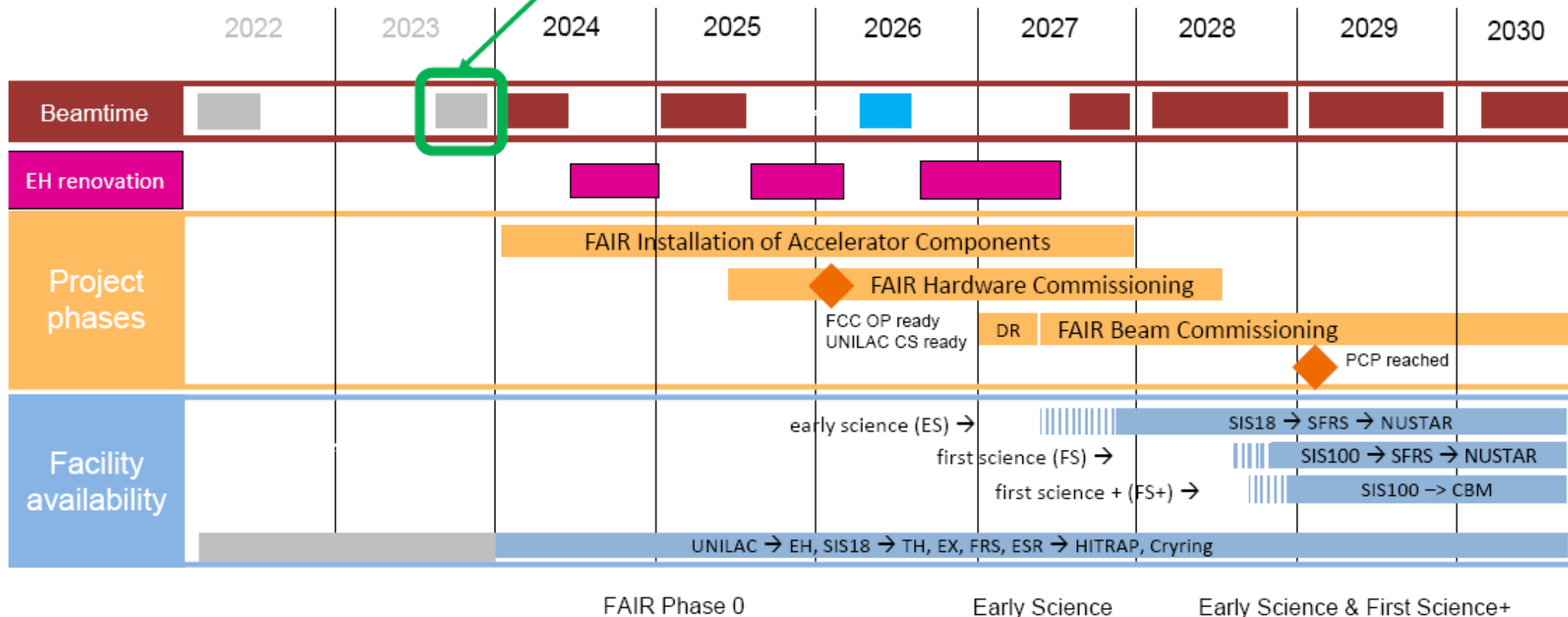


# Beamtime schedule 2025



# Beamtime scenario GSI/FAIR 2024-2028

Engineering run und Physics run am CRYRING



Stephan Reimann / Daniel Severin – 6. GSI/FAIR Beamtime Retreat 2023

- Engineering run 2023: Priority on preparation for experiment beamtime in 2024/25
  - Highlights: Dual beams; Pion-beam preparation; Intensity record
- Experiments granted in 2022 will run in 2024 and 2025

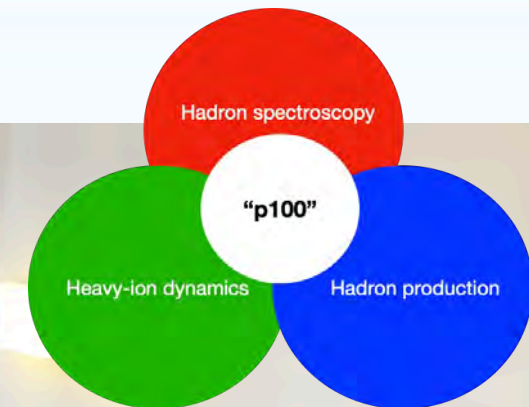


# Physics opportunities with proton beams at SIS100



6-9 February 2024  
Wuppertal University  
Europe/Berlin timezone

- 3-day workshop in Wuppertal
- Follow-up of satellite workshop at MESON2023
- 43 invited talks, 90 participants
- theory & experiment



- $|S| = 2, 3$  Hyperon Spectroscopy & Production
- Hyperon Production: from pp to pA & AA
- Light-meson Production and  $K^-$  Rescattering
- Hyperon Interaction Studies
- Hyperon Weak & Electromagnetic Structure
- Proton-hidden charm Final State, Open Charm
- Exotics
- Hard Hadronic Processes: Transition GPDs
- Forward Spectators and Neutrons
- Input for p+A and A+A Physics, polarization

A vertical bar on the right side of the slide, divided into three colored segments: blue at the top, orange in the middle, and green at the bottom.

Strangeness

Charm

“Nuclei”



# White paper in the making

## 0. Executive summary

### 1. Introduction

- key questions in strong QCD
- context, objectives, process of whitepaper

### 2. Exploiting hadronic beams in the field of QCD matter

- general key features
- state-of-art in experiment and theory

### 3. Hadron-hadron interactions

- final-state interaction & partial-wave analysis
- baryon-baryon interactions
- meson-baryon interactions
- femtoscopy
- short-range correlations
- charm-nucleon dynamics
- hypernuclei

### 4. Composition of hadrons

- hadron spectroscopy
  - baryon spectroscopy: double+triple strangeness
  - charm spectroscopy
  - spectral/line-shape studies
- structure of hadrons
  - e.m. transition form factors of light baryons
  - e.m. & weak transition form factors of hyperons
- structure of the proton: GPD, GFF, radii

### 5. Exotic nature of hadrons

- XYZ: spectroscopy, production and media propagation
- diquark correlations
- dibaryons
- intrinsic charm of the proton

### 6. Hadron production mechanisms

- production mechanisms of light mesons, strangeness and charm
- near-threshold production studies of hadrons in p+p/A
- connection to LHC energies/neutrino physics

### 7. Hadrons as probes to study dense matter

- elementary p+p, p+n reactions
- hadron properties in dense matter
- connection to dilepton spectrum
- short-range correlations

### 8. Experimental infrastructure

- GSI/FAIR proton (& possibly pion-beam) facility
- experimental setups: hades, cbm
- modifications to enable elementary proton-driven studies
- international play-field

### 9. Discussion & conclusions

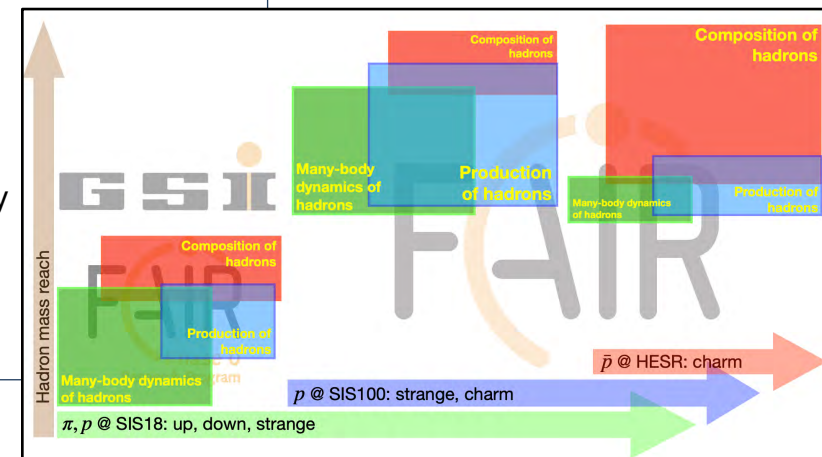
- roadmap

*“Strong interaction studies using hadronic beams at GSI/FAIR”*

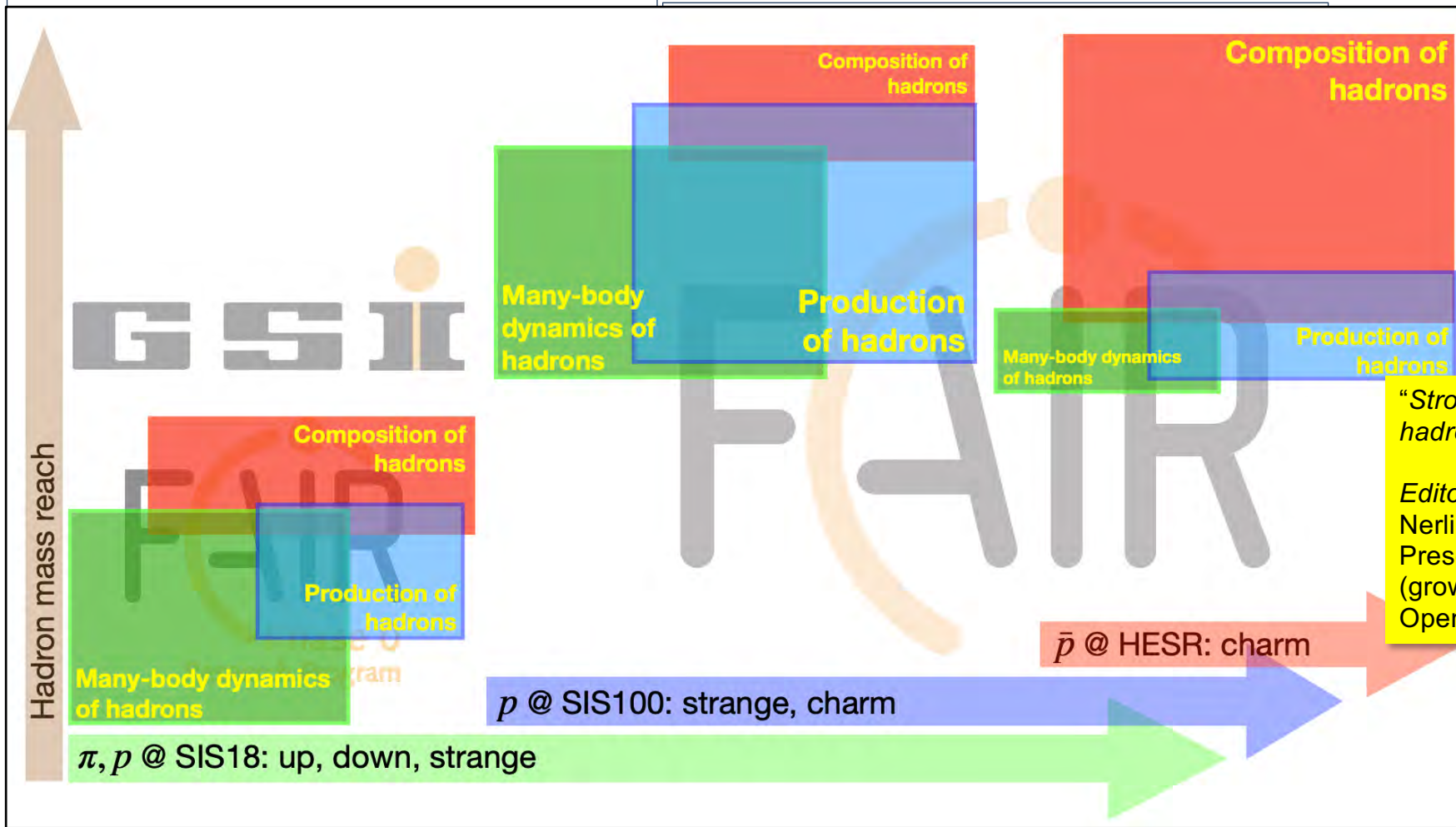
*Editors: J. Messchendorp & F. Nerling*

*Presently ~35 contributors (growing)*

*Open for additional contributions!*



# White paper in the making



*“Strong interaction studies using hadronic beams at GSI/FAIR”*

Editors: J. Messchendorp & F. Nerling  
Presently ~35 contributors (growing)  
Open for additional contributions!



- A new Admin. Man. Dir. is expected to start in few weeks
- The search for a new Sc. Man. Dir. has started
- The FAIR Council chair is Catarina Sahlberg (VR Sweden) and GSI AR-chair is Volkmar Dietz (BMBF Germany)
- Efforts to secure contributions from all FAIR Partners is on-going
- The FAIR Commissioning Phase has started
- The Dec 2024 Council meeting will take place in India
- Difficult task for the management: integrate beamtime operation, installation and commissioning of the new facilities and essential interventions on the buildings (radiation shielding, fire protection...)



An aerial photograph of a modern university campus. The buildings are interconnected by a network of yellow walkways and feature extensive green roofs. The campus is surrounded by dense green trees and a large green field in the background. The text "Looking forward for new science from 2028 onwards!" is overlaid in white at the top right.

**Looking forward for new science from 2028 onwards!**

**Thank you very much!**



Where are heavy elements created?

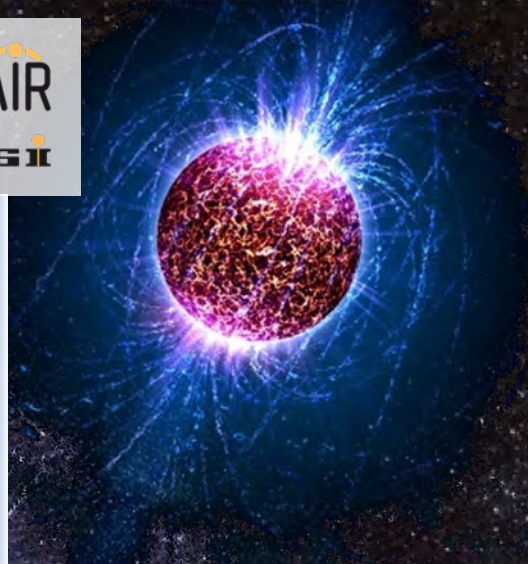


**NUSTAR**



What is in the interior of a neutron star?

**CBM**



**PANDA**

Glueballs:  
What are protons and neutrons made of?  
What is the structure of hadrons?



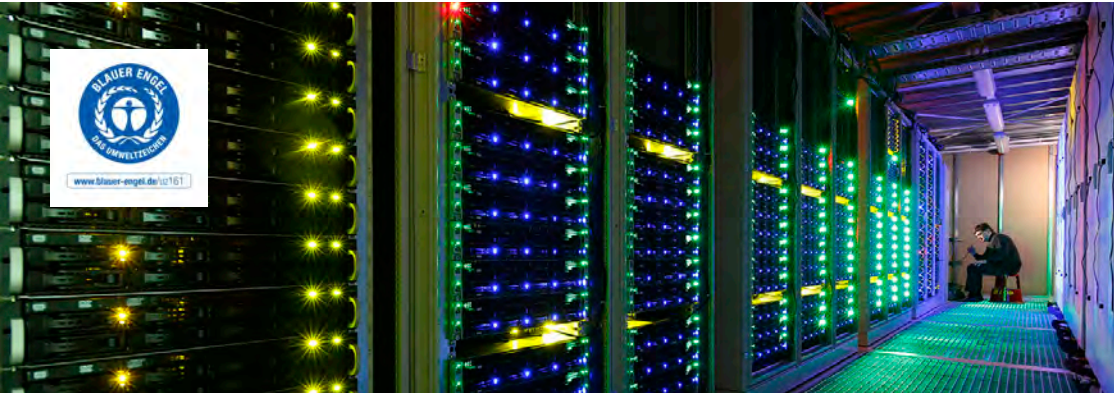
**APPA**

How do materials behave under high pressure?





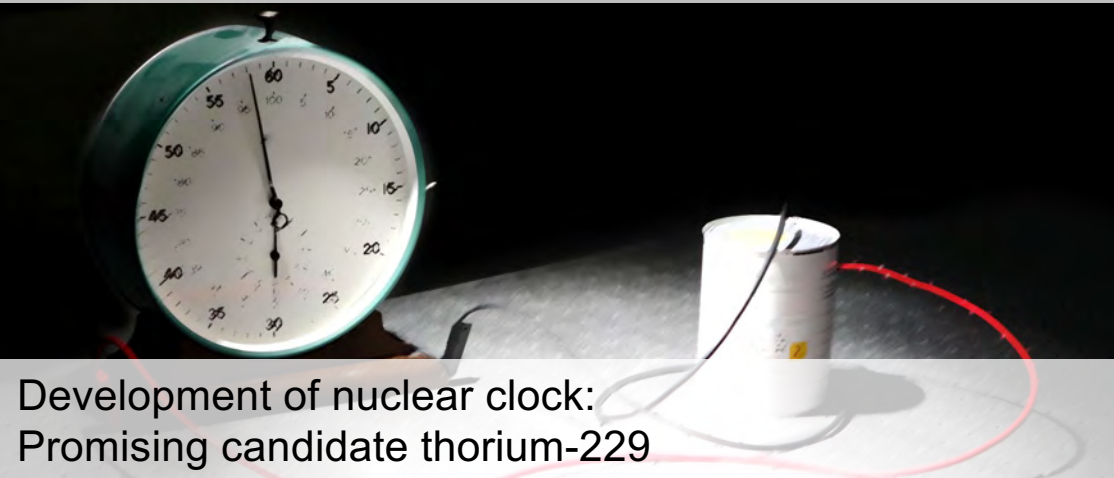
# Direct applications



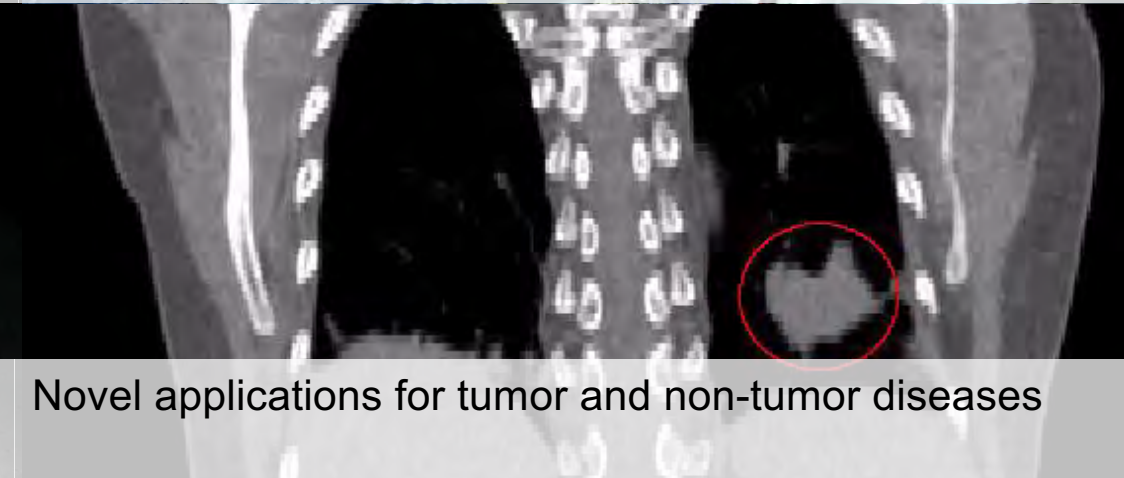
High-performance and scientific computing, big data, green IT



Space radiation protection, unique facility for simulation, collaboration with ESA



Development of nuclear clock:  
Promising candidate thorium-229



Novel applications for tumor and non-tumor diseases