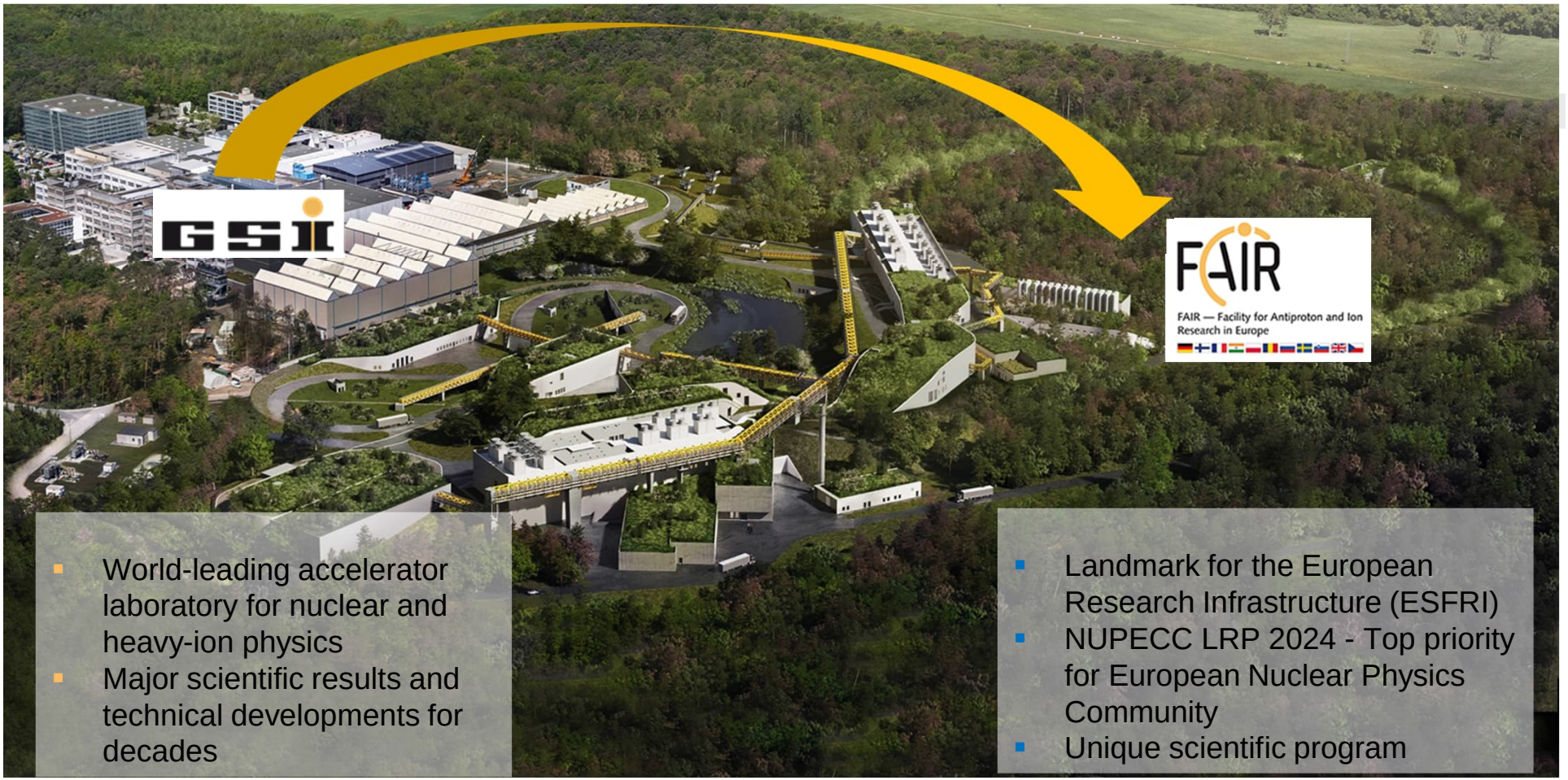
The FAIR/GSI Facility
Status and future perspectives

Thomas Nilsson
GSI/FAIR Scientific Managing Director

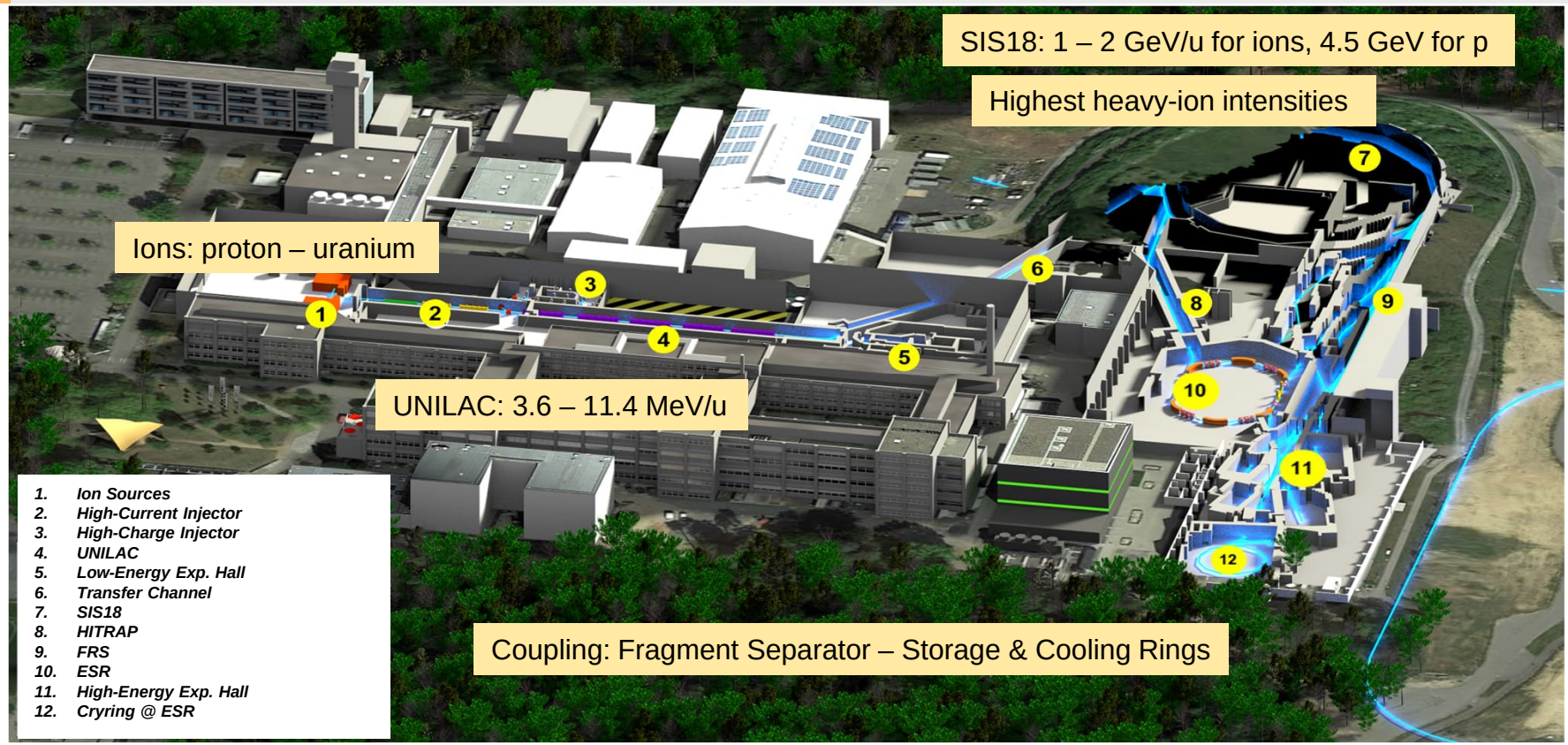
MESON2026, KRAKÓW
25th - 30th June 2026



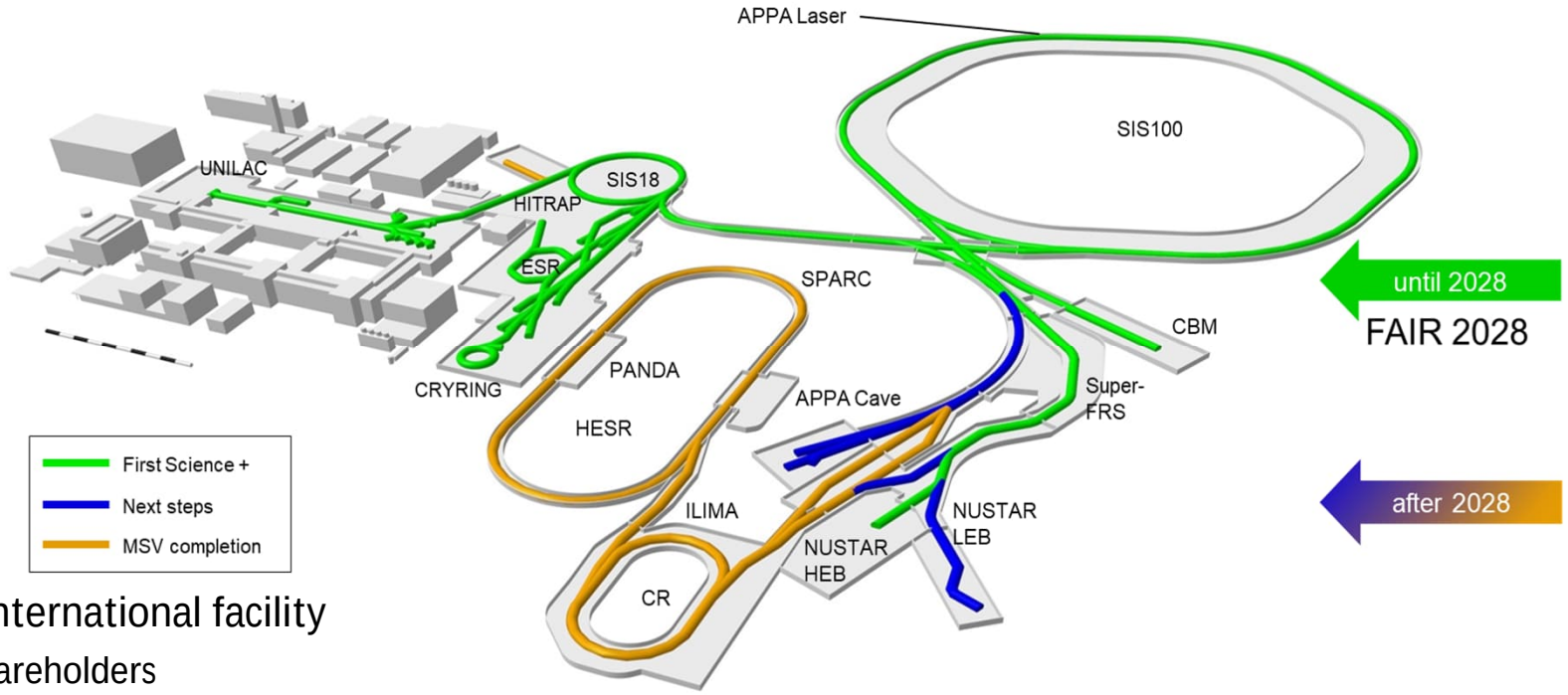
- World-leading accelerator laboratory for nuclear and heavy-ion physics
- Major scientific results and technical developments for decades

- Landmark for the European Research Infrastructure (ESFRI)
- NUPECC LRP 2024 - Top priority for European Nuclear Physics Community
- Unique scientific program

GSI: Unique Accelerator Complex for Heavy Ions



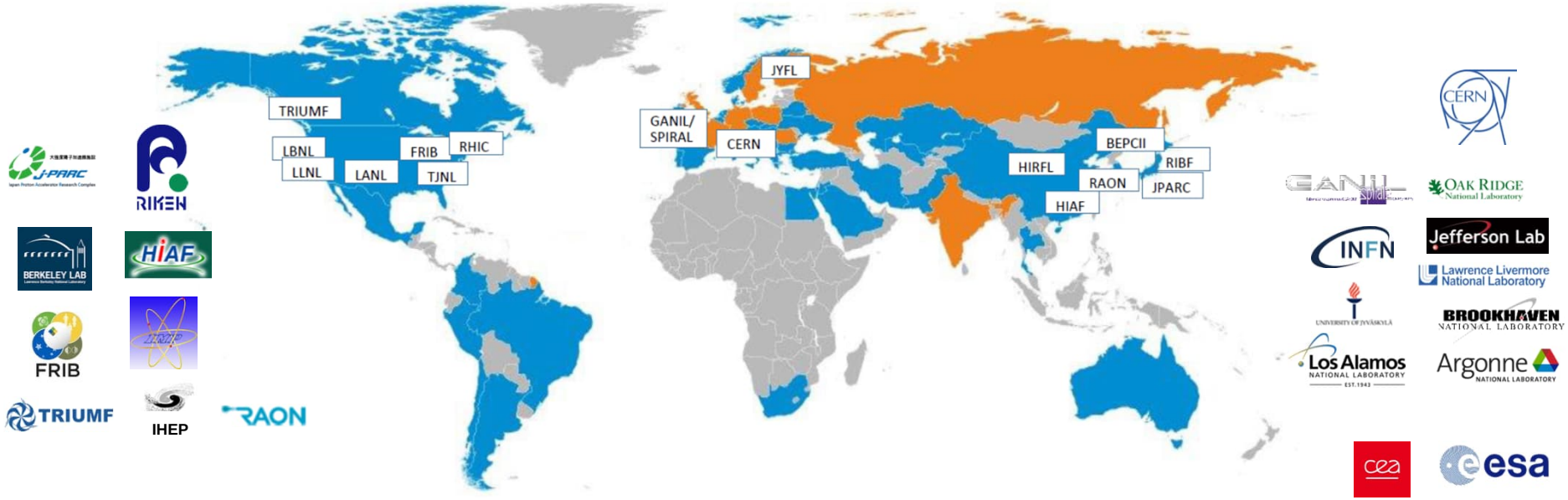
FAIR – Facility for Antiproton and Ion Research



FAIR international facility

- 9 shareholders
- + 1 associated partner
- + 1 aspirant partner

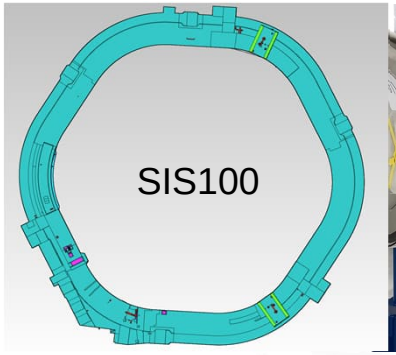
Worldwide Collaboration & Competition



- With major research facilities / institutions / projects from all over the world
- With Scientists from more than 200 institutions from 53 countries (Orange + Blue)
  - **Orange:** countries, which are shareholders of FAIR
  - **Blue:** countries contributing to research and technical development projects at GSI and FAIR
- In total more than 3000 scientists and engineers are involved in R&D for GSI and FAIR

FAIR2028 Main Installations

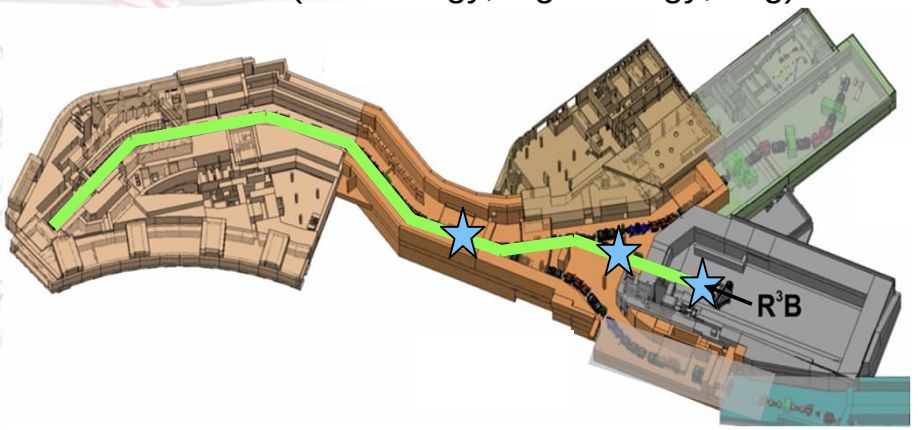
SIS100



- **Core accelerator of FAIR**, which acts as a feeder for experimental stations (and storage rings)
- Circumference 1,100 m; rigidity: 100 Tm
  - maximum proton energy ~ 29 GeV
  - maximum Uranium U^{92+} ~ 10 GeV/u
- Optimized for intense beams of heavy ions
- Provides slow and fast extraction
- Superconducting fast-ramping dipole magnets

Super-FRS

- **High-acceptance two-stage separator (Bρ-ΔE-Bρ)** for production, separation and identification of **radioactive nuclear beams**
  - Length 350 m; rigidity: 2-20 Tm
  - Pre- (normal conducting) and main (superconducting) separator stages
- Three branches (low-energy, high-energy, ring)

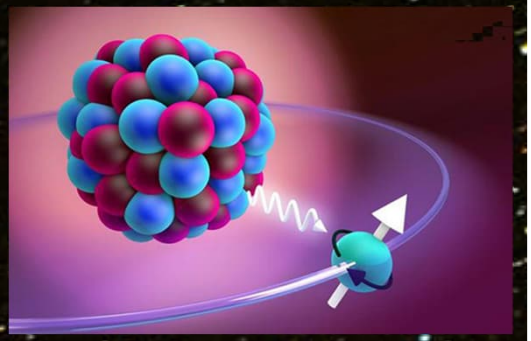


View to the future : SIS100

© GSI/FAIR, Zeitrausch

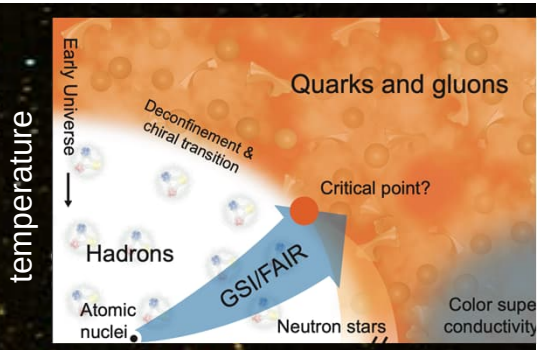
View to the future : Super-FRS

APPA



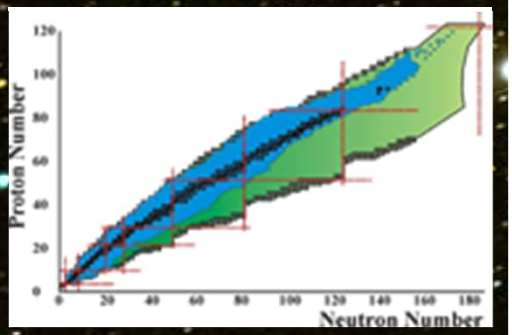
- Precision tests of QED
- Cosmic ray simulator for irradiation studies
- Materials under high pressure

CBM HADES



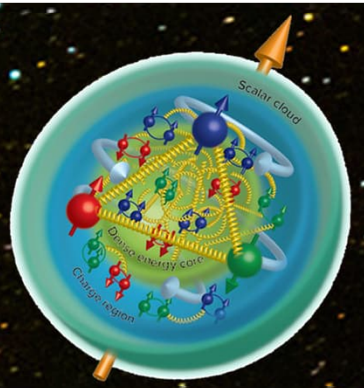
- QCD matter at high baryon densities
- Phase transition and critical point
- Particles in dense medium

NUSTAR



- Nucleosynthesis of heavy elements
- Structure of exotic nuclei (e.g. hypernuclei)
- Neutron matter equation of state

panda

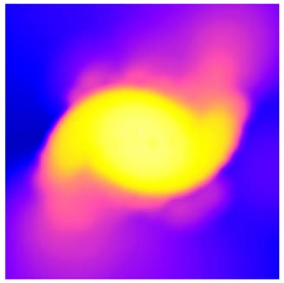


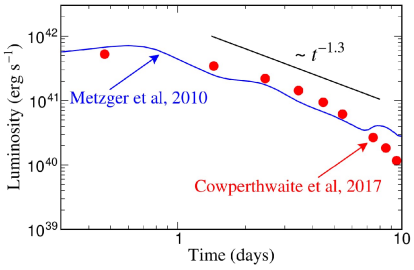
- Gluonic excitations: Hybrids, glueballs
- Precision spectroscopy of charmonium states
- Time-like form factors, nucleon structure

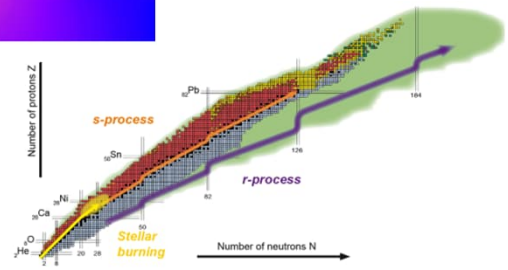
The physics of neutron star mergers - in the lab

Tightly linked to experiments at GSI/FAIR:

- High density matter probed by CBM/HADES and NUSTAR
- Structure and reactions of exotic neutron-rich nuclei studied by NUSTAR



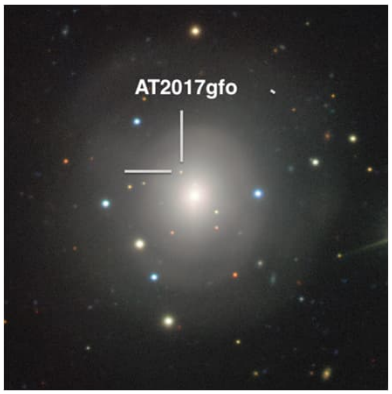


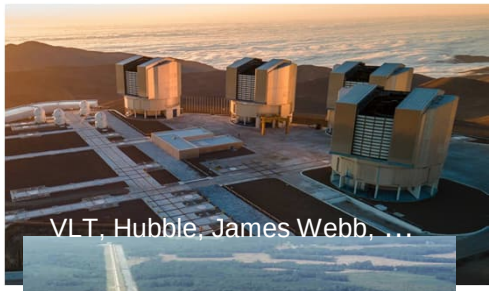


GSI

IN THE UNIVERSE LAB

FAIR

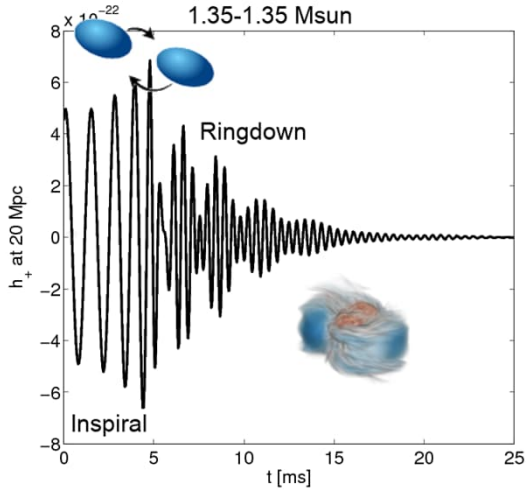


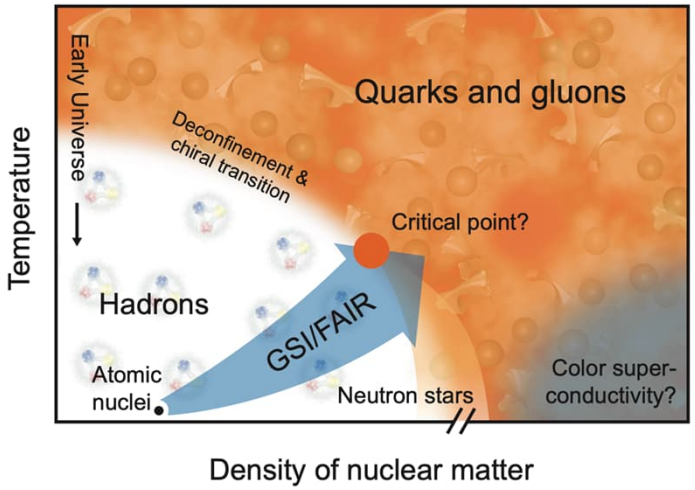


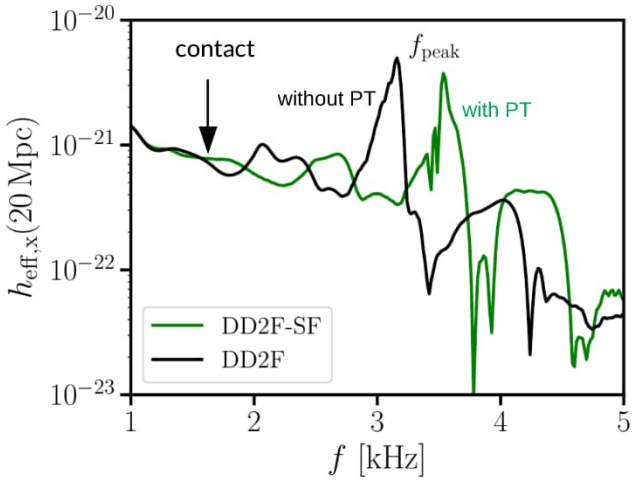
Multimessenger astrophysics and FAIR

Gravitational Waves

- QCD phase diagram probed by CBM/Hades at FAIR
- Signatures first order phase transition to Quark Gluon plasma in gravitational waves postmerger signal





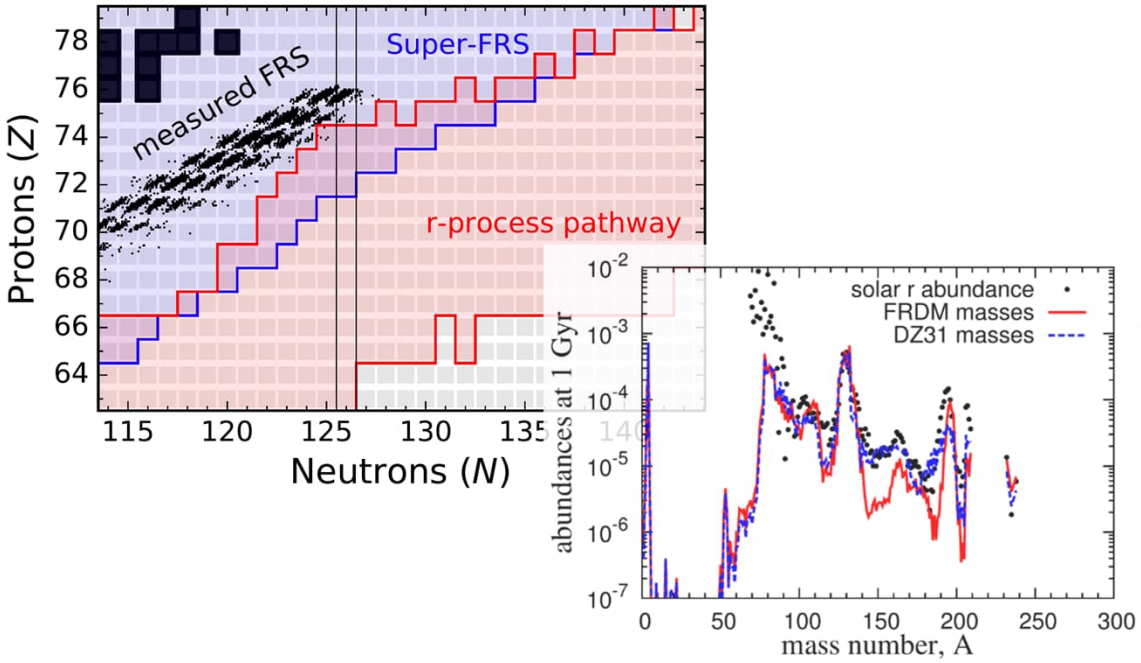


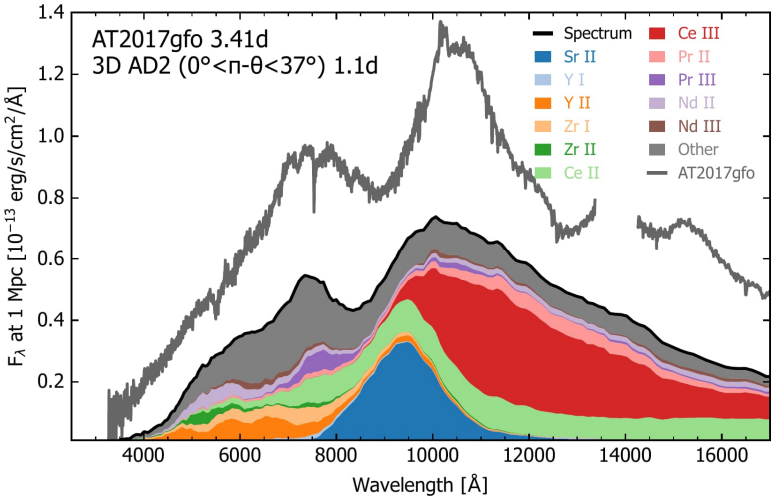
Bauswein et al, PRL 122, 061102 (2019)

Multimessenger astrophysics and FAIR

Electromagnetic signals from r-process

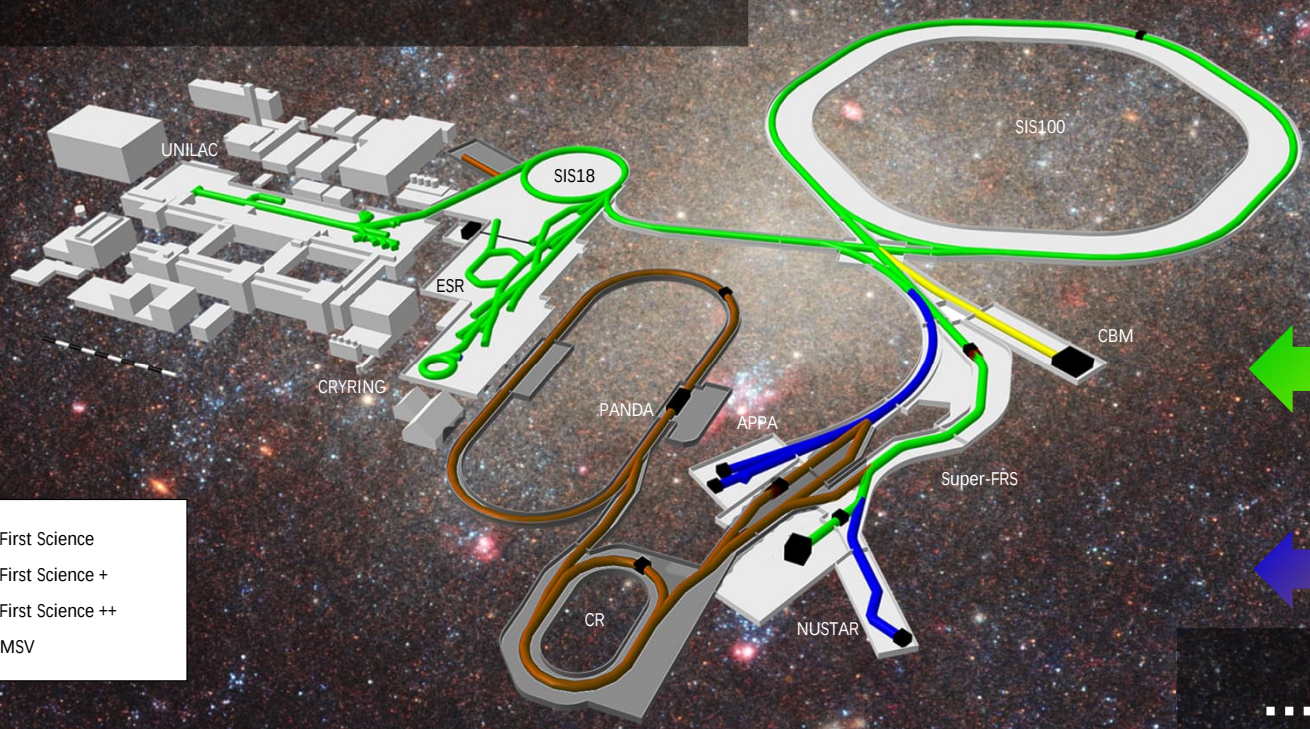
- Masses and beta-decay data for exotic nuclei by NUSTAR
- Nucleosynthesis predictions and resulting astronomical transients





Shingles et al, ApJL 954, L41 (2023)

FAIR 2028 – vision…



until 2028

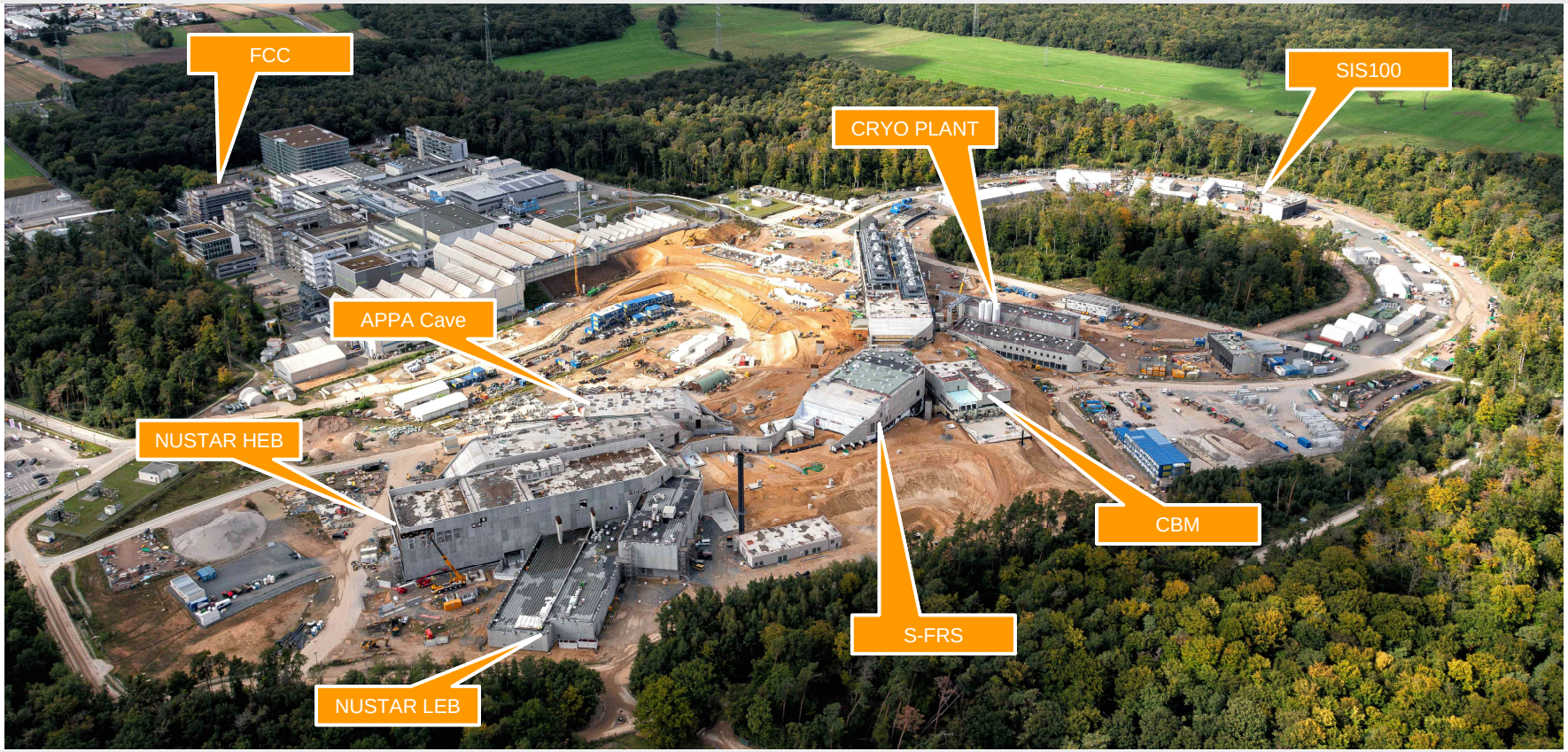
after 2028

…to reality

Foto: NASA Goddard

FAIR Project Progress – Civil Construction

- Construction site view



FAIR Project Progress – Civil Construction
- Central Transfer building

SIS100 tunnel

© J. Hosan, GSI/FAIR

SIS100 dipoles

Commissioning Cryoplant

Super-FRS SC Magnet

Inside the FAIR Control Center (FCC)

FAIR Project Progress – Experimental Caves

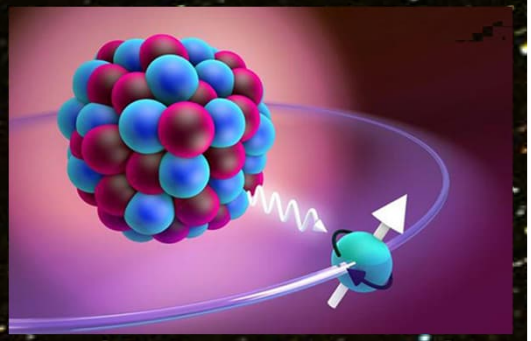
Example: CBM cave

- Crane and platform available
- Access roads built
- Magnet foundation poured
- Magnet holding structure accepted

FAIR Commissioning ongoing!

- **Q3 2025: Start of commissioning of cryo-plant and cooling water system**
- **Q4 2025: Initial steps for HEBT commissioning**
- **Q1 2026: Takeover of main control room in FAIR Control Centre (FCC)**

APPA



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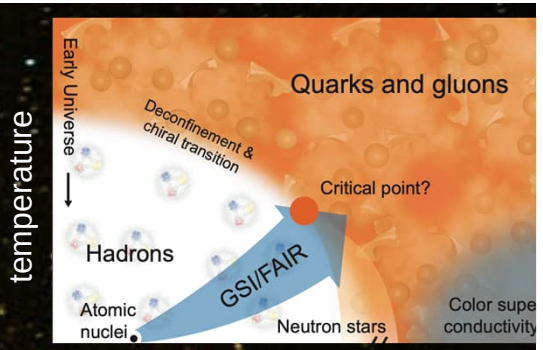

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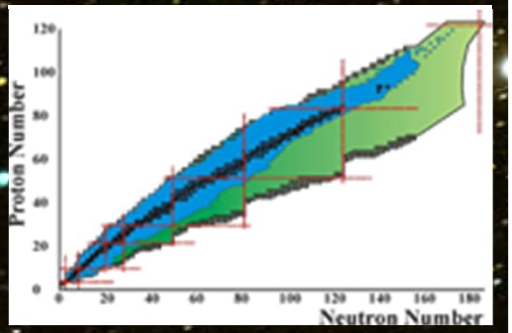

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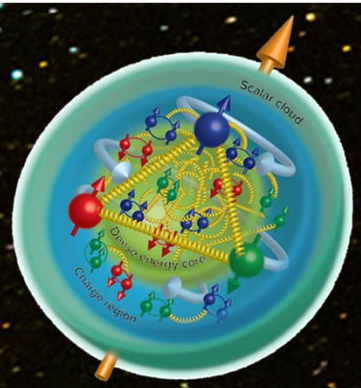

- Gluonic excitations: Hybrids, glueballs
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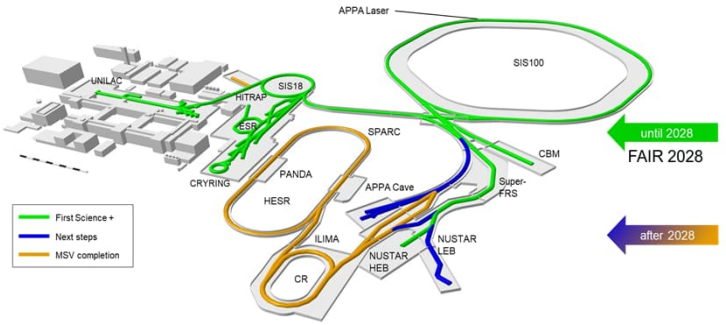
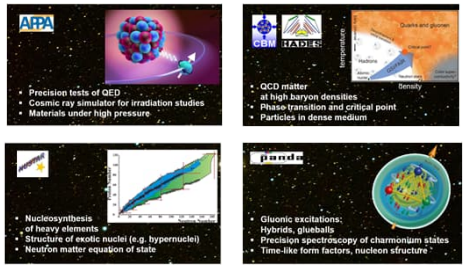
Scientific vision: FAIR 2028

- 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 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.

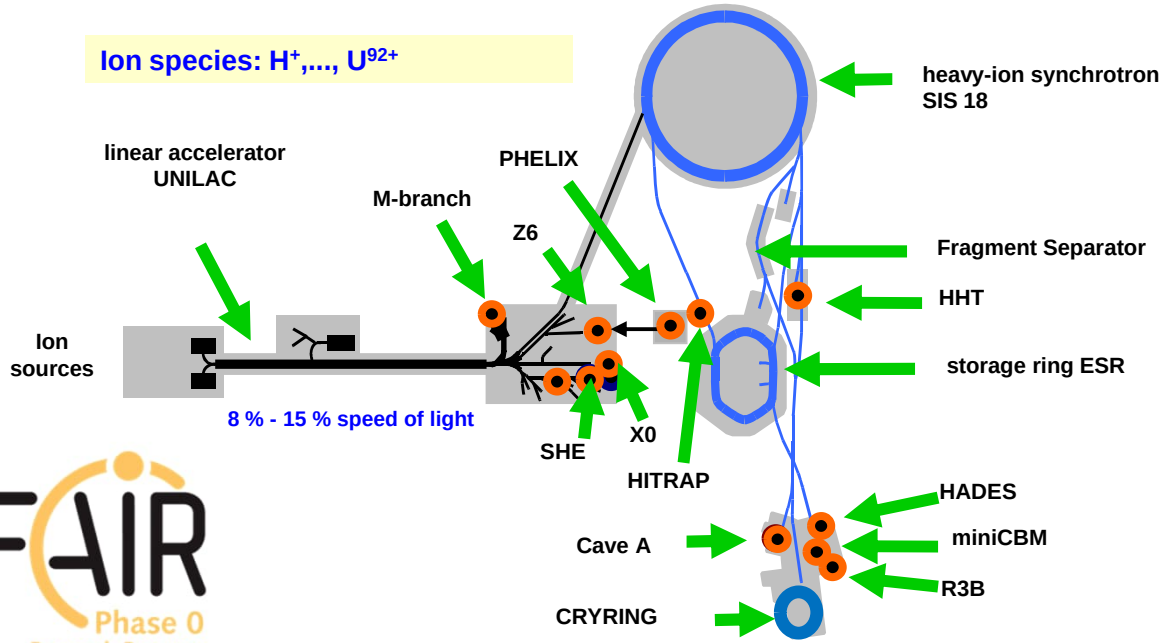


FAIR Phase-0 Scientific Programme

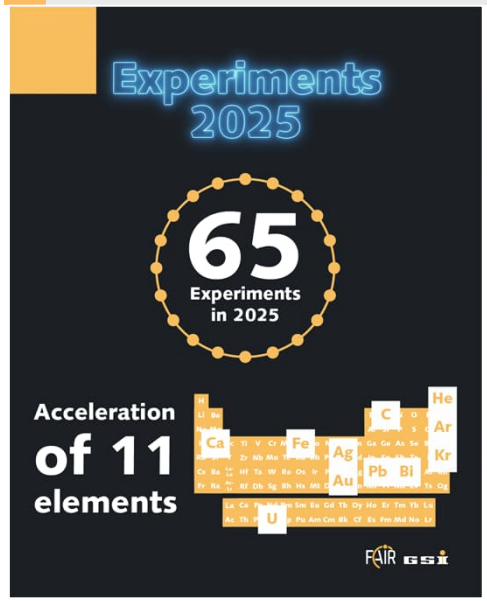
- Started in 2019, annual runs of ~110 days until FAIR operation
- Supported by FAIR partners, so far: Finland, France, Germany, (Romania*), Sweden and the UK

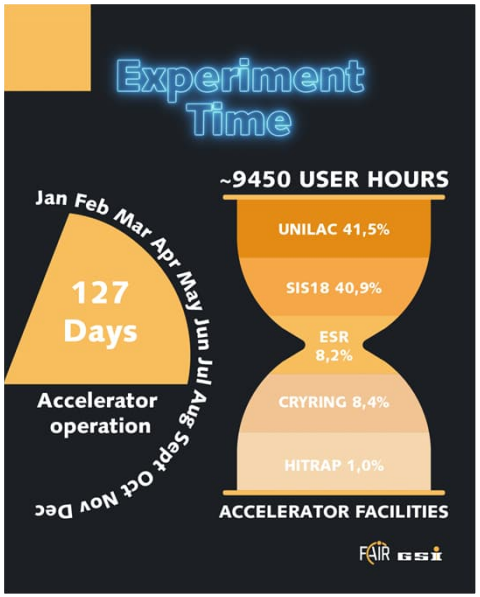
*Romania contributed 2019-22

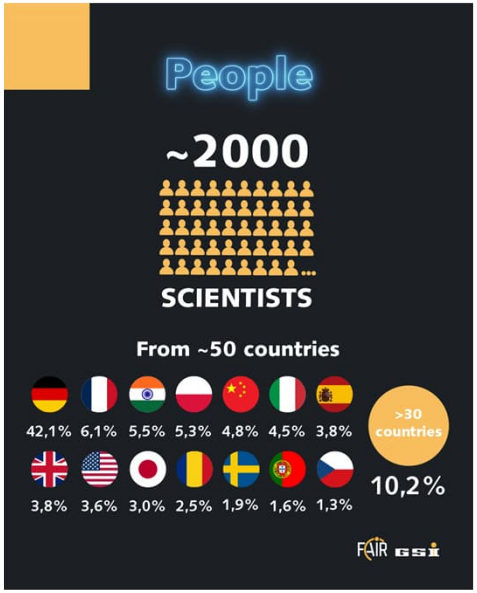
- Harvesting rich results of data taking
- Beam time 2025
  - Extremely successful data taking for experiments and machine studies
  - Record number of physics days
  - Minimal downtimes

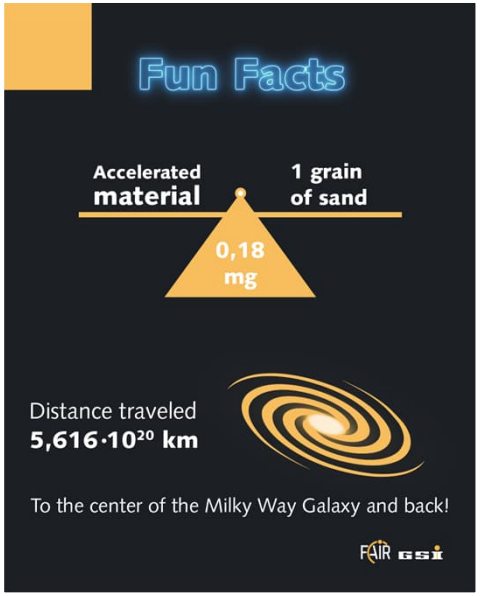


FAIR Phase 0 - Beamtime 2025



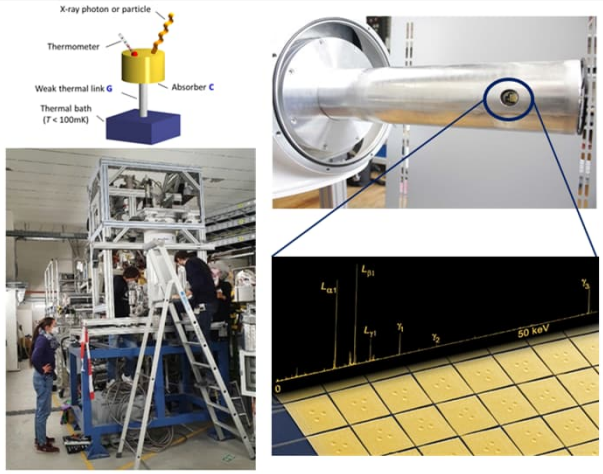




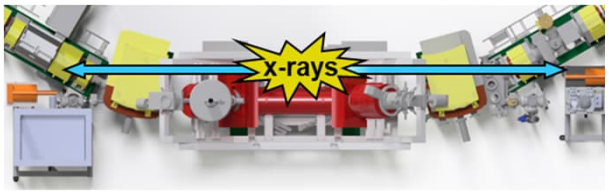


Some highlights
… QED in Strong Electromagnetic Fields

Metallic Magnetic Microcalorimeter (MMC) Detectors

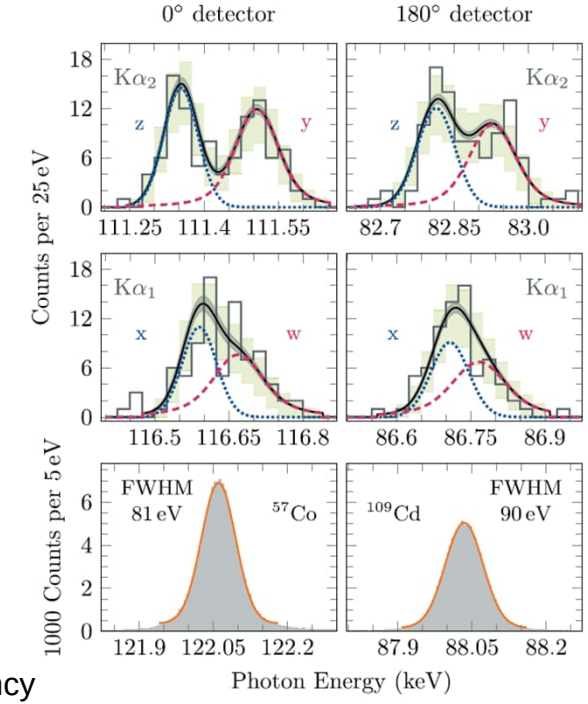


Combination of high spectral resolution and broad bandwidth acceptance offers unique possibilities.



- ✓ insensitive to geometric misalignments
- ✓ combining 0° and 180° provides unique redundancy
- ✓ coincidences between x-rays and down-charged ions

Substate Resolved Kα Transition Energies in Helium like Uranium



First well-resolved K_α spectra recorded for a high-*Z* system.

Spectral resolution of $\Delta E < 100$ eV FWHM @ 100 keV was achieved

First exploitation of microcalorimeter timing capabilities with $\Delta t_{FWHM} < 400$ ns.

P. Pfäfflein, et al. Phys. Rev. Lett. 134, 153001 (2025)

Biophysics

Space radiation protection

- ESA reference facility for ground-based space radiation protection studies
- Current ESA-supported programs ongoing: IBER/IRES/ROSSINI/GCRsim
- ESA/FAIR Summer School in Darmstadt

Particle therapy

1997

2024

- First European center to treat patients with high energy ^{12}C-ions (440 patients treated on site)
- Now extensive research program in particle therapy covering from nuclear physics to molecular biology

HULC Camera tested at GSI, used in ARTEMIS-II

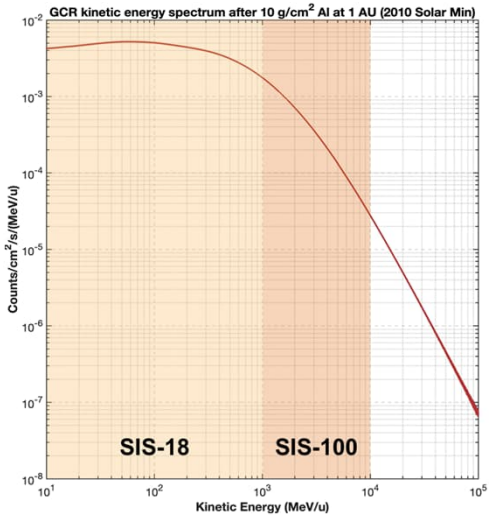
The HULC - Handheld Universal Lunar Camera

Tested at GSI - Cave A with 1 GeV/u ^{238}U-Beam in 2025

Photo: Tim Wagner, GSI

ARTEMIS II in eclipse, April 6, 2026, Foto by HULC, @NASA

Galactic Cosmic Ray Simulator



Life **2014**, *4*, 491-510; doi:10.3390/life4030491

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Review

Space Radiation: The Number One Risk to Astronaut Health beyond Low Earth Orbit

Jeffery C. Chancellor [1,2], Graham B. I. Scott [1,3] and Jeffrey P. Sutton [1,4,*]

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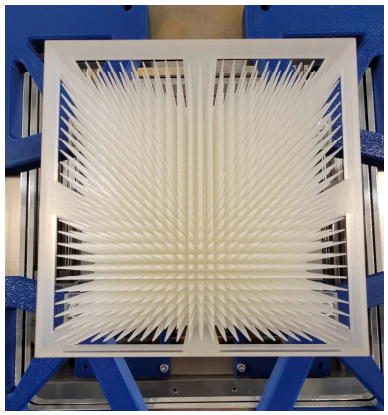
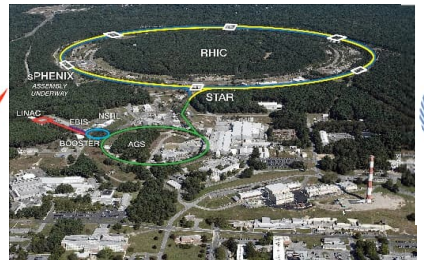
2 Department of Materials Science and Engineering, Dwight Look College of Engineering, Texas A&M University, 3003 TAMU, College Station, TX 77843-3003, USA

3 Department of Molecular and Cellular Biology, Baylor College of Medicine, 6500 Main Street, Suite 910, Houston, TX 77030-1402, USA

4 Department of Medicine, Baylor College of Medicine, 6500 Main Street, Suite 910, Houston, TX 77030-1402, USA



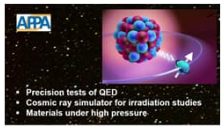


NASA Space Radiation Laboratory (NSRL) at BNL

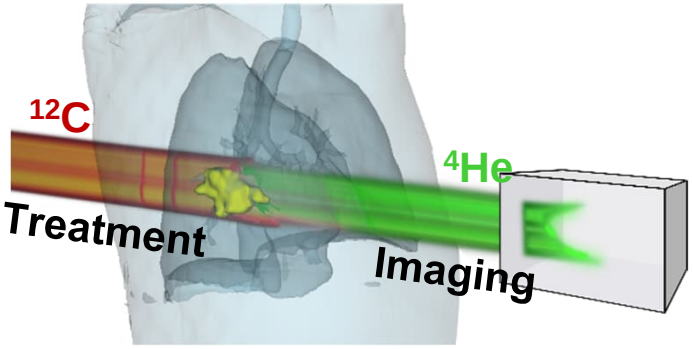
BIOMAT at FAIR

- Cutoff energy **10 GeV/n at SIS100** vs. **1 GeV/n at SIS18 or BNL** (NASA)
- This will make FAIR <u>the best facility in the world</u> to simulate GCR in lab

Some highlights
… Imaging with mixed C- and He beams

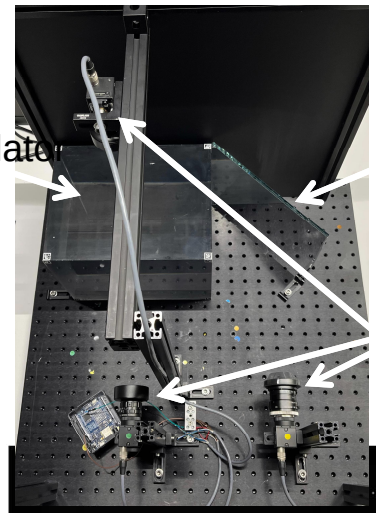


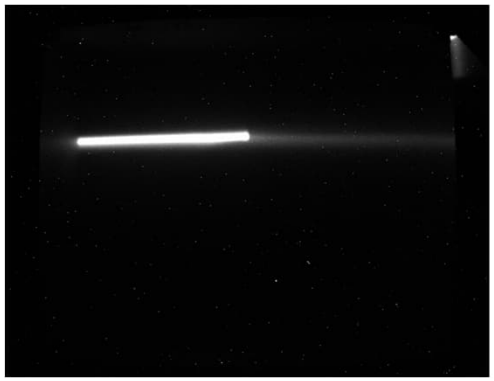
C- and He ions simultaneously accelerated

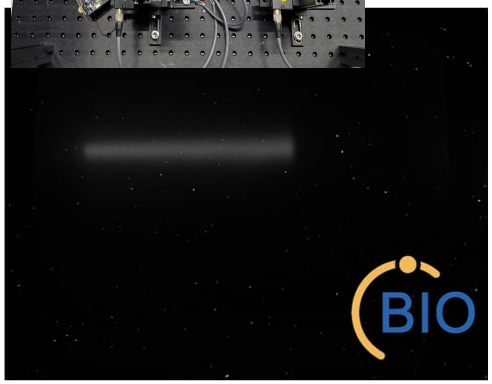


May 2025 – First images with a scintillator-camera system (UCL)

Carbon beam stopped with rangeshifter







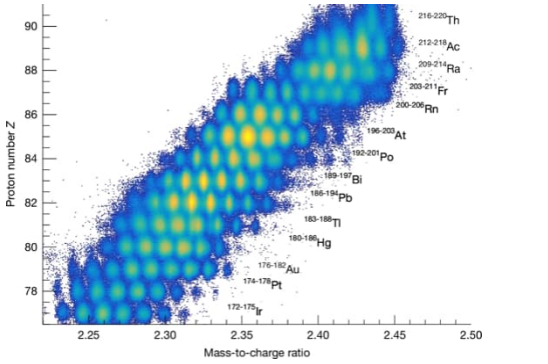
ERC Christian Graeff

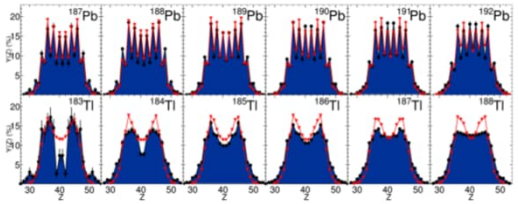
NUSTAR-R3B at the Super-FRS

Some highlights
… New island of asymmetric fission

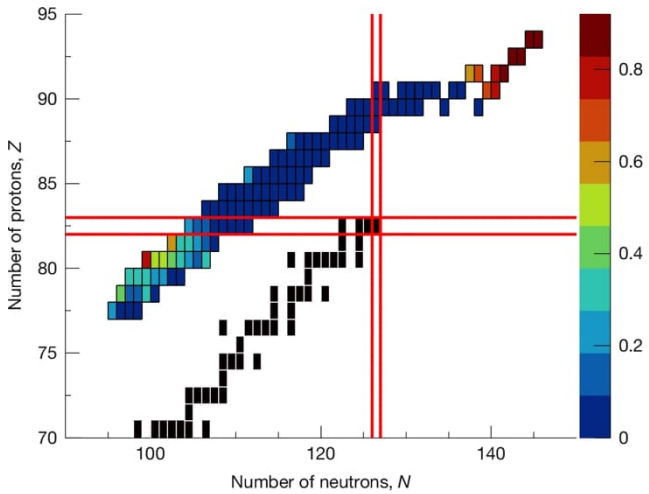
Fission of exotic nuclei

- Important in r-process nucleosynthesis:
  fragment distributions + fission barriers
- Experiment: Charge distributions for for 100 neutron-deficient isotopes produced in Coulomb fission
- **New asymmetric fission island in the sub-lead region discovered**





Map of evolution of asymmetric fission



P. Morfouace, Nature doi:10.1038/s41586-025-08882-7 (2025)

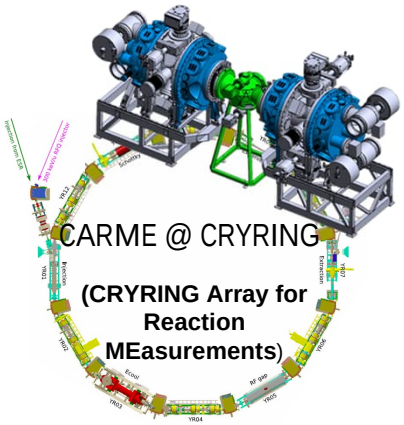
First Science at R³B

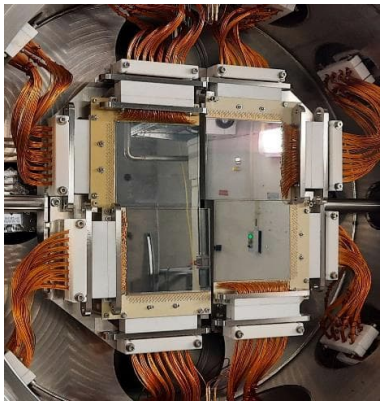
- (p,2p) induced fission enables measurement of excitation energy (-> fission barriers)
- Charge- and mass-distributions + fission barriers towards r-process nuclei

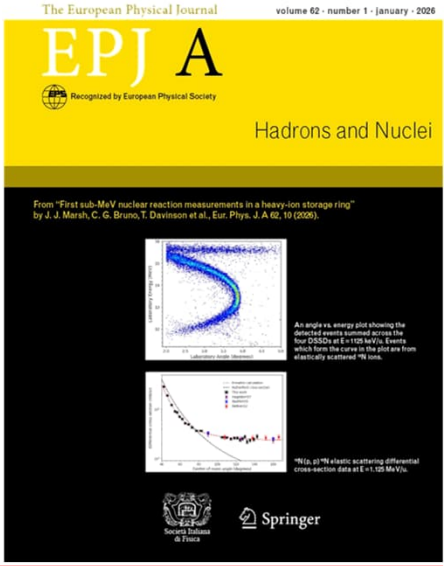
First measurement of astrophysically relevant reactions at CRYRING

J.J. Marsh et. al EPJ A 62, 10, (2026); doi: 10.1140/epja/s10050-025-01783-3

- ^{15}N(p,p) and ^{15}N(p,α) at 0,426 MeV/u
- ^{15}N from the local MINIS source





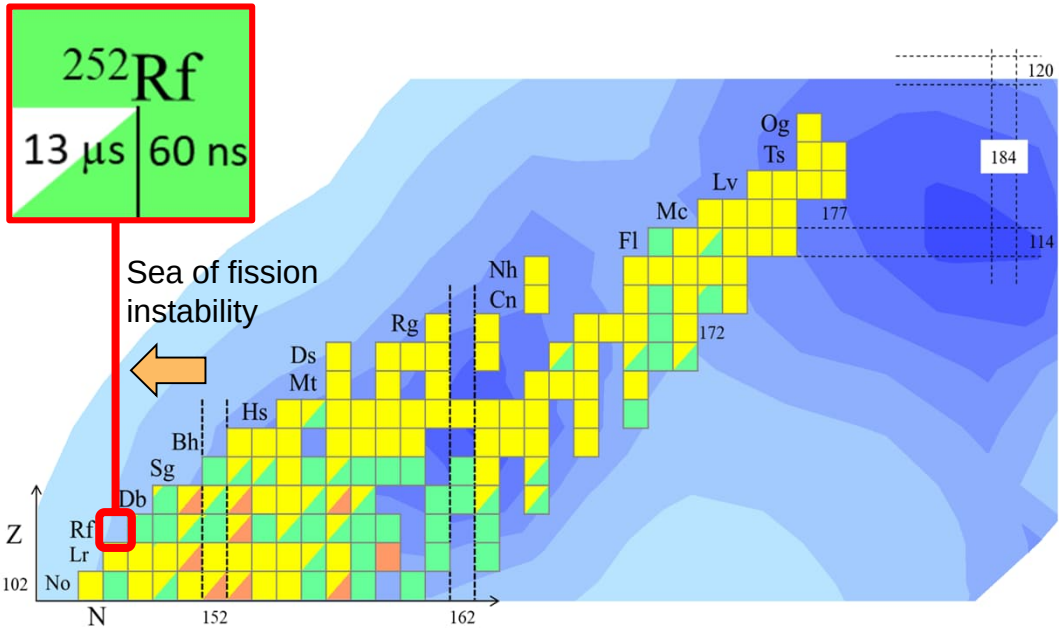


CARME at CRYRING
PI Carlo Bruno
ERC Starting Grant ELDAR

Discovery of 60-ns $^{252}_{104}$Rf: Marking the shoreline of the Island of Stability

J. Khuyagbaatar, P. Mosat et al., Phys. Rev. Lett. 134, 022501 (2025)
Editors' Suggestion / Featured in Physics

- Shoreline towards the Sea of Fission Instability is reached in the new ^{252}Rf
- Detection only possible thanks to longer-lived high-*K* state



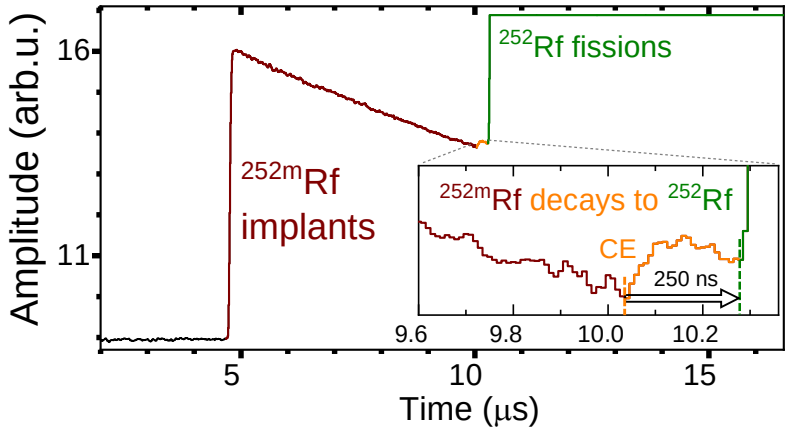
Prediction: "**Clouds of stability**" of superheavy nuclei

K-isomeric state (Rf-252m): **50 µs**
Ground state (Rf-252): **100 ns**
J. Khuyagbaatar, Eur. Phys. J. A 58, 243 (2022).

Experiment: ^{50}Ti+^{204}Pb @**TASCA**

K-isomeric state (Rf-252m): **13^{+4}_{-3} µs**

Ground state (Rf-252): **60^{+90}_{-30} ns**

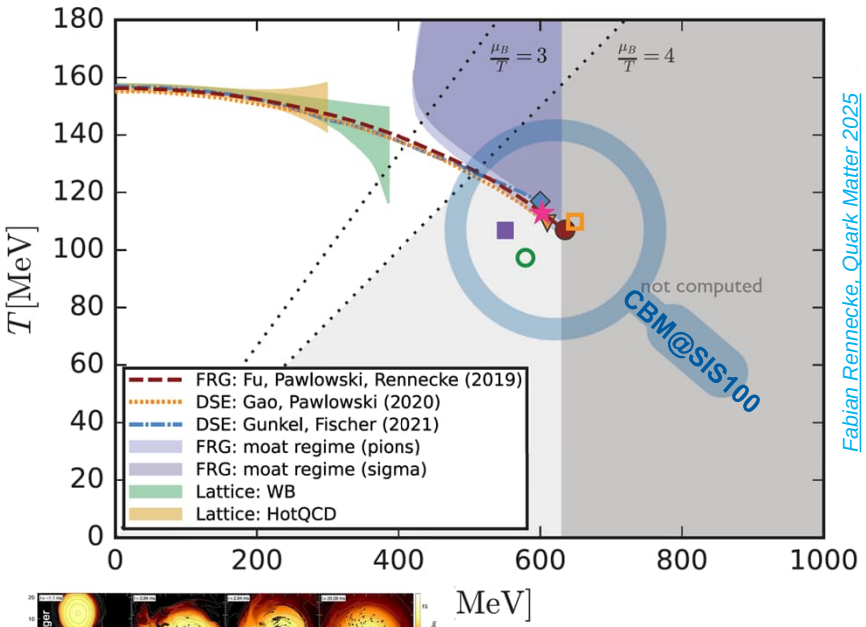


SHE Chemistry

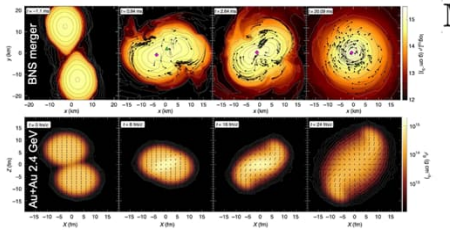
CBM – Compressed Baryonic Matter

Final setup in cave including HADES

CBM Mission – *Explore strong-interaction matter at high(est) net-baryon densities*



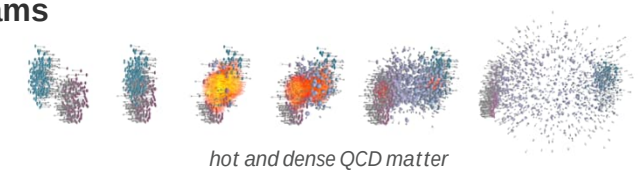
Fabian Rennecke, Quark Matter 2025



Search for landmarks of the QCD matter phase diagram:

- isolate unambiguous signals of new phases of QCD matter, order of phase transitions, conjectured QCD critical point
- establish high net-baryon density EoS
- probe microscopic matter properties

→ **heavy-ion beams**

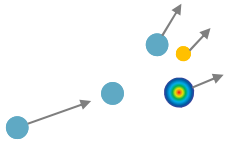


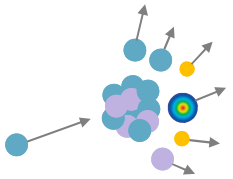
hot and dense QCD matter

Study various aspects of meson/baryon physics:

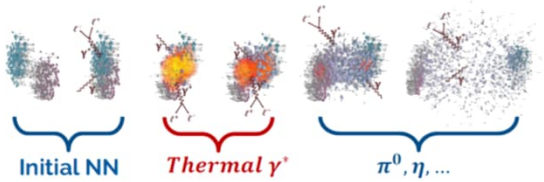
- (*u, d, s, c*) hadron production mechanism, spectroscopy (|*s*|=*2,3,* |*c*|=*1*), interactions, hadron structure
- electromagnetic transition form-factors

→ **p, d beams**

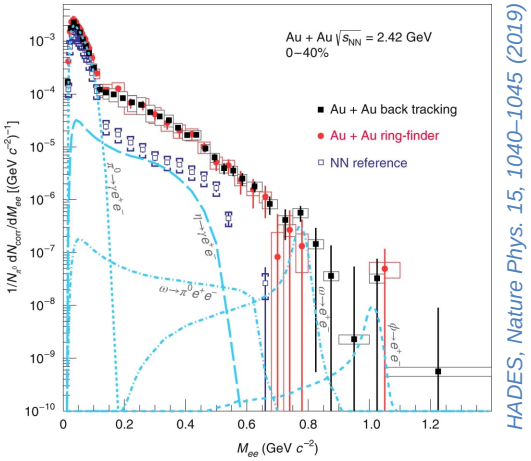




Some highlights
… Accessing dense matter with dileptons at HADES



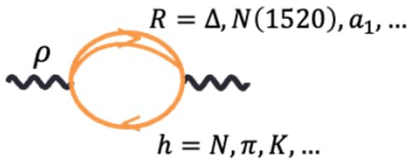
Measured signal is integral over whole evolution



HADES, Nature Phys. 15, 1040–1045 (2019)

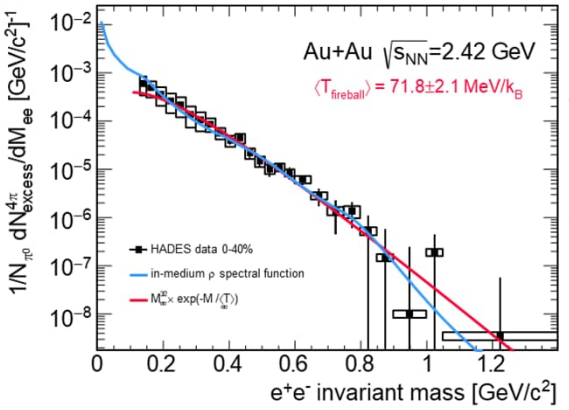
→ isolate thermal contribution

- radiation explained by medium modified vector mesons (VMD, „radiation of the cloud“)



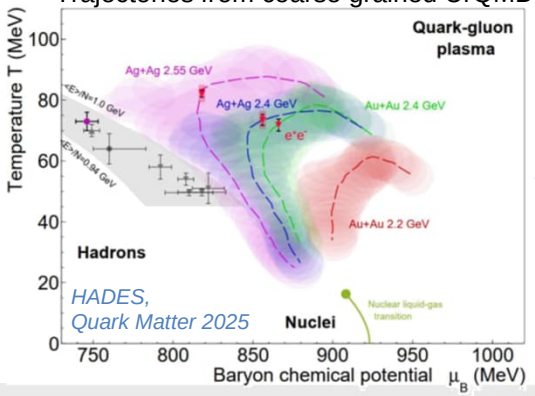
Rapp, van Hees;arXiv:1411.4612v

- spectral distribution reproduced by a fit assuming thermal radiation
- significantly higher temperatures at higher beam energies
- no indication of ρ-meson at lower beam energies
- spectral distribution provides information on
  - ρ-a_1 mixing (chiral symmetry restoration)
  - caloric curve



HADES, Nature Phys. 15, 1040–1045 (2019)

Trajectories from coarse grained UrQMD



HADES, Quark Matter 2025

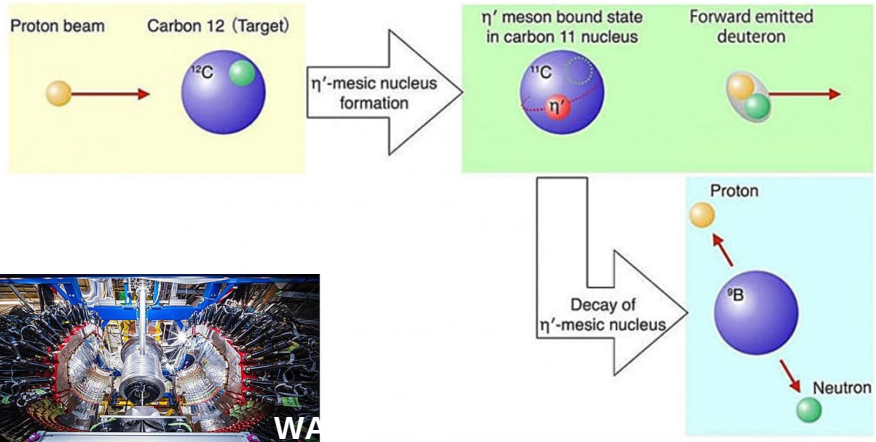
HADES, Quark Matter 2025

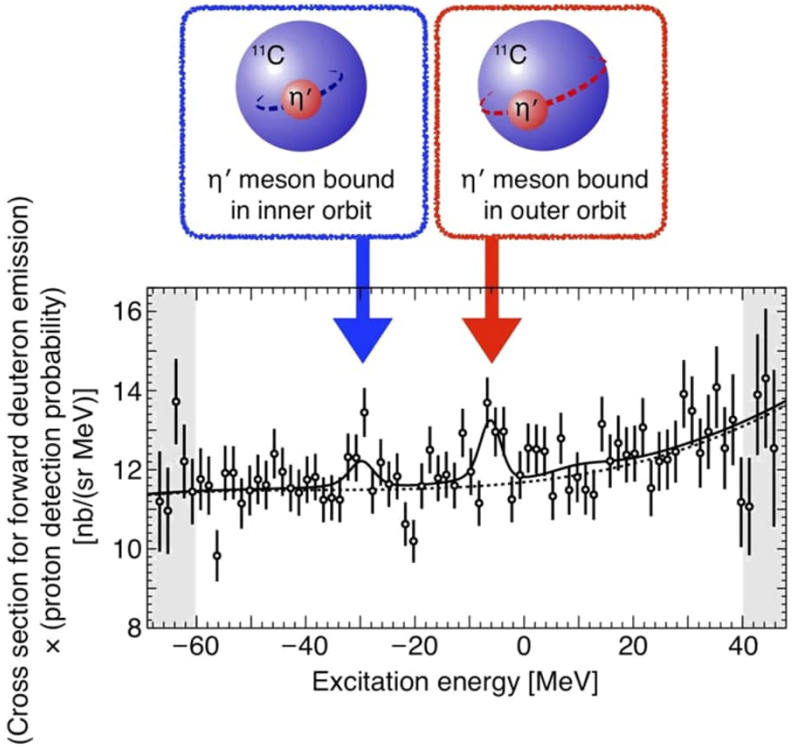
Where does mass come from?
First signal of bound η' mesons in nuclei

R. Sekiya et al., Phys. Rev. Lett. ***136***

Super-FRS EC

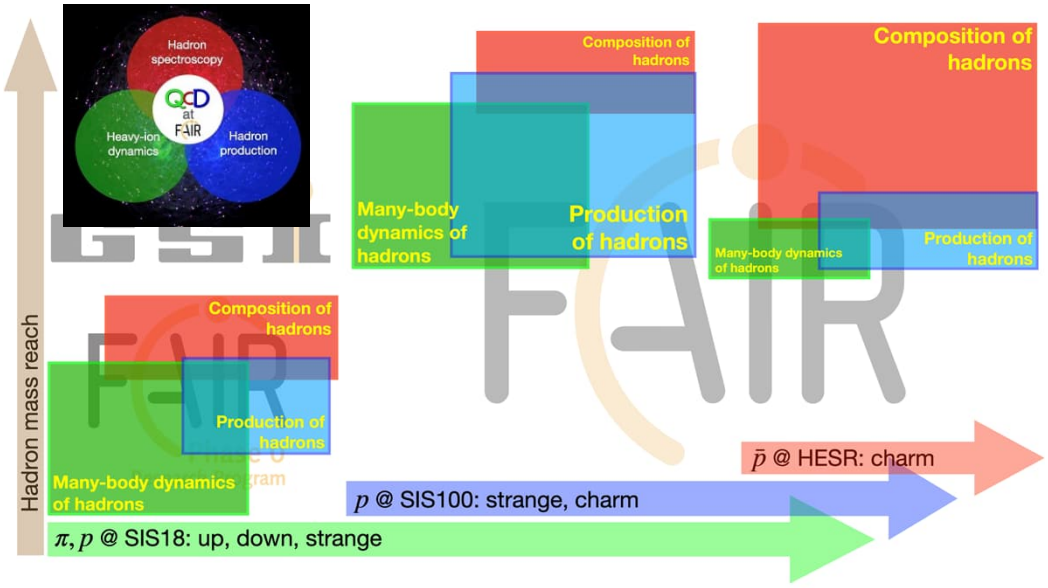
First detection of a system consisting of a ^{11}C nucleus and a η′ meson





Talk by V. Metag

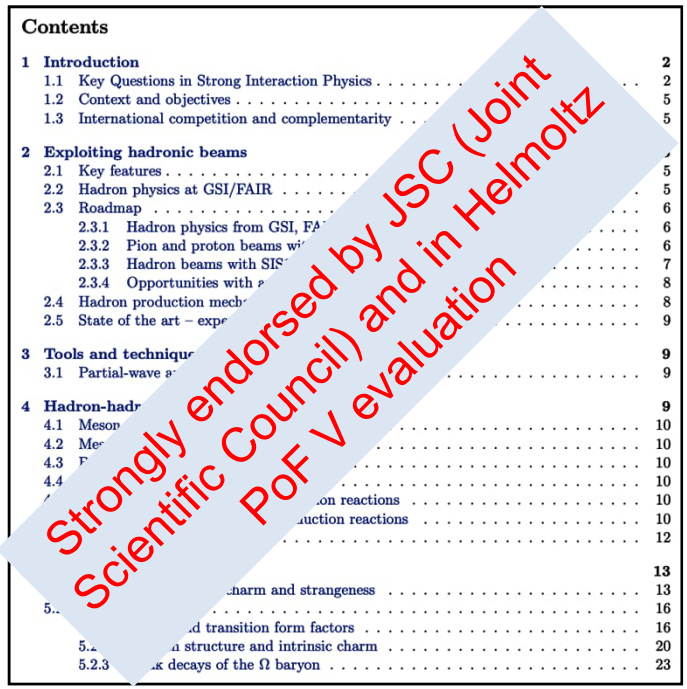
Pion- and proton-induced QCD studies at GSI/FAIR
Hadron physics with CBM, HADES, and NUSTAR



Roadmap

- **Versatile** program during the various phases of FAIR
- **FAIR Phase0**: pions/protons at HADES@SIS18
  - **FS+**: protons at CBM@SIS100
    - …towards antiprotons at HESR

Hadron Physics at GSI and FAIR: Prospects for the Next Decade


Contents

1 Introduction 2
1.1 Key Questions in Strong Interaction Physics . . . 2
1.2 Context and objectives . . . 5
1.3 International competition and complementarity . . . 5

2 Exploiting hadronic beams
2.1 Key features . . . 5
2.2 Hadron physics at GSI/FAIR . . . 5
2.3 Roadmap . . . 6
2.3.1 Hadron physics from GSI, FA . . . 6
2.3.2 Pion and proton beams wi . . . 6
2.3.3 Hadron beams with SIS . . . 7
2.3.4 Opportunities with a . . . 8
2.4 Hadron production mech . . . 8
2.5 State of the art – expe . . . 9

3 Tools and techniqu 9
3.1 Partial-wave a . . . 9

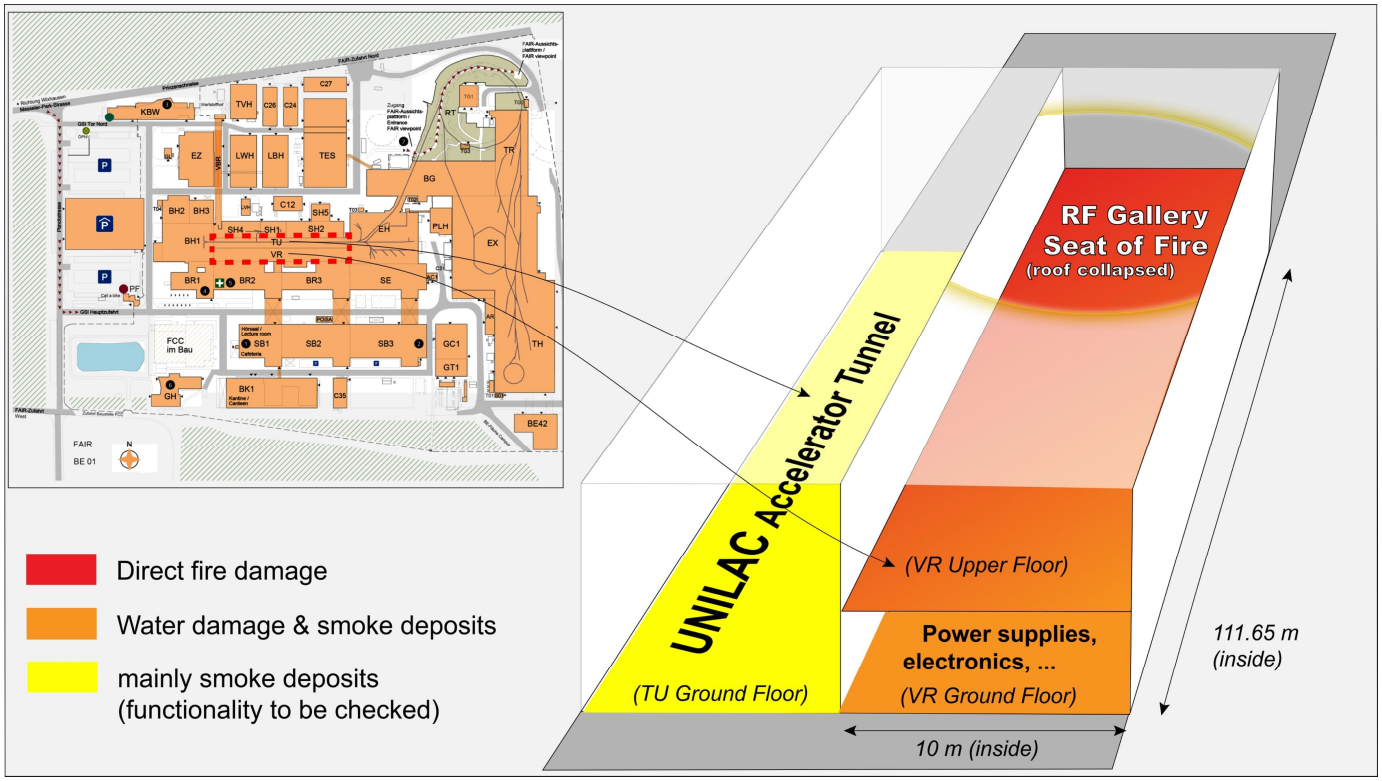
4 Hadron-hadr 9
4.1 Meson . . . 10
4.2 Me . . . 10
4.3 . . . 10
4.4 . . . 10
. . . on reactions . . . 10
. . . uction reactions . . . 10
. . . 12
. . . 13
5. . . harm and strangeness . . . 13
5. . . 16
. . . d transition form factors . . . 16
5.2 . . . n structure and intrinsic charm . . . 20
5.2.3 . . . decays of the Ω baryon . . . 23

Strongly endorsed by JSC (Joint Scientific Council) and in Helmoltz PoF V evaluation

Fire incident at GSI on February 5, 2026

- On February 5, 2026, at around 6:00, a major fire broke out at GSI.
- The fire originated in the area of the radiofrequency (RF) supply for the UNILAC linear accelerator at GSI.
- The reporting chains and the GSI/FAIR crisis management team functioned efficiently. Cooperation with the fire brigade and the authorities proceeded smoothly.
- Approximately 200 emergency personnel were on site.
- The fire was completely extinguished by Friday morning, February 6, 2026.

Location of the fire



Information regarding the fire incident

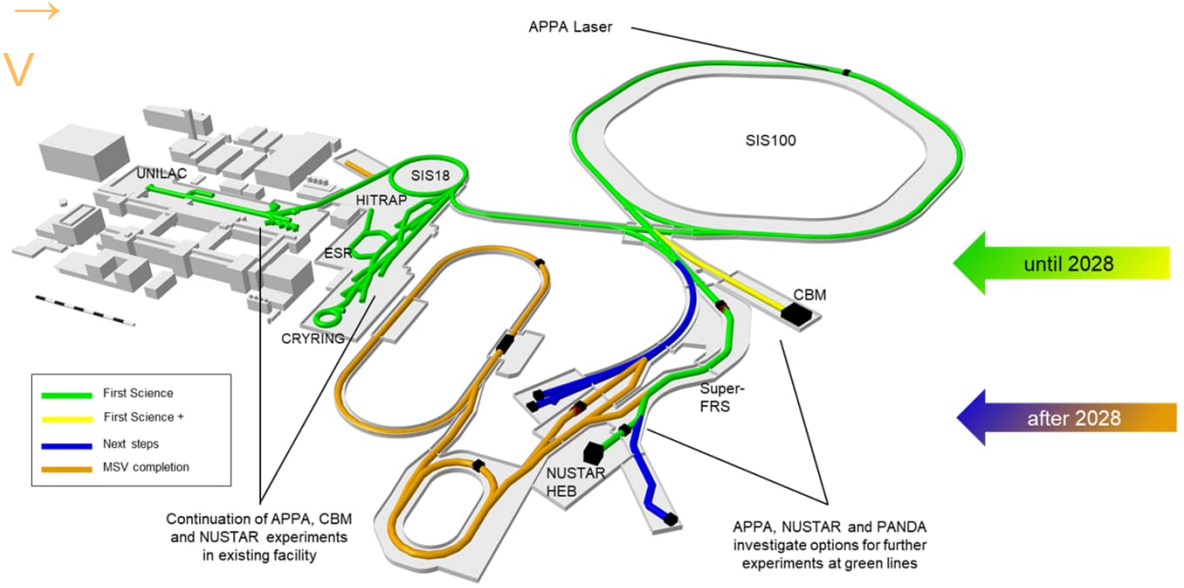
- **No persons were injured**, neither on the GSI site at the time of the fire nor among the emergency personnel.
- The fire department conducted measurements at the fire site and throughout the city. **No hazardous substances were detected during the entire operation**. There was no danger to the public.
- **Damage assessment is ongoing**
- **Fire safety systems operated as planned**
- Many experimental and infrastructure areas at GSI **were not (directly) affected**, including:
  - **SIS18 synchrotron** and its associated **experimental facilities** (ESR, FRS, CRYRING, HITRAP, HADES, R3B…)
  - **PHELIX high-power laser** and the **GreenITCube** data center
  - The vast majority of offices remain usable (entire South Building, KBW, and BK1), as well as the cafeteria and canteen
  - The **FAIR construction site was not affected**. On-site work resumed without restrictions on Friday, 06.02.2026

- The overarching objective is to rapidly **identify solutions for the continuation of research** in close collaboration with the scientific community. Objectives:
  - Beams for FAIR commissioning by Q4 2027
  - Intermediate injector for FAIR2028 by Q4 2028

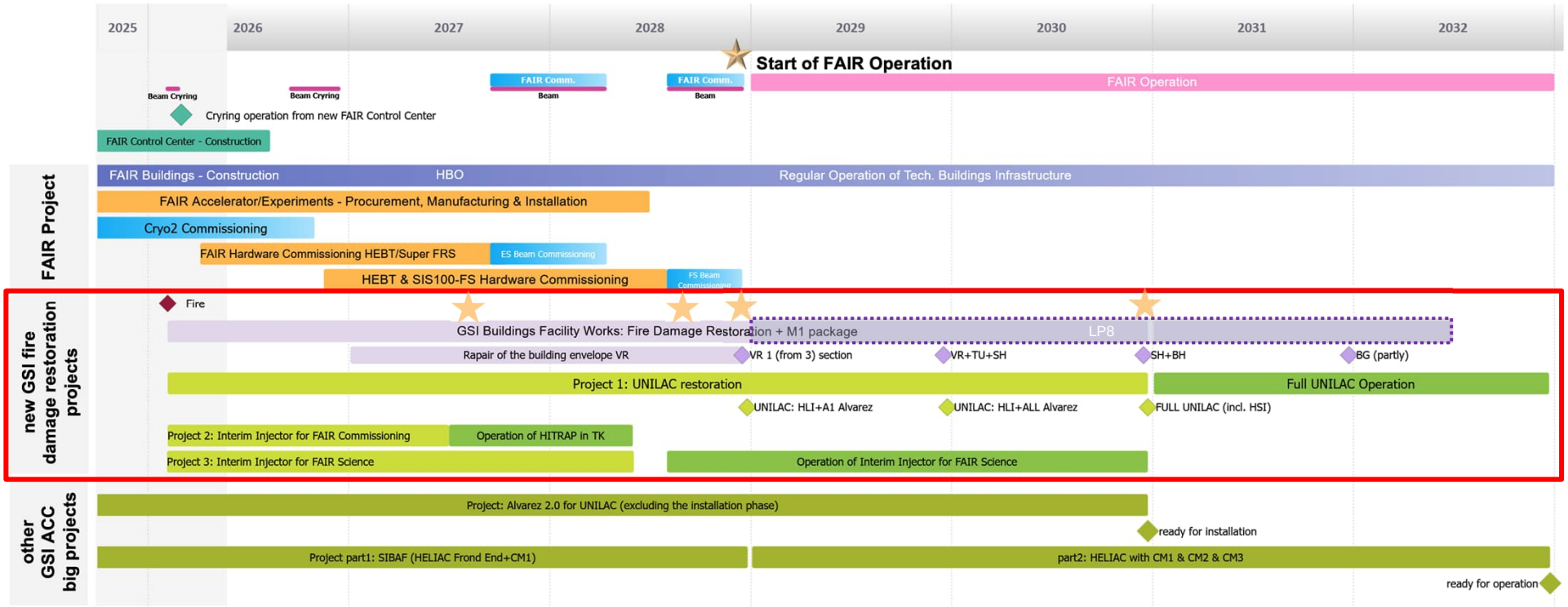
Following fire: Scientific priorities

No priority change due to fire:

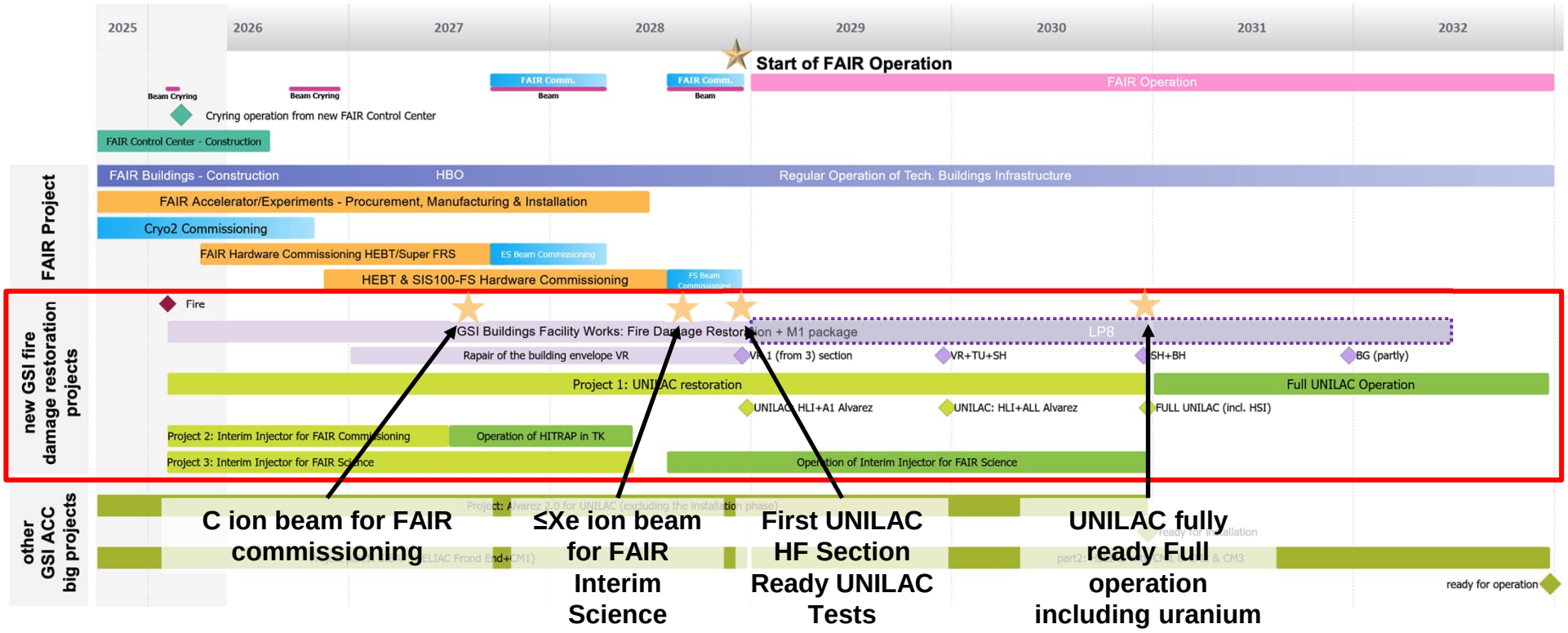
- FAIR / GSI research → FAIR2028 and POF V experiments



Integrated Campus Schedule



Integrated Campus Schedule



Research Perspectives and Beam Requirements

Short term (1-2 years):

- Experiments with **available beams, alternatives for science**

Mid term (3-5 years):

- Resumption of the full physics program
- **FAIR2028** (possibly delayed)

Long term (>5 years):

- Ensuring research dependent on long beam-pulse structure - **superheavy elements, parts of materials research and fusion-related research** and redundancy of the injector chain

- Beams for commissioning the FAIR machines and detectors (min. 12C) in Q4/2027
- Heavy ion beams (up to Xe or heavier) for an intermediate science program latest Q4/2028 until Q4/2030
- Full GSI/FAIR capabilities with UNILAC as a high-intensity short-pulse machine within Q4/2030
- HELIAC for long-pulse operation as of 2032

2027: start FAIR Commissioning with beam

min. ^{12}C-beam at low intensity (1E7-1E8/spill, $^{12}C^{5+}$ up to 1,5GeV/u)
(PARTIH I HITRAP in transfer channel)

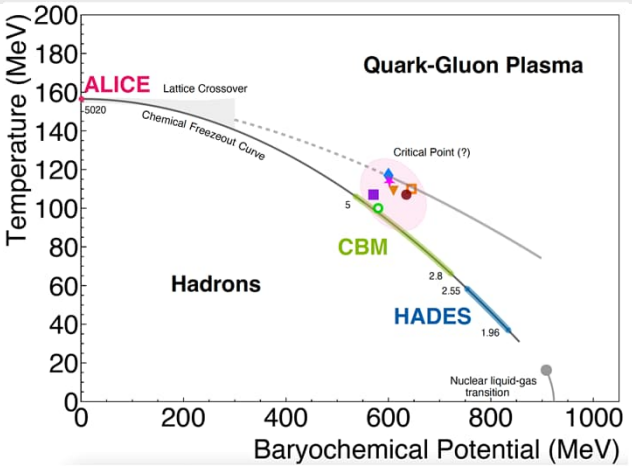
- Main focus: **technical commissioning** with beam of FAIR HEBT (beam transport lines) and Super-FRS

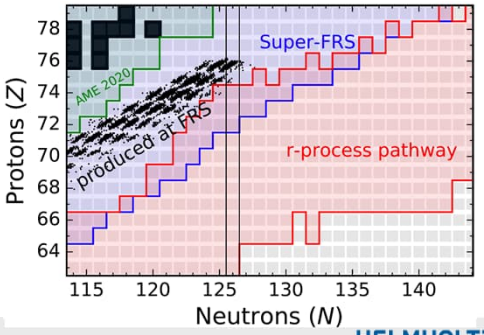
- Beam parameters not sufficient for a broad competitive user beamtime, focus is on detector tests and selected experiments (e.g. BIO)

2028 – 2030: Further commissioning and intermediate science

min. Xe-beam at medium intensity (InterLAC)

- Commissioning
  - accelerators Super-FRS, SIS100 commissioning
  - detectors for NUSTAR (Super-FRS, R3B), CBM and APPA-Laser experiments
- **Adapted FAIR 2028 science programme** for all communities. Examples are:
  - Measurements with light and medium heavy beams at CBM
  - Galactic cosmic ray simulator at 10 GeV/u (biophysics/ESA)
  - Adapted NUSTAR FS program with focus on R3B with light and medium heavy RIBs



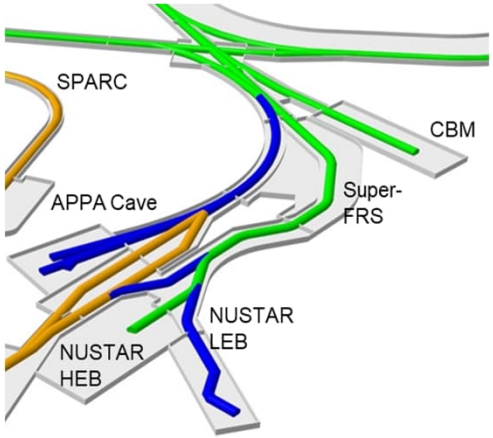


Next steps FS++

APPA cave serving:

- atomic physics
- plasma physics
- biophysics
- material science
- …

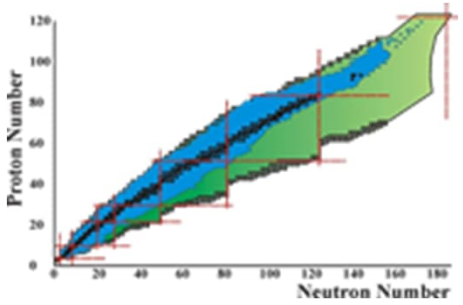
Strong relevance for fusion research!

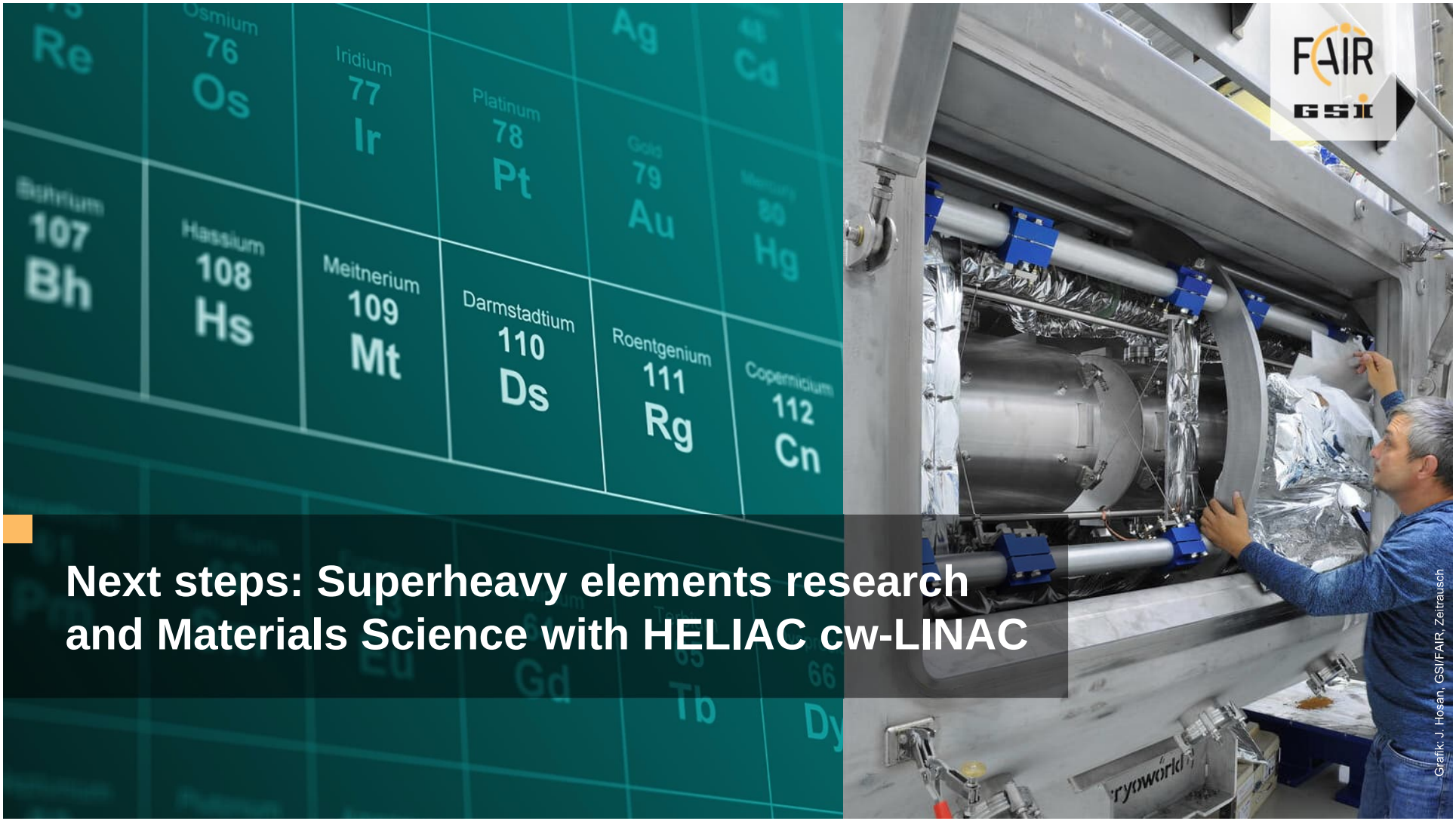


NUSTAR LEB serving:

- high-resolution gamma-ray spectroscopy with AGATA
- decay spectroscopy
- mass measurements
- laser spectroscopy

…




Osmium
76
Os
Iridium
77
Ir
Platinum
78
Pt
Gold
79
Au
Bohrium
107
Bh
Hassium
108
Hs
Meitnerium
109
Mt
Darmstadtium
110
Ds
Roentgenium
111
Rg
Copernicium
112
Cn
FAIR
GSI
Next steps: Superheavy elements research
and Materials Science with HELIAC cw-LINAC
Grafik: J. Hosan, GSI/FAIR, Zeitrausch

Conclusions

- FAIR is steadily progressing towards delivering science
  - Construction and commissioning on a good path
  - GSI UNILAC fire will not delay the start of FAIR2028, albeit with a modified programme
- The scientific scope of FAIR2028 will entail a world-leading scientific programme
  - Full exploitation of the approved construction scope including adaptations
- Moderate further steps will lead to a strong scientific payback
  - APPA and NUSTAR LEB caves constructed
  - HELIAC superconducting cw-LINAC
- Path defined towards science with storage rings and antiprotons/PANDA
  - Remains construction goal of FAIR convention, currently no resource-loaded schedule


Thank you for your attention!