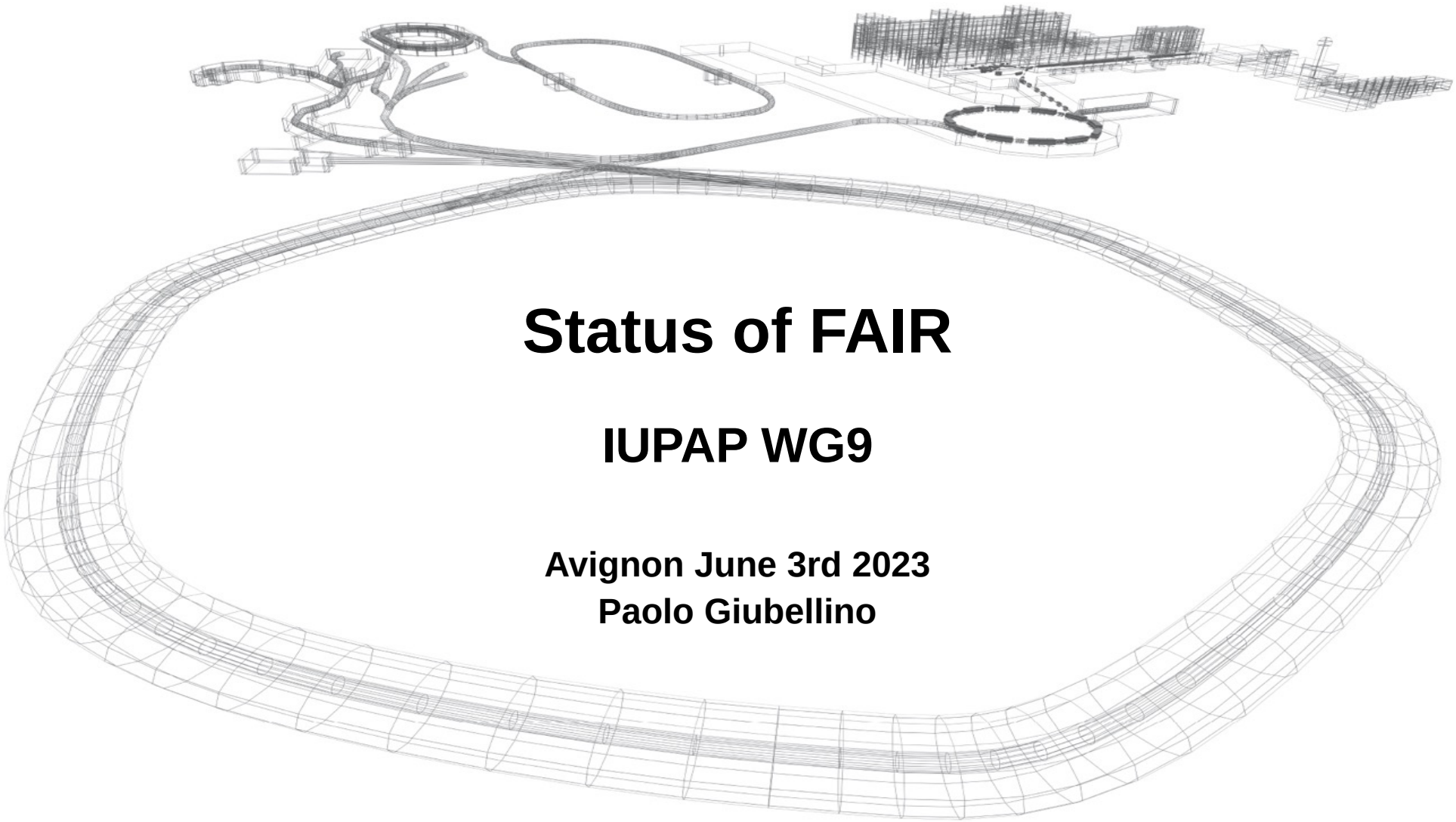


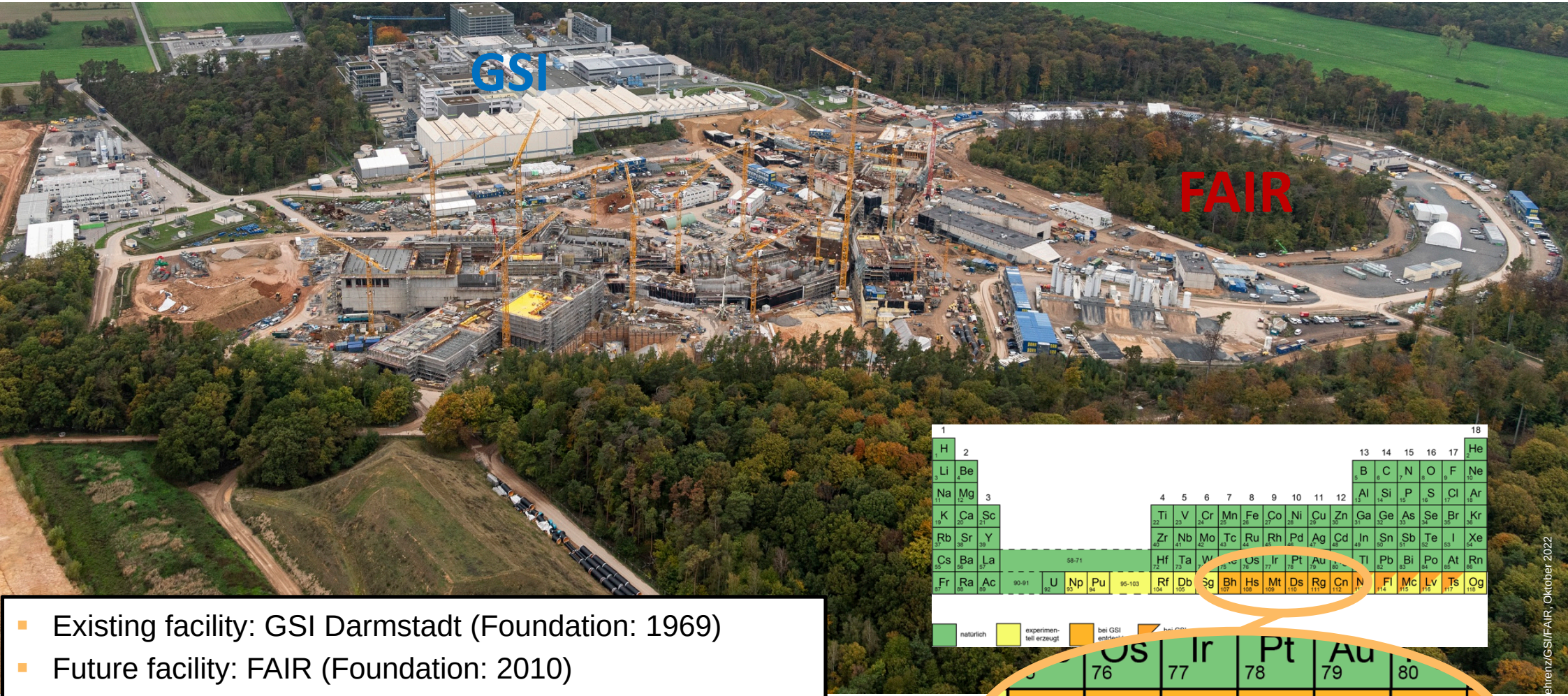
Status of FAIR

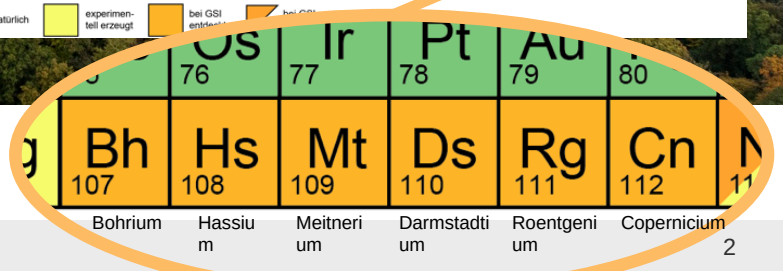
IUPAP WG9

Avignon June 3rd 2023

Paolo Giubellino

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



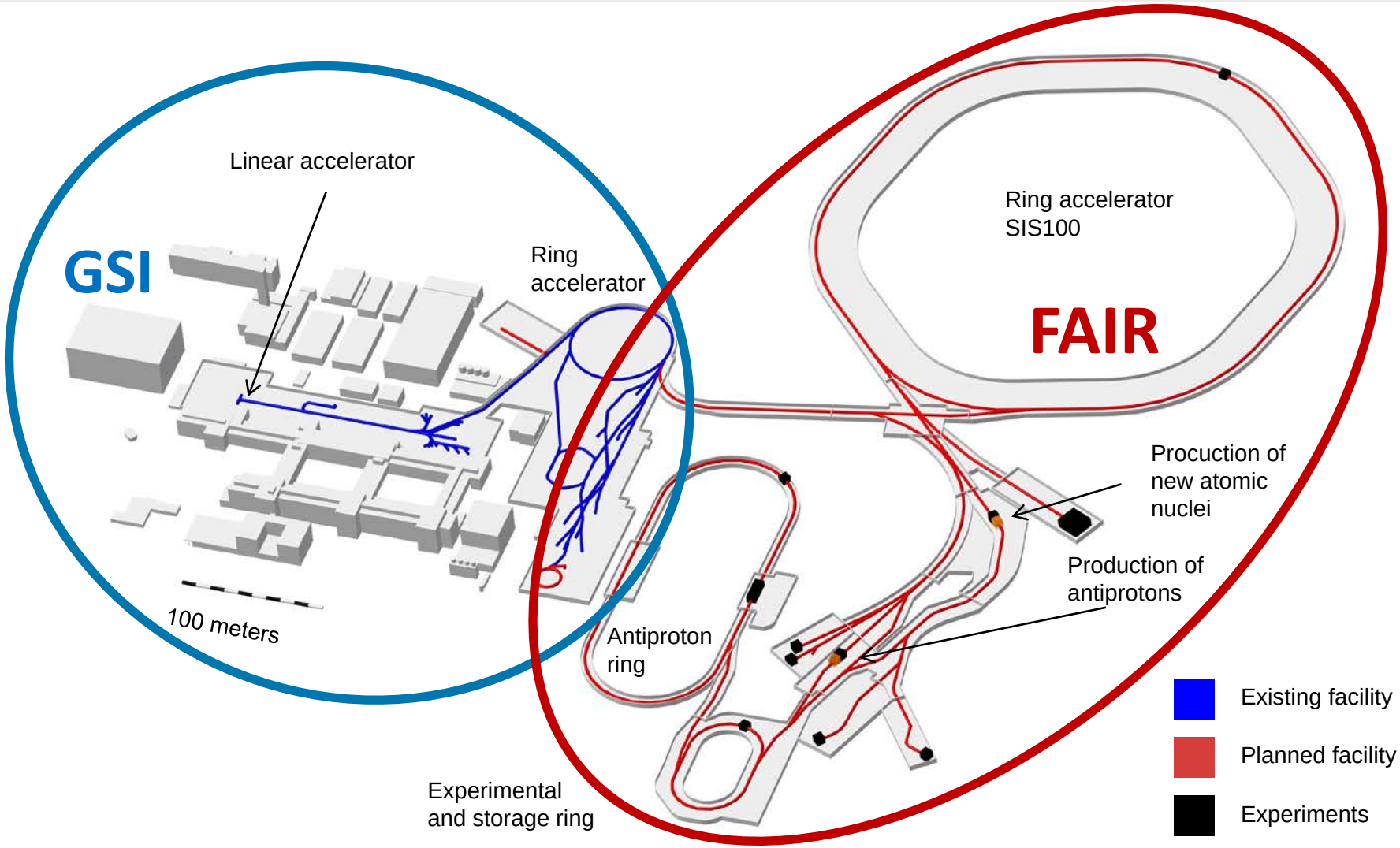


- Existing facility: GSI Darmstadt (Foundation: 1969)
- Future facility: FAIR (Foundation: 2010)
- Landmark in the European research roadmap (ESFRI
- Employees on location: approx.1580

FAIR: a World-wide project

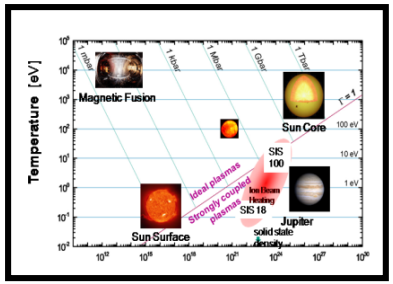
- FAIR governed by international convention
  - 9 shareholders:
  - + 1 associated partner:
  - + 1 aspirant partner:
  - Over 3000 Scientists and Engineers from all over the world
- More than 200 institutions from 53 countries are involved with their scientists (orange + blue)

GSI/FAIR – The facility



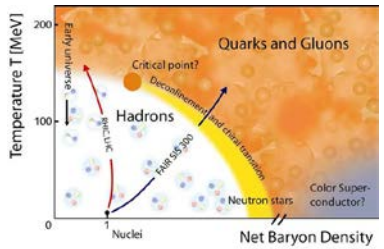
- Intensity
- Precision
- Storage rings

The FAIR science: four pillars



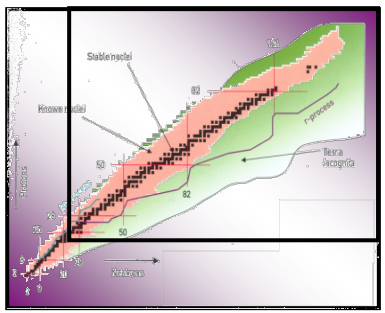
atomic physics, biophysics,
plasma physics, material research

APPA



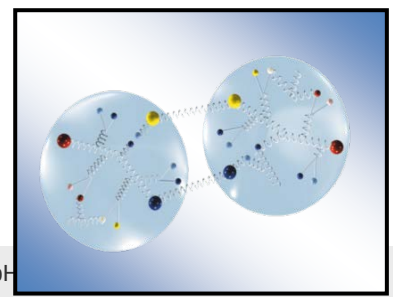
nuclear- and quark-matter

CBM



nuclear structure and
nuclear astrophysics

NuSTAR



hadron structure and dynamics

PANDA

Civil Construction

Movie on
https://edms.cern.ch/file/2893949/LATEST/FAIR*.mp4

FAIR SIS100 accelerator tunnel

FAIR SIS 100 supply tunnel

April 2023

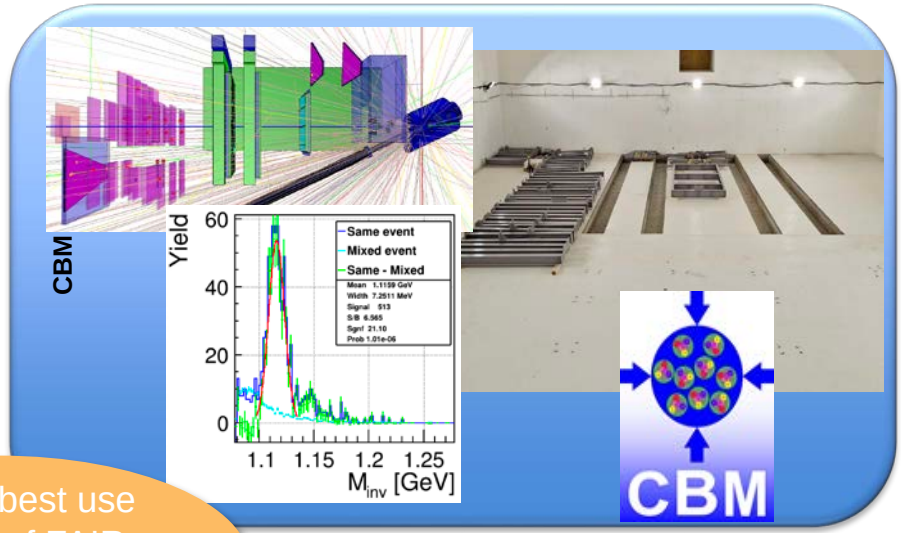
FAIR Area South

FAIR CBM Cave

Accelerators: delivery of components continues steadily

- Storage area: approx. 9.900 m²
- 4.195 objects (Components, assemblies, boxes, etc.)
- 50% of SIS100 components stored
- 90% of HESR components stored

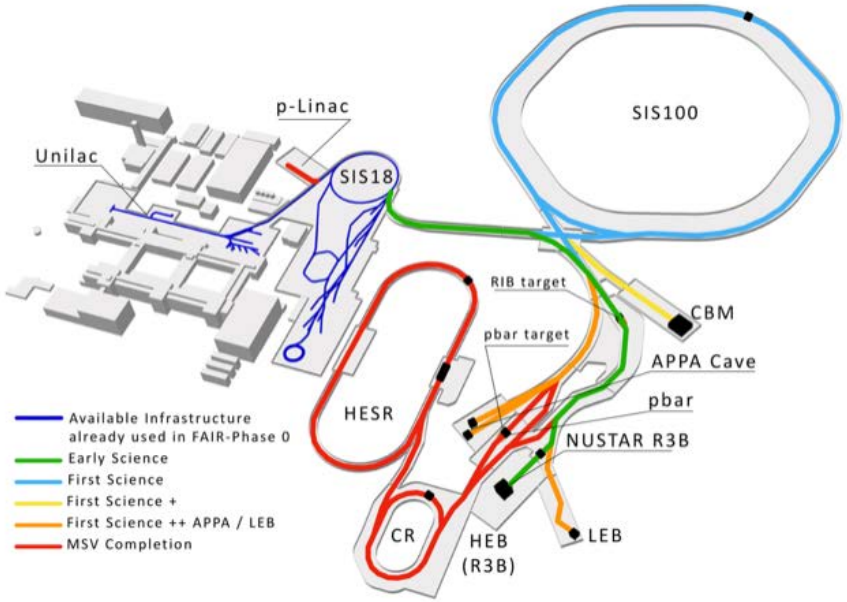
Experiment Construction



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

Current status following FAIR Council decisions in March 2023

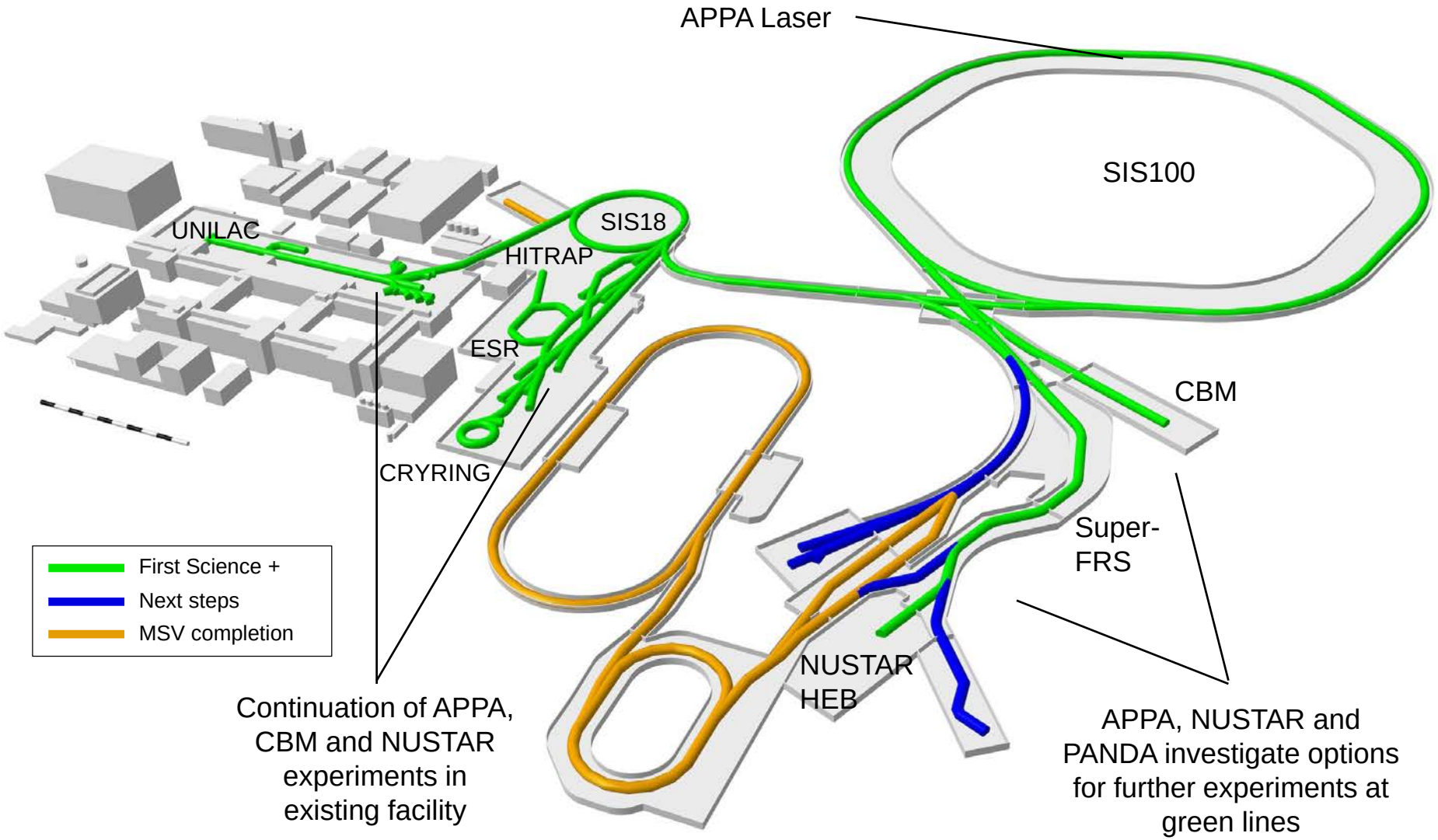
- Due to budget constraints a Scientific Review panel was tasked by the FAIR Council in 2022 to perform a “First Science and Staging Review of the FAIR Project”.
- The Scientific Review panel recommended in October 2022 that the scenario FS+ (SIS100, Super-FRS-HEB and CBM) would be the most appropriate starting scenario to achieve world leading science.
- FAIR Council decided on 9th & 10th March 2023 to use the additional funds provided by Germany to proceed with FS and to make further decisions on FS+ based on the contributions by other shareholders in future meetings, possibly already in July 2023. Council stated that “*the realisation of the MSV… …remains the aim of the FAIR-Project*”



until 2028 (ES,FS,FS+)

after 2028

FAIR 2028


APPA Laser
SIS100
UNILAC
SIS18
HITRAP
ESR
CRYRING
CBM
Super-
FRS
NUSTAR
HEB
First Science +
Next steps
MSV completion
Continuation of APPA, CBM and NUSTAR experiments in existing facility
APPA, NUSTAR and PANDA investigate options for further experiments at green lines

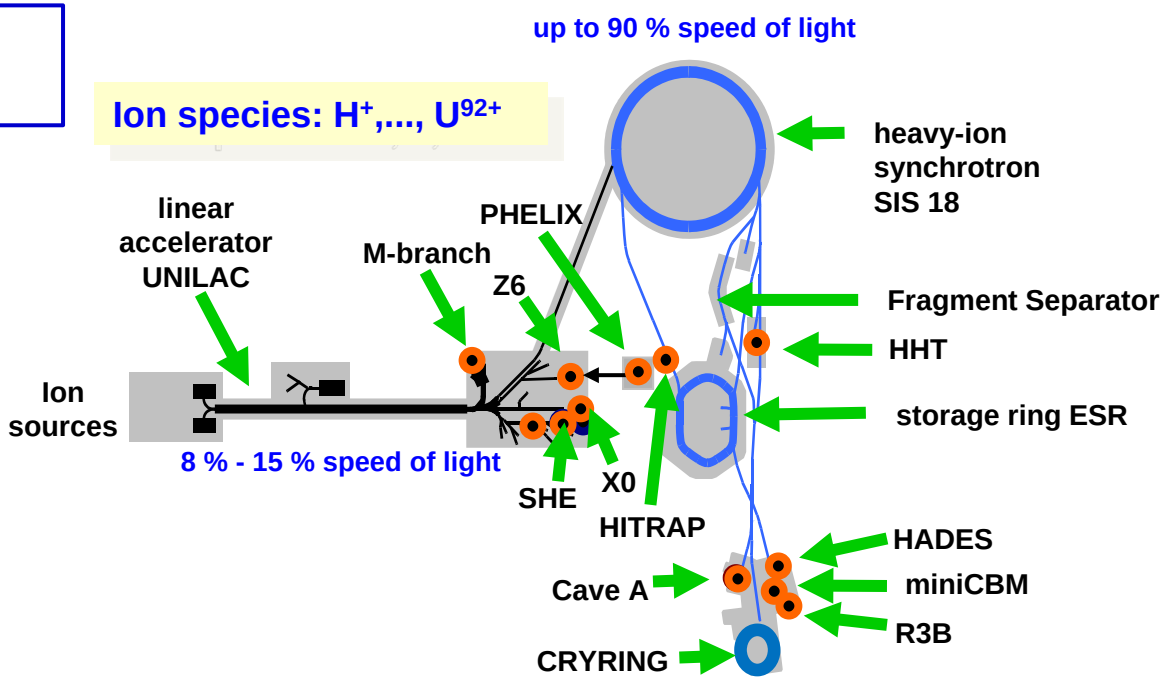
Evolution towards FAIR 2028

- Up to 2025 we continue with FAIR the annual block of continuous beamtime for Phase-0, from 2026 onwards we enter the mixed-mode of Phase-0 with the commissioning of the new beamlines.
- Annual beamtime 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.

- The construction of further components towards the completion of the MSV will require additional funding. If provided by ~ 2026, the MSV could be completed by 2031-2032. The timetable is dictated by the availability of funds

Ongoing: Early science program FAIR Phase-0

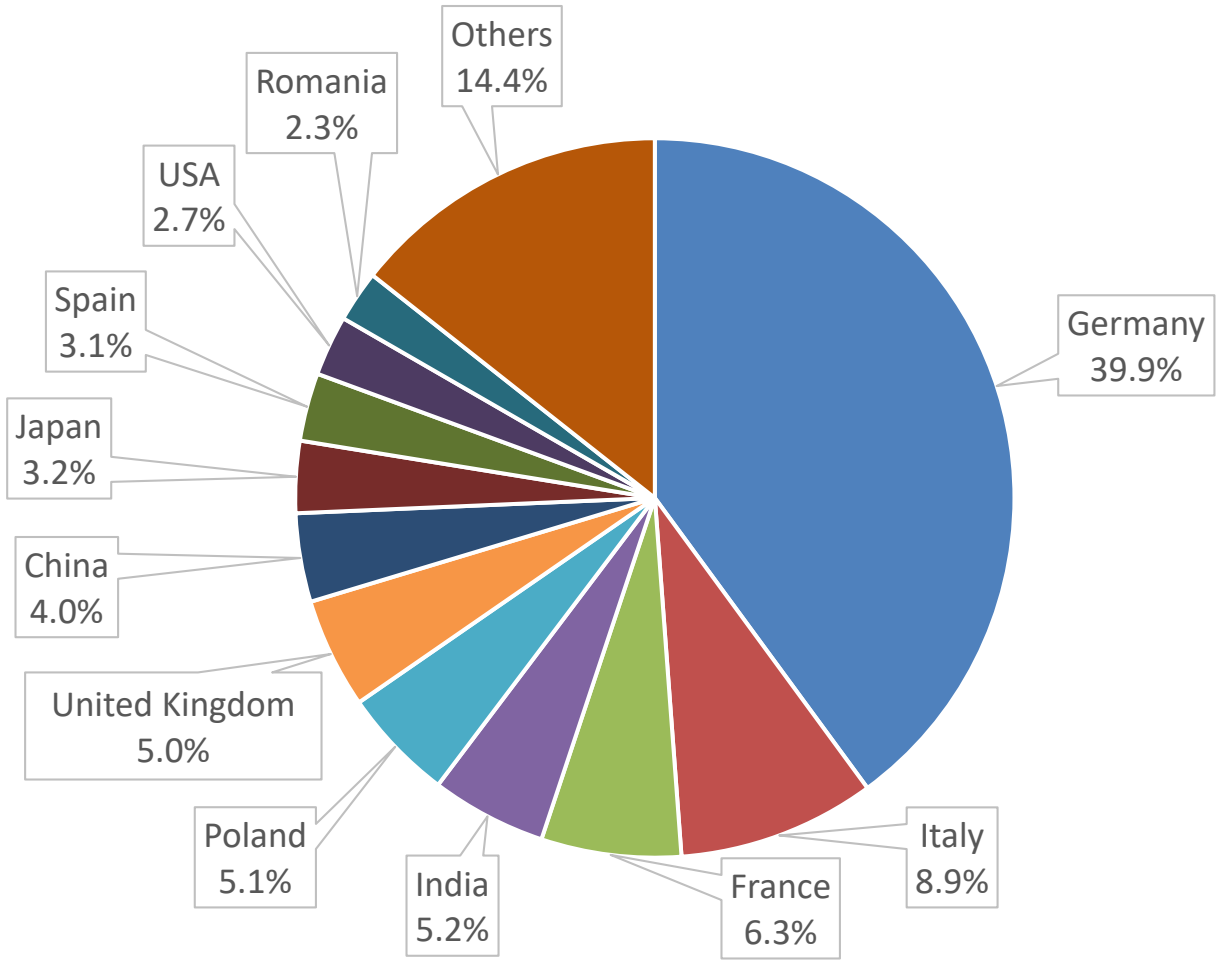
- Started in 2019, annual runs of ~110 days until FAIR operation



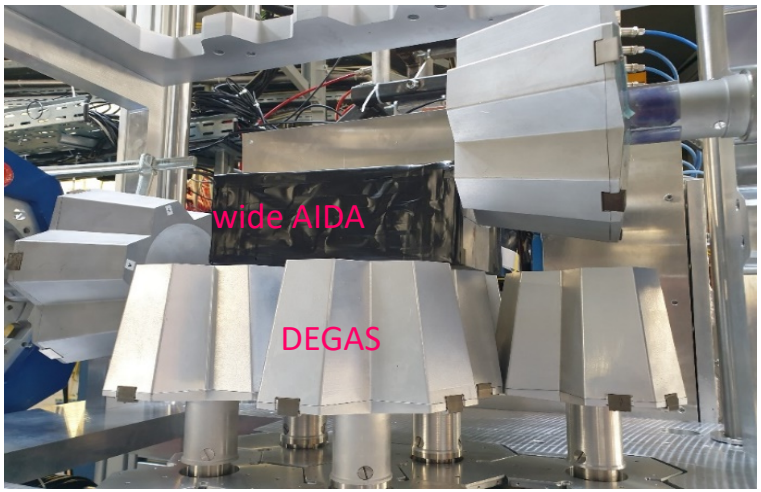
- Science while commissioning FAIR
  - 2021 and 2022 runs completed as planned
  - The program will continue in the coming years
  - Up to 2025 we continue with FAIR Phase-0, from 2026 onwards we enter the mixed-mode with the commissioning of the new beamlines

Beamtime proposals 2022

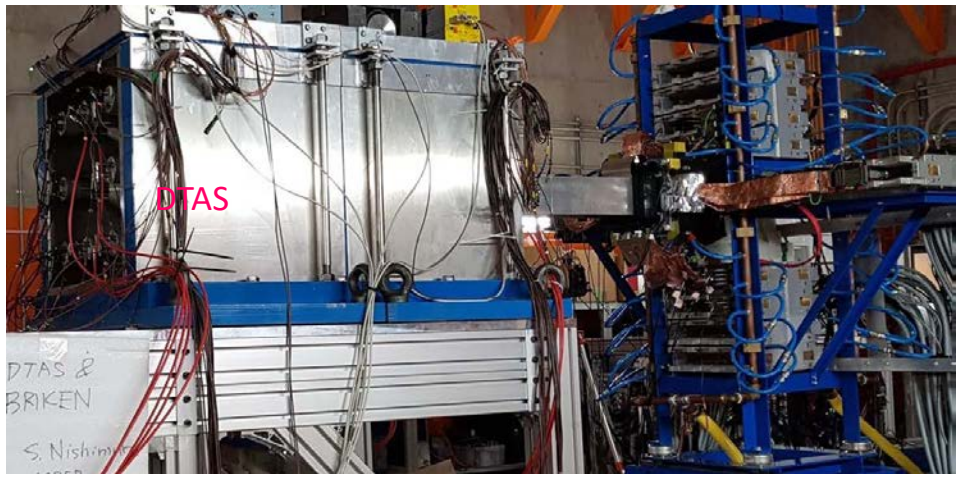
- 124 proposals submitted (to all 4 PACs: G-PAC, Mat-PAC, Bio-PAC and PPAC)
- 1729 participants of proposals
- From institutes in 45 countries (15% internal users)
- Committee evaluation took place in September 2022
- Beamtime granted in October 2022



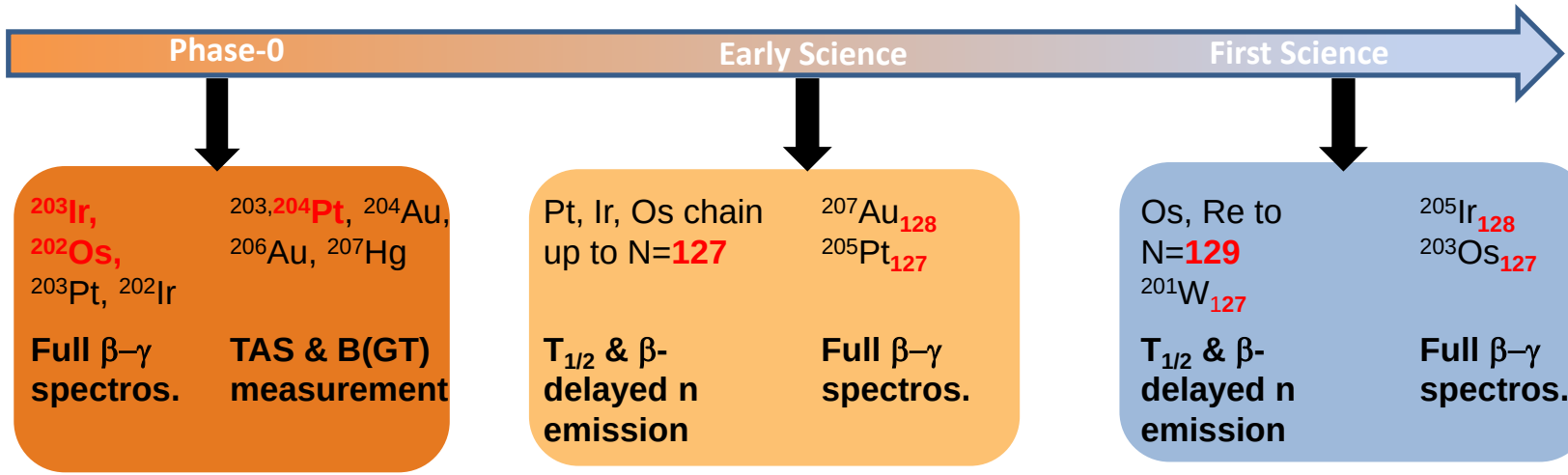
NUSTAR:
DESPEC set-ups prepared for Phase-0 and ready for ES/FS



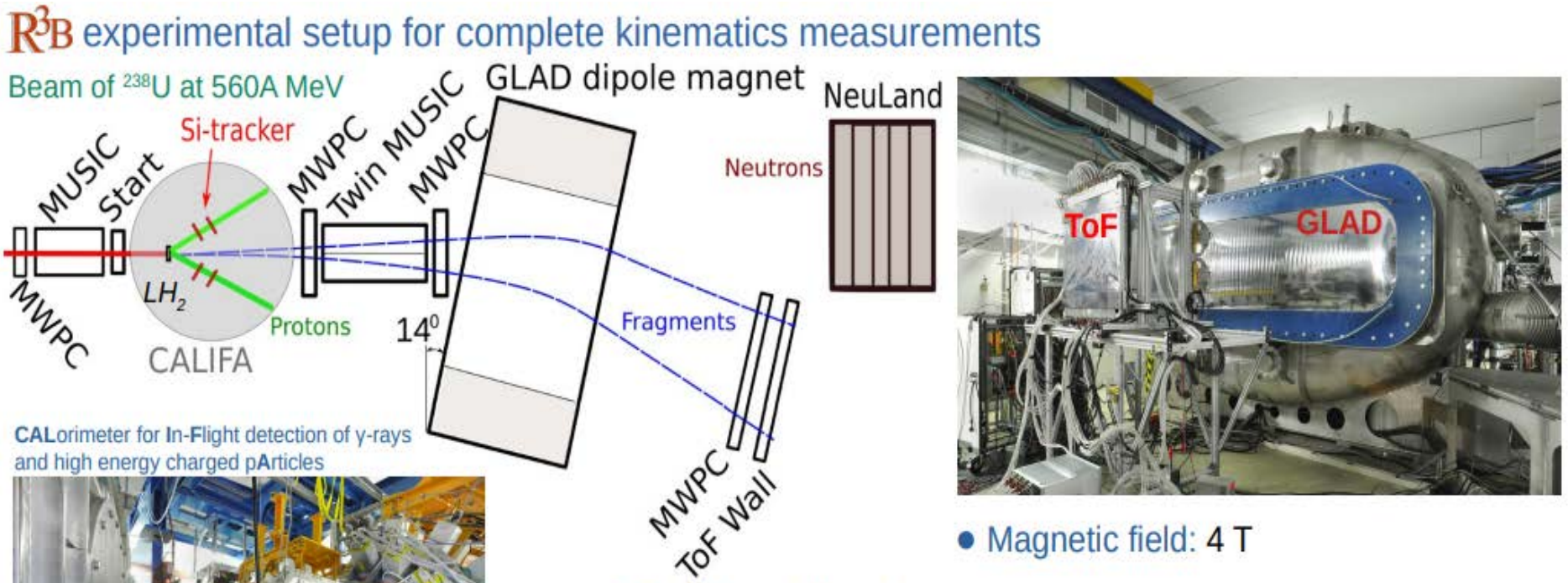
DESPEC High-resolution set-up with novel DEGAS Ge detectors



DESPEC High-efficiency set-up with the DTAS Total Absorption Spectrometer



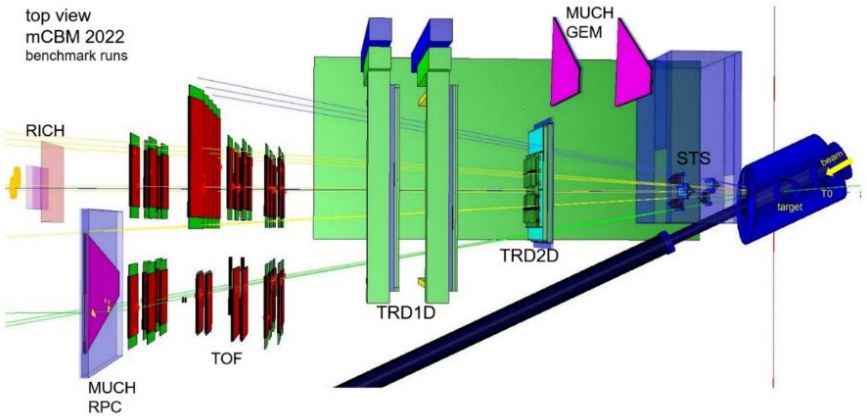
NUSTAR:
R3B set-ups prepared for Phase-0 ready for ES/FS



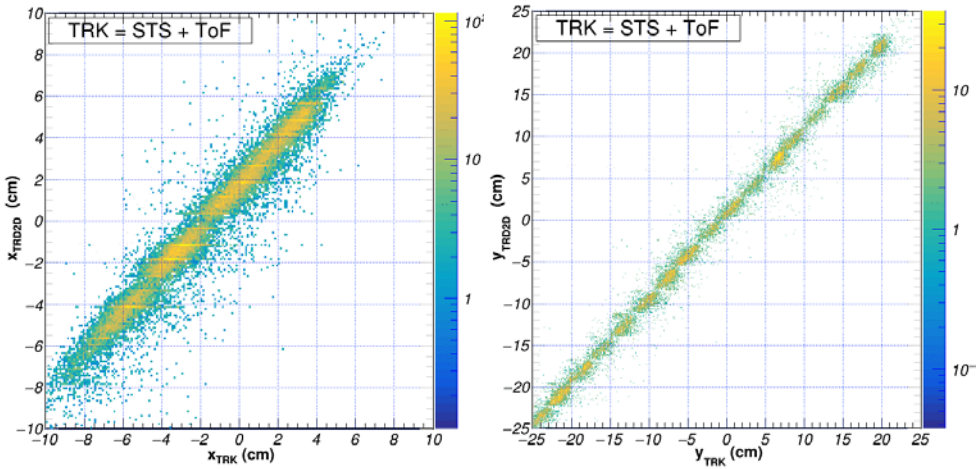
- Magnetic field: 4 T
- CALIFA and Si-tracker: Proton momenta and γ-rays
  Energy res. protons(gamma) 1%(5% at 1 MeV), Position res. 70µm
- MUSIC, ToF wall and MWPC detectors: Fission fragments
  ΔZ~0.37 , ToF~40ps, Position res. 200µm (FWHM)
- NeuLand: Neutron multiplicities (max. 10 neutrons)

mCBM: Data analysis in progress

Ni + Ni collisions at 1.93 AGeV

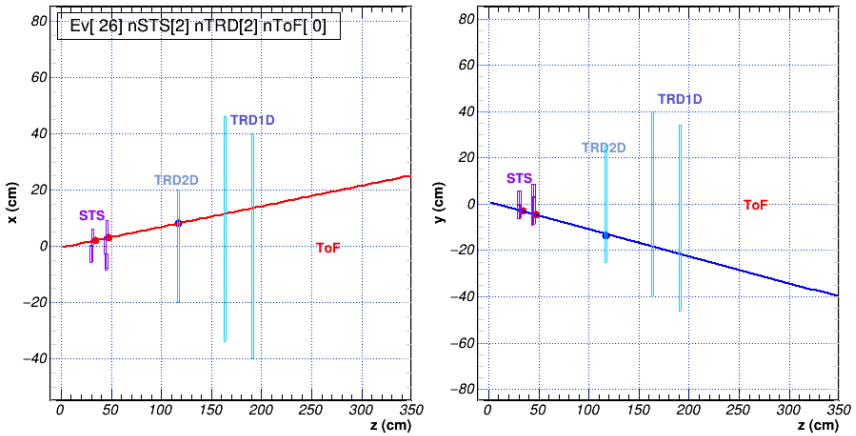


TRD2D hit

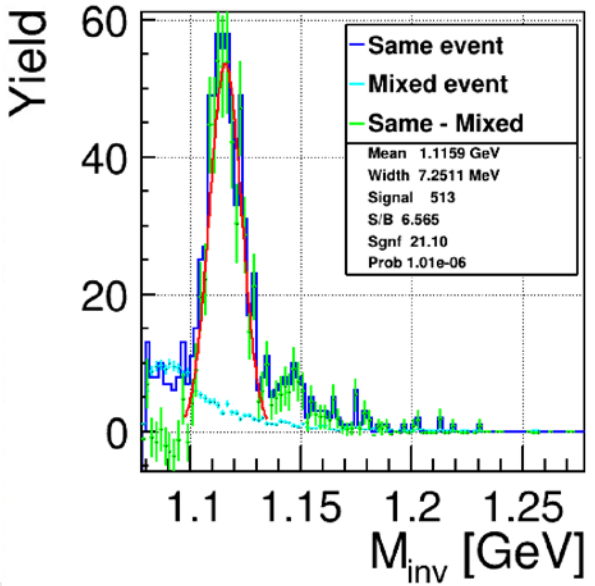


STS-TOF track → intersection in TRD2D plane

data-driven detector alignment



using mult=1 sample



preliminary data analysis in progress

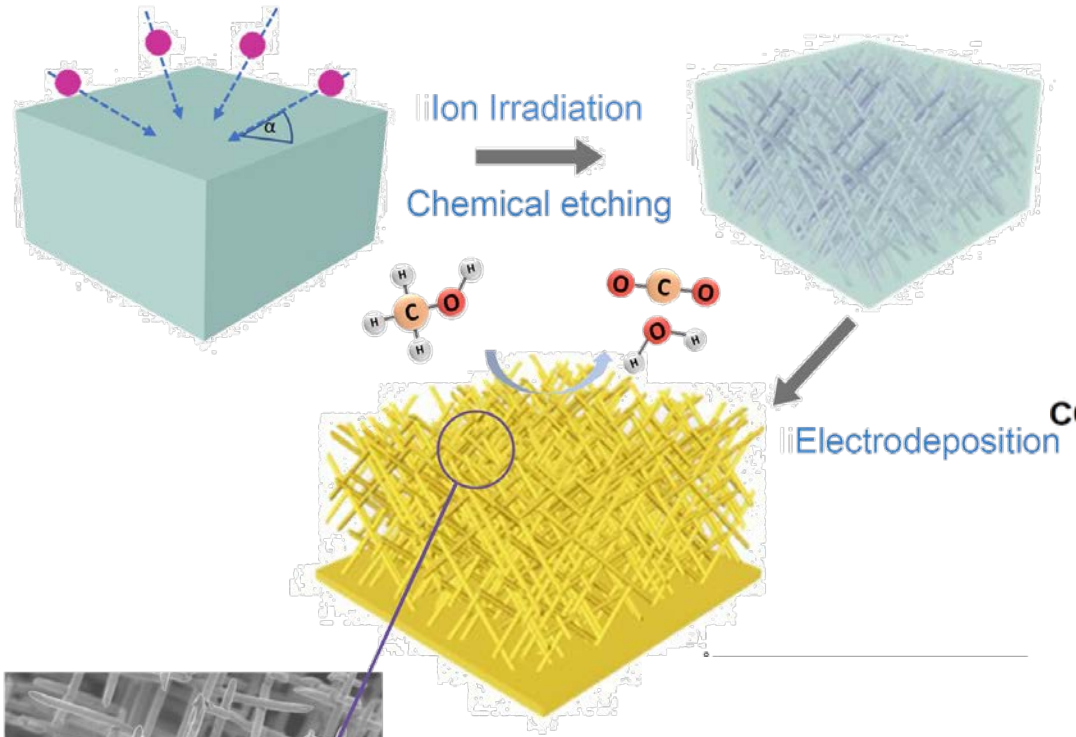
Research highlight
FLASH radiotherapy

- FLASH Radiotherapy, is a novel approach of RT using ultra-high dose rate aiming to get **unchanged tumor control protection (TCP)** and **decreased normal tissue complication probability (NTCP).**

- GSI has demonstrated for the first time that the FLASH effect can be obtained with accelerated carbon ions (18 Gy in one spill of 150 ms) paving the way to clinical translation in particle therapy

- The paper made the cover of the prestiogious *Nature Reviews Clinical Oncology*

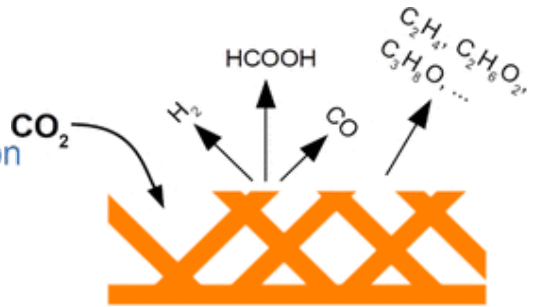
Materials Research
3d, highly interconnected nanowire networks

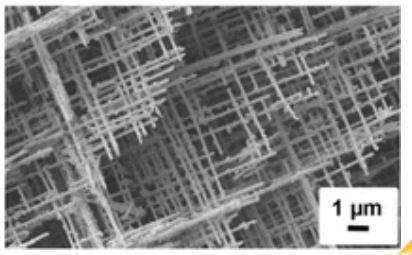


Li et al, RSC Advances 13 (2023) 4721-4728

3D nanowire networks with high surface area for catalytical applications

Copper nanowire-electrodes:
CO_2 reduction and formation of commodity chemicals





Ulrich et al, ACS Applied Nano Materials 6 (2023) 4190–4200

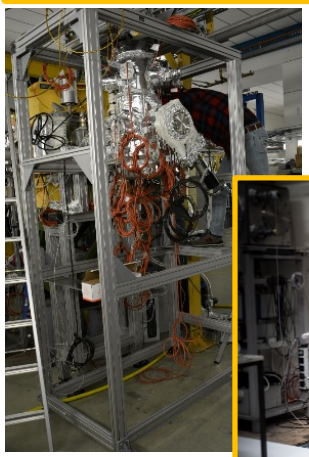
Advantages:
- Tailored nanowire density and diameter
- Excellent interconnectivity
- Surface area network > 500 larger than planar
- High current densities
- Excellent stability during performance

Experiment Installations and Testing at CRYRING

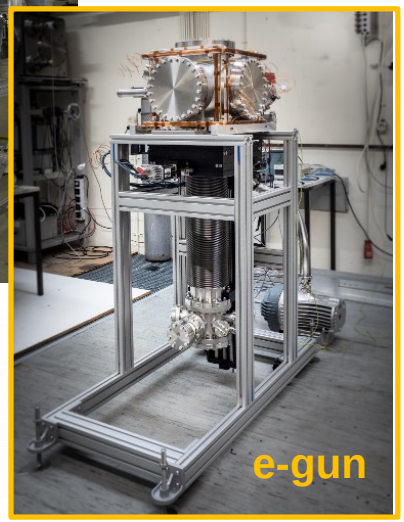
CARME spectrometer

- ✓ Installation in ring of the forward part
- ✓ First test experiments

E- transversal target



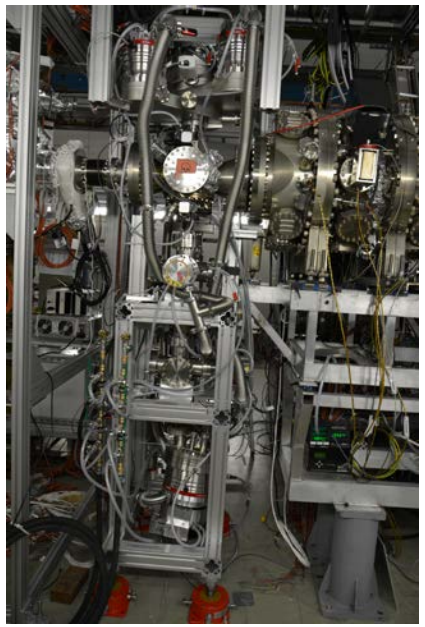
Top interaction Chamber:



SPONSORED BY THE Federal Ministry of Education and Research

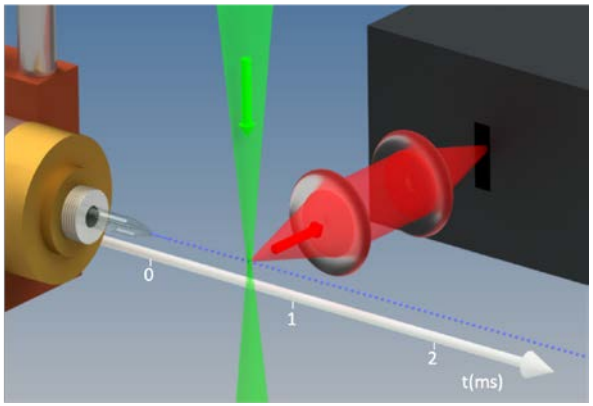
- ✓ The upper part is installed in the ring and ready backing and vacuum test.
- ✓ System ready for installation

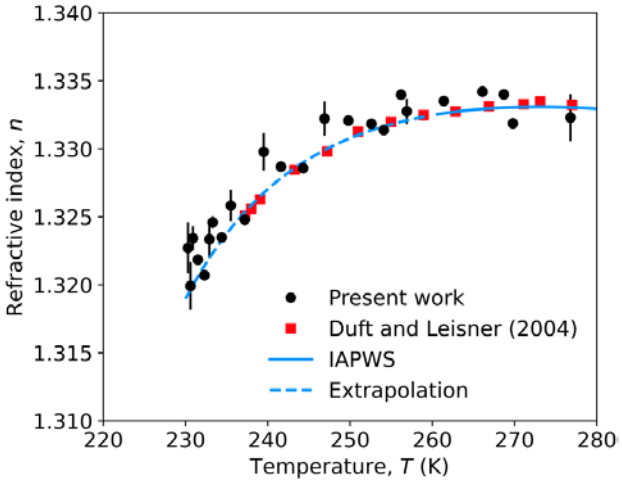
Gas-Jet target



- ✓ Two successful experiments on H-like gold beam on N_2 and He.
- ✓ Target areal densities of up to $6x10^{11}$ cm^{-2} at target width of Δx = 1 mm achieved.

Refractive index of supercooled water down to 230 K (- 43,15º C)





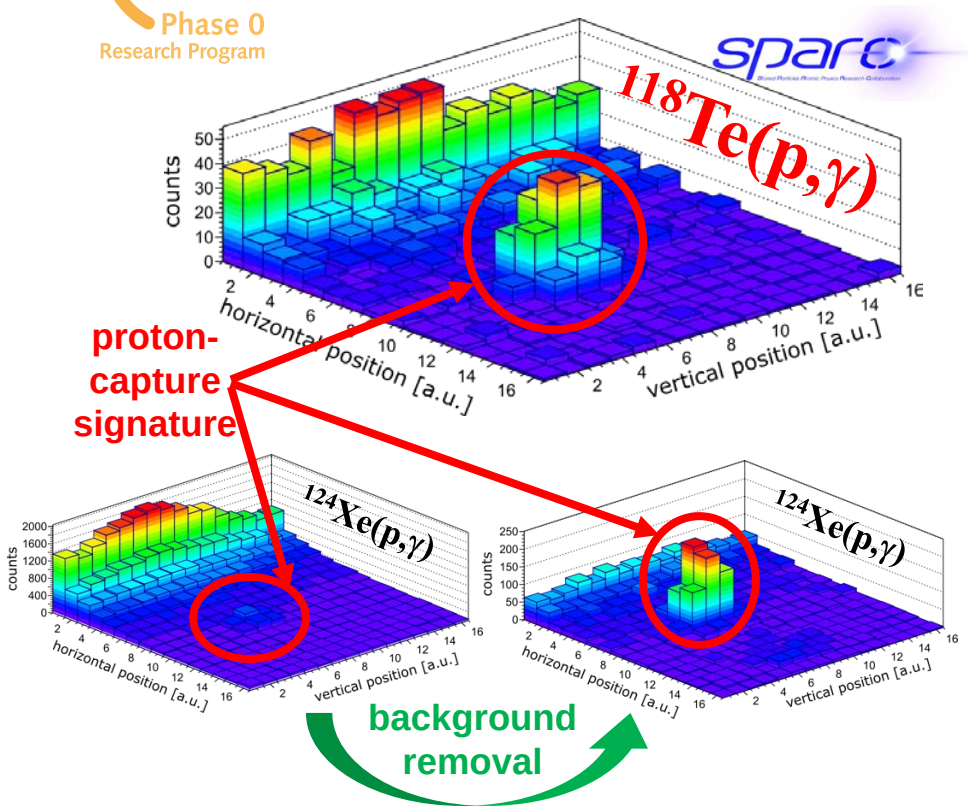
- Knowledge of the refractive index *n* of supercooled water is crucial for improving climate models.
- Water microjets in vacuum probed by Raman scattering allowed the determination of refractive index *n* for visible light down to 230 K.

Goy *et* al., J. Phys. Chem. Lett. **13**, 11872 (2022)

GSI Atomic Physics

Ground-breaking experiment opening way for nuclear astrophysics experiments at FAIR with ESR

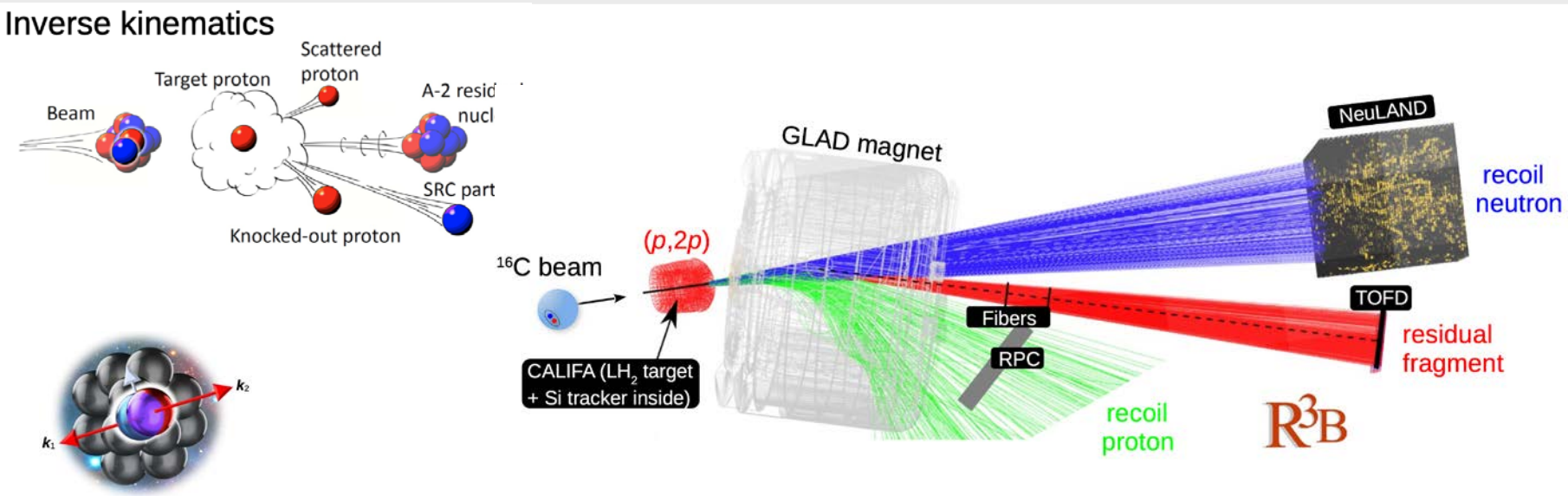
- E127: Proton-capture rates for nuclear astrophysics:
  First reaction study on stored radio-beam at low energies
- Study of radioactive ^{118}Te (6 days half-life)
  - production, storage, accumulation and deceleration in FRS-ESR
  - proton-capture measurements realized at 7 MeV/u and 6 MeV/u
- New background-free detection method demonstrated



Jan Glorius et al.

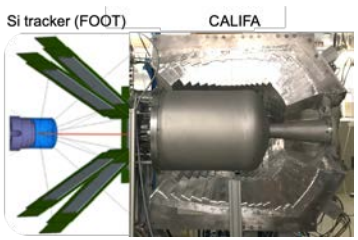
SPONSORED BY THE Federal Ministry of Education and Research

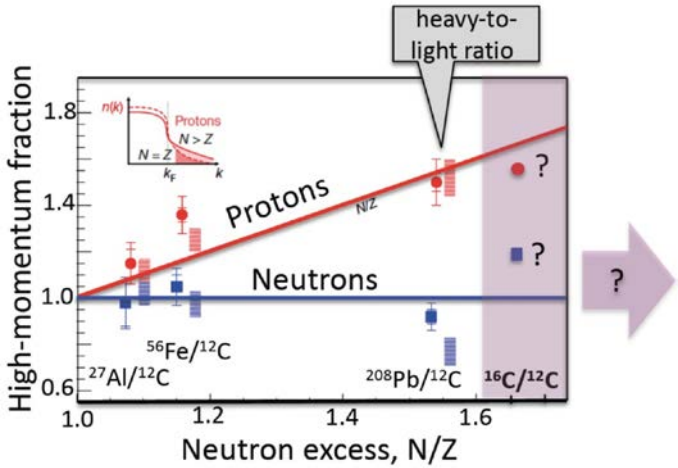
Short range correlations in n-rich nuclei measured with R3B



Conclusions from JLAB experiments:
Protons more correlated in neutron-rich nuclei (stable nuclei)
Open: - effect of mass ratio or asymmetry?
- development towards large N/Z

R3B experiments:
- changing N/Z at similar mass
- kinematically complete measurement
- ^{12}C, ^{16}C beams
- FAIR Phase0 experiment performed at R3B in May 2022 (A. Corsi et al.)





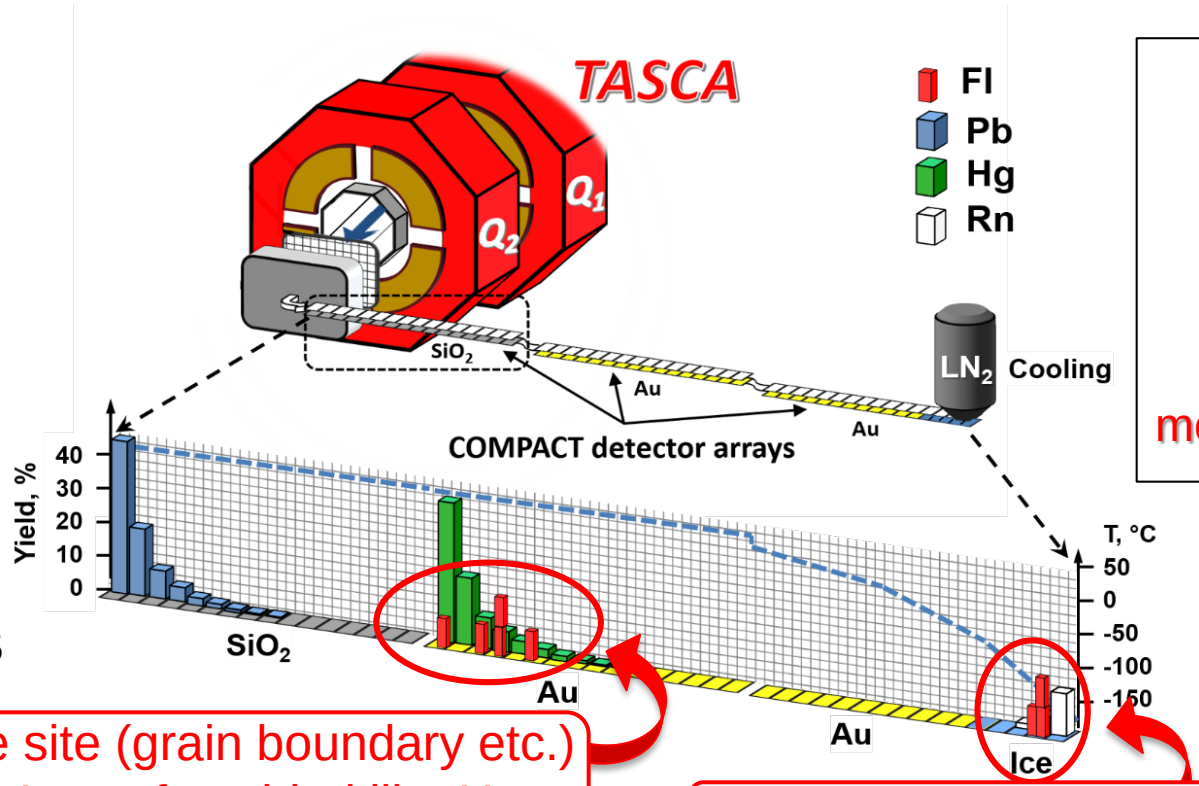
Chemical properties of element 114, Flerovium

- Flerovium: heaviest element with experimentally studied chemical properties
- Eight registered atoms in three beamtimes of total 2.5 months duration

Production:
^{244}Pu(^{48}Ca,3-4n)
^{288}Fl: $t_{1/2}$ ~0.7 s
^{289}Fl: $t_{1/2}$ ~2.0 s

Isolation in **TASCA**;
Chemical study and detection: COMPACT

A. Yakushev *et al.*,
Front. Chem. 10 (2022) 976635



Volatility:
Rn > **Fl** > Hg >> Pb

Reactivity:
Rn < **Fl** < Hg << Pb

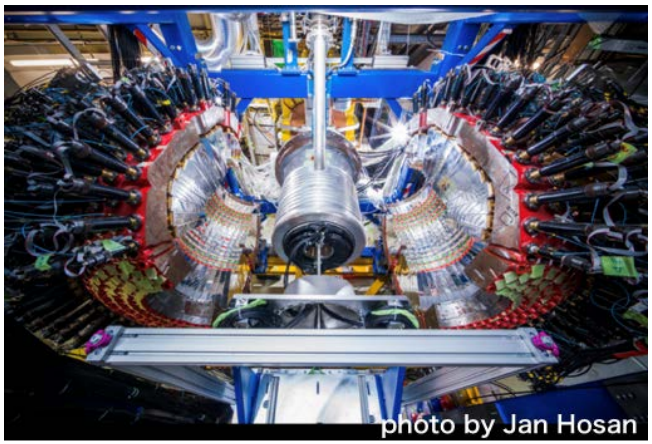
Fl is the most volatile metal in the periodic table

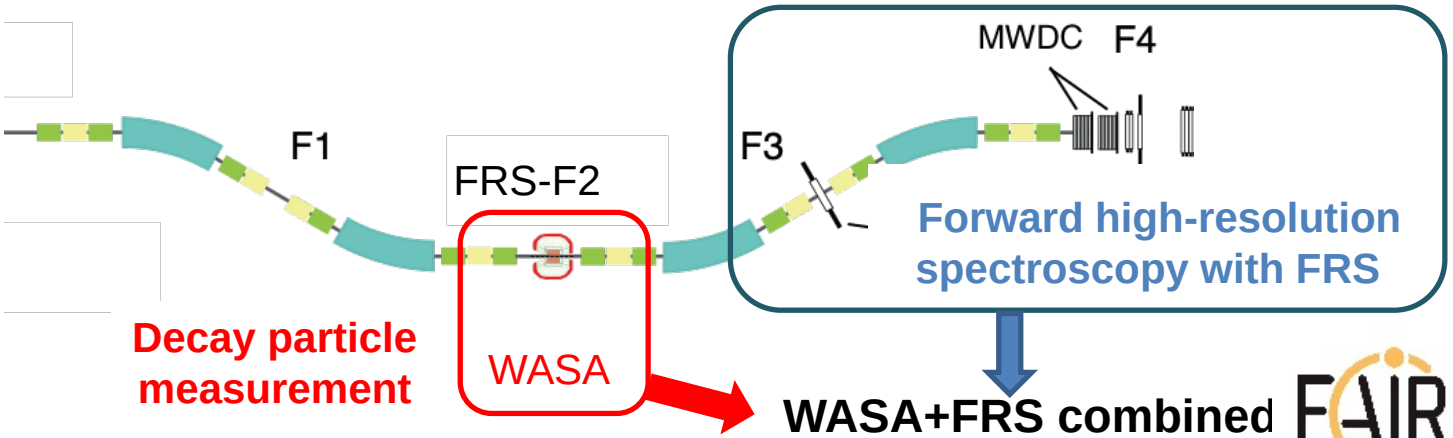
Atoms hitting a reactive site (grain boundary etc.) on the inhomogeneous Au surface bind like Hg

Other atoms reach location of Rn adsorption

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

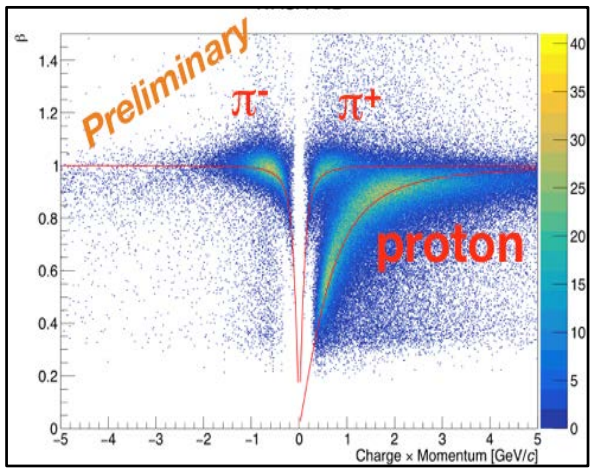
WASA-FRS Experiments



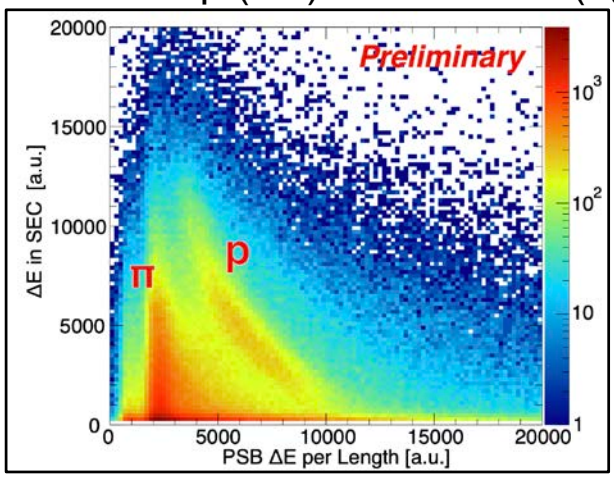


WASA+FRS combined analysis is ongoing

Achieved WASA Particle ID with Momentum vs β (left) and E vs ΔE (right)



Y. K. Tanaka et al., Acta Phys. Pol. B Proc. Suppl.16, 4-A27 (2023)



Development of Track Finder with Graph Neural Network

Development of machine learning analyses with graph neural network for the WASA-FRS experiment

H. Ekawa[1], W. Dou[1,2], Y. Gao[1,3,4], Y. He[1,5], A. Kasagi[1,6], E. Liu[1,3,4], A. Muneem[1,7], M. Nakagawa[1], C. Rappold[8], N. Saito[1], T. R. Saito[1,9,5], M. Taki[10], Y. K. Tanaka[1], H. Wang[1], and J. Yoshida[1,11]

[1] High Energy Nuclear Physics Laboratory, Cluster for Pioneering Research, RIKEN, Wako, Japan.
[2] Department of Physics, Saitama University, Saitama, Japan.
[3] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China.
[4] University of Chinese Academy of Sciences, Beijing, China.
[5] School of Nuclear Science and Technology, Lanzhou University, Lanzhou, China.
[6] Graduate School of Engineering, Gifu University, Gifu, Japan.
[7] Faculty of Engineering Sciences, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi, Pakistan.
[8] Instituto de Estructura de la Materia, Consejo Superior de Investigaciones Científicas (CSIC), Madrid, Spain.
[9] GSI Helmholtz Center for Heavy Ion Research, Darmstadt, Germany.
[10] Graduate School of Artificial Intelligence and Science, Rikkyo University, Tokyo, Japan.
[11] Department of Physics, Tohoku University, Sendai, Japan.

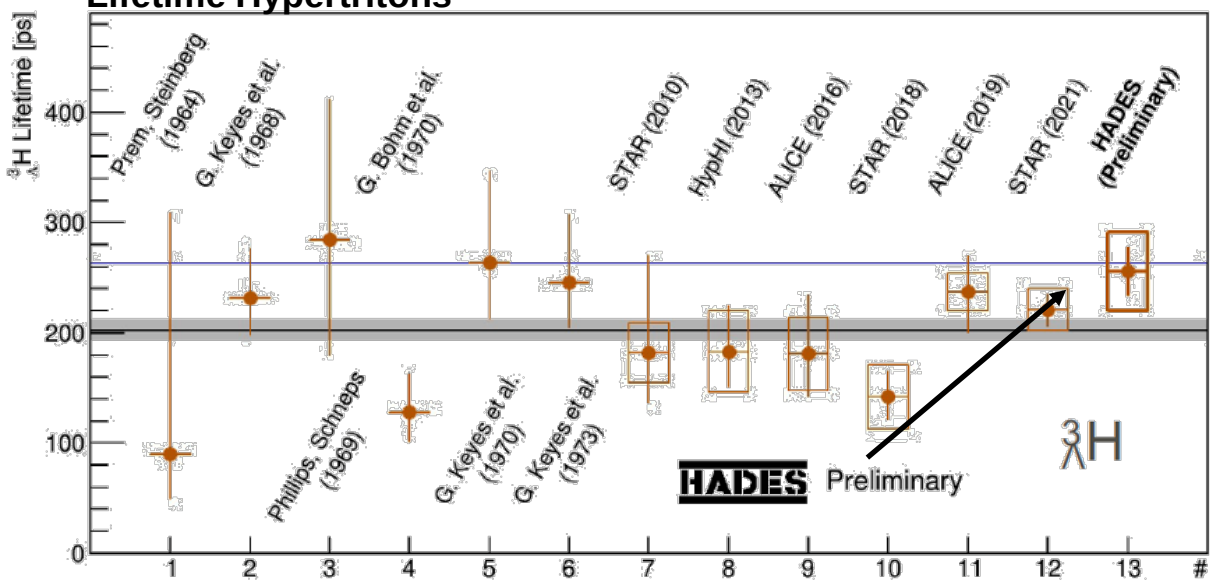
H. Ekawa et al., Accepted in EPJA (2023 April)

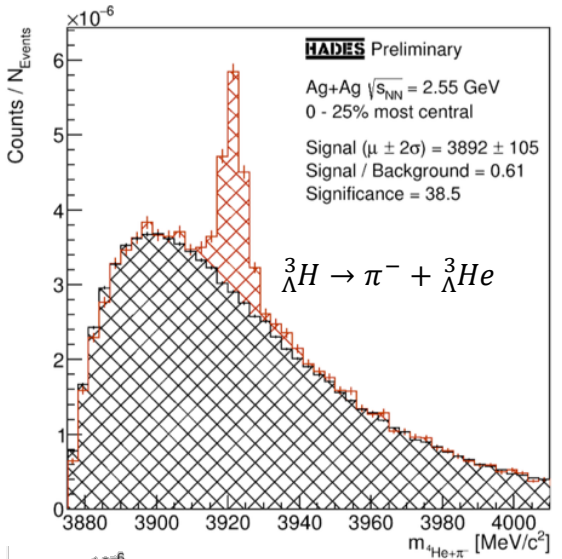
Hypernuclei production in Ag+Ag collisions

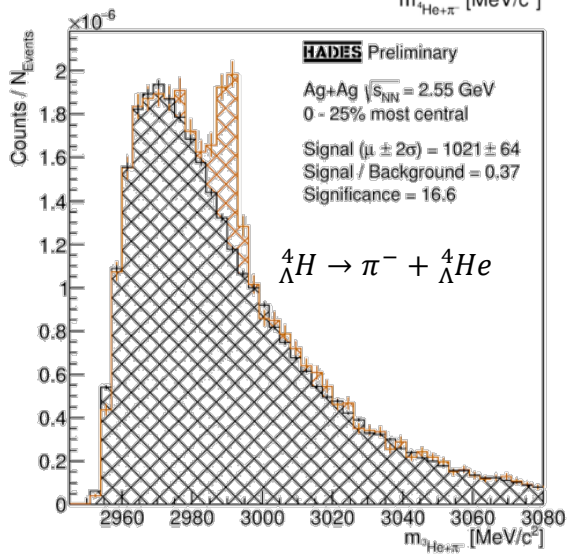
HADES

- ~ 4000 Hyper-Triton and
  ~ 1000 Hyper-Helium candidates reconstructed.
- Observed lifetime in-line with STAR/ALICE measurements
- Reference measurement of Λ lifetime: $\tau_\Lambda = (262 \pm 2)\, ps$

Lifetime Hypertritons



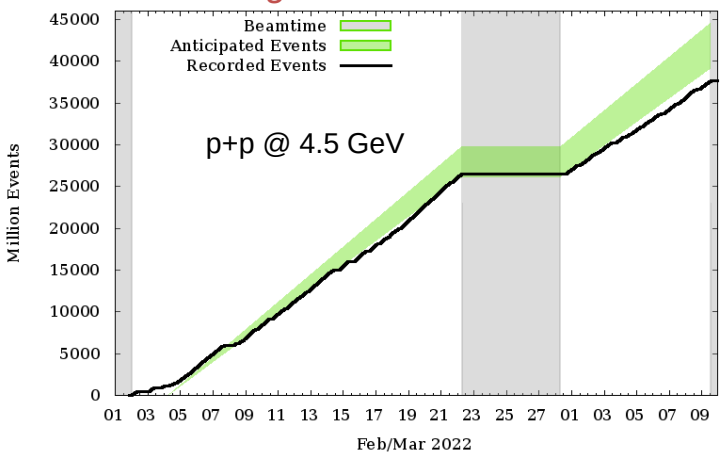




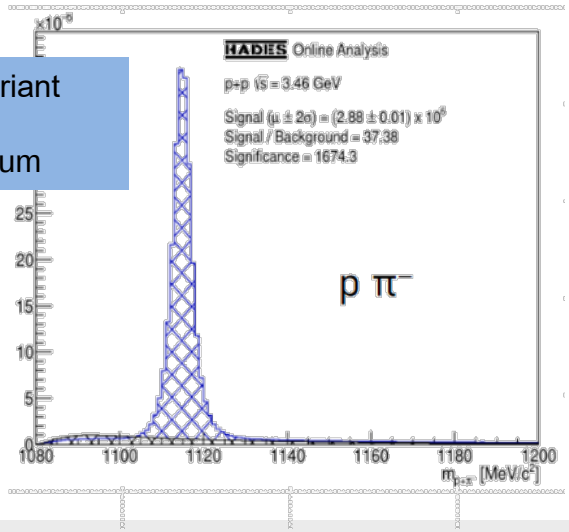
Production and electromagnetic decay of hyperons

- Successful beam time: 42 B events collected !
- Promising online results
- New detector systems performed very well: STS forward tracker stations (PANDA), forward RPC (HADES) photon camera (CBM), inner TOF (FAIR-NRW), LGAD T0 (HADES)

Integrated statistics



Λ invariant mass spectrum




Thank you!!
Photo: C. Betz

Nomenclature: Steps of FAIR

Currently running **FAIR Phase-0** experiments will mostly continue to operate on the GSI/FAIR campus, while the step below are progressively implemented

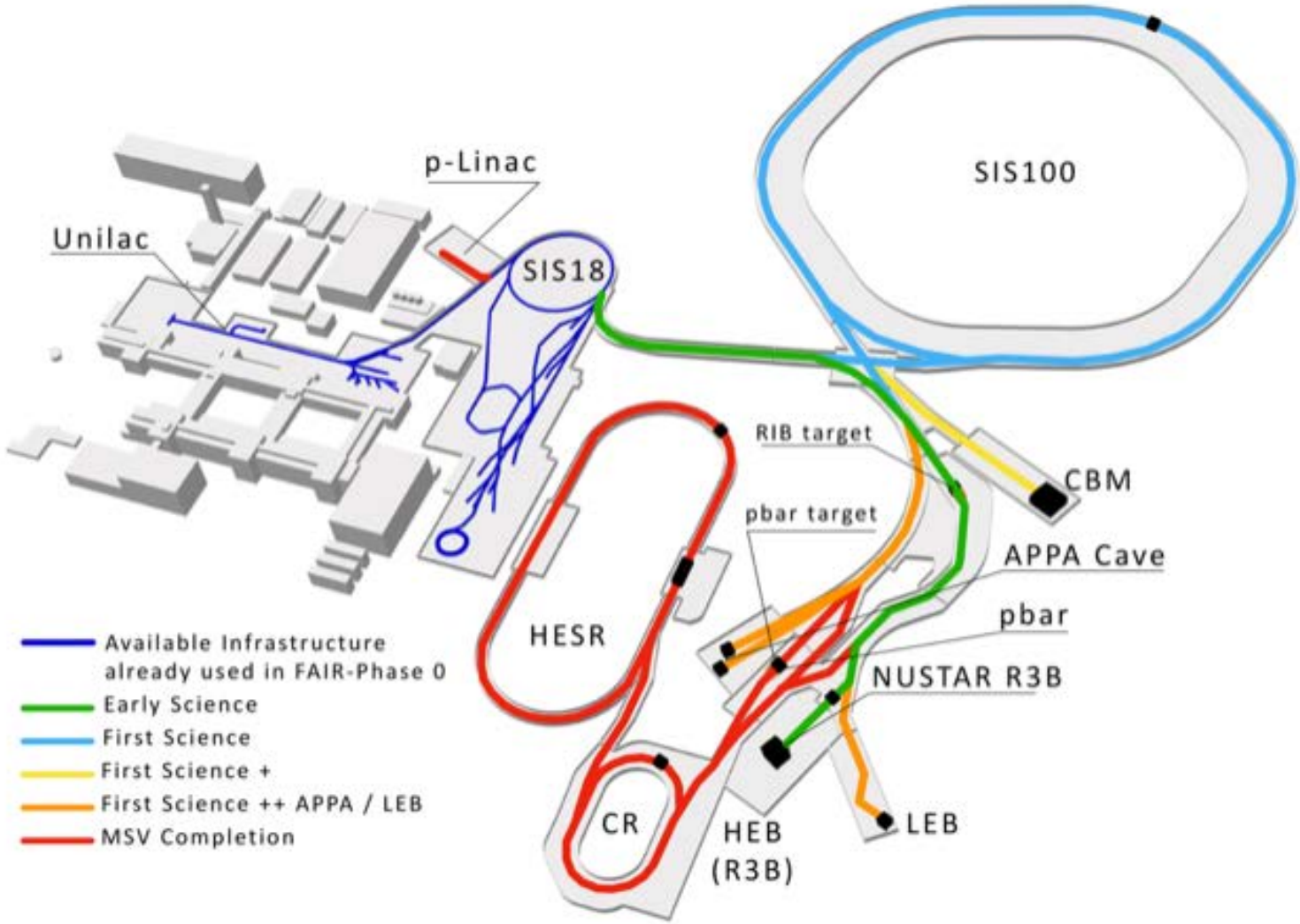
Steps for the construction of new facilities (defined by Review/Council)

- **Early Science (ES):** FAIR pre-cursor programme at the Super-Fragment-Separator (S-FRS) und NUSTAR High-Energy Branch (HEB) served by beams from SIS18.
- **First Science (FS):** first science at the Super-Fragment-Separator (S-FRS) und NUSTAR High-Energy Branch (HEB) served by beams from SIS100.
- **First Science + (FS+):** in addition to FS the CBM branch served by beams from SIS100.
- **First Science ++ (FS++):** in addition to FS+:
  - the branch into the APPA cave, and
  - the NUSTAR Low-Energy Branch (LEB)
- **MSV completion (MSVc):** Completion of the Modularised Start Version.

FAIR 2028

The steps are incremental, i.e. earlier steps are completely subsumed in the later steps.

FAIR steps


p-Linac
Unilac
SIS18
SIS100
RIB target
CBM
pbar target
APPA Cave
pbar
NUSTAR R3B
HESR
CR
HEB
(R3B)
LEB
Available Infrastructure
already used in FAIR-Phase 0
Early Science
First Science
First Science +
First Science ++ APPA / LEB
MSV Completion

Our vision for the medium-term future: 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 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.

Some Research highlights of GSI/FAIR in 2022

Pushing the boundaries of the periodic table

- Determination of the properties of the heaviest chemically studied element so far, element 114, by experimenting with only eight atoms existing for fractions of a second

A.Yajushev et al., Front. Chem., (2022)

Origin of the chemical elements

- Theoretical work regarding gravitational waves and the synthesis of elements in neutron star mergers
- Recently honored with Leibniz Award, ERC Advanced Grant, ERC Synergy Grant

K. Langanke et al., Frontiers in Physics (2021), DOI 10.1088/1361-6633/abf207
O.Just et al., Monthly Notices of the Royal Astronomical Society, Vol. 509 (2022), P1377–1412
A.Bauswein et al., Phys. Rev. Lett. 125, 141103