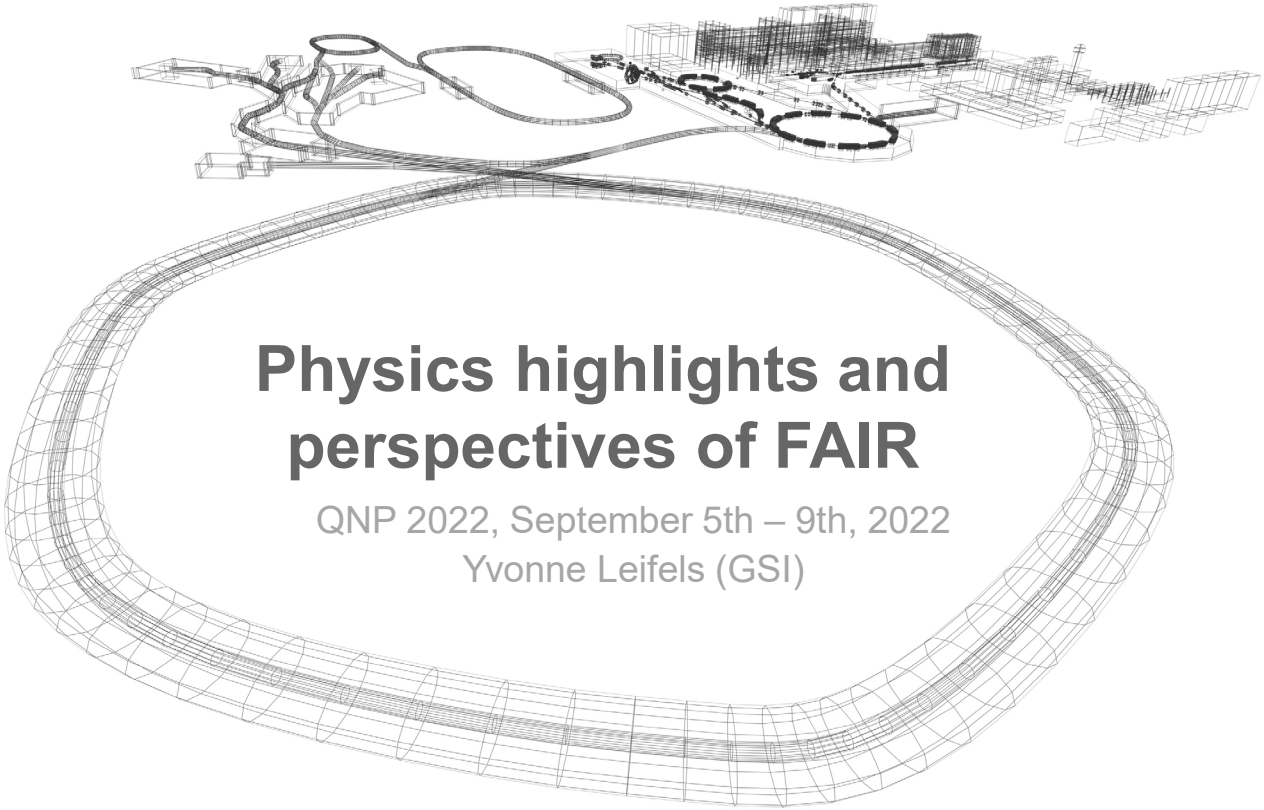
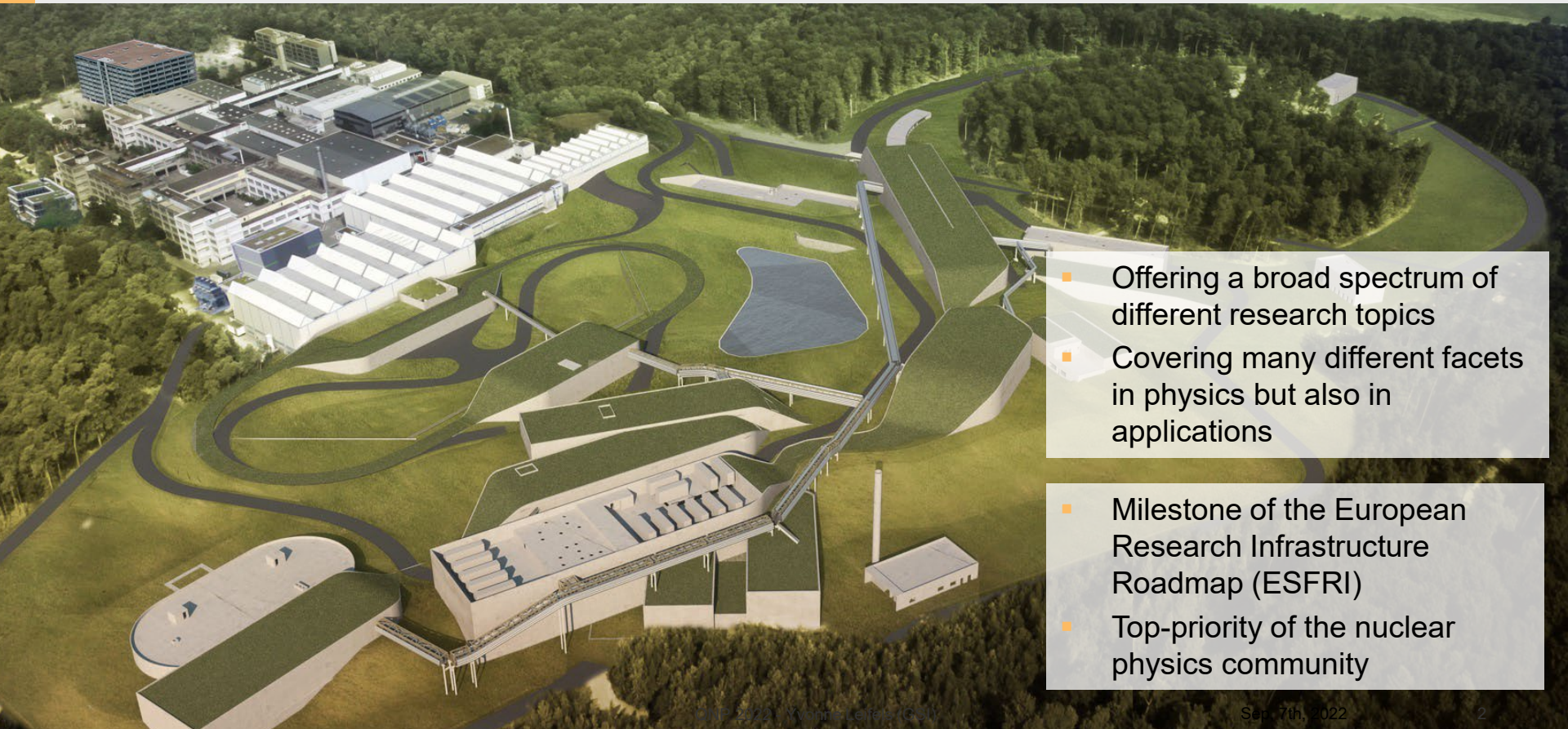


Physics highlights and perspectives of FAIR

QNP 2022, September 5th – 9th, 2022

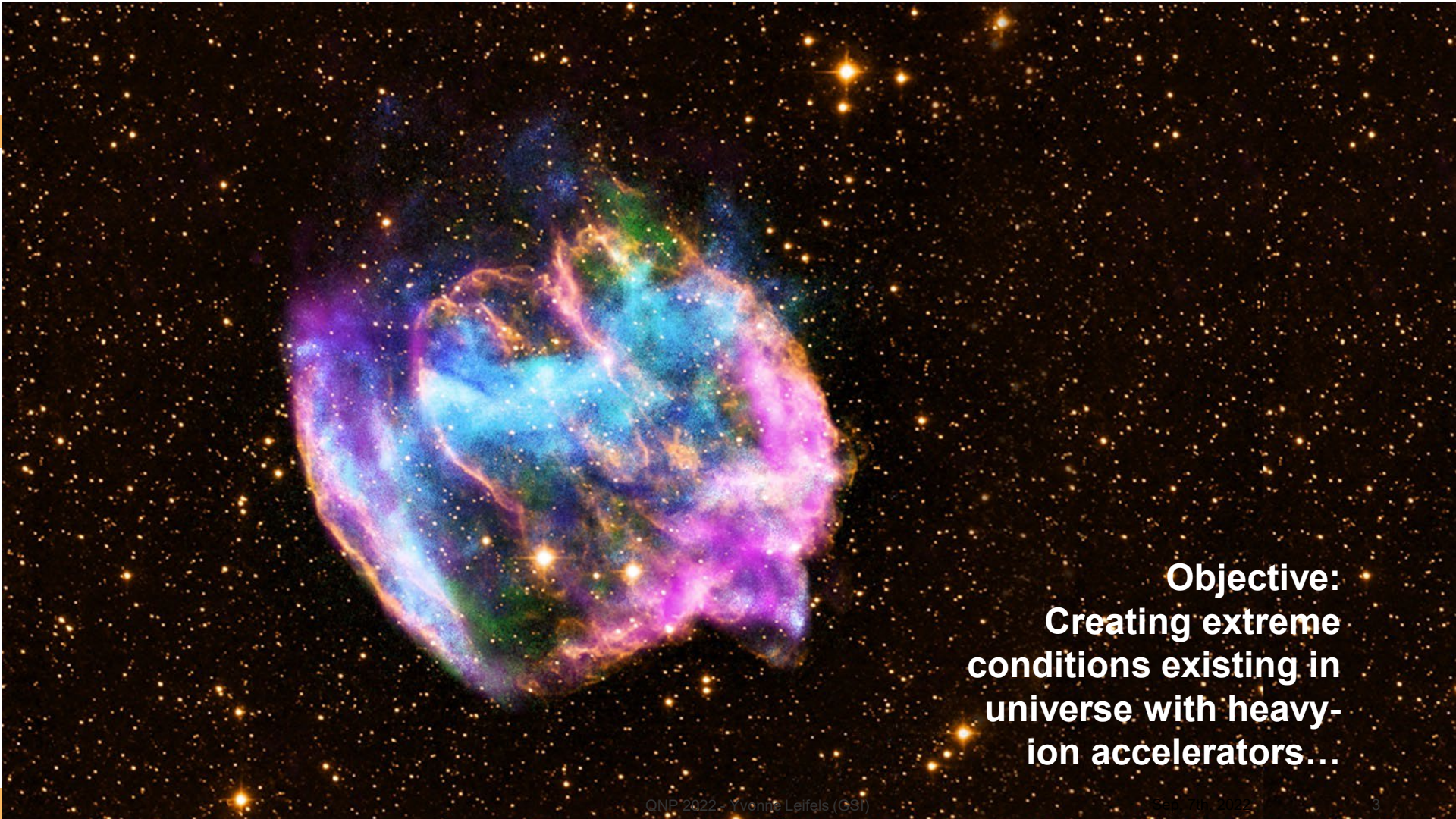
Yvonne Leifels (GSI)

FAIR – Facility for Antiproton and Ion Research



- Offering a broad spectrum of different research topics
- Covering many different facets in physics but also in applications

- Milestone of the European Research Infrastructure Roadmap (ESFRI)
- Top-priority of the nuclear physics community



Objective:
Creating extreme conditions existing in universe with heavy-ion accelerators…

… to answer fundamental questions:

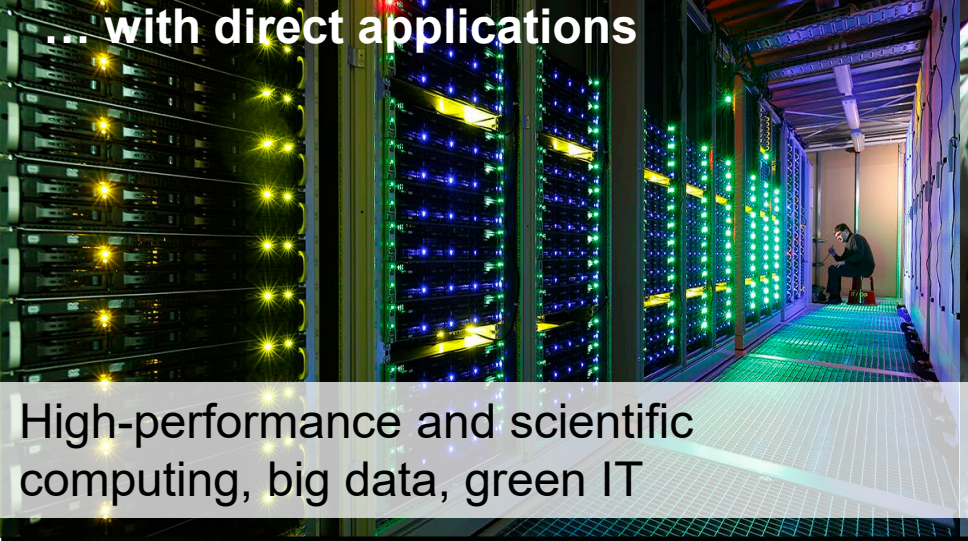
Synthesis of chemical elements in the cosmos

Building blocks of life: Production of carbon and oxygen in stars

Neutron star mergers: equation of state, strong force, neutron rich nuclei

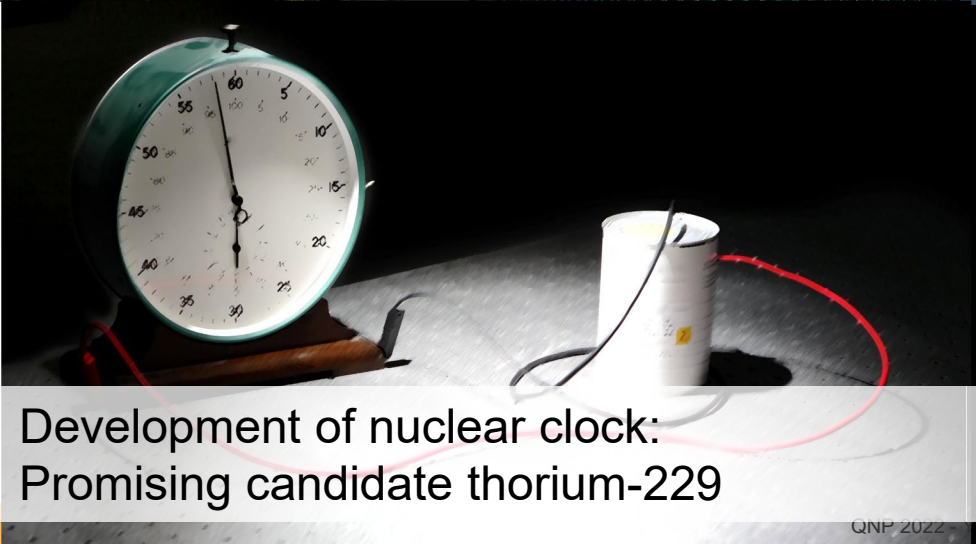
Matter in the interior of Earth and of large planets

… with direct applications

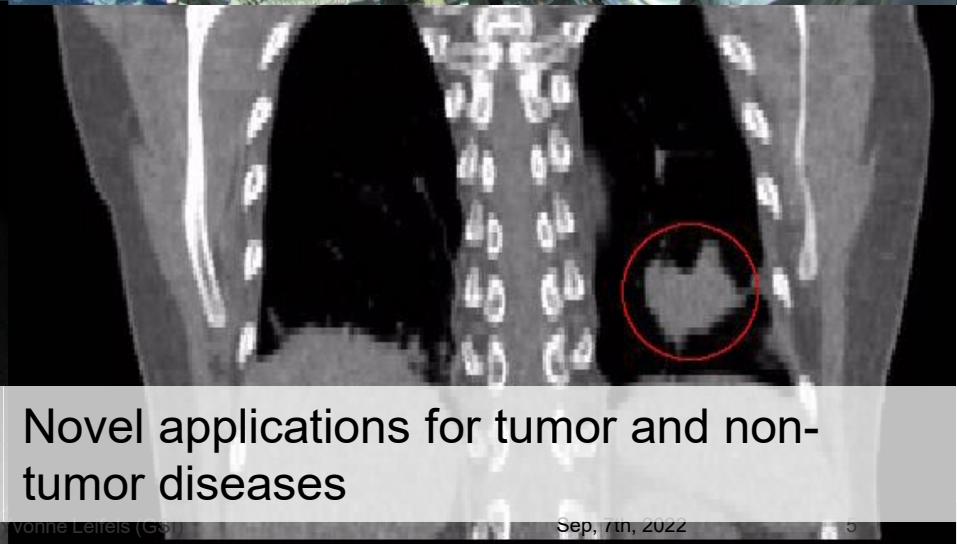


High-performance and scientific computing, big data, green IT

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

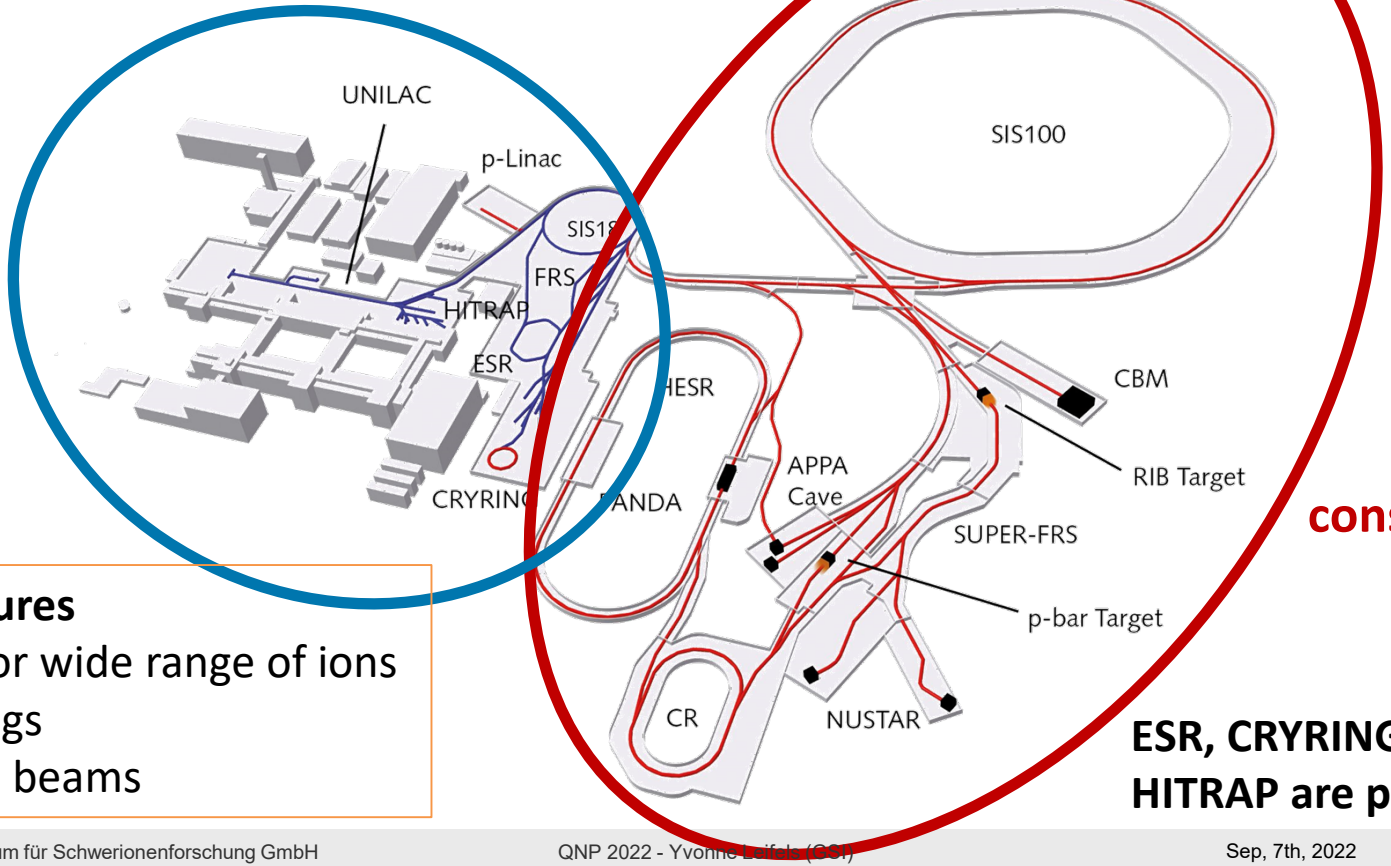


Development of nuclear clock: Promising candidate thorium-229



Novel applications for tumor and non-tumor diseases

GSI, existing (upgraded to integrate with FAIR)



FAIR, under construction

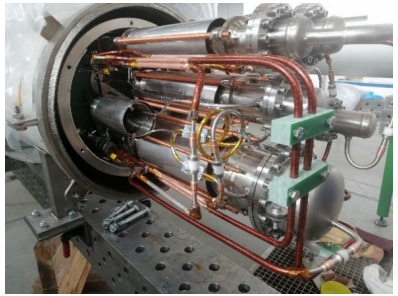
ESR, CRYRING, & HITRAP are part of FAIR

FAIR key features

- intensity for wide range of ions
- storage rings
- antiproton beams

FAIR accelerators

SIS100



- rigidity: 100 Tm
- super-conducting
- accelerating intermediate charge states of HIC
- cryogenic UHV system

protons: 2×10^{13}/cy, 29 GeV

U^{28+} : 5×10^{11} /cy, 2.7 GeV/u

U^{92+} : 10^{10} /cy, 10 GeV/u

ESR – CRYRING

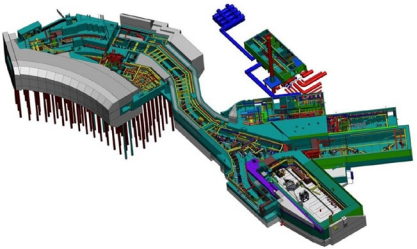
ESR

- rigidity: upto 10 Tm
- electron cooling
- typical energies ~ 300 MeV/u

CRYRING

- rigidity 0.04 – 1.44 Tm
- ion source for stand alone operation

Super-FRS



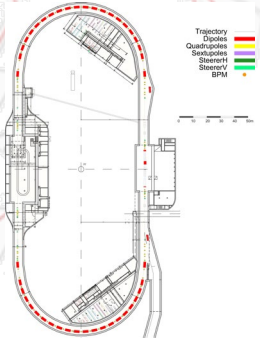
ACCEPTANCE

- horizontal $\Phi_x = \pm 40$ mrad
- vertical $\Phi_y = \pm 20$ mrad
- momentum $\Delta p/p = \pm 2.5$ %
- magnetic rigidity 2 - 20 Tm

MOMENTUM RESOLUTION

- first stage = 750
- second stage = 1500

CR - HESR



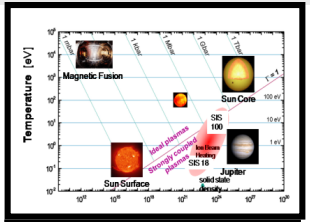
CR

- max. rigidity 13 Tm
- fast bunch rotation, coasting beam
- stochastic cooling

HESR

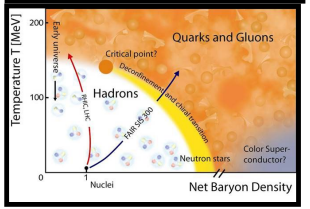
- rigidity: 5-50 Tm
- accelerating p, anti-p and highly charged ions
- stochastic (and electron) cooling

FAIR research is organized in four pillars



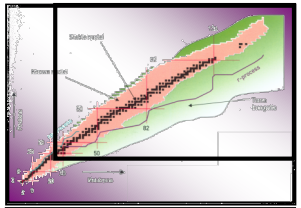
atomic physics, biophysics,
plasma physics, materials research

APPA



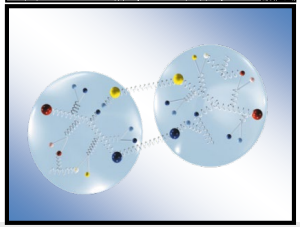
nuclear- and quark-matter

C.B.M



nuclear structure and
nuclear astrophysics

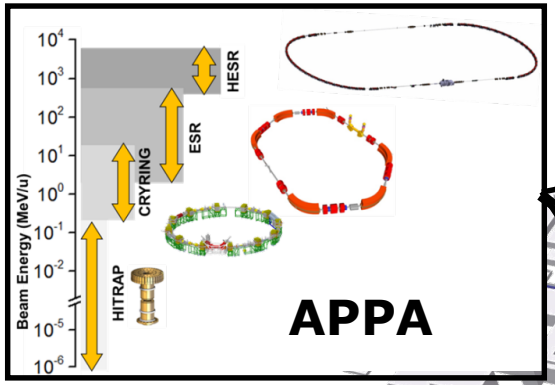
NuSTAR

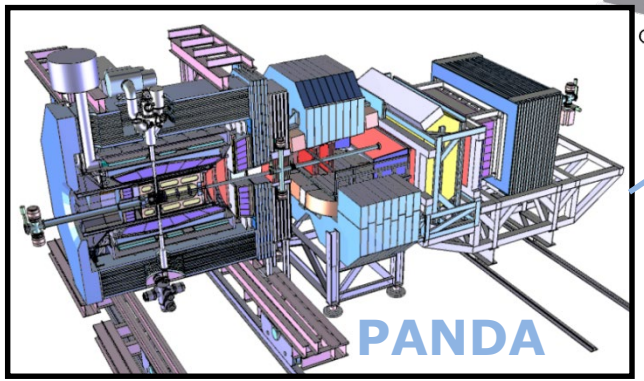


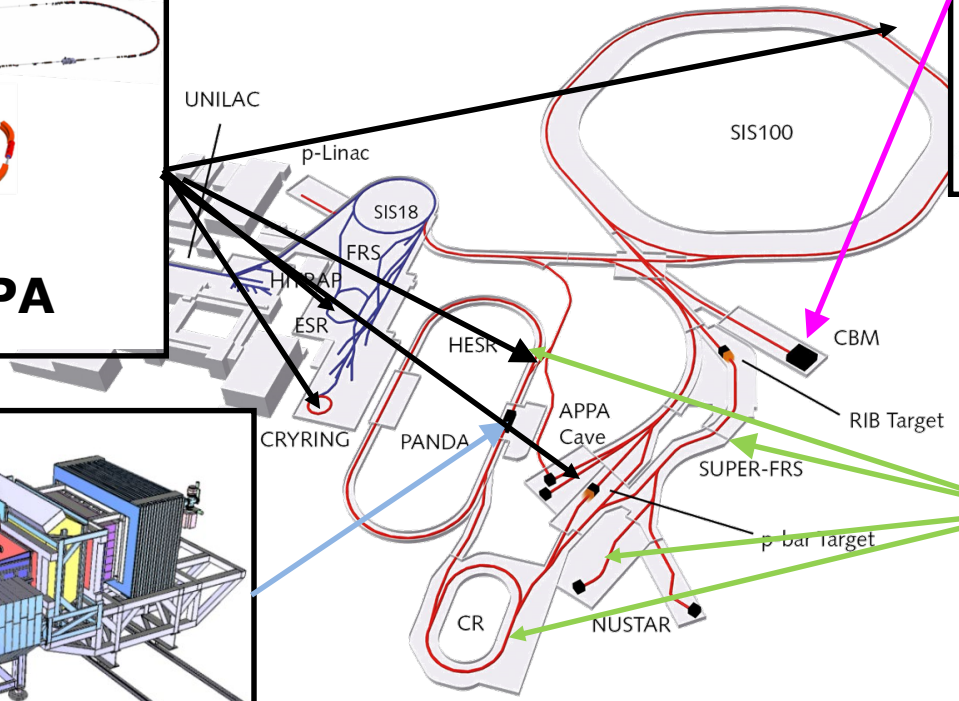
hadron structure and dynamics

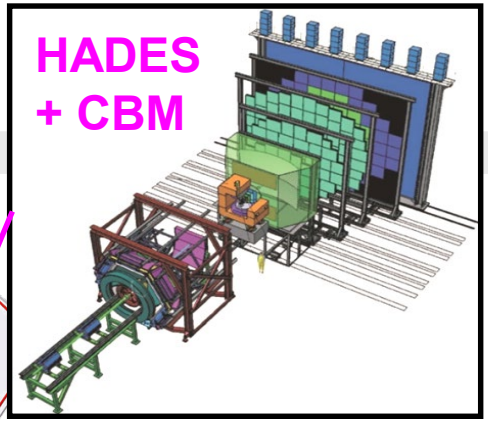
PANDA

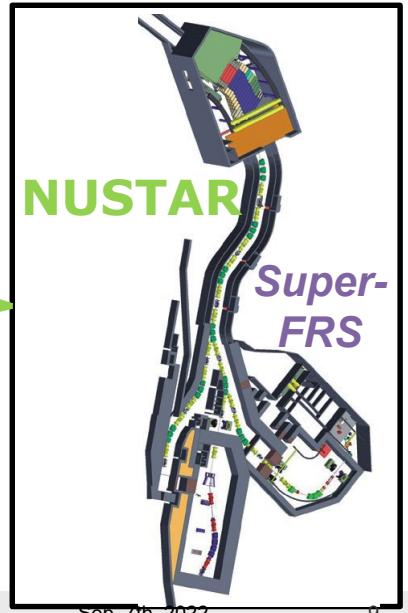
FAIR facility











FAIR civil construction progressing well

Drone videos available via www.gsi.de

FAIR civil construction

Some examples

- building hosting cryogenics completed
- coating and TBI installation for SIS100 tunnel ongoing
- concrete works for CBM cave completed, crane installation started

FAIR accelerators

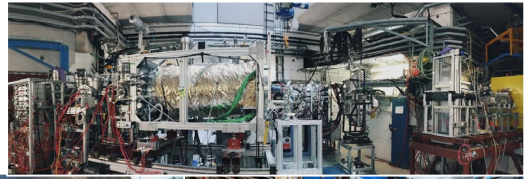
SIS100 – Pumping chambers

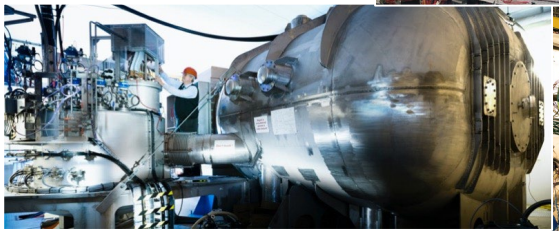
SIS100 – Dipole magnets

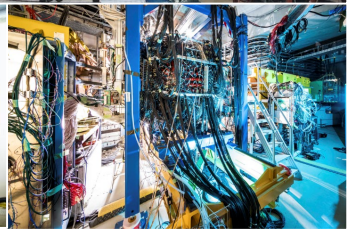
Power supplies | India

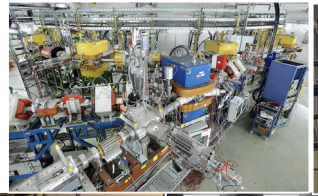
SIS100 sc quadrupole testing facility / Salerno

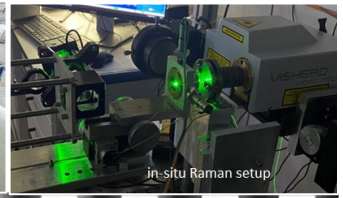
FAIR experiments

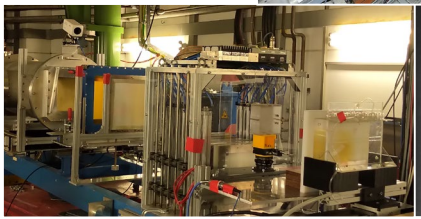


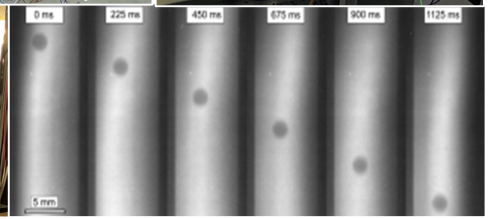


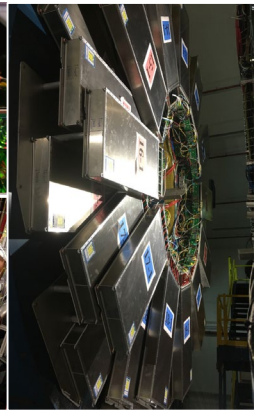


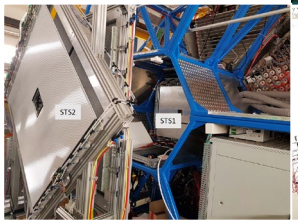


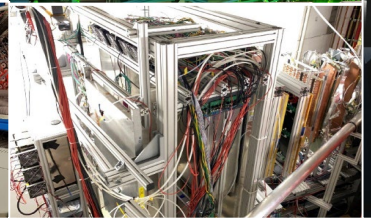


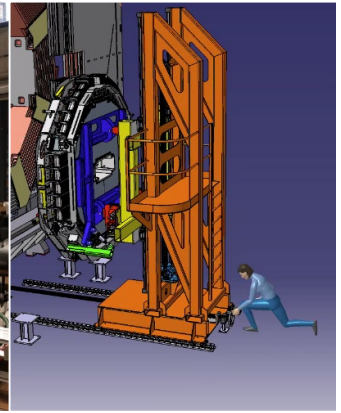










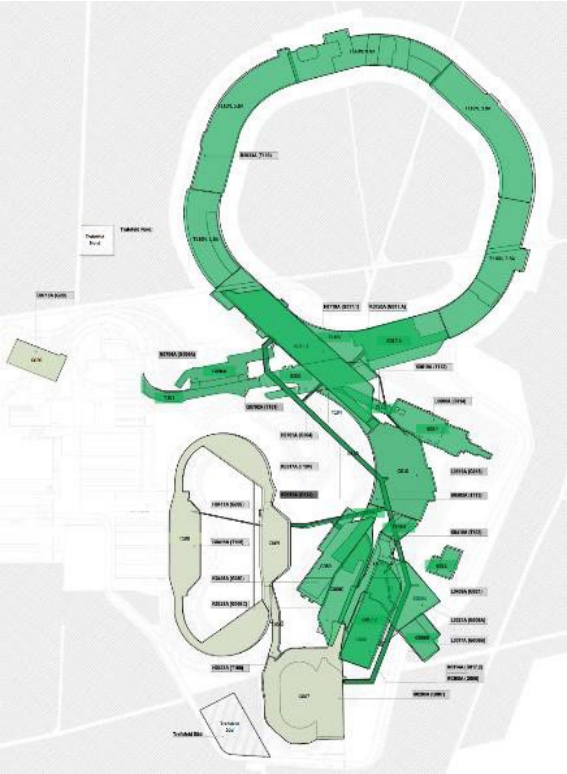


Current status of FAIR

Intermediate Objective (IO) as an interim step towards full FAIR Modularized Start Version MSV

IO comprises

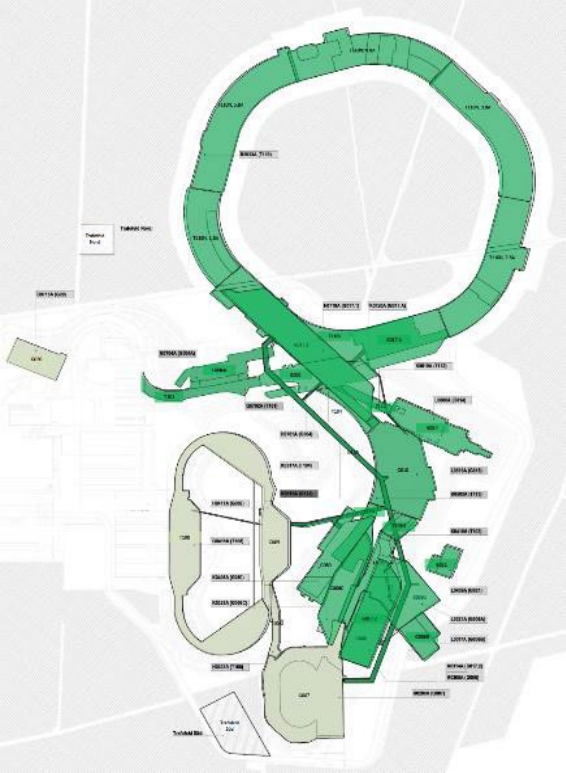
- the full scope of accelerators and experiments for the MSV
- the realization of the buildings for MSV except the buildings for CR, HESR and pLinac.



- over 60% of concrete work for IO complete, all orders for technical building equipment for IO have been placed
- over 40% of accelerator components for the entire FAIR MSV have been manufactured and tested, and most of the remaining components have been commissioned
- close to 50% of experiment components for FAIR MSV have been completed and most of remaining components have been commissioned

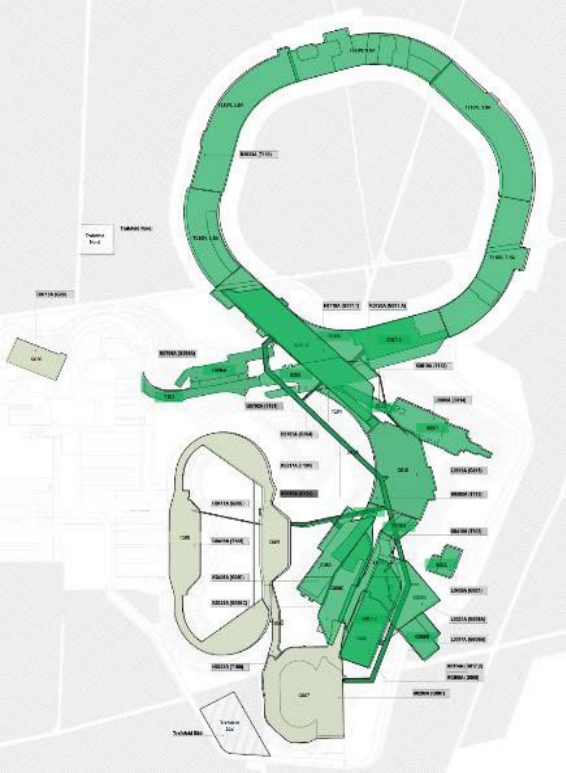
Challenges

- Several events are affecting the project realization progress and financial needs
  - the COVID pandemic, especially affecting the supply chain
  - the sharp increase on the international markets of raw materials and electronic components
  - more lately, the invasion of Ukraine by Russia
    - probable need to produce components elsewhere, potential funding gap
- These events result in delays and in substantial additional financial needs



Consequences

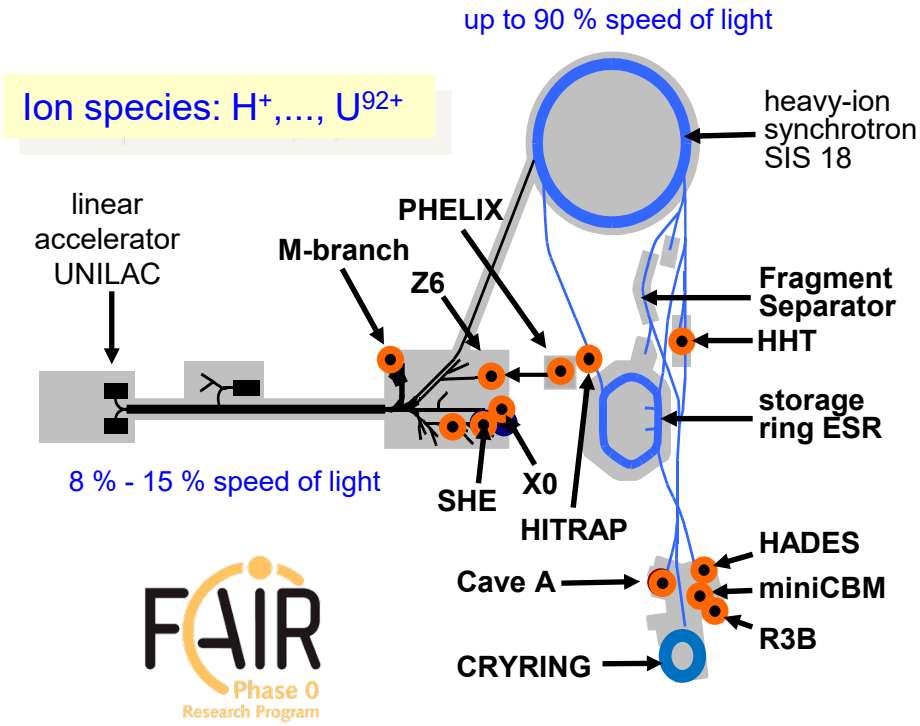
- Market survey was performed in response to the potential non availability of components for experiments and accelerators foreseen to be built in Russia
  - no show stoppers
  - for all components alternative producers identified
  - a decision on continuation of the contracts with Russian producers is expected at the next Council Meeting
- Following the identification of these additional financial needs, “First Science” and staging review has been launched by the FAIR Council
  - initiated by the FAIR Council: International group of experts, co-Chairs are Prof. Rolf Heuer and Prof. Robert Tribble
  - results of review are foreseen in September 2022 and will be basis for further action



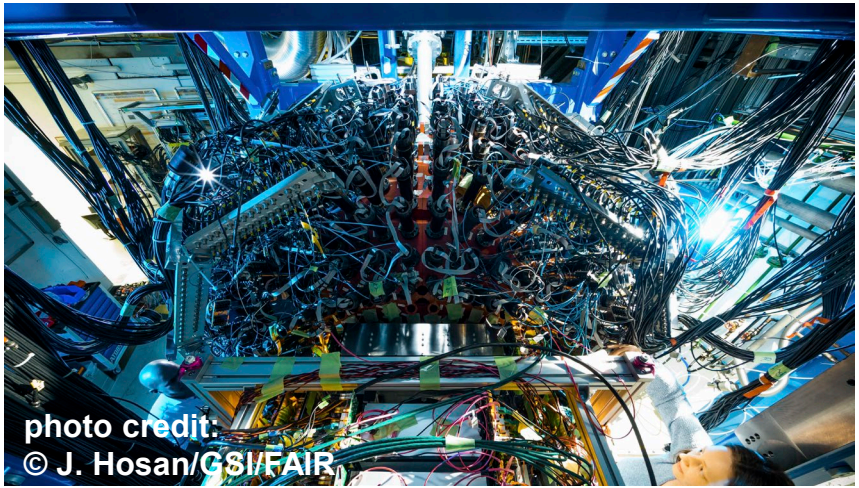
FAIR Phase-0 at (but not only) the GSI facilities

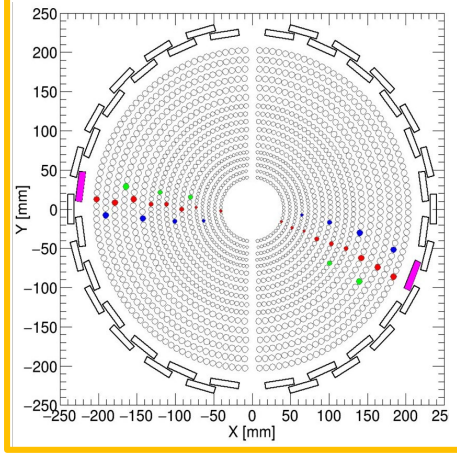
Staged approach to FAIR science started in 2019

- working towards start of FAIR
- progressive commissioning of GSI accelerators and already existing FAIR detectors
- 3 months user beamtime/year at GSI
- 2021 and 2022 runs completed as planned
- In a dedicated G-PAC meeting in Dec 2021, the medium-term strategy has been defined in consultation with the community
- Following call for 2023/24 bem time, the individual PACs will evaluate the proposals in Sep 2022



Study of hyper nuclei WASA @ FRS





WASA detector:
- 18 tons of weight
- s.c. solenoid magnet (700 A, 1.0 Tesla)
- ≈10,000 electronic channels
- installation work: July 2021 – January 2022

Data stream:
- up to 300 MB/second
- 50 TB recorded in 1 week of beamtime

Main detectors:
- Scintillator barrel
- Mini Drift Chambers
- CsI calorimeter
- Fiber tracking detectors

- Novel spectroscopic techniques are explored to study exotic nuclei and exotic atoms
- For the first time a calorimeter is coupled to a high-resolution spectrometer for relativistic beams

Experiments:
- Search for eta'-mesic nuclei (S490, K. Itahashi et al.)
- Hypernuclei spectroscopy (S447, T. Saito et al.)

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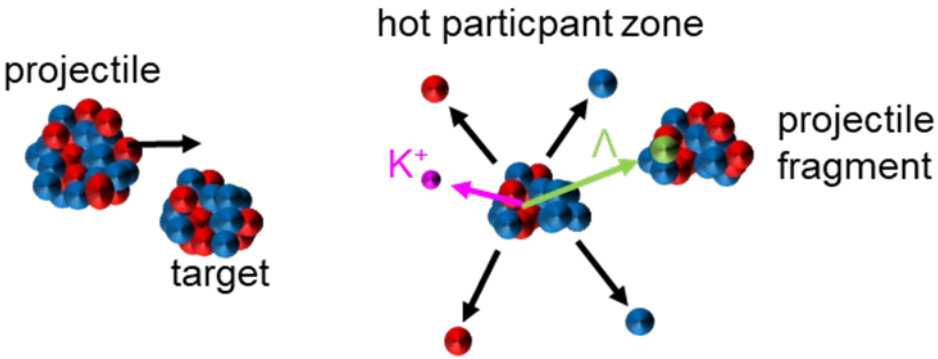

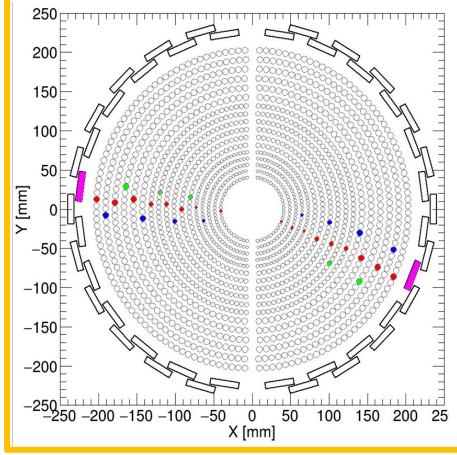

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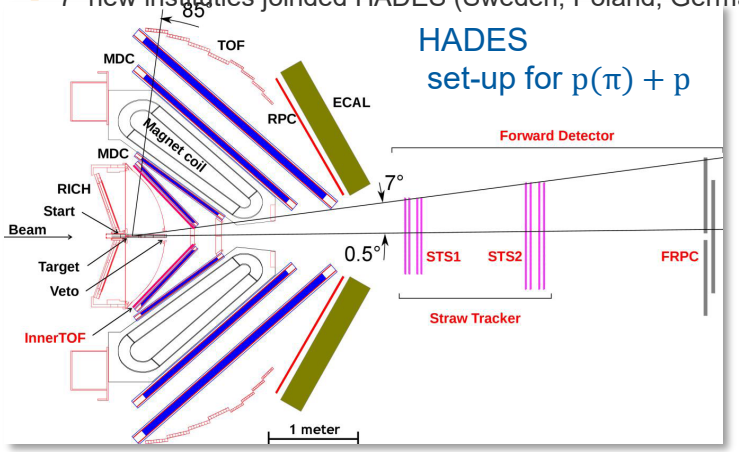
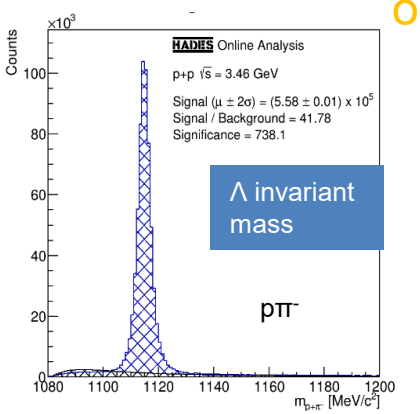
HADES 2022

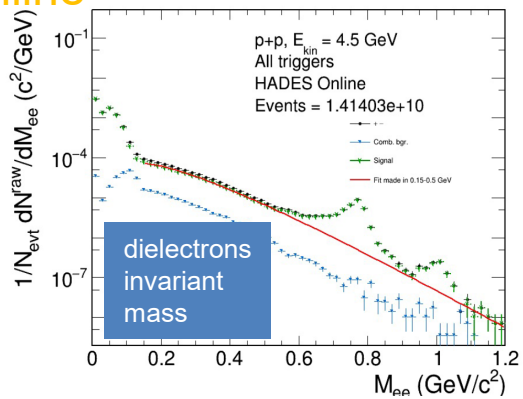
Production and electromagnetic decay of hyperons

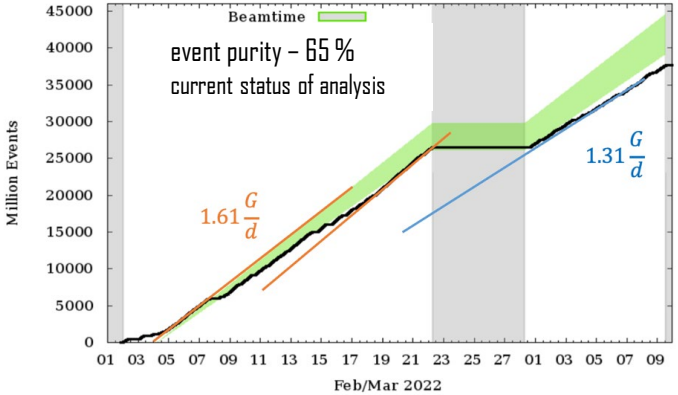
- Successful beam time: 42 B events collected
- New detector systems: STS forward tracker stations (PANDA), forward RPC (HADES), photon camera (CBM), inner TOF (FAIR-NRW), LGAD T0 (HADES)
  - 7 new instituties joinded HADES (Sweden, Poland, Germany)





online





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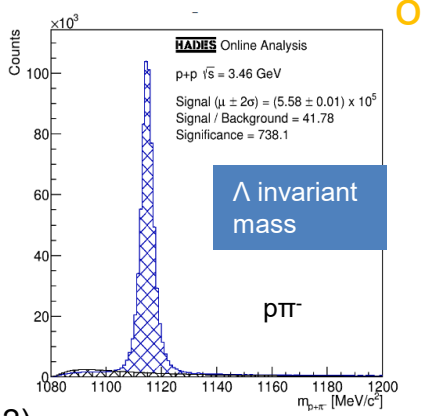
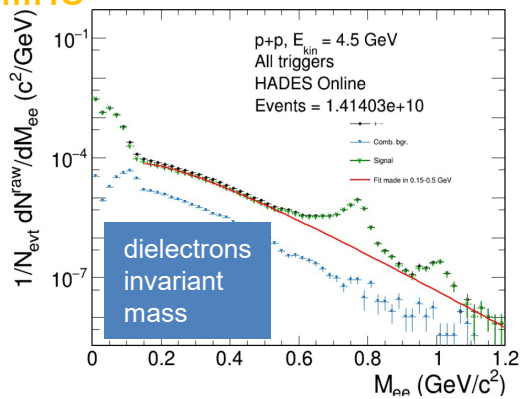
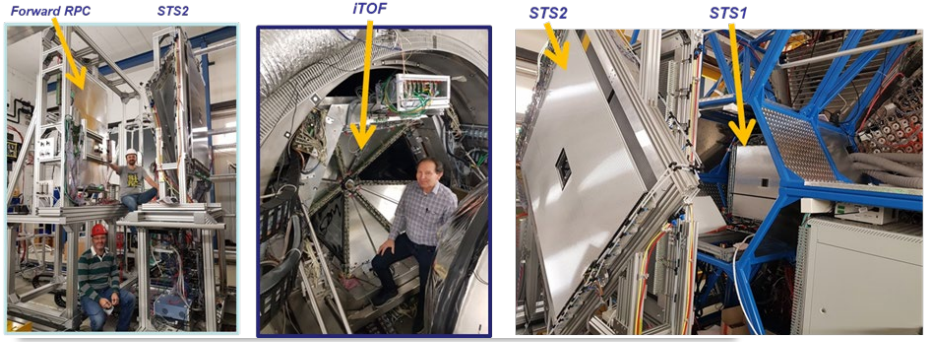


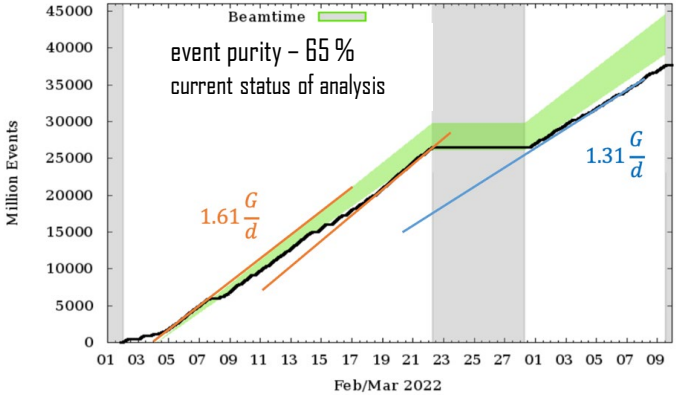
online



Two PANDA-type forward straw stations (STS1 and STS2)

Small polar angle region (0.5° < θ < 7°) for hyperon reconstruction

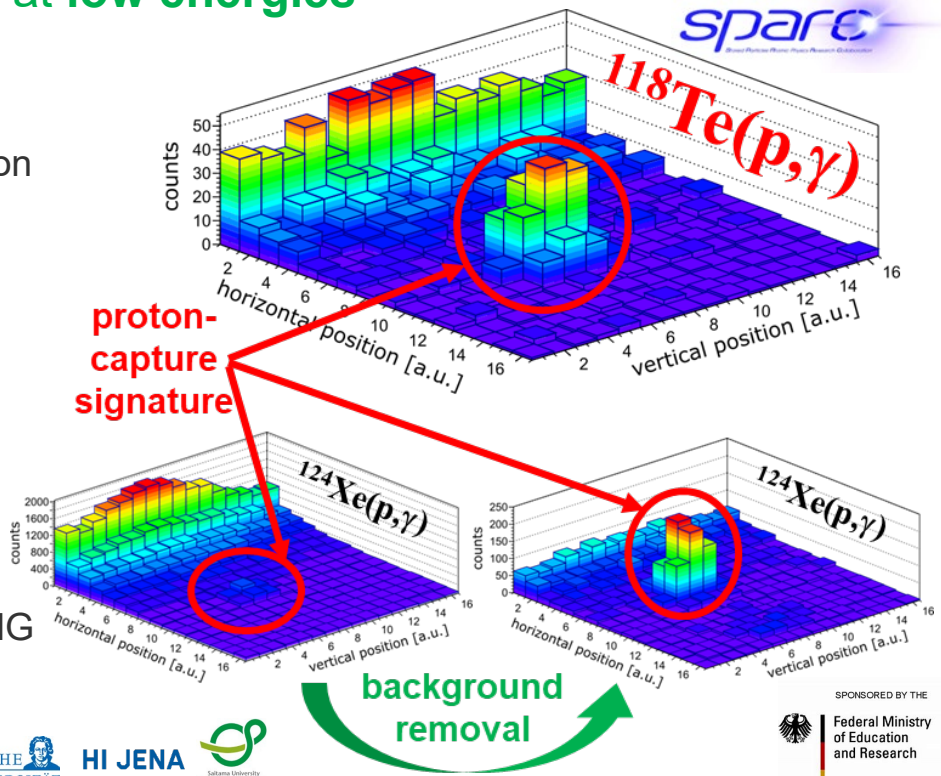




Proton-capture rates for nuclear astrophysics:

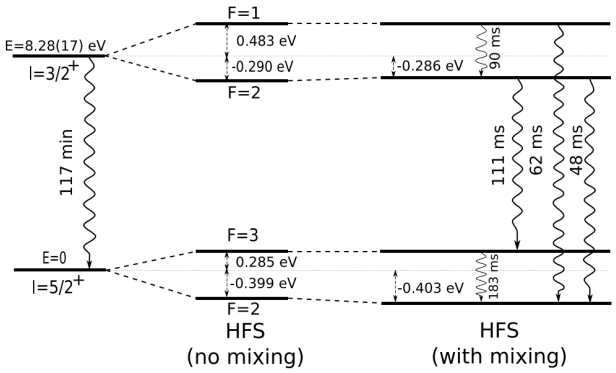
First reaction study on stored exotic beam at **low energies**

- study of radioactive ^{118}Te (6 days half-life)
  - production, storage, accumulation and deceleration of ^{118}Te in FRS-ESR
  - proton-capture measurements realized at 7 MeV/u and 6 MeV/u
  - clear signatures with good statistics
- new background-free detection method
  - maximized sensitivity for detection of proton-capture reactions
- future prospects:
  - full access to Gamow window energies in CRYRING



Laser excitation of the ^{229}Th nucleus using Nuclear Hyperfine Mixing (NHM)

NHM of H-like $^{229}Th^{89+}$: the door opener for nuclear laser spectroscopy:
nuclear clock!



V. M. Shabaev, …, C. Brandau et al., PRL. **128**, 043001 (2022)

Drastic changes of nuclear life time
Excitation: ~10^6 more probable
and: ~10^6 more decay γ's

Laser Spectroscopy at ESR:
An intense „10 eV"-laser exploiting the Doppler Shift

C. Brandau, W. Nörthershäuser et al., JLU Gießen, TU DA, GSI

Redesign of in-ring VUV fluorescense detection system

MgF_2-coated Al-mirrors for the detection of photons below 115nm
(Collaboration Fraunhofer IOF, Jena)

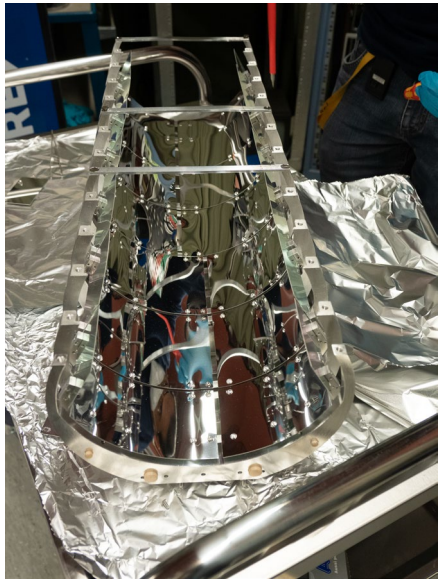


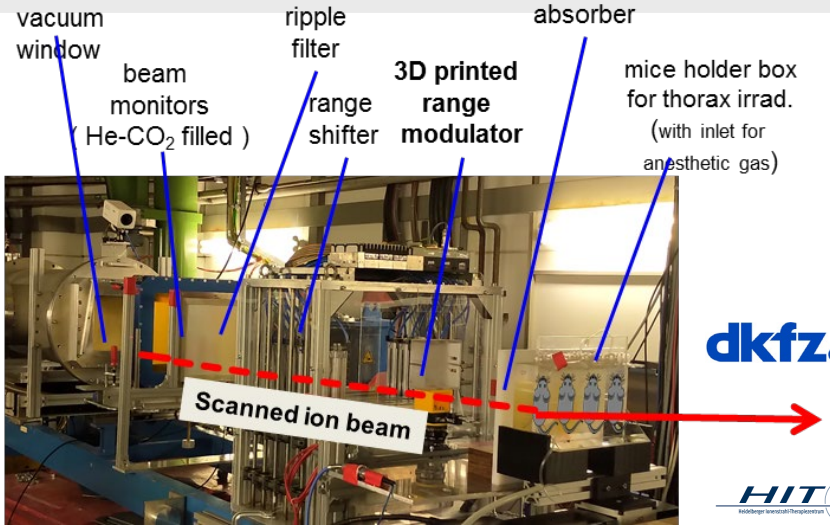
Foto: C. Brandau

Achievements:

- $2*10^4$ bunched $^{229}Th^{89+}$ in ESR per 10^9 ^{238}U ions in SIS (future upgrade path identitfied)
- Issue-free 30Hz high-intensity laser operation @320nm
- Short ion bunches (~5ns): refined experiment timing
- New „background-free", low beam-intensity bunch-length measurements (recombination in cooler + particle detectors)

Feasibility of measurement method was demonstrated !

Biophysics: Flash therapy and therapy with radioactive ions



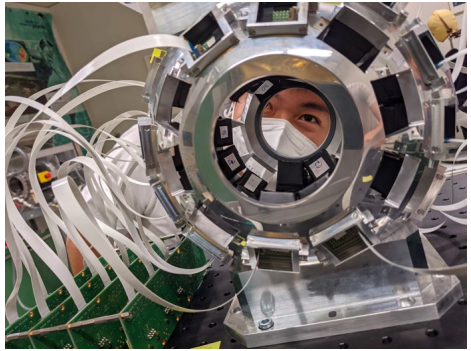
dkfz.

HIT

Same effect on the tumor with less damage to healthy tissue

Beam:
240 MeV/u ; ^{12}C
Beam intensity :
$5\times10^9 \pm 20\%$ ions per spill
$> 3\times10^9$ ions per spill

Extraction time: <200 ms
Doses: 12-18 Gy.
Dose-rate: typ. **100 Gy/s**
Field size: ~ 20 x 16 mm^2
SOBP 2 cm (> 60 keV/µm)



Hybrid γ-PET detectors for RIB

APPA

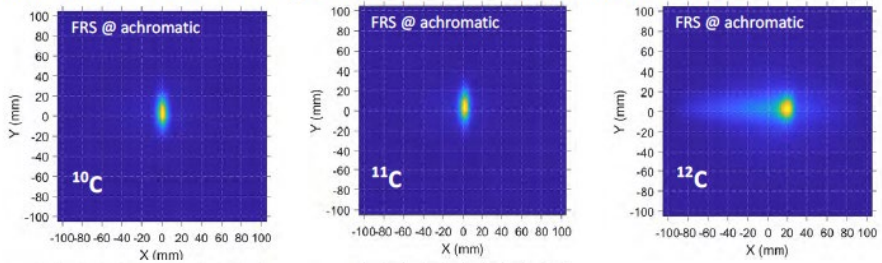
NUSTAR

LMU

BARB (ERC Grant) – Cancer Therapy with radioactive isotopes for simultaneous treatment and PET

~270 MeV/u, ~120 mm range in water

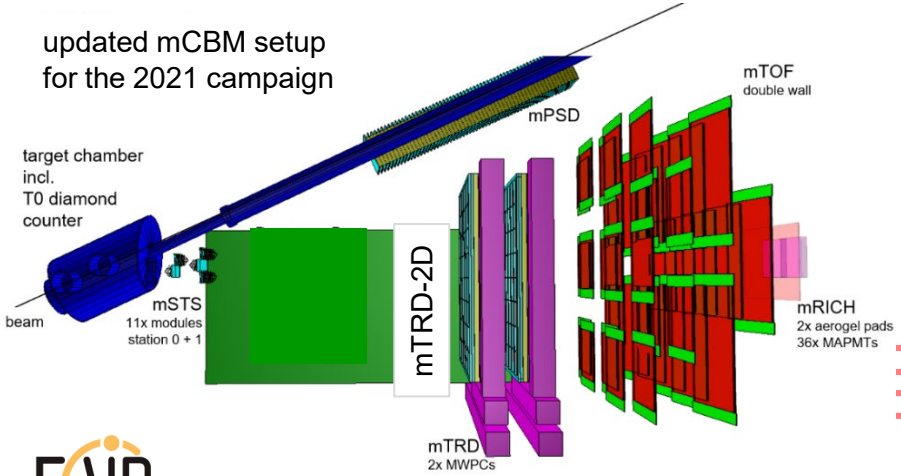
3D PET planar image



www.gsi.de/BARB

mCBM @ SIS18 in 2021 - precursor and demonstrator for CBM @ SIS10

updated mCBM setup
for the 2021 campaign



DAQ container

updated
data transport
with CRIs

optical
fibers
50m

CRI (PCIe)
@ FLES
entry
nodes

optical
fibers

300 m

FLES
processing
nodes

triggerless-
streaming FEE
assigning
time stamps
to hits

1 m
Copper

GBTx

50 m
optical

TFC
(CRI based)

CRI FPGA
µSlice building

FLES entry nodes

300 m
optical
InfiniBand

Green
IT
Cube

Timeslice Building

Event
Reconstruction

Event Selection

Archiving

Summary and Conclusion

FAIR Phase-0 at GSI

- Staged approach to FAIR science which allows smooth transition from GSI to FAIR operation
  - education of young scientists and engineers
  - maintaining expertise and skills
  - commissioning of accelerator and detector equipment
- To continue with annual runs until start of FAIR
- During commissioning of FAIR accelerators user beam time will be spread through the year

Start of FAIR

- Installation of experiments in the new experimental halls, starting with infrastructure items, during the installation of technical infrastructure
- Major revision necessary because of general explosion of prizes for raw materials and the sanction against Russia after the invasion in Ukraine
  - FAIR shareholders initiated a scientific review
    - still ongoing
  - several scenarios are being evaluated
  - final decision(s) expected end of the year

Photo: C. Betz