Update on the FAIR campaign

Kathrin Wimmer

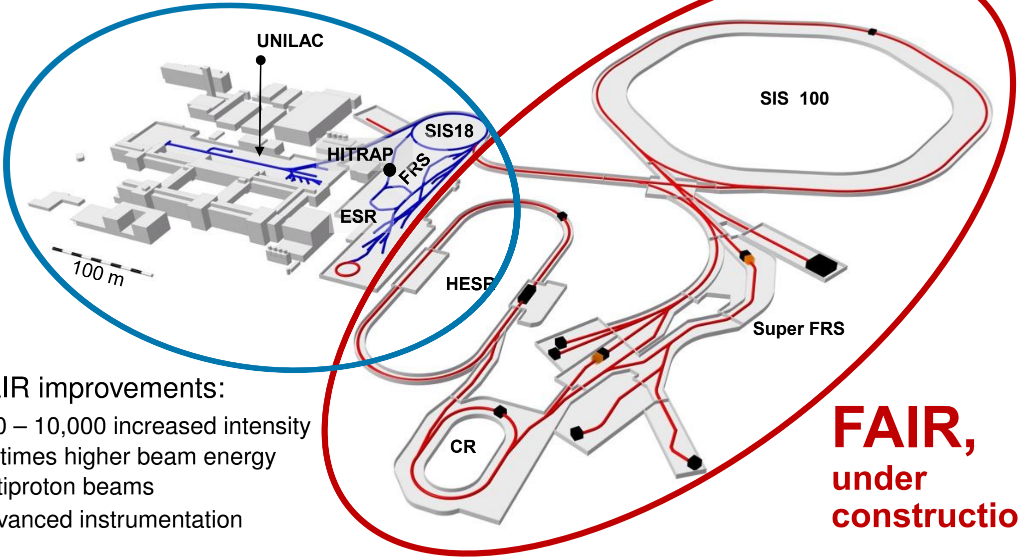
GSI Helmholtzzentrum für Schwerionenforschung

9. September 2024

European Research Council
Established by the European Commission

The GSI/FAIR accelerator complex

GSI, existing (upgraded for FAIR integration)

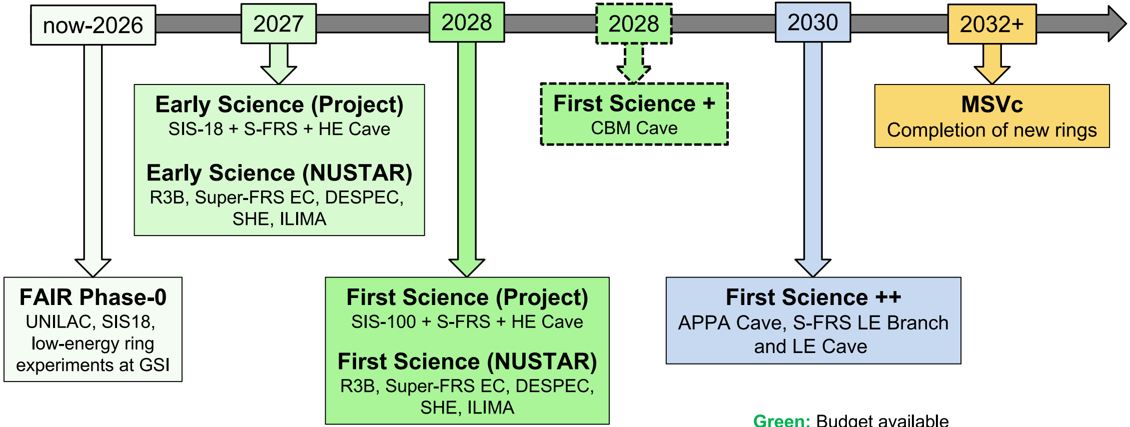


FAIR improvements:

100 – 10,000 increased intensity
10 times higher beam energy
Antiproton beams
Advanced instrumentation

FAIR, under construction

The FAIR timeline



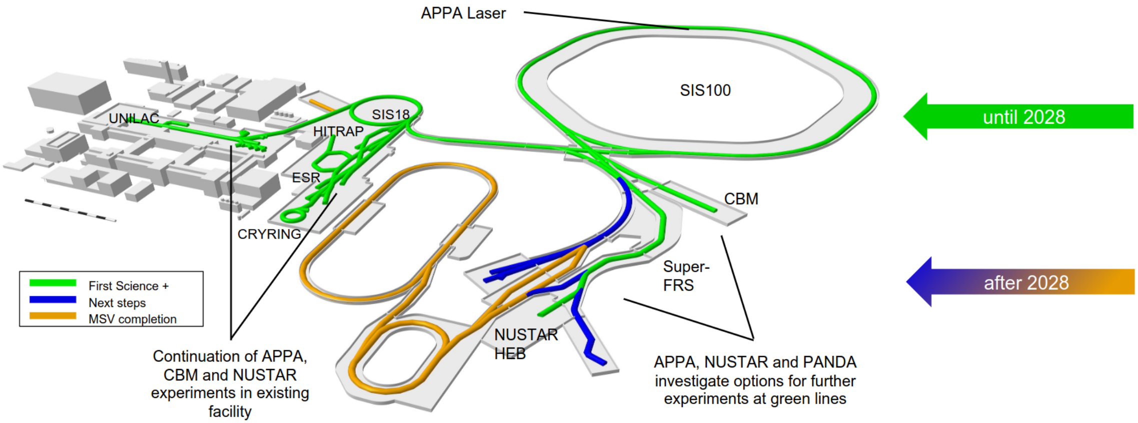
– Timeline dependent on Council decisions and timely delivery of SIS100 quadrupoles
– Additional funding needed in 2026 for continuation of skilled workforce

Green: Budget available
Green: Budget decision expected soon
Blue: Civil construction complete
Orange: Significant additional investment required

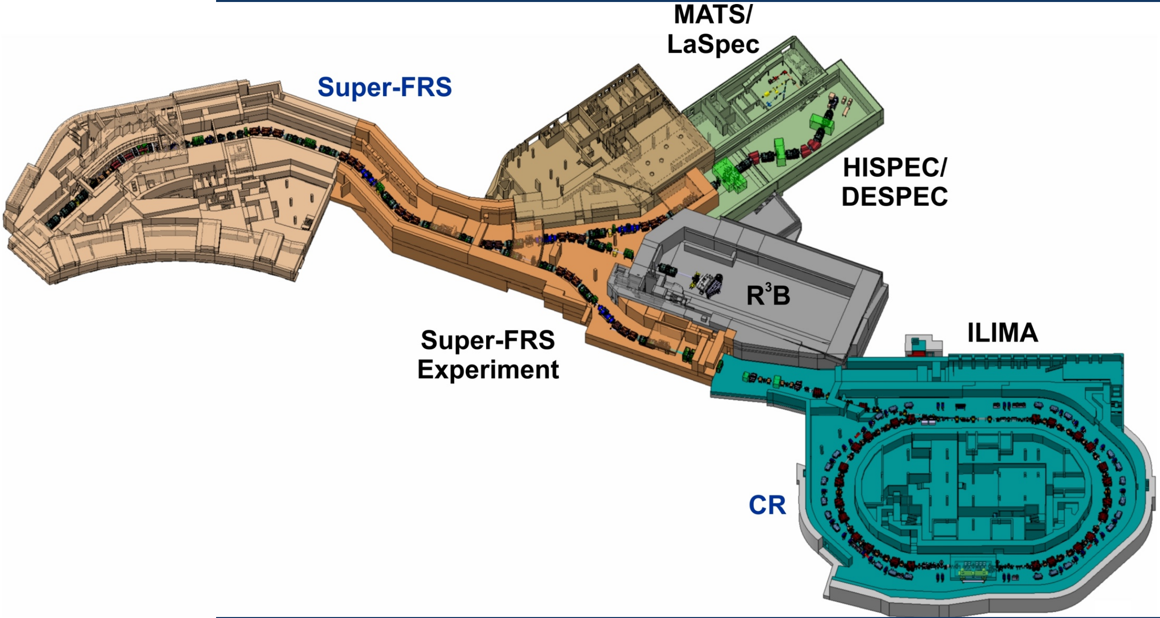
Courtesy Helena Albers

- AGATA to be installed at the low-energy (LE) branch of Super-FRS

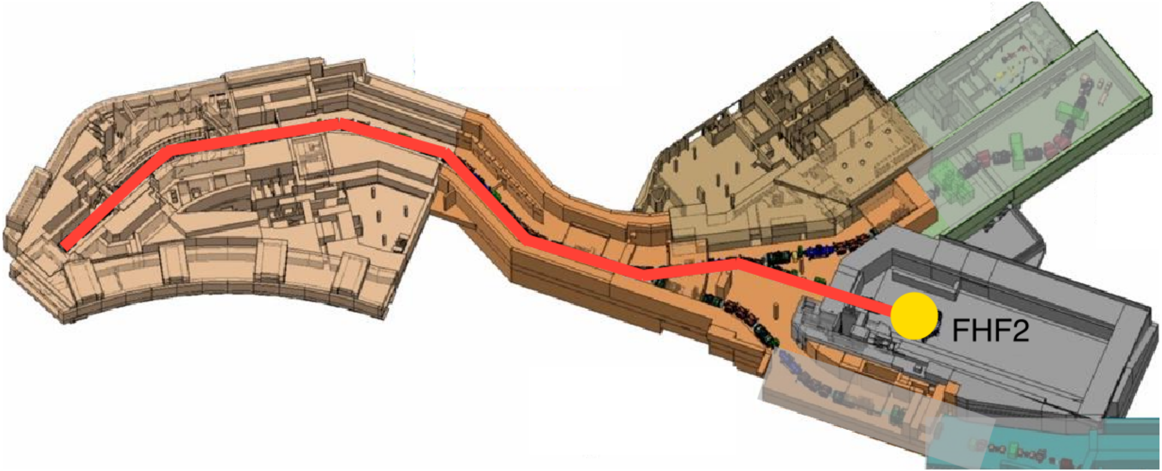
The FAIR timeline



- Until 2028 “First Science”: NUSTAR experiments with SIS100 beams at Super-FRS
- S-FRS provides secondary beams to R^3B, Super-FRS EC, and DESPEC
- Continue experiments at GSI (SHE at UNILAC, ESR, CRYRING)

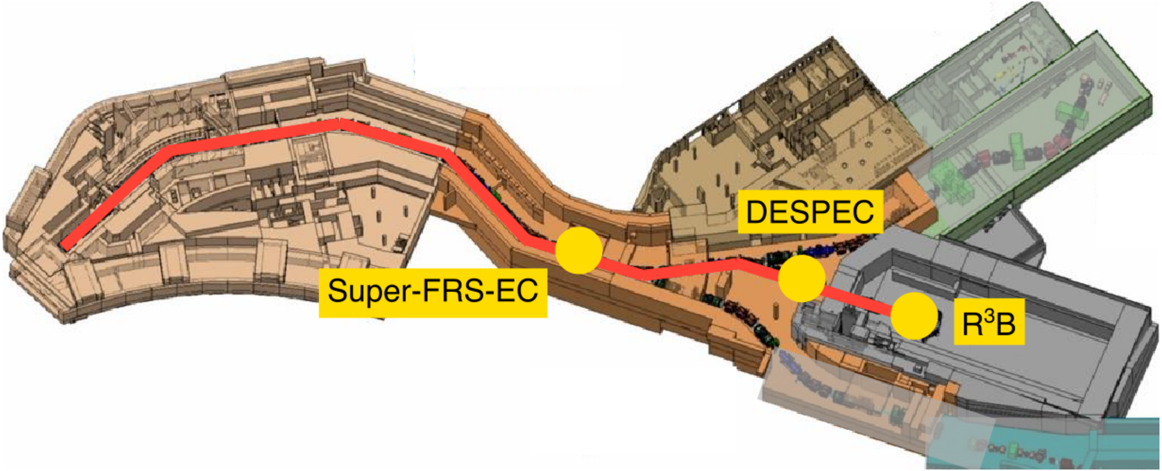

MATS/
LaSpec
Super-FRS
HISPEC/
DESPEC
R3B
ILIMA
Super-FRS
Experiment
CR

The NUSTAR timeline for early and first science



- Commissioning of Super-FRS and common NUSTAR experiment at FHF2 in Q4 2027
- Early (SIS18) and First Science (SIS100) experiments on one beam-line to HEC
- Funding decision on FS++ (including Low Energy Branch) aimed for in 2026, operation 2030

The NUSTAR timeline for early and first science



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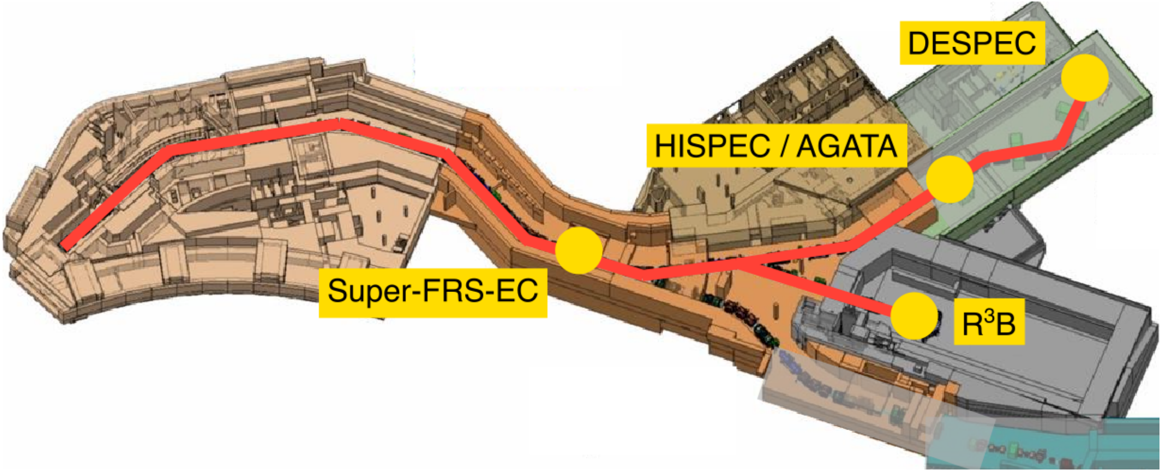

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FAIR construction site April 2024

D. Fehrenz, GSI/FAIR, https://www.gsi.de/forschungbeschleuniger/fair/bau_von_fair/bilder_und_videos

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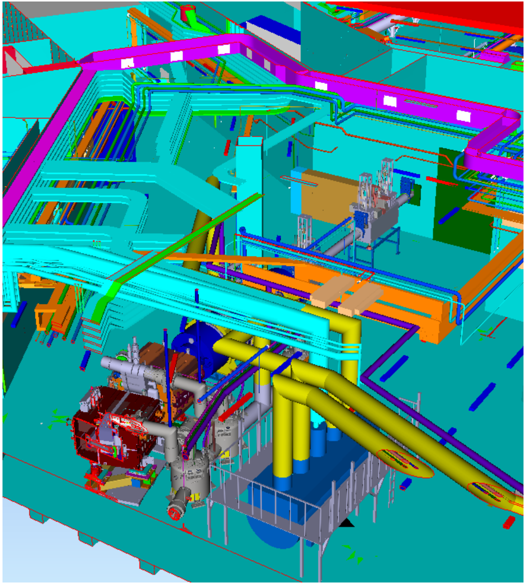
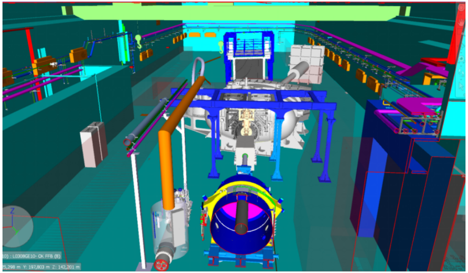


- FHF1 area after Super-FRS
- Beam splitter toward HEC (straight) and LEC (left)

H. Albers, P. Hofmann

FAIR construction site April 2024



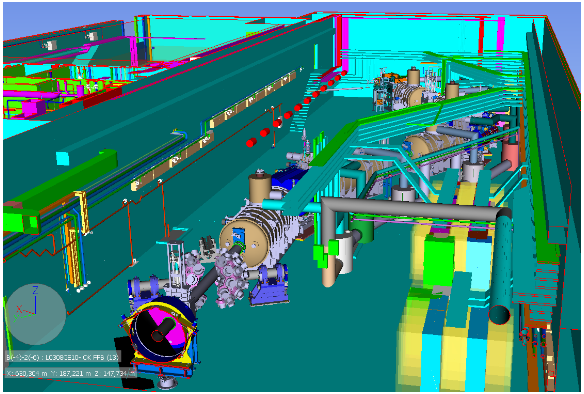
- High-energy cave
- Installation of building infrastructure

H. Albers, P. Hofmann

Artist view:

GSI/FAIR, Zeitrausch, https://www.gsi.de/medien-news/mediathek/bilderdatenbank

FAIR construction site April 2024



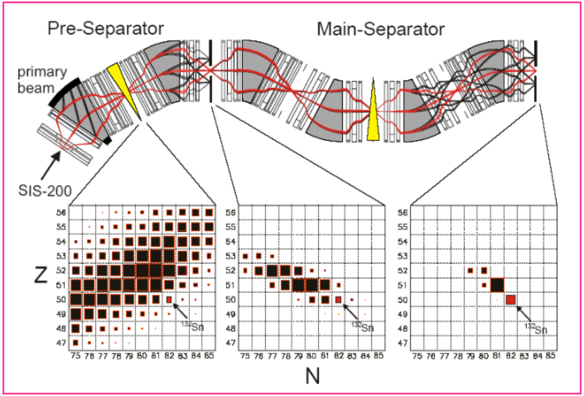
- Low-energy cave
- Building completed, but installation of instrastructure awaits funding decision
- Operation currently planned for First Science++ phase from 2030

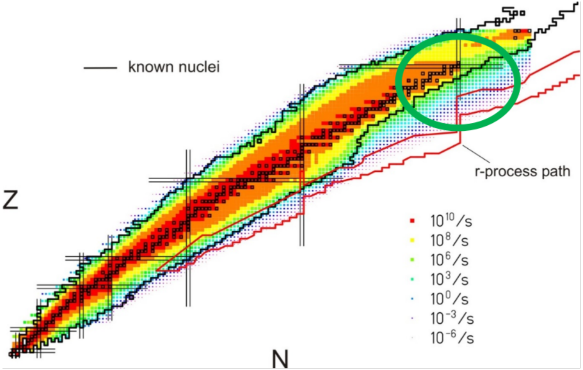
H. Albers, P. Hofmann

FRS tunnel

GSI/FAIR, Zeitrausch, https://www.gsi.de/medien-news/mediathek/bilderdatenbank

Super Fragment-Separator





- Two stage separation and identification
- Large reach for many radioactive beams
- Typical required intensities for in-beam spectroscopy 10-100 pps

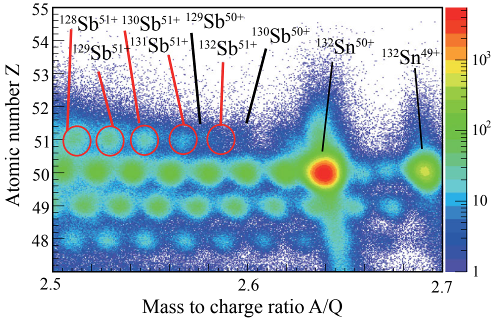
Super Fragment-Separator

- $B\rho - \Delta E - TOF$ method

$$\frac{dE}{dx} = \frac{4\pi e^4 Z^2}{m_e v^2} Nz \left[ln\left(\frac{2m_e v^2}{I}\right) - ln(1-\beta^2) - \beta^2 \right]$$

$$TOF = \frac{L}{\beta c}$$

$$\frac{A}{Q} = \frac{B\rho}{\beta\gamma}\frac{c}{m_u}$$



- Challenge: separation of charge states
- Increase in primary beam intensity and transmission
- Competitive intensities throughout the periodic table

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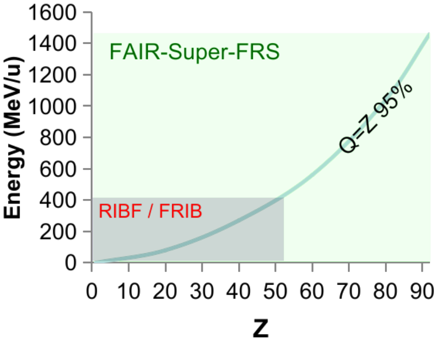

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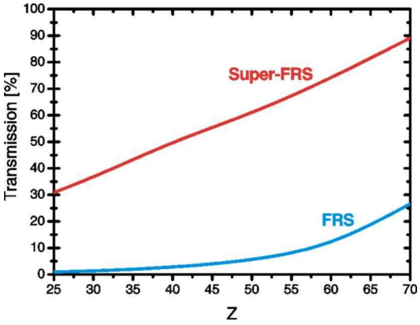

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  $\rightarrow$ Benefit from high beam energy
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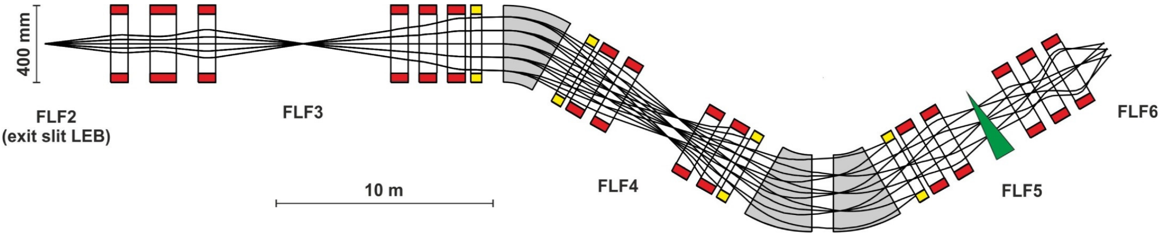
- Competitive intensities throughout the periodic table

Facility	U intensity per spill
Phase 0 at GSI	$2 \cdot 10^9$
Early Science	$8 \cdot 10^9$
First Science SIS100	$2 \cdot 10^{10}$
Final full intensity with SIS100	$3 \cdot 10^{11}$

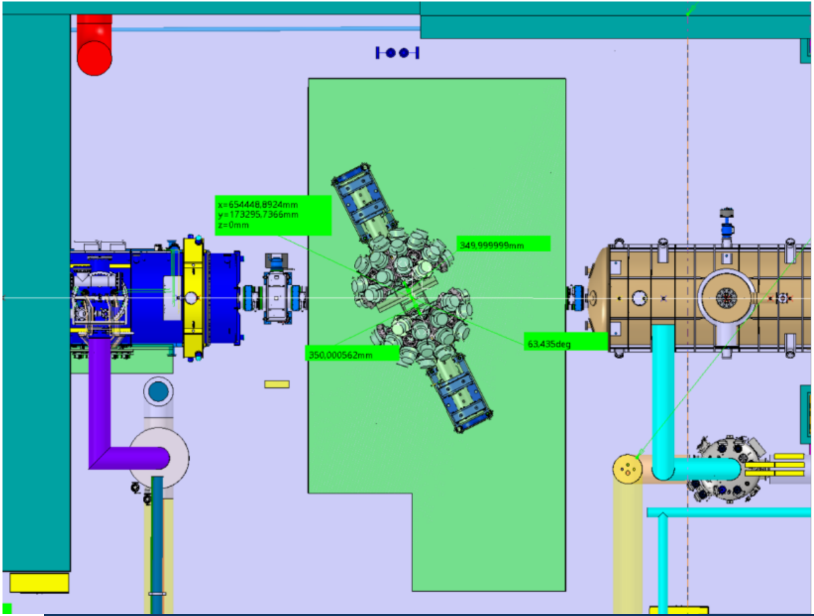
Low-energy branch



Conceptual design with flexible operation

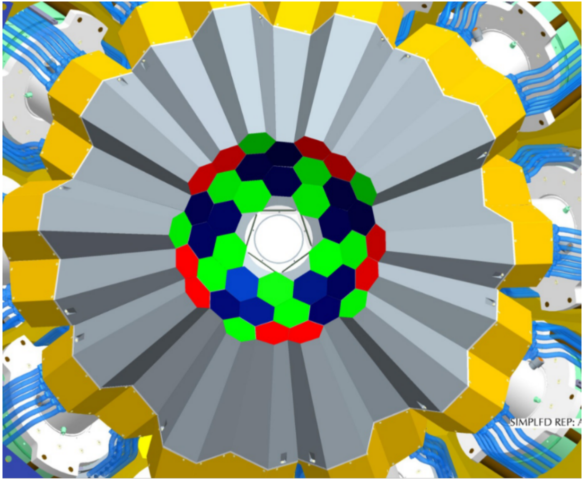
- Secondary target at FLF3
- Large acceptance spectrometer
- 3 dipole magnets with 30° deflection angle, maximum rigidity 7 Tm (about 300 *A*MeV depending on the species)
- High-resolution / energy buncher mode
- Dispersion matching (main-separator and energy buncher)
- Intermediate focus at focal plane FLF4
- Large experimental area, about 7 m along the beam line at FLF3

AGATA at FLF3

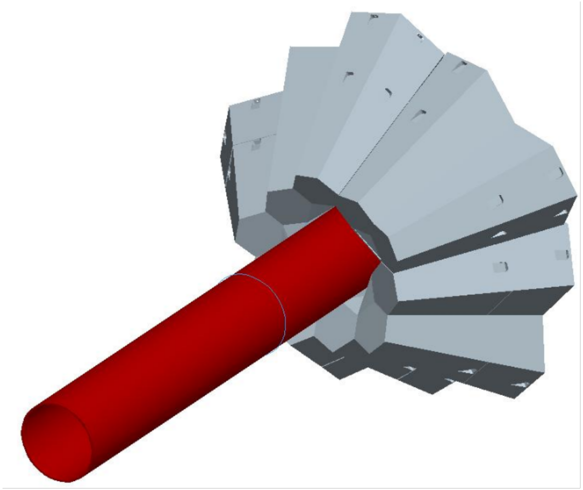


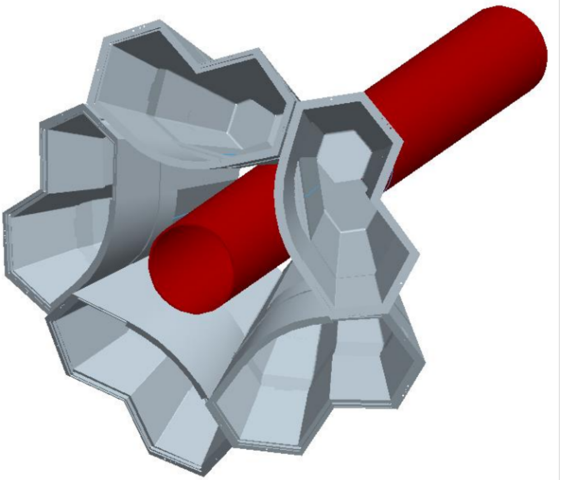
AGATA at FLF3

- Beam rates 100 Hz to 100 kHz
- Beam spot size at secondary target $\sim 2 - 3$ cm
- Typical target size 8×8 cm^2
- Fast secondary particles are created
  $\longrightarrow$ Could damage most forward detectors
  or lead to dead-time
- Consider acceptance of spectrometer for several beam species
- Exit of target chamber 120 mm beam pipe
- Diameter pentagon 160 mm
- Use doubles at most forward angles around a pentagon
- Need five double cryostats (existing)



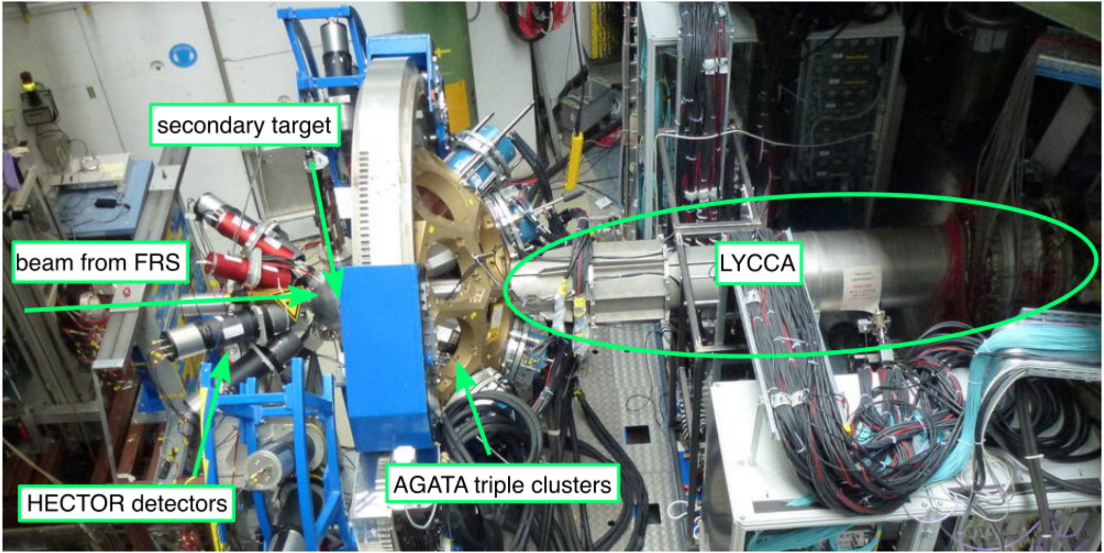
Double cryostats with a 120 mm beam pipe





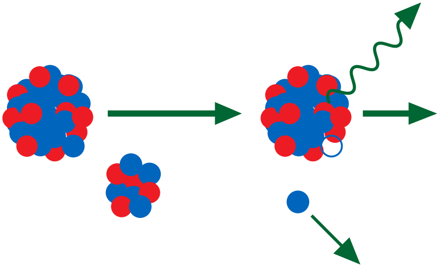
Experimental techniques and considerations

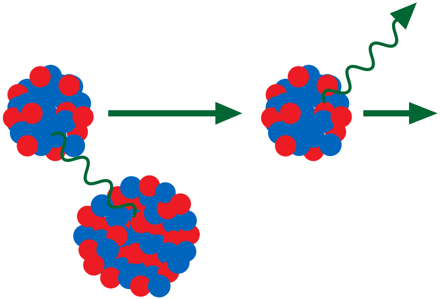
- AGATA at GSI 2012-2014 (PreSPEC campaign)



Direct reactions

- Direct knockout reactions and Coulomb excitation at relativistic beam energies ($\beta \sim 0.5\ c$)
- Peripheral collision probe the surface of the nucleus





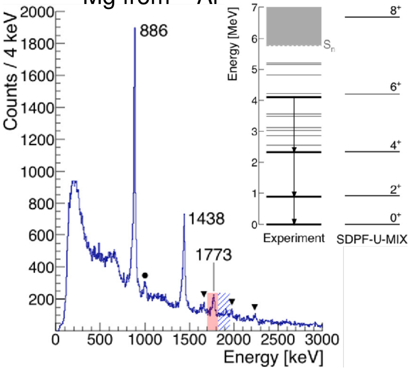
- Remove one nucleon in the collision with a light target
- Single-particle properties

- Excitation in the electromagnetic field of a high Z target
- Collective properties

M. A. Bentley, G. Benzoni, K. Wimmer, "Agata: in-beam spectroscopy with relativistic beams", Eur. Phys. J. A **59** (2023) 172.

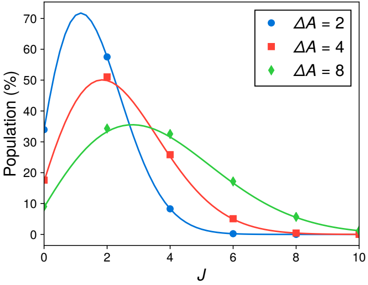
Secondary fragmentation and lifetimes

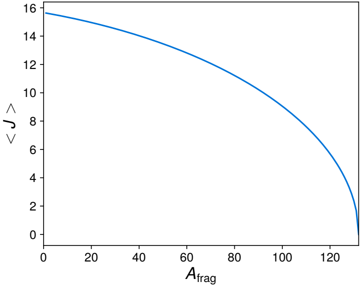
^{32}Mg from ^{46}Ar



H. Crawford et al., Phys. Rev. C **93** (2016) 031303(R).

- Multi-nucleon removal reaction from ^{132}Sn





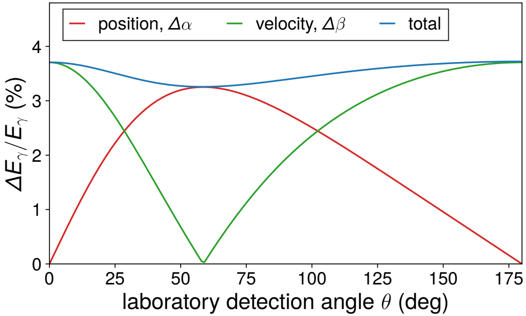
- Simple analytical expression for the angular momentum distribution

M. de Jong et al., Nucl. Phys. A **613** (1997) 435.

- Many nucleon removal reaction populate “high-spin” states
- Few nucleon removal limits feeding of 4^+ states
- Measure lifetimes of several states in one experiment

Secondary fragmentation and lifetimes

- Choice of target affects resolution



- Background from atomic processes
- Radiative electron capture $\sim Z_p^2 Z_t$
- Primary Bremsstrahlung $\sim Z_p^2 Z_t$
- Secondary Bremsstrahlung $\sim Z_p^2 Z_t^2$

calculator https://github.com/wimmer-k/Coulex

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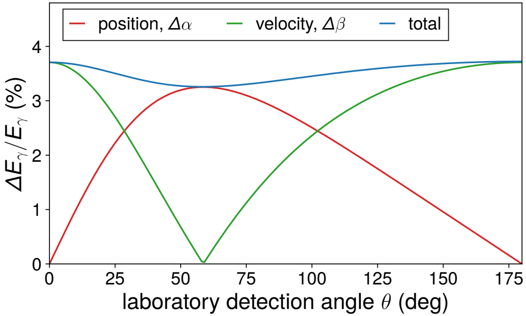

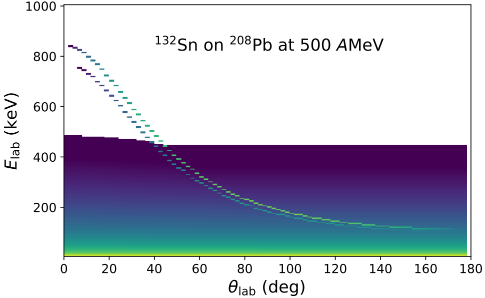

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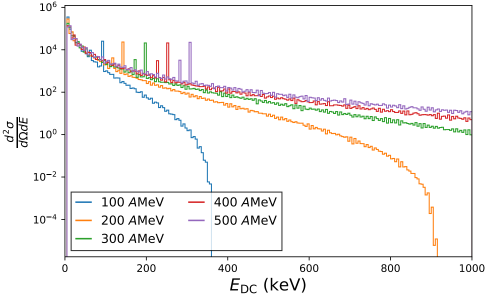

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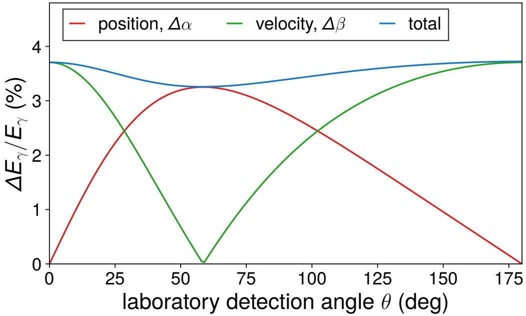

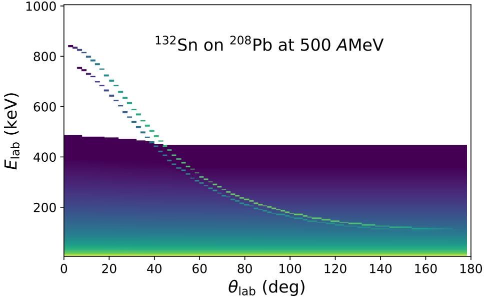

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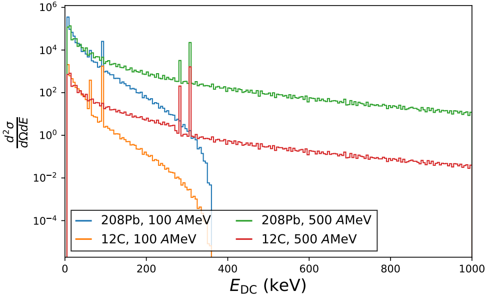
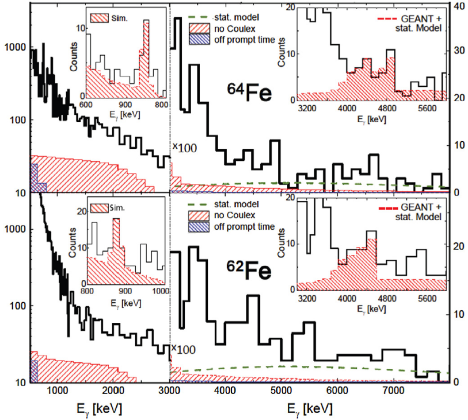
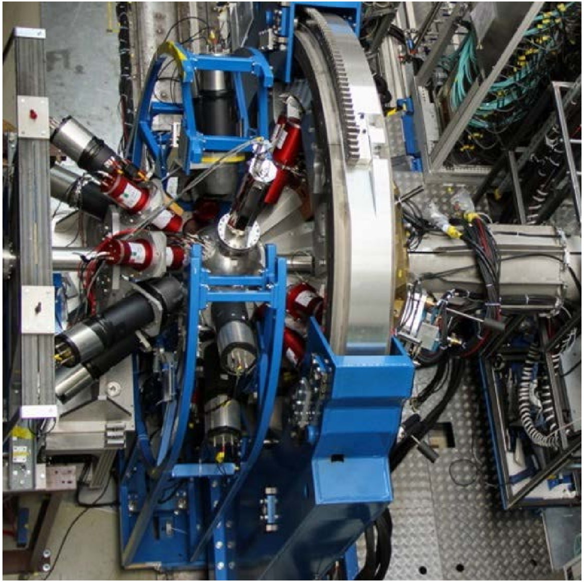


Secondary devices

- Additional γ-ray detectors around the target
- PRESPEC campaign:
  HECTOR array with $LaBr_3$ and BaF_2 detectors



R. Avigo et al., Phys. Lett. B **811** (2020) 135951.



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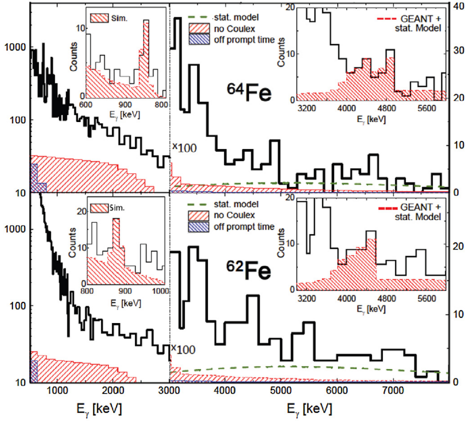

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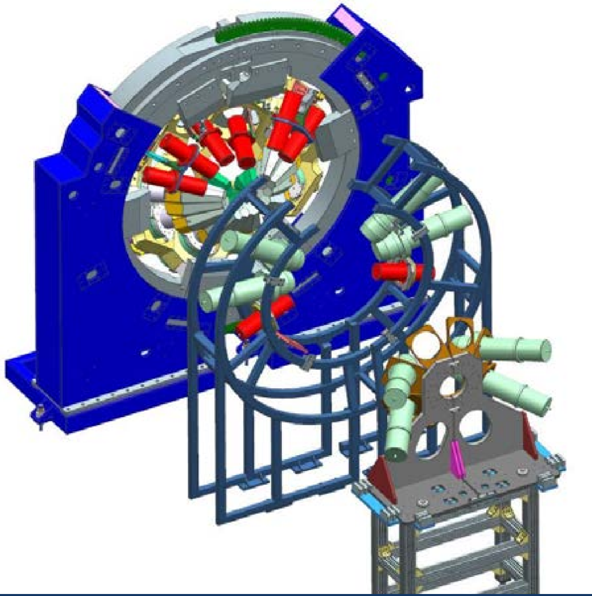

Targets

- Standard solid target, 8 $\times$ 8 cm^2, beam tracking
- Plunger setup for lifetime measurements
  University of Cologne, Germany and Horia Hulubei NI, Romania
- Liquid hydrogen, deuterium, helium targets
- To access the most exotic nuclei thick targets have to be used (few mm or g/cm^2)
- Reaction and emission at different velocities
- (Angle dependent) spread in Doppler reconstructed spectrum
- Different mean decay velocities and different depths in the target
- With an active target resolution can be greatly improved

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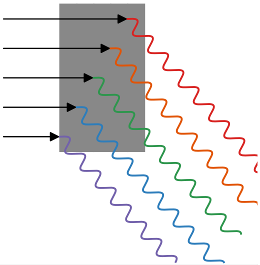

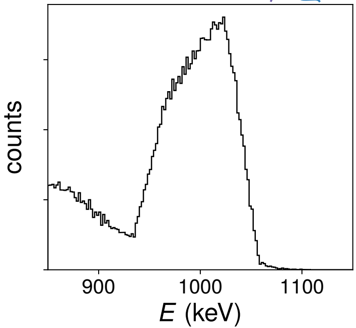

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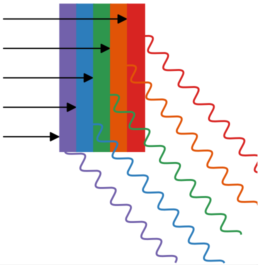

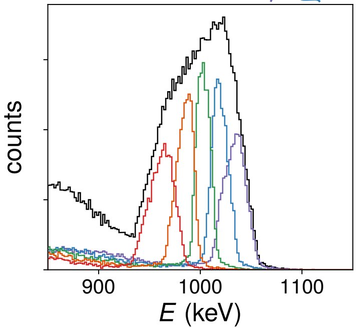

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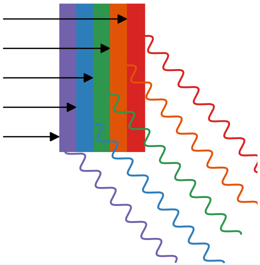

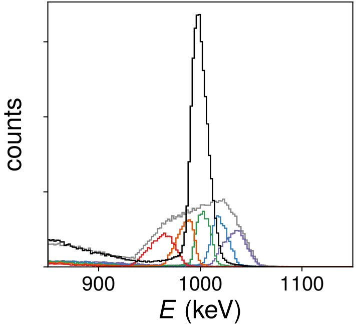

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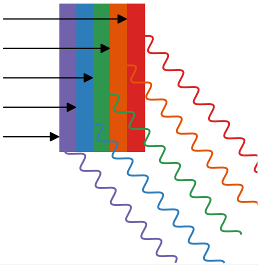
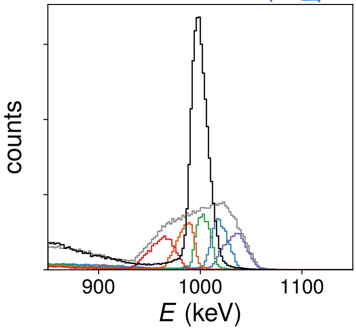
- Multiply statistics without sacrifice to resolution
- Increased sensitivity for lifetime measurements





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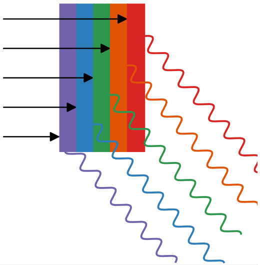
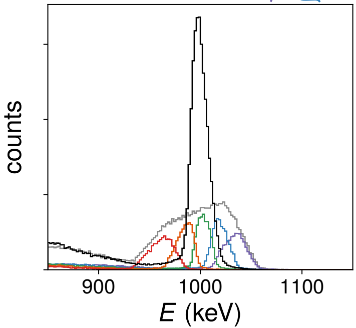
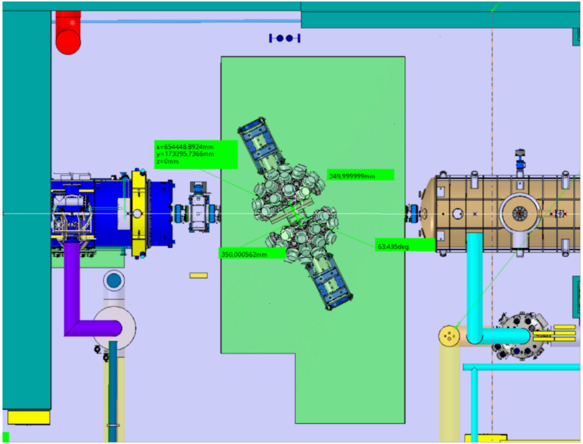
LIfetime measurements with Solid Active targets





Summary

- FAIR construction under way, buildings finished
- Installation of SIS100 magnets started
- First FAIR experiments in 2027



- Main benefit for AGATA from higher primary beam intensities with SIS100
- Commissioning of low-energy branch currently forseen for 2030
- Installation of AGATA in late 2030
- Start experiments with AGATA in 2031

Thank you for your attention

Backup

High-energy cave progress

P. Hofmann, NUSTAR newsletter 2024