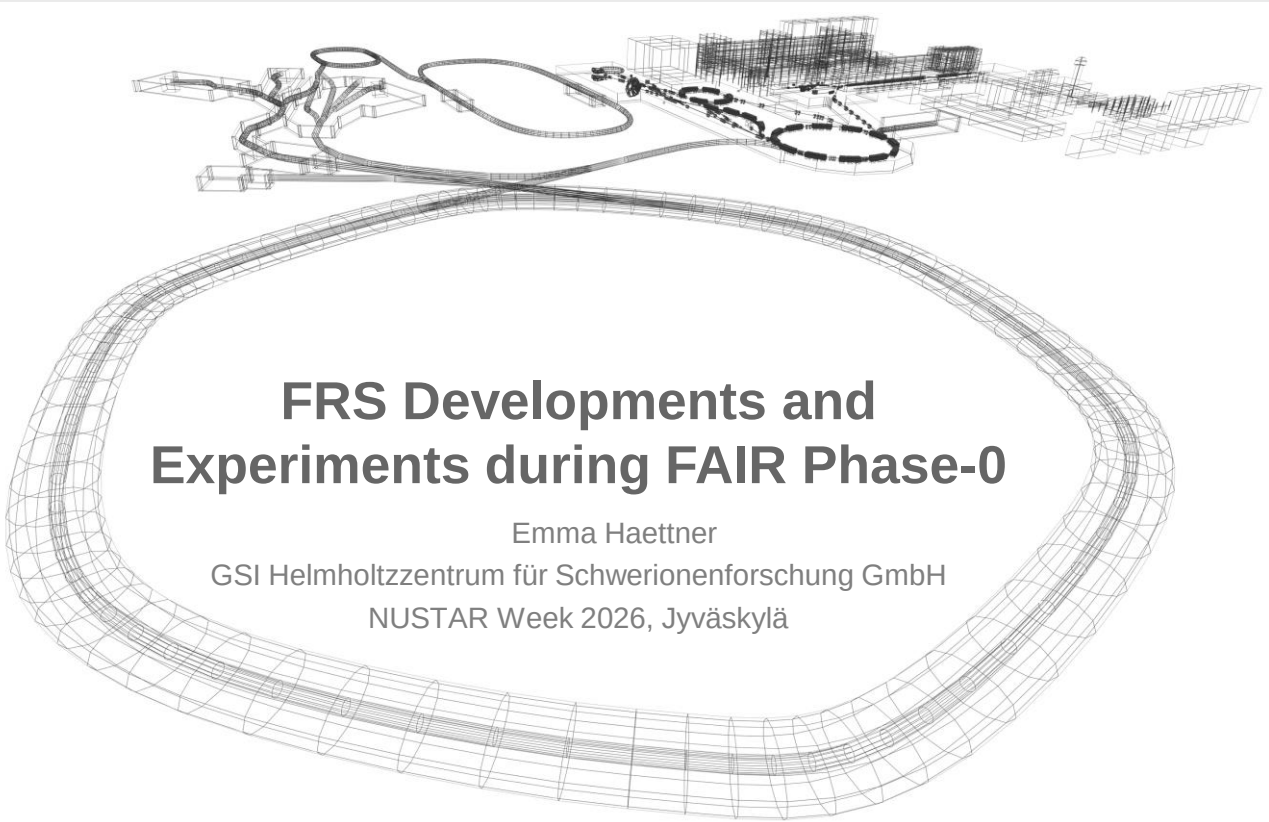




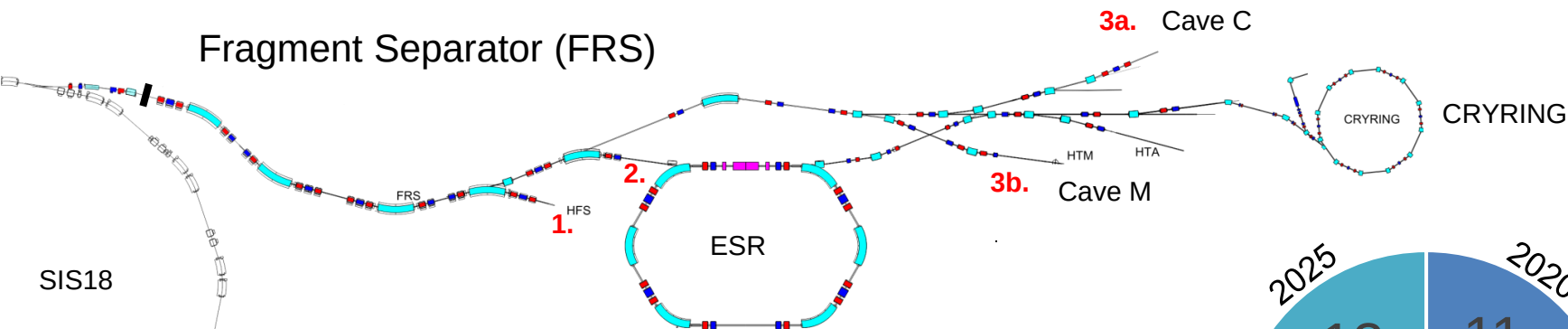
FRS Developments and Experiments during FAIR Phase-0

Emma Haettner

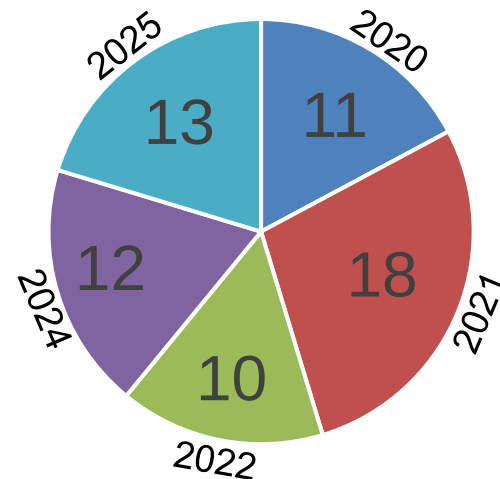
GSI Helmholtzzentrum für Schwerionenforschung GmbH

NUSTAR Week 2026, Jyväskylä

FRS Experimental Program in FAIR Phase-0



- 1.** Decay spectroscopy, masses, lifetimes of ions stopped in gases and solids, high-resolution momentum measurements of mesic and hyper nuclei
- 2.** Masses, lifetimes, direct reactions, stored bare and few-electron ions
- 3a.** Reactions studies in complete kinematics, fission studies, nucleon-nucleon correlations
- 3b.** Bio-medical experiments with positron emitters



In total: ~64 Experiments!

Preparations for FAIR Phase-0

A difficult beginning

- In preparation of FAIR Phase-0, it was noticed that the coils, when excited, are lifted and bang on the iron yoke
- Observed in all 4 dipole magnets of the main branch of the FRS
- After 30 years of experiments, the coil clamps were broken, most of the screws were ruptured, damping material had crumbled

Together with the GSI Magnet Group, **all four magnets were repaired in 2019**, enabling the FAIR Phase-0 program at the FRS to start in 2020.



Steps towards a successful experimental program

Driven by the needs of the experiments and the goal of maximizing scientific output, the developments of the FRS have focused on:

- **Improvement of working conditions**
- **Renewal of essential systems**
- **Increased flexibility**
- **Development of new functionalities**
- **Serve as a test platform for FAIR experiments**
- **Build-up of expertise**

FRS Environment – Improved working conditions



- Refurbished preparation area
- Cooling of the experimental cave
- Installation of two new storage lifts
- New crane in S1
- New gas storage
- Improved access to the experimental areas



Renewal of essential systems and improvements for reliability: Power supplies – vacuum infrastructure

Upgrade of the power supplies:

- Replacement to a system compatible to FAIR standards
- Improved ventilation to avoid overheating



Upgraded
power supplies

Upgrade of the vacuum system:

- Replacement of old equipment (pumps and sensors)
- Relocation of radiation sensitive equipment



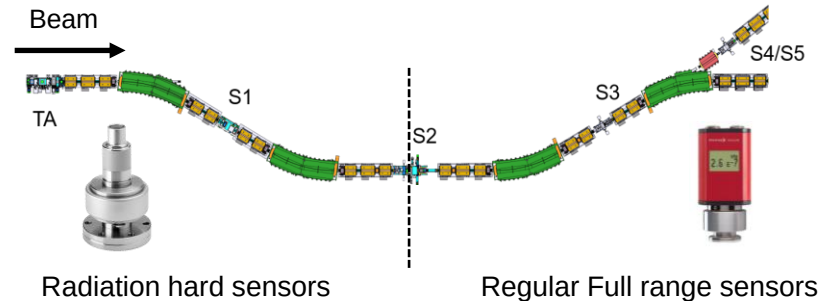
New pipes



New vacuum
pumps



Relocated
controllers



Renewal of essential systems and improvements for reliability: Upgrade of FRS steppermotors

The steppermotors are an essential system with ~60 channels

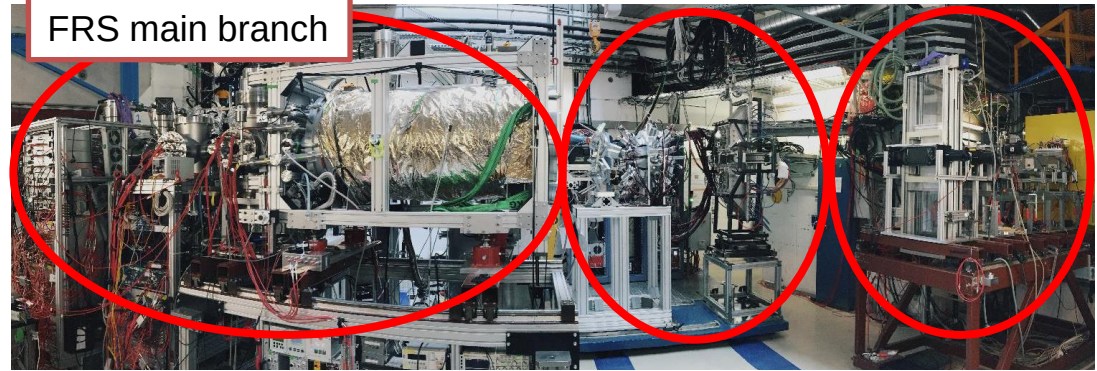
- **Issues with the old system**
 - Rather high failure rate
 - Limited availability and high cost of spare parts
 - **Replaced with Cosylab system (Slovenian in-kind contribution to FAIR)**
 - **New possibilities**
 - Move several drives simultaneously (e.g. TA current grids!)
 - Save and retrieve stepper-motor settings
 - fewer losses due to human mistakes
 - Keep components moving to distribute heat and prevent damage
 - Recent example: Pb target damaged by U beam
- More time for data taking



New Cosylab hardware (FAIR standard) installed in new room

T.Weber, S.Glöckner, D.Madzelan

- Need: Fast and efficient changeover between experiments, e.g. Ion Catcher and DESPEC
- Modular concept at FRS F4 was implemented
- Essential to accommodate the rich FAIR Phase-0 experimental program



**FRS standard
Equipment
for particle ID**

Example from 2025: 7 days gap

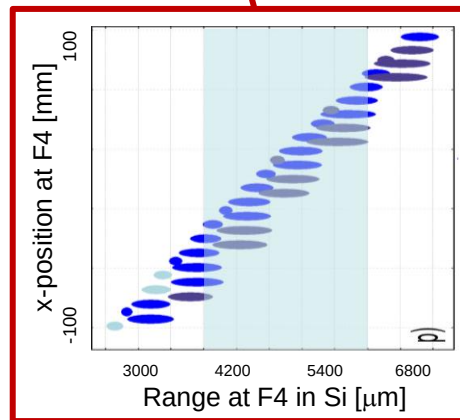
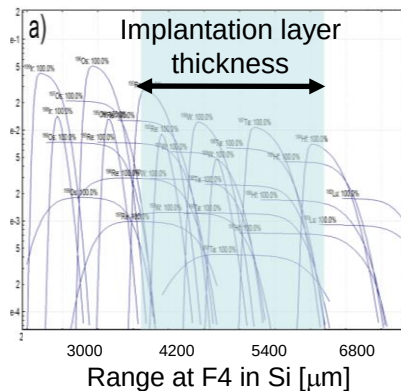
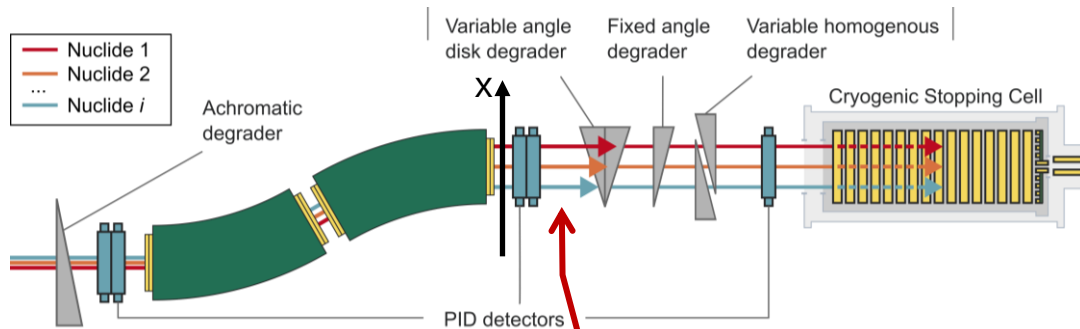
February	Sat	Sun	Mon	Tue	Wed	Thi	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
2025	1	2	3		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
IS N															107-Ag												78-Kr	
SIS						160, HFS, 107-Ag			056, HFS, 107-Ag					110, HTD, 107-Ag	ACC, 107-Ag	S-FRS Defectortest, HTD, 107-Ag					0302, HFS, 107-Ag						115, HFS, 78-Kr	

HISPEC/DESPEC

→ Time efficient method to study broad area of the nuclear chart

Fragment separation in achromatic mode:

- The residual range of various isotopes are different
- The beam spot sizes at the final focal plane are small
- The range correlates with the horizontal x-position
- A shaped degrader brings the ions to a common mean range

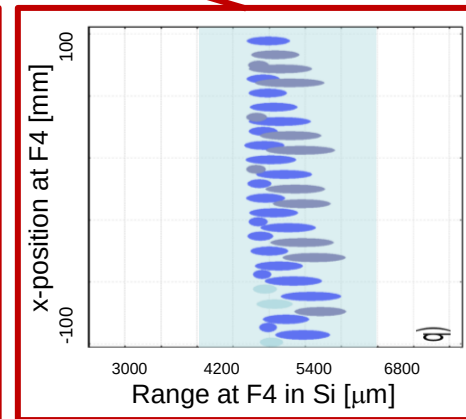
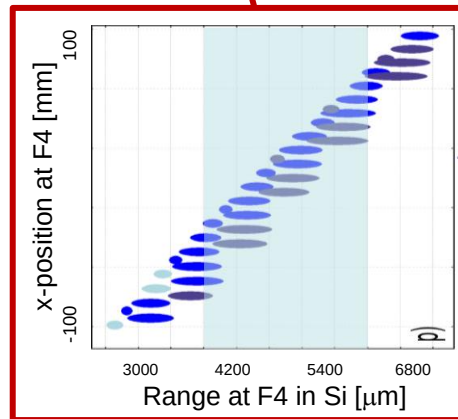
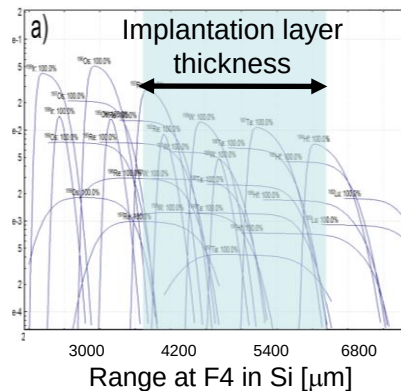
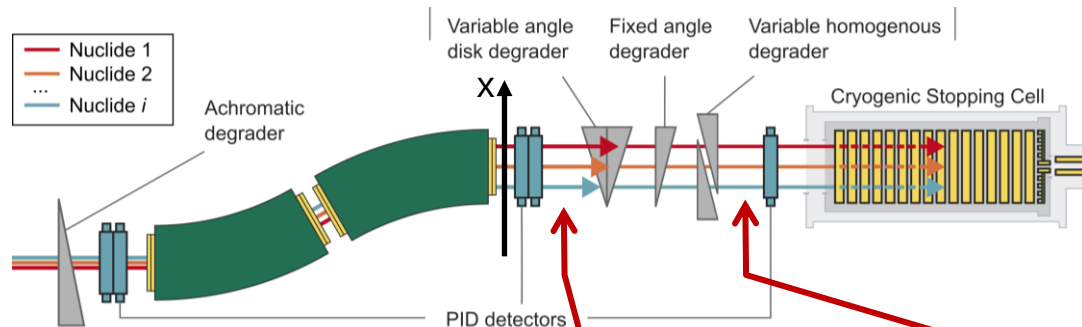


New functionalities – Mean range bunching

→ Time efficient method
to study broad area of
the nuclear chart

Fragment separation in
achromatic mode:

- The residual range of various isotopes are different
- The beam spot sizes at the final focal plane are small
- The range correlates with the horizontal x-position
- A shaped degrader brings the ions to a common mean range



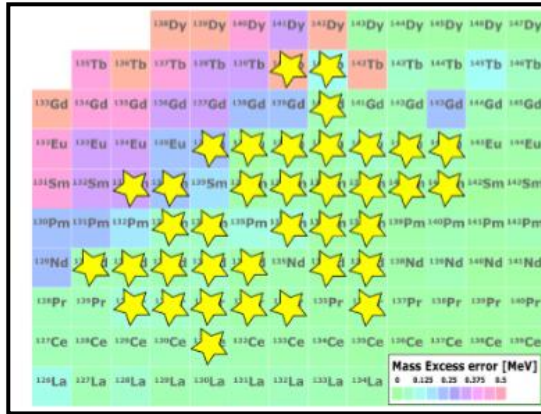
Mean range bunching - examples

Method successfully applied in various stopped beam experiments!

1. Measuring many masses at the same time with FRS Ion Catcher:

2. Implant several different nuclides in the AIDA

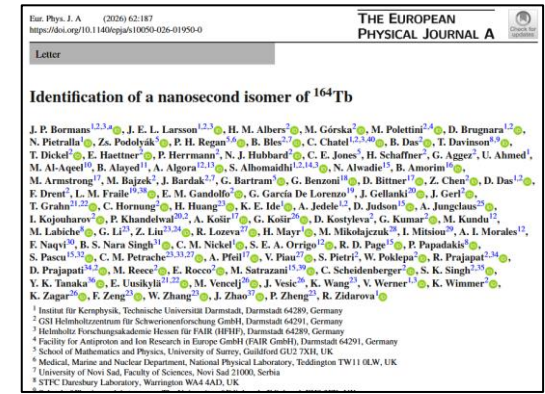
Exp S482, C.Hornung et al.



Exp S450, Zs.Podolyák et al.



Exp G-22-00100, H.Albers et al.



T. Fowler-Davis, PhD Thesis, 2025

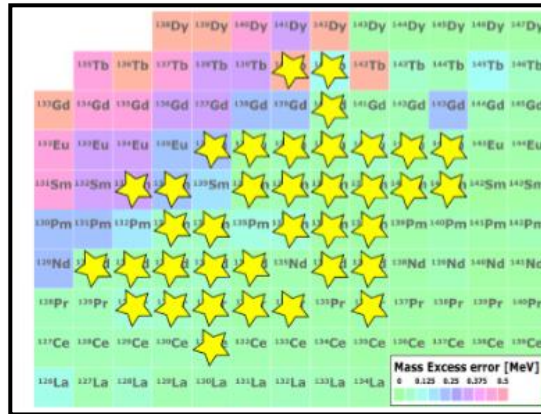
All marked nuclides measured at the same time!

Mean range bunching - examples

Method successfully applied in various stopped beam experiments!

1. Measuring many masses at the same time with FRS Ion Catcher:

Exp S482, C.Hornung et al.

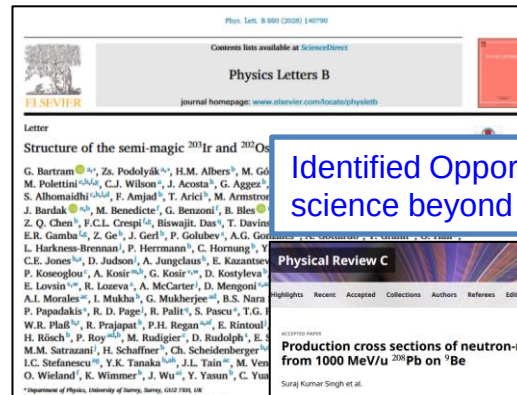


T. Fowler-Davis, PhD Thesis, 2025

All marked nuclides measured at the same time!

2. Implant several different nuclides in the AIDA

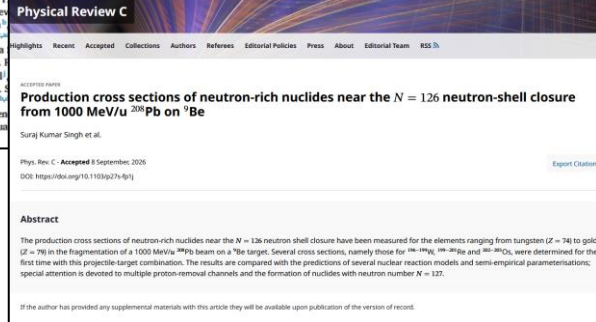
Exp S450, Zs.Podolyák et al.



Exp G-22-00100, H.Albers et al.

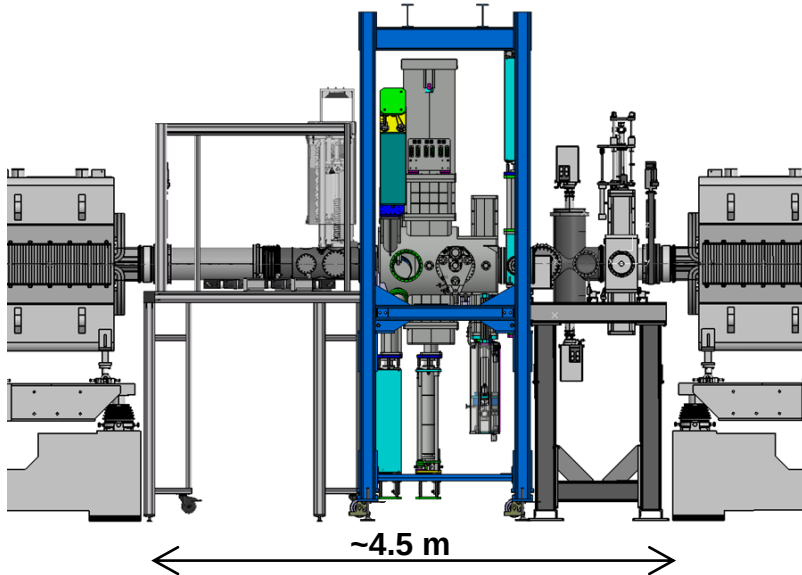


Identified Opportunity: Explore more science beyond the main goal!



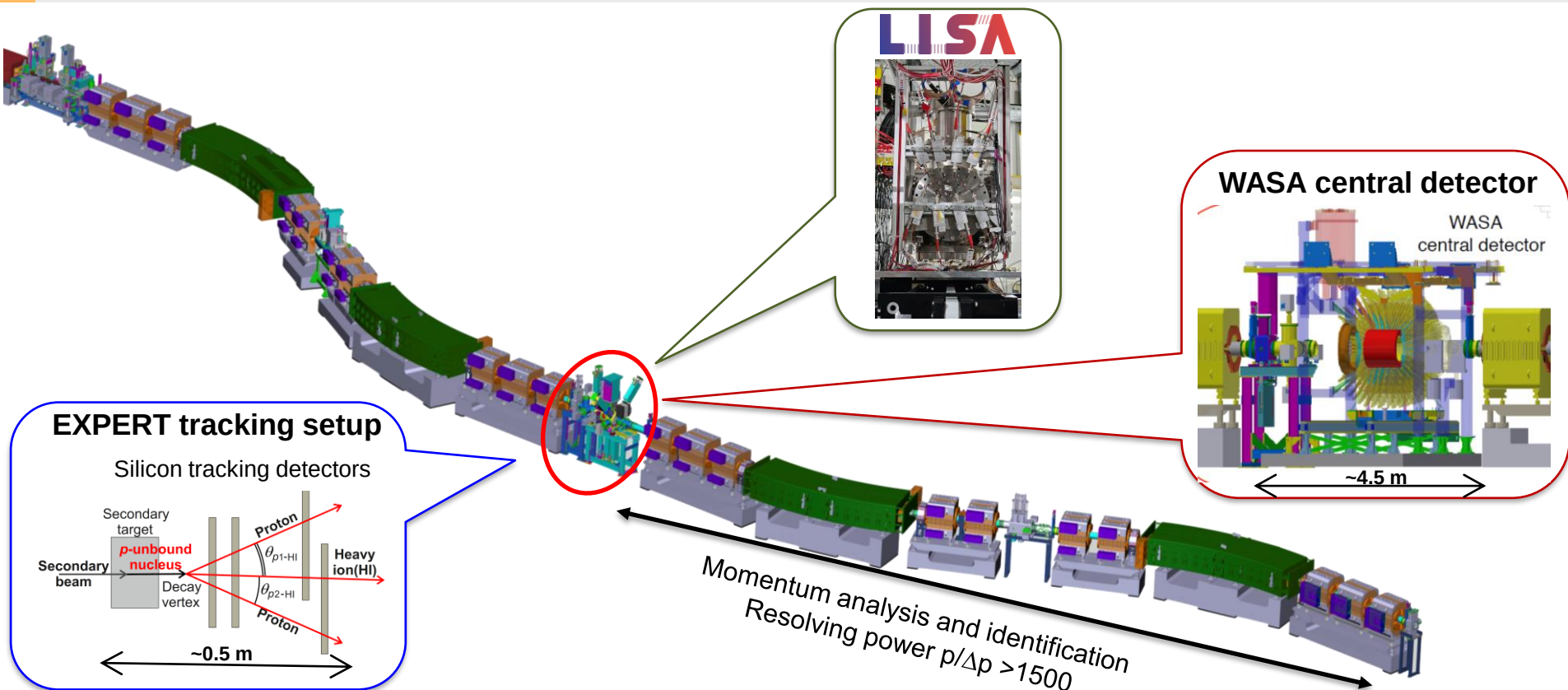
Flexibility – modular concept for fast changeover of setups – FRS S2

The future of FRS S2: – Easier integration and change of setups

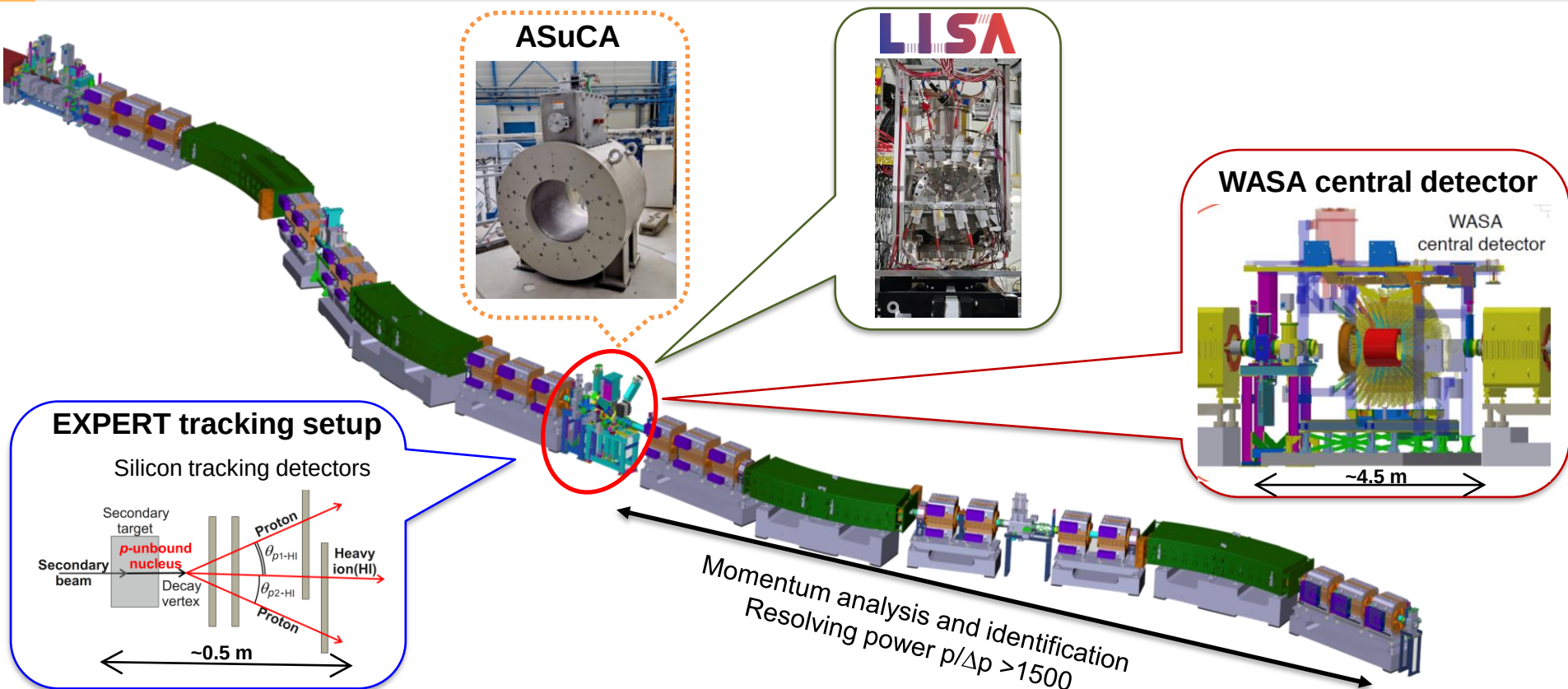


- All equipment mounted on drives
 - Fast change from one prepared experimental configuration to another
 - Allows use of current grids downstream from S2 (was not the case in 2020)
- Quicker and easier change between big experimental setups (e.g. ASuCA – standard setup)

Experiments with ancillary detectors inside the FRS



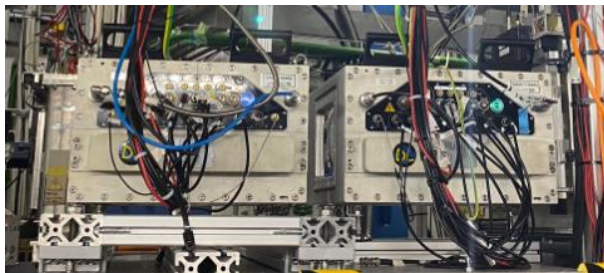
Experiments with ancillary detectors inside the FRS



New detectors – Travelling MUSIC for Z identification

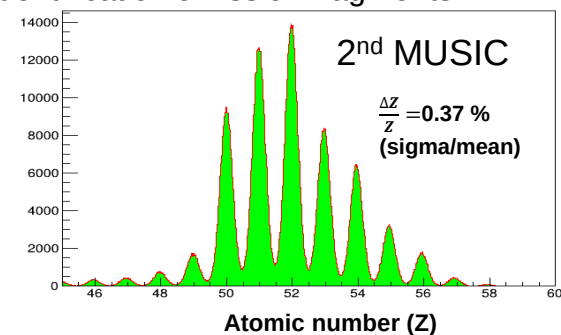
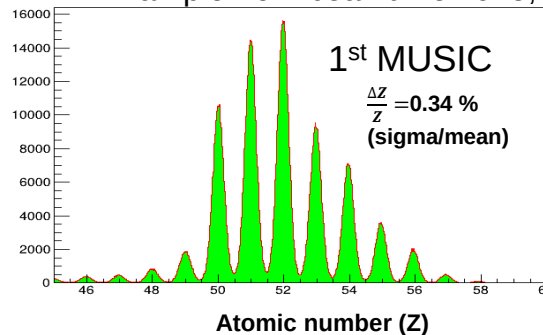
New MUSIC detectors

- Design characteristics
 - **Temporal stability** due to gas pressure stabilization
 - **Integrated radioactive source** for system checks before beam
 - **Position information** through drift time (horizontal) and anode structure (vertical)
 - **Remote-controlled electronics**
- Enables Z measurement at S2 and is a prerequisite for the experiments shown on the following slide



Travelling MUSICS at F2

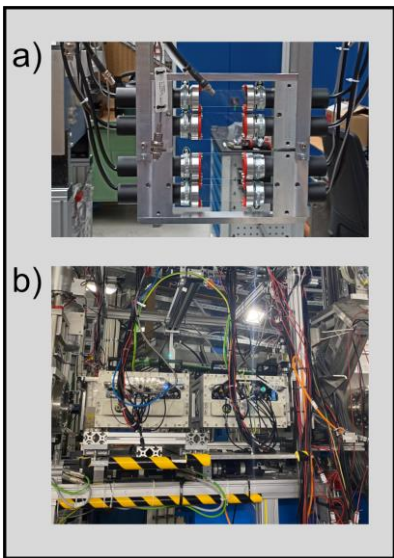
Example from beamtime 2025, Z identification of fission fragments



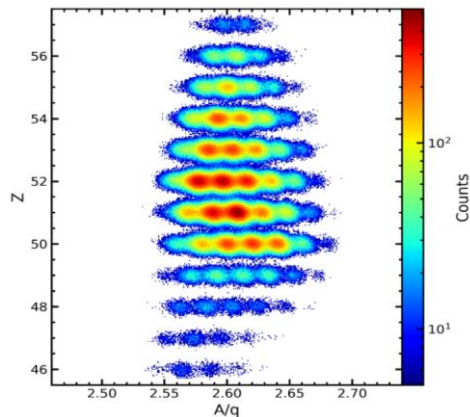
FRS as separator-spectrometer – reaction studies with secondary beam

Implementation of new detectors:

- a) SCI-TOF at F1
- b) MUSIC(s) at F2

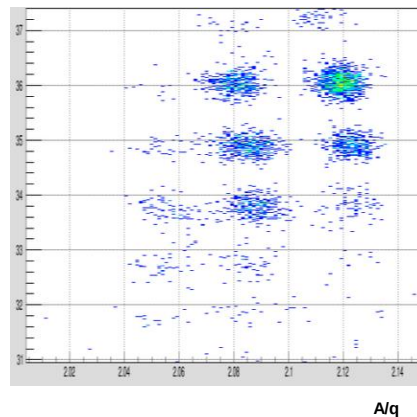


R. Kanungo, Neutron skin measurement of ^{132}Sn and ^{144}Xe



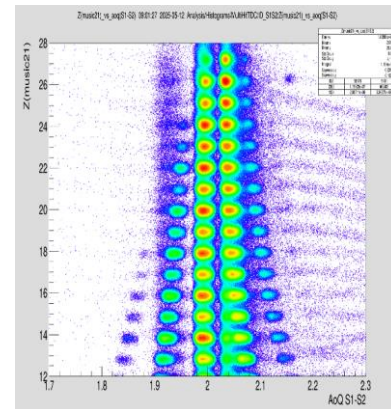
Fission fragments produced from of ^{238}U

M. Pfützner, Study of a nuclear sandbank at the proton unbound bromine isotopes



Fragments around ^{76}Kr produced from fragmentation of ^{78}Kr

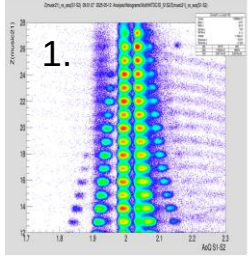
K. Wimmer, Testing diamond detectors for development of an active target



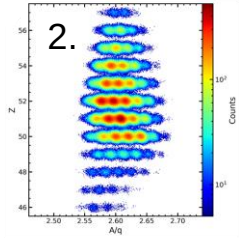
$N=Z$ fragments produced from fragmentation of ^{56}Fe

Separation TA-F2

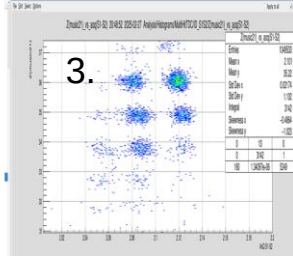
N=Z fragments produced from fragmentation of ^{56}Fe



^{132}Sn produced from fission of ^{238}U



Fragments around ^{76}Kr produced from fragmentation of ^{78}Kr



TA-F2:

1. Only B_p Separation. All $N=Z$ isotopes to F2
2. B_p - ΔE - B_p Separation with homogeneous degrader at F1
3. B_p - ΔE - B_p Separation with wedge degrader to be achromatic at F2.

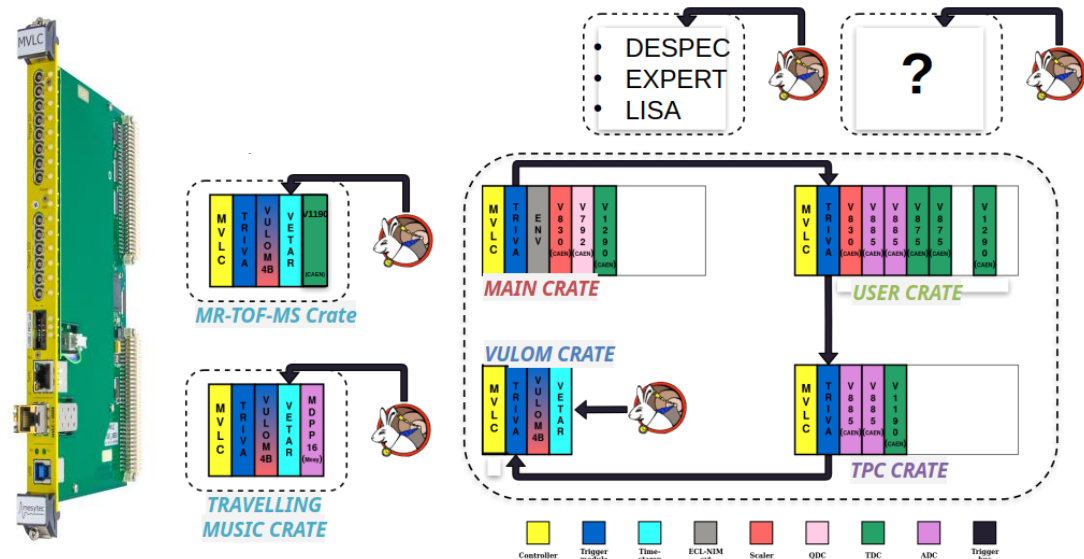
Realized by a wedge of fixed thickness and angle, made for the specific case

Development of a disc degrader for S1:
Realize more flexible experimental conditions for B_p - ΔE - B_p + spectrometer experiments

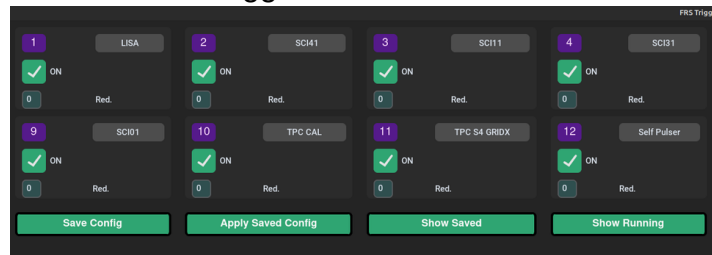


DAQ upgrade: Higher Rates

- Change to FPGA-based VME controller
- Rate increase** of about a factor 2-3
- Easy integration of additional systems** by White Rabbit, flexibility to accomodate additional setups!
- Possible to include slow control information in files, e.g. B_p of separator, drive positions
- Software trigger control – essential step for remote control of the separator



Software trigger control



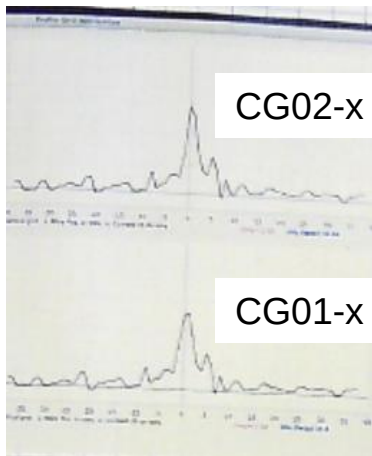
M. Bajzek, N.Kurz, M. Reese, Y.Tanaka

Refurbishment – Current Grids (CG)

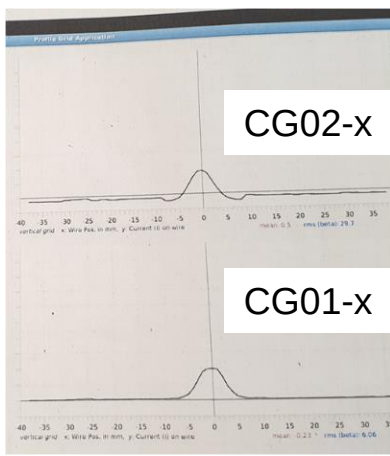
Status 2022: Profiles grid were not in a good shape

- Several measurements and adjustments on existing grids helped to improve the CG signals

Before adjustments



After adjustments



New Current grid(s)

- FAIR prototype
- First detector at S2
 - Angular information
 - Faster, easier beam alignment
 - Particularly useful for FRS-ESR and FRS-Cave M experiments

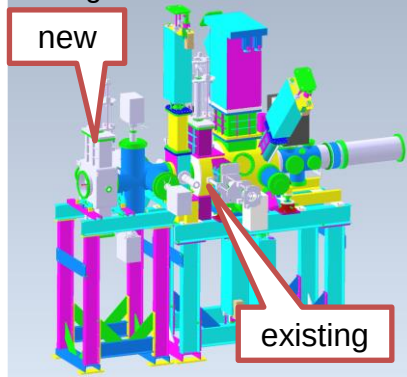
New detector



New drive

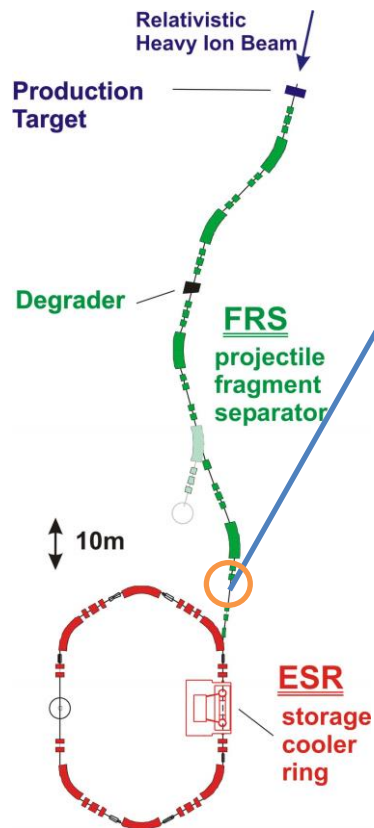


Diagnostics chamber S2

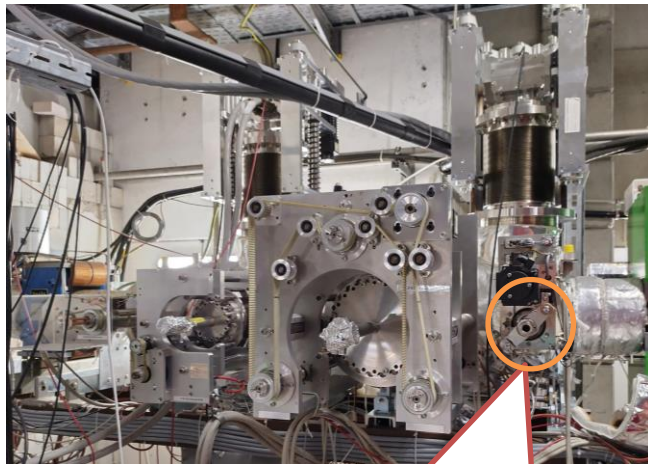


E. Rocco

New functionalities – new X-slit in front of ESR



Diagnostics chamber in front of the ESR



Successful experiment!

New X-slit: Essential for blocking $^{205}\text{Pb}^{81+}$ contaminants produced in projectile fragmentation to enter ESR

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Article | [Open access](#) | Published: 13 November 2024

High-temperature ^{205}Tl decay clarifies ^{205}Pb dating in early Solar System

Guy Leckenby , Ragandeep Singh Sidhu, Rui Jiu Chen , Riccardo Mancino, Balázs Székely, Mei Bai, Umberto Battino, Klaus Blaum, Carsten Brandau, Sergio Cristallo, Timo Dickel, Iris Dillmann, Dmytro Dmytriev, Thomas Faestermann, Oliver Forstner, Bernhard Franczak, Hans Geissel, Roman Gernhäuser, Jan Glorius, Chris Griffin, Alexandre Gumbert, Emma Haettner, Pierre-Michel Hillenbrand, Amanda Karakas, Jiamwei Zhao
+ Show authors

Nature 635, 321–326 (2024) | [Cite this article](#)

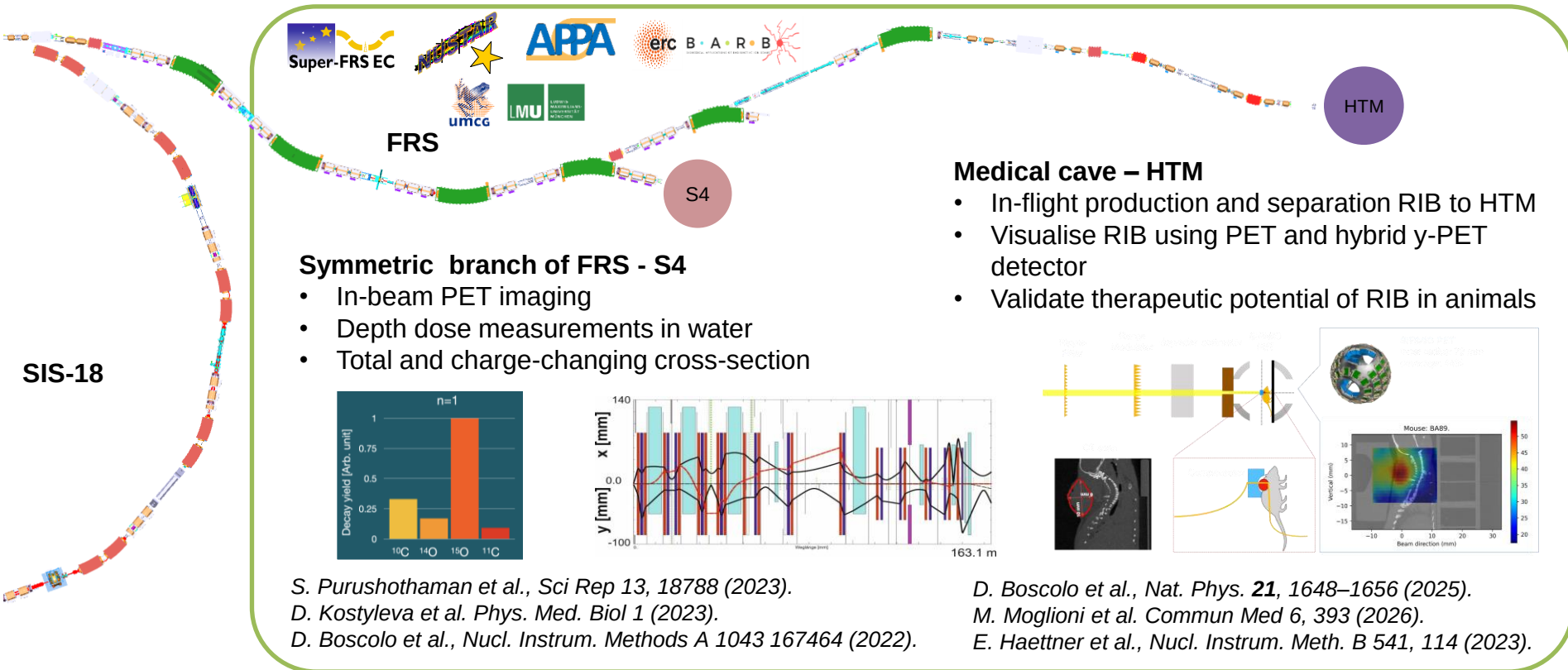
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25k Accesses | 31 Citations | 181 Altmetric | [Metrics](#)

Abstract

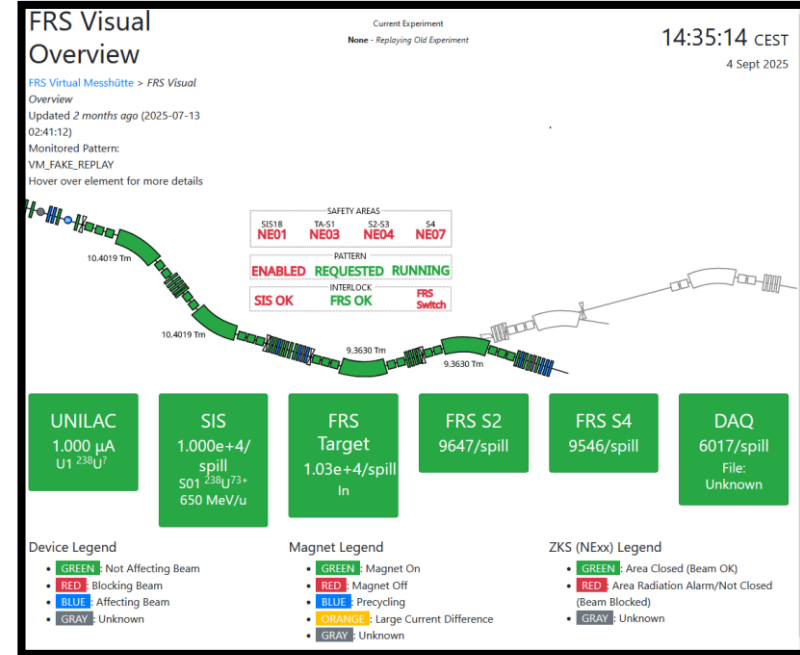
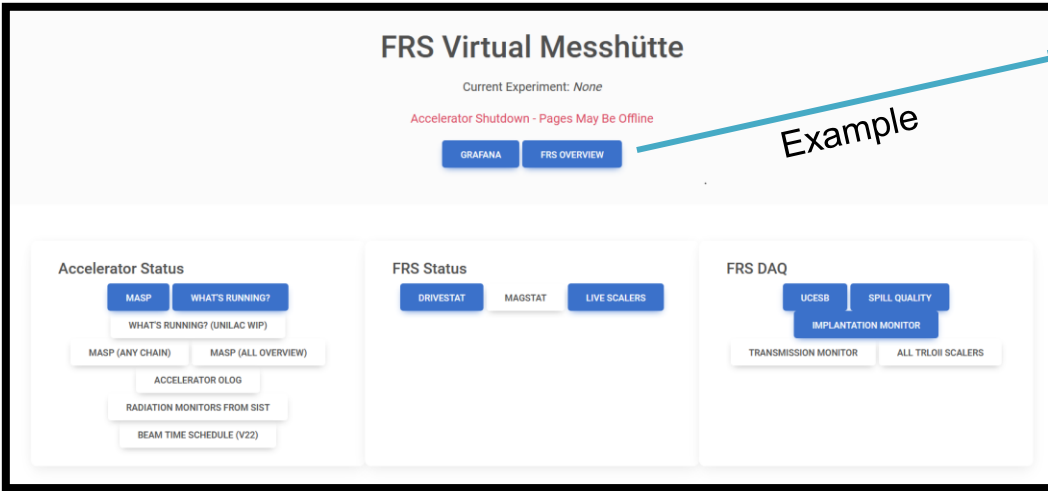
Radioactive nuclei with lifetimes on the order of millions of years can reveal the formation history of the Sun and active nucleosynthesis occurring at the time and place of its birth^{1,2}. Among such nuclei whose decay signatures are found in the oldest meteorites, ^{205}Pb is a powerful example, as it is produced exclusively by slow neutron captures (the *s* process), with most being synthesized in asymptotic giant branch (AGB) stars^{3,4,5}. However, making accurate abundance predictions for ^{205}Pb has so far been impossible because the weak decay rates of ^{205}Pb and ^{205}Tl are very uncertain at stellar temperatures^{6,7}. To constrain these decay rates, we measured for the first time the bound-state β^- decay of fully ionized $^{205}\text{Tl}^{81+}$, an exotic decay mode that only occurs in highly charged ions. The measured half-life is 4.7 times longer than the previous theoretical estimate⁸ and our 10% experimental uncertainty has eliminated the main nuclear-physics limitation. With new, experimentally backed decay rates, we used AGB stellar models to calculate ^{205}Pb yields. Propagating those yields with basic galactic chemical evolution (GCE) and comparing with the $^{205}\text{Pb}/^{204}\text{Pb}$ ratio from meteorites^{2,10,11}, we determined the isolation time of solar material inside its parent molecular cloud. We find positive isolation times that are consistent with the other *s*-process short-lived radioactive nuclei found in the early Solar System. Our results reaffirm the site of the Sun's birth as a long-lived, giant molecular cloud and support the use of the ^{205}Pb – ^{205}Tl decay system as a chronometer in the early Solar System.

First Image-guided treatment of mouse tumours with radioactive ^{11}C beams



The FRS Virtual Messshütte

When you cannot be in the Messshütte...



The FRS Virtual Messshütte provides:

- Remote monitoring FRS status and key parameters → FCC (FAIR Control Center) suitable
- Monitoring of accelerator status
- Overview of DAQ status
- Access from anywhere via web interface for computers and mobile devices (lxfrrs.gsi.de/vm)

N. Hubbard

FAIR Phase-0 was a challenge and opportunity for FRS, many experiments triggered many developments

- Improve **flexibility and reliability** has been a key to be unique and competitive
- FRS is **refurbished and compatible** with FAIR environment and standards and ready for new experiments:
 - FRS-ESR program is unique
 - FRS-Cave M program is unique
 - Place for first tests of new detectors and experimental setups, e.g. ASuCA

Acknowledgements



Local FRS Experiment Group

**All people in NUSTAR who contributed to successful experiments
at FRS in FAIR Phase-0**

GSI Technical departments

GSI Management for the financial support to the projects

