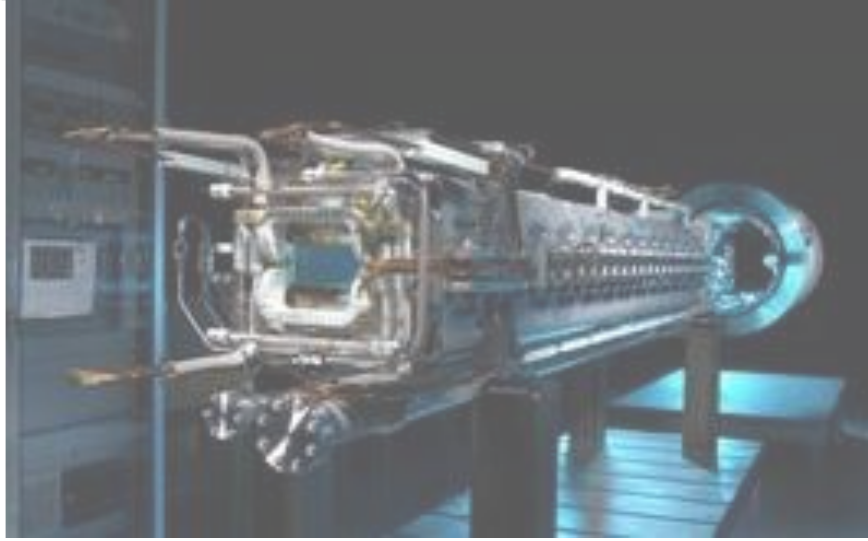


NUSTAR Collaboration Report

Zsolt Podolyák

RRB, 17 May 2024

Finland France Germany India Poland Romania Russia Slovenia Sweden UK Czech Republic

News from the NUSTAR Board of Representatives

outgoing members

Andreas Heinz
(Chalmers, Sweden)

Anu Kankainen
(JYFL, Finland)

spokesperson

Zsolt Podolyák
(Surrey, UK)

new elected members

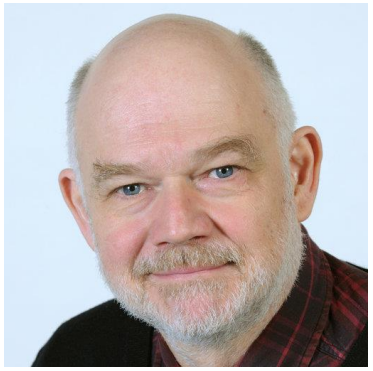
Lola Cortina
(Valencia, Spain)

Michael Block
(Mainz, Germany)

- Deputy spokesperson: Michael Block

https://fair-center.eu/user/experiments/nustar/nustar-collaboration/board-of-representatives

News from the NUSTAR Council

new chair elect	chair	old chair elect (resigned)
		
Wolfram Korten	Berta Rubio	Zsolt Podolyák
(CEA, Saclay, France)	(IFIC, Valencia, Spain)	(Surrey, UK)

Practically, there was a swap (through elections) between Wolfram Korten and Zsolt Podolyák

https://fair-center.eu/user/experiments/nustar/nustar-collaboration/council

News from the NUSTAR Management Team

Technical Coordinator	Resource Coordinator	Technical Coordinator (a.D.)
		
Helena Albers	Alexander Herlert	Jürgen Gerl
(since 11/23)	(renewed 11/23)	(10/11 to 10/23)

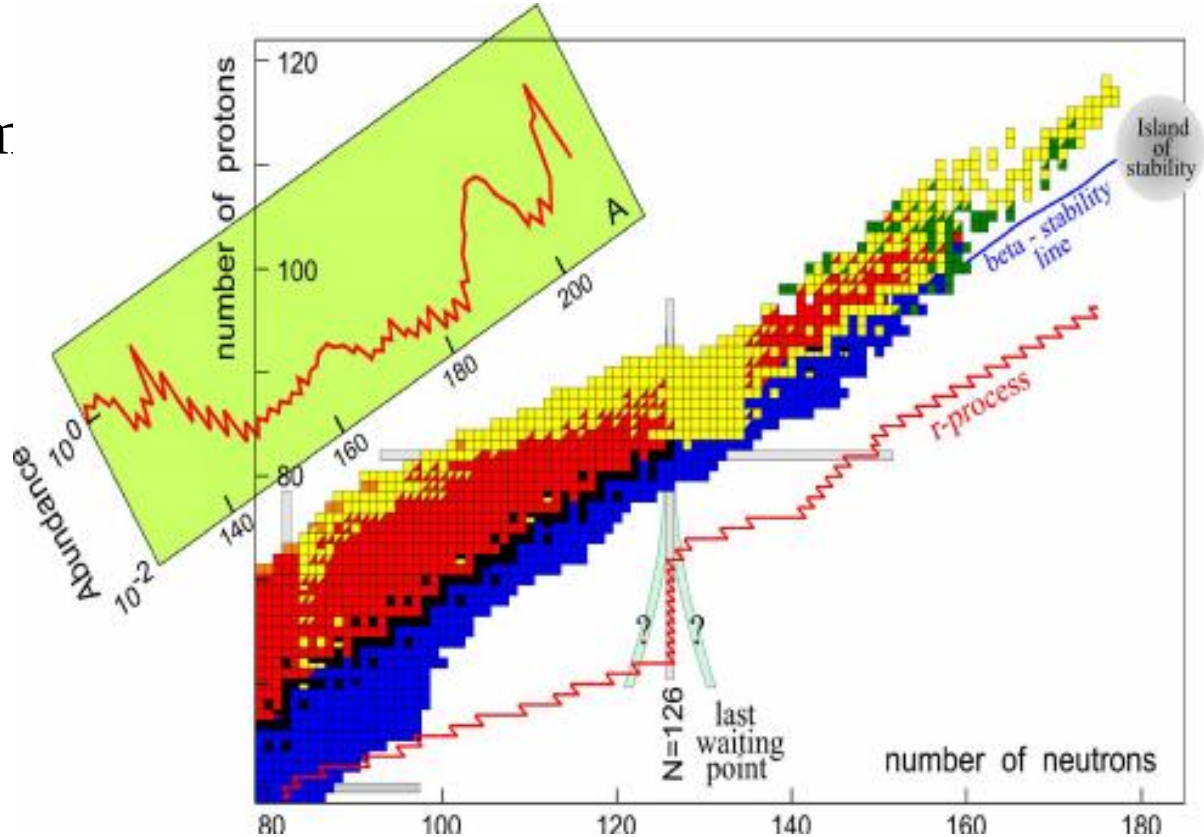
https://fair-center.eu/user/experiments/nustar/nustar-collaboration/management-team

Timeline 2021 – 2029?

2021-2022	FAIR-0 experiments
2023	No experiments (but there were tests)
2024-2025	FAIR-0 experiments
2026-2027	FAIR-0 experiments (G-PAC in 2025)
End 2027 ->	**Early Science, then First Science**

The 11 Greatest Unanswered Questions of Physics

1. What is dark matter?
2. What is dark energy?
3. **How were the heavy elements from iron to uranium made?**
4. Do neutrinos have mass?
5. Where do ultrahigh-energy particles come from
6. Is a new theory of light and matter needed to explain what happens at very high energies and temperatures?
8. Are protons unstable?
9. What is gravity?
10. Are there additional dimensions?
11. How did the universe begin?



https://www.discovermagazine.com/the-sciences/the-11-greatest-unanswered-questions-of-physics

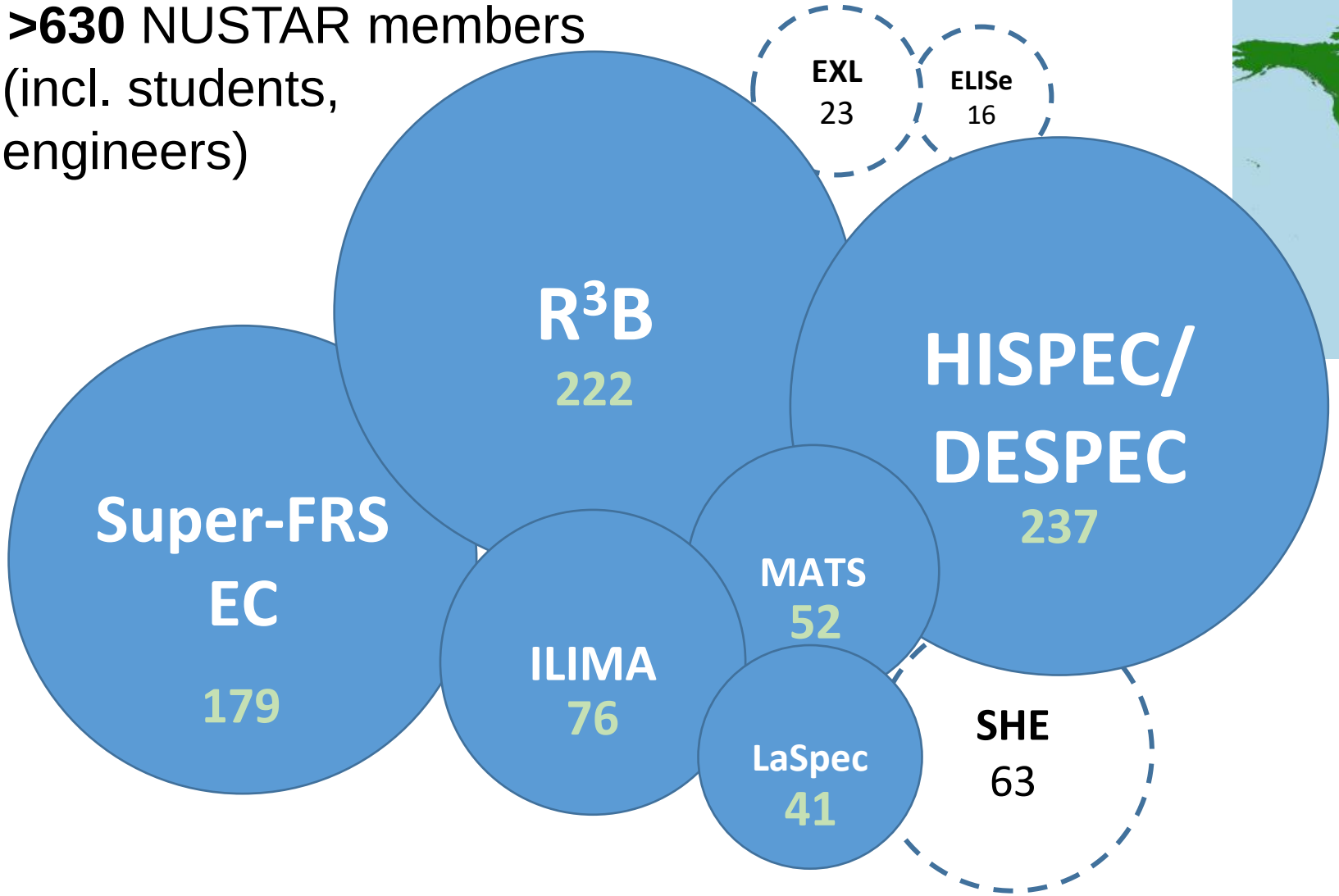
Overarching physics case: the creation of the (heavy) chemical elements

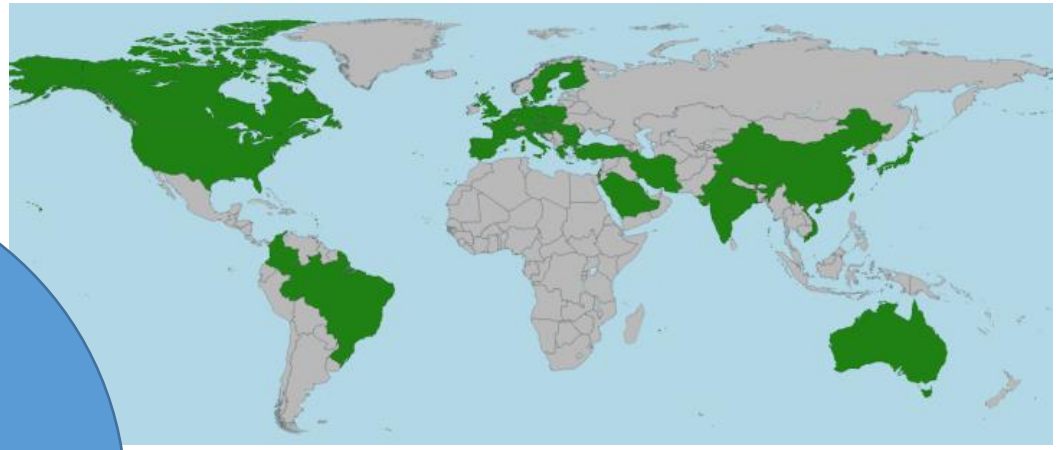
Big physics question requiring information on:

- Equation of State
- Limits of existence
- Lifetimes,
- Masses
- P_{xn} values
- Fission
- Reactions in star environments

NUSTAR
One science, different observables, instrumentations

>630 NUSTAR members (incl. students, engineers)





> 1000 listed "interested" scientists

> 630 registered members (incl. students, etc.)

~ 420 senior members (PhD holder w/o Russia)

> 150 institutes from 36 countries

Status: October 8, 2023

NUSTAR experiments: 2021 -2024

- **Very successful experimental campaigns in 2021 and 2022**
  - Almost all experiment could be performed, not always with expected beam intensities (Pb)
- Summary of experiments
  - DESPEC: 27 days
  - ILIMA: 17 days
  - R3B: 44 days
  - S-FRS EC: 29 days
  - SHE: 90 days
  - **Total: 113 days (SIS18) + 94 days (UNILAC)**
- Phase-0 is still very productive
  - First technical and scientific papers published, many more are in preparation!
  - Essential to test detectors and to keep NUSTAR active within the community!
- In **2023** only engineering beam time, and NUSTAR detector tests.
- Phase-0 beamtimes **restarted in February 2024**.

Highlights and plans of the NUSTAR experiments

FAIR-0: $^{12}C+^{12}C$ benchmark case

A benchmark case to provide very precise data that minimise the uncertainty asociated to the reaction models

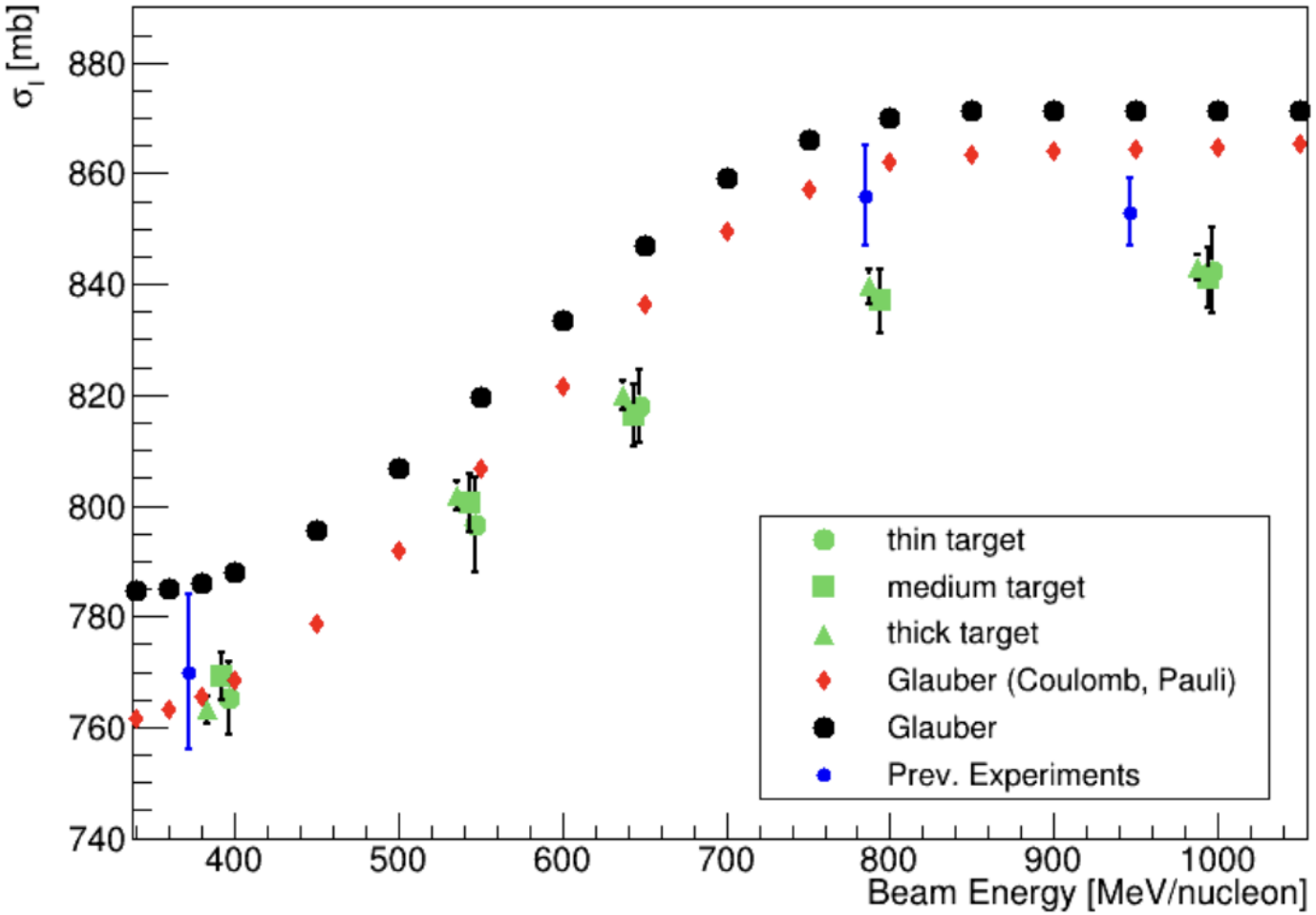
Exp. precision +-0.387%

Determined by the called Transmission method

$$\sigma_R = \sigma_{inel} + \sigma_I$$

$$\sigma_R = -\frac{1}{N_t} ln \left(\frac{R_i}{R_o} \right)$$

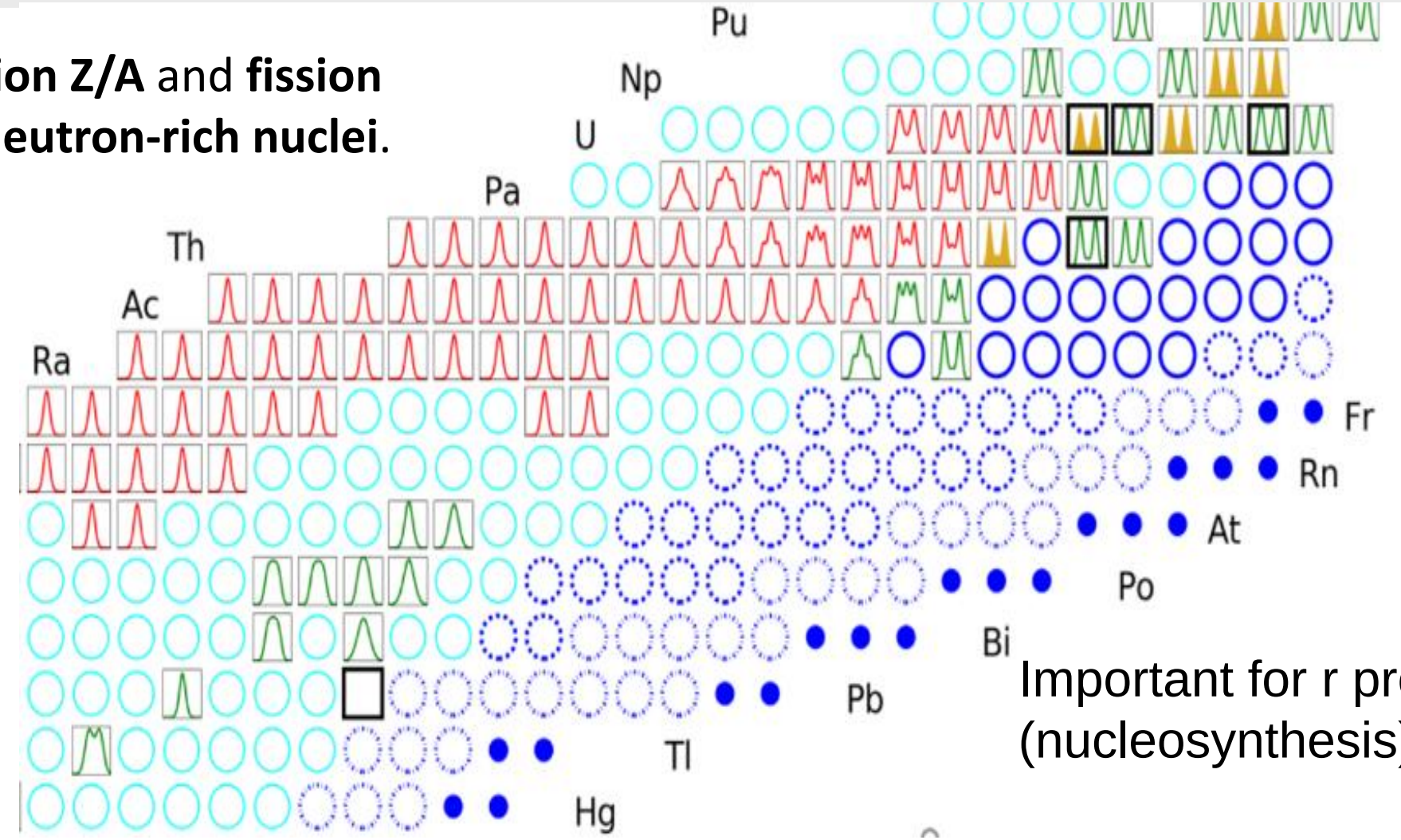
$R_{i/o}$ is the ratio of non-interacting nuclei after target and incoming nuclei for target in (out)



L. Ponath et al., submitted to PLB

Fission

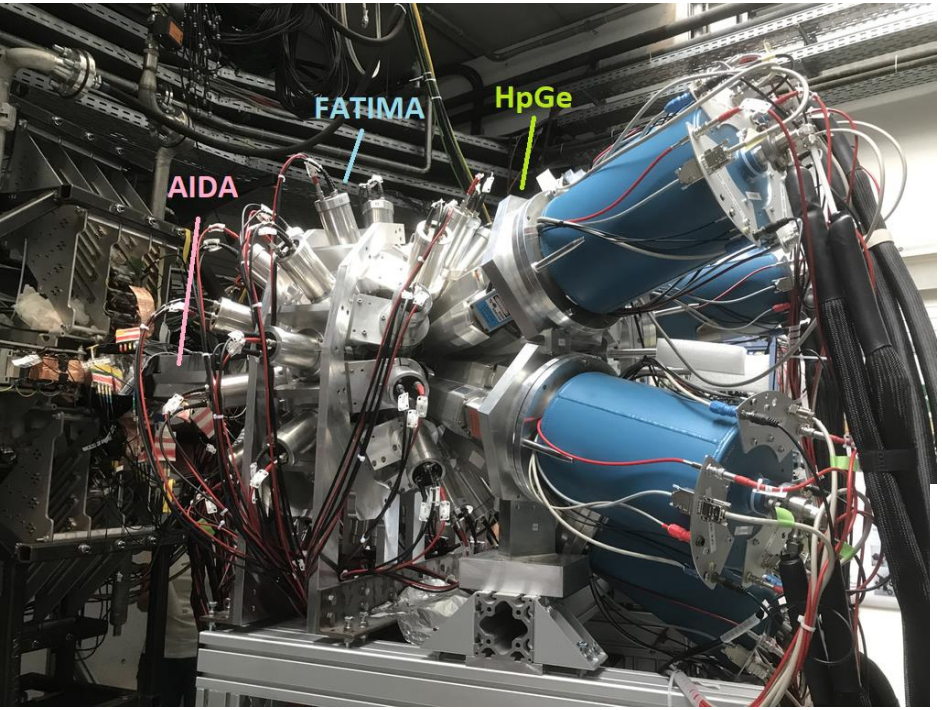
First results on **fission Z/A** and **fission barriers** of **heavy neutron-rich nuclei**.



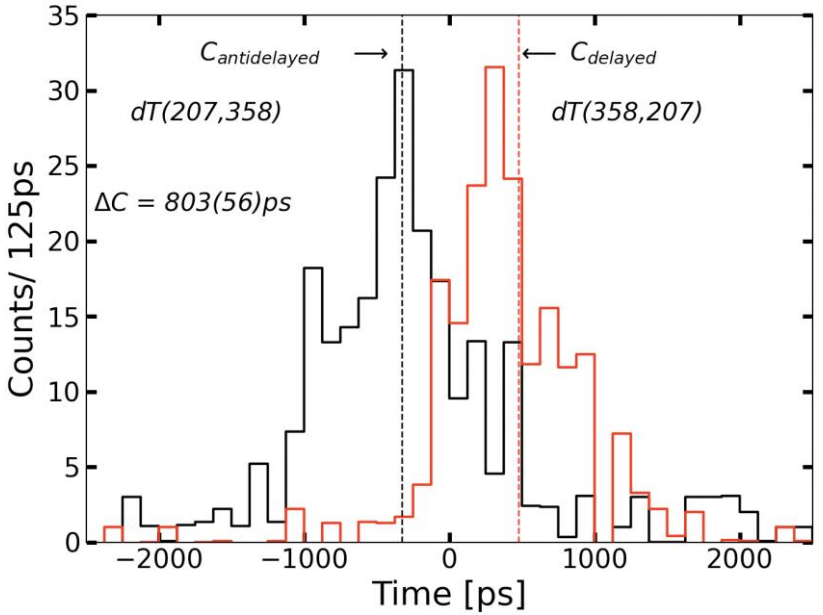
Important for r process (nucleosynthesis)

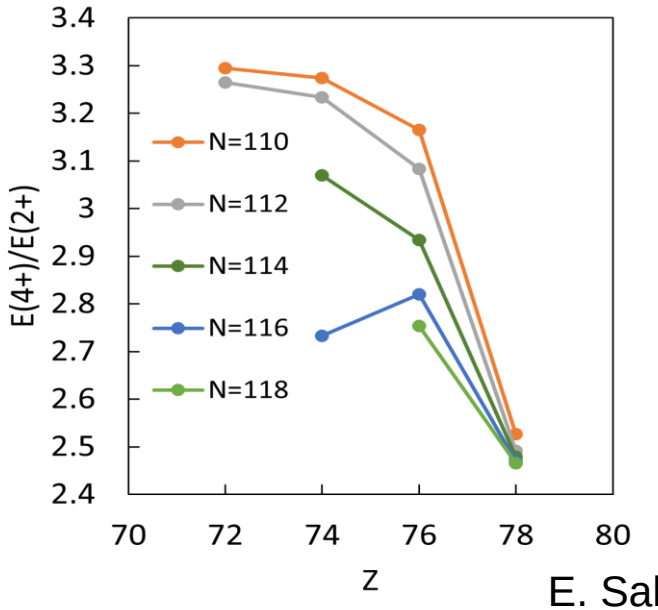
measured Z (red) and A (green) fission yields in actinides and pre- actinides together with the neutron-rich (dark blue circles and dots) and other nuclei (light blue circles) that can be investigated at FAIR

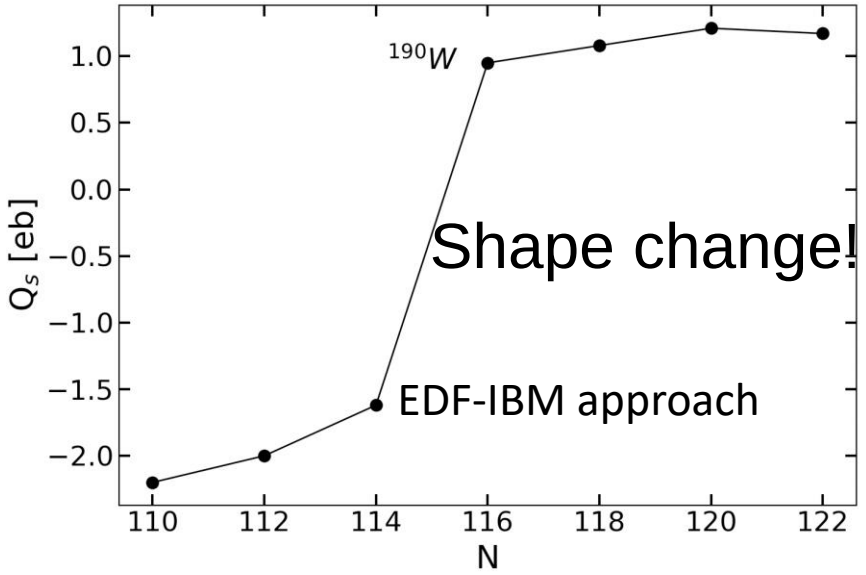
FAIR-0: Prolate-oblate shape transition at $^{190}W_{116}$



Hybrid array for fast-timing measurements





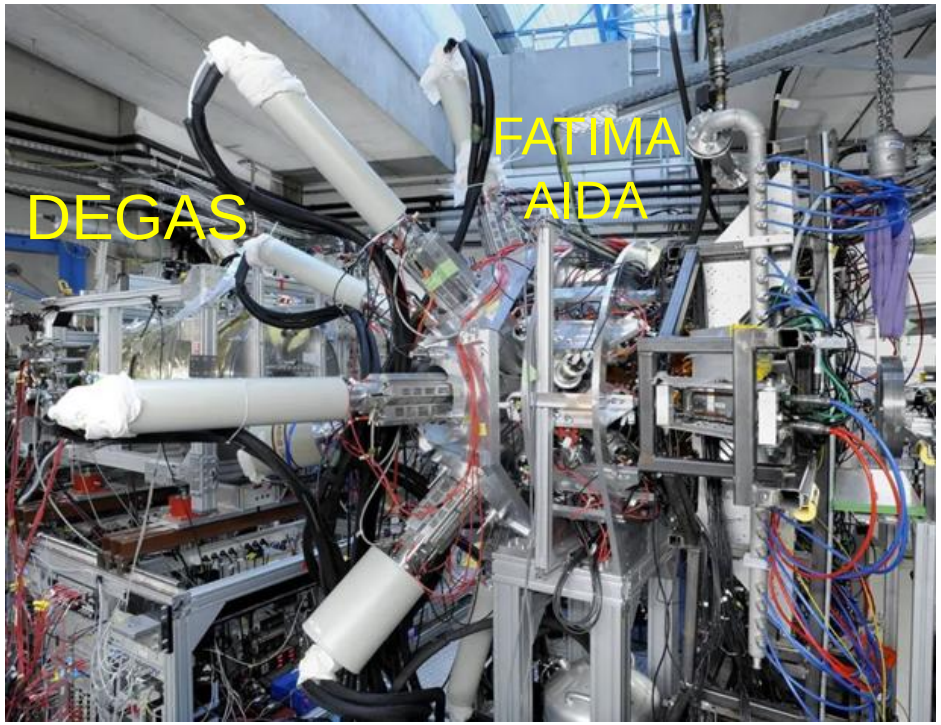


E. Sahin, V. Werner et al., manuscript submitted to PLB

New beam: ^{170}Er

First used in April 2024

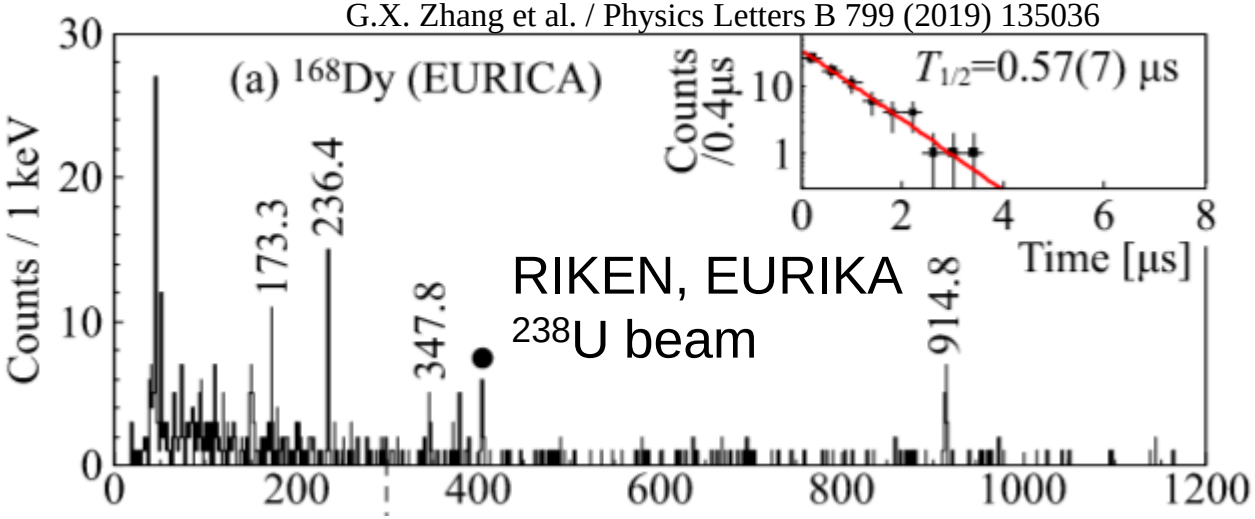
New beams => New opportunities

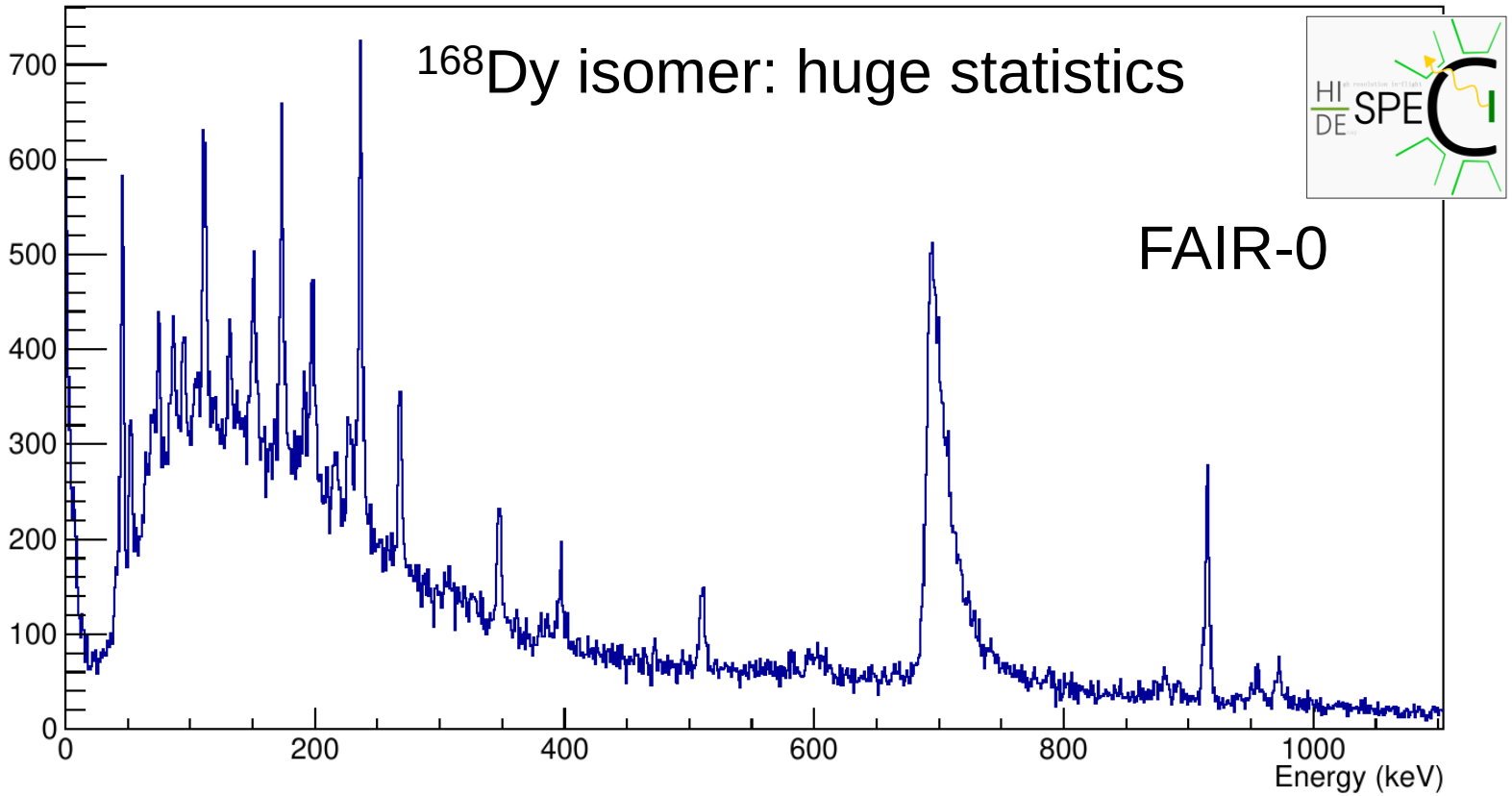


Prospect for new isotopes!
(proton-rich side)

Super-FRS EC

G.X. Zhang et al. / Physics Letters B 799 (2019) 135036





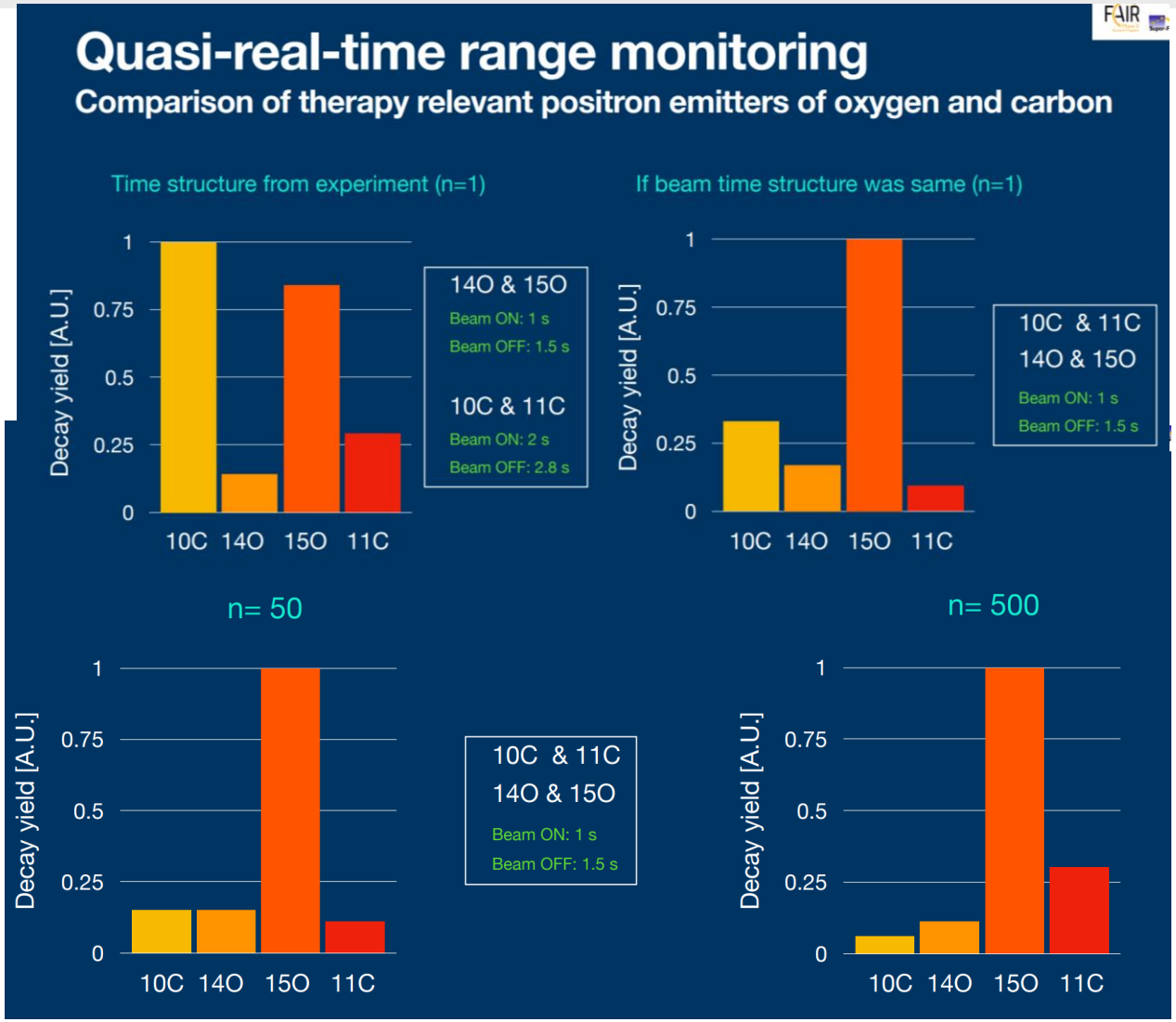
Quasi-real-time range monitoring in hadron therapy using positron emitters of carbon and oxygen

Best candidate?

^{16}O beam -> ^{15}O 43 mb 122 s
^{14}O 1.2 mb 71s

^{12}C beam -> ^{11}C 47 mb 1221 s
^{10}C 4.3 mb 19 s

Sivaji Purushothaman et al., Sci Rep 13, 18788 (2023)
Quasi-real-time range monitoring by in-beam PET:
a case for ^{15}O



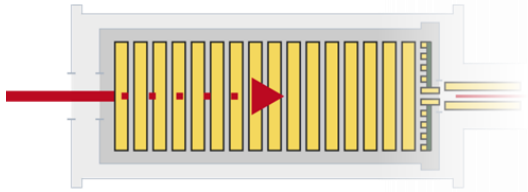
BIOMAT

(also hadron therapy with ^{11}C on mouse in Feb. 2024)

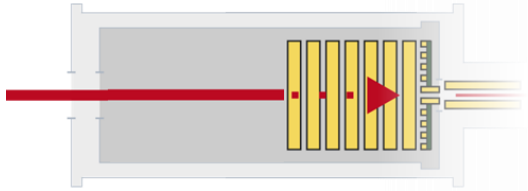
Rate capability test of the Cryogenic Stopping Cell

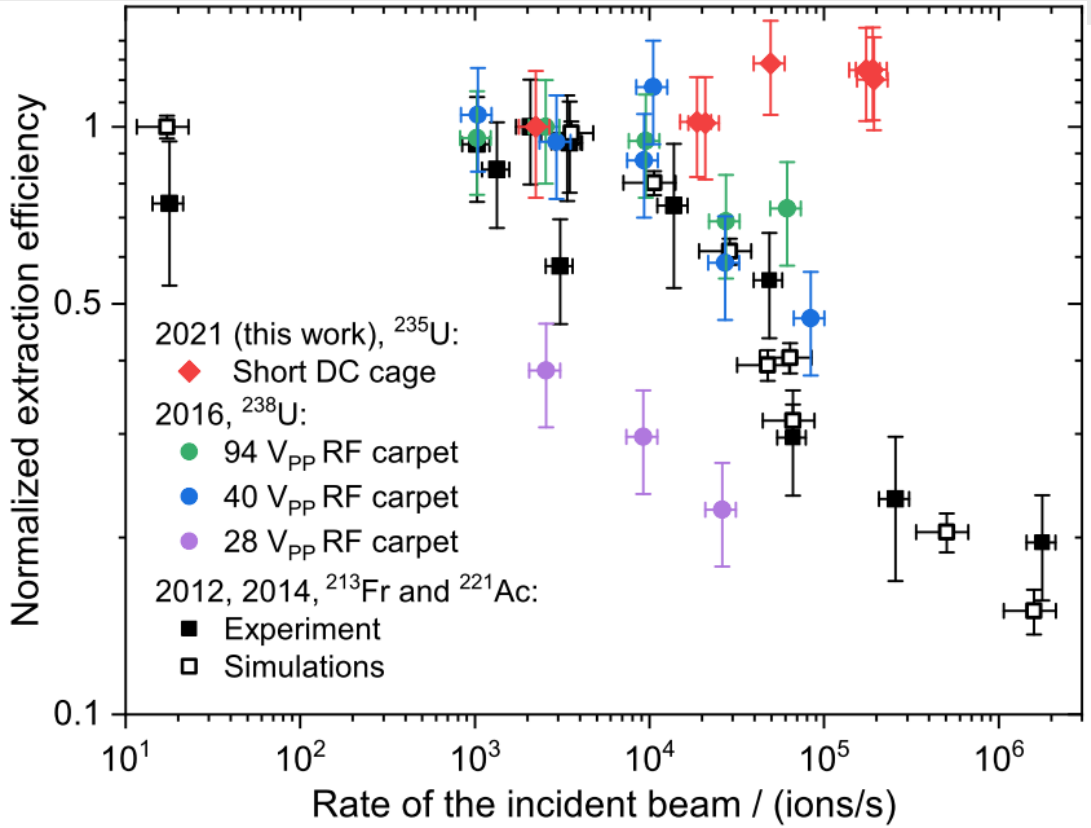
Testing the concepts of strong fields and short distance with the present FRS-IC

2012, 2014, 2016:
Present CSC



2021 (this work):
Present CSC + short DC cage

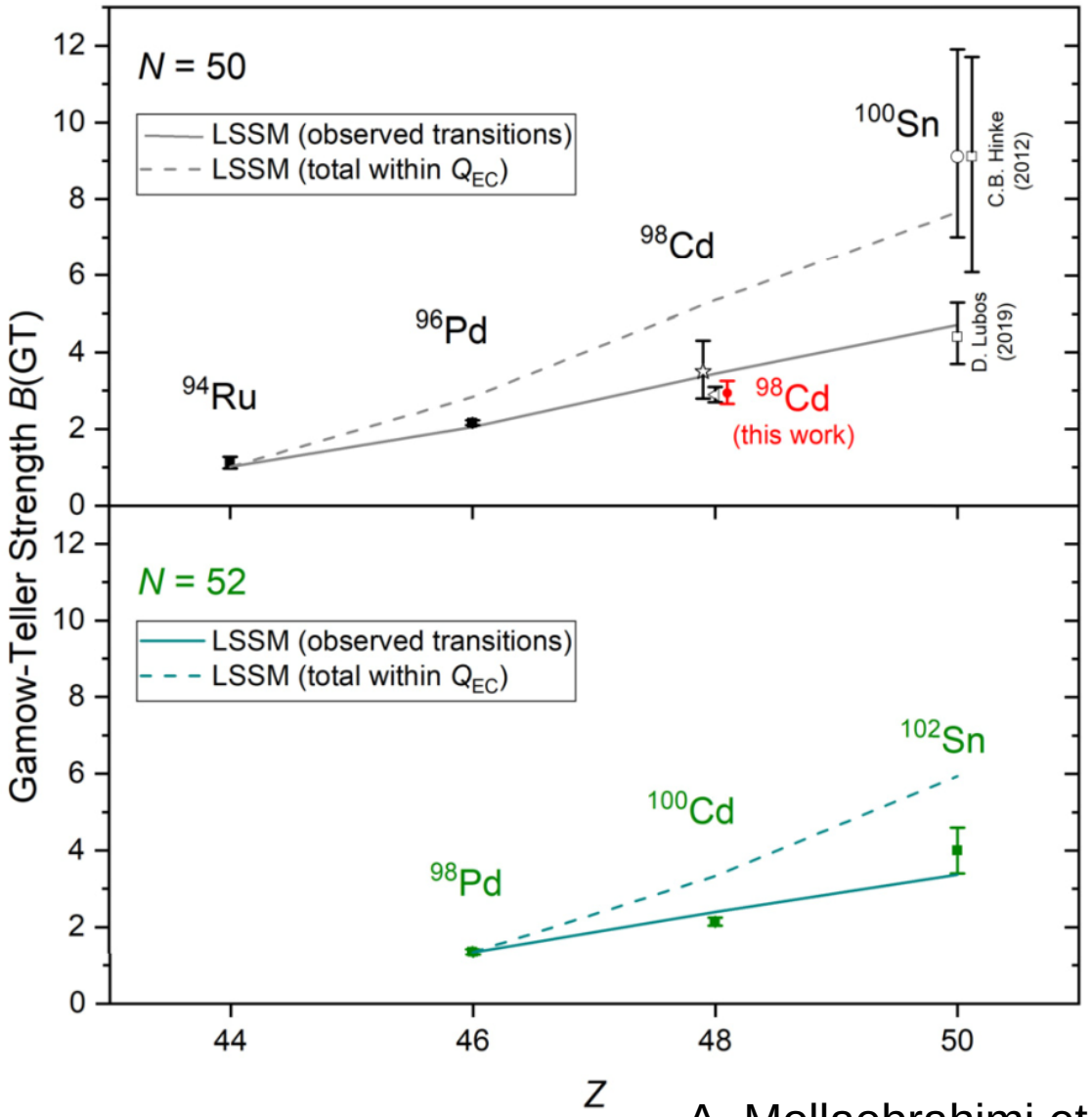




J.W. Zhao, D. Amanbayev, et al., NIM B 547 (2024) 165175

- New result of $2 \cdot 10^5$ ions/s surpasses previous rate capability limit of 10^4 ions/s is by more than 1 order of magnitude
- It validates the simulation model and provides additional support for the selected design concepts

FAIR-0: Gamov-Teller Strength at N=50 and the puzzle of ^{100}Sn mass



First direct mass measurements of ^{98}Cd and ^{97}Rh with the FRS Ion Catcher

^{100}Sn mass:

New results in discrepancy of **^{100}Sn Q_{EC} values** (Hinke et al. [1] and Lubos et al. [2])

- In recent work Mougeot et al. [3] derive the mass of ^{100}Sn from mass measurements of $^{99\text{-}101}$In and published ^{100}Sn Q_{EC} values
  → value of Hinke et al is favored
- **This work**:
  Evolution of shifted two-neutron shell gap at N=50:
  → Value of Hinke et al. [1] is favored.
  Evolution of Gamov-Teller Strength at N=50:
  → value of Lubos et al. [2] is favored.

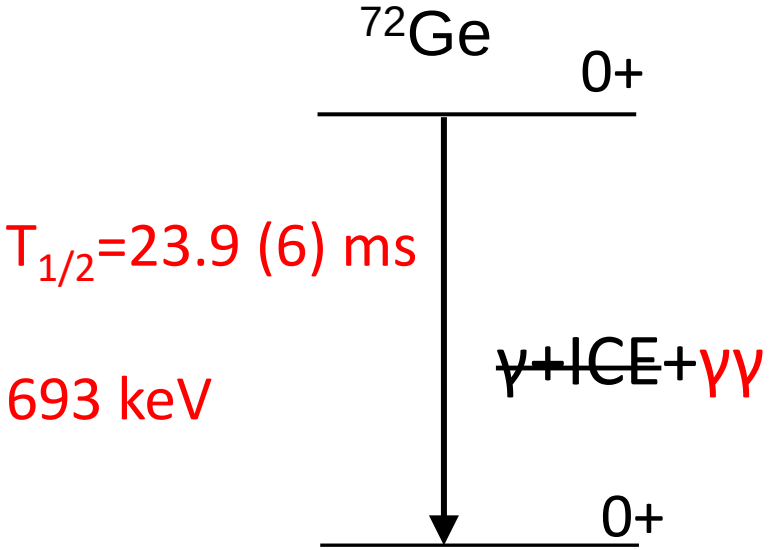
Overall situation unclear, further experiments required

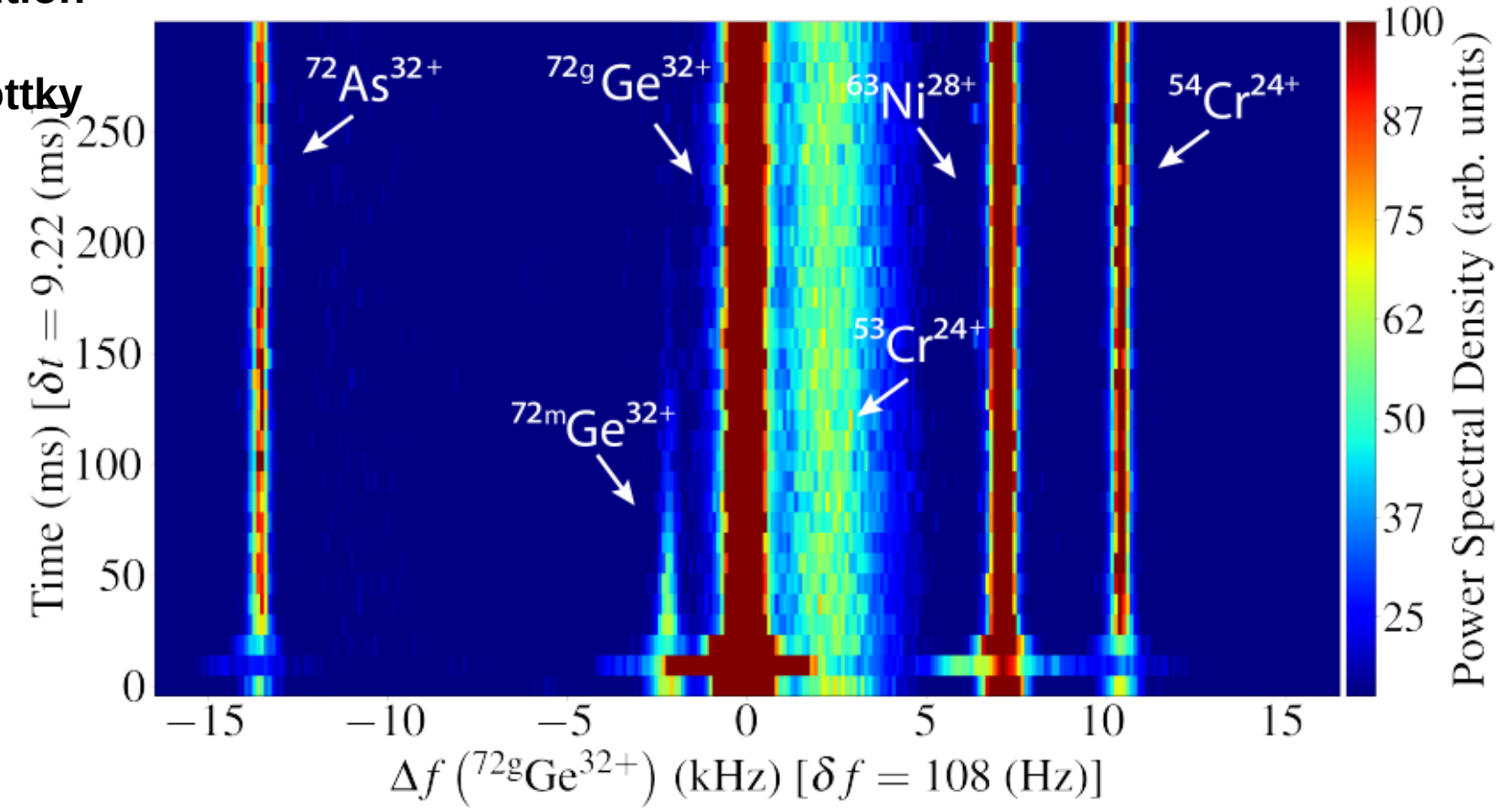
*[1] C.Hinke et al., Nature **486** (2012) 341*
*[2] D.Lubos at al., PRL **122** (2019) 222502*
*[3] M.Mougeot et al., Nature Phys. **17** (2021) 1099*

A. Mollaebrahimi et al., Phys.Lett. B 839, 137833 (2023)

FAIR-0: Two-phonon decay
Combined Schottky + Isochronous Mass Spectrometry

- **High precision isochronous condition**
  - **Mass resolution ~10^{-6}**
- **Single-ion sensitivity of new Schottky**





excitation energies down to ~ 100 keV
and half-lives as short as ~ 10 ms.

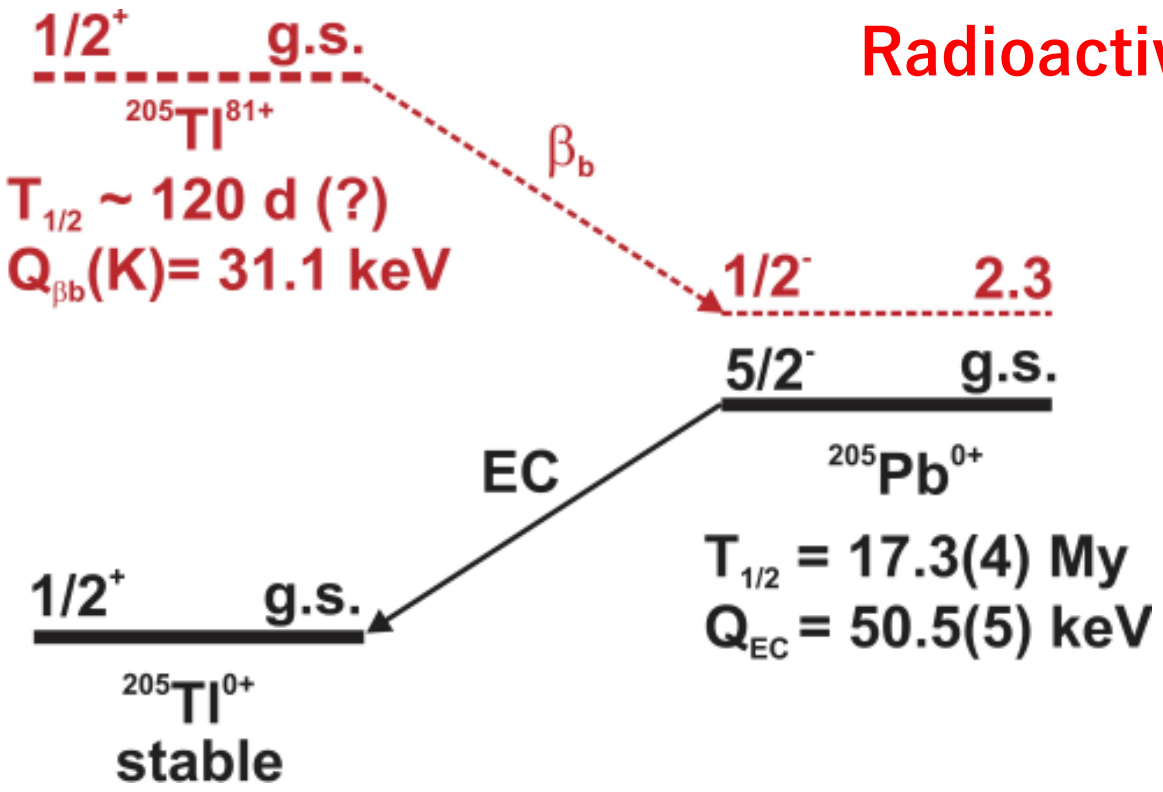
D. Freire-Fernandez, W. Korten et al
Phys. Rev, Lett., accepted

This week (^{98}Mo and ^{98}Zr) in May 2024

FAIR-0: Bound-state beta decay of ^{205}Tl

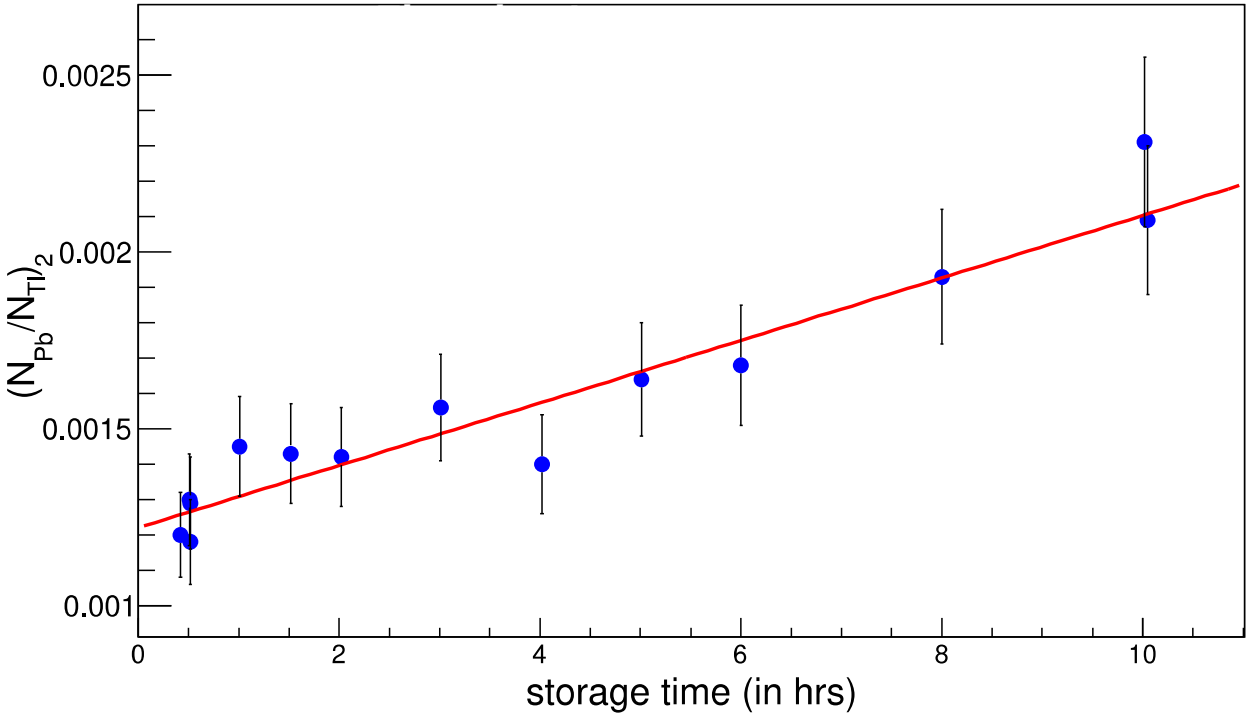
Lifetime of Highly Charge Ions

^{205}Tl: Stable in neutral atoms
Radioactive in bare ions



Technical key points:

- Accumulation of 2nd beam of FRS
- Long storage of cooled ions
- Gas jet stripper
- In-ring Particle detector
- Resonant Schottky detector

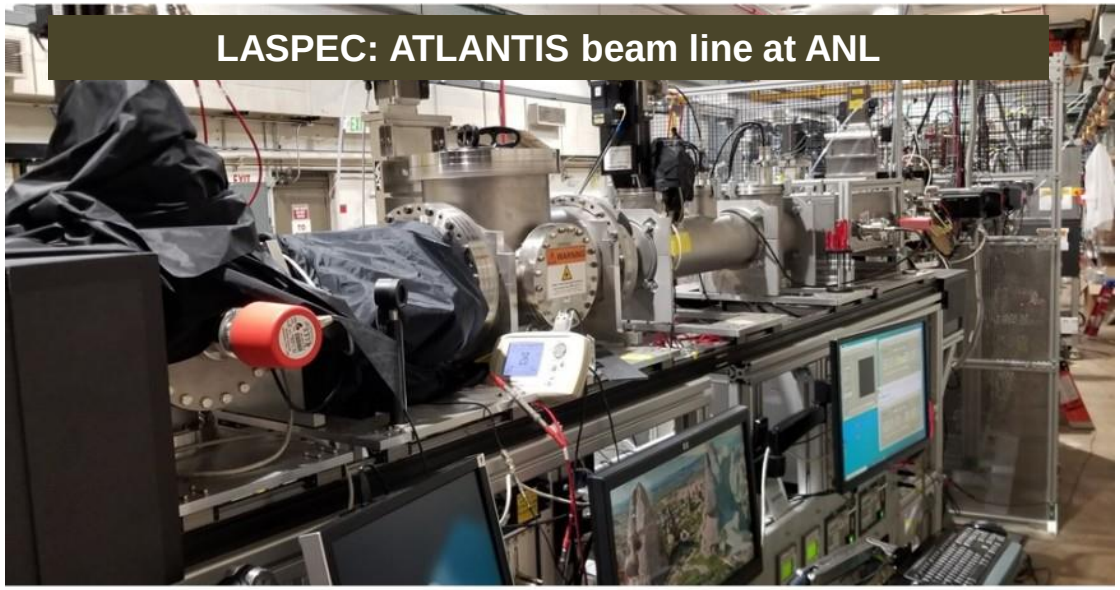


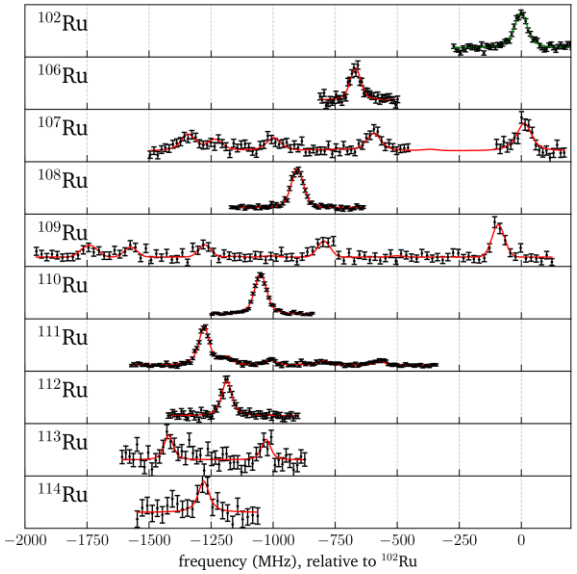
- LOREX project: new solar neutrino detector
- Cosmochronometer of the s-process

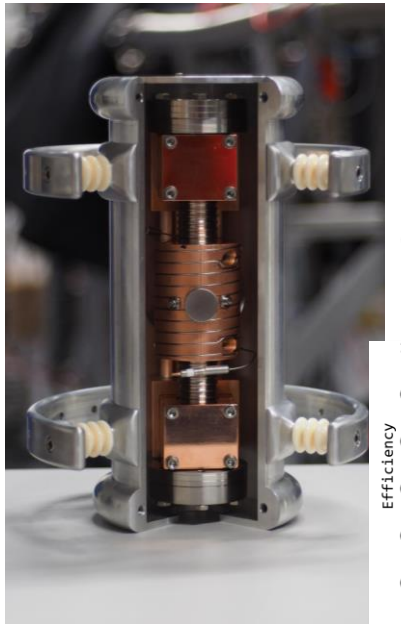
LASPEC: Atlantis at ANL

ATLANTIS: the LaSpec beamline from Mainz, installed at ANL

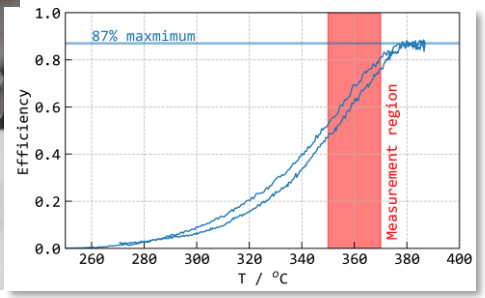
- **Successful beamtimes in 2022, 2023: Ru + Pd**
  Using ^{252}Cf fission beams
- **Planned experiments in 2024+: Tc, Ce, Nd, La, Rh**
  Using beams from neutron-induced fission on ^{235}U targets
- **Beams of <100/s due to novel buncher & charge exchange cell**

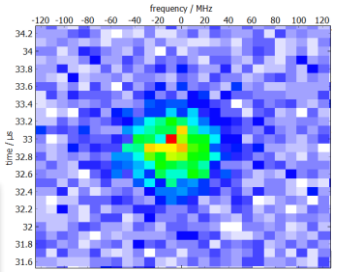




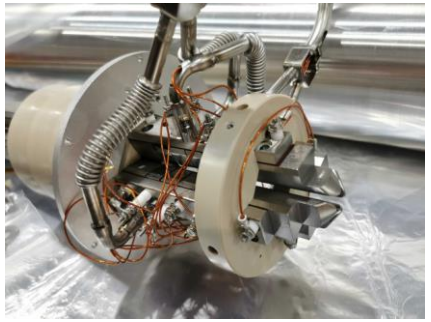


CEC operation with Mg
>85% efficiency





$\Delta t < 1\mu s$
$t_{\text{storage}} > 30s$
$\Delta E < 40MHz\ (3V)$
eff.: ~80%

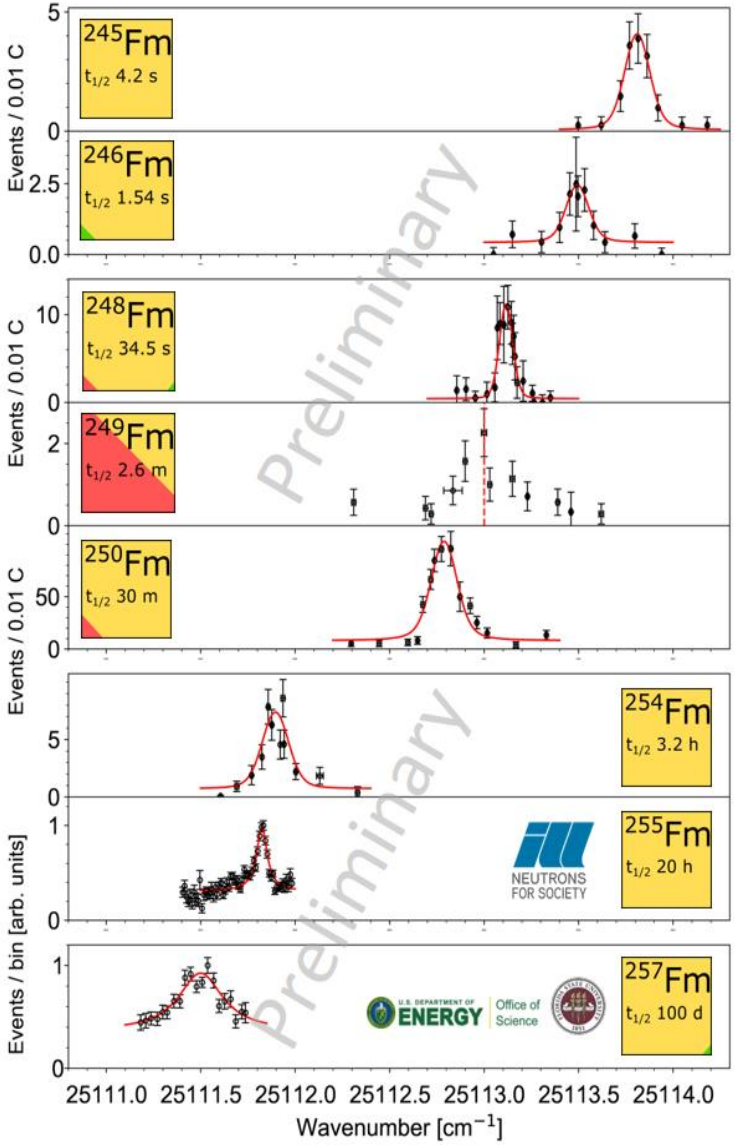


Cooler & Buncher RFQ

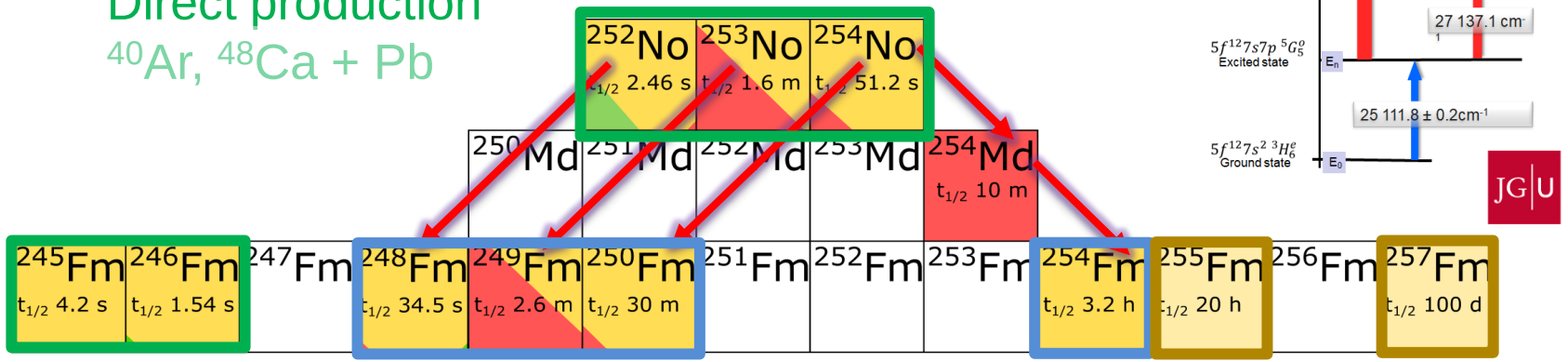
Publication on Ru charge radii in preparation

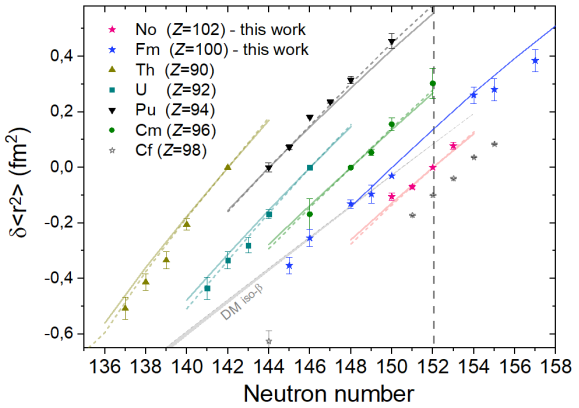
B. Maaß, K. König, L. Renth, P. Müller, W. Nörtershäuser, G. Savard et al.

SHE: Extending Laser spectroscopy to Fm (Z=100)



8 Fm isotopes from different production schemes





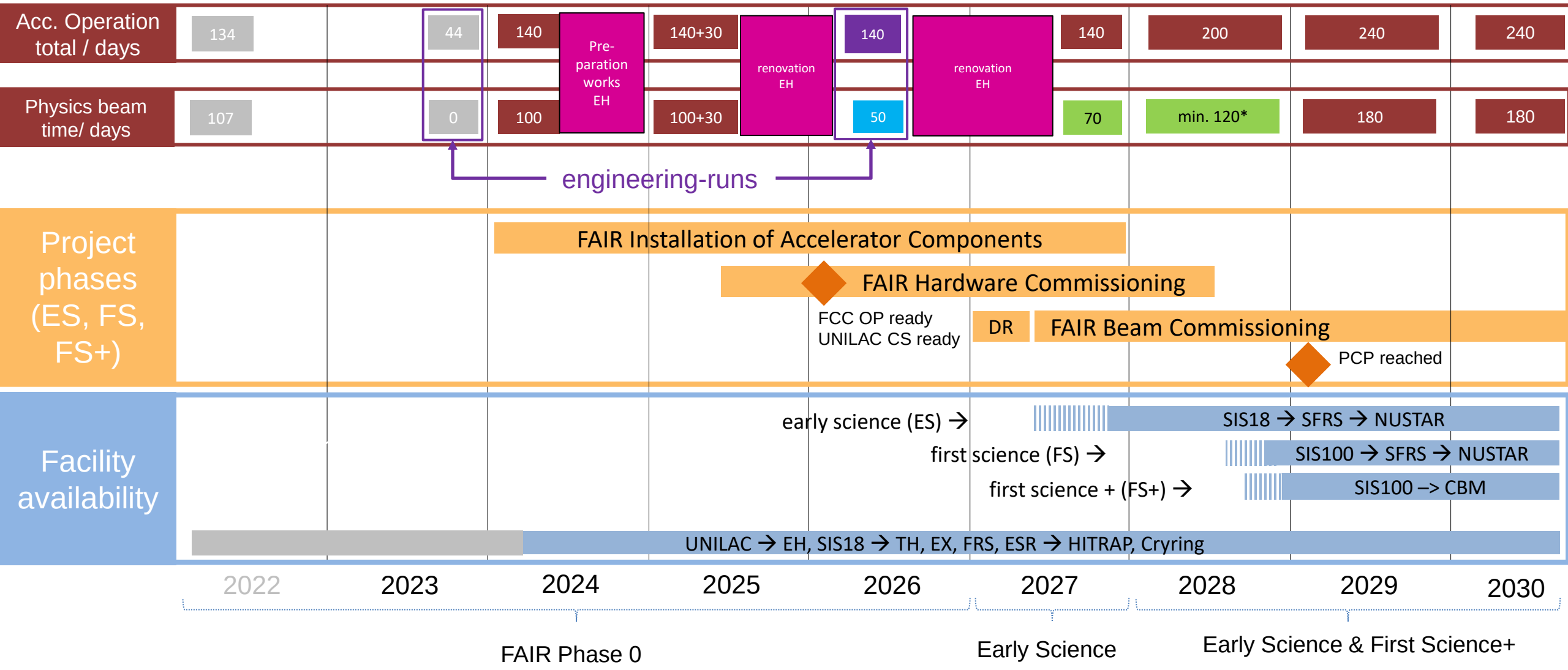
Deduced information for size and deformation

$$\delta\langle r^2\rangle^{AA'} = \left(\Delta\nu^{AA'} - \frac{A-A'}{AA'}M\right)\frac{1}{F}$$

Exp.: RADRIS collaboration (S. Raeder et al.)

This research is supported by the U.S. DOE, Office of Science, BES Heavy Element Chemistry program. The isotopes used in this research were supplied by the U.S. DOE Isotope Program, managed by the Office of Science for Nuclear Physics.

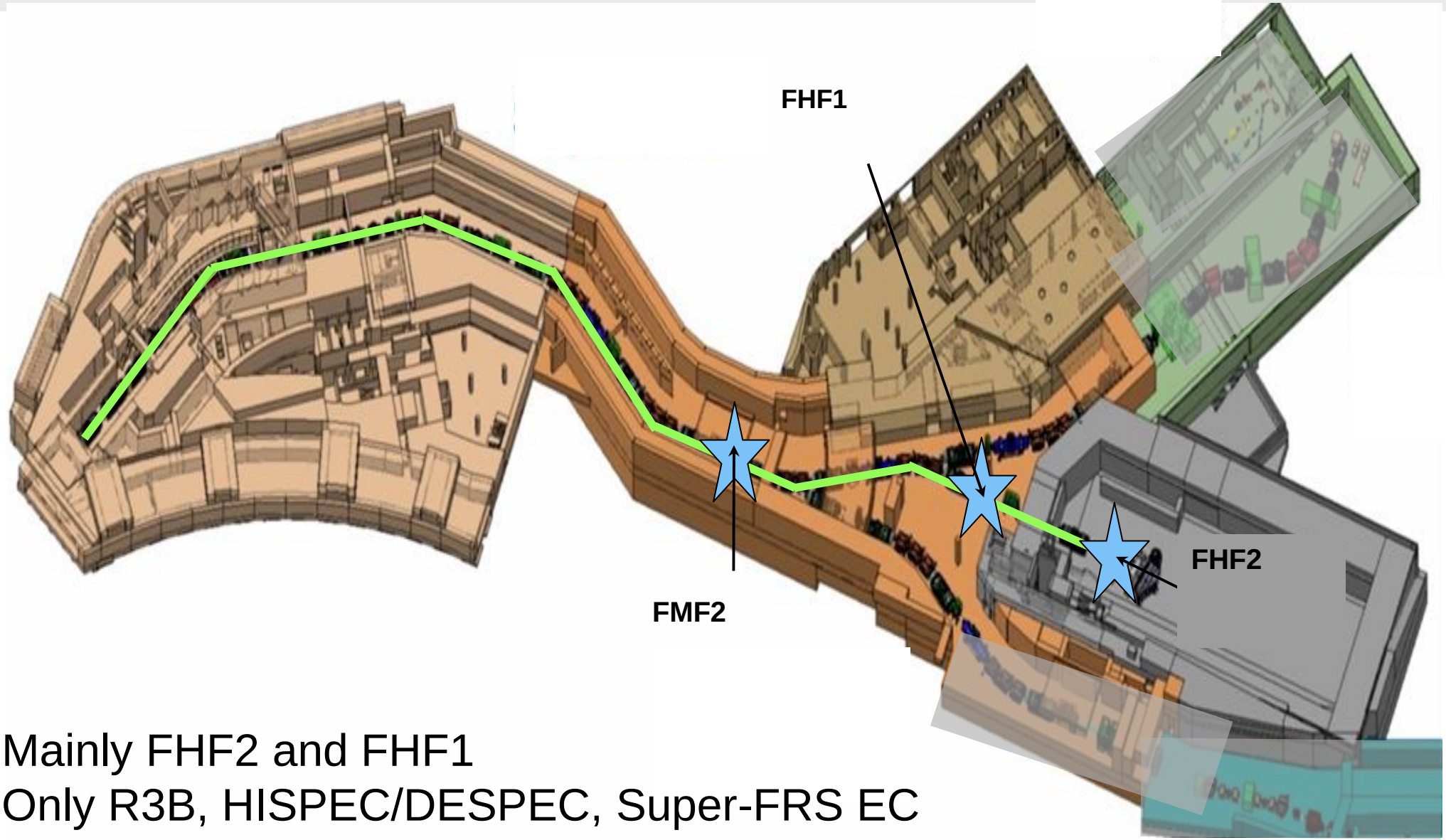
FAIR/GSI strategic operation scenario: ES, FS, towards FS+



Colours explanation (Physics beamtime modes)

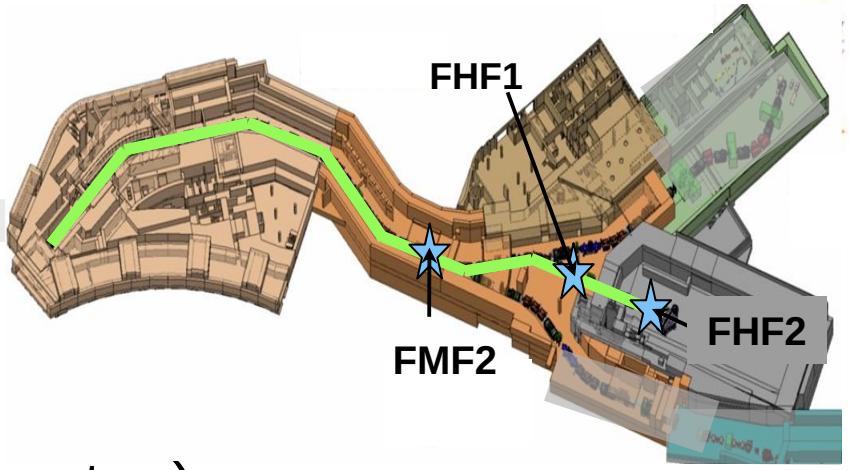
Mode A	Physics beamtime	- highest priority on physics - full parallel operation - full on-call service at any time
Mode B	Best effort operation (BEO)	- priority on physics - limited parallel operation - on-call service by arrangement
Mode C	Second priority	- priority on FAIR commissioning - limited parallel operation - on-call service by arrangement

Experiments location at Super-FRS (ES and FS)



Mainly FHF2 and FHF1
Only R3B, HISPEC/DESPEC, Super-FRS EC

Constrains, timeline (thoughts)



-R3B starts moving into High-Energy Cave in 2026
=> no R3B experiment in 2027 at FRS
-Super-FRS commissioning upto FHF2 in 2027 (simple setup)

-Common NuSTAR experiment at FHF2

-Experiments at FHF1 and FHF2 (also ESR via FRS, SHE etc.)
this needs rearranging FHF1
while one area is used, the other cannot be accessed (radiation safety)
=> we need: beam in blocks (setting up between blocks and
when beam not to Super-FRS)

-When R3B target area installed, only R3B experiments at FHF2
-DESPEC and Super-FRS EC experiments at FHF1

Start of FAIR: First NUSTAR experiment

Main aim to show that FAIR is running

⇒Need to be **published fast**

⇒Low risk (follows directly from SuperFRS commissioning)

⇒Use some new capability:

- secondary beam intensity
  - from primary beam
  - from transmission
- higher beam energy (> 1GeV/u)
- higher SuperFRS transmission
- equipment

Lessons from FRIB (and RIKEN):

Exps.: May 2022 first exp
First publications:
PRL on new lifetimes N>28 (published Nov. 2022)
PRL on unexpected isomer 32Na (June 2023)
PRL on new isotopes 198Pt beam (Feb. 2024;
exp Feb. 2023)

Summary and conclusions

FAIR Phase-0 is productive and assures readiness for Early and First Science

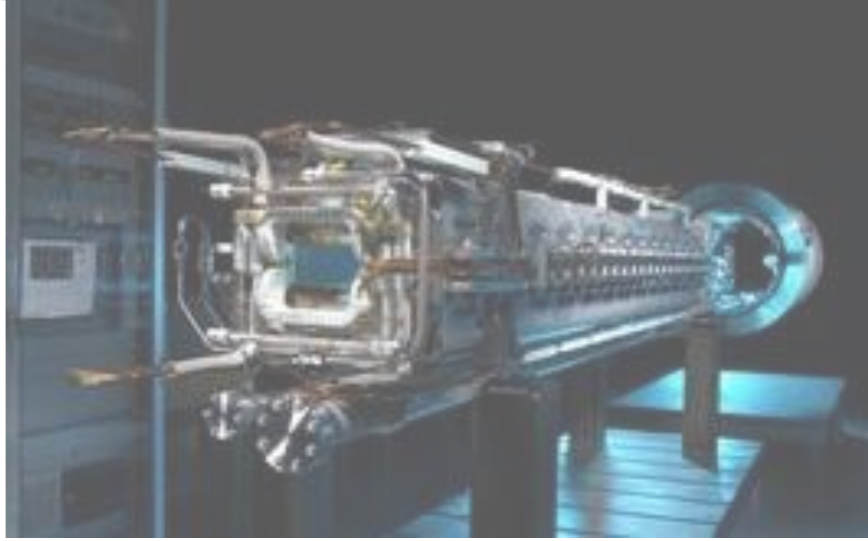
NUSTAR ES&FS experiments will mark the start of FAIR

- Exciting science opportunities based on SuperFRS and SIS100 (aligned with NuPECC LRP)
- Overarching physics case: creation of the chemical elements

Optimisation of the FAIR injector chain already for Early Science in parallel to FAIR construction (beam intensities!)

Vision for the completion of Super FRS low-energy branch (FS++) and ring branch (MSV)?

- GSI POF-5 strategy is being defined until 2034!



Thank you

FAIR RRB, 17 May 2024

Finland France Germany India Poland Romania Russia Slovenia Sweden UK Czech Republic