Experiments with radioactive beams (at SIS-18 in 2024)

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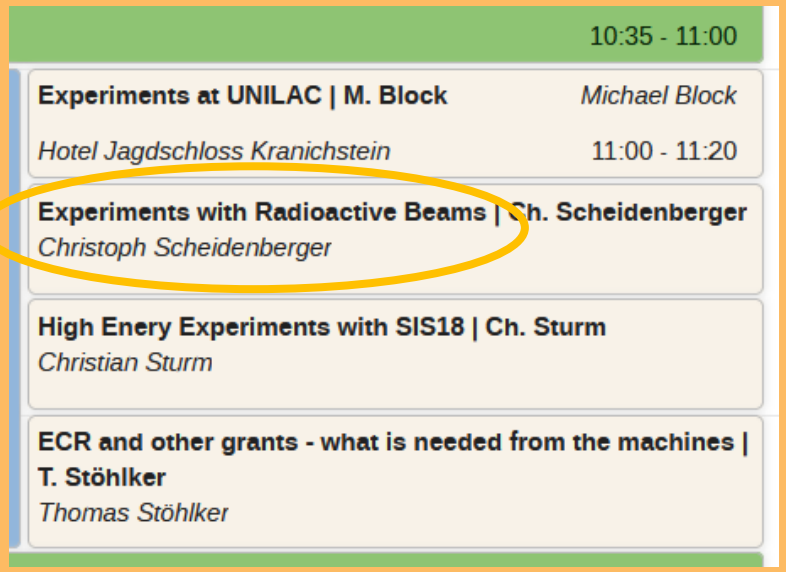
(GSI Darmstadt, JLU Gießen, HFHF)

GSI/FAIR 7th Accelerator Beam Time Retreat

11-12 July 2024, Kranichstein (Germany)

Agenda



- NUSTAR science
- Physics goals of experiments 2024
- New developments & tests
- Maintenance activities
- Résumé

NUSTAR science

Nuclear structure, astrophysics, reactions and superheavy element research

- NUSTAR physics covers the entire nuclear chart!
- Complementary approaches to answer fundamental physics questions

What are the limits for existence of nuclei?
Where are the proton and neutron drip lines situated?
Where does the nuclear chart end?

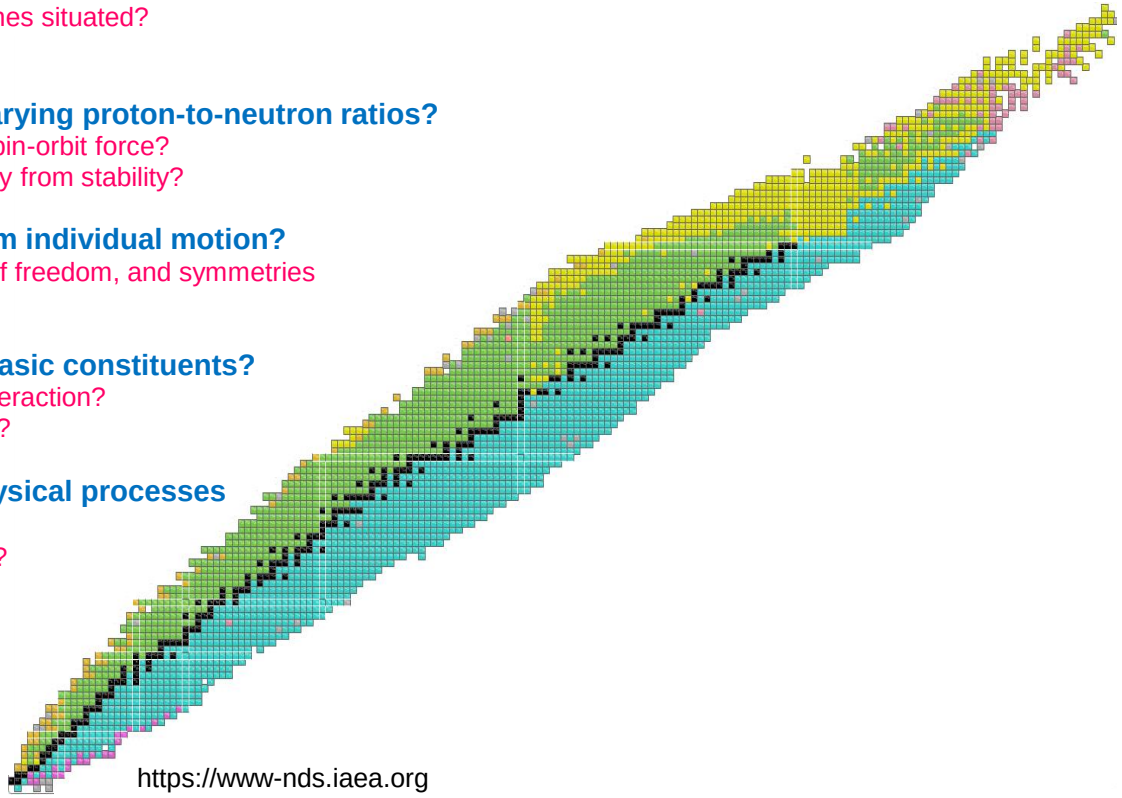
How does the nuclear force depend on varying proton-to-neutron ratios?
What is the isospin dependence of the spin-orbit force?
How does shell structure change far away from stability?

How to explain collective phenomena from individual motion?
What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?

How are complex nuclei built from their basic constituents?
What is the effective nucleon-nucleon interaction?
How does QCD constrain its parameters?

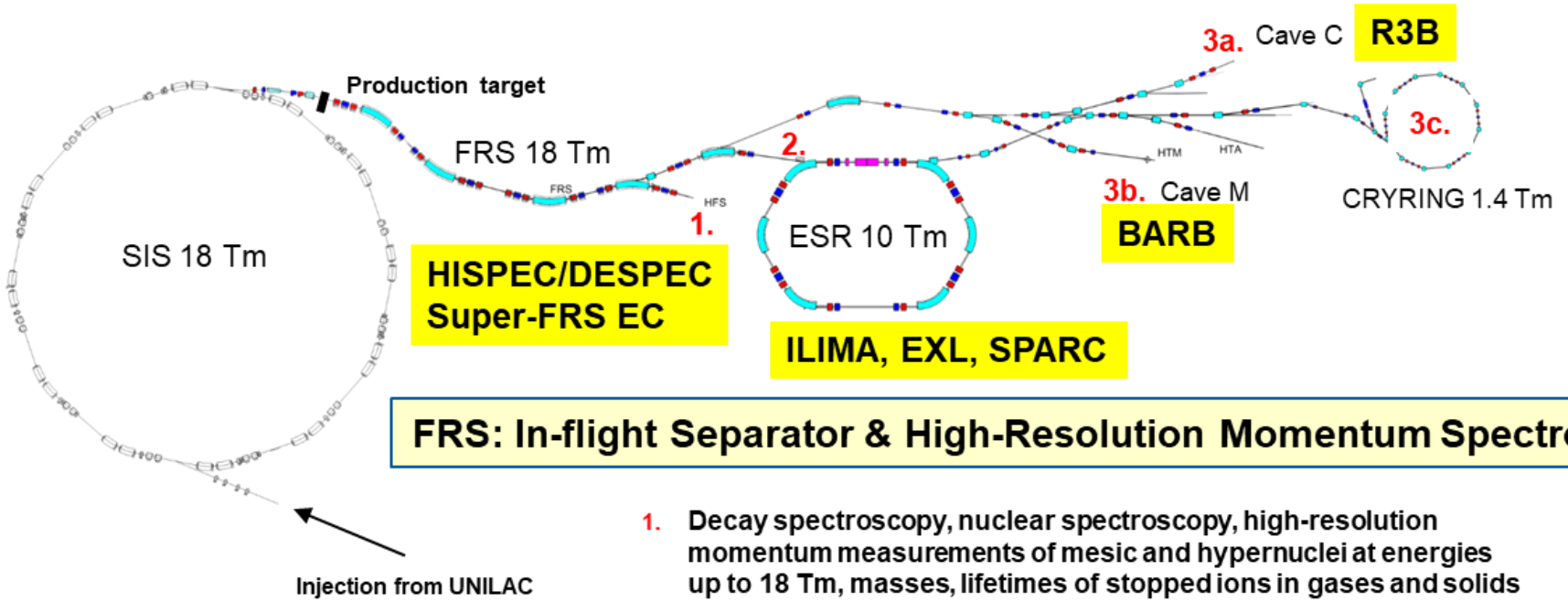
Which are the nuclei relevant for astrophysical processes and what are their properties?
What is the origin of the heavy elements?

Applications
Medical imaging, radioisotopes for medical applications, etc.



https://www-nds.iaea.org

Experiments with exotic nuclei at GSI in FAIR Phase-0



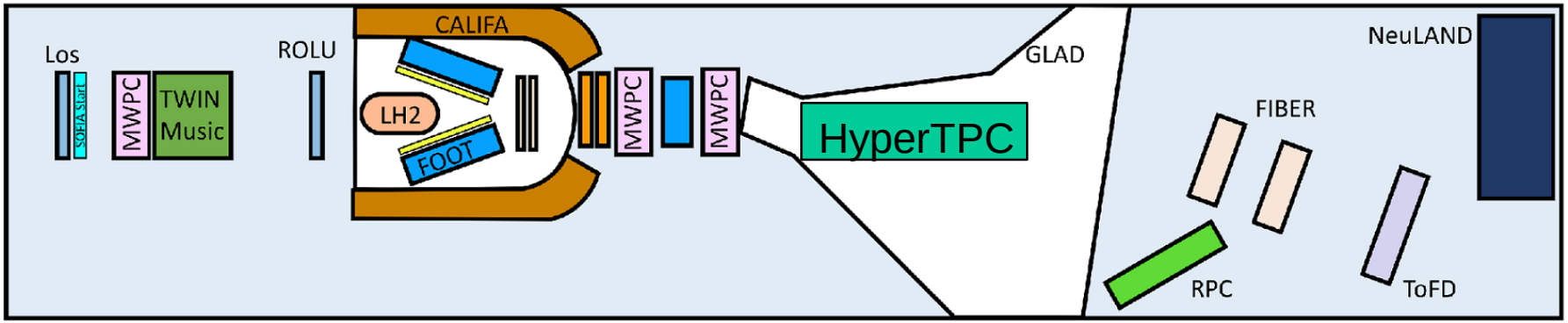
FRS: In-flight Separator & High-Resolution Momentum Spectrometer

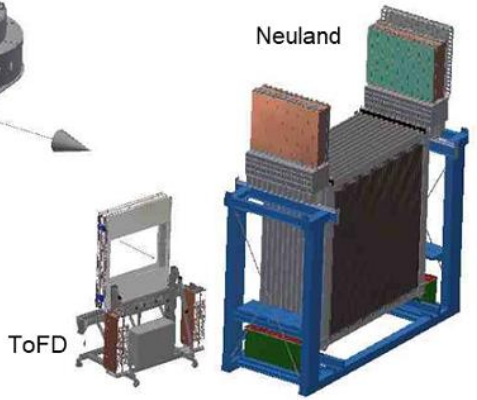
1. Decay spectroscopy, nuclear spectroscopy, high-resolution momentum measurements of mesic and hypernuclei at energies up to 18 Tm, masses, lifetimes of stopped ions in gases and solids
2. Lifetimes of highly-charged ions, isomeric beams, direct reactions, stored ions at 400 MeV/u – few MeV/u , bare and few-electron ions
3a. Reactions studies in complete kinematics
3b. Bio-medical experiments with positron emitters
3c. Astrophysical reaction studies in the Gamow window

Experiments with FRS in 2024

Experiment number	Spokesperson	Title	Shifts	Dates	Primary beam
G-22-00118	Roman Gernhäuser, TU München (DE)	R3B - 2023 commissioning	12	11.02.-15.02.	12C
G-22-00111	Vratislav Chudoba, Silesian Univ. (CZ)	Towards limits of nuclear structure by using a 9C beam	6	15.02.-17.02.	12C
BIO	Marco Durante, GSI Darmstadt (DE)	Biomedical Applications of Radioactive ion Beams	9	17.02.-20.02.	12C
G-22-00091	Marina Petri, York Ac (GB)	Probing nucleon-nucleon correlations in atomic nuclei via (p,pd) QFS reactions	15	20.02.-22.02. 25.02.-28.02.	18O
G-22-00100	Helena Albers, GSI Darmstadt (DE)	Structure of neutron-rich, rare-earth nuclei far from stability	22	21.04.-29.04.	170Er
G-22-00160	Christoph Scheidenberger, GSI Darmstadt (DE)	FRS developments for APPA and NUSTAR experiments: Performance improvements and R&D work with heavy-ion beams	3	15.05.	100Mo
G-22-00092	Kathrin Wimmer, GSI Darmstadt (DE)	Testing diamond detectors for development of an active target	6	16.05.-18.05.	100Mo
G-22-00143	Matjaz Vencelj, IJS Ljubljana (SI)	TEST of DESPEC Fibre Impanter (FIMP)	9	18.05.-21.05.	100Mo
G-22-00117	Paul Constantin, NIPNE (RO)	In-cell multi-nucleon transfer reactions at the FRS Ion Catcher - a new perspective towards broadband heavy neutron-rich isotope studies with stable and unstable beams	12	24.05.-28.05.	238U
G-22-00179	Ali Mollaebrahimi, JLU (DE)	First test of MNT reactions with secondary beams at the FRS Ion Catcher	3	29.05.-30.05.	238U
G-22-00180	Tuomas Grahn, JYU (FI)	Measurement of production cross sections of neutron-deficient fragments in the range of Z=82 to Z=89 in the reaction 238U+9Be	6	30.05.-01.06.	238U
G-22-00182	Jianwei Zhao, GSI Darmstadt (DE)	Fission isomer studies with the FRS	6	01.06.-03.06	238U
G-22-00181	Peter Reiter, Uni Köln (DE)	Extending the quest towards the N=126 r-process waiting point	15	11.06.-16.06.	238U
Total	**13 experiments**		**124**	**shifts**	

G-22-00118: R³B comissioning 2024



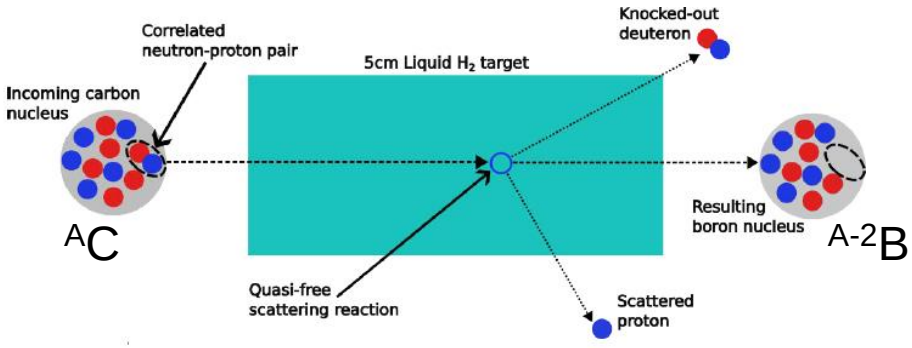


Goal: one common setup, tested and prepared for the campaign 2024+2025: **G-22-00118, G-22-00091, G-22-00073**

R.Gernhäuser, et al.

G-22-00091: Probing nucleon-nucleon correlations in atomic nuclei via (p,pd) QFS reactions

It is the goal of this experiment to measure such correlations and their isospin dependence



(p,pd) quasi-free scattering (QFS) reaction of a carbon isotope incident on a LH_2 target.

G-22-00091: 400 MeV/u ^{18}O,^{12}C primary beams, 21 shifts, $^{10,12,14,16}C$ beams

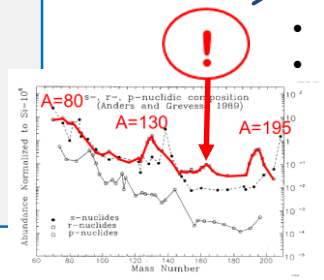
M.Petri, S.Paschalis, A.O.Macchiavelli, et al.

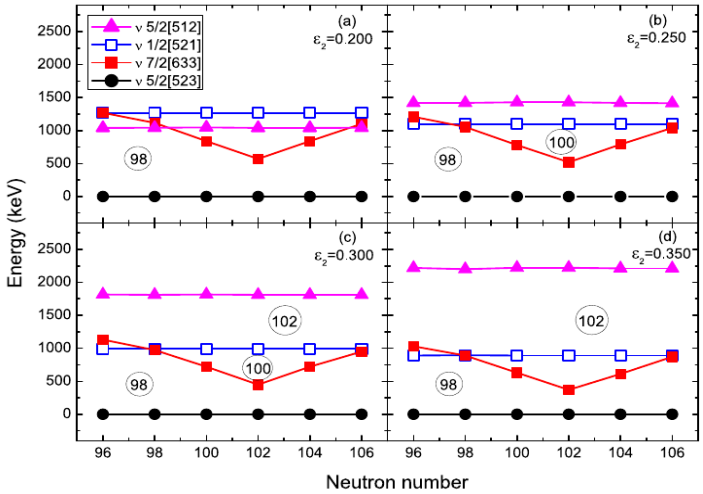
G-22-00100: Structure of neutron-rich, rare-earth nuclei far from stability

- Rare-earth nuclei mid-way between Z=50,82 and N=82,126 are **highly collective**
- ^{170}Dy (N=104), doubly-midshell, **highest $N_\pi N_\nu$** of any nucleus with A<208
- Smooth decrease of 2_1^+ energies towards N=104 **not observed**
- 'Rare-Earth' peak of **r-process** abundances influenced by structure of deformed neutron-rich, rare-earth isotopes (e.g. [1])

Open questions:

- Are there deformed subshell closures?
- Where are they located and what is their nature?
- What is the underlying physics at play?
- Where is the highest deformation, and why?





- Conflicting interpretations from (e.g.) isomer decay spectroscopy [2], masses [3], β-decay halflives [4], decay properties [5],...
- Recent PSM calculations [6] indicate location and size of subshell gaps **highly-dependent** on **deformation** and **neutron number N**

- **Main Experimental Goals:**
  - 2^+ (and 4^+) **lifetimes** in even-even neutron-rich Dy, Gd and Sm isotopes
  - **Level structures** of poorly-known nuclei after beta decay
  - New data on **isomeric decays**, search for new isomers

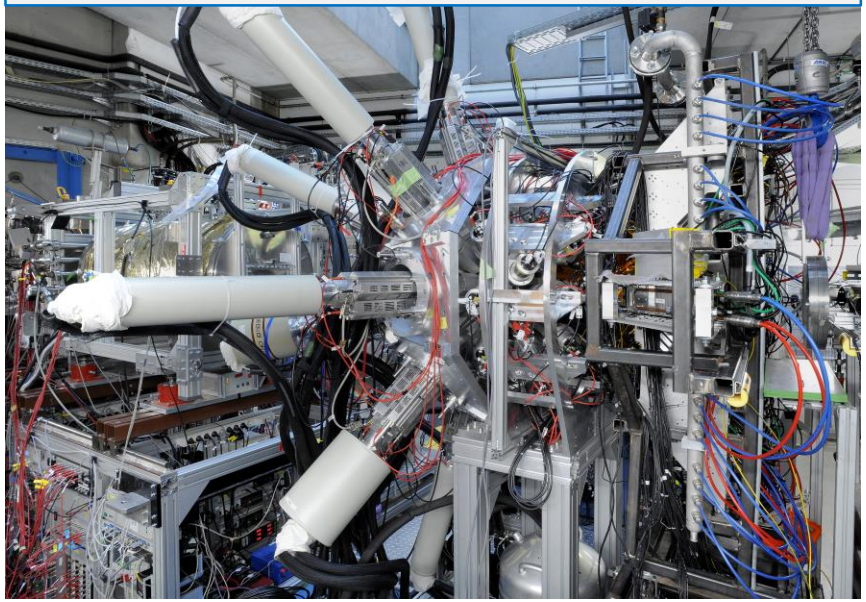
[1] Mumpower *et al.*, PRC 85, 045801, 2012)
[2] Z. Patel *et al.*, PRL **113**, 262502 (2014)
[3] M. Vilen *et al.*, PRL **120**, 262701 (2018)
[4] J. Wu *et al.*, PRL **118**, 072701 (2017)
[5] D.J. Hartley *et al.*, PRL **120**, 182502 (2018)
[6] Y.X. Liu *et al.*, J. Phys. G: Nucl. Part. Phys. 47, 055108 (2020)

H.M.Albers, T.Grahn, C.M.Petrache, V.Werner, et al.

G-22-00100: Structure of neutron-rich, rare-earth nuclei far from stability

Main Experimental Goals:

- 2^+ (and 4^+) **lifetimes** in even-even neutron-rich Dy, Gd and Sm isotopes
- **Level structures** of poorly-known nuclei after beta decay
- New data on **isomeric decays**, search for new isomers



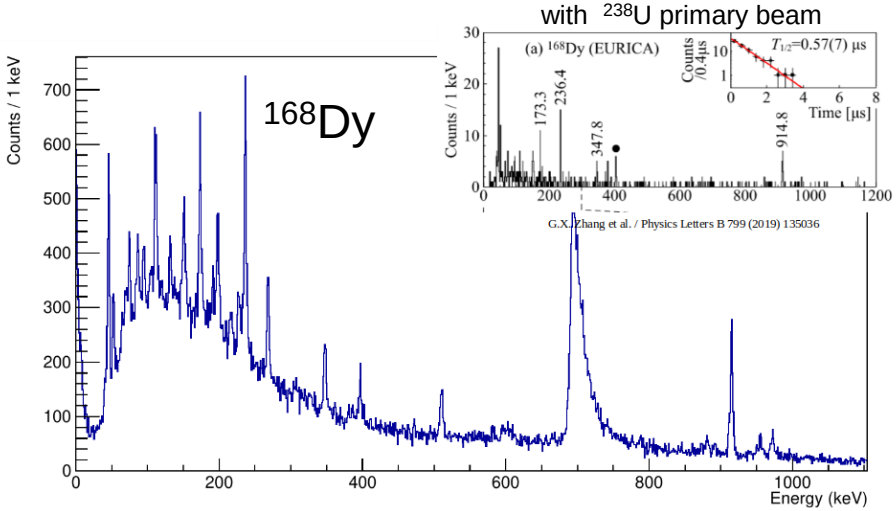
DESPEC Hybrid DEGAS + FATIMA Gamma Array, Photo courtesy G. Otto

H.M.Albers, T.Grahn, C.M.Petrache, V.Werner, et al.

Experiment details:

- ~22 shifts of data collection in April 2024
- Fragmentation of ^{170}Er beam
- Exotic ions transported to focal plane of Fragment Separator with event-by-event particle ID
- Ions stopped in **DESPEC** fast-timing setup
- Implantation stack: 24x8 cm^2 AIDA DSSDs + βPlast scintillators
- Hybrid γ-ray array of **12 DEGAS triple clusters** plus **36 FATIMA modules**

Results from EURICA at RIKEN with ^{238}U primary beam

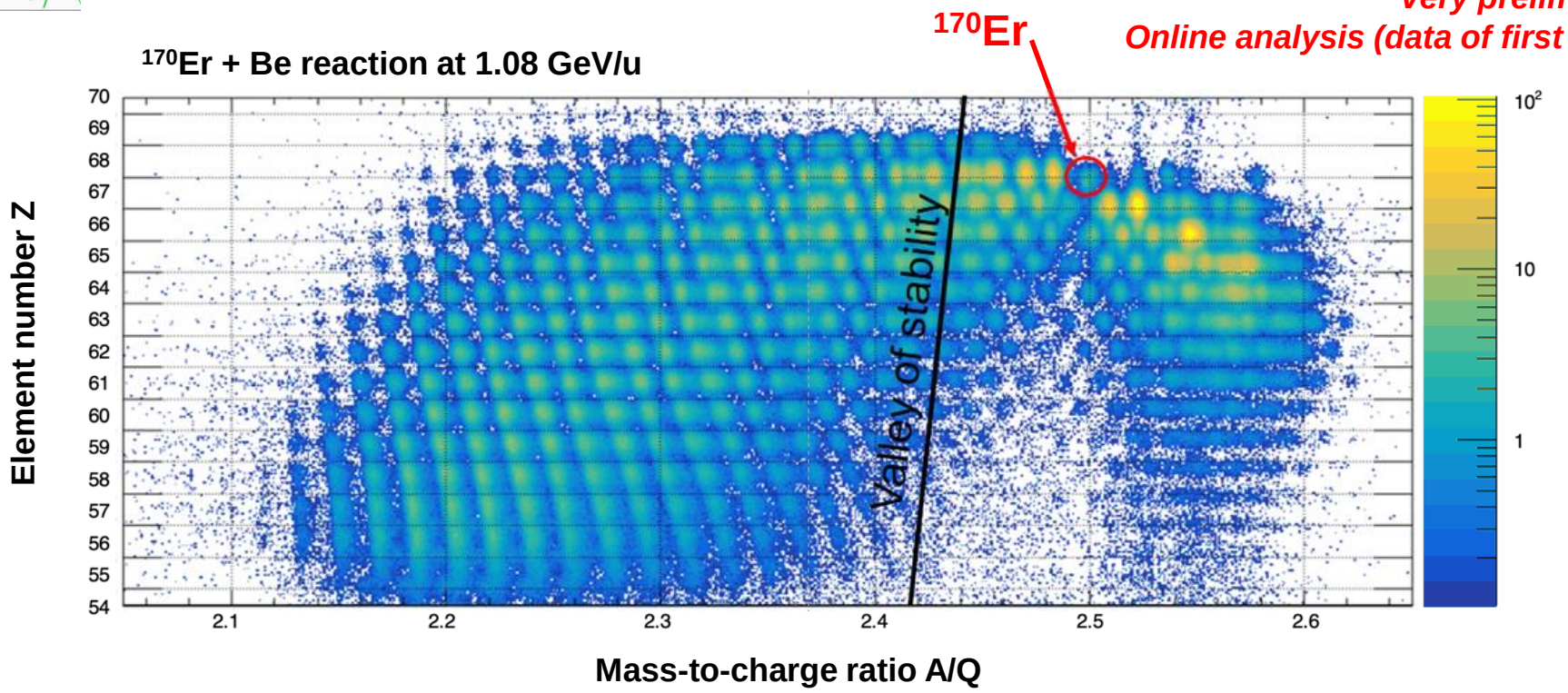


Subset of online data, DEGAS HPGe spectrum

^{170}Er: new beams ➔ new opportunities!

Measurement of fragmentation cross sections with the newly-developped Er beam

Very preliminary
Online analysis (data of first night)



◇ **Excellent particle separation and identification with the FRS !**

◇ **Wide range of cross section data serve as important basis for developments of future FRS/SFRS and NUSTAR experiments with the newly developed Er beam, uniquely available at GSI/FAIR**

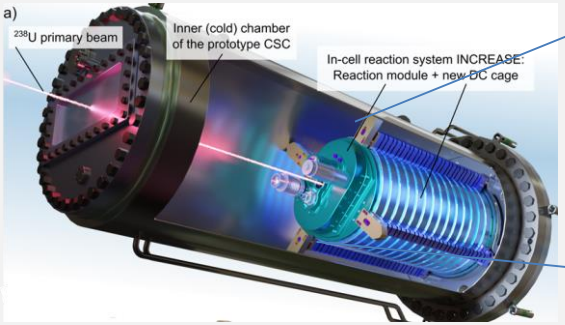
◇ **Similar for ^{100}Mo, ^{238}U et al.**

Y.Tanaka, E.Haettner, S.Singh, et al.

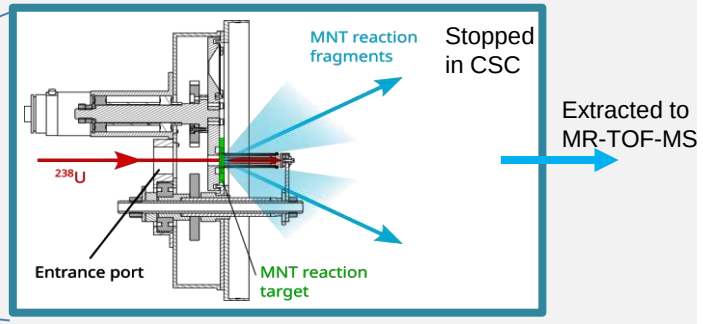
G-22-00117 + G-22-00179: Test of multi-nucleon transfer reactions with slowed-down primary + secondary beams

MNT with secondary beams = Accelerate to relativistic energy + Slow-down to Coulmb barrier

in-cell MNT reaction



T. Dickel et al., J. Phys.: Conf. Ser. 1668 (2020)

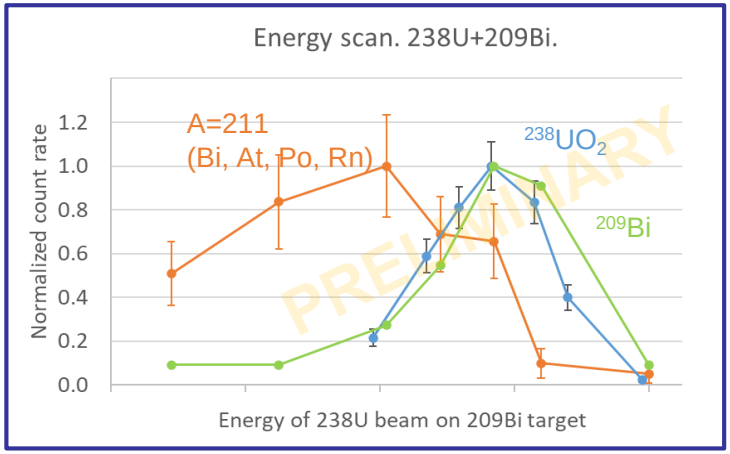


A. Rotaru, D. Amanbayev et al. NIM B 512 (2022)

Beams: primary beam ^{238}U, secondary beam ^{236}U
Targets: ^{209}Bi, ^{64}Ni, ^{238}U
500 MeV/u initial energy
10^5…10^6 ions/s on target

This may open new directions for Coulomb barrier reactions with secondary beams at the Super-FRS Ion Catcher: intensites will be significantly higher

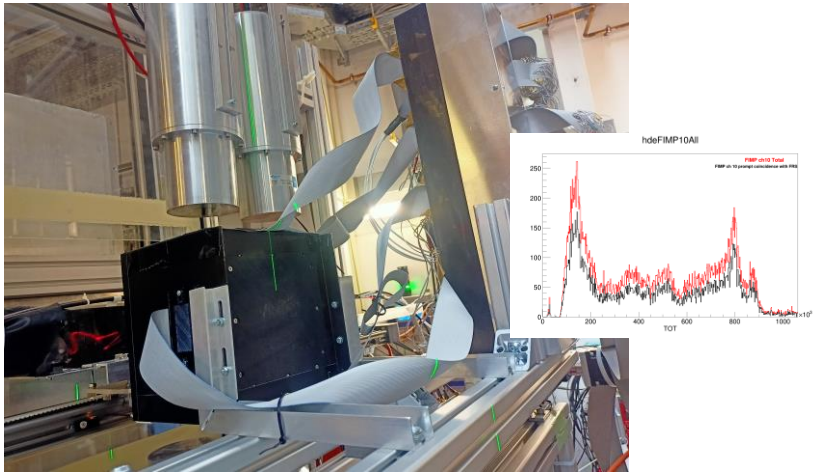
P.Constantin, A.Mollaebrahimi, T.Dickel, et al.



Online analysis shows events of the expected isotopes
Detailed data analysis ongoing

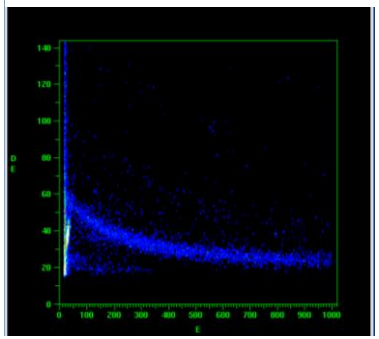
Developments & tests

FIMP (**F**iber **IMP**lantation detector)



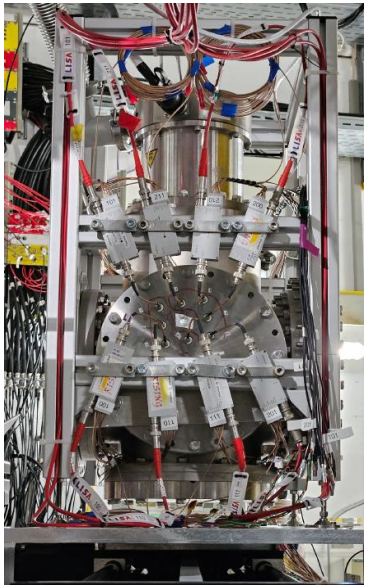
G-22-00143: M.Vencelj, et al.

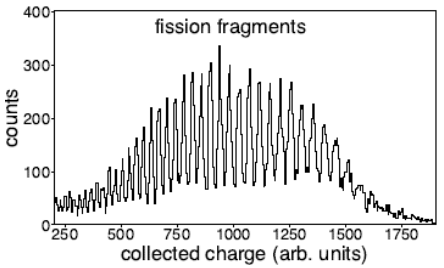
Bolometer (for low-E PID)



G-22-00160: S.Kraft-Bermuth, et al.

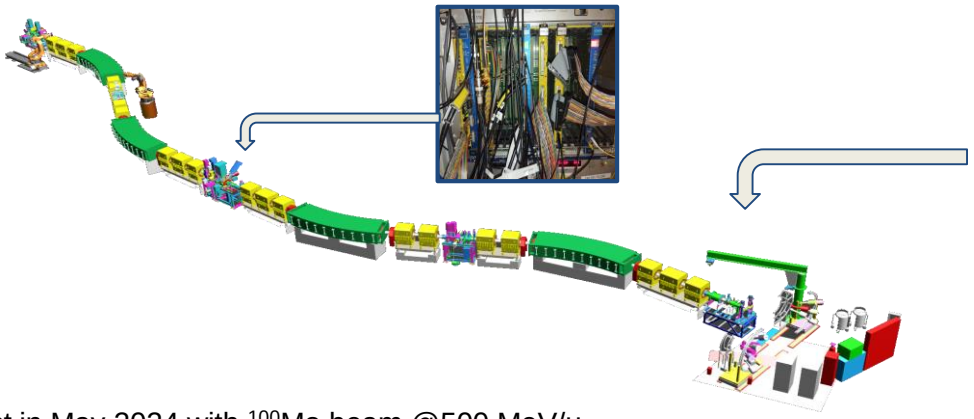
LISA (**LI**fetime meas. with **S**olid **A**ctive targets)





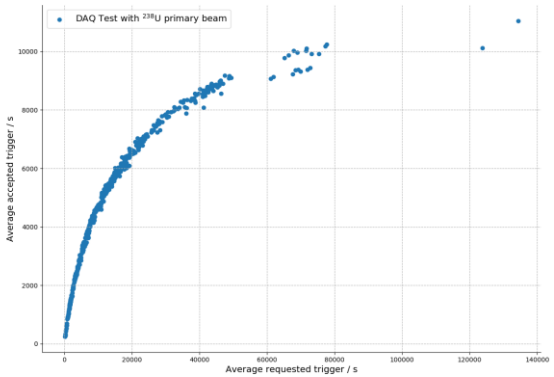
G-22-00092: K.Wimmer, et al.

FRS DAQ acceleration



3 DAQ crates in FRS Messhuette

Test in May 2024 with ^{100}Mo beam @500 MeV/u
Benchmarked performance of all three MVLC crates



FRS MBS was modified:

before: **RIO4** single crate readout: 11…15 kHz (4 MB/s)
after: **MVLC** single crate readout 33…40 kHz (12 MB/s)
➔ **gain factor ~ 2.5 in readout speed, ~ 3 in data rate**

➔ MBS with MVLC was successfully used in all approved experiments of 2024

Special thanks to all the GSI collaborators, especially from **EE department**:
Nikolaus Kurz , Jörn Adamczewski-Musch , Sergey Linev, Michael Reese et al.
Super-FRS Experiment Collaboration:
Martin Bajzek, Yoshiki Tanaka, Stephane Pietri, Emma Haettner, Christine Hornung, Jianwei Zhao

Ceterum censeo…
(same remarks as every year)

For efficient use of beam-on-target time:

- Improved micro-spill structure
- Routine feature: improved macro-spill structure

Stay competitive on the world-wide scale:

- Higher beam intensity at 1GeV/u

Increase the duty cycle of slowly-extracted SIS-18 beams:

- Many NUSTAR experiments run with 1…2 sec. extraction time: fast ramping up and down of SIS-18 will increase the duty factor
  ➔ factor 2(?) higher average beam intensity on target!

Strategic aim

Successful experiments, effective and efficient use of all resources and beamtime

- Increase **reliability** of (user) setups, **uptime** of FRS, **safety** for everybody working here
- Improve **flexibility** and **user friendliness** for a big variety of experiments
- Keep FRS up and **compatible** with FAIR environment and standards

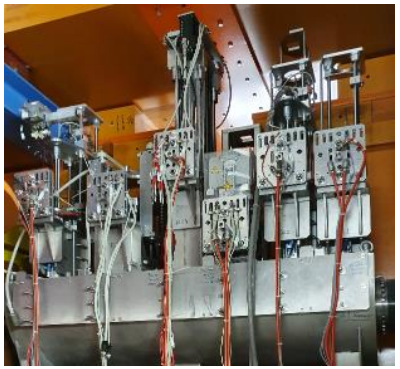
Many projects underway, support from many GSI groups

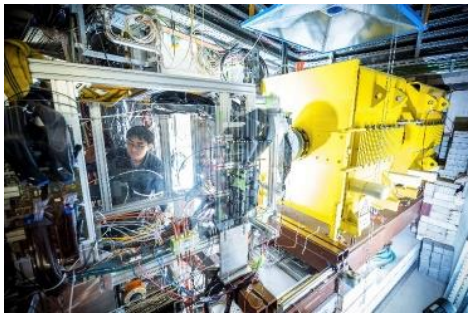
– Very helpful!

– Thank you!

– Support is highly appreciated!

Overview of ongoing upgrade and maintenance activities



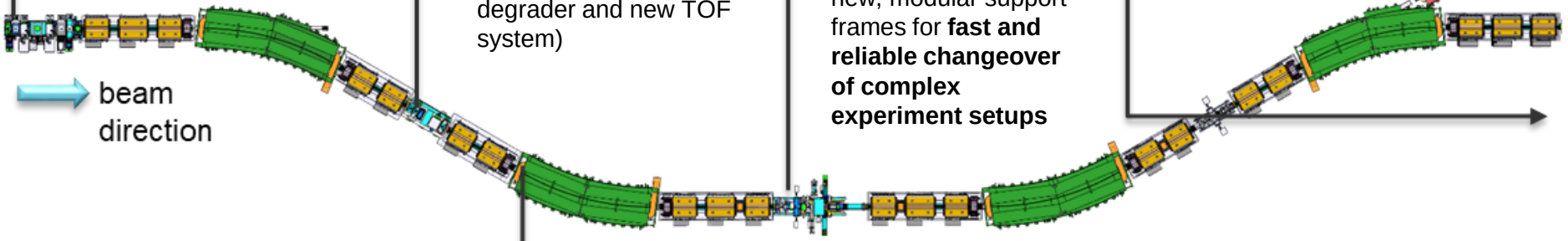


Target area:
Preparation for complete remote handling, cope with higher beamintensities

S1 focal plane:
Improved separation and identification of secondary beams (new, turnable disc degrader and new TOF system)

S2 focal plane:
Implementation of new, modular support frames for **fast and reliable changeover of complex experiment setups**

S4 final focal plane
Preparation and installation of setups for experiments 2025



Quadrupole magnets:
ACCU - upgrade of all power supplies (in order to **stay compatible with FAIR control system**)

Steppermotors and insertions:
64-channel COSYLAB system available; installation started

FRS environment and Messhütte:
Many activities ongoing to **maintain/improve safety, reliability, IT infrastructure**

DAQ: Upgrade to higher rate capability

Résumé

Overarching physics case: creation of the chemical elements, nuclear structure far-off stability,

A rich, high-level science program with many unique features is underway

FAIR Phase-0 is crucial for ES/FS at Super-FRS: preparations, tests, developments, training

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

The results of FAIR Phase-0 are the basis for the POF-5 strategy until 2034

Thank you for a lot of support!

NUSTAR
Annual Meeting 2024