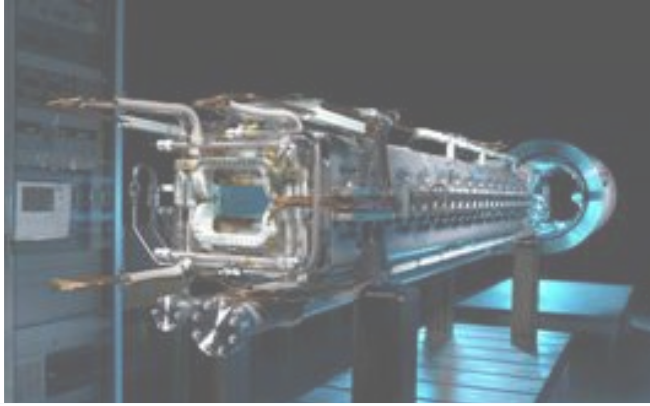




Bericht zu NUSTAR

NUSTAR: status & response to the "First-Science and Staging Review of the FAIR Project"

Norbert Pietralla, *TU Darmstadt*
für die NUSTAR.de - Community

KHuK Meeting Dez. 2022
Physikzentrum, Bad Honnef, 9.12.2022

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

FAIR

FAIR: “The Universe in the Laboratory”

Neutron Star Mergers

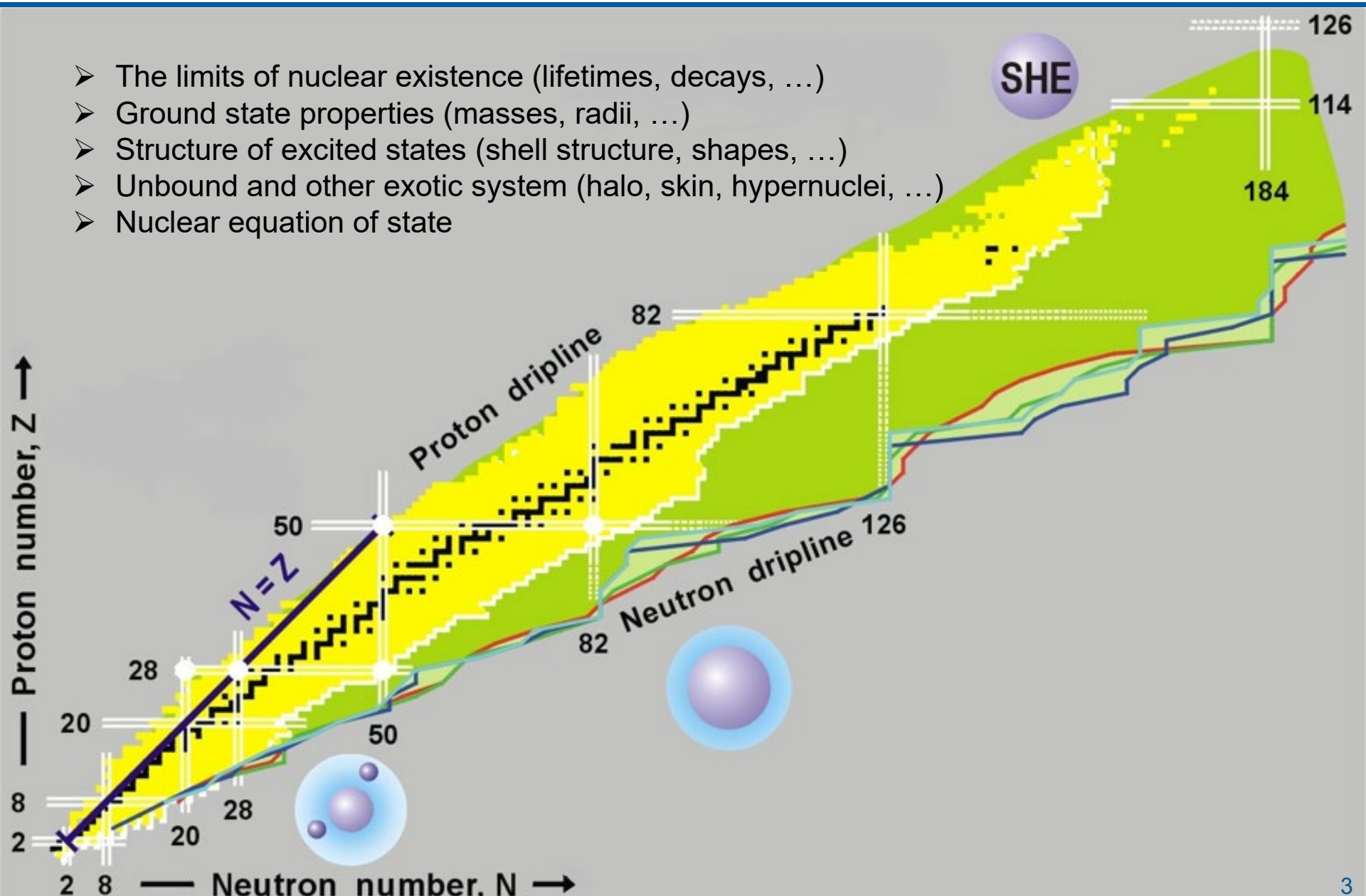
FAIR Research Pillars

- Equation of State (**Hades, CBM**)
  - Gravitational wave signal
  - Amount of ejecta
- Baryon-Baryon interaction (**PANDA**)
- Exotic neutron-rich nuclei (**NUSTAR**)
  - r-process nucleosynthesis and abundances of the heaviest elements
  - Nuclear equation of state
  - Kilonova EM transient lifetime
- Plasma and atomic opacities (**APPA**)

FAIR offers unique opportunities for studying fundamental questions!

NUclear STructure Astrophysics and Reactions

- The limits of nuclear existence (lifetimes, decays, …)
- Ground state properties (masses, radii, …)
- Structure of excited states (shell structure, shapes, …)
- Unbound and other exotic system (halo, skin, hypernuclei, …)
- Nuclear equation of state



Recent Developments

Report

from the Committee for

First-Science and Staging Review of the FAIR Project

Submitted to FAIR Council, October 2022

Outline

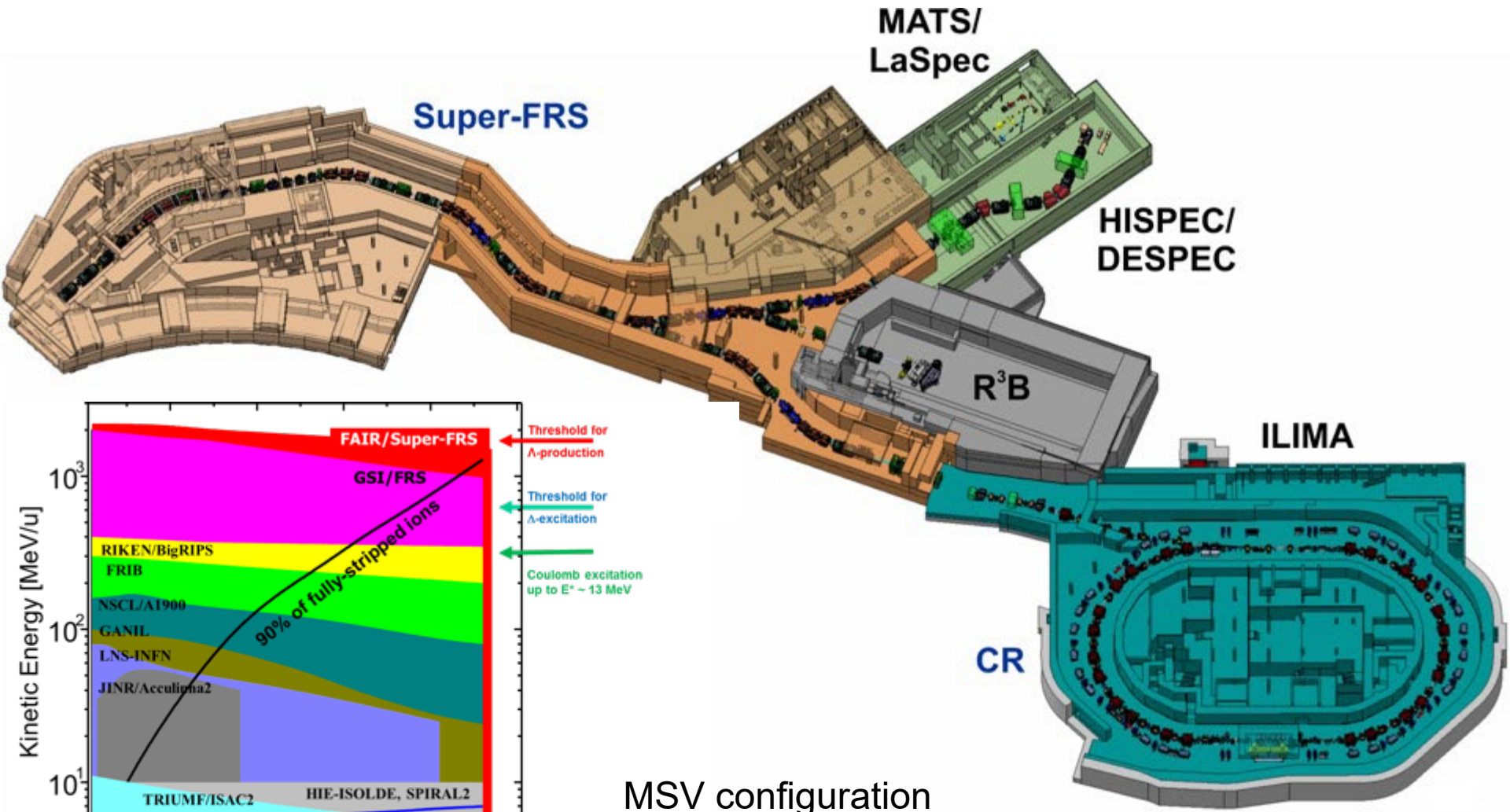
- **NUSTAR project overview**
  - **Collaborations**
  - **Progress of establishment of facility**
  - **Selected highlights or examples**
- **NUSTAR funding overview**
- **Recommendations from the Report & Consequences**
- **Summary**

NUSTAR – Project Overwiew

PSP code	Super-FRS	RIB production, separation, and identification
1.2.2	**HISPEC/ DESPEC**	In-beam γ-spectroscopy at low and intermediate energy, n-decay, high-resolution γ-, β-, α-, p-, spectroscopy
1.2.3	**MATS**	In-trap mass measurements and decay studies
1.2.4	**LaSpec**	Laser spectroscopy
1.2.5	**R^3B**	Kinematical complete reactions with relativistic radioactive beams
1.2.6	**ILIMA**	In-ring scans of mass and lifetimes of nuclei in ground and isomeric states
1.2.10	**Super-FRS**	High-resolution spectrometer experiments
1.2.11	**SHE**	Synthesis and study of super-heavy elements
1.2.8	**ELISe(*)**	Elastic, inelastic, and quasi-free e^--A scattering
1.2.9	**EXL(*)**	Light-ion scattering reactions in inverse kinematics

(*) NESR required – alternative/intermediate “operation” within FAIR IO under consideration.

The Super-FRS facility for NUSTAR@FAIR



MSV configuration

Progress of NUSTAR Buildings

The construction site on Feb. 8, 2022

Concrete Shell ready

Movie played by Paolo G. yesterday night

NUSTAR-Highlights from FAIR Phase-0

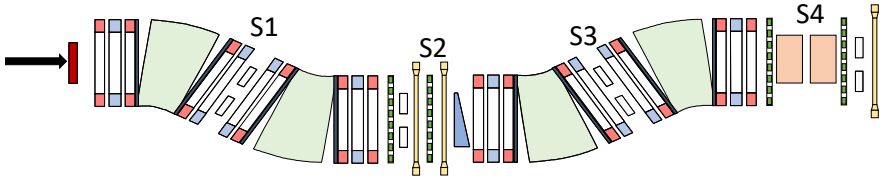
necessarily incomplete

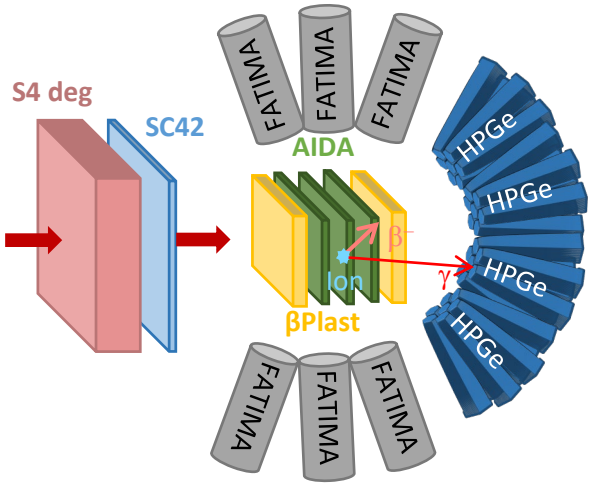
my personal selection

Decay measurements @ FRS/S-FRS–GSI/FAIR

Selection and identification: $B\rho - \Delta E - B\rho$

$ToF - B\rho - \Delta E$





PHYSICAL REVIEW C **105**, L031304 (2022)

Letter

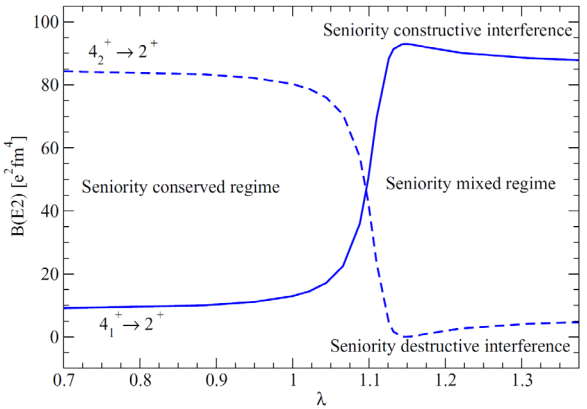
Nature of seniority symmetry breaking in the semimagic nucleus ^{94}Ru

B. Das,[1,*] B. Cederwall,[1,†] C. Qi,[1] M. Górska,[2] P. H. Regan,[3,4] Ö. Aktas,[1] H. M. Albers,[2] A. Banerjee,[2] M. M. R. Chishti,[3] J. Gerl,[2] N. Hubbard,[2,5] S. Jazrawi,[3,4] J. Jolie,[6] A. K. Mistry,[2,5] M. Polettini,[7,8] A. Yaneva,[2,6] S. Alhomaidhi,[2,5] J. Zhao,[2] T. Arici,[2] S. Bagchi,[9] G. Benzoni,[8] P. Boutachkov,[2] T. Davinson,[10] T. Dickel,[2,11] E. Haettner,[2] O. Hall,[10] Ch. Hornung,[2] J. P. Hucka,[5] P. R. John,[5] I. Kojouharov,[2] R. Knöbel,[2] D. Kostyleva,[2] N. Kuzminchuk,[2] I. Mukha,[2] W. R. Plass,[2,11] B. S. Nara Singh,[12] J. Vasiljević,[1] S. Pietri,[2] Zs. Podolyák,[3] M. Rudigier,[5] H. Rösch,[5] E. Sahin,[2,5] H. Schaffner,[2] C. Scheidenberger,[2] F. Schirru,[2] A. Sharma,[13] R. Shearman,[4] Y. Tanaka,[2] J. Vesić,[14] H. Weick,[2] H. J. Wollersheim,[2] U. Ahmed,[5] A. Algora,[15,16] C. Appleton,[10] J. Benito,[17] A. Blazhev,[6] A. Bracco,[7,8] A. M. Bruce,[18] M. Brunet,[3] R. Canavan,[3,4] A. Esmaylzadeh,[6] L. M. Fraile,[17] G. Häfner,[19,6] H. Heggen,[2] D. Kahl,[10] V. Karayonchev,[6] R. Kern,[5] A. Korgul,[20] G. Kosir,[14] N. Kurz,[2] R. Lozeva,[19] M. Mikolajczuk,[20,2] P. Napiralla,[5] R. Page,[21] C. M. Petrache,[19] N. Pietralla,[5] J.-M. Régis,[6] P. Ruotsalainen,[22] L. Sexton,[10] V. Sanchez-Temble,[17] M. Si,[19] J. Vilhena,[23] V. Werner,[5] J. Wiederhold,[5] W. Witt,[5] P. J. Woods,[10] and G. Zimba[22]

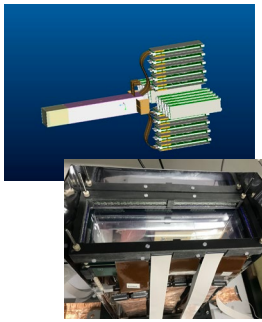
[1]*KTH Royal Institute of Technology, 10691 Stockholm, Sweden*

[2]*GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*

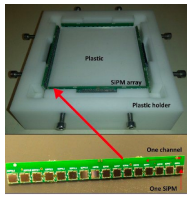
PHYSICAL REVIEW C **105**, L031304 (2022)



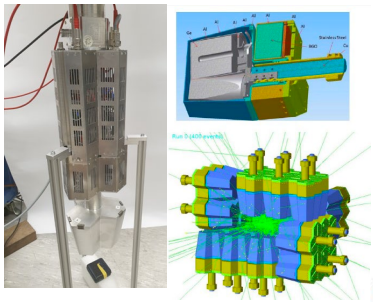
DESPEC instrumentation



AIDA: stack of DSSSD:
8x8 cm^2 and 24x8 cm^2 ;128x128 pixels
Wide dynamic range



3 mm thick plastic detector
upstream and downstream from AIDA
SiPM readout

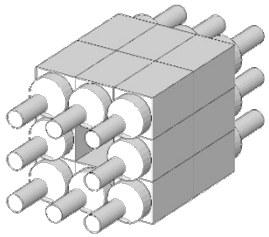


DEGAS DEspec Germanium Arra ter
28 triple Clusters of Euroball with
BGO back-catchers and
Box configuration a m^2 AIDA

A – 36 LaBr3(Ce) detectors (of medium
nergy resolution) for fast-timing coincidences
to measure excited state lifetimes in the 100
ps–ns regime using γ–γ and fast-β–γ coinc.

All sub-systems fully commissioned at GSI
(single detectors + coupling into GSI DAQ)

S452 „A~190 Isomers“
ErUM-FSP T07
05P21RDFN1



DTAS gamma-calorimeter
NaI(Tl) large volume 1515×25 cm^3
Central hole accommodating AIDA

DESPEC instrumentation

Nuclear Inst. and Methods in Physics Research, A 890 (2018) 148–154

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Simulated characteristics of the DEGAS γ-detector array

G.S. Li [a,*], C. Lizarazo [a,b], J. Gerl [a], I. Kojouharov [a], H. Schaffner [a], M. Górska [a], N. Pietralla [b], S. Saha [a,b], M.L. Liu [c], J.G. Wang [c]

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[b] Technische Universität Darmstadt, Institut fur Kernphysik, D-64289, Darmstadt, Germany
[c] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, 73000, People's Republic of China

Nuclear Inst. and Methods in Physics Research, A 969 (2020) 163967

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

FATIMA — FAst TIMing Array for DESPEC at FAIR

M. Rudigier [a,b,*], Zs. Podolyák [a], P.H. Regan [a,c], A.M. Bruce [d], S. Lalkovski [a,e], R.L. Canavan [a,c], E.R. Gamba [d], O. Roberts [d], I. Burrows [f], D.M. Cullen [g], L.M. Fraile [h], L. Gerhard [j], J. Gerl [i], M. Gorska [i], A. Grant [f], J. Jolie [j], V. Karayonchev [j], N. Kurz [i], W. Korten [k], I.H. Lazarus [f], C.R. Nita [l], V.F.E. Pucknell [f], J.-M. Régis [j], H. Schaffner [i], J. Simpson [f], P. Singh [k], C.M. Townsley [a], J.F. Smith [m], J. Vesic [l,n]

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[b] Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstrasse 9, 64289, Darmstadt, Germany
[c] National Physical Laboratory, Teddington, Middlesex, TW11 0LW, United Kingdom
[d] School of Computing Engineering and Mathematics, University of Brighton, Brighton BN2 4GJ, United Kingdom
[e] Faculty of Physics, University of Sofia, 1164 Sofia, Bulgaria
[f] STFC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, United Kingdom
[g] Nuclear Physics Group, Schuster Laboratory, University of Manchester, Manchester, M13 9PL, United Kingdom
[h] Grupo de Física Nuclear & IPARCOS, Universidad Complutense de Madrid, CEI Moncloa, 28040 Madrid, Spain
[i] GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany
[j] Institut für Kernphysik der Universität zu Köln, Zülpicher Strasse 77, D-50937 Köln, Germany
[k] Irfu, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
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[m] School of Engineering, University of the West of Scotland, Paisley PA1 2BE, United Kingdom
[n] Josef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia

Nuclear Inst. and Methods in Physics Research, A 1033 (2022) 166662

Contents lists available at ScienceDirect

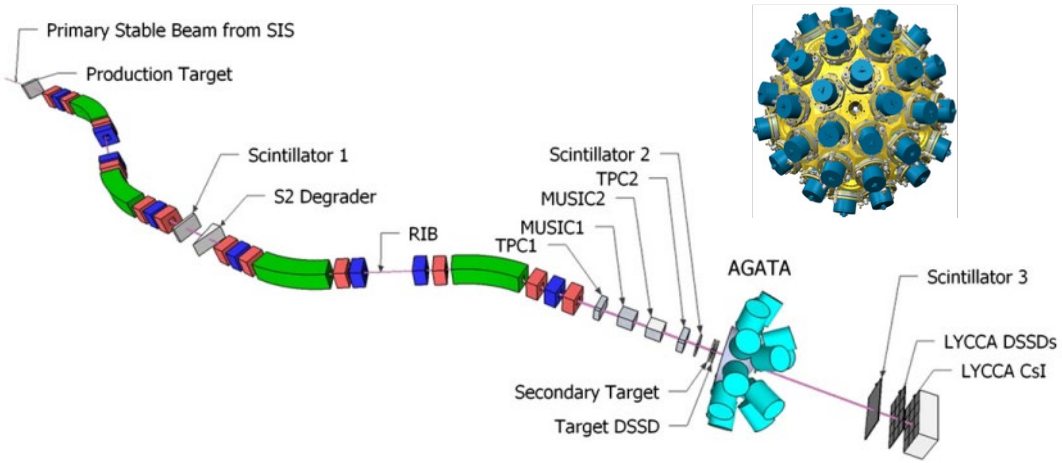
Nuclear Inst. and Methods in Physics Research, A

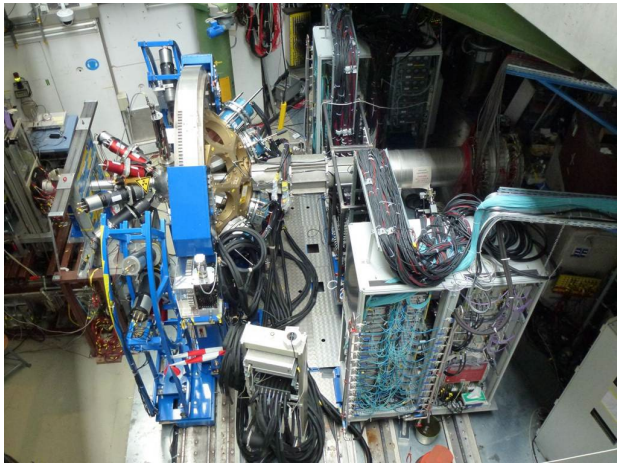
journal homepage: www.elsevier.com/locate/nima

The DESPEC setup for GSI and FAIR

A.K. Mistry [1,2,*], H.M. Albers [2], T. Arıcı [3], A. Banerjee [2], G. Benzoni [4], B. Cederwall [5], J. Gerl [2], M. Górska [2], O. Hall [6], N. Hubbard [1,2], I. Kojouharov [2], J. Jolie [7], T. Martinez [8], Zs. Podolyák [9], P.H. Regan [9,10], J.L. Tain [11], A. Tarifeno-Saldivia [12], H. Schaffner [2], V. Werner [1], G. Ağgez [3], J. Agramunt [11], U. Ahmed [1], O. Aktas [5], V. Alcayne [8], A. Algora [11,13], S. Alhomaidhi [1,2], F. Amjad [2], C. Appleton [6], M. Armstrong [7], M. Balogh [14], K. Banerjee [15], P. Bednarczyk [16], J. Benito [17], C. Bhattacharya [15], P. Black [6], A. Blazhev [7], S. Bottoni [4,18], P. Boutachkov [2], A. Bracco [18,4], A.M. Bruce [19], M. Brunet [9], C.G. Bruno [6], I. Burrows [20], F. Calvino [12], R.L. Canavan [9,10], D. Cano-Ott [8], M.M.R. Chishti [9], P. Coleman-Smith [20], M.L. Cortés [1], G. Cortes [12], F. Crespi [18,4], B. Das [5], T. Davinson [6], A. De Blas [12], T. Dickel [2], M. Doncel [21], A. Ertoprak [5,3], A. Esmaylzadeh [7], B. Fornal [16], L.M. Fraile [17], F. Galtarossa [14], A. Gottardo [14], V. Guadilla [11,22], J. Ha [23,24], E. Haettner [2], G. Häfner [25,7], H. Heggen [2], P. Herrmann [1], C. Hornung [2], S. Jazrawi [9,10], P.R. John [1], A. Jokinen [26], C.E. Jones [19], D. Kahl [6,27], V. Karayonchev [7], E. Kazantseva [2], R. Kern [1], L. Knafla [7], R. Knöbel [2], P. Koseoglou [1], G. Kosir [28], D. Kostyleva [2], N. Kurz [2], N. Kuzminchuk [2], M. Labiche [20], J. Lawson [20], I. Lazarus [20], S.M. Lenzi [23], S. Leoni [4,18], M. Llanos-Expósito [17], R. Lozeva [25], A. Maj [16], J.K. Meena [15], E. Mendoza [8], R. Menegazzo [24], D. Mengoni [14], T.J. Mertzimekis [29], M. Mikolajczuk [22,2], B. Million [4], N. Mont-Geli [12], A.I. Morales [11], P. Morral [20], I. Mukha [2], J.R. Murias [17], E. Nacher [11], P. Napiralla [1], D.R. Napoli [14], B.S. Nara-Singh [30], D. O'Donnell [30], S.E.A. Orrigo [11], R.D. Page [31], R. Palit [32], M. Pallas [12], J. Pellumaj [14], S. Pelonis [29], H. Pentilla [26], A. Pérez de Rada [8], R.M. Pérez-Vidal [14], C.M. Petrache [25], N. Pietralla [1], S. Pietri [2], S. Pigliapoco [24], J. Plaza [8], M. Polettini [4,18], C. Porzio [4,18], V.F.E. Pucknell [20], F. Recchia [23], P. Reiter [7], K. Rezynkina [24], S. Rinta-Antila [26], E. Rocco [2], H.A. Rösch [2,1], P. Roy [15,2], B. Rubio [11], M. Rudigier [1], P. Ruotsalainen [26], S. Saha [33], E. Şahin [1,2], Ch. Scheidenberger [2], D.A. Seddon [31], L. Sexton [6], A. Sharma [34], M. Si [25], J. Simpson [20], A. Smith [35], R. Smith [20], P.A. Söderström [27], A. Sood [5], A. Soylu [36], Y.K. Tanaka [37], J.J. Valiente-Dobón [14], P. Vasileiou [29], J. Vasiljevic [5], J. Vesic [28], D. Villamarin [8], H. Weick [2], M. Wiebusch [2], J. Wiederhold [1], O. Wieland [4], H.J. Wollersheim [2], P.J. Woods [6], A. Yaneva [7], I. Zanon [14], G. Zhang [23,24], J. Zhao [2,38], R. Zidarova [1], G. Zimba [26], A. Zyriliou [29]

HISPEC with its core instrument AGATA





AGATA: γ-tracking array
- very high γ-ray efficiency
- excellent peak-to-total ratio
- unprecedented position resolution due to γ-ray tracking

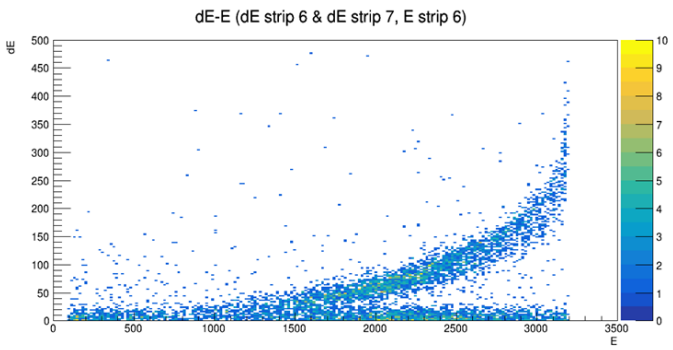
➔ Move to GSI > 2026

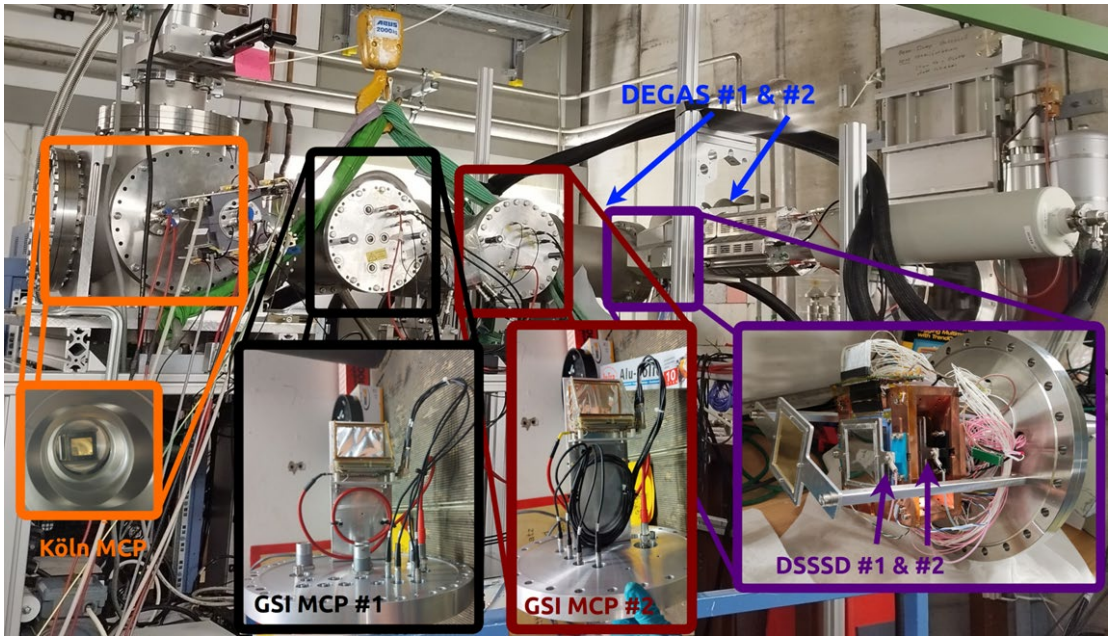
Physics opportunities with the Advanced Gamma Tracking Array: AGATA
W. Korten et al., Eur. Phys. J. A (2020) 56:137

AGATA Phase-2 MoU „3π-configuration“ signed by GSI

S497 Test of beam tracking / ID for „HISPEC-10“

- **HISPEC-10:** S-FRS beams slowed down to **energies of 5-10 MeV/u**
- Enable **experiments at Coulomb barrier energies**, exciting high spin states.
  Coulomb excitation, transfer, fusion evaporation: explore new realms of nuclear landscape
- Tests were performed in cave A using a primary Pb-208 beam in June 2022



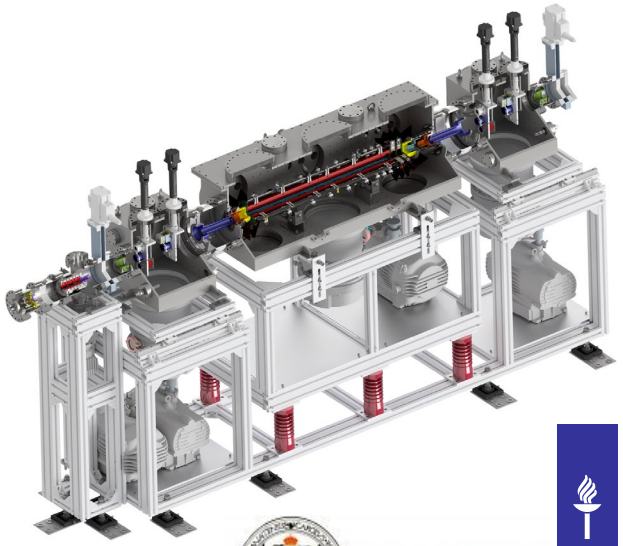


Financed by BMBF under Verbundprojekt 05P2021
(ErUM-FSP T07) Förderkennzeichen: 05P21PKFN1

MATS – Programme for Phase-0 and Day-1

FAIR phase 0:

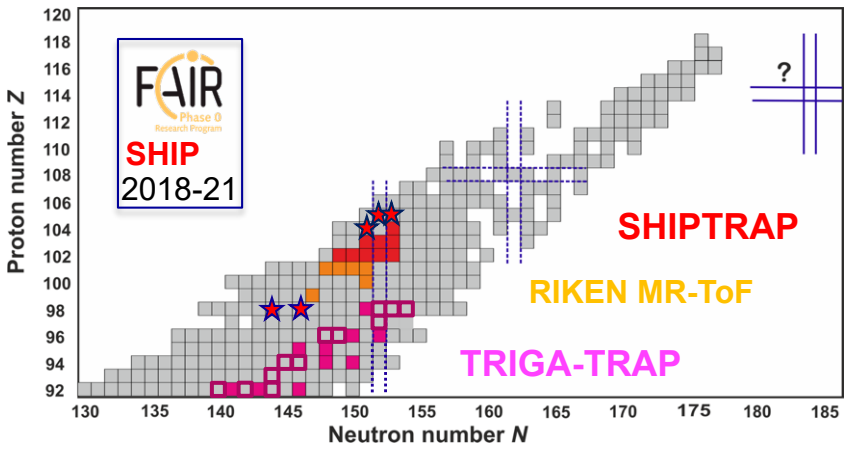
- construction of MATS RFQ proceeding at JYFL
- sc magnet for 2nd line: contribution from U Granada, delivery end of 2022
- MATS ready for installation in 2024
- operation of MATS prototype TRIGA-TRAP at TRIGA Mainz
  - for technical and methodical developments
  - for mass measurements of long-lived actinide isotopes
- experiments at ISOLTRAP, SHIPTRAP, JYFLTRAP, ... until completion of LEB building



FAIR phase 1:

- experiments on neutron-rich nuclides relevant for 3rd r-process peak at LEB
- experiments on selected neutron-rich isotopes, e.g., Zr isotopes

SHE – Mass Measurements with SHIPTRAP



Displayed data from following references

SHIPTRAP GSI / TRIGA-TRAP U Mainz

- O. Kaleja et al., Phys. Rev C (2022) in press
- B. Andelic, PhD thesis Uni Groningen 2021
- O. Kaleja, PhD thesis Uni Mainz 2020
- E. Minaya Ramirez et al. Science 337, 1207 (2012)
- M. Block et al., Nature 463, 785 (2010)
- M. Eibach et al., Phys. Rev. C 89, 064318 (2014)

RIKEN:

- P. Schury et al. Phys. Rev. C 104, L021304 (2021)
- Y. Ito et al., Phys. Rev. Lett. 120, 152501 (2018)

- SHIPTRAP campaign in 2021: first mass measurement of ^{258}Db (Z=105)
- SHIPTRAP: mass measurements carried out with PI-ICR method with rates of ≈ 0.00002/s and 5 detected ions in total
- TRIGA-TRAP: mass measurements of long-lived actinide isotopes ongoing
- both traps can reach rel. mass uncertainty down to a few 10^{-9}

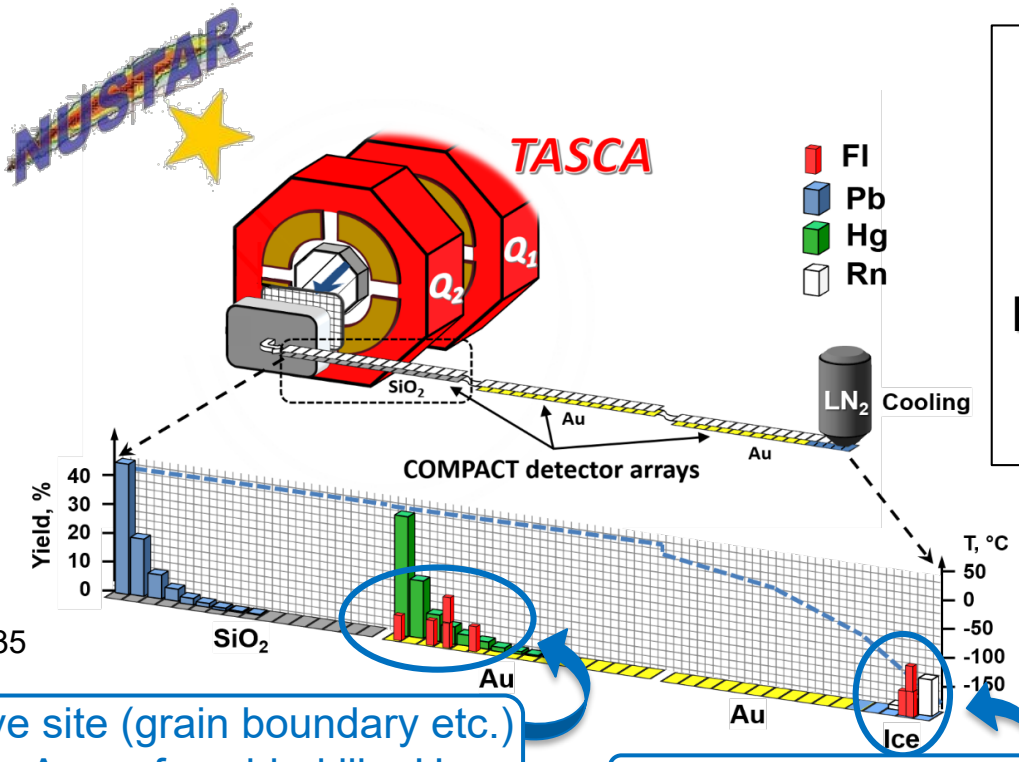
Chemical properties of Z=114, Flerovium

- Flerovium: heaviest element with experimentally studied chemical properties
- **Eight** registered atoms in three beamtimes of total 2.5 months duration

Production:
^{244}Pu(^{48}Ca,3-4n)
^{288}Fl: $t_{1/2}$ ~0.7 s
^{289}Fl: $t_{1/2}$ ~2.0 s

Isolation in **TASCA**; Chemical study and detection: COMPACT

A. Yakushev *et al.*,
Front. Chem. 10 (2022) 976635



Volatility:
Rn > **Fl** > Hg >> Pb

Reactivity:
Rn < **Fl** < Hg << Pb

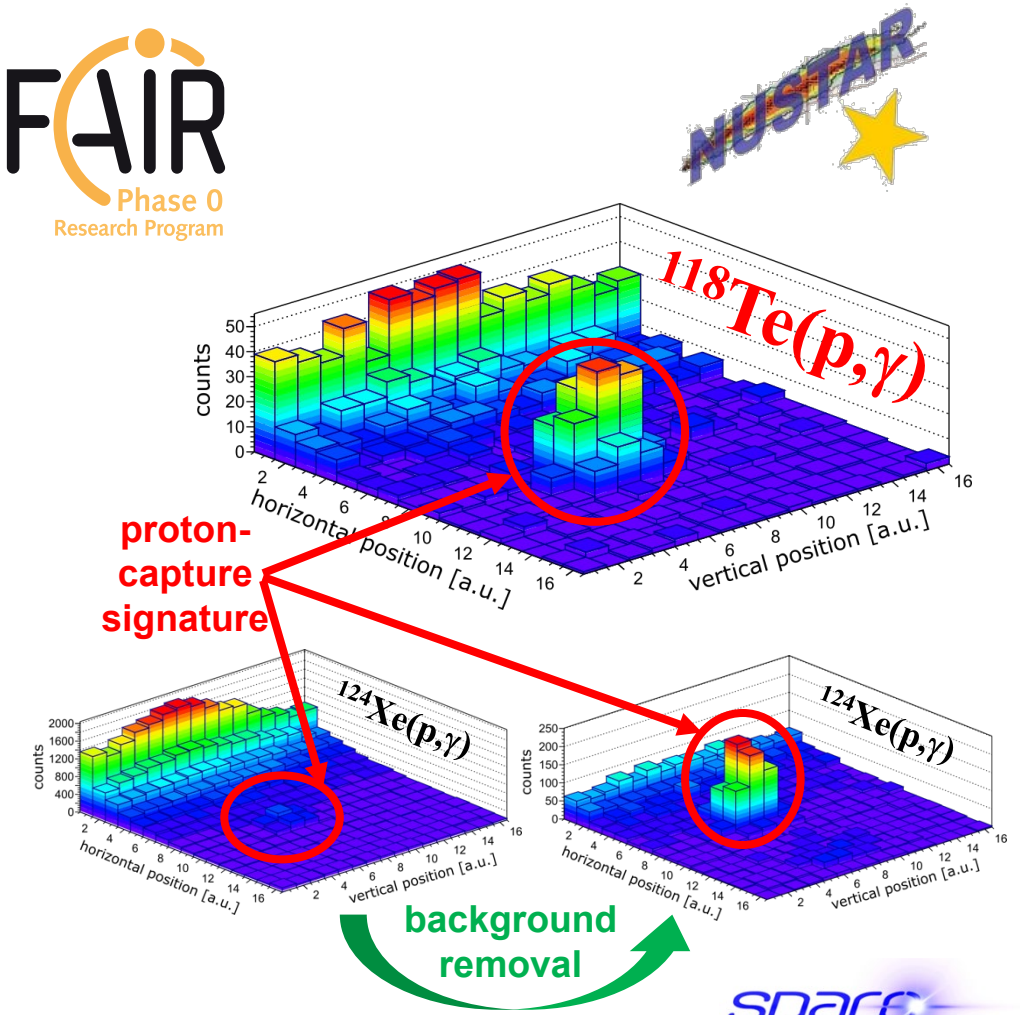
Fl is the most volatile metal in the periodic table

Atoms hitting a reactive site (grain boundary etc.) on the inhomogeneous Au surface bind like Hg

Other atoms reach location of Rn adsorption

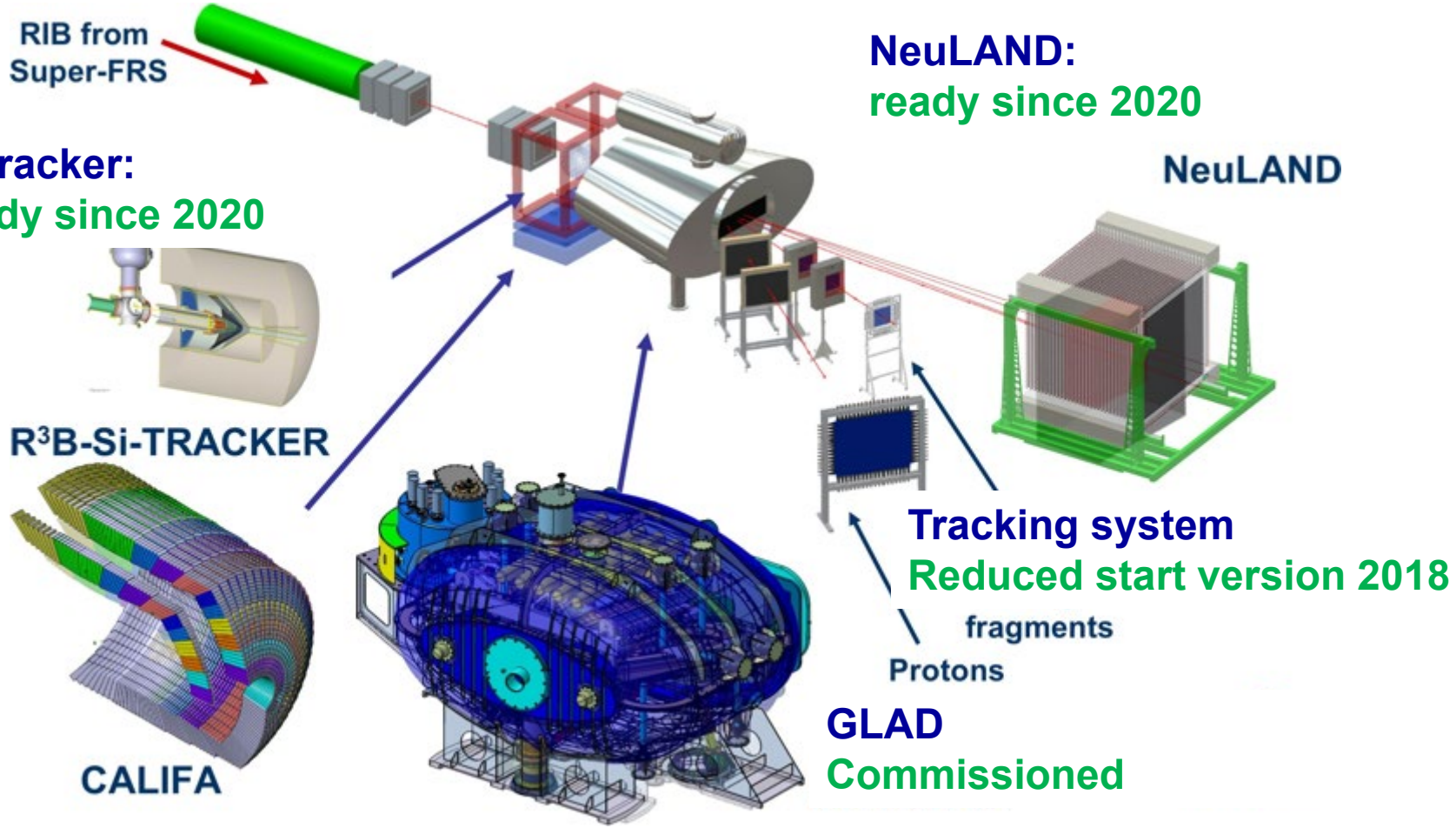
In-ring experiments for nuclear astrophysics at ESR

- E127: Proton-capture rates for nuclear astrophysics:
  First reaction study on stored radio-beam at low energies
- Study of radioactive ^{118}Te (6 days half-life)
  - production, storage, accumulation and deceleration in FRS-ESR
  - proton-capture measurements realized at 7 MeV/u and 6 MeV/u
- New background-free detection method demonstrated



^{124}Xe: Jan Glorius et al.
PRL 122, 092701 (2019)

Start version from Phase 0 to Day-1



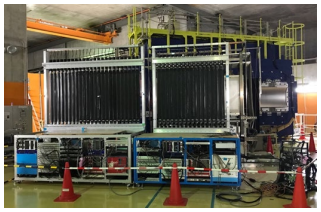
NeuLAND Detector at RIKEN and GSI

NeuLAND@SAMURAI

- Fully functional demonstrator (4 double-planes) used at RIKEN in the time period from 2016 to 2019
- Joint operation with local NEBULA neutron detector for multi-neutron tracking (up to 4 neutrons)

physicsworld TOP 10 BREAKTHROUGH 2022

Discovery 4n-resonance
M.Duer et al., NATURE (2022)



NeuLAND@GSI

- Continuation of production of double planes
- Implementation on new electronics and HV system
- 13 double planes installed at R3B for FAIR Phase-0 experimental program

New vertex tracker

A new vertex tracker for R^{3}B assembled for FAIR Phase-0 2022

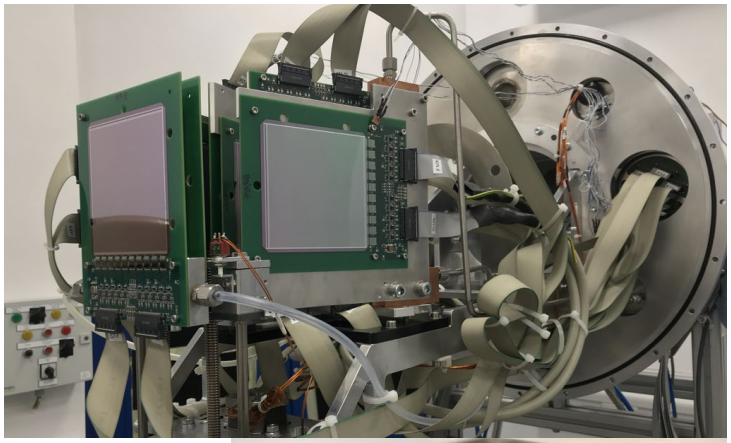
R3B 2022 FAIR Phase-0 experiments

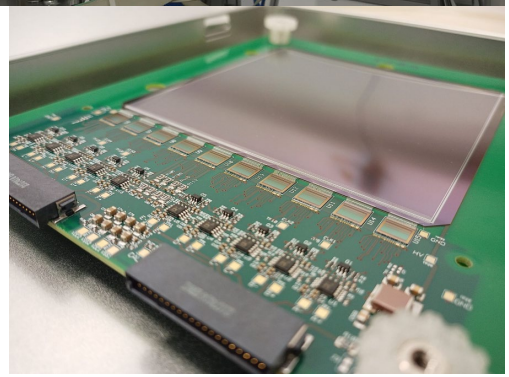
- Short-range correlations (SRC) in neutron-rich nuclei
  Successful test with stable ^{12}C beam at JINR (Nature 2021)
  first experiment with a radioactive beam performed
- Search for multi-neutron resonances close to the 2*n* and 4*n* thresholds

New detection systems for 2022 and future installed

- Extending NeuLAND to 14 double planes (1.4 m total depth)
- Large-are Resistive-Plate chamber for proton detection behind GLAD
- Vertex tracker for (*p,2pX*) quasi-free scattering experiments based on Si-microstrip detectors

- Physics programs at R3B based on (*p,2pX*) reactions:
  shell structure, cluster structure, SRC, unbound states, fission …

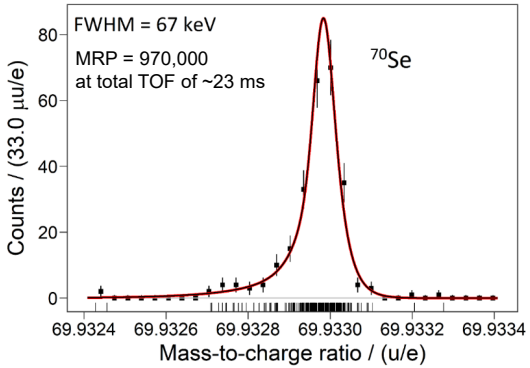




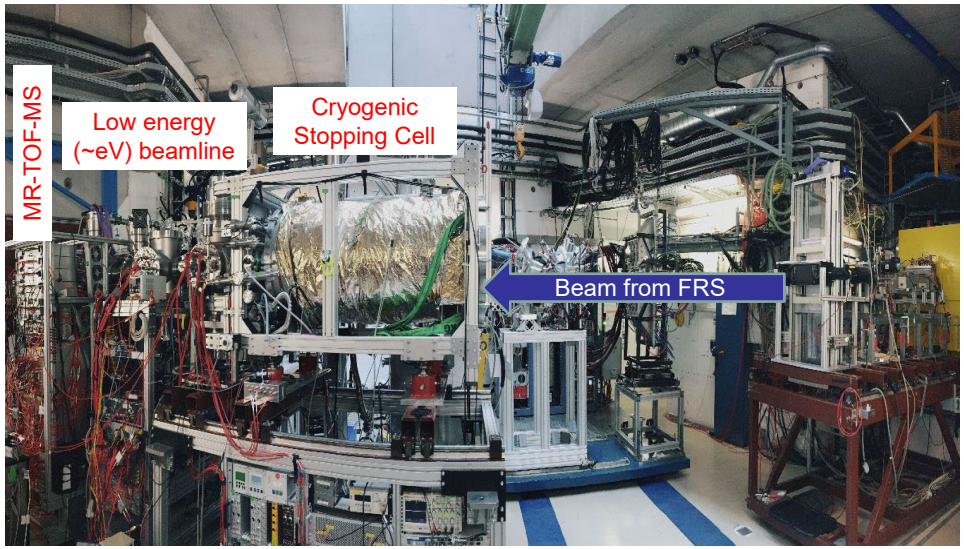
Si microstrip vertex tracker assembled for 2022 FAIR Phase-0 beam time

Results with the FRS Ion Catcher

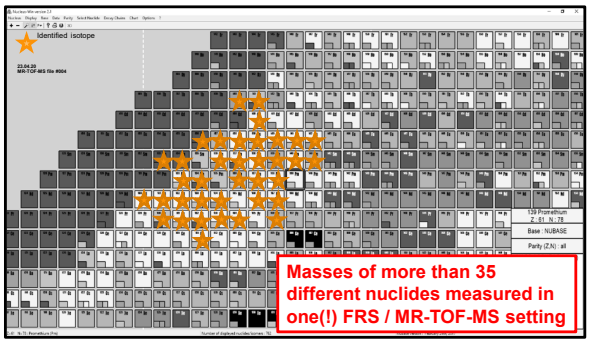
S459+: Mass measurements at A=70: World record for MR-TOF-MS mass resolving power



I. Mardor et al., PRC 103 (2021) 034319

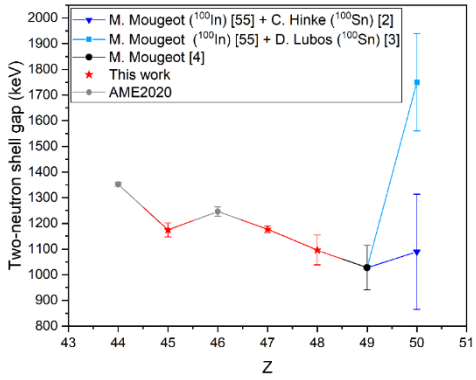


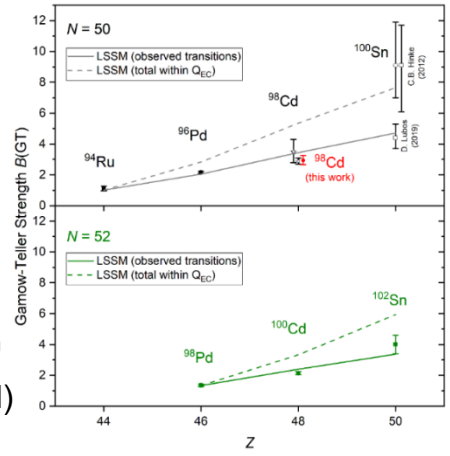
S482: n-deficient light lanthanides (new isotopes, masses, lifetimes): Efficient data taking



C. Hornung et al.

S474: Shell gap and Gamov-Teller strength at N=50: Implications for the ^{100}Sn mass



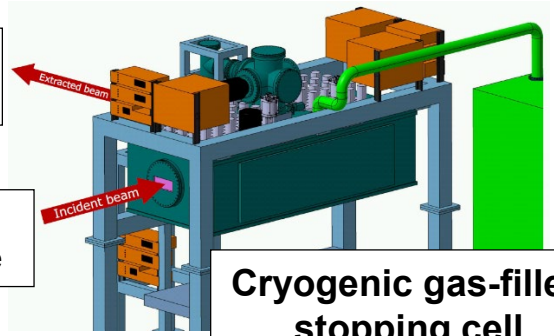


A. Mollaebrahimi et al., PLB (submitted) http://arxiv.org/abs/2209.13713

Stopping Cell of the Super-FRS

Beam to Experiments
5 keV, low-emittance

Beam from Super-FRS
>> MeV/u, large-emittance



Cryogenic gas-filled stopping cell

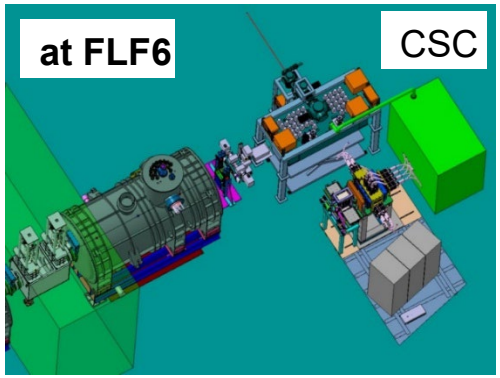
The stopping cell is required for

- **all experiments with MATS (mass measurements)**
- **all experiments with LaSpec (laser spectroscopy)**
- **and some experiments with Super-FRS-EC (MNT reaction studies, in-cell decays)**

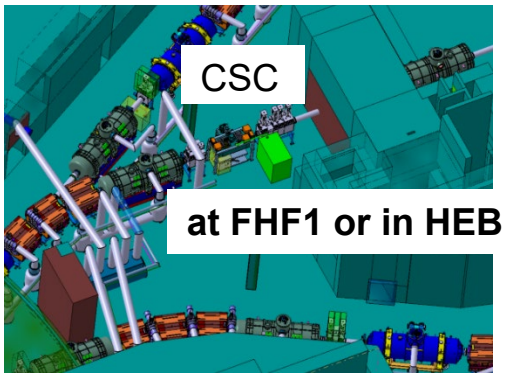
Collaboration

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN · GSI · TEL AVIV UNIVERSITY · UNIVERSITY OF JYVÄSKYLÄ · eli Nuclear Physics · IFIN-HH · Kernfysisch Versneller Instituut university of groningen · THE UNIVERSITY of EDINBURGH

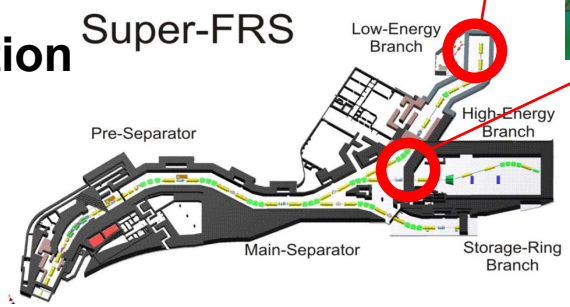
Currently under construction at JLU Giessen / GSI (2021-2026)



- Mass measurements
- Laser spectroscopy experiments
- In-cell decays



- Commissioning
- Mass measurements, branching ratios (**early and first science**)
- High-rate experiments (e.g. MNT reaction studies)



Bundesministerium für Bildung und Forschung

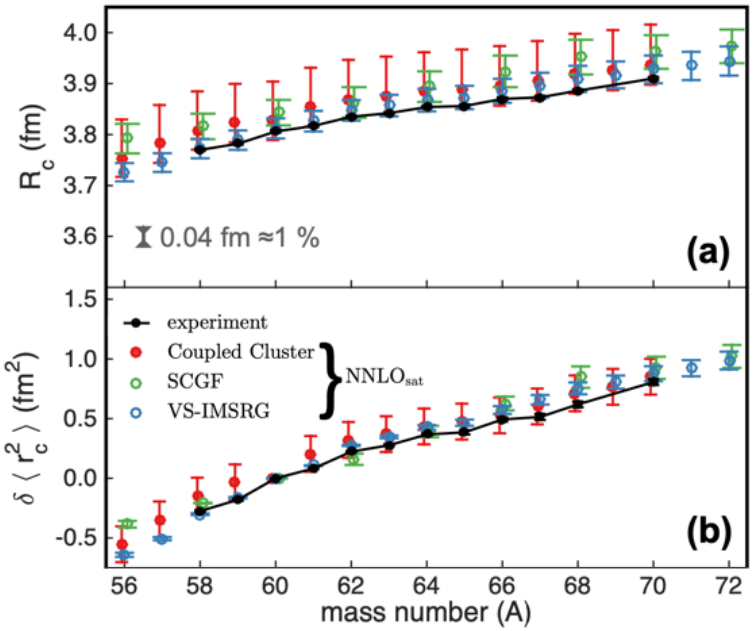
Theory for NUSTAR and ISOLDE

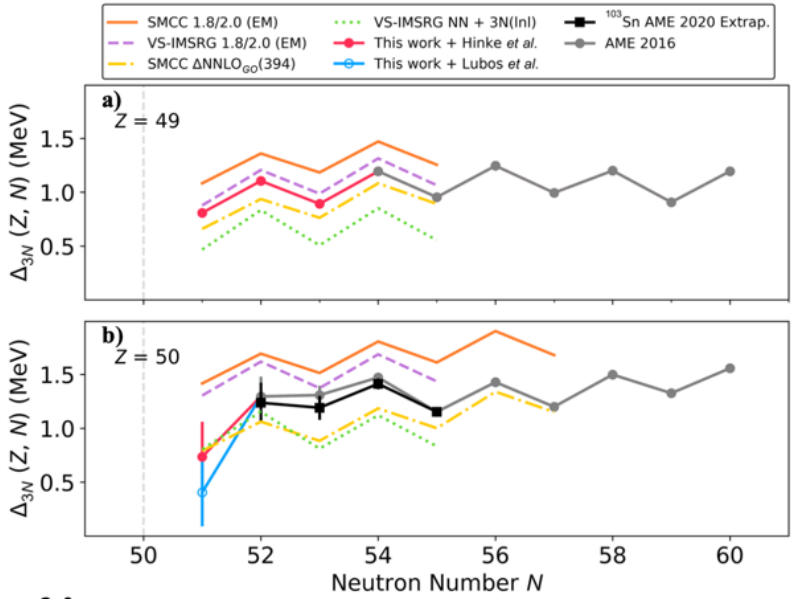
PIs: H.-W. Hammer, K. Hebeler, R. Roth, A. Schwenk

- Strong collaboration between Theory and Experiment, essential for exp. analysis and interpretation

- Evolution of charge radii from $^{55\text{-}70}$Ni in excellent agreement with ab initio calculations
  PRL 128, 022502 (2022), PRL 129, 132501 (2022)

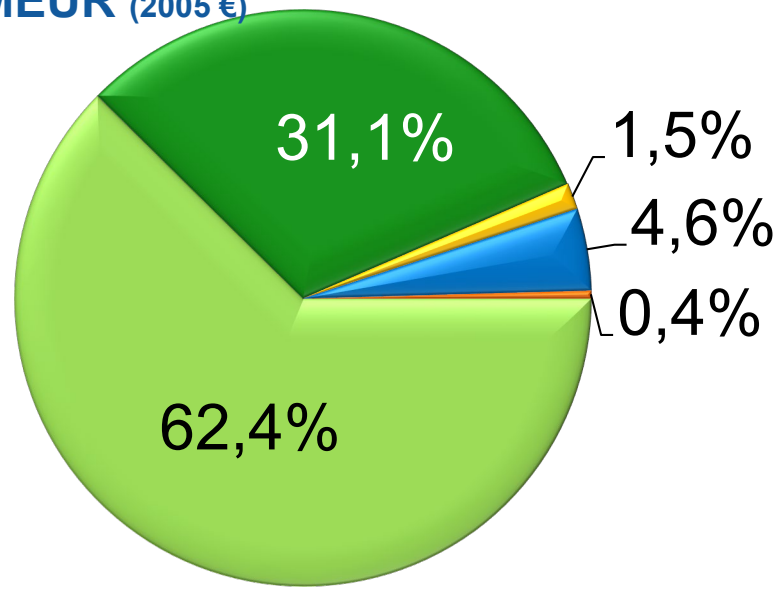
- Mass measurements of $^{99\text{-}101}$In: neutron odd-even staggering consistent with all calculations, helps to constrain Q-value for beta decay of ^{100}Sn
  Nature Phys. 17, 1099 (2021)





Progress of NUSTAR Funding („Day-1“ of IO)

33.8 MEUR (2005 €)



- secured/expected FAIR
- secured external
- EoI
- Common Fund
- to be assigned

Status: February, 2022

- Bulgaria
- Canada
- Czech Republic
- **Finland**
- **France**
- **Germany**
- Hungary
- **India**
- Israel
- Japan
- Netherlands
- **Poland**
- **Romania**
- **Russia**
- Slovenia
- Spain
- **Sweden**
- **United Kingdom**

+ Common Fund (all member institutions)

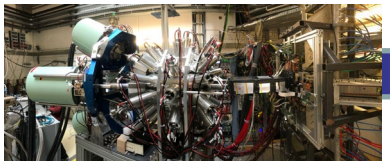
➢ **Construction-MoU**

NUSTAR – status of **Day-one** configuration

	NUSTAR sub-system	TDR	Cost [k€ 2005]	Funding	Construction	Date completion	Test/ Commissioning
Day 1	LEB infrastr.		1,955			12/2026	
	HISPEC/DESPEC		10,781			09/2024	
	MATS		1,173			08/2024	
	LaSpec		253			05/2024	
	R3B		17,993			08/2024	
	ILIMA		1,101			07/2025	
	Super-FRS EC		568			12/2023	
		92.9% *value weighted*	33,825	93.6% *secured*	63.7% *value weighted*		45.9% *value weighted*
Change since report 2022 I		**+ 0.4%**	**+ 0.0**	**+ 0.1%**	**+ 0.0%**		**+ 0.6%**

status: September 2022

Progress of HISPEC/DESPEC



HISPEC with AGATA

2020 — Commissioning and first exp

2021 — From isomers to beta-decay spect.

2022 — From high-res to high-eff studies

2024 — DESPEC Exp program at S4 area

2026 — and at HEB using SIS18 + S-FRS

>202

➔ perform **high-resolution (DEGAS/FATIMA), high-efficiency studies (DTAS) and exclusive measurements (BELEN)** with the aim of a complete picture of the β-decay process in key regions (N~126)

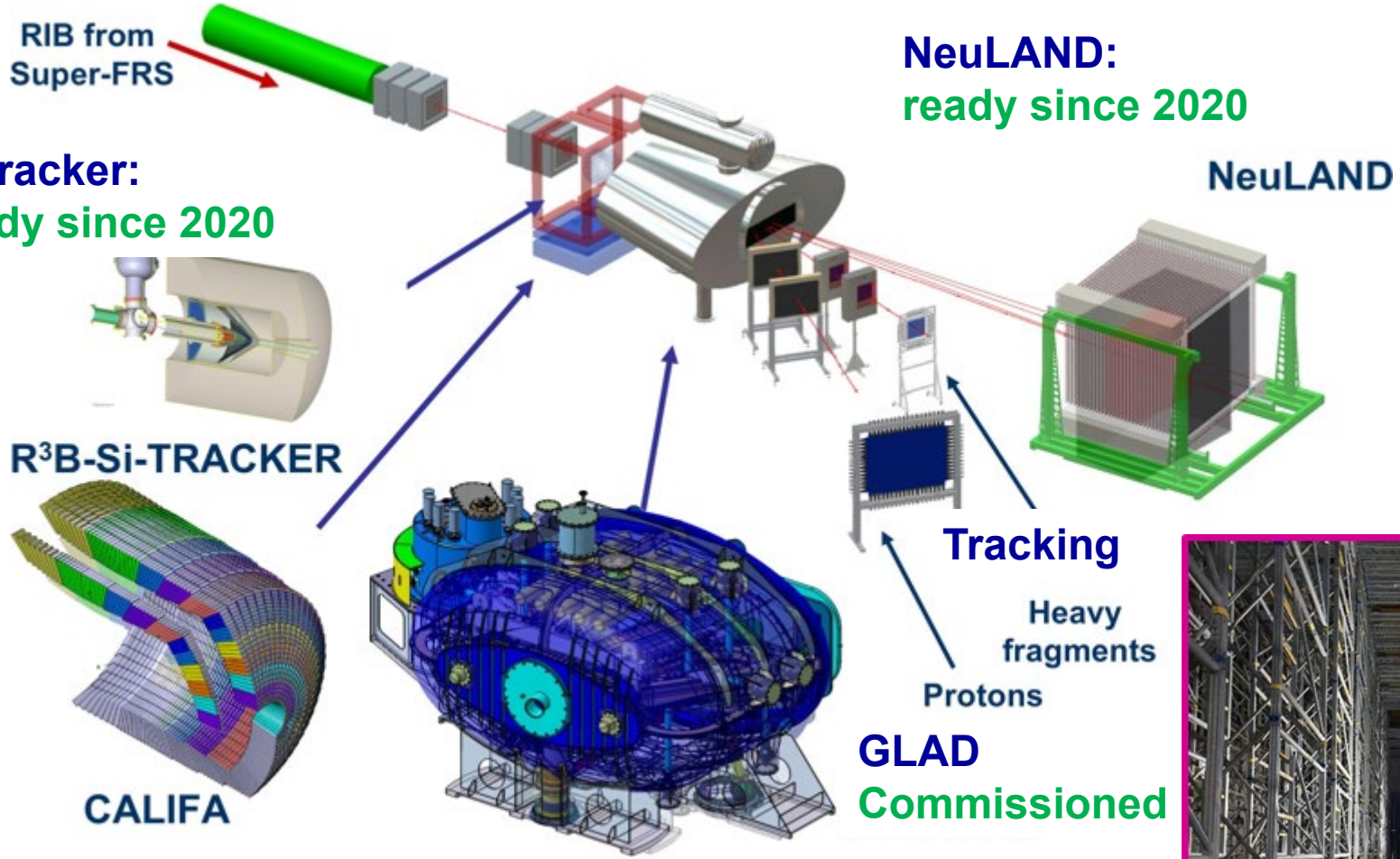
➔ 2023-2025: finalize detectors, read-out, DAQ **towards early science in 2026 using SIS18+superFRS in HEB**

➔ Exploit GSI-FAIR beams with unique **HISPEC instrumentation and AGATA** for High-resolution γ spectroscopy and Lifetime measurements (LISA ERC-CoG by K.Wimmer)

Physics opportunities with the Advanced Gamma Tracking Array: AGATA
W. Korten et al., Eur. Phys. J. A (2020) 56:137

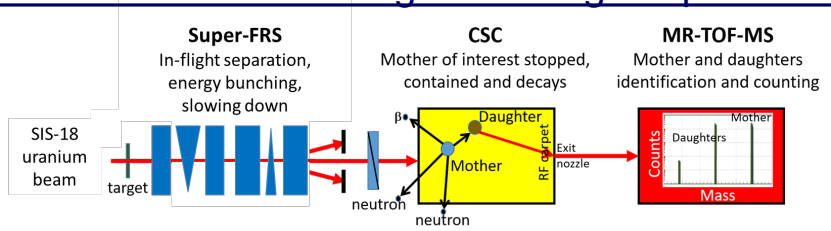
from G.Benzoni for HISPEC/DESPEC at EuNPC

Early Science in HEB from 2026 on



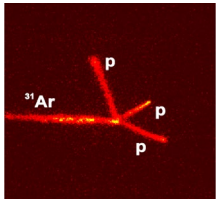
Spectrometer experiments with increasing Super-FRS performance

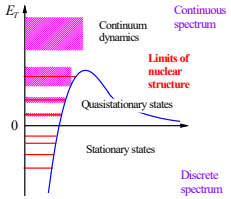
Early science: Take advantage of 2-stage separation of fission fragments



β-delayed single- and multi-neutron emission probabilities (P_{xn}) (and also **mass, $Q_{\beta xn}$, S_{xn}** and **$T_{1/2}$**)

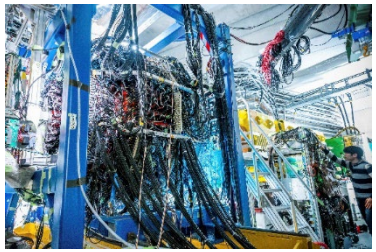
First science: In-flight decays of medium-heavy (very exotic) drip-line nuclei

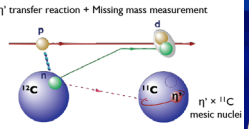


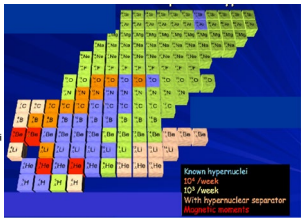


2p-radioactivity studies, search new modes of radioactivity (4p, 2n, 4n), structure beyond drip-line

First science ++: 4π-open-geometry calorimeter coupled to high-resolution spectrometer



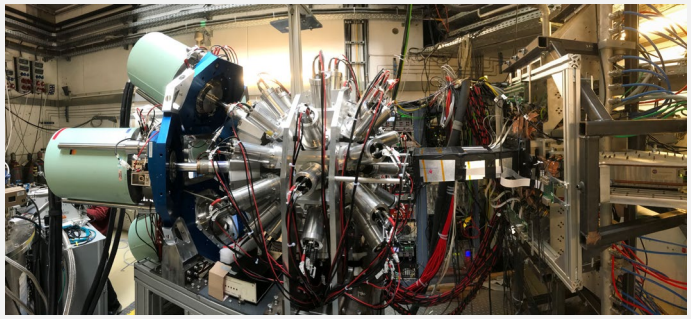




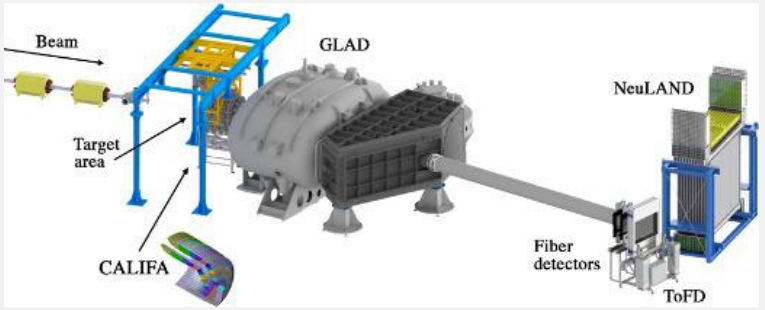
Exotic atoms, binding energies and lifetimes of exotic hypernuclei, EoS study with strangeness

Early Science Set-ups

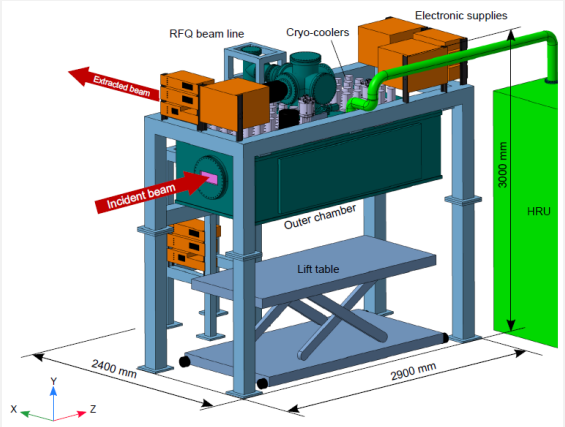
HISPEC/DESPEC
Plan to move DEGAS/FATIMA from FRS/S4 to S-FRS starting in 2026 after phase-0 and combine with AGATA-3π.



R3B
Plan to move full set-up with GLAD from Cave-C to HEB starting in Q4 2024. Phase-0 experiments not requiring GLAD may still run in 2025.



Super-FRS EC
Plan to get the CSC ready for first experiments. All other components for early science are ready and in operation.



- All sub-collaborations have basic set-ups ready for 2026.
- Additional detector modules and the CSC are planned to be available.
- Minor infrastructure items are not yet funded/available.

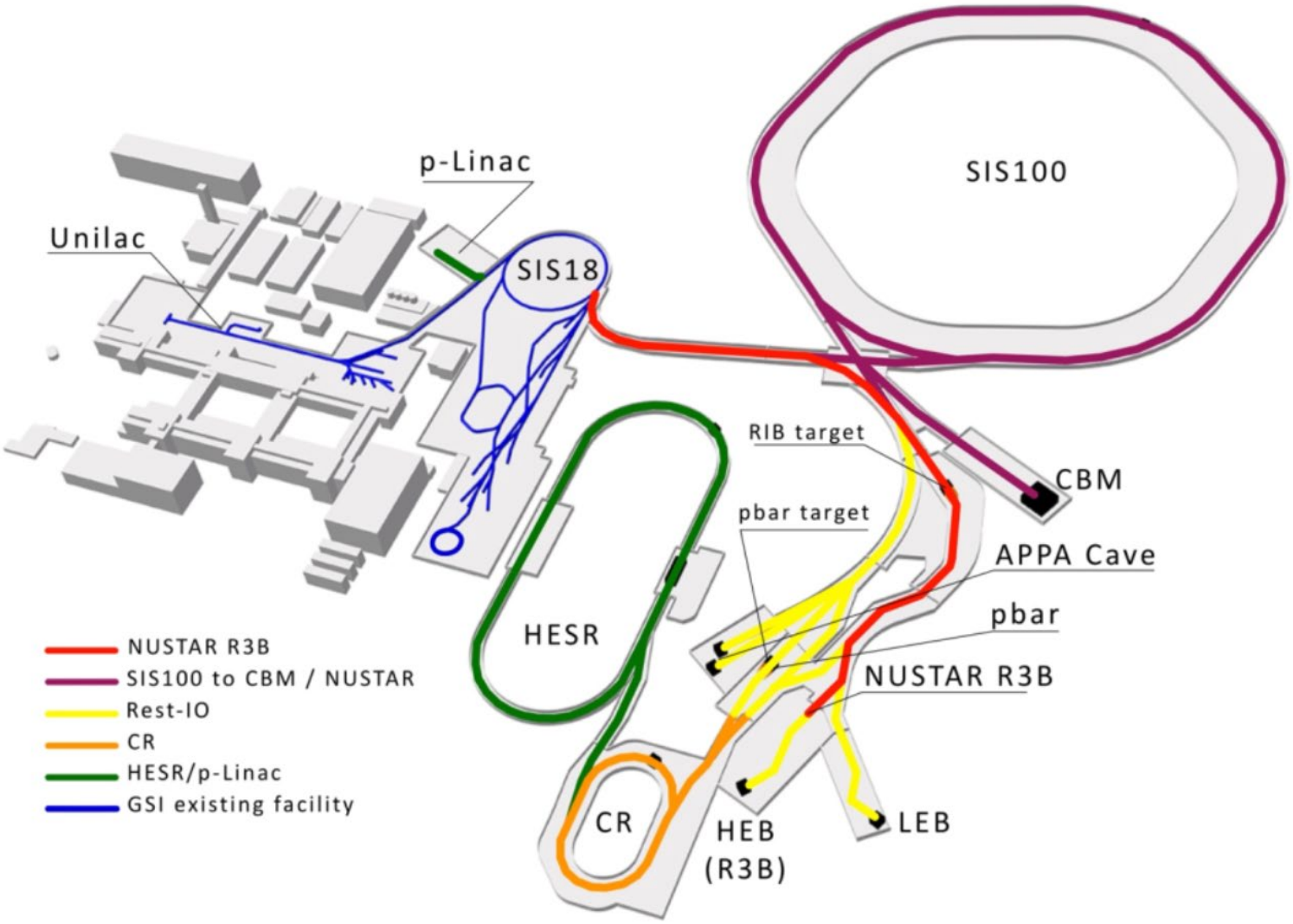
Recommendations from the Report

- *Unique* discovery potential for heavy radioactive beams (Z>70) at rates and purities not achievable elsewhere.

The committee came unanimously to the following recommendations in order to advance FAIR to science beyond Phase-0:

- First priority should be the completion of the S-FRS into the HEB cave for NUSTAR to carry out the Early Science program.
- Completion of SIS100 needs to have the next highest priority.
- If resources are tightly constrained, completing SIS100 with beams into the S-FRS and HEB cave, plus setting up and commissioning the CBM experiment offers an intermediate solution for developing world-class science at FAIR.
- Completing the infrastructure and instrumenting the APPA cave should have priority over instrumenting the additional area in LEB for NUSTAR.

Proposed Staging Sequence



Evolution of the FAIR/NUSTAR program

- **FAIR Phase-0**
  - **Successful usage of FAIR equipment at GSI or partner laboratories**
- **IO-prio1 “Early-Science” (starting end of 2026)**
  - **S-FRS with SIS18 beams in HEB cave (R3B, HISPEC/DESPEC[AGATA], S-FRS-EC)**
- **IO-prio2 “First Science”**
  - **SIS100 beams through S-FRS to HEB cave (R3B, HISPEC/DESPEC[AGATA], S-FRS-EC)**
  - **Instrumenting LEB for minimizing re-arrangements of experiments**
- **Proceed towards MSV**
- **Proceed towards Full-FAIR**
- Major new investments and upgrades for all experiments.

Highlights of NUSTAR Early-Science program

- **Understanding the 3rd r-process peak** by means of comprehensive measurements of lifetimes, masses, neutron branching ratios, dipole strength, and the level structure along the **N=126 isotones**;
- **Equation of State (EoS) of asymmetric matter** by means of measuring the dipole polarizability and neutron-skin thicknesses of **heavy neutron-rich isotopes** (in combination with the results of the first highlight);
- **Exotics**: **Hypernuclei** with large N/Z asymmetry and **nucleon excitations** in nuclei

Thank you very much!