

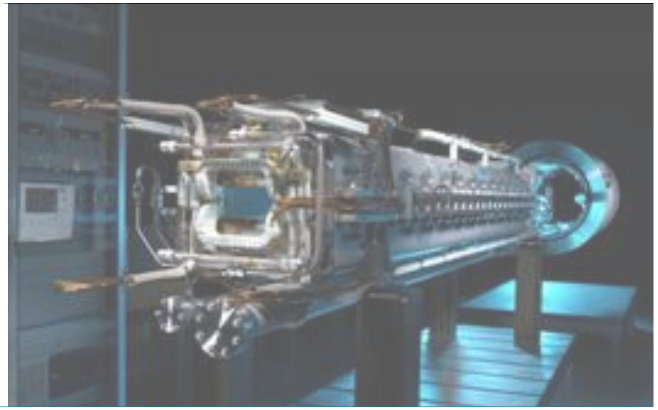

Exploring the extremes with NUSTAR @ FAIR

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KVI-CART/University of Groningen

NUSTAR annual meeting

Darmstadt, Germany, March 1, 2017

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

Definition of NUSTAR experiment phases

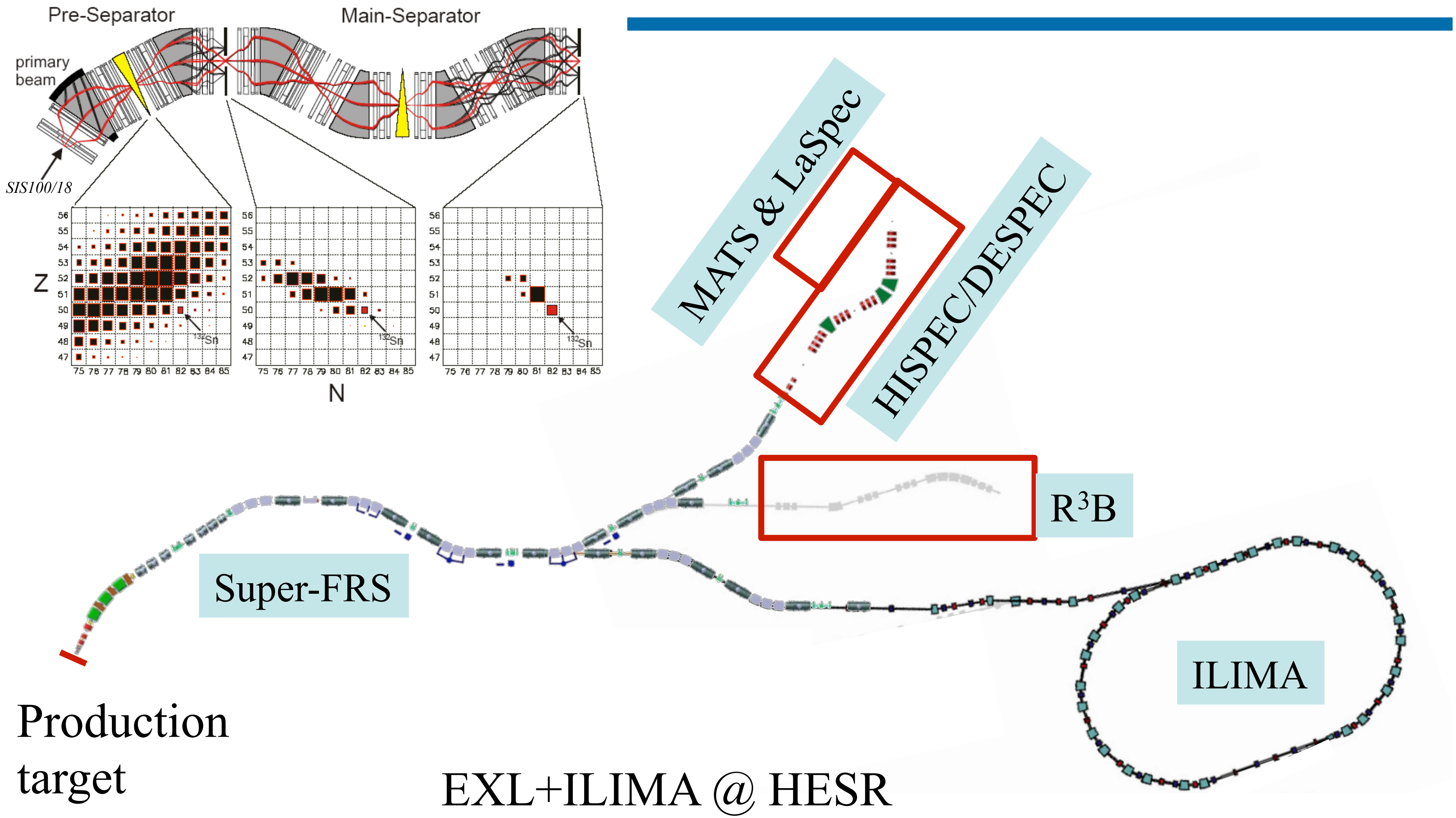
- **Phase 0**
  - R&D and experiments to be carried out with present facilities and FAIR/ NUSTAR equipment
- **Phase 1** **2023/2024**
  - Core detectors and subsystems completed
  - First measurements with FAIR/Super-FRS beams
  - ➢ **Carry out experiments with highest visibility as part of the core program and within the FAIR MSV**
- **Phase 2** **2025**
  - FAIR evolving towards full power
  - Completion of experiments within MSV
  - ➢ **Essentially the full program of MSV can be performed**
- **Phase 3**
  - Moderate projects, which have been initiated on the way (outside MSV) can be included (e.g. experiments related to return line for rings)
- **Phase 4**
  - Major new investments and upgrades for all experiments

What are the highlights of MSV Phase 1 program?

- Understanding the 3rd r-process peak by means of comprehensive measurements of masses, lifetimes, neutron branchings, dipole strength, and 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 tin isotopes with N larger than 82 (in combination with the results of the first highlight);
- Exotic hypernuclei with very large N/Z asymmetry.

“PARTS” needed

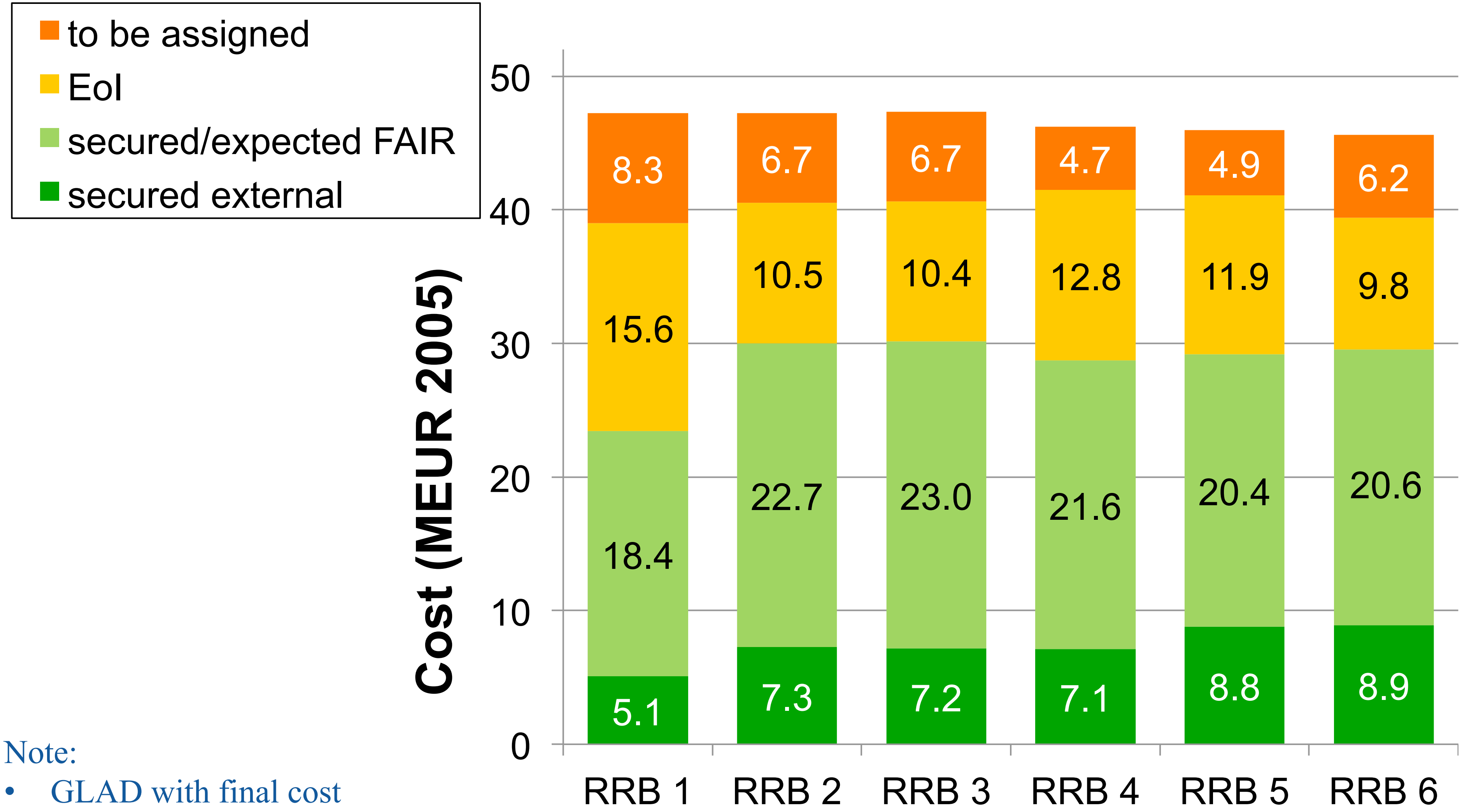
NUSTAR experimental areas, ESSENTIAL to run!



Rich program due to approximately 2000 h beam time for NUSTAR experiments per year!

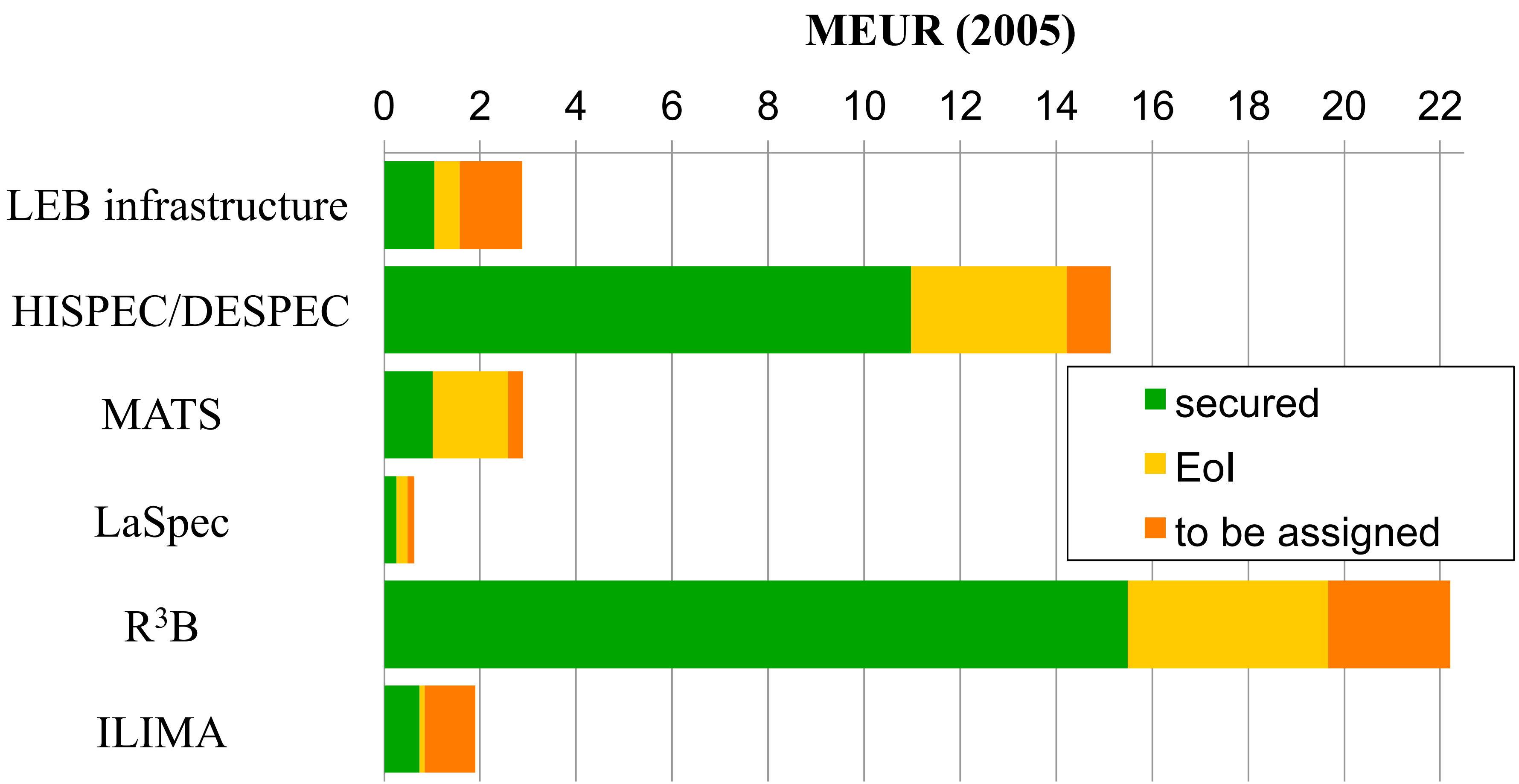
Funding and TDRs

Evolution of NUSTAR project funding

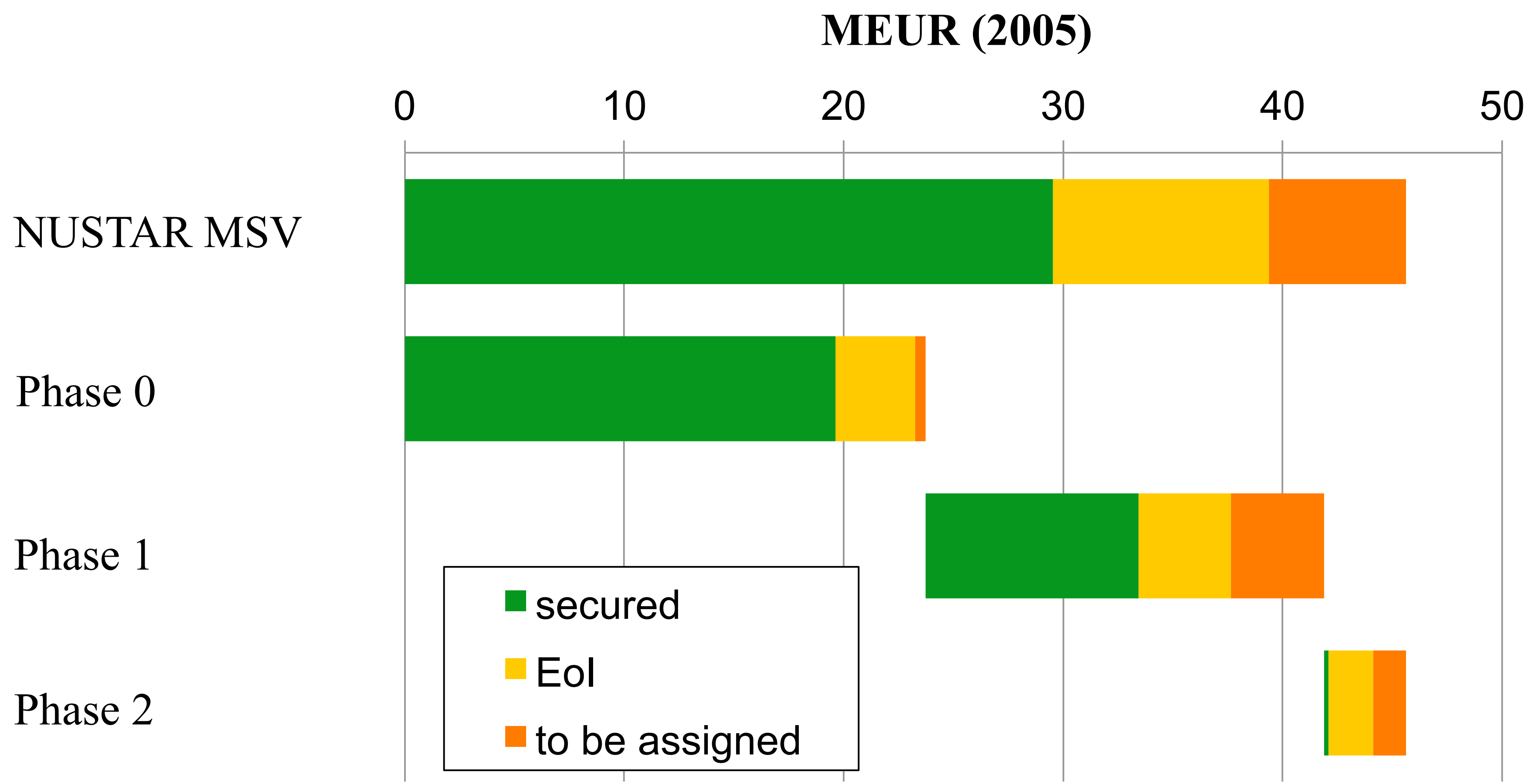


Note:
- GLAD with final cost
- UK included in FAIR

Status of NUSTAR experiment funding



NUSTAR experiment funding – phases



Further iterations within NUSTAR sub-collaborations in progress

Status Technical Design Reports (34 TDRs)

- Approved TDRs (16):
  - HISPEC/DESPEC (9) (LYCCA, Plunger, AIDA, BELEN, MONSTER, DTAS, DEGAS, FATIMA, NEDA)
  - MATS + LaSpec (1) (all subsystems)
  - R^3B (6) (Multiplet, NeuLAND, CALIFA-barrel, CALIFA forward endcap, GLAD, tracking detectors)
- Submitted (3):
  - R^3B (1) (Active target)
  - NUSTAR DAQ
  - EXPERT (special case)

TDRs expected (15) (submission profile – 2016)	
2017	2018
14	1

NUSTAR work packages

Status: Nov 2016

Common Questionnaire for the Experiments

- How are the objectives of the experiment affected by the delay in the realisation of the MSV of FAIR? Are there any other consequences (technical, financial etc.) due to the delay?
- Which are the competing experiments internationally? Is there any risk of being upstaged due to the delay? Are there any changes in the focus of efforts in the experimental group due to the delay?
- What measures, if any, have been taken to meet the criticisms/ observations in the review (conducted by the German government) last year? Are there any substantial modifications envisaged in the experimental setup?
- What is your Phase 0 programme? Please provide details like which accelerator(s) would be used, which experimental equipments/detectors would be employed and where, which part(s) of the collaboration would be involved etc.
- If other accelerators (*i.e.*, outside of GSI) would be used, have they been approached for the necessary access?
- How much beamtime (how many days) would be needed for the phase 0 programme?
- Has the collaboration carried out simulations of the performance of FAIR detectors (proposed to be employed during Phase 0) at these different energies/ luminosities?
- Would there be any publishable results from the Phase 0 activities using FAIR detectors? Are there any discovery potentials during Phase 0?
- What are the finances needed? How do the collaborations plan to secure the funding? Have the respective RRB-s been approached over this issue?
- What experiments will be started in Phase 1 of FAIR and which parts will have to wait for the full MSV? From Phase 0 to Phase 1, would it be a gradual transition or a totally new venture?
- Any other issues you would like the Joint Scientific Council to consider.

Action 1: provide feedback for JSC

What is your Phase 0 programme? Please provide details like which accelerator(s) would be used, which experimental equipments/detectors would be employed and where, which part(s) of the collaboration would be involved etc.

Would there be any publishable results from the Phase 0 activities using FAIR detectors?
Are there any discovery potentials during Phase 0?

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NUSTAR

How are the objectives of the experiment affected by the delay in the realisation of the MSV of FAIR? Are there any other consequences (technical, financial etc.) due to the delay?
We have, from the onset, built in an approach in which experiments are continuously carried out at various laboratories for testing equipment but also for physics measurements where other facilities could meet the demands of the experiment. In 2018, much of the equipment will move to GSI/FAIR to start our phase-0 campaign. In this respect, our timing is well in tune with the plans and the recent developments and we have not been suffering so much from the delay except that this delay has caused a decline in the motivation which is primarily coming from funding problems. The funding agencies have sometimes used this delay for postponing the funding of experiments.
Which are the competing experiments internationally? Is there any risk of being upstaged due to the delay? Are there any changes in the focus of efforts in the experimental group due to the delay?
On the international arena, we are facing competition from several laboratories (RIKEN, NSCL, GANIL, ISOLDE and JYFL, and in the near future FRIB and TRIUMF) but this is primarily for light and medium heavy nuclei. We might be able to challenge other facilities on the intensity front for these nuclei at a later stage but the first experiments are being and will be performed elsewhere. Where we have a clear lead is in the realm of the heavy nuclei (above Z=60) where our charge identification capabilities make us unique. We, therefore, plan that a large part of our effort will be going in using heavy nuclei. Also, GSI/FAIR can accelerate heavy ions to energies more than 400 MeV/nucleon which is higher than the other facilities (present and planned) and gives unique opportunities for a wider range of RIB physics. GSI/FAIR is the only place in the world, where a high-resolution spectrometer is available in this energy range. Last but not least, there is no competition in the foreseeable future worldwide for the NUSTAR research at heavy-ion storage rings.
What measures, if any, have been taken to meet the criticisms/observations in the review (conducted by the German government) last year? Are there any substantial modifications envisaged in the experimental setup?
The review was very positive about our activities and we did not have to change our course in any major direction. Nevertheless, we have made changes which are primarily dictated by new developments on the technology front and/or related to planning issues.
What is your Phase 0 programme? Please provide details like which accelerator(s) would be used, which experimental equipments/detectors would be employed and where, which part(s) of the collaboration would be involved etc.
In almost all the experiments performed in phase 0, SIS18 and FRS will be used to produce radioactive ions. Specific programs are detailed below. A large fraction of the required beams will be ^{208}Pb (or ^{238}U and protons) which are rather standard beams. **R3B:** Advantage will be taken from the installation of GLAD plus partly already available new detection systems (tracking, neutron detection, vertex tracker, gamma detection) which will allow, for the first time, for experiments with the highest energies up to 1 GeV/u even for neutron-rich beams. This will open unique opportunities even for light nuclei. Examples are the measurement of the full dipole response of halo nuclei or quasi-free (p,pN) knockout reactions. For heavier beams, Coulomb break-up and (p,2p) fission measurements will be among the first experiments. **DeSPEC:** Decay Spectroscopy of heavy neutron-rich nuclei around N=126, Z=82 and also heavy deformed nuclei. These are related to the r-process path (third r-process abundance peak) and shape evolution (prolate-triaxial-oblate-spherical) in nuclei. The detectors (AIDA, DEGAS, DTAS and FATIMA) will be placed at S4 area of FRS. Also the Ion Catcher can be used for the planned measurements. **ILIMA:** Mass and lifetime measurements will be done for heavy neutron-rich nuclei at the ESR by employing an improved time-of-flight detector as well as novel non-destructive highly-sensitive Schottky detectors. Experiments addressing the influence of atomic shell on nuclear decay rates will be conducted at lowest energies at CRYRING. **EXL:** Scattering experiments on proton/helium gas jet targets are planned at the ESR. Proton-induced reaction relevant for astrophysics at low energies will be performed at CRYRING by using a dedicated windowless detector setup installed directly into the ultra-high vacuum of the ring. **Super-FRS:** The plans is to use already existing equipment, prototype and new detectors for FAIR at the main focal planes of the FRS for various high-resolution experiments, like nucleon correlation and tensor-force studies. Setups like the dipole magnet for the study of hypernuclei, eta'-mesic nuclei and Delta resonances will be used at S2; other detectors, like the Ion Catcher or the O-TPC, will be placed at S4. Two-proton radioactivity and exotic in-flight decays in the unknown ^{26}S can be studied using new equipment like GADAST modules.
If other accelerators (i.e., outside of GSI) would be used, have they been approached for the necessary access?
Several NUSTAR sub-systems (AIDA, NEULAND, DESPEC LaBr (fast-timing array)) have already been used successfully for detector tests and physics measurements at other laboratories, and in particular at RIKEN. In all these cases, the sub-collaboration has taken proper steps in making agreements with the host laboratory to make sure that the equipment and beams are properly matched to the needs of the collaboration. As for the storage-ring physics, there are plans to employ the CSRe storage ring in Lanzhou to test basic concepts and also part of the equipment for ILIMA and EXL.
How much beam-time (how many days) would be needed for the phase 0 programme?
We are counting on at least 60 days per year of various beam types in 2018 onwards. We will plan to combine many experiments in such a way that beams can be used in several experiments in parallel thus reducing the overall beam-time requirement. We have a track record of running successful experiments in this way.
Has the collaboration carried out simulations of the performance of FAIR detectors (proposed to be employed during Phase 0) at these different energies/luminosities?
This work has been done in the past and is ongoing since various sub-collaborations are preparing their proposals for the upcoming PAC meeting which will take place in 2017.
Would there be any publishable results from the Phase 0 activities using FAIR detectors? Are there any discovery potentials during Phase 0?
Absolutely. We will use phase 0 with two goals in mind: setting up and commissioning of the FAIR detectors and doing the first physics experiments with albeit smaller detector acceptances and lower intensities of the required beams. We expect new physics to result from the experiments, and this and the details of the new instrumentation will be published in appropriate journals.
What are the finances needed? How do the collaborations plan to secure the funding? Have the respective RRB-s been approached over this issue?
The funding of the beam-time must be discussed at a higher level (FAIR and GSI councils). More than 60% of the NUSTAR experiment funding is already guaranteed and we are continuing to lobby for extra money. With the announcement of the building of FAIR, we anticipate that more groups will join the activities bringing in more money with them. Considering our staged approach, we think that we will have the equipment more than 90% ready by the year 2022 when the Super-FRS beams will be available and fully ready when the full MSV starts in 2025. *We should only note here that the ageing infrastructure of GSI needs attention for the upcoming beam-time.*
What experiments will be started in Phase 1 of FAIR and which parts will have to wait for the full MSV? From Phase 0 to Phase 1, would it be a gradual transition or a totally new venture?
Once again, with our staged approach, we will have an evolution from phase 0 to phase 1 and to the full MSV for most of our experiments, with the exception of HISPEC, MATS and LaSpec which start their program at phase 1 of FAIR. It should be noted that MATS and LaSpec are performing their tests and measurements elsewhere in the coming years and before moving to LEB. We, therefore, expect no show-stoppers on the way.
Any other issues you would like the Joint Scientific Council to consider.
We hope the JSC fully supports our program for phase 0 and phase 1 so that we can lobby for extra funding. The question of maintaining and renewing the present infrastructure should be addressed.

Desirable beams (as collected in York 2016)

^{1}H, ^{2}H

^{12}C

^{36}Ar, ^{40}Ar

^{40}Ca

^{78}Kr, ^{86}Kr

^{124}Xe, ^{136}Xe

^{208}Pb

^{238}U

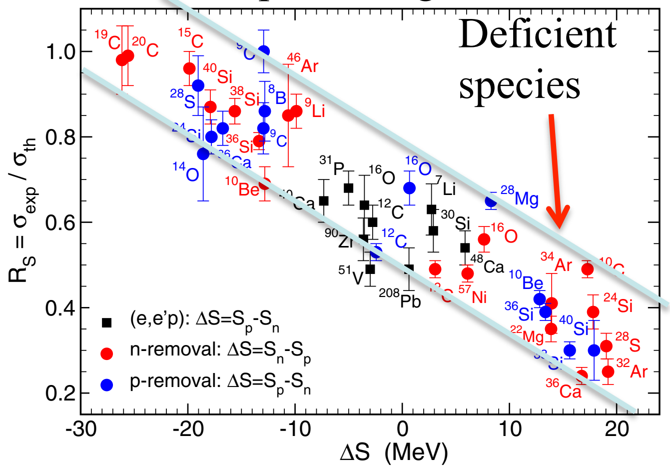
Recent highlights

R^3B

Recent highlight: Quenching of single-particle strength - Dependence on neutron-proton asymmetry -

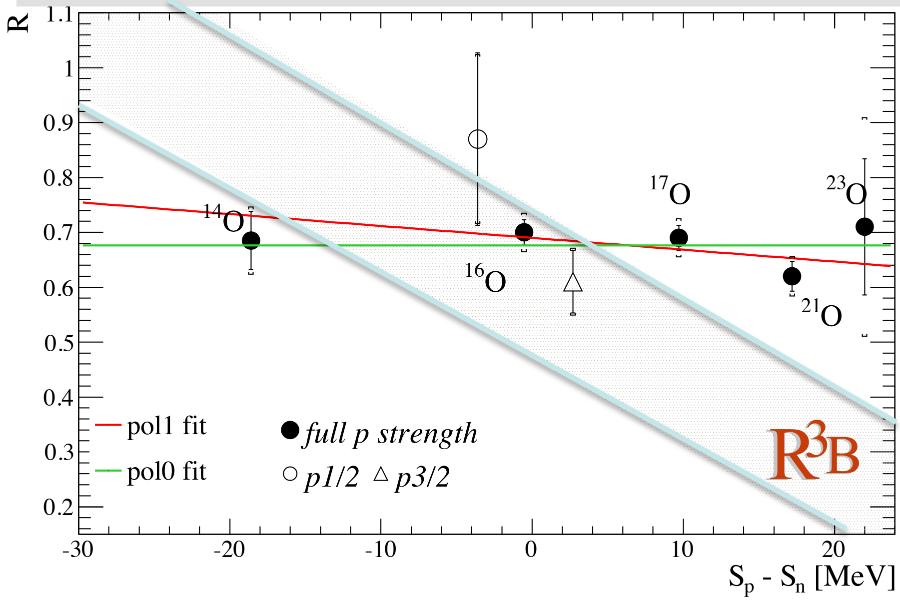
The Puzzle

Results from knockout experiments using extended composite targets at 50-100 MeV/u



J.A. Tostevin and A. Gade, PRC 90 (2014) 057602

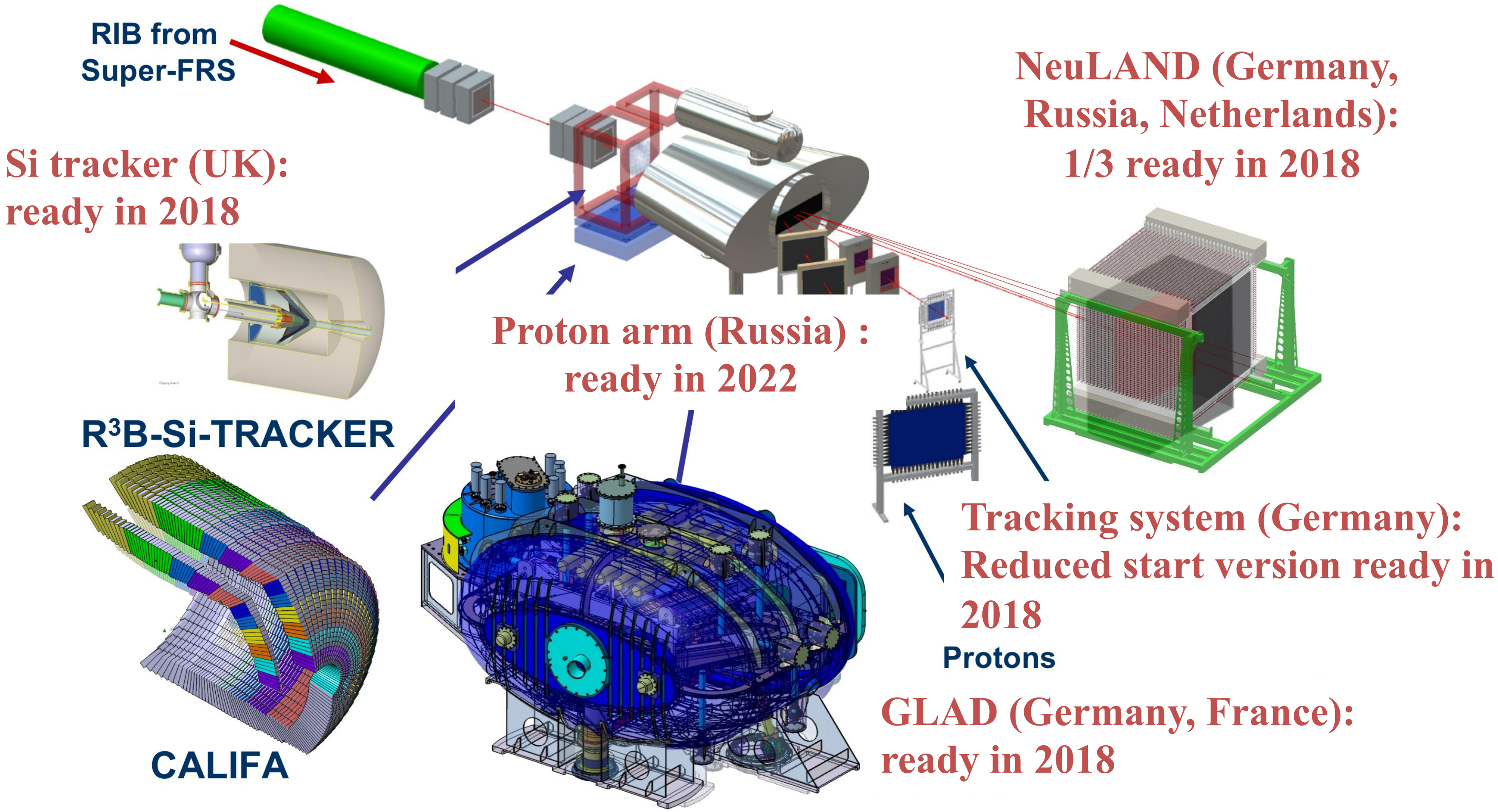
(p,2p) in inverse kinematics at R^{3}B



L. Atar et al. (R^{3}B collaboration), publication in preparation

- ✔ Quantitative benchmark experiment against ^{12}C(*e,e'p*) successfully accomplished
- ✔ First exclusive large-acceptance (*p,2p*) experiment with radioactive beams accomplished
- ✔ Clean reaction mechanism, quantitative reaction theory developed and tested
- ✔ Wide range in asymmetry (S_p-S_n) covered
- ➔ **Only weak dependence on asymmetry observed!**
- ➔ Long-standing puzzle might have been clarified
- ➔ Reason for systematic change of cross sections for conventional knockout to be clarified

Start version for Phase 0 (Status 2018)



CALIFA (Sweden, Spain, Germany, Russia):
Barrel without backward part ready in 2018
Frontcap missing! -> part of the program delayed

R³B Phase 0 physics program in 2018/19 (green/orange)

R³B program will strongly benefit from the availability of 1 GeV/nucleon beams (installation and commissioning of GLAD will be finished in 2017).

➔ Large fraction of the physics program can be started with partly completed detection systems in 2018:

- Dipole response of neutron-rich nuclei: partly possible for light nuclei already 2018 ✔
- Dipole strength of halo nuclei up to 30 MeV excitation energy (reduced n efficiency) ✔
- Pygmy and Giant Resonances, Dipole polarizability (EoS of asymmetric nuclear matter): needs CALIFA; delayed until construction accomplished (2020 depending on funding) No
- (*p*,2*p*) – single-particle and shell structure: possible to start already 2018 ✔
- (*p*,2*pN*) – *NN* tensor short-range correlations: needs CALIFA; delayed to 2020 No
- (*p*,2*p*) fission - fission barriers: possible already in 2018 ✔
- Fission (elm. excitation) - nuclear structure: possible (reduced information on neutrons) ✔
- Light drip-line nuclei: up to 2*n* decays possible (reduced NeuLAND efficiency) ✔
- Beyond neutron drip-line: up to 2*n* decays possible (reduced NeuLAND efficiency) ✔
- Pure neutron systems, multi-neutron (>4) decays: (needs NeuLAND completion) No
- Spectroscopy of 2^+ states of heavy neutron-rich nuclei ✔
- Elastic and inelastic scattering using the active target (smaller prototype available) (✔)
- Nuclei at and beyond the proton drip-line (needs PAS, ready only in 2022) No

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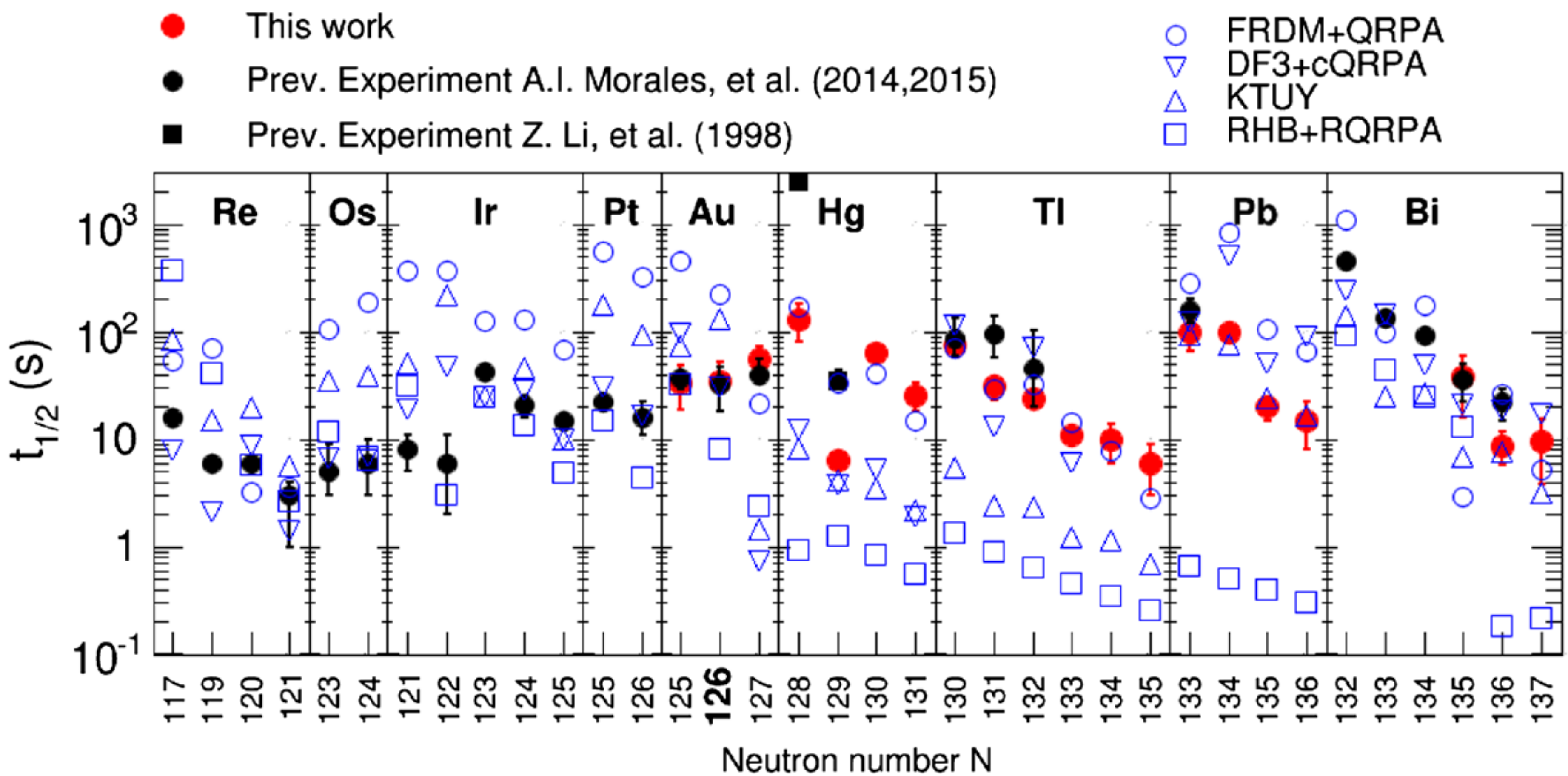
HISPEC/DESPEC

PRL 117, 012501 (2016) PHYSICAL REVIEW LETTERS week ending 1 JULY 2016

First Measurement of Several β-Delayed Neutron Emitting Isotopes Beyond $N = 126$

R. Caballero-Folch,[1,2] C. Domingo-Pardo,[3,*] J. Agramunt,[3] A. Algora,[3,4] F. Ameil,[5] A. Arcones,[5] Y. Ayyad,[6] J. Benlliure,[6] et al.

Relevant for the nucleosynthesis of heavy elements



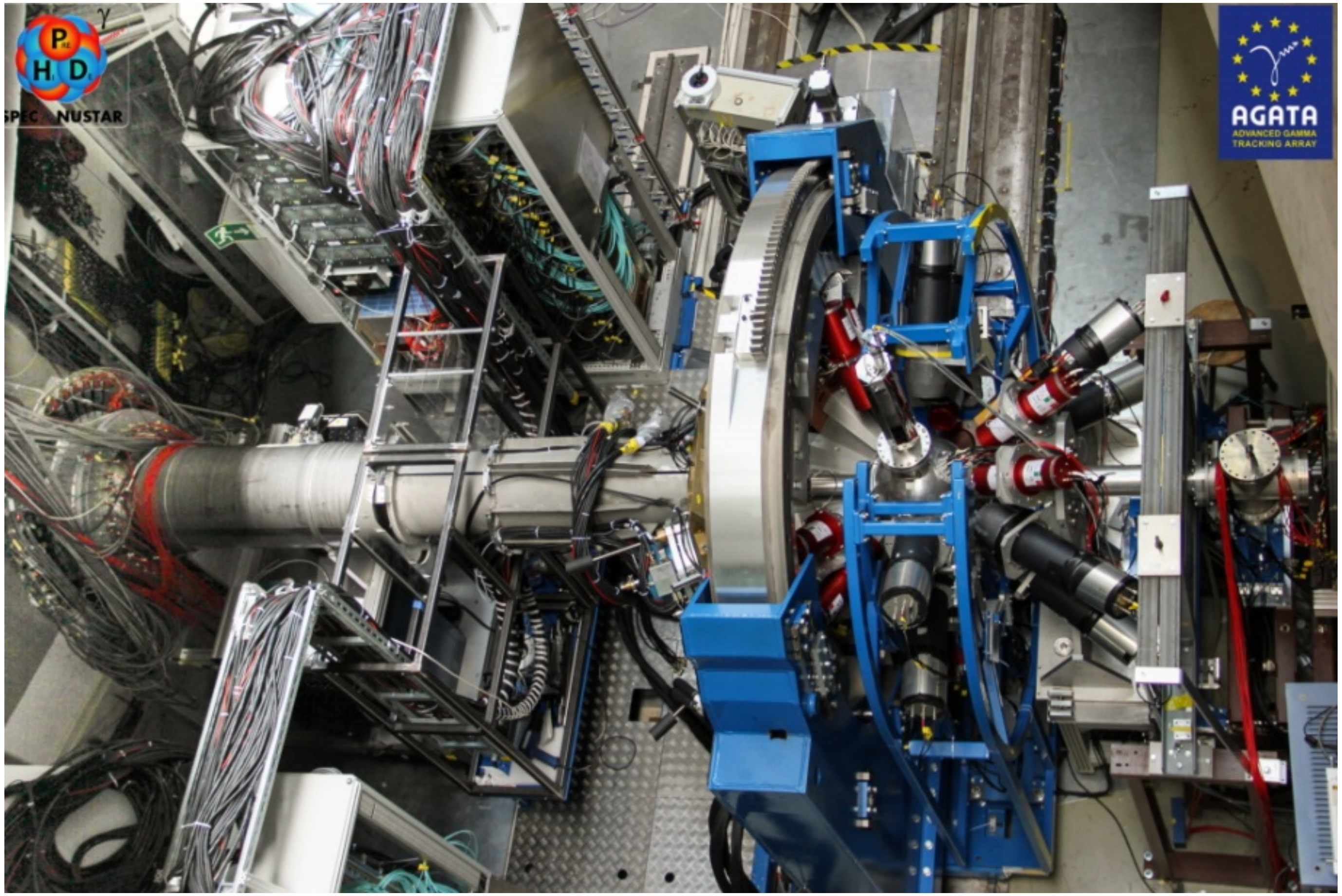
BELEN neutron counter used; DESPEC experiment at GSI

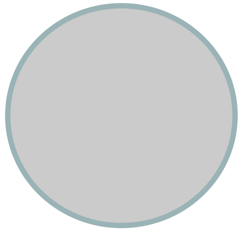
PHYSICAL REVIEW LETTERS Nov. 2016

Role of the Δ Resonance in the Population of a Four-Nucleon State in the ^{56}Fe → ^{54}Fe Reaction at Relativistic Energies

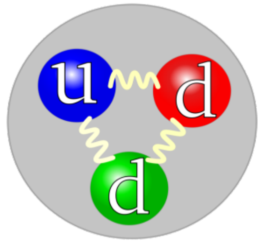
Zs. Podolyák,[1] C. M. Shand,[1] N. Lalović,[2,3] J. Gerl,[3] D. Rudolph,[2] T. Alexander,[1] P. Boutachkov,[3] M. L. Cortés,[3,4] *et al.*

connects hadron structure with nuclear structure:





OR



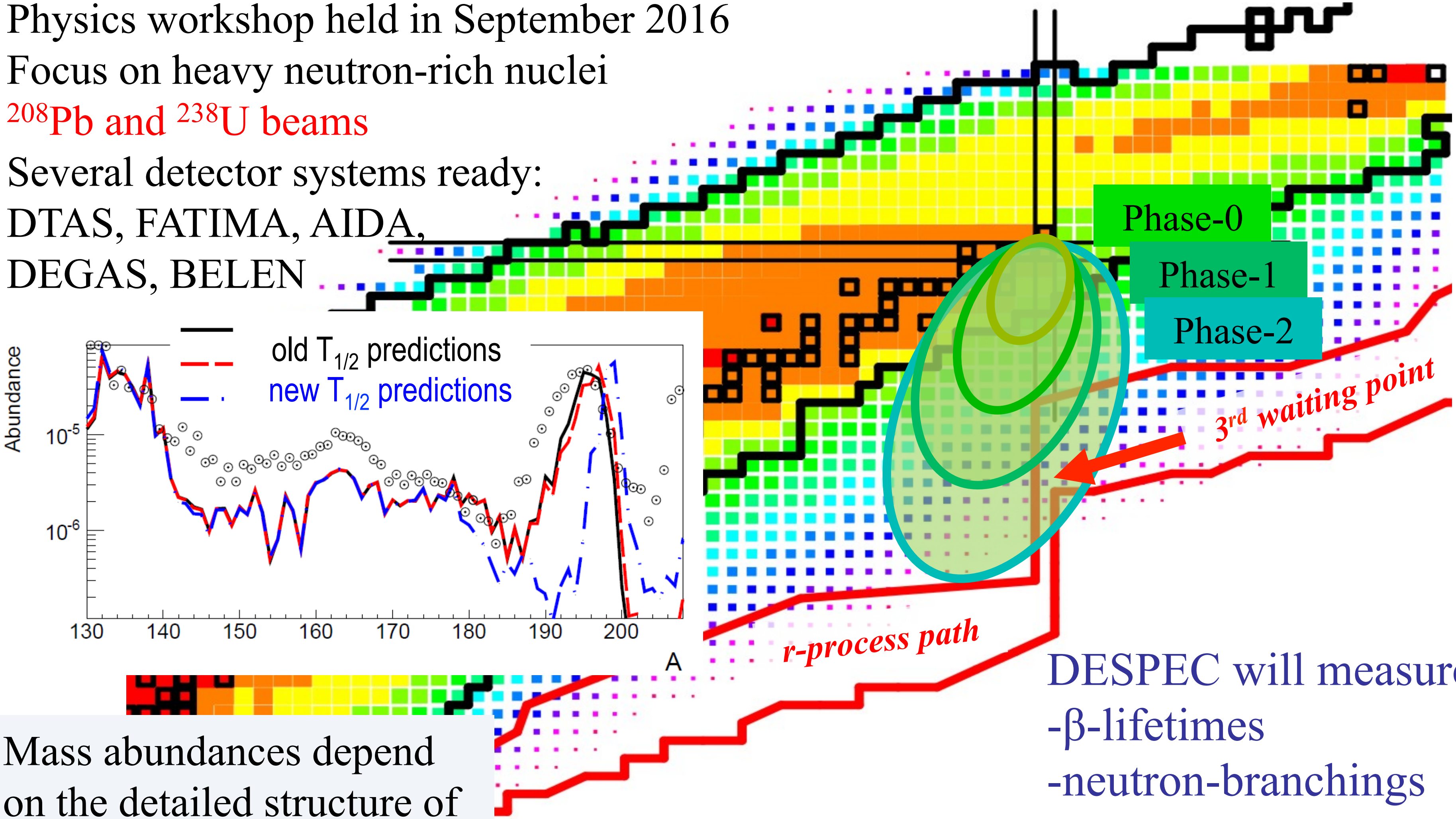
?

10^+ isomer populated via the Δ resonance

AGATA at GSI; HISPEC/DESPEC exp.

DESPEC in 2018-2020 (Phase 0)

Physics workshop held in September 2016
Focus on heavy neutron-rich nuclei
^{208}Pb and ^{238}U beams
Several detector systems ready:
DTAS, FATIMA, AIDA,
DEGAS, BELEN



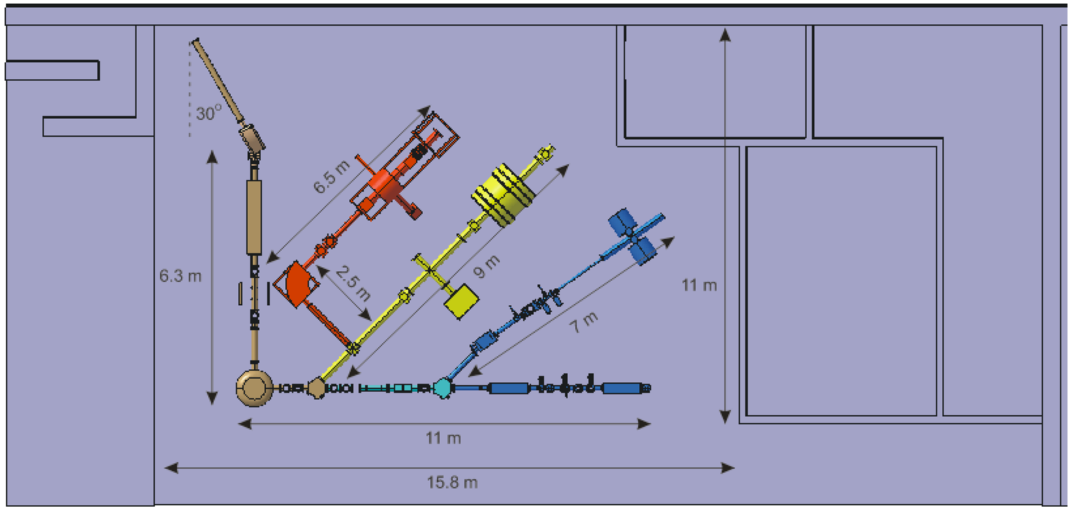
Mass abundances depend on the detailed structure of N=126 nuclei around the 3rd r-process waiting point

DESPEC will measure
- β-lifetimes
- neutron-branchings
- strength distributions
- level structure

MATS

MATS Status 2016

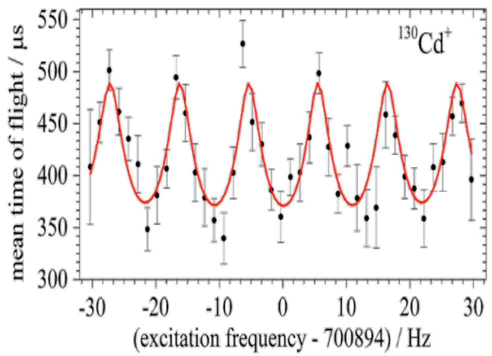
- progress in civil construction planning
- detailed requirements for LEB building are being collected
- optimized beamlime layout



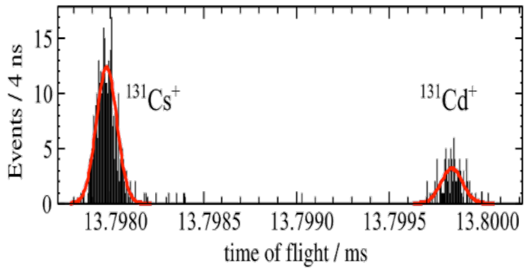
- project plans on work package level are being consolidated /updated
- R&D on major components well advanced:
  e.g.: recent breakthrough in phase-based mass measurements (PI-ICR) results in higher precision and faster measurements (*S. Eliseev et al. PRL 2013*)
- FAIR **phase 0**: TRIGA-TRAP operation and further R&D at various facilities
- all major components will be ready for full physics performance in FAIR **phase 1**
- investment funding will be requested for optimized cryogenic (4K) precision trap
- EBIT charge breeder kept as upgrade option for FAIR **phase 2**

MATS Phase 0: Developments for mass measurements of n-rich nuclides

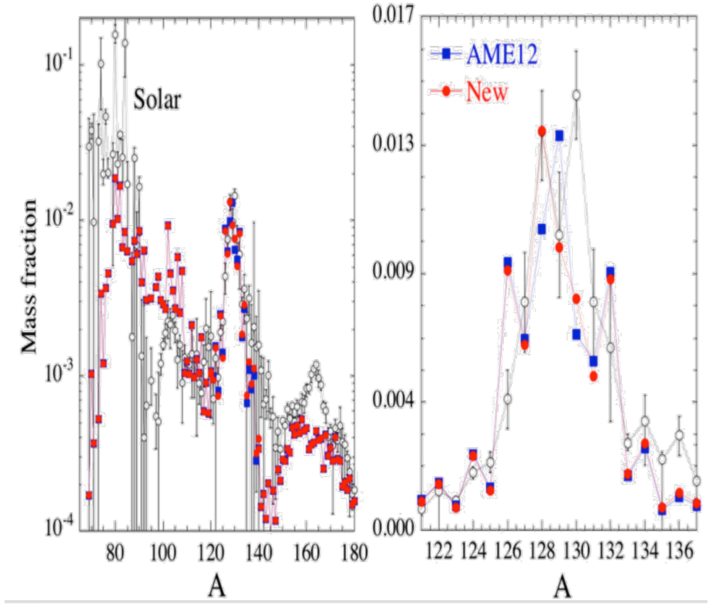
Masses of n-rich Cd isotopes around N=132 measured with ISOLTRAP at CERN



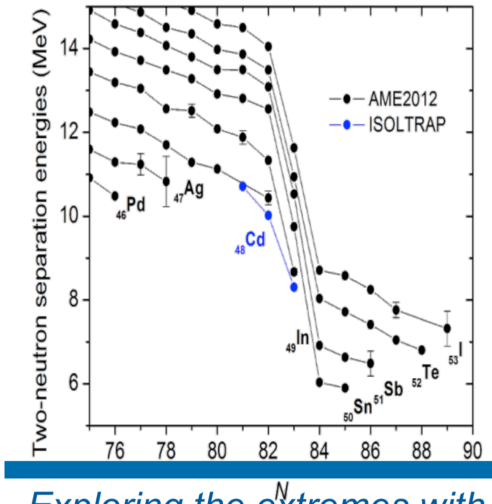
Penning trap



MR-ToF



D. Atanasov et al., PRL 115, 232501 (2015)

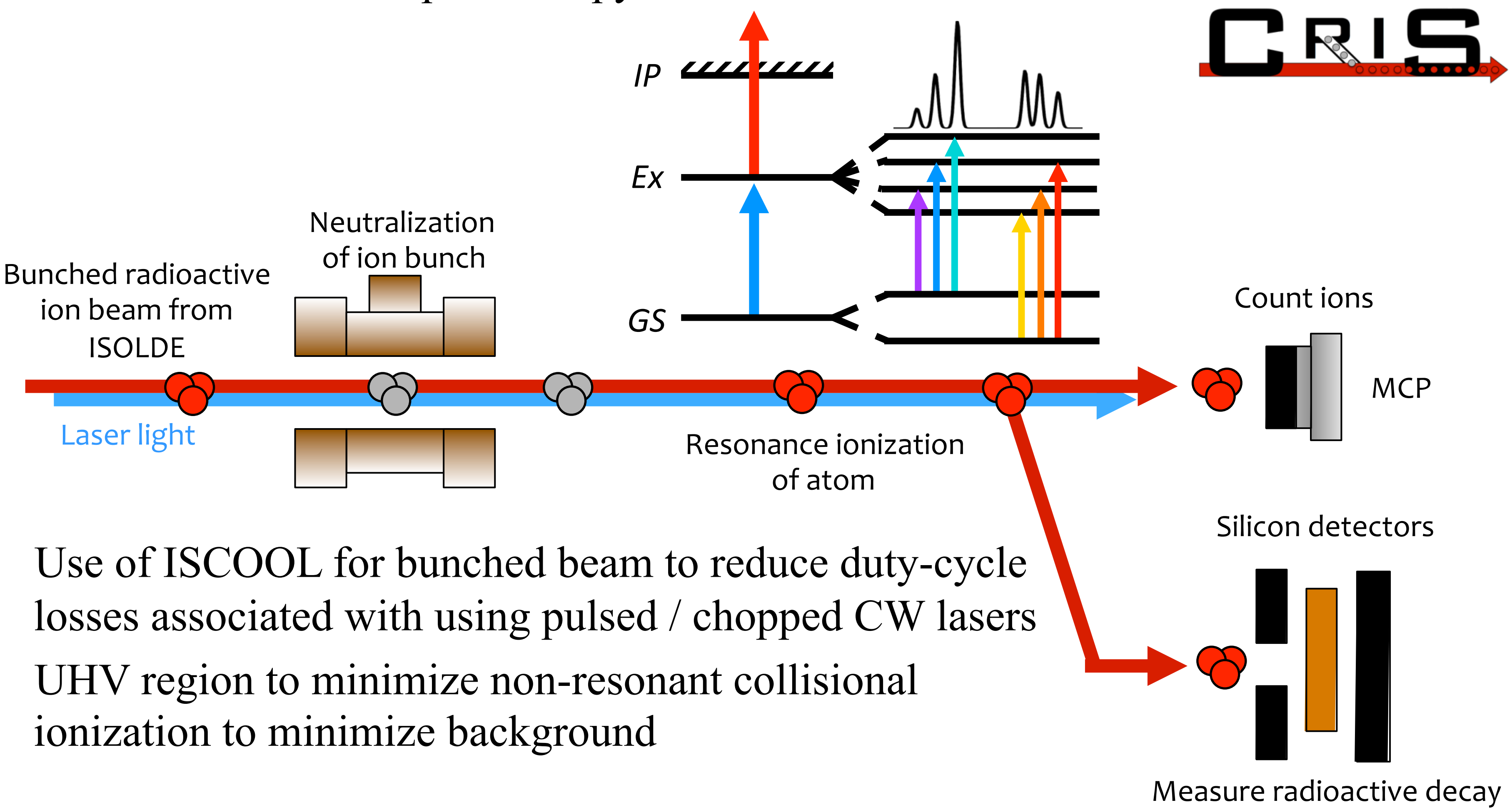


- New mass values show deviation from Atomic Mass Evaluation 2012
- Astrophysical network calculations with new data result in better agreement with the solar abundances in A=132 region
- High-precision mass measurements of additional *n*-rich nuclides accessible at FAIR important to support r-process studies

LaSpec

LaSpec – The CRIS technique

At LaSpec we endeavour to adapt and implement new techniques of laser spectroscopy of exotic radioactive nuclei. One such technique is CRIS, Collinear Resonance Ionization Spectroscopy.



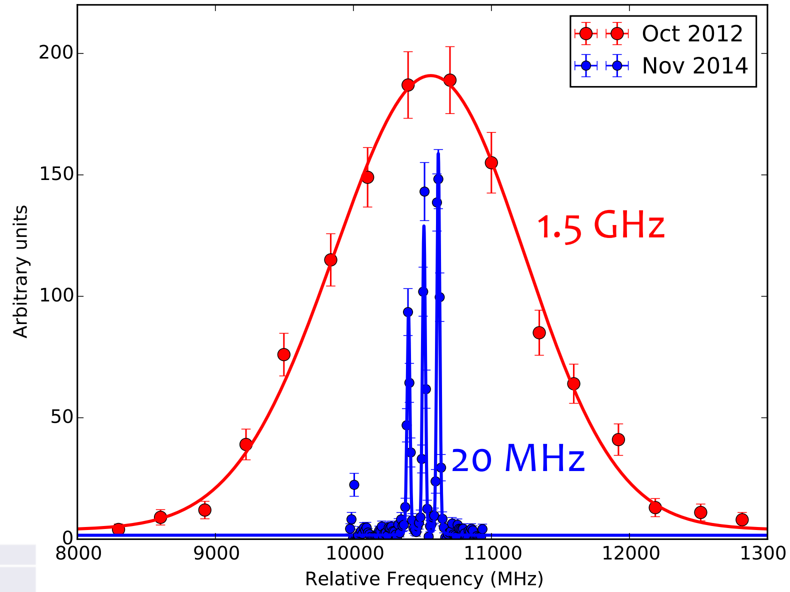
- Use of ISCOOL for bunched beam to reduce duty-cycle losses associated with using pulsed / chopped CW lasers
- UHV region to minimize non-resonant collisional ionization to minimize background

CRIS development

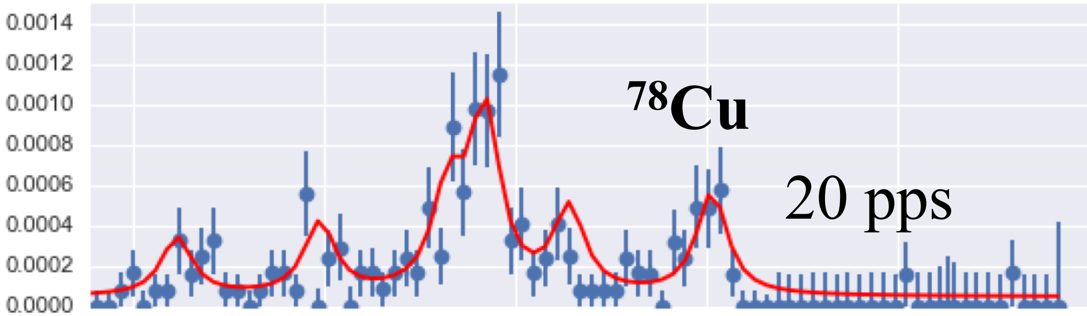
In 2015, a new method of chopped CW delayed ionization RIS was demonstrated that measured ^{219}Fr ($t_{1/2}$ = 20 ms) with a linewidth of 20(1) MHz.

This year, the CRIS experiment introduced an injection-seeded laser system (on loan from JYFL) to test 249 nm and measured ^{78}Cu with a yield of 20 pps as part of the ERC funded FNPMLS project.

Background rate of 1 count every 400 s
Total experimental efficiency of ~1%



R. de Groote et al, Phys. Rev. Lett. 115, 13250 (2015)



MHz

LaSpec Phase 0

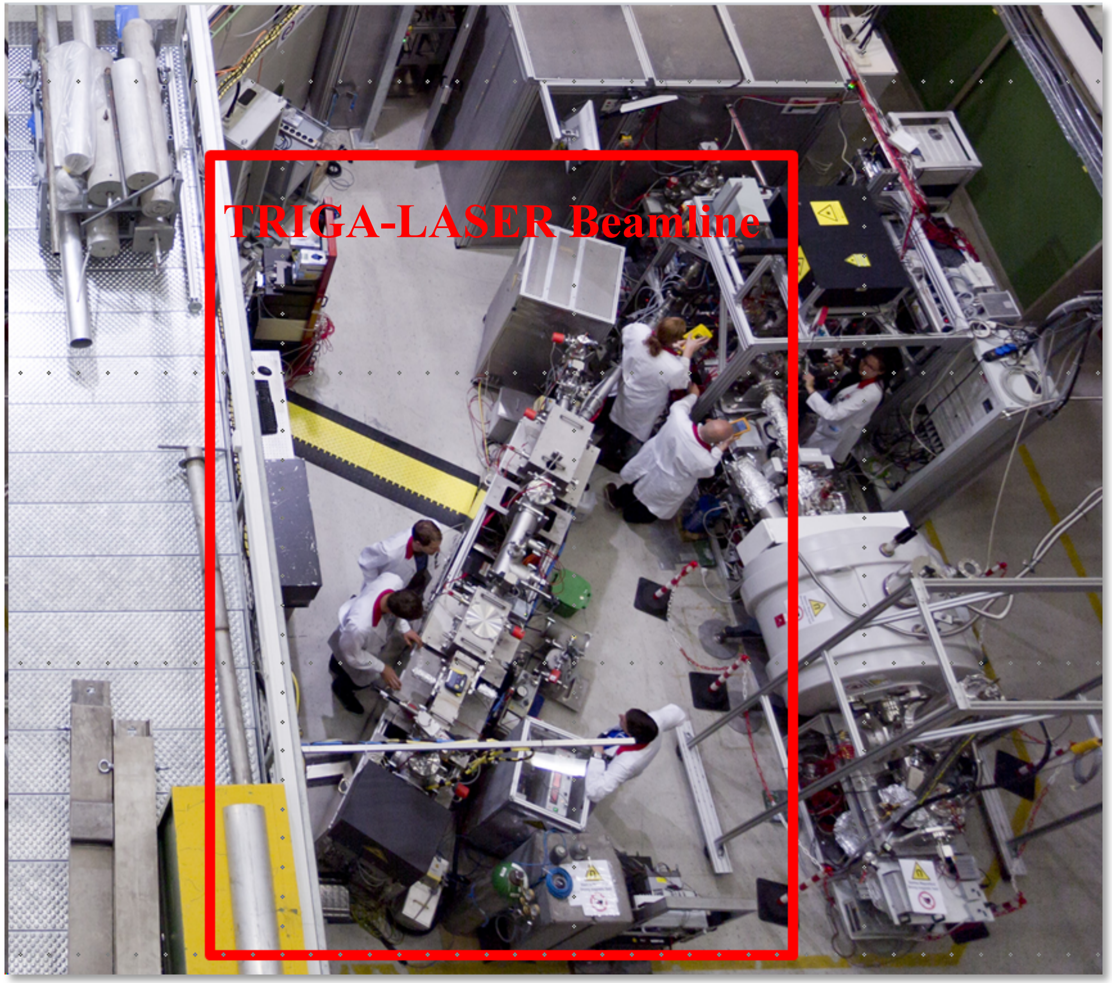
ATLAS & CARIBU:
Conditions comparable to LEB (Beams at 5 kV)

→ Perfect place to test and optimize the new prototypes

→ Flagship experiment: charge radius of proton halo ^{8}B

→ CARIBU: many isotopes available from ^{252}Cf fission

→ 2021/22: Return to FAIR

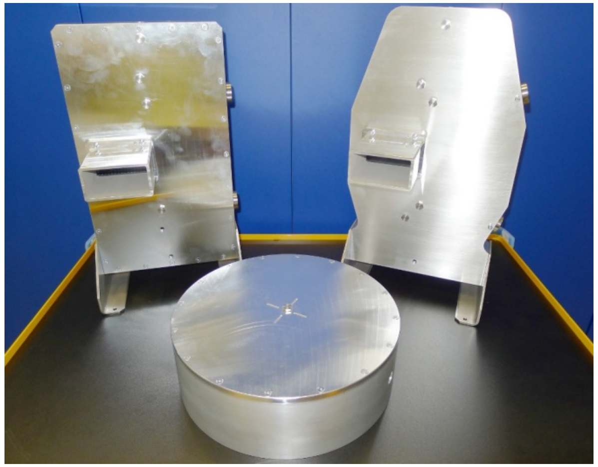


ILIMA

ILIMA: Schottky Mass Spectrometry

Isochronous mode in CR: need position information

Transversally and longitudinally sensitive Schottky detectors for ILIMA@CR:

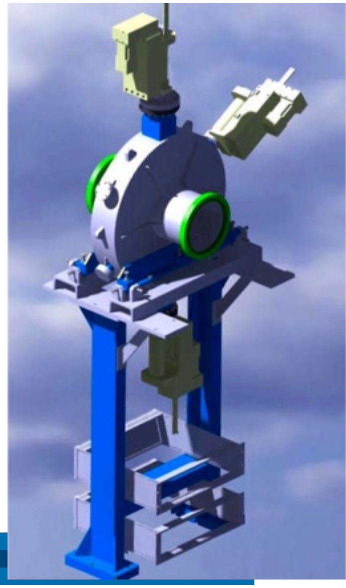


So far:

- ✓ Conceptual design and simulation of transversal Schottky cavities
- ✓ Verification using scaled R&D models
  - ✓ Chen et al. NIM A826 (2016) 39

On going:

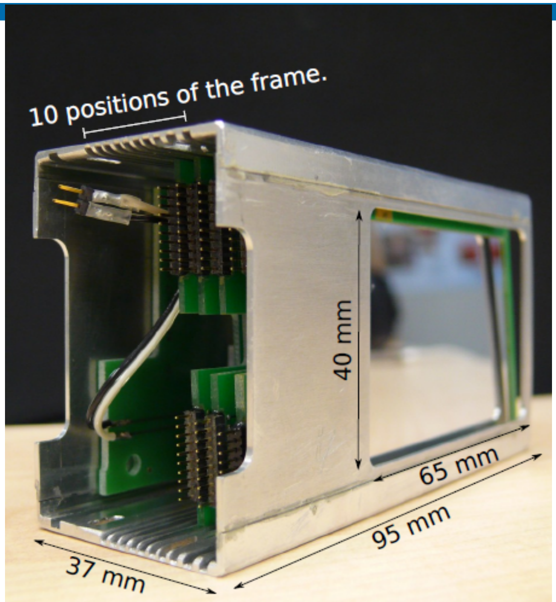
- ➢ Verification of impedance variability using a full-scale vacuum R&D model
  - ➢ Delivery Feb. 2017
- ➢ New GPU-based electromagnetic computation node

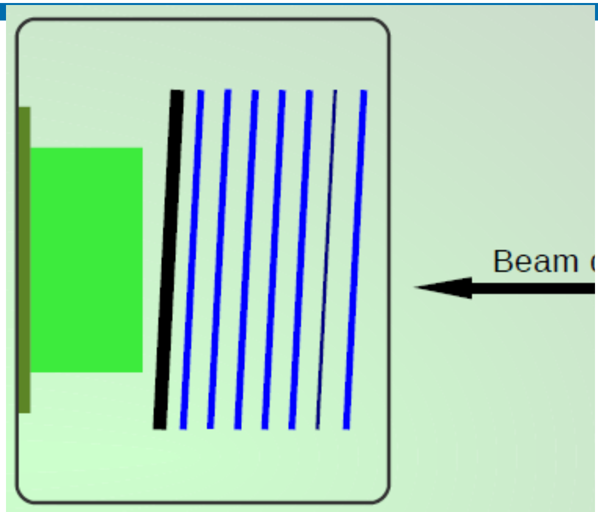


Planned:

- ❖ Beam tests in S-DALINAC facility
- ❖ Further studies on multiple detector analysis

ILIMA: CsISiPHOS detector for in-ring decay



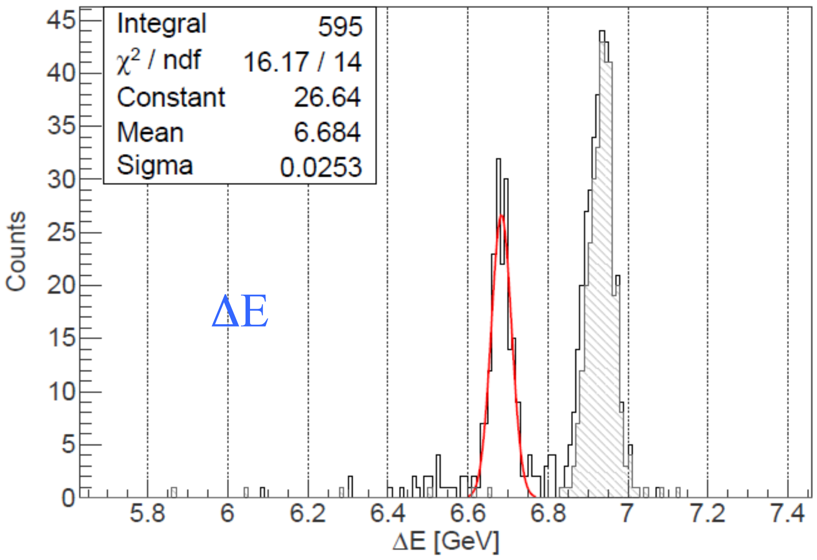


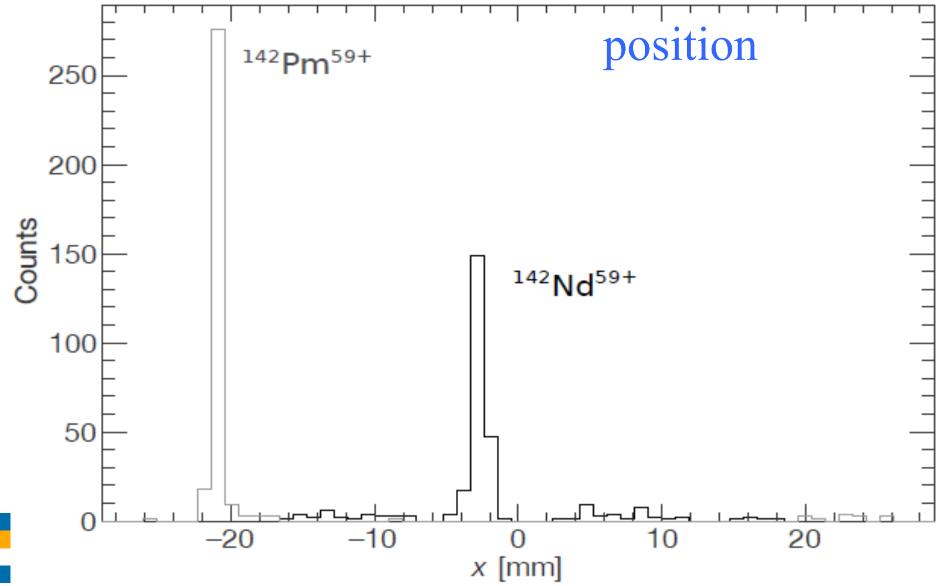
DSSD stack for ΔE-E active area 40mm x 60mm also with CsI calorimeter + Si photo-diode, to identity Z and A.

Prototype tested in the ESR:

Najafi et al., NIM A836 (2016) 1

β^+ decay: $^{142}Pm^{60+} \rightarrow {}^{142}Nd^{59+}$, atomic electron capture $\rightarrow {}^{142}Pm^{59+}$





ILIMA: Phase 0

- **Mass, isomer and lifetime measurements will be done for heavy neutron-rich nuclei, especially in the region of the nuclear chart between ^{208}Pb and the r-process path.**

- **These measurements would be done at the ESR by employing an improved time-of-flight detector as well as novel non-destructive highly-sensitive Schottky detectors.**

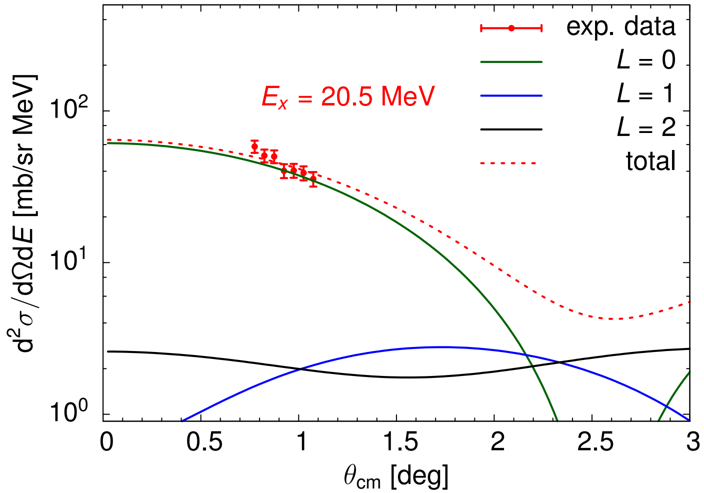
- **Experiments addressing the influence of atomic shells on nuclear decay rates will be conducted at lowest energies at CRYRING.**

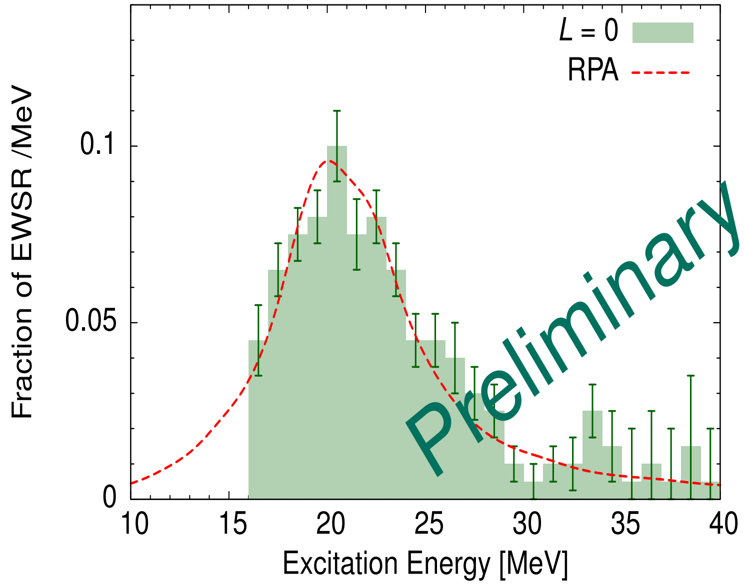
EXL

Recent highlight: Inelastic alpha scattering off ^{58}Ni (100 MeV/u)

ExL

Giant Monopole Resonance of ^{58}Ni





First ExL pilot experiment at ESR sets the world records:

- Lowest c.m. angle measured in inverse kinematics
- Most accurate extraction of monopole strength in inverse kinematics

With only one detector !!!

centroid [MeV]	EWSR [%]	
20.5(6)	79^{+12}_{-11}	present data
$21.5^{+3.0}_{-0.3}$	74^{+22}_{-12}	PRC **61**, 067307 (2000)
$20.8^{+0.9}_{-0.3}$	85^{+13}_{-10}	PRC **73**, 014314 (2006)
21.1	94	RPA calculation [4]

[4] G. Colò et al, Comput. Phys. Commun. 184 (2013)

Published Oct. 2016: J.C. Zamora et al., Phys. Lett. B 763 (2016) 16

ExL

Phase 0 program (2018/19)

Giant Monopole Resonance of ^{56}Ni

Upgrade of detection system:

- Three more detectors plus new readout
- Closer geometry
- Detection system for recoil

➔ Increase of solid angle substantially

➔ Further reduced background

➔First measurement of the Giant Monopole Resonance in an unstable nucleus will be possible already in 2019!

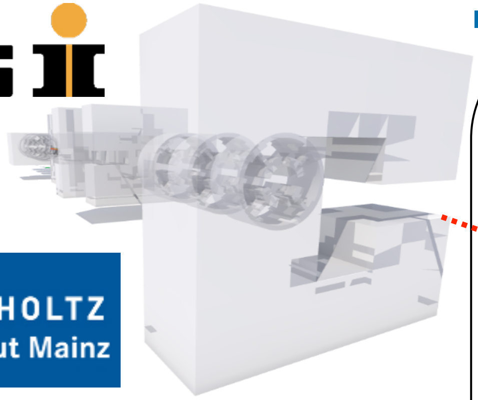
SHE

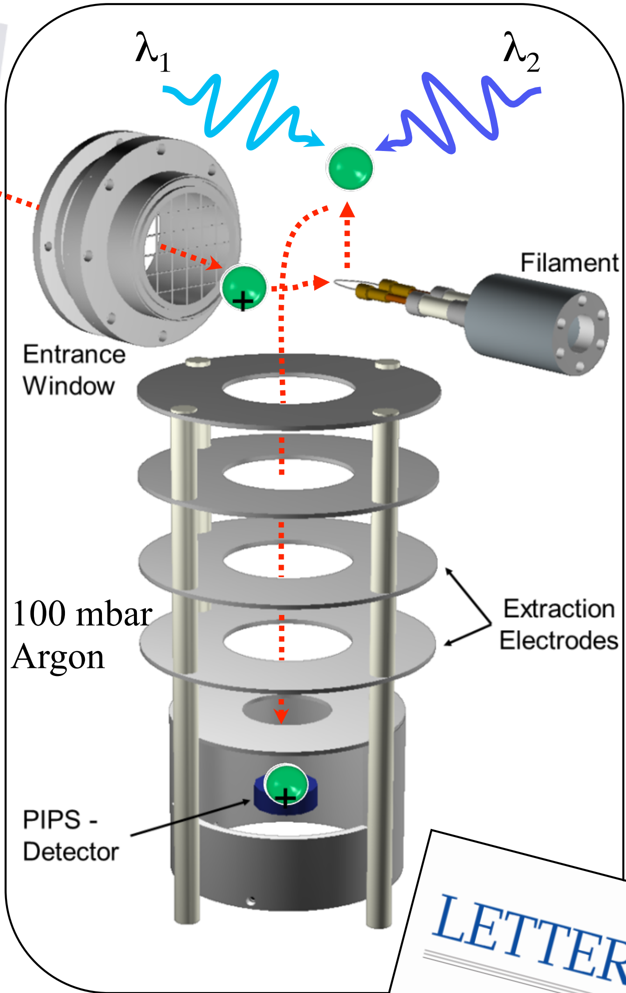
Super Heavy Elements (SHE):
First Spectroscopic Investigation of Nobelium (Z=102)

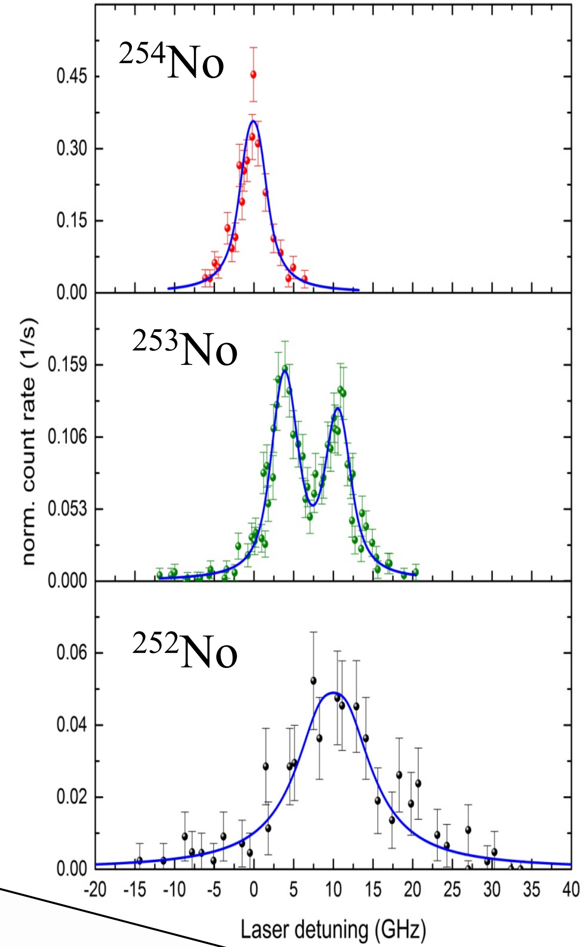
GSI

JGU

HELMHOLTZ Institut Mainz







Achievements:

➔ First ever successful laser spectroscopy beyond fermium

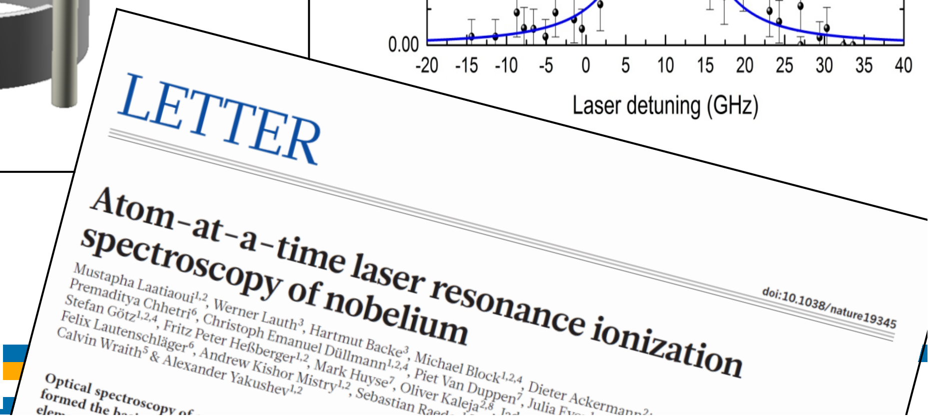
➔ Production rates: ~ 1 atom/s

➔ Overall efficiency up to 10%

➔ First ionization potential of nobelium precisely measured

➔ Nuclear spin and moments extracted for the isotope ^{253}No

Bundesministerium für Bildung und Forschung



LETTER

doi:10.1038/nature19345

Atom-at-a-time laser resonance ionization spectroscopy of nobelium

Mustapha Laatiaoui[1,2], Werner Lauth[3], Hartmut Backe[3], Michael Block[1,2,4], Dieter Ackermann[2], Premaditya Chhetri[6], Christoph Emanuel Düllmann[1,2,4], Piet Van Duppen[7], Stefan Götz[1,2,4], Fritz Peter Heßberger[1,2], Mark Huyse[7], Oliver Kaleja[2,8], Felix Lautenschläger[6], Andrew Kishor Mistry[1,2], Sebastian Raed... Calvin Wraith[5] & Alexander Yakushev[1,2]

Optical spectroscopy of ...

TECHNISCHE UNIVERSITÄT DARMSTADT

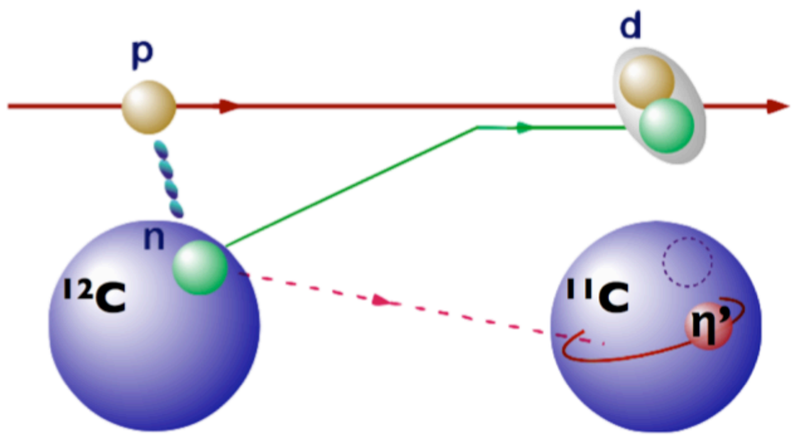
KU LEUVEN

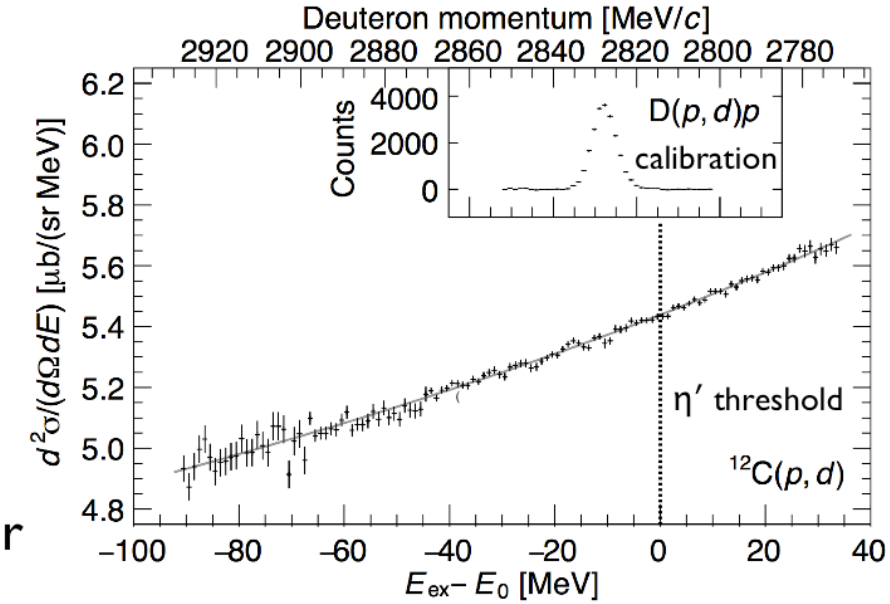
UNIVERSITY OF LIVERPOOL

Media coverage

Super-FRS

Search for η′ mesic nuclei by spectroscopy of $^{12}C(p,d)$ reaction with FRS





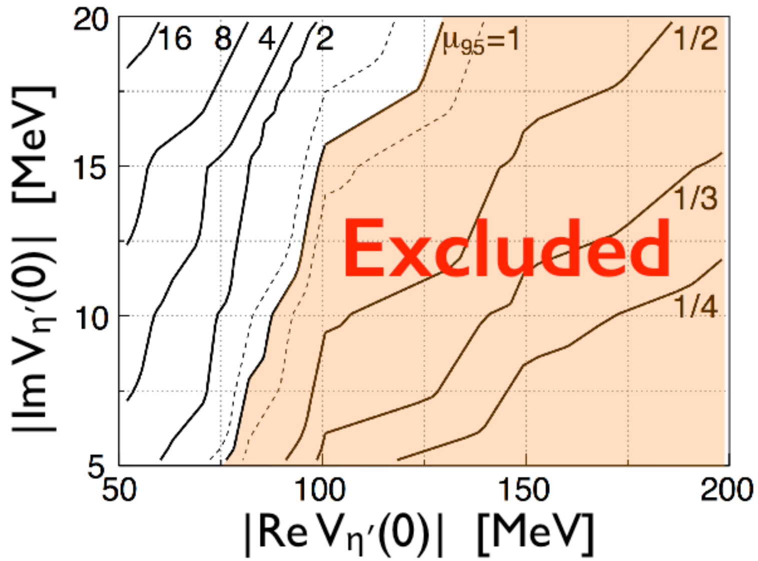
- ◇ FRS used as high-resolution spectrometer
- ◇ extremely good statistics achieved
- ◇ stringent constraints on η′-nucleus potential

PRL 117, 202501 (2016) PHYSICAL REVIEW LETTERS week ending 11 NOVEMBER 2016

Measurement of Excitation Spectra in the $^{12}C(p,d)$ Reaction near the η' Emission Threshold

Y. K. Tanaka,[1,*] K. Itahashi,[2,†] H. Fujioka,[3,‡] Y. Ayyad,[4] J. Benlliure,[5] K.-T. Brinkmann,[6] S. Friedrich,[6] H. Geissel,[6,7] J. Gellanki,[8] C. Guo,[9] E. Gutz,[6] E. Haettner,[7] M. N. Harakeh,[8] R. S. Hayano,[1] Y. Higashi,[10] S. Hirenzaki,[10] C. Hornung,[6] Y. Igarashi,[11] N. Ikeno,[12] M. Iwasaki,[2] D. Jido,[13] N. Kalantar-Nayestanaki,[8] R. Kanungo,[14] R. Knöbel,[6,7] N. Kurz,[7] V. Metag,[6] I. Mukha,[7] T. Nagae,[3] H. Nagahiro,[10] M. Nanova,[6] T. Nishi,[2] H. J. Ong,[4] S. Pietri,[7] A. Prochazka,[7] C. Rappold,[7] M. P. Reiter,[7] J. L. Rodríguez-Sánchez,[5] C. Scheidenberger,[6,7] H. Simon,[7] B. Sitar,[15] P. Strmen,[15] B. Sun,[9] K. Suzuki,[16] I. Szarka,[15] M. Takechi,[17] I. Tanihata,[4,9] S. Terashima,[9] Y. N. Watanabe,[1] H. Weick,[7] E. Widmann,[16] J. S. Winfield,[7] X. Xu,[6,7] H. Yamakami,[3] and J. Zhao[9]

(η-PRiME/Super-FRS Collaboration)



(Super-)FRS Experiments: modes, science topics, phases

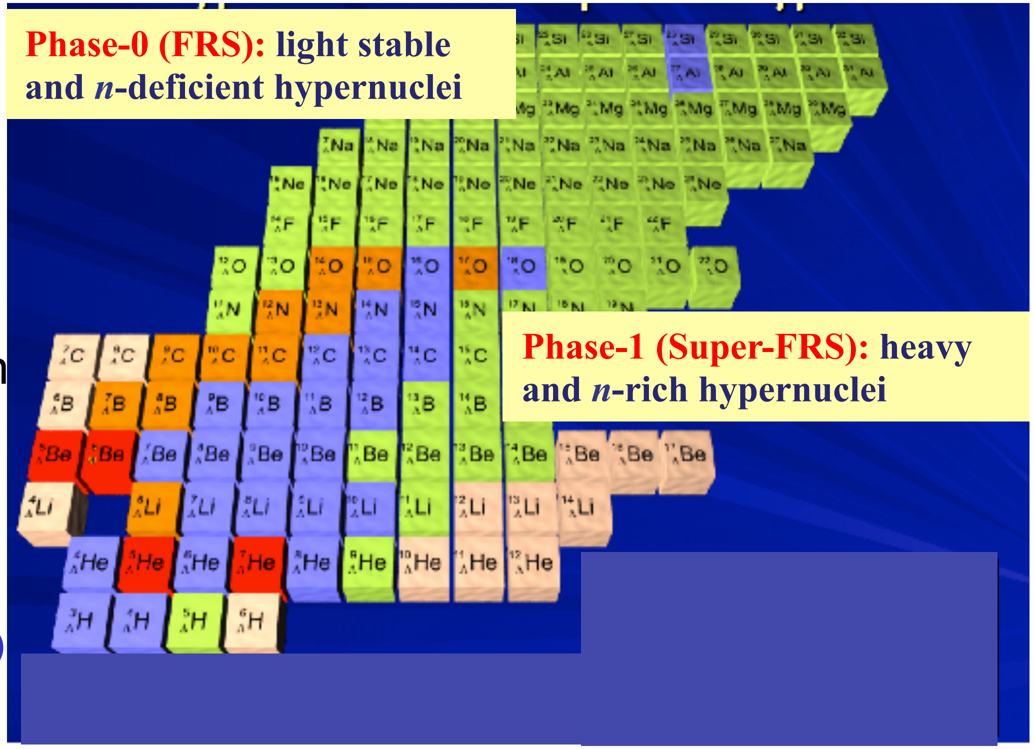
	Phase-0	Phase-1
(Super-)FRS for high mass and charge resolution		
Rare isotope yields, gross properties and limits of existence	(+)	++
Atomic collisions at relativistic energies, channeling	+	+
(Super-)FRS as high-energy high-resolution spectrometer		
Spectroscopy of meson-nucleus bound system (mesic atoms)	Inclusive	Exclusive
Exotic hypernuclei and their properties	Stable	Exotic
Importance of tensor forces in nuclear structure	+	++
Delta resonances probing nuclear structure	Stable	Exotic
(Super-)FRS as multi-stage separator and spectrometer		
Nuclear radii and momentum distributions	+	++
In-flight radioactive decays and continuum spectroscopy by particle emission	+	++
Low-q experiments with an active target	(+)	+
Reaction studies and synthesis of isotopes with low-E RIBs	(+)	++

Exotic (n-rich) hypernuclei and their properties

- Production of hypernuclei at high-energy (>1.2 GeV/u) in peripheral collisions of heavy ions has large cross sections (micro-barn)
- The method is also suitable for determination of lifetimes of hypernuclei via weak decay channel ($\Lambda_{free} \rightarrow p\pi^{-}$ or $n\pi^{0}$, τ~0.26 ns)

  (Lorentz factor on lifetime!)

Strangeness sector of nuclear chart

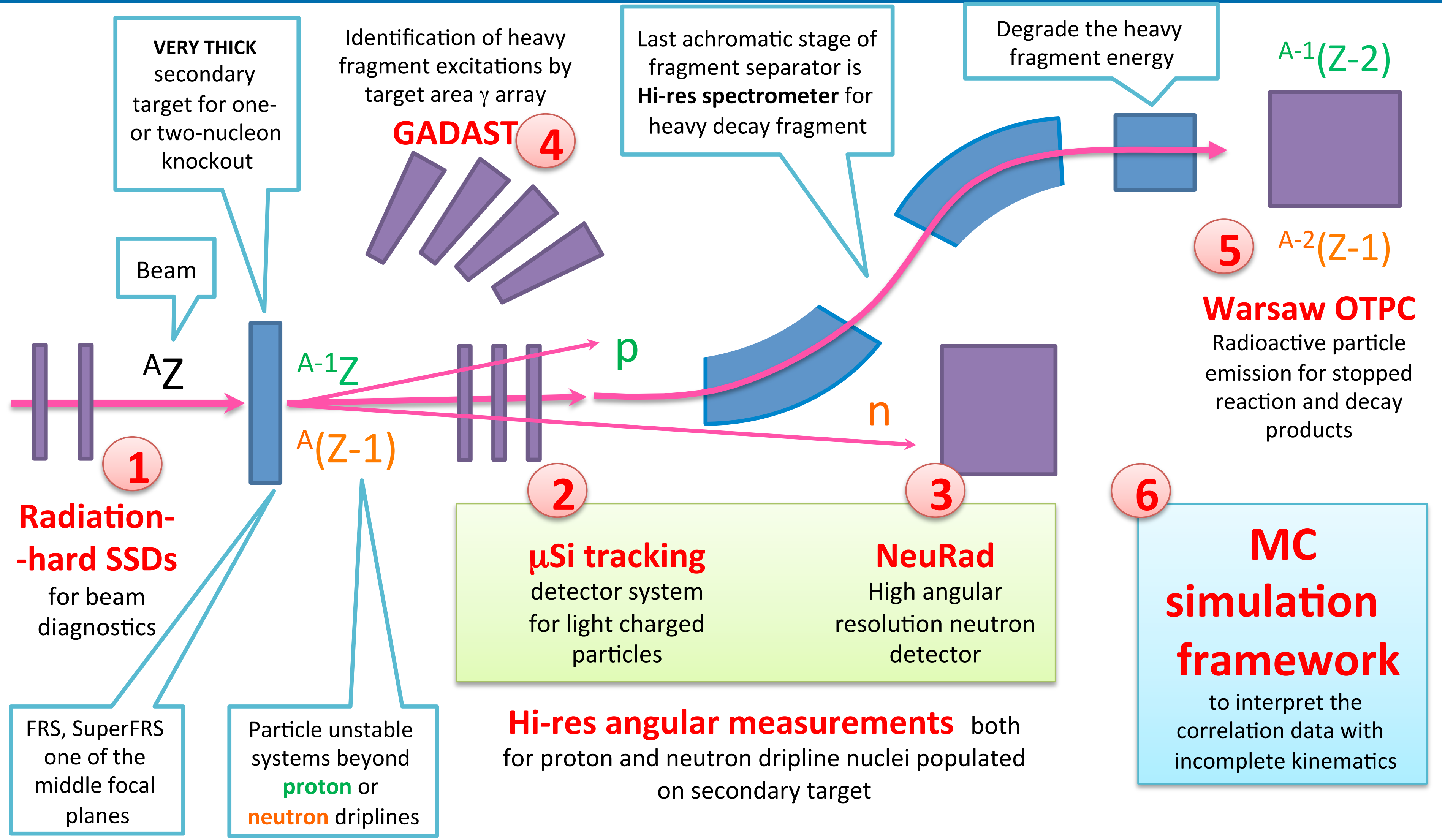


- **Pilot experiments at GSI (HypHI) show evidence of $^{3}{}_{\Lambda}$H, $^{4}{}_{\Lambda}$H, $^{3}{}_{\Lambda}$n**
- **FRS experiments provide precise binding energies and lifetimes**
- Super-FRS will provide identification of heavy nuclei and explore the strange sector in very exotic nuclei

C. Rappold et al., Phys. Rev. C 88, 041001 (2013)

A. Botvina et al., Phys Rev C 88, 054605 (2013)

EXPERT: **EX**otic **P**article **E**mission and **R**adioactivity by **T**racking



Preparing for PAC 2018/2019

In almost all the experiments performed in Phase 0, UNILAC, SIS18 and FRS will be used to produce heavy elements and radioactive ions. Specific programs are detailed below (same order as in the cost book). HISPEC, MATS and LaSpec will perform their Phase-0 measurements elsewhere. A large fraction of the required beams will be ^{48}Ca and ^{50}Ti (UNILAC) and ^{238}U, ^{208}Pb, ^{136}Xe, ^{40}Ar, ^{18}O, ^{12}C and protons (SIS18), which are rather standard beams. The novel NUSTAR NDAQ data acquisition system will enable higher throughput and improved reliability.

DeSPEC: Will focus on the study of heavy neutron-rich nuclei around N=126, Z=82 and also heavy deformed nuclei. These are related to the nucleosynthesis of heavy elements in the rapid neutron capture process (third r-process abundance peak) and complex shape evolution (prolate-triaxial-oblate-spherical) in nuclei. DESPEC is highly-modular and the newly-developed detectors AIDA, DEGAS, DTAS and FATIMA placed at S4 area of FRS will provide unique opportunities even for nuclei produced with very low yields (10^{-1}-100/s). Also the Ion Catcher can be used for some of the planned measurements.

R3B: Advantage will be taken from the installation of GLAD plus partly already available new detection systems (tracking, neutron detection, vertex tracker, gamma detection) which will allow, for the first time, for experiments with the highest energies up to 1 GeV/u even for neutron-rich beams. This will open unique opportunities even for light nuclei. Examples are the measurement of the full dipole response of halo nuclei or quasi-free (p,pN) knockout reactions. The readiness of one third of the neutron detector NeuLAND will make high-resolution measurements of two-neutron decays of neutron-rich nuclei at the drip line and beyond possible already from 2018. For heavier beams, Coulomb break-up to determine astrophysical relevant reaction rates and (p,2p) fission measurements to deduce fission barriers of exotic nuclei will be among the first experiments.

ILIMA: At the ESR, mass and lifetime measurements relevant to the r-process will complement the DeSPEC program for heavy neutron-rich nuclei (N=82 and N=126) by employing an improved time-of-flight detector as well as novel non-destructive highly-sensitive Schottky detectors. Beta-delayed neutron emission measurements will be trialled. Experiments addressing the influence of atomic shells on nuclear decay rates will be conducted (together with SPARC) at the lowest energies at CRYRING.

EXL: Scattering experiments on proton/helium gas jet targets are planned at the ESR. Among the first experiments, the collaboration plans the first measurement of the Giant Monopole Resonance in a radioactive nucleus using alpha scattering. Proton-induced reaction relevant for astrophysics at low energies will be performed at CRYRING by using a dedicated windowless detector setup installed directly into the ultra-high vacuum of the ring.

Super-FRS: Pioneering studies are planned exploiting the unique combination of high-energy and high-resolution of the FRS separator-spectrometer for experiments, like atomic collision, nucleon knockout, nucleon correlation, nuclear radii and tensor-force studies and the discovery of new isotopes. The plans are to use existing experience and equipment, prototype and new detectors for FAIR at the focal planes of the FRS. New large-scale setups like the dipole magnet for the study of hypernuclei, eta'-mesic nuclei and delta resonances are planned to be used at mid-focal plane; other new detectors, like the Ion Catcher or the O-TPC, will be placed at final focal plane. New decay modes like the two-proton radioactivity and exotic in-flight decays will be studied using new equipment like the EXPERT setup. Both heavy and light projectile beams are employed.

SHE: Experiments will use UNILAC beams with highest intensities of ^{48}Ca and ^{50}Ti and the SHIP and TASCA separators to perform studies of the heaviest elements. We will investigate chemical properties of elements $Z > 112$ and nuclear structure and atomic physics in elements with $Z > 102$.

Action: Provide feedback for technical coordinator

Ill-assigned items (1): This was handed in at the end of this year.

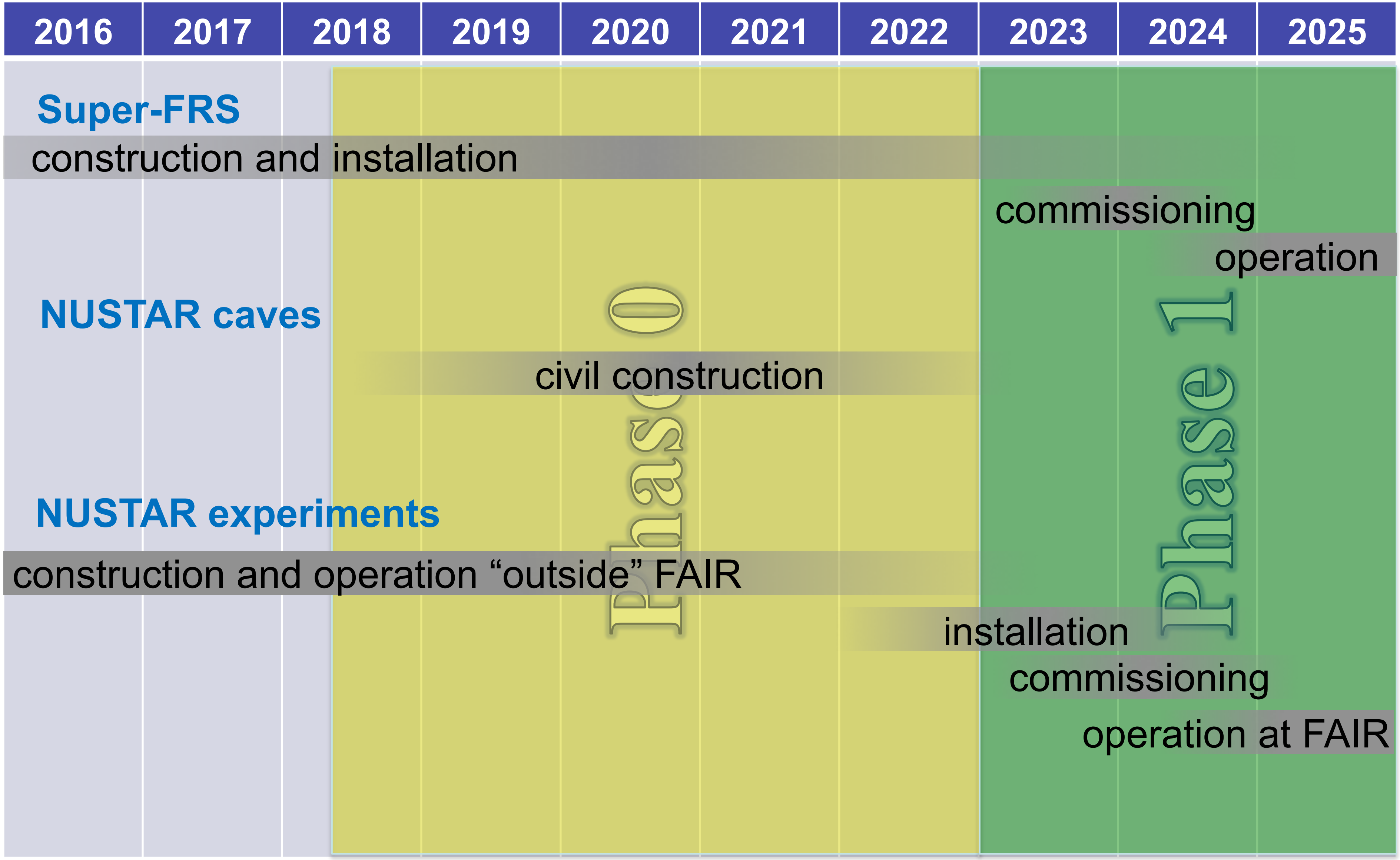
(1) The items which are thought to belong to accelerator or building.

Missing items (2): This is being prepared by Jürgen Gerl.

(2) The items which are thought to belong to experiments.

Timeline

Scenario for NUSTAR Phase 0 and 1



Thank you!