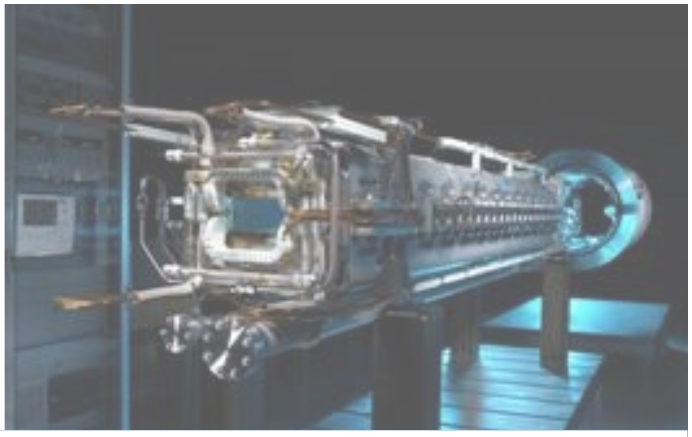


NUSTAR Status Report

Wolfram Korten
IRFU - CEA Paris-Saclay

NUSTAR Annual Meeting

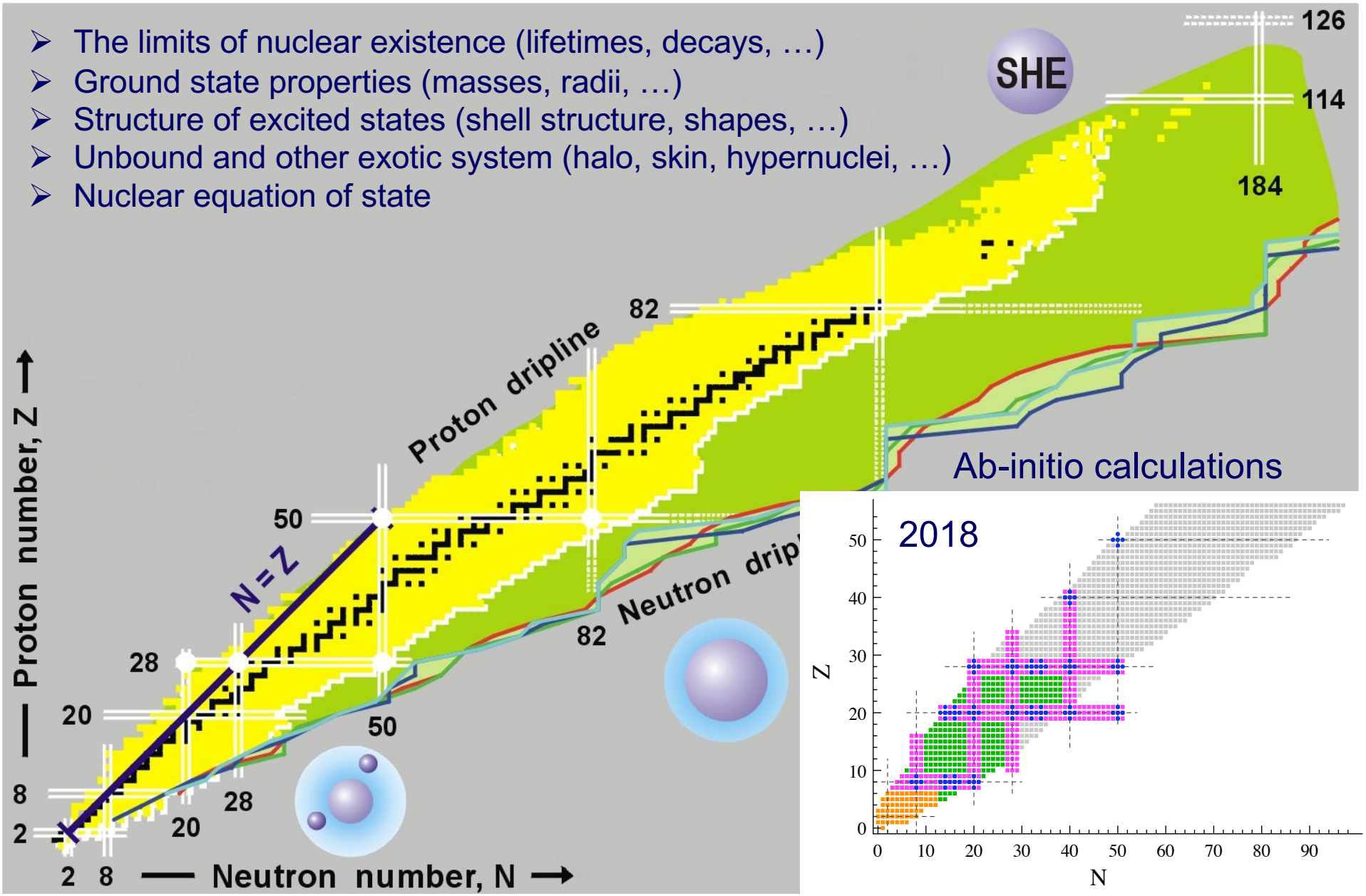
Darmstadt, Germany, February 27th, 2019

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

FAIR

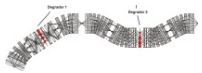
NUclear STructure Astrophysics and Reactions

- 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

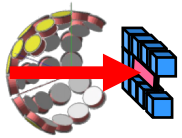


NUSTAR experiments

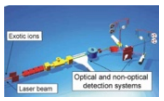
Super-FRS



HISPEC/ DESPEC

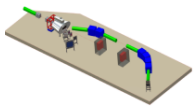


LASPEC

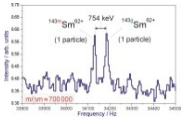


MATS

R3B



ILIMA



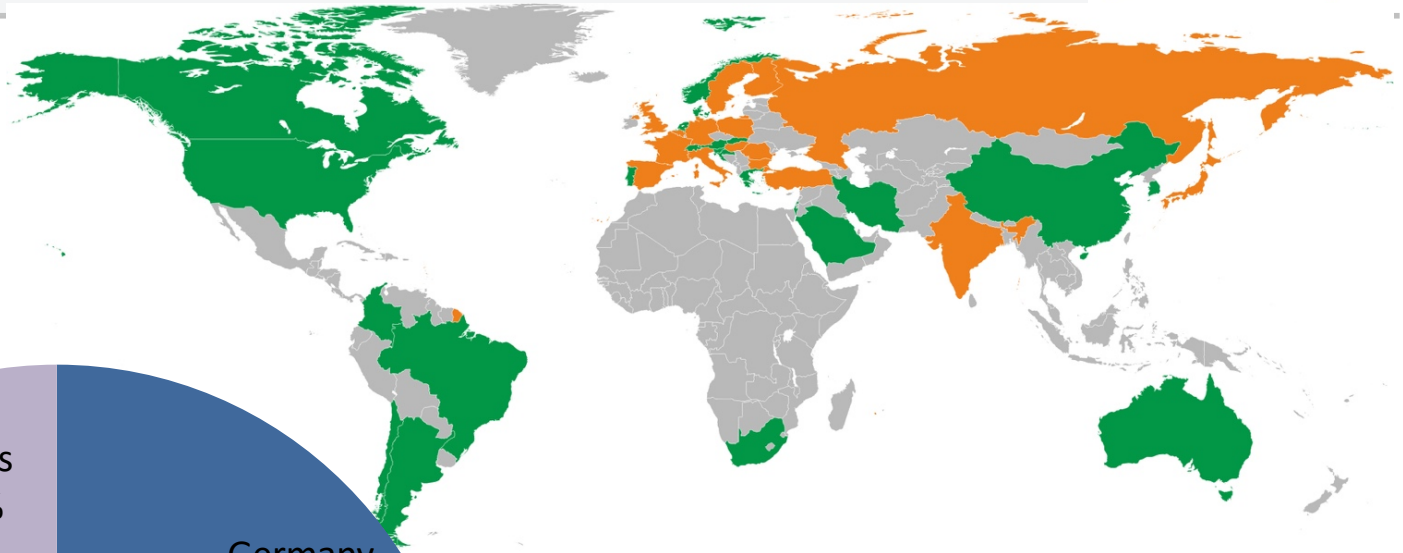
SHE

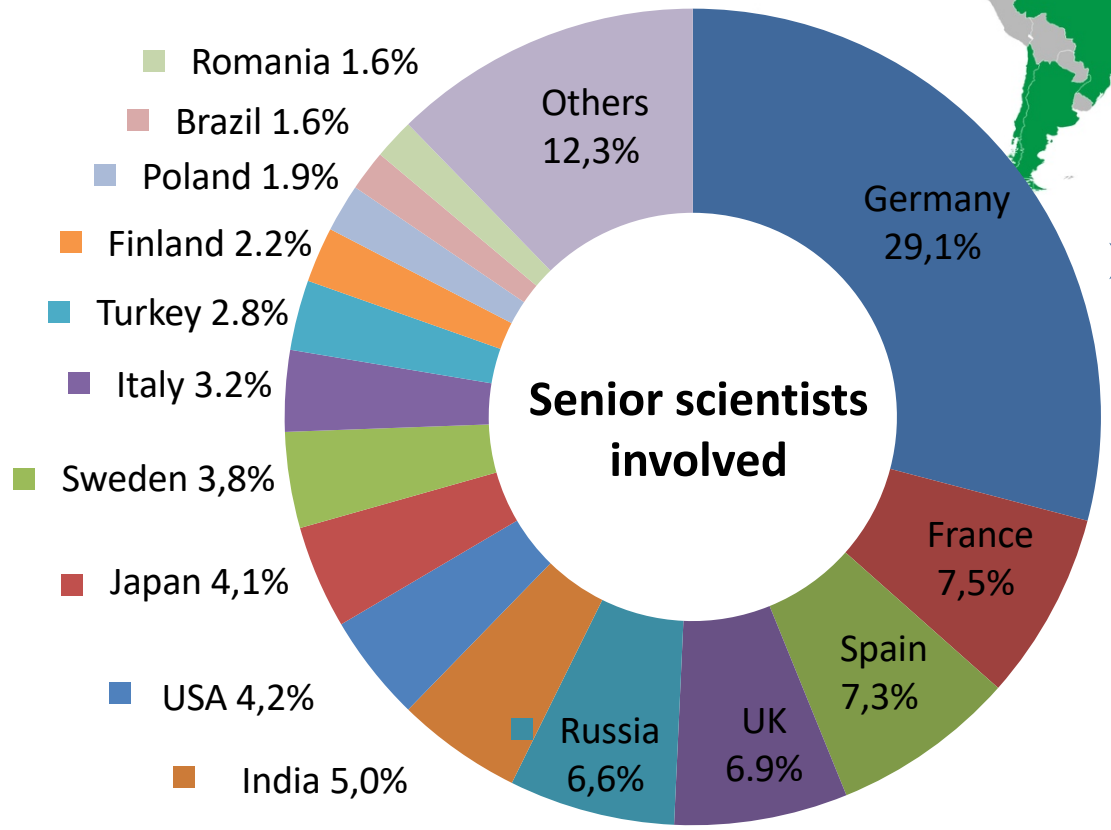
ELISE

EXL

	Super-FRS	HISPEC/DESPEC	LASPEC	MATS	R3B	ILIMA	SHE	ELISe	EXL
Masses		Q-values, isomers		dressed ions, highest precision	unbound nuclei	bare ions, mapping study	precision mass of SHEs		
Half-lives	ps...ns-range	ground state and isomers μs...s			resonance width, decay up to 100ns	bare ions, ms…years	μs...days		
Matter radii	interaction x-section				interaction cross sections				matter densitiy distribution
Charge radii	charge-changing cross sections		mean square radii		charge-changing cross sections			charge density distribution	
Single-particle structure	high resolution, angular momentum	high-resolution particle and γ-ray spectroscopy	magnetic moments, nucl. spins	evolution of shell str., pairing int., valence nucl.	quasi-free knockout, short-range & tensor correlations	evolution of shell closures, pairing corr.	shell structure of SHEs		low momentum transfers
Collective behavior		electromagnetic transition strength	quadrupole moments	halo structure	dipole response, fission	changes in deformation		electromagnetic transition strength	monopole resonance
EoS					polarizability, neutron skin			neutron skin	neutron skin, compressibility
Exotic Systems	bound mesons, hypernuclei, nucleon resonances	rare and exotic e.m. and particle decays			n-rich hypernuclei	exotic decay modes			

The NUSTAR collaboration





- 800 registered “interested” scientists in the NUSTAR data-base from **39 countries and more than 180 institutes**

Secured funding and expression of interest in funding (September 2018): **from 19 countries** (incl. 9 FAIR partner countries)

Update in progress for new MoU

- Sharing of running costs

Recent FAIR meetings and activities

- ECSG and ECE meeting (Oct. 8 – 10, 2018)
  - **TDRs approved (ILIMA ToF, HI, Schottky detectors)**
- FAIR AFC meeting (Oct.18 – 19, 2018)
  - **Discussion on General Conditions for Experiments (ongoing)**
- FAIR/GSI Joint Scientific Council meeting (Nov. 8-9, 2018)
  - **NUSTAR Day-1 physics program formally endorsed**
- 8th FAIR RRB meeting (Nov. 26-27, 2018)
  - **Status of Day-1 configuration (and physics program)**
- FAIR Council meeting (Dec. 5-6, 2018)
  - **In-kind requests approved (ILIMA TToF & HI)**
- FAIR Experiments and Accelerators Workshop
  - December 14, 2018, Darmstadtium
- FAIR Review (Feb. 5, 2019)
  - **Presentation of Phase-1 physics program (up to 5 years)**
  - **Panel meeting (Feb. 21-22, 2019)**

FAIR review – assessment of experiments

Assessment:

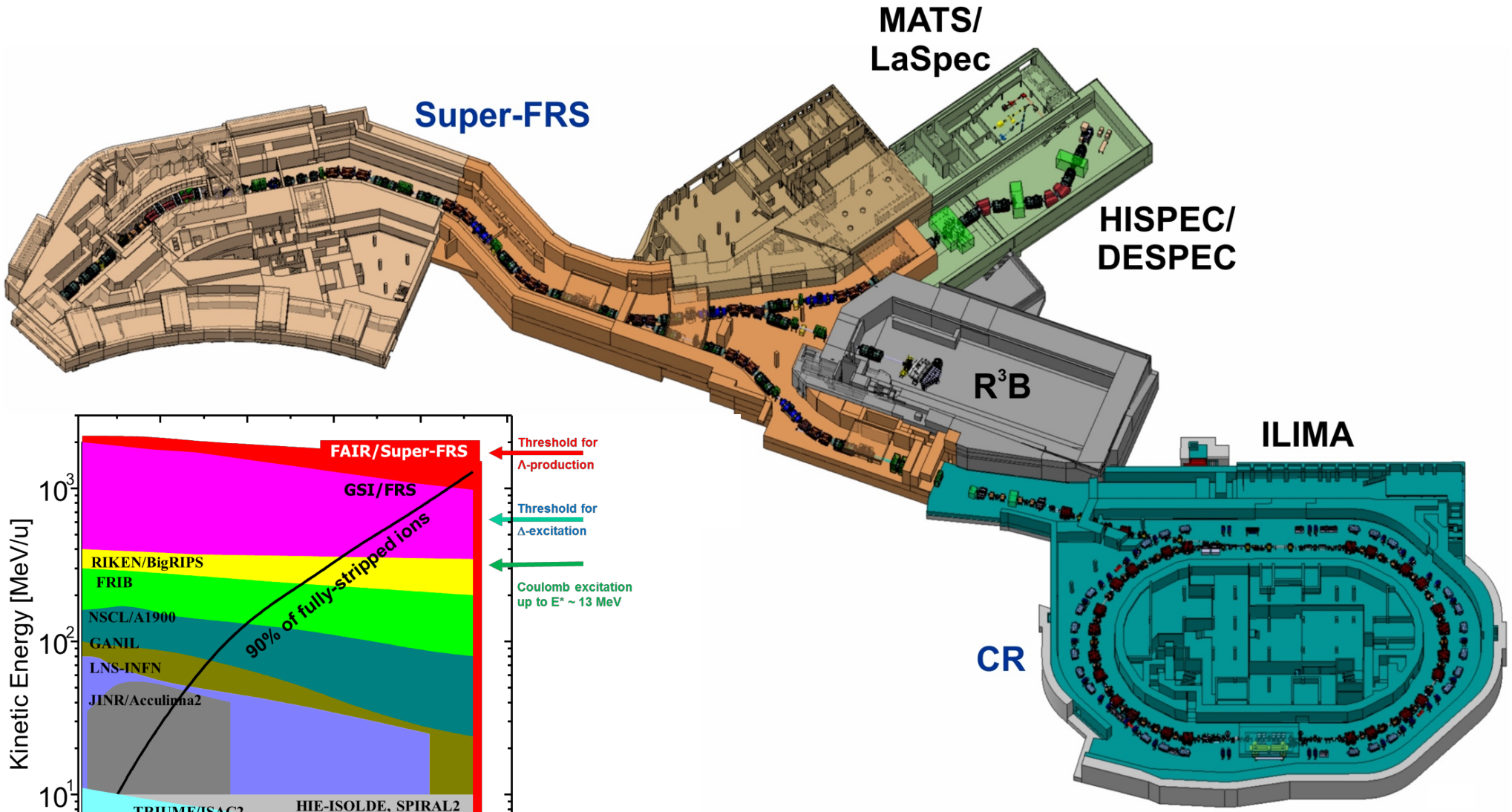
- The FAIR collaborations defined so-called **Day-1 configurations** that can be realized with the currently available funding and that will be used as soon as the SIS100 becomes operational.
- The **research programs enabled by the Day-1 configurations** define the FAIR science **to be assessed** at this time.

→ **Presentation of "Day-1" physics program (up to 5 years)** to the review committee (on Feb.5th)

Uniqueness of the NUSTAR Day-1 program

- **Understanding the 3rd r-process peak** by means of comprehensive measurements of lifetimes, masses, neutron emission probabilities, dipole strength, and the level structure along the **N=126 isotones**;
- **Equation of State (EoS) of asymmetric nuclear matter** by 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

The Super-FRS facility for NUSTAR@FAIR



World-wide highest energy RIB

Intensity gain of up to 10^3 compared to GSI

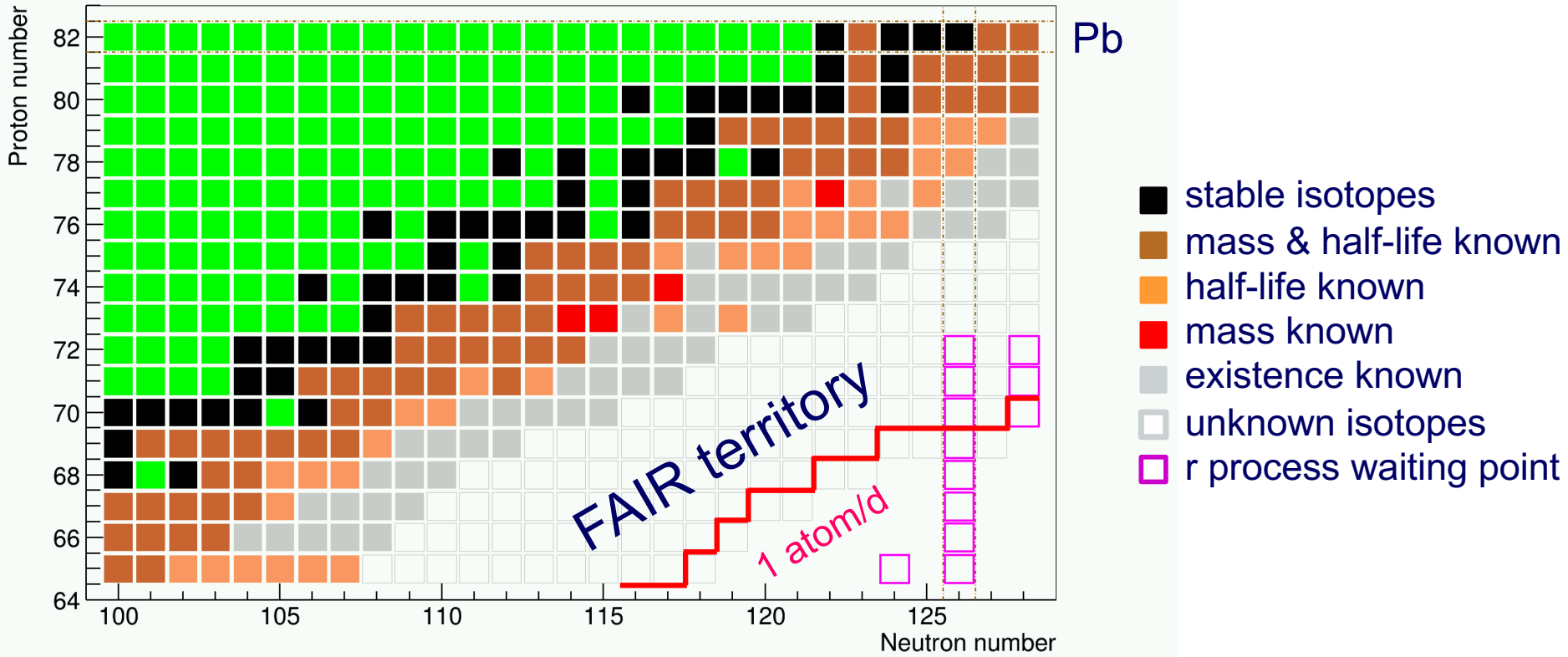
Competitiveness of NUSTAR

- RIB energies and Super-FRS performance
  - Competitive luminosity and highest purity, in particular for heavy isotopes (Z>70)
  - New excitation modes accessible (“hypernuclei”)
  - High-resolution spectrometer mode (at 20 Tm)
- Storage ring experiments
  - World-wide unique range from keV to GeV
  - Largely unrivalled experience
- New and improved instrumentation, e.g.,
  - R3B dipole magnet
  - Cryogenic Stopping Cell for low-energy beams

Search for new isotopes and their properties

Towards the r process waiting points at the N=126 shell closure

Understanding the **3rd r-process abundance peak** by studying neutron-rich isotopes towards the **N=126 shell closure** and their ground-state and decay properties



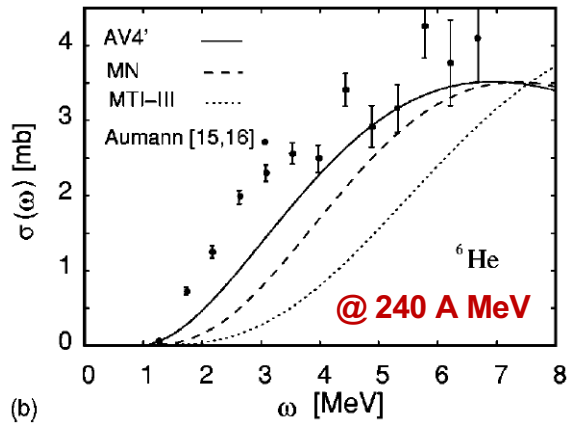
Each improvement (FRS → Super-FRS; SIS18 → SIS100) will brings us deeper into the unknown territory

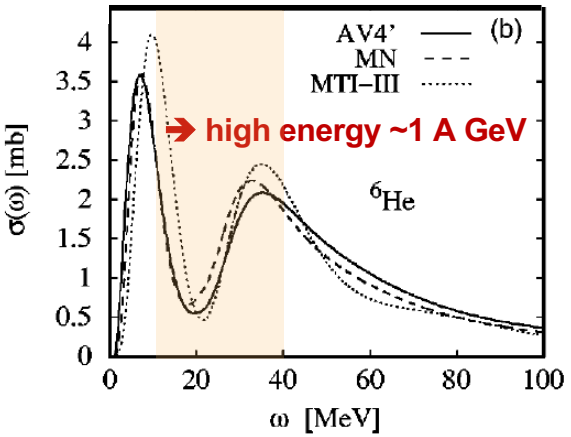
Dipole strength distributions in neutron-rich nuclei

Access to the Equation of State in neutron-rich nuclear matter

- Soft E1 excitation in ^{6}He : Core vs. neutron skins & halos → density / asymmetry

GSI

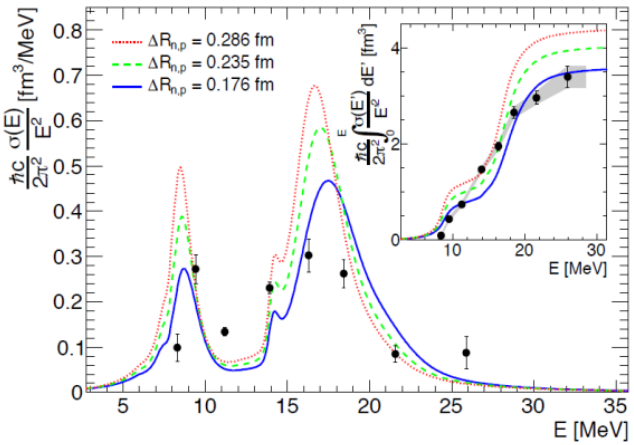




FAIR

S. Bacca et al.
PRL **89** (2002) 052502
PRC **69** (2004) 057001

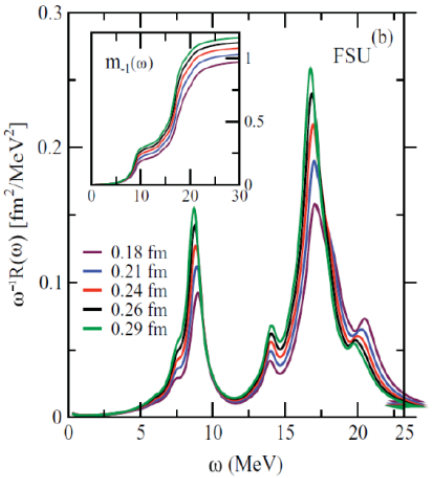
- low lying E1 strength in heavy neutron-rich nuclei (relevant for r-process cross sections)



$$\alpha_D = \frac{\hbar c}{2\pi^2}\int_0^\infty \frac{\sigma(E)}{E^2}dE$$

D. Rossi et al.
PRL **111** (2013) 242503

skin thickness **^{68}Ni**
0.175(21) fm



208+x Pb & N=126 isotones

~1 A GeV → bare ions Fragment identification

J. Piekarewicz, PRC **83** (2011) 034319

Exotic hypernuclei and their properties

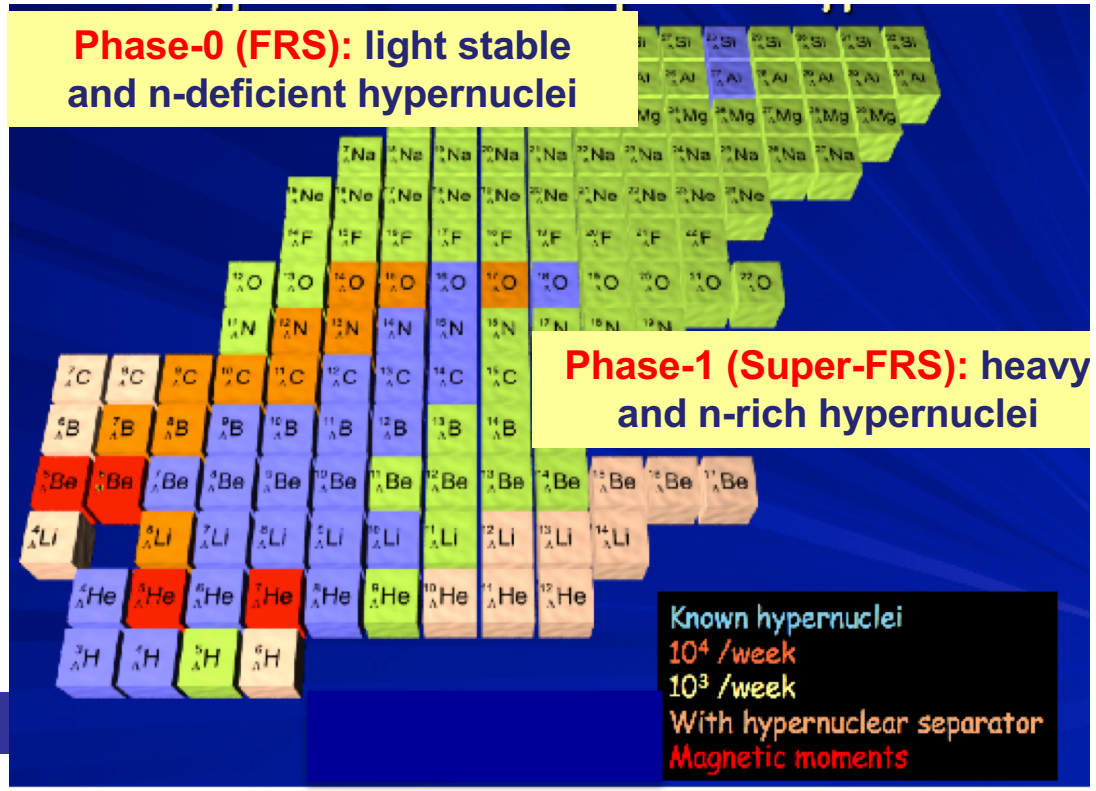
- Production of hypernuclei at high-energy (>1.8*A* GeV) heavy-ions peripheral collision is expected to have large cross sections.
- The method is also suitable for determination of lifetimes of hypernuclei via weak decay channel ($\Lambda_{free} \rightarrow p\pi^-$ or $n\pi^0$, τ~0.26 ns).

- **Pilot experiment at GSI (HypHI) shows evidence of $^3_\Lambda$H, $^4_\Lambda$H, $^3_\Lambda$n**
- Verify existence of **nnΛ** bound state
- Confirm short lifetime of **$^3_\Lambda$H**
- Future goals: Invariant mass spectroscopy of **proton-rich** and **neutron-rich hypernuclei**
- **Super-FRS in high-resolution mode** will lead to δE~1MeV

C.Rappold et al., Nucl. Phys. A913 (2013) 170

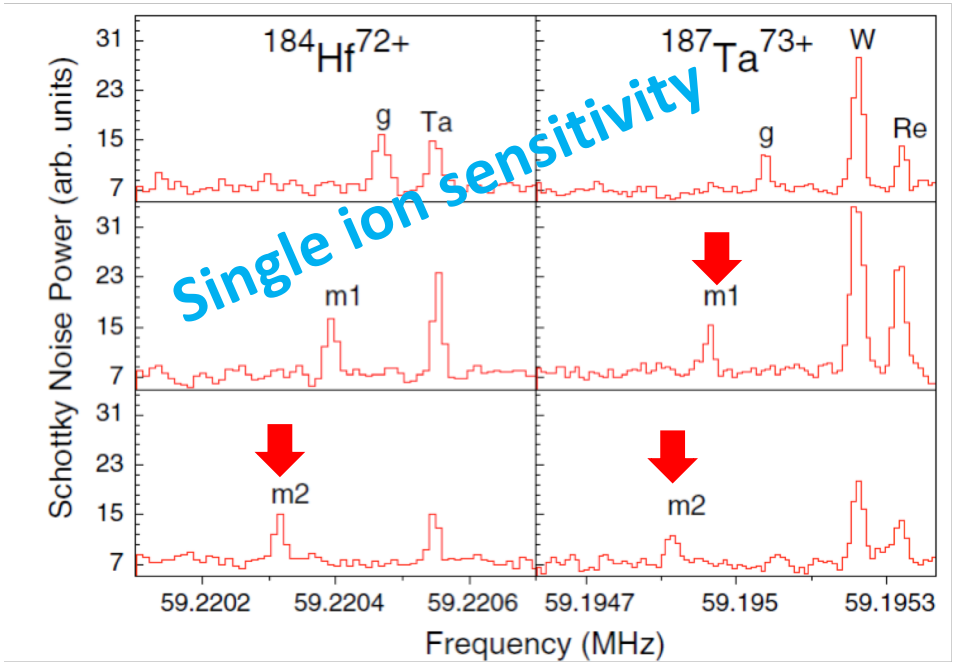
C.Rappold et al., Phys. Lett. B 728 (2014) 543

Strangeness sector of nuclear chart



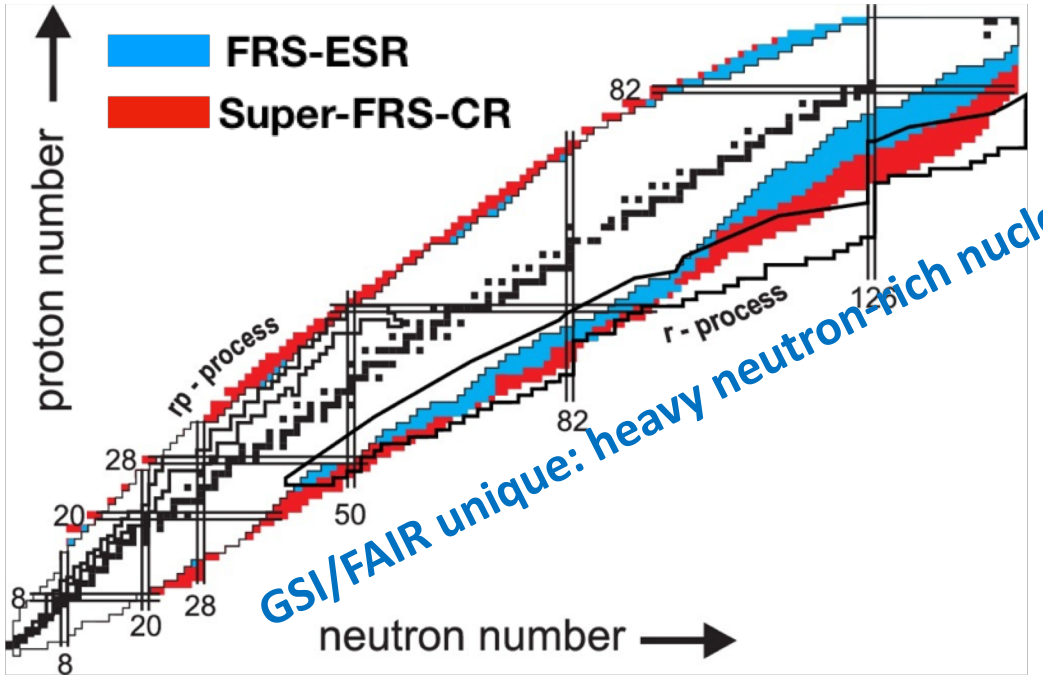
Physics with stored radioactive ion beams : Masses, isomers, reactions and exotic decays

Long-lived isomers in the Experimental Storage Ring: New isomers in $^{186-188}$Hf



M.W. Reed et al., PRL105 (2010) 172501
M.W. Reed et al., PRC86 (2012) 054321

Masses of more than 1000 in a single exp
Mass accuracy: 1.5 ·10^{-7}
Mass resolving power: 2 ·10^{6}
Results:
more than 300 new masses
more than 300 improved masses



Evolution of the FAIR/NUSTAR program

- **Phase 0 (2018-202x)**
  - R&D and experiments to be carried out with present facilities, e.g., GSI and external, with FAIR/NUSTAR equipment (basic set-ups)
- **Phase 1 (from 2024/25)**
  - Core detectors and subsystems completed (Day-1 configuration)
  - First measurements with FAIR/Super-FRS beams

➢ **Carry out "Day-1 experiments" with highest visibility and within the FAIR MSV**

- **Phase 2**
  - FAIR evolving towards full power
  - Completion of all 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.

The road towards FAIR MSV

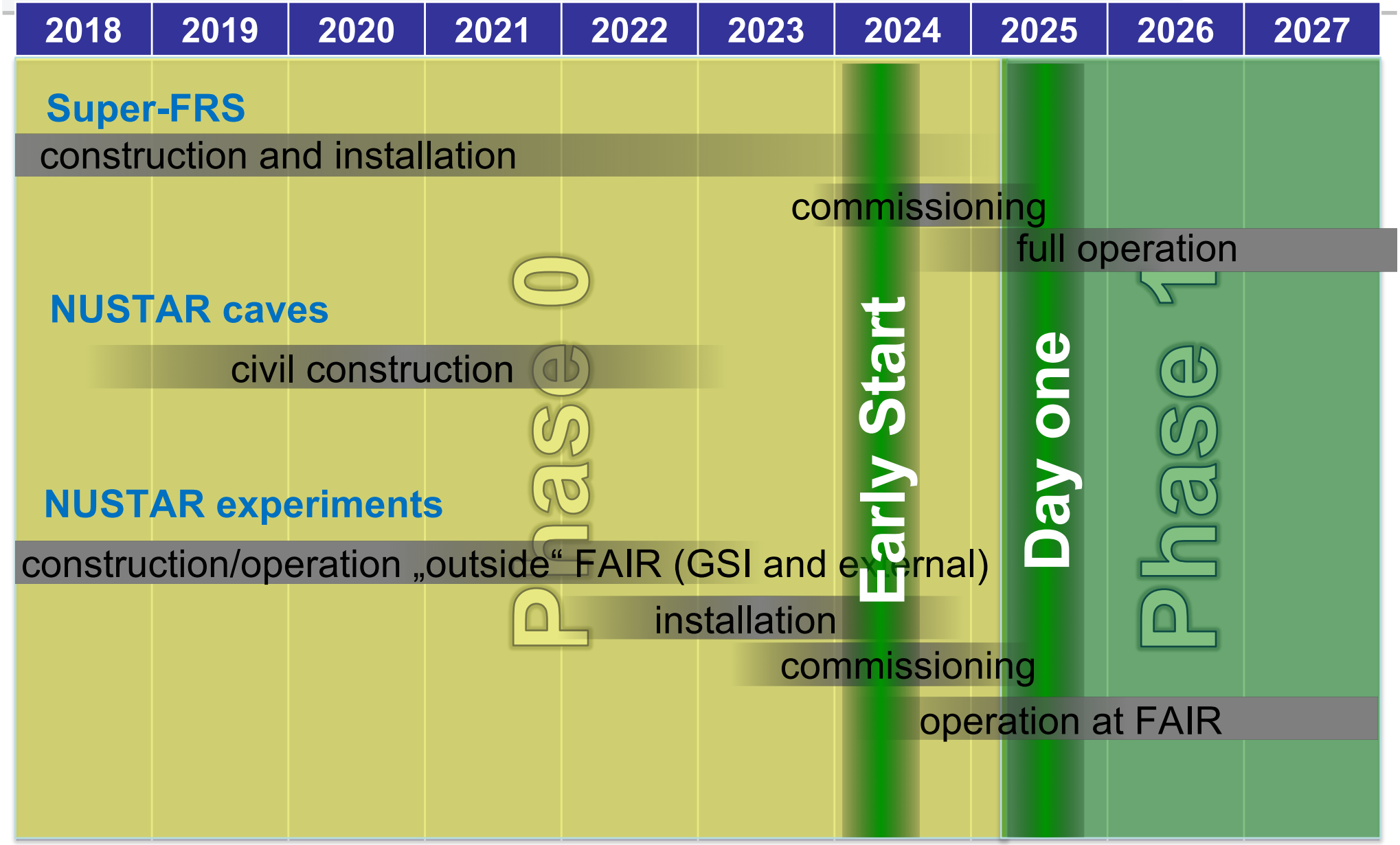
Facility	U beam intensity/spill at production target	Luminosity [fb^{-1}]
Today at GSI with **FRS** (Phase 0)	$1...2x10^{9}$	~0,1
Super-FRS with upgraded **SIS18**	$5x10^{9}$	1-2
Commissioning phase **SIS100**	$2x10^{10}$	5
Full final intensity with **SIS100**	$4x10^{11}$	100

Phase 0	→	**Day-1**	→	**Full MSV**
preparation	→	**discovery**	→	**detailed studies**
• **0.1 fb^{-1}**	→	**2-5 fb^{-1}**	→	**100 fb^{-1}**
• (near) stability	→	exotic	→	very exotic nuclei

NUSTAR Phase 0 program (2019-2x)

- All PAC approved experiments should be carried out in 2019-20
  - Status will be discussed in a dedicated session
- All FAIR pillars are asked to define **priority physics cases** (along unique features of GSI/FAIR)
  - Discussion within individual NUSTAR sub collaborations
  - Submission of updated NUSTAR physics case in summer 2019
  - Request to FAIR council to continue Phase-0 program (beyond 2020)
- Submission of new proposals for spring 2020 (?)
  - Discussion within individual NUSTAR collaborations
  - Presentation at the next NUSTAR week ?

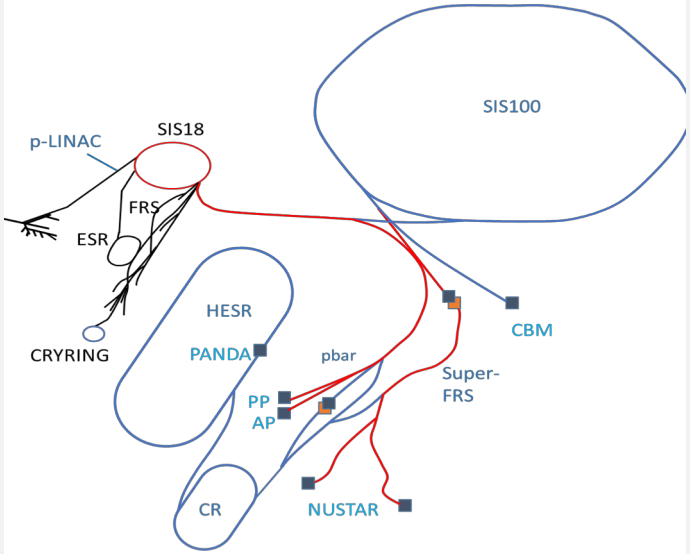
Towards NUSTAR Day-1



Start-of-operation opportunities for early FAIR MSV science with SIS18

„SIS18 to HESR“:

- In the current planning the **HESR** would be completed in 2023, but receive beams in early 2026. A connection from SIS18-Target Hall to HESR could allow for ion beams in early 2024.
- Science benefit: early physics in the areas **APPA/SPARC,** decay and (pilot) reaction studies for **NUSTAR**, and early testing and hadron physics at **PANDA**.
- Long-term benefit due to increased flexibility for parallel operation at FAIR
- Additional costs for this option: about **20 M€** for additional beamline
- No technical risks, depends on civil construction schedule
- CR building to be built for power supply to HESR



Interesting opportunities for early science both are viable in parallel. To be considered in defining the overall sequence of commissioning

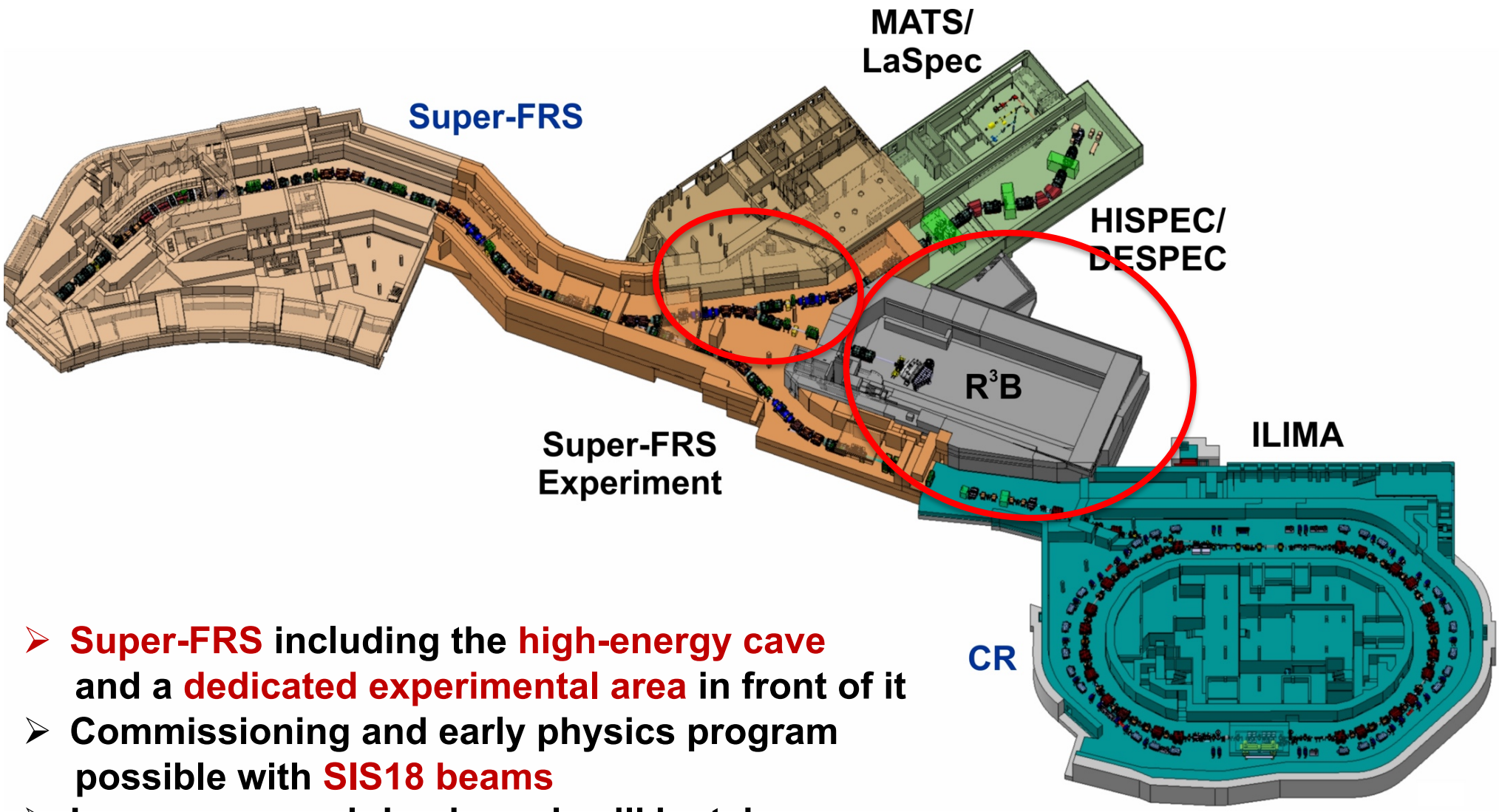
Will be evaluated again in 2-3 years

„SIS18 to Super-FRS & APPA“

- In the current planning the **Super-FRS** would be completed mid 2024 and get beam late 2025. The direct connection from SIS18 to **Super-FRS** and **APPA** would allow for **early operation in late 2024 or early 2025.**
- Science benefit: earlier start of NUSTAR experiments with exotic ion beams from **Super-FRS**, and of **APPA** experiments (Plasma and BioMAT research).
- No additional costs for this option,
- Some technical risks, but parallel commissioning of **Super-FRS** and **SIS100** (from mid 2024 ?)
- CR building to be built for power supply to SFRS

Adapted from P. Giubellino

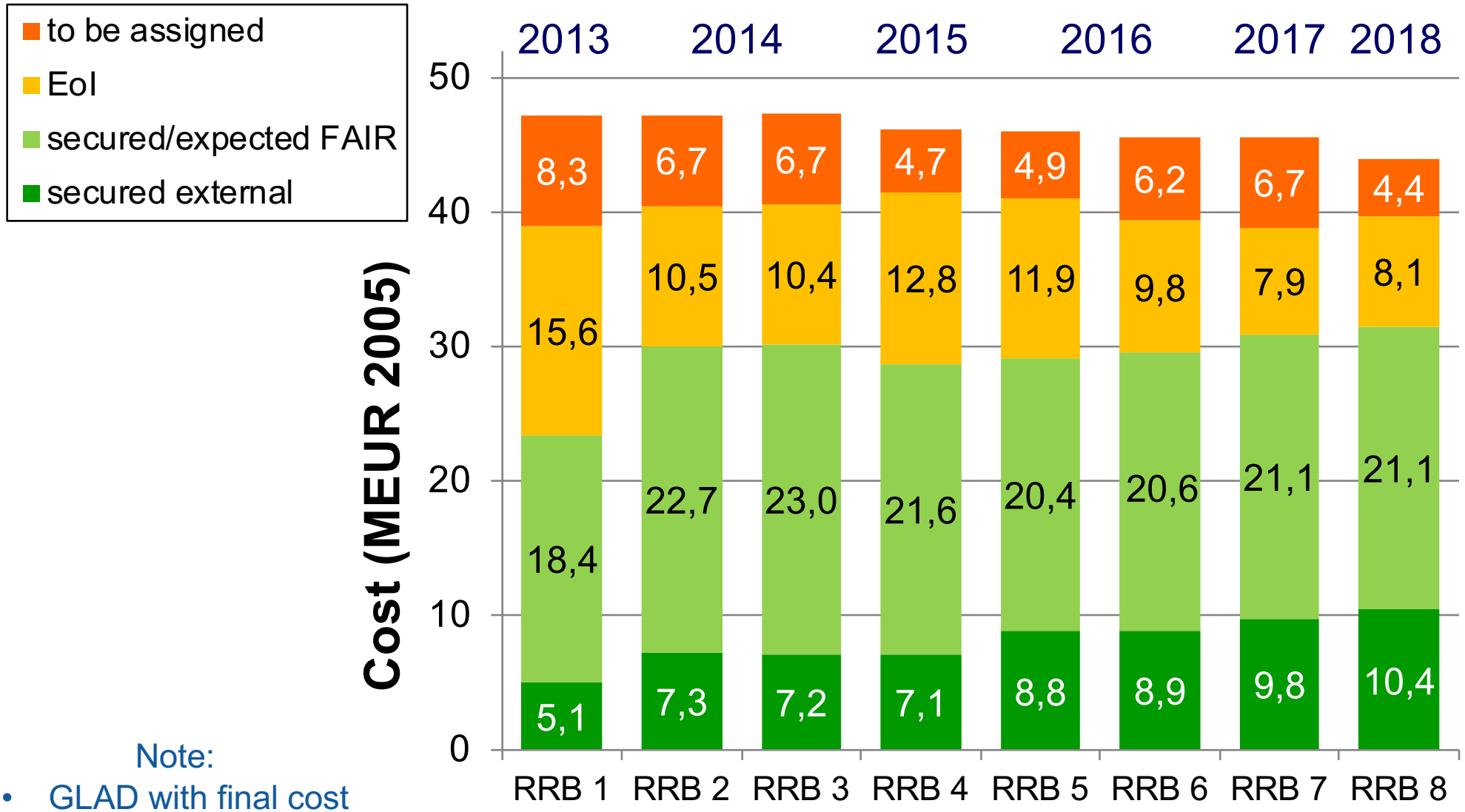
NUSTAR Early Implementation (2024)



- **Super-FRS** including the **high-energy cave** and a **dedicated experimental area** in front of it
- Commissioning and early physics program possible with **SIS18 beams**
- Low-energy and ring branch will be taken consecutively into operation, but should not be delayed

NUSTAR funding and organisation

Evolution of NUSTAR project funding (MSV)

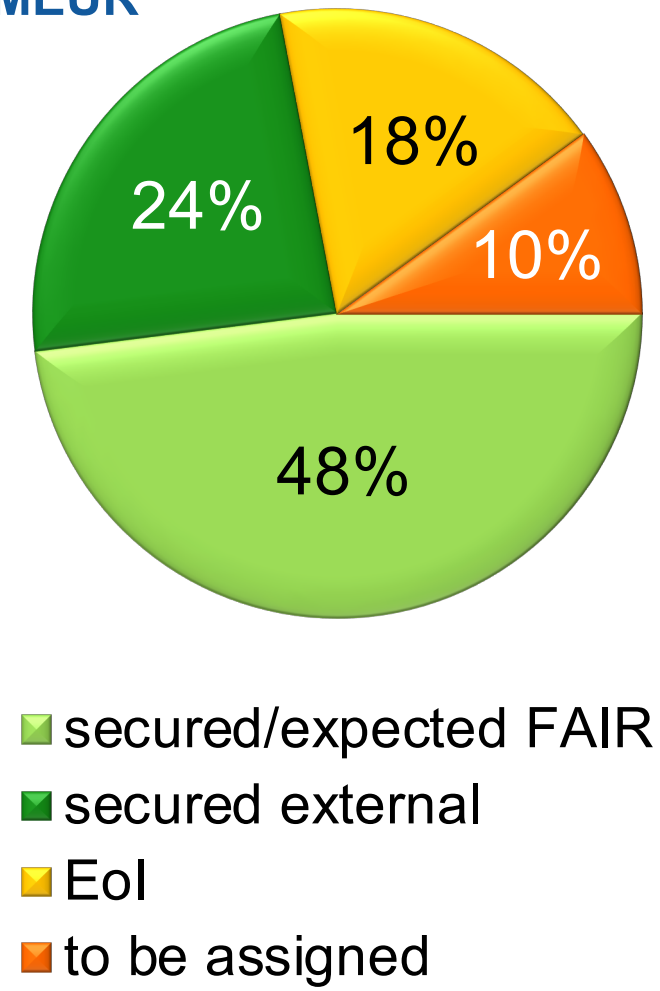


Note:

- GLAD with final cost
- UK included in FAIR

NUSTAR MSV – funding status

44.0 MEUR



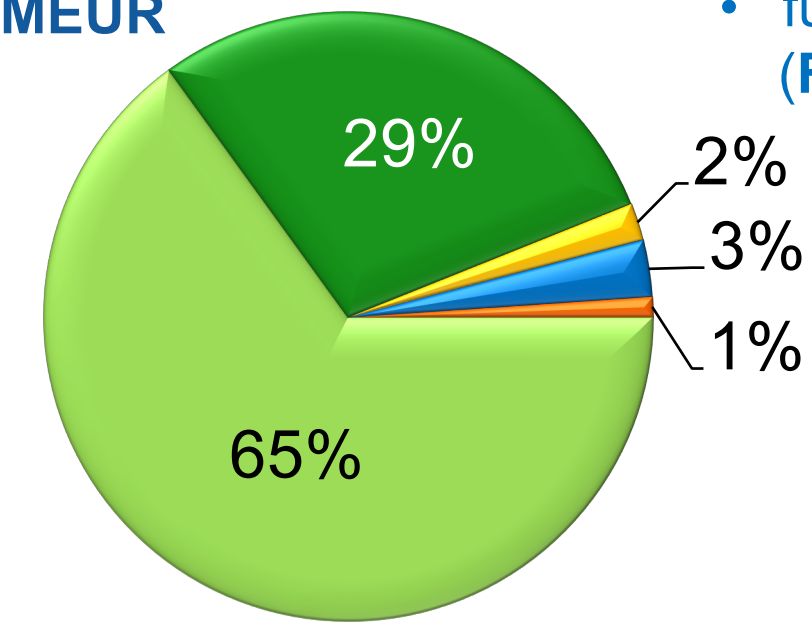
- funding (secured and expected) from:
  (**FAIR members/associates** in bold face)

Australia	Israel
Belgium	Netherlands
Bulgaria	**Poland**
Canada	**Romania**
Finland	**Russia**
France	Spain
Germany	**Sweden**
Hungary	Turkey
India	**United Kingdom**

Status: February 2019
Courtesy A. Herlert

Day-one configuration – funding status

32.5 MEUR



- funding (secured and expected) from:
  (**FAIR members/associates** in bold face)

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

Common Fund to be shared equally among NUSTAR members (with PhD)
➢ to be defined in the new MoU

Status: February 2019
Courtesy A. Herlert

New constitution of the NUSTAR Council

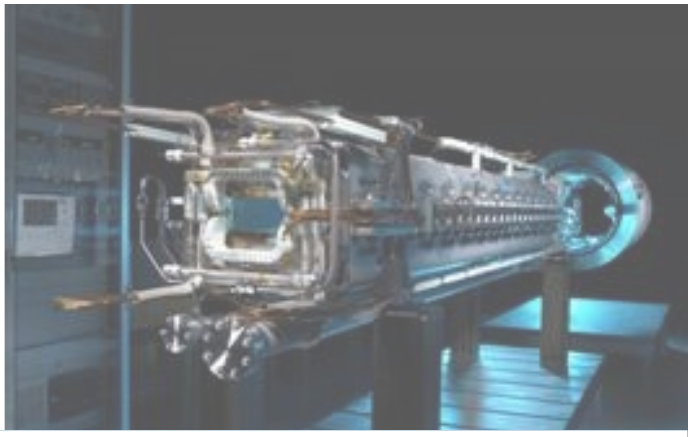
- New membership rules approved by present NUSTAR Council
  - By electronic vote
- New NUSTAR Council will constitute this week
- In brief – what are the new rules?
  - Any *secured* contribution to *any* of the sub-collaborations which goes beyond the threshold of 50 k€/sub-collaboration (2005 price) should result in a *voting right* in the council.
  - If funding is not yet secured: observer status
  - Any *manpower contribution* by any institute to NUSTAR which is equivalent to a minimum of 100 k€ or 2 FTE should result in a *voting right* in the council.
    - This would be a maximum of one representation in the council regardless of the number of sub-collaborations in which an institute is involved.
    - This amount is meant for personnel in the form of temporary scientific positions (graduate student or post-doc) but also technicians who would work for this amount for NUSTAR-related projects.

New Memorandum of Understanding

- General Conditions for Experiments
  - Draft version submitted to FAIR management in February 2018
  - Slightly modified version (April 2018) sent to AFC for discussion
  - Will be discussed at AFC meeting in May 2019
- MoU
  - Similar structure of the MoU for all FAIR experiments
    - NUSTAR MoU compared to the one from CBM and PANDA:
    - Slightly re-structure document (new ordering of articles)
    - Adapt annexes if needed
  - Updating NUSTAR organizational structures and procedures
  - Soon to be discussed within NUSTAR BR
  - MoU for CBM presented as blueprint at the last FAIR-RRB meeting
  - NUSTAR Common Fund of ~1MEuro (still to be clarified with member countries)

Conclusions

- All **NUSTAR** experiments will be ready with their principal equipment for **Day-1 experiments**, that is as soon as
  - **first beams from the Super-FRS will become available**
- **NUSTAR** will be **world-wide competitive** due to the unique properties of the **accelerators** (energy, intensity), the **Super-FRS** (transmission, rejection, resolution), the **storage rings** and other **new instrumentation**
- **Uniqueness of the NUSTAR Day-1 research program:**
  - **New isotopes and ground state properties relevant for the r-process**
  - **Evolution of the nuclear structure very far from stability**
  - **Equation of State (EoS) of asymmetric matter**
  - **Exotic nuclear matter (Hypernuclei, nucleonic excitations, …)**



Thank you for your attention

NUSTAR Annual Meeting

Darmstadt, Germany, February 27th, 2019

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

FAIR