

# Exploring the extremes with NUSTAR @ FAIR

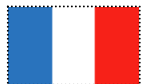
*Nasser Kalantar-Nayestanaki  
KVI-CART/University of Groningen*

**NUSTAR week 2015**

Warsaw, Poland, September 28, 2015



Finland



France



Germany



India



Poland



Romania



Russia



Slovenia



Sweden



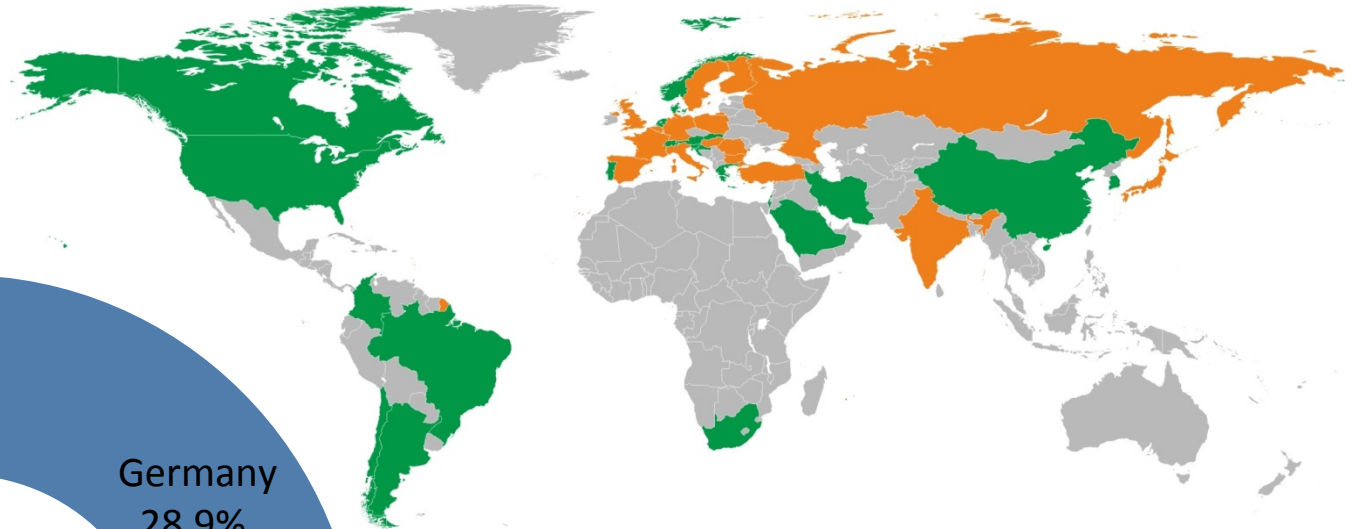
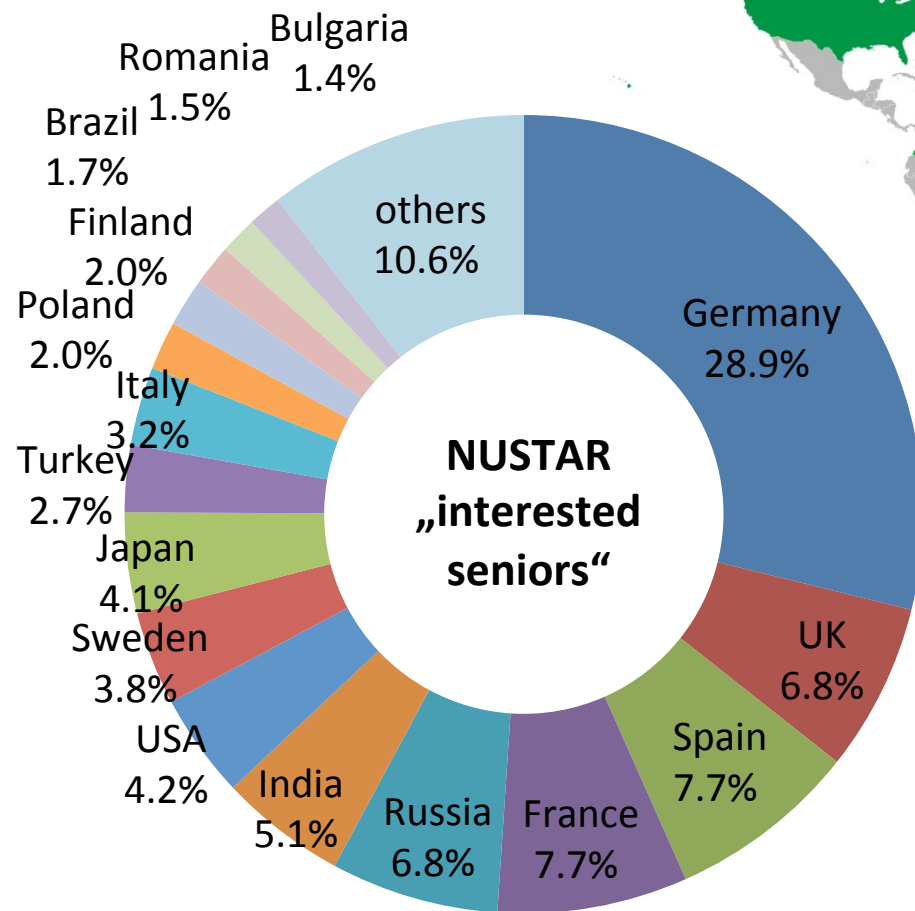
UK



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# NUSTAR collaboration

# NUSTAR Collaboration



> 800 registered “interested”  
scientists in NUSTAR data base

39 countries

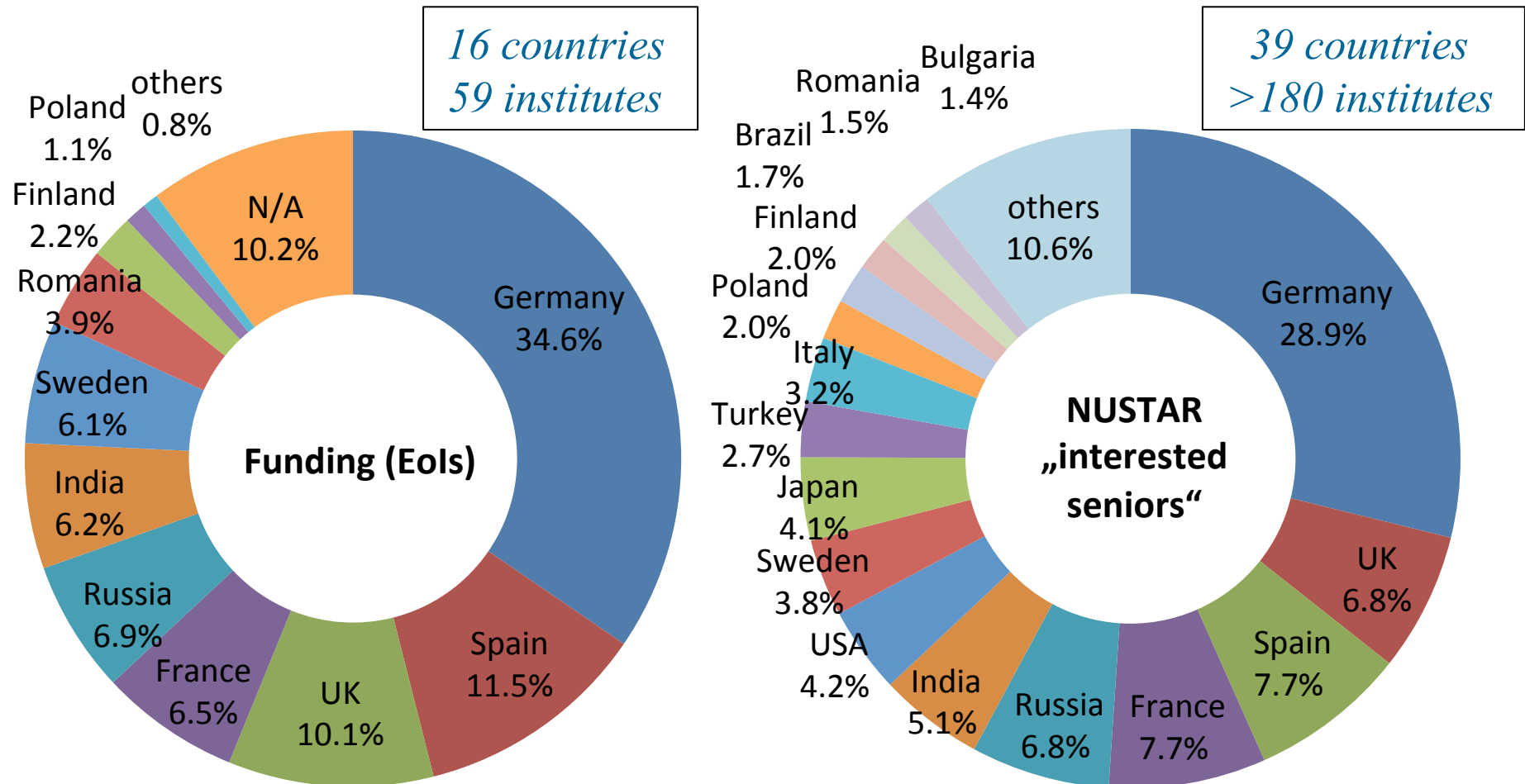
more than 180 institutes

Secured funding and expression of  
interest in funding

(status: January 2015)

16 countries (incl. 10 FAIR partner  
countries)

# Comparison: funding vs. senior scientists



Finland



France



Germany



India



Poland



Romania



Russia



Slovenia



Sweden



UK

# NUSTAR - The Project 1.2



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

(\*) **NESR required** – alternative/intermediate “operation” within MSV under discussion.  
SHE physics case is being evaluated by ECE.

# Previous meetings

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NUSTAR Week 2009 (Dubna, Russia)

NUSTAR Week 2010 (Lund, Sweden)

NUSTAR Week 2011 (Bucharest, Romania)

NUSTAR Week 2012 (Kolkata, India)

NUSTAR Week 2013 (Helsinki, Finland)

NUSTAR Week 2014 (Valencia, Spain)

**This week**

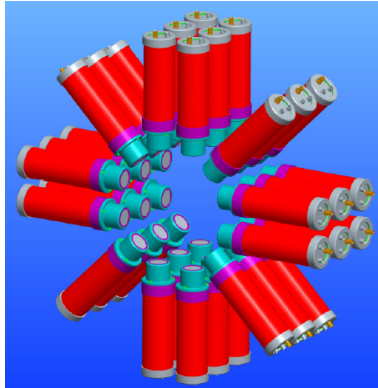
NUSTAR Week 2015 (Warsaw, Poland)

**Next year**

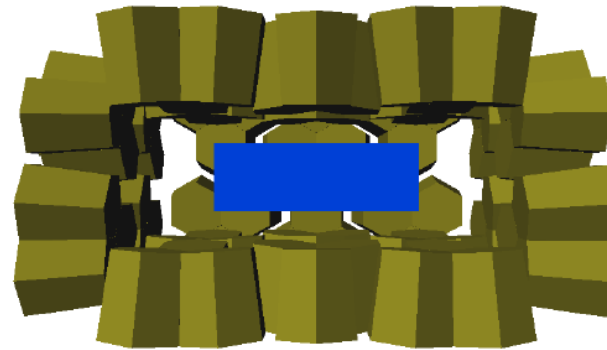
NUSTAR Week 2016 (York, UK)

# TDRs approved (6<sup>th</sup> ECE meeting)

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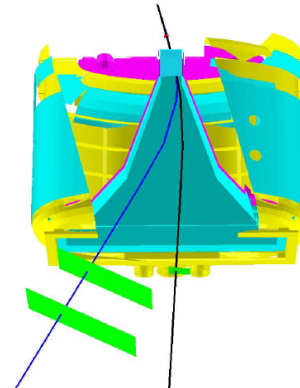
FATIMA  
(fast timing array)



DEGAS  
(DESPEC Germanium Array Spectrometer)



CALIFA  
forward endcap

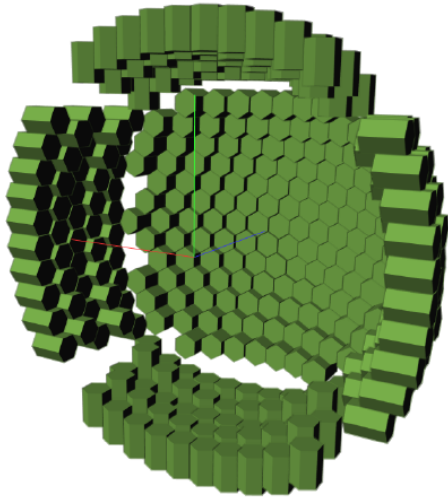


R3B tracking detectors



# TDRs under evaluation (submitted)

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NEDA

(Neutron detector array for HISPEC)

submitted September 2014

Final round of evaluation

ECE waiting for resubmission



ACTAR

(Active target for the R<sup>3</sup>B experiment)

submitted September 2015

Next ECE meeting in January 2016



# Status Technical Design Reports (34 TDRs)

- Approved TDRs (15):
  - HISPEC/DESPEC (8): LYCCA, Plunger, AIDA, BELEN, MONSTER, DTAS, DEGAS, FATIMA
  - MATS + LaSpec (1): all subsystems
  - R<sup>3</sup>B (6): Multiplet, NeuLAND, CALIFA-barrel, CALIFA forward endcap, GLAD, tracking detectors
- Submitted (3):
  - HISPEC/DESPEC (2): AGATA, NEDA
  - R<sup>3</sup>B (1): Active target
  - AGATA treated as special case

TDRs expected (16) (submission profile – August 2015)				
2014	2015	2016	2017	2018
0	8	8	0	0

# NUSTAR work packages (63 with TDR)

ILIMA	R <sup>3</sup> B	LaSpec	MATS	HISPEC/ DESPEC		
1.2.6.1		1.2.4.1	1.2.3.1	1.2.2.1		
1.2.6.3		1.2.4.2	1.2.3.2	1.2.2.2		
1.2.6.4		1.2.4.3	1.2.3.3	1.2.2.3		
1.2.6.5		1.2.4.4	1.2.3.4	1.2.2.4		
1.2.6.6		1.2.4.5	1.2.3.5	1.2.2.5		
		1.2.4.7	1.2.3.6	1.2.2.6		
		1.2.4.8	1.2.3.7	1.2.2.7.1		
			1.2.3.8.1	1.2.2.7.2		
			1.2.3.8.2	1.2.2.8		
			1.2.3.8.3	1.2.2.9		
				1.2.2.10		
				1.2.2.11		
				1.2.2.13		
				1.2.2.14		
				1.2.2.15		
				1.2.2.16.1		
				1.2.2.16.2		
				1.2.2.16.3		
				1.2.2.17		
				1.2.2.18		

TDR approved
  TDR submitted
  TDR in preparation
  No TDR expected

# In-kind contributions to experiments (FAIR)

Status as of FAIR Council meeting #16 (June/July 2015)

Country	Contribution (in MEUR 2005)	Budget for NUSTAR (in MEUR 2005)	Expected in addition (in MEUR 2005)
Finland	1.300	0.454	0.000
France	2.530	2.530	0.000
Germany	25.100	6.020	0.000
India	5.800	0.375	1.075
Poland	5.700	0.500	0.000
Romania	4.000	1.820	0.000
Russia	24.270	1.000	2.185
Slovenia	0.000	0.000	0.000
Sweden	4.300	1.575	0.000
UK	5.000	4.500	0.000
Total	78.000	18.774	3.260

latest changes:

- Finland want to provide in-kind (MATS and LaSpec)
- Clarification of Indian contributions (DEGAS and MONSTER)
- Additional Russian contributions (submit as soon as well defined for Council)

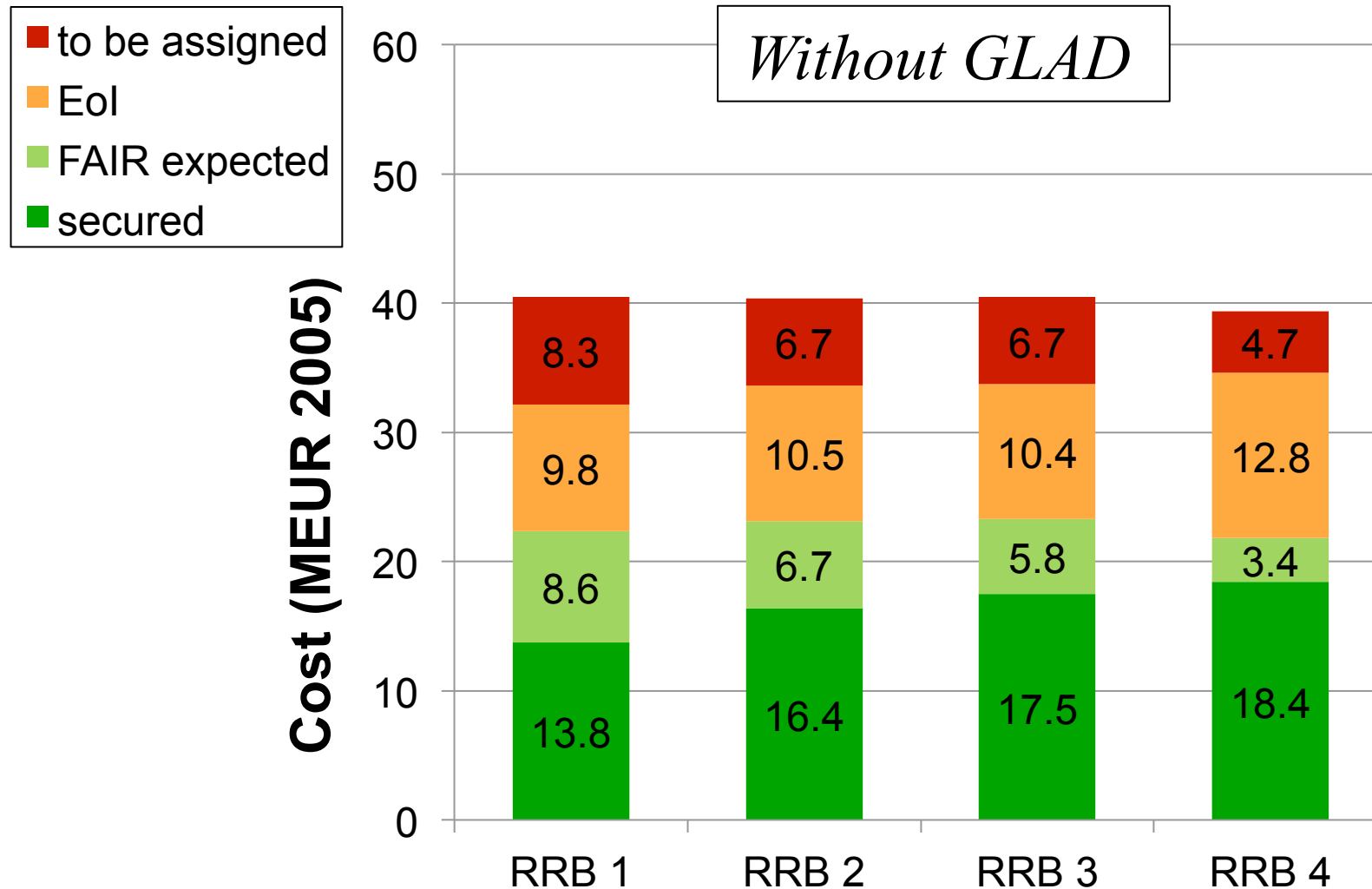
# Funding

Status experiment funding (NUSTAR) - January 12, 2015

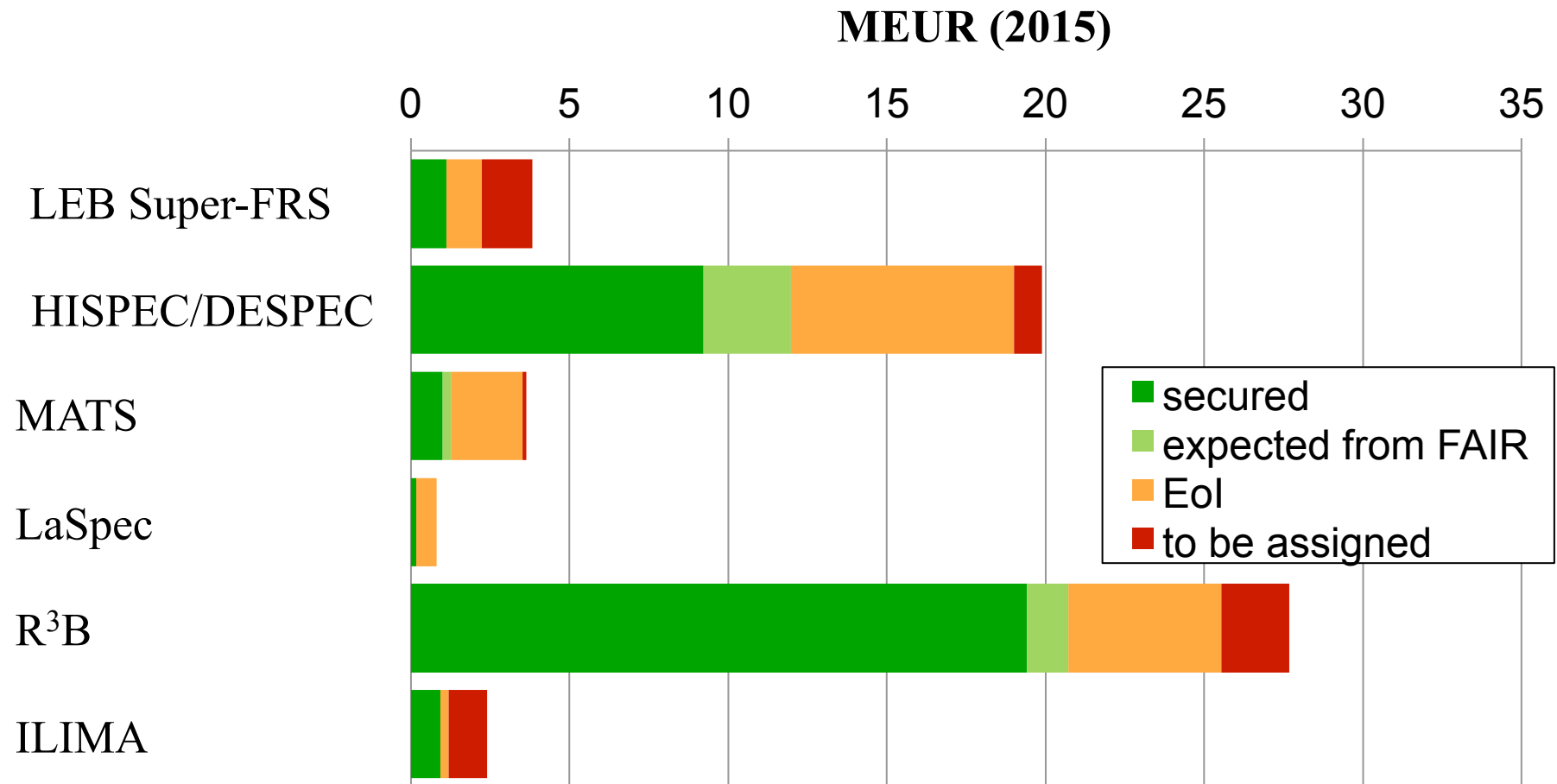
PSP code	Experiment/Project	Prices (KEUR in 2005)					
		Estimated cost	Secured amount	Expected FAIR	Amount spent	Eol	To be assigned
1.2.1	LEB Super-FRS	3050	886	0	0	885	1280
1.2.2	HISPEC/DESPEC	15773	7322	2184	3436	5564	705
1.2.3	MATS	2893	795	206	760	1804	87
1.2.4	LaSpec	640	144	0	144	496	0
1.2.5	R3B	21961	15400	1039	12460	3828	1696
1.2.6	ILIMA	1902	740	0	0	212	950
<b>Sum</b>		<b>46219</b>	<b>25287</b>	<b>3429</b>	<b>16800</b>	<b>12789</b>	<b>4718</b>

NUSTAR		54.7%	7.4%	36.3%	27.7%	10.2%
1.2.1	LEB Super-FRS	29.0%	0.0%	0.0%	29.0%	42.0%
1.2.2	HISPEC/DESPEC	46.4%	13.8%	21.8%	35.3%	4.5%
1.2.3	MATS	27.5%	7.1%	26.3%	62.4%	3.0%
1.2.4	LaSpec	22.5%	0.0%	22.5%	77.5%	0.0%
1.2.5	R3B	70.1%	4.7%	56.7%	17.4%	7.7%
1.2.6	ILIMA	38.9%	0.0%	0.0%	11.1%	49.9%

# Evolution of NUSTAR project funding (RRBs)



# Status of NUSTAR experiment funding



# NUSTAR MoU

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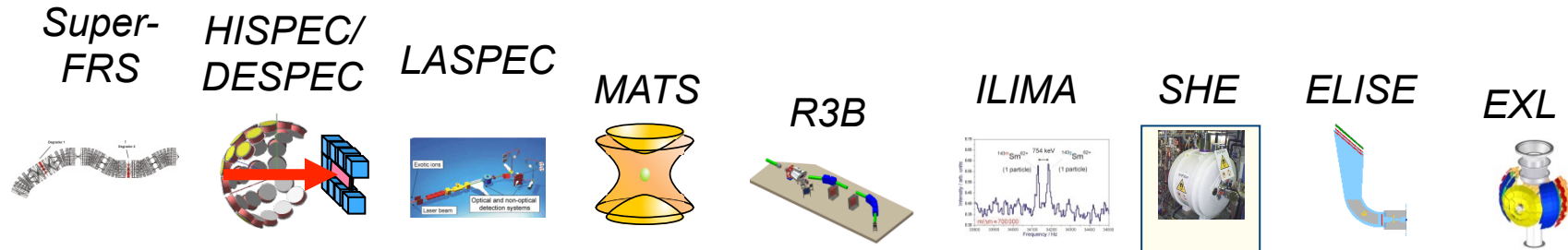
- Recent developments
  - New NUSTAR organizational structures
    - NUSTAR Council Chair (to be elected end of 2015)
    - New definition of Council membership (ongoing)
  - Work on NUSTAR database ongoing
    - Additional structure for teams within institutes
  - Present roadmap:
    - Final version **expected in 2016** (ready for signature)



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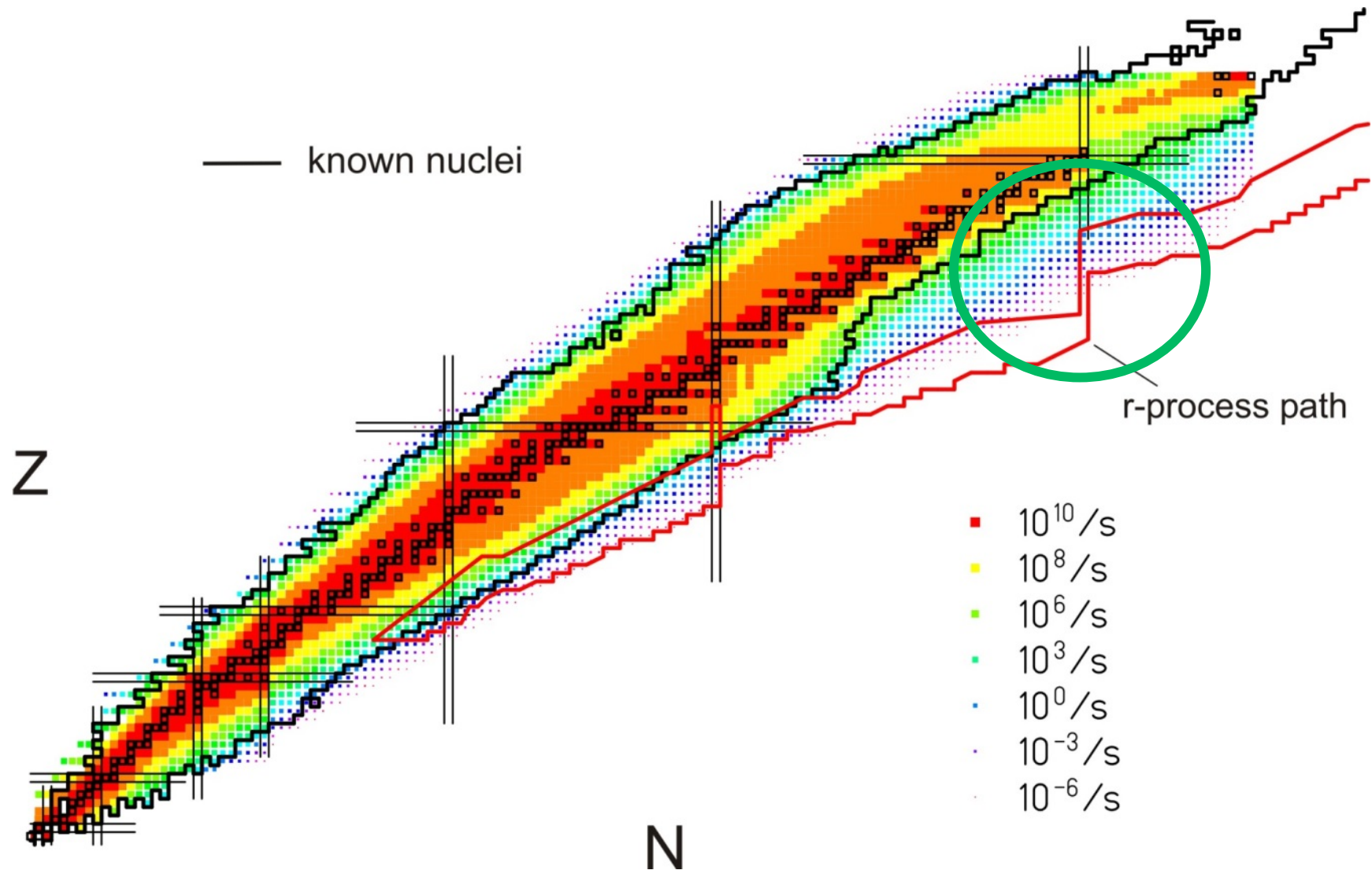
# Reminder of the Physics

# Complementarity of NUSTAR experiments



	Super-FRS	HISPEC/DESPEC	LASPEC	MATS	R3B	ILIMA	SHE	ELISE	EXL
<b>Masses</b>		Q-values, isomers		dressed ions, highest precision	unbound nuclei	bare ions, mapping study	precision mass of SHEs		
<b>Half-lives</b>	ps...ns-range	dressed ions, $\mu$ s...s			resonance width, decay up to 100ns	bare ions, ms...years	$\mu$ s...days		
<b>Matter radii</b>	interaction x-section				interaction x-section				matter density distribution
<b>Charge radii</b>	charge-changing cross sections		mean square radii		charge-changing cross sections			charge density distribution	
<b>Single-particle structure</b>	high resolution, angular momentum	high-resolution particle and $\gamma$ -ray spectroscopy	magnetic moments, nucl. spins	evolution of shell str., pairing int., valence nucl.	quasi-free knockout, short-range and tensor	evolution of shell closures, pairing corr.	shell structure of SHEs		low momentum transfers
<b>Collective behavior</b>		electromag. transitions	quadrupole moments	halo structure	dipole response	changes in deformation		electromag. transitions	monopole resonance
<b>EoS</b>					polarizability, neutron skin			neutron skin $\rightarrow$	neutron skin, Compressibility
<b>Exotic Systems</b>	bound mesons, hypernuclei, nucleon res.								

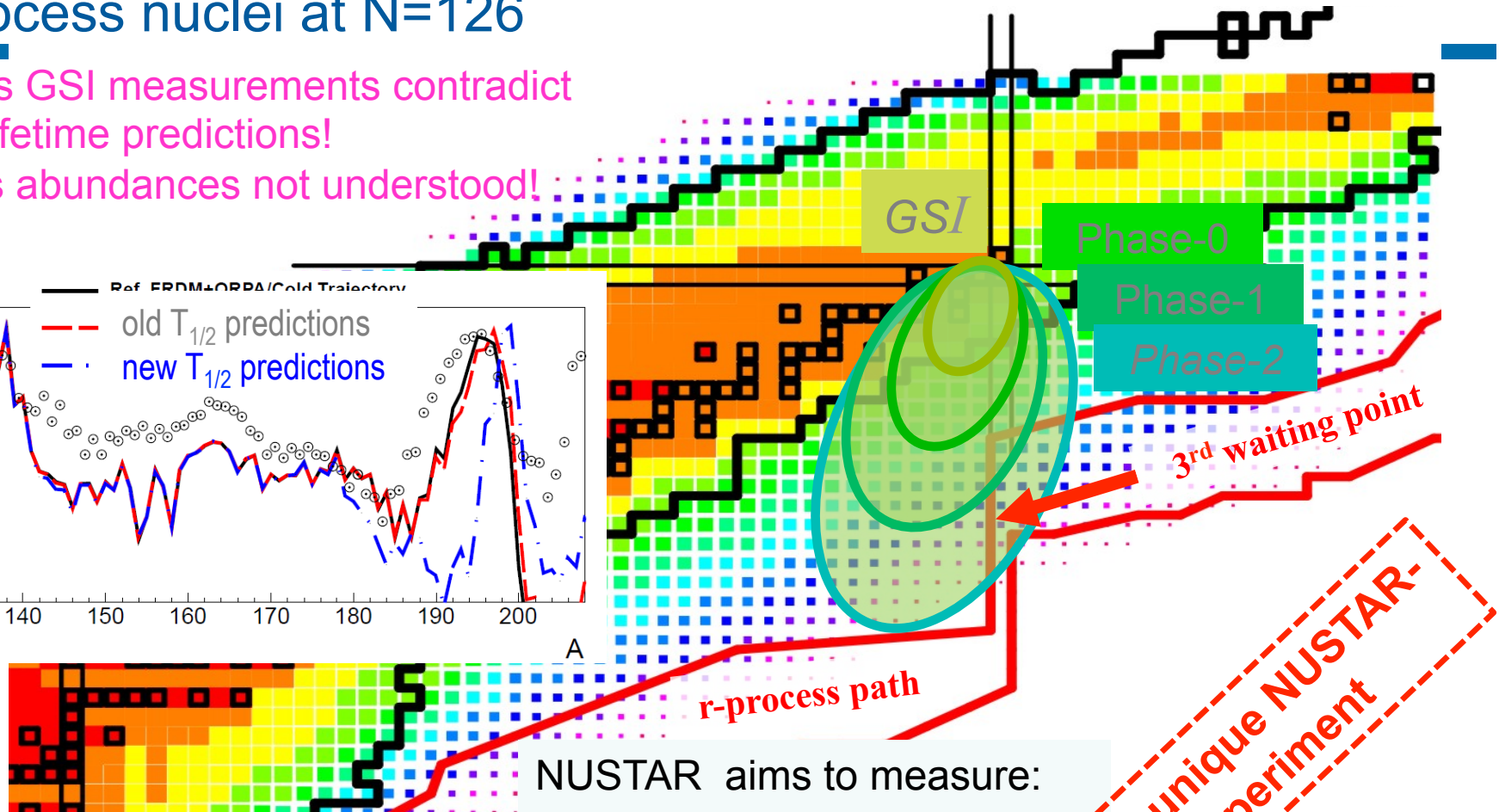
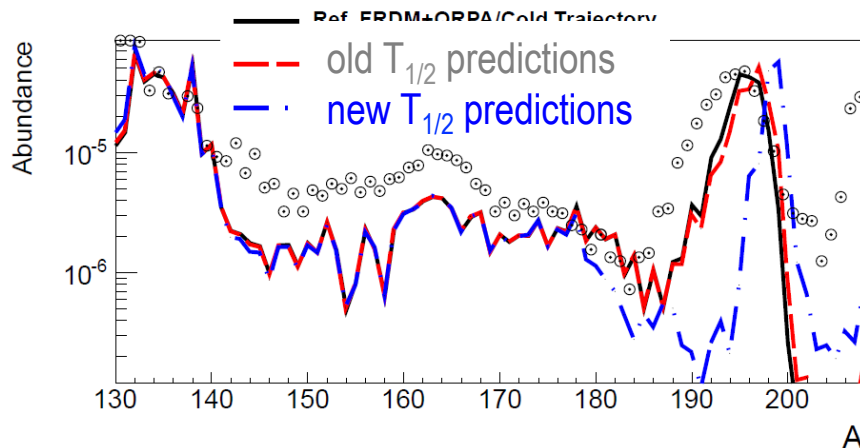
# Physics case



# Phase 1 Physics with HISPEC/DESPEC: r-process nuclei at N=126

Previous GSI measurements contradict  
earlier lifetime predictions!

→ Mass abundances not understood!



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

NUSTAR aims to measure:

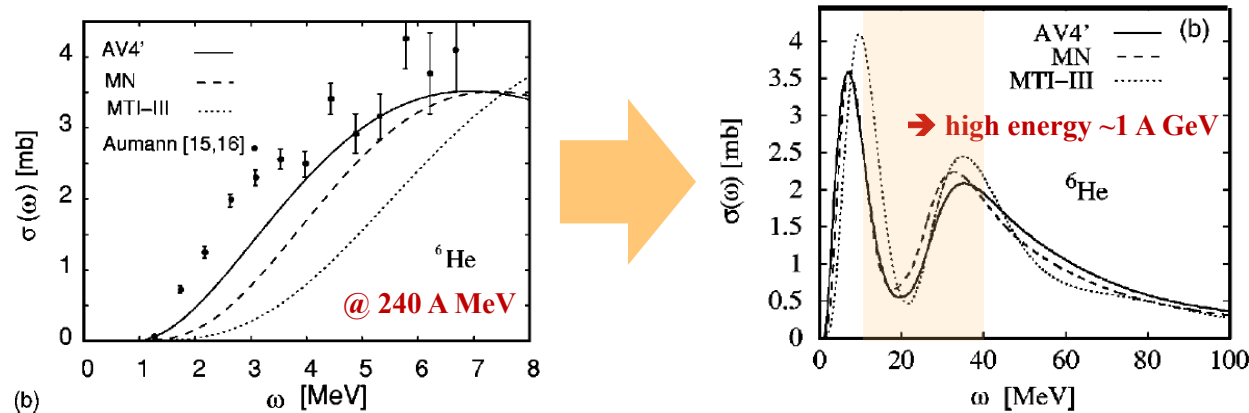
- masses
- $\beta$ -lifetimes
- neutron-branchings
- strength distributions
- level structure

Important unique NUSTAR-  
LEB experiment

# Phase 1 Physics with R3B setup:

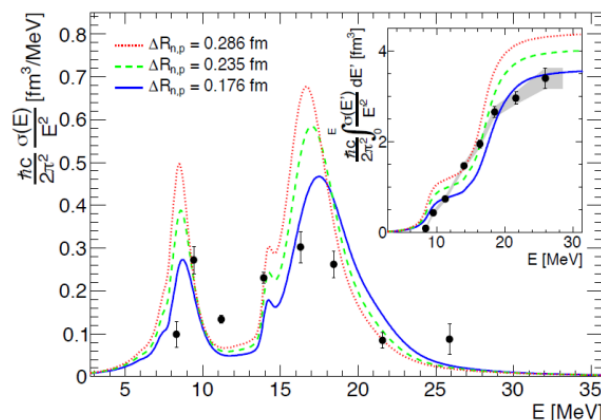
## Dipole strength Distributions in heavy neutron-rich nuclei

- core vs. neutron skins & halos → density / asymmetry



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

- access to EoS (e.g. neutron star) & low lying E1 strength (r-process)

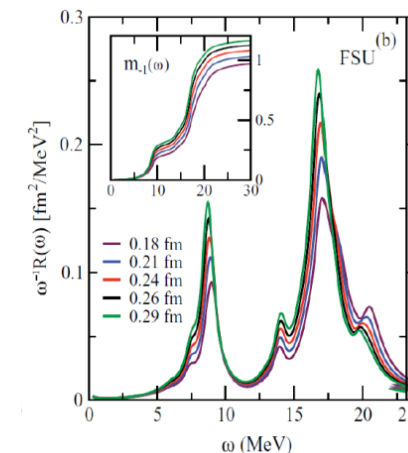


D. Rossi et al.  
PRL **111** (2013) 242503

skin thickness  $^{68}\text{Ni}$   
0.175(21) fm

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

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

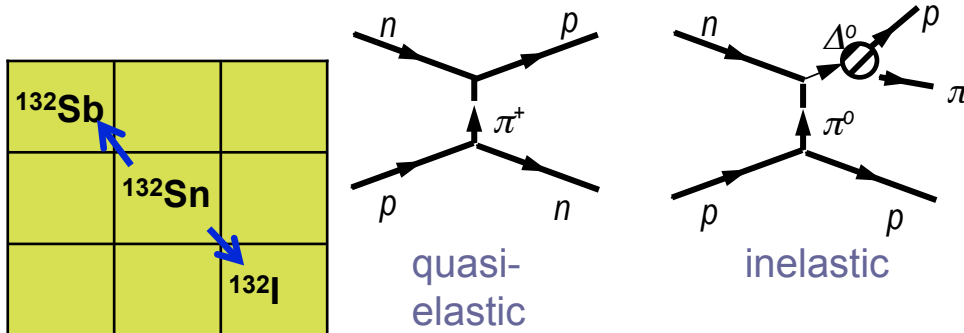


**Pb chain &  
N=126 isotones**

**~1 A GeV →**  
bare ions  
Fragment  
identification

# Phase 1 Physics with high-resolution spectrometer: Nucleon resonances in asymmetric nuclear matter

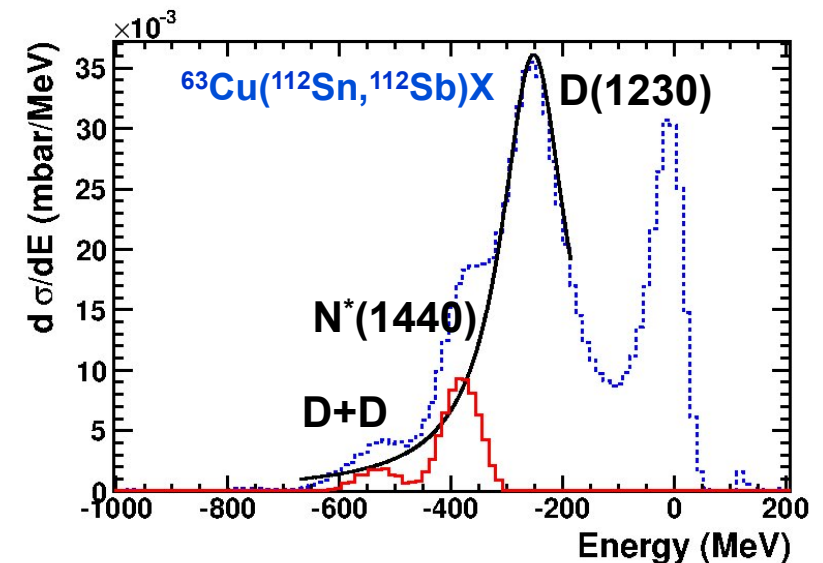
## Isobaric charge exchange reactions



Relativistic neutron-rich projectiles ( $>600$  MeV/u)  
High-resolving power spectrometer  
 $\rightarrow$  Pilot experiments with stable beams at FRS/GSI in 2017+  
 $\rightarrow$  Experiments with asymmetric nuclear beams at Super-FRS/FAIR

## Physics case

- ✓ Nuclear Structure Physics with the excited nucleon.
- ✓ In-medium baryon resonances.
- ✓ Role of nucleon excitations in massive neutron stars.
- ✓ Constraining the symmetry energy  $s(n,p)/s(p,n)$



The momentum recoil induced by the pion emission proves the excitation of the resonances

# What are the highlights of MSV day-1 program?

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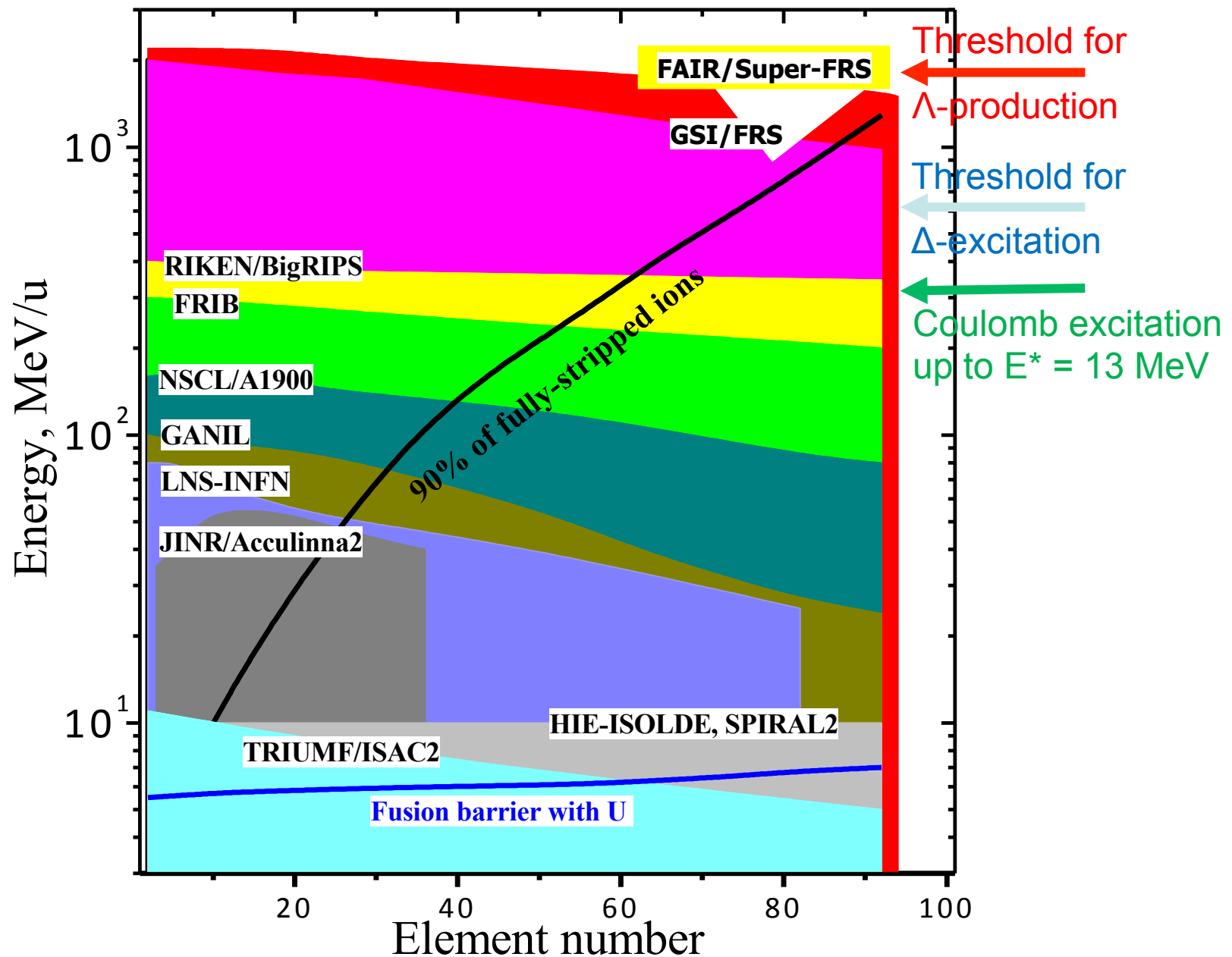
- Understanding the 3<sup>rd</sup> r-process peak by means of comprehensive measurements of masses, lifetimes, neutron branchings, dipole strength, and level structure along the N=126 isotones;
- Equation of State (EoS) of asymmetric matter by means of measuring the dipole polarizability and neutron skin thicknesses of tin isotopes with N larger than 82 (in combination to the results of the first highlight);
- Exotic hypernuclei with very large N/Z asymmetry.



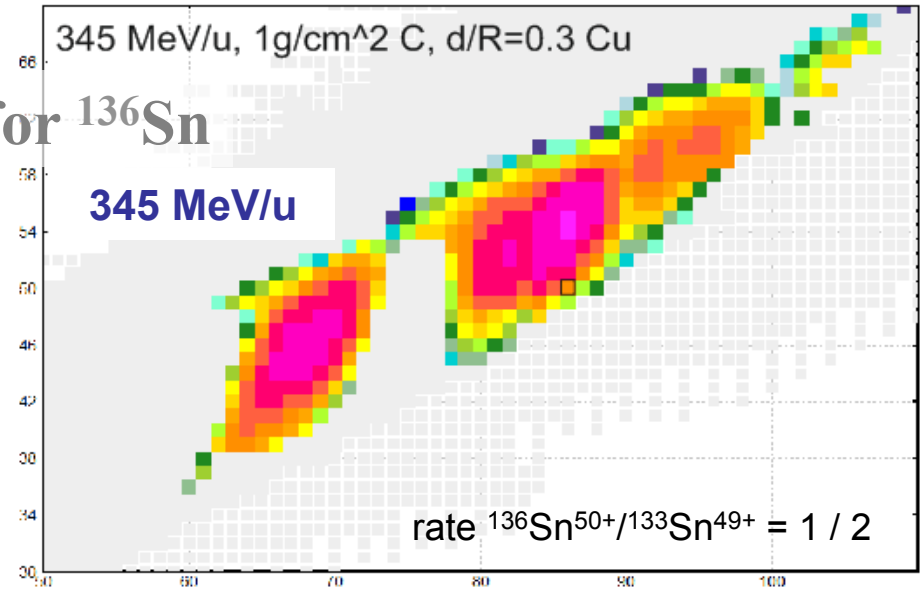
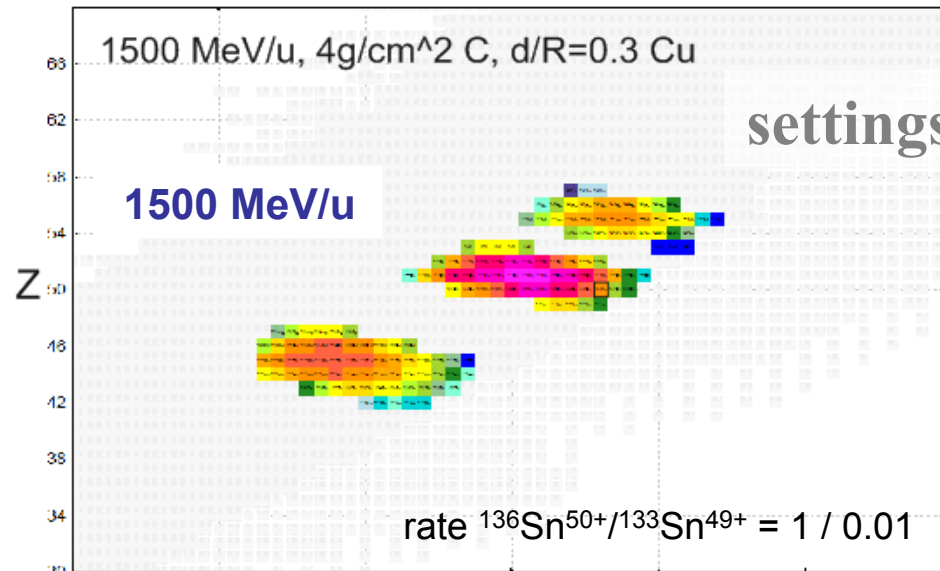
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“PARTS” needed

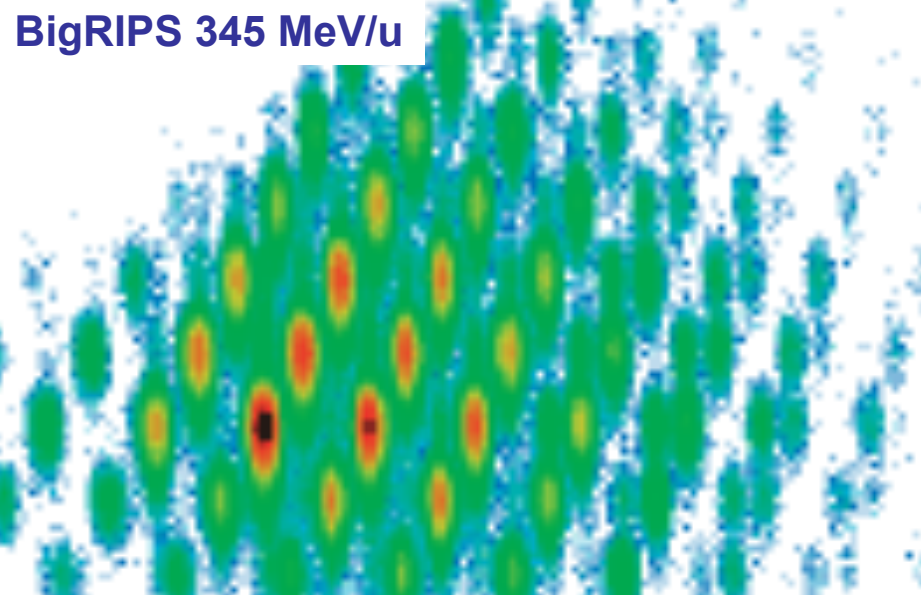
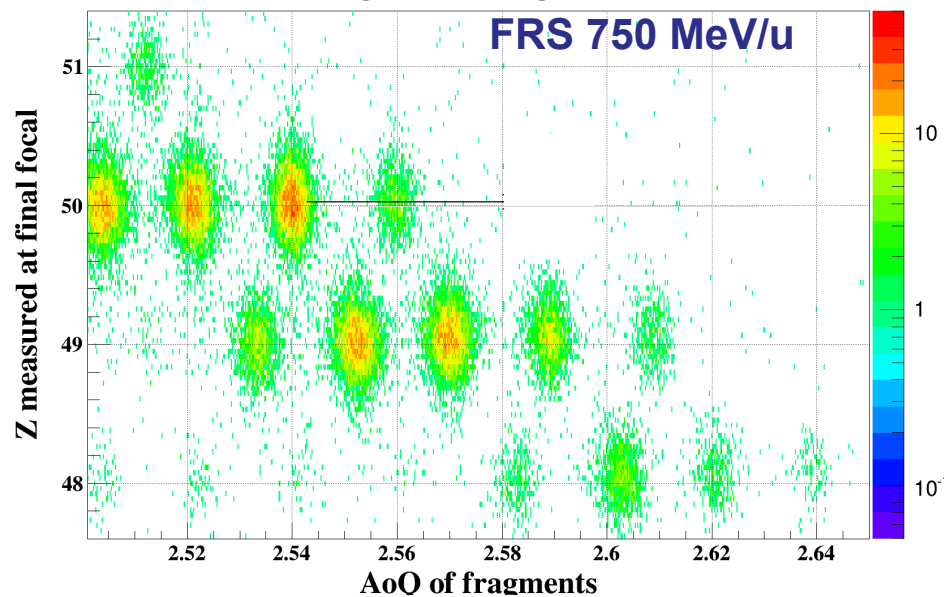
# RARE-ISOTOPE BEAM FACILITIES



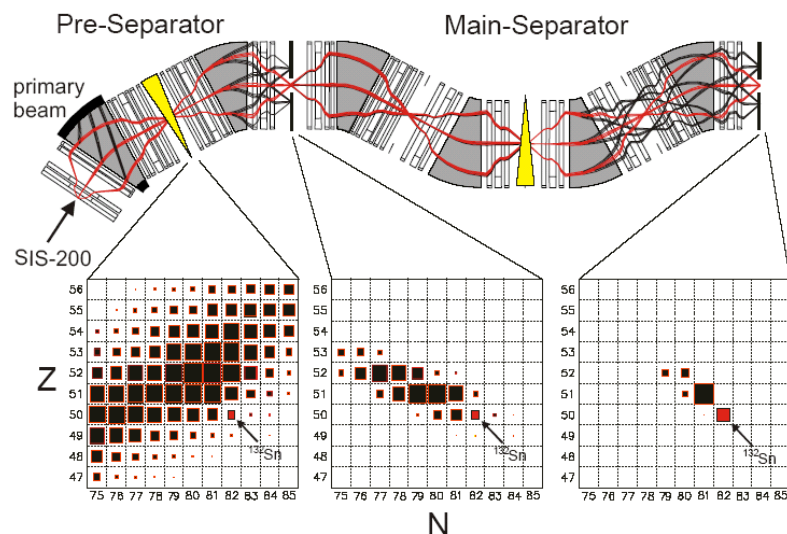
# Charge-separation capability for different Energies



Setting in the Sn region, FRS



# NUSTAR experimental areas, ESSENTIAL to run!



Production  
target

Super-FRS

MATS & LaSpec

HISPEC/DESPEC

R<sup>3</sup>B

ILIMA

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

# SIS100 essential!

Facility	U beam int. per spill at production target
previously at GSI	$1...2 \times 10^9$
after the SIS18 upgrade at GSI	$8 \times 10^9$
commissioning phase SIS100	$2 \times 10^{10}$
final full intensity with <b>SIS100</b>	$3 \times 10^{11}$

- High energies for unique separation and unique experiments
- Competitive intensities throughout the periodic table

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# Timeline

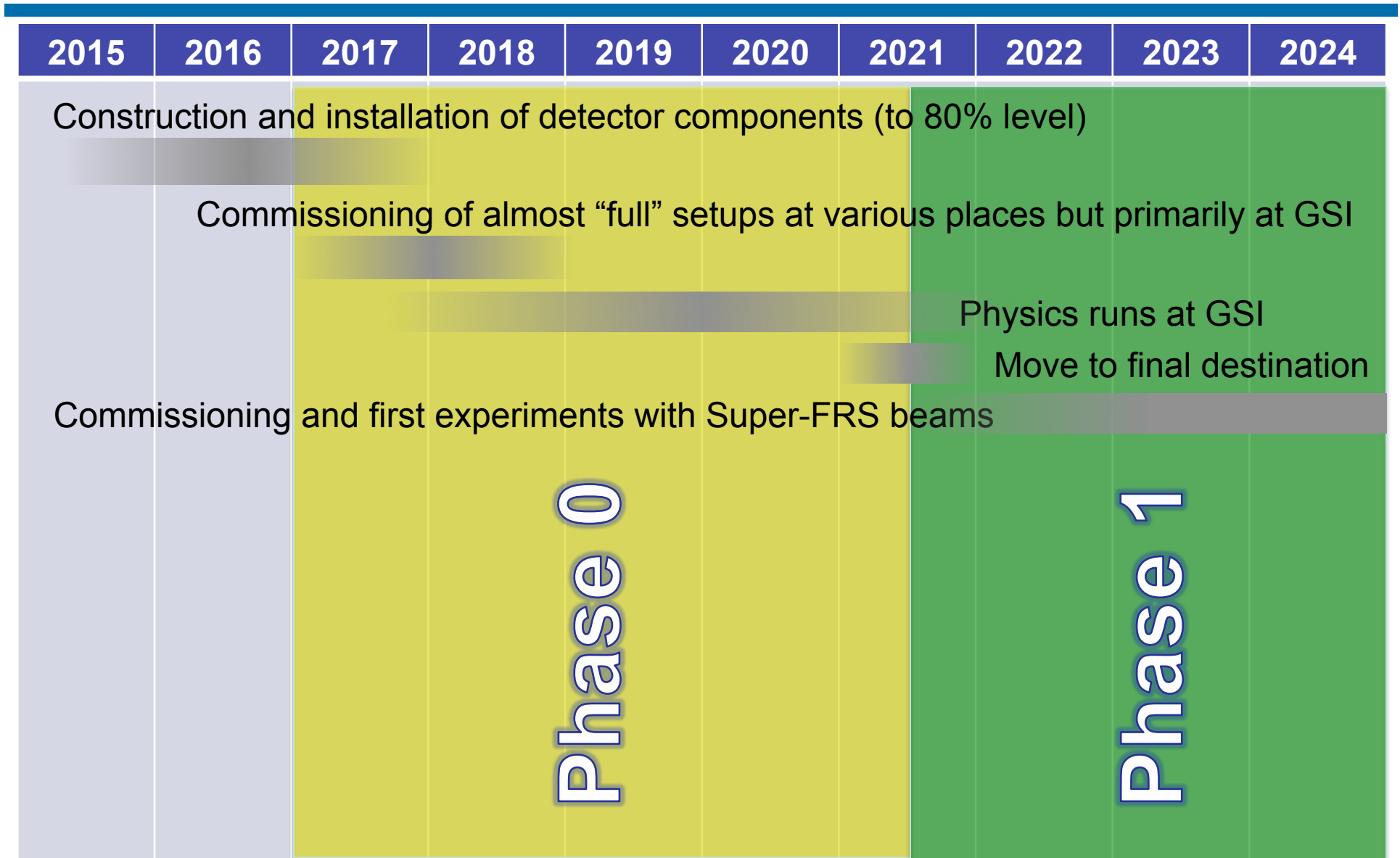
# Definition of NUSTAR experiment phases

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- **Phase 0**
  - R&D and experiments to be carried out with present facilities and FAIR/NUSTAR equipment
- **Phase 1**
  - 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**
  - 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



# Timeline for phase-0 and phase-1 at GSI/FAIR



# New detailed planning in progress ...

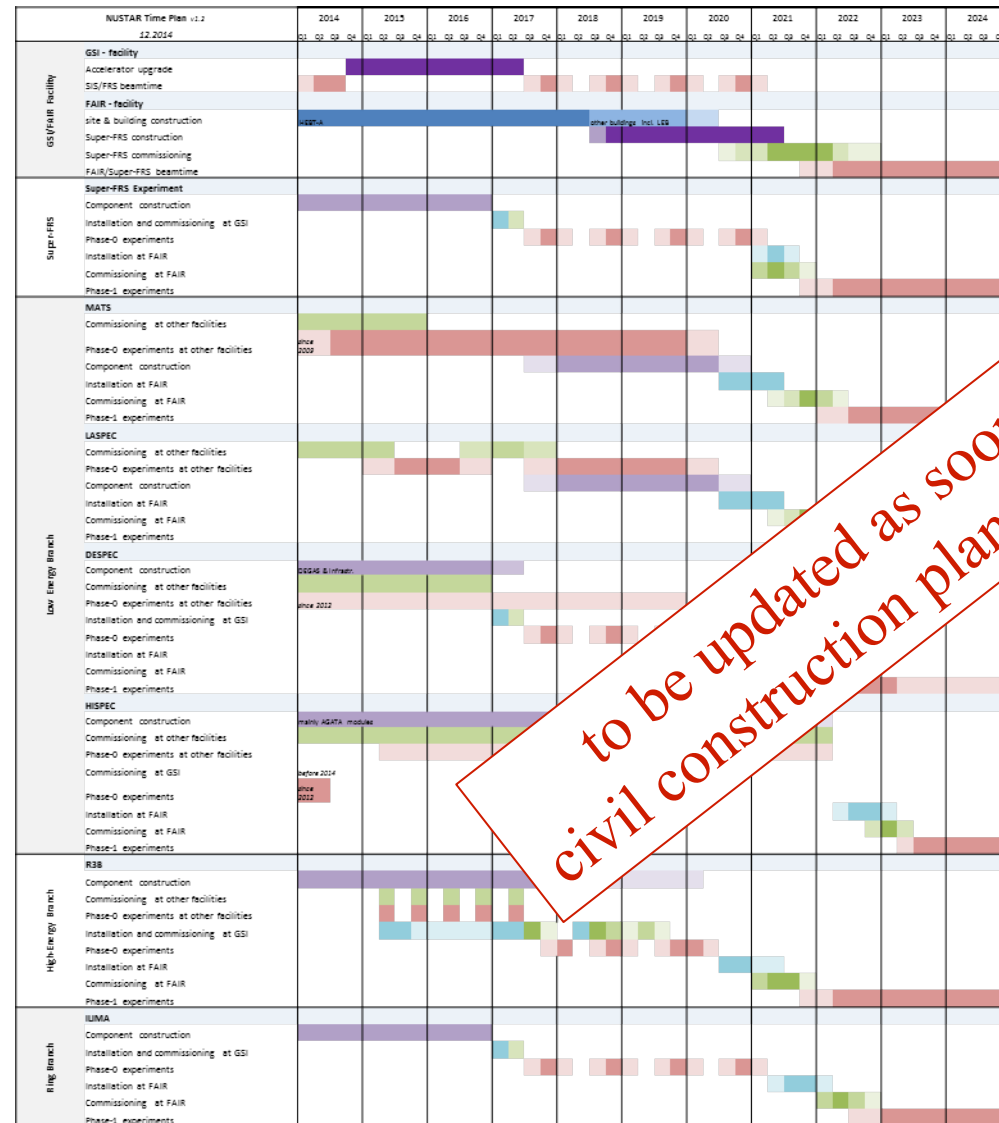
GSI/FAIR

Super-FRS (exp.)

Low energy branch

High energy branch

Ring branch

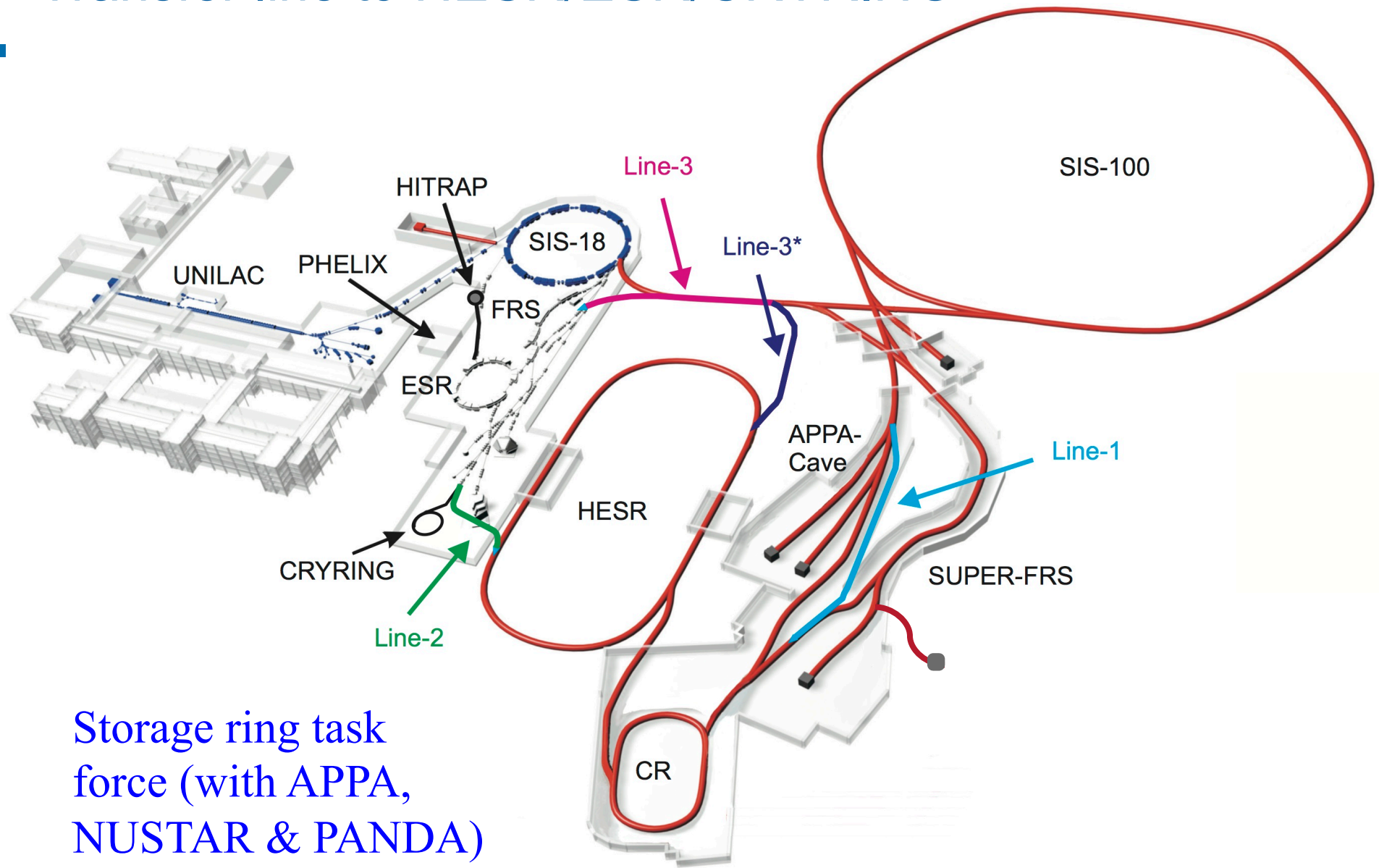


# Latest news from FAIR/GSI

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- Search for Technical and Scientific Managing Directors ongoing
- SIS-100, HEBT, and Super-FRS to be built under present financial conditions
  - Negotiations with all shareholders on cost increase took place.
  - waiting for final decision on full MSV at FAIR Council meeting tomorrow.
- Re-structuring of GSI (in light of future merger with FAIR and to better use available resources) ongoing
- Major milestones from civil construction and accelerator available

# Transfer line to HESR/ESR/CRYRING



Storage ring task  
force (with APPA,  
NUSTAR & PANDA)  
very active!

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Thank you!