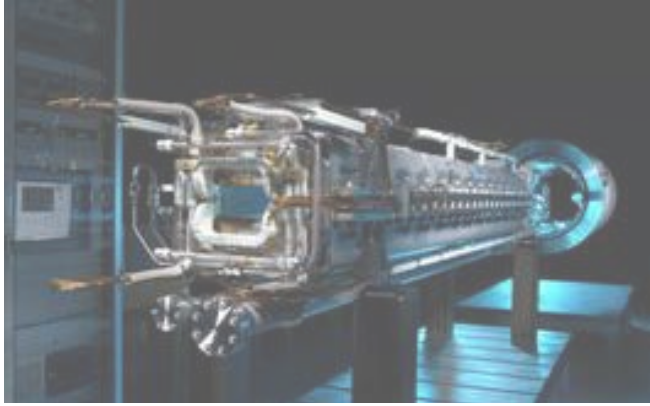




Unraveling stellar alchemy with NUSTAR
From ideas to in-kind

Alexander Herlert
FAIR

2nd In-kind Contributions Workshop (IKCW 2015)
GSI/FAIR Darmstadt, November 4, 2015

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

NUclear **S**tructure, **A**strophysics and **R**eactions

What are the limits for existence of nuclei?

Where are the proton and neutron drip lines situated?

Where does the nuclear chart end?

How does the nuclear force depend on varying proton-to-neutron ratios?

What is the isospin dependence of the spin-orbit force?

How does shell structure change far away from stability?

How to explain collective phenomena from individual motion?

What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?

How are complex nuclei built from their basic constituents?

What is the effective nucleon-nucleon interaction?

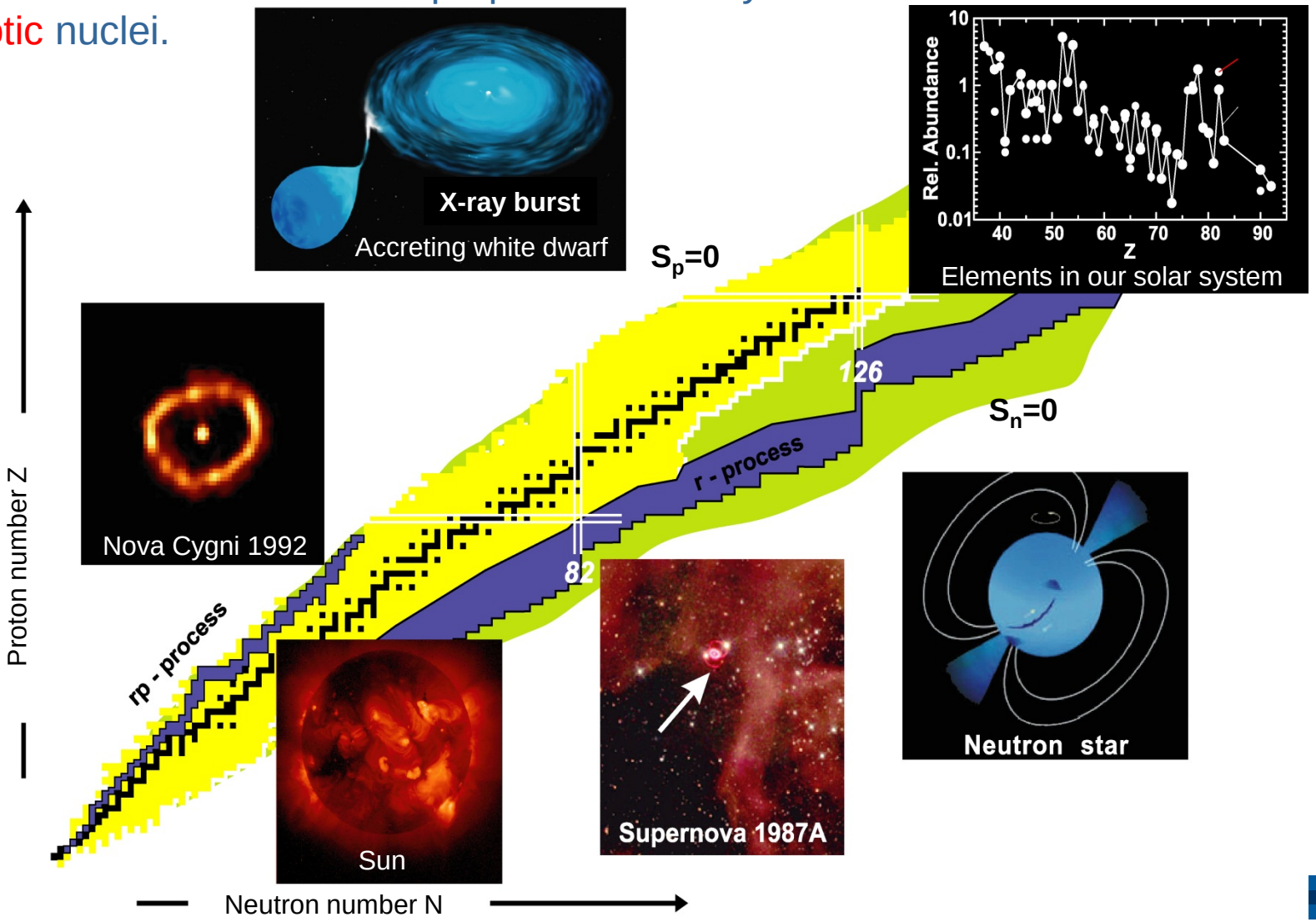
How does QCD constrain its parameters?

Which are the nuclei relevant for astrophysical processes and what are their properties?

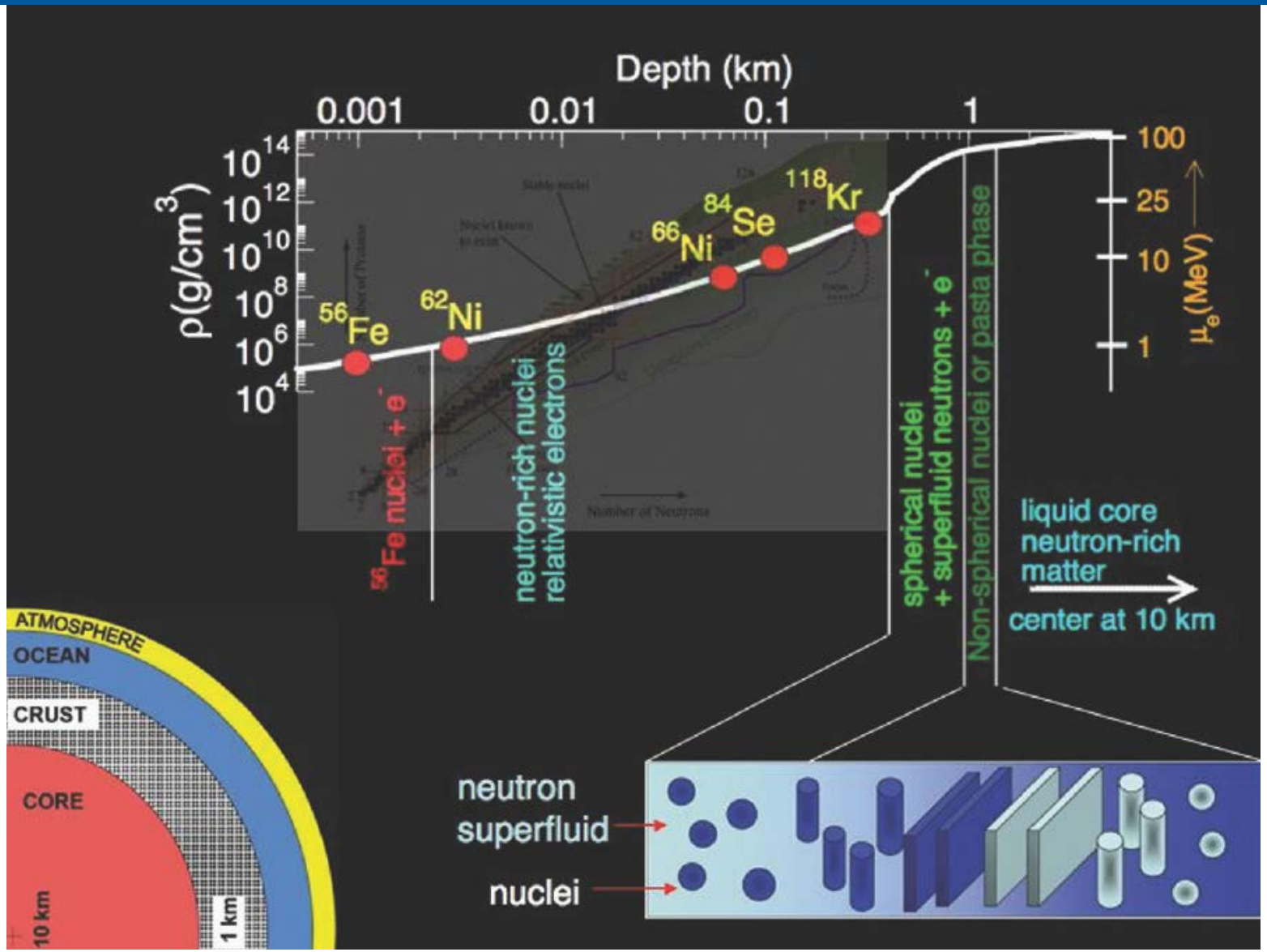
What is the origin of the heavy elements?

Nuclear physics in the universe

For the understanding of nucleosynthesis and stellar dynamics we need to know properties of many exotic nuclei.

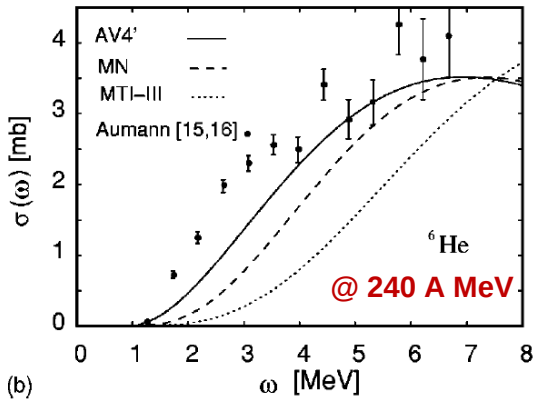


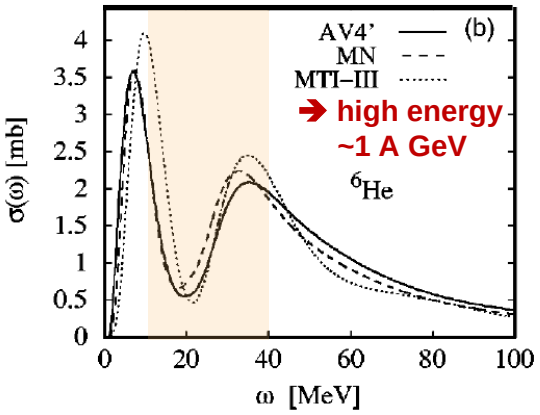
Nuclei in neutron stars



Dipole strength distributions in heavy neutron-rich nuclei

core vs. neutron skins & halos → density / asymmetry

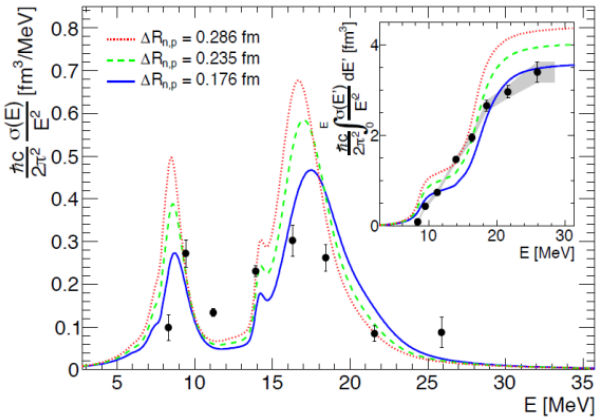




to be measured with R³B

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

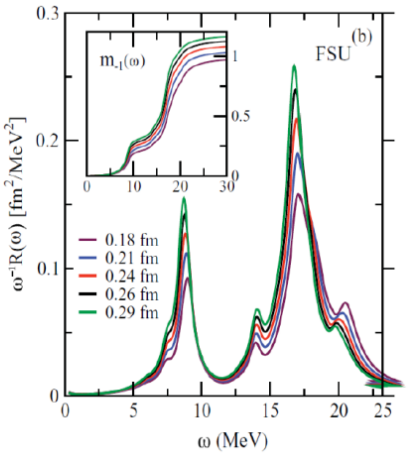
access to EoS (e.g. neutron star) & low lying E1 strength (r-process)



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

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

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



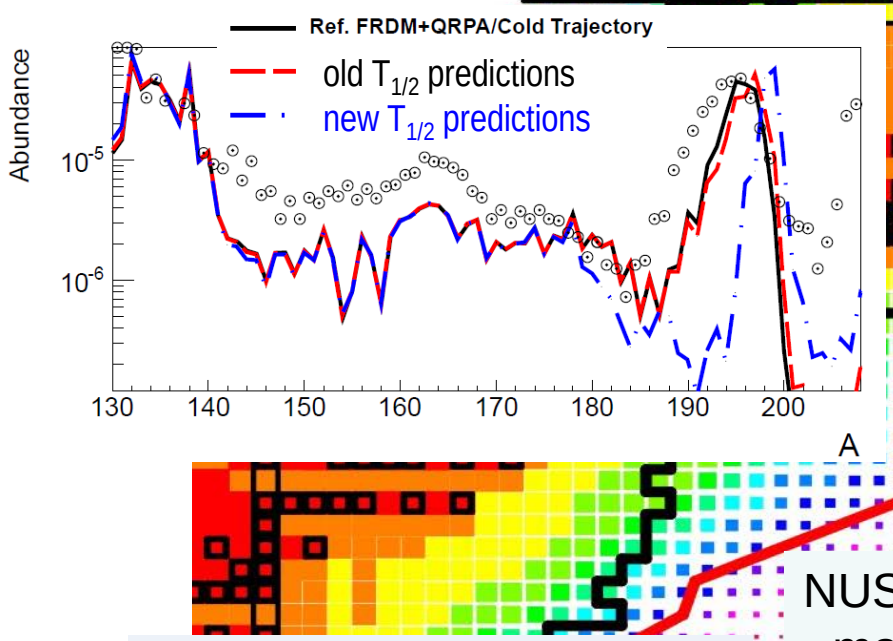
Pb chain & N=126 isotones

~1 A GeV →
bare ions
Fragment identification

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

The N=126 physics case

Previous GSI measurements
contradict earlier lifetime predictions!
→ Mass abundance not understood!



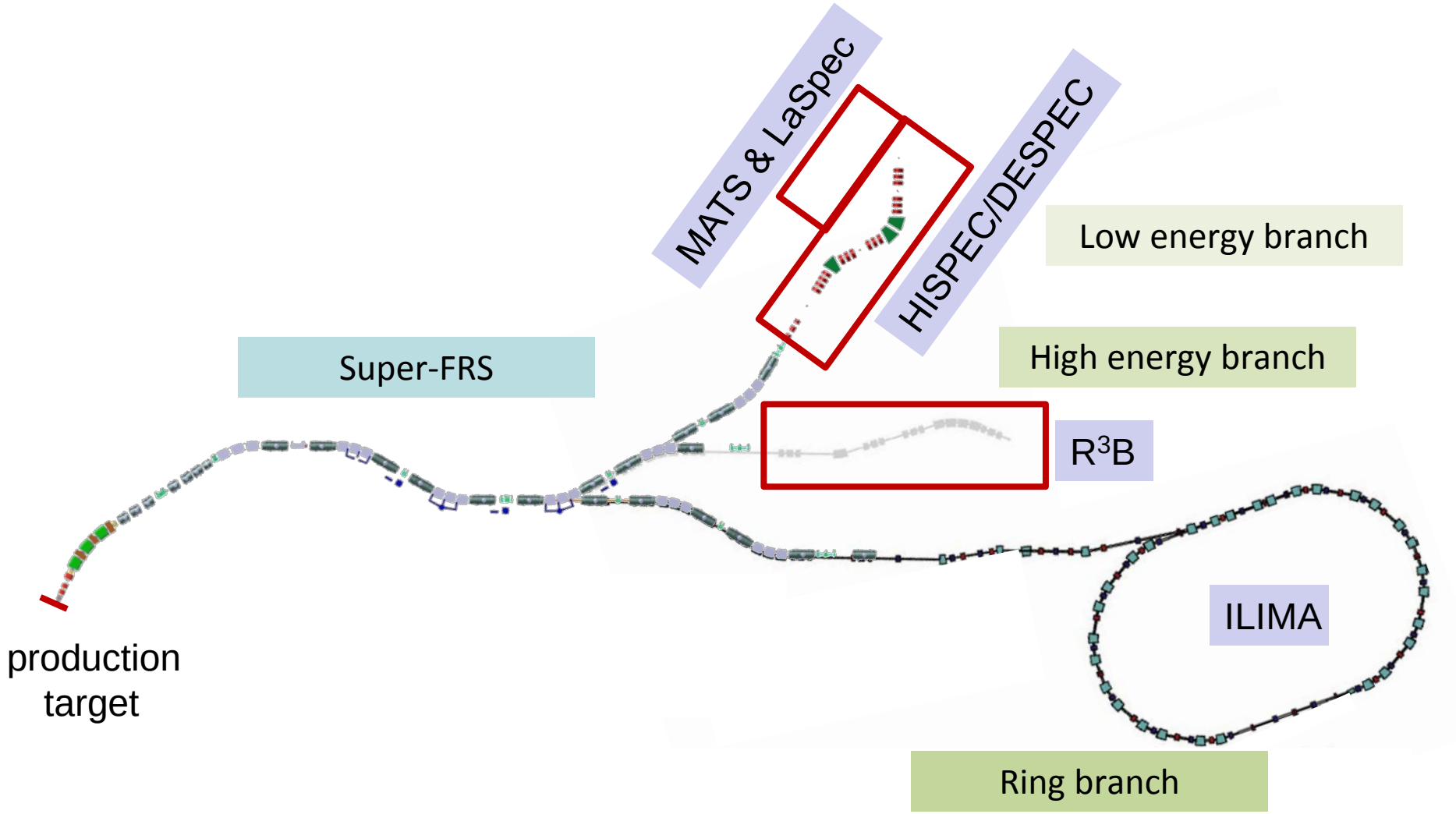
Mass abundance depends
on the detailed structure
of N=126 nuclei around the
3rd r-process waiting point

NUSTAR aims to measure:
- masses
- β-lifetimes
- neutron-branchings
- strength distributions
- level structure

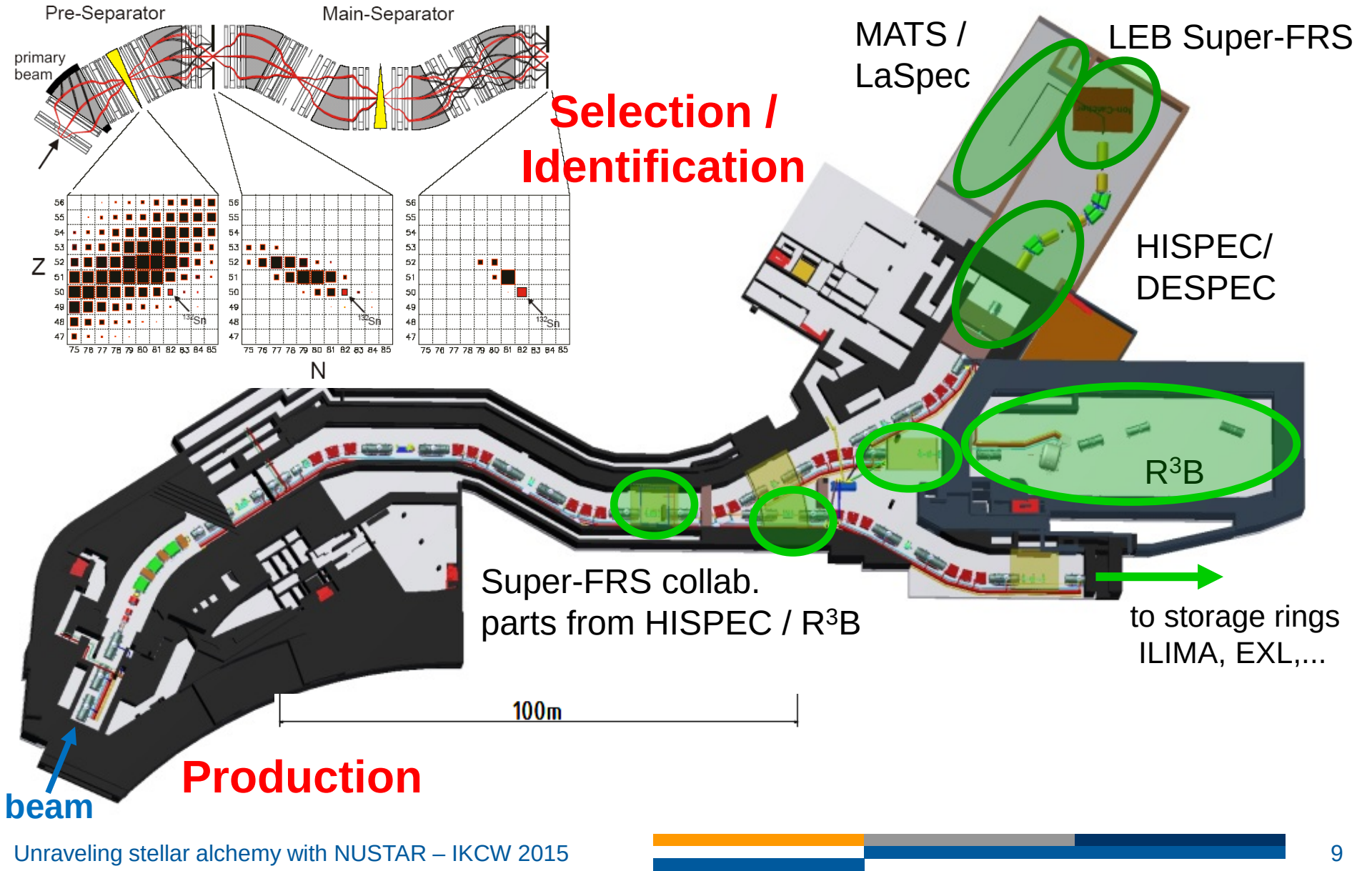
Important unique NUSTAR-LEB experiment

NUSTAR @ FAIR

NUSTAR @ FAIR

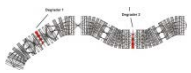

MATS & LaSpec
HISPEC/DESPEC
Low energy branch
Super-FRS
High energy branch
R³B
ILIMA
production target
Ring branch

RIB production and experiments

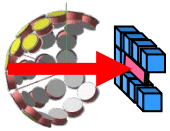


Complementarity of NUSTAR experiments

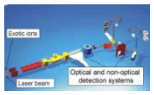
Super-FRS



HISPEC/ DESPEC

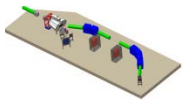


LaSpec

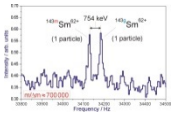


MATS

R^{3}B



ILIMA



SHE

ELISE

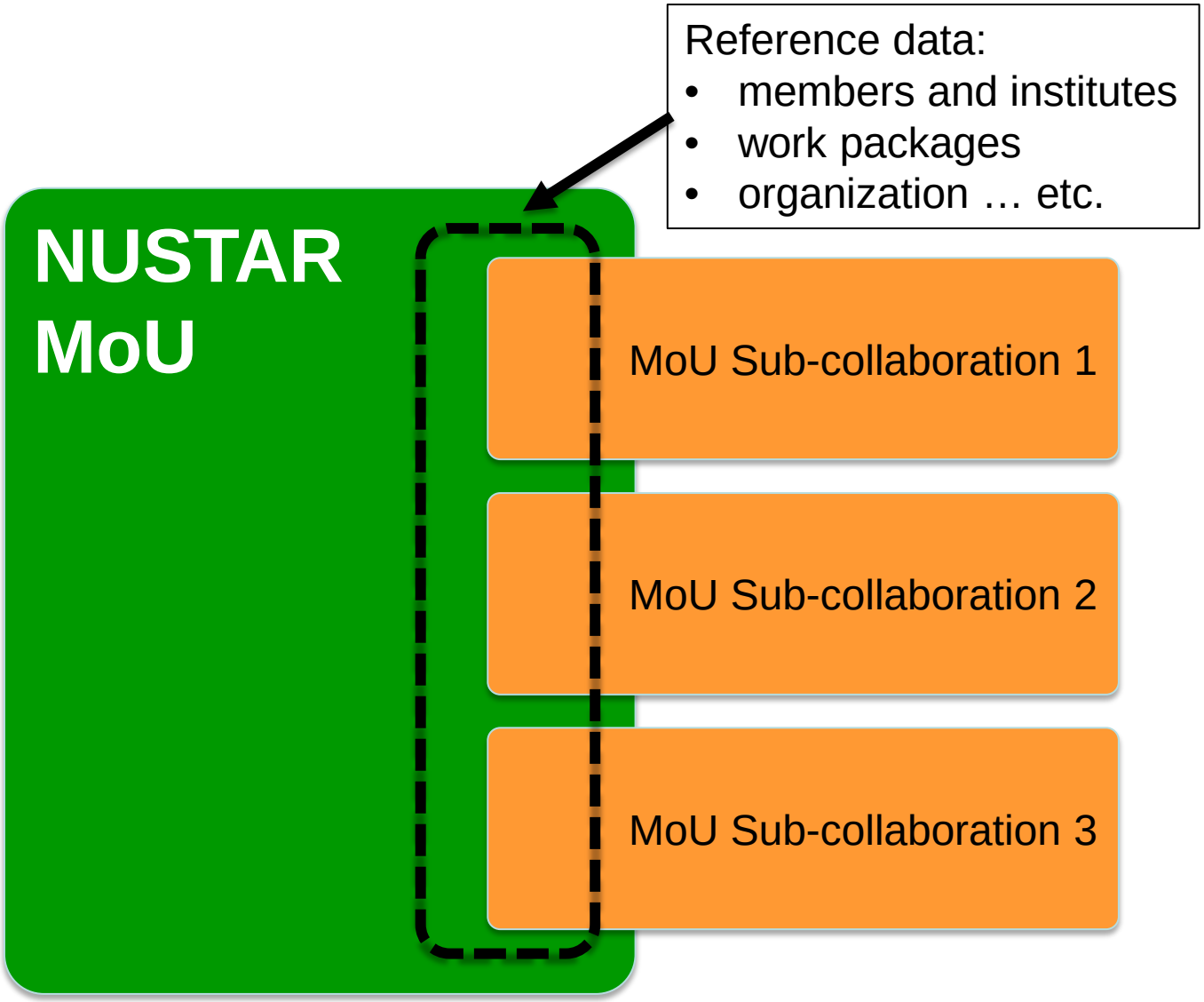
EXL

	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	dressed ions, µs...s			resonance width, decay up to 100ns	bare ions, ms...years	µs...days		
Matter radii	interaction x-section				interaction x-section				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 and tensor	evolution of shell closures, pairing corr.	shell structure of SHEs		low momentum transfers
Collective behavior		electromag. transitions	quadrupole moments	halo structure	dipole response	changes in deformation		electromag. transitions	monopole resonance
EoS					polarizability, neutron skin			neutron skin →	neturon skin, Compressibility
Exotic Systems	bound mesons, hypernuclei, nucleon res.								

NUSTAR Collaboration

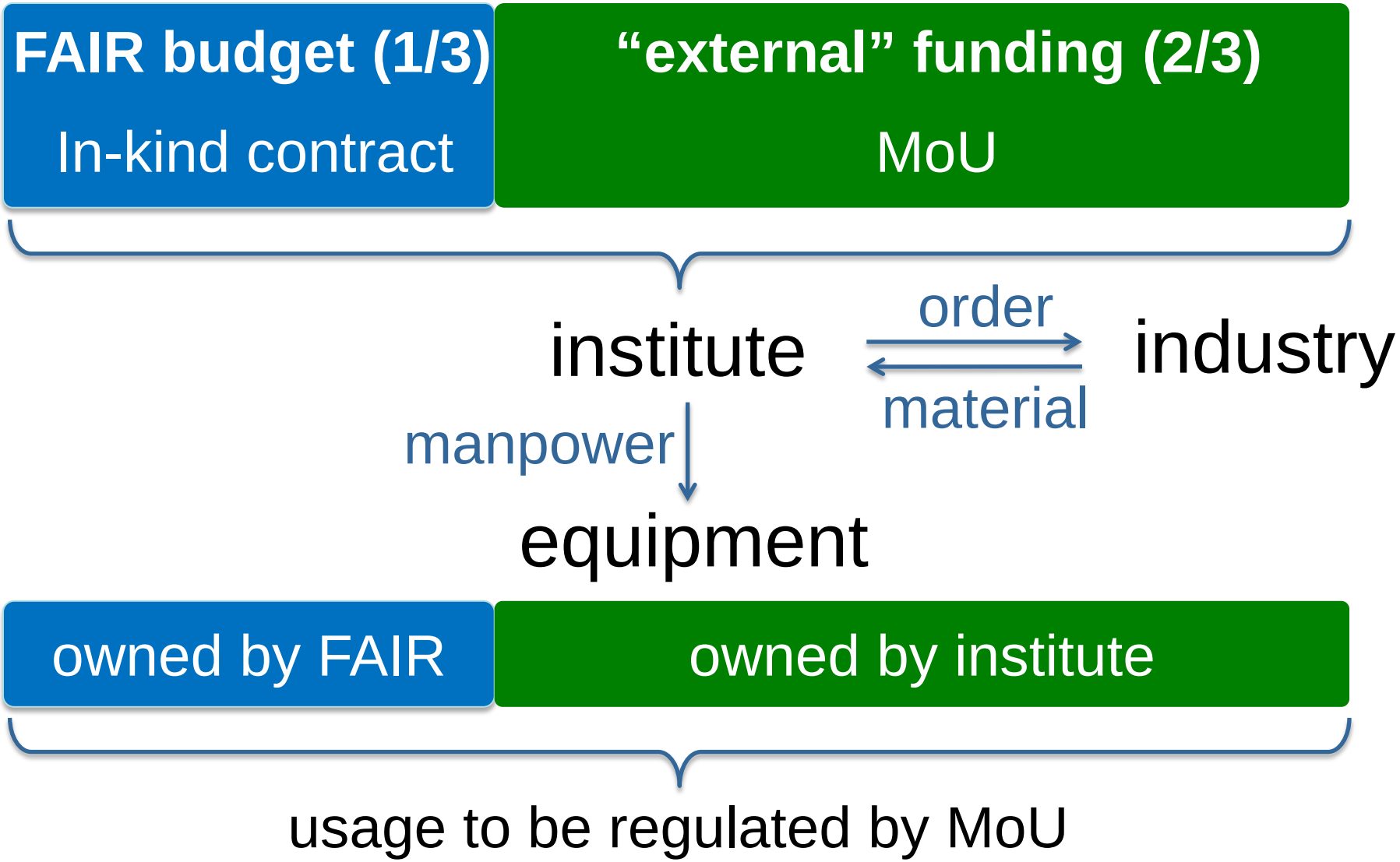
- 850 registered “interested” scientists in NUSTAR database
- 39 countries and more than 180 institutes

Organizational structure

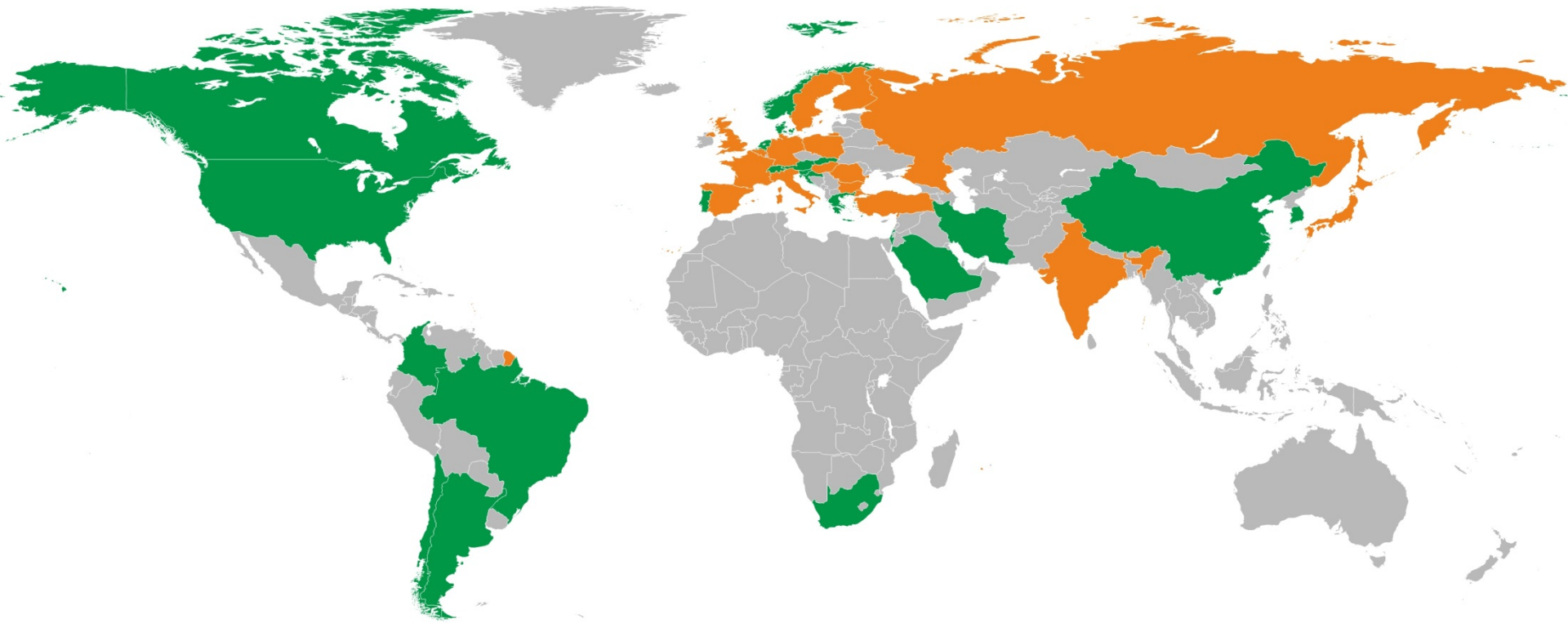


From the idea to in-kind

Different types of funding



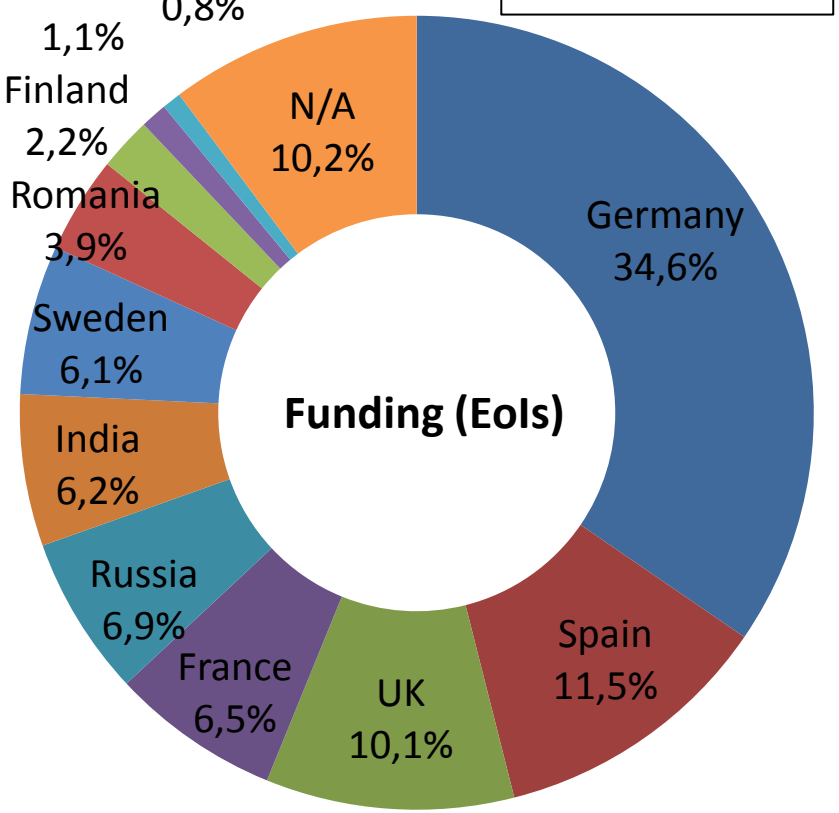
NUSTAR Collaboration – funding



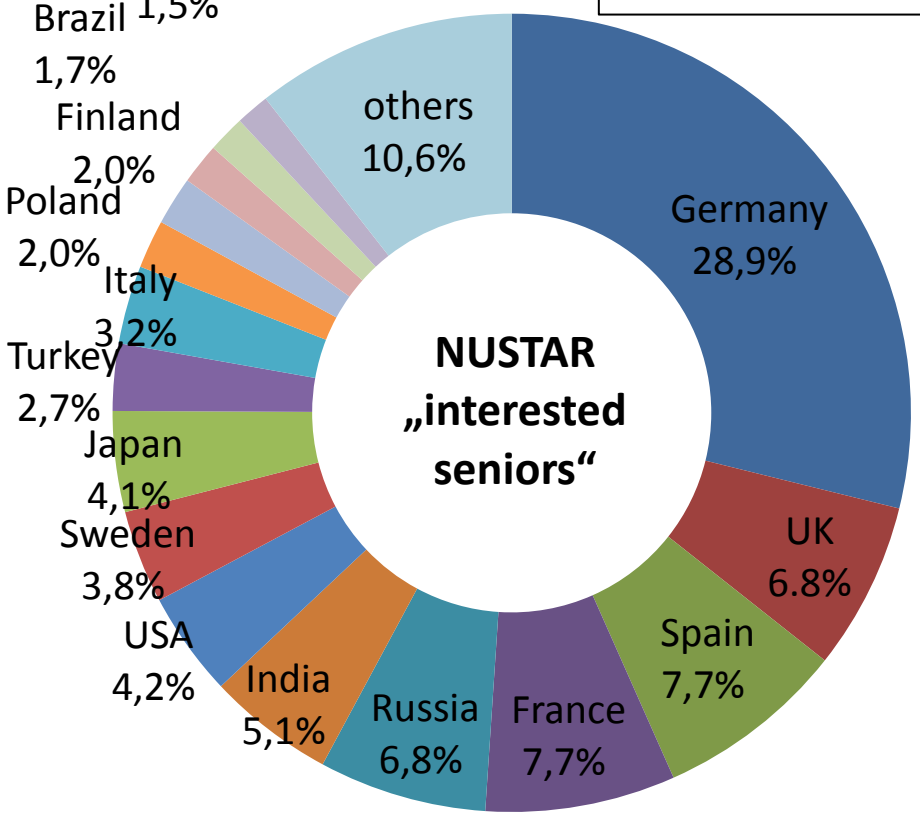
- Secured funding and expression of interest in funding
  (status: July 2015)
  16 countries (incl. 9 FAIR partner countries)

Comparison: funding vs. senior scientists

16 countries
59 institutes

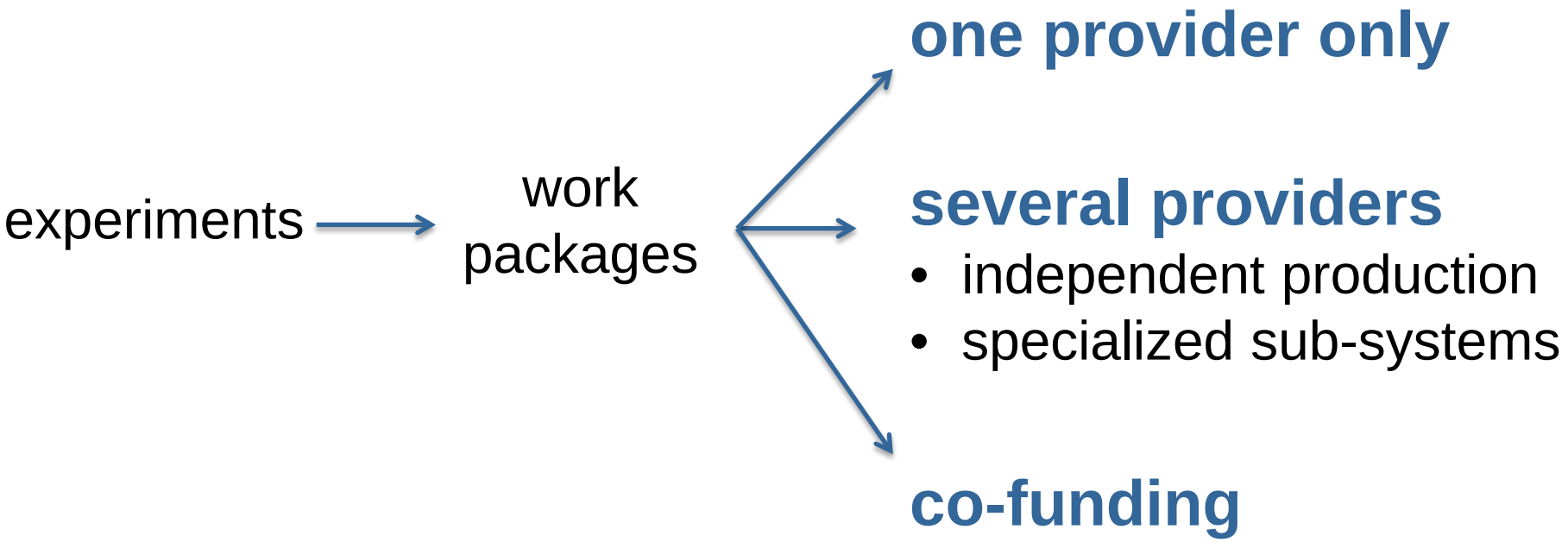


39 countries
>180 institutes



Finland France Germany India Poland Romania Russia Slovenia Sweden UK

Different types of collaborative work



NUSTAR project structure

Modularized Start Version (MSV)	
1.2.1	LEB Super-FRS
1.2.2	HISPEC/DESPEC
1.2.3	MATS
1.2.4	LaSpec
1.2.5	R^3B
1.2.6	ILIMA

Extending or beyond MSV	
1.2.8	ELISe
1.2.9	EXL

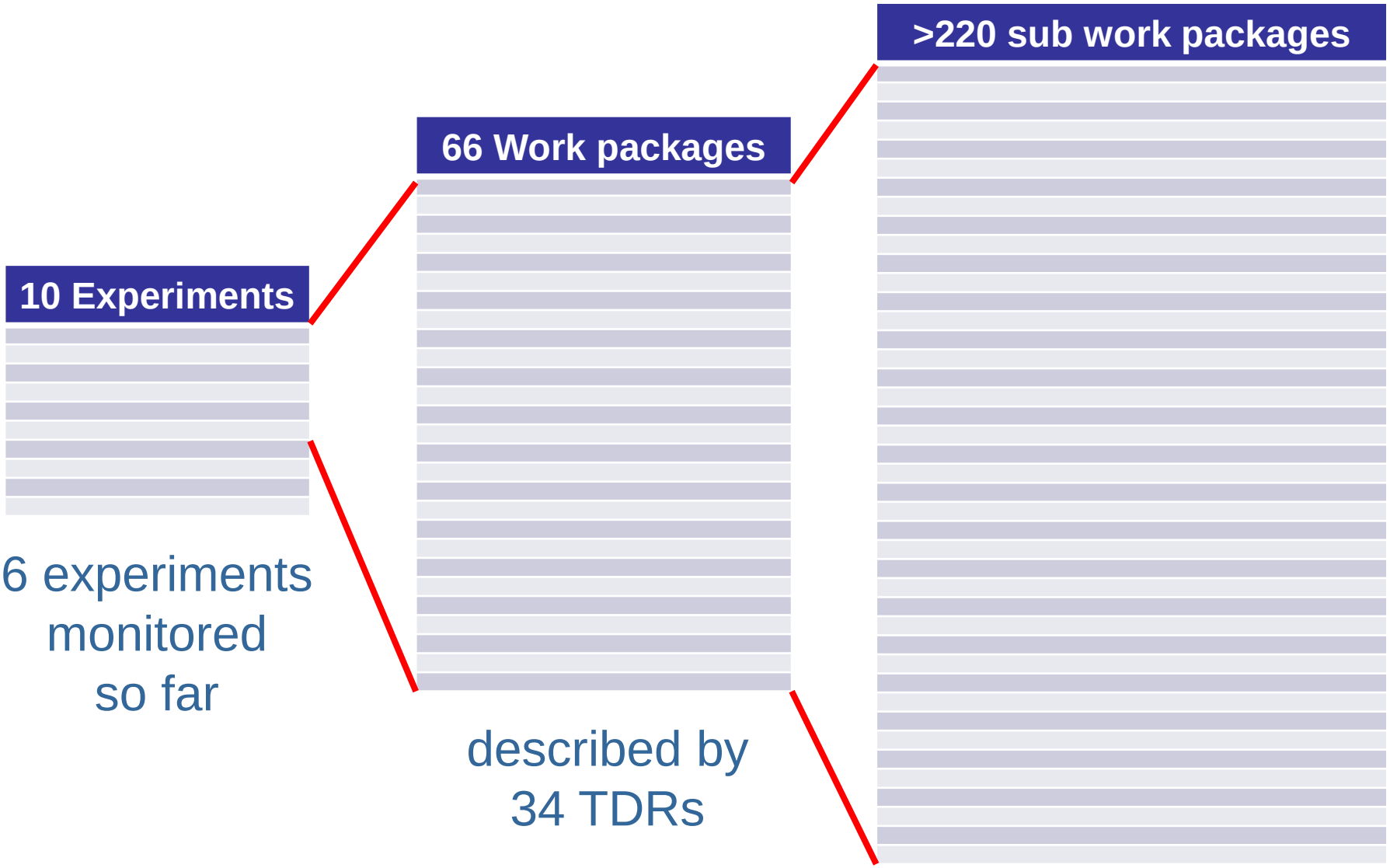
New experiments	
1.2.10	Super-FRS Experiments
1.2.11	SHE

1.2 NUSTAR

initially NESR required – alternative/intermediate „operation“ within MSV under discussion

„operation“ within MSV planned

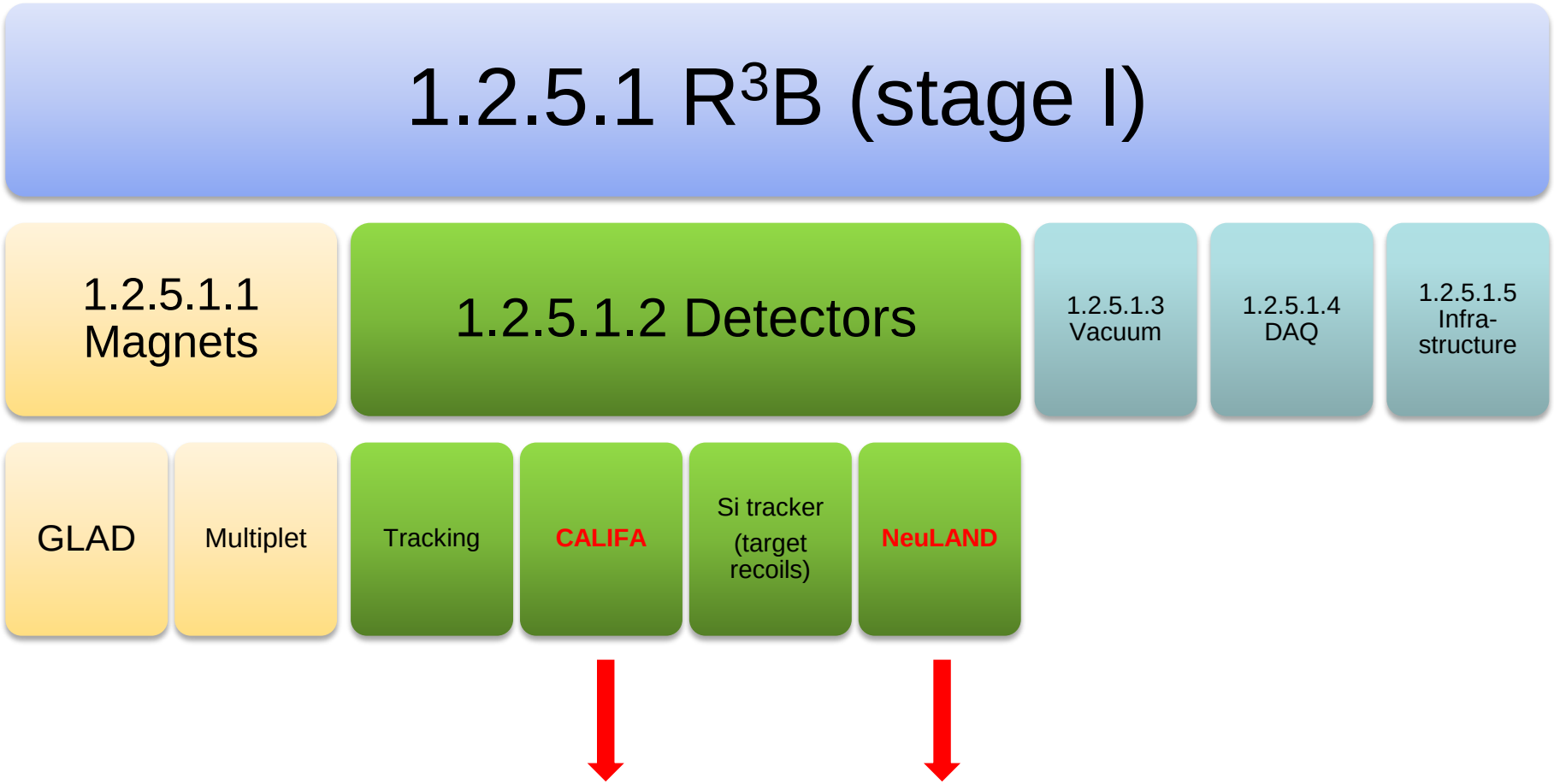
Work packages of NUSTAR



NUSTAR work packages (63 with TDR)

Described by 34 TDRs

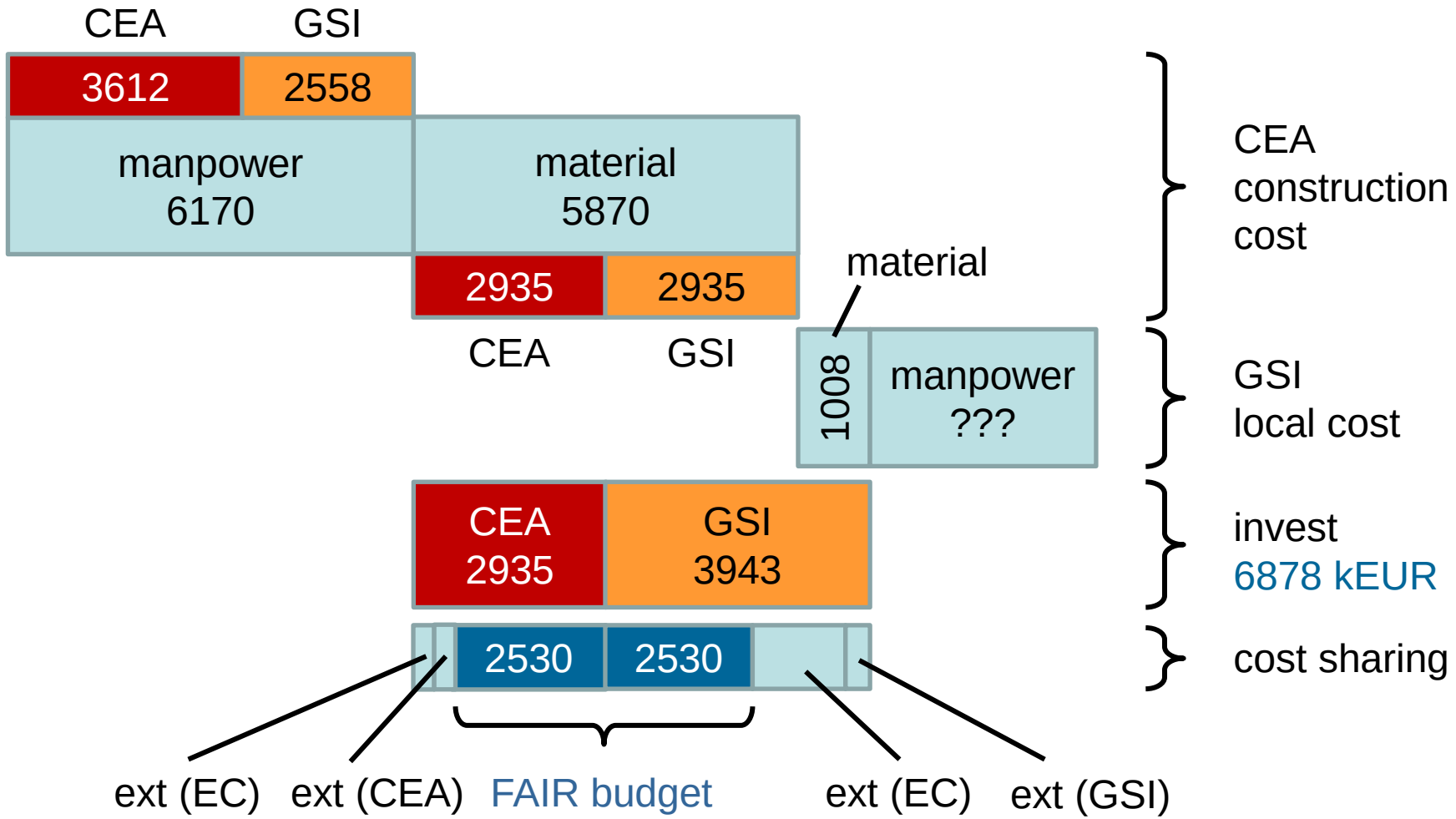
NUSTAR project structure: example R³B



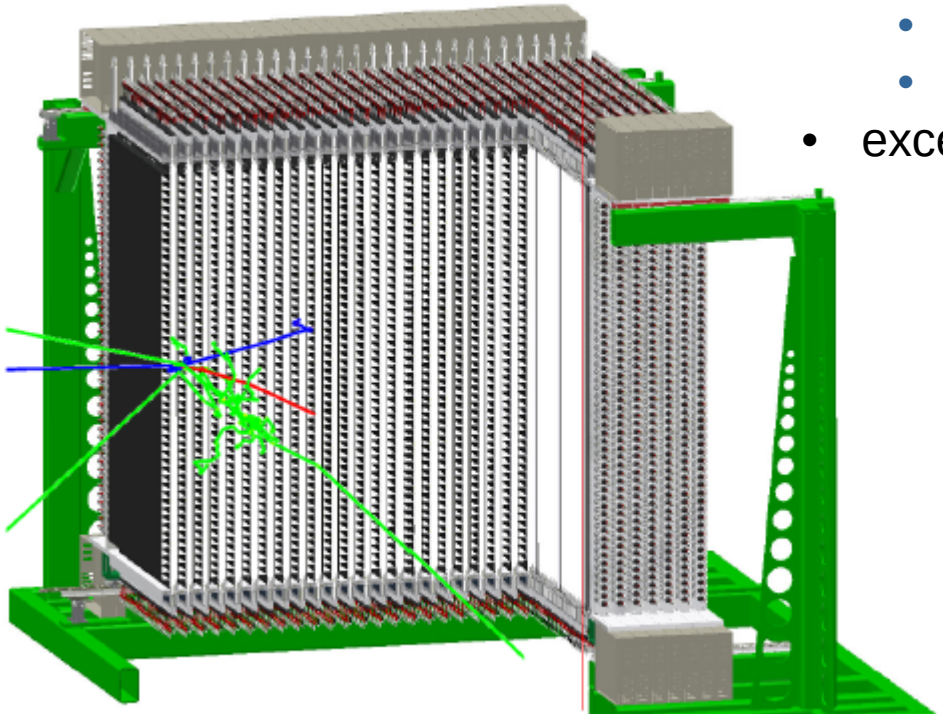
GLAD magent @ CEA Saclay

R³B – GLAD construction cost

- GLAD magnet construction cost (July 2015)
  - Detailed cost overview (CEA Saclay + GSI local cost) in kEUR 2005



NeuLAND neutron detector



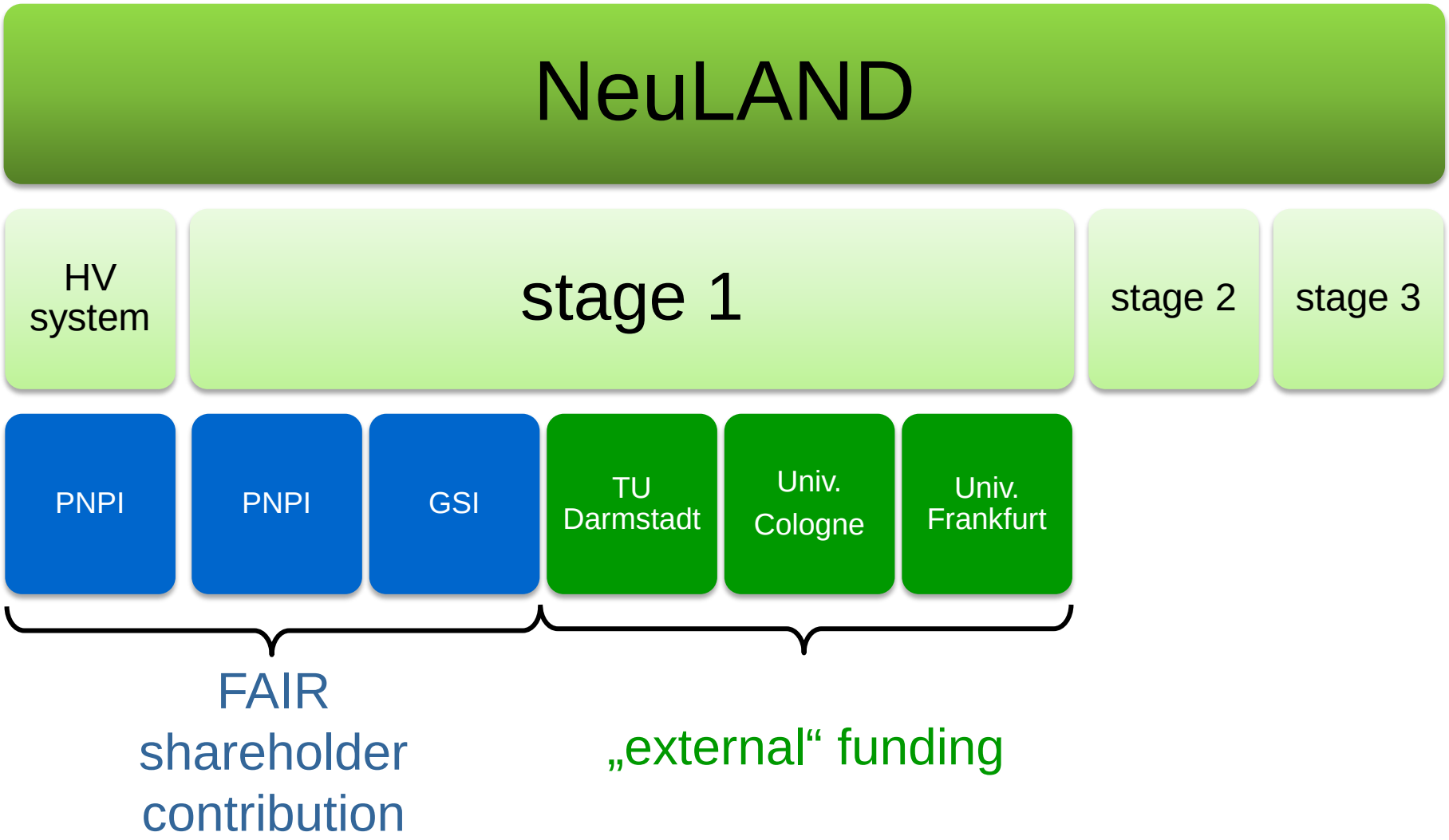
- 30 double planes
  - 100 x 100 scintillator bars x 30 planes
  - 6000 PMTs
- excellent multi-neutron capability

		200 MeV generated				
	%	1n	2n	3n	4n	5n
detected	1n	**88**	31	6	1	0
	2n	2	**62**	37	10	2
	3n	0	5	**49**	38	14
	4n	0	0	8	**48**	54
	5n	0	0	0	3	**26**
	6n	0	0	0	0	3

		600 MeV generated				
	%	1n	2n	3n	4n	5n
detected	1n	**92**	22	2	0	0
	2n	2	**71**	32	7	1
	3n	0	6	**55**	32	9
	4n	0	0	10	**57**	50
	5n	0	1	1	4	**35**
	6n	0	0	0	0	5

		1000 MeV generated				
	%	1n	2n	3n	4n	5n
detected	1n	**89**	12	1	0	0
	2n	7	**78**	23	3	0
	3n	0	8	**63**	26	5
	4n	0	0	12	**63**	40
	5n	0	0	0	7	**46**
	6n	0	0	0	0	8

Work packages and funding: NeuLAND



Definition of NUSTAR experiment phases

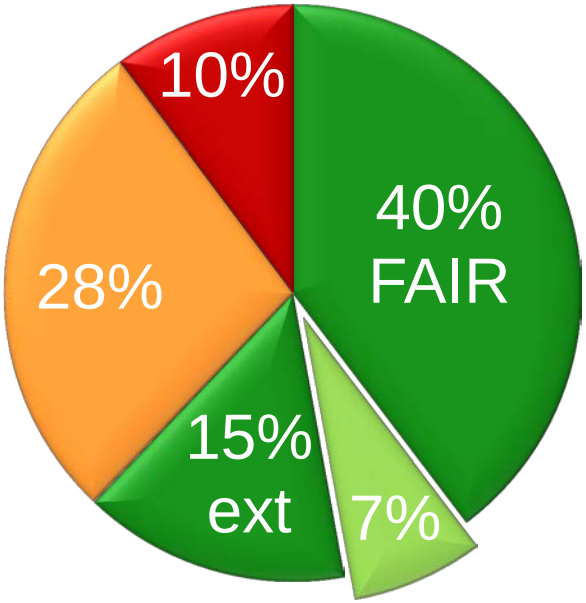
- **Phase 0**
  - R&D and experiments to be carried out with **present facilities** and **FAIR/NUSTAR equipment**
- **Phase 1**
  - Core detectors and subsystems completed
  - First measurements with FAIR/Super-FRS beams
  - ➢ **Carry out experiments with highest visibility as part of the core program 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)

Phases of HISPEC/DESPEC – funding

Description		Beam tracking and identification detectors	HISPEC/DESPEC Beamline	Mechanics + installation	Common EDAQ	Safety	Cabling and related (HISPEC/AGATA)	Active target (MINOS)	Active target (India)	AGATA	HYDE	LYCCA	Plunger	AIDA	DEGAS	FATIMA	BELEN	MONSTER	NEDA	DTAS	Isomeric Moments
TDR										?											
PSP code		1.2.2.1	1.2.2.2	1.2.2.3	1.2.2.4	1.2.2.5	1.2.2.6	1.2.2.7.1	1.2.2.7.2	1.2.2.8	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
phase	0									X		X		X	X	X	X			X	
	1	X	X	X	X	X	X			X			X		X	X		X			
	2									X					X			X	X		
	3								X		X				X						X

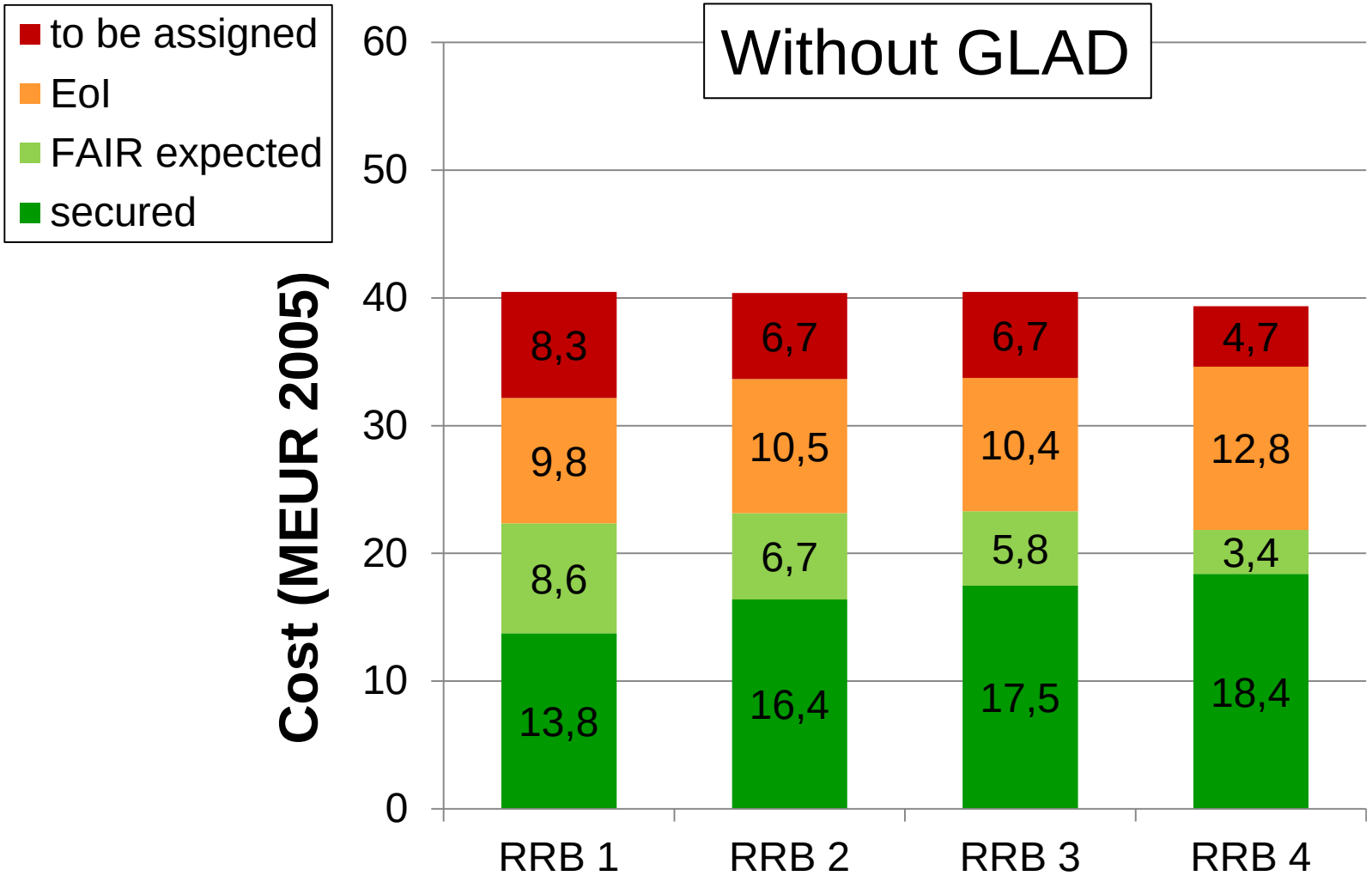
(status: July 2015)

Secured funding, EoIs, and to be assigned



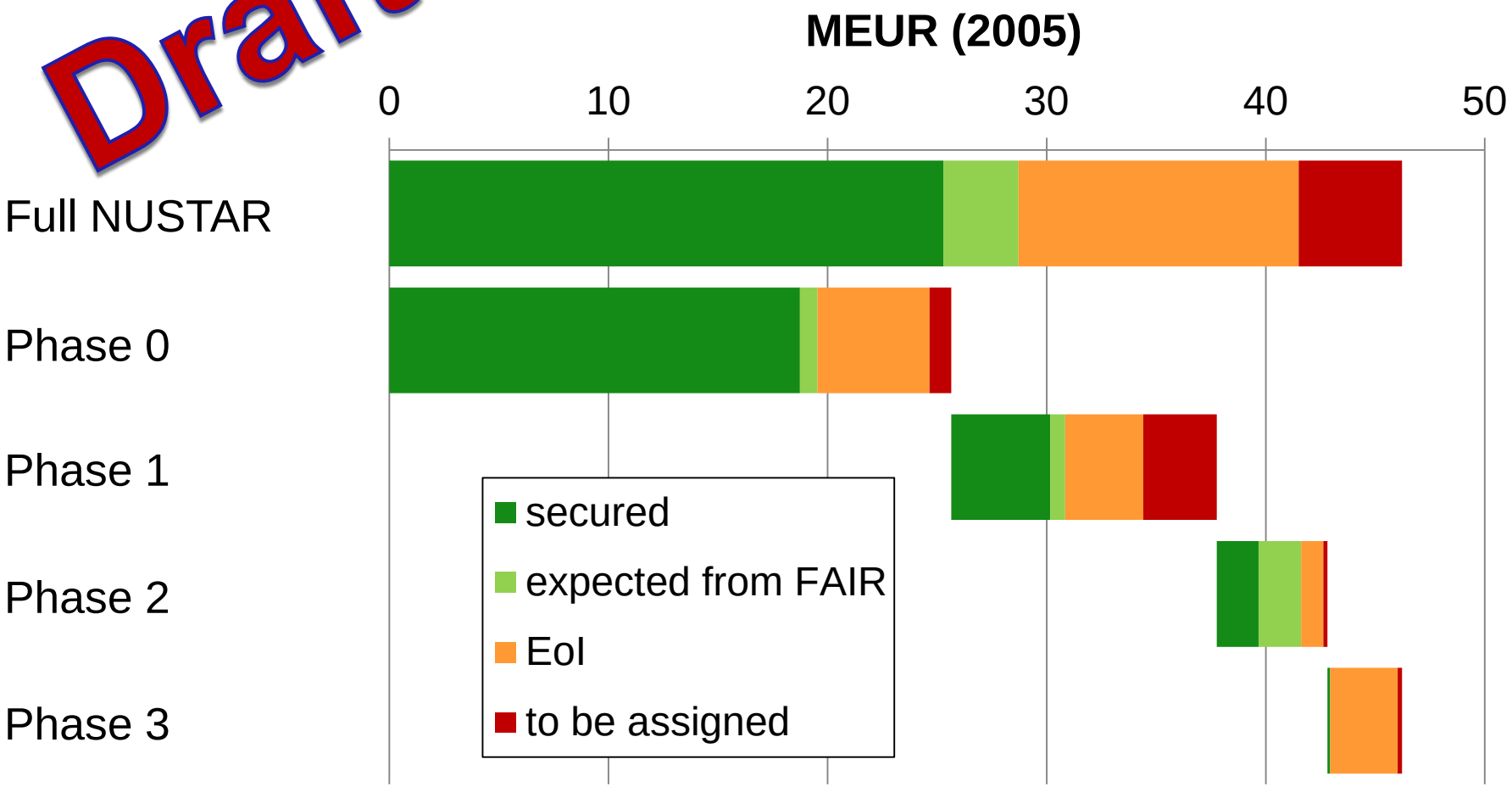
- FAIR shareholders and associates
  - Finland
  - France
  - Germany
  - India
  - Poland
  - Romania
  - Russia
  - Sweden
  - UK
- Additional funding from:
  - Belgium
  - Bulgaria
  - Hungary
  - Israel
  - Italy
  - Japan
  - Spain
  - Turkey

Evolution of NUSTAR project funding (RRBs)



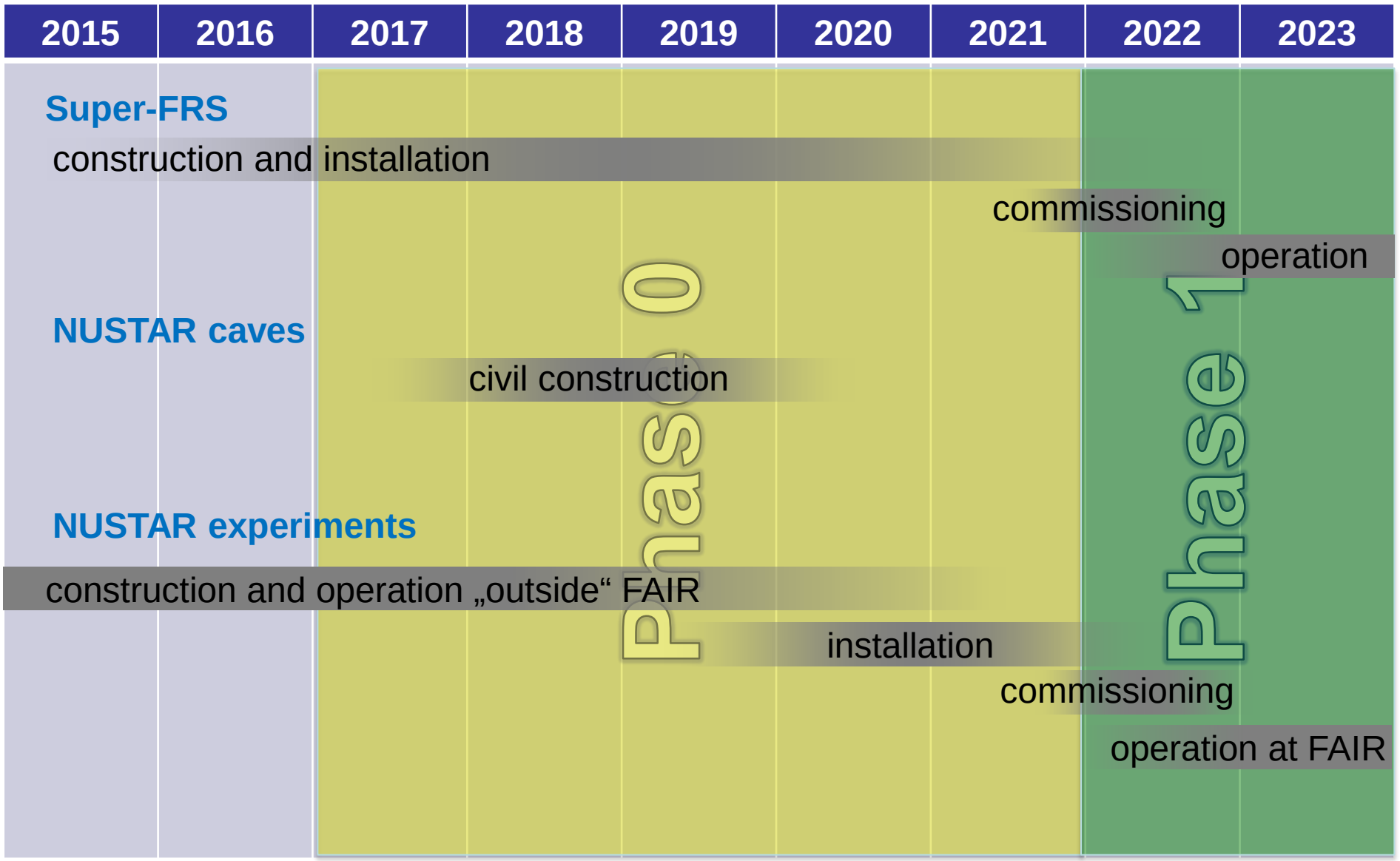
NUSTAR experiment funding – phases

Draft

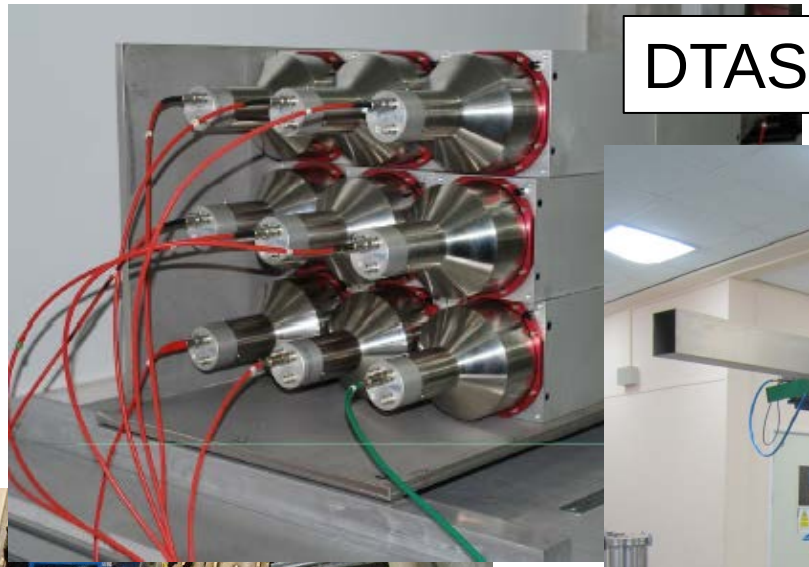


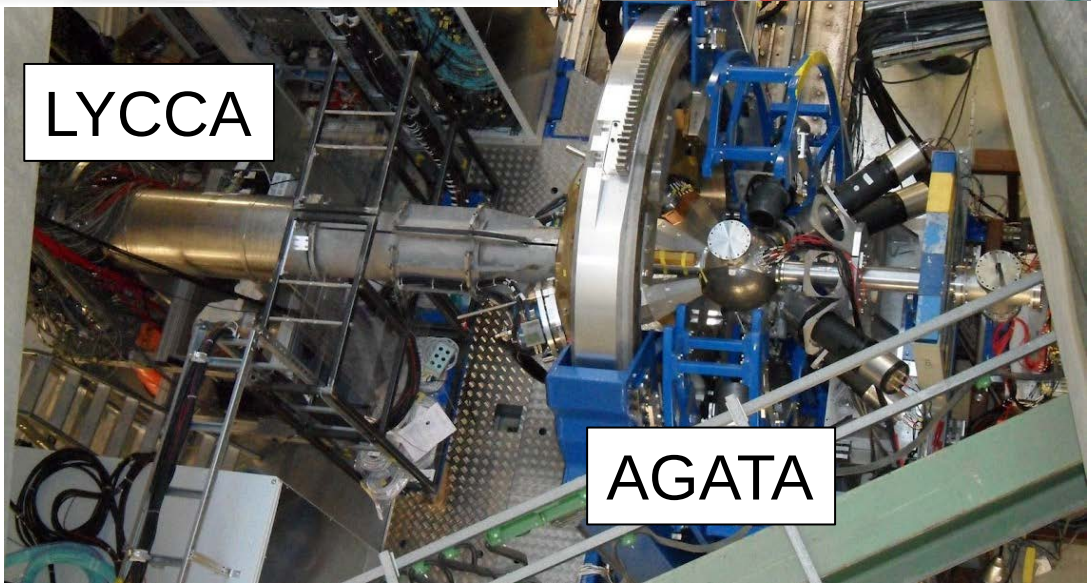
July 2015 - iteration within NUSTAR Collaboration ongoing

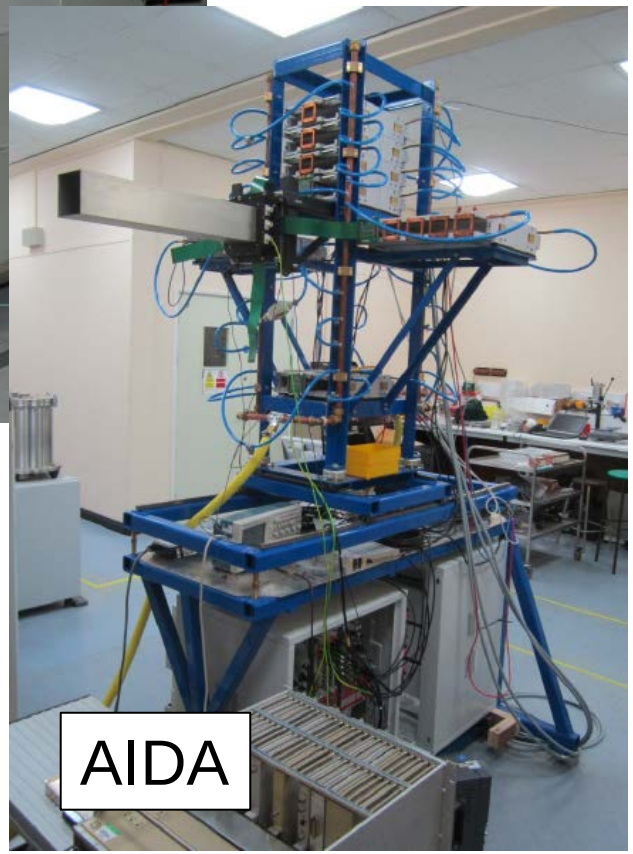
Scenario for phase 0 and phase 1 operation



HISPEC/DESPEC – ready for operation

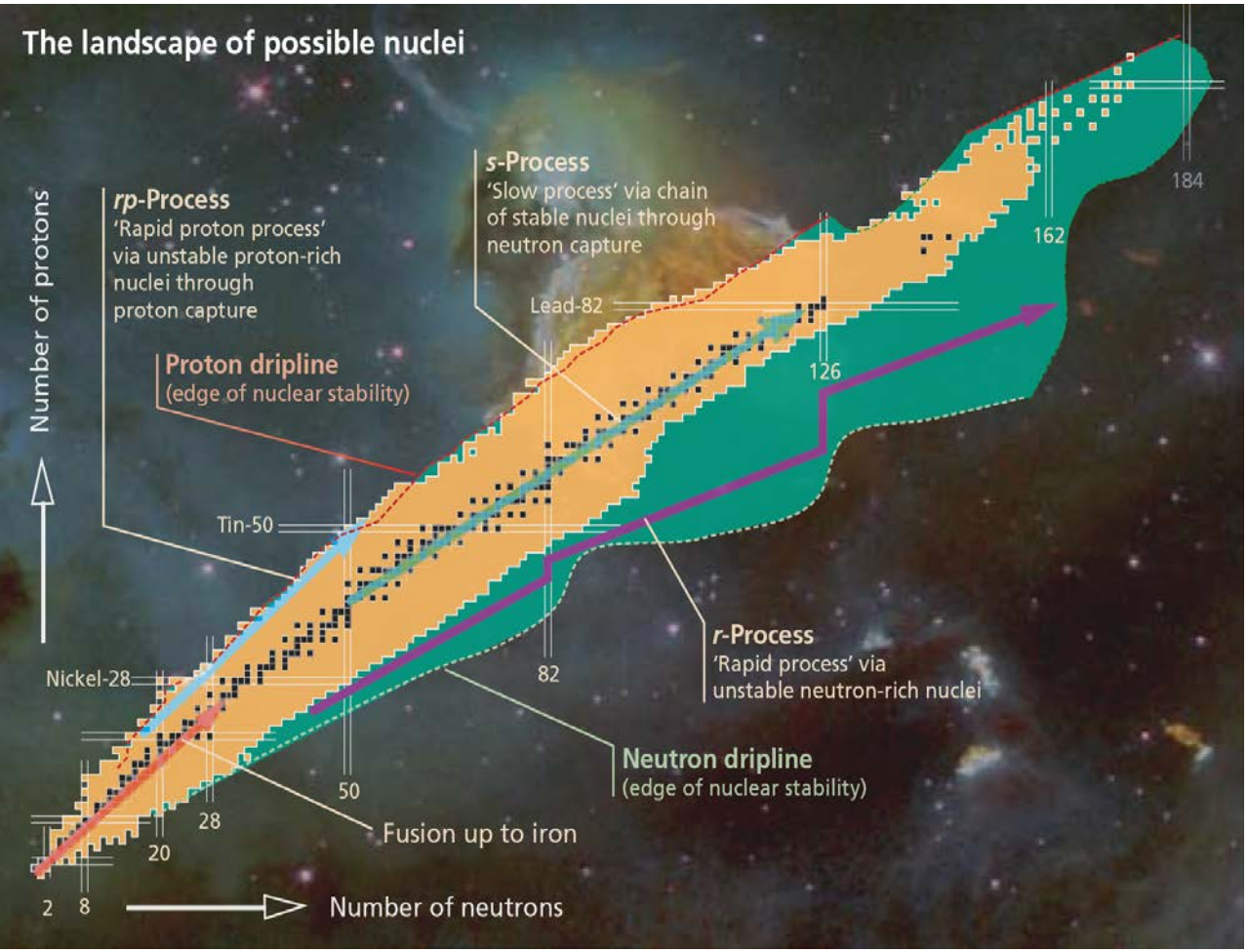






With in-kind from international partners …

… the NUSTAR project aims at studying exotic nuclei ...



Physics subject

to understand the formation of the elements and to finally describe the atomic nucleus

Instrumentation

a multitude of novel particle and radiation detectors with sophisticated electronics and data acquisition systems

Applications

many new devices and methods for medicine, security, industry other research areas

... and is on a good way!