

Nuclear Structure with NUSTAR at GSI/FAIR



J. Gerl

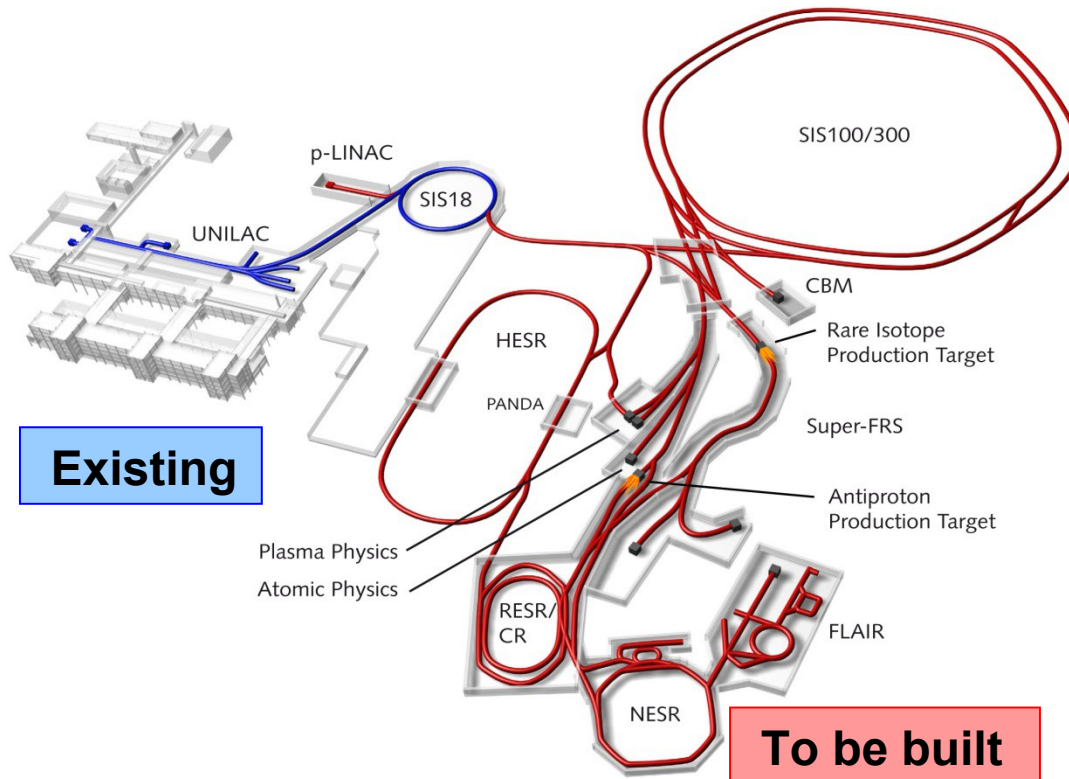
SSNET Workshop

November 9, 2016

Gif sur Yvette, France

FAIR NUSTAR JG

FAIR – The Facility



Existing

To be built

Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

Primary Beams

- $10^{12}/s$; 1.5-2 GeV/u; $^{238}\text{U}^{28+}$
- Factor 100-1000 over present in intensity
- $2(4) \times 10^{13}/s$ 30 GeV protons
- $10^{10}/s$ $^{238}\text{U}^{73+}$ up to 25 (- 35) GeV/u

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Storage and Cooler Rings

- Radioactive beams
- e – A collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons

New FAIR/GSI Organisation



Divisions

Priorities

FAIR / GSI

FAIR/GSI Research

25 Research Depts.

5 Technical infrastr. Depts.

FAIR Experiment Coord.

FAIR Project

Site & Buildings

5 Machine Sub-Projects

4 Experiment Sub-Projects
Common Systems

Accelerator Operations

9 Machine Depts.

Technology Lab.

Workshops

Administration

11 Admin. Depts.

FAIR-Project

Phase-0 Research Programme

GSI Accelerator Upgrade

GSI/FAIR Campus Development

FAIR Civil Construction



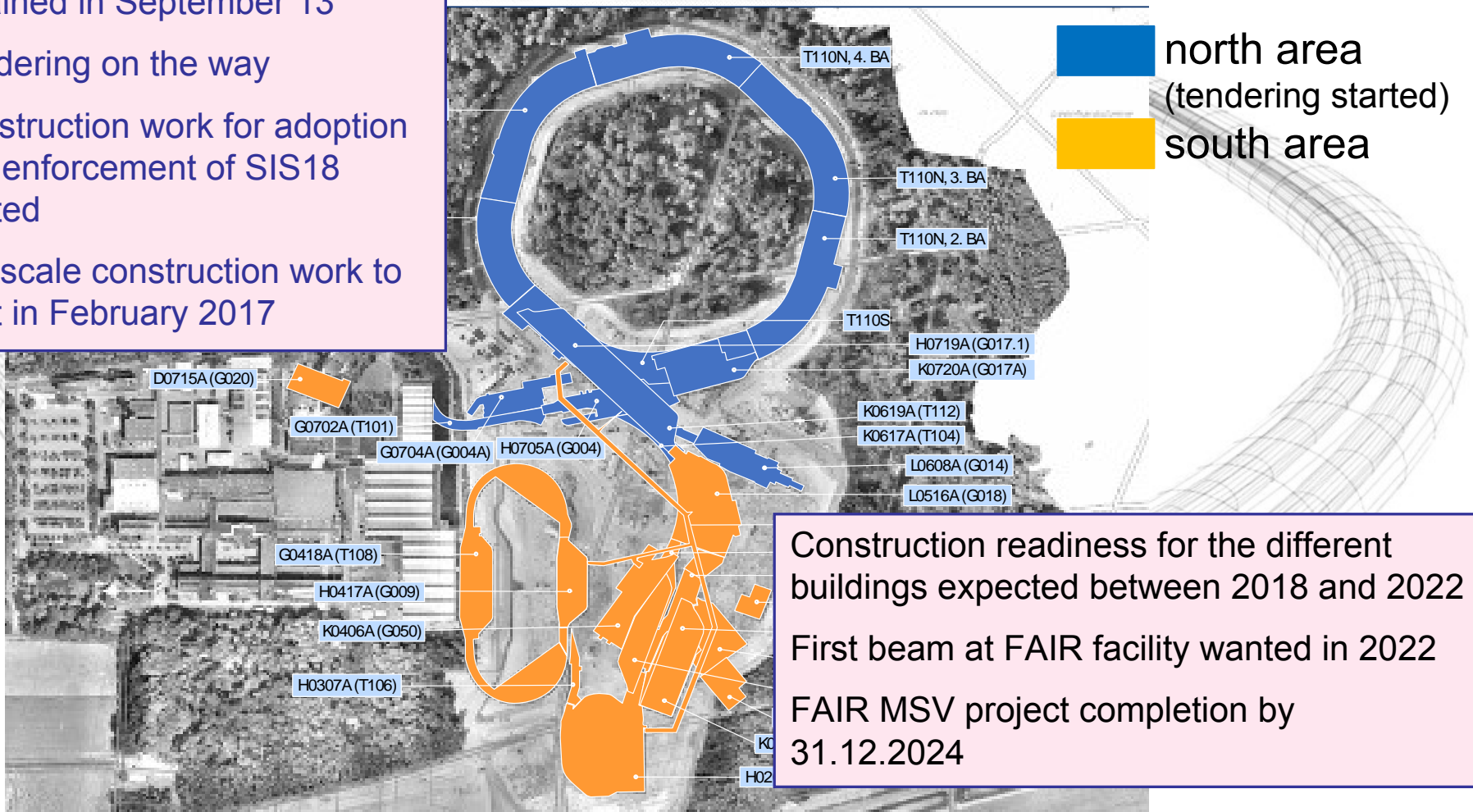
Final BMBF signature for 1. stage of construction funds obtained in September 13

Tendering on the way

Construction work for adoption and enforcement of SIS18 started

Full scale construction work to start in February 2017

... Realization along the beam line



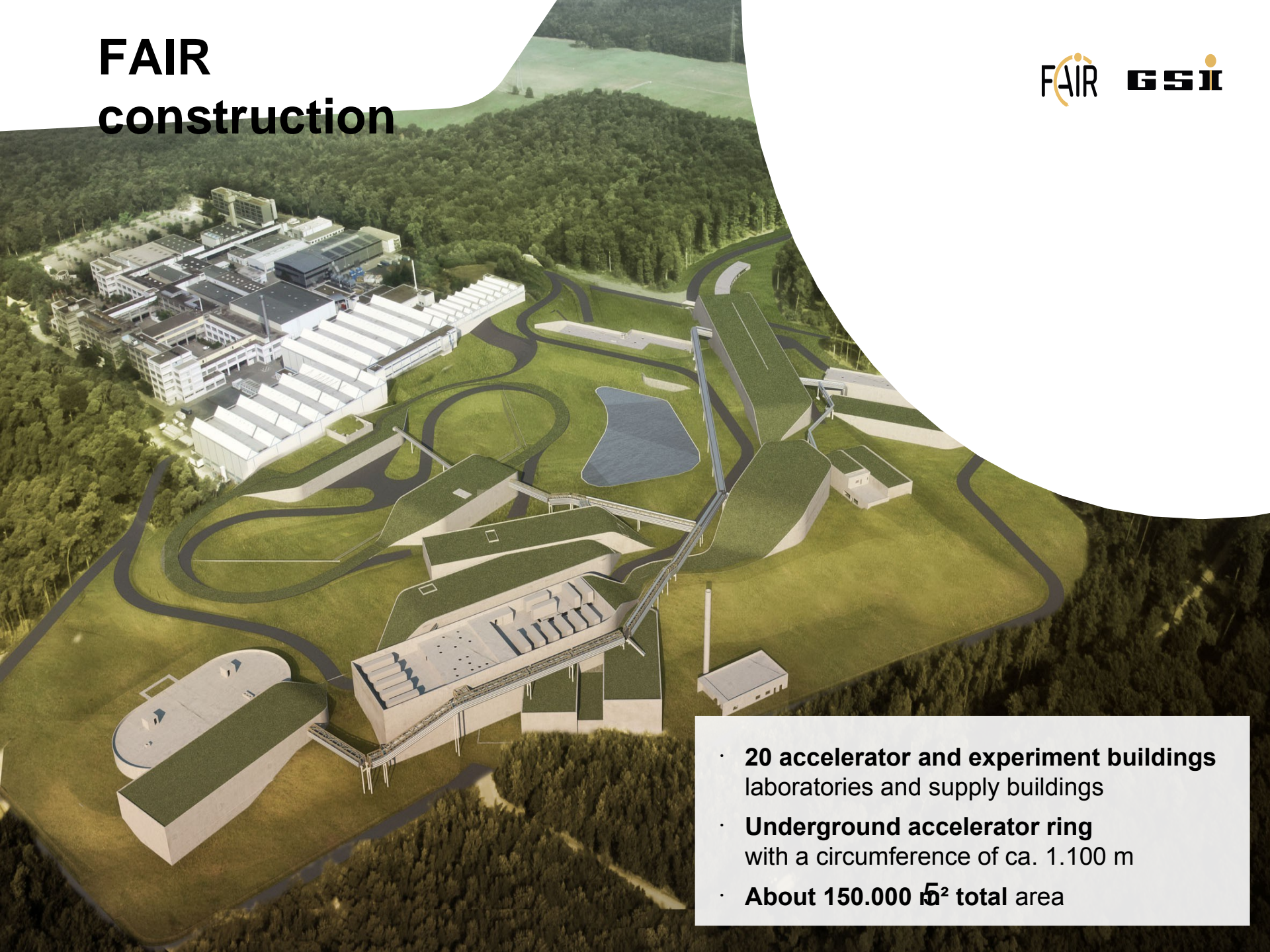
Construction readiness for the different buildings expected between 2018 and 2022

First beam at FAIR facility wanted in 2022

FAIR MSV project completion by 31.12.2024

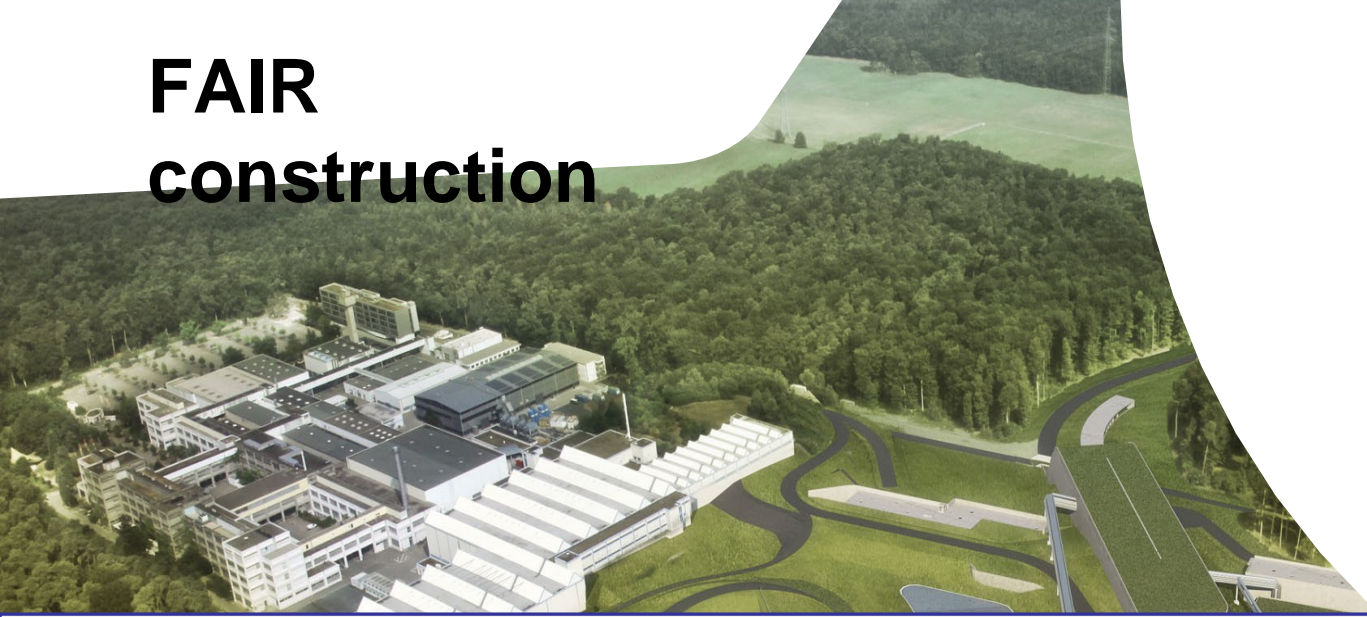
FAIR NUSTAR JG

FAIR construction



- **20 accelerator and experiment buildings**
laboratories and supply buildings
- **Underground accelerator ring**
with a circumference of ca. 1.100 m
- **About 150.000 m² total area**

FAIR construction

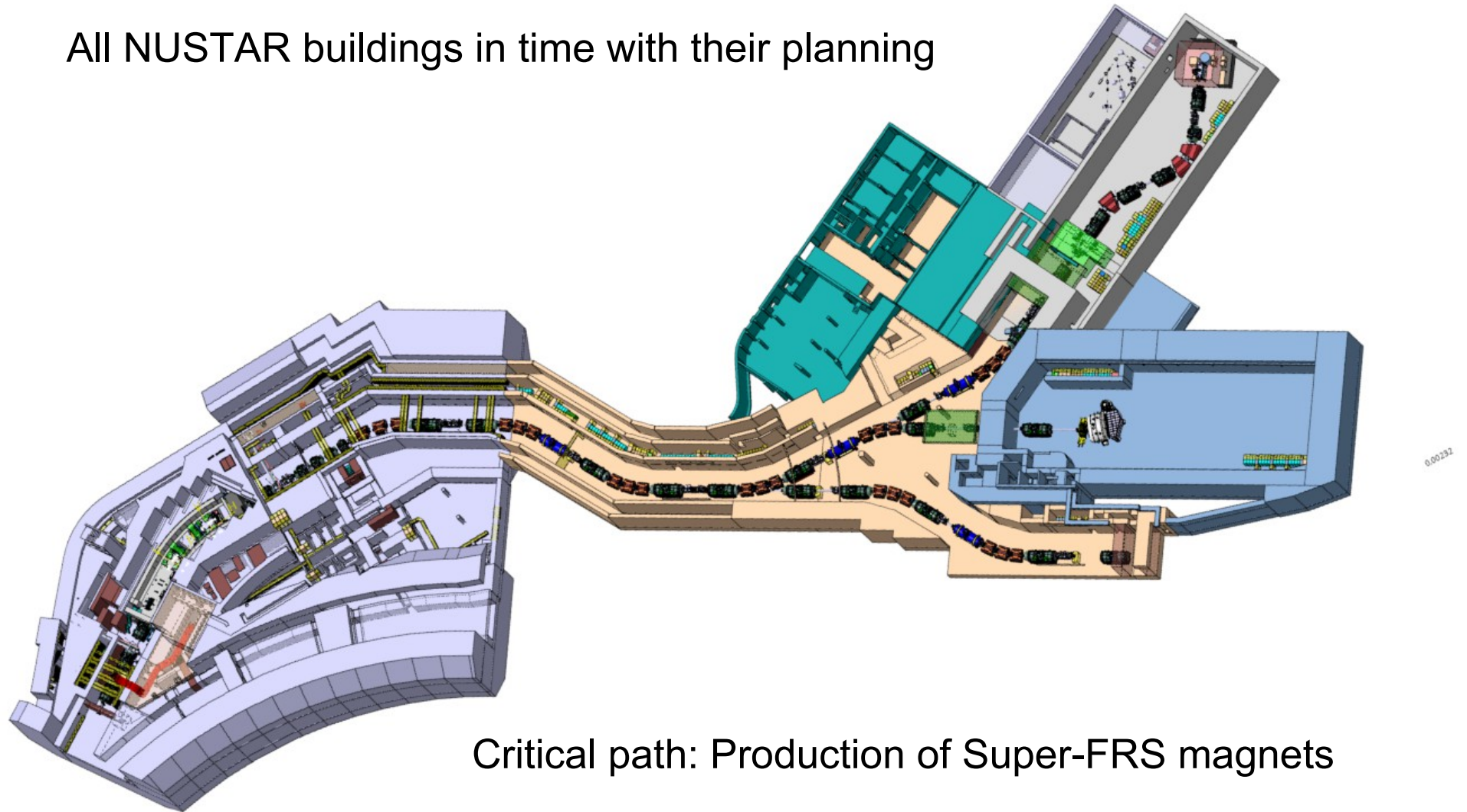


- Construction area $686.373 \text{ m}^2 = 96$ soccer fields
- Total floor space $158.661 \text{ m}^2 =$ mid size airport
- 1.327 Ground piles 60.000 m
- Excavated earth $1.200.200 \text{ m}^3$
- Concrete $625.000 \text{ m}^3 =$ weight of 5.000 family homes

Super-FRS and NUSTAR caves

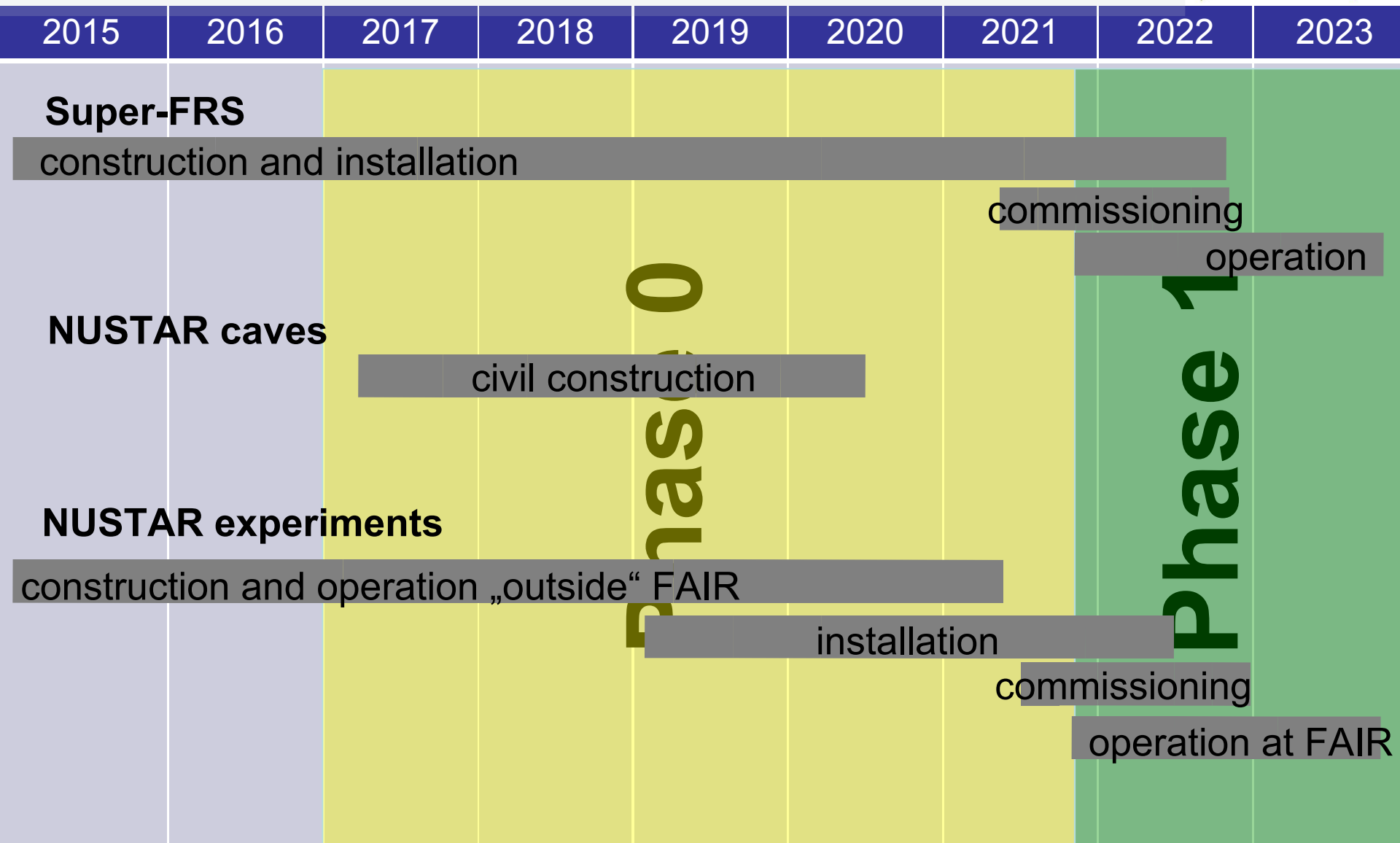


All NUSTAR buildings in time with their planning



Critical path: Production of Super-FRS magnets

NUSTAR Time Line



Beam time FAIR Phase-0



Officially announced as planning basis

Calender year	2018	2019	2020	2021
beam time commissioning/equipment tests [months]	1.5	1.5	1.5	1.5
beam time experiments [months]	3	4	4	4
Total beam time [months]	4.5	5.5	5.5	5.5

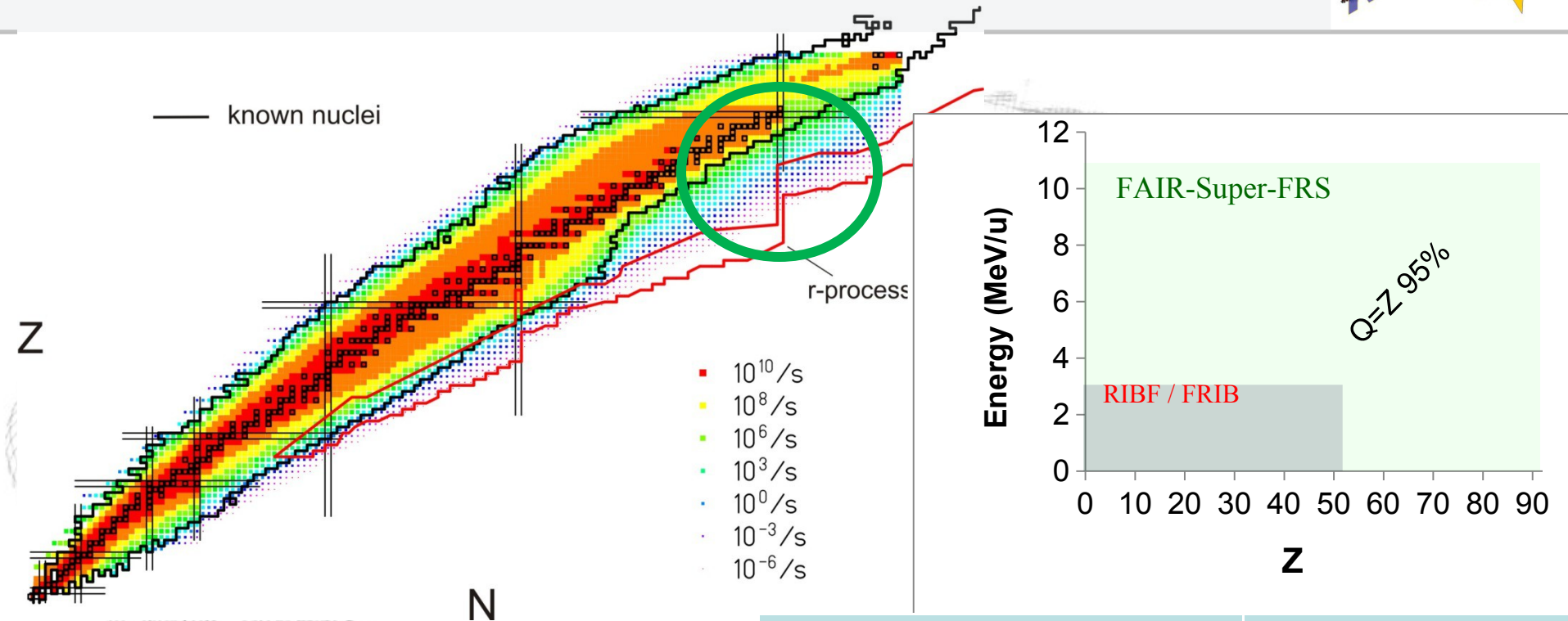
Call for proposals by the end of 2016; PAC Meeting in Spring 2017

Beam time 2018

2018 Version vom 06.07.2016 (S.Reimann)															
							FERIEN								
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Einschränkungen für Experimentbetrieb		
IQ	Shutdown				MC	BC	MK	MK	BT	MK		TS	MK	Shutdown	keine
UNILAC	Shutdown		HF-Test		MC	HC	BC	MK	MK	BT	MK		MK		im Langpulsbetrieb nur A3 Energie
SIS18	SIS18 upgrade inkl. periodische Dry Runs				MC	BC	MK	MK	BT	MK			MK		für 2-3 Monate max. 2 Experimente gleichzeitig
HEST	Periodische Dry Runs (3-4Tage am Stück)				MC	BC	MK	MK	BT	MK			MK		keine
ESR	Periodische Dry Runs (3-4Tage am Stück)					MC		BC	MK				MK		nur Speicherbetrieb mit interem Target
CRYRING	Periodischer Teststrahlbetrieb local (2x4 Wochen am Stück)						MC	BC							kein Experimentbetrieb möglich
MC	Machine Checkout = Trockeninbetriebnahme incl. Kontrollsystem-/Betriebssoftware Inbetriebnahme														
BC	Beam Commissioning = Inbetriebnahme mit Strahl / Inbetriebnahme Strahlwege (Primärstrahl) mit Pilotstrahl, timing System etc.														
MK	flex. MK-Beamtime (Maschinenexperimente, Maschinenentwicklung, Geräteinbetriebnahmen, Operateursausbildung, FAIR-Detektorentwicklung, Qualifizierung+Referenzmessungen)														
BT	Beamtime = Strahlzeit für PAC-Vergabe vorgesehen														
TS	Flexible technische Strahlunterbrechung für Reparaturen, Softwareupdates usw. (als Block oder verteilt)														
HC	HF-Konditionierung														

FAIR NUSTAR JG

Uniqueness and Competitiveness



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

Facility	U beam int. per spill at production target
previously at GSI	1...2x10 ⁹
after the SIS18 upgrade at GSI	8x10 ⁹
commissioning phase SIS100	2x10 ¹⁰
final full intensity with SIS100	3x10 ¹¹

Highlights of the initial Phase – 1 programme

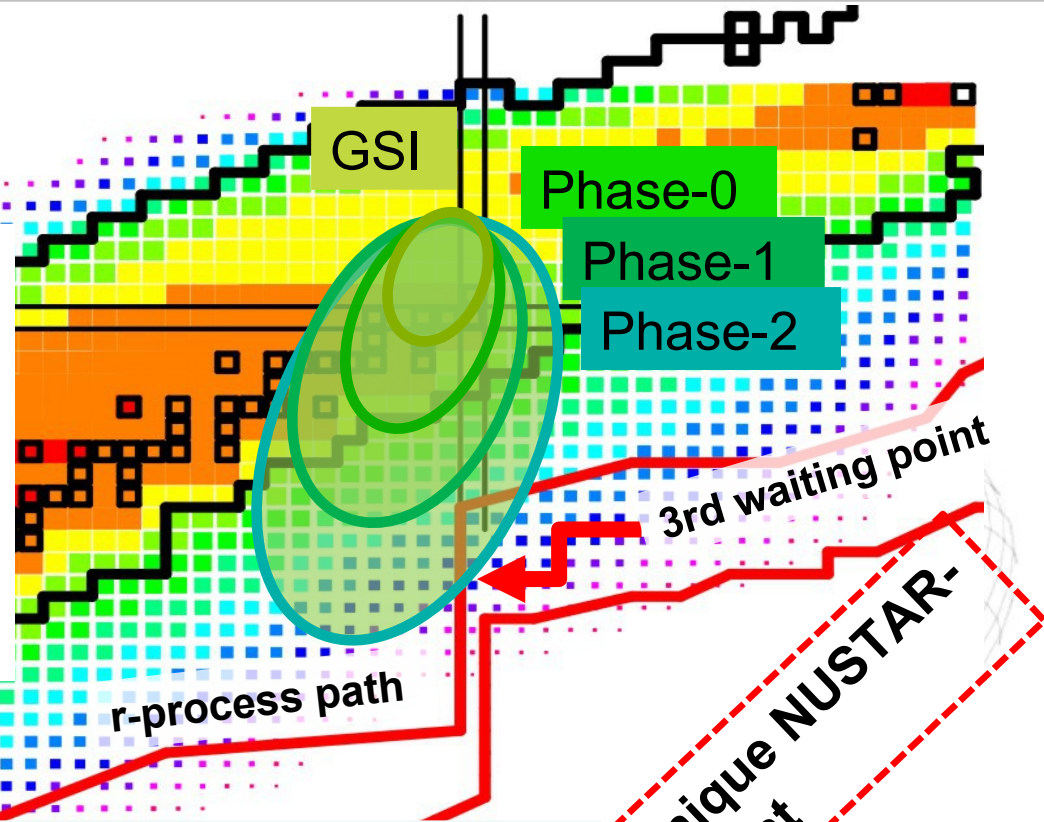
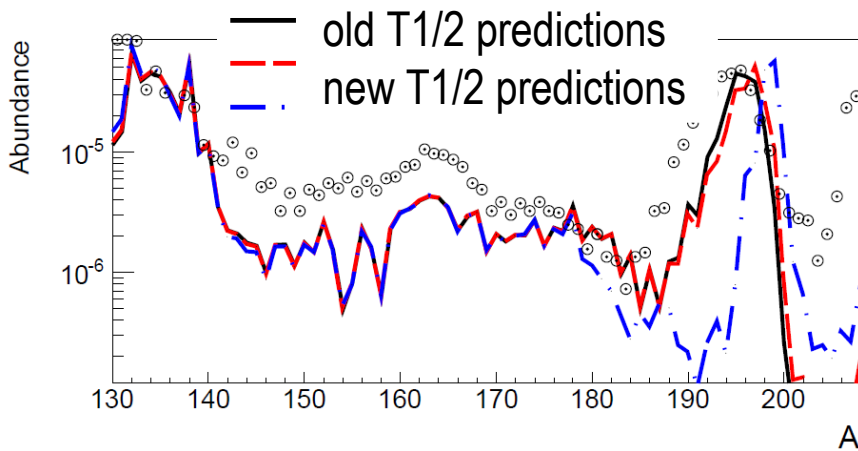


- Understanding the 3rd r-process peak by means of comprehensive measurements of masses, lifetimes, neutron branchings, dipole strength, and level structure along the $N=126$ isotones;
- Equation of State (EoS) of asymmetric matter by means of measuring the dipole polarizability and neutron skin thicknesses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

The N=126 Physics case



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



NUSTAR aims to measure:

- masses
- β -lifetimes
- neutron-branchings
- strength distributions
- level structure

Important unique NUSTAR-
LEB experiment

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

Experimental opportunities for high-resolution spectroscopy at FAIR/NUSTAR



Research field	Experimental method (beam-energy range)	Physics goals and observables	Beam int. (particle/s)
Nuclear structure, reactions and astrophysics	Intermediate energy Coulomb excitation, In-beam spectroscopy of fragmentation products (E/A ~ 100 MeV)	Medium spin structure, Evolution of shell structure and nuclear shapes, transition probabilities, moments,	101...105
	Multiple Coulomb excitation, direct and deep-inelastic, fusion evaporation reactions (E/A ~ 5 MeV; Coulomb barrier)	high spin structure, single particle structure, dynamical properties, transition probabilities, moments,	104...107
	Decay spectroscopy (E/A = 0 MeV)	half-lives, spins, nuclear moments, GT strength, isomer decay, beta-decay, beta-delayed neutron emission, exotic decays such as two proton, two neutron.	10-5...103

Extracted from HISPEC/DESPEC Technical Proposal , 12.2005

HISPEC

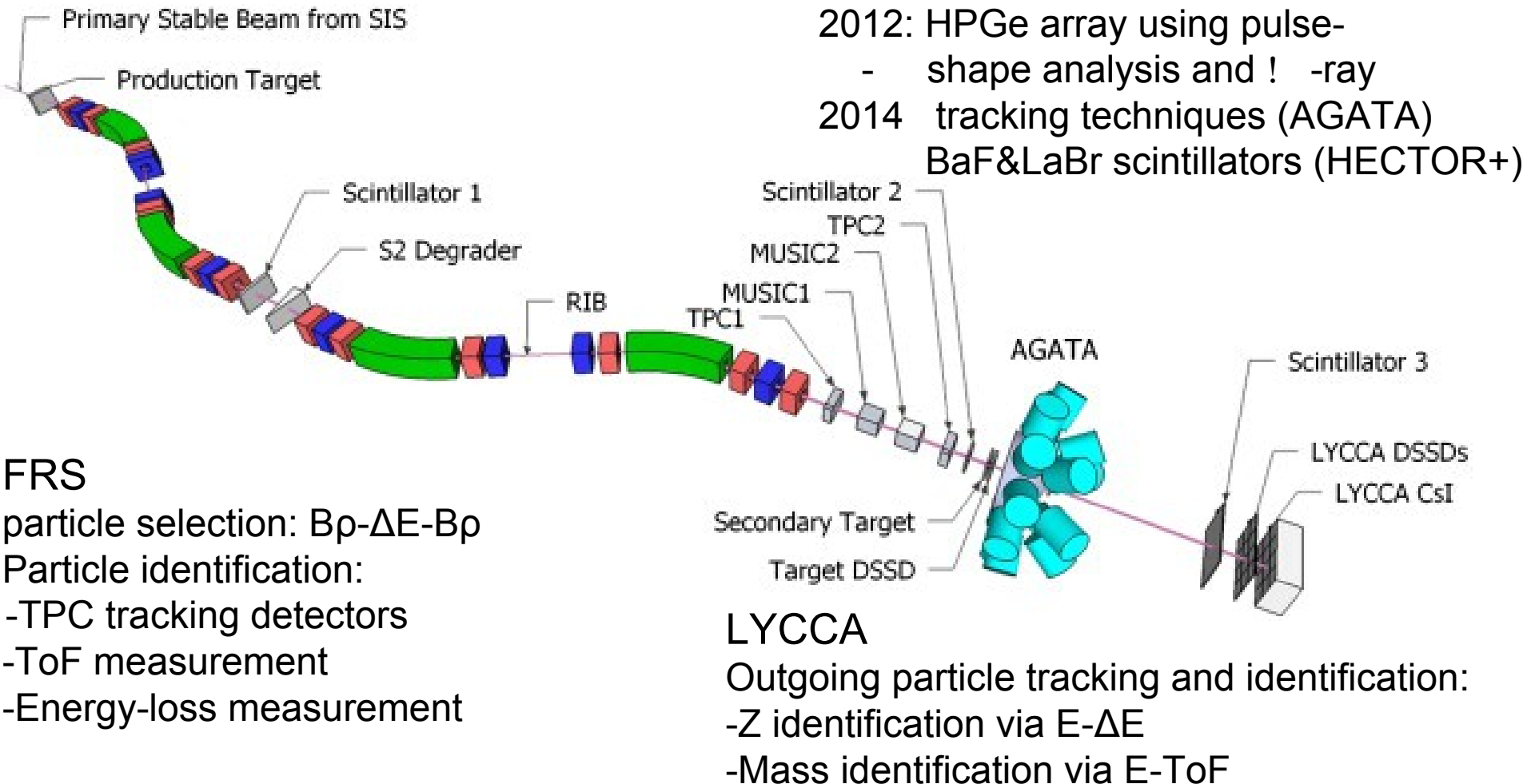
- LYCCA *heavy ion calorimeter with ToF capability in operation*
- AGATA *gamma spectrometer in operation*
- Hyde *light particle array prototype*
- NEDA *Neutron detector array prototype*

DESPEC

- AIDA *active implantation device prototype*
- MONSTER *neutron ToF array under construction*
- BELEN *neutron detection array in operation*
- DTAS *Decay Total Absorption Spectrometer in operation*
- DEGAS Ge Array *gamma spectrometer in development*
- FATIMA *Fast timing array in operation*

EDAQ *dedicated electronics and DAQ based on several branches*

While waiting: PreSPEC @ GSI



PRESPEC-AGATA = HISPEC-0

LYCCA

Flexor

AGATA

AGATA

Tracking array

3x2+6x3 crystals

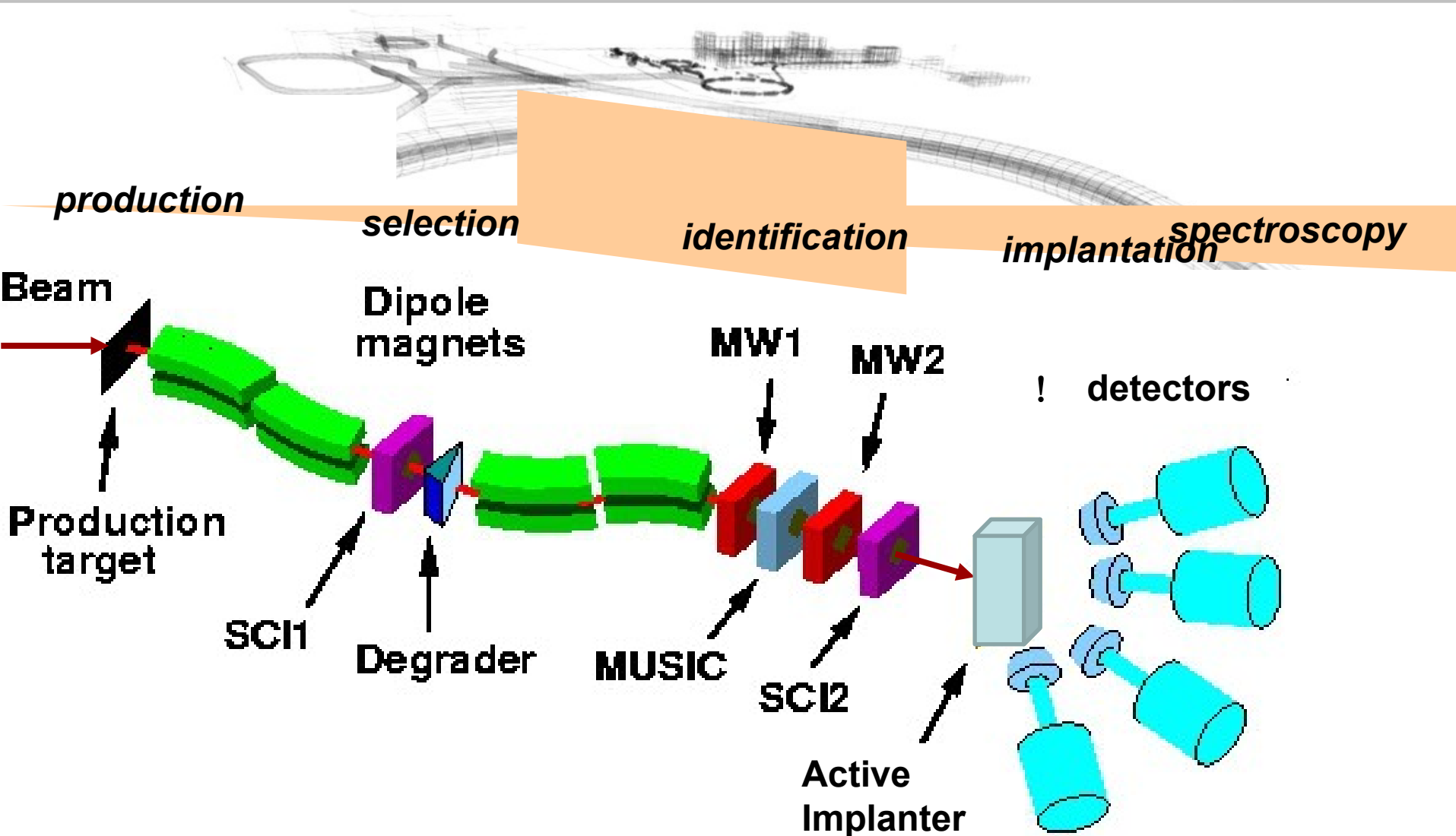
$R = 12 - 40 \text{ cm}$

! $Ph = 5 - 9\%$

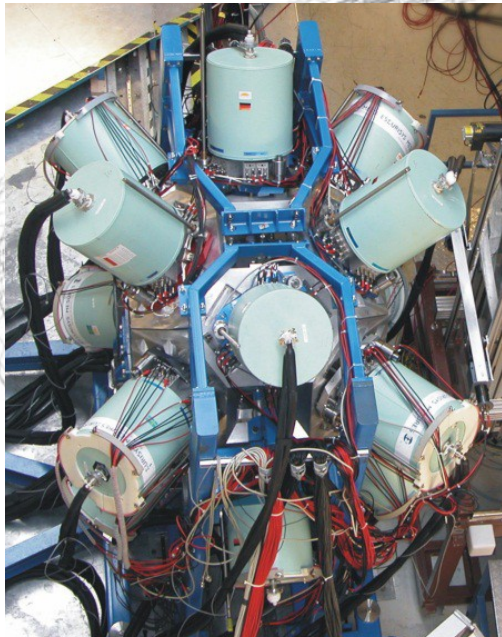
! $E = 0.4 - 1.2\%$

Experimental Campaign 2012, 2014

DESPEC: Decay Spectroscopy



Gamma-Spectroscopy: What is the problem?



Background radiation

100 Hz 500 Hz per crystal

Isomer decay gamma

1 mHz 1 Hz

**Solution:
shielding
and/or
imaging**

AIDA – DEGAS Set-up



AIDA

Trigger-less Si-DSSSD array

Active area: 24x8 cm², 8x8 cm²

Pixels: 3x128x128 = 49152

Layers: variable

E-range: 20 MeV + 20 GeV

Processing time: 20μs

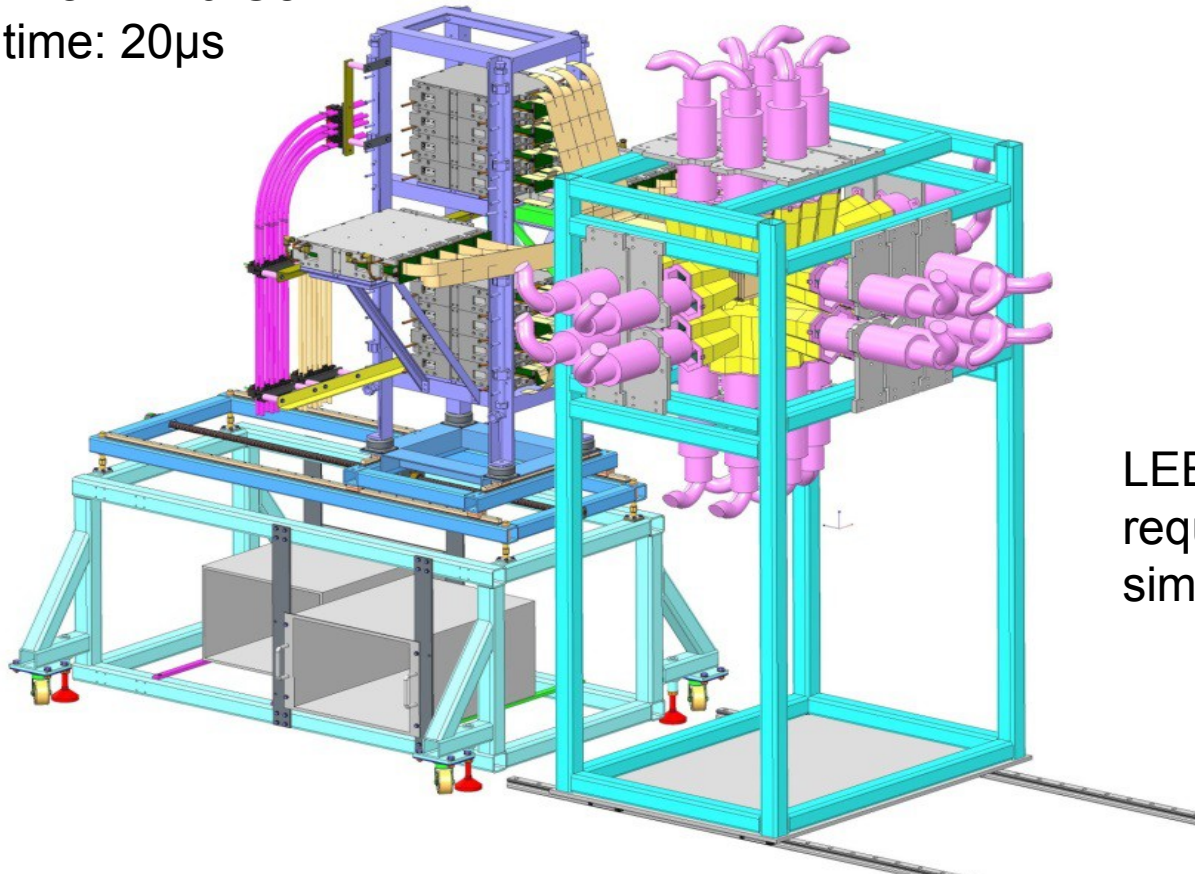
DEGAS

Shielded Triple Cluster Ge array

No. Ge Det.: 3x28 = 84

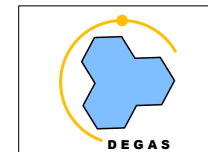
Efficiency: 23%

E-range: 50 keV ... 5 MeV



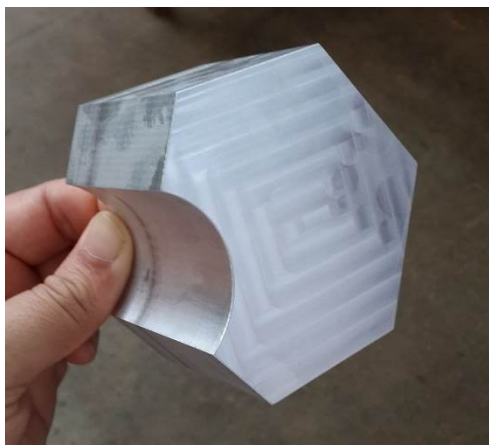
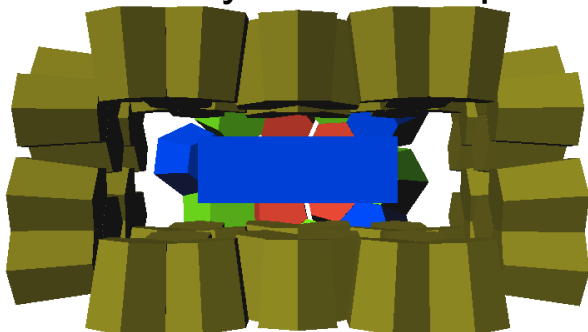
LEB beam
requirements
similar to FRS/S4

DEGAS Detector Realization



TDR approved in 7.2015

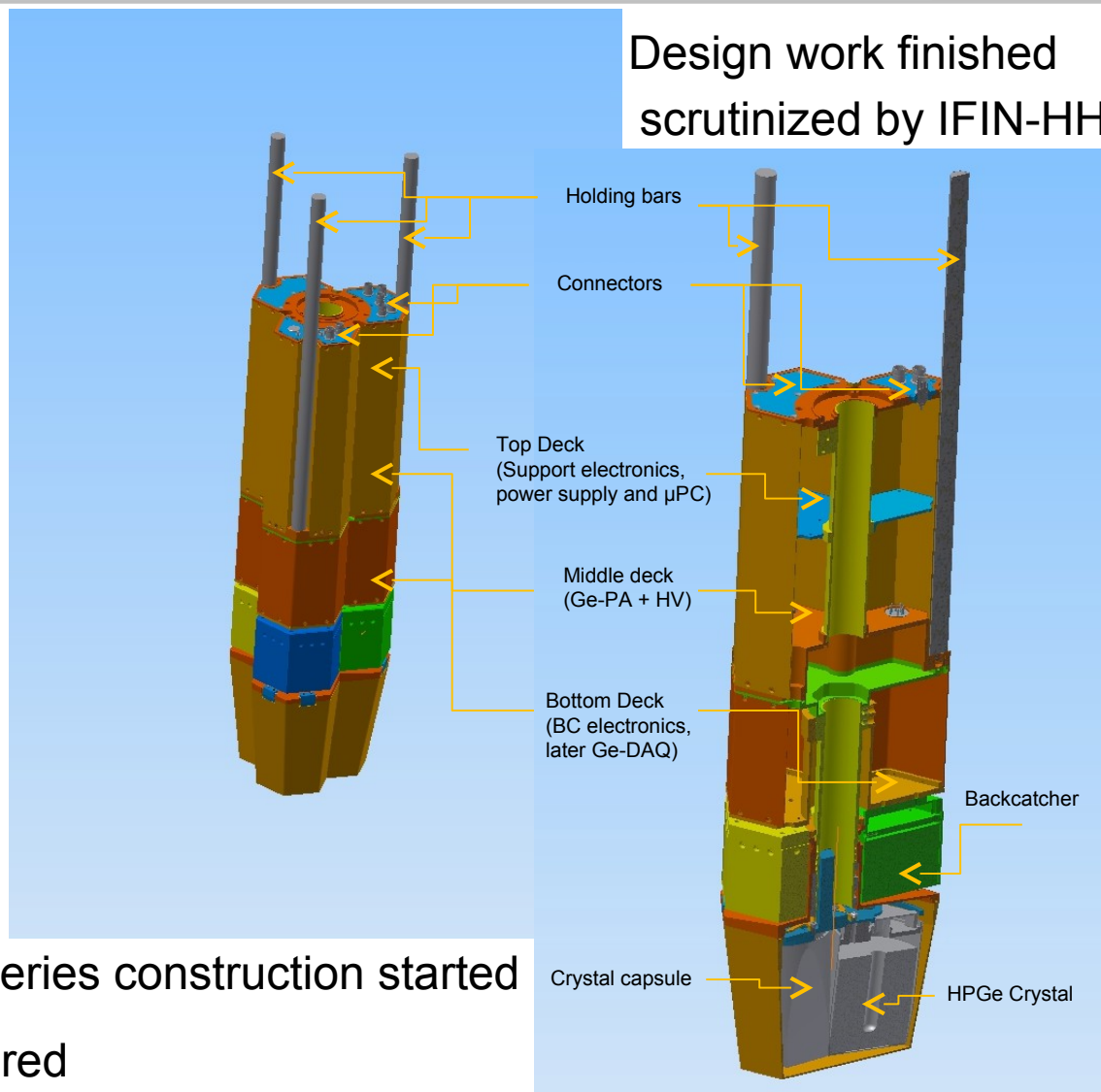
Ge Array with 28 Triples



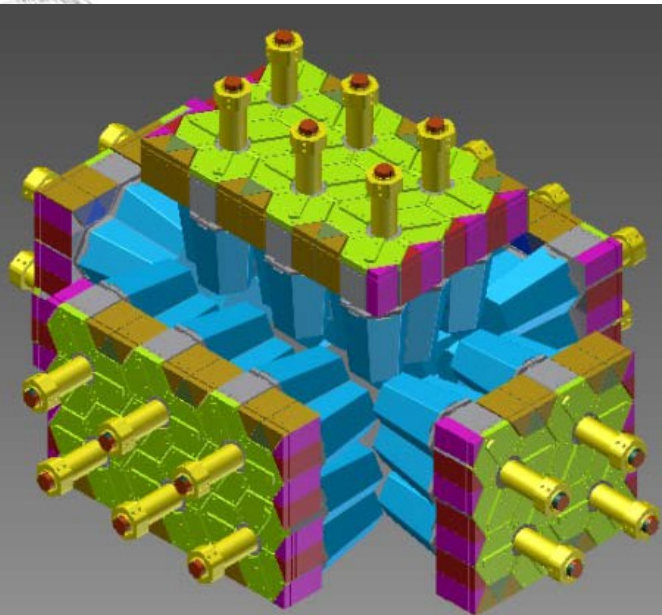
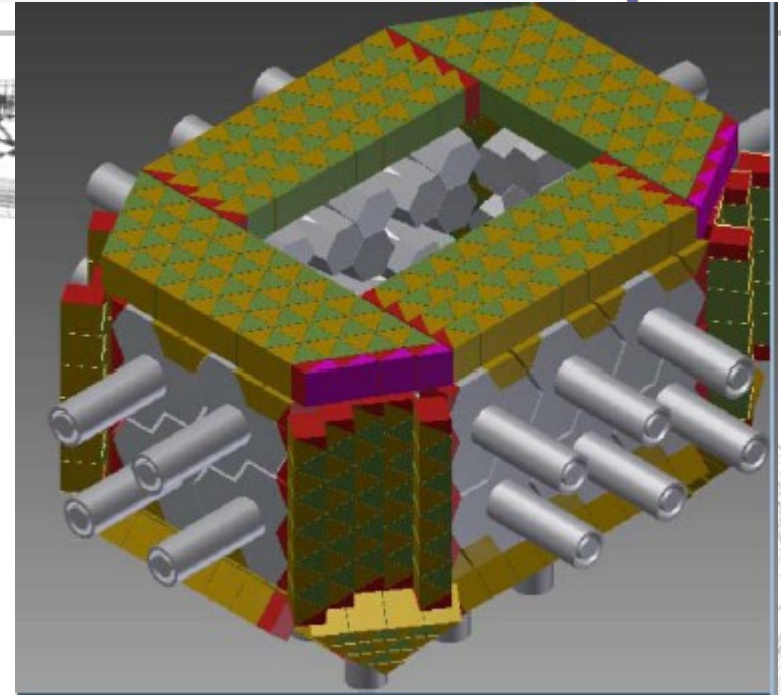
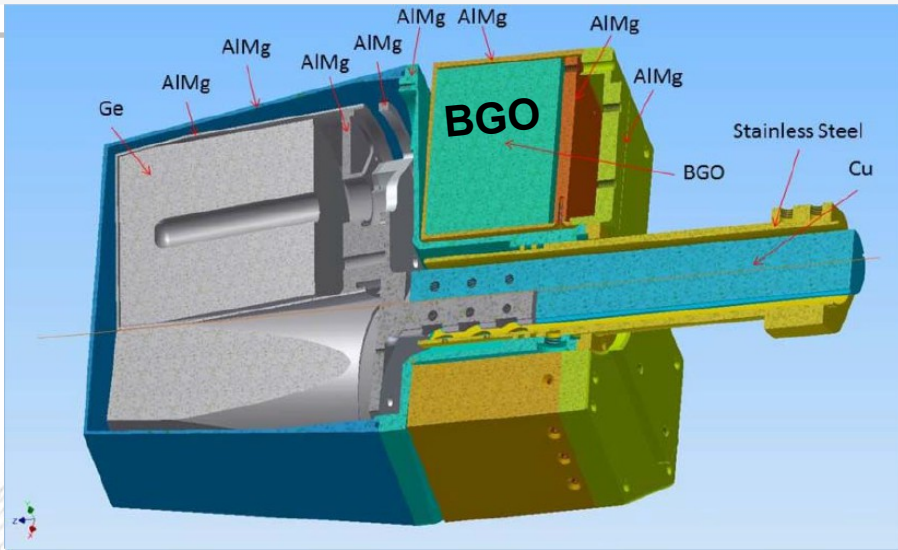
Pre-series construction started

Funding: Phase I 100% secured
Phase II ! 80% secured

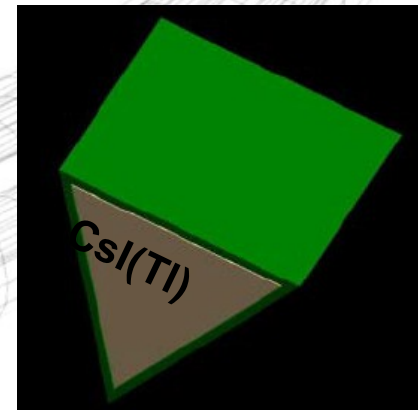
Design work finished
scrutinized by IFIN-HH



DEGAS Shield Design



- Active scintillator shields
- Background reduction
- Compton suppression
- SiPM read-out time, energy



Conclusions



- NUSTAR spectroscopy at GSI/FAIR enables unique and important contributions to our understanding of the structure of exotic nuclei
- Planned and available instrumentation is state-of-the-art
- Planning and preparation for NUSTAR Phase-0 experiments at GSI from 2018 onwards has started
- Initial set-ups both for Phase-0 and Phase-1 need to be defined as soon as possible
- **All looks very promising now!!!**