Perspectives for γ-ray spectroscopy at GSI/FAIR

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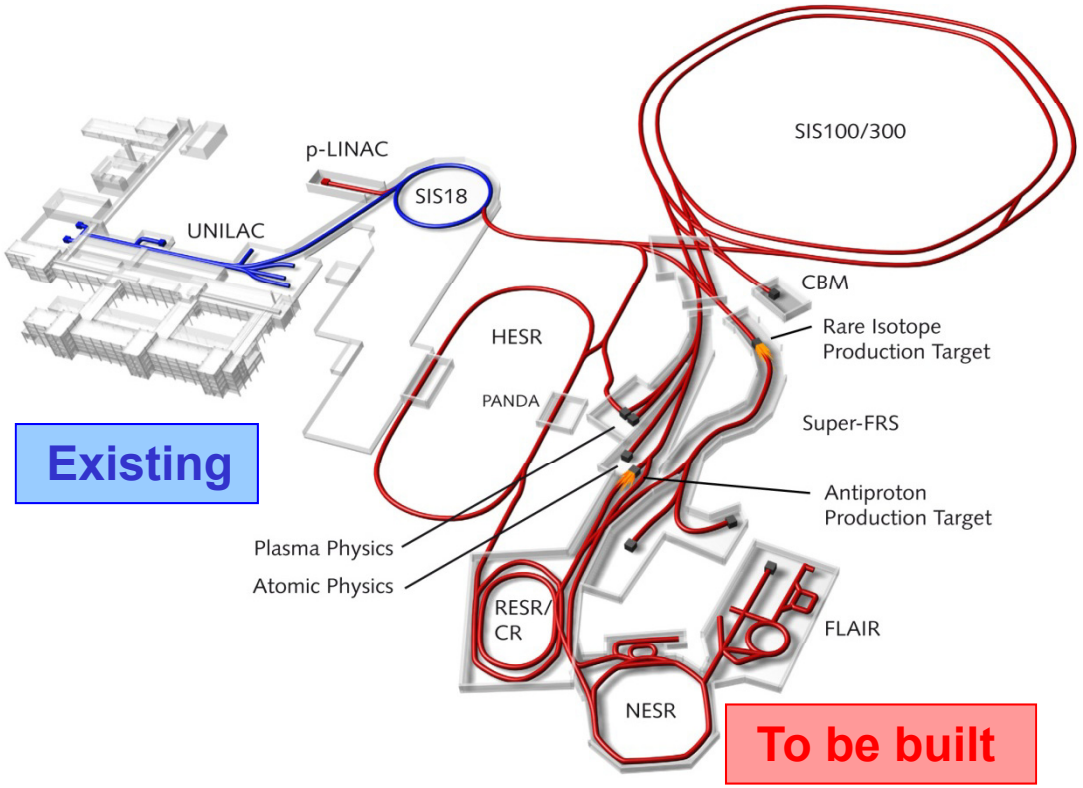
GSI

June 28, 2016
NUSPIN 2016 Workshop
Venice, Italy

Facility for Antiproton and Ion Research – The Facility



Primary Beams

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- 2(4)x10^{13}/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ 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

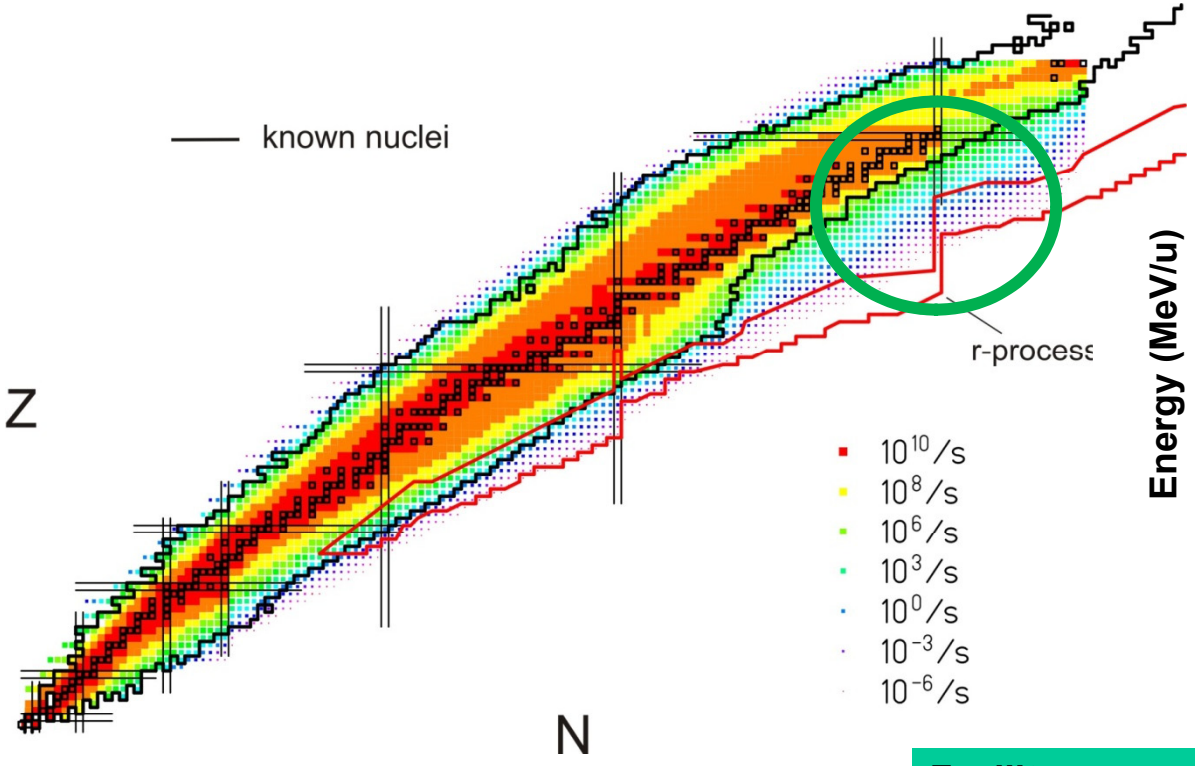
Storage and Cooler Rings

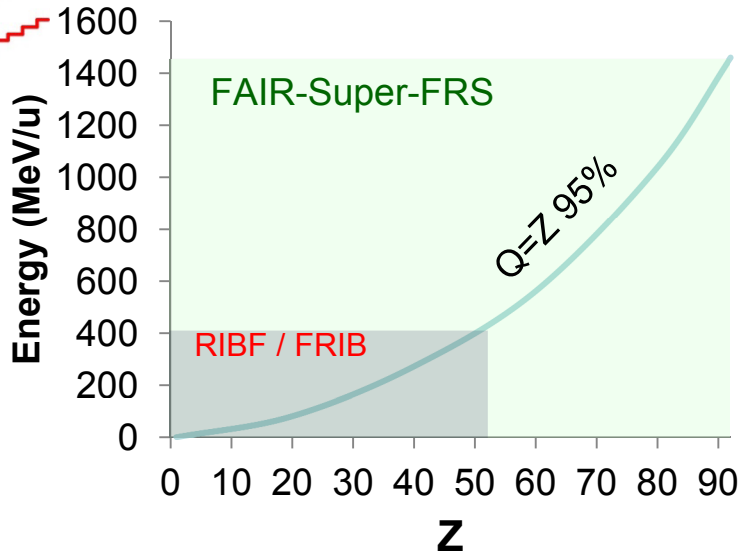
- Radioactive beams
- e – A collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons

Key Technical Features

- Cooled beams
- Rapidly cycling superconducting magnets

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}

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,	$10^{1}...10^{5}$
	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,	$10^{4}...10^{7}$
	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.	$10^{-5}...10^{3}$

Extracted from HISPEC/DESPEC Technical Proposal , 12.2005

Planned instrumentation

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*

-EDAQ *dedicated electronics and DAQ based on several branches*

DESPEC

-AIDA *active implantation device* *prototype*

-MONSTER *neutron ToF array* *under construction*

-BELEN *neutron detecion array* *in operation*

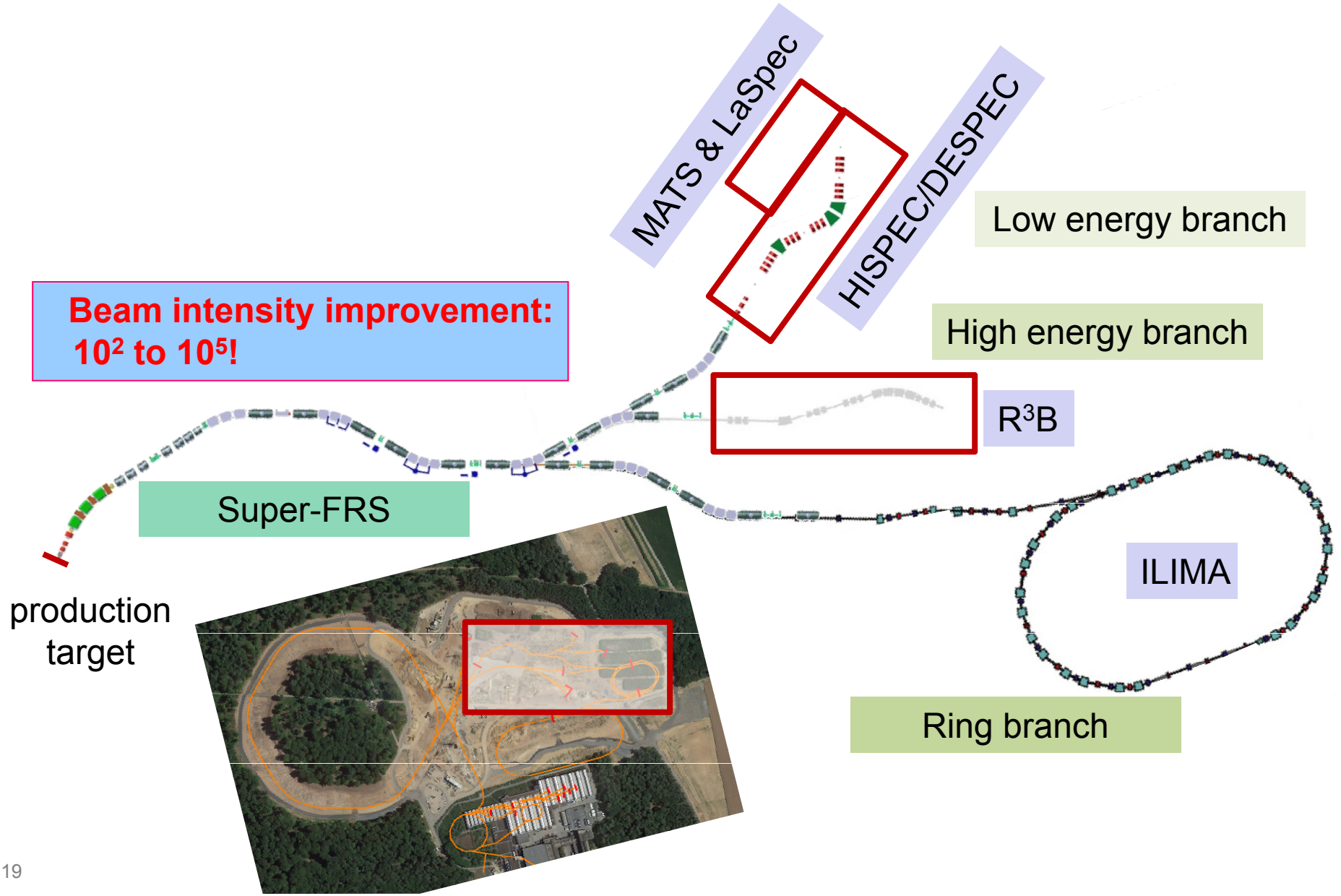
-DTAS *Decay Total Absorption Spectrometer* *in operation*

-DEGAS Ge Array *gamma spectrometer* *in development*

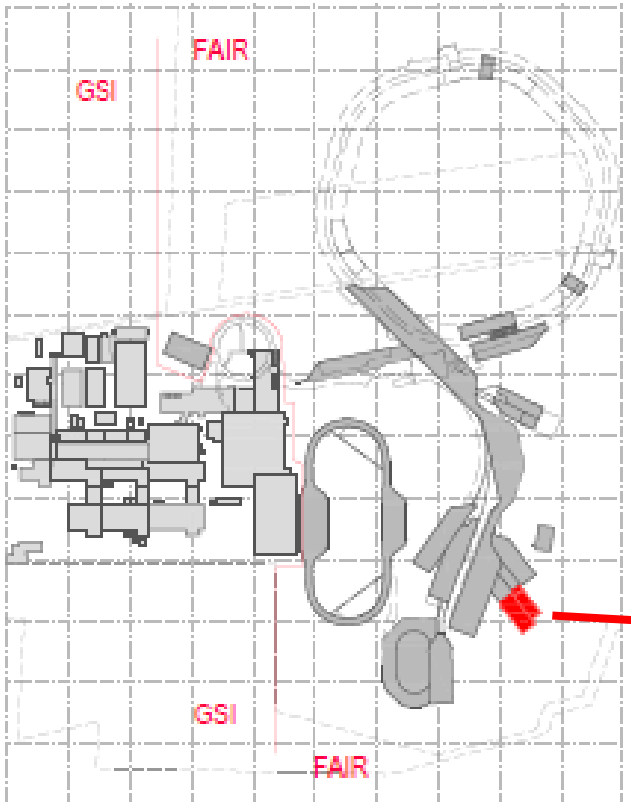
-FATIMA *Fast timing array* *in operation*

-EDAQ *dedicated electronics and DAQ based on several branches*

NUSTAR experimental areas @ FAIR



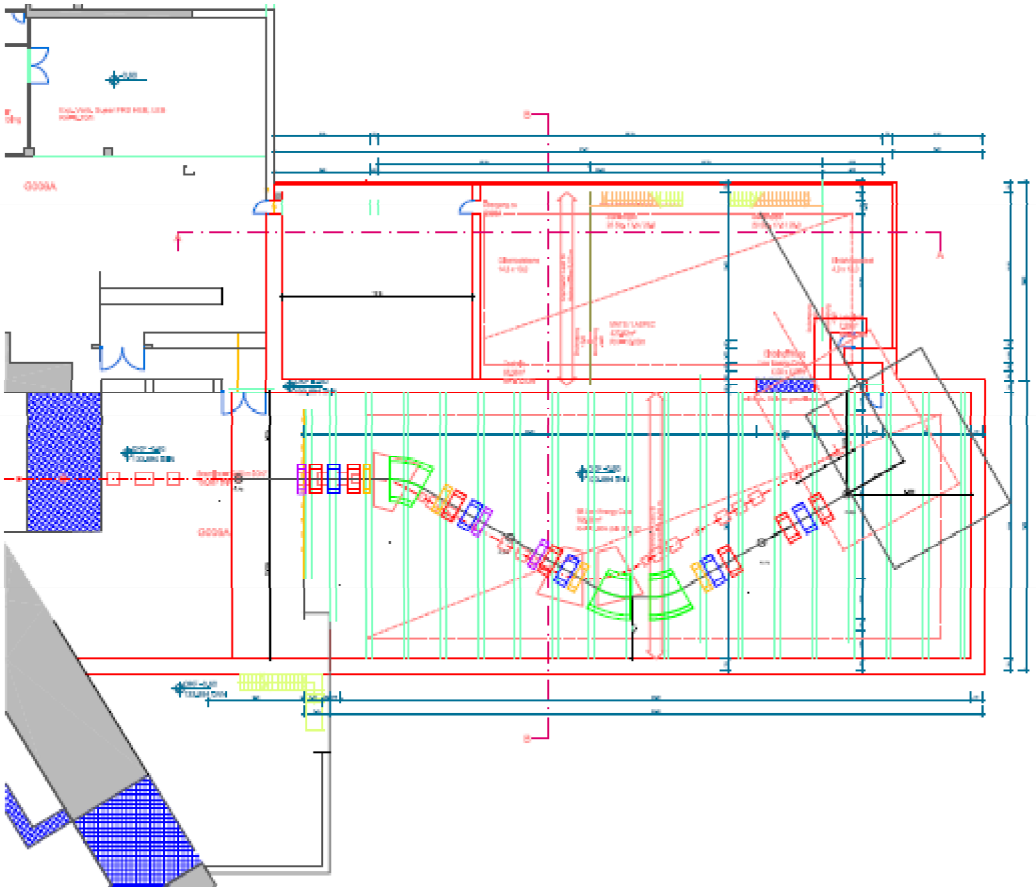
LEB Building B006b



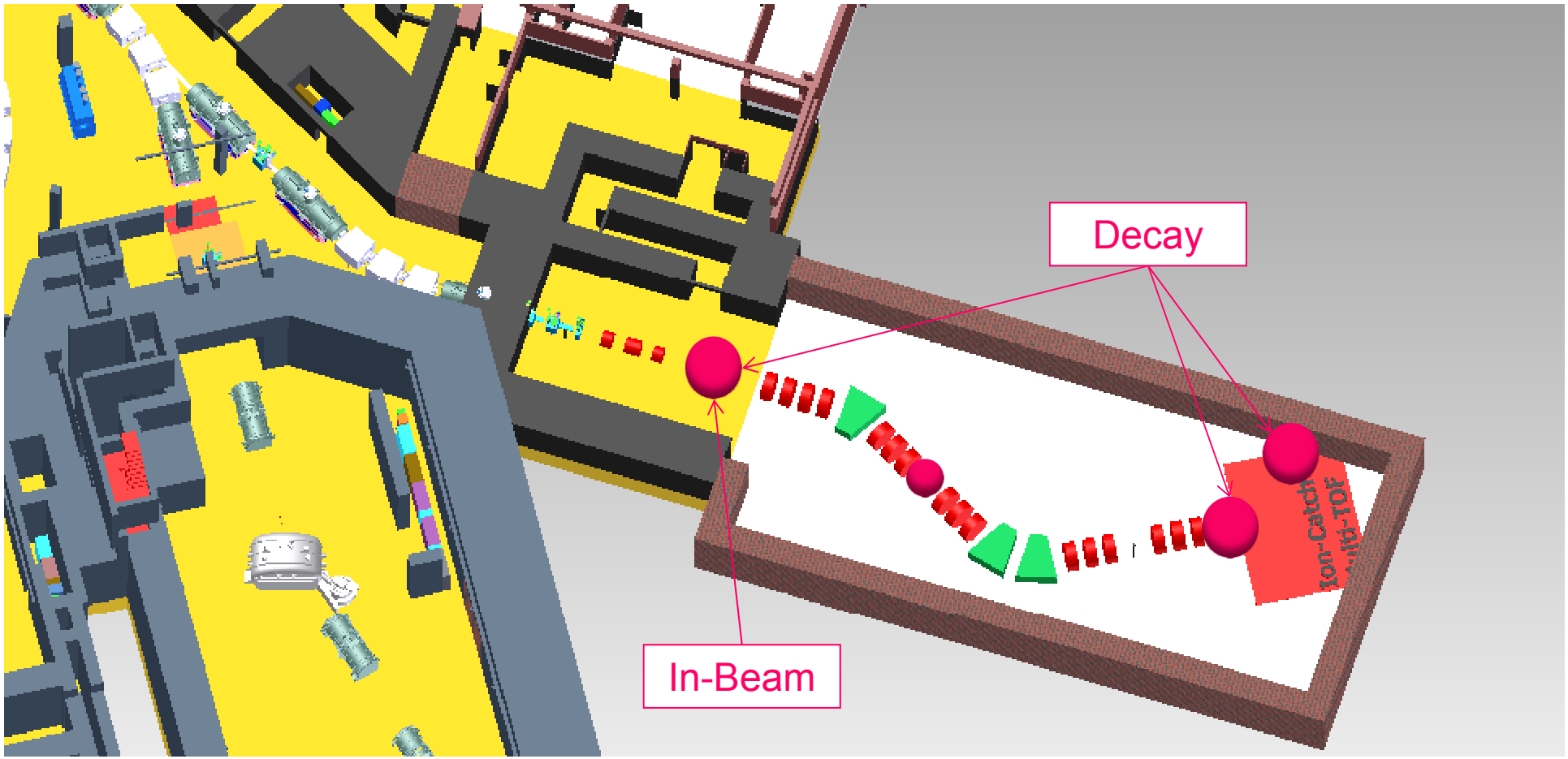
FAIR will be built „along“ the beam line

For technical reasons complex B006 needs to come early

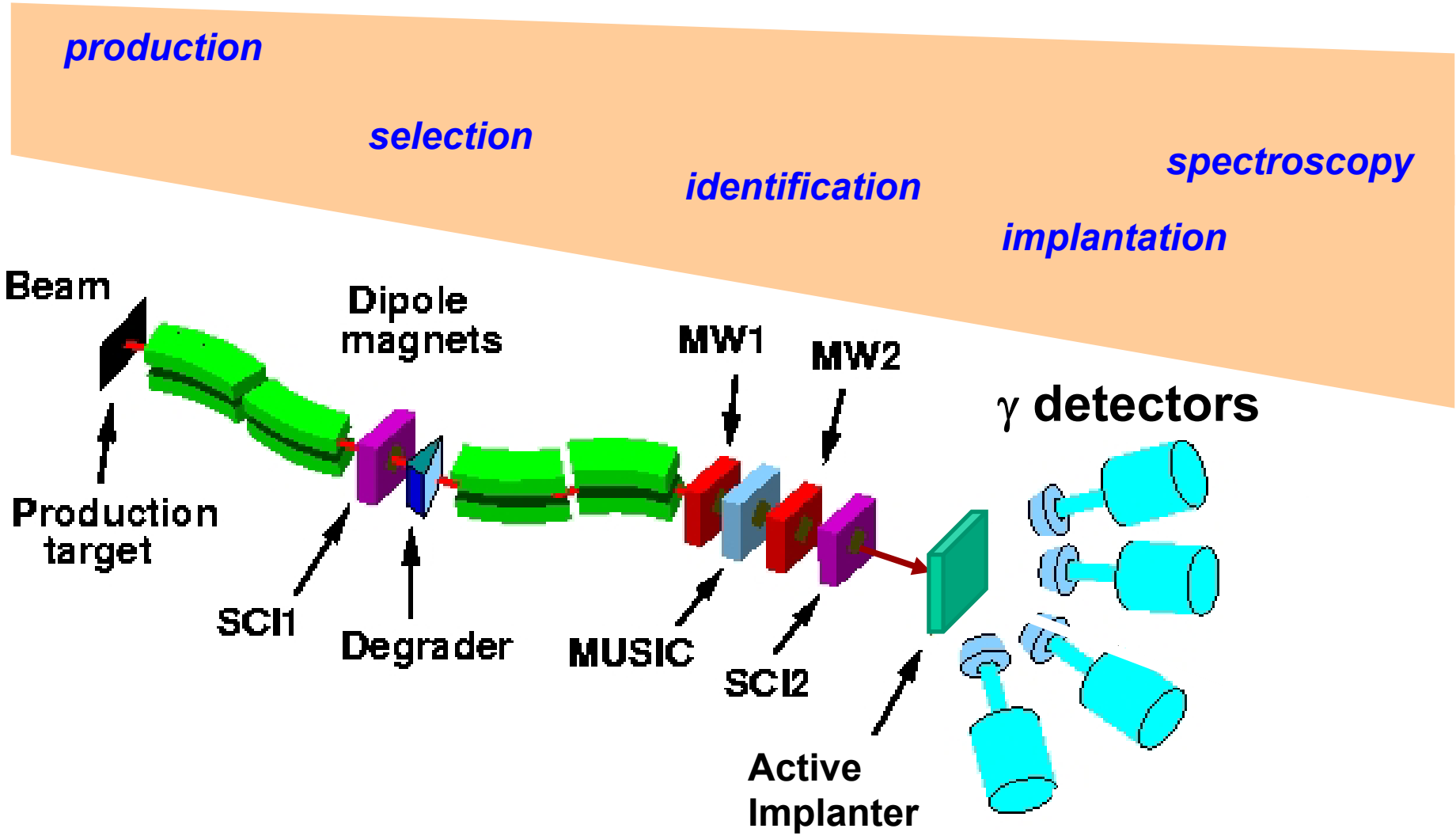
Therefore realization of B006b got priority!!!



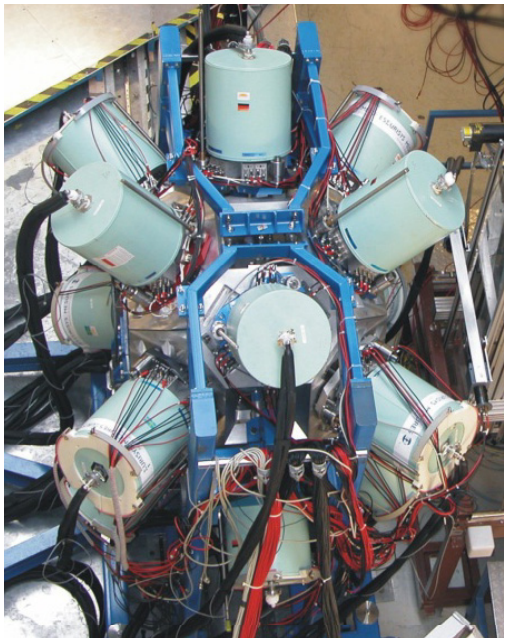
HISPEC/DESPEC Setups in the LEB

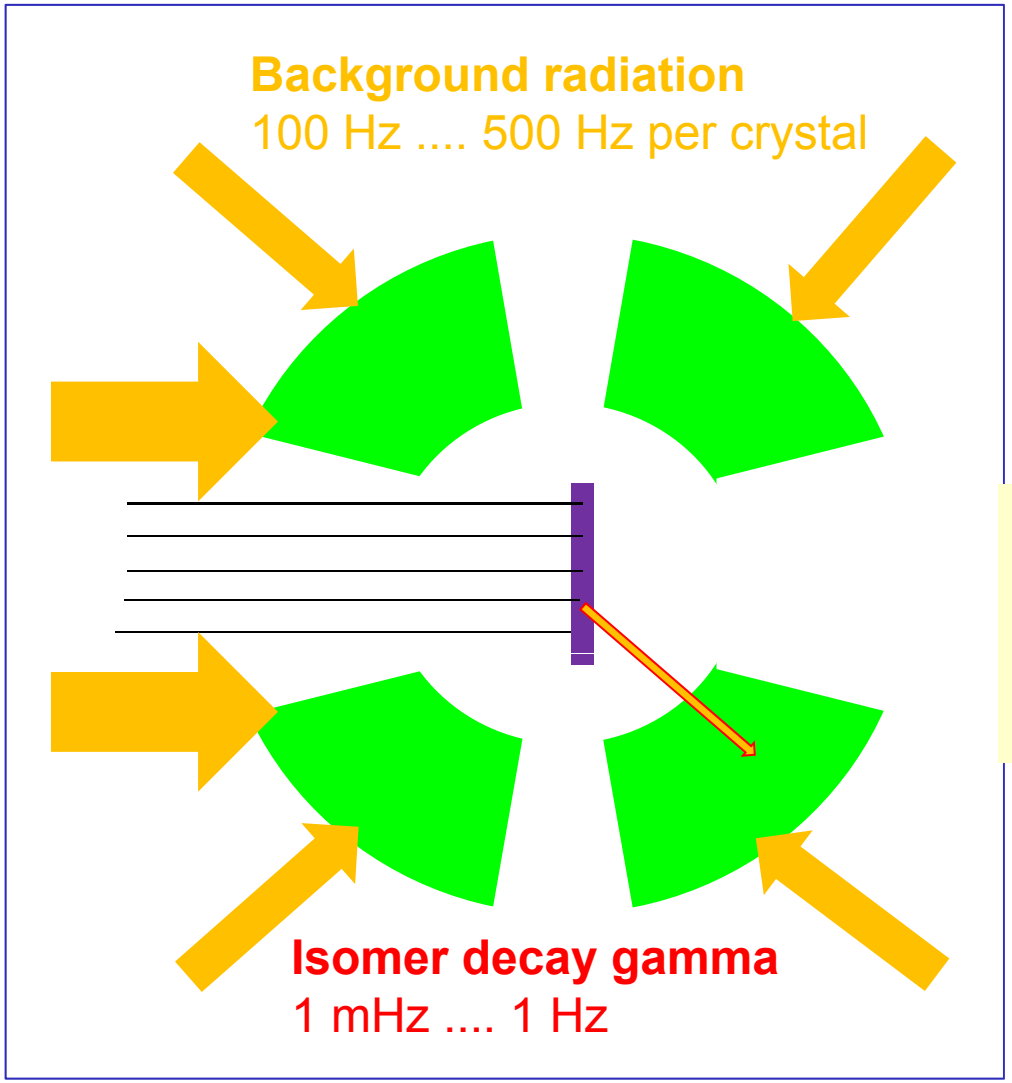


DESPEC: Decay Spectroscopy



Gamma-Spectroscopy: What is the problem?



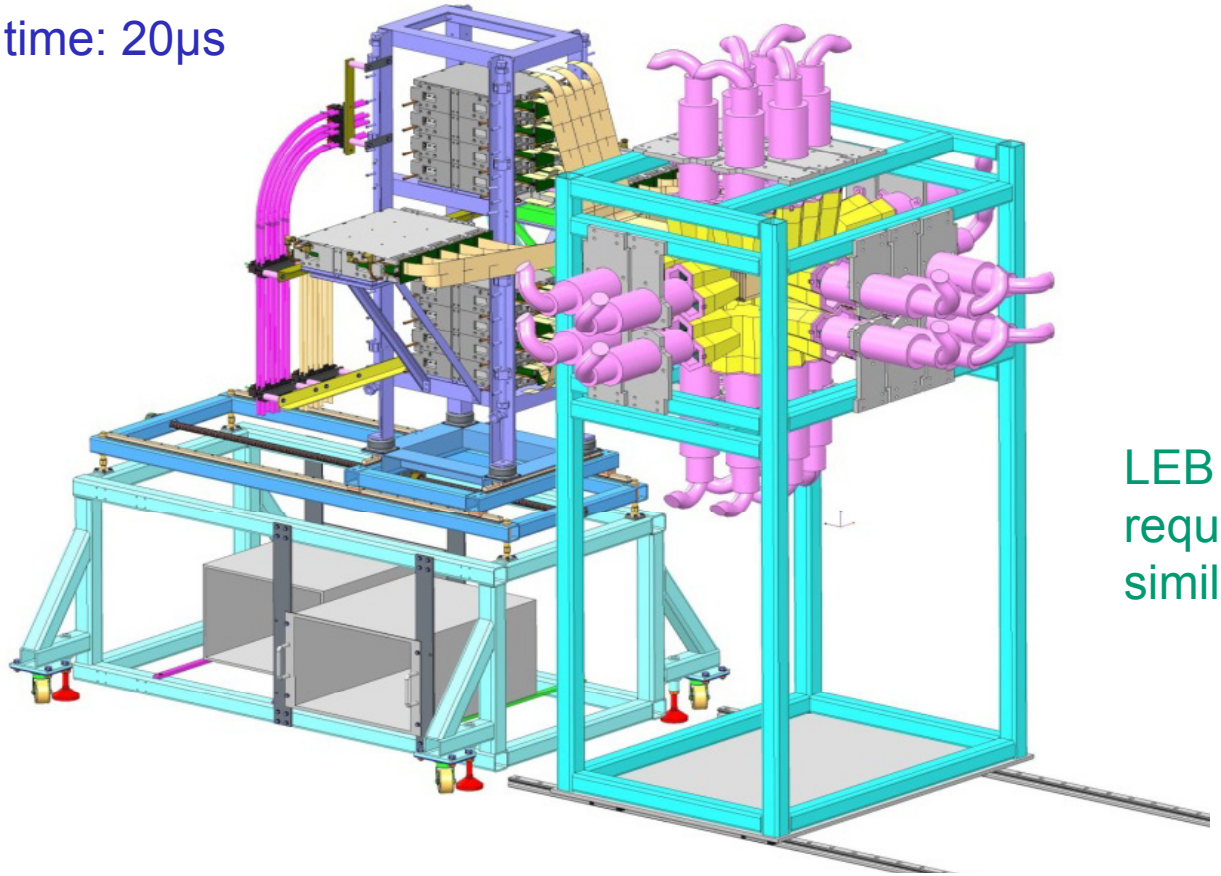


Solution: shielding and/or imaging

AIDA – DEGAS Set-up

AIDA
Trigger-less Si-DSSSD array
Active area: 24x8 cm^2, 8x8 cm^2
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

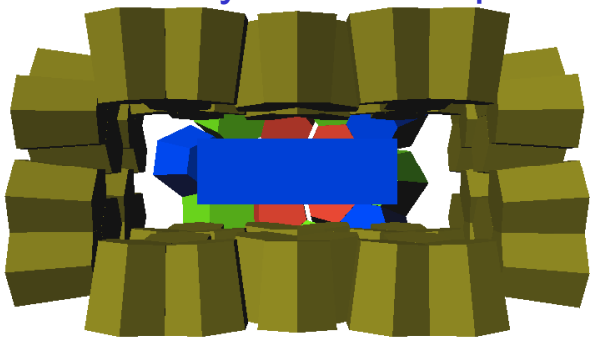


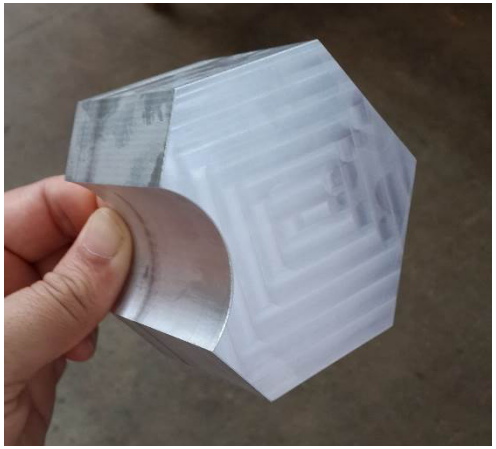
LEB beam requirements similar to FRS/S4

DEGAS Detector Realization

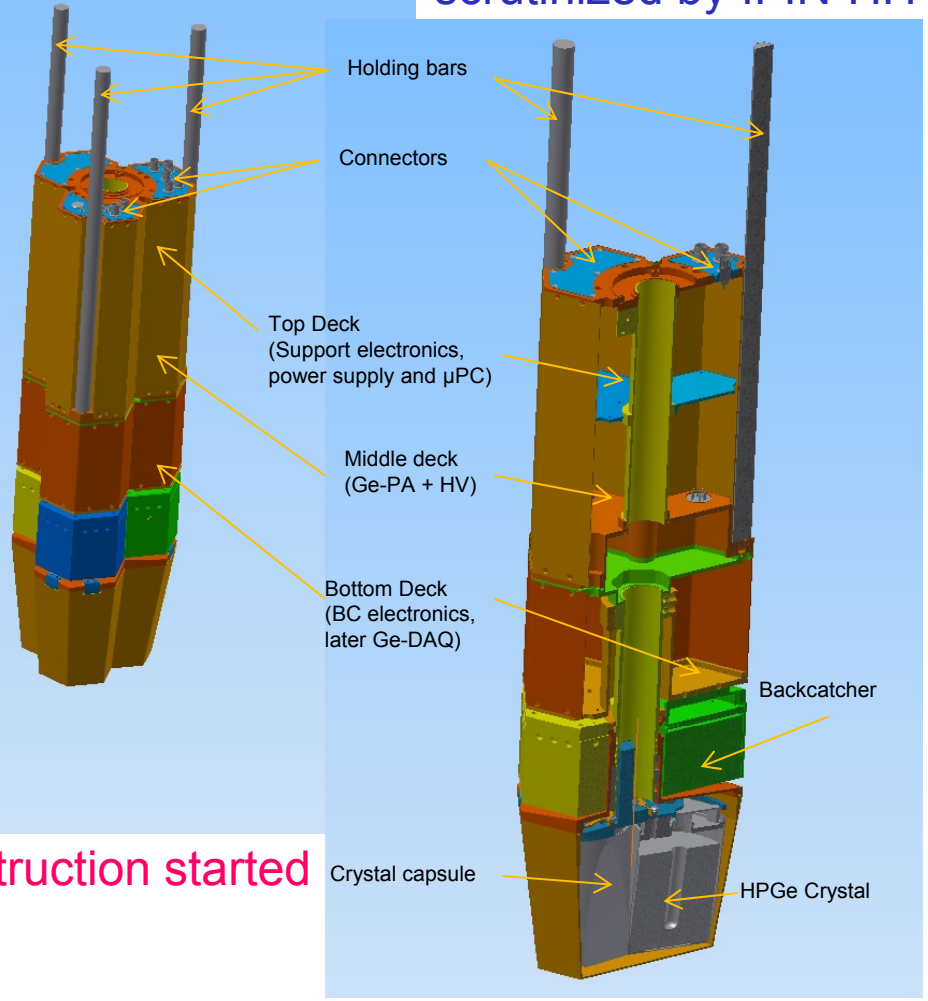
TDR approved in 7.2015

Ge Array with 28 Triples





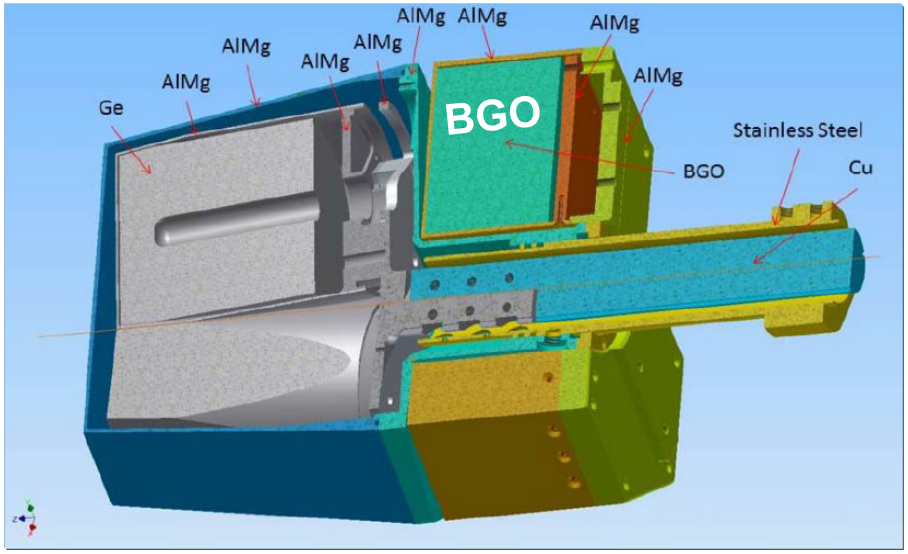
Design work finished
scrutinized by IFIN-HH

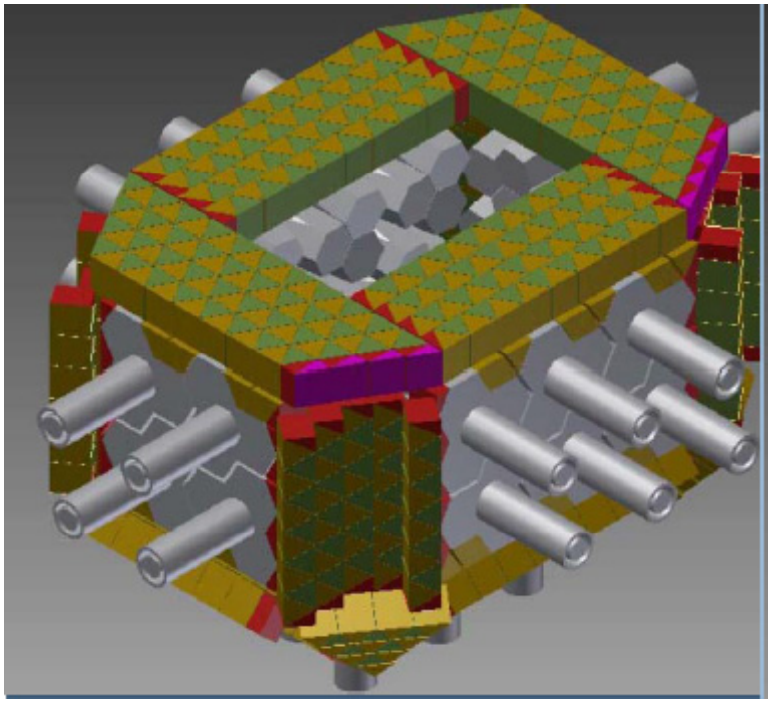


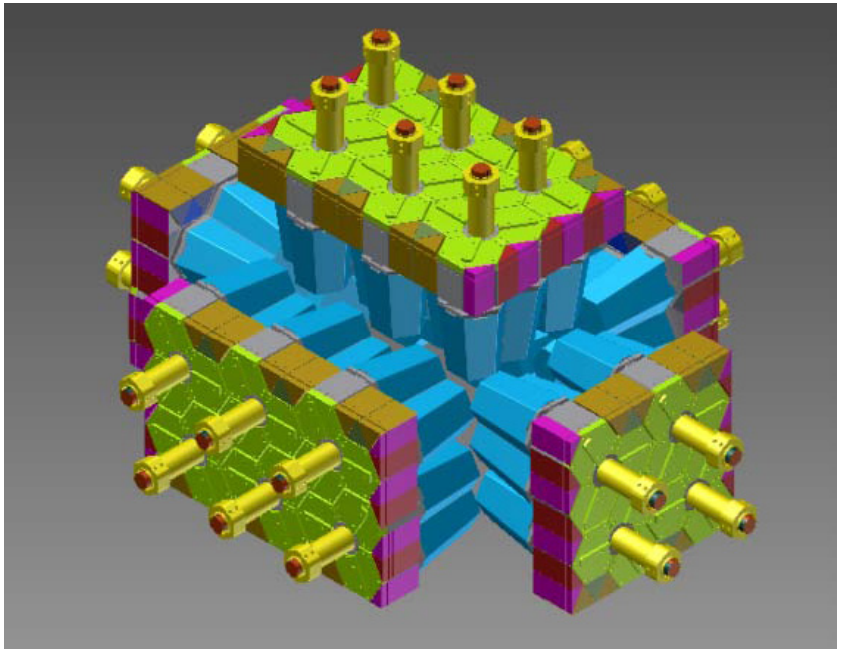
Pre-series construction started

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

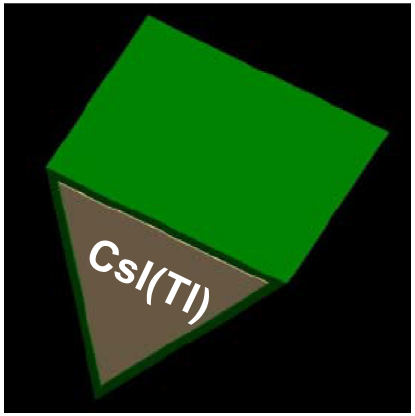
DEGAS Shield Design



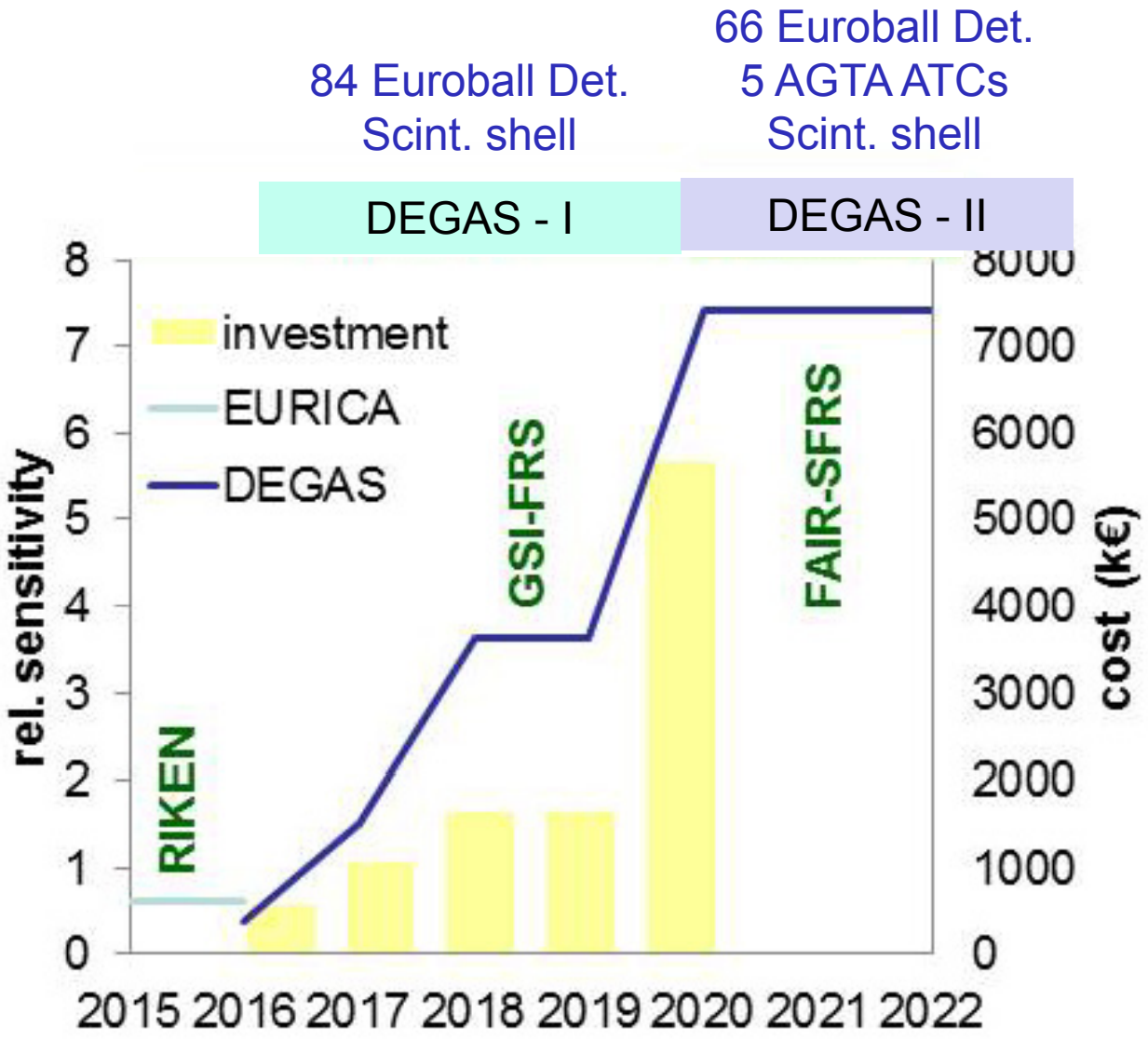




- Active scintillator shields
- Background reduction
- Compton suppression
- SiPM read-out
- time, energy

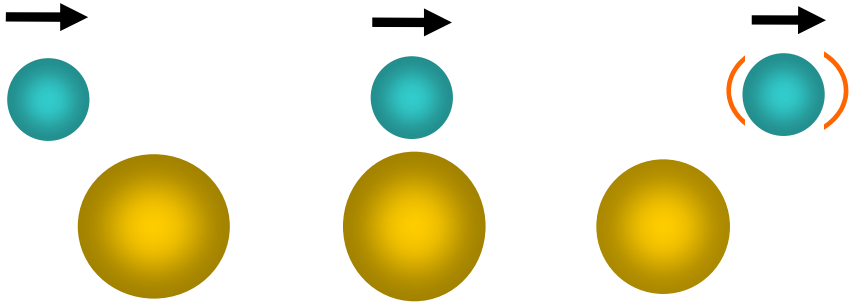


DEGAS Phases

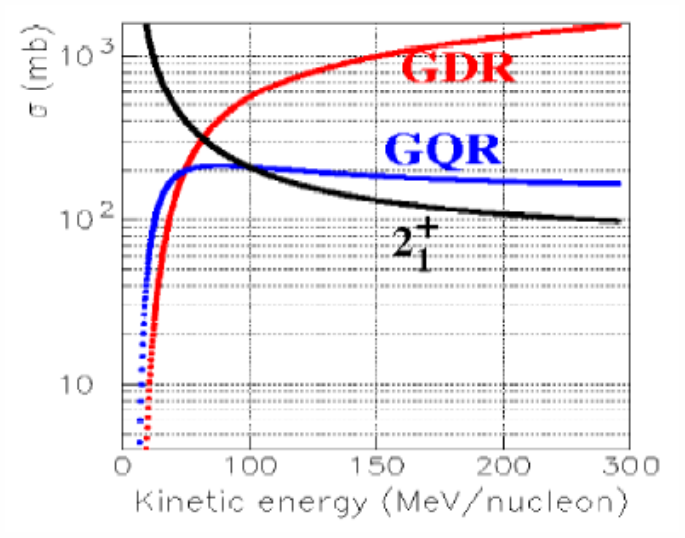


Reactions at relativistic beam energies

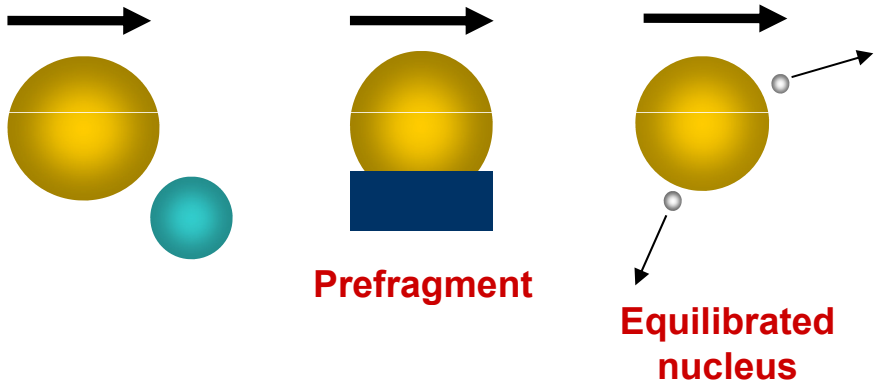
Single step Coulomb excitation

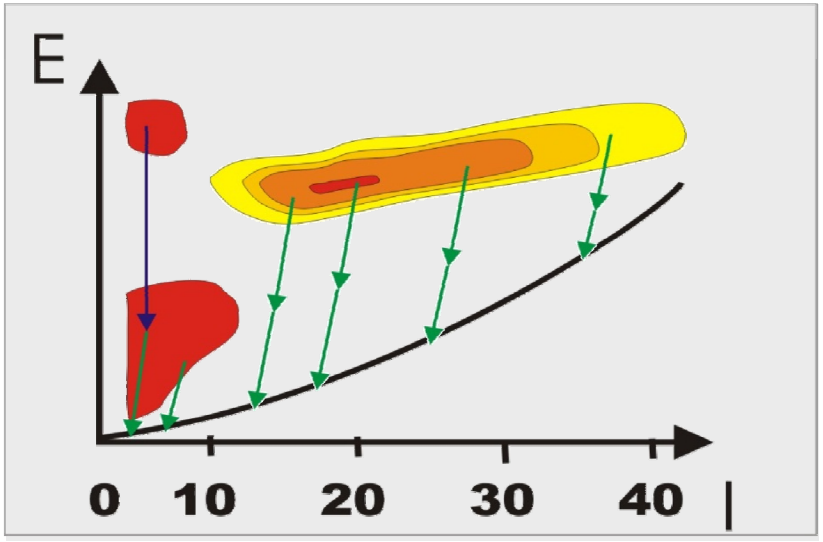


^{112}Sn →Au

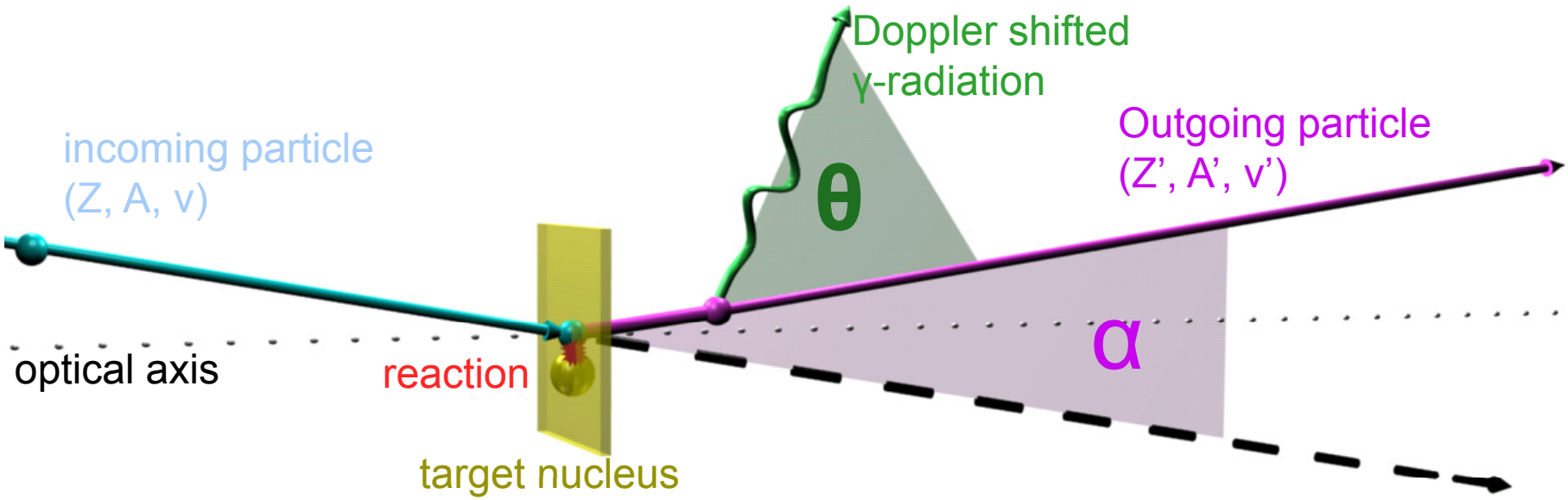


Secondary knock-out / fragmentation





Challenges of In-beam ejectile γ-spectroscopy



Challenges

- Incoming particle selection and identification: here FRS @ GSI
- v/c ≈ 0.5: large Doppler-shift of γ-radiation
- High accuracy in α and θ → granular detectors
- Outgoing particle identification: LYCCA
- Detection of γ-radiation: AGATA

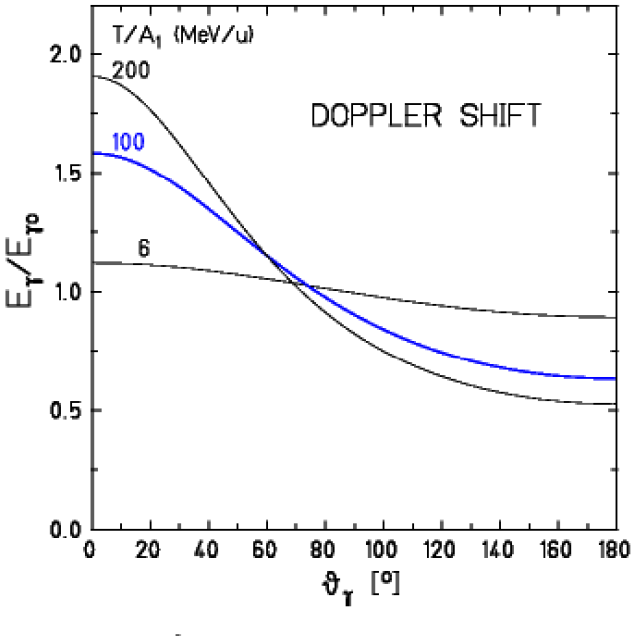
Doppler Effect

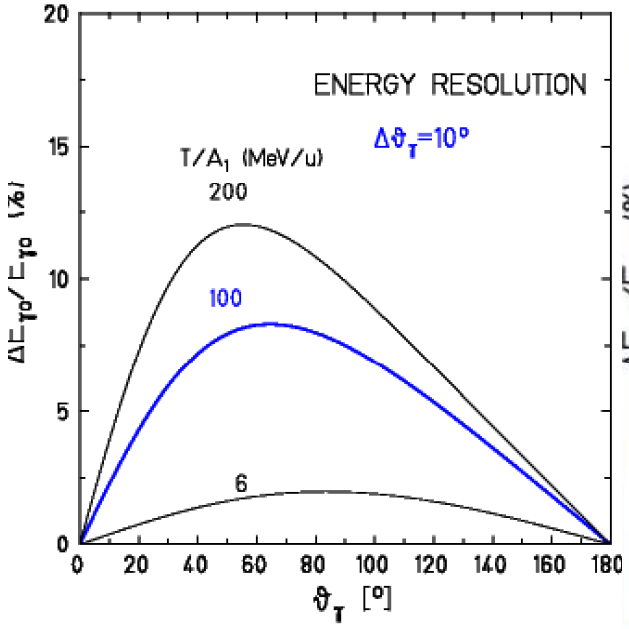
Doppler shift

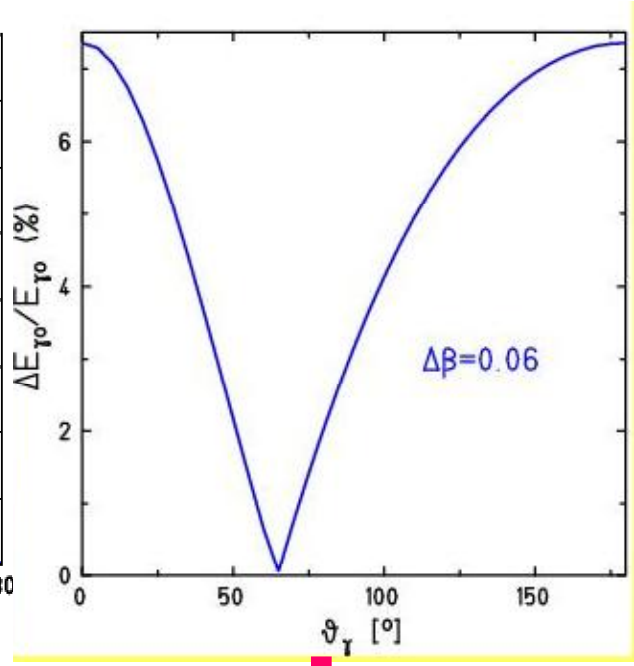
Doppler broadening

eff. solid angle

beam straggling







position sensitive γ detector

thin target ⟷ > E(beam)

$\Delta x = 5$ mm

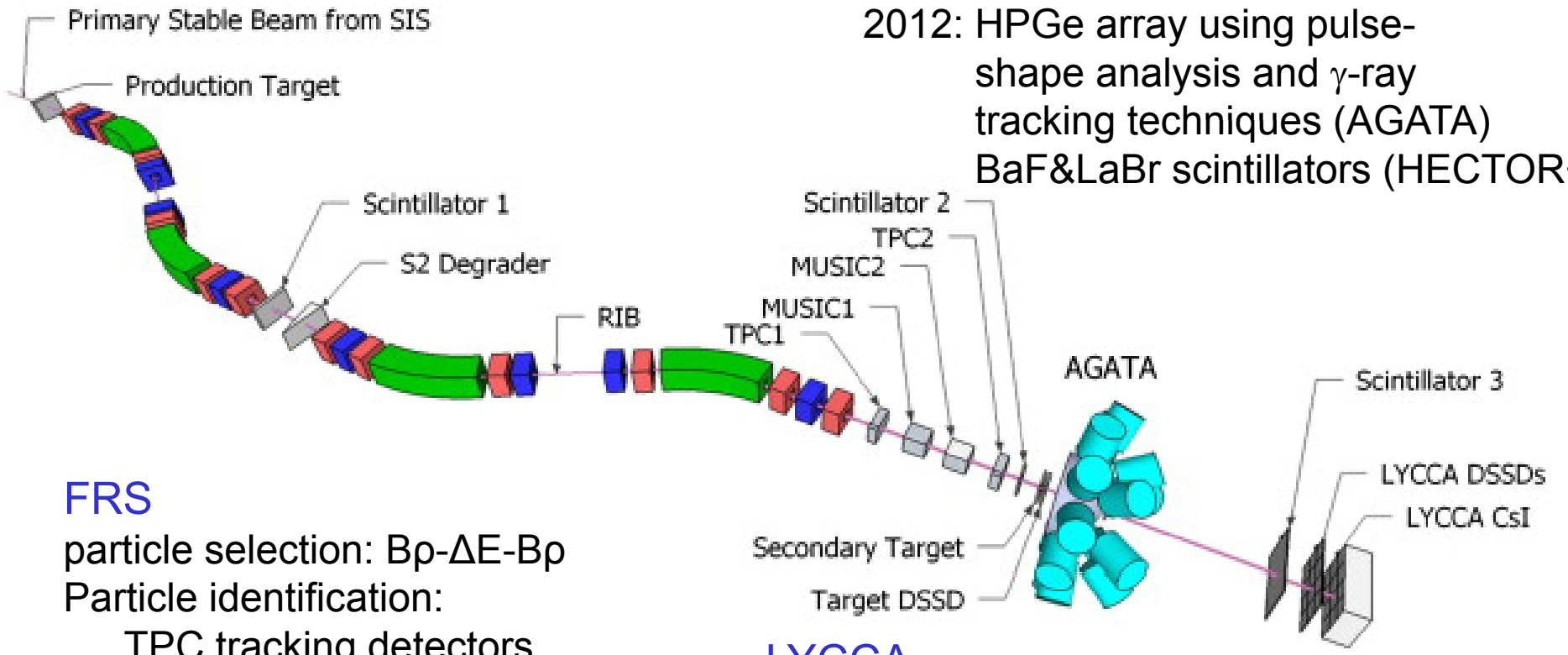
≈ 1 g/cm^2

≈100 MeV/u

While waiting for FAIR - HISPEC: PreSPEC @ GSI

Gamma-ray detection

2011: 105 HPGe detectors (Euroball)
BaF Scintillators (HECTOR)
2012: HPGe array using pulse-shape analysis and γ-ray tracking techniques (AGATA)
BaF&LaBr scintillators (HECTOR+)



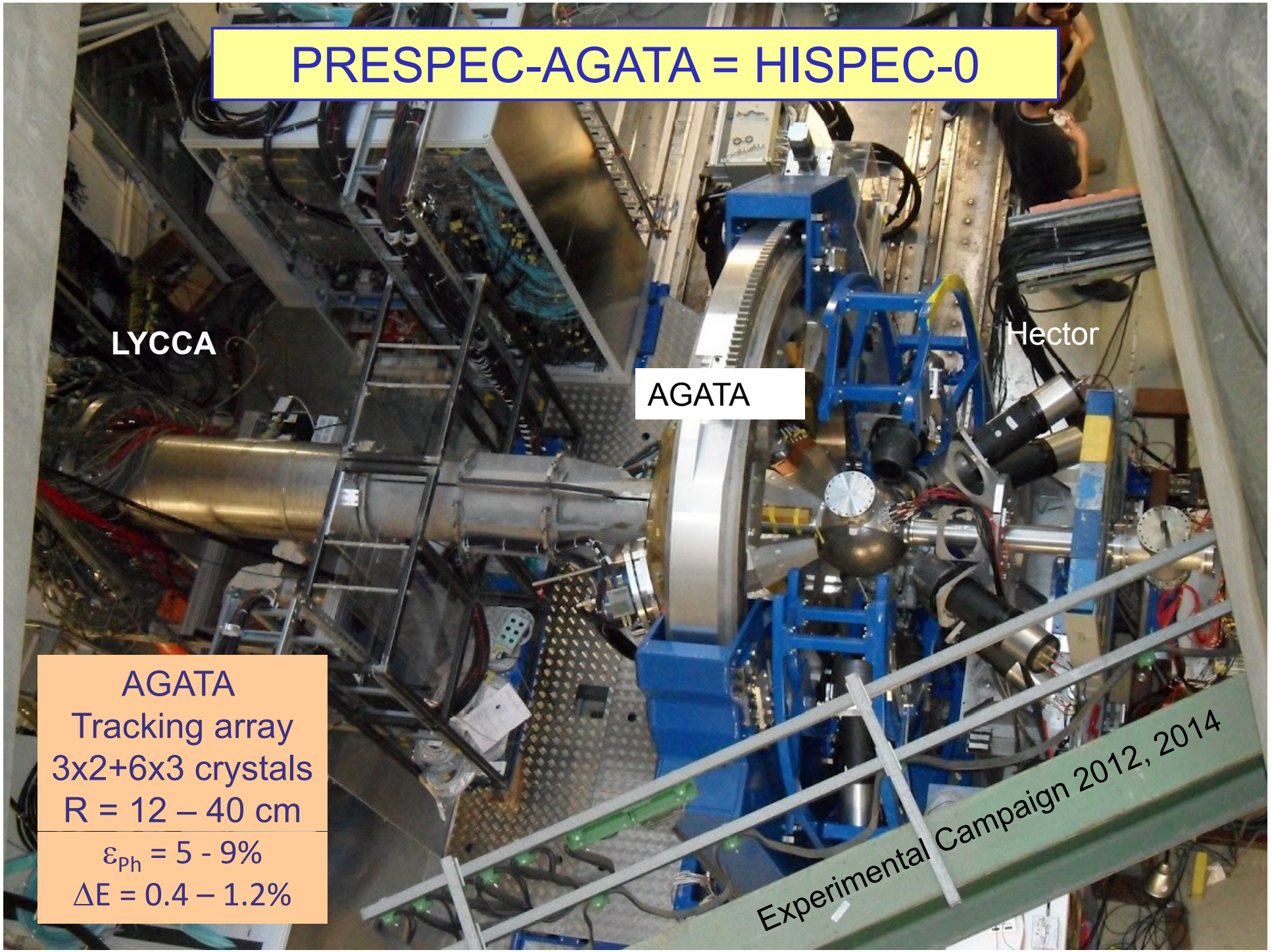
FRS

particle selection: Bρ-ΔE-Bρ
Particle identification:
- TPC tracking detectors
- ToF measurement
- Energy-loss measurement

LYCCA

Outgoing particle tracking and identification:
- Z identification via E-ΔE
- Mass identification via E-ToF

PRESPEC-AGATA = HISPEC-0



AGATA
Tracking array
3x2+6x3 crystals
R = 12 – 40 cm

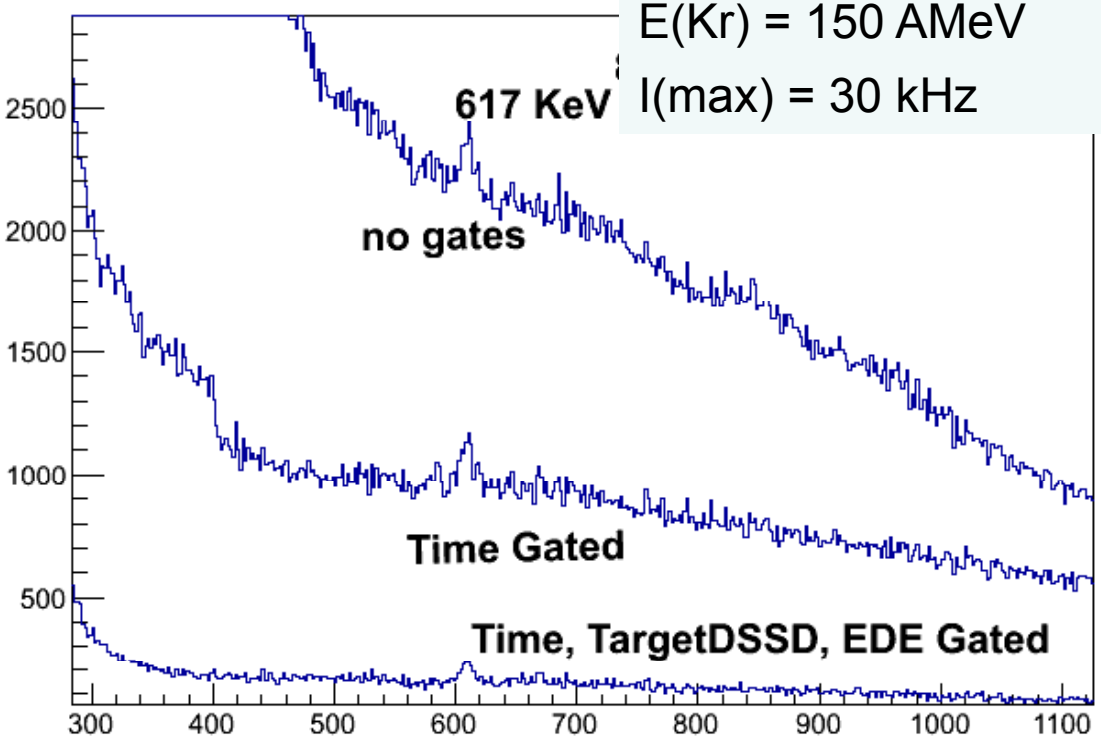
ε_{Ph} = 5 - 9%
ΔE = 0.4 – 1.2%

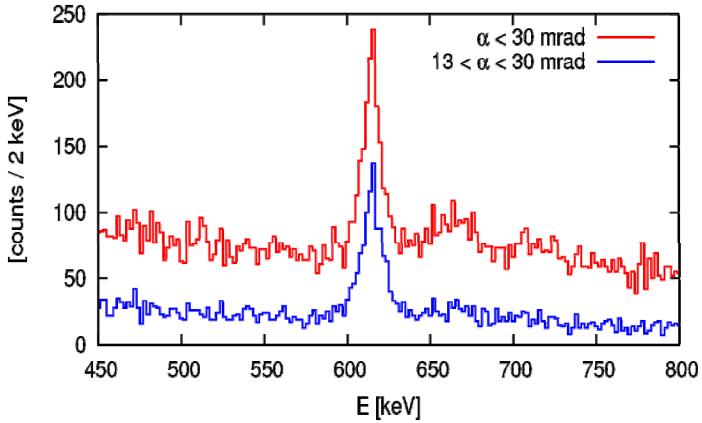
^{80}Kr induced reactions

^{80}Kr Coulomb Excitation

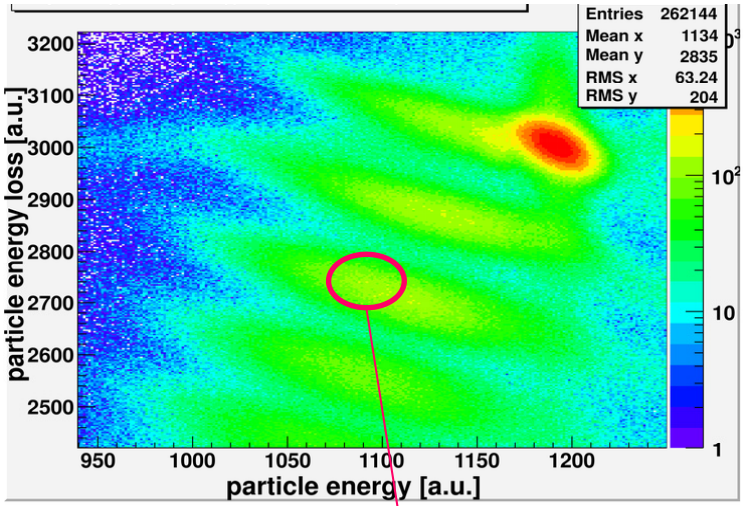
E(Kr) = 150 AMeV

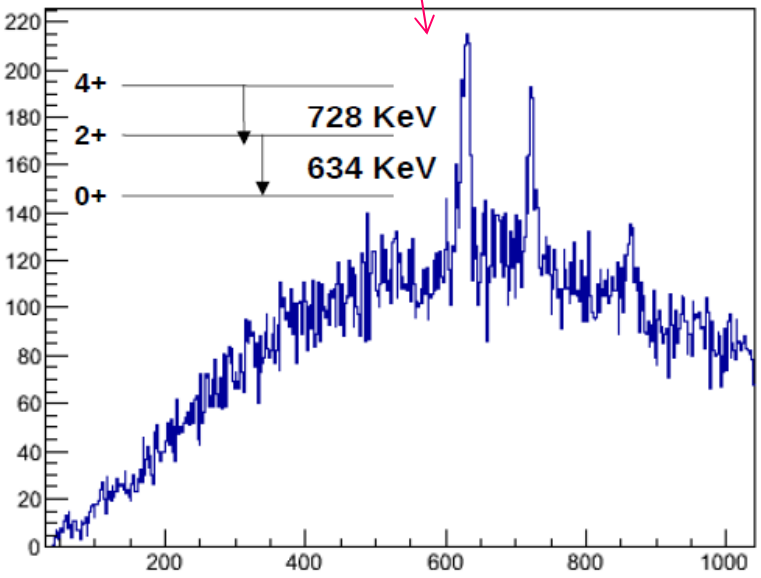
I(max) = 30 kHz





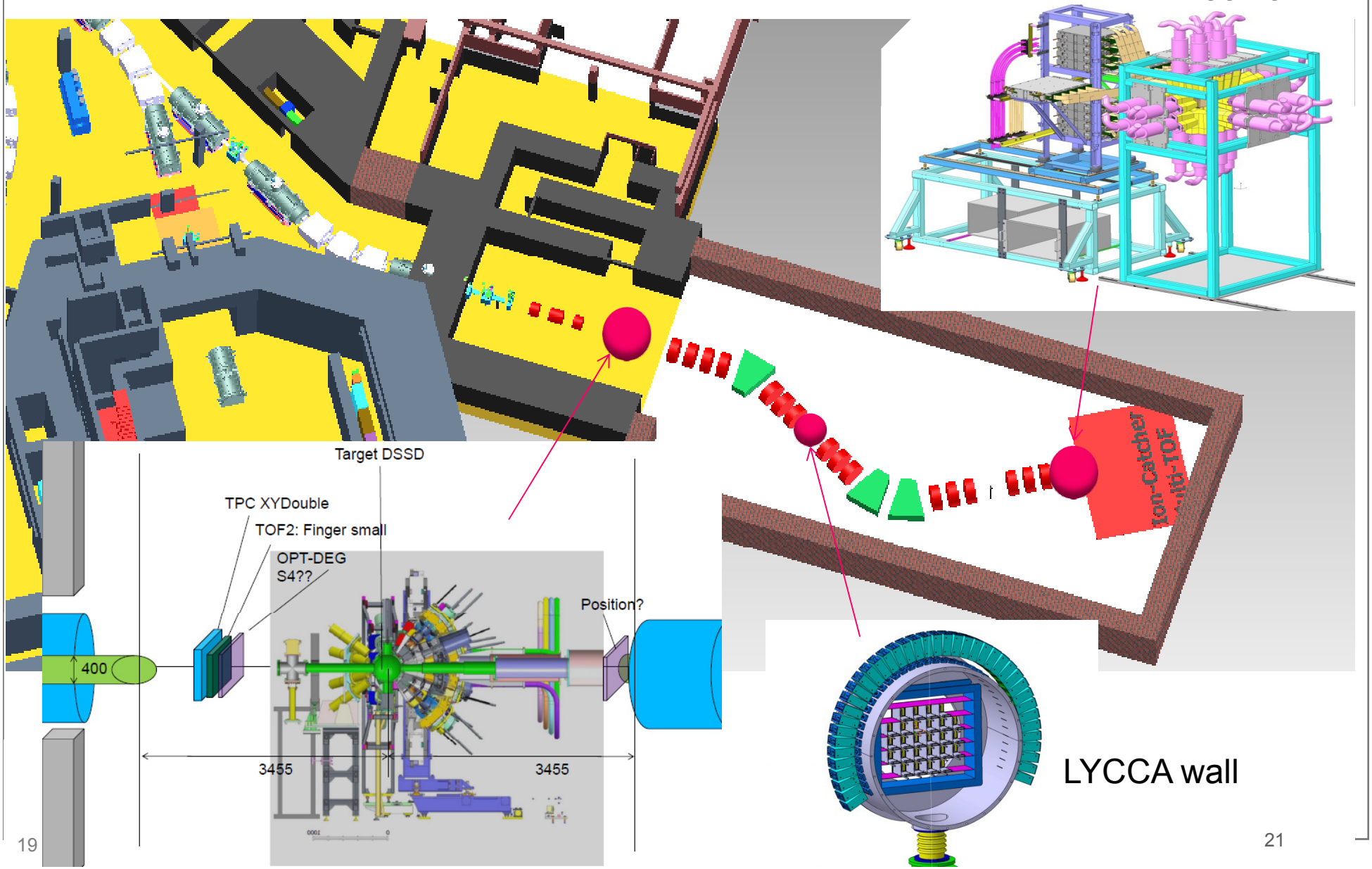
^{74}Se fragmentation





HISPEC at the LEB

β, α, isomer tagging

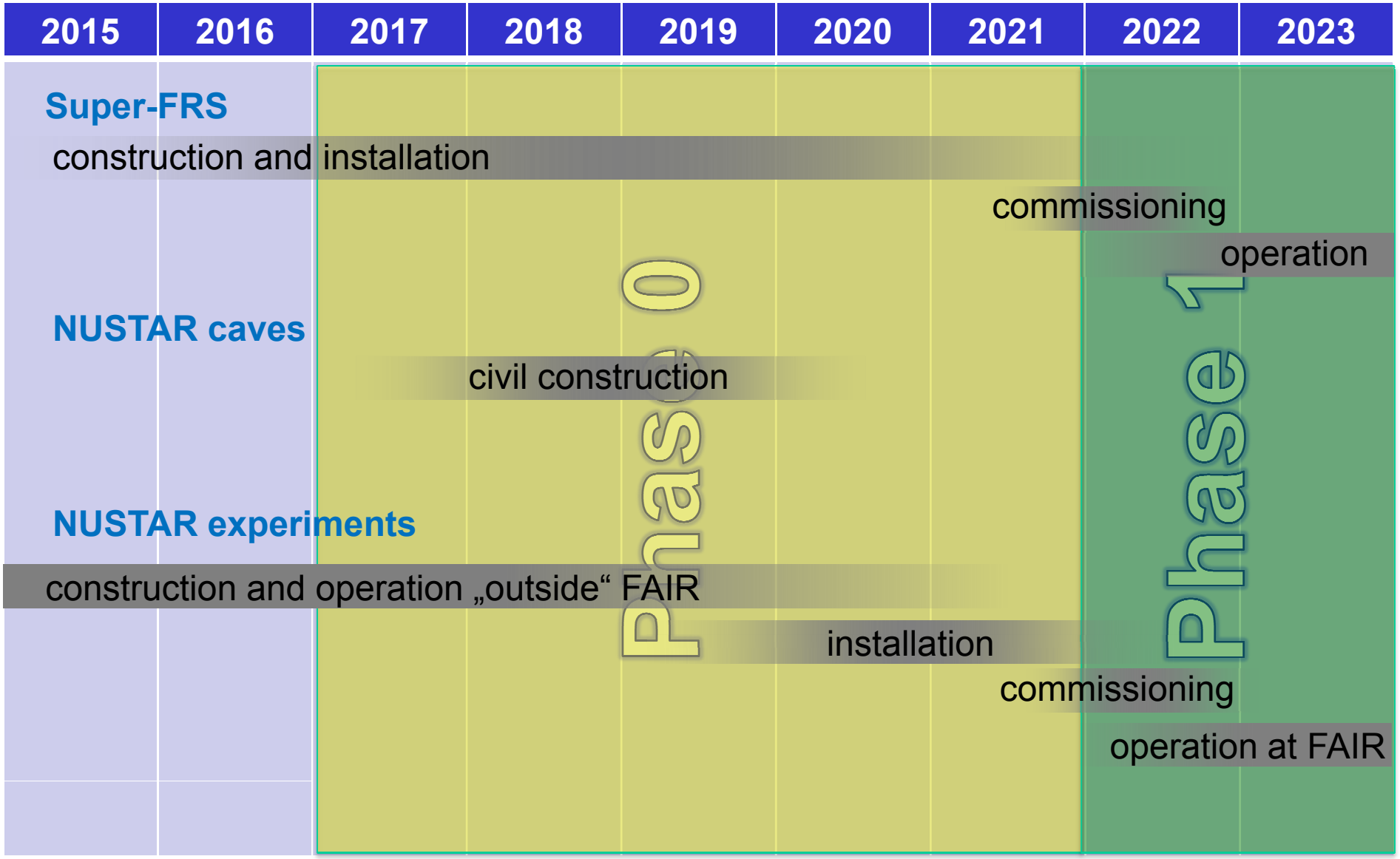


LYCCA wall

NUSTAR - Phases

- **Phase 0**
  - R&D and experiments to be carried out with present facilities (GSI and others) and FAIR/NUSTAR equipment (basic set-ups)
- **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 ("day-1")**
- **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 or R^3B spectrometer)
- **Phase 4**
  - Major new investments and upgrades for all experiments

NUSTAR time line



Beam time at GSI

Current planning:

2016 Break for SIS-18 upgrade and UNILAC renovation,
Operation of UNILAC (experiments) and SIS (tests)
for 12 respectively 7 weeks

2017: Break for SIS-18 upgrade and shielding enforcement

2018: Q1-2: SIS-18 commissioning
Q3-4: 3-4 months, experiment programme

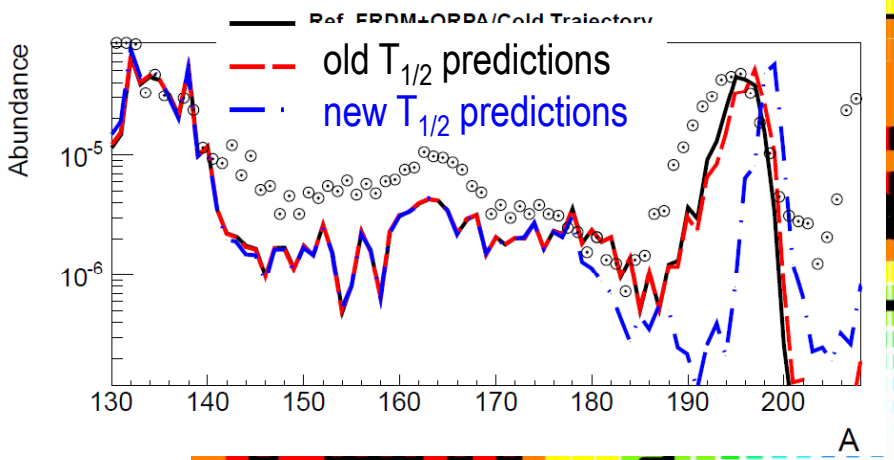
2019: 5-6 months, FAIR preparations and experiment programme

2020: 5-6 months, FAIR preparations and experiment programme

DESPEC
DEGAS Phase 1

The N=126 Physics case

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



Mass abundances depend
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

Conclusions

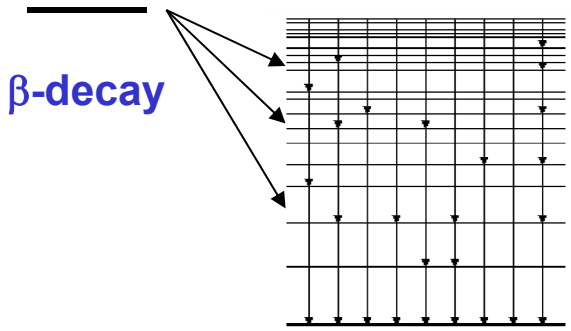
- FAIR will offer many opportunities for in-beam and decay spectroscopy
- Rare isotope beams of all elements will be available at relativistic energies, slowed-down to Coulomb barrier energies and stopped
- Decay studies are planned with the DEGAS Ge-detector array comprising 28 triple detectors with active scintillator shields
- In-beam studies are planned with a dedicated array of AGATA detectors
- The NUSTAR Phase-0 experimental programme will start in 2018 employing the FAIR injectors.
- DESPEC decay spectroscopy experiments with DEGAS at FRS/S4 will be among the first NUSTAR experiments
- A Physics workshop to discuss ideas for experiments with DEGAS will be held at the NUSTAR Week in York (September 27)

...thank you

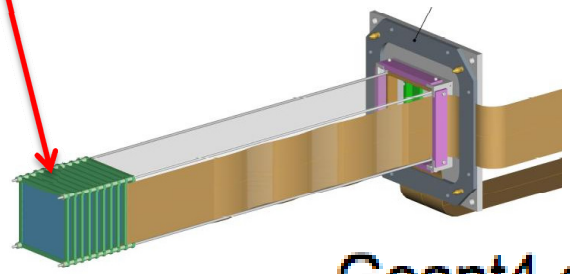
SIS18 Uranium Intensity Expectations 2018

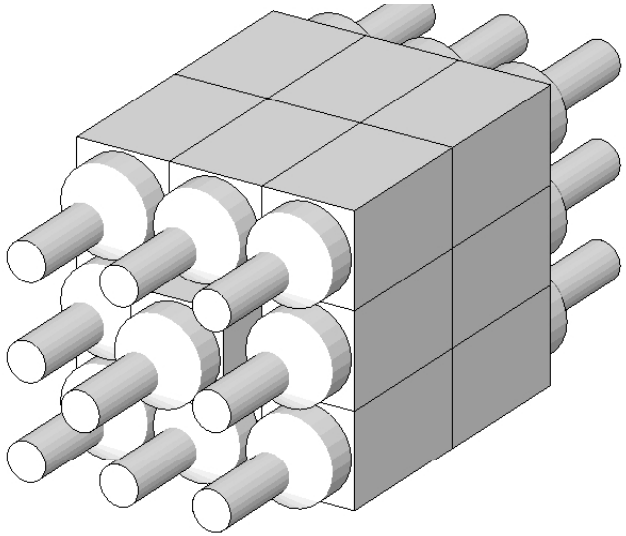
		SIS operation today	SIS operation after upgrade (2017-2020)
Reference Ion		U^{73+}	U^{73+}
Maximum Energy		1 GeV/u	1 GeV/u
UNILAC Current		1 emA	**3 emA**
Maximum Intensity per Cycle		$4 \cdot 10^9$	**$1 \cdot 10^{10}$**
Maximum Intensity per Second	**Fast Extraction**	$2 \cdot 10^9$ /s	$2 \cdot 10^{10}$ /s
Repetition Rate		0.5 Hz	**2 Hz**
Maximum Intensity per Second	**Slow Extraction**	$6 \cdot 10^8$ /s	$4 \cdot 10^9$ /s
Repetition Rate for 5 s Spill		0.14 Hz	**0.18 Hz**
Slow extr. efficiency		50 %	**75%**

Decay Total Absorption Spectrometer (DTAS)



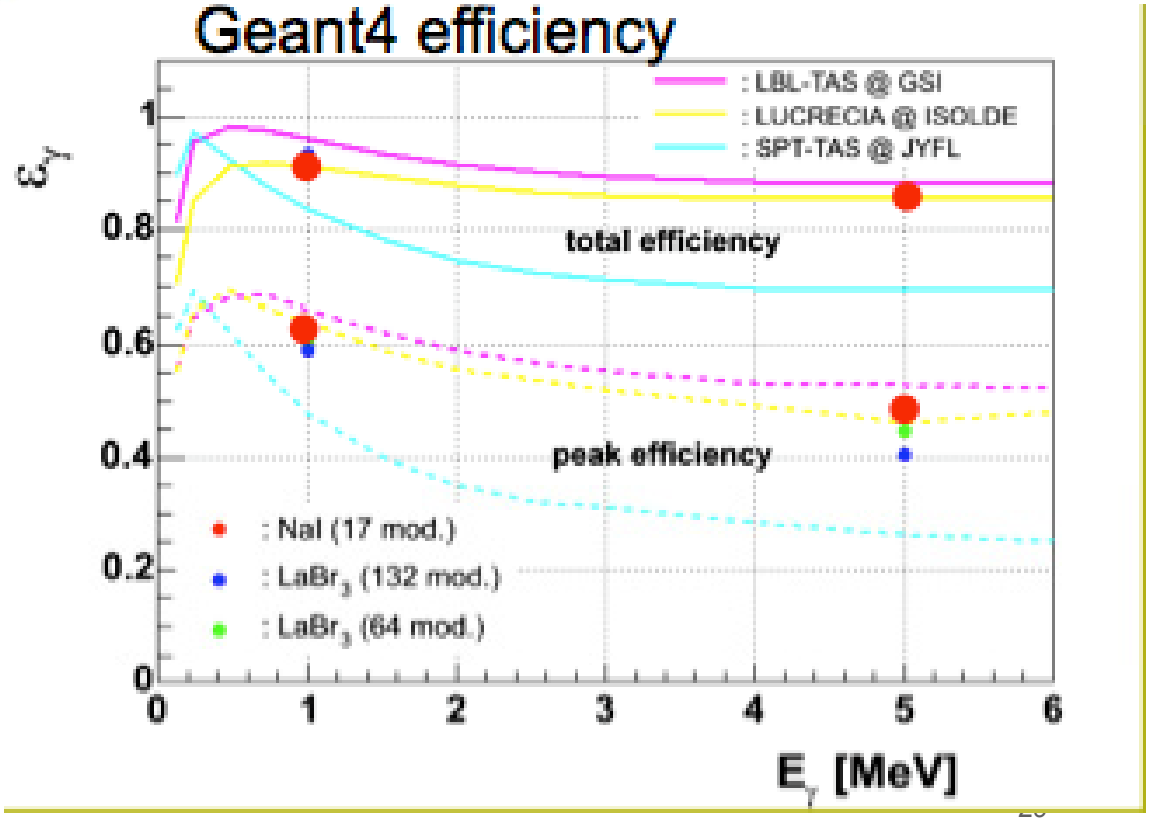
Designed to be coupled to AIDA implantation detector



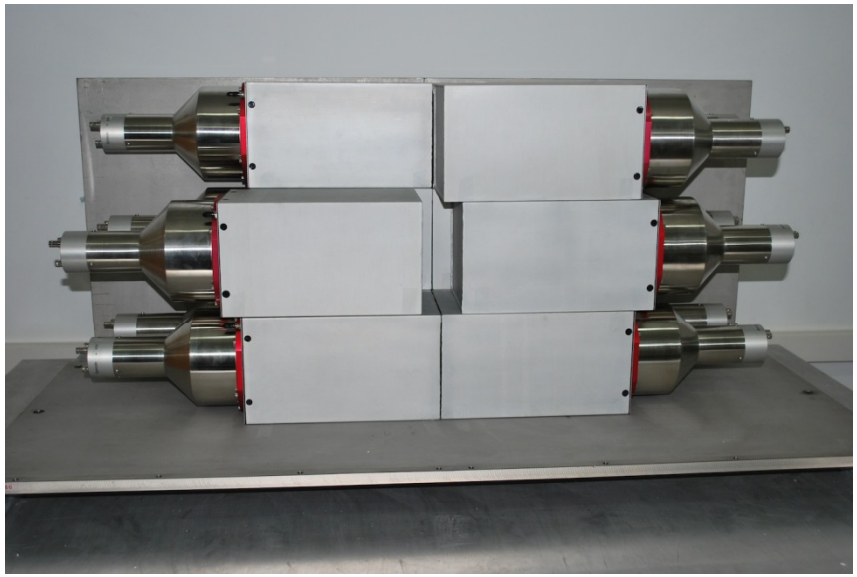


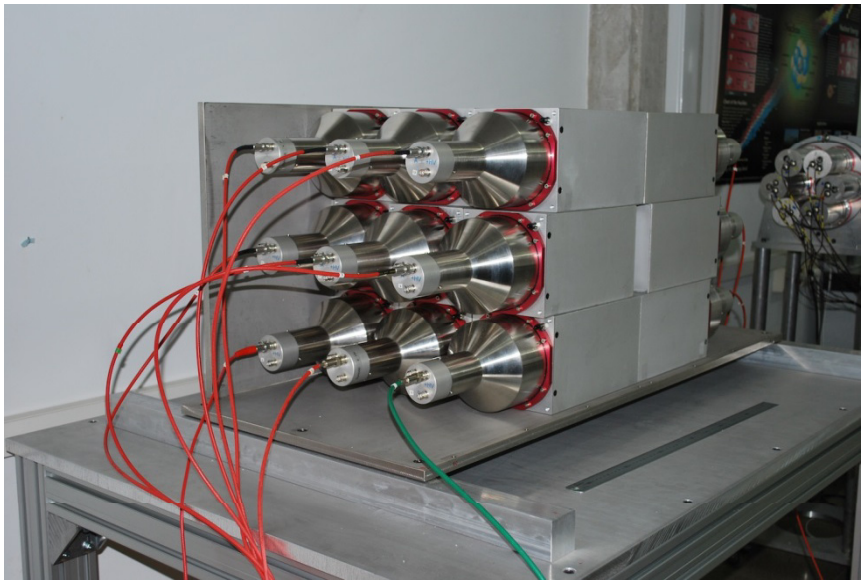
16 + 2 NaI(Tl) crystals:

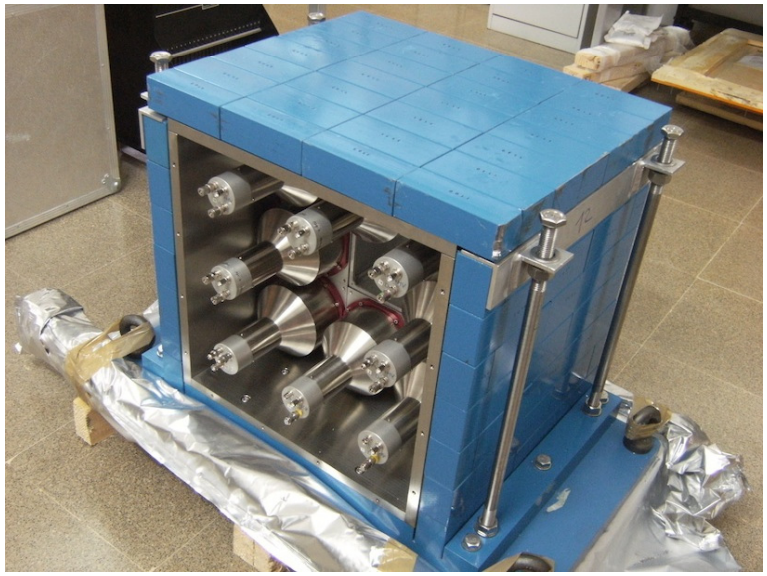
- 15×15×25 cm^3
- Minimum dead-material
- 5” PMT: ETL9390

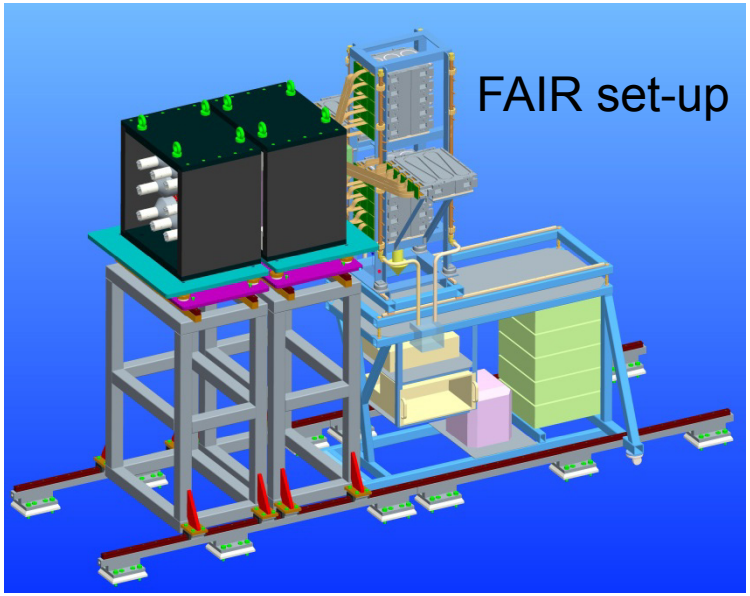


DTAS ready for use









First Experiments at JYFL

β-decay intensity distribution of delayed neutron emitters