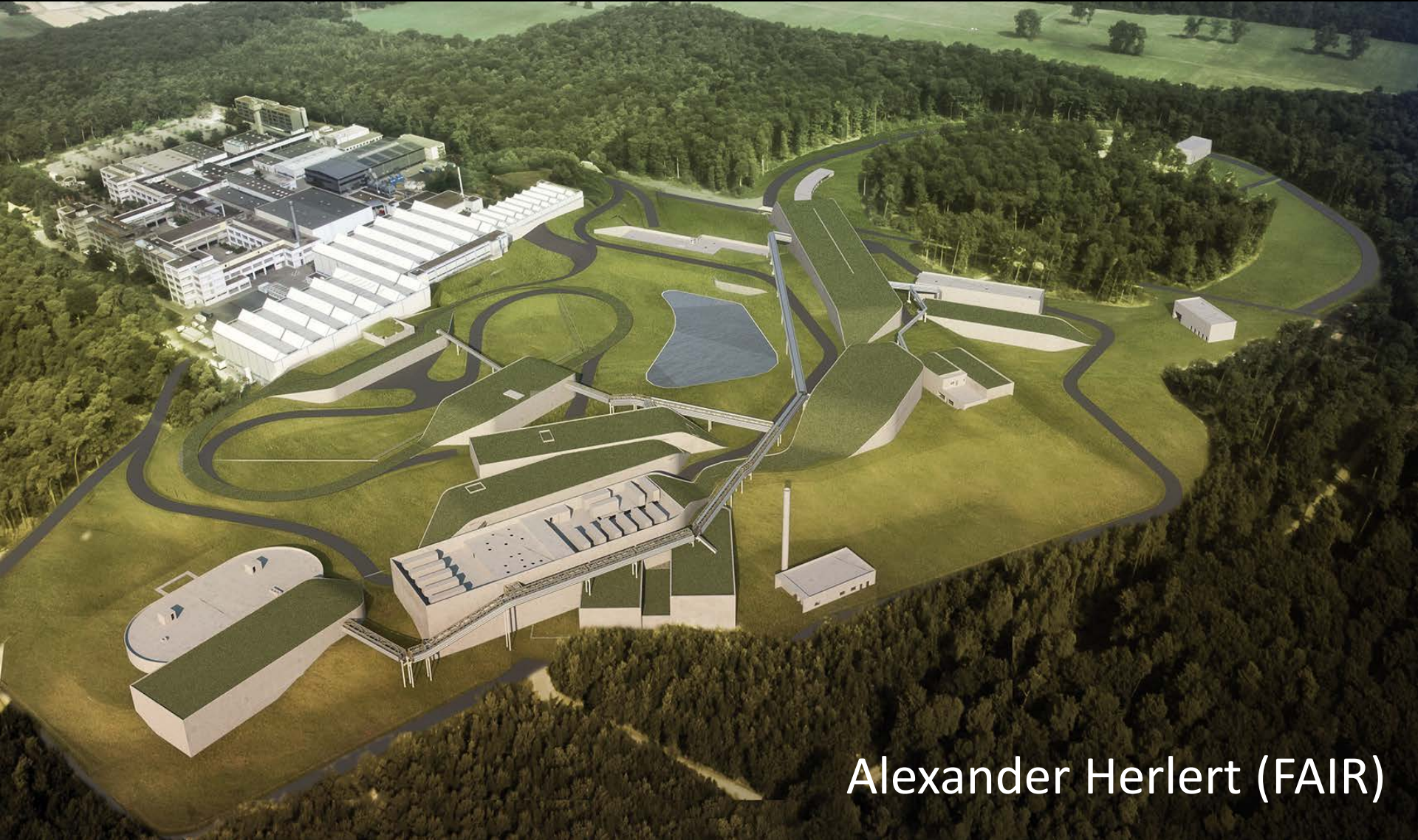
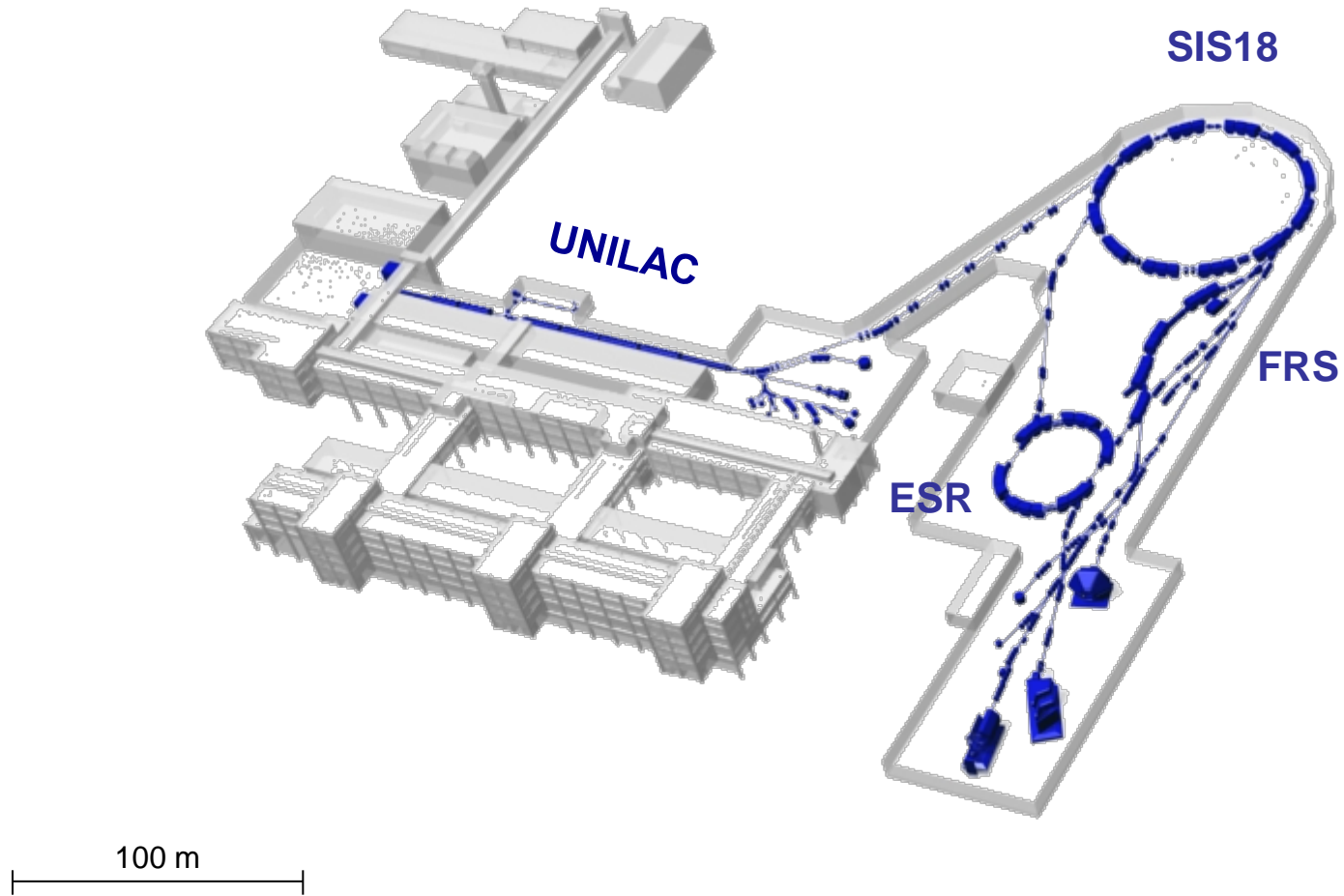
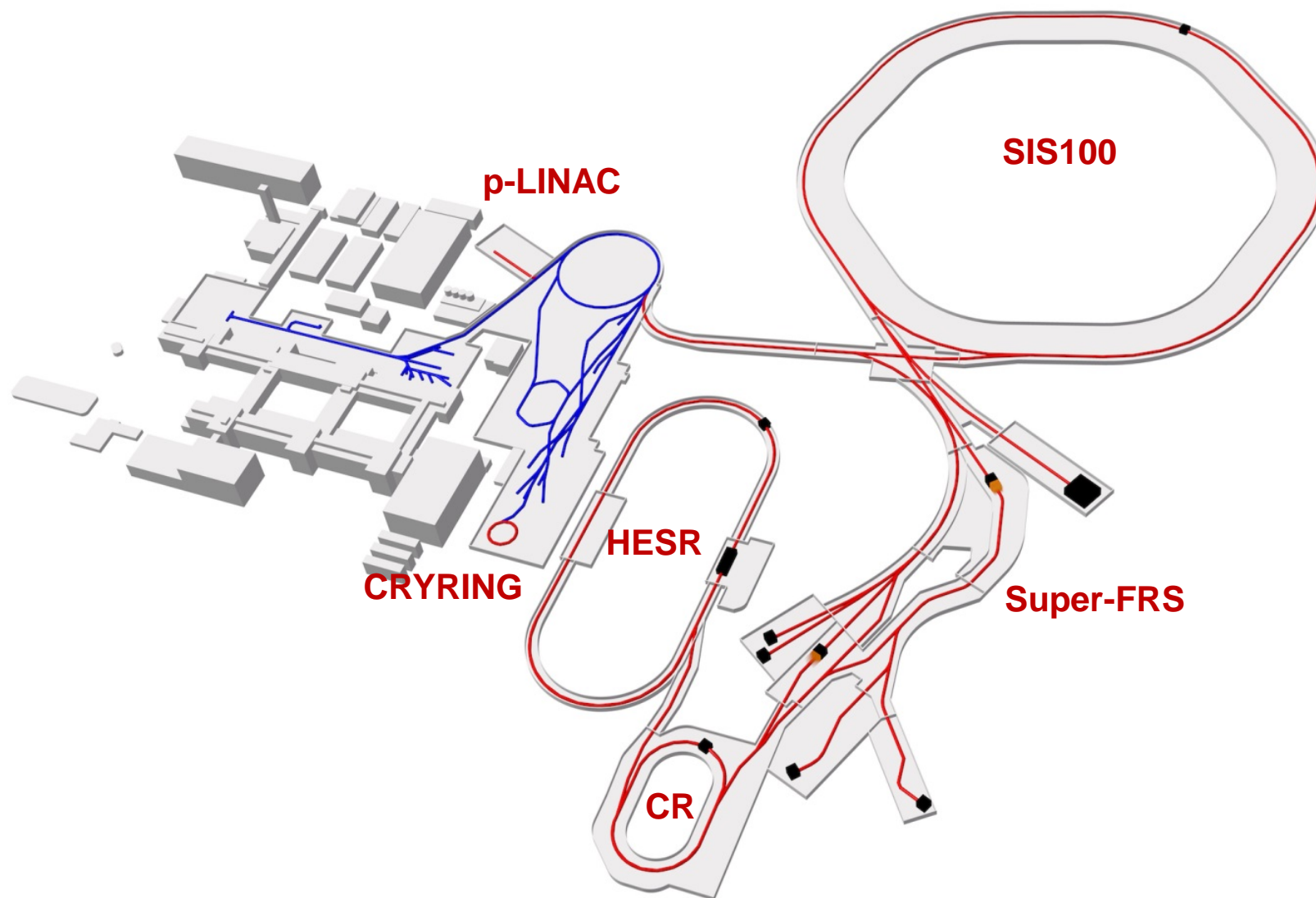


# Exploring the extremes with NUSTAR at FAIR



Alexander Herlert (FAIR)

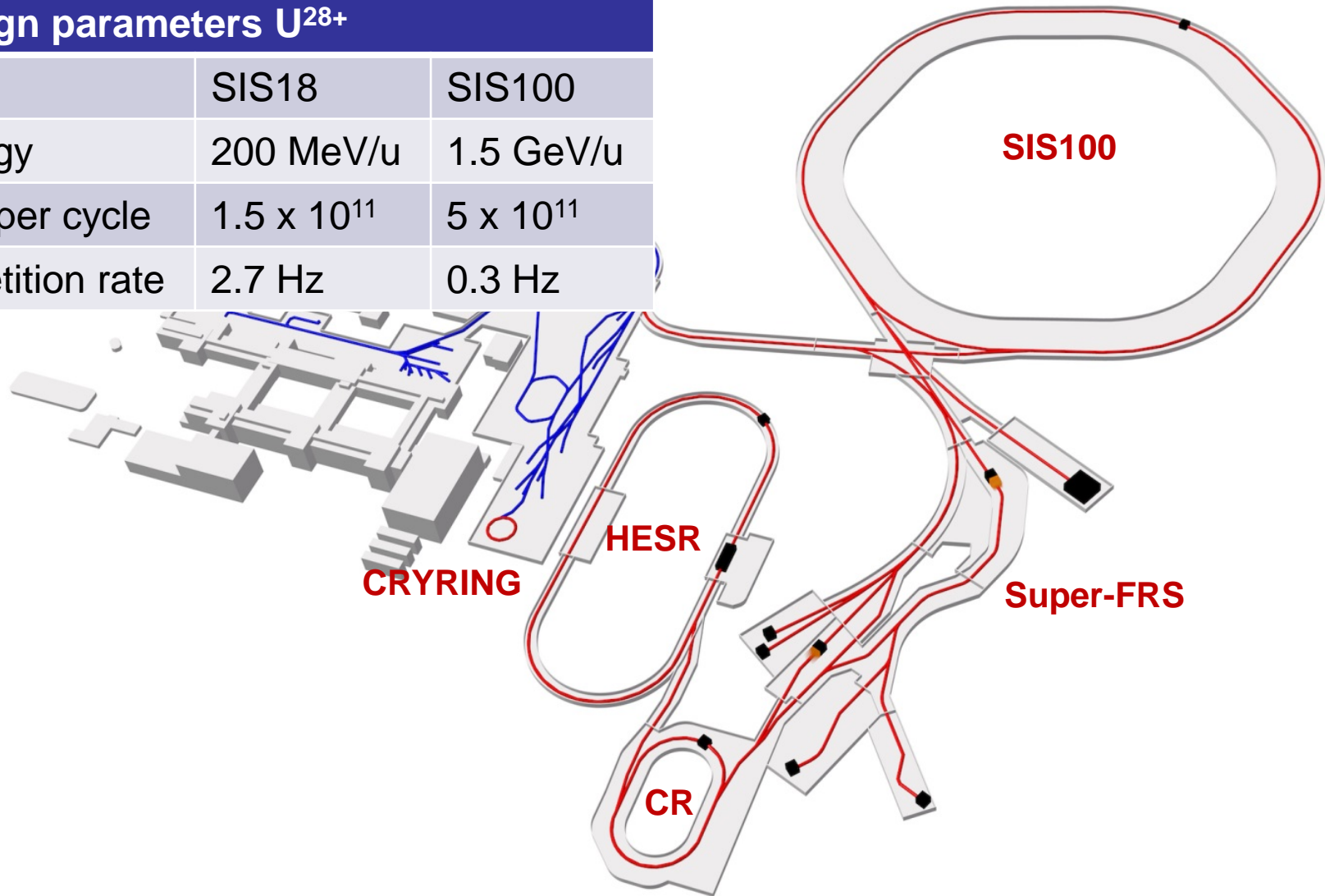




# ... to FAIR (modularized start version)

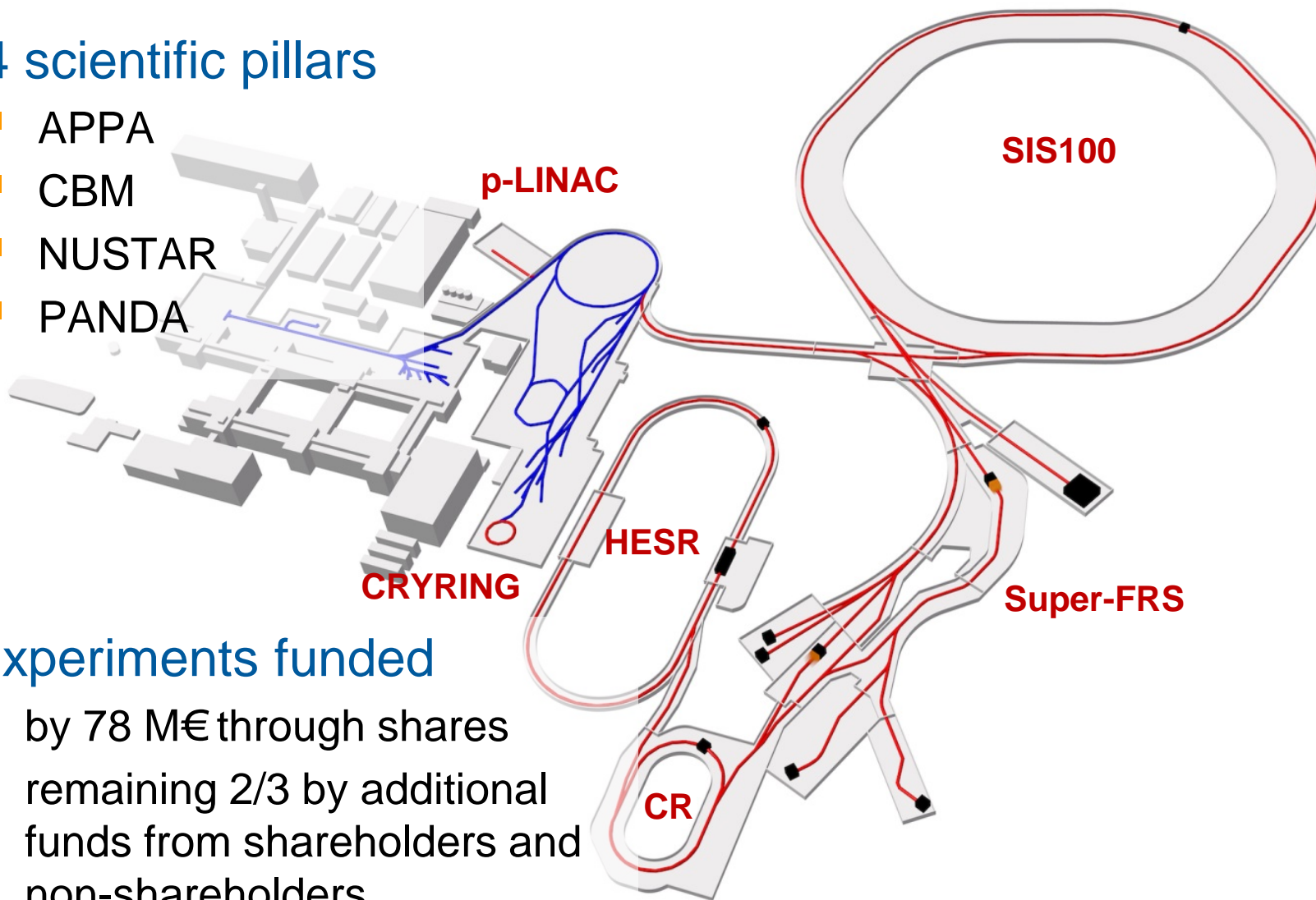
## Design parameters $U^{28+}$

	SIS18	SIS100
Energy	200 MeV/u	1.5 GeV/u
Ions per cycle	$1.5 \times 10^{11}$	$5 \times 10^{11}$
Repetition rate	2.7 Hz	0.3 Hz



- 4 scientific pillars

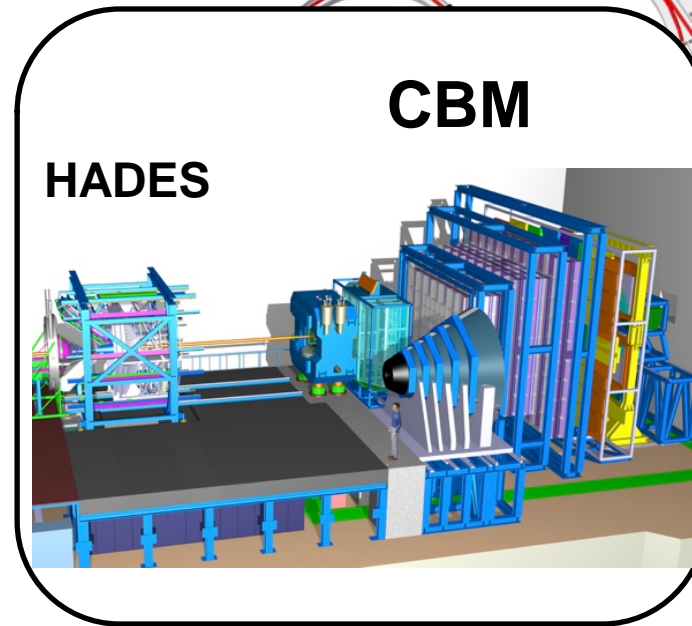
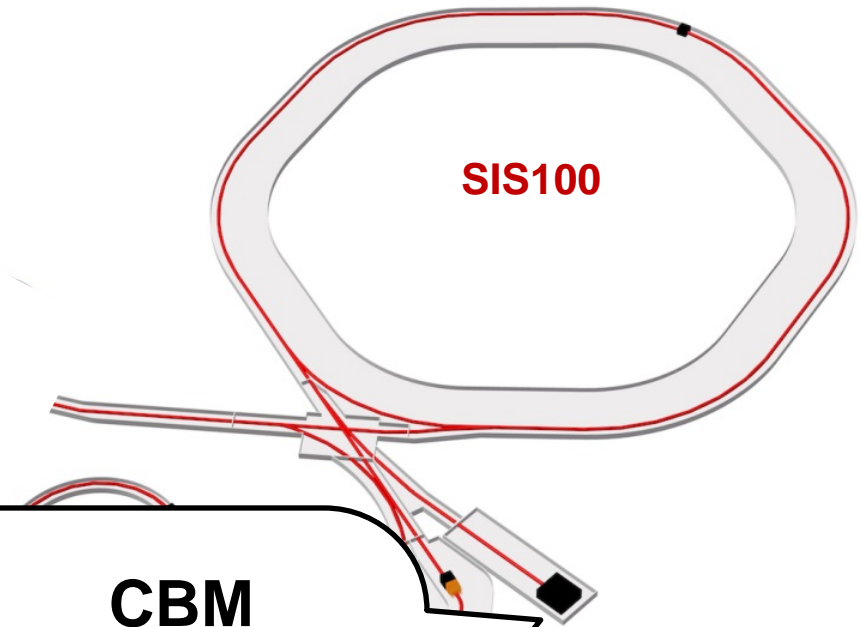
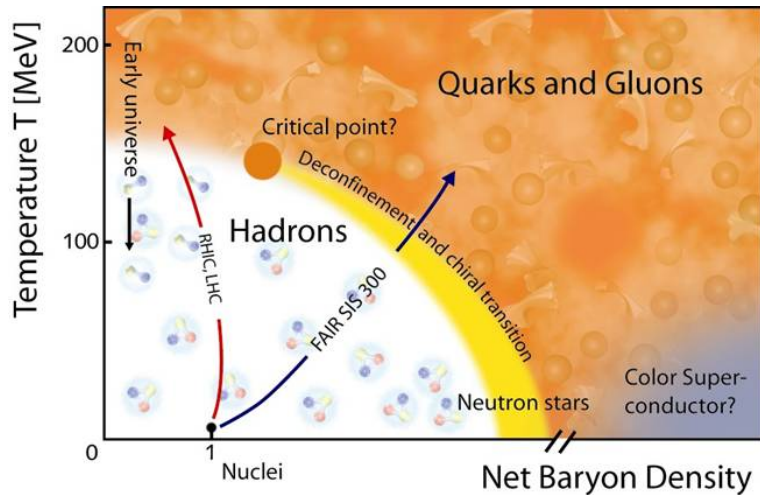
- APPA
- CBM
- NUSTAR
- PANDA



- Experiments funded

- by 78 M€ through shares
- remaining 2/3 by additional funds from shareholders and non-shareholders

# CBM – Compressed Baryonic Matter



- The equation-of-state at high baryonic density
- New phases of strongly-interacting matter
- Deconfinement phase transition at high baryonic density
- QCD critical endpoint
- ...

# PANDA – Antiproton Annihilations at Darmstadt



## Gluonic excitations

- Hybrids, glueballs

## Charmonium states

- Precision spectroscopy

## Time-like

- Form factors, nucleon structure

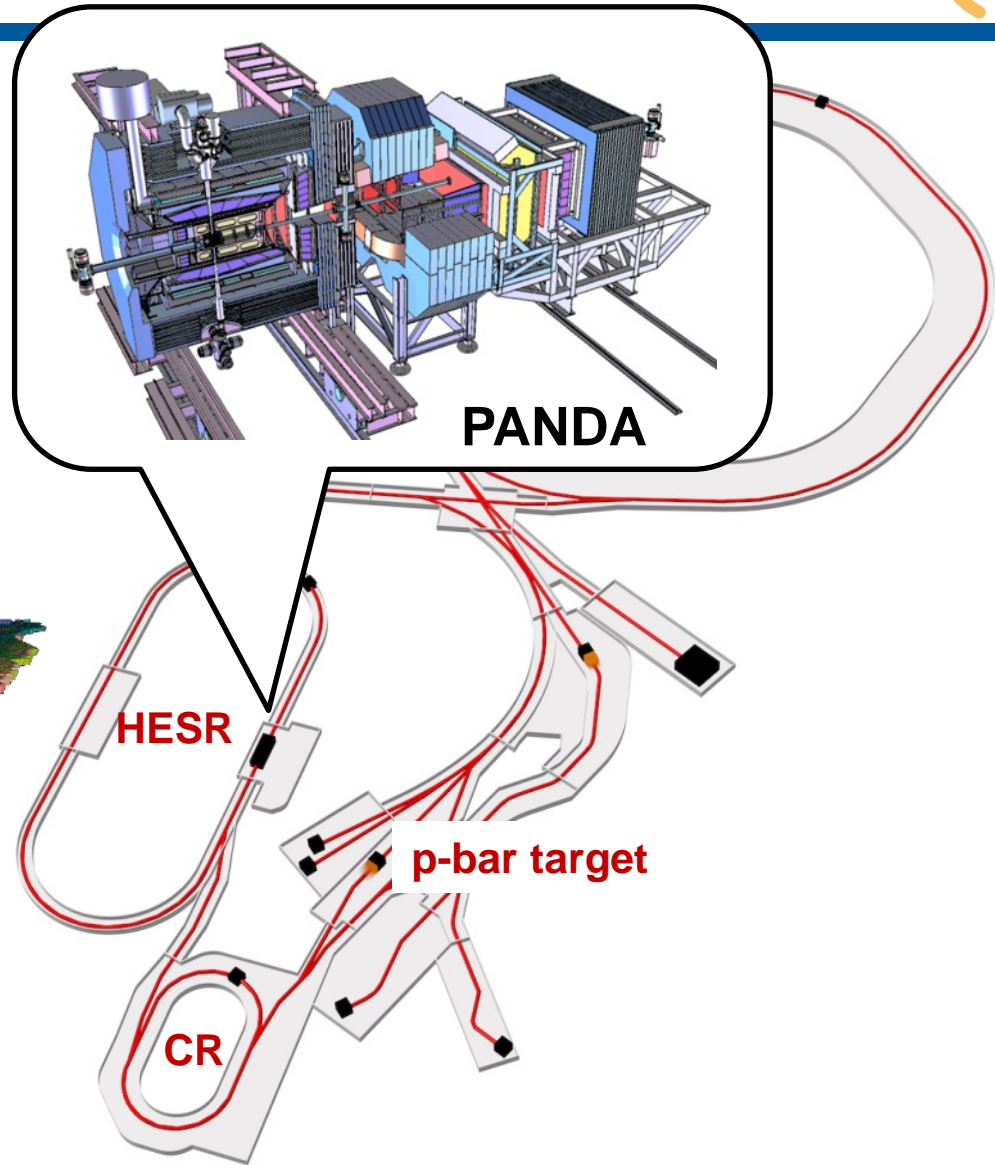
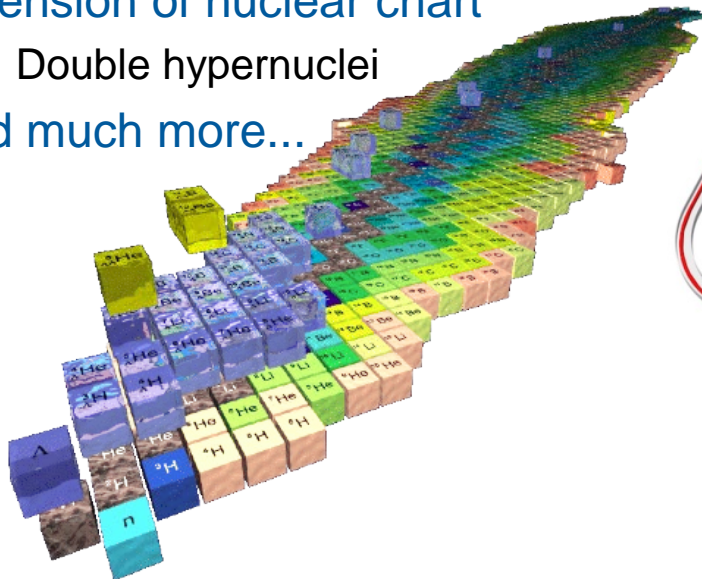
## In medium mass modifications

- Extension to the charm sector

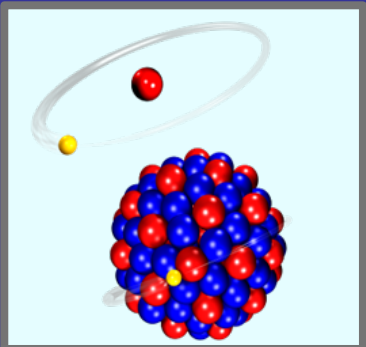
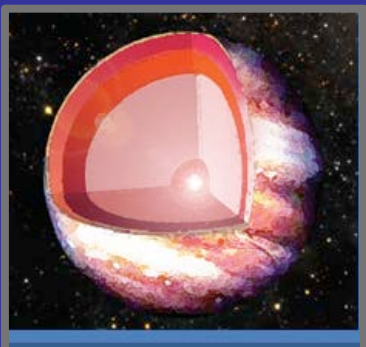
## Extension of nuclear chart

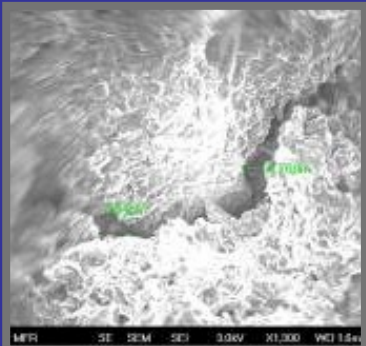
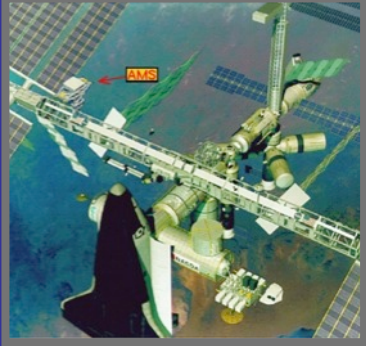
- Double hypernuclei

## And much more...



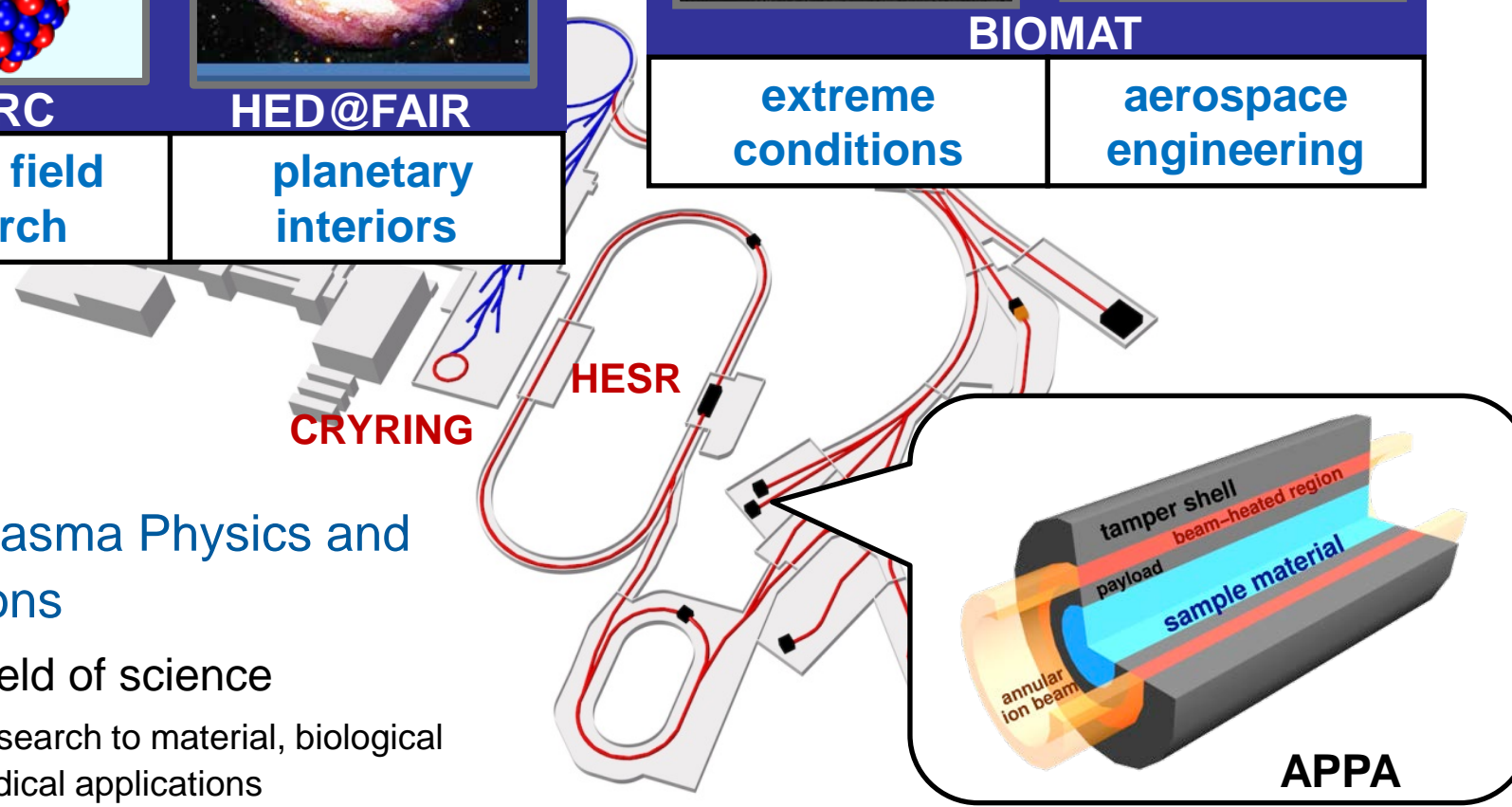
# APPA

<p><b>Atomic Physics</b></p>  <p><b>SPARC</b></p> <p>strong field research</p>	<p><b>Plasma</b></p>  <p><b>HED@FAIR</b></p> <p>planetary interiors</p>
--	--

<p><b>Materials</b></p>  <p><b>BIOMAT</b></p> <p>extreme conditions</p>	<p><b>Biophysics</b></p>  <p>aerospace engineering</p>
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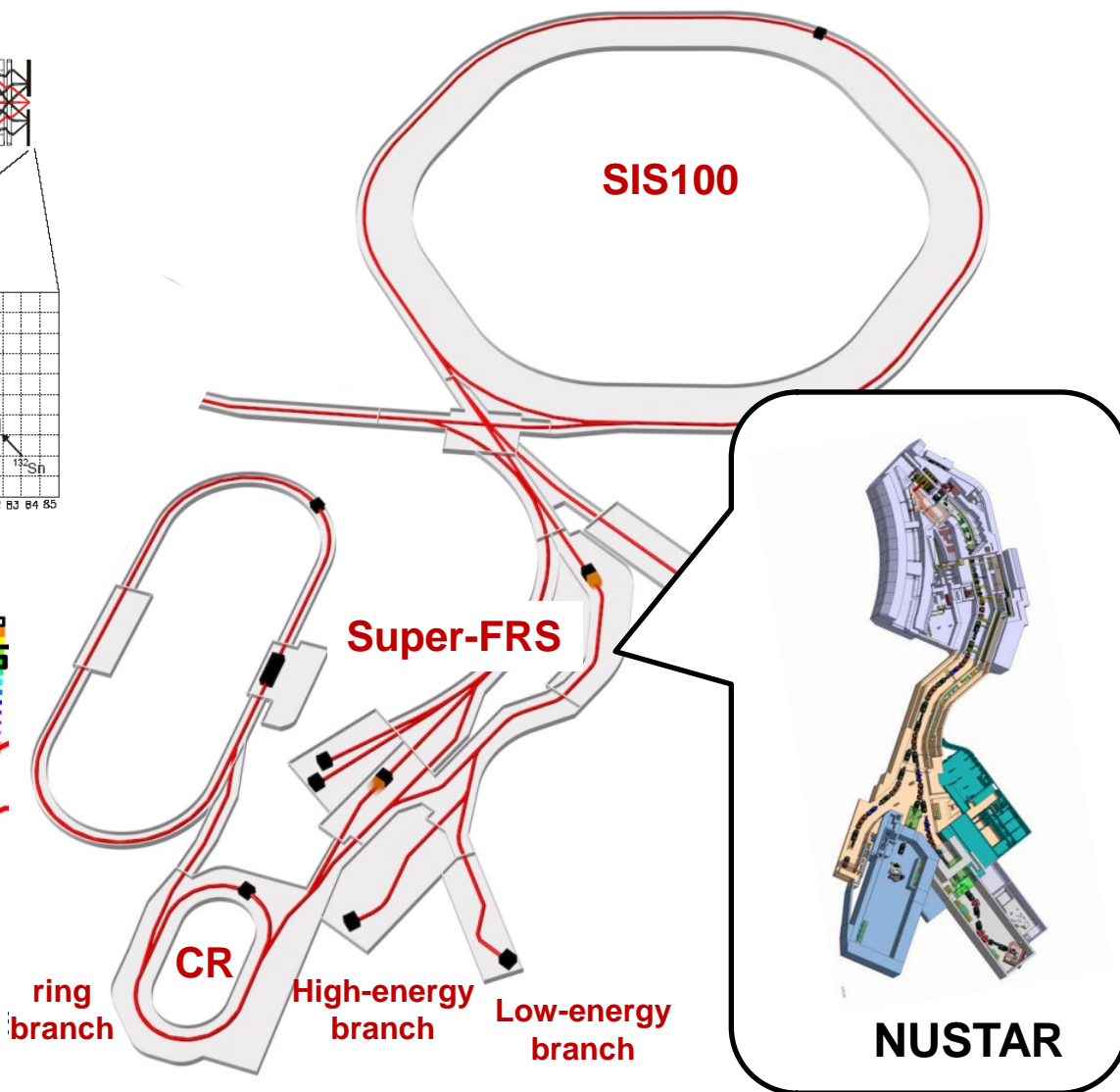
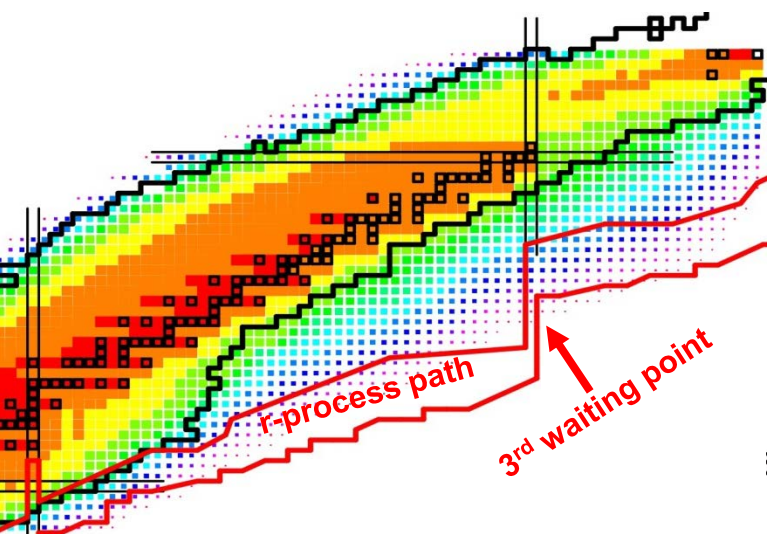
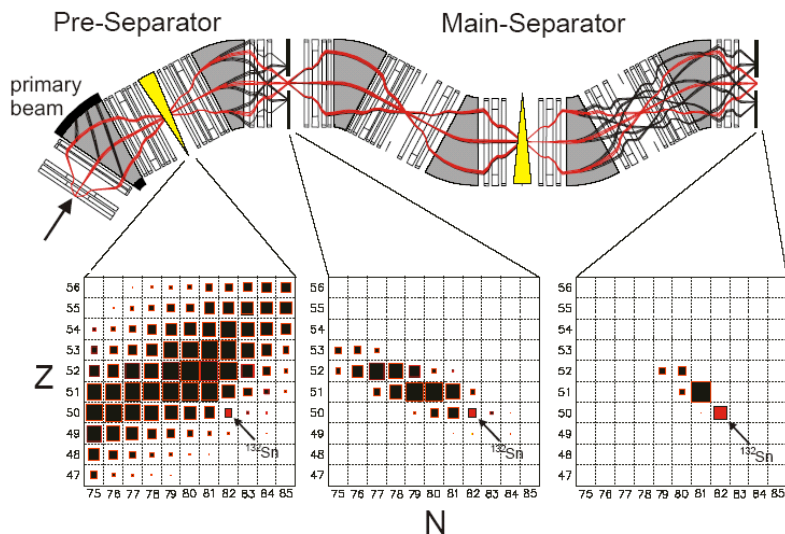
## Atomic, Plasma Physics and Applications

- Wide field of science  
basic research to material, biological and medical applications



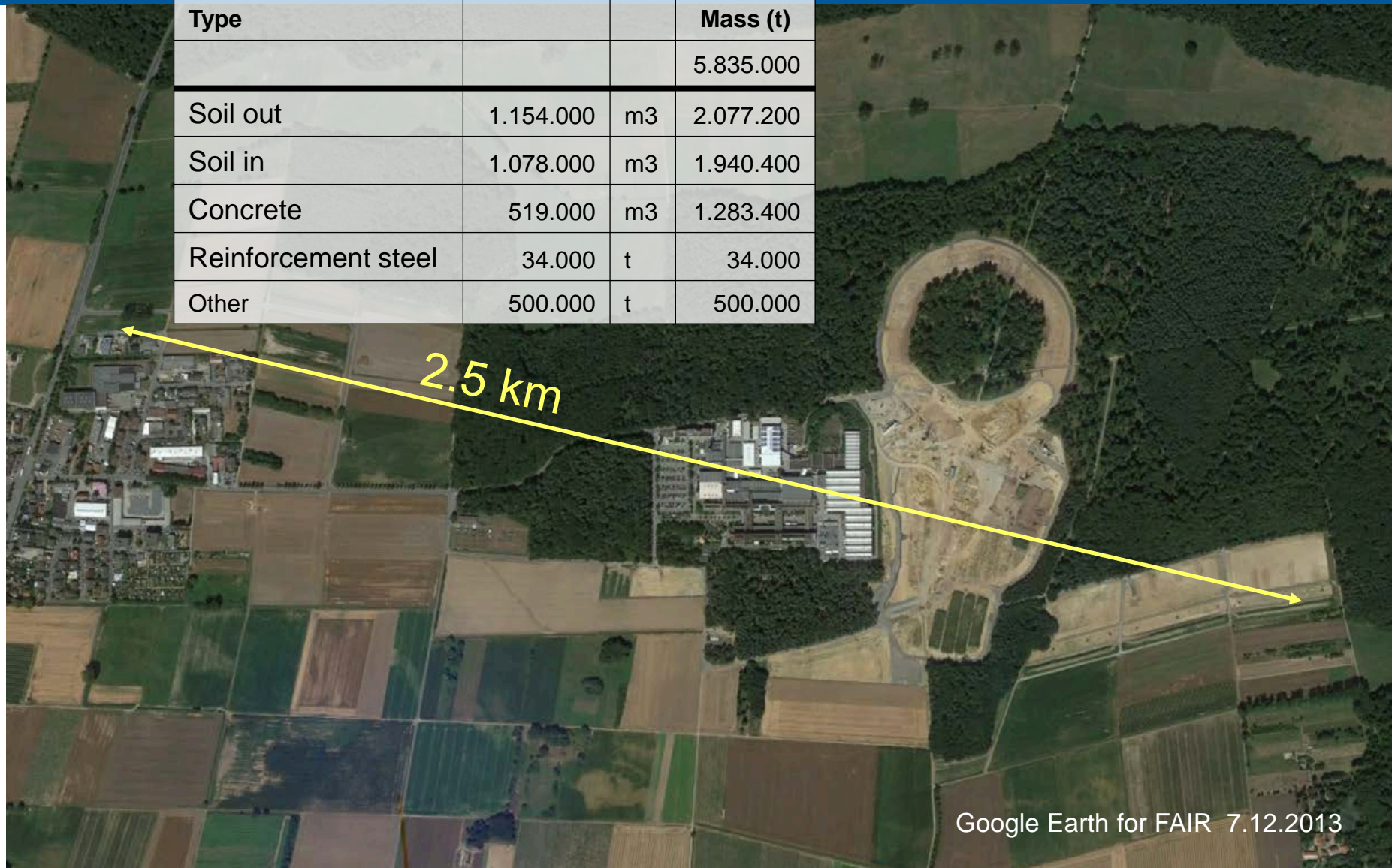


# NUSTAR – Nuclear Structure, Astrophysics and reactions



# Civil construction: Satellite's view

Type			Mass (t)
			5.835.000
Soil out	1.154.000	m3	2.077.200
Soil in	1.078.000	m3	1.940.400
Concrete	519.000	m3	1.283.400
Reinforcement steel	34.000	t	34.000
Other	500.000	t	500.000



Google Earth for FAIR 7.12.2013

# Civil construction: ground preparation

Areal view May 2013



About 500 pillars erected



05.05.2013

# FAIR Groundbreaking



(photo: G. Otto, GSI)

# FAIR Groundbreaking



(photo: G. Otto, GSI)

# FAIR construction



September 2017



(photo: T. Middelhave)

# FAIR construction



SIS 100 tunnel

LEB building area

SIS 18 shielding

Connection SIS18 to SIS100

Power station south

CBM shielding

# FAIR construction



Power station north

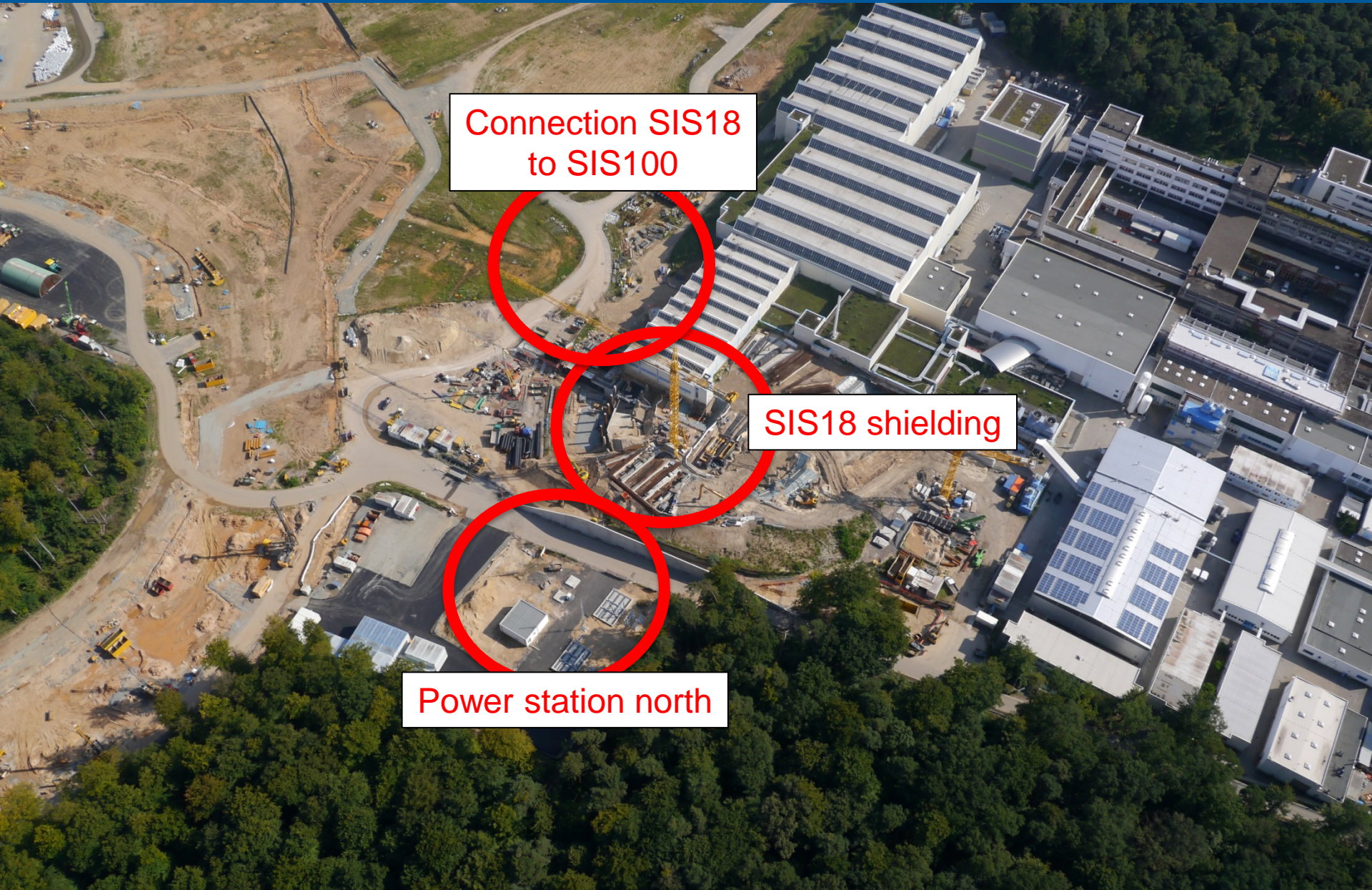




# FAIR construction



# FAIR construction



Connection SIS18  
to SIS100

SIS18 shielding

Power station north

# SIS18 shielding (table construction)



# Retention wall



# SIS18 – concrete shielding



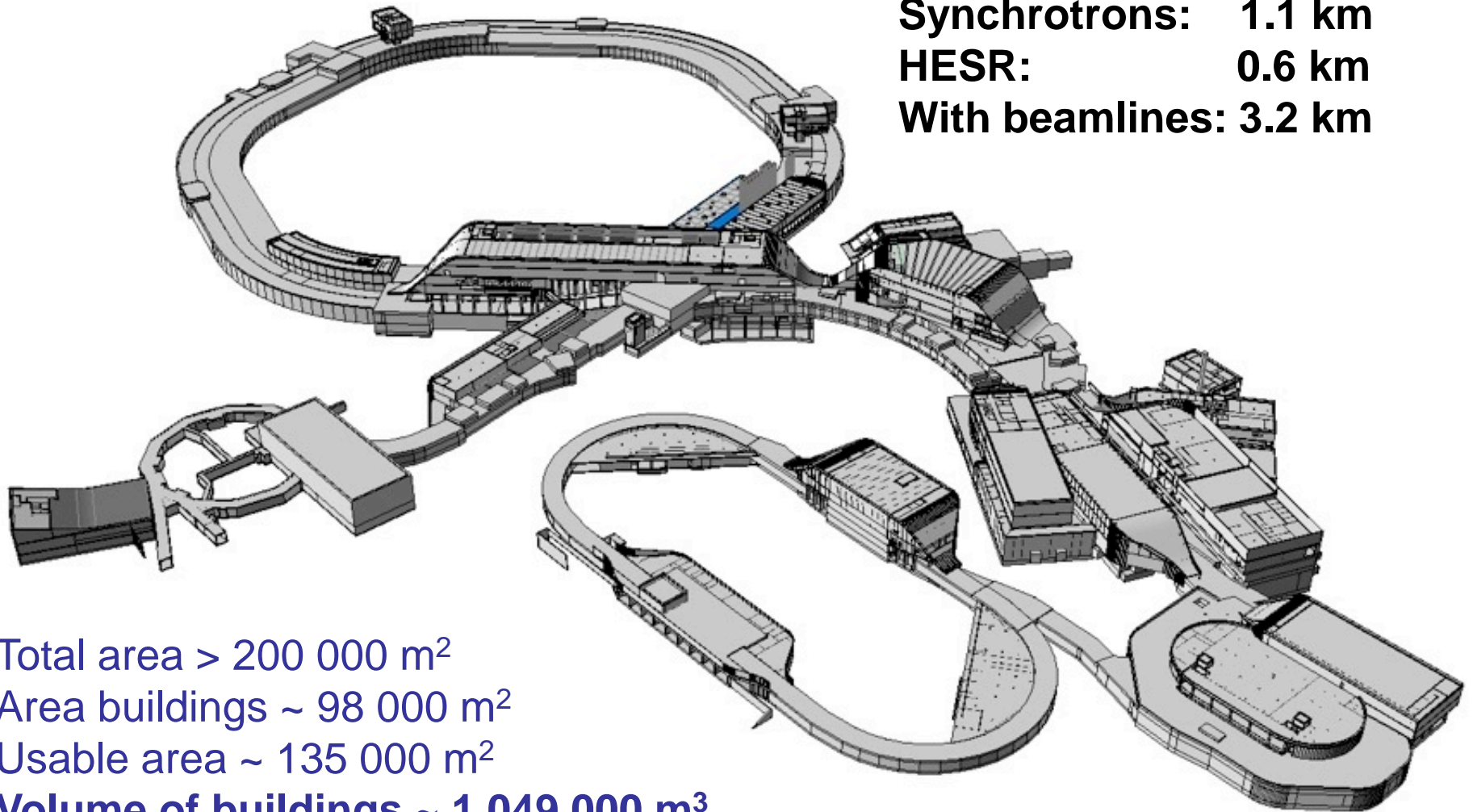
# Connection SIS18 to SIS100



(photo: G. Otto, GSI)



Nov 2017 (photo: M. Bernards)



**Synchrotrons: 1.1 km**  
**HESR: 0.6 km**  
**With beamlines: 3.2 km**

Total area > 200 000 m<sup>2</sup>

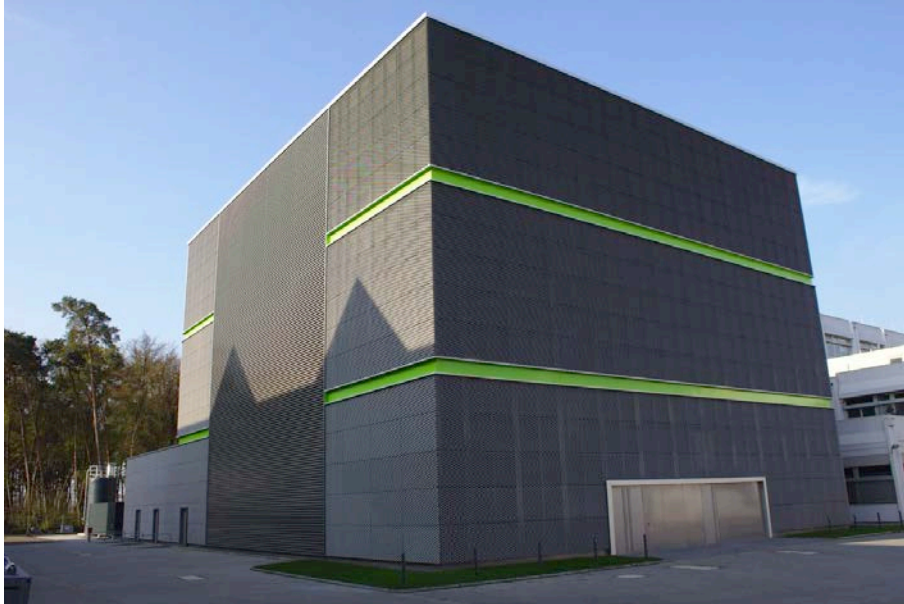
Area buildings ~ 98 000 m<sup>2</sup>

Usable area ~ 135 000 m<sup>2</sup>

**Volume of buildings ~ 1 049 000 m<sup>3</sup>**

Substructure: ~ 1500 pillars, up to 65 m deep





**Constructed: Dec '14 – Nov '15**

**Building:** 6 Floors, 4.645 sqm  
768 19" racks  
(256 racks in 1<sup>st</sup> stage)

**Cooling/  
Power:** 12 MW  
(4 MW in 1<sup>st</sup> stage)

**Cost:** 16 M€ (1<sup>st</sup> stage: 11.5 M€)

Common data center for

- FAIR Tier 0
- FAIR Experiment Online Clusters (HLT's)
- GSI Computing (ALICE Tier 2, National Analysis Facility)



Constructed: Dec '14 – Nov '15

**Building:** 6 Floors, 4.645 sqm  
768 19" racks  
(256 racks in 1<sup>st</sup> stage)

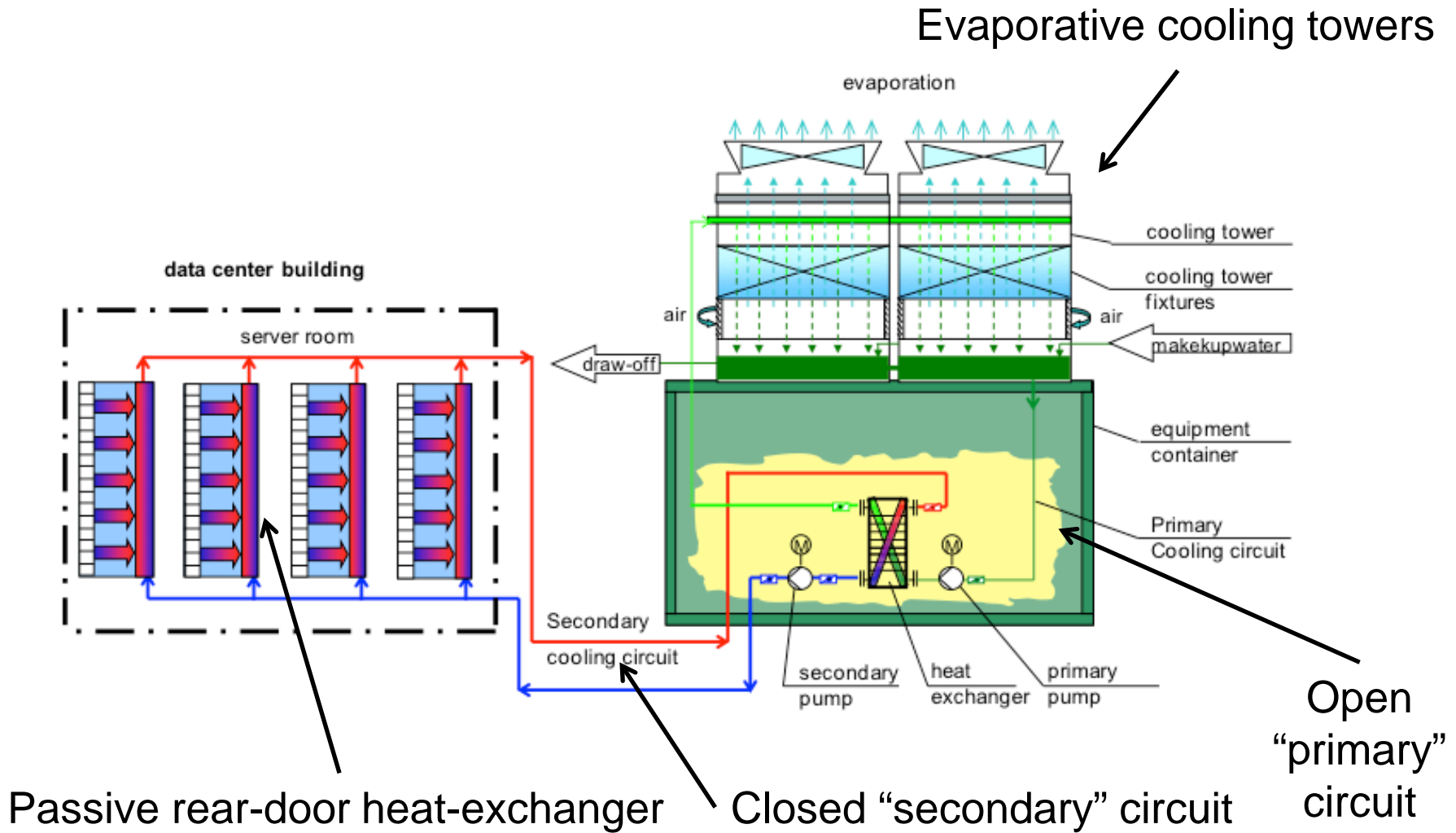
Cooling/  
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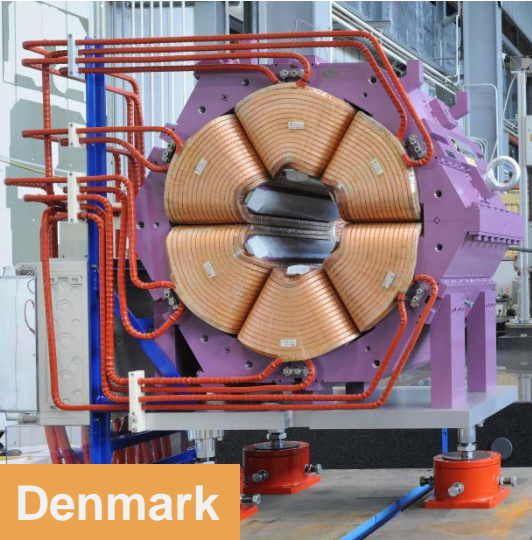
Common data center for

- FAIR Tier 0
- FAIR Experiment Online Clusters (HLT's)
- GSI Computing (ALICE Tier 2, National Analysis Facility)

# Green Cube Cooling Concept



# Procurement of FAIR accelerator components is progressing well ...



- Accelerator and detector contributions from many different partner institutions

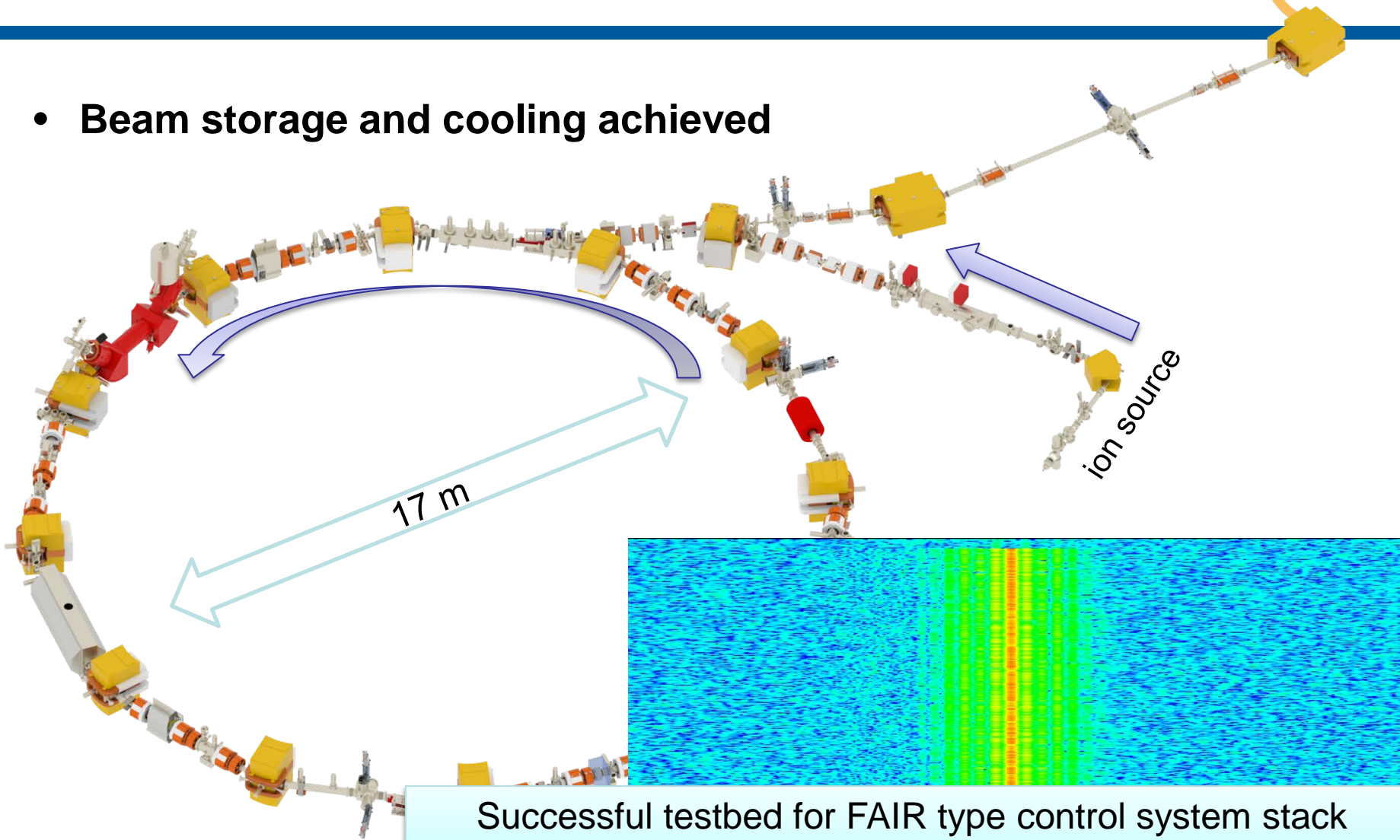
# SIS100 dipole – first of series

October 2017



(photo: G. Otto, GSI)

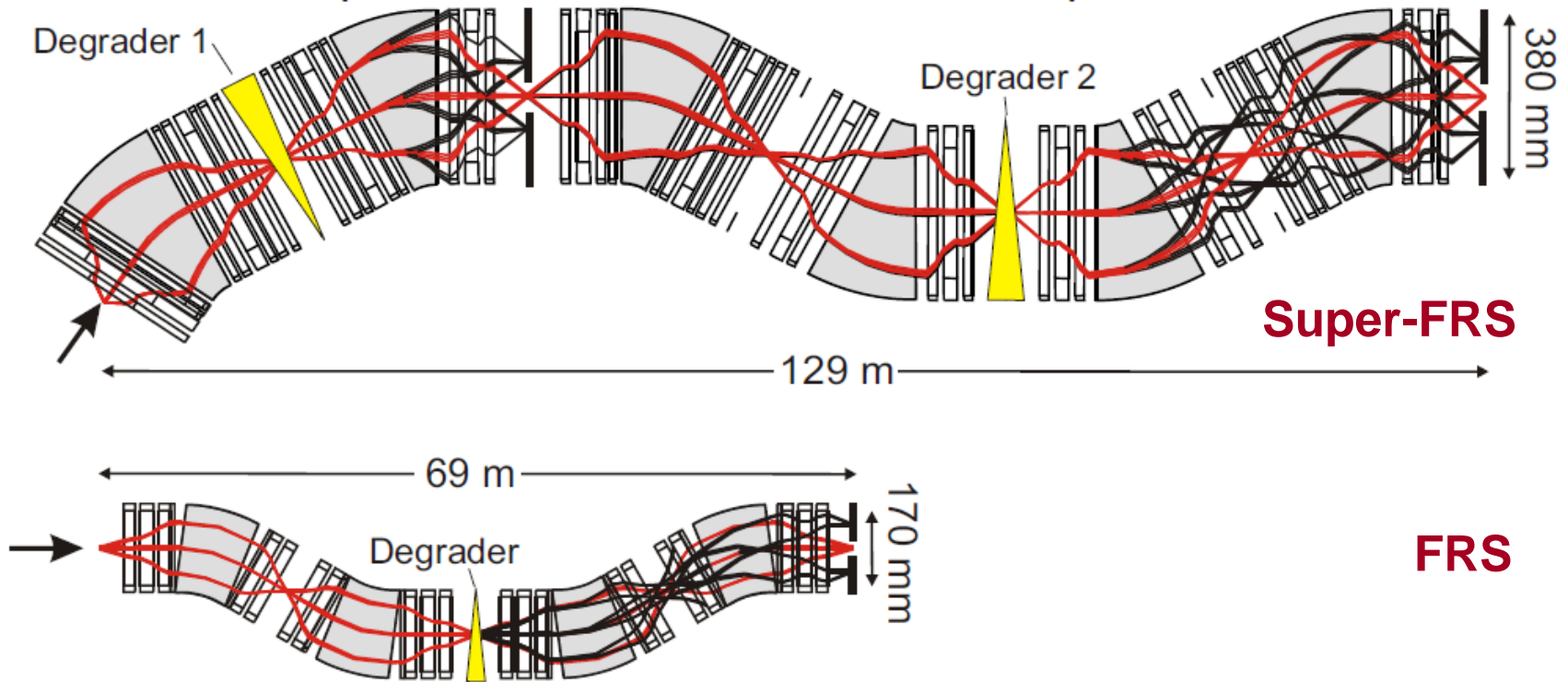
- **Beam storage and cooling achieved**



Successful testbed for FAIR type control system stack

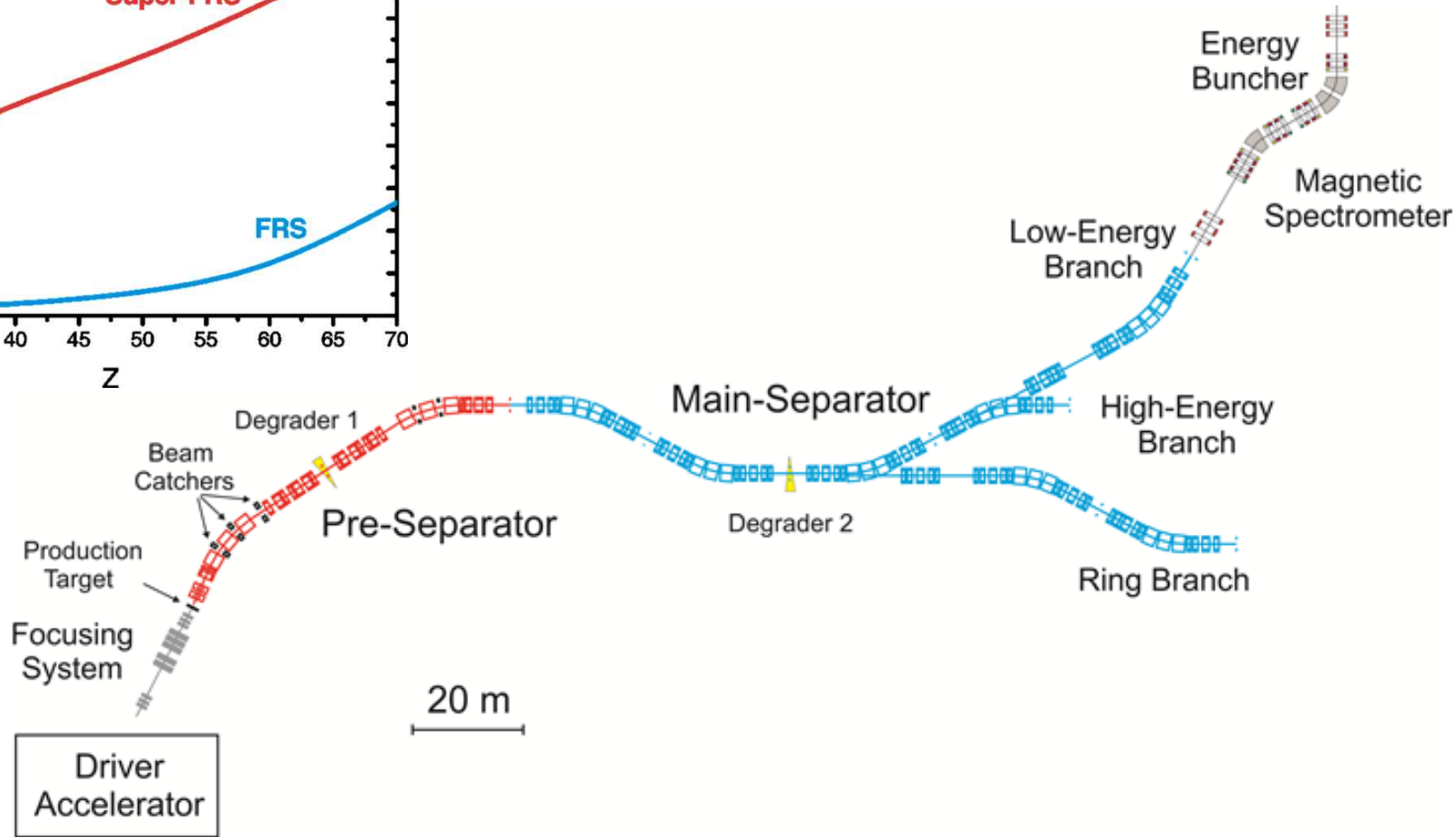
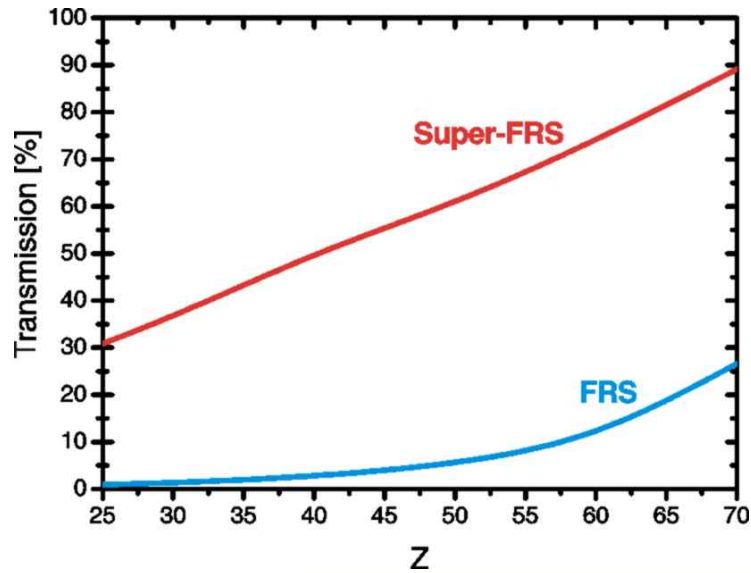
We will be ready for physics with decelerated ions for upcoming beam period 2018/19

# GSI FRS → FAIR Super-FRS



	$B\rho_{\max}$	$\Delta p/p$	$\Delta\Phi_x, \Delta\Phi_y$	resolving power	gain factor	
					$^{19}\text{C}$	$^{132}\text{Sn}$
FRS	18 Tm	1.0 %	$\pm 13, \pm 13$ mrad	1500	1	1
Super-FRS	20 Tm	2.5 %	$\pm 40, \pm 20$ mrad	1500	5	10
				including primary rate	1000	7500

# Super-FRS beam line



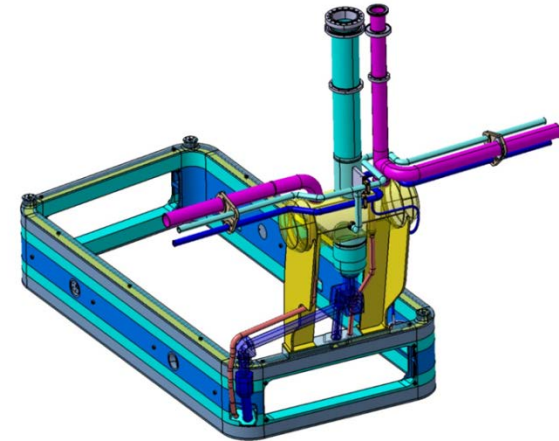
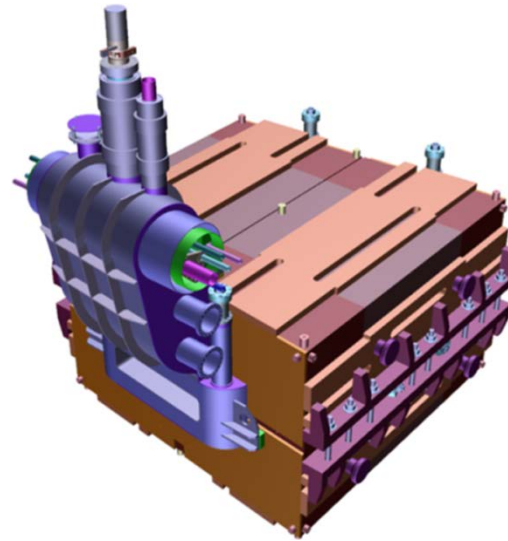


## Scope

- 3 units 11°, 18 units 9.75°
- Warm iron, SC coil
- Aperture  $\pm 190\text{mm} \times \pm 70\text{mm}$
- Weight: 50 to 60 ton

## Collaboration with CEA, Saclay:

- ✓ TCC signed , includes:
  - Detailed design
  - Documentation (CDR, DS, 3D Model)
- ✓ Steering board kick-off , June 7, 2017
- Technical follow-up



## Tender Status :

- ✓ Announcement published April 7, 2017
- ✓ Qualifying submission closed May 12, 2017
  - 6 out of 7 companies invited to tender
- ✓ Offers received by mid of July, 2017
- ✓ Offers analyzed (with CEA colleagues);
  - Offer negotiation fixed for October 2017
  - Contract award expected still in 2017

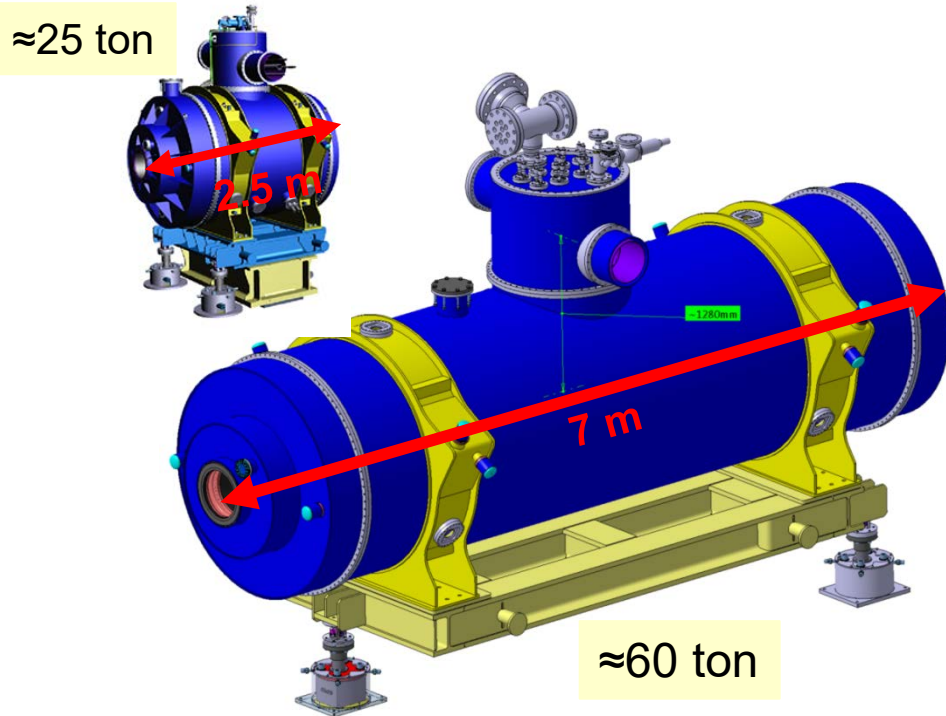
- 8 short multiplets (PS)
  - QS configuration
- 25 long multiplets (mainly MS)
  - Quadrupol triplet
- include corrector elements & steerer

## Main characteristics:

- iron dominated, cold iron (up to 37 tons)
- common helium bath
- warm beam pipe (38 cm inner diameter)
- per magnet 1 pair of current leads
- max. current <300A for all magnets

## Schedule FoS SC multiplets

- ✓ Contract closed 07/2015
  - (ASG, Genova)
- ✓ Design phase for SM done, for LM running
  - ✓ PDR 07/2016
  - ✓ FDR 12/2016
  - ✓ PRR 07/2017 (short multiplet)
    - PRR LM Q4/2017
    - FAT of FOS short multiplet Q1/2018



# Magnet testing at CERN

- ✓ Collaboration between CERN and GSI
  - CERN Building 180: Infrastructures, renovation done.
- ✓ Cold (4K) testing of the SC dipoles and multiplets
  - 3 test benches installed, 59 magnet cryo-modules
- ✓ Commissioning of the cryo-facility running
  - Procurement of last missing components in progress (Jumper-line/elec. cabinets)
  - FoS SM testing foreseen to start in Q2 2018



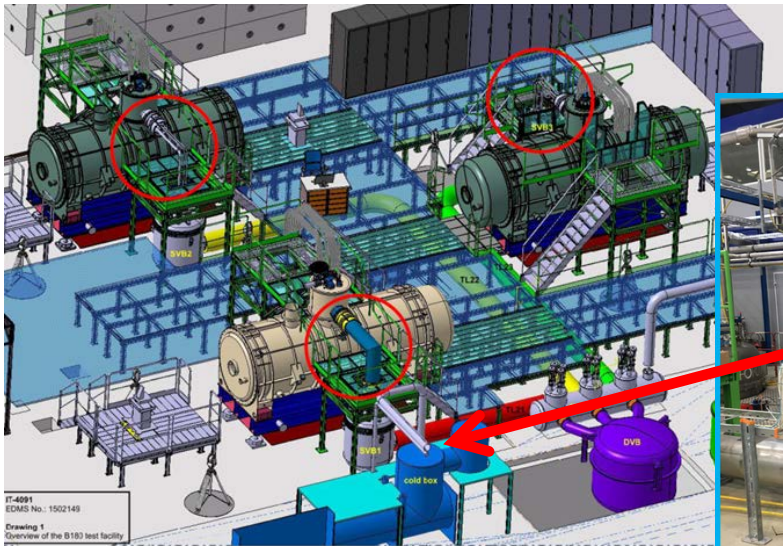
**B.180 CERN**



**Control room**



**Power cable**

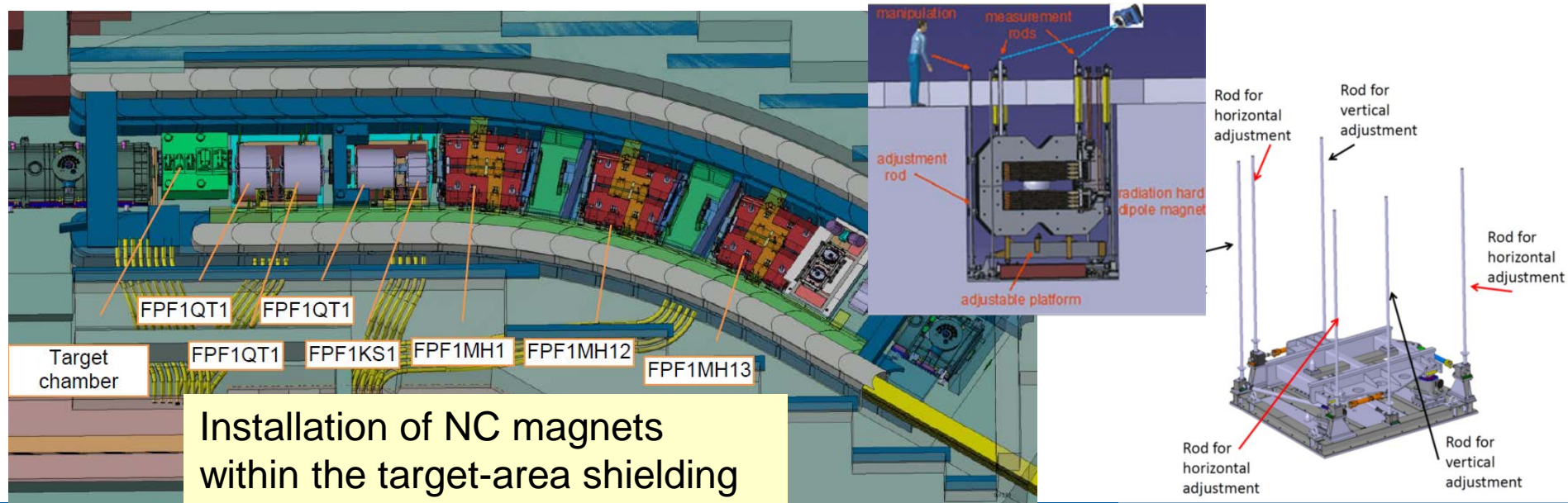
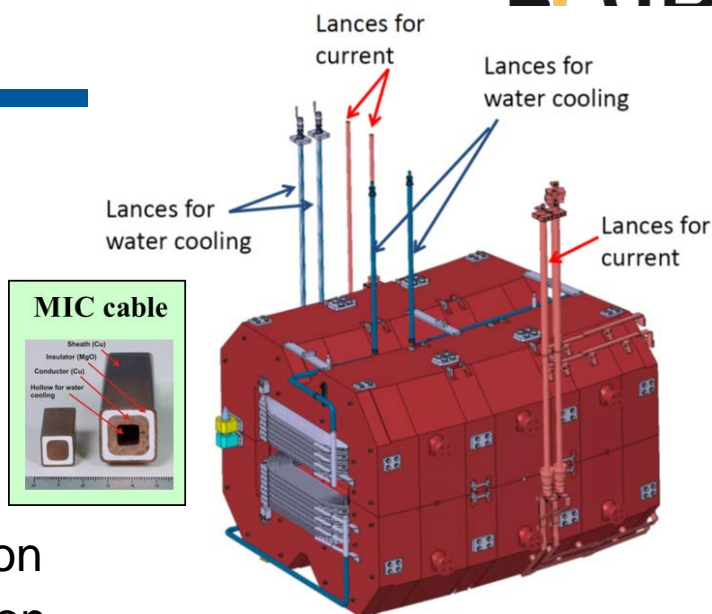


IT-4091  
ECMS No.: 1502149  
Drawing 1  
Overview of the B180 test facility



# Radiation resistant magnets

- 3 dipole, 3 quadrupole, and 2 sextupole
- Normal conducting magnets using MIC cable
- Remote connectors and alignment
- ✓ Prototype dipole built and tested by BINP
  - delivered and set-up to GSI
- ✓ Dedicated support structure constructed
- ✓ Dipole: specification released, tender in preparation
- Quadrupole & sextupole: specification in preparation



**Build. 018**

(Target building)



100 m

**Build. 006a**

(Service building)

**Tunnel 103**

**Build. 006b**

(LEB cave)

**Build. 006**

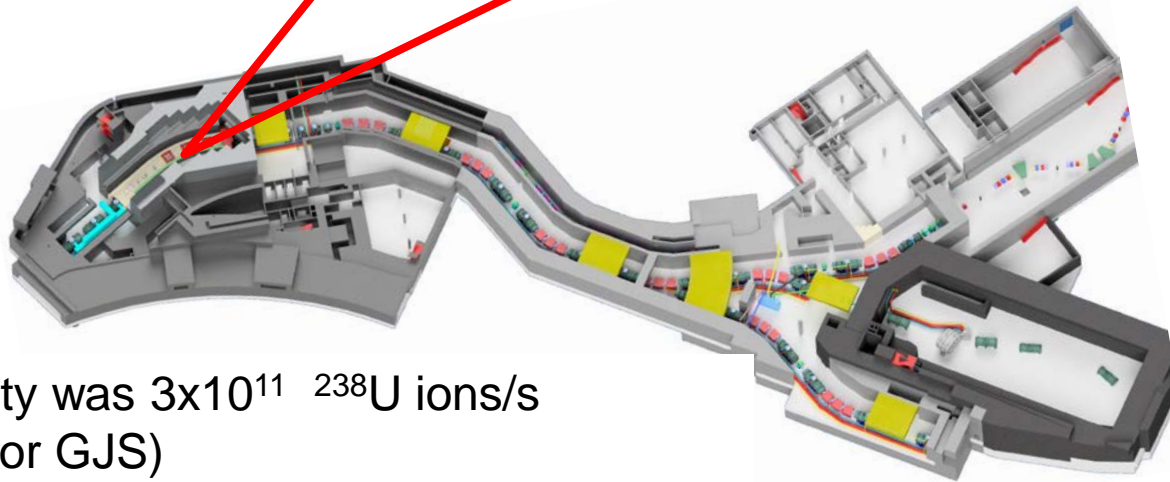
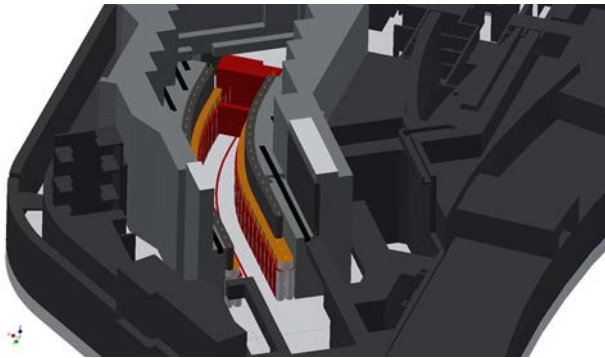
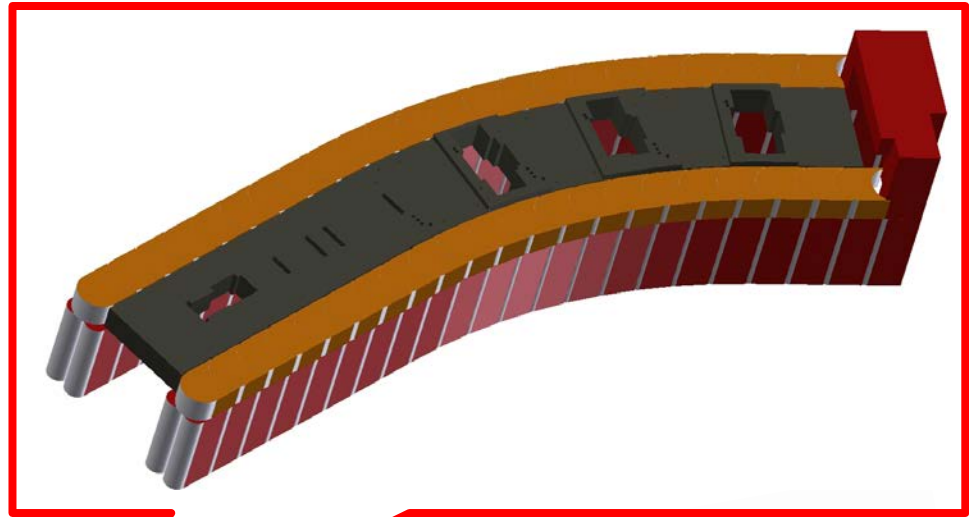
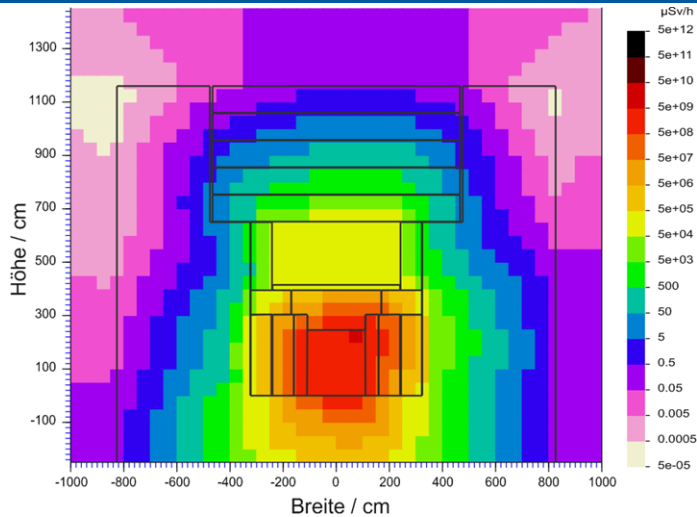
(HE cave)

**To CR**

0.00235

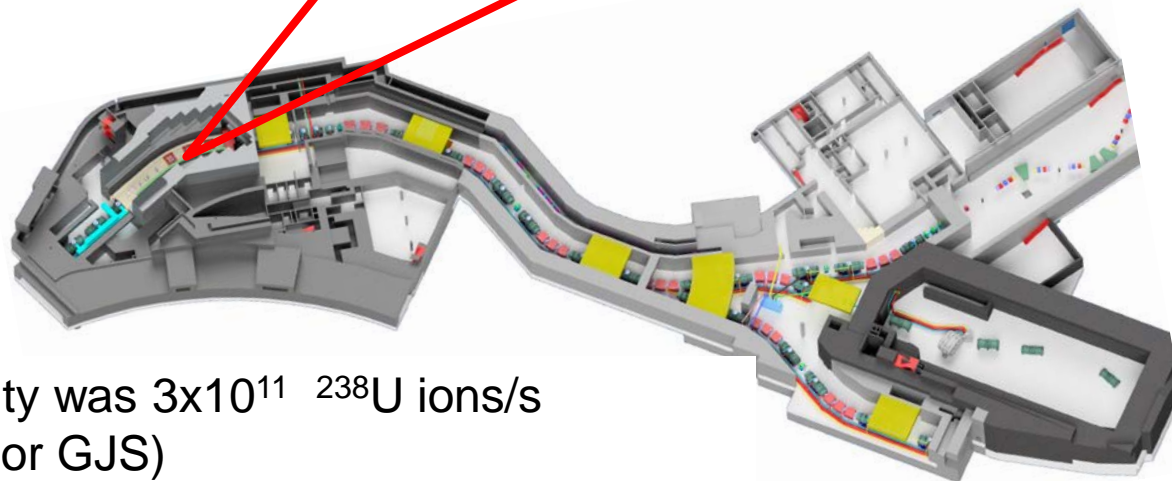
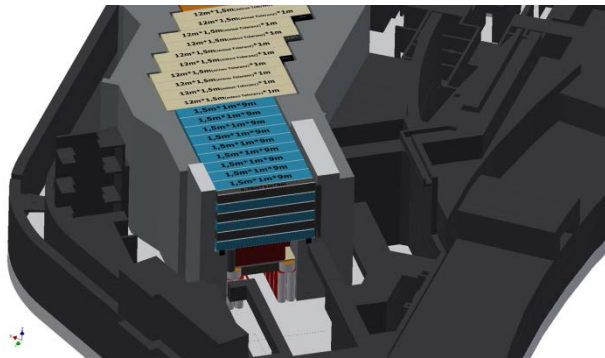
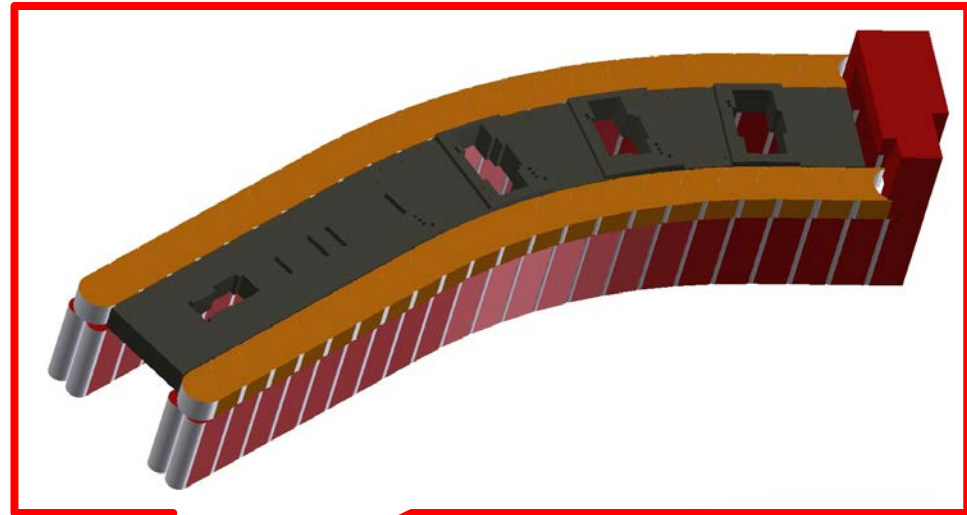
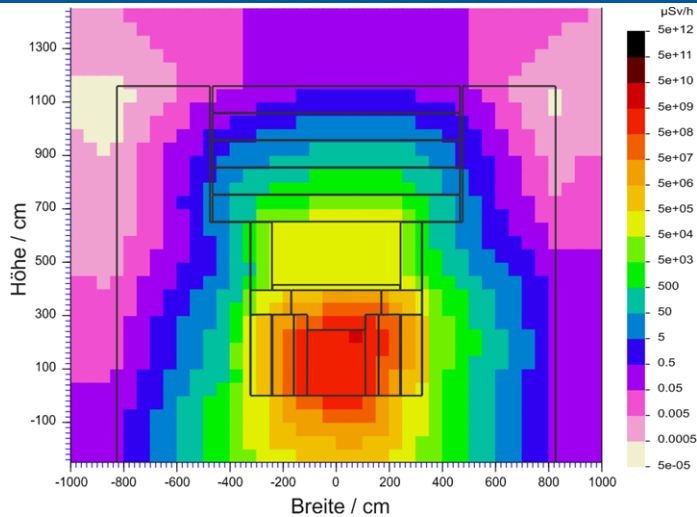
- ✓ CC planning Phase 1&2 done
  - LEB cave integrated
- CC planning Phase 3 running
  - end of 4<sup>th</sup> phase scheduled for Q4/2017 (equal to execution planning → prepare tender documents)
- Technical service planning (phase 1 done)
  - Building installation planning
  - Cable planning & routing (CDB filled)
  - Detector gas supply planning

# Target area shielding

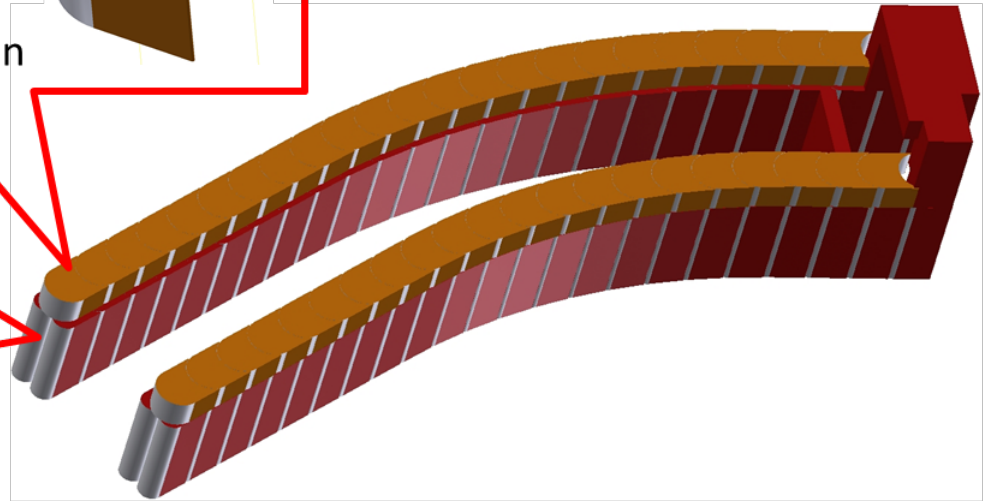
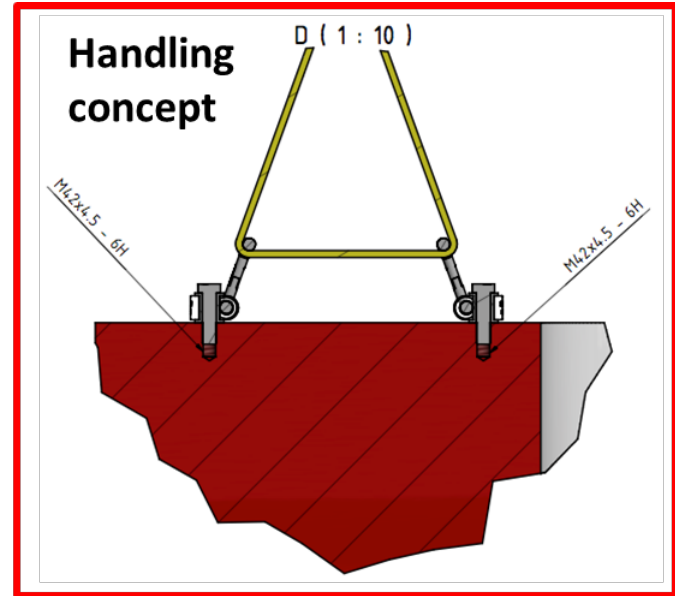
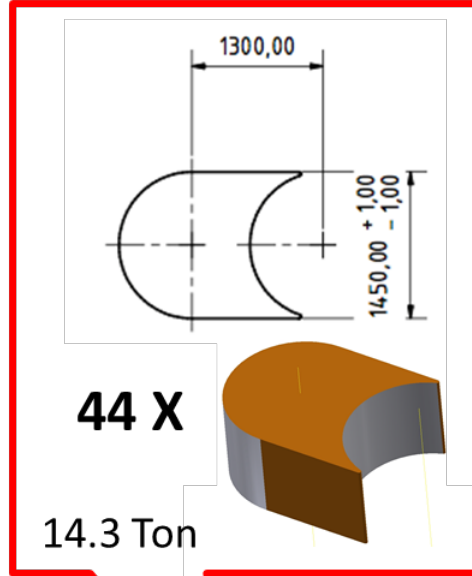
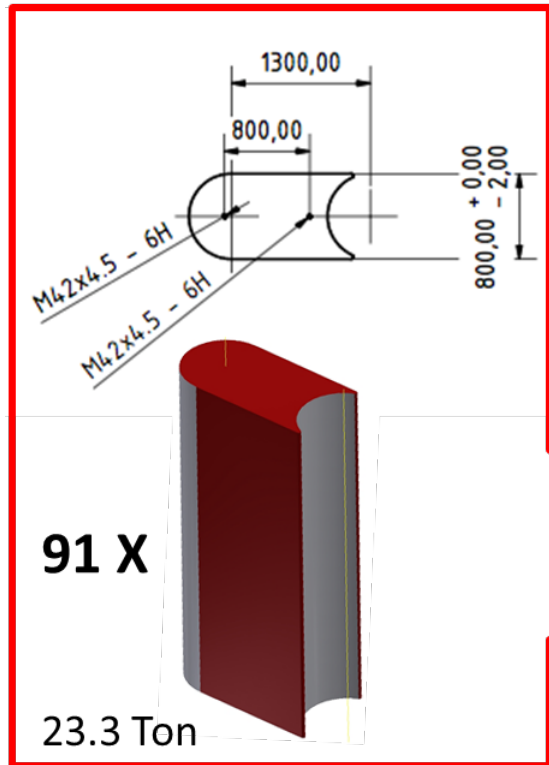


- based on FLUKA, beam intensity was  $3 \times 10^{11}$   $^{238}\text{U}$  ions/s
- cast iron (grade GJL 150 - 250 or GJS)
- steel slabs (grade S235, between beam and maintenance tunnel)
- concrete slabs (upper roof shielding)

# Target area shielding

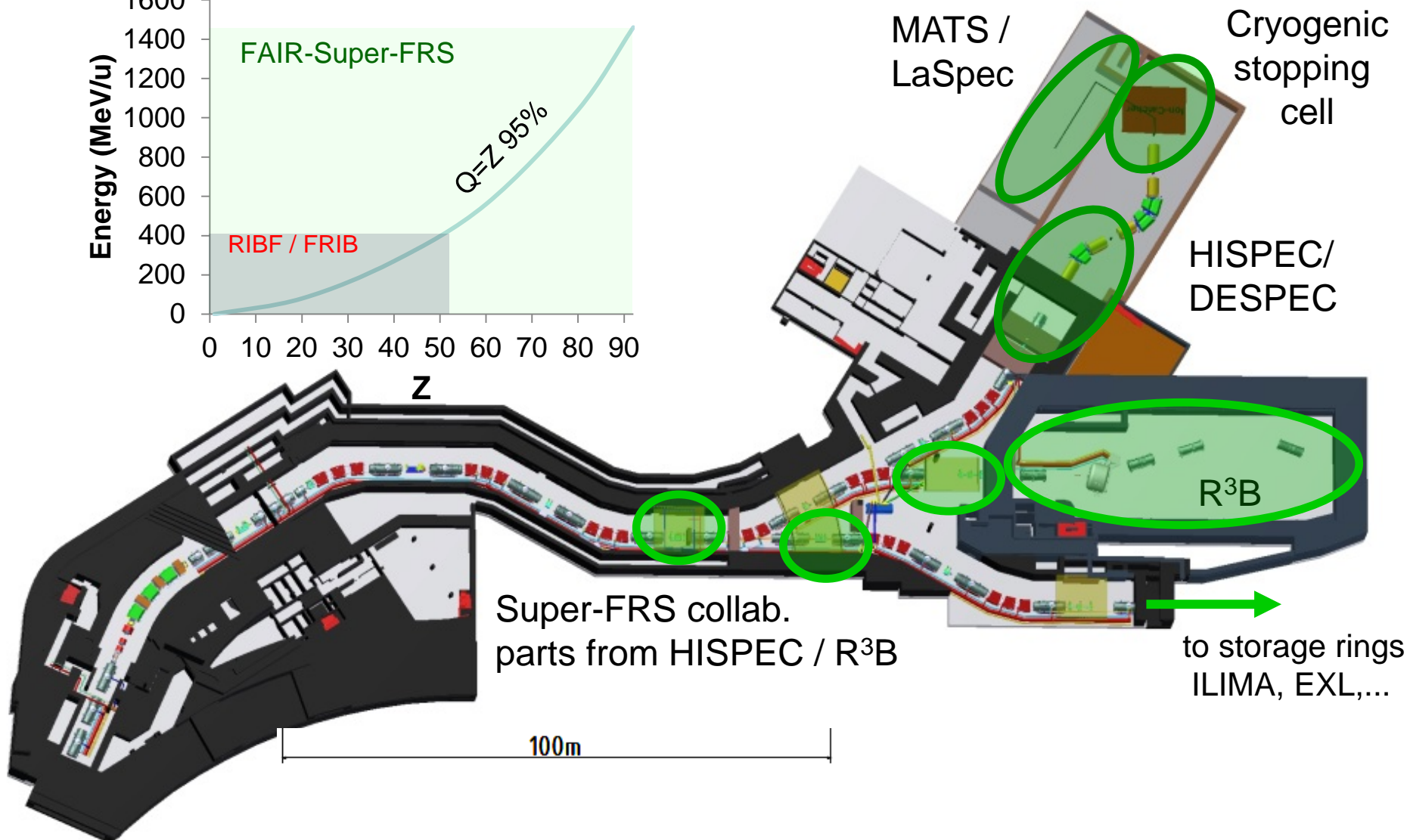
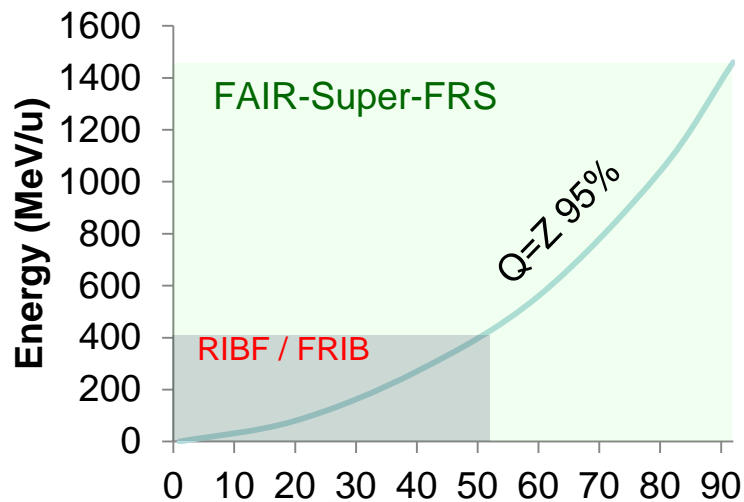


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- concrete slabs (upper roof shielding)





# Location of experiments



Super-FRS collab.  
parts from HISPEC / R<sup>3</sup>B

to storage rings  
ILIMA, EXL,...

## 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?

# NUSTAR – The project 1.2



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

(\*) **NESR required** – alternative/intermediate “operation” within MSV under discussion.  
SHE physics case to be evaluated.

- **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**

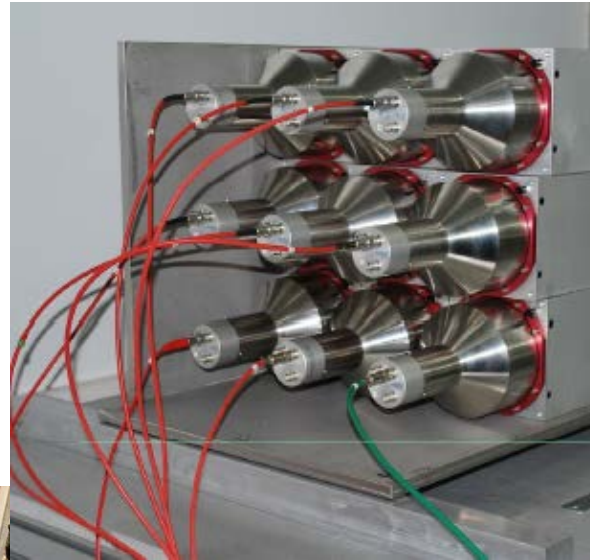
- Major new investments and upgrades for all experiments

# HISPEC/DESPEC – ready for operation

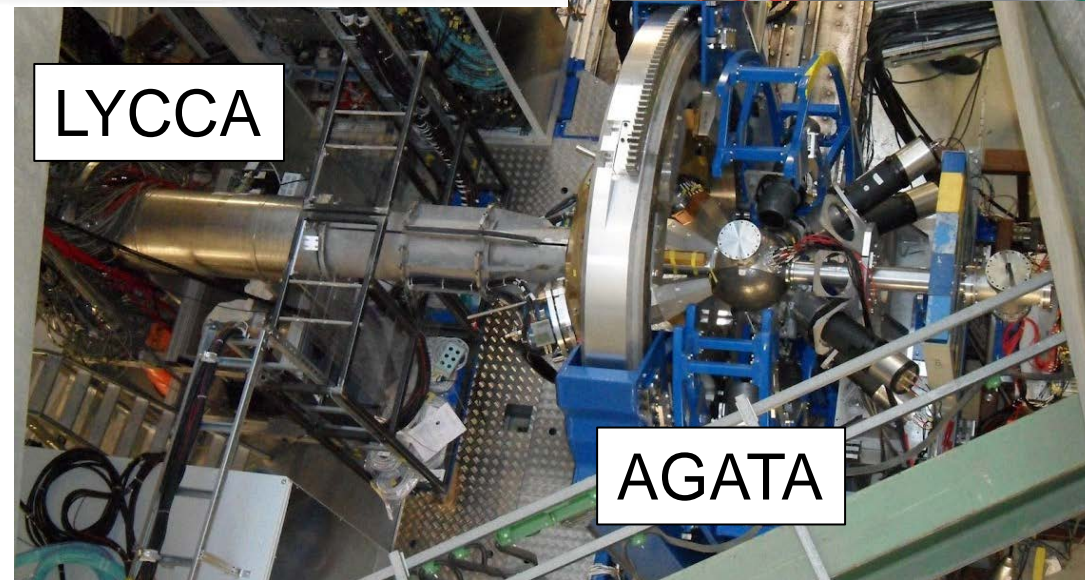
BELEN



DTAS

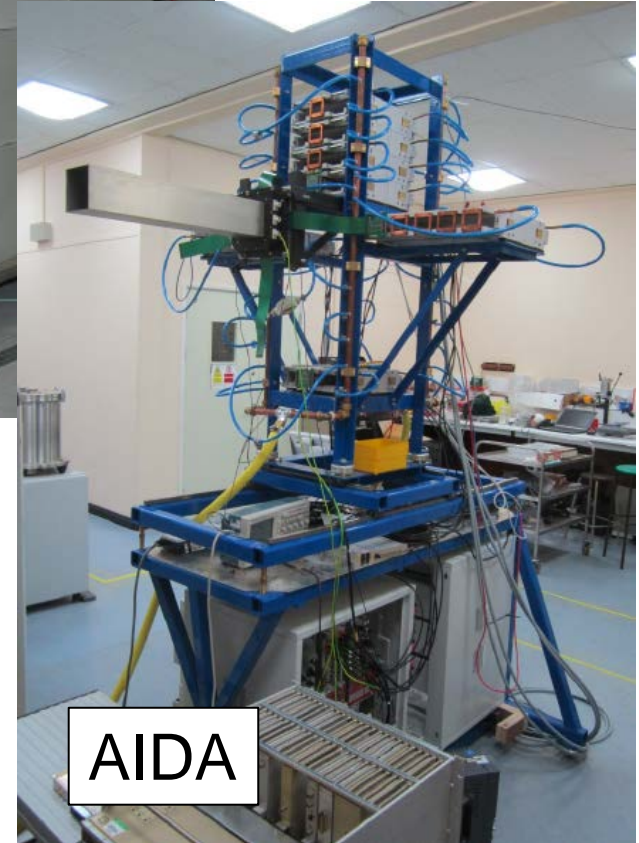


LYCCA



AGATA

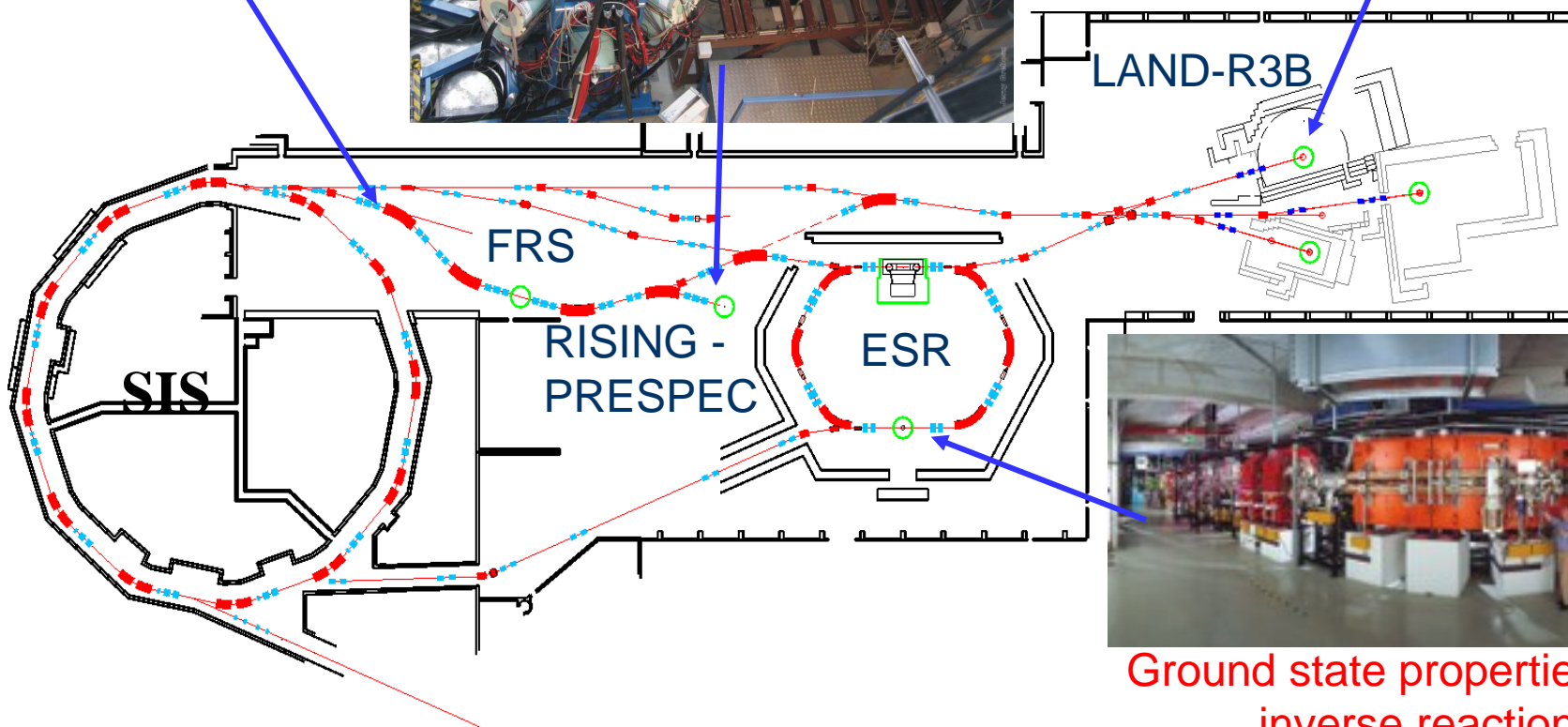
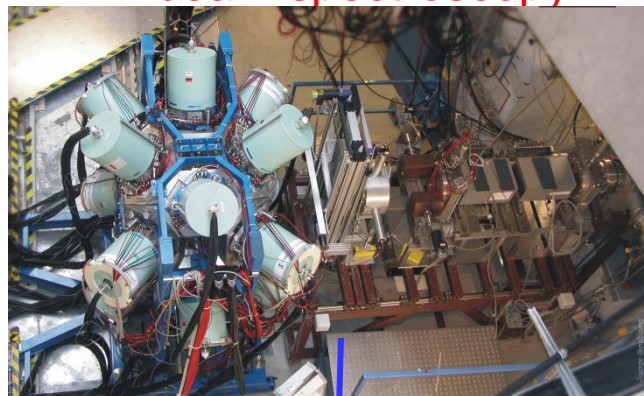
AIDA



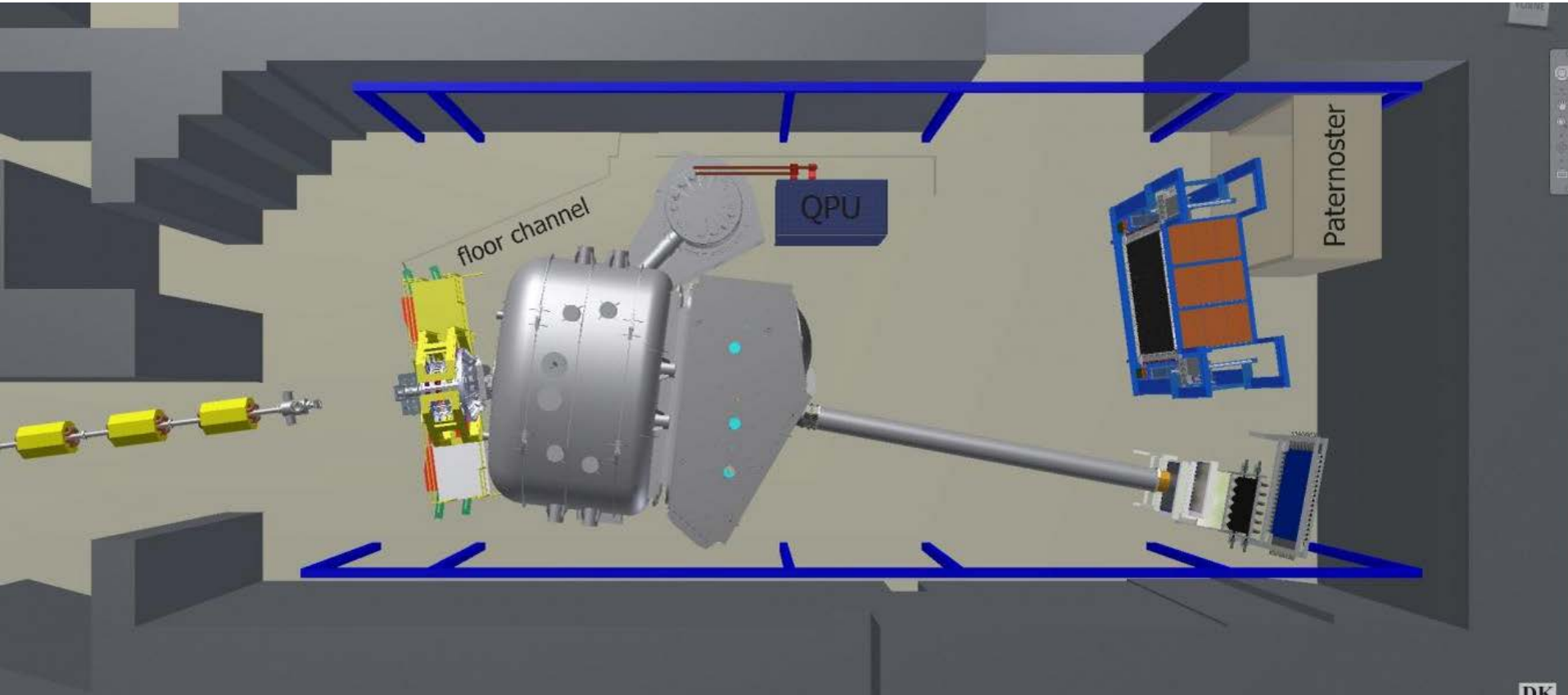
Decay studies,  
In-beam spectroscopy

Reaction studies

production and  
separation of  
exotic nuclei



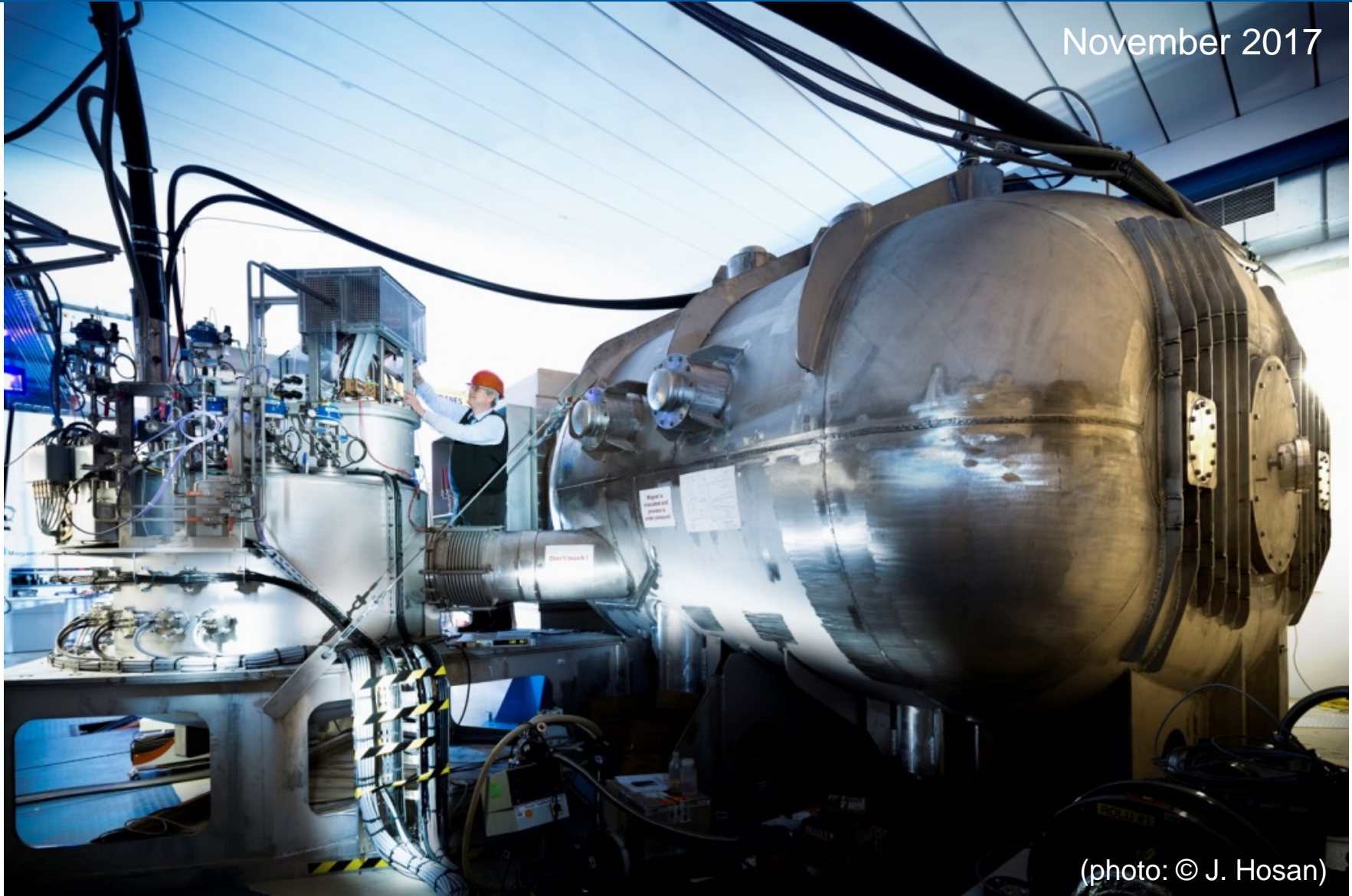
Ground state properties  
inverse reactions



- Full integration test and potential later experiment runs in Cave-C
- Move fully commissioned systems to FAIR high energy Cave

# GLAD cryogenics test in progress ...

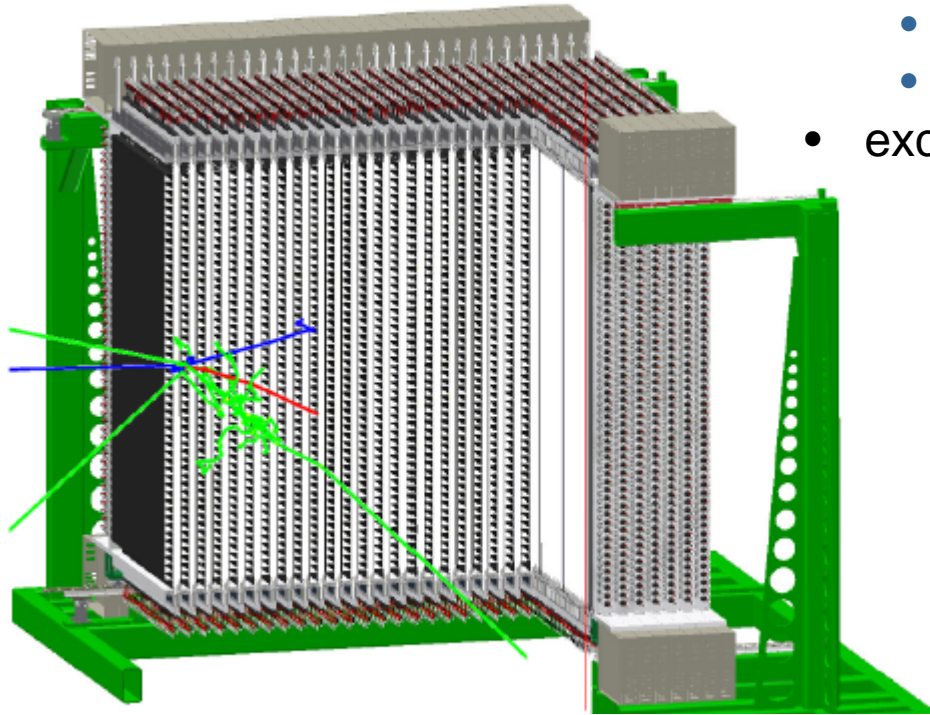
November 2017



(photo: © J. Hosan)

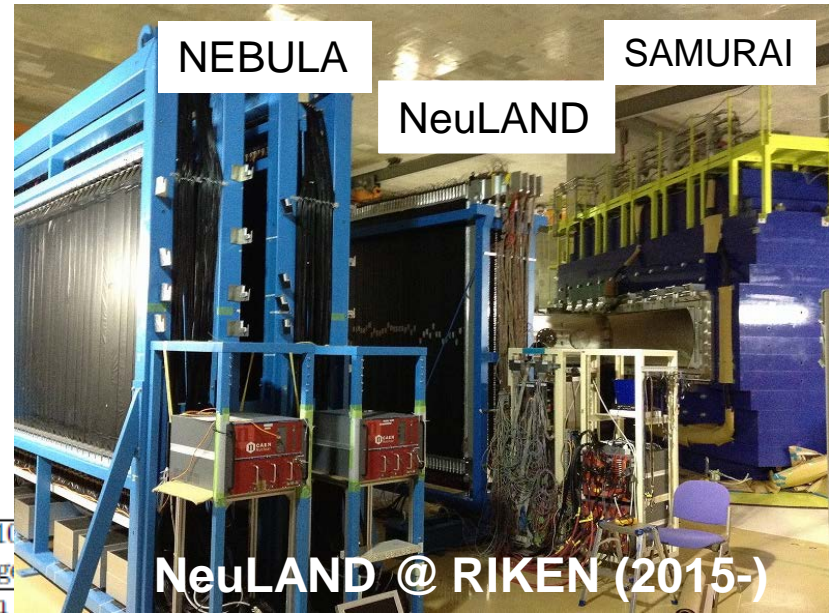
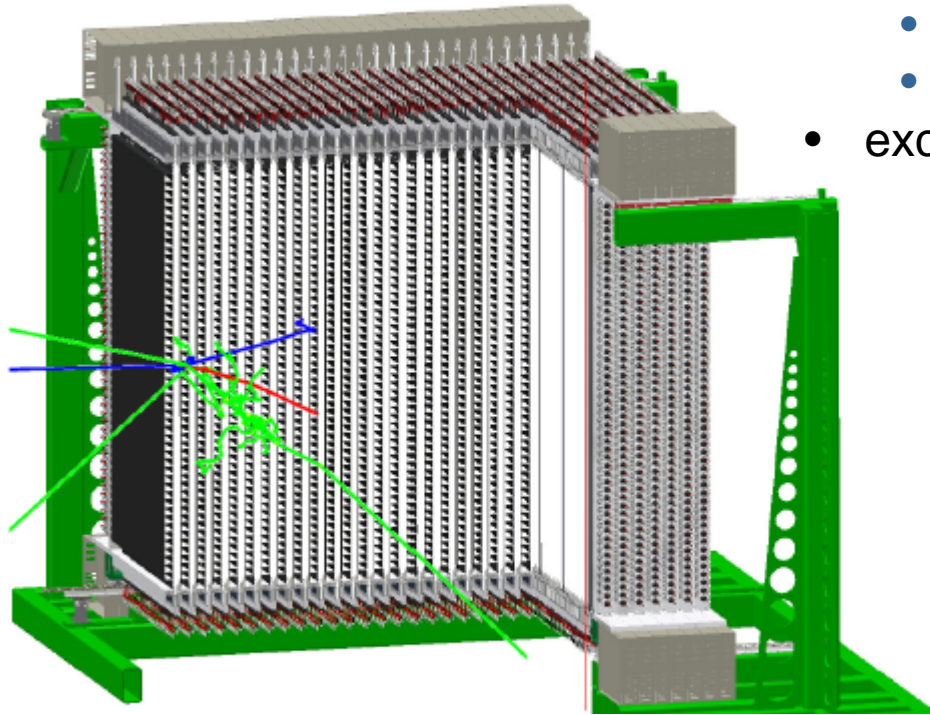


- 30 double planes
  - 100 x 100 scintillator bars x 30 planes
  - 6000 PMTs
- excellent multi-neutron capability



		200 MeV generated											600 MeV generated											1000 MeV generated							
		%	1n	2n	3n	4n	5n							%	1n	2n	3n	4n	5n							%	1n	2n	3n	4n	5n
detected	1n	<b>88</b>	31	6	1	0	detected	1n	<b>92</b>	22	2	0	0	detected	1n	<b>89</b>	12	1	0	0	detected	1n	<b>89</b>	12	1	0	0				
	2n	2	<b>62</b>	37	10	2		2n	2	<b>71</b>	32	7	1		2n	7	<b>78</b>	23	3	0		2n	7	<b>78</b>	23	3	0				
	3n	0	5	<b>49</b>	38	14		3n	0	6	<b>55</b>	32	9		3n	0	8	<b>63</b>	26	5		3n	0	8	<b>63</b>	26	5				
	4n	0	0	8	<b>48</b>	54		4n	0	0	10	<b>57</b>	50		4n	0	0	12	<b>63</b>	40		4n	0	0	12	<b>63</b>	40				
	5n	0	0	0	3	<b>26</b>		5n	0	1	1	4	<b>35</b>		5n	0	0	0	7	<b>46</b>		5n	0	0	0	7	<b>46</b>				
	6n	0	0	0	0	3		6n	0	0	0	0	5		6n	0	0	0	0	8		6n	0	0	0	0	8				

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



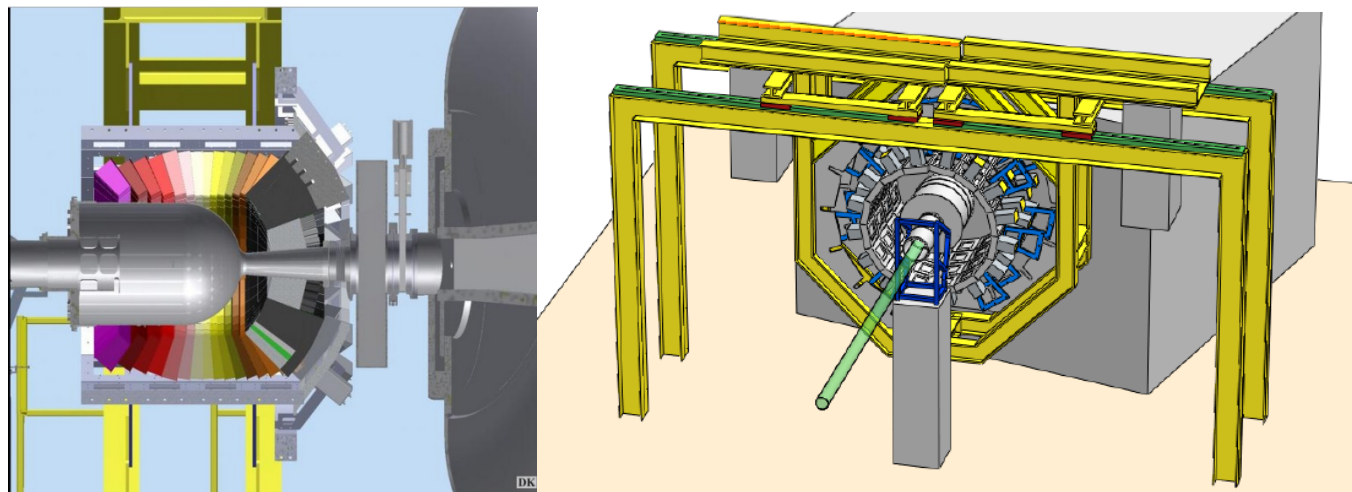
NeuLAND @ RIKEN (2015-)

		200 MeV generated					600 MeV generated					1000 MeV generated								
		%	1n	2n	3n	4n	5n	%	1n	2n	3n	4n	5n	%	1n	2n	3n	4n	5n	6n
detected	1n	<b>88</b>	31	6	1	0	1n	<b>92</b>	22	2	0	0	1n	<b>89</b>	12	1	0	0		
	2n	2	<b>62</b>	37	10	2	2n	2	<b>71</b>	32	7	1	2n	7	<b>78</b>	23	3	0		
	3n	0	5	<b>49</b>	38	14	3n	0	6	<b>55</b>	32	9	3n	0	8	<b>63</b>	26	5		
	4n	0	0	8	<b>48</b>	54	4n	0	0	10	<b>57</b>	50	4n	0	0	12	<b>63</b>	40		
	5n	0	0	0	3	<b>26</b>	5n	0	1	1	4	<b>35</b>	5n	0	0	0	7	<b>46</b>		
	6n	0	0	0	0	3	6n	0	0	0	0	5	6n	0	0	0	0	8		

The construction of 12 petals (~ 768 Borell detection channels) is foreseen to be completed withing the next 6 months



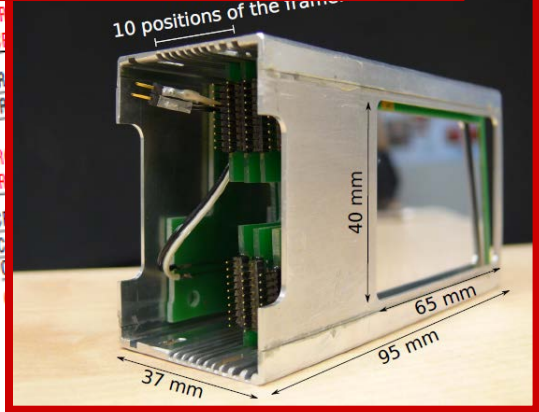
**Full detector expected by 2018**



D. Cortina

TDR in final round  
"Schottky pickups"

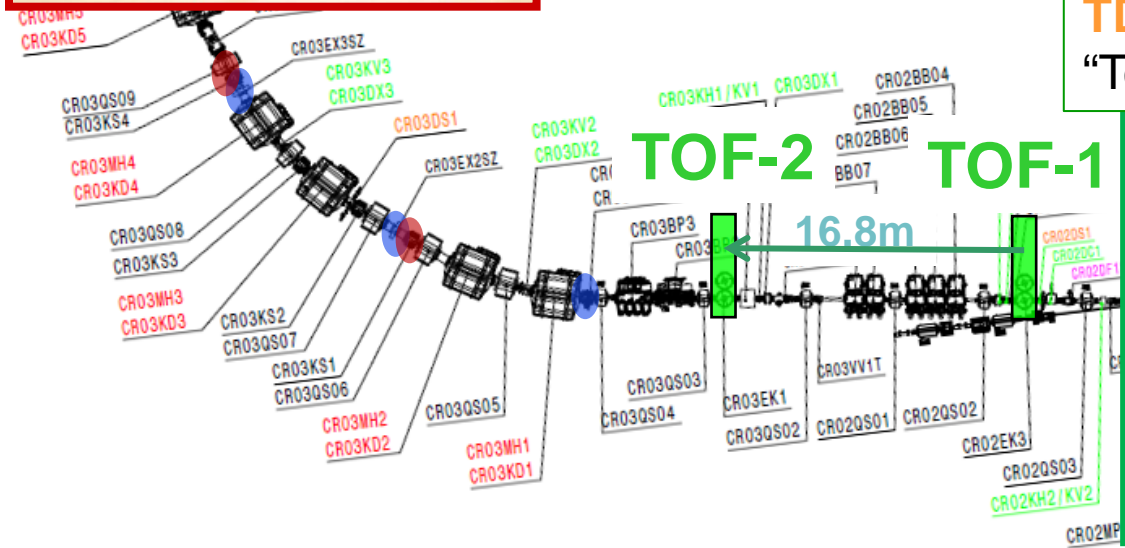
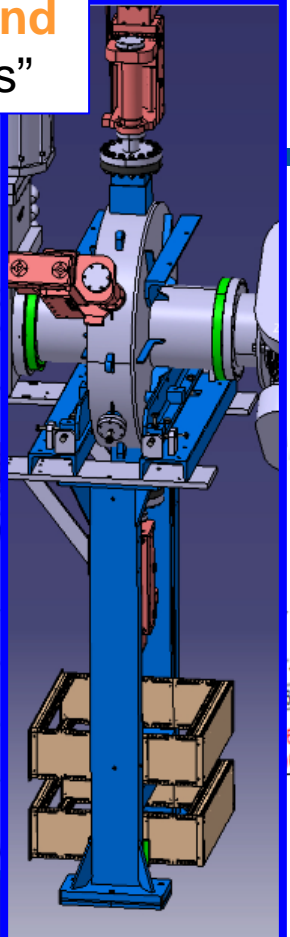
TDR submitted  
"Heavy ion detector"



# ILIMA@CR

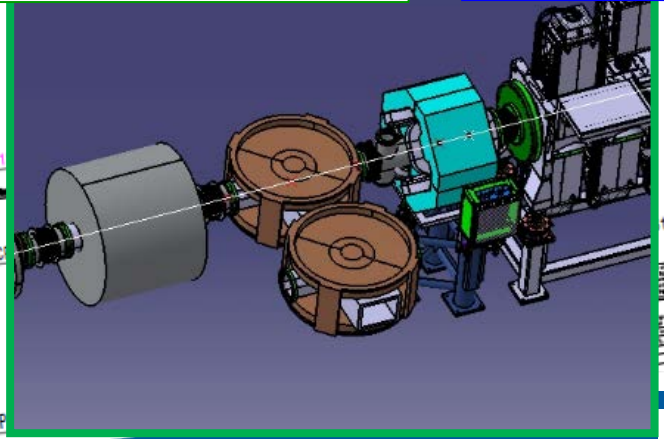
- Schottky pickups also horizontal and vertical
- Detector pockets
- ToF detectors

TDR in final round  
"ToF detector"



## TOF-2 TOF-1

16.8m

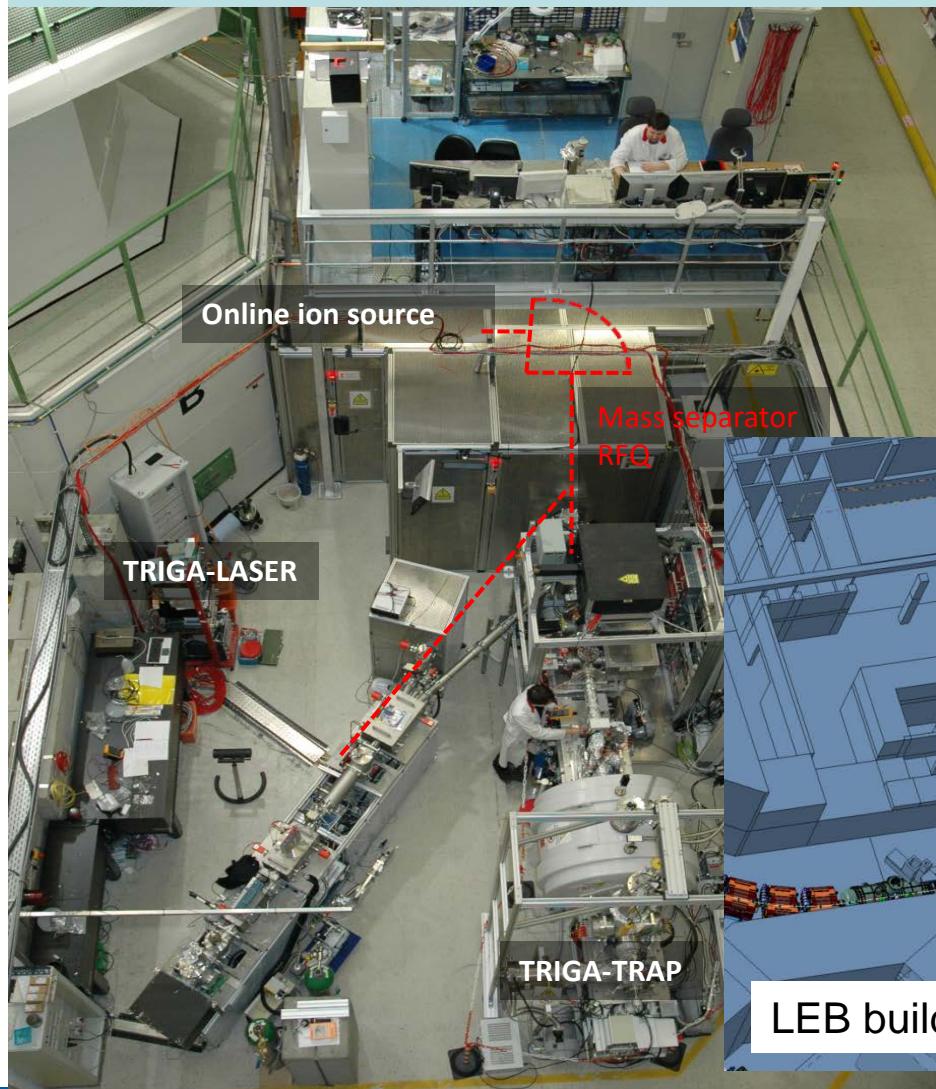


stand: 12.02.201

NO	DESCRIPTION	DATE	BY
1	...	...	...
2	...	...	...
3	...	...	...
4	...	...	...
5	...	...	...
6	...	...	...
7	...	...	...
8	...	...	...
9	...	...	...
10	...	...	...

project start @ TRIGA: 01/2008  
start data taking: 05/2009

Nucl. Instrum. Meth. A 594, 162 (2008)

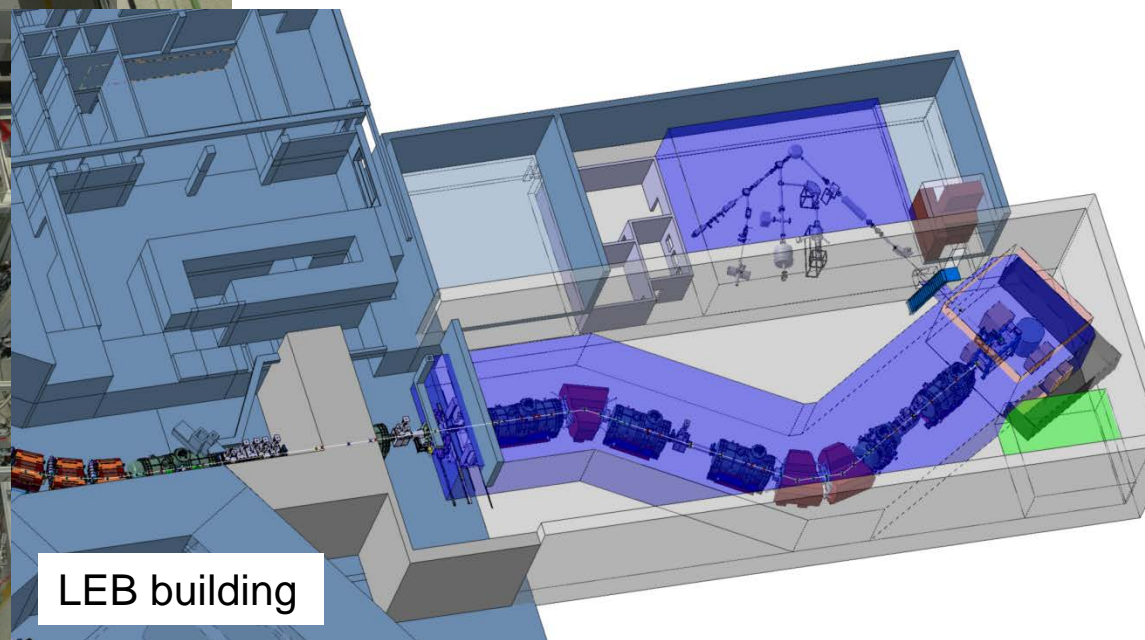


## TRIGA-Laser

serving as a prototype for  
LASPEC

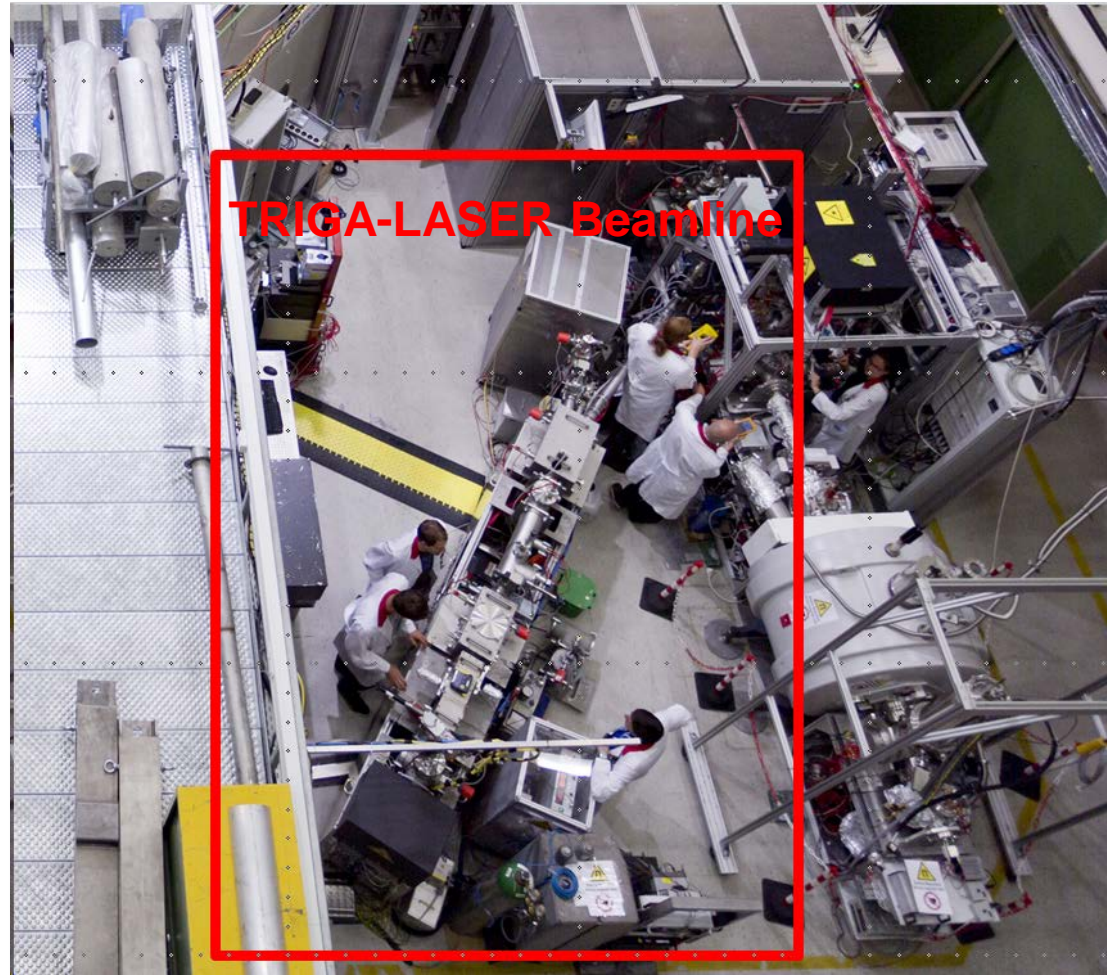
## TRIGA-TRAP

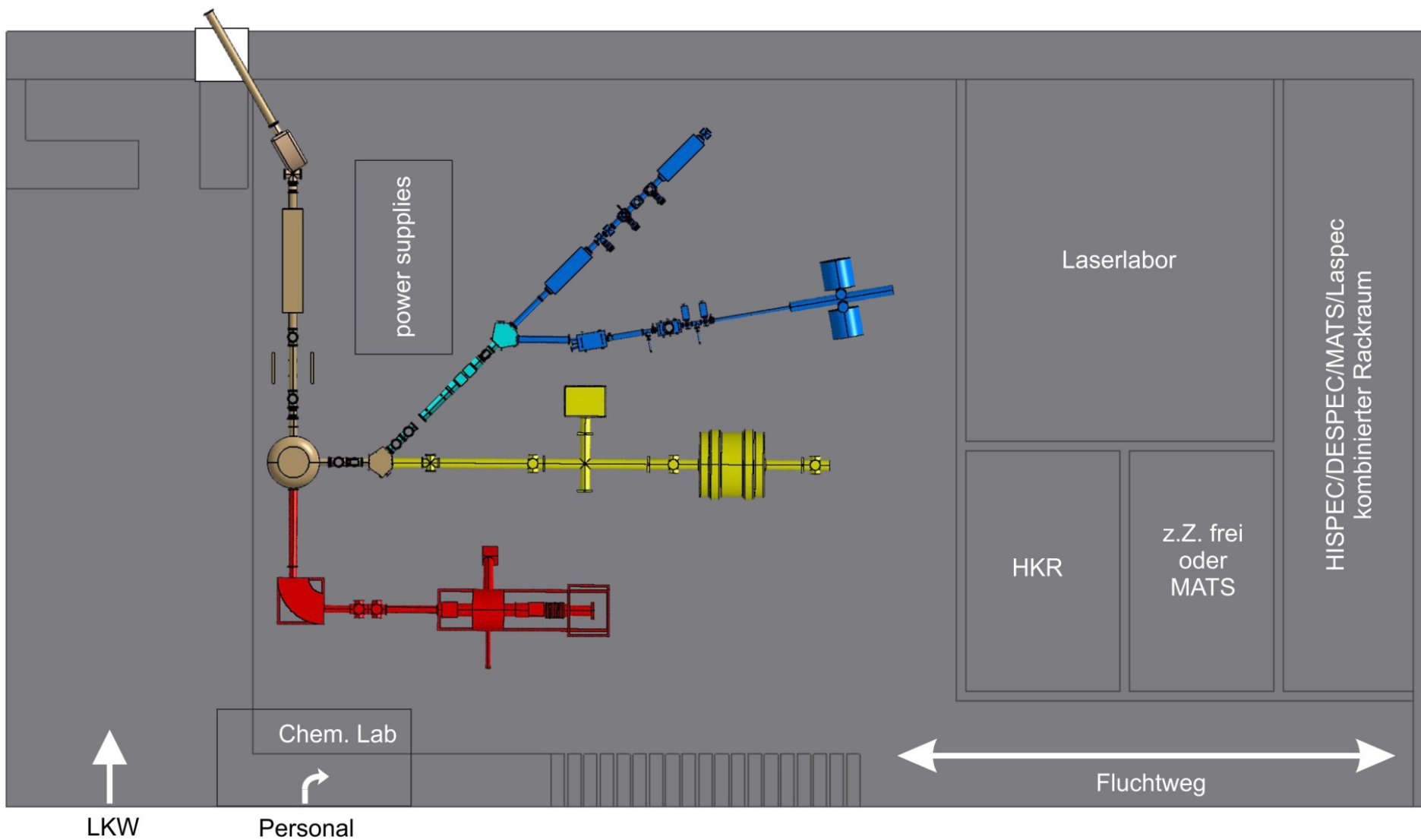
serving as a prototype for  
MATS

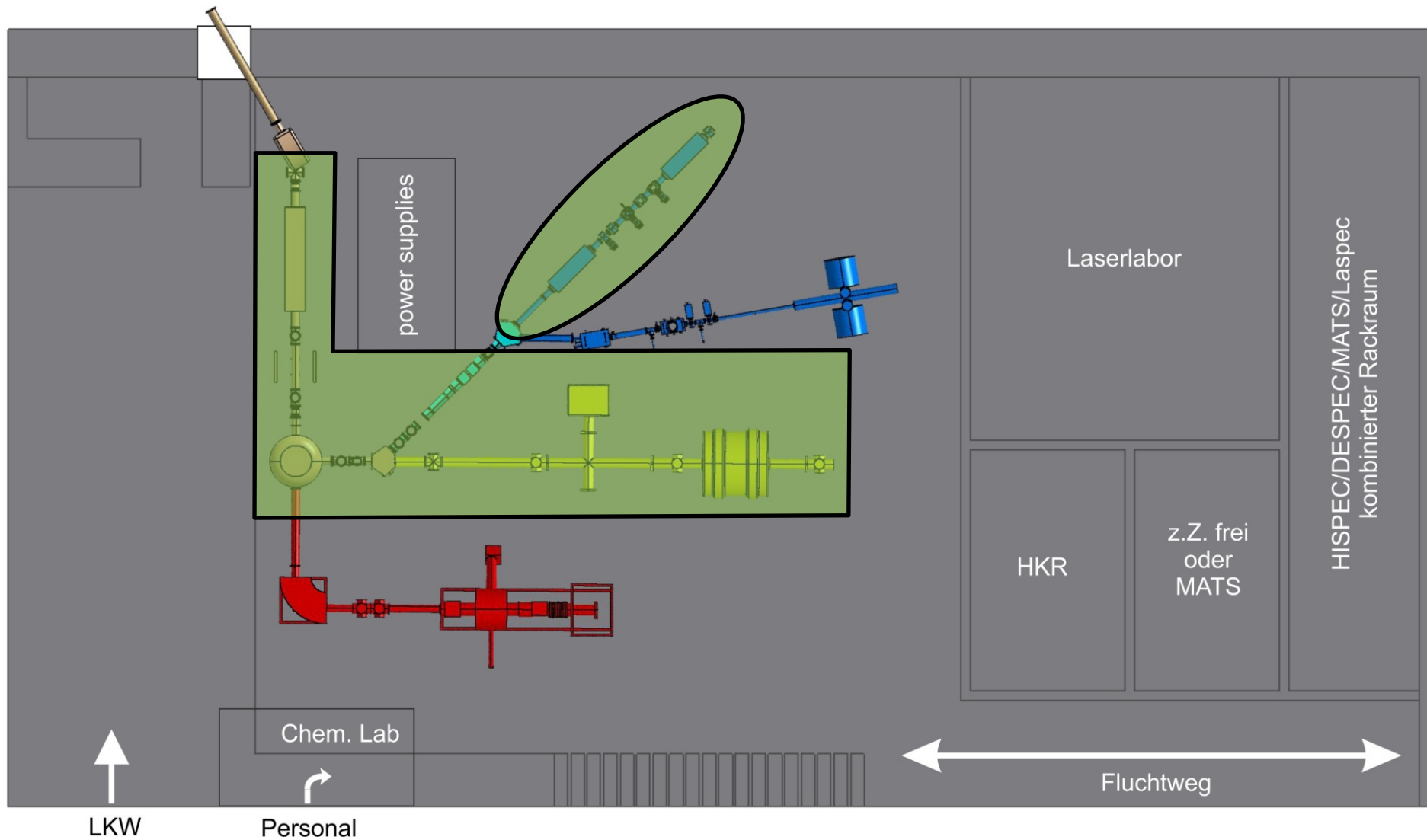




- ATLAS & CARIBU:  
Conditions comparable to LEB  
(Beams at 5 kV)
- Perfect place to test and optimize the new prototypes
  - Flagship experiment: charge radius of proton halo  $^8\text{B}$
  - CARIBU: many isotopes available from  $^{252}\text{Cf}$  fission
  - 2021/22: Return to FAIR

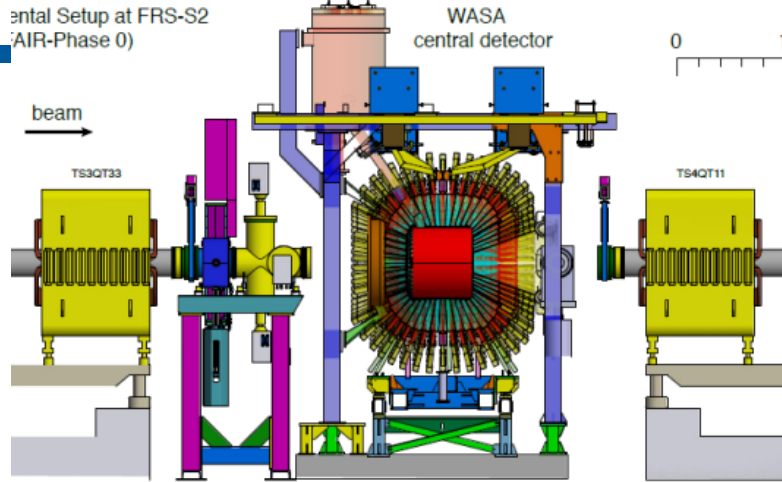








# WASA@FAIR (to be installed first at FRS-S2)

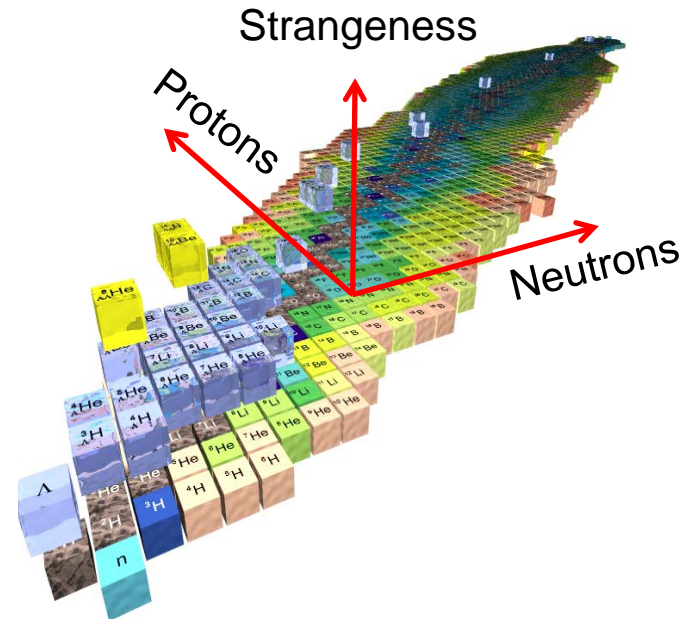
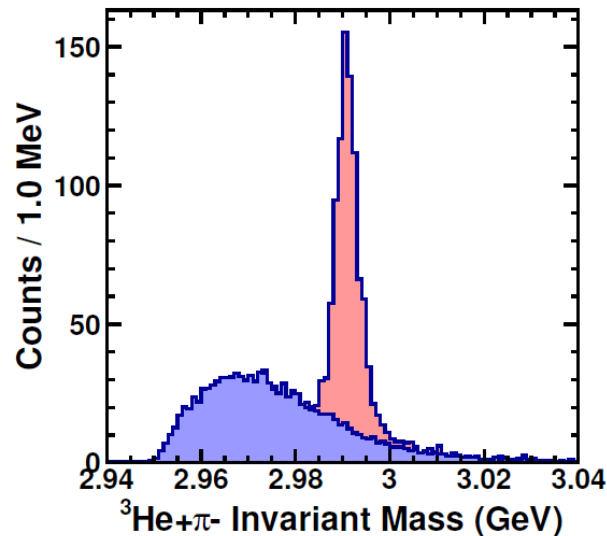
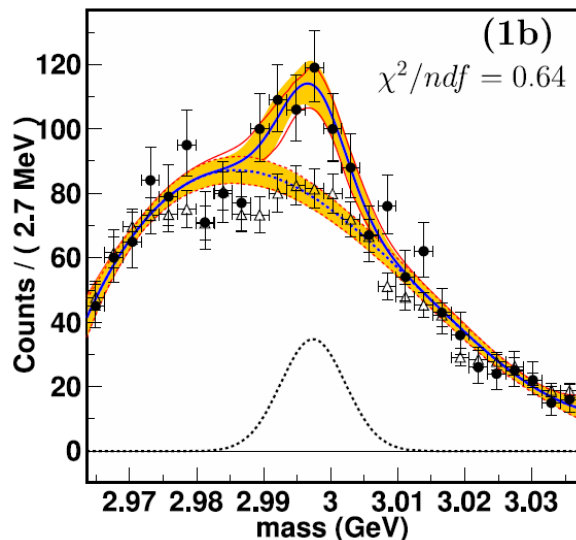


**Combination of WASA with FRS** provides unique setup for exclusive measurements:

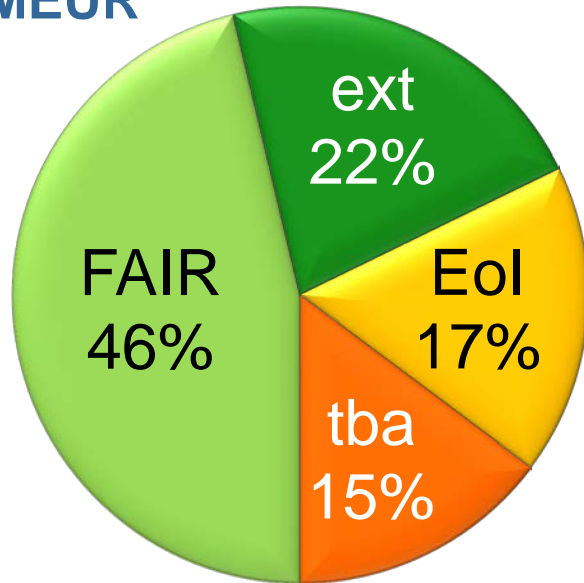
- FRS for high resolution spectroscopy of forward particles
- WASA for decay particles

## Hypernuclei:

Goals: Short lifetime of  ${}^3_{\Lambda}\text{H}$  and  ${}^4_{\Lambda}\text{H}$   
Solve puzzle of  $nn\Lambda$  state



45.6 MEUR



- secured/expected FAIR
- secured external
- EoI
- to be assigned

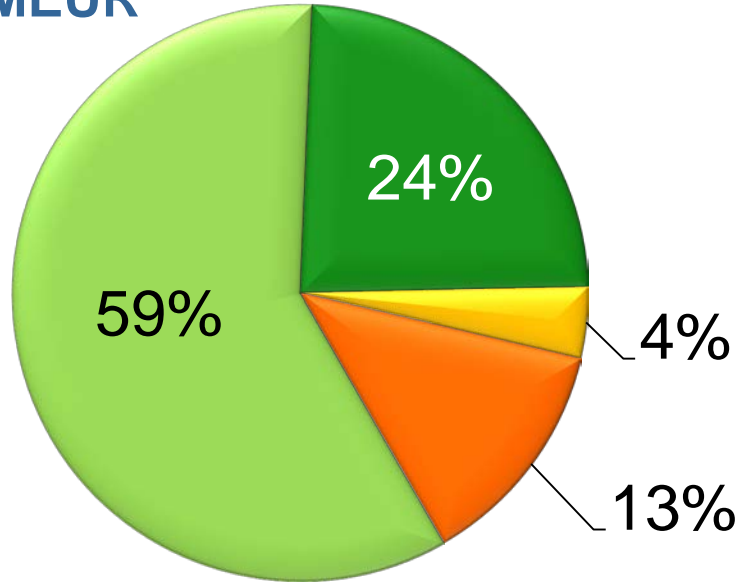
- funding (secured and expected) from:  
(**FAIR members/associates** in bold face)

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

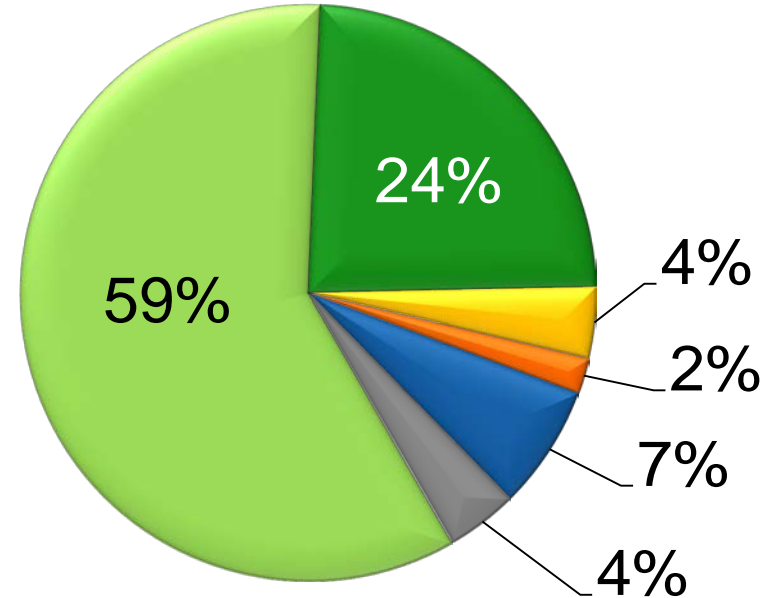
Status: November, 2017

# Day one configuration – funding status

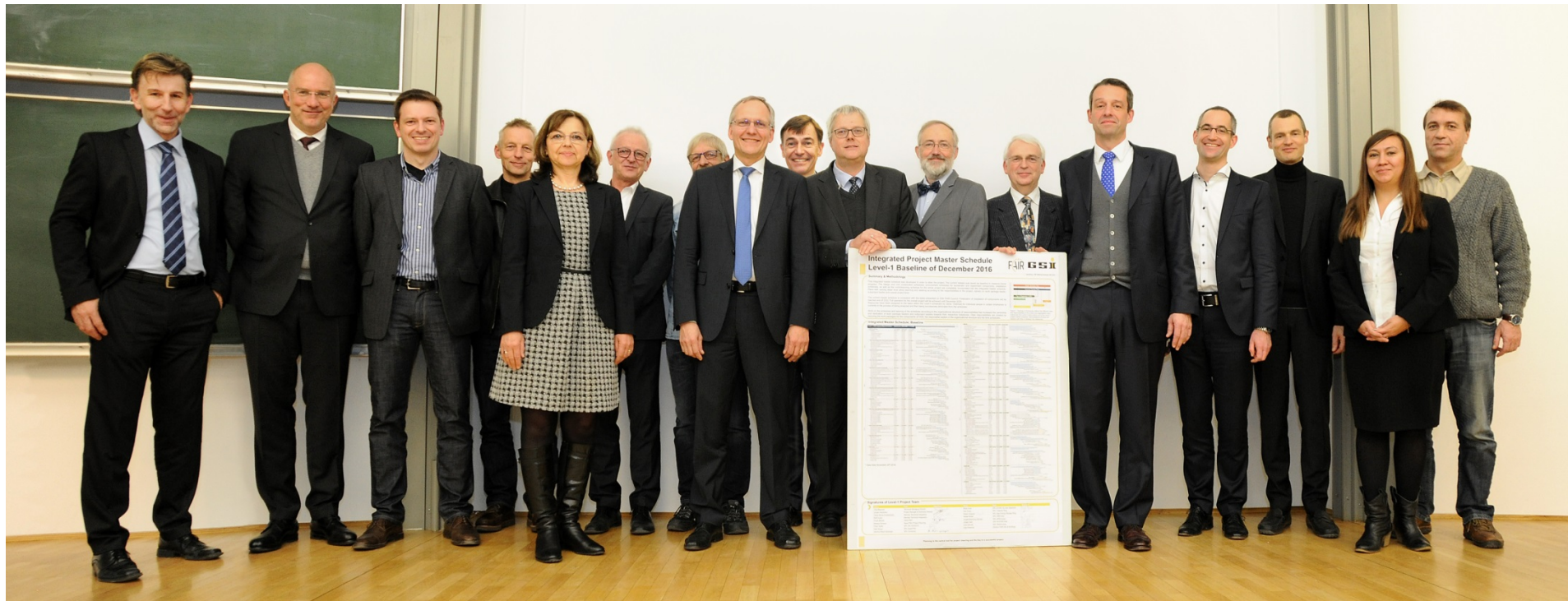
35.9 MEUR



- secured/expected FAIR
- secured external
- Eol
- to be assigned



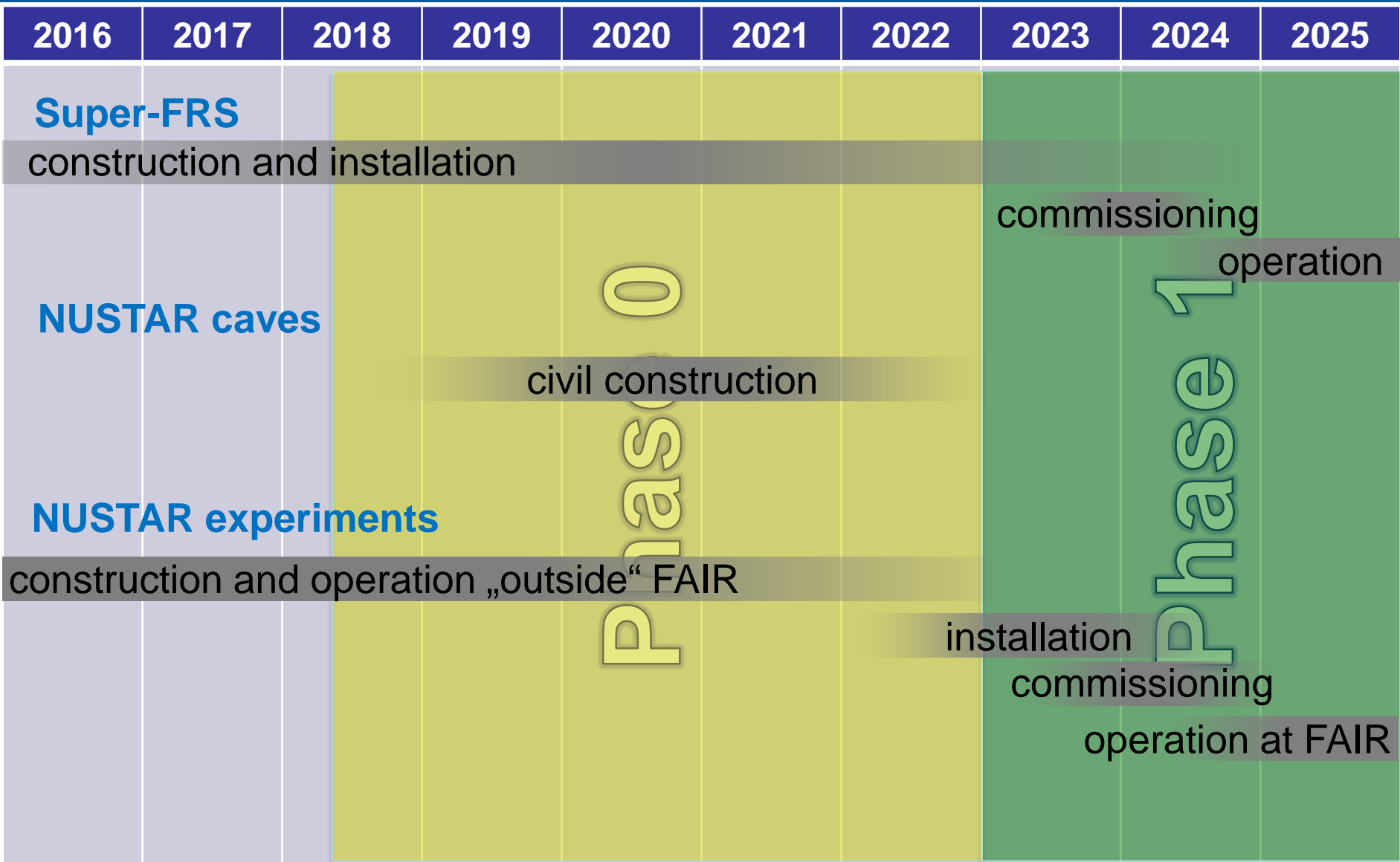
- secured/expected FAIR
- secured external
- Eol
- to be assigned
- Infrastructure Common Fund
- R3B multiplet



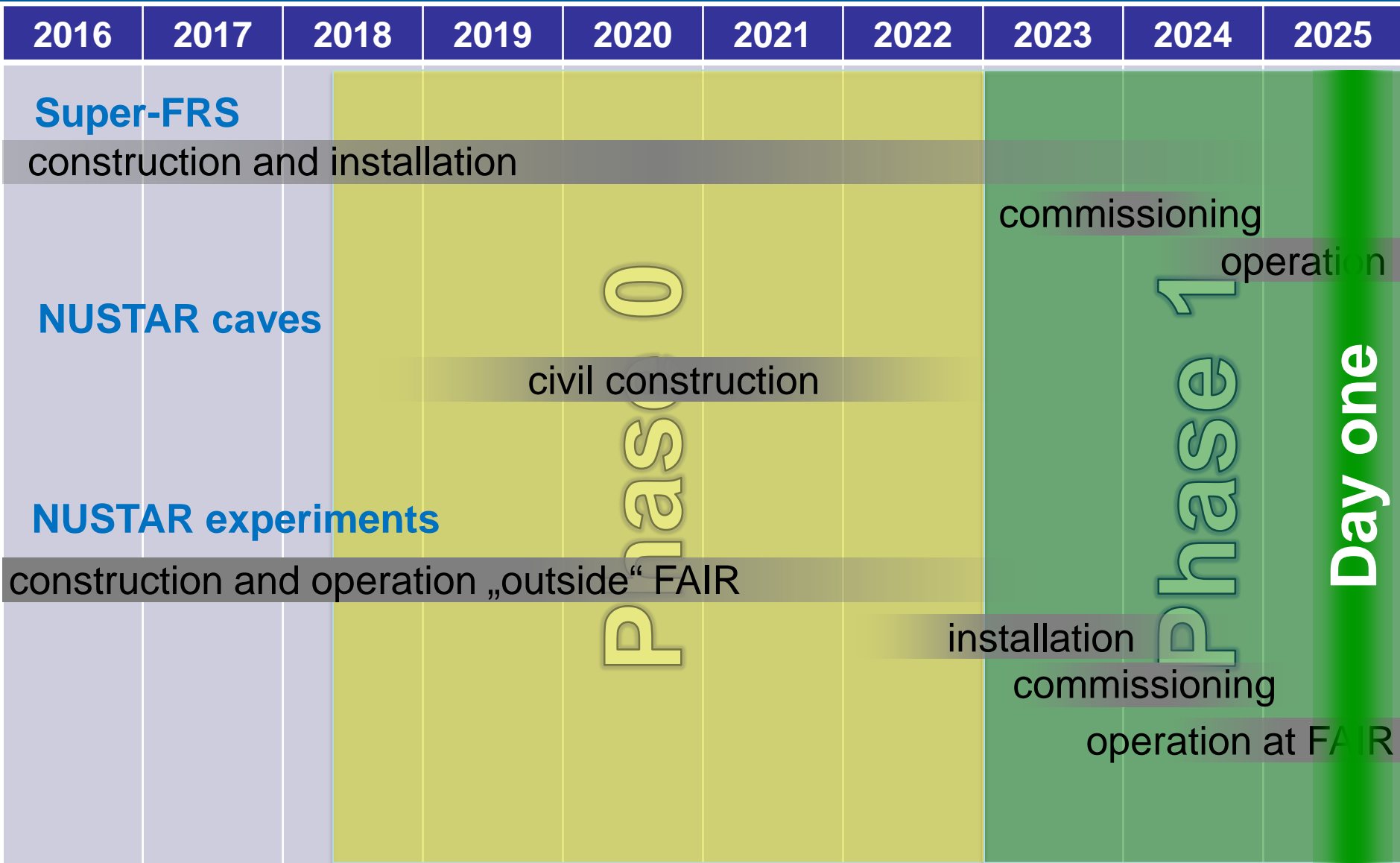
December 7, 2016

(Photo: G. Otto)

# Scenario for NUSTAR Phase 0 and 1



# Scenario for NUSTAR: Day one



# GSI – Accelerator operation in 2018



**DRAFT**



# GSI – Accelerator operation in 2018



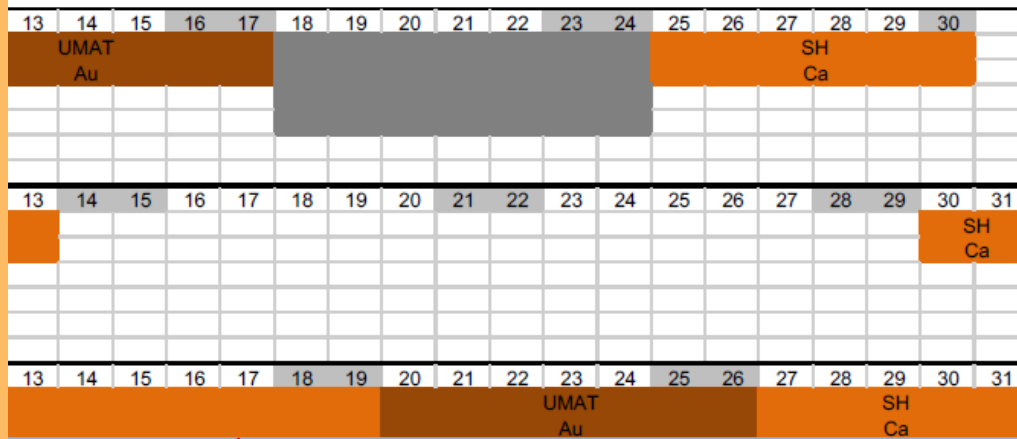
total

93 Proposals granted

UNILAC: 153 days

SIS18: 120 days

ESR/Cryring: 63 days



			main	parasitic
Sep	CRYRING			
	UNILAC	1 2	218	0
	UNILAC			
	SIS		94	81
	SIS			
Oct	ESR			
	CRYRING			
	UNILAC	1 2	58	22
	UNILAC	UBIO C	85	34
	SIS	SBIO, R3B/S	62	38
Nov	SIS	C		
	ESR			
	CRYRING			
	UNILAC	1 2	294	174
	UNILAC			
<b>Total Granted G-PAC Proposals (A)</b>			<b>811</b>	<b>349</b>
<b>TOTAL</b>			<b>846</b>	

2018 +2019



## NUSTAR Member Database

**Nustar Member Database**

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and  
GSI Helmholtzzentrum für  
Schwerionenforschung GmbH  
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Welcome to the NUSTAR Member Database



**Enter your name or email address for login or registration...**

**Confirm**

Stay tuned ... and get involved ...



Thanks a lot for your attention!