FAIR: Facility for Antiproton and Ion Research – A World-Wide Unique Accelerator Facility

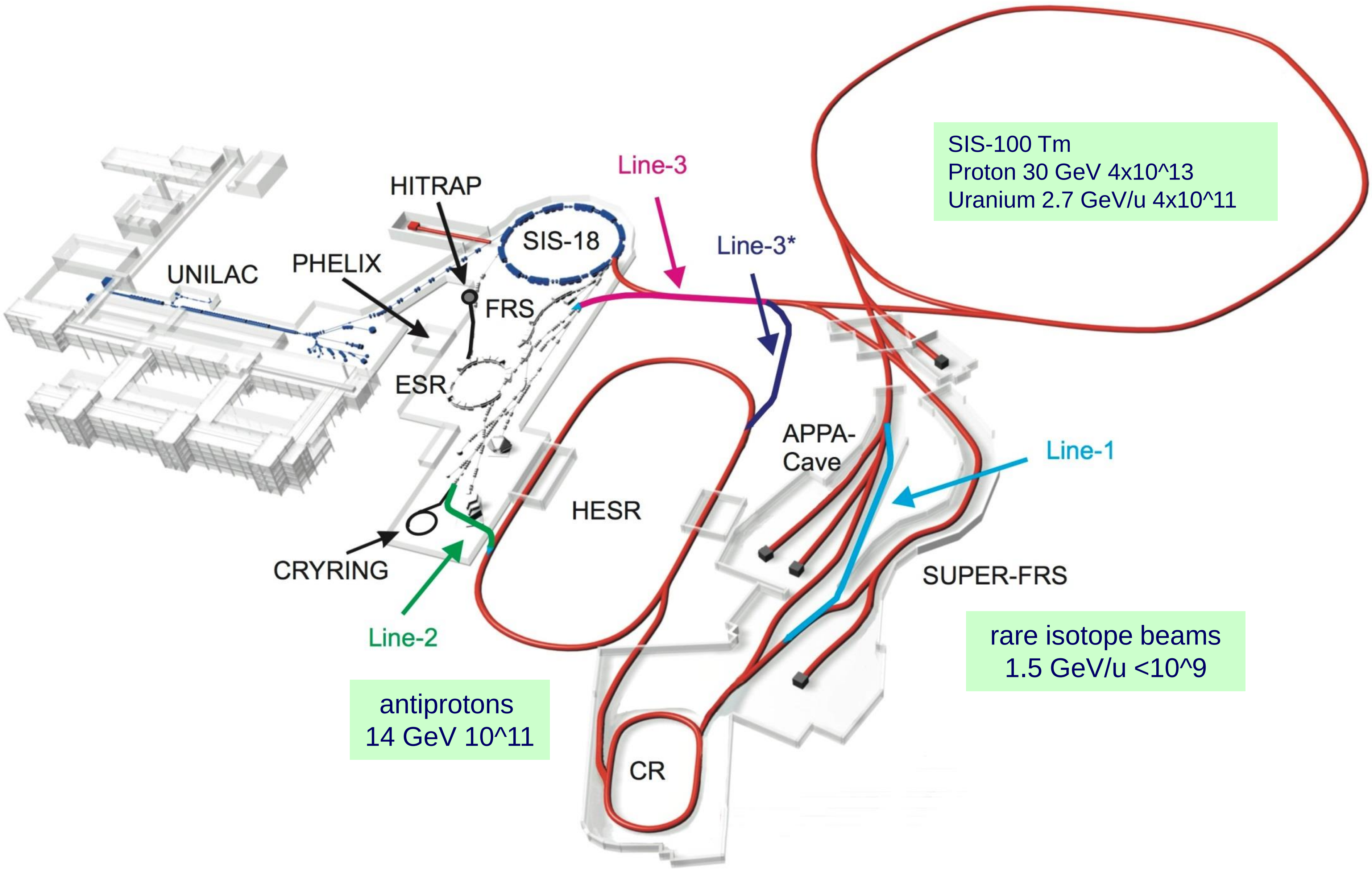
- ESFRI Landmark
- Top priority for European Nuclear Physics Community
- Driver for Innovation in Science and Technology

Brief history

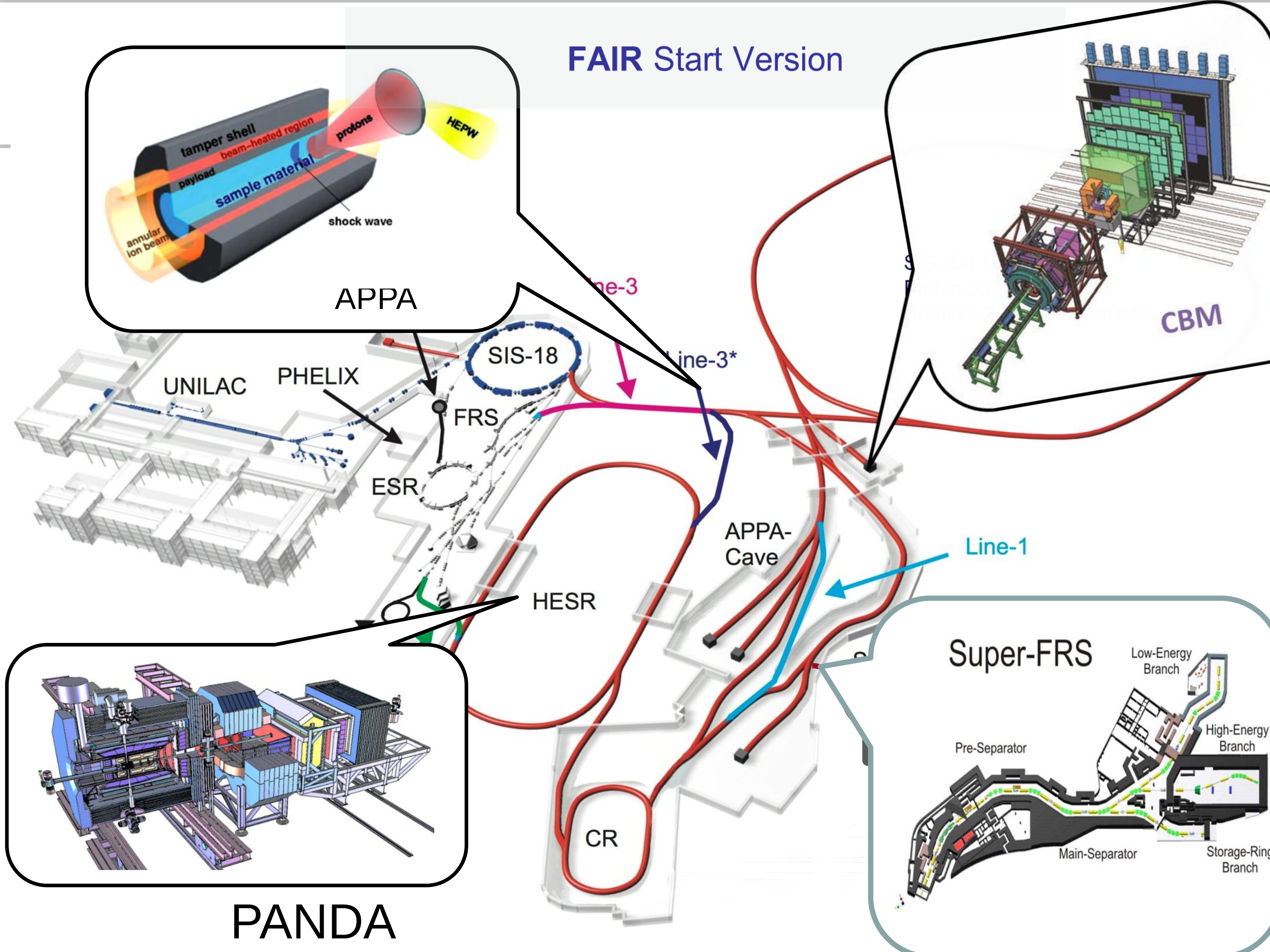
1999-2005 Conceptual and Technical Design of the FAIR Facility

2003	Principal approval by German Government
2007	Official Launch of the international FAIR Project
2010	Signing of intergovernmental agreement (FAIR Convention) Total cost of 1,027 M€ (2005 prices) Finland is a shareholder of FAIR through the FAIR-NORD consortium
2017	Phase-0 experimental program started successfully
2019	FAIR progress and cost review: Total cost increase by 850 M€
2025	Day-1 experiments expected to start

FAIR Start Version

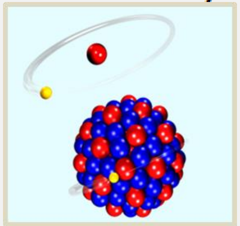


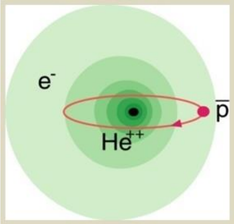
FAIR Start Version



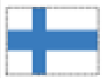
FAIR Research Pillars:

- a fore-front scientific program in many areas





APPA

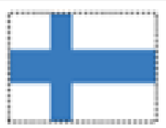


- Atomic Physics and Fundamental Symmetries,
- Plasma Physics,
- Materials Research,
- Radiation Biology,
- Cancer Therapy with Ion Beams / Space Research

CBM

- Dense and Hot Nuclear Matter

NUSTAR



- Nuclear Structure and Reaction Studies with nuclei far off stability,
- Physics of Explosive Nucleosynthesis (r-process)

PANDA

- Hadron Structure & Dynamics with cooled antiproton beams

Interdisciplinary Research Approach:
Neutron Star Mergers and FAIR science …

Neutron Star Mergers

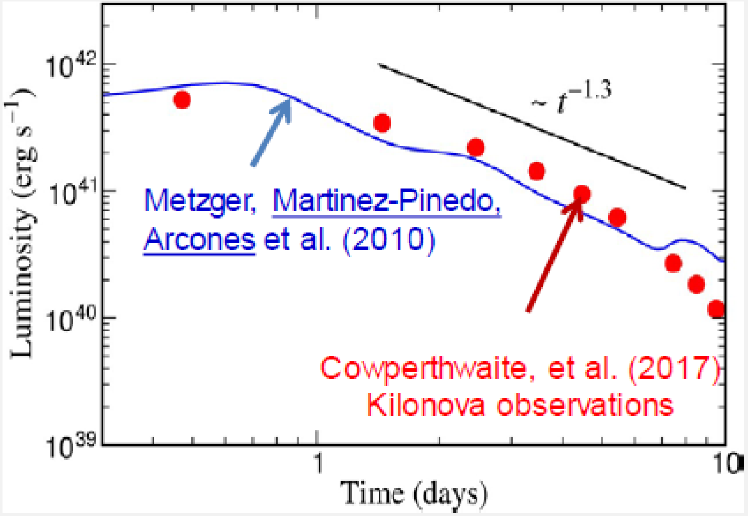
FAIR Research Pillars

- Equation of State (**Hades, CBM**)
  - Gravitational wave signal
  - Amount of ejecta
- Baryon-Baryon interaction (**PANDA**)
- Exotic neutron-rich nuclei (**NUSTAR**)
  - r-process nucleosynthesis and abundancies of the heaviest elements gold, platinum and beyond
- Plasma and atomic opacities (**APPA**)
  - Kilonova electromagnetic transient

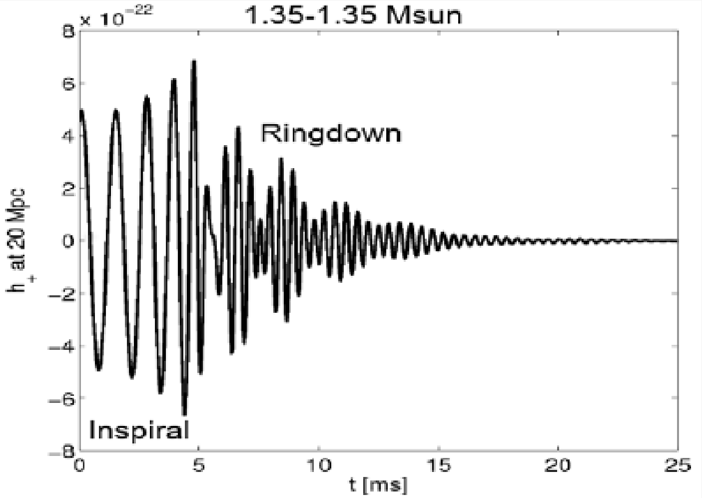
FAIR offers unique opportunities for studying these fundamental questions!

Further push of FAIR science motivation

... by multimessenger study of a neutron-star merger



Electromagnetic “Kilonova” Signal



Gravitational Wave Signal

Theoretical prediction by GSI researchers (2010):

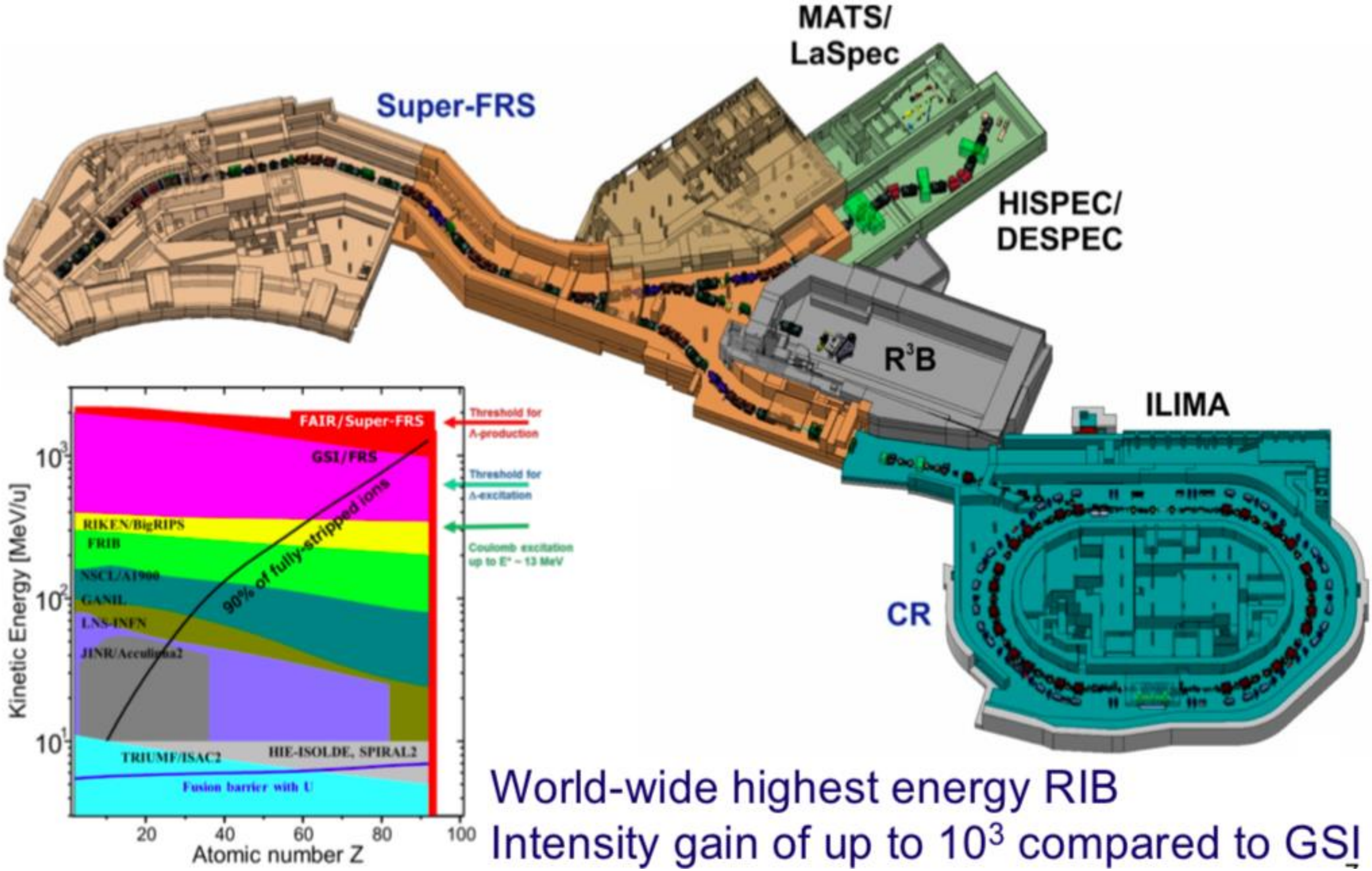
Neutron star mergers are the astrophysical site of the r-process producing the very heavy elements like Pt, Au and beyond,
thereby exhibiting a characteristic electromagnetic “Kilonova” signal.

Confirmation by Ligo, Virgo and other astronomer groups (2017)

via detection of both
gravitational and electromagnetic waves emerging from such an event.

FAIR was designed to study the properties neutron star matter and to trace back the production paths of the heavy elements!

Super-FRS for NUSTAR



World-wide highest energy RIB

Intensity gain of up to 10^3 compared to GSI

Super-FRS scheme

Super-FRS characteristics:

$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mrad

φ_x = +/- 40 mrad

φ_y = +/- 20 mrad

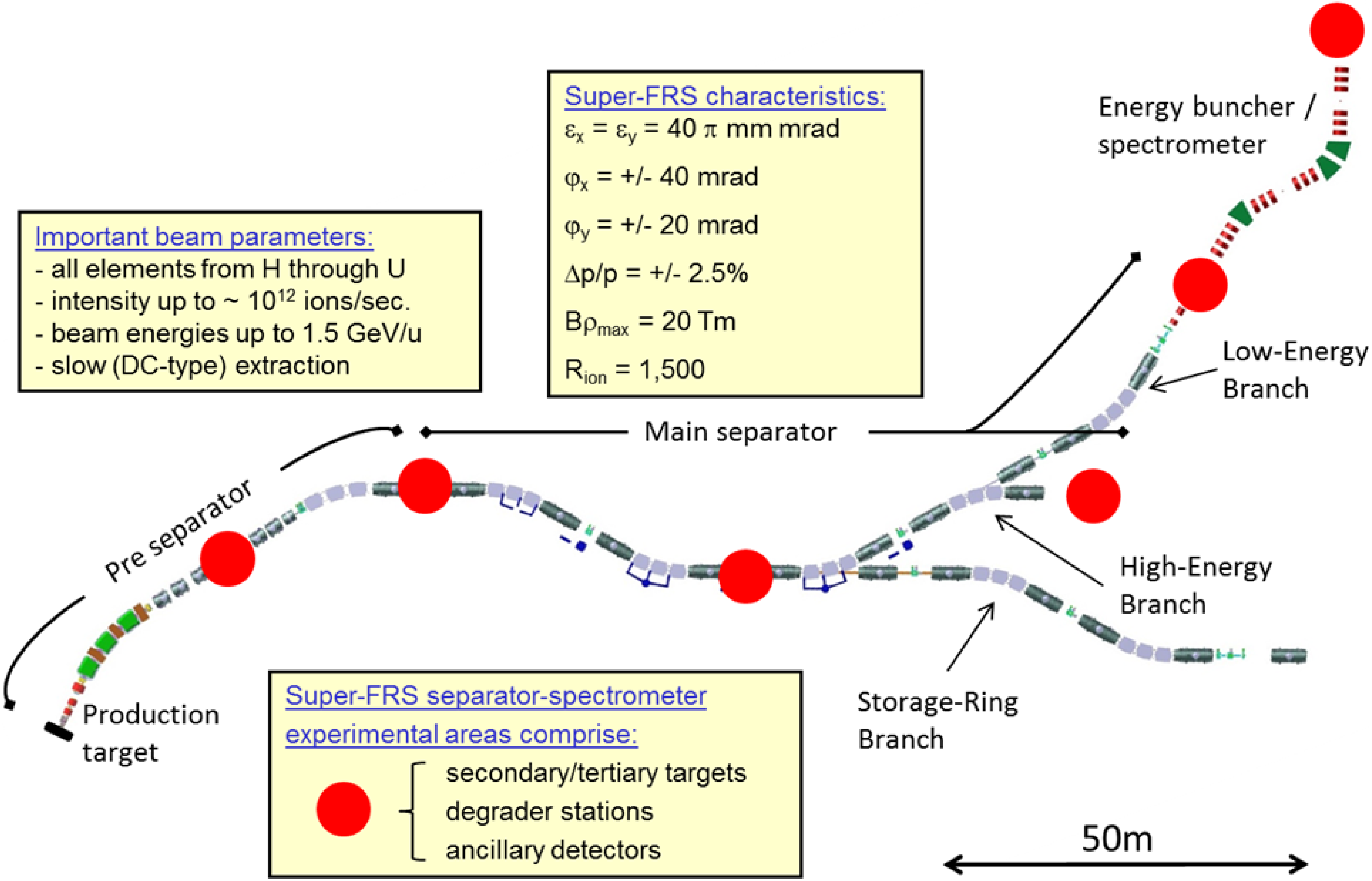
$\Delta p/p$ = +/- 2.5%

$B\rho_{max}$ = 20 Tm

R_{ion} = 1,500

Important beam parameters:

- all elements from H through U
- intensity up to ~ 10^{12} ions/sec.
- beam energies up to 1.5 GeV/u
- slow (DC-type) extraction



Super-FRS separator-spectrometer experimental areas comprise:

- secondary/tertiary targets
- degrader stations
- ancillary detectors

Finnish hardware contributions

- Initial investment of Finland 5 M€ in 2005 value
  - 1.5 M€ cash
  - 3.5 M€ in-kind (accelerator and experiments)

Accelerator Super-FRS	**2005 value**
GEM-TPC tracker system	560 000€
SEM-Grid beam position-profiler	560 000€
MUSIC particle id	142 000€
Detector ladders and drives	560 000€
Helium recycling unit	187 000€
Target container	712 000€

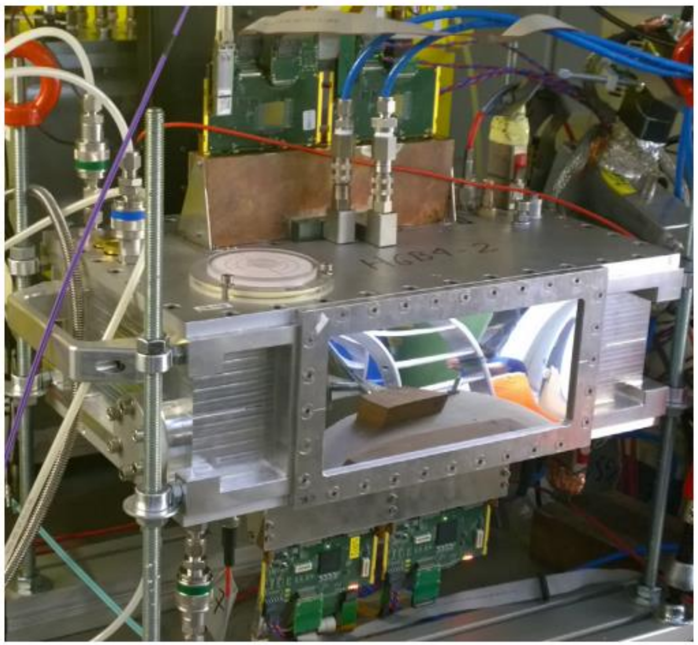
NUSTAR collaboration	**2005 value**
RILIS, Laser Spec	226 000€
MONSTER, Neutron array	120 000€
RFQ, ion cooler & buncher	215 000€
DEGAS Array for γ-rays	268 000€

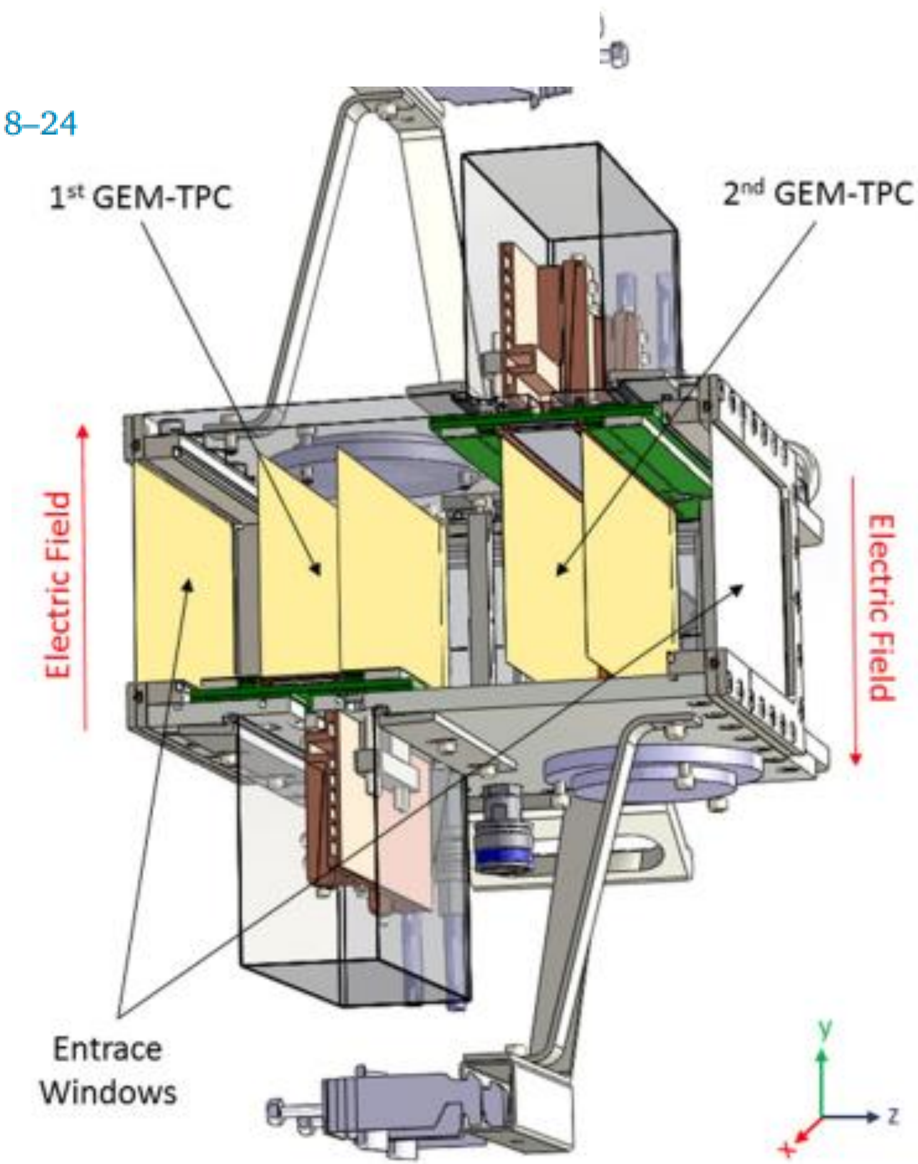
A GEM-TPC in twin configuration for the Super-FRS tracking of heavy ions at FAIR

F. García [a,*], T. Grahn [a,b], J. Hoffmann [c], A. Jokinen [a,b], C. Kaya [c], J. Kunkel [c], S. Rinta-Antila [a,b], H. Risch [c], I. Rusanov [c], C.J. Schmidt [c], H. Simon [c], C. Simons [c], R. Turpeinen [a], B. Voss [c], J. Äystö [a,b], M. Winkler [c]

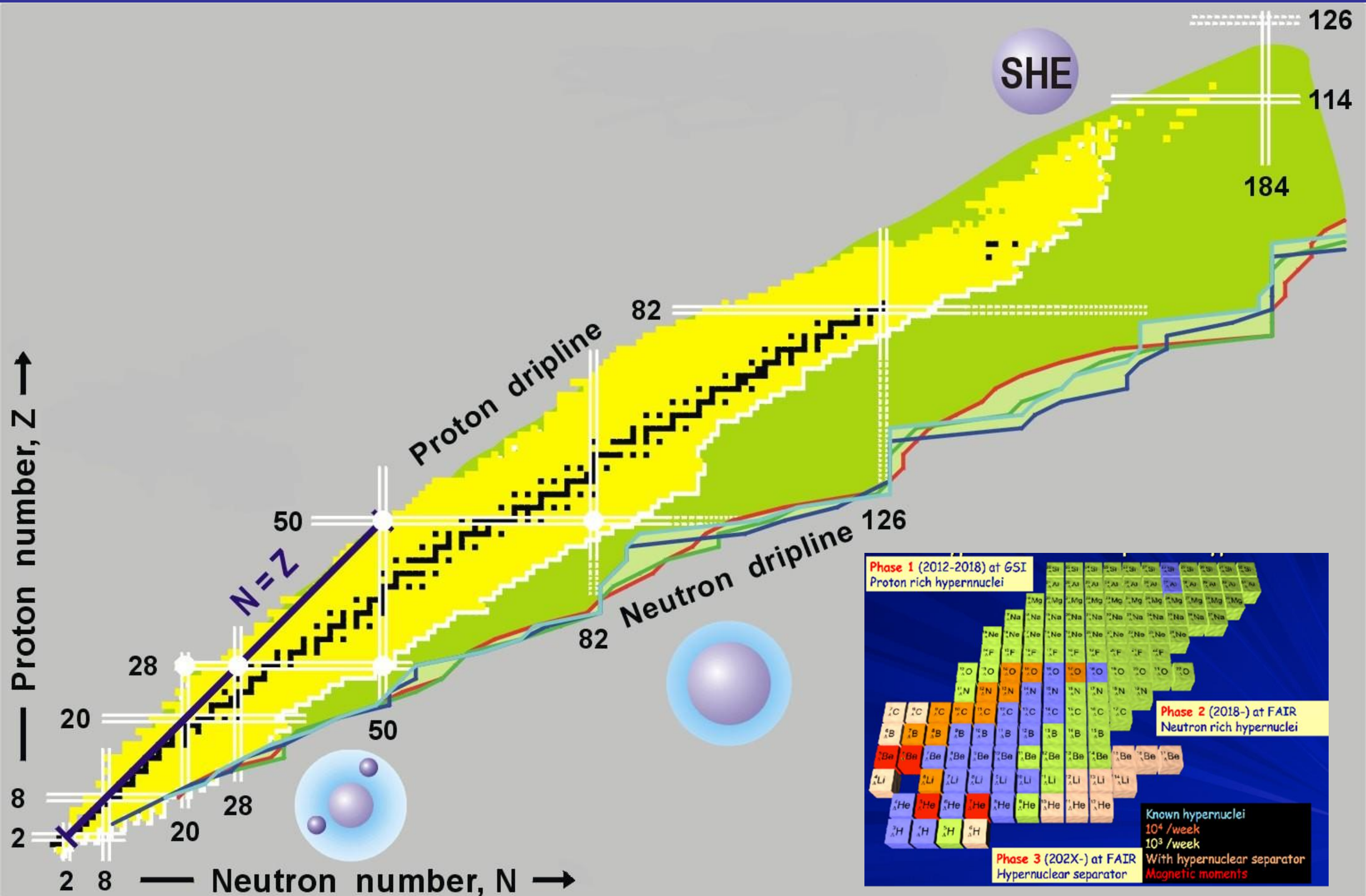
[a] *Helsinki Institute of Physics, University of Helsinki, 00014 University of Helsinki, Finland*
[b] *Department of Physics, University of Jyväskylä, 40014 University of Jyväskylä, Finland*
[c] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt 64291, Germany*

Nuclear Inst. and Methods in Physics Research, A 884 (2018) 18–24





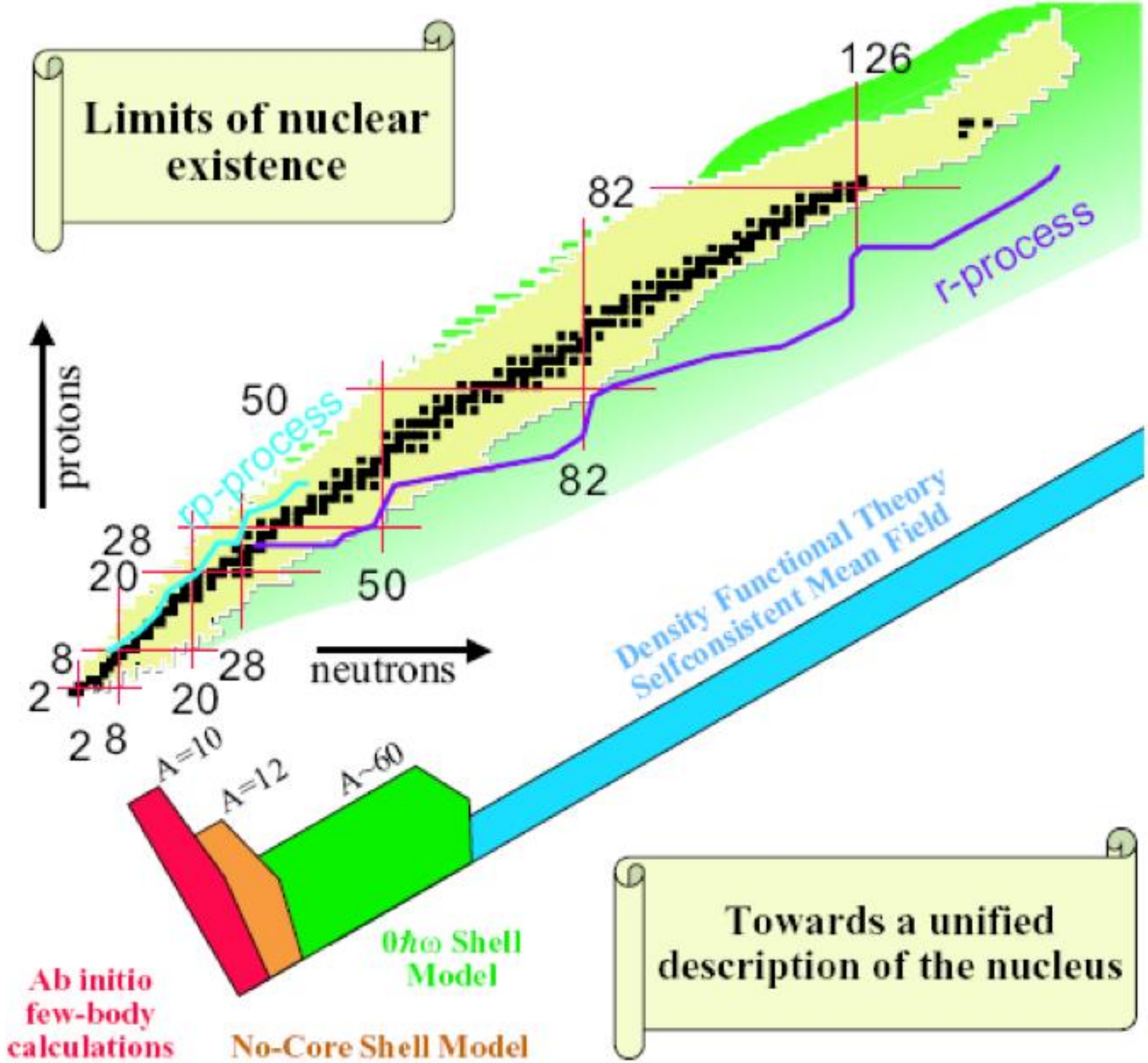
NUSTAR - Nuclear Structure, Astrophysics and Reactions



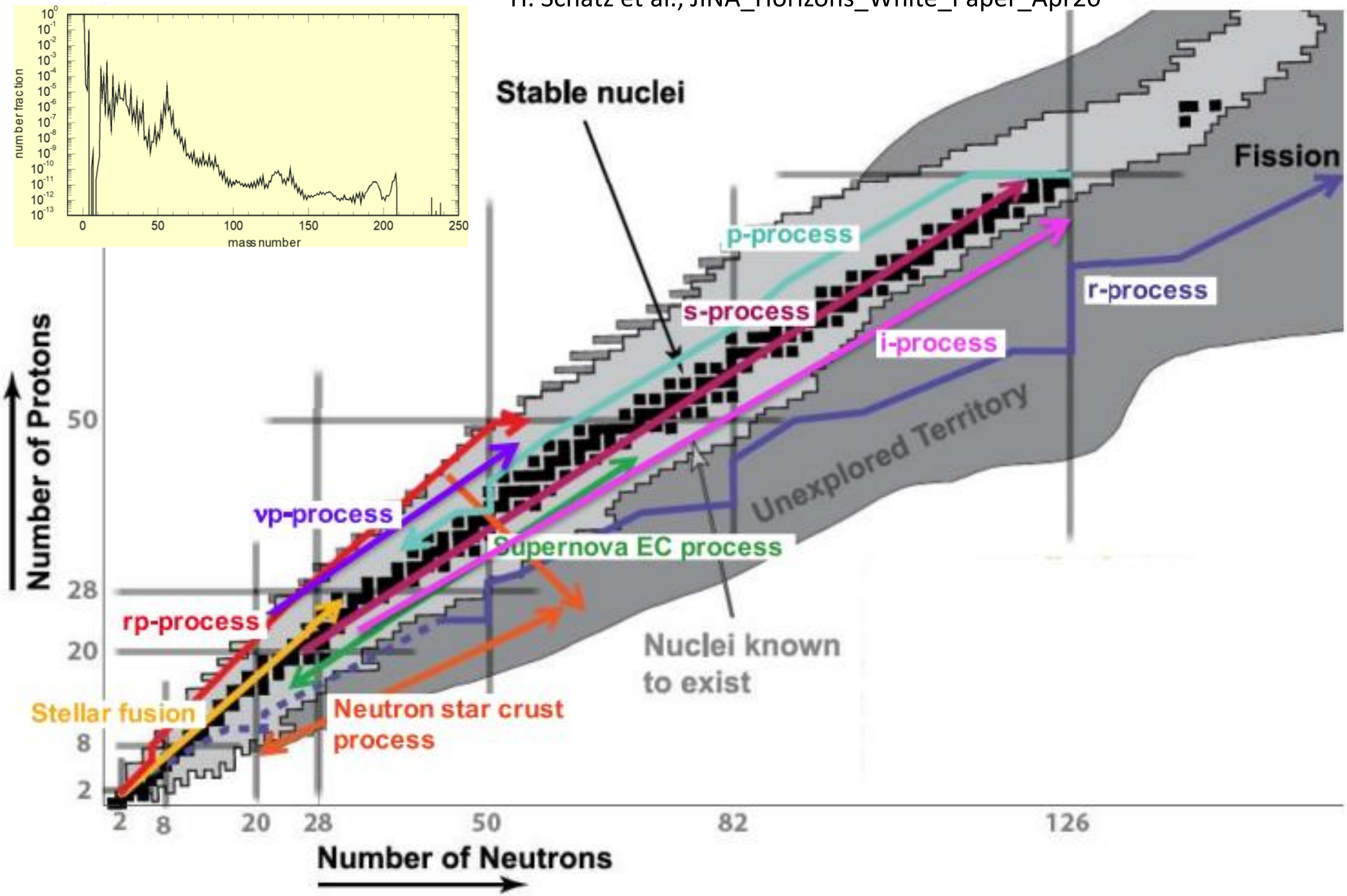
NUSTAR - Experiments

PSP code	**Super-FRS**	RIB production, separation, and identification of rare isotopes
1.2.2	**HISPEC/ DESPEC**	γ-ray spectroscopy at low and intermediate energy, n-decay, high-resolution γ-, β-, α-, p-, spectroscopy
1.2.3	**MATS**	Ion traps – masses and binding energies - precision physics
1.2.4	**LaSpec**	Evolution of nuclear shapes and radii
1.2.5	**R^3B**	Kinematical complete reactions with relativistic radioactive beams
1.2.6	**ILIMA**	Large-scale scans of masses and lifetimes of nuclei in ground and isomeric states
1.2.10	**Super-FRS**	High-resolution spectrometer and discovery experiments on rarest nuclei up to the neutron drip-line
1.2.11	**SHE**	Synthesis and study of super-heavy elements
1.2.8	**ELISe(*)**	Elastic, inelastic, and quasi-free e^--A scattering
1.2.9	**EXL(*)**	Light-ion scattering reactions in inverse kinematics

(*) NESR required – alternative/intermediate “operation” within FAIR MSV under consideration.


Limits of nuclear existence
126
82
50
rp-process
r-process
protons
28
20
8
2
2 8
20
28
50
82
neutrons
Density Functional Theory
Selfconsistent Mean Field
A=10
A=12
A~60
0ħω Shell Model
Ab initio few-body calculations
No-Core Shell Model
Towards a unified description of the nucleus

H. Schatz et al., JINA_Horizons_White_Paper_Apr20



Uniqueness of the NUSTAR Day-1 Program

- **Understanding the 3rd r-process peak** by means of comprehensive measurements of lifetimes, masses, neutron branching ratios, dipole strength, and the level structure along the **N=126 isotones**;
- **Equation of State (EoS) of asymmetric nuclear matter** by measuring the dipole polarizability and neutron-skin thicknesses of **heavy neutron-rich isotopes** (in combination with the results of the first highlight);
- **Exotics**: **Hypernuclei** with large N/Z asymmetry and **nucleon excitations** in nuclei

Each improvement (FRS → Super-FRS; SIS18 → SIS100) will brings us deeper into the unknown territory

Summary

- Finland is committed to FAIR via a Consortium between HU/HIP and Swedish Research Council (Shareholder)
- Main focus and highest priority for the Finnish FAIR activities is the timely delivery of the agreed in-kind instrumentation.
- FAIR Day-1 experiments will start in 2025. This is preceded by the on-going phase-0 science program.
- In nuclear physics FAIR is complementary to and extends significantly the profile of JYFL ACCLAB research.
- Science opportunities provided by the other three (APPA, PANDA, CBM) pillars of FAIR will provide additional opportunities for Finland.
- For the moment FAIR is in active construction state.

Thanks to all collaborators at GSI-FAIR, HIP and JYFL

&

!! Happy Anniversary HIP !!

Spares

JYFL – N.P. & accelerator driven research

- JYFL professors in experimental nuclear physics
- Ari Jokinen, HIP Nuclear Matter Program leader
- Paul Greenlees, Juha Uusitalo
- Iain Moore
- Anu Kankainen
- Tuomas Grahn, ass. Prof., HIP FAIR project leader

- JYFL professors in theoretical nuclear physics
- Jouni Suhonen
- Markus Kortelainen, ass. Prof.

- Timo Sajavaara, professor in accelerator-based material science

- Kari Peräjärvi, professor of practice in radiation physics (STUK)

FAIR Review 2019

chaired by Lyn Evans, CERN

I. Executive Summary

The FAIR Project is based on the scientific pillars APPA, CBM, NUSTAR and PANDA. Their programmes will enable unique and world leading discovery science. **The breadth and reach of these programmes will remain unsurpassed at the planned start of FAIR operation in 2025 and for many decades beyond.**

With foresight and adequate planning of resources, the different parts of the Project can be brought on sequentially, beginning to produce world-leading science before the end of 2025. However, it will be very challenging to finish the whole Project by the end of 2025 with the available resources, even if the additionally required funds will be available.

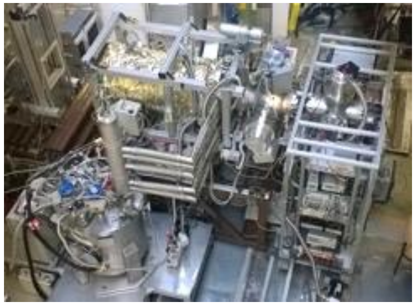
The Committee recommends the highest priority be given to completing all civil construction and installing the Super-FRS first, using the SIS18 – Super-FRS beam line for commissioning and early operation. All other accelerator components are then to be commissioned subsequently following availability and installation.

(Super-)FRS experiments

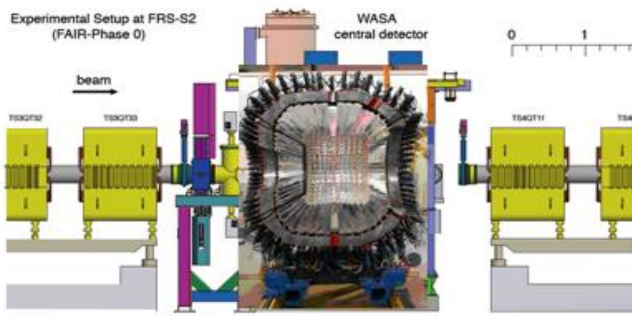
High-resolution spectrometer experiments at the border line of nuclear, atomic and hadron physics

(Super-)FRS as multiple-stage magnetic system (separator, analyser, spectrometer, energy buncher) combined with ancillary detectors, e.g. with:

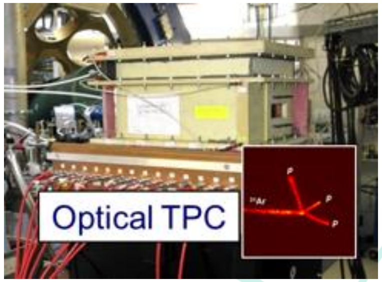
FRS Ion Catcher

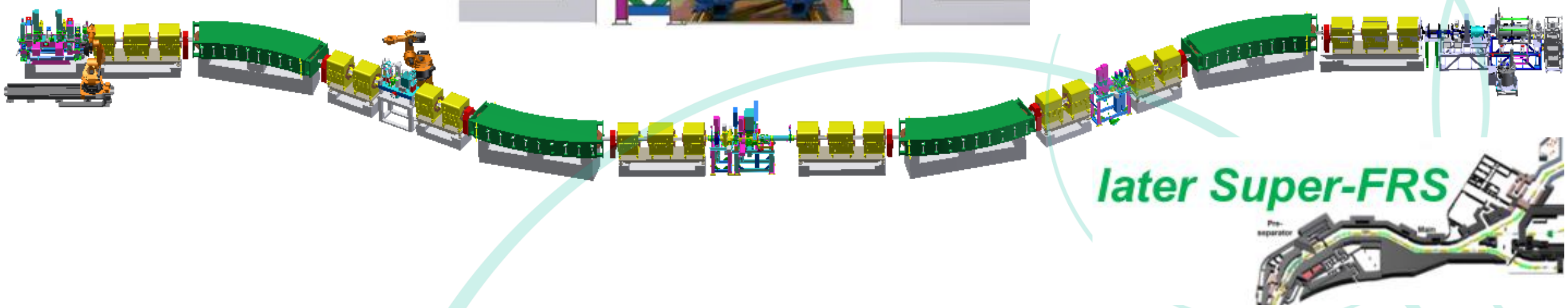


WASA



EXPERT

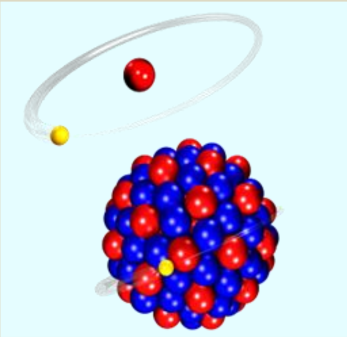


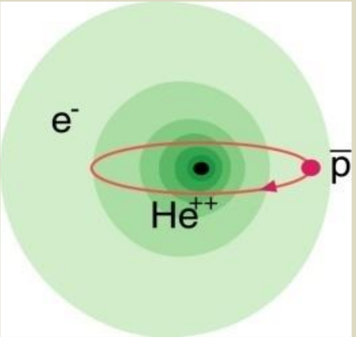


APPA: Atomic Physics, Plasma Physics, and Applied Sciences

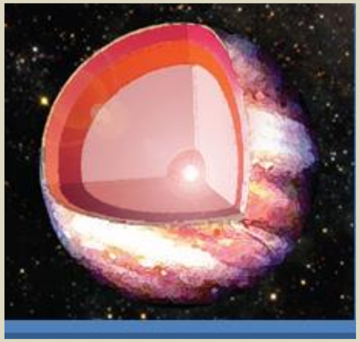
FACILITY CAPABILITY	SCIENTIFIC CAPABILITY
Highest Charge States	*Extreme Static Fields*
Relativistic Energies	*Extreme Dynamical Fields and Ultrashort Pulses*
High Intensities	*Very High Energy Densities and Pressures*
High Charge at Low Velocity	*Large Energy Deposition*
Low-Energy Anti-Protons	*Antimatter Research*

Atomic Physics





Plasma

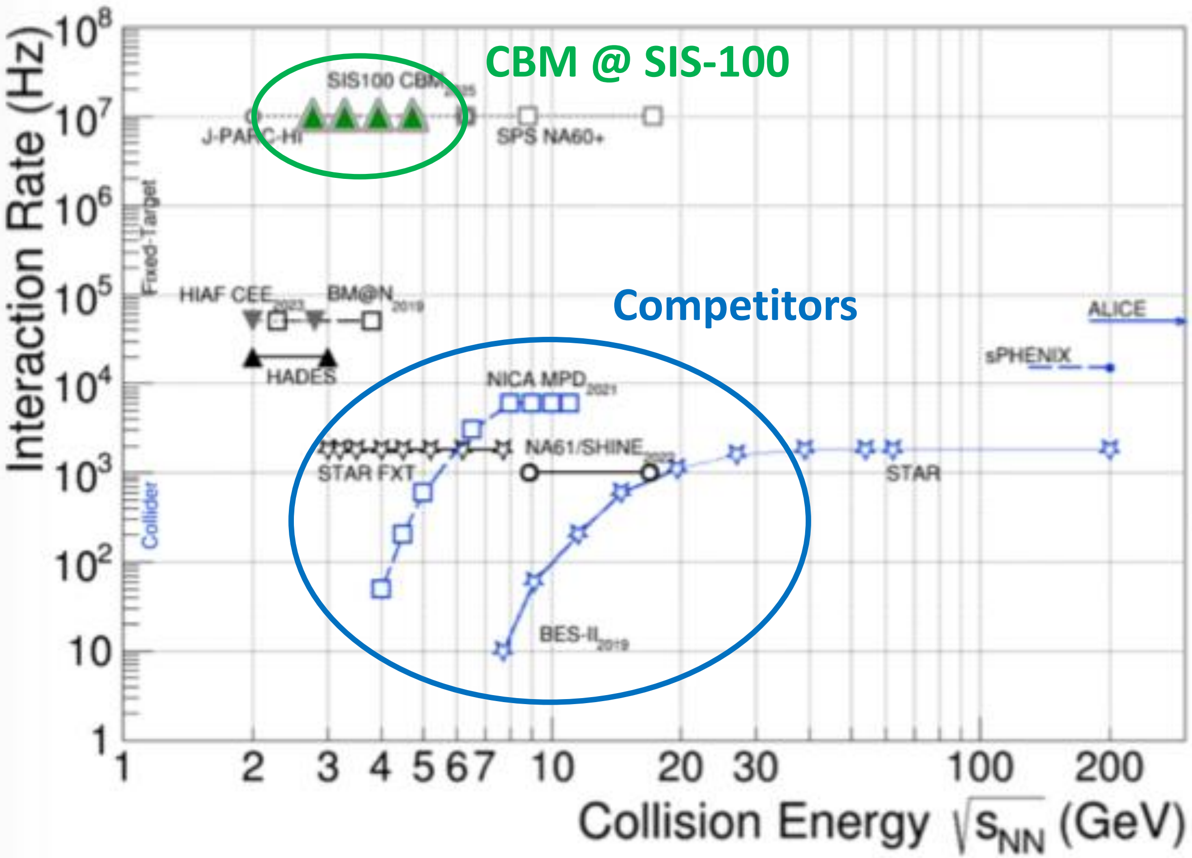


Materials

Bio

SPARC	FLAIR	HED	MAT/BIOMAT	BIO/BIOMAT
strong field research ... probing of fundamental laws of physics	**antimatter** ... matter / anti-matter asymmetry	**warm dense matter** ... states of matter common in astrophysical objects	**radiation hardness** ... mechanical and electrical degradation of materials	**space travel** ... cosmic radiation risk and shielding

CBM in Comparison



CBM's unique feature:
High statistics measurement of rare probes

The CBM physics program:

- QCD equation of state
- QCD phase transition
- Critical point signatures
- Chiral symmetry restoration at high μ_B
- Strange nuclear matter
- Charm in cold and dense nuclear matter

HESR and PANDA

High Energy Storage Ring (HESR) providing cooled 14 GeV antiproton beams is critical to physics potential of PANDA. Energy resolution of ~50 keV permits resonance scans for precise determination of masses and widths of hadron states.

Unique features: Access to hadron states with exotic quantum numbers and high spins, large production cross sections, lower backgrounds than fixed target searches.

JÜLICH Forschungszentrum