

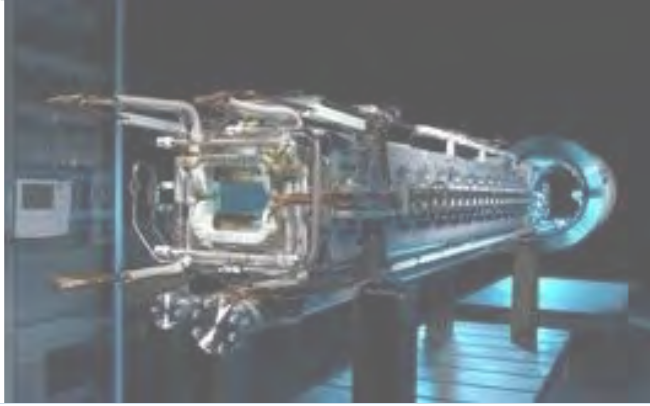

FAIR - Facility or Antiproton and Ion Research

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*For the Finnish FAIR Collaboration

HIP project leader: Tuomas Grahn

Slides in this talk are derived from from presentations given by colleagues at FAIR meetings

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

FAIR

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

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!

FAIR Review 2019

Extract from the report:

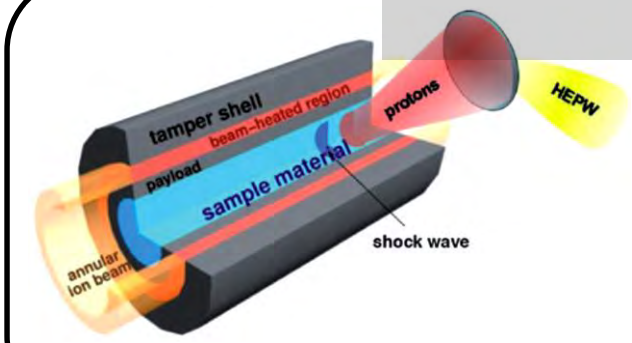
I. Executive Summary

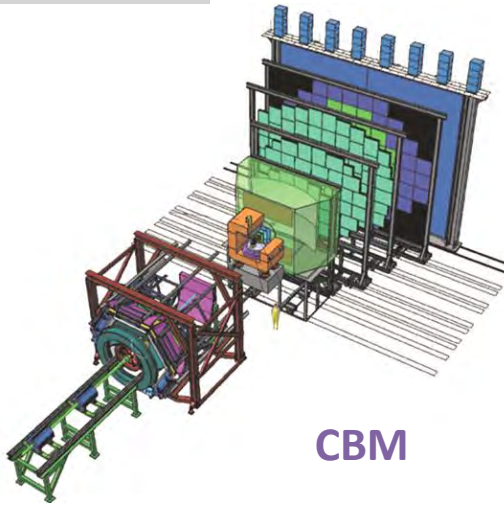
The FAIR Project is based on the scientific pillars APPA, CBM, NUSTAR and PANDA. Their programmes will enable unique and world leading discovery science. **The breadth and reach of these programmes will remain unsurpassed at the planned start of FAIR operation in 2025 and for many decades beyond.**

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.

FAIR Start Version





APPA

UNILAC

PHELIX

SIS-18

FRS

ESR

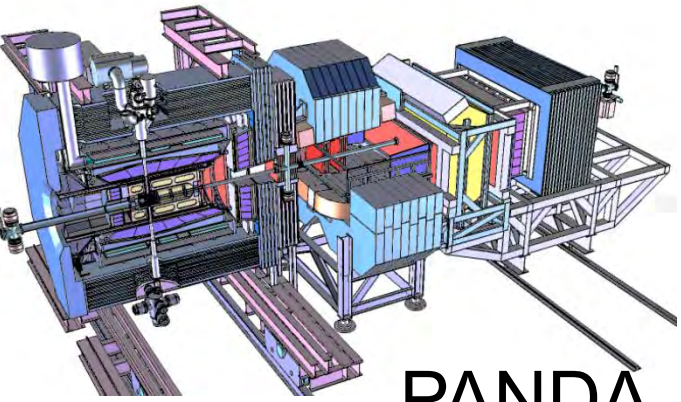
HESR

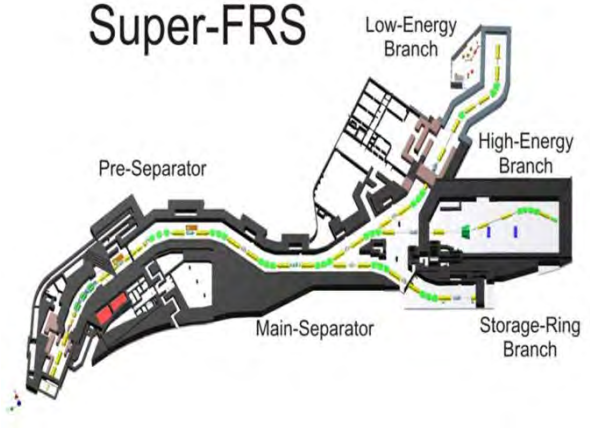
CR

APPA-
Cave

Line-3*

Line-1

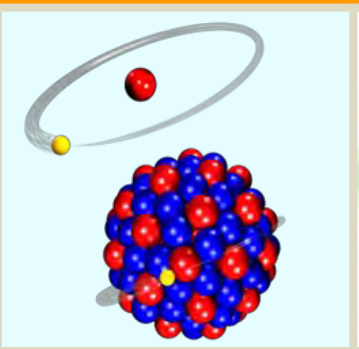


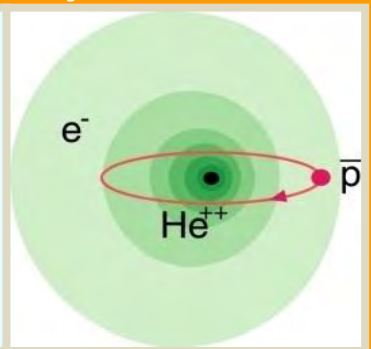


APPA: Atomic Physics, Plasma Physics, and Applied Sciences

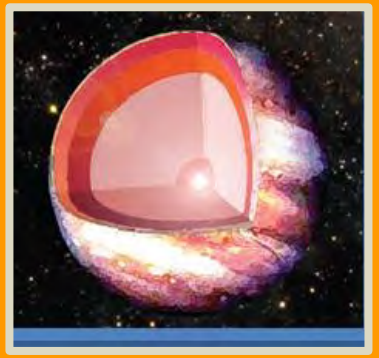
FACILITY CAPABILITY	SCIENTIFIC CAPABILITY
Highest Charge States	*Extreme Static Fields*
Relativistic Energies	*Extreme Dynamical Fields and Ultrashort Pulses*
High Intensities	*Very High Energy Densities and Pressures*
High Charge at Low Velocity	*Large Energy Deposition*
Low-Energy Anti-Protons	*Antimatter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

Neutron stars

Temperature
$T < 10$ MeV

Density
$\rho < 10\ \rho_0$

Lifetime
$T \sim$ infinity

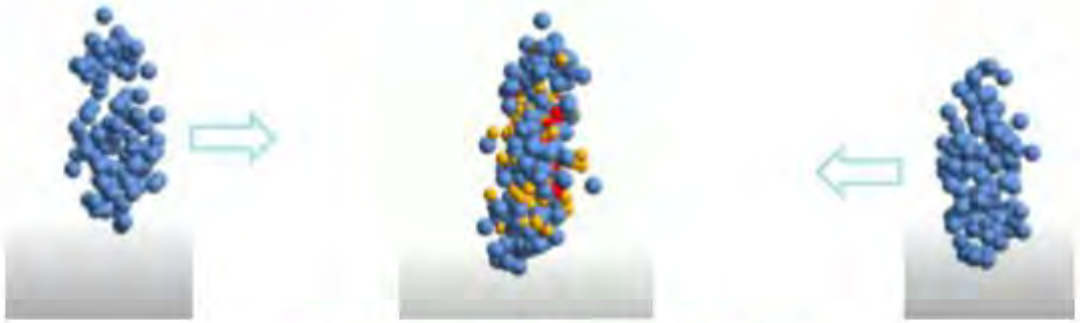
Neutron star merger

Temperature
$T < 50$ MeV

Density
$\rho < 2 - 6\ \rho_0$

Reaction time
(GW170817)
$T \sim 10$ ms

Heavy ion collisions at SIS100



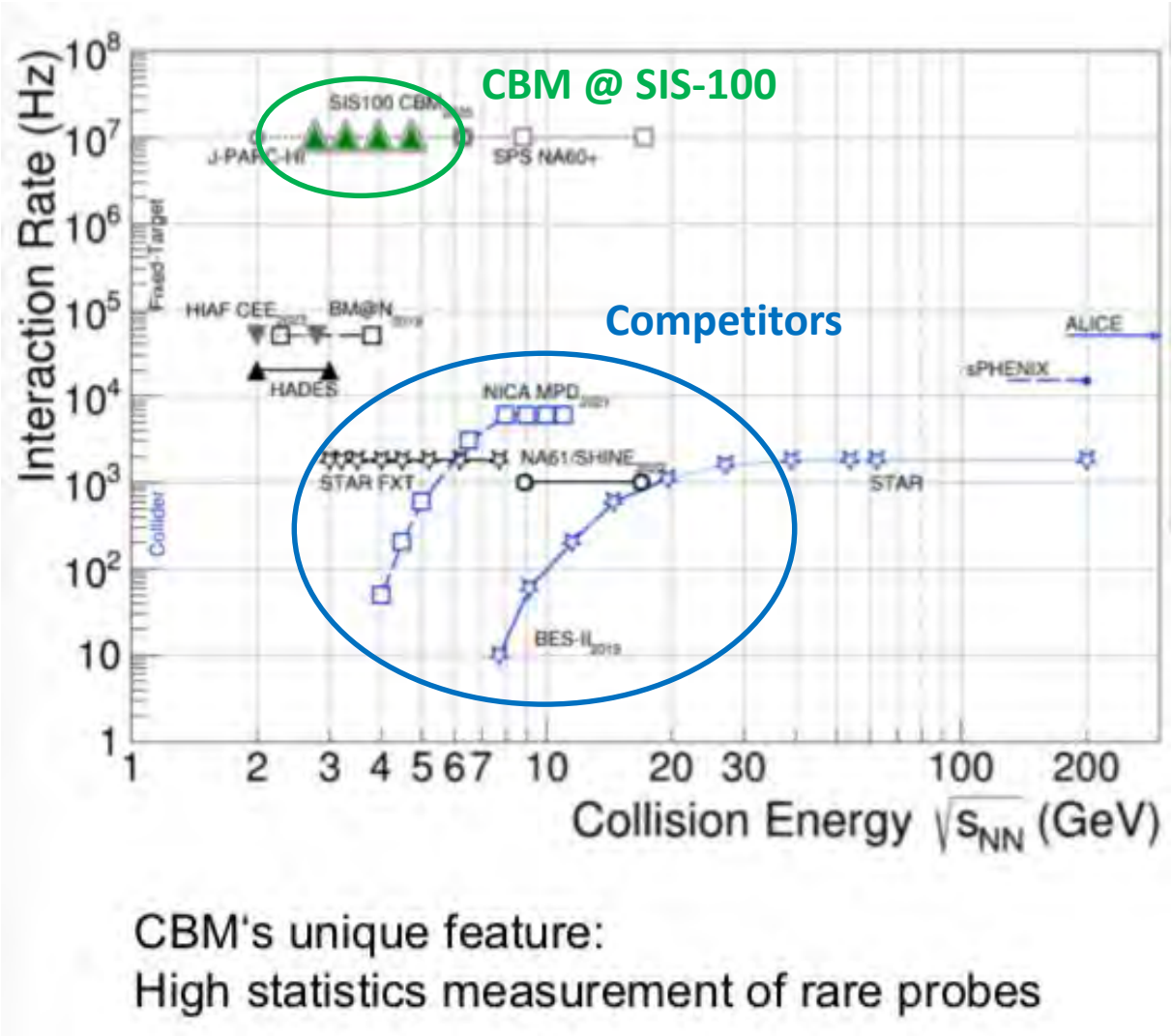
Compressed Baryonic Matter

Temperature
$T < 120$ MeV

Density
$\rho < 8\rho_0$

Reaction time
$t \sim 10^{-23}$ s

CBM in Comparison



The CBM physics program:

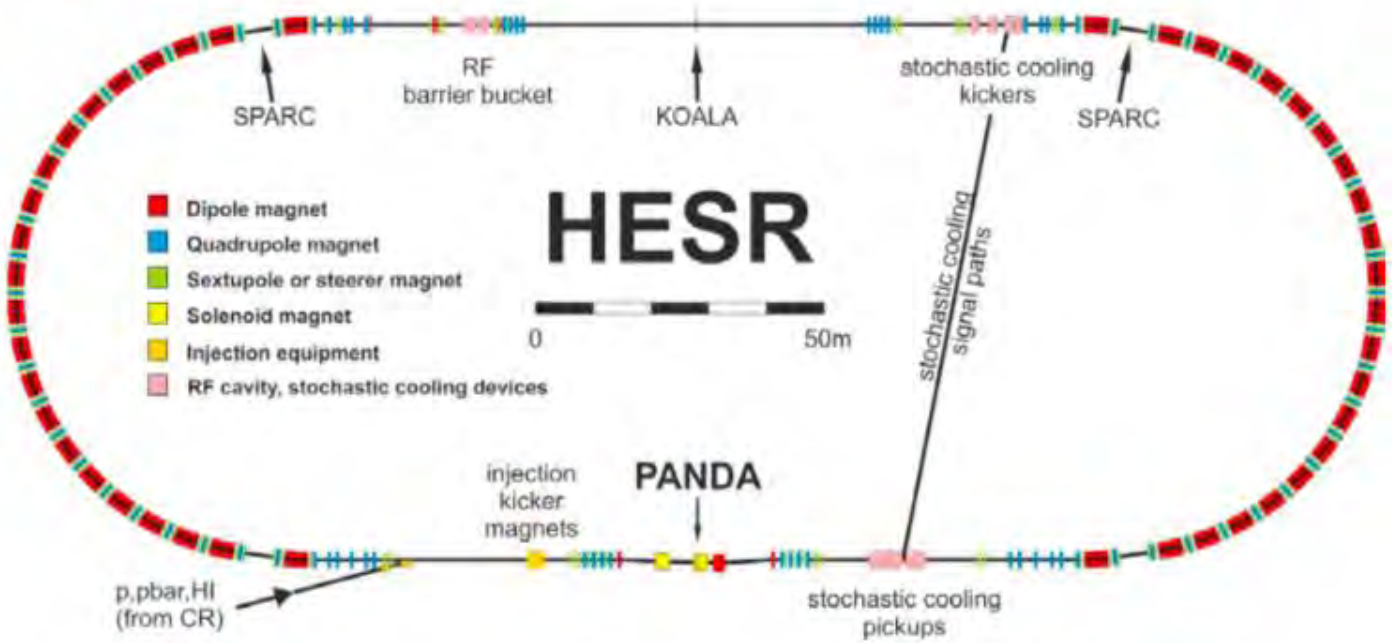
- QCD equation of state
- QCD phase transition
- Critical point signatures
- Chiral symmetry restoration at high μ_B
- Strange nuclear matter
- Charm in cold and dense nuclear matter

HESR and PANDA

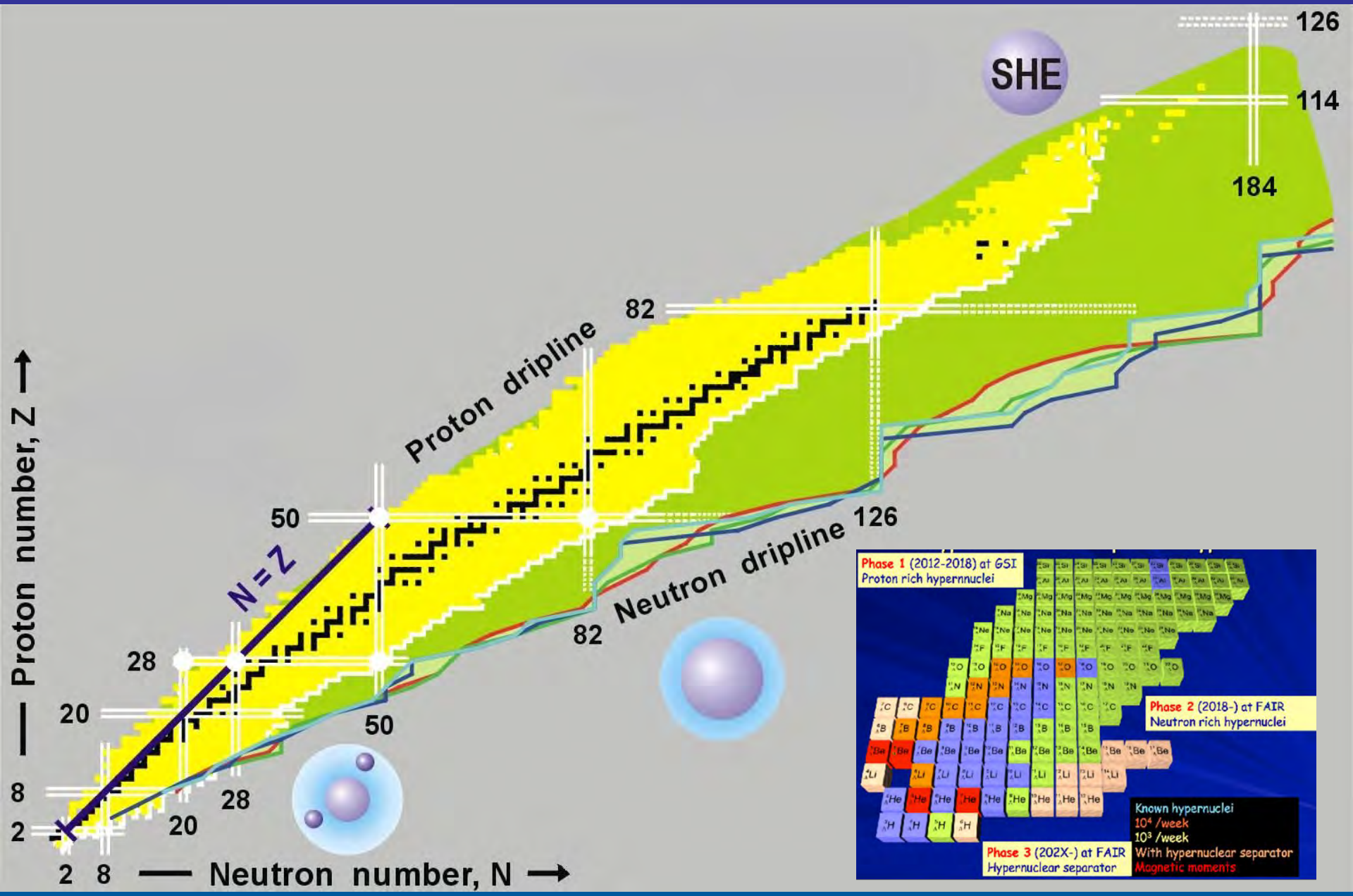
High Energy Storage Ring (HESR) providing cooled antiproton beams is critical to physics potential of PANDA. Energy resolution of ~50 keV permits resonance scans for precise determination of masses and widths of hadron states.

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

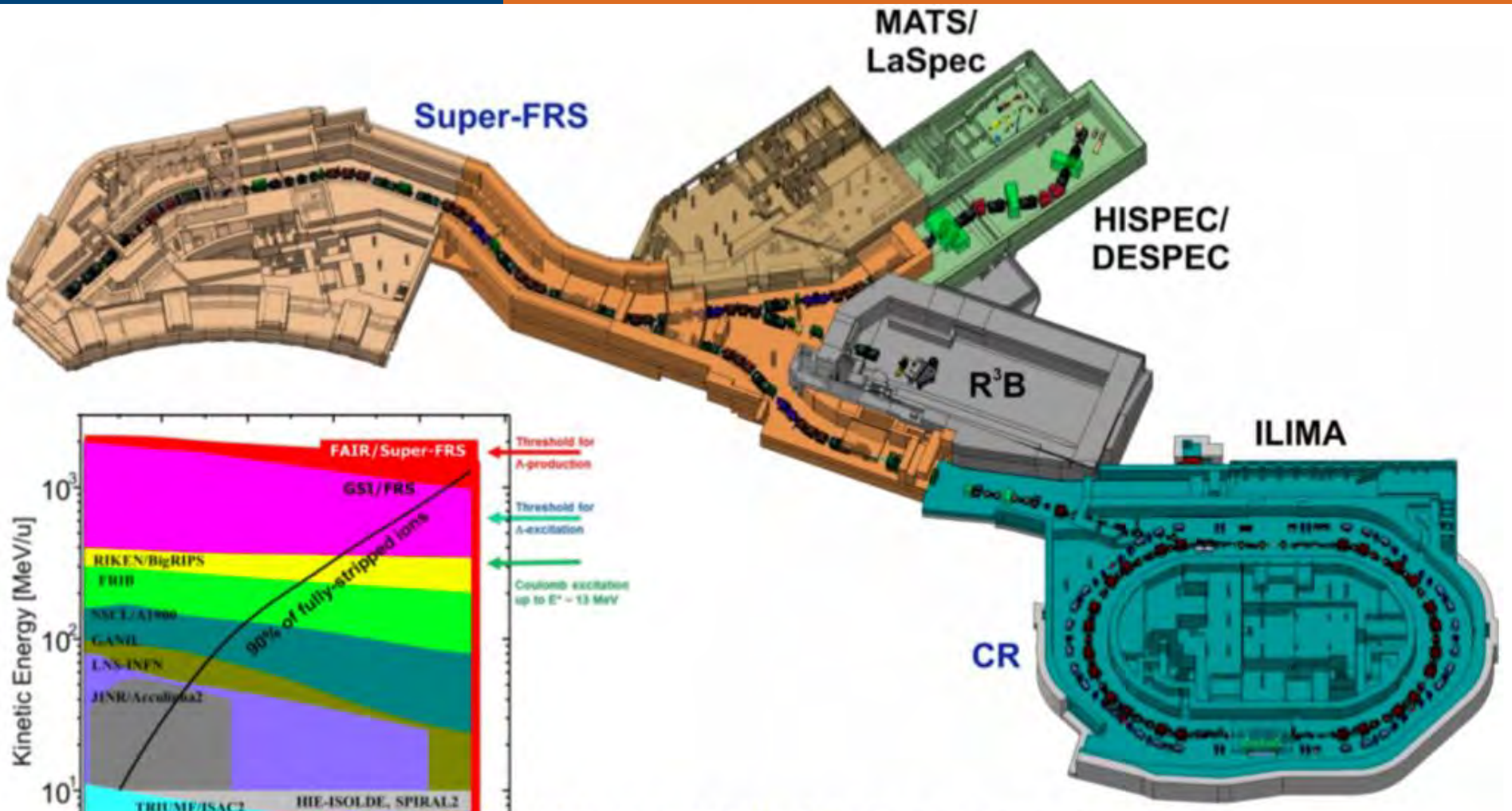
JÜLICH Forschungszentrum



NUSTAR & nuclear landscape



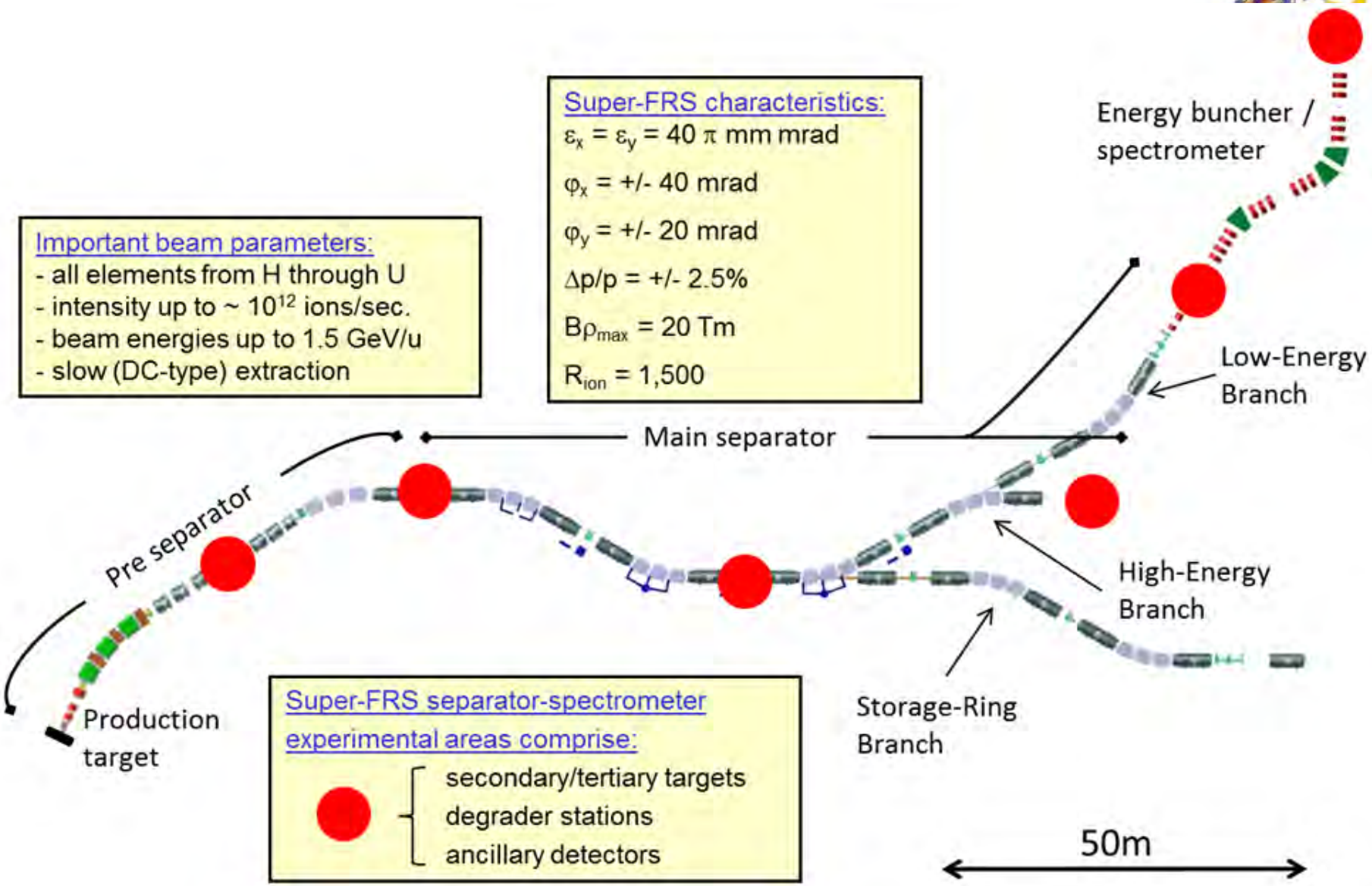
The Superconducting Fragment Separator



World-wide highest energy RIB

Intensity gain of up to 10^3 compared to GSI

Super-FRS scheme



NUSTAR - Experiments

	PSP code	Super-FRS	RIB production, separation, and identification
	1.2.2	**HISPEC/ DESPEC**	In-beam γ-spectroscopy at low and intermediate energy, n-decay, high-resolution γ-, β-, α-, p-, spectroscopy
	1.2.3	**MATS**	In-trap mass measurements and decay studies
	1.2.4	**LaSpec**	Laser spectroscopy
	1.2.5	**R^3B**	Kinematical complete reactions with relativistic radioactive beams
	1.2.6	**ILIMA**	Large-scale scans of mass and lifetimes of nuclei in ground and isomeric states
	1.2.10	**Super-FRS**	High-resolution spectrometer experiments
	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.

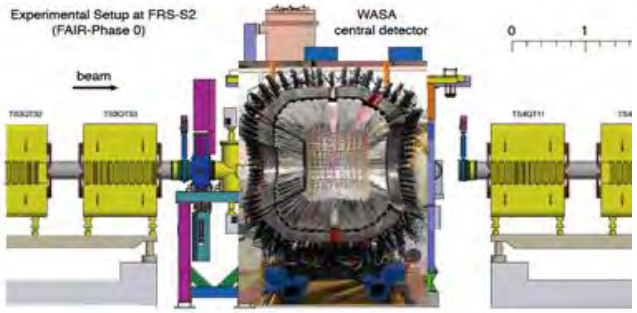
(Super-)FRS experiments

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

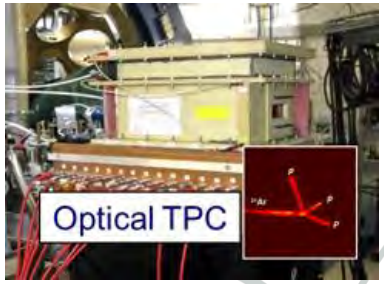
(Super-)FRS as multiple-stage magnetic system (separator, analyser, spectrometer, energy buncher) combined with ancillary detectors, e.g. with:

FRS Ion Catcher

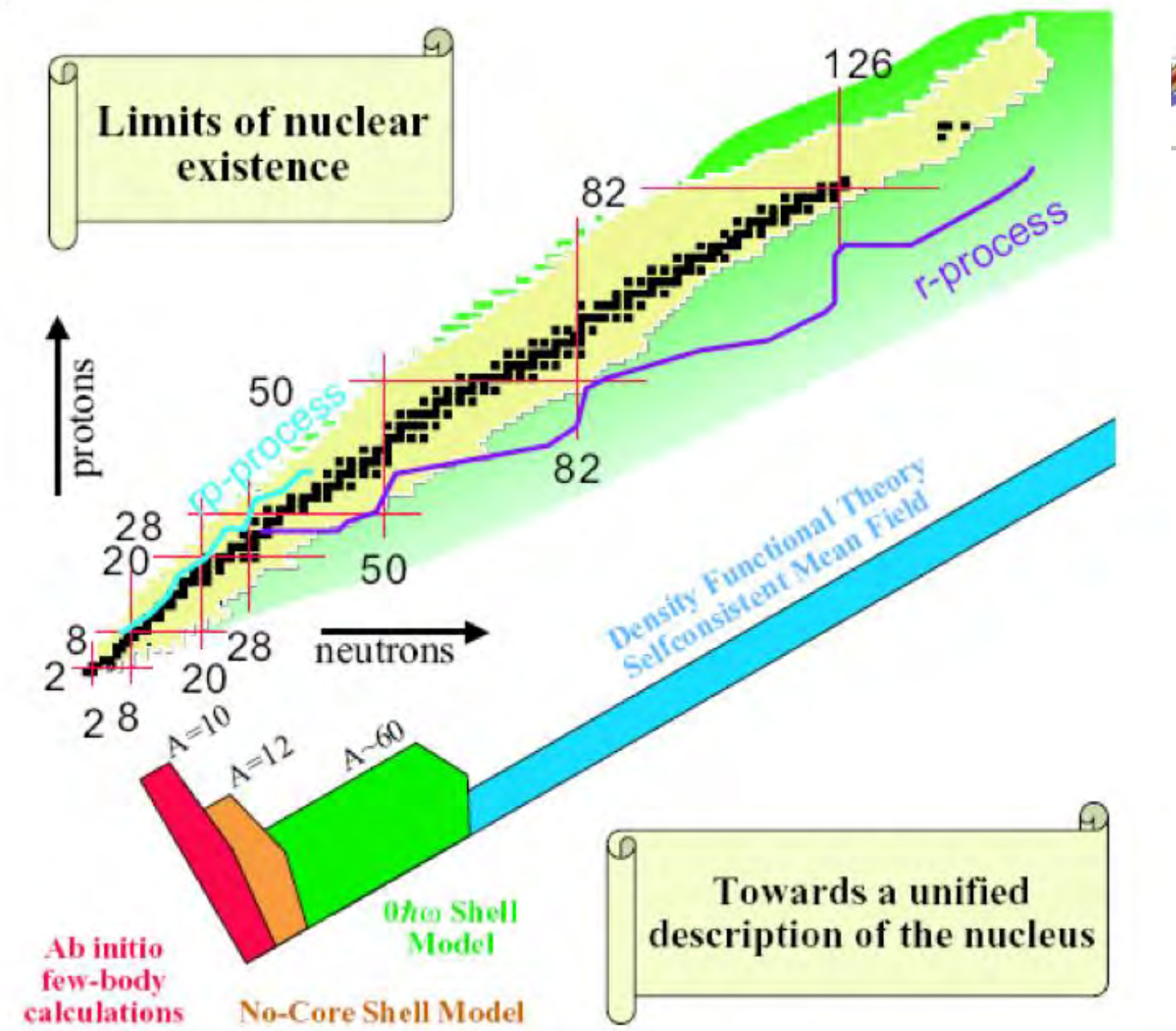
WASA



EXPERT

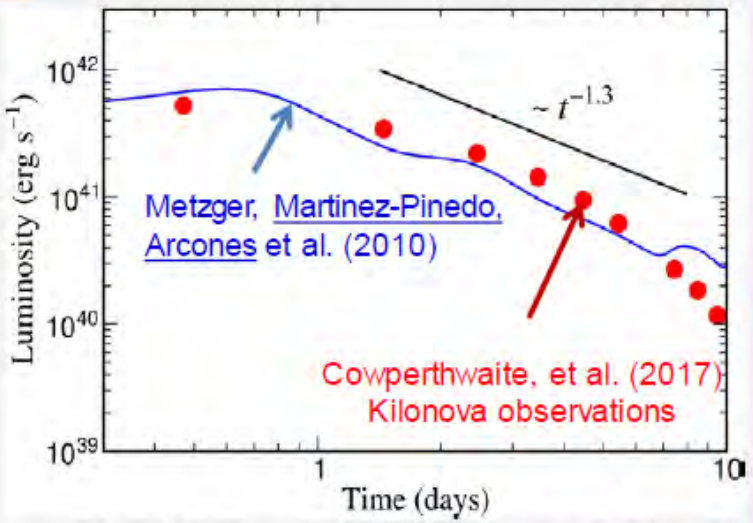


later Super-FRS

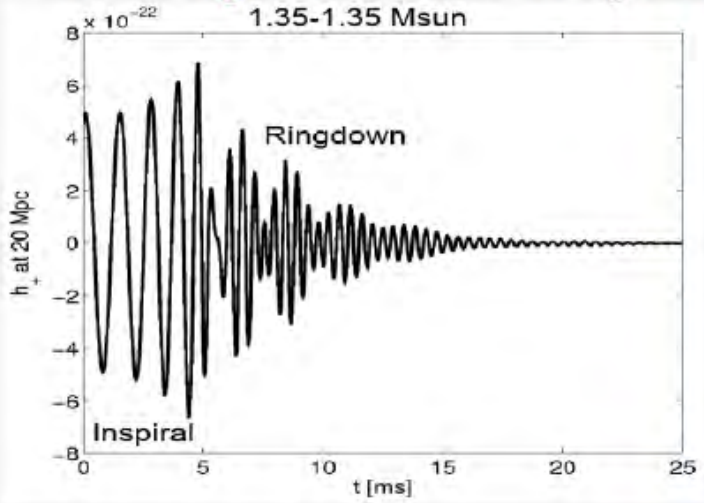

Limits of nuclear existence
126
82
50
82
50
28
20
8
2
28
20
2 8
protons
neutrons
rp-process
r-process
Density Functional Theory
Selfconsistent Mean Field
A=10
A=12
A~60
0ħω Shell Model
Ab initio few-body calculations
No-Core Shell Model
Towards a unified description of the nucleus

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!

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

Finnish in-kind projects

Accelerator Super_FRS	Time of delivery	M€ (2005 value)	Status
Beam diagnostics GEM-TPC	2022-2023	0.560	Assigned
Detector feed throughs	2022-2023	0.635	Assigned
Transport container system	~ 2024	0.712	Assigned
Beam Profile Detector	2022-2023	0.560	Contract signed
ΔE detectors (MUSIC)	2022-2023	0.142	Contract signed
Cryogenic beam stopping cell	~ 2024	0.187	Contract signed
Experiments			
RILIS System for LaSpec	~ 2025	0.106	Assigned
HISPEC/DESPEC: MONSTER	2019	0.120	Contract signed, done
MATS: RFQ and Switchyard	~ 2025	0.215	Assigned
HISPEC/DESPEC: DEGAS	~ 2024	0.268	Assigned
Cash	done	1.500	
Total commitment		5.000	

Beam diganostics, tracking & manipulation

The road towards FAIR MSV

Facility	U beam intensity/spill at production target	Luminosity [fb^{-1}]
Today at GSI with **FRS** (Phase 0)	1...2x10^{9}	~0,1
Super-FRS with upgraded **SIS18**	5x10^{9}	1-2
Commissioning phase **SIS100**	2x10^{10}	5
Full final intensity with **SIS100**	4x10^{11}	100

Phase 0	→	**Day-1**	→	**Full MSV**
preparation	→	**discovery**	→	**detailed studies**
• **0.1 fb^{-1}**	→	**2-5 fb^{-1}**	→	**100 fb^{-1}**
• (near) stability	→	exotic	→	very exotic nuclei

Summary

- Finland is committed to FAIR via a Consortium between HU/HIP and SRC (Shareholder)
- FAIR Day-1 experiments will start in 2025, however some early start scenarios are discussed
- For the moment the main focus of the HIP FAIR Operations are the in-kind deliverables and nuclear physics related to the NUSTAR experiments, e.g. phase 0.
- However, one should investigate science opportunities provided by the other three (CBM, APPA, PANDA) pillars of FAIR

Status of FAIR Project: Civil Construction

Progress since official start on 4th of July 2017

https://youtu.be/WJGs68298YA

Excavation SIS100 tunnel

Upgraded SIS18 completed ready for FAIR and FAIR phase 0

Excavation transfer building & CBM cave

Start of concrete shell works for SIS100