



Challenges and new opportunities for polish science and technology in FAIR

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- ✓ FAIR status
- ✓ FAIR-Phase0
- ✓ Polish contributions:
infrastructure
experiments

FAIR: layout of facility & status

SIS100 → protons 29 GeV to U^{92+} 11 GeV/u (14 GeV C, Ca)

250 superc. magnets, 11 ton He, ~140 GWh Energy/year

✓ High Intensity beams: 5×10^{11} /s (U^{28+})->light-ions-> 2×10^{13} p/s

✓ High intensity radioactive beams :

Super-Fragment Separator-SFRS :

HEB in construction, completion of LEB next step

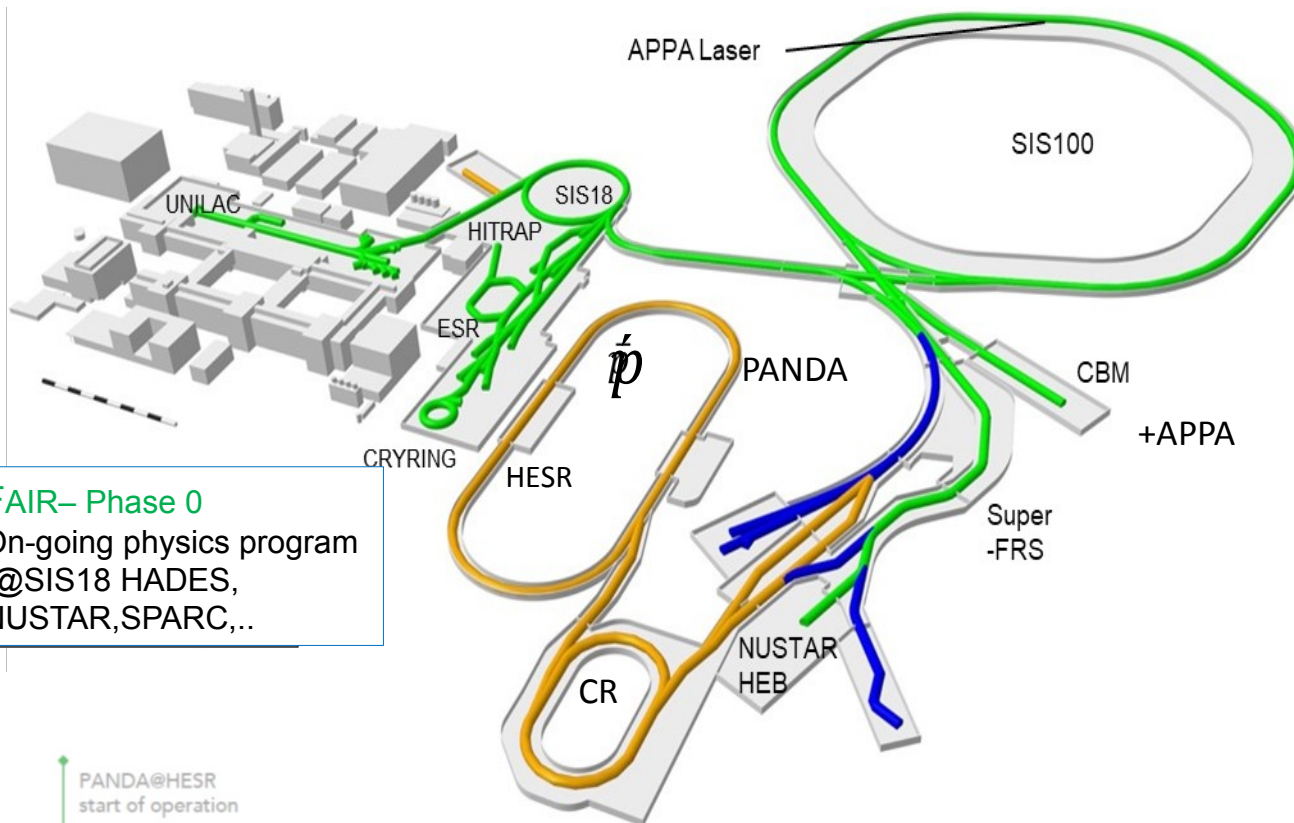
✓ CBM on track with completion till 2028

still lacking about 30 mln EUR: „step-by-step”

realization

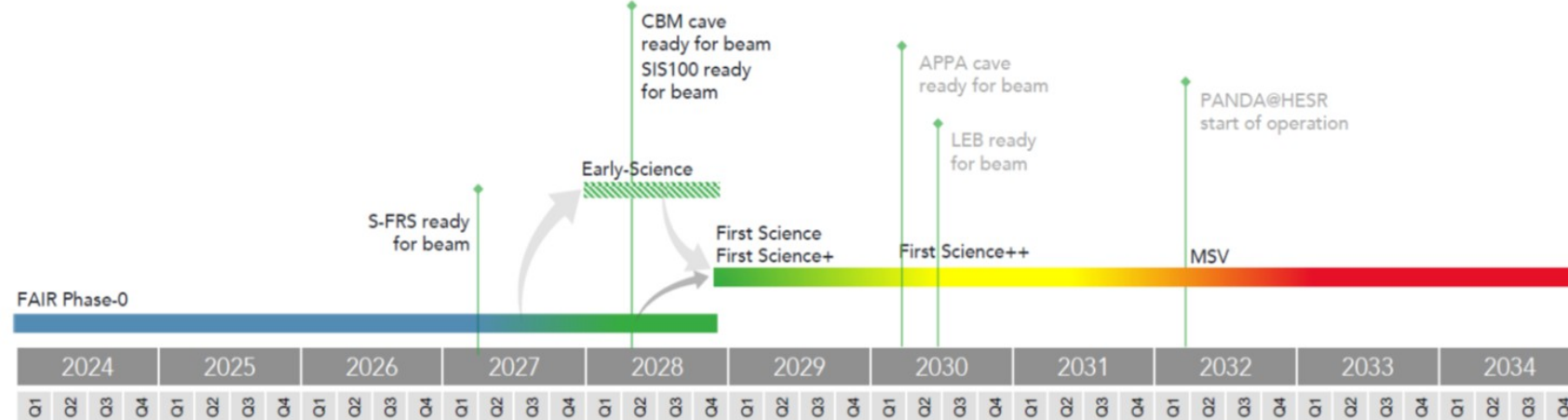
✓ storage rings : ESR, CRYRING

➤ antiprotons (HESR) Collector Ring (CR) on hold (>2032?)



FAIR- Phase 0

On-going physics program
@SIS18 HADES,
NUSTAR, SPARC,...

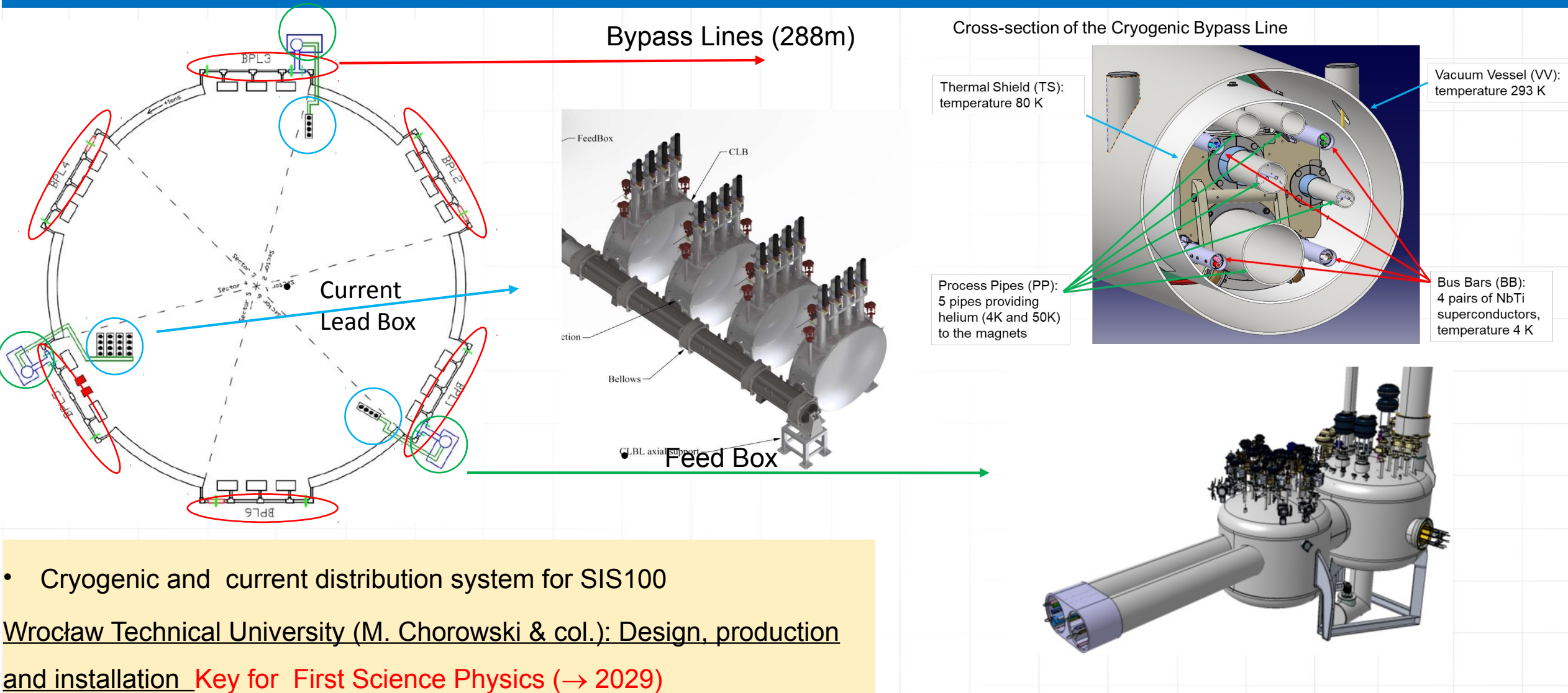


FAIR @ 2025



- ✓ Civil construction completed
- ✓ 2024: Start of Installation of SIS100 and SFRS components in tunnels

Polish in-kind contribution to SIS100



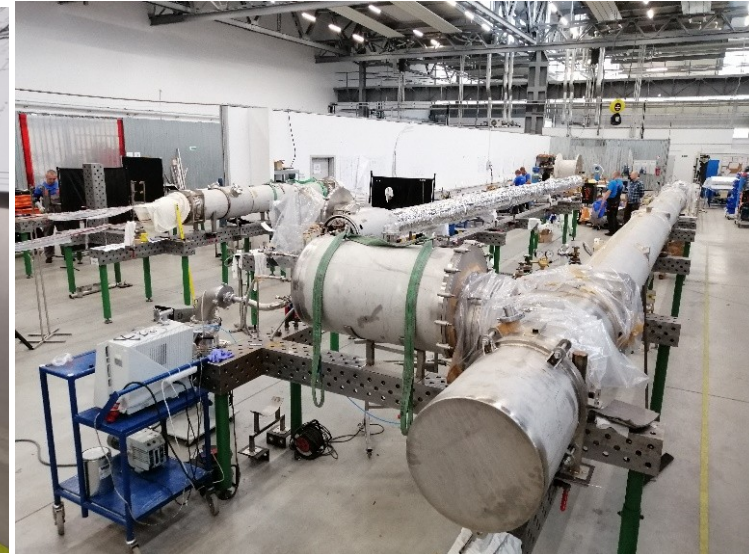
Cryogenic systems for SIS100

ByPassLines: 1 (out of 6) lines@SIS100

@KRIOSYSTEM s.a



Politechnika
Wroclawska



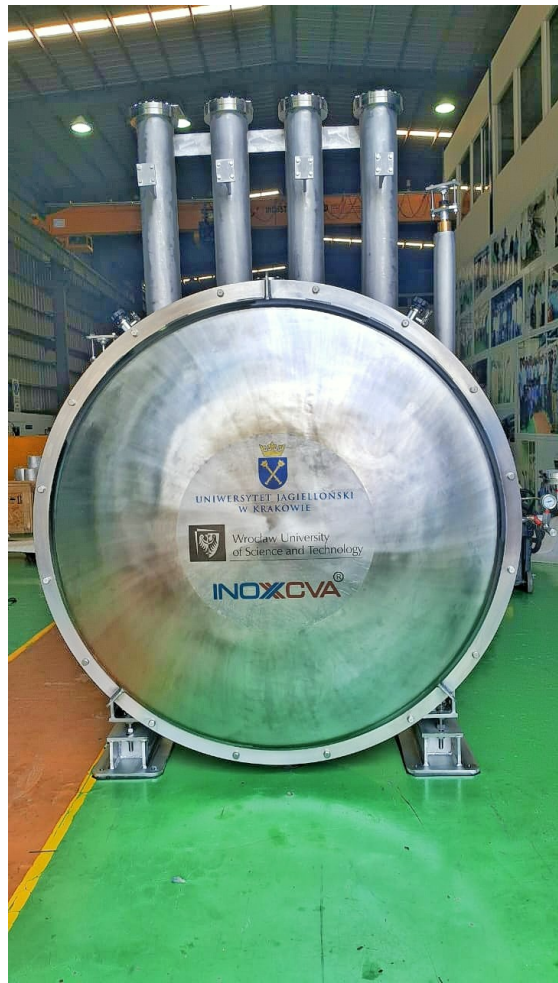
✓ Bypass Lines production by KRIOSYSTEM completed in 2024 installation at FAIR

Current Lead Boxes
and links (INOX' India)

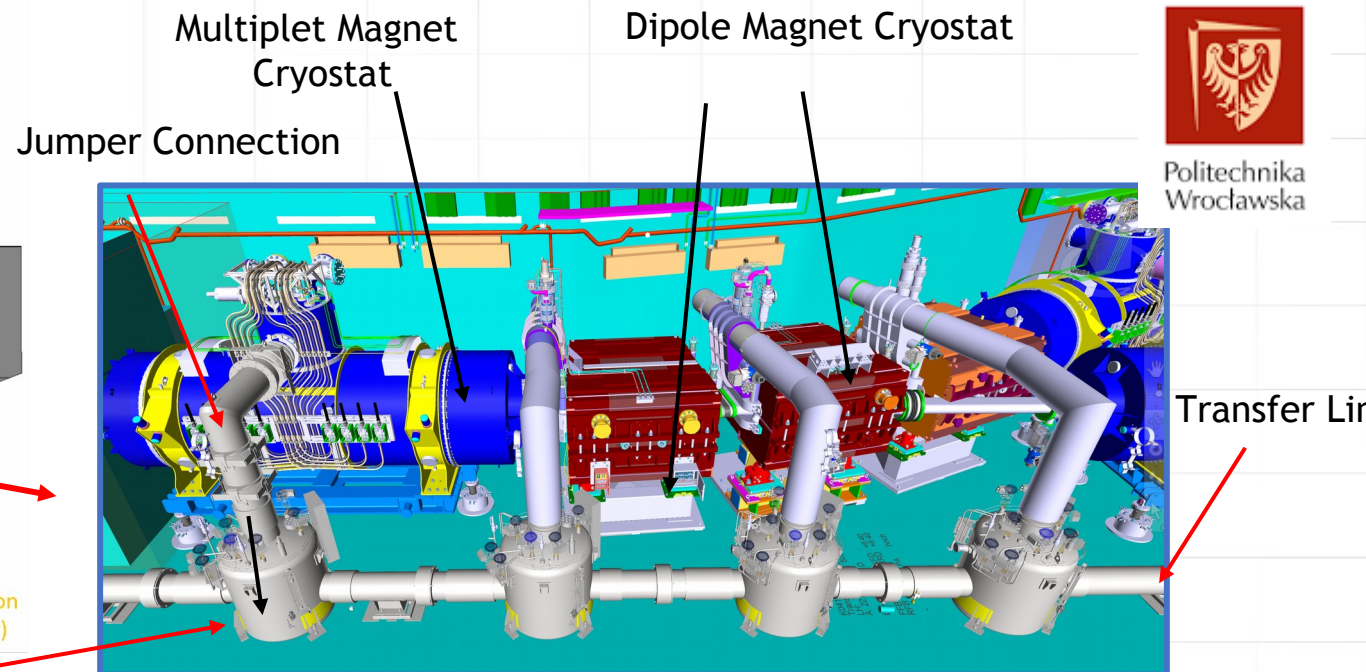
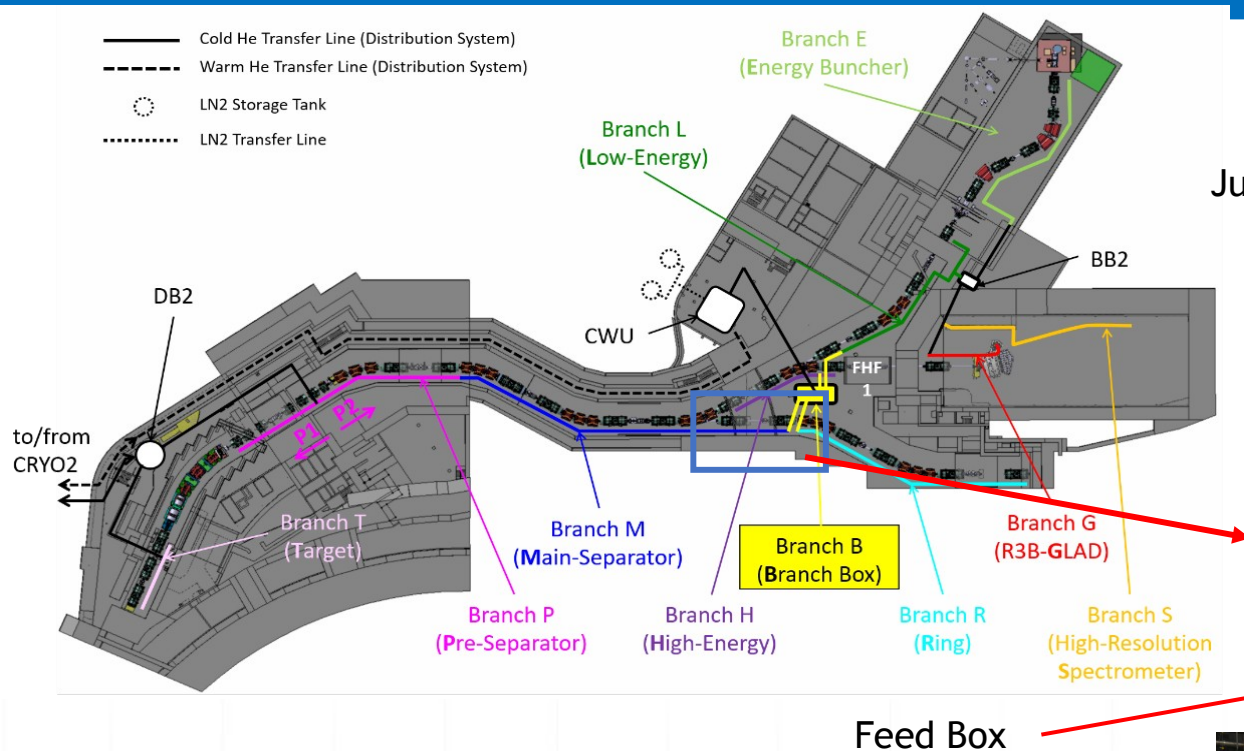
Transfer of current supply from
warm conductors to cold
superconductors

Completion scheduled on 03.2026

Feed Boxes on 08.2026



In-kind to SFRS



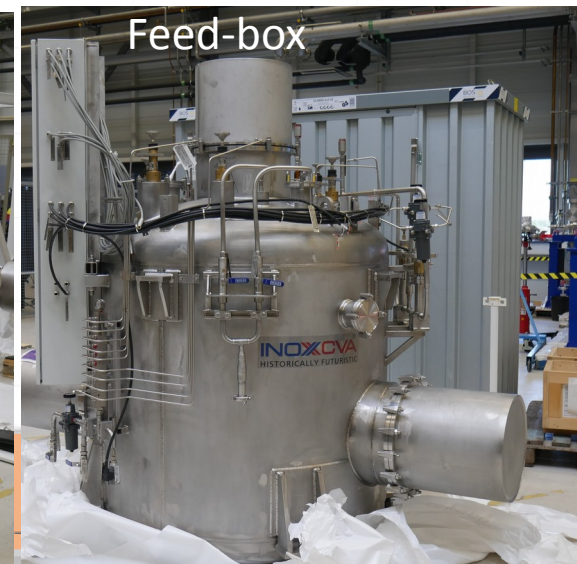
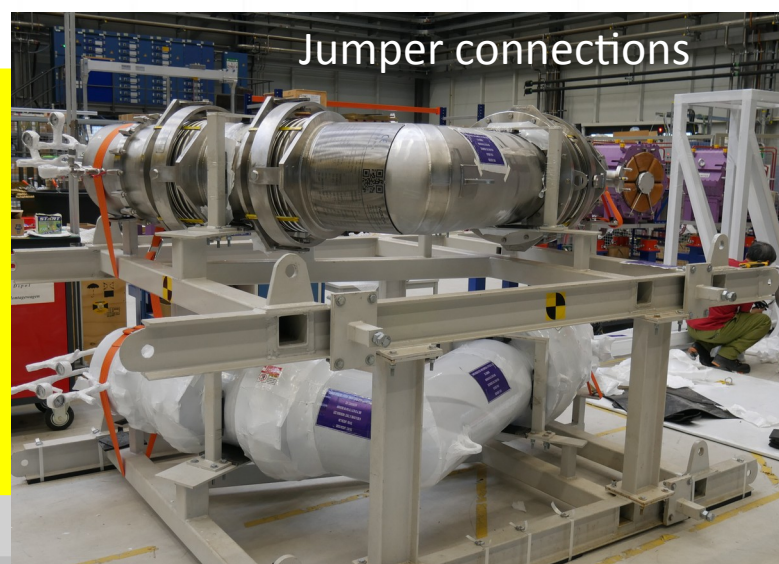
Politechnika
Wroclawska

Wrocław Technical University: Design of the cryogenic system ,
8 branches of SFRS, production of two branches (T,P)

✓ First Branch produced (T) tests on-going at FAIR

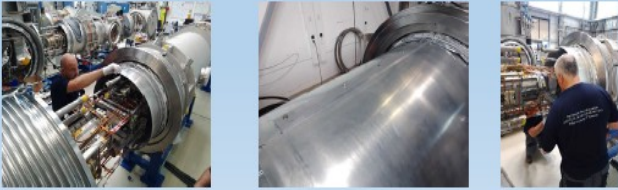
Key element for for **SFRS**

Completion of T,P by end of 2025 – start of Early Science 2027



IFJ-PAN (DAI) installation SIS100 (not yet in-kind)

- Installation of thermal shields between QDM and DM (07.09 – 16.09)



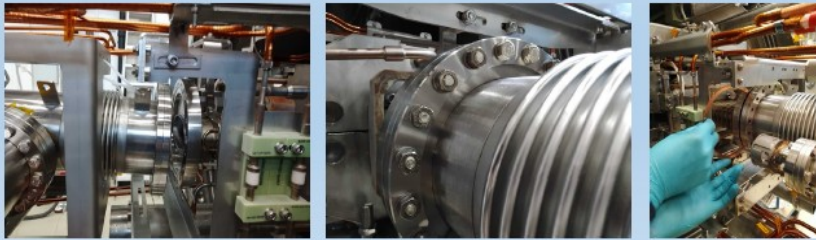
- Installation of thermal shields between QDM and DM (07.09 – 16.09)



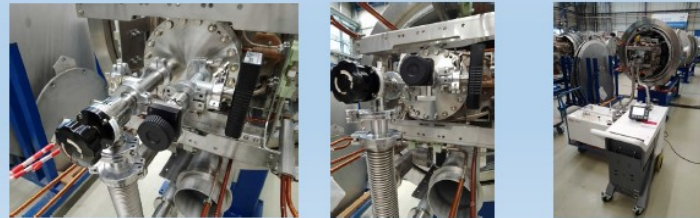
- MLI Wrapping of interconnection between QDM and DM



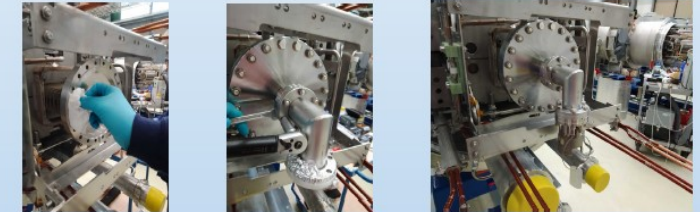
- Beamline interconnection between DMs (14.10)



- Connection of the vacuum eq. to the beamline at the downstream side of the DM-DM string (21.10)



- Installation of vacuum equipment on the beamline in EB (20.10)



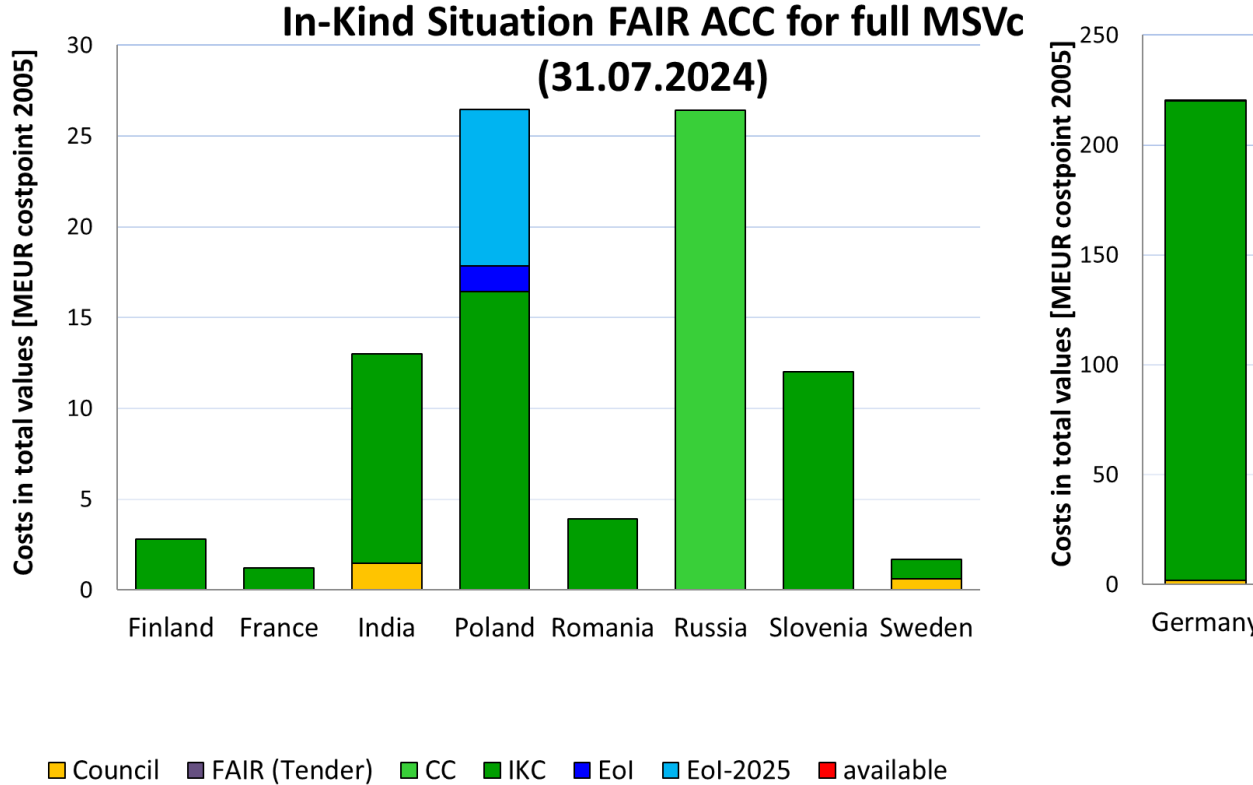
Experience gained in other Big Science projects: ESS Lund, E-XFEL, ITER-Cadarache, LHC-ATLAS,...

Activities at FAIR :

- Preparation of procedures in installation processes
- Preparation of quality control and assessment processes
- Execution of Installation

Preparation of new in-kind contribution

In-kind contributions to FAIR



Poland : 3'd country with largest In-Kind contributions to FAIR (above 95% of resources allocated to IK):
8 - infrastructure
11 - experiments

- 15 in realization (4 completed)
- 4 contracts in preparation
- 2 Expression of Interest (IFJ PAN- installation SIS100/SFRS)

Experiments

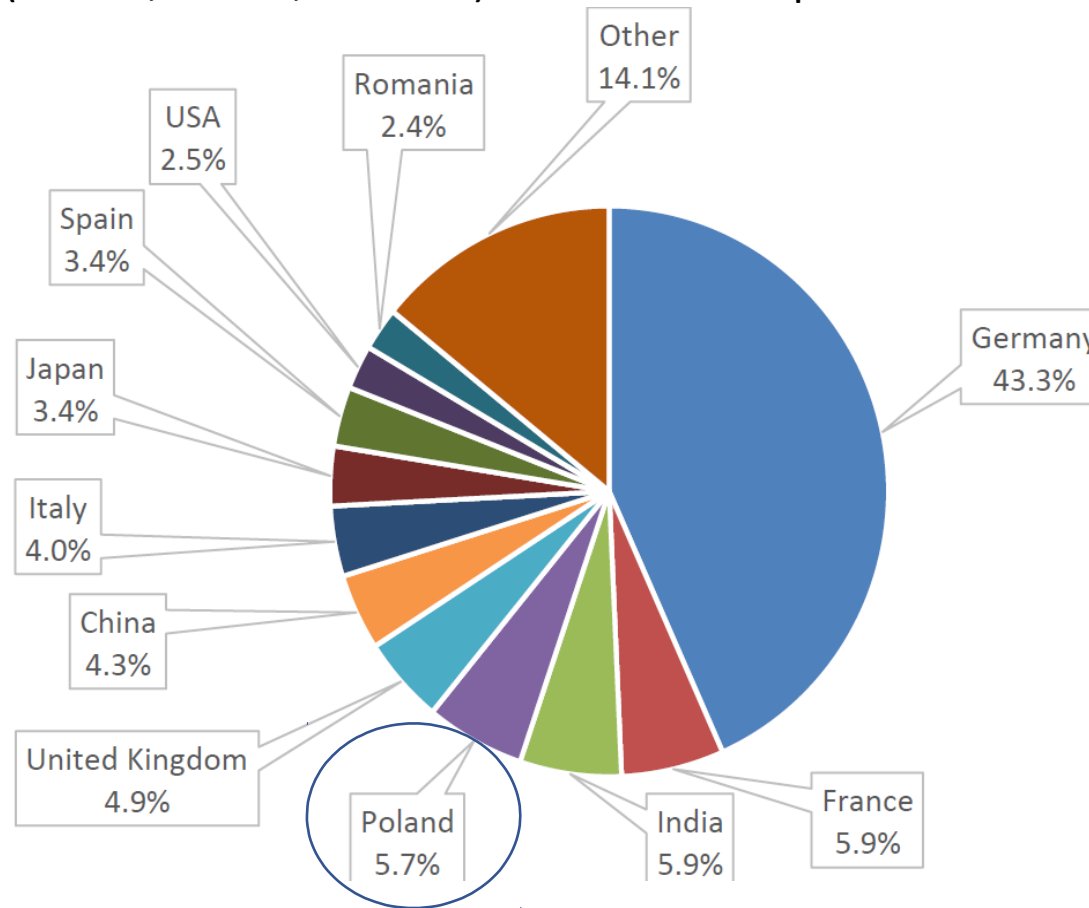
FAIR-Phase0 program

A path towards science at FAIR after completion of SIS100 and SFRS since 2016..

Successful beam campaigns for all pillars. 2022-2024 about 124 proposals submitted to PAC, 65 granted with beams

Continuation during construction of FAIR

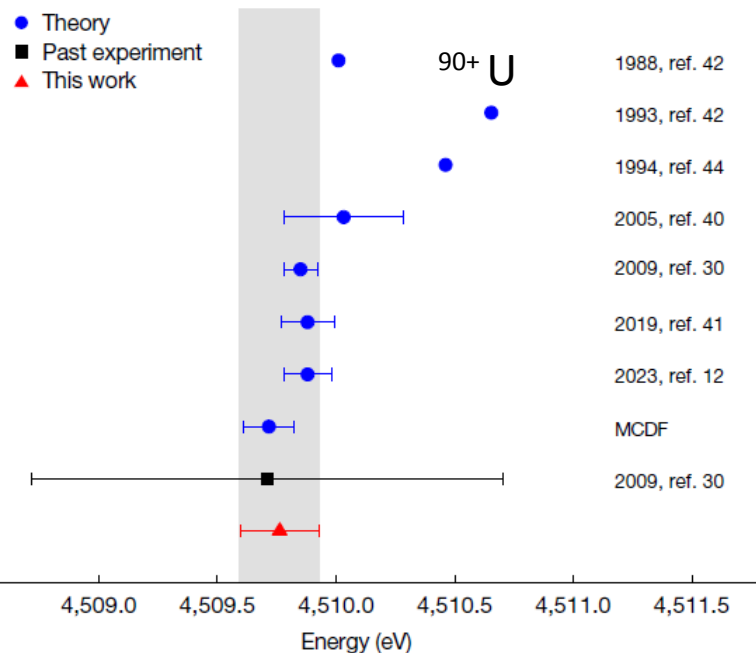
Active role of polish groups (HADES, SPARC, NUSTAR) with several important contributions –(next slides)



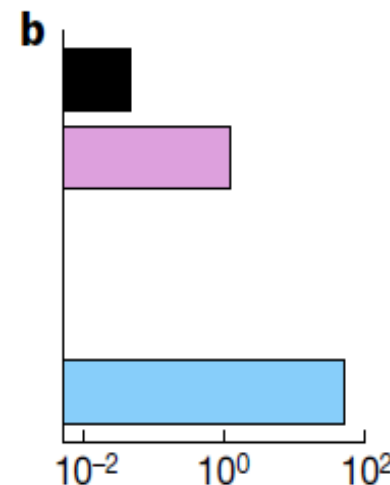
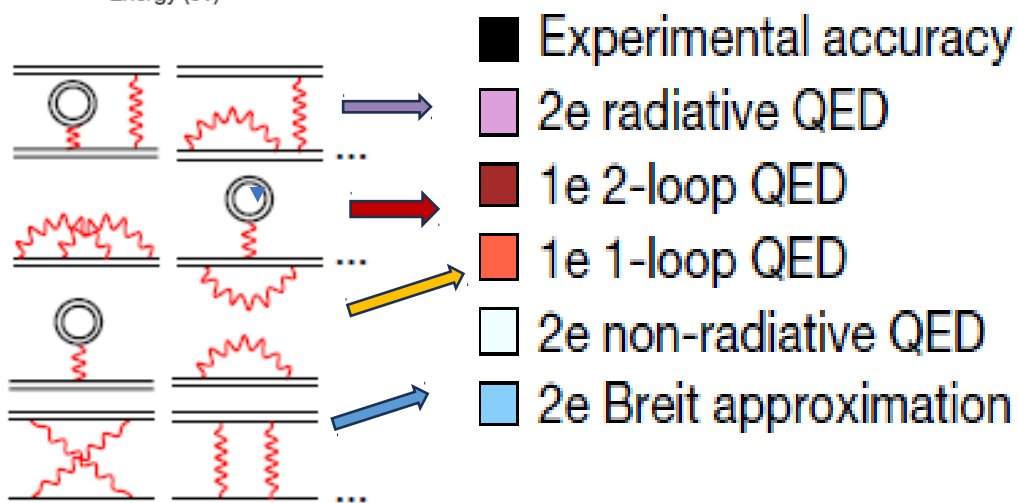
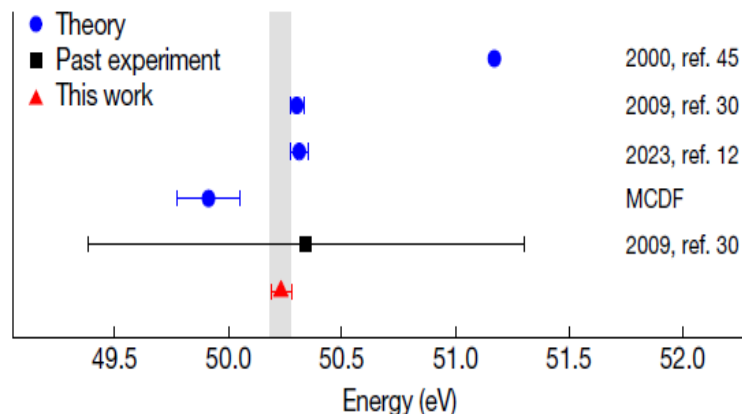
QED: e-e interactions in strong EM fields

$$1s_{1/2}2p_{3/2} J = 2 \rightarrow 1s_{1/2}2s_{1/2} J = 1$$

Sparc [Nature](#) **625**, 673–678 (2024)



ΔE „He“- „Li“ like U



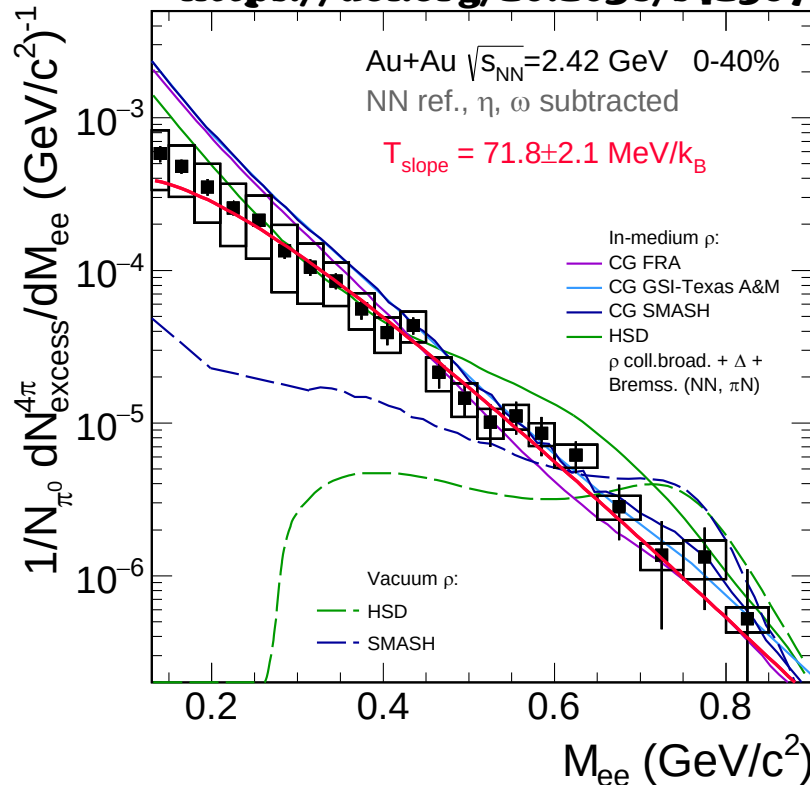
cancellation of nuclear size effect,
sensitivity to 2-loop QED corrections

QCD: diagnostics of nuclear matter

HADES Nature (2021)

<https://doi.org/10.1038/s41567-019-0583-8>

Nupec Long Range Plan'2024



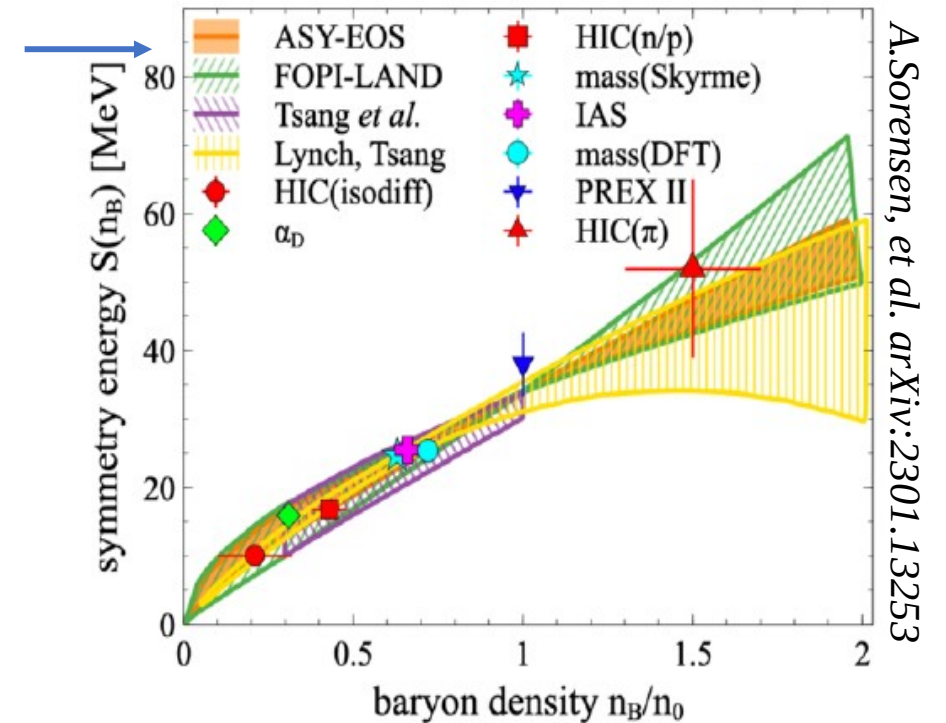
Spectroscopy of in-medium melting of ρ in medium

Dileptons as thermometer

Mass spectrum falls exponentially $\rightarrow$ "Planck-like"

Fit $\frac{dN}{dM} \sim M^{\frac{3}{2}} \times \exp\left(-\frac{M}{T}\right)$ in range $M=0.2-0.8$ GeV/ c^2

$\langle T \rangle_{\text{emitting source}} = 72 \pm 2$ MeV/ k_B

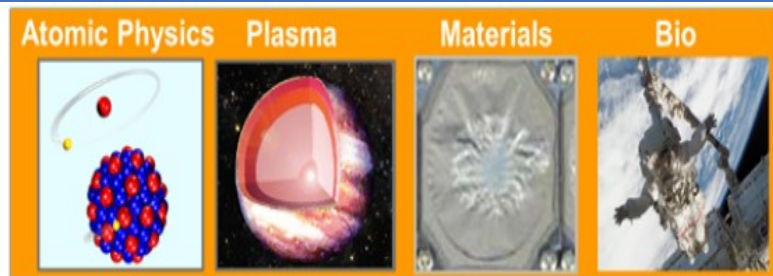


A.Sorensen, *et al.* arXiv:2301.13253

Constraints on Symmetry Energy from properties of nuclei and Heavy Ion collisions and model calculations

important input to EOS of Neutron Star (radius vs mass relations), comparison to constraints from astrophysics observations (GW, NICER, ..)

FAIR:Research Research Pillars

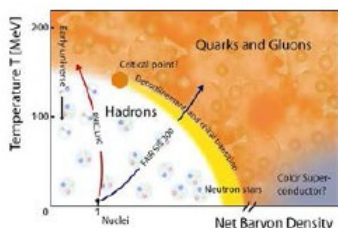


Atomic Physics, Plasma physics
and applications

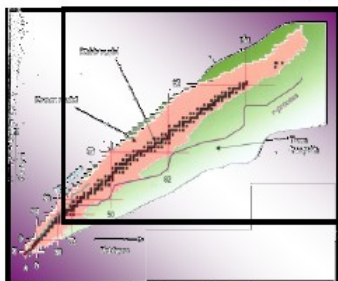
APPA

Scientists
World / Poland

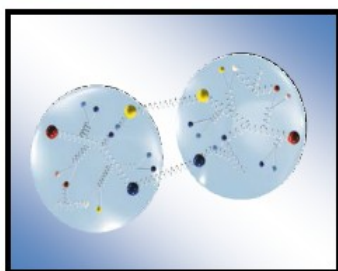
700 / 13



Compressed Baryonic Matter **CBM**



Nuclear STructure
Astrophysics and Reactions **NuSTAR**



hadron structure with Antiproton
ANihilation (at DArmstadt)

PANDA



400 / 44

660 / 20

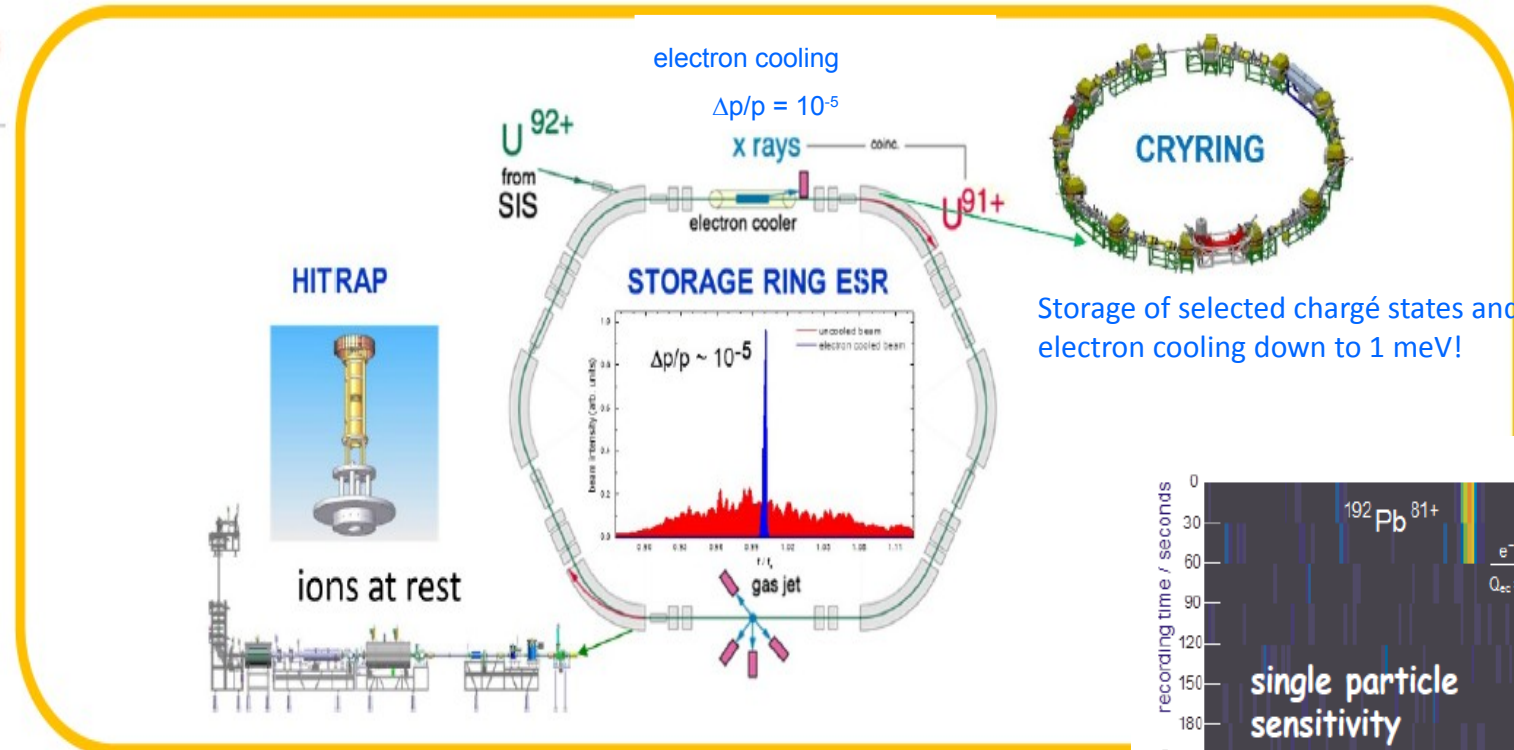
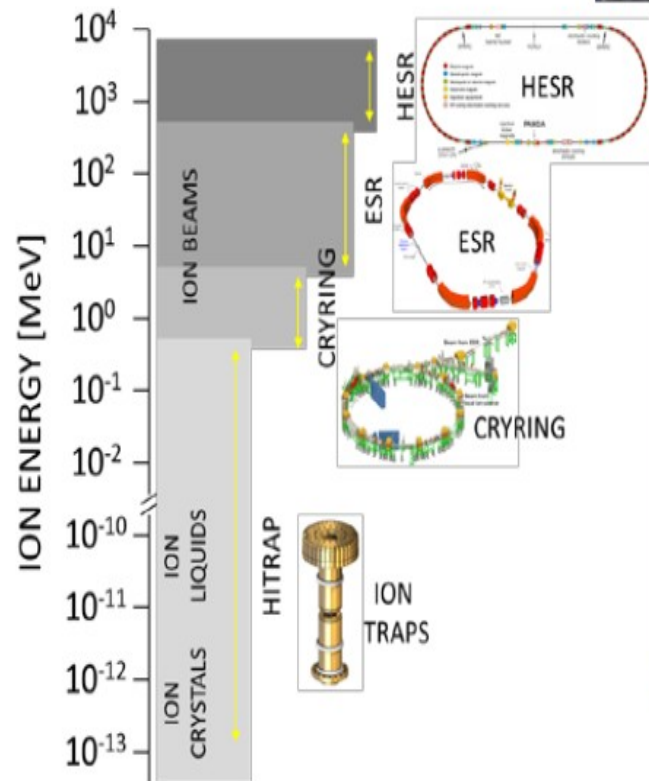
450 / 20

+ 46 scientists &
engineers contributing
to infrastructure

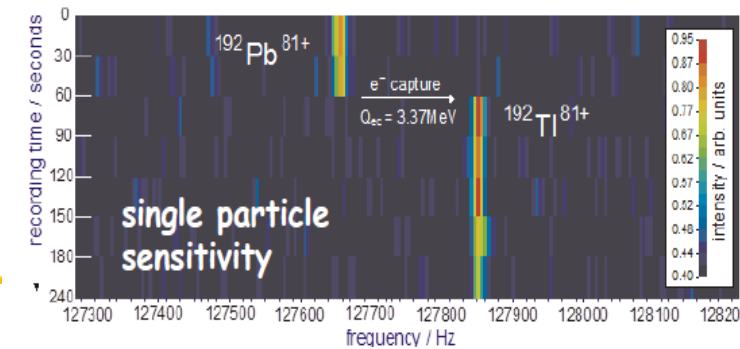
SPARC physics - research driven by storage rings



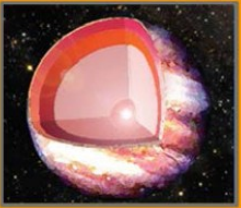
From rest to relativistic energies (up to 4.9 GeV/u)



Storage of selected charge states and electron cooling down to 1 meV!



APPA (Atomic, Plasma Physics and Applied Sciences)

Atomic Physics	Plasma	Materials	Bio
			
SPARC strong field research ... probing fundamental laws of physics	HED warm dense matter ... states of matter common in astrophysical objects	MAT/BIOMAT radiation hardness ... mechanical and electrical degradation of materials	BIO/BIOMAT space travel ..cosmic radiation risk and shielding particle therapy radioactive beams FLASH therapy

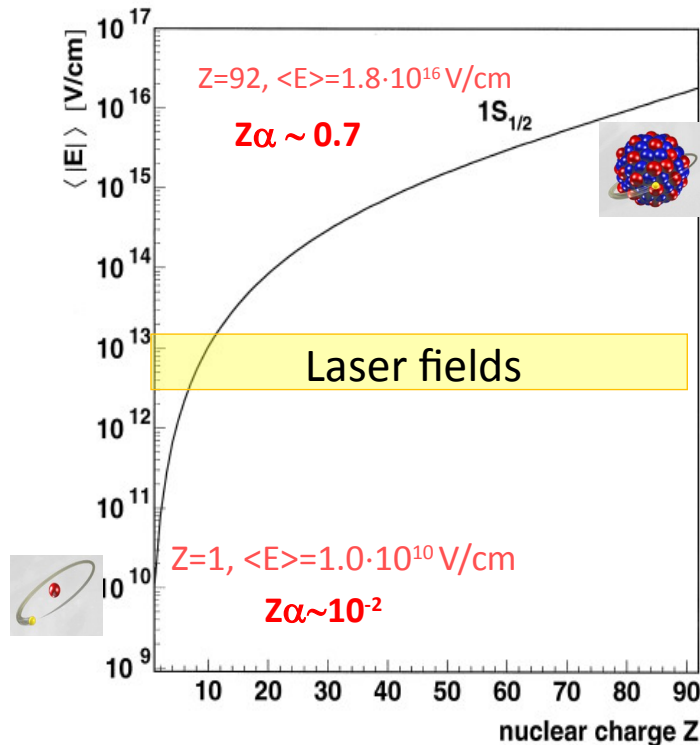
SPARC

Atomic Physics
430 physics 26 countries



BIOMAT

Biophysics and material science
150 physicist 20 countries



Research areas of polish groups

➤ Precise tests of QED in strong em. fields (SPARC)- high precision tests in He-like Uranium atoms, radiative electron capture processes (in-kind contribution of UJK -high resolution von Hamos spectrometer)

➤ New methods of radiotherapy with ion beams and effects of radiation on cells (relevant for space missions) (BIOMAT)

On-line imaging of dose induced by radioactive (^{11}C) with SciFi-Compton Camera developed at JU

NUSTAR (Nuclear Structure Astrophysics and Reactions)

Polish participation

- **Super FRS**

Production and decays of radioactive isotopes (2p radioactivity)

- **HISPEC/DESPEC:**

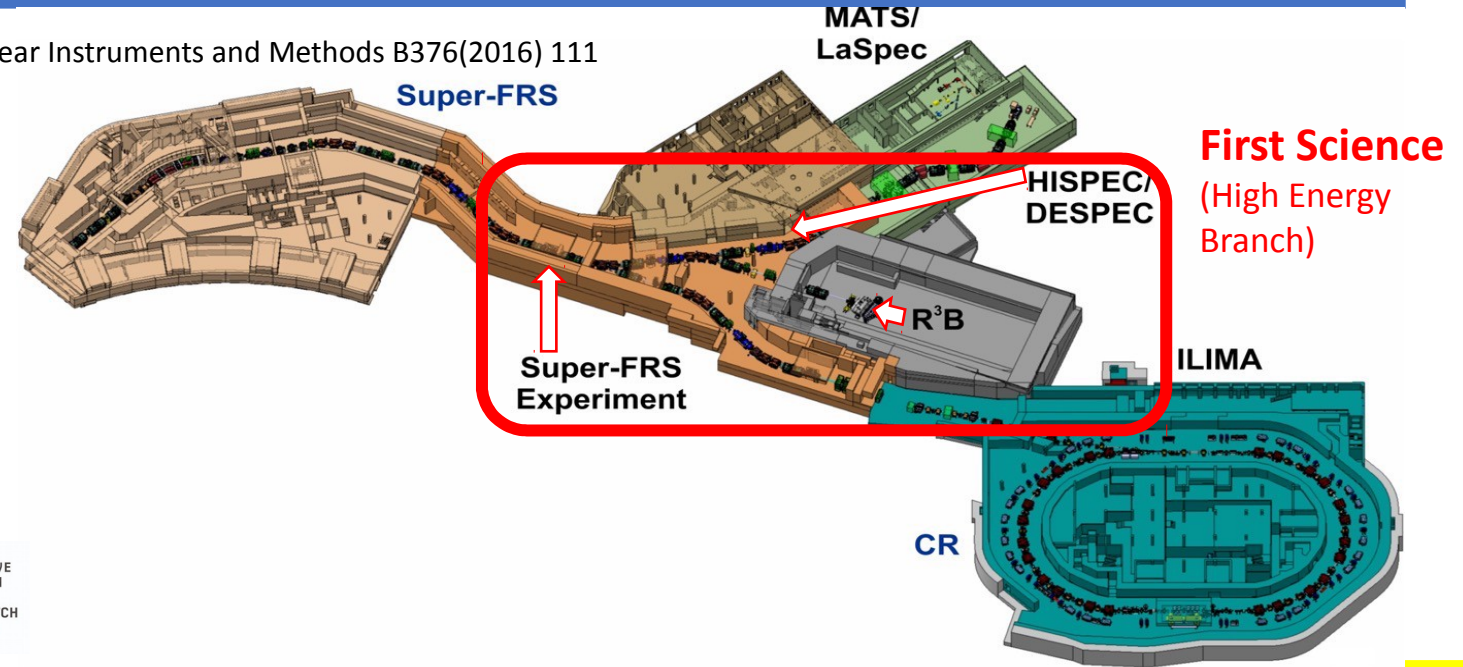
High resolution in-flight (HISPEC) and with stopped beams (DESPEC) gamma spectroscopy

- **R³B, ASY-EOS**

Reactions with Relativistic Radioactive Beams,
Equation of State (Symmetry energy, compressibility)-ASY-EOS

- **SHE:** Super-Heavy Element Research

Nuclear Instruments and Methods B376(2016) 111



Research Areas

- Limits of existence of nuclei (neutron and proton drip lines)
- Properties of proton and neutron rich nuclei (life time, deformations,...)
- Structure of their excited states (energy levels, decay modes)
- synthesis of superheavy nuclei
- origin of heavy nuclei in the universe (input to astrophysics -models)
- exotic nuclei – hipernuclei, hyperon-nucleon interactions
- Equation of State (EOS) of nuclear matter , symmetry energy (neutron stars)

Tests of NUSTAR detectors in CCB@IFJ

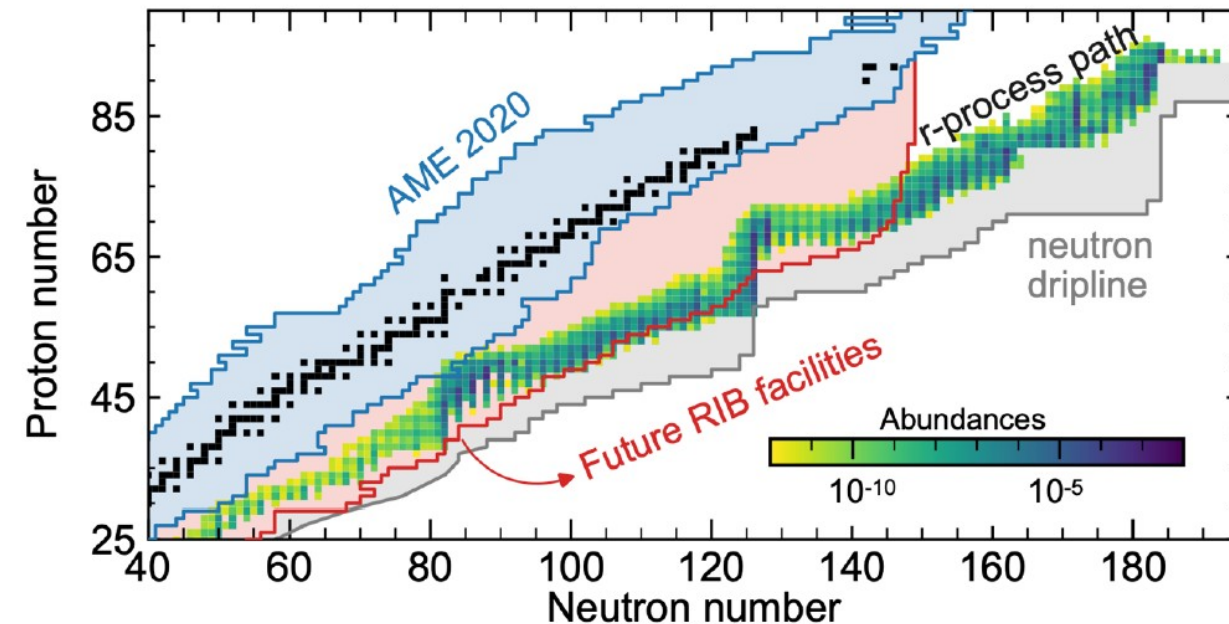
Super Fragment Separator (SFRS) @ FAIR

- Main machine for NUSTAR is SFRS FAIR will provide the most energetic and intense

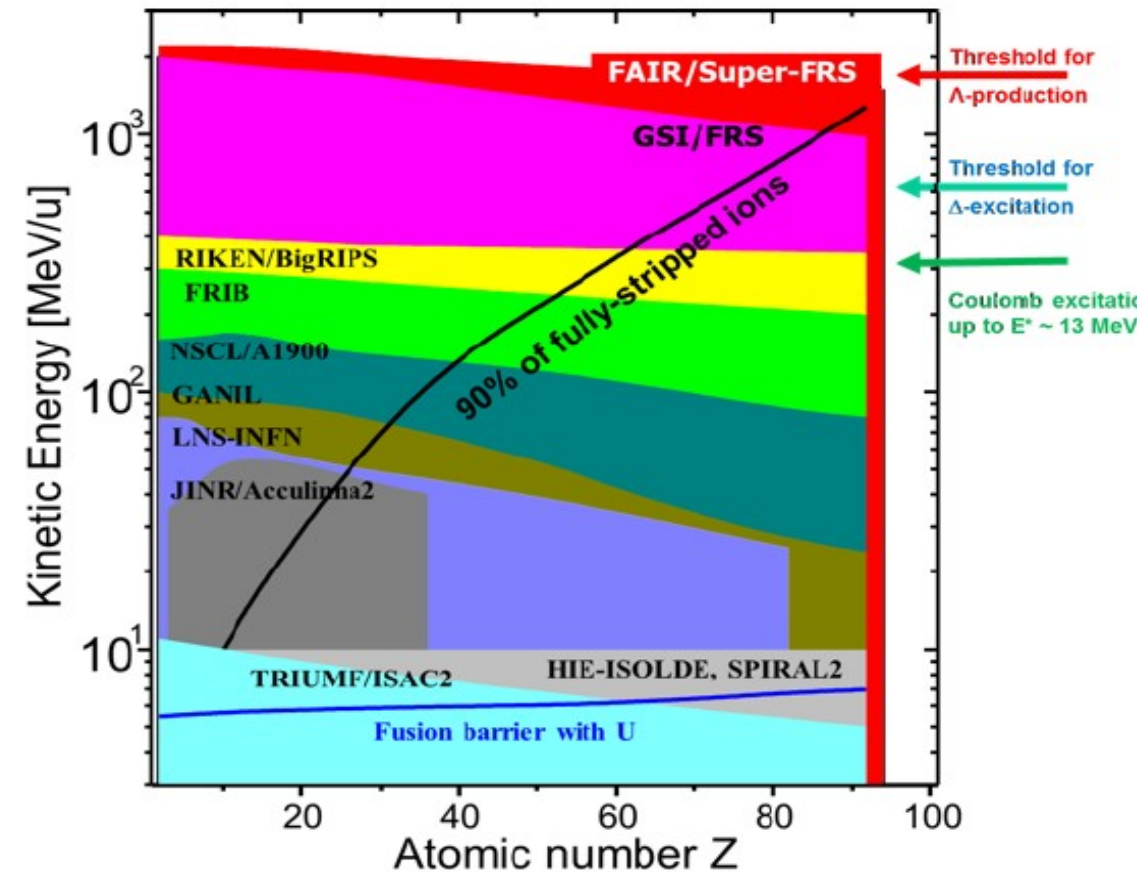
Radioactive Ion Beam facility in world

Isotopes accessible with SFRS

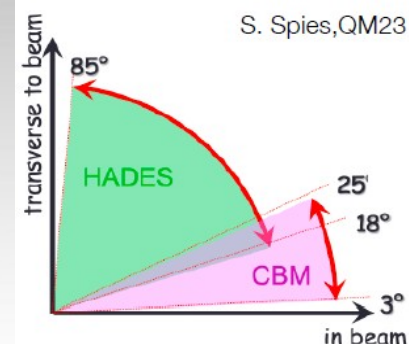
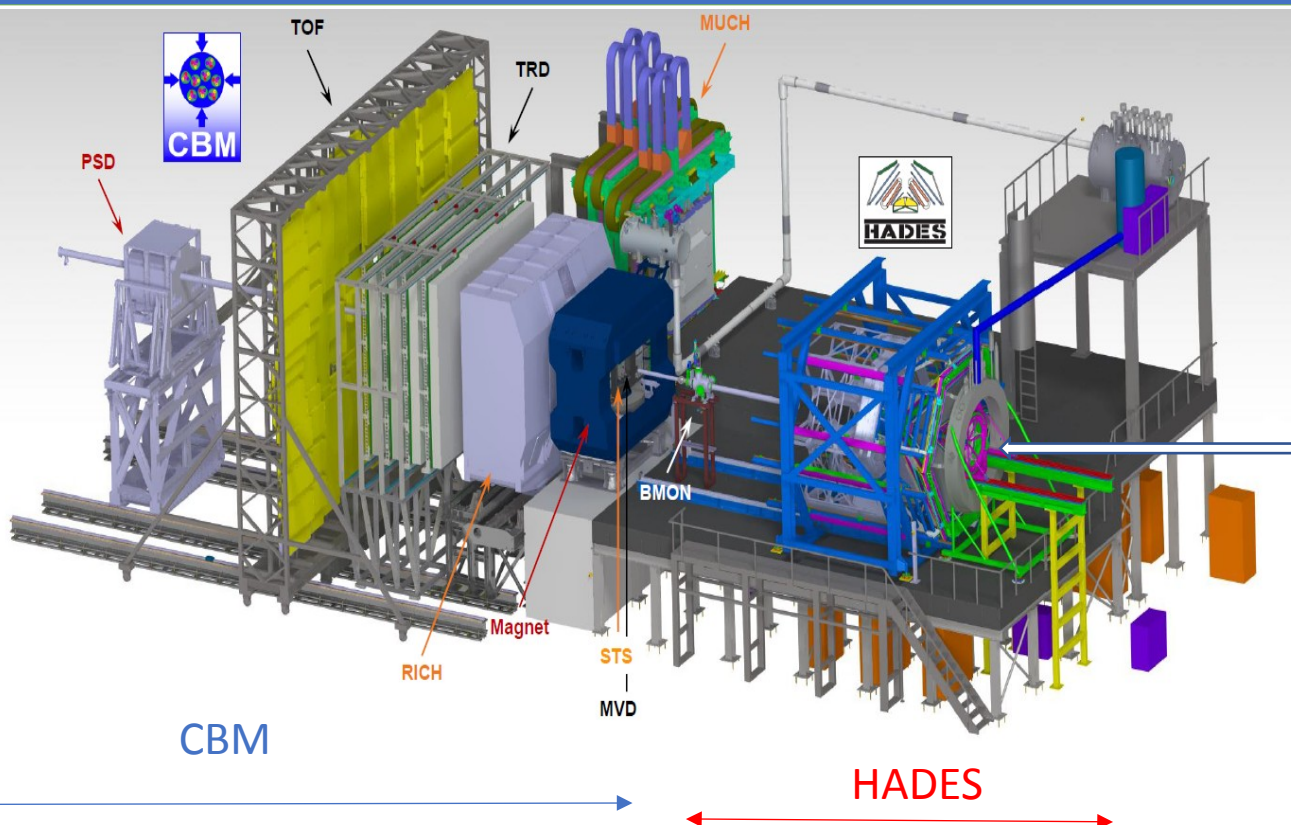
NUPECC Long Range Plan'2024



SFRS@ FAIR Access to heavy ($Z > 90$) radioactive beams
(also short lived isotopes- (ns- μ s) !



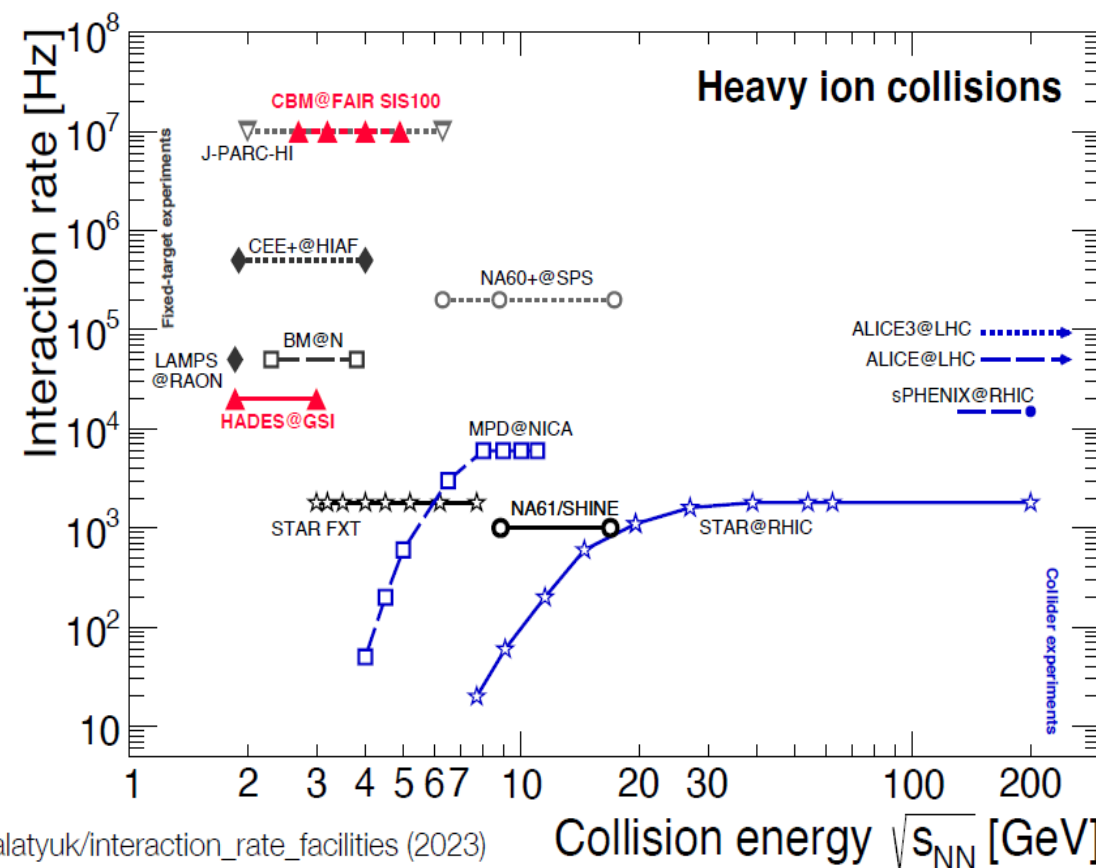
CBM & HADES at SIS100



Eur.Phys.J.A 53 (2017) 3, 60

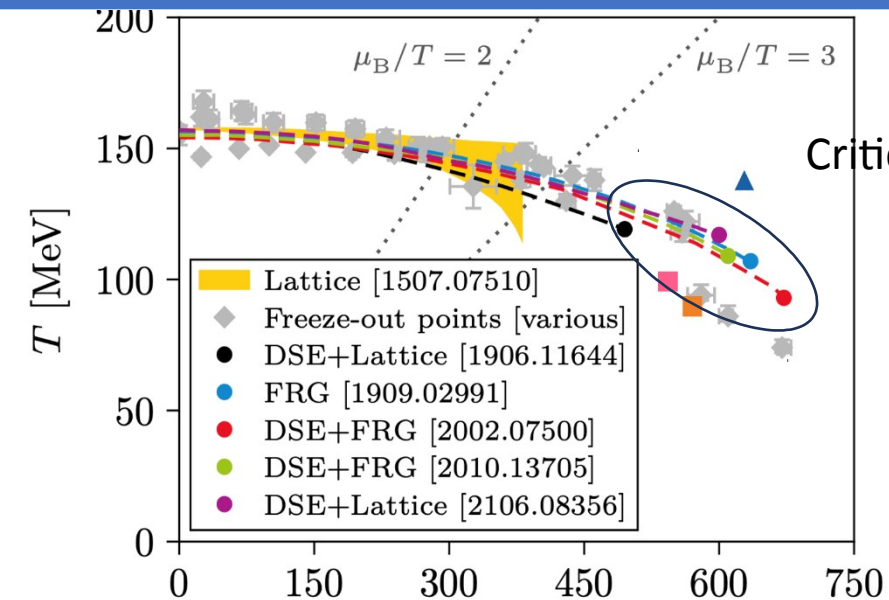


Politechnika
Warszawska



- High rate capability (CBM 10 MHz , HADES 20 kHz)
- Excelent PID (light fragments, p/pions/kaons/leptons)
- fluctuations (higher order cumulants) -search for critical point, phase transition (quarkonic matter)
- production of multistrangeness (EOS) and charm close to threshold (pA,pp)
- Low and Intermediate mass dileptons (Chiral symmetry restoration)

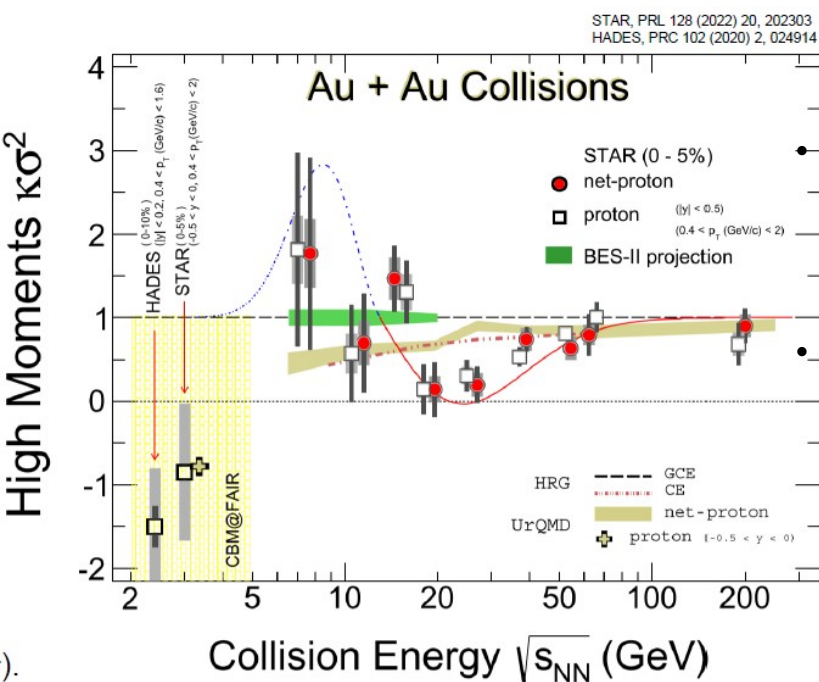
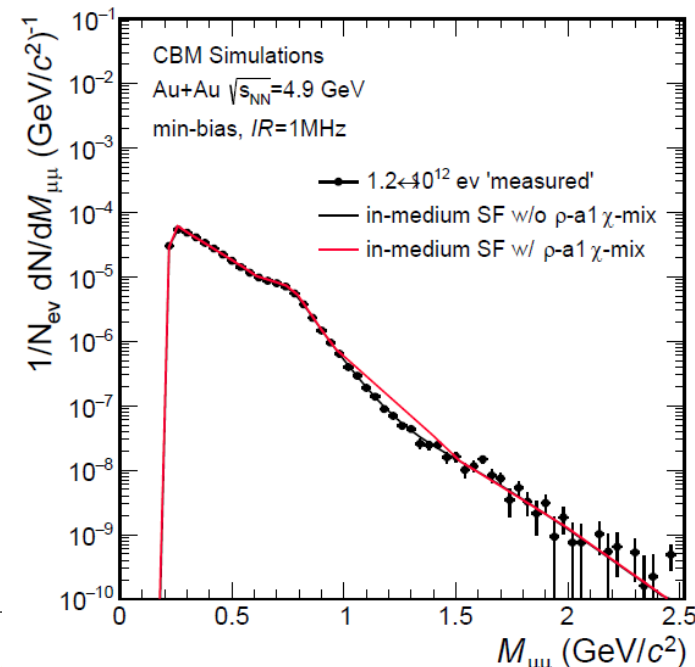
QCD phase diagram-observables



Critical Point?

Chiral symmetry restoration- ρ/a_1

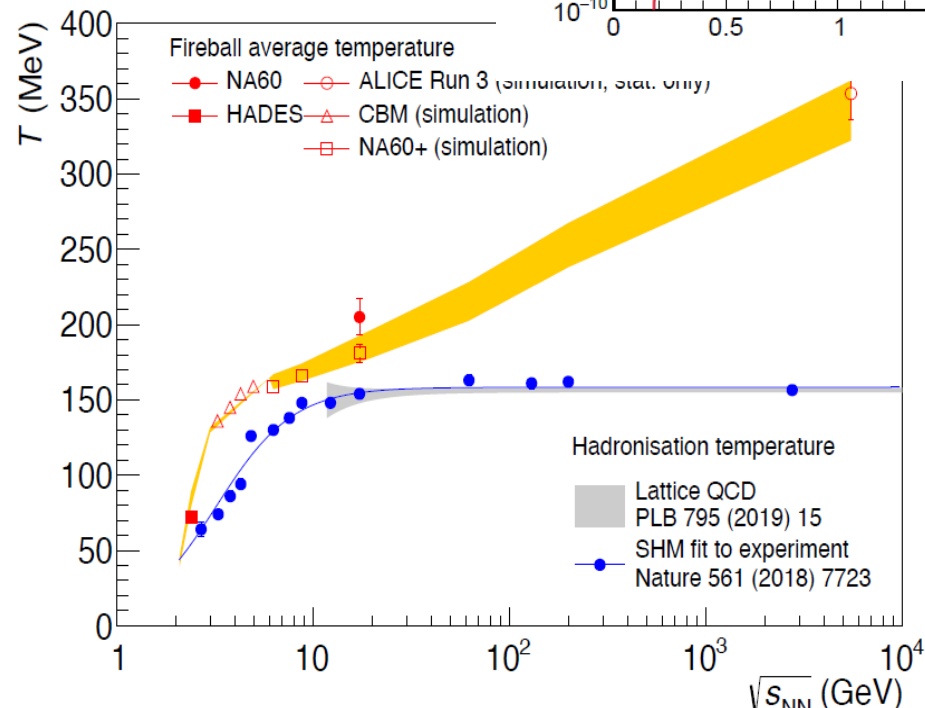
T measurement with dileptons



Ratio 4'th/2'nd moment of net-proton mult.

Distributions

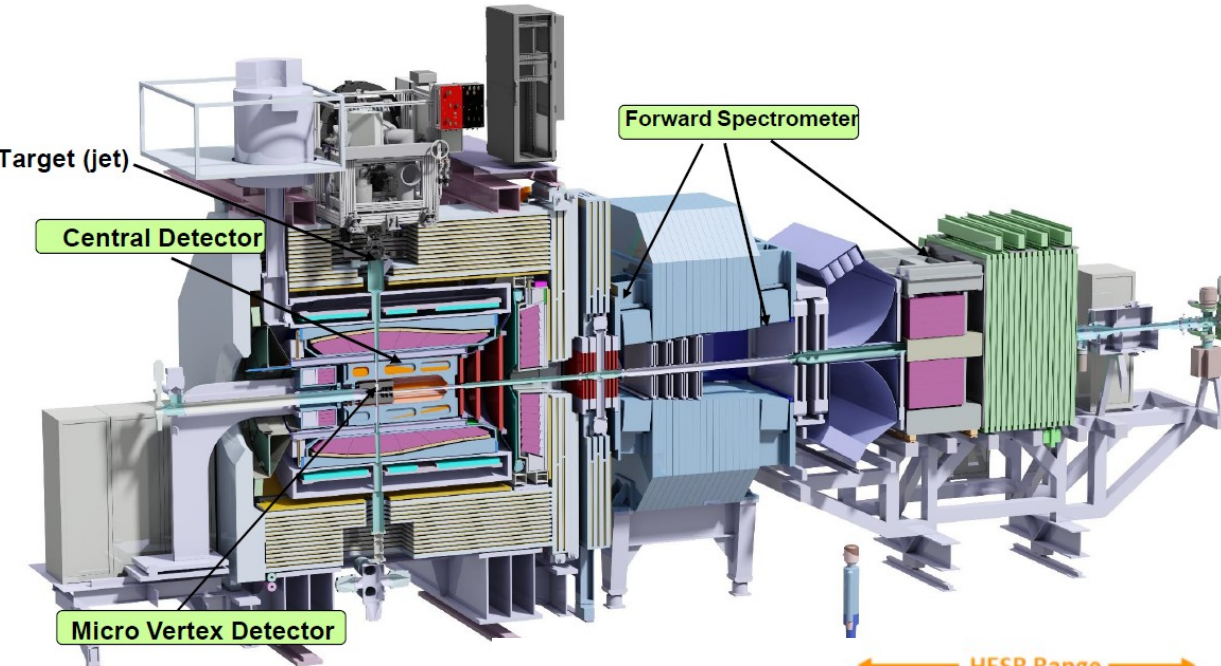
Non-monotonic excitation function expected for CP



Proton ANnihilation in Darmstadt (PANDA)

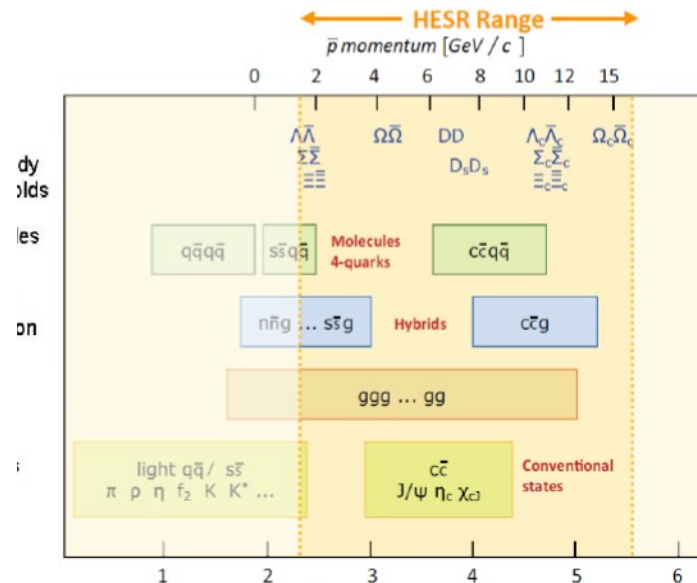
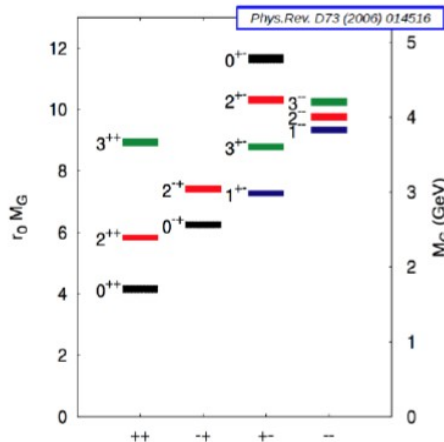
Scientific program
arXiv:0903.3905v1

PANDA



Glueball mass spectrum

LQCD calculations



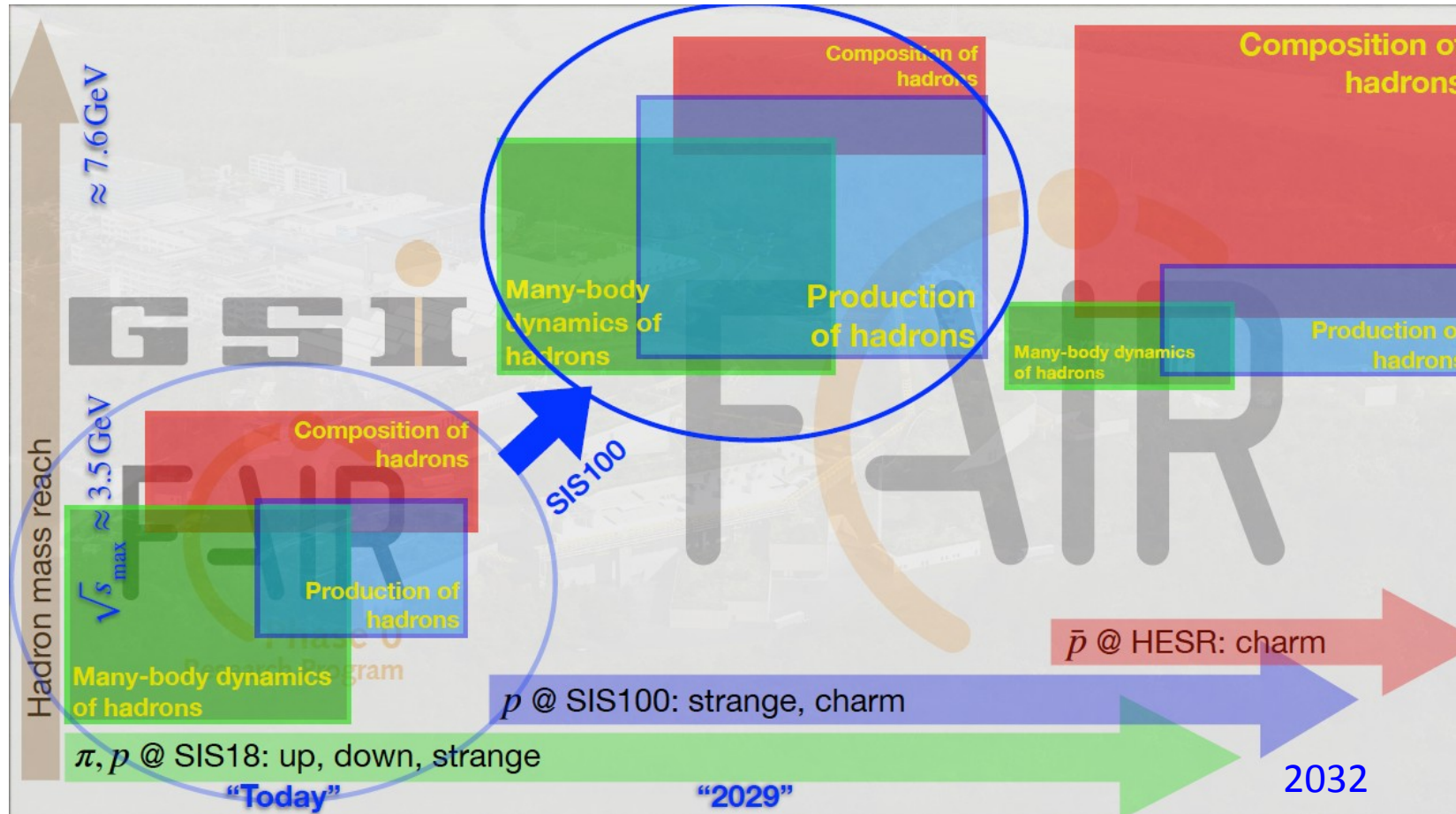
Research area

- Hadron production and spectroscopy (in particular with strangeness and charm content) in proton-proton annihilation
- Search for exotic states (tetraquarks, pentaquarks, glueballs,...) in $p\bar{p}$ (in formation processes)
- precise scan of hadron mass distributions: resolution determined by HESR $\Delta E \approx 5$ keV
- Structure of proton (em. form factors, GPD distribution functions)
- ...

PANDA on hold (not in FirstScience+ scope), not expected before 2032, discussion on solutions are ongoing.

Hadron physics @FAIR with SIS100

Discussion started in 2024– white paper in preparation



- Use the opportunity of 30 GeV proton beam from SIS100 and CBM/HADES detector (>2028)

- ✓ Spectroscopy of baryons states with double and triple strangeness (only few states are known)
- ✓ hyperon-nucleon interactions
- ✓ ...

Exclusive charm production close to production threshold :

- ✓ gluon and charm content of nucleon
- ✓ Exotic charm baryons $P_c(4312)$, $P_c(4400)$, $P_c(4457)$
- ✓ ...

- Cold matter effects (Vector Mesons)

Use the opportunity of secondary pion beam at SIS18 and HADES detector

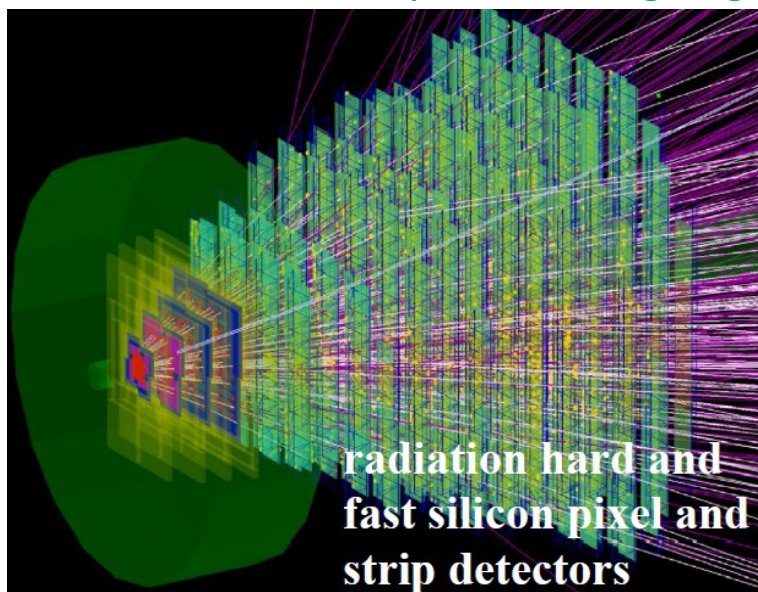
- ✓ Electromagnetic structure of baryons
- ✓ Meson production and interaction
-

In-Kind contributions to CBM/PANDA

Detectors, dedicated read-out electronics (ASIC, FPGA) and read-out firmware, control systems for target

CBM : Silicon Trackin Stations(STS) -4 contracts
Sensors 1.8 mln channels, development and production of
ASIC"STS-XYTER", front-end boards

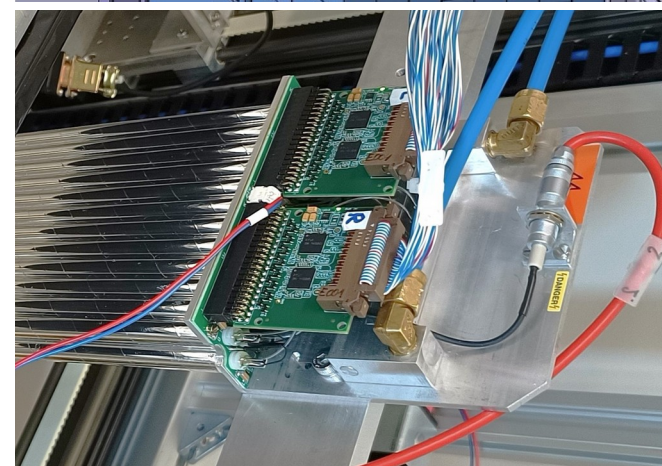
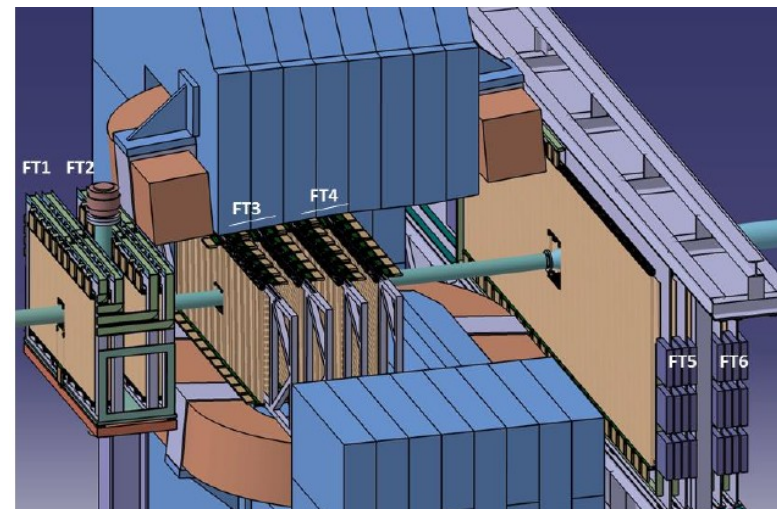
✓ Production completed – on going tests



½ ladder with read-out



PANDA : Straw Tube Tracker in Forward Detector about 12k straws,
(50% completed) of ASIC „PASTTREC”, (completed) , read-out
boards (TDC) and data processing



One module of
straws with
read-out cards

Summary

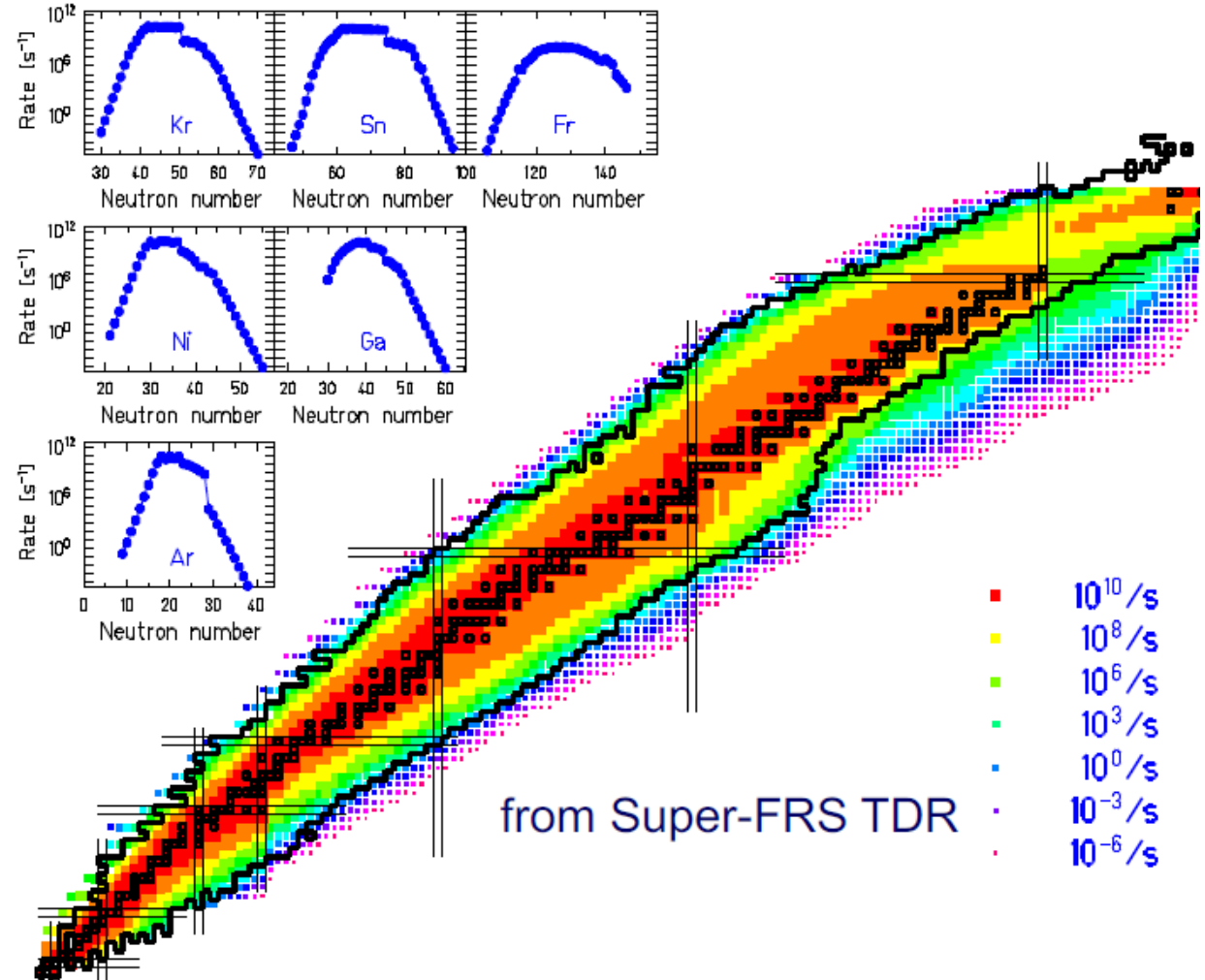
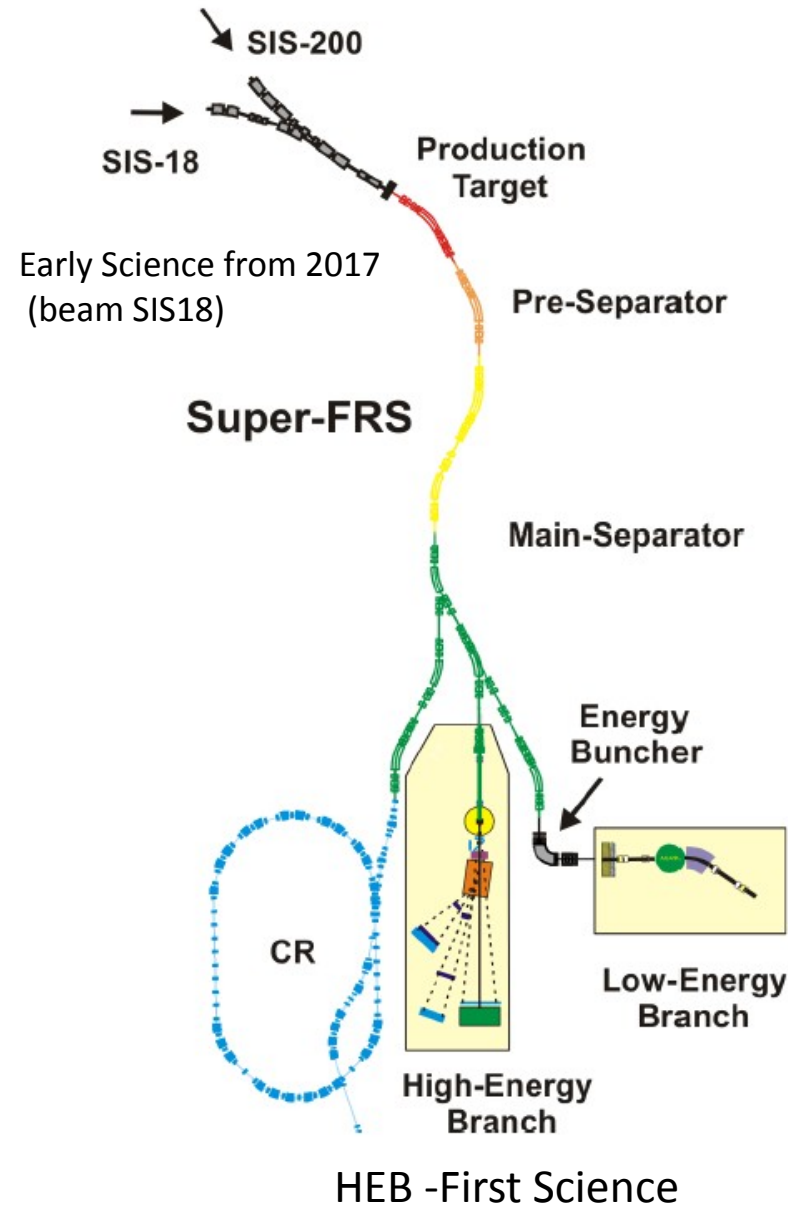
- FAIR is a unique project on a European landscape of that opens new possibilities for research in atomic, nuclear and materials physics and their applications.
- FAIR is now in installation and integration phase aiming in completion of the new SIS100 accelerator, Super Fragment Separator (SFRS) and NUSTAR and CBM detectors by end of 2028.
- Polish in kind contributions are critical for timely completion of the FirstScience configuration
- Polish research groups actively participate in FAIR's research pillars. The challenge is to maintain their potential and extend polish participation , particularly among young researches.

<https://fair.uj.edu.pl/>

Super Fragment Separator (SFRS)- production rates

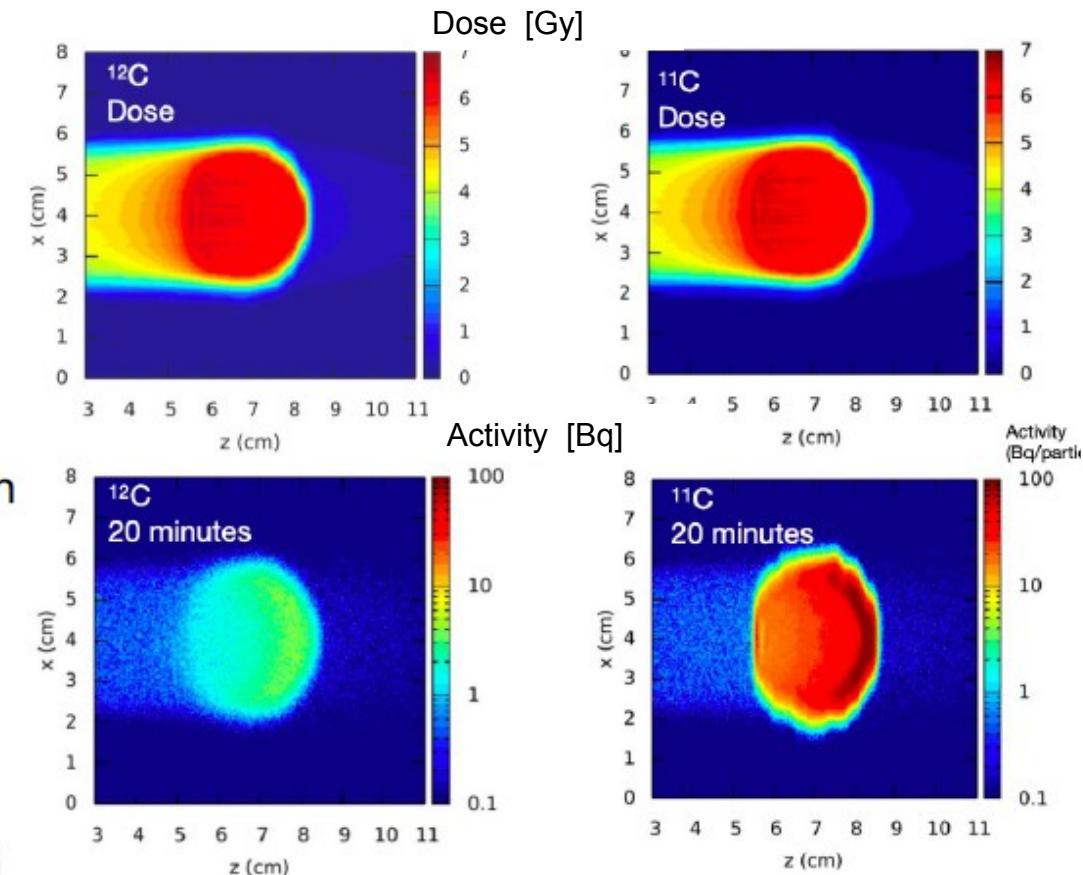
Beams of neutron rich nuclei;

Spectroscopy in flight and rest, mass and life time measurements, reaction mechanisms



Cancer therapy with Radioactive Beams?

- Cancer therapy with radioactive beams (for example ^{11}C , ^{15}O) of large intensity ($\sim 10^7$ p/s)
- Much better control of effective range (< 0.5 mm) $\rightarrow$ better correlation of Activity and Dose



Boscolo et al., *Front. Oncol.* 2021

www.gsi.de/BARB

