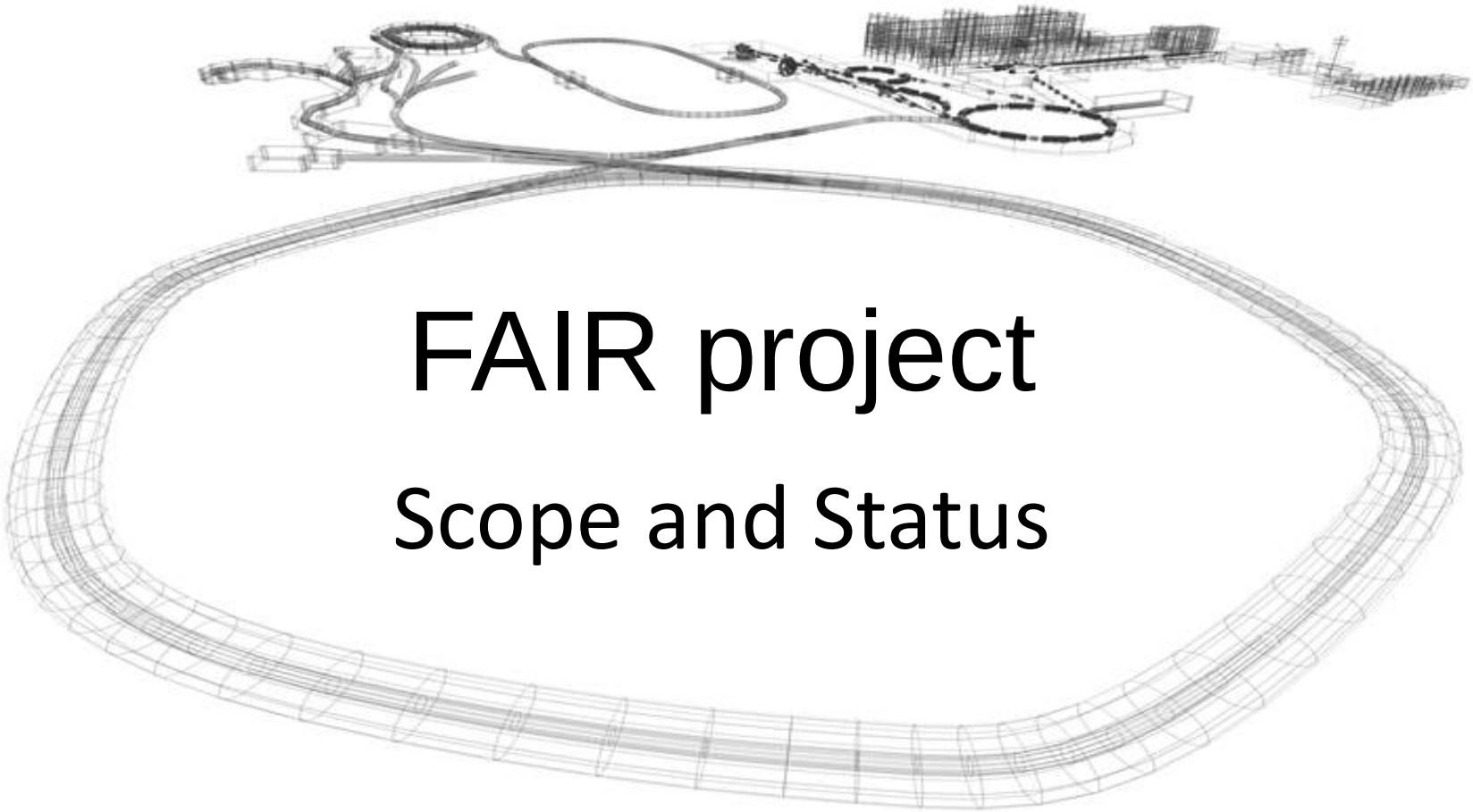
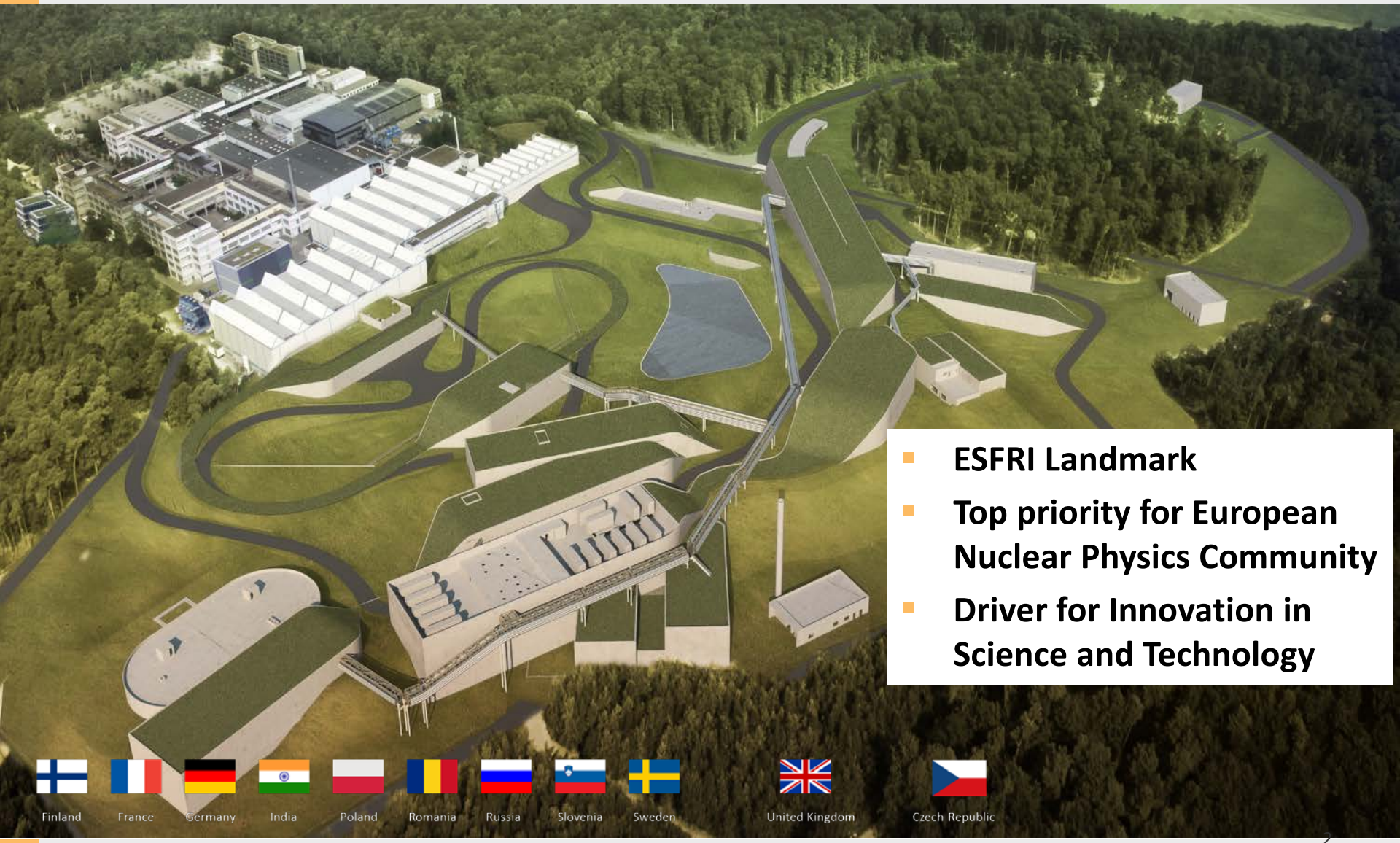


FAIR project

Scope and Status

Norbert Herrmann
Heidelberg University

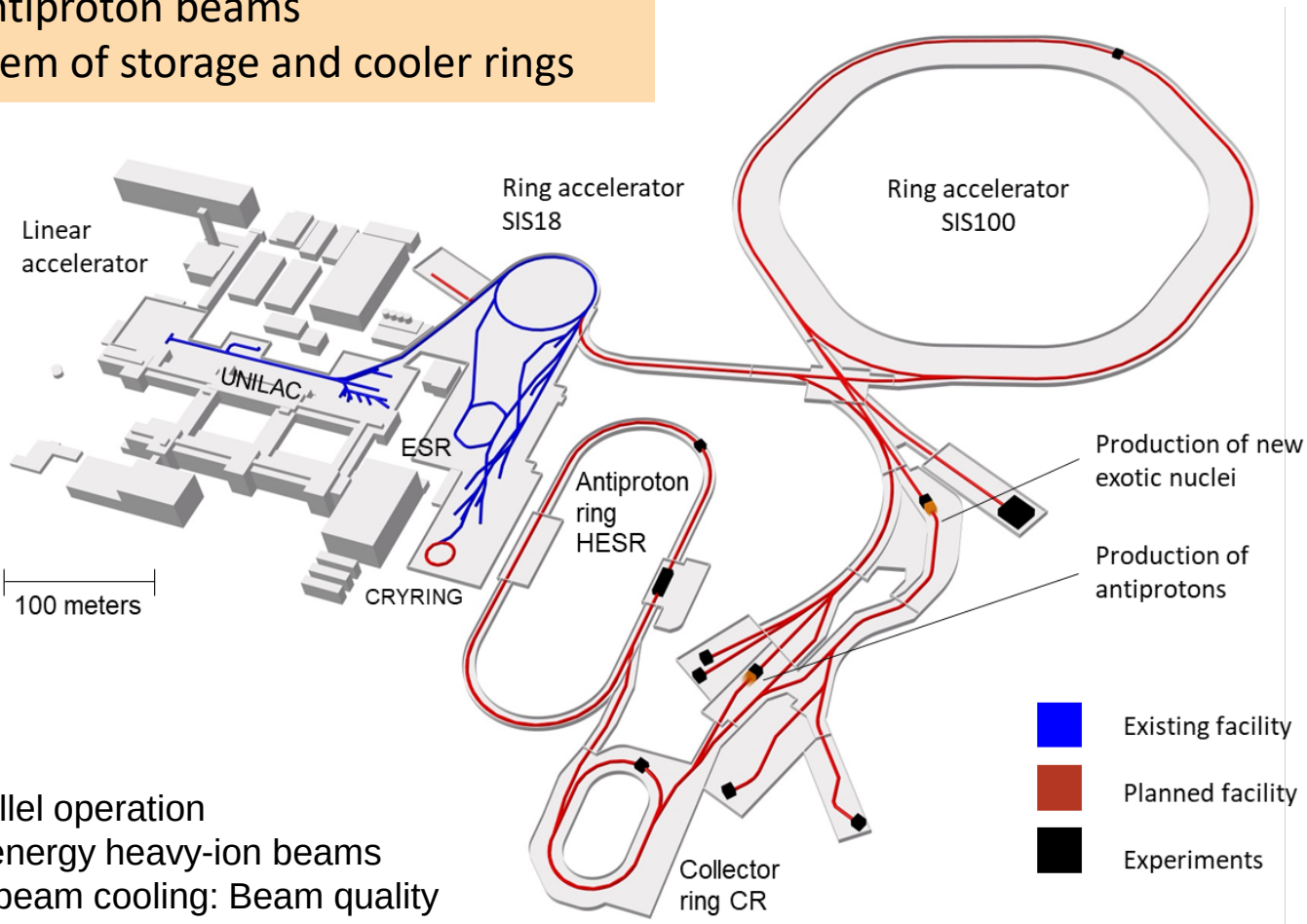
FAIR: Facility for Antiproton and Ion Research – A World-Wide Unique Accelerator Facility



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

FAIR – The Facility

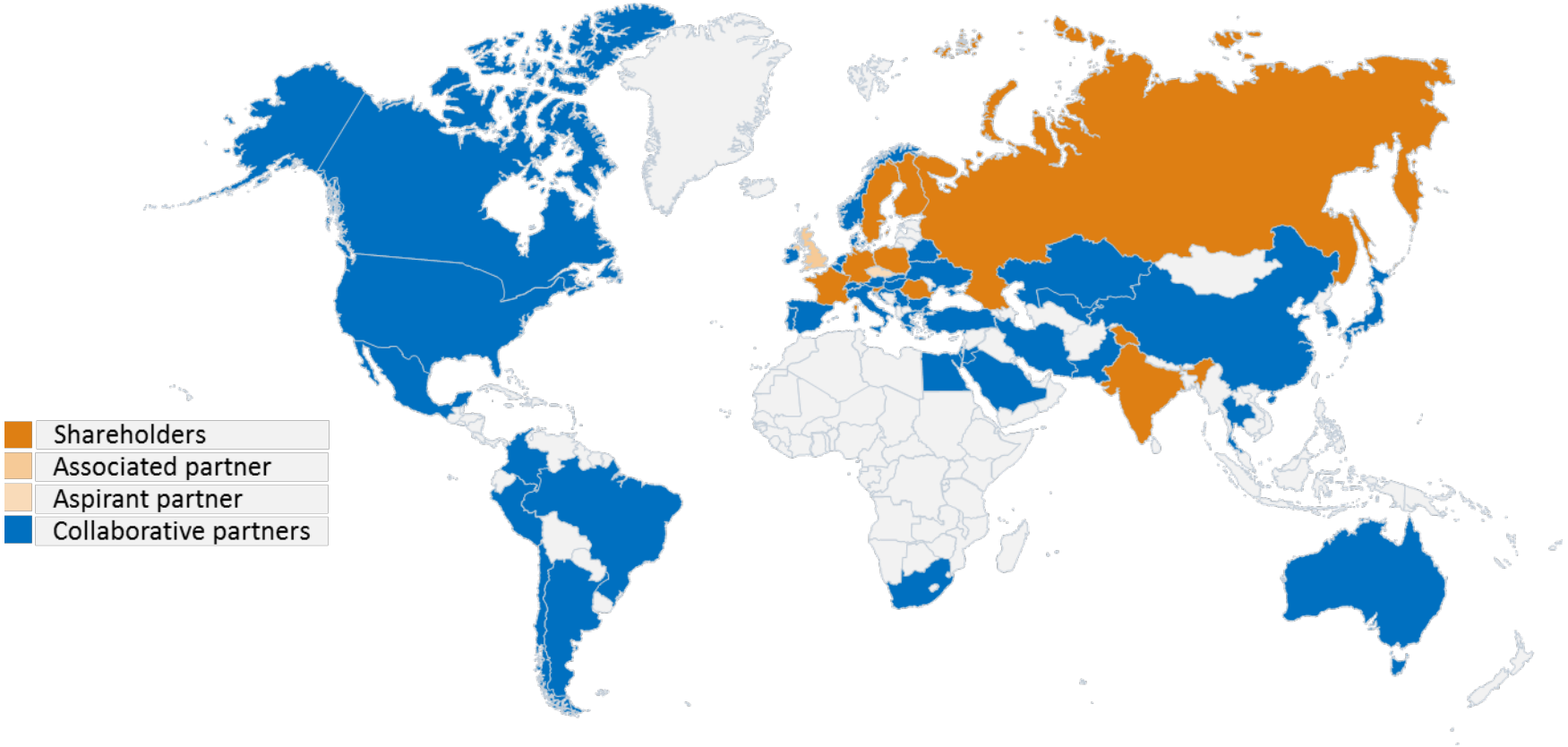
- **Intensity gain: x 100 – 1000**
- 10 x energy (comp. to GSI)
- **Antimatter:** antiproton beams
- **Precision:** System of storage and cooler rings



Unique features:

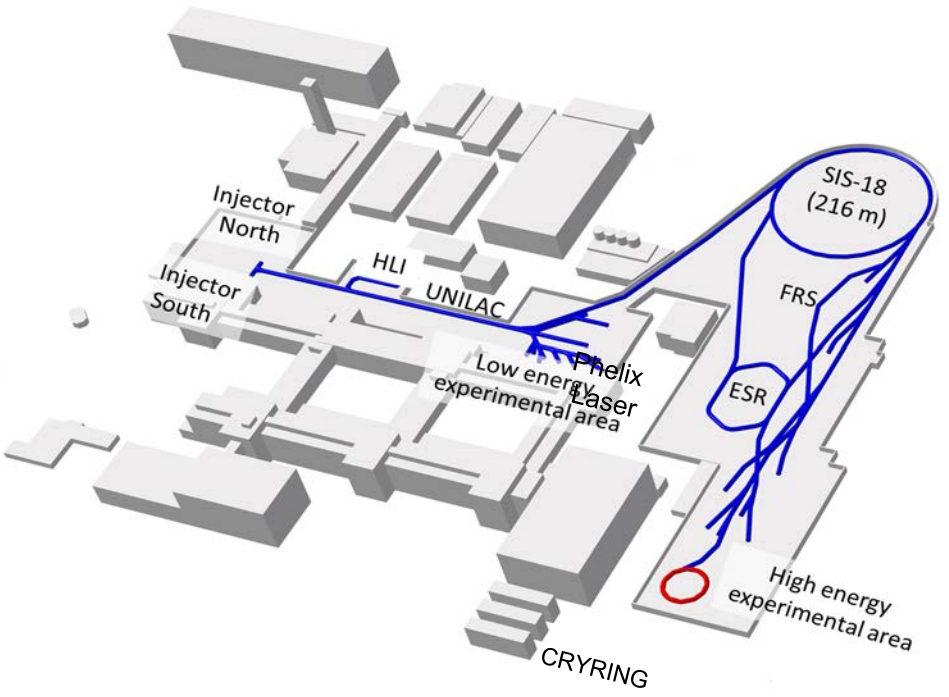
- Flexibility and parallel operation
- **Intense** and high-energy heavy-ion beams
- Storage rings and beam cooling: Beam quality

FAIR: International Cooperation



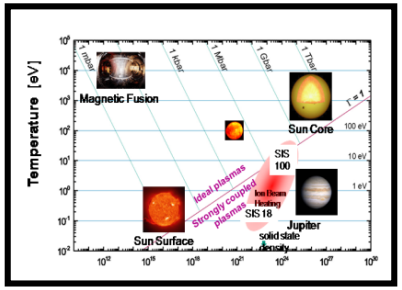
- **9 international FAIR Shareholders**
- 1 Associated Partner (United Kingdom)
- 1 Aspirant Partner Czech Republic (Since 2018)
- Participation of **3.000 scientists from all continents**

GSI – Almost 50 Years of Scientific and Technical Competence



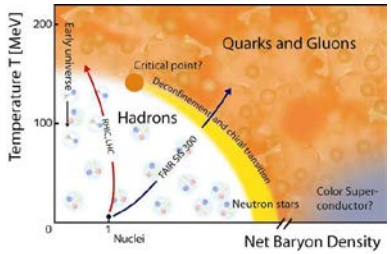
- Reference laboratory for nuclear physics in Europe, one of the top heavy-ion accelerator facilities in the world

The FAIR science: four pillars



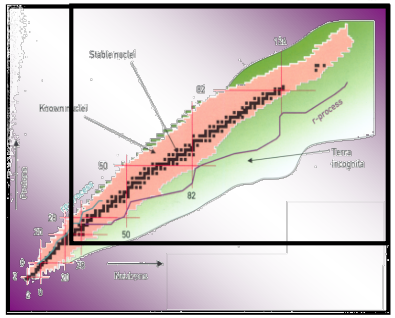
atomic physics, biophysics,
plasma physics, material research

APPA



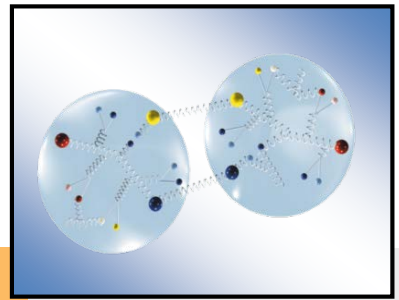
nuclear- and quark-matter

CBM



nuclear structure and
nuclear astrophysics

NuSTAR



hadron structure and dynamics

PANDA

Status of FAIR Project: Civil Construction

Progress since official start on 4th of July 2017

Status of FAIR: Accelerators:
construction / procurement progress

36 sc dipole SIS100 modules manufactured at BNG and 22 shipped to GSI and tested

SIS100 quadrupole units shipped from JINR to BNG for integration in FOS module

All 51 HEBT vacuum chambers of batch 1 delivered (BINP, Russia)

The series production of RF – debunchers

All HESR Dipoles are produced, in Jülich and 65% are delivered to FAIR

Delivery of 1st 6 series Power Converter from India, (ECIL, India)

Status of FAIR: Accelerators:
construction / procurement progress

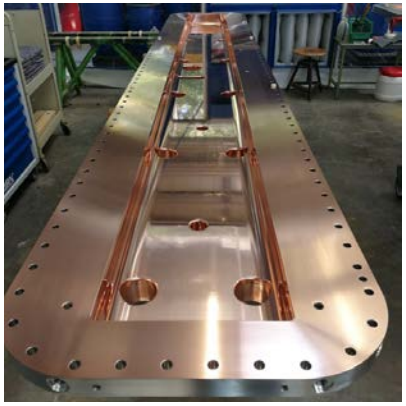
Two FoS vacuum chambers for the quadrupole doublet modules of the SIS100 arrived from China. They will be installed by the integrator in the quadrupole units

First-of-Series of the Super-FRS short SC Multiplet arrived in February 2019 at CERN test facility for execution of the Site Acceptance Test

First HESR Stochatic cooling pick-up and kicker in operation at COSY

Successfully First-of-Series FAT for the Super-FRS short SC Multiplet took place in Italy at January 2019

Copper plating and first tests of the RFQ accelerator cavity for the pLinac have been completed and match specifications



Three new MA acceleration cavities installed and commissioned with beam

Distributed testing infrastructure for the FAIR superconducting magnets

GSI: Series test facility for the SIS100 s.c. dipole magnets, string test, current leads and local cryogenics components.

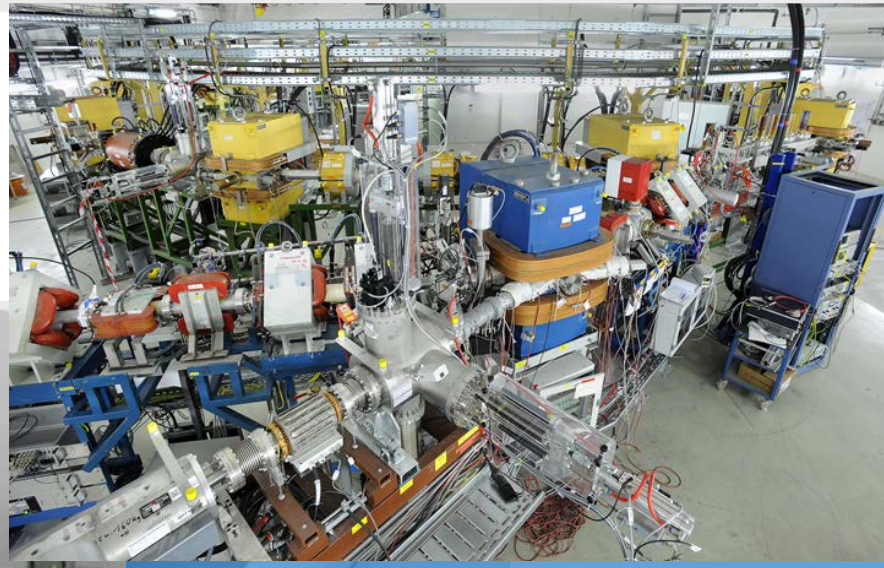
CERN: Test facility completed for the Super-FRS s.c. dipoles and multipletts

INFN: Test facility in Salerno for testing the series of SIS100 quadrupole modules

JINR, Series test facility in Dubna for testing of the series of SIS100 s.c. quadrupole units

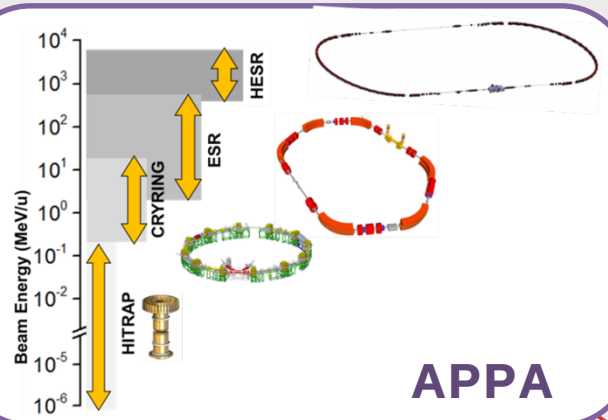
New CRYRING@GSI/FAIR

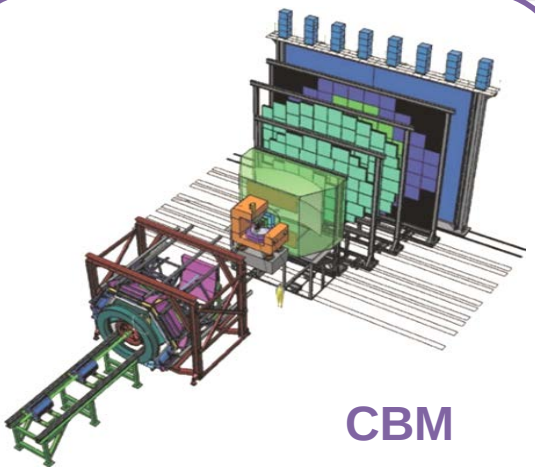
- FIRST FAIR accelerator
- ready for experiments and tests

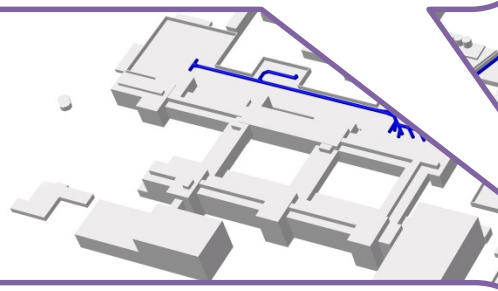


View from local injector to the ring

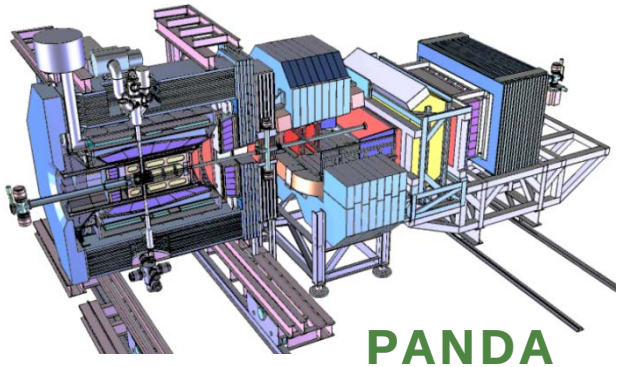
FAIR – four research pillars

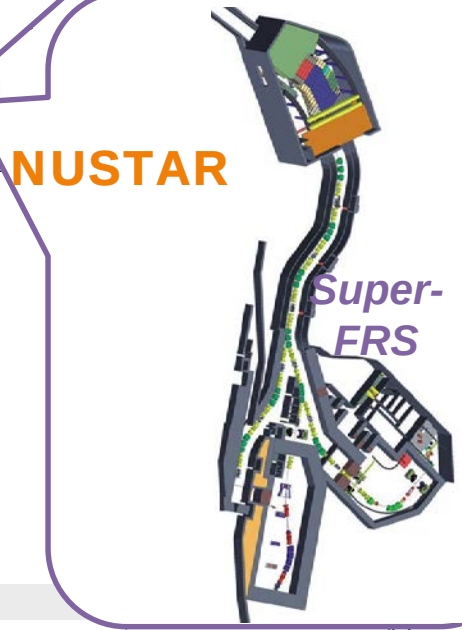




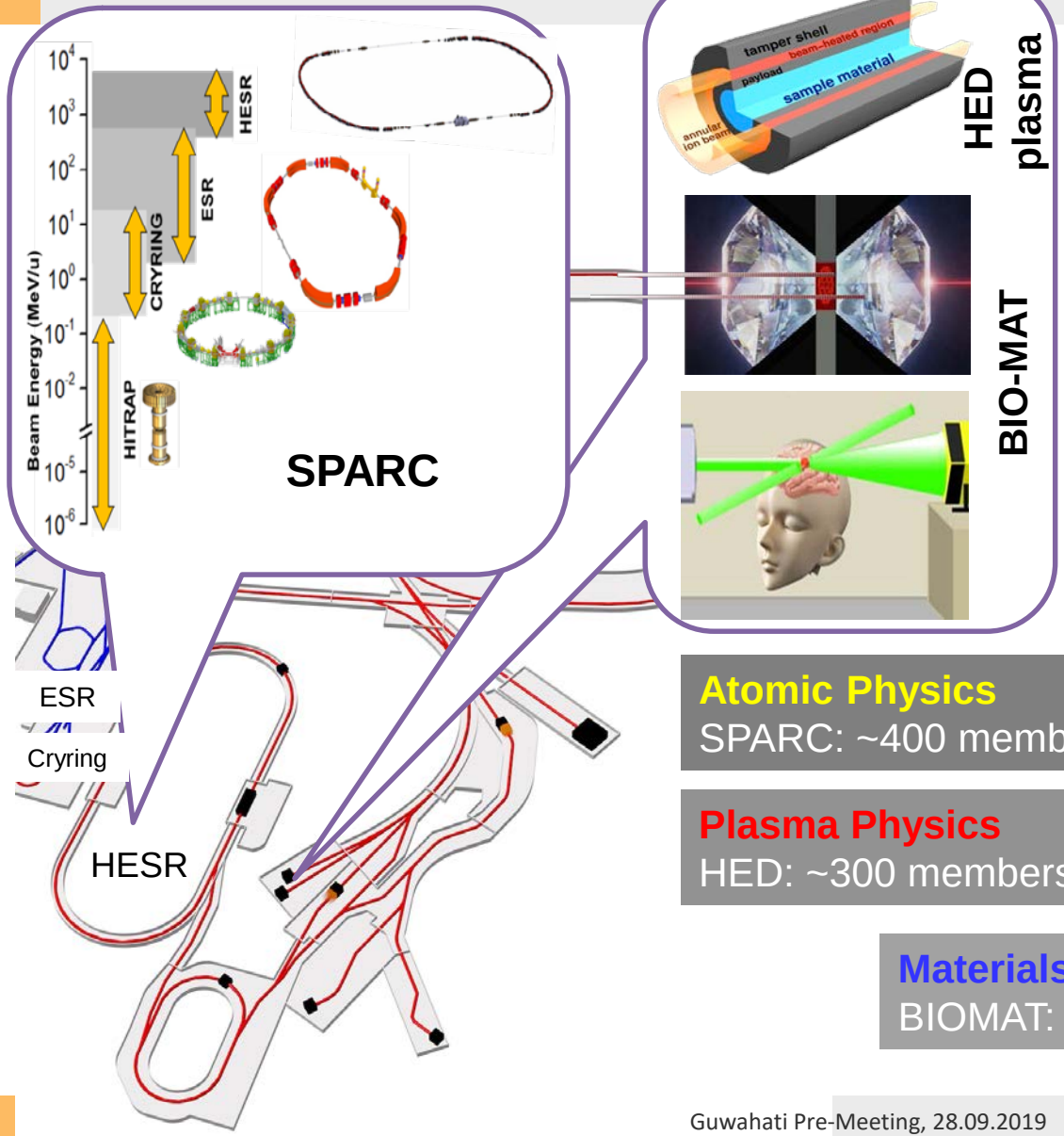


HESR





APPA



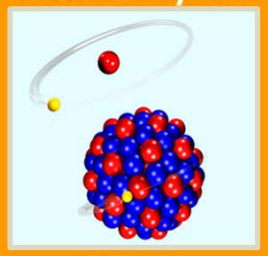
- Atomic, Plasma Physics and Applications
  - About 800 members
  - Wide field of science
    - basic research into material, biological and medical applications and space research

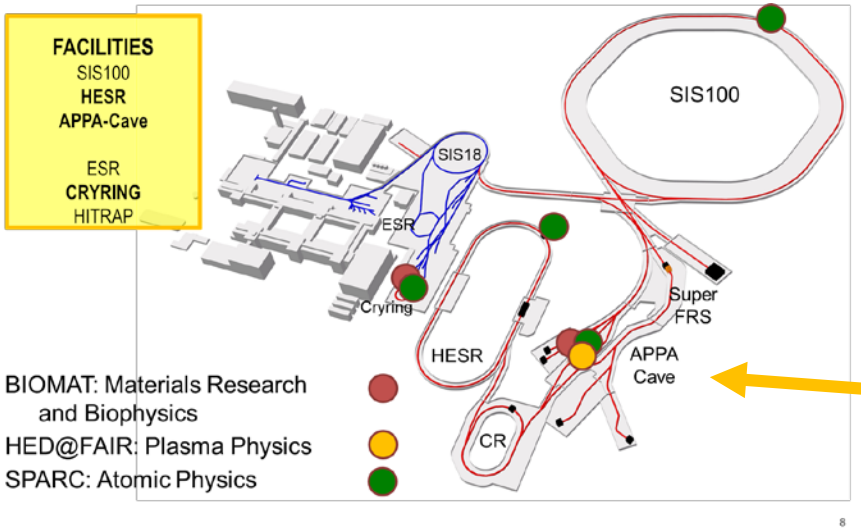
Atomic Physics
SPARC: ~400 members from 26 countries

Plasma Physics
HED: ~300 members from 16 countries

Materials Research and Biophysics
BIOMAT: ~100 members from 12 countries

APPA - Atomic Physics, Plasma Physics, and Applied Sciences

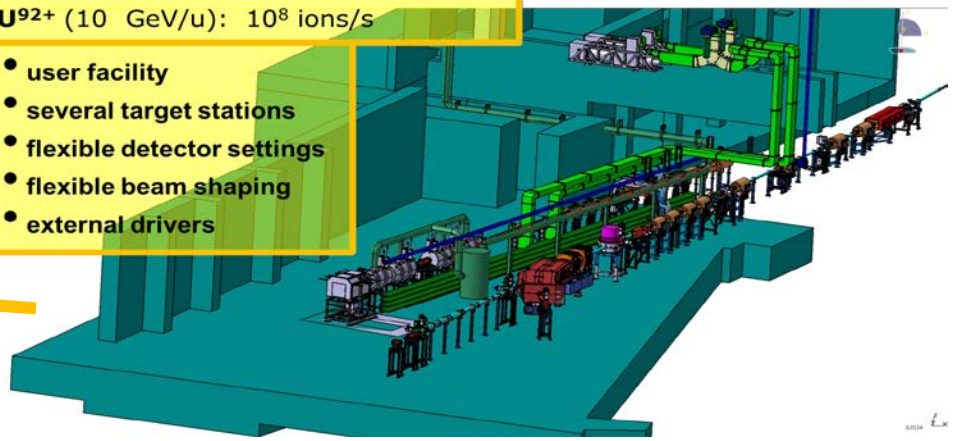
Atomic Physics	Plasma	Materials	Bio
			
SPARC	HED@FAIR	MAT/BIOMAT	BIO/BIOMAT
strong field research … probing of fundamental laws of physics	**warm dense matter** … states of matter common in astrophysical objects	**radiation hardness** … mechanical and electrical degradation of materials	**space travel** … cosmic radiation risk and shielding



protons (10 GeV): 2 x 10^{13} p/bunch
U^{28+} (2 GeV/u): 5 x 10^{11} ions/bunch
U^{92+} (10 GeV/u): 10^{8} ions/s

- user facility
- several target stations
- flexible detector settings
- flexible beam shaping
- external drivers

APPA Cave



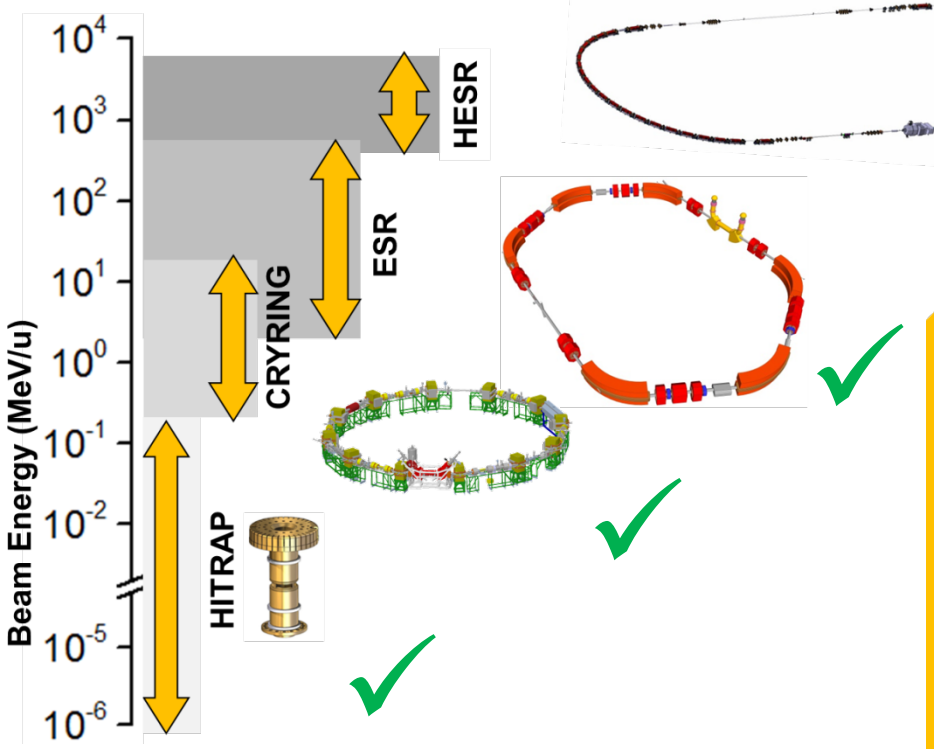
Ion Beam Facilities / Trapping & Storage

Worldwide Unique

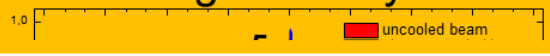
Precision: Stored and Cooled

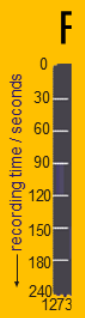
Highly-Charged Ions (e.g. U^{92+}) and Exotic Nuclei

From Rest to Relativistic Energies (up to 4.9 GeV/u)



Cooling: The Key for Precision

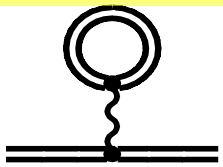




- Radiative corrections in the non-perturbative regime
- Correlated multi-body dynamics for atoms and ions
- Precision determination of fundamental constants
- Influence of atomic structure on nuclear decay properties
- Astrophysics with Stored Highly Charged Ions

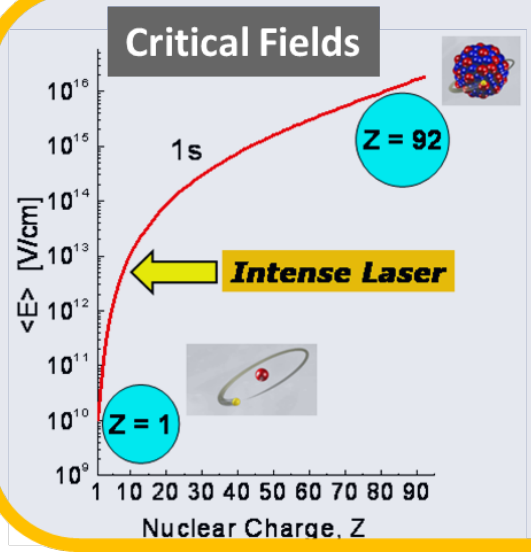
Precision Frontier: Atomic & Fundamental Physics

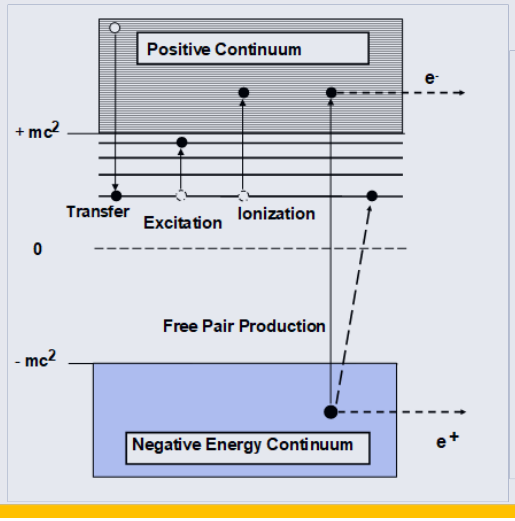
Interplay between Relativity, Correlation, and QED in the Non-Perturbative Regime

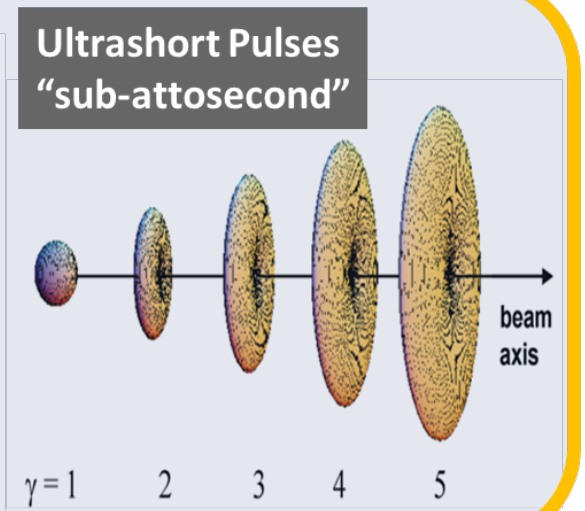


$$\alpha Z \approx 1$$

- Radiative corrections in the non-perturbative regime
- Correlated multi-body dynamics for atoms and ions
- Precision determination of fundamental constants
- Influence of atomic structure on nuclear decay properties
- Astrophysics with Stored Highly Charged Ions





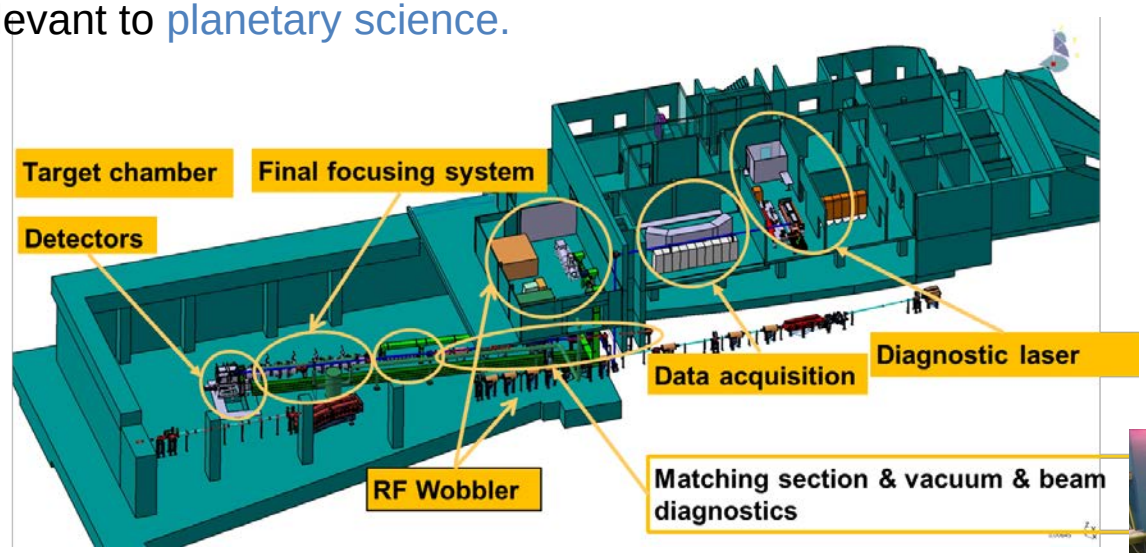


APPA Cave for Plasma Physics / HED@FAIR

Properties of materials driven to extreme conditions and relevant to planetary science.

Shocked matter and material equation of state (EOS).

Basic properties of strongly-coupled plasma created with heavy ion beams and lasers.



External Drivers

Dynamic compression (shocks, ramp) or fast heating by external drivers:

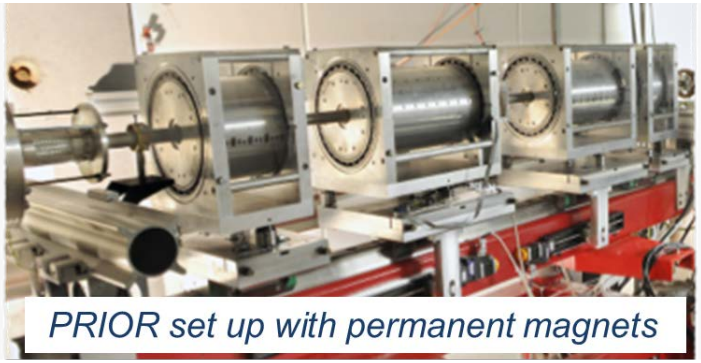
e.g.: high energy laser

PHELIX@GSI

Proton Radiography PRIOR:

Use protons for precise density measurements

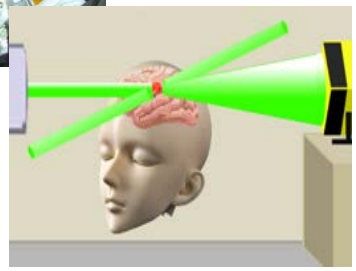
Resolution: σ_x=10μm

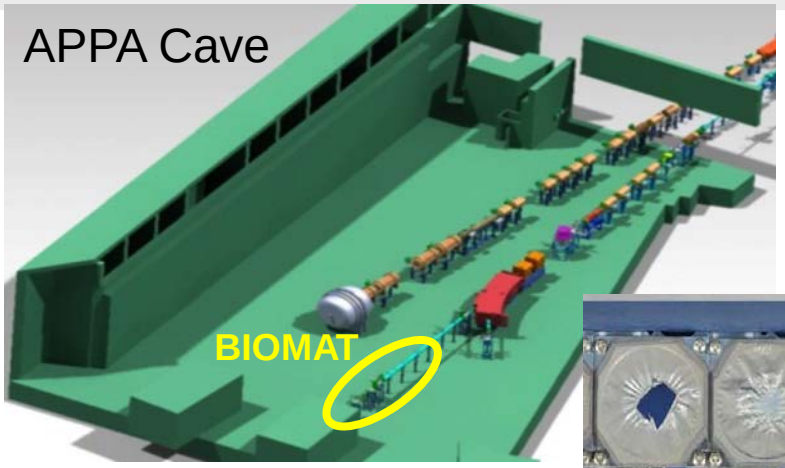


PRIOR set up with permanent magnets

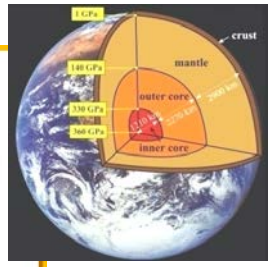
BIOMAT / Materials Research & Bio Physics

Biophysics





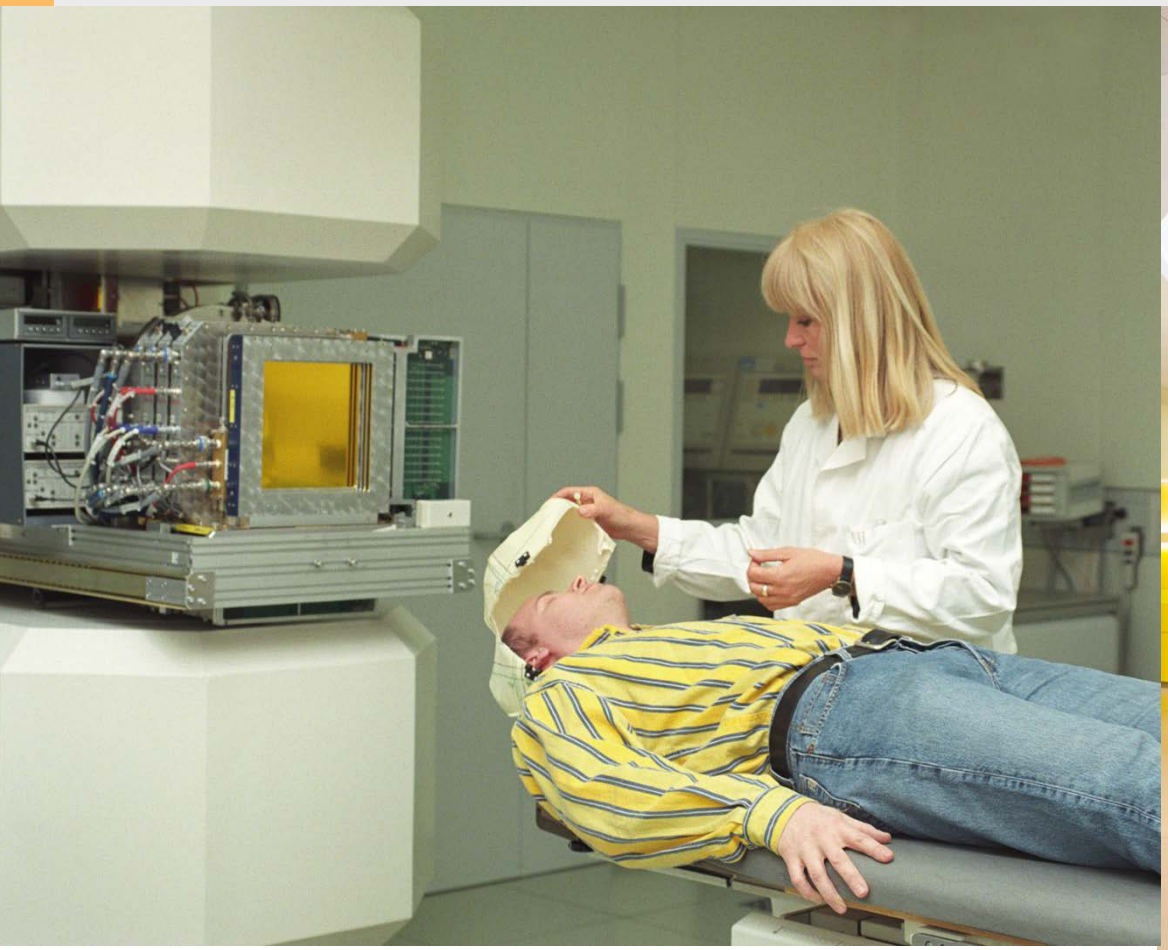
Materials Research



- Simulation of galactic radiation
  main hindrance toward manned space exploration
- Widely unknown biological effects of heavy ions
- Space radiation biophysics
  NASA and ESA started a large experimental campaign
- Particle therapy

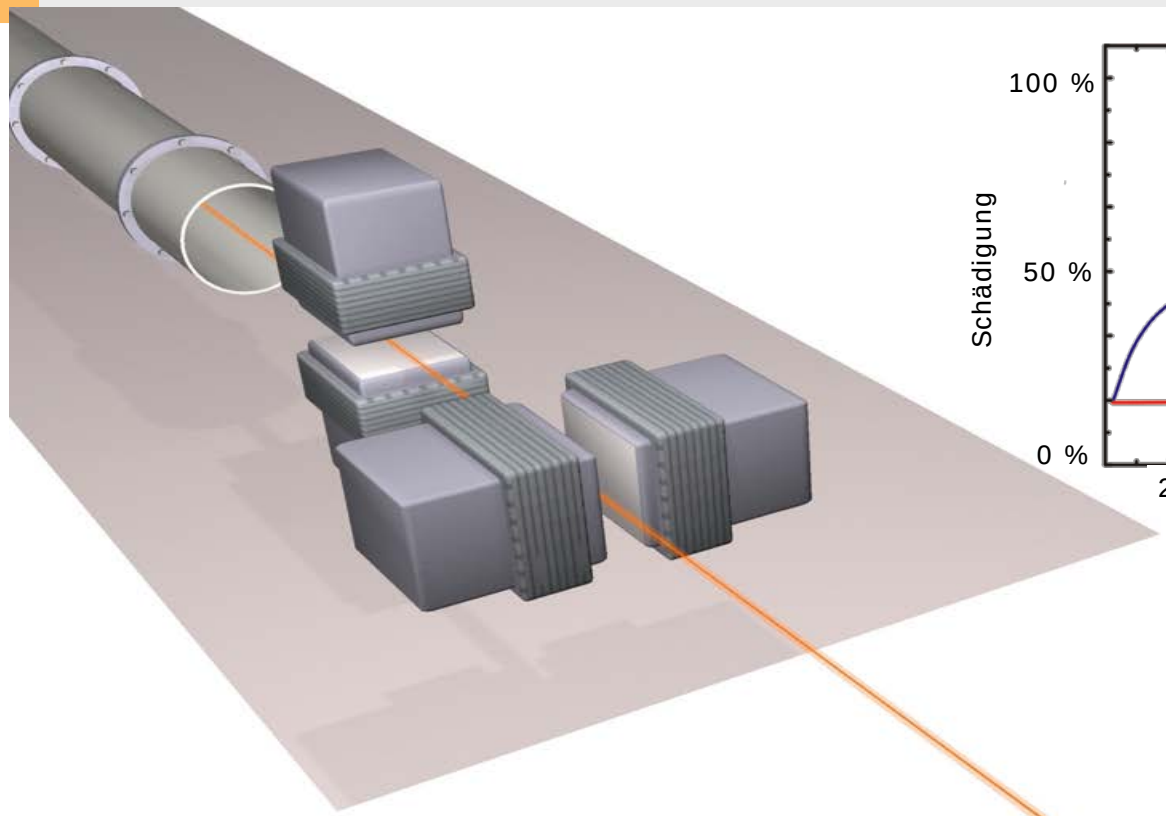
- Materials behavior under extreme conditions
- Irradiations under high pressure solids with new phases, unknown phase transitions in mineralogy and geophysics
- Radiation hardness of accelerator and spacecraft components
- Ion-matter interaction at relativistic beam energies

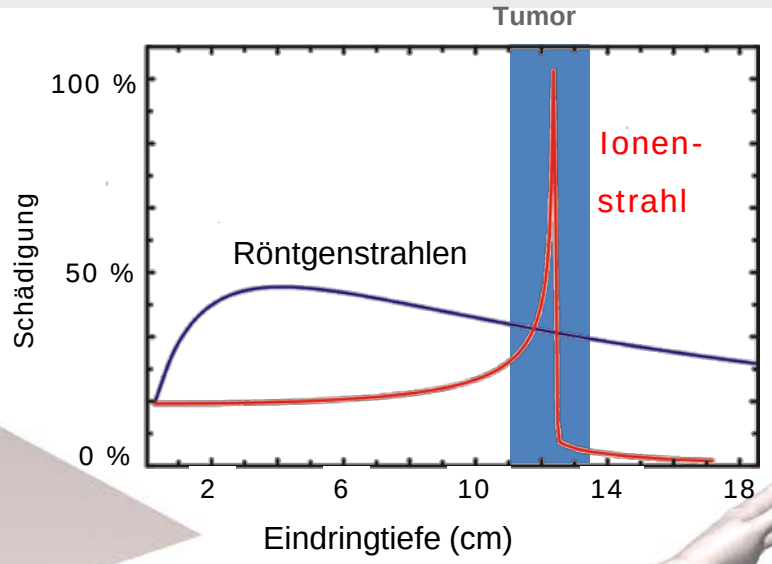
Major GSI Discoveries

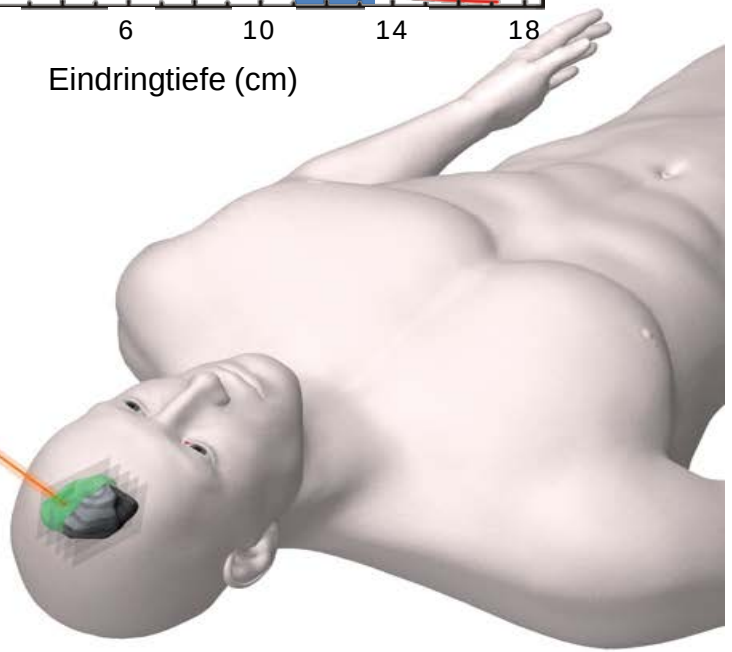


- Innovation in cancer therapy
- 440 patients treated on campus before transfer to specialized clinics (e.g. Heidelberg)

Ion Beam Therapy



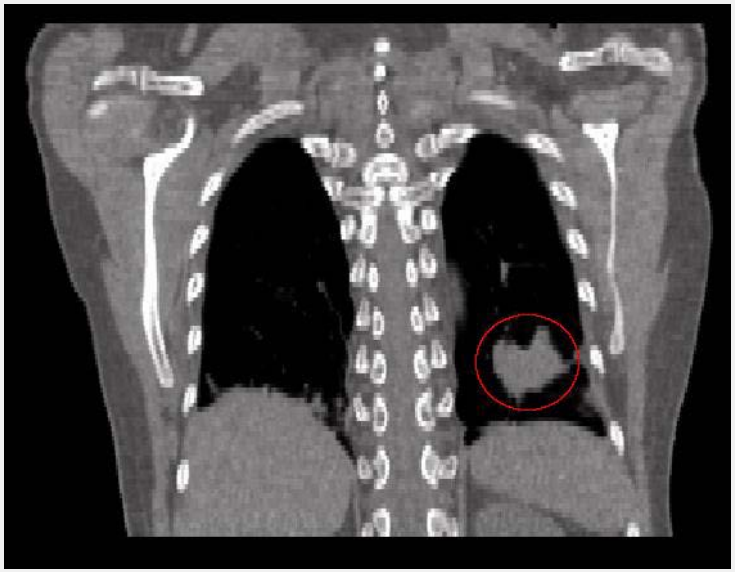




- precise like a scalpel
- extremely efficient in destroying the tumor cells
- spares the healthy tissue

continues to address new challenges

Challenge:
Interplay between target movement and beam scanning



Solution:
Advanced beam delivery system:
➡ Speed, Flexibility, Modularity

Novel Applications for non-Tumor Diseases
(e.g. Heart Arrhythmia)

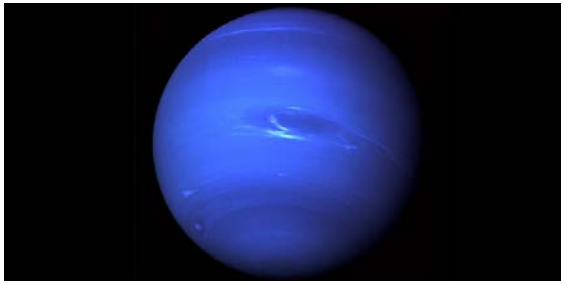
Localized irradiation to destroy dysfunctional „pacemaker“ areas
A particle scalpel

Questions about the Universe

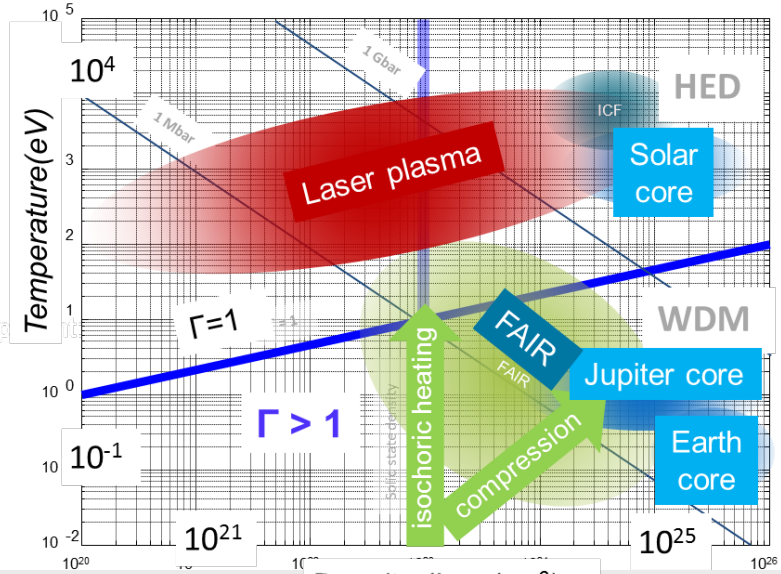
Matter in the interior of the Earth and of large planets

- The interior of our Earth is most likely composed of liquid iron. What is exactly the melting curve for iron?

- Does hydrogen form a metallic state under the extreme conditions of pressure and temperature on and in Jupiter? How does hydrogene separate from He?



- Are there diamond layers in Uranus and Neptune? What role does the high-density metallic state of water play for the magnetic field in Uranus and Neptune?



More Universe in the lab …

FAIR will be able to produce the full CR spectrum

Space radiation protection

ESA ground-based facility for European studies on space radiation risk and countermeasures (IBER)

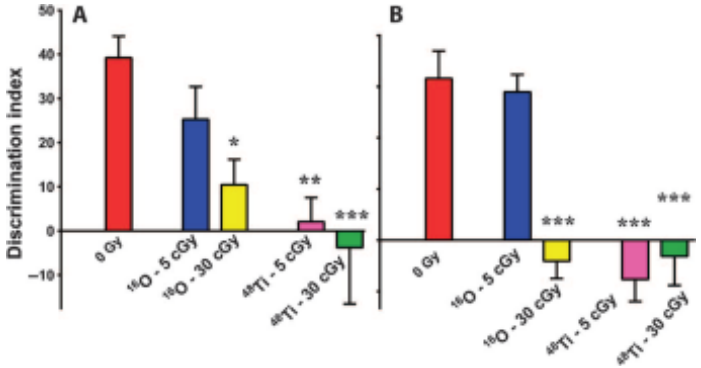
Unique worldwide facility for simulation of the full GCR including very high energy heavy ions

RESEARCH ARTICLE

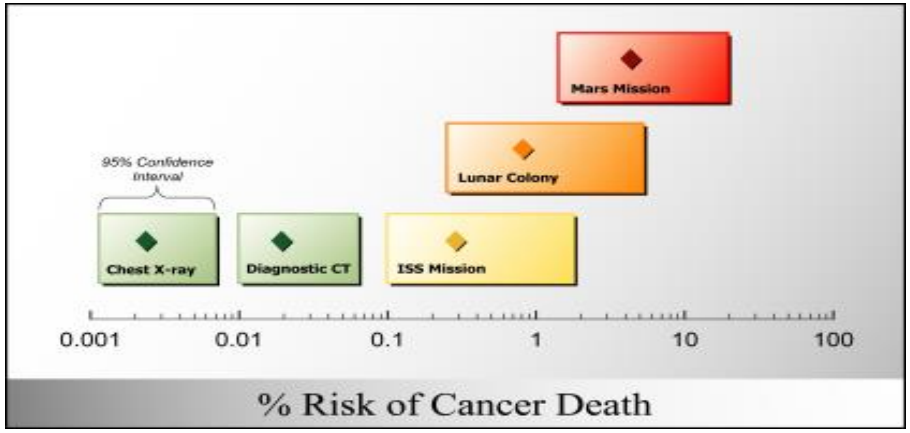
COGNITIVE NEUROSCIENCE

What happens to your brain on the way to Mars

Vipan K. Parihar,[1] Barrett Allen,[1] Katherine K. Tran,[1] Trisha G. Macaraeg,[1] Esther M. Chu,[1] Stephanie F. Kwok,[1] Nicole N. Chmielewski,[1] Brianna M. Craver,[1] Janet E. Baulch,[1] Munjal M. Acharya,[1] Francis A. Cucinotta,[2] Charles L. Limoli[1]*

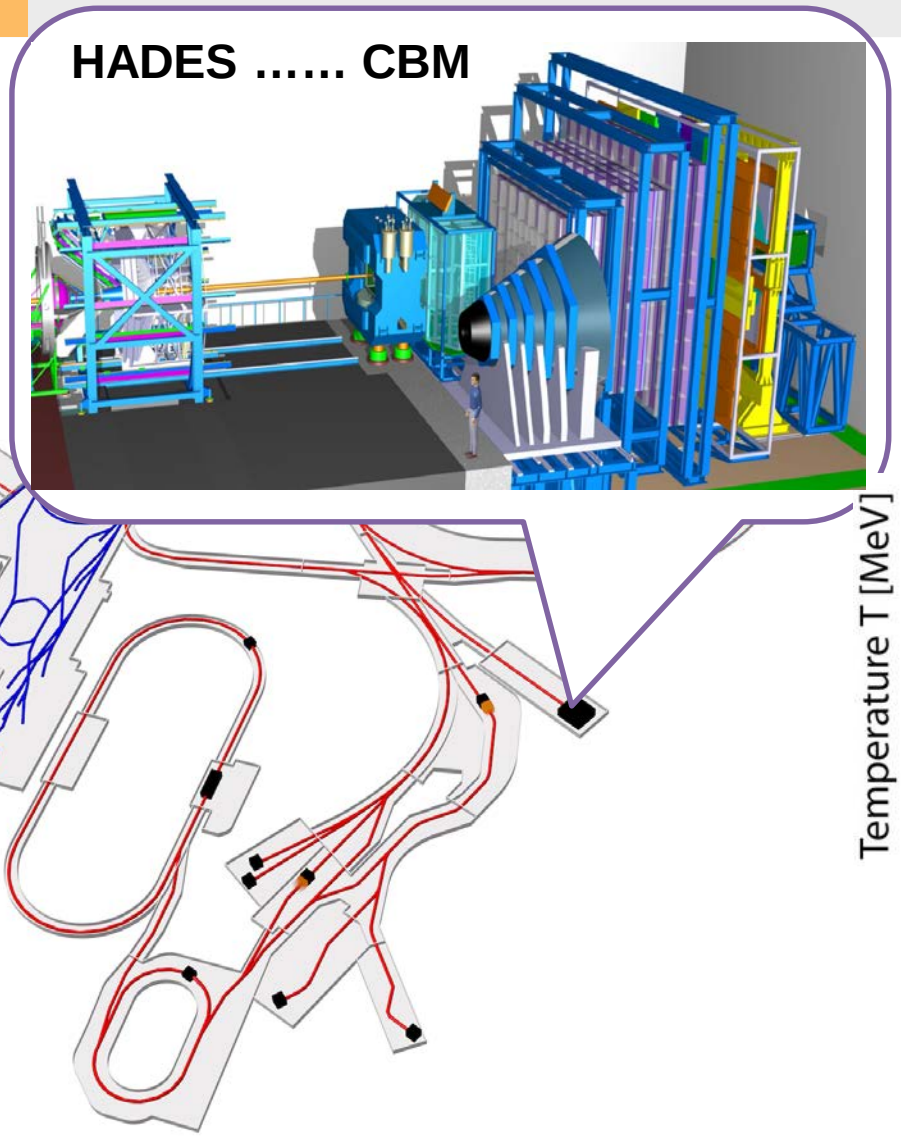


(**A**) recognition memory (**B**) spatial memory

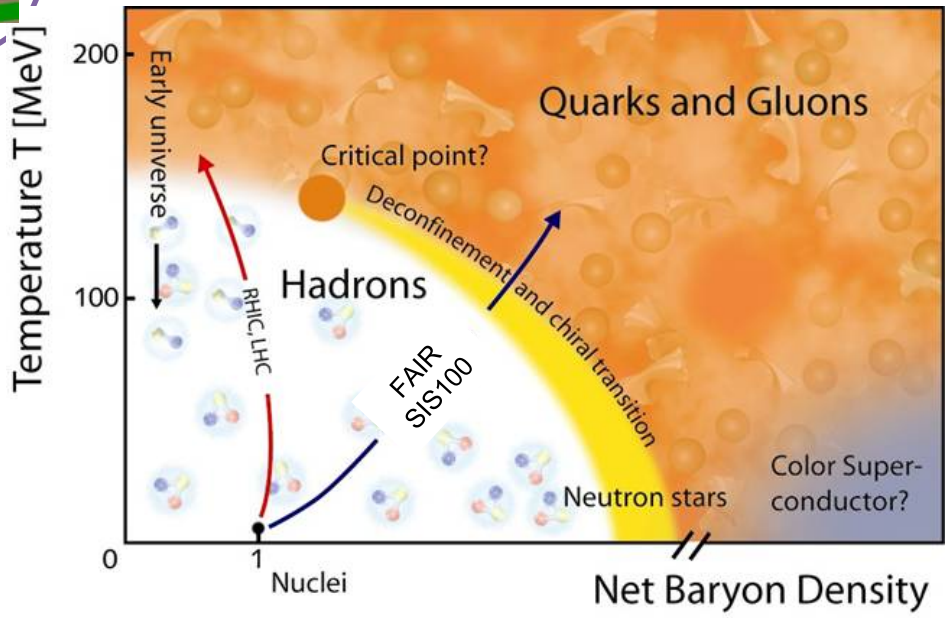


Durante & Cucinotta, *Nature Rev. Cancer* (2008)

C.B.M.

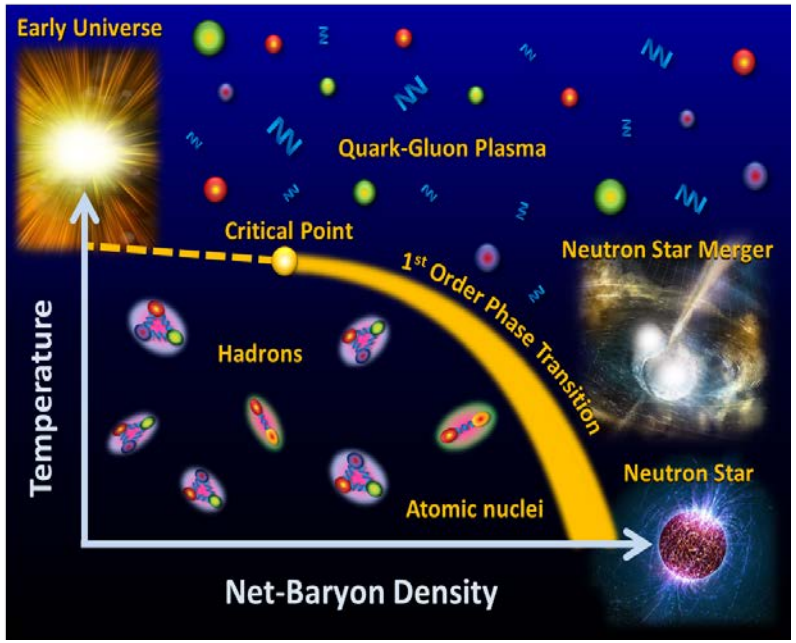


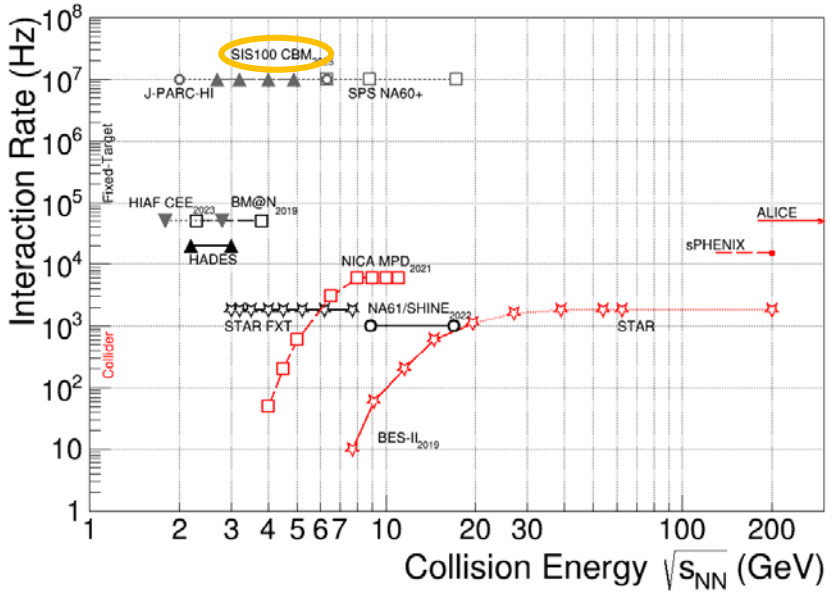
- Compressed Baryonic Matter Experiments
  - About 400 members



CBM - Compressed Baryonic Matter

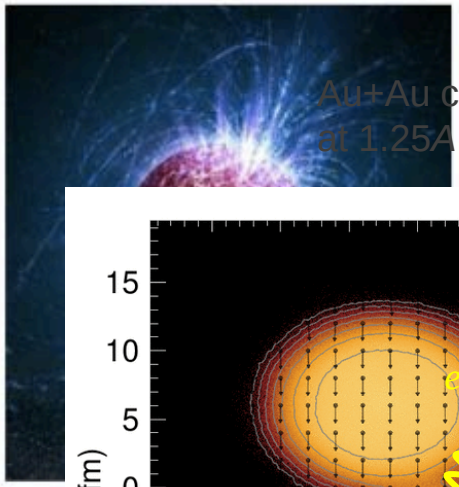
CBM Experiment at FAIR: Systematically explore QCD matter at large baryon densities with high accuracy and rare probes, at highest interaction rates in the field.





Tetyana Galatyuk, Quark Matter 2018, “Future high-μB facilities“

C.B.M. and Neutron Stars or Mergers …



Neutron stars

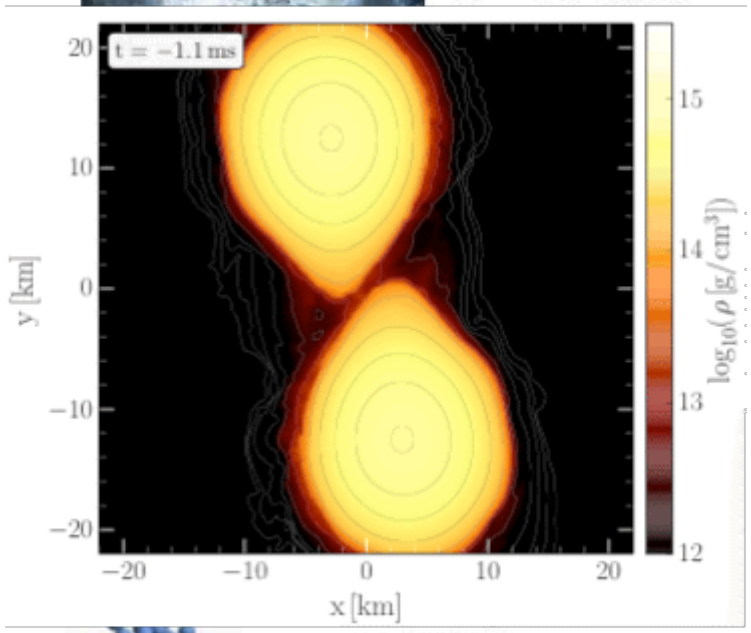
Au+Au collision
at 1.25A GeV

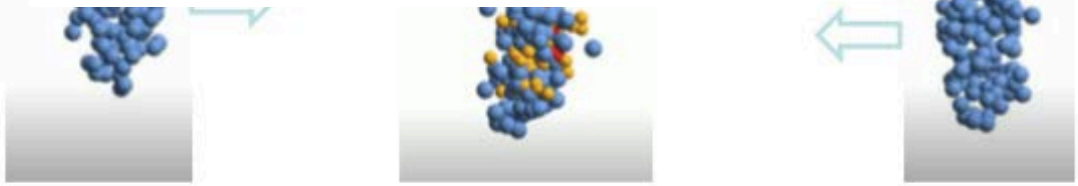
Temperature
T < 10 MeV

Neutron star merger

Neutron Star merger

Temperature
T < 50 MeV





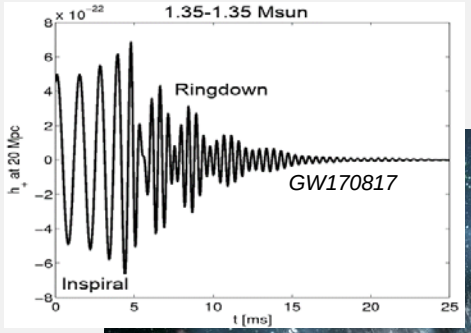
$\rho < 8\rho_0$

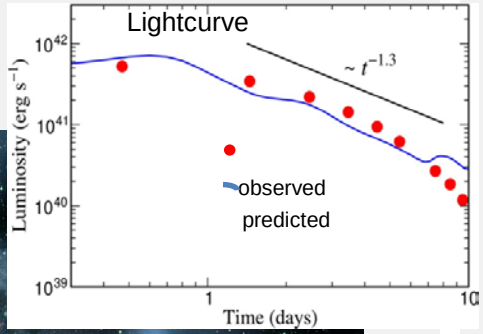
Reaction time
$t \sim 10^{-23}$ s

Compressed Baryonic Matter

Neutron Star Mergers and FAIR research …
… has recently attracted strong attention

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

Electromagnetic "Kilonova" signal due to "r process" in a NS merger has recently been verified by astronomical observations (August 2017) predicted by GSI scientists paving the way to the solution of one of the greatest science puzzles of the century

Neutron Star Mergers and FAIR research …
… has recently attracted strong attention

PHYSICAL REVIEW LETTERS

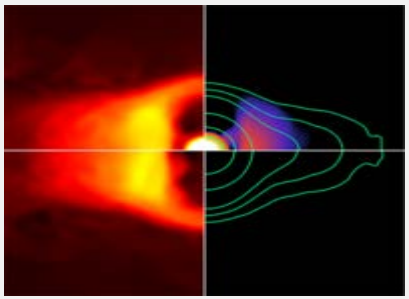
Volume 122

12/15 February 2019

HIGHLIGHTED ARTICLES

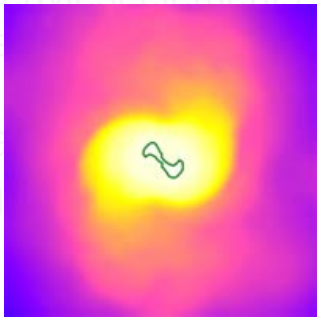
Signatures of Quark-Hadron Phase Transitions in General-Relativistic Neutron-Star Mergers

Elias R. Most, L. Jens Papenfort, Veronica Dexheimer, Matthias Hanauske, Stefan Schramm, Horst Stöcker, and Luciano Rezzolla



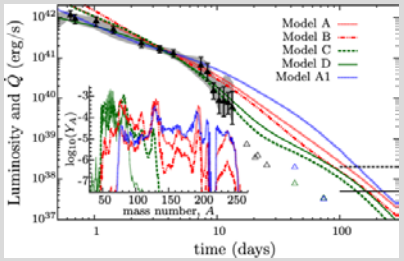
Identifying a First-Order Phase Transition in Neutron-Star Mergers through Gravitational Waves

Andreas Bauswein, Niels-Uwe F. Bastian, David B. Blaschke, Katerina Chatziioannou, James A. Clark, Tobias Fischer, and Micaela Oertel



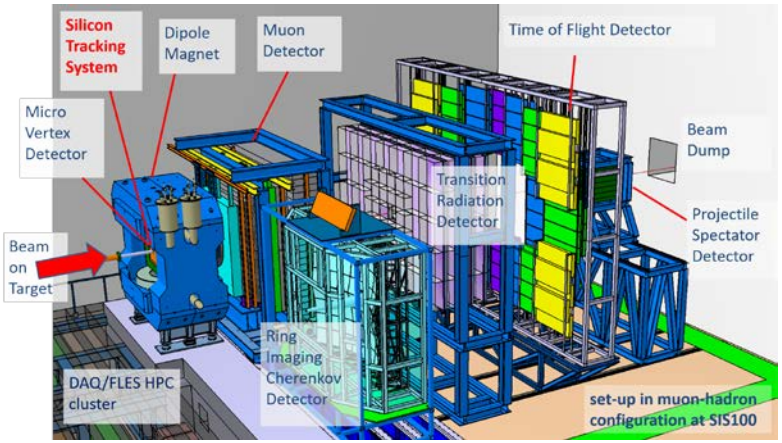
Fingerprints of Heavy-Element Nucleosynthesis in the Late-Time Lightcurves of Kilonovae

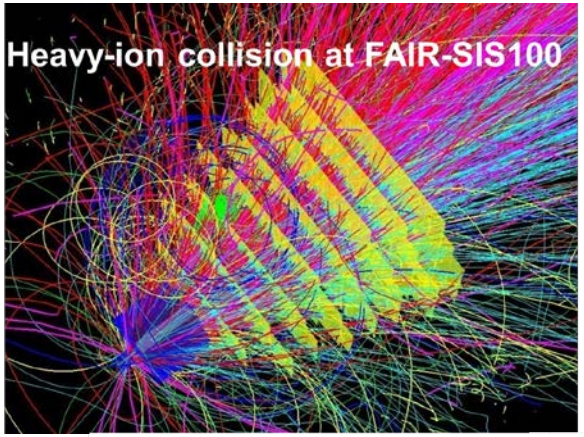
Meng-Ru Wu, J. Barnes, G. Martínez-Pinedo, and B. D. Metzger

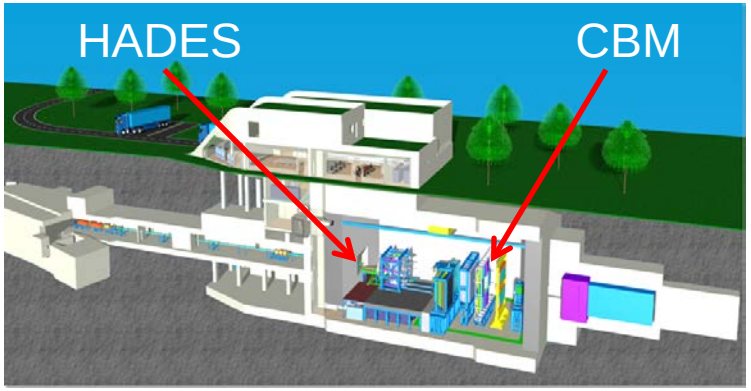


CBM Experiment at FAIR

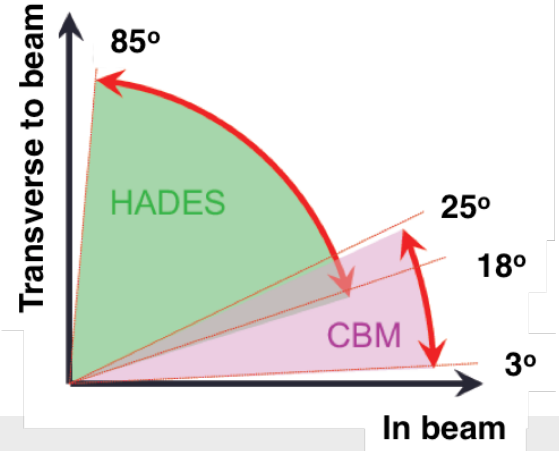
- typical collision system: Au^{79+} +Au at 4 to 11 AGeV
- Day 1: beam intensity: $5x10^7$ ions/sec; interaction rate 0.5 MHz
- MSV: beam intensity: 10^9 ions/sec; interaction rate 10 MHz



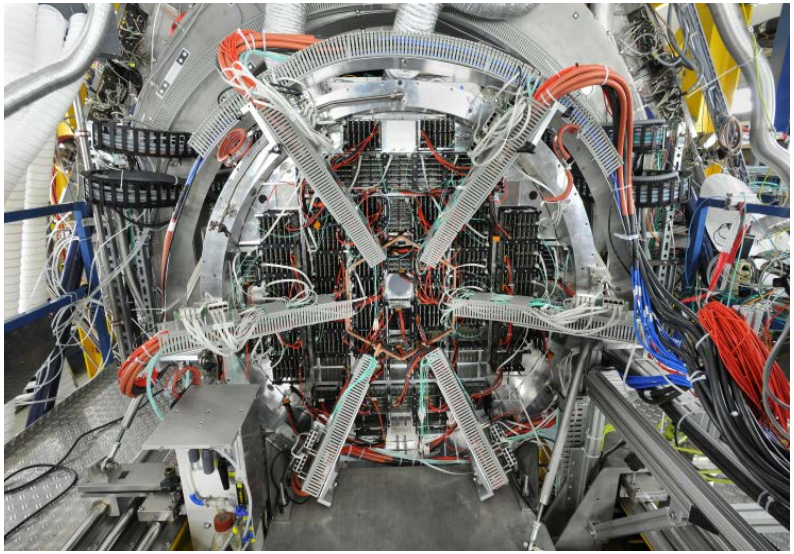




Polar angle coverage



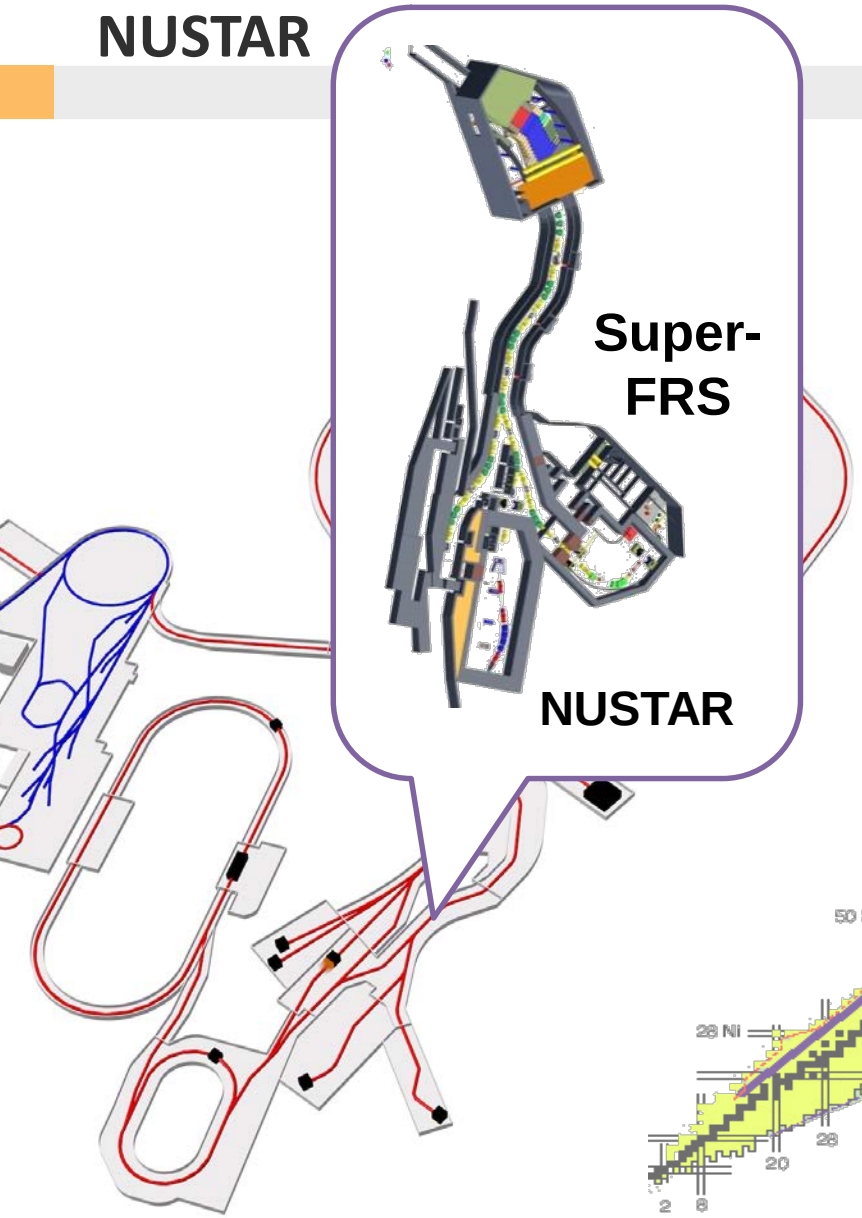
Status of FAIR: experiments
CBM and HADES



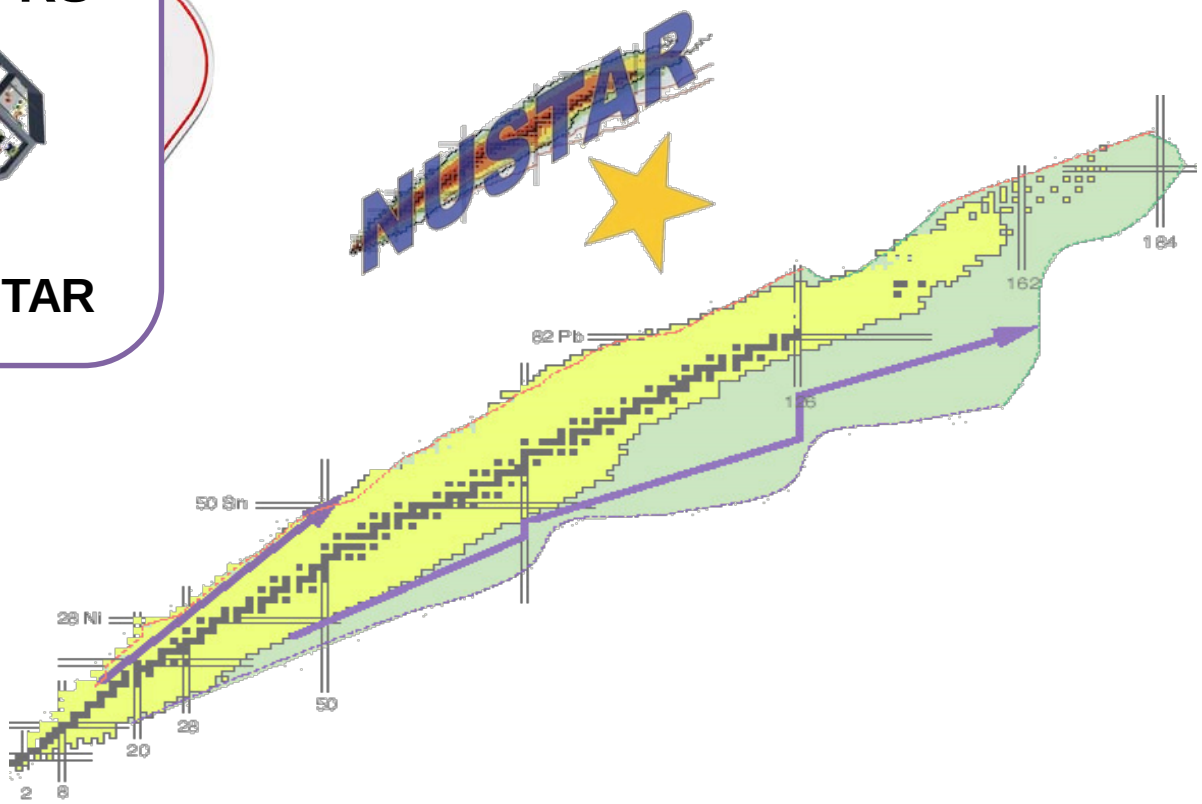
Forefront Technologies

- Technological advancements in high-performance & scientific computing, Big Data, Green IT

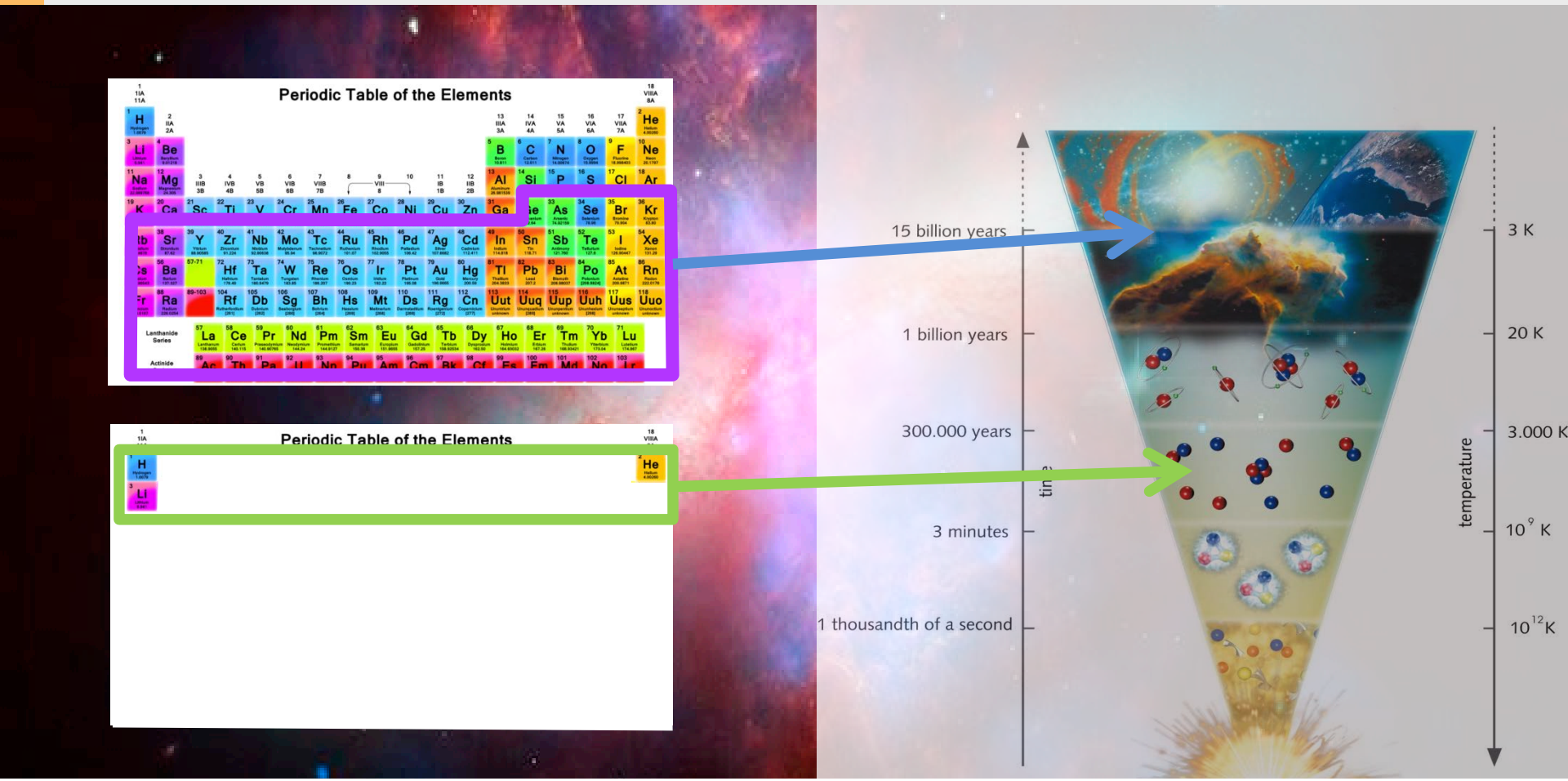
NUSTAR



- Nuclear Structure, Astrophysics and Reactions
  - About 800 members



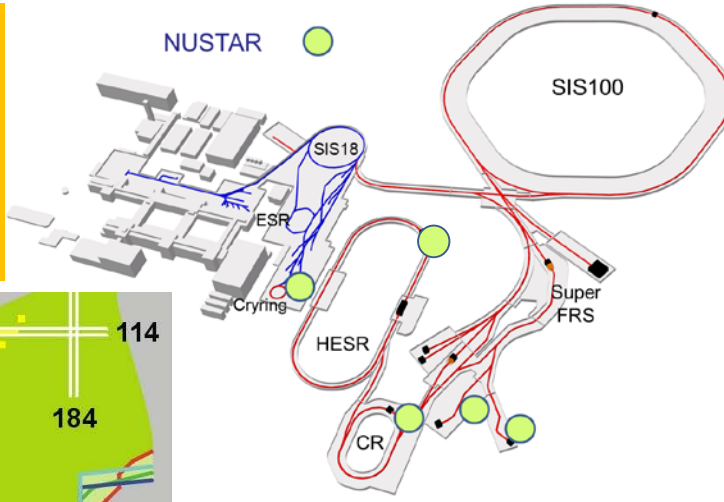
Questions about the Universe …

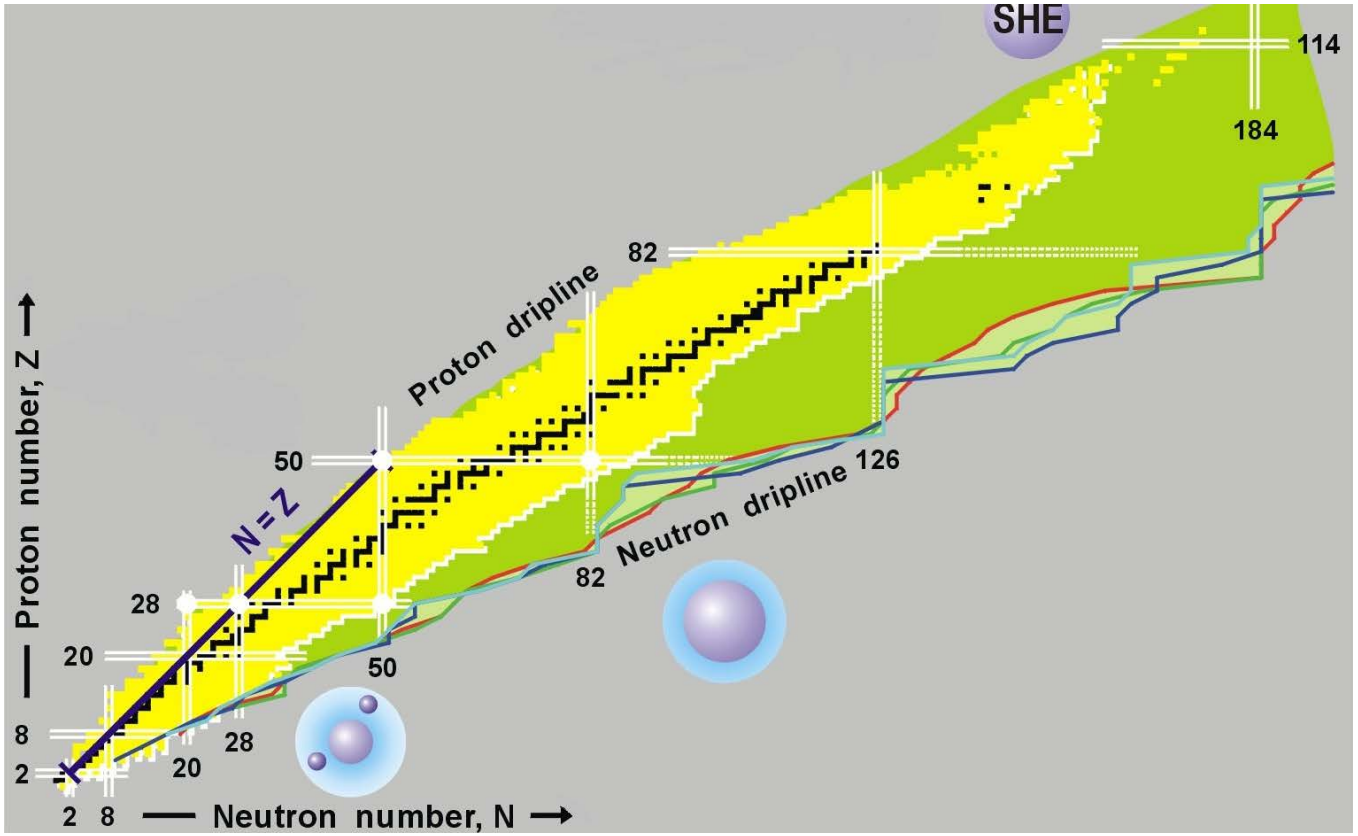


- Where and how were the heavy elements made in the universe?
- Where does the periodic table of elements end?

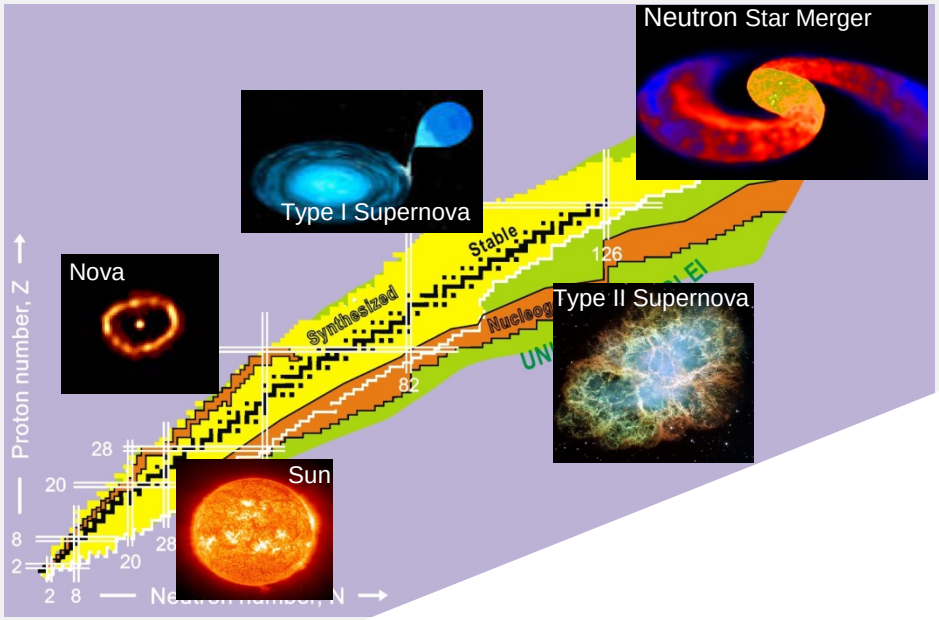
NUclear STructure Astrophysics and Reactions

- The limits of nuclear existence (lifetimes, decays, …)
- Ground state properties (masses, radii, …)
- Structure of excited states (shell structure, shapes, …)
- Unbound and other exotic system (halo, skin, …)
- Nuclear equation of state



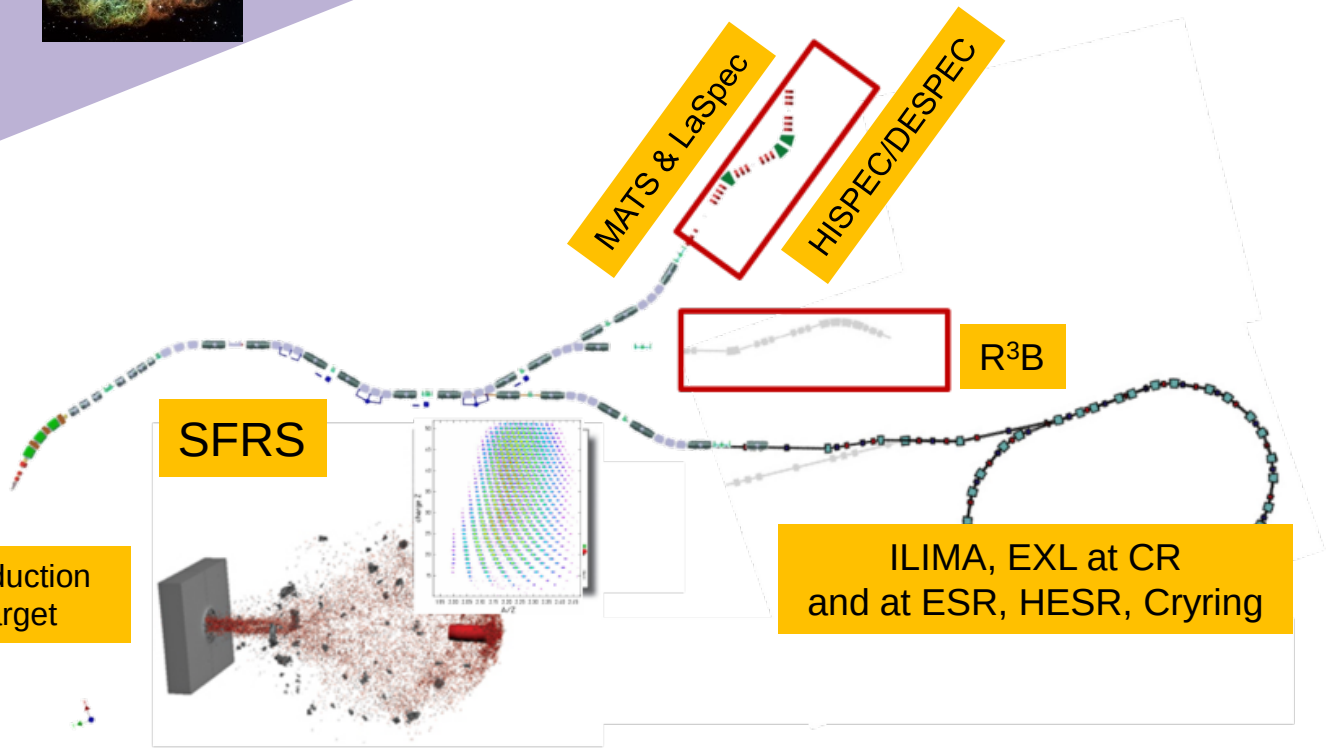


NUSTAR
- Origin of Elements in the Universe



„Nucleosynthesis sites“ in the universe

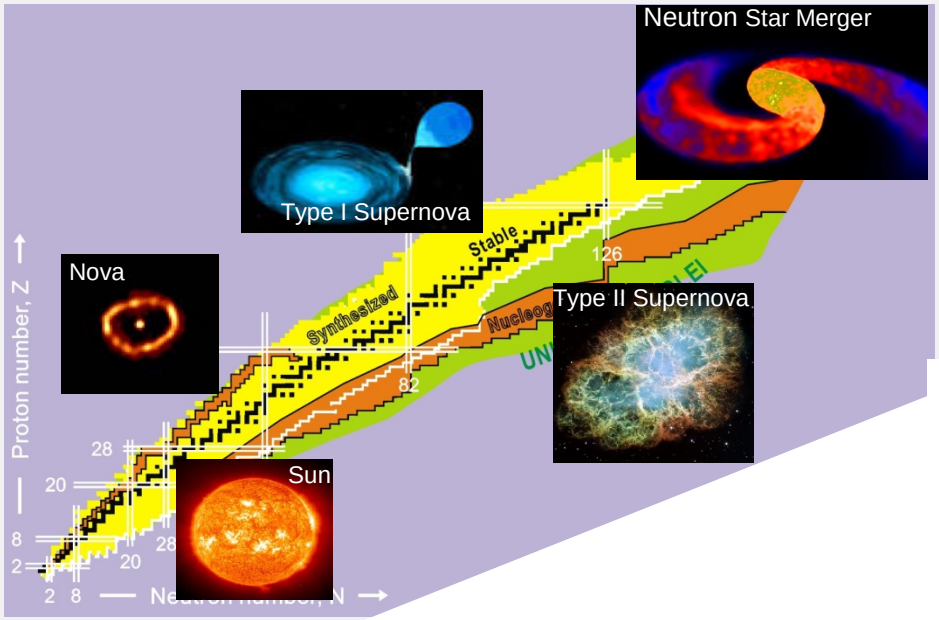
„Nucleosynthesis sites” at FAIR



Primary intensities vs. GSI: x 100

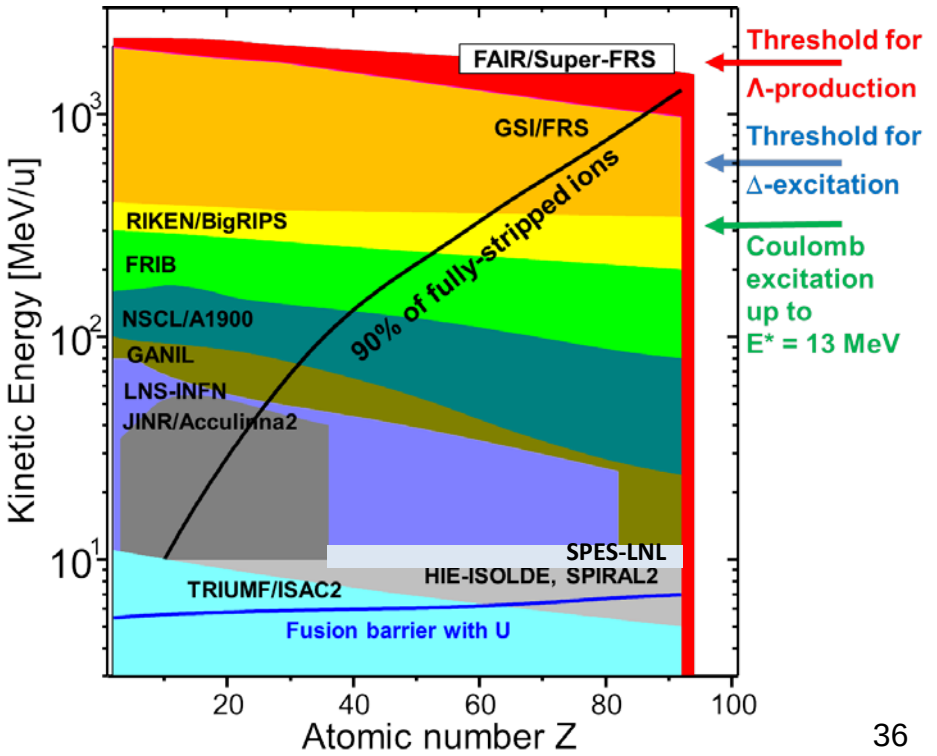
SIS 100

NUSTAR
- Origin of Elements in the Universe



„Nucleosynthesis sites“ in the universe

High SIS100 energies + SFRS: superior charge separation and beam quality



Primary intensities vs. GSI: x 100

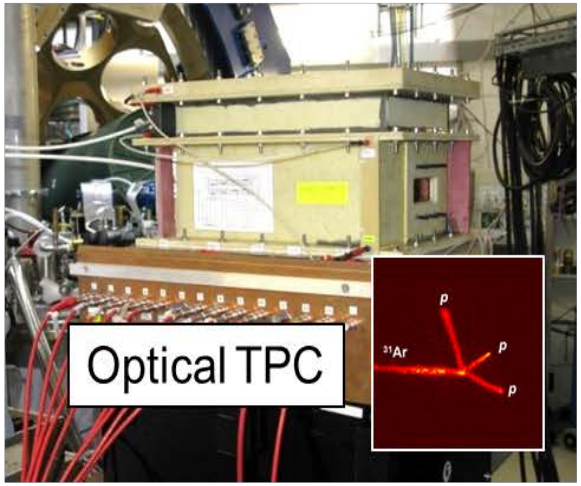
SIS 100

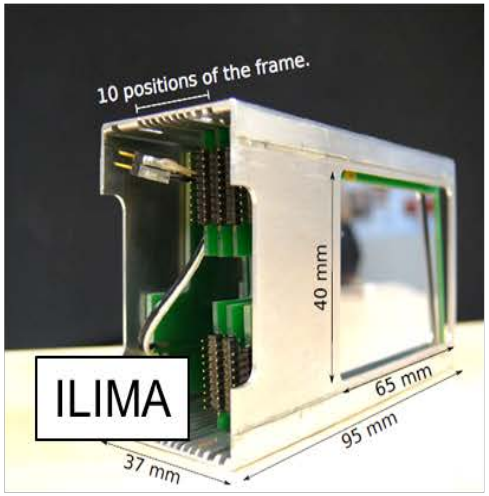
production target

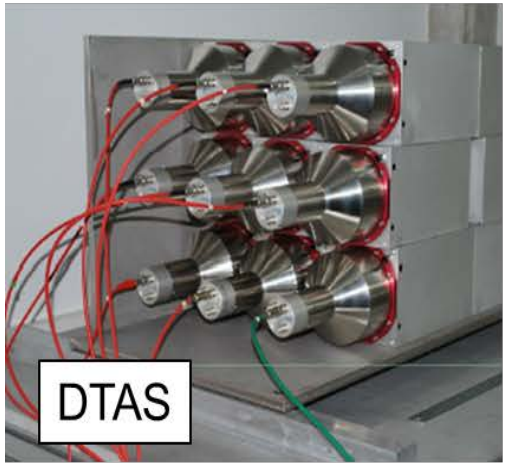
SFRS

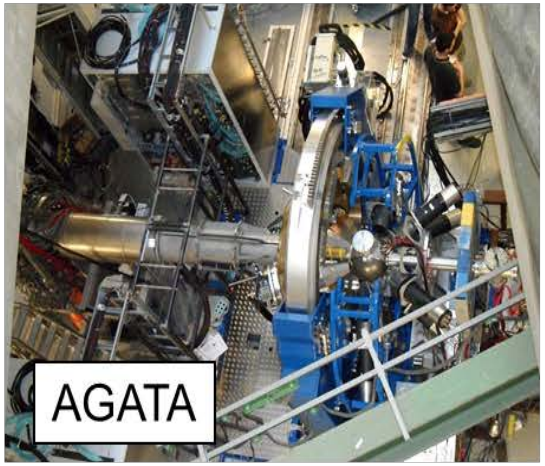
Status of NuSTAR experiments

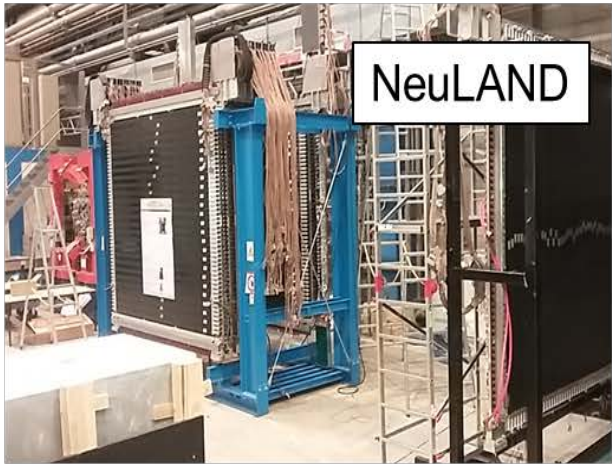
- detector R&D and construction



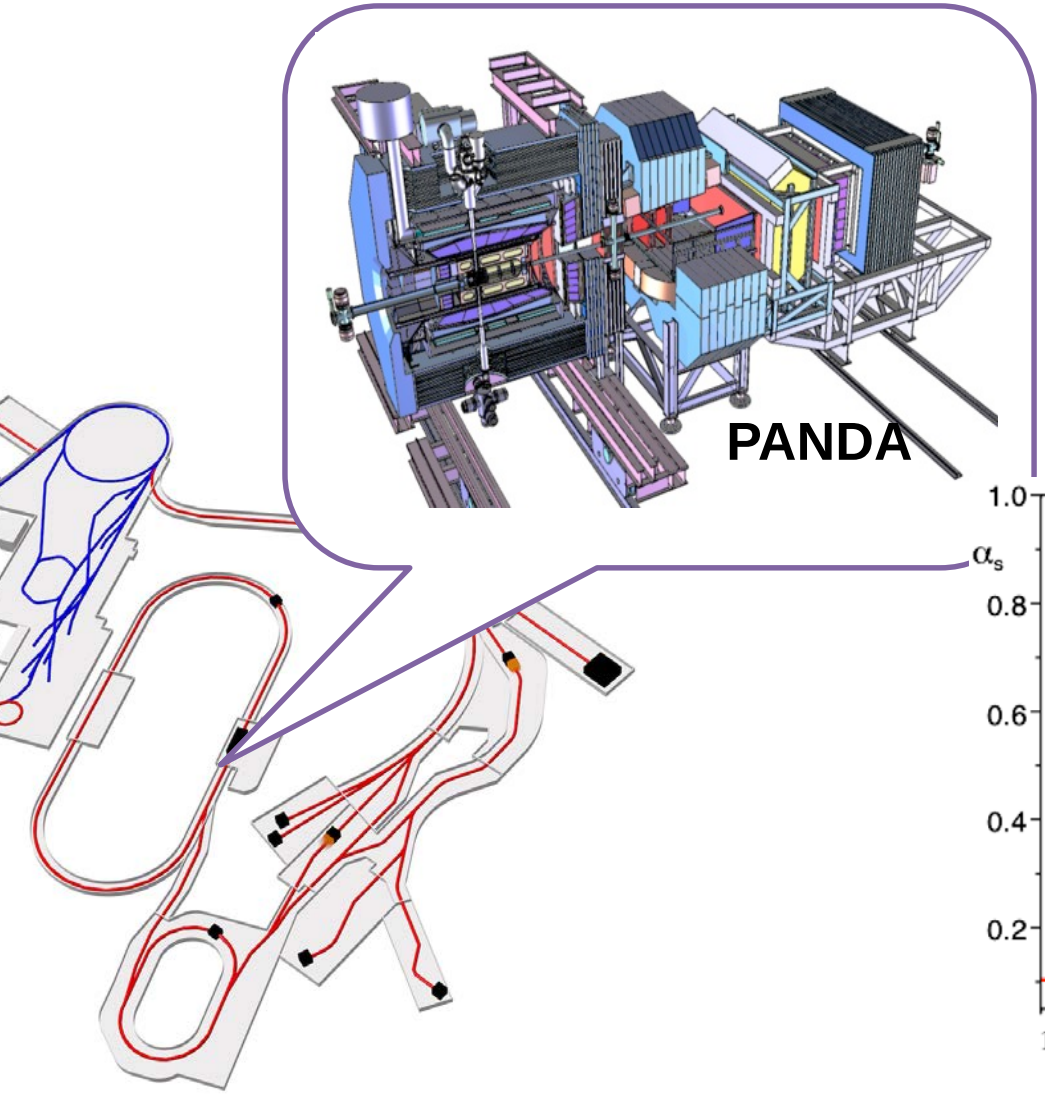




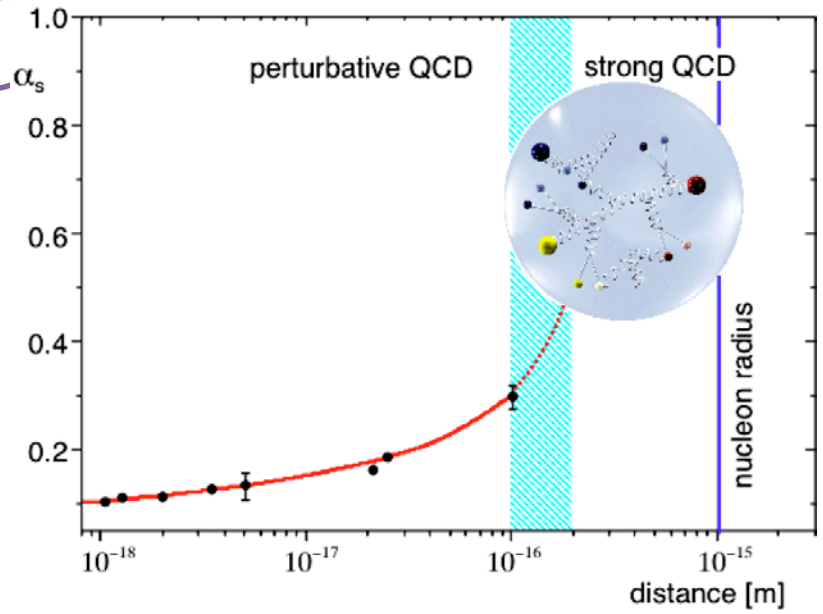




PANDA



- antiProton ANnihilations at DArmstadt
  - About 500 members

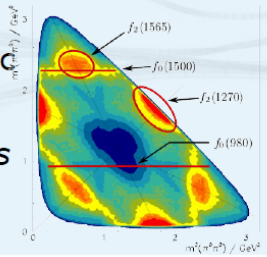


PANDA - AntiProton Annihilation at Darmstadt

Bound States of Strong Interaction

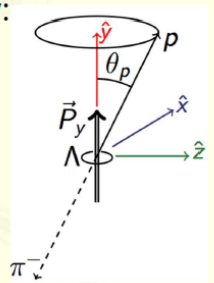
Spectroscopy

- New narrow XYZ: *Search for partner states*
- Production of exotic *QCD states: Glueballs & hybrids*



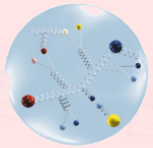
Strangeness

- Hyperon spectroscopy: *excited states largely unknown*
- Hyperon polarisation: *accessible by weak, parity violating decay*



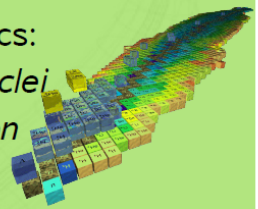
Nucleon Structure

- Generalized parton distributions: *Orbital angular momentum*
- Drell Yan: *Transverse structure, valence anti-quarks*
- Time-like form factors: *Low and high E, e and μ pairs*



Nuclear Hadron Physics

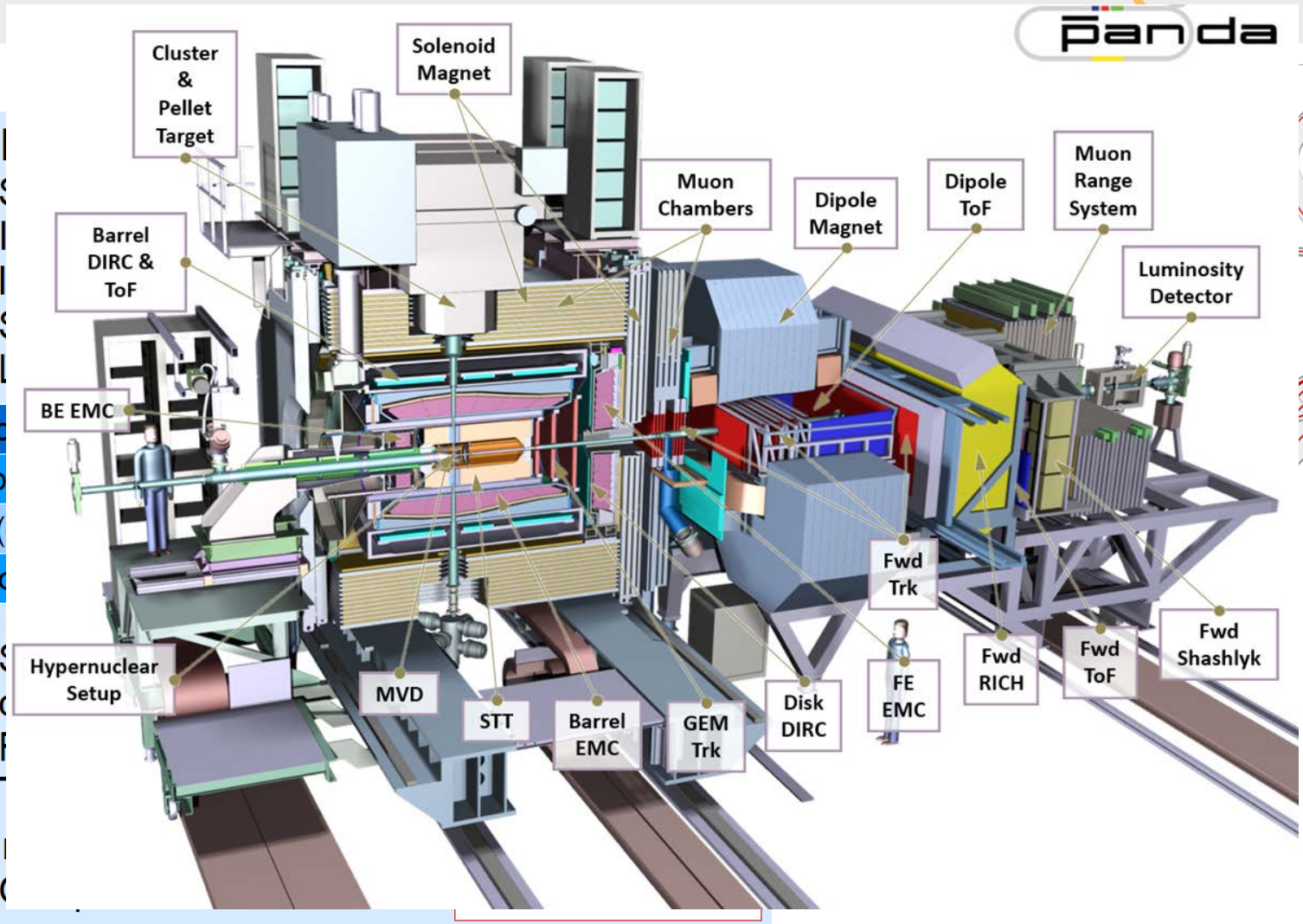
- Hypernuclear physics: *- Double Λ hypernuclei - Hyperon interaction*
- Hadrons in nuclei: *Charm and strangeness in the medium*

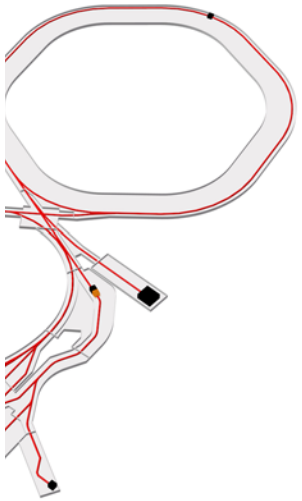


NUPECC Long Range Plan

The combination of PANDA's discovery potential for new states, coupled with the ability to perform high-precision systematic measurements is not realised at any other facility or experiment in the world.

PANDA - AntiProton Annihilation at Darmstadt

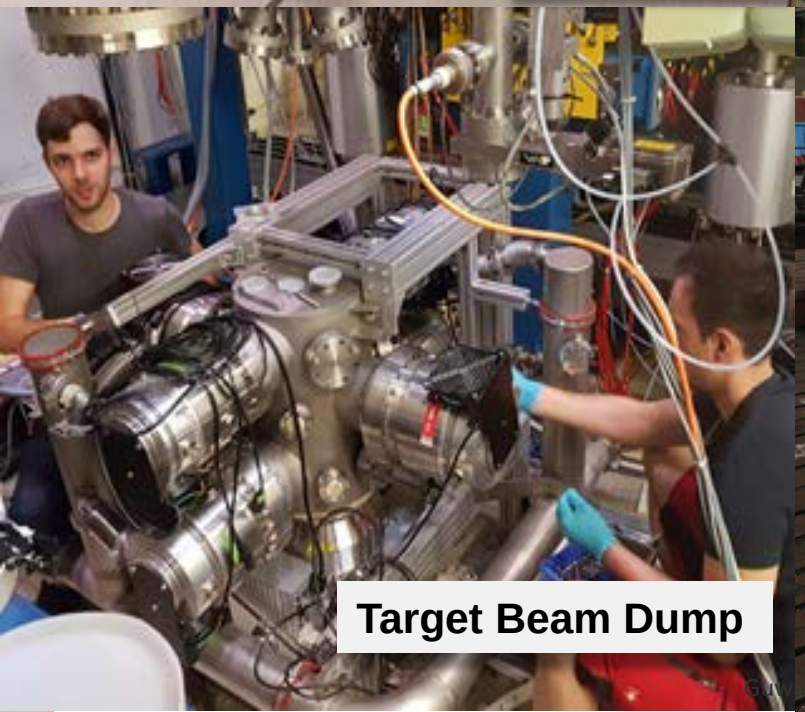





Cluster Jet Target


Pellet Target


Muon Detector


Target Beam Dump


panda
Magnet Yoke Octant

FAIR Review Spring 2019

FAIR review committee
with external experts
(civil construction, accelerator and experiments),
chaired by
Lyndon Evans (CERN)

Report on the progress
of the FAIR project

Name	Affiliation
Juha Äystö	Helsinki Institute of Physics (HIP), Finland
Catherine Césarsky	Former ESO DG, Chair of SKA Board
Bernard Dormy	Chair of AFC (until August 2018) and former Chair of TREF CERN and AFC ESS
Lyndon Evans - **CHAIR**	The European Organization for Nuclear Research (CERN), Switzerland
Norbert Holtkamp	SLAC Stanford, USA
Barbara Jacak	Department of Physics, University of California, USA
Thomas Klinger	Wendelstein 7-X Project, Max-Planck-Institut für Plasmaphysik, Germany
Berndt Mueller	Brookhaven National Laboratory, USA Duke University, USA
Agneta Nestenborg	The European Spallation Source (ESS) ERIC, Sweden
Abhijit Sen	Institute for Plasma Research (IPR), India
Dmitriy Sinyushin	JSC State Specialized Design Institute (SSDI), Russian Federation
Matthias Vollmer	Federal Ministry for Environment (BMU), Germany
Yifang Wang	Institute of High Energy Physics (IHEP), China

- original total costs of FAIR project: 1,262 M€ (2005 prices)
- additional costs 530 M€ (2005 prices)

Recommendation: „The FAIR Modularized Start Version (MSV) is to be constructed and completed in full as soon as possible. All else would be an extreme loss of science and waste of resources.“

FAIR Project Outlook

- Council decisions in July 2019 support continuation of project execution as per plan
- Further council decisions planned in extraordinary Council in 1st week of October 2019

The two largest FAIR shareholders (Germany and Russia) have conveyed their common position to the Council members, that it is their desire to realize the MSV in the originally approved version (in the Convention) and they will try to find the money for it.

- Council in Dec. 2019
- Award of civil construction area south in Q4 2019
- Tendering of Technical Building installation will be continued as per plan
- Continue resource balancing and recruiting
- Thorough follow-up of manufacturing and delivery of accelerator components
- Finalization of In-kind contracts and FAIR tenders according to FAIR baseline, requiring full support of shareholders

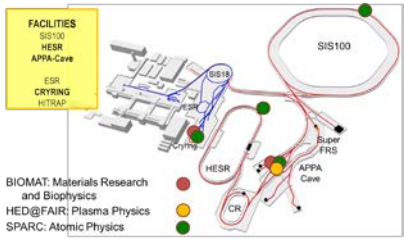
Schedule for FAIR Science

- Working towards the completion of FAIR by 2025
- Major thrust is on construction of FAIR accelerators and experiments.
- At the same time ***staged approach to FAIR science and progressive commissioning of accelerators and detectors***:

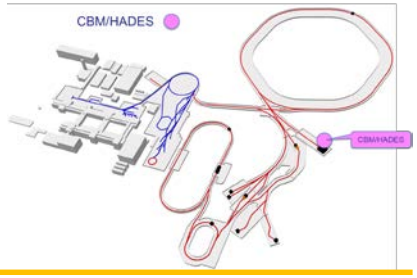
FAIR Phase 0 Research Program

- ***FAIR phase 0 : start in 2018/2019***
- FAIR day 1 configurations/ phase 1 experiments with FAIR accelerators progressively approaching design parameters → from 2024/25 …

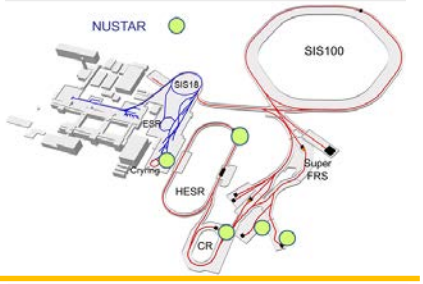
APPA



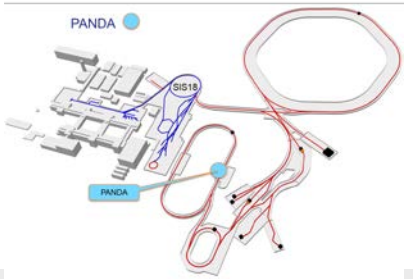
CBM



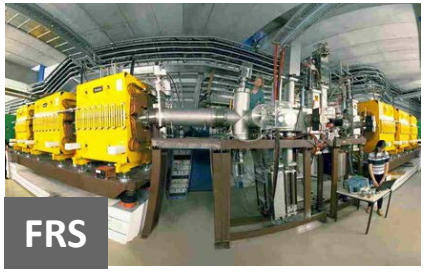
NUSTAR



PANDA



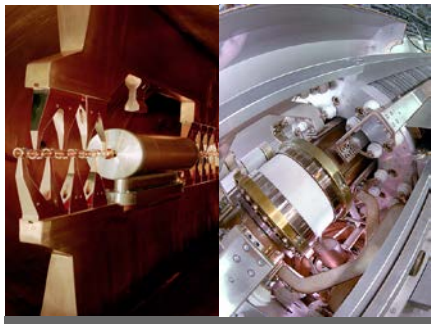
Accelerator and Experimental Facilities available for FAIR phase-0

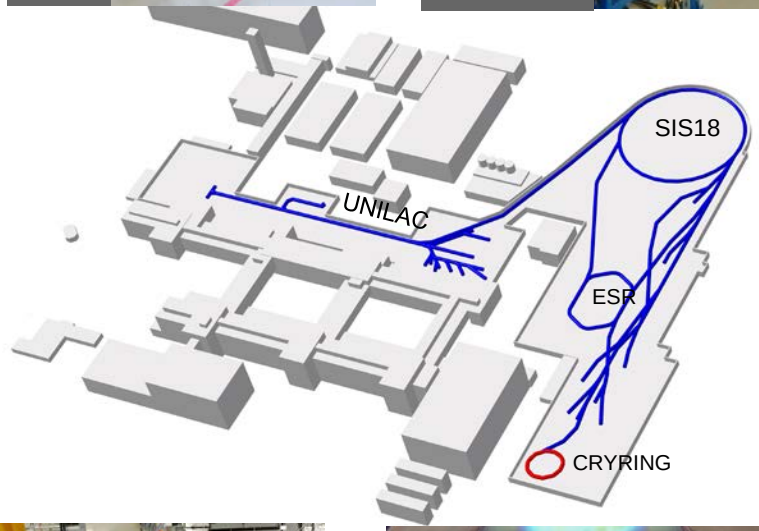

FRS


ESR


HITRAP


Cryring

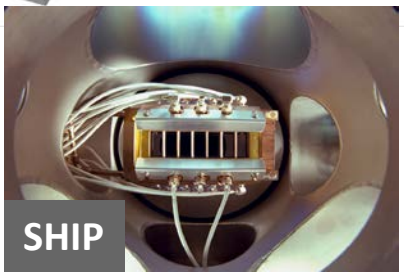

UNILAC / SIS18




R3B


PHELIX

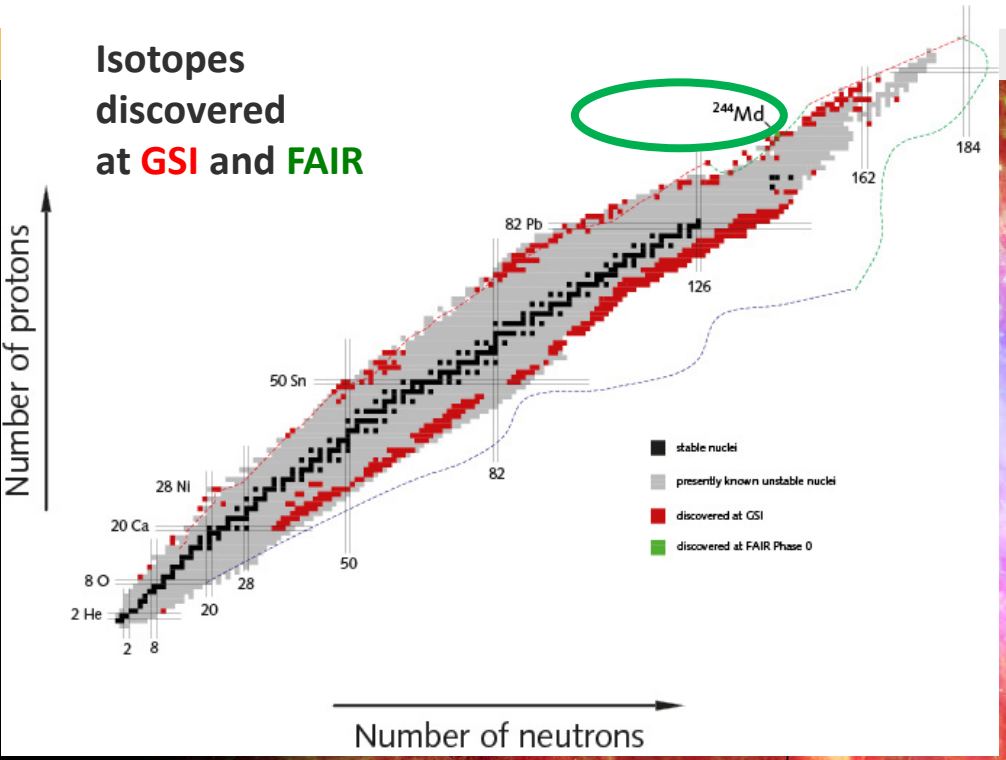

TASCA

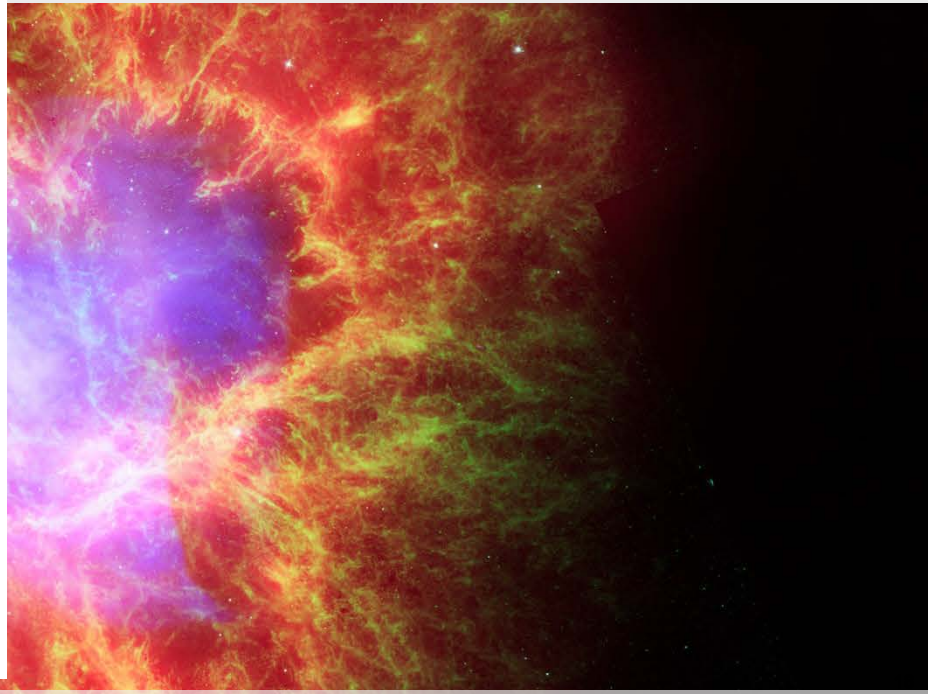

SHIP

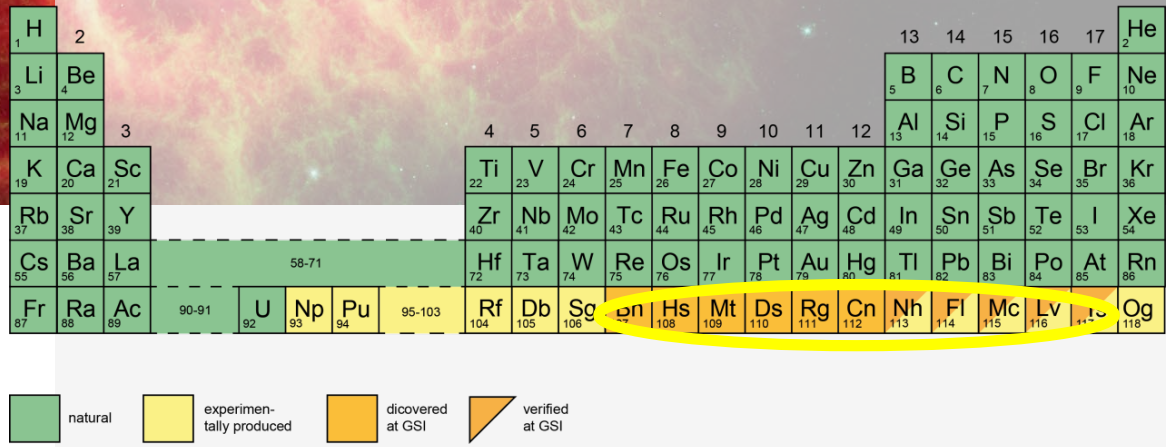

HADES

Major GSI Discoveries

Isotopes discovered at GSI and FAIR

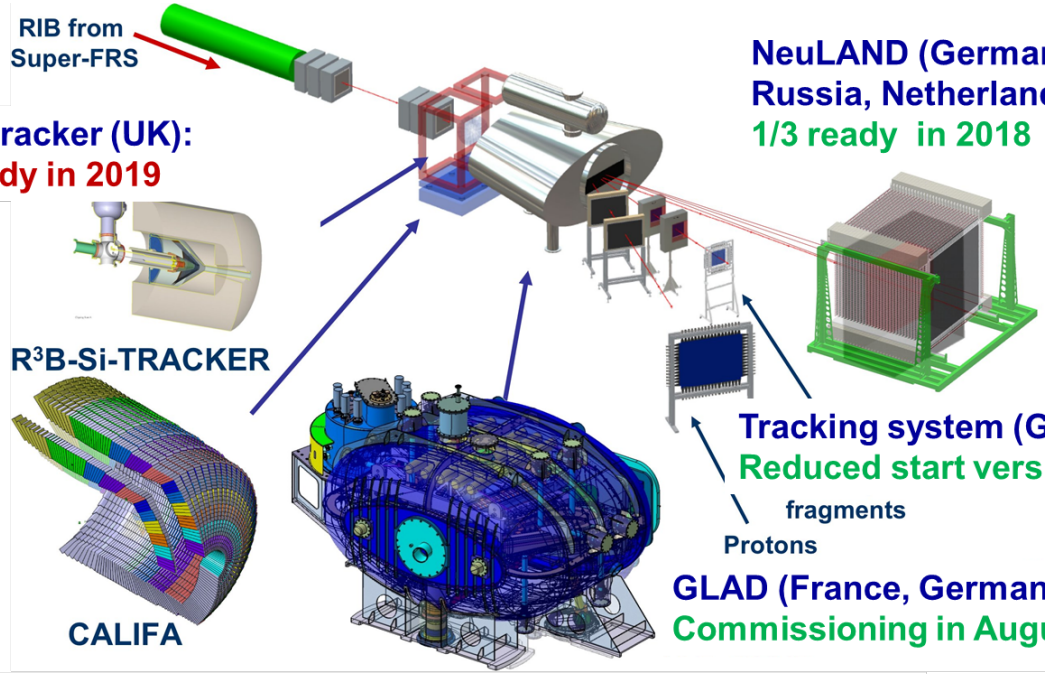






- New chemical elements
- Hundreds of new isotopes
- New decay modes

R3B Start Version for Phase 0

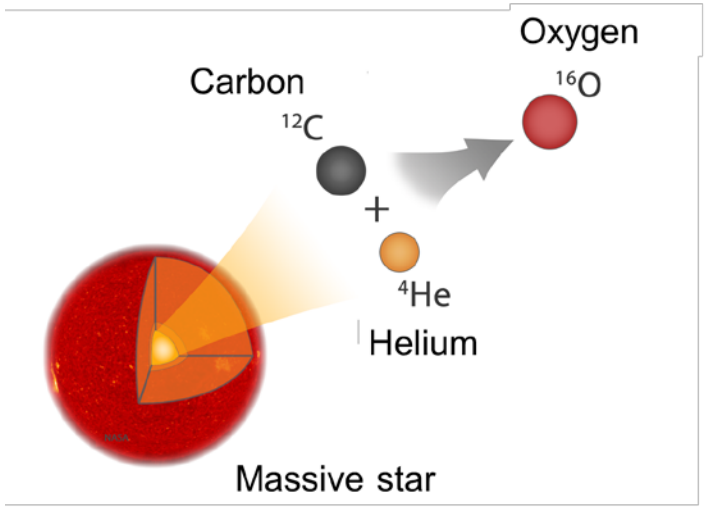


CALIFA (Sweden, Spain, Germany, Russia):
Barrel without backward part ready in 2018
+ 80% of the endcap ready in 2019

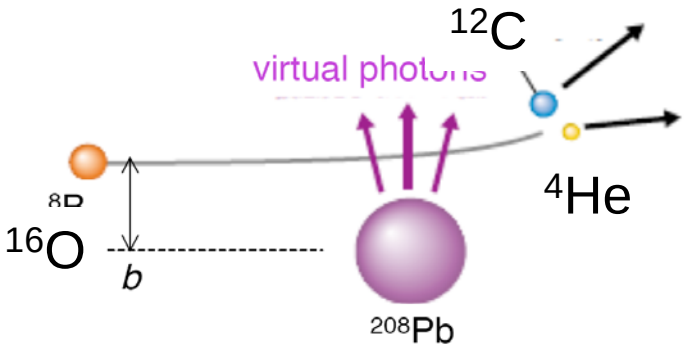
GLAD magnet (French in-kind contribution)

Questions about the Universe …

How Nature makes the building blocks of life



rate insufficiently known at astrophysically energies

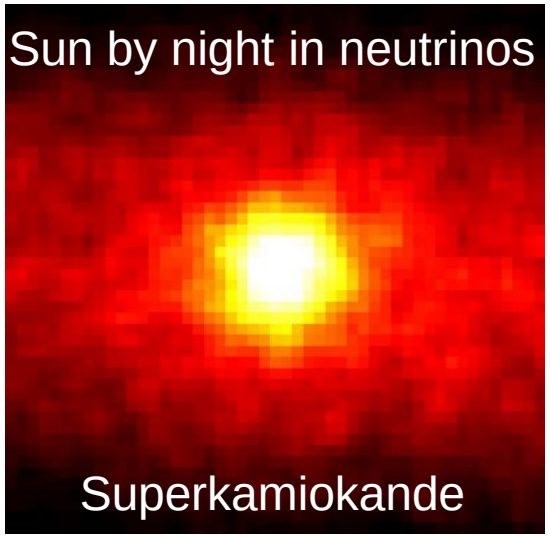


Alpha fusion on ^{12}C is the stellar reaction of paramount importance,

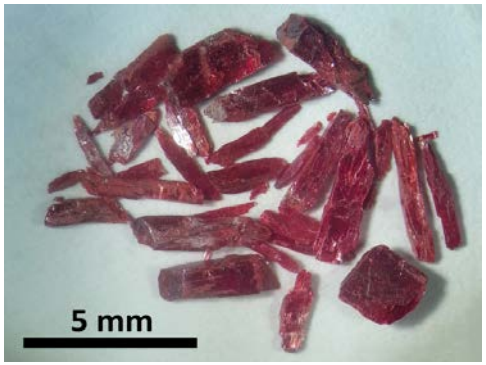
W.A. Fowler, Nobel lecture 1983

Experiment in inverse kinematics (Coulomb dissociation) requires high energies -> GSI/FAIR

Neutrinos from the Sun

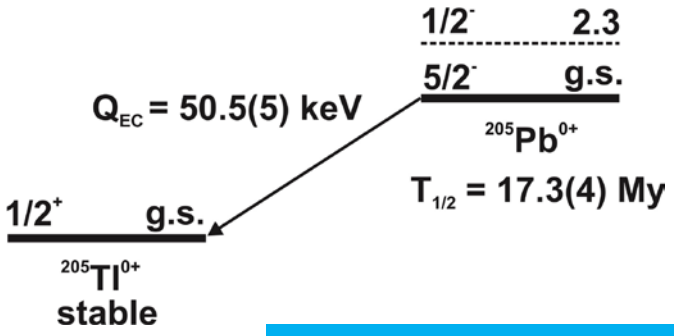


1. Neutrino Physics: The LOREX Project



Lorandite ($TlAsS_2$) as Solar pp-neutrino detector
GSI/FAIR – provides capture cross-section

Did the sun always shine like today? Looking backwars via LOREX project

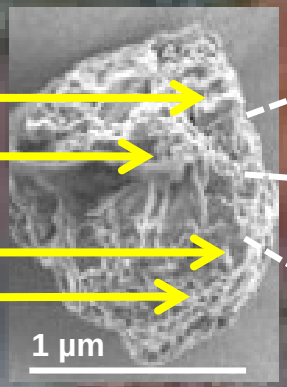


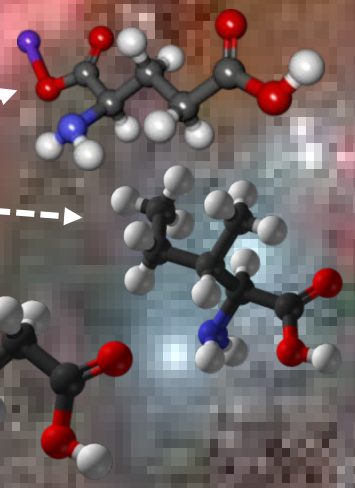
Measurement unique for storage rings -> GSI/FAIR

Studying cosmic radiation induced processes

astrophysical ice grains (H_2O, CH_4, CO_2, NH_3, SO_2...)

200 MeV Ca ions

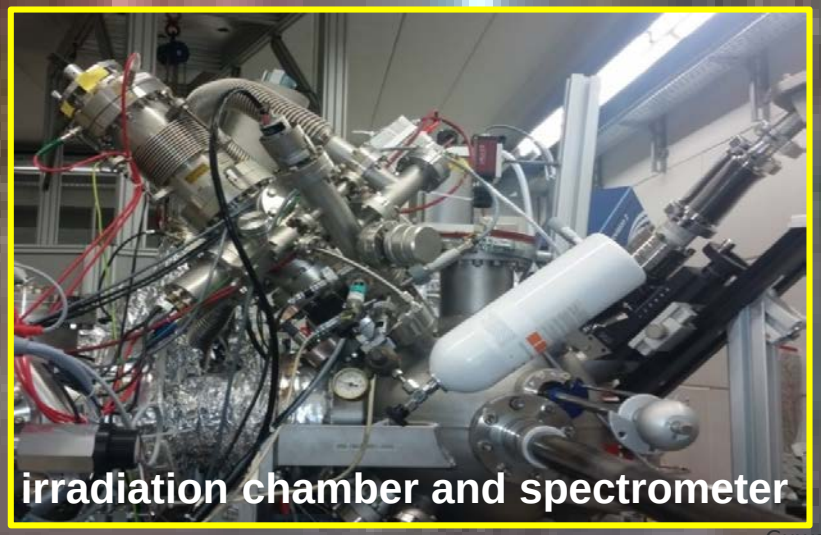




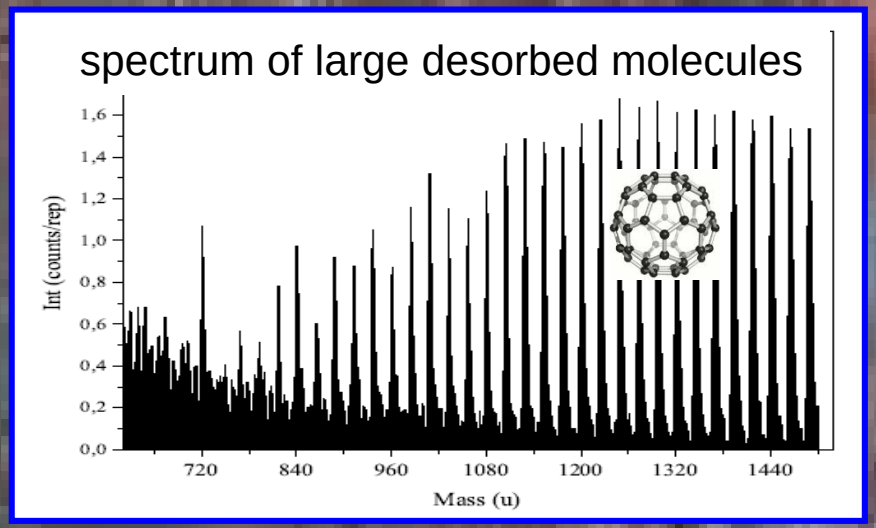
C_nH_m polyaromatic hydrocarbons

$C_6H_{13}NO_2$ amino acids

C_{60}, C_{70} fullerenes



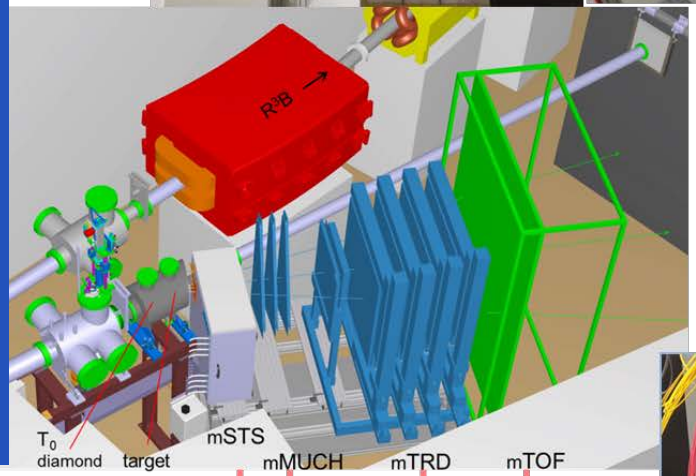
irradiation chamber and spectrometer



First beam on miniCBM@SIS18

A glimpse of actual beam-ready miniCBM setup which received beam on target.

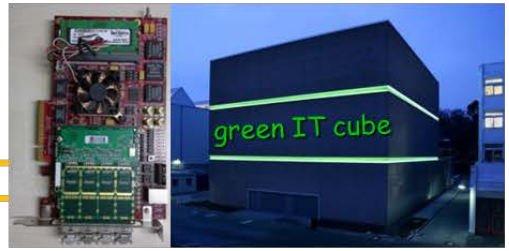
Data from combined read-out chains of the subsystems mSTS, mMUCH and mTOF is possible.



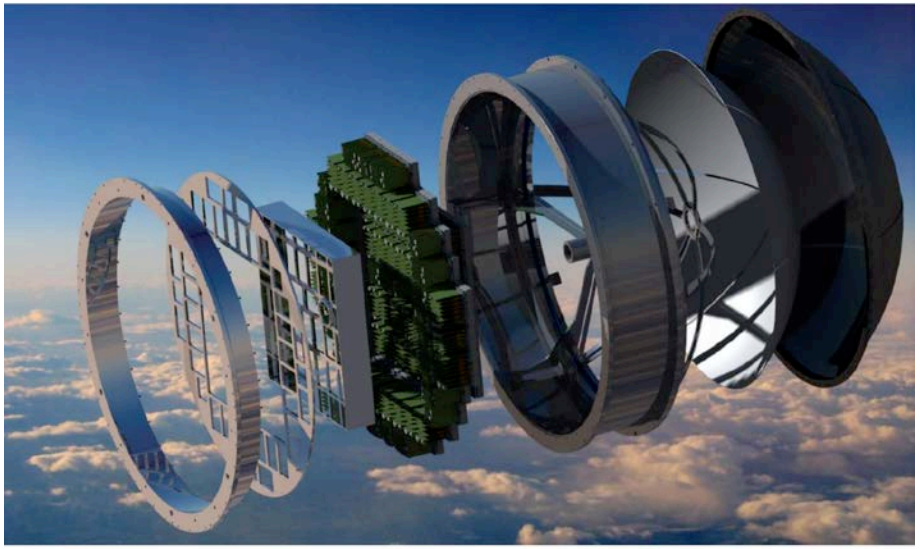
mCBM@SIS18

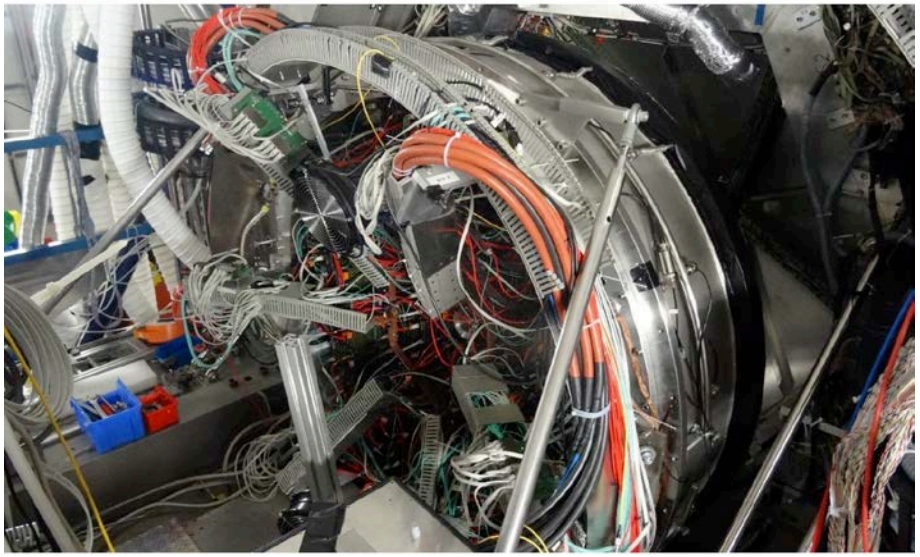
A CBM full system test-setup
for high-rate nucleus-nucleus collisions at GSI/FAIR

- CBM prototype detector systems
- free streaming read-out and data transport to the mFLES
- up to 10 MHz collision rate
- first commissioning beam in December 2018

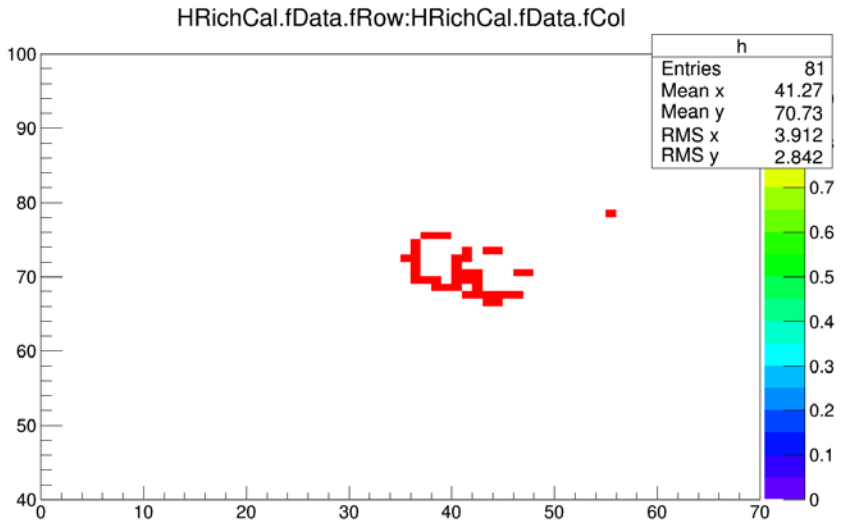


HADES RICH upgrade





- New, multi-anode PMT based photo detector jointly developed by CBM/HADES collaboration
- Replaces original CSI coated pad chamber
  - ***FAIR Phase-0 detector project***
- First beam data obtained February 26, 2019 during commissioning of the beam on the HADES target (March 3 – 29).
- Likely a double-ring from a π^0 Dalitz event



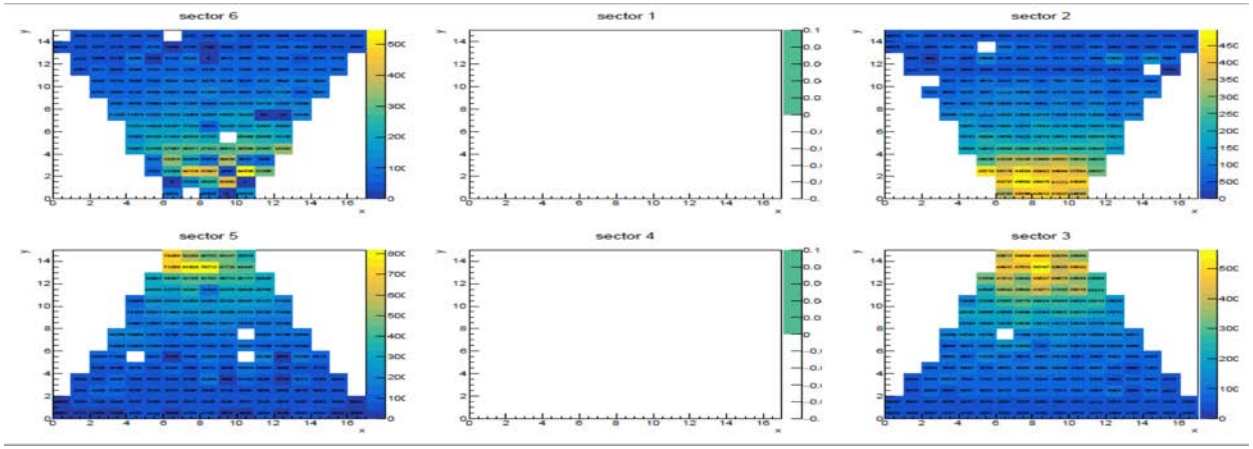
The new HADES ECAL

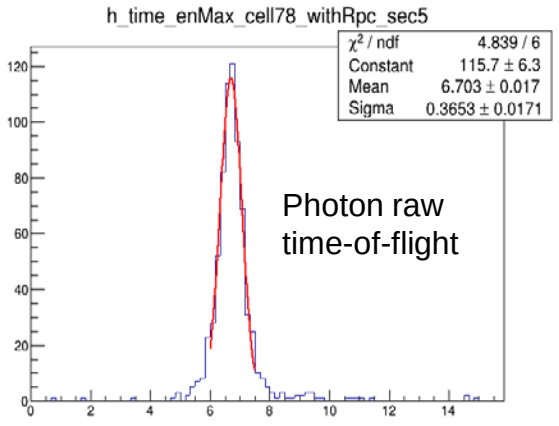
- Based on lead glass recycled from OPAL
- Refurbished and complemented with HADES TRB3 PADIWA read-out system based on commodity hardware (cell phones, FPGAs)

FAIR in-kind contribution

- Four sectors ready for beam
- Contributing teams: JU Krakow, CU Prague/Rez, GSI, TU Darmstadt
- Online-QA spectra from January 27, 2019

Calorimeter main frame (blue) in-kind contribution Poland

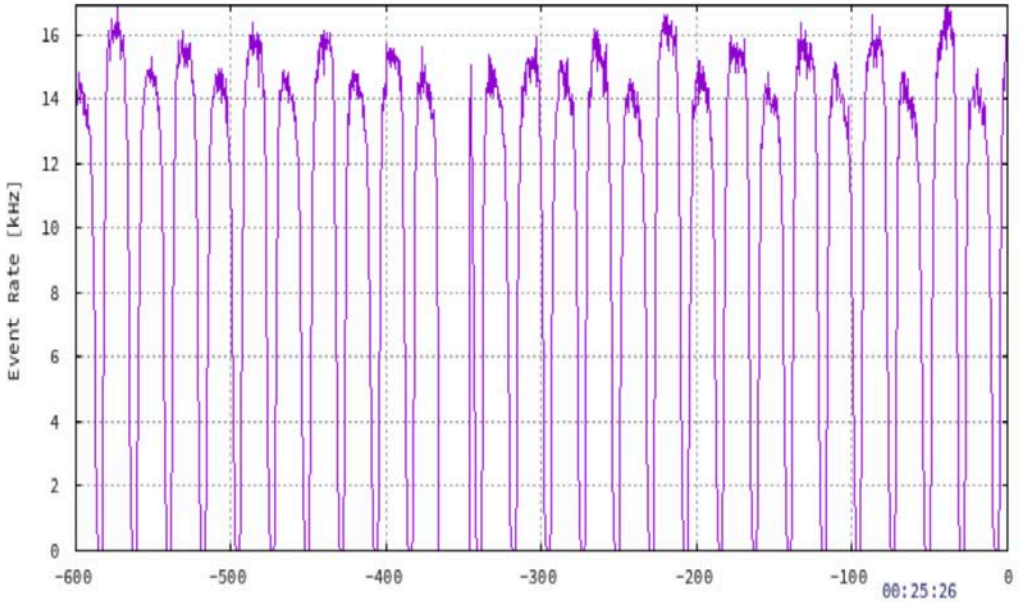


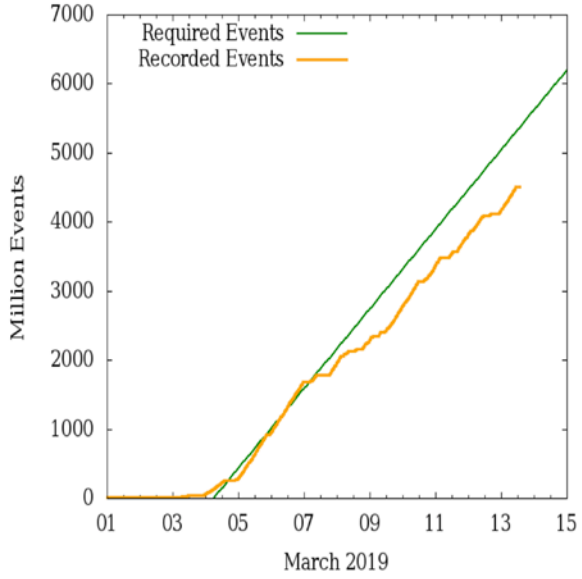


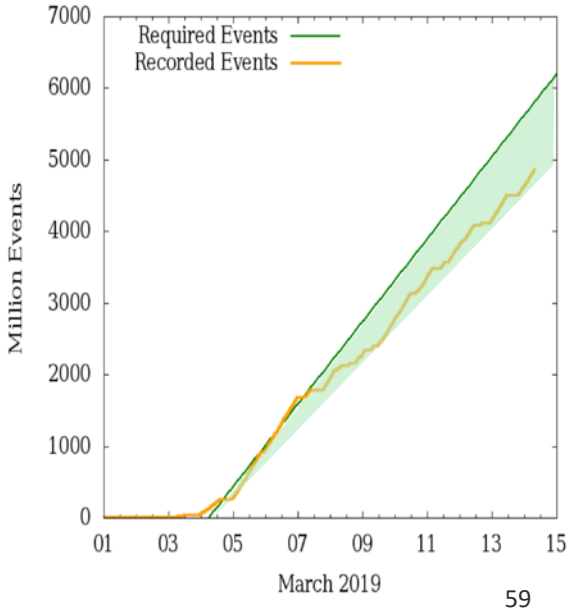
From HADES: Status of the experiment

Excellent!

- ECAL (four sectors) and MAPMT-based RICH fully operational
- Data acquisition chain, including new TRB3-TDC boards, event building and storage can go up to 20 kHz in the flat top.
- Due to compromise between detector stability, reconstruction performance and statistics we typically run with around 15 kHz.

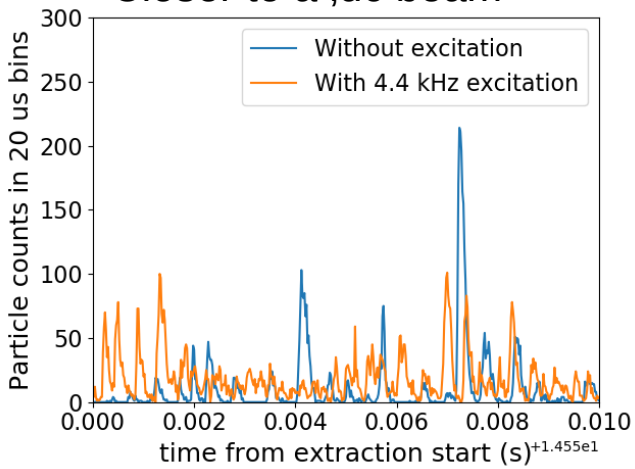




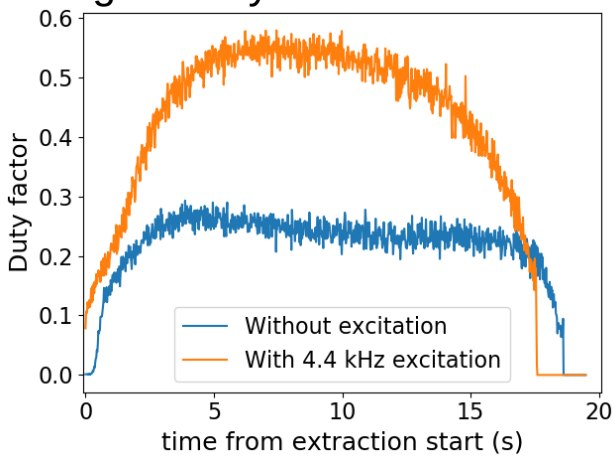


Slow extraction of beams to HADES

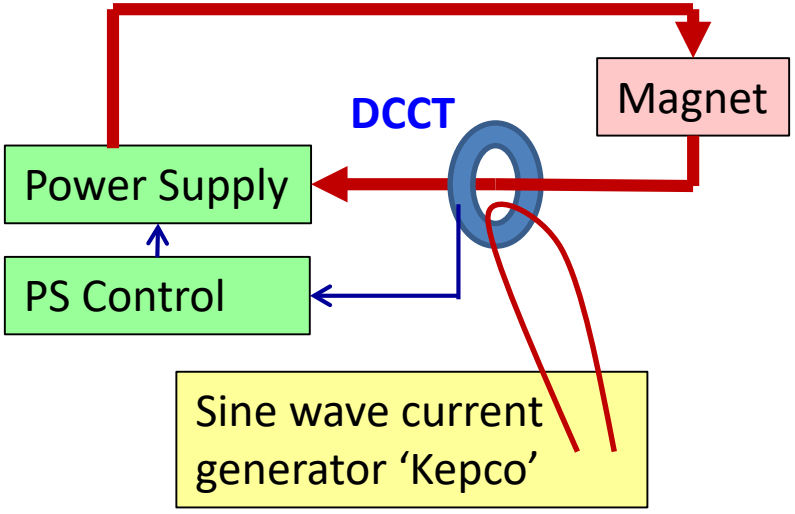
Closer to a ‚dc beam‘



Higher duty factor for HADES



Tune variation by fixed frequency modulation at the magnet's power supply:



- Ripple in quadrupole power supplies of several 100 Hz causes spill structures of duration ~ 1 ms with peaks and voids.
- Application of high frequency with f ~ 5 kHz splits spill peaks and fills voids.
- Spill ripple power spectrum with a tiny additional peak but total ripple power reduced by one order of magnitude.

FAIR is coming

FAIR is a unique opportunity for world science.

- A fascinating and broad science program, with world class experiments

The Project is rapidly developing

- Both civil construction and procurement of accelerator components proceed rapidly, aiming at the start of FAIR by 2025
- The experiments are getting ready
- First-class intermediate research program, FAIR phase 0, since 2018.
- A major international review has recently confirmed the validity and the feasibility of the project

A perfect ground for new talents!

Unique Opportunities . . . & Challenges