

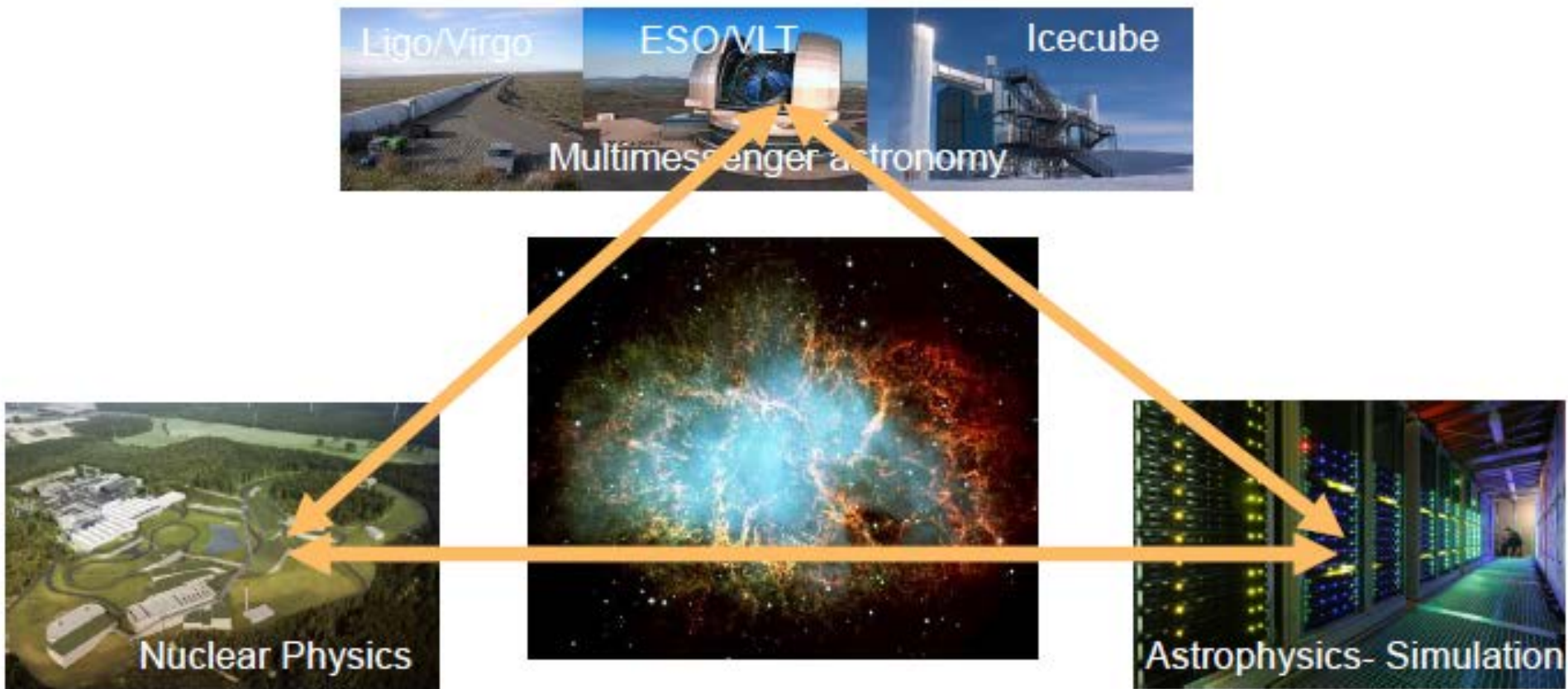
A detailed wireframe model of a particle accelerator, showing a large, oval-shaped ring with various internal structures and smaller components. The model is rendered in a light gray, grid-like style.

FAIR

the Universe in the Lab

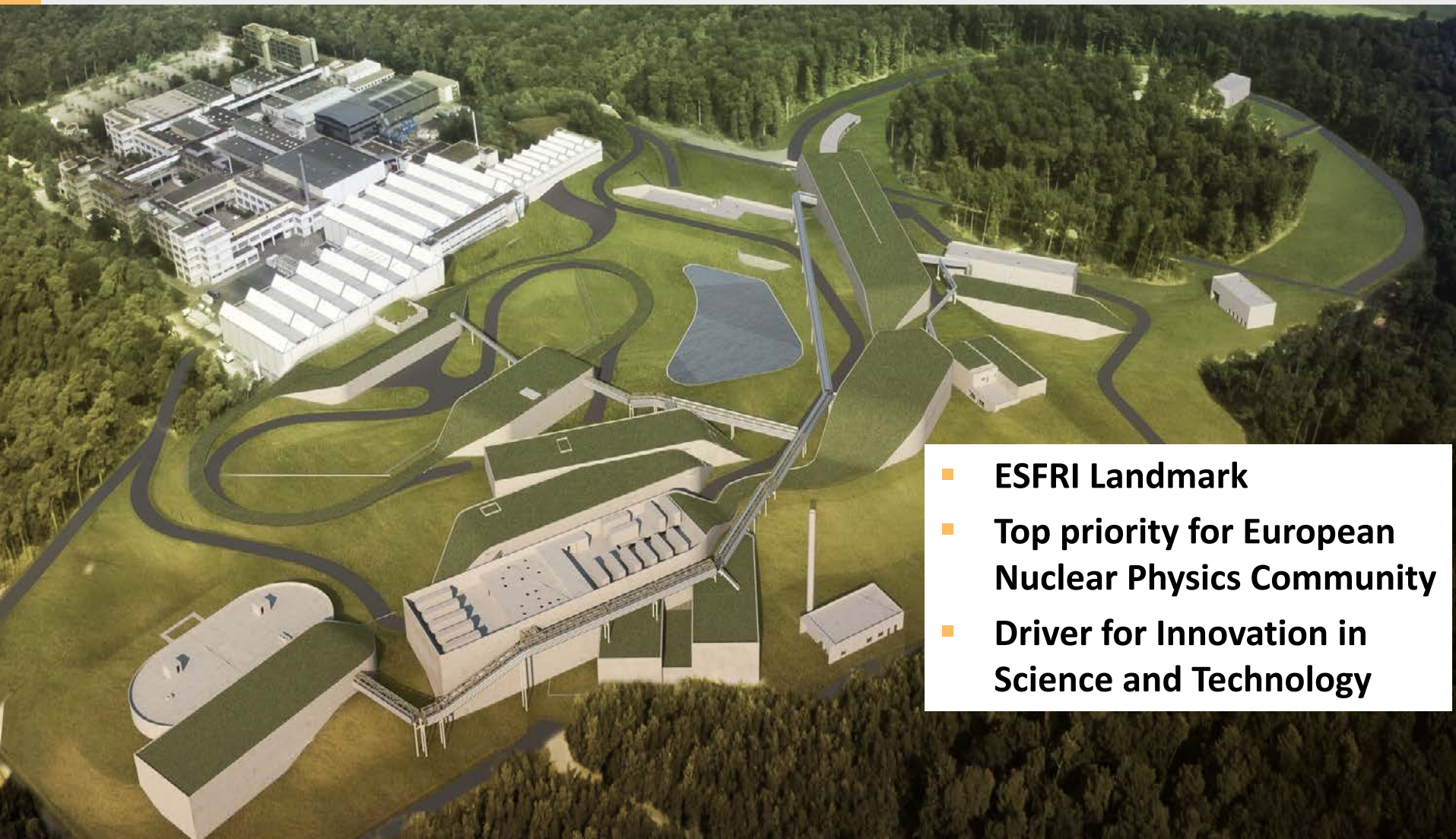
Paolo Giubellino
Cracow, October 27th 2021

On the trail of the secrets of the universe



FAIR: Facility for Antiproton and Ion Research

– builds on Competence of GSI and the Community worldwide



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



Finland



France



Germany



India



Poland



Romania



Russia



Slovenia



Sweden



United Kingdom



Czech Republic

3 March 2017

Why Darmstadt?

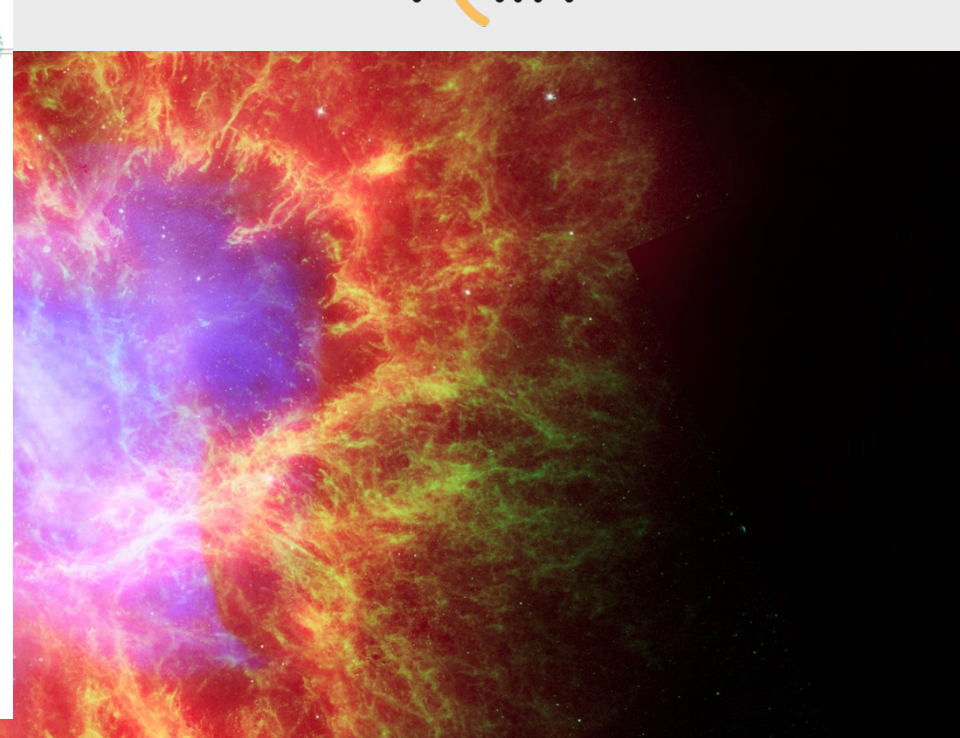


GSI – Scientific expertise for more than 50 years

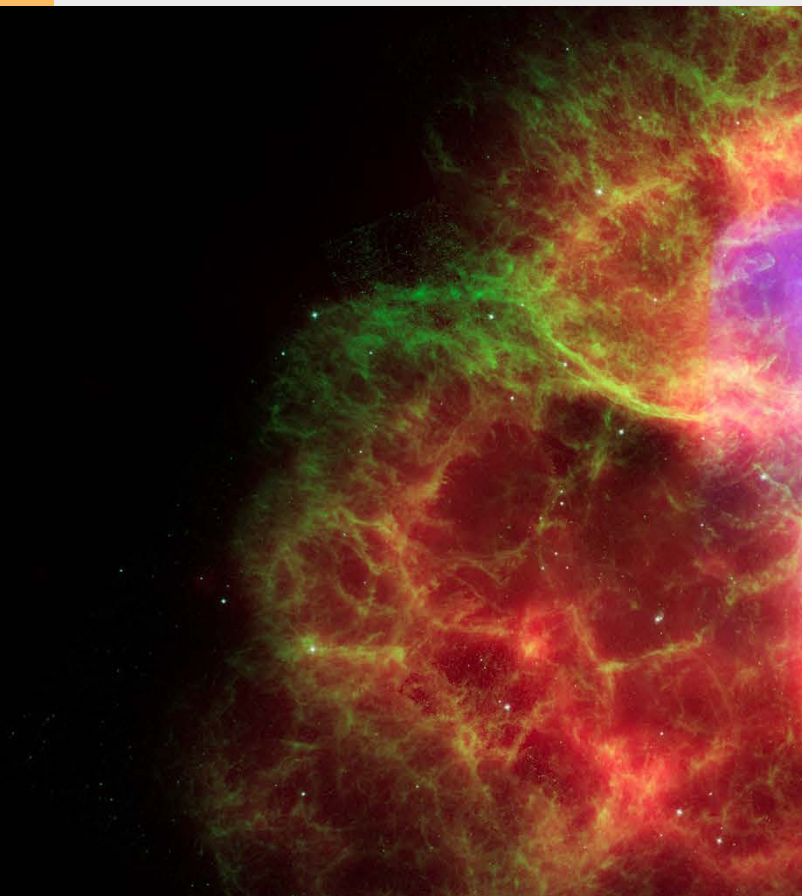


Photo: G. Otto/GSI/FAIR

Number of protons $\rightarrow$

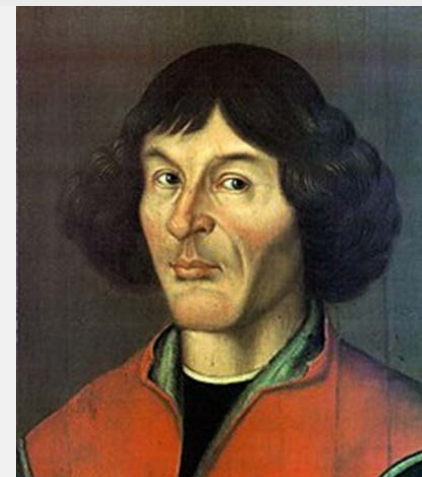


-
- The periodic table shows elements from Hydrogen (H) to Oganesson (Og). A yellow oval highlights the elements from Bh (107) to Og (118). The legend indicates that elements from Bh to Og are experimentally produced (yellow). Elements from Ts (117) to Og (118) are also verified at GSI (orange triangle).



^{112}Cn – Copernicium in honor of Niklas Copernicus

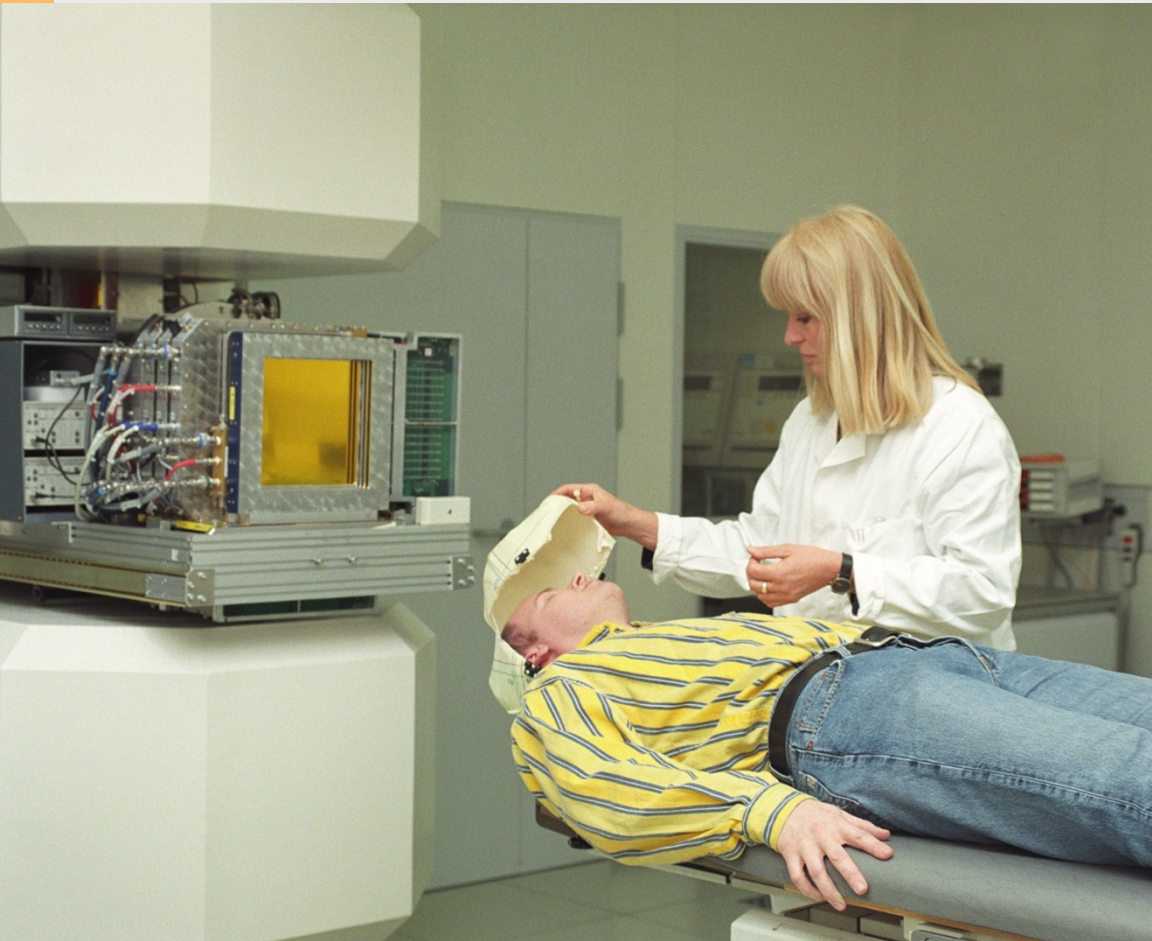
in recognition of many years of
excellent collaboration of GSI
with Polish scientists



76	77	78	79	80		
Os	Ir	Pt	Au	Hg		
107	108	109	110	111	112	113
Bh	Hs	Mt	Ds	Rg	Cn	Nh
Bohrium	Hassium	Meitnerium	Darmstadtium	Roentgenium	Copernicium	Nihonium

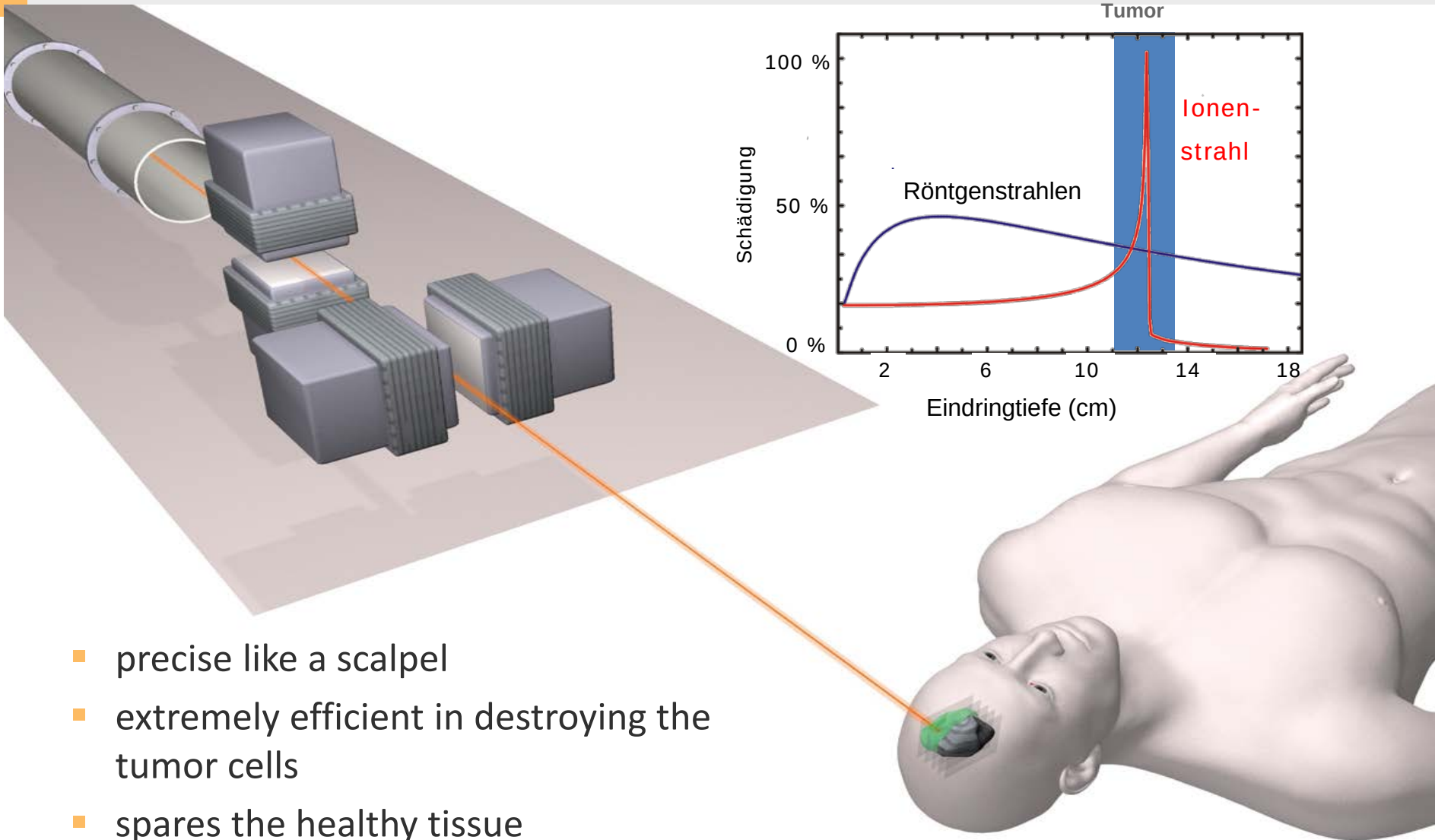
Legend: natural (light blue), experimentally produced (light yellow), theoretically predicted (light green)

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



- Innovation in cancer therapy

Major Developments: Ion Beam Therapy



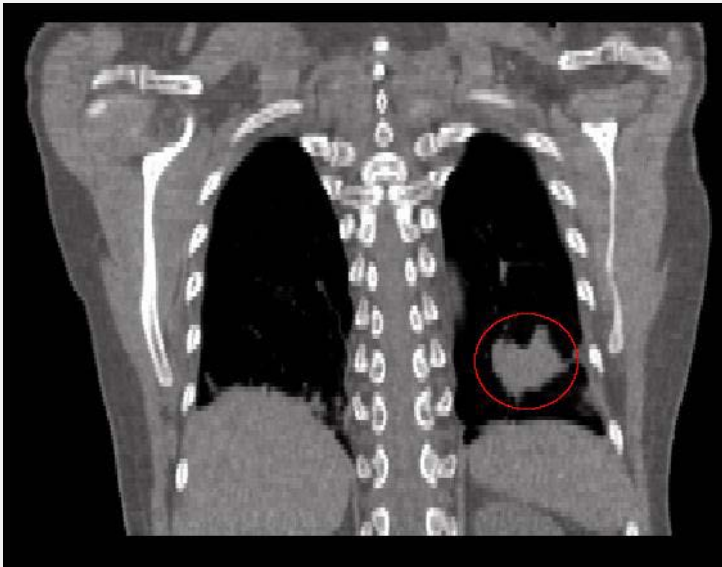
- precise like a scalpel
- extremely efficient in destroying the tumor cells
- spares the healthy tissue

And continues to address new challenges



Challenge:

Interplay between target movement
and beam scanning

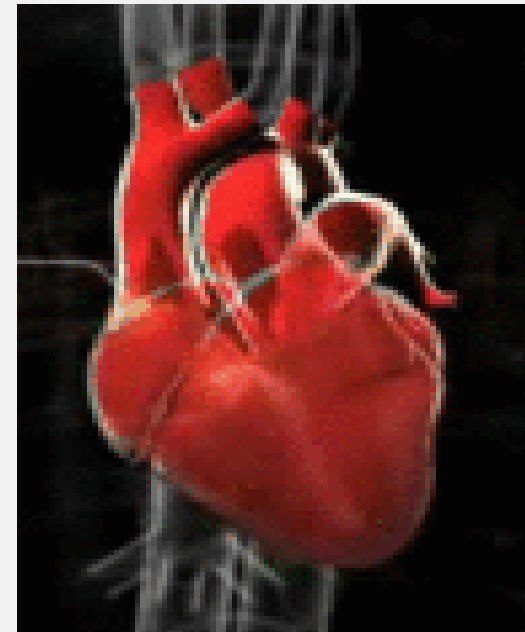


Solution:

Advanced beam delivery system:

→ Speed, Flexibility, Modularity

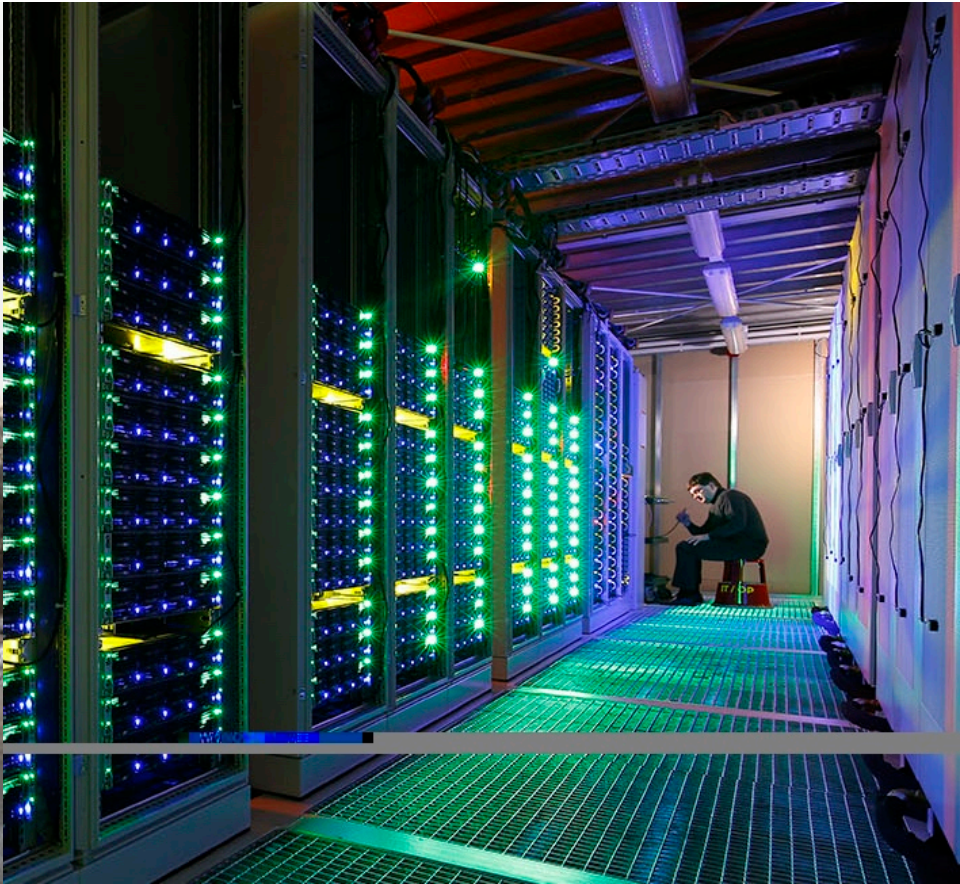
**Novel Applications for
non-Tumor Diseases**
(e.g. Heart Arrhythmia)



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



www.blauer-engel.de/uz161



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

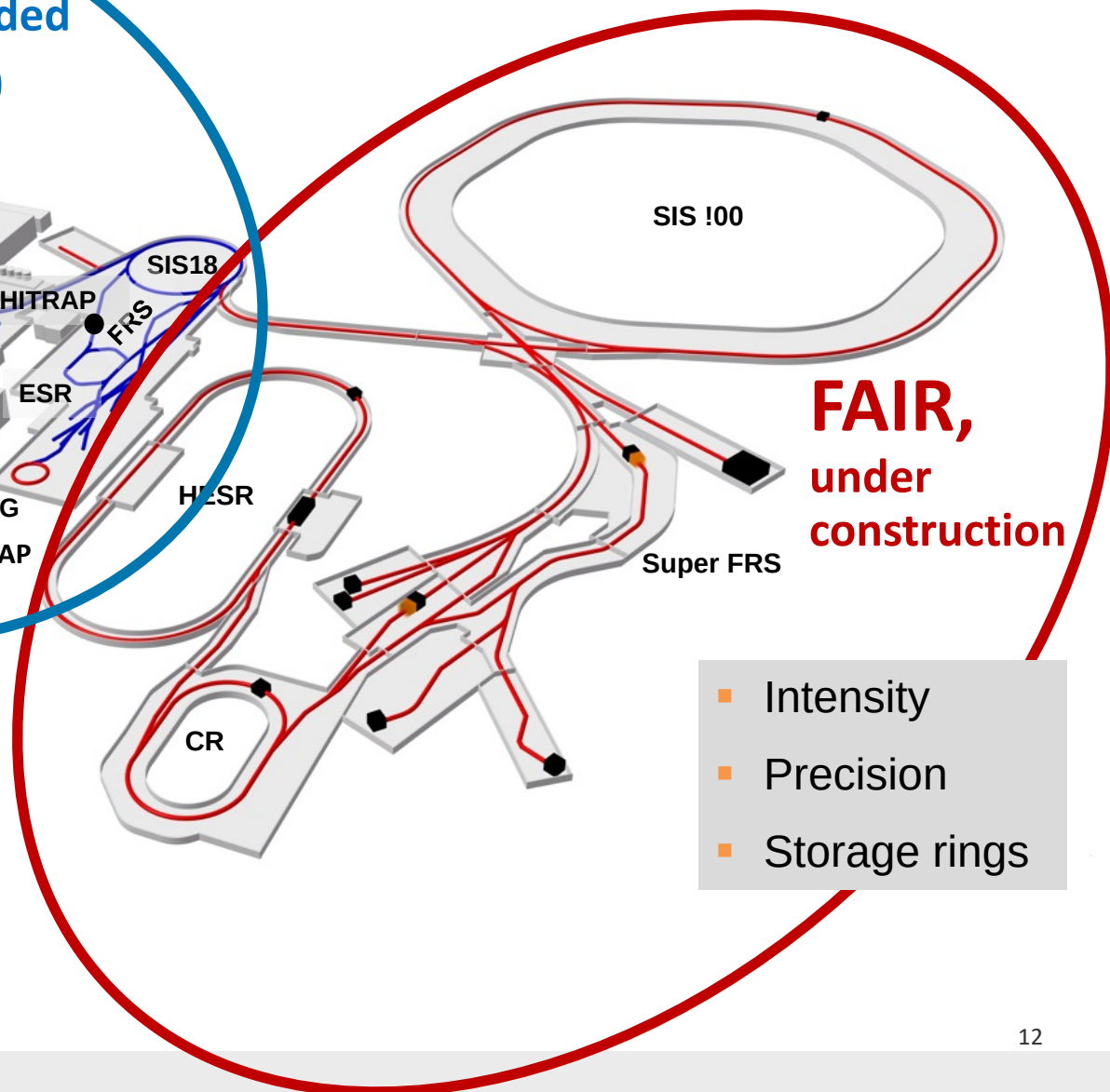
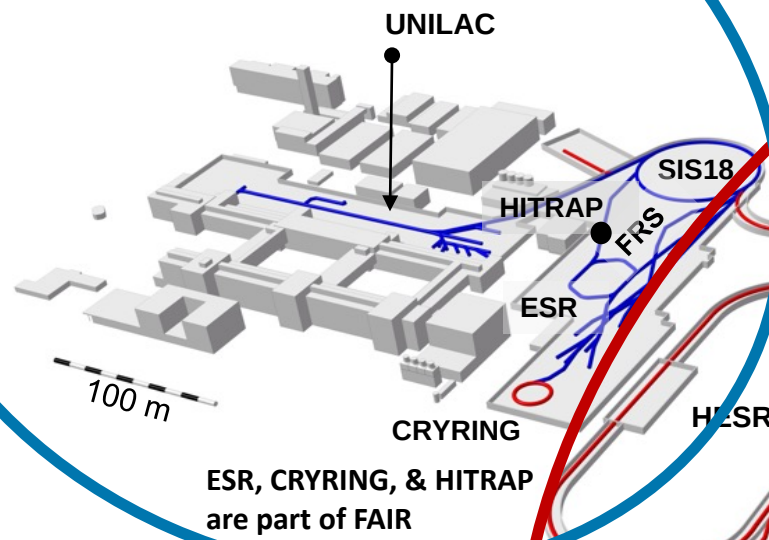
A Talent Factory



- A unique capability to attract and create talent and know-how.
- Training and education of the next generation of scientists, engineers and computing experts from all over the world:
 - Graduate Schools with currently more than 300 doctoral students from all over the world
 - International Postdoc Programs
 - Multiple training programs for students
 - Bilateral Agreements with several countries for training and education of young scientists and engineers



GSI, existing (upgraded to integrate with FAIR)



FAIR, under construction

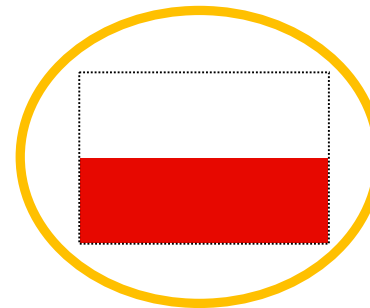
FAIR “Gain factors” rel. to GSI

- 100 – 10.000 x intensity
- 10 x energy
- antiproton beams

- Intensity
- Precision
- Storage rings

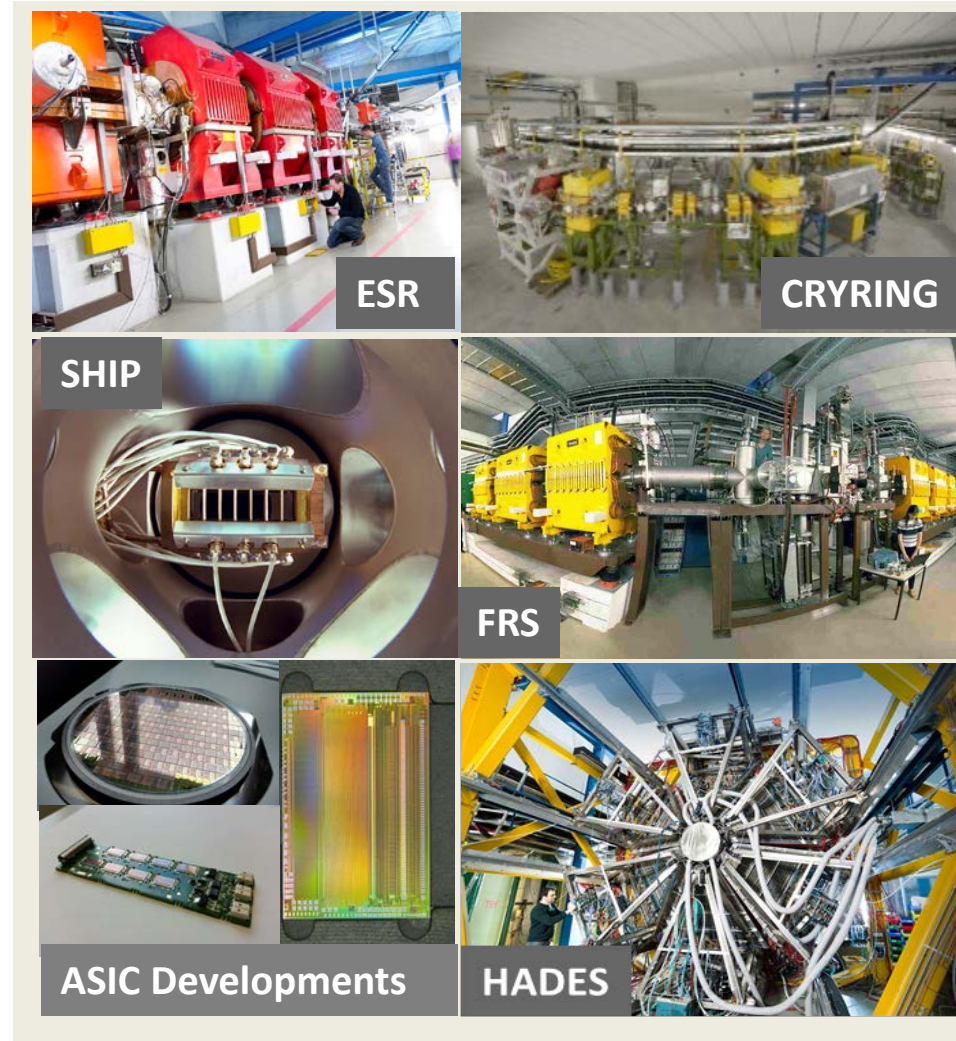


- FAIR governed by international convention
 - 9 shareholders:
 -   
 - + 1 associated partner: 
 - + 1 aspirant partner: 
- Over 3000 Scientists and Engineers from all over the world
- More than 200 institutions from 53 countries are involved with their scientists (orange + blue)



Longstanding Collaboration with Polish scientists and institutes for many decades:

- Atomic Physics → ESR, Cryring
- Nuclear Structure Physics, SHE research → SHIP, FRS + SFRS, Aladin-Land, R3B, RISING, AGATA, HISPEC/DESPEC
- Hadron and Hadronic Matter → FOPI, KAOS, HADES, CBM, PANDA
- Accelerator & Detector Technology
- Theory
- Electronics and data acquisition



Poland's Participation and Contribution to the FAIR Project



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APPA Physics — Atomic, Plasma Physics and Applications
CBM — Compressed Baryonic Matter experiment

NUSTAR — Nuclear STRUCTure, Astrophysics and Reactions
PANDA — Antiproton Annihilation at Darmstadt experiment

Shareholder ★
Collaborators and Contributors to FAIR ●
Collaborating Researchers and Scientists ●

Poland: **Key player** in the FAIR Project

- Shareholder: **Jagiellonian University, Kraków**
- Total financial contribution (2005 prices):
29.5 M€ (thereof 23.7 in kind,
5.8 M€ in cash),
- Participating institutions:



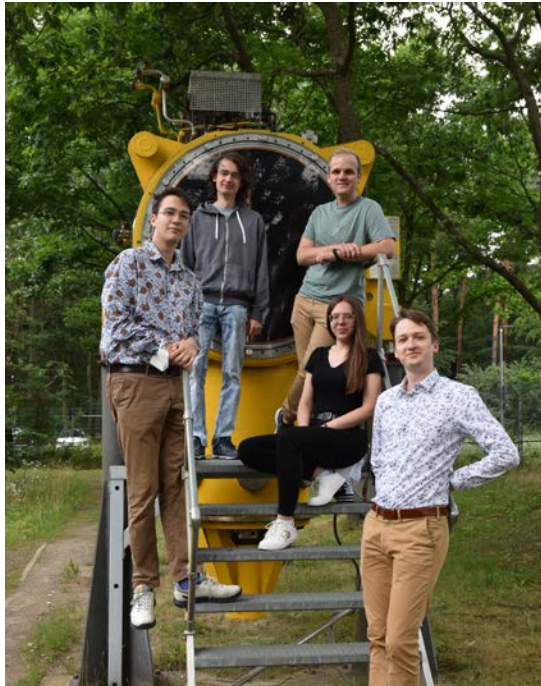
Ministry of Science
and Higher Education
Republic of Poland



Politechnika
Warszawska



Glimpse: Young researchers from Polish Universities



Growing partnerships

At the Germany-Poland –Czech Republic Science Platform in Dresden FAIR was discussed as a example of successful cooperation between Germany and Poland



Growing partnerships

Two cooperation MOUs on GET_INVolved Programme were signed at the event with Polish Universities



Creating extreme conditions existing in the universe with heavy ion accelerators



Foto: NASA, ESA, G. Dubner (IAFE, CONICET, University of Buenos Aires) et al.; A. Loll et al.; T. Teram et al.; F. Seward et al.; VLA/NRAO/AUI/NSF; Chandra/CXC; Spitzer/JPL-Caltech; XMM-Newton/ESA; and Hubble/STScI (oben); Penn State University (unten)

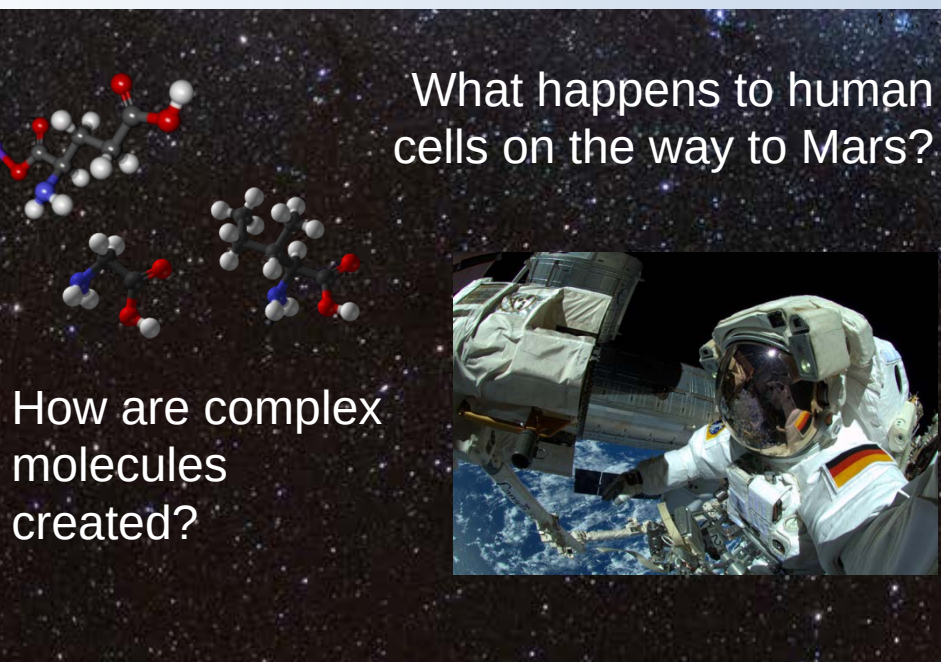
**To find answers to fundamental questions about the Universe :
The Universe in the lab ...**

Where are heavy elements created?



What is in the interior of a neutron star?

What happens to human cells on the way to Mars?

This block contains two images. On the left, there are several 3D ball-and-stick molecular models of complex organic molecules, including what appears to be a sugar molecule and a more complex branched structure. On the right, there is a photograph of an astronaut in a white spacesuit with a German flag patch, floating in space next to a large white satellite module.

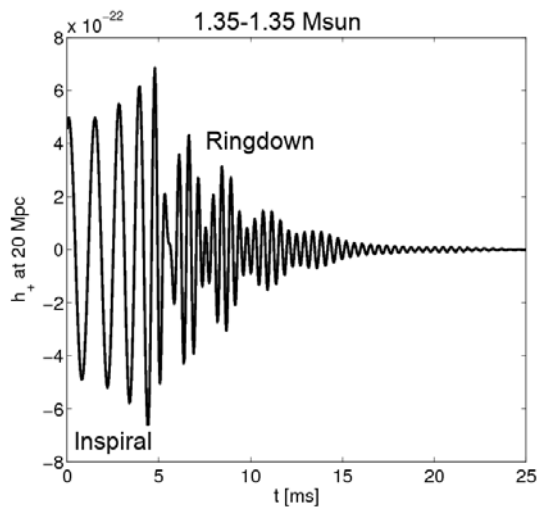
How are complex molecules created?

How do materials behave under high pressure?

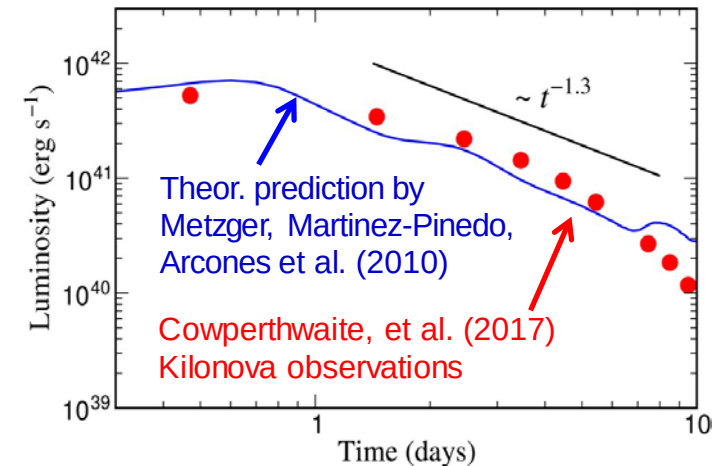
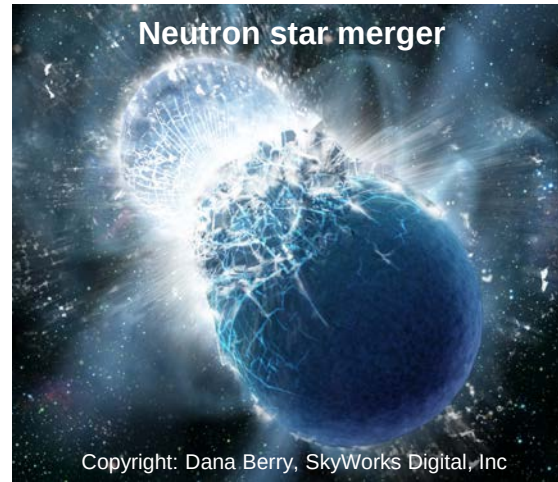
This block contains three images of celestial bodies. On the left is a large, blue, gaseous planet (Jupiter). In the center is a smaller, orange and white striped planet (Uranus). On the right is a small image of Earth, showing blue oceans and white clouds.

Fotos: Uranus, Jupiter, Erde Quelle: <http://de.wikipedia.org>

Neutron star mergers and their role for the production of heavy elements



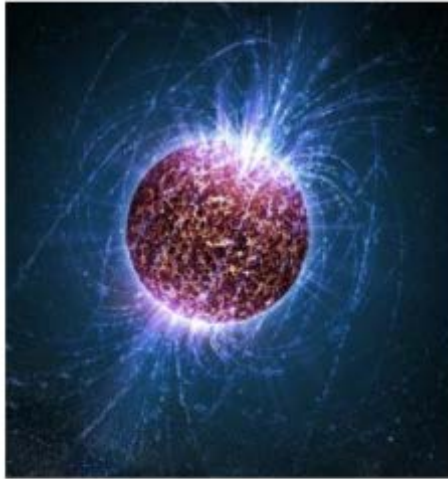
Gravitational wave signal



Elektromagnetisch "Kilonova"-Signal

Electromagnetic afterglow - "Kilonova-lightcurve" - reveals that heavy elements, e.g. Au and Pt, were produced (r-process), as predicted by GSI theorists.

Neutron Stars and Mergers vs HI collisions



Neutron stars

Temperature
 $T < 10 \text{ MeV}$

Density
 $\rho < 10 \rho_0$

Lifetime
 $T \sim \text{infinity}$



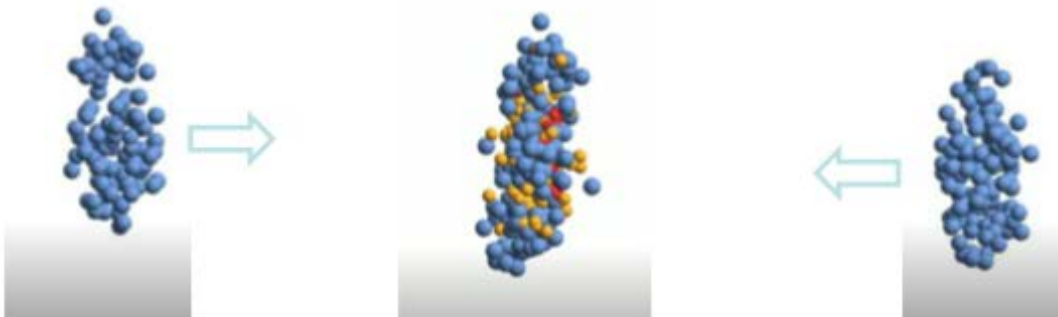
Neutron star merger

Temperature
 $T < 50 \text{ MeV}$

Density
 $\rho < 2 - 6 \rho_0$

Reaction time
(GW170817)
 $T \sim 10 \text{ ms}$

Heavy ion collisions at SIS100



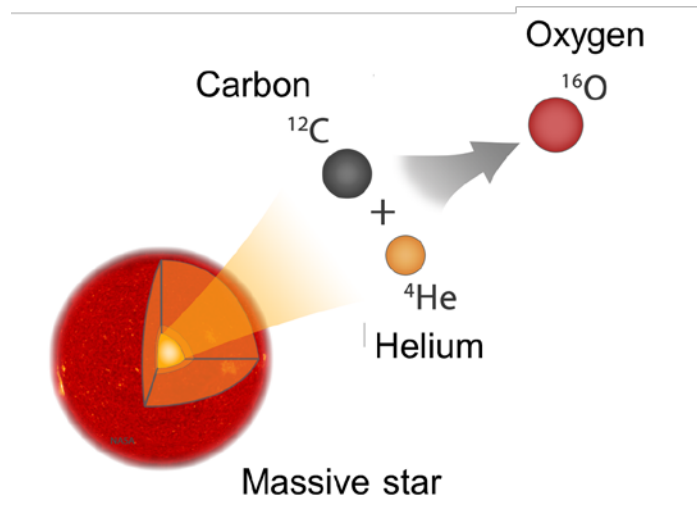
Temperature
 $T < 120 \text{ MeV}$

Density
 $\rho < 8\rho_0$

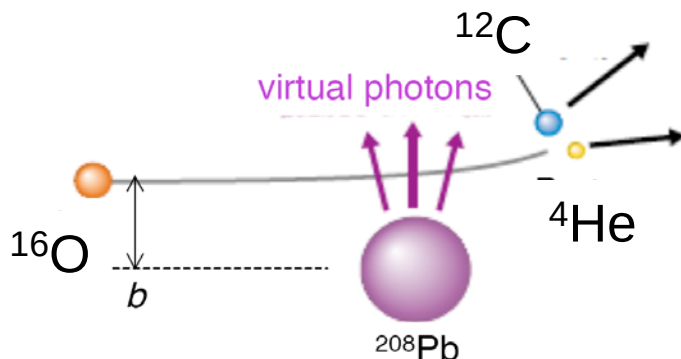
Reaction time
 $t \sim 10^{-23} \text{ s}$

Compressed Baryonic Matter

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

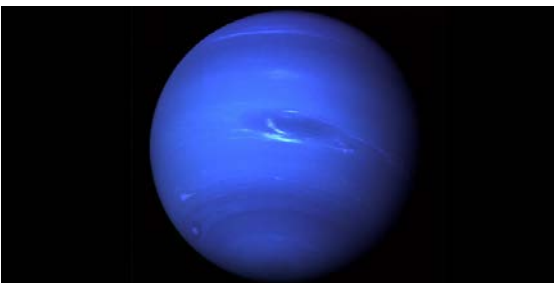
Matter in the interior of the Earth and of large planets



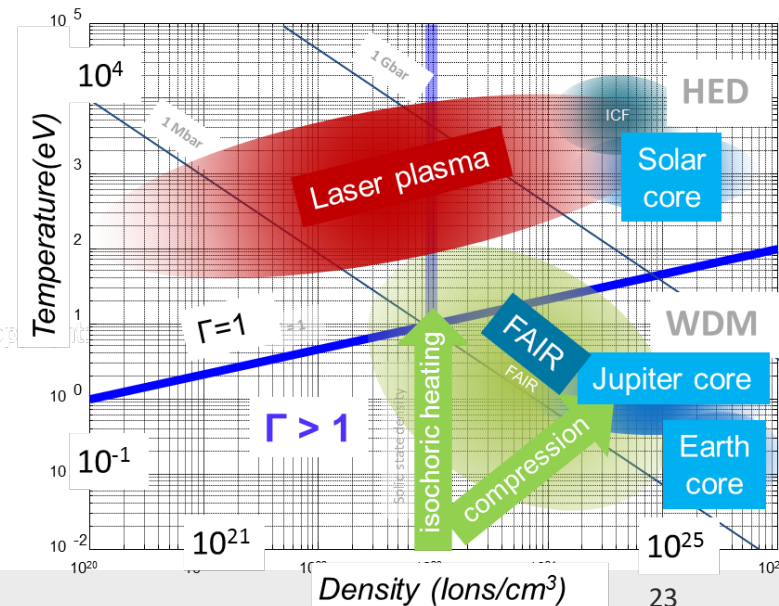
- The interior of our Earth is most likely composed of liquid iron. What is exactly the melting curve for iron?



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



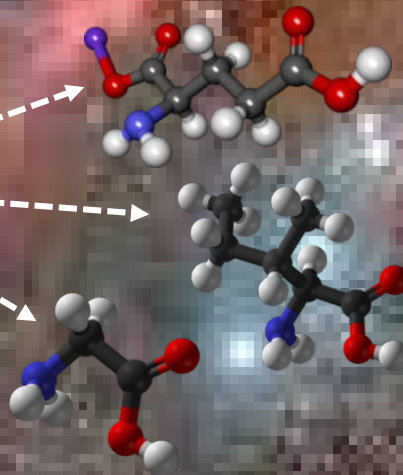
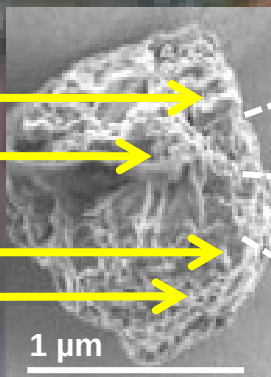
- Are there diamond layers in Uranus and Neptune? What role does the high-density metallic state of water play for the magnetic field in Uranus and Neptune?



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

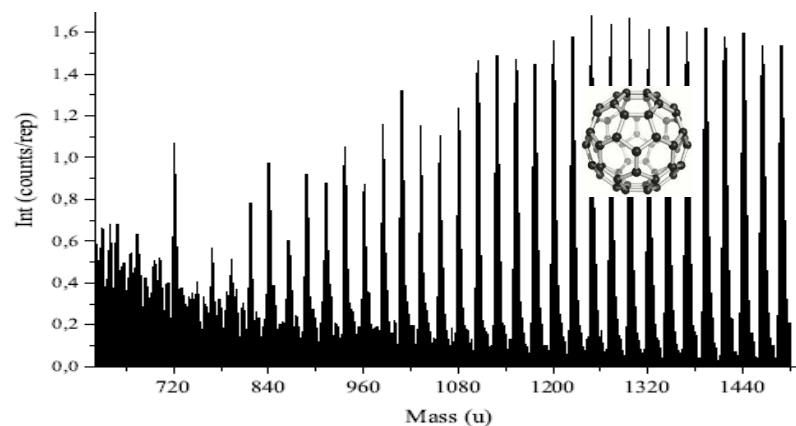
$\text{C}_6\text{H}_{13}\text{NO}_2$ amino acids

C_{60} , C_{70} fullerenes



irradiation chamber and spectrometer

spectrum of large desorbed molecules



... with direct applications



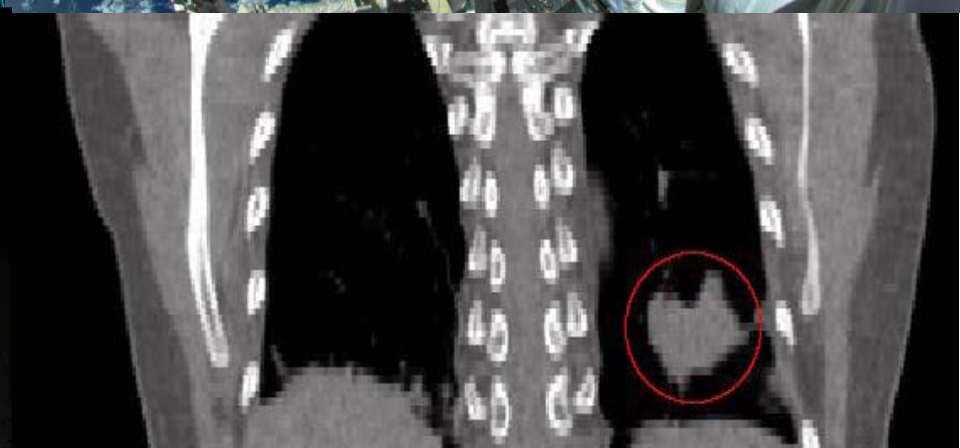
High-performance and scientific computing, big data, green IT



Space radiation protection, unique facility for simulation, collaboration with ESA



Development of nuclear clock:
Promising candidate thorium-229

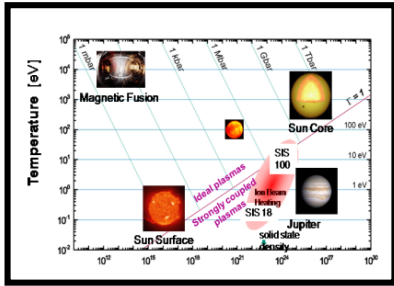


Novel applications for tumor and non-tumor diseases

The Facility (JB)

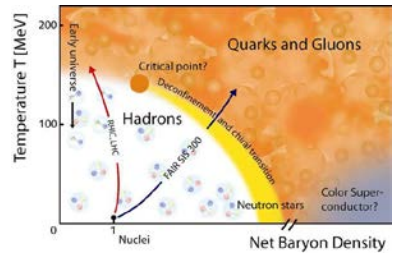


The FAIR science: four pillars



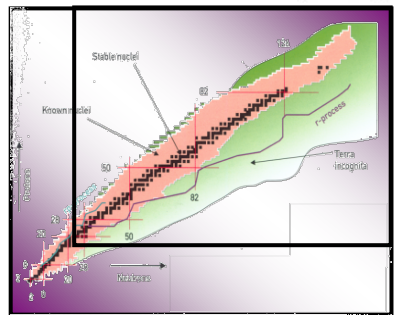
atomic physics, biophysics,
plasma physics, material research

APPA



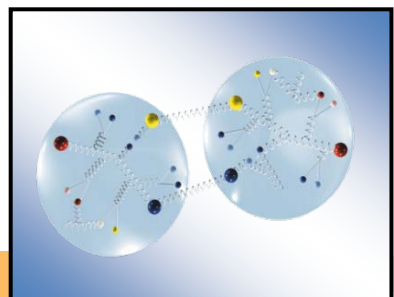
nuclear- and quark-matter

CBM



nuclear structure and
nuclear astrophysics

NuSTAR



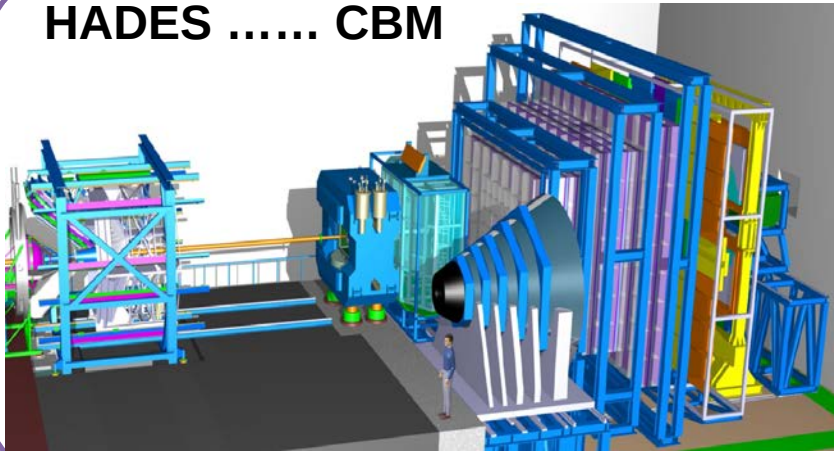
hadron structure and dynamics

PANDA

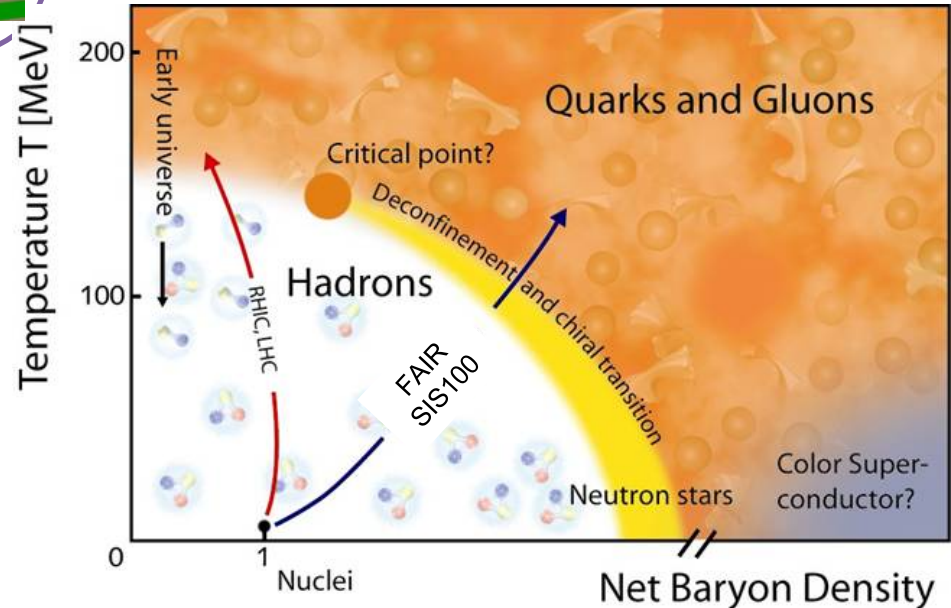
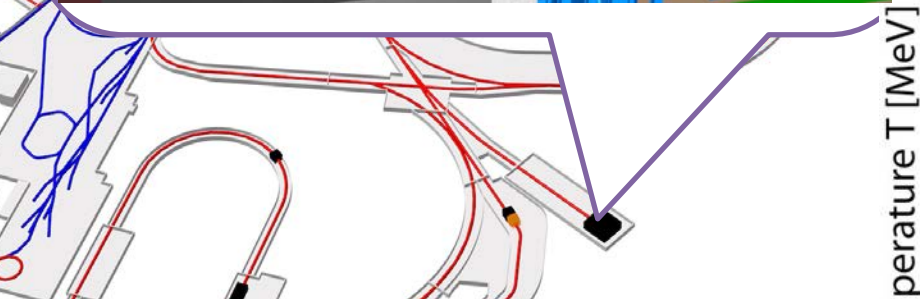
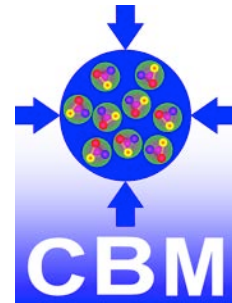


C.B.M.

HADES CBM



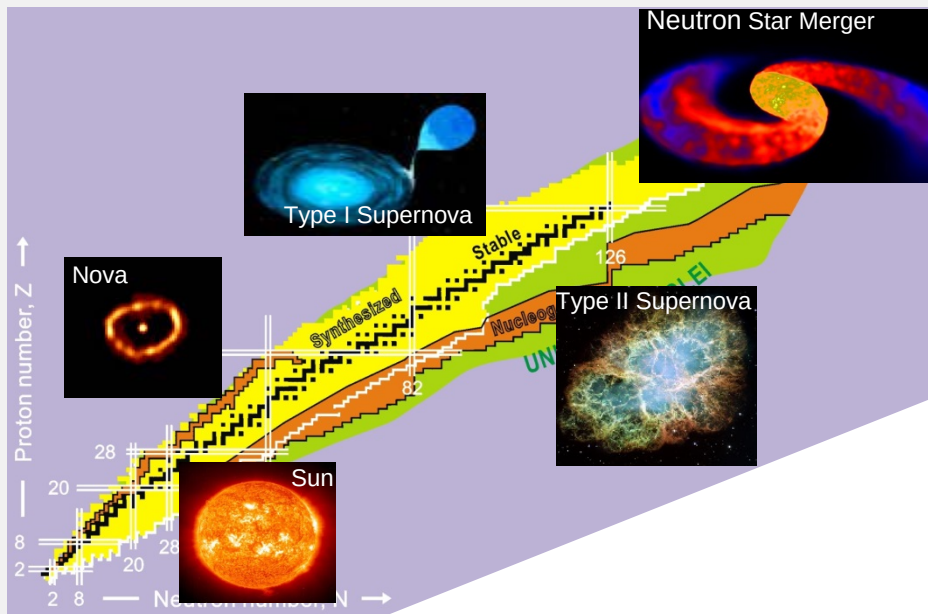
- Compressed Baryonic Matter Experiments
 - About 400 members





NUSTAR

- Origin of Elements in the Universe



„Nucleosynthesis sites“ in the universe

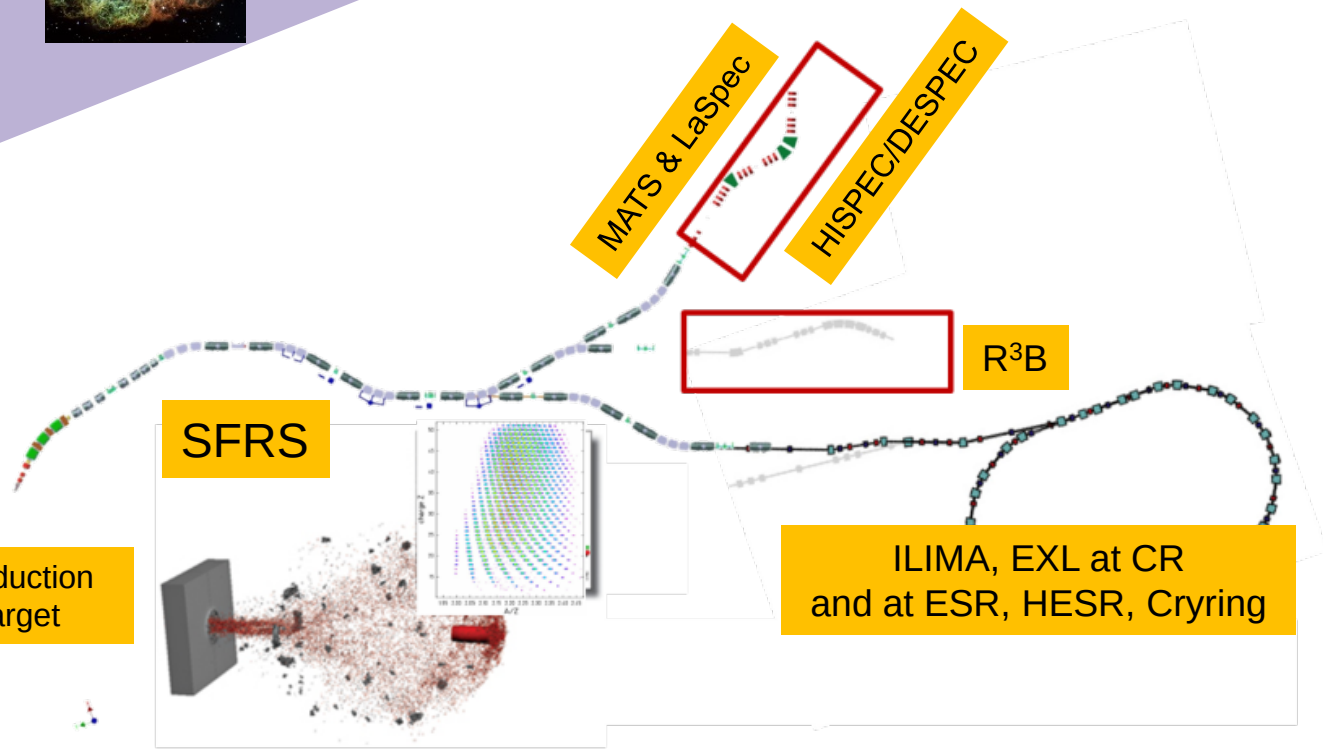
„Nucleosynthesis sites“ at FAIR

Primary intensities vs. GSI: x 100

SIS 100



production target

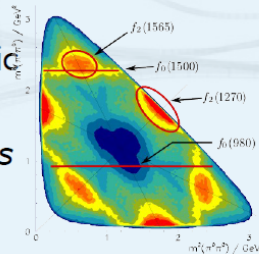


PANDA - AntiProton Annihilation at Darmstadt

Bound States of Strong Interaction

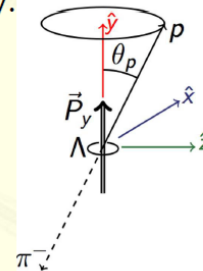
Spectroscopy

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



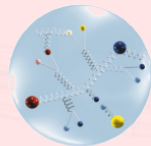
Strangeness

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



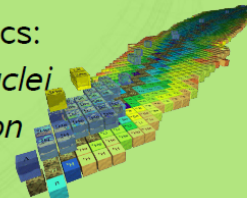
Nucleon Structure

- 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*



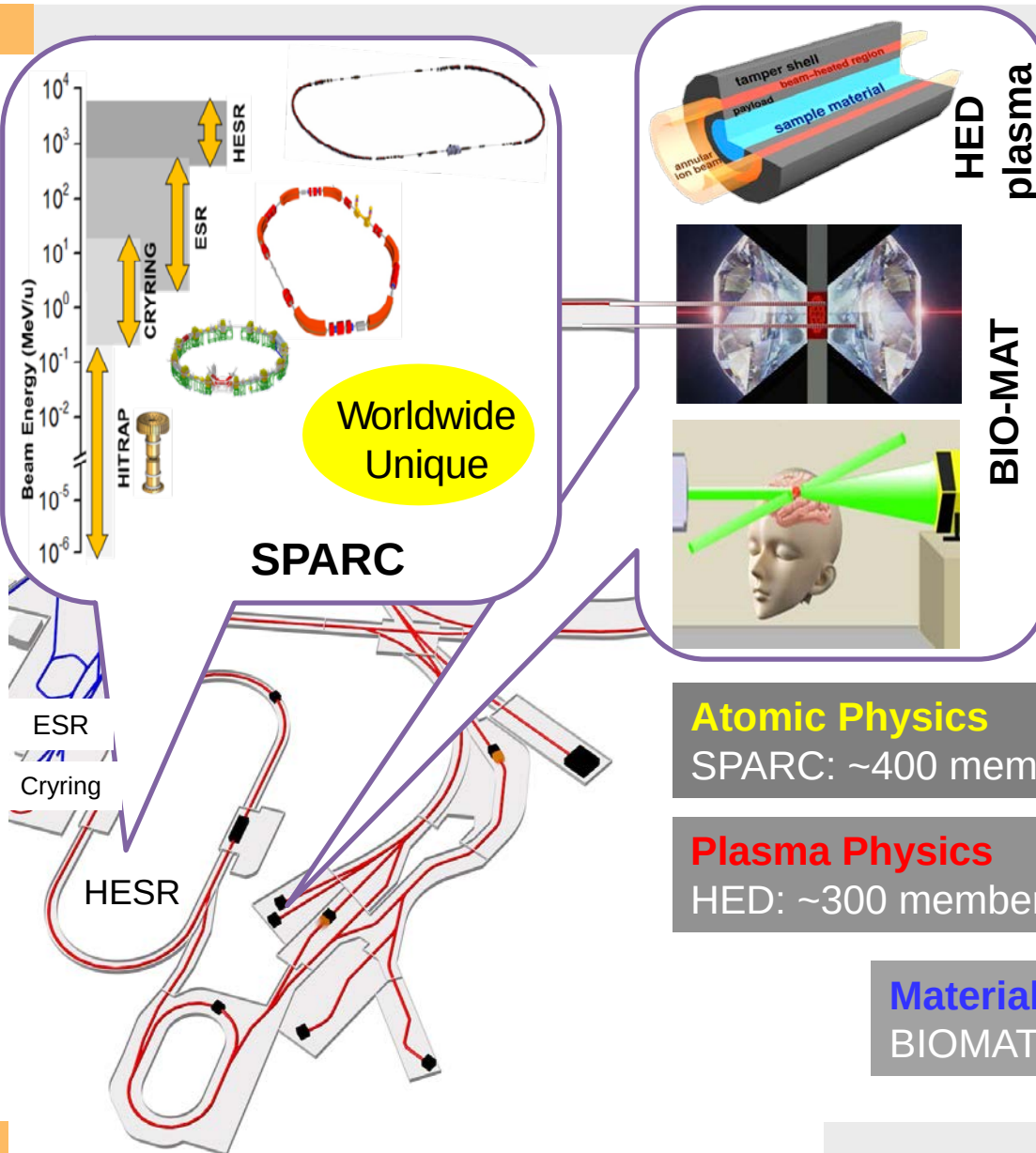
Nuclear Hadron Physics

- 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.



- 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

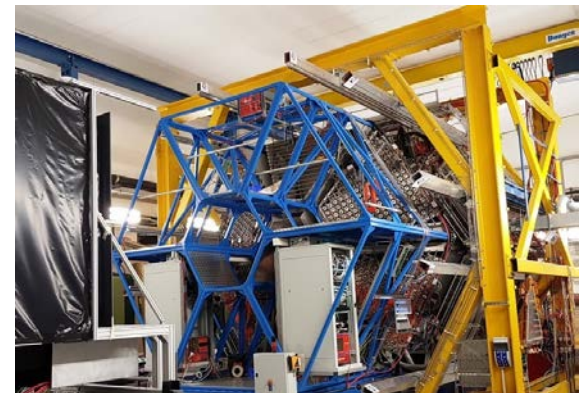
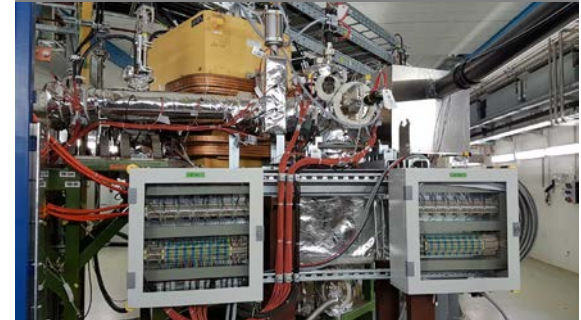
Materials Research and Biophysics

BIOMAT: ~100 members from 12 countries

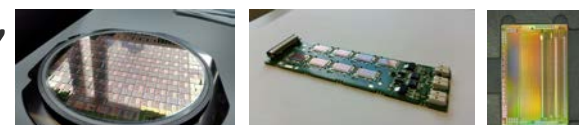
Polish Contributions to FAIR Experiments

- Polish scientists and institutions are involved in all experimental pillars of FAIR.
- APPA experiments
 - Mostly in SPARC experiments, e.g. Cryring
 - Involved institutions – WU Warsaw, Jagiellonian University, Cracow Soltan Institute, Lodz Univ., Polish Academy of Sciences,
- CBM and HADES experiments
 - in Silicon tracker and development of read-out electronics,
 - Mechanical frames
 - Involved institutions – AGH Kraków, JU Kraków, WU Warsaw, Univ. Silesia

CRYRING UHV infrastructure



HADES upgrade towards FAIR

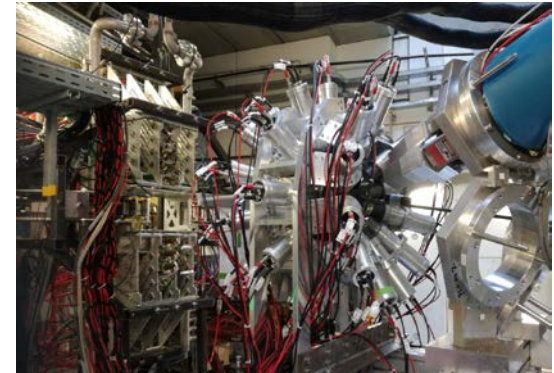


ASIC Developments

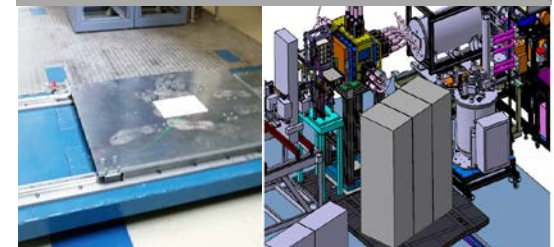
Polish Contributions to FAIR Experiments

Polish scientists and institutions are involved in all experimental pillars of FAIR.

- NUSTAR experiments
 - in HISPEC/DESPEC and R3B experiments; detectors (e.g. O-TPC), mechanical constructions
 - Involved institutions – Inst. Exp. Phy, Warsaw, IFJ PAN, Krakow, NCNR Otwock-Swierk
- PANDA experiments
 - DAQ for Straw Tube Trackers (STT), Slow control for the GEM detectors and cluster JET
 - Involved institution – AGH Kraków, JU Kraków, IFN PAN Kraków, NCNR Otwock-Swierk



NUSTAR:AIDA+FATIMA+DEGAS



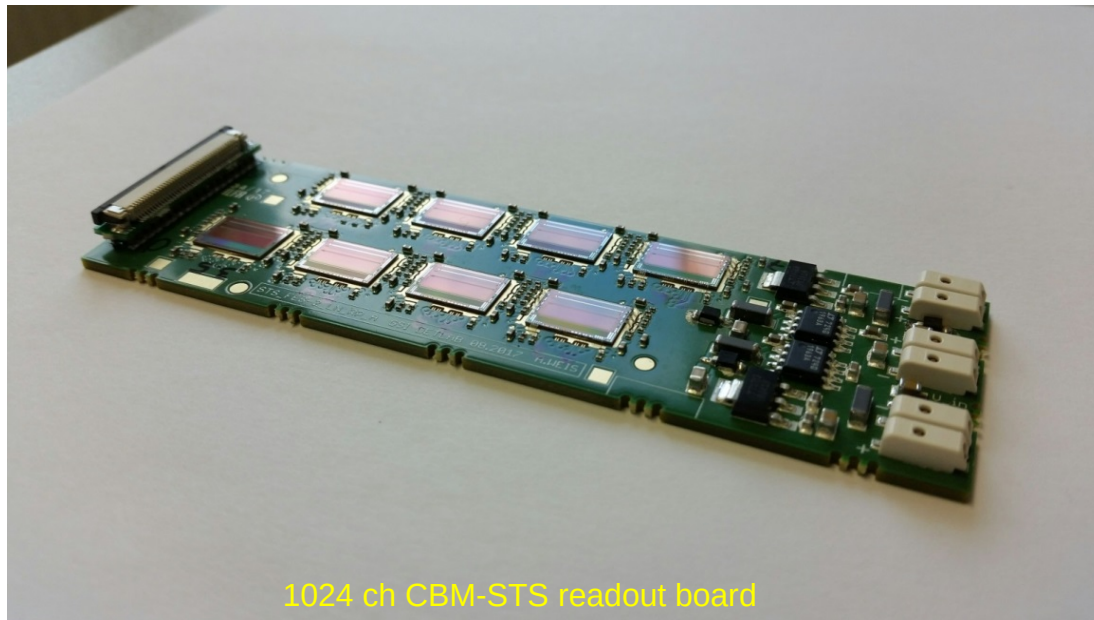
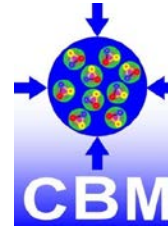
Ultra precise positioning systems



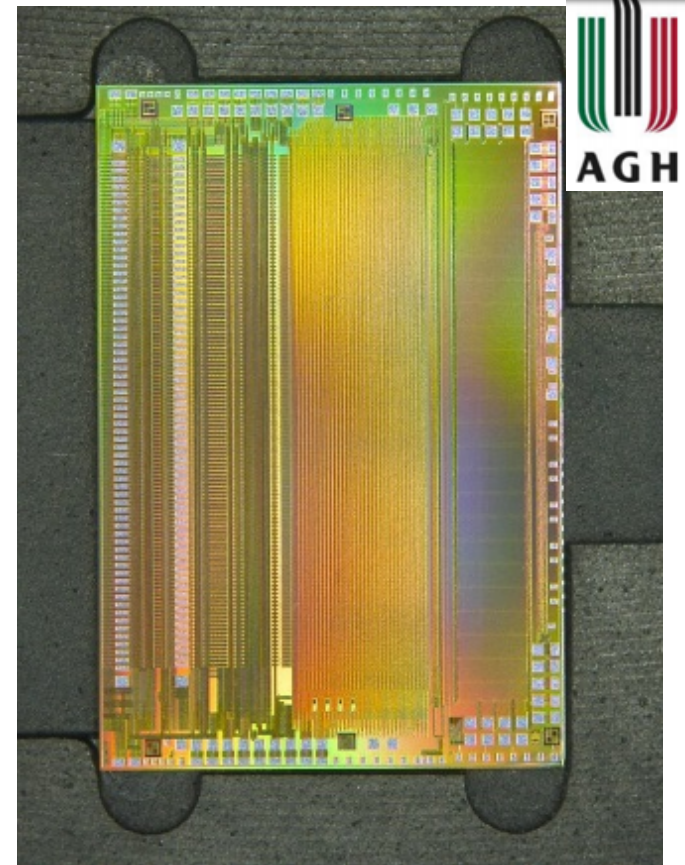
PANDA Straw Tube Tracker

128ch Readout ASIC serves as STS-XYTER and Much-XYTER r/o

- Moderate Time ($\sim 5\text{ns}$) and Energy res. (5bit)
- 1000 electrons noise
- Switchable Gain, Identical Readout Logic
- GBTx-based DAQ, 32 Mbit/s each chip
- Power optimized, radiation tolerant



1024 ch CBM-STX readout board

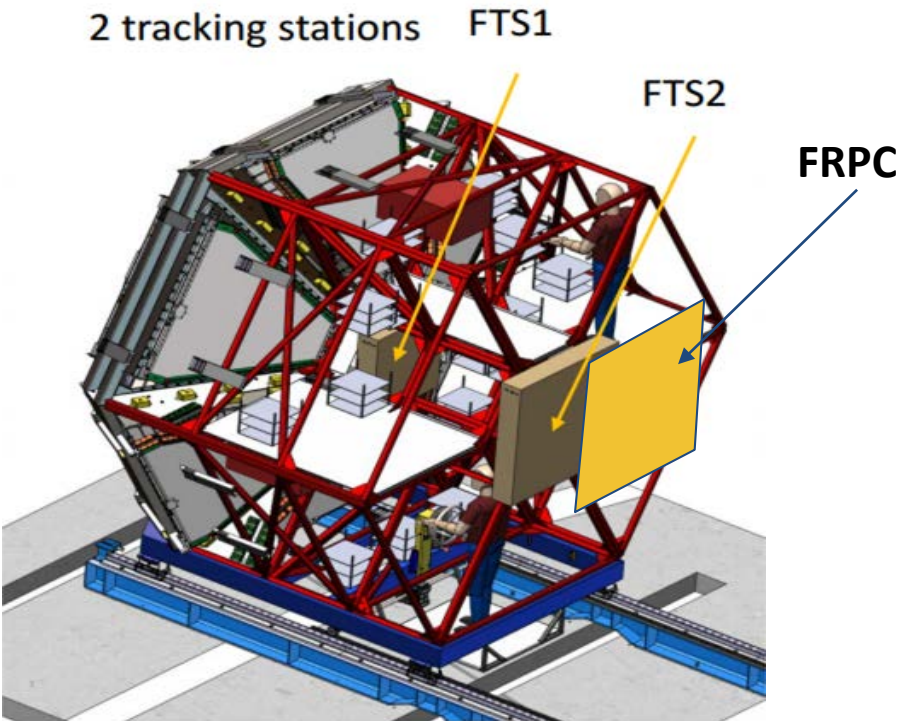


- Microchip ASIC developed at AGH Krakow,
- Design internationally reviewed,
- Detector Integration by international groups

Purpose and Concept

- Increase HADES acceptance for NN collisions ($0.5^\circ < \theta < 6.5^\circ$)
- Two tracking stations and RPC detector (**FTS2 designed and produced at JU Cracow, front-end electronics JU and AGH Kraków based on dedicated ASIC for straw tubes**)
- Test and commissioning of PANDA Forward Straw tube tracker modules
- PID via TOF, dE/dx (straw tube) – no Magnetic Field

HADES



HADES Electromagnetic Calorimeter



HADES

Purpose and Concept

- Based on lead-glass modules
- Significant improvement in electron-to-pion suppression
- Enables photon measurements
- Performance: $\Delta E/E = 5\%$ at 1.0 GeV (photons)

ZUGIL S.A. Team during mainframe and rail system installation at HADES together with HADES members and designers from Cracow University of Technology



Mainframe production and installation: ZUGIL Spółka Akcyjna ul. Sieradzka 56, 98-300 Wieluń, Poland

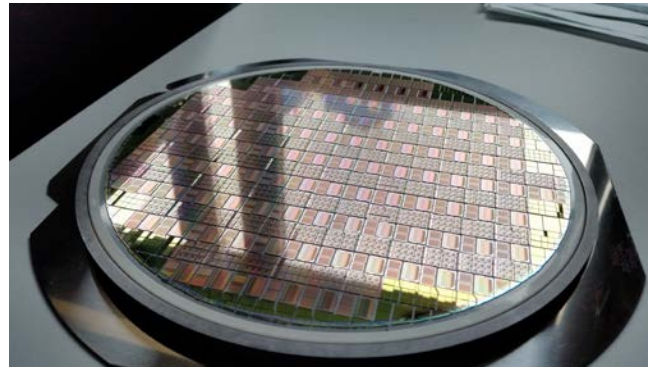
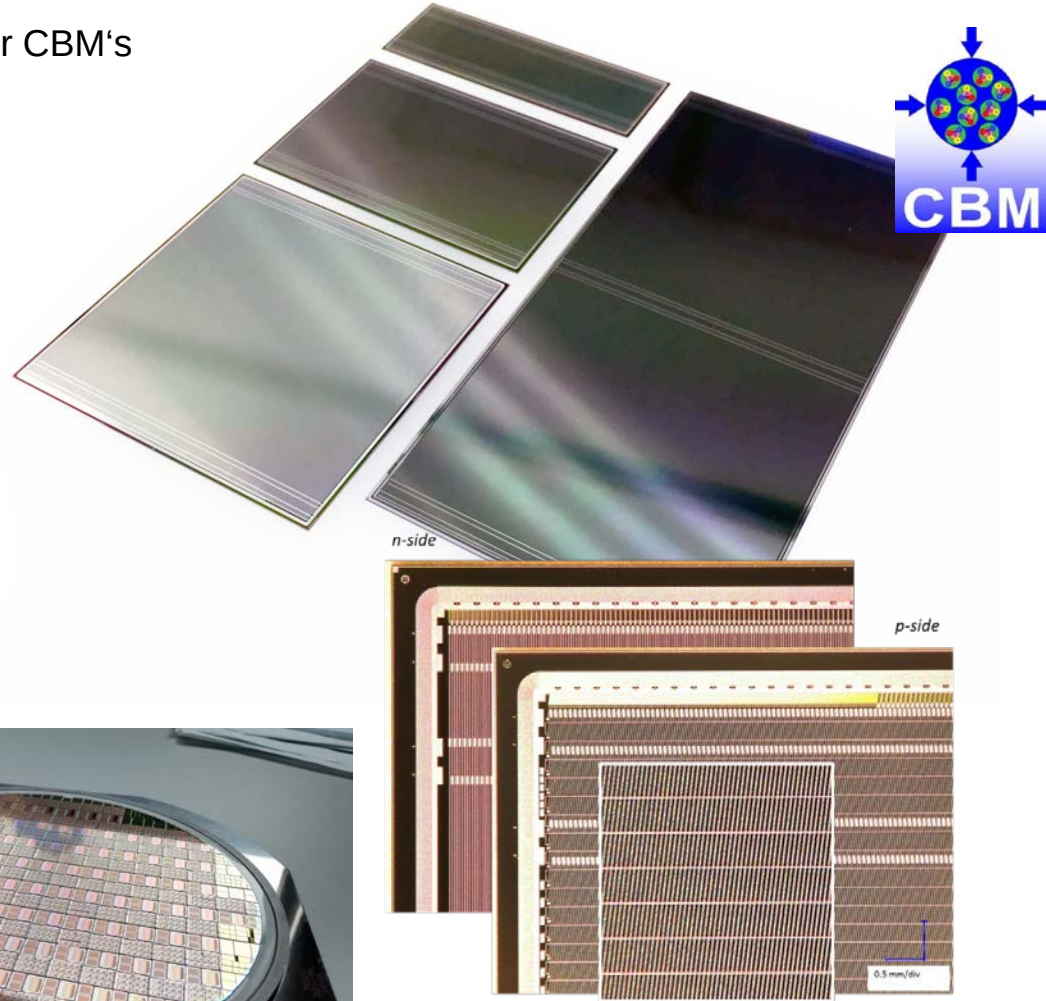
ECal Mainframe



Rail System

Silicon Microstrip Sensors

- highly-granular, radiation tolerant sensors for CBM's main tracking detector „STS“
- final prototypes developed by the CBM Collaboration and produced in industry:
 - *double-sided strip segmentation*
 - *1024 strips per side*
 - *4 main variants*
 - *6.2 cm total width*
 - *2.2, 4.2, 6.2 and 12.4 cm long*
 - *strip lengths matched to particle densities in STS*
- about 1100 sensors required
- Polish contribution to the acquisition from industrial vendor



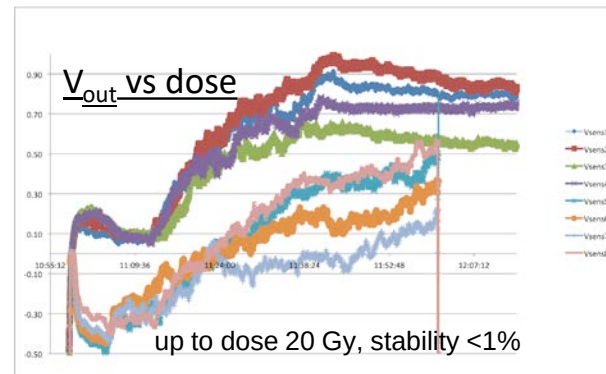
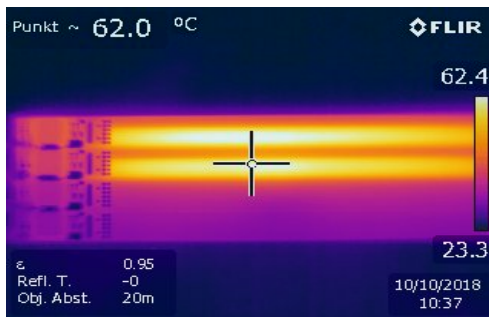
Proton irradiations @IFJ Krakow

- 58 MeV proton beam of high quality and intensity available in Institute of Nuclear Physics (IFJ PAN) in Krakow/PL
- High precision dosimetry assured (equipment and experience)
- Irradiation of electronic (LDOs) and mechanical parts (bonded ASICs e.g. FEB8) for several CBM@FAIR related projects
- Planned runs: FEB-C, diebonded ASICs, pull test sample

Radiation test of FEB-C and test of conductive glue



Low Voltage Drop regulators
(IR photo)



Dummy-FEB8 with diebonded ASIC's for radiation tests



Pulltest samples (behaviour of silver conductive glue)

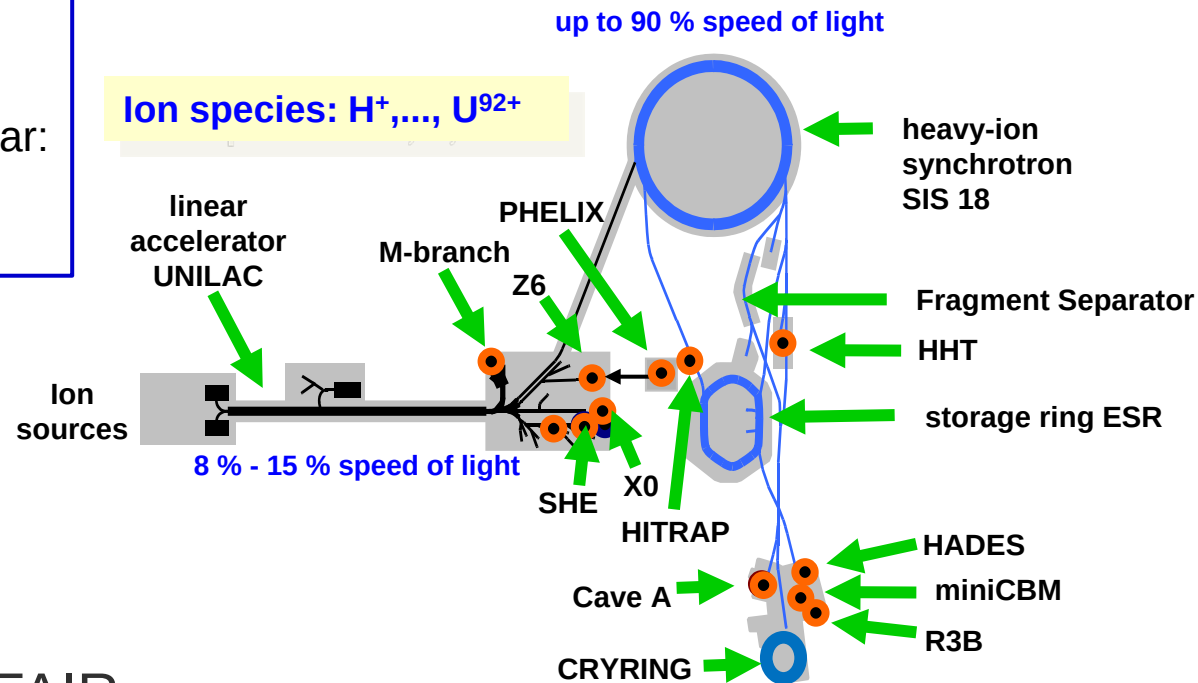


- While working towards start of FAIR, *staged approach to FAIR science and progressive commissioning of accelerators and detectors*:
 - FAIR phase 0 : started in 2019, to continue with annual runs till start of FAIR
 - Until 2024 a block of 3 months beamtime per year. The scheme for 2025/2026 will be developed depending on commissioning progress, to ensure that the activities will be compatible
 - Installation of infrastructure items of the experiments in the new experimental halls, DURING the installation of technical infrastructure, 1 or 2 years before final delivery of the completed buildings
 - FAIR day 1 configurations/ phase 1 experiments with FAIR accelerators progressively approaching design parameters
 - Full FAIR operation

Early science program FAIR Phase-0



- Since 2019, annual runs of < ~110 days until FAIR operation
- Supported by FAIR partners, so far: Finland, France, Germany, Romania, Sweden and the UK

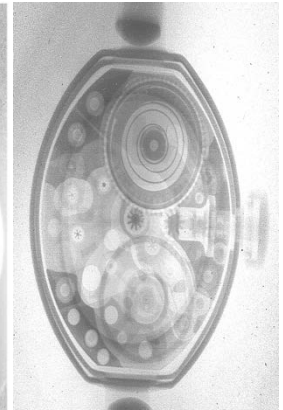


Science while realizing FAIR

- strong response by scientific community, over 1 thousand scientists involved, demand largely exceeding the available beamtime, confirming the attractiveness of the experimental opportunities
- 1/3 of the 2020 experiments could not be performed, mostly because of Covid-19, and are being performed in 2021/22
- the 2021 beamtime has been performed as planned

Example: PRIOR II, Proton Microscope

- Proton radiography
- Upgrade with new PRIOR magnets complete
- Commissioning in February 2021
- Achieved resolutions
 - spatial $20\ \mu\text{m}$
 - in time $10\ \text{ns}$



PRIOR-I (2014)

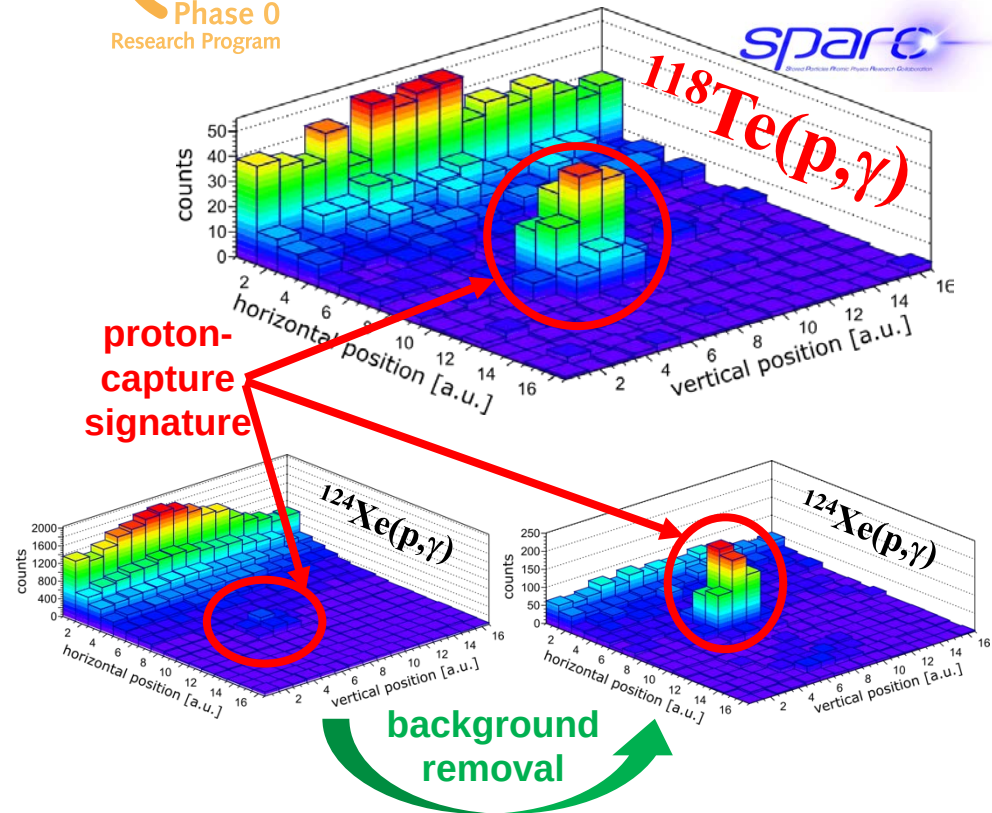
PRIOR-II (2021)



Ground-breaking experiment opening way for nuclear astrophysics experiments at FAIR with ESR



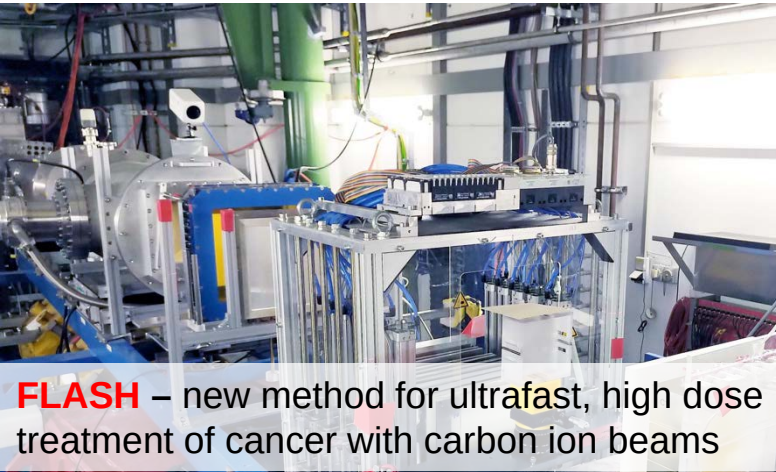
- E127: Proton-capture rates for nuclear astrophysics:
First reaction study on stored radio-beam at low energies
- Study of radioactive ^{118}Te (6 days half-life)
 - production, storage, accumulation and deceleration in FRS-ESR
 - proton-capture measurements realized at 7 MeV/u and 6 MeV/u
- New background-free detection method demonstrated



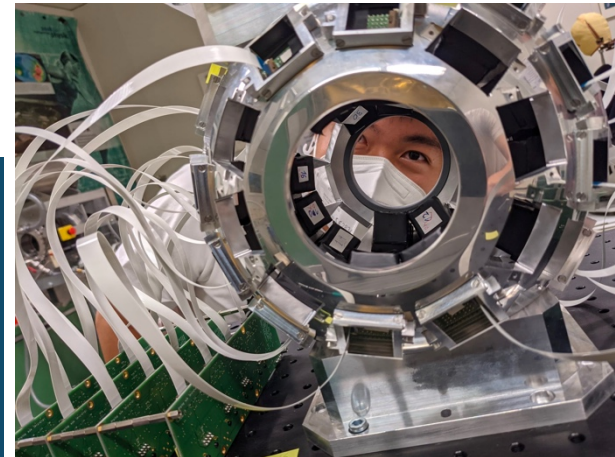
Jan Glorius et al.



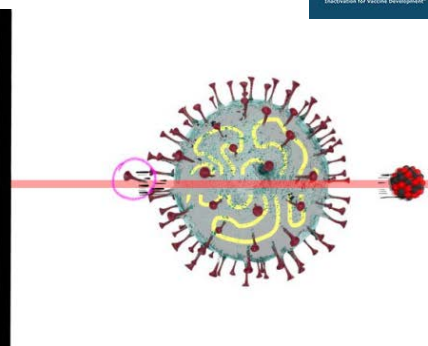
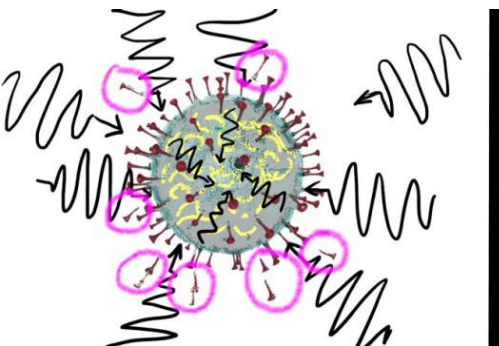
Biophysics FAIR Phase-results examples



FLASH – new method for ultrafast, high dose treatment of cancer with carbon ion beams



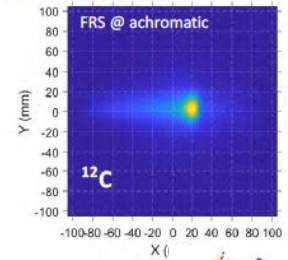
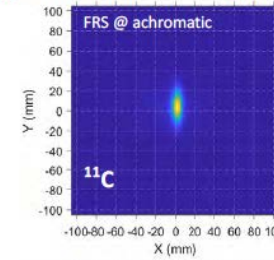
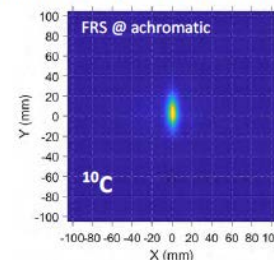
Hybrid γ -PET detectors for RIB



BARB (ERC Grant) – Cancer Therapy with radioactive isotopes for simultaneous treatment and PET

~ 270 MeV/u, ~ 120 mm range in water

3D PET planar image



Research on COVID-19 vaccines production with heavy ion beams in cooperation with HZI-Braunschweig

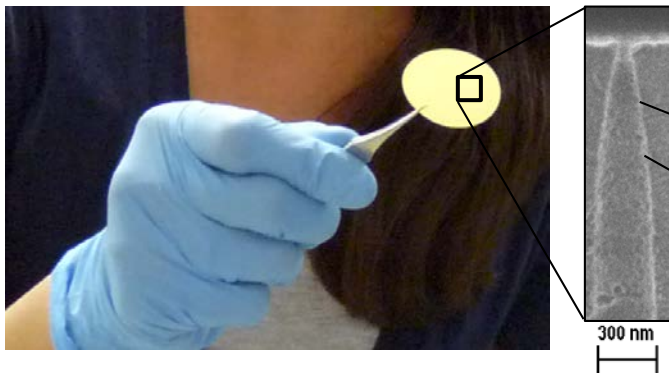
www.gsi.de/BARB



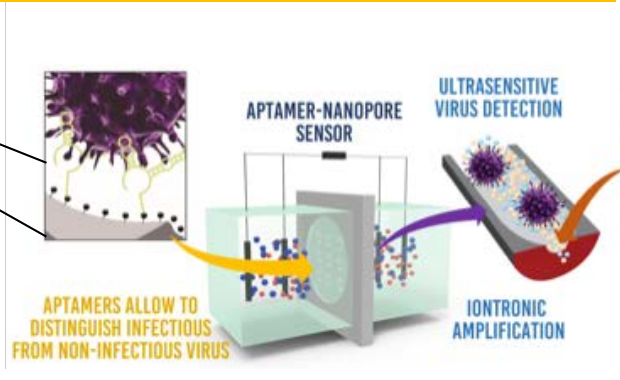
Latest news: Combination of heavy ion beam therapy with mRNA-Vaccine in cancer therapy (Cooperation with TRON)

- New sensor for SARS-CoV-2 and other viruses based on GSI/FAIR nanotechnology
 - better and faster virus detection with single nanopore membranes
 - detection of SARS-CoV-2 in saliva, serum or wastewater without sample pretreatment
 - same sensitivity as a qPCR test, result in 2 hours
 - sensor distinguishes infectious from non-infectious corona viruses

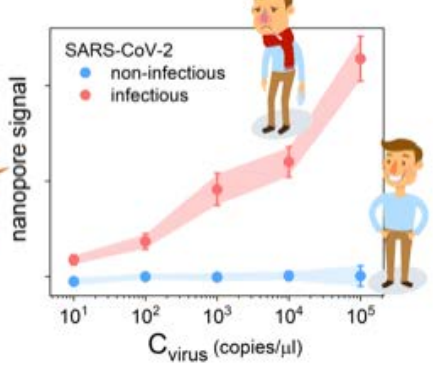
Highly sensitive nanopore by Ion-track nanotechnology

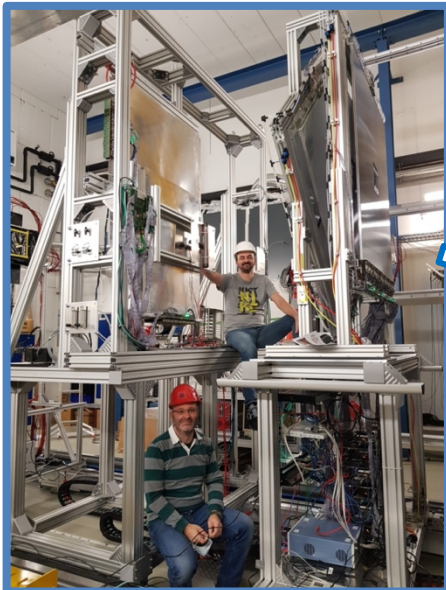


High selectivity by coating nanopore with selective aptamers that bind specific virus (tested with SARS-CoV-2 and adenovirus)



Transport measurements through coated nanopore indicate infectious state of tested virus





Forward RPC

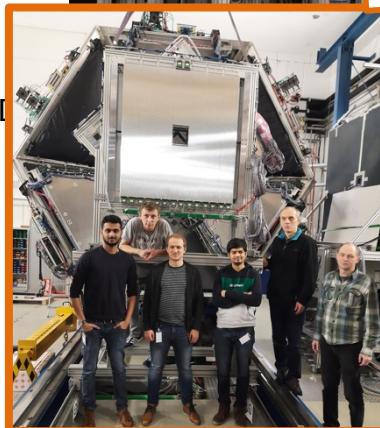
LIP Coimbra

- Based on R&D for neuLAND
- TRB3 read-out

STS2

Jagiellonian Univ.

- PANDA straw technology
- PANDA PASTTREC FEE chip



iTOF

TransFAIR, Jülich

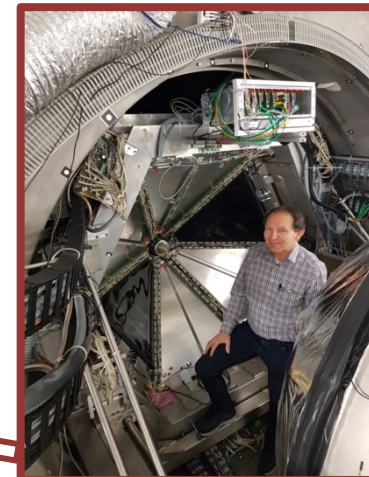
- APD read-out
- Enhances trigger power



STS1

TransFAIR, Jülich

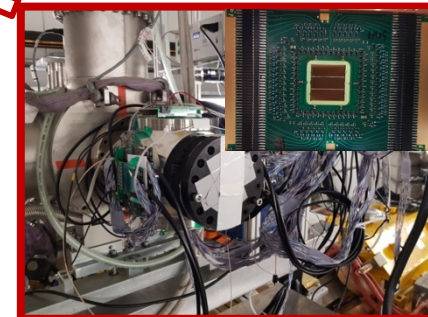
- PANDA straw technology
- PANDA PASTTREC FEE chip



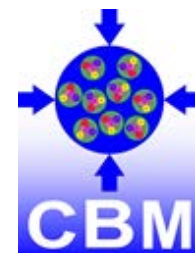
T0

GSI, TU Darmstadt

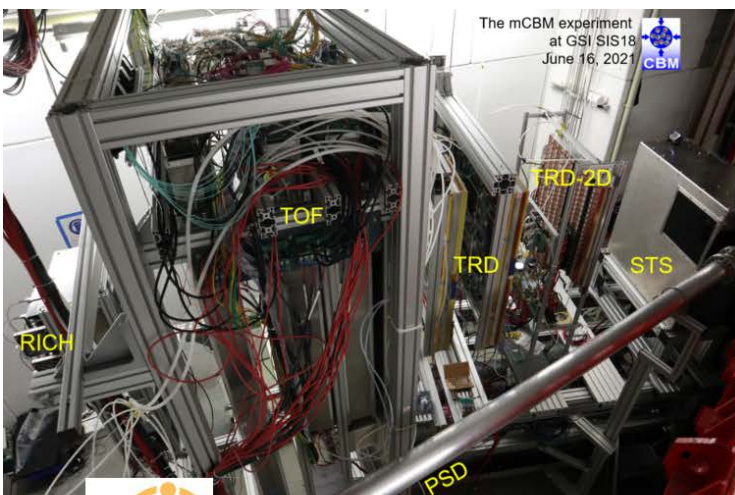
- LGAD technology
- In-beam detector



CBM in Phase-0: mCBM



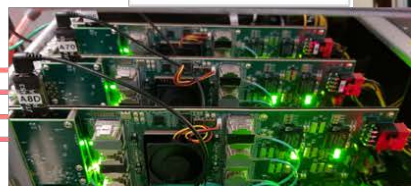
- During the last campaign, mCBM was successfully tested with the highest collision rates available in FAIR Phase-0
- Customised chain of electronics to process and transfer the data of all subsystems to the final data processing proven its capability



DAQ container

CRI (PCIe)
@ FLES
entry
nodes

optical
fibers
50m



optical
fibers
300 m



FLES
processing
nodes

triggerless-
streaming FEE
**assigning
time stamps
to hits**

1 m
Copper

GBTx

50 m
optical

TFC
(CRI based)

CRI FPGA
μSlice building
FLES entry nodes

300 m
optical
InfiniBand

Green
IT
Cube

Timeslice Building

Event
Reconstruction

Event Selection

Archiving

FAIR: Unique Opportunities . . . & Challenges

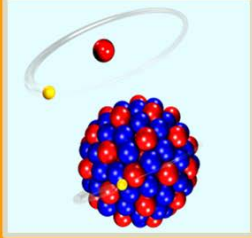
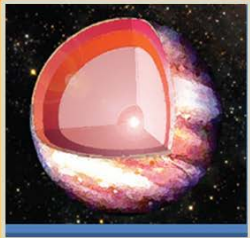


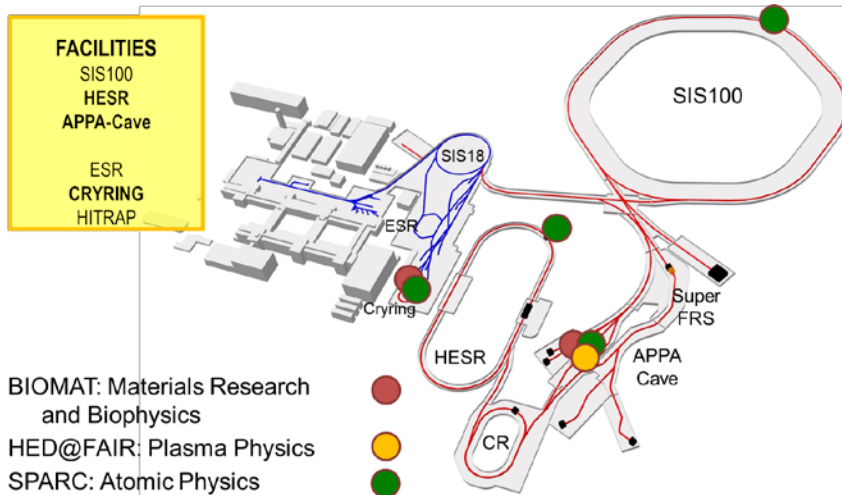
Dziękuję!!

Backup

APPA - Atomic Physics, Plasma Physics, and Applied Sciences

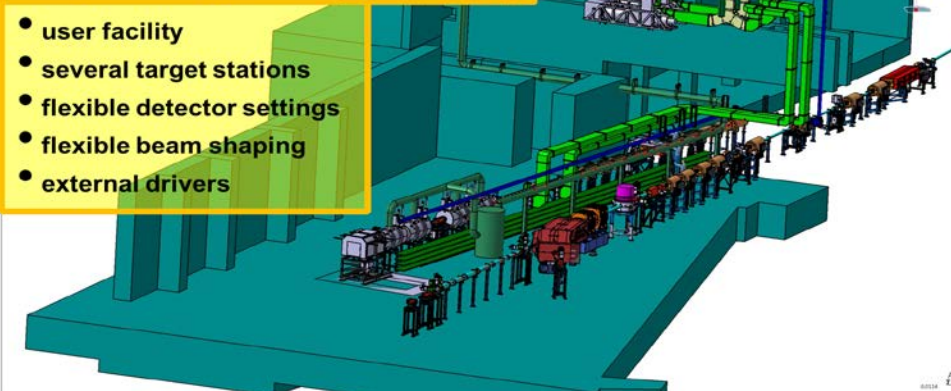


Atomic Physics	Plasma	Materials	Bio
			
SPARC	HED@FAIR	MAT/BIOMAT	BIO/BIOMAT
strong field research ... probing of fundamental laws of physics	warm dense matter ... states of matter common in astrophysical objects	radiation hardness ... mechanical and electrical degradation of materials	space travel ...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



protons (10 GeV): 2×10^{13} p/bunch
U²⁸⁺ (2 GeV/u): 5×10^{11} ions/bunch
U⁹²⁺ (10 GeV/u): 10^8 ions/s

APPA Cave



FAIR - The Universe in the Laboratory

From Neutron Star Mergers to Platinum and Gold



How Matter behaves at
extreme electromagnetic
Field Strengths

FAIR/ APPA

How Matter behaves at
extreme Densities and
Temperatures

FAIR/ CBM-HADES

How the chemical
elements evolve from
Neutron-Star Matter

FAIR/ NUSTAR

How the Protons
and Neutrons are
formed

FAIR/ PANDA

