The FAIR project: status and prospects

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On the trail of the secrets of the universe
FAIR: Facility for Antiproton and Ion Research

- ESFRI Landmark
- Top priority for European Nuclear Physics Community
- Driver for Innovation in Science and Technology
GSI — Scientific expertise for more than 50 years
GSI Discoveries

Isotopes discovered at GSI and FAIR

- New chemical elements
- Hundreds of new isotopes
- New decay modes
## Innovation in cancer therapy

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

- 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 and FAIR – The Facility

**GSI**, existing (upgraded to integrate with FAIR)

FAIR “Gain factors” rel. to GSI
- 100 – 10,000 x intensity
- 10 x energy
- antiproton beams

- Intensity
- Precision
- Storage rings
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
FAIR facility - worldwide production and delivery of accelerator components and

- SIS100: Quadrupol-Magnet
- SIS100: Vacuum Chambers
- SIS100: Dipole-Magnet
- p-Linac: RFQ- Development
- HESR: Dipole-Magnets
- HESR: Quadrupol-Magnets
- CR: Dipole-Magnet
- Power Converters
- HEBT: Dipole-Magnet
- SFRS: Multiplet-Magnet CERN test facility
## Construction Dimensions

<table>
<thead>
<tr>
<th>Ground</th>
<th>Concrete</th>
<th>Steel</th>
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<td>2 Mio. m³</td>
<td>600,000 m³</td>
<td>65,000 t</td>
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- Ground will be moved
- Concrete will be installed
- Steel will be deployed

### Status as of Oct. 2021: more than 50% executed

- Correspond to 5,000 single-family houses
- Correspond to 8-times the football stadium of Frankfurt
- Correspond to 9 Eiffel Towers
Civil construction progressing well, concrete works of underground ringtunnel completed in May 2021. Manufacturing of accelerator and experiment components by all partner countries ongoing worldwide. Many accelerator and experiment components are delivered and tested ready for installation.
FAIR in construction
FAIR in construction
FAIR in construction
Creating extreme conditions existing in the universe with heavy ion accelerators

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?

How do materials behave under high pressure?

What happens to human cells on the way to Mars?
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: $T < 10$ MeV
- Density: $\rho < 10\, \rho_0$
- Lifetime: $T \sim \infty$

**Neutron star merger**
- Temperature: $T < 50$ MeV
- Density: $\rho < 2 - 6\, \rho_0$
- Reaction time: $T \sim 10$ ms

**Heavy ion collisions at SIS100**
- Temperature: $T < 120$ MeV
- Density: $\rho < 8\, \rho_0$
- Reaction time: $t \sim 10^{-23}$ s

*Compressed Baryonic Matter*
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 FAIR science: four pillars

atomic physics, biophysics, plasma physics, material research

nuclear- and quark-matter

nuclear structure and nuclear astrophysics

hadron structure and dynamics

APPA

CBM

NuSTAR

PANDA
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
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

SFRS

ILIMA, EXL at CR and at ESR, HESR, Cryring

MATS & LaSpec

HISPEC/DESPEC

R³B
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.
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 µm
  - in time 10 ns
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

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
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
FAIR: Unique Opportunities . . . & Challenges

We look forward to an exciting science program for the coming years!
Backup
Upgrades for the FAIR Phase-0 beam time in 2022

- Improved physics performance through instrumentation of the very forward hemisphere using FAIR technology.
- Dedicated to the joint HADES-PANDA physics program on electromagnetic properties of hyperons.

**Forward RPC**
LIP Coimbra
- Based on R&D for neuLAND
- TRB3 read-out

**STS2**
Jagiellonian Univ.
- PANDA straw technology
- PANDA PASTTREC FEE chip

**STS1**
TransFAIR, Jülich
- PANDA straw technology
- PANDA PASTTREC FEE chip

**T0**
GSI, TU Darmstadt
- LGAD technology
- In-beam detector

iTOF
TransFAIR, Jülich
- APD read-out
- Enhances trigger purity
APPA - Atomic Physics, Plasma Physics, and Applied Sciences

**Facilities**
- SIS100
- HESR
- APPA-Cave
- ESR
- CRYRING
- HITRAP

**APPA Cave**

**Protons** (10 GeV): $2 \times 10^{13}$ p/bunch

**U^{28+}** (2 GeV/u): $5 \times 10^{11}$ ions/bunch

**U^{92+}** (10 GeV/u): $10^8$ ions/s

- User facility
- Several target stations
- Flexible detector settings
- Flexible beam shaping
- External drivers

**Areas of Focus**
- **Atomic Physics**
  - SPARC
  - Strong field research: probing of fundamental laws of physics

- **Plasma**
  - HED@FAIR
  - Warm dense matter: states of matter common in astrophysical objects

- **Materials**
  - MAT/BIOMAT
  - Radiation hardness: mechanical and electrical degradation of materials

- **Bio**
  - BIO/BIOMAT
  - Space travel: cosmic radiation risk and shielding
How Matter behaves at extreme electromagnetic Field Strengths
FAIR/ APPA

How the chemical elements evolve from Neutron-Star Matter
FAIR/ NUSTAR

How Matter behaves at extreme Densities and Temperatures
FAIR/ CBM-HADES

How the Protons and Neutrons are formed
FAIR/ PANDA

S. Rosswog
Alpha fusion on $^{12}\text{C}$ is the stellar reaction of paramount importance,

W.A. Fowler, Nobel lecture 1983

Experiment in inverse kinematics (Coulomb dissociation) requires high energies -> GSI/FAIR
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 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$_2$O, CH$_4$, CO$_2$, NH$_3$, SO$_2$…)

C$_n$H$_m$ polyaromatic hydrocarbons
C$_{6H_{13}}$NO$_2$ amino acids
C$_{60}$, C$_{70}$ fullerenes

spectrum of large desorbed molecules

irradiation chamber and spectrometer