Status of the FAIR facility in Darmstadt

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Abstract. The Facility for Antiproton and Ion Research (FAIR) is currently being built in Darmstadt, Germany. The SIS100 accelerator is at the heart of FAIR and will provide proton and heavy-ion beams for a variety of experiments. There are four main research pillars at FAIR specialized in the field of nuclear, hadron and elementary particle physics, atomic and antimatter physics, high density plasma physics, as well as applications in condensed matter physics, biology and the biomedical sciences. In these proceedings I briefly review the main research pillars of FAIR and the status of its realization.

1. Foreword
The Facility for Antiproton and Ion Research (FAIR) [1] is currently being build as the extension of the GSI Helmholtz Centre for Heavy Ion Research [2] in Darmstadt, Germany. FAIR is one

![Figure 1. Schematic aerial view of the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.](image-url)
of the largest European projects of the future in the direction of fundamental research with antiprotons and heavy ions. The partner countries which signed an international treaty in March 2014 are Finland, France, Germany, India, Poland, Romania, Russia, Slovenia and Sweden, while the UK is an associate member and the Czech Republic is an aspirant partner. The overall project price is about 2,000 million euros [3]. The current funding by partner countries is sufficient to cover all costs of building the SIS100 accelerator, Super-FRS separator, APPA and CBM experimental halls, and all auxiliary accelerators and all experiments at four pillars APPA, CBM, NUSTAR, and PANDA (details about FAIR pillars are provided below). As of today, FAIR and GSI provide unique opportunities for gaining international scientific experience for the young generation with ample opportunities for financial support of internships and summer schools for bachelor, master and PhD students. Active cooperation, joint developments of detector components, and knowledge exchange with facilities in Russia such as NICA at JINR [4] are fostering the progress of the FAIR community preparation for future experiments.

2. FAIR accelerator complex

There are two main linear accelerators which will provide proton (Linear Accelerator, p-LINAC) and heavy ion (Universal Linear Accelerator, UNILAC) beams (see figure 2). They will inject beams into the existing heavy ion synchrotron (SIS18). After additional acceleration with SIS18 the beams are directed into the future proton and heavy ion synchrotron SIS100. The SIS100 primary beams with have intensities of $10^9$/s for gold ions with beam kinetic energy $E_{\text{kin}}$ up to 11 GeV/u, intensities of $10^9$/s for light ions (C, Ca, et.al.) with energy up to $E_{\text{kin}} = 14$ GeV/u, and $10^{11}$/s for protons up to $E_{\text{kin}} = 29$ GeV. The facility will be also equipped with the collector ring (CR), the accumulator ring (RESR), the new experimental storage ring (NESR), the super fragment separator (Super-FRS), and the high energy storage ring (HESR) (see figure 3). The resulting proton and ion beams, as well as produced via secondary interaction antiproton beams and rare isotopes will be used for a number of experiments at FAIR which are subdivided into four experimental pillars.

![Figure 2. Schematic view of the accelerator complex at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.](image)
3. FAIR pillars
The four experimental pillars at FAIR are (see figure 3):

- The proton-antiproton annihilation (PANDA) experiment,
- The compressed baryonic matter (CBM) experiment,
- The nuclear structure, astrophysics and reactions complex (NUSTAR),
- The atomic and plasma physics experiments and application oriented research in biophysics, medical physics and materials science (APPA).

![Figure 3. The four experimental pillars at FAIR: (i) proton-antiproton annihilation (PANDA) experiment, (ii) the compressed baryonic matter (CBM) experiment, (iii) nuclear structure, astrophysics and reactions complex (NUSTAR), and (iv) atomic and plasma physics experiments and application oriented research in biophysics, medical physics and materials science (APPA).](image)

The PANDA setup [5] will be used to study physics of strong interactions such as charmonium spectroscopy, exotic states with charm quarks and multi-gluon states (glueballs). The CBM experiment [6] is designed to explore the quantum chromodynamics (QCD) phase diagram in the region of high net-baryon densities. The goal of the CBM experiment at SIS100 is to discover fundamental properties of QCD matter: the phase structure at large baryon-chemical potentials, effects of chiral symmetry, and the equation-of-state at high density as it is expected to occur in the core of neutron stars.

The research of the NUSTAR collaboration [7] is relying on radioactive beams separated and identified by the Super-FRS. Among the research programs are high resolution in-flight spectroscopy, laser spectroscopy, precision measurements of very short-lived nuclei using an advanced trapping system, lifetime and mass measurements of isomers, electron-ion scattering experiments in a storage ring SR, exotic nuclei studied in light-ion induced reactions at the NESR storage ring, and the super-heavy element research.
The APPA pillar [8] will combine the atomic and plasma physics experiments and application oriented research in biophysics, medical physics and materials science. An exceptionally strong electric and magnetic field generated by the relativistic highly charged ions may lead to the creation of real particle-antiparticle pairs and/or optical transitions for lasers in the x-ray region. With APPA experiments the precision probes of the quantum electrodynamics (QED) near the critical field limit will be possible.

The APPA pillar will also investigate radiation hardness of carbon-based materials and composites used as production targets, beam-collimators or beam-dumps at FAIR. Various aspects of the interaction of highly energetic heavy ions with solid state matter will be investigated, such as ion-track formation, material radiation hardness, matter stabilization at high pressure by ion irradiation, fabrication of nanostructures with ion-tracks, and microprobes with heavy ions.

4. FAIR construction status

The commissioning of the SIS100 accelerator at FAIR and its first beams are scheduled for 2025. The civil construction of FAIR began in 2017. Already in 2018 the SIS18 accelerator upgrade was finished. The FAIR-Phase-0 program, which is a set of FAIR related experiments at GSI and other existing facilities worldwide has been launched in 2019. As of 2020, the SIS100 tunnel is completely excavated with 1/3 of the SIS100 tunnel being completed. A drone made movie of the aerial view of the FAIR construction site can be viewed online at [9]. The CBM experimental hall concrete work is in full progress. A bidding for the construction of the southern part of FAIR is opened and its construction will begin shortly.

5. Summary

An overview and preparation status of the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany is presented. The construction of the SIS100 accelerator ring and the CBM hall are at its full swing. The commissioning of the SIS100 accelerator at FAIR and its first beams are planned for 2025.

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