A facility for antiproton and ion research

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An International accelerator facility, known as the Facility for Antiproton and Ion Research (FAIR) is being built at Darmstadt, Germany. Equipped with unprecedented beam intensity, the facility will be used to perform experiments on the areas of nuclear physics, high energy physics, hadron physics, atomic and plasma physics apart from advanced research in accelerator technology. The facility will be built in collaboration with several countries including India and will be operational by 2017.

Preamble and introduction

The accelerator facility at GSI-Darmstadt has been at the centre of many pioneering discoveries. It is known for discovering six new elements, the latest one being Copernicium, celebrated very recently.

The accelerator complex, expected to be operational by 2016, is well on its way to be upgraded to a truly international facility with antiprotons and heavy ion beam lines. A set of four beamlines will be operational with the objective of using: (i) radioactive ion beams for nuclear physics; (ii) exploring novel phenomena in hadron physics using antiprotons; (iii) laser and plasma physics, and (iv) physics of strongly interacting matter at extreme density. Research in biological and material sciences is also on the agenda. The facility is to accelerate a very wide range of isotopes, from proton to uranium with an energy range of 2–45 GeV/u. The beam intensity is three orders of magnitude higher than any other existing facility. In accelerator technology, a facility for antiproton and ion research (FAIR), will be a unique facility.

Another unique feature of FAIR is its management structure. Participating countries, India included, will be shareholders in the FAIR-Gmbh. This structure of management is radically different from CERN where only the European countries are member states and India has an observer status.

This unique accelerator with the construction cost of about 1.2 billion Euro will truly be an international facility with participation from more than 10 countries in the initial phase including Germany, France, UK, Russia, Italy, China and India. Indian researchers working in the fields of nuclear and high energy physics, hadron physics and accelerator physics have expressed keen interest in participating in this facility. The Department of Science and Technology (DST), Government of India, being the nodal agency in this collaborative effort, has been working along with the Department of Atomic Energy (DAE), Government of India in building up the detailed plan for participation and implementation. A large number of bilateral visits have taken place and the discussions included physics with FAIR, technological challenges and industry participation.

FAIR accelerator facility

At its heart the FAIR accelerator has a double ring facility with a circumference of 1100 m. A system of cooler-storage rings for effective beam cooling at high energies and various experimental halls will be connected to the facility. The existing GSI accelerators, e.g. SIS-18 and UNILAC serve as injectors for the new facility. The double-ring synchrotron will provide ion beams of unprecedented intensities and considerably increased energy. The system of storage-cooler rings allows the quality of these secondary beams – their energy spread and emittance – to be drastically improved. Moreover, in connection with the double ring synchrotron, an efficient parallel operation of up to four scientific programmes can be realized at any one time. The project is based on several technological innovations, the most important ones include: (i) highest beam intensities; (ii) brilliant beam quality; (iii) higher beam energies; (iv) highest beam power and (v) parallel operation[1].

FAIR, as shown schematically in Figure 1, will consist of the following main accelerator components: (i) a proton LINAC for injecting high intensity proton beam to the main ring; (ii) two rings with rigidities of 100 and 300 Tm respectively (known as SIS100 and SIS300) housed in the same tunnel; (iii) superconducting fragment separator (Super-FRS) consisting of three branches, i.e. a high energy branch providing beams up to 1 GeV/u, a ring branch and a low energy branch (LEB). Antiprotons produced by a primary proton beam, will be filled into the high energy storage ring (HESR) which collide with the fixed target inside the PANDA detector.

Indian participation at FAIR

In February 2008, an agreement towards participation in FAIR was signed between the German Government and

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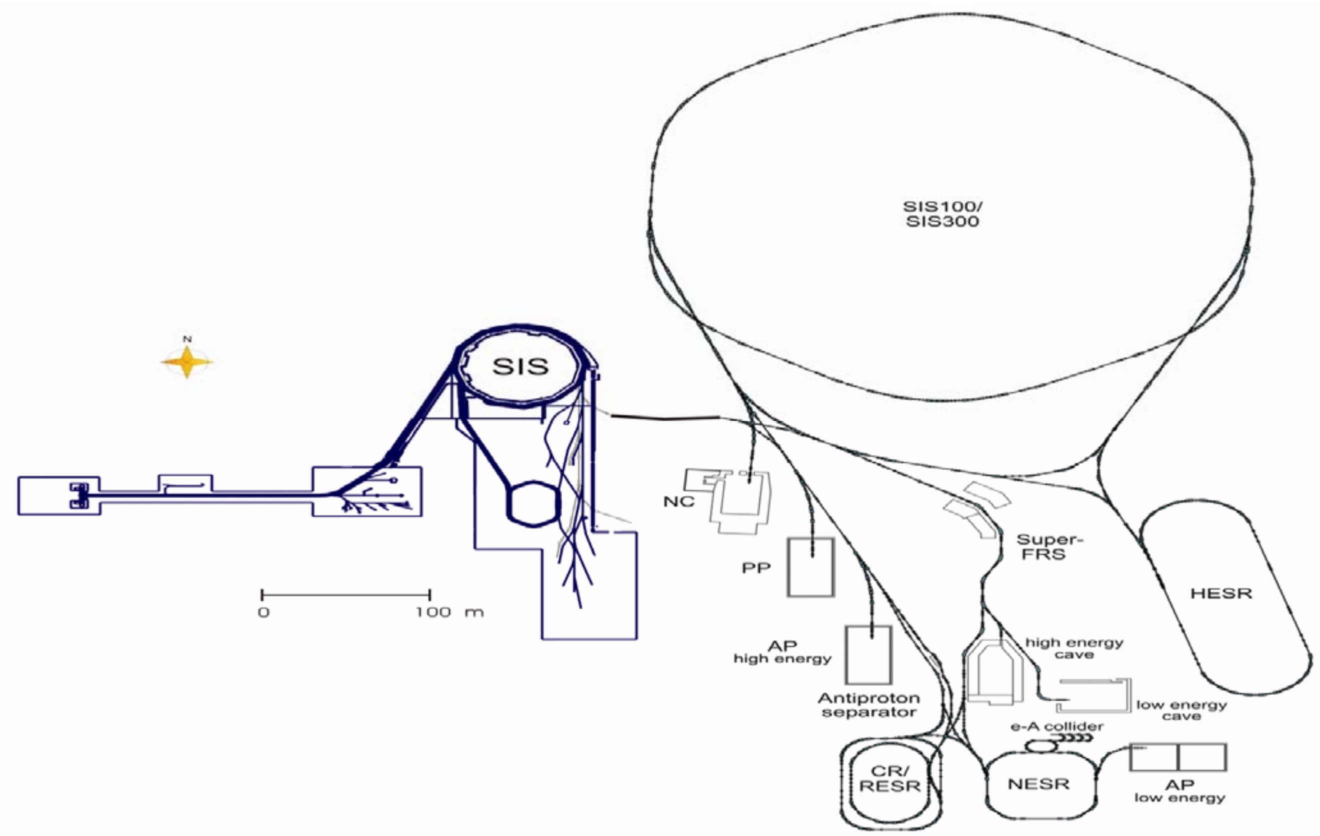

Figure 1. Layout of the FAIR facility.

Figure 2. FAIR meeting at VECC-Kolkata (8–10 March 2010). Detailed discussions took place on physics and technological aspects of Indian participation at FAIR.

the Indian Government. India made a financial commitment to the tune of 36 million Euro, about 250 crore INR, mostly in kind. Subsequently, members from the Indian research community and the industry met several times to prepare a plan which is now being discussed with the scientific community and funding agencies. Notable places where meetings on FAIR took place in India are at ECIL-Hyderabad, BARC-Mumbai, TIFR-Mumbai and IUAC-New Delhi. The latest in the series of technical meetings is the meeting held at VECC-Kolkata titled 'Physics with FAIR: Indian participation', during 8–10 March 2010 (Figure 2). On 4 October 2010 FAIR was founded where India signed as a founder member.

Indian participation mainly focuses on the following areas: To build hi-tech components for FAIR accelerators. The effort will have a major participation from Indian industries. This aspect has direct impact in terms of accessing and working in hi-technology areas along with other advanced countries. The preliminary list of items presently identified include (i) superconducting magnets for Low Energy Buncher, beam-stopper in Super-FRS and a large number of power converters for FAIR accelerator rings. To build (ii) large detector systems for CBM, PANDA and NuSTAR experiments. These detector systems will subsequently be used for extracting physics information where the Indian scientific community will play an active role.

I intend to present here briefly a rather more personalized account of the evolution of the FAIR saga.

Our research units, VECC and SINP, have been involved with CERN facility in Geneva as well as with Relativistic Heavy Ion Collider (RHIC) at Brookhaven

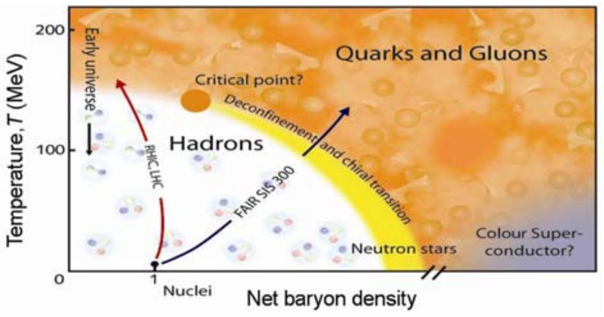

Figure 3. The phase diagram of strongly interacting matter. The 'rainbow' depicts a journey from low-density, high temperature regions to high density, low temperature regions as the collision-energy decreases in high energy heavy ion collisions.

National Laboratory, USA. The experiments and the associated theoretical studies for CERN and RHIC essentially explore at relatively high temperature and low net-baryon density region of the phase diagram (Figure 3). At LHC, one expects the point of observation going up the rainbow of the phase diagram, even to higher temperature and almost baryon-free zone, somewhat analogous to the scenarios at the very early universe, a microsecond after the Big Bang. At that primordial epoch, the conventional wisdom states that the universe must have consisted of quarks, gluons, leptons and photons. At LHC, colliding two nucleii, we try to understand, about the earlier epoch, apart from other phenomena.

If one slides down that 'rainbow' and goes to the other extreme point in the phase diagram, we come across a region of a rather high baryon density but very low temperature, almost cold-hadron matter. This is the region of the so-called CBM (compressed baryonic matter). Using the ion beam at FAIR, the CBM detector system is sort of custom-built to study that region of the phase diagram, complimentary to LHC's very early universe. This is fantastically exciting to my mind.

With time, the high baryon density and low temperature regime looks more and more exciting and challenging. A whole new set of phenomena, Colour Flavour Locked (CFL) states, colour superconducting quark matter, and quarkonia are some of the promising candidates.

Neutron stars, as remnants of the supernova explosion, seem to throw up ever increasing puzzles – the matter density near the vicinity of the core is similar to CBM matter, so that the scenario looks even more exciting. Thus LHC on one side and CBM at FAIR, on the other hand, attracted our attention. This complimentarity compelled to lead us on to FAIR.

I conclude with an overview of our goals and a brief on the outlook. What do we expect to learn from FAIR?

(i) A deeper understanding of the structure of matter from a very fundamental basis and in particular, the non-linear processes which come into play in a complex system.

(ii) A clearer understanding of the universe and cosmological objects which construct the universe, the working of the hierarchical structure, transcending from the microscopic to the macroscopic and vice versa.

(iii) The state-of-the-art science and technology of such an advanced accelerator and its spin-off to industry.

The areas of research and development we hope to cover using the FAIR facility:

(i) Nuclear astrophysics and study of the short-lived nuclei far from the stability line – a better understanding of the *r* and *s* processes when matter was formed within three minutes of the creation of the universe.

(ii) With antiprotons, we hope to understand the theory of strong interaction, the quantum chromo-dynamics (QCD) with the tantalizing possibility of the points of departure from the standard model.

(iii) A better understanding of the quark-hadron phase diagram.

(iv) New developments in quantum electrodynamics and the properties of ultra-high electromagnetic fields.

(v) Science of very dense electromagnetic plasma by using powerful lasers.

(vi) A wide and rich field of applied research and material science.

FAIR not only addresses key questions in different research fields of science, but it also covers the complexity involved in common areas which runs through many areas of the research programmes from non-perturbative QCD and the nuclear many-body system to biological molecules and systems.

Clearly the outlook is bright, wide and full of promise – the most fascinating aspect is the multidimensional use of FAIR. We thus hope to learn a lot and more important is that we want to contribute handsomely to the world of science – it is thus a unique and historic opportunity for India.

1. http://www.gsi.de/fair/ and related sites therein.
2. *CBM Physics Book*, Springer, 2011; http://www.gsi.de/fair/experiment/CBM/PhysicsBook.html