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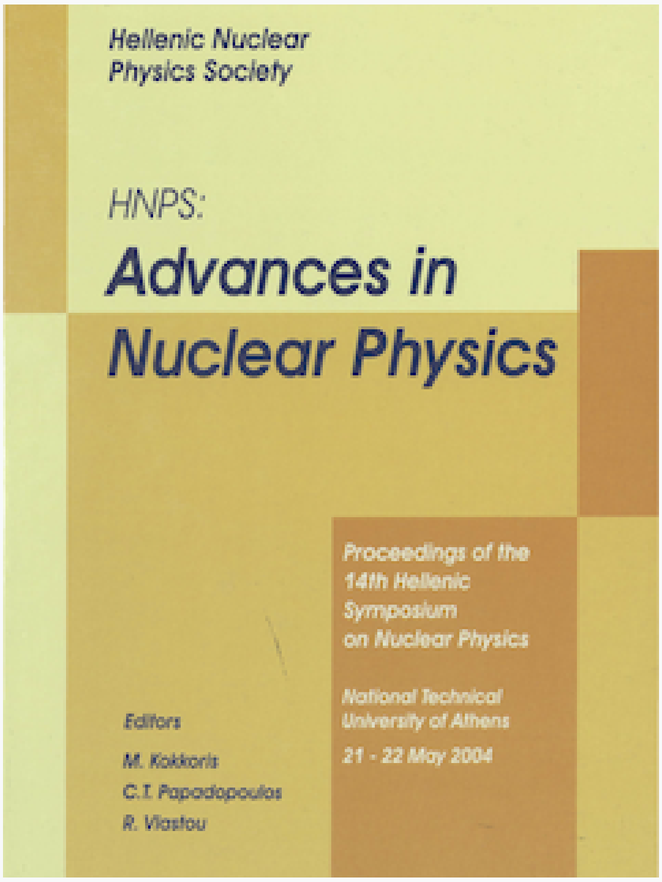

FAIR: The Future European Facility for Antiproton And Ion Research

G. Münzenberg

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FAIR: The Future European Facility for Antiproton And Ion Research

G. Münzenberg

GSI Darmstadt, Planckstr. 1, 64220 Darmstadt and Johannes Gutenberg Universität Mainz

Abstract

FAIR, the new international Facility for Antiproton and Ion Research at GSI, will cover a broad spectrum of hadronic, nuclear, and atomic physics research and application. A system of synchrotrons will provide intense proton and heavy ion beams of intermediate energy with the option to produce secondary beams of radioactive nuclei and antiprotons. NUSTAR, NUclear STructure, Astrophysics and Reactions, will play a premier role within the FAIR research program. Nuclei at the limits of binding will become accessible and new probes for reaction studies with unstable nuclei become available.

1 Introduction

FAIR, the new international Facility for Antiproton and Ion Research at GSI will cover five areas of research [1] including:

- Structure and dynamics of nuclei, based on radioactive beams with high energy to investigate nucleonic matter, fundamental symmetries, and for astrophysics.

- Hadron structure and quark-gluon dynamics, based on antiproton beams to investigate non-perturbative QCD, quark-gluon degrees of freedom, confinement and chiral symmetry.

- Nuclear matter and the quark-gluon plasma, based on relativistic heavy-ion beams to investigate the nuclear phase diagram, compressed nuclear and strange matter, and de-confinement and chiral symmetry.

- Physics of dense plasmas and bulk matter based on bunch compression of the accelerated heavy-ion beams to create short intense pulses to investigate the properties of plasmas at high density, phase transitions and the equation of state, and laser – ion interactions with plasmas.

- Ultra high electromagnetic fields and their applications based on the combination of intense ion beams and a petawatt laser to investigate QED and critical fields, ion-laser interactions, and the ion - matter interaction.

To meet the various beam conditions required by these research areas FAIR is a flexible system of heavy-ion accelerators and storage-rings. It provides beams of all chemical elements of the periodic table up to uranium, including rare isotopes with low abundances in nature as well as secondary beams of radioactive isotopes and antiprotons. Parallel operation of the ring systems and dedicated beam-lines permit to run different experiments simultaneously. This guarantees sufficient beam-time for all research programs [1].

Fig. 1 displays the present and future accelerator systems. The existing system consists of the UNIversal Linear ACcelerator UNILAC, the heavy-ion synchroton SIS 18, and the Experimental Storage Ring ESR. The new facility comprises the double-ring synchrotrons SIS 100/300 and a system of storage-cooler rings: The Collector Ring CR, the RESR, not shown in the figure, the New Experimental Storage Ring NESR, and the High Energy Storage Ring HESR.

The UNILAC provides beams for experiments near Coulomb-barrier, primarily the superheavy-element program [2] and simultaneously serves as injector for the synchrotron complex. Two RFQ-injectors, one equipped with an ECR ion source, the other one with two high-intensity sources allow for flexibility in the choice of the primary ion beams.

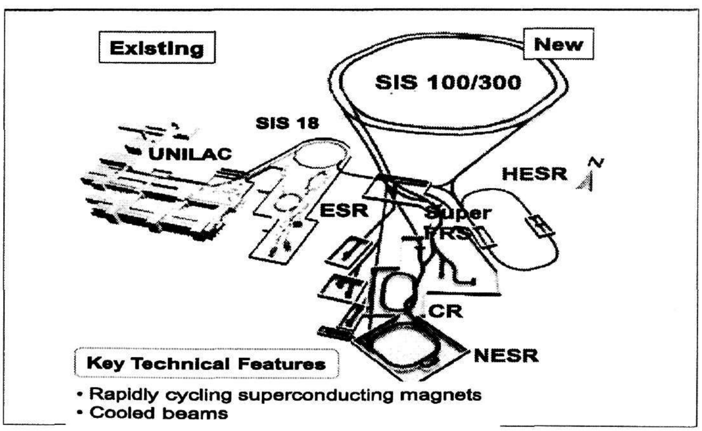

Fig. 1. Layout of FAIR. The NUSTAR part is highlighted. It comprises the Super-FRS, the CR and the NESR.

An important and unique characteristic of FAIR will be the parallel operation of different experiments making use of the high flexibility of the storage rings and beamlines. For the existing UNILAC, SIS18, ESR facility parallel operation of different experiments is already routine now.

For the NUSTAR program SIS 100 is operated in a fast cycling mode. It accelerates ions up to uranium to energies of 1 AGeV at intensities of the order of 10^{12}/s which can be slowly extracted for reaction experiments or with fast extraction for injection into the storage-ring complex. In addition the SIS 300 can be used as a stretcher ring for intense DC heavy-ion beams.

The program to investigate nuclear matter and the quark-gluon plasma requires highest energies at moderate intensities using the SIS100/SISI300 accelerator combination. Energies up to 35 AGeV are available for uranium.

Antiprotons are produced with intense proton beams of 30 GeV at a secondary target placed in front to the CR-NESR. They are collected and cooled and then injected into the SIS100 for acceleration up to 30 GeV. The accelerated antiproton beams are transferred into the high energy storage and cooler ring HESR for fixed-target in-ring experiments.

Intense, bunched beams at moderate energies around 35 AGeV are required for the plasma physics program.

2 NUSTAR, the research program with radioactive beams

Central topics of NUSTAR, the research program for NUclear STructure, Astrophysics, and Reactions within FAIR are: the exploration of nuclear structure at the limits of nuclear stability in isospin and charge including exotic decay modes and the evolution of shells. The aim is to understand correlations and pairing, in-medium modification of the nucleon-nucleon interaction, and the behavior of nuclear matter with extreme neutron-to-proton ratios.

As an example Figure 2 displays a collection of highlights of nuclear structure research at GSI. These include: the investigation of halo nuclei, to investigate correlations and clusters, nuclear skins to investigate neutron and proton distributions inside nuclei, the discovery of the two-proton decay in ^{45}Fe, a new decay mode far-off stability, B(E2) values, the evolution of pairing in the isospin degree of freedom as an example for large-scale mass measurements to investigate the systematic behavior of the nuclear landscape far-off stability including new regions of shells and deformations and other global phenomena, and the creation and investigation of new heavy and superheavy elements [2].

Figure 3 displays the layout of the NUSTAR facility at FAIR [3]. Its principal instrument is the superconducting FRagment Separator Super-FRS, a tandem of two high resolving energyloss-type spectrometers. SUPER-FRS has a high ion-optical flexibility. It can optionally be operated as low-resolution, high transmission beamline, for in-flight separation of isotopic clean beams of radioactive nuclides created in the production target by fragmentation or fission of heavy ions, or in a spectrometer mode for reaction studies of high resolution.

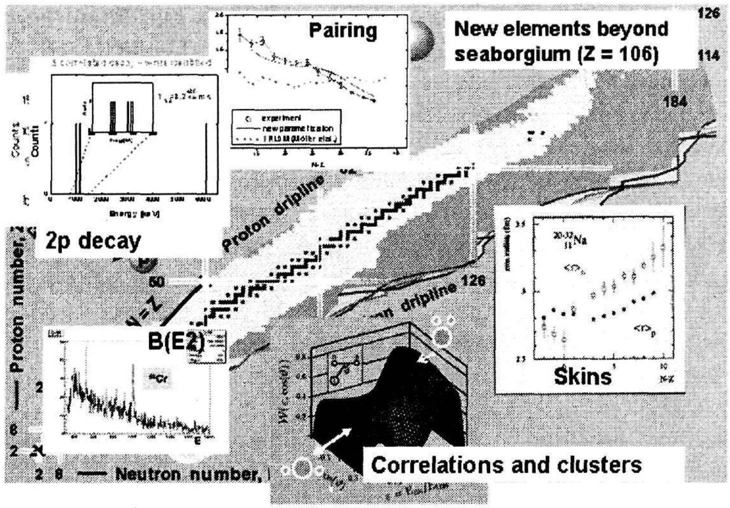

Fig. 2. Highlights of nuclear structure research at GSI

Decay spectroscopy and in-beam gamma spectroscopy, reaction studies in reversed kinematics, and precision experiments in the storage-ring systems will be the principal research fields of NUSTAR. One of the key features of NUSTAR is the high projectile energy of up to 1 AGeV for all ions up to uranium. The advantage is clean separation in-flight for all fragments up to uranium as all heavy ions are bare at this high energy which is most important to separate fission fragments of the heavy group. Fission fragments will give access to the large region of practically unknown neutron rich species.

Super-FRS mostly will work as in-flight separator to provide unstable nuclei for spectroscopy and reaction studies. For these experiments the Super-FRS feeds three branches (Fig. 3):

- A low energy branch for spectroscopy, including in-beam gamma spectroscopy, and reaction studies at low energies e.g. below 100 AMeV. The special feature is a combination of a dispersive magnet and a shaped energy degrader acting as energy buncher to create in-flight separated isotopic beams of low momentum spread. The low-energy branch can be equipped with a broad spectrum of instrumentation including an ion catcher-trap system, silicon arrays for decay

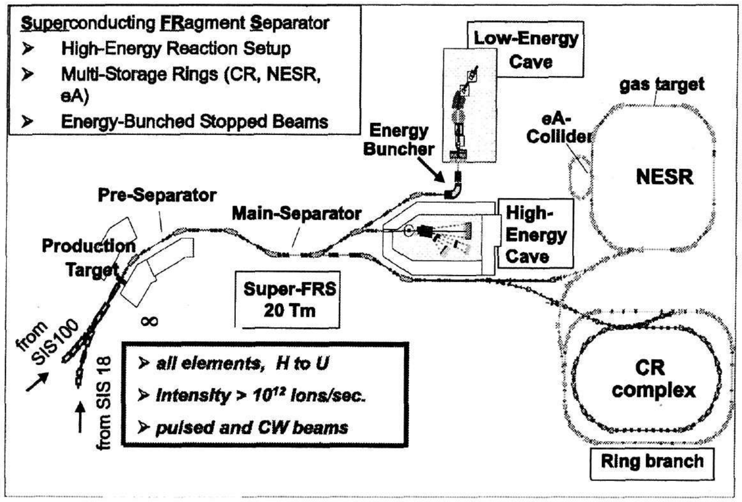

Fig. 3. The GSI NUSTAR facility with the Super-FRS and its three branches: low-energy, high energy for nuclear reactions, and the storage-ring complex with the small electron-heavy ion collider

studies with implanted radioactive nuclei, a laser setup, and the advanced germanium ball AGATA for in-beam gamma spectroscopy.

- A high energy branch for reaction studies with unstable nuclei. This branch will be an upgrade of the existing LAND-Aladin setup with a new superconducting dipole of 4 Tm bending power, an upgraded large area neutron detector, and improved particle detectors for heavy fragments and charged particles. The setup will also contain a target calorimeter and proton detectors to investigate proton scattering in reversed kinematics [4].

- A ring branch, equipped with the CR to collect and cool the in-flight separated fragment beams. The CR will be equipped with stochastic cooling to achieve fast cooling of radioactive heavy ion beams within the order of seconds. Operation in the isochronous mode will allow direct mass measurements of short lived species down to microsecond half-lives. Experiments will be generally performed in the NESR which has an electron cooler, an internal gas jet, and a cluster target. An additional ring between CR and NESR, the RESR, will match the injection energy into the NESR as required for the experiments. The internal NESR targets will allow reaction studies with highest precision and scattering at low momentum transfer. The effective target thickness is enhanced by six orders of magnitude as the beam passes the target on each revolution with a frequency of 10^6/s.

A small electron ring operated in a colliding mode with the NESR allows performing low-energy electron scattering for structure studies. With this setup it will not only be possible to investigate electron scattering on radioactive nuclei a small electron ring operated in a colliding mode with the NESR allows performing low-energy electron scattering for structure studies. With this setup it will not only be possible to investigate electron scattering on radioactive nuclei but also to measure electron scattering in complete kinematics with the detection of all participants in the exit channel [5], not possible with the presently used stable-beam electron scattering facilities. This mini collider is a new and challenging development in the NUSTAR program.

The following Letters of Intent have been submitted for the NUSTAR research program (see: www.gsi.de/nustar):

Low Energy Branch , (C.Scheidenberger (GSI))

HISPEC High-resolution in-flight gamma-ray spectroscopy, Z. Podolyak (U.Surrey)

DESPEC Decay spectroscopy with Implanted Ion Beams , B. Rubio (CSIC Valencia)

MATS Precision measurements of very short-lived nuclei using, K.Blaum (U.Mainz)

an advanced trapping system for highly-charged ions

LASPEC LASER spectroscopy for the study of nuclear properties , P. Campbell

(U.Manchester)

NCAP Neutron capture measurements , M.Heil (FZ Karlsruhe)

Exo+pbar Antiprotonic radioactive nuclides , M. Wada (RIKEN)

High-Energy Branch

R^{3}B A universal setup for kinematically complete measurements

of reactions with relativistic radioactive beams , T. Aumann (GSI)

Ring Branch

ILIMA Study of isomeric beams, lifetimes and masses , Yu. Novikov (NPI St.Petersburg)

EXL Exotic nuclei studied in light-ion induced reactions at the NESR storage ring , M. Chartier (U.Liverpool)

ELISE Electron-ion scattering in a storage ring (e-A collider) , H. Simon (GSI)

pbar-A Antiproton-ion collider: measurement of neutron and

proton rms radii of stable and radioactive nuclei, P. Kienle (TU Munich)

PIONIC Spectroscopy of pionic atoms with unstable nuclei , K. Itahashi (RIKEN)

Heavy-element research will play a central role in the mid-term and future GSI program. Recent achievements in heavy element research are the reported discoveries of new elements, element 113 from RIKEN and an island of elements 114 to 128 from JINR Dubna [6]. Interesting questions including production, assignment, and structure as well as chemical and atomic properties arise. Theoretical calculations cannot yet clearly answer the question where the next double shell closure above lead, stabilizing the superheavy elements, is located. Predictions are Z=114, Z=120, and Z = 125, the magic neutron number is N=184. Intensity upgrades of the accelerators and new experimental developments are under way at Dubna, Riken, and GSI. Figure 4 shows the upgrade of the UNILAC at GSI with a new front-end, the main a part of which is a new 28 GHz ECR ion source. The expected gain in intensity is a factor of 10.

3 Organization of FAIR and NUSTAR

The GSI FAIR project is a multi-national project [1], steered by the International steering Committee ISC-FAIR. The total cost according to the CDR is 675 M. The German government will pay 65% the state of Hesse 10%. The final decision on the construction of FAIR will be made after the commitment of partner states to contribute 25% of construction cost. To organize funding and contracting, phase one of the project will be run on the basis of Memoranda of understanding (MOUs). The Scientific and Technical Issues STI-FAIR committee will combine the three scientific Program Advisory Committees PAC QCD, PAC NUSTAR (NUclear Structure, Astrophysics, and Reactions), and PAC APPA (Atomic Physics, Plasma Physics, and Applications), as well as the Technical Advisory Committee.

Acknowledgments

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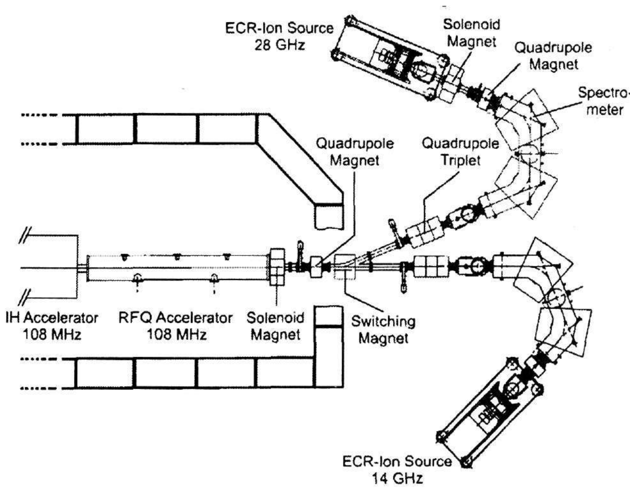

Fig. 4. Frontend of the new injector for intense beams at the UNILAC

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