THE ACCELERATOR FACILITY OF THE FACILITY FOR ANTIPROTON AND ION RESEARCH

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Abstract

The accelerators of the facility for Antiproton and Ion Research – FAIR are under construction. The very sophisticated system of accelerators is designed to produce stable and rare isotope beams with a significant variety of intensities and beam energies. FAIR will explore the intensity frontier of heavy ion accelerators and the ion and antiproton beams for the experiments will have highest beam quality for cutting edge physics to be conducted. The main driver accelerator of FAIR will be the SIS100 synchrotron. In order to produce rare isotope beams (RIB), which are several orders of magnitude more intense compared to beams provided by existing RIB facilities, a unique superconducting fragment separator is under construction. A system of storage rings will collect and cool secondary particles from the FAIR. As the construction of the FAIR accelerators and the procurement has started, an overview of the designs, procurements plans and infrastructure preparation can be provided.

INTRODUCTION

The FAIR facility in the Modularized Start Version (MSV) [1] will consist of six circular accelerators (SIS18, SIS100, CR, HESR, ESR and CRYRING), of two linear accelerators (p-Linac, UNILAC) and of about 1.5 kilometres of beam lines see Fig. 1. The existing GSI UNILAC-SIS18 accelerators will serve as injector to the FAIR SIS100 synchrotron. GSI is in charge of the SIS100, the HEBT, Super-FRS and the overall technical coordination of the FAIR accelerator complex. Many systems are constructed in consortia with international partners. The Research Centre Jülich will build the HESR - High Energy Storage Ring - for the research with high-energy antiprotons using the PANDA detector; BINP Novosibirsk takes care of the construction of the collector ring CR.

The driver accelerator of FAIR is the fast ramping, superconducting heavy ion synchrotron - SIS100 - that allows the acceleration of the most intense beams of stable elements from Protons (30 GeV) to Uranium (10 GeV/u) [2]. The FAIR driver accelerator will provide high energy/ high intensity proton and heavy ion beams to the various experimental stations. The CBM- Plasma- and Biomat-experiments are directly supplied with primary beams from the SIS100. Two target stations for the generation of secondary beams (pbar and RIBs) allow the conversion of primary ions into secondary particles.

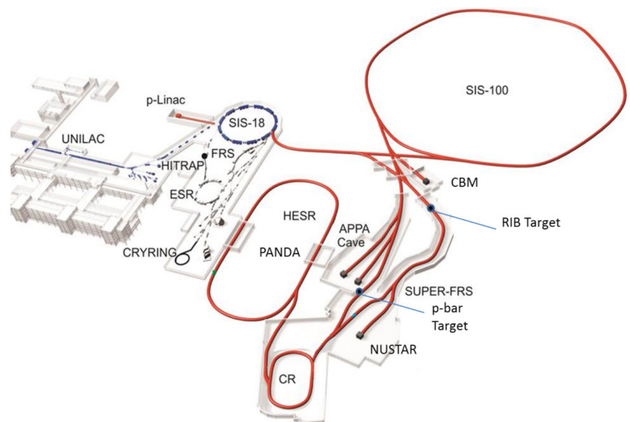

Figure 1: Overview of the GSI and the FAIR accelerator facility.

The Super-FRS will be the most powerful in-flight separator worldwide for exotic nuclei up to relativistic energies. Rare isotopes of all elements up to uranium can be produced and spatially separated within some hundred nanoseconds, thus very short-lived nuclei can be studied efficiently. The Super-FRS is a large-acceptance superconducting fragment separator with three branches serving different experimental systems. The accelerator facility is complemented by a system of storage rings. The main task of the collector ring (CR) is stochastic cooling of radioactive ions or antiproton beams from the production targets. In addition, this ring offers the possibility for mass measurements of short-lived ions, by operating in isochronous mode. The high-energy storage ring (HESR) is optimized for antiprotons of energy up to 14 GeV. This ring will operate with an internal target and associated detector set-up (PANDA).

OPERATION SCENARIOS

The main system parameter of the FAIR accelerators shown in Table 1, are the basis for the operation of the facility. The following typical operation scenarios of the FAIR accelerator facility are foreseen:

A) High intensity, high energy proton beams at energies up to 29 GeV: The proton linac injects protons into the SIS18 at 70 MeV beam energy, which will then be accelerated to 4 GeV in the SIS18. Merging of four proton bunches from SIS18 into a single bunch and subsequent compression into a 50 ns pulse for acceleration up to 29 GeV is accomplished in the SIS100. Thereby a single bunch of up $2*10^{13}$ protons will be delivered to the anti-

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Table 1: System Parameter of the FAIR Ring Accelerators

	SIS18	SIS100	CR	HESR
Circumference [m]	216	1083	215	575
Max. beam magnetic rigidity [Tm]	18	100	13	50
Injection energy of protons or anti protons [GeV]	0.07	4	3	3
Final energy of protons or antiprotons [GeV]	4	29	3	14
Injection energy of heavy ions [GeV/u]	0.0114	0.2	0.74	0.74
Final energy of heavy ions U(28+) [GeV/u]	0.2	2.7		
Final energy of heavy ions U(/73+/92+) [GeV/u]	1	11	0.74 (92+)	0.2-4.9 (92+)
Max. beam intensity for protons or antiprotons /spill	$5*10^{12}$	$2*10^{13}$	10^{8}	10^{10}
Max. beam intensity of U-ions /spill	$1.25*10^{11}$	$4.5*10^{11}$	10^{8}	10^{8}
Required static vacuum pressure [mbar]	$< 10^{-11}$	$<5*10^{-12}$	$<10^{-9}$	$<10^{-9}$

proton target. Alternatively the proton beam can be slowly from the SIS 100 for fixed target experiments.

B) Low charge-state, high current 238-Uranium (28+) beams at energies up to 1.5 GeV/u: The upgraded UNILAC injects high current bunches of $^{238}U^{28+}$ into the SIS18 for further acceleration up to 200 MeV/u. Four SIS18 bunches with max. $1.25*10^{11}$ will be provided to the SIS100 at 200 MeV/u. SIS100 will accelerate the $^{238}U^{28+}$ ions up to 1.5 GeV/u for fast extraction of 50 ns pulses or alternatively for slow extraction over 2 s.

C) High charge-state, high energy U^{73+}/U^{92+} beams at energies up to 11 GeV/u: U^{73+} beams injected from the UNILAC into the SIS18 (with maximum intensities of $2x10^{10}$ ions) will be accelerated to about 1 GeV/u. Following complete stripping to U^{92+} four batches will be transferred to the SIS100 for further acceleration up to 11 GeV/u and subsequent slow extraction. Instead of injection into the SIS100, the SIS18 can provide U^{73+} beams at energies between 0.1 and 1 GeV/u for slow or fast extraction into the ESR or the GSI target hall.

The SIS18/SIS100 beams can be delivered to several experiments in a pulse to pulse sharing mode, thereby allowing a very efficient parallel operation of several experimental programs at a time.

PRIMARY BEAM SYSTEM

The primary beam system consist on the linac injectors UNILAC and the proton linac (p-linac), the normal conducting synchrotron SIS18, the superconducting synchrotron SIS100 and the high energy beam transport system (HEBT) towards the target stations. The envisaged injection intensities for protons and Uranium ions are depicted in Table 1. UNILAC and SIS18 undergo a significant upgrade program to cope with the future FAIR requirements. The p-linac will deliver protons up to 70 mA at 70 MeV and will fill the SIS18 up to the space charge limit. Main components are the electron cyclotron resonance (ECR) source, a Radio Frequency Quadrupole (RFQ) and a DTL section composed of so called cross bar (CH)-type cavities. These structures are the key element of the 20 m long linac as these H-type structures have high shunt impedances and generate high gap fields. Details will be given in [3].

SIS100 is a worldwide unique heavy ion synchrotron dedicated to accelerate highest intensities of intermediate charge state heavy ion and of proton beams. From the technical point of view, most challenging issues are the fast ramped superconducting magnets (4 T/s) and the acceleration of intense heavy ion beams. The latter requires a unique lattice design (charge separator lattice) in combination with an ultra-high vacuum system based on distributed cryo pumping with actively cooled magnet chambers, adsorption pumps and dedicated cryo-catchers for local suppression of gas desorption. The s.c. superferric Quadrupole modules of SIS100 (83 pcs) are very demanding due to their technical complexity and are presently on the critical path. The quadrupole units (quadrupole magnet + corrector magnet) will be built at JINR, Dubna, whereas other components (vacuum chambers, cryocatcher, BPM's, local current leads, cryostats etc.) will be provided by GSI. Details will be presented in [2].

The HEBT consists of 29 sections with a total length of ca. 1.5 km. All beam lines are normal conducting with nominal magnetic rigidity 100Tm, 18Tm, 13Tm, and allowing parallel operation. The key components of the HEBT system are mainly provided by international in-kind partners. Almost all HEBT magnets (338/356) are assigned to the Efremov Institute, St. Petersburg, Russia. The remaining magnets are assigned to the Budker Institute and GSI. All related vacuum chambers will be built by the Budker Institute. Standard diagnostics vacuum chambers and the power supplies of the HEBT magnets are assigned to the Bose Institute, India. A first contract with ECIL (Electronics Corporation of India Limited) comprising 78 quadrupole power converters was signed and production started. The contract with the Slovenian in-kind partner was signed in November 2014, comprising BPM pre-amplifiers, Data Acquisition for BPM, Pressurized Air Drives and Control, DAQ for Beam-Loss Monitor System, DAQ for Beam Current Transformer.

THE FAIR TARGET STATIONS

The FAIR target stations will convert the intense primary beams into secondary particles for further use in experiments. For the Super-FRS it is intended to use a rotating carbon wheel (approximately 500 mm in diameter) as the production target. Since it is intended to have maintenance only once per year, the operation of the target wheel, as well as other components in the target area, must be reliable over a rather long period. The maintenance concept itself is based on the so called 'vertical beam plug' system. Individual components are provided together with a shielded plug (see Fig. 2); the same concept is well established e.g. at PSI and TRIUMF.

The development of the target system will be done in collaboration with KVI-CART. Super-FRS will be based on iron-dominated superconducting magnets. Those types of magnets are well established at in-flight separator facilities and are in operation e.g. at A1900 at the NSCL/MSU. Due to the higher beam rigidity of 20 Tm at Super-FRS (compared to approximately 9 Tm at the other facilities) our magnets need to be considerably larger in particular in size and weight. The Super-FRS multiplets are up to 7 m long, 2.5 m in diameter and have a weight of approximately 60 tons.

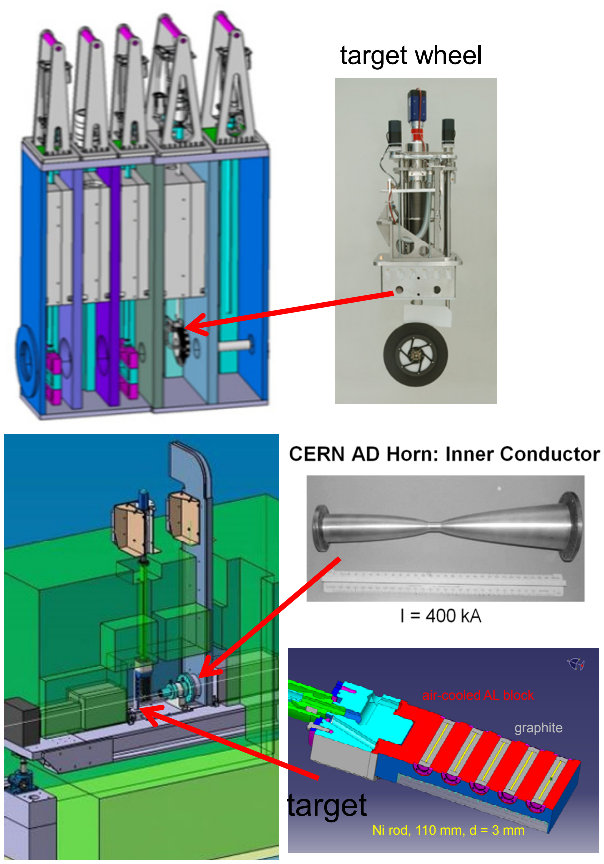

Figure 2: The target stations of Super-FRS (upper panel) and for antiproton production of FAIR.

The antiproton production target consists of five Ni-rods embedded in an aluminium block and is air cooled due to the high activation level. All major components like target or magnetic horn are unique. One major challenge is the high radiation level in the target area, thus radiation protection issues dominate significantly the design work. The second major challenge is the high peak pulse current of 400 kA for the magnetic horn for focusing. The magnets of the separator are part of the CR-magnet series or only slightly modified. A handling concept for highly activated targets and horns, which is essential for the operation permit, has been developed in cooperation with the company "Kraftanlagen Heidelberg".

THE FAIR STORAGE RINGS

The Collector Ring (CR) is a dedicated storage ring which is designed for fast cooling of hot beams coming from the antiproton separator or the Super-FRS. In addition, the CR is planned to be used for mass measurement of short-lived rare isotope beams from the Super-FRS in the isochronous mode. The fast cooling is going to be performed in two steps: 1- fast bunch rotation; 2 – stochastic cooling (SC). These tasks define the architecture of the CR, where the main emphasis is laid on the effective stochastic cooling. The key components of the CR are the high power RF de-buncher system, the full aperture kicker magnets and large aperture magnets, which must guarantee sufficient ring acceptance. In addition the stochastic cooling must be adapted for cooling of both antiprotons and rare isotopes at quite different energies. A prototype pick-up tank has been built at GSI. Procurement contract for power amplifiers, which are the most challenging part and main cost-driver of the system, is signed.

The HESR is designed and optimized for antiproton operation with PANDA. It is capable to accelerate antiprotons with beam momentum from 0.8 GeV to 14 GeV. The designed lattice is flexible enough to also accommodate the acceleration and store of positively charged ions up to Uranium between 0.7 GeV/u and 5 GeV/u with reversed magnet polarity. In addition to its flexibility, another unique feature of HESR in the Modularized Start Version (MSV) is the Stochastic cooling system. It will be available for all beam species. For antiprotons, stochastic cooling covers the entire momentum range, while for heavy ions stochastic cooling is available above beam momentum 0.8 GeV/u. Currently, most of the components of HESR, especially long lead items like main dipoles and quadrupoles, power supplies are ordered and well on production schedule. First magnets and power converters are in house at Forschungszentrum Jülich.

ACKNOWLEDGMENT

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