FAIR: CHALLENGES OVERCOME AND STILL TO BE MET*

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Abstract

FAIR will be one of the leading accelerator facilities worldwide making use of a highly sophisticated and cost-effective accelerator concept. The intensity frontier will be pushed by several orders of magnitude for the primary and especially for the secondary beams. To reach the unprecedented beam parameters several technical challenges such as operation with high brightness, high current beams, control of the dynamic vacuum pressure or the design of rapidly cycling superconducting magnets have to be mastered. For most of those challenges solutions have been found and prototypes are being built. The remaining open questions are addressed in close collaborations with the partners of FAIR.

STATUS OF FAIR PROJECT

The FAIR project has passed most important milestones with respect to political as well as to technical realization.

On November 7th, 2007 officials from FAIR partner countries celebrated the Launch of the FAIR Start Version. Delegates from Austria, Germany, Spain, Finland, France, Poland, Romania, Russia, Sweden, Great Britain and the State of Hessen jointly announced the beginning of the realization of the FAIR project in Darmstadt (see Fig. 1).

Figure 1: Officials from the FAIR partner states celebrating the Launch of the Start Version: Austria, Germany, Spain, Finland, France, Poland, Romania, Russia, Sweden, Great Britain and State of Hessen.

More than 1400 international participants joined the official signing ceremony for the Communiqué on the Official Launch of FAIR. The International Steering Committee decided on a two staged approach for the realisation of the facility. The Start Version will have a volume of 940 M€ (price basis 2005), thereby allowing the construction of a world-leading facility in its scientific domains.

SCIENTIFIC DOMAINS

In most general terms, the scientific thrusts of the facility can be summarized by the following broad research goals. The first goal is to achieve a comprehensive and quantitative understanding of all aspects of matter that are governed by the strong force. Matter at the level of nuclei, nucleons, quarks and gluons is governed by the strong interaction and is often referred to as hadronic matter. The research goal of the present facility thus encompasses all aspects of hadronic matter, including the investigation of fundamental symmetries and interactions among the constituents describing the relevant degrees of freedom for this regime.

The second goal addresses many-body aspects of matter. The many-body aspects play an important and often decisive role at all levels of the hierarchical structure of matter. They govern the behavior of matter as it appears in our physical world.

These two broad science aspects, the structure and dynamics of hadronic matter and the complexity of the physical many-body system, transcend and determine the more specific research programs that will be pursued at the future facility:

- Investigations with beams of short-lived radioactive nuclei, addressing important questions about nuclei far from stability, areas of astrophysics and nucleo-synthesis in supernovae and other stellar processes, and tests of fundamental symmetries.
- The study of hadronic matter at the sub-nuclear level with beams of antiprotons, including the two key aspects: confinement of quarks and the generation of the hadron masses. They are intimately related to the existence (and spontaneous breaking) of chiral symmetry, a fundamental property of strong interactions.
- The study of compressed, dense hadronic matter in nucleus-nucleus collisions at high energies.
- The study of bulk matter in the high-density plasma state, a state of matter of interest for inertial confinement fusion and astrophysical settings.
- Studies of Quantum Electrodynamics (QED), of extremely strong (electro-magnetic) fields, and of ion-matter interactions.

The following figure depicts the FAIR baseline accelerator layout and shows the locations of the different experiments [1].

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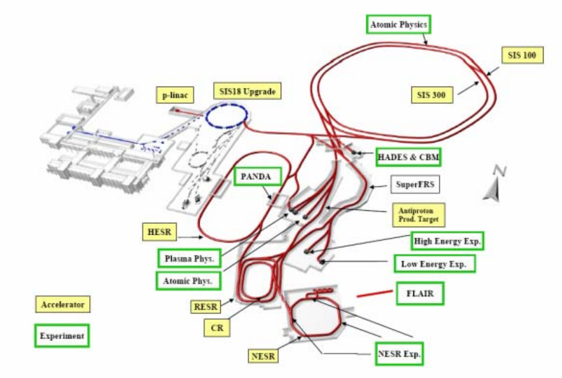


Figure 2: FAIR baseline layout.

The experiment requirements are the driving force behind the accelerator design. Some of the most challenging requirements are shown in the table below.

Table 1: Experiment Requirements (exemplarily)

Experiment	Reqirements
NUSTAR	2 x 10^{11}/pulse U^{28+} @ 1500 MeV/u bunch compression to 70 ns highest gain factors for exotic nuclear beams
CBM	Heavy-ion beam intensities of 10^{10} particles/s @ 34 GeV/u for U^{73+}
PANDA	pbar in wide momentum range (1.5-15 GeV/c) High luminosity and high momentum resolution
FLAIR	Cooled antiprotons in the 20 keV range
SPARC	Cooled and high brilliance beams of rare isotopes
Plasma Physics	High intensity beams bunch compression to 70 ns

ACCELERATOR REQUIREMENTS

To fulfil those requirements, the planned accelerators with their main characteristics are listed in Table 2. The beam intensity frontier is pushed forward – FAIR will deliver 100-1000 times higher primary beam intensities than presently. To open up new possibilities for experiments the beam brightness frontier will be pushed further. FAIR targets to deliver beams with highest phase space densities. The intense primary beams will be compressed up to 70 ns long pulses and the radioactive ions and antiprotons will be cooled to provide for excellent beam qualities.

Table 2: Accelerator Components and Key Characteristics

Ring/Device	Beam	Energy	Intensity
SIS100 (100Tm)	protons	30 GeV	2x10^{13}
	^{238}U	1 GeV/u	3x10^{11}
	(intensity factor 100 over present)		
SIS300 (300Tm)	^{40}Ar	45 GeV/u	2x10^{9}
	^{238}U	34 GeV/u	2x10^{10}
CR/RESR/NESR	ion and antiproton storage and experiment rings		
HESR	antiprotons	14 GeV/u	~10^{11}
Super-FRS	rare isotope beams	1 GeV/u	<10^{9}

SELECTED CHALLENGES AND SOLUTIONS

This section concentrates on selected challenges and presents solutions applied to the design of the FAIR accelerators. For a more detailed approach, the references to proceedings contributions are given.

The Technical Design Reports for the machines of the FAIR Start Version will be available soon.

Dynamic Vacuum Pressure

To cope with the problem of an increase of the vacuum pressure due to dynamic influences, different solutions have been found for SIS18 [2] and SIS100 [3]. They both have in common that beam losses are well localized, the desorption is minimized, and the pumping speed is increased.

Within the SIS18 Upgrade program the magnet vacuum chambers are NEG coated and for the SIS100 the lattice is adopted to easily control the beam losses. For both machines special collimation systems are under investigation.

Rapidly Cycling Superconducting Magnets

The fast ramping of the SIS100 demands advancements in the development of rapidly cycling superconducting magnets [4]. A first prototype of a still straight SIS100 dipole magnet fabricated at BNG in Würzburg is now ready for testing (see Fig. 3). The second prototype delivered by BINP is scheduled for the end of 2008.

For a full qualification and testing of the superconducting magnets a dedicated test facility is at GSI's disposal.

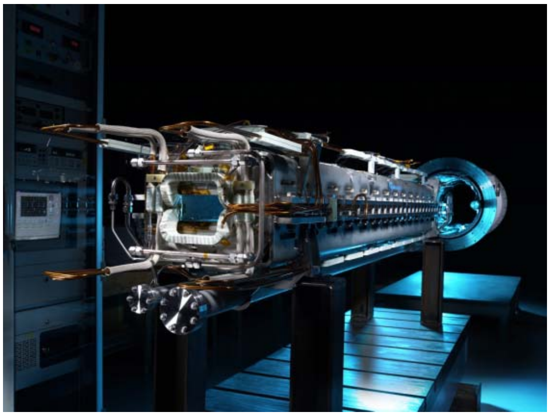


Figure 3: Photograph of the full size model of the SIS100 dipole (©BNG).

Further developments aim for curved dipole magnets for the SIS100 and SIS300. For both machines curved dipole prototypes are currently under development.

Large Aperture Magnets

To provide the experiments with high intense secondary beams, large aperture magnets have to be designed. Especially for the Super-Fragment-Separator the high radiation level in the target area is an additional challenge, here the superconducting magnets of the 1st stage of the Pre-Separator must be designed to resist the high radiation. Although all magnets will be operated in DC mode, the settings must be changed frequently, so that a laminated design is mandatory. As an example for such magnets the superferric dipole magnets for the Super-FRS are presented here.

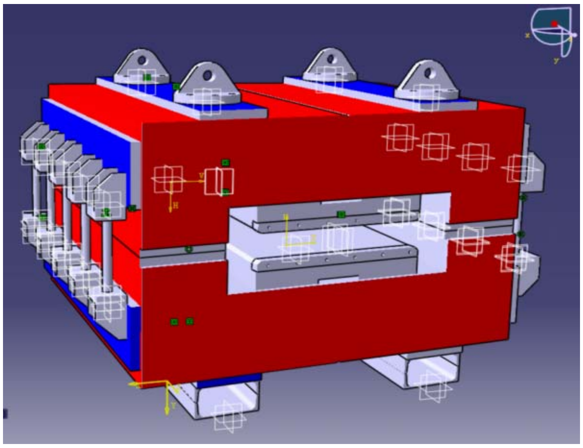


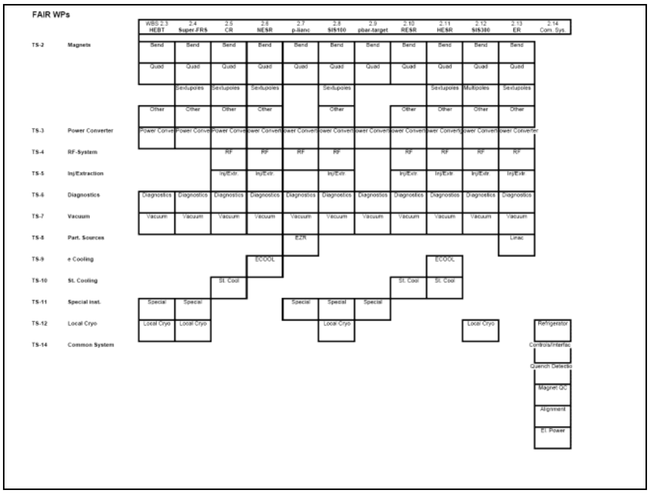
Figure 4: 3D model of the Super-FRS dipole prototype built at IMP Lanzhou, China.

Storage Rings for Cooled Rare Isotopes and Antiprotons

One of the main pillars of FAIR is the provision of high quality secondary beams of antiprotons and rare isotopes [5]. To achieve and prepare those beams a sophisticated interplay between pre-cooling, accumulation, and cooling is mandatory. The cooling schemes adopted are based on either stochastic cooling as in the CR or electron cooling in the NESR. The rf systems used for acceleration or deceleration are integrated into the cooling procedures. Deceleration will offer secondary beams over a large range of energies down to particles at rest.

FAIR – AN INTERNATIONAL EFFORT

FAIR will be built and operated in close collaboration with partner institutions within the FAIR partner countries. Adopting the in-kind approach, where countries contribute to a facility through components or (sub)system deliveries, the FAIR project for the accelerators was structured in 12 accelerator sub-systems, each further structured in the respective technical systems, as shown in the Figure below.



FAIR WPs

		WBS 2.3 HEBT	2.4 Super-FRS	2.5 CR	2.6 NESR	2.7 p-linac	2.8 SIS100	2.9 pbar-target	2.10 RESR	2.11 HESR	2.12 SIS300	2.13 ER	2.14 Com. Sys.
TS-2	Magnets	Bend	Bend	Bend	Bend	Bend	Bend	Bend	Bend	Bend	Bend	Bend	
		Quad	Quad	Quad	Quad	Quad	Quad	Quad	Quad	Quad	Quad	Quad	
			Sextupoles	Sextupoles	Sextupoles		Sextupoles			Sextupoles	Multipoles	Sextupoles	
		Other	Other	Other	Other		Other		Other	Other	Other	Other	
TS-3	Power Converter	Power Conve	Power Conve	Power Conve	ower Convert	ower Conver	ower Convert	ower Conver	ower Convert	wer Converg	ower Convert	ower Converter	
TS-4	RF-System			RF	RF	RF	RF		RF	RF	RF	RF	
TS-5	Inj/Extraction			Inj/Extr.	Inj/Extr.		Inj/Extr.		Inj/Extr.	Inj/Extr.	Inj/Extr.	Inj/Extr.	
TS-6	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	Diagnostics	
TS-7	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	Vacuum	
TS-8	Part. Sources					EZR						Linac	
TS-9	e Cooling				ECOOL					ECOOL			
TS-10	St. Cooling			St. Cool					St. Cool	St. Cool			
TS-11	Special inst.	Special	Special			Special	Special	Special					
TS-12	Local Cryo	Local Cryo	Local Cryo				Local Cryo				Local Cryo		Refrigerator
TS-14	Common System												Controls/Interfac Quench Detectio Magnet QC Alignment El. Power

Figure 5: Work Breakdown Structure for the FAIR Accelerators.

Following a call for Expression of Interest (EoI) to contribute with in-kind components in late autumn 2007, FAIR received an overwhelming response for planned contributions [5]. A detailed analysis of the EoIs and discussion took place in April 2008 at GSI, where it was ascertained that 80% of the required accelerator items were covered by EoIs .

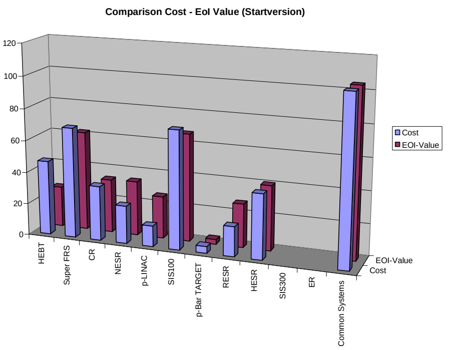


Figure 6: Comparison between cost of accelerators and defined EoI-value.

CONCLUSION

It can be said that the design of the FAIR accelerators is in a very advanced state, allowing for the start of construction of the first components in early 2009, following the foundation of the FAIR company. This challenge, although not a technical one, will hopefully be overcome by late autumn this year. With the efforts of all our partners FAIR will provide highest quality beams for experiments beginning in 2013. The FAIR complex will support a wide variety of research fields. Due to the high luminosity which exceeds current facilities by up to a factor of 10000, experiments will be feasible that could not be done elsewhere. It promises to become a focal point of heavy ion, antimatter, nuclear and atomic physics.

Figure 7: Artist impression of FAIR.

ACKNOWLEDGEMENTS

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REFERENCES

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