HIC for FAIR-Workshop

Detectors and Accelerators

28.07.2015 - 31.07.2015
Mövenpick Hotel, Hamburg

1. Introduction

FAIR – the Facility for Antiproton and Ion Research – will comprise an international centre of heavy ion accelerators that will drive forefront heavy ion and antimatter research. The goal of the FAIR facility is to provide antiproton and ion beams of unprecedented intensities as well as qualities by a unique accelerator to specifically experimental facilities comprising cutting edge detector systems. Some of the facility's strengths are the broad range of rare-isotope, anti-proton and high-intensity ion beams that can be provided and the flexibility with which these can be reconfigured and provided in parallel to multiple experiments. Both areas are addressed by the Helmholtz International Center for FAIR (HIC for FAIR) that constitutes a unique think tank for forefront interdisciplinary theoretical and experimental research associated with FAIR.

HIC for FAIR explores new concepts and methods for the construction, operation and scientific exploitation of the international research centre FAIR. In particular the expert groups 3 and 4 in HIC for FAIR contribute to the development and design of experimental equipment and detectors as well as on accelerator systems and components. Both expert groups identified the need of a workshop to discuss the requirement of the experiments on the accelerators. The HIC for FAIR workshop “Detectors and Accelerators” was therefore jointly organized by the HIC for FAIR expert groups 3 and 4 in collaboration with GSI, to identify and discuss the physical and technical limits of both detectors and accelerators related to the beam parameter. In addition, the required adjustment and optimization of the FAIR accelerator's performance to serve the needs of the experimental set-ups was identified and discussed. Therefore, the organizers invited experts on accelerator and detectors physics to fulfil these important aims. The workshop has taken place from July 28 to July 31 at the Mövenpick Hotel in Hamburg.

Overview talks on the FAIR/GSI accelerators and detectors delivered both communities – accelerators and experiments – according background information. More details were given by talks, which did focus on the performance and technical limits of the different systems. Discussions on identified “hot topics” have taken a significant fraction of the workshop schedule. Figure 1 shows the agenda of the workshop. This report is the summary and result of this so-called “Hamburg workshop”. The main issue identified during the discussion can be shortly summarized as follows:

The ion source performances should be improved for several isotopes, whereby for few elements to safety regulation and to the rareness of some isotopes can be a huge challenge. The structure of the slow extracted beam from the SIS18 and SIS100 synchrotrons on macro- and micro- time-scales must be more smoothly. Detector protection, collimation, and a beam aborting system shall be installed. Until the FAIR facility comes online, GSI should continue to conduct a high-level research programme. During the workshop the proposed 2.7 Hz mode of operation of SIS18 has been discussed, and the requirements of the detectors for this new operation mode have been specified. Another outcome of this workshop is to continue the discussion in a similar regular meeting.

We would like to thank all participants for their contributions to this workshop, their well-prepared talks and fruitful discussions. A special thank goes to P. Lindenberg and N. Azevedo Simoes for organising the event and editing this report.

Sabrina Appel, Thomas Aumann, Oliver Boine-Frankenheim, Oksana Geithner, Oliver Kester and Ralph Steinhagen

HIC4FAIR-Workshop Detectors & Accelerators

TIME	Tuesday Location	Wednesday Location Titel	Speaker			Thursday Location Titel	Speaker			Friday Location Titel	Speaker		
9:00		Welcome+ Introduction	Tom und OBF	-	Chair	Beam requirements			Chair	GSI Facility Aspects and Requirement			Chair
		Overview Accelerator Systems											
9:00		Primary Beams	P. Spiller	30 Min.	O. Kester	NUSTAR Low Energy Experiments	A. Herlert	20 Min.	R. Reifarth	Linac / SIS18	Jens Stadlmann	30 Min.	O. Geithner
		Secondary Beams (RB)	H. Weick	15 Min.		NUSTAR High Energy and Spectrometer Experiments	H. Simon	20 Min.		ESR / Cryring	Markus Steck	30 Min.	
		Secondary Beams (pbar)	U. Weinrich	15 Min.						**NUSTAR**	H. Scheit	20 Min.	
		Storage Rings (CR)	O. Dolinskiy	15 Min.		NUSTAR Storage Ring Experiments	Y. Litvinov	20 Min.		**HADES**	T. Galatyuk	15 Min.	
		Storage Rings (HESR)	D. Prasuhn	15 Min.		Discussion				**SPARC**	Y. Litvinov	15 Min.	
10:30-11:00		Break				Break				Break			
		Overview Detector Systems				Expected Machine Performance							
		Detectors: APPA	T. Stöhlker	30 Min.	T. Aumann	Options for parallel operation	R. Steinhagen	30 Min.	O. Boine-Frankenheim	*Discussion on perspectives of GSI operation from 2017 - xx (T. Aumann and O. Boine-Frankenheim)*			
		CBM	W. Müller	30 Min.		Risk analysis and expected machine availability	C. Omet	30 Min.					
11:00	Arrival	NUSTAR	J. Gerl	30 Min.		Beam parameters available from SIS18 and SIS100 on the targets	V. Kornilov	30 Min.					
		PANDA	L. Schmitt	30 Min.		Internally targets and luminosity	D. Prasuhn	15 Min.					
						Super-FRS performance: production, separation, detection	H. Weick	15 Min.					
						Conversion rates pbar	K. Knie	15 Min.					
13:00-14:00		Lunch				PANDA	Lars Schmitt	30 Min.		Lunch			
		Beam requirements				Lunch							
14:30		Expected intensity limits from beam physics	O. Boine-Frankenheim	30 Min.	S. Appel	*Discussion with primary beam and CBM + APPA (C. Sturm, S. Appel)*				*Summary (O. Kester)*			
		Beam induced activation and collimation	I. Strasik	30 Min.									
		SPARC	A. Bräuning-Demian	20 Min.									
		Plasmaphysic	A. Blazevic	20 Min.		*Discussion with secondary beam and NUSTAR + PANDA (Y. Litvinov, L. Schmitt / T. Aumann)*							
		Materials Research	D. Severin	20 Min.									
		BIO	D. Severin										
16:30-17:00		Break				Break							
		Beam requirements											
17:00		CBM Running Scenario (C. Sturm) / Beam focus, beam halo and time structure (J. Pietraszko)	C. Sturm / J. Pietraszko	60 Min.	O. Boine-Frankenheim	*Discussion with primary beam and CBM + APPA (C. Sturm, S. Appel)* *Discussion with secondary beam and NUSTAR + PANDA (Y. Litvinov, L. Schmitt / T. Aumann)*				*Departure*			
18:00-18:30		Discussion				*Discussion all (Tom und OBF)*							
18:30	**Welcome Dinner**	Free time				Free time							

Figure 1: Agenda of the HIC for FAIR workshop "FAIR Detectors and Accelerators"

2. Ion source development

2.1. Present status and required development

Ion source development has to tackle several issues. The development of beams from elements requested and not yet in routine operation is required. The ion sources have to deliver higher intensities while keeping the beam emittance, therewith increasing the beam brilliance. Brilliance improvement in the injector chain is mandatory to reach the necessary beam intensities at injection level in the synchrotrons. This is addressed by the UNILAC upgrade programme. In addition, a higher repetition rate (up to 2.7 Hz) of beam pulses from the high current sources is another issue to be addressed.

Beams from a significant fraction of elements from the periodic system have been developed at GSI and are delivered by three injectors housing different ion source types. Two are feeding the high intensity injector (high current sources - VARIS+MUCIS - and the Penning ionization gauges, PIGs) and the electron cyclotron resonance ion source (ECRIS) provides beams to the high charge state injector. The beams available are summarized in table 2.1. Only the PIG can run repetition rates > 5 Hz. The VARIS source cannot run the repetition rate required by FAIR for certain heavy elements: Au, Pb, Bi and U yet.

Table 2.1: Overview of the elements presently provided by the GSI ion sources for operation.

Element	Ion Beam	Ion Source	Duty Factor	Beam current in front of the RFQ	Space-charge limit of the RFQ
H_2	${}^{1}H_3^+$	MUCIS	5 Hz / 1 ms	1 mA	0.75 mA
D_2	${}^{2}H_3^+$	MUCIS	5 Hz / 1 ms	2 mA	1.5 mA
C	${}^{12}C^+$	VARIS	1 Hz / 0.5 ms	3 mA	3 mA
CH_4	${}^{12}C^+$	MUCIS	2 Hz / 1 ms	1 mA	3 mA
	${}^{12}CH_3^+$	MUCIS	2 Hz / 1 ms	3 mA	3.8 mA
N_2	${}^{14}N_2^+$	CHORDIS	5 Hz / 1 ms	4 mA	7 mA
O_2	${}^{16}O_2^+$	MEVVA	1 Hz / 0.5 ms	3 mA	8 mA
Ne	${}^{20}Ne^+$	MUCIS	5 Hz / 1 ms	5 mA	5 mA
Mg	${}^{24}Mg^{2+}$	VARIS	1 Hz / 0.5 ms	2 mA	3 mA
Ar	${}^{40}Ar^+$	MUCIS	5 Hz / 1 ms	20 mA	10 mA
	${}^{40}Ar^{2+}$	PIG	50 Hz / 4 ms	330 µA	5 mA
Ca	${}^{40}Ca^{2+}$	PIG	50 Hz / 5 ms	100 µA	5 mA
Ti	${}^{48}Ti^{2+}$	VARIS	1 Hz / 0.5 ms	20 mA	6 mA
	${}^{50}Ti^{2+}$	PIG	50 Hz / 5 ms	70 µA	6.3 mA
V	${}^{51}V^{2+}$	PIG	50 Hz / 5 ms	20 µA	6.4 mA
Cr	${}^{52}Cr^+$	VARIS	1 Hz / 0.5 ms	5 mA	13 mA
	${}^{52}Cr^{2+}$	PIG	50 Hz / 5 ms	70 µA	6.5 mA
Fe	${}^{56}Fe^{2+}$	VARIS	1 Hz / 1 ms	8 mA	7 mA
Ni	${}^{58}Ni^{2+}$	VARIS	1 Hz / 0.5 ms	5 mA	7.3 mA
Kr	${}^{86}Kr^{2+}$	MUCIS	5 Hz / 1 ms	7 mA	10.8 mA
Mo	${}^{100}Mo^{2+}$	VARIS	1 Hz / 0.5 ms	0.5 mA	12.5 mA
Ag	${}^{107}Ag^{2+}$	VARIS	1 Hz / 1 ms	10 mA	13.4 mA

Xe	$^{124}\mathrm{Xe}^{3+}$	MUCIS	5 Hz / 1 ms	4 mA	10.3 mA
Nd	$^{142}\mathrm{Nd}^{3+}$	VARIS	1 Hz / 0.5 ms	1.5 mA	11.8 mA
Sm	$^{152}\mathrm{Sm}^{3+}$	PIG	10 Hz / 4 ms	60 µA	12.7 mA
Ta	$^{181}\mathrm{Ta}^{3+}$	VARIS	1 Hz / 0.5 ms	8 mA	15 mA
Au	$^{197}\mathrm{Au}^{4+}$	VARIS	0.5 Hz / 0.5 ms	4.5 mA	12.3 mA
	$^{197}\mathrm{Au}^{8+}$	PIG	50 Hz / 2 ms	20 µA	6.2 mA
Pb	$^{208}\mathrm{Pb}^{4+}$	VARIS	0.5 Hz / 0.4 ms	5 mA	13 mA
	$^{208}\mathrm{Pb}^{4+}$	PIG	15 Hz / 2 ms	100 µA	13 mA
Bi	$^{209}\mathrm{Bi}^{4+}$	VARIS	0.5 Hz / 0.5 ms	12 mA	13.1 mA
	$^{209}\mathrm{Bi}^{4+}$	PIG	10 Hz / 1 ms	200 µA	13.1 mA
U	$^{238}\mathrm{U}^{4+}$	VARIS	1 Hz / 0.5 ms	12 mA	15 mA

Beside the reference ions (protons, Au and U), a lot of different projectiles are required by the FAIR experiments like NUSTAR, CBM/HADES and BIOMAT. Some of them are: Ca, He, Ni, Kr, Xe, Sn, Pb and Th. If there is no experience from operation, beam development from new elements requires a period of about 3-6 month dedicated to ion source beam test. In particular for enriched material the production of cathodes and the procurement of material need to be investigated. For cathode material like thorium for instance, an extensive approval procedure and additional invest money will be required.

2.2. Upgrade program

The upgrade program for the GSI ion sources comprises the source terminal area of the HSI, a new uranium terminal and the superconducting 28 GHz ECRIS at the HLI. The uranium terminal is required in order to separate the uranium operation from the operation of beams from other elements to avoid cross contamination. The VARIS high current source will be optimized for uranium operation. A typical repetition rate for this type of ion sources is 1 Hz with a pulse length of 0.5 ms. The main development of the VARIS will be the 2.7 Hz operation. The high repetition rate is critical due to the thermal load on the cathodes, which deliver the material for the metal vapour that feeds the dense plasma of metallic ions. To increase to repetition rate for heavy elements (gold, lead, bismuth and uranium) further systematic investigations especially on the cathode material are required. In particular for materials with low melting points a development of cathodes using alloys or composite materials is required. The development of new beams is summarized in table 2.2:

Table 2.2: High current ion source beam development for FAIR

Ion Species	**Ion Source**	**Duty Cycle**	**Achieved Particle Intensity (RFQ entrance)**
p^{+}	high current	4 Hz	$1.9*10^{12}$ (gas stripper)
$^{4}\mathrm{He}^{+}$	high current	2.7 Hz	-
$^{9}\mathrm{Be}^{+}$	ECR or HC	1 Hz	-
$^{14}\mathrm{N}_2^{+}$	high current	2.7Hz	$2.5*10^{12}$

$^{40}Ar^{+}$	high current	2.7 Hz	$1.2*10^{13}$
$^{48}Ca^{10+}$	ECR	2.7 Hz	$6.3*10^{9}$
$^{58}Ni^{2+}$	high current	2.7 Hz	$1.6*10^{12}$
$^{86}Kr^{2+}$	high current	2.7 Hz	$2.2*10^{12}$
$^{107}Ag^{2+}$	high current	2.7 Hz	$3.1*10^{12}$
$^{112}Sn^{2+}$	ECR or HC	2.7 Hz	10^{9}
$^{124}Xe^{3+}$	high current	2.7 Hz	$8.3*10^{11}$
$^{197}Au^{4+}$	high current	2.7 Hz	$7*10^{11}$
$^{203}Tl^{4+}$	Not clear yet	1 Hz	-
$^{208}Pb^{4+}$	high current	2.7 Hz	$7.8*10^{11}$
$^{209}Bi^{4+}$	high current	2.7 Hz	$1.9*10^{12}$
$^{232}Th^{4+}$	Not clear yet	1 Hz	-
$^{238}U^{4+}$	high current	2.7 Hz	$1.9*10^{12}$

28GHz ECR ion source will have a warm-bore superconducting magnet system (solenoids and sextupole). The magnetic design will follow closely the FRIB ECR ion source, which is based on the VENUS ECRIS design by Berkeley. The GSI ECRIS will use a cryoplant for cryogenics supply instead of cryo-cooler, because the source does not need to be operated on a high voltage platform. The oven technology for production of metallic ions needs to be adopted too.

2.3. Interface: Source and UNILAC

The beams from the high current ion source are accelerated by the potential of the high voltage platform and then transported towards the HSI-RFQ. This transport is the link between the ion sources and the linac. The existing beam transport system of the high current sources (MEVVA, MUCIS) to the RFQ section has to be modified in order to reduce the beam losses due to a restricted acceptance. For the uranium terminal a new connection towards the RFQ is planned, the so-called “compact LEBT”. This 'Compact LEBT' will have the advantage to allow a dispersion free beam path towards the RFQ.

The LEBT design is based on magnetic quadrupole lenses, which allow a high degree of beam neutralization by electrons from ionization of residual gas atoms being present in the beam line. Magnetic element focusing is also dependent on the rigidity of the ions, which allows beam separation of various particle species by defocusing and scraping. The ions with the wrong charge state or beam energy will be defocussed by the quadrupole lenses and can be scraped away by collimators. Those ions, with the wrong charge state and which are too close to the beam axis get finally lost within the HSI-RFQ.

3. Synchrotron extraction

3.1. Fast extraction

The fast extraction of short bunches from SIS18 and SIS100 serves two main purposes: first, the production and subsequent storage of secondary beam in the CR for NUSTAR and PAND; second, the generation of hot dense matter for APPA.

The NUSTAR community has the following beam requirements in front of the Super-FRS target for the storage ring experiments (CR, HESR): short bunches with energy range of 400 MeV/u – 2.7 GeV/u, repetition rate up to 1 Hz and maximum permitted beam intensities ($5*10^{11}$ U^{28+}). The maximum intensity is mainly restricted by the dynamic vacuum and space charge effects in both synchrotrons.

The required bunch length is usually stated as "50 ns". The actual bunch length requirement arises from the maximum momentum spread after fast debunching in the CR. In order to reach a momentum spread of 1 % (4σ) after debunching an initial bunch length (before debunching) of approximately 50 ns (4σ) is required. However, the bunch length requirement for the primary beam is not very strict. Longer bunches could be tolerated for optimized rf-voltage profiles. This should be studied more in detail. The transverse emittance of the primary beam is usually assumed to be 10 mm mrad (2σ, not normalized at 1 GeV/u). A more detailed discussion of the required beam spot on the production target is still needed, as this determines the budget for emittance increase in SIS100[1]. During the workshop a possible application of intense ($1\text{-}2*10^{10}$), energetic (1 GeV/u), short U^{73+} bunches from SIS18 with maximum repetition rate (> 1 Hz) has been identified. Very exotic ions (yield approx. 1 per bunch) could be identified with this mode of operation.

For plasma physics experiments (APPA) the repetition rate is not important. The required energy range is from 200 MeV/u to 1.5 GeV/u, space charge limited intensities, bunch length "50 ns" or as short as possible. Again the required spot sizes require further discussions. Furthermore some experiments require short bunches with momentum spreads below $5*10^{-4}$. Such conditions can only be met at high beam energies and/or by using cooling techniques, like for example laser cooling in SIS100. In addition at low momentum spreads longitudinal space charge and impedance effect play an important role and have to be studied.

Other potential applications of laser cooled, short (ns) bunches from SIS100 are in the material sciences.

3.2. Slow extraction

A majority of the planned experiments relies on slow extraction from SIS100. Especially for CBM/HADES and NUSTAR the micro-spill structure as well as the halo of the extracted beam is a concern. The present micro-spill structure from SIS18 shows pronounced peaks on time scales < 1 ms. Activities aiming at an improvement of the micro-spill structure in SIS18 started very early (for example, U. Blell, EPAC 96) with a dedicated feedback system and continue to the present date (for example, M. Kirk, IPAC13) with optimizations of the RF-knock-out extraction scheme. The source of the micro-spill structure is not exactly known. Candidates are power supply ripple in combination with the details of the beam's tune distribution. Slow extraction relies on the complex interplay of external perturbations and nonlinear forces (sextupoles) acting on coarsely populated parts of the tune distribution. Therefore the micro-spill structure can have different sources. Experience with successful measures can be obtained from the AGS and JPARC. Besides dedicated feedback systems also narrow band noise and rf excitation at higher

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[1] For NUSTAR we even have to enlarge the spot in fast extraction mode, to make the target survive. So the emittance is not critical. It can be critical for APPA (Plasma) or for the HEBT. A not too small emittance is even better for the beam dumps in Super-FRS.

harmonics were employed. A 'slow extraction project team' should be established. Slow extraction of bunched beams is another requirement. The extracted bunch spacing should be > 5 MHz. This will be discussed with the rf experts. Also here one could benefit from the experience gained at the AGS with the micro-bunching of slow extracted beams (Glenn et al., PAC99).

4. SIS18 2.7 Hz operation mode

4.1. SIS18 Performance

The high repetition (booster) mode of the SIS18 will be required to serve the SIS100 with sufficient ion beam intensities. Therefore SIS18 has been prepared for a "2.7 Hz"-operation and could provide the fast ramping and repetition rate in 2018. For the operation in 2018 the power connection to the transformer station "Freifläche Nord" will be required.

For the preparation of SIS18 a new pulse power connection, a new main dipole power supply and three cavities running at the second harmonic (h=2) have been installed. The two ferrite loaded h=4 cavities cannot reach the required acceleration voltage for the design ramping speed of 10 T/s, thus the resulting bucket area is not sufficient. For SIS100 injection a bunch to bucket injection scheme with harmonic number 10 is specified with 4 times 2 bunch extractions from SIS18 (for heavy ions). In order to increase the bucket area the h=2 metallic alloy (MA) cavity have been installed and will provide the required voltage of 50 kV.

It has been discussed whether the SIS18 high repetition mode can be beneficial for experiments. A quasi-slow extraction over max. 300 ms has been discussed as well. In principle it should be possible to expel the ions via the KO-excitation fast enough. Beams with high rep rate can already be delivered by the MUCIS and the ECRIS. For the VARIS operation, source development will be required as described above.

4.2. Requirements and benefits for the detectors and research projects

The option of the high-repetition mode of SIS18 is obviously of direct benefit for all experiments using fast extraction as the storage-ring experiments. It has been pointed out during the workshop that also some external-target experiments can gain luminosity by a fast cycling of SIS18. For NuSTAR, these are for instance experiments which measure with very low secondary-beam rate as the implantation experiments like DESPEC. Such experiments can be performed below 1 Hz, which means that one bunch from SIS18 contains in average less than one ion hitting the final focal plane. In such a case, the extraction time can be as short as for the fast-extraction mode. But even experiments which run in an optimal way in a DC-like mode, will gain substantially in luminosity for certain cases. The rate limitation of R3B, for instance, lies at around 10^6 ions/sec instantaneous rate, due to the spill micro structure often at 10^5/sec (see section 3.2). In an extraction mode with a spill length in the order of 100 msec, R3B could accept 10^4 ions/spill on target. Since a substantial fraction of the R3B physics program can be pursued with secondary-beam rates in the order of 1 to 10 kHz, a fast-cycling mode with an extracted spill-length of around 100 msec would be extremely beneficial for the R3B program starting 2018 at GSI. The gain factor in such a case is basically directly the cycle-frequency ratio. The hard intensity limit is the slow extraction efficiency leading to beam losses in the septum wires. If the energy deposition in the wires it too high it will damage the septum. That limits the minimum extraction time and repetition rate for a given beam intensity.

5. Accelerator and detector protection

5.1. Beam halo collimation in rings

During the workshop, I. Strašík presented the outcome of his systematic and detailed study of the halo collimation of ion beams from proton up to uranium in the FAIR synchrotron SIS100. In order to achieve required collimation efficiency for all primary ions the collimation in SIS100 is separated into two concepts. One system has been developed for protons and fully stripped ions (e.g. $^{238}U^{92+}$) and the second one for partially stripped ions (e.g. $^{238}U^{28+}$). A detailed description can be found in: I. Strašík, I. Prokhorov and O. Boine-Frankenheim: Beam halo collimation in heavy ion synchrotrons, Rev. ST Accel. Beams 18, 081001 (2015).

Beam dynamics mechanisms can cause a beam halo formation which is one of the reasons for uncontrolled beam losses. The beam losses interact with the accelerator structure and cause various problems such as residual activation of the accelerator structure. A tolerable level of the uncontrolled beam losses is 1 W/m for protons and it is increasing with increasing ion mass. For example, the loss criterion for 1 GeV/u uranium beam is 5 W/m. In order to prevent uncontrolled activation of the accelerator structure a collimation system is used.

For protons and fully stripped ions a well-established two stage betatron collimation system is going to be applied in SIS100. The two stage collimation system consists of a primary collimator (a thin foil) which intercepts and scatters the halo particles and secondary collimators (bulky blocks) which are needed to absorb the scattered particles. The single pass and multi pass collimation efficiency for proton and ion beams in SIS100 was determined by using particle tracking simulations. It was found that the single pass efficiency is between 60% and 70% for all considered ion species at injection energy. The multi pass collimation efficiency at injection energy is about 99% from protons up to $^{20}Ne^{10+}$. The efficiency starts to decrease for 40Ar18+ and drops to the level of the single pass efficiency for $^{132}Xe^{54+}$. This is due to the substantially higher momentum losses of heavy ions in the primary collimator. The multi pass collimation efficiency of heavy ions in SIS100 is significantly improved with the help of the cryocatchers. They are part of the special collimation-pumping system originally designed for the interception of partially stripped ions after interaction with residual gas molecules. Because of the cryocatchers, the 99% efficiency level is reached up to $^{132}Xe^{54+}$, and even for $^{238}U^{92+}$ the efficiency remains at almost 90% at injection energy. In consequence of using cryocatchers in SIS100, the multipass collimation efficiency is also sufficiently high at extraction beam energies.

The collimation of partially stripped ions relies on the charge state change using a stripping foil. The stripped ions are then deflected by two warm quadruples in the slow extraction area of SIS100 towards the absorbers. The performance of the collimation system depends almost only on the stripping efficiency of the foil. The 0.5 mm thick titanium foil was found to be optimal for collimation of partially stripped ions in SIS100. The charge state of all considered primary ions (from $^{238}U^{28+}$ to $^{20}Ne^{5+}$) is changed using the foil sufficiently for required collimation performance. The particle tracking simulations then showed that the stripped ions are properly deflected and then intercepted by the absorbers.

5.2. Beam halo collimation in transport lines

Beam collimation is an important topic for SPARC, CBM and NUSTAR experiments:

- SPARC in APPA cave requests very small beam spot. Additional difficulties for design of a SPARC collimation system are beam parallelism and high energy (up to 10 GeV/u) requirements. F. Hagenbuck and A. Bräuning-Demian are the responsible persons to work-out a solution within dedicated working group.

- CBM and NUSTAR experiments require a halo-free beam. CBM beam line includes now a collimation system in HEBT in front of the cave. For NUSTAR the percentage of the halo has to be clarified (O. Geithner, H. Weick, S. Ratschow and D. Ondreka).

5.3. Beam aborting system (input experiments)

During the HIC4FAIR workshop, the BIOMAT, NUSTAR, CBM/HADES and related physics communities expressed their interest that SIS100 shall also provide a 'spill-abort feature' for slowly extracted beams in order to precisely control the total dose impacting on a given target and cycle. This functionality has been previously extensively used as part of SIS18's 'therapy' mode of operation for bio-medical applications. Re-purposing and using the SIS100 emergency dump may not be viable option for regular operation, since this particular dump may not be able to repeatedly absorb near-nominal intensities due to potential heating and activation issues (i.e. dump should be used max. ~5 times a day [info: C. Omet]). The request is a new machine design criteria from an accelerator point of view, and as such need to be evaluated and discussed with the concerned experimental community in more detail (e.g. detailed requirements, constraints, procedure, reliability, activation of components, etc.).

In addition to a wide range of (typically low-intensity) rare isotope beams, FAIR will also provide high-intensity and high-energy primary beams that may – either 'by design' or 'by accident' – be extracted to the experimental areas and that may potentially damage sensitive equipment intercepting these beams. Each experiment should thus – in their own self-interest (investment protection) – perform an evaluation of the required level of equipment protection (FMECA: Failure Mode, Effects, and Criticality Analysis), and in case these equipment cannot be passively protected against such failures, gather the required information necessary to group and connect the experiment to the fast-beam-abort system.

Online information of the delivered beam quality as observed by the experiment's detectors would be very valuable for operation and tuning of the primary beam parameters inside the accelerator as well as the extracted beam, for which the standard non-invasive accelerator-based beam diagnostic system can often provide only a limited quantitative estimate of the beam parameters.
The information should be ideally provided in real-time or on a cycle-to-cycle basis, and preferably use common accelerator controls interfaces (i.e. FESA) to ease their integration into day-to-day operation.
The type of information (figure of merit, micro-spill structure, emittance, beam position on target, etc.) should be standardized as much as reasonably possible across the different experiments to ease comparison and to limit the amount of required specialised software interfaces.
The FAIR Commissioning and Control Working Group (FC^{2}WG) provides the platform to discuss these machine-experiment controls interface details (link: https://fair-wiki.gsi.de/FC2WG).

5.4. Risk analysis for FAIR machines

A detailed risk analysis for the operation of SIS100 machine was presented. There is a legal necessity for such assessment (§§ 5, 6 German Occupational Safety and Health Act, § 3 German Ordinance on Industrial Safety, § 6 German Ordinance on Hazardous Substances, §§ 89, 90 Works Constitution Act). Possible risk sources were identified and the correspondent mitigation measures were proposed. As an outcome of the presented work, expected machine availability (SIS100) was estimated to be 66%. The availability of SIS18 has to be determined too and will reduce the value further. Similar analysis shall be done for all FAIR machines in the future to serve the German Law and help to establish a realistic concept for FAIR operation.

5.5. Beam dump in the experiment caves

Beam dumps in experimental caves are still open topic and belong to the FAIR ACC subproject. Nevertheless, the experiment collaborations are responsible to define the contact persons (work package lead = WPL) for their caves. The correspondent WPL will take care of technical concept, schedule and cost estimates for cave dumps. GSI has expertise for concept and design of the dumps in Super-FRS (beam catcher behind the primary target, H. Weick) and p-bar (K. Knie) departments.

6. True parallel operation

6.1. Low interference between experiments

Interferences between experiments affecting the quality of the primary beam and particle spill structure are known effects, and have already been observed at SIS18 and ESR in particular for experiments with significantly different magnetic rigidity requirements. These effects are partially mitigated by the new LSA-based accelerator control system which can modify existing cycles by adding, for example, 'chimneys' at the end of each cycle or by adding dedicated preconditioning cycles that improve the hysteresis by defining a known fixed magnetization prior to a potentially cross-talk sensitive experiment cycle. However, while these techniques enable a more flexible pairing of any experiments, they also reduce facility's duty cycle as an inevitable drawback.

Another important source for inter-experiment interferences beyond these magnetic hysteresis effects are the limited HEST and planned HEBT beam transfer line beam diagnostic. Due to cost minimization reasons, these systems have been stripped down to an absolute necessary minimum to operate the facility and need to rely largely on invasive beam measurement techniques, needed for the setup of low-intensity beams. However, the latter limit the setup or tuning of new – in particularly high intensity – beams in parallel to other experiments (e.g. for anti-proton production, plasma physics, etc.). In view of these limitations, the present FAIR operation strategy targets thus

- a quasi-periodic cycle operation that minimizes major beam pattern changes by design (e.g. beam time schedule being optimized for synchronized beam and experiment changes).
- to minimize the known overhead costs of changing between experiment combinations through putting more emphasis on deploying semi-automatic (beam-based) tools and procedures that aid operators during day-to-day operation (e.g. beam-based feedbacks, sequencer, etc.).

However, even while mitigating some of the issues, these measures cannot fully remove the overhead costs of parallel operation. Thus, as a recommendation, future upgrades should tackle existing bottlenecks in the transfer line diagnostic through adding more non-invasive beam instrumentation in these sections of the machine (e.g. ionization profile monitors, new electro-optics BPMs capable of measuring slow extracted un-bunched beam, etc.).

6.2. Transfer line between SIS18 and HESR

HESR is the 5th (6th, assuming future FAIR upgrades with RESR) accelerator of a rather long beam production chain that has been originally designed primarily for p-bar accumulation, cooling and in-ring collisions.

An important consequence of the chain's length is the large complexity and consequently required high availability of the preceding FAIR accelerators to achieve the required availability of HESR for physics.

A dedicated beam line has been already foreseen to reduce the complexity and dependence on the other to be commissioned accelerators during early commissioning. This transfer line would also simplify, speed-up and allow commissioning of HESR with primary beams in case anti-protons are yet not available or only with insufficient intensities. However, this transfer line is not part of the early MSV0-3 and would also not be able to support a rare isotope beam (RIB) -based physics programme at HESR which in recent years received an increased interest and importance from FAIR's physics community. An additional beam-line between SIS18 and HESR (via FRS and/or ESR) has been proposed as an upgrade option after the MSV has been realized [B. Franzke, S. Ratschow et al.]. This new transfer line would open up additional parallel operation scenarios through

- improving the exploitation of the existing GSI facility and its existing capabilities (e.g. RIBs production via FRS),
- breaking-up and reducing the complexity of the accelerator chain to HESR,
- providing a beneficial redundancy and back-up option for HESR's RIB physics programme in case SIS100, Super-FRS, or CR are being blocked and used by other physics experiments, or unavailable due to maintenance or repairs, etc.

The proposal is a new FAIR design criteria, and as such need to be evaluated and discussed with the concerned accelerator and experimental community in more detail.

6.3. Stretcher ring

In addition to interleaving experiments and time-sharing of a given accelerator, the Modularised Start Version (MSV0-3) of FAIR can already serve two experiments at the same time (true parallelism) with, for example, slowly extracted beam out of SIS18 and SIS100 (e.g. APPA & Super-FRS, Super-FRS & CBM, APPA&CBM). This mode of operation's main constraints are the maximum rigidity and maximum intensity that can be achieved per spill which is less for SIS18 compared to those achievable by SIS100.
An additional stretcher ring after SIS100 – if needed and requested – would allow alleviating these limitations, upgrading FAIR's MSV parallel operation capabilities, and enable the possibility to provide slowly extracted beams with similar beam rigidity and intensity to both Super-FRS and CBM at the same time, for example. This would increase the duty factor of the facility by a factor of up to two.

The necessity and required cost-benefit analysis of such a new machine needs to be further discussed in detail and depends strongly on the required beam parameters (e.g. 'fixed energy' vs. 'extraction energies beyond SIS100').

7. Miscellaneous

7.1. SPARC stripper

SPARC Collaboration in APPA cave and HESR require a beam stripper with several foils for production of different charge states of the projectiles. Presently a stripper in HEBT behind SIS18 was designed with a single foil. The place, foreseen for the stripper in HEBT, is not suitable for the larger stripper (to handle several foils). F. Hagenbuck and A. Bräuning-Demian are the responsible persons to work-out a solution within dedicated working group.

7.2. EXL experiment in HESR

EXL is an in-ring experiment to investigate exotic nuclei by light-ion scattering in inverse kinematics at the storage ring using stored radioactive-ion beams and a gas-jet target. A pilot experiment has been successfully conducted recently at the present ESR. In view of the fact, that the NESR is not part of the MSV, the collaboration has discussed the operation of EXL at the ESR, provided an additional beam line would allow transport of radioactive beams from the S-FRS to the ESR. It has been discussed at the workshop, that the use of the HESR could be potentially an alternative; at least it should be considered as an additional option. In particular, the fact that the HESR allows re-acceleration and storage of high-energy ions up to about 5 GeV/nucleon will open new physics opportunities beyond the current EXL physics programme, which cannot be realized otherwise at FAIR, and also not worldwide. A large and unique physics potential, as has been pointed out by Aumann during the workshop, would emerge for instance for heavy-ion induced electromagnetic excitation as well as proton-induced knockout reactions at very large momentum transfer. The former process would allow the extraction of the dipole response of nuclei up to high excitation energies due to the hard photon spectrums seen by the 5 GeV/nucleon beams when passing heavier target nuclei like, for instance, provided by a Xe gas-jet target. Large-momentum-transfer knockout reactions induced by 6 GeV/c protons could be used to investigate the role of short-range tensor correlations in exotic nuclei as a function of neutron-to-proton asymmetry. The development and the prototyping of the EXL detector systems, so far, have not taken into account reactions at such energies. The necessary adaptions and their compatibility (mechanics, UHV ...) with the HESR have to be studied.

During the discussions the following technical challenges have been identified:

- The re-acceleration of ions to 5 GeV/nucleon is too slow in the present layout to be used with radioactive ions; additional RF cavities and modified dipole power supplies would be required.
- In order to cover also the physics cases of EXL at lower beam energies, an efficient cooling system is required while deceleration; this would imply the need for an additional electron-cooling system.
- The vacuum conditions in the HESR have to be carefully considered and beam life time as a function of beam energy has to be studied.
- It seems that geometrical space would be available along a long straight section, which would provide in addition space for neutron detection around zero degree at about 10 to 15 m from the target. Heavy fragments could be analysed after the first arc after the straight section using additional detection systems.

In the ideal case, the HESR should provide also the option to use the EXL detector at lower beam energies, in order to avoid the need of re-building this large and complex device at different target areas[2]. This would imply the need for good vacuum, fast deceleration, and an electron cooler. However, it has to be emphasised that an important part of the EXL physics programme requires low-energy beams at energies even below 100 MeV/nucleon which are too low for the minimum rigidity at which the HESR can be operated and therefore need the ESR. The subject will be discussed further in the collaboration in close contact with the HESR experts.

7.3. Beam transport HEST

The maximum available production rate of 400k π/spill (@ $9*10^{11}$ N_2/spill) couldn't be reached during the last beam time in 2014 for the HADES experiment. The intensity of the primary beam had to be decreased due to the high radiation level in NE5 (HEST), SIS18 and adjacent areas. After 40 days of operation with high current nitrogen beam around 90% of the total annual dose in TK and EX halls has been reached. Several possible causes have been discussed, i.e. halo particles produced in the SIS by diffusion processes or scattered particles created at the wires of the electrostatic extraction septum.

A new upgrade program for the HEST aims the beam losses reduction in the transfer line between SIS18 and the pion production target. Several additional beam diagnostic devices are in course of preparation, i.e. a Secondary-Electron Transmission Monitor SEETRAM with thin foils for online transmission measurement. BLMs at the expected hotspots will be used for online beam loss measurements. An upgrade of the fluorescence screens with an additional special halo screen to allow detection of halo particles and beam misalignment. This screen will be tested in the beam time 2016.

An optimization of the beamline aperture is foreseen with replacement of the several vacuum chambers during the upcoming shutdown (2015-2016). A new dipole chamber of TE3MU1 with an increased vertical aperture of 10% and larger sized vacuum chambers in the quadrupole doublet in front of the production target are in planning. A modification of the beryllium targets are scheduled together with the opening of the pion target next year. Moreover, an additional concrete shielding at the pion production target is planned.

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[2] It shall be generally clarified if there is space in HESR beam line, which could be constantly available for the EXL detectors. If not, they have to be dissembled every time during APPA or PANDA measurements.