Status of the FAIR Project
Upgrade of the GSI Accelerator Facilities and Construction of FAIR

Peter Spiller

GSI-Helmholtzzentrum für Schwerionenforschung
Start and Progress of FAIR Civil Construction

- Contract signed for site preparation area North. Excavation, retaining walls, ground water lowering etc.
- Contracts signed for building shell construction area North. Start of SIS100 tunnel construction: June 2018.
- Contract signed for site logistics.
- Contract signed for cranes and elevators.

July 4th 2017 Official Ground Breaking Ceremony

Excavation of SIS100 tunnel. Present depth: -16 m
CIVIL CONSTRUCTION SITE OF FAIR
STATUS FEBRUARY 2018

FACILITY FOR ANTIPROTON AND ION RESEARCH IN EUROPE GMBH
DARMSTADT, GERMANY
Accelerator Topology of GSI and FAIR

FAIR is the big brother of GSI. The Concept of the Facility Topology is Identical

- High Intensity Primary Beams (all ions)
- Production Targets
- Separators
- Cooled Secondary Beams (pbar, RIB)
- Fixed targets

(*) Subproject leadership of CR and HESR transferred to BINP and FZJ. Subproject execution conducted with big success.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Beam Intensity</td>
<td>x 500-1000</td>
</tr>
<tr>
<td>Secondary Beam Intensity</td>
<td>x 10 000</td>
</tr>
<tr>
<td>Heavy Ion Beam Energy</td>
<td>x 30</td>
</tr>
<tr>
<td>Cooled pbar Beams</td>
<td></td>
</tr>
<tr>
<td>Parallel operation</td>
<td></td>
</tr>
</tbody>
</table>
RIB Generation, Debunching and Cooling

Matching primary beam to production target and storage ring

Short SIS 100 bunches:
- target matching
- RIB/pbar pre-cooling
  - $dp/p = \pm 0.1\%$

60 ns

Collector Ring (CR)
- circumference 212 m
- rigidity 13 Tm

CR ring properties:

<table>
<thead>
<tr>
<th>RIB</th>
<th>pbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>energy</td>
<td>740 MeV/u</td>
</tr>
<tr>
<td>mom. accept.</td>
<td>$\pm 1.5%$</td>
</tr>
<tr>
<td>trans. accept.</td>
<td>$200\times10^{-6}$ m</td>
</tr>
<tr>
<td>Cooling down time</td>
<td>1.5 s</td>
</tr>
</tbody>
</table>

RF voltage in the CR: 200 kV (1.5 MHz)

- bunch rotation
- adiabatic debunching

0.1 ms duration

after bunch rotation and debunching in CR
## Reference Primary Beam Parameters

### SIS18

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Protons</th>
<th>Uranium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of ions per cycle</td>
<td>$5 \times 10^{12}$ (x50)</td>
<td>$1.5 \times 10^{11}$ (x100)</td>
</tr>
<tr>
<td>Inc. s.c. tune spread</td>
<td>-0.5</td>
<td>-0.5</td>
</tr>
<tr>
<td>Initial beam energy</td>
<td>70 MeV</td>
<td>11 MeV/u</td>
</tr>
<tr>
<td>Ramp rate</td>
<td>10 T/s</td>
<td>10 T/s</td>
</tr>
<tr>
<td>Final beam energy</td>
<td>4.5 GeV</td>
<td>200 MeV/u</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>2.7 Hz (x3)</td>
<td>2.7 Hz (x3)</td>
</tr>
</tbody>
</table>

### SIS100

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Protons</th>
<th>Uranium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of injections</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Number of ions per cycle</td>
<td>$2.5 \times 10^{13}$</td>
<td>$5 \times 10^{11}$</td>
</tr>
<tr>
<td>Inc. s.c. tune spread</td>
<td>-0.2</td>
<td>-0.3</td>
</tr>
<tr>
<td>Maximum Energy</td>
<td>29 GeV</td>
<td>2.7 GeV/u</td>
</tr>
<tr>
<td>Ramp rate</td>
<td>4 T/s</td>
<td>4 T/s</td>
</tr>
<tr>
<td>Beam pulse length after compression</td>
<td>50 ns</td>
<td>90 - 30 ns</td>
</tr>
<tr>
<td>Extraction mode</td>
<td>Fast and slow</td>
<td>Fast and slow</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>0.7 Hz</td>
<td>0.7 Hz</td>
</tr>
</tbody>
</table>

- FAIR peak intensity goals can only be reached by lowering the projectile charge states
- Incoherent space charge tune shift limits the maximum intensity in SIS18: $-dQ \propto Z^2/A$
- Poststripper charge states will be used (e.g.: $Ar^{18+} > Ar^{10+} \ldots\ldots\ldots U^{73+} > U^{28+}$)
- Without stripping loss (charge spectrum) significantly enhanced particle current ($N_{uranium} \times 7$)!
### Intermediate Charge State Heavy Ions

Existing and planned Heavy Ion Accelerators operated with Low Charge States worldwide

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Location</th>
<th>Charge State</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGS Booster</td>
<td>BNL, USA</td>
<td>Au$^{31+}$</td>
<td>5x10^9</td>
</tr>
<tr>
<td>LEIR</td>
<td>CERN</td>
<td>Pb$^{54+}$</td>
<td>1x10^9</td>
</tr>
<tr>
<td>NICA Booster</td>
<td>JINR; Russia</td>
<td>Au$^{32+}$</td>
<td>4x10^9</td>
</tr>
<tr>
<td>SIS18</td>
<td>GSI/FAIR, Germany</td>
<td>U$^{28+}$</td>
<td>1.5x10^{11}</td>
</tr>
<tr>
<td>SIS100</td>
<td>FAIR, Germany</td>
<td>U$^{28+}$</td>
<td>5x10^{11}</td>
</tr>
<tr>
<td>B Ring</td>
<td>HIAF, China</td>
<td>U$^{34+}$</td>
<td>1x10^{11}</td>
</tr>
</tbody>
</table>

Key Issue Dynamic Vacuum: SIS18 served as a pilot facility for the development of
- new accelerator concepts
- new accelerator technologies and
- understanding and benchmarking

... to overcome **Vacuum Instabilities and Ionization Beam Loss** at high intensity heavy ion operation.

**Ionization Beam Loss and Dynamic Vacuum** determine the system design and the accelerator technologies of SIS18 and SIS100 and generate the biggest challenges with respect to beam loss.
Key Technologies for SIS18 and SIS100: Dynamic Vacuum and Charge Exchange

The Dominating Intensity Limitation for Heavy Ion Beams in Synchrotrons is the Interaction with the Residual Gas and thereby generated Charge State Changes. Due to Desorption Processes at High Beam Intensities the Static Residual Gas Pressure becomes the so called Dynamic Vacuum. Ionization in the Dynamic Vacuum is the dominating beam loss mechanism which appears much below the space charge limit.

Ionisation loss drives pressure bumps which itself accelerates the ionisation process.

> Dynamic vacuum instability

Simulations
STRAHLSIM: Unique code for dynamic vacuum and charge exchange driven beam loss in time and space comprising:
- Machine optics and collimation system
- Atomic cross sections for charge exchange (energy dependend, projectil- and target dependend etc.)
- Properties of pumping system (conventional, crogenic, NEG. local distributed etc.)
- Ion induced gas desorption processes
- Realistic machine cycles

New Technologies
- New synchrotron optics: Charge separator lattice (peaked distribution of ionizaton loss)
- NEG coating (distributed pumping)
- Low desorption surfaces and materials
- Ion catcher systems - room temperature and cryogenic
- Cryogenic (actively cooled) magnet chambers (distributed pumping)
- Cryo-adsorption pumps
SIS18 Upgrade Program 2005 – 2013
Implementation of New Key Technologies

The upgrade program is dedicated to intermediate charge state heavy ion operation for FAIR.
SIS18 Upgrade Program 2013 – 2018
Implementation of New Key Technologies

The upgrade program is dedicated to intermediate charge state heavy ion operation for FAIR

Three new MA acceleration cavities installed (50 kV, h=2) and power converters

Replacement of main dipole power converter (for 10 T/s, 50 MW)

In the past, the EU has supported the upgrade program as an investment in a major European Research Infrastructure.

SIS18/SIS100 IPM magnet system manufactured and delivered

Bipolar dipole magnet and power converter for the connection of transfer line to SIS100

The originally defined SIS18 upgrade program will be completed in 2018.
World record intensity for intermediate charge state heavy ions in heavy ion booster.

The feasibility of high intensities with intermediate charge state heavy ions has been demonstrated. world record

At SIS100 commissioning:
An intensity of $U^{28+}$-beams of $1-2 \times 10^{11}$ per cycle is safe (rep. rate about 0.5 Hz)

Further upgrade measures are investigated for reaching the intensity goal for the most heavy ions (e.g. Uranium with $1.5 \times 10^{11}$ per cycle at a (high) repetition rate of 2.7 Hz.)
Preparation of the Existing Accelerator Tunnels and Buildings for FAIR
SIS18 Civil Construction GAF and WTK

GAF (Gebäude Anbindung FAIR):

- **Shielding enhancement** on top of the existing SIS18 tunnel and at other locations for fast cycled operation with 5x10^{12} Protons per Second. (3% Proton beam loss at final energy)

- **Radioactive air management** system
- **Fire prevention system** (nitrogen venting)
- **Interface** to the FAIR tunnel 101
- An inner and outer **reinforcement wall**
- **Power link** of main operation building to new transformer station North

WTK (Westwand Transfer Kanal)

- **Beam dump** for the proton linac on the western side of the transfer channel (TK)
- Shielding enhancement of the TK eastern wall and interface for an early construction of the p-linac building

All works will be completed until May 2018.
Status GAF and WTK Project

New transformer station North completed. (pulse power SIS18 and SIS100).

Reinforcement of SIS18 roof and new technical operation building TG1 completed.

Interface for FAIR tunnel 101 completed.

Interface for new Proton linac completed.
Progress in Subproject P-Linac
New main injector for pbar-Program

Close collaboration in development of Rf linac structures with IAP (institute for applied physics) in Frankfurt/M. Since the p-Linac will be connected to the GSI campus media infrastructure, it will be the first FAIR accelerator commissioned.

Status and Step towards Installation

- Proton source at CEA, Saclay:
  Based on IPHI sourced design.
  Peak Proton beam 60 mA extracted.

- Successful test of prototype ladder RFQ
- Manufacturing of vacuum chamber for ladder RFQ at IAP completed.

- 2018: Low level, tuning and high power tests at Rf test stand at IAP.

- Successful test of prototyp CH cavity
- Q4 2017: Design freeze at IAP for CH structures

- Installation of ion source and ladder RFQ in final building until Q4 2020

> Commissioning with beam
Key Technologies

GSI has a world wide leadership in **fast ramped** superconducting magnets

1. **R&D on fast ramped superconducting, window-frame magnets for SIS100**
   4 T/s up to 1.9 T

   R&D goals:
   1. Reduction of eddy/persistant current effects at 4 K
      (at most in iron yoke)
   2. Optimization of field quality
   3. Long term mechanical stability for (>2·10^8 cycles)

   ![Optimization of Nuclotron Cable](image)
   - Insulation concepts
   - Winding technologies
   - ANSYS models etc.

   ![AC loss reduction 40 W>15W](image)

   SIS100 Prototype Dipole

2. **R&D on fast ramped, superconducting costheta magnets for SIS300 and others**
   1 T/s up to 4.5 T (world record ramp rate)

   R&D goals:
   1. Reduction of AC loss by improved cable and coil design
   2. Optimize conductor cooling (e.g. laser cutted cable)

   ![Optimization of Rutherford Cable](image)
   - Reduced filament twist pitch
   - Strand coating
   - Stainless steel core

   ![Fast ramped SIS300 Dipole in Cryostat](image)
Key Technologies

GSI builds the fastest superconducting synchrotrons with full flexibility in cycling

Control of Magnet Cooling at Different Heat Loads:
- Single layer magnet coil with low hydraulic resistance
- High current Nuclotron cable
- Hydraulically adjusted magnet cooling circuits
- Active heaters to stabilize the crogenic load
- Variable supply LH He supply pressure
- LH He pumps

Alternative coil design and high current cable

Table II: Operation Cycles and Expected Losses

<table>
<thead>
<tr>
<th>Cycle</th>
<th>$B_{max}$ (T)</th>
<th>$t_1$ (s)</th>
<th>$t_2$ (s)</th>
<th>Cycle Period (s)</th>
<th>$Q_1$ (J/cycle)</th>
<th>$P_s$ (W)</th>
<th>$Q_x$ (J/cycle)</th>
<th>$P_t$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2</td>
<td>0.1</td>
<td>1.4</td>
<td>3.5</td>
<td>35.2</td>
<td>25.2</td>
<td>13.1</td>
<td>9.4</td>
</tr>
<tr>
<td>2a</td>
<td>1.2</td>
<td>0.1</td>
<td>1.4</td>
<td>3.5</td>
<td>35.2</td>
<td>25.2</td>
<td>13.1</td>
<td>9.4</td>
</tr>
<tr>
<td>2b</td>
<td>0.5</td>
<td>0.1</td>
<td>1.0</td>
<td>3.8</td>
<td>8.8</td>
<td>8.8</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>2c</td>
<td>2.0</td>
<td>0.1</td>
<td>1.82</td>
<td>3.8</td>
<td>89</td>
<td>48.9</td>
<td>24.4</td>
<td>18.9</td>
</tr>
<tr>
<td>3a</td>
<td>1.2</td>
<td>1.3</td>
<td>2.6</td>
<td>3.8</td>
<td>13.5</td>
<td>13.1</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>3b</td>
<td>0.5</td>
<td>1.0</td>
<td>1.9</td>
<td>3.8</td>
<td>8.8</td>
<td>4.6</td>
<td>3.3</td>
<td>1.8</td>
</tr>
<tr>
<td>3c</td>
<td>2.0</td>
<td>1.7</td>
<td>3.4</td>
<td>3.8</td>
<td>89</td>
<td>26.2</td>
<td>34.4</td>
<td>10.1</td>
</tr>
<tr>
<td>4</td>
<td>2.0</td>
<td>0.1</td>
<td>5.0</td>
<td>3.8</td>
<td>89</td>
<td>17.8</td>
<td>34.4</td>
<td>6.9</td>
</tr>
<tr>
<td>5</td>
<td>2.0</td>
<td>0.1</td>
<td>5.0</td>
<td>3.8</td>
<td>89</td>
<td>17.8</td>
<td>34.4</td>
<td>6.9</td>
</tr>
</tbody>
</table>
Key Technologies

GSI has unique expertise in inductively (e.g. MA) loaded cavities

<table>
<thead>
<tr>
<th>SIS100 Acceleration Cavities</th>
<th>$V_{0,\text{total peak}}$</th>
<th>$f$ [MHz]</th>
<th>#</th>
<th>Status</th>
<th>Technical Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 kV</td>
<td>1.1–2.7</td>
<td>20</td>
<td>FOS</td>
<td>Ferrit ring core, &quot;narrow&quot; band cavities. Fast tuning</td>
<td></td>
</tr>
<tr>
<td>SIS100 Compression Cavities</td>
<td>640 kV</td>
<td>0.395–0.485</td>
<td>16</td>
<td>FOS + Series</td>
<td>Magnetic alloy ring core, broad band cavities. Slow tuning</td>
</tr>
<tr>
<td>SIS100 Barrier Bucket Cavities</td>
<td>2*15 kV</td>
<td>1.5MHz (barrier) 110-270kHz (repetition)</td>
<td>2</td>
<td>Spec</td>
<td>Magnetic alloy ring core, very broad band (low duty cycle) cavities. No tuning</td>
</tr>
<tr>
<td>SIS100 Longitudinal Feed-Back Cavities</td>
<td>10 kV</td>
<td>0.7-5.0 (3db BW)</td>
<td>2</td>
<td>Spec</td>
<td>Magnetic alloy ring core, very broad band (low duty cycle) cavities. No tuning</td>
</tr>
<tr>
<td>CR Debuncher Cavities</td>
<td>200kV</td>
<td>1.1-1.5</td>
<td>5</td>
<td>FOS + series</td>
<td>Magnetic alloy ring core, broad band cavities (pulsed and CW operation). Slow tuning</td>
</tr>
<tr>
<td>SIS18 h=4 Acceleration Cavities</td>
<td>30 kV</td>
<td>0.8-5.4</td>
<td>2</td>
<td>Running</td>
<td>Ferrit ring core, &quot;narrow&quot; band cavities. Fast tuning</td>
</tr>
<tr>
<td>SIS18 h=2 Acceleration Cavities</td>
<td>48 kV</td>
<td>0.4-2.8</td>
<td>3</td>
<td>Running</td>
<td>Magnetic alloy ring core, very broad band (low duty cycle) cavities. No tuning</td>
</tr>
<tr>
<td>SIS18 Bunch Compression Cavities</td>
<td>40 kV</td>
<td>0.8-1.1</td>
<td>1</td>
<td>Running</td>
<td>Magnetic alloy ring core, broad band cavities. Slow tuning</td>
</tr>
</tbody>
</table>

GSI is continuously surveying the available nanocrystalline (Fe-base) and amorphous (Co-based) magnetic alloys on the world market (Vitrovac, Vitroperm, Finemet etc.)
Heavy Ion Synchrotron SIS100 – Unique Features

SIS100 is a world wide unique synchrotron designed and optimized for the generation of high intensity heavy ion beams.

- It has a **flexible lattice structure**, enabling different optical settings for different user modes.
- It has a lattice cell (charge separator lattice) with an optimized design for the control of beam loss by ionization at highest intensities of Uranium beams.
- It has a unique and **extreme XHV system**, making extensive use of cryo-pumping to suppress vacuum instabilities at highest heavy ion intensities.
- It is a **fast ramped superconducting** synchrotron with ramp rates up to 4 T/s and a minimum cycle time of less than 1 second.
- It is equipped with **powerful Rf systems** for acceleration, compression, generation of barrier buckets and buckets for longitudinal stabilization.
- It provides **different extraction modes** for fixed target experiments and optimal time structures for matching to production targets and storage rings.
- Its cryogenics system is designed to **control of a dynamic heat load** of up to 75% (3.4 kW <> 14.7 kW) with big difference from cycle to cycle in a parallel operation of multiple users.
SIS100 Procurement Highlights

Fast ramped (4 T/s) s.c. dipole magnets
Series production started. 21 modules delivered.

Series production of bunch compression
and acceleration cavities started.

First cryogenic bypass line with integrated bus
bar system shipped and tested

All main magnets, all main Rf and all
injection devices under contract. 50 %
of procurement milestones achieved. 65
% of SIS100 value under contract.
World Wide Testing Infrastructure for the Series of Superconducting Magnets

GSI: Series test facility for the SIS100 s.c. dipole magnets, string test, current leads and local cryogenics components.

CERN: Test facility completed for the Super-FRS s.c. dipoles and multiplatelets

INFN: Test facility in Salerno for testing the series of SIS100 quadrupole modules

JINR, Series test facility in Dubna for testing of the series of SIS100 s.c. quadrupole units
Advantage of high projectile energy:
Clean mass/isotope separation without charge state contamination

Features of Super-FSR
The most powerful in-flight separator for exotic Nuclei world wide

<table>
<thead>
<tr>
<th>Facility</th>
<th>Max. Magnetic Rigidity ( B_{\text{pmax}} / [\text{Tm}] )</th>
<th>Momentum Acceptance ( \Delta p/p )</th>
<th>Angular Acceptance ( \phi_x / [\text{mrad}] )</th>
<th>Angular Acceptance ( \phi_y / [\text{mrad}] )</th>
<th>Momentum Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRS</td>
<td>18</td>
<td>( \pm 1 % )</td>
<td>( \pm 7.5 )</td>
<td>( \pm 7.5 )</td>
<td>1500 ((\varepsilon=20\pi \text{ mm mrad}))</td>
</tr>
<tr>
<td>Super-FRS</td>
<td>20</td>
<td>( \pm 2.5 % )</td>
<td>( \pm 40 )</td>
<td>( \pm 20 )</td>
<td>1500 ((\varepsilon=40\pi \text{ mm mrad}))</td>
</tr>
</tbody>
</table>

High projectile energy and multiple separator stages to efficiently reduce the background from contaminations

High primary rate requires two stage separation
Pre-Separator
Main-Separator

Separation of uranium fission fragments with the two degrader stages of the Super-FRS \((1.1 \text{ A GeV }^{238}\text{U on 4 g/cm}^2 \text{ C target})\)

10^{11}/s 1/d

Advantage of high projectile energy:
Clean mass/isotope separation without charge state contamination

Large Acceptance and Increased Transmission of Fission Products.
Procurement Highlights of the Super-FRS

Large aperture radiation hard normal conducting and superconducting magnets

S.c multiplets awarded.
FOS short multiplett in assembly.

Prototype superferric dipole magnet. Redesign completed by CEA.
Contract awarded for series production.
Key Technologies

GSI/FAIR makes extensive use of powerful ion beam cooling techniques

<table>
<thead>
<tr>
<th>Stochastic Cooling</th>
<th>Ion energy</th>
<th>Frequency band width</th>
<th>Microwave power</th>
<th>Pick-up and kicker Electrodes</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR stochastic cooling system</td>
<td>Ions: 740 MeV/u</td>
<td>1 - 2 GHz</td>
<td>8 kW</td>
<td>Plunging: ±80 mm (at 30 K)/ Slotline (at 300 K), no plunging, ±70 mm</td>
<td>dp/p&lt; ± 1 % (pbar) dp/p&lt; ± 0.5 % (ions) ε&lt; 240 π mm mrad</td>
</tr>
<tr>
<td></td>
<td>Antiprotons: 3 GeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HESR stochastic cooling system</td>
<td>Antiprotons (and heavy ions)</td>
<td>2 - 4 GHz</td>
<td>3x 0.6 kW (long) 3x 0.32 kW (trans)</td>
<td>Slot-ring couplers (at 20 K)/ Slot ring</td>
<td>dp/p&lt; 10⁻³ ε&lt; 5 π mm mrad</td>
</tr>
<tr>
<td></td>
<td>1.5 – 15 GeV/c</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESR stochastic cooling system</td>
<td>Ions</td>
<td>0.9 – 1.7 GHz</td>
<td>2 kW (total)</td>
<td>Quarter wave structure, no plunging</td>
<td>dp/p&lt; ±0.35 % ε&lt; ± 20 π mm mrad</td>
</tr>
<tr>
<td></td>
<td>400 - 550 MeV/u</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electron Cooling (at GSI)</th>
<th>Ion energy</th>
<th>Maximum electron current</th>
<th>Cathode diameter</th>
<th>Magnetic field in cooling section</th>
<th>Effective length of cooling section</th>
<th>Magnetic expansion factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIS18 electron cooling system</td>
<td>Ions: &lt; 60 MeV/u</td>
<td>1.5 A</td>
<td>25.4 mm</td>
<td>0.03 – 0.15 T</td>
<td>1.8 m</td>
<td>1 to 8</td>
</tr>
<tr>
<td>ESR electron cooling system</td>
<td>Ions: 3 - 430 MeV/u</td>
<td>2 A</td>
<td>50.8 mm</td>
<td>0.01 – 0.2 T</td>
<td>2.8 m</td>
<td>No magnetic expansion</td>
</tr>
<tr>
<td>CRYRING electron cooling system</td>
<td>Ions: ~ 100keV/u – 10MeV/u</td>
<td>3 A, typical 110mA</td>
<td>4 mm</td>
<td>0.01 – 0.3 T</td>
<td>1.1 m</td>
<td>10 - 100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Laser cooling</th>
<th>Ion energy</th>
<th>Ion species (e.g. Li-like ions)</th>
<th>Laser power</th>
<th>Laser repetition rate</th>
<th>Effective length of cooling section</th>
<th>Final δp/p and cooling time (calc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIS100 laser cooling (R&amp;D)</td>
<td>up to 10 GeV/u</td>
<td>Up to Z=60</td>
<td>200 mW in the UV</td>
<td>up to 10 MHz</td>
<td>20 m</td>
<td>Down to 10⁻⁷ in one second</td>
</tr>
</tbody>
</table>
Status and GSIs Role in CR (Collector Ring and HESR (High Energy Storage Ring))

The subproject leadership for CR has been transferred to BINP. The suproject leader for HESR is FZJ.

GSI’s general involvement:
- Overall project management
- Definition of technical standards
- Approval of technical specifications
- DMU and integration into building
- Set-value generation
- Interfaces to controls and beam instrumentation

CR-Collector Ring
- All technical specifications and DMU available.
- Collaboration contract for dipole design and manufacturing signed with BINP.
- Contract for manufacturing of all other components (beside Rf and cooling) in preparation.
- Debuncher cavities (German inkind) delivered and accepted. Series production released.
- Stochastic cooling tank, pick-ups and amplifiers under development at GSI (German inkind).

HESR-High Energy Storage Ring
All accelerator components will be produced until end of 2018!
- All dipole and quadrupole magnets manufactured.
- All quadrupol power converters manufactured.
- Sextupole magnets and steerers delivered by Romanian inkind provider.
- Prototype stochastic cooling system installed in COSY ring.
- Prototype barrier bucket cavity installed in COSY.
Summary

- FAIR area North: Civil construction launched and progressing fast
- SIS18 upgrade will be completed in 2018 in time for re-commissioning for FAIR phase 0.
- GAF/WTK civil construction will be completed 2018, including interface to p-linac
- SIS100 all contracts for large series signed. Series production started. Man items delivered, e.g. 20 superconducting dipole modules
- Procurements are progressing well for all FAIR accelerators.
- Manufacturing of HESR components will be completed end of 2018 (beside dipole p.c).
- p-Linac and pbar target: Re-launched for advanced installation and early commissioning.
- Installation in FAIR buildings and tunnels will start in 2021
- First beam from SIS100 earliest in 2023
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