Approaches to High Intensities for FAIR

Peter Spiller
on behalf of the GSI and FAIR project teams
GSI, Darmstadt

EPAC
February 26, 2006
New: Cooled pbar Beams (15 GeV)
Intense Cooled Radioactive Beams
Parallel Operation

Poster: D. Krämer
(FAIR division leader)
1. High Intensity- and Compressor Stage

SIS100 with fast-ramped superconducting magnets and a strong bunch compression system.

\[ B_\rho = 100 \text{ Tm} - B_{\text{max}} = 2 \text{ T} - \frac{dB}{dt} = 4 \text{ T/s} \]

Intermediate charge state ions e.g. U^{28+}-ions up to 2715 MeV/u
Protons up to 30 GeV

2. High Energy- and Stretcher Stage

SIS300 with superconducting high-field magnets and stretcher function.

\[ B_\rho = 300 \text{ Tm} - B_{\text{max}} = 6 \text{ T} - \frac{dB}{dt} = 1 \text{ T/s (short straight dipoles)} \]
\[ \text{or} \quad B_{\text{max}} = 4.5 \text{ T} - \frac{dB}{dt} = 1 \text{ T/s (long bent dipole)} \]

Highly charges ions e.g. U^{92+}-ions up to 34 GeV/u
Intermediate charge state ions U^{28+}- ions at 1.5 to 2.7 GeV/u with 100% duty cycle
SIS100 - Technical Subsystems

Talk Beam Stability and Impedances:
O. Boine-Frankenheim

S1: Transfer to SIS300
S2: Rf Compression
   (MA loaded)
S3: Rf Acceleration
   (Ferrite loaded)
S4: Rf Acceleration
   (Ferrite loaded)
S5: Extraction Systems
   (slow and fast)
S6: Injection System plus RF Acceleration and Barrier Bucket
Secondary Beams and Storage Rings

**RIB Physics**

- 1×10^{12} ions
- 50 ns bunch

**Pbar Physics**

- SIS 100
  - 2.5×10^{13} protons
  - 50 ns bunch

- Pbar-target
  - 1×10^{8} pbars per cycle at 3 GeV

**Atomic Physics**

- 1×10^{10} ions

**Super-FRS**

- max. 5×10^{9} RIBs per cycle at 740 MeV/u

**CR/RESS-Complex**

- Bunch rot., ad. debunching, stoch. precooling
- Fast deceleration to 200 - 400 MeV/u
- Accumulation of up to 5×10^{11} pbars

**NESR**

- Electron cooling, deceleration to E < 100 MeV/u, in-ring-experiments (gas-jet-target, e-A collisions, electron target), fast and slow extraction

Peter Spiller, EPAC06, Edinburg. 26.6.2006
Secondary Beams Storage Ring Complex

from Super- FRS and pbar-separator

to atomic physics cave, HITRAP, FLAIR

Collector Ring
bunch rotation
adiabatic debunching
fast stochastic cooling
isochronous mode

electron-
ucl. collider

RESR
pbar accumulation
fast RIB/pbar
deceleration

NESR
e⁻-cooling
deceleration
Secondary Beams: High Energy Storage Ring

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<tbody>
<tr>
<td>Circumference</td>
<td>574 m</td>
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<tr>
<td>Max. Rigidty</td>
<td>50 Tm</td>
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<tr>
<td>Bmax</td>
<td>4 T</td>
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<tr>
<td>High resolution (HR) mode:</td>
<td>E &lt; 8 GeV</td>
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<td></td>
<td>2·10^{31} cm^{-2}sec^{-1}</td>
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<td></td>
<td>dp/p = 10^{-5}</td>
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<tr>
<td></td>
<td>Magnetized electron cooling</td>
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<tr>
<td>High luminosity (HL) mode:</td>
<td>1.5 &lt; E &lt; 15 GeV</td>
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<tr>
<td></td>
<td>2·10^{32} cm^{-2}sec^{-1}</td>
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<tr>
<td></td>
<td>dp/p = 10^{-4}</td>
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<tr>
<td></td>
<td>Stochastic cooling (long. + transv.)</td>
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<td>Pellets</td>
<td>H₂, 20 000/s</td>
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</table>

HESR consortium: FZ Jülich, TSL, GSI

INTAS study group on beam cooling equilibrium

Peter Spiller, EPAC06, Edinburg. 26.6.2006
FAIR Project (staged planning)

Stage 1

Stage 2

Stage 3
## SIS18 - Requirements for FAIR

<table>
<thead>
<tr>
<th>Fair Stage</th>
<th>Today</th>
<th>0 (Existing Facility after upgrade)</th>
<th>1 (Existing Facility supplies Super FRS, CR, NESR)</th>
<th>2,3 (SIS100 Booster)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Ion</td>
<td>U^{73+}</td>
<td>U^{73+}</td>
<td>U^{73+}</td>
<td>U^{28+} (p)</td>
</tr>
<tr>
<td>Maximum Energy</td>
<td>1 GeV/u</td>
<td>1 GeV/u</td>
<td>1 GeV/u</td>
<td>0.2 GeV/u</td>
</tr>
<tr>
<td>Maximum Intensity</td>
<td>3x10^9</td>
<td>2x10^{10}</td>
<td>2x10^{10}</td>
<td>2x10^{11}</td>
</tr>
<tr>
<td>Repetition Rate</td>
<td>0.3 Hz</td>
<td>1 Hz</td>
<td>1 Hz</td>
<td>2.7 – 4 Hz</td>
</tr>
</tbody>
</table>
UNIversal Linear ACcelerator

Machine coordination: W. Barth, L. Dahl

MUCIS, MEVVA
LEBT
HSI (RFQ, IH1, IH2)
36 MHz
Gas Stripper

HLI (ECR, RFQ, IH)
108 MHz
Poststripper (Alvarez, Cav.)

High Current Injector HSI
ALVAREZ
Single Gap Resonators

Peter Spiller, EPAC06, Edinburg. 26.6.2006
MEVVA and VARIS Ion Sources

MEVVA
metal vapor vacuum arc

VARIS
vacuum arc ion source

22 emA (67%) U$^{4+}$ were reached during test runs at HSI-RFQ input

Machine coordination:
P. Spaedtke, R. Hollinger

Optimization of plasma parameters and geometry
High Current Test Injector HOSTI

- Assembly of a High Current Test Injector for the exploration of the matching of maximum ion currents to the post-acceleration gap.
- Optimizing the post acceleration gap and LEBT system concerning beam quality (Brillance).
- Minimization of transmission losses.

From 94 emA U^{4+} only 37 emA are accelerated to 2.2 keV/u
Only 17 emA arrive at RFQ entrance: Losses > 80 %
Status – Uranium Beams

- LEBT
- HSI (RFQ, IH1, IH2)
- Poststripper (Alvarez, Cav.)
- Foil Stripper

- Gas stripper
- 108 MHz

- 36 MHz

- Dez 01
- Jul 02
- Au-02
- Okt 02
- Mz 03
- Au-03
- Au-03 (2)
- Okt-03
- Dec-03

**Status – Uranium Beams**

- \( \text{U}^{4+} \)
- \( \text{U}^{28+} \)
- \( \text{U}^{73+} \)

**Beam current [emA]**

0 2 4 6 8 10 12 14

**LEBT**
**HSI**
**Gas stripper**
**Alvarez**
**Single Gap Resonators**
**Foil Stripper**
**SIS-injection**

2.0 emA
New Front-end System for U⁴⁺

RFQ-Upgrade: Exchange of RFQ-rods, modified IRM, 
> longer and larger acceptance
Conservation of Emittance for SIS-Injection

New power supplies → higher focusing strength (phase advance) in Alvarez-Quadrupoles

$$\Delta \Phi_0 = 39^\circ$$

$$\Delta \Phi_0 = 51^\circ$$

- Improvement of beam brilliance: 40-50 %
- Charge state separation at high intensities
- Lower transmission losses in TK and the SIS

TK charge state separator

Peter Spiller, EPAC06, Edinburg. 26.6.2006
UNILAC Upgrade (2005-2009)

- High Current Test Bench for Ion Development (Post acceleration)
- Dedicated U^{4+}-High Current-Frontend (Compact LEBT + RFQ upgrade)
- Further investigation of the high current matching to Alvarez-DTL
- Increased zero current phase advance in the Alvarez-DTL
- High current beam diagnostics along whole UNILAC
- Compact charge separator for the separation of U^{73+} under sc-conditions
- Space charge limit for light ions almost achieved
- Low-charge state heavy ion operation characterized by major ionization loss

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Number of Particles/Cycle</th>
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</thead>
<tbody>
<tr>
<td>0-15</td>
<td>$10^9$</td>
</tr>
<tr>
<td>16-30</td>
<td>$10^{10}$</td>
</tr>
<tr>
<td>31-45</td>
<td>$10^{11}$</td>
</tr>
<tr>
<td>46-60</td>
<td>$10^9$</td>
</tr>
<tr>
<td>61-75</td>
<td>$10^{11}$</td>
</tr>
<tr>
<td>76-90</td>
<td>$10^9$</td>
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<td>76-90</td>
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**SIS18 - Intensity Status and Requirements**

<table>
<thead>
<tr>
<th></th>
<th>$^{73}$ operation - Stage 1</th>
<th>$^{28}$ operation - Booster Mode</th>
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</thead>
<tbody>
<tr>
<td>UNILAC Status</td>
<td>2 mA</td>
<td>3 mA</td>
</tr>
<tr>
<td>UNILAC FAIR</td>
<td>5 mA</td>
<td>15 mA</td>
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<tr>
<td></td>
<td></td>
<td>(1.5 MW)</td>
</tr>
<tr>
<td>SIS18 Status</td>
<td>$4 \times 10^9$</td>
<td>$3 \times 10^9$</td>
</tr>
<tr>
<td>SIS18 FAIR</td>
<td>$2 \times 10^{10}$</td>
<td>$2.7 \times 10^{11}$</td>
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</table>
Beam Loss by Charge Change $U^{28+} \rightarrow U^{29+}$

- Dipole
- Coulomb-Scattering
- Projectile-Ionization or $\beta$ decay
- Target-Ionization
- Desorption
- Beam loss induced desorption degenerates the residual gas pressure and composition
  - Degenerated residual gas pressure reduces the beam life time
    > Instable during high intensity operation, heavy ion operation
UHV system upgrade

- Generation of extremely low static pressures of $p_0 < 5 \times 10^{-12}$ mbar and increased average pumping speed by up to a factor of 100
- Stabilization of dynamic pressure to $p(t)_{\text{max}} < 10^{-9}$ mbar
- Removal of contamination with heavy residual gas components

- Replacement of all dipole- and quadrupole chambers by new, NEG coated chambers
- Improved bake-out system for operation up to 300K

Poster: TUPCH174
Scrapers System

Goals:
- Minimization of desorption gas production
- Capture and removal of desorbed gas
- Stabilization of the dynamic pressure

**Poster: TUPCH173**
Low charge state, $U^{28+}$ operation

**Final $U^{28+}$-operation**

Only the combination of the following measures leads to the desired results:

1. New NEG coated chambers
2. Catcher system for ionized beam ions in combination with low desorption yield materials
3. Fast ramping - short cycle time
4. Minimization of systematic beam losses

Simulation with STRAHLSIM

*Poster: MOPCH078*
The construction and set-up of the new 110 kV connection is finished!

The new planned operation mode of SIS18 with 10 T/s up to 18 Tm (instead of 12 Tm) has even higher pulse power requirements which must be evaluated.

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<tr>
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<th>Peak Power</th>
<th>Field Rate</th>
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<tbody>
<tr>
<td>SIS18</td>
<td>± 42 MW</td>
<td>10 T/s</td>
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<tr>
<td>SIS100</td>
<td>± 30 MW</td>
<td>4 T/s</td>
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<tr>
<td>SIS300</td>
<td>± 30 MW</td>
<td>1 T/s</td>
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Power measurements in the power grid and near large power plants where conducted successfully and promising.

High average intensity means fast ramping and short cycle times and high pulse power.
New Acceleration Cavity

Two or three Gap MA (Finemet) Cavity (1.5 MW)

- Sufficient Rf voltage for fast ramping with low charge state heavy ions
  \[ U^{73^+} \text{ acceleration with } 4 \text{ T/s (2x10}^{10} \text{ ions)} \]
  \[ U^{28^+} \text{ acceleration with } 10 \text{ T/s (2.7x10}^{11} \text{ ions)} \]

- Sufficient bucket area for low loss acceleration

- Flat bunch profile (larger Bf) for less inc. tune shift
  Two harmonic acceleration
  \( h=4 \) (existing cavity) and \( h=2 \) (new Kavität)

- Compatibility with SIS100 Rf cycle
SIS18 upgrade program

Supported by EU Construction contract:

- **Task 1: RF System**
  New $h=2$ acceleration cavity and bunch compression system for FAIR stage 0, 1 (2009)

- **Task 2: UHV System**

- **Task 3: Insertions**
  Set-up of a „desorption“ collimation system (2007/2008)

- **Task 4: Injection / Extraction Systems**
  New injection septum, HV power supply and large acceptance extraction channel (2007)

- **Task 5: Beam Diagnostics Systems**
  Fast residual gas profile monitor and high current transformer (2007)

- **Task 6: Injector**
  Set-up of a TK charge separator (2007)
**SIS100 Project Overview**

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<td>Commissioning and Operation</td>
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**UNILAC, SIS18 upgrade**  
**SIS100 R&D phase**  
**Construction phase**

**Demonstration of U^{28+} operation in SIS18**
FAIR Baseline Technical Report 2006

submitted to ISC on March 23rd, 2006
6 Volumes with more ca. 3400 pages and more than 2500 authors
plus Cost Book

+ 2 folders on civil construction and a Supplement
The lattice has been optimized for low charge state, heavy ion operation.
Each lattice cell is a charge separator

- Maximum beam acceptance
- Dispersion free straight sections
- Low dispersion in the arcs
- Six superperiods

Poster: MOPCH079

― Quadrupol unit of the arcs includes sextupole, BPM and collimator

― „small“ aperture magnets for fast ramping
― (no transverse-longitudinal coupling in rf systems)
― (momentum spread during compression) $D_x = 2.5m$
― (space for large tune spread and long storage time)

Peter Spiller, EPAC06, Edinburg. 26.6.2006
Operation Modes – Working Point

Standard for compression, fast extraction and shift of transition energy – dispersion free, reduced collimation

Optional for compression, fast extraction and shift of transition energy – almost dispersion free, good collimation

Standard for slow extraction

Poster: G. Franchetti