Present and future beams for SHE research at GSI

W. Barth, GSI - Darmstadt

1. Heavy Ion Linear Accelerator UNILAC
2. GSI Accelerator Facility – Injector for FAIR
3. Status Quo of the UNILAC-performance
4. Unilac Upgrade Measures
5. Design of a cw superconducting linac
6. Conclusion
The GSI **UNI**versal **Linear AC**celerator

High Current Injector

Alvarez

Single Gap Resonators

Present and future beams for SHE research at GSI, W. Barth

3rd Workshop on recoil separator for Super Element Chemistry & Physics
High Charge State Injector (HLI)
High Charge State Injector (HLI)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Source</td>
<td>EZR (CAPRICE-Typ)</td>
</tr>
<tr>
<td>m/q</td>
<td>8.5</td>
</tr>
<tr>
<td>Extraction Voltage</td>
<td>2.5 \cdot (m/q)</td>
</tr>
<tr>
<td>Beam Energy</td>
<td>2.5 keV/u (\beta = 0.23 %)</td>
</tr>
<tr>
<td>Beam Emittance</td>
<td>0.46 \pi\text{-mm-mrad (norm.)}</td>
</tr>
<tr>
<td></td>
<td>200 \pi\text{-mm-mrad (unnorm.)}</td>
</tr>
<tr>
<td>Mass Resolution</td>
<td>\Delta m/m = 3 \cdot 10^3</td>
</tr>
</tbody>
</table>
High Charge State Injector (HLI)
**High Charge State Injector (HLI)**

- **Structure type**: four-rod
- **Input energy**: 2.5 keV/u ($\beta = 0.0023$)
- **Output energy**: 300 keV/u ($\beta = 0.025$)
- **Radio frequency**: 108 MHz
- **Repetition frequency**: 100 Hz
- **Duty cycle**: 50 %
- **Max. RF power(U**$^{+}$**)**: 125 kW
- **Max. voltage**: 90 kV
- **Length**: 3 m
- **Tank diameter**: 0.5 m
- **Radial acceptance (norm.)**: $\geq 0.8 \text{ mrad}$
- **Longitud. emittance**: $30 \text{ keV/u mrad}$
- **Energy spread**: $\pm 1.0 %$
- **Bunch width**: $\pm 0.3 \text{ ns (}\pm 10 \text{ deg)}$

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High Charge State Injector (HLI)

Diagram showing various components and processes involved in the High Charge State Injector (HLI) system, including:

- Stripper
- Beam Diagnostics
- Quadrupole
- Rebuncher / Chopper
- Solenoid

Key details:
- 50 Hz/5 ms
- 108 MHz
- 100 Hz/5 ms
- 1.4 MeV/u
- 0.3 MeV/u
- 0.0025 MeV/u

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input energy</td>
<td>300 keV/u ($\beta = 0.025$)</td>
</tr>
<tr>
<td>Output energy</td>
<td>1.4 MeV/u ($\beta = 0.055$)</td>
</tr>
<tr>
<td>Radio frequency</td>
<td>108 MHz</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>50 %</td>
</tr>
<tr>
<td>Max. RF power (U^{26+})</td>
<td>100 kW</td>
</tr>
<tr>
<td>Max. field strength</td>
<td>150 kV/cm</td>
</tr>
<tr>
<td>Length</td>
<td>3.55 m</td>
</tr>
<tr>
<td>Shunt impedance</td>
<td>310 MΩ/m</td>
</tr>
<tr>
<td>Radial acceptance (norm.)</td>
<td>1.5 $\pi \cdot \text{mm} \cdot \text{mrad}$</td>
</tr>
<tr>
<td>Radial acceptance (unnorm.)</td>
<td>60 $\pi \cdot \text{mm} \cdot \text{mrad}$</td>
</tr>
<tr>
<td>Longitudinal acceptance</td>
<td>150 $\pi \cdot \text{keV/u} \cdot \text{deg}$</td>
</tr>
<tr>
<td>Emittance</td>
<td>70 $\pi \cdot \text{keV/u} \cdot \text{deg}$</td>
</tr>
<tr>
<td>Energy spread</td>
<td>$\pm$ 0.5 %</td>
</tr>
<tr>
<td>Bunch width</td>
<td>$\pm$ 0.3 ns ($\pm$ 10 deg)</td>
</tr>
</tbody>
</table>
Future Internationale Accelerator Facility at GSI: FAIR (Facility for Antiproton and Ion Research)

Status Quo

UNILAC

p-linac

Linac Upgrade for SHE

HITRAP

100 m
Future Internationale Accelerator Facility at GSI: FAIR (Facility for Antiproton and Ion Research)

Status Quo

Beams now:

$Z = 1 - 92$

(protons to uranium) up to 2 GeV/nucleon

FAIR

Beams in the future:

100 – 1000 fold intensity

$Z = -1 - 92$

(protons to uranium plus anti-matter, i.e. anti-protons) up to 35 - 45 GeV/nucleon
Example of UNILAC 3-Beam Operation

MEVVA
$^{238}_{\text{U}}^{4+}$ 1 Hz / 0.3 ms

ECR
$^{12}_{\text{C}}^{2+}$ 50 Hz / 5.0 ms

SIS

$^{238}_{\text{U}}^{73+}$ 1 Hz / 0.3 ms

$^{208}_{\text{Pb}}^{26+}$ 38 Hz / 5.0 ms

$^{12}_{\text{C}}^{2+}$ 10 Hz / 5.0 ms

PIG
$^{208}_{\text{Pb}}^{9+}$ 50 Hz / 5.0 ms

Mixed Mode Poststripper

1000 ms

20 ms
Particle Current in the GSI-Unilac (routine operation)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Ion Source [μA]</th>
<th>Experiment [μA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}$Ca$^{7+}$</td>
<td>3.6</td>
<td>0.5</td>
</tr>
<tr>
<td>$^{48}$Ca$^{7+}$</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>$^{54}$Cr$^{7+}$</td>
<td>1.7</td>
<td>0.9</td>
</tr>
<tr>
<td>$^{58}$Fe$^{8+}$</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>$^{70}$Zn$^{10+}$</td>
<td>1.6 (2.5)*</td>
<td>0.6 (0.9)*</td>
</tr>
</tbody>
</table>

* reached in 8/2004
Comparison of Performances for Different ECR Ion Sources

![Graph showing comparison of performances for different ECR ion sources](image)

- Red line: 28 GHz SC-ECRIS (extrapolated)
- Orange line: 28 GHz SERSE (Catania)
- Pink line: 18 GHz SERSE (Catania)
- Green line: 18 GHz RT-ECRIS (Catania)
- Blue line: 14 GHz GSI-CAPRICE II

**Xe charge state**

**Intensity (µA)**

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The GyroSerse Project

Sectional View

Magnetic System

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>28-37 GHz</td>
</tr>
<tr>
<td>Max. RF power</td>
<td>10 kW</td>
</tr>
<tr>
<td>$B_{\text{radial}}$</td>
<td>3 T</td>
</tr>
<tr>
<td>$B_1$ (injection)</td>
<td>4.5 T</td>
</tr>
<tr>
<td>$B_2$ (extraction)</td>
<td>3.5 T</td>
</tr>
<tr>
<td>$\phi_{\text{chamber}}$</td>
<td>180 mm</td>
</tr>
<tr>
<td>$L_{\text{chamber}}$</td>
<td>700 mm</td>
</tr>
<tr>
<td>$\phi_{\text{cryostat}}$</td>
<td>1000 mm</td>
</tr>
<tr>
<td>$L_{\text{cryostat}}$</td>
<td>2150 mm</td>
</tr>
</tbody>
</table>

S. Gammino, private communication
**New Front-end for the High Charge State Injector**

50% duty factor → **intensity-gain factor x2**

**New RFQ-structure:**
- gain of the duty factor
- higher injection energy
- increased acceptance

**Additional 28 GHz-ion-source:**
- intensity gain of factor 5 (metalls) / 50 (gases)
- higher charge states for increased duty factor

**LEBT – Laminated magnets:**
- redundancy for ion sources
- preparation for future pulse to pulse operation with different ion-species
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High Duty Cycle RF-Operation of the GSI-High Charge State Injector (HLI) and the Alvarez-accelerator

Presently:
duty factor (beam) = 25 % (rf: 35 %), $A/\xi \leq 8$

Upgrade:
(new RFQ-structure, higher charge state from 28 GHz-ECR)

$A/\xi \leq 6.5$, duty factor = 50 % (rf: 60 %)

Performance of all rf-tube-amplifiers (Alvarez@1.5 MW, IH+RFQ+Single Gap@200 kW, Rebuncher@ 4 kW) is sufficient to meet the requirements.
Upgrade of the Beam Transport to the SHIP-Target (2004)

Emittance Measurement

Quadrupole-Doublet

Octupoles

Profile Grids

Quadrupole-Triplet

Target Area
Transverse Beam Shaping with Octupole lenses

Measured beam profiles at the target position

- Transmission losses of 30% (first tests: 2003)
- Increase of underground noise by a factor of 1000 (first tests: 2003)
Two Heavy Ion Linacs for Different Duties...

Synchrotron Injector

- Poststripper section in operation since 30 years.
  - Alvarez structure operation among the highest duty factors worldwide.
  - Drift tubes with internal quadrupoles.
  - 108 MHz rf power amplifiers in use from the beginning.

Option

- Rebuilt of the Poststripper section.
  - Low duty cycle.
  - High voltage gain.
  - Emittance growth reduction.
  - New operating rf frequency.
  - New beam inflector into SIS 18.

⇒ Relaxed SIS 18 operation.

\[ N_{\text{max}} \propto \beta_i^2 \gamma_i^3 \frac{A}{q^2} \]

25 A MeV U^{28+} increases \( N_{\text{max}}, \text{SIS18} \) by a factor of 2.
A Dedicated cw Linac for SHE Production

• No interference with synchrotron operation.

• Significant increase in available time and in flexibility for tests and for experiments.

• Optimum beam matching to the target wheel; highest counting rates.
Small and fast Solution

- **Room temperature linac:**
  - HLI (1.4 AMeV)
  - 217 MHz DTL
    (IH section, 4 tanks \( P_{rf} < 100 \) kW each).
  - \( A / q < 5 \); \( W < 6 \) AMeV; \( L_{tot} \approx 20 \) m
    \((Z_{eff} \approx 140 \text{ MW/m}; P_{tot,rf} \approx 320 \text{ kW}; P_{plug} \approx 700 \text{ kW}, \text{ for } 217 \text{ MHz cavities})\)

- \( 4 \times \lambda/4, 108 \) MHz, 2 gap cavities for energy variation, superconducting (two cryostats).
Main components:
- Room temperature RFQ and IH-DTL at 108 MHz
- Superconducting CH-DTL (324 MHz) and QWR (108 MHz)
Rebuilt of the HLI with small modifications:

- Improved mechanical design with respect to cooling, especially:
- Cooling of the IH drift tubes.
- Cooling of the RFQ mini vanes.
- Improvement of longitudinal beam dynamics.
Due to the following experimental requirements:

- **Variation of the output energy, 3.8 – 7.5 MeV/u**
- **Final energy spread < ± 3 keV/u**

the following layout resulted:

- **7 CH tanks**
  
<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Output Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4-1.85 MeV/u</td>
<td>2.5 MeV/u</td>
</tr>
<tr>
<td>3.35 MeV/u</td>
<td>4.25 MeV/u</td>
</tr>
<tr>
<td>5.25 MeV/u</td>
<td>6.15 MeV/u</td>
</tr>
<tr>
<td>7.15 MeV/u</td>
<td>2.5 MeV/u</td>
</tr>
</tbody>
</table>

- **An ‘energy modulator’ (2 gap resonators)**
  
  +/- 0.5 MeV/u

- **A 4 gap debuncher cavity (after a 5 m drift space) for the final longitudinal beam shaping.**
Room temperature CH-model (copper)

- 19 gaps
- $\beta=0.08$
- $L=105$ cm
- $\varnothing 34$ cm

- Validation of the simulations
- Tuning (Frequency- and field distribution)
- Higher Order Modes (HOM)
Beam dynamics for the CH – DTL (transverse beam envelopes)
Conclusions

- Improvements of beam intensities from Unilac by factors 10 (metals) to 100 (gases) for SHIP seem feasible:
  • 28 GHz ECR source.
  • Duty factor upgrade to 50 %.

- An optimized synchrotron injector Unilac together with a new cw linac offer attractive long term capabilities:
  • Rebuilt of the Unilac post stripper section as a pulsed high current linac (emittance growth reduction, higher beam energy and SIS current limit, factors ~ 2).
  • New cw linac with independent beam time schedule.

- Two main options for the cw linac:
  • Small solution $A/q \leq 5$, $3.8 < W < 6$ AMeV, room temperature IH linac with 4 s.c. quarter wave cavities (two cryostats) for energy variation.
  • Big solution $A/q \leq 7$, $3.8 < W < 7.5$ AMeV, 108 MHz HLI (1.4 AMeV) & s.c. 324 MHz CH linac & energy modulator (2 gap, $\lambda/4$).