Design Studies for a New Heavy-Ion Injector Linac for FAIR

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GSI, Darmstadt, Germany
Contents

• FAIR project and design intensities
• UNILAC: Present constraints and proposals
• Acceleration of intermediate charge states
• Conceptual heavy-ion high energy linac study
• Conclusions
FAIR
Facility for Antiproton and Ion Research

UNILAC  SIS18

p Linac

SIS100
Circumference
1080 m

Nuclear Matter
Physics
(30 – 45 GeV/u)
Heavy-Ion Beams

RIB Production
Target

Antiproton
Production Target

HESR

Super
FRS

Nuclear Structure &
Astrophysics
Rare Isotope Beams (RIBs)

RESR

CR

HESR

SIS100

Hadron Physics
0 – 15 GeV
Antiprotons

Plasma Physics
Intense, Short
Heavy-Ion Bunches

Green Paper
The Modularized Start Version,
GSI, October 2009

Antiproton Production Target

Bernhard Schlitt, HIAT2012, Chicago, June 20, 2012
**FAIR Design Beam Intensities**

### Intense primary heavy-ion beams for RIB production:

<table>
<thead>
<tr>
<th></th>
<th>UNILAC</th>
<th>SIS18 (today / required)</th>
<th>SIS100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference primary ion</td>
<td>$^{28}\text{U}$</td>
<td>$^{28}\text{U}$</td>
<td>$^{28}\text{U}$</td>
</tr>
<tr>
<td>Reference end energy</td>
<td>11.4 MeV/u</td>
<td>200 MeV/u</td>
<td>1.5 GeV/u</td>
</tr>
<tr>
<td>Ions per cycle / beam current</td>
<td>15 emA</td>
<td>2 $\times$ E10 / 1.5 $\times$ E11</td>
<td>4 E11</td>
</tr>
<tr>
<td>Cycle rate (1/s)</td>
<td>2.7</td>
<td>1 / 2.7</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- Intensity for experiments factor 100 over present
- Four SIS18 cycles into one SIS100 cycle

### Proton beams for pbar physics program:

<table>
<thead>
<tr>
<th></th>
<th>LINAC</th>
<th>SIS100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference end energy</td>
<td>70 MeV/u</td>
<td>30 GeV</td>
</tr>
<tr>
<td>Ions per cycle / beam current</td>
<td>70 mA</td>
<td>4 E13</td>
</tr>
</tbody>
</table>

→ Upgrade program for UNILAC & SIS18

→ Separate proton linac injector
GSI UNIversal Linear ACcelerator UNILAC

High Charge State Injector (1991)

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

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

1.4 MeV/u

High Current Injector (1999)

PIG

11.4 MeV/u
to SIS 18

Alvarez (1975)

Single Gap Resonators (1975)
UNILAC Upgrades for FAIR

W. Barth, LINAC08, p. 31

Further upgrades ongoing → L. Dahl, THB04

- $U^{4+}$
- $U^{28+}$
- $U^{73+}$

- LEBT
- HSI
- Gasstripper
- Alvarez
- Single Gap Resonators
- Foil Stripper
- SIS-Injection

Beam current [emA]

- 2.7 emA
- 5.7 emA
- 20
- 18
- 16
- 14
- 12
- 10
- 8
- 6
- 4
- 2
- 0

- Dez 01
- Okt 02
- Oct-03
- June_07
- Design

Bernhard Schlitt, HIAT2012, Chicago, June 20, 2012
Multi-Beam Operation at the UNILAC

FAIR requirements:
- Extremely high pulse intensities
- Highest magnetic rigidities
- Highest RF and focusing fields
- Low repetition rate (max. 3 Hz) and duty cycle (< 0.1 %)
  (100 µs pulse length)

Super-Heavy Element Program:
- High duty cycle required → 100 %
- High average intensities
- High average RF power, DC magnets
- Presently available:
  25 % duty cycle
  (5 ms pulse length @ 50 Hz)
Operation Limitations & Repair Program

178 Tank-Quadrupoles
- ground faults (coils), water & vacuum leaks (coils, drift tubes, supports)

Leak Tightness of all Tanks

Drift Tubes
- massive sparkovers
- beam induced surface defects

Copper Surface Quality
- inner tank blanket at different positions
Present Linac Limitations

• Most of the Alvarez tanks and all single gap resonators in operation since 1975

• Increasing operation limitations, breakdowns & maintenance
  ⇒ Issue of machine reliability
  ⇒ Substitution of the DTL cavities

• Operation of quadrupoles only in dc-mode
  ⇒ Limited flexibility for multi-beam operation
  ⇒ Limitations due to high power dissipation for strong focusing fields

• Max. duty factor limited to 25 %

→ Massive injector upgrade required!
• Proton Linac Injector for FAIR  
  70 MeV, 70 mA, 325 MHz, 0.1 % Duty Cycle  

• Heavy-Ion High Energy (HE) Linac Injector for FAIR  
  Replacement of UNILAC Post-Stripper Section, Low Duty Cycle  

• SC CW Heavy-Ion Linac for Super-Heavy Element Program  
  3.5 – 7.3 MeV/u, 1 mA, 217 MHz, 100 % Duty Cycle  

→ S. Mickat, WEC03
Increased Lifetimes for Higher Charge States

\[ \Delta Q_y^{sc} \propto N \cdot \frac{q^2}{A} \cdot \frac{1}{\beta^2 \gamma^3} \]

For the same injection energy:

\[ U^{28+} \rightarrow U^{38+} \Rightarrow \Delta Q \rightarrow +85\% \]

Compensation by higher injection energy:

- 15 mA, \( U^{28+} \), 11.4 MeV/u: \( \Delta Q \approx 0.51 \)
- 20 mA, \( U^{38+} \), 22 MeV/u: \( \Delta Q \approx 0.48 \)

... for higher injection energy:

\[ \rightarrow \text{smaller emittance } (\propto \frac{1}{\beta}) \]
\[ \rightarrow \text{shorter injection pulse} \]
Uranium Charge States vs. Beam Energy

Gas stripper must be shifted to higher beam energies
Investigated High-Energy (HE) Linac Concept

1st Stage: 108 MHz IH-DTL up to 11.4 MeV/u (replacing exist. post-stripper)
Gas stripper moved to 3 MeV/u, charge separator can be re-used
4 new pre-stripper IH tanks: 95 MV, 20 mA U⁴⁺, A/q ≤ 59.5
4 new post-stripper IH tanks: 53 MV, 24 mA U³⁸⁺, A/q ≤ 6.26

2nd Stage: Energy upgrade to 22 MeV/u by 325 MHz CH-DTL structures
5 to 6 CH tanks: 67 MV, 24 mA U³⁸⁺
Extension of existing building for 325 MHz klystron gallery

Separated function lattice, only external magnetic quadrupol triplets
Proposed H-Mode Structures

108 MHz IH-DTL

Tank Half Shells

Drift Tubes

Girders


325 MHz CH-DTL Hot Model

Shunt Impedances

Pre-Stripper Beam Dynamics (KONUS)

By G. Clemente, GSI

20 mA U4+

Bernhard Schlitt, HIAT2012, Chicago, June 20, 2012
Pre-Stripper Design

1. Effective Voltage Distribution
   - IH3
   - IH4
   - IH5
   - IH6
   - Gap
   - ≤ 950 kV / gap
   - Averaged voltage gain ≈ 8 MV/m

2. Max Electric Field on Axis
   - IH3
   - IH4
   - IH5
   - IH6
   - Gap
   - ≤ 19 MV/m

3. 20 mA U4+

4. 108 MHz Buncher: 6 x 350 kV_eff
Microwave Studio Simulations (IH3)

Electric field distribution

Voltage distribution
## Stage 1: 108 MHz IH-DTL Linac

<table>
<thead>
<tr>
<th>Cavity</th>
<th>ΔW (MeV/u)</th>
<th>P_{beam} (kW)</th>
<th>V_{eff} (MV)</th>
<th>Gaps</th>
<th>Beam Aperture</th>
<th>Length (m)</th>
</tr>
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<tbody>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Pre-Stripper (U4+)</td>
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<tr>
<td>IH3</td>
<td>0.40</td>
<td>454</td>
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<td>35</td>
<td>22</td>
<td>~ 2.9</td>
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<td>IH4</td>
<td>0.45</td>
<td>538</td>
<td>28.7</td>
<td>33</td>
<td>22 – 24</td>
<td>~ 3.1</td>
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<td>IH5</td>
<td>0.416</td>
<td>500</td>
<td>26.8</td>
<td>30</td>
<td>24</td>
<td>~ 3.1</td>
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<tr>
<td>IH6</td>
<td>0.346</td>
<td>416</td>
<td>23.9</td>
<td>27</td>
<td>24</td>
<td>~ 3.0</td>
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<tr>
<td></td>
<td>Post-Stripper (U38+)</td>
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<tr>
<td>IH7</td>
<td>1.80</td>
<td>271</td>
<td>11.5</td>
<td>14</td>
<td>35</td>
<td>~ 1.8</td>
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<tr>
<td>IH8</td>
<td>2.37</td>
<td>356</td>
<td>15.9</td>
<td>19</td>
<td>35</td>
<td>~ 3.0</td>
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<tr>
<td>IH9</td>
<td>2.20</td>
<td>330</td>
<td>15.3</td>
<td>18</td>
<td>35</td>
<td>~ 3.3</td>
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<tr>
<td>IH10</td>
<td>2.20</td>
<td>330</td>
<td>15.0</td>
<td>18</td>
<td>35</td>
<td>~ 3.7</td>
</tr>
</tbody>
</table>

**Total RF power demands for each cavity including beam power < 1.3 MW**
Conclusions

- Replacement of existing UNILAC post-stripper by new linac optimized for FAIR injection
  low duty cycle, short pulses, fixed end energy

- Presented HE linac study very costly and huge efforts
  215 MV, shift of gas-stripper section, extension of RF gallery

- Alternative option:
  108 MHz IH-DTL for U28+ up to 11.4 MeV/u
  85 MV, about 5 new IH tanks, no higher charge state

- Investigation of alternative stripper options to increase charge state without extension of present pre-stripper
  plasma stripper, Li film stripper ?, (foil stipper)

- Prototype IH & CH structures will be designed & constructed
## Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>2017</td>
<td>Commissioning start of FAIR accelerators using ion beams from existing UNILAC</td>
</tr>
<tr>
<td>2019</td>
<td>FAIR proton linac commissioning</td>
</tr>
<tr>
<td>2022</td>
<td>First heavy ion beams from new high-energy linac for FAIR (using proton beams for FAIR during installation and commissioning of the HE linac)</td>
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</tbody>
</table>
Thank you for Attention!