

# A NEW HIGH ENERGY UNILAC AS AN HIGH CURRENT HEAVY ION INJECTOR FOR THE FAIR-SYNCHROTRONS

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## Abstract

The GSI UNILAC serving as a high duty factor heavy ion linac is in operation since nearly 35 years. An upgrade program dedicated to FAIR will be finished until 2011. For the FAIR project the synchrotron SIS 18 has to be filled up to the space charge limit. After re-commissioning of the UNILAC the replacement of the main DTL is foreseen. A new 4 MV/m 108 MHz IH-LINAC provides a high intensity 5 MeV/u  $U^{4+}$ -beam. The existing gas stripper section is reused to perform a beam intensity of 24 emA in charge state 42+. The existing UNILAC-tunnel may house a high efficient linac structure. A superconducting or normal conducting 324 MHz-CH-linac (crossbar H-structure) is under consideration as well as rf-resonators of half wave or quarter wave type. The new high energy linac should be able to boost the beam energy up to 30 MeV/u. A further upgrade option is a second 100 m-linac (324 MHz) to enhance the beam energy to up to 150 MeV/u ( $U^{63+}$ ), sufficient to feed the FAIR 100 Tm synchrotron in direct line. The paper will report on the ongoing conceptual layout of a new UNILAC-concept.

main drift tube linac. The ion beam delivered by the HLI may either be injected into the SIS via a transfer channel or delivered to an experimental hall.

## UNILAC UPGRADE FOR FAIR

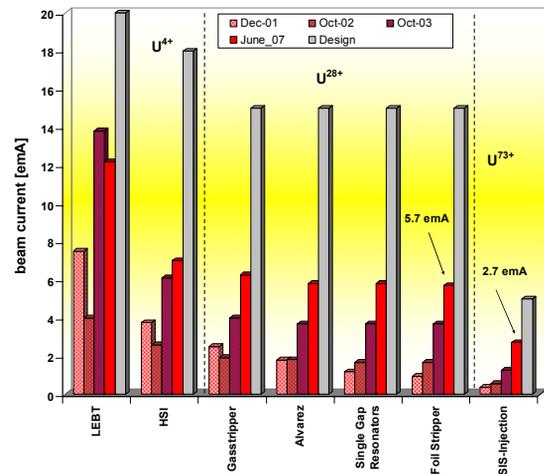


Figure 2: Improvement of the UNILAC-uranium beam intensities [2].

## INTRODUCTION

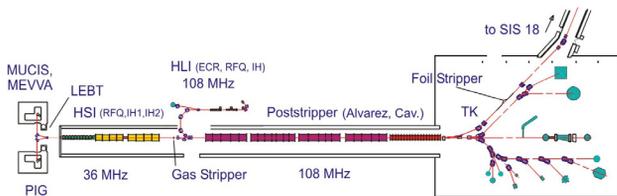


Figure 1: Schematic overview of the GSI UNILAC and experimental area.

Besides two ion source terminals and a low energy beam transport system (LEBT) the High Current Injector (HSI) [1] of the UNILAC comprises a 36 MHz IH-RFQ accelerating the ion beam from 2.2 keV/u up to 120 keV/u and a short 11 cell adapter RFQ (Super Lens). The IH-DTL, consisting of two separate tanks, accelerates the beam up to the final HSI-energy of 1.4 MeV/u. After stripping and charge state separation the Alvarez DTL provides for beam acceleration up to  $\beta = 0.155$ . The transfer line (TK) to the synchrotron SIS 18 is equipped with a foil stripper and another charge state separator system.

Highly charged ion beams from an ECR ion source of CAPRICE-type are accelerated in the High Charge State Injector (HLI) consisting of an RFQ and an IH-resonator to final beam energy of 1.4 MeV/u. The HLI- as well as the HSI-injector serves in a time-sharing mode for the

The improved ion source performance, an upgrade of the HSI-structures, the increased stripper gas density, the optimization of the Alvarez-matching, the reduction of the number of Single Gap Resonators, the applied sweeper mode for foil stripper operation, the installation of a new compact charge separation system and the use of various newly developed beam diagnostics comprised the successful development program [3]. In Fig. 2 the achieved uranium intensities in the UNILAC and TK are summarized (2001-2007), reached by ongoing upgrade measures and by an extended experimental program dedicated to improve the overall UNILAC performance for heavy ion high current operation. In June 2007 an  $U^{73+}$  intensity of 2.7 emA (37.1  $\mu$ A) was reached for the first time, which corresponds to  $2.3 \cdot 10^{10}$  particles per 100  $\mu$ s. Before foil stripping 5.7 emA (203  $\mu$ A) of  $U^{28+}$  beam intensity was achieved ( $1.25 \cdot 10^{11}$  particles per 100  $\mu$ s). Presently the optimized total particle transmission through HSI, stripper section, Alvarez DTL, Single gap resonator chain, and TK is not larger than 50 % if the particle losses during charge state separation behind the two strippers are taken into account. Additionally the measured transverse beam emittance exceeds the acceptance of the synchrotron.

The bottleneck of the whole UNILAC is the front-end system of the High Current Injector. For this reason the UNILAC-upgrade for FAIR will be continued with the installation of a new front-end for high intensity heavy



Figure 3: New RFQ-electrodes for tank 1 including input radial matcher; preinstalled copper plated electrodes with support rings for another tank.

ions. It is shown in an upgrade design study that the transverse RFQ-acceptance can be significantly increased while the emittance growth can be reduced. Both goals are achieved with only a moderate change of the RFQ electrode geometry. The beam parameters in the final focusing elements of the LEBT were optimized together with the improved design of the input radial matcher; the length of the gentle buncher section was considerably increased to provide slow and smooth bunching resulting in a reduced influence of space charge forces. The baseline design was optimized for an  $U^{4+}$  beam current of 20 emA and a total transverse emittance of 280 mm-mrad (unnorm.). Beam dynamics simulations were done for the same beam current and emittance, but with different matching for the old and the new design. The new RFQ design [4] provides for an increase of more than 40 % of the beam current. Higher beam emittance behind the new RFQ is formed by a few percent of the particles, while the core of the beam (20 mm-mrad) contains the required beam current. The HSI-RFQ upgrade will start in spring 2009. Additionally, the offered primary proton beam intensities will be increased by a new ambitious proton linac, which should be commissioned in 2012 [5].

## HE-LINAC

Table 1: Future Requirements.

purpose	upgrade measure
FAIR-requirements: 15 emA, $U^{28+}$ (0.5 TmA)	Ongoing UNILAC-Upgrade (realized until 2010)
>15 emA, $U^{28+}$ , (FAIR+)	not feasible with the existing UNILAC
Multibeam-operation with ion beams of different rigidity	<ul style="list-style-type: none"> <li>• fast ramped power supplies</li> <li>• 168 fastly ramped quadrupoles</li> <li>• 168 new drift tubes (not recommended)</li> </ul>
Increase of the "beam on target time" especially for the ambitious Super Heavy Element program - 50 % duty factor for $A/q \leq 5.9$	<ul style="list-style-type: none"> <li>• Exchange of the rf-power tubes for Alvarez tank 1-3</li> <li>• Required average rf-power <math>\leq 46</math> kW for the operation with the 200 kW-rf- tubes (not recommended)</li> </ul>
100 % duty factor	not feasible with existing UNILAC

For Uranium (reference ion) the UNILAC as an injector for FAIR has to deliver  $3.3 \cdot 10^{11}$   $U^{28+}$ -particles per 100  $\mu$ s ( $4 \cdot 10^{10}$   $U^{73+}$ ) to the present synchrotron SIS 18. With the

FAIR-accelerator facility higher intensities will be achieved compared to the present GSI accelerators, through faster cycling and, for heavy ions, lower charge state which enters quadratically into the space charge limit (SCL). The desired energy of up to 1.5 GeV/u for radioactive beam production is delivered by the synchrotron SIS 100, which also generates intense beams of energetic protons up to 30 GeV for pbar-production. The energy of 30 GeV/u for heavy ions is generated by using higher charge states in combination with the slower cycling synchrotron SIS 300. The different future requirements to the UNILAC-operation concerning FAIR and the experimental programme using high duty factor heavy ion beams with UNILAC-beam energies are summarized in Tab. 1. In a first step the replacement of the existing Alvarez-DTL is recommended, assuring stable FAIR-injector-operation for the next decades. Behind the HSI a new 4 MV/m-IH-LINAC (108 MHz, length: 50 m) provides a high intensity 5 MeV/u  $U^{4+}$ -beam. The existing gas stripper section is reused to prepare for a beam intensity of 24 emA in charge state  $42+$ . In the current LINAC-tunnel a high efficient 324 MHz-CH-LINAC (35 m) is able to boost the beam energy up to 30 MeV/u. The transfer line to the SIS 18 will be reused, including the foil stripper and the already newly installed compact charge state separator system [6], providing charge states of up to  $82+$ . If the gas stripper is replaced by a solid state stripper, a LINAC-beam energy of 42 MeV/u (charge state  $63+$ ) could be realized. Fig. 4 shows the measured tantalum charge states for different UNILAC-beam energies as a basis for the general layout of the future pre- and post stripper-sections.

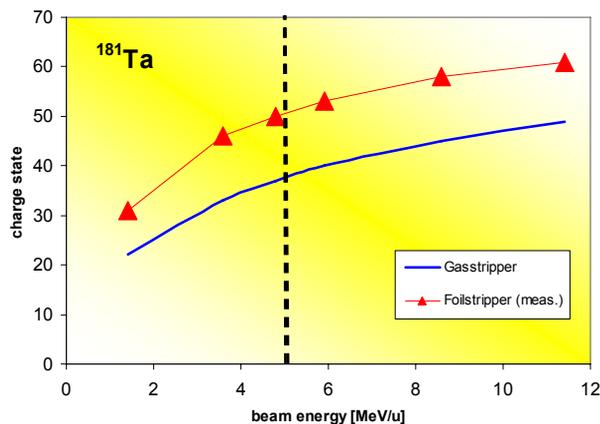


Figure 4: Measured main stripper charge state for different beam energies [7].

## 150 MEV/U-BOOSTER LINAC

A further upgrade option may provide a second 100 m-CH-LINAC (324 MHz) to enhance the beam energy to up to 100 MeV/u ( $U^{41+}$ )/150 MeV/u ( $U^{63+}$ ), sufficient to feed the new 100 Tm-synchrotron (SIS 100) in direct line. The different LINAC-options are compared in Tab. 2.

Table 2: Comparison of Long-Term LINAC-Options

	measure	output	purpose
existing UNILAC	UNILAC + Upgrade + fast ramped quadrupoles	11.4 MeV/u, 15 emA, U <sup>28+</sup> (5emA, U <sup>73+</sup> )	15 emA, U <sup>28+</sup> , full multi beam operation
High Energy-LINAC (HE)	HSI + 108 MHz IH-DTL (5 MeV/u), reused gasstripper section (24 emA, U <sup>41+</sup> ), 324 MHz-CH-DTL (4 MV/m)	30.0 MeV/u, 24 emA, U <sup>41+</sup> (10.5 emA, U <sup>82+</sup> ) alternatively: solid state-stripper: 42 MeV/u, 43 emA, U <sup>63+</sup>	4.6×10 <sup>11</sup> ions/s achievable; reduced desorption rate; 50 % lower sc-tune shift → UNILAC-intensity may be increased by a factor of 2
Upgrade option	HE_Linac + 324 MHz-CH-Booster-LINAC (225 m tot. length)	100.0 MeV/u, 24 emA, U <sup>41+</sup> alternatively: 150.0 MeV/u 43 emA, U <sup>63+</sup>	direct injection into the FAIR-SIS 100 (upgrade-option)

### CW-HEAVY ION LINAC

The accelerator upgrade for the GSI heavy element program (SHIP-Upgrade) is based on a new high charge state injector front-end consisting of an advanced ECR ion source and an improved RFQ-accelerator. The largest step for the increase of the beam intensity is expected from a new superconducting 28-GHz ECRIS source - this activity is supported through EURONS European Commission Contract No. 506065. The beam coming from the new ECR source will be delivered to the HLI by a second LEBT-system. A new RFQ for high duty factor-operation and an improved beam dynamics design will be installed end of 2009. An upgrade program for all rf-amplifiers and rf-structures is foreseen to increase the duty factor from 27 % to 50 % [8].

The proposed design version represents a stand alone linear accelerator with 100 % duty factor. The maximum beam energy of 7.5 MeV/u is achieved by superconducting CH structures following the existing 1.4 MeV/u HLI-injector [8, 9].

### FUTURE MULTIPURPOSE HEAVY ION LINAC

The UNILAC-upgrade program for FAIR will be realized in the next three years; the required U<sup>28+</sup>-beam intensity of 15 emA (for SIS 18 injection) should be available until 2012 [10]. The replacement of the Alvarez-DTL by a new high energy linac is advised to provide a stable operation for the next decades. An additional linac-upgrade option sufficient to boost the beam energy up to 150 MeV/u may help to reach the desired heavy ion intensities in the SIS 100. The SHIP-upgrade program has also to be realized until 2011, such that an enhanced primary beam intensity at the target is available. It is recommended to build a new cw-heavy ion-LINAC until 2015.

A first conceptual layout of a multipurpose high intensity heavy ion facility concerning the basic future require-

ments is shown in Fig. 5. The high duty factor heavy ion beam could be delivered to the UNILAC-experimental hall by using the CH-section in transport mode. All focussing magnets, beam diagnostics devices, as well as rf-components should be able to provide for multi beam operation. Heavy ion beams from the cw-linac could be also accelerated up to 30 MeV/u and transported to the SIS 18. The whole injector family is housed by the existing constructions.

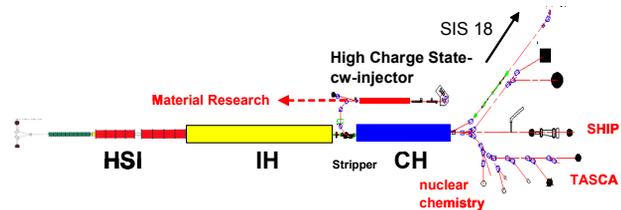


Figure 5: Conceptual layout of a multipurpose high intensity heavy ion facility [11].

### REFERENCES

- [1] U. Ratzinger, The New GSI Prestripper Linac for High Current Heavy Ion Beams, LINAC96, Geneva, Switzerland, p. 288 (1996).
- [2] W. Barth, The Injector Systems of the FAIR Project LINAC 2008, Victoria, Canada, to be published (2008) invited talk
- [3] W. Barth, Development of the UNILAC towards a Megawatt Beam Injector, LINAC2004, Lübeck, Germany, p. 246 (2004).
- [4] W. Barth, Upgrade of the UNILAC High Current Injector RFQ, LINAC 2008, Victoria, Canada, to be published (2008)
- [5] L. Groening, et. al., A Dedicated Proton Linac for the Antiproton Physics Program of FAIR, LINAC04, Lübeck, Germany, p. 42 (2004)
- [6] W. Barth, Commissioning of the new GSI-charge state separator system for high current heavy ion beams, LINAC 2008, Victoria, Canada, to be published (2008)
- [7] B. and J. Delaunay, Etat de Charges de Particule Accelerees, Partie du Rapport Ions Lourds, (1974).
- [8] W. Barth, et. al., UNILAC-Upgrade for the Heavy Element Research at GSI-SHIP, EPAC06, Edinburgh, Scotland (2006).
- [9] U. Ratzinger, Stand des Designs eines möglichen cw-Linacs bei GSI, GSI-internal report (2002)
- [10] W. Barth, et. al., Technical Status Reports - Accelerator Facilities, GSI, (2005).
- [11] W. Barth, et. al., Long term Perspective for the UNILAC, LINAC2006, Knoxville, U.S.A., (2006)