NEW DEVELOPMENTS FOR THE PRESENT AND FUTURE GSI LINACS

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Abstract

For more than three decades, GSI has successfully operated the Universal Linear Accelerator (UNILAC), providing ions from protons to uranium at energies from 3 to 11 MeV/u. The UNILAC will serve for a comparable period as injector for the upcoming FAIR facility which will ask for short pulses of high peak currents of heavy ions. The UNILAC Alvarez-type DTL has been in operation since the earliest days of the machine, and it needs to be replaced to assure reliable operation for FAIR. This new DTL will serve the needs of FAIR, while demands of high duty cycles of moderate currents of intermediate-mass ions will be met by construction of a dedicated superconducting cw-linac. FAIR requires additionally provision of primary protons for its anti-proton physics program. A dedicated proton linac is under design for that task. The contribution will present the future linacs to be operated at GSI. Finally, we introduce a novel method to provide flat ion beams for injection into machines having flat injection acceptances.

FUTURE REQUIREMENTS

All beams provided for FAIR (Fig.1) will be delivered through the existing synchrotron SIS18. The according requirements to the beams of its injectors are listed in Table 1.

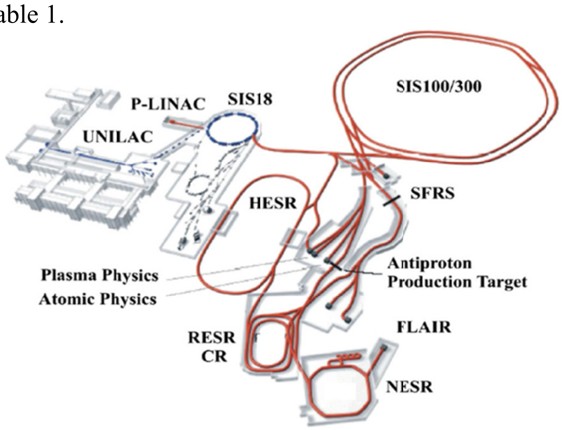

Figure 1: The FAIR accelerators.

The existing UNILAC [1] is in operation since the early 70ies and it is proposed to replace it with a new High Energy (HE) linac, providing all ion species except protons. For the latter a dedicated injector is currently under design and construction. Finally, a third sc cw-linac for the provision of intermediate-mass ions is under design. Figure 2 sketches the conceptual layout of the three injectors. In the following the dedicated developments related to these machines are highlighted together with a general concept for flat beam provision for any ion linac.

Table 1: FAIR Injector Beam Parameters

Ion	$^{238}U^{28+}$	$^{238}U^{73+}$	Protons
E [MeV/u]	11.4	11.4	70
I_{Pulse} [emA]	15	5.5	70
Mom. Spread	10^{-3}	10^{-3}	10^{-3}
$\beta\gamma\varepsilon_x$ [µm]	0.8	0.8	4.2
$\beta\gamma\varepsilon_y$ [µm]	2.5	2.5	4.2

70 MEV PROTON LINAC

Acceleration in this linac will be done by Cross-bar H-Cavities (CH) operated at 325 MHz, which extend the high impedances of the H-cavity family to higher beam velocities, i.e. especially to protons. The R&D related to CH cavities [2] was started 10 years ago and it is about to be finished with the testing of the first prototype shown in Fig. 3.

Figure 3: Prototype of CH-cavity.

It can provide acceleration from 11 to 24 MeV/u and houses a quadrupole triplet within a prolonged drift tube separating two CH-cavities. The first cavity has 13 gaps and the second one has 14 gaps.

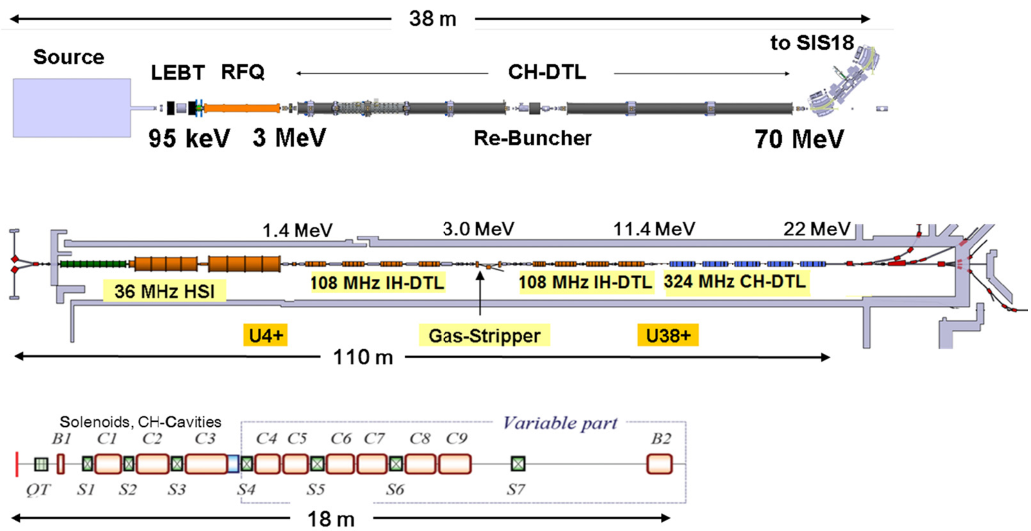

Figure 2: Conceptual layouts of the future linacs at GSI. From top to buttom: proton linac, sc cw-linac, and high energy linac. Dimensions are not to scale.

This tube in turn is integrated into a rectangular rf-coupling cell coupling the two CH-cavities. Each of them resonates in the TE_{211}-mode, while the coupling cell resonates in the TM_{010}-mode. Rf-coupling into the coupled CH-cavity pair is done in this coupling cell like into an Alvarez-type cavity. Initial rf-tuning is done through proper choice of all drift tubes lengths. Fine tuning is accomplished by five plungers. First results from rf-tuning w.r.t. field flatness are promising. Copper plating is quite demanding and it will be started in summer of 2012. High power rf-tests are planned for 2013.

HIGH ENERGY (HE) LINAC

In the existing UNILAC acceleration from 1.4 to 11.4 MeV/u is done by conventional 108.4 MHz Alvarez-type DTLs preceded by a stripping section, i.e. 4+ to 28+ for uranium. The new HE linac [3] (Fig. 2) will delay stripping to 3 MeV/u, thus to higher charge states (38+ for a gaseous stripper). This choice was made to mitigate beam loss from collisions with beam ions with residual gas molecules in the subsequent synchrotron SIS18. The respective cross sections are significantly lowered if higher charge states are used. Since the tune spread in the SIS18 increases with the charge state, the injection energy is shifted from 11.4 to 22 MeV/u to assure a constant injection acceptance. Up to 11.4 MeV/u H-cavities are used without changing the frequency. Each of them will be about 3 m in length requiring an rf-power of less than 1.2 MW. Figure 4 shows a simulation model of the first cavity.

Beam energies beyond 11 MeV/u allow for transition to CH-cavities with a frequency transition to 325.2 MHz, i.e. to the proton linac frequency. Accordingly, these CH-cavities can be powered with the same kind of klystrons as for the proton linac.

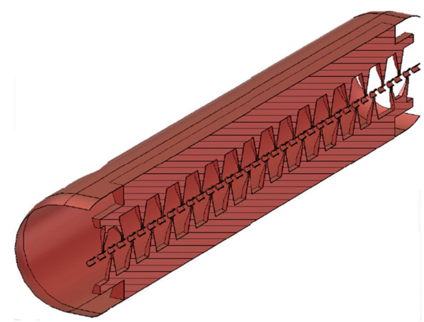

Figure 4: Simulation model of the first HE-linac IH-cavity.

An alternative layout of the HE linac foresees stripping with a solid state medium instead. It could provide a charge state of 55+ for uranium. However, it would cause very strong space charge forces shortly behind the stripper. Otherwise it would require a shift of the complete stripping section to higher energies.

SC CW-LINAC

Since its early days the UNILAC served physics experiments close to the Coulomb barrier, i.e. high duty-cycle (≤ 25%) beams at few MeV/u of energy. The new HE-linac will serve exclusively as injector for the FAIR facility. In order to provide long duty cycle beams beyond the UNILAC lifetime, a dedicated cw-linac is currently under design [4] at the Helmholtz-Institute at Mainz (HIM) together with the Frankfurt University and GSI. Its conceptual layout is shown in Fig. 2. It will comprise nine sc-CH-cavities [5] operated at 217 MHz for acceleration and seven solenoids for transverse focusing; its cw-operation will allow for an effective reduction of beam times by a factor of about 20 (example for the search of Element 120). Table 2 summarizes the design parameters.

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The linac will use an upgraded version of the existing High Charge Injector (HLI) at GSI providing 1.4 MeV/u ions initially provided by an ECR source.

Table 2: The CW-linac Design Parameters

Output energy	2.5 – 7.5 MeV/u
Injection energy	1.4 MeV/u
A/q	≤ 6.0
Beam current	1.0 mA
Length of acceleration	12.7 m
Energy spread	± 3.0 keV/u

Currently a first testing cryomodule, a so-called demonstrator, is under construction and design. It comprises a sc CH-cavity with adjacent solenoids. The assembly is integrated into a horizontal cryomodule as shown in Fig. 5. It will serve as a testing device for assembly, alignment, and especially verification of alignment during cooling down. The set-up will be tested with beam at a 1.4 MeV/u branch of the HLI at GSI.

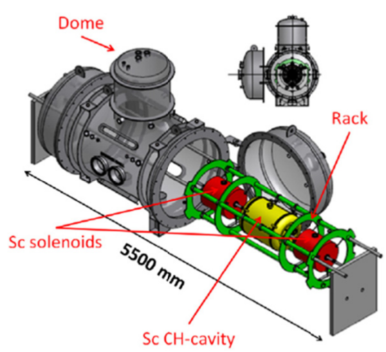

Figure 5: The demonstrator cryomodule for the new sc-cw-linac at GSI.

FLAT ION BEAM CREATION

As seen from Table 1 the design beam parameters of the SIS18 injector linacs are flat, i.e. different requirements for the horizontal and vertical emittances to be provided by the linac. However, the two transverse emittances of a linac are generally equal, and so it is at the existing UNILAC. Since keeping both emittances below the more stringent design value might be quite hard, it is considered to transfer emittance from the horizontal to the vertical plane. Such a transfer requires non-symplectic beam transformations, which cannot be performed by linear optical elements even if they are tilted. It requires a modification of the beam's eigen-emittances [6]. Such a modification can be achieved by placing a charge stripper inside a longitudinal field region. Inside such a solenoidal stripper transverse inter-plane correlations are created in a non-symplectic way. They are to be removed afterwards symplectically with tilted quadrupoles (skews). A set-up providing a flat ion beam is proposed in [7] as shown in Fig. 6.

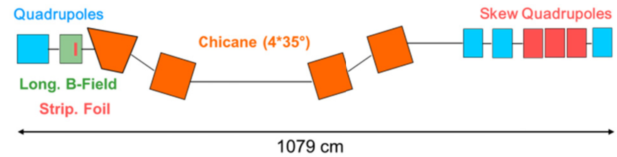

Figure 6: Beam line to transfer emittance from the horizontal to the vertical plane.

Although a solenoid is a symplectic device, the re-set of the beam's charge state makes the overall transformation non-symplectic. This re-set eliminates the stripped electrons as well as the stripping media from the overall system. This omission cannot be modelled by a proper Hamiltonian and causes the non-symplecticity. Figure 7 shows the beam's envelopes and rms-emittances along the beam line. A beam of initially equal horizontal and vertical emittances finally features a transverse rms-emittance ratio of 12. The envelopes were obtained from simulations using the TRACK code. It should be mentioned that the results do not change if the solenoidal field is modelled through 4D-matrices or through particle tracking based on 3D-field maps.

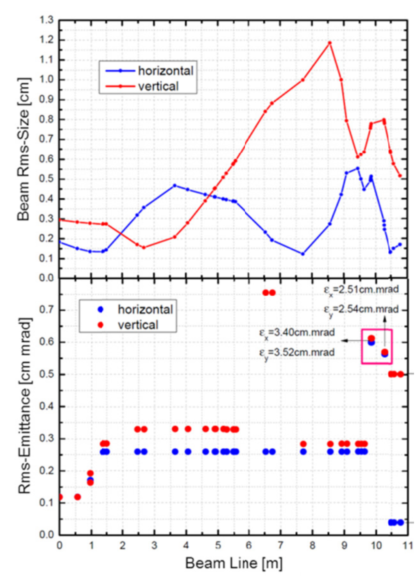

Figure 7: Beam envelopes and rms-emittances along the emittance-transfer beamline.

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