STATUS OF THE HITRAP DECELERATOR AT GSI

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Abstract

Within the European Network HITRAP (Heavy Ion TRAP) trapped and cooled highly charged ions up to U^{92+} will become available for a variety of attractive experiments in atomic physics. Heavy ions are produced, accelerated and stripped in the GSI accelerator complex and are successfully stored and decelerated in the ESR down to 4 A MeV. To be captured in HITRAP, the ions have to be decelerated to energies below 6 A keV. The decelerator proposed to achieve these energies is a combination of one IH Drift tube cavity operating in the H11(0) mode and one RFQ. The linac frequency is 108.408MHz. The decelerator linac will be installed in the re-injection beam line between ESR and synchrotron SIS. The A/q range of the linac is up to 3. A very efficient deceleration by up to 11 MV along the 2.7 m long IH cavity with a rf power of 200kW is achieved by applying the KONUS beam dynamics. The deceleration from 500 A keV down to 6 A keV is provided by a 1.8 m long 4-rod RFQ. The beam dynamics as well as the cavity design of that linac will be described. This decelerator is being developed in collaboration between GSI and the Frankfurt University.

PRODUCTION OF U^{92+} AND DECELERATION DOWN TO 3 A MeV AT ESR

Typical high charge state production consists in a first acceleration stage to 11.4 A MeV in the UNILAC and stripping up to U^{73+}. Higher charge states U^{91+}, U^{92+} are obtained after a second acceleration stage to about 400 A MeV in SIS and subsequent stripping in the transfer line from SIS to ESR.

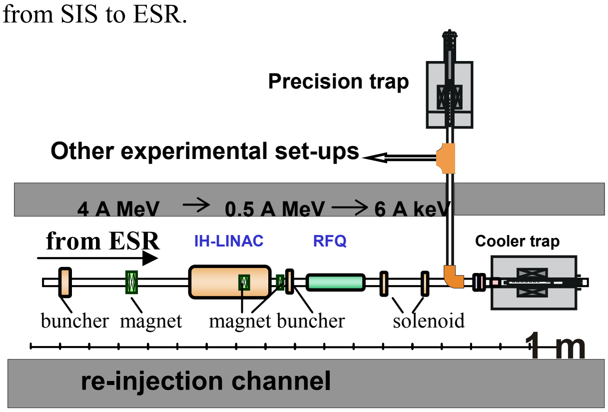

Figure 1: Scheme of the HITRAP facility.

In the ESR the beam is at first cooled by an electron cooler, then decelerated down to 30 A MeV with a ramp rate of 0.15T/s in 7s. The beam is re-cooled to restore its quality; this allows further deceleration with good efficiency. For the deceleration down to 3 A MeV, the ramp rate has to be reduced to 0.05T/s in order to avoid beam loss. The second deceleration stage required 5s. At 3 A MeV the beam is cooled again.

The fast beam extraction in a 1µs bunch towards the re-injection tunnel is supported by the existing hardware but wasn't applied frequently so far. Although deceleration down to 3 A MeV in the ESR was successfully demonstrated, the bunch will be extracted at 4 A MeV to simplify the operation. Furthermore a deceleration from 4 A MeV down to 6 A keV still allows a compact design for the HITRAP decelerator.

Especially, two available 200kW rf power transmitters originally used to drive UNILAC single gap resonators are well suited to provide a decelerator linac voltage up to 12 MV.

HITRAP DECELERATOR

The decelerator and trap array is shown by fig. 1 and main parameters are listed in table1. The HITRAP decelerator design was done for an A/q range up to 3 [1]. The needed repetition time is approximately 10 seconds at a low duty cycle of 0.15%. Intermediate rf pulses may be needed to keep the linac in resonance.

Table1: Main decelerator parameters. Beam energy: W; velocity β; effective voltage gain /electrode voltage in the IH/RFQ; Shunt impedance in the IH/RFQ; length L; power consumption P.

	IH LINAC		RFQ	
	input	output	input	output
W [A.MeV]	4	0.5	0.55	0.006
β	0.0924	0.0328	0.0343	0.0036
frequency in MHz	108.408			
U_0 [MV]	10.5		0.07	
Z_0 in [MΩ/m] for IH in [kΩ.m] for RFQ	260		110	
aperture radius[mm]	6 - 5		4	
number of cells	25		143	
L [m]	2.72		1.8	
P[kW]	180		80	

IH cavity

To reach a high deceleration rate in the 2.7 m long IH cavity, the so-called KONUS (Kombinierte Null Grad Struktur) dynamics is used [2]. In the KONUS scheme the particles are decelerated in a number of gaps with 180 degree synchronous phase, which are followed by quadruple triplet, and rebunching phase with 215 degree bunch center phase. Figure 3 shows the 98% beam envelopes from the buncher to the RFQ entrance calculated with LORASR, which is an adequate code to study the KONUS dynamics.

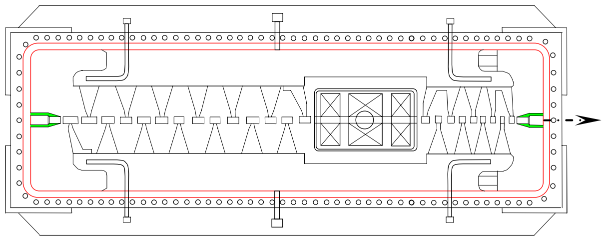

Figure 2: Schematic drawing of the IH cavity design with one internal lens.

Matching Sections

A first matching section consisting in a one first harmonic buncher and one quadrupole triplet provides the microbunch structure and the transverse matching to the IH for the 1µs pulse from the ESR. The buncher used is a 108MHz quarter wave resonator. This buncher mainly defines the decelerator beam transmission of about 28%.

A second matching section between the IH cavity and the RFQ, consisting also in a one first harmonic buncher and one quadrupole triplet, provides to the RFQ convergent emittances in all planes. The second buncher is a spiral resonator and is already available at GSI. The power supplies for bunchers are 2kW amplifiers.

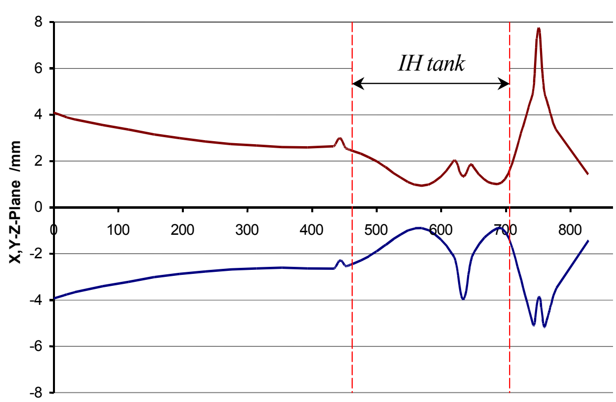

Figure 3: 98% beam envelope along the 2 matching sections and the IH tank.

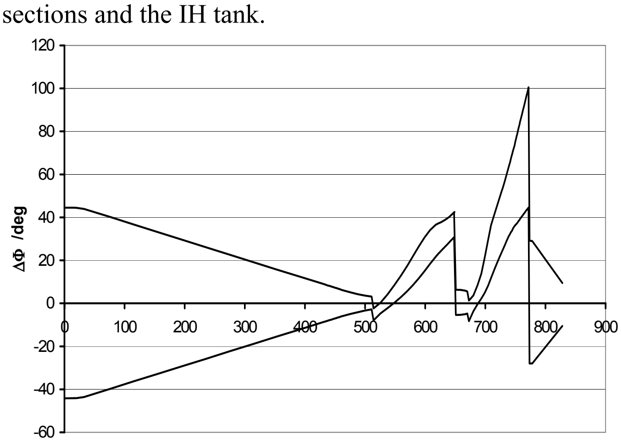

Figure 4: 98 % phase spread along the 2 matching sections and the IH tank.

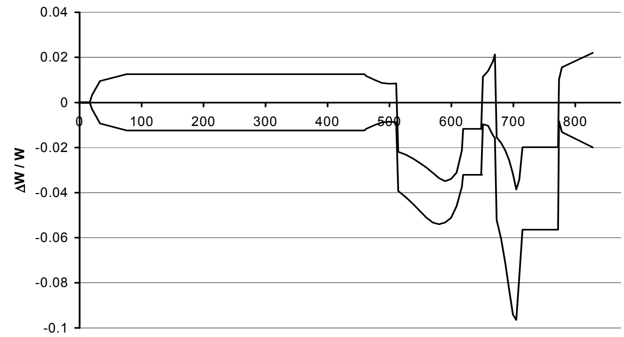

Figure 5: 98 % Energy spread of the IH-DTL along the 2 matching sections and the IH tank.

4-rod RFQ

The 4-rod RFQ design follows the concepts as applied on the GSI HLI-RFQ [3], the injector for high charge states (A/q>1/9), which are accelerated from 2.5 A keV to 300 A keV. The design of an RFQ for A/q≤3 eases the rf-power problems and allows for a 1.8m short RFQ structure. As mentioned above an identical second 200kW rf amplifier is foreseen to operate the RFQ.

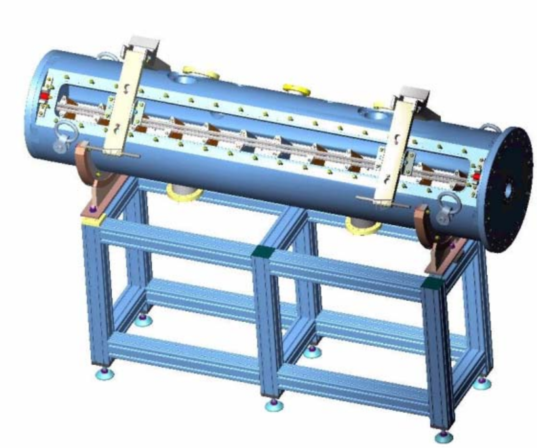

Figure 6: Schematic drawing of the planned RFQ.

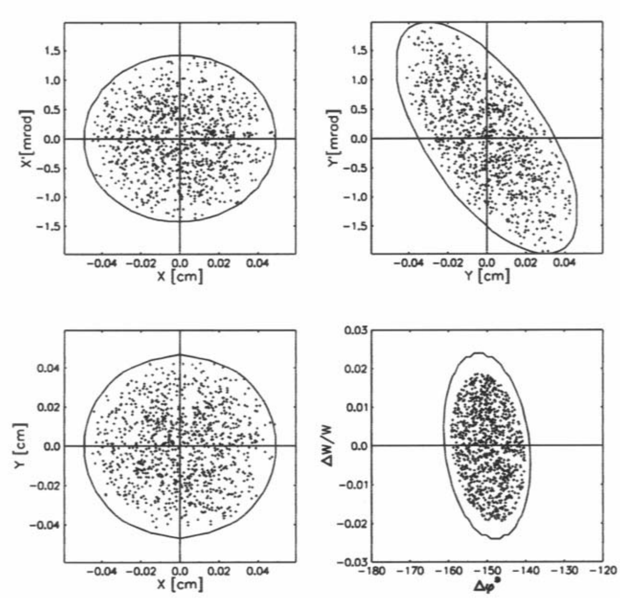

Figure 7: Input emittances of the RFQ.

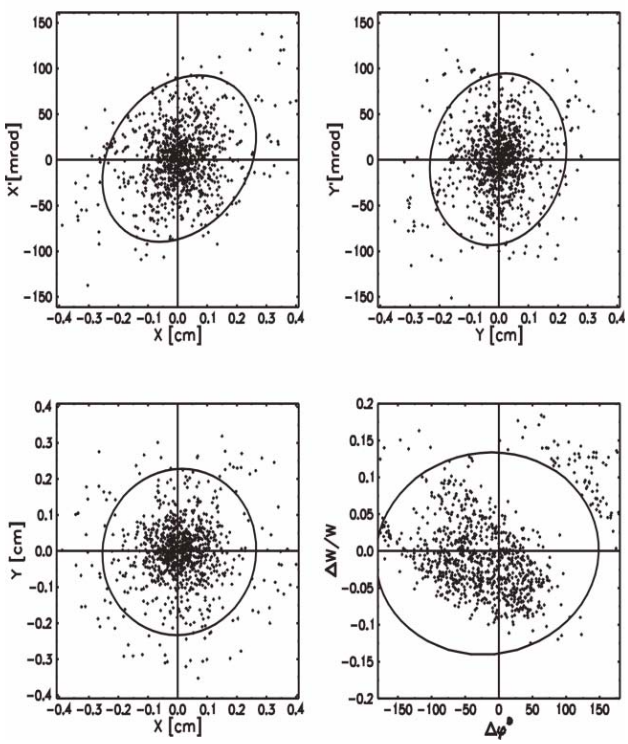

Figure 8: Output emittances behind the RFQ at 6 AkeV

LEBT SECTION

The LEBT section performs the matching of the ions into the 5 T soleonidal magnetic field of the cooler trap. As the RFQ output 6D emittance projections in the vertical and horizontal planes are similar, transport is done with two solenoidal magnets.

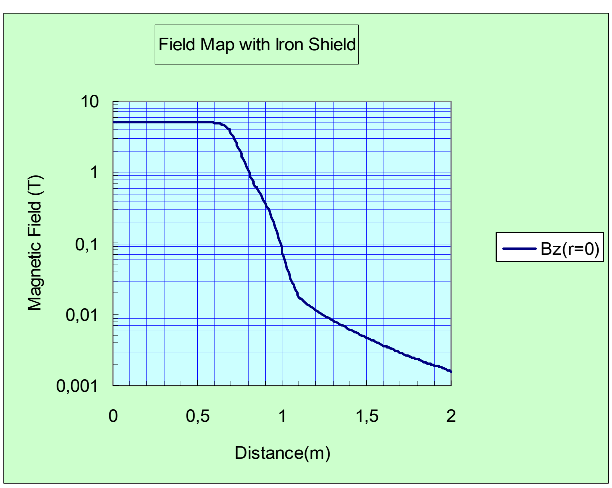

Figure 9: Solenoidal magnetic field of the trap along the axis. The origin is the center of the cooler trap.

Matched injection means a minimum radial-energy increase, i.e. minimum conversion of axial energy into transverse energy.

Parameters to play with injection are the radial size and position on the field axis of the focus. Trajectories are calculated with SIMION 3D 7.0. The optimization is performed in a 4 step iteration:

1. Determination of radial size which gives the smallest transverse energy increase for different at a fixed focus position.
2. Determination of the focus position which gives the smallest transverse energy increase pickup with the previous radial size.
3. Step 1 is reloaded with the focus position obtained in step 2.
4. Step 2 is reloaded with the radial size obtained in step 3 and verification that an overall minimum has been found.

Table 2: Beam energies, velocities and normalized emittances along the decelerator.

	Trans-mission	$\varepsilon_{x,n}=(\varepsilon_{y,n})$ [πmm mrad]	$\varepsilon_x=(\varepsilon_y)$ [πmm mrad]	δp/p
ESR		0.06	0.7	10^{-4}
Entrance IH	30%	0.2	2.2	$1.3\ 10^{-2}$
Entrance RFQ	100%	0.24	7.3	$2\ 10^{-2}$
Exit RFQ	93%	0.37	100	$8.3\ 10^{-2}$

SUMMARY AND OUTLOOK

The proposed HITRAP decelerator meets the specification: the 0,37 π mm.mrad normalized linac output emittance is well below the 0,72 π mm.mrad upper limit for an efficient injection into the cooler trap.

Nevertheless further investigations on the beam matching into the strong magnetic field of the trap have to be done. The fast extraction of the 4A MeV beam from the ESR is planned to be tested in September 2004.

Since some components are already available at GSI, the mid term HITRAP project is rather economic. The cost estimation is less than 700 k€ for the decelerator and associated matching section. The first beam is scheduled in early 2007.

REFRENCES

[1] *HITRAP technical design report,* GSI-10/2004.

[2] U. Ratzinger, Habilitationsschrift, Frankfurt University, July 1998, Germany.

[3] J. Klabunde et al., *Upgrade of the HLI-RFQ accelerator*, LINAC 1994, Tsukuba, Japan.