PROPOSAL OF A CONVENTIONAL MATCHING SECTION AS AN ALTERNATIVE TO THE EXISTING HSI MEBT SUPERLENS AT GSI UNILAC*

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Abstract

We propose a new design for the MEBT section of the High Current Injector (HSI) [1] at the GSI UNILAC as part of the planned UNILAC upgrade for the FAIR project. The existing MEBT section was designed in 1996 [2] and was based on a novel concept called the superlens (SL) which uses a magnetic quadrupole doublet lens combined with an 11-cell RFQ cavity for transversal and longitudinal focusing. In 2009 the RFQ section in front of the MEBT was upgraded [3] which led to significant changes in the RFQ output particle distribution. Recent LORASR simulations show that for high currents the superlens transmission decreases to 90 % (related to 20.75 mA U^{4+} at input). Moreover, the matching to the following IH-DTL is not ideal. This leads to further losses in the IH-DTL and to a decrease of the overall UNILAC efficiency. To reach the FAIR requirement of 18 mA U^{4+} current at the 1.4 AMeV gas jet stripper of the UNILAC within normalized transverse emittance values below 0.6 mm mrad and to provide more flexibility for varying current level operation, a new design based on two magnetic quadrupole triplet lenses and a 2-gap buncher is proposed. The design shows full transmission at 20.75 mA U^{4+} current and improved matching to the IH-DTL, leading to lossless beam transport along the IH-DTL. For improved transmission through the IH-DTL, the effect of the input phase was investigated.

PERFORMANCE OF THE CURRENT SUPERLENS MEBT

Simulations show that after the RFQ upgrade in 2009 [3] the superlens has to be operated at high currents to meet the FAIR requirements due to the losses in the superlens and following IH-DTL. Figure 1 shows that the aperture of the superlens electrodes is too small for the incoming beam which leads to significant losses of up to 10 % at full current. To investigate the matching of SL and IH-DTL, the input acceptance of the IH-DTL was determined by using the original design input distribution (ideal) and by increasing the emittance until particles were lost (acceptance). Comparison of the superlens output distribution with the IH-DTL acceptance (see Fig. 2) shows that the superlens is not ideally matched to the IH-DTL. This results in high emittance growth and in losses along the IH-DTL, leading to a total transmission of 85.7 % for the SL+IH-DTL. This corresponds to an output current behind the IH-DTL of 17.78 mA U^{4+} for an input current of 20.75 mA U^{4+}. In conclusion, the superlens has to be operated at its limit, accepting high particle losses, to reach the FAIR-requirements of 18 mA U^{4+} at the end of the HSI prestripper section.

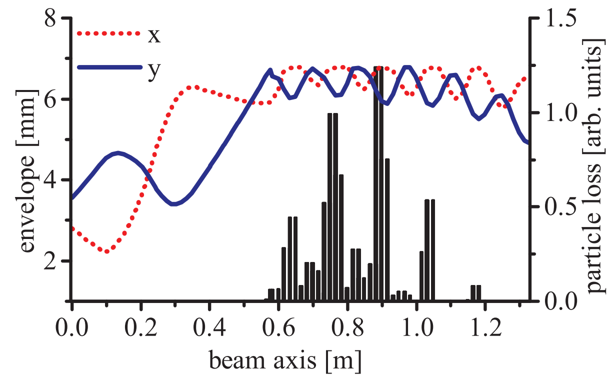

Figure 1: Loss profile of the current MEBT superlens for 20.75 mA U^{4+}. Plottet beam envelopes are 100 %, the superlens aperture is 6.8 mm.

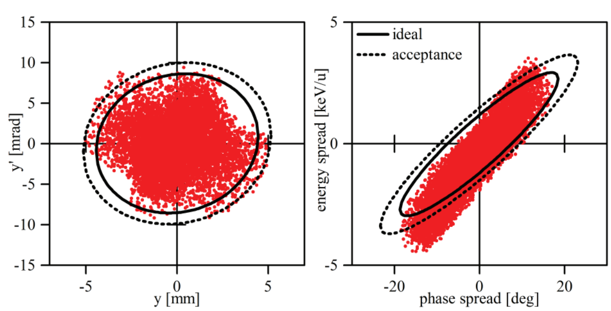

Figure 2: Output distributions of the superlens MEBT with IH-DTL acceptance ellipses.

CONVENTIONAL MATCHING SECTION

As an alternative to the current MEBT section, a conventional design (see Fig. 3) consisting of two magnetic triplet lenses and a two-gap buncher cavity is proposed. This layout allows to reuse the existing XY-steerer, the vacuum valve and the diagnostics box. It also provides some spare room for additional/redesigned components. The lenses have field gradients of 91.5 $\frac{T}{m}$ which results in 1.1 T at the magnet pole tips (for 24 mm pole aperture).

The buncher cavity is designed for 36.136 MHz, therefore a spiral cavity might be chosen due to its low diameter (0.5 m, e.g. [4]). The effective gap voltage for a beam current

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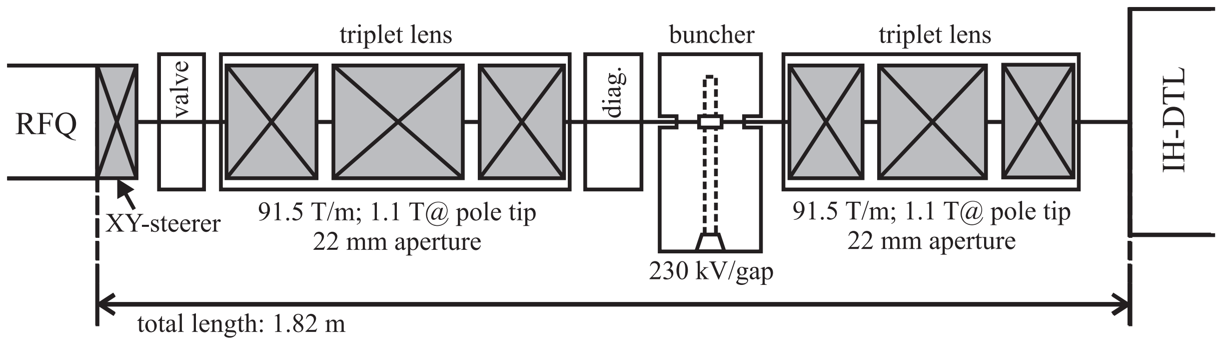

Figure 3: Layout of the proposed MEBT section showing all components including the valve, XY-steerer and diagnostics box from the current MEBT section.

of 20.75 mA U^{4+} is 230 kV. With a total length of ~1.82 m it is 0.42 m longer than the current MEBT. A short alternative fitting within the existing MEBT length was also investigated (see Table 2).

Beam Dynamics Simulation

For the design of the MEBT section an equivalent waterbag distribution was modeled based on the RFQ output distribution after the upgrade in 2009. All simulations were performed using this waterbag distribution as input. The proposed design shows full transmission for 20.75 mA U^{4+} input current. It was optimized using LORASR simulations to match the IH-DTL requirements and to provide flexibility for varying current level operation. The MEBT output distribution is shown in Fig. 4.

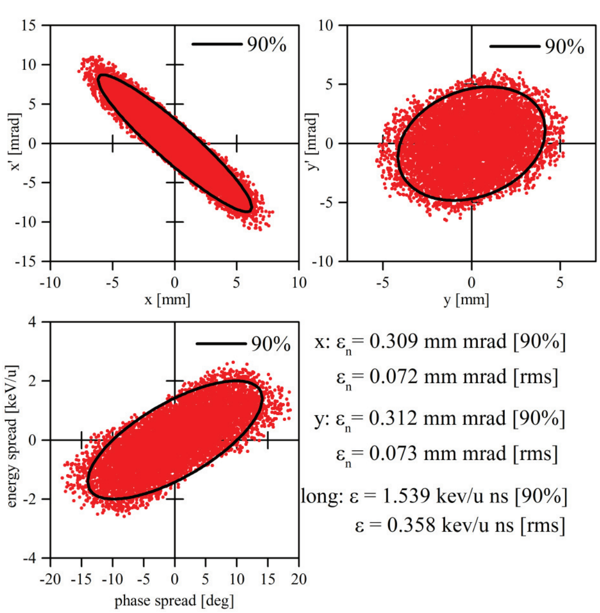

Figure 4: Output particle distribution of the proposed MEBT section.

The longitudinal output of the proposed MEBT design shows a wider energy spread for a given phase and spans a smaller phase range compared to the initial design distribution of the IH-DTL. To compensate this, longitudinal

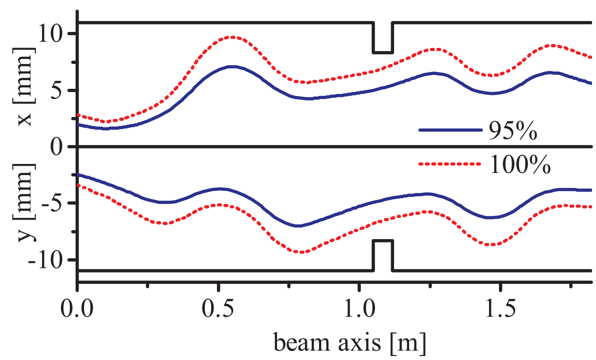

Figure 5: Transversal beam envelopes of the proposed MEBT design. Apertures are plotted in black.

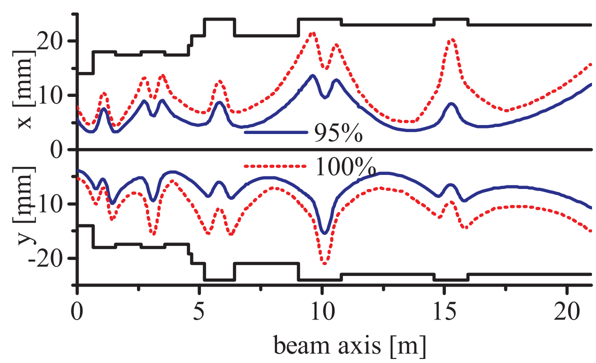

Figure 6: Transversal beam envelopes of the IH-DTL using the input from the proposed MEBT design. Apertures are plotted in black.

matching is improved by changing the input phase at the IH-DTL entrance. Decreasing the starting phase ϕ_{in} of the bunch center particle for the first zero degree section of the IH-DTL by 5 degrees is beneficial for the output of the proposed MEBT design (for the current superlens or the ideal input distribution of the IH-DTL however, this would result in slightly worse transmission and emittances). Using this approach, the simulation shows full transmission through the IH-DTL and the resulting longitudinal rms emittance is improved from 0.625 $\frac{keV}{u}ns$ to 0.517 $\frac{keV}{u}ns$. Using

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the same input distribution while changing the current, full transmission through MEBT+IH was confirmed for 10 mA, 18 mA, 20.75 mA and 98.99 % transmission for 35 mA U^{4+} (see Table 2) with adjusted gap voltages and magnetic field gradients. This of course neglects changes of the input distribution for the different currents but still shows how flexible the new design is in terms of operating current.

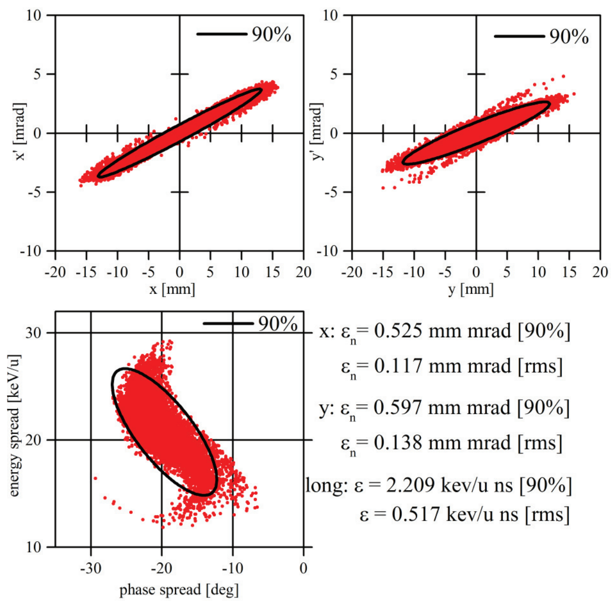

Figure 7: Output particle distribution of the IH-DTL with optimized MEBT.

Table 1: Comparison of the Simulated Parameters of the Superlens and the Proposed MEBT

	SL MEBT	New MEBT
Total length	1.4 m	1.82 m
Design current	16.5 mA	20.75 mA
Design A/q	65	59.5 (U^{4+})
MEBT-out	20.75 mA U^{4+}	20.75 mA U^{4+}
Transmission	87.94 %	100 %
$\epsilon_{n,90\%}$[mm mrad]	x:0.486 y:0.4	x:0.309 y:0.312
$\epsilon_{90\%}[\frac{keV}{u}$ ns]	1.524	1.539
ϵ_{rms} [mm mrad]	x:0.108 y:0.09	x:0.072 y:0.073
ϵ_{rms} [$\frac{keV}{u}$ ns]	0.389	0.358
IH-out		
Transmission	85.7 %	100 %
$\epsilon_{n,90\%}$[mm mrad]	x:0.732 y:0.694	x:0.525 y:0.597
$\epsilon_{90\%}[\frac{keV}{u}$ ns]	4.59	2.209
ϵ_{rms} [mm mrad]	x:0.162 y:0.158	x:0.117 y:0.138
ϵ_{rms} [$\frac{keV}{u}$ ns]	1.279	0.517

The performance of the conventional matching section and the current superlens MEBT are compared in Table 1. The improvement of rms emittances behind the IH-DTL is 27.8 %, 12.7 % for x-x',y-y' and 59.6 % for the longitudinal plane respectively. Figure 6 shows the transversal beam envelopes along the IH-DTL. The beam is not limited by the existing apertures in the IH-DTL. The resulting output distribution of the IH-DTL is shown in Fig. 7.

Table 2: Comparison of the Simulated Parameters of the Proposed MEBT for 35 mA U^{4+} and the Short Alternative MEBT for the Design Current of 20.75 mA U^{4+}

	MEBT 35 mA	Short
Total length	1.82 m	1.39 m
Current	35 mA U^{4+}	20.75 mA U^{4+}
IH-out		
Transmission	98.99 %	99.96 %
ϵ_{rms} [mm mrad]	x:0.136 y:0.159	x:0.125 y:0.157
ϵ_{rms} [$\frac{keV}{u}$ ns]	0.575	0.54

CONCLUSION

The proposed alternative MEBT design shows huge benefits over the current superlens MEBT. The existing MEBT shows restricted flexibility at modified beam parameters, resulting in emittance blow up and in beam losses. By designing a conventional matching section based on the current RFQ output, the required current of 18 mA U^{4+} can, according to simulations, be reached and even surpassed without losses in the prestripper section. Achieved emittances after transmission through the IH-DTL are significantly reduced - by even 59.6 % in the longitudinal plane! Transversal beam dynamics requires the section to be 0.42 m longer than the current MEBT, which can partly be used for additional diagnostics. Simulations with currents from 10 to 20.75 mA U^{4+} show lossless transmission for the MEBT+IH and low losses at 35 mA U^{4+}. Upgrading the MEBT section would significantly improve the overall UNILAC efficiency and provide flexibility for high current operation which is required for FAIR.

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