# ERROR EFFECTS AND PARAMETER ANALYSIS FOR A HIDIF DTL*

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*Abstract*

In the framework of the European HIDIF (Heavy Ion Driven Inertial Fusion) study, a conventional 200 MHz Alvarez DTL (Drift Tube Linac) that accelerates a high current (400 mA) $Bi^+$ ion beam from 10 MeV/u up to 50 MeV/u has been proposed as main linac. Single particle beam dynamics calculations have been performed in presence of field amplitude and phase errors, misalignments, and using different input distributions. The beam dynamics design has been checked in order to fulfil the stringent conditions for injection into the following rings, keeping a small rms emittance growth and avoiding halo formation, which could cause losses from the very intense beam. Results of beam dynamics calculations are presented and discussed. The longitudinal phase space distribution is shown after a bunch rotation cavity, located 170 m behind the linac.

## 1 INTRODUCTION

A driver scenario for heavy ion driven inertial fusion has been worked out, which is based on a rf linac and storage rings approach [1]. The scheme is given in Fig. 1: at the low energy end the required powerful beam is created by 16 single beams, which are extracted from an array of ion sources, preaccelerated and merged together by a funnel tree in several steps [2]. For proper ring injection the beam is also chopped into macropulses of 250 ns before being injected into the main linac, where the main acceleration to the final energy of 10 GeV takes place. The following rings serve for accumulation and bunch compression to achieve the needed current multiplication.

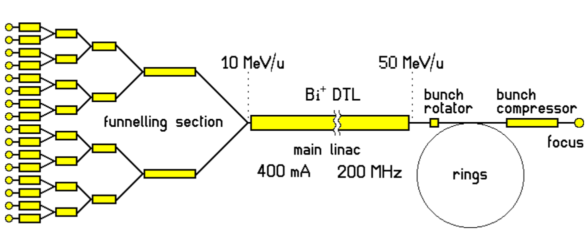


Fig. 1: Scheme of the heavy ion driven inertial fusion.

## 2 LAYOUT OF THE MAIN LINAC

A preliminary layout of the main linac has been made for an Alvarez type DTL, leading to the parameters of Table 1 [3]. With a 5F5D focusing scheme the maximum pole tip field is limited to 1.15 T (bore radius 1.6 cm).

The electric field amplitude of 3.0 MV/m gives a calculated shunt impedance of 26 MΩ/m. Single particle beam dynamics simulations showed that the strong requirements for good ring injection (transverse emittance $< 4\pi$ mm mrad, momentum spread $< \pm 2\times10^{-4}$ for 99% of the beam, very low particle losses) could be fulfilled with the following beam parameters at the linac input: injection energy 10 MeV/u, bunch length $\pm 18^o$, momentum spread $\pm 0.14\%$, transverse emittance 0.176 $\pi$ mm mrad (rms, norm.), 4d waterbag distribution transversely and 2d waterbag longitudinally (which means a cylindrical bunch). Only a small increase in the rms emittances ($< 5\%$ transversely, $< 10\%$ longitudinally) was observed, but no errors or misalignments were included in the calculations. Therefore in a next step the influence of phase and amplitude jitter of the accelerating electric field has been investigated and different initial distributions at the linac input were used.

Table 1: Linac and beam parameters.

| | | |
|---|---|---|
| Mass number | 209 (Bi+) | |
| Frequency | 200.0 | MHz |
| Current | 400 | mA |
| Number of cells | 9775 | |
| Total length (10-50 MeV/u) | 3383 | m |
| Min. aperture radius | 1.6 | cm |
| Max. pole tip field | 1.15 | Tesla |
| Electric field amplitude $E_0T$ | 2.80-2.88 | MV/m |
| Total energy gain | 40.0 | MeV/u |
| Peak beam power, 60% chopping | 690 | kW/m |
| Peak dissipated power | 320 | kW/m |
| Average shunt impedance | 26 | MΩ/m |
| Transv. rms norm. emittance | 0.176-0.183 | $\pi$ mm mrad |
| Long. rms norm. emittance | 1.66-1.83 | $\pi$ ns keV/u |

## 3 PARTICLE DYNAMICS SIMULATIONS

### 3.1 Main Linac

For the calculations, uncorrelated phase and amplitude errors were assumed randomly distributed between the limits of ±1% in amplitude and $\pm 1^o$ in phase. As a result, the center of the bunch starts to oscillate with respect to the design phase and energy, as shown in Fig. 2-L*eft*.

When repeating the calculations for different sets of errors, the position of the bunch center at the linac output changes, as shown in Fig. 2-*Right*, where its position is plotted for 100 sets. Due to limitations in computing time,

* Work in Frankfurt supported by the BMBF.

no space charge was included here. In all simulations the bunch moves as a whole, only little additional filamentation and emittance growth appear. These important results have also been achieved in all calculations with the full design current of 400 mA.

In addition, the input distribution has been changed: calculations have been done with Gaussian distributions cut at 2.5 and 3 $\sigma$ and with a 6d waterbag (which means an ellipsoidal bunch). Keeping the old rms values, only small differences in output emittances could be seen [4].

In Fig. 3 the full emittances are plotted along the linac for a 6d waterbag input distribution, including phase and amplitude errors; they are compared to the case with 4d-2d waterbag input and no errors. The transverse emittances are slightly larger because the rms value was kept constant. The radius for 100% of the beam stays however below 9 mm compared to an aperture radius of 16 mm. In the plot of longitudinal emittance one can clearly see the movement of the bunch center, which is not subtracted.

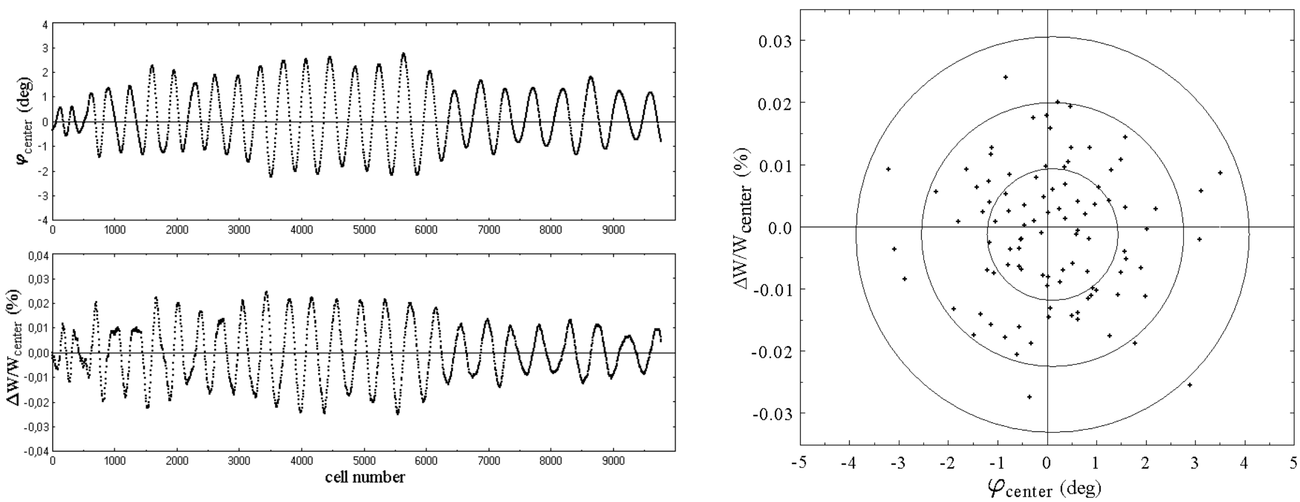


Fig. 2: Center of bunch position with uncorrelated amplitude and phase errors: *Left*: along the linac with 20,000 particles and full current. *Right*: at linac output with 5000 particles and no current (statistics over 100 different sets).

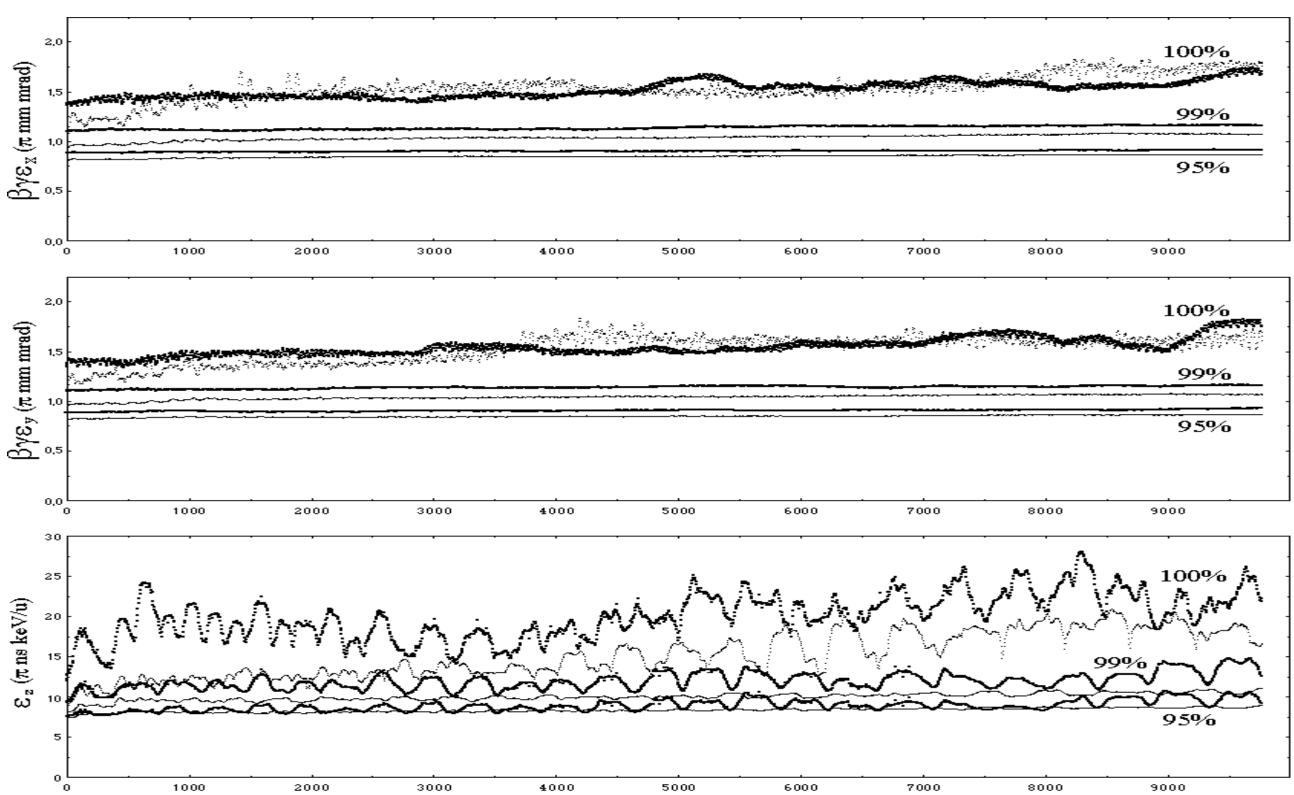


Fig. 3: Full (100%, 99%, 95%) emittance along the linac for a 6d waterbag input with 20,000 particles, including errors (bold curves) compared to a 4d-2d waterbag input with 20,000 particles and no errors (light curves).

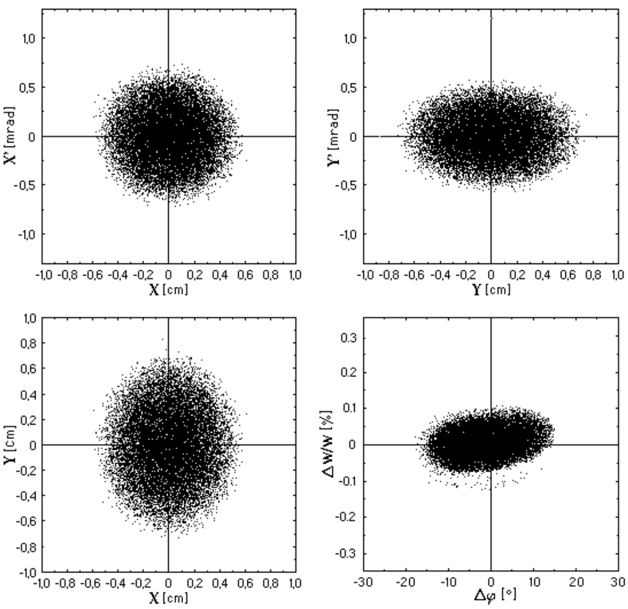


Fig. 4: Output distribution at the linac end for 20,000 particles; 6d waterbag input, phase and amplitude errors.

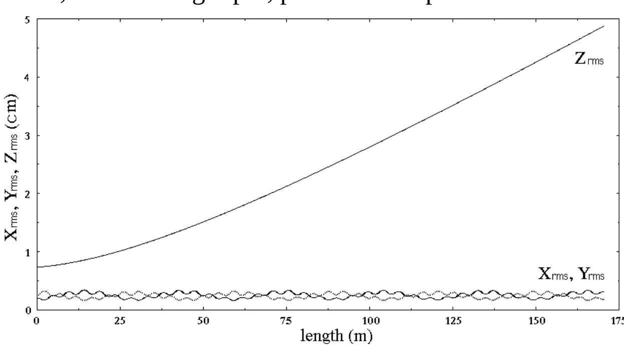


Fig. 5: Bunch rms length and radius along transfer line.

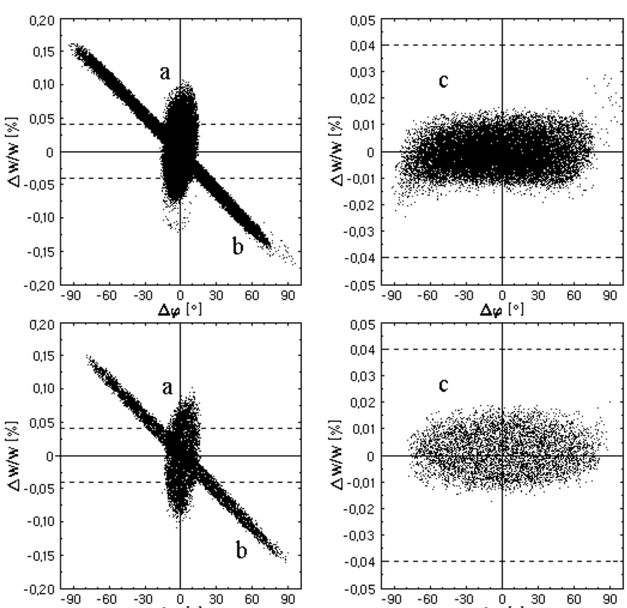


Fig. 6: Longitudinal phase space: a) at linac end; b) at transfer line end; c) after linear rotation. *Up*: for 20,000 particles with 6d waterbag input and errors. *Down*: for 5000 particles with 4d-2d waterbag input and no errors.

In Fig. 4 the output emittances are plotted at the end of the linac for 6d waterbag with errors: only in the longitudinal plane some additional filamentation can be seen.

First calculations with additional errors in the quadrupole gradients indicate that also the resulting effects should be studied carefully [4].

## *3.2 Transfer Line*

To meet the conditions for ring injection the beam must be transported and rotated into the right position in a transfer line. After about 170 m, the phase width of the bunch increased to about $\pm 80^{\circ}$ and, due to the not negligible longitudinal space charge forces, the energy spread is enlarged by about a factor 1.5. By a bunch rotation cavity placed here, the energy spread can now be reduced below the required value of $\pm 4\times 10^{-4}$ (Figs. 5–6). In principle, image-charge cannot be neglected, but they only have minor effects on the particle distribution [5]. Taking into account the resulting phase and energy deviations of Fig. 2-*Right*, phase and amplitude errors smaller than $\pm 1^{\circ}$ and ±1% (randomly distributed) are tolerable in the linac.

# 4 CONCLUSION

A layout of a 400 mA $Bi^{+}$ DTL accelerating the ions from 10 to 50 MeV/u with less than 10% rms emittance growth has been found. Investigation of phase and amplitude errors combined with different input distributions showed an increase of the longitudinal rms emittances up to 15%, but the bunches stay well confined with only small additional filamentation effects. After bunch rotation in the transfer line, the requirement for proper ring injection can be fulfilled: more than 99% of the particles have a momentum spread $< \pm 2\times 10^{-4}$. Transversely the ratio between rms and full emittance is somewhat smaller than 10, but about half of the aperture is filled only, which is considered to be a good safety margin.

In a next step the influence of beam mismatch has to be investigated, which can cause a strong emittance growth, especially in the longitudinal phase space.

Future plans in the HIDIF study group deal with a higher gain machine, which implies for the linac a higher current and a larger beam emittance.

# REFERENCES

[1] I. Hofmann, “HIDIF − an approach to high rep-rate inertial fusion”, Proc. of 12th Int. Symp. on Heavy Ion Inertial Fusion, Heidelberg, Germany, September 1997, to be published on Nucl. Instr. & Meth. A.

[2] A. Schempp “The injector for the HIDIF study”, *ibid*.

[3] G. Parisi, H. Deitinghoff, K. Bongardt, M. Pabst, “A heavy-ion DTL design for HIDIF”, *ibid*.

[4] G. Parisi, Ph.D. Thesis, in preparation.

[5] K. Bongardt, M. Pabst, A.P. Letchford, V.G. Vaccaro, L. Verolino “Filamentation effects and image charges in high β proton transfer lines”, Proc. of EPAC’96, Sitges, Spain, June 1996, p. 1224.