# NUMERICAL SIMULATIONS FOR THE FRANKFURT FUNNELING EXPERIMENT*

J. Thibus†, A. Schempp, IAP, J.W. Goethe-University, Frankfurt a.M., Germany

*Abstract*

High beam currents are necessary for heavy ion driven fusion (HIF) or XADS. To achieve these high beam currents several ion beams are combined at low energies to one beam using the funneling technique. In each stage a r.f. funneling deflector bunches two accelerated beam lines to a common beam axis. The Frankfurt Funneling Experiment is a scaled model of the first stage of a HIF driver consisting of a Two-Beam RFQ accelerator and a funneling deflector [1]. Our two different deflectors have to be enhanced to reduce particle losses during the funneling process. This is done with our new developed 3D simulation software DEFGEN and DEFTRA. DEFGEN generates the structure matrix and the potential distribution matrix with a Laplace 3D-solver. DEFTRA simulates ion beam bunches through the r.f. deflector. The results of the simulations of the two existing deflectors and proposals of new deflector structures will be presented.

## INTRODUCTION

The Frankfurt Funneling Experiment consists of two multicusp ion sources, a Two-Beam RFQ accelerator and a funneling deflector to bend both beam lines to a common beam axis. In 2000 first experiments with both kind of funneling deflectors have shown that funneling can be done [2].

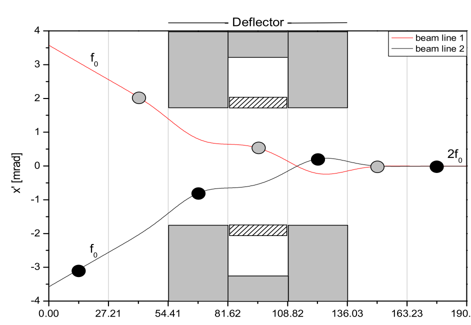


Figure 1: Principle of funneling. Two beam lines with $f_0$ are combined to $2f_0$.

Due to unmodulated RFQ electrodes in the last section the matching of the RFQ accelerator to the funneling deflector was not optimal. The beam radius and the phase width were too large. The unmodulated electrodes have now been replaced by modulated electrodes and first beam tests were done. For more information about the status of the experiment see paper [1].

The principle of funneling is displayed in fig. 1. The r.f. deflector bends alternately both beam lines to a common beam axis. In cells with even numbers the electric field bends the bunches of both beam lines in the correct direction, but not in the odd cells. To reduce this effect the odd cells are enlarged in aperture and a drift tube can be placed in the gap (shaded rectangle).

## THE SIM CODES

### *RFQSIM*

Beam dynamic transport through the RFQ accelerator is done by RFQSIM. RFQSIM is a particle simulation program especially for RFQ accelerator structures. It transports macro particle bunches in the 6-dimensional phase space segmentally through the RFQ and more than 15 transport modules such as bunchers, quadrupole, lenses and drift tubes. These modules can be placed before and behind the accelerator.

### *DefGen*

The 3D potential distribution of a deflector with fringe ranges is computed with DEFGEN [3]. The program needs an input file with geometry data to generate the structure matrix $\Theta(x, y, z)$ and the potential matrix $\Phi(x, y, z)$ of the deflector. The $\Theta$ matrix contains information of the type of the matrix element of the potential matrix $\Phi$, e.g. electrodes, drift tubes, free space, beam axis. Due to symmetry effects DEFGEN generates only a quarter of the whole 3D area to reduce iteration time and memory allocation (fig. 2). After discretisation of the deflector geometry the potential matrix $\Phi$ is generated. The matrix elements $\Phi(x, y, z)$ of the potential matrix contain the initial potential values $\Phi_0(x, y, z)$ as well as first approximated values of the free space potential. The potential distribution of the matrix is solved with a finite difference method. To shorten iteration time the Laplace Equation

$$\Delta\Phi = \left(\frac{\delta^2}{\delta x^2} + \frac{\delta^2}{\delta y^2} + \frac{\delta^2}{\delta z^2}\right)\Phi(x, y, z) = 0 \qquad (1)$$

is solved with the technique of successive over-relaxation.

* Work supported by BMBF
† thibus@iap.uni-frankfurt.de

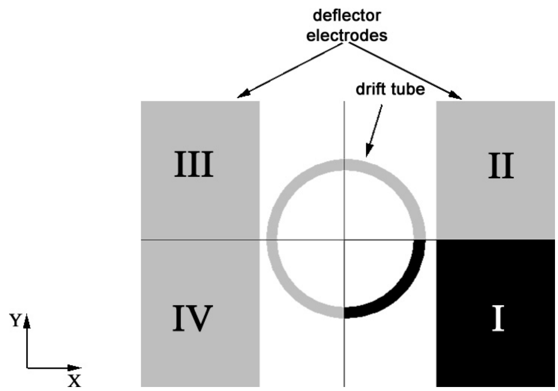


Figure 2: Schematic front view of a deflector. Only section I of the potential matrix is calculated and used for the other three sections.

## *DefTra*

DEFTRA is a particle simulation program to transport two beam lines through a funneling deflector. It needs a particle distribution file from RFQSIM. Alternatively a generated distribution can be used. Different distribution functions will be implemented. Furthermore the structure and the potential matrices generated by DEFGEN are required. The bunch of each beam line is transported segmentally through the structure and the fringe ranges. The number of segments correlates with the number of meshes along the z axis. On the basis of the present position on the mesh of the $\Phi$ matrix of each macro particle in the bunch and the corresponding r.f. phase the three electric field components for each particle are determined. The momentum of the three coordinates is calculated and transfered to the particle. It is transported to the next segment. After all particles of the macro bunch are calculated in this segment the routine repeats the calucation for the next segment. This is done over all segments. Among other things the $\Theta$ matrix is used to check if a particle collides with the deflector structure. If this happens the particle gets lost.
The development of the simulation software DEFTRA is not finished yet. It will be improved with several analysis routines like emittance tracking and a space charge routine.

# FUNNELING DEFLECTORS

In this section the potential distributions of three deflector structures are presented. The first two deflectors belong to the experiment, the third is a proposed study. In all types the cell length is $\beta\lambda/2$ = 27.24 mm.

## *The Single Cell Deflector*

The electrode aperture of the single cell deflector is 13 mm. Figure 3 shows the potential distribution in top view with four fringe cells on each side.

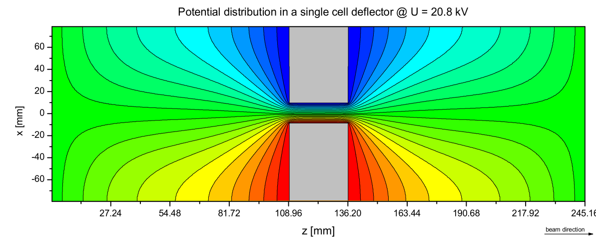


Figure 3: Intersection at the beam axis of the single cell deflector in top view of the potential distribution matrix.

## *The Multi Cell Deflector*

The multi cell deflector consists of 17 cells including drift tubes. The electrodes have an alternating aperture of 30 mm and 80 mm, beginning with 30 mm. The drift tubes have an radius of 15 mm. In figure 4 the first 5 cells are shown.

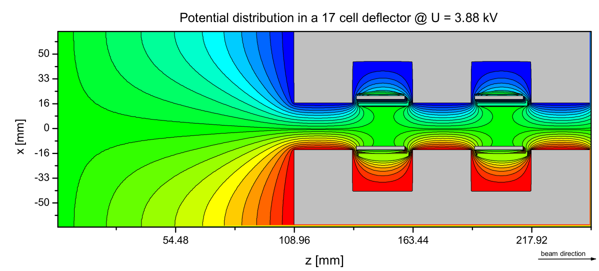


Figure 4: Top view of first 5 cells of the 17 cell deflector including fringe ranges.

## *A Proposed 9 Cell Deflector*

To reduce beam losses, beam divergency and phase spreading of the 17 cell deflector several shorter versions are investigated. A top view of a possible newer deflector version is shown in figure 5. The electrode aperture in the short gaps starts from 30 mm to 22 mm, the drift tubes in the large gaps vary from 15 mm to 12 mm.

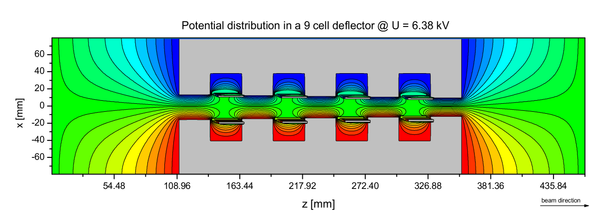


Figure 5: Intersection at the beam axis of the nine cell deflector in top view of the potential distribution matrix.

## RESULTS OF BEAM SIMULATION

Our Two-Beam RFQ accelerator is driven at a frequency of $f = 54$ MHz. The whole set-up is scaled in $He^+$ instead of $Bi^+$ of the first funneling stage of a HIF driver. The deflector is placed approximately 0.5 m behind the RFQ in the beam crossing point. Due to different deflector lengths the distance of the drift to the deflector varies.

All deflector simulations were done with DEFTRA with the same particle distribution output file from RFQSIM. Figure 6 shows the emittances of one beam axis directly behind the RFQ with an offset angle of $x' = 37.5$ mrad. The figures 7 to 9 display the emittance plots behind the respective deflector. Due to a better comparison the plots show only one beam axis. The beams are bent from $x' = 37.5$ mrad to $x' = 0.0$ mrad.

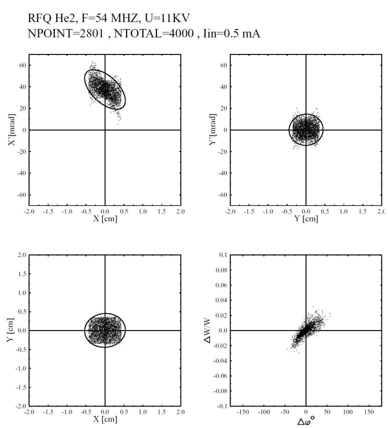


Figure 6: Emittances directly behind the RFQ. The x' coordinate has an offset of 37.5 mrad.

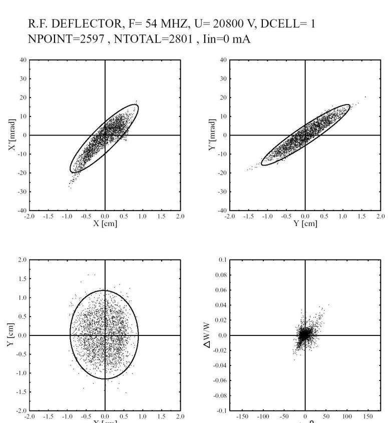


Figure 7: Emittances 11 cm behind the single cell deflector.

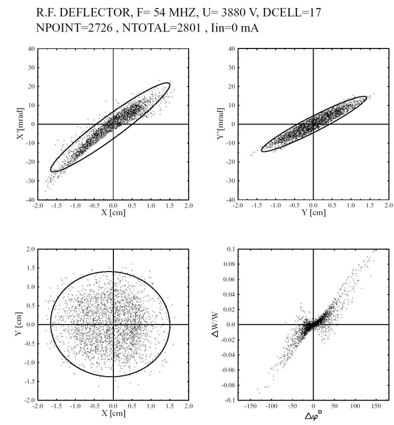


Figure 8: Emittances 11 cm behind the 17 cell deflector.

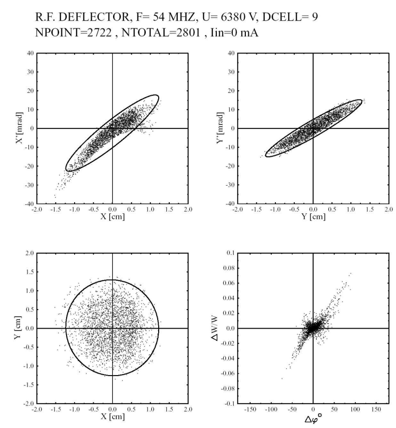


Figure 9: Emittances 11 cm behind the 9 cell deflector.

## CONCLUSIONS

The simulations show that the beam radius and the phase width of the existing 17 cell deflector are too large. Because of the short electrode aperture of 13 mm the particle losses in the single cell deflector (92.7% transmission) are greater than 17 cell deflector with an aperture of 30 mm (97.3%). Another disadvantage of the single cell deflector is the large bending voltage of about 21 kV ($He^+$) which corresponds to a MV for $Bi^+$. The 9 cell deflector is a good compromise. Further investigations have to be done to find an optimal structure.

## REFERENCES

[1] H. Zimmermann, U. Bartz, N. Mueller, A. Schempp, J. Thibus, “The Frankfurt Funneling Experiment”, EPAC’04, Lucerne, Switzerland, July 2004

[2] H. Zimmermann, A. Bechtold, A. Schempp, J. Thibus, “Funneling with the Two-Beam-RFQ”, XX Int’l Linac Conference 2000, Monterey, California, p. 791-793

[3] J. Thibus, “Status der numerischen Berechnungen zum Ionenstrahl-Funneling”, Int-Rep 01/04, IAP Frankfurt, March 2004