

THE FRANKFURT FUNNELING EXPERIMENT*

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Abstract

Funneling is a technique to multiply beam currents of rf-accelerators in several stages at low energies to prevent problems with space charge. The Frankfurt Funneling Experiment is a prototype of such a stage. Two beams are accelerated in a Two-Beam RFQ and combined to one beam axis with a funneling deflector. The last part of the RFQ electrodes of our Two-Beam RFQ has been replaced to achieve a 3d focus of both beams at the beam crossing point behind the RFQ in the center of the deflector. A new designed multi cell funneling deflector and first results of the new experimental set-up will be presented.

INTRODUCTION

The maximum beam current of a linac is limited by the beam transport capability at the low energy end of the accelerator. For a given ion source current and emittance the linac current limit is proportional to $\beta=v/c$ for electric and to β^3 for magnetic focusing channels and ideal emittance conservation.

The funneling scheme is making use of the higher current limits at higher beam energies by doubling the beam current combining two bunched beams preaccelerated at a frequency f_0 with an rf-deflector to a common axis and injecting into another rf-accelerator at frequency $2*f_0$ as shown in figure 1. Ideally the beam emittance could be staying as low as for one single beam, while extracting twice the beam from a single ion source would result in at least twice the emittance for the following accelerators.

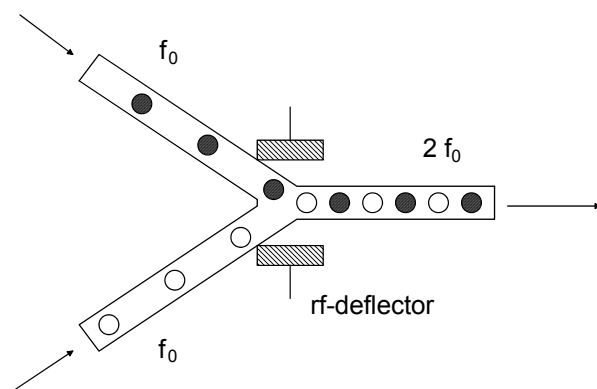


Figure 1: Principle of funneling.

At HIDIF a tree of ion linacs is planned to increase the heavy ion beam current from 25 mA Bi^{+} at the first linac to 400 mA at 10 MeV/u for the main linac.

The first linac is an RFQ with two beam channels in one resonator. By the use of the Two-Beam RFQ the two beams are brought very close together while they are still radially and longitudinally focused. Additional discrete elements like quadrupole-doubles or -triplets, debunchers and bending magnets, as they have been proposed in first funneling studies, might not be necessary [1,2,3]. A short rf-funneling deflector is placed at the beam crossing position behind the RFQ [4].

EXPERIMENTAL SETUP

The Two-Beam RFQ is designed for He^{+} -ions instead of Bi^{+} to reduce experimental expenses, facilitate operation and beam diagnostics (figure 2). Two small multicusp ion sources [5,6] and electrostatic LEBT lenses are used. The LEBTs are directly mounted at the front of the RFQ (figure 14). The angle of the two beam axis of the Two-Beam RFQ is 75 mrad.

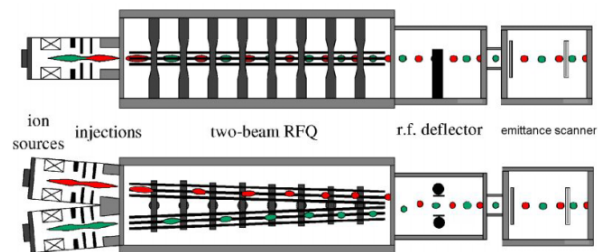


Figure 2: Scheme of the experimental setup.

The Two-Beam RFQ consists of two sets of quadrupole electrodes, where the beams are bunched and accelerated driven by one resonant structure. The RFQ electrodes are divided in two sections. The first section, which is about two thirds of the total length of 2 meters, bunches and accelerates the beam to a final energy of 160 keV. The second part has been a transport section at first with unmodulated RFQ-electrodes.

For first beam tests one RFQ-channel has been modified such, that the second unmodulated section has been replaced by a section which should match the beam to the funnel deflector to optimize beam radius and phase width. This will allow us to compare both beams directly.

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THE NEW RFQ ELECTRODES

While the old transport section had unmodulated electrodes with constant aperture, in the new design the bunch drifts for 12 cells with increasing aperture [4]. The last 8 cells have a modulation up to $m = 1.4$ to bunch the beam with the time focus at the funneling deflector. At the same time the focusing is made stronger to avoid a diverging beam and get more beam into the aperture of the deflector. Thus the RFQ provides a longitudinal and radial focus at the deflector.

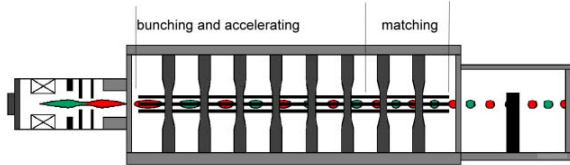


Figure 3: Accelerating and matching sections of the RFQ electrodes.

Figure 4 shows the comparison of beam dynamics simulations for the old and the new RFQ electrode end matching section. The new electrode design reduces beam radius and phase spread at the position of the funneling deflector 54 cm behind the RFQ.

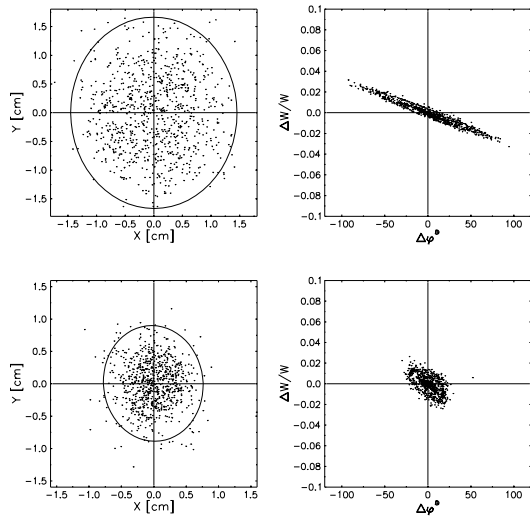


Figure 4: Transverse beam dimension and phase spread of the old (top) and the new (down) RFQ electrode matching section.

MULTI CELL DEFLECTOR

For beam bending to a common axis we use two types of deflectors, the single and the multi cell funnel deflector[7]. The multi cell deflector allows beam bending at lower voltages in the bending gap. The geometry of the multi cell deflector consists of some deflector plates divided by spaces or sections with larger aperture with same cell length of 2.54 cm (figure 6). In this geometry, the particles will see the deflecting field in one direction

several times but the deflection in the opposite direction is always less. For beam funneling, the frequency of the deflector has to be the same as the accelerator frequency, so that the bunches from different beam axes will see opposite field directions because of the phase shift of 180° between each bunch. Figure 5 shows the simulated electric field in the bending gap.

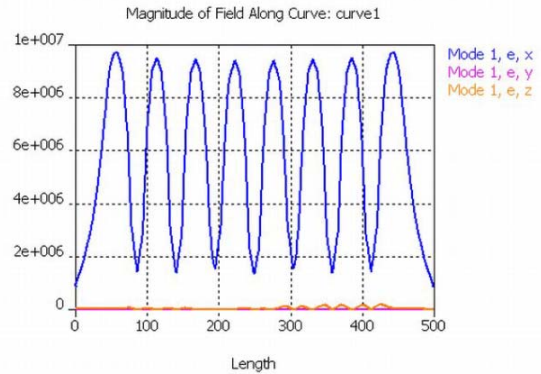


Figure 5: Microwave Studio simulation of the electric field along the bending axis.

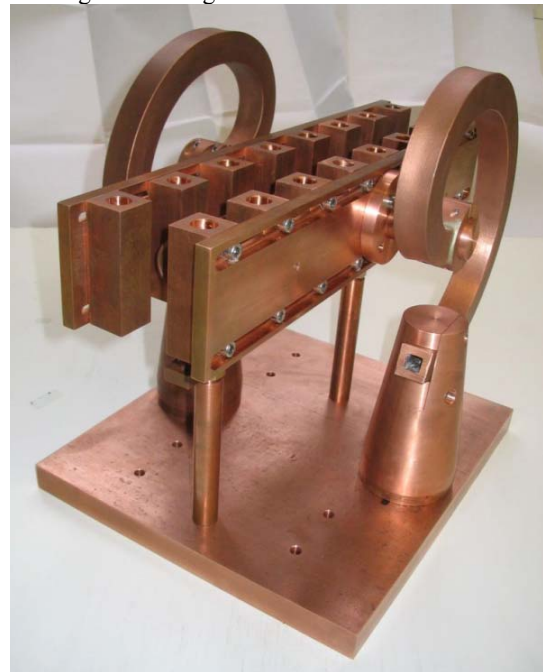


Figure 6: View of the multi cell funneling deflector.

BEAM TESTS

We have done a number of beam experiments to test the new matching out section.

Figure 7 shows an emittance measurement with one upgraded RFQ channel at the point of beam crossing. The emittance from the beamline with the matching section reduces the beam radius. The measurements are in good agreement with our simulations shown in figure 8 and

figure 4. Figure 10 shows a view of the Frankfurt Funneling Experiment.

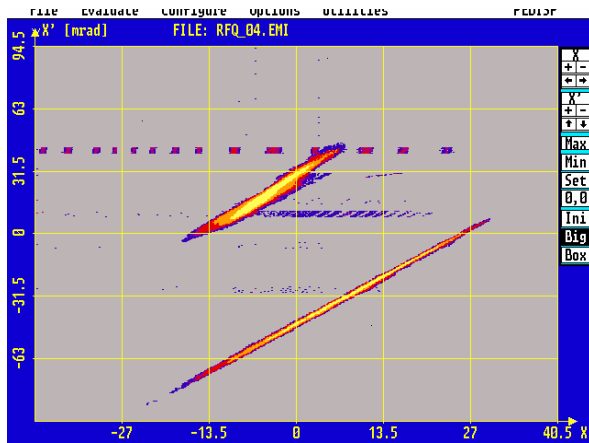


Figure 7: measured emittances with one upgraded RFQ channel.

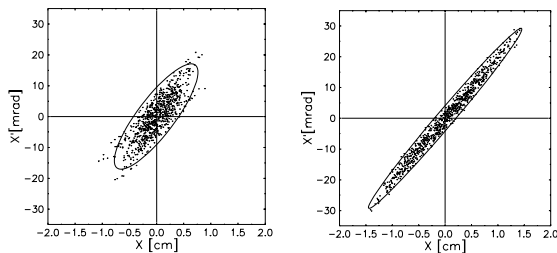


Figure 8: The simulations corresponding to the two RFQ-beams in figure 7.

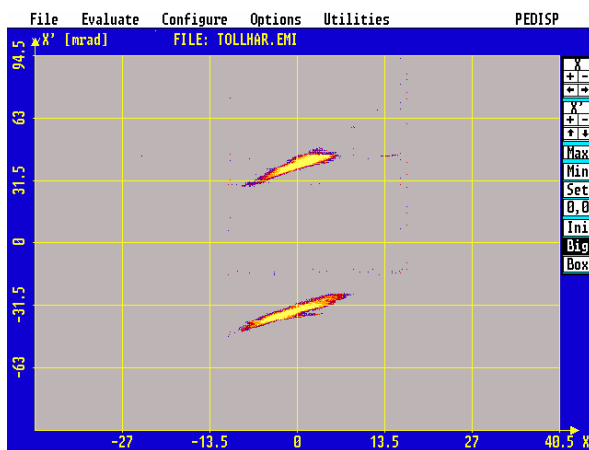


Figure 9: Emittance with the upgrade of both accelerators:

Figure 9 shows the measured emittance with the upgrade of both RFQ channel.



Figure 10: View of the Funneling experiment.

CONCLUSIONS

Our experiments with the Two-Beam RFQ have shown that funneling can be done [7,9], but the beams were not yet matched to the funneling deflector. To achieve a good funneling the beam radius and phase width at the point of the funneling deflector has to be as small as possible.

By adding a new matching section to one RFQ channel we were able to compare the two beams and see the first RFQ match.

The upgrade of both beamlines has been done. Next step will be new funnel experiments with two matched beams in our new laboratory in Niederursel, outside Frankfurt.

REFERENCES

- [1] K. Bongardt and D. Sanitz, "Funneling of Heavy Ion Beams," Primary Report, Kernforschungszentrum Karlsruhe, 11 04 02P14C (September 1982).
- [2] J.F. Stovall, F.W. Guy, R.H. Stokes and T.P. Wangler, "Beam Funneling Studies at Los Alamos," Nucl. Instr. and Meth. A278 (1989) p. 143.
- [3] K.F. Johnson, O.R. Sander, G.O. Bolmer, J.D. Gilpatrick, F.W. Guy, J.H. Marquardt, K. Saadatmand, D. Dandoval and V. Yuan, "A Beam Funnel Demonstration: Experiment and Simulation", Particle Accelerators, Vols. 37-38 (1992), p. 261.
- [4] A. Schempp, "Design of Compact RFQs," Proc. LINAC 96, CERN 96-07, p. 53.
- [5] K.N. Leung, "Multicusp Ion Sources," Rev. Sci. Instrum. 65(4) (1994), p. 1165.
- [6] R. Keller in: The Physics and Technology of Ion Sources, Edited by I. G. Brown, Wiley-New York.
- [7] H. Zimmermann, A. Bechtold, A. Schempp, J. Thibus, "Funneling with the Two-Beam RFQ," EPAC 2002, Paris, p. 972.
- [8] A.Schempp "Funneling Experiments," NIM A464 (2001), p. 395.
- [9] J. Thibus, U. Bartz, N. Müller, A. Schempp, H. Zimmermann, "The Frankfurt Funneling Experiment," EPAC 2004, p. 1213.