

# THE FRANKFURT FUNNELING EXPERIMENT\*

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## Abstract

The Frankfurt Funneling Experiment is a scaled model of the first funneling stage of a HIF driver to study the funneling technique. Funneling is a procedure to multiply beam currents at low energies in several stages. In each stage two beam lines are combined into a common beam line. The funneling technique is required for new proposed high current accelerator facilities like HIDIF. The main goal is to prevent emittance growth during the funneling process. Our experiment consists of two ion sources, a Two-Beam RFQ accelerator, a funneling deflector and a beam diagnostic system. We have funneled two beams to a single beam, but the measurements have shown a bad matching of the RFQ to the funneling deflector. With our new RFQ electrode design we achieve a special three dimensional matching to the deflector. The results of our measurements and simulations 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  $\beta^3$  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.

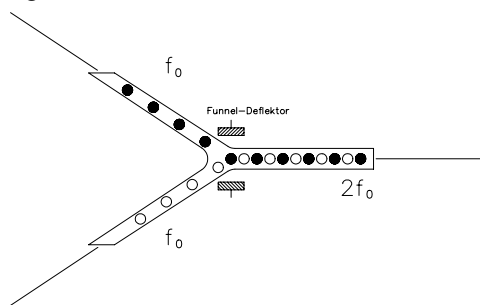


Fig. 1: Principle of funneling.

A tree of ion linacs is planned to increase the heavy ion beam current from 25 mA  $\text{Bi}^+$  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-doublers and -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  $\text{He}^+$ -ions instead of  $\text{Bi}^+$  to reduce experimental expenses, facilitate operation and beam diagnostics (fig. 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 (fig 6). The angle of the two beam axis of the Two-Beam RFQ is 75 mrad.

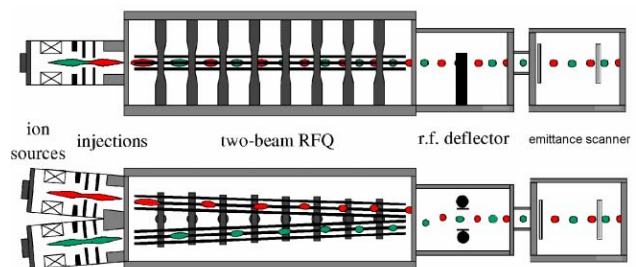


Fig. 2: Scheme of the experimental set-up.

The Two-Beam RFQ consists of two sets of quadrupole electrodes (fig. 4), 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. 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 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.

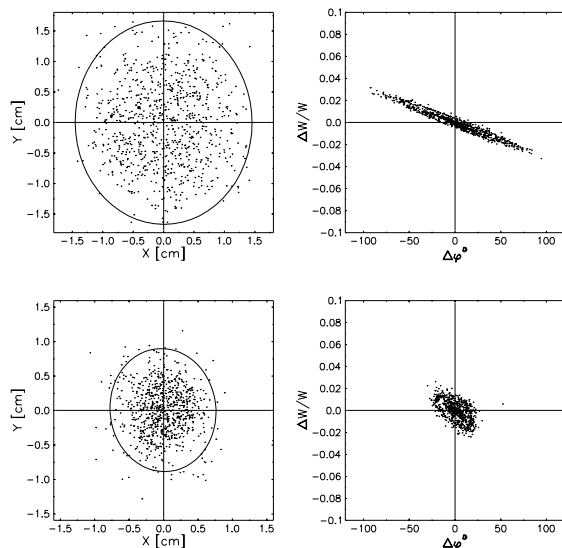


Fig. 3: Beam data with the old (top) and the new (down) RFQ electrode matching section.



Fig. 4: RFQ-Electrodes.

## BEAM TESTS

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

Figure 5 shows the beam pulses of the RFQ at the point of the beam crossing, 54 cm behind the RFQ. The matching section in the new beamline reduces the pulse length. The Faraday cup used has only a restricted bandwidth and cannot resolve the pulses with high resolution. But the results clearly show the improvements of the pulse width.

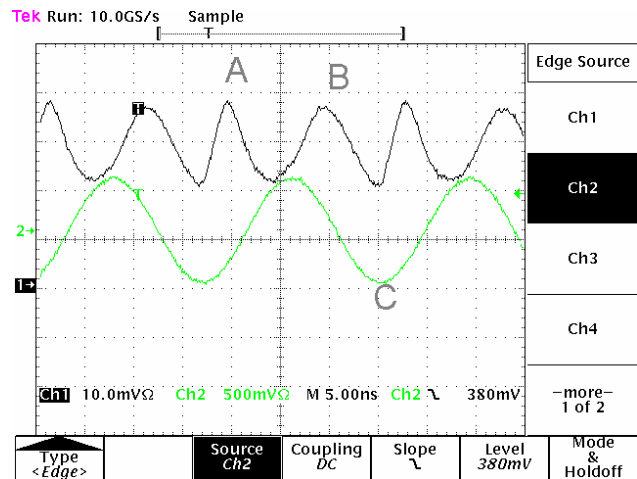


Fig. 5: Beam bunch measurements with both beams.

A: New matching electrode end section  
B: Unmodulated electrode end section  
C: 54 MHz RF-signal

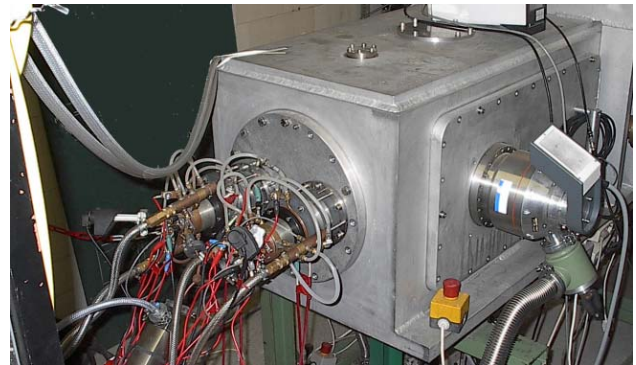


Fig. 6: Ion sources mounted directly to the RFQ tank.

Fig. 7 shows an emittance measurement with both beams 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 fig. 7. Fig. 9 shows a view of the Frankfurt Funneling Experiment.

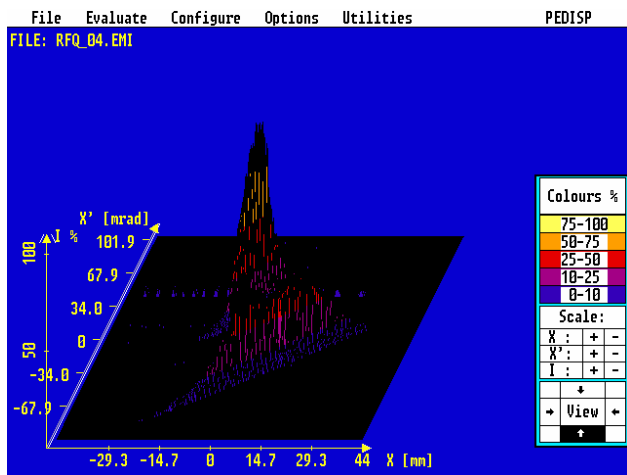


Fig. 7a: Measured emittances of both RFQ channels.

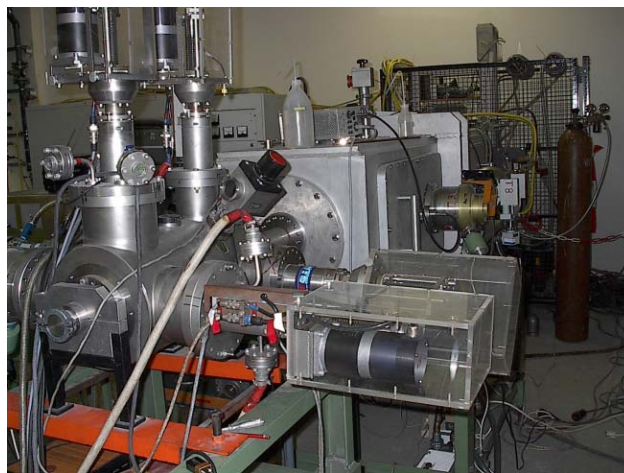


Fig. 9: View of the Funneling experiment.

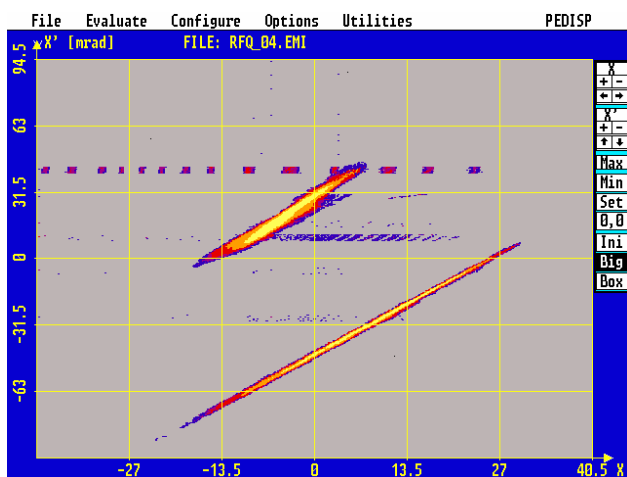


Fig. 7b: Measured emittances of both RFQ channels.

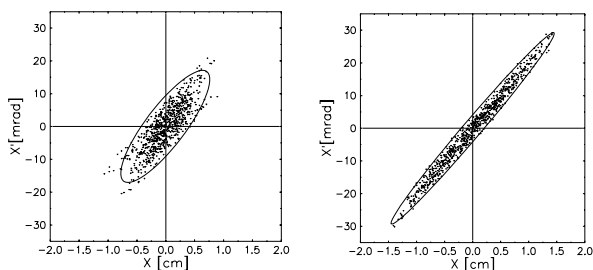


Fig. 8: The simulations corresponding to the two RFQ-beams in fig. 7.

## CONCLUSIONS

Our experiments with the two beam RFQ have shown that funneling can be done [7,9], but the beams are not matched to the funnel deflector. To achieve a better 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 could compare the two beams and see the first such an RFQ match.

The second new RFQ matching electrodes are now installed in the RFQ. Next step will be new funnel experiments with two matched beams.

## 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] H. Zimmermann, J. Thibus, N. Müller, I. Müller, A. Schempp, "The Frankfurt Funneling Experiment", PAC 2003, p. 2823