

## A NOVEL DESIGN FOR ION BEAM FUNNELING BY THE USE OF A TWO-BEAM RFQ AND A MULTIGAP-DEFLECTOR\*

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### Abstract

Heavy ion inertial fusion (HIIF) injector linacs start with a set of low frequency radio-frequency quadrupoles (RFQs), because of the small values of the current limits of linear accelerators in the low energy part. For a higher ion energy, the frequency is increased to reach a better accelerator efficiency. The accumulation of ion beam current in such a driver linac is done by multiple stages of funneling: in each stage the accelerator frequency is doubled and two beams with 180 degrees phase shift are combined to fill all the rf-buckets of the high frequency accelerator stage. In the ideal case, there is no change of the emittance and the beam current and brightness are doubled.

For the first funneling stage a two-beam RFQ, where two beams are bunched and accelerated in a single r.f. cavity and a novel scheme for an rf funneling deflector operating at low voltages has been developed. With the use of convergent beams, a short funneling structure placed around the beam crossing position seems to be possible.

### Introduction

A heavy ion inertial fusion (HIIF) driver could start with a set of low frequency radio-frequency quadrupoles (RFQs) which employs electrical r.f. focussing and provides bunched ion beams with high transmission[1,2]. The layout of a HIIF injector is shown in Figure 1.

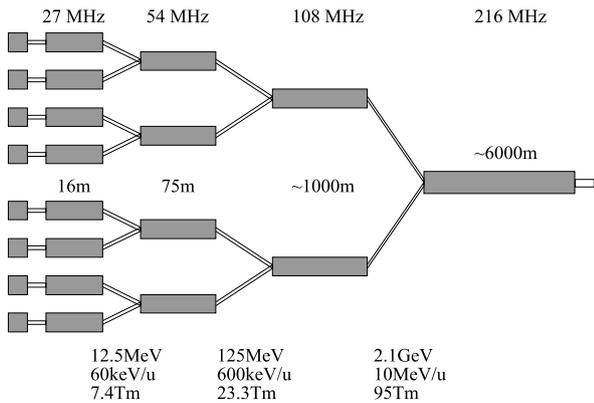


Fig. 1. Layout of a 27...216 MHz HIIF injector system for 200 mA of Bi<sup>+</sup>.

Initial funneling experiments have been done with systems of discrete elements such as quadrupole doublets and

triplets, debunchers, deflectors and bending magnets [3,4,5]. Another solution for beam funneling is the use of an accelerator structure which provides two beams within one cavity and a single r.f. deflector structure which bends the two beams to one common axis.

### The two-beam RFQ

The two-beam RFQ consists of two sets of quadrupole electrodes driven by one resonant structure. For this reason the new two-beam RFQ brings the two beams very close together while they are still radially and longitudinally focused. For the beam funneling experiment an electrode geometry of the two-beam RFQ that gives identical radial beam orientations is favourable. The two possible electrode geometries are shown in Figure 2.

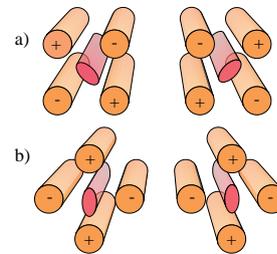


Fig. 2. Different electrode geometries for the two-beam RFQ. a) the standard geometry for a 4-rod RFQ, b) the preferred geometry for the two-beam RFQ.

The electrode capacity should be as small as possible to achieve an efficient r.f. structure. Therefore the inner electrodes of the two quadrupoles have the identical r.f. phase. With such an electrode geometry a smaller beam separation and convergent beam axes have become possible. For the support of the chosen electrode geometry (Figure 2 b) an RFQ structure with symmetric stems from the bottom to the top of the cavity is taken to minimise the dipole effects.

To study the properties of the new two-beam RFQ resonator, various kinds of prototype resonators were built and tested [6,7]. Also calculations with the MAFIA code were done for comparison with the low level measurements. A prototype resonator with a reduced length and parallel beam axis has been designed and built. The resonator consists of two pairs of electrodes with a length of 100 cm supported by four symmetric stems in linear arrangement. In high power tests the maximum r.f. input power in pulsed mode was limited to 12 kW by the r.f. power amplifier. At this

\* Work supported by the BMBF.

power an electrode voltage of 27 kV was measured. For the beam funneling experiments a two-beam RFQ 2 m long with convergent beam axes is under construction. Figure 3 shows a view of the two-beam RFQ.

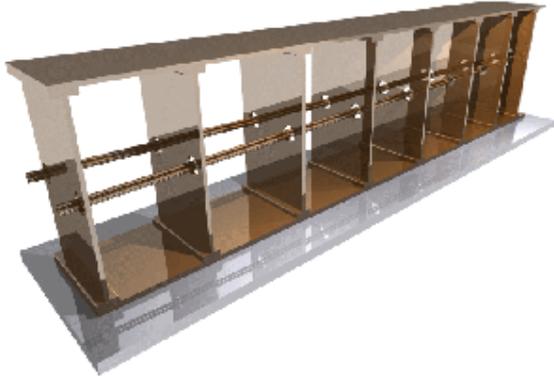


Fig. 3. View of the two-beam RFQ.

**The multigap deflector structure**

The electrode geometry of the multigap deflector consists of some deflector plates divided by spaces or sections with larger aperture with equal length. 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. The length of the capacitors have to be proportional to the particle velocity and to the inverse of the frequency of the deflector system. Figure 4 shows a scheme of the electrode geometry and the behaviour of the particles along the multigap deflector.

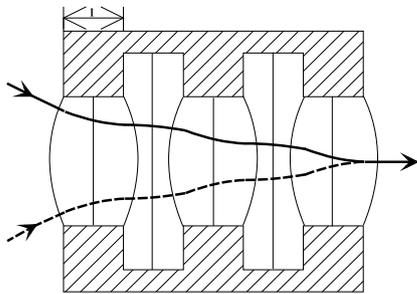


Fig. 4. Scheme of the multigap deflector.

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. If the two incoming beams are parallel, the cell length of the deflector has to be  $\beta\lambda$  ( $\beta = v/c$  with  $c =$  speed of light and  $\lambda =$  wavelength of the deflector frequency) to get a displacement only. If the two beams are not parallel, the cell length has to be  $\beta\lambda/2$  to reach a maximum change of the beam angle [8]. The r.f. resonator for the multi-gap deflector will be a structure as it is used for 4-Rod-RFQs with two

stems. Each stem is electrically contacted with one of the deflector electrodes and will sustain the other electrode by a ceramic support. For longer electrodes it is possible to use an rf structure with more stems to preserve mechanical stability. Figure 5 shows a view of the multigap deflector.

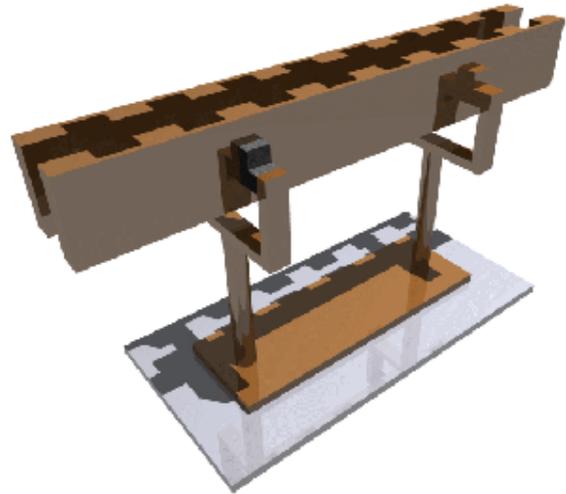


Fig. 5. View of the multigap funneling deflector.

**The two-beam funneling experiment**

The funneling experiments will be carried out with He<sup>+</sup> ions to facilitate ion source operation and beam diagnostics. Two small multicusp ion sources and electrostatic lenses, built by LBNL [9,10], will be used. A IGUN [11] simulation of one lens is plotted in figure 6.

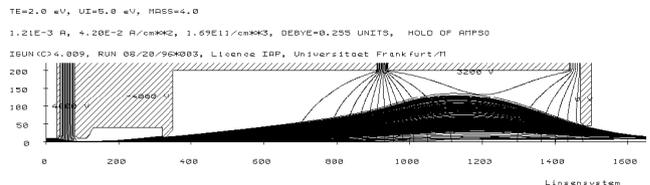


Fig. 6. IGUN simulation of the electrostatic lens.

The ion sources and injection lens will be attached directly on the front of the RFQ with an angle of 76 mrad, the angle of the beam axes of the two-beam RFQ. Figure 7 shows a photograph of the multicusp ion source attached to the injection system.

With this angle of 76 mrad the distance between the two beams at the RFQ input will be more than 160 mm and about 40 mm at the output. The electrodes are supported by eight flat stems. To achieve a proper voltage distribution along the electrodes, the distance between the supports has to be reduced along the resonator. The RFQ electrode design is in progress with the use of the PARMTEQ code. For the phase shift of 180° between the bunches of each beam, two different electrode designs with different electrode lengths are required.

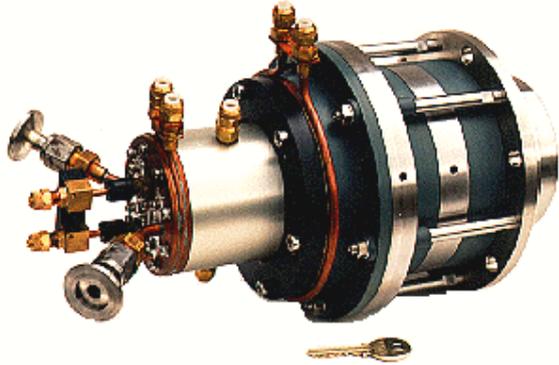


Fig. 7. Photograph of the multicusp ion source attached to the injection system.

Behind the RFQ the funneling deflector will be placed before the beam crossing. Figure 8 shows the experimental set-up of the funneling experiment. Beam diagnostics in front of and behind the RFQ and behind the funneling deflector are in preparation. The funneling resonator is under construction and a prototype for r.f. measurements has been finished.

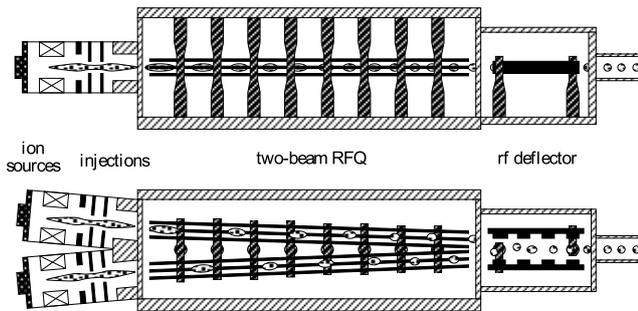


Fig. 8. Experimental set-up of the two-beam funneling experiment.

In Table 1 the main parameters of the planned experiment with He<sup>+</sup> and the design parameters of a first HIIF funneling stage for Bi<sup>+</sup> are shown.

Table 1

Two-beam RFQ	He <sup>+</sup>	Bi <sup>+</sup>
f <sub>0</sub> [MHz]	54	27
Voltage [kV]	10.5	180
R <sub>p</sub> -value [kOhm·m]	150	250
Q <sub>0</sub> -Value	2000	3000
T <sub>in</sub> [keV]	4	230
T <sub>out</sub> [MeV]	0.16	12.54
Length [m]	2	16
Angle between beam axes [mrad]	76	76
Multigap funneling deflector		
f <sub>0</sub> [MHz]	54	27
Voltage [kV]	6	273
Length [cm]	54	233
Beam separation at input [mm]	40	44

### Conclusions

The experiments and results achieved by building and evaluating the two-beam RFQ prototype resonators have provided the needed knowledge to proceed with the final design of the two-beam RFQ resonator for funneling. The MAFIA calculations for the RFQ structure and the PARMTEQ calculations for the electrode design are finished. A multigap deflector for funneling is under development. A first deflector prototype for low level measurements has been built. The ion sources and injection systems are manufactured and are running on a test stand. Next steps are the assembly of the experimental setup and the synchronisation of the two ion sources.

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