

# A TWO-BEAM RFQ FOR ION BEAM FUNNELING\*

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## Abstract

The front end of a spallation source linac, e.g. for the european spallation source (ESS) and also a heavy ion inertial fusion (HIIF) driver injector has to provide a high current and small emittance ion beam which cannot be provided by one single ion source. The space charge forces at the low energy part of the linac are the strongest current limitations. For these reasons the required beam will be reached by several funneling stages, where two identically bunched ion beams are combined into a single beam with twice the frequency, current and brightness. For the most critical 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 r.f. funneling deflector operating at low voltages has been developed. With the use of convergent incoming beams, the funneling structure will be placed around the beam crossing position. The experimental setup of a combination of a two-beam RFQ with such a deflector for funneling of two  $\text{He}^+$ -beams at low energies will be presented.

## 1 INTRODUCTION

The proposed ESS RFQ injector system consists of two parallel 54 mA RFQ-linacs, operating at 175 MHz. The beams will be combined in a new funnel system to a 107 mA beam at 350 MHz [1].

Each RFQ-line is split into two sections, one from 50 keV to 2 MeV and the second from 2 MeV to 5 MeV with the chopping line between the two RFQs to enable chopping with an unneutralised beam at a moderate energy to reduce the required chopping voltages but at an energy high enough so that the beam can be transported through the line with a minimum emittance growth. For the funnel section a new design is used, where now a two-beam RFQ will bring the beams close together. Thereby the beams can be combined in a single resonator driven rf-deflector. Figure 1 shows a schematic drawing of the ESS RFQ injector system.

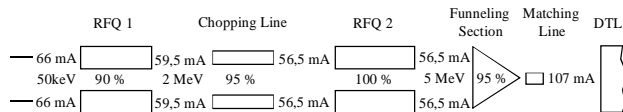


Figure 1: Schematic drawing of the ESS RFQ injector system.

A heavy ion inertial fusion (HIIF) driver could start with a set of low frequency RFQs which employs electrical r.f. focusing and provides bunched ion beams with high transmission [2,3]. The layout of a HIIF injector is shown in Figure 2.

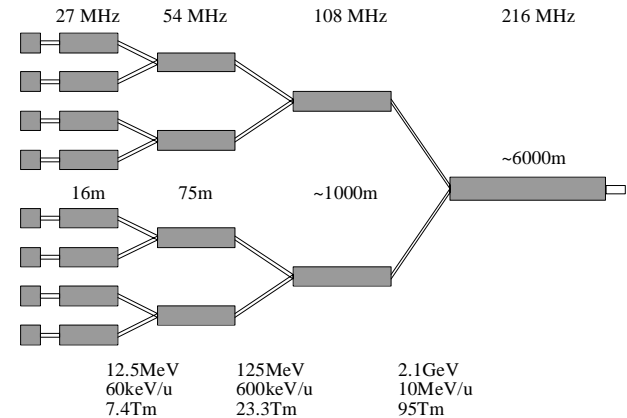


Figure 2: Layout of a 27...216 MHz HIIF injector system for 200 mA of  $\text{Bi}^+$ .

Initial funneling experiments have been done with systems of discrete elements such as quadrupole doublets and triplets, debunchers, deflectors and bending magnets [4,5,6].

## 2 THE TWO-BEAM RFQ

A new system with a two-beam RFQ and a resonator driven deflector has been investigated. A first two-beam funneling experiment includes a two-beam RFQ where the beams are bunched and accelerated with a phase shift of  $180^\circ$  between each bunch. In the two-beam RFQ the beam separation at the RFQ exit can be kept small. Therefore the r.f. funneling deflector system can operate at low voltages. To study the properties of the new two-beam RFQ resonator, different types of prototype resonators were built and tested. Also calculations with the electrostatics CAD program MAFIA [7] have been done for comparison with the low-level measurements.

For the ESS case, a combination of a two-beam RFQ, which joins the two separated RFQ 2-resonators, and a single- or multi-gap deflector has been proposed. Figure 3 shows a scheme of the ESS funneling section. In table 1, the main parameters of the two-beam RFQ and the rf-deflector are shown.

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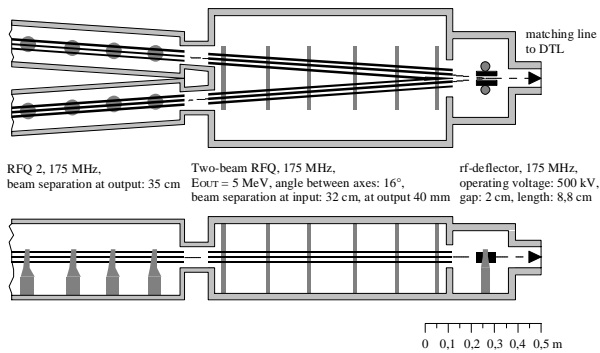


Figure 3: Scheme of the ESS funneling section.

Two-beam RFQ	
$f_0$ [MHz]	175
$E_{in}$ [MeV]	5
$E_{out}$ [MeV]	5
Length [m]	1
$N_{cav}$ [kw]	250
Angle between beam axes [mrad]	284
R.f. deflector	
$f_0$ [MHz]	175
Voltage [kV]	500
Length [cm]	8.8
$N_{cav}$ [kw]	65
Beam separation at input [mm]	12.6

Table 1: Main parameters of the two-beam RFQ and the r.f. deflector for the ESS funneling section.

### 3 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.

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  $180^\circ$  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 multigap 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 r.f. structure with more stems to preserve mechanical stability.

### 4 THE TWO-BEAM FUNNELING EXPERIMENT

The funneling experiments in Frankfurt will be carried out with  $\text{He}^+$  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.

The ion sources and injection lenses 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 4 shows a photograph of the ion source attached to the very compact electrostatic injection system.

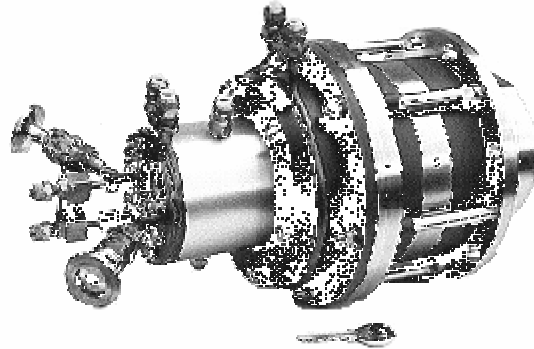


Figure 4: Photograph of the multicusp ion source attached to the injection system.

Figure 5 shows an emittance plot of the ion beam behind the extraction system. The divergent part is originated by the neutral beam and is therefore negligible.

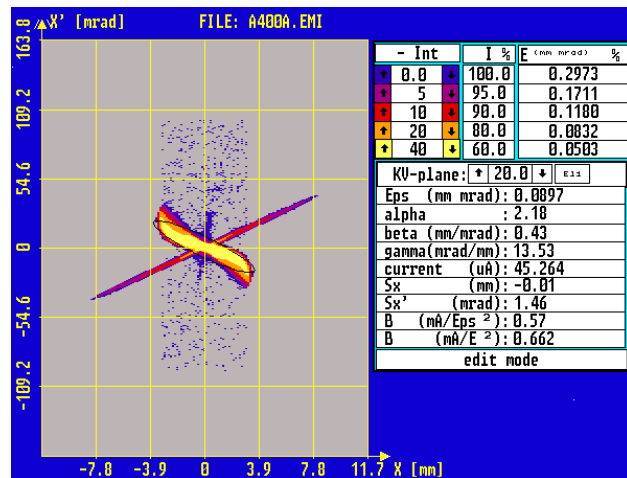


Figure 5: Emittance plot of the ion source.

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.

Behind the RFQ the funneling deflector will be placed before the beam crossing. Figure 6 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.

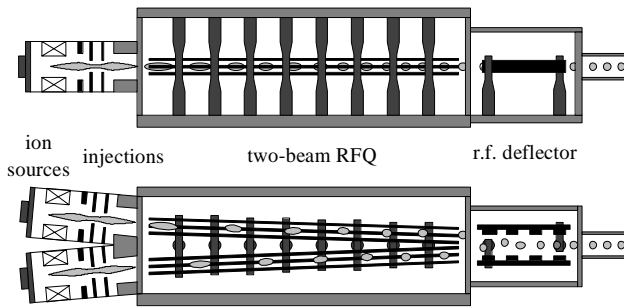


Figure 6: Experimental set-up of the two-beam funneling experiment.

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
Quality factor	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
<b>Multigap funneling deflector</b>		
f <sub>0</sub> [MHz]	54	27
Voltage [kV]	6	273
Length [cm]	54	233
Beam separation at input [mm]	40	44

Table 2: Main parameters of the experiment with He<sup>+</sup> and the design parameters of a first HIF funneling stage for Bi<sup>+</sup>.

## 5 CONCLUSION

Figure 7 shows a photograph of the low energy end of the two-beam RFQ. For first r.f. measurements unmodulated electrodes have been mounted. With these electrodes, a resonance frequency of about 57 MHz and a quality factor of 2500 was measured. Due to the lower capacity of the unmodulated electrodes compared to the modulated ones, the design frequency of 54 MHz should finally be reached. The RFQ electrode design is finished. The RFQ electrodes are divided in two parts with different functions. The first part (Figure 8) bunches and accelerates the ion beam the output energy, the second part consists of a drift length and the matching to the funneling deflector.

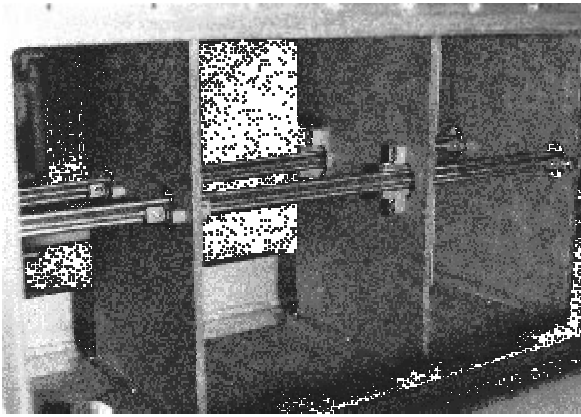


Figure 7: Photograph of the low energy end of the two-beam RFQ with prototype electrodes mounted.

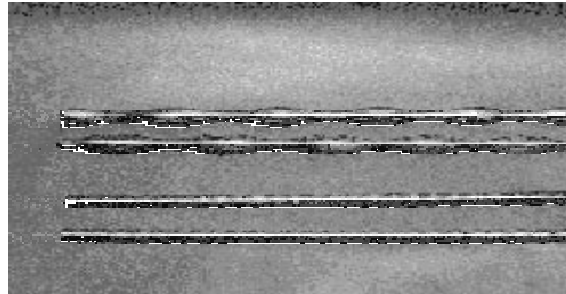


Figure 8: Photograph of the low- and the high-energy end of the two-beam RFQ electrodes.

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