# Beam Dynamics Calculations for the Simultaneous Acceleration of Ions with Different Charge to Mass Ratios in a RFQ [*]

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## *Abstract*

Radio Frequency Quadrupole (RFQ) accelerators are well known to capture, bunch, accelerate or transport ion beams very efficiently even with high space charge forces and at low ion energies due to the strong electrical quadropole focusing . In case of direct injection into the RFQ different charge states or masses are offered simultaneously besides the design charge to mass ratio. Particle dynamics calculations have been performed to study the behaviour of such mixed beams in the RFQ. Examples of resulting changes e.g. in beam currents or beam quality at the output, resp. will be discussed.

## 1 INTRODUCTION

Radio Frequency Quadrupole Accelerators [1, 2] are widely used for preacceleration of low energy ion beams, due to the strong electric focusing also in presence of high space charge forces. The transverse focusing field is generated by four quadropole electrodes excited by an appropriate rf structure, the longitudinal field is created by modulation of the electrodes along the beam axis. The RFQ is a fixed velocity structure, the design is done for a specific charge to mass ratio of the ions. Once the electrodes are machined, input and output energy per nucleon and the velocity profile are frozen. When direct injection from the ion source into a RFQ is considered, different charge to mass ratios are offered which differ from the design value. Particle dynamic calculations and measurements already proved [3, 4], that also ions with charges and masses far away from the design ion are drifting through the RFQ are partly accelerated or decelerated with few transverse losses due to the strong electric focusing, which is independent of the ion velocity. PARMTEQ calculations have been performed for different parameter sets of RFQs to investigate the beam behaviour of such "mixed" beams. The input and particle dynamic routines of PARMTEQ have been changed in such a way, that ions with the same charge state but different masses can be handled in the same run. Three examples will be presented and discussed in the following.

## 2 SOME EXAMPLES

### 2.1 Light ions

Fig.1 shows the output emittances of a 1.5 MeV high current proton RFQ, when the injected beam contains 2/3 of protons and 1/3 of $H_2^+$. Whereas the protons are accelerated to their final energy with a transmission better than $90\%$ most of the hydrogen molecules are drifting through the RFQ with their initial energy, some being partly accelerated, their total transmission is also high. A clear increase of all emittances as well as of the transverse beam size could be observed. The same data set was used for $D^{1+}$ as design ion and protons were introduced as the second beam component. Now the deuterons and most of the protons were accelerated some protons drifting through the RFQ, as can be seen from Fig.2. Now the protons would spoil the outcoming beam emittances.

### 2.2 Highly charged heavy ions

The RFQ data set for the GSI high charge state injector [5] was taken for the case of three charge states (no space charge) injected simultaneously. Fig.3 gives again the output emittances, which show, that no major degradition of beam quality occurs. This could be a method to increase the beam current, when only low intensity beams can be extracted from a source.

### 2.3 Singly charged heavy ions

In heavy ion inertial fusion scenarios the use of different isotopes or ions in the same accelerator is proposed either for increasing the current limit in the main linac [6] or for better pulse shaping in the final focus system [7] by telescoping of ion beams. The accelerator starts normally with a set of 16 or 32 ion sources and RFQs, by funneling the single beams are combined

for further acceleration in the main linac. For ease of design, fabrication and handling it was checked, whether all RFQs of one funnel step could be designedidentically, and operated with the same electrode voltage. Results of calculations showed, that this is possible for not too big mass differences ($< 20\%$) if the injection energy per nucleon is the same for all ion species. In Fig.4 output distribution for Bi and Re are plotted ($T_{out} = 30keV/u$), showing mainly a phase shift for the different bunches.

## 3 REFERENCES

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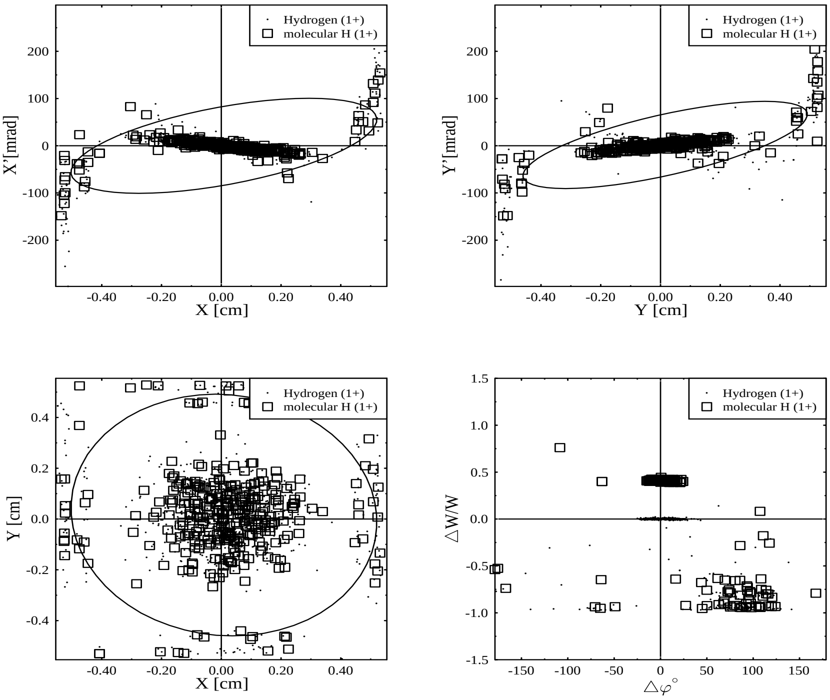

Figure 1: Output emittances of a high current proton RFQ,$T_p = 0.1 - 1.5MeV$, $f = 175MHz$, mixture of protons and molecular Hydrogen $(D^{1+})$ , 396 cells, 1000 particles, $I_{design} = 70mA$

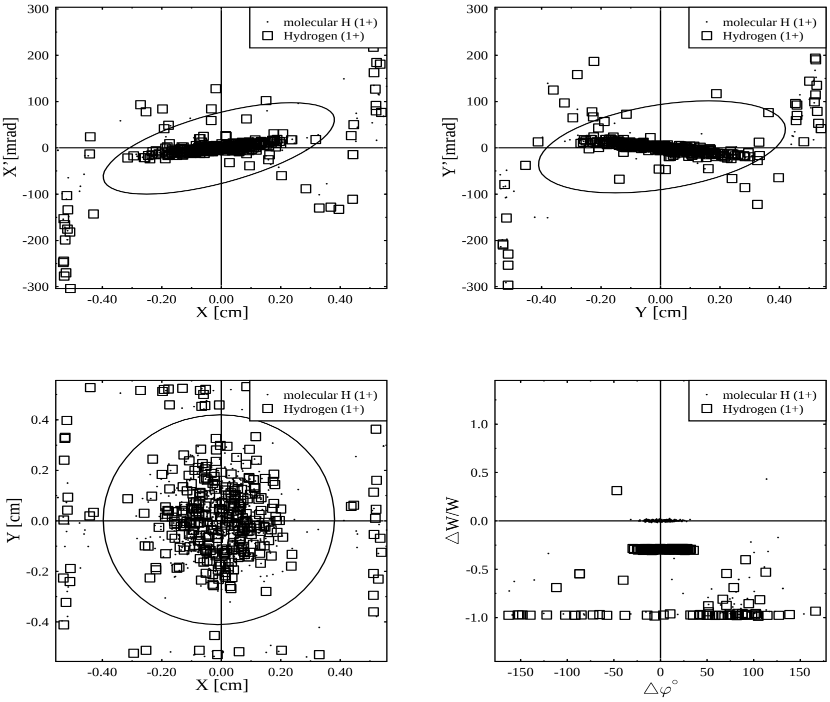

Figure 2: Output emittances of a high current molecular Hydrogen or Deuterium $D^{1+}$ RFQ , $T_{ion} = 0.1 - 3MeV$, $f = 175MHz$, mixture of molecular Hydrogen or $D^{1+}$ and protons, 396 cells, 1000 particles, $I_{design} = 70mA$

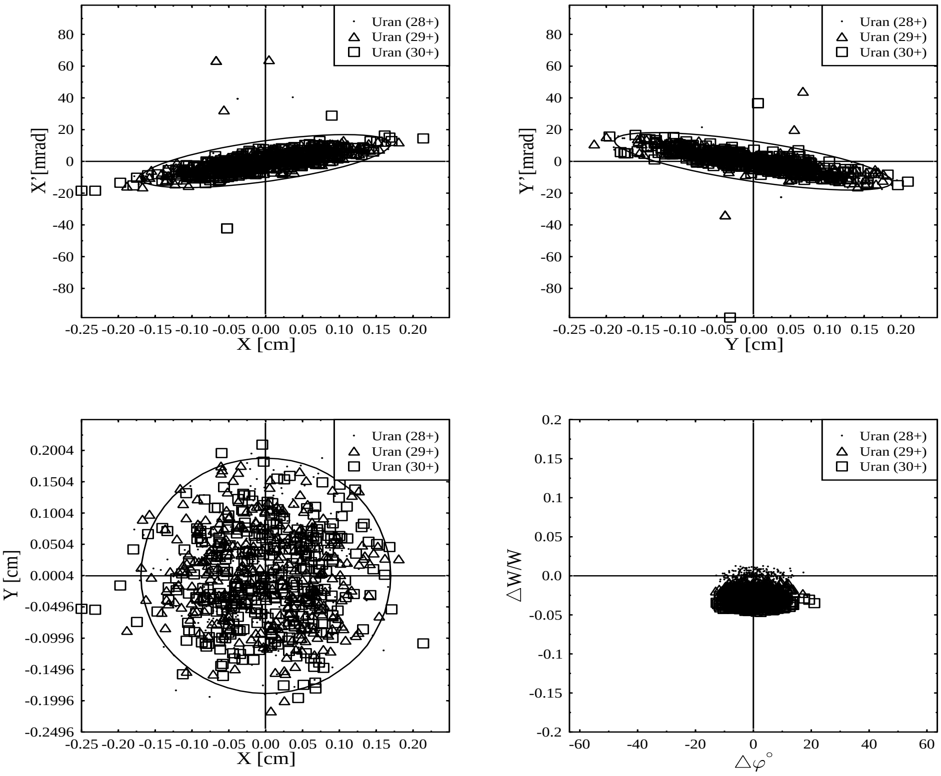

Figure 3: Example of output emittances for the simultaneous acceleration of $U^{28+}$, $U^{29+}$, and $U^{30+}$ in a RFQ, 286 cells, 1000 particles, $I_{design} = 0mA$

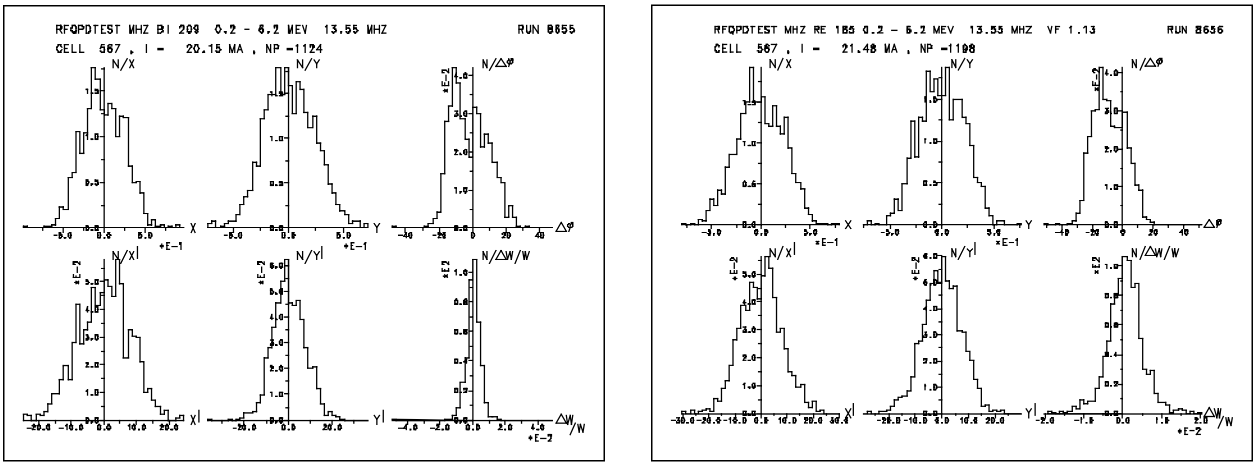

Figure 4: Output distributions after an RFQ operated with the same electrode voltage for $Bi^{1+}$ and $Re^{1+}$ ions, input energy 1keV/u. The Re - bunches are shifted in output phase.