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Feasibility Study on Three Charge States Acceleration of Uranium Beam with 70MHz Heavy Ion RFQ

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1. Introduction

We are developing a Radio Frequency Quadrupole (RFQ) as a lower energy part for a 200-MeV/u heavy ion linear accelerator. The RFQ accelerates the 10-keV/u heavy ion beams from ion source (hydrogen molecules to uranium) and injects the 300-keV/u beam to the superconducting linac. Table I shows the basic parameters for the RFQ accelerator.

Table I: Basic RFQ Parameters

A/q	≤ 7.5
Reference particle	$^{238}U^{33+}$
Beam current	8 pμA
Input energy	10 keV/u
Final Energy	300 keV/u
Duty	100% (CW)
Beam power	214 W

If an ion source can supply 8 pμA $^{238}U^{33+}$ beam, we can use a conventional LEBT (low energy beam transport) with two solenoids. But the 8 pμA $^{238}U^{33+}$ beam is the state-of-art. We should prepare a backup plan for the case of that the stable beam current isn't available. Fig. 1 shows the LEBT which can match $^{238}U^{32+}$, $^{238}U^{33+}$ and $^{238}U^{34+}$ from an ion; source to a RFQ.

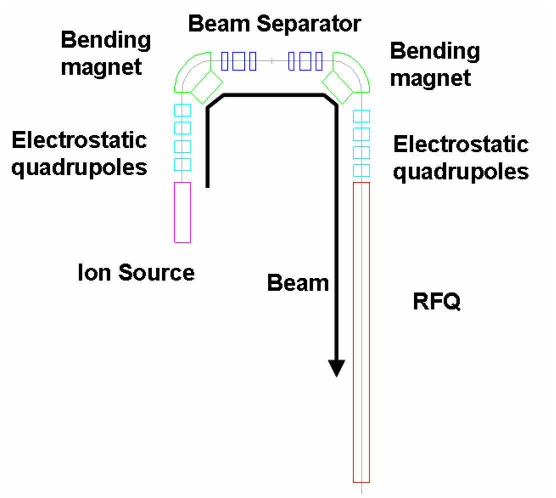


Fig. 1. LEBT to match $^{238}U^{32+}$, $^{238}U^{33+}$ and $^{238}U^{34+}$ from an ion source to a RFQ

2. Beam Dynamics

For the rf frequency, we chose 70 MHz which is between others such as Isotope Science Facility at Michigan State University (80.5 MHz) [1] and Advanced Exotic Beam Laboratory (AEBL) at Argonne National Laboratory (57.5 MHz) [2]. Table II shows the main design parameters.

Table II: RFQ Design Parameters

RF frequency	70 MHz (λ = 4.3 m)
Beta	4.62e-3 → 2.53e-2
Kilpatrick	<1.6
Vane voltage	75 kV
Emittance	0.1π mm-mrad (nor. rms)

We used the PARMTEQM code [3] to create a RFQ structure with the parameters in Table II and to simulate the beam dynamics through the RFQ with the reference particle of $^{238}U^{33+}$. The length of the RFQ is 5.0 m and the transmission rate is 94.3 %. Fig. 2 shows the beam traces along the RFQ.

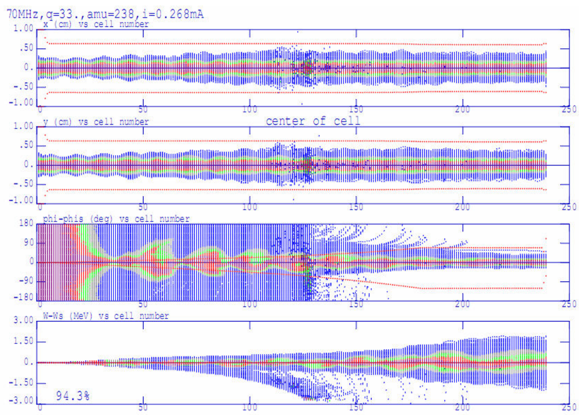


Fig. 2. Uranium Beam Traces along Heavy Ion RFQ

Fig. 3 shows the beam at the exit of the RFQ in phase space. The full beam size is about 5-mm diameter and the energy spread is within ±3% which is tolerable for the downstream superconducting accelerator. We verified the acceleration of ions from hydrogen to uranium with the same structure and the lower vane voltage by simulations.

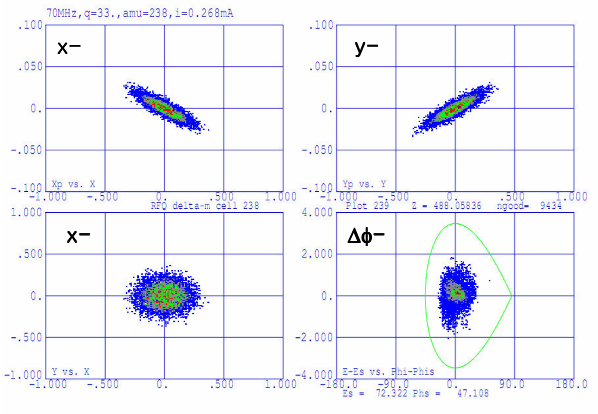


Fig. 3. RFQ Output Uranium Beam in Phase Space

For the simultaneous acceleration of the three charge state ($^{238}U^{32+}$, $^{238}U^{33+}$ and $^{238}U^{34+}$) from an ion source, we checked the transmission of the charge states in Table II. For the every charge state, more than 85% can be transmitted and accelerated. When the 8 pμA of the one charge state isn't available from an ion source, we can use the three charge states to get enough current. The three charge states currents are expected to be almost same.

Table III: Transmissions of three charge states

Charge State	Kinetic Energy	Transmission
32	2.308 MeV	86.8 %
33	2.380 MeV	94.3 %
34	2.452 MeV	91.3 %

Fig. 4 shows the three charge states beam at a RF bucket. The three beams occupy the almost same phase space. As a result, the beams have the same beam properties. But if we plot the beam in the longitudinal direction in detail, as shown in Fig. 5 (a), we can find that there is 8.1 degree separation between the $^{238}U^{32+}$ and $^{238}U^{33+}$, but 0.3 degree between $^{238}U^{33+}$ and $^{238}U^{34+}$. 0.3 degree is negligible, but 8.1 degree can be a big number for the superconducting cavities in the downstream. Also we should check the energy acceptance of the down stream accelerator as shown in Fig. 5(b).

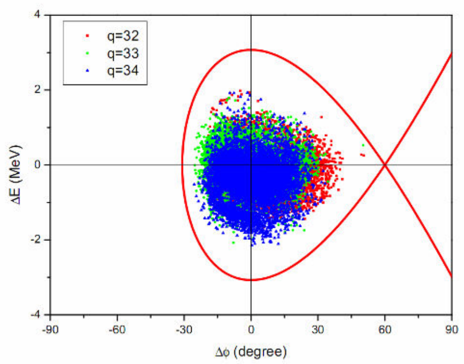
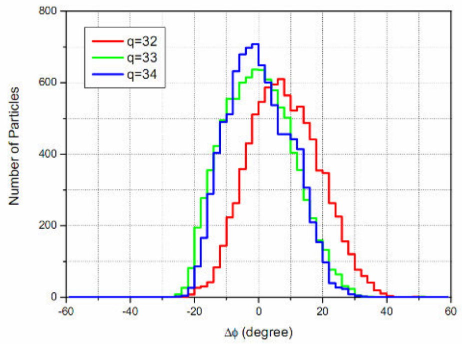
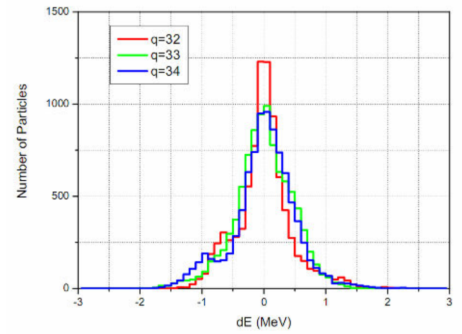


Fig. 4. RF bucket with the three charge states



(a) in phase



(b) in energy

Fig. 5. Beam profile in longitudinal direction for the three charge states

3. Conclusions

We studied the feasibility that a heavy ion RFQ can accelerate the three charge states ($^{238}U^{32+}$, $^{238}U^{33+}$ and $^{238}U^{34+}$) beams from an ion source. For the three charge states, more than 85% transmission is simulated and the beam properties are almost same. But we should check the effect due to the 8.1 degree separation between the $^{238}U^{32+}$ and $^{238}U^{33+}$ in the superconducting accelerator in the down stream, and the energy acceptance of the accelerator.

Acknowledgement

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