Energy measurement of beam from SRC for GUINNESS WORLD RECORDS^{TM} registration

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The SRC (Superconducting Ring Cyclotron) was registered into GUINNESS WORLD RECORDS^{TM} as the highest beam energy cyclotron on April 11 2022.[1)] The energy of the beam from the SRC was measured mainly using BigRIPS prior to the registration. The acceleration of ^{238}U up to 345 MeV/nucleon was chosen to maximize the energy of the extracted beam.

The energy E_T of the beam extracted from the SRC is expressed as

$$E_T = \sqrt{(M_0c^2)^2 + (pc)^2} - M_0c^2 \quad (1)$$

$$pc = Q \times ecB\rho \quad (2)$$

$$M \sim M_0/M_{amu} \quad (3)$$

where M_0, M, M_{amu}, p, c, Q, e, and $B\rho$ express the rest ion mass, mass number, unified atomic mass unit, momentum, speed of light, charge state, elementary charge, and magnetic rigidity, respectively. Therefore, M, Q, and $B\rho$ must be measured or defined. Z is also required to be defined in the measurement.

Firstly we must show that the accelerated particle is ^{238}U ($Z = 92$, $M = 238$). Mass spectra were measured in the ion source plasma used in the RIBF accelerator complex. Measurements were taken at 2 kV and 22 kV extraction voltages. M/Q was calibrated using the two peaks of $m/q = 1$ and $m/q = 2$ at 22 kV. The obtained data show that the mass of the heaviest element in the source is approximately 236. The only nuclei that are stable in nature at these mass numbers are ^{232}Th or ^{238}U. The color of the sample in the ion source was dark brown, a typical color of UO_2, while the color of ThO_2 is white. From these reasons, it can be deduced that the Z and M of the accelerated ion beam are 92 and 238, respectively. The accelerated ion, therefore, is ^{238}U.

Secondly, the beam energy is roughly measured. This measurement helps us to define charge state of the accelerated beam in the succeeding measurement. A target of Be is placed at F0 in BigRIPS, and the energy of the particles in full strip ($Q = Z = 92$) is measured. Three target thicknesses are prepared: 0.5 mm, 1 mm, and 2 mm. The obtained data are plotted as shown in Fig. 1 together with linear regression. When the thickness of the target is zero, the approximation indicates the beam's original energy. Because the energy loss is not proportional to the thickness of the target, it is a little off from the correct answer but is still accurate enough to identify Q in the next process.

Thirdly, magnetic rigidity $B\rho$ of the accelerated beam is measured through the BigRIPS without the target. Because the charge is still undetermined, the blue dots in Fig. 2 show that the energy can jump from one value to another under a constant $B\rho$ condition. In contrast, from the results obtained previously, we know that the energy is approximately around the orange line, so thus we determined Q to be 86. We deduced the extracted energy of 82400 MeV by combining the measured $B\rho$ value with $Q = 86$.

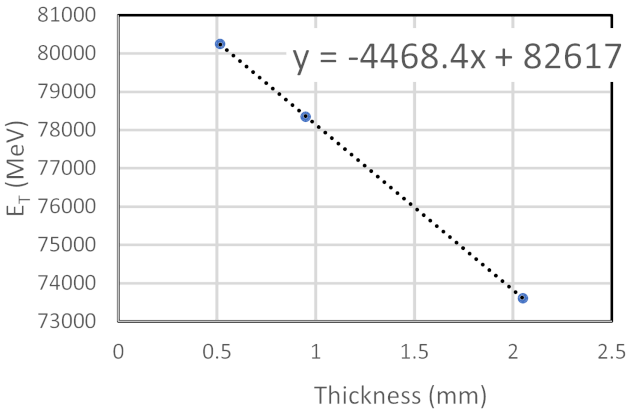

Fig. 1. Energy of $^{238}U^{92+}$ versus the target thickness with linear regression.

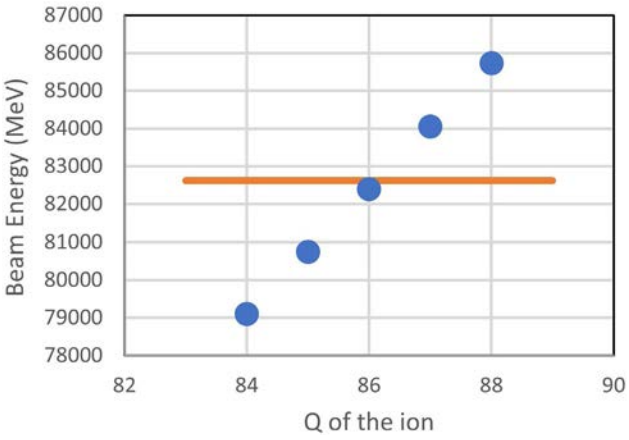

Fig. 2. Beam energy converted from the measured $B\rho$ as a function of assumed Q values of the accelerated ion.

Reference

1) https://www.guinnessworldrecords.com/world-records/675272-highest-beam-energy-cyclotron.

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