Energy-degraded beam on BigRIPS F0

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Uranium (and Xe, Kr) beams, which are accelerated up to the SRC, have a fixed beam energy of 345 MeV/nucleon because fixed-frequency accelerators are operated upstream. If a lower energy beam is required, the beam energy would be lowered with material as an energy degrader at the first stage of BigRIPS. Subsequently, the lower energy beam would be delivered into the downstream beamline. The energy-degraded beam would be transported to F2 or F3, where reaction targets would be placed. The disadvantages of the method are: 1) Transport of a relatively intense primary beam to F2 or F3 is required for the measurement of the reaction cross section, which might be subject to radiation shielding limitations. 2) Reaction products should be separated using downstream of F3 in BigRIPS, which requires a completely different approach compared to the measurement of production cross sections at 345 MeV/nucleon. This in turn might lead to large systematic errors.

Based on these reasons, the possibility of providing energy degraded beam to BigRIPS F0 was investigated and tested. A primary beam transport beamline is located from the G01 port to BigRIPS F0 downstream of the SRC exit. At an intermediate beam profile monitor port T11 beam can focus in both X and Y directions. Therefore, if this type of transport optics are used and an energy degrader material are located at T11, it is expected that the primary beam can be transported to the F0 focal plane without increasing phase space of the primary beam largely. Figure 1 shows the calculated transport from T11 to the F0 focal plane. In fact, this transport method has been previously used in dispersion matching experiments[1)] for verification of dispersion matching. Conversely, an energy degrade material has never been placed here before. This test was the first attempt to investigate the transport of energy-degraded primary beam to BigRIPS F0.

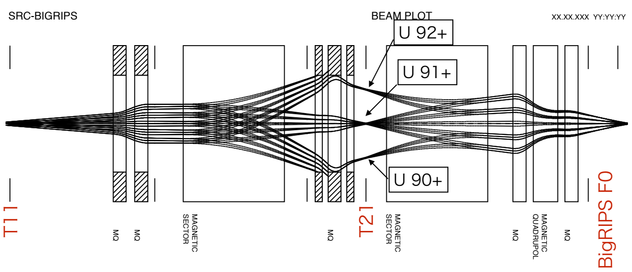

Fig. 1. Beam envelop from the T11 focus to BigRIPS F0. U beams with three different charge states are transported in the calculation.

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The energy degrader plate was inserted from one of the ports at T11. It made of aluminum with 8 steps, each with a thickness ranging from 1.7 mm to 9.3 mm. After passing through each steps, uranium primary beam with 345 MeV/nucleon was degraded into 300, 250, 200, 150, 100, 75, 50 and 25 MeV/nucleon. When the energy degrader plate is withdrawn, the 345 MeV/nucleon U beam passes unchanged with the 86^+ charge 345 MeV/nucleon U beam passes unchanged with the 86^+ charge state. The beam is then transported to F0 by adjusting the magnetic field of the dipole magnets DMT2,3 to match the magnetic rigidity required for the 86^+ beam.

The U beam that has passed through the energy degrade plate has a dispersed charge state, and it is deflected by the DMT2 and DMT3 magnets from T11 and transported to F0 as shown in Fig. 1. It can be observed that a beam with a charge state whose rigidity is tuned to the central trajectory can pass through the triplet quadrupole magnets between DMT 2 and 3, while beams with neighboring charge states are considered to be partially blocked by walls in the middle of the Q magnet.

Tests of the transport were performed as a program DA03 on 2021/11 and 2022/03. Figure 2(a) shows one of the results on a profile monitor at T21 with the 250 MeV/nucleon transport. The neighboring charge state was actually observed as a separate peak on the momentum dispersion axis (X) in the profile monitor located at T21. The magnetic rigidity was set at 92^+ in the central trajectory. The results verified that the beam passing through the central orbit is 92^+ of the charge state, because 91^+ beam was observed at neighboring higher momentum while 93^+ was not observed. In this condition, the beam spread was confirmed by an alumina fluorescent plate at F0 shown in Fig. 2(b1), which is comparable with those observed at 345 MeV/nucleon (Fig. 2(b2)). At 150 MeV/nucleon, the condition was not as good as that at 250 MeV/nucleon and the T21 separation was

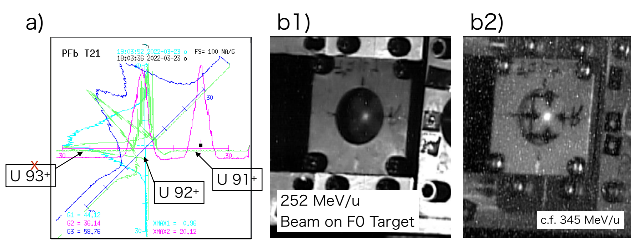

Fig. 2. a) Beam profile at T21 with U 250 MeV/nucleon. b1) Beam spot at F0 and b2) that of 345 MeV/nucleon for comparison.

not sufficient. The beam spread, as monitored by the alumina fluorescent plate, was significantly larger than those at 345 or 250 MeV/nucleon.

In conclusion, the energy degraded beam from 345 MeV/nucleon at BigRIPS F0 was successfully delivered. This method proved that the energy-degraded beam can be delivered without using the first stage of BigRIPS, by utilizing the primary beam transport beamline from T11. On the other hand, it should be noted that the use of beams with different charge states are blocked by the beam duct along the beam line, especially at DMT2 or Q magnets between DMT2 and 3. Therefore, the effects of heat and radiation should be considered, not only for normal high-intensity beams but also for sufficiently reduced intensity beams.

Reference

1) T. Nishi *et al.*, Nucl. Instrum. Methods Phys. Res. B **317**, 290 (2013).