Ion-optical measurements using uranium primary beam with different charge states

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Transfer matrix elements are essential for various ion-optical diagnoses, especially for trajectory reconstruction[1)] to improve the particle identification power of the BigRIPS. Thus, it is very important to measure the transfer matrix elements precisely to realize the best possible performance of the BigRIPS.

Primary beams of heavy ions such as uranium could be unique tools for measuring the transfer matrix elements because they are distributed into several charge states after passing through materials such as targets, degraders, and detectors. Such beams with different charge states have the following characteristics:

(1) Small widths at position x and angle a.
(2) Discrete peaks in magnetic rigidity (δ) spectrum. (Each peak is narrow and the peak position is definitely known.)
(3) Same velocity for all the charge states.

Some ion-optical parameters can be measured precisely by utilizing these characteristics. Indeed, we performed such measurements in 2007 during the first BigRIPS commissioning by using uranium beams.

Positions of a ^{238}U beam were measured with parallel plate avalanche counters (PPACs) installed in the BigRIPS foci F3, F5, and F7. The ion-optical system from F3 to F7 is a four-bend achromatic spectrometer with an intermediate dispersive focus F5. Figure 1 shows a spectrum of horizontal position x at F7 versus x at F5 of the ^{238}U beam after it passes through the PPACs at F3. Different charge states generated by the F3 PPACs had different positions at F5 due to the F3-F5 dispersion $(x|\delta)_{35}$, as indicated by red (dashed) lines. The measured result was 31.5 mm/%, which is consistent with the designed value of 31.7 mm/% calculated by COSY INFINITY. Charge state transition because of the PPACs occurred at F5 also. Events connected by each blue (solid) line in Fig. 1 have the same charge state between F5 and F7. They have very different positions at F5 but have the same magnetic rigidity. This situation allows measurement of the F5-F7 magnification $(x|x)_{57}$, which corresponds to the slope of the blue lines. The measured and COSY results were 1.069 and 1.080, respectively. Each green (dash-dot) line in Fig. 1 indicates events of the same charge state transition (ΔQ) at F5. The vertical distances of the green lines indicate the F5-F7 dispersion $(x|\delta)_{57}$. The measured and COSY results were -32.9 mm/% and -34.2 mm/%, respectively. Because the slope of the green lines is $(x|\delta)_{37}/(x|\delta)_{35}$, the green lines become horizontal due to the achromaticity of the F3-F7 optical system. Indeed, the F3-F7 dispersion of -1.1 mm/% deduced from the slope of the green lines was small.

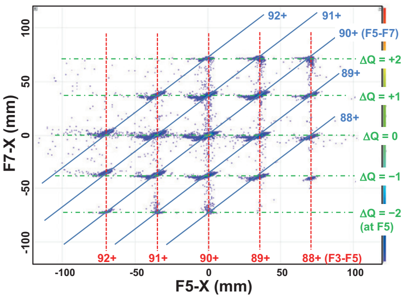

Fig. 1. Spectrum of F7-x vs. F5-x measured with a ^{238}U primary beam after it passes through PPACs at F3. Red and blue lines have information on the F3-F5 dispersion and the F5-F7 magnification, respectively. The F3-F7 dispersion and the F5-F7 dispersion can be deduced from green lines.

Charge states are also useful to measure the $(\ell|\delta)$ parameter, where ℓ is a flight-path-length difference with respect to the central orbit. Because all the charge states have the same velocity, ℓ can easily be deduced by the time-of-flight (TOF) measurements. Figure 2 shows the TOFs from F3 to F7 as a function of δ measured by plastic scintillators at F3 and F7 with ^{238}U primary beam. Different charge states were generated by the F3 scintillator. BigRIPS was tuned so that the 90$^+$ charge state came at the center of F3, F5, and F7. 89$^+$, 90$^+$ and 91$^+$ charge states were selected individually with slits at the dispersive focus F5. The (TOF$|\delta$) value was obtained as -0.0498 ns/% by a quadratic fitting, indicated by a solid curve in Fig. 2. Then, $(\ell|\delta)$ was estimated as -10.2 mm/%, while the COSY result was -6.53 mm/%.

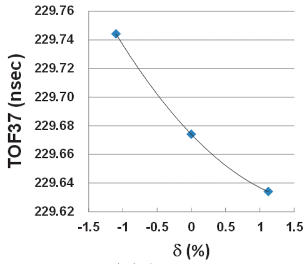

Fig. 2. Measurement of $(\ell|\delta)$ with primary beams. TOF from F3 to F7 was measured for each charge state by selecting the charge state with the F5 slits. The solid curve represents a quadratic fitting, and the slope corresponds to $(\ell|\delta)$.

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References

1) N. Fukuda et al.: Nucl. Instr. Meth. **B317**, 323 (2013).