Development of ion-optics mode for the SAMURAI beam line

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We have developed an ion-optical mode for the SAMURAI beam line, which connects the SAMURAI spectrometer[1)] to the BigRIPS separator[2)]. The schematic view is shown in Fig. 4 of Kobayashi *et al.* (2013)[1)]. There are four standard focal planes: F7, which is the last focal plane of the BigRIPS separator; F8; F12; and F13, which is the reaction target position of the SAMURAI spectrometer. There are two STQ magnets[3)] between F7 and F8, and two between F8 and F12, while only one STQ is located between F12 and F13. The beam shutter between F7 and F8 and the D7 dipole magnet for the ZeroDegree spectrometer restrict the space in the vertical direction in this beam line. To diagnose the beam emittance, we use the PPAC detectors at F7, F8, and F12, and beam drift chambers at F13.

In order to fabricate the beam optics of the SAMURAI beam line, two problems need to be resolved. First, there is only one STQ between F12 and F13; therefore, stronger magnetic fields are required for focusing the beam at both F12 and F13. Second, the beam envelope inside the D7 magnet in the vertical direction needs to be made thin, because the gap in D7 is ±61 mm. To solve these problems, we focus the beam inside the D7 magnet instead of on F8 and F12. At F8 and F12, the beam is set to parallel. This makes it easier to diagnose the beam optics using the PPAC detectors and adjust the magnetic field of each quadrupole magnet. The magnification from F7 to the focal point inside the D7 magnet in the vertical direction is set to be around 2 to reduce the angular magnification and make the beam envelope thinner. The beam trajectories for the SAMURAI beam line are shown in Fig. 1. The position and angular spreads at F7 are set to be ±6 mm and ±10 mrad, respectively, in both the horizontal and vertical directions, which are the typical root-mean-square (r.m.s.) values for the fragments produced from light projectiles such as ^{18}O and ^{48}Ca. Table 1 summarizes the transfer matrices from F7 to F8, F12, and F13. The matrices in the horizontal direction $\begin{pmatrix} (x|x) & (x|a) \\ (a|x) & (a|a) \end{pmatrix}$ and those in the vertical direction $\begin{pmatrix} (y|y) & (y|b) \\ (b|y) & (b|b) \end{pmatrix}$ are shown in the left and right columns, respectively.

From May 2012, we have used this ion-optics mode for transporting the secondary beams to the SAMURAI spectrometer. The typical r.m.s. spot size at F13 was around 10-15 mm, when the r.m.s. spot size of F7 was 6 mm. In such a case, the transmission efficiency from F7 to F13 is around 90%.

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Table 1. Transfer matrices from F7 to F8, F12, and F13. The left and right columns show matrices in the horizontal and vertical directions, respectively.

beam line	horizontal	vertical
F7-F8	$\begin{pmatrix} -1.09 & 4.28 \\ -0.23 & 0.00 \end{pmatrix}$	$\begin{pmatrix} -2.80 & 2.20 \\ -0.45 & 0.00 \end{pmatrix}$
F7-F12	$\begin{pmatrix} 0.76 & -2.99 \\ 0.33 & 0.00 \end{pmatrix}$	$\begin{pmatrix} 0.85 & -2.20 \\ 0.45 & 0.00 \end{pmatrix}$
F7-F13	$\begin{pmatrix} 1.86 & 0.00 \\ -0.43 & 0.54 \end{pmatrix}$	$\begin{pmatrix} 2.16 & 0.00 \\ -0.66 & 0.46 \end{pmatrix}$

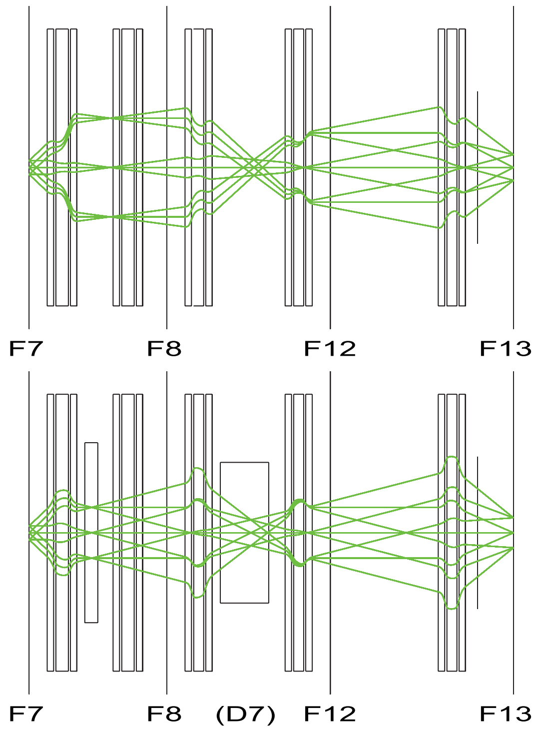

Fig. 1. Beam trajectories from F7 to F13. F13 is the reaction target position of SAMURAI. Top and bottom panels show the trajectories in the horizontal and vertical directions, respectively. The position and angular spreads at F7 are ±6 mm and ±10 mrad, respectively, in both the directions. The box triplet shows each STQ magnet.

References
1) T. Kobayashi et al. : Nucl. Instrum. Meth. Phys. Res., **B 317**, 294 (2013).
2) T. Kubo: Nucl. Instrum. Meth. Phys. Res., **B 204**, 97 (2003).
3) K. Kusaka et al.: IEEE Trans. Appl. Supercond., **14**, 310 (2004).