High-resolution spectroscopy at the OEDO-SHARAQ


Center for Nuclear Study, Graduate School of Science, University of Tokyo

The Optimized Energy Degrading Optics for radioactive ion beams (OEDO) system was constructed in 2017, and successfully demonstrated RI beam productions with slowdown scheme from ~200 MeV/u down to 15–50 MeV/u. The starting point of the OEDO system was an upgrade of the High-Resolution Beamline (HRB) and the Spectroscopy with High-resolution Analyzer of RadioActive Quantum beams (SHARAQ) spectrometer for opening up new possibilities in nuclear experimental studies with low-energy RI beams. The idea of OEDO is to manipulate a degree-of-freedom in the longitudinal phase space of RI beam. To obtain a beam with a small spot size and a small energy spread, the OEDO system transforms the spreads of horizontal position and angle of the beam to the timing spread, which corresponds to the rotation of the phase space ellipse on the position-(angle-) timing plane to obtain a small position (angle) spread. In the commissioning and physics experiments, the new beamline with OEDO system has exercised the performance well. The achievements were reported recently in the refereed articles [1, 2].

While at the same time, the high-resolution RI spectroscopy at 100–300 MeV/u is still an attractive performance of the SHARAQ spectrometer. Practically, because several beamline magnets were rearranged in the construction of the OEDO beamline, the performance of the high-resolution RI spectroscopy at the OEDO+SHARAQ scheme should be checked for future high-resolution experimental studies. This report describes applicability evaluation of such high-resolution studies at OEDO.

In upgrade from HRB to OEDO, we carefully thought the compatibility between the high-resolution and energy-degradation performances. Figure 1 shows a list of magnet arrangements for HRB or OEDO beamline, where the boxes with “STQ,” “D,” and without labeling indicate a superconducting Triplet Quadrupole magnet, a Dipole magnet and a normal-conducting quadrupole magnet, respectively. The wiring with two magnets means that these magnets are controlled by a power supply. The arrangement labeled by “HRB” is the original before OEDO. “OEDO design” is the proposed configuration at the OEDO planning, which was detailedly written in Ref. [3]; “OEDO” is the present magnet configuration where the commissioning and previous experiments were done.

However, the present OEDO beamline could not satisfy the designed compatibility due to deficiency in performances of quadrupole magnets. Thus, we found a solution to obtain the compatibility by minimum re-arrangements of quadrupole magnets. The “OEDO-DM” in Fig. 1 is a new magnet configuration of the OEDO beamline for high-resolution spectroscopy. The exchanging between OEDO and OEDO-DM shows the dotted arrows. One of important properties of the OEDO-DM is that the change of magnets is completed only in the E20 experimental room. Accordingly, the change can be even possible during the irradiation beam time to the other experimental area in RIBF.

The dispersion matching ion optics in BigRIPS-OEDO-SHARAQ scheme is shown in Fig. 2. The ion trajectories in the figure show the results of the first-order calculation. The beam parameters at F3 is assumed to be 3 mm of horizontal spot size (x), 10 mr of horizontal outgoing angle (α), 3 mm of vertical spot size (y), 30 mr of vertical outgoing angle (β), and 0.3% of momentum spread (δp). The magnet settings for this mode were the same between F3 and FE7, while modified between FE7 to S0. The setting of SHARAQ spectrometer is similar to the previous setting for the SHARAQ03 experiment [4]. The S0 and S2 are the secondary target position and the final focal plane of the SHARAQ spectrometer, and thus the ion optics between FE7 and S0 were modified under conditions that the transport matrix elements of F3–S0 are similar values in the HRB and OEDO-DM magnet configurations.

Table 1 shows the difference the transport matrix elements calculated based on the HRB and OEDO-DM configurations. The matrix elements in a horizontal (vertical) row are concerned to the same final (initial) beam parameters. Comparing the HRB and OEDO-DM configuration, the corresponding matrix elements are almost identical, therefore the OEDO-DM configuration is able to provide the DM ion optics for high-resolution spectroscopy.

The application scope of the OEDO-DM configuration is determined by the maximum bending power of component magnets. When the OEDO beamline is tuned to compose the ion trajectory shown in Fig. 2, field strengths of the component magnets are proportion to the magnetic rigidity of the RI beam and a ratio of the field strengths is constant. Therefore, the applicable limit of the OEDO-DM transport is determined by a magnet which reaches the performance limit at the lowest magnetic rigidity. The applicable limit of the OEDO-DM transport is 5.3 Tm and is much lower than

Figure 1. Magnet arrangements for the HRB or OEDO beamline. Details are written in the text.
Figure 2. Ion-optical trajectories of the DM mode in BigRIPS-OEDO-SHARAQ scheme.

Table 1. Transport matrix elements between F3–S0 calculated based on the HRB and OEDO-DM configurations.

<table>
<thead>
<tr>
<th></th>
<th>( x )</th>
<th>( y )</th>
<th>( b )</th>
<th>( \delta_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRB</td>
<td>( -0.97 )</td>
<td>( +0.27 )</td>
<td>( +0.00 )</td>
<td>( +0.00 )</td>
</tr>
<tr>
<td>OEDO-DM</td>
<td>( -1.09 )</td>
<td>( +0.26 )</td>
<td>( +0.00 )</td>
<td>( +0.00 )</td>
</tr>
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</table>

that of the HRB, which is 8 Tm. Since 5.3 Tm corresponds to 140 MeV/u of triton, a matching with neutron-rich RI beams produced by BigRIPS is practically insufficient. The limit is absolutely determined by the magnet indicated by an arrow in Fig. 2, and all of the other magnets are applicable to a 8-Tm RI beams. Because the peak integrated gradient length (GL) of the pointed magnet is 0.52 T, 1.5-times enhancement of the corresponding magnet is necessary to obtain applicability for 8-Tm beams. However, the resolve of this deficient is critical for the performance of high-resolution spectroscopy at the OEDO-SHARAQ.

To enhance the performance of the OEDO-SHARAQ system not only with the OEDO mode but also with the OEDO-DM mode, we continue to study an update design of the whole system of the beamline. At the present, new installation of a normal conducting quadrupole magnet with large bore radius which provide a strong magnetic field is the best possible solution. We aim at continuous progress of experimental performance of the OEDO-SHARAQ system and at accelerating progress of widespread nuclear physics researches by using the system.

References