Separated flow operation of the SHARAQ spectrometer for in-flight proton-decay experiments†

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The SHARAQ spectrometer[1)] is a high-resolution magnetic spectrometer designed for radioactive isotope (RI) beam experiments at the RI Beam Factory (RIBF). The spectrometer has opened up new experimental opportunities in combination with the high-resolution beam line. One interesting example is a new type of missing-mass spectroscopy with an RI beam used as a probe. To date, investigations of spin-isospin properties in nuclei have been strongly promoted by RI-induced charge-exchange reactions such as (t, ^{3}He), (^{12}N, ^{12}C), (^{10}C, ^{10}B), and (^{8}He, ^{8}Be).

We have developed a new ion-optical mode of SHARAQ operation. The new mode, called the "*separated flow mode*", enables the invariant-mass spectroscopy of proton-unbound states with SHARAQ and thus extends the research field of the nuclear chart toward proton-rich nuclei. In addition, proton-unbound nuclei can be used as probe particles. One interesting example is the parity-transfer reaction (^{16}O, ^{16}F(0^-, g.s.))[2)]. This reaction has a unique sensitivity to unnatural parity states and can be used as a powerful tool to probe 0^- states in a target nucleus.

In the separated flow mode, the SHARAQ spectrometer is used as two spectrometers with different magnet configurations of "QQD" and "QQDQD" at the same time (see Fig. 1). The reaction products from the target (S0) are separated and analyzed in either of these two configurations depending on their mass-to-charge ratios (A/Z). The particles with $A/Z \sim 1$, such as protons, are analyzed in the "Q1-Q2-D1" configuration and detected in the S1 focal plane, which is located on the low-momentum side downstream of the D1 magnet. On the other hand, the heavy-ion products are analyzed in the "Q1-Q2-D1-Q3-D2" configuration to increase the resolving power and detected at the S2 final focal plane. Therefore, this new technique enables us to perform coincidence measurements of the proton and heavy-ion pairs produced in the decays of proton-unbound states in nuclei. Details of the ion-optical properties and the focal-plane detector systems can be found in our published paper.

The separated flow mode was successfully introduced in an experiment with the reaction (^{16}O, ^{16}F) at a beam energy of 247 MeV/u (SHARAQ08 experiment). The outgoing ^{15}O + p produced in the decay of ^{16}F were measured in coincidence with SHARAQ.

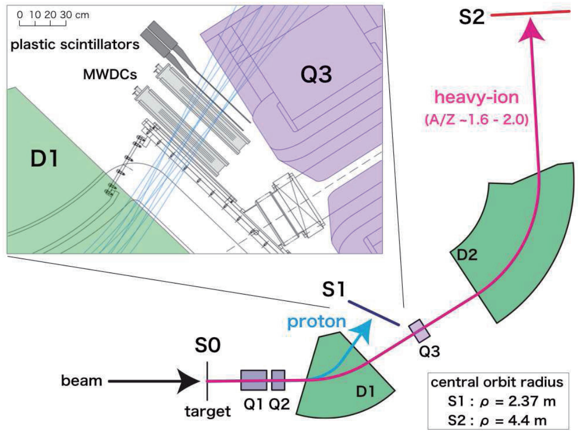

Fig. 1. Schematic layout of the SHARAQ spectrometer. The SHARAQ spectrometer consists of two superconducting quadrupole magnets (Q1 and Q2), one normal conducting quadrupole magnet (Q3), and two dipole magnets (D1 and D2) in a "QQDQD" configuration. In the separated flow mode, the protons and the heavy-ion products from the target (S0) are separated and measured in coincidence at two different focal planes (S1 and S2) of SHARAQ. The inset shows the tracking detector system at S1, which consists of two multi-wire drift chambers (MWDCs) and two plastic scintillators.

For the relative energy between the ^{15}O particle and the proton, a resolution of 100 keV (FWHM) was achieved, and the 0^- g.s. of ^{16}F ($E_{\rm rel}$ = 0.535 MeV) was clearly separated from the excited states, the 1^- state at 0.193 MeV ($E_{\rm rel}$ = 0.728 MeV) and the 2^- state at 0.424 MeV ($E_{\rm rel}$ = 0.959 MeV). In addition, a high resolution of ∼2 MeV (FWHM) was achieved for a ^{16}F kinetic energy of 3,940 MeV. Such an accurate missing-mass measurement combined with an invariant-mass method gives unique opportunities to explore little-studied excitation modes in nuclei using new types of reaction probes with particle-decay channels.

References
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