New ion-optical operating modes of BigRIPS and ZeroDegree spectrometer for production and separation of high-quality rare isotope beams and high-resolution spectrometer experiments[†]

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BigRIPS[1)] is a powerful two-stage in-flight separator that has been used for frontier experiments with exotic nuclei for more than a decade. The ion-optical system is very versatile owing to the multi-stage structure of BigRIPS combined with the ZeroDegree spectrometer[2)] or the Superconducting Ring Cyclotron (SRC). Various optical modes can be flexibly realized according to the purpose of experiments. Two categories of developments are presented here.

One is a new operating mode of BigRIPS aiming at a higher ion-optical resolving power. BigRIPS itself has a two-stage structure consisting of F0-F2 and F3-F7 with a matching section F2-F3 in between. In each stage, the isotopic separation of projectile fragments at an overall achromatic focus is performed in the $B\rho$-ΔE-$B\rho$ operation with an achromatic energy degrader positioned in a dispersive focal plane. In principle, the two stages act independently and their isotopic separation powers can be added or subtracted depending on the sign of the optical magnification in the matching section F2-F3. In the standard operating mode of BigRIPS, the two spatial separations with energy degraders are subtractive. The ion-optical solution for adding the $B\rho$-ΔE-$B\rho$ separation power (the additive mode) is obtained by adding an x-focus at F2.5. The spatial-separation performance of the standard and additive modes of BigRIPS is demonstrated in the simulation with different combinations of achromatic F1- and F5-degraders. With the resulting increased spatial separation power, the isotopic background can be substantially reduced. On the other hand, the standard mode has a slightly better overall transmission and is superior in providing an isotope cocktail focused on a small-area detector or a secondary target. One can favorably use either the standard or the new additive mode depending on the experimental requirements and priorities.

Higher ion-optical resolving powers of the first and second BigRIPS stages are also investigated with the goals of further reducing the background and yielding access to new isotopes of heavier elements. First, the resolving power of the second stage was doubled (the high-resolution Ddouble mode[3)]). Improved particle identification was confirmed by the first test experiments. The simulation of a test case indicated that the increased resolving power of both the first and second stages in the additive mode can reduce the background to a large extent. The actual use of the proposed and prepared additive, standard, and higher-resolution ion-optical modes primarily depends on the detailed goals of future BigRIPS experiments.

The other development is a dispersion-matched system with BigRIPS for high-resolution spectrometer experiments. The BigRIPS and ZeroDegree spectrometer are presently two independent, coupled achromatic systems. A new dispersion-matched mode of BigRIPS and ZeroDegree will enable novel experiments. In this experimental scenario, the F8 focal plane is dispersive and accommodates the secondary target. The secondary target can be viewed, *e.g.*, by the γ-ray detector array, and thus, high-resolution momentum measurements after a removal reaction can be performed at F11 in coincidence with γ-spectroscopy.

For high-resolution spectroscopy experiments with high-intensity light projectiles, SRC and BigRIPS can be operated as a dispersion-matched system. In this mode, the dispersive beamline from SRC to F0 and the BigRIPS stages up to F5 form an overall achromatic system. The momentum spread of high-intensity primary beams from the SRC is canceled in the position spectra at F5, for instance, in the experiments studying pionic states. The first experimental tests of the proposed ion-optical mode have been successfully performed.

The described different ion-optical developments will be a base for novel BigRIPS experiments with exotic nuclei and mesic atoms, and thus, contribute to a better understanding of the strong interaction and properties of hadronic matter.

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