Neutron intruder states and collectivity beyond $N = 50$ towards ^{78}Ni

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The recent spectroscopy of ^{78}Ni,[1)] together with the identification of shape coexistence just below the $N = 50$ shell closure for ^{80}Ge[2)] and ^{79}Zn,[3)] indicates that deformed intruder configurations could play a crucial role in low-energy structure properties in this region and towards the limits of the nuclear chart. Such configurations are predicted to originate from multiparticle-multihole excitations[4)] above the $N = 50$ and $Z = 28$ shell gaps pushed down in energy due to neutron-proton correlations, which enhance quadrupole collectivity. Quantifying how collectivity develops near ^{78}Ni is crucial because it influences binding energies and the drip-line location[5)] with consequences for nucleosynthesis calculations relying on these inputs. Because these states involve many-particle excitations, their theoretical description is challenging, and identifying them experimentally is, thus, of prime interest to constrain models. So far, very few experimental indications of these configurations have been obtained in ^{80}Ge and ^{79}Zn, but no direct evidence of these configurations exist for $N = 50$ or above in more exotic species.

During the RIBF196 experiment in November 2020, we sought to identify and characterize for the first time such 2p-1h intruder states in ^{83}Ge and ^{81}Zn which are the last two odd-even $N = 51$ isotones above ^{79}Ni. To do so, we used neutron knockout from ^{84}Ge and ^{82}Zn, both having two neutrons in the $s_{1/2}d_{5/2}$ valence space above $N = 50$. This direct reaction allows the removal of one of the neutrons from the quasi-full $g_{9/2}$ orbital below $N = 50$ to selectively populate $9/2^+$ intruder states based on a $\nu(g_{9/2})^{-1}(s_{1/2}d_{5/2})^{+2}$ configuration and extract their spectroscopic factors.

In addition, the first spectroscopy of low-lying levels in ^{82,84}Zn[6)] recently indicated that magicity was strictly confined to $N = 50$ in ^{80}Zn with the onset of deformation developing towards heavier Zn isotopes. To reproduce these findings, it was demonstrated that state-of-the-art shell model calculations needed to include sufficient valence orbitals above $N = 50$ (full *gds* valence space) and to allow the breaking of the ^{78}Ni core. Simultaneously to the study of the intruder states mentioned above, these low-lying states in ^{82}Zn were populated using proton removal from ^{83}Ga, and their lifetimes will be studied by line-shape analysis.

To reach these scientific goals, we performed an experiment in which a primary beam of ^{238}U with a mean intensity of 60 particle nA at 345 MeV/nucleon collided with a 4-mm thick ^{9}Be primary target at the object point of the BigRIPS separator. The secondary beam was purified using Al degraders at the F1 and F5 dispersive planes (8- and 2-mm thick). The secondary cocktail beam containing approximately 61%, 7.4% and 0.2% of ^{84}Ge,^{83}Ga and ^{82}Zn, respectively, at averaged rates of approximately 6100, 740, and 20 s^{-1} impinged for 2.5 days on a 6-mm-thick ^{9}Be target at 253, 248, and 242 MeV/nucleon. Event-by-event identification of projectiles and reaction residues in terms of the atomic number (Z) and mass-to-charge ratio (A/Q) was achieved using the TOF-$B\rho$-ΔE method in both the BigRIPS and ZeroDegree spectrometers. A preliminary particle identification plot in BigRIPS without higher-order optical corrections is shown in Fig. 1. De-excitation γ-rays of the neutron and proton knockout residues ^{83}Ge,^{82}Zn and ^{81}Zn were detected using the HiCARI germanium array (described separately[7)]) surrounding the secondary reaction target. A 0.5-mm-thick lead shield was placed around the beam pipe surrounding the target to reduce the rate of low-energy atomic background in the detectors. Known and unknown transitions in ^{83}Ge were clearly identified online. The statistics obtained in this neutron-knockout channel will allow clear identification of the states populated and their possible intruder character after careful analysis of the feeding pattern.

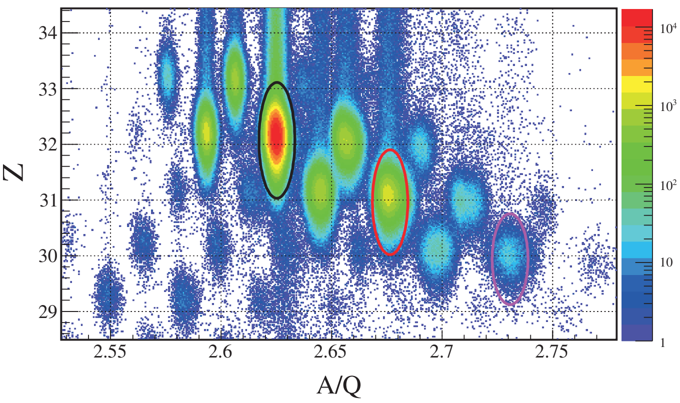

Fig. 1. Preliminary particle identification of the secondary beam in BigRIPS. Black, red and purple ellipsoids indicate ^{84}Ge, ^{83}Ga, ^{82}Zn respectively, see text for details.

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