First Spectroscopic study of $^{56}$Ca

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The first measurement of low-lying excited states of $^{56}$Ca was performed as part of the third SEASTAR$^{3}$ (Shell Evolution And Search for Two-plus energies At the RIBF) campaign in May 2017. In a simple shell-model description, this nucleus has two neutrons in the $f_{5/2}$ orbital outside the closed (sub)-shell nucleus $^{54}$Ca.$^{3,9}$ The location of its $2_1^+$ energy gives a measure-ment of the difference between $0^+$ and $2^+$ two-body matrix elements in $\nu(f_{5/2})^2$, which is of importance to understand the nature of the very neutron-rich, potential closed (sub)-shell nucleus $^{60}$Ca. Theoretical predic-tions of this energy level vary from 0.5 to 2 MeV; therefore, its experimental determination is desirable.

A $^{70}$Zn beam accelerated to 345 MeV/nucleon impinged on a 10-mm thick $^9$Be primary target with an average intensity of $\sim$160 pnA at the entrance of the BigRIPS separator to produce the radioactive secondary beam. BigRIPS was tuned to select and identify particles of interest via the measurement of $B_\rho$, $\Delta E$ and ToF by using standard beamline detectors. The particle identification of BigRIPS is shown in Fig. 1. The average production rate of $^{57}$Sc nuclei was 13.6 s$^{-1}$. To induce knock-out reactions populating low-lying states in $^{56}$Ca, the secondary beam impinged

![BigRIPS PID](image)

![SAMURAI PID](image)

Fig. 1. BigRIPS particle identification (left) and SAMURAI particle identification for $^{57}$Sc secondary beam (right). The $^{57}$Sc$(p, 2p)$ reaction channel is selected.

The beam energy in front of the secondary target was measured to be $\sim$250 MeV/nucleon. The upgraded DALI2$^{4,5}$ array, which contains 226 NaI(Tl) detectors, was used to measure gamma rays emitted from the in-flight particles. The reaction residues were identified using the SAMURAI spectrometer. The identification of the residues from the $^{57}$Sc secondary beam is also shown in Fig. 1, from which the $^{56}$Ca isotopes are selected.

Currently, the gamma-ray spectrum in coincidence with the $^{57}$Sc$(p, 2p)$ reaction channel is under analysis. This preliminary energy spectrum shows a candidate peak of the $2_1^+ \to 0_1^+$ transition observed at an energy consistent with the aforementioned range of theoretical predictions. The spectra coincident with other reaction channels, which produce $^{56}$Ca, are also under analysis.

References

4) I. Murray et al., In this report.