# Proton removal and lifetimes in the Ca isotopes: Spectroscopy and reaction studies

H. L. Crawford,*1 S. Paschalis,*2 and M. Petri*2 for the RIBF170R1 Collaboration

Nucleon knockout reactions are an essential and powerful tool to study the single-particle structure of nuclei far from stability. Through comparison of measured ($\sigma_{\mathrm{exp}}$) and theoretical ($\sigma_{\mathrm{th}}$) inclusive and exclusive cross-sections they provide a method to assign specific single-particle configurations and occupancies of states in nuclei. However, the theoretical description of knockout reactions is challenging, requiring both a treatment of the reaction dynamics and the nuclear structure of initial and final states.

The ratio $R = \sigma_{\mathrm{exp}}/\sigma_{\mathrm{th}}$ has been found, in stable nuclei and specifically for $(e, e'p)$ and single-nucleon transfer reactions[1,2)] to be consistently less than 1 ($R \sim 0.6$), a reduction attributed to short and long-range correlations not captured in the shell-model. However, moving away from $\beta$-stability, a study by Tostevin and Gade[3)] using available one-nucleon removal data on unstable isotopes performed at intermediate energies ($\sim$100 MeV/nucleon) shows a dependence of $R$ on the difference in the proton and neutron separation energies of the initial system. This dependence is in contrast to both transfer reaction data taken at lower energies and to new data reported recently by the R$^3$B collaboration[4)] and RIBF[5)] for quasi-free one-proton knockout at higher energies.

Given the important implications of disentangling the reaction and structure effects related to the origin of the $\Delta S$ dependence of $R$ observed in knockout reactions, we have performed an experiment to directly explore the isospin dependence of proton knockout on both C and H targets at RIBF energies. In addition to the reaction cross-sections, we were also able to take advantage of the opportunity presented by the HiCARI high-resolution $\gamma$-ray array[6)] at RIBF to simultaneously explore lifetimes in the neutron-rich Ca isotopes, which provide an important testing ground for interactions derived from chiral Effective Field Theory and many-body methods.

The experiment was performed in December 2020 at the RIBF as part of the HiCARI campaign. A $^{70}$Zn primary beam was accelerated to 345 MeV/nucleon and fragmented on a $^{9}$Be primary target to produce secondary beams centered on $^{38,48,54}$Ca. Fragments were separated and identified within BigRIPS using the standard $\Delta E$-TOF-$\Delta E$ method. The secondary beam impinged on 1 g/cm$^2$ thick C and 1.2 g/cm$^2$ thick CH$_2$ targets at the F8 focal plane, which induced knockout reactions. The reaction residues were identified in the ZeroDegree spectrometer. The preliminary particle identification plots for the setting on $^{54}$Ca are shown in Fig. 1. De-excitation $\gamma$-rays were detected within the HiCARI array.

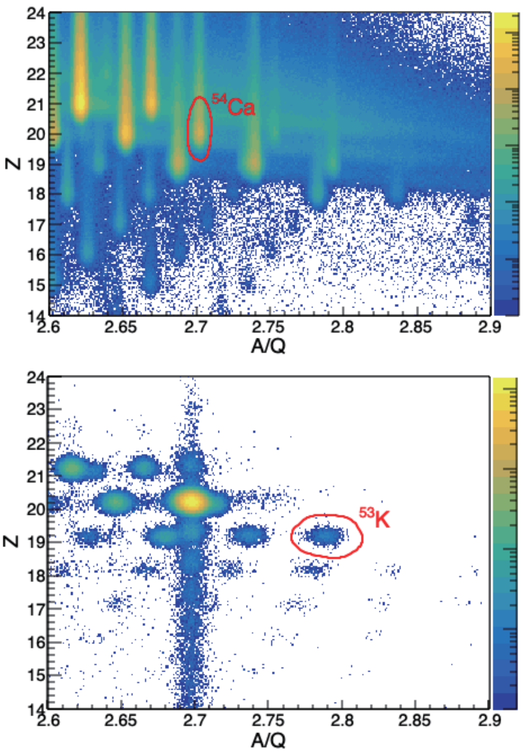


Fig. 1. (Top) Particle identification plot for incoming beam particles in BigRIPS for the setting of $^{54}$Ca. (Bottom) Reaction residue particle identification in the ZeroDegree spectrometer, gated on incoming $^{54}$Ca particles.

Currently, the proton removal inclusive and exclusive cross-sections from $^{38,48,54}$Ca to final states in $^{37,47,53}$K are under analysis. In addition, $\gamma$-ray spectra in the most neutron-rich Ca isotopes, namely $^{53,54}$Ca are being carefully analyzed. Preliminary energy spectra show evidence for lifetimes within the sensitivity range for line-shape analysis, which will be pursued in the next stages of analysis.


References

1) B. P. Kay *et al.*, Phys. Rev. Lett. **111**, 042502 (2013).
2) G. Kramer *et al.*, Nucl. Phys. A **679**, 267 (2001).
3) J. A. Tostevin, A. Gade, Phys. Rev. C **90**, 057602 (2014).
4) L. Atar *et al.*, Phys. Rev. Lett. **120**, 052501 (2018).
5) S. Kawase *et al.*, Prog. Theor. Exp. Phys. **2018**, 021 D01 (2018).
6) K. Wimmer *et al.*, in this report.


*1 Nuclear Science Division, Lawrence Berkeley National Lab
*2 Department of Physics, University of York