Evidence for a new nuclear ‘magic number’ in $^{54}$Ca


Over recent years, the evolution of nuclear shell structure in exotic, neutron-rich nuclei has attracted much attention on both the experimental and theoretical fronts. In the neutron-rich $fp$ shell, the onset of the $N = 32$ subshell closure is well established from the structural characteristics of $^{52}$Ca$^{1,2}$, $^{54}$Ti$^{3,4}$ and $^{56}$Ca$^{5,6}$. This subshell gap is reproduced successfully by numerous theoretical predictions. In the framework of tensor-force-driven shell evolution$^7$, the onset of the $N = 32$ subshell closure results as a direct consequence of a sizable $\nu p_{3/2} - \nu p_{1/2}$ gap, which presents itself as the $\nu f_{5/2}$ orbital shifts up in energy owing to a weakening of the attractive $\pi f_{7/2} - \nu f_{5/2}$ interaction as protons are removed from the $\pi f_{7/2}$ orbital. Another important manifestation of some theories is the prediction of a large subshell gap at $N = 34$, which develops if the $\nu f_{5/2}$ orbital lies sufficiently high in energy above the $\nu p_{1/2}$ orbital. It has already been shown that no significant $N = 34$ subshell gap exists in $^{56}$Ti$^{1,8}$ or $^{58}$Cr$^{6,9}$ and, therefore, the size of the energy gap in $^{54}$Ca is an important structural characteristic that requires experimental input. Moreover, the single-particle states of $^{53}$Ca should also reflect the nature of the $N = 34$ subshell closure in isotopes far from stability.

The structures of $^{54}$Ca and $^{55}$Ca were investigated using in-beam $\gamma$-ray spectroscopy at the RIBF to address this issue. A primary beam of $^{70}$Zn$^{50+}$ ions at 345 MeV/n was used to create a radioactive beam containing $^{55}$Sc and $^{56}$Ti, which was focused on a 10-mm-thick...