SEARCH FOR INTRUDER STATES IN ^{68}Ni AND ^{67}Co*

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The level schemes of ^{68}Ni and ^{67}Co were extended following ^{70}Zn-induced deep-inelastic reactions. No evidence for a previously reported proton intruder 0^+ state at 2202 keV in ^{68}Ni was found. In ^{67}Co, two new states at 3216 and 3415 keV have been established; additional states associated with the intruder configuration have yet to be identified.

1. Introduction

The role of intruder orbitals in the structure of nuclei in the ^{68}Ni region has received increased attention recently. Proton intruders from across the $Z = 28$ shell gap are believed to strongly influence the low-lying structure

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of odd-Z nuclei on both sides of the gap [1–5]. For example, the deformed $\Omega^\pi = 1/2^-$ level of the $p_{3/2}$ proton from above the $Z = 28$ shell gap is proposed as the origin of the $(1/2^-)$ level located at 492 keV in ^{67}Co. In even-Z ^{68}Ni, a proton two-particle, two-hole excitation $(2p2h)$ is expected rather than a single proton intruder; Ref. [6] reported observation of a 0^+ isomer at 2202 keV, which they attributed to this $2p2h$ state. As the origins of these states are speculative, we set out to find deformed structures built upon them to provide evidence of their intruder nature.

2. Experiment

Excited states of ^{68}Ni and ^{67}Co were populated following deep-inelastic-scattering (DIS) reactions between a 440 MeV ^{70}Zn beam and ~ 50 mg/cm^2 ^{238}U, ^{208}Pb, and ^{197}Au targets. The beam, provided by the ATLAS facility, had a timing structure of one $\sim$0.3 ns beam pulse every 412 ns, allowing for the measurement of prompt and delayed $\gamma\gamma$ coincidences with the Gammasphere array of 100 Compton-suppressed Ge detectors [7] as described in, *e.g.*, Ref. [8]. Both the target-like and projectile-like species can be mutually excited during the DIS reaction process, so γ rays emitted from partner nuclei are found within the same coincidence events. Many of the target-like partners produced in this study have isomers that are well suited for delayed gates in cross-coincidence with the nuclei of interest.

3. Results

^{68}Ni was produced in these reactions through the removal of two protons from the ^{70}Zn beam. For the ^{208}Pb target, the partner nuclei are the Po isotopes with $A \leq 210$. Figure 1 shows a spectrum of prompt γ rays in coincidence with the prompt 2033 keV $2^+ \to 0^+$ transition in ^{68}Ni and delayed γ rays in ^{210}Po. The expected lines feeding the 2^+ state are clearly identified — see the partial level scheme in Fig. 1.

One goal of this study was to search for states built upon the 0^+ isomer reported at 2202 keV in Ref. [6], to attempt to verify the claimed $\pi(2p2h)$ intruder nature of this state. However, no evidence for this state was observed in our work. In particular, the reported 168 keV isomeric decay to the 2_1^+ state is not observed in coincidence with the 2033 keV transition in the delayed $\gamma\gamma$ data from any of our three targets — see inset of Fig. 1. These results are presented in detail in Ref. [8]. Additional analysis of ^{68}Ni by our collaboration using similar DIS reactions can be found in Ref. [9].

The removal of a third proton from the ^{70}Zn beam leads to population of excited states in ^{67}Co. Recchia *et al.* [10] recently reported results on this nucleus from the ^{70}Zn + ^{238}U DIS reaction studied with the CLARA–
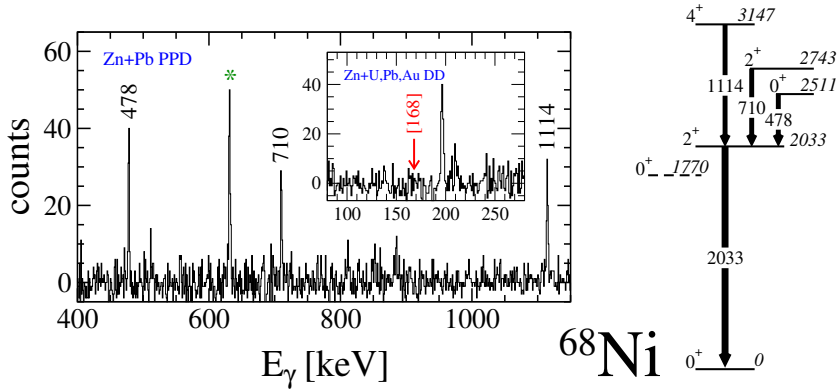
Fig. 1. Left: Prompt spectrum from a double gate on the prompt 2033 keV ^{68}Ni γ ray and delayed ^{210}Po lines in the ^{70}Zn + ^{208}Pb data. The asterisk marks a prompt ^{210}Po γ ray. Inset: Sum of gates on 2033 keV in all three delayed $\gamma\gamma$ data sets. Right: Partial ^{68}Ni level scheme. The 0_2^+ state was not observed here.

PRISMA setup at Legnaro, where event-by-event isotopic identification of the ions was achieved. They identified ten new γ rays, some of which were organized into a level scheme based on energies and intensities, but no $\gamma\gamma$ coincidences were possible. With our similar DIS reactions and higher coincidence efficiency, we were able to confirm and extend the 1612–1188 keV sequence proposed in Ref. [10] based on our prompt $\gamma\gamma\gamma$ coincidence spectra. This sequence is not seen in the delayed data, and is thus not fed by an isomer. The spectrum gated on 1612 and 1188 keV is presented in Fig. 2 along with a partial level scheme from the present work. Several other unplaced γ rays listed in Ref. [10] have also been observed here and appear to feed the 1612 keV level. Thus far, decays to the suggested 492 keV intruder isomer have yet to be identified in this work.

At first glance, the observed sequence in ^{67}Co is suggestive of a weak coupling of $\pi f_{7/2}^{-1} \otimes \{^{68}$Ni ground-state band$\}$, forming an $E2$ band up to $(23/2^-)$. While the 1188 and 199 keV transitions are similar in energy to their supposed ^{68}Ni counterparts, the other two transitions are too compressed, by ~ 400 keV each. Alternatively, the 1612 keV level may come from $\pi f_{7/2}^{-1} \otimes \nu(2p2h)$, based on the 0_2^+ state in ^{68}Ni indicated in Fig. 1. (Note that the energy of that state is not well known.) This would imply a $7/2^-$ assignment for the 1612 keV level, which would also be consistent with the large anisotropy ratio measured for the 1612 keV γ ray in Ref. [10]. More analysis is needed if definitive conclusions are to be drawn.
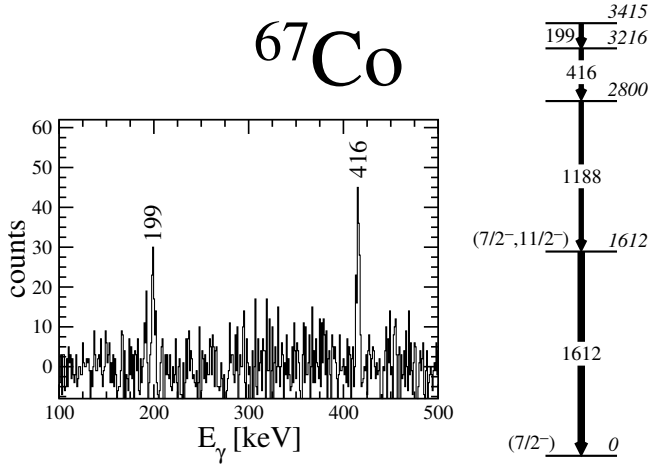
Fig. 2. Left: Spectrum from a double gate on the 1612 and 1188 keV γ rays in ^{67}Co in the ^{70}Zn + ^{208}Pb prompt data. Right: Partial ^{67}Co level scheme.

4. Summary

In our efforts to identify a deformed structure associated with the proposed $\pi(2p2h)$ 0^+ intruder state in ^{68}Ni [6], we discovered no evidence for the state itself at 2202 keV. In ^{67}Co, the intruder sequence has not been identified, but the level scheme has been extended; an interpretation must await additional analysis.

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