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Abstract. The proton inelastic scattering on ^{68,70,72}Ni isotopes was measured at the NSCL at MSU, employing the S800 spectrometer coupled to the GRETINA γ-ray array. The aim of the experiment was to determine the degree of collectivity in these neutron-rich $Z = 28$ isotopes. The use of a hadronic probe allows to complement previous Coulomb excitation measurements of the reduced transition probability B(E2; $0^+ \to 2^+$) and deduce the neutron-to-proton transition matrix elements ratio. The high resolution in γ-ray energy achievable with GRETINA gives large control on feeding transitions, thus reducing possible systematics errors in the determination of transition strengths.

1. Introduction

Moving along isotopic and isotonic chains far from stability, some of the known magic numbers disappear, and other proton or neutron numbers emerge as magic, implying a more local applicability of the concept of magicity than what was assumed in the past [1]. Understanding the evolution of the shell structure is one of the fundamental goals of contemporary Nuclear Physics. Nowadays it is widely accepted that the major contribution to the shell evolution is given by the monopole part of the nucleon-nucleon interaction, and in particular the tensor force, which is responsible for the strong attraction between a proton and a neutron in spin-flip partner orbits and the repulsion between protons and neutrons occupying shells with parallel spin configurations [2]. The neutron-proton interaction is then responsible for modifications in the spacing of single-particle orbitals and, as a consequence, in the size of shell gaps [3].

In this regard, the Ni isotopic chain is particularly interesting because the $Z = 28$ gap is predicted to reduce moving from ^{68}Ni to ^{78}Ni, due to the attraction between the $\pi f_{5/2}$ and $\nu g_{9/2}$ and the repulsion between the $\pi f_{7/2}$ and $\nu g_{9/2}$ orbitals. A signature of shell evolution is given by the reduced transition probability B(E2; $2^+ \to 0^+$), which gives direct information on how quadrupole correlations evolve along the isotopic chain and can be measured by means of electromagnetic or hadronic probes. The use of electromagnetic probes (e.g. Coulomb excitation) gives access only to proton transition matrix elements, while the neutron counterpart can be extracted using hadronic probes, like proton inelastic scattering, which are sensitive to both protons and neutrons.

From the B(E2) value one can infer about the nuclear degree of collectivity through the quadrupole deformation parameter β_2, which can be extracted either via electromagnetic transition amplitudes (β_2^{C}) or through the so-called *deformation length* δ measured in proton inelastic experiments ($\beta_2^{(\mathrm{p,p'})}$). If protons and neutrons contribute equally to the excitation, their respective deformations should be similar and $\beta_2^{\mathrm{C}} \simeq \beta_2^{(\mathrm{p,p'})}$. Figure 1 shows the systematic of β_2^{C} and $\beta_2^{(\mathrm{p,p'})}$ for Ni isotopes. One can notice that $\beta_2^{(\mathrm{p,p'})}$ is systematically larger than β_2^{C}, an indication that along the $Z = 28$ shell closure valence neutrons give a larger contribution to the development of collectivity.

For neutron-rich Ni isotopes with $N \geq 40$ there are large discrepancies between different (p,p'), Coulomb excitation and direct lifetime measurements. Some point to a reduced collectivity in mid-shell Ni isotopes [4, 5, 6], others point instead to an enhancement of collectivity [7, 8, 9]. Most of these measurements, performed with radioactive ion beams with low intensity (usually less than 10^4 pps) suffer from both low statistics and low resolutions, which make the effect of possible feeding transitions difficult to control. This may result in pretty large systematic errors.

In the present experiment, this issue will be addressed by employing a high-resolution γ-ray detector which allows to better identify the different levels populated in the reaction and their possible contribution to the observed intensity of the γ transition de-exciting the 2^+ state of interest.

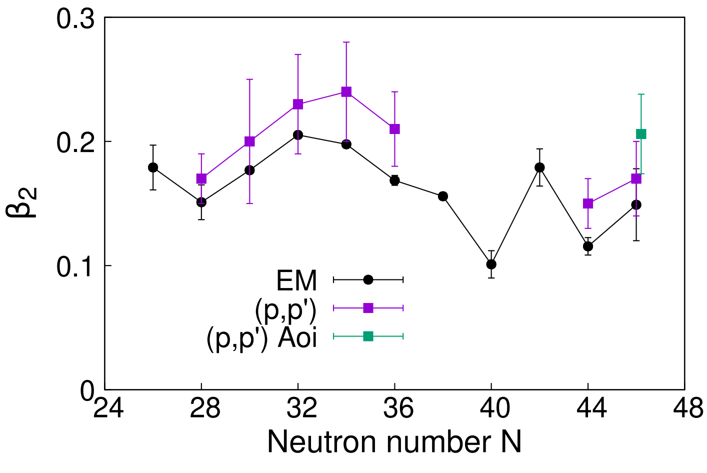

Figure 1. Adopted values for the deformation parameter β_2 from electromagnetic probes (EM) and β_2 from proton inelastic scattering (p,p') for Ni isotopes (adapted from Ref. [4]).

2. The experiment

The experiment was carried out at the National Superconducting Cyclotron Laboratory (NSCL) of the Michigan State University (MSU). Secondary beams of ^{68,70,72}Ni at energies of 70-80 MeV/u, produced by the fragmentation of a primary ^{76}Ge beam at 130 MeV/u on a Be primary target, are selected with the A1900 fragment separator [10] and impinge on a LH_2

cryogenic target with a thickness of 7.8 mm, corresponding to an areal density of approximately 60 mg/cm^2. The target is surrounded by the GRETINA segmented γ-ray array [12], composed of 28 crystals. The reacted and unreacted beamlike ions are identified in the S800 spectrometer [11] on an event-by-event basis. Some details on the preliminary data analysis were already reported in Ref. [13].

Figures 2 and 3 show examples of particle identification matrices in the entrance and exit channels, respectively, for runs where the settings were optimized for the selection of ^{68}Ni. The identification in the entrance channel is obtained by correlating Time-of-Flight differences of the ions between the focal plane of the A1900 and the object position of the S800, in the exit channel combining ToF and ΔE information, where the energy loss is measured in the ionization chamber at the focal plane of the S800 spectrometer.

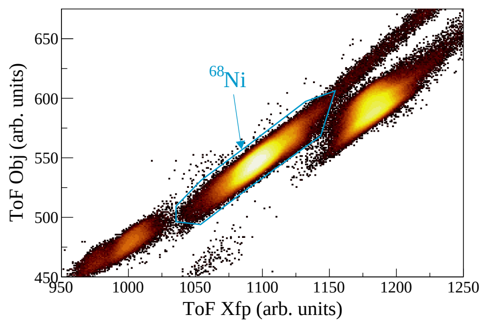

Figure 2. Particle identification in the entrance channel.

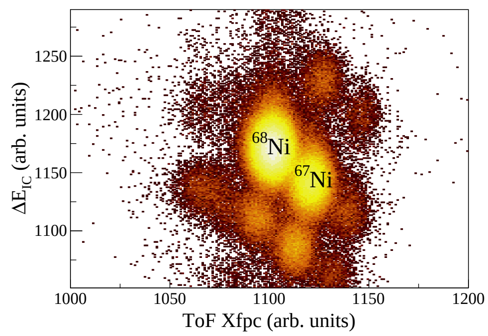

Figure 3. Particle identification in the exit channel with a gate on ^{68}Ni in the entrance channel (azure gate in the figure on the left) and the request of a coincidence in GRETINA.

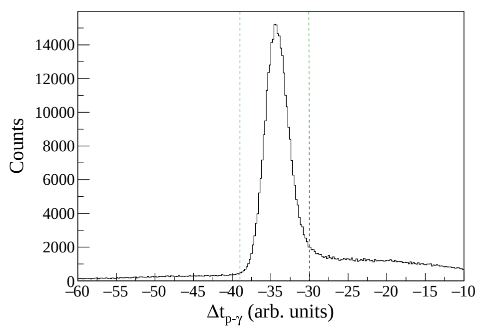

Figure 4. Time spectrum between GRETINA and the S800 spectrometer. The prompt coincidence peak is within the dashed green lines.

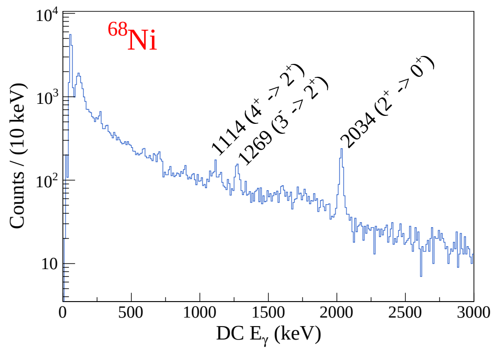

Figure 5. γ-ray spectrum obtained after gating on ^{68}Ni in the entrance and exit channels amd with an additional gate on the prompt time peak between GRETINA and the S800.

By gating on the same incoming and outgoing ion, one can select elastic and inelastic scattering events. With an additional gate on the prompt time coincidence peak between GRETINA and the S800 (see Fig. 4), one can look at the Doppler-corrected γ-ray spectrum, reported in Fig. 5. The main transitions belonging to ^{68}Ni can be clearly seen thanks to the

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high resolution of GRETINA.

The intensity of the peaks is related to the exclusive (p,p') cross section for a given state, which in turn depends on the transition probability. Since both the 3^- and 4^+ states decay to the 2^+, it is extremely important to subtract their contribution from the intensity of the $2^+ \to 0^+$ transition in order not to overestimate the value of the deformation length δ, goal of this analysis.

3. Conclusions

The evolution of collectivity in neutron-rich Nickel isotopes when pregressively filling the $g_{9/2}$ shell above $N = 40$ has been studied by measuring the proton inelastic scattering of ^{68,70,72}Ni in inverse kinematics. The analysis is still ongoing but preliminary results show that the high resolution of the GRETINA γ-ray array will allow to pin down with a higher confidence level the contributions of feeding transitions to the extracted transition probabilities. This will allow to determine the deformation length and the neutron-to-proton matrix element ratio in these nuclei with reduced systematic errors.

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