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Probing core polarization around ^{78}Ni: intermediate energy Coulomb excitation of ^{74}Ni.

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Abstract. The study of the evolution of nuclear shells far from stability provides fundamental information about the shape and symmetry of the nuclear mean field. Nuclei with large neutron/proton ratio allow to probe the density dependence of the effective interaction. Indeed, it was recently shown that tensor and three-body forces play an important role in breaking and creating magic numbers. Of particular interest is the region of ^{78}Ni where the large neutron excess coincides with a double shell closure.

We have recently measured the $B(E2; 0^+ \rightarrow 2^+)$ of the ^{74}Ni nucleus in an intermediate-energy Coulomb excitation experiment performed at the National Superconducting Cyclotron Laboratory of the Michigan State University. The ^{74}Ni secondary beam has been produced by fragmentation of ^{86}Kr at 140 AMeV on a thick Be target. Selected radioactive fragments impinged on a secondary ^{197}Au target where the measurement of the emitted γ-rays allows to extract the Coulomb excitation cross section and related structure information. Preliminary B(E2) values do not point towards an enhancement of the transition matrix element and the comparison to what was already measured by Aoi and co-workers in [1] opens new scenarios in the interpretation of the shell evolution of the Z=28 isotopes.

1 Introduction

In recent years, the availability of neutron-rich radioactive ion beams has allowed to explore new regions of the nuclear chart. In spite of that fact most exotic nuclei have been produced with quite low intensities, new interesting results revealed an evolution of the nuclear structure far from the valley of β stability. Some of the well established fundamental properties of the nuclear models, like the magic numbers, had to be reviewed in the light of new experimental observations: new features have been included in nuclear models in order to reproduce experimental data. Indeed it was recently shown that tensor and three-body forces play an important role in breaking and creating magic numbers [2].

One region of particular interest is the neutron-rich tail of the Ni isotopic chain. For instance, the ^{78}Ni nucleus corresponds to a double shell closure and is characterized by a large neutron excess. Different theories (see [3]) predict that at this N/Z ratio one could expect an increase of the proton-neutron interaction strength that would modify the relative energies of the single particle states, thus reducing the Z=28 energy gap. In such a scenario, particle-hole excitations should be strongly increased, driving to enhanced collectivity. The determination of the B(E2) values of the low-lying transitions is therefore very important to measure these features and to constrain the interaction used for the shell model calculations. This was recently done by Aoi and collaborators in [1] who performed a proton scattering experiment of the ^{74}Ni nucleus and actually observed the enhancement of collectivity. In this work we present some preliminary results of the $B(E2; 0^+ \rightarrow 2^+)$

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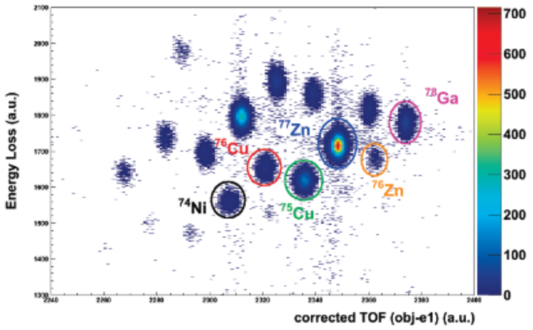

Figure 1. Focal plane particle identification matrix. Ions have been identified with respect to the most intense ^{77}Zn beam.

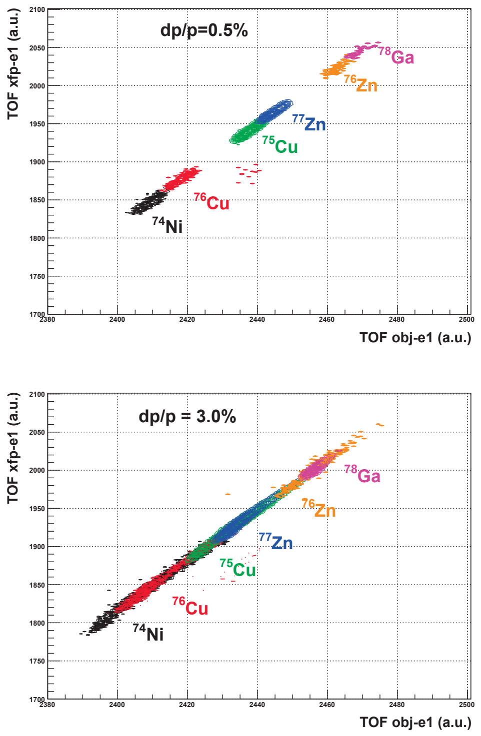

Figure 2. Incoming particle identification in runs without target. The different species are tagged using the focal plane identification (see fig. 1). A good separation is achieved if dp/p=0.5% (top panel) while the situation is worse if dp/p=3.0% (lower panel).

measurement for the same nucleus using the Coulomb excitation technique.

2 Experiment

The experiment was performed at the National Superconducting Cyclotron Laboratory (NSCL) of the Michigan State University (MSU). A primary beam of ^{86}Kr has been accelerated by the Coupled Cyclotron Facility [4] up to an energy of 140 AMeV and directed towards a 399 mg/cm^2 thick ^{9}Be primary target. Fragmentation reactions produced a broad spectrum of stable and radioactive nuclei. The isotopes of interest have been then selected by the A1900 Fragment Separator [5] and transported to the S3 experimental hall where the S800 spectrometer is placed [6]. The A1900 momentum acceptance was set to 3% and the selected cocktail-beam contained ^{74}Ni with an energy of 67 AMeV and an intensity of 0.7 pps. The beam purity was $\approx$ 1.5% , the main contaminants being: ^{77}Zn, ^{76}Cu and ^{75}Cu. This admixture of isotopes passed through the S800 analysis line and hit the ^{197}Au secondary target (642 mg/cm^2 thick, 9 cm diameter). Coulomb excitation occurred and the de-excitation γ-rays have been measured using the CAESAR 4π scintillator array [7].

After the secondary target, forward traveling particles entered the S800 superconducting spectrometer and were measured by the S800 focal plane detectors [8]. At this position a set of two Cathode Readout Drift Chambers, one Ionization Chamber and one plastic scintillator are used for the scattered particles identification and tracking. A plot of the outgoing particles identification is shown in figure 1 where the ΔE-TOF correlation is used. After a proper correction of the time of flight, accounting for effects like the different path of the particles through the S800 spectrograph, the ^{74}Ni blob is nicely separated. This is not the case for the incoming beam identification where the A1900 momentum acceptance plays an important role. Given the extremely low production cross section of the ^{74}Ni nucleus, the A1900 was used with a higher momentum acceptance with respect to what is normally done at NSCL (dp/p=3% instead of 0.5%). As shown in figure 2, in this situation the TOF-TOF correlation technique typically used for the beam tagging is not capable to provide a clean separation over the whole range of the particles. Because of this and due to the need of selecting only ^{74}Ni ions, a small subset of events could be considered safe for the data analysis and a very strict gate was applied to the incoming beam particle identification (i.e. only the lowest-left part of the correlation shown in figure 2 was selected). Coulomb scattering events have been selected applying a gate on the incoming and outgoing ^{74}Ni ions from the previously mentioned correlations and performing a cut on the safe impact parameter. This was obtained from the scattering angle distribution shown in figure 3 and considering as safe impact parameter distance the sum of the two nuclear radii plus 2 fm (see, for instance, [9] and [10]). The coincident γ-ray spectrum was Doppler corrected on an event-by-event basis using the scattered particles velocity and trajectory information as measured by the S800 detectors. A proper time gate was also applied.

3 Result

The γ-ray spectrum is used to extract the experimental de-excitation cross section. Its integral can be estimated scaling a GEANT4 simulation of the CAESAR array on the experimental data adding a doubly-exponential background function to account for low-energy brehmsstrahlung events.

The B(E2; $0^+ \to 2^+$) value for the transition from the ground state to the first excited state of the ^{74}Ni nucleus can be calculated using the cross section obtained from the experimental data. No normalization to other known nuclei is possible due to the problems in the beam particles tagging discussed in the previous paragraph. For this reason the results of the DWEIKO [11] calculation are linearly scaled to extract the experimental B(E2). Even if the analysis is still going on, preliminary results do not show evidences of collectivity enhancement, displaying a B(E2) value about 40% lower than the one obtained in the (p,p') experiment.

4 Discussion

Figure 4 shows some theoretical expectations and the evaluated data for the neutron rich side of the Ni isotopic chain.

It has to be noticed that this work provides the most exotic probe of shell model calculations in this region since no data are available yet for N = 48 or higher. From the theoretical point of view this region has been widely studied using different interactions like the GXPF1A and the JUN45 (see [12] and references therein). The valence space covers typically the *fpg* shells using a ^{40}Ca inert core.

The GXPF1A and JUN45 are state of the art interactions used in shell model calculations in the *fp* and *fpg* model spaces respectively. The values reported by Pritychenko in [12] were obtained in a reduced valence space, namely the *pf* shells for the GXPF1A extended up to the $g_{9/2}$ orbital for the JUN45. The most straight forward evolution of these results is represented by the Monte Carlo Shell Model Calculation performed by N. Shimizu and co-workers in [13] (black line of figure 4). In this case the interaction used is based on a connection between the GXPF1A and the JUN45 forming the so-called A3DA interaction that has been properly tuned and used within the Monte Carlo Shell Model approach. The obtained results are in good agreement with respect to the calculations performed for the lighter Ni isotopes and compatible with the result of the present work. It is worth noticing that the model by N. Shimizu and co-workers predicts an increase of the B(E2) value for the ^{78}Ni nucleus, opposite to what one could expect given the nominal double shell closure at Z = 28 and N = 50. This feature is very interesting and it underlines the importance of a better determination of the ingredients needed to describe the structure in this exotic mass region.

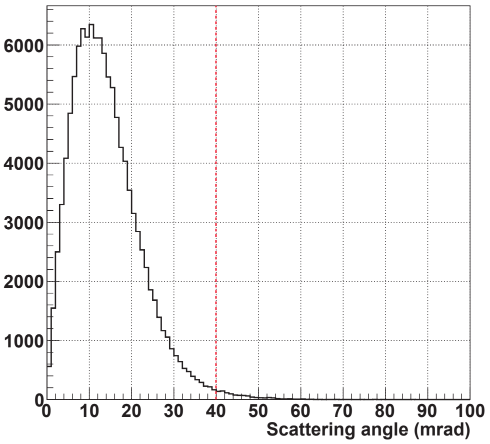

Figure 3. ^{74}Ni ions scattering angle distribution. The cut on the safe impact parameter is obtained selecting only events where $\theta_{lab} < 40$ mrad.

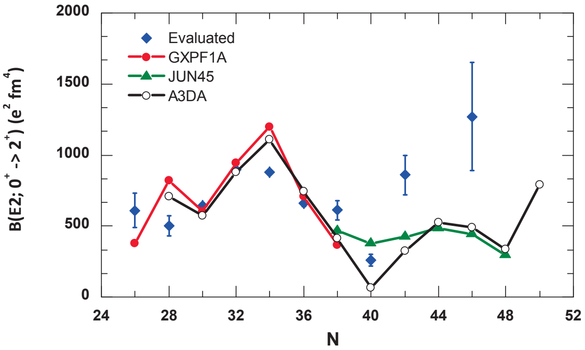

Figure 4. Experimental values and theoretical expectations for the B(E2↑) matrix element of the known even-even Ni isotopes. Data are from [12] and [13].

Concerning the experimental data shown in figure 4 as evaluated by Pritychenko and co-workers, it is important to recall that the only experimental information available on the ^{74}Ni nucleus is the one obtained in the already mentioned experiment by Aoi and collaborators. The measured value is quite different from the one obtained in this work but it has to be underlined that the two results have been derived using different techniques. By definition, the Coulomb excitation mechanism is only sensitive to the electromagnetic interaction between the reaction partners (nuclear interactions contributions have been explicitly removed by the cut on the impact parameter), while Aoi and co-workers performed a proton scattering experiment where both the nuclear and Coulomb interactions act in the excitation process. If this difference is confirmed, there could be the indication of an important de-coupling of the neutron and proton shells in presence of a strong neutron excess. This feature could lead to different proton/neutron core deformations. It is clear that new measurements in the same mass region are needed to confirm and complete the result of the present study.

5 Summary

The ^{74}Ni nucleus was studied by intermediate energy Coulomb excitation. Even if with limited statistics due to the extremely low beam intensity, it was possible to extract the B(E2↑) value for the excitation to the first 2^+ state. This was done scaling the measured excitation cross section to the results obtained with the DWEIKO code. An absolute normalization of the measured value seems, at the moment, difficult to obtain due to the strong low-energy background shadowing the target excitation line and to the lack of nuclei with known B(E2; $0^+ \rightarrow 2^+$) values in the secondary beam composition.

The preliminary result can be compared to some up-to-date shell model calculations and shows the importance of the extension of the valence space to higher orbitals when moving towards very neutron-rich nuclei. The previously observed increase of collectivity seems quenched when observed using pure electromagnetic probes. If confirmed by more extensive studies in this region using different approaches, this evidence could be symptom of a de-coupling of the proton/neutron cores.

This work, complementing the information obtained by Aoi and collaborators, represents the most exotic access to the nuclear structure properties of the neutron rich side of the Nickel isotopic chain and underlines once more the importance for new generation facilities that will provide more intense and more exotic radioactive ion beams, allowing for a more complete and precise study of the evolution of the nuclear shells.

6 Aknowledgments

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