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Evolution of collectivity in the ^{78}Ni region: Coulomb excitation of ^{74}Ni at intermediate energies

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Abstract. The study of the collective properties of nuclear excitations far from stability provides information about the shell structure at extreme conditions. Spectroscopic observables such as the energy or the transition probabilities of the lowest states, in nuclei with large neutron excess, allow to probe the density and isospin 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. Emblematic is the case of the evolution of the Ni isotopic chain where several features showed up moving from the most neutron rich stable isotope (^{64}Ni) towards the ^{78}Ni nucleus where the large neutron excess coincides with a double shell closure. In this framework, we have recently performed an experiment with the goal to extract the $B(E2; 0^+ \to 2^+)$ value for the ^{74}Ni nucleus in an intermediate-energy Coulomb excitation experiment: preliminary results are discussed.

1 Introduction

The collective features of nuclear excitation are directly linked to fundamental nuclear structure properties like the symmetry and shape of the nuclear mean field. The availability of neutron-rich radioactive ion beams allows to investigate such properties far from the valley of β stability. One region of

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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 [2] and [3]) predict that at extreme isospin conditions, specific components of the effective interaction, like the tensor force, could modify the single particle energies leading to an enhancement of collectivity. The experimental determination of the B(E2) values of the low-lying transitions is therefore very important to quantify these effects and to constrain the interaction used for the shell model calculations. In this contribution we present some preliminary data of a ^{74}Ni Coulomb excitation experiment.

2 Experiment

The exotic nuclei of interest have been produced by fragmentation of a ^{86}Kr primary beam on a ^{9}Be target at the Coupled Cyclotron Facility of the National Superconducting Cyclotron Laboratory (NSCL). The fragments emitted by the primary reactions have been selected by the A1900 Fragment Separator [4] with a momentum acceptance of 3% and transported to the S800 spectrograph setup [5]. After the A1900 separator, the selected cocktail-beam contained ^{74}Ni with an intensity of 0.7 pps and a purity of ≈ 1.5%, the main contaminants being: ^{77}Zn, ^{76}Cu and ^{75}Cu. This secondary beam passed through the S800 analysis line and hit the ^{197}Au target (642 mg/cm^2 thick, 9 cm diameter) where Coulomb excitation occurred. At this position the CAESAR 4π scintillator array [6] was used to detect the de-excitation γ-rays.

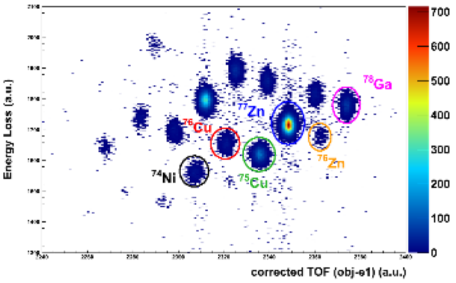

Figure 1. S800 focal plane particle identification matrix. Ions have been identified with respect to the most intense ^{77}Zn beam.

The scattered particles entered the S800 superconducting spectrometer and were measured by the S800 focal plane detectors [7]. These have been used for particle identification and tracking purposes and are composed of: a set of two Cathode Readout Drift Chambers, one Ionization Chamber and one plastic scintillator. 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. The opposite situation occours for the incoming beam identification obtained using the TOF-TOF correlation along the transport line. In this case 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%). Both cases are illustrated in figure 2: the right panel displays the actual experimental condition: it is clear that only the lower-left part of the plot provides a clean selection of incoming ^{74}Ni

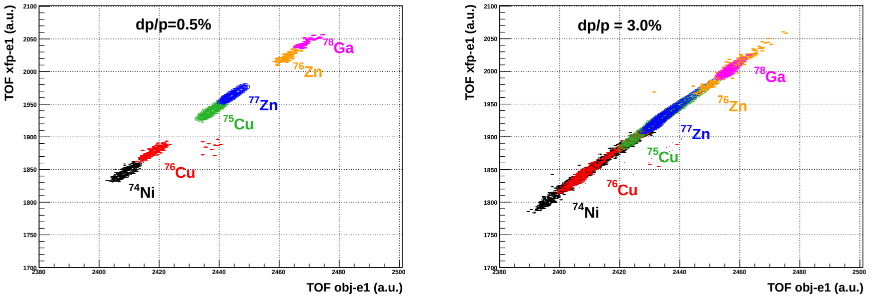

Figure 2. Incoming particle identification in runs without target. The different species are tagged using the focal plane identification (see fig. 1). A good separation is achieved if dp/p=0.5% (left panel) while the situation is worse if dp/p=3.0% (right panel).

ions, so a strict gate was applied on this region.
After the incoming and outgoing ^{74}Ni ions selection, pure Coulomb scattering events have been extracted requiring a "safe" impact parameter condition (see [8] and [9]). 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, moreover a proper time gate was applied. A preliminary γ-ray spectrum integral has been 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. Due to the presence of a huge low-energy background, the add-back procedure described in ref. [6] was not used. Because of the problems in the beam particles tagging previously discussed, the normalization to other known nuclei has not been obtained yet. For this reason a preliminary estimation of the B(E2) value can only be obtained scaling the cross section calculated using the DWEIKO code [10] (with a given matrix element) to the measured cross section. The analysis is under completion and a fine tuning of the experimental setup simulation is needed in order to finalize the result. Despite this, preliminary estimations do not show evidences of collectivity enhancement, displaying a B(E2) value about 40% lower than the one obtained in the (p,p') experiment by Aoi and collaborators in [1].

3 Discussion

Figure 3 shows some theoretical expectations and the experimental evaluation performed in [11] for the neutron rich side of the Ni isotopic chain. The GXPF1A and JUN45 interactions (see [11] and references therein) have been used for shell model calculations considering a reduced valence space, namely the pf shells for the GXPF1A extended up to the $g_{9/2}$ orbital for the JUN45. Following these results, N. Shimizu and co-workers performed a more extended calculation within the Monte Carlo Shell Model approach [12] (black line of figure 3). In this case the interaction used is based on a connection between the GXPF1A and the JUN45 forming the so-called A3DA interaction. In general, the experimental results for the lighter Ni isotopes, are in good agreement with respect to the calculations performed. We underline 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. It is important to notice that for the evaluation shown in figure 3, in the ^{74}Ni case, only one experimental point has been used and this was deduced from

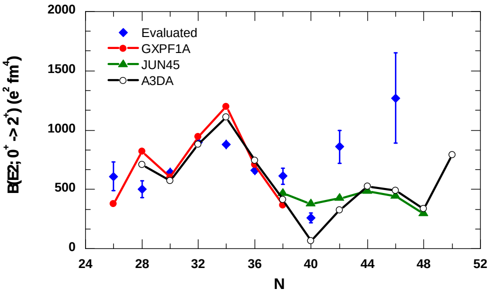

Figure 3. Experimental values and theoretical expectations for the B(E2↑) matrix element of the known even-even Ni isotopes. Experimental data are from [11] while the calculation of A3DA are from [12].

a proton scattering experiment (see [1]). Since this last technique is sensible to both the nuclear and Coulomb interactions, the 40% difference in the B(E2) that our data seems to indicate could be a hint of the neutron and proton shells de-coupling in presence of a strong neutron excess, leading to different proton/neutron core deformations.

4 Conclusion

The analysis of a ^{74}Ni intermediate energy Coulomb excitation experiment has been discussed. The B(E2) to the first 2^+ state, as estimated from a preliminary analysis, seems significantly lower with respect to what was previously obtained. If confirmed in the final analysis, this evidence could be symptomatic of the proton/neutron cores de-coupling. The comparison of different up-to-date shell model calculations shows the importance of the extension of the valence space to higher orbitals when moving towards very neutron-rich nuclei and underlines the need of experimental information in this region.

References

[1] N. Aoi et al., Physics Letters B **692**, 302 (2010)
[2] O. Sorlin M.-G. Porquet, Progr in Part and Nucl Phys **61**, 602 (2008)
[3] T. Otsuka et al., Phys. Rev. Lett. **97**, (2006) 162501
[4] A. Stolz et al., Nucl Instr and Meth B **241**, 858 (2005)
[5] D. Bazin et al., Nucl Instr and Meth B **204**, 629 (2003)
[6] D. Weisshaar et al., Nucl Instr and Meth A **624**, 615 (2010)
[7] J. Yurkon et al., Nucl Instr and Meth A **422**, 291 (1999)
[8] T. Glasmacher, Nuclear Physics A **693**, 90–104 (2001)
[9] W. W. Wilcke et al., At Data and Nucl Data Tables **25**, 389-619 (1980)
[10] C.A. Bertulani, Comp Phys Comm **116**, 345 (1999)
[11] B. Pritychenko et al., At Data and Nucl Data Tables **98**, 798 (2012)
[12] N. Shimizu et al., Prog. Theor. Exp. Phys. 01A205 (2012)