Vol. 38 (2007) *ACTA PHYSICA POLONICA B* No 4

COULOMB EXCITATION OF ^{68}Ni AT 600 AMeV*

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(Received December 10, 2006)

The γ decay following the Coulomb excitation of ^{68}Ni at 600 AMeV has been measured using the RISING array at GSI. The ^{68}Ni beam has been produced from the fragmentation of ^{86}Kr at 900 AMeV from the UNILAC-SIS on a ^{9}Be target and selected using the Fragment Separator. After the selection of Coulomb excited ^{68}Ni isotopes a peak centered at approximately 10.8 MeV has been observed in all type of RISING γ detectors. Because of the reaction mechanism the measured peak is interpreted to have a dipole nature and to come from the Pygmy Dipole Resonance. The measured data are consistent with the predictions of the Relativistic Mean Field and the Random Phase Approximation approaches.

PACS numbers: 21.60, 23.20, 25.70.De, 27.50+e

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[*] Presented at the Zakopane Conference on Nuclear Physics, September 4–10, 2006, Zakopane, Poland.

1. Introduction

The Isovector Giant Dipole Resonance (IVGDR) is one of the most important and easily accessible nuclear collective modes. A large amount of experimental data exists for nuclei in the proximity of the stability line. These data have contributed to the studies on the effective nucleon–nucleon interaction in the medium and, in general, to a deeper understanding of the structure of nuclei. At the moment, there are only very few experimental data for nuclei far from the stability line. In particular, the question on how the Giant Dipole Resonance strength evolves when going from stable to exotic, weakly bound, nuclei with extreme neutron to proton ratio is presently under discussion, both theoretically and experimentally, in connection with the existence of the so called Pygmy Resonances (PR) or soft mode [1–6].

Such topic has recently collected very high interest beyond the nuclear structure field as it could significatively change our understanding of the neutron capture process in the r-process. In fact, neutron-rich nuclei with loosely bound valence neutrons may exhibit very strong (γ, n) strength components (the so called Pygmy Resonance) near particle thresholds and thus very enhanced neutron capture rates (see for example Ref. [7,8]). This means that the Pygmy Resonance can have a striking impact on the calculated r-abundance distribution.

There are two different experimental techniques available for the measurement of the dipole strength in radioactive exotic nuclei. The first one, called virtual photon neutron breakup, consists of producing relativistic radioactive beams and have a kinematic complete measurement of the breakup products produced in the secondary target [9]. This technique does not need high intensity beams but it is limited by the fact that it cannot give any information below the particle binding energy. The second technique, named virtual photon scattering, consists of producing relativistic radioactive beams and measuring the γ-decay of the Coulomb excited projectiles. Such method, even though requires high beam intensity, produces directly the E1 strength distribution and is sensitive both below and above the particle binding energy (see for example Ref. [11–13]).

In such kind of experiments, a critical factor is the capability to disentangle dipole states from others (mainly quadrupole states) which could be excited in the Coulomb scattering reaction. Fig. 1 (taken from Ref. [9]) shows the cross section for electromagnetic excitations of different collective states as a function of beam energy in the case of a medium mass nucleus. It is clear that the dipole cross section increases with the beam energy while quadrupole states shows the opposite behavior. It is, therefore, important to have the highest possible beam energy to ensure the excitation of mainly dipole states.

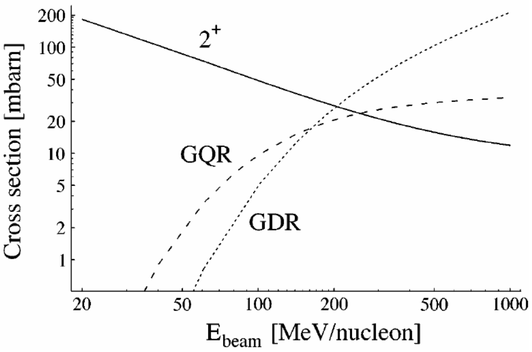

Fig. 1. The cross section for electromagnetic excitations of different collective states as a function of beam energy for a medium mass nucleus on a Au target [10].

For the ^{68}Ni isotopes recent theoretical calculations have predicted that the contribution of the low-energy region to the dipole strength distribution increases with the neutron excess [2,3] and few percents of the Energy Weighted Sum Rule are concentrated around 10 MeV.

Recently, experiments focusing on the measurement of the dipole response of ^{68}Ni have been performed using both the virtual photon scattering (using the RISING detector array) and the virtual photon breakup technique (using the LAND array). The experiments have been performed at GSI at the Fragment Separator (FRS) facility where ^{68}Ni can be produced at relativistic energy with a sufficient high intensity (approximately 10^3–10^4 pps) for a Coulomb scattering experiment.

In this paper the preliminary results of the analysis of the data acquired with the RISING array will be presented. In Sec. 2 the experimental setup will be discussed, while in the third one, the high-energy γ-ray spectra measured in the RISING detectors will be presented.

2. The experiment

The γ-ray emission from Coulomb excited ^{68}Ni has been measured using the RISING array [14,15] located after the FRS spectrometer. The particle identification after the target is performed by the CATE calorimeter [14,16] which, in the present experiment, consisted of nine position sensitive Si detectors coupled to four 6 cm thick CsI arranged to equally share the intensity of the incident beam. High and low energy gamma rays have been measured using 15 HPGe clusters of the Euroball array [17,18], 7 HPGe segmented clusters from the Miniball array [19] and 8 BaF_2 from the HECTOR array [20] located at different angles.

The ^{68}Ni beam was produced from the fragmentation of ^{86}Kr at 900 *A*MeV from the UNILAC-SIS with an intensity of $\sim 10^{10}$ particle per spill. The spill length was approximately 6 seconds long with a period of 10 seconds. The primary beam was focused on a ^{9}Be target 4 g thick and the ^{68}Ni ions were selected using the Fragment Separator. The s4 scintillator, placed after the FRS and a couple of meters before the secondary Au target (3 g/cm^{2}), registered approximately 4×10^{4} events per spill. In the beam cocktail which arrived on target the ^{68}Ni isotopes constitutes approximately 30% of the total incident isotopes as can be seen in Fig. 2.

A total of approximately 3×10^{7} ^{68}Ni events was collected during 6 days of beam time.

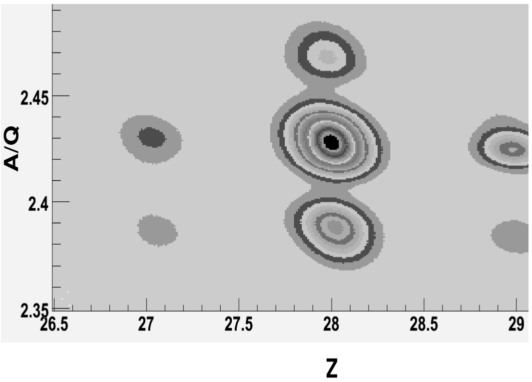

Fig. 2. The beam cocktail which arrives on the secondary target as measured after the FRS. In the x-axis the Z of the incident isotope is plotted while in the y-axis the A/Q ratio is indicated. The strongest spot in the center is relative to ^{68}Ni.

3. Results

All the beam particles were stopped in the CATE calorimeter placed approximately 1.5 meter after the target. Both the spectra from the silicon detectors and CsI scintillators were corrected, on an event by event basis, for the time drifts, the beam velocity and the position of interaction. The events with multiplicity larger than one were rejected and a consistency check between the incident direction, the interaction position and the firing detector was made. The left-upper panel of Fig. 3 shows the spectra obtained by the CATE calorimeter requiring incoming ^{68}Ni ions. In the right panels the projected spectra of the central silicon detector and one CsI are plotted. The achieved FWHM is sufficient to discriminate between different masses and charges. In the left-lower panel the Time of Flight (TOF) spectra of the BaF$_2$ detectors with and without the condition of a ^{68}Ni event detected in CATE is shown. It is clear that the condition eliminates completely almost all the background except for the gamma flash coming from CATE which arrives 12 ns after the prompt peak.

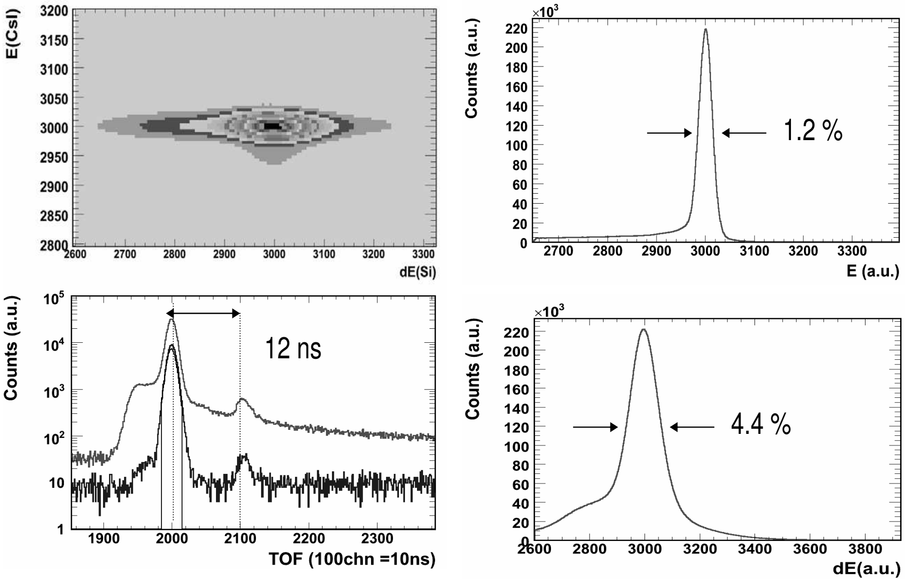

Fig. 3. The $E-\Delta E$ spectra acquired with the CATE calorimeter. In the upper-left panel the $E-\Delta E$ matrix measured in coincidence with incident ^{68}Ni isotopes is displayed. The CsI and Silicon spectra are shown in the upper-right and lower-right panels, respectively. In the left-lower panel the Time of Flight spectra of $\mathrm{BaF_2}$ detectors before and after the requirement of a ^{68}Ni event in CATE calorimeter are shown.

The measured high-energy gamma-ray spectra in the three different types of γ detectors of the RISING setup are shown in Fig. 4. In the upper-left panel, the Doppler corrected $\mathrm{BaF_2}$ spectra are shown. Only the ^{68}Ni events before and after the secondary target have been selected with an additional condition on the prompt time of flight peak and on the overall RISING γ multiplicity equal to one. The displayed spectra is from the detectors at 90 degrees. A peak structure centered between 10–11 MeV is evident. The line superimposed to the spectra shows the results of an accurate GEANT simulation of a monochromatic 10.8 MeV incident γ-ray. In the simulations both the Doppler broadening induced by the energy loss in the target and by the detectors subtended solid angle has been taken into account. The spectra of the $\mathrm{BaF_2}$ detectors placed backwards, at 142 degrees, are dominated by background radiation. In fact, because of the very large Doppler-shift a $\sim$ 10.8 MeV γ-ray in the center of mass is measured as a $\sim$ 4 MeV γ-ray, where, unfortunately, the background radiation is still too intense.

A peak structure at the same energy has also been observed in the Doppler Corrected HPGe Cluster spectra and segmented HPGe Miniball spectra, as can be seen in the upper-right and lower-left panels of Fig. 4.

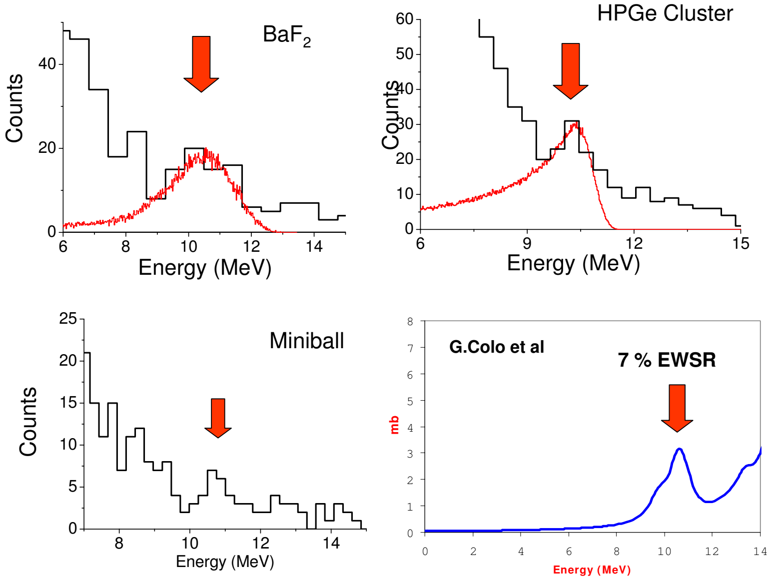

Fig. 4. The high-energy γ-ray spectra measured in the BaF$_2$ detector (upper-left panel), in the EUROBALL cluster detectors (upper-right panel) and in the MINIBAL HPGe segmented detectors (lower-left panel). The theoretically calculated ^{68}Ni dipole strength is displayed in the lower-right panel [21]. The continuous lines superimposed in the upper plots are the results of GEANT simulation of the peak lineshape. The arrows indicate the observed 10.8 MeV peak.

As was done for the BaF$_2$ detectors, only the scattered ^{68}Ni events within the TOF prompt peak and with a RISING multiplicity equal to one have been selected. In addition, in both HPGe detector types, only those events which emerged from two capsules activated in a single cryostat have been accepted. In the case of the HPGe cluster detectors, the peak line-shape corresponding to a 10.8 MeV γ-ray has been simulated using GEANT and superimposed to the spectrum.

In the right-lower panel of Fig. 4 the low energy part of the Pigmy Dipole response theoretically calculated within the RPA approach is displayed [21].

It is evident from all the plots of Fig. 4 that, even though the statistic is low and the background is high, all three detector types provide a coherent scenario, namely a peak between 10–11 MeV. The peak line-shape is consistent to GEANT simulations of the detector response and the experimental results are consistent with theoretical calculations.

It is, however, important to notice that the analysis is not complete yet. The Dipole Response of the other isotopes present in the beam cocktail needs to be analyzed and an absolute estimate of the "strength" of the measured dipole peak is still to be extracted from the available data.

4. Conclusion

In the paper we present preliminary results on the measurement, at the FRS with the RISING array, of the high energy γ-rays emitted by the Coulomb excited ^{68}Ni. A peak centered between 10–11 MeV has been observed consistently in all detector types of RISING. Its position is in the energy range theoretically predicted by RMF and RPA calculations for the Pygmy Dipole Resonance. This is the first evidence of such resonance state measured using relativistic radioactive beams and the virtual photon scattering technique and opens possibilities for a systematic study of such excited states in exotic nuclei.

The work has been supported by the Italian National Institute of Nuclear Physics (INFN), by the Polish Ministry of Science and Higher Education (grants 1-P03B-030-30 and 620/E-77/SPB/GSI/P-03/DWM105/2004-2007), by the UE under the contract N°: RII3-CT-2004-506065, by the German BMBF under grant N°: 06KY205I and 06BN-109, and by EURONS (European Commission contract number 506065).

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