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COLLOQUIA: COMEX7

Extra yield in hot Ni isotopes below the Giant Dipole Resonance

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Summary. — The high-energy γ-rays from the GDR decay of ^{56,60,62}Ni* nuclei at finite temperature, produced in the reactions ^{32,34,36}S + ^{24,26}Mg at bombarding energies between 78 and 90 MeV, were measured and analyzed with statistical model using a Monte Carlo approach. It is found that the present analysis gives some evidence on the presence of an extra yield on the tail of the Giant Dipole Resonance which may be attributed to a Pygmy Dipole Resonance in an excited nucleus.

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1. – Introduction

For several decades the γ decay from the Giant Dipole Resonances has been studied intensively at zero and finite temperature [1-3]. The presence in the E1 strength function of an additional strength at energy around the neutron binding energy, denoted as Pygmy Dipole Resonance (PDR), was identified in several nuclei (see [4] and refs. therein) and was related to the neutrons excess to the $N = Z$ core. Indeed, the strength of the PDR was found to become stronger with increasing neutron excess, a good example of this trend has being seen in the Ni isotopes, studied also with radioactive beams [5, 6]. The interest on this mode is related to the possibility to test nuclear structure models and the connection to the neutron-skin [7] and due to its possible impact in stellar and astrophysical processes [8]. Nevertheless no experiments so far have searched the PDR mode at finite temperature (called HOT-PDR), in spite of the fact that in literature few predictions for it are available [9, 10]. Here the first preliminary results of this search are presented. Since it is not obvious that the PDR can survive in highly excited, hot, thermalized and rotating nuclei, the experimental findings are important to answer this question.

2. – The experiment

In order to create a series of nuclei at finite temperature that differ only in neutron number we created three different Compound nucleus (CN) in the Ni isotopical chain with an excitation Energy of 49 MeV (see table 1) using the IFIN 9MV Tandem facility that delivered a beam of Sulfur isotopes impinging on solid Magnesium targets. The Magnesium targets were gold plated in order to avoid deterioration. Three different Ni isotope compound nuclei were created in order to observe a possible trend in the strength of the HOT-PDR with neutron number. The first measured Ni Isotope, ^{56}Ni is a $N = Z$ nucleus where no extra neutrons are distributed around the core and so we do not expect a measurable HOT-PDR. The other two compound nuclei were ^{60}Ni and ^{62}Ni with 4 and 6 extra neutrons with respect to the $N = Z$ core. The beam had an intensity of around 1-2 pnA and was pulsed by electrostatic condensator with a time resolution of around 1-2 ns.

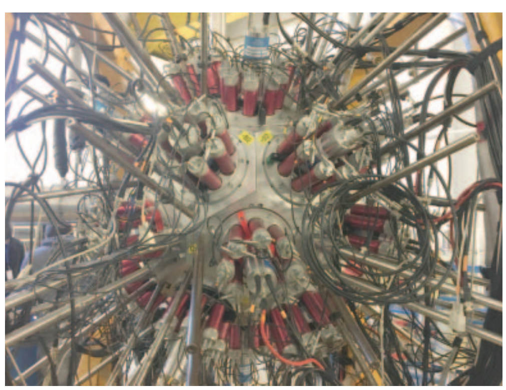

Fig. 1. – Photograph of the $LaBr_3$:Ce and $CeBr_3$ ELIGANT detectors [11] mounted in the experimental configuration together with BGO Anti-Compton Shield.

TABLE I. – *Table of the reaction parameters and of the populated CN.*

Beam	Beam Energy [MeV]	Target [1mg/cm^2]	CN	E* [MeV]	L_{max}	Fusion cross section [mb]
^{32}S	90	^{24}Mg	^{56}Ni	49.1	19.1	530
^{34}S	79	^{26}Mg	^{60}Ni	49.3	14.6	338
^{36}S	78	^{26}Mg	^{62}Ni	49.3	12.1	247

This time resolution is sufficient to separate neutrons from γ-rays emitted in coincidence during the decay of the compound nuclei by using their different time of flight between the target and the large volume scintillator detectors (TOF-discrimination). The γ-rays were detected by Compton surpressed large-volume $LaBr_3$:Ce and $CeBr_3$ detectors (see fig. 1). In addition 4 compton suppressed HPGe detectors were mounted at 90 degree to observe γ-decay radiation from residues. A more detailed description of the set-up can be found in [11].

3. – Results

The γ-ray yield of all three reactions were measured and compared with the Monte Carlo statistical Model simulations. As shown in fig. 2 a good agreement was found. The decay of the compound nucleus follows a chain of light charged particles (LCP), neutron and γ-ray emissions and populates different residues. They can be identified in the γ-ray spectra taken with the 4 HPGe detectors. With the help of residues population a normalisation of the measured γ-decay yield was possible. For the evaluation of the statistical model the Monte Carlo code GEMINI^{++} [12] was used. In order to verify the correctness of the statistical model simulations, the measured amount of the residues populated in the reactions were compared to the simulations. A good agreement of the ratio between the most populated residue and the less strong ones was found. The average temperature on which the HOT-PDR is built during the CN decay was evaluated to be $< T_{PDR} >= 1.6 MeV$, calculated with Monte Carlo statistical model [12]. The statistical model parameters, such as the dominating initial conditions that dominate the subsequent steps of the decay [2] like widths, positions, strengths of the E1 resonances states of the equilibrated CN were chi-square fitted to the first CN reaction which builts a $N = Z$ nucleus ^{56}Ni for which no extra yield coming from the HOT-PDR is expected. The used statistical model [12] takes into account isospin mixing suppression effects [13, 14] even if it is a small effect if compared to the expected extra yield. This fusion evaporation reaction gives rise to an excited CN that decays after thermal equilibration. This is used to fit the position and width of a GDR formed by two overlapping Lorentzial curves (due to a small deformation) in this Ni isotope and to tune the statistical model parameters like Level Density. These values have then been kept fixed to analyze the γ-ray yield from the two heavier isotopes. For the latter the kinematics, mass and beam energy were changed. The Deformation of the CN, position and widths of the two GDR peaks were treated as free parameters to fit the high energy part of the GDR for the compounds ^{60,62}Ni and it was assumed that only the GDR is present. The chi-square minimisation resulted in a prolate deformation with a beta-value around 0.2 and a splitting of the GDR in line with the predictions of the Lublin-Strasbourg Drop (LSD) model [15]. The resulting fits reproduce very well the GDR at high energy but not the low energy part. No sets of physical parameters could reproduce the lower energy tail of the GDR, even assuming an unphysical huge deformation and an extremely large GDR width and strength as starting

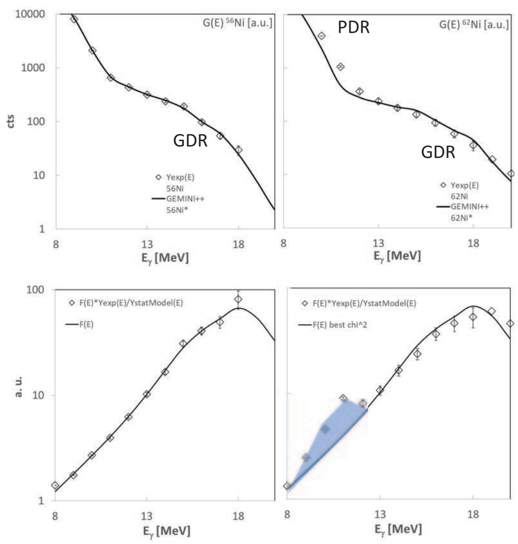

Fig. 2. – Plot of the γ-ray yields for the decay of two different CN in the upper panels. In the lower panels a normalized, linearized spectra (see text) compared with the Lorentzian function used in the statistical model calculations to describe the GDR decay [3]. The extra yield energetically below the GDR is shaded in the lower normalized plots. One can note the increase with neutron number of the extra yield at energy lower than the GDR centroid.

conditions of the statistical decay steps and chains, the data could not be reproduced, see fig. 2. The more natural assumption is to look at the extra yield at the tail of the GDR as coming from an additional strength in the tail of the GDR. This extra resonance could be attributed to the HOT-PDR state since it appears only in the neutron rich Ni isotopes at finite temperatures as predicted in [9, 10]. A good agreement with the data can be found, as seen in fig. 3, by introducing an additional resonance at lower energy around 10.3 MeV for the Ni isotopes with $N \gtrsim Z$. For the pygmy resonance a strength of around 4% of the Thomas-Reich-Kuhn (TRK) energy weighted sum rule [1] of the GDR is used in the case of ^{62}Ni to reproduce the data.

4. – Conclusions

In this experiment three different compound nuclei were built and populated at the same excitation energy, similar angular momentum and temperature. Their subsequent γ-ray emission was measured with the ELIGANT scintillator array. At finite and zero temperature no or very small PDR is expected in the $N = Z$ nucleus ^{56}Ni. This CN was used to benchmark the statistical model and from this starting point the GDR γ-ray decay yield of the heavier more neutron rich Ni isotopes with 4 and 6 additional neutrons were fitted, allowing only different kinematics and the fit of the high energy part of the strength function. The measured yield can not be reproduced by GDR decay unless one adds lower lying resonance as starting condition of the statistical subsequent decay steps, called here HOT-PDR. This resonance has been found to be at around 10 MeV and with a much smaller strength than the GDR. The appearance of such HOT-PDR may be related to the difference of the hot rotating neutron fluid with respect to the proton fluid, especially for the nucleons located near the surface. The hot rotating neutron

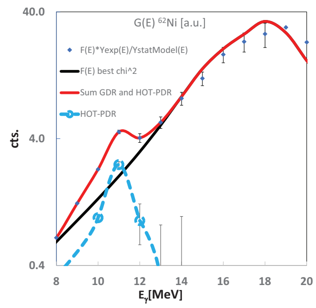

Fig. 3. – Plot of the linearized measured γ-ray Yield of the decay of ^{62}Ni together with the best chi-square fit of the statistical model using the γ-ray emission from GDR and adding strength in the lower energy tail in the statistical model calculation to reproduce the measured data.

fluid grows probably faster and forms a skin like enhancement in excited nuclei [16]. This feature may influence strongly stellar and astrophysical processes. These aspects should be addressed by theoretical evaluations. The authors plan to continue [17] this explorative research and to measure in the near future more neutron rich Ni isotopes at different temperatures to detect also light charge particles to pin down the statistical model and to reduce the uncertainties.

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