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Double Giant Dipole Resonance in Hot Nuclei

M. Cinausero[a], V. Rizzi[b], G. Viesti[b], D. Fabris[b], M. Lunardon[b], S. Moretto[b], G. Nebbia[b],
S. Pesente[b], M. Barbui[a], E. Fioretto[a], G. Prete[a], A. Bracco[c], F. Camera[c],
B. Million[c], S. Leoni[c], O. Wieland[c], G. Benzoni[c], S. Brambilla[c], A. Airoldi[c],
A. Maj[d] and M. Kmiecik[d]

[a]I.N.F.N. Laboratori Nazionali di Legnaro, Italy

[b]I.N.F.N. and Dipartimento di Fisica dell'Università di Padova, Italy

[c]I.N.F.N. and Dipartimento di Fisica dell'Università di Milano, Italy

[d]Institute of Nuclear Physics, Cracow, Poland

Signals from Double Dipole Giant Resonances (DGDR) in hot nuclei have been searched in a γ-γ coincidence experiment using the HECTOR array at the Laboratori Nazionali di Legnaro. The experimental single γ-ray spectrum and the projection of the γ-γ matrix have been compared with a standard Monte Carlo Statistical Model code including only the single GDR excitation. These calculations have been used as background to determine the extra-yield associated with the DGDR de-excitation. Results have been compared with a previous experiment confirming the presence of the DGDR excitation in fusion-evaporation reactions.

1. INTRODUCTION

The observation of the Double Giant Dipole Resonance (DGDR) in heavy-ion and pion induced reactions [1], has attracted considerable interest. The main interest in the study of the properties of multi-phonon states is in the search for phonon-phonon interaction and anharmonicity effects as a function of nuclear temperature. Some detailed theoretical calculations [2] predict, indeed, a positive correlation between temperature, strength and width of the resonance.

A way to study temperature effects on the DGDR would be the use of heavy-ion induced fusion-evaporation reactions, once the possibility to discriminate DGDR contribution from the bulk of the compound nucleus decay will be demonstrated.

This possibility has been recently evidenced [3] by the analysis of a large set of data collected with the EUROBALL III array, in which the HPGe Clusters were used as high energy γ-ray detectors. The analysis was focused on events in which two energetic ($E_\gamma > 8$ MeV) photons were emitted, searching for the decay of the DGDR built on excited states. The two energetic photons events are characterized by a multiplicity value larger than the estimated upper limit for the emission of two uncorrelated photons along the same

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de-excitation cascade. The reported result suggested the attribution of such events to the DGDR decay. Nevertheless, the quality of the EUROBALL III data do not allowed a quantitative study of the DGDR because of the impossibility of the neutron events suppression and of the limited knowledge of the Cluster detectors response function at high γ -ray energy.

Consequently, a new experimental study has been recently carried out in this field at the Tandem facility of the Laboratori Nazionali di Legnaro, by using the HECTOR BaF_2 array.

2. EXPERIMENTAL DETAILS

In the experiment, the ^{90}Zr compound nucleus has been populated at the temperature T$\sim$3 MeV via the fusion reaction ^{26}Mg+^{64}Ni. The 160 MeV ^{26}Mg beam with an intensity of about 5 nA was delivered by the XTU Tandem accelerator and used to bombard a 500 μg/cm^2 thick ^{64}Ni target. The HECTOR [4] array was used to detect high energy γ-rays. The array consists of 8 large (14 cm $\times$ 17 cm) BaF_2 scintillators and 38 smaller (3" $\times$ 3") BaF_2 crystals used as a multiplicity filter. The large BaF_2 scintillators were calibrated using an AmBe source (4.4 MeV γ-ray energy) and the reaction 46 MeV ^{11}B+^{2}H $\rightarrow$^{12}C*+n, producing a 15.1 MeV γ-ray from the ^{12}C* de-excitation. The photomultiplier stability was monitored during the data taking with a LED signal. Neutron events were rejected by using the measured time of flight with the start signal given by the multiplicity filter.

The events were collected on tape when at least one of the large BaF_2 detector of the array fired in coincidence with the multiplicity filter.

The total statistics collected was 0.2×10^9 single events and $0.9\times10^6\gamma$-γ coincidence events between the large BaF_2 detectors. From the single events we have built the inclusive γ-ray spectrum summing over all the large BaF_2 detectors. The coincidence events have been used to build the symmetric γ-γ matrix. Thus, events in which two high energy photons were emitted were identified by setting gates on this matrix.

3. EXPERIMENTAL RESULTS

In Fig.1 the experimental inclusive γ-ray spectrum is reported. The spectrum evidenced an exponential tail at high energy (E_γ > 25 MeV) that is believed to be due to a bremsstralhung component.

In fact, as reported in the work of M. Kicinska-Habior et al. [5], for light beams even at 4-5 MeV/nucleon, a bremsstralhung component appears in the high energy part of the γ-ray spectrum. This component is usually parameterised with an exponential function $A\times\exp[-E_\gamma /E_o]$ and has to be subtracted from the measured spectrum, in view of comparing the experimental results with Statistical Model Calculations.

The single γ-ray spectrum has been used to tune standard Statistical Model Monte Carlo calculations in which only the single Giant Dipole Resonance (GDR) excitation is included. A total of 10^7 fusion events have been generated. GDR parameters (energy E_D = 17 MeV and width Γ_D = 12 MeV) were derived from [6]. In the Monte Carlo generated events the response function of the BaF_2 detectors has been used to obtain event-by-event the energy of the detected photons. As mentioned later, this method to fold the response

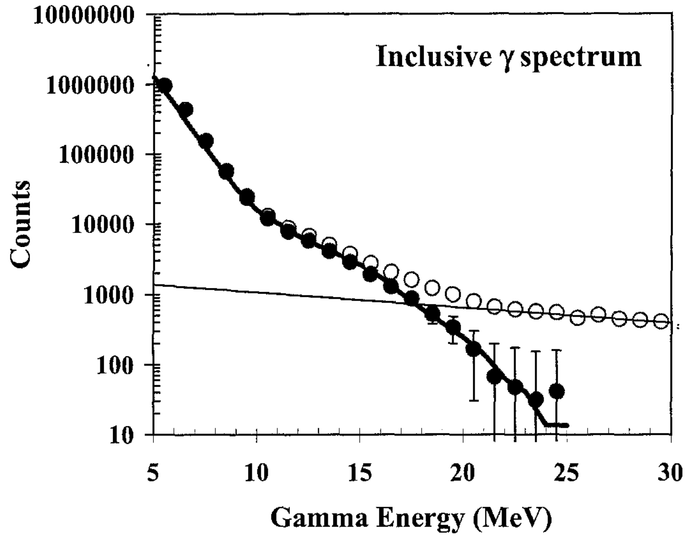

Figure 1. The experimental inclusive gamma spectrum. Open circles are the total experimental data. Black circles are the data after the subtraction of the bremsstralhung component (thin solid line). Thick solid line is the line shape resulting from Monte Carlo Statistical Model calculations.

function event-by-event is essential when looking to the γ-γ coincidence events.

As reported in Fig. 1, the line-shape of the experimental spectrum is well reproduced by Statistical Model calculations in which standard input parameters are used. In particular, the value of the level density parameter $a = A/7.5$ was employed. The relatively low value for the Strength parameter (S = 70% of the EWSR) resulting in the best fit of the line-shape is probably caused by some contaminations of the inclusive data from reaction mechanisms different from fusion-evaporation.

For a comparison with the coincidence data, the Monte Carlo generated events, corrected for the detector response function, have been sorted building the symmetric γ-γ matrix. The response function correction to the Monte Carlo produced events allow us to apply gates on the first matrix axis that are compatible with the experimental ones. In the search for DGDR signals, the experimental γ-ray spectrum obtained by setting a gate between 10 and 20 MeV on one axis of the γ-γ matrix has been compared with the corresponding spectrum from Monte Carlo calculations. The comparison of the two spectra is reported in Fig. 2.

Also in this case, a significant bremsstralhung contribution above 25 MeV has been evidenced in the matrix projection. The slope of this contribution is similar to the one

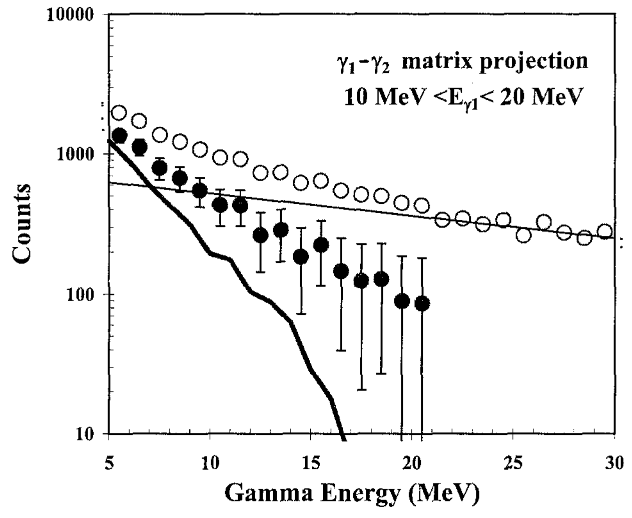

Figure 2. The projection of the γ-γ matrix with a cut between 10 and 20 MeV on the first axis. Open circles are the total experimental data. Black circles are the data after the high-energy component subtraction (thin solid line, for details see the text). Thick solid line is the prediction from Statistical Model Monte Carlo calculations.

obtained in the single spectrum. Furthermore, considering different projections of the matrix (i.e. the total one and the 5-8 MeV gate), we observed that the slope and the relative weight of the brebsstralhung component remain constant, accounting for about the 70% of the total projection statistics. As already verified for the inclusive events, additional selection on the fold and sum energy on the multiplicity filter does not reduce significantly the relative weight of this contribution. Therefore, for the comparison with the Monte Carlo data, the subtracted (i.e, total minus bremsstrahlung) experimental spectrum has been considered.

As reported in Fig. 2 the experimental data show an enhanced yield of γ-rays in the region between 10 and 20 MeV with respect to the Statistical Model calculations that include only the single GDR excitation. To avoid the bias due to the arbitrary normalization of the calculated data in the statistical region of the spectrum (i.e. at 5 MeV) the ratio between the total counts in the spectrum and the counts in the 10-20 MeV range has been considered for the experimental and calculated spectrum. This ratio is 0.36$\pm$0.06 (0.17$\pm$0.01) for the experimental (calculated) spectrum. This means that the experimental probability for two coincident γ-ray rays in the GDR region is about two times the same quantity predicted by Statistical Model calculations that include only the single GDR excitation. In this respect, the results from the present experiment are a clear confirmation of the findings reported in ref.[3].

Table 1
Comparison of the present results with the findings of ref.[3]. For details see the text.

	HECTOR 10 MeV $< E_\gamma <$ 20 MeV	EBIII (ref.[3]) $E_\gamma >$ 8 MeV
P(1γ)	$(1.22\pm0.01) \times 10^{-4}$	5×10^{-4}
P(2γ,statistical)	$(5.8\pm0.3) \times 10^{-7}$	2×10^{-7}
P(2γ,experimental)	$(1.3\pm0.3) \times 10^{-6}$	1×10^{-6}

In Table I we compare probabilities P for the detection of a single and two coincident γ-rays in the GDR region extracted in the present experiment with the results reported in ref.[3]. The quoted probabilities include an estimate of the solid angle subtended by the detectors. The probability of a single photon detection ($P(1\gamma)$) is a Monte Carlo estimate in the present case and an experimental value for the EUROBALL III data. As far as the detection of two *statistical* (i.e. non-correlated) photon ($P(2\gamma,statistical)$) it concerns, the present value is again a Monte Carlo estimate, whereas the EUROBALLIII value is an upper limit given by the simple estimate $P(2\gamma,statistical)=(P(1\gamma))^2$. The actual probability of detecting two coincident gamma rays is a pure experimental value in the EUROBALLIII case, whereas in the present work is the Monte Carlo estimate corrected for the above quoted enhancement of the experimental yield between 10 and 20 MeV in the projection of the γ-γ matrix.

As seen from Table I, the present results are in good agreement with our previous findings, taking into account the fact that two different reactions has been studied, thus confirming with a more refined analysis the order of magnitude of the effect evidenced in the previous experiment [5].

4. CONCLUSIONS AND PERSPECTIVES

In the present work we have confirmed the possibility of detecting signals from the excitation of DGDR in heavy-ion induced fusion-evaporation reactions. Considering the γ-γ coincidences, the comparison with standard Monte Carlo calculations, in which only the single GDR is included, shows that the emission probability of two photons in the GDR region of the gamma energy spectrum (i.e. between 10 and 20 MeV) is about a factor two with respect to the calculated one. This enhancement is believed to be due to the emission of two correlated γ-rays from the de-excitation of DGDR states.

Experimental limitations in the present work are mainly related to the absence of an effective fusion trigger. Cuts in the fold or in the sum energy applied in the multiplicity filter are not effective in the present case in selecting fusion-evaporation reactions. In fact, it is known from long time [7] that the gamma multiplicity is not an effective fusion trigger for medium-light compound nuclei because of the dumping of angular momentum in charged particle emission.

Further studies in this field will require an improved experimental set-up and a different selection of the mass region to reduce contaminations from different reaction mechanisms. A Statistical Model code in which the two-phonon excitation is included is also needed to extract the DGDR parameters in reproducing the spectrum line-shape.

REFERENCES

1. see for exmple T. Aumann, P.F. Bortignon, H. Emling, Annu. Rev. Nucl. Part. Sci. 48, 351 (1998) and references therein.
2. N. Dinh Dang et al., Phys. Rev. C 59, 3128 (1999)
3. G. Viesti et al., Phys. Rev. C 63, 034611 (2001)
4. A. Maj et al., Nucl. Phys. A 571, 185 (1994)
5. M. Kicinska-Habior and Z. Trznadel, Acta Phys. Pol. B 30, 535 (1999) and references therein
6. J.H. Gundlach et al., Phys. Rev. Lett. 65, 2523 (1990)
7. J. B. Natowitz, E. T. Chulick, and M. N. Namboodiri, Phys. Rev. C 6, 2133-2139 (1972)