Eur. Phys. J. A **12**, 5–8 (2001)

THE EUROPEAN
PHYSICAL JOURNAL A

Short Note

The GDR in selected decays from ^{147}Eu* and the moment of inertia at very high spins

M. Kmiecik[1], A. Maj[1,a], A. Bracco[2], F. Camera[2], B. Million[2], and O. Wieland[2]

[1] Niewodniczański Institute of Nuclear Physics, ul. Radzikowskiego 152, PL-31-342 Kraków, Poland
[2] Dipartimento di Fisica, Università di Milano and INFN sez. Milano, I-20133 Milano, Italy

Received: 1 June 2001 / Revised version: 20 September 2001
Communicated by D. Schwalm

Abstract. The high-energy γ-rays from the GDR decay of ^{147}Eu*, produced in the reaction ^{37}Cl+^{110}Pd at bombarding energy of 160 and 170 MeV, were measured in coincidence with discrete transitions in residual nuclei and analyzed with statistical model using a Monte Carlo approach. It is found that the present analysis gives information on the moment of inertia at very high spins in different residual nuclei.

PACS. 24.30.Cz Giant resonances – 24.10.Lx Monte Carlo simulations

1 Introduction

The high-energy γ-rays from ^{147}Eu nucleus have been previously studied extensively in exclusive experiments [1] to investigate the properties of the Giant Dipole Resonance (GDR) at final temperature. In particular the angular-momentum dependence of the GDR strength function has been deduced from high-energy γ-ray spectra gated by γ-multiplicity. The most relevant conclusion of that work was that the GDR width has a weak angular-momentum dependence in accordance with the thermal shape fluctuation model [2] predictions for ^{147}Eu at $T \approx 1.3$ MeV. In the experiment reported in [1] high-energy and low-energy γ-ray spectra were measured in coincidence, so that GDR data corresponding to specific residual nuclei were also obtained. In this paper we present the analysis of these data, focusing on the statistical model calculations of the high-energy γ-ray spectra gated by $3n$, $4n$ and $5n$ channels separately. For these calculations we use the Monte Carlo implementation of the statistical model code CASCADE. We expect that this type of analysis is probing in detail the physical quantities entering the statistical model. Among them is the moment of inertia, which could be not the same for all residues and might affect the high-energy γ-ray spectra gated by the specific decay channels. Information on moment of inertia is particularly interesting, as it is difficult, in general, to measure discrete transitions along yrast line at very high spins.

2 Experimental method

The description of the experiment is reported in detail in [1]. The employed reaction was ^{37}Cl on ^{110}Pd at the incident energy of 160 and 170 MeV. The compound nucleus ^{147}Eu was produced at the excitation energies of 74 and 81 MeV and maximum angular momentum 58 and 64.5 $\hbar$, respectively. The high-energy γ-ray spectra here presented (collected in large-volume BaF$_2$ detectors) were measured in coincidence with discrete γ-transitions (detected in the Ge array) and with the highly efficient multiplicity filter. In all cases the condition of having a coincidence fold greater than 2 in the multiplicity filter was applied, together with the neutron discrimination based on time of flight. The most intense known discrete transitions of the residual nuclei ^{142,143,144}Eu, corresponding to $3n$, $4n$ and $5n$ evaporation channel respectively, were used to gate the high-energy γ-ray spectra.

3 Data analysis and results

The γ-ray spectra associated with selected evaporation channels cannot be analyzed by the statistical model calculations based on the standard CASCADE code [3]. In fact, this type of selection corresponds to sampling decay chains originating from different parts of the angular-momentum distribution of compound nucleus and ending up in the specific residual nucleus. The only way to model this in rather realistic way is to make use of the Monte

---

[a] e-mail: `Adam.Maj@ifj.edu.pl`

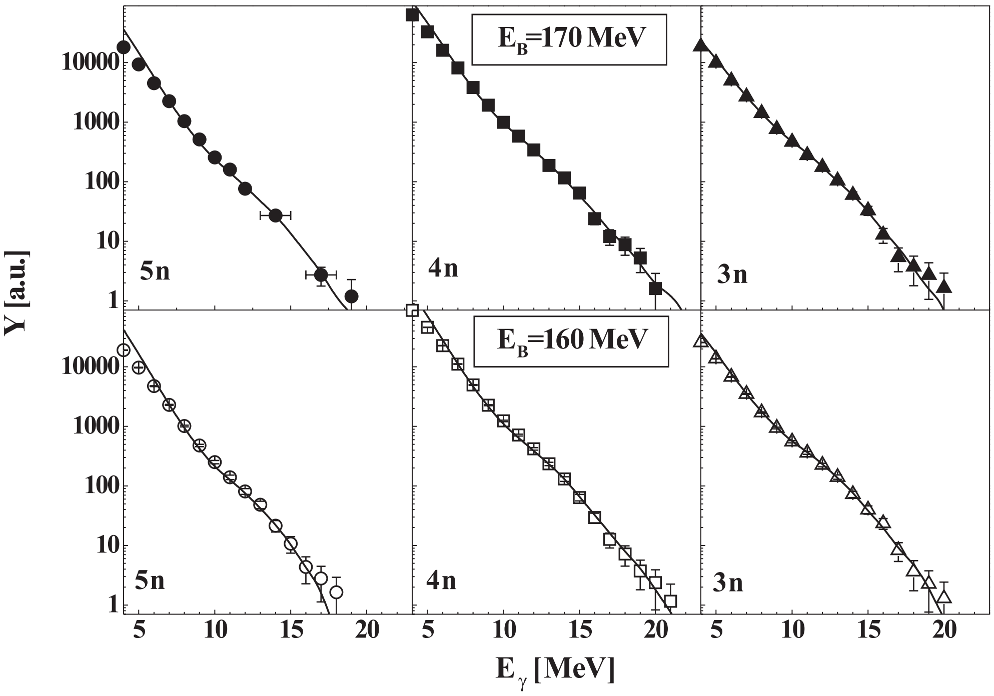

Fig. 1. High-energy γ-ray spectra from the decay of ^{147}Eu* measured in coincidence with discrete lines in the residual nuclei in the $5n$, $4n$, $3n$ evaporation channels at two beam energies: 170 and 160 MeV. Points correspond to experimental data and lines show the best fitted spectra. For calculations corresponding to $4n$ and $5n$ the used yrast line was the same as in the analysis of not gated data [1], while for the $3n$ channel an adopted yrast line was applied (see fig. 3, below).

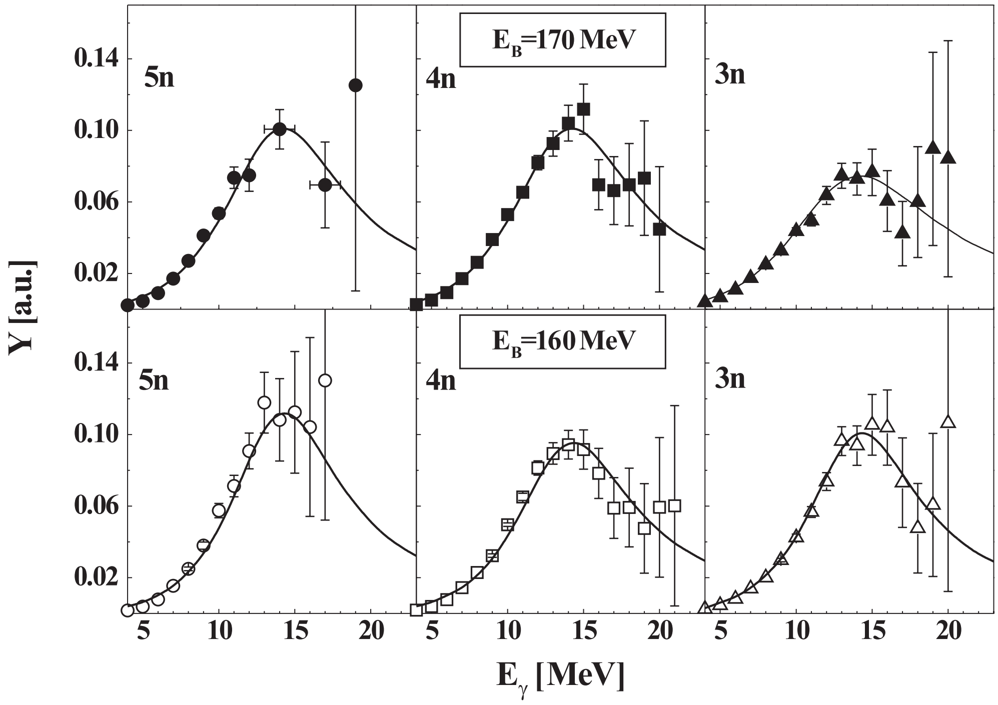

Fig. 2. The GDR strength function represented by the quantity $F_L(E_\gamma)*Y_\gamma^{\mathrm{exp}}(E_\gamma)/Y_\gamma^{\mathrm{cal}}(E_\gamma)$, where $Y_\gamma^{\mathrm{exp}}(E_\gamma)$ is the experimental spectrum shown in fig. 1 and $Y_\gamma^{\mathrm{cal}}(E_\gamma)$ is the calculated theoretical spectrum. The GDR strength function is represented by the single Lorentzian function $F_L(E_\gamma)$ with parameters (energy, width and strength) taken from the best fit to the experimental spectrum.

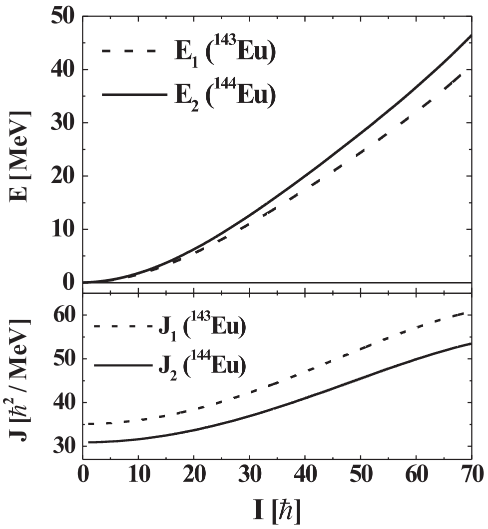

Fig. 3. Top: Yrast lines $E = \frac{\hbar^2}{2\Im} I(I{+}1)$, where $\Im$ is the moment of inertia used in Monte Carlo CASCADE calculations. The dashed line shows the yrast line corresponding to $4n$ and $5n$ channels (^{143}Eu and ^{142}Eu). The yrast line adopted for the $3n$ channel (^{144}Eu) is plotted with the solid line. Bottom: the two moments of inertia used.

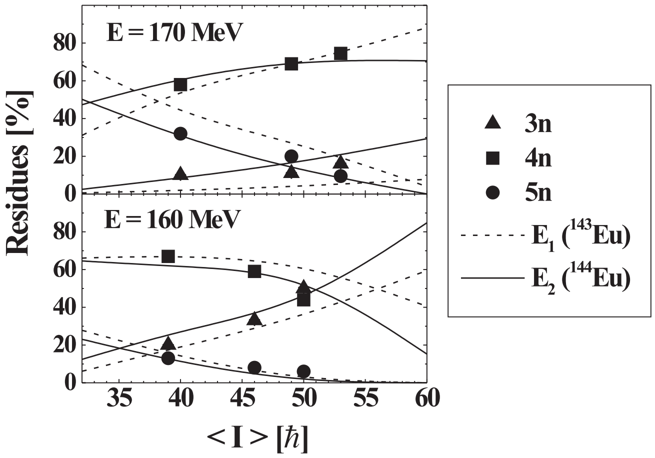

Fig. 4. Fraction of residue cross-section as a function of spin. The experimental points and the calculations (dotted lines) using the yrast line obtained from high-spin states in ^{143}Eu, were taken from [1]. The calculations using the adopted yrast line for ^{144}Eu are shown as solid lines.

Carlo technique in the simulation of the statistical decay process. Therefore, the Monte Carlo version of the CASCADE code, previously used for the analysis of the heavier mass data [4], was implemented for this mass region in order to choose the most appropriate values of the statistical model parameters (*e.g.* level density, transmission coefficients, yrast line etc.). Some of these parameters are expected to be the same as those deduced from previous works, while others could depend on residual nuclei and therefore probed only by selecting the evaporation channels.

Table 1. The parameters of the GDR, strength $S_{\rm GDR}$ (in units of the Energy Weighted Sum Rule) and width $\Gamma_{\rm GDR}$, as obtained from the statistical model fit to the experimental γ-ray spectra gated by discrete transitions in the three residual nuclei. $E_{\rm GDR} = 14.3$ MeV was kept fixed in the fitting procedure.

Reaction channel	$S_{\rm GDR}$	$\Gamma_{\rm GDR}$ (MeV)
	$E_{\rm beam} = 170$ MeV	
$3n$	0.9 ± 0.2	12.0 ± 0.8
$4n$	1.0 ± 0.1	9.8 ± 0.5
$5n$	1.0 ± 0.1	9.8 ± 1.0
	$E_{\rm beam} = 160$ MeV	
$3n$	1.0 ± 0.2	8.8 ± 0.7
$4n$	1.0 ± 0.1	9.3 ± 0.4
$5n$	0.9 ± 0.1	8.8 ± 0.8

Statistical model Monte Carlo calculations of the high-energy γ-decay are in general time consuming due to a very small γ-decay branch. Moreover, if one wants to adopt a fitting procedure, it is necessary to reduce, if possible, the number of free parameters. Consequently, we have decided to keep the value of the energy of the centroid of the GDR fixed for all of the decay channels and equal to the value $E_{\rm GDR} = 14.3$ MeV deduced from the previous analysis of the ungated spectra [1]. In fact, it is known from the existing systematics [5] that the centroid energy is a very stable quantity against large variations of temperature and angular momentum. In contrast, the width of the GDR ($\Gamma_{\rm GDR}$) and the strength of the GDR ($S_{\rm GDR}$) were treated as free parameters in the fitting procedure. The high-energy γ-spectra were fitted in the region $E_\gamma = 8$–17 MeV and the values of the width and strength were obtained from the χ^2-minimization. Concerning the other parameters not describing the GDR strength function we have used the same values reported in [1], obtained from the angular-momentum gated data. In particular, in the calculations the angular-momentum distribution was assumed to have $l_{\rm max}$ 58 and 64.5 $\hbar$ (for $E_{\rm B} = 160$ and 170 MeV, respectively) and diffuseness of 2 $\hbar$, as predicted by the model of Winther [6]. The yrast line parameters used were obtained from the fit to the experimental energies of the yrast states in ^{143}Eu known up to spin 123/2 $\hbar$. This choice resulted in a very good fit of the two most intense evaporation channels, namely $5n$ and $4n$, with values of the $\Gamma_{\rm GDR}$ and $S_{\rm GDR}$ consistent with the previous analysis of the less exclusive data. This is shown in four panels of fig. 1 and fig. 2 (the left most and the central panels), in which the best fitting calculations are compared with the experimental spectra.

In the case of the high-energy γ-ray spectra corresponding to the $3n$ channel (ending in ^{144}Eu) we found, that it was not possible to fit them well with the same set of parameters used for the other channels, without obtaining unrealistic values of the GDR parameters, especially the strength. A possible explanation for this should be related to a property of the specific residual nucleus, the most natural being the moment of inertia, since it defines the yrast line and therefore the phase space for the decay. Therefore we fit the $3n$ data by changing the values of the moment of inertia. The best fit was obtained by assuming that the moment of inertia of ^{144}Eu ($3n$ channel) is smaller by 12% than the value of ^{143}Eu. This is illustrated in fig. 3 by showing both the rotational yrast lines and the ratio of the moment of inertia of those two nuclei. One can see that the adopted moment of inertia gives a difference of the yrast line mainly for the highest-spin region, as compared to the one used for ^{143}Eu and ^{142}Eu (constructed from the superdeformed yrast states of ^{143}Eu known up to spin $123/2\ \hbar$). This smaller moment of inertia reflects that ^{144}Eu might not be superdeformed. This is supported by the fact that superdeformed yrast bands have been so far identified only in ^{142}Eu ($5n$ channel) and ^{143}Eu ($4n$ channel), while not in ^{144}Eu ($3n$ channel). Although other explanations, as for example different level density dependence on excitation energy above yrast line at highest spins, cannot be ruled out, they seem to be less probable.

We have investigated the consequence that this choice of moment of inertia has on the relative population intensities of the final residual nuclei. These new calculations (solid lines) are displayed in fig. 4 and compared with data and calculations (dotted lines) also reported in [1]. They give a better account of the experimental findings, particularly at the highest spins, therefore supporting the present approach.

Table 1 summarizes the results for the best fitting values of the GDR widths and strengths for the three residual nuclei at the two beam energies. From this table one can see that, with the exception of the $3n$ channel at the 170 MeV, all the deduced values are consistent among themselves and with the data from spectra not gated by selected discrete lines [1]. The larger value of the GDR width from the compound nucleus decay leading to ^{144}Eu ($3n$ channel) at 170 MeV is not fully understood. It might reflect a better selection of the decay chains from the highest angular momenta. It is known, that a larger GDR width is related in general to a larger effective deformation of the compound nucleus [7]. Since the $3n$ data are the most sensitive to $l_{\max}$, the present results could indicate that angular-momentum–driven deformation effects manifest themselves only at highest ($> 60\ \hbar$) spins.

4 Conclusions

The present analysis of high-energy γ-rays emitted by the decay of ^{147}Eu associated to the three mostly populated residual nuclei reveals two interesting results. One is that this type of analysis is sensitive to the nuclear moment of inertia in the high–angular-momentum region, for which the information is scarce. The second is that the selection of different evaporation channels might allow to probe different spin regions, and therefore to investigate spin effects in the GDR width.

Financial support from the Polish State Committee for Scientific Research (KBN Grants No. 2 P03B 001 16 and 2 P03B 045 16), from INFN (Italy) and from the EU TMR contract No. ERBFMRX-CT97-0123 is acknowledged.

References

1. M. Kmiecik et al., Nucl. Phys. A **674**, 29 (2000).
2. W.E. Ormand et al., Nucl. Phys. A **618**, 20 (1997).
3. M. Kmiecik et al., APH N.S., Heavy Ion Phys. **13**, 179 (2001).
4. F. Camera et al., Phys. Rev. C **60**, 014306 (1999).
5. P.F. Bortignon, A. Bracco, R.A. Broglia, *Giant Resonances: Nuclear Structure at Finite Temperature* (Gordon Breach, New York, 1998).
6. A. Winther, Nucl. Phys. A **594**, 203 (1995).
7. A. Bracco et al., Phys. Rev. Lett. **74**, 3748 (1995).