GAMMA-DECAY OF THE GDR IN THE GEMINI++ CODE*

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(Received February 13, 2013)

The GEMINI++ simulation code [R.J. Charity, *GEMINI: A Code to Simulate the Decay of Compound Nucleus by a Series of Binary Decays*, IAEA, Trieste, Italy, 2008, p. 139.] has been extensively used for the description of charged particle decay and fission fragment emission following heavy-ion fusion-reactions. In this paper, we report on enhancing the capabilities of this code by adding the possibility of emission of high-energy gamma rays from the decay of Giant Dipole Resonance (GDR).

DOI:10.5506/APhysPolB.44.611
PACS numbers: 24.10.Pa, 24.30.Cz

1. Introduction

New fusion-evaporation experiments are based on complete measurement of charged-particle and gamma-ray spectra. The analysis, usually performed using statistical model calculations, is split into two parts by applying different codes for particle and gamma ray emission calculation. In particular, gamma-ray emission has correctly been treated by the MC CASCADE code [1], while GEMINI [2], a newer Monte Carlo code based on the statistical model, has been successfully used for the description of charged-particle

* Presented at the Zakopane Conference on Nuclear Physics "Extremes of the Nuclear Landscape", Zakopane, Poland, August 27–September 2, 2012.

decay and fission-fragments emission following heavy-ion fusion-reactions in the wide mass and excitation energy regions [3]. However, the existing treatment of gamma decay in the GEMINI++ code was too simplistic, especially GDR decay was defined by a formula with global parametrization; also, gamma emission was not considered below the entry line.

We have undertaken an effort to enhance the capabilities of this code by adding the possibility of emission of high-energy gamma rays from GDR, as it has been done in the CASCADE code. This new feature, combined with the experimental detector positions filter of the calculated events, allows for a (simultaneous) comparison of charged-particle and high-energy gamma-ray spectra with the experimental results.

2. The GDR implementation in the GEMINI++ code

Firstly, we introduced the description of the GDR line-shape, by the analytical formula, which includes three Lorentzian components

$$\sigma = 2.09 \times 10^{-5} \frac{Z(A-Z)}{A} \sum_{k=1}^{3} \frac{S_k E_\gamma^2 \Gamma_{\mathrm{GDR},k}}{\left(E_\gamma^2 - E_{\mathrm{GDR},k}^2\right)^2 + E_\gamma^2 \Gamma_{\mathrm{GDR},k}^2}\,, \tag{1}$$

where $E_{\mathrm{GDR},k}$ are GDR components energies, $\Gamma_{\mathrm{GDR},k}$ — corresponding Lorentzian widths and S_k — GDR intensities. Then, the GDR decay width is defined by

$$\Gamma_\gamma^{E1} = \sigma\, E_\gamma^2 \frac{\rho(E^* - E_\gamma)}{\rho(E^*)}, \tag{2}$$

where ρ is the level density at the initial excitation energy E^* or at the excitation after γ emission $E^* - E_\gamma$. Initial values of the widths, energies and intensities of the GDR were taken from the systematics. Then, during the fitting procedure those parameters are changed to obtain the lowest χ^2 value, when comparing to experimental data.

To the existing calculation of $E1$ and $E2$ type transitions, we added the gamma transitions of $M1$ and $M2$ character. The decay widths, for multipolarity l, are defined by [4]

$$\Gamma_\gamma^{Ml} = Wu_l\, F_l\, D_0\, A^{2(l-1)/3}\, E_\gamma^{2(l+1)} \frac{\rho(E^* - E_\gamma)}{\rho(E^*)}\,, \tag{3}$$

where $Wu_1 = 2.1 \times 10^{-8}$ and $Wu_2 = 1.5 \times 10^{-14}$, E_γ is γ-ray energy, D_0 is equal to 1 MeV and F_l is a correction factor for the Weisskopf formula ($F_1 = 0.025$, $F_2 = 9.0$ W. u. for E type and $F_1 = 0.01$, $F_2 = 1.2$ W. u. for M transitions) according to Ref. [5].

Also the decay of compound nucleus was permitted to continue until the excitation energy of nucleus reaches the yrast line value.

3. The GDR in the GEMINI++ code: comparison with the experiment

To check the correctness of the above implementations, we compared calculations done by GEMINI++ with Monte Carlo CASCADE, and with the experimental data taken recently in LNL Legnaro by the HECTOR and GARFIELD collaborations.

The experimental setup consisted of the GARFIELD [6] array for light charged particle identification and energy measurement, the HECTOR [7] detectors for γ energy measurements and 32 phoswich detectors from the FIASCO experiment [8] for selection of evaporation residues. A ^{48}Ti beam at 300, 450 and 600 MeV bombarded a ^{40}Ca target producing ^{88}Mo compound nuclei with excitation energies of 124, 192 and 261 MeV. A more detailed description of this experiment is available in Ref. [9].

The correctness of GEMINI++ input parameters which were used to parametrize the level density and the yrast line, and by this the deformation of the nucleus as a function of the angular momentum, was checked by comparing the calculated light charged-particle energy spectra with the experimental data. Figure 1 shows very good agreement between calculations and experiment.

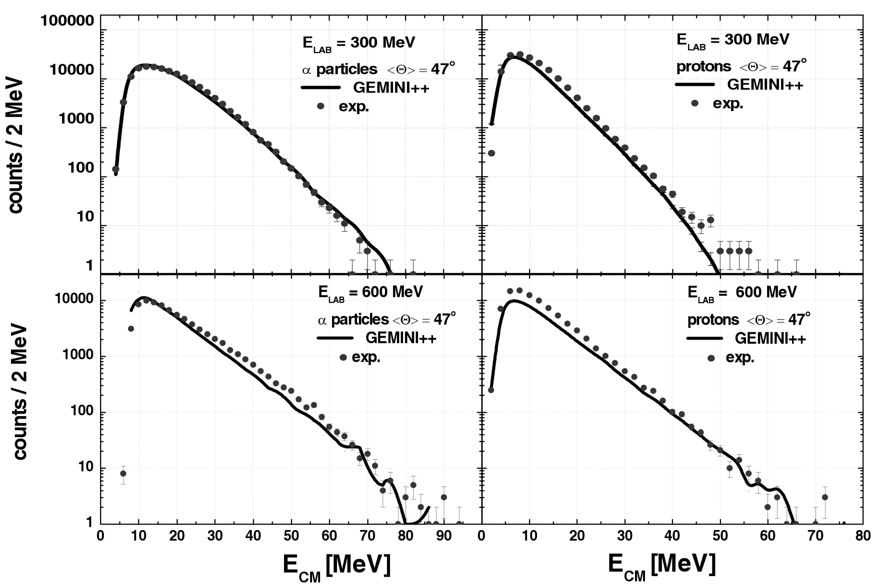

Fig. 1. Experimental alpha and proton energy spectra compared to GEMINI++ calculations for $^{48}\mathrm{Ti} + {}^{40}\mathrm{Ca} \rightarrow {}^{88}\mathrm{Mo}^*$ reaction at beam energy of 300 (upper panel) and 600 MeV (bottom panel). The covered Θ angles were between 41 and 52°.

In the next step, the experimental gamma spectrum gated on evaporation residues was compared to the results of GEMINI++ calculations in which the geometry of the evaporation residue detectors, such as positions and opening angles, were taken into account. Very good agreement was achieved and is displayed in Fig. 2. For the 300 MeV beam energy, the experimental spectra have also been compared to the results of calculations with Monte Carlo CASCADE, to check the compatibility of both codes. The obtained spectra are practically the same.

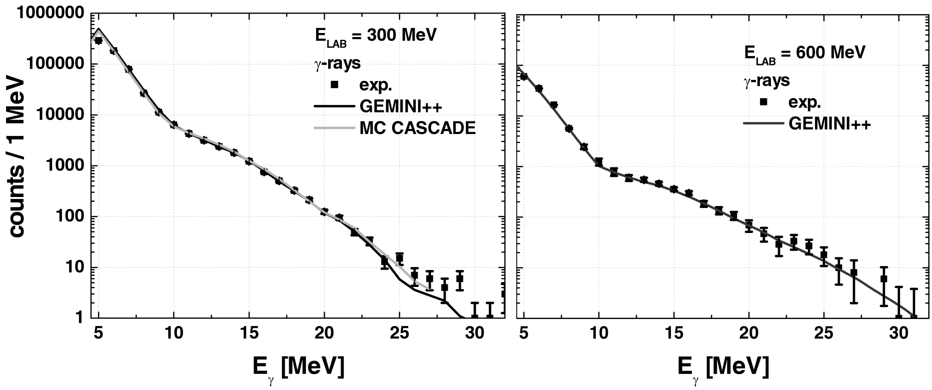

Fig. 2. Experimental gamma spectra compared to GEMINI++ calculations for ^{48}Ti + ^{40}Ca → ^{88}Mo* reaction at beam energy of 300 and 600 MeV.

4. Conclusions

The GEMINI code has been tested as a tool for the complete analysis of experimental data containing charged-particle spectra as well as gamma rays from compound-nucleus decay at high excitation energy. The calculated charged-particle spectra, filtered by the experimental conditions, agree quite well with the measurements. At the same time, the spectra of high-energy gamma-rays which were computed by GEMINI showed good agreement with the measured distributions allowing to extract the GDR parameters. Overall, the results of the comparison between calculations and experiment show a satisfactory performance of the modified GEMINI++ code in describing the decay of the compound nucleus up to excitation energies of ~ 260 MeV.

Finally, the new GEMINI++ code will be especially useful for preparation and analysis of GDR measurements for reactions at very high excitation energies with huge fission probability.

This work was supported by the Polish Ministry of Science and Higher Education under contracts No. N N202 486339 and 2011/03/B/ST2/01894.

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