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# Investigation of the disappearance of collective motion in nuclei of mass A~ 120-130

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**Abstract.** A study of hot Giant Dipole Resonance (GDR) in nuclei of mass A=120~130 in an excitation energy range from 150 to 330 MeV, where the GDR quenching is expected to arise, has been undertaken using the MEDEA multi-detector system. Hot nuclei were populated using complete and incomplete fusion reactions. The characterization of hot system was performed through the study of residue time of flight combined with the analysis of light charged energy spectra detected in coincidence. Gamma-ray energy spectra show an evolution of the GDR main features both in terms of width and multiplicity. Evidences of a saturation of gamma multiplicity appear at high excitation energy at variance with predictions of statistical model calculations. Gamma-ray energy spectra can been reproduced in a phenomenological way introducing in the statistical model a sharp suppression of the gamma-ray emission above E* = 240 MeV. A comparison of experimental data to models describing the GDR disappearance will be presented.

## 1 Introduction

The study of the properties of Giant Dipole Resonance (GDR) in hot nuclei through its gamma decay has allowed to gain a deeper understanding of collective behaviour of nuclear matter at high excitation energies. The most complete systematics has been obtained on medium mass nuclei in the mass region A ≈ 110-130 [1]. The experimental results have clarified many features of the evolution of the GDR parameters as a function of excitation energy. In particular, below about E* = 200 MeV the width increases due to both temperature and spin effects from 5 MeV up to about 14 MeV and the strength exhausts 100% of the Energy Weighted Sum Rule (EWSR), while above E*= 300 a suppression of the

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GDR gamma emission was observed [1]. This is at variance with the statistical model predictions which show a progressive increase of gamma-ray multiplicity with excitation energy, due to the higher number of steps available for the gamma-rays to compete with particle emission. Different theoretical interpretations have been suggested to reproduce the experimental behavior, but no precise understanding has been achieved, possibly due to the lack of data in the excitation energy region where the decrease of GDR emission sets in. In order to fill this gap, a study of $\gamma$ emission from hot nuclei of mass A ~ 120 - 130 with excitation energies between 150 and 335 MeV was undertaken at the LNS Catania, using the MEDEA + SOLE + MACISTE setup [2].

## 2 Experimental Set-up

The experiment was carried out at the Laboratori Nazionali del Sud - Catania using $^{116}$Sn beams of 17 and 23 MeV/A delivered by the Superconducting Cyclotron impinging on 1 mg/cm$^2$ thick $^{12}$C and $^{24}$Mg targets. Light charged particles and gamma rays were detected with the MEDEA multi-detector, made of 180 $BaF_2$, arranged in a spherical configuration covering from 30° to 170° polar angles and covering full angular range in azimuthal angles. Fusion-like residues emerging from the target at polar angles up to 3 degrees were focused by the magnetic field of superconducting solenoid SOLE on the focal plane detector MACISTE. MACISTE consists of four telescopes arranged on a 70 x 70 cm$^2$ surface leaving a variable central hole for the beam transit. Each telescope, with a useful area of 30x40 cm$^2$, is divided in 2 parts and consists, in turn, of an ionization chamber for the energy loss measurement, a multi wire proportional chamber for the impact position and time of flight determination and, for the energy measurements, a large area plastic scintillator detector, 2 cm thick. Particle and $\gamma$-ray identification in $BaF_2$ was performed using the combined information of time of flight (ToF) and pulse shape analysis of the photomultiplier signal. Evaporation residues were identified through their time of flight, measured with respect to the cyclotron RF.

## 3 Analysis

The time of flight spectra of the residues are consistent with a scenario of complete or close to complete fusion reactions. In order to select a defined excitation energy for each reaction, only events falling in an interval extending in a region of ±3% of the ToF peak were retained in the analysis and the study of light charged particle and gamma ray-spectra was undertaken accordingly. The excitation energy of the system was inferred assuming a complete fusion reaction and then subtracting the amount of energy removed during the pre-equilibrium stage. Pre-equilibrium emission was evaluated through an analysis of light charged particle energy spectra which was performed through a simultaneous fit of spectra at all angles, assuming the emission from two moving sources, one describing compound nucleus and the other describing pre-equilibrium emission. In figure 1, as an example, the proton spectra for the different reactions indicated in each panel are shown. Solid lines are the result of the moving source fit and testify the excellent quality of the obtained fit. Similar procedure was adopted in the study of deuteron, triton and alpha energy spectra. The amount of energy removed during the pre-equilibrium stage ranges from 35 MeV for the reaction $^{116}$Sn+$^{12}$C 17*A* MeV to 120 MeV for the $^{116}$Sn+$^{24}$Mg 23*A* MeV reaction. Overall procedure leads to excitation energies $E^* = 150\pm10$ MeV for $^{116}$Sn+$^{12}$C 17*A* MeV reaction, $E^* = 190\pm10$ MeV for $^{116}$Sn+$^{12}$C 23*A* MeV reaction, $E^* = 270\pm20$ MeV for $^{116}$Sn+$^{24}$Mg 17*A* MeV reaction and $E^* = 335\pm30$ MeV for $^{116}$Sn+$^{24}$Mg 23*A* MeV reaction. The corresponding masses are A = 124, A = 123, A = 132 and A = 128 respectively.

In order to study the GDR decay, gamma-ray spectra measured around 90°, where the Doppler effect is negligible, were analysed. Bremsstrahlung contribution arising from n-p collisions in the first stage of the reaction was evaluated fitting the high energy part of the spectra ($E_\gamma > 35$ MeV) with an exponential function and then subtracted for a correct comparison with a statistical decay code. Because the GDR gamma-rays can be emitted at all steps during the de-excitation process, the extraction of its parameters (centroid, width, strength) relies on a comparison of the experimental spectrum to a statistical model calculation performed with code DCASCADE taking into account the whole decay sequence.

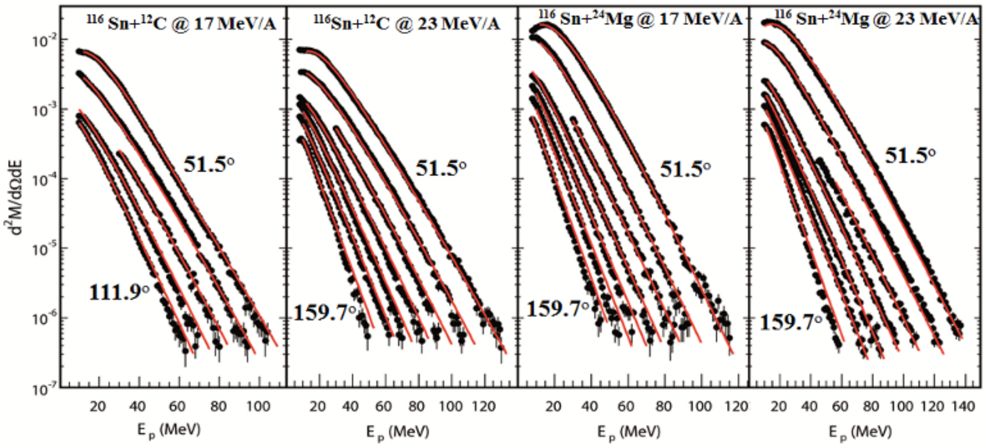

**Figure 1.** Proton spectra detected with MEDEA in coincidence with evaporation residues. The red line are the result of the moving source fit as described in the text.

As input to the calculations the initial masses and excitation energies inferred from the procedure previously described were used. They are crucial ingredients in the calculation since they strongly influence the gamma-ray multiplicity during the de-excitation process of the hot system. Therefore a precise determination is mandatory to draw any conclusions about the energy at which the saturation sets in. Statistical gamma spectra were reproduced assuming a Lorentzian line shape for the GDR and a strength equal to 100 % of the Thomas-Reiche-Kuhn (TKR) sum rule. For the cases $E^* = 150$ and 190 MeV the centroid energy $E_{GDR}$ and width $\Gamma_{GDR}$ were determined from a best fit to the data. $E_{GDR}$ turned out to be $14.3\pm0.3$ MeV in both cases while the width increases from $11.5\pm1$ MeV to $12.5\pm1$ MeV. At higher excitation energies it is no longer possible to fit the centroid energy and the GDR width because no reasonable parameter set leads to a good data reproduction. Therefore, the calculations were performed using $E_{GDR} = 14$ MeV and $\Gamma_{GDR} = 14$ MeV values consistent with the experimental data on GDR in this mass region [3]. A constant level density parameter $a = A/K$ was used for each calculation. The values of K adopted range from 10.8 for $E^* = 150$ MeV to 12 for $E^* = 335$ MeV. In fig. 2 the DCASCADE calculations (red lines), folded with detector response, are compared to the experimental gamma-ray spectra after bremsstrahlung subtraction (solid symbols). The agreement is excellent up to 190 MeV demonstrating that the statistical model scenario perfectly describes the experimental data up to this excitation energy. At $E^* = 270$ MeV the DCASCADE calculations overestimate the experimental yield, indicating the onset of a GDR quenching that becomes progressively important with excitation energy as shown by data at $E^* = 335$. Such a result is not affected by a specific choice of the level density parameter adopted in calculations. The data at 270 MeV and 335 MeV of excitation energy can be reproduced assuming a sharp suppression of the GDR emission above 240 MeV of excitation energy (sharp cut-off), as shown by the black line in fig. 2. This is a very simple approach pointing to a sudden disappearance of the GDR at 240 MeV of excitation energy. However, different theoretical models have suggested possible explanation for the GDR quenching leading to excitation energy dependent reduction factors. Chomaz ascribes the GDR quenching to the broadening of GDR gamma width with temperature [4] while Bortignon et al. proposed an alternative way to explain the saturation of GDR gamma multiplicity, based on the competition between the equilibration time of the GDR and the particle evaporation time [5]. Both models were implemented in the DCASCADE code and results are shown in the right panel of fig. 2. Despite both model prescriptions still overestimate the experimental data at high excitation energies, the comparison with Bortignon model gives a better data reproduction but fails to reproduce the high energy part of the spectra. The calculations using an increasing width with temperature show a similar trend but lead to larger overestimate of the experimental yield.

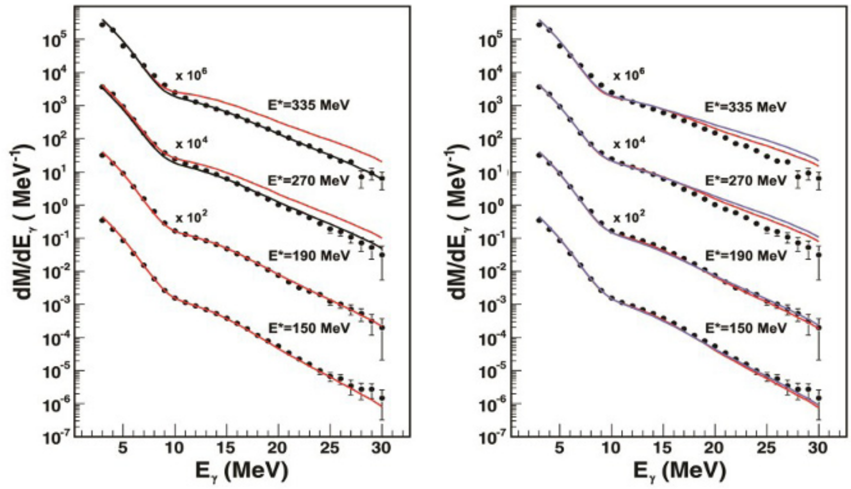

**Figure 2.** Left panel: Comparison of gamma spectra after bremsstrahlung subtraction for all the reactions investigated with statistical model calculations shown as red lines. Black lines indicate statistical model calculations including a sharp cut-off of the GDR above 240 MeV excitation energy. Right panel: comparison of gamma spectra with statistical model calculations including prescriptions according to Chomaz model (blue line) and Bortignon model (red line).

## 3 Conclusions

The evolution of the Giant Dipole Resonance (GDR) properties in hot nuclei of mass A = 120~130 has been investigated through the study of four different reactions at 17 and 23*A* MeV. Hot nuclei were populated through complete and incomplete fusion reactions in an excitation energy region between 150 and 335 MeV. Excitation energies and masses of the compound systems were determined combining ToF information with the analysis of light charged particle spectra to determine the amount of pre-equilibrium emission. Evolution of the GDR main features has been extracted through the comparison of the gamma energy spectra with statistical model calculations. Very good data reproduction is obtained up to E* = 190 MeV while a quenching of the GDR gamma yield appears in the data at E* = 270 MeV and becomes progressively important with increasing excitation energy. The comparison with model predictions suggests that the GDR gamma-ray saturation is consistent with a disappearance of the GDR strength at high E*.

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