Pygmy Dipole Response in Samarium isotopes

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Abstract. The influence of nuclear shape deformation on the Pygmy Dipole Response (PDR) was investigated using $(\alpha,\alpha'\gamma)$ scattering on ^{144}Sm and ^{154}Sm. Experiments were conducted at iThemba LABS, coupling for the first time the K600 magnetic spectrometer with the BaGeL (Ball of Germanium and LaBr detectors) array. Preliminary results showcasing the efficacy of the facility and set-up for performing these 0° scattering experiments to investigate the PDR region are presented.

1. Introduction

The low-lying electric dipole (E1) response, commonly referred to as the Pygmy Dipole Resonance (PDR), has been interpreted within the hydrodynamic model as an oscillation of excess neutrons against a proton-neutron saturated core [1]. Its strength has been linked to the neutron skin by several theoretical approaches, providing possible constraints on the nuclear equation of state [2-4]. These constraints play a vital role in the description of neutron stars. In addition, the PDR has an influence on reaction rates in the astrophysical r-process, which is responsible for the nucleosynthesis of elements heavier than iron [5].

A large effort has been put towards understanding the fundamental nature of the PDR, both experimentally and theoretically as summarised in the review papers of Refs. [6-7]. The multi-messenger approach, which uses complimentary probes, has highlighted the different aspects of the response due to the mixed isospin nature of the PDR. While previous studies have provided a wealth of information, they have mostly been concentrated on spherical nuclei. Therefore one of the open question that still remains regarding the PDR is the influence that deformation plays on this low-lying dipole response.

In the case of the Giant Dipole Resonance (GDR), a splitting in the response for deformed nuclei is observed thereby giving rise to a double-hump structure. This splitting has been attributed to the different contributions arising from the K=0 and K=1 quantum numbers, as defined along and perpendicular to the nuclear deformation axis. The aim of this study was therefore to observe if a similar splitting-like effect would occur in the PDR response when considering a deformed nucleus. Thus inelastic ($\alpha,\alpha'\gamma$) experiments were conducted, comparing the PDR response in the spherical ^{144}Sm nucleus to the prolate deformed ^{154}Sm.

2. Setup and data analysis

The 0° scattering ($\alpha,\alpha'\gamma$) experiments on ^{144}Sm and ^{154}Sm were performed at iThemba Laboratory for Accelerator Based Sciences (iThemba LABS), over two individual experimental campaigns. In each experiment, the Seperated Sector Cyclotron (SSC) provided a beam of alpha particles accelerated to 120 and 117 MeV, respectively. The K600 magnetic spectrometer and its focal plane detection system were used for the α-particle detection whilst the BaGeL array (Ball of Germanium and LaBr detectors) was used for detecting the coincident γ-rays.

The K600 focal plane detection system consisted of a UX type vertical drift chamber (VDC) for position and angle determination, as well as a plastic scintillator detector used for generating the trigger signal for the system and for particle identification. Technical specifications for the zero-degree facility at iThemba LABS can be found in Ref. [8].

The BaGeL array, which consisted of eight HPGe and two LaBr detectors, was coupled to the K600 for the first time at iThemba LABS. The detectors were mounted on an oyster clamp structure at backward scattering angles surrounding the scattering chamber which housed the targets. In the second experiment, the number of HPGe and LaBr detectors were increased to twelve and six, respectively.

The timing signals for the gamma detectors were delayed and operated subject to the trigger signal received by the K600 focal plane. Coincident events could be selected by applying a gate on events occurring within the prompt time peak. Energy calibrations were performed using known excitation peaks and known decay transitions from ^{24}Mg in-beam data for the K600 and BaGeL detectors respectively. The ^{24}Mg calibration data were measured in between the Samarium targets data. The HPGe detector efficiencies were determined using the coincident gamma decays measured for the 6.4 MeV and 7.98 MeV excitations in ^{24}Mg as enlisted in Ref. [9].

3. Results and discussion

Figure 1 shows the coincident matrix of ^{144}Sm data for events occurring within the prompt-time peak of the HPGe detectors. On the x-axis, the energies corresponding to the excited states are plotted as determined from subtracting the measured energies of the detected alpha particles from the original beam energy whilst accounting for energy loss through the system. On the y-axis, the energy distribution of the coincident γ-rays measured in the 12 HPGe detectors, when operated in addback mode is plotted.

Specific transitions to the ground state and first excited states are indicated in the red and blue dashed lines respectively, as represented on the decay scheme in the inset. In order to compare the dipole response for the two Sm isotopes, a projection of the gamma decays within the ground state diagonal is extracted. This cut selection is employed since low-lying dipole transitions predominantly decay directly to the ground state. The cut selection satisfying the requirement that $|E_x\text{-}E_\gamma| <= 110$ keV was used in order to account for the full widths of the peaks as a result of the K600 detection energy resolution.

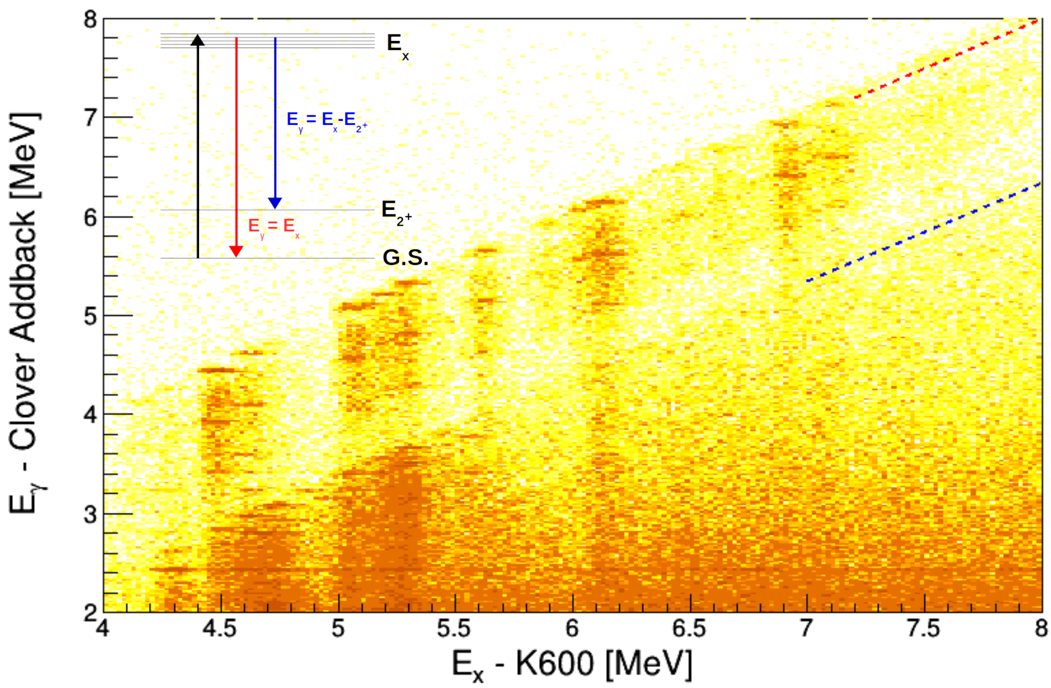

Figure 1. The coincidence matrix obtained for ^{144}Sm.

The multipolarities of the observed states were determined by comparing the ratio of counts for detectors positioned at two distinct angles, to the theoretically calculated ratio of the angular distributions. The α-γ angular correlations were calculated using the program ANGCOR [10], which requires an input of the m-state amplitudes. These were obtained using Distorted-Wave Born Approximation calculations with the program CHUCK3 [11]. A Global optical-model [12] was used for the input parameters required by CHUCK3. The angular distributions obtained from ANGCOR were then averaged over the full solid angle of the K600 acceptance. The procedure summarised above and the necessary input files for each step is described in full detail in Ref. [13]. The experimental ratio integrated over the energy range 4-8 MeV is shown relative to the expected theoretical ratios for E1, E2 and E3 transitions in Figure 2. A predominant E1 character of the states in the region of interest for ^{144}Sm can thus be confirmed.

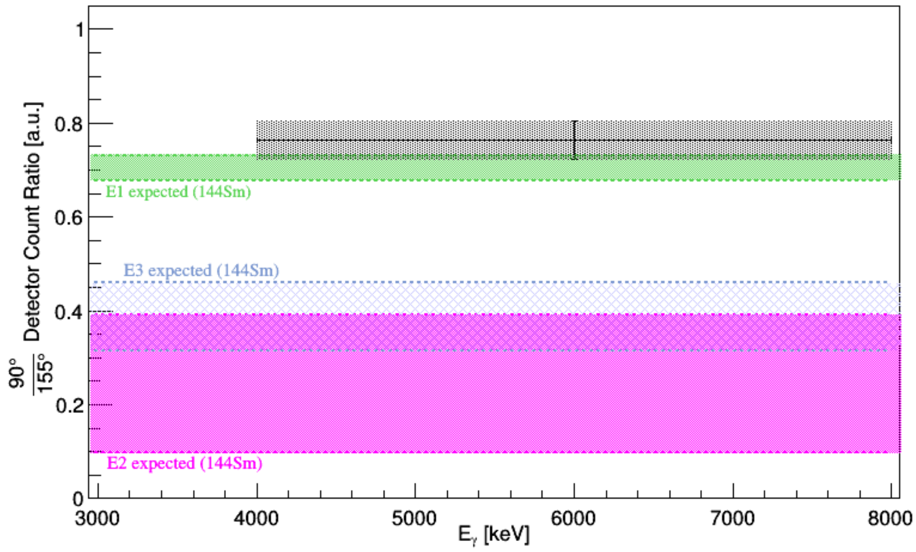

Figure 2. Angular correlation ratio of the states observed in the Ground state decay band in ^{144}Sm. The theoretical ratios expected for E1, E2 and E3 multipolarities are indicated by the bands.

4. Summary

Using the $\alpha'\gamma$ technique with the K600 and BaGeL facilities of iThemba LABS, it was possible to excite the PDR in ^{144}Sm and ^{154}Sm. Low-lying dipole states were observed between 4-8 MeV for ^{144}Sm Their dipole nature was confirmed via the α-γ angular correlation. These results will be compared with ^{154}Sm results to understand the effect of the ground state deformation on the PDR.

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