

Decay pattern of the Pygmy Dipole Resonance in ^{140}Ce

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Abstract. The decay behavior of low-lying dipole states in ^{140}Ce was investigated exploiting the γ^3 -setup at the HI γ S facility using quasi-monochromatic photon beams. Branching ratios of individual excited states as well as average branching ratios to low-lying states have been extracted using $\gamma-\gamma$ coincidence measurements. The comparison of the average branching ratios to QPM calculations shows a remarkable agreement between experiment and theory in the energy range from 5.0 to 8.5 MeV.

1 Introduction

The electric dipole (E1) strength in atomic nuclei has been investigated intensively in the past decades, especially in the region of the isovector Giant Dipole Resonance [1]. However, for many nuclei additional low-lying E1 strength in the vicinity of the neutron threshold has been observed, which is usually denoted as Pygmy Dipole Resonance (PDR) [2]. The properties of this phenomenon have been studied in stable (see e.g. [3–11]) and in a few radioactive nuclei [12–14], in particular in the $Z=50$ and $N=82$ mass region. The underlying nature of the PDR is still unclear, and strong experimental and theoretical effort is put into its investigation. One suitable method to study the low-lying E1 strength below the neutron threshold is the Nuclear Resonance Fluorescence (NRF). So far, measurements have been restricted mostly to ground-state transitions. Still, for a complete understanding of the decay pattern, cascading transitions involving low-lying excited states have to be investigated as it has been done in indirect measurements using a quasi-monochromatic photon beam [7, 15–18]. However, the branching ratios for primary transitions are often too small to be observed directly in standard NRF experiments due to the large amount of low-energy background and the corresponding sensitivity limit.

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2 Experiment and Results

The sensitivity problem for weak transitions between excited states was countered with the experimental γ^3 -setup consisting of fast LaBr detectors with high γ -ray detection efficiency and HPGe detectors with high energy resolution [19]. This setup was installed at the High Intensity γ -ray Source (HI γ S) [20] at Triangle Universities Nuclear Laboratory by the γ^3 -collaboration. The γ^3 -setup allows for investigating the direct decays as well as cascade transitions via low-lying excited states. Due to the combination of the quasi-monochromatic photon beam of the HI γ S facility and the method of $\gamma-\gamma$ coincidences, the experimental sensitivity increases substantially.

The measurements were performed on a 2.3 g ^{140}Ce target in two γ^3 -campaigns in 2012 and 2013 covering the energy range from 5.2 to 8.3 MeV [21]. Using $\gamma-\gamma$ coincidence data from the detector array discrete as well as average branching ratios for transitions to low-lying excited states were extracted. Figure 1 shows an HPGe-LaBr coincidence matrix for a beam energy of 6.5 MeV. The decay of the 2_1^+ state to the ground state can be clearly identified in both detectors represented by the vertical and horizontal lines at 1596 keV, respectively. In order to investigate the branching ratios of discrete excited states to the 2_1^+ state using the high energy resolution of the HPGe detectors, the energy condition $E_{\text{LaBr}} = 1596$ keV was set for the LaBr spectra. The branching is defined as the ratio of the

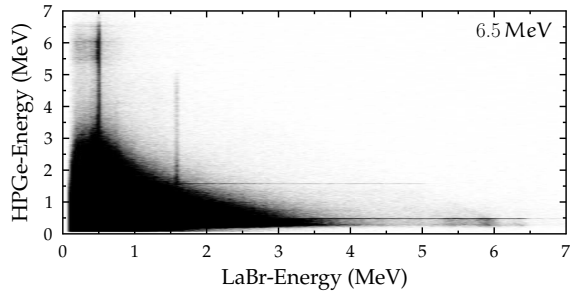


Figure 1. HPGe-LaBr coincidence matrix for $E_{beam} = 6.5$ MeV.

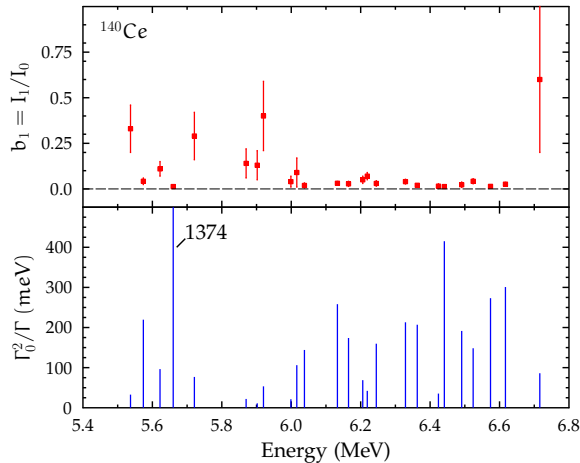


Figure 2. Upper panel: Branching ratios of individual excited states to the 2_1^+ state in the energy region of 6.5 MeV. Lower panel: Corresponding ground-state transition strengths.

intensity of the primary transitions to the 2_1^+ state and to the ground-state: $b_1 = \Gamma_1/\Gamma_0$. The results are shown in the upper panel of Fig. 2 in comparison to their ground-state transition strength (lower panel). Most of the states which deexcite strongly to the ground state have a very small branching ratio and vice versa.

However, the extraction of branching ratios of discrete levels becomes more complicated at higher excitation energies due to the increasing level density. Therefore, the average branching ratio $\langle b_1 \rangle$ for each beam energy setting can be deduced using LaBr-LaBr coincidences, which have a much higher efficiency compared to the HPGe detectors, but worse energy resolution. The value for $\langle b_1 \rangle$ is determined in a similar way as for individual states. After setting an energy condition on the $2_1^+ \rightarrow g.s.$ transition, the integrated intensity from primary transitions located at $E_{prim} = E_{beam} - E_{2_1^+}$ is extracted. In Fig. 3 the experimental $\langle b_1 \rangle$ values are shown together with predictions from calculations using the quasiparticle phonon model (QPM) [22]. The comparison of the experimental and the theoretical results shows that the microscopical QPM model is capable of describing the decay behavior of ^{140}Ce in the region below the neutron separation threshold.

The results show that it is possible to extract branching ratios for individual levels to low-lying states in the few percent level, while even smaller branchings can be

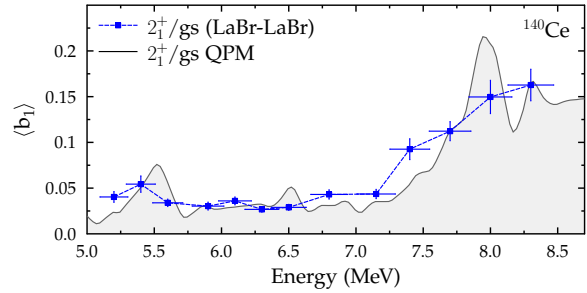


Figure 3. Average branching ratio to the 2_1^+ state compared to calculations within the QPM.

deduced for averaged quantities at higher excitation energies. A complete description of the γ^3 -setup and a complete set of the results on the $E1$ strength in ^{140}Ce was recently published in the doctoral thesis of B. Löher [21].

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