What Is Possible to Find out about the Dipole Photon Strength Function from Study of Resonance Neutron Radiative Capture by ^{195}Pt Nucleus Measured in DANCE Experiment

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Abstract

The ^{195}Pt(n,γ)^{196}Pt reaction was measured with the multi-detector array DANCE (Detector for Advanced Neutron Capture Experiments) consisting of 160 BaF_2 scintillation detectors at the resonance neutron beam of the Los Alamos Neutron Science Center. The multi-step cascade γ-ray spectra from individual neutron resonances were prepared and compared with predictions based on different photon strength function models. The simulated spectra were obtained by the DICEBOX statistical model code in combination with the GEANT4-based simulation of the detector response. From a comparison of the experimental and simulated spectra for multiplicities m=2–7 a piece of new information on the photon strength functions of ^{196}Pt was derived.

Introduction

The neutron radiative capture plays an important role in the process of nucleosynthesis as well as in the dynamics of nuclear reactors and ADS. The correct and reliable description of (n,γ)-reaction requires detailed understanding of the cascade γ-decay of highly excited nuclear states. This in turn needs information on the photon strength functions (PSFs) and the level density (LD). Due to the extremely complicated structure of highly excited nuclear states mainly a statistical approach can serve as a basis for the analysis of related experimental data and their theoretical analysis. During past decades many phenomenological information on PSF and LD was obtained using various experimental methods and related data analyzes [1–10].

At excitation energy near and below the neutron binding energy B_n the main contribution into PSF comes from E1 and M1 strengths and for discrete excitations near the ground state from the E2 strength too. The E1 part of PSF is mainly given by the giant dipole resonance (GDR) but some additional structures such as the pygmy resonances and scissors modes can play an essential role.

An existence and the global features of the GDR were proved and studied in many experimental and theoretical investigations but the PSF properties near and below B_n are under the question. Data from several different experimental techniques [7–8] indicate a presence of resonance-like structures in the PSF at $E_\gamma \sim$ 4–8 MeV in several A ~ 190–200 nuclei. Unfortunately, previously used experimental methods did not usually allow to determine unambiguously the detailed characteristics of these resonances.

Beside that at low $E_\gamma \leq 2$ MeV two effects violating the traditional GDR picture were observed. The first one [10,11] is a possible temperature dependence of the GDR width that leads to a non-zero value of the E1 strength when E_γ goes to zero. The second one [2–4] is the sharp increase of the E1 PSF for $E_\gamma \leq 2$ MeV observed in many nuclei (although not as heavy as Pt) from Oslo-type experiments [12]. Additional experimental approaches need to clear out the PSF properties at these very low E_γ. One of them – analysis of multi-step cascade (MSC) spectra – exploits coincidence γ-ray spectra measured with detector system DANCE [13,14] in combination of the resonance neutron beam of the Los Alamos LANSCE neutron spallation source [15]. Analysis and first results of the decay properties of ^{196}Pt with this method is a subject of this contribution.

Experiment

The experimental MSC spectra were obtained at the neutron spallation source LANSCE using the detector array DANCE. The pulsed 800 MeV H^- beam from the LANSCE linear accelerator was injected into the proton storage ring after being stripped to H^+ by a thin foil. The average current was 100 μA. The pulsed beam was then extracted with a repetition rate of 20 Hz and struck a tungsten spallation target. The resulting fast neutrons were moderated in the upper-tier water moderator and sent to flight path 14 at the Manuel Lujan Jr. Neutron Scattering Center. The DANCE detector array is installed at 20 m on this flight path.

The DANCE spectrometer [13,14] is designed for studying neutron capture cross sections on small samples. It consists of 160 BaF_2 scintillation crystals surrounding a sample and subtending a solid angle of near 4π. A ^{6}LiH shell about 6 cm thick is placed between the sample and the BaF_2 crystals to reduce the scattered neutron flux striking the crystals. The remaining background from scattered neutrons interacting with the BaF_2 crystals is subtracted in the off-line analysis. Besides the BaF_2 crystals, the DANCE setup includes four additional detectors that are used to monitor the neutron flux.

Data analysis and simulation procedure

The acquisition system of the DANCE array allows obtaining spectra of deposited energy sums from individual events [16] from well-resolved (s-wave) neutron resonances using the time-of-flight technique. These spectra, sorted according to detected multiplicity are shown in Fig. 1. They consist of a prominent peak (Q-value peak) in vicinity of the neutron binding energy B_n and a long tail down to low sum energy. The events in the peak deposited all the energy emitted by γ rays in the detector array while events at the low energy tail correspond to γ-cascades for which a part of the emitted energy escaped detection.

From γ cascades that deposited energy sum in the vicinity of B_n, specifically between 7 and 8 MeV, we constructed so-called MSC spectra [16]. They are for a few resonances presented in Fig. 2. The spectra are normalized to the same area in all shown multiplicities. In total we were able to extract MSC spectra from 5 and 11 resonances with $J^\pi = 0^-$ and 1^-, respectively. As a result of expected Porter-Thomas fluctuations of individual transitions intensities the spectra are not identical but sometimes substantially differ, especially for low multiplicities *m*. For comparison presented below we have made an unweighted average of these spectra for resonances with given spin.

Experimental MSC spectra were compared with predictions of simulations based on different models of PSFs and LD. The predictions were obtained with help of the statistical model code DICEBOX [17], which was used for simulation of the cascades starting at isolated resonances with given spin and parity, with subsequent modelling of the response of the DANCE array to these cascades with a code based on the GEANT4 package [18]. In the DICEBOX code complete information on properties of low-lying levels in ^{196}Pt was taken from available experimental data [19] below excitation energy of 1.88 MeV. Experimental data indicate that the information is not complete above this energy. At higher energies the levels and individual transitions were generated using the PSFs for different transitions types (E1, M1 and E2) and LD models. The code allows to treat correctly expected fluctuations in positions of levels as well as Porter-Tomas fluctuations of transition intensities via concept of different nuclear realizations [17].

So far, we have tested a consistency of experimental spectra with predictions for a few PSFs models. These models were based mainly on widely-used models, such as those available in the RIPL-3 database, or were inspired by available experimental data [7–9].

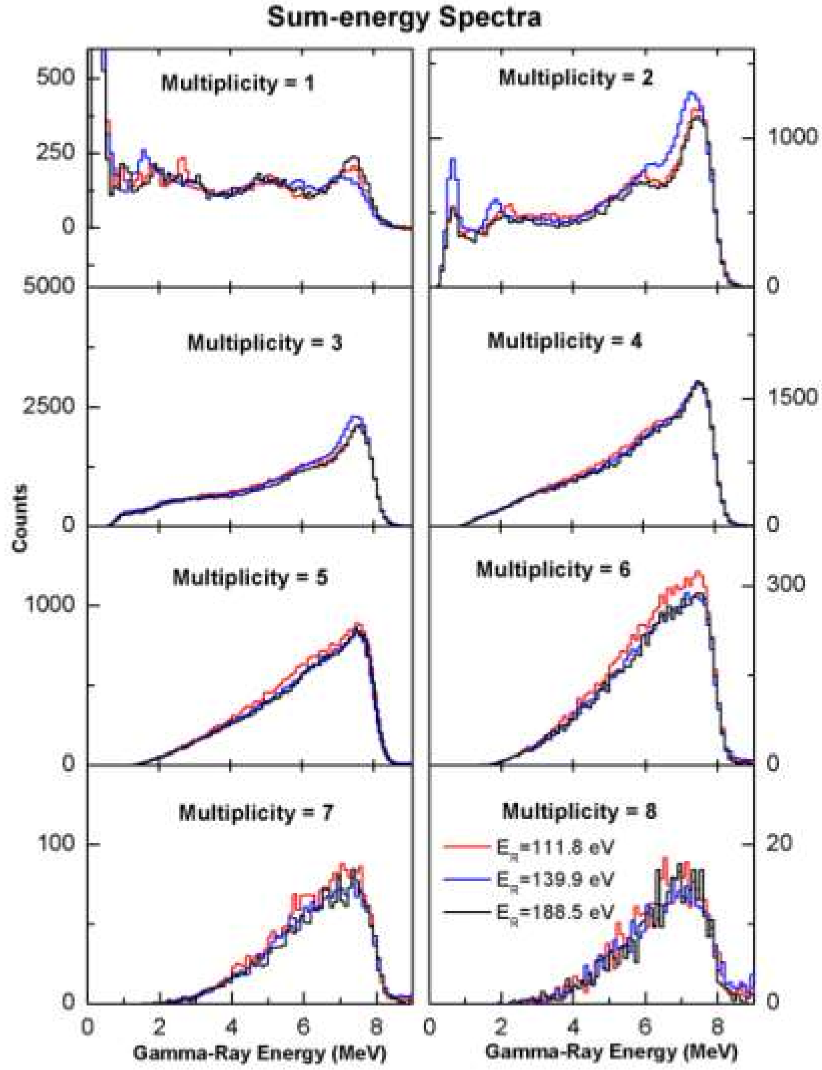

Fig. 1. Examples of the spectra of deposited energy sums for the neutron resonances with $J^{\pi}= 1^{-}$. Spectra for resonances with neutron energies E_n = 111.8 eV, 139.9 eV, and 188.5 eV are shown.

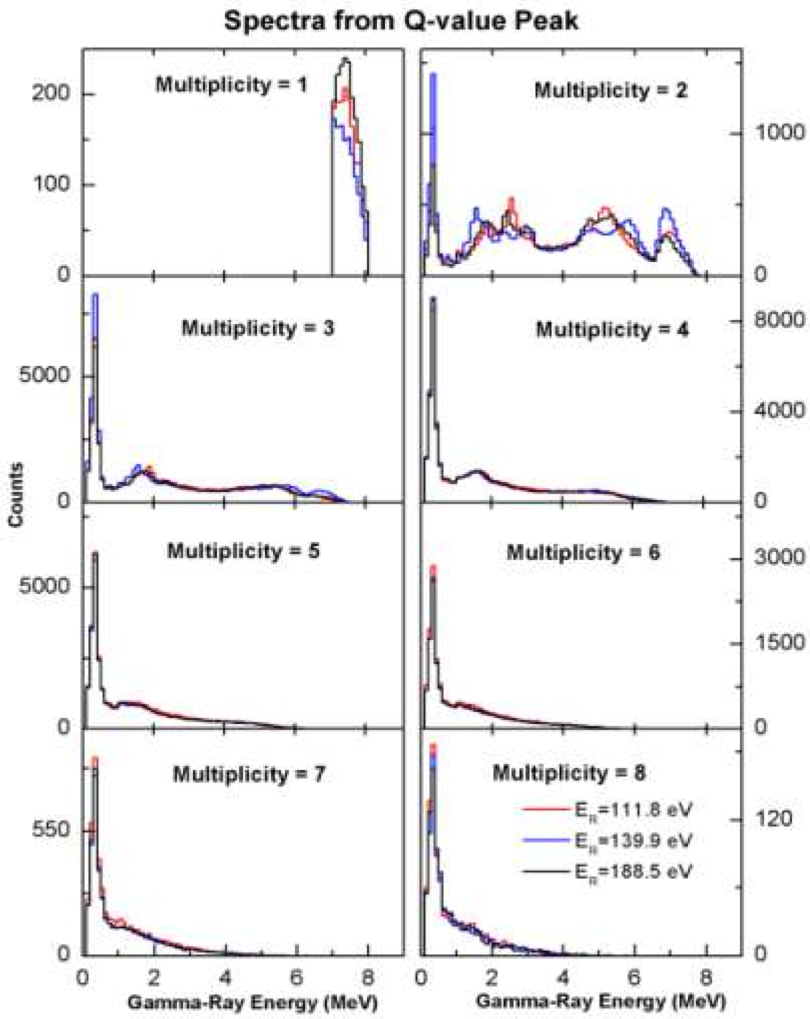

Fig. 2. Examples of multi-step γ-cascade spectra for some neutron resonances with $J^{\pi}= 1^{-}$. Only events depositing energy in the Q-value peak between 7 and 8 MeV were used for construction of the MSC spectra. Resonance energies are indicated in the legend.

Results and discussion

Simulations with PSFs that do not contain any resonance structure near $E_{\gamma} \sim 5.6$ MeV were found to be unable to reproduce the shape of the MSC spectra. As a result our data confirm a presence of a resonance-like structure at these energies. Postulation of the resonance structure near this energy significantly improves the agreement between simulated and experimental spectra. A very good reproduction of experiment was obtained with a model based on experimental data from Oslo experiment [8] that is shown in Fig. 3. The comparison of experimental MSC spectra with the predictions with this model is shown in Fig. 4 for s-wave resonances with both spins $J^{\pi}= 0^{-}$ and 1^{-}. The experimental data averaged over all measured neutron resonances are shown as lines while the gray corridors correspond to predictions. The corridor characterizes the fluctuations of spectra from different nuclear realizations and corresponds to the average +/– one standard deviation.

In reality, data from this experiment (similarly to any available experimental data [7–8]) is not available for at $E_\gamma < 2$ MeV. An extrapolation for these energies is thus required. A reasonable reproduction of MSC spectra requires PSF which is not very far from a constant value for $E_\gamma < 2$–2.5 MeV. Predictions with PSFs models having either a zero limit or a limit higher than about 2×10^{-8} MeV^{-3} for $E_\gamma = 0$ are unable to correctly predict the MSC spectra.

We have also found that the predicted spectra are sensitive to parity dependence of the LD, at least for excitation energies below about 3 MeV. A parity dependence can be expected as there are only a few negative parity levels below about 2 MeV known in ^{196}Pt. The simulations with some parity dependence introduced below about 3 MeV seem to describe the experimental MSC spectra better than simulation with the same number of positive- and negative-parity levels at all energies.

The comparison also indicates that the M1 strength, at least for $E_\gamma \sim 3$–4 MeV, is not negligible but our sensitivity to different E1/M1 composition at $E_\gamma > 4$ MeV seems to be partly limited.

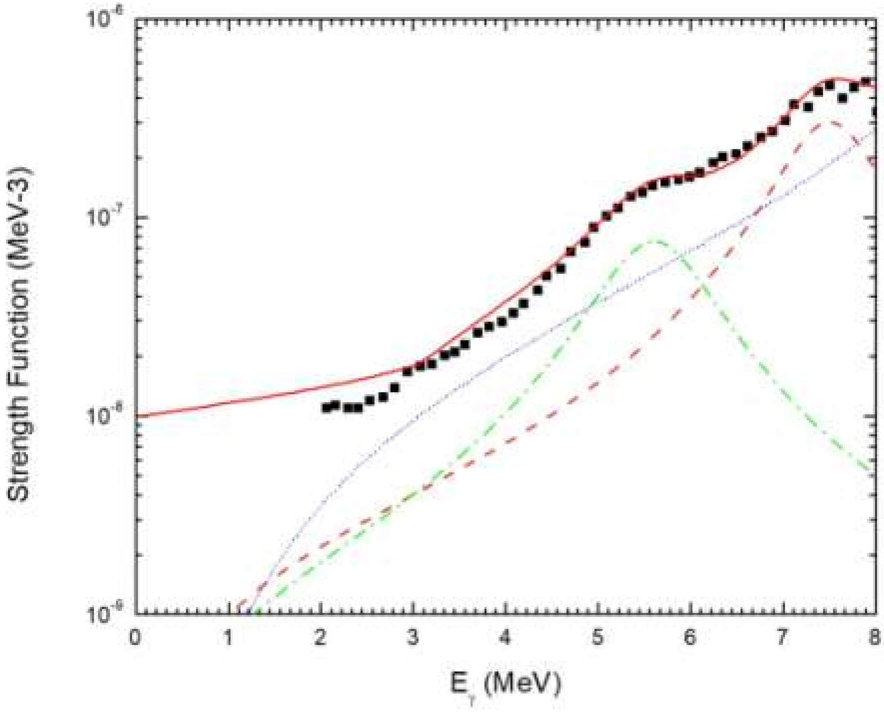

Fig. 3. The PSFs (lines) used in simulations presented in Fig. 4 together with PSF from [8] (black squares). Sum of used E1 and M1 PSFs (full line) consists of a GDR tail (based on QRPA calculations as published in [8] – dotted line), two resonance structures (dash and dot-and-dash lines) and a tail toward low E_γ (not shown).

Conclusion

The multi-step cascade spectra from several neutron resonances formed in the ^{195}Pt(n,γ)^{196}Pt reaction were measured with the DANCE detector array at the Los Alamos Neutron Science Center. Comparison of these spectra with their counterparts obtained from simulations based on different models of photon strength functions and level density confirms presence of a resonance structure in the PSF near 5.6 MeV and a non-zero limit of PSF for very low energies.

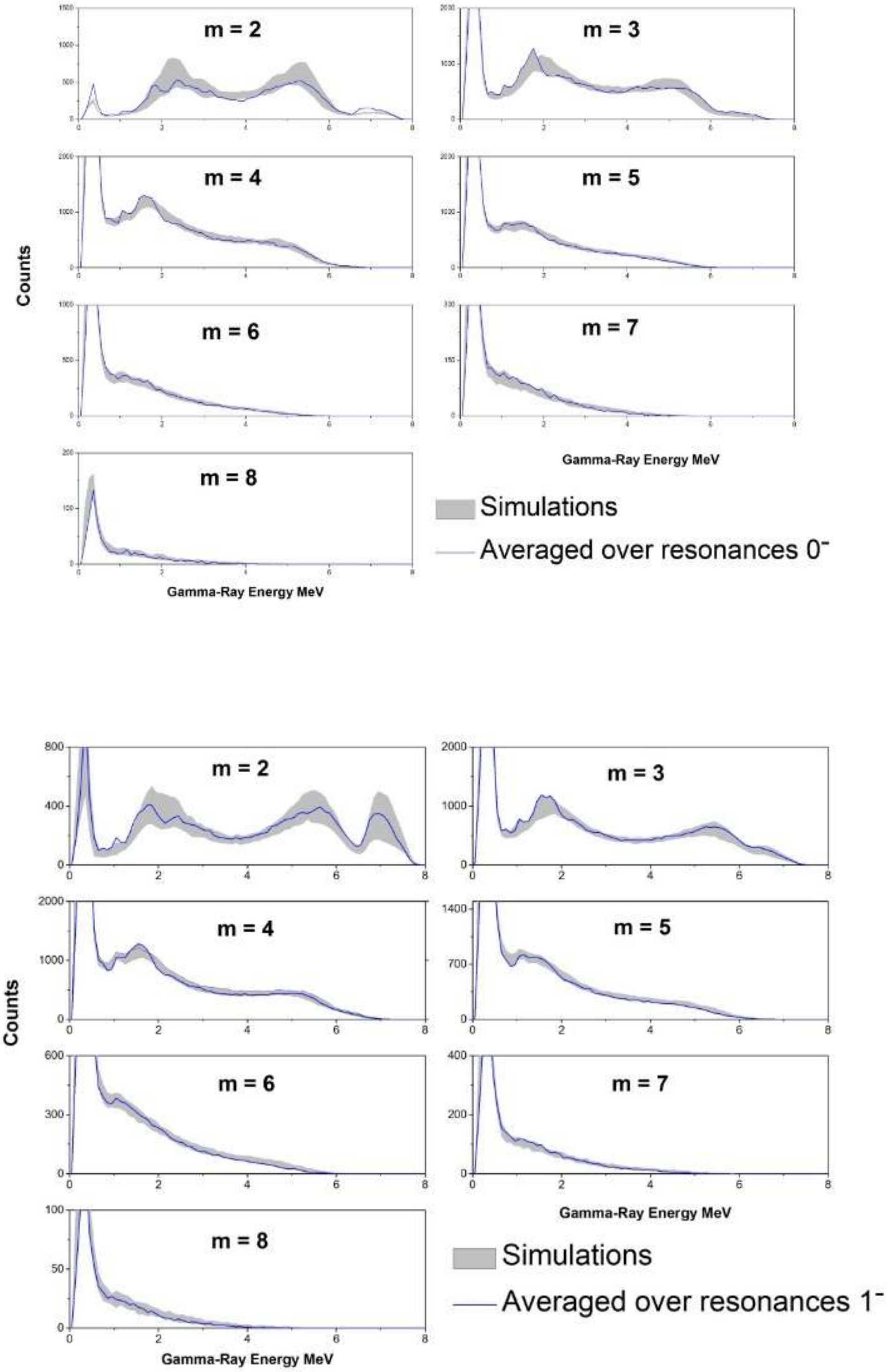

Fig.4. Comparison of the simulated MSC spectra (gray region) and experimental ones (lines) averaged over all measured neutron resonances coming from radiative neutron capture on ^{193}Pt. The upper and lower panels correspond to spectra from $J^{\pi}= 0^{-}$ and 1^{-} resonances.

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