Study of photon strength functions via $(\vec{\gamma}, \gamma', \gamma'')$ reactions at the γ^3-setup

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Abstract. One of the basic ingredients for the modelling of the nucleosynthesis of heavy elements are so-called photon strength functions and the assumption of the Brink-Axel hypothesis. This hypothesis has been studied for many years by numerous experiments using different and complementary reactions. The present manuscript aims to introduce a model-independent approach to study photon strength functions via γ-γ coincidence spectroscopy of photo-excited states in ^{128}Te. The experimental results provide evidence that the photon strength function extracted from photoabsorption cross sections is not in an overall agreement with the one determined from direct transitions to low-lying excited states.

1 Introduction

The photon strength function (PSF) serves as an essential input for nuclear astrophysical model calculations. It plays an important role in capture and photo-disintegration reactions as well as in astrophysical scenarios describing the nucleosynthesis. In the past, different experimental methods and approaches have been used to study the PSF (see, e.g., Refs. [1–5] and references therein). However, many of these methods are model dependent either in the reaction mechanism itself or in the data analysis. In this contribution, we present a model-independent approach, exemplarily for ^{128}Te, to extract the PSF in real-photon scattering experiments using quasi-monochromatic photon beams provided by the High Intensity γ-ray Source (HIγS) [6] at Duke University, Durham, NC, USA.

2 Methods

In the following, two independent methods are introduced to determine the PSF for the excitation as well as for the decay channel in a single experiment exploiting the monochromatic character of the photon beam provided by the HIγS facility.

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The photoabsorption cross section σ_γ $(= \sigma_{\gamma\gamma} + \sigma_{\gamma\gamma'})$ is linked to the PSF built on the ground state by $f(E_\gamma) \propto \sigma_\gamma / E_\gamma$ assuming predominantly dipole transitions. The procedure to determine σ_γ as a function of the excitation energy at HIγS was discussed in detail in previous works, such as [5, 7–9]. The idea is sketched in Fig. 1.a). After photoexcitation of the nucleus in a given enery range defined by the energy and the width of the quasi-monochromatic photon beam, σ_γ is reconstructed by measuring all ground-state transitions $(\sigma_{\gamma\gamma})$ and all events cascading via intermediate levels $(\sigma_{\gamma\gamma'})$, where $\sigma_{\gamma\gamma'}$ can be approximated by the intensity observed for the $2^+_1 \rightarrow 0^+_1$ transition [7].

The second approach is illustrated in Fig. 1.b) and c) and was firstly introduced in Ref. [2] using proton-γ-γ correlations in ^{94}Mo$(d,p)^{95}$Mo reactions. Due to the novel γ-γ coicidence setup γ^3 [10] it is feasible for the first time to apply this method in $(\vec{\gamma}, \gamma'\gamma'')$ reactions, here shown for the example of ^{128}Te. Primary transitions from excited states at E_{x_1} to low-lying excited levels yield information on the PSF at the corresponding transition energies: $f(E_\gamma = E_{x_1} - E_{2^+_1}) \propto I_{x_1 \rightarrow 2^+_1}$, with $I_{x_1 \rightarrow 2^+_1}$ being the associated transition intensity. The observation of several direct transitions to low-lying states per excitation energy and beam-energy setting, respectively, allows to reconstruct the PSF over a broad γ-ray energy range, which is schematically shown in Fig. 1.c) for a hypothetical PSF. These two outlined approaches allow to independently study the PSF in the excitation and the decay channel, respectively.

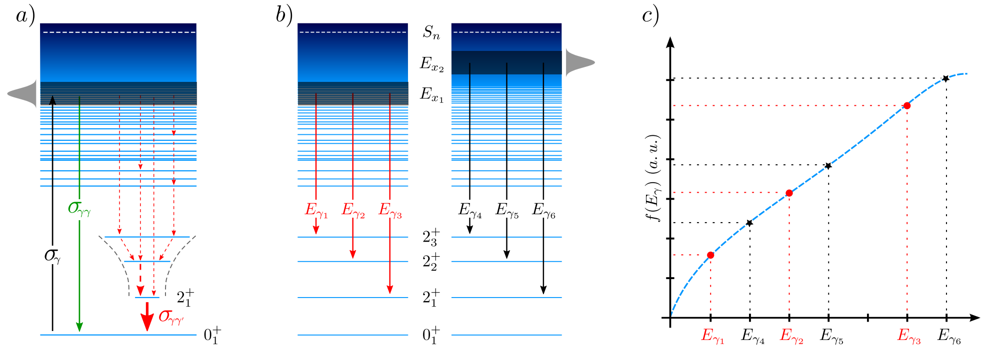

Figure 1. For details see text.

3 Experiment & Results

For the present work a metallic and highly-enriched (99.8 %) ^{128}Te target was used to perform photon-scattering experiments with quasi-monochromatic γ-ray beams with energies between 3 MeV and 9 MeV in steps of about 250 keV. The spectral distribution of the beam is usually about FWHM $\approx$ 3 % of the beam energy.

Typical γ-ray spectra for the measurement of primary transitions to low-lying excited states after photo-excitation via an 8 MeV γ-ray beam are shown in Fig. 2.a). The blue spectrum is obtained from a gate on the energy of the $2^+_1 \rightarrow 0^+_1$ transition (E_γ = 743 keV). The peak at $\sim$ 7.26 MeV corresponds to the full-energy events of the direct population of the 2^+_1 level from excited states at 8 MeV. Primary transitions to other levels, such as 2^+_3 (green spectrum) and 2^+_4 (red spectrum) are determined in a similar fashion. The individual transition intensities can be converted into values of the PSF at the corresponding γ-ray energy.

All measured transition intensities for beam energies from 5.8 MeV to 8.5 MeV are shown in Fig. 2.b) as a function of the γ-ray energy (black filled squares). For the measurements with beam energies above 6.4 MeV decays into up to the 2^+_8 state are observed. Due to the steps of $\sim$ 250 keV between two measurements it is possible to obtain data points at the same or similar γ-ray energy from different beam-energy settings. The fluctuations of the data points exhibit a factor of about 2-3, which is larger than expected from Porter-Thomas fluctuations of around 5 % to 15 %. This is one indication that the average decay properties of photo-excited states in ^{128}Te below the neutron separation threshold (S_n = 8.78 MeV) cannot be described by a single excitation-energy independent PSF.

Nevertheless, the current data set is used to compute a moving average weighted by a Gaussian distribution with FWHM = 300 keV (grey shaded band). That averaged PSF is compared to the PSF extracted from photoabsorption cross sections (blue filled squares) shown in Fig. 2.c). A deviation of both PSFs as a function of the γ-ray energy is observed. This observation additionally indicates that the PSF built on the ground state (photo-excitation) differs from the PSF built on excited states (photo-deexcitation) for the present case of ^{128}Te, which is in contradiction to the Brink-Axel hypothesis [11, 12]. However, additional systematic studies applying the outlined approach and comparison to data from complementary experiments are crucial before general conclusions on the Brink-Axel hypothesis can be drawn.

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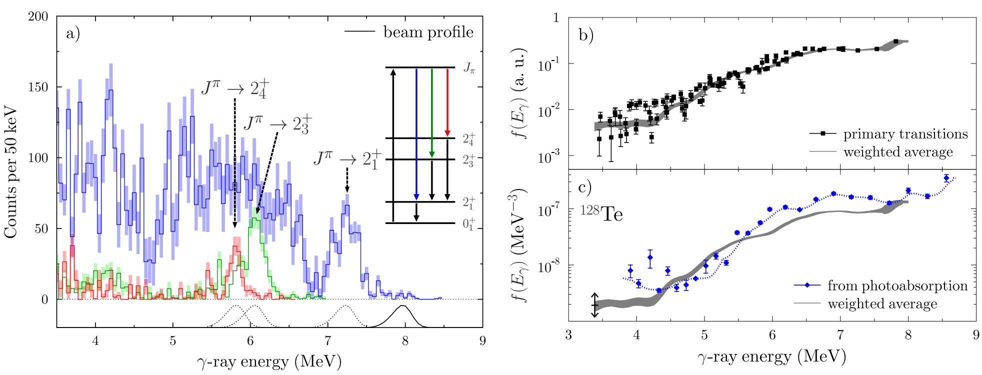

Figure 2. For details see text.

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