Study of photon strength functions via \((\vec{\gamma}, \gamma', \gamma'')\) reactions at the \(\gamma^3\)-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 \(\gamma-\gamma\) coincidence spectroscopy of photoexcited 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 \(\gamma\)-ray Source (HI\(\gamma\)S) \([6]\) 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 HI\(\gamma\)S facility.

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The photoabsorption cross section $\sigma_\gamma = \sigma_{\gamma\gamma} + \sigma_{\gamma\gamma'}$ 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 $\sigma_\gamma$ as a function of the excitation energy at $\text{HIyS}$ 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 energy range defined by the energy and the width of the quasi-monochromatic photon beam, $\sigma_\gamma$ is measured 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-$\gamma$-$\gamma$ correlations in $^{94}\text{Mo}(d,p)^{95}\text{Mo}$ reactions. Due to the novel $\gamma$-$\gamma$ coincidence setup $\gamma^{2}$ [10] it is feasible for the first time to apply this method in ($\vec{\gamma}$, $\gamma'\gamma''$) reactions, here shown for the example of $^{128}\text{Te}$. Primary transitions from excited states at $E_{x_{i}}$ to low-lying excited levels yield information on the PSF at the corresponding transition energies: $f(E_\gamma = E_{x_{i}} - E_{2_{1}^{+}}) \propto I_{2_{1}^{+} \rightarrow 0_{1}^{+}}$, with $I_{2_{1}^{+} \rightarrow 0_{1}^{+}}$ 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 $\gamma$-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 %) $^{128}\text{Te}$ target was used to perform photon-scattering experiments with quasi-monochromatic $\gamma$-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 $\gamma$-ray spectra for the measurement of primary transitions to low-lying excited states after photo-excitation via an 8 MeV $\gamma$-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 ($E_{\gamma} = 743$ 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 $\gamma$-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 $\gamma$-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 $\gamma$-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 $\gamma$-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](https://example.com/figure2.png)

**Figure 2.** For details see text.

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