Progress in photon strength function of ^{58}Fe using Oslo and shape methods

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In August 2021, an experiment was performed using the Detector Array for Photons, Protons and Exotic Residues (DAPPER) to measure the photon strength function (PSF) of ^{58}Fe. An important quantity in neutron capture cross-section calculations for s/r-process nucleosynthesis, the PSF describes the energy-dependent strength of gamma-ray emission from nuclei. The ^{58}Fe nucleus was excited using an indirect method of the (d,pγ) transfer reaction in inverse kinematics. The resulting coincidence between protons and gamma-rays is used to extract the PSF using the well-documented Oslo method [1] and an offshoot of the original method called the Shape method [2] which reduces the dependence on external data. The current progress in extracting the PSF using these methods will be discussed.

DAPPER utilizes an S3 annular silicon and 128 BaF_2 scintillators to detect the coincidence between charged particles and gamma-rays respectively. The charged particle of interest in this experiment is the proton from the (d,p) which is utilized to calculate the initial excited state of the ^{58}Fe nucleus. Fig. 1 shows the raw coincidence data from the August experiment. From this point, a simulation of the array is required to generate a response function that describes how the experimental setup treats the true gamma-ray energies. This is done by simulating many initial gamma-rays in GEANT4 and recording the intensities of the photopeak, annihilation and escape peaks where applicable.

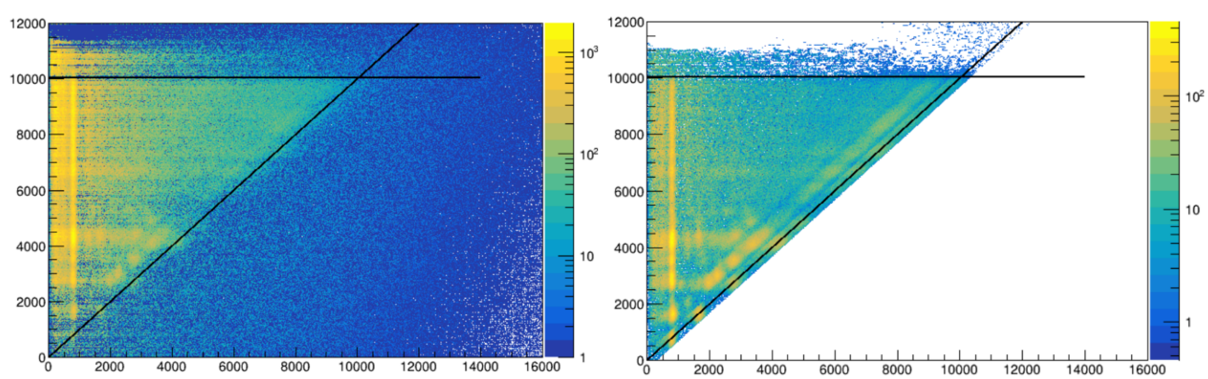

Fig. 1. Raw coincidence data with calculated excitation energy and the total gamma-ray energy. Panel A shows the ungated data while panel B shows the data gated on the total gamma-ray energy peak. The horizontal line indicates the neutron separation energy of ^{58}Fe and the diagonal is the y=x line.

To model the Compton background, these peaks of interest are removed from the spectra and the characteristic shape is retained. These values are then interpolated for all gamma energies. The resulting response matrix is folded into the raw matrix using an iterative procedure [3]. This unfolded matrix is then used to pull out the primary gamma-rays from each state. It is assumed that the primary gamma-rays for the decay from a specific state can be obtained by subtracting a weighted sum of all lower lying states gamma spectra. This is done for each excitation bin and the resulting primary matrices are shown in Fig. 2.

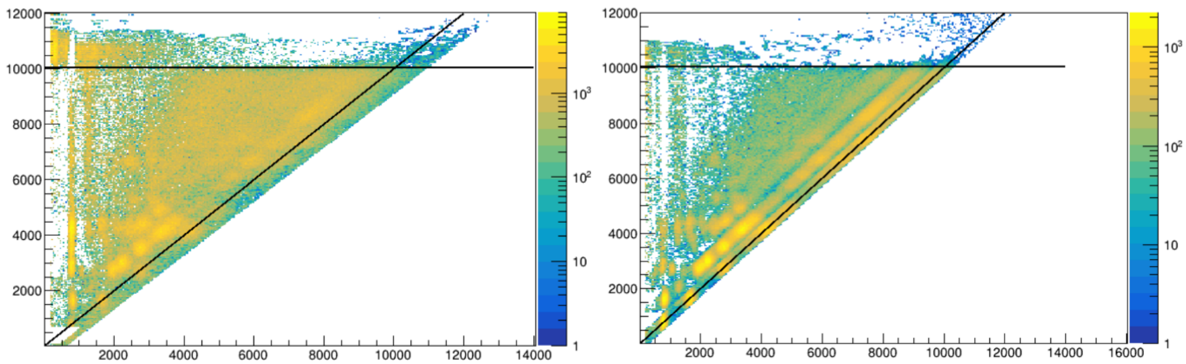

Fig. 2. Primary matrices of data using current GEANT4 simulated DAPPER response. Clear states and transitions can be observed.

From this point, the Oslo method and Shape method begin to differ. To proceed with the original Oslo method, an absolute normalization is performed using external data like gamma partial widths, and s-wave spacing at the neutron separation energy to constrain the infinite possible solutions to Equation 1, which relates the primary matrix ($P(E_x, E_\gamma)$) to the nuclear level density (NLD) at the final state ($\rho(E_x - E_\gamma)$) and the transmission coefficient ($T(E_\gamma)$). A simultaneous extraction is performed and the NLD and PSF are determined. The preliminary results are shown in Fig. 3.

$$P(E_x, E_\gamma) \propto \rho(E_x - E_\gamma) T(E_\gamma) \quad (1)$$

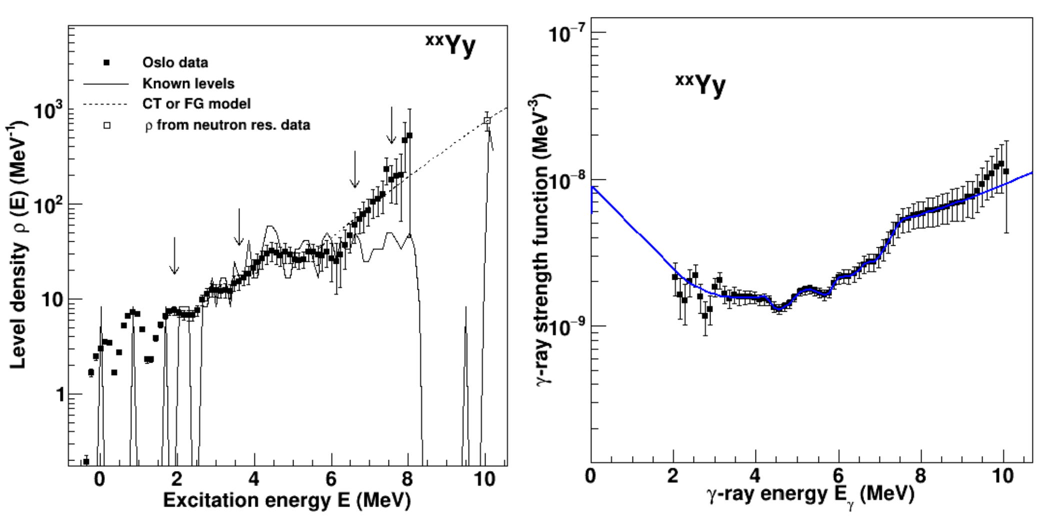

Fig. 3. Extracted NLD and PSF from the Oslo method.

The Shape method utilizes the entries (N) in strong gamma transitions to final states (D) to obtain a ratio of the strength which is estimated from Eq. 2. A sewing method is then used to obtain the characteristic shape of the PSF which is overlayed with the Oslo method PSF in Fig. 4. See reference [2] for a detailed description of the sewing procedure.

$$f(E_\gamma) \propto \frac{N_D}{E_{\gamma D}^3} \qquad (2)$$

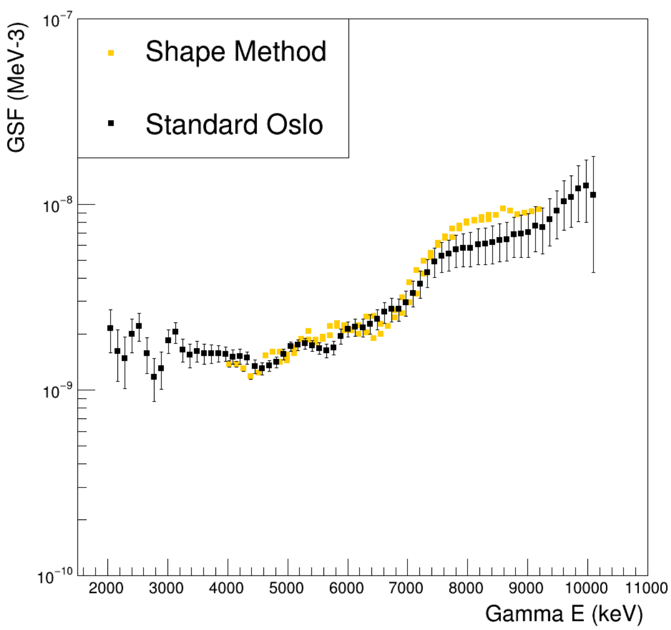

Fig. 4. Comparison of scaled Shape method PSF to Oslo method PSF. There is self-consistency in the slopes indicating proper use of methods however, the simulated DAPPER response is still in progress.

The self-consistency between the two methods validates the use of the Shape method to acquire the characteristic features of the PSF without requiring normalization to external data. Due to the current state of the GEANT4 simulation of DAPPER, the response matrix is not well representing the experimental data and so the extracted PSFs here are preliminary. Current work is ongoing to improve the simulated response which will reproduce a more accurate primary matrix.

[1] A. Schiller *et al.,* Nucl. Instrum. Methods Phys. Res. **A447**, 498 (2000).
[2] M. Wiedeking *et al*., Phys. Rev. C **104**, 014311 (2021).
[3] M. Guttormsen *et al*., Nucl. Instrum. Methods Phys. Res. **A374**, 371 (1996).