DAPPER: PSF forward analysis on ^{58}Fe

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The purpose of DAPPER (Detector Array for Photons, Protons, and Exotic Resides) is to measure the photon strength function (PSF) of nuclei. The PSF describes the average quantum mechanical component of photon emission probabilities and thus it is important in describing the de-excitation process of neutron capture reactions. Of particular interest are the PSFs of nuclei away from the line of stability. Direct neutron capture reactions on radioactive nuclei are typically not feasible due to both the beam and the target being unstable, thus these measurements typically require radioactive beams. To get around this problem indirect (d,pγ) reactions will be used. In order to first test the methodology and setup of the proposed radioactive beam experiment a stable inverse kinematic experiment was done with ^{57}Fe(d,pγ)^{58}Fe. The analysis methodology that I am using to constrain the photon strength function is known as the forward method [1].

The DAPPER array consists of 128 BaF_2 detectors and an S3 Annular Silicon detector. The primary benefit of BaF_2 detectors is that they provide high gamma ray efficiency which will be important for any future radioactive beam experiments. The proton produced in the reaction can then be detected by the S3 annular silicon detector in order to calculate the excitation energy of the residue. On August 2nd 2021 the first run with DAPPER was conducted. ^{57}Fe at 7.5 MeV/u was on a CD_2 target at the end of the MARS (Momentum Achromat Recoil Spectrometer) line to produce ^{58}Fe and a free proton. Carbon targets were also used in order to subtract out the gamma rays associated with reaction on carbon.

The forward method works by simulating the gamma ray cascade assuming a certain PSF and nuclear level density (NLD), and then comparing the simulation to the experimental results. In order to compare the simulated data to the experimental ones the simulated cascades must be subject to the same experimental constraints as the experimental data. To do this we have chosen to use GEANT4 to simulate DAPPER's response. To test the GEANT4 simulation of the DAPPER array multiple gamma ray sources where used. Shown in Fig. 1 is the simulated efficiency compared to its experimental counterpart as a function of gamma ray energy (γE). Efficiency was evaluated for both simulation and experiment by taking the ratio between the yield within 300keV*sqrt(γE) of the known γE of the peak and the number of gamma rays of that energy. This gate formalism was chosen to account for the absolute resolution of the BaF_2 detectors broadening for higher energy gamma rays. The simulated efficiencies are systematically too high by roughly 10%. However, the general trend of efficiencies as a function of gamma ray energy and multiplicity appears to be reproduced by the GEANT4 simulation. Specifically, due to the large effective Z of the BaF_2 crystals the efficiency as a function of energy appears roughly flat. Further work with lab testing is currently planned to better understand the source of the difference.

In addition to the GEANT4 simulation the initial spin of the ^{58}Fe nucleus must also be accounted for. For each PSF and NLD multiple initial spins states must also be sampled, and their contributions then

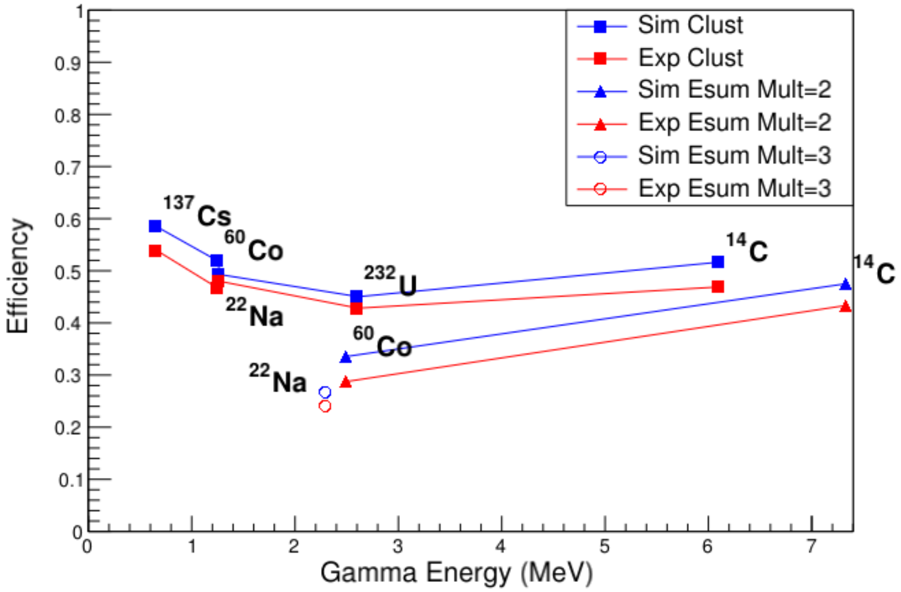

Fig. 1. : Efficiency of simulated (blue) and experiment (red). Efficiency is defined as ratio of the integral within 300KeV*sqrt(γE) symmetric gate of the gamma ray energy and the number of decays. Square points are for the cluster efficiency, triangles are for true multiplicity 2 BaF_2 Esum, and open circles are for true multiplicity 3 BaF_2 Esum. No error bars calculated.

must be weighed by a predicted spin distribution as a function of excitation energy. Dr. Potel provided some theoretical predictions of how much each l-wave contribution to the (d,p) reaction, allowing us to predict the yield as a function of excitation energy for each of the different J states (Fig. 2) [2]. Due to a strong d-wave contribution the spin population of 1^-, 2^-, and 3^- are the major contributors. Yield is

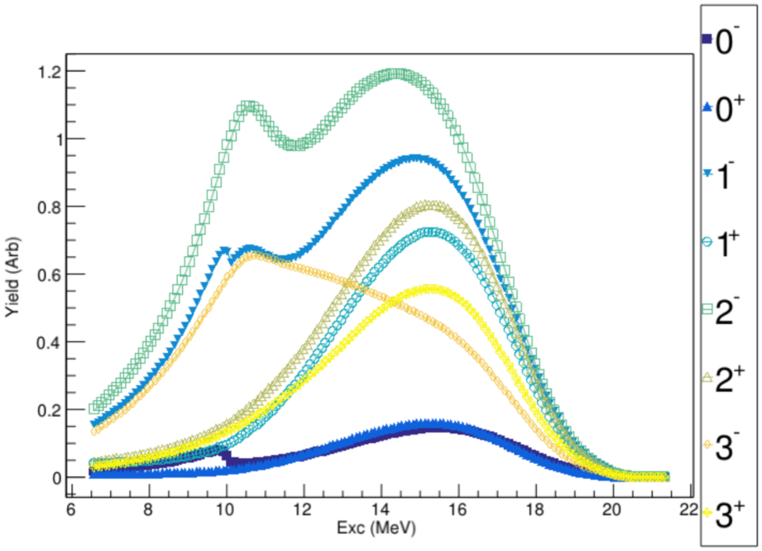

Fig. 2. Predicted spin distribution of the initial state populated in ^{58}Fe for both positive and negative parities up to spin 3.

integrated over the angular range of the S3 detector. With those distributions the same gating conditions can be applied to both experiment and simulation to determine which models are consistent with the data. Currently the only major remaining hindrance to a final result lies in the GEANT4 simulation not agreeing perfectly with the experimental standards used.

[1] F. Becvar, Nucl. Instrum. Methods Phys. Res. **A417**, 434 (1998).
[2] G. Potel, F.M. Nunes, and I.J. Thompson, Phys. Rev. C **92**, 034611 (2015).