DAPPER: PSF forward analysis on ^{58}Fe using d,p reaction in inverse kinematics

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The photon strength function (PSF) is important in describing photon emission probabilities and thus it plays a role in radiative neutron capture reactions. Experiments have shown an enhancement in the PSF at low energy for some nuclei. This low energy enhancement (LEE) could have a large effect on r-process nucleosynthesis, where many nuclei with unmeasured neutron capture cross sections are produced in nature. Experiments have shown an LEE in both ^{56}Fe and ^{57}Fe nuclei [1-3]. A measurement of ^{58}Fe's PSF could see if this trend continues. In addition, doing a measurement of ^{58}Fe's PSF helps to prepare for a future measurement of ^{60}Fe's PSF, which will require a radioactive beam. DAPPER (Detector Array for Photons, Protons, and Exotic Residues) probes PSFs using inverse kinematics (d,p) reactions. DAPPER consists of 128 BaF_2 detectors, to detect the gamma rays with high efficiency, and one S3 Annular Silicon detector, to detect the proton. A beam experiment was done on August 2nd, 2021, to measure ^{58}Fe's PSF. The analysis methodology that I am using to constrain the photon strength function is known as the forward method [4].

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. 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 must be weighed by a predicted spin distribution as a function of excitation energy. Dr. Potel provided some theoretical predictions of how much spin state contributes to the (d,p) reaction, allowing us to predict the yield as a function of excitation energy for each of the different J states [5].

Extensive work has been done to compare multiple models to experimental results. To select on more statistical initial state population higher excitation energy regions are used in this analysis. Given this concern the region gated on is the 9 to 9.5 MeV region. One model that was explored is the quasiparticle random-phase approximation (QRPA) PSF provided by PSF database [6] coupled with Hartree-Fock-Bogolyubov (HFB) NLD [7] sourced from RIPL3. The QRPA-PSF model agrees well with earlier measurements of ^{56}Fe and ^{57}Fe PSFs at higher gamma ray energy but differ at lower energy values where the LEE has a large effect. Using the nominal values for the QRPA-PSF and the HFB NLD, DICEBOX simulations were run and then compared to experimental results in Fig. 1. Overall decent agreement was found with the reduced chi square calculated for each spectrum.

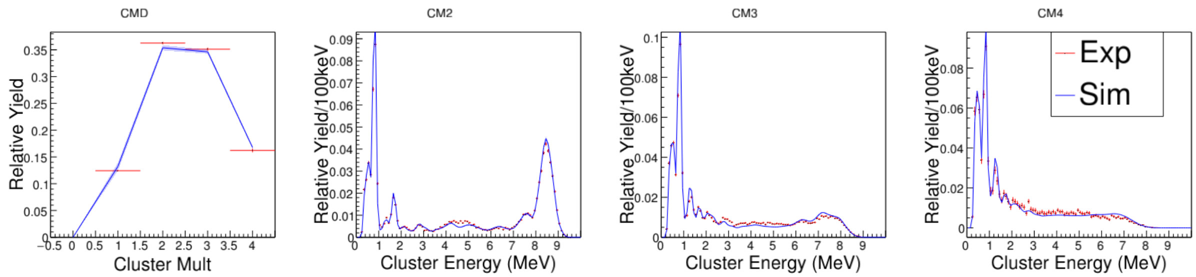

FIG.1. Comparison between simulation (blue) and experiment (red), gating on the 9 to 9.5 MeV E* region. Each spectrum is normalized to areas of 1 for both simulation and experiment. Only statistical errors are shown and are typically small for the simulation. Only events with the Esum within 300 keV of the excitation energy were included (Total Sum Gate (TSG) gate).

The QRPA-PSF provided by the PSF database has several phenomenological corrections applied to it. One of these terms is for the LEE, which is modeled as an exponential decay from zero energy. To see the effect on the Sim-Exp agreement the constant value (Cval) for that exponential was tweaked and then the simulations were run again. The reduced chi square was then re-evaluated for each of these new LEE strengths to yield the trends seen in Fig. 2. The cluster multiplicity distribution shows a trend of

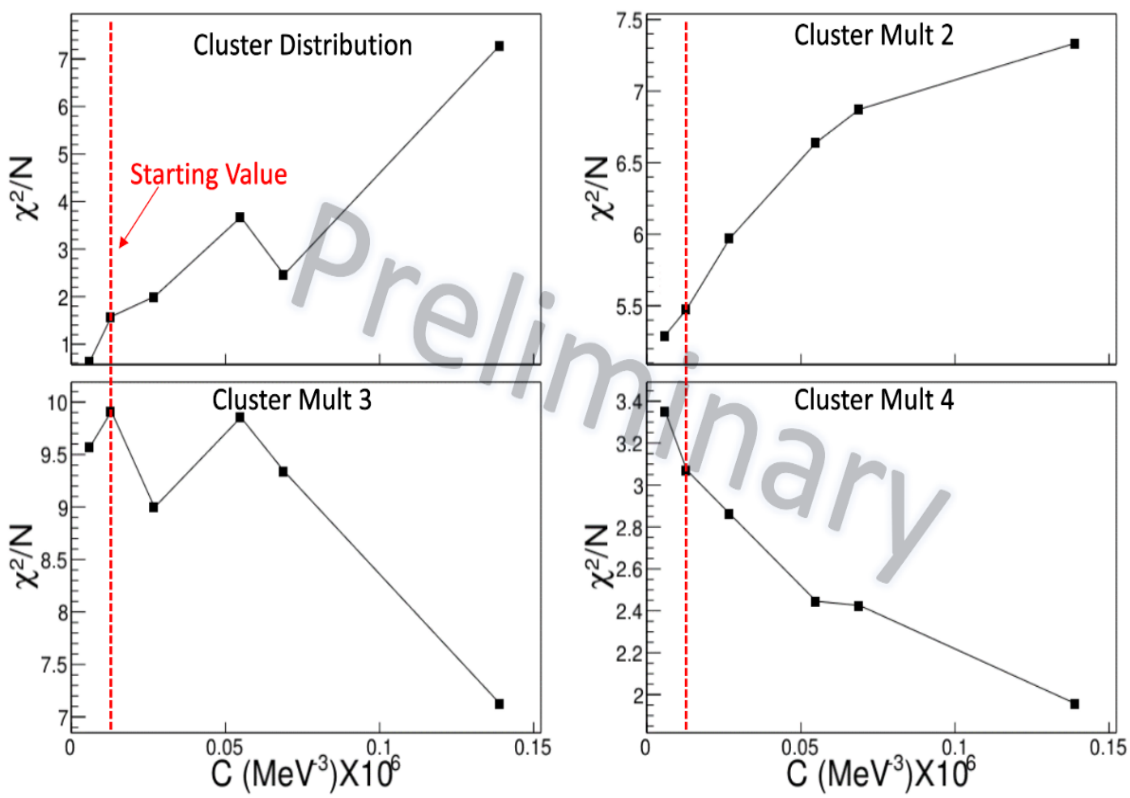

FIG.2. Reduced Chi2 evaluation for each spectrum evaluated as a function of the LEE constant value. Once more the region evaluated is between 9 to 9.5 MeV E* with the total sum gate.

having worse agreements as the LEE is increased, which is also seen in the cluster mult 2 energy distribution. The cluster mult 3 energy distribution only shows better agreement for an extreme value of the LEE, while the cluster mult 4 energy distribution exhibits the opposite trend as seen for the cluster mult 2 energy distribution. If the LEE was the only source of disagreement between the simulation and the experiment all the distributions should show similar chi square minima. Since this is not observed other sources of discrepancies need to be explored within the chosen model space.

Many models have been simulated, and a comprehensive evaluation of the trends is being prepared. For the sake of brevity, only an example MSC plot for the cluster mult 2 energy distribution is shown in Fig. 3. This demonstrates the effect of changing the models used in the DICEBOX simulation. Substantial changes in the simulated energy shape can be seen in the middle energy region. The CT-Oslo-EBFG NLD coupled with the QRPA PSF approximates the results from Austin's thesis and shows good agreement in the central region. This gives some evidence that the Forward and Oslo analysis method can corroborate each other. The BSFG-GLO and CT-SLO model used in Dr. Bennet's study of ^{58}Fe's PSF [8] over predict the observed energy distribution in the middle energy region. Publication on the final results will likely occur within one to two years.

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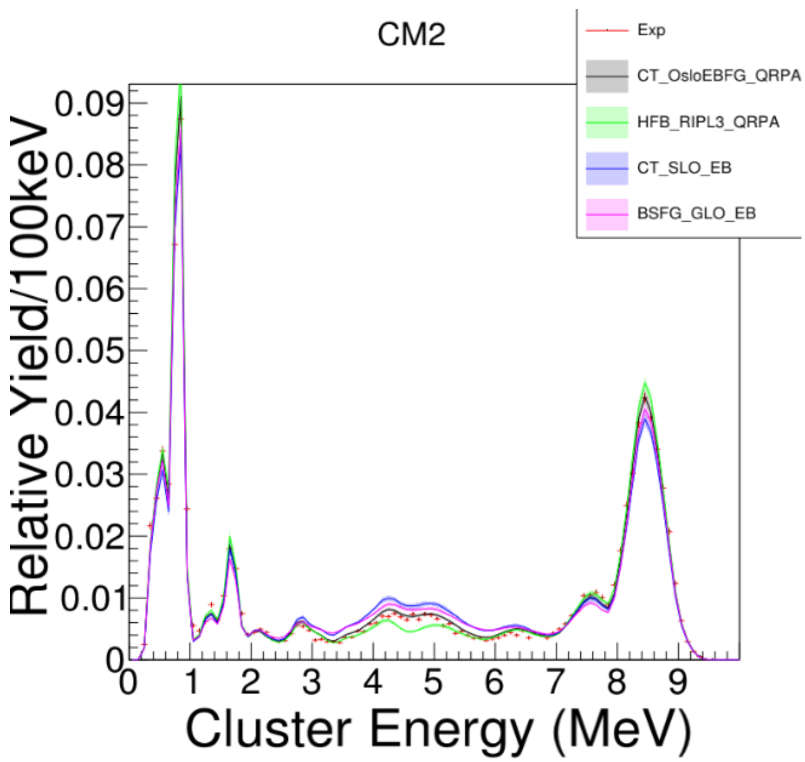

FIG.3. Cluster multiplicity 2 energy comparison between the experiment (red) and various models. In black is a model using Austin's Oslo CT NLD with the EBFG normalization with the QRPA PSF with from the PSF database corresponding to 10 MeV excitation energy, in green is the HFB RIPL3 NLD with the QRPA PSF, blue is the constant temperature NLD with a simple Lorentzian model adopted in Dr. Bennet's dissertation on ^{58}Fe's PSF, and in pink is a simulation using a BSFG NLD with a GLO PSF also used in Dr. Bennet's work.

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