DAPPER gamma ray response

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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 photon strength function describes the bulk 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 is the measurement of PSFs away from the line of stability, requiring radioactive beams. Direct neutron capture reactions on radioactive nuclei are typically not feasible due to both the beam and the target being unstable. 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 ^{57}Fe(d,pγ)^{58}Fe experiment was done.

The DAPPER array is composed of 128 BaF_2 detectors and an S3 annular silicon detector. BaF_2 detectors provide high gamma ray efficiency which will be critical for future radioactive beam experiments. The proton produced in the reaction can be detected by the S3 annular silicon detector in order to measure the excitation energy of the residue. In addition, a faraday cup was installed at the end of the line to monitor the beam rate. On August 2nd 2021 the first run with DAPPER was conducted. ^{57}Fe at 7.5 MeV/u was accelerated at the end of the MARS line and impinged on a CD_2 target to produce an excited ^{58}Fe nucleus and a free proton. Carbon targets were also used in order to subtract out the gamma rays associated with reaction on carbon. A ^{13}C(d,pγ)^{14}C reaction was run in DAPPER, with a 8.0 MeV/u ^{13}C beam, in order to get high energy gamma rays for the calibration of the BaF_2 detectors.

One of the principal needs of a gamma ray detector array for radioactive beam measurements is to have high efficiency. Running a carbon subtraction on 13C (d,p) data we took allows us to test efficiency for high energy gamma rays. In Fig. 1A) the excitation energy of the ^{14}C is plotted against the

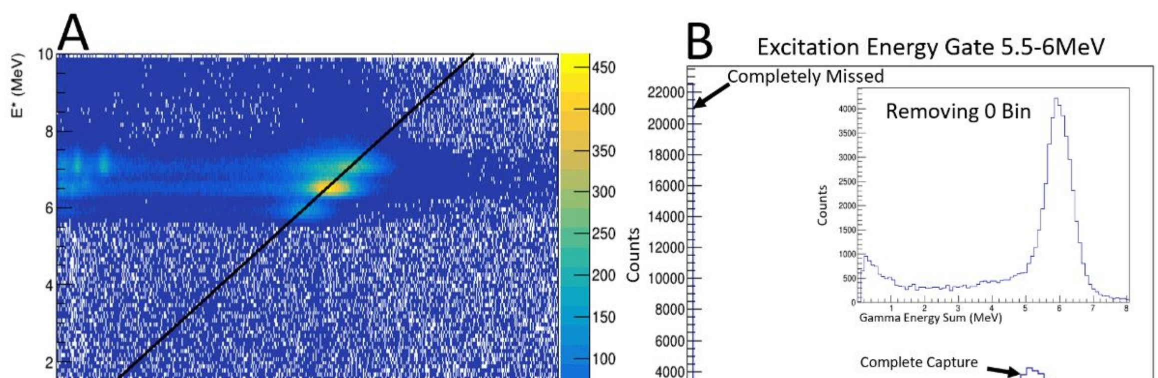

Fig. 1. A) Excitation energy of ^{14}C plotted as a function of the sum of the gamma ray energy seen in the BaF_2 detectors. The black line is the y=x line showing complete capture of the gamma rays in the array. Clear bands corresponding to the excited states of ^{14}C are seen. B) Gamma energy sum spectra, gating on excitation energies between 5.5 and 6 MeV. This gate picks up the first excited state of ^{14}C which emits a 6.0938 MeV gamma ray to the ground state. A strong complete capture peak is observed.

sum of all the energy seen in the BaF_2 detectors is shown. A strong y=x line is observed for regions of excitation corresponding to known states in ^{14}C. This indicates good collection efficiency for gamma ray collection in the DAPPER array. Gating on the first excited state of ^{14}C produces the energy sum spectrum seen in Fig. 1B). From this gate the probability we see something in the array is 73% for the 6.1 MeV gamma ray. The probability we get a sum within 300 KeV of the expected energy is 36%, if we expand the gate to be within 1 MeV this probability increases to 48%.

The energy calibration for the BaF_2 detectors has also been improved and quantified. The BaF_2 detectors were calibrated with multiple gamma ray sources placed in the target position. This allows us to both measure the efficiency of the array and get a well constrained energy calibration. In Fig. 2A) an example energy calibration is shown. Six gamma peaks are used in this energy calibration, ranging

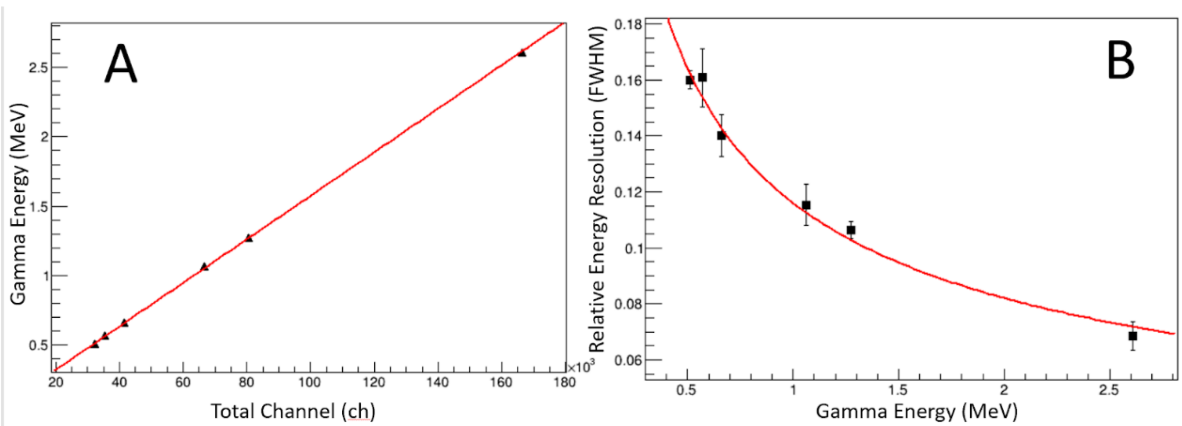

Fig. 2. A) Example energy calibration for one of the BaF_2 detectors. Red line is a linear fit through all points; error bars are smaller than marker size. The detector response looks very linear all the way up to 2.6MeV. B) Relative energy resolution as a function of gamma ray energy for the same detector. Red line is an $a/\sqrt{E}$ fit to the data points, where a is a free parameter.

in energy from 0.511 MeV to 2.6 MeV. Fig. 2B) shows the energy resolution as a function of gamma ray energy; this quantity also needs to be measured in order to construct an accurate response function. A summary of all the detectors relative energy resolution at 1 MeV is shown in Fig. 3).

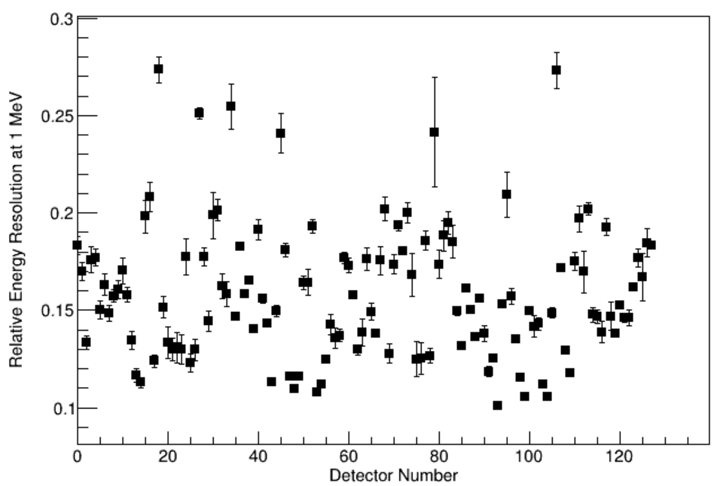

Fig. 3. Relative energy resolution at 1 MeV for each detector.

With the information from the source and $^{13}C(d,p\gamma)^{14}C$ reaction data as well as a constrained response function for the DAPPER array will soon be made. This response function will let us conduct our analysis of the ^{58}Fe PSF. In addition to being required for the current analysis, the response function will also be useful for simulating future experiments and testing their viability before they are scheduled and conducted.