DAPPER upgrade for radioactive beam contamination separation

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The Detector Array for Photons, Protons, and Exotic Residues (DAPPER) has been designed to measure the photon strength function (PSF) of nuclei; specifically, to be used for radioactive beam experiments. Photon strength functions are important in the understanding of the de-excitation of neutron capture reactions. The proposed reactions that DAPPER is commissioned to complete are inverse kinematic (d,pγ) in order to get around the instability of neutron beams and radioactive targets. The first experiment in August 2021 using DAPPER was ^{57}Fe (d,pγ) ^{58}Fe to probe for the PSF of ^{58}Fe. The follow up experiment is the radioactive beam reaction ^{59}Fe (d,pγ) ^{60}Fe to probe for the PSF of ^{60}Fe.

DAPPER consists of 128 BaF_2 detectors for measuring the gamma rays and an S3 annular silicon detector which detects the protons ejected at backward angles from the projectile of interest. The ^{59}Fe beam proposed for the radioactive beam experiment has the composition given in Table 1. When the proton is measured from any (d,pγ) reaction, determining which of the incident nuclides it was, will determine if we keep the event on an event-by-event basis. As we are interested in the ^{60}Fe PSF, events where ^{59}Fe was not incident on the CD_2 targets should be thrown out. A detector capable of Co-Fe separation is necessary for the experiment, to reduce error and determine a meaningful PSF.

Table 1. ^{59}Fe Radioactive Beam Composition.

Nuclide	Percent Abundance
^{59}Fe	79%
^{59}Co	13%
^{57}Co	7%

The proposed experiment will be 7.5 MeV/u ^{59}Fe beam at 3×10^5 pps impinged on a CD_2 target. Most detectors are unable to withstand the high rate of heavy ions without permanent damage. At Argonne National Lab and Oak Ridge National Lab, there are arrays currently using ionization chambers (IC) for (d,pγ) reactions for PSF's of interest [1]. Ionization chambers are able to handle the rate of direct beam we are interested in without permanent damage unlike a silicon. Due to the array's space constraints at the end of MARS (Momentum Achromat Recoil Separator), the preferred spot to add an ionization chamber is before the target. By placing the IC before the target, we reduce the beam velocity and increase our cross section. A reduction in beam velocity may reduce the likelihood of populating the high excitation states of ^{60}Fe. A simulation was developed using CycSrimDev to model the experimental results.

To model the experimental results, the first step was to determine how we collect charge from IC at high rate. Inside the IC there is gas (typically CF_4) at some pressure and alternating cathode and anode foils to produce an electric field to collect the electrons from the ion-pair. Signals from all anodes can be combined and used to measure how much energy loss the particle experienced. Iron, possessing a lower Z than cobalt, results in less energy loss, a feature which can be exploited in order to separate the two nuclei. The windows will experience a bowing effect due to the pressure difference outside and inside the IC. Therefore, the area between the first foil and entrance window as well as the last foil and exit window cannot be used in data collection. Energy loss in all foils and windows themselves are accounted for in reducing beam velocity appropriately, but not used in data collection. The final summed energy loss through the areas of data collection for each nuclide are then smeared with a Gaussian of some width.

Fig. 1 shows the results from the simulation containing the following dimensions: Foils are 0.5 μm Mylar, Windows are 2 μm Mylar, CF_4 gas at 110 Torr, 9 foils in total, 5cm total gas length where the foils are equidistant across the 5cm of gas length. At 5% FWHM, the isotopic resolution can be seen, however with 10% FWHM, this isotopic resolution cannot be realized. 10% FWHM was taken from an IC similar to that in the simulation that quoted a ~10% FWHM at a rate of $3\text{x}10^5$ pps [2].

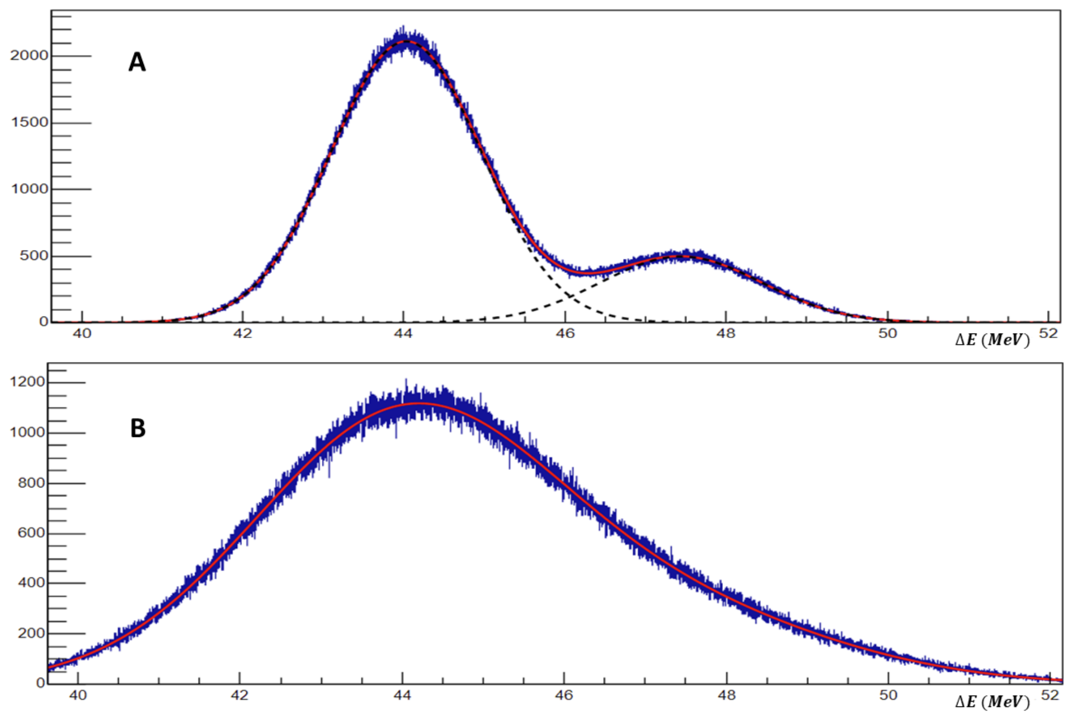

Fig. 1. Simulation results for IC that would be used for energy loss placed before the target. A is 5% FWHM. The dashed lines are fitting the two peaks respectively. Left peak represents ^{59}Fe and the right peak is both ^{59}Co and ^{57}Co. B is 10% FWHM.

At Oak Ridge and Argonne, the IC's are ΔE-E detectors at the end of the beamline. Each anode is output separately giving the experimentalist the versatility to determine which anodes in the IC are designated for the ΔE & E detector for separating contaminants optimally [1,3] . An Yttrium Aluminum Perovskite (YAP: Ce) array was constructed to be used at the end of DAPPER as a rate monitor [4]. Fig.2-A is produced by using the IC already implemented in the simulation as the ΔE detector and the YAP: Ce array for the E detector assuming 10% FWHM for both. Increasing the pressure and length of gas to 130

Torr and 15 cm respectively, we get Fig. 2-B. Fig. 2-B has some degree of separation where the densest circle represents the ^{59}Fe and the other two less dense are the cobalt isotopes. The changes to the IC for Fig. 2-B are done to model if we put the IC after the target and before the YAP: Ce array. The E detector is most useful when the particles are depositing their final energy closer to the Bragg peak as this is when the iron and cobalt nuclei have the largest difference in energy loss. If we could have a ΔE-E detector for the radioactive beam experiment, it would allow for a cut in 2-D energy space to minimize the contamination of cobalt and loss of iron events.

Currently, the specifications of the system in the simulation are being optimized to aid in the

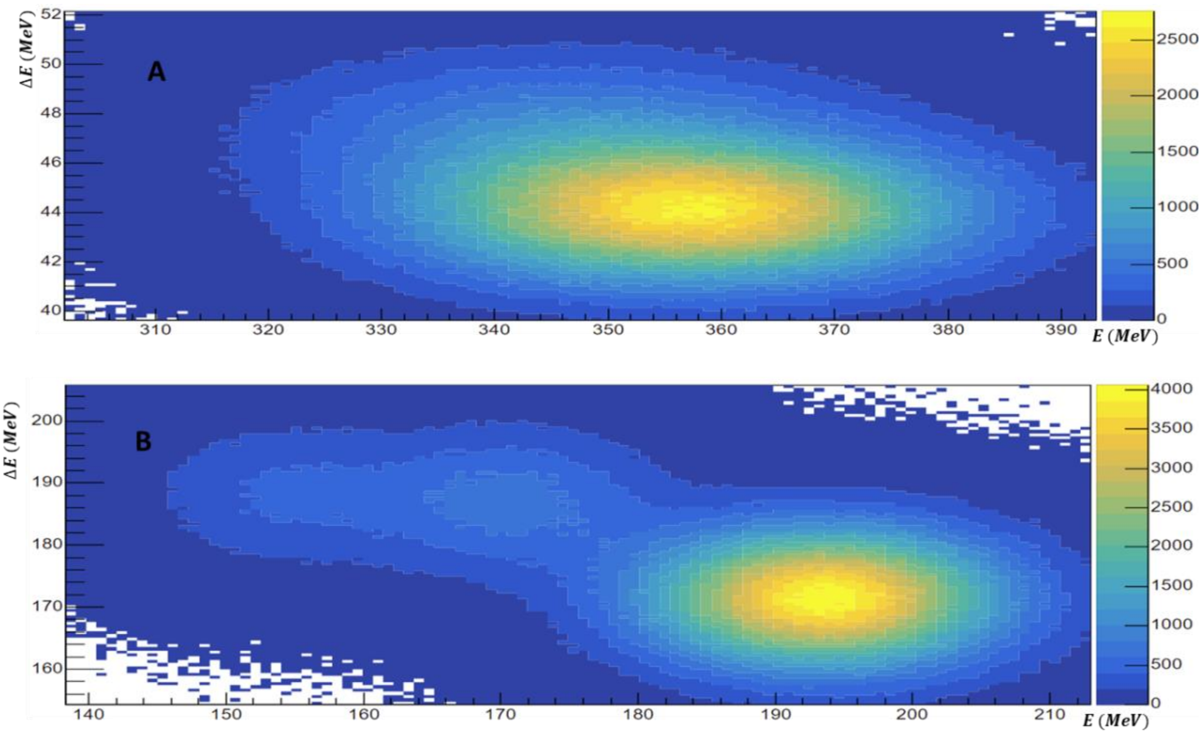

Fig. 2. Simulation results for IC as an ΔE detector and YAP:Ce array as an E detector. Both detectors have 10% FWHM. A is IC with 110 Torr and 5 cm gas length. B is C with 130 Torr and 15cm gas length.

production of a prototype of an IC for the DAPPER array's upgrade. Once the prototype is built, we will be able to with source data and/or a test run with a heavy ion "cocktail" beam be able to better understand the energy resolution of both the IC and YAP: Ce array before the proposed experiment.

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[2] J. Vadas *et al.*, Nucl. Instrum. Methods Phys. Res. **A837**, 28 (2016).
[3] S.D. Pain *et al.*, Physics Procedia 90,455 (2017).
[4] A. Abbott *et al.*, Progress in Research, Cyclotron Institute, Texas A&M University (2020-2021), p. V-38.