Optimizing detector configuration for breakup reactions using Monte-Carlo simulation

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Optimum configuration for detector setup in a nuclear reaction experiment is a very important aspect to consider. Often, nuclear physicists perform experiments when two or more breakup fragments are required to be detected in coincidence. In these cases, an optimum detector configuration is very much desired in order to achieve maximum statistics. A proper simulation of reaction kinematics for the actual experiment will give insight into judging the experimental hurdles. Nowadays with the advancement of data acquisition systems, nuclear physicists are performing experiments with an increasing number of detectors. In reactions involving weakly bound projectiles where the projectile easily breaks down into two or three fragments, they can undergo all sorts of reactions, e.g., incomplete fusion, transfer reactions, etc. In the case of coincidence measurements, where these individual breakup fragments need to be detected simultaneously posess a major challenge in designing an experiment as the angular spread information of these fragments should be known or esimated. Depending on the beam energy, the angular spread of the breakup fragments can be very compact or extended; proper care and thought have to be given in these cases.

The entire simulation code was developed using object-oriented FORTRAN. For the simulation of a nuclear reaction involving two or more breakup fragments, we have first simulated the reaction kinematics using energy and momentum conservation techniques. The velocity of breakup fragments was calculated in the rest frame of the parent nuclei and then converted into the lab frame. For a particular reaction channel, events have to follow the corresponding differential cross-section. One can readily calculate the cross-section for a given reaction at a given beam energy using sophisticated coupled channel codes. We have employed the "Inverse Cumulative Distribution Function" method [2] to generate events using the reaction cross-section. In this method, first the given cross-section is converted into probability distribution function by normalising the cross-section so that, $\int_{-\infty}^{+\infty} p(x)dx = 1$. The "Cumulative Distribution Function" is given by,

$$CDF(x) = \int_{-\infty}^{x} p(x)dx \qquad (1)$$

Value of CDF ranges from 0 to 1. Thus uniformly sampling CDF within 0 and 1 and inversing the Eq. 1, we can sample random number from p(x).

Once the lab velocity of the breakup fragments to be detected is known, the direction of the fragments is known as well. One module was developed to check for successful hits for given detector geometries. In the simulation, one can provide the exact detector configuration (size, shape, and placement) and thus the outgoing particles, when successfully detected in coincidence, are accepted. By varying the detector numbers and configuration for a given beam energy, one can find the optimum detector geometry which maximises the coincidence count rate.

Although provision for studying two, three, and four outgoing fragments in the reaction channel using the simulation code is available, only three fragment breakup simulations

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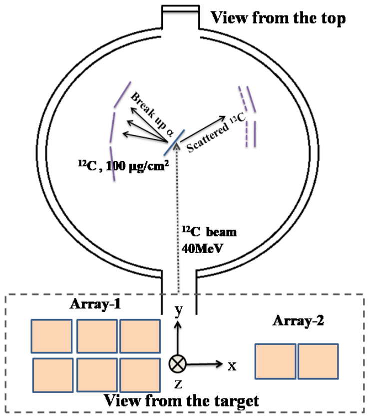

FIG. 1: Experimental setup considered for the simulation, Array-1 and Array-2 are on the opposite side of the beam

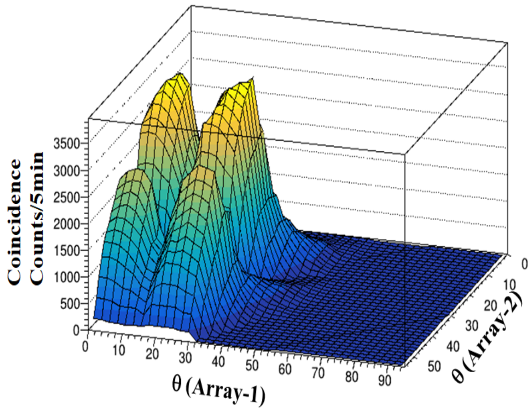

FIG. 2: Simulated coincidence plot for the chosen reaction. z-axis shows the coincidence counte whereas x and y-axis show polar θ for Array-1 and Array-2 respectively

are presented. The reaction chosen was the breakup of ^{12}C into three α particles via Hoyle state populated by inelastic scattering by the ^{12}C beam; $^{12}\text{C} + {}^{12}\text{C} \rightarrow \alpha{+}\alpha{+}\alpha{+}^{12}\text{C}$. 57 MeV of α beam energy was chosen for the simulation. The cross-section of the above reaction channel was taken from Szilner *et al.*[1], which the event generator follows for event generation. The rest of the code simulates the reaction; outgoing fragments are checked for coincident detection; and a counter is used to track successful detections. The detector configuration, as shown in Fig. 1 was considered for simulation in which the detectors are double-sided silicon strip detectors (DSSD) (50mm×50mm). 4π integrated Hoyle events resulting from 300 seconds of 60 nA ^{12}C beam was chosen for the simulation. A plot for the maximum coincidence count is shown in Fig. 2 and it shows that, not all placements for the detectors are suitable. We see that for the given reaction at the given beam energy, maximum coicidence counts are achieved when Array-1 and Array-2 are placed around +30° and -30°, respectively. Different detector configurations were simulated to find maximum coincidence counts as shown in Fig. 3. It shows how, by altering the geometry, we can achieve maximum coincidence counts. Thus, depending on other experimental constraints, a suitable configuration can be chosen.

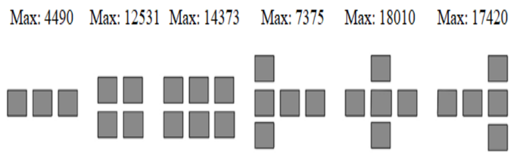

FIG. 3: Different detector configurations and corresponding maximum counts

Using the Monte-Carlo breakup simulation code, we were able to identify a suitable detector configuration for the chosen reaction, which we also plan to perform in the near future. We presented a simulation for three-body breakup from the Hoyle state, but our code can be used for two-body and four-body breakup reactions as well. Such simulations to find an optimum detector geometry is extremely important before carrying out any experiment to measure breakup cross sections.

References

[1] S. Szilner *et. al.*, Phys. Rev. C, 55, 1312 (1997)

[2] A. Baishya, GitHub (2022), github.com/abhijitb498/random