Neutron cross-talk in modular detector arrays

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Introduction

Neutron Time of Flight spectrometers have been extensively used since early eighties to study the fusion-fission dynamics in heavy ion induced nuclear reactions[1]. The disentanglement of time scales of quasi-fission from fusion fission reactions from the shape of the pre-scission neutron multiplicity distribution has added a new dimension to our understanding on reaction dynamics[2]. Measurement of one-fold neutrons in coincidence with fission fragments only allows the extraction of average neutron-multiplicity which can be decomposed into pre- and post-scission components from the angle and energy correlation with fission fragments. The measurements of neutron fold distribution in coincidence with fission fragments is necessary to obtain the width and other higher moments of these distributions. The accuracy of the measurement of the shape of these distributions is determined by the statistical uncertainties of the higher fold distributions. Therefore a neutron time of flight spectrometer with very high efficiency and good granularity is required to carry out studies in the field of fusion-fission dynamics where co-existence of different reaction mechanisms differing by the composite system life time or the evolution path followed by the fissioning system is possible.

It is important to note that as we go for a high efficiency modular detector system cross talk between neighboring detectors increases considerably. Cross talk occurs when a particle that is detected in a detector is subsequently detected in the neighboring detector/detectors. In this paper, an algorithm is proposed to infer the degree and type of neutron cross talk between detectors that are placed side by side. The detection of high fold events relies on the ability to disentangle real neutron-neutron coincidences from those resulting from the scattering of one neutron through two (or more) detectors, i.e. cross-talk, which in the case of low neutron multiplicity cases becomes extremely important. In this context, it is desirable to minimize the amount of false coincidences given by neutron cross talk. Different methods have already been developed to identify and reject cross-talk by taking into account the kinematical and geometrical considerations[3,4].

Neutron Crosstalk

While designing the geometry of a modular detector array care should be taken to keep the detector spacing optimum for the range of neutron energy detected. The neutron spectrum from heavy ion induced reactions at near barrier energies is well-known, and it can be approximated to good accuracy by a Maxwellian form peaking around 2-3 MeV and maximum energy roughly touching 10MeV. Considering these facts, the support structure under consideration for the upcoming modular neutron array at IUAC is a geodesic dome of frequency 4 with a radius of 1 meter. The detectors can be arranged in such a structure with the neighbouring detectors subtending an arc of ~15^o, corresponding to a distance of ~25 cm.

A Monte-Carlo simulation has been carried out using GEANT3[5] and FLUKA[6] to study the cross talk probability in the proposed array for a heavy ion induced fusion-fission reaction experiment at near barrier energy. The results are compared with the Monte Carlo simulation of the cross talk data reported for DeMoN array[7]. The cross talk rate observed in the recent experiment carried out to measure the average neutron multiplicity in ^{212,214}Rn [8] using the existing 24 detector array at IUAC also matches with the simulation results.

The preliminary results indicate that the cross talk contribution in singles is ~0.1% for the proposed detector geometry. Based on that, for two fold coincidences (for systems with $<\nu_n^{pre}>= 3$) less than 10% of the events would arise from cross-talk. The simple way of minimizing the possible cross talk events can be done by using a software algorithm for the suppression of events from the first neighbour detectors (each detector within the proposed geodesic dome structure has 5-6 first neighbours). Such an algorithm does not considerably affect the genuine neutron-neutron coincidence rate. However, as the neutron emission is isotropic in the types of reactions we are interested in, the possibility of two neutrons generated in the same event hitting the neighbouring detectors is not negligible. Therefore we propose here a more detailed algorithm by considering the light out put produced by the recoiling charged particle.

Details of Algorithm

The data obtained from individual neutron detector consists of ;

(1) Neutron Time of Flight from the target,T
(2) Pulse height of the light output produced by the recoiling charged particle,L
(3) Pulse shape distribution,P

A simultaneous analysis of all these three parameters in the experimental data set, $D(T,L,P)$ can be utilized to identify the cross talk events. Knowing the response matrix $M(E,T,L,P)$ of the detector, incident neutron energy(E) can be calculated. It has been observed that the pulse shape distribution is a function of incident neutron energy (there by time of flight information) and the energy lost by the incident neutron in the detector medium (which in turn is the amplitude of the light out put) at a given energy threshold. $P(E,L)$ has a normal distribution which can be obtained by the characterization of the detector for its pulse shape discrimination property.

For cross talk identification we consider that neutron is getting scattered by i^{th} detector and falling on the neighboring j^{th} detector. The algorithm to identify cross talk events is based on the following conditions.

1) $L_j < L_{max}(E_j)$
2) $P_{min}(E_j,L_j) < P_j < P_{max}(E_j,L_j)$

If either of the above conditions is not satisfied the event will be considered as a cross talk event (in the second condition *FWHM* of $P(E,L)$ obtained from the detector characterization puts the maximum and minimum limits). An additional verification of $E_i^{out} > L_j$ is imposed on the second condition to minimize the ambiguity. Here E_i^{out} is calculated by assuming single interaction of neutron in the i^{th} detector. The above mentioned conditions are validated by the geometrical limits (like maximum and minimum scattering angle possible) considering neutron getting scattered off the proton present in the scintillator. The major limitation of the algorithm comes from the fact that neutron interaction in organic scintillator is complex in nature and n-p scattering is not the only reaction channel even though it is the prominent one. The performance of the algorithm is to be demonstrated using simulations employing Monte-Carlo codes GEANT3 and FLUKA.

Conclusions

With the aim of detecting high fold neutrons in reactions having low multiplicities we have studied the effect of cross talk in a modular detector system in a closed geometry retaining a relatively high detection efficiency. The proposed algorithm to identify cross talk events make use of the available experimental observables from a TOF spectrometer. A proper calibration of the detection system for its energy response matrix M, as a function of T,P and L is required to correlate the occurrence of cross talk events with the experimental observables. The reliability of the algorithm is verified using the experimental data of ref[8] .

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