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The NArCoS Project: efficiency estimation and the cross talk problem studied through Monte Carlo simulations

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With the advent of the new radioactive beam facilities it is necessary to develop neutron detection systems integrated with charged particle ones. The integration of the neutron signal, especially in using neutron rich beams, becomes a mandatory requirement in order to study the property of the nuclear matter in extreme conditions. For this reason new detectors using new materials have to be built. In this contribution, some new results about the efficiency estimation and the cross talk problem studied through GEANT4 simulations, related to the NArCoS project, will be described with the aim to design a new detector of both good energy and angular resolution. The detection of neutrons and charged particles in the same elementary detection cell is envisaged.

1. Introduction

The study of the dynamical evolution of a heavy ion collision at the Fermi energy is an active area of the present-day in both nuclear reaction and nuclear structure research. One of the most important issues is to probe the full time scale of the heavy ion reactions (from prompt emission, 10-50 fm/c, to sequential decays, several hundreds of fm/c) and the spatial shape configuration of short mean-life sources involved in the reaction process: their formation and decay. It is of great interest for nuclear studies to contain transport theory [1] and reaction models by experimental determination of quantities sensitive to the isospin degree of freedom and its influence on the evolutionary phase of a nuclear reaction at medium energies. Among the most powerful experimental methods, aimed to pin-down the time scale of the early phase of the collision, the two (and multi)-particle intensity interferometry (HBT-Effect) of neutrons and charged particles is an important technique to reach those purposes. Many works, both from the experimental and theoretical sides have been done in the field of light charged particles (LCP), e.g., for like-particles correlations with p- p, d-d, … systems as well as un-like particles, d-t, d-alpha, etc… systems. Also, some works [2,3] using heavier charged particles of intermediate mass fragments (IMF) of typical values of atomic number in the range: $3 \leq Z \leq 25$ have been accomplished. In contrast, few investigations have been reported by including uncharged particles in the main trigger and in particular for n-n, n-p, and n- IMF correlations [4,5]. In and any of two (or multiple) particles (HBT) correlation studies, it is crucial to preserve good relative linear momentum resolution (in both intensity and detection angle) in order to extract sufficiently accurate experimental information (with respect to typical characteristics of the nuclear matter, e.g., typical nuclear sizes of 5-10 Fermi, Fermi motion at normal density, etc.).

In brief, we will present a preliminary research proposal aimed at developing a first prototype of multi-element plastic-scintillator array, NArCoS (Neutron Array for Correlation Studies), integrating 16 detection modules by assembling 64 elementary detraction cells, able to detect neutrons in coincidence with LCPs and IMFs with both good angular and energy resolution, by supporting reasonable efficiency. One candidate that is suggested for this purpose is an array of plastic scintillators EJ-276 (ex-EJ-299-33) [6,7,8,9]. Particular emphasis will be devoted to the cross talk problem that is a crucial problem in coincidence measurements.

2. The project and the cross talk problem

2.1 Description

Our final goal is to construct a modular and versatile multi-detector array (NArCoS) in order to measure at the same time neutrons and charged particles with both high angular and energy resolution. The candidate for the elementary cell is a cube of 3x3x3 cm^3 of dimension of the plastic scintillator EJ276 (ex EJ299-33). Four consecutively assembled cells allow to achieve a segmented cluster having dimension of 3x3x12 cm^3. The surface size and total thickness of the cluster have been fixed in order to match with the angular resolution required for correlation studies ($\approx 1°$) and a reasonable neutron efficiency at the Fermi energy, where the maximum of the proton kinetic energy is expected to be less than 200 MeV. In particular, the estimation neutron detection efficiency, based on the software generator GEANT4 shows a mean value $\approx$ 9% for one detection cell and $\approx$ 25% for one cluster (irradiated by a point-like source at reasonable energy threshold). The Fig. 1. shows the efficiency simulation results, for one elementary cell (left side, Figure 1.) and for one cluster (right panel, Figure 2.) for incident neutron energy between 5 and 50 MeV (5 MeV steps) and by considering different energy threshold values. For previous studies (see below), we assume that the most likely identification threshold value is 1.5 MeV.

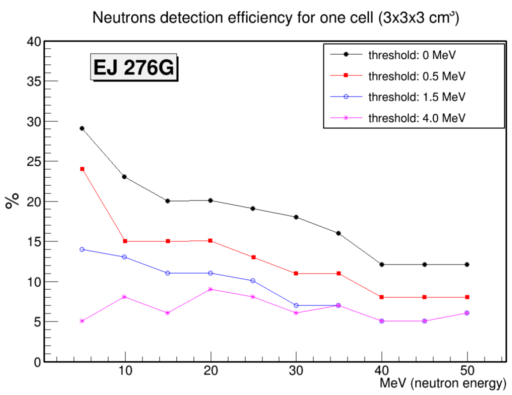

Figure. 1. GEANT4 efficiency simulations for one elementary cell. The lines represent different considered threshold values 10]

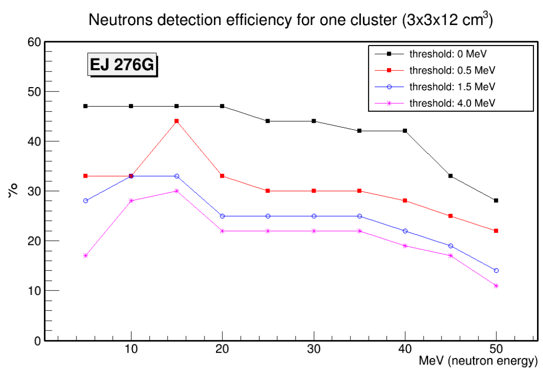

Figure. 2. GEANT4 efficiency simulations for one cluster. The lines represent different considered threshold values [10]

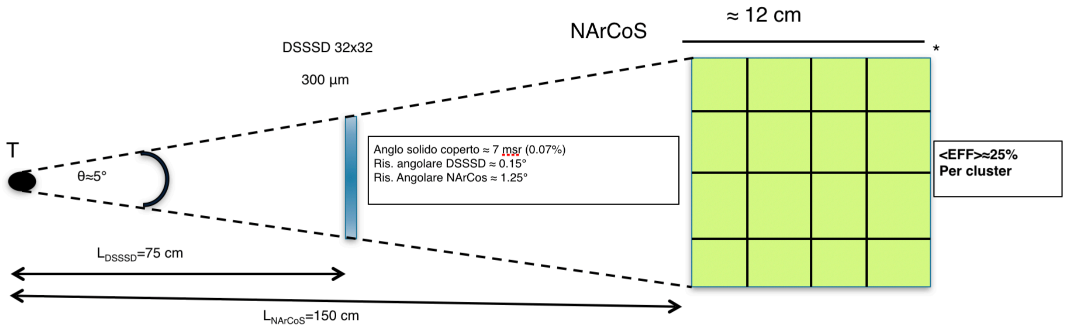

Figure 3. Schematic view of the NarCos prototype coupled with the DSSSD with the indication of the adopted geometrical configuration from the target source[8,10].

Since the EJ276 plastic scintillator is able to discriminate neutron, gamma and charged particles [6] we plan to use a Double Sided Silicon Strip Detector (DSSSD) of 300 μm of thickness, with 32 vertical strips in the front side and 32 horizontal strips in the back side, acting as veto detector in order to distinguish primary neutrons against primary protons or other primary light charged particles. The DSSSD, placed at a distance of 75 cm from the target, (see Figure 3) will geometrically fit with the full surface coverage of the wall of the plastic scintillators, as it is shown in Figure 3. More geometrical details have been discussed in the ref [10].

2.2 The cross talk problem

In coincidence measurements one of the biggest issue is represented by the cross talk problem. This problem could affect the measurement of more than one of the interested particles. In the specific case of a neutron correlator, made by many elementary detection cells, it may occur in different ways. For instance, a neutron can interact sequentially with two or more elementary cells. In a typical plastic material, one of the most probably interaction is the elastic scattering with a Hydrogen nucleus, so that the so called proton recoil, interacting with the plastic scintillator produces scintillation photons. There is a probability that the scattered neutron, continuing its path in another elementary cell, could interact with another Hydrogen nucleus, and consequently it generate a second detectable proton recoil nucleus. Of course, in order to be efficiently detected, both the two recoiling protons (the primary and the second one) must have enough energy to overcome the threshold value in the deposit energy in order to produce sufficient scintillation light to be seen by the photon-electron transducer (e.g. Silicon Photo-Diode). It is clear that this kind of cross talk can occur either in two adjacent or separate-in space elementary cells. Another case of cross talk can occur for instance when, after the first elastic scattering the recoil nucleus has enough energy to share its energy between two adjacent cells (punching through effect). In Figure 4 a preliminary study of the cross talk probability for the case of only one cluster (four consecutively elementary cells) by means of the GEANT4 simulation software is shown. No pile-up due to the re-scattering by environments (see below) are considered. The red line represents the cross talk probability for neutron from 5 MeV to 50 MeV (5 MeV steps). The detection threshold is assumed to be 1.5 MeV. This probability increases slowly from about 1% at 5 MeV up to 9% at 50 MeV, of neutron kinetic energy. In the cross talk probability there is the integration of all the possible cross talk events simulated by the software. The blue line, is the complementary set, i.e., the probability of good events. The two probabilities are calculated taking into account the detection efficiency in the plastic scintillator (green line). The next step will be to estimate the cross talk probability extending the number of clusters up to the final configuration. The final and more difficult step is to try to disentangle between a good event and a bad event (cross talk events plus pile-up). In the past,

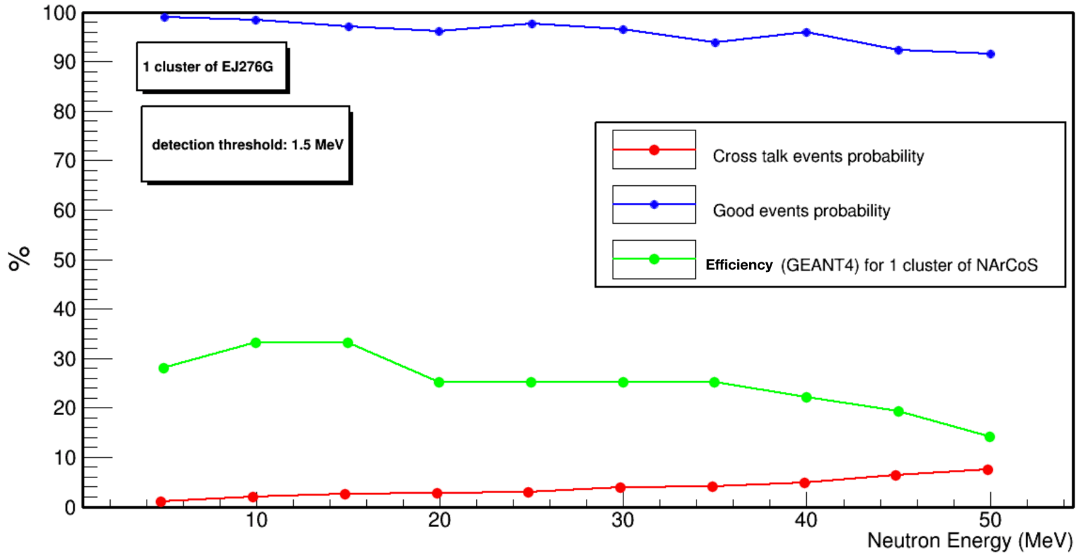

Figure 4. GEANT4 simulated cross talk probability (red line), good events probability (blu line) and efficiency (red line) for detail see text.

with different detection system N. Colonna et al. [11] studied the influence of the cross talk in a real coincident measurement and published a complex methodology to try to separate good events from bad events [11].

Another issue is represented to the background treatment and subtraction. The background is a different problem with the respect to the intrinsic cross talk because it is caused by neutrons that can be re-scattered from the environment (scattering chamber and/or other detector systems). In this case, the possible coincident event (within the resolving time of the coincident system) is seen like a real neutron-neutron event coming from the induced nuclear reaction induced by the beam projectile on the target nuclei.

3. Conclusion

In conclusion in this paper we briefly described a preliminary project aimed to build a neutron correlator able to detect also charged particles. The results carried out so far by exploiting capability of EJ276 scintillator coupled by PM are encouraging. It seems possible to build a versatile and modular detector for neutrons and light charged particles with good angular and energy resolution, read by using, beside the PMs and analogic read-out, silicon technology (Photo Diode-PD or, alternatively, Silicon Photo-multiplier-SIMP) and signal digitalization. The studies of the background and of the cross-talk problems and theirs influence on the experimental results are in progress using the GEANT4 software and by performing further experimental tests. Also, the studies on the timing properties of the EJ-276 green shifted version, performed by using silicon technology (PD, or SiMP) are going on.

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