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Study of the cross-talk probability by using Geant4 simulations for the neutron correlator NArCoS

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Summary. — The NArCoS project aims to develop a novel detection system for simultaneously identifying neutrons and light-charged particles with high angular and energy resolution. This system uses advanced EJ-276G plastic scintillators and SiPM photosensors as the core detection units in a segmented multidetector. In this study, we analyzed simulated data of two geometric configurations using the GEANT4 toolkit to assess cross-talk probability in relation to neutron energy and detection threshold. This research served as a preliminary step for the CROSSTEST experiment.

1. – Introduction

In heavy ion collisions at Fermi energy, measuring particle-particle relative energy or linear momentum correlations helps distinguish between prompt (<100 fm/c) and sequential reactions ($\simeq$1000 fm/c) [1-4]. While many studies focus on correlations of light charged particles (LCPs) and intermediate mass fragments (IMFs) [5, 6], fewer investigate neutron-neutron, neutron-proton, and neutron-IMFs correlations [6-8]. Recent research highlights the accuracy of plastic scintillator EJ-276G, produced by Eljen Technologies [9], for pulse shape analysis [10] and its use in heavy ion reactions [11], achieving sub-nanosecond timing resolution with SiPM arrays [12]. The NArCoS project (Neutron Array for Correlation Studies) aims to develop a detector for high-resolution neutron and light charged particle detection in the energy range of 10 AMeV to 100 AMeV [13]. The elementary cell detection is a cube of $3 \times 3 \times 3\,\mathrm{cm}^3$ of EJ276-G fast plastic scintillator coupled with a SiPM matrix housed on a PCB board. This hodoscope will function alone or with high-granularity 4π-detectors like CHIMERA [2,14] or FARCOS [15] at Laboratori Nazionali del Sud in Catania. The need for effective neutron and charged particle detection is driven by new radioactive ion beam facilities (RIBs), such as FRAISE at INFN-LNS [16], SPES at Laboratori Nazionali di Legnaro (LNL) [17], and FAIR at GSI Darmstadt [18], where the NeuLAND [19] neutron detector is being assembled.

2. – Cross-talk simulation results

The cross-talk effect, a known issue in neutron detection experiments from few to tens of MeV [7], arises from neutrons interacting in multiple detection cells and from gamma rays and neutrons re-scattered from surrounding structures. This background generates false signals, distorting neutron multiplicity and simulating unreal reaction events. A preliminary GEANT4 [20] simulation of a four-cell cluster showed cross-talk probability increasing from about 1% at 5 MeV to 9% at 50 MeV neutrons [13]. A more recent study investigated two geometric configurations of the elementary cell: the matrix configuration and the three-cluster configuration (see fig. 1). Reasonable cross-talk probabilities (2–4%) were observed with detection thresholds of 1 and 1.5 MeV, even for higher energy neutrons (up to 10 MeV). Efficiency values were estimated to be over 10% for the matrix configuration and over 30% for the three-cluster configuration with the same detection thresholds (0, 0.5, 1.0, 1.5 MeV) for higher energy neutrons (10 MeV) [21].

The study of the matrix configuration (see left panel in fig. 1) evaluated cross-talk (CT) contributions along the x and y directions. The overall cross-talk is mainly due to the double-hit cross-talk DH(1-i) from the central cell ID = 1 to another cell i with $i = 2, \ldots, 9$. Other combinations like DH(i-j) ($i \neq j, j = 2, \ldots, 9$) not involving cell ID = 1, triple-hit cross-talk TH(1-i-j), and others are negligible (fig. 2(a), (b)). Significant contributions to DH cross-talk come from CT 1-3, CT 1-5, CT 1-7, and CT 1-9, with smaller contributions from CT 1-2, CT 1-4, CT 1-6, and CT 1-8 due to geometrical reasons (fig. 2(c), (d)).

The study of the three-cluster configuration (see right panel in fig. 1) evaluates cross-talk contributions along the z direction. The overall cross-talk consists of two main contributions: DH (1-i) from cell ID = 1 and DH (i-j) not involving cell ID = 1, with

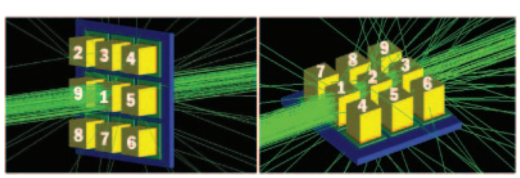

Fig. 1. – Simulation of the neutron flux (green tracks) on the matrix configuration (left) and the three-cluster configuration (right). The white numbers represent the IDs assigned to each elementary cell.

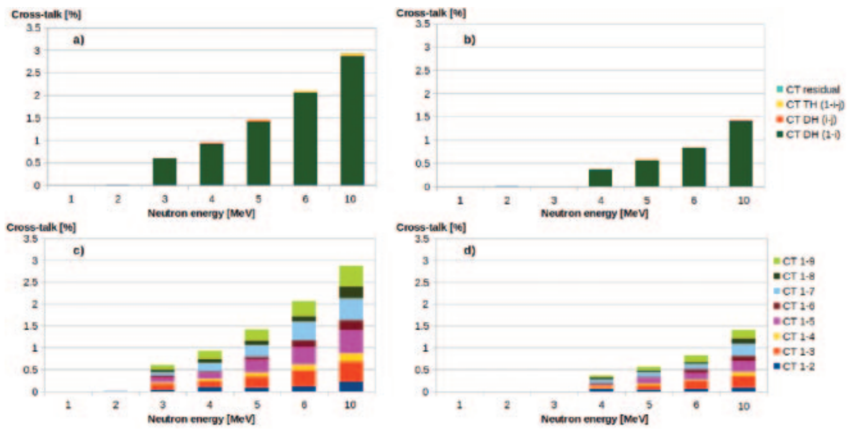

Fig. 2. – Cross-talk contributions as a function of the neutron energy for the matrix configuration with cell detection threshold of 1 MeV (a) and 1.5 MeV (b). Corresponding double-hit cross-talk contributions from cell ID = 1 to another cell ((c), (d)).

other combinations being negligible (fig. 3(a), (b)). DH (1-i) is primarily due to CT 1-2, CT 1-5, and CT 1-8 (fig. 3(c), (d)), while DH (i-j) is mainly due to cross-talk from cell ID = 2 to others, specifically CT 2-3, CT 2-6, and CT 2-9 (fig. 3(e), (f)). Other DH combinations are less than 0.4% and 0.3% for detection thresholds of 1 MeV and 1.5 MeV, respectively.

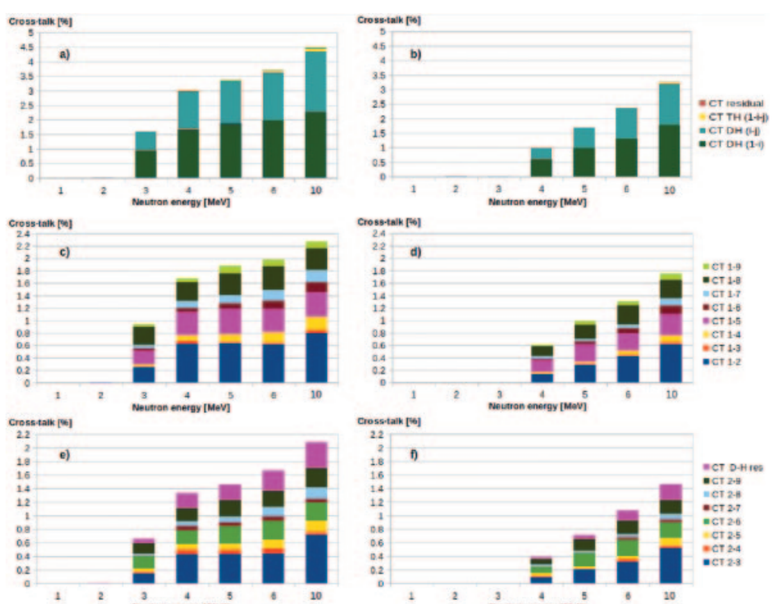

Fig. 3. – Cross-talk contributions as a function of the neutron energy for the three-cluster configuration for cell detection threshold of 1 MeV (a) and 1.5 MeV (b). Corresponding double-hit cross-talk contributions from cell ID = 1 ((c), (d)) and not involving cell ID = 1 ((e), (f)).

3. – Conclusion

In this study, we simulated and analyzed GEANT4 data to investigate the cross-talk probability for two different detection configurations of the NArCoS detector. In the matrix configuration, the main cross-talk contribution comes from double-hit interactions between the central cell ID = 1 and its neighboring cells. In the three-cluster configuration, significant cross-talk contributions include double-hit interactions from cell ID = 1 to cell ID = 2 and from cell ID = 2 to cell ID = 3. These configurations were experimentally tested in the CROSSTEST experiment in November 2023 at LNL using a 9-cell prototype. The analysis of these data is still in progress.

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