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Geant4 simulations for the cross-talk probability contributions in the new correlator NArCoS

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Summary. — The target of the ANCHISE project is the development of a new detection system able to detect with high angular and energy resolution neutrons and light-charged particles at the same time. The idea is to use the new-generation of plastic scintillators EJ276-G coupled with a SiPM photosensor as the elementary detection cell of a segmented multidetector. In the present contribution, we analyzed the data obtained simulating two geometrical configurations of the elementary cell with the GEANT4 toolkit, in order to study the cross-talk probability as a function of the incident neutron energy and of the detection threshold. The present study was preparatory for the CROSSTEST experiment.

1. – Introduction

In heavy ion collisions at Fermi energy, particle-particle relative energy (or linear momentum) correlation measurement is a valid experimental data analysis tool in order to distinguish between prompt ($<$100 fm/c) and sequential reactions ($\simeq$1000 fm/c) [1-6]. Many experimental and theoretical works focused on correlations of light charged particles (LCPs) and intermediate mass fragments (IMFs) [5,7,8], while only few investigations have been reported for n-n, n-p, and n-IMF correlations [8-10]. Recent papers show the accuracy of the plastic scintillator EJ-276, produced by Eljen Technologies [11], in terms of the discriminating power using pulse shape analysis with radioactive sources [12], and in reactions induced by heavy ions [13]. Sub-nanosecond timing resolution can be achieved by using a new generation of compact SiPM arrays directly coupled with the scintillator [14]. The NArCoS project (Neutron Array for Correlation Studies) purpose is to develop a new detector able to detect neutrons and light charged particles with high angular and energy resolutions [15-17]. The hodoscope will detect neutrons in nuclear reactions in the energy range between 10 AMeV $\leq$ E/A $\leq$ 100 AMeV, from light to heavy ion collisions, and it will work in a stand-alone mode or coupled with high-granularity 4π-detector systems like CHIMERA [2, 18] or other light charged particle correlators like FARCOS [19, 20] at Laboratori Nazionali Sud in Catania (LNS). Proper detection of neutrons and charged particles is motivated by the recent efforts to construct new facilities for radioactive ion beams (RIBs) worldwide like, for example, FRAISE at INFN-LNS [21, 22], SPES at Laboratori Nazionali di Legnaro (LNL) [23] and FAIR at GSI Darmstadt [24]. In particular at GSI, the assembly of NeuLAND [25], a large area neutron detector designed for the physics program proposed for the R^{3}B facility, will be completed soon.

2. – Cross-talk and efficiency simulation results

The cross-talk effect is a predictable phenomenon in experiments aimed at neutron detection [9] from low energy to several tens of MeV. It comes from neutrons interacting in two or more detection cells and from gammas and neutrons re-scattered from the wall and environmental structure. This background generates spurious signals that simulate unreal reaction events with a distorted neutron multiplicity. A preliminary study, performed by simulating through the GEANT4 toolkit [26] a cluster of four elementary cells, shows that the cross-talk probability increases slowly from about 1% for 5 MeV up to 9% for 50 MeV neutrons [17]. In a more recent paper [27] two different geometrical configurations of the elementary cell were investigated: the matrix configuration and the three-cluster configuration. A flux of 10^5 neutrons impinging on the central cell of the considered configuration was simulated, as shown in fig. 1. Details about the simulation parameters and the detector configurations can be found in ref. [27]. Reasonable values of the cross-talk probability (2-4%) were found for both geometrical configurations with detection thresholds of 1 and 1.5 MeV even for higher energy neutrons that represent the worst case scenario. Efficiency values larger than 10% for the matrix configuration and larger than 30% for the three-cluster configuration were estimated with detection thresholds of 1 and 1.5 MeV for higher energy neutrons [27].

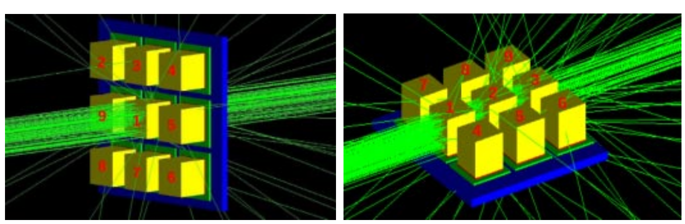

Fig. 1. – Simulation of the neutron flux (green tracks) on the matrix configuration (left) and the three-cluster configuration (right). The red numbers represent the IDs assigned to each elementary cell in order to uniquely identify the one of interest for both studied configurations.

3. – Cross-talk contributions in the matrix configuration

The study of the matrix configuration (see left panel of fig. 1) allows the evaluation of the cross-talk contributions along the x and y directions. The overall cross-talk is basically given by the double-hit cross-talk DH(1-i) from the central cell ID=1. Other possible cross-talk combinations, like double cross-talk DH(i-j) not involving the cell ID=1, triple-hit cross-talk TH(1-i-j) or other possible combinations are negligible, as shown in fig. 2(a), (b). Figure 2(c), (d) shows that four considerable contributions, with very similar yields, to the double-hit cross-talk, are the cross-talks CT 1-3, CT 1-5, CT 1-7, CT 1-9 (from the central cell ID=1 to cells ID=3, 5, 7, 9); smaller contributions come from CT 1-2, CT 1-4, CT 1-6, CT 1-8, for simple geometrical reasons.

4. – Cross-talk contributions in the three-cluster configuration

The study of this configuration allows the evaluation of the cross-talk contributions along the z direction (neutron flux direction that simulates the neutron flight direction). Figure 3(a), (b) shows that the overall cross-talk is given by two principal contributions: the double-hit cross-talk (DH 1-i) from cell ID=1 (see right panel in fig. 1), and the double-hit cross-talk (DH i-j) not involving cell ID=1. Other possible cross-talk combinations are negligible. The double-hit cross-talk (DH 1-i) from cell ID=1 is mainly due to the cross-talk CT 1-2, CT 1-5 and CT 1-8, as shown in fig. 3(c), (d); smaller or negligible contributions come from other cells. The larger contribution to the double-hit cross-talk (DH i-j) from cell i to cell j is the cross-talk (DH 2-i) from cell ID=2 to other cells. Figure 3(e), (f) shows that the cross-talks CT 2-3, CT 2-6 and CT 2-9 are the significant contributions to the double-hit cross-talk from cell ID=2. Other double-hit cross-talk combinations (CT DH-res) are smaller than 0.4 % and 0.3 % for cell detection threshold of 1 MeV and 1.5 MeV.

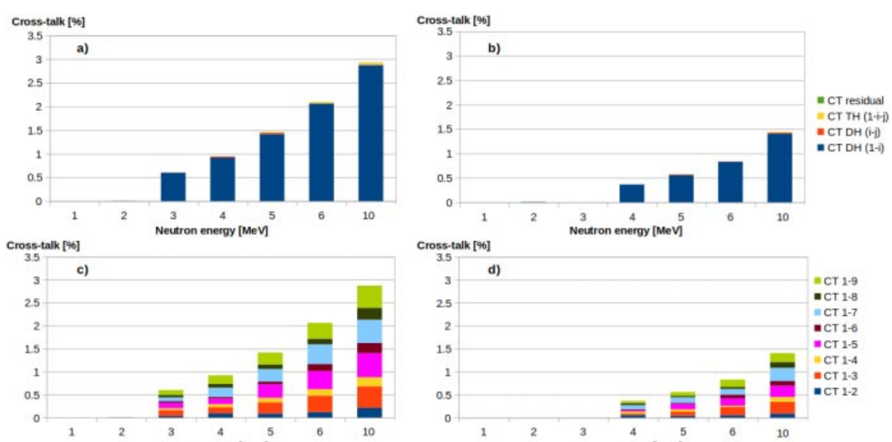

Fig. 2. – Cross-talk contributions percentage values as a function of the neutron energy for the matrix configuration with cell detection threshold of 1 MeV (a) and 1.5 MeV (b). Corresponding double-hit cross-talk contributions from cell ID=1 to another cell ((c),(d)).

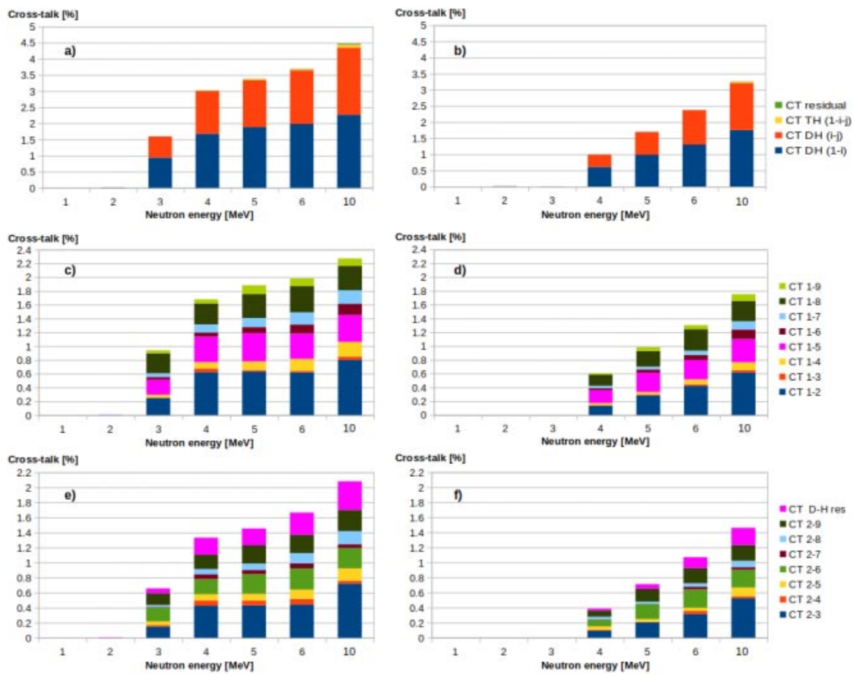

Fig. 3. – Cross-talk contributions percentage values as a function of the neutron energy for the three-cluster configuration for cell detection threshold of 1 MeV (a) and 1.5 MeV (b). Corresponding double-hit cross-talk contributions from cell ID=1 ((c),(d)) and not involving cell ID=1 ((e),(f)).

5. – Conclusion

In this work we simulated with GEANT4 a single module prototype of NArCoS made by 9 elementary adjacent cells in order to investigate the cross-talk probability for two different detection configurations of the elementary cell. In the matrix configuration the principal contribution to the overall cross-talk is given by the double-hit cross-talk from the central cell ID=1 to the cells above, on the right, under and on the left with respect to the central one. In the three-cluster configuration the major contributions to the overall cross-talk are the double-hit cross-talk from the cell ID=1 and the double-hit cross-talk not involving cell ID=1; for the first, the bigger contribution is given by the cross-talk from cell ID=1 to cell ID=2; the second is mostly due to the cross-talk from cell ID=2 to cell ID=3. In the next future the final prototype of 64 elementary cells will be simulated and the efficiency and cross-talk probability will be evaluated. The two configurations of the elementary cell here investigated were experimentally studied in the CROSSTEST experiment, performed in Novembre 2023 at LNL, in which a prototype made by 9 elementary cells was tested.

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REFERENCES

[1] Van Driel J. *et al.*, *Phys. Lett. B*, **98** (1981) 351.
[2] Pagano A. *et al.*, *Eur. Phys. J. A*, **56** (2020) 102.
[3] Russotto P. *et al.*, *Phys. Rev. C*, **91** (2015) 014610.
[4] Pirrone S. *et al.*, *Eur. Phys. J. A*, **55** (2019) 22.
[5] Russotto P. *et al.*, *Eur. Phys. J. A*, **56** (2020) 12.
[6] Verde G. *et al.*, *Phys. Rev. C*, **67** (2003) 034606.
[7] Bauer W. *et al.*, *Annu. Rev. Nucl. Part. Sci.*, **42** (1992) 77
[8] Pagano E. V. *et al.*, *J. Phys.: Conf. Ser.*, **1014** (2018) 012011.
[9] Colonna N. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **381** (1996) 472.
[10] Ghetti R. *et al.*, *Phys. Rev. Lett.*, **87** (2001) 102701.
[11] Eljentechnology, *Pulse shape discrimination EJ-276D and EJ-276G*, https://eljentechnology.com/products/plastic-scintillators/ej-276D.
[12] Pagano E. V. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **889** (2018) 83.
[13] Pagano E. V. *et al.*, *Nucl. Instrum. Methods Phys. Res. A*, **905** (2018) 47.
[14] Taggart M. *et al.*., *J. Phys.: Conf. Ser.*, **763** (2016) 012007.
[15] Pagano E. V. *et al.*, *Nuovo Cimento C*, **41** (2018) 181.
[16] Pagano E. V. *et al.*, *Nuovo Cimento C*, **43** (2020) 12.
[17] Pagano E. V. *et al.*, *J. Phys.: Conf. Ser.*, **1643** (2020) 012037.
[18] De Filippo E and Pagano A. *et al.*, *Eur. Phys. J. A*, **50** (2014) 32.
[19] Pagano E. V. *et al.*, *EPJ Web of Conferences*, **117** (2016) 10008.
[20] Acosta L. *et al.*, *J. Phys.: Conf. Ser.*, **730** (2016) 012001.
[21] Russotto P. *et al.*, *J. Phys.: Conf. Ser.*, **1014** (2018) 012016.
[22] Martorana N. S. *et al.*, *Front. Phys.*, **10** (2022) 1058419.
[23] Marchi T. *et al.*, *J. Phys.: Conf. Ser.*, **1643** (2020) 012036.
[24] https://www.gsi.de/en/researchaccelerators/fair.
[25] Boretzky *et al.*., *Nucl. Instrum. Methods Phys. Res. A*, **1014** (2021) 165701.
[26] Allison J. *et al.*., *Nucl. Instrum. Methods Phys. Res. A*, **835** (2016) 186.
[27] Santagati G. and Pagano E. V. *et al.*, to be published in *RAD Conference 2023 Proceedings*.