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The NArCoS Project: the latest results

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With the advent of new facilities for radioactive ion beams 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, related to the NArCoS preliminary proposal, 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.

KEYWORDS: Plastic scintillator, γ and neutron discrimination, digitalization

1. Introduction

The study of the dynamical evolution of a heavy ion collision at Fermi energy is an active area of the present-day in both nuclear reaction and structure researches. One of the most important issues is to probe the full time scale of the heavy ion reaction (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. Among the most powerful experimental methods, 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) correlations with e.g., light like particles p-p, d-d, … systems as well as un-like particles, d-t, d-alpha, etc… systems. Also, some works [1,2] 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 [3]. In and any of two (or multiple) particles (HBT) correlation studies, it is crucial to preserve good relative linear momentum resolution i.e., $\delta\mathbf{p} \approx 5$ MeV/c (in both intensity and detection angle) in order to extract sufficiently accurate experimental information (with respect to typical characteristics of the nuclear

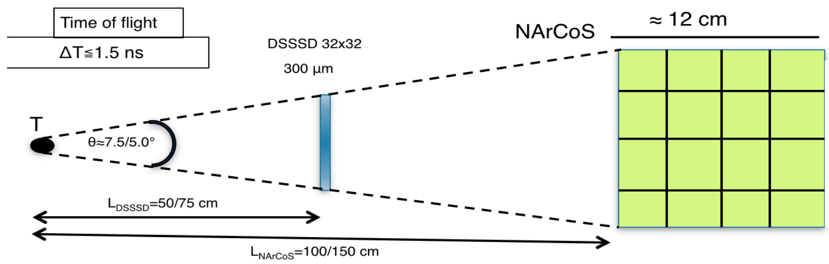

Fig. 2. Schematic view of the NArCoS prototype coupled with the DSSSD with the indication of the adopted geometrical configuration from the target source[6].

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 (16 detection modules by assembling 64 elementary detection 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) [4,5,6,7].

2. The project and the latest results

2.1 Description

Our final goal is to construct a modular and versatile multi-detector in order to measure at the same time neutrons and charged particles with both high angular and energy resolution, NArCoS (Neutron Array for Correlation Studies). 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 one segmented single 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 require for correlation studies (≈ 1°) and reasonable neutron efficiency at the Fermi energy, where the maximum of the neutron/proton kinetic energy is expected less than 200 MeV.

The estimation neutron detection efficiency, based on the software generator GEANT4 (using the QGSP_BIC_HP library for the interaction between neutron and the

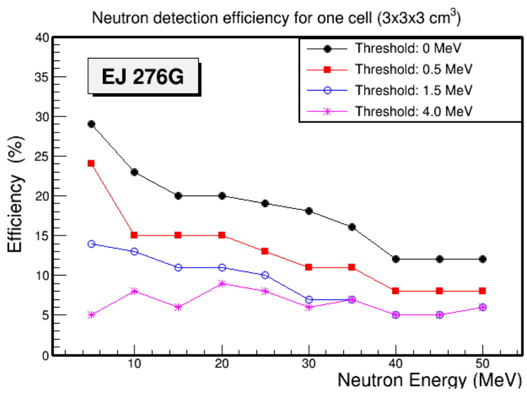

Fig. 1a. GEANT4 efficiency simulations for one elementary cell. The lines represent different considered threshold values

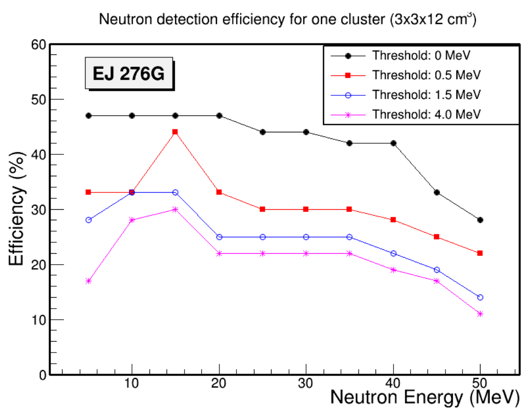

Fig. 1b. GEANT4 efficiency simulations for one cluster. The lines represent different considered threshold values

scintillator) shows a mean value ≈ 9% for one detection cell and ≈ 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, 1a) and for one cluster (right panel, 1b) for incident neutron energy between 5 and 50 MeV (5 MeV steps) and by considering different energy threshold values.

Since the EJ276 plastic scintillator is able to discriminate neutron, γ and charged particles (see next subchapter) [4] we plan to use a Double Sided Silicon Strip Detector (DSSSD) of 300 μm of thickness as veto detector in order to distinguish primary neutrons against primary protons or other light charged particles. The DSSSD (placed at some distance, see Fig.2) will geometrically fit with the full surface of the wall of the plastic scintillators, as it is shown in Fig. 2.

2.2 Experimental results on EJ299-33

The EJ299-33 plastic scintillator cell has been tested both in low-background condition [4] and high-background conditions [6]. In the first case the plastic γ-neutron pulse shape discrimination (PSD) capabilities were tested by using ^{60}Co γ-source, ^{241}Am and ^{228}Th α-sources and AmBe source for neutron and γ. The EJ 299-33 scintillator was optically coupled to a quartz window photomultiplier tube (PMT) 9514B manufactured by EMI operated at a bias of 1.7 KV. A good linearity in the energy calibration [4,6] was achieved. The output signal from the PMT detector was digitized by GET (General Electronics for TPC) electronics [8], using a sampling frequency of 100 MHz. The result obtained for the PSD capability of the scintillator is shown in Fig. 3 in the case of Thorium and AmBe sources. In Fig. 3 the Fast and Slow component are given by the integration of the first 100 ns and a portion of 400 ns (excluding the fast component) of the PMT current signal, respectively. The total component (Fig. 4) is the sum of the fast and slow components [4].

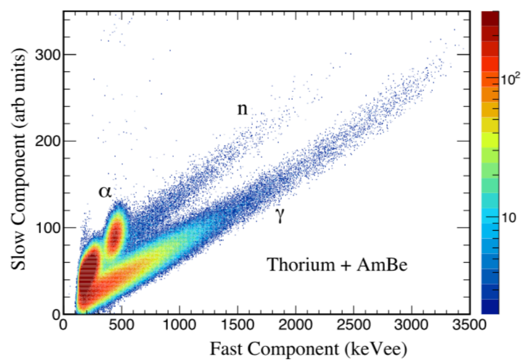

Fig. 3. 2D plot of PSD showing alpha, neutron and γ-ray discrimination taken with ^{228}Th and Am–Be sources [4,6].

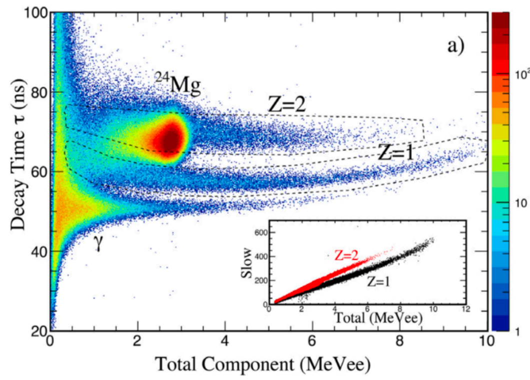

Fig. 4. Decay time τ of the digitized signals, as obtained by exponential fits [5,6] as a function of the total component. Good separation of γ-rays, Z=1 and Z=2 particles is seen.

We achieved a very good Figure of Merit (FOM) = 1.03 for neutron - γ for the fast component slices between 1100 and 1200 keVee, corresponding to a neutron energy in the range of 5.0 - 5.5 MeV. Details have been reported in [4]. We also estimated a neutron detection threshold of about 1 MeV and a discrimination threshold of about 1.5 MeV by using the parametrization method reported in [9].

In the high-background tests we used the same acquisition system [6]. However, this time, instead to use sources, we performed a real in beam experiment. The beam was ^{24}Mg delivered by the Tandem accelerator of the LNS having the kinetic energy of 71 MeV and the target nucleus was ^{92}Zr. Also in this case we obtained a good separation between the γ particles identification locus and proton/neutron one as it is shown in Fig. 4 (in the case of this test we did not distinguish the primary neutrons signals from the protons ones due the fact that they both are seen as protons in the plastic scintillator). In the Fig. 4 the y-axis is obtained by doing and exponential fit to the tail of the digitalized pulse deliverd from the PM-tube[5,6]. Empirical cuts (dashed lines) in order to separate Z=1 and Z=2 particle-loci are shown. The insert in Fig. 4 shows the results of the cut-selection on the Slow Vs Total discrimination correlation plot. The ^{24}Mg elastic scattering contribution is indicated.

Also under the condition of high-background condition case we achieved a good separation of FOM (γ,p) = 1.31 and FOM(p,α) = 1.51 for the Total component slices between 3.7 and 4.8 MeVee (that excludes the ^{24}Mg contaminant). The identification threshold is indicated by a FOM(γ,HI) = 0.51, corresponding to a Total component slices between 0.5 and 1.0 MeVee [5,6]. Good quantal efficiency was assured by the PM coupling. However, in order to test also performances by using silicon read-out technology like, Photo Diode (PD) or Silicon Multiplier (SiMP), it is envisaged, in a next future, to test the EJ276 green shifted version.

3. Conclusion

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

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