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NArCoS: A new correlator for neutrons and charged particles with high angular and energy resolution (Neutron Array for Correlation Studies)

E. V. Pagano(1), C. Boiano(5), P. Russotto(1), E. De Filippo(3), G. Cardella(3), A. Castoldi(4)(5), E. Geraci(2)(3), B. Gnoffo(2)(3), C. Guazzoni(4)(5), G. Lanzalone(6)(1), C. Maiolino(1), N. S. Martorana(3), F. Noto(1), A. Pagano(3), S. Pirrone(3), G. Politi(2)(3), L. Quattrocchi(7)(3), F. Risitano(7)(3), F. Rizzo(2)(1)(8), G. Santagati(3), M. Trimarchi(7)(3) and C. Zagami(2)(1)(8)

(1) *INFN, Laboratori Nazionali del Sud - Catania, Italy*
(2) *Dipartimento di Fisica e Astronomia "Ettore Majorana", Università di Catania Catania, Italy*
(3) *INFN, Sezione di Catania - Catania, Italy*
(4) *Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano Milano, Italy*
(5) *INFN, Sezione di Milano - Milano Italy*
(6) *Facoltà di Ingegneria e Architettura, Università Kore - Enna, Italy*
(7) *Dipartimento di Scienze MIFT, Università di Messina - Messina, Italy*
(8) *CSFNSM, Centro Siciliano di Fisica Nucleare e Struttura della Materia - Catania, Italy*

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Summary. — An overview concerning the electronic frontend and readout system for the first version prototype of the neutron correlator NArCoS is reported. The proposed prototype of electronic is designed for the next source and beam commissioning experiments like CROSSTEST performed in November 2023 at LNL.

1. – Introduction

The efforts of the international community aimed at building new facilities for radioactive beams (RIBs), such as FRAISE at LNS-INFN [1, 2], SPES at LNL-INFN [3], FAIR at GSI [4], FRIB at MSU [5], in particular for the neutron rich ones, it will allows to study Heavy Ion (HI) collisions under extreme conditions of isospin asymmetry. In this perspective it is expected a more important role of neutron contribution during the collision events.

The NArCoS project [6] (Neutron Array for Correlation Studies) is aimed to construct a novel detector devoted to detect neutrons (and light charged particles) performing high angular and energy resolutions. Conceptually the prototype is an array of 64 plastic scintillator detectors (EJ 276 family [7]) having the dimension of 3x3x3 cm^3 arranged in a cubic geometry and individually read by SiPM. The plastic scintillator, both in the ordinary and in the green shifted versions, has proved good PSD capabilities in the neutron-gamma and neutron-alpha separation in many test where were used both radioactive source at low background condition [8] and beams in high background [9]. Taking into account a distance of 150 cm from the interaction target the neutron angular resolution is estimated to be about 1° in the laboratory frame. The neutron energy measurement is entrusted to the time-of-flight (ToF) technique for which about 5% of energy resolution is estimated (Δt = 500 ps). The energy range of interest for neutrons is the intermediate one (2 MeV $\leq$ E/A $\leq$ 100 MeV) and they will be detected through the proton recoil technique. For this reason it will be mandatory to use a veto detector in order to disentangle a charged particle from a primary neutron since in the plastic scintillator both particles are seen as charged (mainly protons at the energy of interest of this project). The mission of this project is to have a second generation neutron correlator (but also light charged particles), designed to work in a stand alone mode or coupled to high granularity 4π multi-detector systems like CHIMERA [10] at INFN-LNS. Taking benefits to the large isospin asymmetry present in the next exotic beams, it will be possible to study the in-medium nuclear interaction, the equation of state of nuclear matter, the reaction mechanism just to quote few examples. Among some data-analysis techniques the particle-particle correlations involving neutrons is poorly explored in the literature even if in principle it allows the Coulomb interaction to be "turned off" and have a better undersigning of the nuclear force. The project received a new impulse in terms of workforce and economical support thanks to the PRIN2021 ANCHISE (contract 2020H8YFRE), which will provide new studies for the three years 2022–2024, focusing on a dedicated readout digital electronic and the best mechanical configuration. One of the most important issue for the next few years will be the cross-talk study performed both with simulations and with dedicated experiments and tests. The study of cross-talk effect through simulations is already underway, through the Montecarlo based GEANT4 software. The results obtained so far are encouraging although they need to be confirmed through real experiments. In view of the CROSSTEST experiment, two configurations were studied with 9 elementary cells, one called "matrix" and one called "Three-cluster" which both give percentages of cross talk of the order of 3-4% for neutrons of energy between 1 and 10 MeV. For further details about cross talk simulation studies see ref. [11]. In the following sections the prototypal electronic readout system will be briefly described.

2. – The electronics and mechanical prototype

Each one of the cubic plastic scintillator is equipped with a prototypal circuit for the readout system, performing the sum of all the signals coming from a matrix of 25 SiPMs, AFBR-S4N66C013 manufactured by BROADCOM, in order to have a fast signal, with low noise and amplitude that matches with the energy range of interest with the dynamics of the DAC acquisition. Each of the SiPMs has an active area of 6x6 mm^2 - a thickness of 0.3 mm - and contains 39384 square micro cells of 30 μm of pitch, working in avalanche mode. The readout electronics has been implemented on the bottom side, of the same PCB housing in the front side (with respect to the plastic scintillator) the SiPM matrix that is covering an active area of 30x30 mm^2. The front side of the PCB has also some pins useful for the SiPMs power supply, for the output signal, for a test input and for the temperature control as it is shown in the fig. 1, panel a), b) and c). In the d) panel of the fig. 1, is shown the tau as a function of the total identification matrix. The tau in

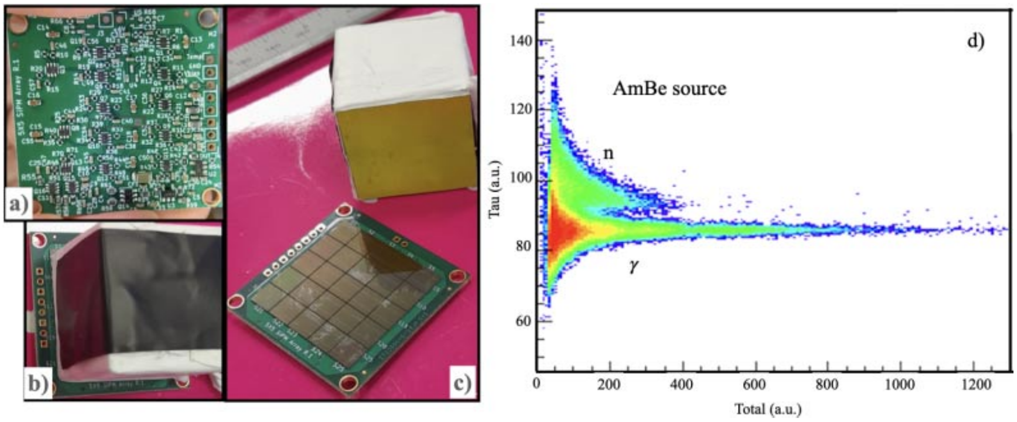

Fig. 1. – Read-out electronic motherboard, (a) front side, (c) back side and the EJ276G (b) the coupled system [12]; (d) tau as a function of total energy identification matrix (for details see text).

the Y-axis, expressed in arbitrary unit, is obtained through an exponential fit procedure in the tail part of the digitalized signal. The total variable, expressed in arbitrary unit, in the X-axis, is the total energy deposited by the particle in the scintillator. Its number is obtained by an integration of the digitalized signal for all of its dynamic range (≈ 600 ns). In the identification matrix is shown the preliminary results of an acquired signal of a neutrons and gammas AmBe source for PSD tests. As it is possible to observe, a good separation between the two particles was achieved. Test was performed at LNS-INFN.

This electronic solution made with a compact design will allow to bring the detectors of the array as close as possible. The circuit has a fast response time of less than 4 ns, while the intrinsic electronic noise of the readout circuit is lower by a factor of 4 than the noise due to the dark current. These characteristics are fundamental for the application of pulse shaping necessary for neutrons discrimination. For this electronics prototype good performances are achieved and in the next future a first prototype of the hodoscope will be ready to be tested with sources and beams. In the Fig 2. is shown the mechanical configuration manufactured for the CROSSTEST experiment and performed in November 2023 at the CN accelerator of INFN-LNL. The CROSSTEST experiment had the purpose of the experimental study of the crosstalk problem among the elementary detection cells at low neutron energy ($E_n < 5$ MeV). A PCB electronics board is shown in the panel a) of the fig. 2 and it is able to connect the read-out SiPM boards to the acquisition system, a DT5742 CAEN digitizer. Moreover the PCB board is equipped with a test input, the High Voltage input to bias the SiPM (33V) and a temperature monitoring sensor output. In the panel b) the mechanics manufactured in order to support the completely setup (PCB board and the plastic scintillators) at the right height is shown.

3. – Conclusion

The first version of the NArCoS prototype in a stand-alone configuration is under test with radioactive source. In particular to test the PSD performances of the setup for many discrimination techniques. The good results so far achieved, both from experimental and

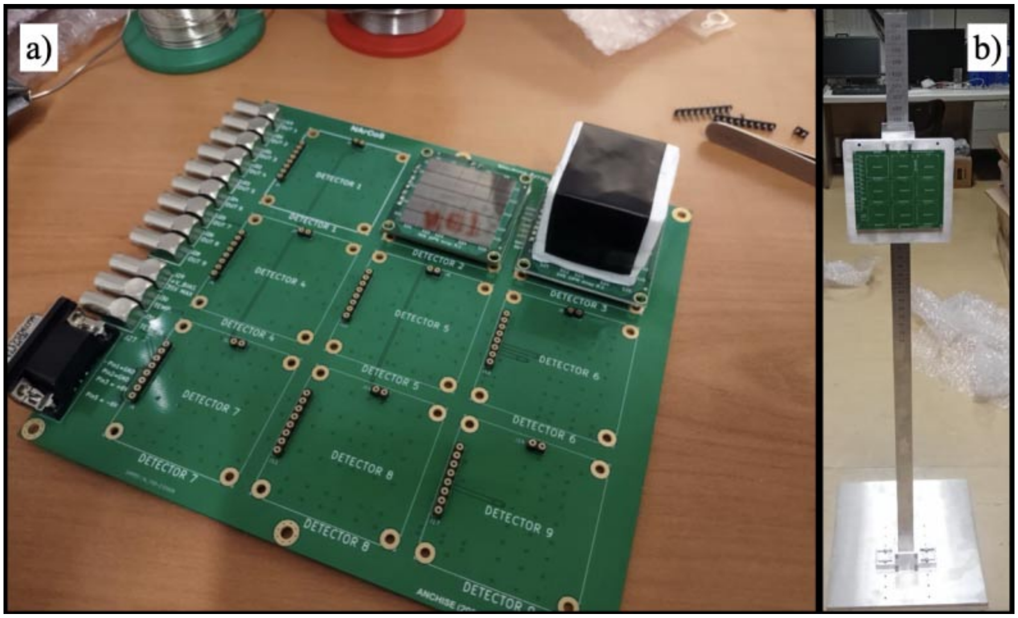

Fig. 2. – Panel (a), a PCB board for housing the 9 scintillators equipped with the SiPM Matrix, panel (b) the mechanical configuration for the CROSSTEST experiment.

from simulation are encouraging to continue in this project. The data analysis of the CROSSTEST experiment is ongoing and timing response test will be made in the next future in order to compare the good timing performances of the ordinary version of the plastic with the green shifted one.

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