THE NEW NEUTRON MULTIPLICITY FILTER NEDA AND ITS FIRST PHYSICS CAMPAIGN WITH AGATA*

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A new neutron multiplicity filter NEDA, after a decade of design, R&D and construction, was employed in its first physics campaign with the AGATA spectrometer. Properties and performance of the array are discussed.

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1. Introduction

Since decades, γ-ray spectroscopy methods are extensively applied to studies of the structure of proton-rich nuclei. Excited states in such nuclei can be populated in fusion–evaporation reactions and the emitted γ-ray radiation can be analysed using HPGe detectors. However, a prerequisite for such studies is the availability of devices and methods which make possible the selection of very weakly populated nuclei. This can be achieved by the detection of neutrons which are emitted from the compound nucleus. The efficiency and quality of the neutron detection are the main factors which set feasibility limits of studies of more and more exotic proton-rich nuclei.

Arrays of neutron detectors, like the Neutron Wall [1, 2] or Neutron Shell [3] have been previously constructed and used in many experiments. In this paper, we report on the construction and the first application of a new NEutron Detector Array (NEDA). Work on NEDA was initiated in 2007 and involved researchers from 21 institutes in 9 European countries. The main aim of the project has been to create a device of unprecedented performance, able to serve as an ancillary device to the state-of-the-art γ-ray spectrometers. The crucial parameter of the array is the efficiency to detect and identify multiple neutrons in experiments in which emission of neutrons is very scarce and a high γ-ray background exists.

2. Basic features of the NEDA array

A lot of effort was put into optimising every parameter and element of NEDA to achieve the best possible performance [4–10]. In particular, extensive Monte Carlo simulations and measurements were carried out to choose the scintillator and to optimise the size of a single detector [4], as well as the geometry of the whole array [5]. These studies lead to constructing a 205 mm long single detector, filled with 3.15 litre of the EJ-301 liquid scintillator. A hexagonal profile with 146 mm side-to-side distance was chosen to fit to 5″ photomultiplier tubes (PMT). The Hammamatsu R11833-100HA PMT was selected for NEDA detectors due to its timing [6] and neutron-gamma discrimination (NGD) capabilities [7].

The detectors used in the first experiments (see below) were produced by the collaboration and showed the light yield of 2850$\pm$100 photoelectrons per MeVee (MeV electron equivalent), which is exceptionally high for such a large-volume detectors [1, 11, 12]. Both the timing and the NGD capabilities are strongly dependent on the light yield of the detector. For the timing, the higher statistics of photoelectrons leads to a better definition of the rising time and thus the Constant Fraction Discrimination and Leading Edge algorithms give better results. The dependence on photoelectrons statistics is even stronger in the case of the NGD, as only 20% of the light is present in the tail of the signal, and this is where the difference between neutrons and γ rays is manifested. Excellent neutron-gamma discrimination of a NEDA detector is illustrated in Fig. 1. The general overview of NEDA with detailed description of electronics is given in the work of Ref. [13], while details on the design, construction and performance of NEDA will be provided in the forthcoming paper [14].

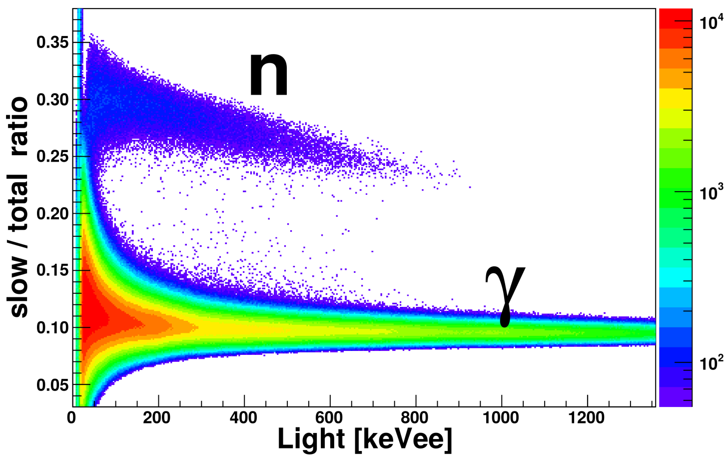

Fig. 1. Neutron-gamma discrimination using the charge comparison method [15]. The spectrum was obtained with a NEDA detector using a ^{252}Cf source. The ratio of slow-to-fast signal integrals is plotted *versus* the total light.

3. First physics campaign of the NEDA array

The NEDA detectors were tested in-beam at GANIL in three short runs in the fall 2017. Consecutively, the setup of the NEDA array, the Diamant charge particle detector [16] and 1π AGATA [17, 18] was commissioned in-beam, and five experiments were run in spring and summer 2018, operating for a total of 1136 hours of beam time. In these studies, 54 NEDA detectors placed in the forward angles were accompanied by 42 Neutron Wall detectors arranged in the arch placed at angles close to 90° with respect to the beam direction. This geometry, named as "NEDA + NW-ring" in Ref. [5] and shown in Fig. 2, covers 1.60π of the solid angle.

Signals from the NEDA detectors were digitised using the NUMEXO-2 front-end electronic units which were primarily developed for the EXOGAM2 array [19]. The NEDA version of a NUMEXO-2 card read signals from 16 detectors, through four Flash ADC Mezzanines with 200 MSps and ENOB $\approx$ 11.6. Each NUMEXO-2 card has two Field Programmable Gate Arrays (FPGA) in which several algorithms were implemented: NGD using the charge comparison method [15], CFD, TDC between CFD and the RF signal

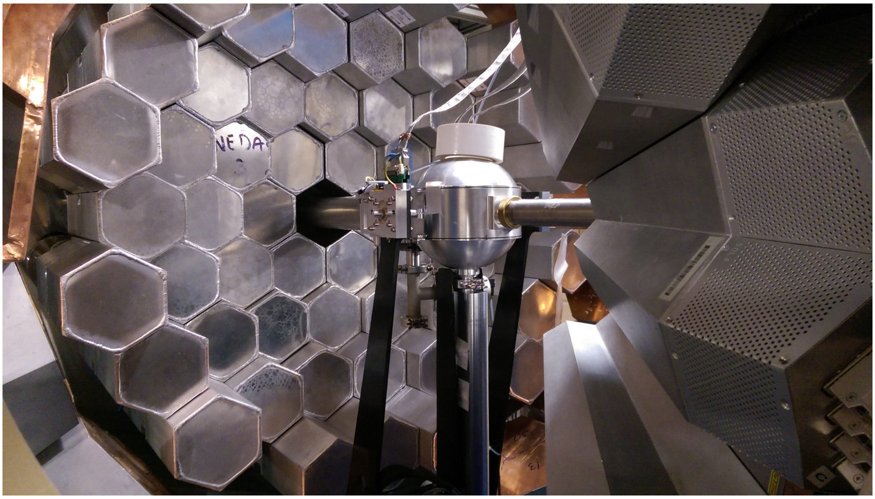

Fig. 2. From right to left (the beam direction): AGATA clusters, ion guide, target chamber with DIAMANT inside, NEDA array. Two triple Neutron Wall detectors are visible in the lower left corner.

of the accelerator, trigger generation, clocking, data packaging and readout. The coupling of NEDA electronics with other detector systems (AGATA and DIAMANT) was done employing the Global Trigger and Synchronisation (GTS) system [20], working with a 100 MHz clock.

A trigger condition of detecting at least 1 neutron was used. Ninety six individual neutron detectors were contributing to the trigger decision and for each of them, the threshold was applied in FPGA on both the time-of-flight and the NGD parameter of the detected particle. This provided a rough online discrimination of neutrons and γ rays, used for the trigger. Further NGD, neutron multiplicity determination and merging data flow of all the sub-systems was carried out by dedicated servers in the NARVAL [21] environment. Several actors (algorithms) were developed within the collaboration for this purpose. Details on the electronics development can be found in Ref. [10].

The physical phenomena addressed with the performed experiments were:

- *(i)* the isospin symmetry breaking for $A = 63$ and 71 mirror nuclei,
- *(ii)* two-body neutron interactions, single-particle energies and core-excitations derived from excited states of $^{102-103}$Sn,
- *(iii)* isoscalar pairing in ^{88}Ru, and
- *(iv)* octupole and quadrupole correlations of xenon isotopes.

The analysis of the collected data is in progress.

An example of the influence of neutron gating on gamma spectra is shown in Fig. 3. The spectra were obtained for the ^{36}Ar + ^{16}O reaction, extracted from the runs for which no neutron condition was present in the trigger. The γ rays at 261 keV and 271 keV correspond to the $7/2^-$ to $5/2^-$ (g.s.) transition in ^{49}Mn ($1p2n$ evaporation channel) and ^{49}Cr ($2p1n$), respectively. Note that the line at 261 keV (the strongest transition associated with the evaporation of two neutrons) can be observed only in the $2n$ gated spectrum, while the 263 keV gamma-ray is dominating this region in the two other spectra.

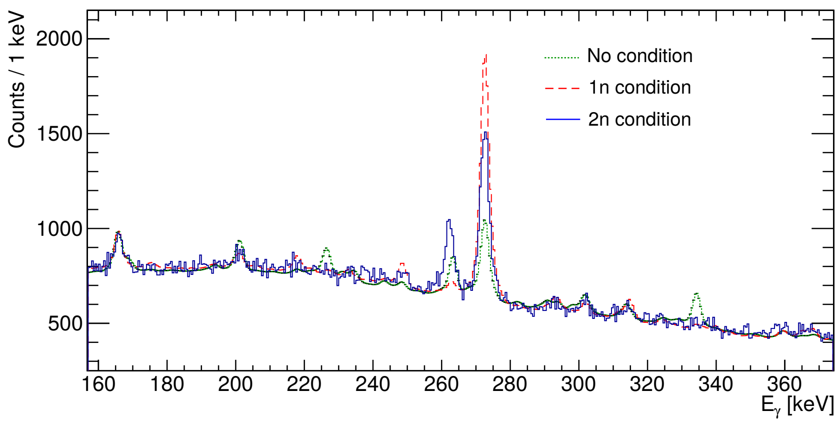

Fig. 3. (Colour on-line) Gamma spectra measured with AGATA spectrometer with a 115 MeV ^{36}Ar beam and ^{16}O target, without any condition (dotted green line) and gated on one and two neutrons (dashed red and solid blue lines, respectively) detected in the NEDA array. The spectra are scaled so the background level for all three of them is the same. The Y-axis scale is true for $1n$ gated spectrum. See discussion in the text.

4. Summary

The design and construction of a new neutron multiplicity filter NEDA were accomplished. The first physical campaign, in which NEDA was used together with the AGATA spectrometer, took place in the period of spring–summer 2018. The online performance of the array was very good and results of the performed experiments should be expected in near future.

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