INTRODUCTION

Since last decades, large arrays of neutron detectors have been used together with γ-ray detectors in order to study very weak populated isotopes. Detection systems such as Neutron Wall [1, 2] or the Neutron Shell [3] have been successfully employed to select channels in fusion-evaporation reactions populating neutron-deficient isotopes, after the emission of one or two neutrons. Neutron Wall for instance, has produced more than 30 peer-reviewed publications since 1998, during its campaign in IReS (Strasbourg, France), GANIL (Caen, France) or LNL-INFN (Legnaro, Italy). One of the biggest achievements has been the clean identification of the $^{92}$Pd and $^{96}$Cd, which spectroscopy information suggests a collective phase of $^{T}=0$pn pairs [4].

The advent of new radioactive ion beam facilities, like FAIR in GSI, SPIRAL2 in GANIL or SPES at LNL, will open access to more and more exotic isotopes, demanding as well more efficient detectors to selectively clean the reaction channels. The NEutron Detector Array NEDA [5, 6] is a new modular detector system, meant to improve the overall performance in neutron detection in such facilities. The total project comprises more than 300 detector units, containing more than 1200 litres of liquid organic scintillator BC501A, placed at a distance of 1 m from the target position and covering a solid angle of $1.9\pi$. It will be operative in its first phase for the AGATA campaign of GANIL in 2017, driving around 50 detector units placed at near 90°-rings in a more closed configuration (51 cm from target). With this setup, it will be sandwiched between Neutron Wall and AGATA [7], meaning an almost double neutron efficiency with respect to the Neutron Wall alone.

The main characteristics of the NEDA array are 1) large neutron efficiency in the range from 1 MeV to about 20 MeV, 2) superior neutron-γ discrimination, which allows the detectors to be used with a high γ-ray background and high count-rate capability, 3) large granularity in order to maximise the detection efficiency for neutron multiplicities larger than one, and finally, 4) an advanced digital front-end electronics, which is fully compatible with the AGATA [7] and GALILEO [8] electronics and data acquisition system, and it will lead to a more sophisticated neutron-γ discrimination algorithms [9, 10].

Most of the NEDA technical advances with respect to former neutron detector arrays rely on the readout chain, from the more efficient high quantum-efficiency (QE) photomultiplier tube (PMT) to the complete use of digital electronics. Indeed, the future detector has the same scintillator BC501A used in the aforementioned neutron detector arrays. It is the angular coverage and geometry of the array structure [5], as well as the optimization of the single detector dimensions that boost the neutron efficiency, specially for 2n and 3n channels [6]. NEDA comprises high granularity, using a dedicated digital sampling electronics
with 14 bits (11.7 effective number of bits, ENOB) and a sampling rate of 200 MS/s [11]. This electronics will lead to operate at higher counting rates without loosing timing and neutron-γ discrimination performance.

**PROTOTYPE DESIGN**

The first prototype of the NEDA single unit has been produced and tested at LNL. The different parts before assembling are shown in Fig. 1. The geometry has been carefully adapted to be as compact as possible, reducing the form factor and dead material as much as possible. It consists on two matching aluminum 6060 alloy bodies, the detector cell and the PMT housing, both sharing the same hexagonal profile, 146 mm side to side, and with 3 mm inner walls. Each unit will be made from an hexagonal bar produced by extrusion of an aluminum bulk. The detector cell is 205 mm long, with an active volume of \( \sim 3.15 l \), filled with liquid organic scintillator EJ-301 (aka BC501A). The inner surface is coated with reflective paint (\( \text{TiO}_2 \) based) EJ-520. On the top flange it has an opening window of 5 inch, made of N-BK7 glass 5 mm thick (92% transmittance), encircling the hexagonal section in order to maximize the direct light gathering.

A pipe is connecting the active volume in the cell with an expansion chamber allocated in the rear part of the PMT housing. The chamber consists on a soft, 3 inch diameter edge welded bellow that expands up to 153 cm\(^3\) in 4.8 cm stroke, leading to an operational temperature range of 40° with minimal pressure differences.

The dimensions, geometry and scintillation material have been chosen after an exhaustive study to optimize the efficiency, minimal 2\( n \) detection misleading (due to neutron scattering between detectors) and pulse-shape-discrimination capabilities [6]. The readout is done with a superbialkali, \( \sim 35\% \) QE, 5 inch PMT Hamamatsu R11833-100HA, optically coupled to the glass window and housed in the hexagonal case. The flange on the top of the PMT housing holds a plastic ring to push the PMT against the glass window. The case is magnetic shielded with a 1 mm thick \( \mu \)-metal inner cylinder.

The uncertainty in the length of the neutron flight path, due to the large dimensions of the detector, does not allow an accurate measurement of the neutron energy using the time-of-flight methods. However, the use of fast PTMs for good timing accuracy is necessary in order to disentangle the fast and slow decay components when doing pulse-shape-analysis to discriminate neutrons and γ-rays, as well as to measure the time-of-flight between adjacent detectors to identify scattered neutrons from two or more real neutron events [2, 12].

For this purpose, we have studied the timing and pulse-shape-discrimination performance of several PMTs [13], measuring the time resolution of optimal PMT candidates with analog and digital electronics and simulating the future digital environment that will be used by NEDA [11]. We have developed a digital constant-fraction algorithm with cubic interpolation of the zero-crossing that brings time resolutions comparable to the analog electronics [13]. The γ-neutron discrimination based on the pulse-shape has been also studied by digital means in order to benchmark the PMTs [14]. Fig. 2 shows the neutron-γ discrimination capabilities as a function of the energy for the NEDA prototype, obtained with digital electronics.

**SUMMARY**

We have produced and tested the first prototype of the detector array NEDA. The compactness of the detector, together with the planned geometry for the whole array will lead to a much more active volume per solid angle coverage. The use of high QE super-bialkali photocathodes together with a dedicated digital electronics in the readout will increase the 1\( n \) and 2\( n \) detection efficiency.