NEEDLE — THE NEW SETUP TO STUDY NEUTRON-DEFICIENT NUCLEI*

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Received 15 December 2022, accepted 6 February 2023, published online 22 March 2023

A state-of-the-art neutron multiplicity filter NEDA has been installed as an ancillary detector to the EAGLE gamma-ray spectrometer at the Heavy Ion Laboratory, University of Warsaw. This significantly broadens the areas of the nuclear chart accessible by employing the Warsaw apparatus. The properties of the new setup are discussed.

DOI:10.5506/APhysPolBSupp.16.4-A36

1. Introduction

Contemporary studies of nuclear structure concentrate on regions far from the valley of β stability. Such regions are accessible experimentally via, *inter alia*, fusion–evaporation reactions in which the nuclei of interest are produced by the emission of a few particles from the compound nucleus. The arrays of HPGe detectors used for these studies must be complemented with ancillary devices to enable accurate identification of the reaction products and thus the reaction channel. In particular, when approaching very neutron-deficient nuclei, the channels with neutron emission lead to the most

* Presented at the Zakopane Conference on Nuclear Physics, *Extremes of the Nuclear Landscape*, Zakopane, Poland, 28 August–4 September, 2022.

exotic nuclear structures produced with very small cross sections. In order to select neutron-evaporating reaction channels, large arrays of liquid scintillator detectors such as the Neutron Wall [1, 2] and the Neutron Shell [3] were constructed. They were successfully used in many experiments, aiming at studying more and more neutron-deficient nuclei, especially along and close to the $N = Z$ line, up to the region of the doubly magic ^{100}Sn. Basing on the decades of experience with the above-mentioned arrays, following the extensive R&D phase, a new neutron multiplicity filter NEDA [4] was constructed. The new array is optimised for high efficiency, excellent capabilities in distinguishing neutrons and gamma rays, as well as proper determination of the multiplicity of neutrons. It should also work at high counting rates. Thanks to these features, NEDA is apt to work as an ancillary device to modern γ-ray spectrometers. Indeed, within its first physics campaign in 2018 [5–7], NEDA was connected to AGATA at GANIL [8], presenting excellent performance. In this paper, we report on the installation of NEDA at the Heavy Ion Laboratory (HIL) in Warsaw, Poland.

2. The NEEDLE setup

The indigenous tool for the γ-spectroscopy investigations at HIL is the EAGLE (central European Array for Gamma Levels Evaluations) setup [9]. The EAGLE frame can host up to 30 HPGe detectors and ancillary devices. It has been recently adapted to accommodate NEDA detectors. Fifteen HPGe detectors have been placed at the backward angles (with respect to the beam direction), and the NEDA detectors have been arranged in the forward hemisphere. Triplets of NEDA detectors have been placed at each of the 15 forward faces of the frame at a distance of 450 mm from the target. Additional 7 NEDA detectors have been mounted downstream of the frame, forming a "forward wall" to detect neutrons at small θ angles with respect to the beam axis. The new aggregate of the detectors named NEEDLE is shown in Fig. 1. The NEEDLE setup is expected to have the photopeak efficiency of 1.4% for γ rays at 1.3 MeV, and about 20% and 2% efficiency to detect 1 and 2 neutrons, respectively. These numbers are based on the measurements for HPGe detectors, evaluation of the data acquired with NEDA at GANIL, and on Geant4 simulations. Note that the clean tagging on multiple neutrons is especially difficult and important, as 1 detected neutron tends to scatter in more than 1 detector, which mimics detection of a larger number of neutrons. In order to tag on multiple neutrons, cuts on the distance, time and amount of light produced in the scintillator are thus required to distinguish the detection of 2 true neutrons from 1 scattered neutron. This is especially important as in the studies of most neutron-deficient nuclei, the cross section typically drops by order of magnitude with each additional neutron emitted.

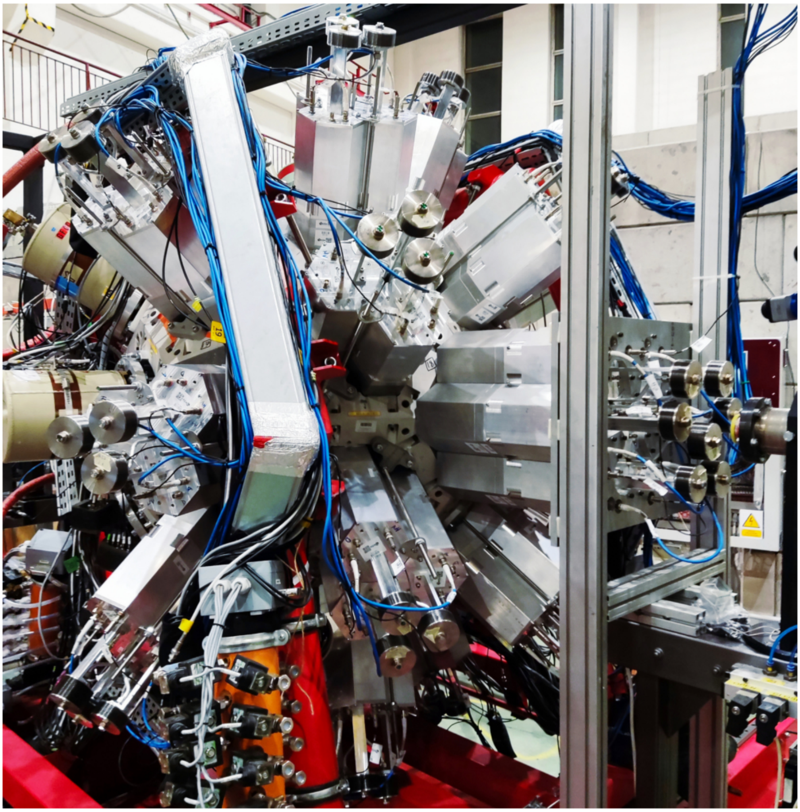

Fig. 1. The NEEDLE setup installed at the beam-line at HIL. From left to right (the beam direction): the HPGe detectors (dewars visible), the NEDA detectors installed in the EAGLE frame, and the NEDA "forward wall".

On the data acquisition side, signals of NEEDLE are processed by six Caen V1725S(B) digitisers: two with the PHA firmware for the HPGe detectors and their anti-Compton shields, four with the PSD firmware for the NEDA detectors. The digitisers are synchronised with the 62.5 MHz clock, and are read via four optical fibres by a server equipped with the Caen A3818C PCI Express CONET2 Controller. For the trigger condition, the coincidence of a number of γ rays in the HPGe detectors and at least 1 FPGA pre-selected neutron in the NEDA detectors can be required. In measurements in which the DIAMANT charged particle detector will be additionally employed (see below), NUMEXO2 digitisers [10] will also be used.

A number of possible physics cases to be studied with NEEDLE were proposed and discussed during the dedicated workshop [11], followed by the PAC meeting. Three projects were accepted and will be executed aiming at: *(i)* single-particle energies and core-excitations in ^{57}Cu, an important waiting point in the rp-process; *(ii)* shape coexistence and octupole correlations in the light Xe isotopes; *(iii)* $X5$ symmetry in yrast and non-yrast bands of ^{134}Sm. In these measurements, NEEDLE will be equipped with additional ancillary devices. Experiment *(i)* requires the installation of the DIAMANT charged particle detector [12], which will further enhance the reaction channel selectivity of the setup. DIAMANT is expected to have an efficiency of 60% and 40% for detecting protons and α particles, respectively. In turn, in experiments *(ii)* and *(iii)*, the Köln plunger [13] will be employed, allowing measurement of lifetimes in the range of approximately 1–100 ps.

We expect that further proposals for experiments with NEEDLE will be presented at the next PAC meetings. Note that the ULESE conversion-electron spectrometer [14], can also be used in connection to NEEDLE, making γ–neutron–electron coincidence measurement possible.

3. Summary

The neutron multiplicity filter NEDA has been installed at HIL in conjunction with the EAGLE γ-spectrometer. The new setup, named NEEDLE, is an excellent tool for the investigation of the structure of neutron-deficient nuclei using the heavy-ion beams of the Warsaw cyclotron.

The installation and use of NEDA at HIL are supported by the National Science Centre, Poland (NCN) (grant No. 2020/39/D/ST2/00466).

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