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MoNA—The Modular Neutron Array

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Abstract

The Modular Neutron Array (MoNA), a highly efficient time-of-flight neutron detector, is being constructed for use at the National Superconducting Cyclotron Laboratory. The modular design of the detector provides significant flexibility and allows the bulk of the assembly and testing to be done by undergraduates at nine of the schools participating in the project.

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1. Introduction

In recent years experiments probing neutron-rich nuclei and nuclear systems have yielded a wealth of new insights into nuclear structure. Unique structures such as two neutron halo nuclei have generated considerable interest in nuclei near the neutron dripline. In addition, the large N/Z ratio of these nuclei near the dripline is predicted to have important effects on collective excitations and the closure of nuclear shells [1].

These neutron-rich nuclei can be produced at rare isotope beam facilities using particle fragmentation and in-flight separation. The recent coupled-cyclotron upgrade at the National Superconducting Cyclotron Laboratory will allow the production of rare isotope beams of significantly greater intensity and energy than was previously possible at the facility. In order to take advantage of these new capabilities a highly efficient neutron

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detector optimized for the neutron energies between 50 and 250 MeV is essential.

A collaboration of 10 colleges and universities is constructing the Modular Neutron Array (MoNA), a flexible high efficiency time-of-flight neutron detector, for use at the NSCL. The modular design of the detector provides important advantages in construction and operation. In addition much of the work on the detector will be done by undergraduate students at the collaborating institutions providing important educational opportunities.

In this report, we will present design studies and simulations of the detector. We will also discuss the educational and training aspects of the project.

2. Design

The MoNA consists of 144 individual detector modules. Each module is based on a $200 \times 10 \times 10\ cm^3$ block of BC-408 plastic scintillator. The scintillator block is connected via a light guide to a 2 in. diameter photo-multiplier tube (Photonis X2262B) on each end. The position along the scintillator block where the light is emitted can be reconstructed by measuring the time difference between the signals from the two photo-multipliers. The average of the two times can be used to determine the neutron's time-of-flight. The vertical position is given by the block in which the neutron was detected.

The MoNA detector modules can be configured in different ways to optimize efficiency and meet a variety of experimental needs. In the nominal configuration the 9 vertical layers of 16 of the scintillator blocks give a detector volume of $2.0 \times 1.6 \times 0.9\ m^3$. In addition 1 cm thick iron converters can be placed between the layers to increase detection efficiency.

3. Detection efficiency

This neutron detector is designed to have a detection efficiency of approximately 70% for neutron energies between 50 and 250 MeV. In order to increase the sensitivity for neutrons above 100 MeV, thin layers of iron will be used as a passive converter material. This concept already has been used successfully with GSIs LAND array, which utilizes plastic scintillator sheets in a combination with iron sheets [2]. It is also commonly used in high-energy physics for neutron calorimeters.

The reason for adding iron to the detector volume is that the nuclear interaction length (at high-particle energies) for this material is only around 17 cm, while it is 80 cm for plastic. If the amount and distribution of iron layers between the scintillator layers are chosen correctly, the overall thickness of the detector can be reduced while maintaining a high detection efficiency.

Fig. 1 shows a perspective view of the MoNA detector in a configuration consisting of 144 pure scintillator blocks (9 layers of 16 blocks) each measuring $200 \times 10 \times 10\ cm^3$ and additional three layers of 1.0 cm iron converter and three layers of 2.0 cm iron converter. The first three layers of the detector do not have any iron converters in order to detect neutrons below 100 MeV with a high efficiency. The thickness of the iron in front of subsequent layers of the detector increases, resulting in a better detection efficiency for neutrons of higher energies.

The addition of three 1 cm and three 2 cm iron converters to the last six layers of the detector yield

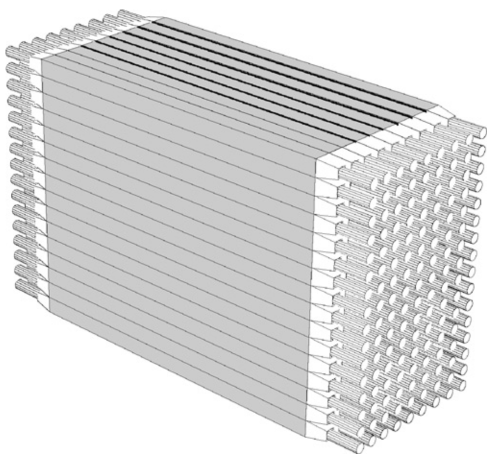

Fig. 1. A perspective front view of the simulated MoNA detector, showing the plastic scintillator blocks (gray) fitted with light guides and photo-multipliers, and the iron plates (in black).

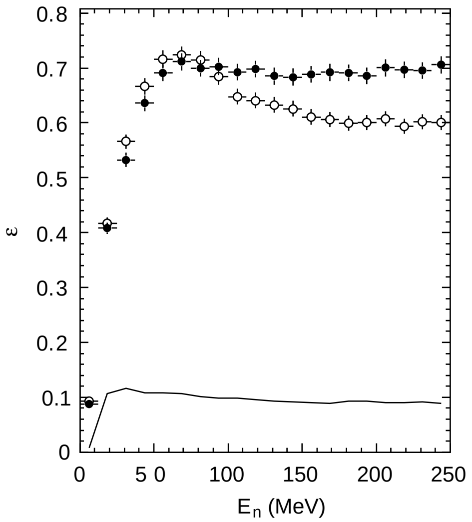

Fig. 2. The calculated efficiency curve for the nominal configuration of MoNA with passive iron converters (closed circles) and without (open circles). The black line shows the efficiency of the existing NSCL neutron walls.

an efficiency curve as shown in Fig. 2 with filled circles. Open circles correspond to an efficiency curve for a detector with no iron converters. The black line shows the efficiency of the existing NSCL neutron walls for comparison. As can be seen from the figure the MoNA detector will offer a factor of 7 increase in single neutron detection efficiency and be approximately 50 times more efficient at the detection of two neutron events.

It should be noted that these efficiency curves are calculations based on the detector description and simulation tool GEANT [3] in conjunction with the FLUKA package [4]. The results of this simulation were checked by experiments at RIKEN using passive iron converters at energies between 20 and 140 MeV [5].

4. The MoNA collaboration

The modular design of the MoNA detector allows construction to be done primarily by undergraduates at the colleges and universities that make up the collaboration. This has a number of advantages. First, the labor is spread among the 10 institutions and work progresses in parallel. Secondly, the undergraduate students gain educational and training benefits from the work.

Each of 9 layers of 16 modules will be constructed by one of the collaborating institutions. The plastic scintillator blocks with attached light guides will be delivered to each school already polished and wrapped. Undergraduate students will assemble and attach the phototubes and magnetic shielding to the scintillators. The modules will then be tested, characterized and calibrated using cosmic rays and radioactive sources. Ultimately the undergraduate students will have the opportunity to participate in the final assembly and testing of the array at the NSCL.

5. Summary

The modular design of the Modular Neutron Array (MoNA) provides significant advantages in the construction and operation of a highly efficient neutron time-of-flight detector. In addition to offering varying operating configurations, the design allows undergraduates at a variety of educational institutions to do the bulk of the construction and testing.

Computer simulations indicate that through the use of passive iron converters the detector can achieve efficiencies of approximately 70% for neutrons between 50 and 250 MeV. These high efficiencies will enable the MoNA detector to significantly enhance the capabilities of the NSCL to study neutron-rich nuclei.

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