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Status of Neutrino Elastic-scattering Observation with NaI(Tl) experiment

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Abstract. Coherent elastic neutrino-nucleus scattering (CEνNS) has an important role in measuring neutrino properties and proving non-standard interactions. Neutrino Elastic-scattering Observation with NaI(Tl) experiment (NEON) aims to detect this CEνNS in a NaI(Tl) crystal using reactor anti-electron neutrino at Hanbit nuclear power plant. NEON detector, which is installed 24 m distance away from the active reactor core, consists of a 15 kg NaI(Tl) in the radiation shielding structures including a 700 L liquid scintillator. Data taking has started from December 2020, which includes 1-month reactor-off period. We report the current status of NEON experiment in this talk.

1. Introduction

The coherent elastic neutrino-nucleus scattering (CEνNS), which was predicted in 1974 [1], has been interested not only in completing the picture of the standard model [2, 3, 4] but also in searching for new phenomena [5, 6, 7]. In 2017, the COHERENT collaboration achieved the first observation of CEνNS using a conventional CsI(Na) detector exposed to the neutrino emissions from the Spallation Neutron Source at Oak Ridge National Laboratory [8]. This was confirmed using a liquid-argon detector [9] recently by the same group. Even though the CEνNS process was observed with the spallation neutron source, the measurement of CEνNS with the reactor electron anti-neutrino has particular interests for astrophysics and a numberseveral of test for new physics [10, 11, 12, 13, 14, 15].

Neutrino Elastic scattering Observation with NaI (NEON) is an experiment with a goal for the first observation of CEνNS with NaI(Tl) crystal using the reactor anti-neutrinos. The detection of light signals from the NaI(Tl) scintillation crystal is a well-established technology in searching for extremely rare events such as weakly interacting massive particles (WIMPs) [16, 17]. Eventually, these efforts realize high-light yields and low-background NaI(Tl) detectors that are essential for not only WIMP dark matter search but also for the CEνNS observation.

2. NEON Detector

We use commercial grade crystals manufactured by Alpha Spectra Inc. (AS). Six crystals with two different shape of 3-inch diameter with 4-inch length and 3-inch diameter with 8-inch length in cylindrical shapes are labeled as NEO-1 to NEO-6. Each crystal's lateral surfaces were wrapped in roughly ten layers of 250 μm-thick polytetrafluoroethylene reflective sheets. We match the size of the crystal end face to that of the PMT photocathode and only use a single

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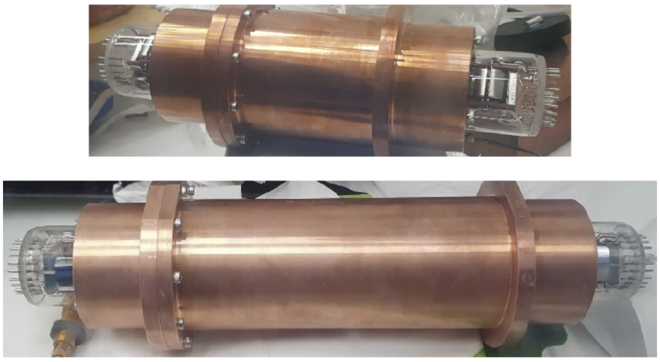

Figure 1. NEON detector. The top is 4 inch crystal encapsulation and the bottom is 8 inch crystal encapsulation.

optical pad between the PMT window and the crystal end face. Then, we insert the crystal and PMTs into the copper tubes in a nitrogen gas environment and seal them to make them air-tight. This detector-sensor combined assembly reduces light losses due to reflections at each optical interface. Applying this design to the NEON crystals, we achieved up to 20 Photo-electrons(PE) per keV light yield [18]. The figure 1 shows the NEON detector. The measured light yields for the NEON crystals are summarized in Table 1.

Crystal	Mass (kg)	Light yield (PE/keV)
NEO-1	1.62	20.5±0.9
NEO-2	1.67	19.3±0.9
NEO-3	1.67	21.8±0.9
NEO-4	3.35	22.4±1.0
NEO-5	3.35	21.8±0.9
NEO-6	3.35	21.7±1.0

Table 1. Mass and Light yield of the NEON crystals. The light yield is measured at 59.6 keV with a ^{241}Am source.

3. Shielding structure

The NEON detector is contained in a 4-layer nested arrangement of shielding components as shown in Fig 2. It provides 4π coverage to shield external radiation from various sources as well as active veto for internal or external sources. The shield is placed on 250 cm $\times$ 200 cm $\times$ 20 cm steel palette base. From the outside inward, the four shielding layers are polyethylene castle, borated polyethylene board, lead castle, and a Linear Alkyl-Benzene (LAB)-based liquid scintillator(LS). The six NaI(Tl) crystal assemblies and their support acrylic table are immersed in the LS.

4. Hanbit Nuclear Power Plants

The NEON detector was installed in November 2020 in the tendon gallery of reactor unit 6 of the Hanbit Nuclear Powder Complex in Yeounggwang, Korea. The location and distance from the reactor core is 24 m. The thermal power of reactor core is 2.8 GW corresponding to $7.1 \times 10^{12}\, cm^2 s^{-1}$ neutrino flux at NEON detector location. The tendon gallery is located at 10 m below ground level under the concrete building wall. The overburden of the experimental

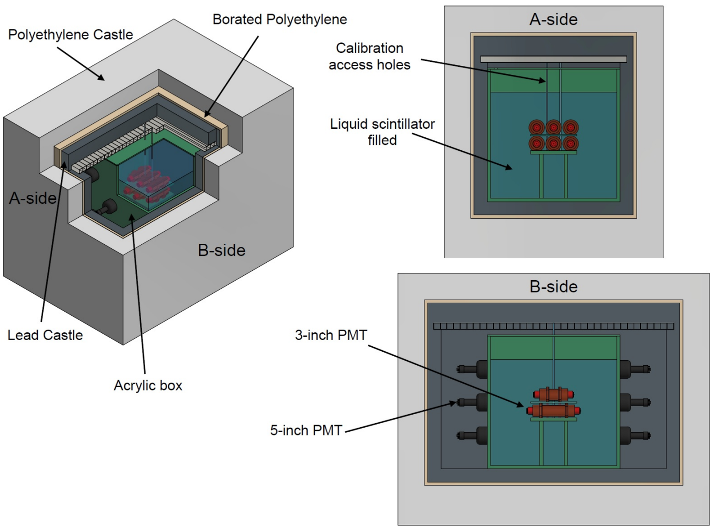

Figure 2. NEON shielding structure. The thickness of polyethylene castle, borated polyethylene board, and lead castle are 20 cm, 5 cm, and 10 cm,respectively. LS is filled in a 10 cm thick acrylic box.

site is about 20 m water equivalent, corresponding to six times lower muon flux compared to the muon flux at the sea level.

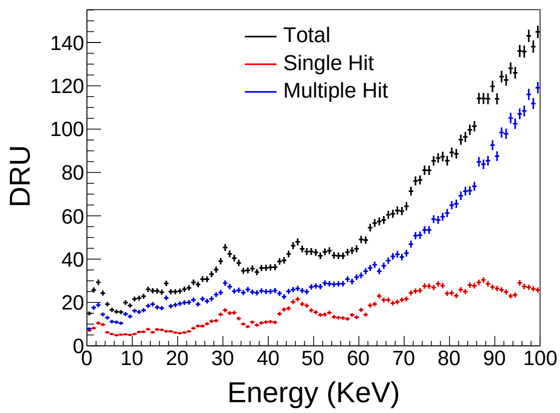

Figure 3. Background distribution of NEO-5

5. Operation

NEON data-taking started early in December 2020. In the initial stage of NEON, we found that PMT-induced noise arises when LS contaminates PMT voltage driver. In order to separate the PMT electronics from LS, we added an additional acrylic box.After shield upgrade, we deposit ∼3 months reactor-on data and ∼1 week reactor-off data until August 2021. From August to October 2021, we perform ^{22}Na calibration campaign for the goal threshold 5 PE using high-purity samples. Figure 3 shows NEO-5 background distribution with 1 week reactor-off data. To reduce PMT noise, We apply a selection from the multi-variable analysis method of crystal waveform shape parameters used in COSINE-100 experiment [16, 17]. The background in 10 $\sim$ 20 keV shows plat distribution and $\sim$5 counts/kg/keV/day(DRU) level.

6. CEνNS Sensitivity

We calculate the CEνNS sensitivity with the condition of 5 DRU background levels, 21 PE/keV crystal light yield, and 15 kg crystal mass by supposing 365(100) reactor-on(off) data sample and 5 PE threshold. The figure 4 shows an example energy distribution of one pseudo-experiment. By 2000 iteration pseudo-experiments, we got a significance level of 4.5 sigmas.

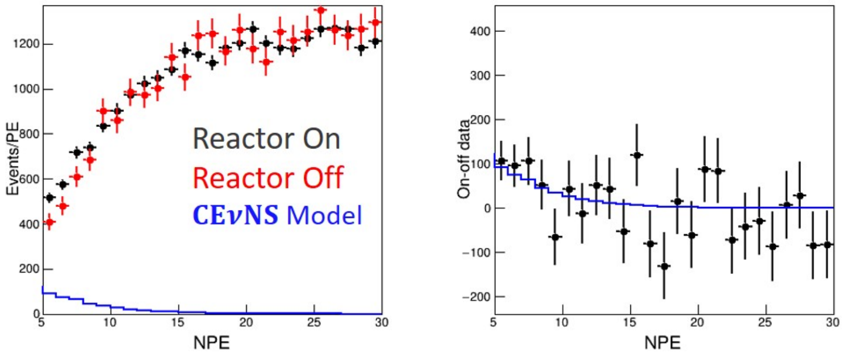

Figure 4. Energy distribution of one pseudo-experiment. The left plot shows the distribution of theoretical CEνNS signal shape(blue), reactor on data(black), and reactor off data(red). The right plots show the distribution of the difference between reactor on and off data.

7. Conclusion

The NEON experiment was successfully installed at the Hanbit Nuclear Power Plant in December 2020. We achieve $\sim$ 21 PE/keV by crystal encapsulation improvement in the development stage. The background level is $\sim$ 5 DRU with LS veto at the reactor site. After shielding upgrade due to PMT noise by LS contamination, we deposit $\sim$3 months reactor-on data and $\sim$1 week reactor-off data until August 2021. We expect more than 4 sigma significance level of CEνNS sensitivity based on ensemble test by supposing 5 PE threshold and 365(100) reactor-on(off) data samples with current experiment condition. The high-purity samples from ^{22}Na calibration will help to reach the goal threshold. In this scenario, the NEON experiment is expected to achieve its goal for the first observation of CEνNS with NaI(Tl) crystal using the reactor anti-neutrinos under stable management.

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