

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

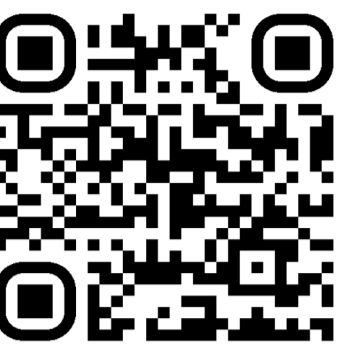
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On behalf of the NEON collaboration

NEUTRINO2024, Milano (Italy)

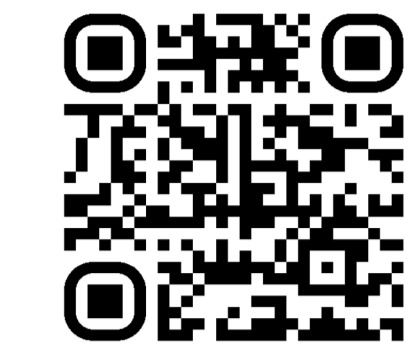
Crystal Encapsulation [arXiv:2404.03691]

NaI Quenching Factor [arXiv:2402.15122]



NEON Proposal [Eur. Phys. J. C 83, 226]

Waveform Simulation [arXiv:2402.17125]



Apr. 8, 2022

Reactor On Sep. 26, 2022

Off

Feb. 22, 2023

On

Physics run (~ 92.3% DAQ efficiency)

NEON Status

About the NEON experiment

Neutrino Elastic scattering Observation with NaI[NEON] is an experiment designed to detect coherent elastic neutrino-nucleus scattering[CEvNS] using reactor electron antineutrinos

COHERENT Collaboration

scattered neutrino

Z boson

nuclear recoil

secondary recoils

scintillation

COHERENT Collaboration

CEvNS was predicted by Daniel Z. Freedman. [Phys. Rev. D 9, 1389] (1974)

- First measurement by the COHERENT collaboration using spallation neutron source. [Science 357, 1123-1126] (2017)
- First measurement of CEvNS on Argon by the COHERENT collaboration. [Phys. Rev. Lett. 126, 012002] (2021)
- Measuring CEvNS has not been achieved by reactor neutrino.

[differential cross section]

$$\frac{d\sigma}{dT} \approx \frac{G_F^2}{2\pi} M \left[2 - \frac{MT}{E^2} \right] \frac{Q_W^2}{4} F^2(Q) \rightarrow \frac{d\sigma}{dT} \propto N^2$$

G_F : Fermi constant
 T : nuclear recoil kinetic energy
 M : mass of nucleus
 $Q =$ momentum transfer
 $Q_W^2 \sim N^2$: weak nuclear charge
 $F^2(Q)$: Form factor ($F = 1$, full coherence)
 N : neutron number
 Z : proton number

NEON will

Republic of Korea Hanbit Nuclear Power Plant, Yeonggwang

Neutrino Flux

Neutrino energy [MeV]

Recoil Energy [keV]

Neutrino energy [MeV]

Neutrinos are produced in beta decays of fission fragments.

- Single flavor ($\bar{\nu}_e$, electron anti-neutrino)
- High flux: $10^{12} \sim 10^{13} \nu/cm^2 s$
- $E_\nu < 10$ MeV \rightarrow fully coherent regime
- Clean in background, active and passive shielding
- Recoil energy is less than few keV.
- Signal quenched \rightarrow Require very low threshold

Site: Hanbit Nuclear Power Plant Unit 6 Tendon gallery
 23.7-m baseline & 20-m.w.e overburden
 Reactor power: 2.815 GW_{th}
 Neutrino($\bar{\nu}_e$) flux at NEON site: $8.1 \times 10^{12} \text{ cm}^{-2} \text{ s}^{-1}$

Crystal Detector Performance

NaI(Tl) Crystals

- 6 NaI(Tl) detectors (total mass of 16.7 kg)
- Encapsulation R&D for increasing light yields[LY].
- ~15 PE/keV [COSINE-100]
- \rightarrow ~23 PE/keV [prototype encasing]
- \rightarrow ~23.7 PE/keV [DET-2]
- * PE: Photoelectrons

Enhancing LYs to lower the energy threshold.

The crystals' LYs remained stable.

DET-4 light yield monitoring

Light Yield [PEs/keV]

Date

Details of crystal information

Detector	Mass (kg)	Size (inch, D x L)	Light yield w/o low gain (PEs/keV)	Light yield w/ low gain (PEs/keV)
DET-1	1.67	3 X 4	22.0 ± 0.4	25.3 ± 0.6
DET-2	3.34	3 X 8	25.6 ± 1.1	27.8 ± 1.4
DET-3	1.65	3 X 4	21.8 ± 0.5	23.3 ± 0.9
DET-4	3.34	3 X 8	23.7 ± 0.4	25.4 ± 0.7
DET-5	3.35	3 X 8	22.4 ± 0.5	23.6 ± 0.8
DET-6	3.35	3 X 8	25.0 ± 0.5	27.9 ± 0.7

Data acquisition

Physics data taking since April 2022.

Engineering run for (May 2021 ~ April 2022)

- 92.3% DAQ efficiency
- exposure : 11142.2 kg x day
- ON / OFF data : 523.2 / 144 days

16.7 days (2.3%) Reactor ON
 38.4 days (5.3%) Reactor OFF
 144.0 days (19.9%) Bad Runs
 523.2 days (72.4%) DOWN

Days since 2022-04-11

100% Efficiency
 DAQ ON
 Good Runs

ON OFF ON

Exposure (kg-day)

Background Modeling

Single Hit Spectrum (reactor OFF)

Counts/day/kg/keV

Energy [keV]

Crystal Internal Contaminants
 Cosmogenics
 External Components (shields)
 External Components (LS)
 External Components (PMT)

Sideband background data agrees well with Geant4 detector simulation.

Waveform Simulation

physics waveform

ADC counts

Time [ns]

Physics data

simulation waveform

ADC counts

Time [ns]

Simulated data

PMT gain
 DAQ Specification
 Trigger condition
 SPE shape
 SPE timing
 Probability

Distributions of pulse shape discrimination parameters [y-axis: Number of events]

Crystal-based Mean Time [μs]

Likelihood parameter

Maximum Cluster Ratio

Event selection Status

The data is being analyzed by separating it into high and low energy regions

- BDT for high energy region (≥ 0.6 keV)
- MLP for low energy region (≥ 5 PE)

Variables

- Time difference (Δt)
- Cluster charge
- Charge asymmetry

Example of Δt

Number of Cluster (N_c) = N

Event rate distribution

Reactor OFF

$N_c = 5$ $N_c = 6$ $N_c = 7$

w/o dead time

w/ dead time

COSINE-100 w/o cut

After MLP Cut

Extraction of scintillation signals

- Chi-square formula
- 1% for exposure time σ_t
- Testing w/ multiple-hit events for bias check
- Extraction w/ single-hit events will be done soon

On-Background

$N_{scint} = -13.9 \pm 16.5$

$N_{scint} = 0.95 \pm 8.21$

Light Dark Matter

- DM mass below few MeV/c²
- Massive gauge boson (vector portal)
- Dark photon mixes kinetically(ϵ) with Standard Model particles.
- LDM produced by dark photons provides strong constraints in the keV mass range.

Dark photon(A') production

Decay into dark matter

[Invisible decay]

Not depend on ϵ
 Requires $m_{A'} > 2m_\chi$

DM-e scattering

ALPs (a) Decay

ALPs (a) production

[Primakoff]

[Compton-like]

[DM mass, σ_e] plane (90% C.L.)

DM-electron cross section, σ_e [cm²]

DM mass, m_χ [MeV/c²]

Total ON-OFF Energy Spectrum with Fit Result

On - Off [Counts/day/kg/keV]

Energy [keV]

Dark Sector Particle Search

Reactor Core

Experiment Site

DM-e scattering

ALPs (a) Decay

ALPs (a) production

[Primakoff]

[Compton-like]

$g_{\gamma\gamma}$ (95% C.L.)

g_{ee} (95% C.L.)

Axion mass [eV/c²]

Axion-Like Particles

- Extension of the QCD axion
- Interacting with leptons from the SM and EM field
- Axion-Like Particle(ALP) searches in NEON cover "cosmological triangle".

$g_{\gamma\gamma}$ (95% C.L.)

g_{ee} (95% C.L.)

Axion mass [eV/c²]