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

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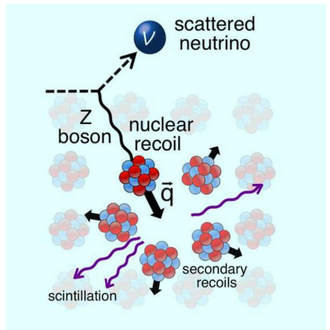
On behalf of the NEON collaboration

Motivation

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)

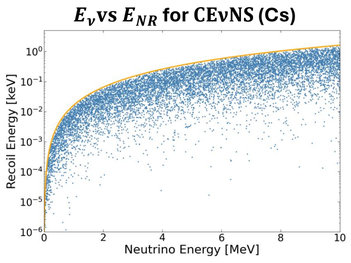


- **Predicted in 1974** by Daniel Z. Freedman [Phys. Rev. D 9, 1389] (1974)
- **First measurement** by the **COHERENT** collaboration using **spallation neutron source.** [Science 357, 1123-1126] (2017)]

$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi}\left[\overbrace{N}^{\sim N^2} - (1-4\sin^2\theta_w)Z\right]^2 F^2(q^2)\mathrm{M}\left(1-\frac{MT}{2E_\nu^2}\right)$$

G_F : Fermi coupling constant
Z : Atomic number of the nucleus
N : Neutron number of the nucleus
E_ν : Neutrino energy
θ_w : Weak mixing angle
$F(q)$: form factor
M : Mass of the nucleus

E_ν vs E_{NR} for CEνNS (Cs)

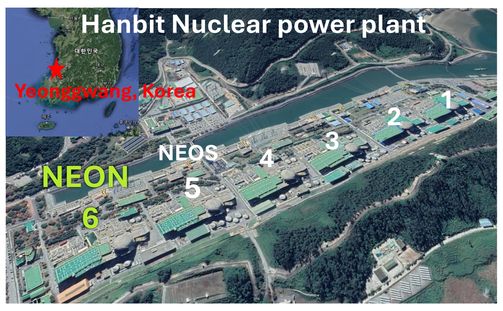


- **CEνNS @ Reactor**
  - **Single flavor** ($\bar{\nu}_e$)
  - **High flux** : $10^{12}\sim10^{13}\ \nu/\mathrm{cm}^2\mathrm{s}$
  - **Fully coherent** regime ($E_\nu < 10$ MeV)
  - **Few keV recoil energy** and **signal quenched**

  →**Require very low threshold**

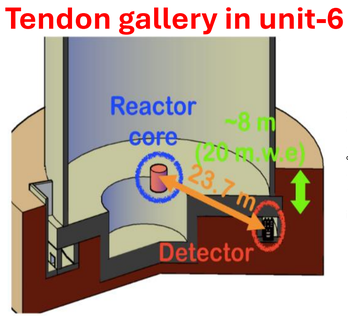
NEON experiment

Neutrino Elastic scattering Observation with NaI

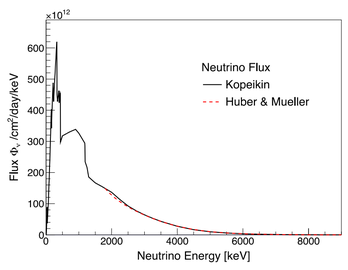


- **Hanbit Nuclear power plant** in **Korea**
- **Unit-6**
  - **2.8 GW** thermal power

Tendon gallery in unit-6

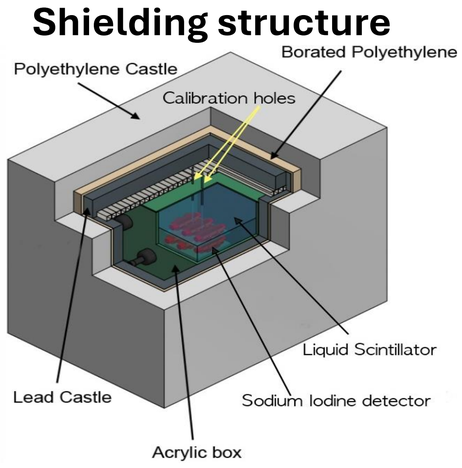


Neutrino flux



- **Tendon gallery**
  - **23.7 m** from **reactor core**
  - **20-m.w.e overburden**
  - **Neutrino flux :** $8.1\times10^{12}\mathrm{cm}^2\mathrm{s}^{-1}$

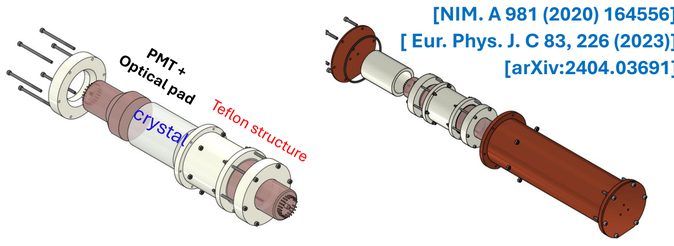
Shielding structure



- **Passive shield**
  - 10 cm **Lead**
  - 20 cm **Polyethylene**
  - 2.5 cm **borated-Polyethylene**
- **Active shield**
  - 800 L **LAB base Liquid Scintillator (LS)**

NEON detector

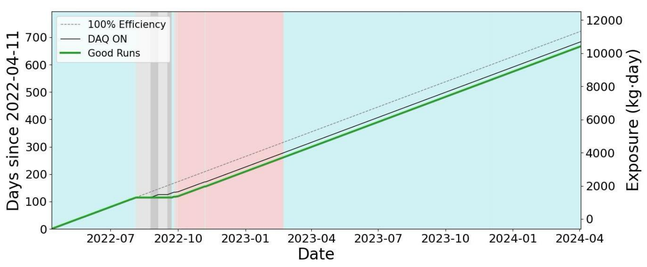
[NIM. A 981 (2020) 164556]
[Eur. Phys. J. C 83, 226 (2023)]
[arXiv:2404.03691]

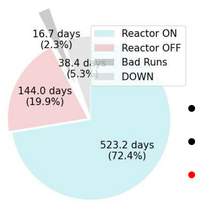


- **6 commercial** NaI(Tl) crystals – **16.6 kg**
- **Direct contact with PMT and crystal**
  - **Light yield ~24 photoelectron(PE)/keV**

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

Operation





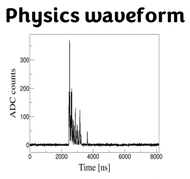
- **Reactor on: 523 days**
- **Reactor off: 144 days**
- **~11,000-kg·days exposure**

The largest exposure from all reactor CEνNS search experiments!

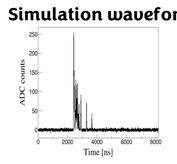
Event selection

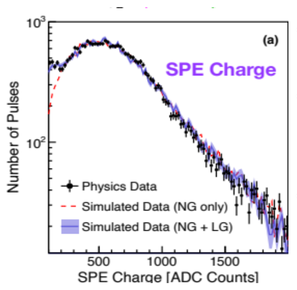
Waveform simulation [NIM A 1065 (2024) 169489]

Physics waveform

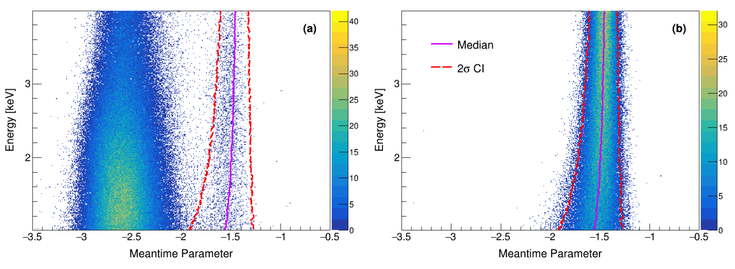


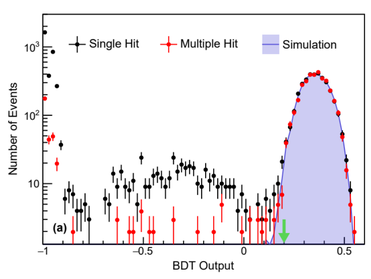
Simulation waveform



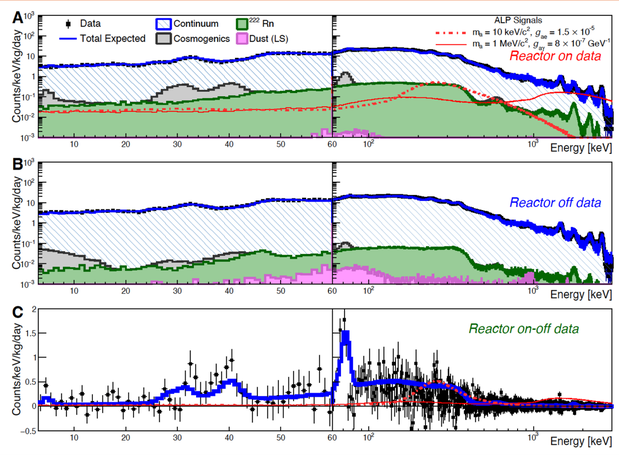


- Consider **Multiplier process** (PMT), **digitizing** (ADC) & **triggering** (TCB)
- **Tuning simulation**
  - Single photoelectron (SPE) properties
  - Low-gain SPE
- **Use for event selection**
  - - **BDT** for high energy region (≳0.6 keV)
  - - Separate analysis for **low energy region** (≳ 5 NPE)





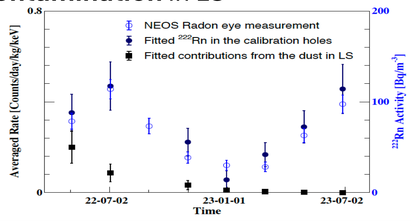
Background modeling



GEANT4 based Monte Carlo simulation

- **Internal** backgrounds
- **Surface** contaminant
- **Cosmogenic** activation
- **External** backgrounds

+ **Seasonal variation** of ^{222}Rn in calibration holes
+ **Dust contamination** in LS [arXiv:2406.06117]

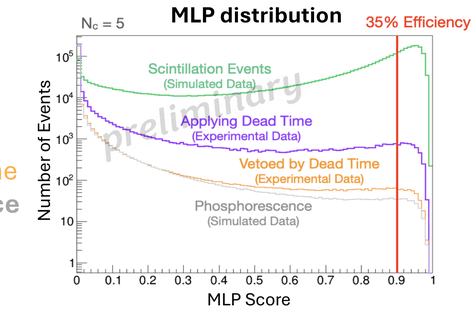


CEνNS Search Analysis

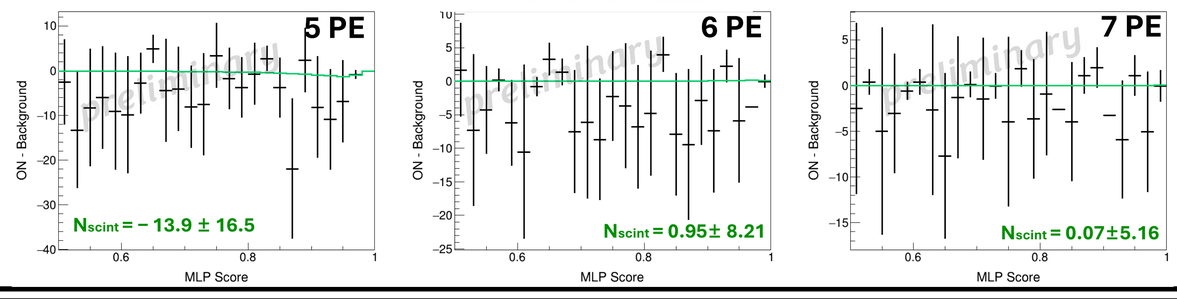
Use machine learning

- **Multilayer perceptron (MLP)**
- **Variables** : Time differences, Cluster charges, Charge asymmetry
- **Samples**
  - **Experimental data** : w/ deadtime, Vetoed by deadtime
  - **Simulation sample** : **Scintillation**, Phosphorescence
- **Chi-square fitting** to extract **scintillation**
- **Testing** w/ **multiple-hit** events for bias test

MLP distribution



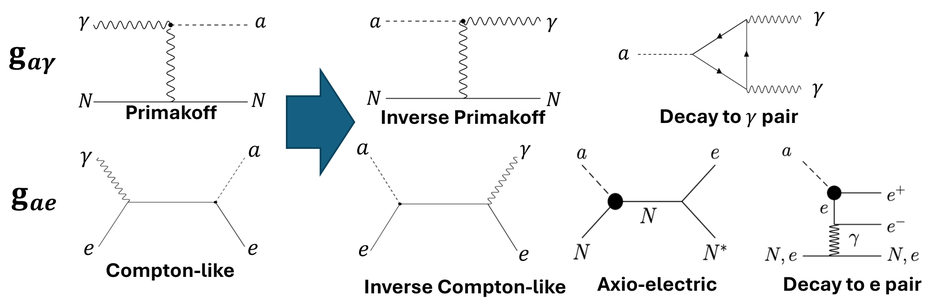
Fit to On-Off data



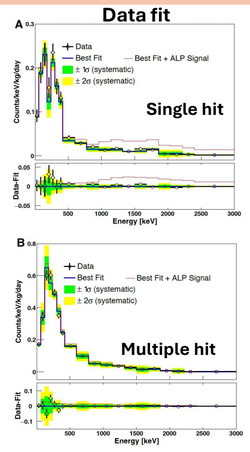
Dark sector analysis

Axion-Like Particle(ALP) search [arXiv:2406.06117]

Reactor core **Detector**

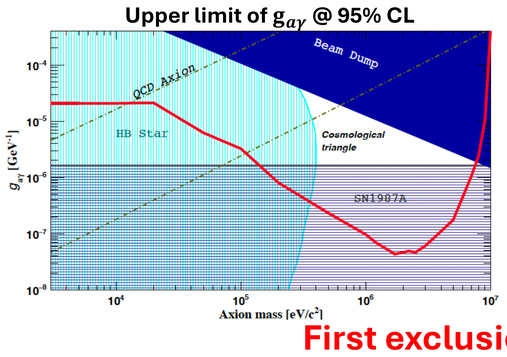


Data fit

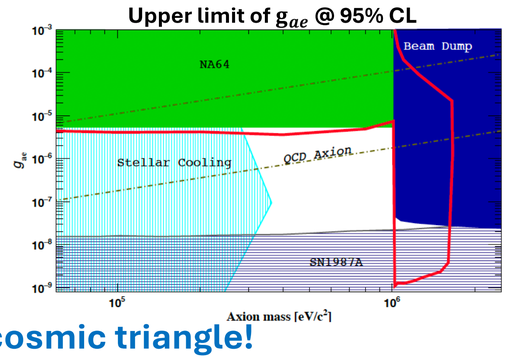


- Consider **ALP** coupling with **photon** ($g_{a\gamma}$) and **electron** (g_{ae})
- Fit to **On-Off data** in **3 ~3000 keV** region

Upper limit of $g_{a\gamma}$ @ 95% CL



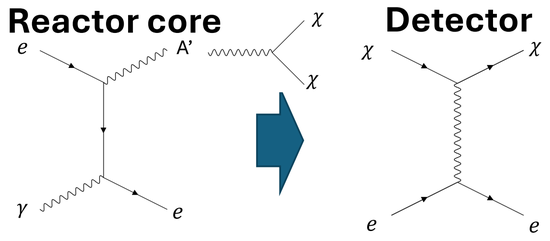
Upper limit of g_{ae} @ 95% CL



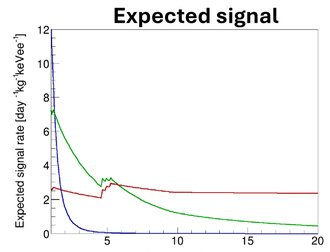
First exclusion to cosmic triangle!

Dark-photon search

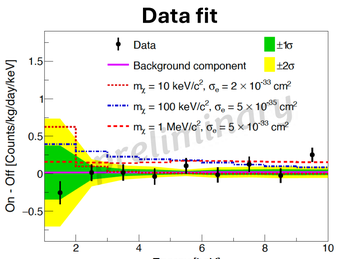
Reactor core **Detector**



Expected signal

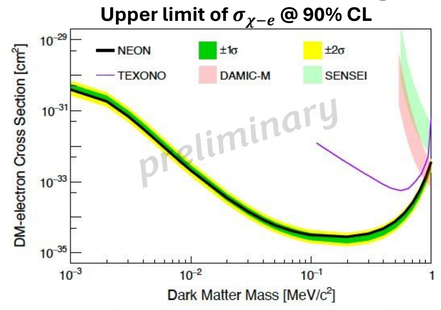


Data fit

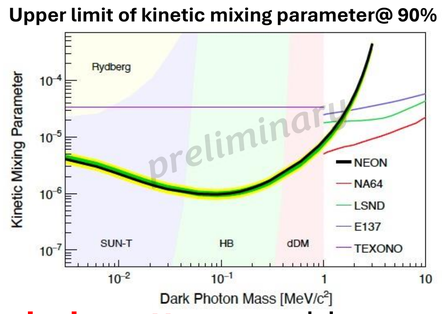


- Assume $m_{A'} = 3m_\chi$
- **Signal** from **dark matter scattering off electrons** in the detector
- Fit to **On-Off data** in **1~20 keV region**

Upper limit of $\sigma_{\chi-e}$ @ 90% CL



Upper limit of kinetic mixing parameter@ 90% CL



Lowest limit for direct **low mass dark matter** search!

Summary

- **NEON** experiment is stably operating to observe **CEvNS of reactor neutrino** using **NaI(Tl) crystal** at Hanbit Nuclear Power Plants.
  - **523 (143) days** of reactor **on** (**off**) data
- **CEvNS search analysis** is ongoing with **event selection** and **background modeling.**
- **Dark Sector analyses** are performed with **on-off data.**
  - **First exclusion** to **cosmic triangle** in **ALP** search
  - **Lowest limit** for the **low mass dark matter** range in laboratory experiments