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

NEON Proposal [Eur. Phys. J. C 83, 226] | Waveform Simulation [arXiv:2402.17125]

Byoung-cheol Koh

Dept. of Physics, Chung-Ang University

On behalf of the NEON collaboration

Crystal Encapsulation [arXiv:2404.03691] | NaI Quenching Factor [arXiv:2402.15122]

NEUTRINO2024, Milano (Italy)

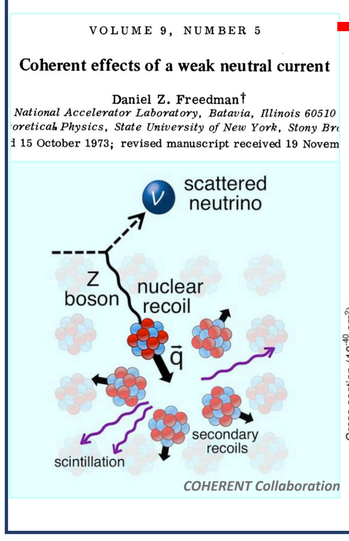
NEON Status

Apr. 8. 2022 — **Reactor On** — Sep. 26. 2022 — **Off** — Feb. 22. 2023 — **On**

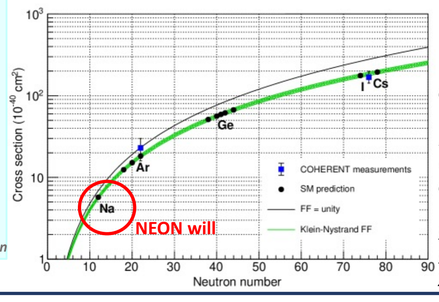
Physics run (~ 92.3% DAQ efficiency)

About the NEON experiment

Neutrino **E**lastic scattering **O**bservation with **N**aI[**NEON**] is an experiment designed to detect **c**oherent **e**lastic **n**eutrino-**n**ucleus **s**cattering[**CEvNS**] using reactor electron antineutrinos



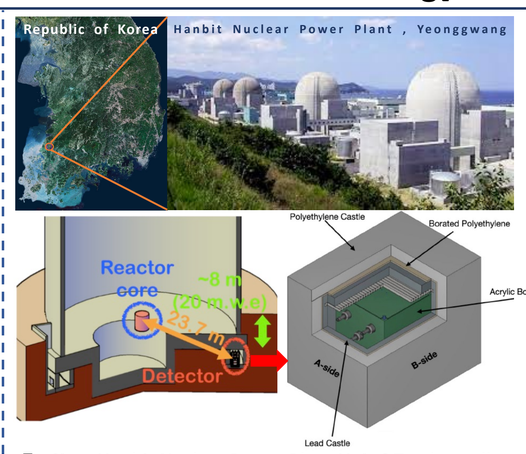
- **CEvNS** was predicted by Daniel Z. Freedman. *[Phys. Rev. D 9, 1389] (1974)*
- First measurement by the COHERENT collaboration using spallation neutron source. *[Science 357, 1123-1126] (2017)*
- First measurement of CEvNS on Argon by the COHERENT collaboration. *[Phys. Rev. Lett. 126, 012002] (2021)*
- Measuring CEvNS has not been achieved by **reactor neutrino.**



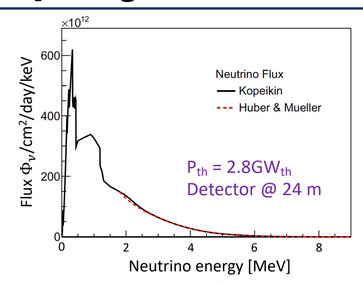
[differential cross section]

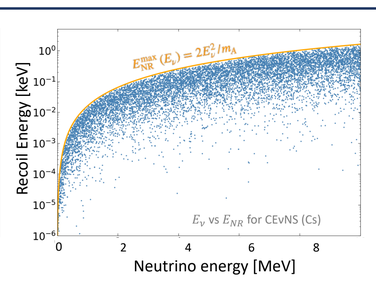
$$\left\langle \frac{d\sigma}{dT} \cong \frac{G_F^2}{2\pi} M \left[2 - \frac{MT}{E^2}\right] \frac{Q_W^2}{4} F^2(Q) \rightarrow \frac{d\sigma}{dT} \propto N^2 \right\rangle$$

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
$Q_W = (1 - 4sin^2\theta_W)Z - N$
$F^2(Q)$: Form factor (F= 1, full coherence)
N : neutron number
Z : proton number



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





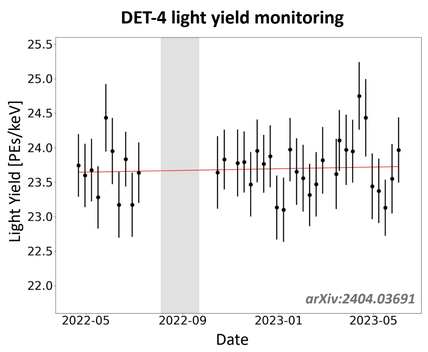
Neutrinos are produced in **beta decays** of fission fragments.

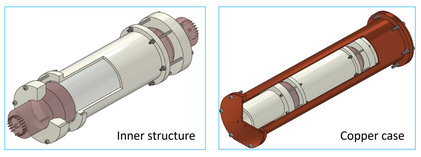
- **Single flavor** ($\bar{\nu}_e$, electron anti-neutrino)
- High flux : 10^{12}~10^{13} $\nu/\mathrm{cm}^2 s$
- E_ν< 10 MeV → **fully coherent** regime
- Clean in background, active and passive shielding
- **Recoil energy** is less than **few keV.**
- **Signal quenched** → Require **very low threshold**

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 PEs/keV [COSINE-100]
  - → ~23 PEs/keV [prototype encasing]
  - → **~23.7 PEs/keV [DET-2]**
  - ※ PEs : Photoelectrons





Details of crystal information

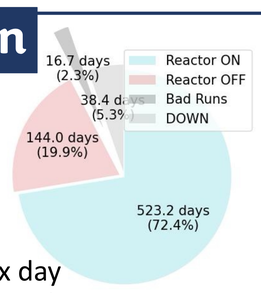
Detector	Mass (kg)	Size (inch, D X L)	Light yield w/o low gain (PEs/keV)	Light yield w/ low gain (PEs/keV)
DET-1	1.67	3 X 4	22.0 ± 0.4	25.3 ± 0.6
DET-2	3.34	3 X 8	25.6 ± 1.1	27.8 ± 1.4
DET-3	1.65	3 X 4	21.8 ± 0.5	23.3 ± 0.9
DET-4	3.34	3 X 8	23.7 ± 0.4	25.4 ± 0.7
DET-5	3.35	3 X 8	22.4 ± 0.5	23.6 ± 0.8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

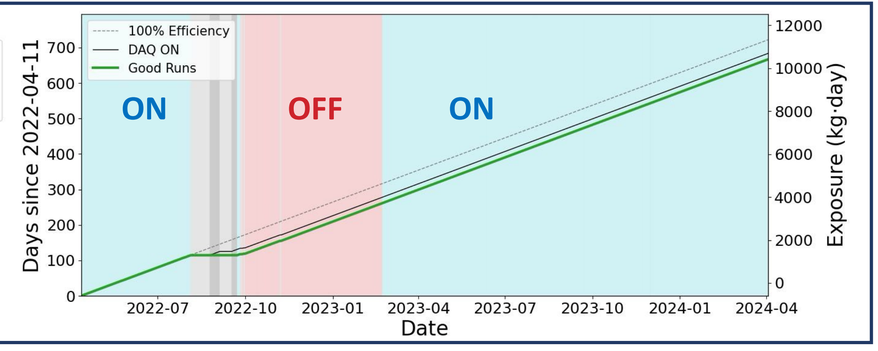
- Enhancing LYs to lower the energy threshold.
- The crystals' LYs **remained stable.**

Data acquisition

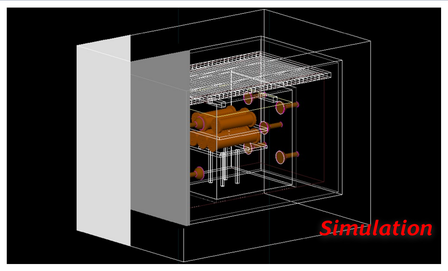
Physics data taking since April 2022.
Engineering run for (May 2021 ~ April 2022)

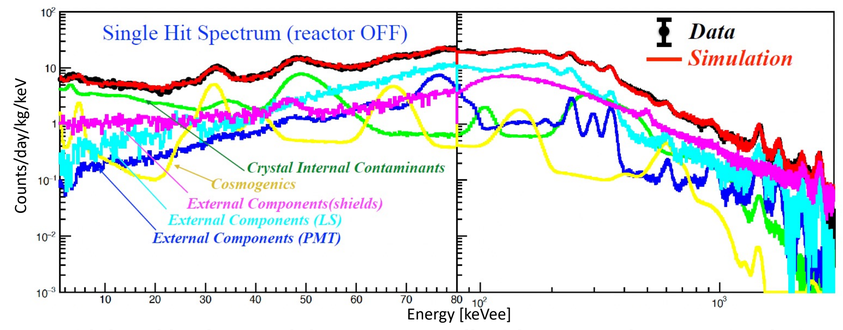
- 92.3% DAQ efficiency
- exposure : 11142.2 kg x day
  - ➢ **ON** / **OFF** data : 523.2 / 144 days





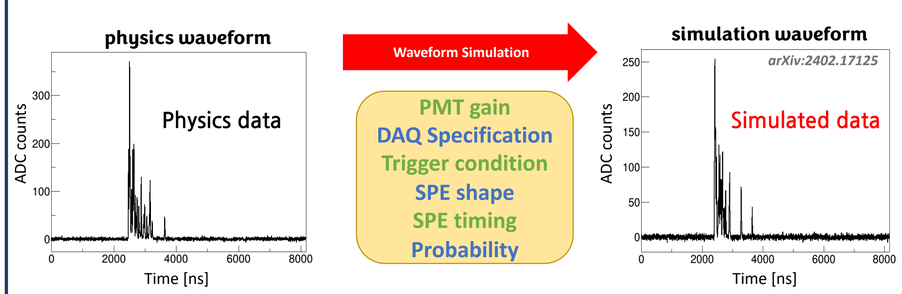
Background Modeling



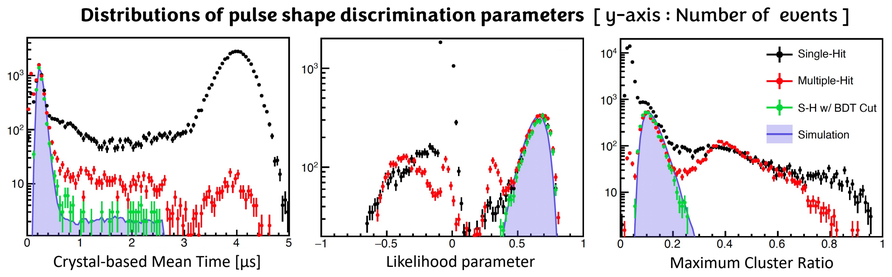


Sideband background data agrees well with Geant4 detector simulation.

Waveform Simulation



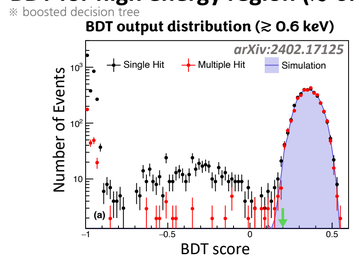
Distributions of pulse shape discrimination parameters [y-axis : Number of events]

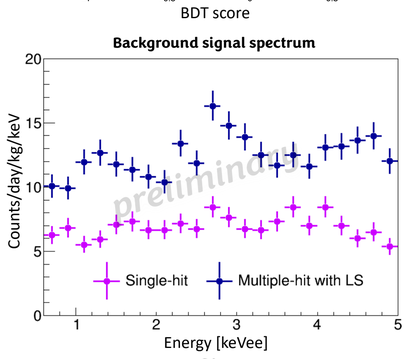


Event selection Status

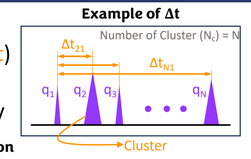
The data is being analyzed by separating it into high and low energy regions

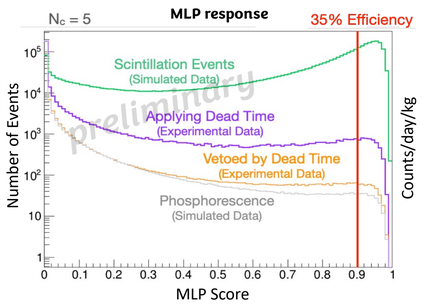
- **BDT for high energy region (≳ 0.6 keV)**
  ※ boosted decision tree

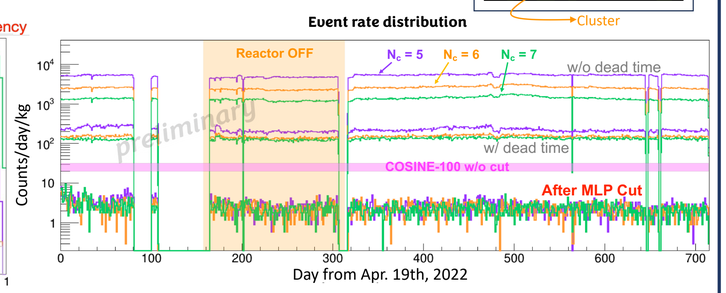




- **MLP for low energy region** (≳ 5 PEs)
  ※ multilayer perceptron
  - high μ rate → phosphorescence
  - Off-line dead time ➞ Dead time w/ high energy event
    - ➢ ~50% efficiency & 92~96% rejection
- Variables
  - Time difference(Δt)
  - Cluster charge
  - Charge asymmetry



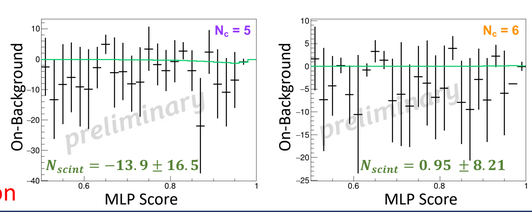




- **Extraction of scintillation signals**
  - Chi-square formula

$$\chi^2 = \sum_i \left(\frac{\left(M_i^{ON} - \tau M_i^{OFF} - \sum_j \beta_j B_j^i - \sigma S_i\right)^2}{M_i^{ON} + \tau^2 M_i^{OFF}} + \left(\frac{\tau - t_i^{ON}/t_i^{OFF}}{\sigma_t}\right)^2 \right)$$

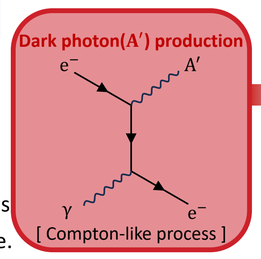
  - 1% for exposure time σ_t
  - Testing w/ multiple-hit events for bias check
  - Extraction w/ single-hit events will be done soon

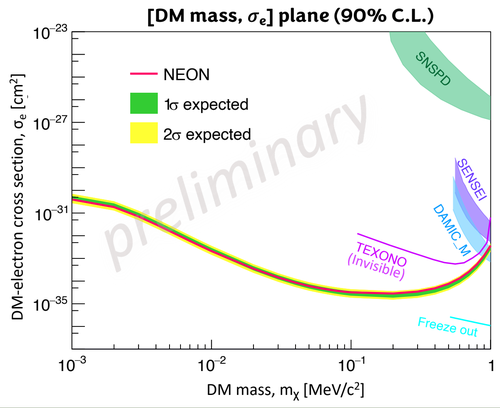


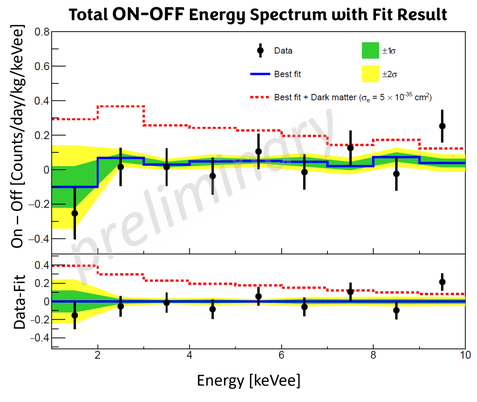
Dark Sector Particle Search

Light Dark Matter

- DM mass below few MeV/c^2
- 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.

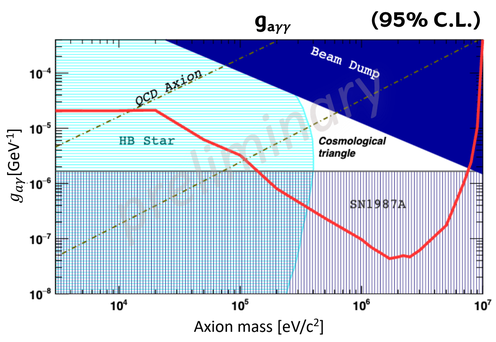


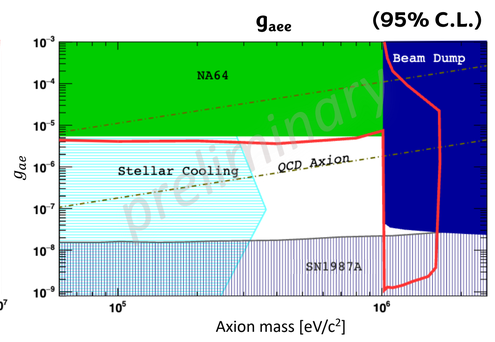




Axion-Like Particles

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





Should you have any questions, please feel free to contact us.
➢ E-mail : bckoh0719@gmail.com