

Status and Recent Developments of the **NEON** experiment



Byoung-cheol Koh

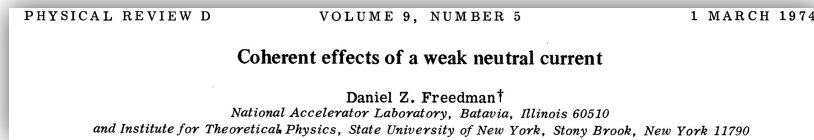
Chung-Ang University

On behalf of the NEON Collaboration

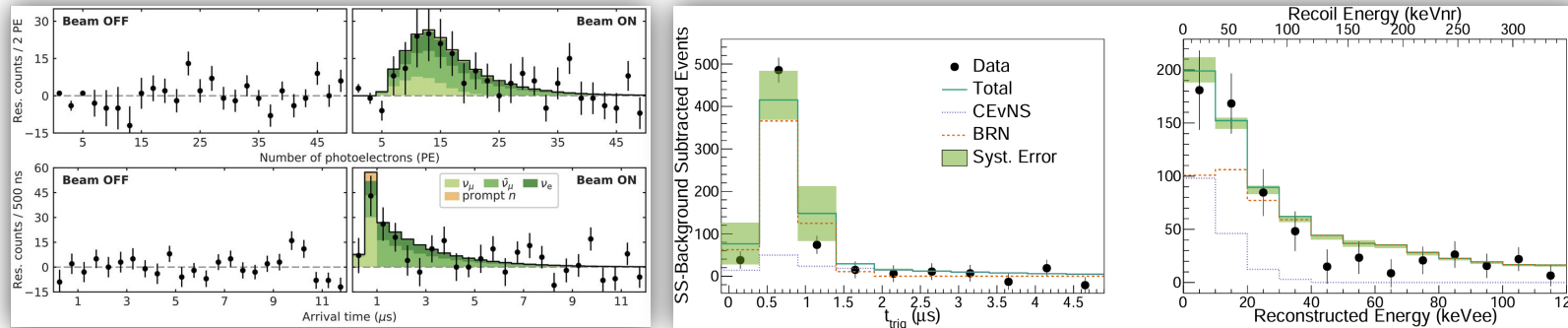
History of CE ν NS

□ CE ν NS (Coherent Elastic Neutrino(ν)-Nucleus Scattering)

- Predicted by D.Z. Freedman in 1974. [Phys. Rev. D 9, 1383]



- First measurement by the COHERENT collaboration in 2017.
(Stopped pion source, CsI[Na] target) [Science 357, 1123-1126], (LAr target, 2020) [Phys. Rev. Lett. 126, 012002]



- Observed by the XENONnT collaboration in 2024.
(Solar ^8B neutrinos, Liquid Xenon, 2.78σ) [Phys. Rev. Lett. 133, 191002]
- Observed by the CONUS+ collaboration in 2025.
(reactor neutrinos, HPGe, 3.7σ) [arXiv:2501.05206v2]

NEON Collaboration

□ Neutrinos Elastic scattering Observation with NaI(Tl)

- 19 collaborators in 6 institutes including active members of COSINE and NEOS

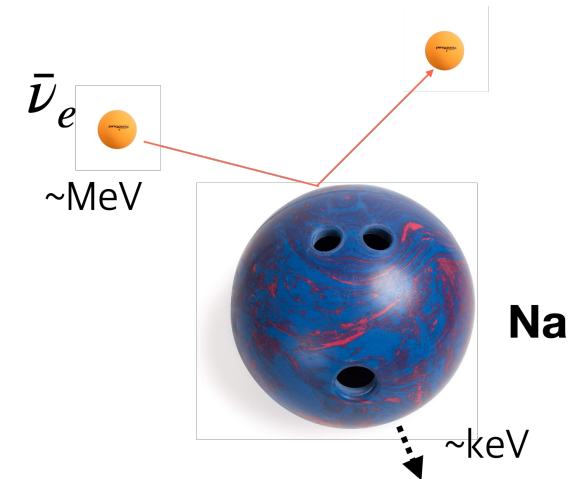
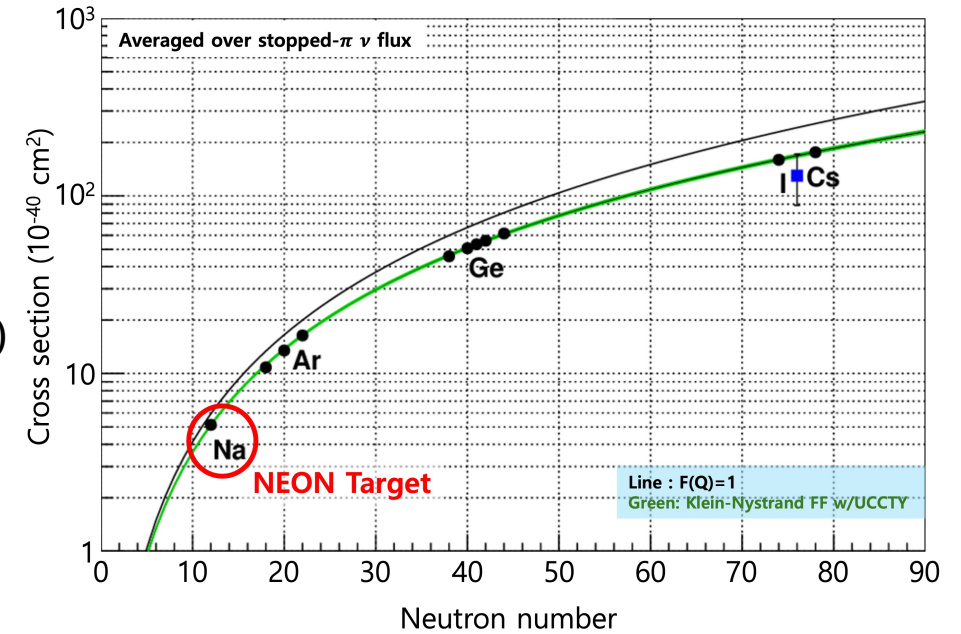


IBS Center for Underground Physics (CUP)
IBS School, University of Science and Technology (UST)
Seoul National University
Korea Atomic Energy Research Institute
Chung-Ang University
Jeju National University



Motivation

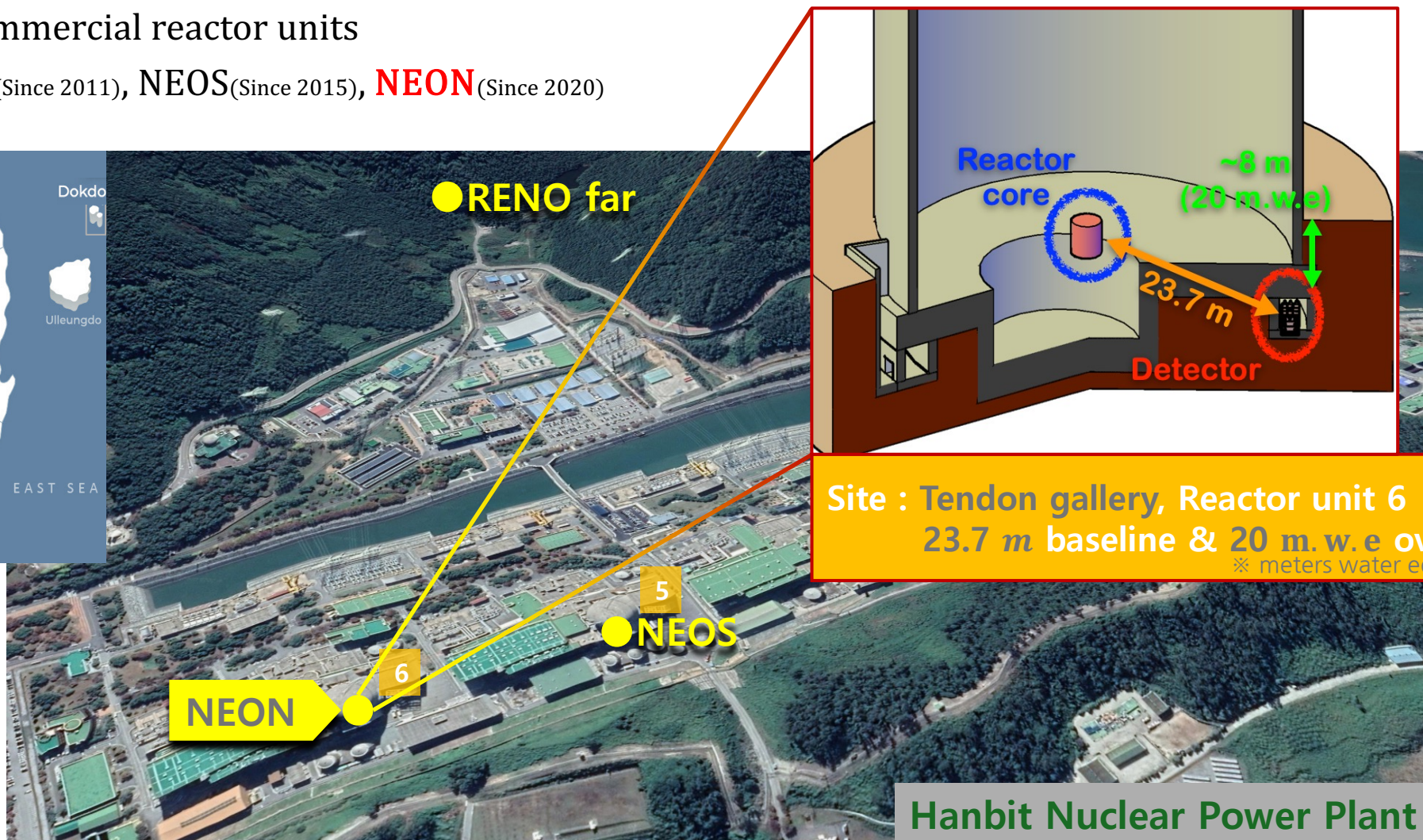
- ❑ Aim at detection of **CEvNS** with **reactor neutrinos** using **NaI(Tl)**
 - Single flavor (electron anti-neutrino)
 - N^2 dependence
 - Full coherency region & complementary observation
- ❑ Test for BSM physics parameters (Light DM, Axion Like Particle, etc)
 - Reactor produce a large amount of the photon flux
- ❑ Other physics contributes
 - MeV-scale Weinberg angle (θ_w)
 - Non-standard interaction
 - Reactor antineutrino anomaly, anomalous spectra of reactor neutrinos
 - Contribute to supernova research
 - etc ...



Experimental Site

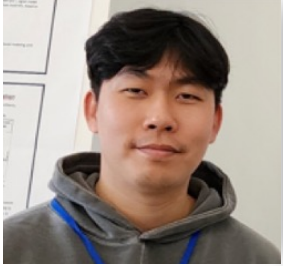
❑ Hanbit nuclear power plant in Yeonggwang, Republic of Korea

- Six commercial reactor units
- RENO (Since 2011), NEOS (Since 2015), **NEON** (Since 2020)



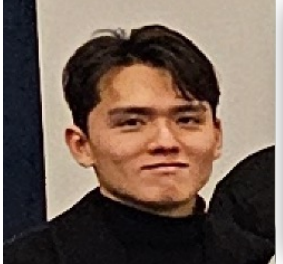
NEON Posters for K-Neutrino Symposium 2025

1. NEON Status by Byoung-cheol KOH



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

2. NEON Deep-learning(DL) & CEvNS Analysis by Gyunho Yu



Deep Learning Event Selection in NEON Experiment



K-neutrino Symposium

Gyunho Yu (IBS-CUP)

On behalf of NEON collaboration



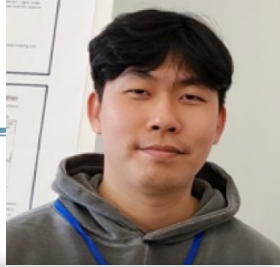
3. NEON Incoherent Neutrino(ν)-Nucleus Scattering progress by SeoHyun Lee



Incoherent Neutrino-Nucleus Scatterings Search with the NEON Experiment

2025K-Neutrino

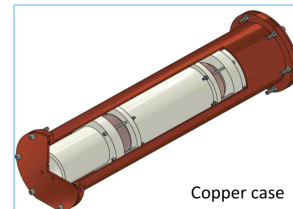
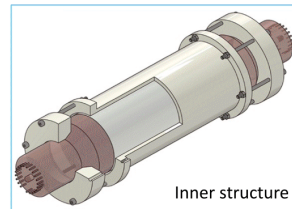
NEON Status - Detector



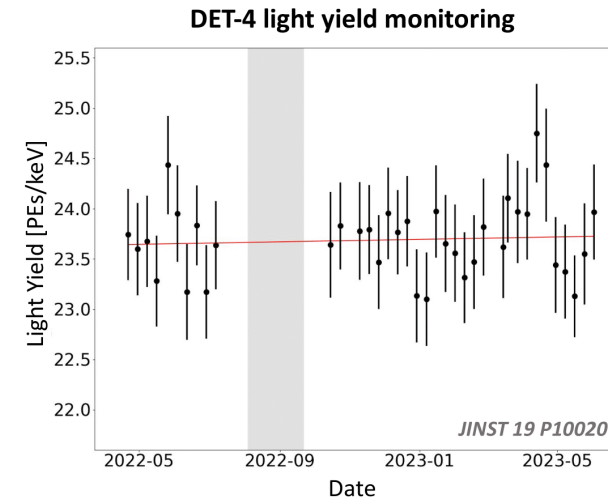
Crystal Detector Performance

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]
 - **~25.6 PEs/keV [DET-2]**
- ※ PEs : Photoelectrons

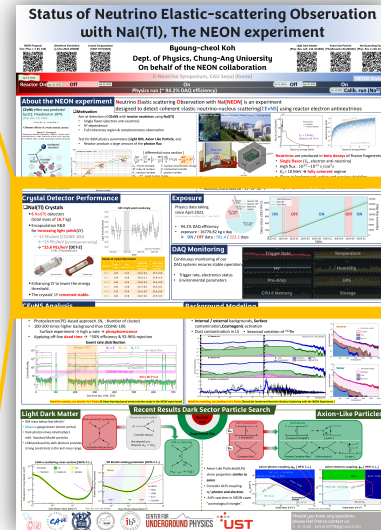


- Enhancing LY to lower the energy threshold.
- The crystals' LY **remained stable**.



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

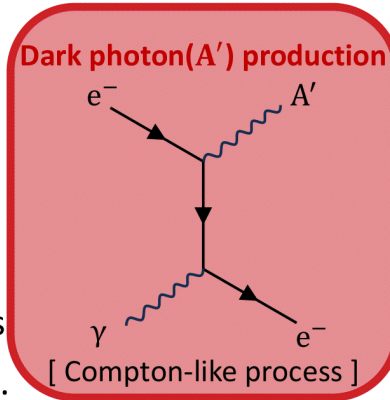


NEON Status – Light Dark Matter[LDM]

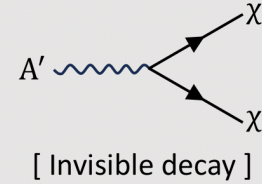


Light Dark Matter

- 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.

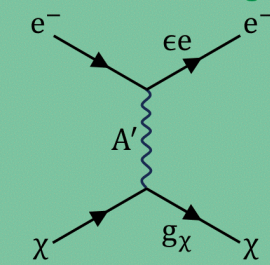


Decay into dark matter



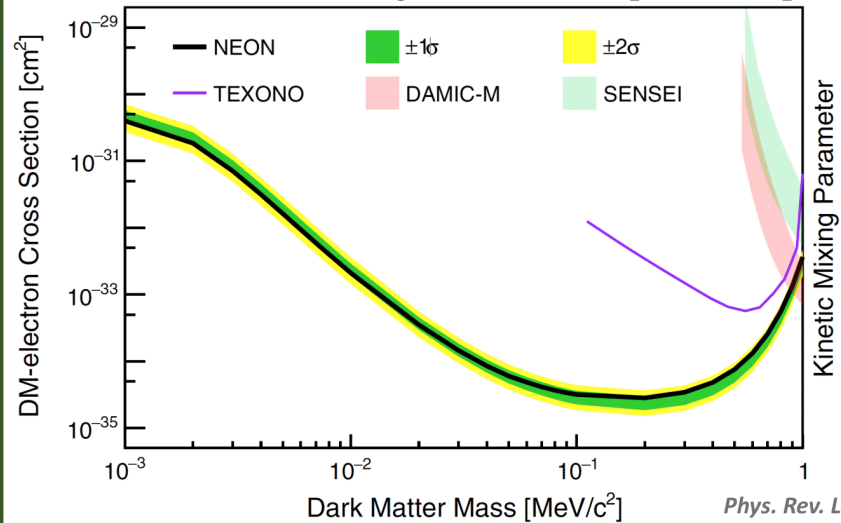
Not depend on ϵ
Requires $m_{A'} > 2m_\chi$

DM-e scattering

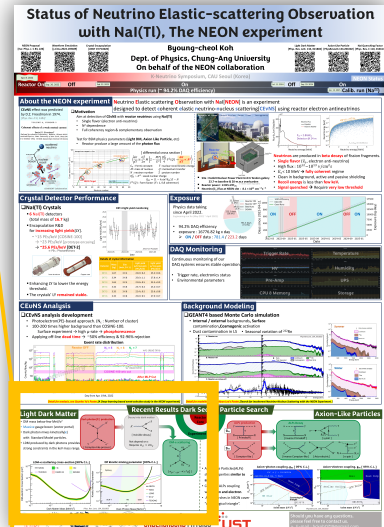
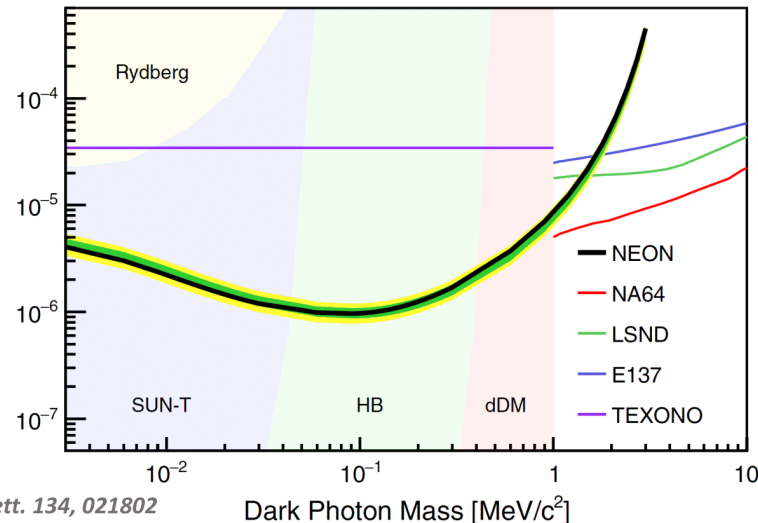


Experiment

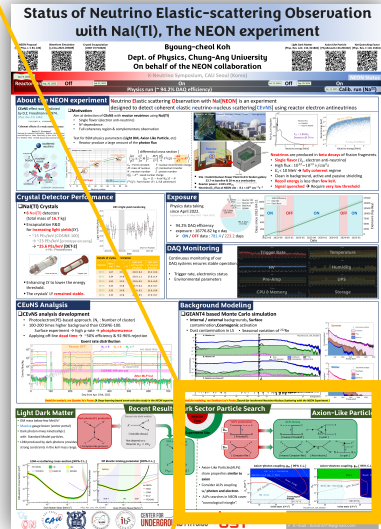
LDM-e scattering cross-section [90% C.L.]



DP kinetic mixing parameter [90% C.L.]

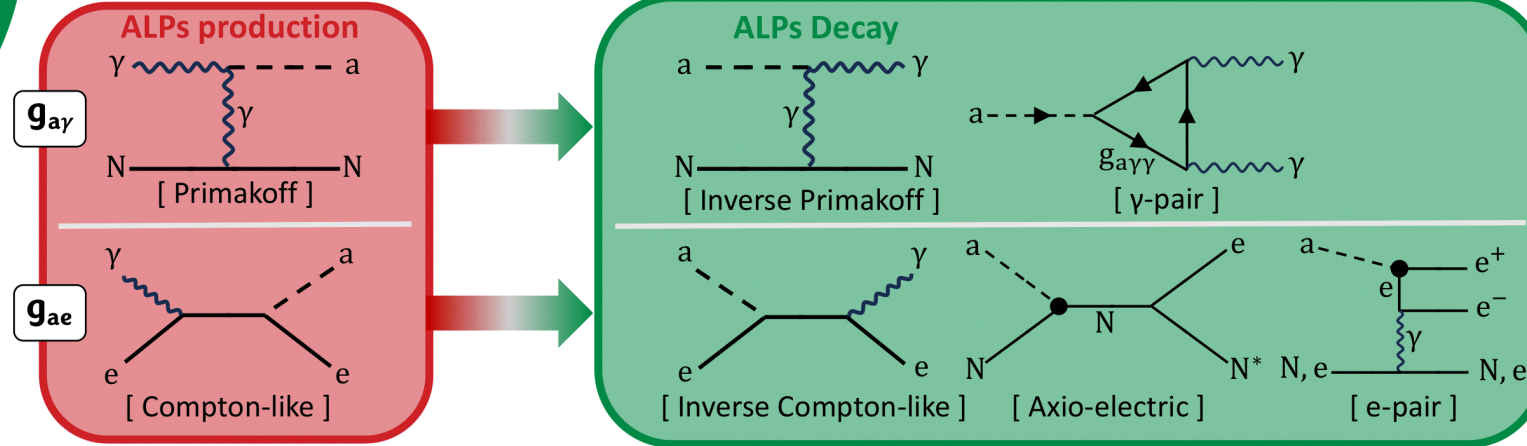


NEON Status – Axion-Like Particles [ALPs]

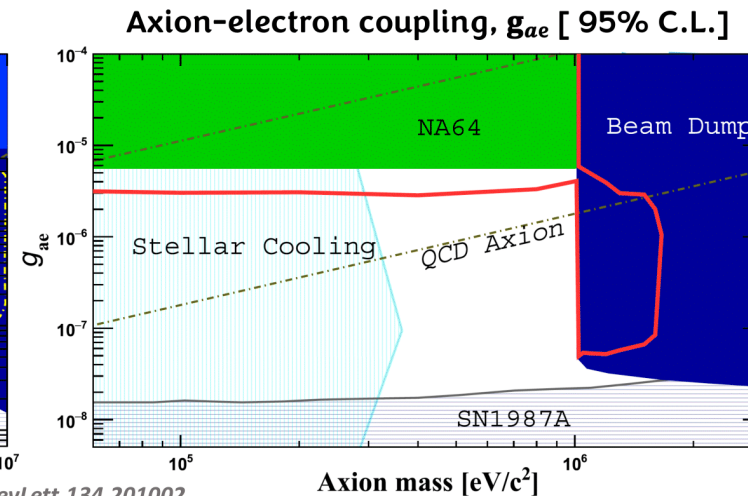
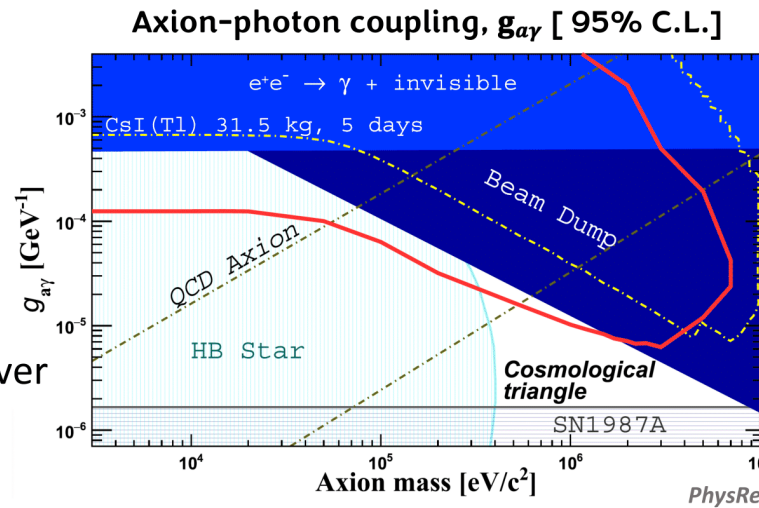


Sector Particle Search

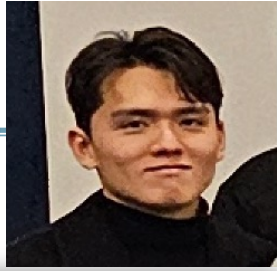
Axion-Like Particles



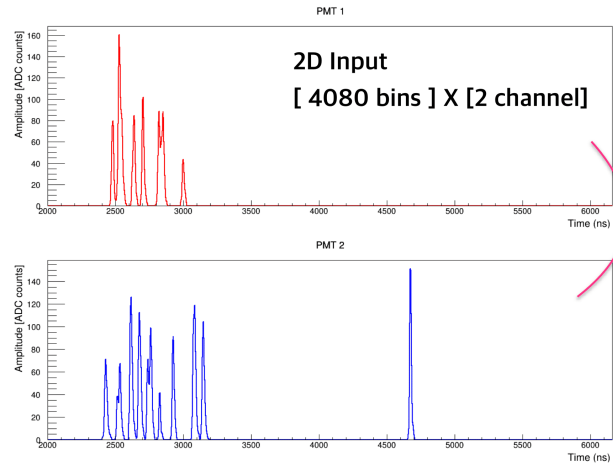
- Axion-Like Particles(ALPs) share properties **similar to axion**
- Consider ALPs coupling w/ **photon and electron**.
- ALPs searches in NEON cover “cosmological triangle”.



DL & CEvNS Analysis – ResNet CNN

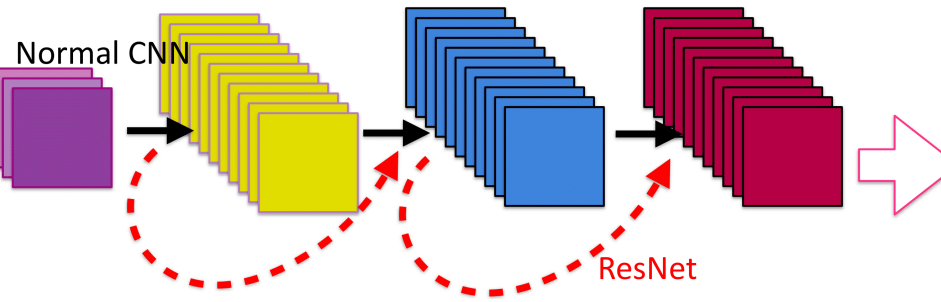


Deep learning strategy : ResNet CNN



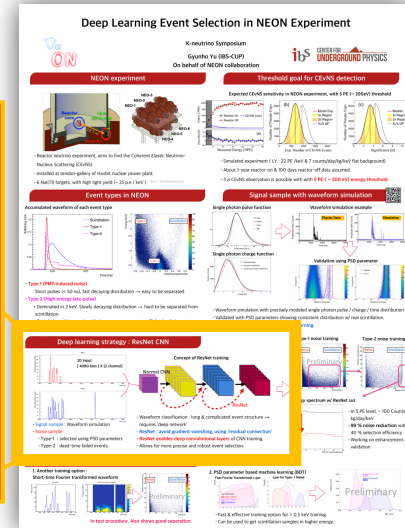
- **Signal sample** : Waveform simulation
- **Noise sample**
 - Type-1 : selected using PSD parameters
 - Type-2 : dead-time failed events.

Concept of ResNet training



- Waveform classification : long & complicated event structure → requires 'deep network'
- **ResNet** : avoid gradient-vanishing, using 'residual connection'
- **ResNet enables deep convolutional layers** of CNN training.
- Allows for more precise and robust event selection.

Recent results
will be
show you on
Poster Session



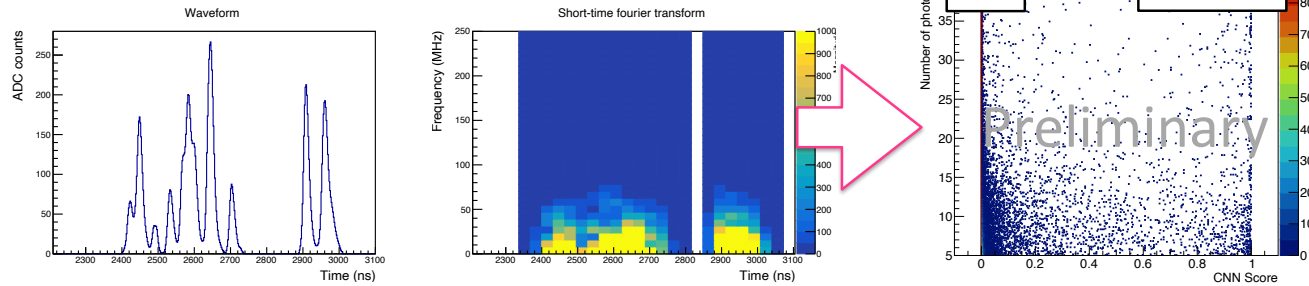
DL & CEvNS Analysis – Machine Learning



Another training strategies

1. Another training option :

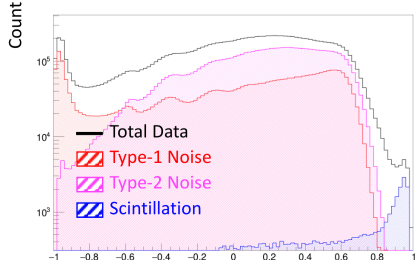
Short-time Fourier transformed waveform



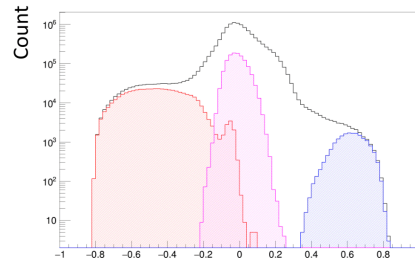
In test procedure. Also shows good separation.

2. PSD parameter based machine learning (BDT)

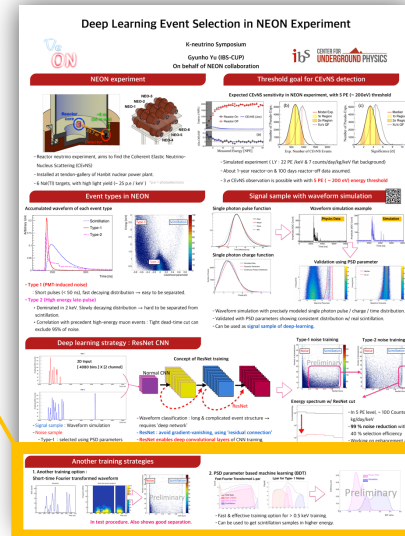
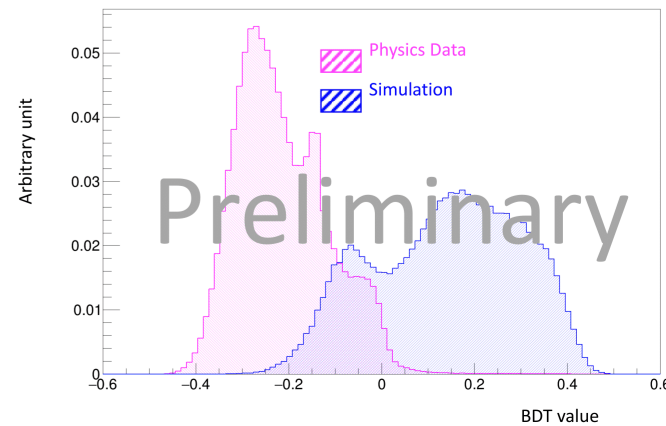
Fast Fourier Transformed L-par



Lpar for Type- 1 Noise



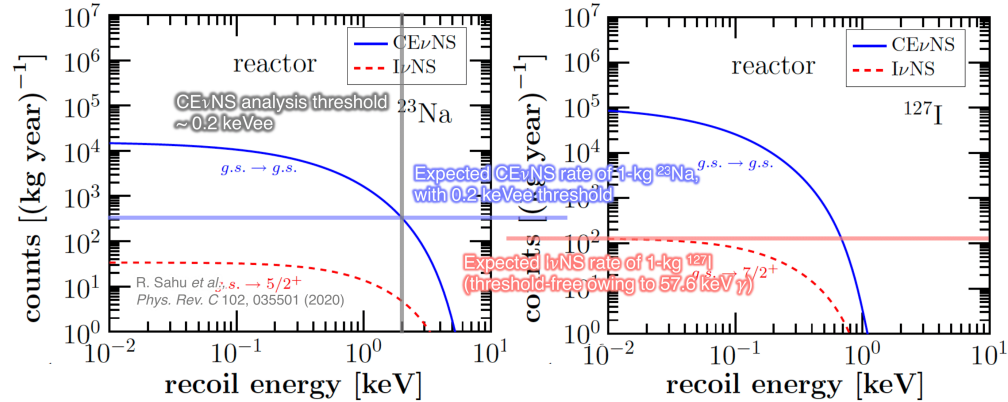
– Fast & effective training option.



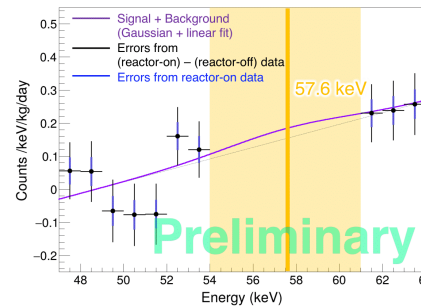
IvNS search – Our new project, IvNS



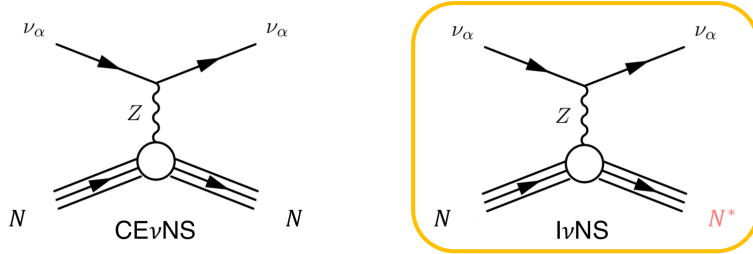
3. Physics Prospects in NEON



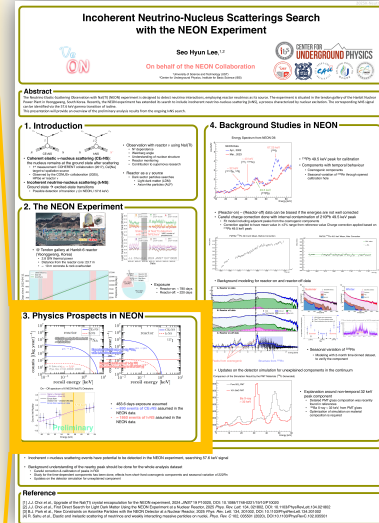
On - Off spectrum of 6 NEON NaI(Tl) Detectors



- 483.6 days exposure assumed
- ~ 890 events of CEvNS assumed in the NEON data
- ~ 1860 events of IvNS assumed in the NEON data



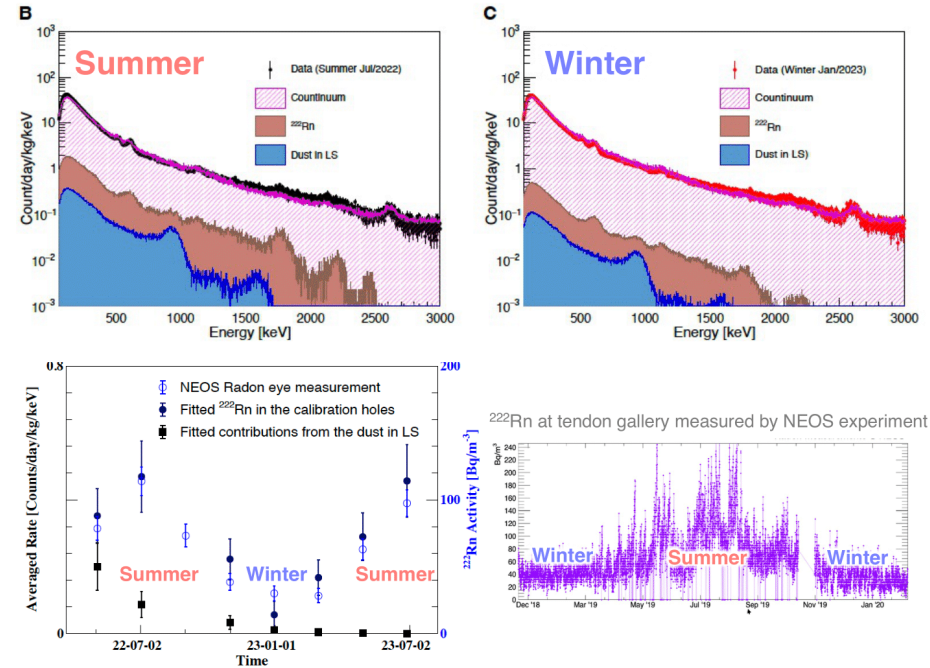
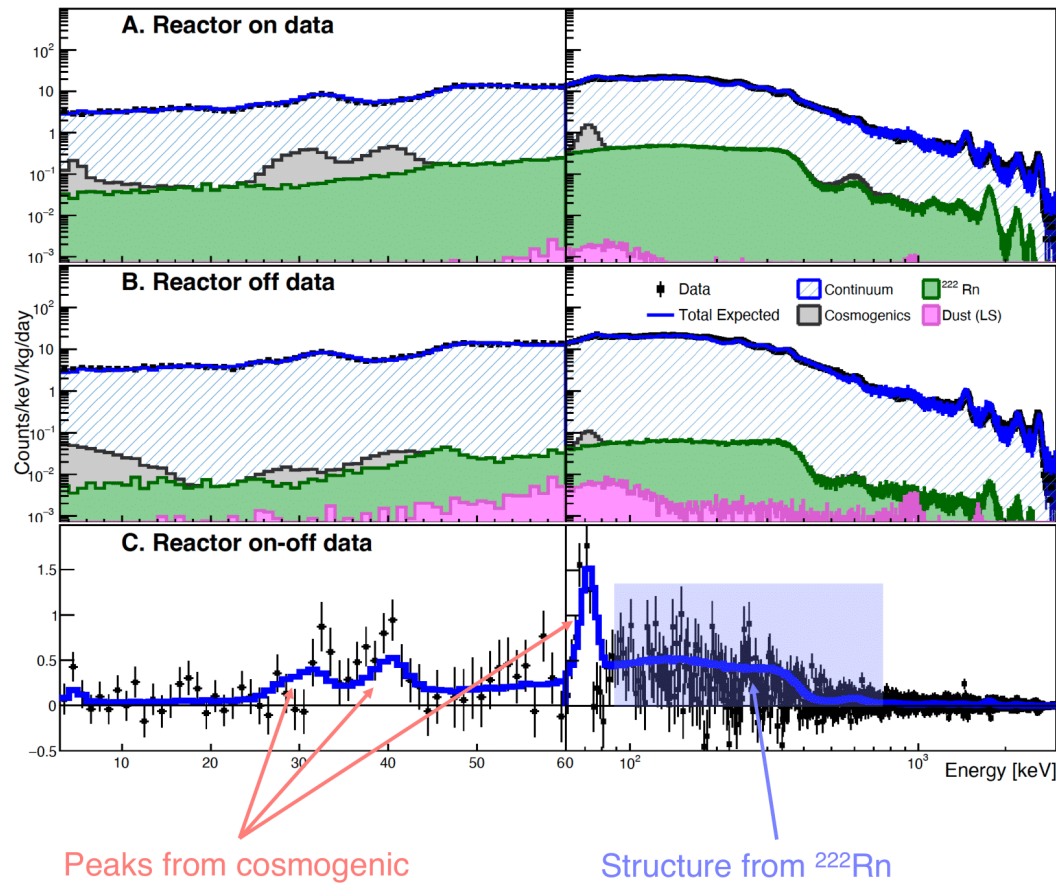
- **Coherent elastic ν -nucleus scattering (CEvNS):**
the nucleus remains at the ground state after scattering
 - 1st measurement: COHERENT collaboration (2017), CsI[Na] target w/ spallation source
 - Observed by the CONUS+ collaboration (2025), HPGe w/ reactor ν
- **Incoherent neutrino-nucleus scattering (IvNS):**
Ground state $\rightarrow$ excited-state transitions
 - Possible detection of transition γ (in NEON, I 57.6 keV)



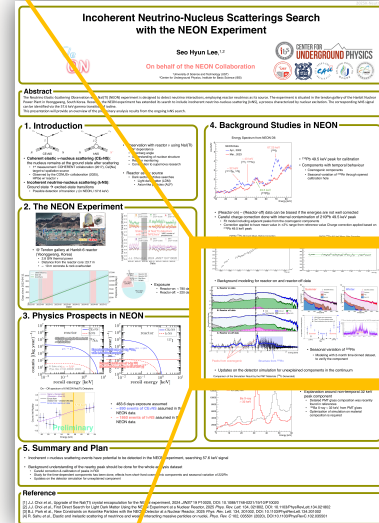
IvNS search – Background Modeling



- Background modeling for reactor-on and reactor-off data



- Seasonal variation of ^{222}Rn
 - Modeling with 2-month time-binned dataset, to verify the component



Summary

- The measurement of **CEvNS using reactor neutrinos** offers various opportunities for new physics.
- The NEON group aims to detect reactor neutrinos using a **NaI crystal detector** with a high light yield of **25.6 PEs/keV**.
- Reactor gamma rays have also been utilized for Dark Sector particle studies.
- Results on Light Dark Matter and Axion-Like Particle searches have been obtained.
- **Event selection via ResNet deep learning** in progress, targeting a **5 PE (~ 200 eV) threshold**.
- **Incoherent ν -nucleus scattering** at 57.6 keV under investigation in NEON.
- **Background understanding** of the nearby peak should be done for the whole analysis dataset.



Back up

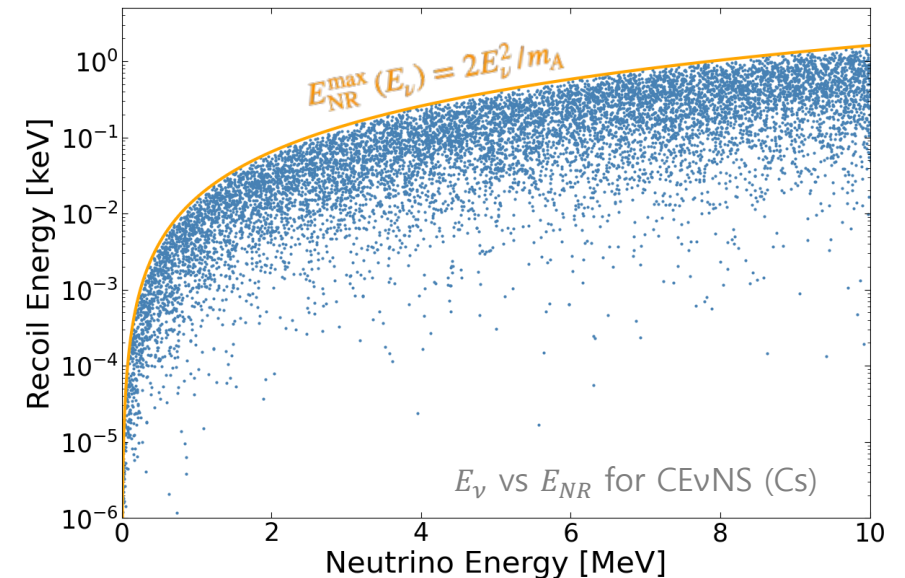
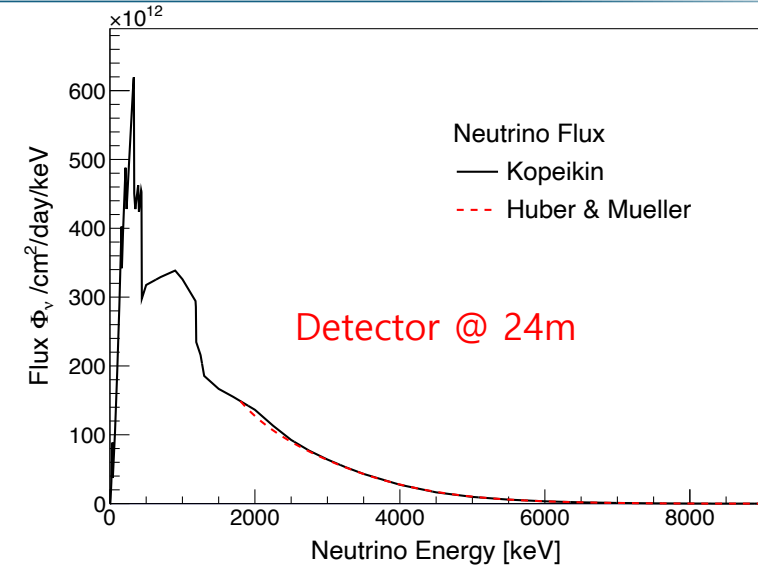
CEvNS of Reactor Neutrinos

☐ Neutrinos in reactor

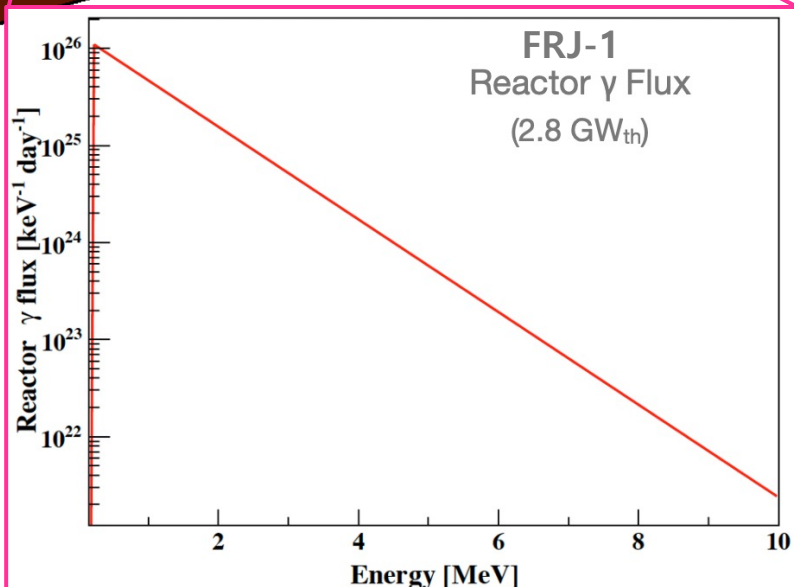
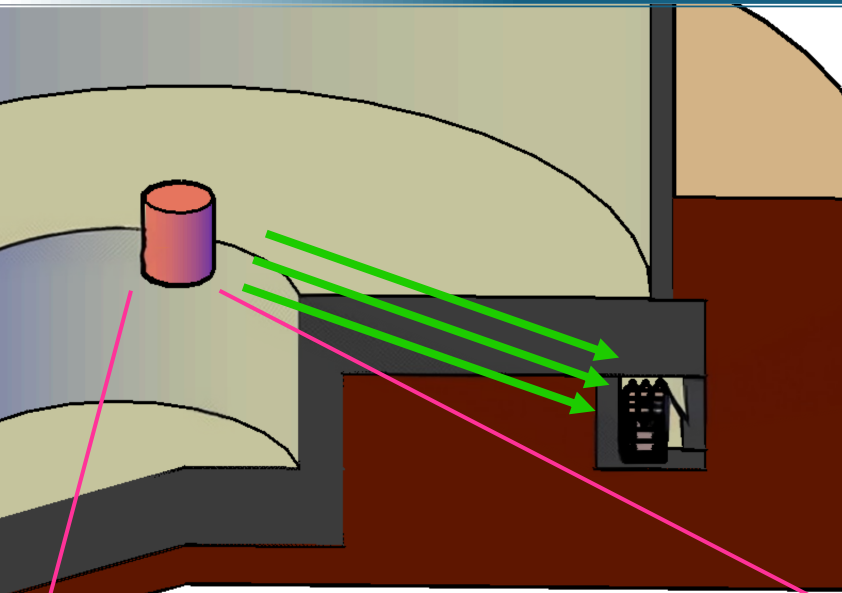
- Single flavor, $\bar{\nu}_e$ from β -decay of fission fragment
- Rich ν flux : $\sim 8.09 \times 10^{12}/\text{cm}^2/\text{sec}$ at 24 m
(2.8 GW_{th}, 24-m baseline, kopeikin model)
- Low ν energy from reactor : $\lesssim 10$ MeV

☐ CEvNS measurement in reactor

- Rich neutrino flux , low recoil energy
 - Requires an extremely low energy threshold
(~ 200 eV threshold in NEON)



Dark Sector Particle Search



❑ Reactor as gamma source

- Huge amounts of γ rays generated in reactor core
- γ can couple to dark sector bosonic particles
→ Rich source of Dark Photon & Axion Like Particles

❑ Light Dark Matter [LDM]

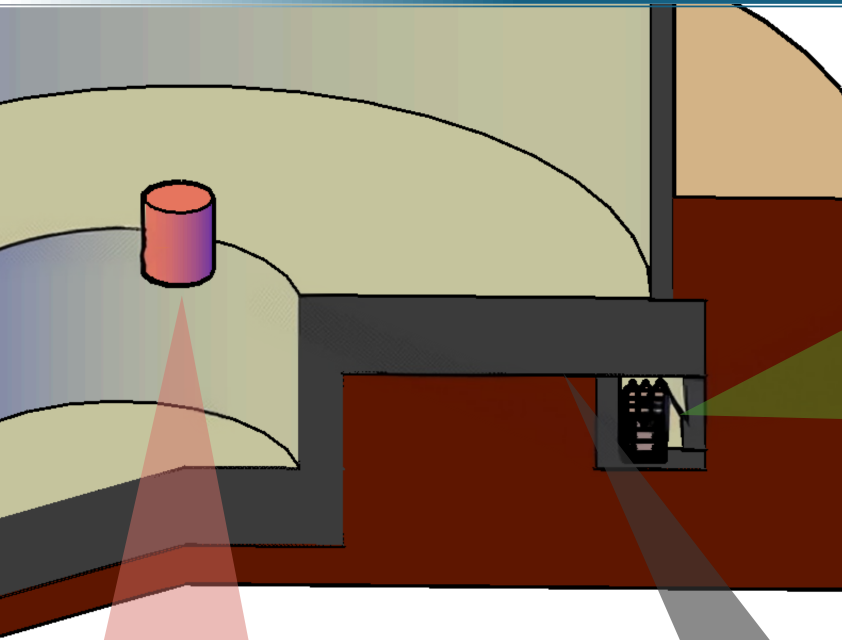
- **low-mass (keV–GeV) dark matter** that scatters off electrons via a dark photon mediator, producing low-energy recoil signals
- exposure
→ Reactor on/off : 1214/1422 kg · days (total 2636 kg · day)
- Target LDM
→ mass : $1 \text{ keV}/c^2 \leq m_x \leq 1000 \text{ keV}/c^2$
→ Analyzed energy : 1~10 keV

❑ Axion Like Particles [ALPs]

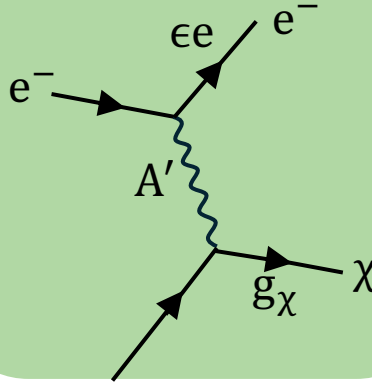
- ALPs share properties **similar to axion**, potential dark matter candidates
- exposure
→ Reactor on/off : 1596/1467 kg · days (total 3063 kg · day)
- Target ALPs
→ mass : $300 \text{ keV}/c^2 \leq m_x \leq \sim 1000 \text{ keV}/c^2$
→ Analyzed energy : 3~3000 keV

Light Dark Matter search

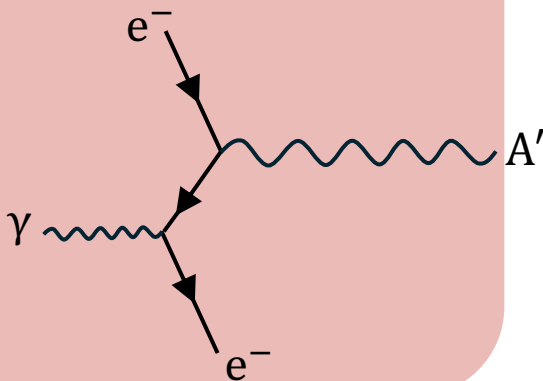
- Assume $m_{A'} = 3m_\chi$
- Signal from dark matter scattering off electrons in the detector
- Fit to On-Off data in 1~10 keV region



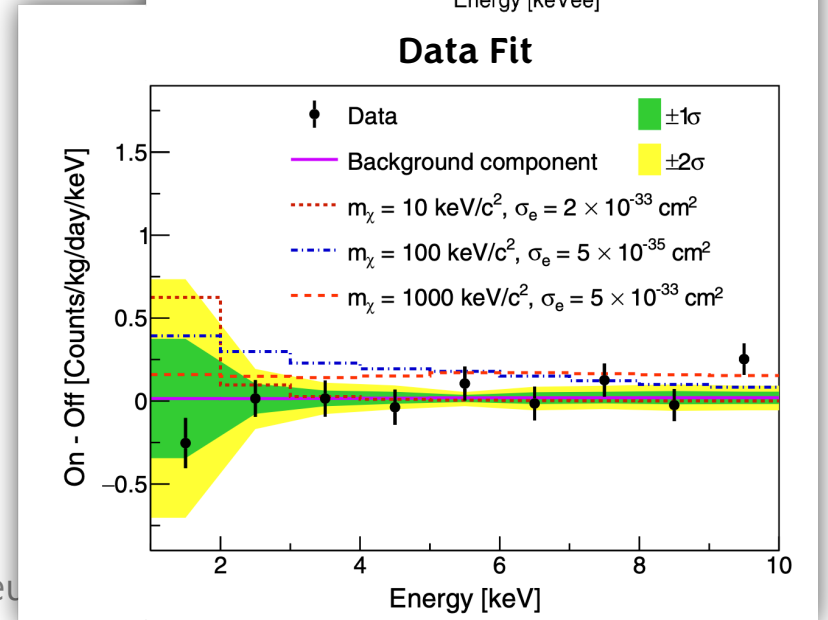
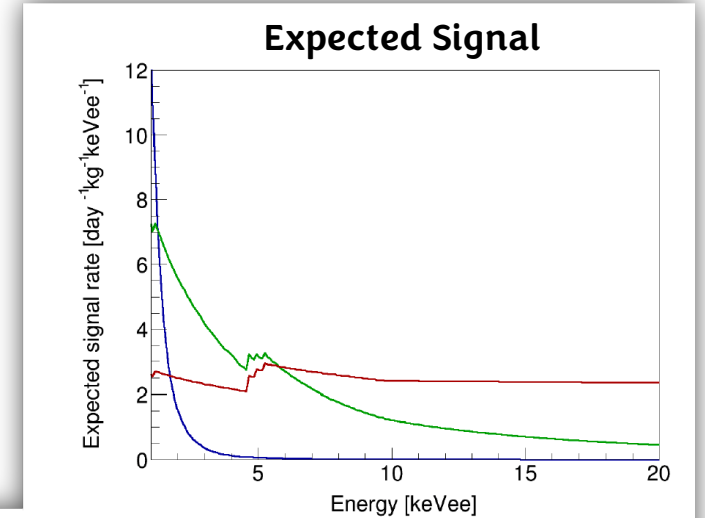
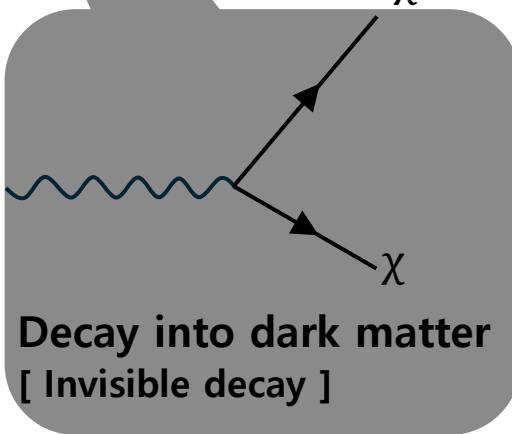
DM- e^- scattering
 $[\sigma_{\chi e^- \rightarrow \chi e^-} \propto \epsilon^2 g_\chi^2]$



Dark photon(A') production
 [Compton-like process]

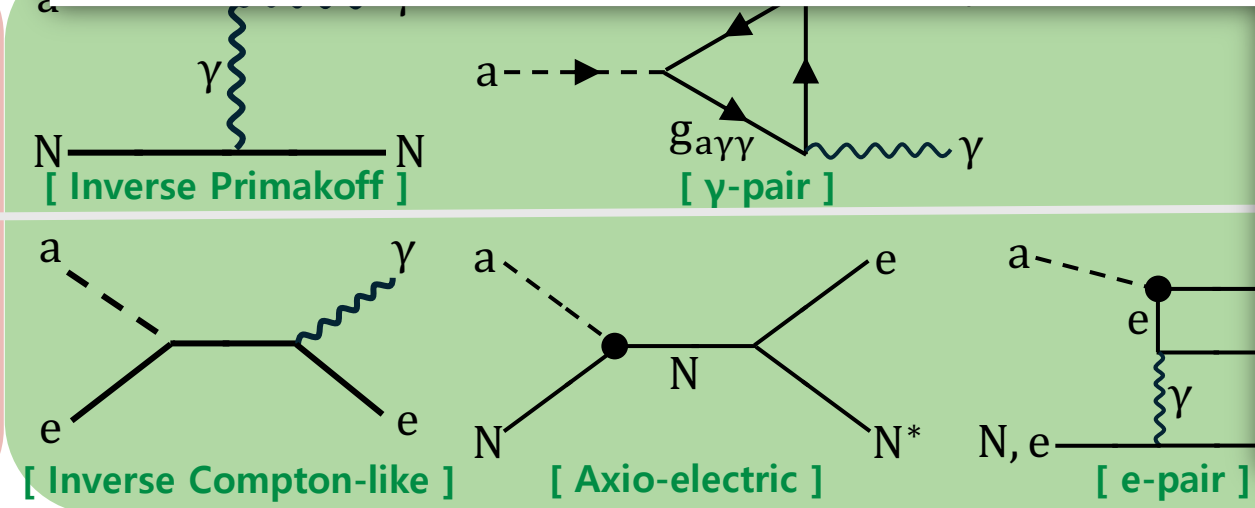
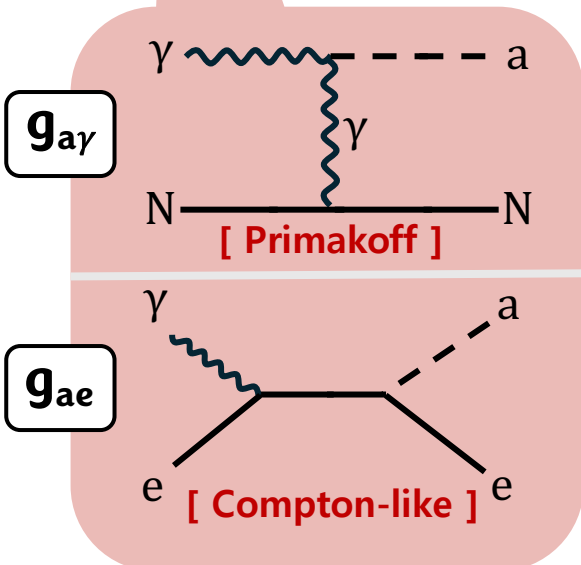
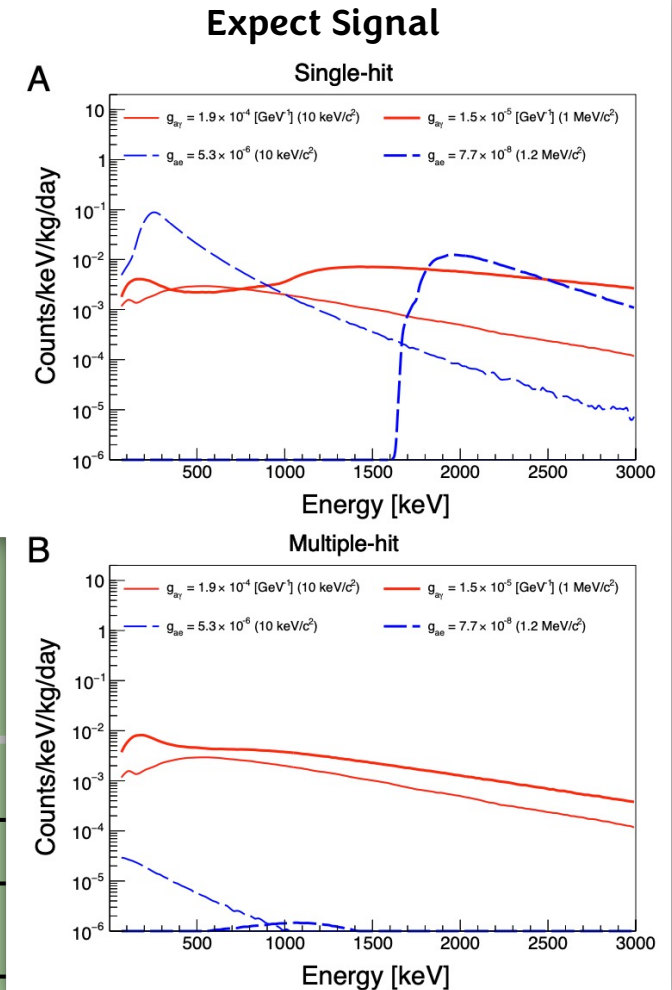
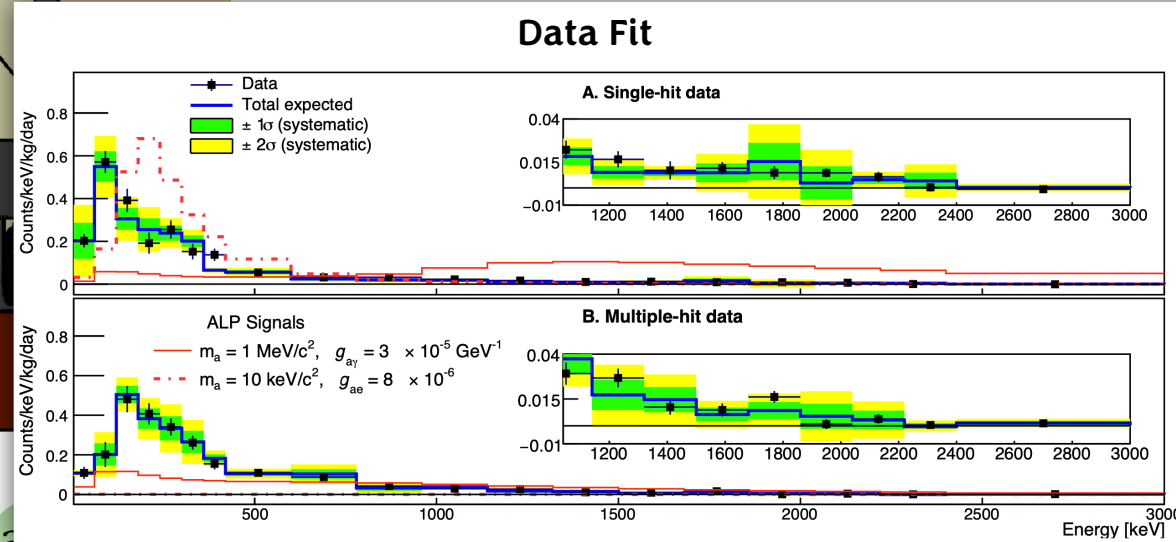


Decay into dark matter
 [Invisible decay]



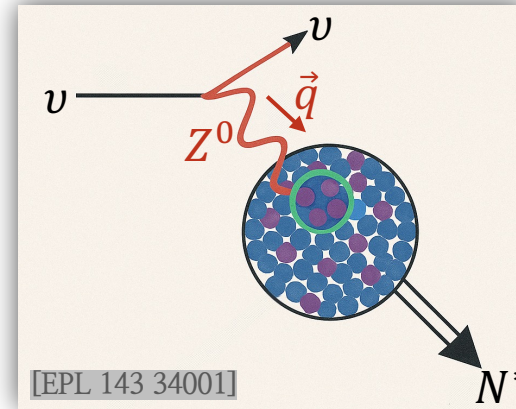
Axion Like Particles[ALPs] search

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



❑ Incoherent $\bar{\nu}$ -Nucleus Scattering : $\bar{\nu}$ NS

- $\bar{\nu}$ NS leaves a nucleus in an excited state.
De-excitation gamma could be detected.
- This helps Nucleus form-factor and the coherent part measure more accurately.



❑ Status of $\bar{\nu}$ NS on NEON

- Searching for $\bar{\nu}$ NS using NaI(Tl) crystals is currently in progress.
- Using CsI(Tl) crystals is also planned (May).
The detector is currently under construction and testing.

