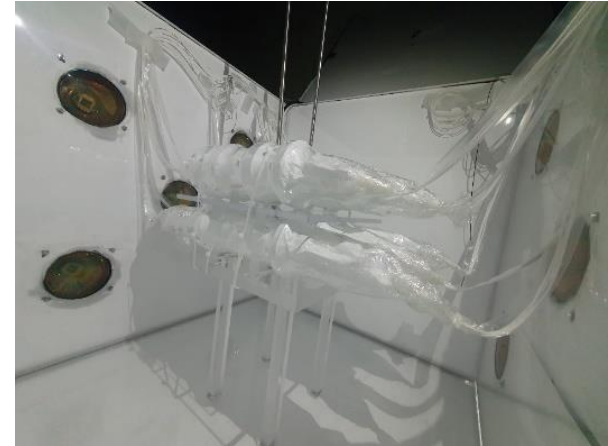


Neutrino Elastic-scattering Observation with NaI(Tl)(NEON)

Jae Jin Choi

On behalf of the NEON collaboration

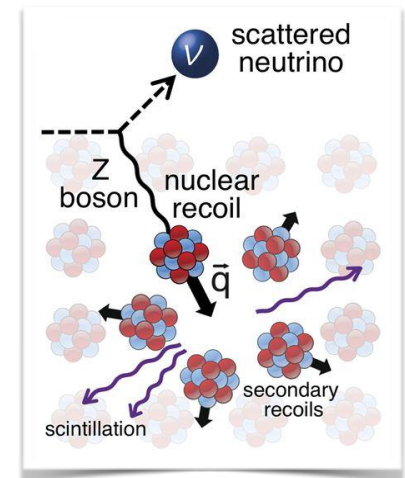


Introduction(CEvNS)

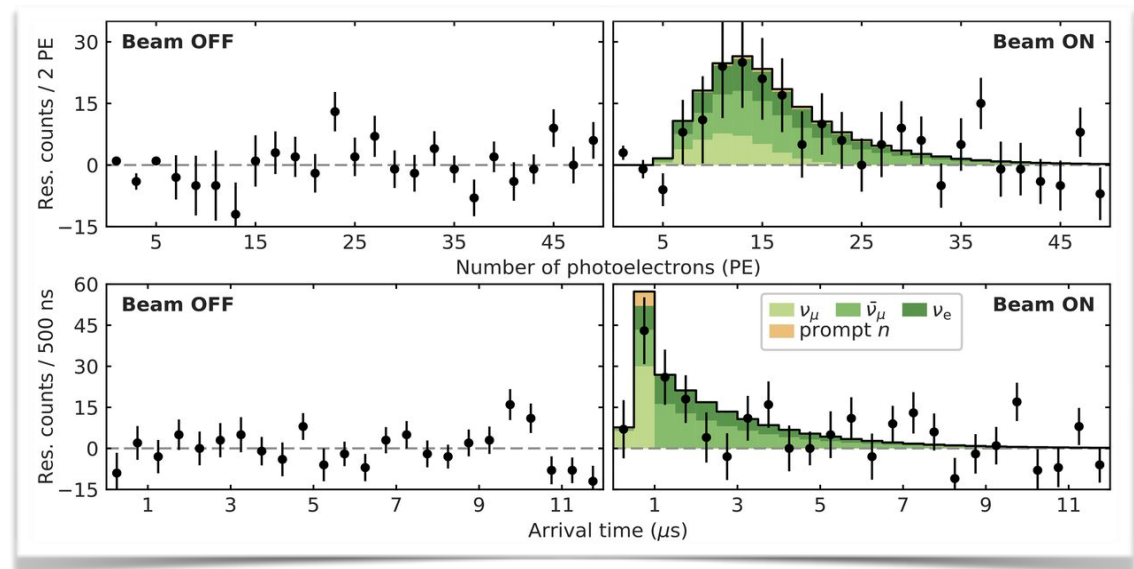
■ CEvNS(Coherent Elastic Neutrino(ν)-Nucleus Scattering)

- Predicted by D.Z. Freedman in 1974
- First measurement by the COHERENT collaboration in 2017 (accelerator neutrinos as the source)

Phys. Rev. D 9, 1389 (1974)

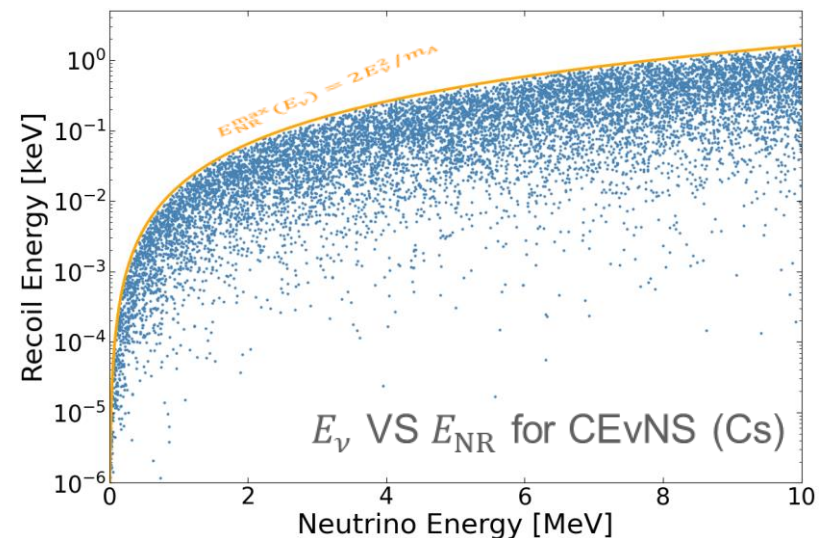
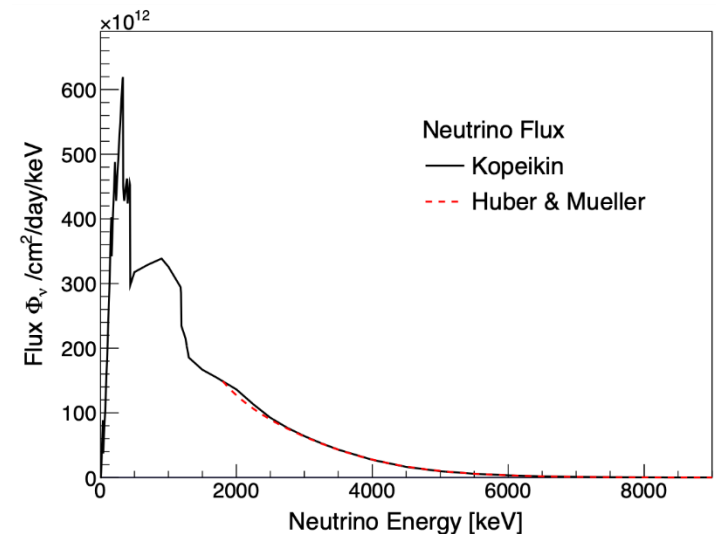


Science 357, 1123-1126 (2017)

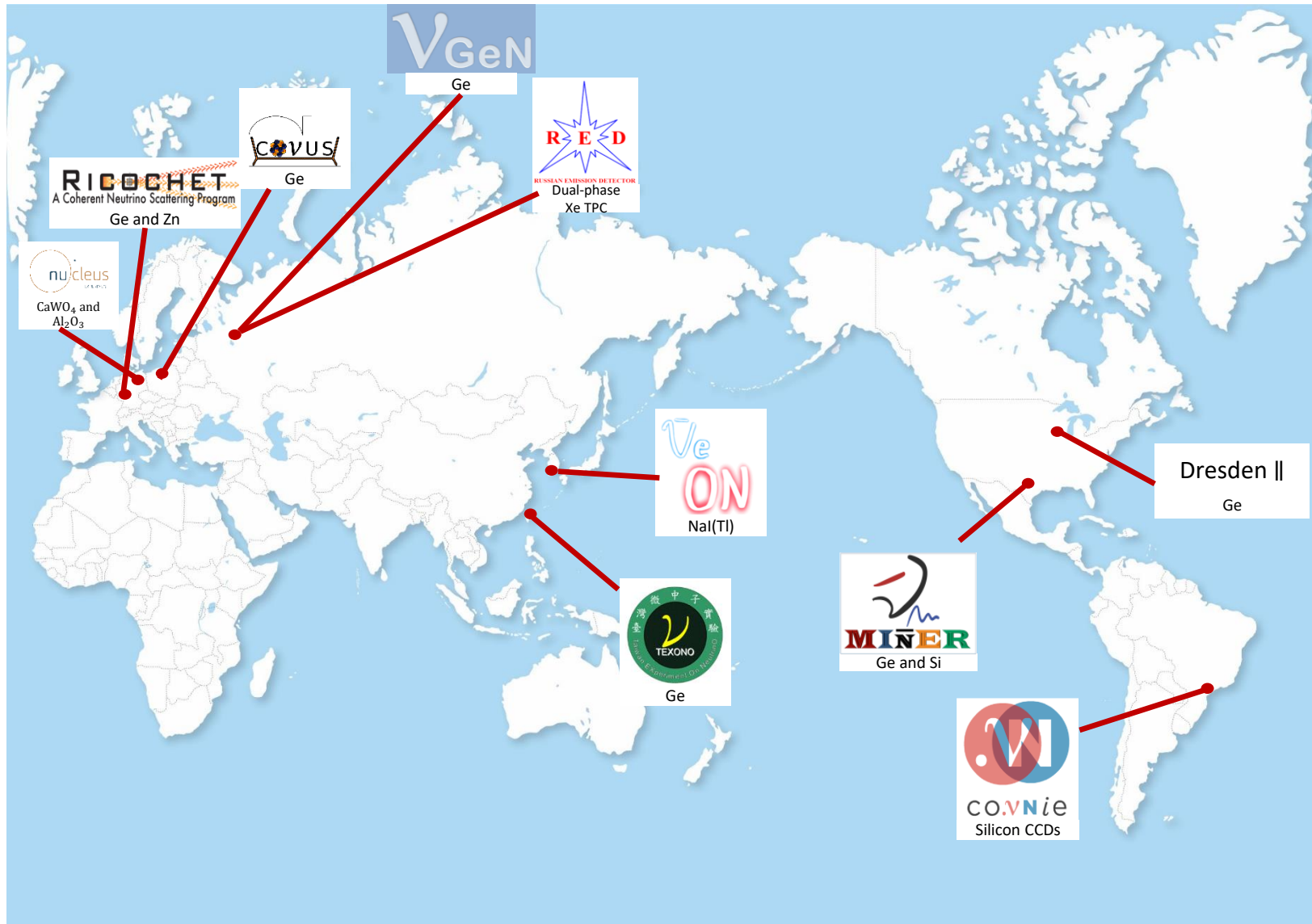


Motivations

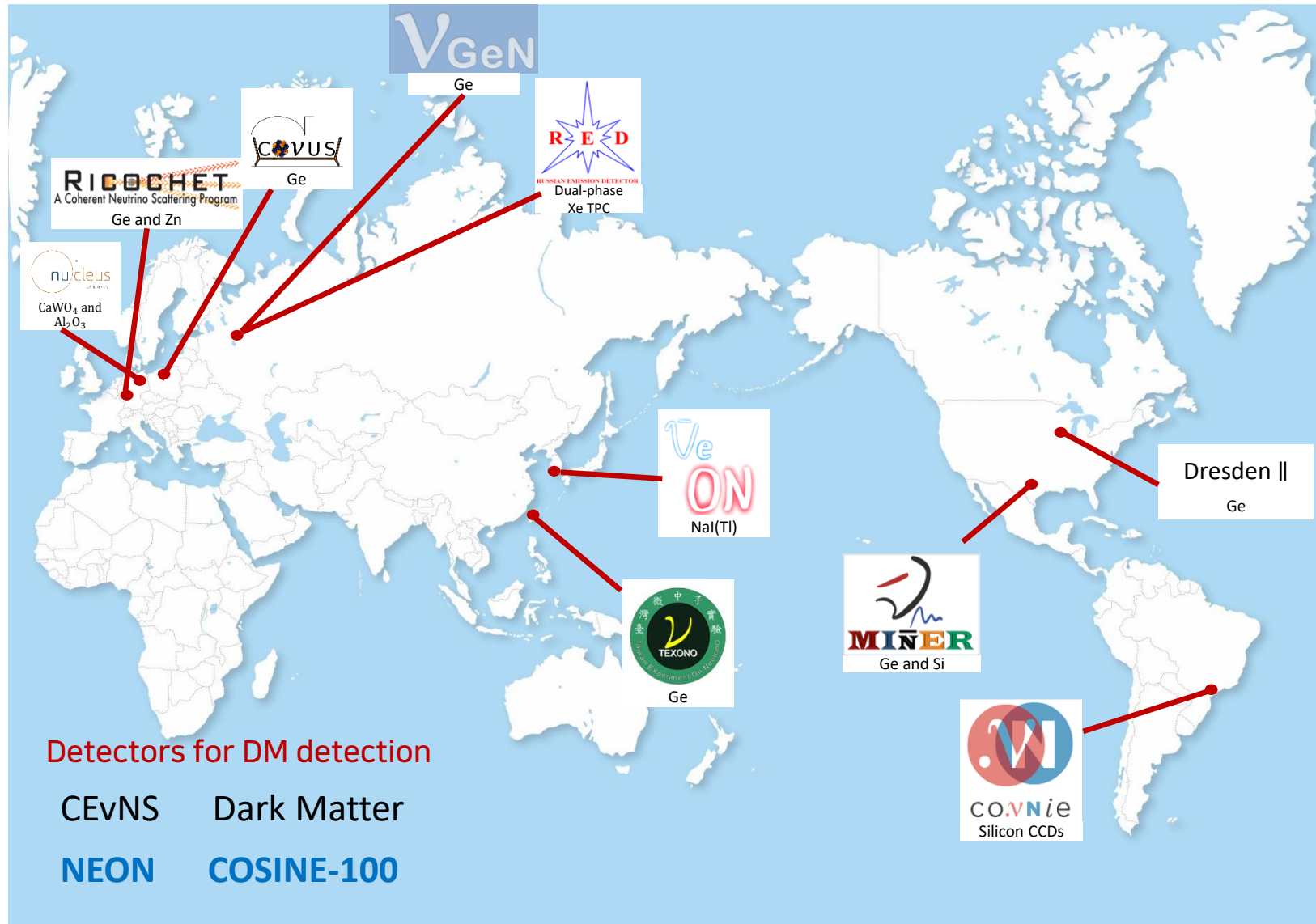
- Neutrinos in reactor
 - ν from β -decay of fission fragments
 - ν flux : $\sim 8.1 \times 10^{12} / \text{cm}^2 / \text{sec}$
(2.8-GW_{th}, 24-m baseline, Kopeikin model)
 - ν energy from reactor : $\lesssim 10$ MeV
- CEvNS measurement in reactor
 - Low recoil energy (× quenching factor)
 - Shallow overburden compared to underground lab -> high background rate
- Further studies
 - Neutrino magnetic moment
 - Weinberg angle precision measurement
 - Sterile neutrinos
 - Nonstandard interaction



CEvNS Experiments using reactor neutrino around the world



CEvNS Experiments using reactor neutrino around the world



The NEON Collaboration

- Neutrino Elastic scattering Observation with NaI(Tl)
 - To observe CEvNS with reactor neutrinos

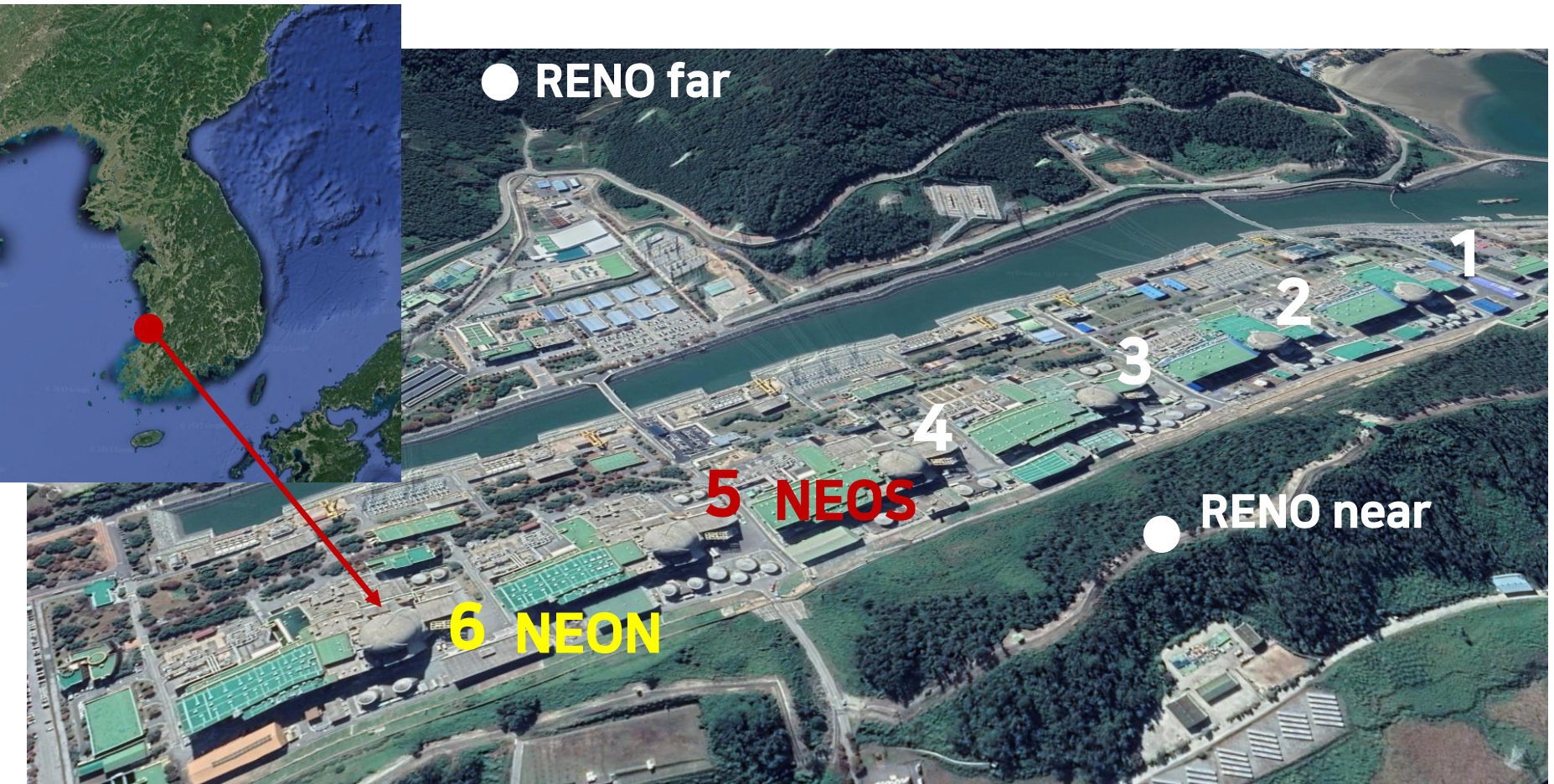


~20 members, 5 institutes, since 2019



NEON Experimental Site

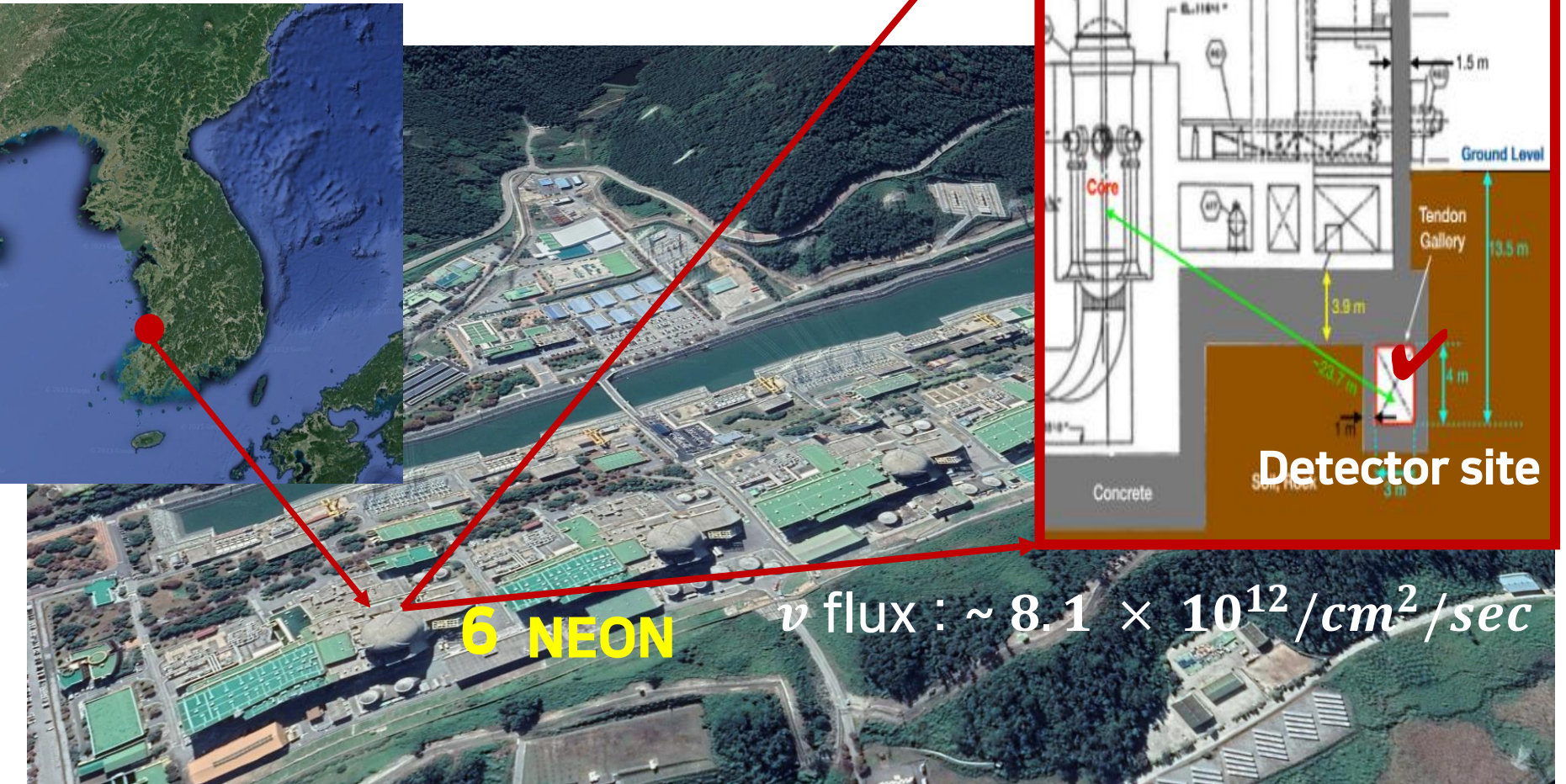
- Hanbit nuclear power plant in Yeonggwang, South Korea
 - Unit 6 reactor
 - Next to the **NEOS** experiment(background understanding)



NEON Experimental Site

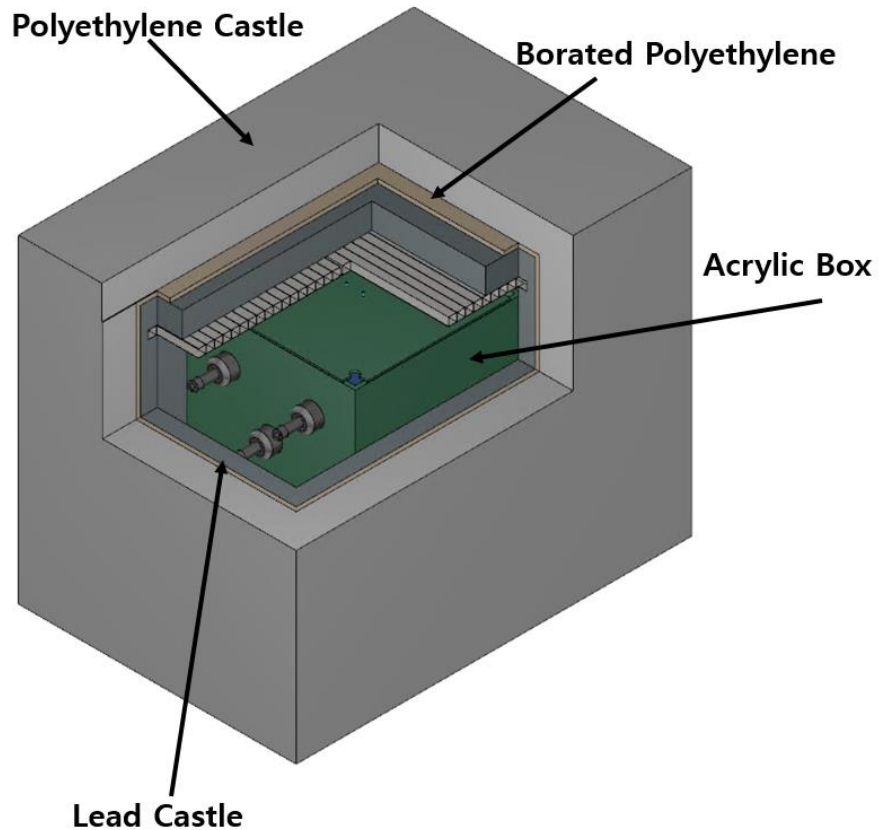
- Hanbit nuclear power plant in Yeonggwang, South Korea

- 2.8-GW_{th}
- 24-m baseline, 20-meter water equivalent



NEON Shielding

- Outer shielding(from acrylic box)
 - 20/30-cm thick polyethylene(PE)
 - 2.5-cm thick borated PE
 - 10/15-cm thick lead



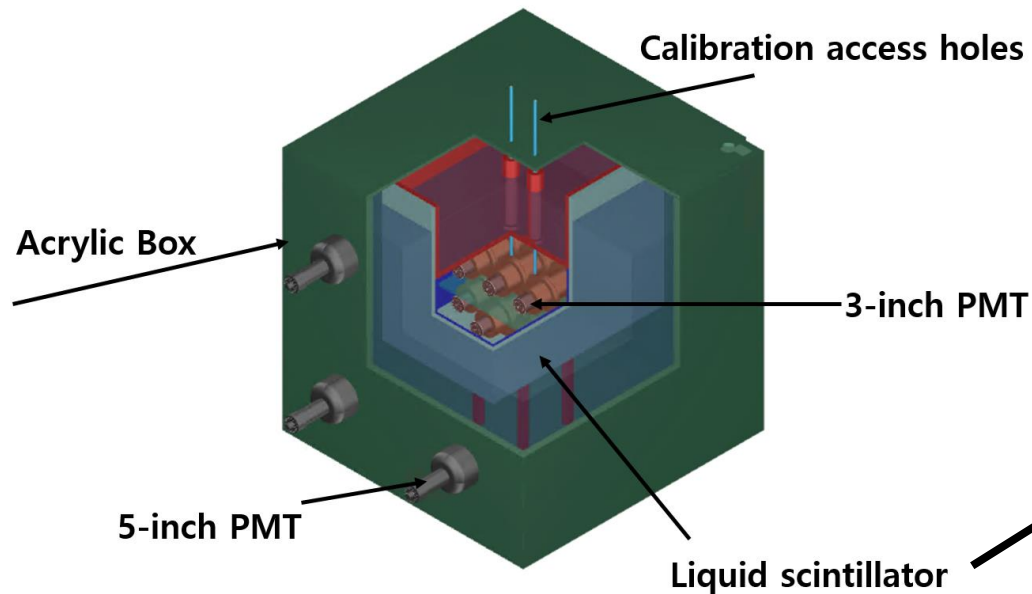
Lead shields



PE & borated PE shields

NEON Shielding

- Inner shielding(from acrylic box)
 - 800-L liquid scintillator in acrylic box
 - 10 of 5-inch PMTs
 - Passive trigger(tagging external background)



Liquid scintillator in the acrylic box

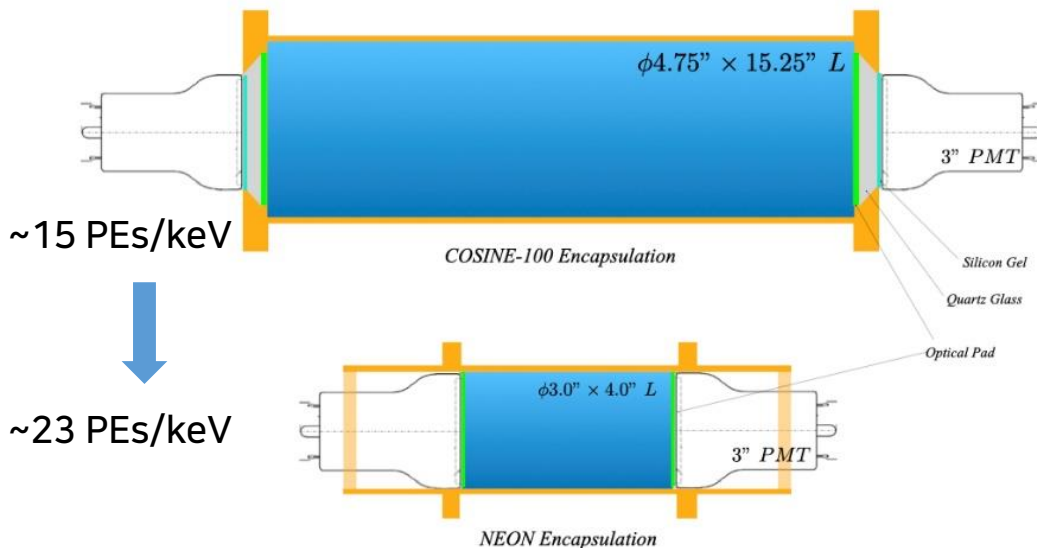


NEON Detector

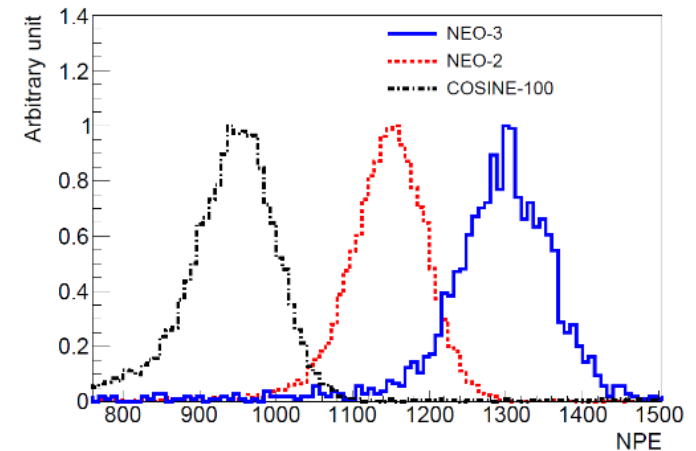
■ NaI(Tl) crystals

- Six NaI(Tl) detectors (16.7 kg of total mass)
- Encapsulation R&D for increasing light yield
- Improving the light yield contributes to achieving a **lower energy threshold**.

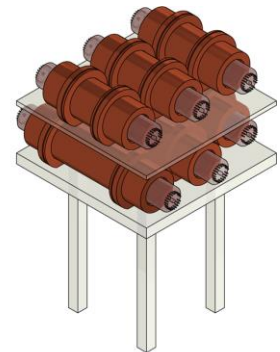
※ PE : Photoelectrons



Nucl. Instrum. Meth. A 981,164556(2020)



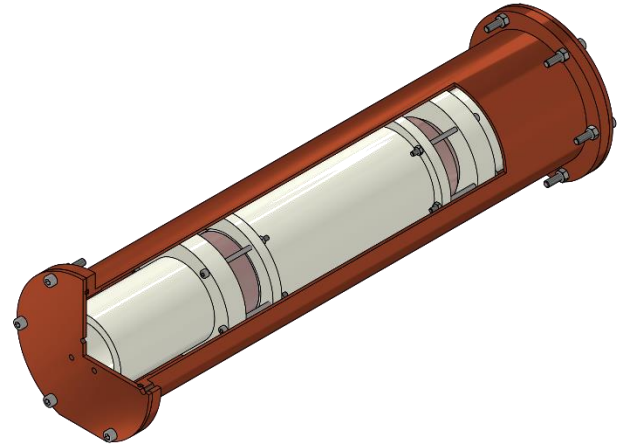
Compared to the COSINE crystal,
50 % Light yield improved!



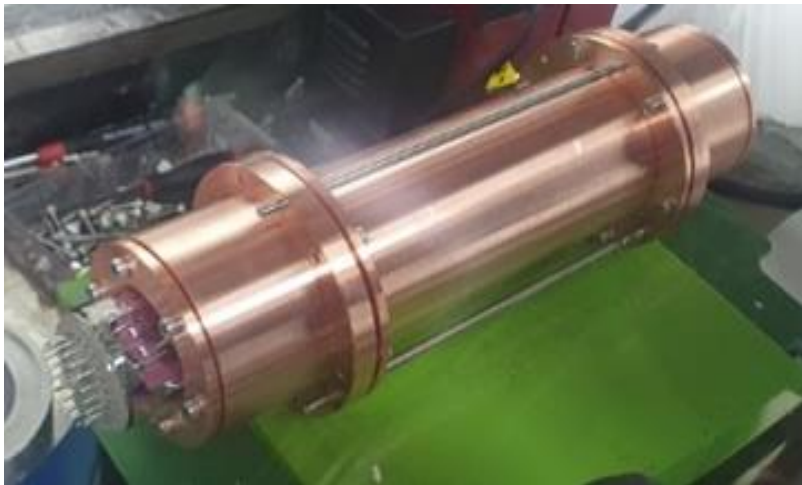
3 × 2 NaI(Tl) crystal array

NEON Detector

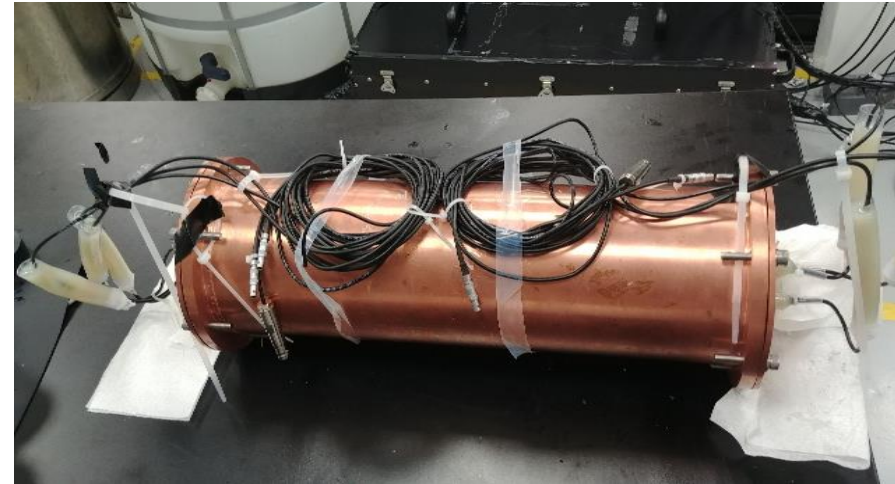
- NaI(Tl) crystals
 - Former detectors had instability issues.
 - ✓ Noise
 - ✓ Gain drop(air leak)
 - **Upgraded encapsulation!**
 - ✓ ~24 PEs/keV light yield



Current NEON detector encapsulation design



Engineering run(until Feb. 2022)



physics run(from Apr. 2022)

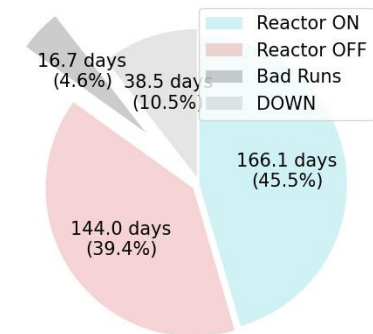
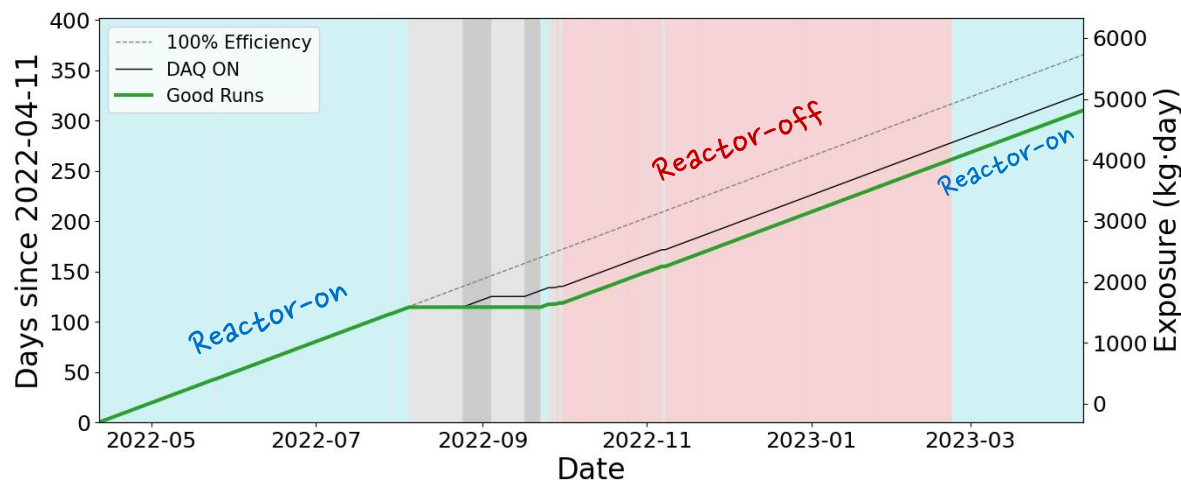
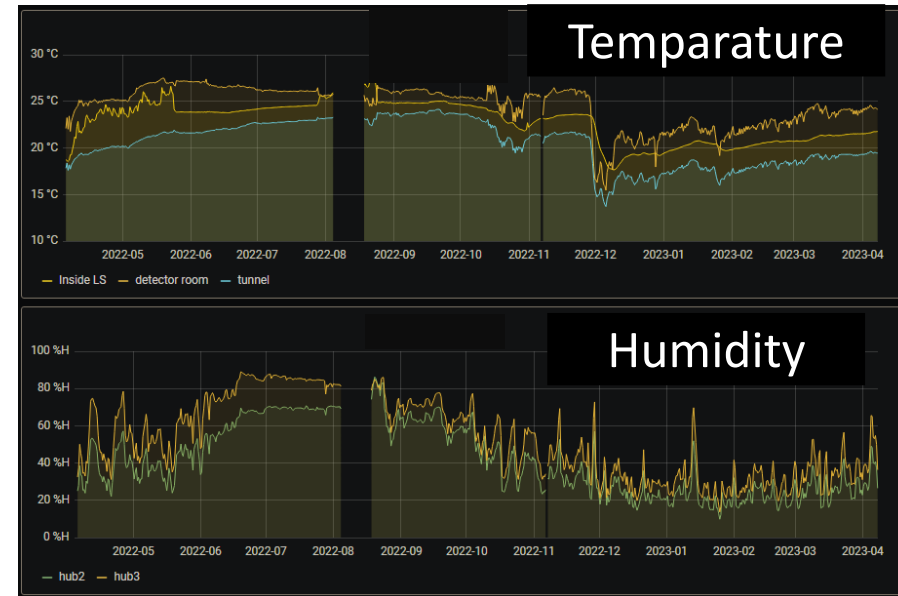
Monitoring and Exposure

■ Monitoring

- DAQ system : trigger rate, HV, preamp
- Surrounding environment
(temperature, humidity)
- Disk space (UPS)

■ Exposure

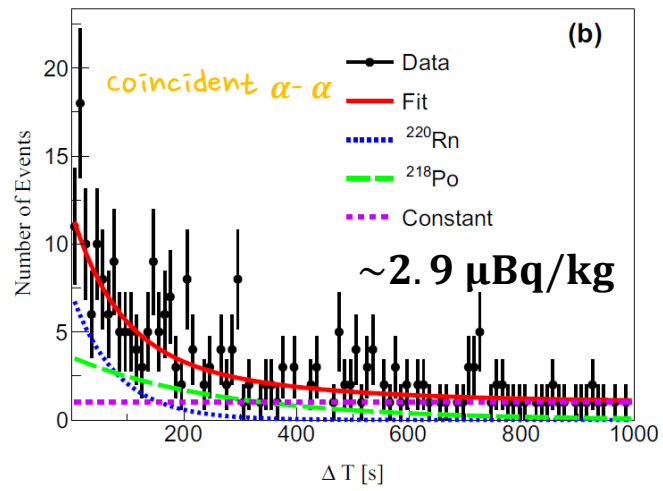
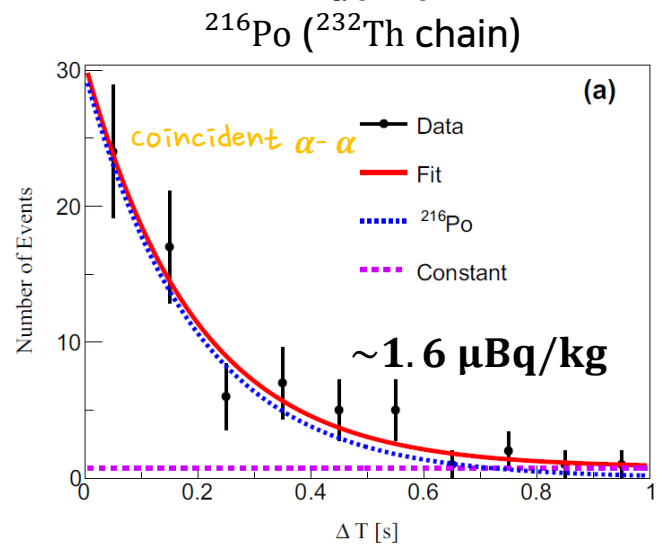
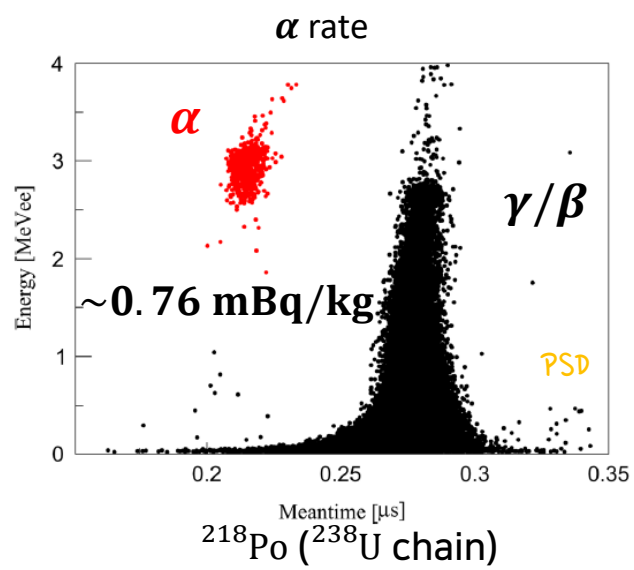
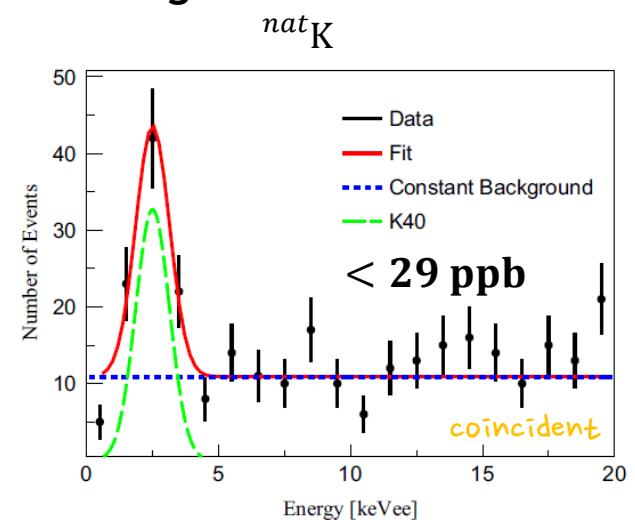
- ~5200-kg*day exposure
- Reactor-on data : 166 days, off data : 144 days



Background Study

Internal Background

Eur. Phys. J. C **83**, 226 (2023)



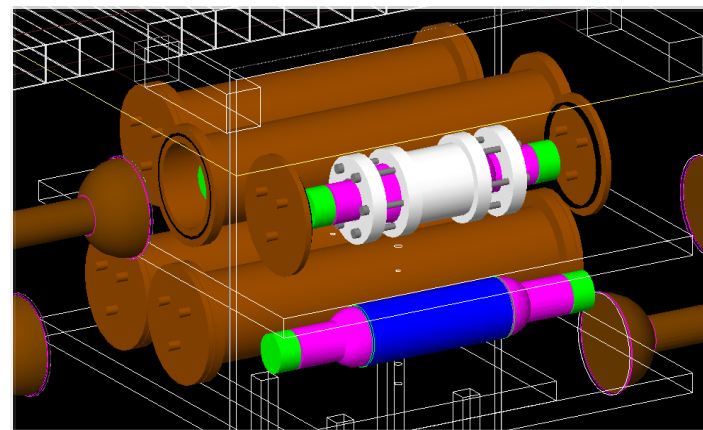
➤ Compared to the COSINE-100 low background crystal, internal background rate is similar.

Background Study

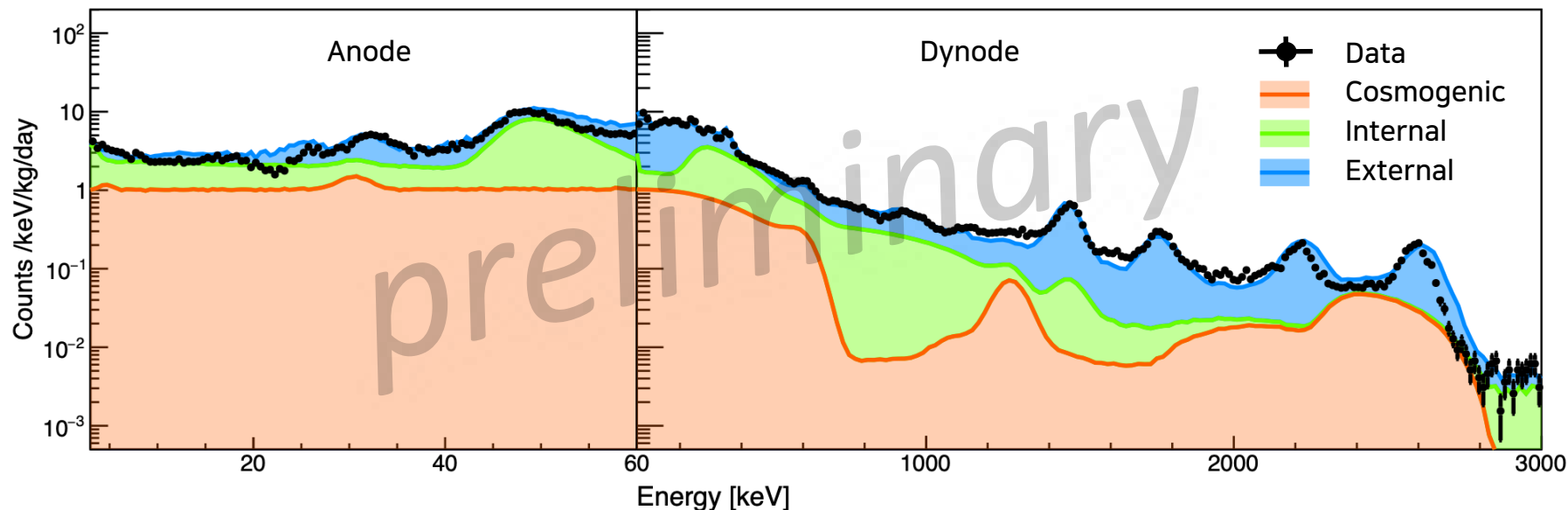
■ Geant4 Simulation & Modeling

- Detector & Shielding Geometry
- PMT radioactivity (COSINE-100)
- Comogenic (COSINE-100)
- Anode (0~60 keV), Dynode (60~3000 keV)

Detector geometry in Geant4



Single-hit events energy spectrum



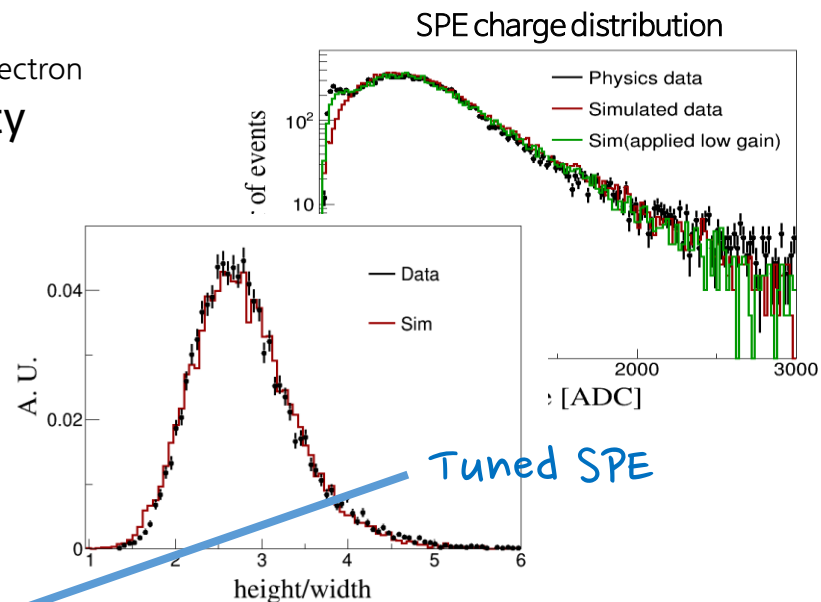
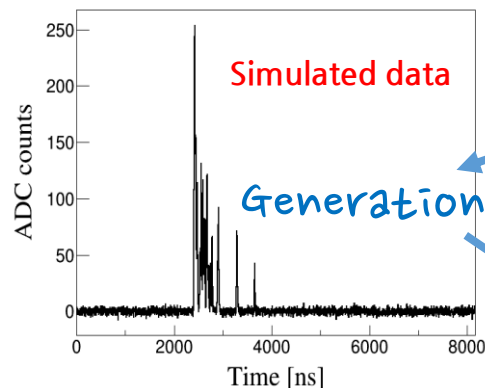
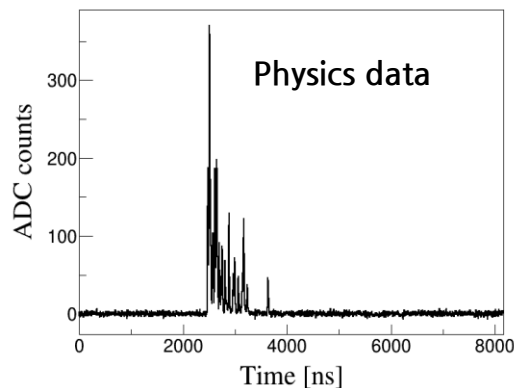
Data Analysis

Waveform Simulation

※ SPE : single photoelectron

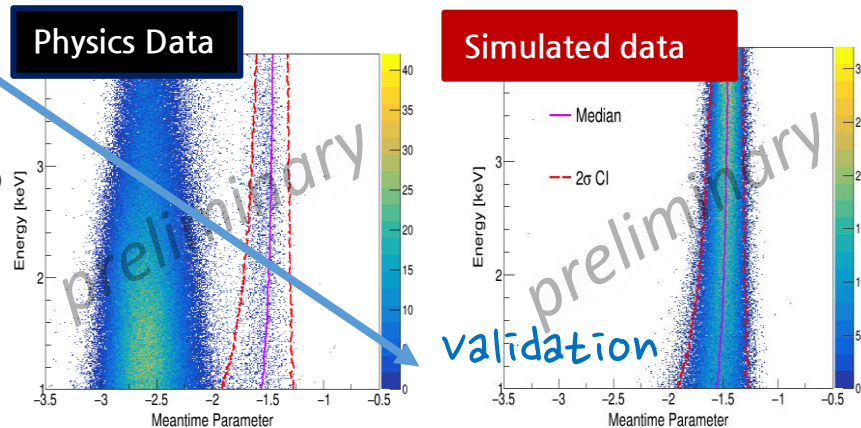
- PMT gain, SPE shape, SPE timing probability
- DAQ spec(ADC), trigger condition
- Tuned low-gain SPE and random PEs

One of physics and simulated data events waveform



Tuned SPE

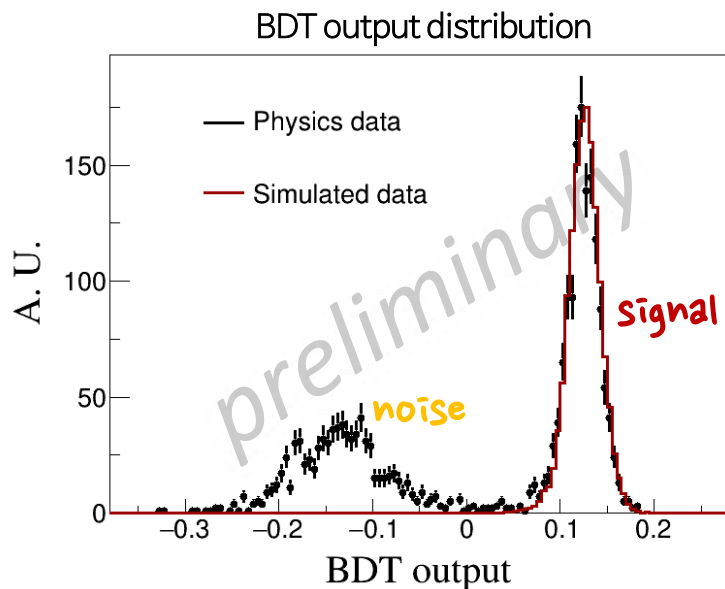
Generation



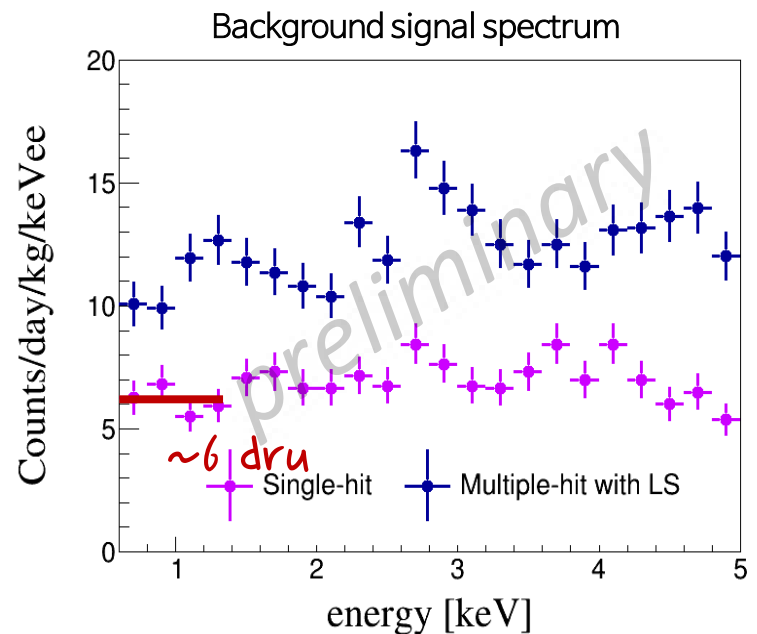
- PSD parameter development for event selection
- Signal training sample for ML/DL

Data Analysis

- Method : the Boosted Decision Tree(BDT, multivariable event selection technique)
 - Scintillation signal sample : simulated data
 - Background sample : physics data



Noise rejection



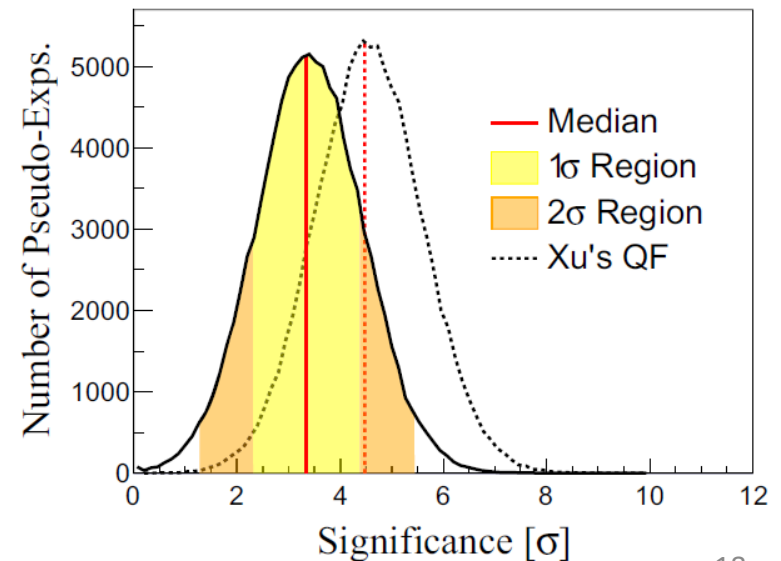
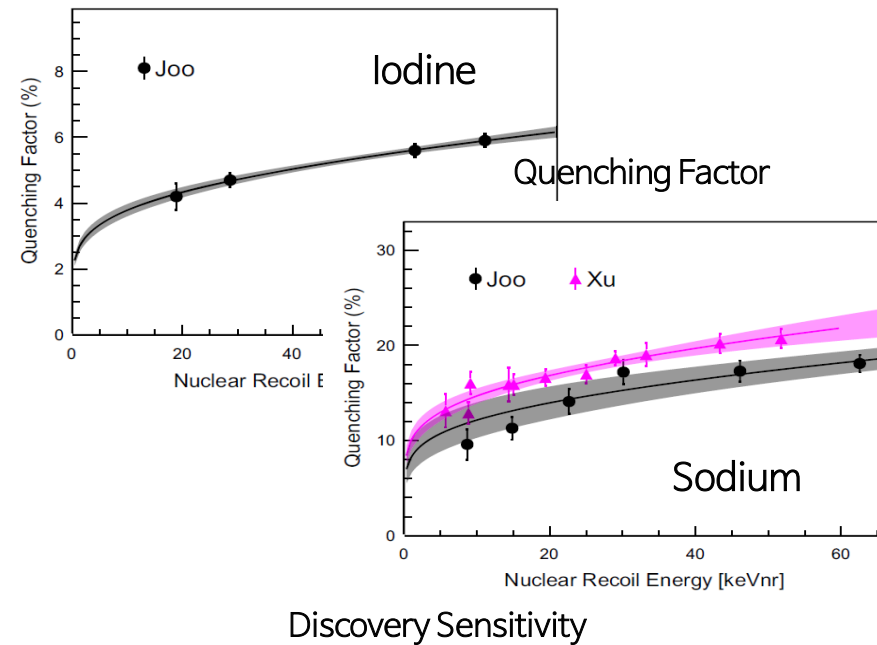
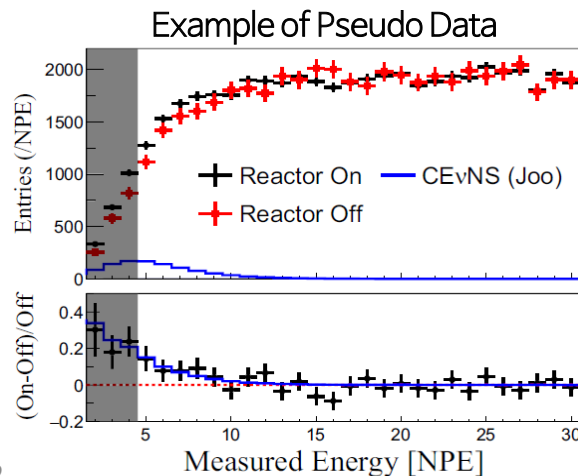
※ dru : counts/day/kg/keV

NEON Sensitivity Study

Assumption for Sensitivity

- Quenching factor : Joo's & Xu's
- Exposure time :
 - ✓ Reactor-On : one year
 - ✓ Reactor-Off : 100 days
- Detector performance
 - ✓ Background level : 7 counts/day/kg/keV
 - ✓ Detector mass : 13.5 kg
 - ✓ Light yield : 22 PEs/keV
 - ✓ Threshold : 5 NPE

※ NPE : number of photoelectrons

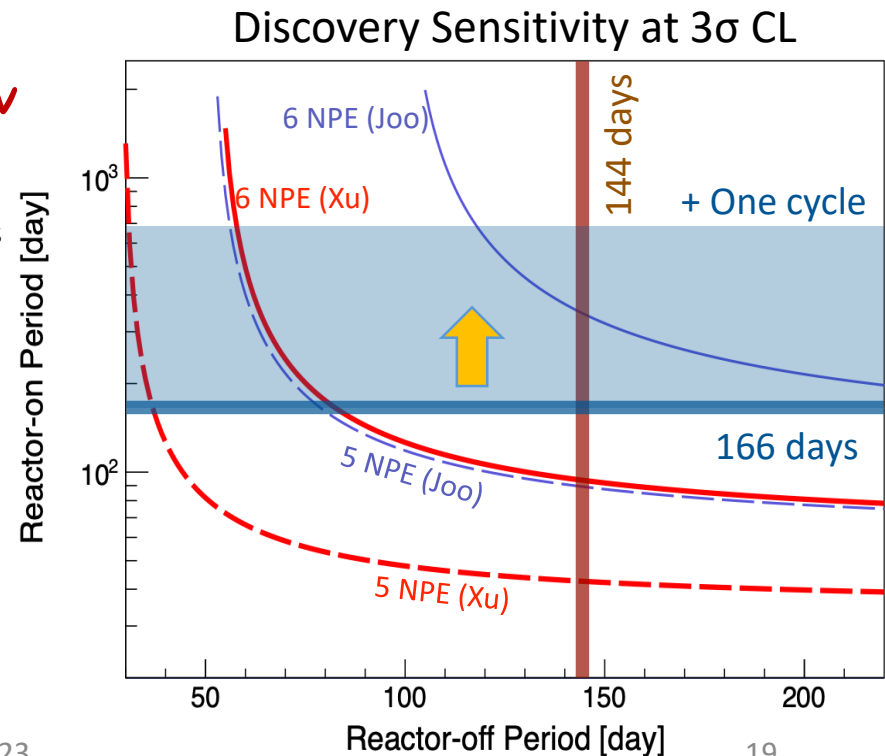


NEON Sensitivity Study

Assumption for Sensitivity

- Quenching factor : Joo's & Xu's
- Exposure time :
 - ✓ Reactor On : one year ✓ 166 days (receiving data)
 - ✓ Reactor Off : 100 days ✓ 144 days
- Detector performance
 - ✓ Background level : 7 counts/day/kg/keV ✓ ~6 dru
 - ✓ Detector mass : 13.5 kg ✓ ~16.7 kg
 - ✓ Light yield : 22 PEs/keV ✓ 24 PEs/keV
 - ✓ Threshold : 5 NPE ✓ on-going

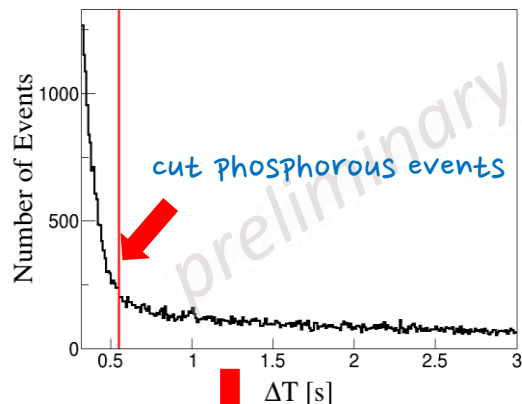
※ NPE : number of photoelectrons



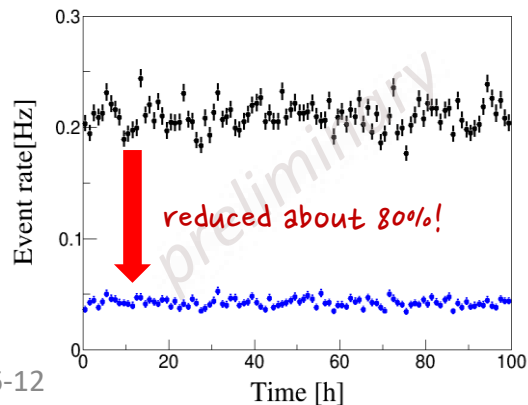
Event Selection Study for the Low Threshold

- Low energy event selection (energy below than 0.6 keV)
 - Phosphorous events by **muons**
 - Removing events using ΔT with muon events.
 - Counting isolated clusters as **NPE**

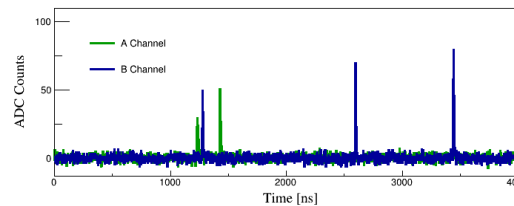
ΔT between muon and other events



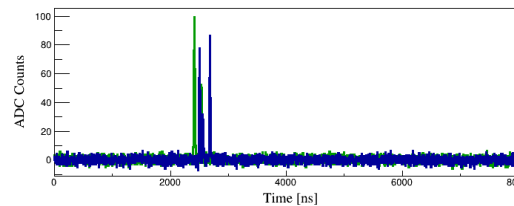
Event rate



A typical phosphorous event

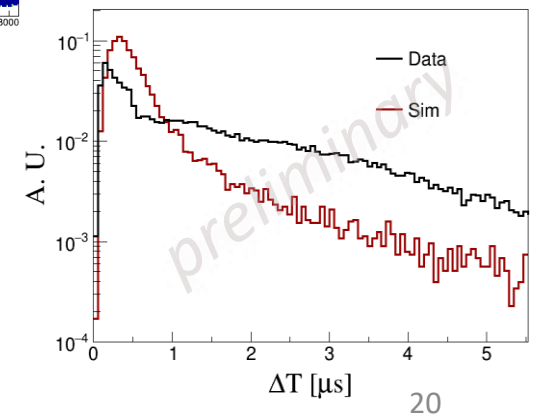


A typical scintillation event



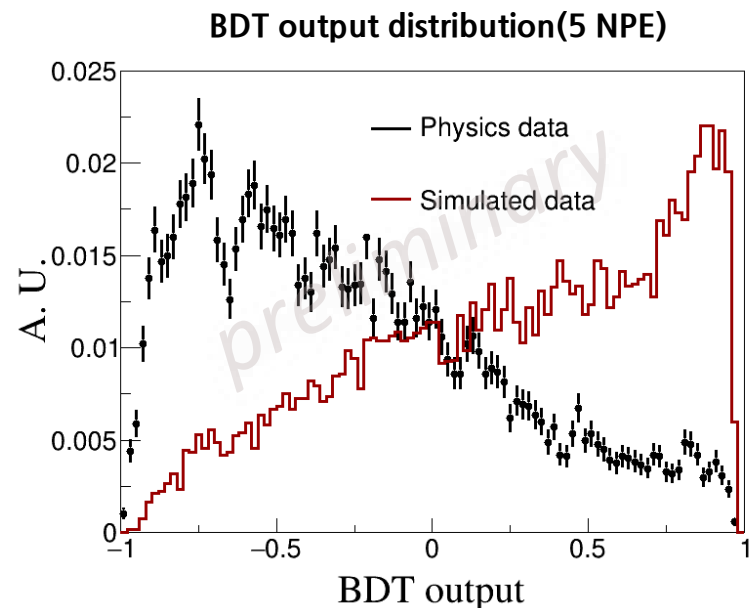
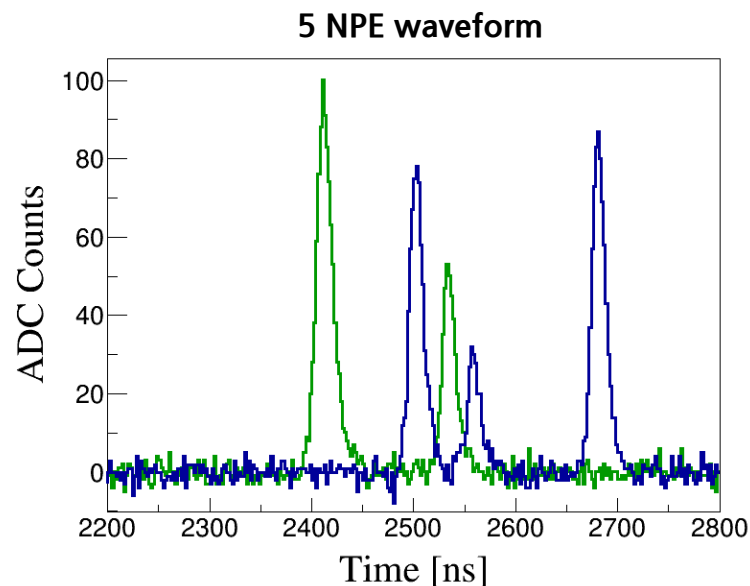
Optimize BDT each NPE using ΔT

ΔT between first SPE and last SPE



Event Selection Study for the Low Threshold

- Preliminary result of low energy event selection
 - Optimize BDT each NPE using ΔT
 - Further improvement by applying **other ML technique**
 - Multilayer perception (MLP)
 - Convolved neural network (DL) of raw pulses



Summary

- The **NEON** experiment aims to **observe CEvNS** using **reactor neutrino** in South Korea.
- Data collection has been stable since April 2022. (Reactor **ON : >166 days**, **OFF : 144 days**)
- Lowering threshold study is ongoing. (**5 NPE**)
- With the attainment of a 5 NPE threshold, We expect to observe CEvNS during this cycle.

Thank you for listening

Backup

CEvNS Experiments using reactor neutrino around the world

