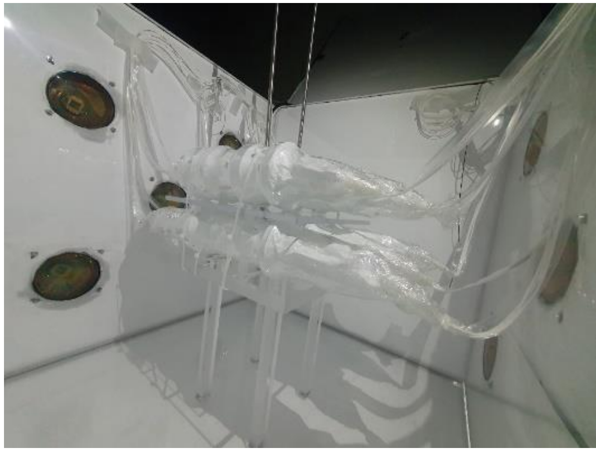
Neutrino Elastic-scattering Observation with NaI(Tl)(NEON)



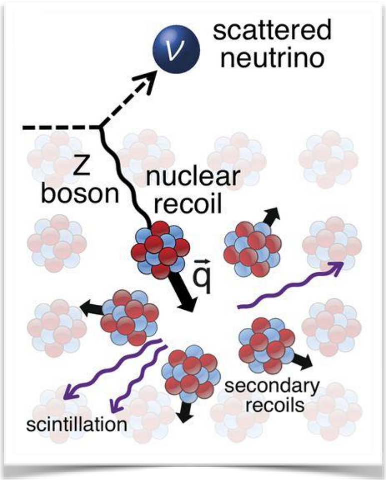
Jae Jin Choi

On behalf of the NEON collaboration

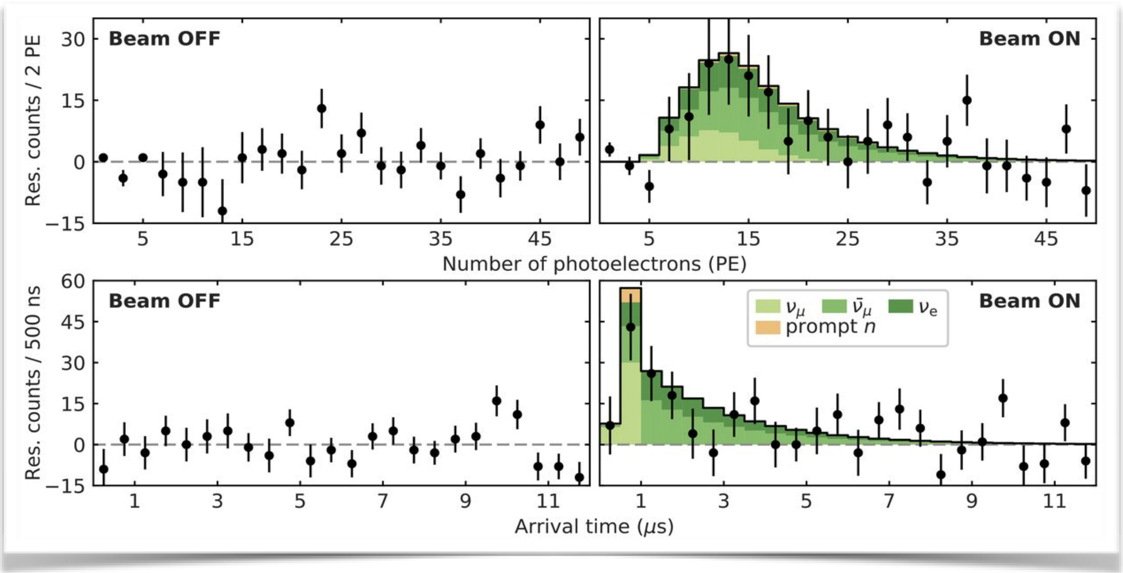
Introduction (CEvNS)

Phys. Rev. D 9, 1389 (1974)

- 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)

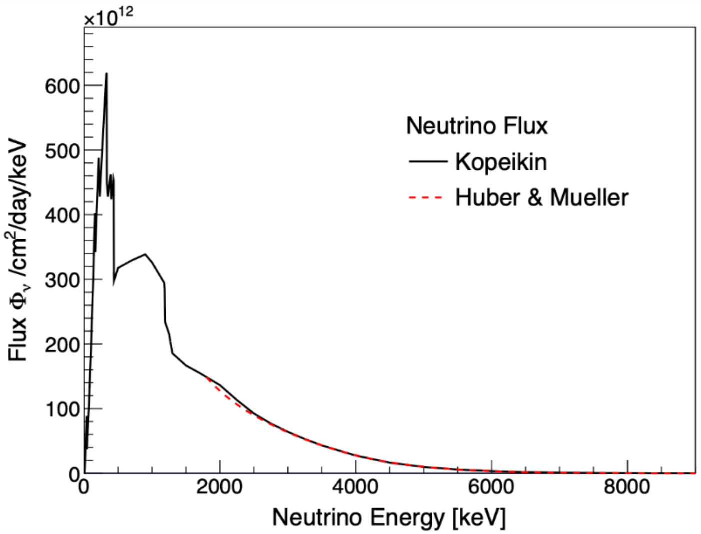


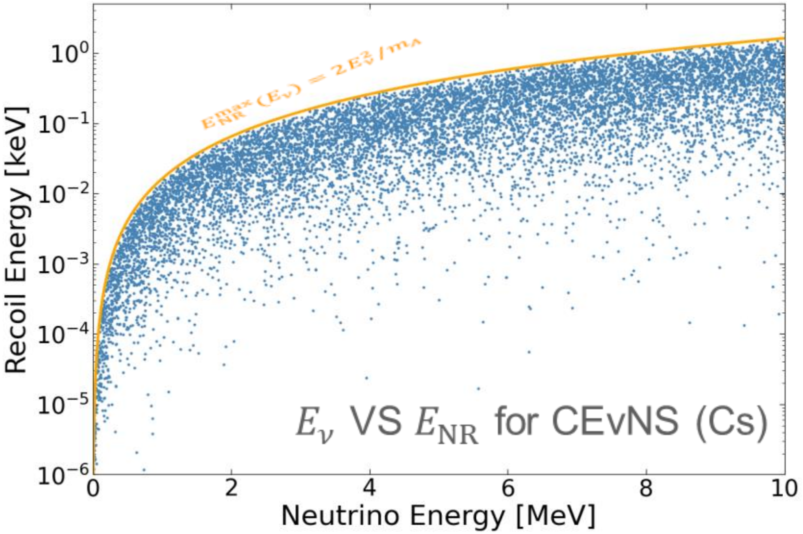
Science 357, 1123-1126 (2017)



Motivations

- Neutrinos in reactor
  - ν from β-decay of fission fragments
  - ν flux : ~ $8.1 \times 10^{12}/cm^2/sec$
    (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 measurment
  - Sterile neutrinos
  - Nonstandard interaction





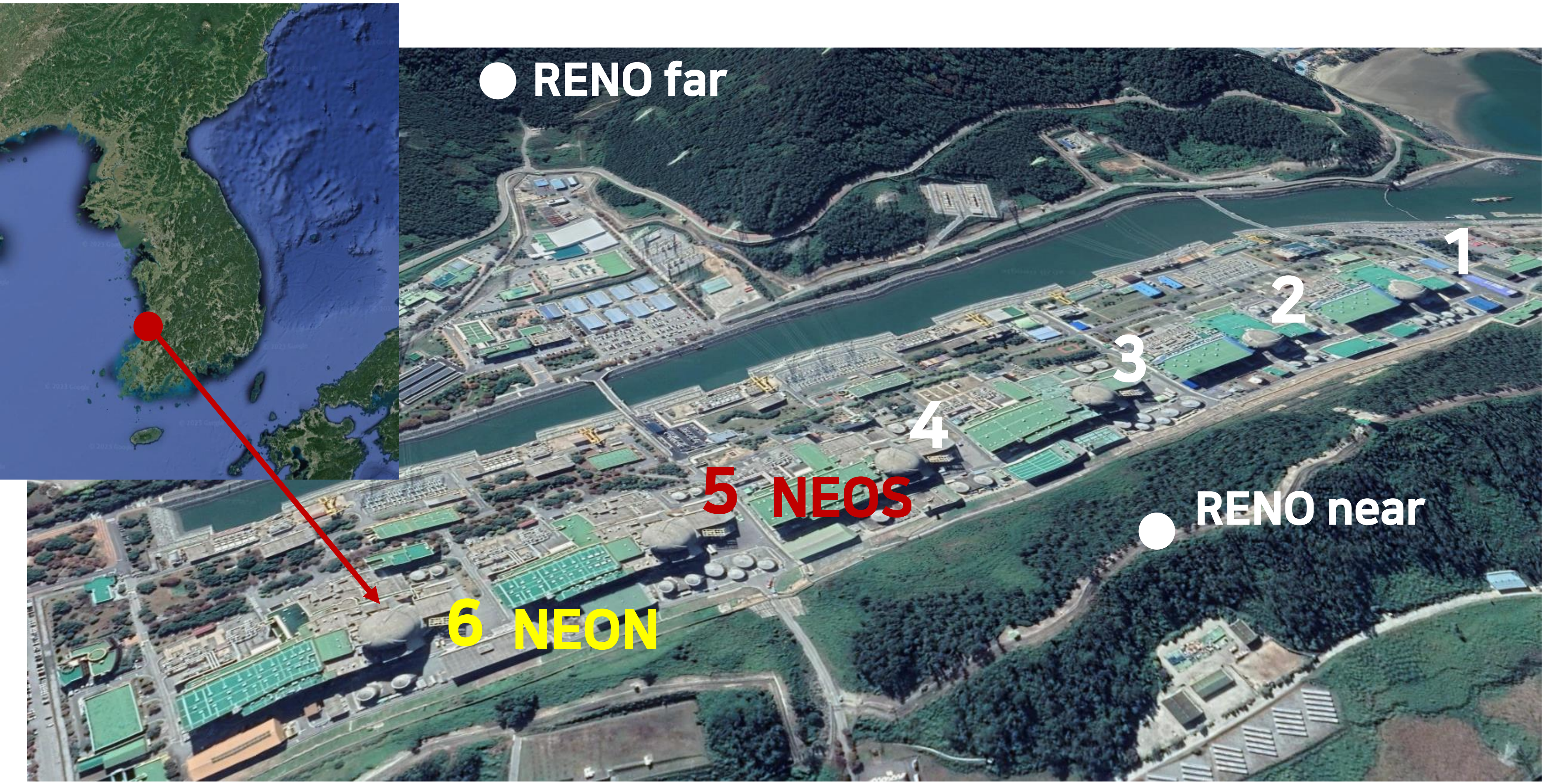
The NEON Collaboration

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

~20 members, 5 institutes, since 2019

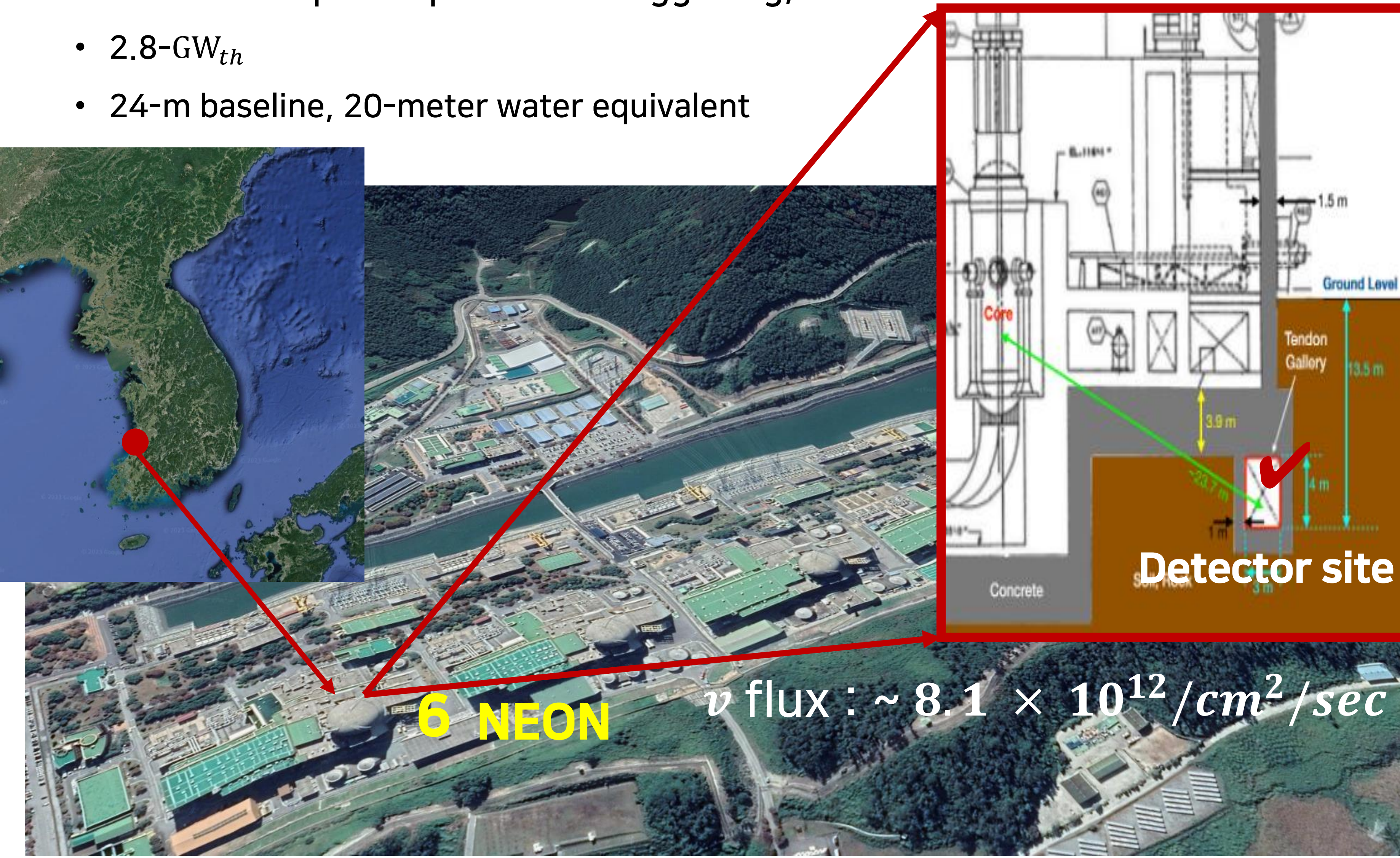
NEON Experimental Site

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



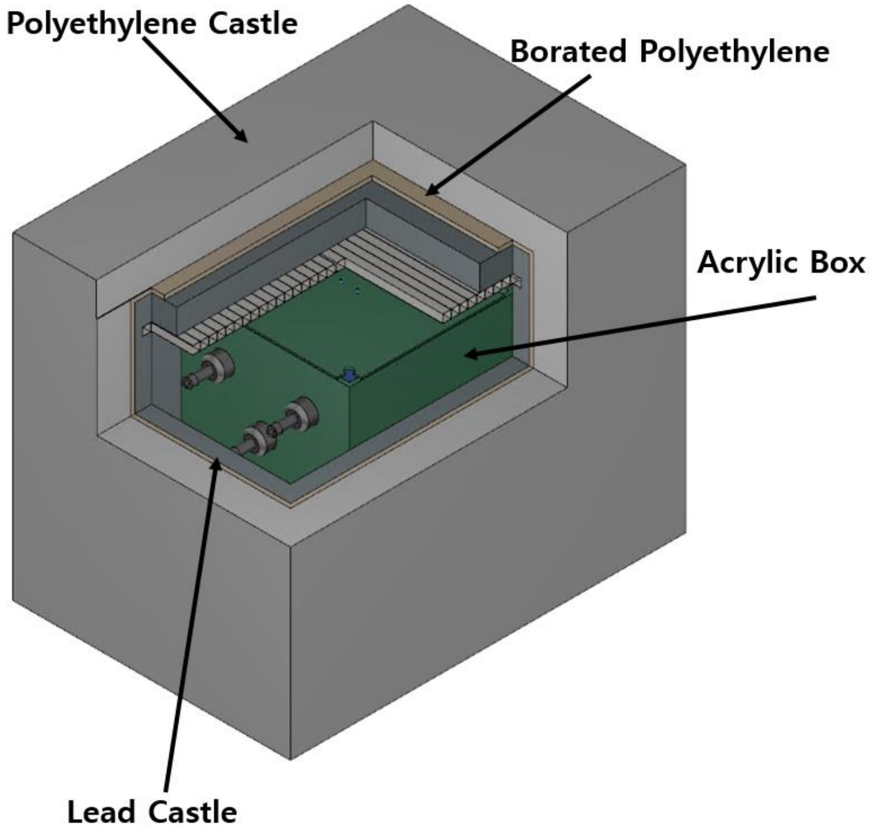
NEON Experimental Site

- 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

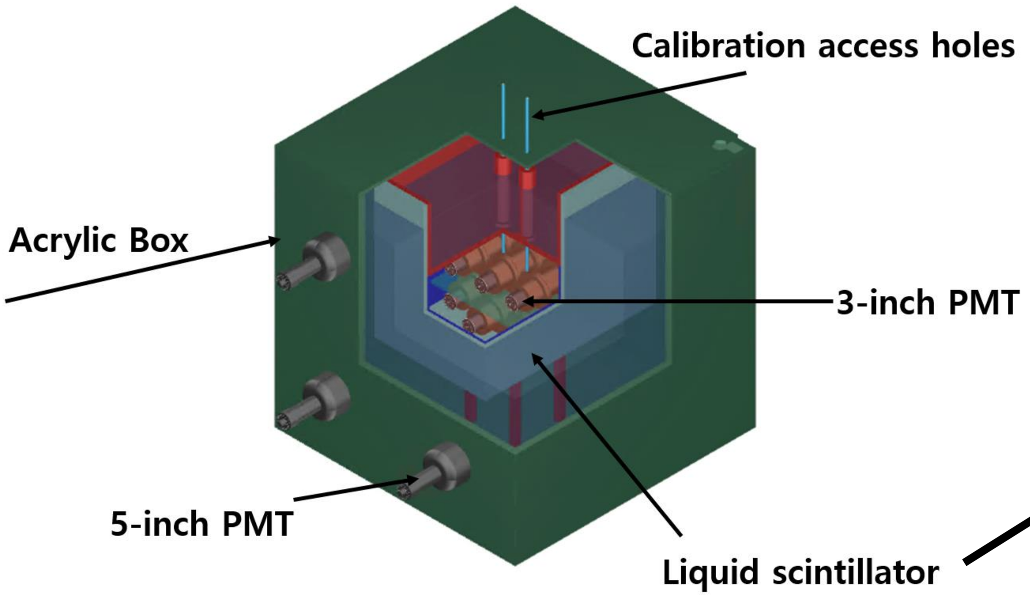


Lead shields

PE & borated PE shields

NEON Shielding

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

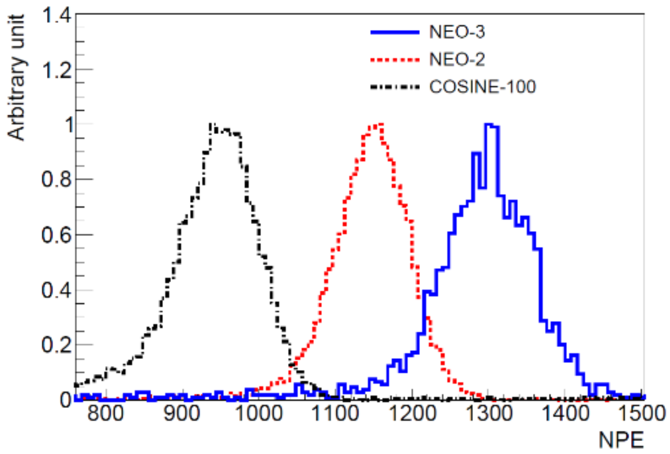


Liquid scintillator in the acrylic box

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.

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

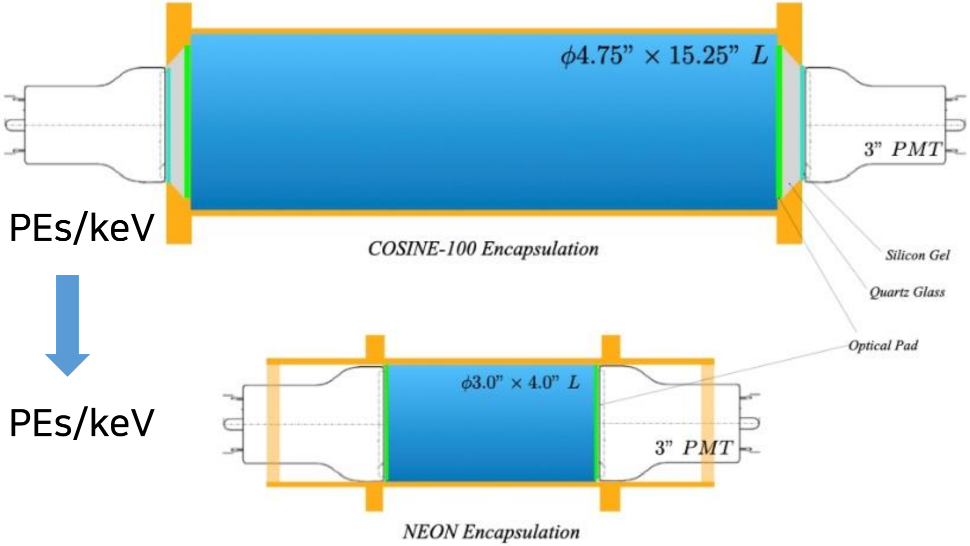


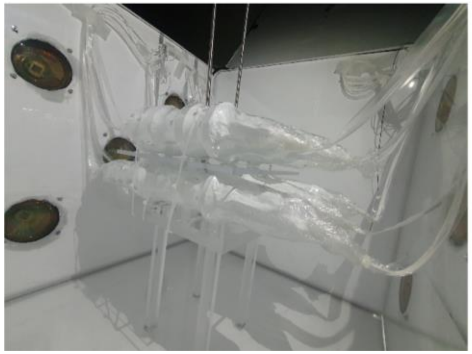
Compared to the COSINE crystal, 50 % Light yield improved!

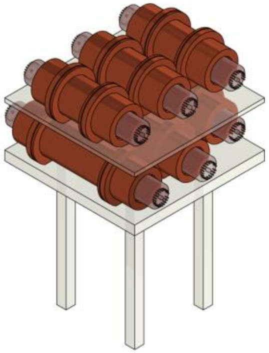
※ PE : Photoelectrons

~15 PEs/keV

~23 PEs/keV



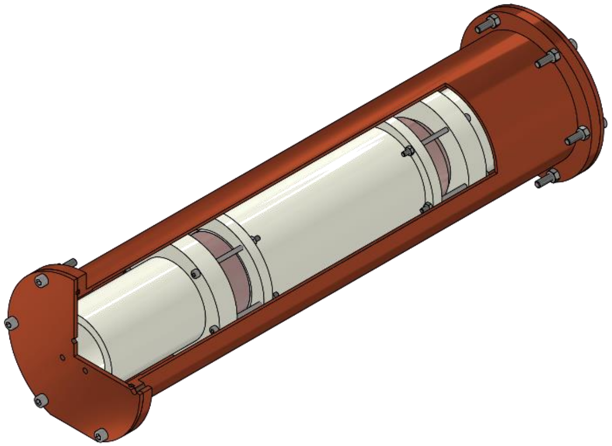




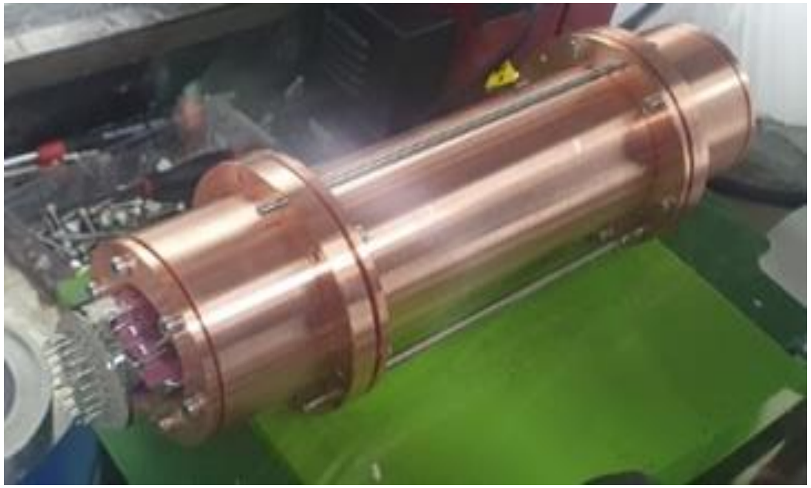
3 × 2 NaI(Tl) crystal array

NEON Detector

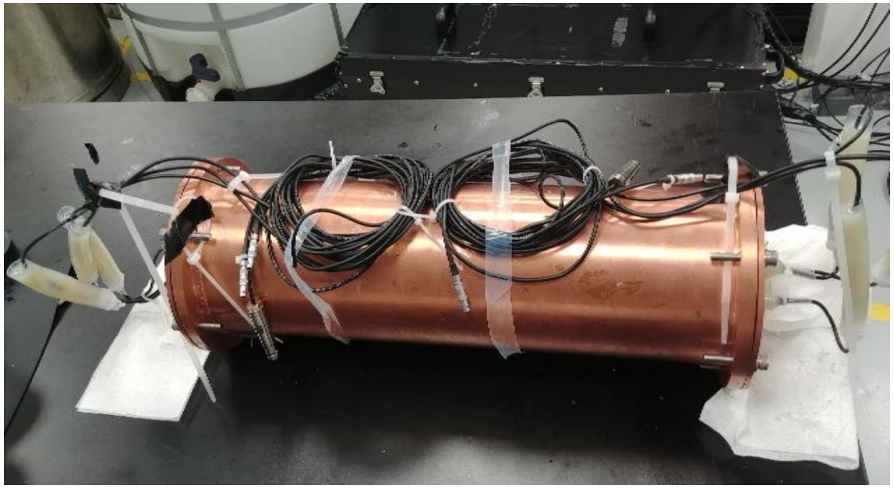
- NaI(Tl) crystals
  - Former detectors had instability issues.
    - ✓ Noise
    - ✓ Gain drop(air leak)
  - Upgraded encapsulation!
    - ✓ ~24 PEs/keV light yield



Current NEON detector encasulation design



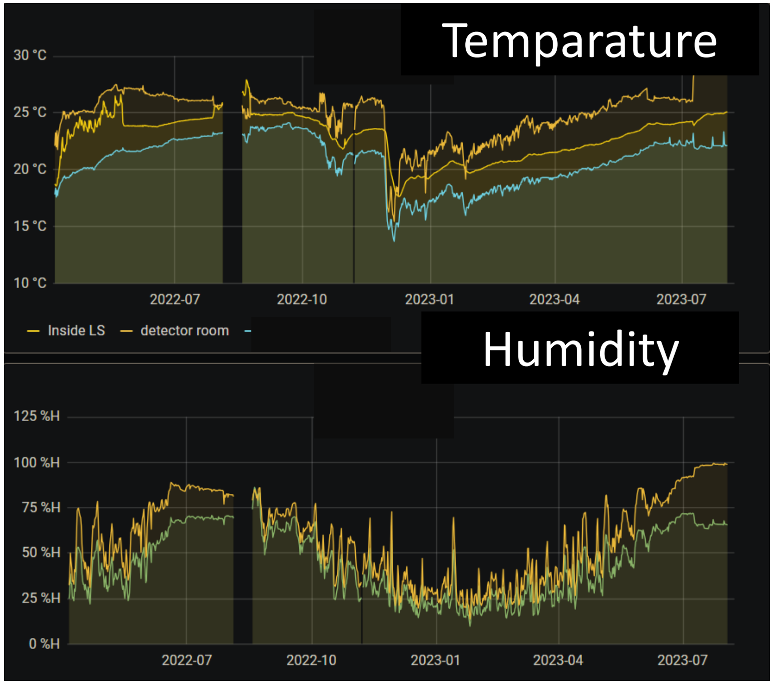
Engineering run(until Feb. 2022)



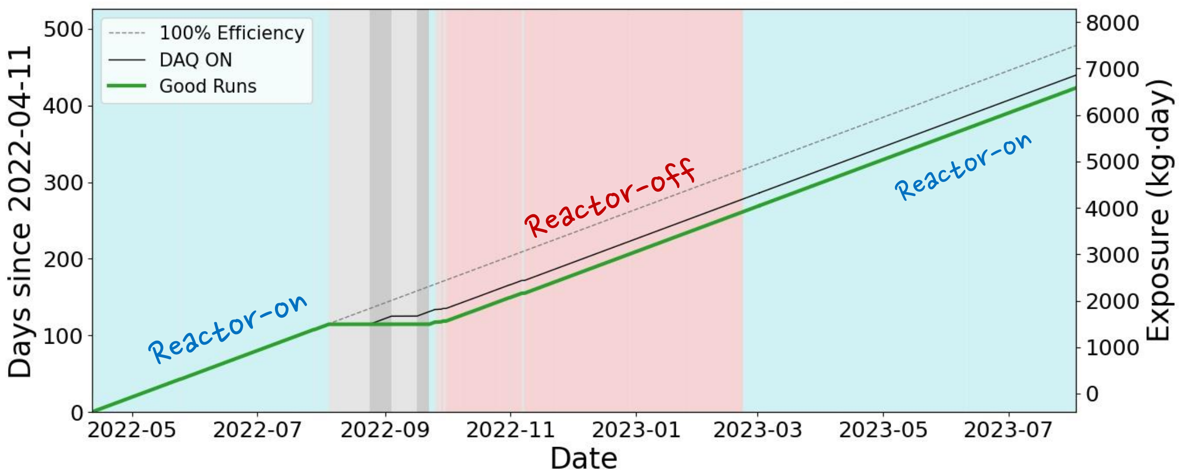
physics run(from Apr. 2022)

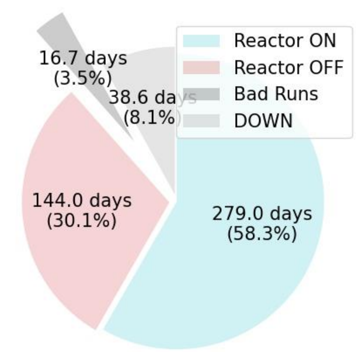
Monitoring and Exposure

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



- Exposure
  - ~7000-kg*day exposure
  - Reactor-on data : 279 days, off data : 144 days



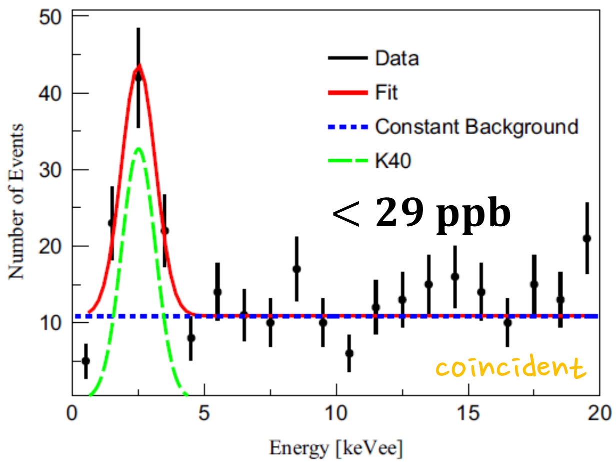


Background Study

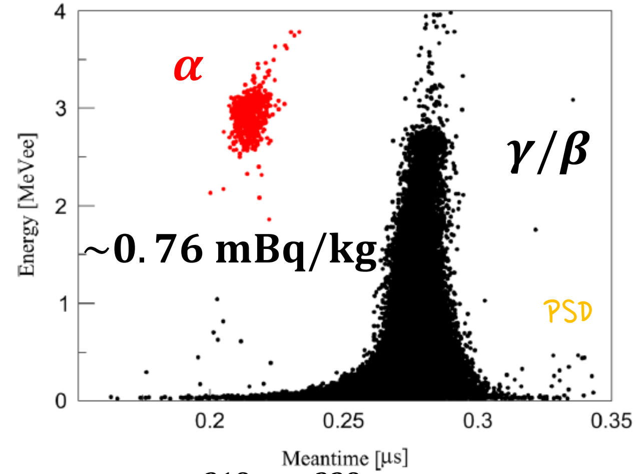
- Internal Background

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

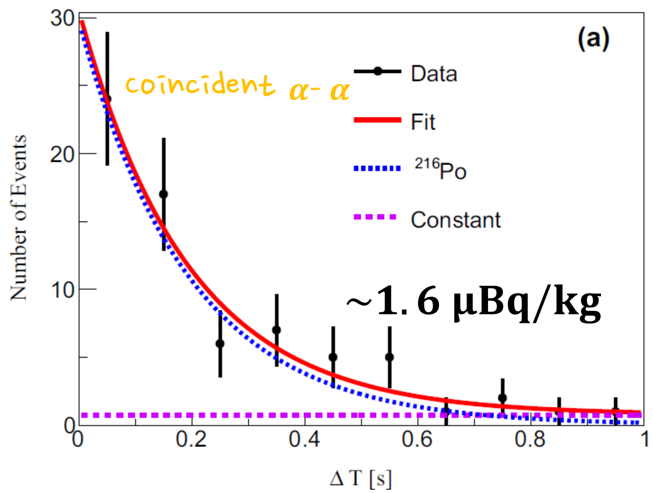
^{nat}K



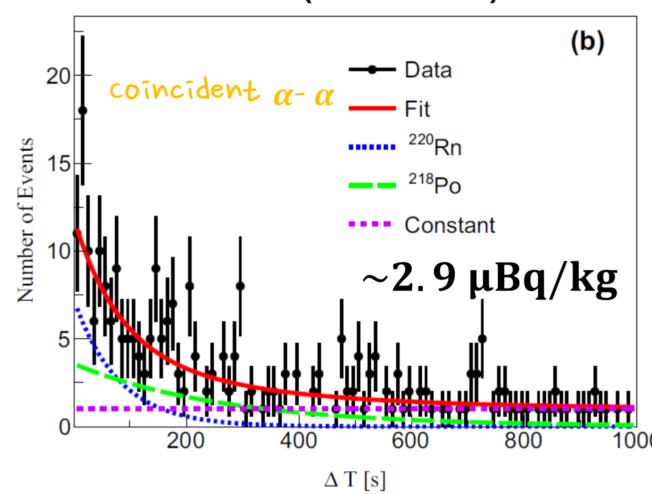
α rate



^{216}Po (^{232}Th chain)



^{218}Po (^{238}U chain)

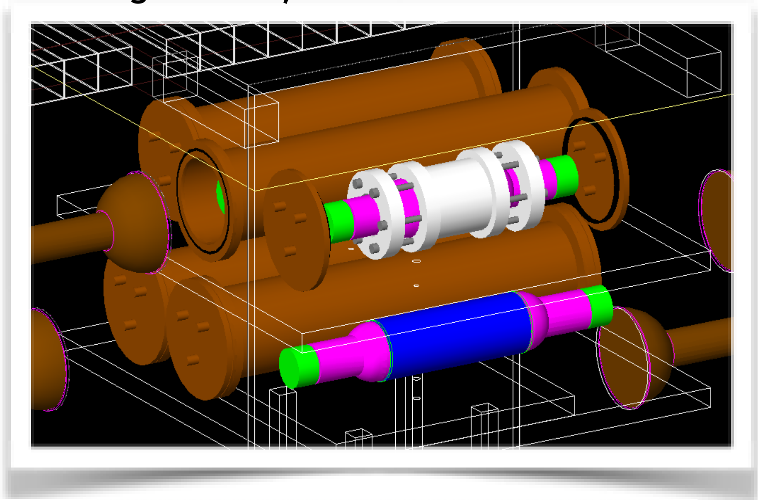


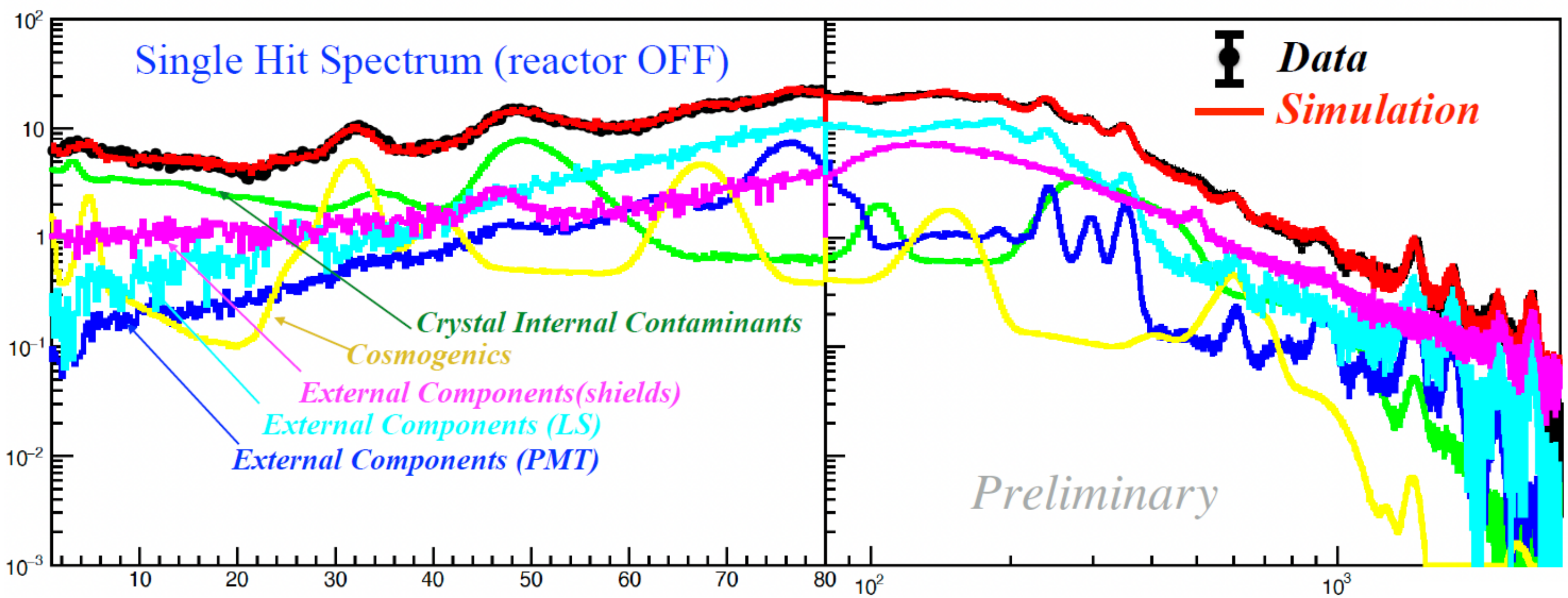
➢ Compared to the COSINE-100 low background crystal, internal background rate is similar.

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



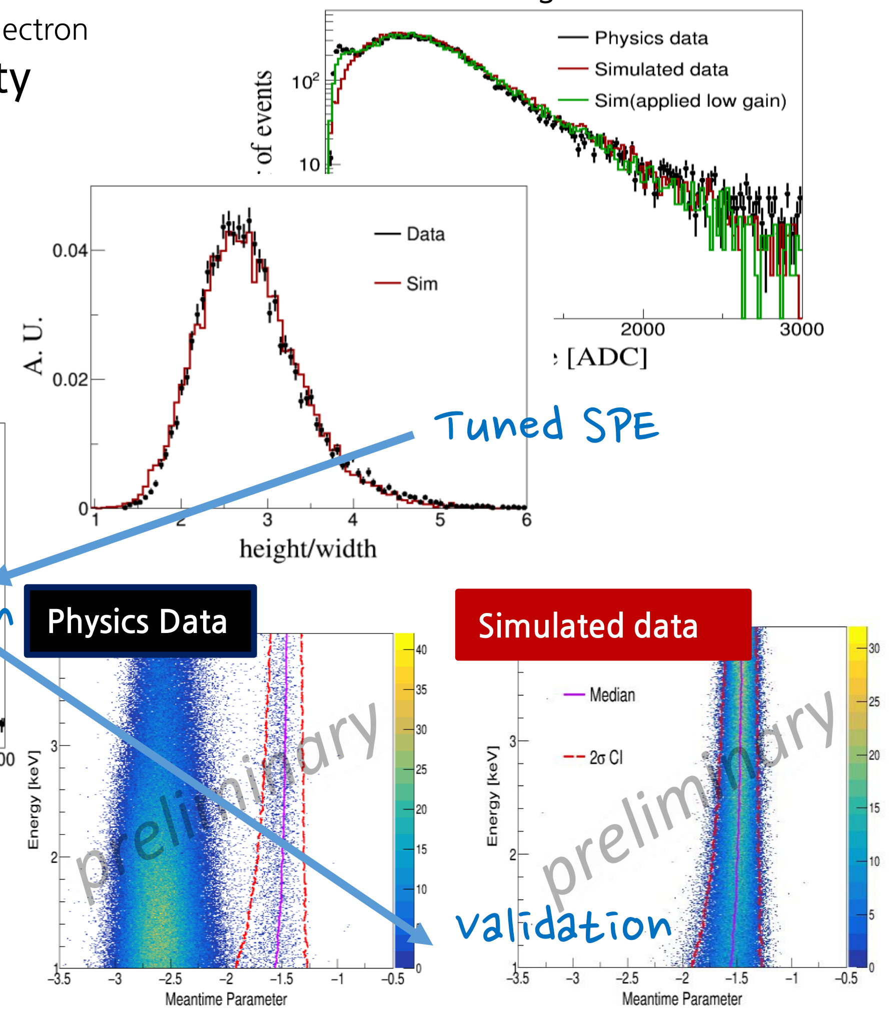


Data Analysis

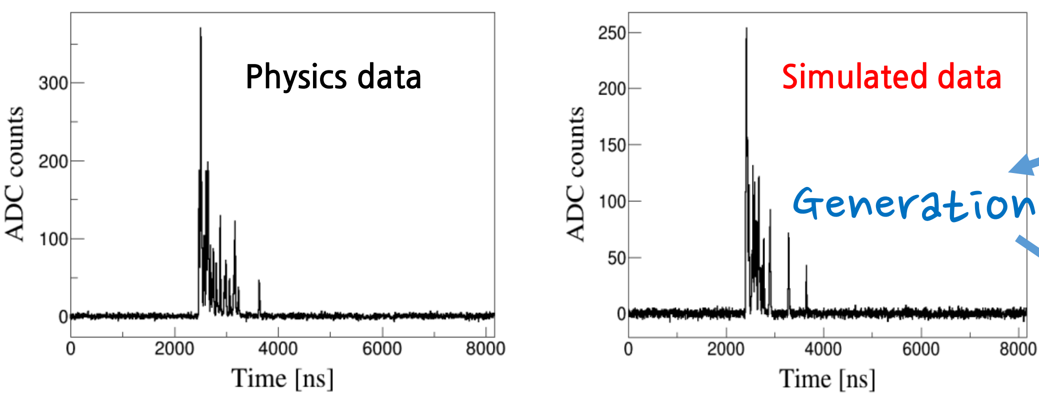
- Waveform Simulation
  - PMT gain, SPE shape, SPE timing probability
  - DAQ spec(ADC), trigger condition
  - Tuned low-gain SPE and random PEs

※ SPE : single photoelectron

SPE charge distribution



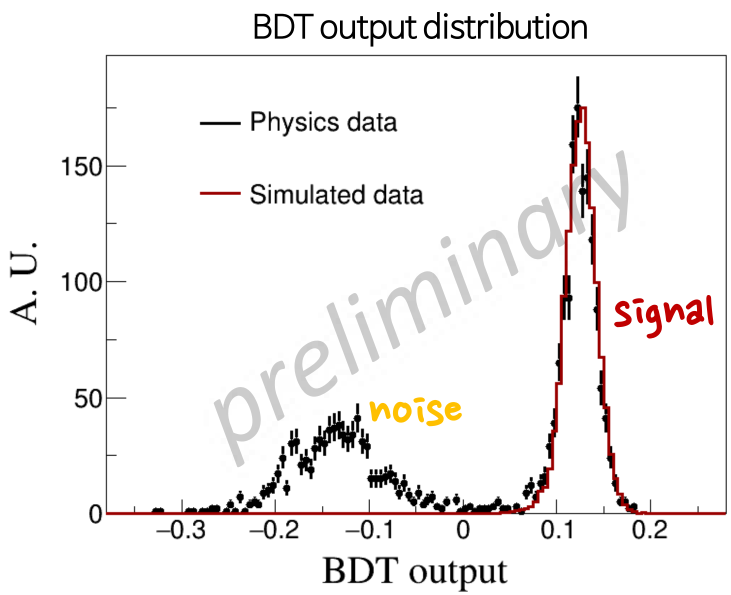
One of physics and simulated data events waveform



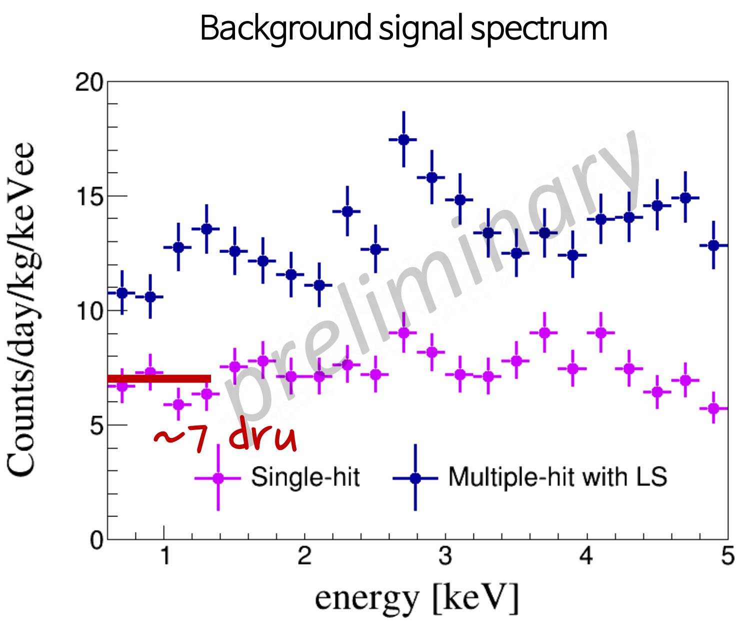
- ➢ PSD parameter development for event selection
- ➢ Signal training sample for ML/DL

Data Analysis

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



Noise rejection



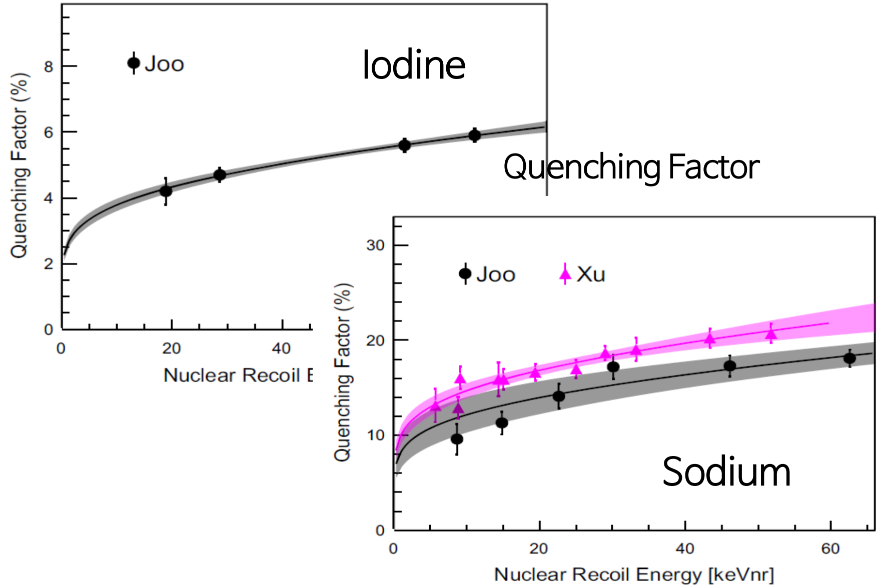
※ dru : counts/day/kg/keV

NEON Sensitivity Study

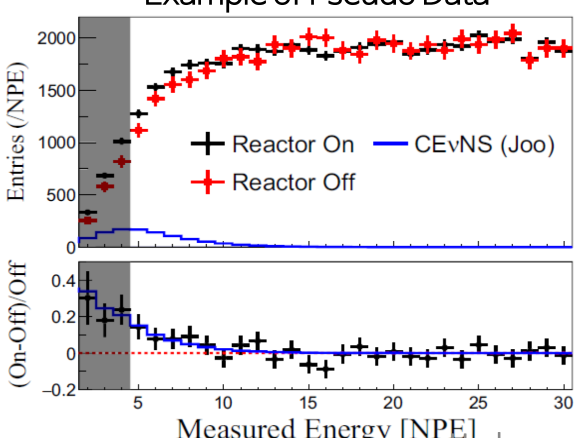
- Assumption for Sensitivity
  - Quenching factor : Joo's & Xu's
  - Exposure time :
    - ✓ Reactor-On : one year
    - ✓ Reactor-Off : 100 days
  - Detector performance
    - ✓ Background level : 7 counts/day/kg/keV
    - ✓ Detector mass : 13.5 kg
    - ✓ Light yield : 22 PEs/keV
    - ✓ Threshold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

※ NPE : number of photoelectrons

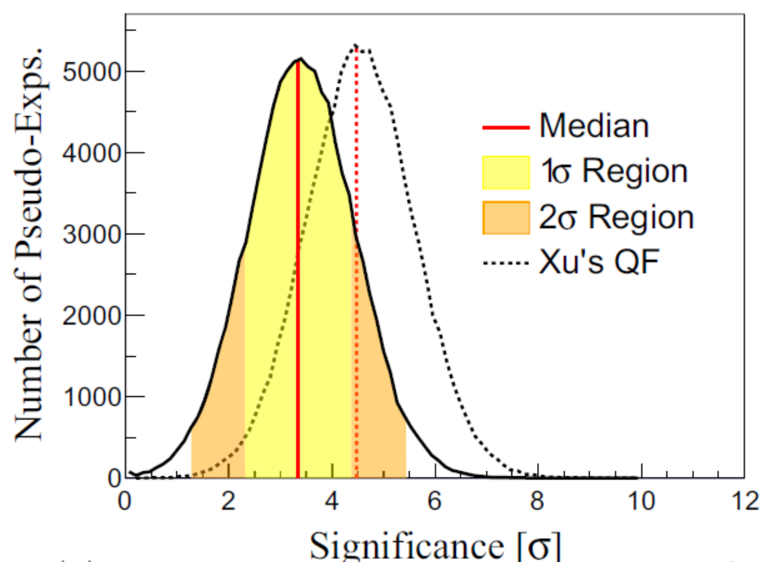
Quenching Factor



Example of Pseudo Data



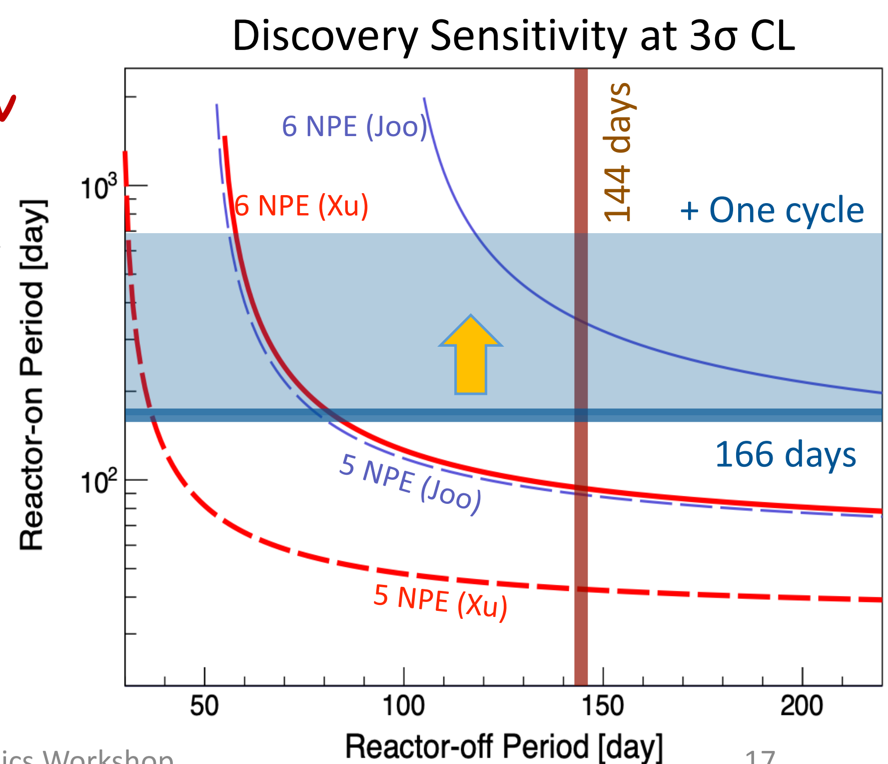
Discovery Sensitivity



NEON Sensitivity Study

- Assumption for Sensitivity
  - Quenching factor : Joo's & Xu's
  - Exposure time :
    - ✓ Reactor On : one year ✓ 279 days (receiving data)
    - ✓ Reactor Off : 100 days ✓ 144 days
  - Detector performance
    - ✓ Background level : 7 counts/day/kg/keV ✓ ~7 dru
    - ✓ Detector mass : 13.5 kg ✓ ~16.7 kg
    - ✓ Light yield : 22 PEs/keV ✓ 24 PEs/kev
    - ✓ Threshold : 5 NPE ✓ on-going

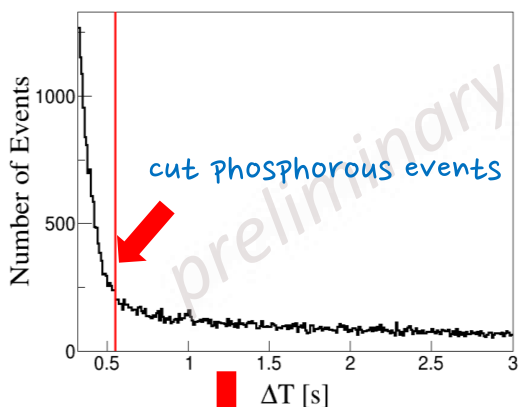
※ NPE : number of photoelectrons



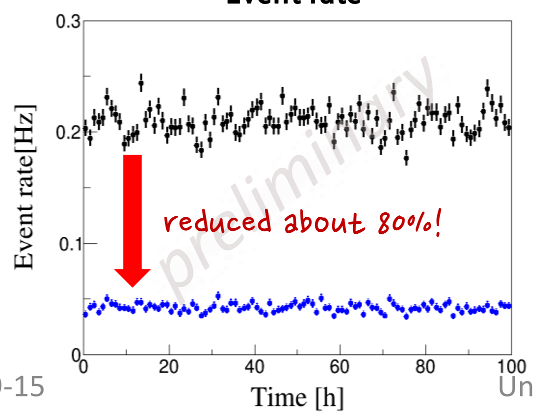
Event Selection Study for the Low Threshold

- 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

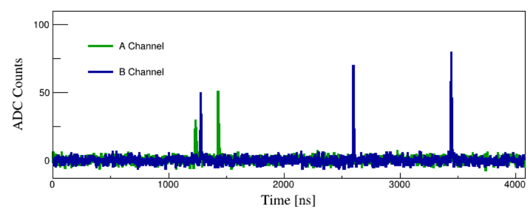
ΔT between muon and other events



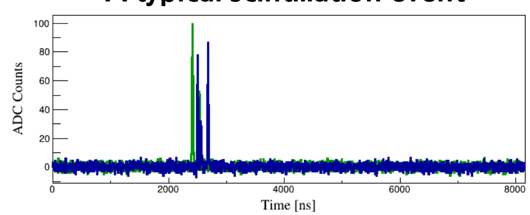
Event rate



A typical phosphorous event

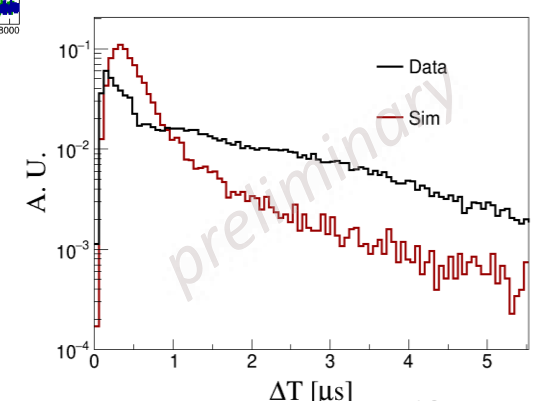


A typical scintillation event



Optimize BDT each NPE using ΔT

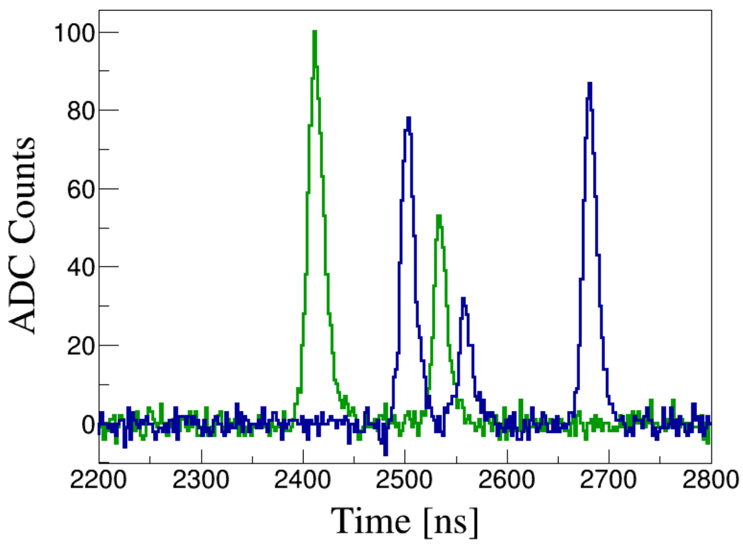
ΔT between first SPE and last SPE



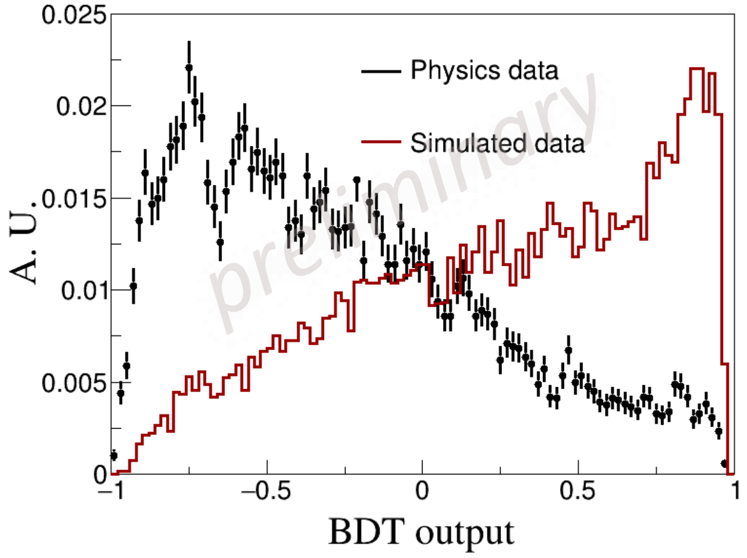
Event Selection Study for the Low Threshold

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

5 NPE waveform



BDT output distribution(5 NPE)



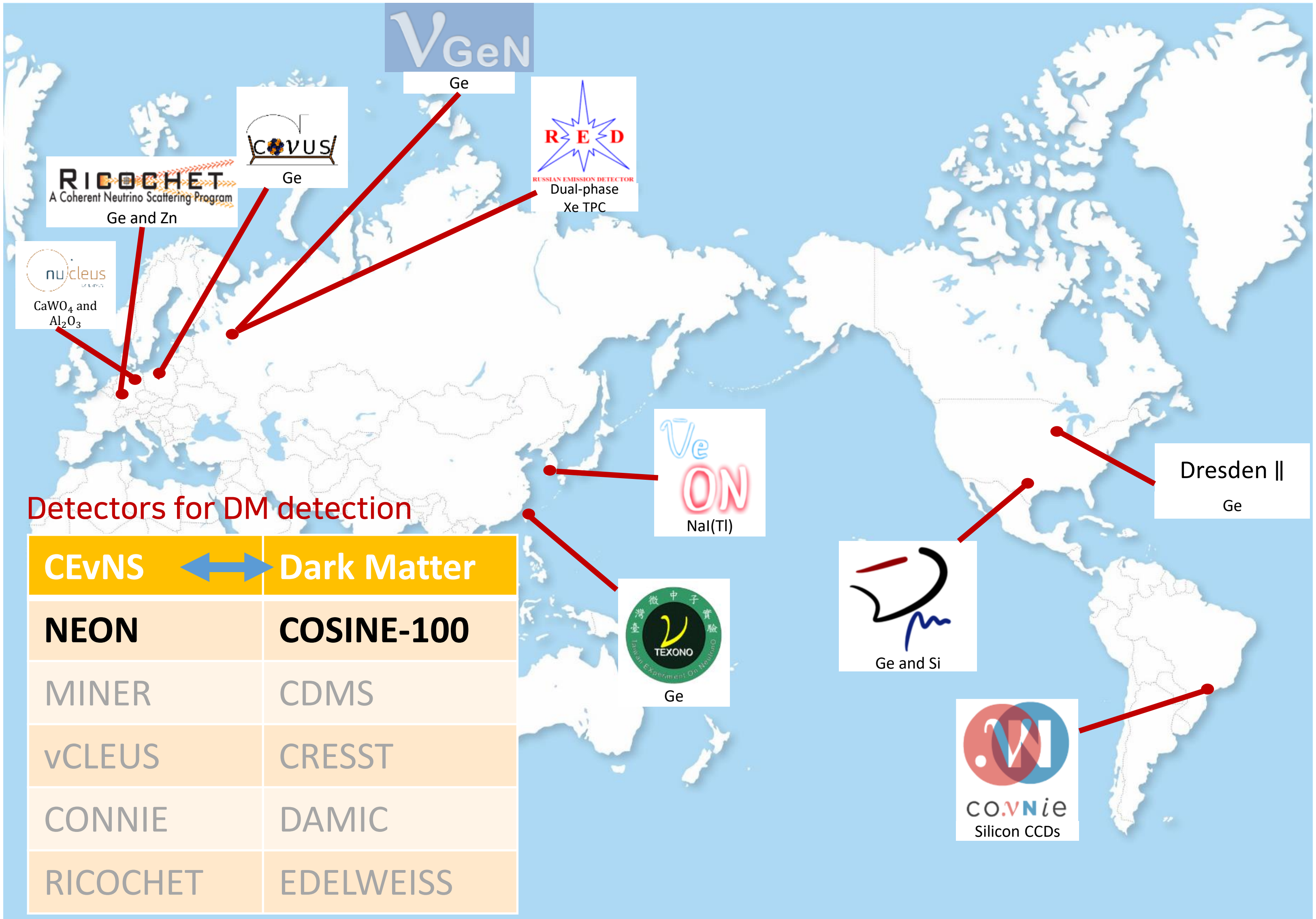
Summary

- The NEON experiment aims to observe CEvNS using reactor neutrino in South Korea.
- Data collection has been stable since April 2022. (Reactor ON : >279 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



Detectors for DM detection

CEvNS ↔	Dark Matter
NEON	**COSINE-100**
MINER	CDMS
νCLEUS	CRESST
CONNIE	DAMIC
RICOCHET	EDELWEISS