A signal search for the dark axion portal in the NEON experiment

Byoung-cheol Koh[*1]

[*1]Department of Physics, Chung-Ang University

On behalf of the NEON collaboration

Dark Matter 2023 March 29 – April 1, 2023

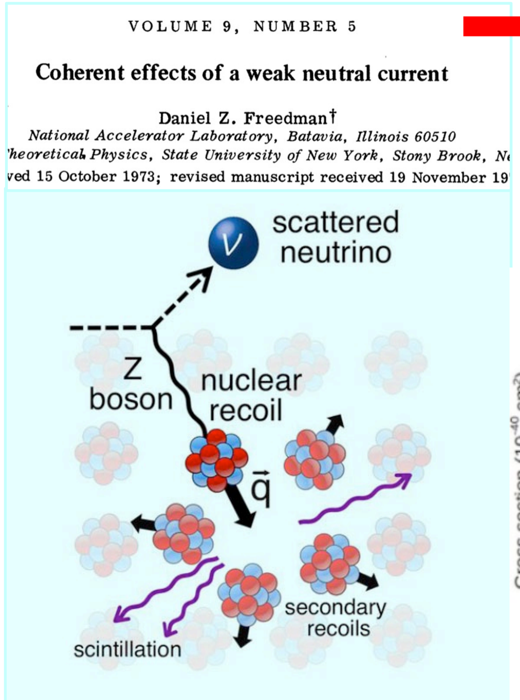
NEON status

May. 8. 2021 | Off | May. 20. 2021 | Reactor On | Sep. 26. 2022 | Off | Feb. 22. 2023 | On

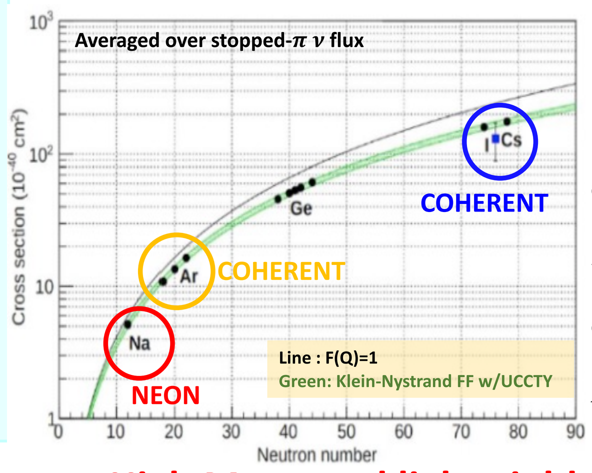
Engineering Run | Apr. 8. 2022 [Upgrade] | Phys run (~ 80% DAQ efficiency)

About 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 COHERENT collaboration** using **spallation neutrino source**. *[Science 357, 1123-1126] (2017)*
- First measurement of **CEvNS on Argon by COHERENT collaboration**. *[Phys. Rev. Lett. 126, 012002] (2021)*
- Measuring CEvNS has not been achieved by **reactor neutrino source**.

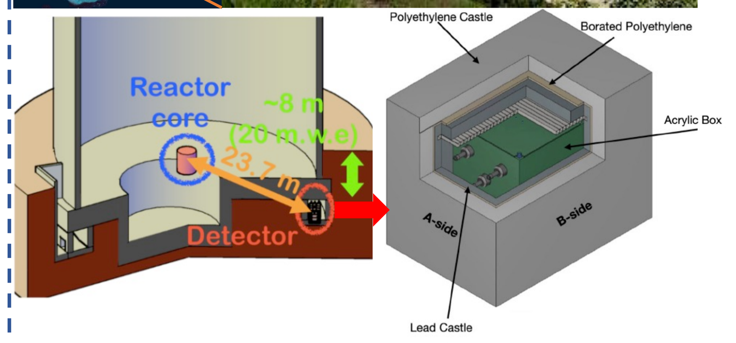


[differential cross section]

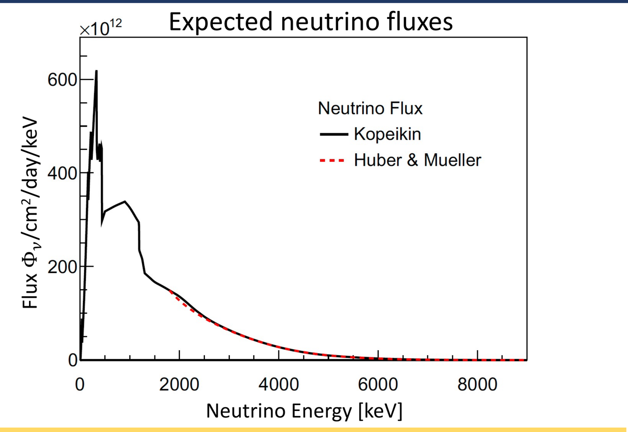
$$\frac{d\sigma}{dT} \cong \frac{G_F^2}{2\pi} M\left[2 - \frac{MT}{E^2}\right]\frac{Q_W^2}{4}F^2(Q) \rightarrow \frac{d\sigma}{dT} \propto N^2$$

G_F : Fermi constant
T: nuclear recoil
M: mass of nucleus
Q= momentum transfer
$Q_W^2 \sim N^2$: weak nuclear charge
$Q_W = (1 - 4\sin^2\theta_W)Z - N$
$F^2(Q)$: Form factor (F= 1, full coherence)

High Measured light yield & Larger recoil energy from Na !!

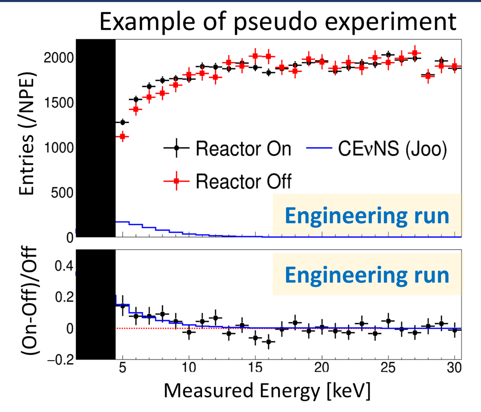


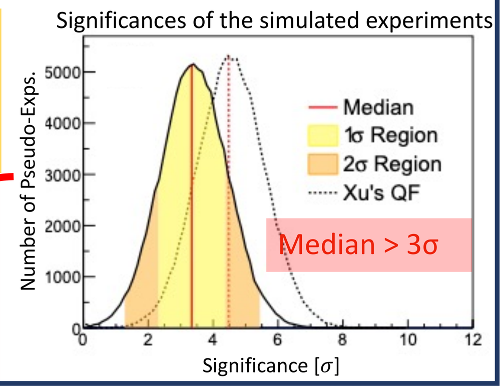
Site : Hanbit Nuclear Power Plant (same as NEOS distance)
Reactor power : 2.815 GW_{th}
Neutrino($\bar{\nu}_e$) flux at NEON site : 8.09 × 10^{12}cm^{-2}s^{-1}
Detector : NaI(Tl) Crystals
13.5 kg (Engineering run)→ 16.7 kg(Phys run)



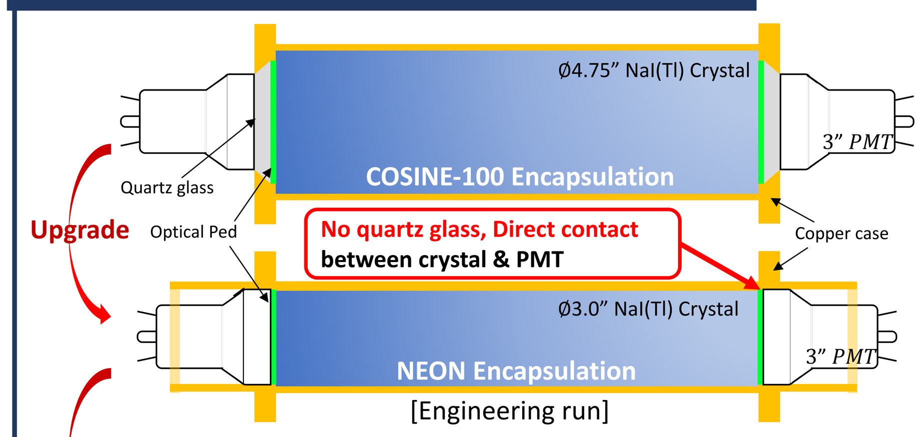
- Single flavor, $\bar{\nu}_e$
- E_ν< 10 MeV → fully coherent regime
- Recoil energy is less than few keV.
- Signal quenched → Require very low threshold

Significance plot information
22 Photo-electrons/keV light yield
Threshold assumption for sensitivity study : 0.2 keV(5-Pes)
Significance level : 3.34 ± 1.03σ
1 year reactor on data
100 days reactor off data





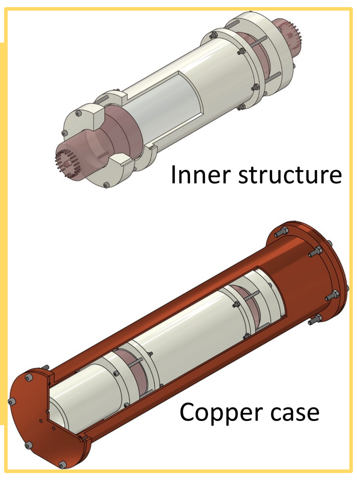
Detector performance

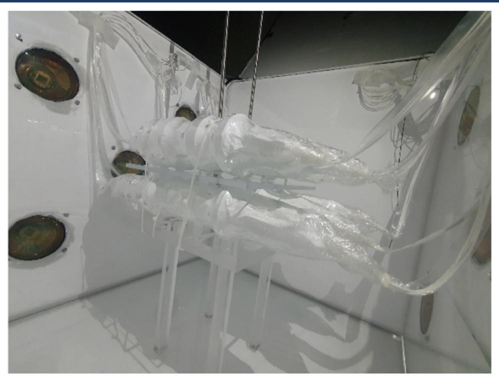


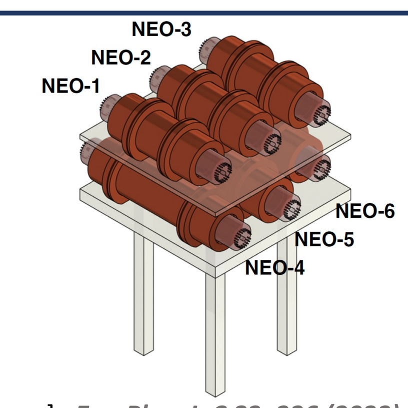
Apr. 8. 2022

NEON Encapsulation Upgrade [Phys run]

Cover the entire PMT area to protect from air leak in the detectors





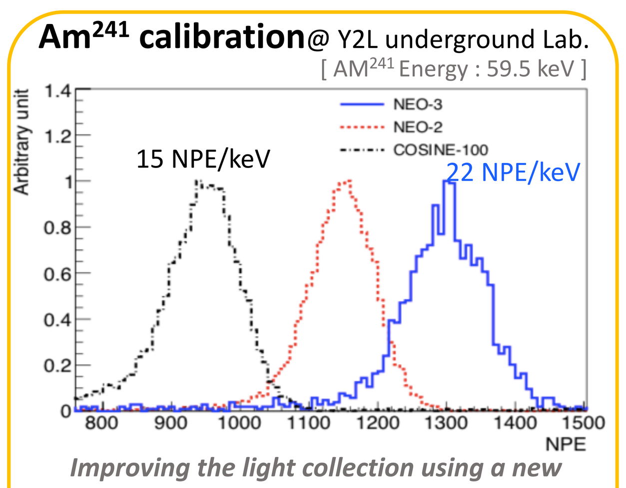


Measured radioactivity levels [Engineering run] *Eur. Phys.J. C 83, 226 (2023)*

Crystal	Mass (kg)	Size (inch, D × L)	^{nat}K (ppb)	α Rate (mBq/kg)	^{210}Pb (mBq/kg)	^{216}Po (μBq/kg)	^{218}Po (μBq/kg)	Light yield (NPE/keV)
NEO-1	1.62	3 × 4	50 ± 20	2.16 ± 0.02	1.89 ± 0.26	1.6 ± 0.7	10.6 ± 4.2	20.5 ± 0.9
NEO-2	1.67	3 × 4	137 ± 28	7.78 ± 0.03	7.46 ± 0.73	< 59.8	< 57.2	19.3 ± 0.9
NEO-3	1.67	3 × 4	46 ± 20	0.56 ± 0.01	0.53 ± 0.13	< 3.6	< 11.2	21.8 ± 0.9
NEO-4	3.35	3 × 8	22 ± 11	0.76 ± 0.01	0.69 ± 0.18	1.6 ± 0.8	< 3.3	22.4 ± 1.0
NEO-5	3.35	3 × 8	< 29	0.76 ± 0.01	0.68 ± 0.17	1.6 ± 0.5	2.9 ± 1.6	21.8 ± 0.9
NEO-6	1.65	3 × 4	< 38	0.94 ± 0.01	0.88 ± 0.21	5.8 ± 1.3	11.0 ± 3.3	21.7 ± 1.0
COSINE-100(C6)	12.5	4.8 × 11.8	17 ± 3	1.52 ± 0.04	1.46 ± 0.07	2.5 ± 0.8	< 0.25	14.6 ± 1.5

Detector performance [Engineering run]
- 7 counts/day/kg/keV flat bkg
- 22 PEs/keV light yield
- 13.5 kg detector mass
- 100 days reactor-off data
- 1 year reactor-on data

Am[241] calibration@ Y2L underground Lab. [Am[241] Energy : 59.5 keV]

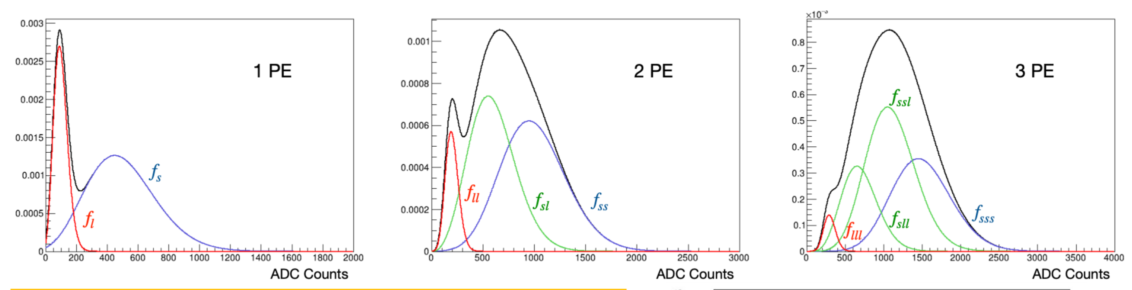


Improving the light collection using a new NaI(Tl) crystal encapsulation.
Nucl. Instrum. Meth. A 981 (2020) 164556

**See Jinyoung Kim's poster for crystal & encapsulation of COSINE-100 upgrade and COSINE-200*

After Upgrade

SPE Model

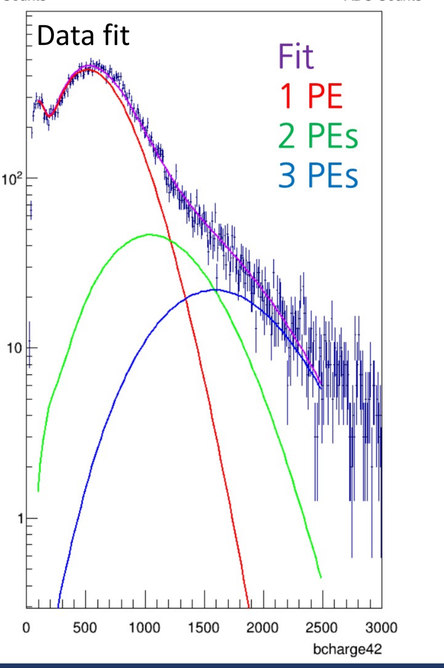


Phys run crystal information

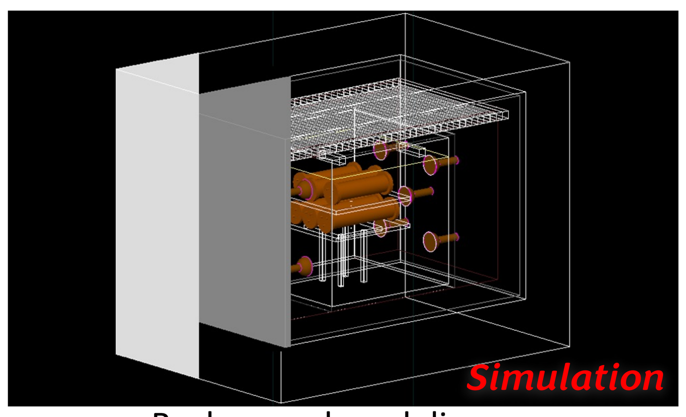
Crystal	Mss(kg)	W/o low gain NPE/keV	W/ low gain NPE/keV
NEO-3	1.67	23.89 ± 0.82	26.81 ± 1.32
NEO-4	3.32	24.48 ± 0.74	27.65 ± 1.15
NEO-6	1.67	20.20 ± 0.42	21.77 ± 0.69
NEO-5	3.32	22.87 ± 0.40	24.34 ± 0.70
NEO-7	3.34	21.99 ± 0.47	23.41 ± 0.88
NEO-8	3.34	26.73 ± 0.79	29.12 ± 1.30

Detector performance [Phys run]
- 6 counts/day/kg/keV (dru) flat bkg
- 24 PEs/keV light yield
- 16.7 kg detector mass
- 140 days reactor-off data
- 1 year reactor-on data

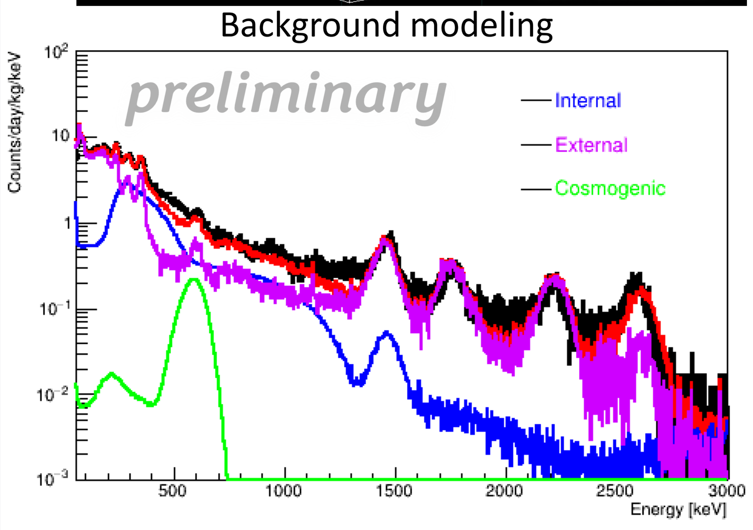
preliminary



Background modeling & Event selection



Background modeling



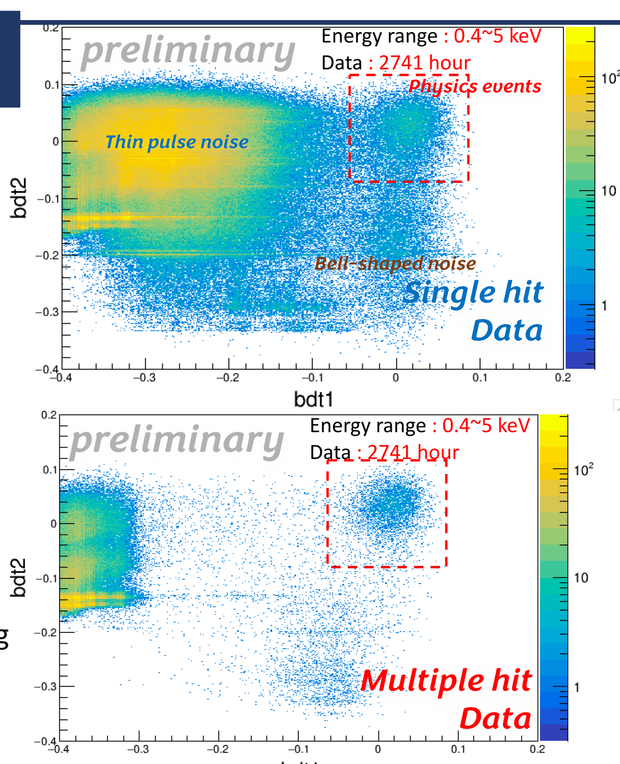
Background study of phys run data is on going

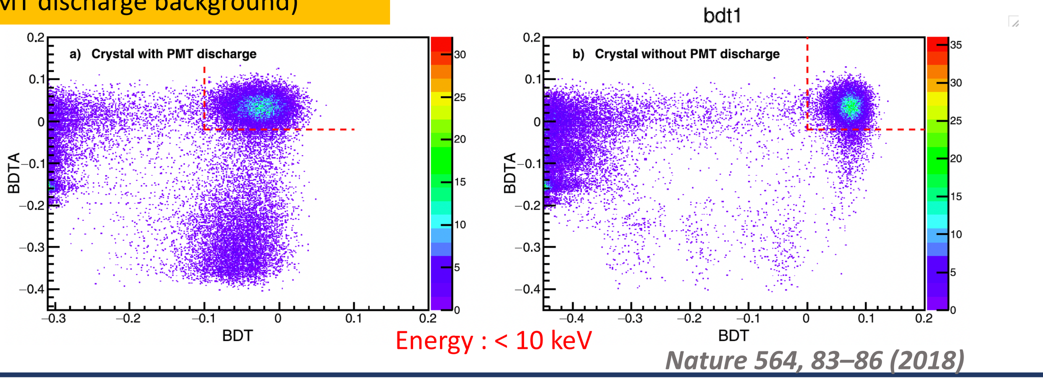
*BDT : Boosted Decision Tree (multivariable event selection technique)

- bdt1 : Type-1 PMT noise (Thin pulse)
- bdt2 : Type-2 PMT noise (Bell-shaped)
- Single hit : events triggered only by crystal-4
- Multiple hit : events triggered by multiple crystals & liquid scintillator (LS)

The study on separating signal events from noise events using BDT is ongoing

Similar behavior with COSINE-100's two-dimensional scatter plots (PMT discharge background)

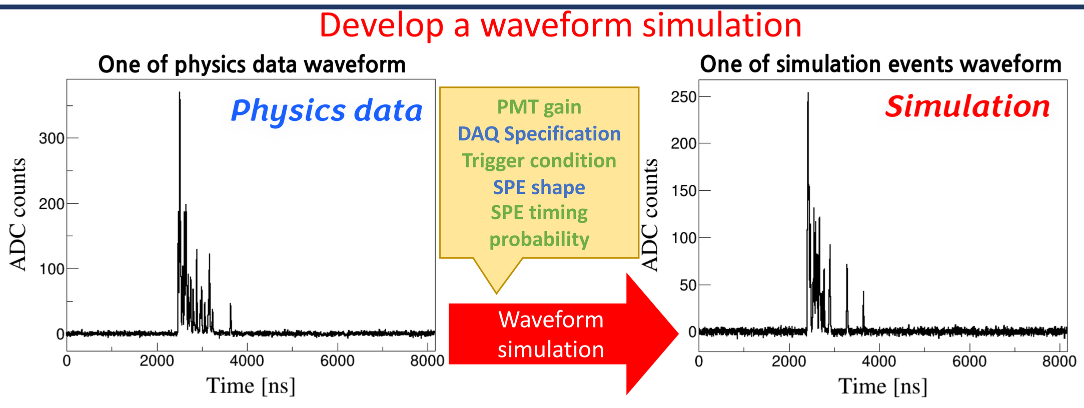


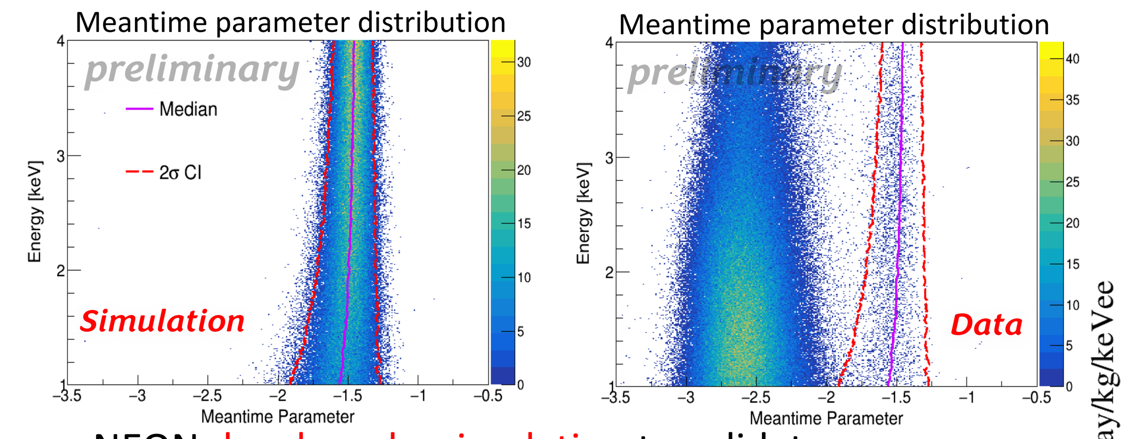


Energy : < 10 keV

Nature 564, 83–86 (2018)

Develop a waveform simulation

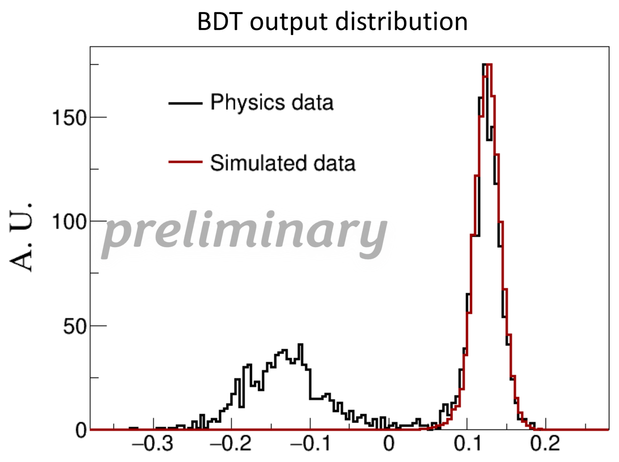




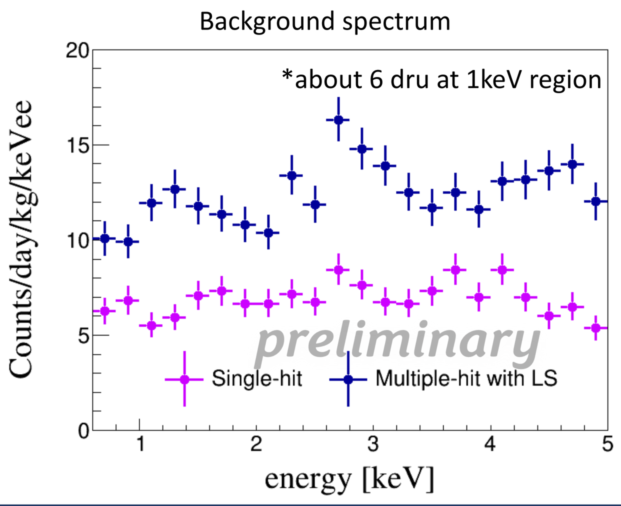
- NEON developed a simulation to validate single photoelectron (SPE) waveforms.
- Simulated SPEs agree with shape of data SPEs.
- Parameter distributions between simulation and physics data agree in the signal region.

- Scintillation signal sample : simulated data
- Background sample : physics data

BDT output distribution

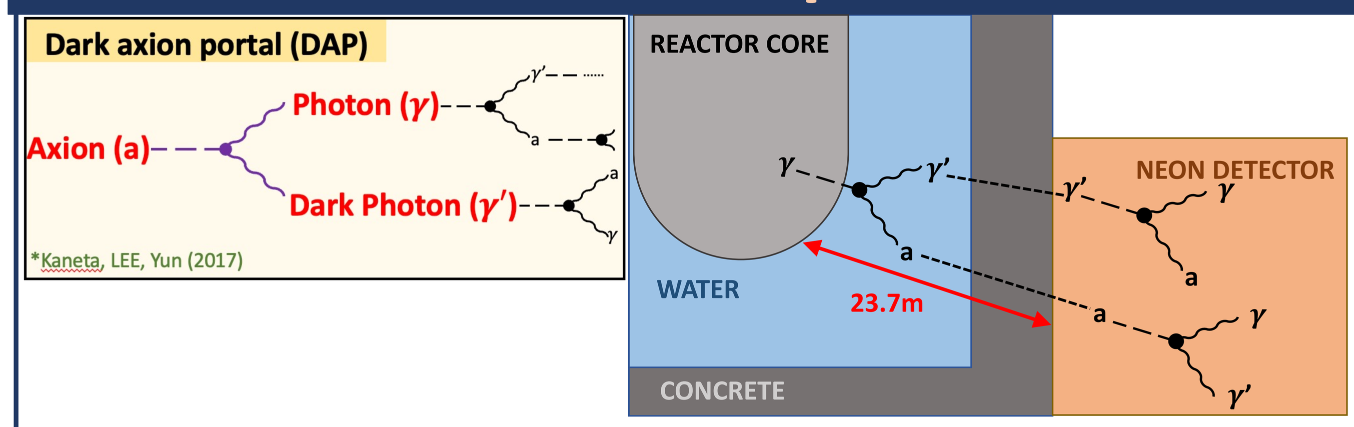


Background spectrum



Towards the dark axion portal observation

While accumulating sufficient data and developing an optimal analysis for the CEvNS measurement, We hope to search for signals from the **Dark Axion Portal**



- **Dark axion portal (DAP)** is a theoretical framework that predicts the existence of axion-like particles that interact with Standard Model particles through a new portal.
- In a reactor core, the **dark photon** can be created and then decay into a **photon** and an **axion** through an **axion-photon-dark photon vertex.**
- In the NEON experiment, a signal search for the dark axion portal is on going.

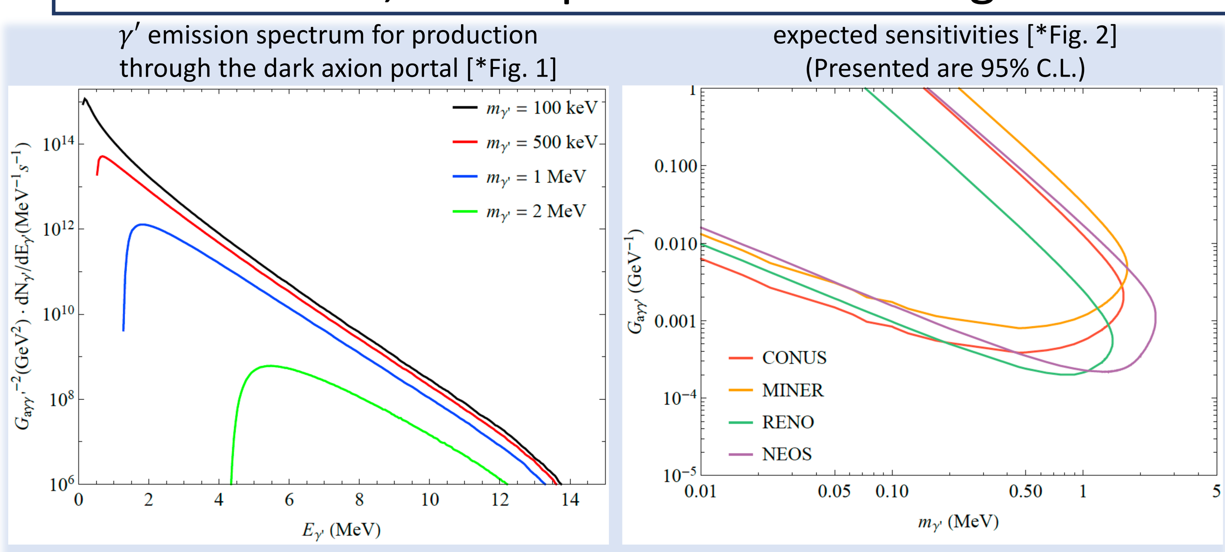


Fig. 1 : dark photons through the dark axion portal ($G_{a\gamma\gamma'}$) in a 1 GW nuclear reactor for four dark photon masses exhibits kinematic cutoffs in the energy spectrum
Fig. 2 : The result with 3.5 MeV-cutoff is shown for NEOS. (contours for one year of data)

Advantages for DAP detection at the **NEON** experiment
- Detector location
  Same neutrino flux as NEOS, 23.7m from core
  No additional reactor background
- Low background, high resolution NaI(Tl) detector
- Low-energy neutrino detection capability
- LS(0.8 tons) is used as active target as well as active veto. (crystal – LS multiple DAP signal)

NEON is planning to analyze DAP
Hope to share good news
in the next presentation!!

[Reference] Figures and information related to DAP
*New searches at reactor experiments based on the dark axion portal,(arXiv:2011.03276v2 [hep-ph] 14 Mar 2021)