한국 원전 중성미자 실험

2023. 12. 22.

양병수 (서울대학교)

2023년 한국물리학회 입자 장 물리 분과회의

목차

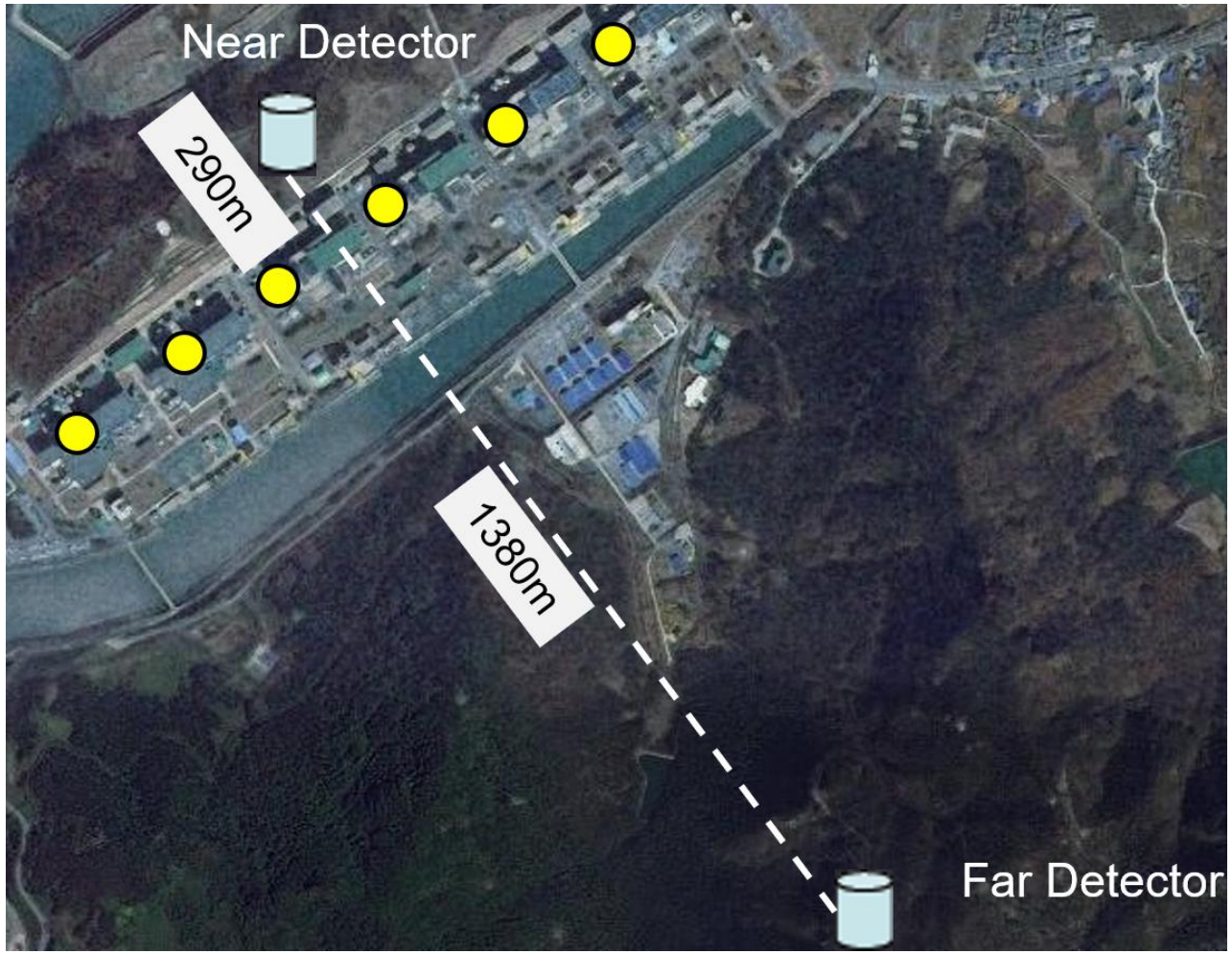
- RENO
- NEOS
- RENE
- NEON

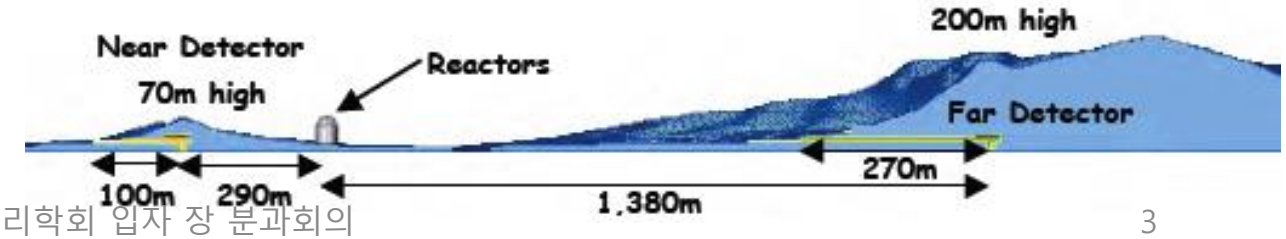
전남 영광군 한빛원자력발전소 전경

- 협조: 오유민 (NEOS), 이원준(RENE), 이현수(NEON)

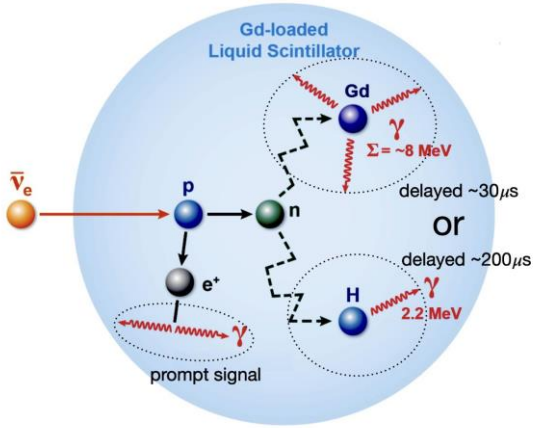
RENO

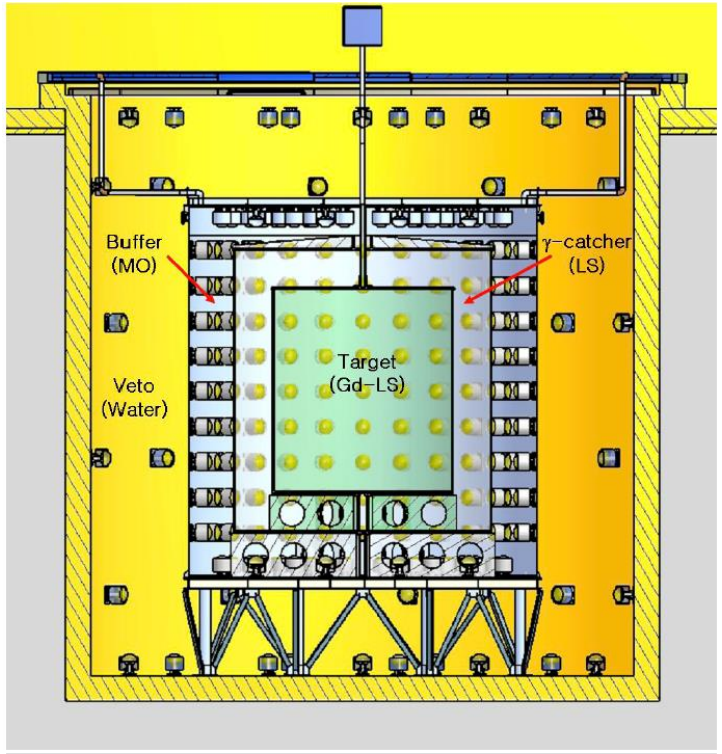
- 주 목표: θ_{13} 측정
- 2011년 8월 데이터 수집 시작
- 현재 7개 기관에서 약 30명 참여

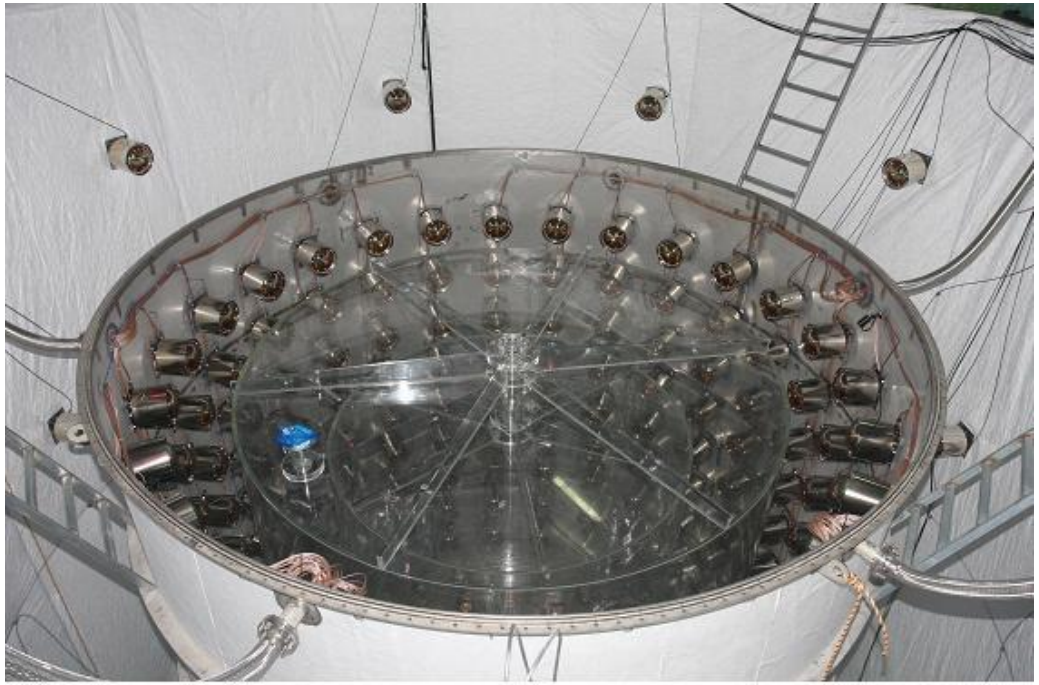




RENO 검출기







- 354 ID +67 OD 10” PMTs
- Target : 16.5 ton Gd-LS, R = 1.4 m, H = 3.2 m
- Gamma Catcher : 30 ton LS, R = 2.0 m, H = 4.4 m
- Buffer : 65 ton mineral oil, R = 2.7 m, H = 5.8 m
- Veto : 350 ton water, R = 4.2 m, H = 8.8m

최근 데이터 현황과 진행 중인 연구

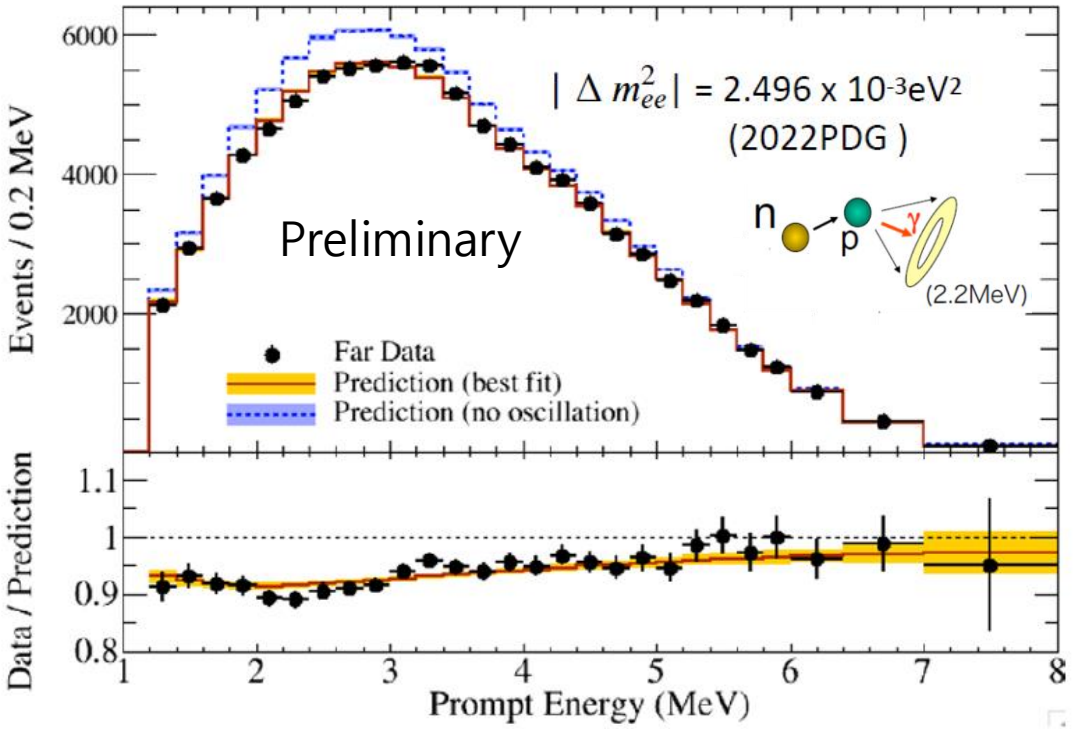
- 데이터 수집 2023년 3월 16일 종료. 다음 실험 RENE를 위해 근거리 검출기 재가동 준비 중.

- 최종 데이터: 2011년 8월 – 2023년 3월. 약 3800일

- 데이터 분석
  1. 데이터 수집 종료 전 기존 연구 마무리
     - nH 2800일 데이터를 사용한 θ_{13} 측정.
     - U235/Pu239 원전 반전자 중성미자 스펙트럼 측정
  2. RENO 전 데이터 총정리 중.

nH 2800일 데이터를 사용한 θ_{13} 측정

- 2023년 한국물리학회 가을학술대회 김상용 박사 보고



Preliminary

$$\sin^2(2\theta_{13}) = 0.082 \pm 0.007(\text{stat.}) \pm 0.011(\text{syst.})$$

JHEP(2019) : 1500days n-H result → $\sin^2(2\theta_{13}) = 0.086 \pm 0.008(\text{stat.}) \pm 0.014(\text{syst.})$

PRL(2018) : 2200days n-Gd result → $\sin^2(2\theta_{13}) = 0.0896 \pm 0.0048(\text{stat.}) \pm 0.0047(\text{syst.})$

- nGd 2200일과 합친 결과
  (nGd, nH 상관관계 고려)

Preliminary

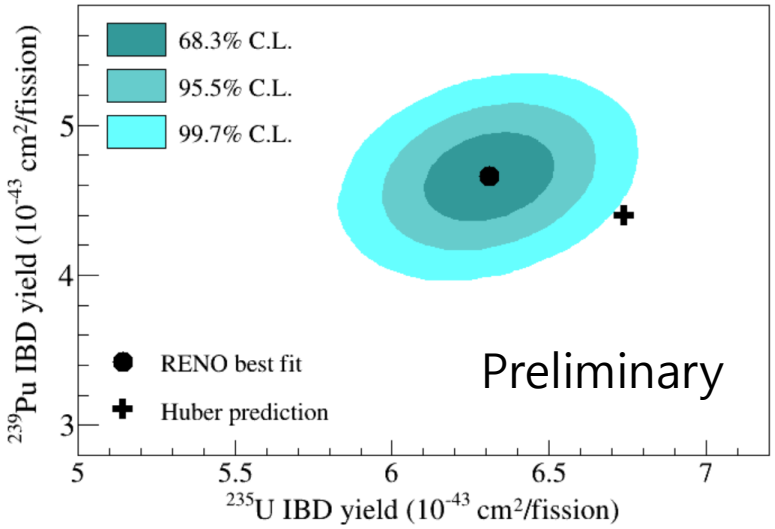
$0.0871 \pm 0.0040(\text{stat.}) \pm 0.0045(\text{syst.}) \; [\pm 0.0060(\text{tot.})]$

- 현재 논문 출판 준비 중.

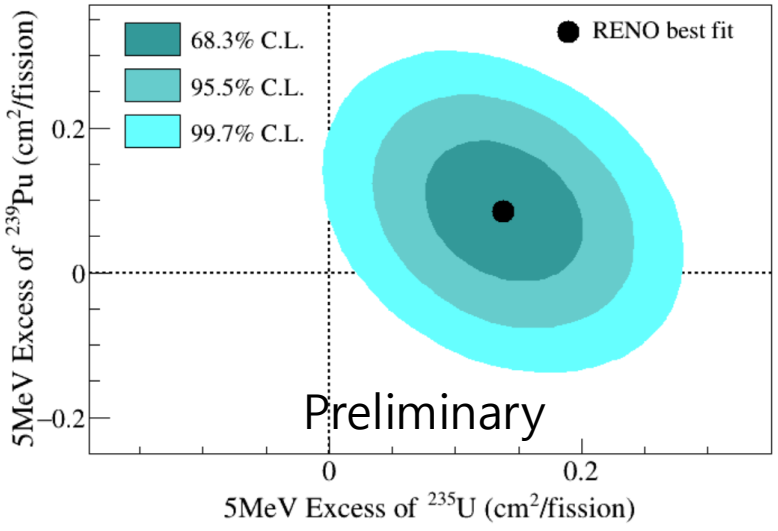
U235/Pu239 원전 반전자 중성미자 스펙트럼 측정

- 2023년 한국물리학회 가을학술대회 김도진 학생 보고
- Pu239보다 U235에 대해 기존 모델과 유의미한 차이 보고
- 논문 출판 준비 중

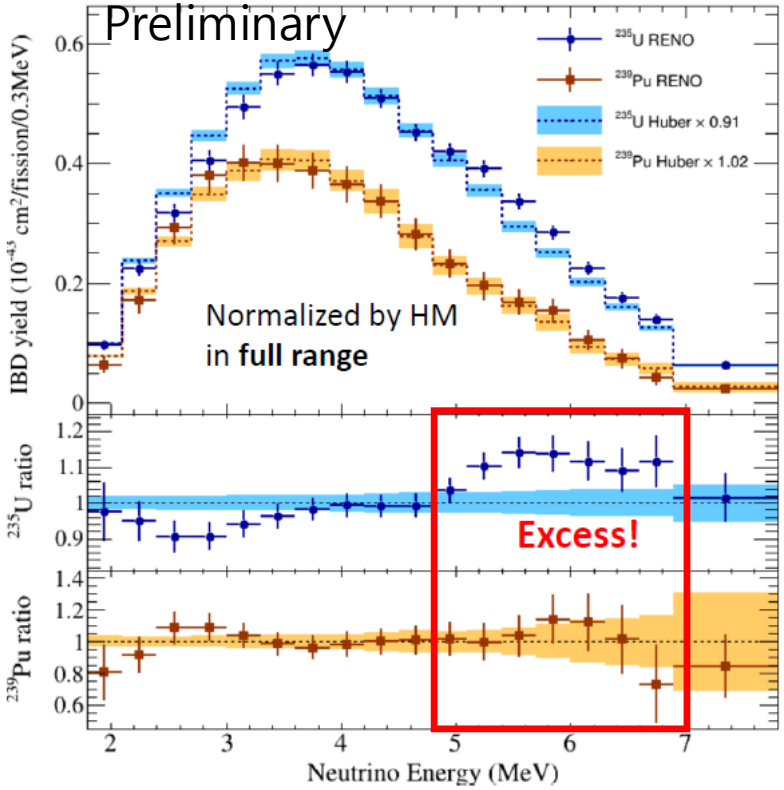
Pu239와 U235의 IBD 수율



Pu239와 U235의 5 MeV 영역 기여



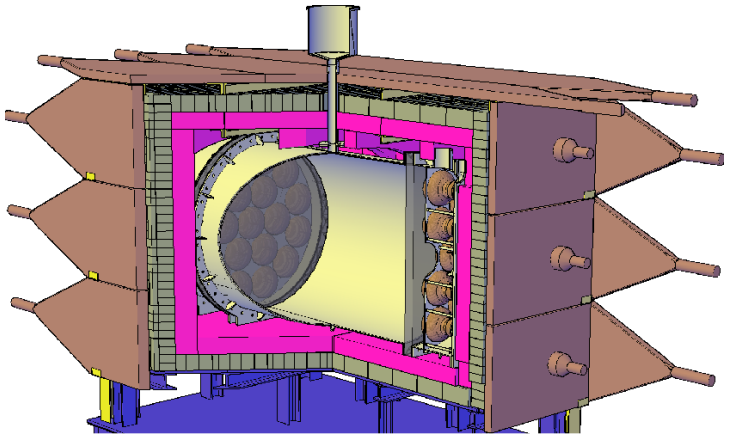
데이터로 구한 원전 반전자중성미자 에너지 스펙트럼

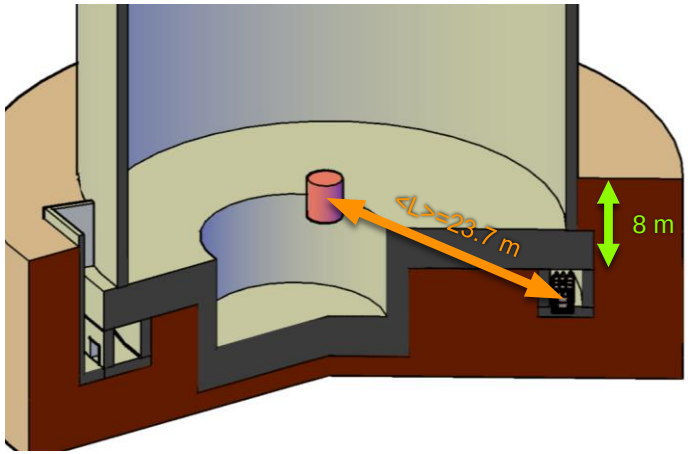


NEOS

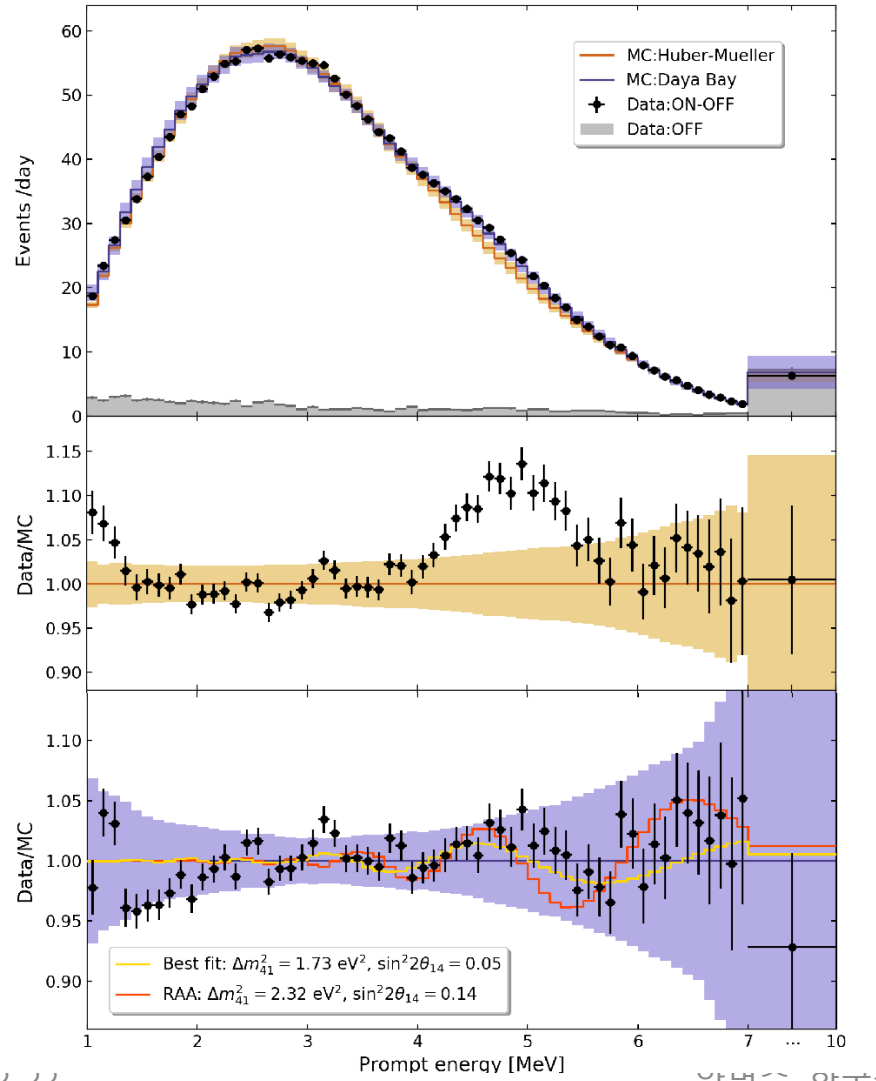
Verification of reactor antineutrino anomaly and light sterile neutrino

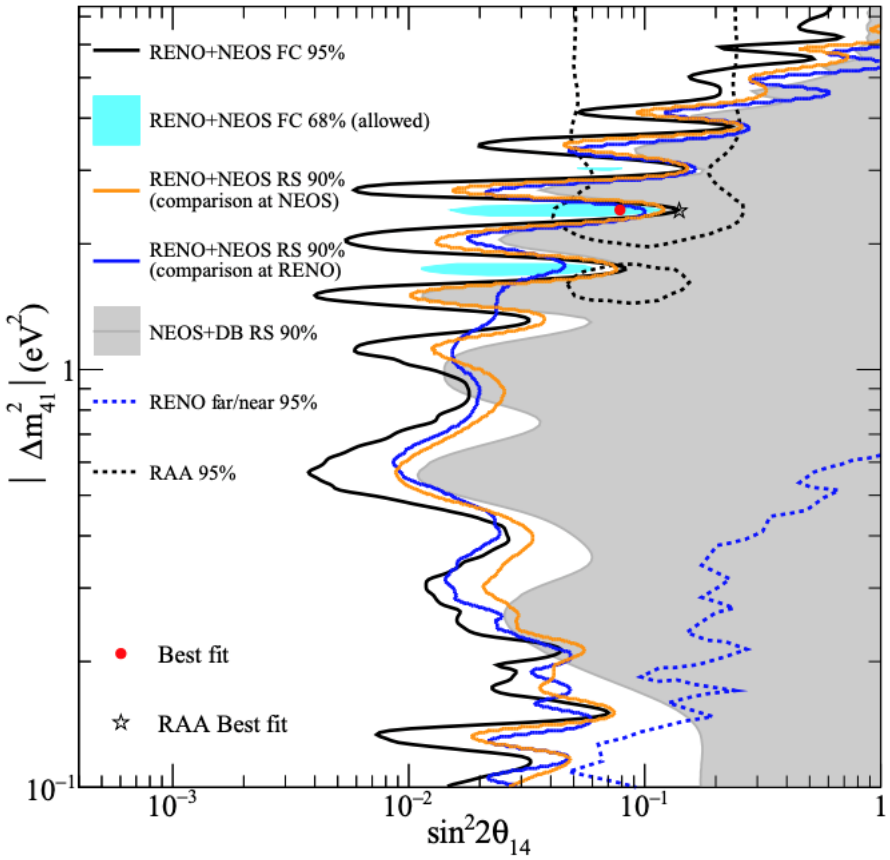
- 1000 L of 0.5% Gd-loaded liquid scintillator
- At 24 m distance from Hanbit-5 reactor core (2.8 GWt), in the tendon gallery
- Data taking—phase 1: 2015-2016, phase 2: 2018-2020





NEOS: sterile neutrino search

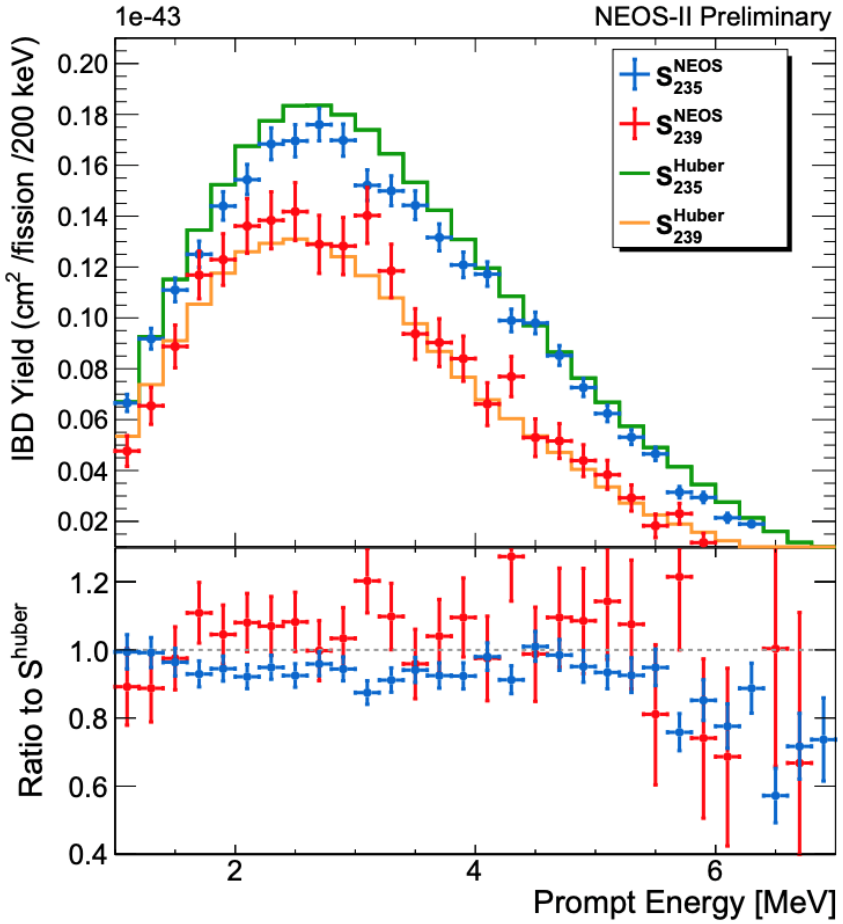


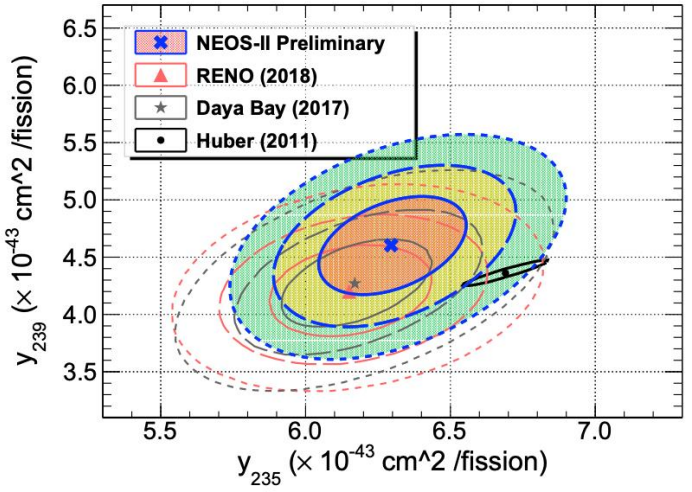


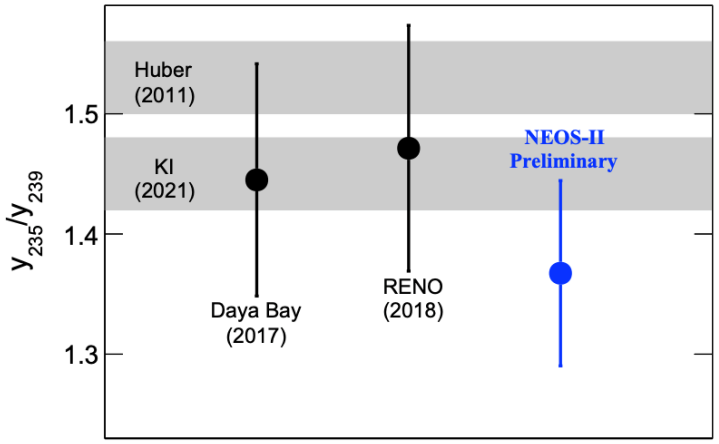
Phys. Rev. D 105 (2022) 111101
Phys. Rev. Lett. 118 (2017) 121802

NEOS: extraction of U/Pu-ν spectrum

Benefitted by measuring anti-ν from a single commercial reactor







RENE Collaboration

Reactor Experiment for Neutrino and Exotics

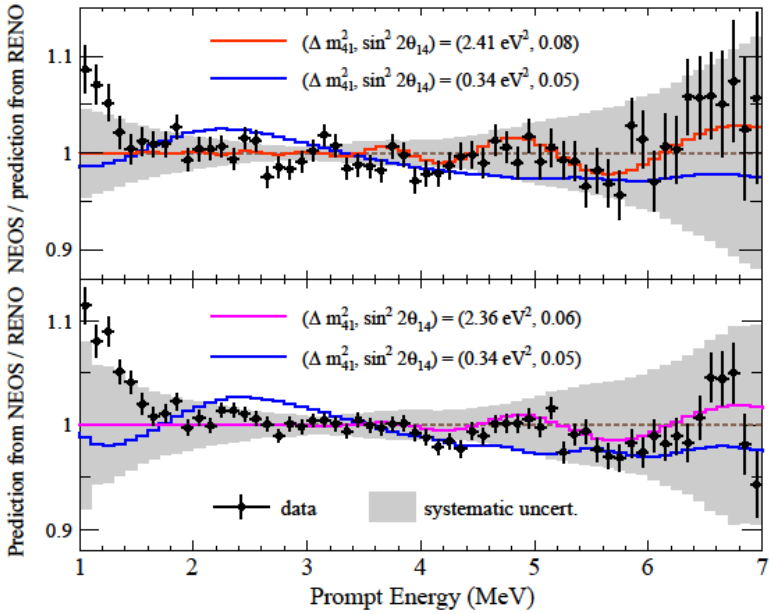
3rd RENE collaboration meeting, 2023년 8월 17일

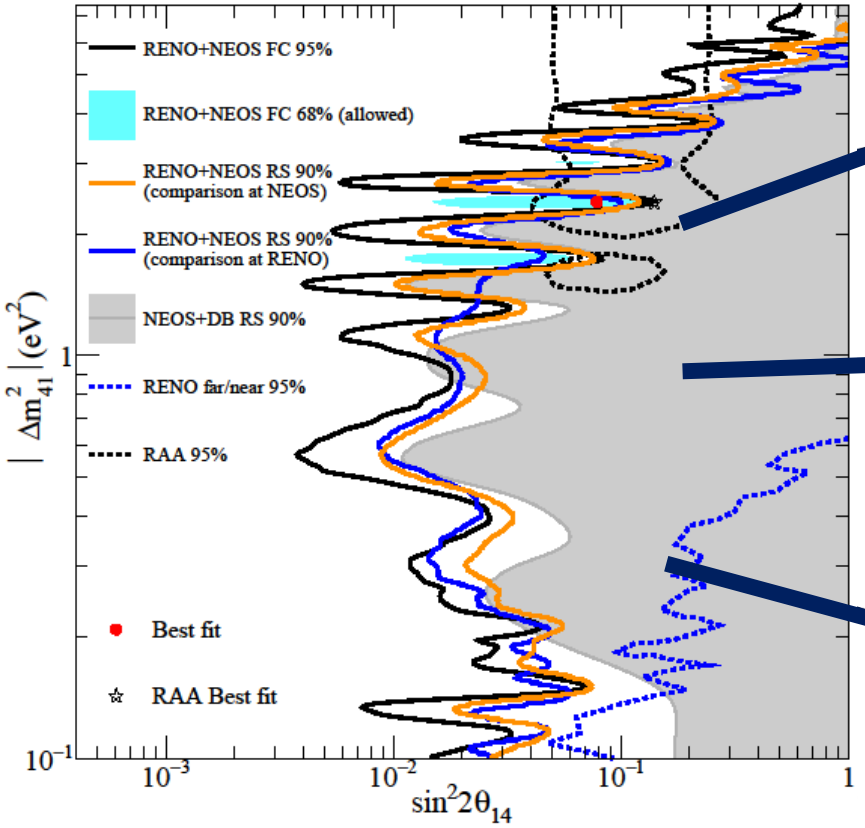
12 institutions & about 30 members

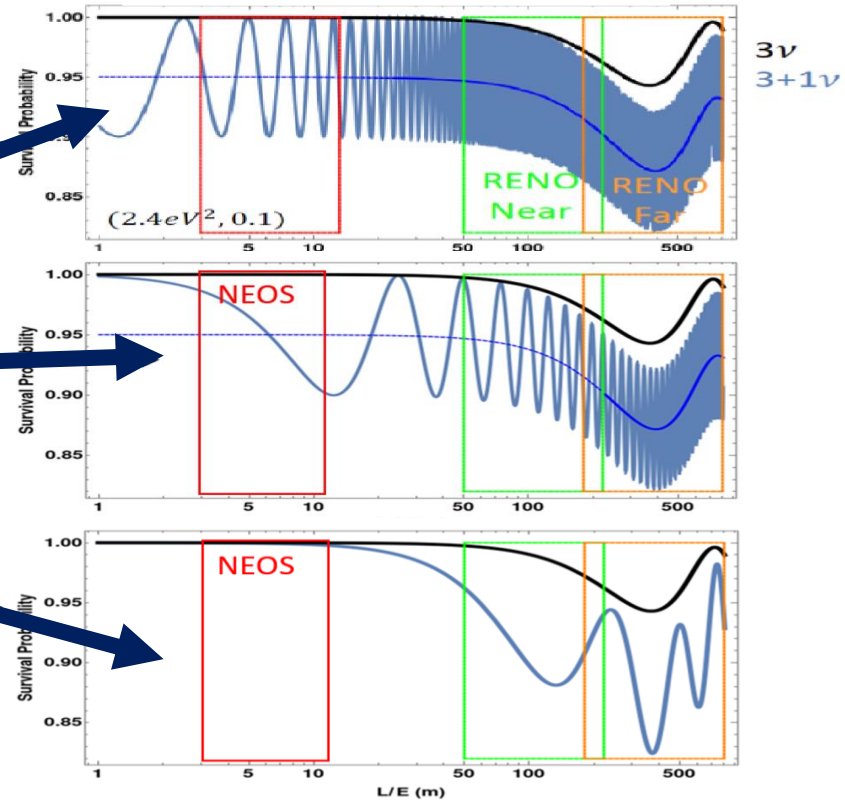
Motivation

RENO-NEOS joint analysis PRD 105 (2022), L111101

Hint for the sterile neutrino at $\Delta m^2_{41} \sim 2\ eV^2$.



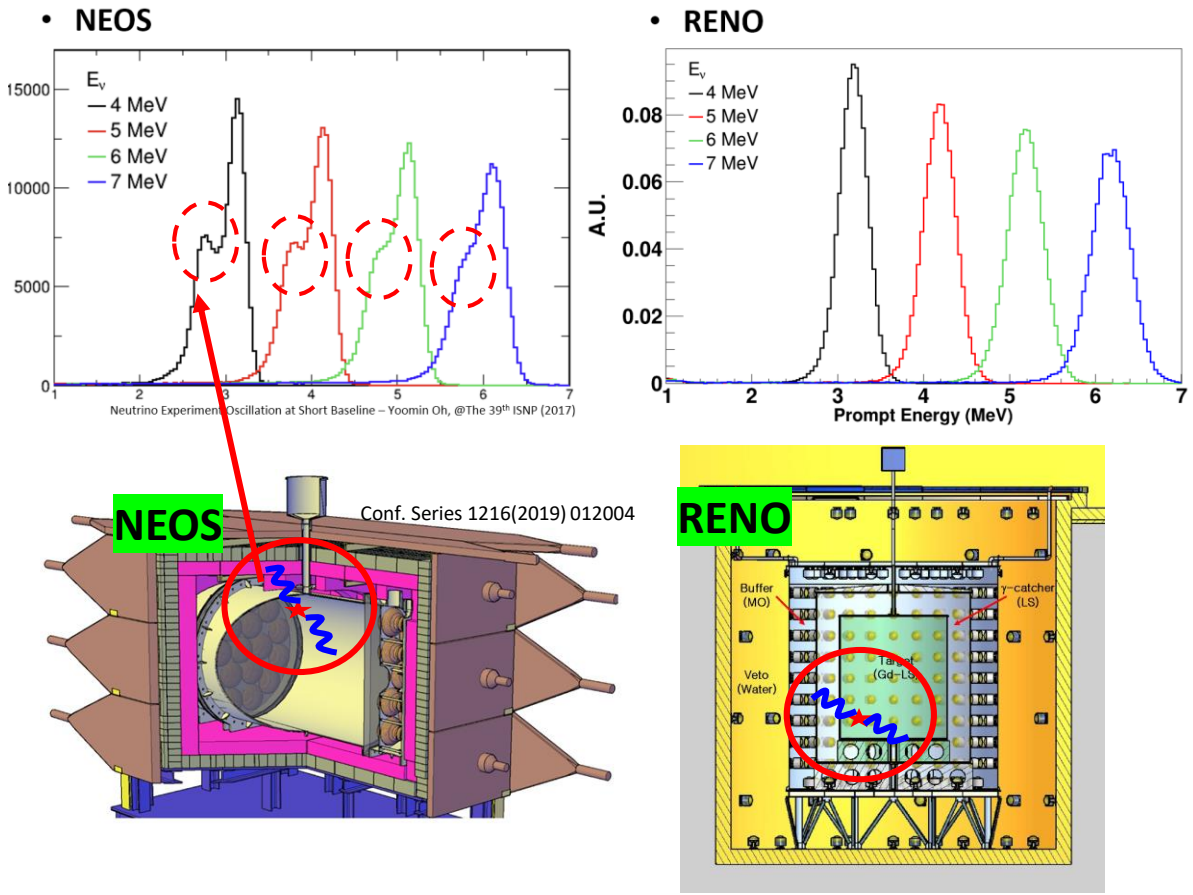


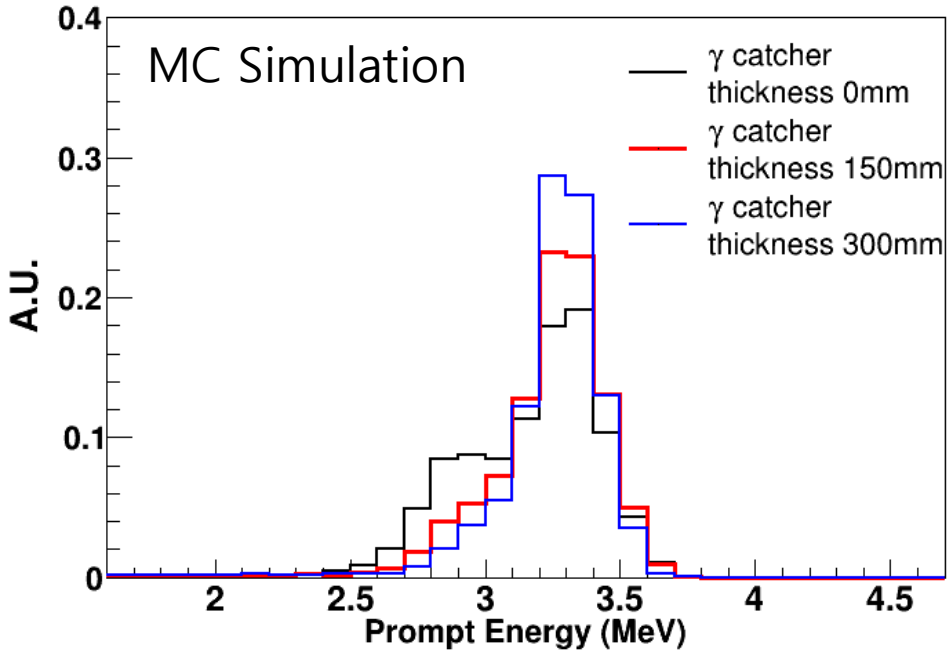


- To confirm θ_{14}, need to **improve systematics.**

Motivation

- **Detector responses.**
  - For NEOS, 2nd peak below the main peak.

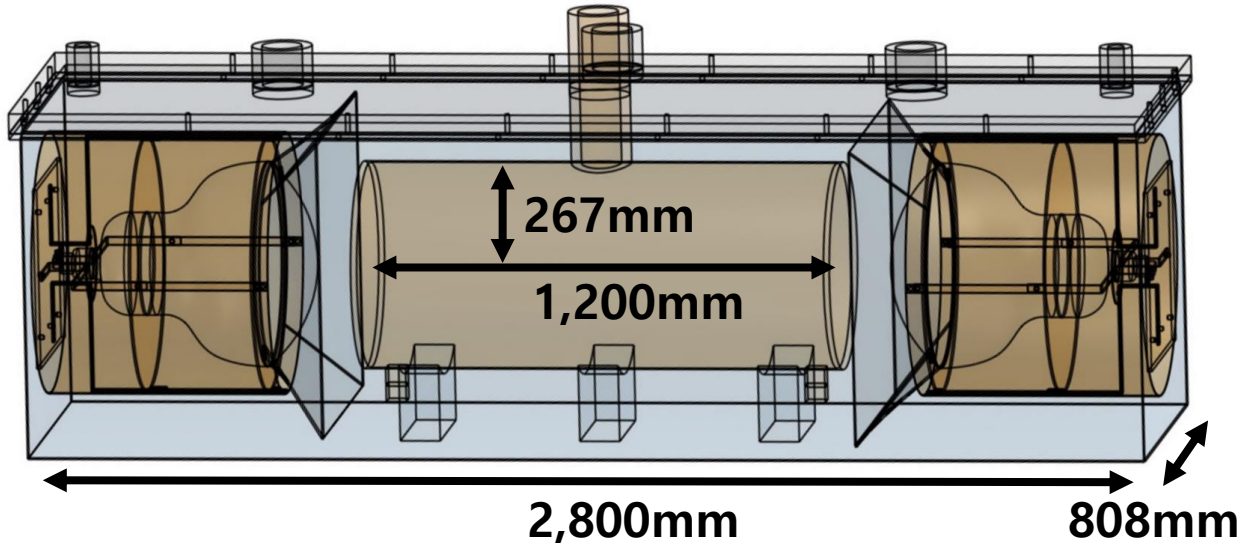


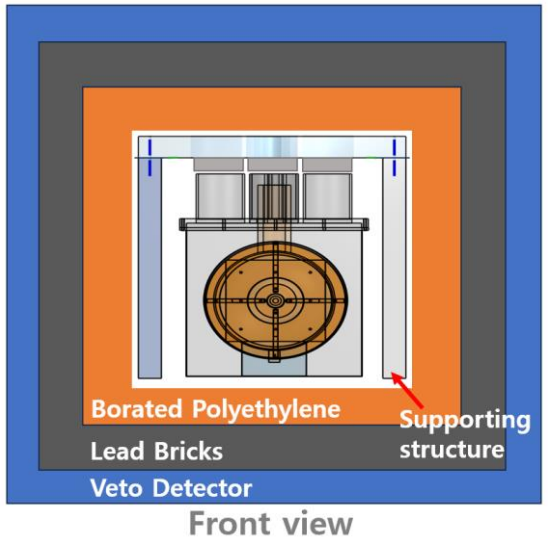


- **Escaping gammas** make the 2nd peak.
- NEOS doesn't have gamma catcher different to RENO.
- **We need the gamma catcher.**

Prototype Detector

- **Prototype detector design.**
  - 2 20-inch PMTs on left & right.
  - 0.5% Gd-LS Target.
  - Box-shaped LS gamma.
  - Stainless steel cone to better collect optical photons.





- **Shielding structure for the prototype.**
  - 267 mm radius cylindrical target.
  - Box-shaped gamma catcher with a side length of 808 mm.
  - 100 mm thick borated PE.
  - 100 mm thick lead bricks.
  - Plastic scintillator for veto detector. (from the NEOS collaboration)

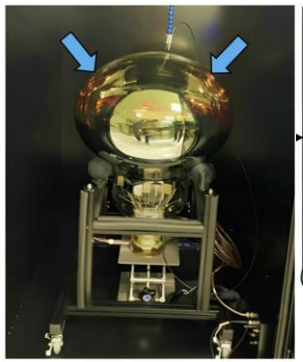
Liquid Scintillator Production

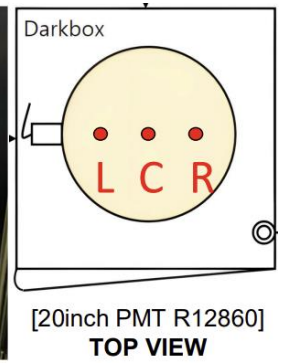
<Gd-LAB>

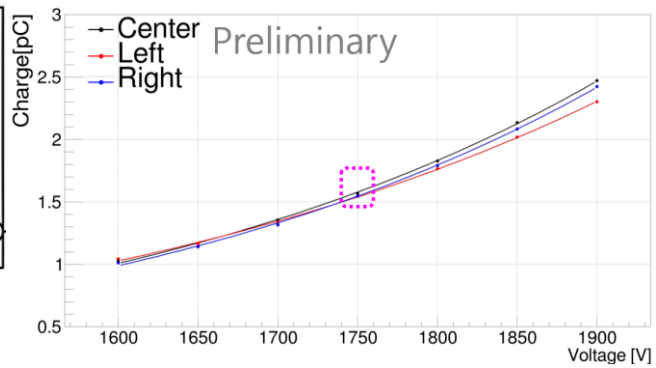
- **Liquid scintillator production.**
  - Last summer, we made ~210L Gd-LAB for Gd-LS at RENO far site.
  - We have LS making and Gd-LAB & LS mixing works left to do.
  - We plan to check the stability of high-concentration Gd-LS, light yield, and so on.

PMT Test and DAQ System

- **PMT test.**
  - We tested the position dependency of the PMT gain.
  - Below 10^7 gain, there is no significant position dependency of the PMT gain.







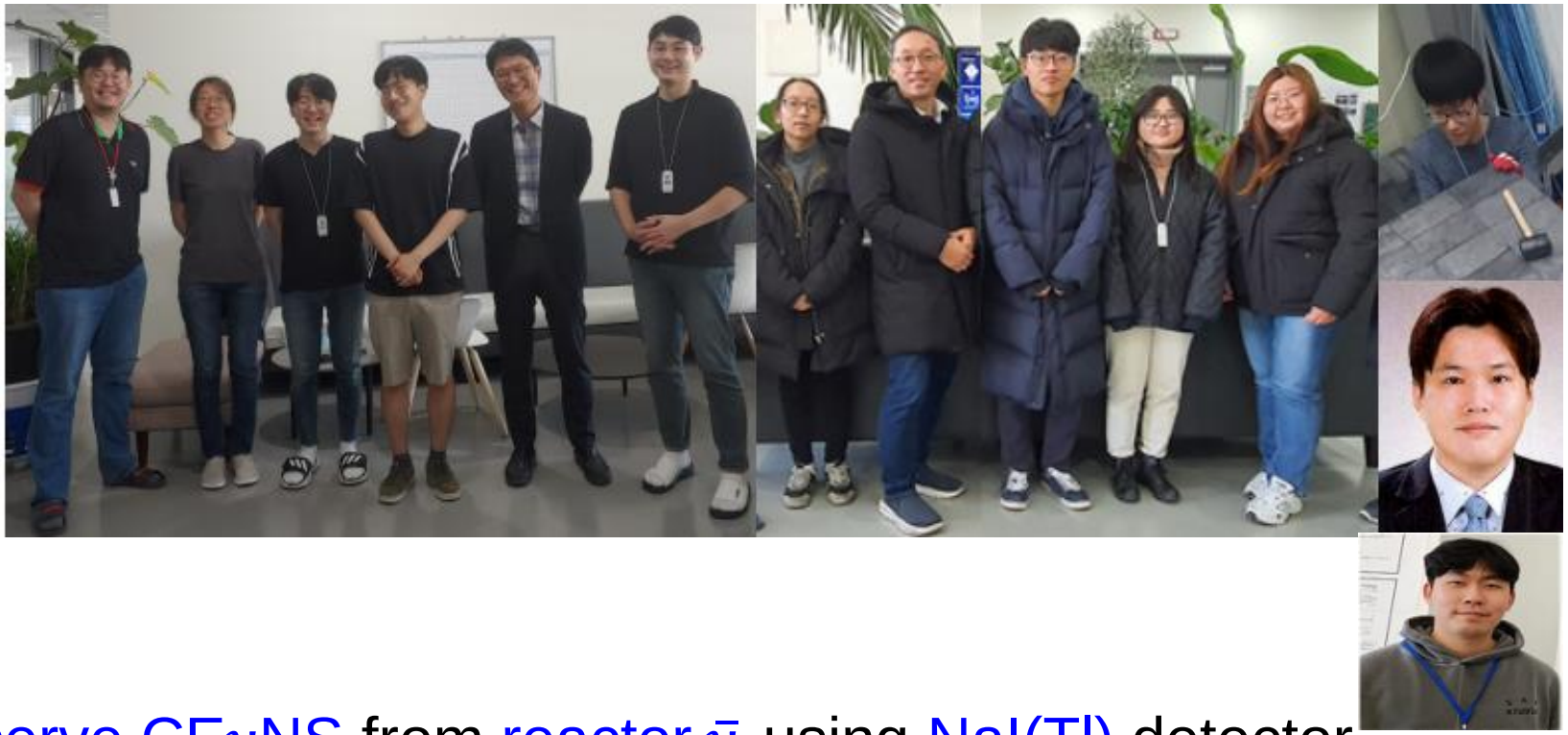
- **DAQ system.**
  - We are currently developing DAQ program for the experiment.
  - We decided to use FADC with 500Ms/s, DT5730SB or NKFADC500.

DT5730SB

NKFADC500

NEON Collaboration

~ 20 members who are all active members of COSINE-100 and/or NEOS



Aim to observe CEνNS from reactor $\bar{\nu}_e$ using NaI(Tl) detector

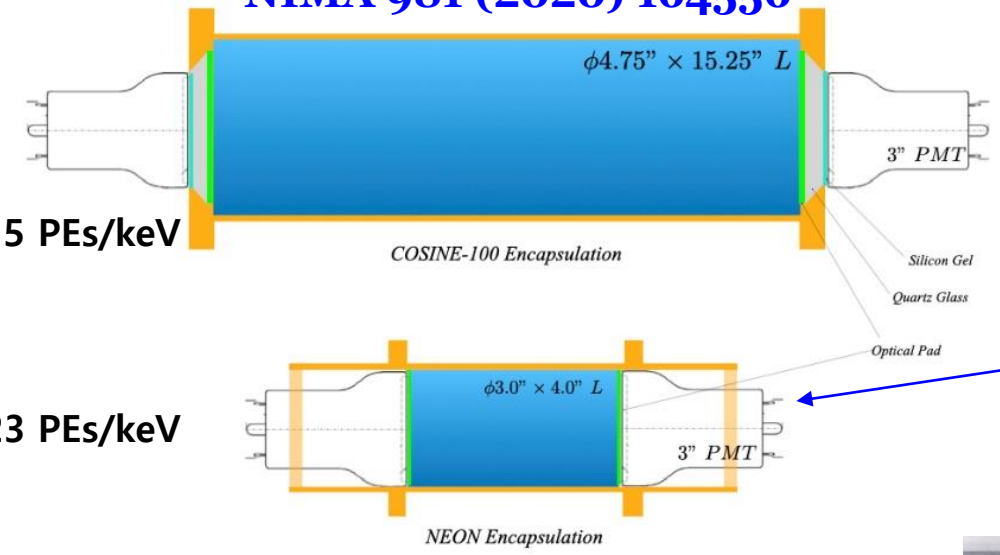
Can take an advantage of COSINE-100 and NEOS experiences

Detector was installed at tanden gallery of Hanbit reactor unit 6
(~24 m from reactor core)

NEON detector

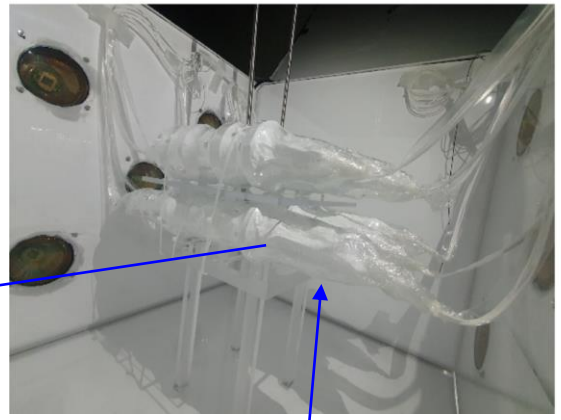
- High light yield NaI(Tl) crystals 3x2 array (total 16.7 kg)

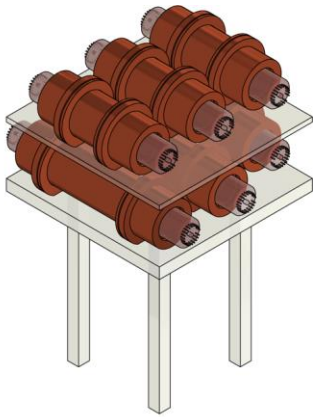
NIMA 981 (2020) 164556

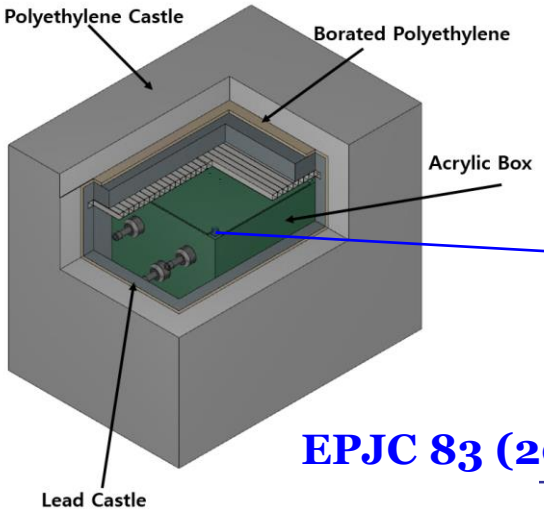


~15 PEs/keV

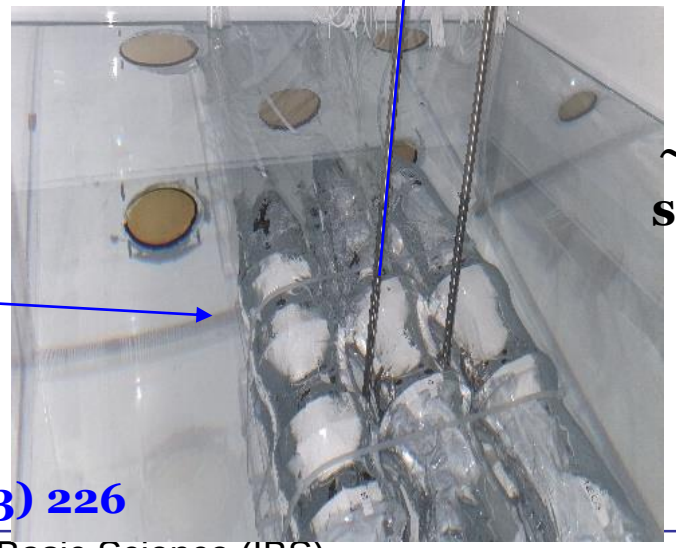
~23 PEs/keV







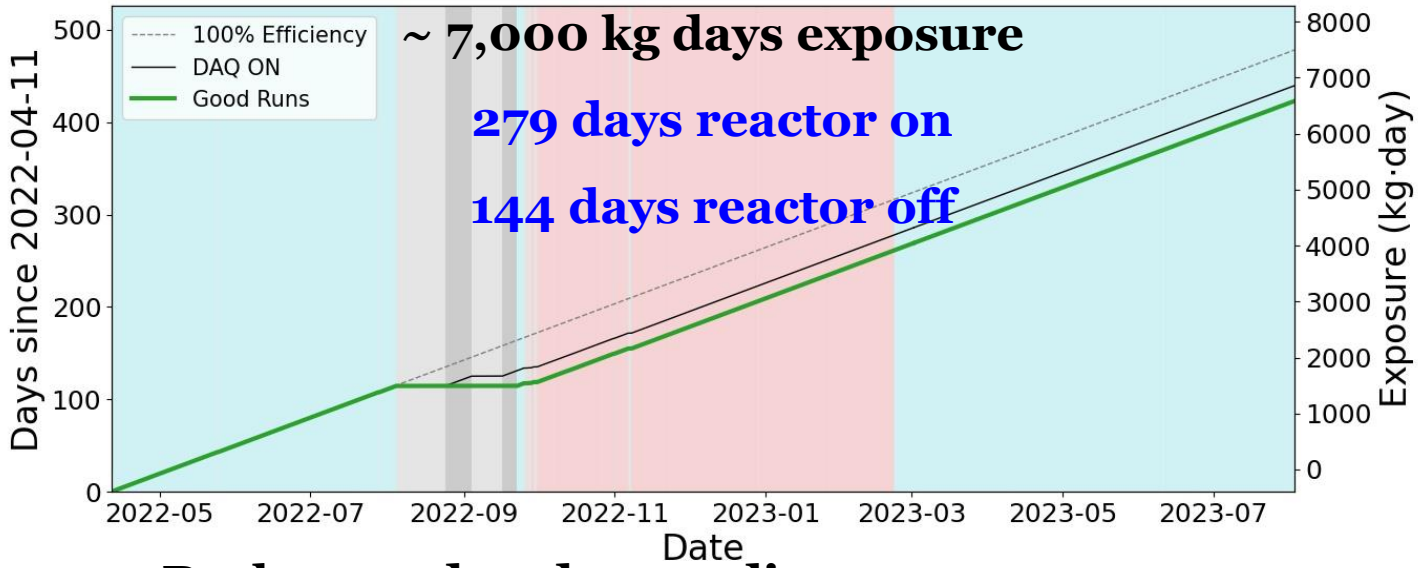
~15 cm lead & ~25 cm PE

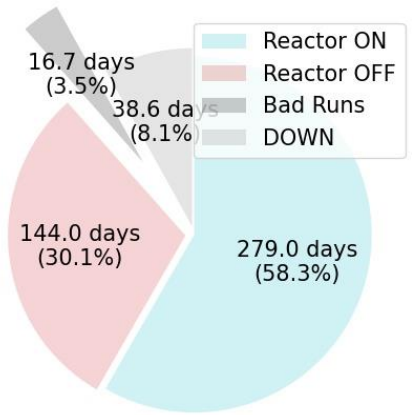


~ 800 L liquid scintillator for active veto

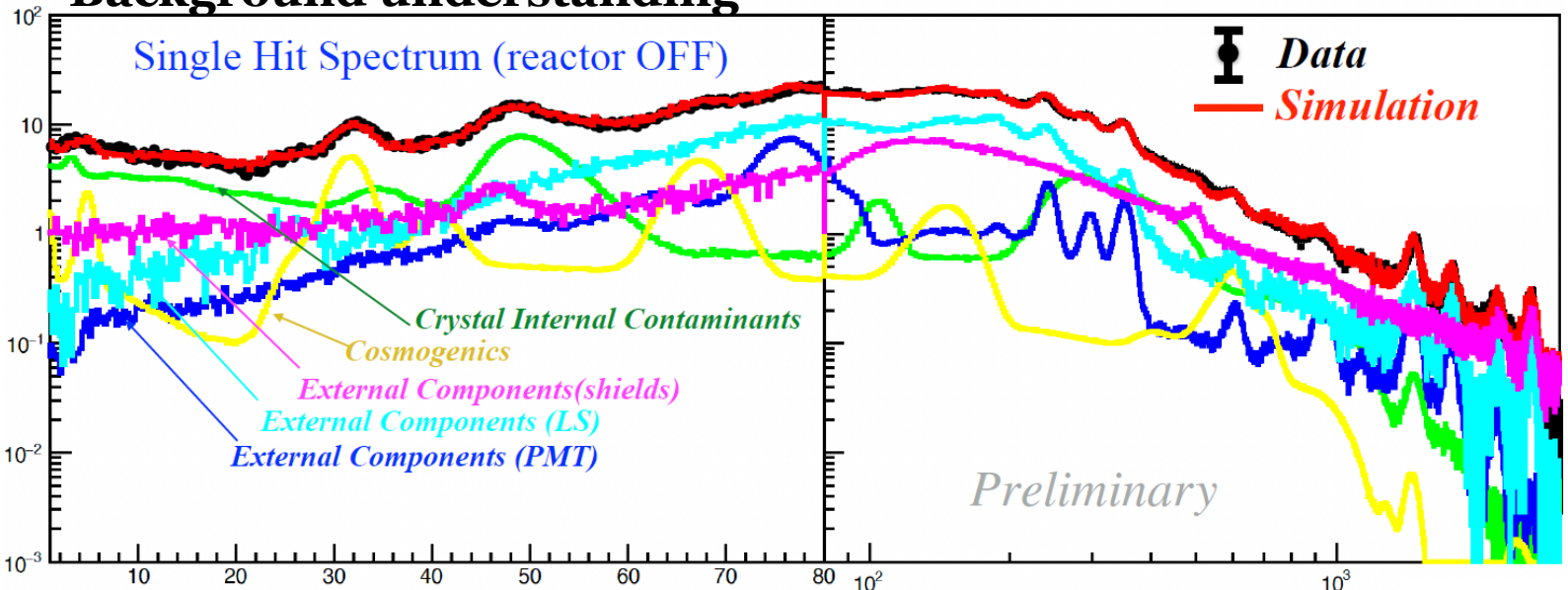
EPJC 83 (2023) 226

Data



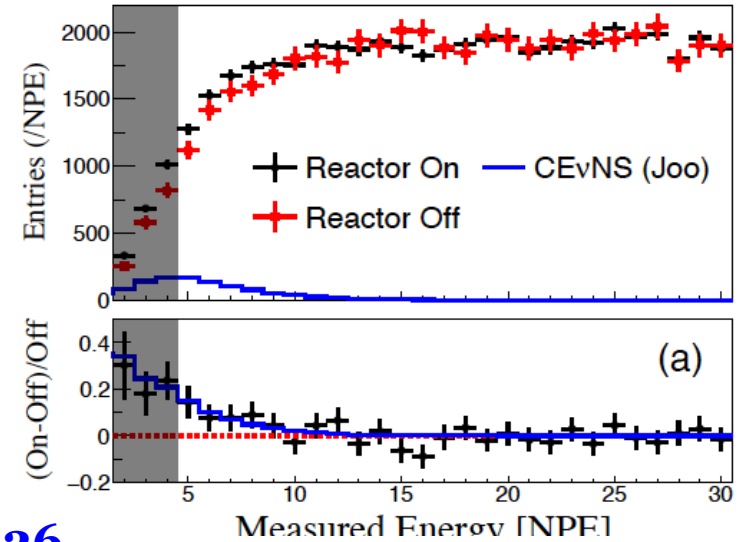


Background understanding



Sensitivity to observe CEvNS

- Flat background ~7 dru
- Detector mass = 13.3 kg
- Reactor on data = 365 days
- Reactor off data = 100 days
- Light yield = 22 NPE/keV
- Threshold = 5 NPE



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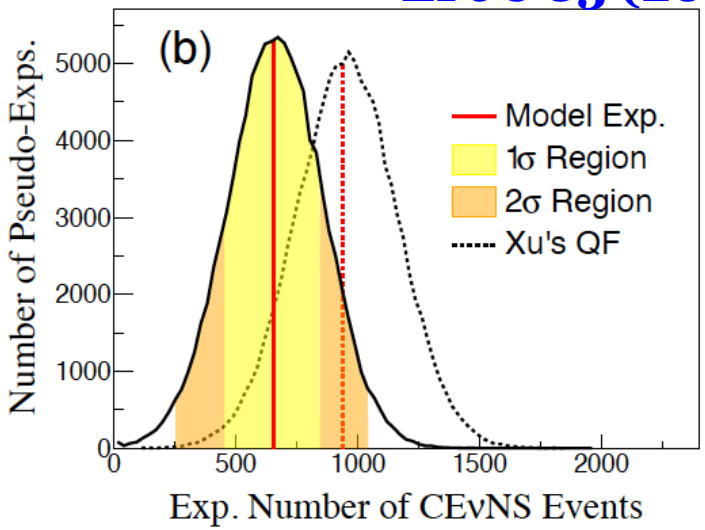
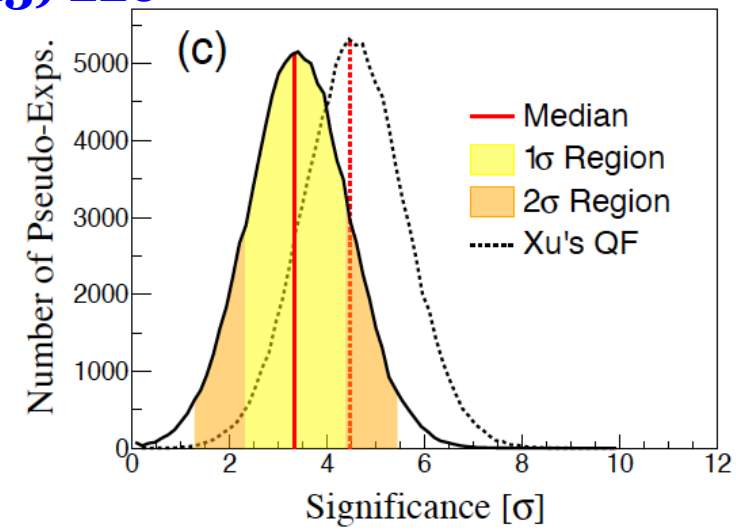


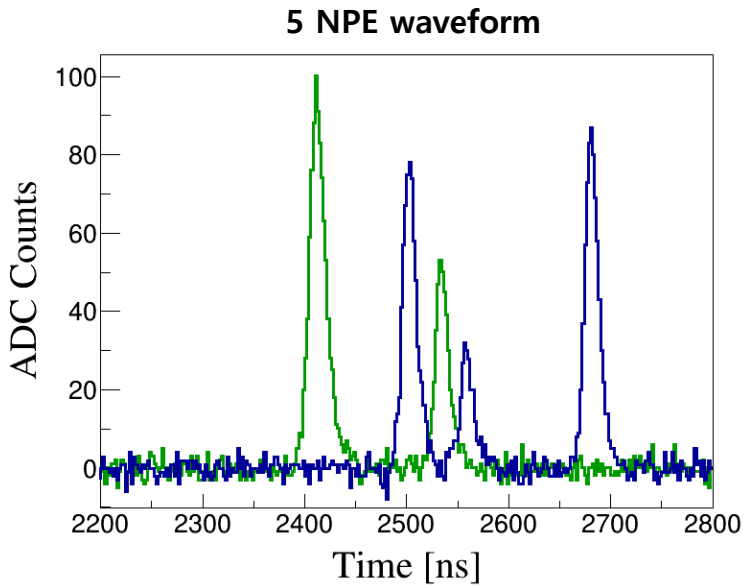


More than 3 sigma observation sensitivity!!

Sensitivity to observe CEvNS

- Flat background ~7 dru
- Detector mass = 16.7 kg
- Reactor on data = 365 days
- Reactor off data = 100 days
- Light yield = 24 NPE/keV
- Threshold = 5 NPE (ongoing)

Achieved!!



Developing multivariable machine learning technique for 5 number of photoelectrons (NPEs) threshold

Stay tune!!