NEOS-II New Results

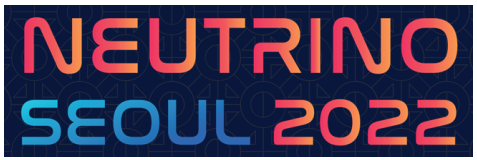
Jinyu Kim

Sejong University, Seoul, Korea

Center for Underground Physics, IBS, Daejeon, Korea

on behalf of the NEOS Collaboration

May 30, 2022



Contents

Neutrino Experiment for Oscillation at Short baseline

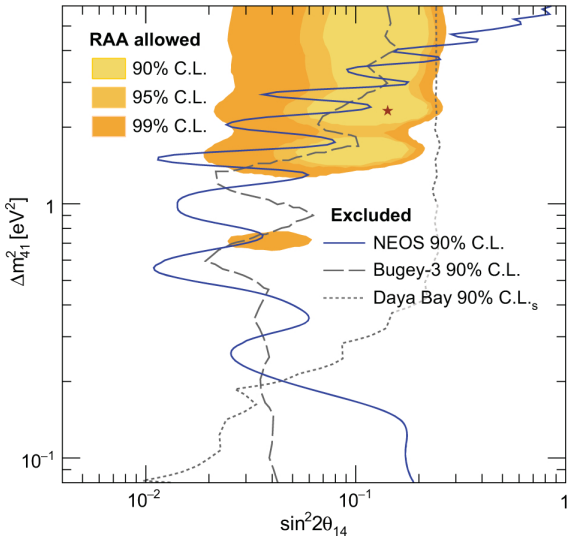
- Introduction
- NEOS detector response
- New results
- Summary

Collaboration: 21 members from 7 institutions.

Motivation of the NEOS-II

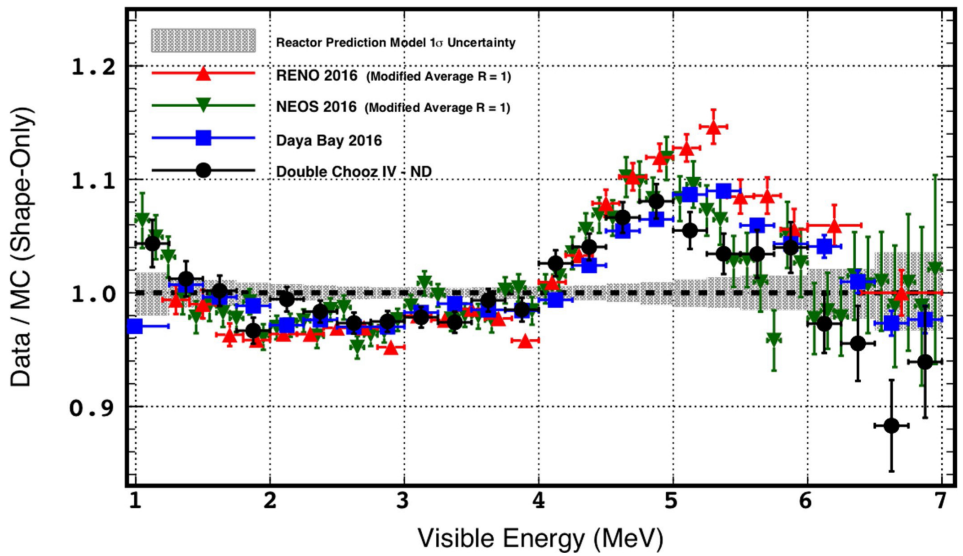
- Reactor antineutrino anomaly (RAA)
  - Flux anomaly: cannot be explained by 3 ν scenario
    - → $\sim$ 1 eV sterile neutrino
  - Spectral anomaly (5 MeV Bump)
    - → Explain it by performing spectrum decomposition

- Sterile Neutrino Search (NEOS 2017)



[NEOS Collaboration. *Phys. Rev. Lett.* **118**, 121802 (2017)]

- 5 MeV Bump (Daya Bay, Double Chooz, NEOS, RENO)

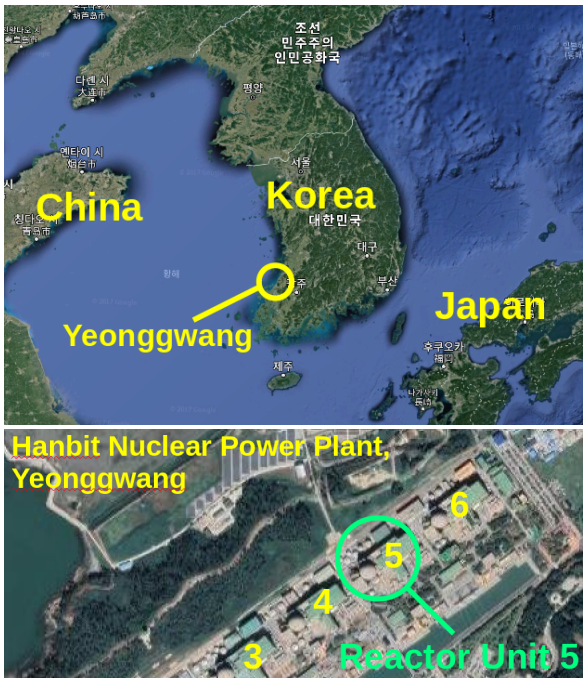


[The Double Chooz Collaboration. *Nat. Phys.* **16**, 558–564 (2020)]

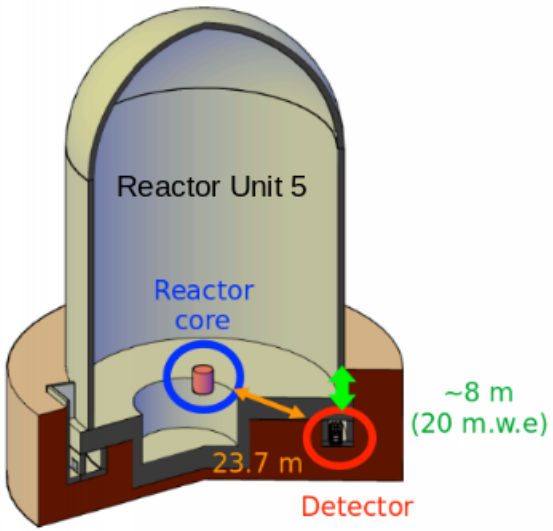
NEOS Site and Detector

- ν Source: Reactor unit 5 in Hanbit Nuclear Power Plant, Yeonggwang, Korea
  - → Low enriched uranium fuel, 2.8 GW_{th} commercial reactor
- Detector deployment: Tendon gallery ($\sim$ 23.7 m from reactor core unit 5)
- NEOS-II data taking completed.
  - Sep 2018 $\sim$ Oct 2020, 45 + 388 + 67 live-days for reactor off/on/off.
  - Reactor on: full fuel cycle

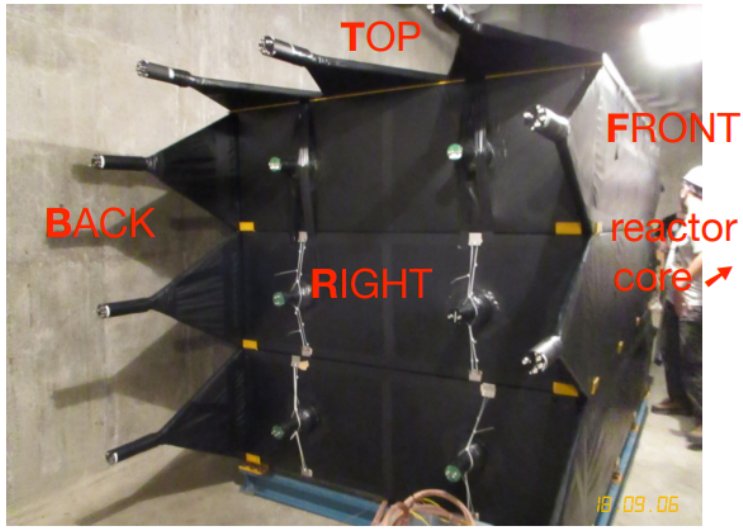
- Location



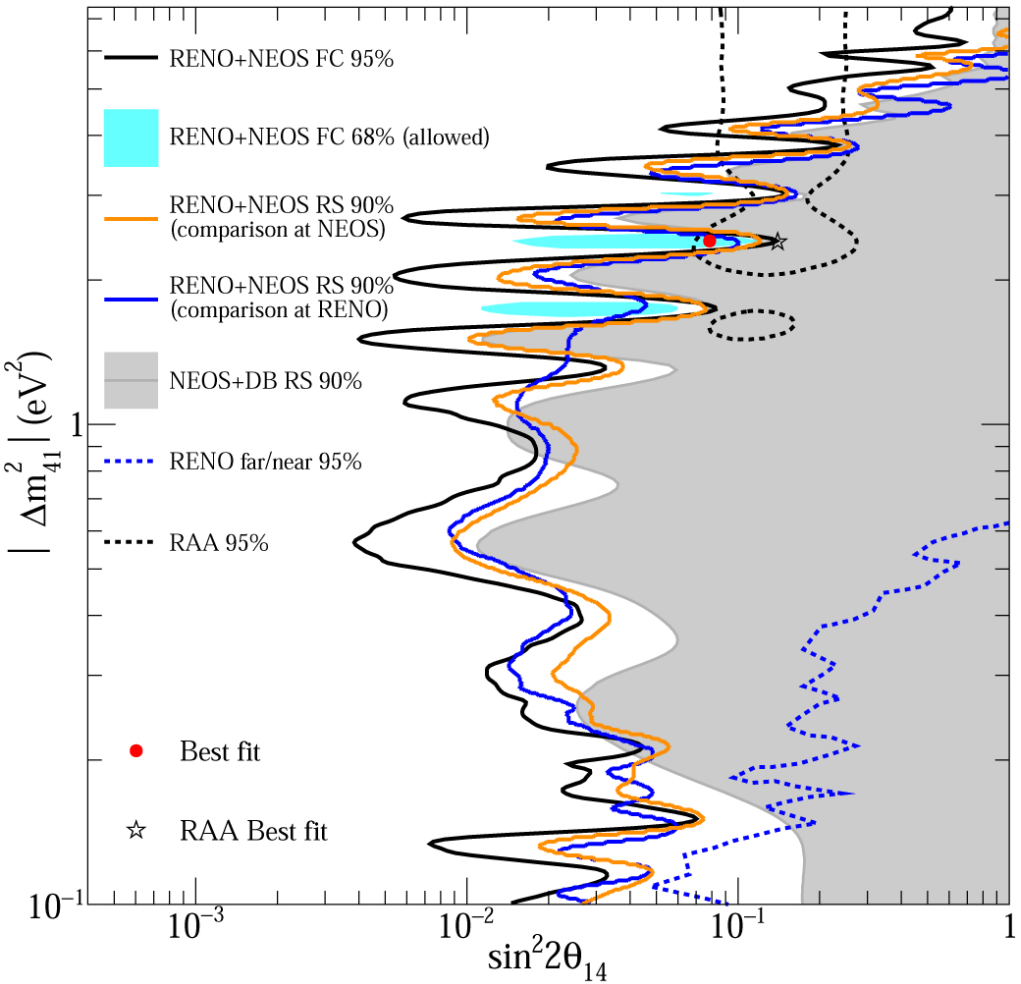
- Hanbit Reactor & Tendon Gallery



- NEOS-II Detector



The Results of NEOS-I

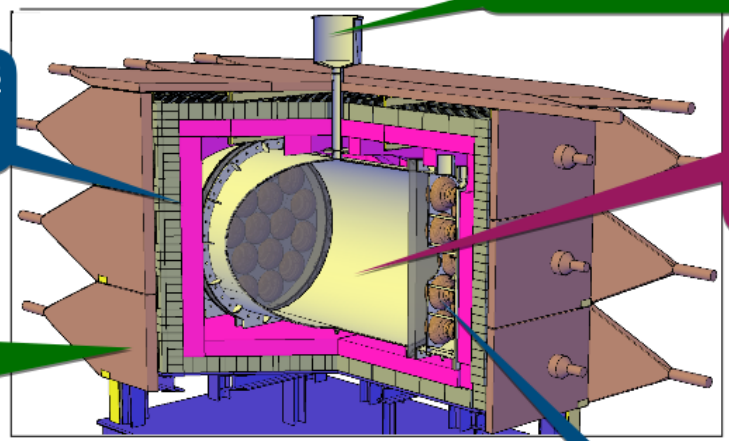


[The RENO and NEOS Collaborations. *arXiv:2011.00896* (2022)]

- Sterile neutrino search
- Shape-only analysis
- Joint analysis of NEOS and RENO collaborations
  - Same reactor complex
    - → $\bar{\nu}_e$ source dependency removed
  - Improvement of reference spectrum uncertainty, compared to the previous result.
  - The results will be published soon (accepted by PRD)

NEOS-II Detector

- Reproduction of Gd-LS for NEOS-II (due to aging, same recipe)



Chimney
For source calibration

Active target
Homogeneous
1 kL volume
0.48% Gd-LS
Mixed LS
(LAB + UG-F)

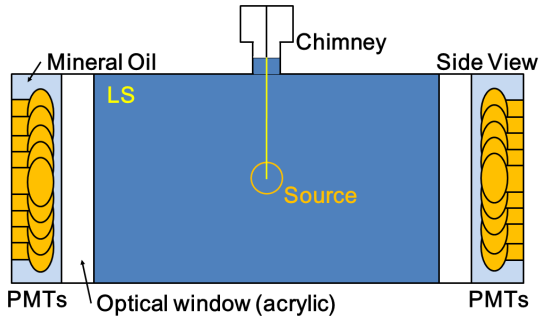
Passive Shieldings
10 cm thick B-PE (n)
10 cm thick Pb (γ)

Muon Detector
3 or 5 cm thick
plastic scintillators
(w/ two PMTs/scint.)
Covering 5 sides
except bottom
(9 with 2'' PMTs)
(6 with 5'' PMTs)

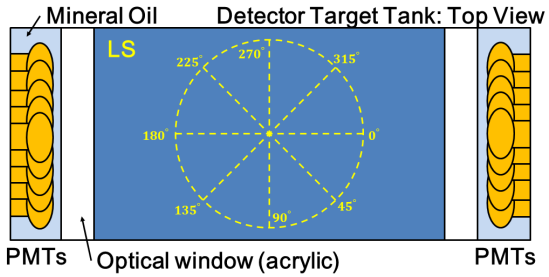
DAQ System
500 MHz Flash ADC for target
(recording waveforms)
62.5 MHz ADC for muon counters

Photomultiplier tubes
Two buffer tanks at both sides of target
Acrylic window b/w target and buffers
19 PMTs (8 inch, R5912) in each buffer

- Source Calibration



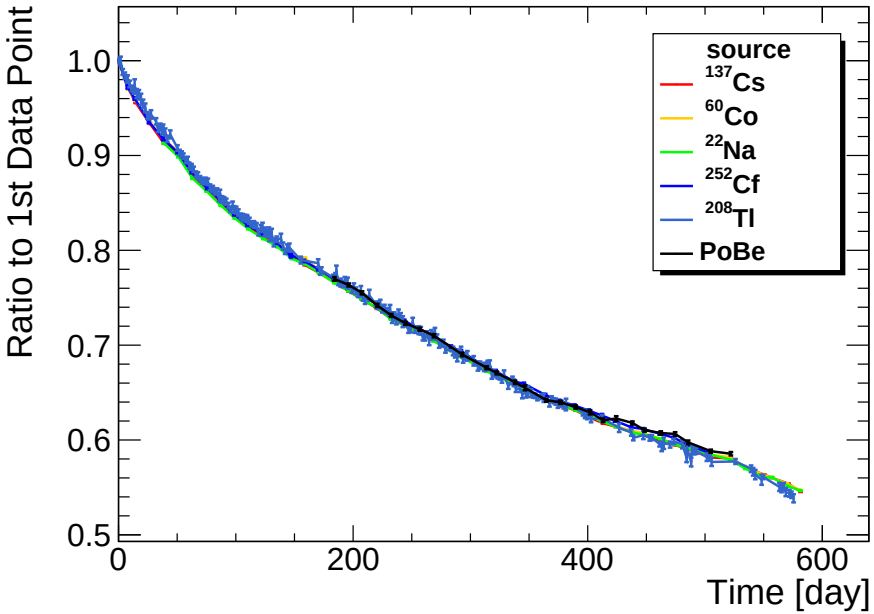
- 3-D Calibration



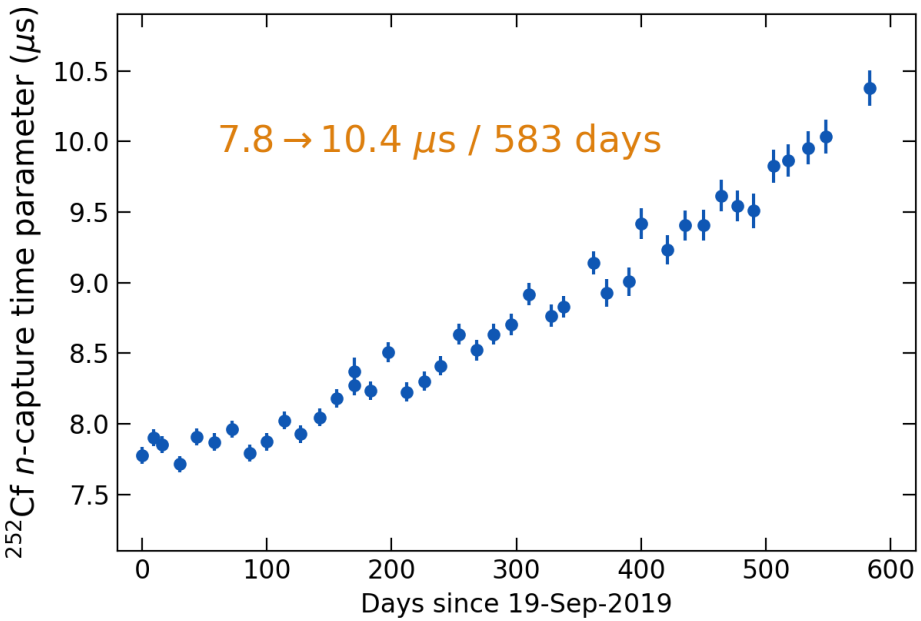
LS Stability Issue

- Precipitation in liquid scintillator(LS). → suspecting high Gd concentration
- LS: 90% LAB based LS + 10% of DIN based LS + 0.5% Gd
- Both light yield and attenuation seem to be decreased.
  → Performing software gain correction and energy resolution smearing in the analysis.

- Charge Decreasing

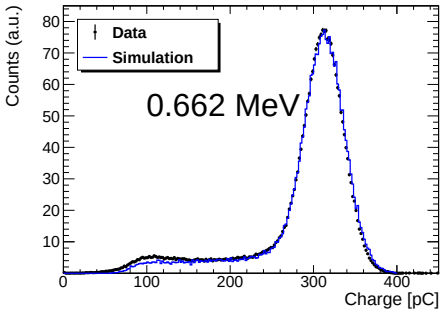


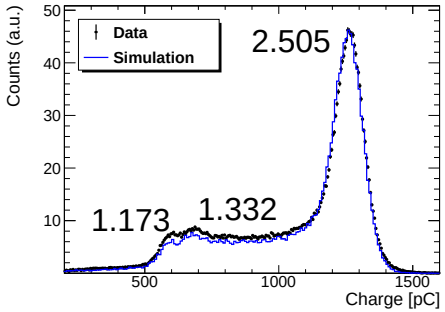
- n-Capture Time (^{252}Cf)

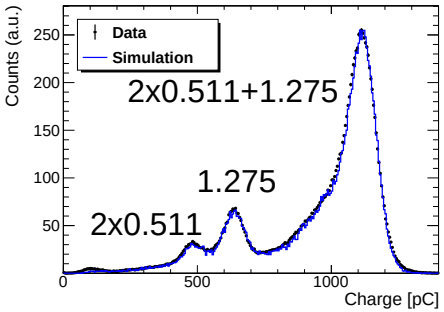


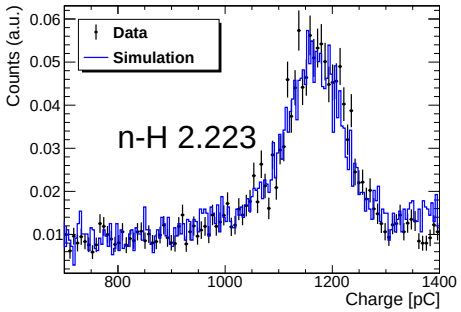
Bi-weekly Source Calibration

- ^{137}Cs
- ^{60}Co
- ^{22}Na
- ^{252}Cf

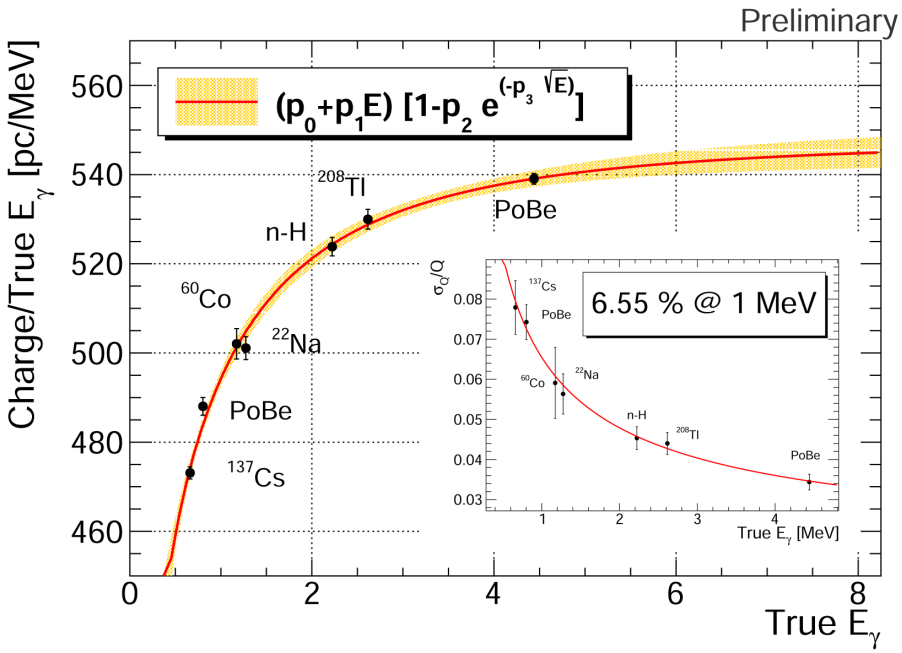




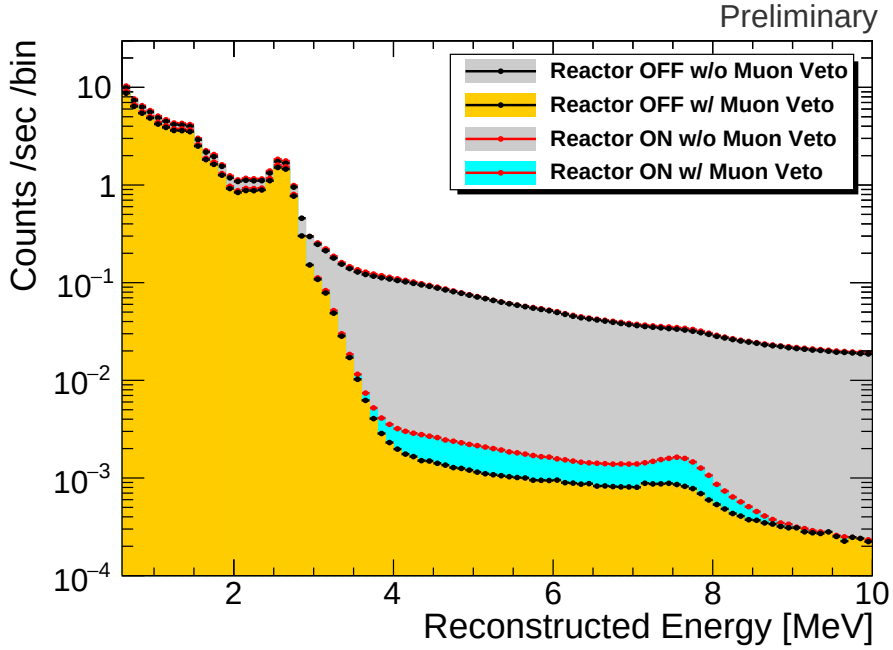




- Energy Calibration applied Non-linearity



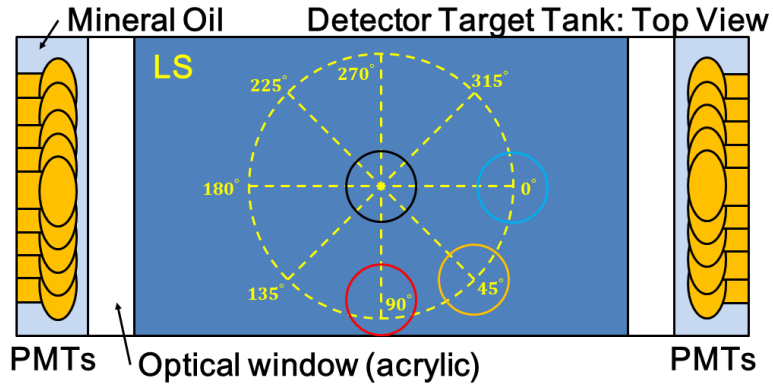
- Reconstructed Energy Spectra



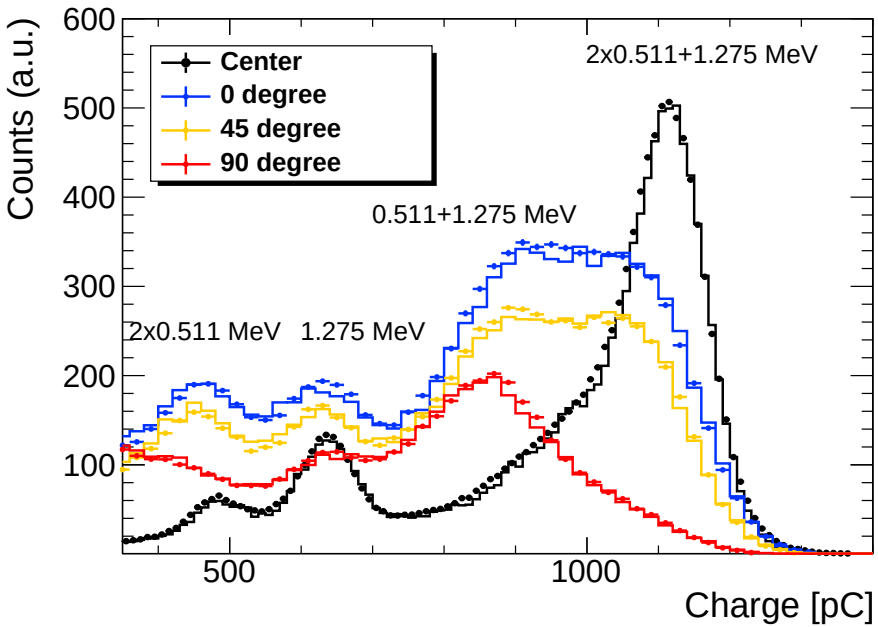
3-D Calibration

- 3-D calibration was done to understand γ-escaping effect.
- Edge near source position
  → fraction of γ-escaping is increased.

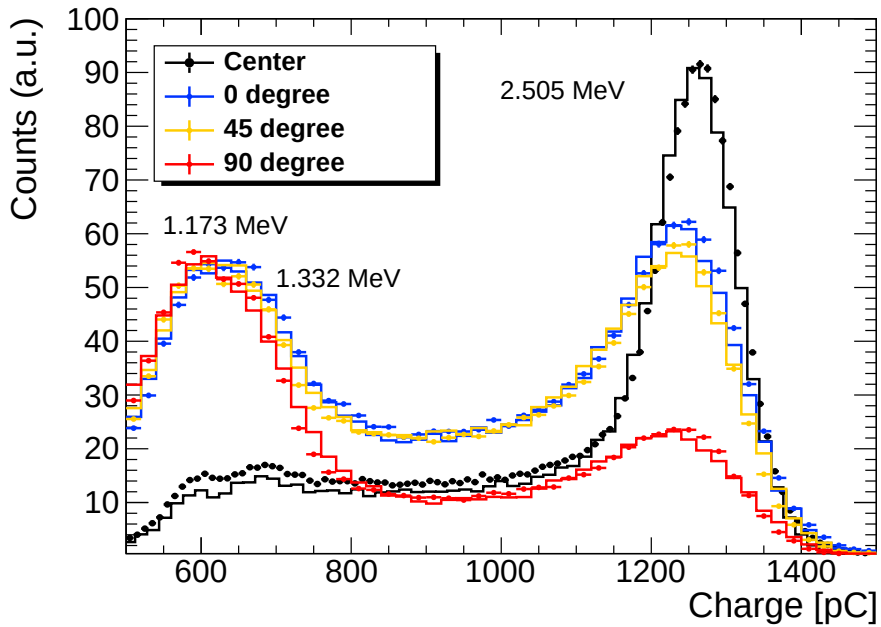
  (see poster DT06-563 in "sterile neutrinos" topic, poster session II-b, 7F. Dirac)



- ^{22}Na



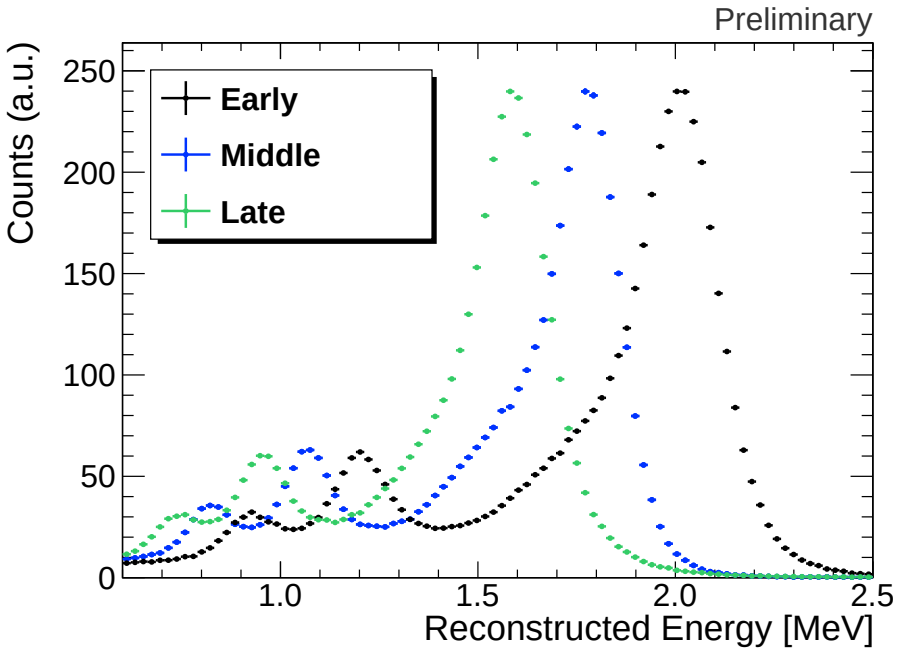
- ^{60}Co



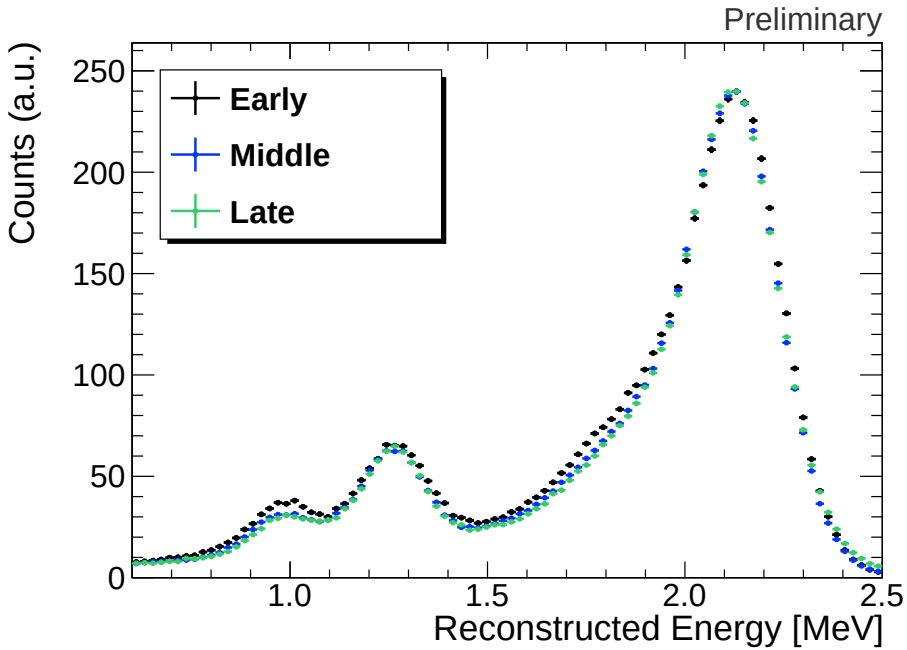
Energy Correction

- gain correction
- energy smearing (set to the resolution for the last run, $\sigma_E/E = 5 \rightarrow 7\%$ at 1 MeV)

- Before Energy Correction (^{22}Na)



- After Energy Correction (^{22}Na)

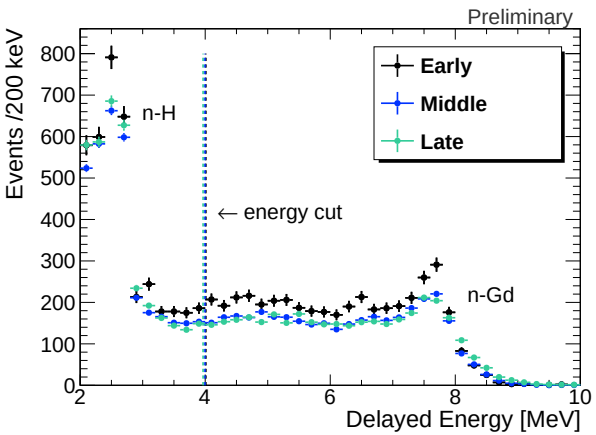


IBD (Inverse Beta Decay) Event Selection

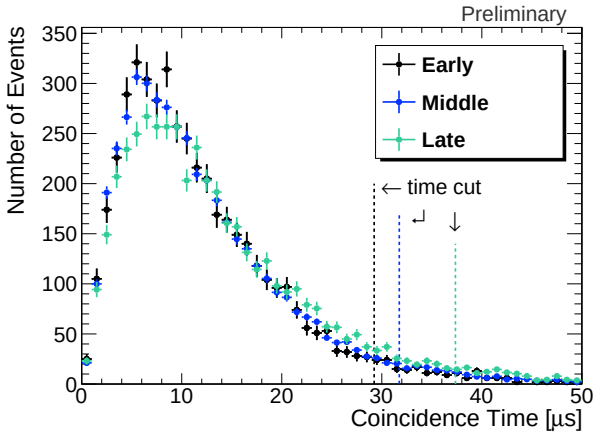
- LS stability issue → selection cuts evolve with time, to maintain same efficiencies.
  - delayed energy cut: 4 → 3.96 MeV
  - coincidence time cut: 28 → 39 μs
- muon: $>$ 150 μs before prompt/delayed signal.
- multiplicity: $>$ 45/150 μs before/after prompt signal.
- Applying machine learning technique to pulse shape discrimination(PSD) cut

  (see poster DT06-172 in "reactor neutrinos" topic, poster session II-a, 6F. Dirac, by Ki Young Jung)

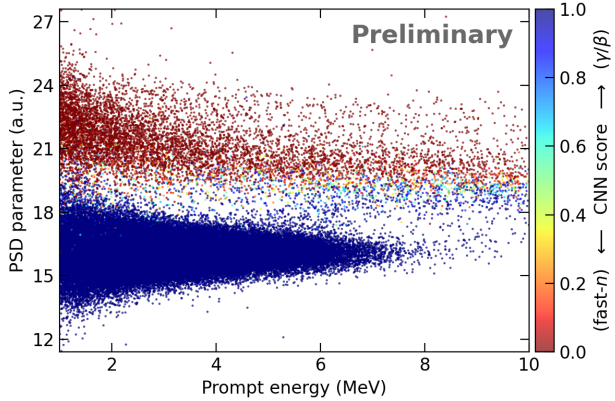
- Delayed Energy Cut



- Coincidence Time Cut

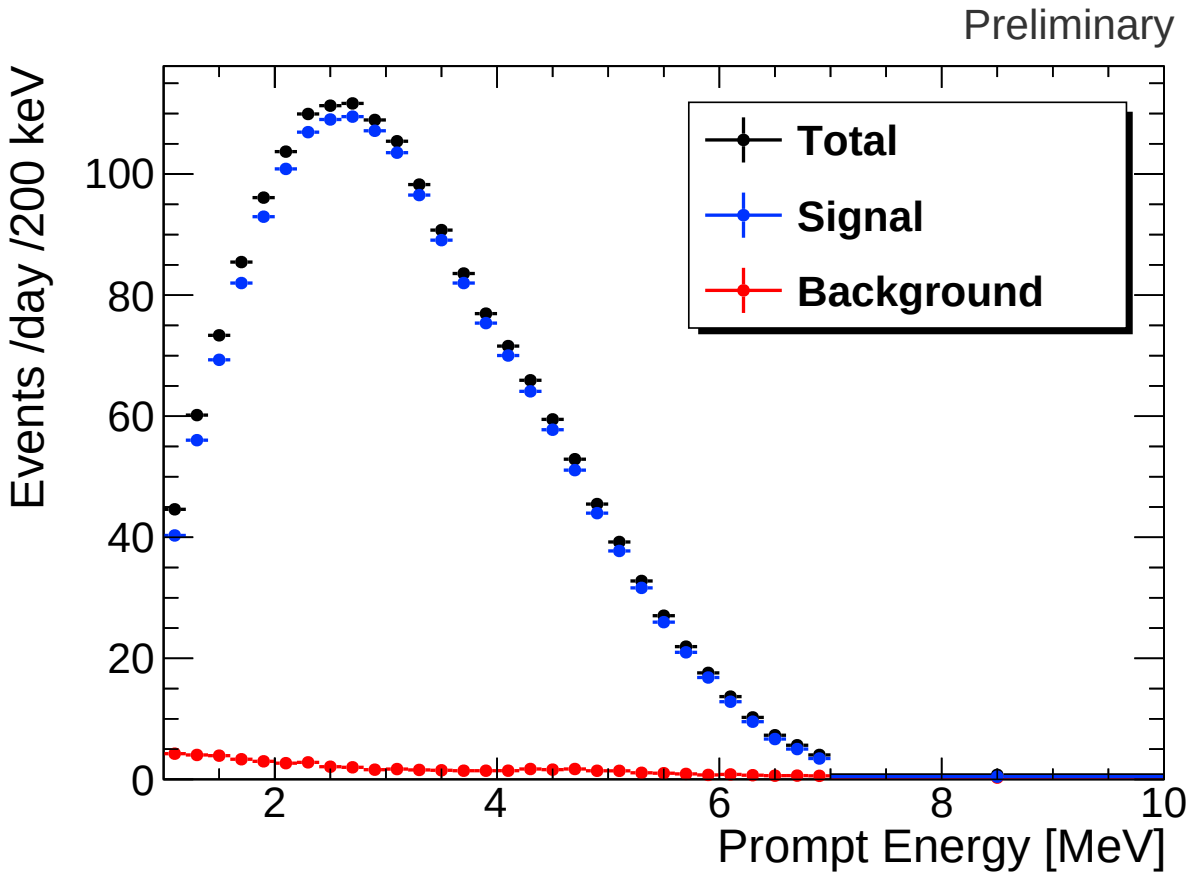


- PSD



Prompt Energy Spectrum

- Reactor on: Nov 2018 - Mar 2020, 388 live-days
- Reactor off: 112 live-days (45/67 live-days for 2 periods)

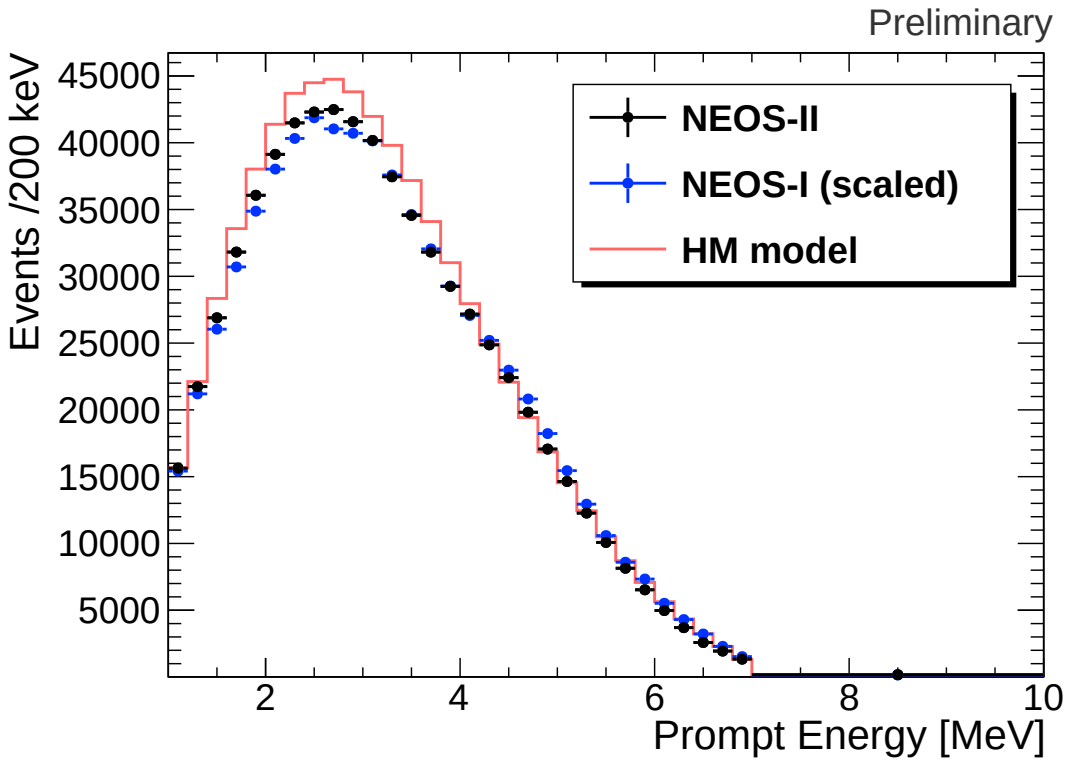


- Averaged IBD Candidate Rate

	IBD Candidate	Signal	Background	S/B Ratio
Rate [#/day]	1835.8 ± 2.2	1778.6 ± 2.1	61.3 ± 0.8	29

Comparison of Prompt Energy Spectra

- Prompt energy spectrum for reactor on period. (Nov 2018 - Mar 2020, 388 live-days)
- Background is subtracted. (averaged background for 2 reactor off periods)
- Huber-Mueller (HM) model for NEOS-II (NEOS-I detector matrix is applied.)
- NEOS-II (388 live-days, full fuel cycle) vs. NEOS-I (the first 180 live-days)

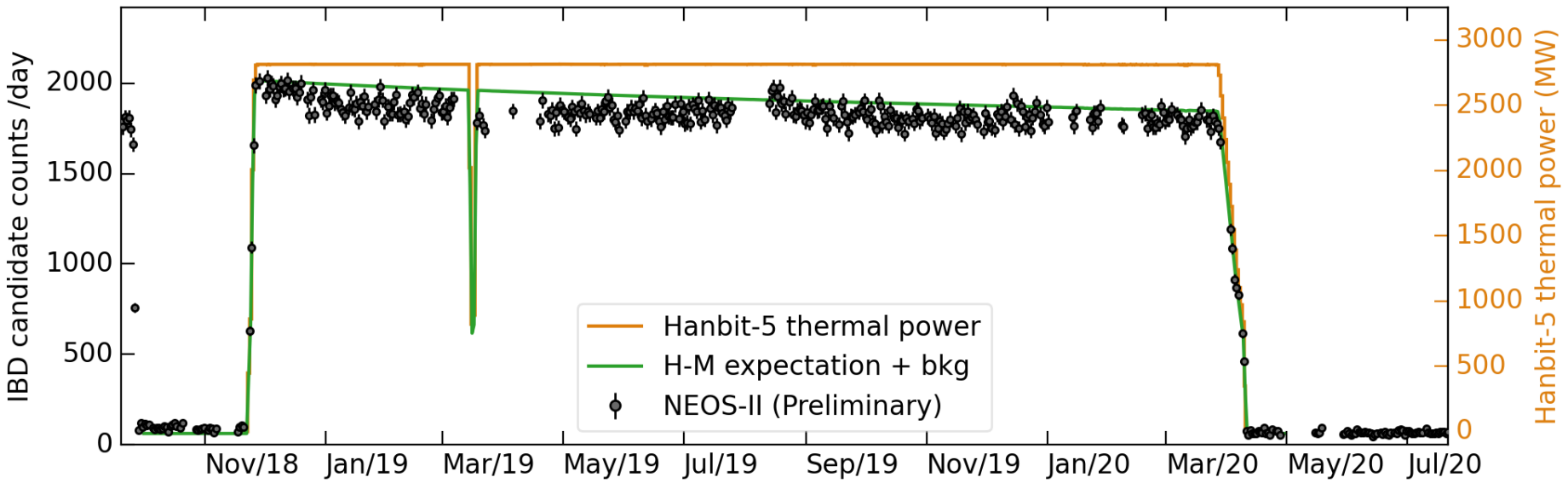


- The Averaged Fission Fractions

Fission Isotope	^{235}U	^{239}Pu	^{238}U	^{241}Pu
NEOS-I	0.66	0.24	0.07	0.04
NEOS-II	0.57	0.30	0.07	0.06

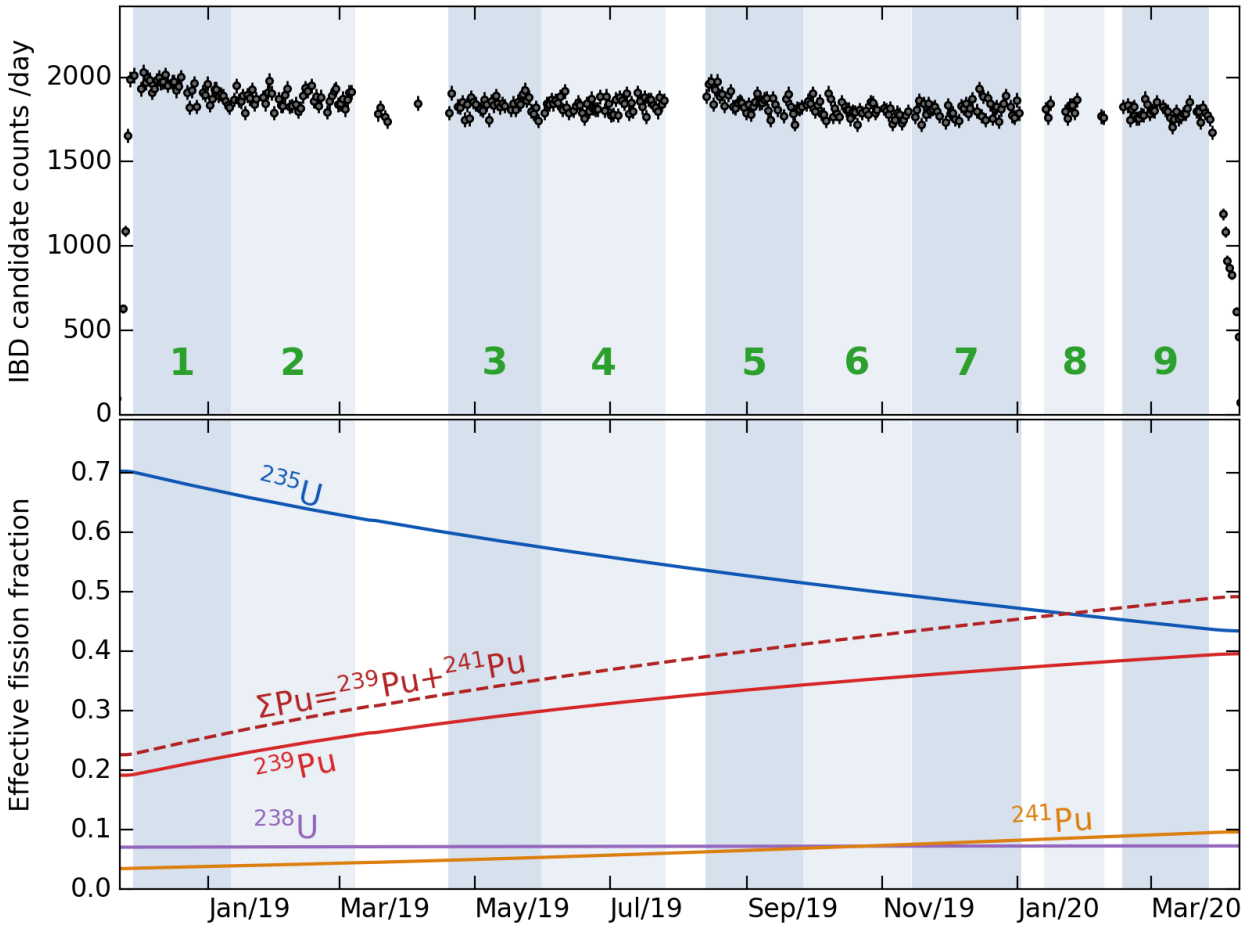
IBD Candidate Rate

- IBD candidate rate for NEOS-II data → compared with the expectation from HM model.
- NEOS-II detection efficiency and average background rate (61.3 events/day) are applied in expected IBD event rate.
- IBD candidate rate for reactor on: 1983 ± 19 (Nov/28) → 1774 ± 19 (Apr/7) events/day
- ∼ 4 % deficit from HM prediction



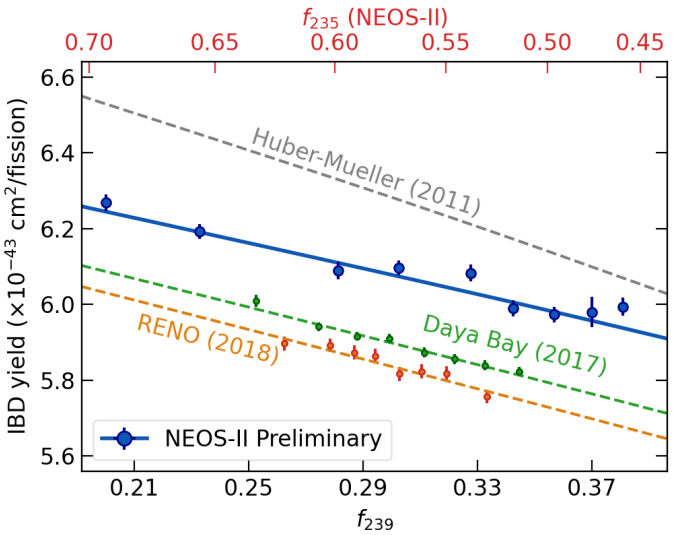
Time Separation for the Extraction

- Fission fractions for certain isotopes change with time (0.7 → 0.4 for ^{235}U, 0.2 → 0.4 for ^{239}Pu)
- Time evolution of fission fraction affect N_{IBD} and the shape of prompt energy spectrum
  → extraction of IBD yields and spectra for fission isotopes

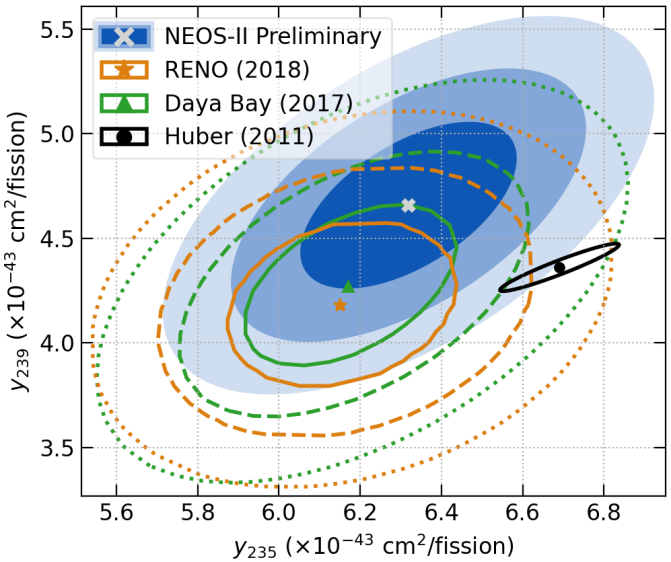


Extraction of IBD Yield

- Total IBD Yield



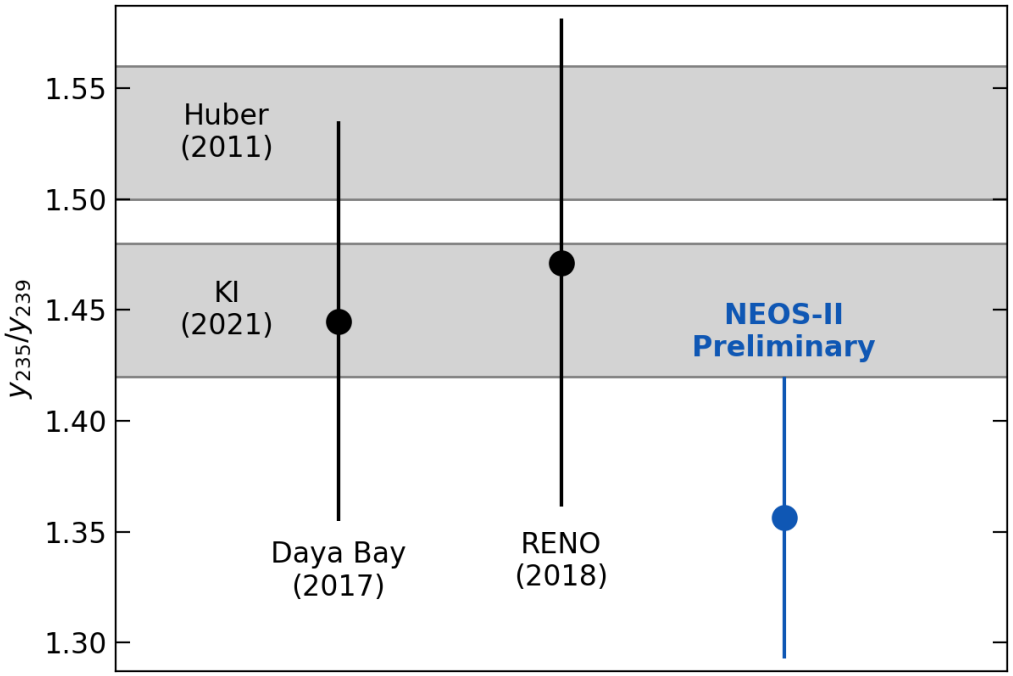
- IBD Yields for ^{235}U & ^{239}Pu



- Extraction of IBD yields for ^{235}U (y_{235}) and ^{239}Pu (y_{239})
- Detection efficiency: $45 \pm 1.3\%$ (not finalized yet.)
- $y_{235}/y_{239} = 1.36 \pm 0.06$
  - $y_{235} = 6.32 \pm 0.18$ [10^{-43}cm^2/fission]
  - $y_{239} = 4.66 \pm 0.26$ [10^{-43}cm^2/fission]

  (f_{235}, f_{239}: fission fractions for ^{235}U, ^{239}Pu)

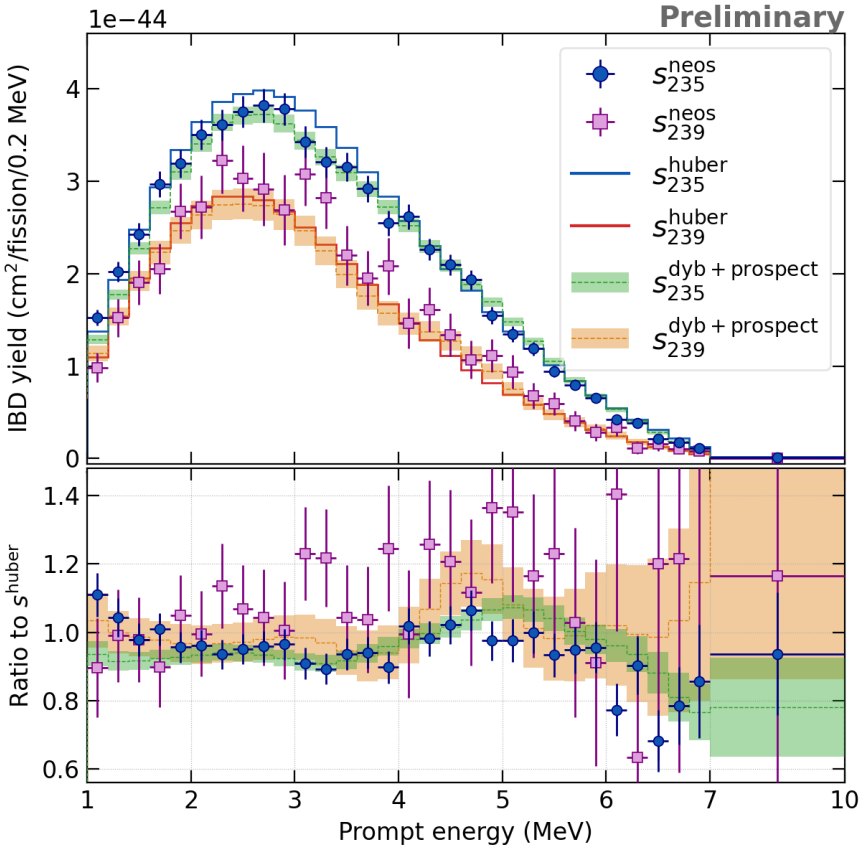
- y_{235}/y_{239}



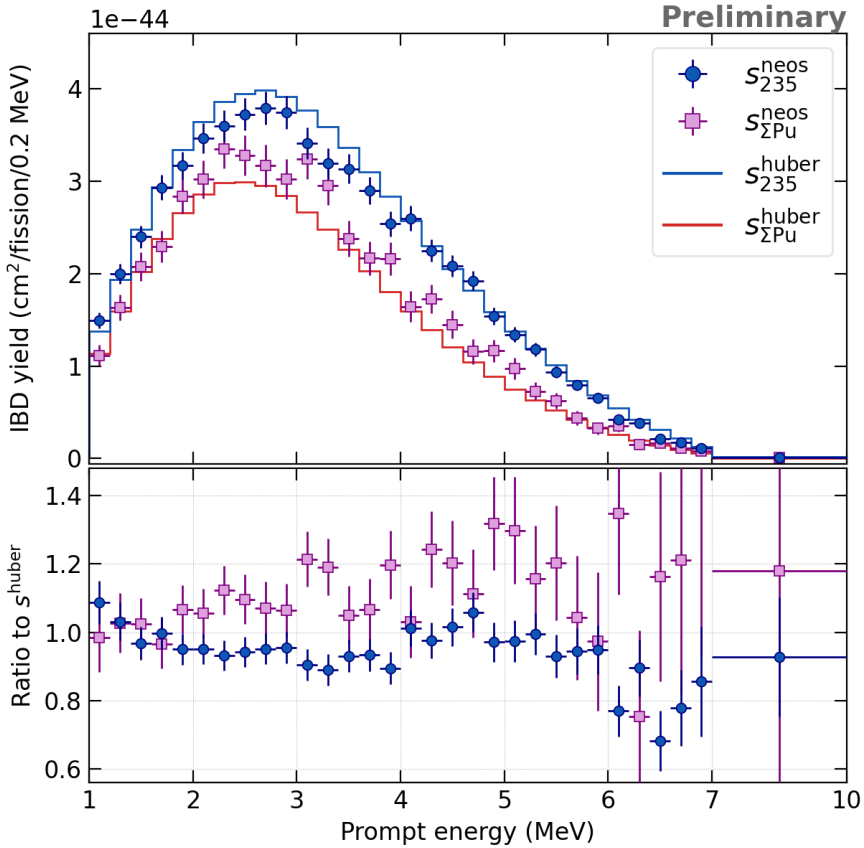
The Results of Spectrum Extraction

- Extraction of ^{235}U and ^{239}Pu spectra
- Small fraction change for ^{238}U/^{241}Pu → constraint by 20%, for HM model
- Deficit for ^{235}U from the Huber model, 5 MeV bump hints for both ^{235}U and Pu

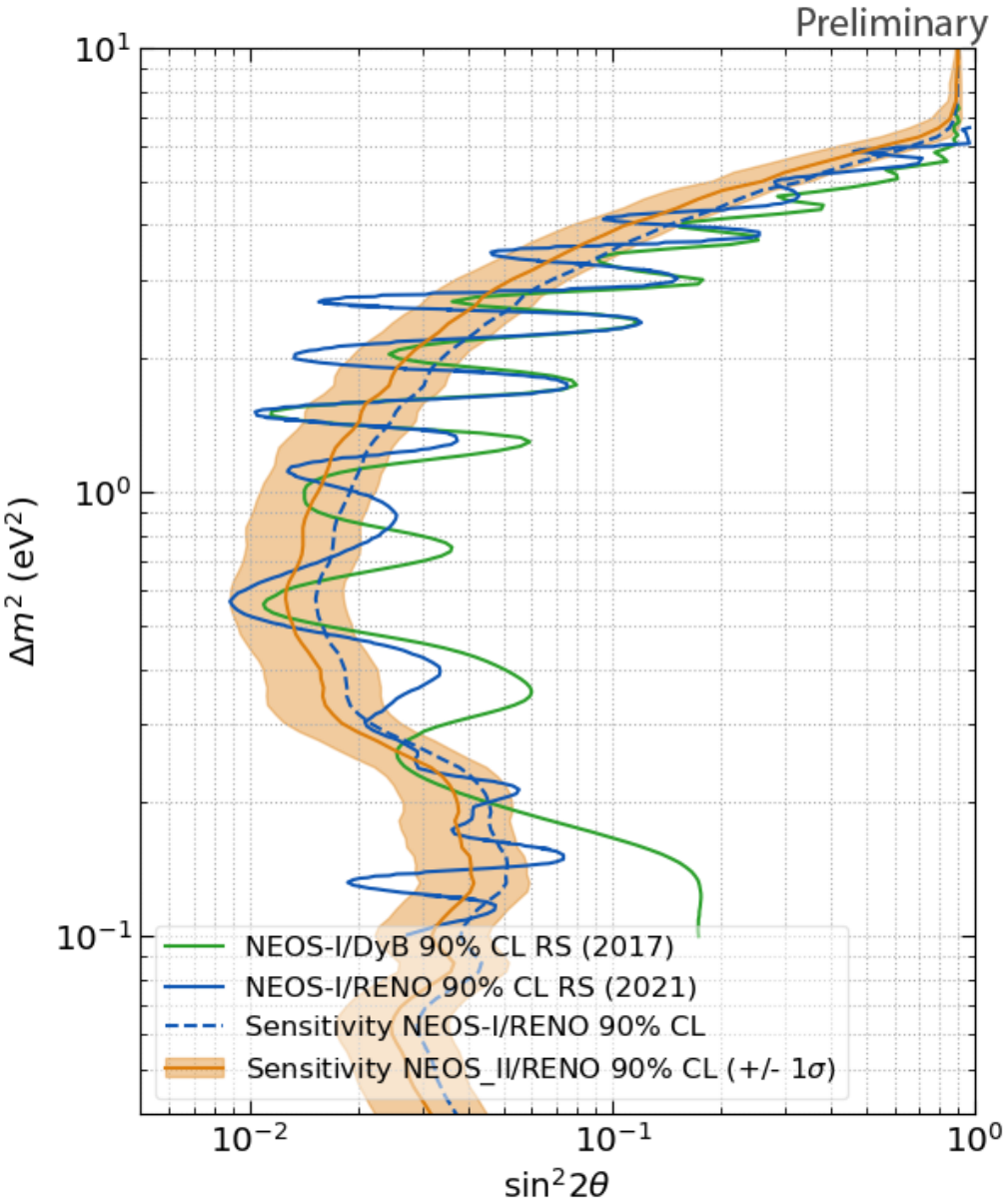
- ^{235}U & ^{239}Pu



- ^{235}U & ΣPu



NEOS Sensitivity for (3+1) ν Oscillation



- Shape-only → rate+shape analysis
- Slightly better sensitivity due to statistical improvement.
- Preparing detector response matrix.

Summary

- NEOS-II completed its operation.
  - NEOS-II measured IBD on Sep 2018 to Oct 2020 (388/112 live-days data for reactor on/off)
- Detector responses are well understood.
  - detector response matrix is being prepared.
- Extraction of IBD yield and spectra for ^{235}U and ^{239}Pu
  - $y_{235}/y_{239} = 1.36 \pm 0.06$ (IBD yield: $y_{235} = 6.32 \pm 0.18$, $y_{239} = 4.66 \pm 0.26$)
  - Spectrum: deficit for ^{235}U, 5 MeV bump are seen in both ^{235}U and Pu.
- Detection efficiency is being finalized.
- Sterile neutrino study (rate+shape) is ongoing.

Thank You!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1398
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