Reactor-Based Searches for Dark Sector Particles and Neutrino Interactions with the NEON experiment

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On behalf of the NEON Collaboration

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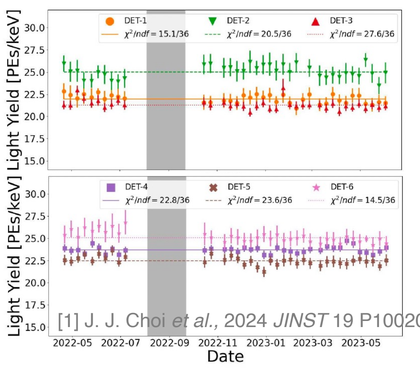
1. Introduction

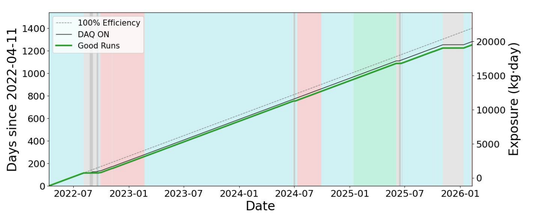
- Observation with reactor ν using NaI(Tl)
  - N^2 dependence
  - Weinberg angle
  - Understanding of nuclear structure
  - Contribution to supernova research
- **Coherent elastic ν-nucleus scattering (CEνNS)**
  - 1st measurement: COHERENT collaboration (2017), CsI[Na] target w/ spallation source
  - Observed by the CONUS+ collaboration (2025), HPGe w/ reactor ν
- **Incoherent neutrino-nucleus scattering (IνNS)**
  - Possible detection of transition γ (in NEON, I 57.6 keV)
- Reactor as a γ source
  - Dark sector particles searches
    - **Light dark matter (LDM)**
    - **Axion-like particles (ALP)**
    - **Dark photons (DP)**
- Other NaI-related searches
  - **Galactic Axion** (440 keV)

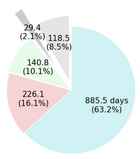
2. The NEON Experiment

- @ Tendon gallery at Hanbit-6 reactor (Yeonggwang, Korea)
  - 2.8 GW thermal power
  - Distance from the reactor core: 23.7 m
  - ~ 10 m concrete & rock overburden



[1] J. J. Choi *et al.*, 2024 *JINST* 19 P10020



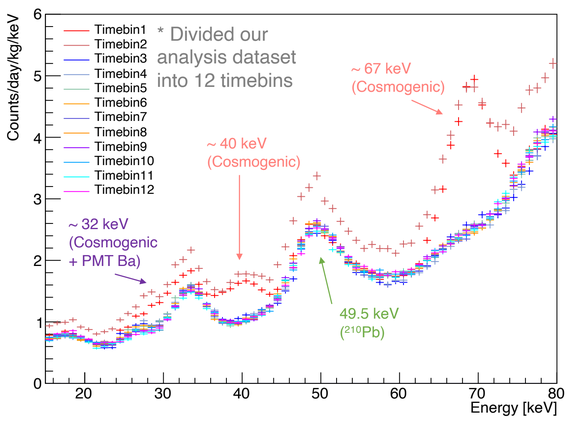


- Total 16.7 kg NaI(Tl)
- Stable light yield of > 22 NPE/keV
- Total exposure: 18563.72 kg·days
  - Reactor-on periods: 886 days
  - Reactor-off periods: 226 days

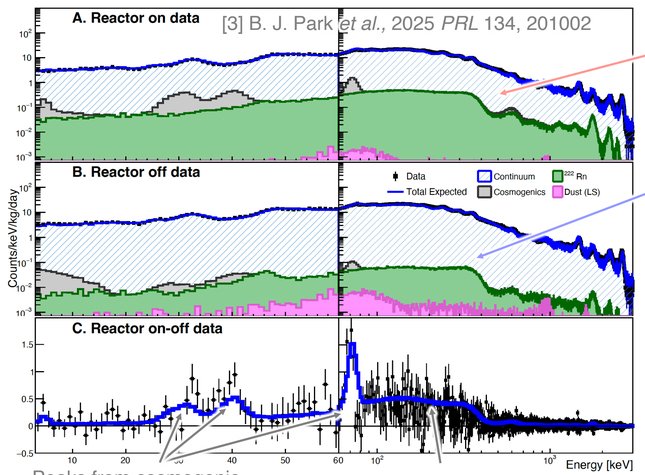
* NPE: number of photoelectrons

3. Background Studies in NEON

D6 Energy Spectrum from Timebins



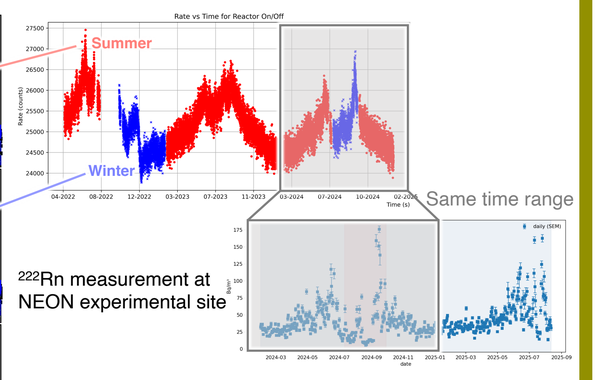
- Components with temporal behaviour
  - Cosmogenic components with comparably short half-life
    - ^{125}I (half-life 59.39 d): ~ 40 keV, 67.25 keV
    - ^{121m}Te (half-life 154 d): ~ 30 keV, ~ 40 keV
    - ^{126}I (half-life 12.93 d): ~ 30keV
- Time-independent components
  - ^{210}Pb 49.5 keV
  - 32 keV Ba from PMT
    → Newly introduced in this modeling (absent in the old result)



[3] B. J. Park *et al.*, 2025 *PRL* 134, 201002

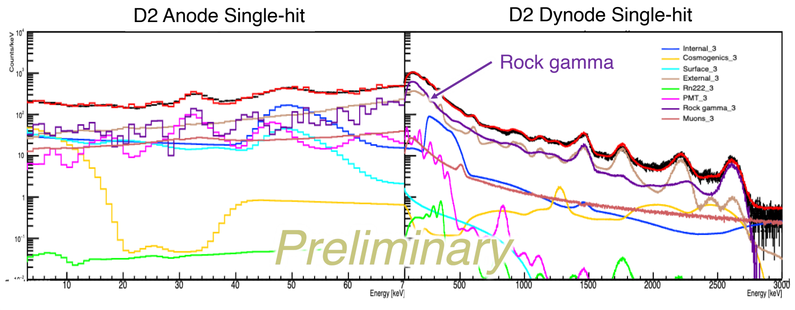
Peaks from cosmogenic components in (on – off) data

Contribution from ^{222}Rn



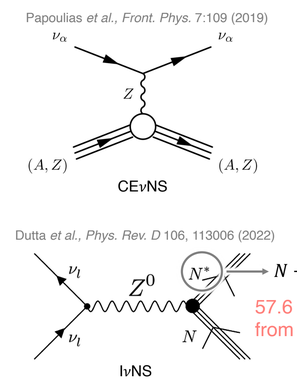
^{222}Rn measurement at NEON experimental site

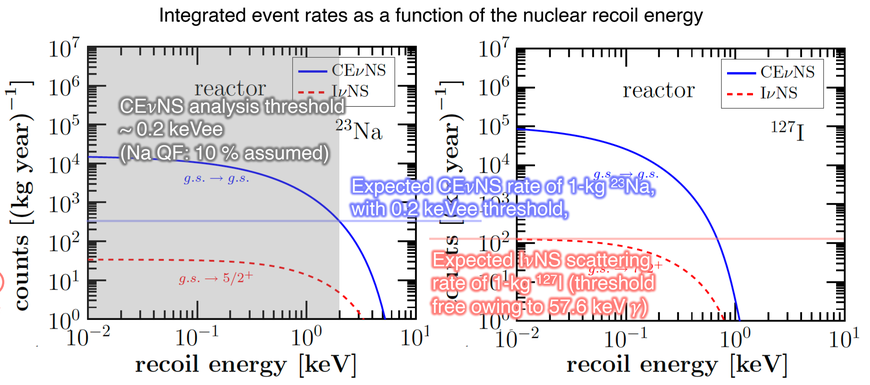
- Higher ^{222}Rn in the summer, lower in the winter
- Event rate fluctuation matches with ^{222}Rn measurement



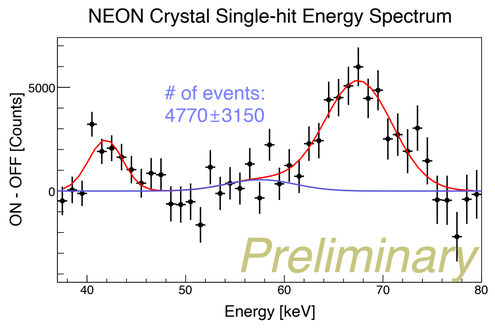
- Large contribution of the rock gamma
  - Combined concrete + soil + etc., not simply composited with standard rock
  - Higher contamination compared to standard rock

4. IνNS Search in NEON





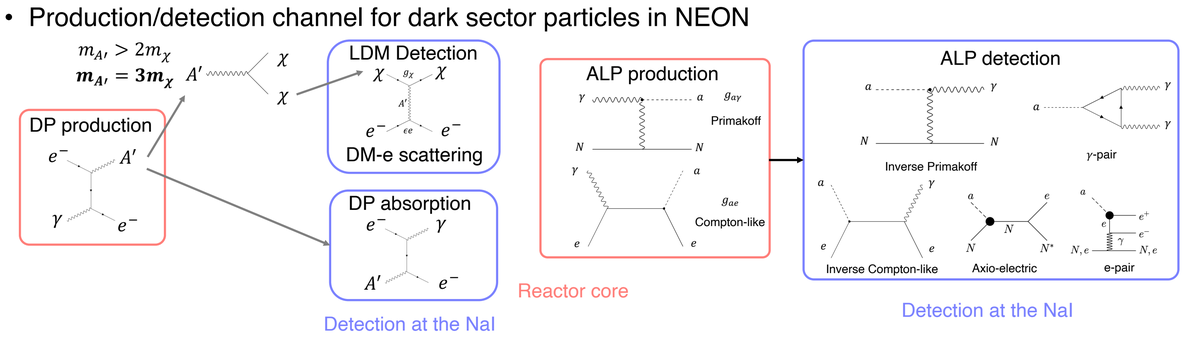
[4] R. Sahu *et al.*, *Phys. Rev. C* 102, 035501 (2020)



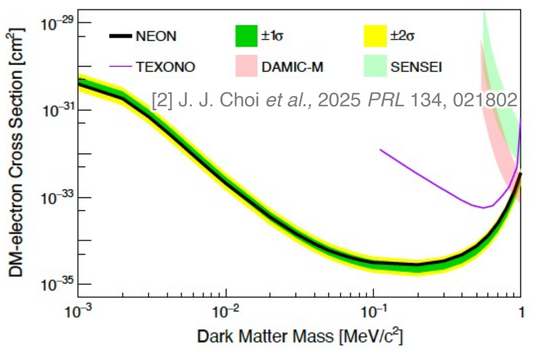
- In 700 days exposure at reactor-on status
  - **~ 2000 CEνNS event** assumed
  - **~ 2500 events of IνNS** assumed
- (Reactor-on) – (Reactor-off) data analysis at 40 ~ 80 keV energy region for 57.6 keV signal search with
  - Signal mean at 57.6 keV, cosmogenic peak at ~ 67 keV and ~ 40 keV
- Improving through detailed modeling of the on and off data

5. Dark Sector Particles Search in NEON

- Production/detection channel for dark sector particles in NEON



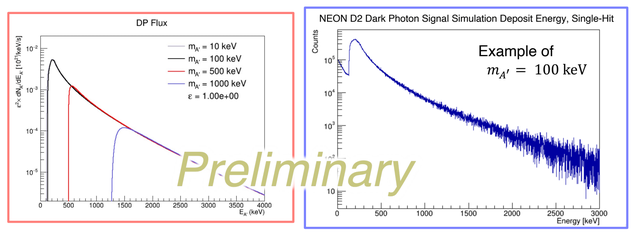
LDM Search in NEON



[2] J. J. Choi *et al.*, 2025 *PRL* 134, 021802

- DM with Sub-MeV scale mass
- LDM produced by dark photons provides strong constraints in the keV mass range
- Extended limit for low mass region

DP Search in NEON

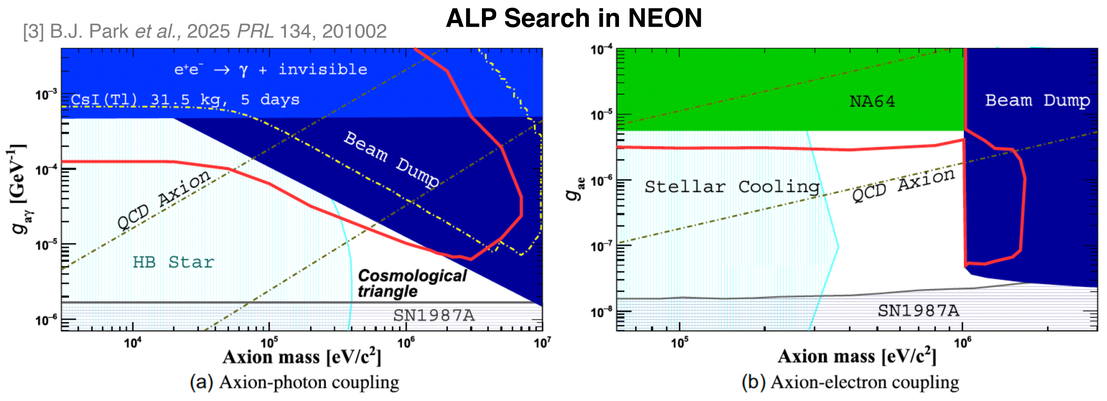


[5] H. K. Park, 2017 *PRL* 119, 081801

- Signal generation of recoiled γ and e^- flux at our detector
- Will be used to get kinetic mixing parameter (ε) sensitivity for our experiment, with (reactor-on) - (modeled reactor-off) data

ALP Search in NEON

[3] B.J. Park *et al.*, 2025 *PRL* 134, 201002

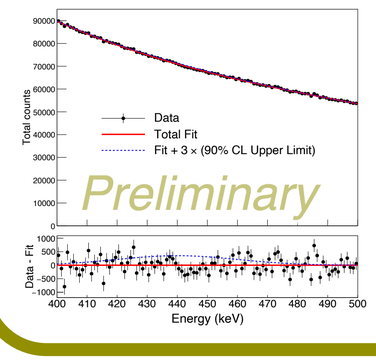


(a) Axion-photon coupling (b) Axion-electron coupling

- Covers the part of the “cosmological triangle”

440 keV Galactic Axion search in NEON

[6] W. C. Haxton *et al.*, *arXiv:2604.26004*



- Axions produced by the carbon-burning stars in our galaxy
  - Caborn burning

$$^{12}\mathrm{C} + {}^{12}\mathrm{C} \rightarrow {}^{24}\mathrm{Mg}^* \rightarrow {}^{23}\mathrm{Na} + p + 2.24\ \mathrm{MeV}$$

- ^{23}Na radiates 440 keV axions through repeated photo-excitation and axio-deexcitation of its first excited state
- Reaching the NaI detector, the axion is resonantly absorbed, producing a 440 keV deexcitation photon
  - Gaussian signal mean fixed at 440 keV + 3rd order polynomial background fit

Reference

[1] J. J. Choi *et al.*, Upgrade of the NaI(Tl) crystal encapsulation for the NEON experiment, 2024 *JINST* 19 P10020, DOI: 10.1088/1748-0221/19/10/P10020
[2] J. J. Choi *et al.*, First Direct Search for Light Dark Matter Using the NEON Experiment at a Nuclear Reactor, 2025 *Phys. Rev. Lett.* 134, 021802, DOI: 10.1103/PhysRevLett.134.021802
[3] B. J. Park *et al.*, New Constraints on Axionlike Particles with the NEON Detector at a Nuclear Reactor, 2025 *Phys. Rev. Lett.* 134, 201002, DOI: 10.1103/PhysRevLett.134.201002
[4] R. Sahu *et al.*, Elastic and inelastic scattering of neutrinos and weakly interacting massive particles on nuclei, *Phys. Rev. C* 102, 035501 (2020), DOI:10.1103/PhysRevC.102.035501
[5] H. K. Park, Detecting Dark Photons with Reactor Neutrino Experiments, 2017 *Phys. Rev. Lett.* 119, 081801, DOI: 10.1103/PhysRevLett.119.081801
[6] W. C. Haxton *et al.*, Revisiting Turner Window Axions: The Untapped Potential of NaI Dark Matter Detectors, *arXiv:2604.26004*