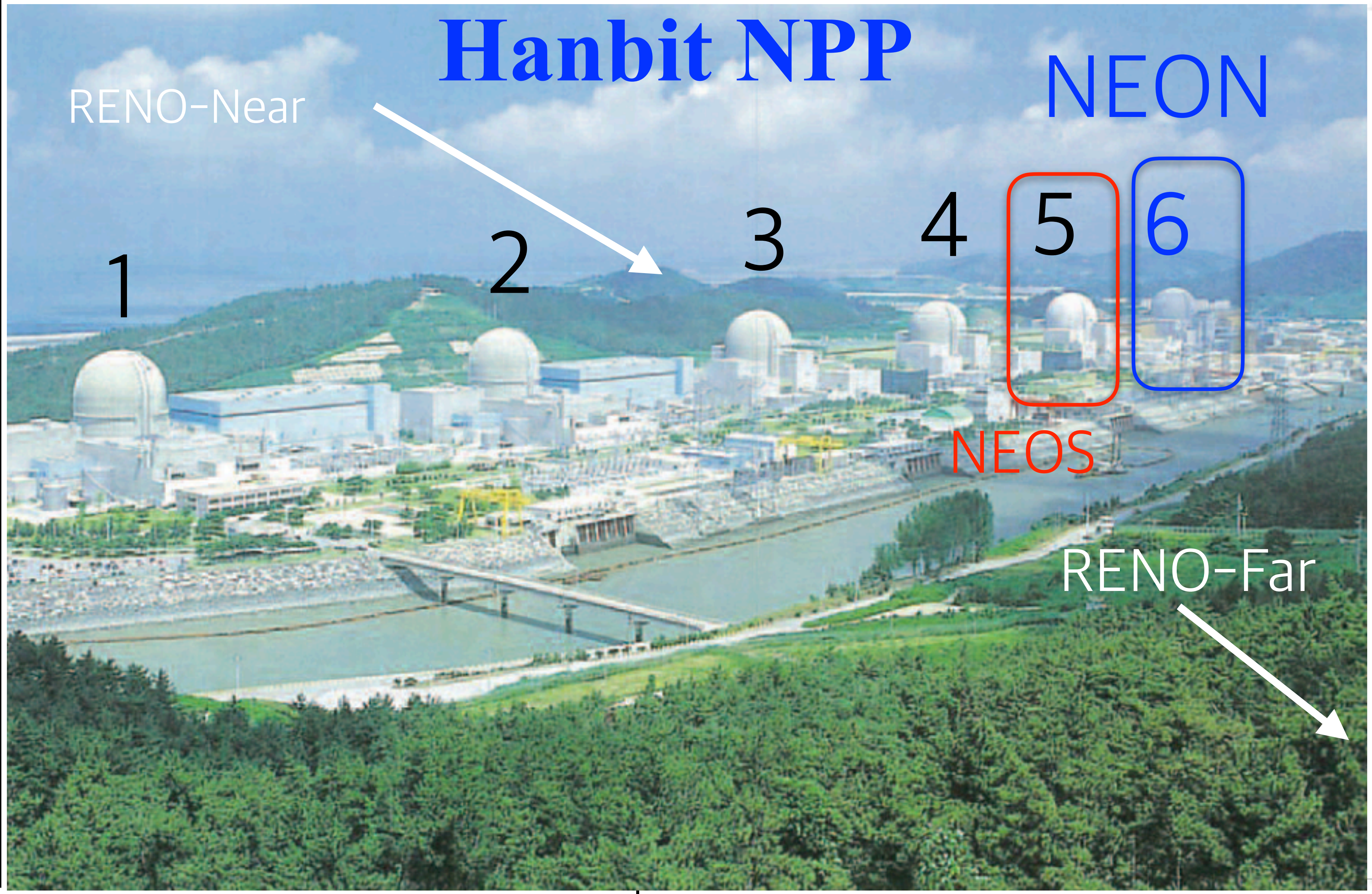
중앙대학교

Center for Underground Physics

TAUP VIENNA 2023

Chang Hyon Ha (Chung-Ang University)
on behalf of the NEON collaboration

Status of the NEON experiment
(**N**eutrino **E**lastic-scattering **O**bservation in **N**aI)



The NEON Collaboration

Goal : Coherent Neutrino Nucleus Scattering (CNNS) measurements in NaI(Tl) crystals from nuclear reactor.
(Low-background dark matter Crystal experts + Reactor neutrino experiment experts)

~20 members, 5 institutes

Active members of
the COSINE and NEOS experiments

NaI(Tl) crystal scintillators for CNNS

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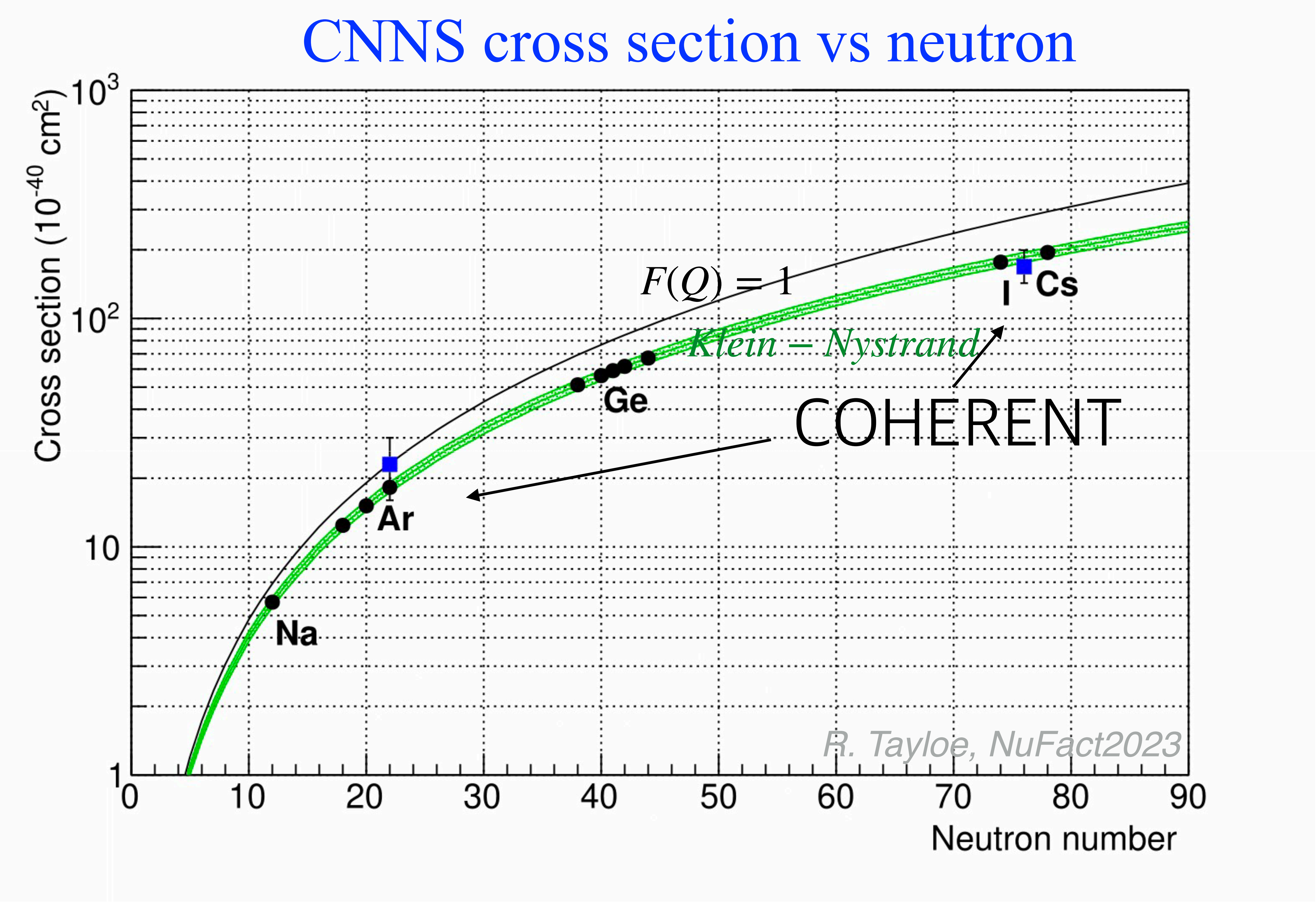

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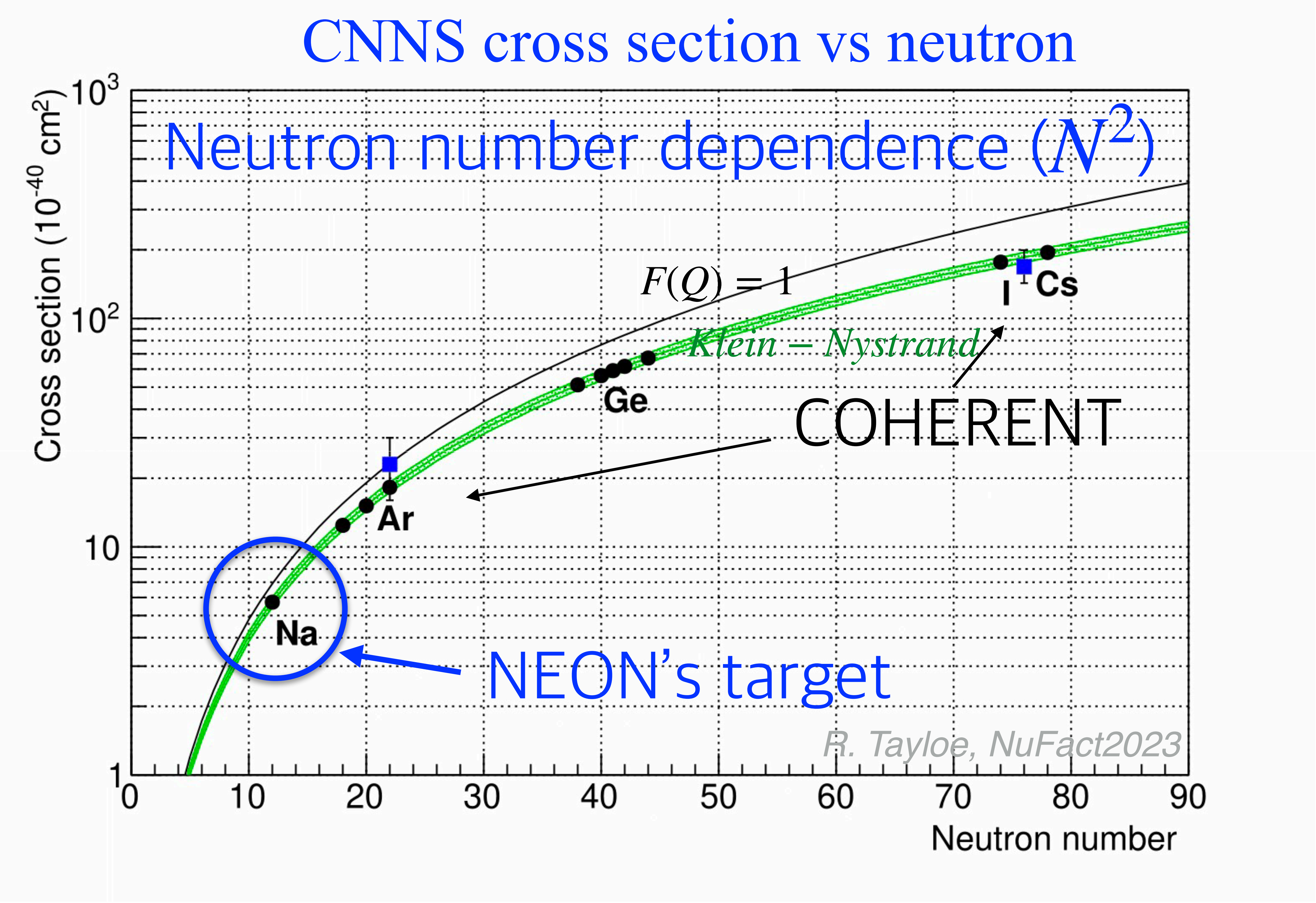
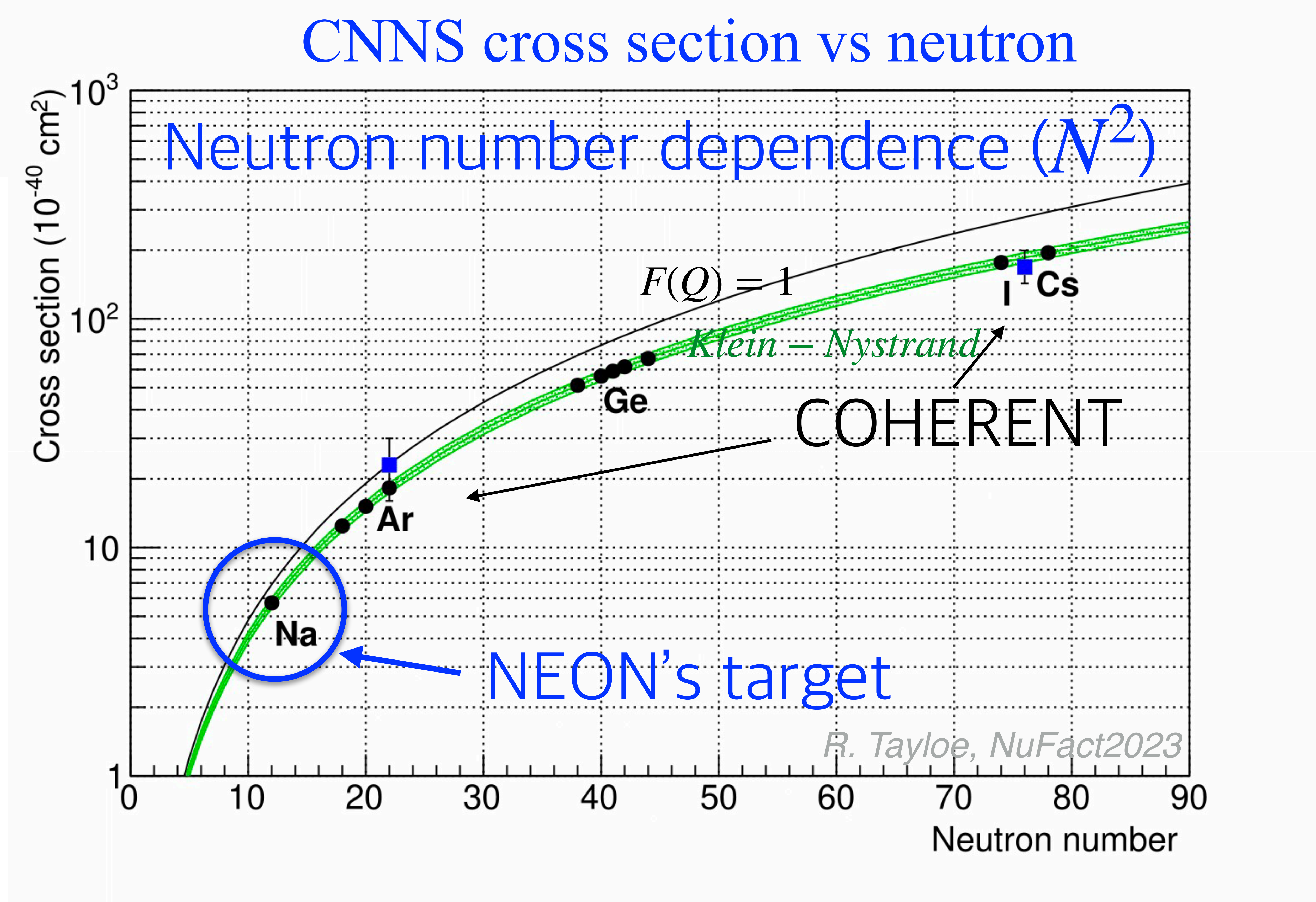


NaI(Tl) crystal scintillators for CNNS

- **Very high light output crystal**
  - **COSINE-100 measures 15 P.E. / keVee**



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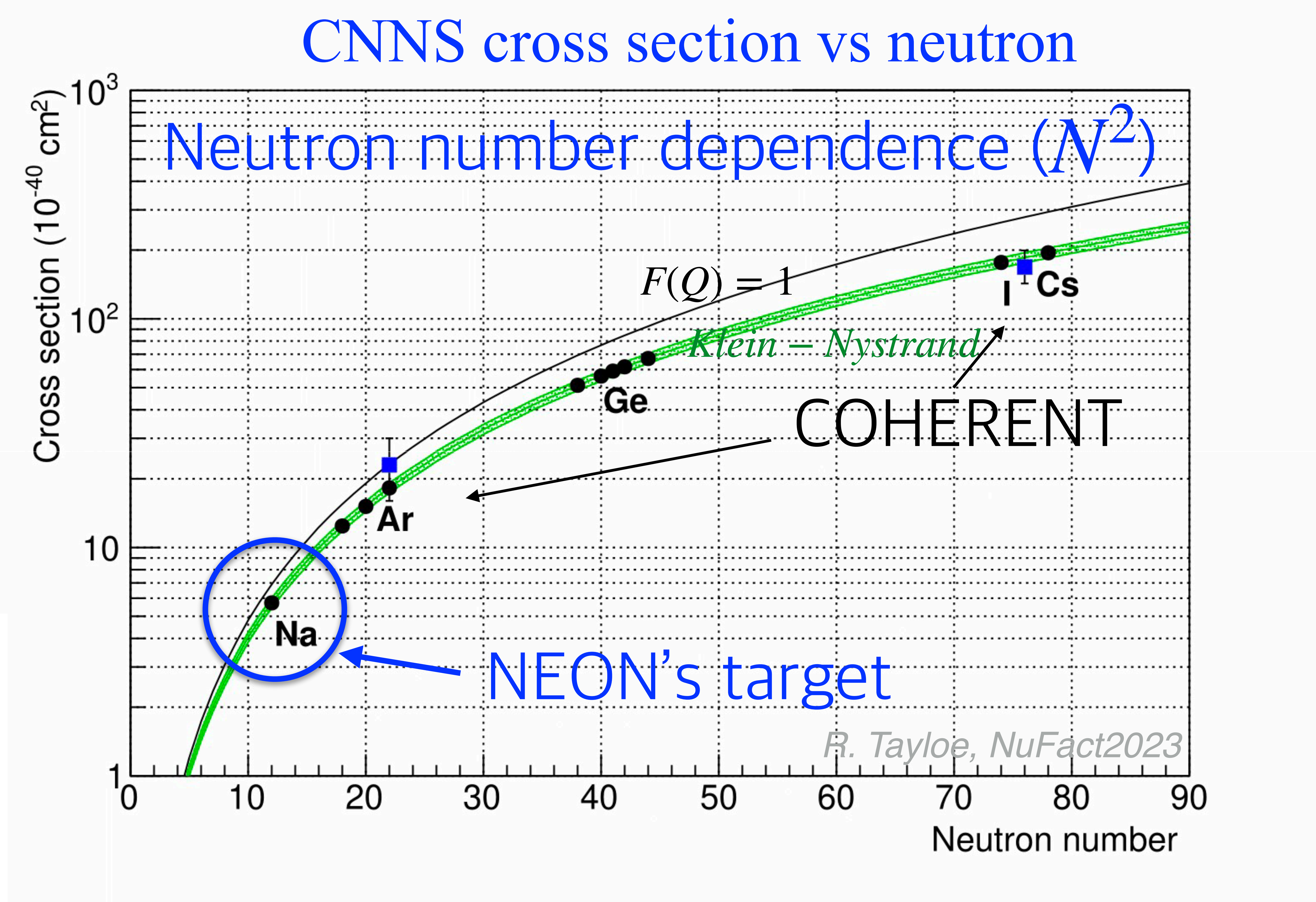
  - **relevant for low energy neutrinos i.e. nuclear reactor neutrinos**
  - **E.g. for 10 MeV ν, the max nuclear recoil energy is 8.7 keV on Sodium and 1.6 keV on Iodine**



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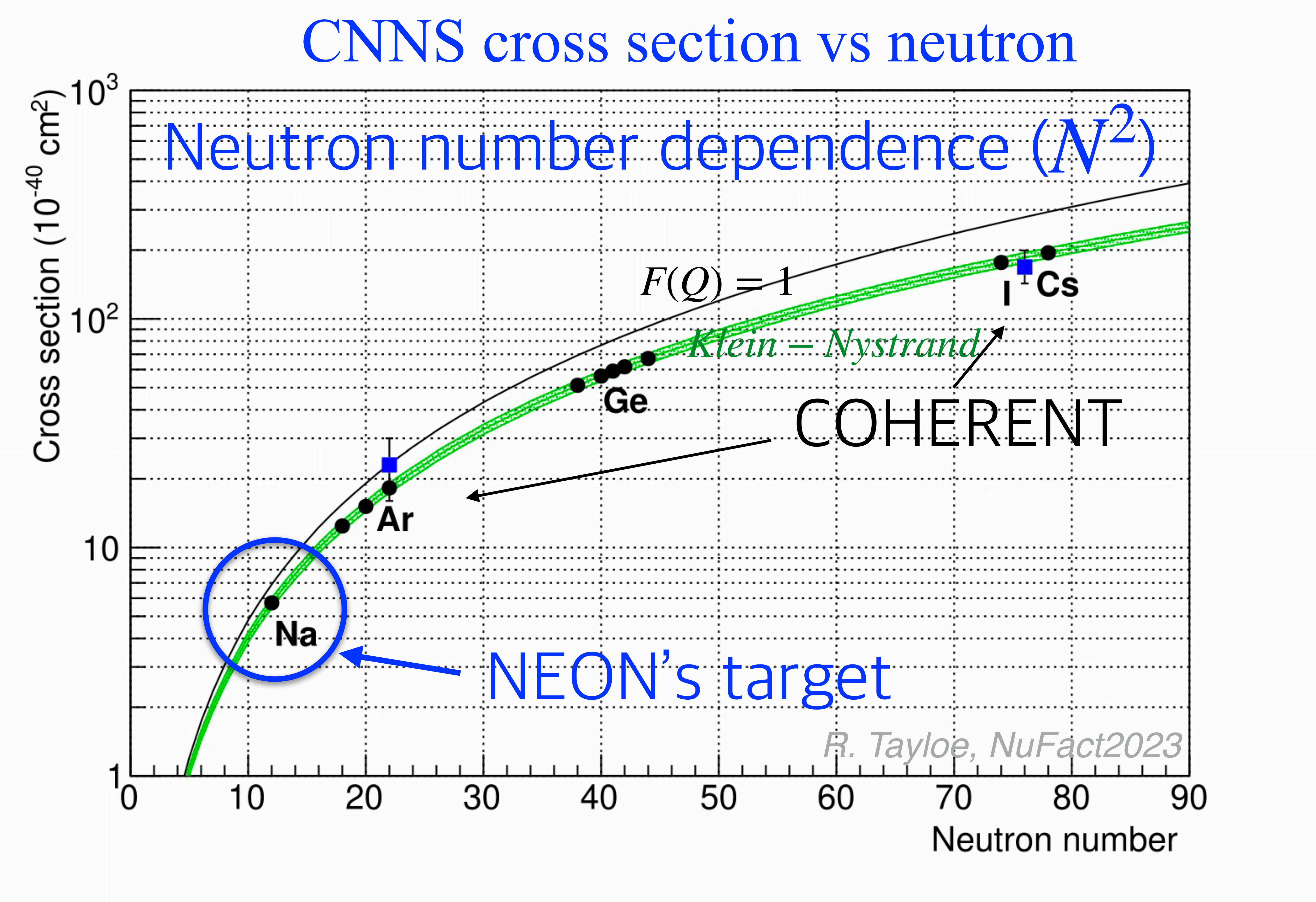
- **Background under control and easily scalable**
  - **COSINE-100 shows 2.5 counts/day/kg/keV (internal origin) at 1 keV threshold.**



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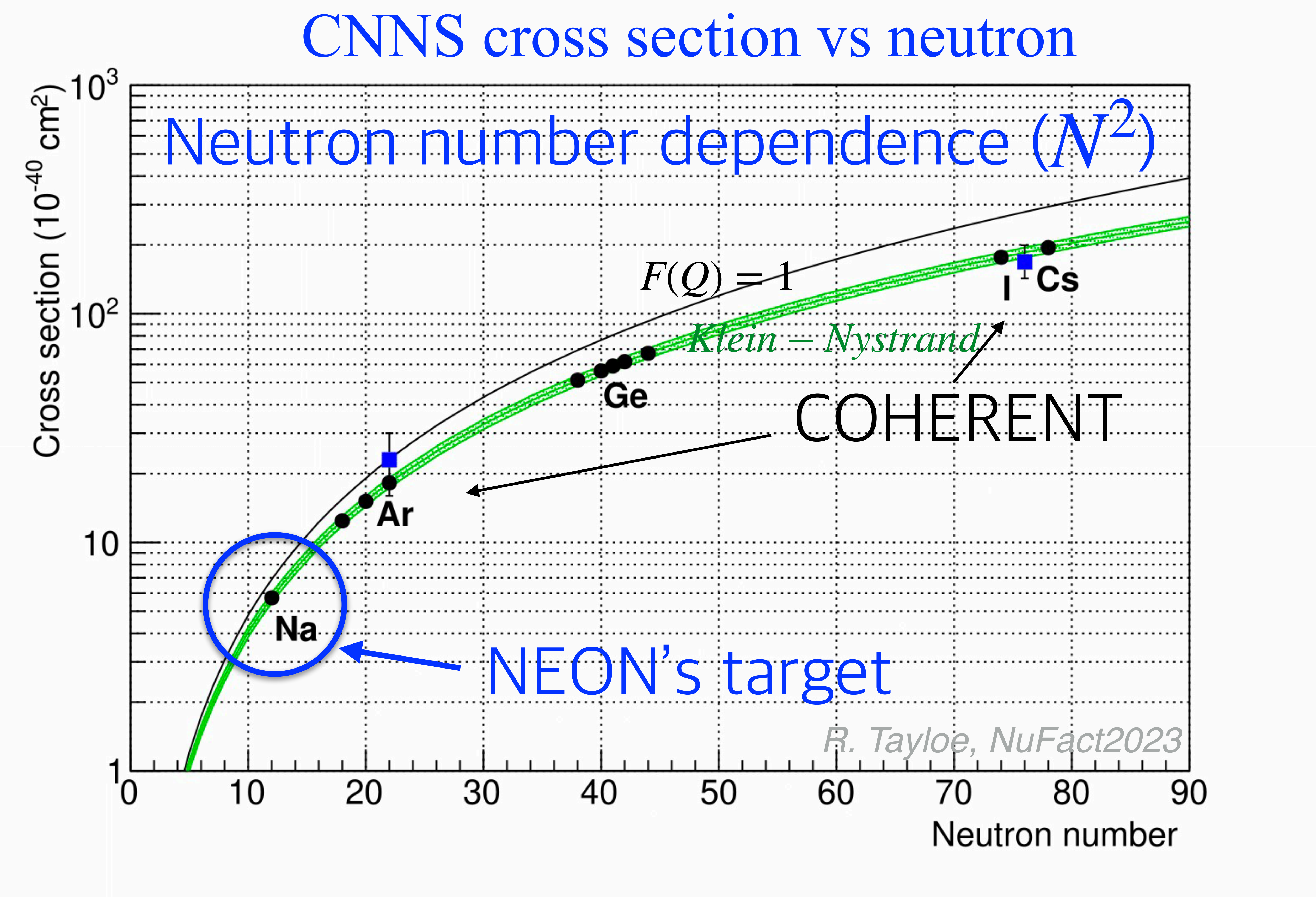

Natural Opportunities for CNNS, Synergy with dark matter detection, and Possible new physics : However, 0.2 keVee threshold is required.

CNNS Event Rate & Requirement on NaI(Tl)

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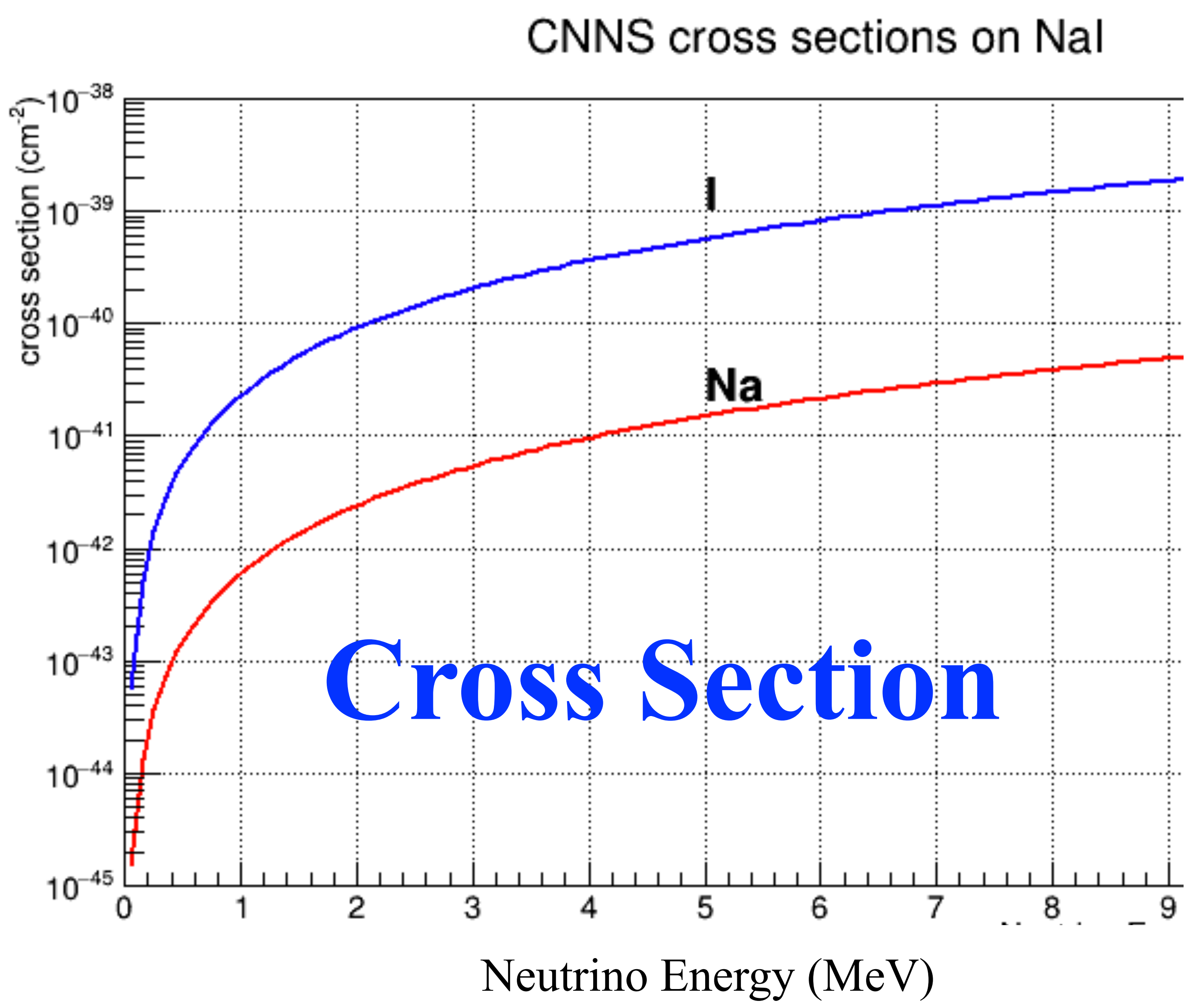

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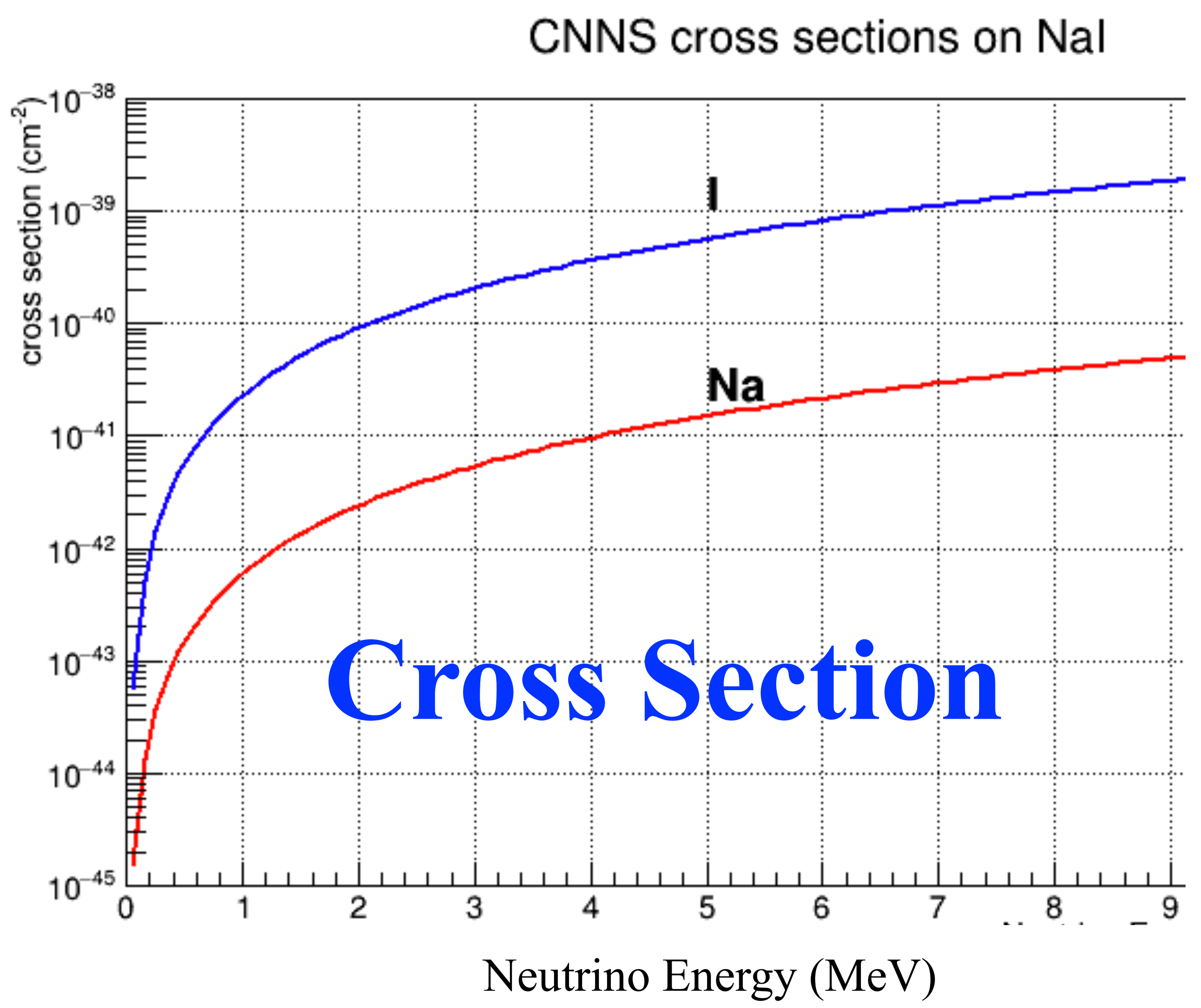

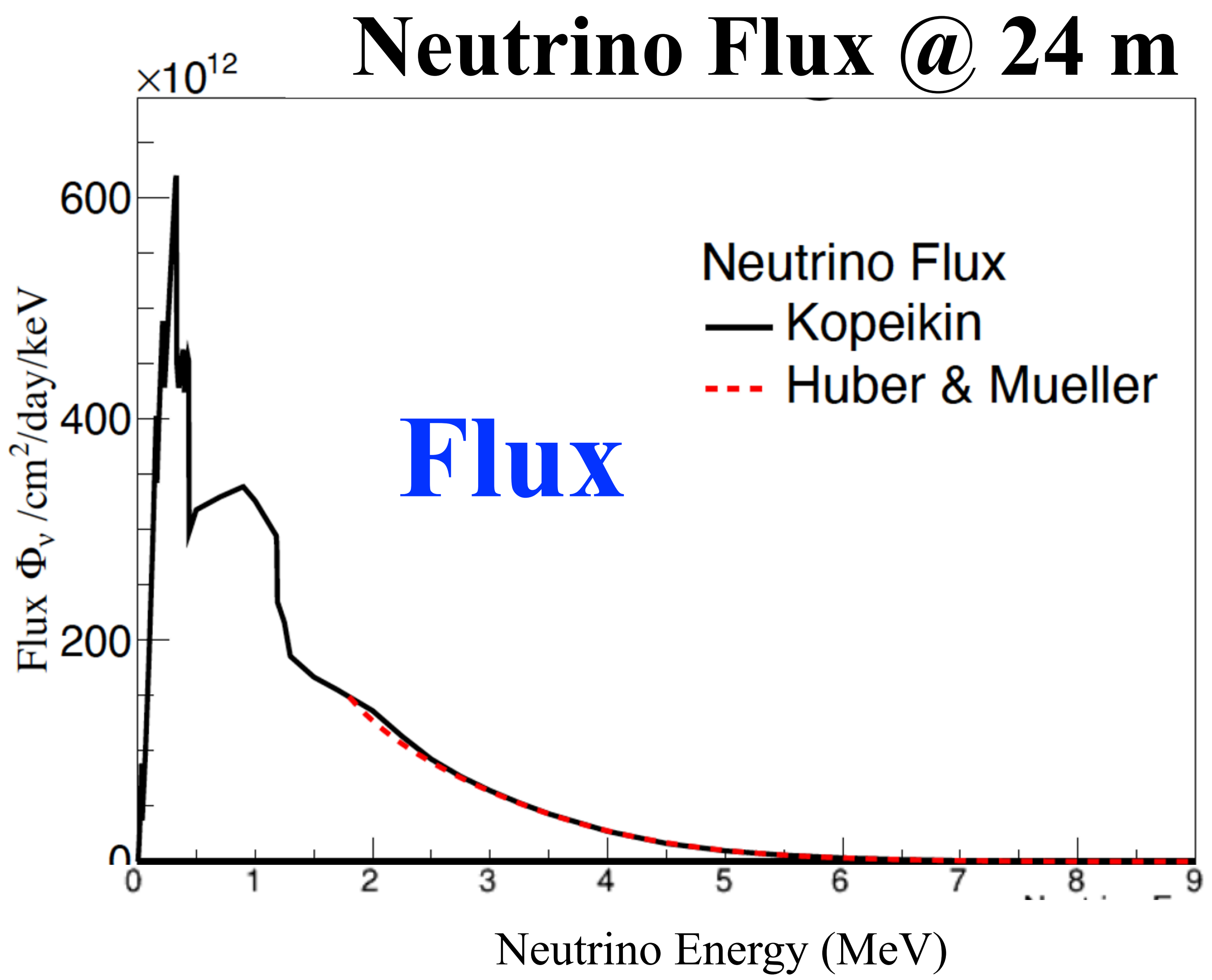

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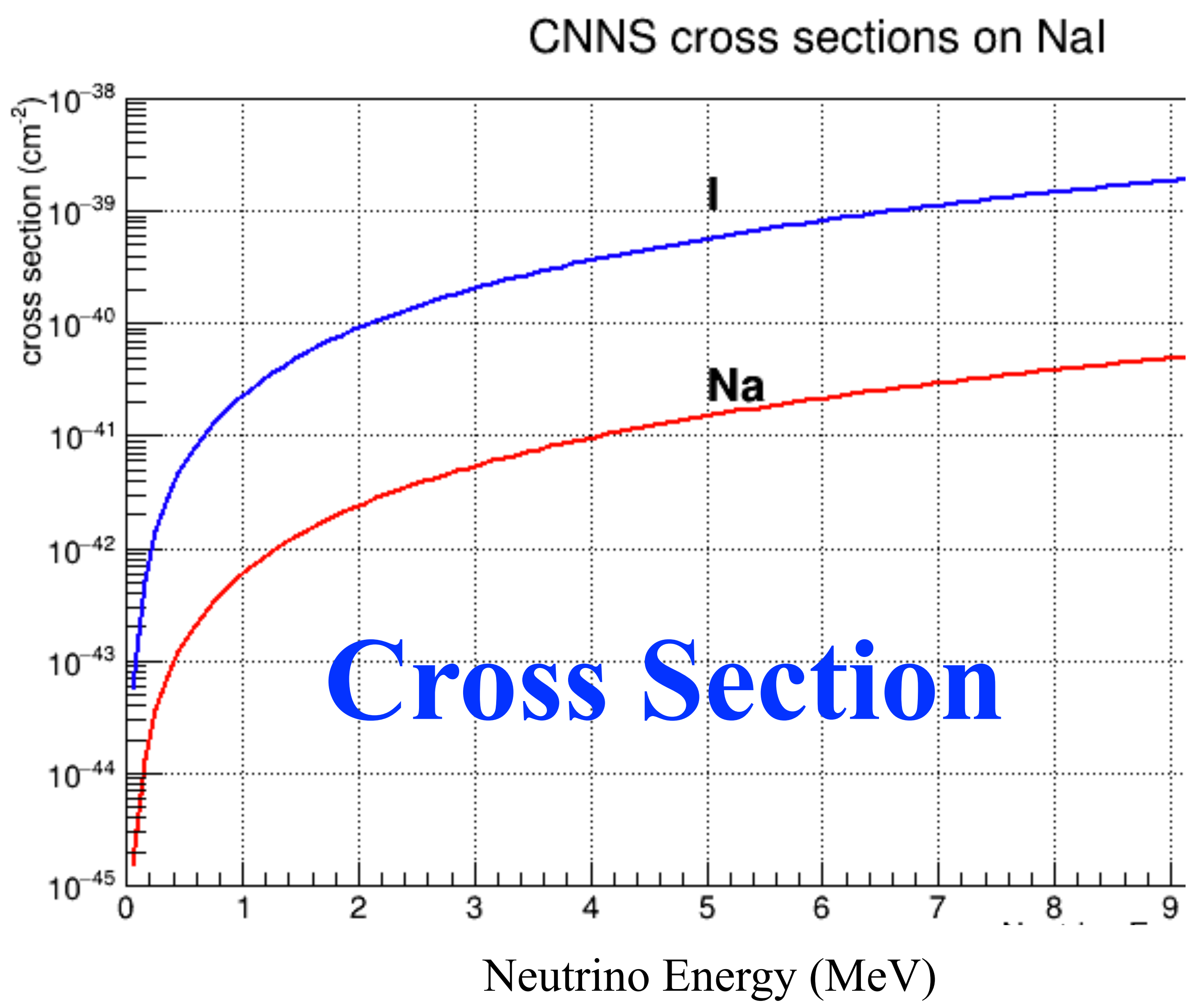

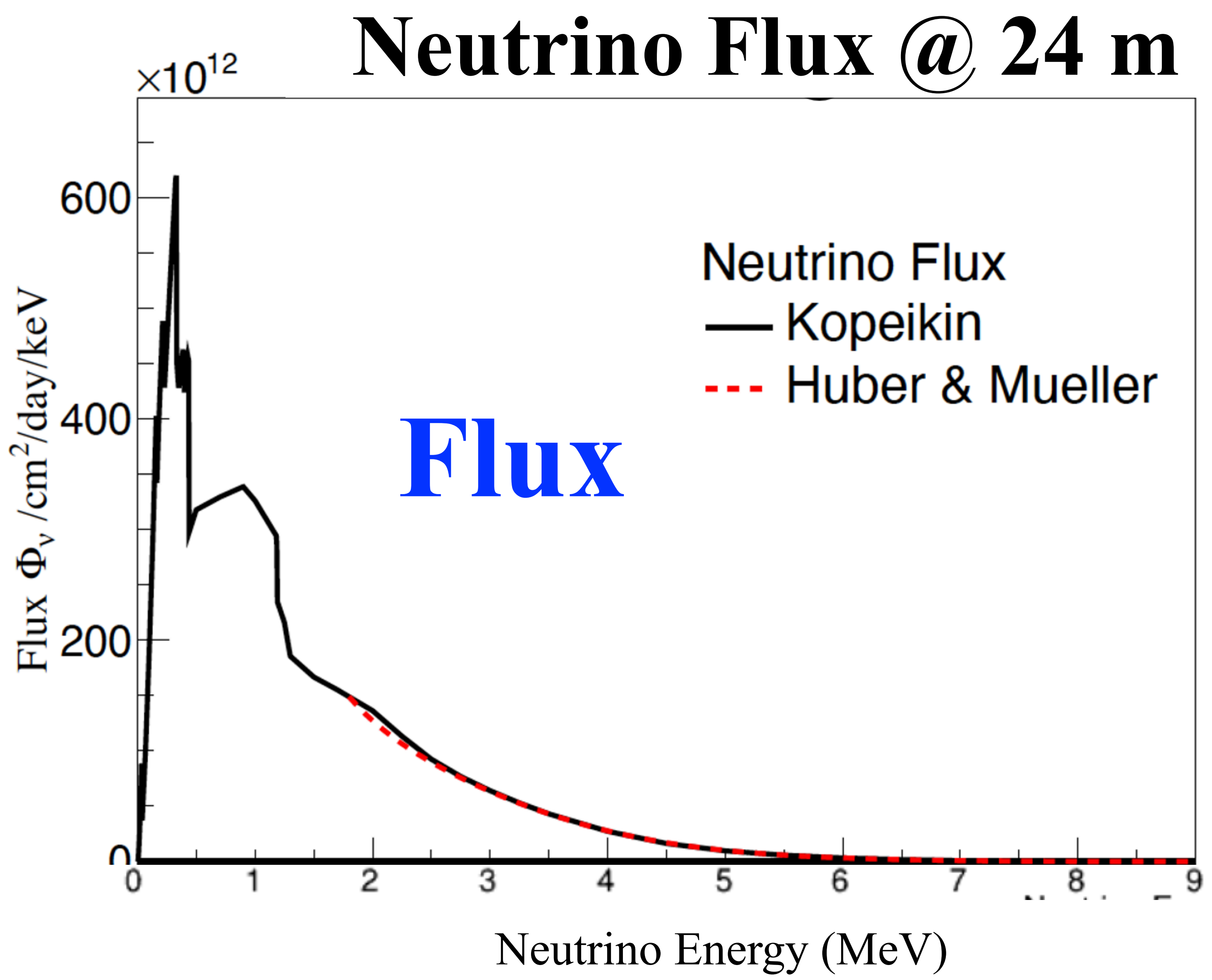

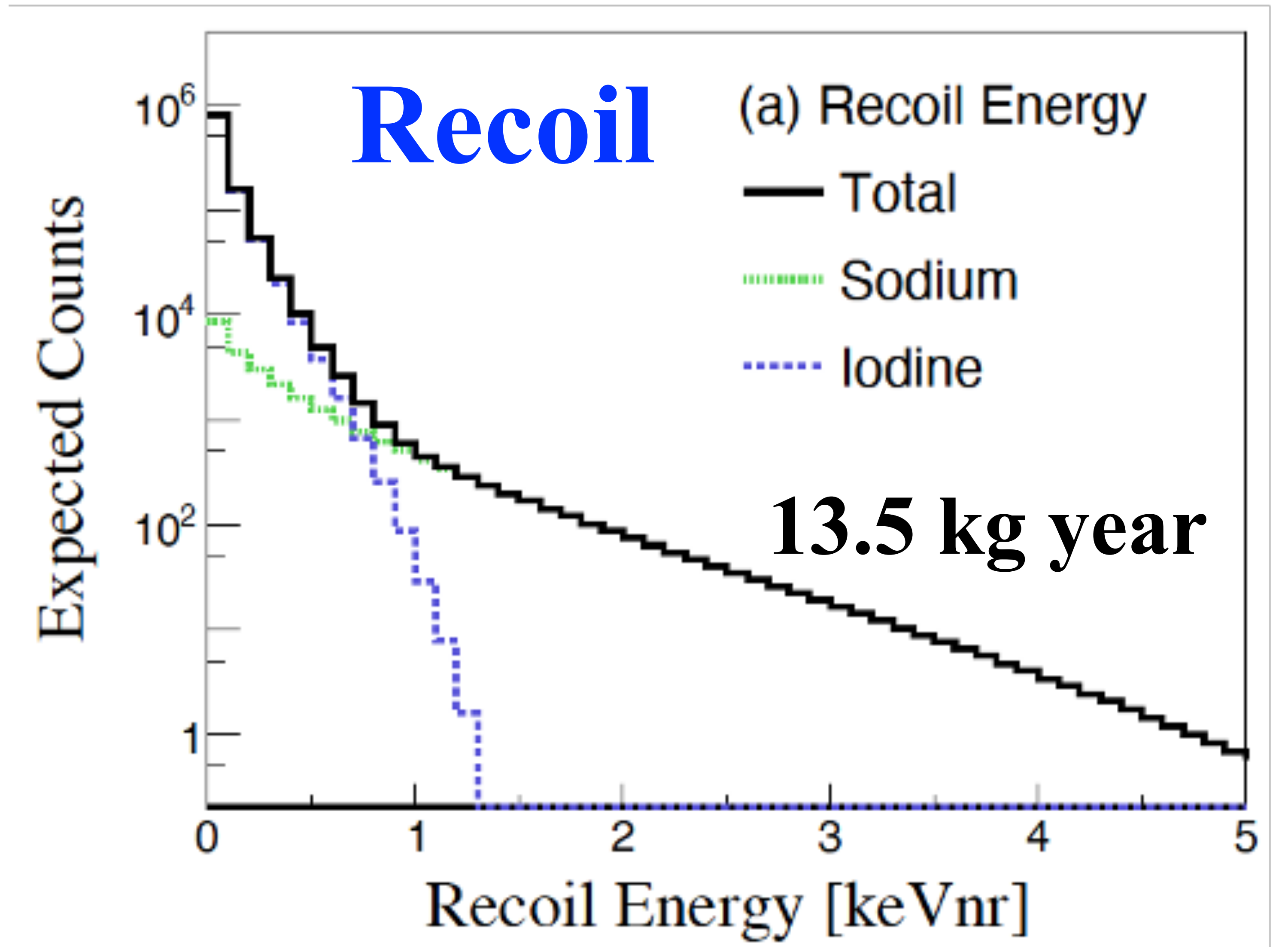

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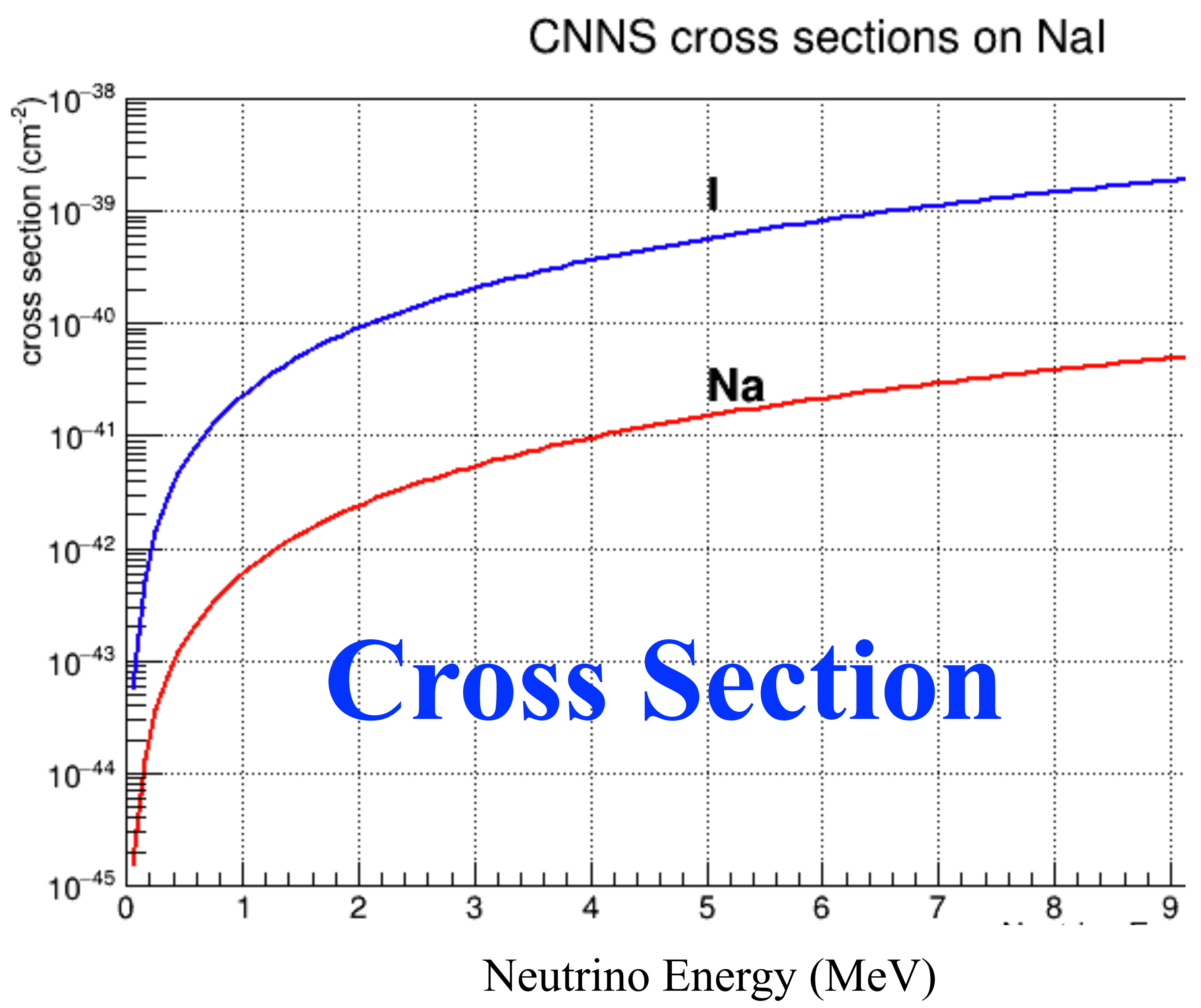
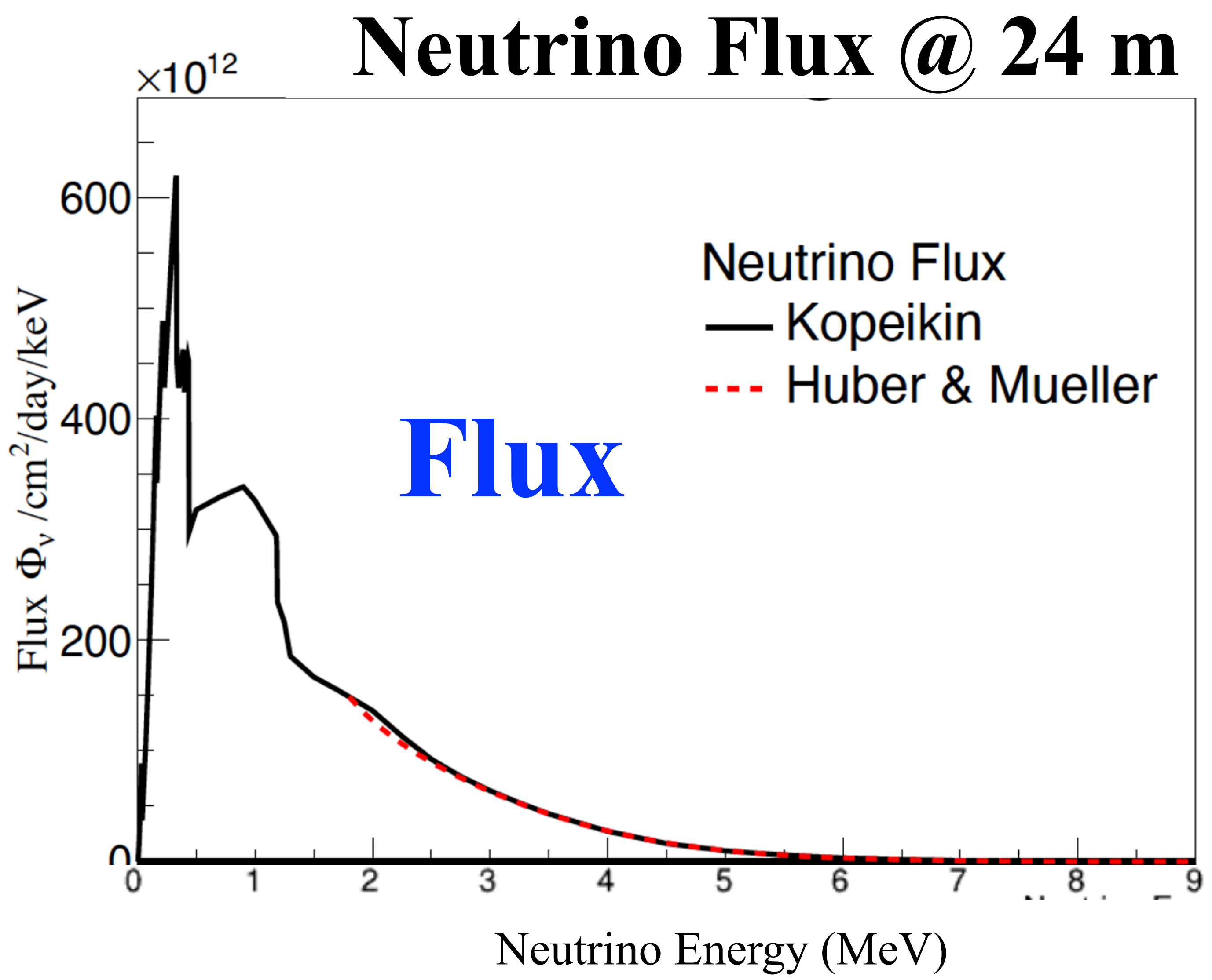
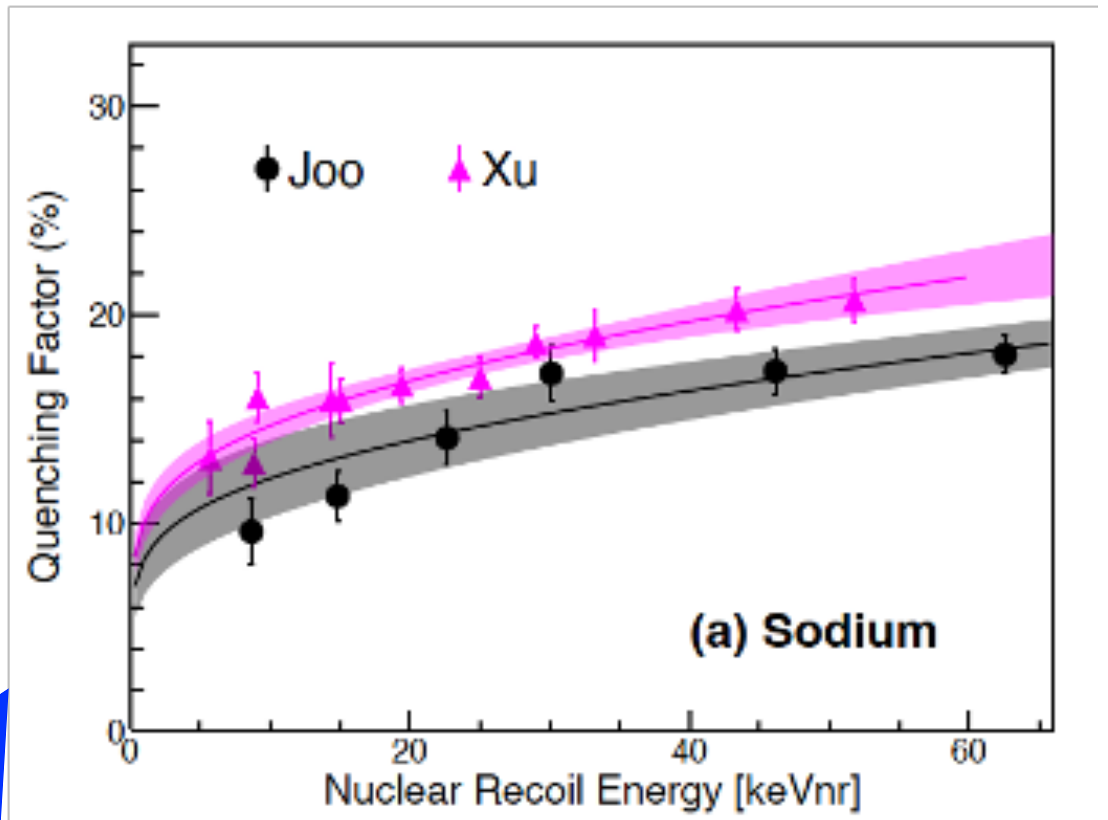
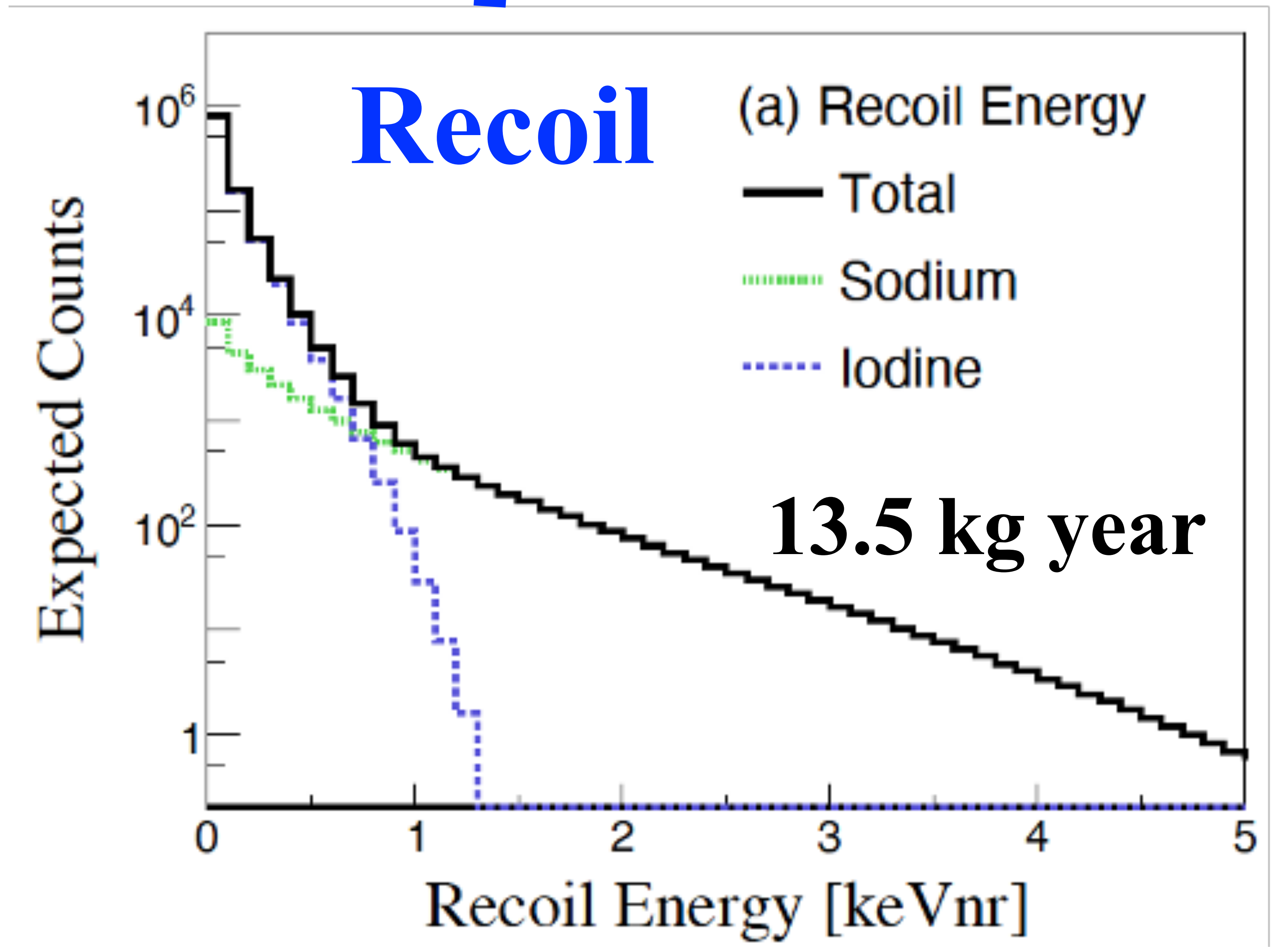






$$QF(E_{dep}) = \frac{E_{ee}}{E_{nr}} = \frac{E_{vis.}}{E_{dep.}}$$



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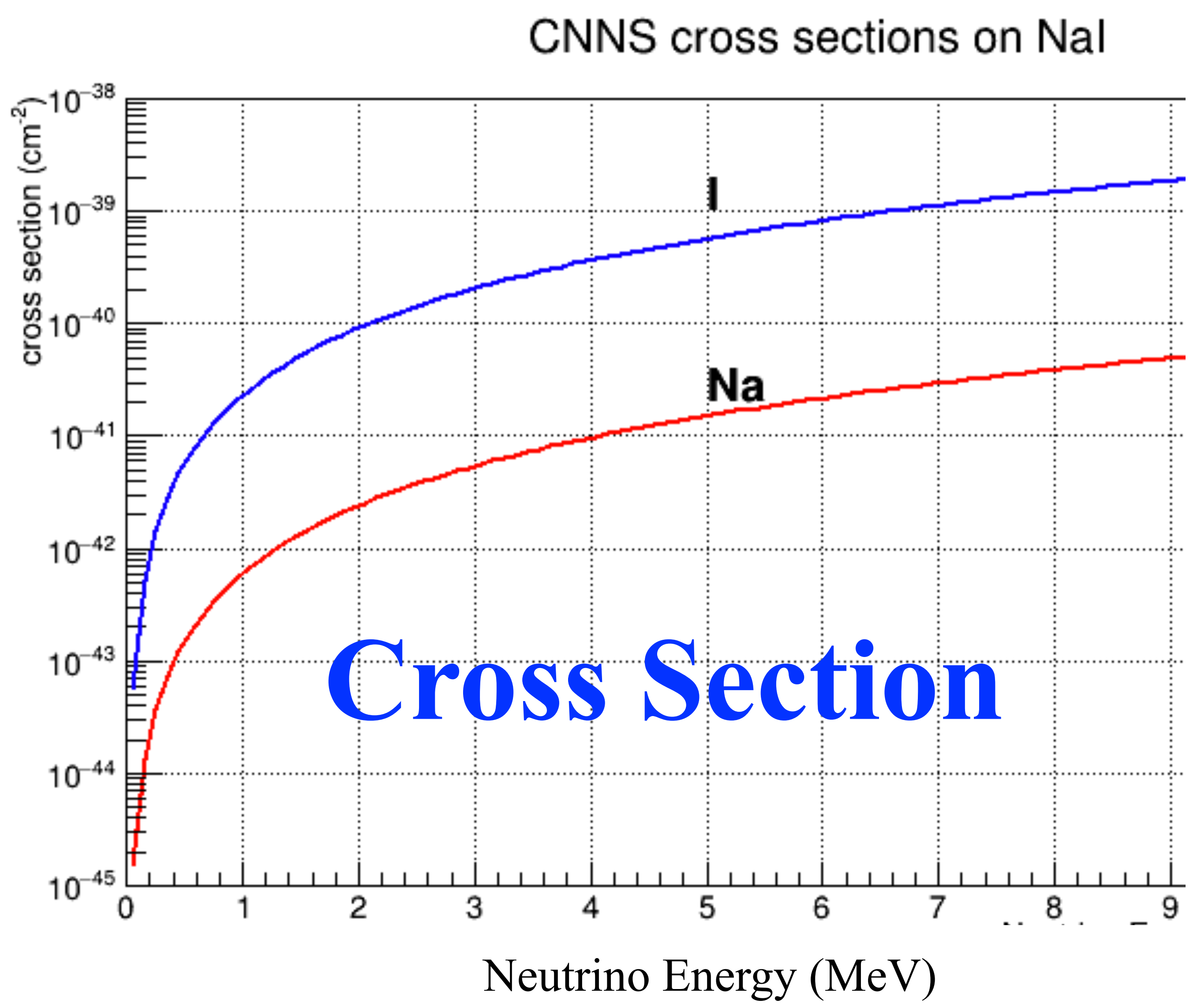

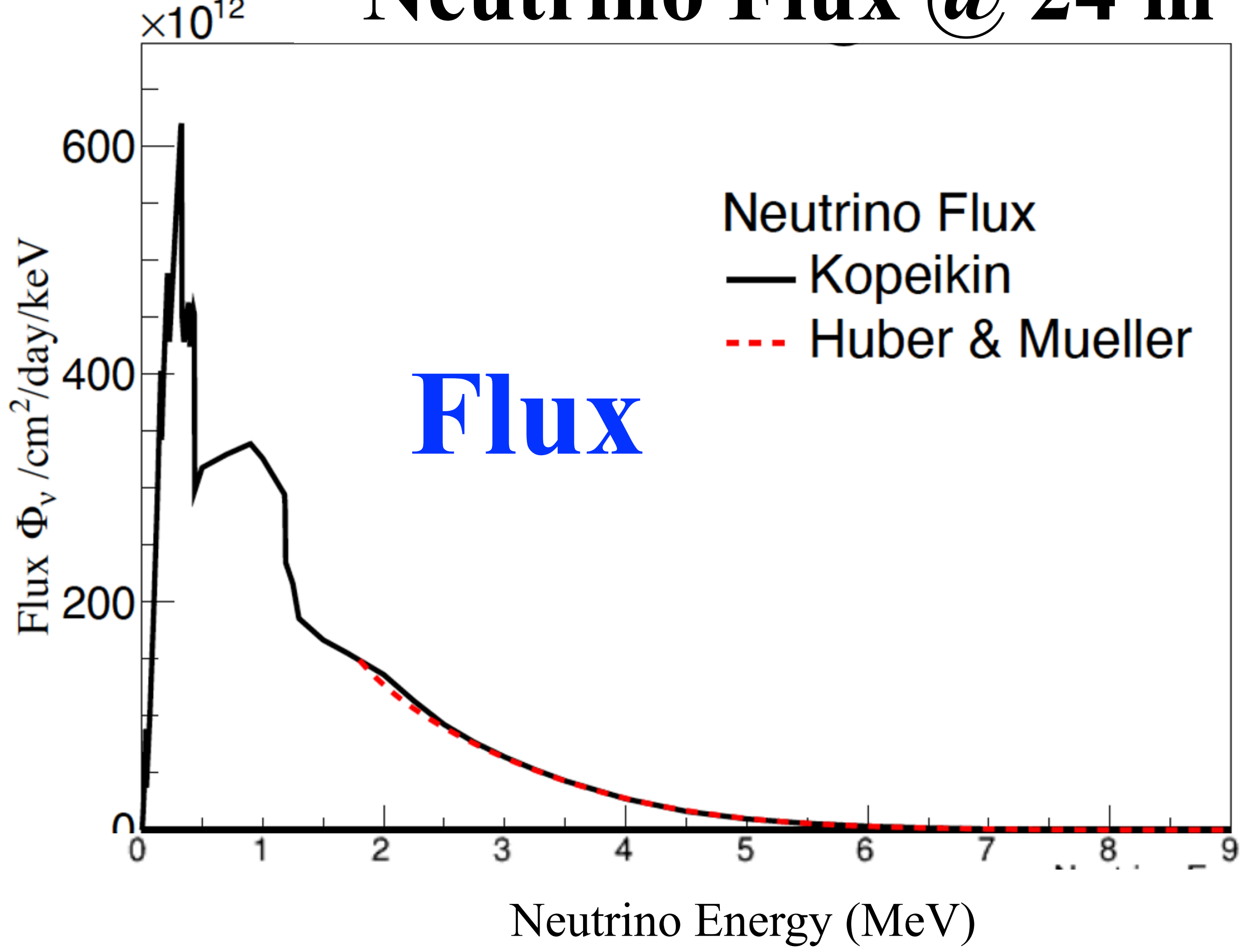

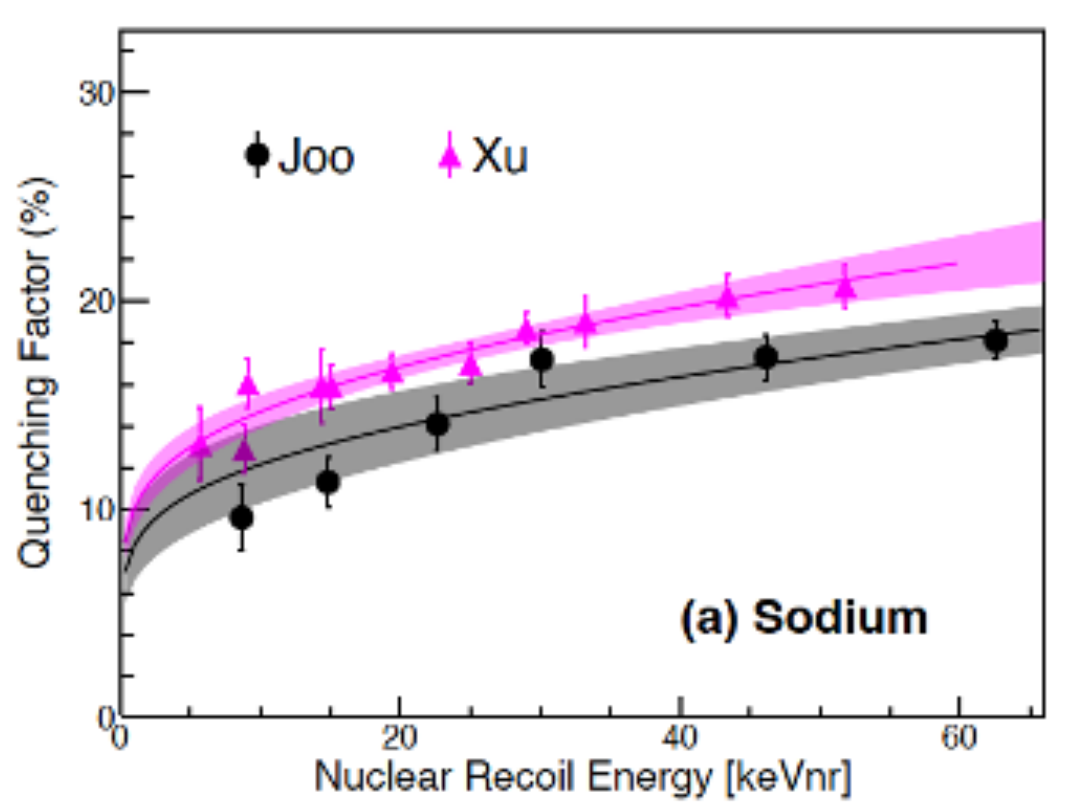

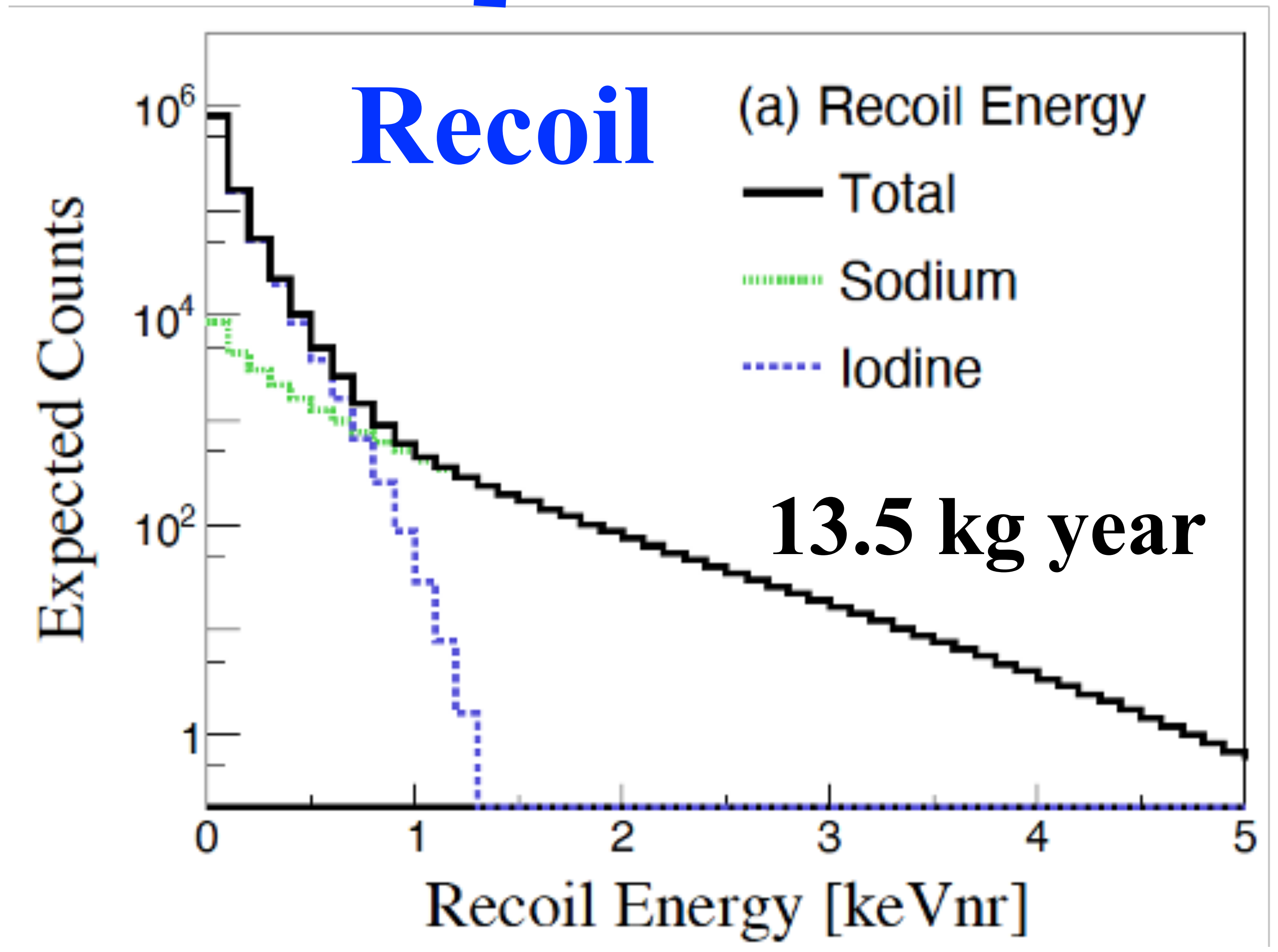

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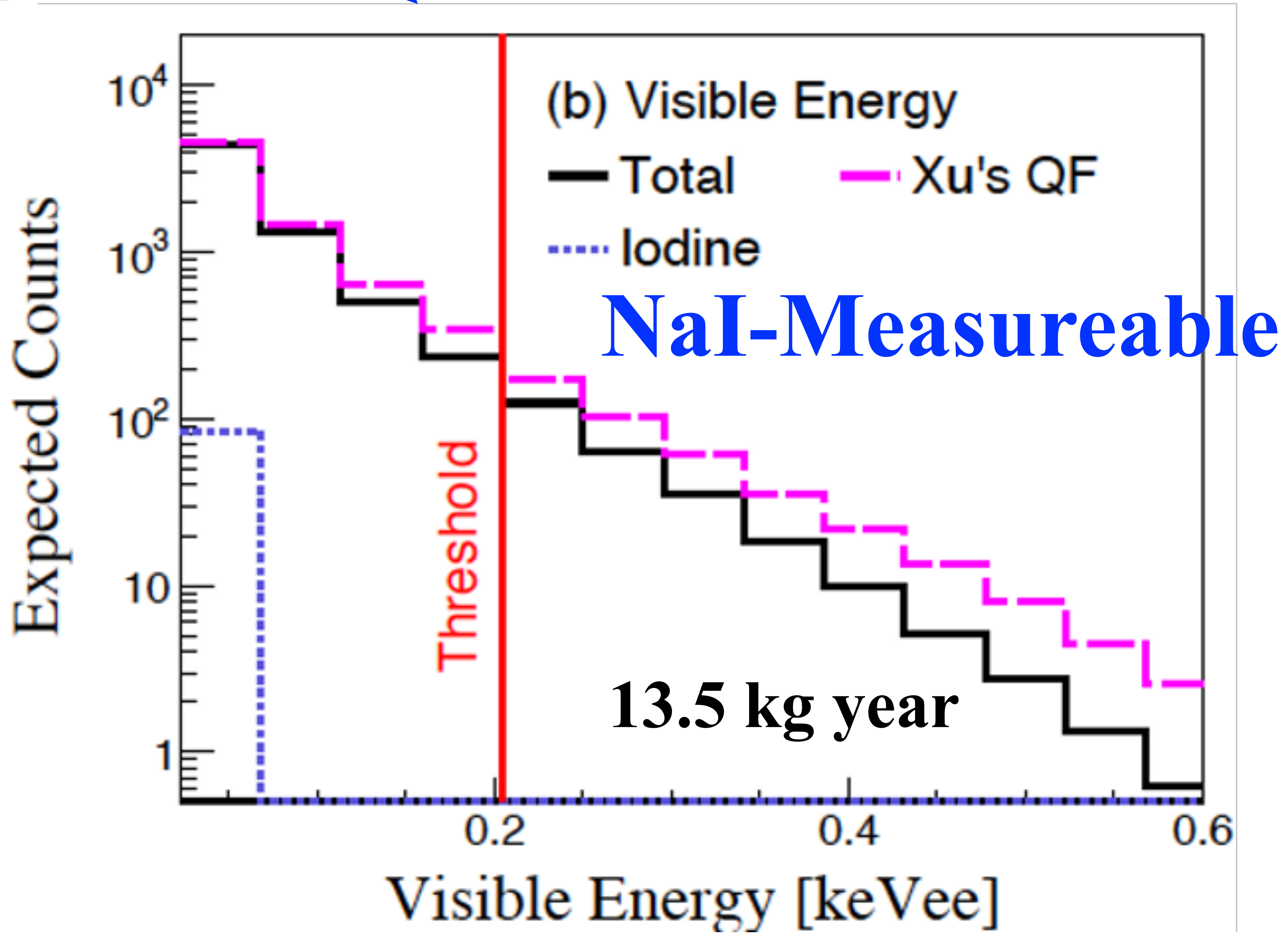
Iodine recoil scintillation negligible



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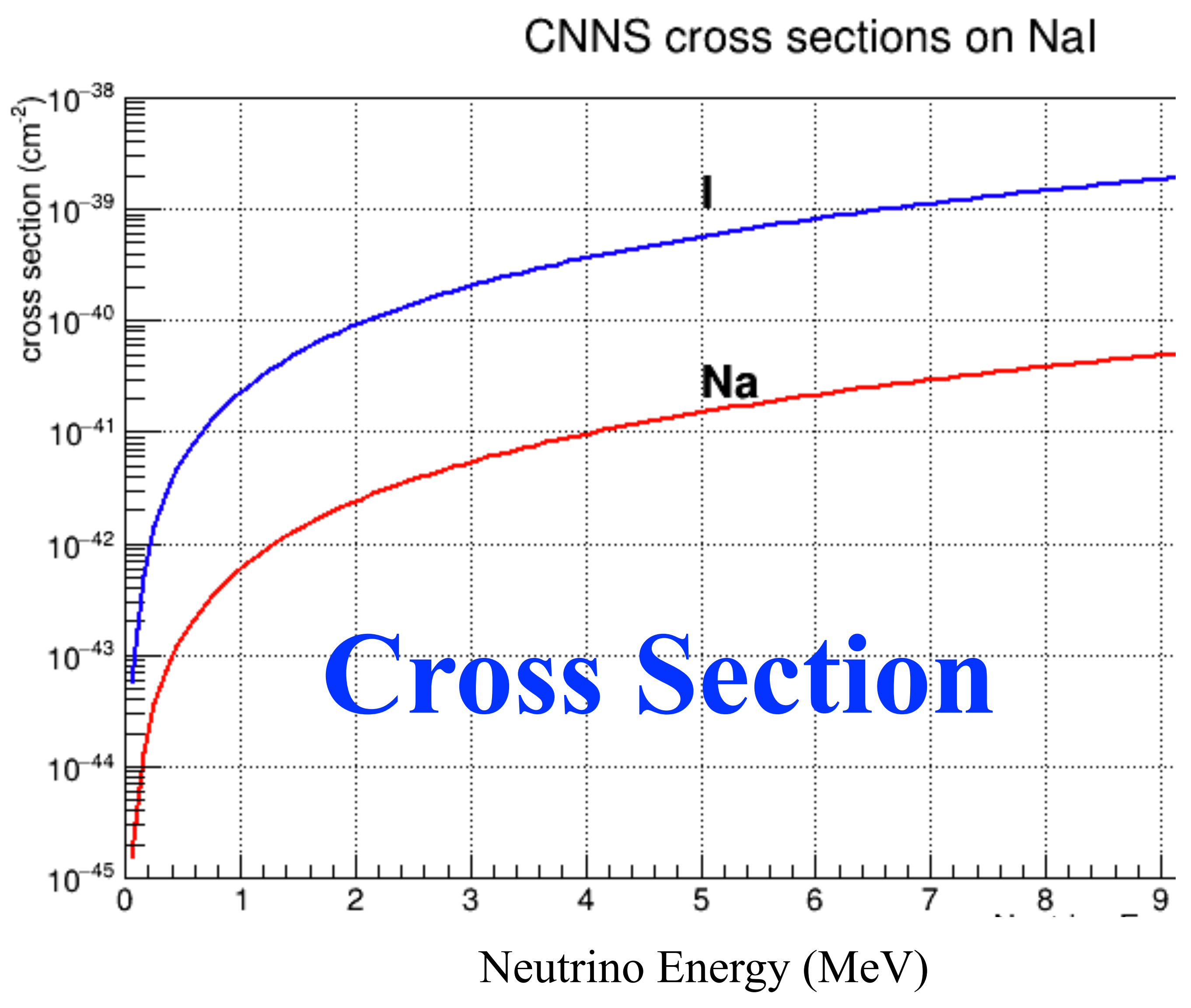

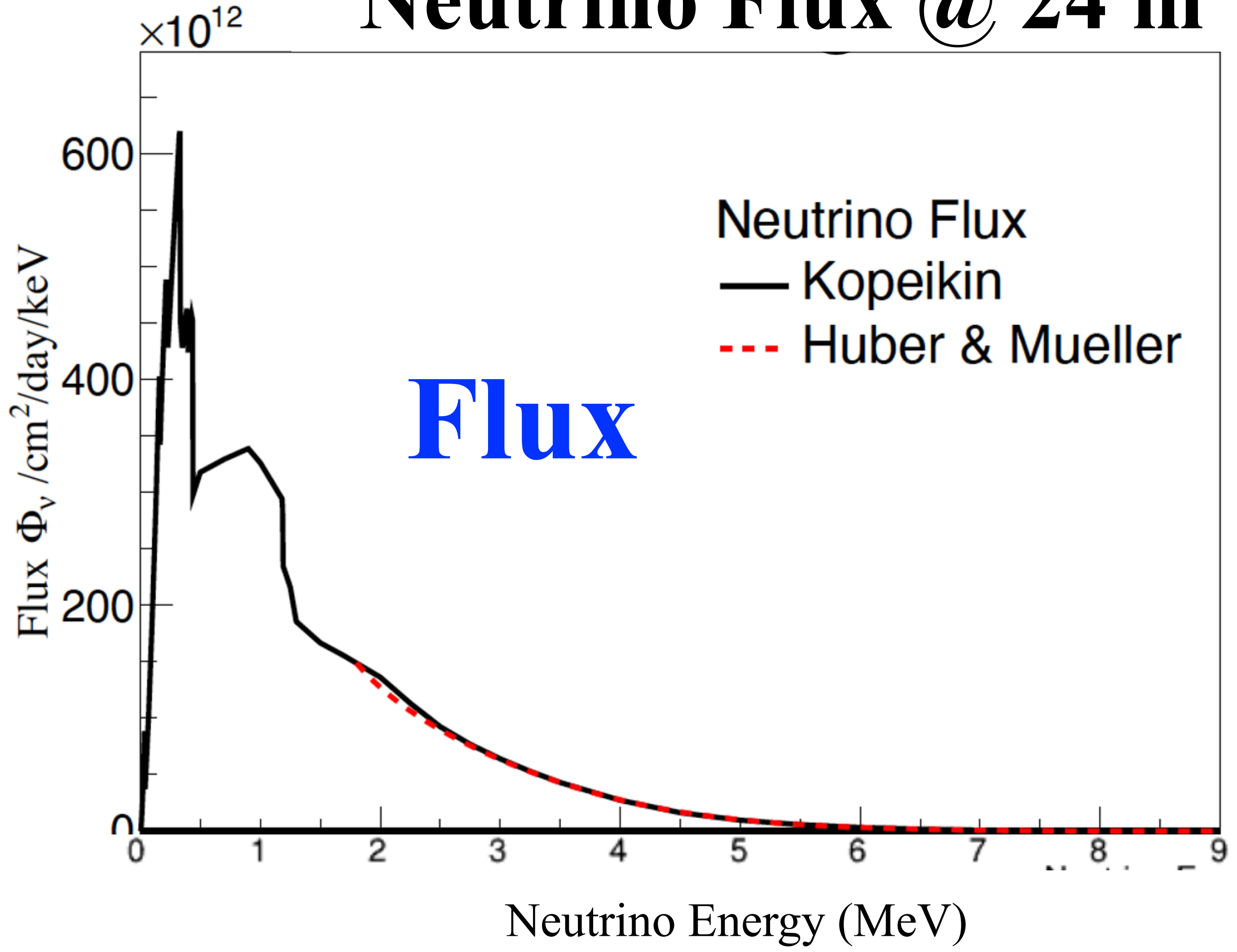

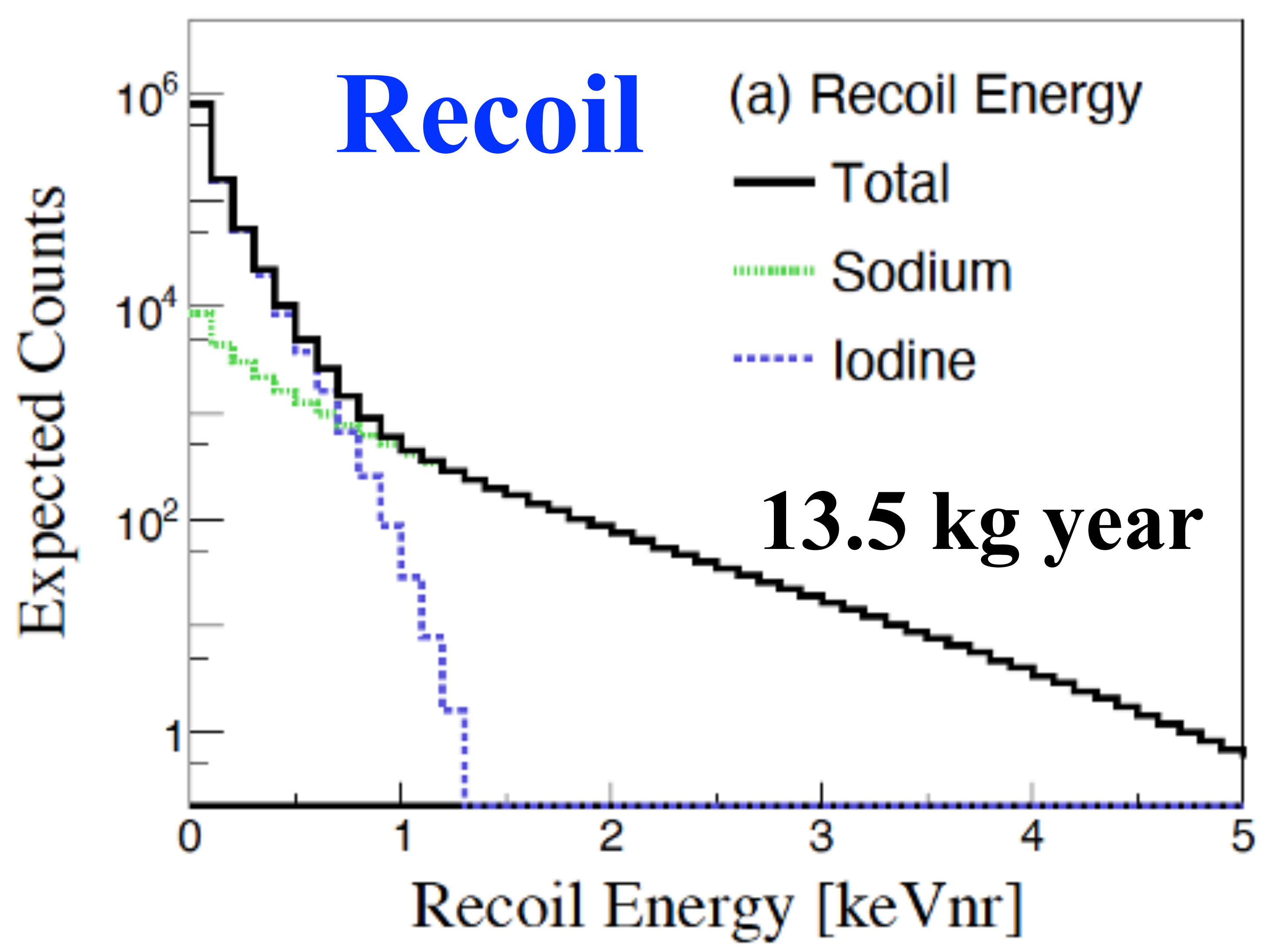

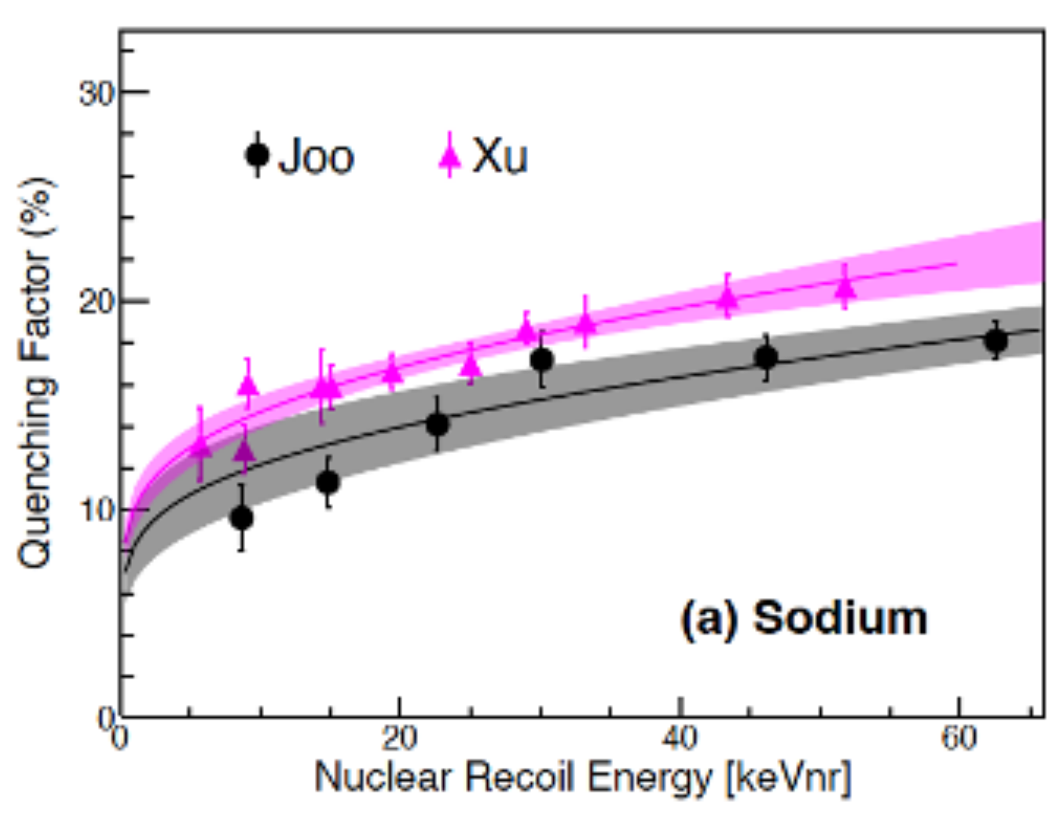

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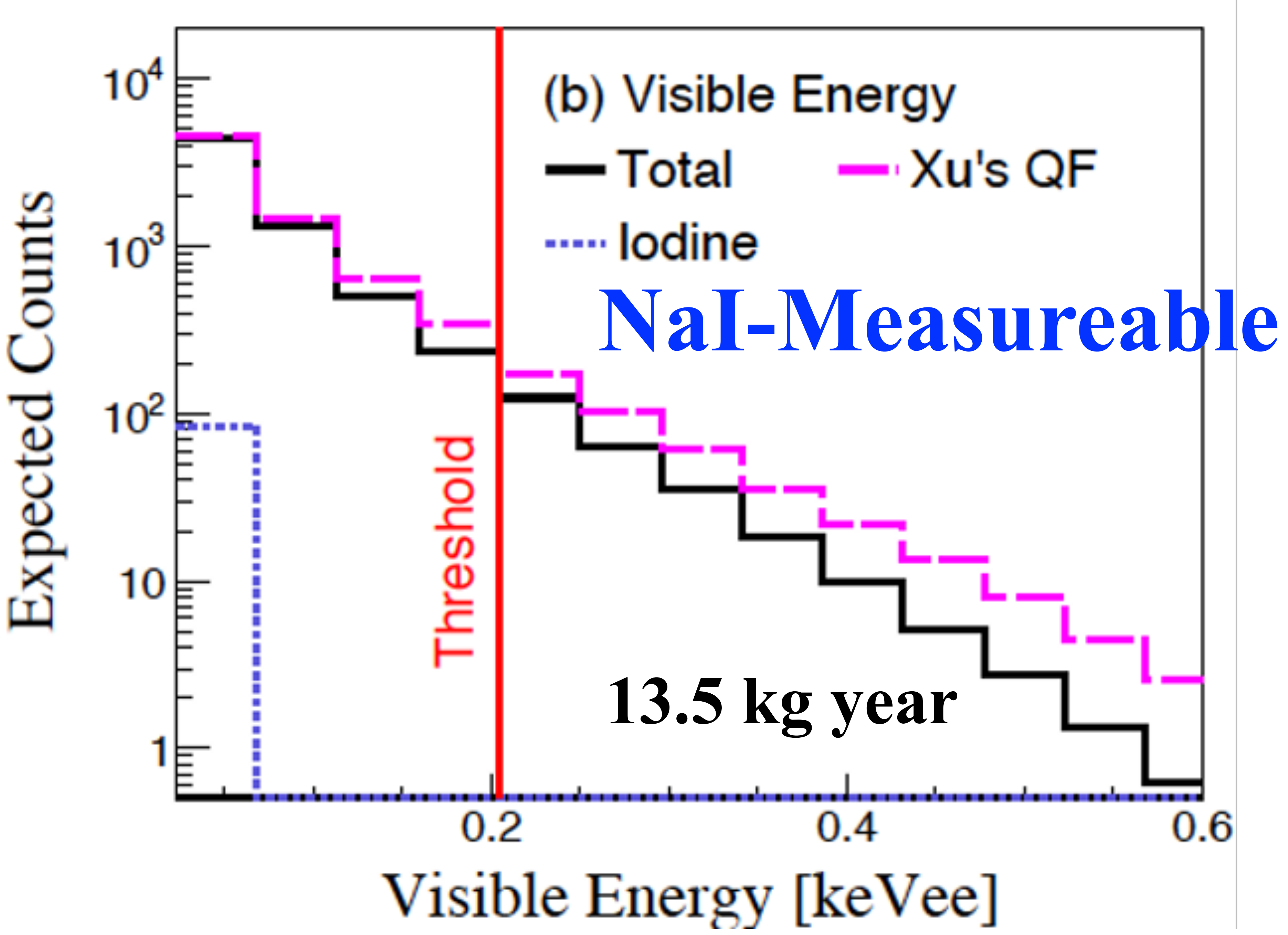

Energy Threshold & **Quenching** are two key factors

Experimental Setup and Conditions

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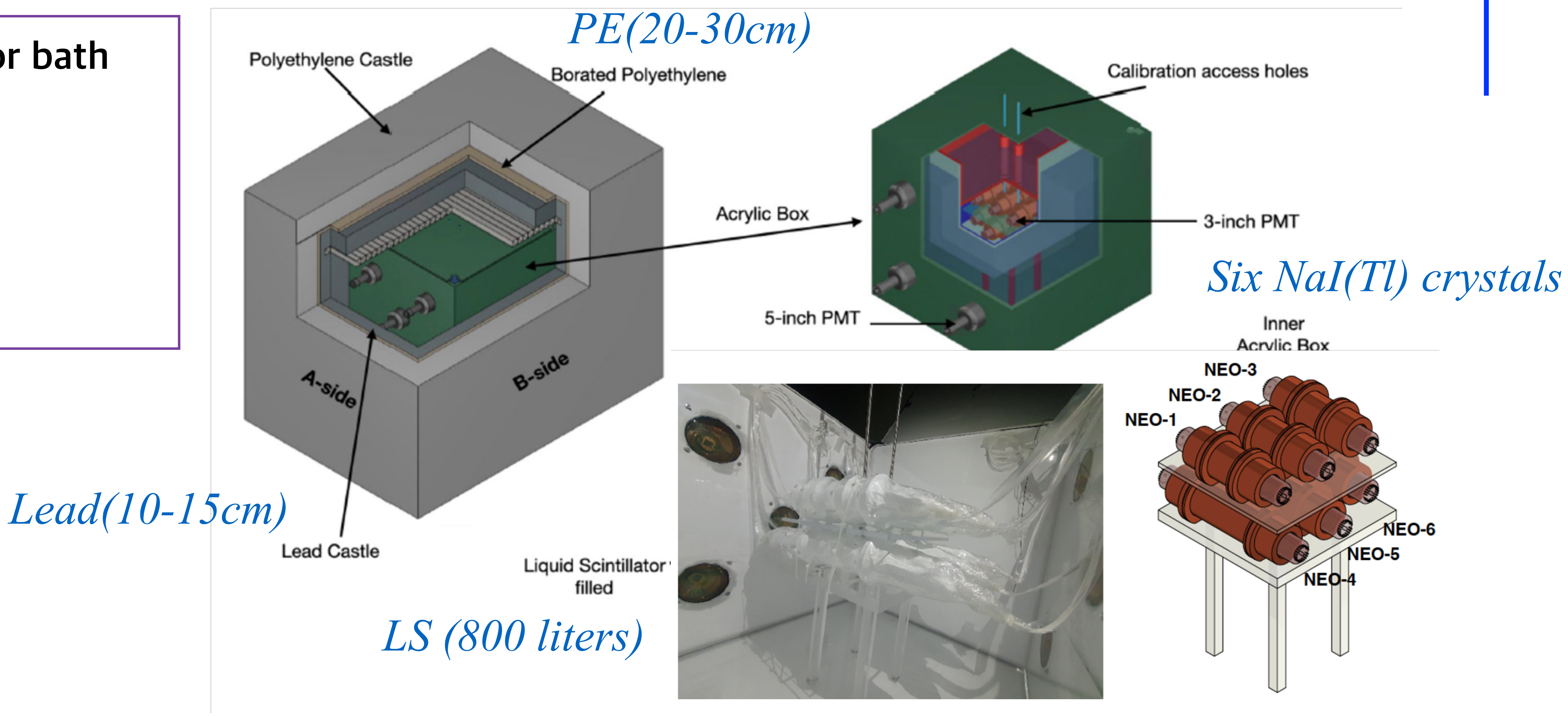
- NaI(Tl) crystals in a Liquid Scintillator bath



Experimental Setup and Conditions

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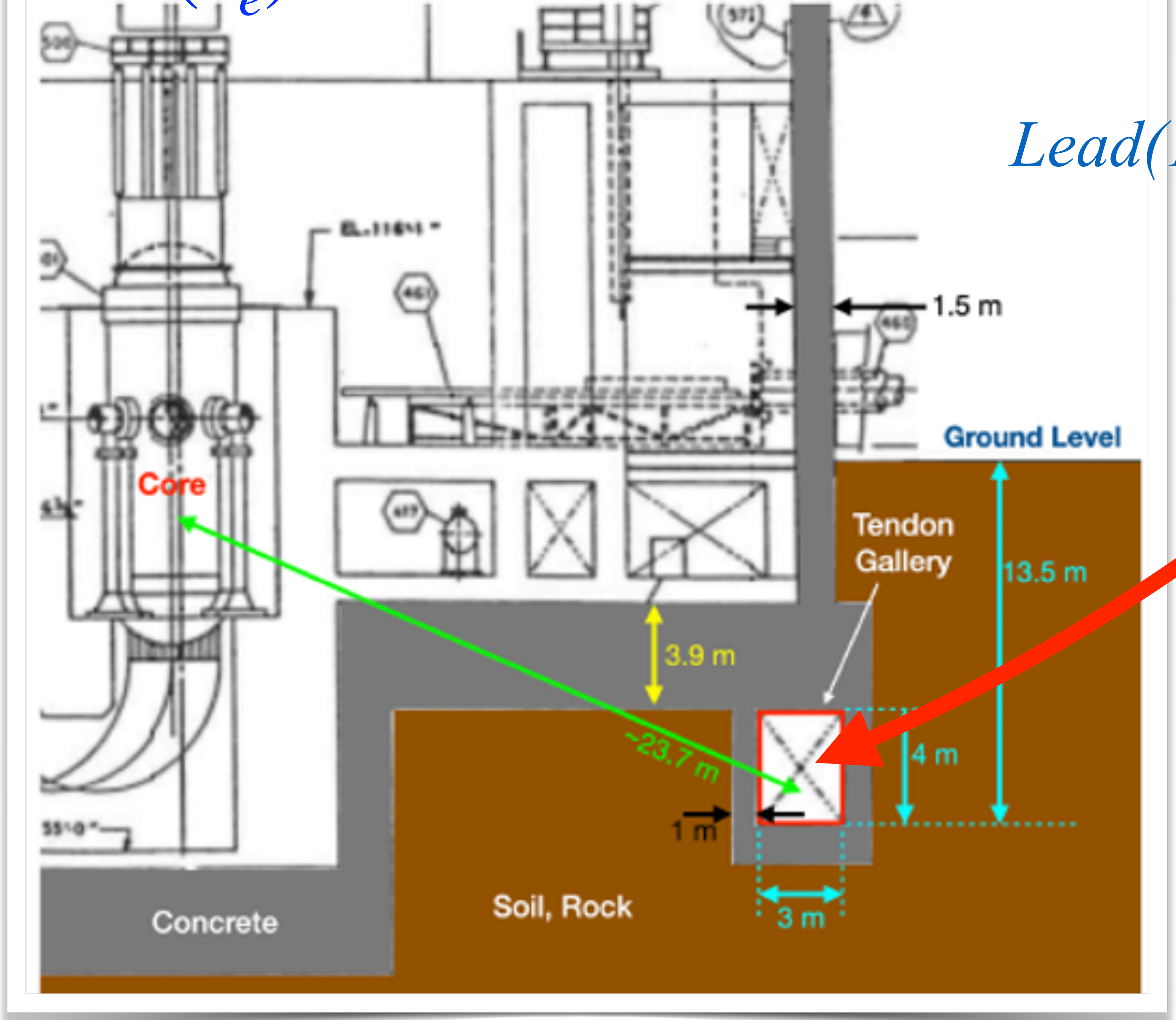
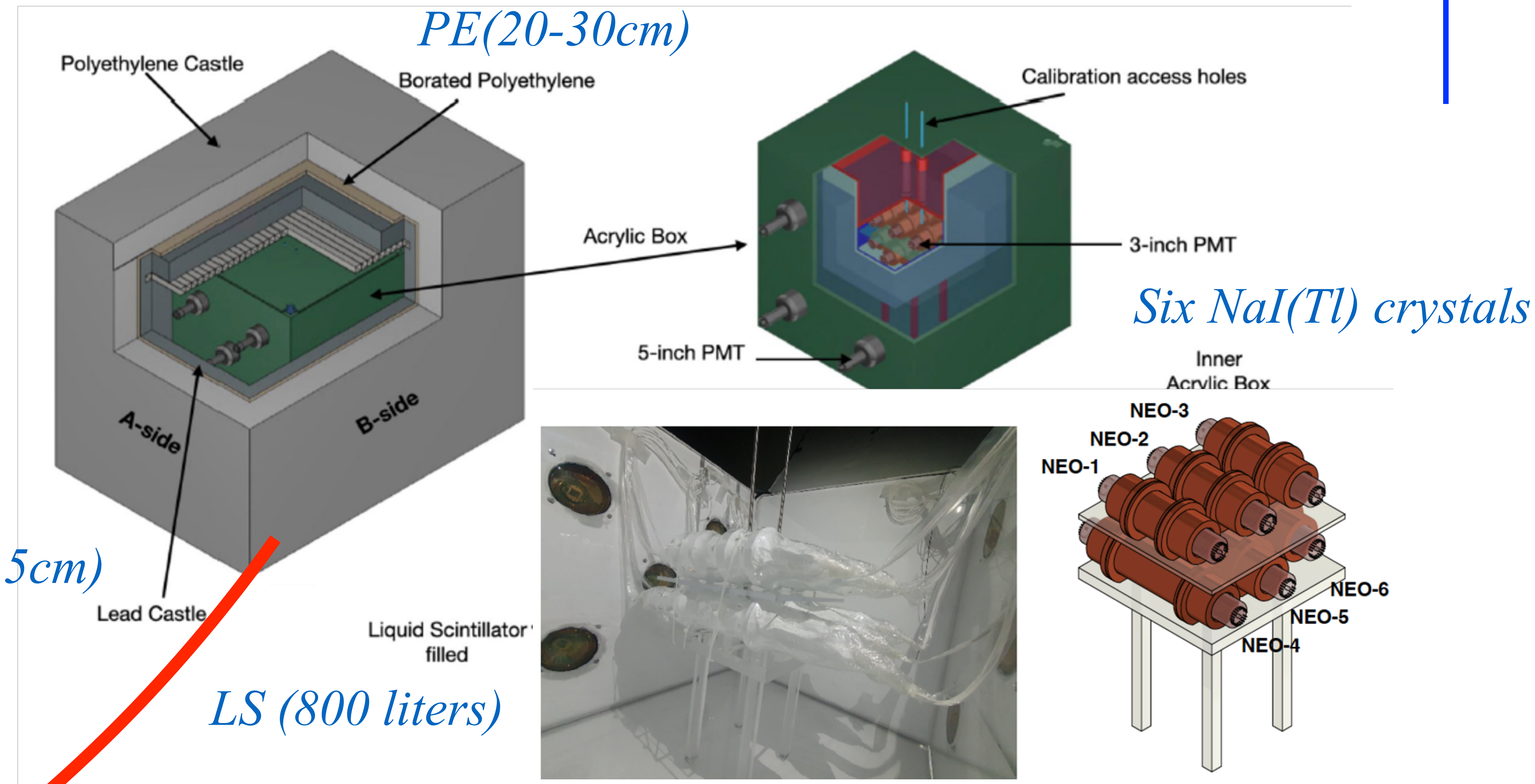
- Located at ~24 m from reactor core (Tendon)
- 10 m concrete overburden (x6 less muon flux)

$$F(\bar{\nu}_e) = 8.09 \times 10^{12}\ cm^{-2}\ sec^{-1}$$





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- NaI(Tl) crystals in a Liquid Scintillator bath
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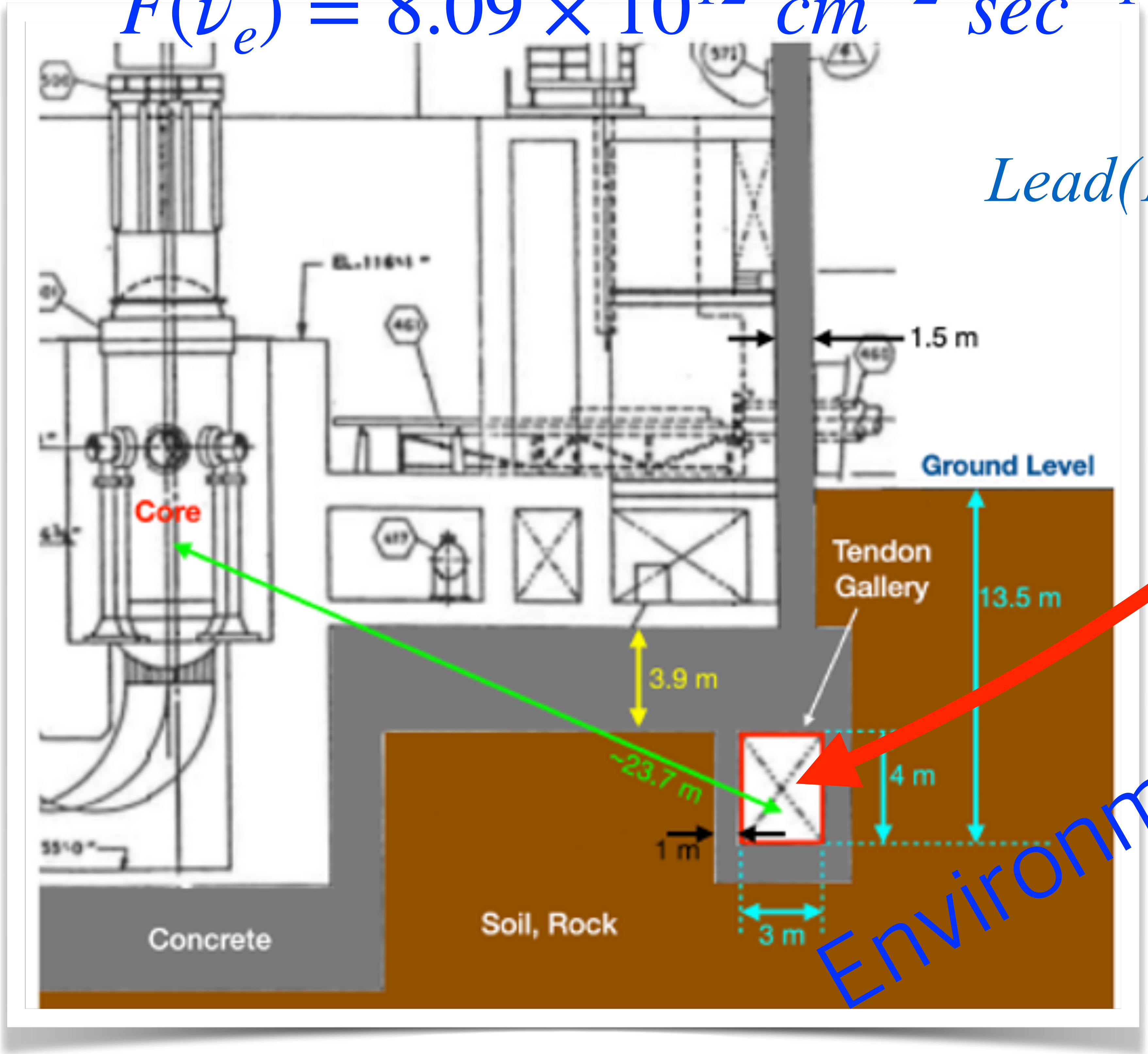
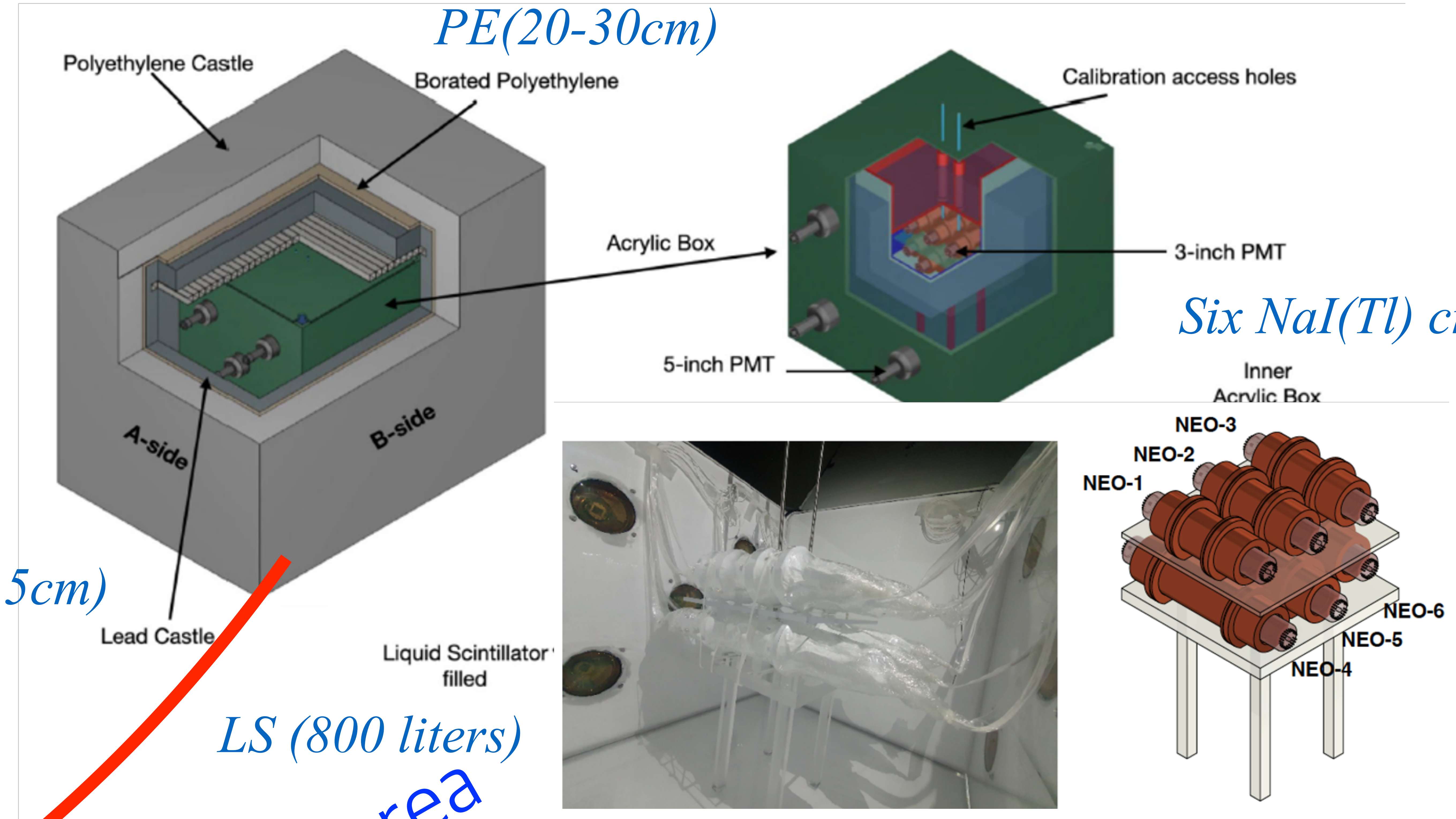
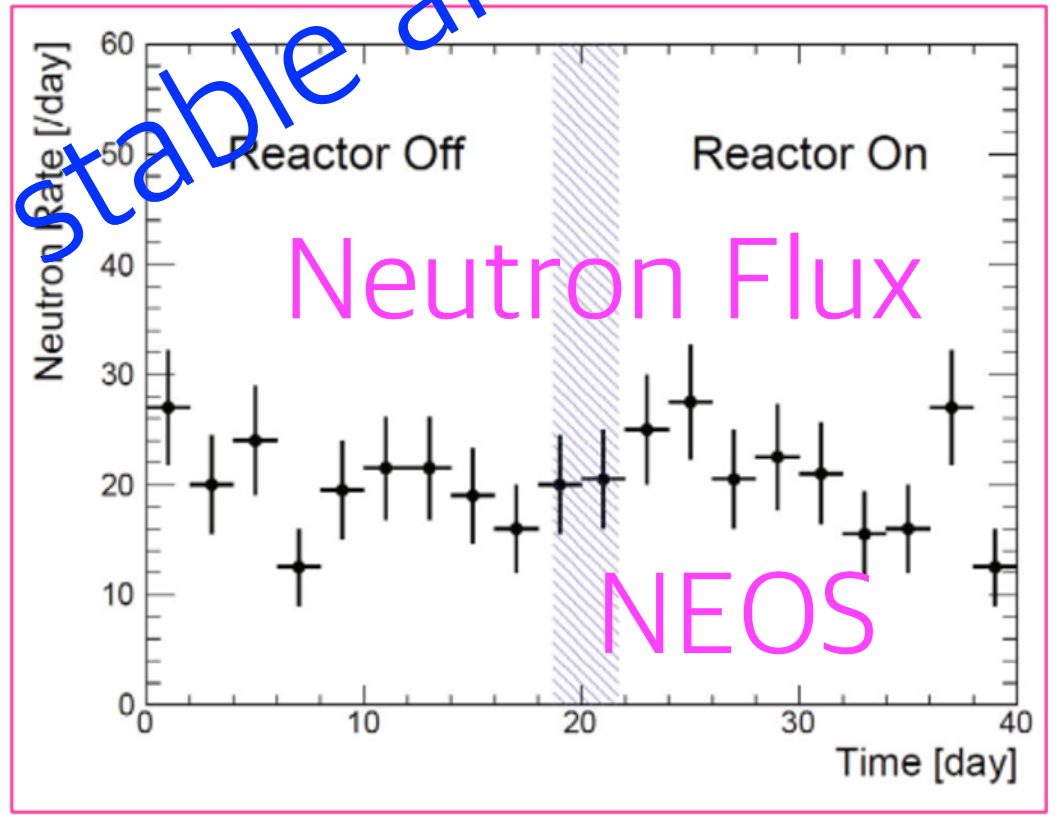
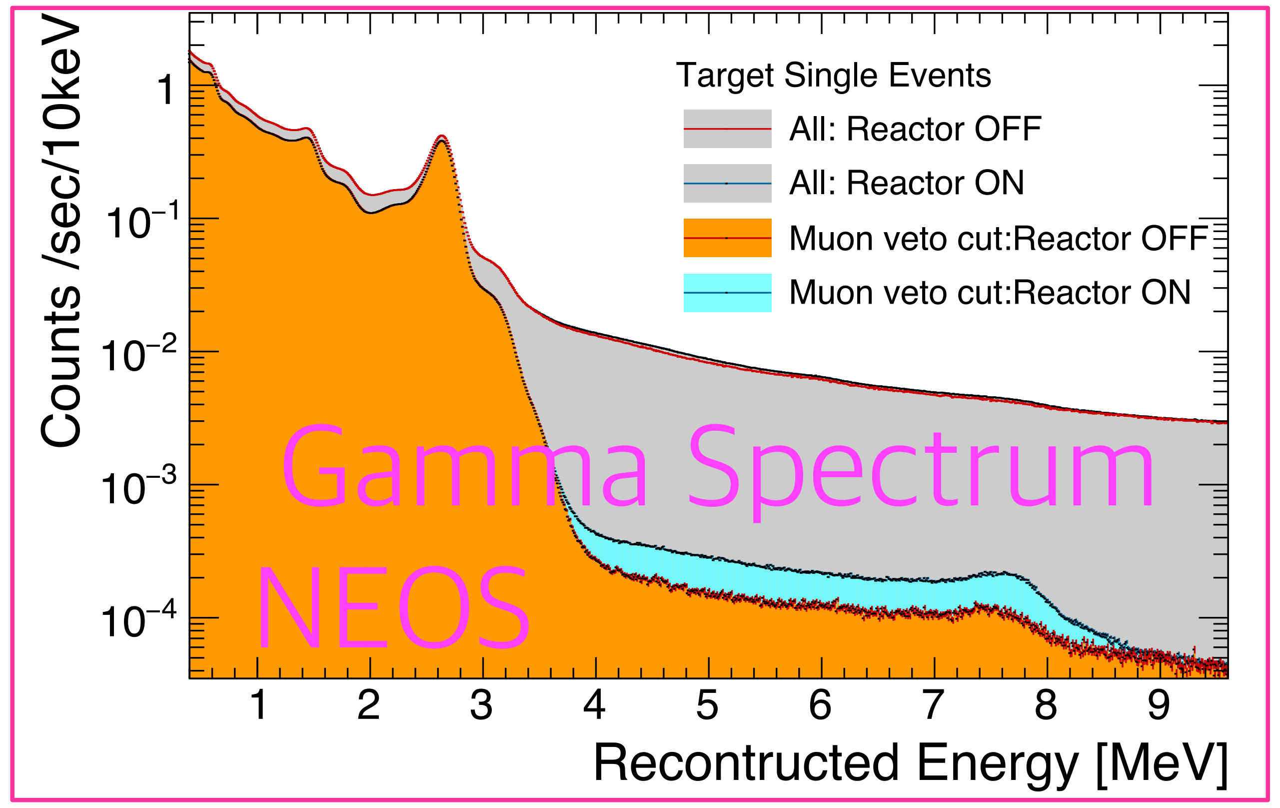
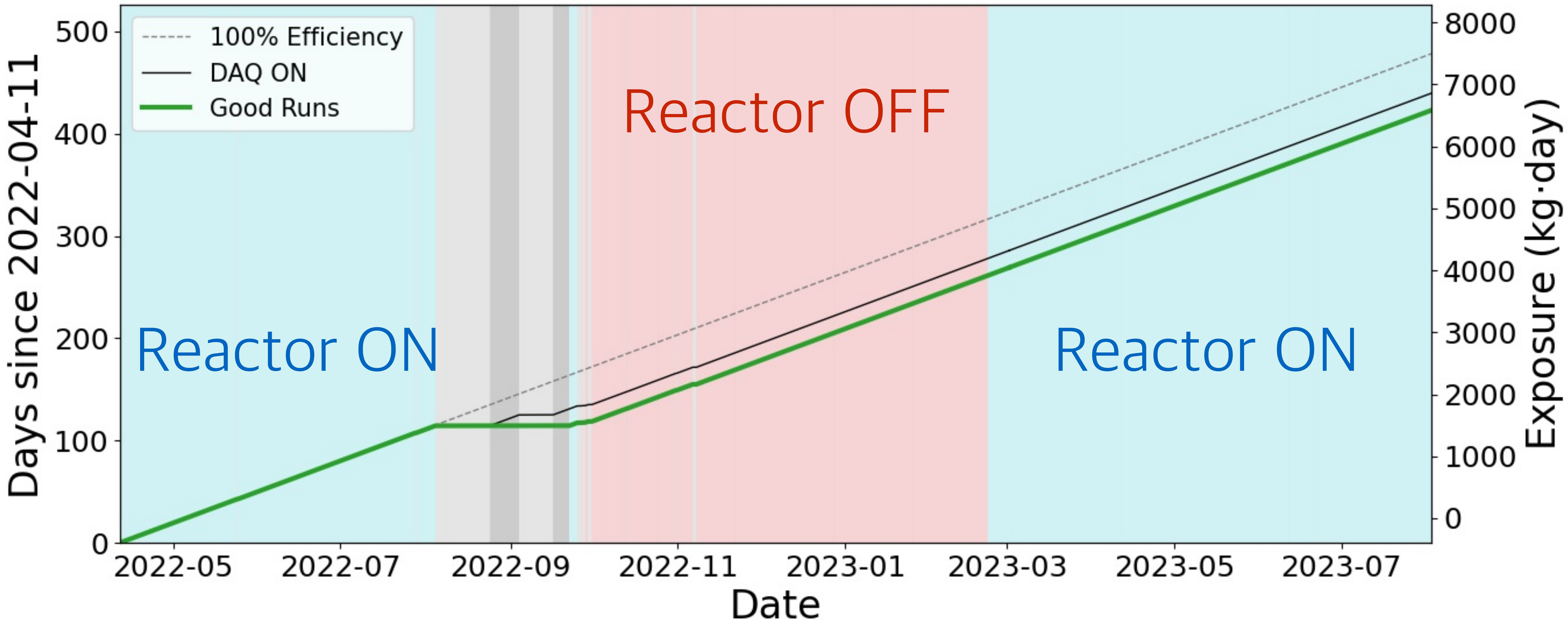


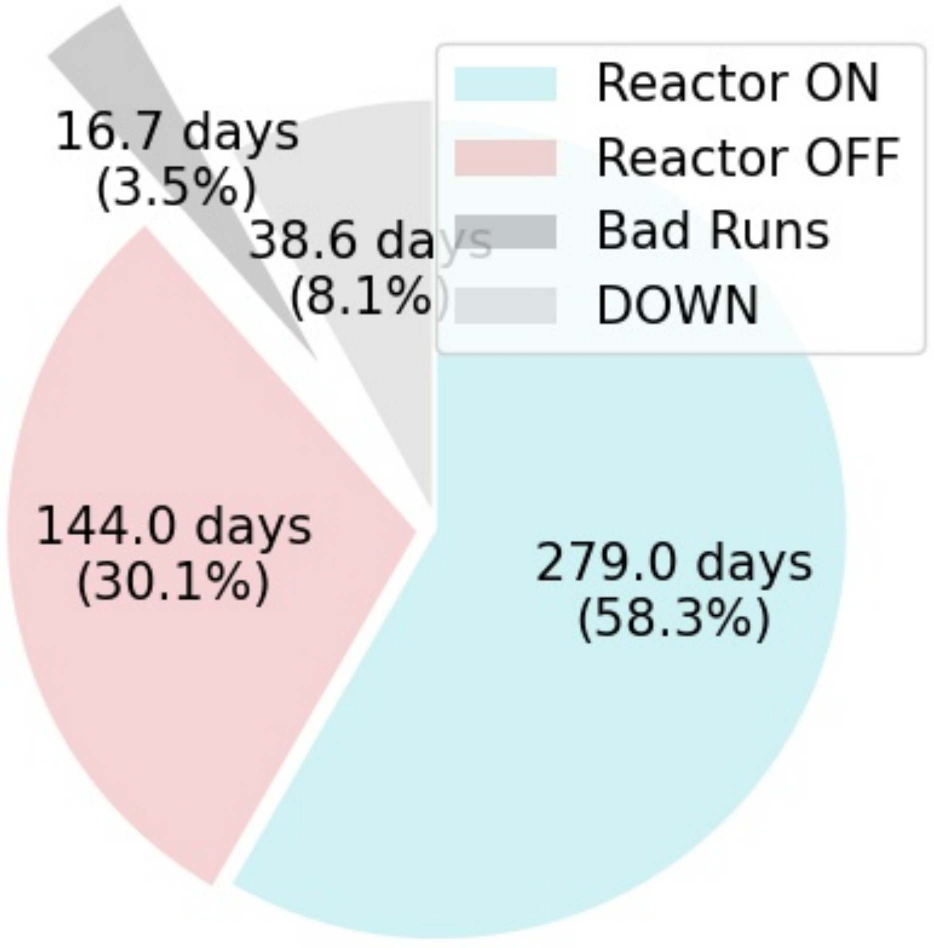






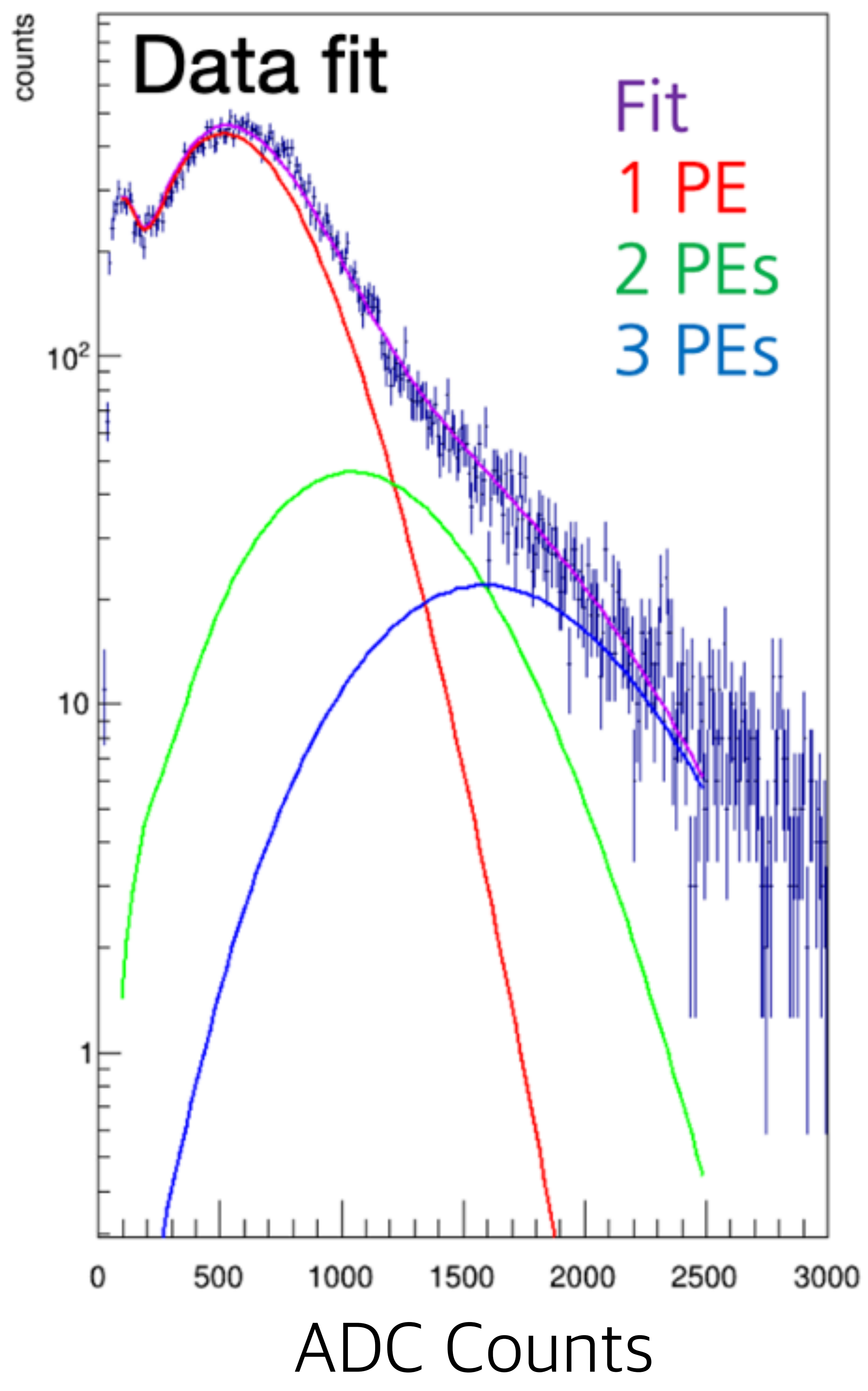
NEON Data Collection and Operations

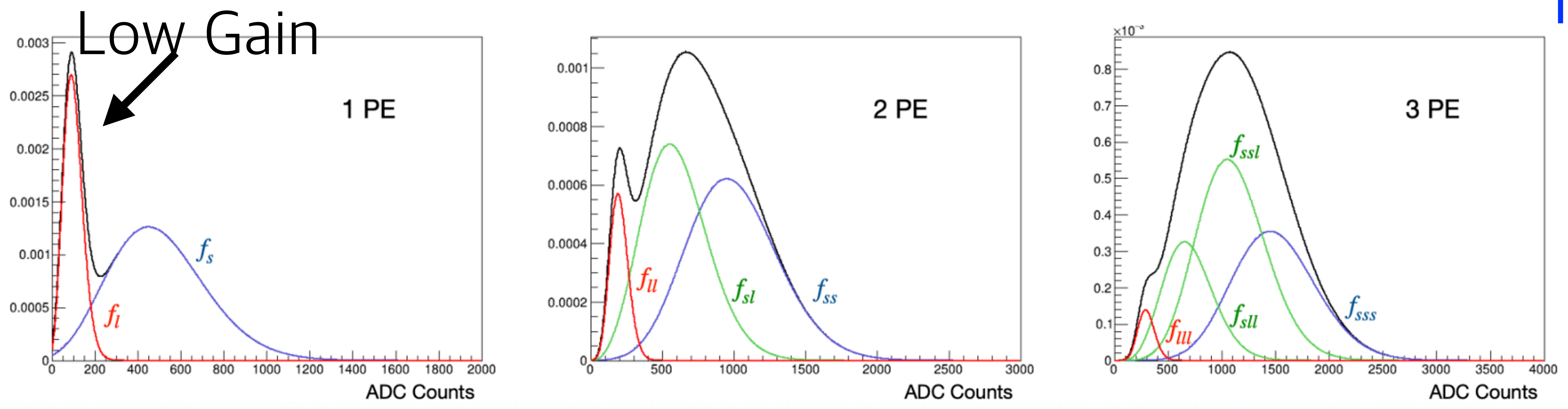


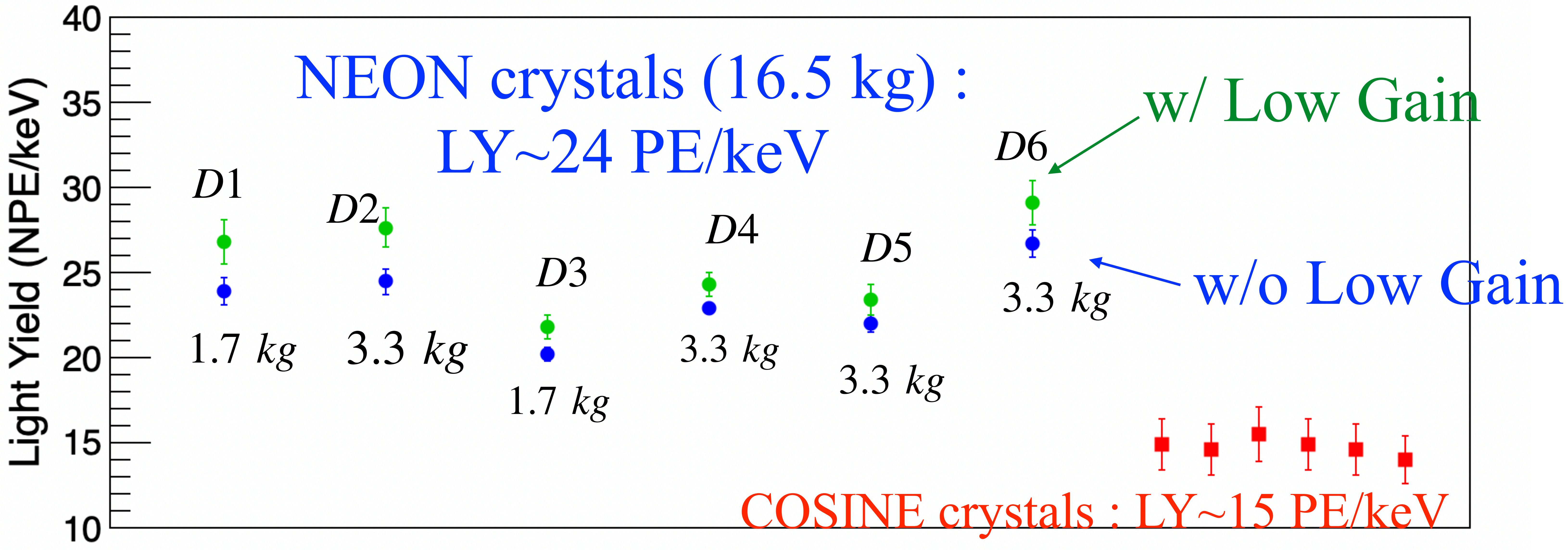


- Physics run started since April 2022 (~1.3 years) with 88% DAQ efficiency.
- 279 days of ON data (58%) & 144 days of OFF data (30%) : 6500 kg day exposure

NEON crystal light yields







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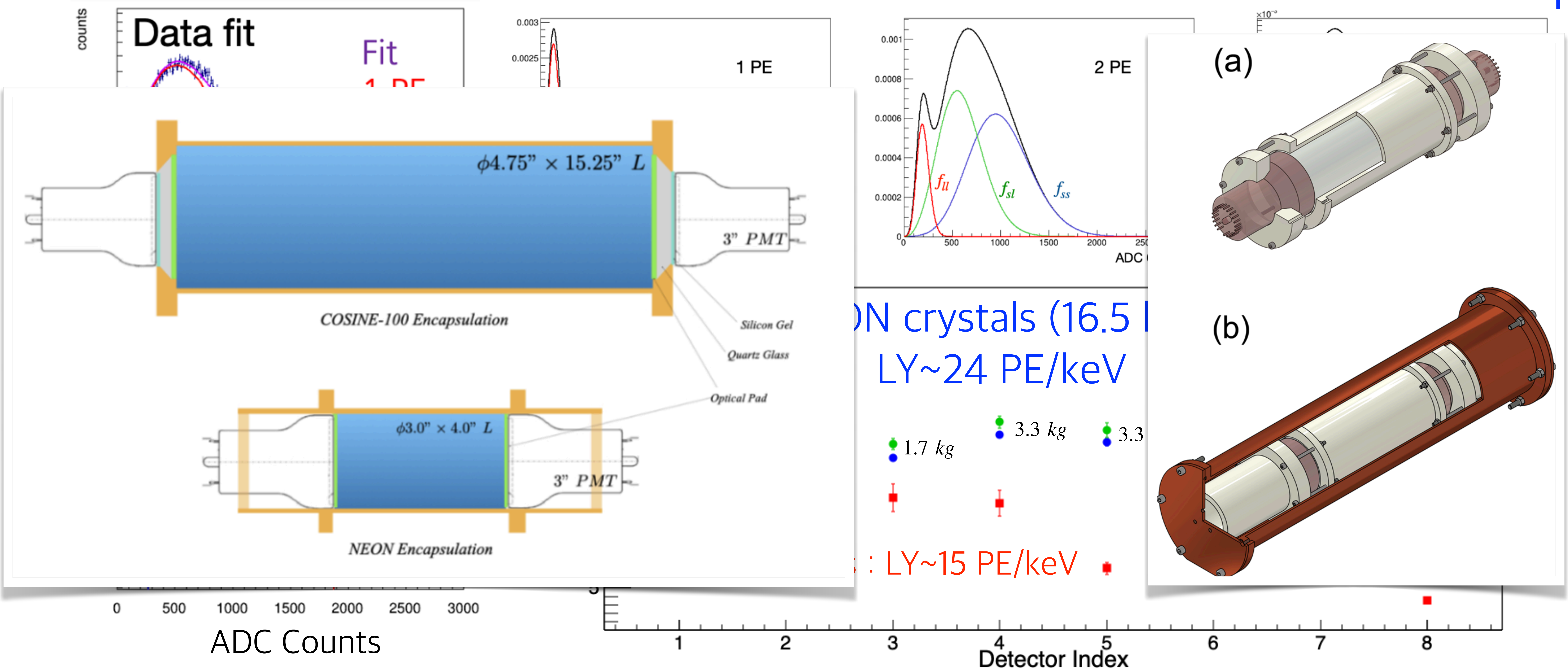

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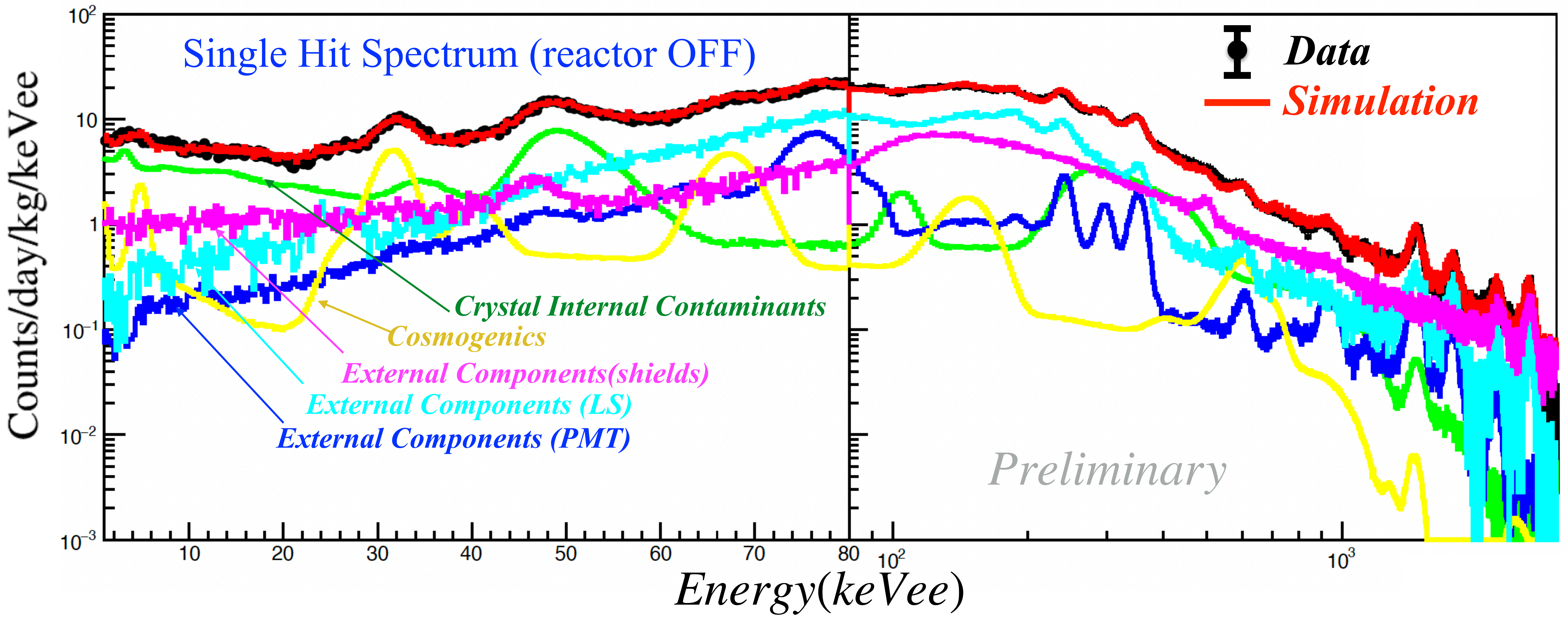
Background Understanding



- Background Modeling is actively on-going up to 3 MeV.
- Single hit low energy at 1~10 keV region : ~ 7 counts/day/kg/keV
- Composition : internal ~60%, cosmogenic~20%, external~20%, muon phosphor~1%

Waveform Simulation and Validations

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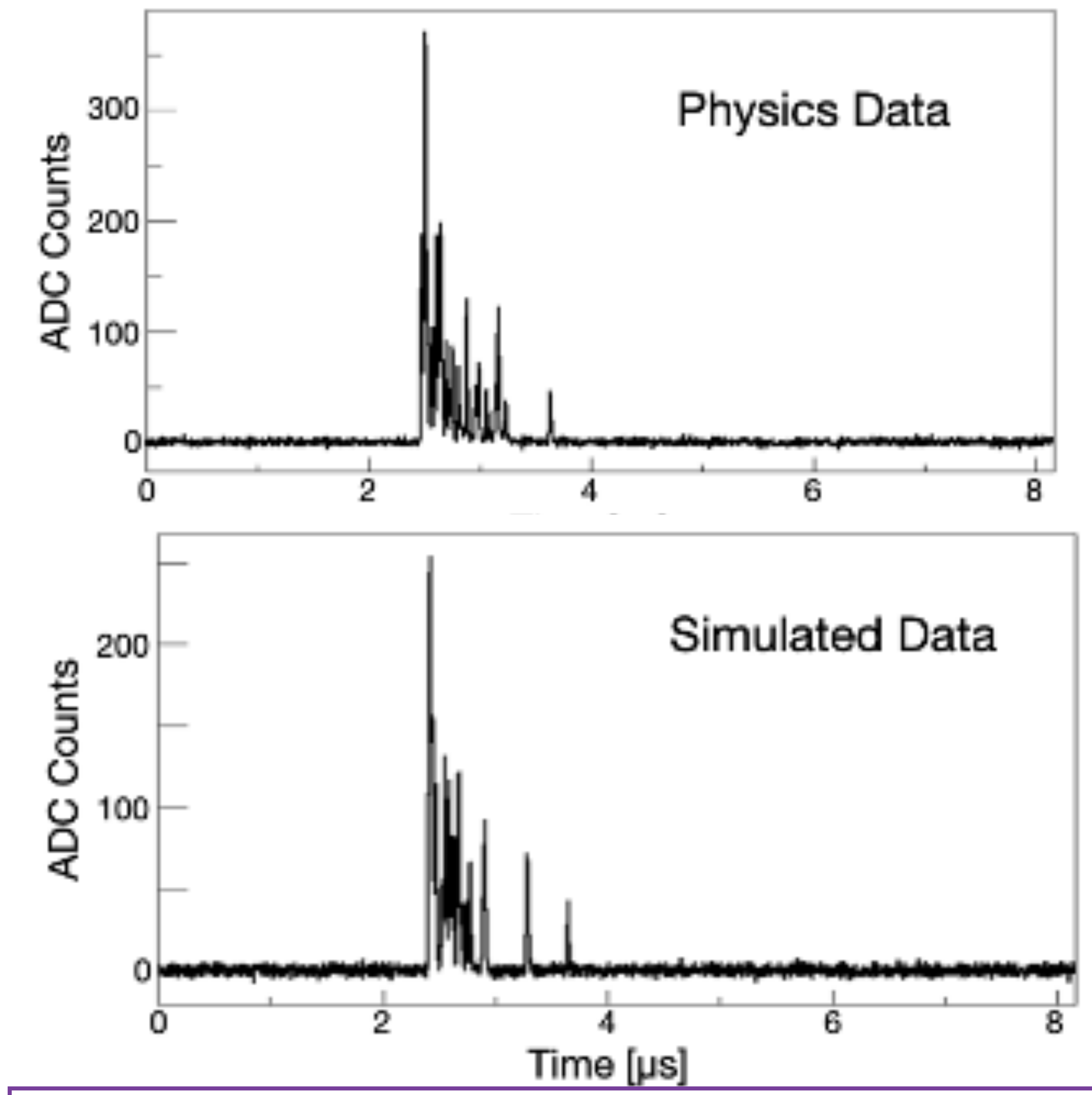

- Waveform simulation is developed to characterize the keV~sub keV scintillation signals.
- Simulation generates raw waveforms as same as the real data

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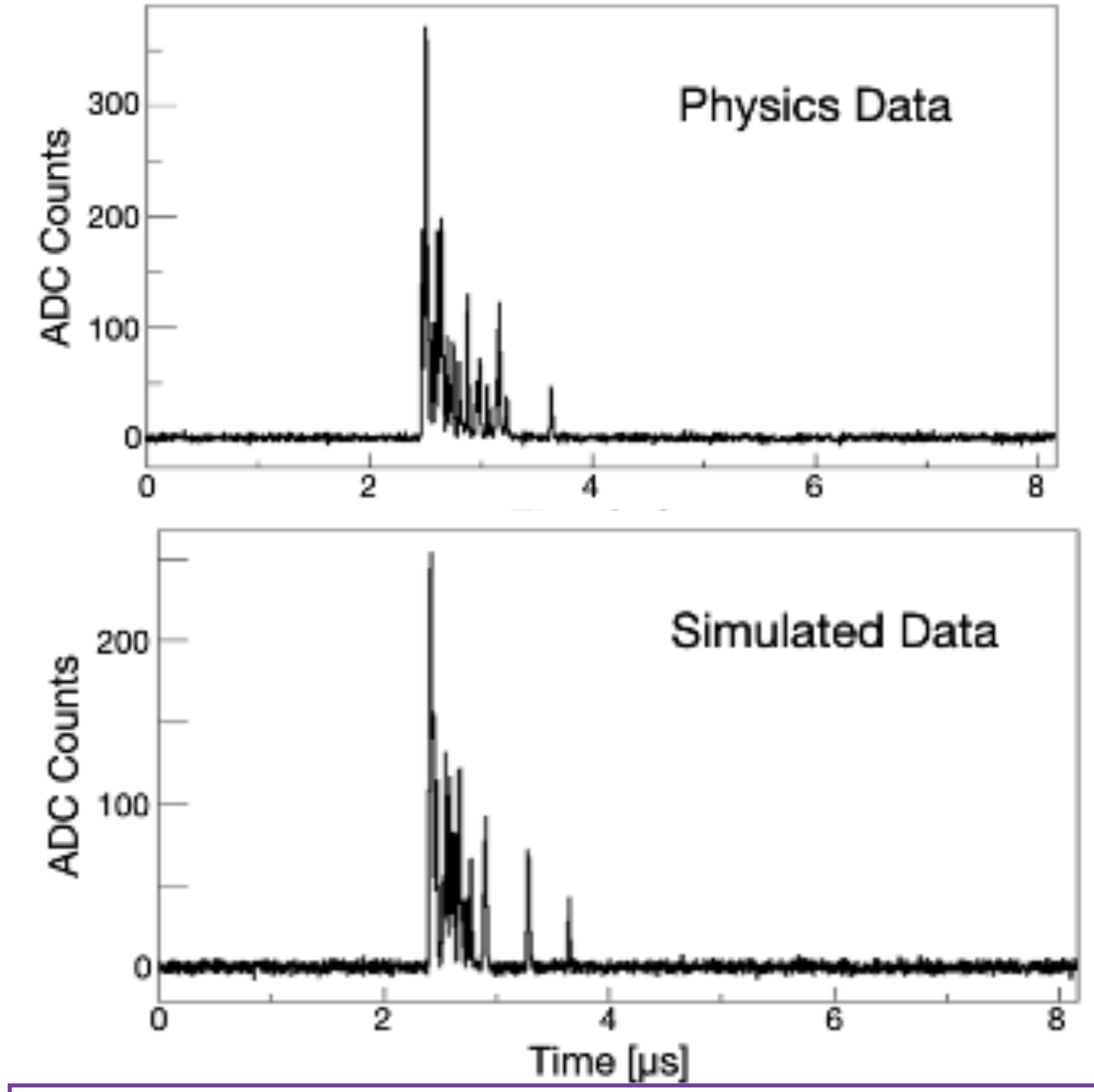

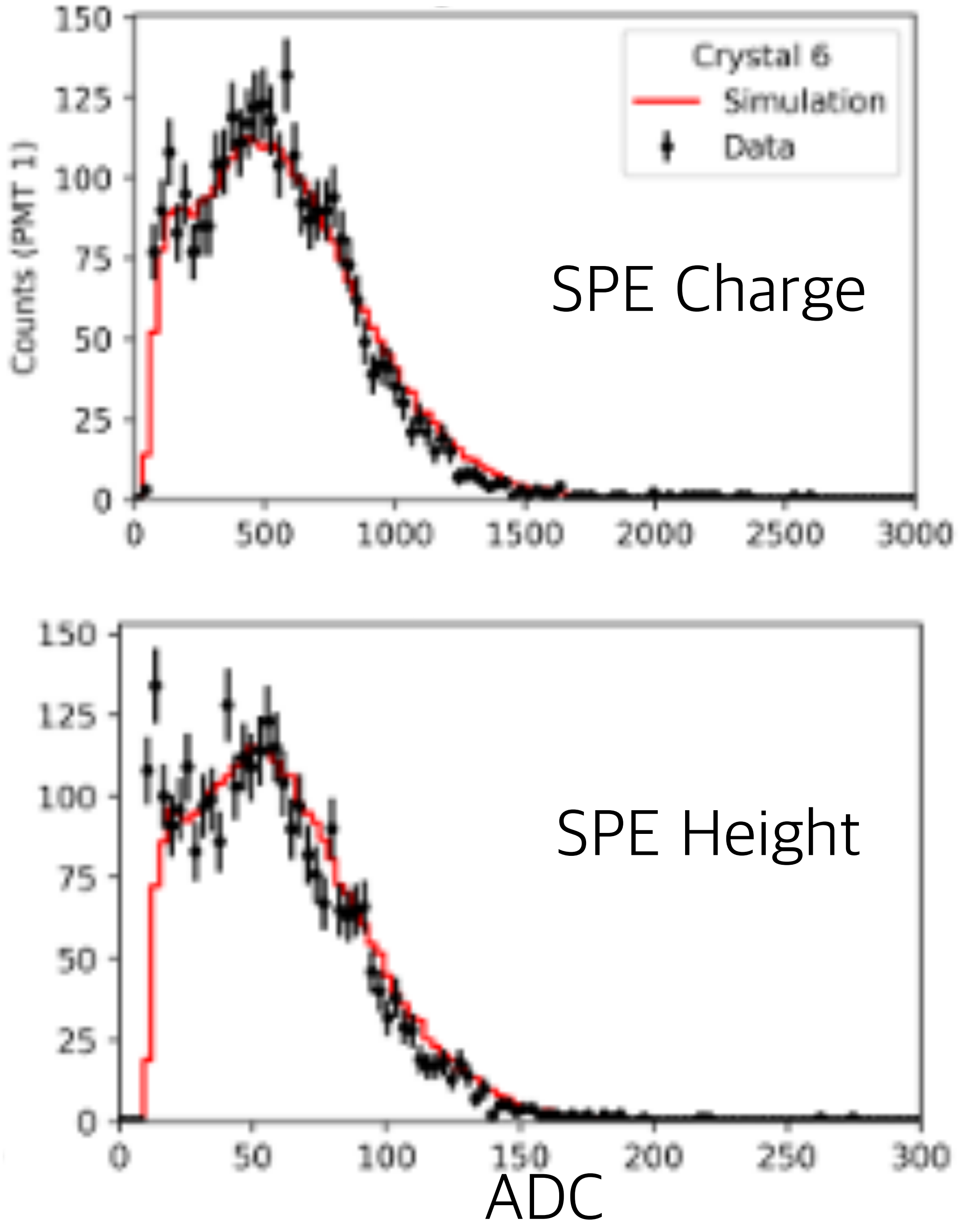

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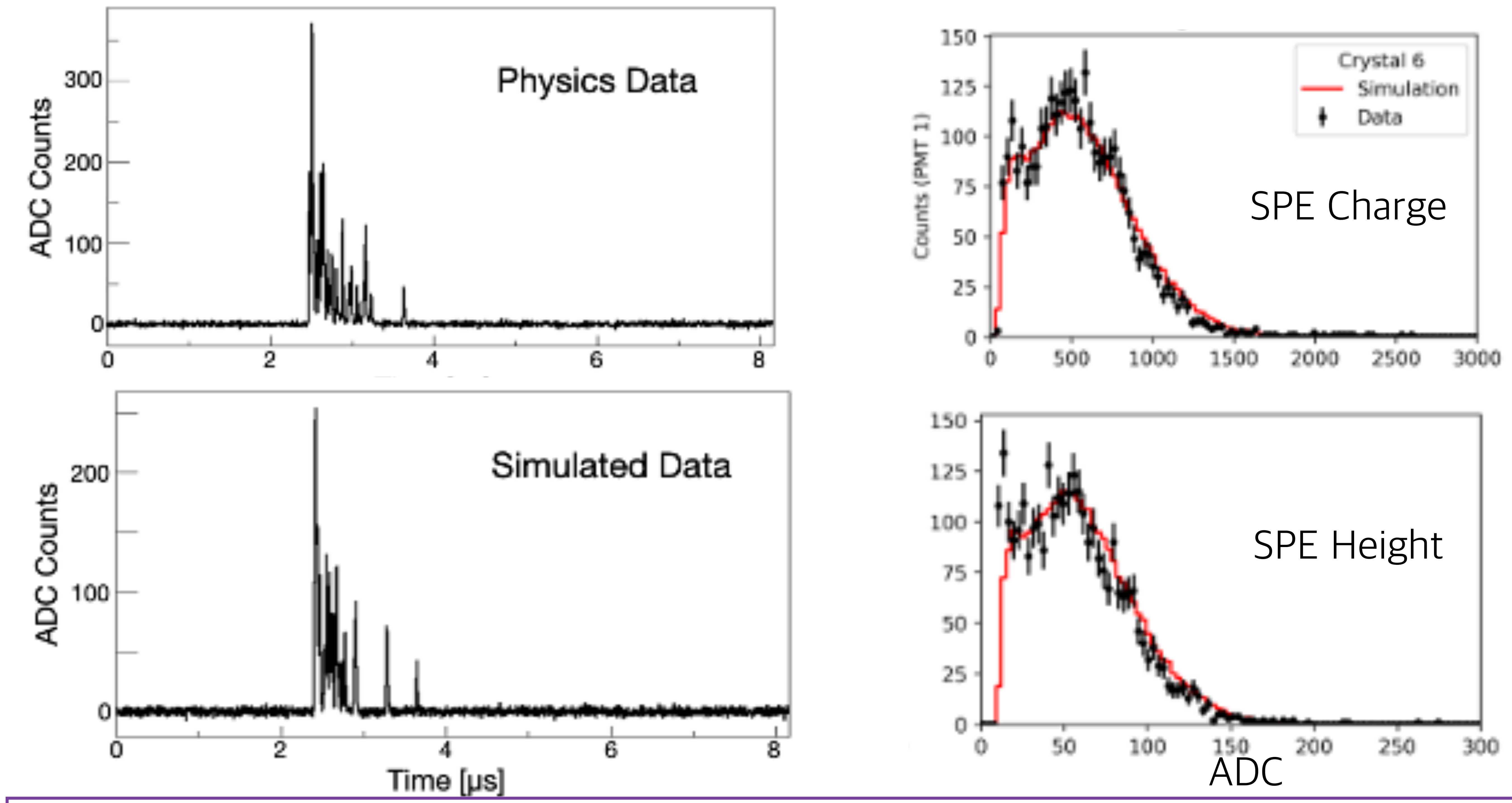
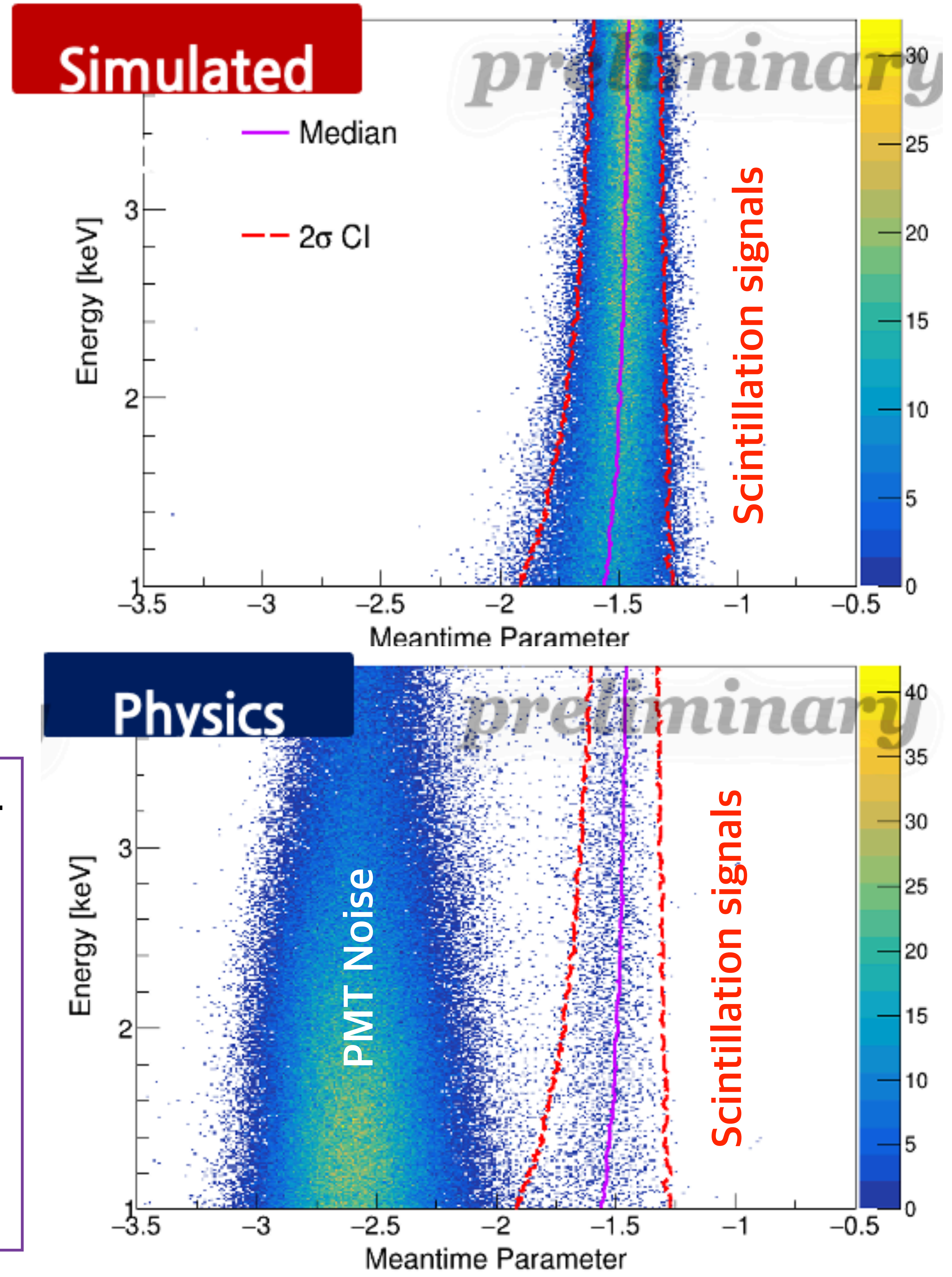
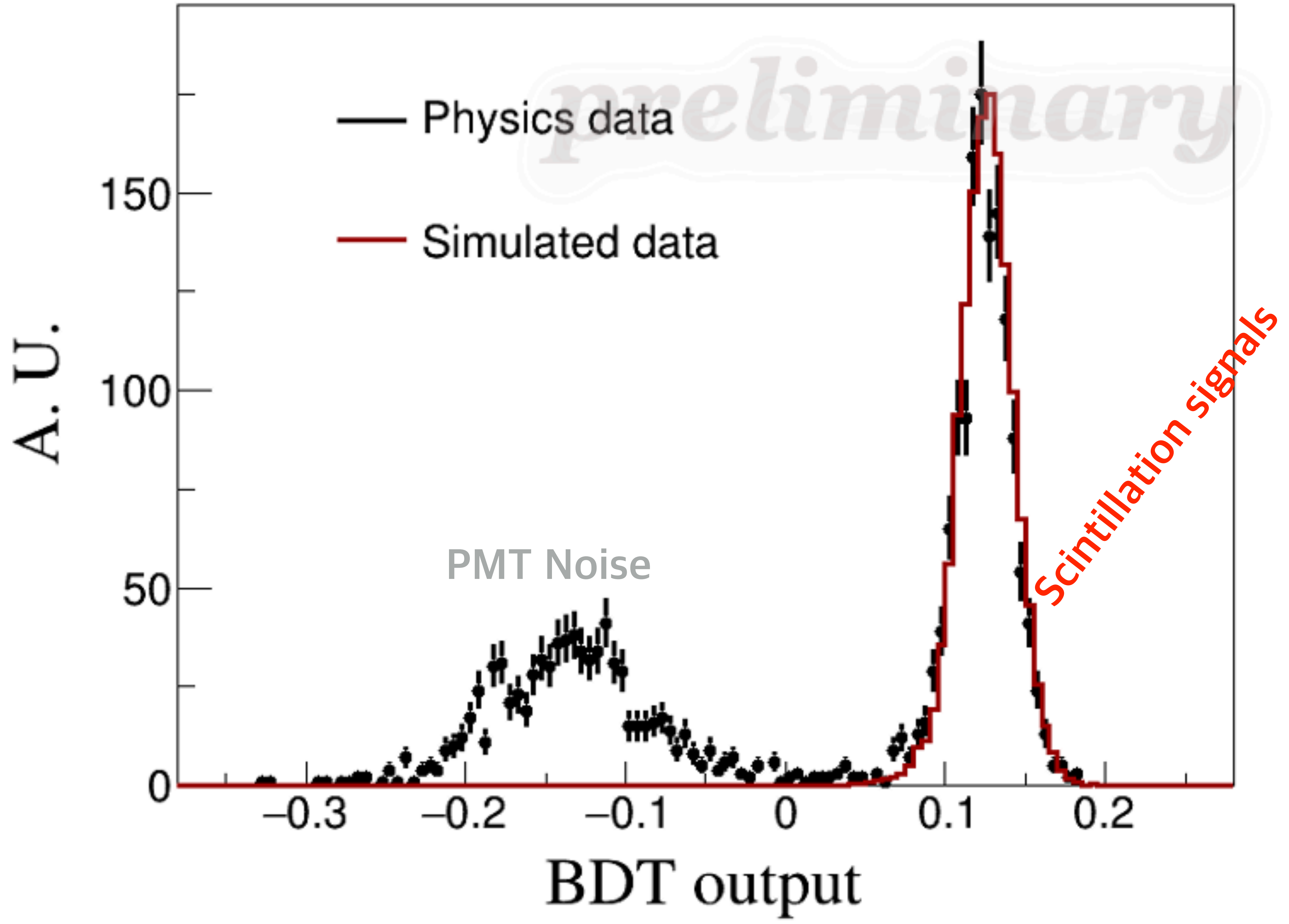


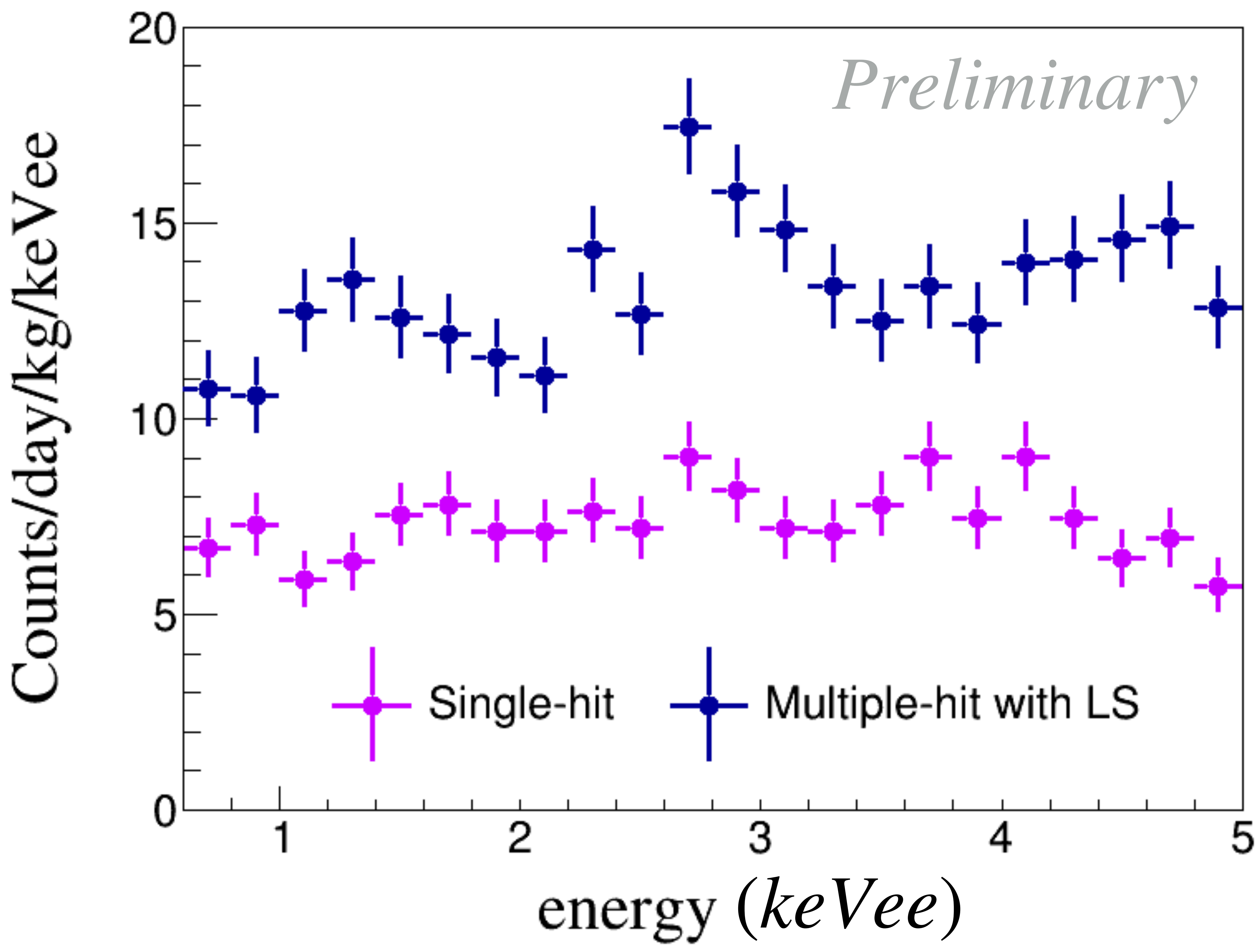


- Waveform simulation is developed to characterize the keV~sub keV scintillation signals.
- Simulation generates raw waveforms as same as the real data
- SPE parameters are tuned to match the real data
- Simulation and real data for the physics variables agree very well (within a few percent level).
- Low energy simulation signals are used for high level variables e.g. Boosted Decision Tree (BDT) score calculation.

Low Energy Spectrum

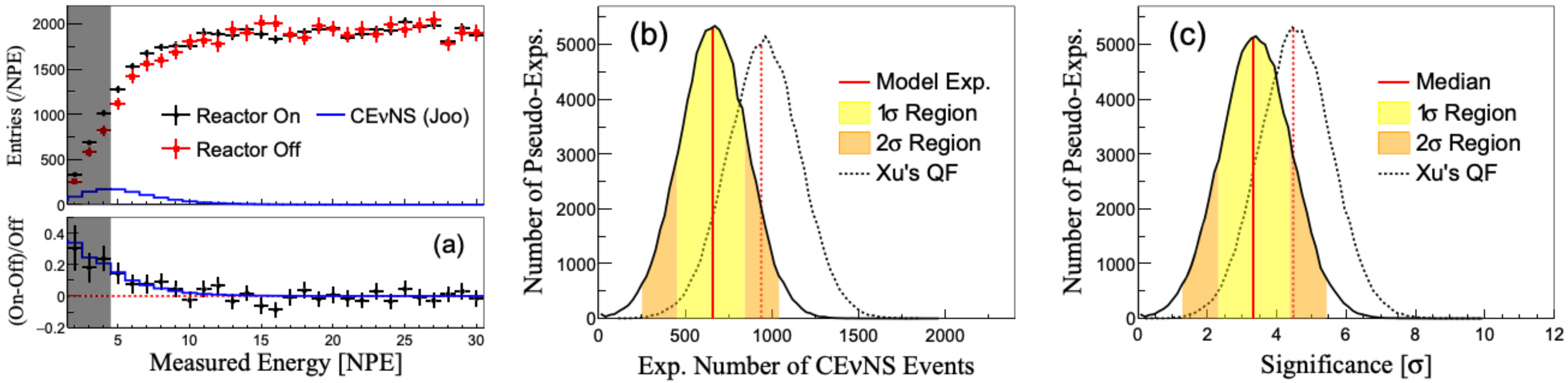
Event selection is done with a series of BDT output variables characterizing different types of PMT noises





With the current algorithms, a threshold of 0.6 keVee with 7 counts/day/kg/keVee is achieved after BDT event selections

Expected Rate and Sensitivity for NEON



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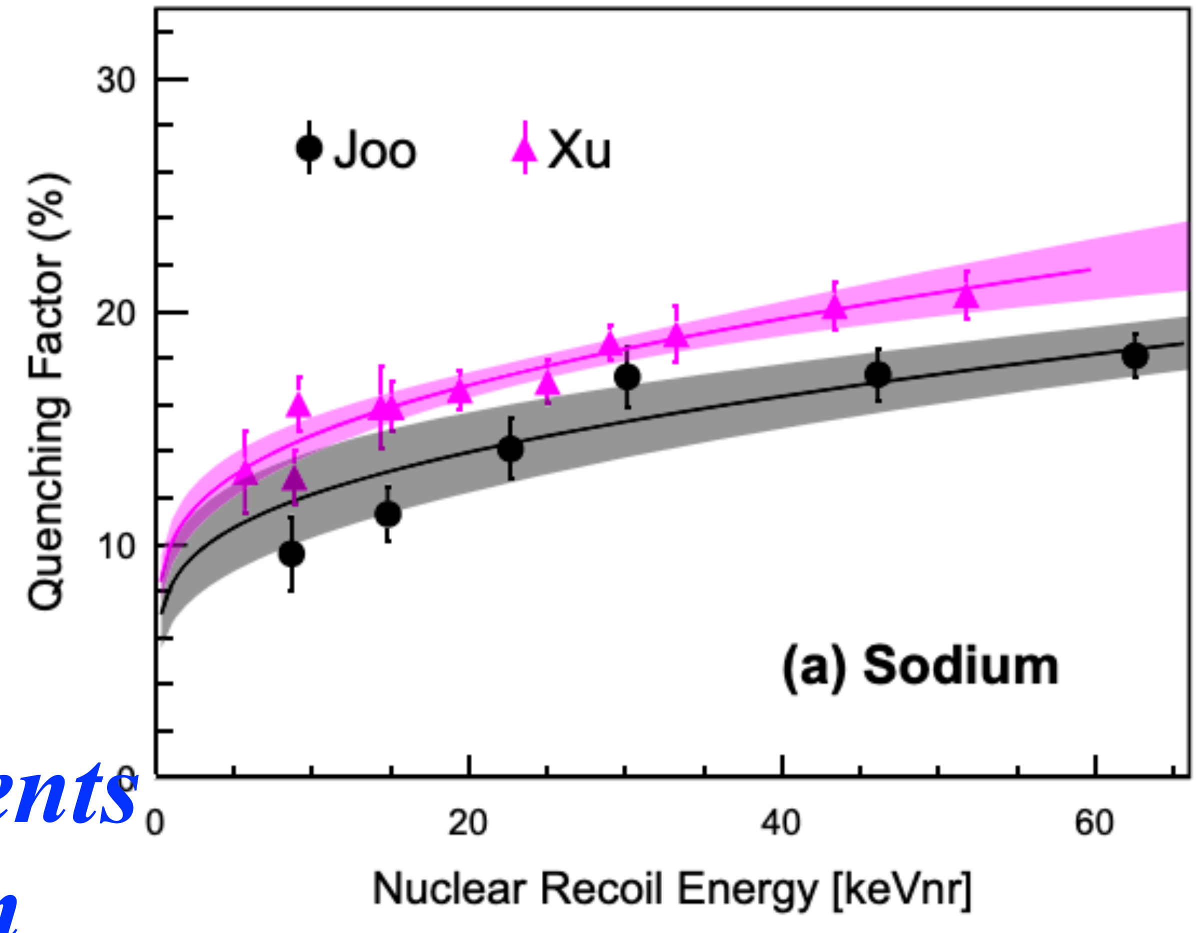
$$\chi^2 = \sum_i \frac{(N_{\mathrm{on},i} - \alpha_t N_{\mathrm{off},i} - \psi E_i)^2}{N_{\mathrm{on},i} + \alpha_t^2 N_{\mathrm{off},i}}$$

- 10^5 Pseudo-experiments



•Assumption for sensitivity study

- ✓ 22-photoelectrons/keV(PEs/keV) light yield
- ✓ 13.5-kg mass of detector
- ✓ 7-counts/kg/day/keV flat background
- ✓ 5-PEs threshold (Currently 14 PEs threshold)
- ✓ 365/100-days reactor-on/-off data

650 ± 197 *(Joo QF)*

941 ± 209 *(Xu QF)*

Updated Joo QF measurements tomorrow 4pm by KWKim (Lowest energy measurement added)

Sensitivity estimation shows that more than 3σ detection is possible assuming the 5-PE threshold is reached.

Summary and Outlook

- CNNS for reactor $\bar{\nu}_e$ opens up several physics opportunities.
- NEON is poised to measure the CNNS process in an array of NaI(Tl) crystals with high light yields of 24 PEs/keVee.
- The experiment is running stably since April 11, 2022, accumulating 279 (144) ON(OFF)-day data.
- Background modeling (~7 counts/day/kg/keV below 5 keV) and exposure are almost ready.
- Current focus is to lower the thresholds down to 5-PEs (~0.2 keVee) by developing waveform simulations and machine learning techniques for event selections (removal of PMT noises).
- With one year ON data, we expect the CNNS at NEON could be detected at more than 3σ level given the 5-PE threshold. Stay tuned!

H.S. Lee : the COSINE-100 presentation on Thursday 4pm.
K.W. Kim : the Quenching Factor presentation on Wednesday 4pm.