清華大學
Tsinghua University

REactor neutrino LIquid xenon Coherent Scattering experiment (RELICS)

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On behalf of the RELICS Collaboration

LIDINE2023, Madrid, Spain
Sep 20-22, 2023

CEvNS Milestones

A fundamental interaction between neutrinos and matter

CEvNS milestones:

- Theoretical prediction-1974
- Experimental validation-2017

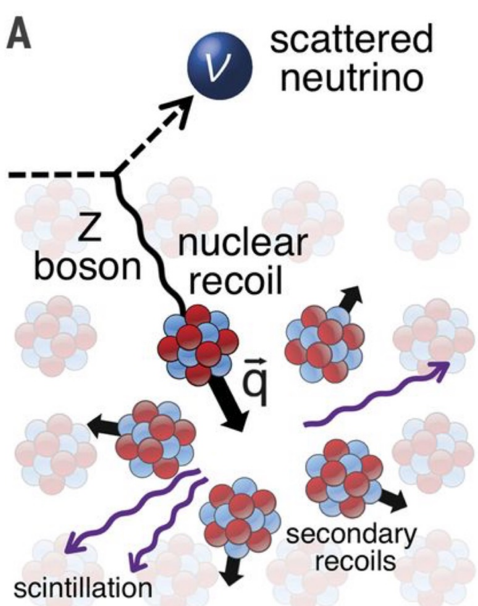
PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

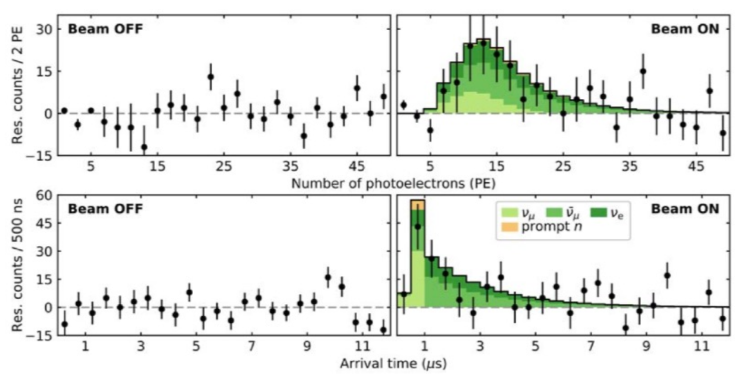
Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \rightarrow \nu + A$ should have a sharp coherent forward peak just as $e + A \rightarrow e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm^2 on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \rightarrow \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.





D. Akimov et al, Science 357 (2017)

Strategy in Studying CEvNS

$$\sigma \propto Q_W^2 \propto (N - (1 - 4\sin^2\theta_W)Z)^2$$

$$\Longrightarrow \boxed{\sigma \propto N^2}$$

- **Low energy threshold**
- **Low background**
- **Large exposure**
- **High neutrino flux**

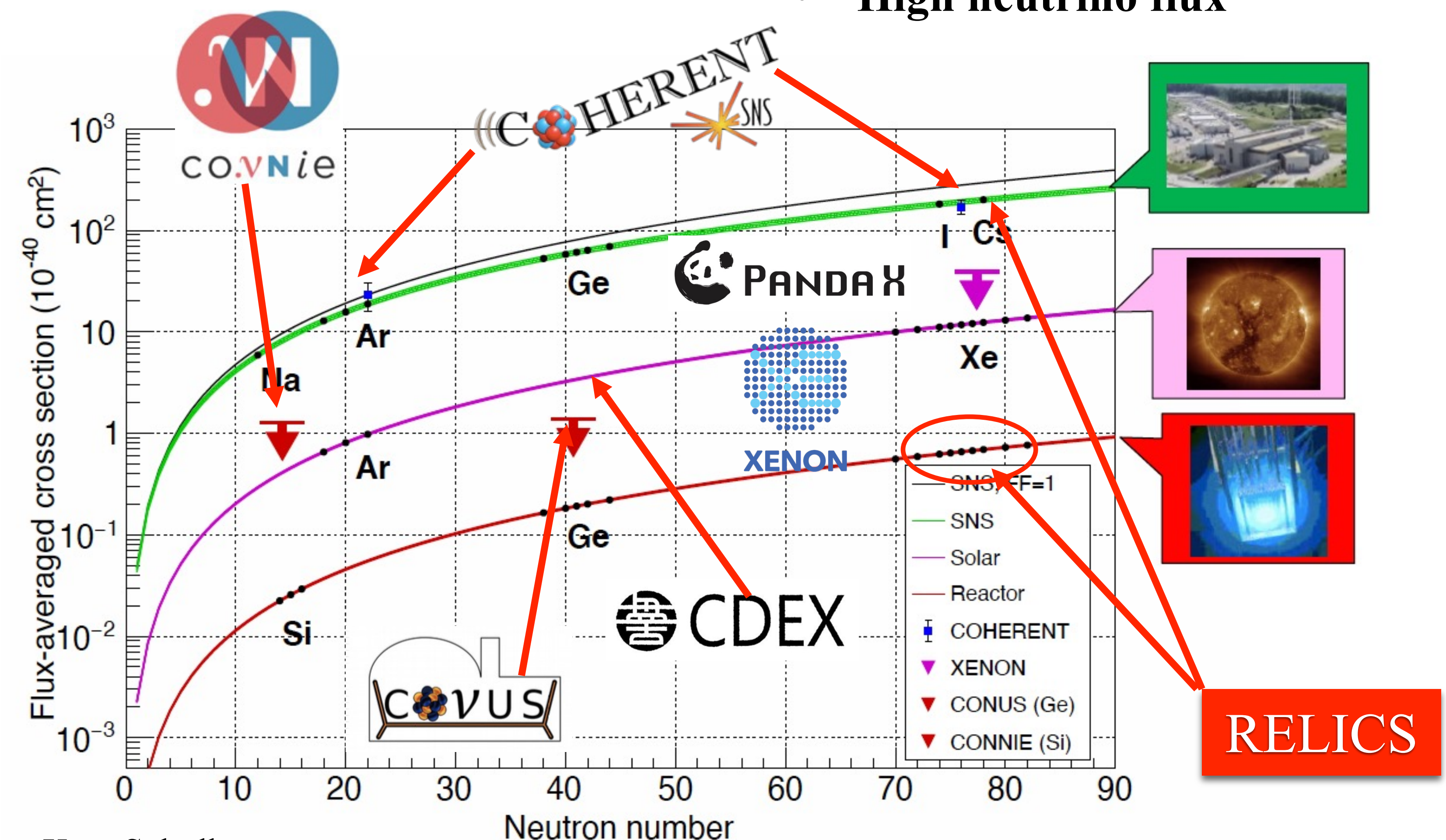
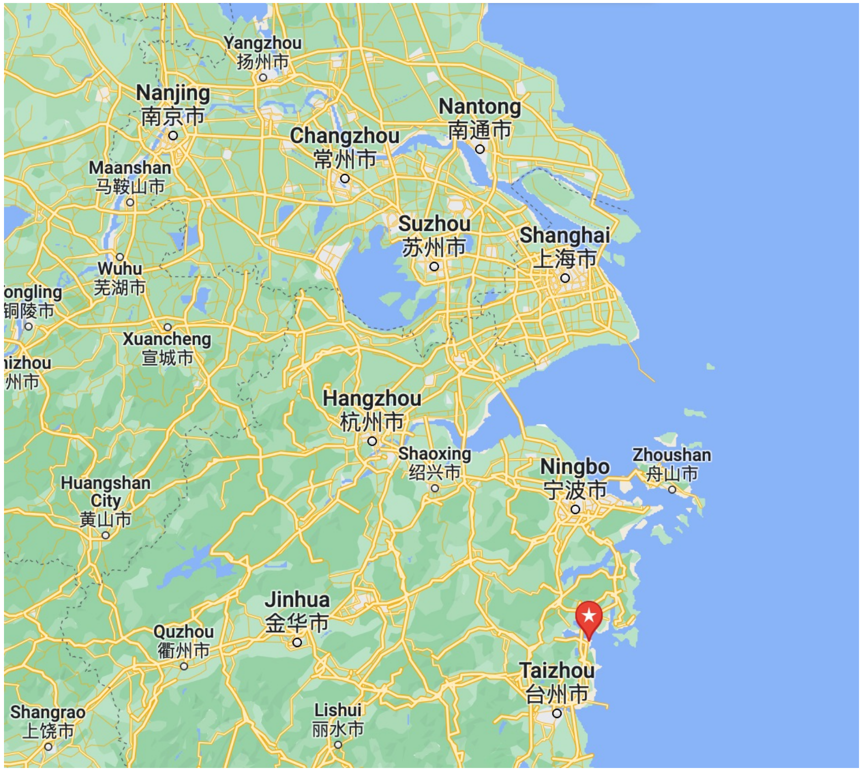
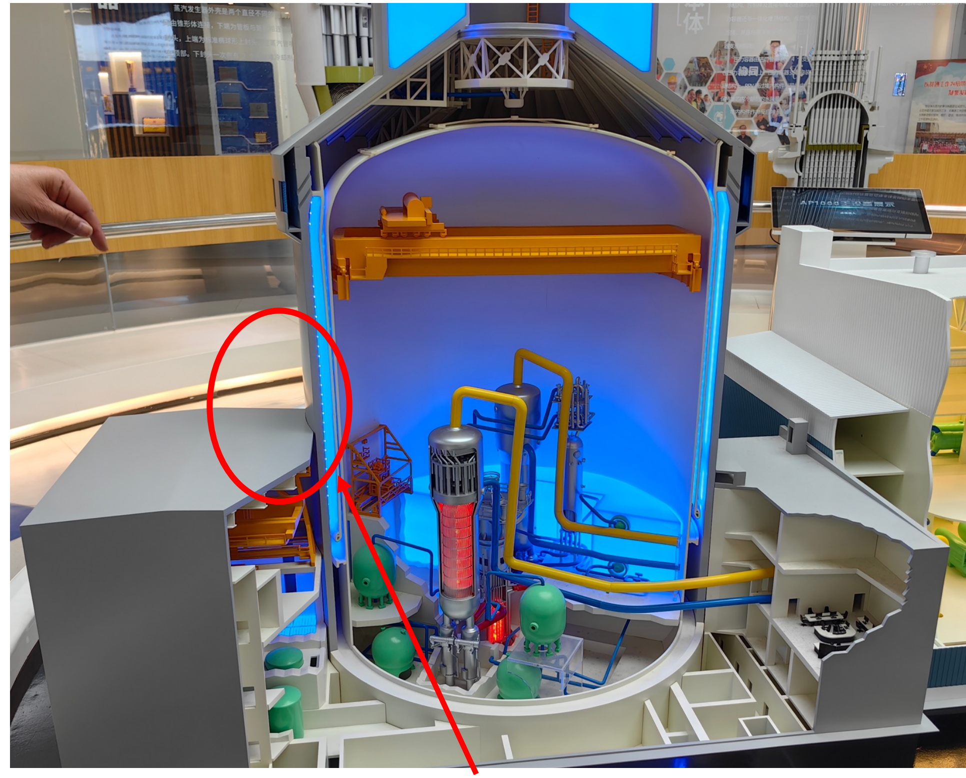


Figure: Kate Scholberg

The RELICS Collaboration

The RELICS Experiment



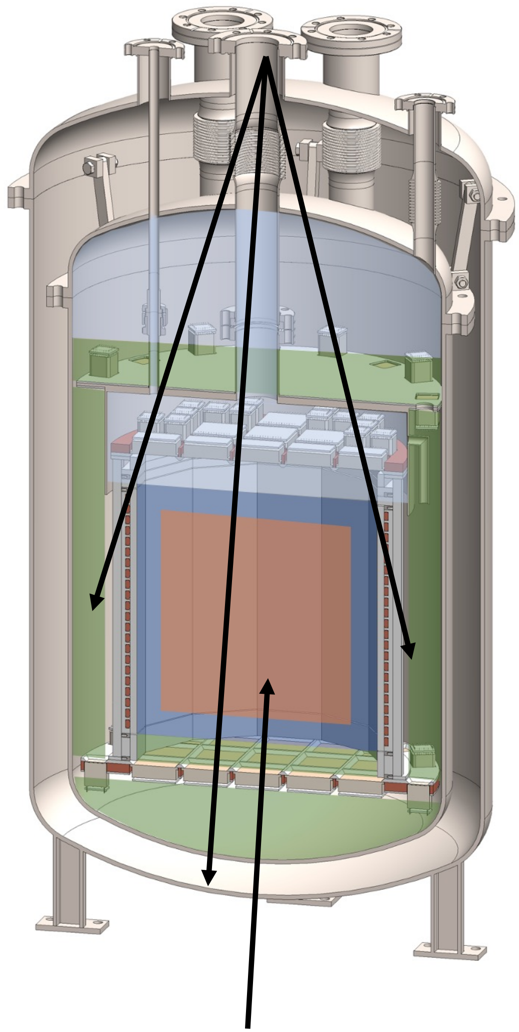


Proposed operation location for RELICS, right outside of containment building.

- ✓ Power ~3GW;
- ✓ Distance to Core ~ 25m;
- ✓ Expected **ν** flux ~ 1e13 **ν**/cm^2/s.

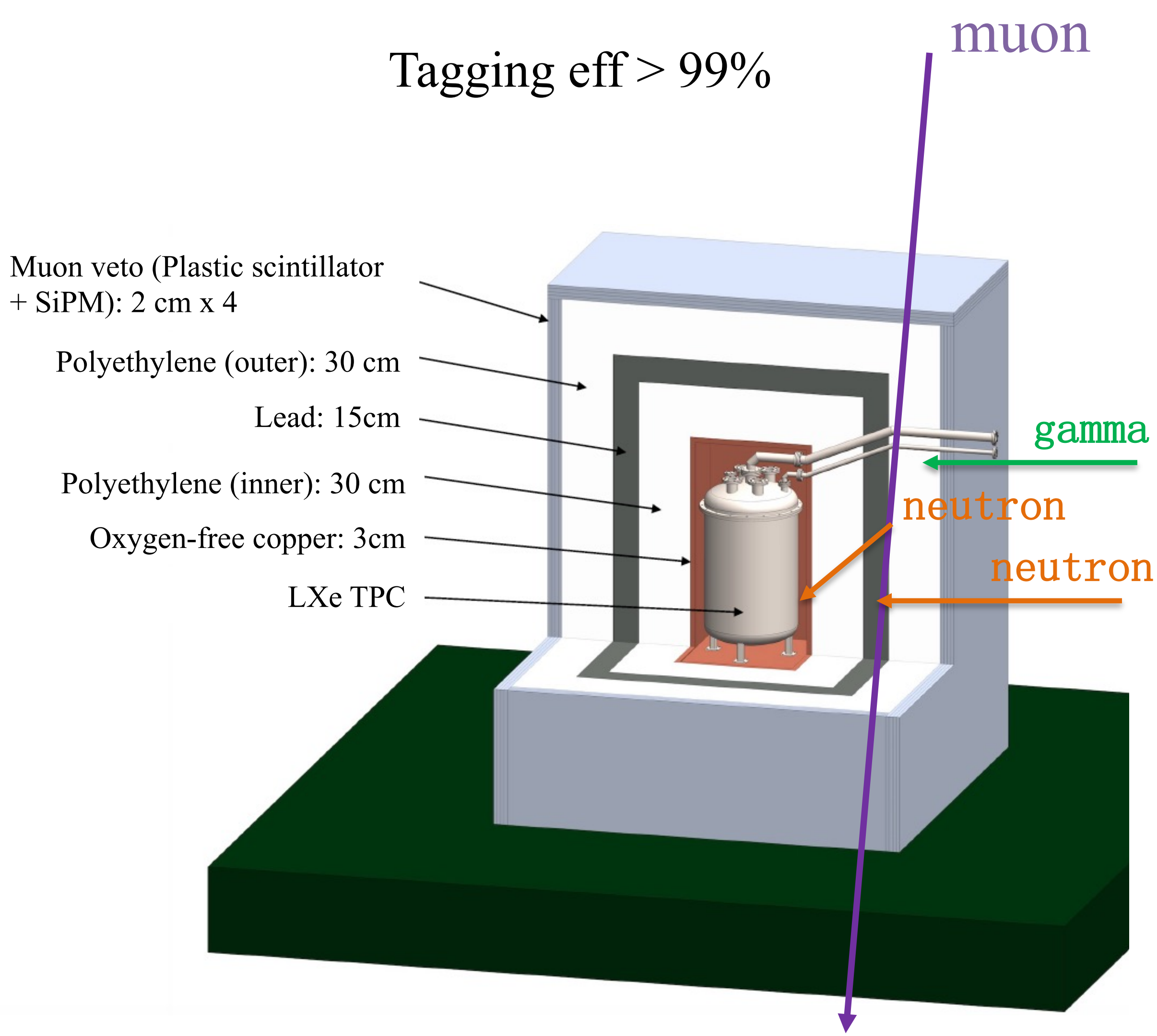
RELICS Detector Design

4π LXe veto

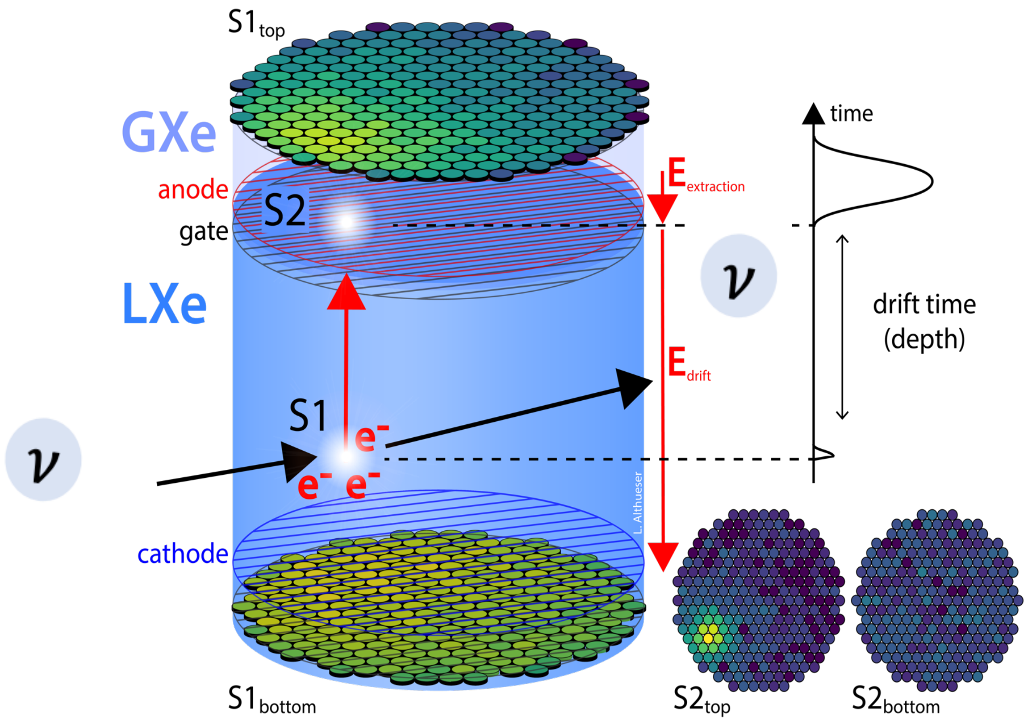


Fiducial Volume ~30kg

Tagging eff > 99%



RELICS Time Projection Chamber



Sensitivity to single electrons:

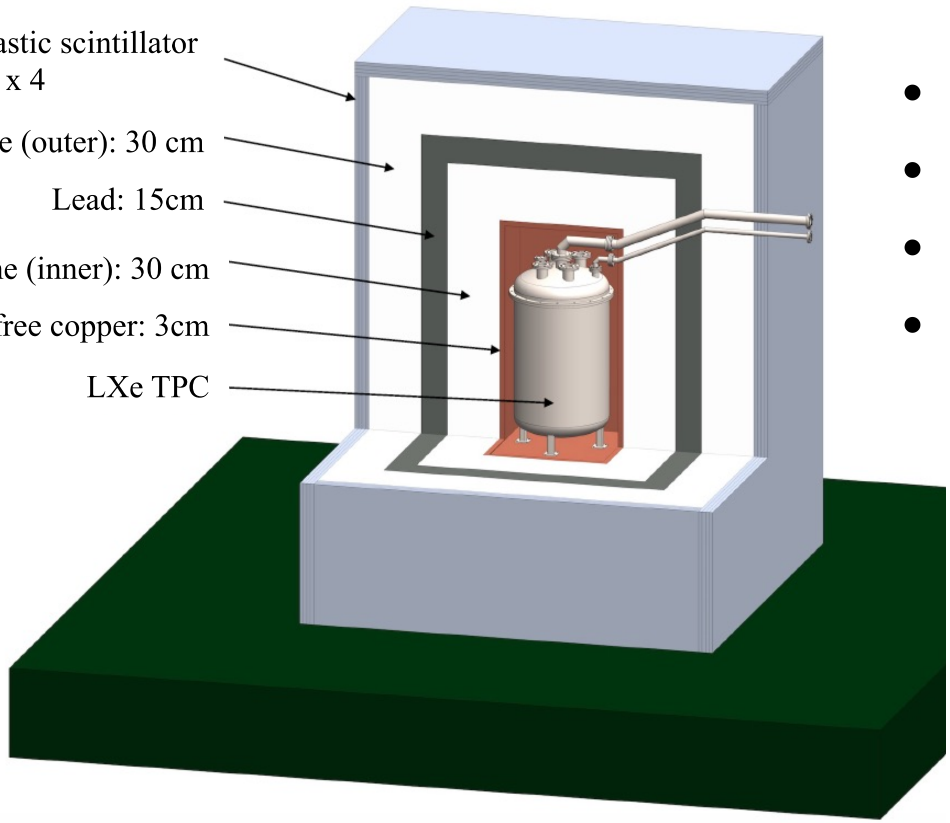
- Optimal position resolution

S2-only analysis to
lower the energy threshold

Optimal background to search for other
Types of exotic signals from reactor

Credit: XENON Collaboration

Backgrounds

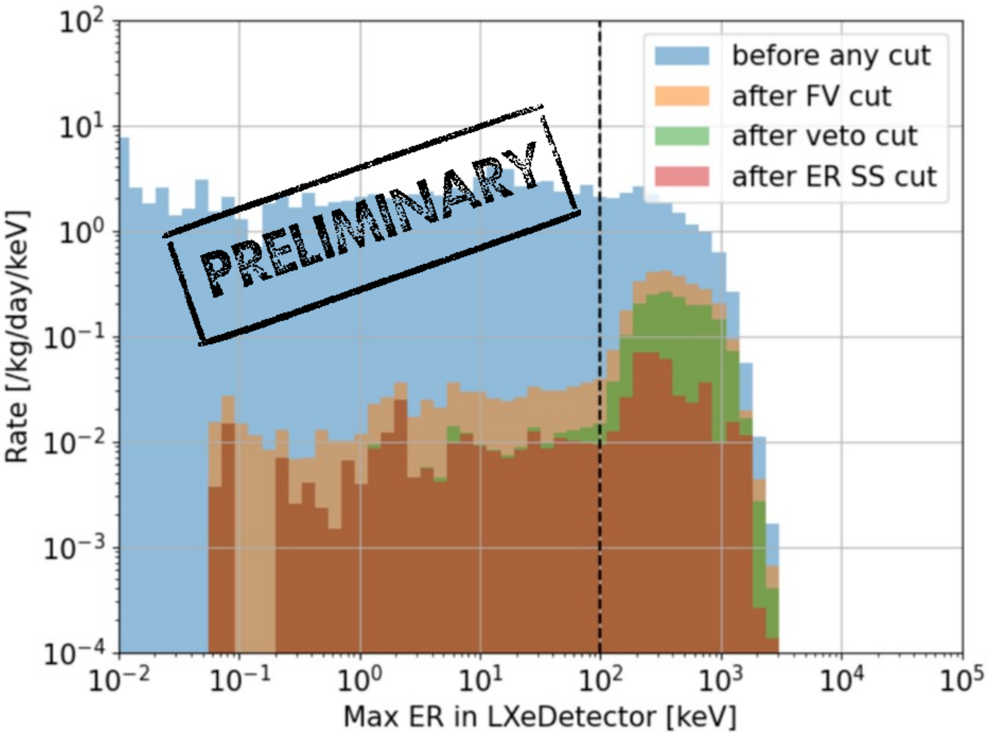


- Material
- Cosmogenic:
  - Xe127、Ar137
- Muon Induced
- Reactor induced
- …
- Instrumental

Material and Cosmogenic Background

放射性核素	聚乙烯	铅	铜	不锈钢	Teflon	PMT 石英窗	PMT 外壳
^{238}U	0.23	0.92	0.08	1.8	0.059	0.14	0.16
^{232}Th	0.09	0.72	0.01	1.9	0.1	0.17	0.07
^{60}Co	0	0.12	0.04	5.4	0.03	0.62	0.01
^{40}K	0.68	0.01	0.03	9	0.75	11.1	0.16
^{210}Pb	0	5.14×10^5	0	0	0	0	0
^{137}Cs	0	0	0	0	0	0.79	0

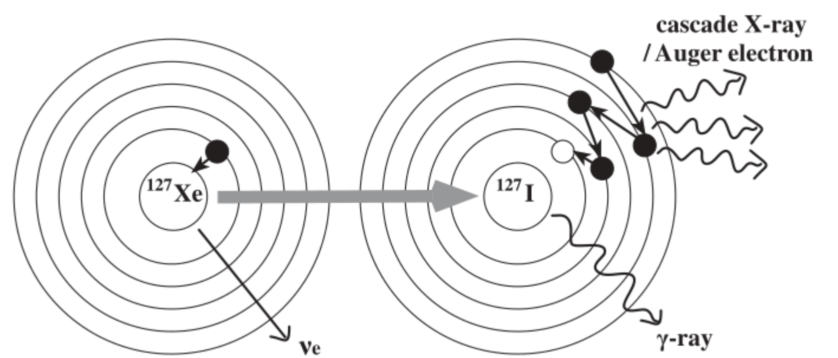
XENON100 Reference Values



source	shield	TPC & Cryostat	Xe127	Ar37
Rate[10^{-2} /kg/day]	0.2	0.2	0.3	<0.2

Ar37:
- ➢ Proton bombard
- ➢ Neutron bombard

Xe127:
- ➢ Muon bombard
- ➢ Neutron capture

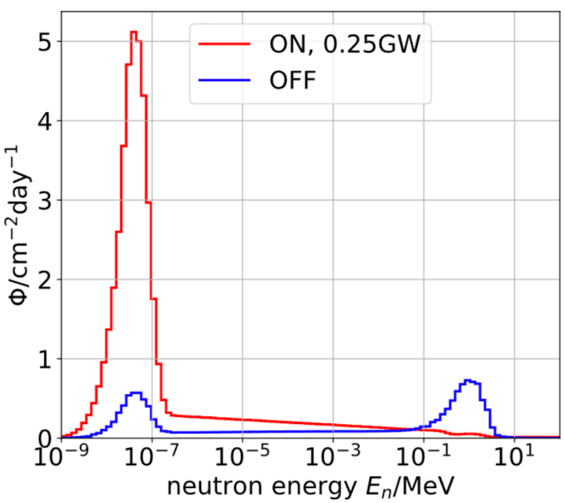


Ar37
L-shell 0.27keV

Xe127
N-shell 0.186keV

Reactor and Environmental Neutrons

Using CONUS measured spectrum

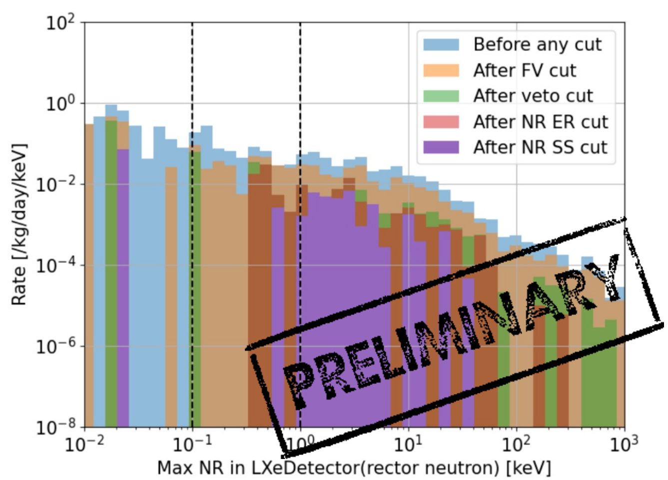


The European Physical Journal C, 2019, 79(8).

中子种类	E_n(MeV)	Φ(cm^{-2}· day^{-1})
热中子	1.0×10^{-9}——4.0×10^{-7}	4.47±0.67
中能中子	4.0×10^{-7}——0.1	4.19±1.15
快中子	0.1——19.6	6.35±0.96
总和	1.0×10^{-9}——19.6	15.03 ±0.99

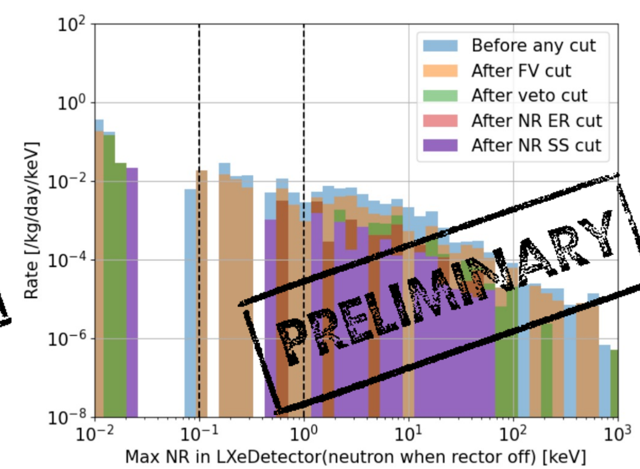
中子种类	E_n(MeV)	Φ(cm^{-2}·GWh^{-1})
热中子	1.0×10^{-9}——4.0×10^{-7}	6.42±0.41
中能中子	4.0×10^{-7}——0.1	1.56±0.21
快中子	0.1——19.6	0.15±0.05
总和	1.0×10^{-9}——19.6	8.13±0.32

Environmental n



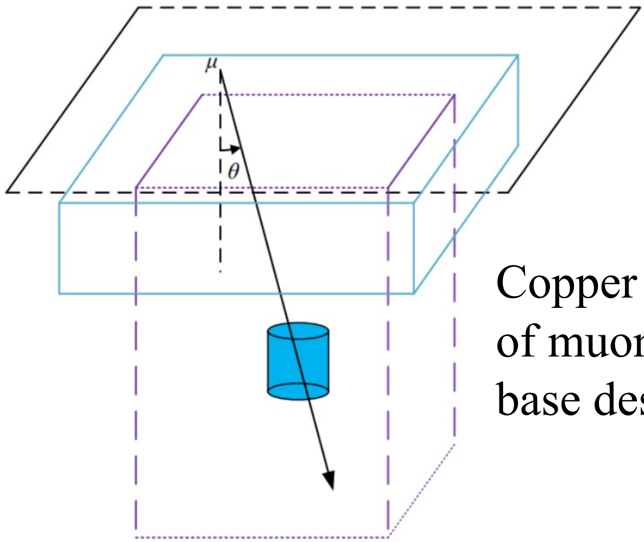
1.2x10^{-2} evts/kg/day

Reactor n

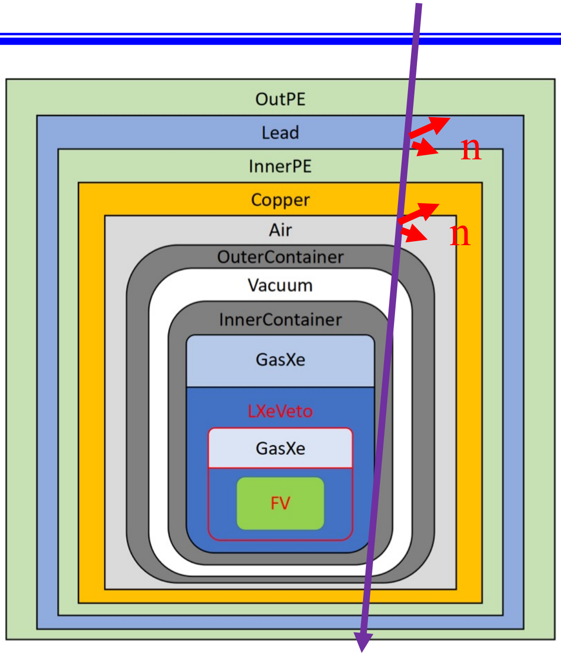


1x10^{-3} evts/kg/day

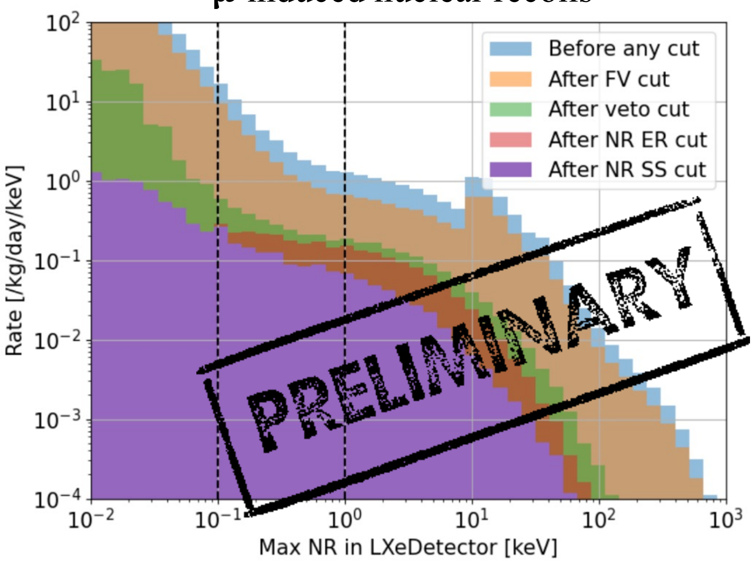
Muon Induced Background

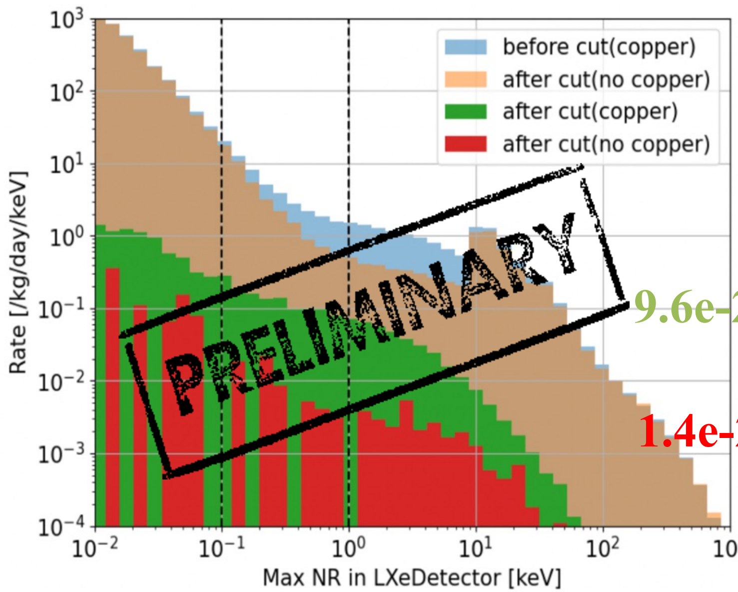


Copper is the dominant source of muon-induced neutron in the base design.



μ-induced nuclear recoils



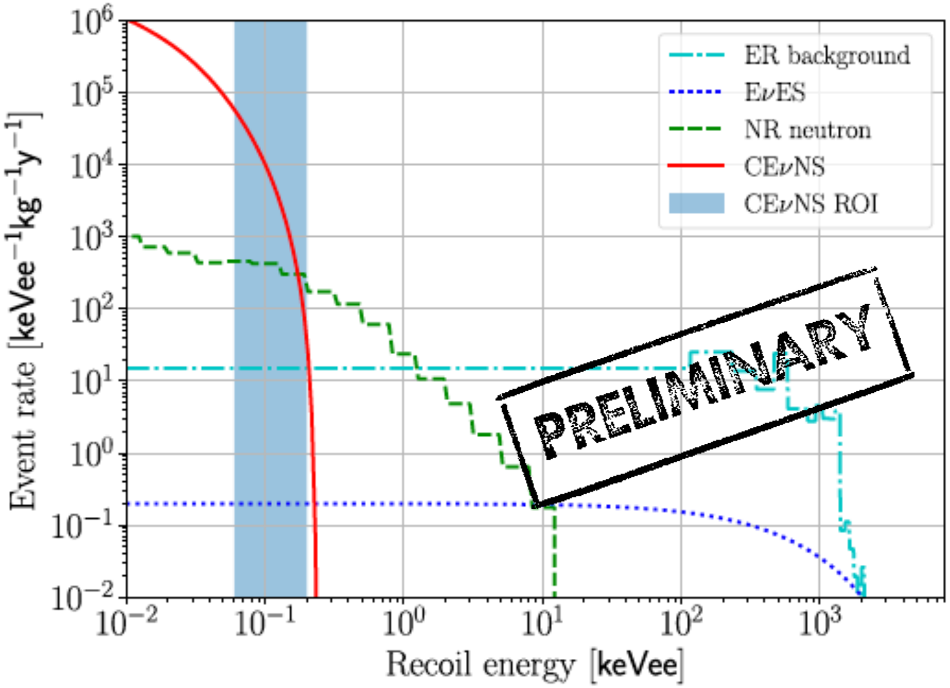


9.6e-2/kg/day

1.4e-2/kg/day

Total Background Budget

Assuming 99% tagging efficiency for muons in the muon-veto detectors

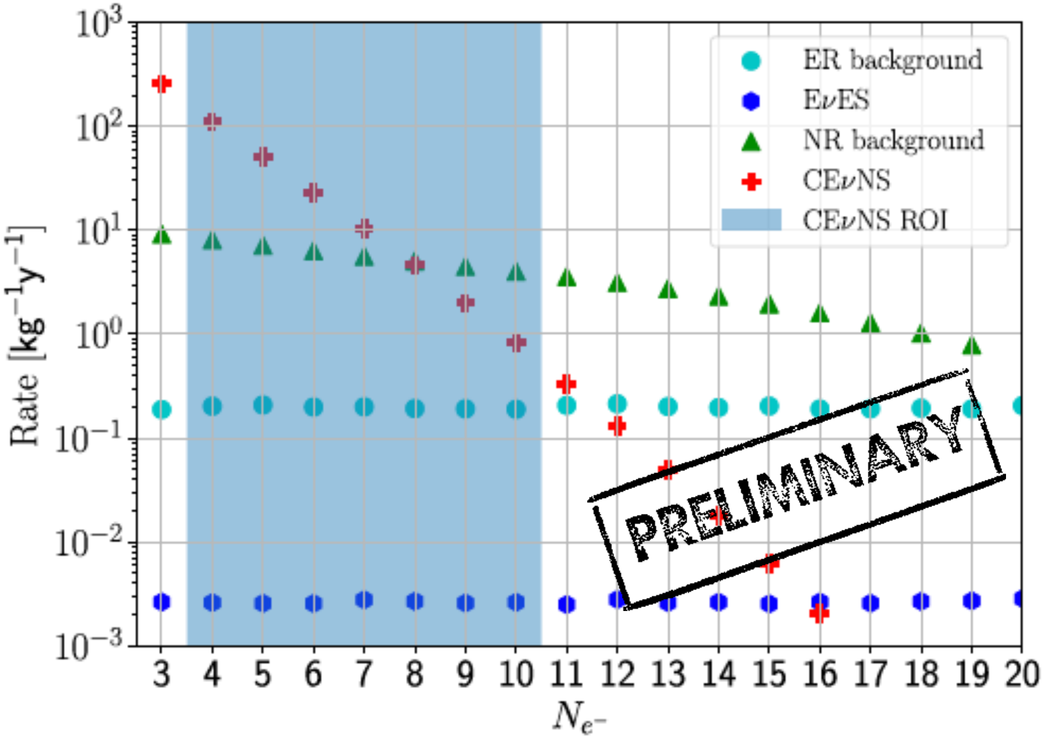


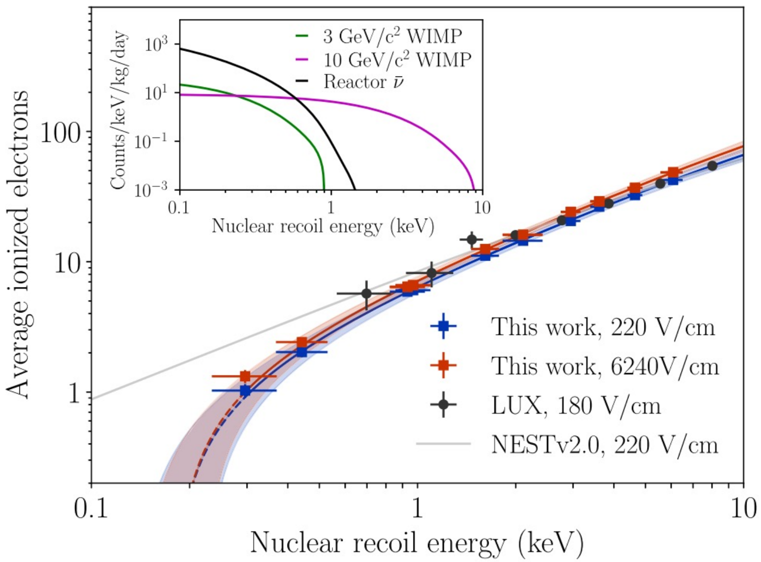
NR: <0.3 event/kg/day

ER: <0.01 event/kg/day/keV

Total Background Budget

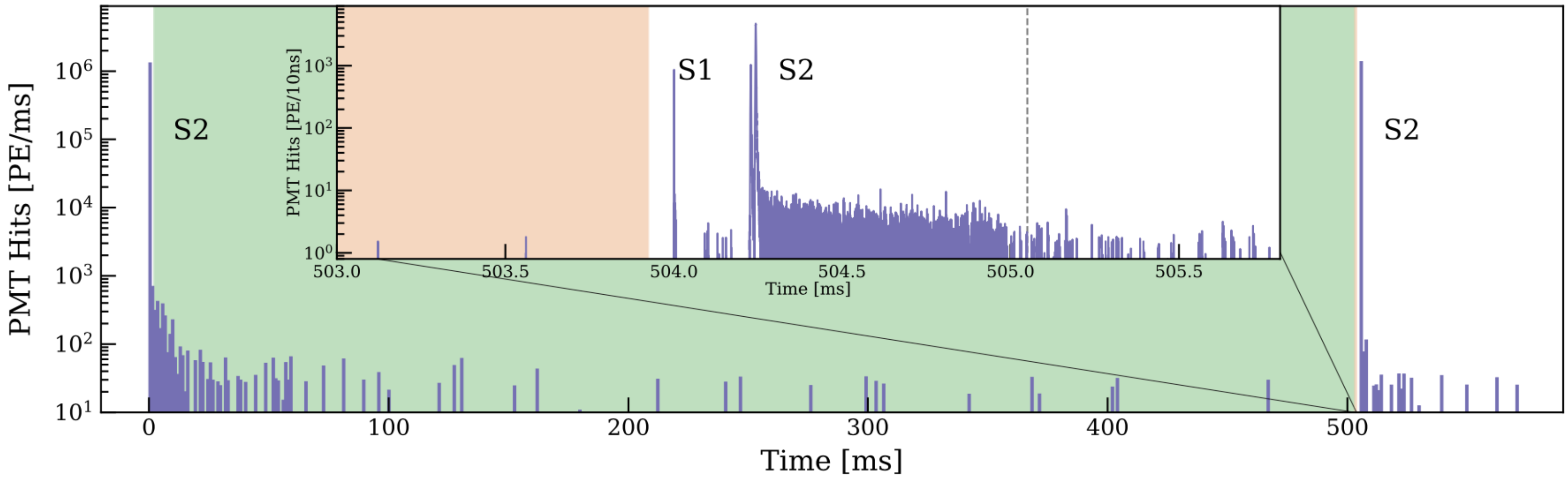
@4 ionization electron, signal rate is 1 order of magnitude higher than background



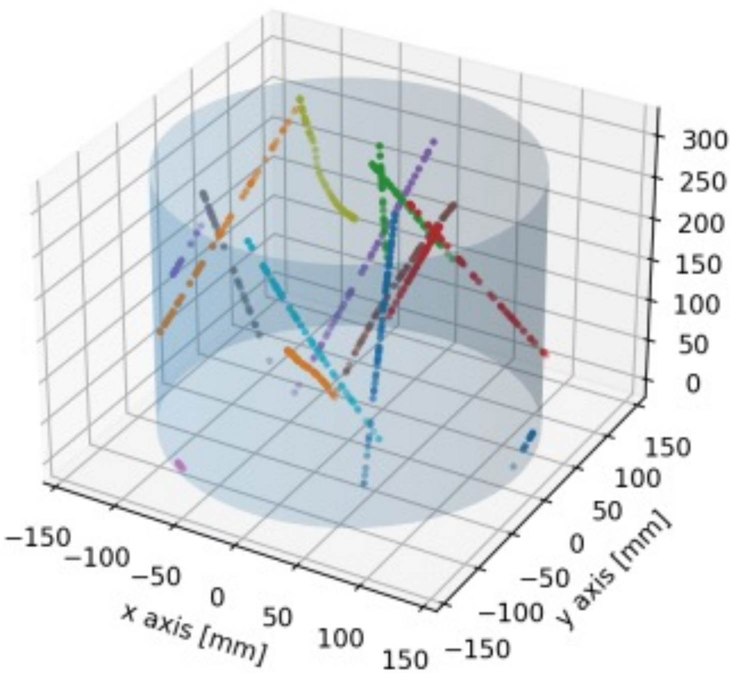


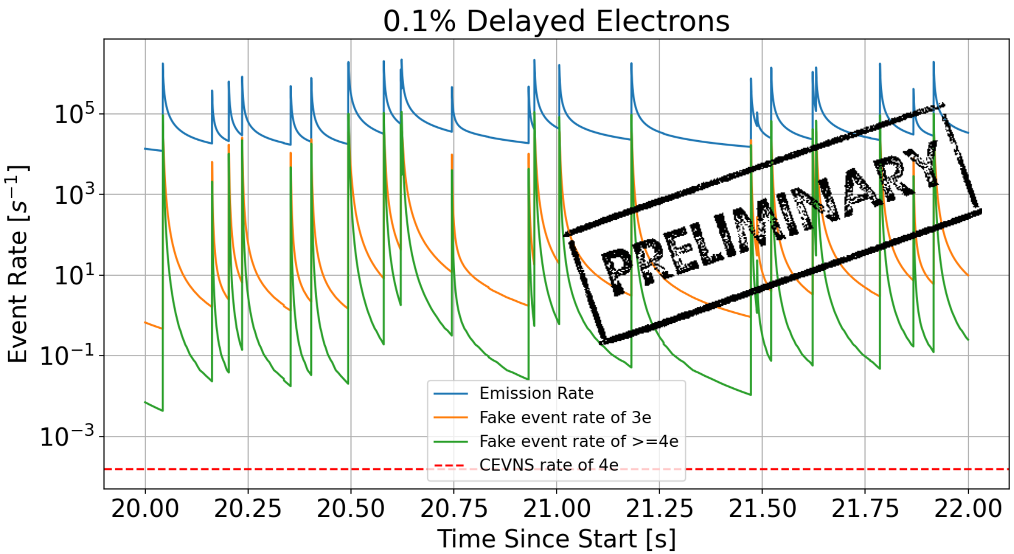
B. Lenardo *et al*., PRL 123, 231106 (2019)

Instrumental Background

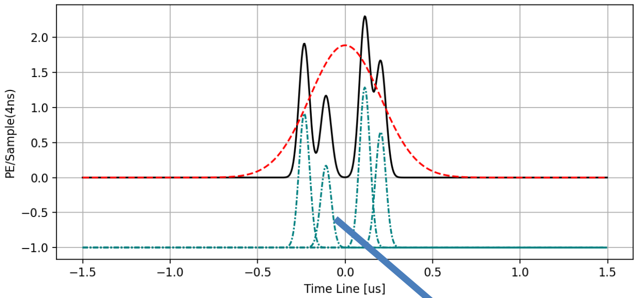


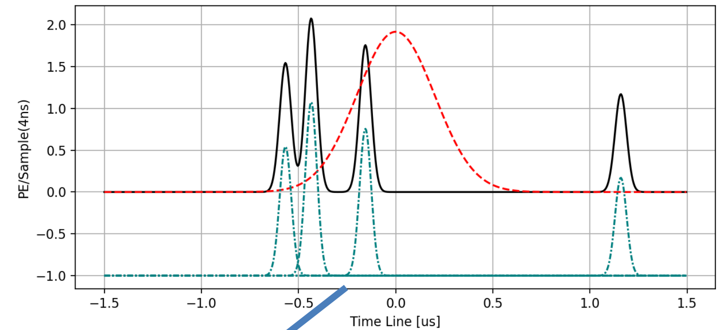
XENON Collaboration, PRD 106, 024328, 2022

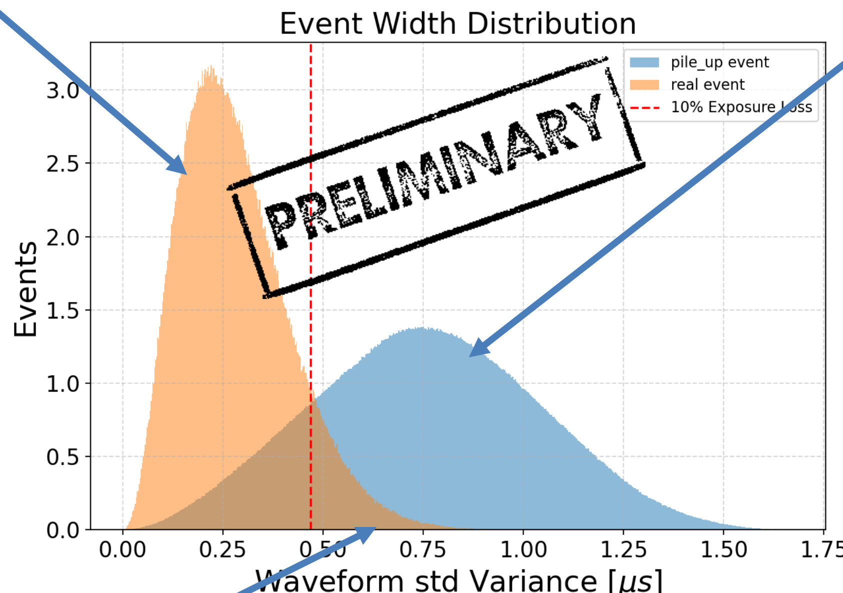


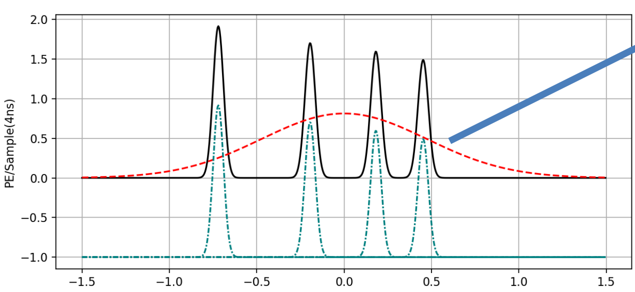


Instrumental Background Suppression



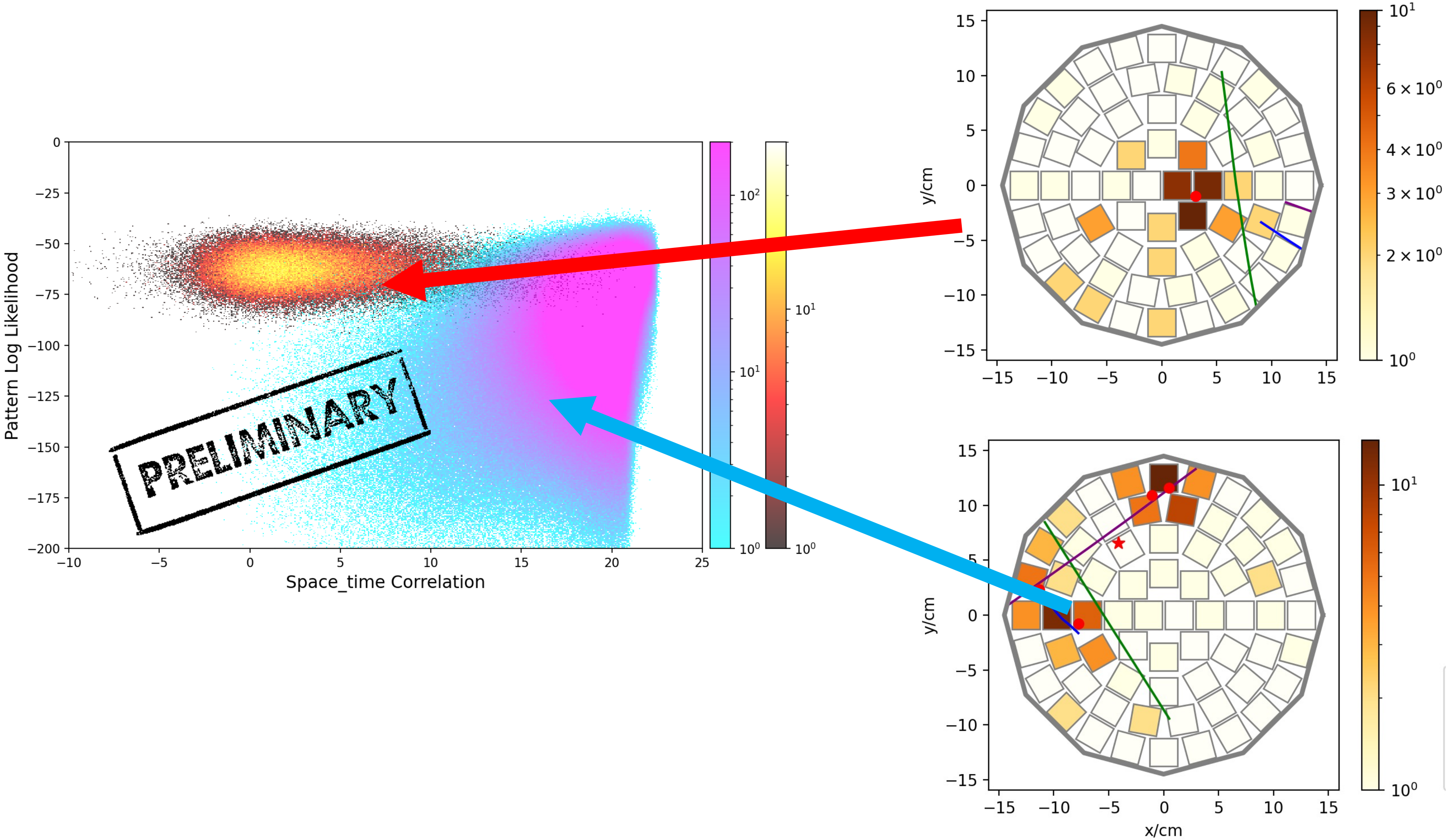




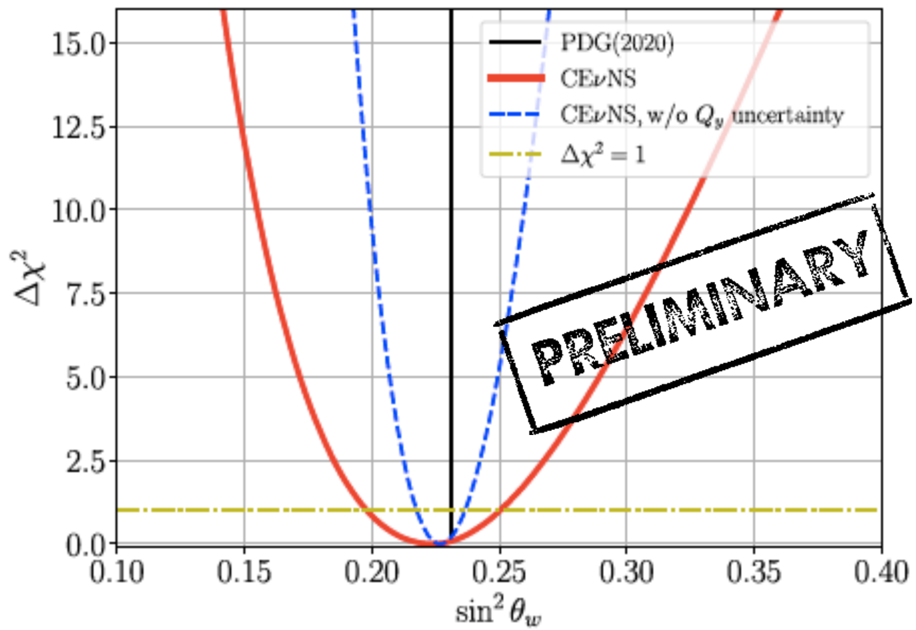


Signal Acceptance	Background Rejection
90.0 ± 0.1 %	83.96±0.03%

Instrumental Background Suppression

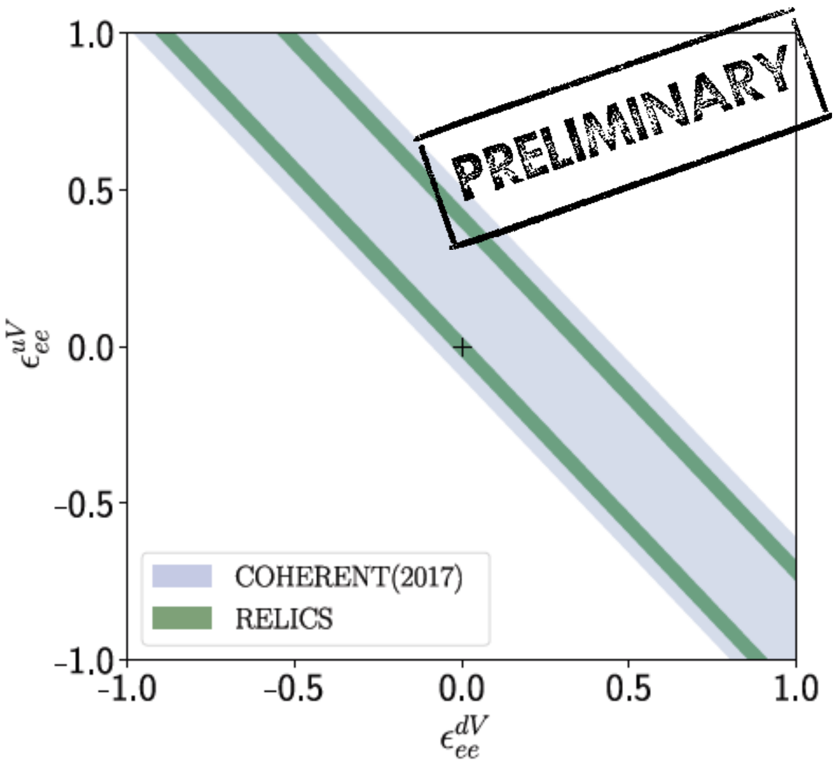


RELICS Sensitivity



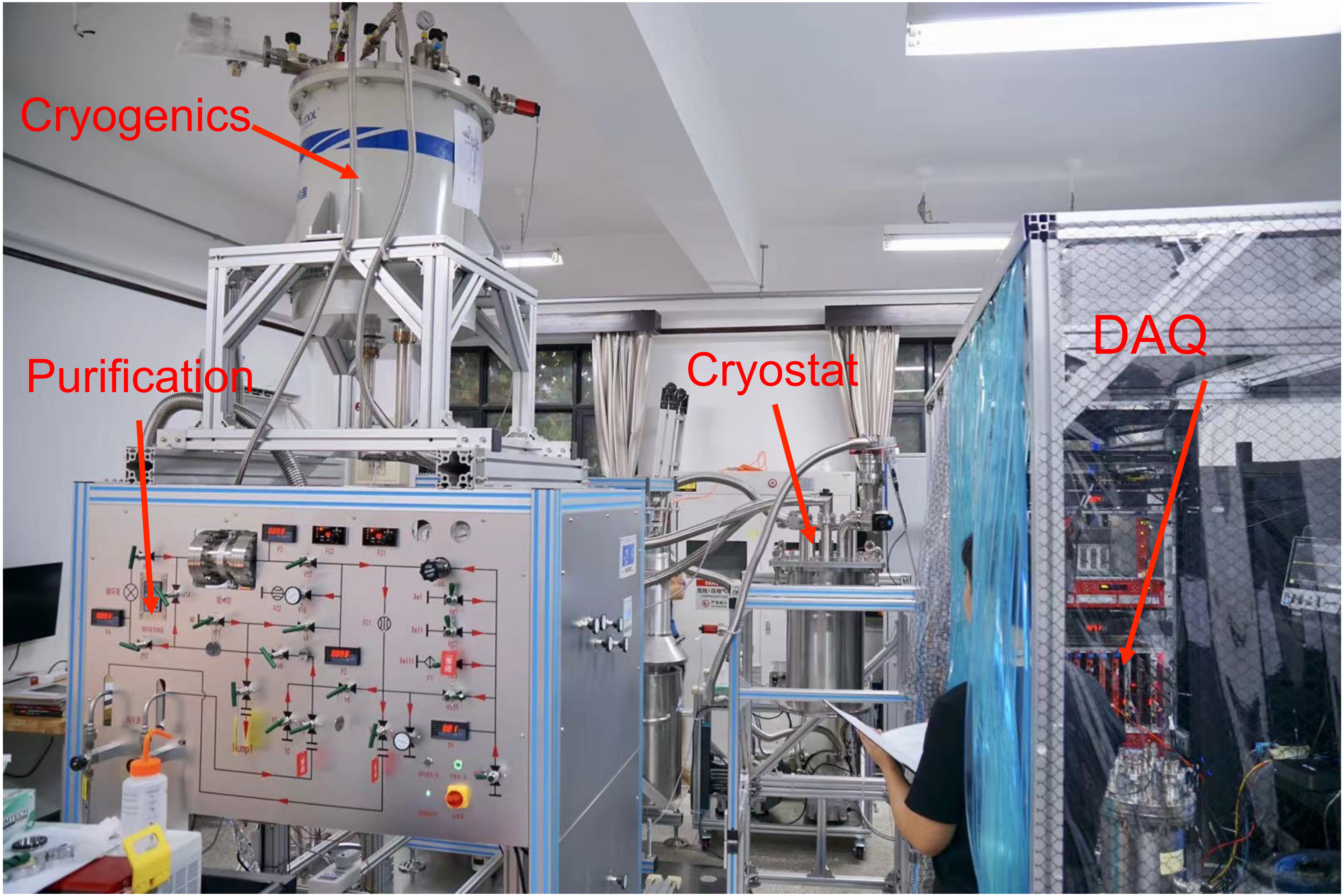
A precise measurement：

- CEvNS cross-section
- Weak mixing angle
  - Statistical uncertainty down to percent level

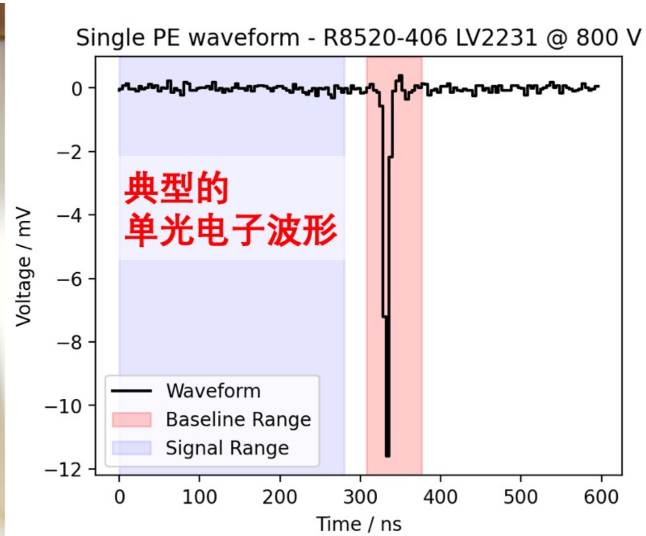


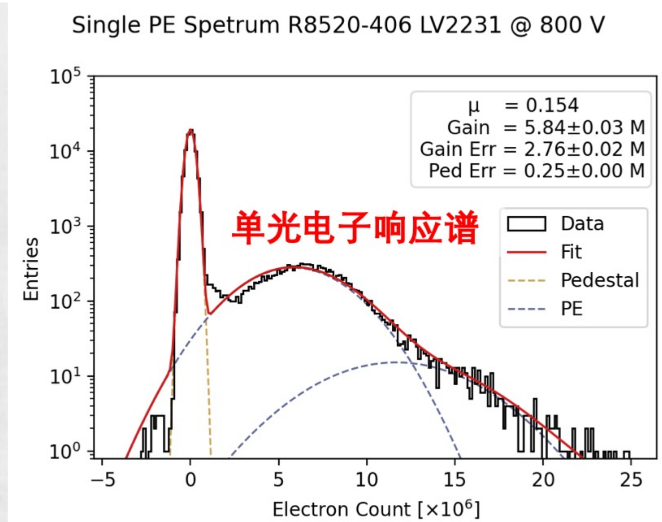
Provide leading constraints on non-st andard neutrino interactions

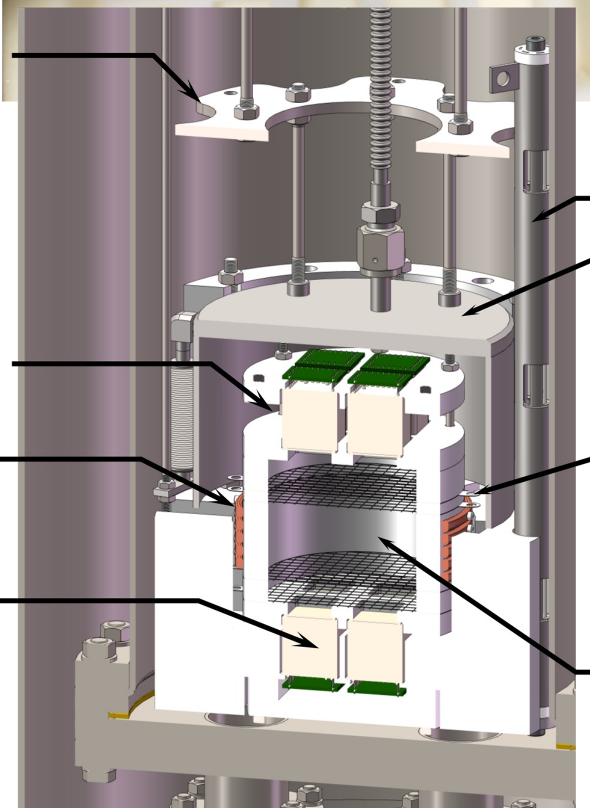
RELICS Demonstrator



RELICS Demonstrator





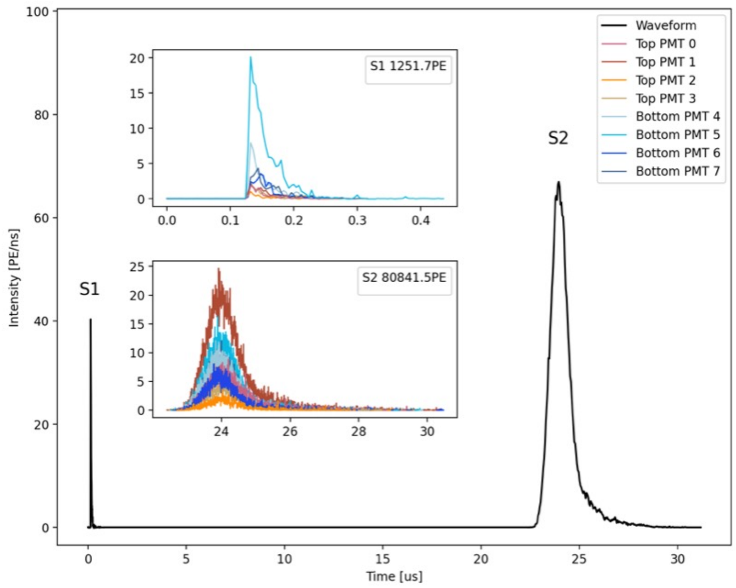


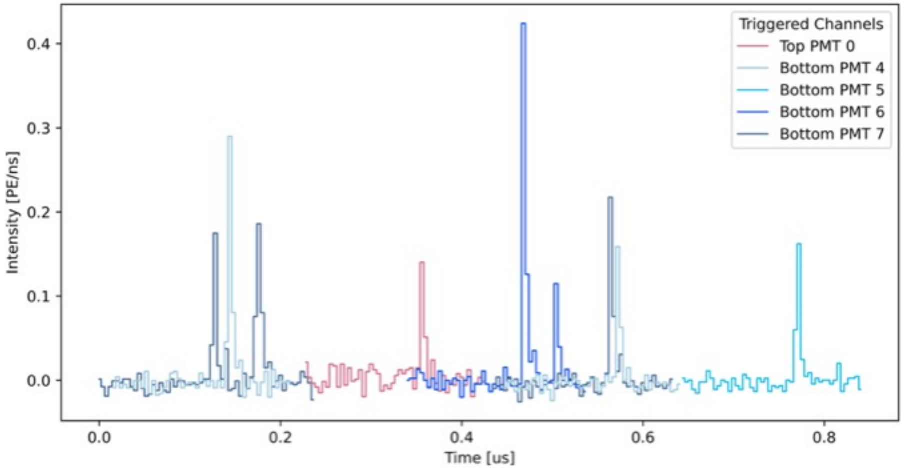
Kg-scale LXeTPC

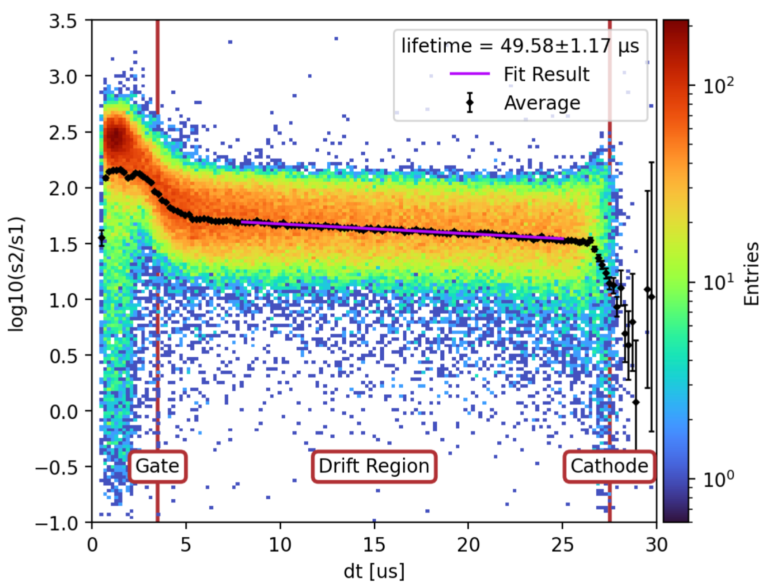
To demonstrate single electron sensitivity

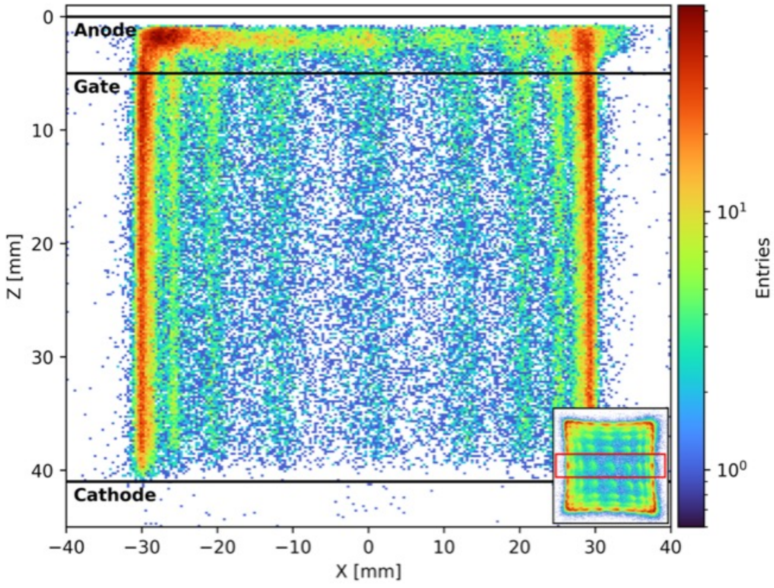
To study how to suppress instru mental background

RELICS Demonstrator

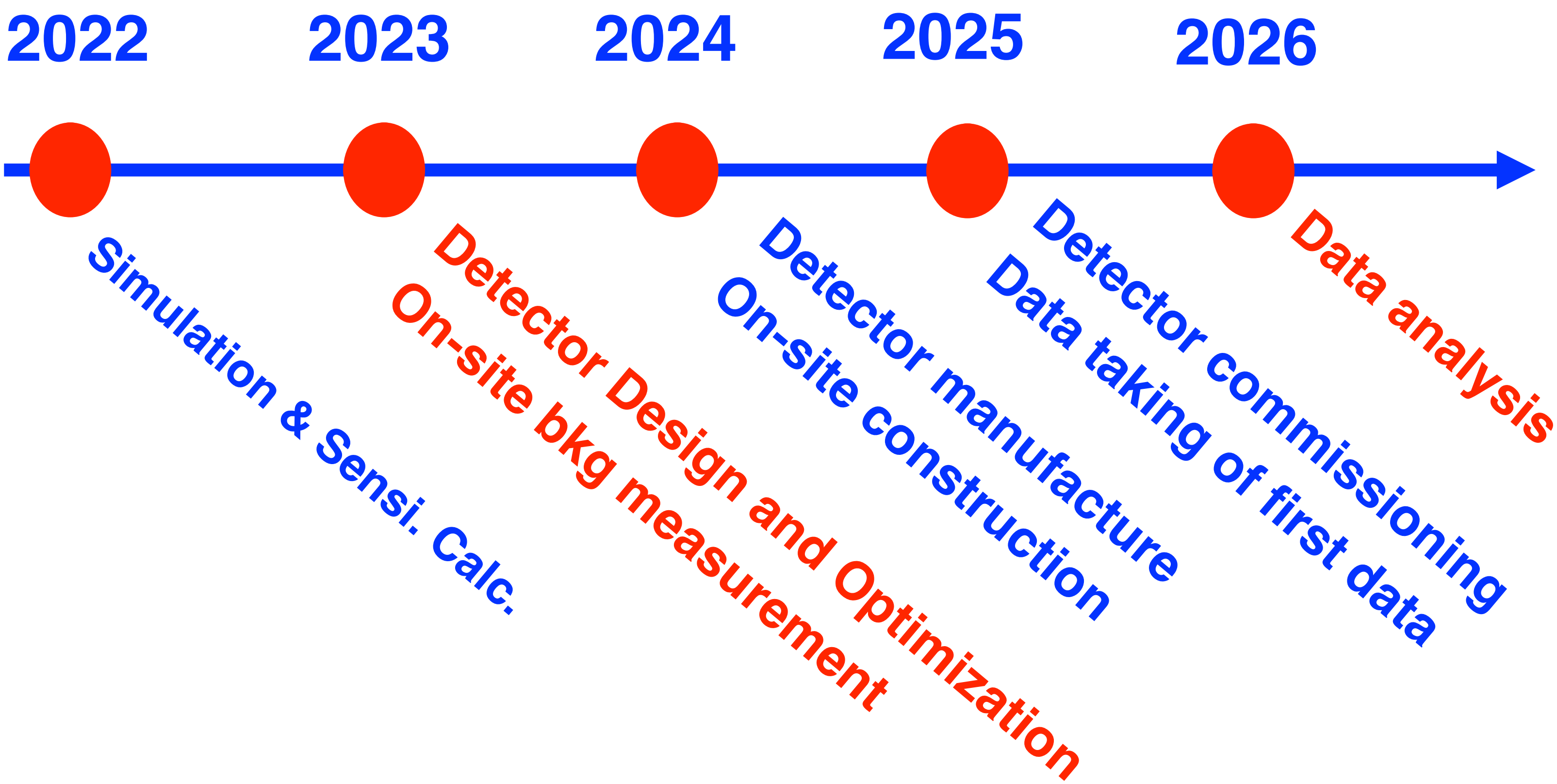








RELICS Timeline



Summary

- Rich physics and application potentials with CEvNS measurements.
- RELICS is a liquid xenon time projection chamber dedicated for CEvNS detection at reactor.
- Background budget has been studied for the RELICS experiment, showing great potential for a precise measurement.
- RELICS demonstrator has been built to study performance of such detector at sea level.