RELICS Experiment for Reactor CEνNS Detection

[Phys. Rev. D 110, 072011 (2024)]

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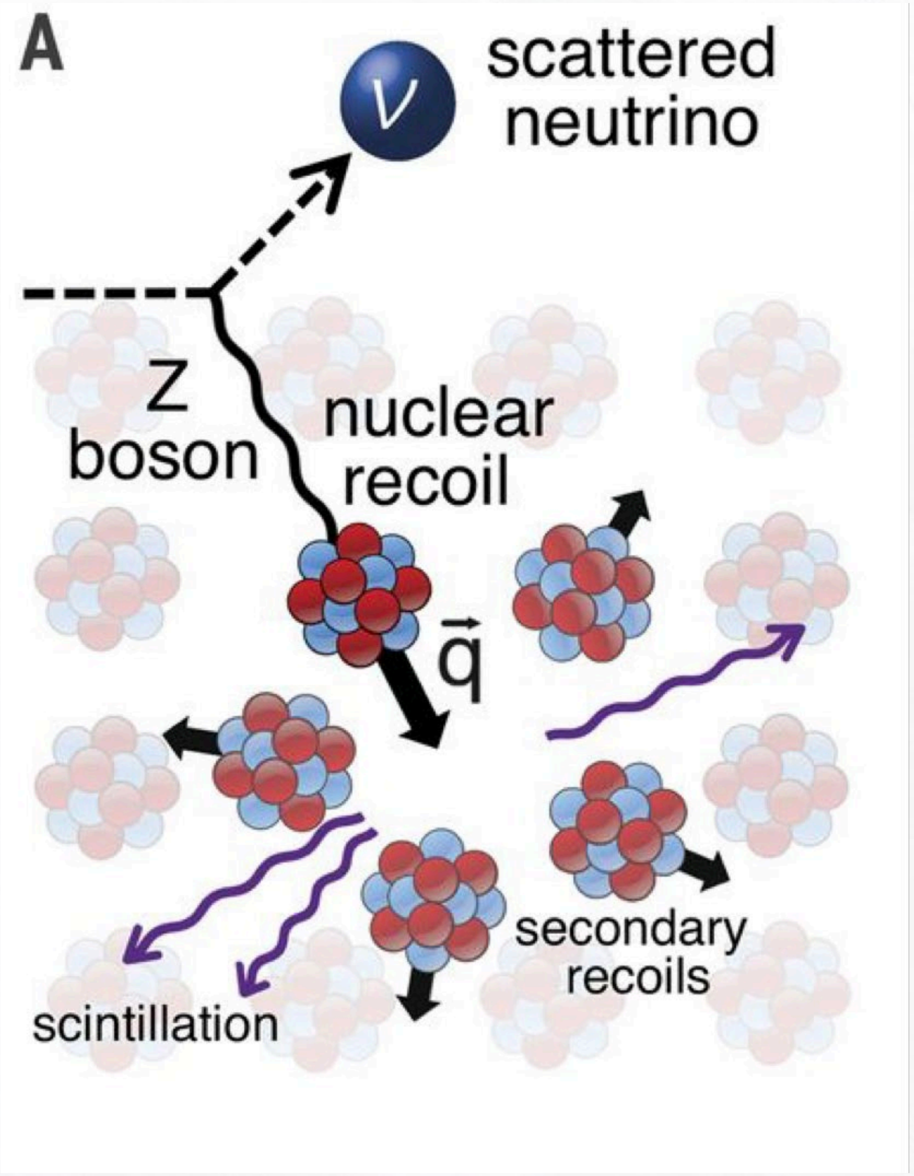
Sun Yat-sen University

On behalf of the **RELICS collaboration**

June 16-18, 2025, Modica, Italy

MAYORANA Workshop

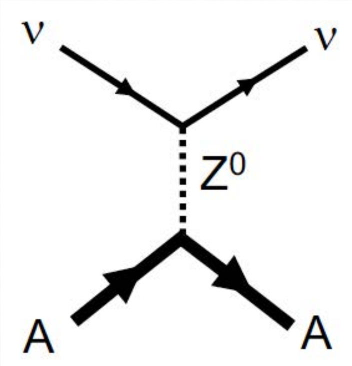
CEνNS: Coherent Elastic Neutrino-Nucleus Scattering



$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M \left(1 - \frac{MT}{2E_\nu^2}\right) F(Q^2)^2.$$

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

$$Q_W \propto N \implies \frac{d\sigma}{dT} \propto N^2$$

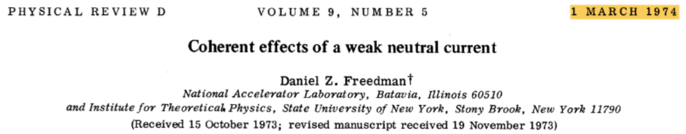


- Z-exchange between neutrino and entire nucleus
- Coherent up to E_ν **~ 50 MeV**
- $qR < 1$
- low recoil energy **< 5 keV**.

CEνNS: Challenges & Worldwide

Theoretical Proposal

D. Freedman, PRD 9 1389 (1974)


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

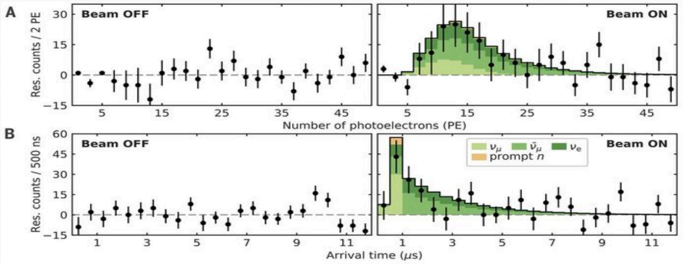
Daniel Z. Freedman†

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)

Experimental Evidence

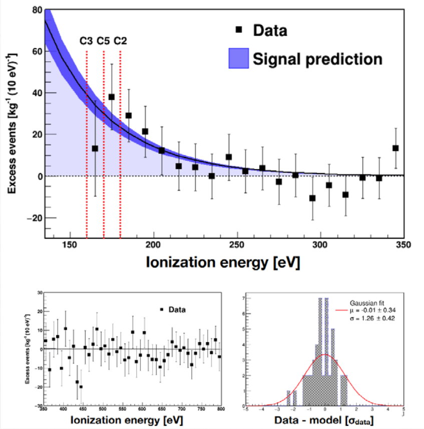
CsI-2017

D. Akimov et al, Science 357 (2017)



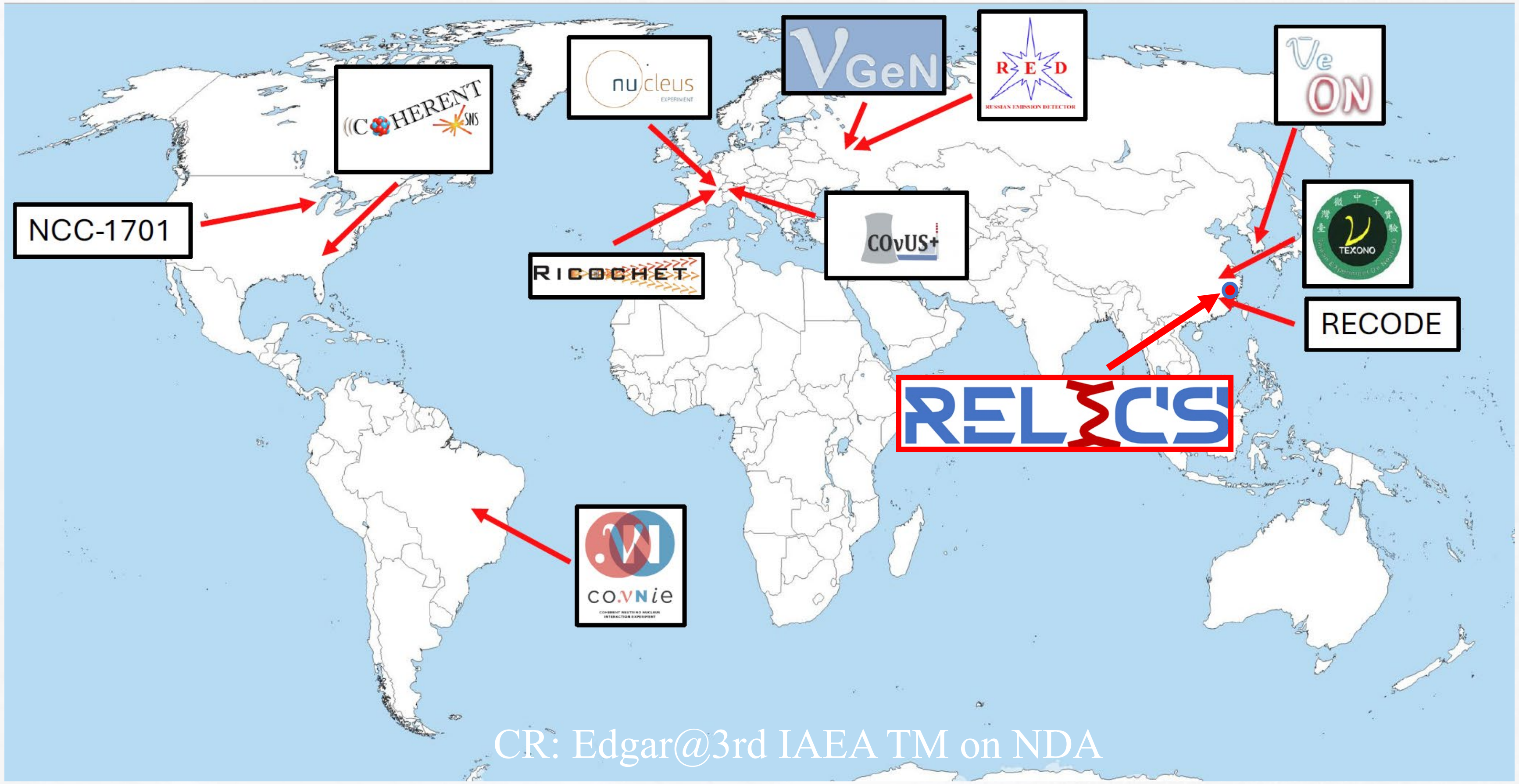
Ge-2025

N.Ackermann et al, arXiv:2501.05206v2



Challenges：

- An intense **neutrino source**
- Low detector **thresholds**
- Incredibly low **backgrounds**

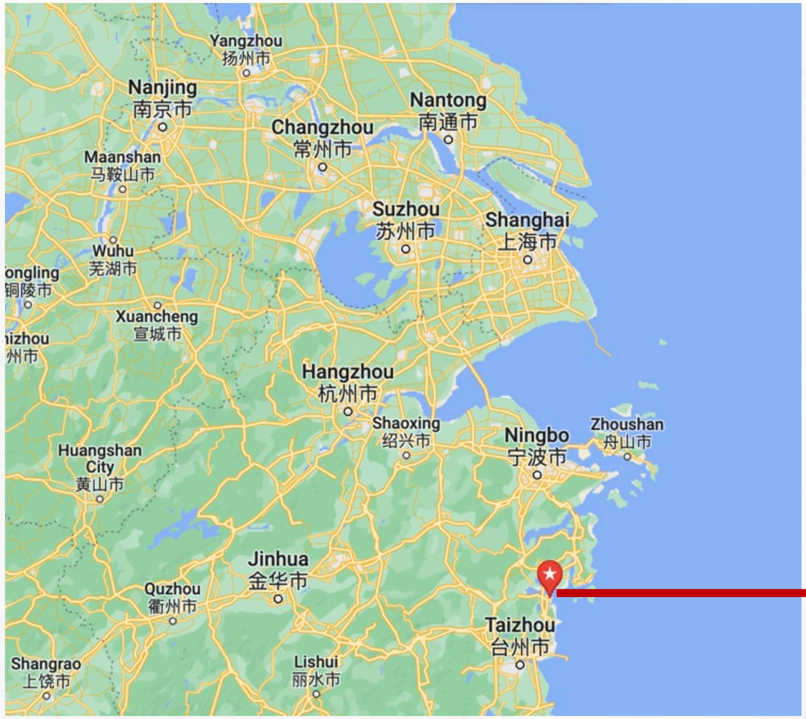


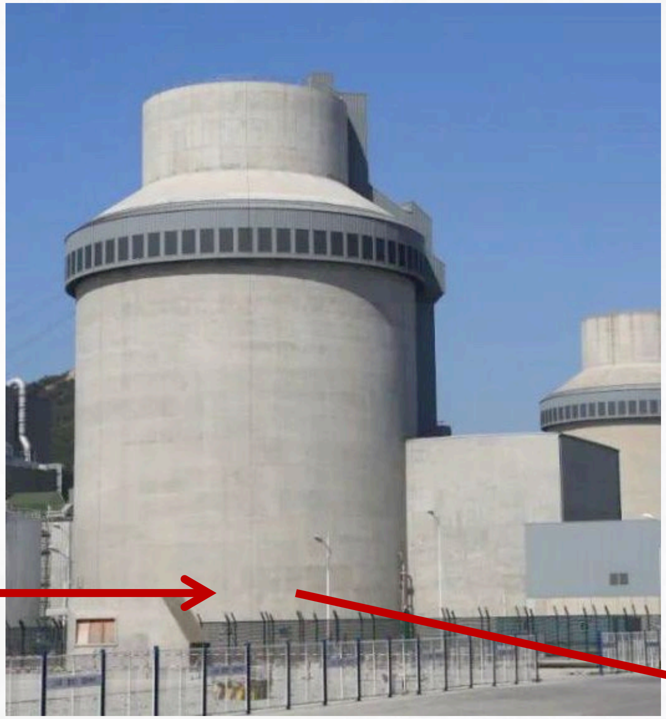
RELICS Collaboration

中山大學 SUN YAT-SEN UNIVERSITY

REactor neutrino LIquid xenon Coherent Scattering experiment

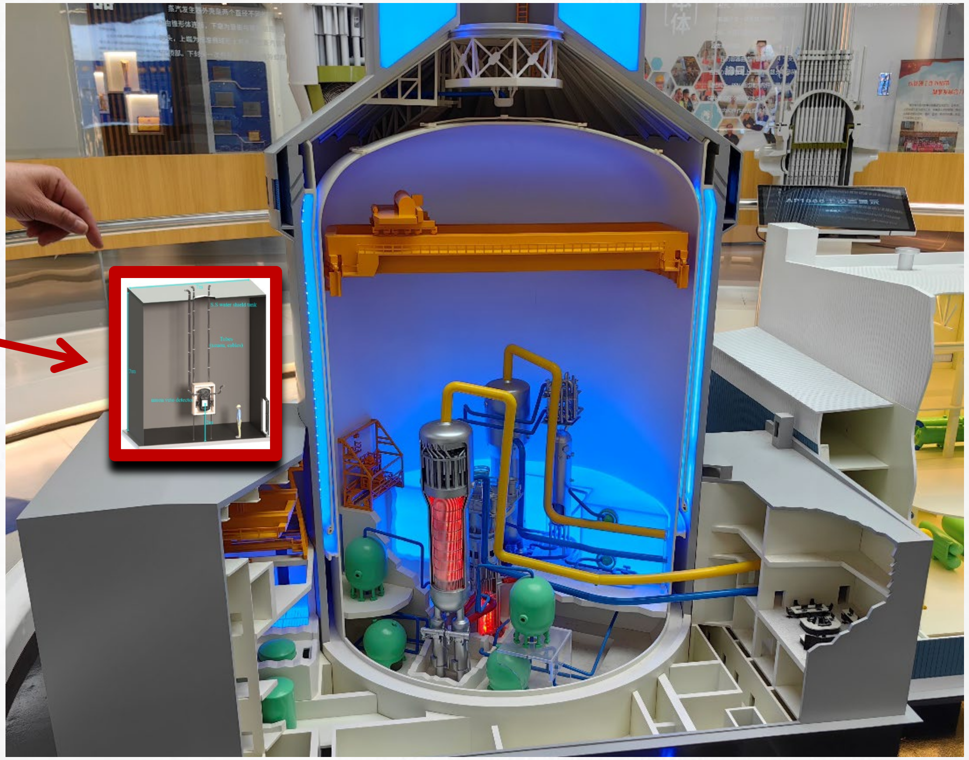
RELICS Site





Challenges :

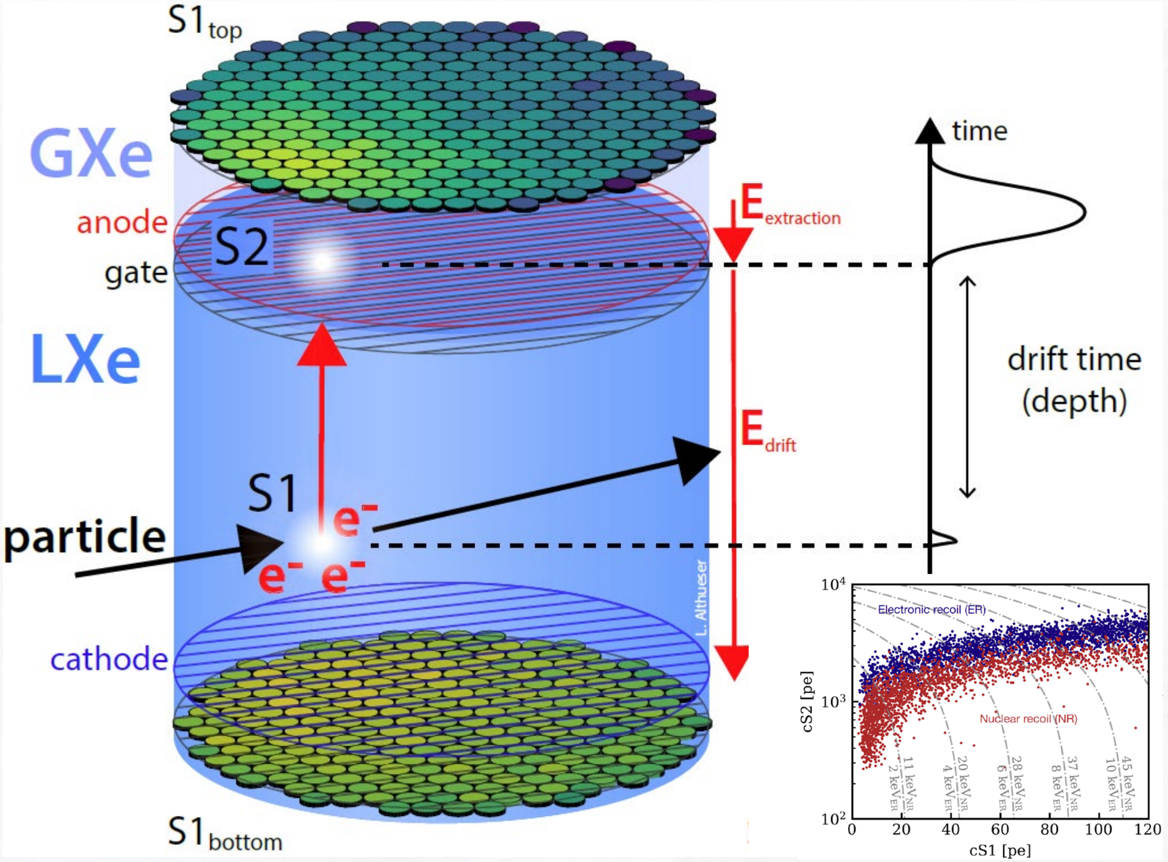
- An intense neutrino source



- Sanmen Nuclear Power Plant, Taizhou, **China**
- Reactor Power ~3.4GW
- Distance to Core ~25m
- Neutrino flux $\mathbf{\sim 10^{13} \nu / cm^2 / s}$

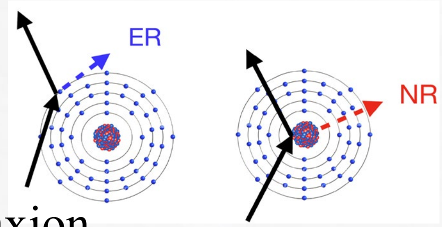
Technology of RELICS: LXeTPC

Liquid **X**enon **T**ime **P**rojection **C**hamber (**LXeTPC**)



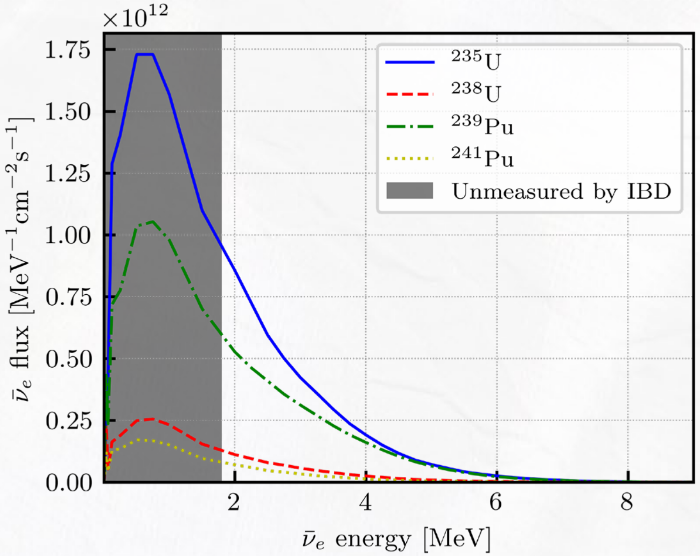
CR: XENONnT Collaboration

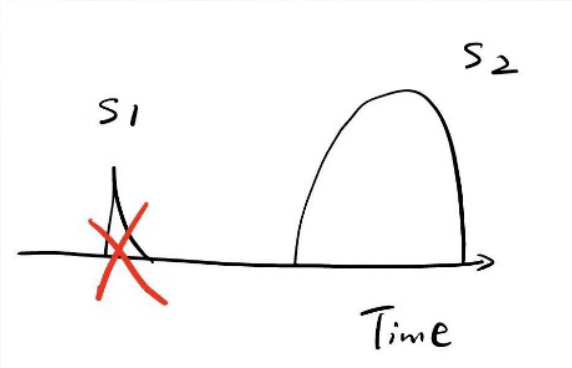
- Energy reconstruction
- 3D position reconstruction
- Particle interaction identification
  - ➢ Electronic recoil (ER)
  - ➢ Nuclear recoil (NR)



β, γ, axion

ν, n, WIMP





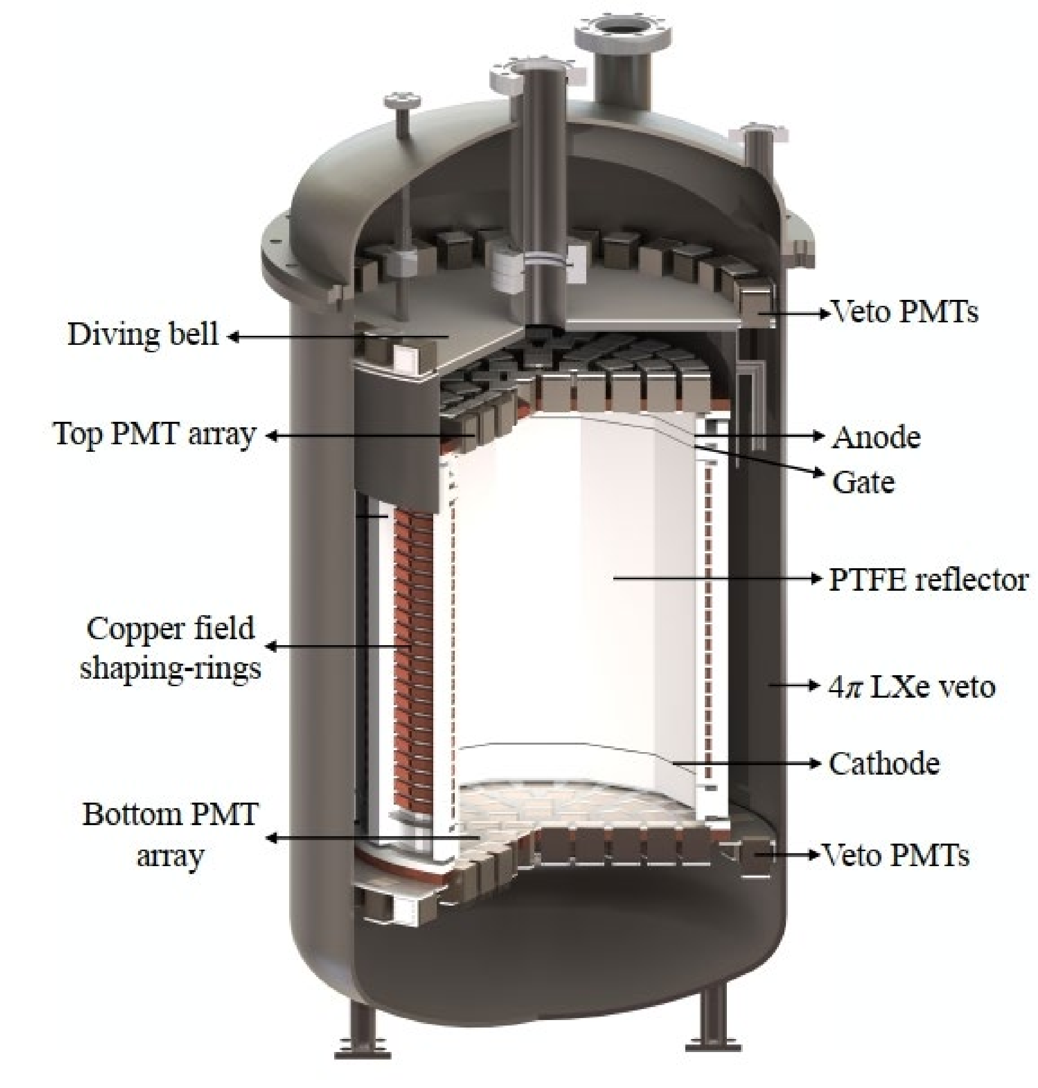
S2-only analysis

- Energy of **Reactor neutrinos** ~ **MeV**
- **S1** signal is **too weak** to detect
- Corresponding **nuclear recoil energy** in LXe ~ **1keV**

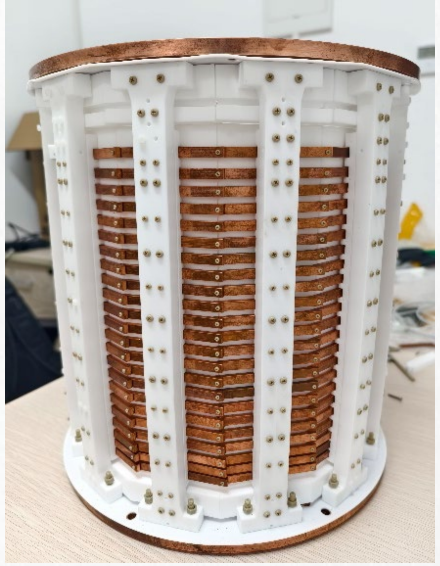
Challenges:

- **Low detector thresholds**

RELICS LXeTPC Design



- **32 kg** LXe fiducial mass.
- **Diving bell** for LXe level control and 4π anti-coincidence.
- **Drift field**: 500V/cm
  Extraction field: 10kV/cm
- Two 64 one-inch **PMT array**



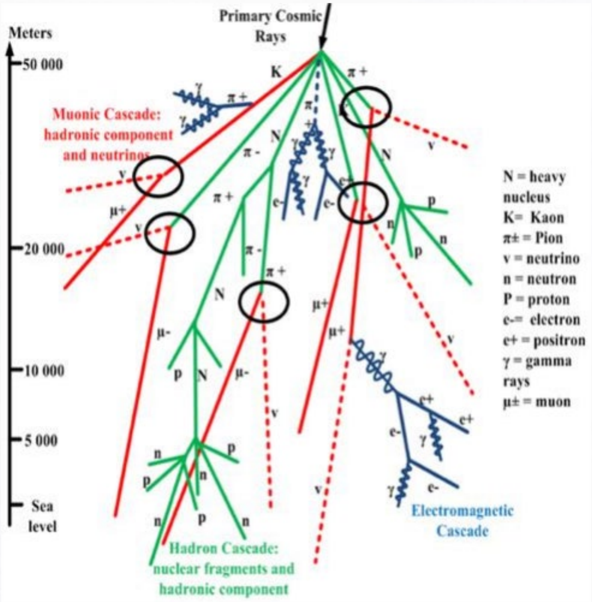
Engineering Prototype

PMT

Background Source

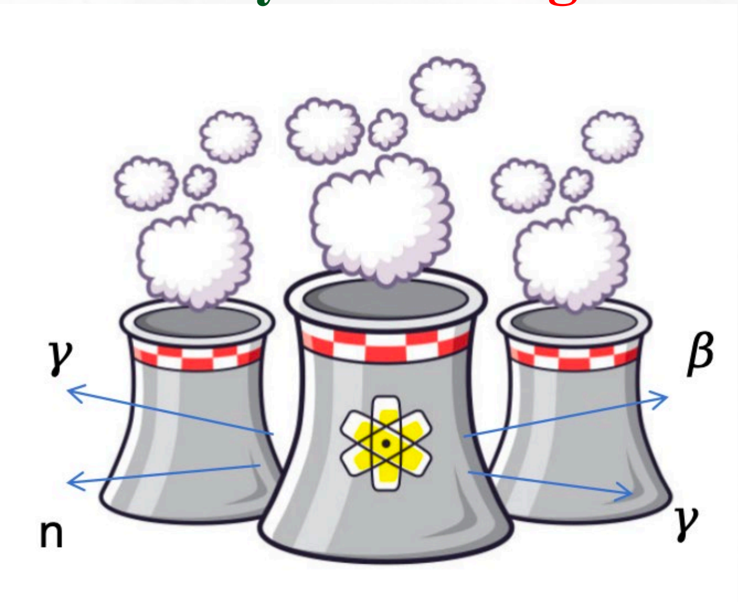
Challenges:

- **Incredibly low backgrounds**



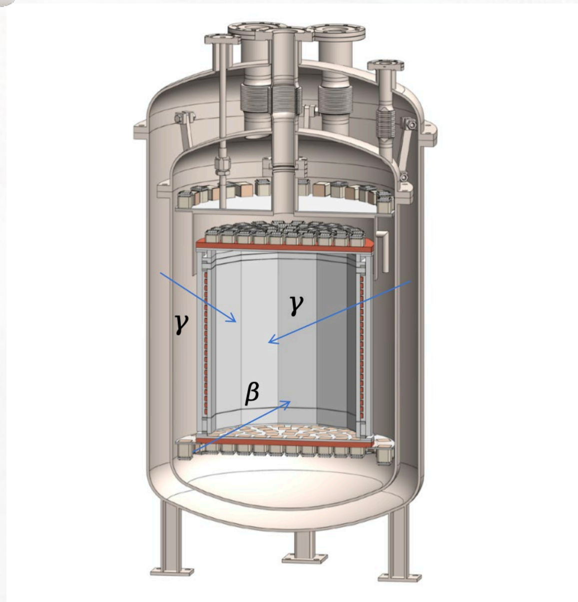
Cosmic ray

- Cosmic muon
- Cosmic ray neutron
- ...



Reactor

- Neutron
- Gamma
- ...

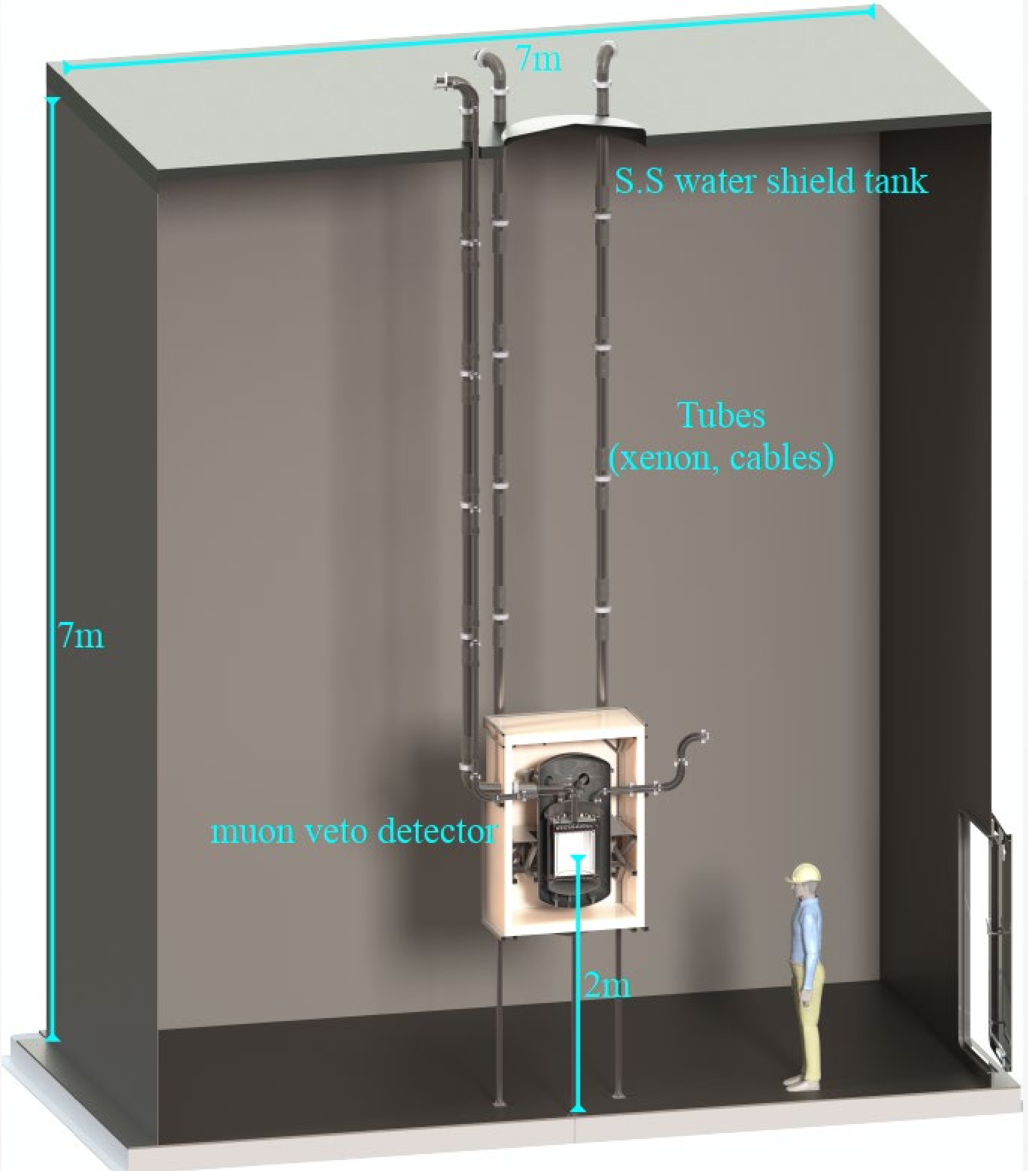


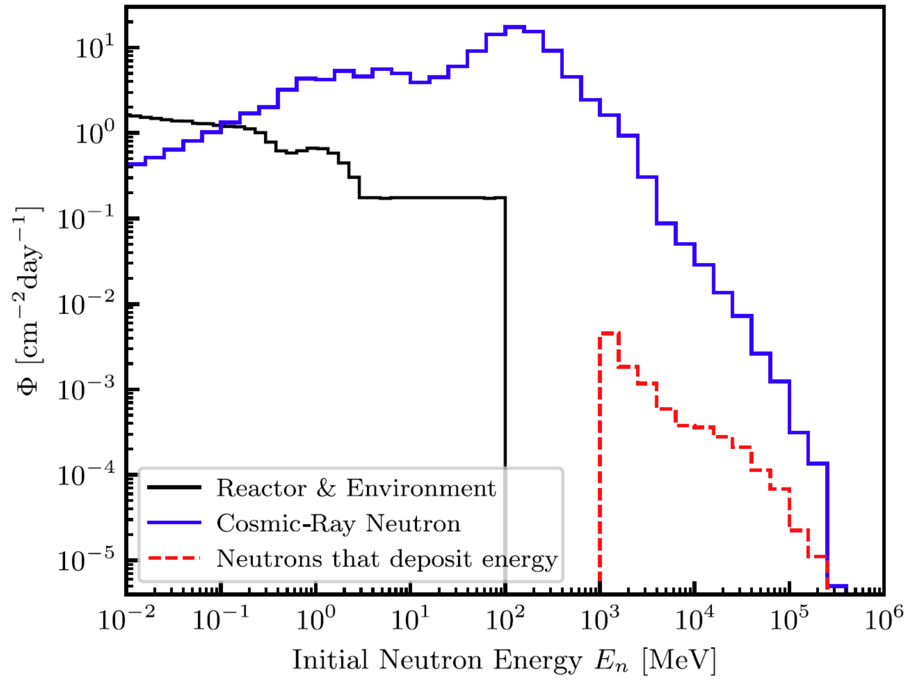
Detector itself

Neutron, gamma from

- Stainless Steel
- PMT
- LXe
- ..

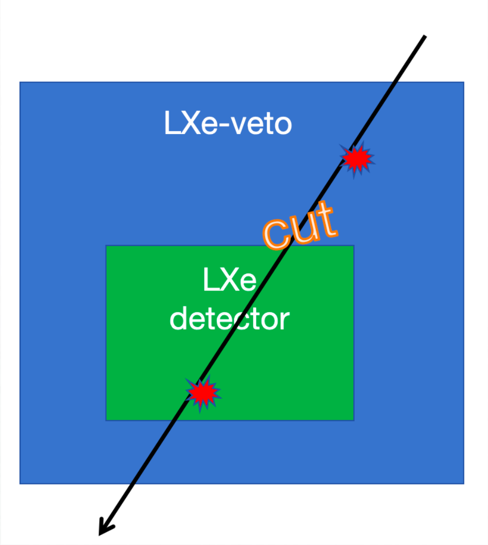
Background Control based on MC : Shield of detector

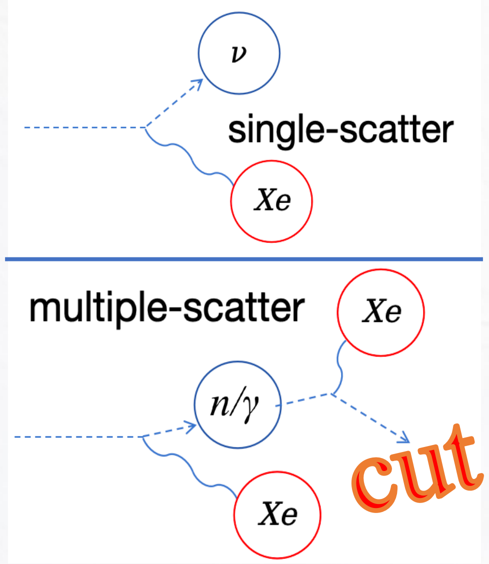




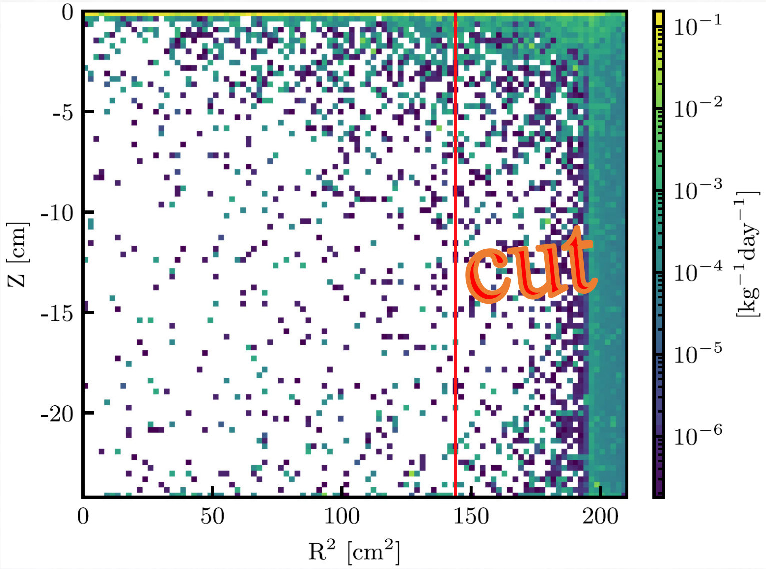
- **7×7×7m water shield** to suppress Cosmic-Ray & Reactor Neutrons induced background
- **4π plastic scintillator** muon veto detector with veto efficiency of 99%
- Low-background materials are selected

Background Control based on MC: Event Selection



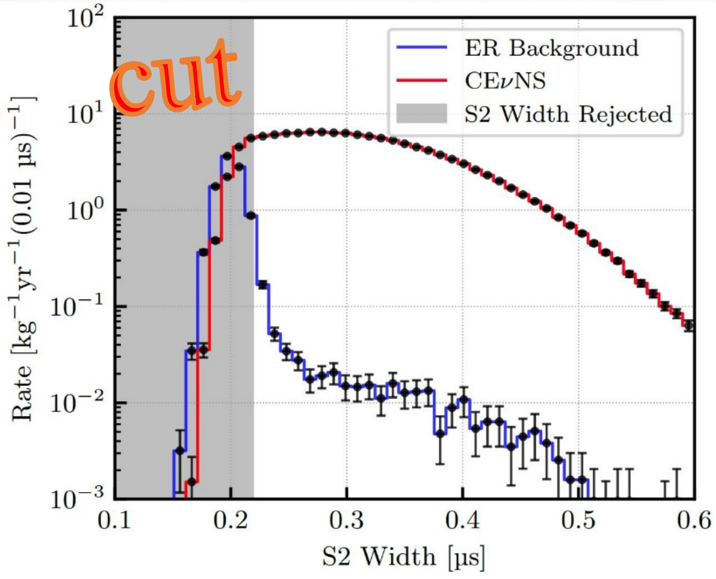


I. 4π LXe-veto:
Remove events with E_{NR} > 500 & E_{ER} >100 keV in the LXe veto region.



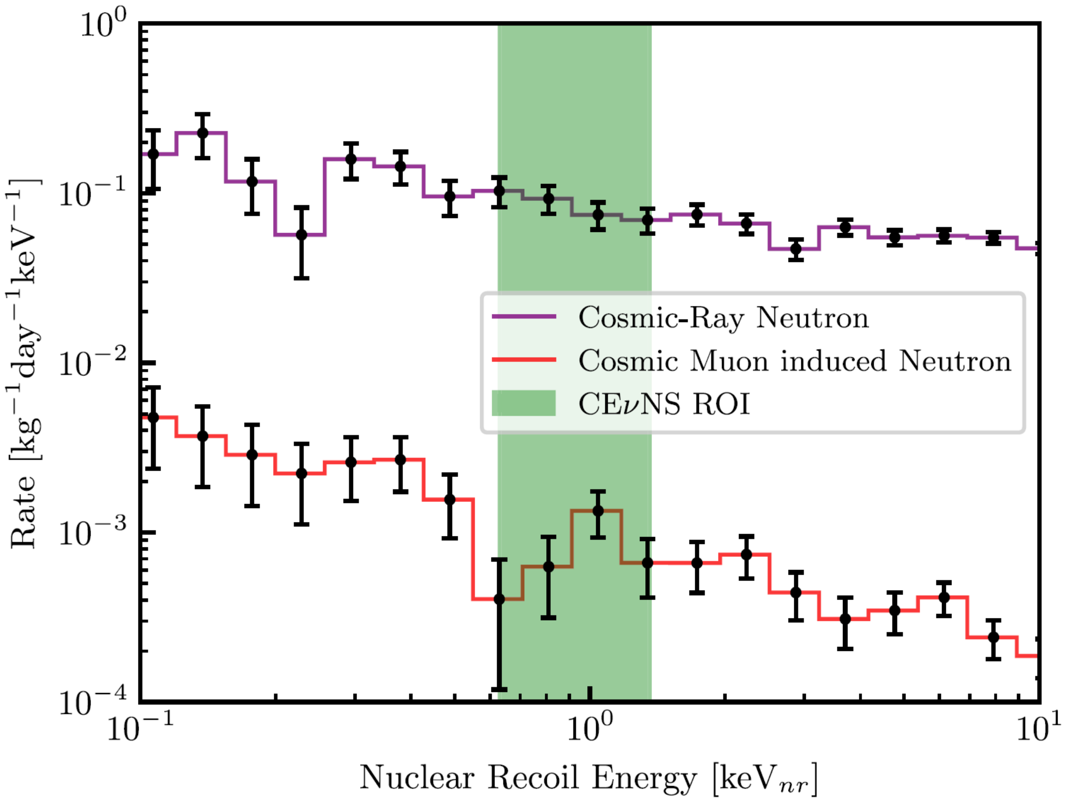
II. Fiducial Volume:
Restrict events to a 12 cm radius FV (32 kg) to reduce edge backgrounds.

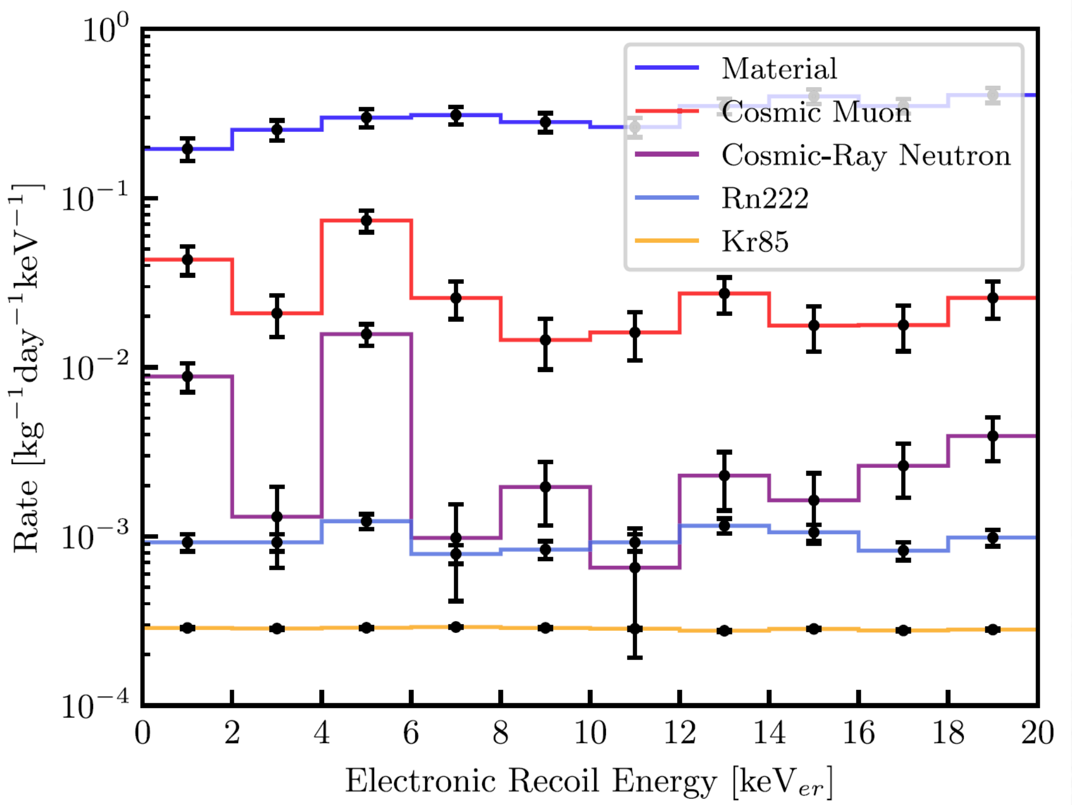
III. Single-scatter
Require E_{ER} < 0.05 keV for NR events and second-largest E_{ER} < 5% of the largest for ER events.



IV. S2 width cut :
Require S2 width > 0.22 μs to exclude events near the liquid-gas interface, targeting detector material backgrounds.

Background of RELICS based on MC





NR background are dominated by

Cosmic Ray Neutrons

Expected case rate:

$$(7.7 \pm 0.7) \times 10^{-2}\ kg^{-1} \cdot\ day^{-1}$$

(Value of **[0.3,1]** keV range)

ER background is dominated by

Material

Expected case rate:

$$(364\ \pm\ 5) \times 10^{-3} kg^{-1} \cdot\ day^{-1} \cdot\ keV^{-1}$$

(Average value of **[0,40]** keV range, before S2 width cut)

Delayed Electrons (DE) Background

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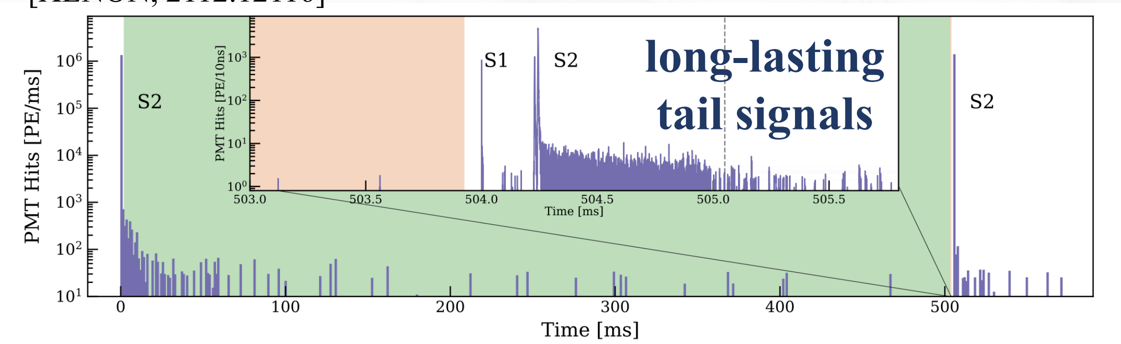
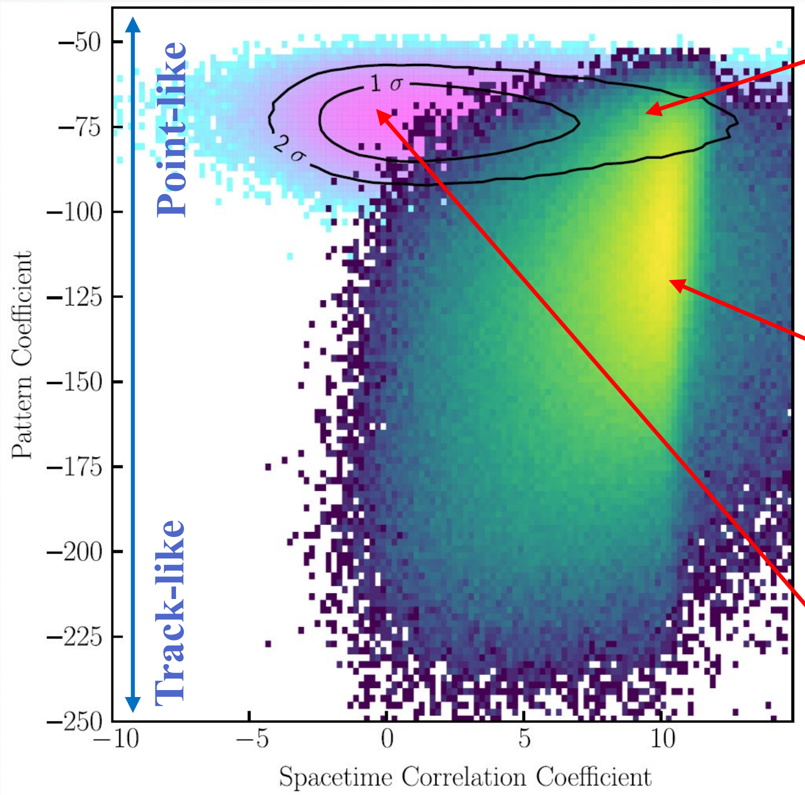
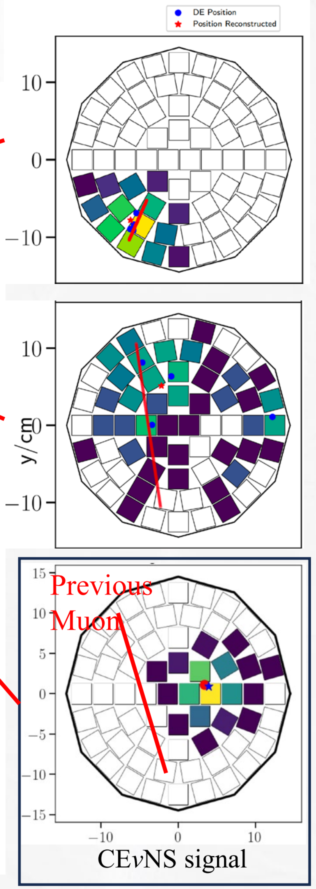
[XENON, 2112.12116]



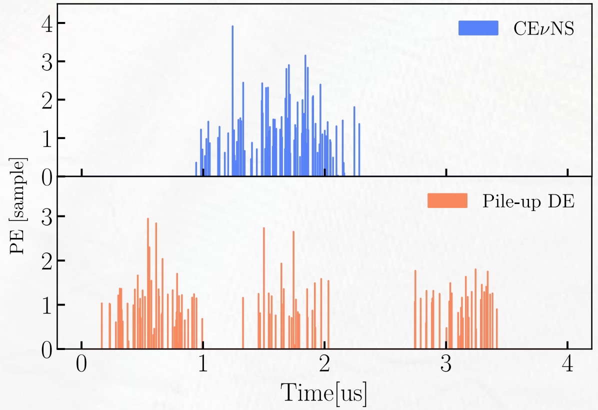
No   Related to last muon?   Yes



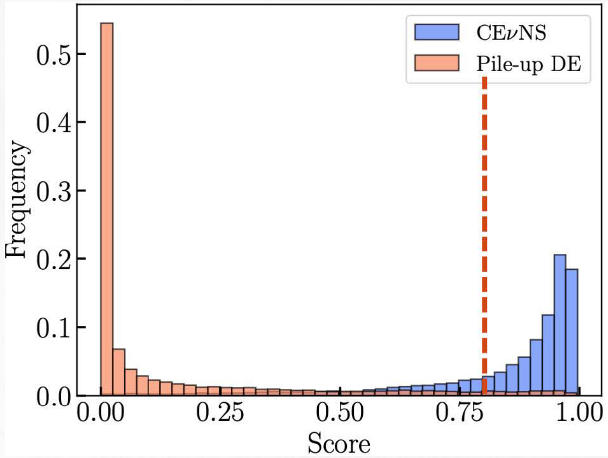


DE pollutes the S2-only channel

- **Pattern + Correlation selection:**
  a) CEνNS : Closer to single - point events.
  b) DE: More linked to the preceding muon track.

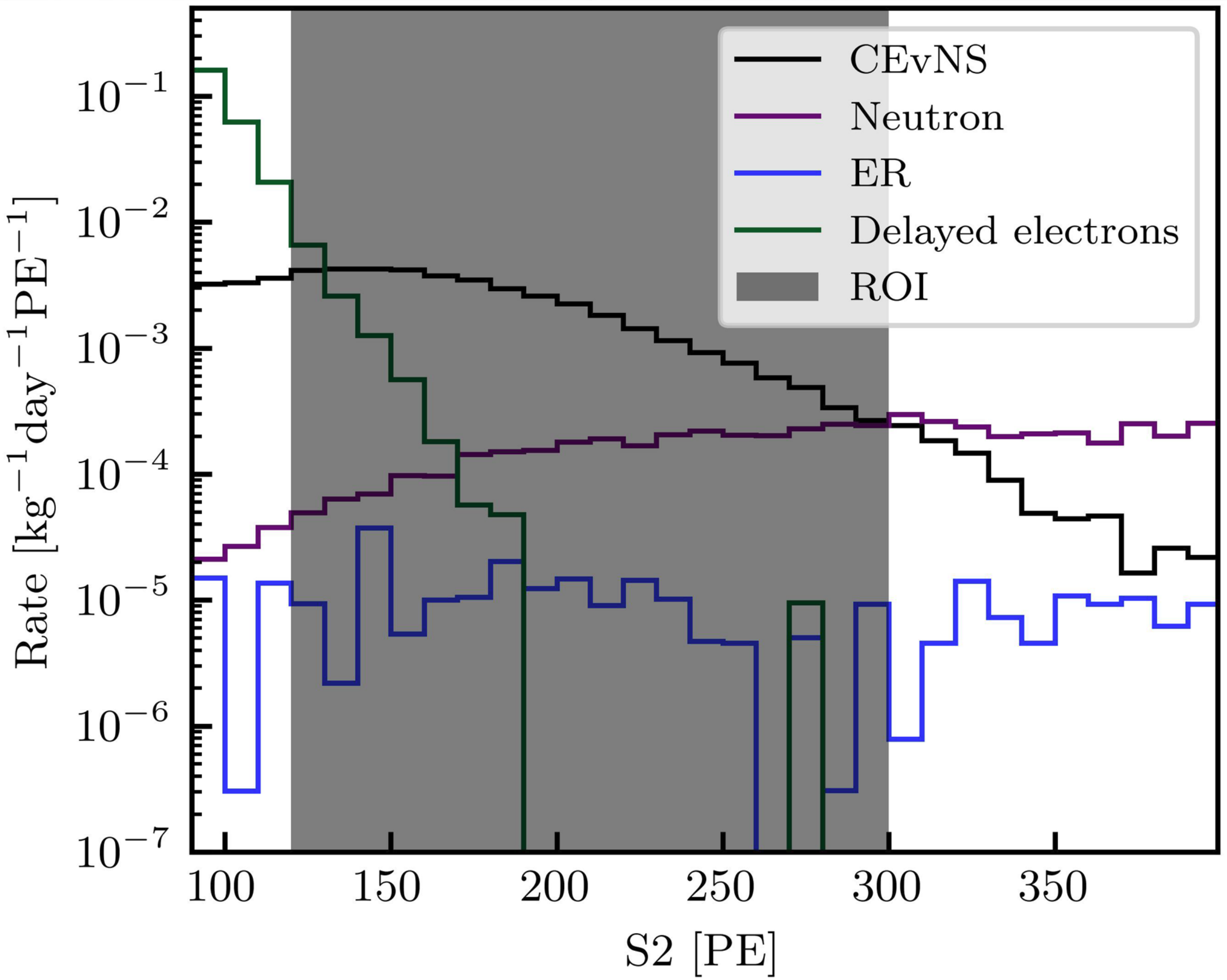


- **Waveform selection:**
  Use CNN to extract waveform features to reduce DE
  a) CEνNS : Guassion
  b) DE: More dispersed



	Signal Acceptance	Background Remaining
Pattern + Correlation	~52%	~ 0.01%
Waveform	~80%	~10%

Total background



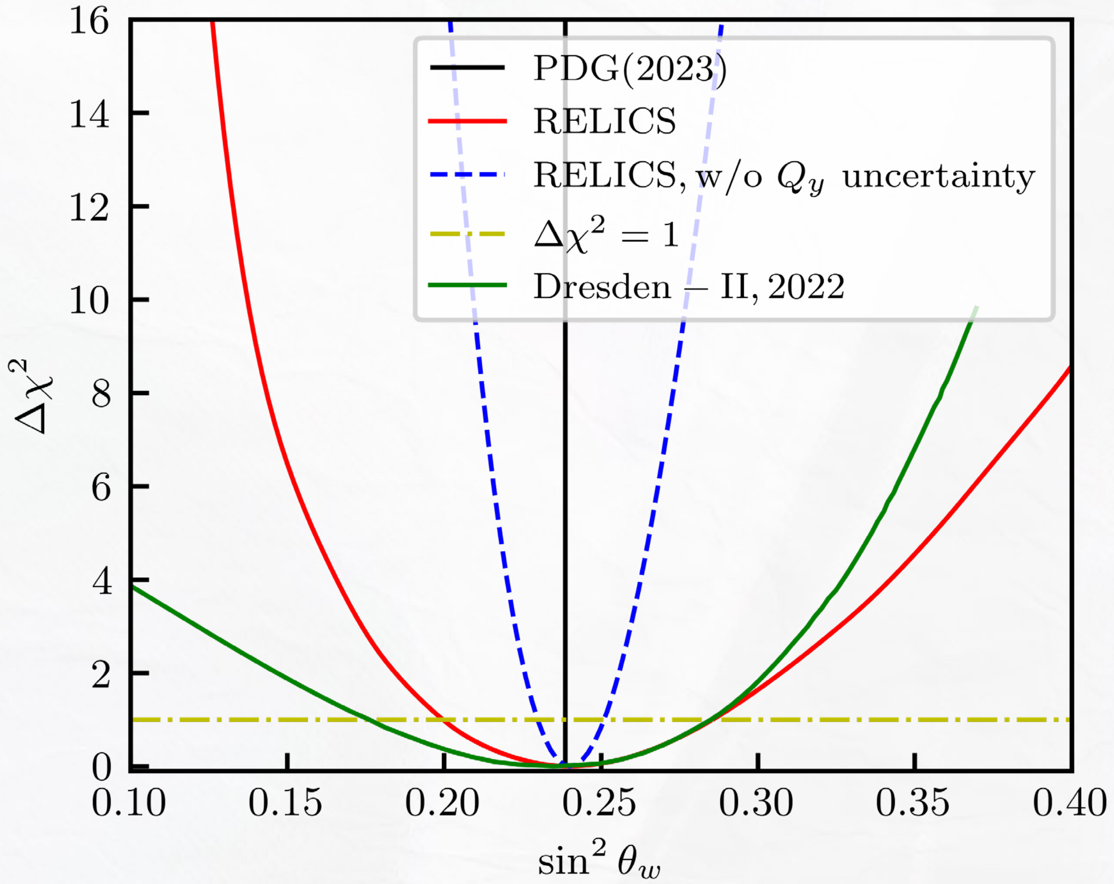
Challenges:

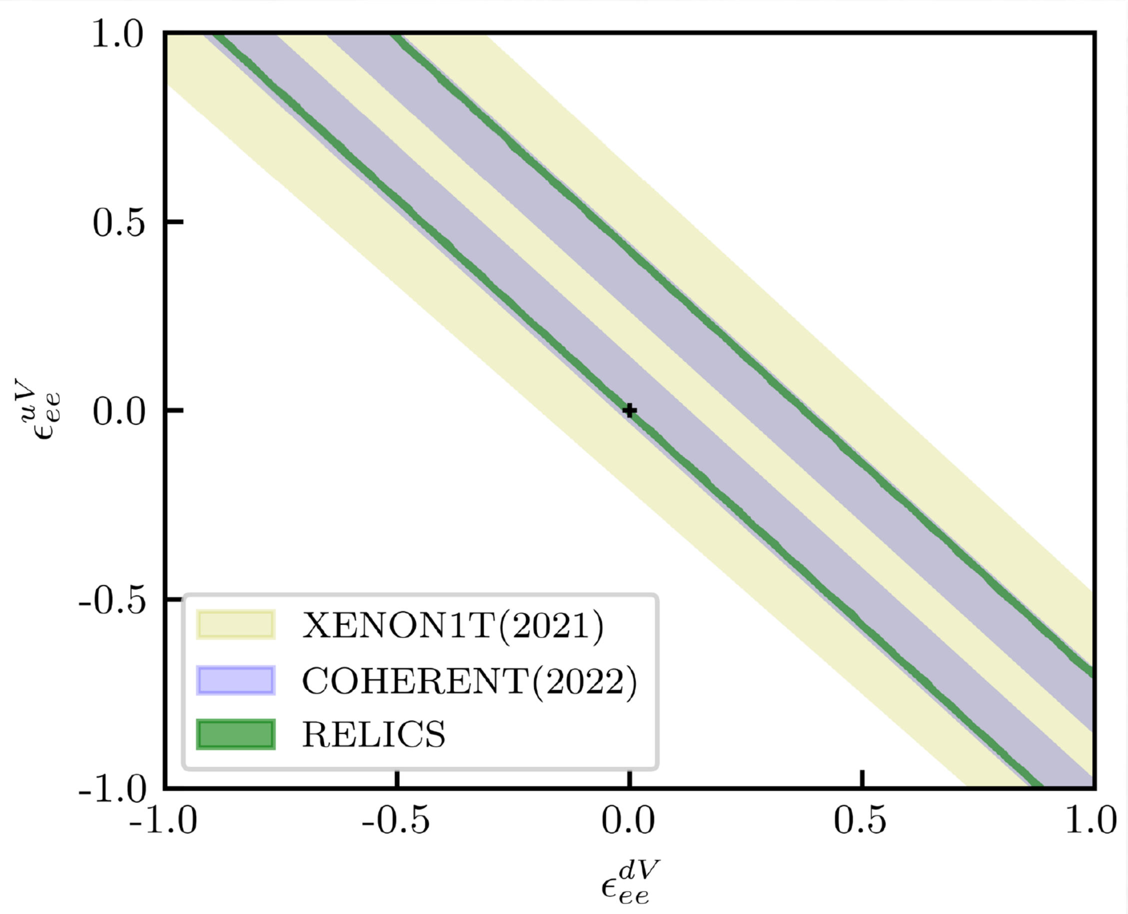
- **Incredibly low backgrounds**

CEvNS ROI: [120, 300] PE

	Events/($32kg \cdot year$)
CEvNS	**4639.7**
Total background	**1687.8**
Pileup DE	1325.1
Cosmic Ray Neutron	339.9
ER	21.1
μ-induced neutrons	1.7

Sensitivity estimation





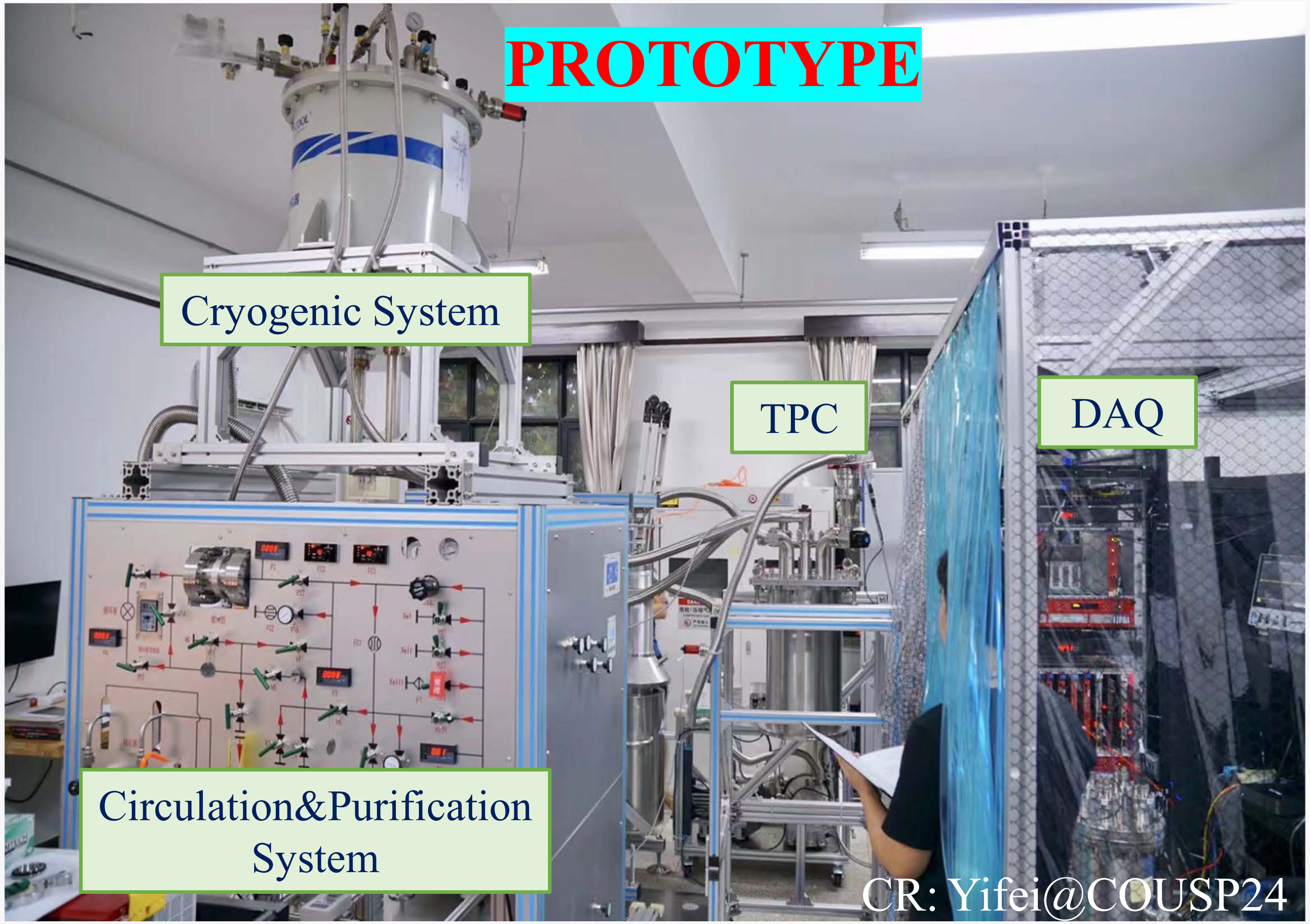
Weak Mixing Angle：

- Can measure the weak mixing angle at low momentum transfers down to the MeV scale.

Non - Standard Neutrino Interactions：

- More competitive constraints than the COHERENT experiment.

Status of RELICS



- 2023

☑ Detector MC simulation
☑ Sensitivity calculation
☑ Prototype development

- 2024

☑ Prototype testing
☑ Detector system design optimization

- **2025**

☐ Shielding and detector fabrication
☐ Detection system on-site

- 2026

☐ On-site detection system commissioning
☐ First-batch physical data acquisition.

- 2027

☐ Physical analysis
☐ Release of first-batch results

Summary

I. RELICS is a low threshold, low background, LXeTPC detector planned for reactor neutrino.

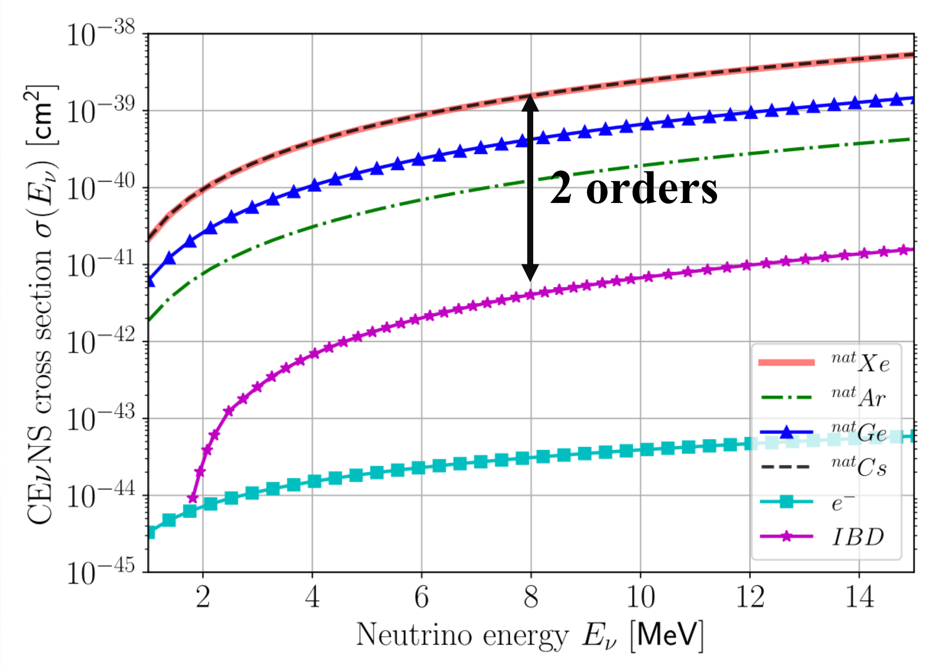
II. The main background sources in RELICS are **delayed electrons**, **cosmic - ray neutrons**, and detector **material**.

III. RELICS will find **~4600** CE*ν*NS events per year, probing **weak mixing angle** and **NSI**.

Outlook

- RELICS has rich physics:
  - Precise measurement of reactor neutrinos
  - Competitive in the search for **axions**, which can explore or close the Cosmological Triangle…

- High application value of nuclear safety:
  - More effectively realize reactor monitoring without direct contact than IBD.



THANKS!

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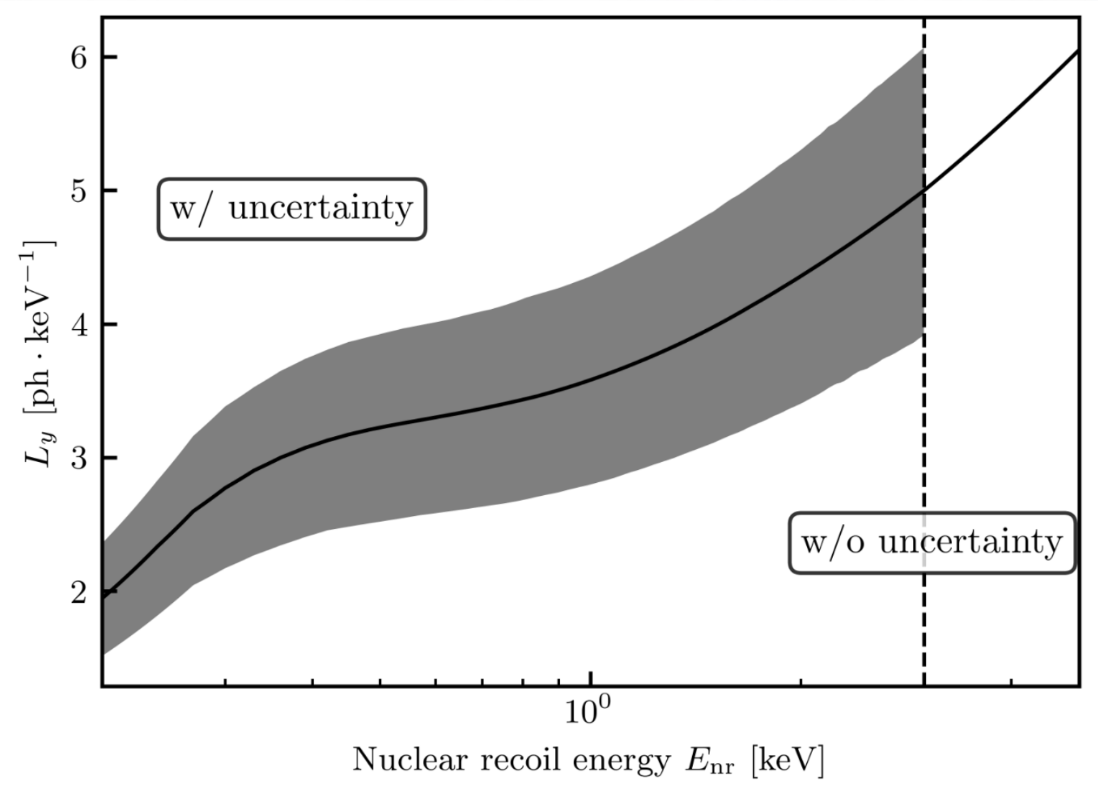
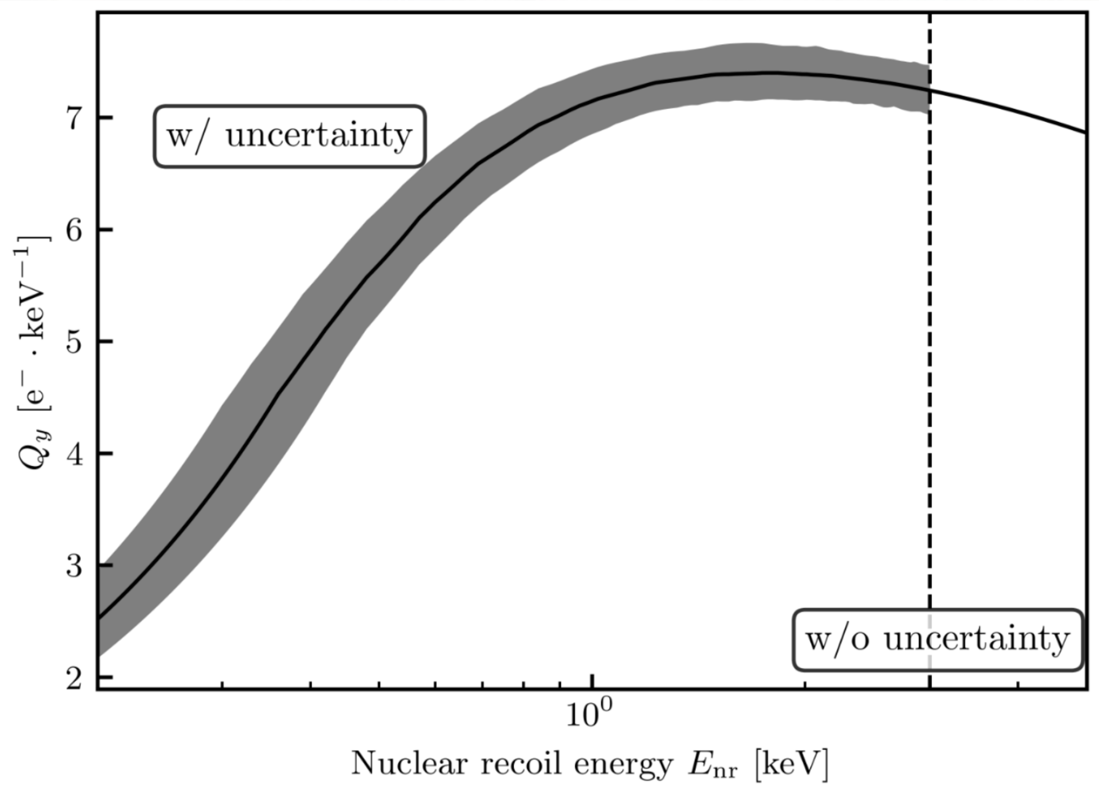
Sun Yat-sen University

Backups

Liquid xenon response



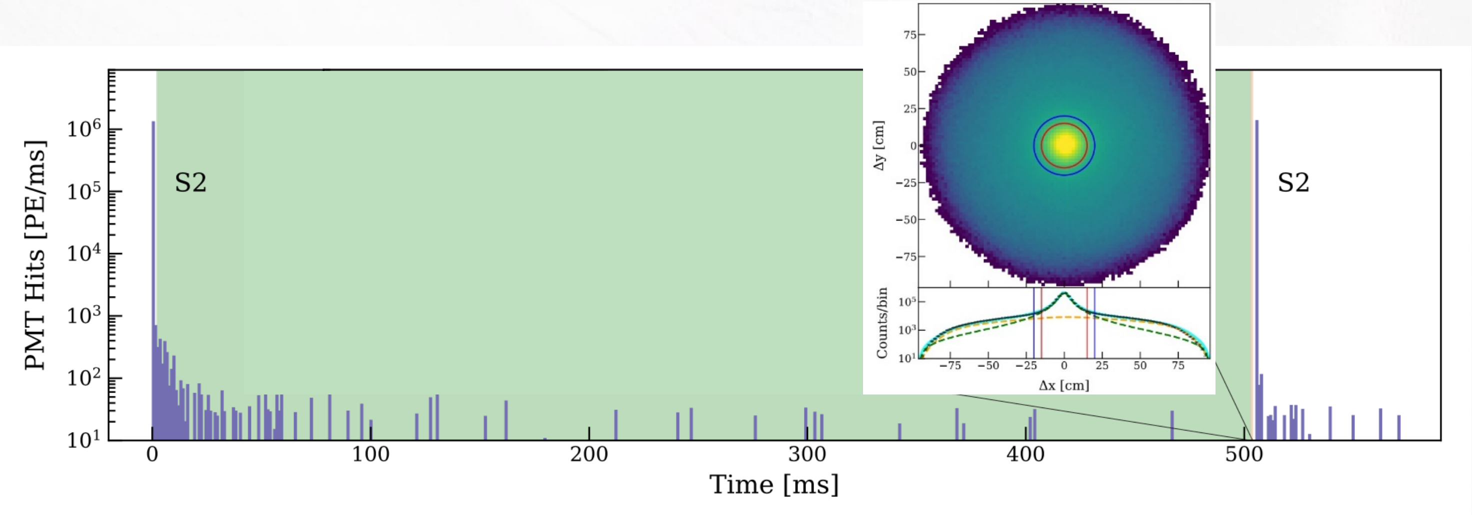


- $E_{NR} > 3keV_{nr}$: light yield (L_y) and charge yield (Q_y) from the NEST model (v2.3.6) are used with 500 V/cm drift field
- $E_{NR} < 3keV_{nr}$: the XENON1T yields model in 8B neutrino search is adopted, and scaled to NEST model at 3 keV_{nr}
- 4π LXe Veto Region: L_y and Q_y are modeled with zero electric field

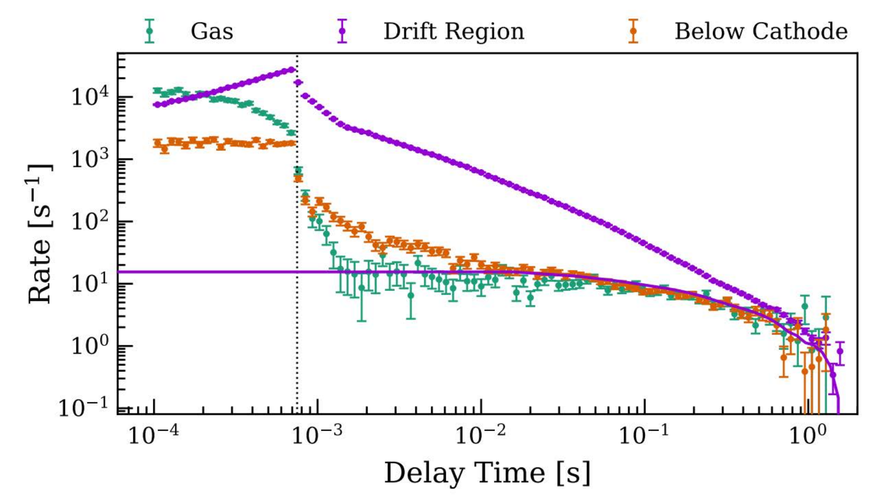
Delayed Electrons (DE) Background

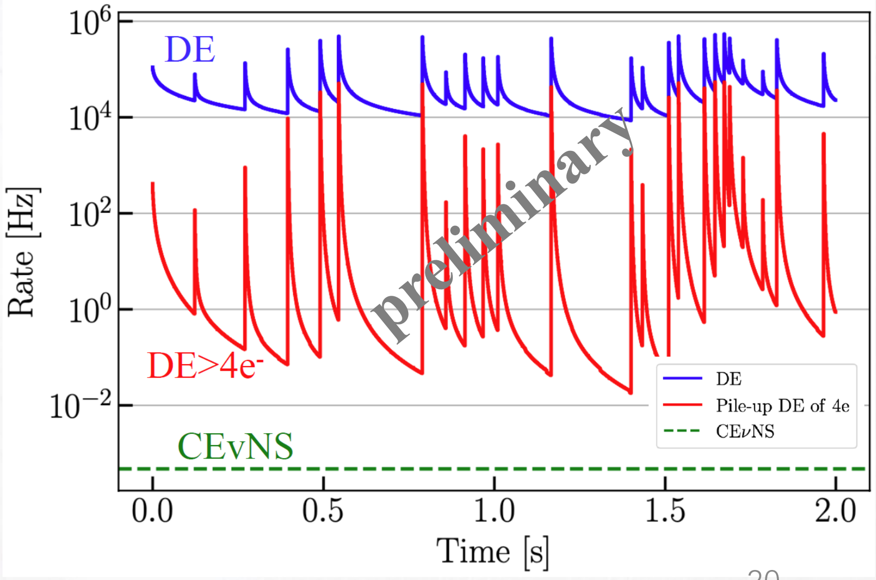
Phys. Rev. D 106, 022001(2020)

Position Correlation



Time Correlation





- Count is closely tied to **xenon purity** and **extraction field**.
- **Position and time correlation**, show **power-law decay** over time, with delays exceeding 2 seconds.
- **Muon (~10Hz)** can produce **DE pile-ups**, major background in CEvNS signal region (4-6e-)

Prototype Testing

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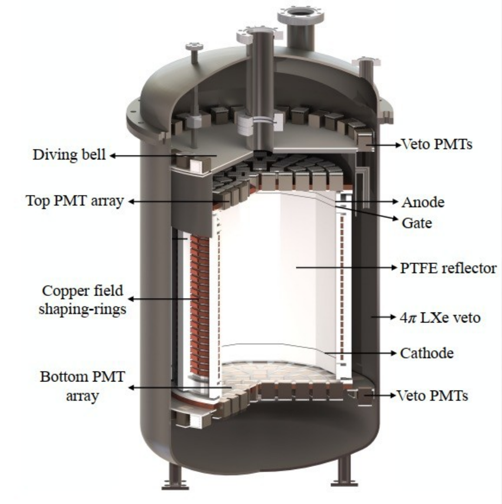
Prototype		Full Detector
✓	Cooling, circulation	✓
✓	DAQ	✓
✓	Calibration	✓
✓	Liquid level control	✓
SOON	Veto (muon, gamma)	✓
✗	Shielding	✓
0.5 kg	Total mass	32 kg
8	PMT number	~128



CR: Yifei@COUSP24