RELICS: Search for Coherent Elastic Neutrino-Nucleus Scattering from reactor neutrinos using LXeTPC

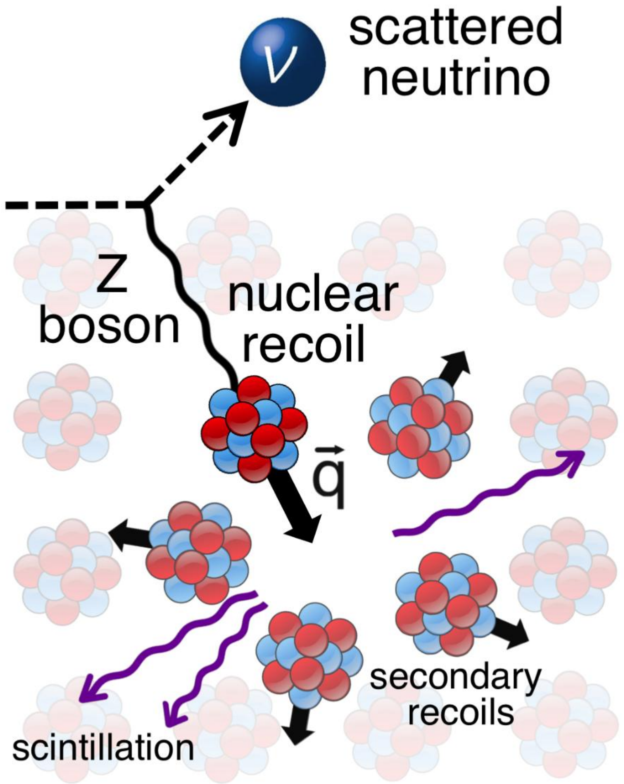
Jiachen Yu (USTC)

yujiachen@mail.ustc.edu.cn

On behalf of the RELICS collaboration

Xichang, Sichuan, China, TAUP2025

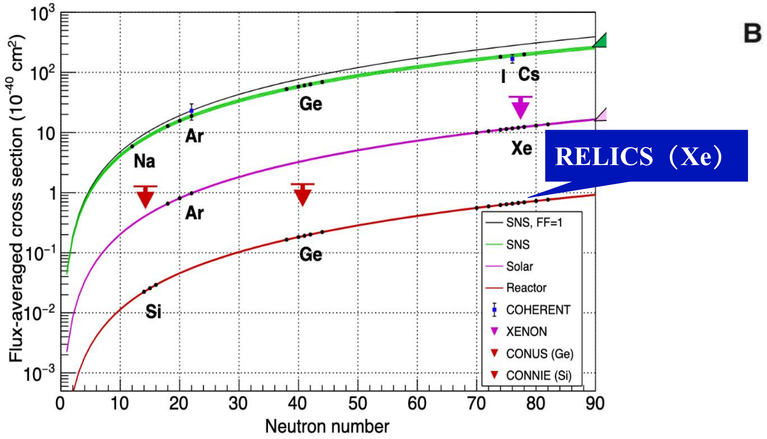
Coherent Elastic Neutrino-Nucleus Scattering: CEνNS

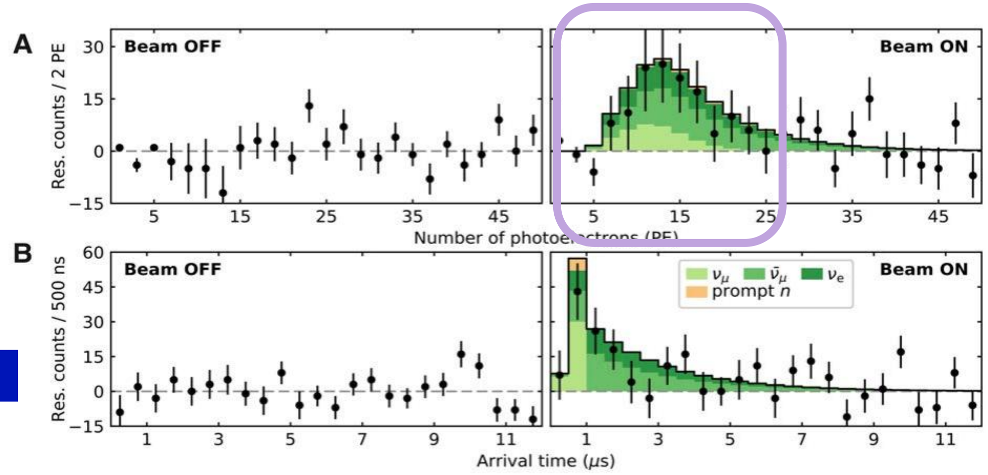


$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M\left(1 - \frac{MT}{2E_\nu^2}\right)F(Q^2)^2.$$

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

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





D. Akimov et al, Science 357 (2017)

Physics:

- weak mixing angle within Low-momentum transfer

Opportunities:

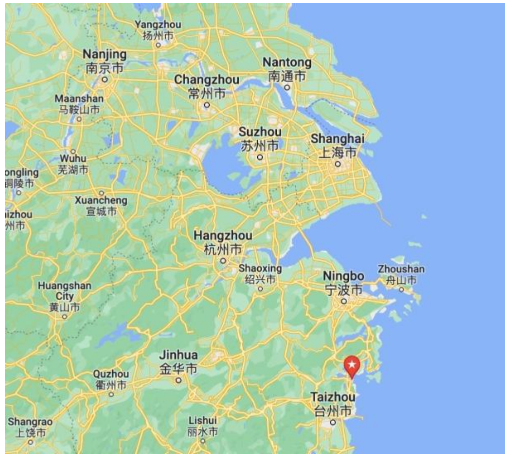
- Cross section proportional to the square of the number of nucleons
- Smaller neutrino detectors

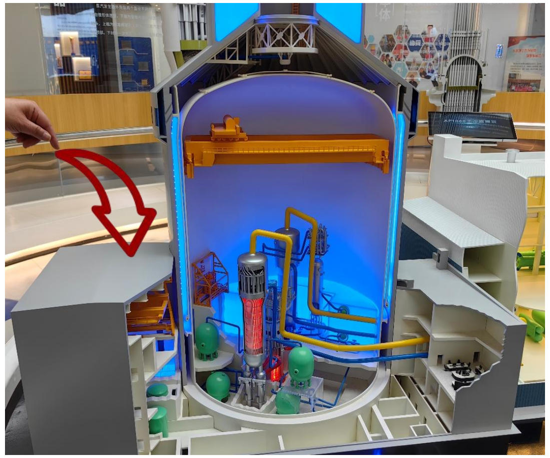
Challenges:

- low nuclear recoil energy
- Energy ROI for RELICS: $[0.3,1]\mathrm{keV_{nr}}$

RELICS Experimental Design

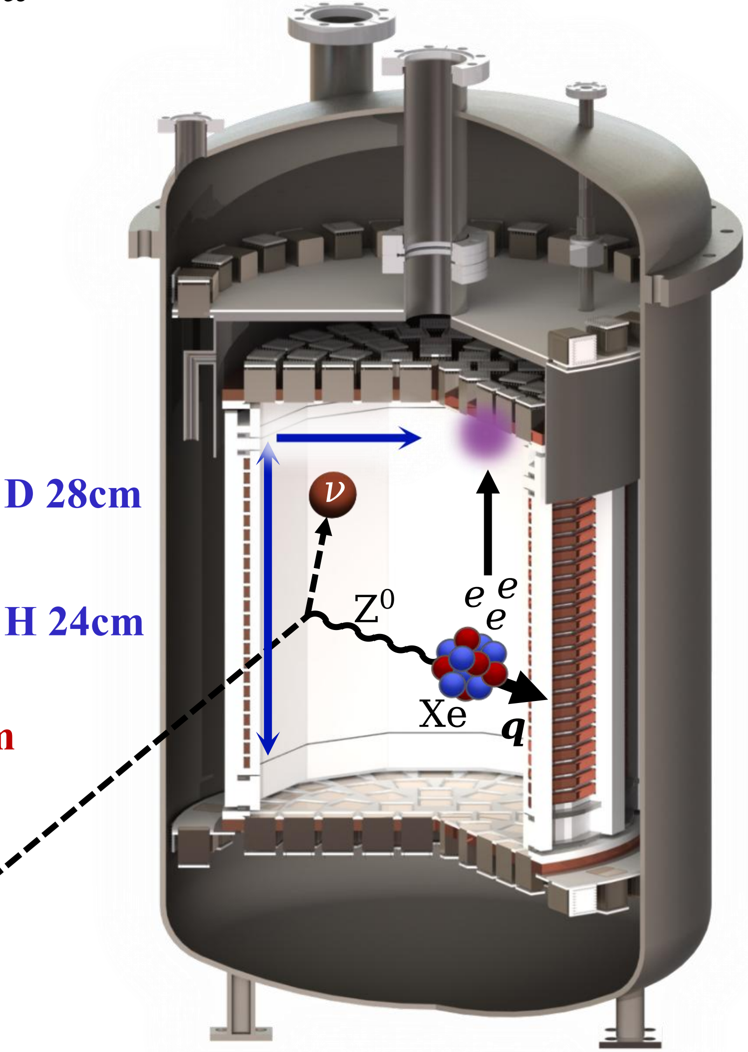
Sanmen Nuclear Power Plant Taizhou , China

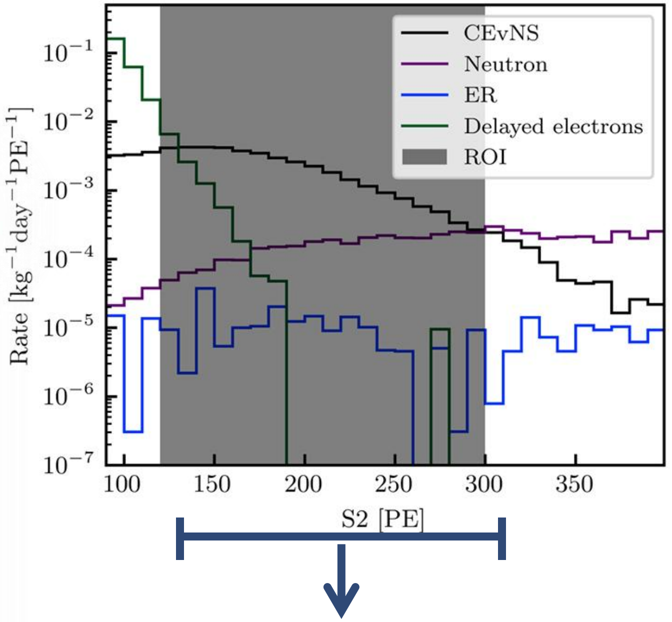




AP1000 Thermal power ~ 3GW

ν flux ~ 10^{13} $cm^{-2}s^{-1}$





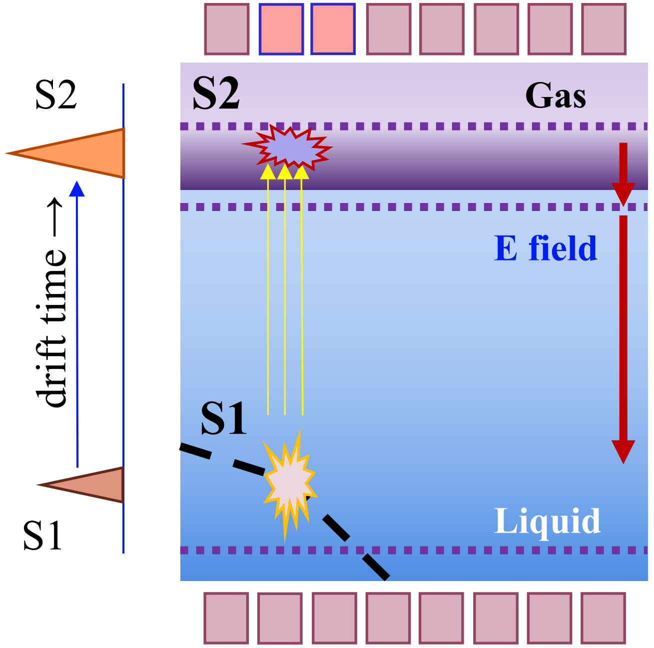
low energy region :

Energy ROI : [0.3,1] keV_{nr}

S2 ROI : [120, 240] PE

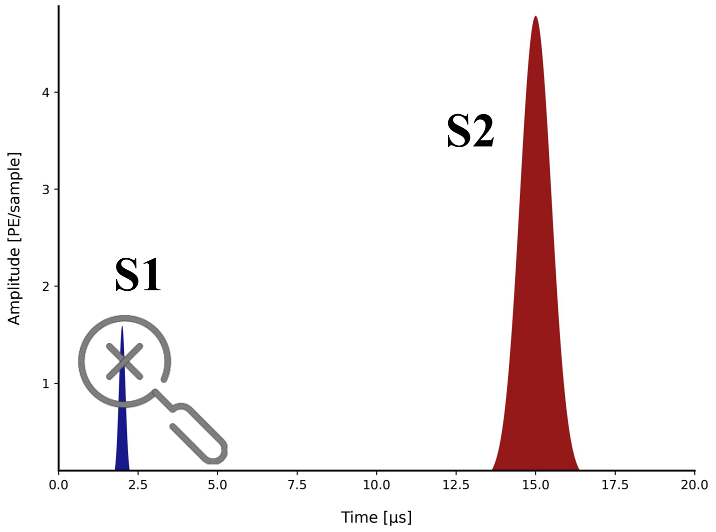
Fiducial Mass 32 kg, 62kg LXe in total

Technology of RELICS Experimental :LXe TPC



Advantages of LXe TPC :

- ☐ high single electron detection efficiency
- ☐ XY position reconstruction
- ☐ low threshold

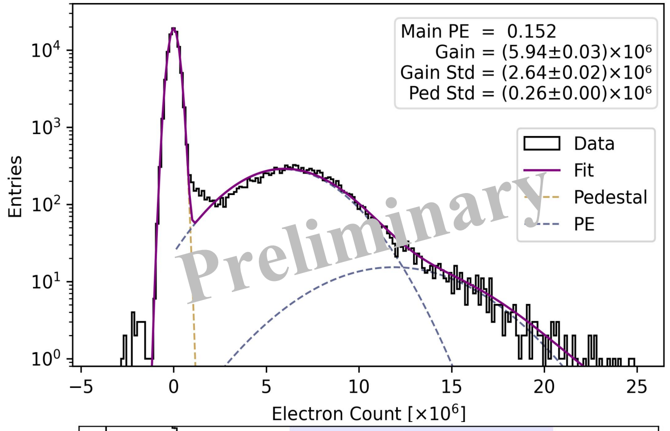


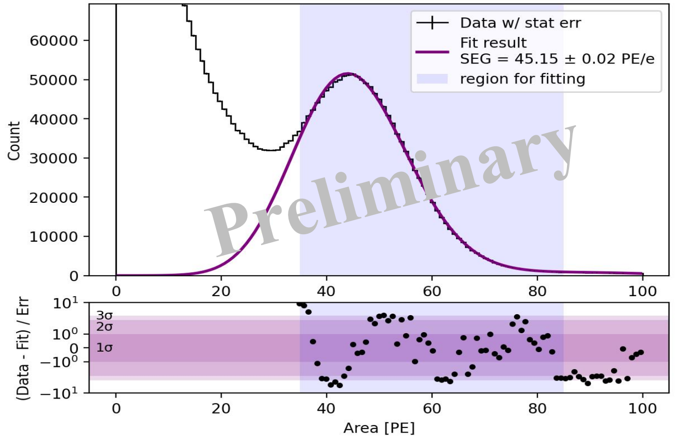
low nuclear recoil energy :

- ☐ Energy ROI : [0.3,1] keV_{nr}
- ☐ S2 ROI : [120, 240] PE

S2-only analysis :

- ☐ S1 signal is too weak to detect
- ☐ Further reduce the energy threshold





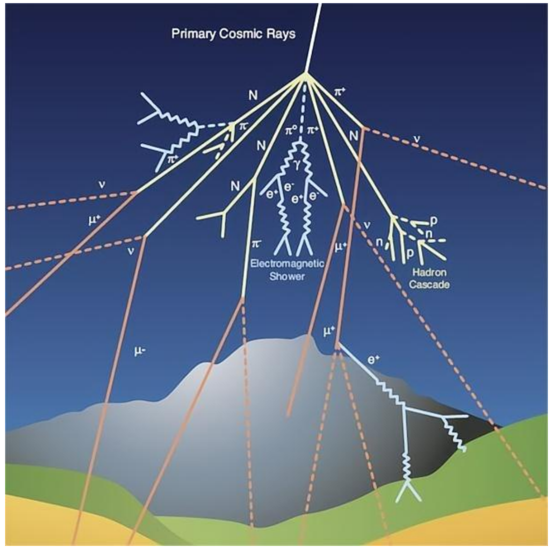
see report by Lingfeng Xie

Low-threshold detection :

- ☐ Single PE trigger rate > 90%
- ☐ Single-Electron detection gain > 30 PE

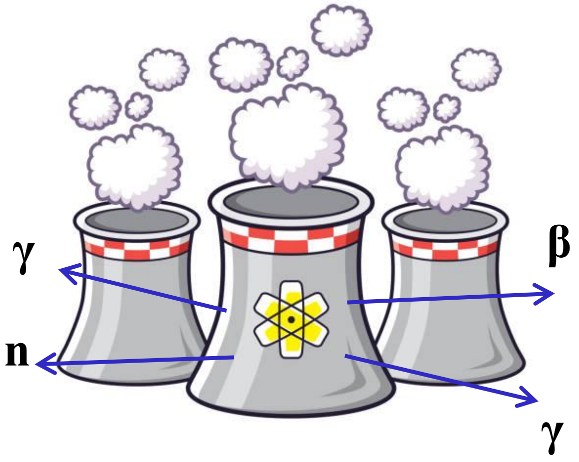
Challenges: Background Sources on ground

Cosmic Ray Particles



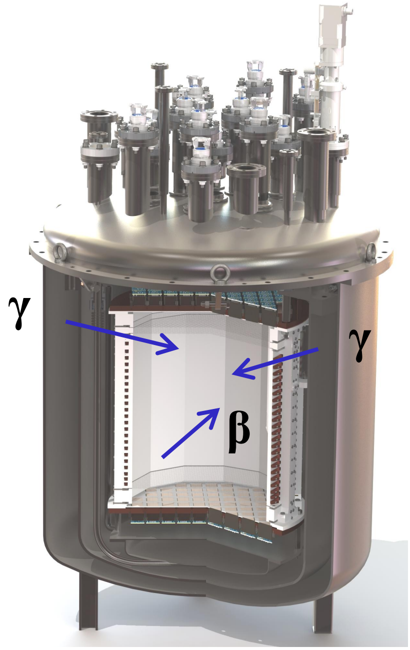
- ☐ Cosmic μ
- ☐ Cosmic neutron
- ☐ Others…

Reactor



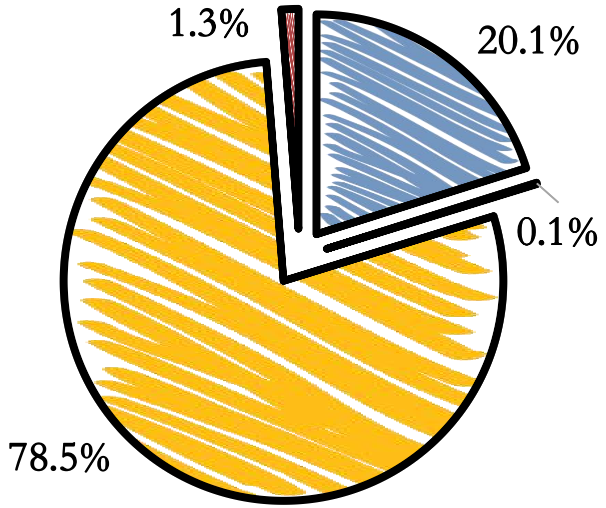
- ☐ Reactor Neutron
- ☐ Reactor γ
- ☐ Others…

Detector Material



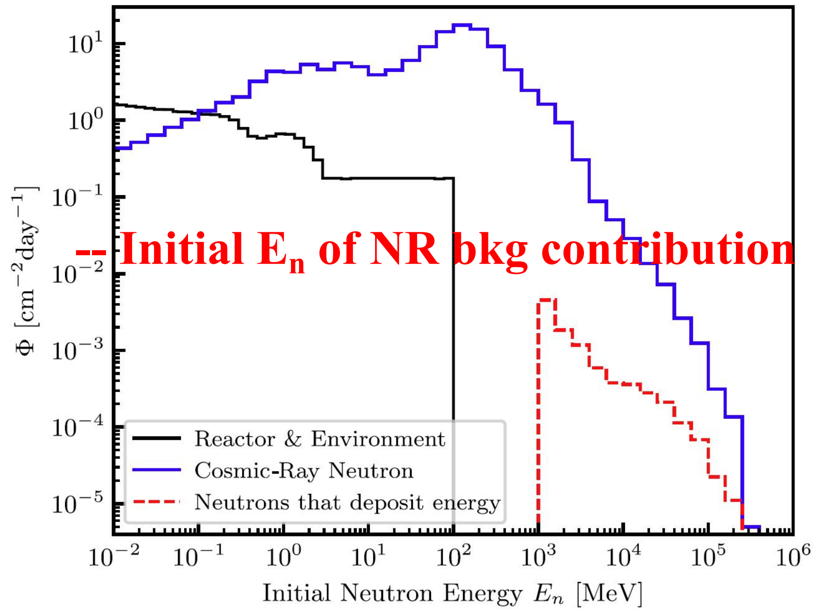
- ☐ Material γ, β
- ☐ Others…

Background ratio



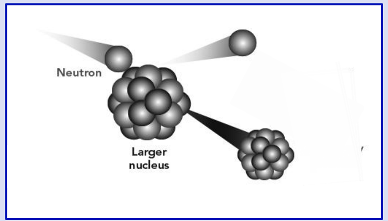
- cosmic ray neutron 20.1%
- muon induced neutron 0.1%
- delayed electron 78.5%
- cosmic & meterial 1.3%

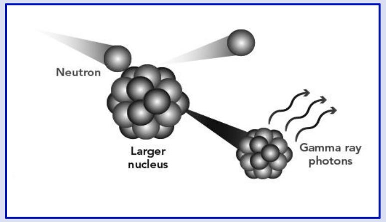
NR Background and Shielding Suppression

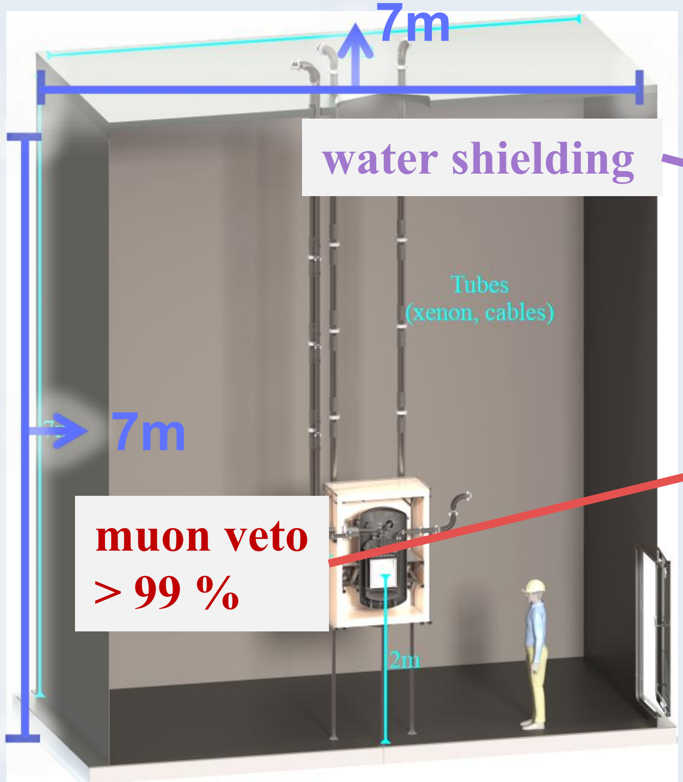


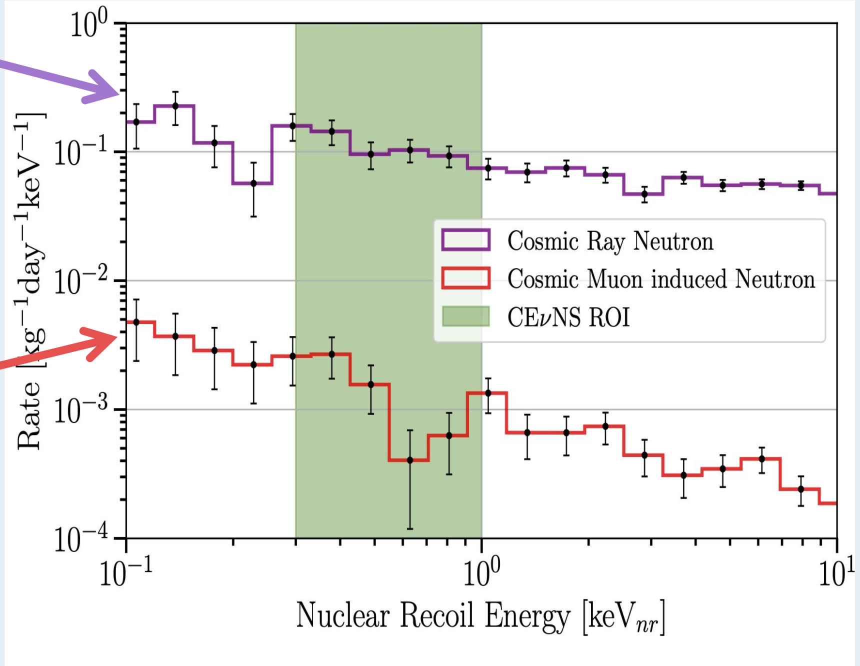
--- Cosmic-Ray neutron

---- Reactor & Environment neutron





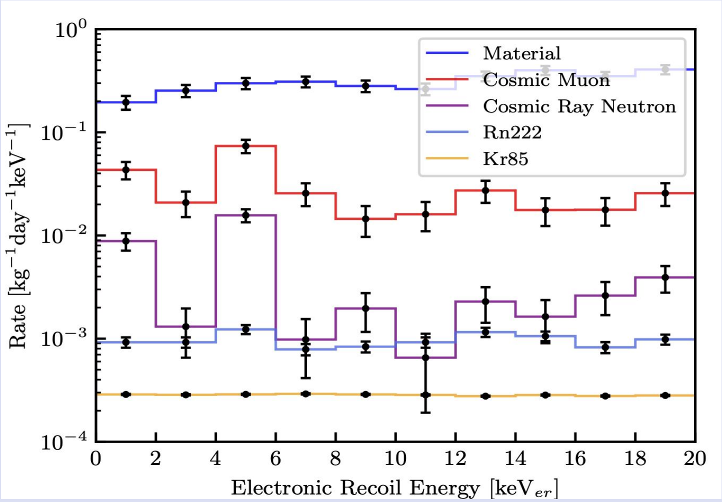




NR Background：

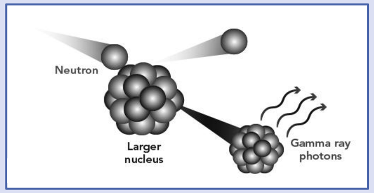
- $(7.7 \pm 0.7) \times 10^{-2}\ kg^{-1} \cdot day^{-1}$ of $[0.3, 1]\ keV_{NR}$
- Dominated by cosmic ray neutron

ER Background Sources and Suppression



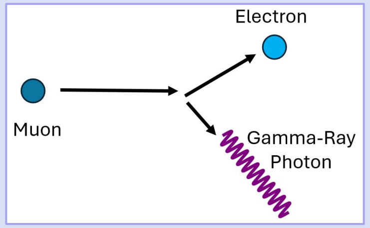
-- Cosmic Ray neutron

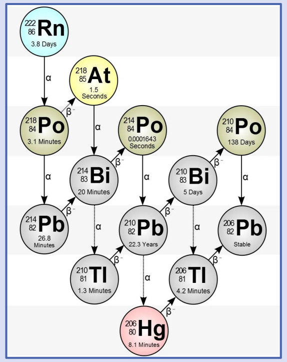
-- Material

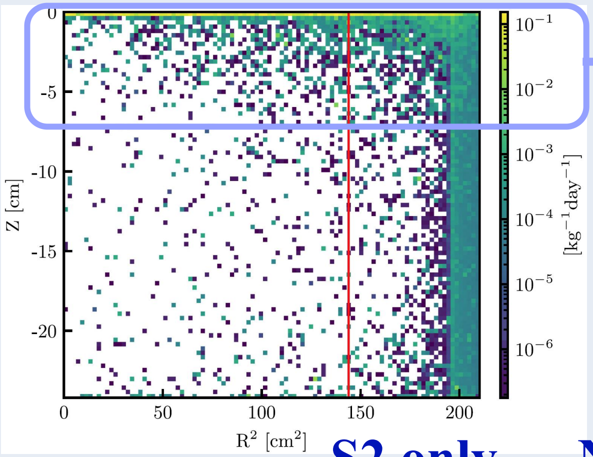


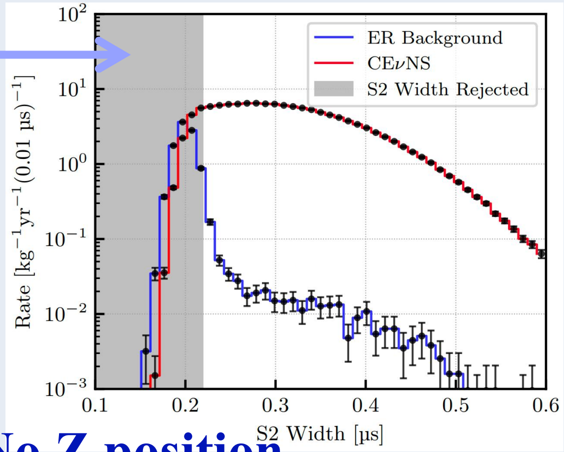
LXe intrinsic -- Rn222 -- Kr85

-- Cosmic Muon









> 95% efficiency

S2 only --- No Z position

Fiducial Volume:

- R < 12 cm
- Edge backgrounds

S2 width cut :

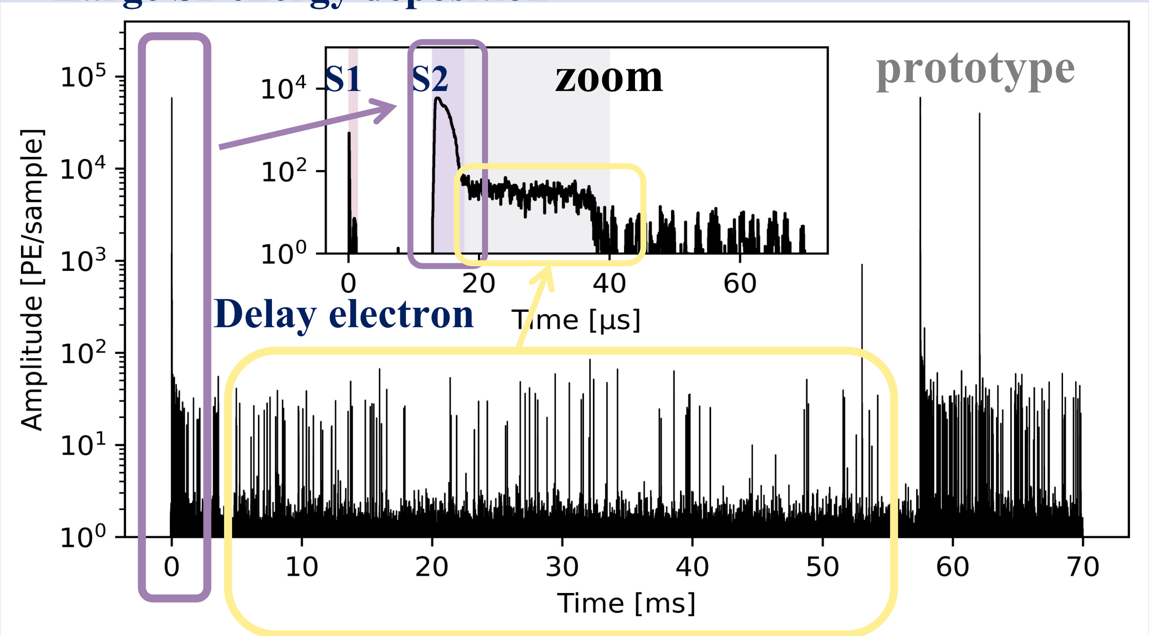
- S2 width > 0.22 μs
- Liquid-gas interface backgrounds

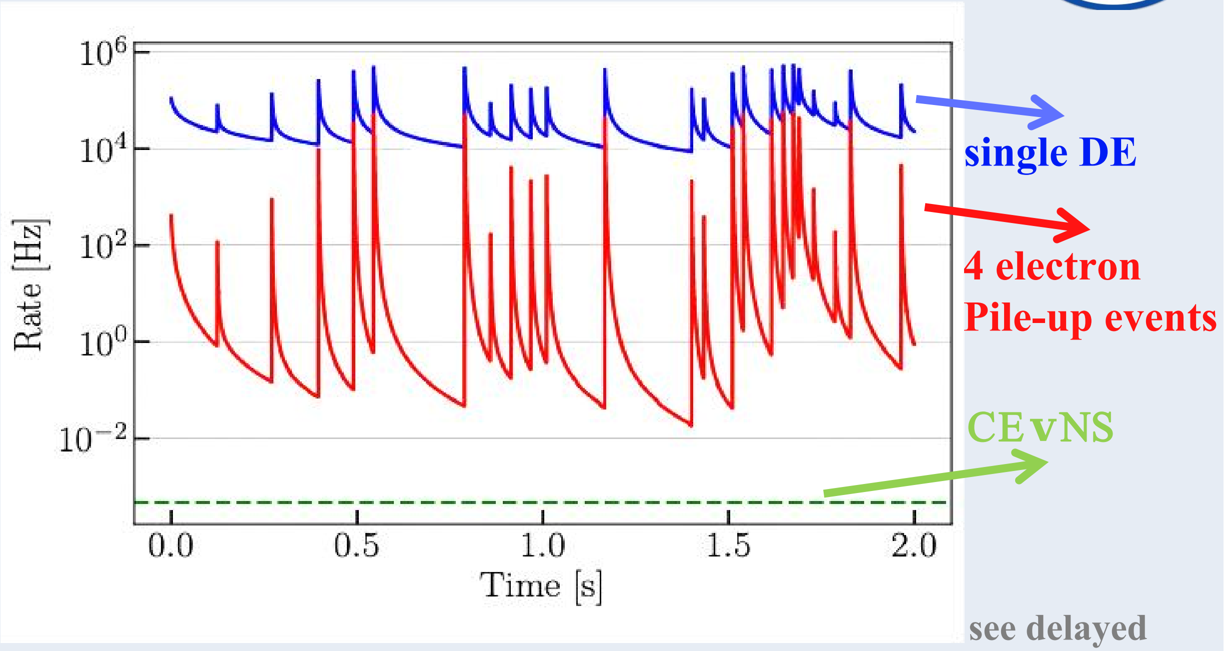
ER Background:

- $(3.10 \pm 0.10) \times 10^{-1}$ kg^{-1}·day^{-1}·keV^{-1} average of [0,20] keV$_{ER}$ before S2 width cut

Delayed Electrons (DE) Background

Large S2 energy deposition





see delayed electron poster by Yang Lei

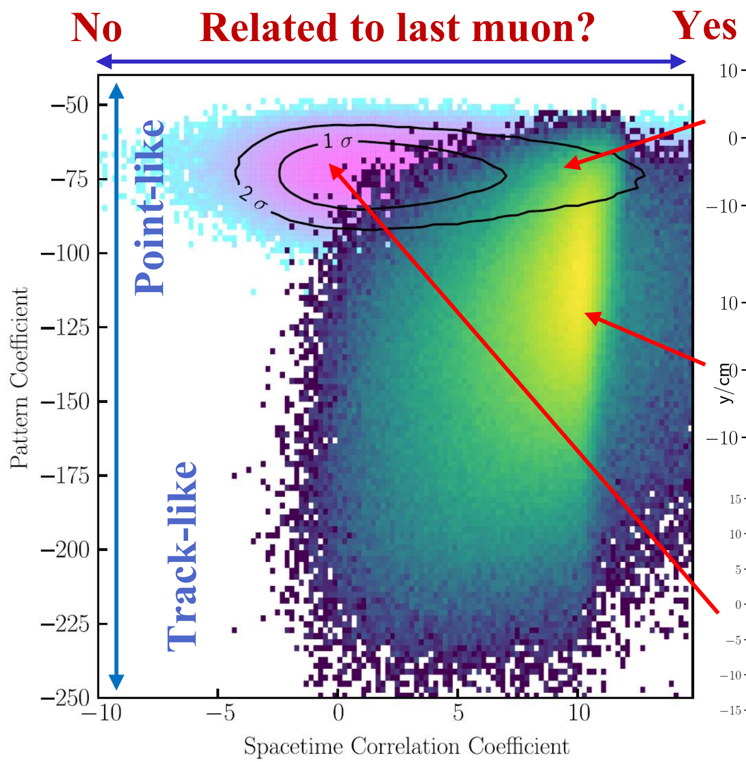
Delayed electron sources:

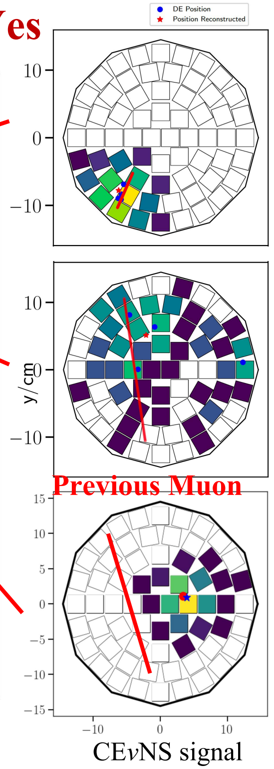
- Observed by large LXeTPCs experiments and prototype
- Emission of electron following large energy deposition
- Pile-up of single electrons distorts the physical signal

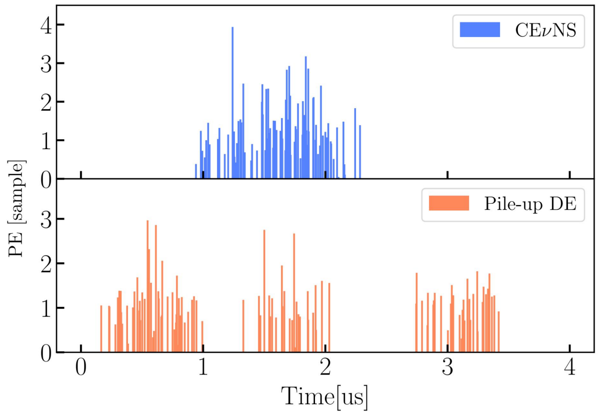
Delayed electron background:

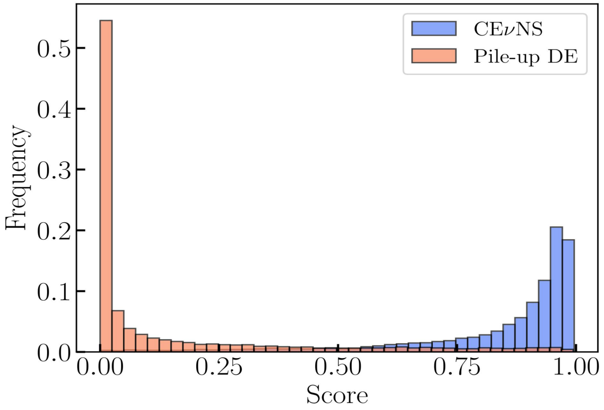
- ~10 Hz muon flux
- Pile-up DE events rate higher than CEvNS events

Delayed Electrons Background Suppression :









Efficiency of Selection Method

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

Pattern + Correlation selection:

- CEvNS : Closer to single - point events.
- DE: More linked to the preceding muon track.

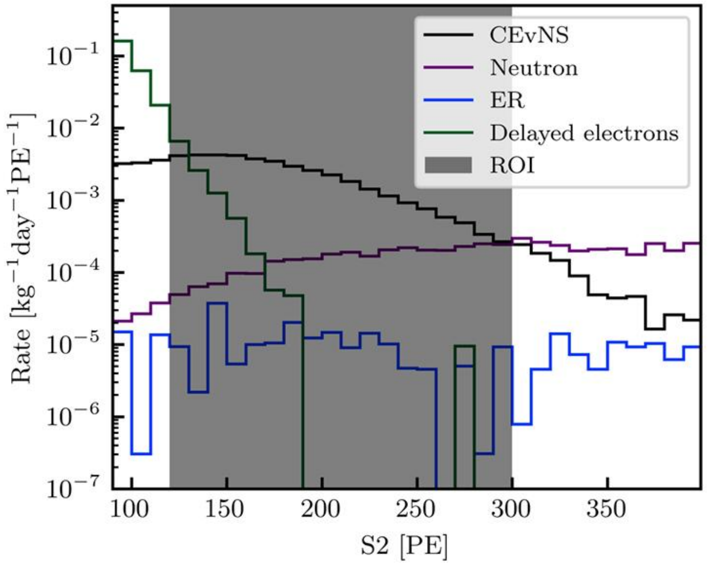
Waveform selection:

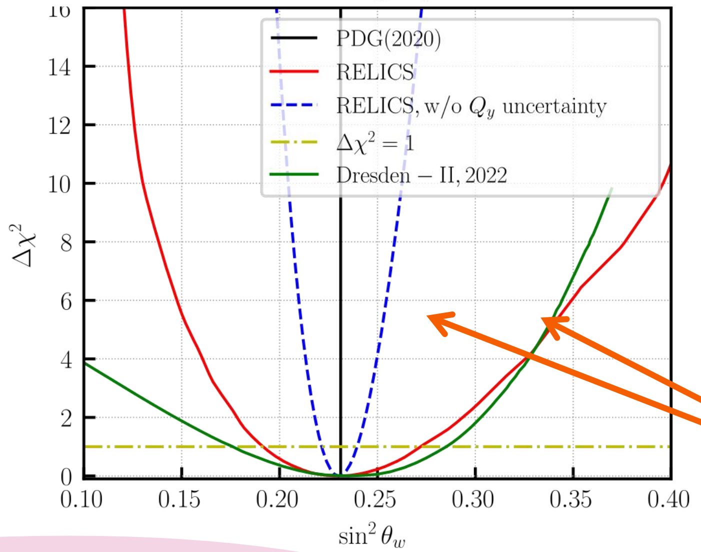
- CEvNS : Gaussion
- DE: More dispersed

Result:

- dead time cut ~ 20ms
- Several orders of magnitude reduction

Physical Potential for CEvNS & Improvement





CEvNS ROI: [120, 240] PE

	Events / (32kg·year)
CEvNS	4639.7
Cosmic Ray Neutron	339.9
Muon Induced Neutron	1.7
ER	21.1
DE Pile-ups	1325.1

Delayed-electrons pile-up events will be dominant background

- ➢ **Improve position reconstruction**

OPEN ACCESS

PDF

Reactor neutrino liquid xenon coherent elastic scattering experiment

Chang Cai[1], Guocai Chen[2], Jiangyu Chen[3], Rundong Fang[4], Fei Gao[1,*], Xiaoran Guo[5,6], Jiheng Guo[4], Tingyi He[7,//], Chengjie Jia[1,‡] *et al.* (RELICS Collaboration)

Share

Show more

Phys. Rev. D **110**, 072011 – **Published 18 October, 2024**

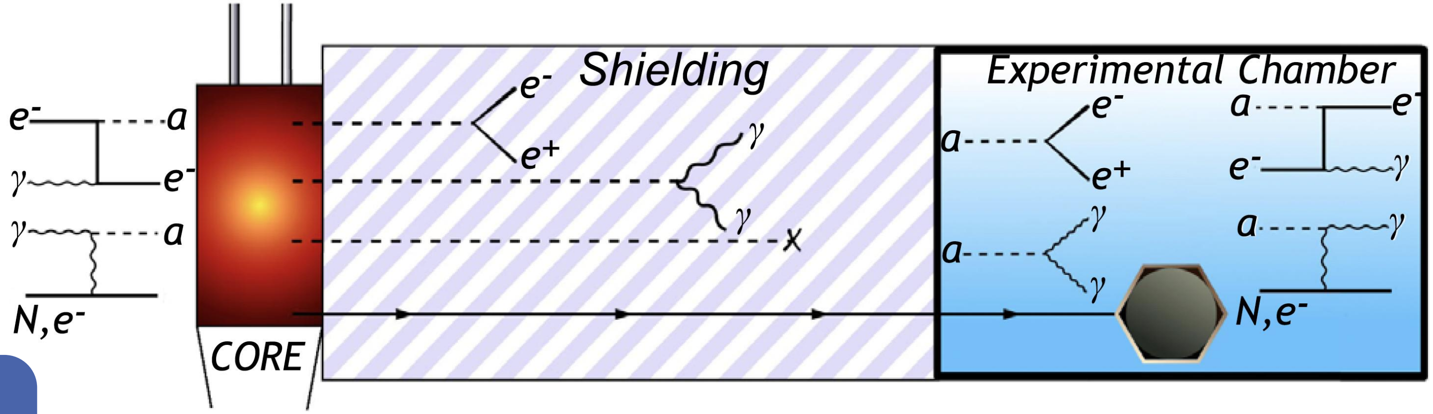
Export Citation

DOI: https://doi.org/10.1103/PhysRevD.110.072011

Uncertainty of the weak mixing angle Caused by Q_y uncertainty

- ➢ **Low NR calibration**

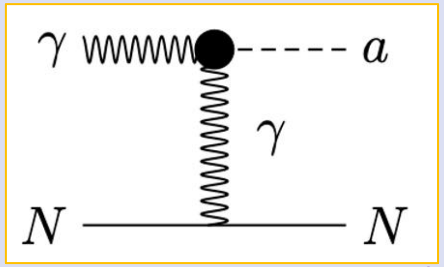
Physical Potential for Axion-like Particles



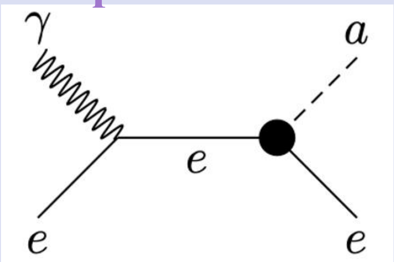
Dent et al., PRL 124, 211804 (2020)

Production

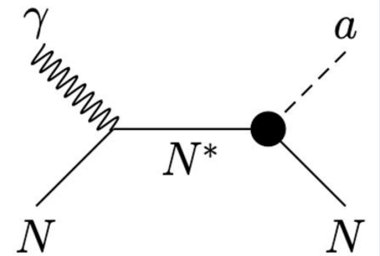
Primakoff Process



Compton-like Scattering

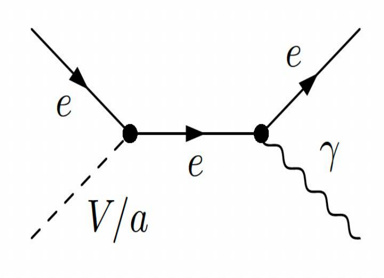


De-excitation of nucleus

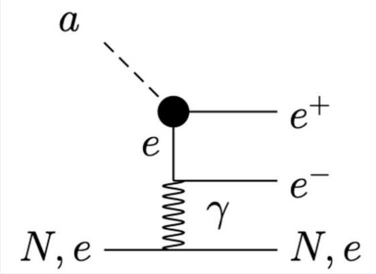


Detection

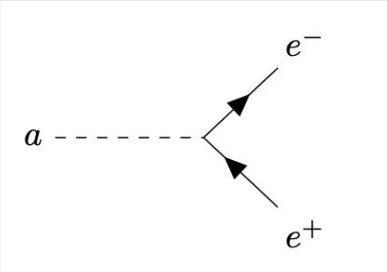
Inverse Compton-like



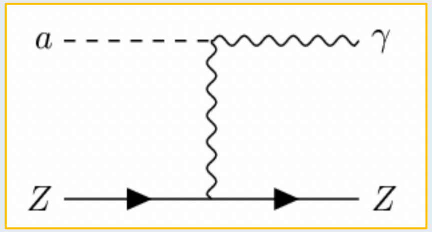
pair production



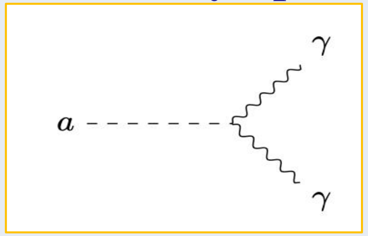
Axion decay e^+e^-



pairs Inverse Primakoff

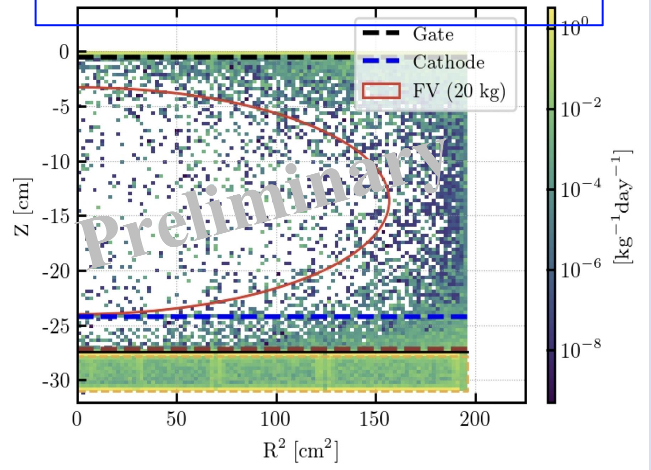


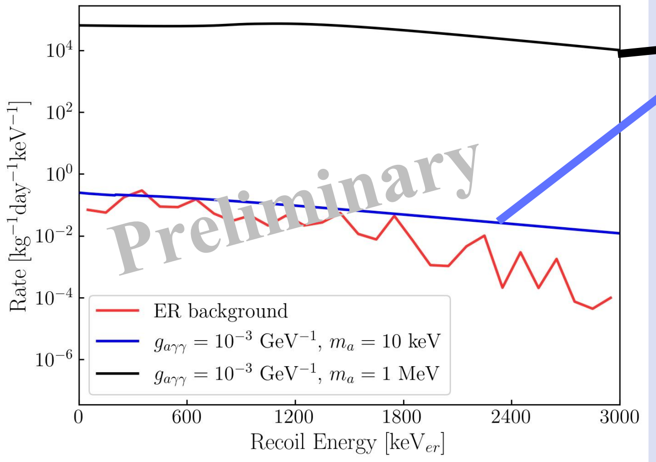
Axion decay - photon

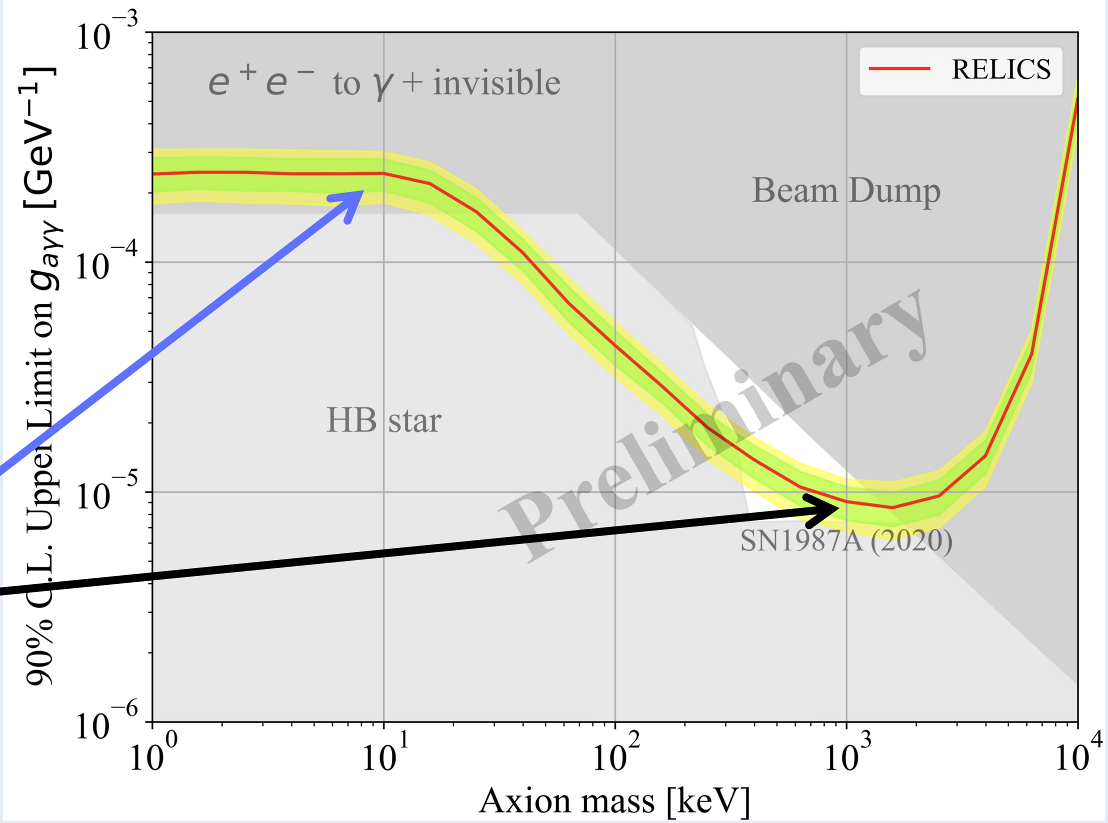


Physical Potential for Axion-like Particles

oval Fiducial Volume





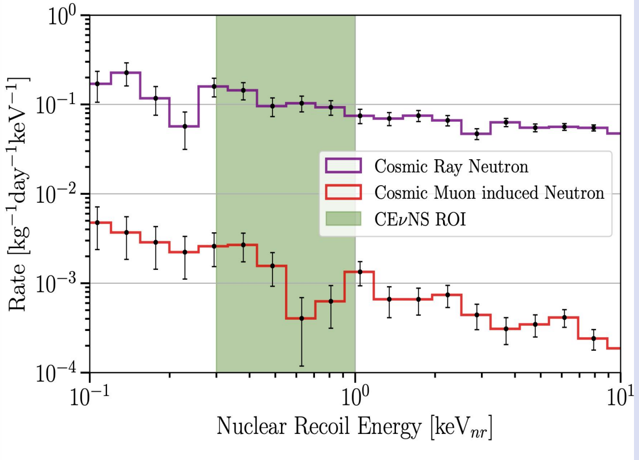


Sensitivity :

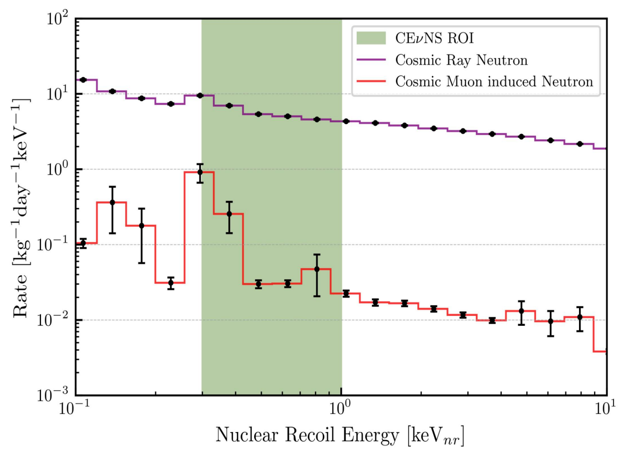
- ☐ **20 kg-year exposure**
- ☐ **Search for the reactor ALPs**

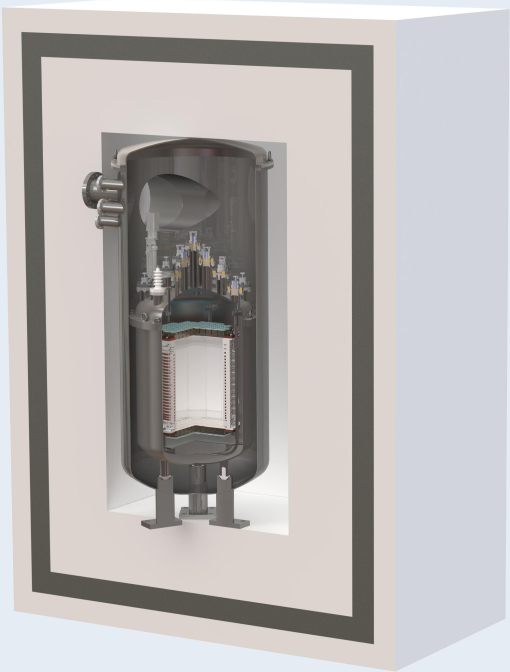
Progress and Future Outlook - construction in 2025

water shielding:



solid shielding:





Shielding layer from outside to inside:

10 cm outer PE

10 cm lead

30 cm inner PE

[0.3,1] keV_{NR} :

solid shielding : $(7.0 \pm 0.4) \times 10^{-1}$ $kg^{-1} \cdot day^{-1}$

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

Preliminary attempt :

- ☐ Background Model Validation (Cosmic background, Delayed Electron...)
- ☐ Technical Testing (Cryogenic System, Data Acquisition System...)
- ☐ Physics Measurement

Summary

RELICS : detect CEνNS from reactor neutrinos using LXe-TPC in energy ROI [0.3,1] keV

1.RELICS will find ~4600 CEvNS events in 32 kg sensitive volume one year of exposure

✅ **suffcent signal obsevation**

2.Delayed-electrons pile-up events will be the dominant background, but can be suppressed by waveform and pattern-spacetime cuts

✅ **low background (shielding & cut selection......)**

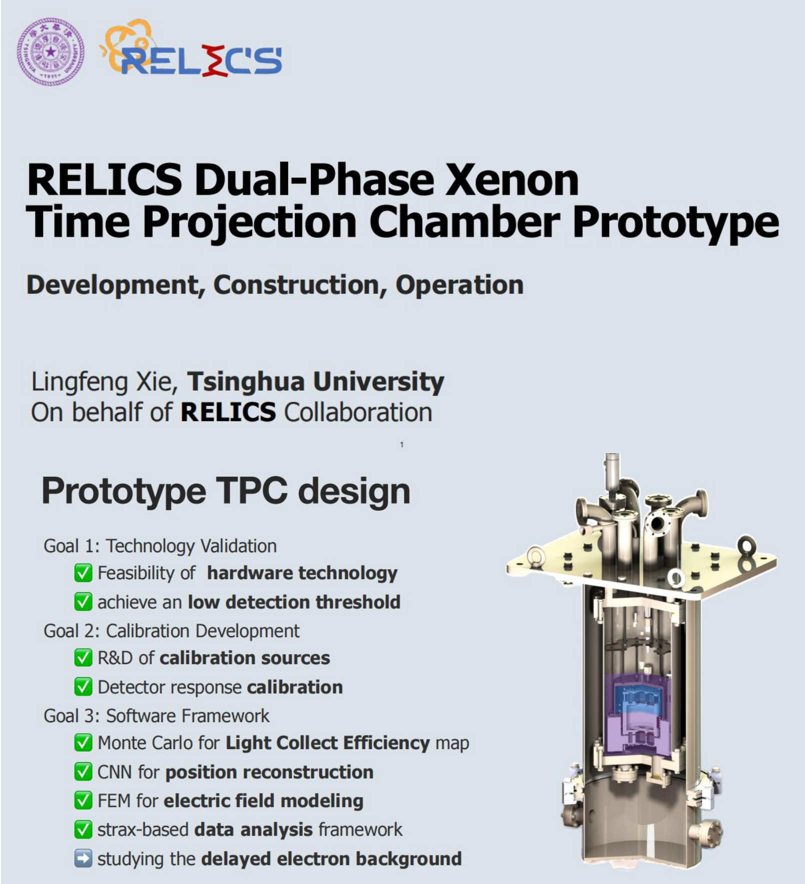
2.The prototype has verified the feasibility of each sub-system for the RELICS experiment and the capability to detect single-electron signals and signals from calibration sources in the low-energy region.

✅ **low threshold (single PE trigger rate& single-electron detection gain......)**

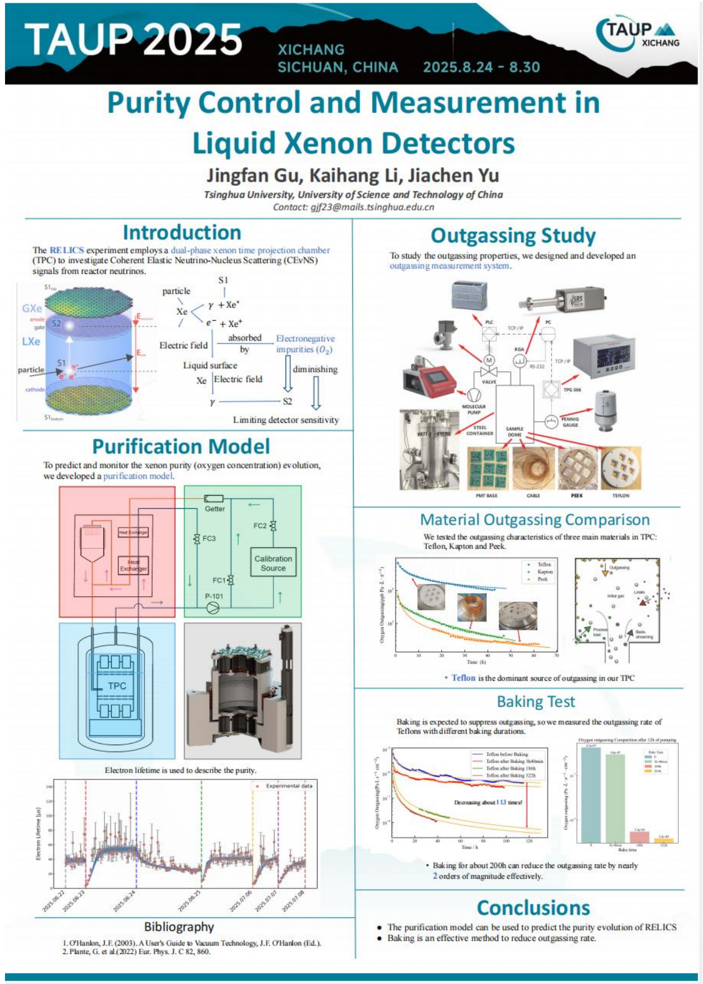
The RELICS detector is scheduled for construction this year and will begin taking data in 2026

other report and poster for RELICS

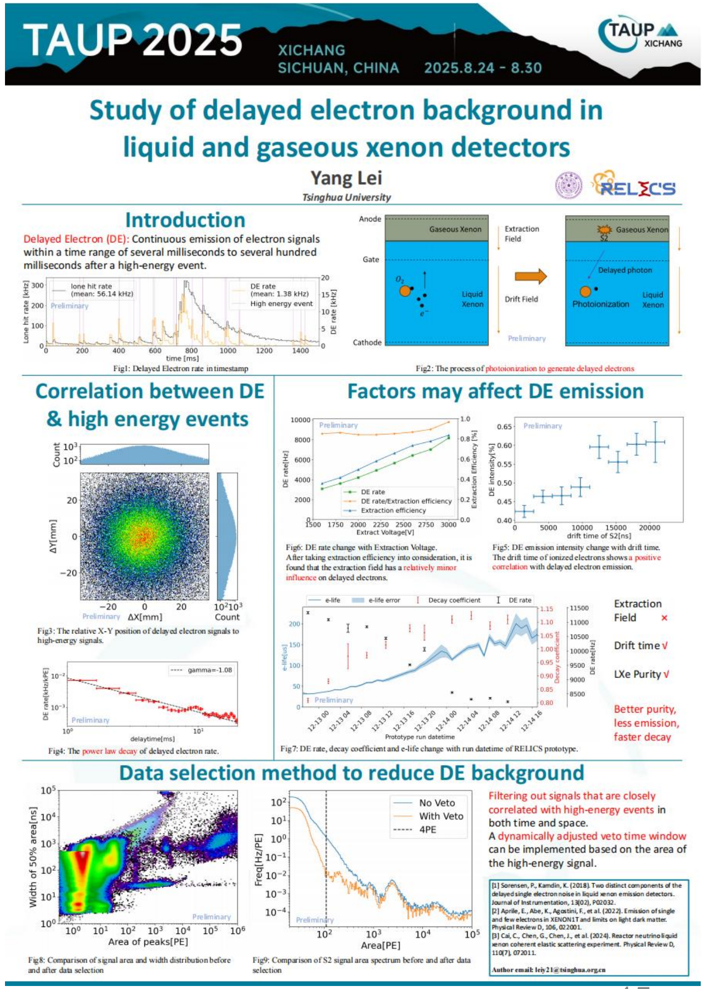
Prototype test - report
Lingfeng Xie 2025.8.27 17:00
Underground Laboratories



Purification Control - poster
number : 290 Jiangfan Gu et.



Delayed Electron - poster
number : 299 Yang Lei



Collaboration meeting 2024 @ GuangZhou

RELICS:REACTOR NEUTRINO LIQUID XENON COHERENT SCATTERING EXPERIMENT

Back up - Site design for RELICS