ReActor neutrino Liquid xenon Coherent Scattering (RELICS) Experiment

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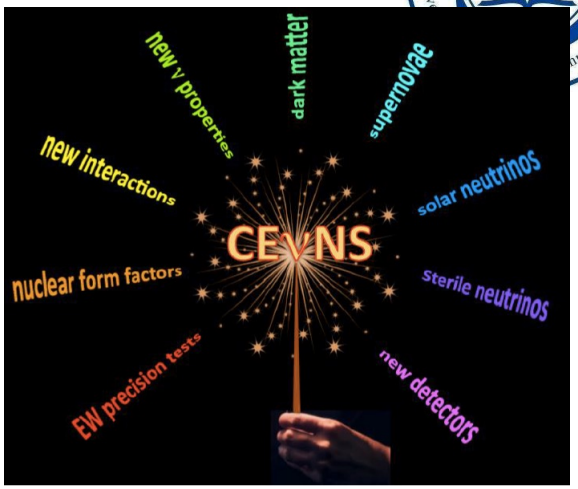
on behalf of RELICS collaboration

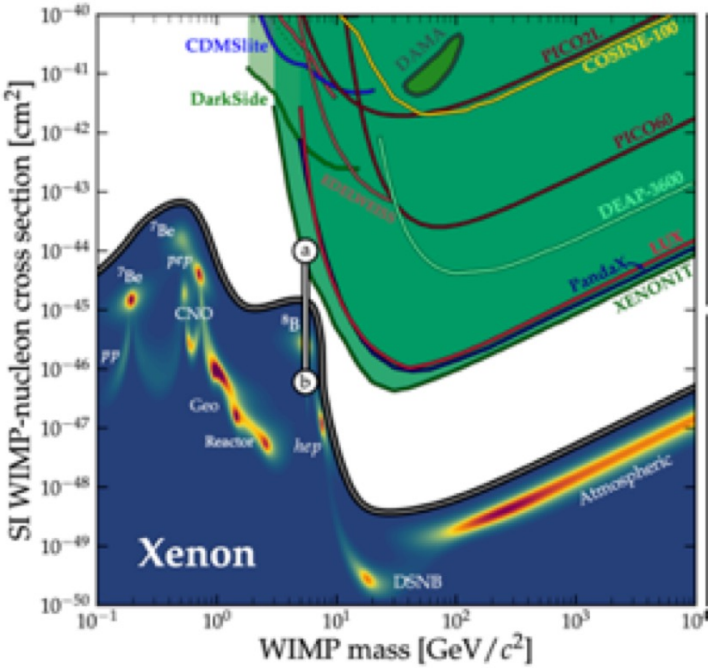
WIN (Zhuhai), 2023-07-05

Experimental Goals

Scientific

- Particle physics
  - Weak mixing angle under low momentum transfer;
  - Beyond-SM neutrino interaction;
  - Anomalous neutrino magnetic moment;
  - Sterile neutrino etc;
- Astroparticle
  - New detection channel for cosmic neutrinos (solar and supernovae);
  - Important background for DM direct search;
- Nuclear physics
  - Nuclear form factor



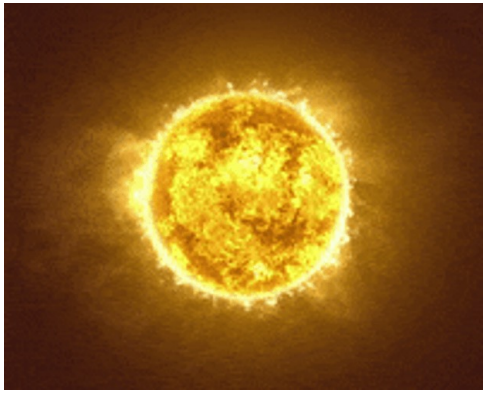


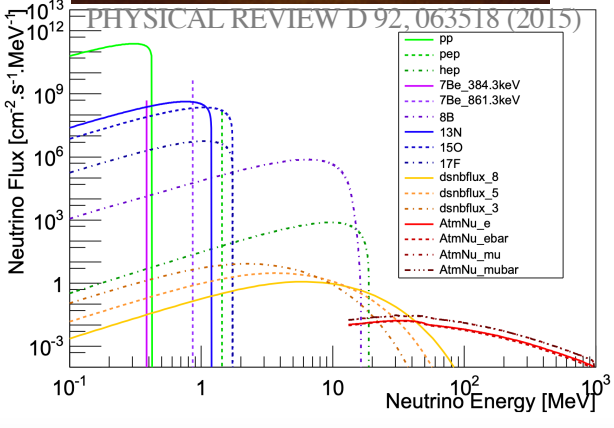
Practical Application

- Nuclear safeguard: More efficient safe way of remote monitoring of nuclear reactors.

Neutrino sources

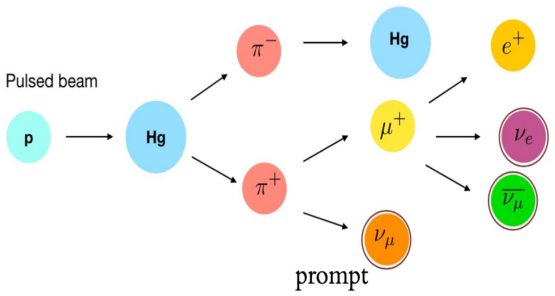
Solar

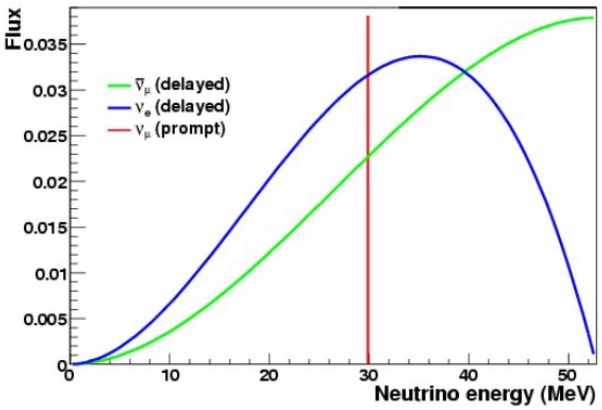




- ~**5e6/s/cm2** for B8 **ν**;
- Mostly E<0.4MeV;
- Not observed yet.

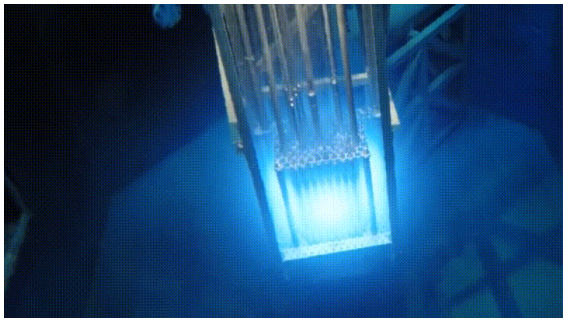
Spallation neutron source

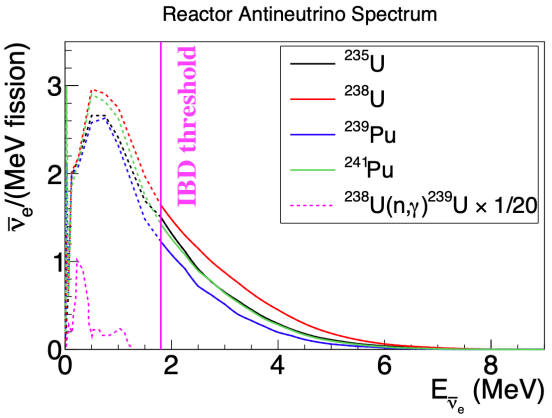




- **1e6/s/cm2 @ 20m**;
- E<50MeV;
- Observed in 2017;

Nuclear reactor





- **1e13/s/cm2 @ 25 m with 3GW power**;
- E<2MeV;
- Not observed yet;

Experimental Status

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

- **Ultra-low energy threshold**
- **Ultra-low background**
- **Large volume**
- **High neutrino flux**

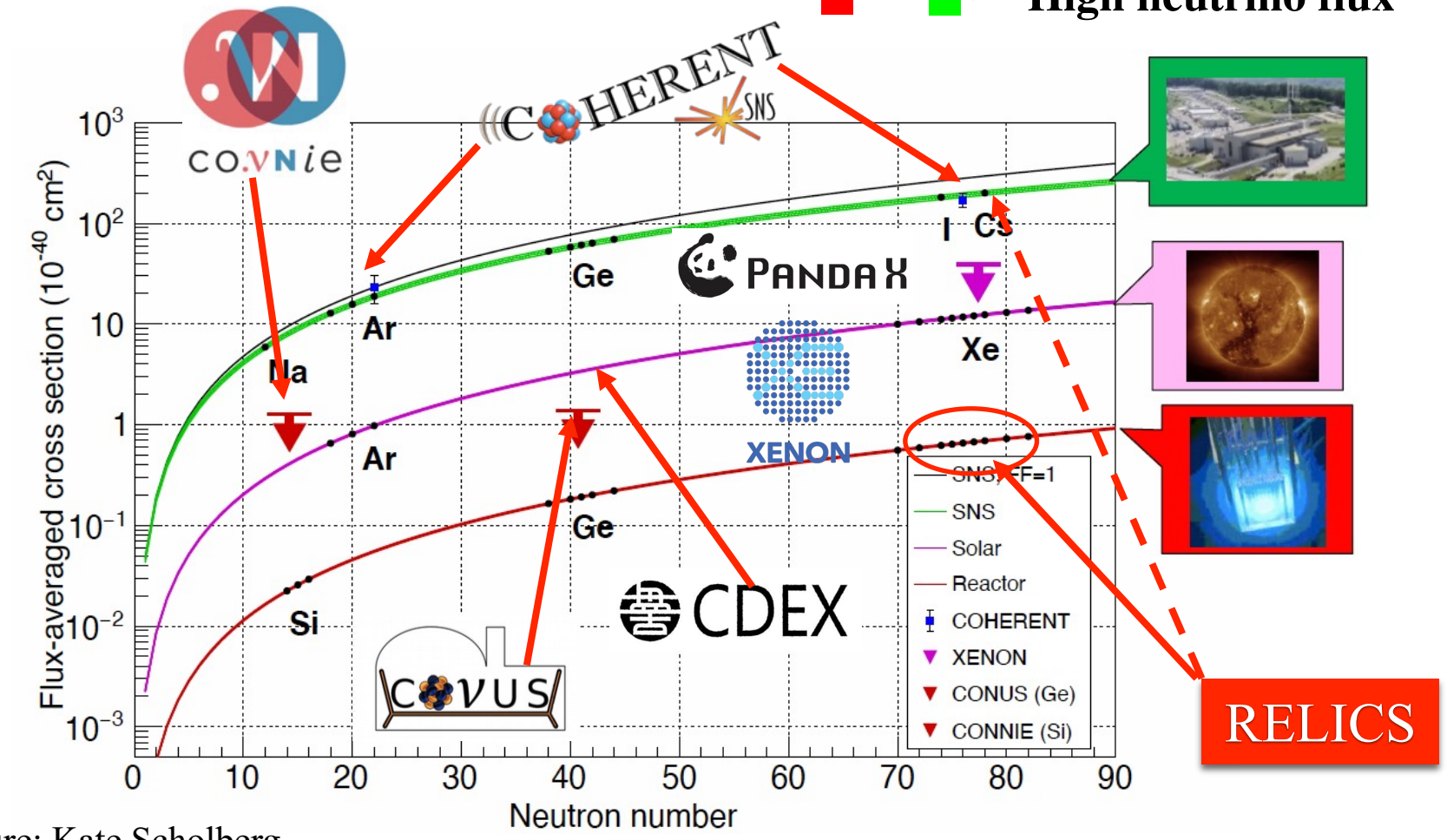
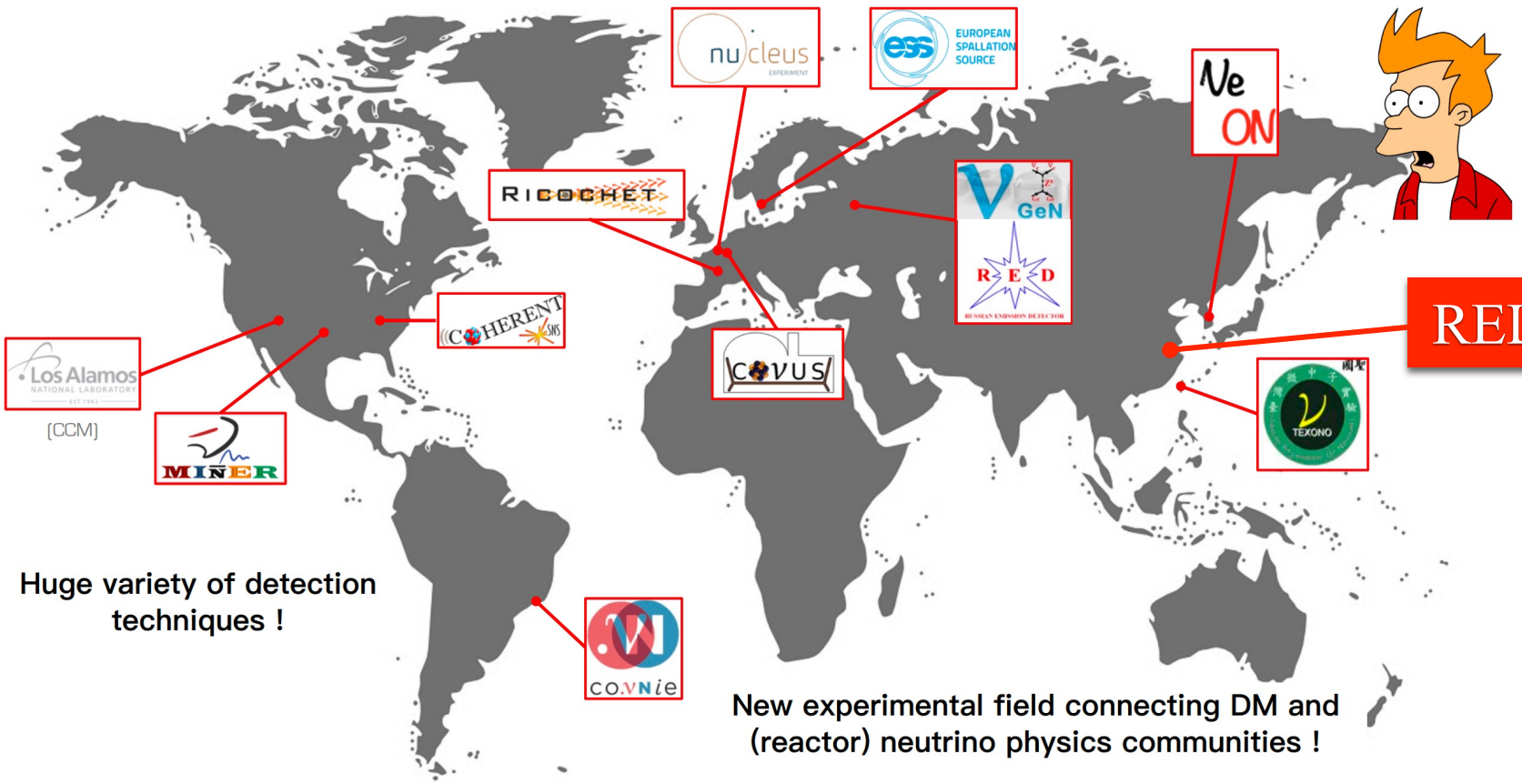


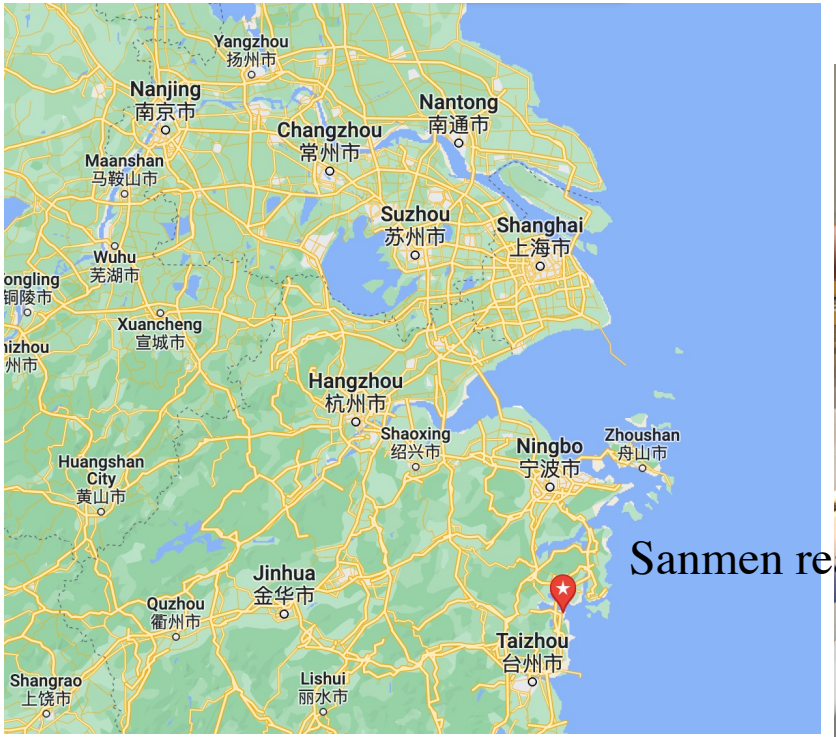
Figure: Kate Scholberg

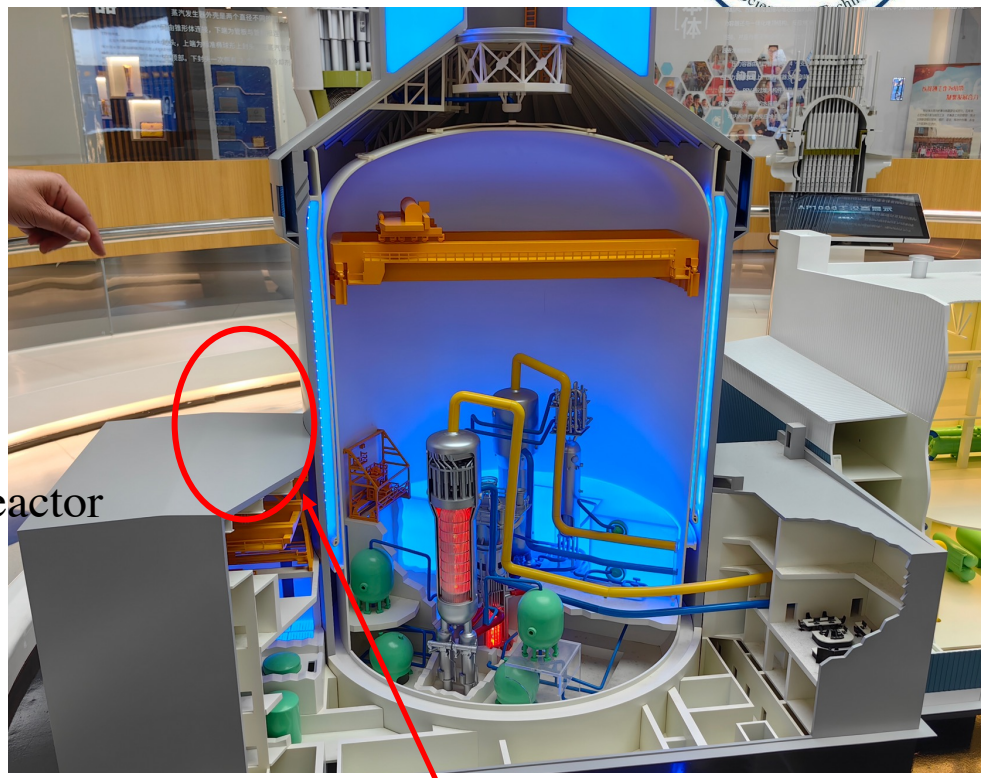
Experimental Status



M. Vivier,
Magnificent CEvNS 2020

RELICS Experiment location





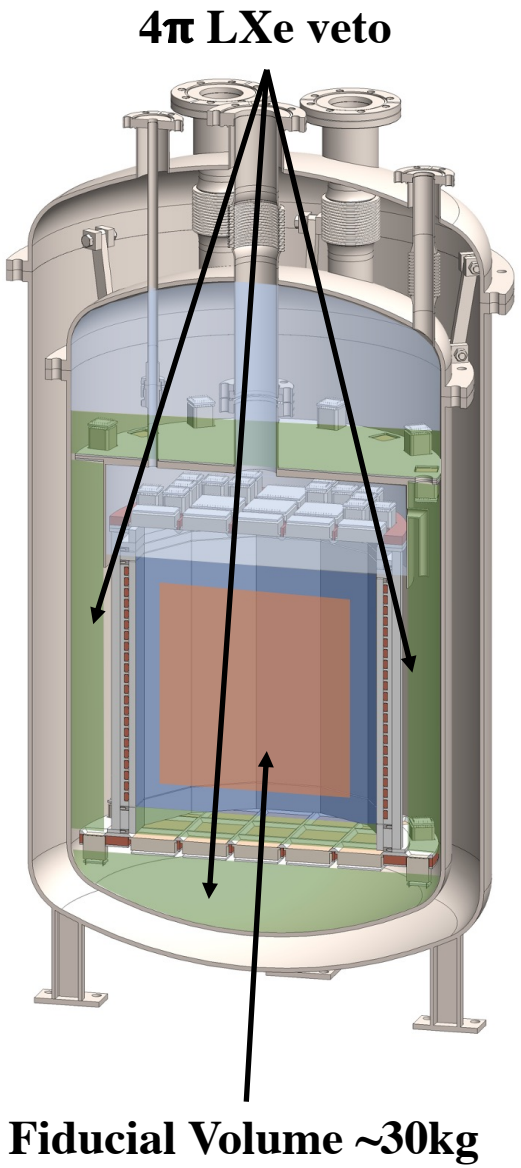
Sanmen reactor

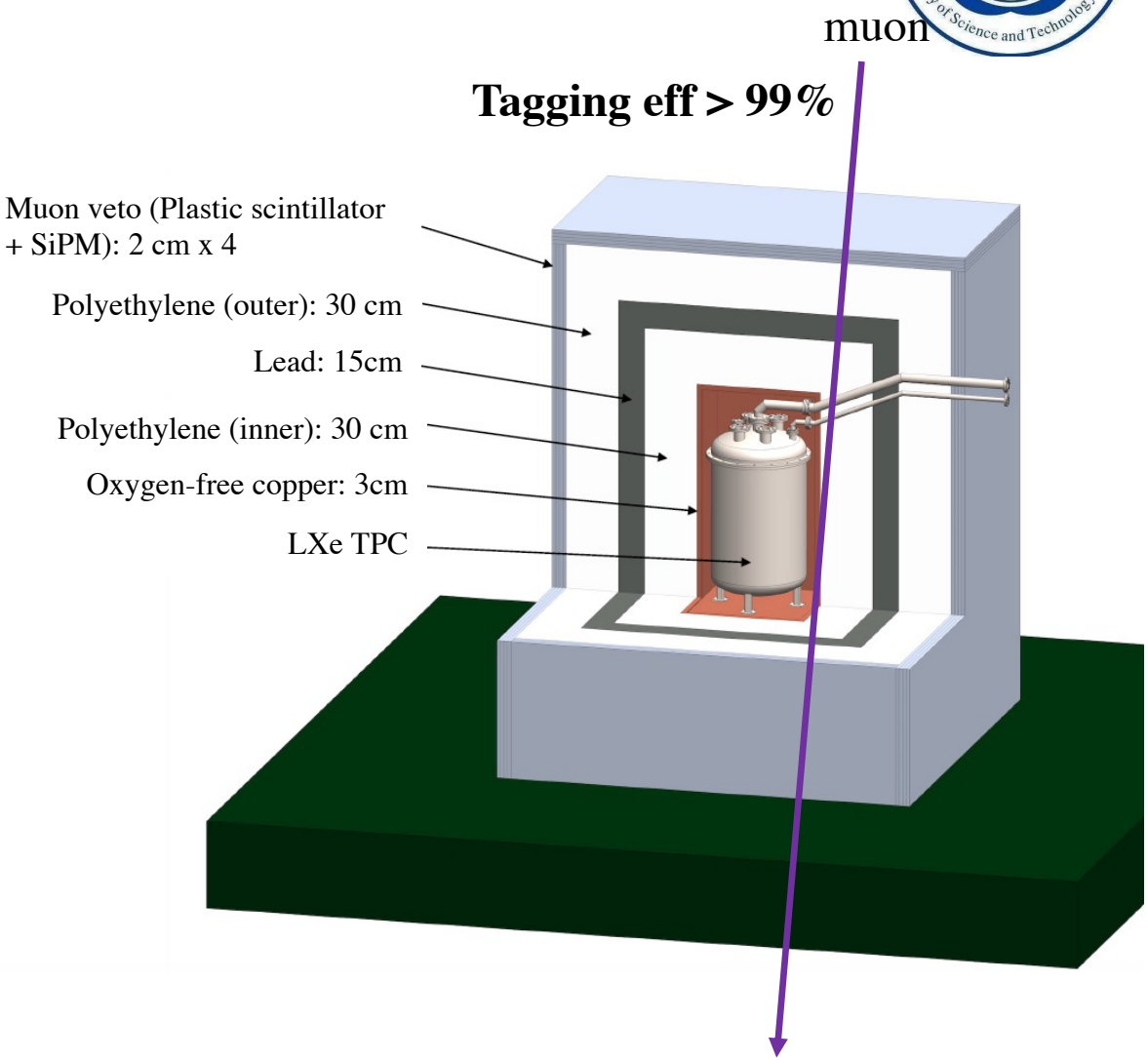
Proposed operation location for RELICS, right outside of containment building.

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

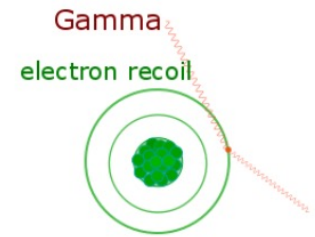
RELICS collaboration

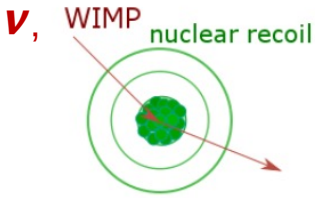
RELICS Detector Design

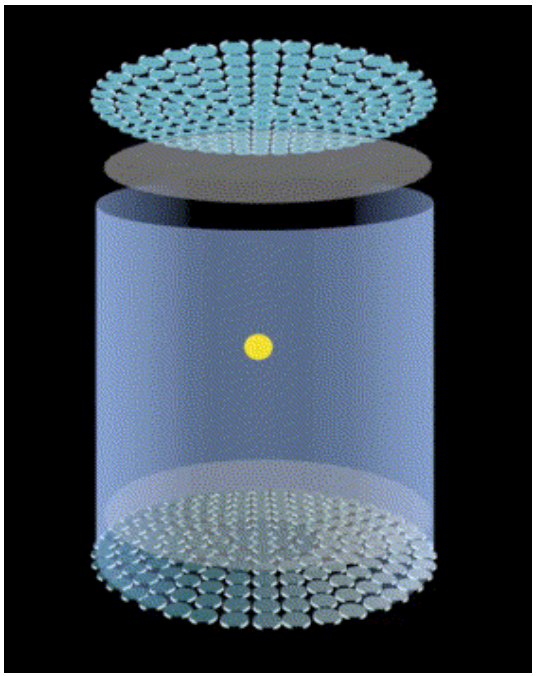


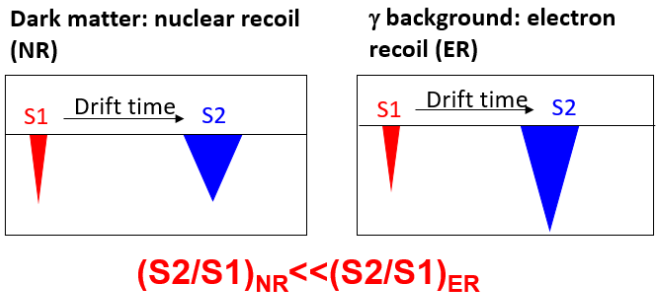


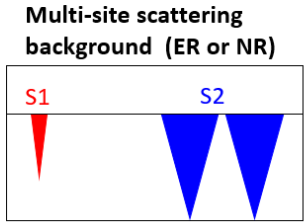
Dual phase Time Projection Chamber

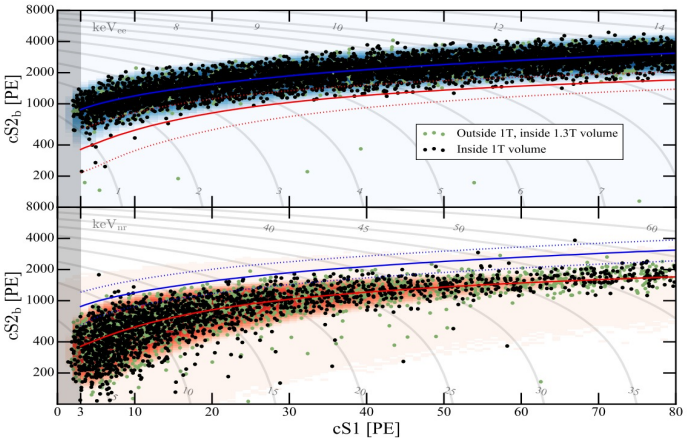


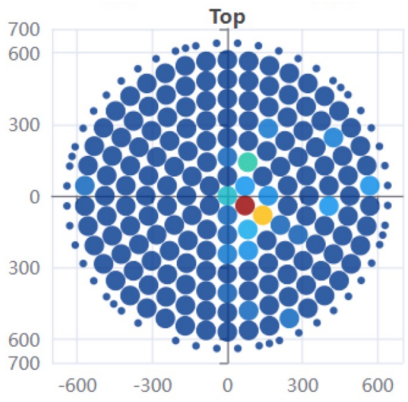








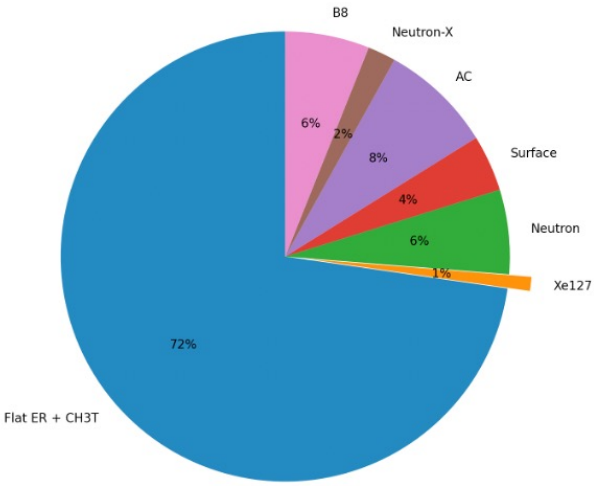


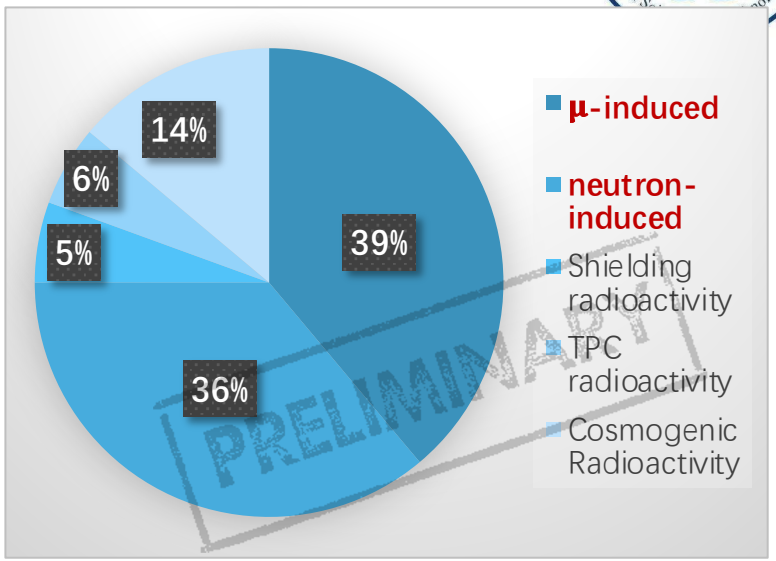


- ❑ Large monolithic target
- ❑ 3D pos. recon. and fiducialization
- ❑ Good ER/NR discrimination
- ❑ Calorimeter capable of seeing a couple of photons/electrons

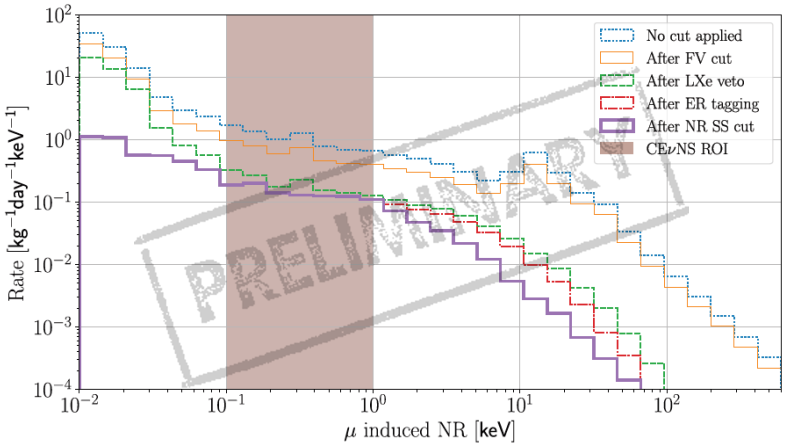
Ongoing works: Background Estimation

PandaX-4T DM Search

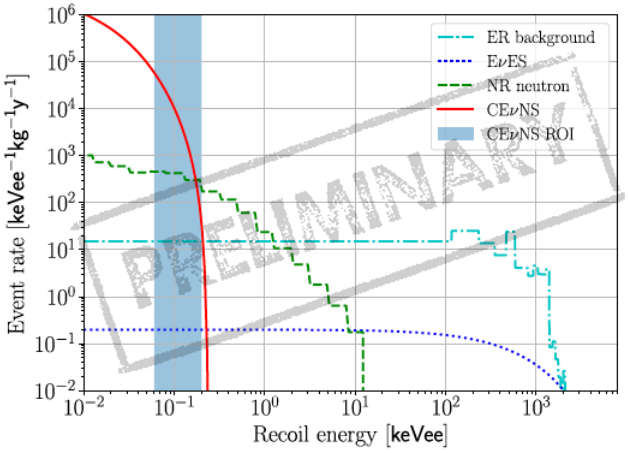




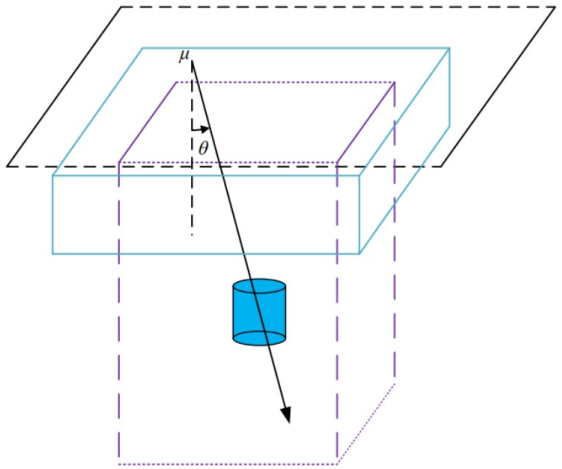
Predicted bkg spectrum



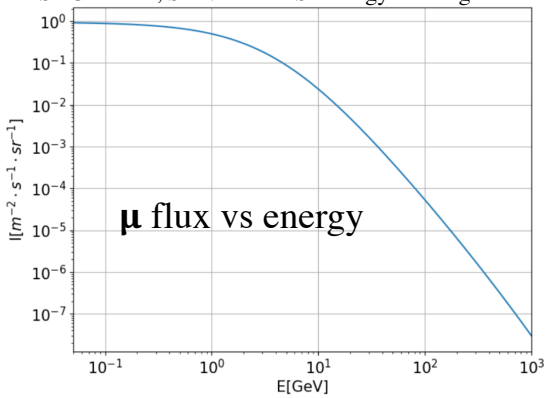
Predicted signal spectrum

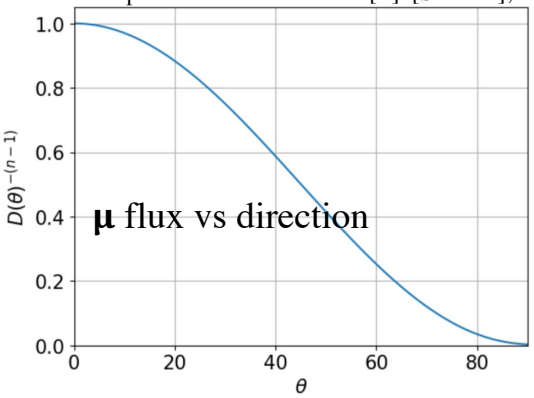


Muon-induced background

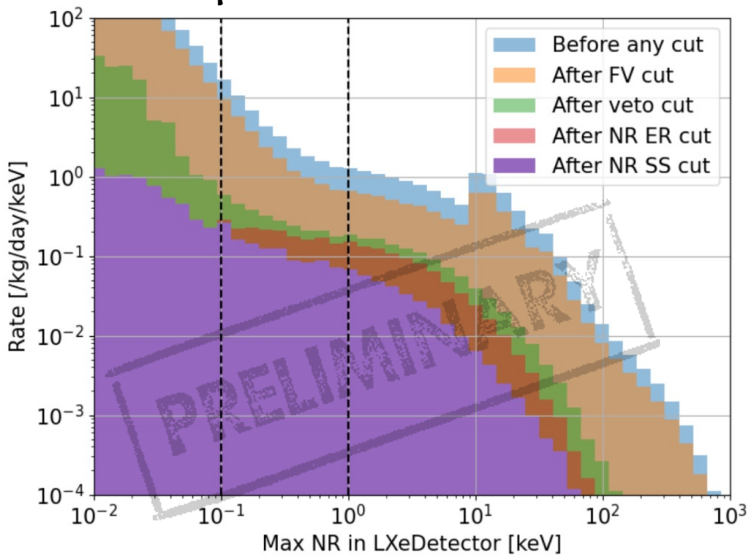


SHUKLA P, SANKRITH S. Energy and angular distributions of atmospheric muons at the earth[Z]. [S.l.: s.n.], 2018.

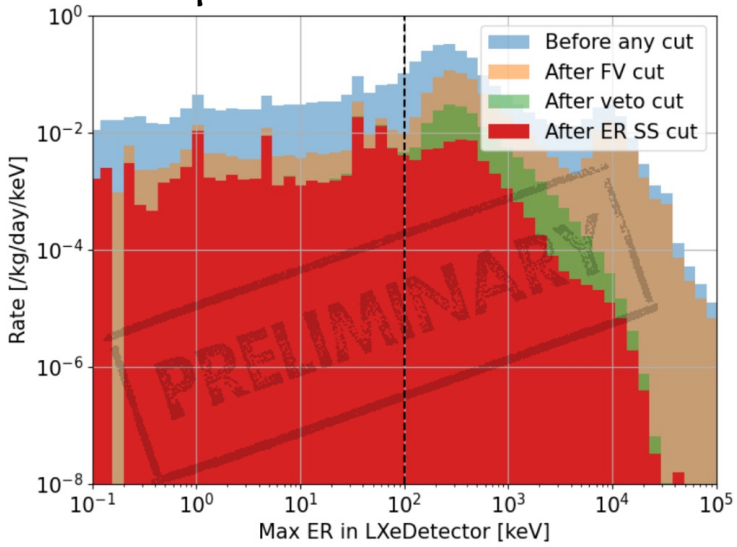




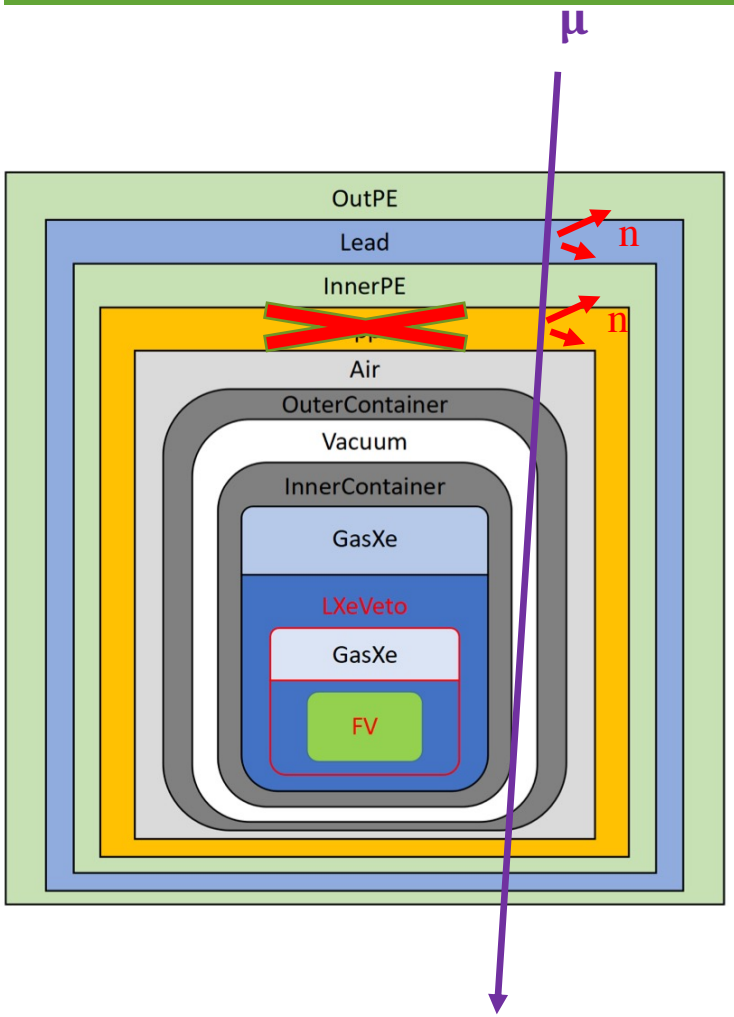
μ-induced nuclear recoils

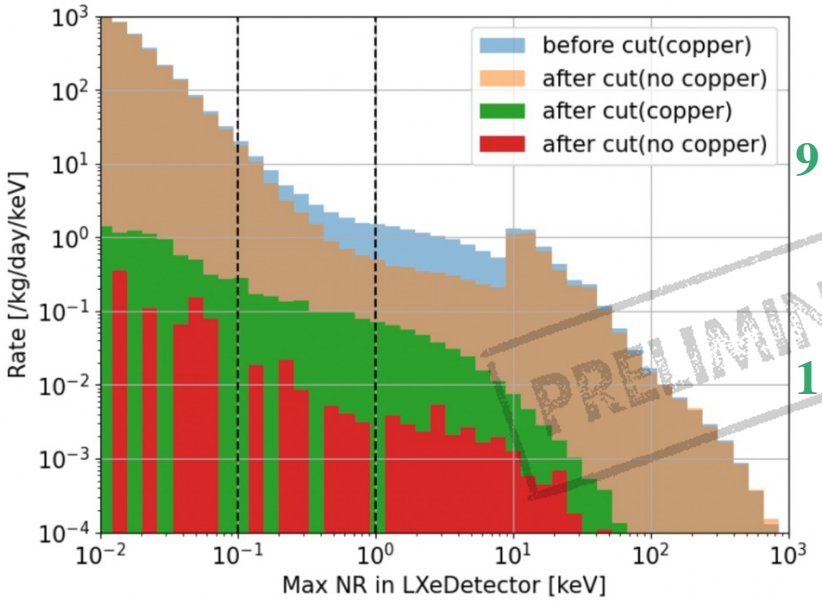


μ-induced electronic recoils



Muon induced neutron on Lead and Copper





9.6e-2/kg/day

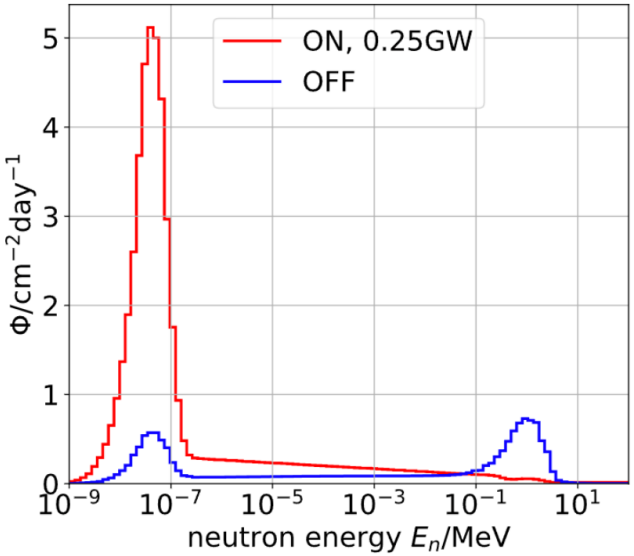
1.4e-2/kg/day

Copper is the dominant source of muon-induced neutron. Need to move to before inner PE layer.

Reactor and environmental neutron

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

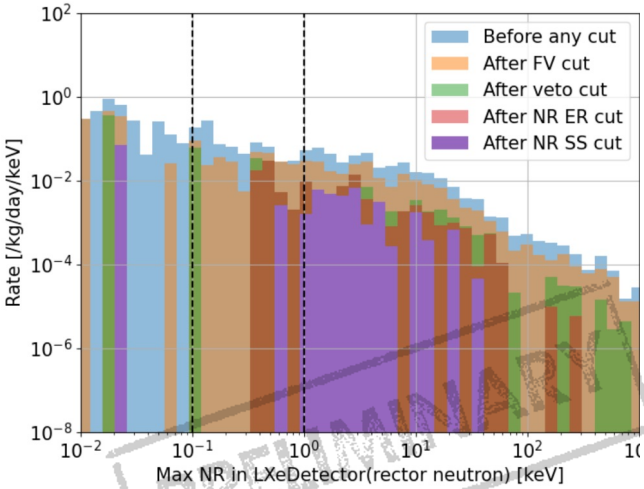
Using CONUS measured spec



中子种类	E_n(MeV)	Φ(cm^{-2}· day^{-1})
thermal	1.0×10^{-9}——4.0×10^{-7}	4.47±0.67
Intermedia	4.0×10^{-7}——0.1	4.19±1.15
Fast	0.1——19.6	6.35±0.96
Total	1.0×10^{-9}——19.6	15.03 ±0.99

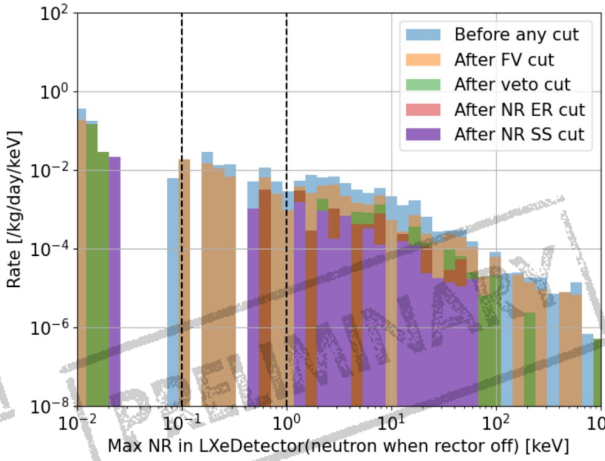
中子种类	E_n(MeV)	Φ(cm^{-2}·GWh^{-1})
thermal	1.0×10^{-9}——4.0×10^{-7}	6.42±0.41
Intermedia	4.0×10^{-7}——0.1	1.56±0.21
Fast	0.1——19.6	0.15±0.05
Total	1.0×10^{-9}——19.6	8.13±0.32

Environmental n



1.2e-2 /day/kg

Reactor n



0.1e-2 /day/kg

Material & Cosmogenic Radioactivity

source	shielding	TPC	Xe127	Ar37
Rate[e-2/kg/day]	0.2	0.2	0.3	<0.2

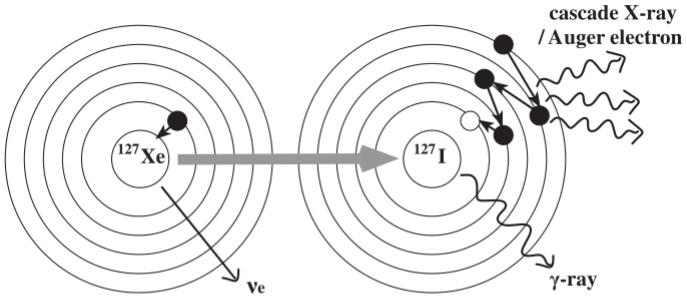
Material radioacitivity [mBq/kg or mBq/pc]

Radioactivity	PE	Lead	Cu	SS	Teflon	PMT window	PMT casing
^{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

Used XENON100 values

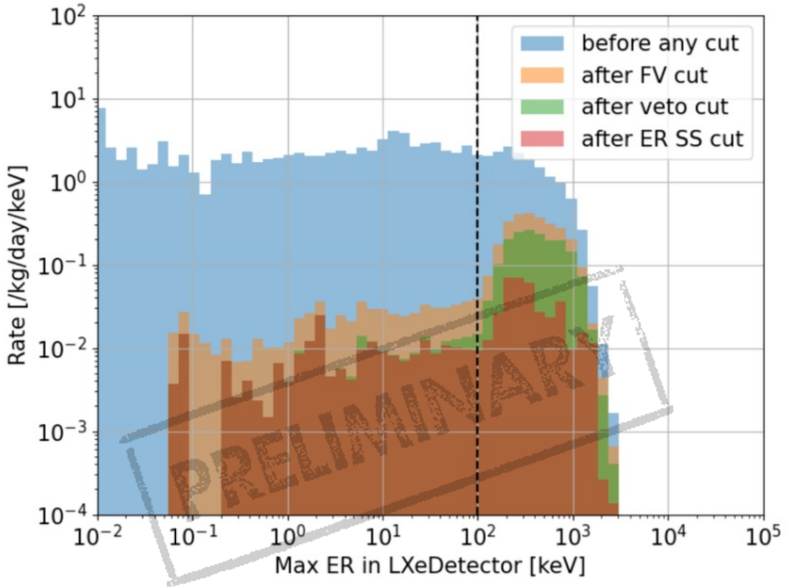
Ar37:
- Proton bombard
- Neutron bombard

Xe127:
- Muon bombard
- Neutron capture

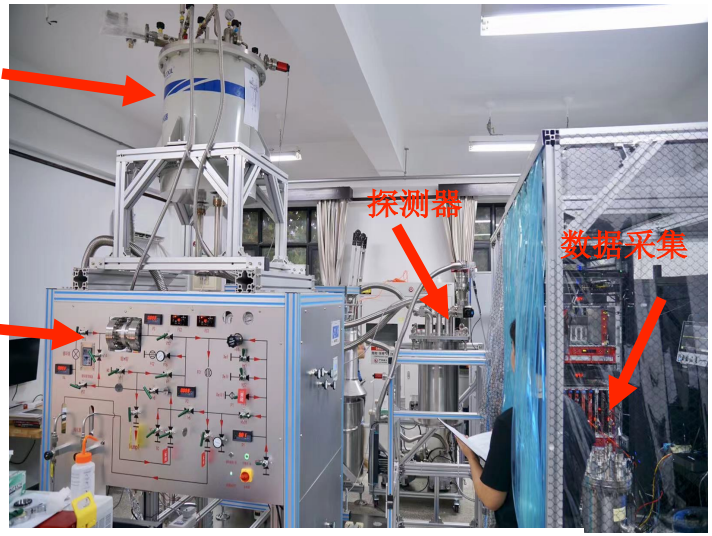


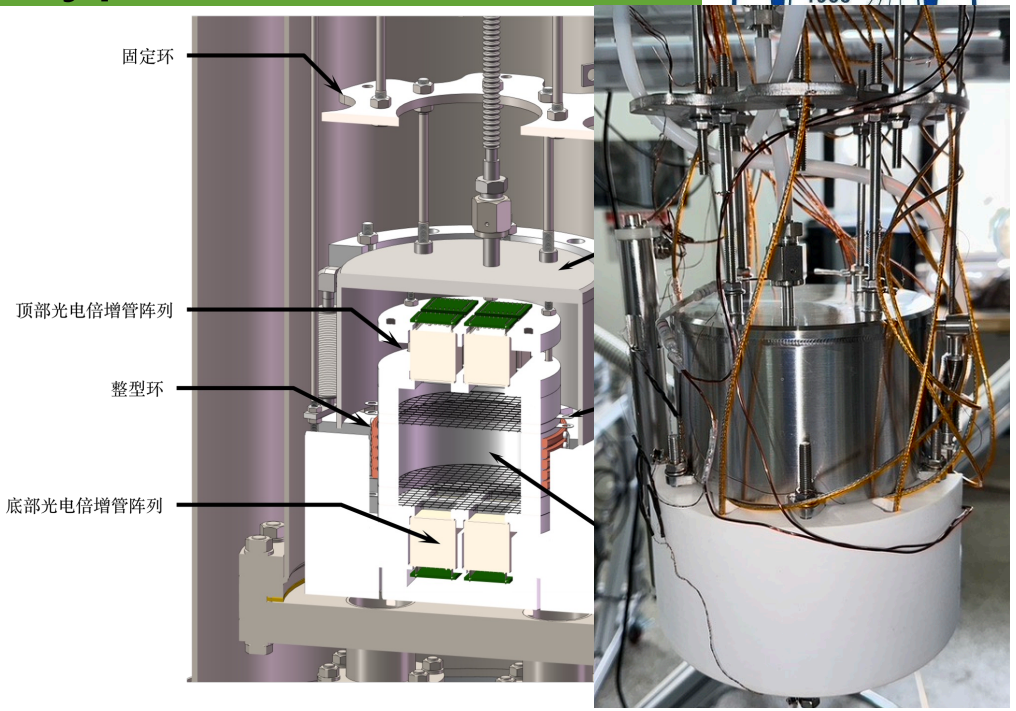
Ar37
L-shell 0.27keV

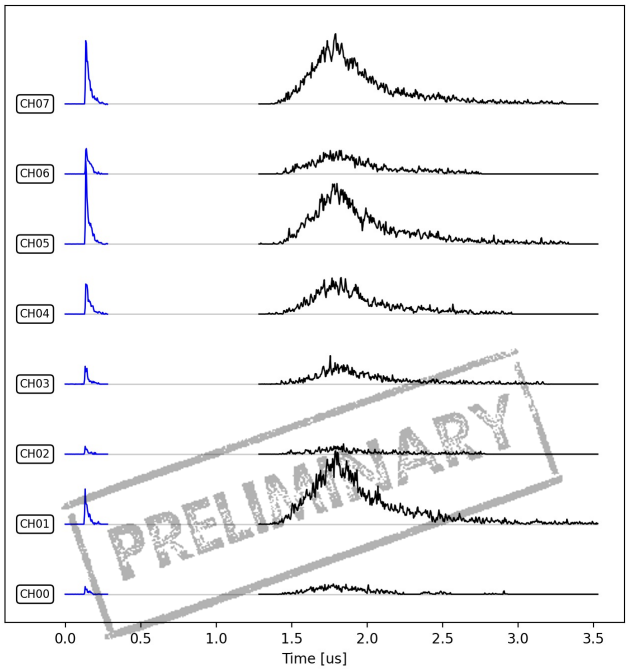
Xe127
N-shell 0.186keV



Ongoing work: TPC prototype test





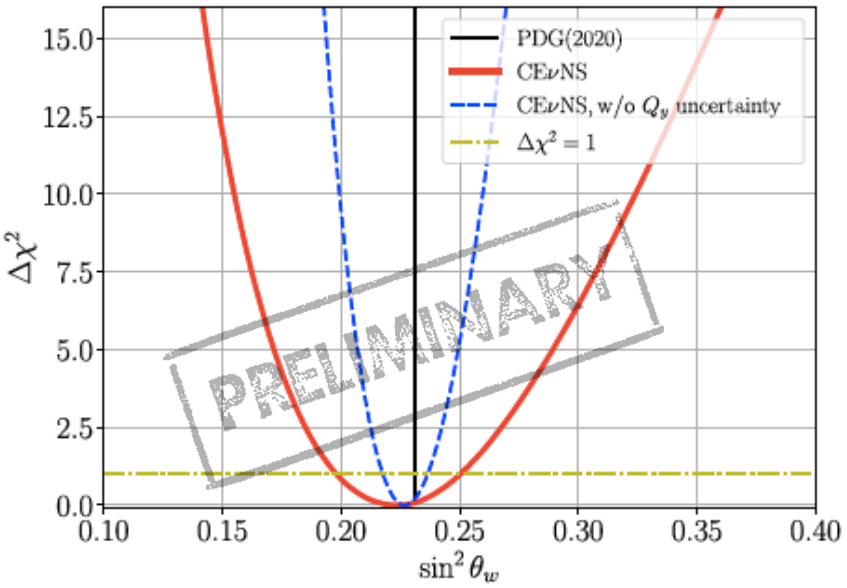


- Small system constructed in Tsinghua;
- First test of prototype TPC;
- Signal observed but with some tripping problem

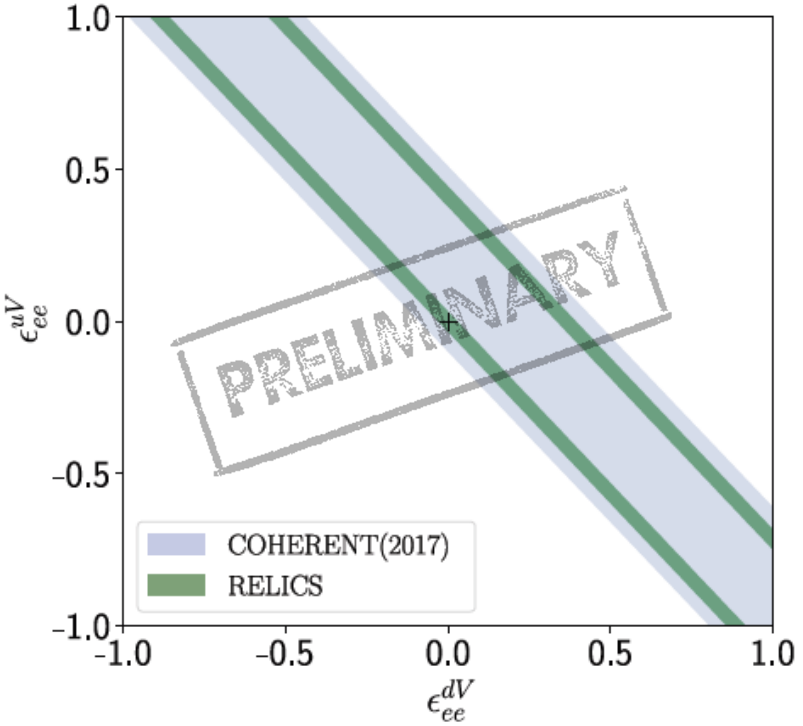
Expected sensitivity

We expect to see >5000 CEvNS in ROI with 30 kg-year exposure.

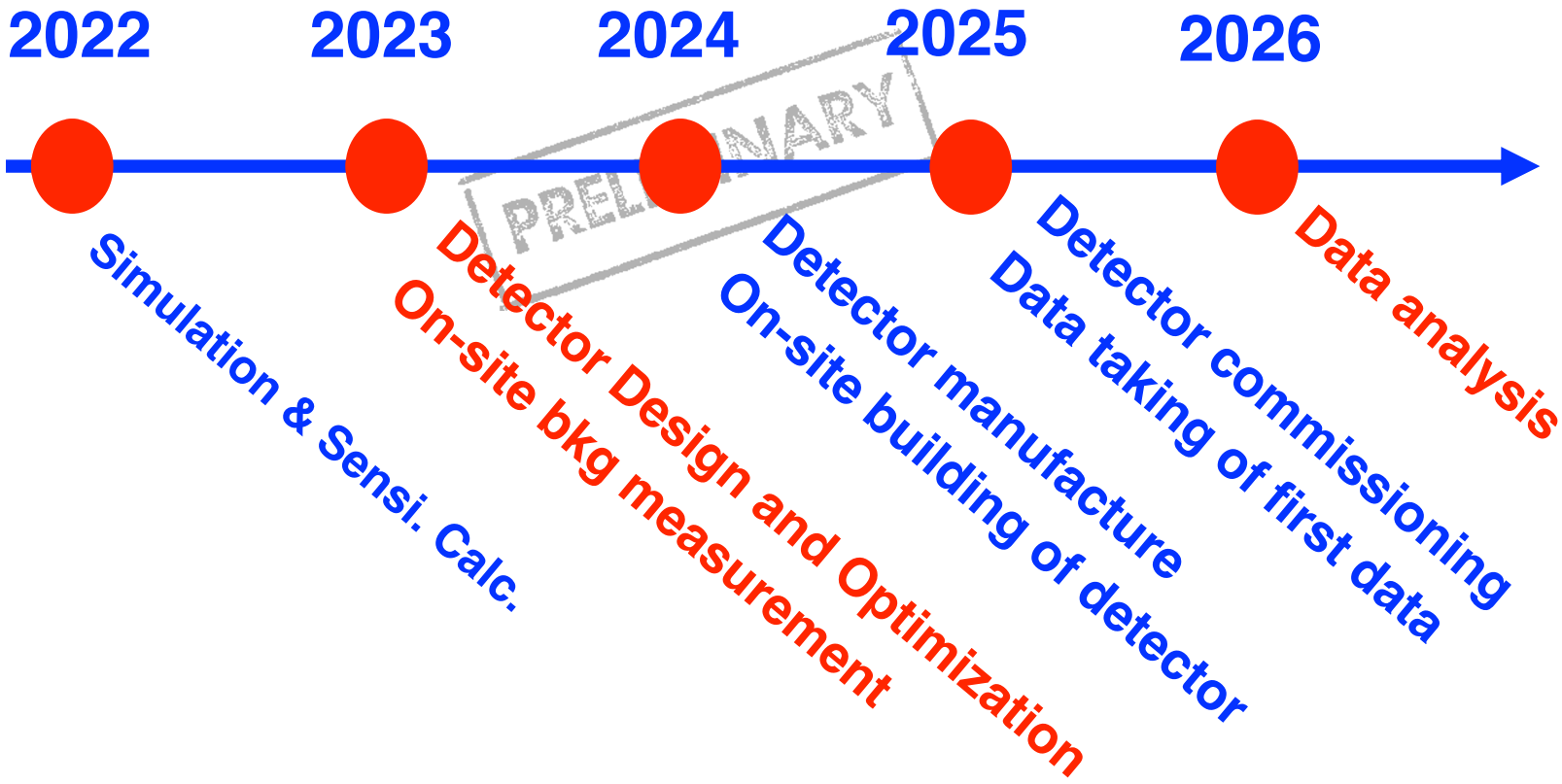
Weak mixing angle under low momentum transfer.



Neutrino-quark Non-standard interaction

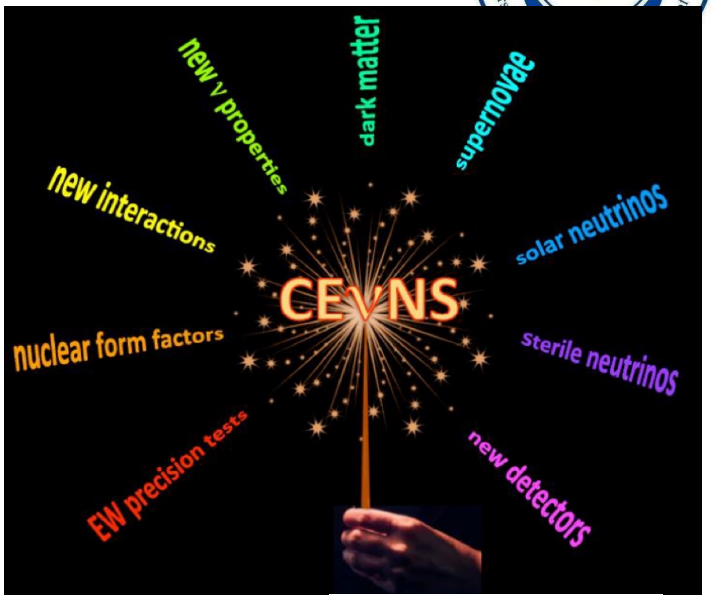


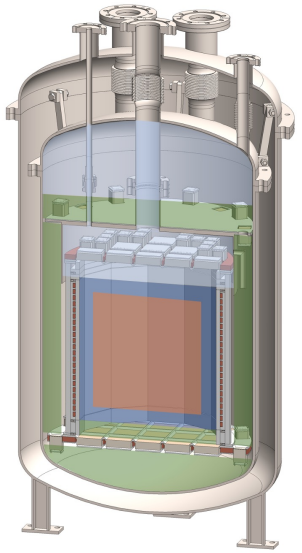
RELICS timeline



Summary and Prospect

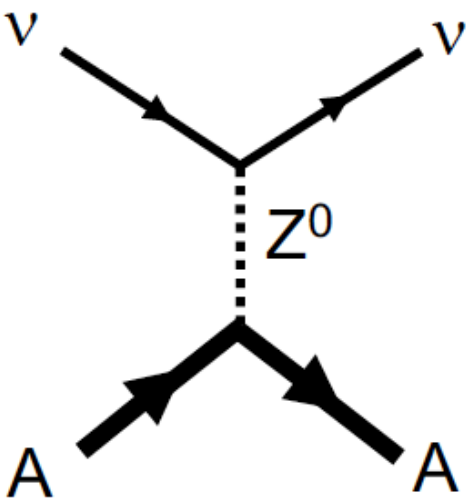
- Rich physics and application for CE**ν**NS;
- CE**ν**NS channel was already confirmed using high-energy and high-luminosity neutrino source from spallation neutron source;
- CE**ν**NS from nuclear process is the next low-hanging fruit; Promising way is low-threshold detector near nuclear plant;
- Great challenge for CE**ν**NS at sea level in terms of muon induced background suppression.
- RELICS is a reactor CE**ν**NS detection experiment using LXe-TPC.





Thank you for your attention!

Coherent Elastic Neutrino-nucleus Scattering

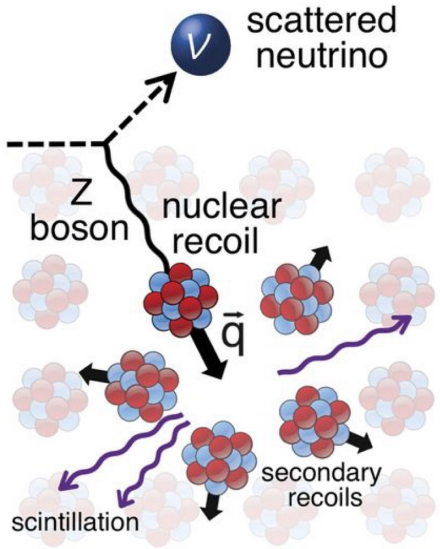


CEνNS

PHYSICAL REVIEW D VOLUME 9, NUMBER 5

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

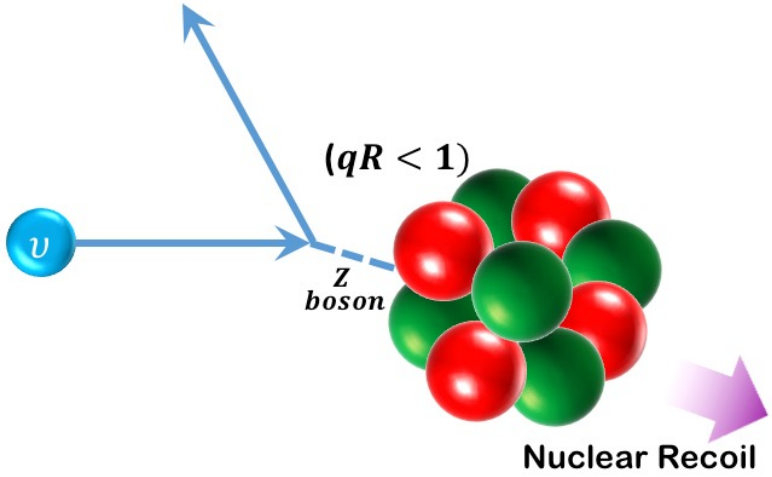


Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical ideas relevant to the experiments.

Coherent Elastic Neutrino-nucleus Scattering

Z-exchange of a neutrino with nucleus:

- nucleus recoils as whole
- coherent up to E_ν ~50MeV



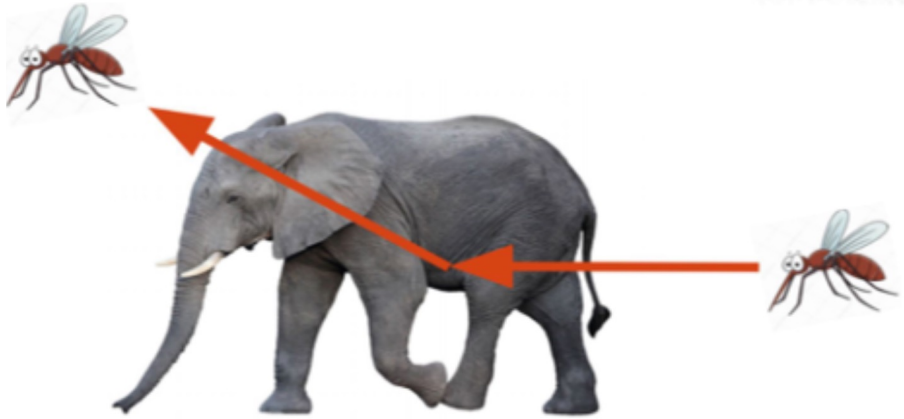
Neutrino wavelength larger than size of nucleus: qR<1

- q：momentum transfer
- R: nucleus size

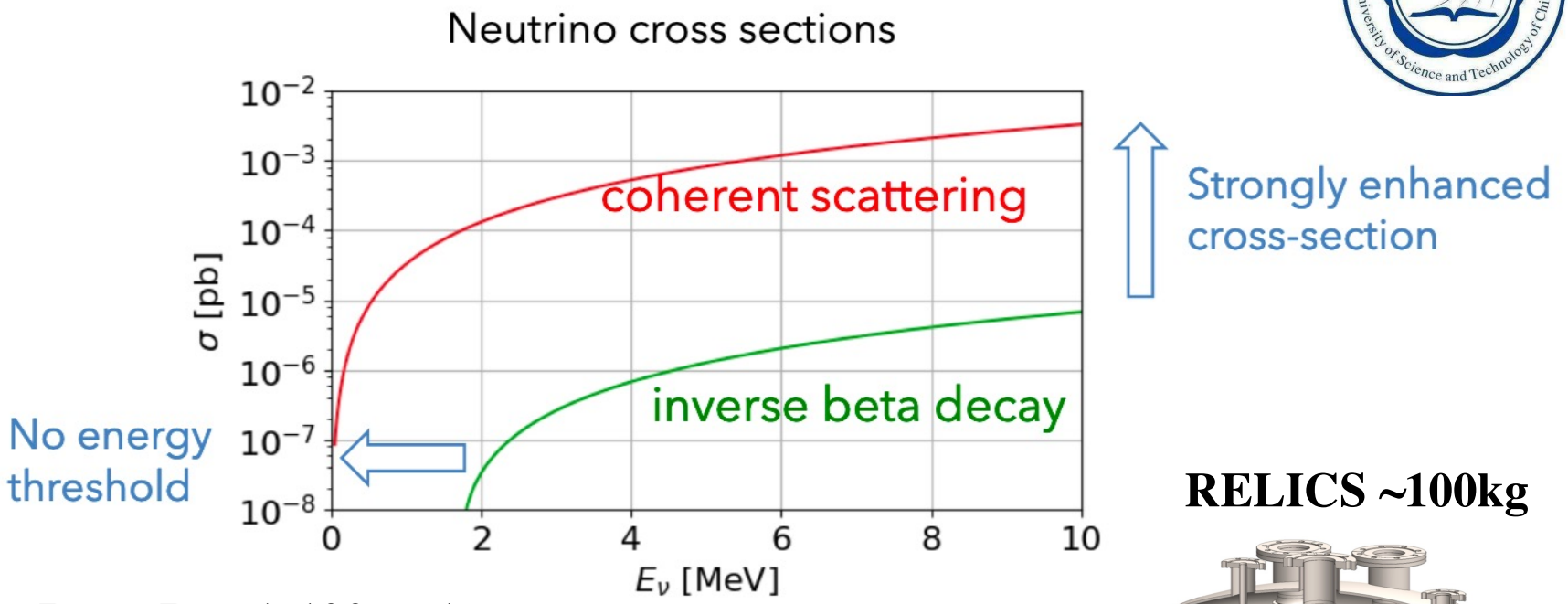
$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M\left(1 - \frac{MT}{2E_\nu^2}\right) F(Q^2)^2.$$

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

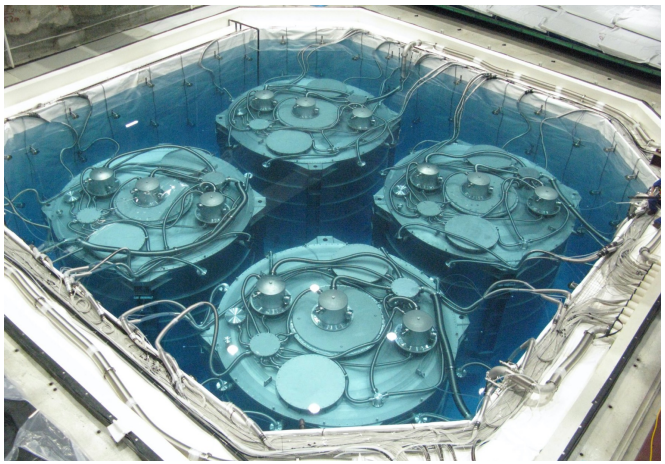
$$Q_W \propto N \Longrightarrow \boxed{\frac{d\sigma}{dT} \propto N^2}$$



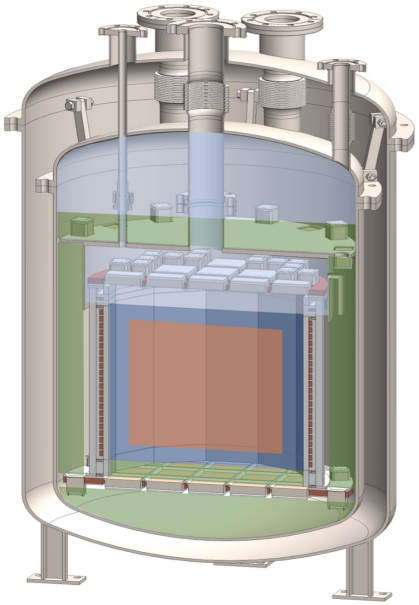
High cross section of CEνNS



Daya Bay (~100 ton)



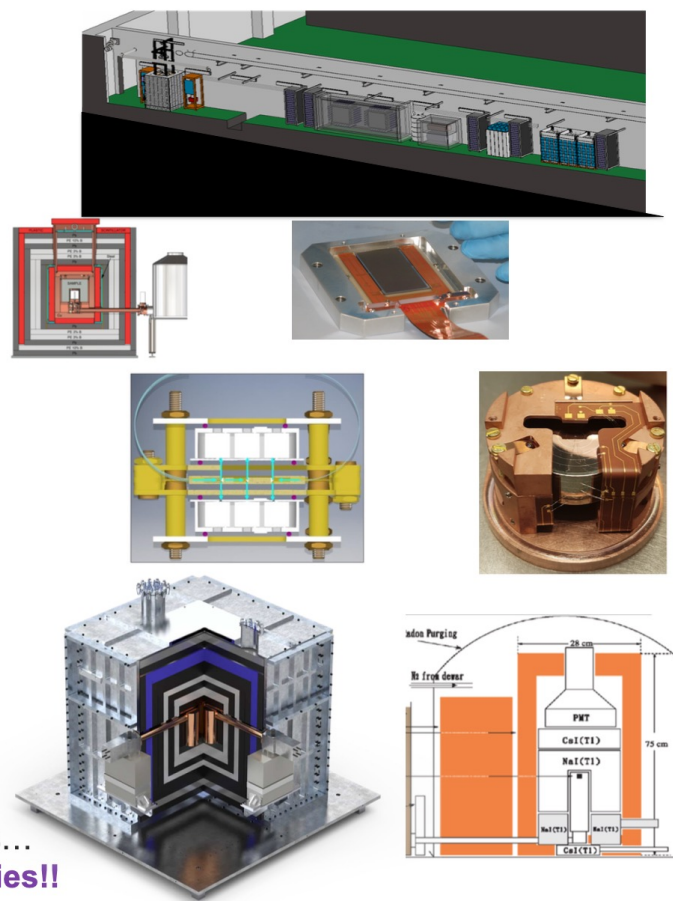
RELICS ~100kg



Detector Techniques for CEνNS

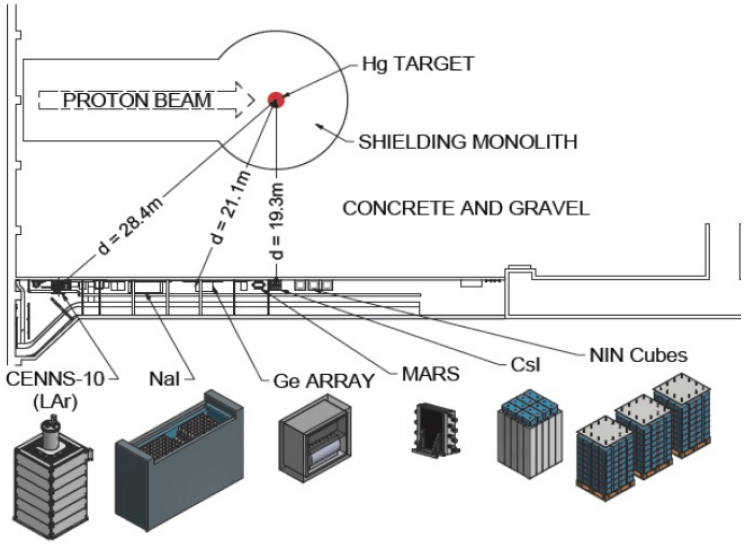
Figueroa-Feliciano (Magnificent CEvNS 2023)

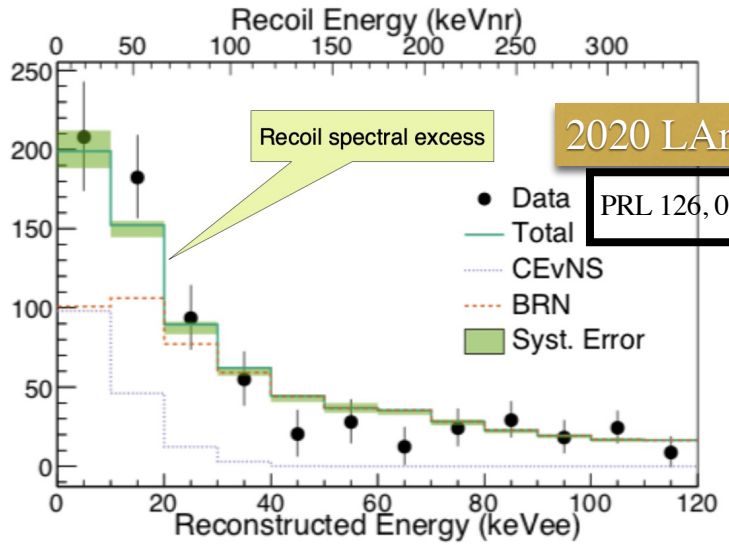
Experiment	Technology	Location	Source
COHERENT	CsI, Ar, Ge, NaI	USA	πDAR
CCM	Ar	USA	πDAR
ESS	CsI, Si, Ge, Xe	Sweden	πDAR
BULLKID	Si/Ge	Italy	Reactor
CONNIE	Si CCDs	Brazil	Reactor
CONUS	HPGe	Germany	Reactor
NEWS-G	Ar+2%CH4	Canada	Reactor
MINER	Ge/Si cryogenic	USA	Reactor
NEON	NaI(Tl)	Korea	Reactor
NUCLEUS	$CaWO_4$, Al_2O_3 cryogenic	Europe	Reactor
νGEN	Ge PPC	Russia	Reactor
RED-100	LXe dual phase	Russia	Reactor
Ricochet	Ge, Zn, Al, Sn cryogenic	France	Reactor
TEXONO	p-PCGe	Taiwan	Reactor
Dresden II	PCGe	USA	Reactor
SBC	Scintillating Bubble Chamber	Fermilab (R&D)	Reactor



+DM detectors, +directional detectors +Solar/SN detectors…
many novel low-background, low-threshold technologies!!

COHERENT Experiment

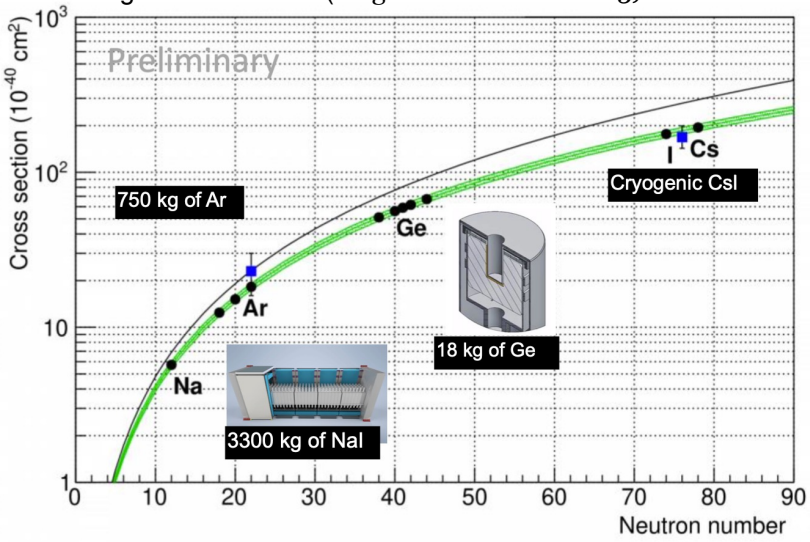


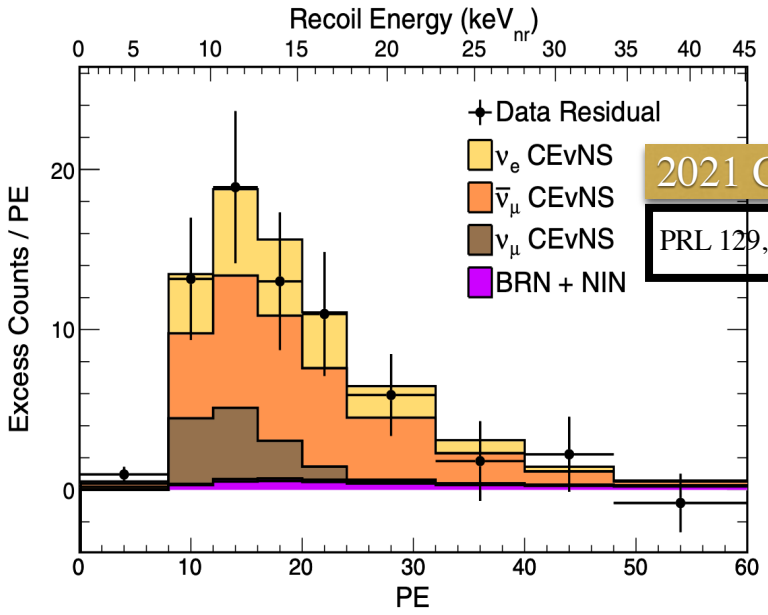


2020 LAr, >3σ

PRL 126, 012002 (2021)

Figueroa-Feliciano (Magnificent CEvNS 2023)





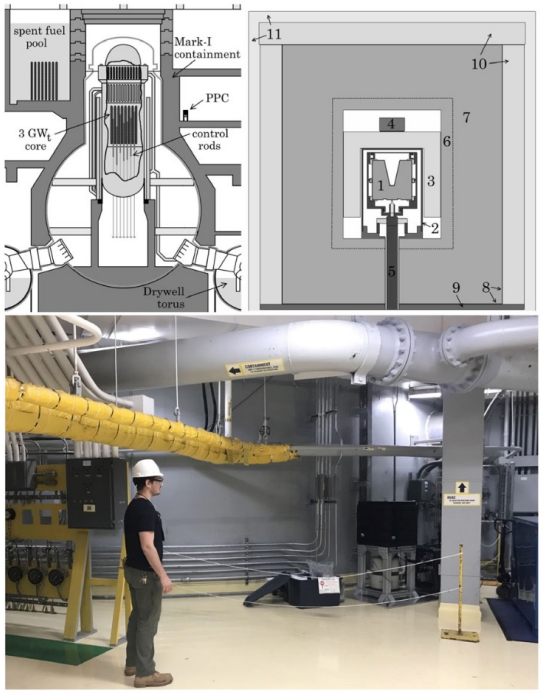
2021 CsI, 11.6σ

PRL 129, 081801 (2022)

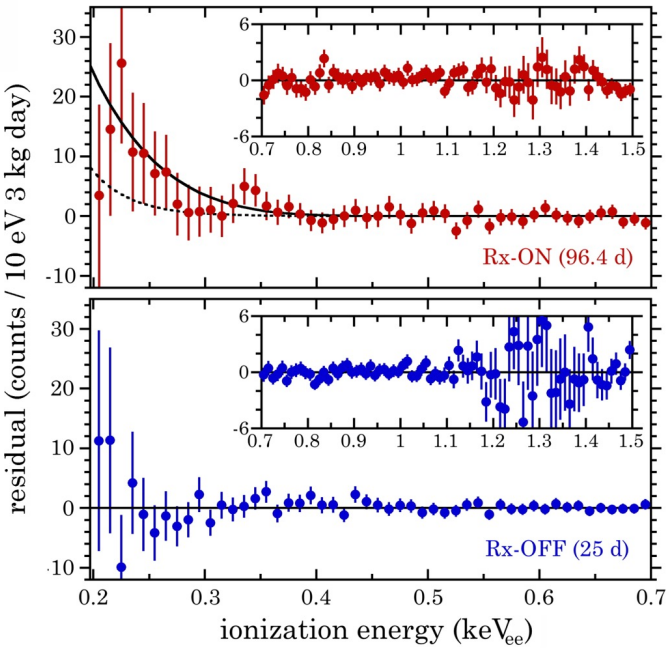
Dresden-II Experiment

- Dresden-II uses a **3-kg** Germanium detector (NCC-1701).
- The experiment collected beam-on data for 96.4 days, located **10.39 meters** from the Dresend-II reactor, with a low detection threshold of **0.2 keVee.**

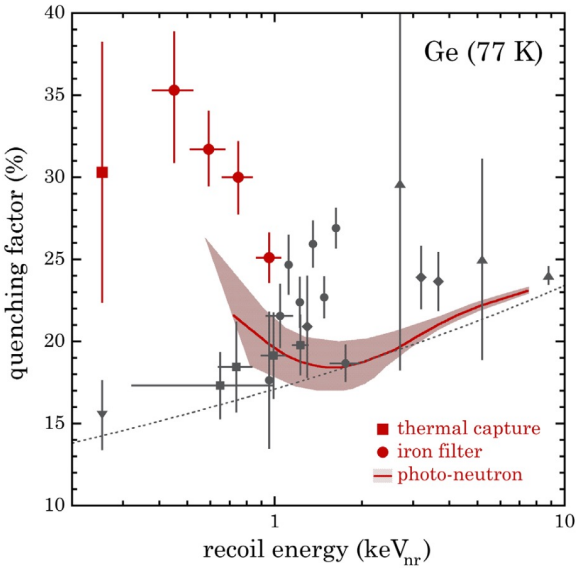
PRD 104, 072003 (2021)



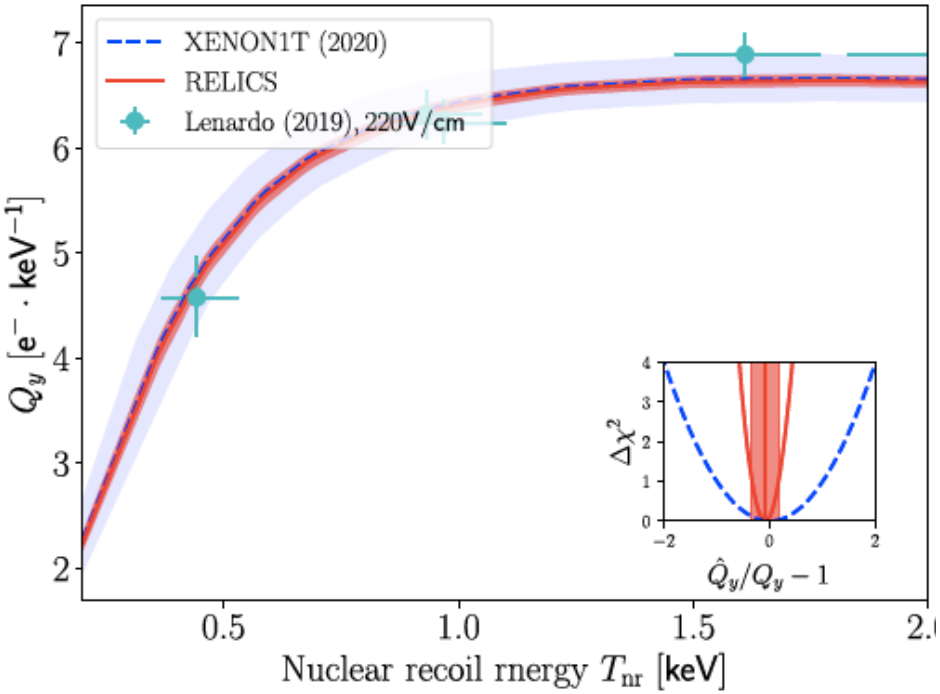
PRL 129, 211802 (2022)

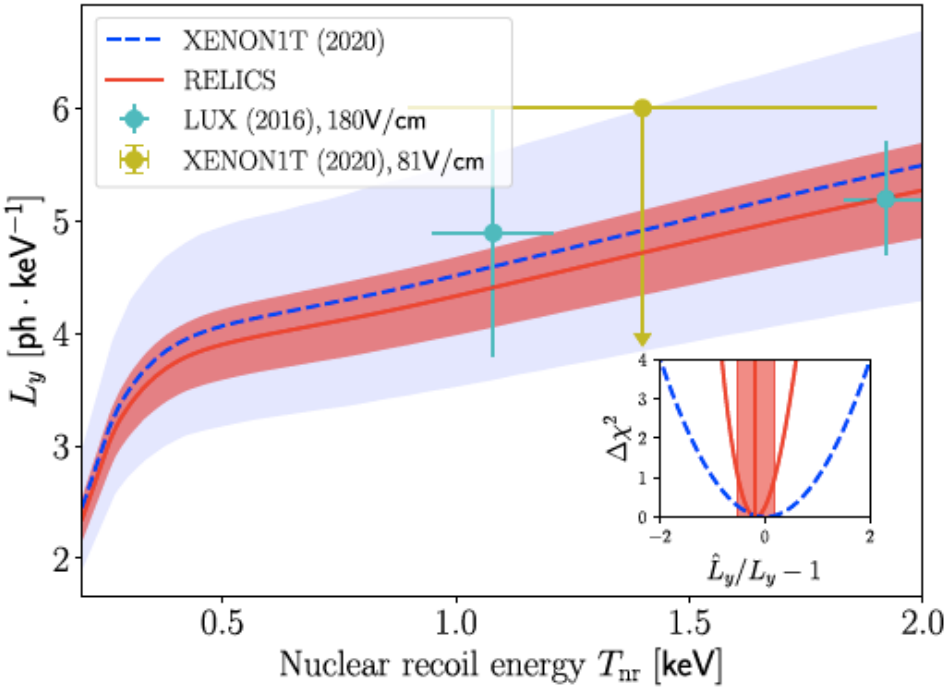


PRD 103, 122003 (2021)



Backup



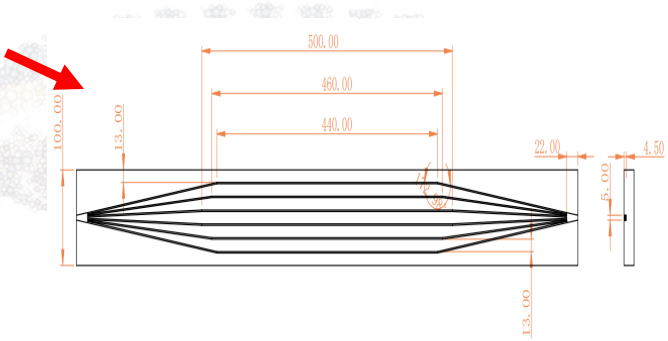


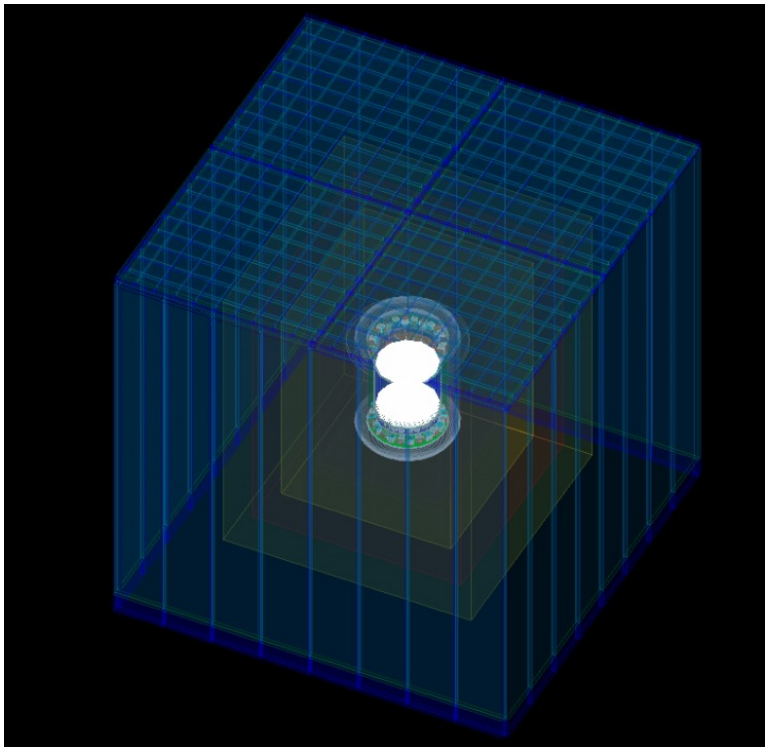
- Constraining the light and charge yield in LXe at <keV region.
- Reduce signal uncertainty in LXe-based DM search experiment.

Ongoing work: Muon veto prototype

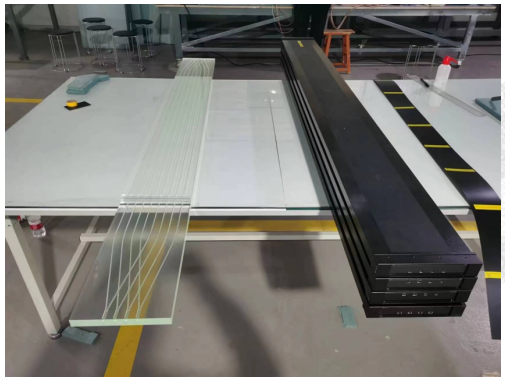
- Design: Plastic scintillator + fibers + SiPM
- Target: >99% muon tag efficiency

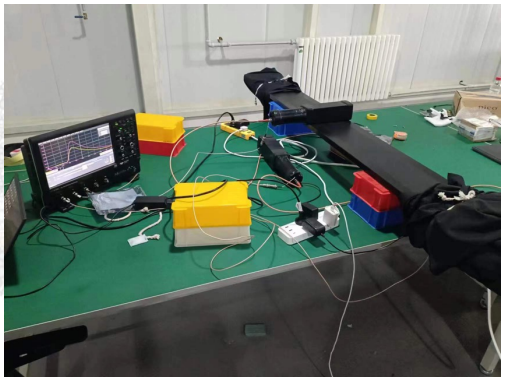
Design of the single piece PS with preliminary fibers layout, and thickness of 2cm. The design is under optimization.





Together with NEREUS experiment, a few pieces has been fabricated for electronics & DAQ development.





Template