RELICS Reactor Neutrino Detection Experiment

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On behalf of **the RELICS Collaboration**

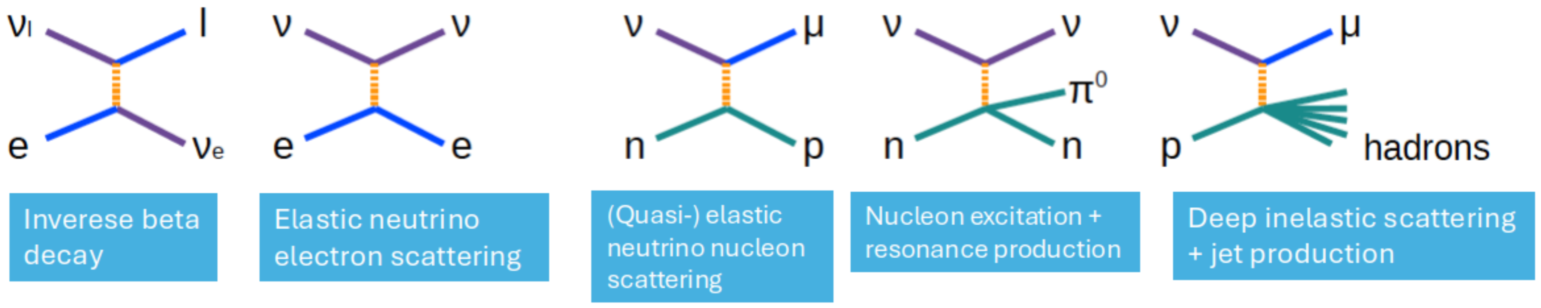
Aug. 22, 2025

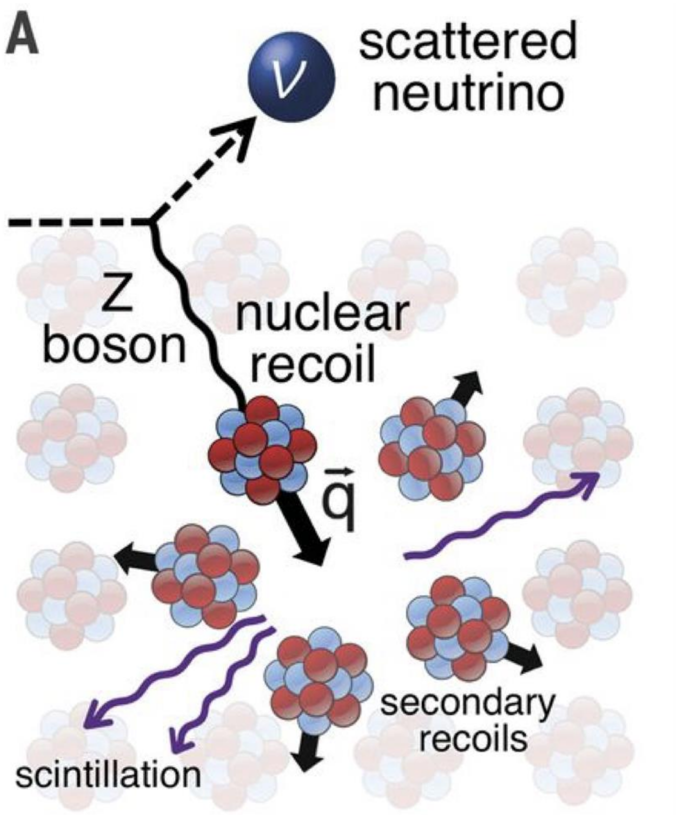
22nd Lomonosov Conference on Elementary Particle Physics

CEυNS Interaction Process

RELICS WESTLAKE UNIVERSITY 西湖大學

Coherent Elastic Neutrino-Nucleus Scattering, CEυNS

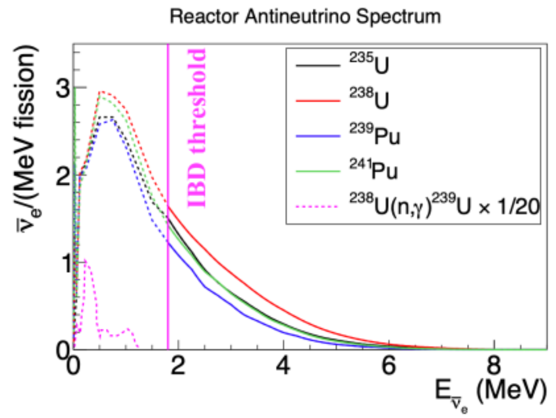




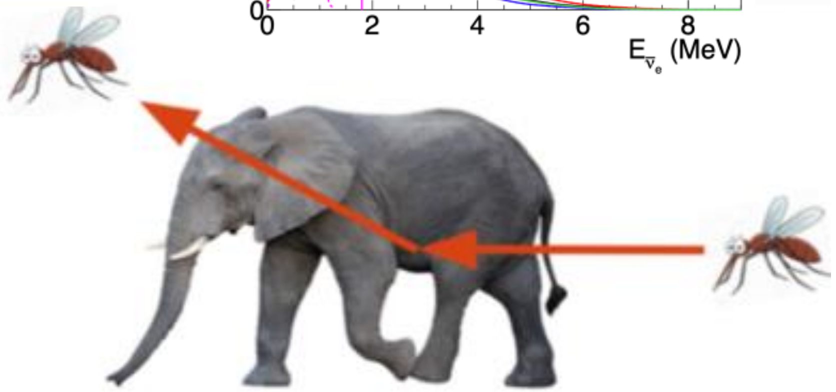
$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} Q_W^2 M \left(1 - \frac{MT}{2E_\nu^2}\right) F(Q^2)^2.$$

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

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



- Proportional to $N_{neutron}^2$
- Neutrino $E_\nu \sim 50\ MeV$
- Recoil energy $< 5keV$



CEνNS: Worldwide Campaign

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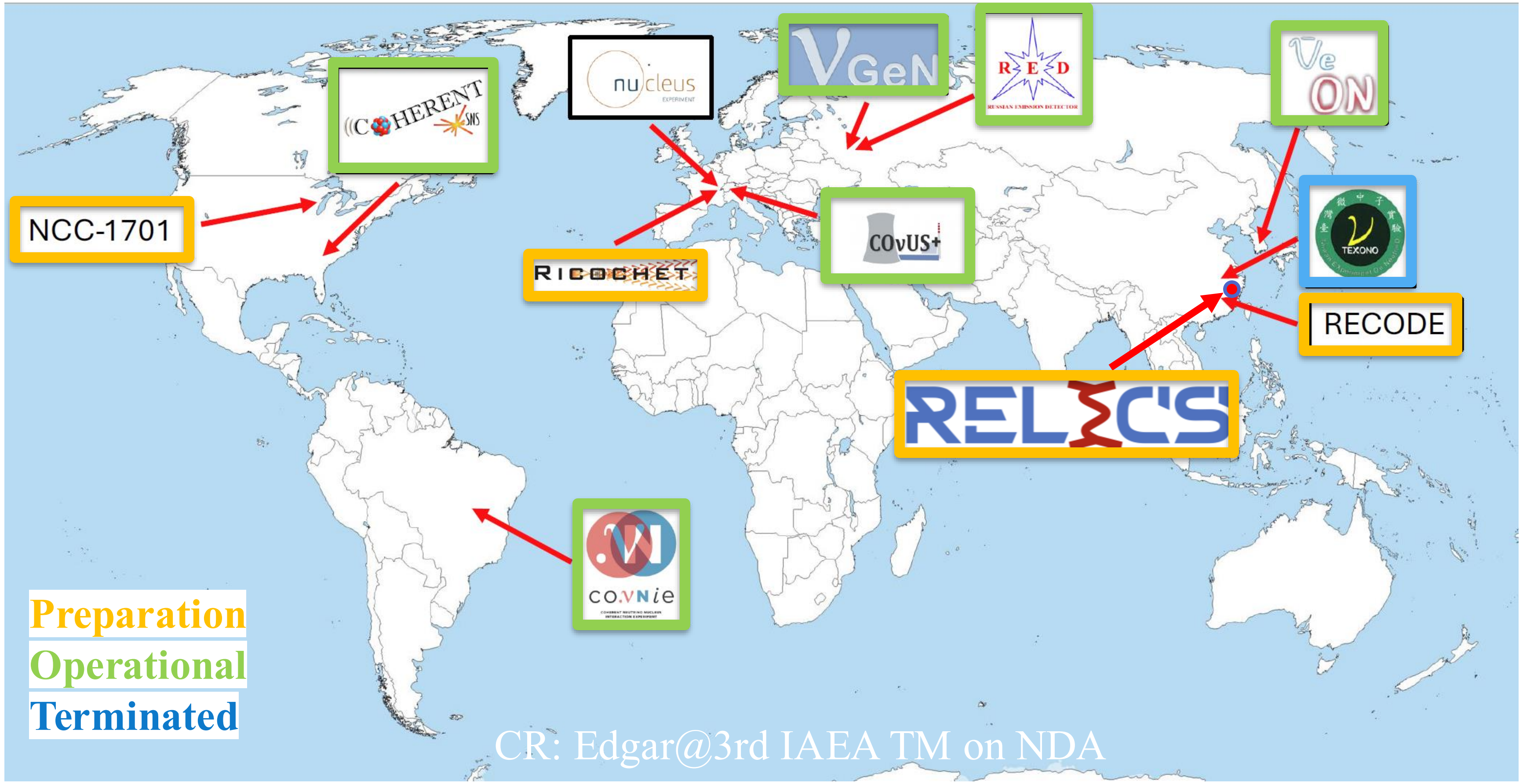


Experimental Conditions

- An intense **neutrino source**
- **Low energy thresholds**
- **Very low background rate**

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

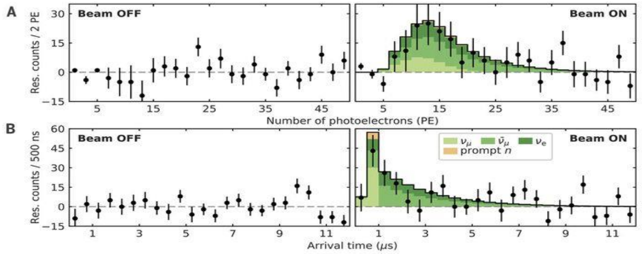
Daniel Z. Freedman†

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

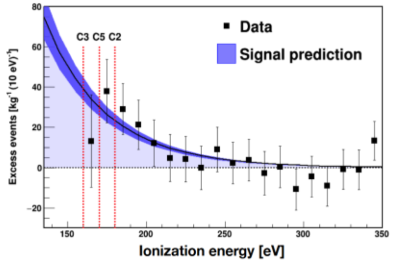
CsI-2017

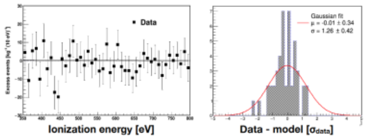
D. Akimov et al, Science 357 (2017)



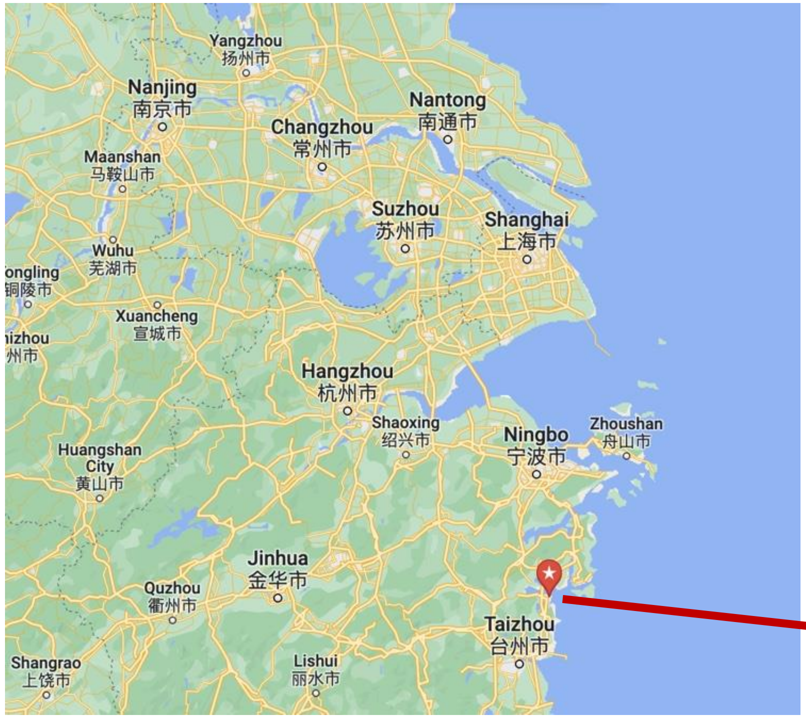
Ge-2025

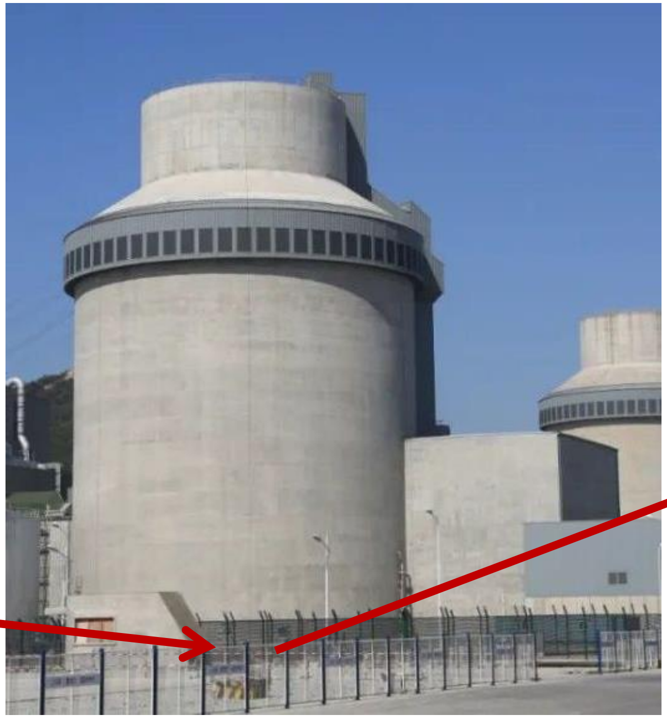
N.Ackermann et al, Nature 643 (2025) 1229-1233

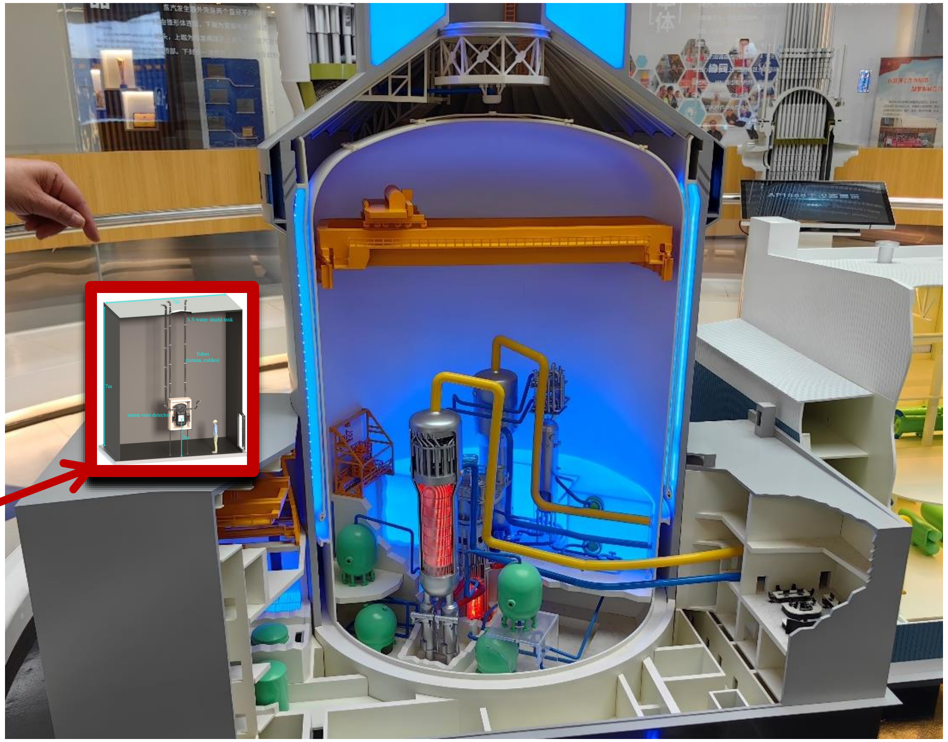




RELICS Experiment Location







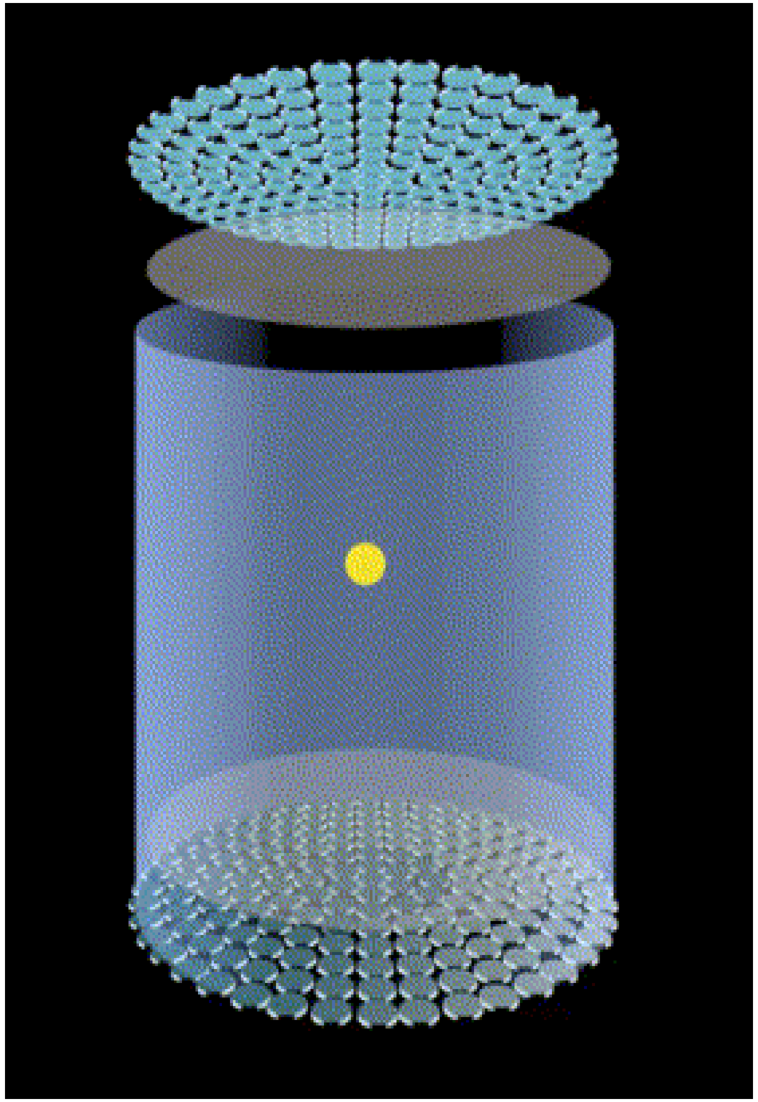
- **Sanmen Nuclear Power Plant, Taizhou, China**
- Reactor Power **~3.4GW** , Distance to Core **~25m**
- Neutrino flux $\sim 10^{13} \nu/cm^2/s$

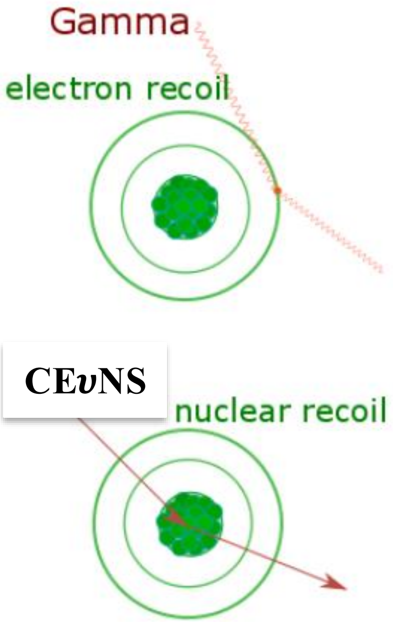
RELICS Collaboration

REactor neutrino LIquid xenon Coherent Scattering experiment (RELICS)

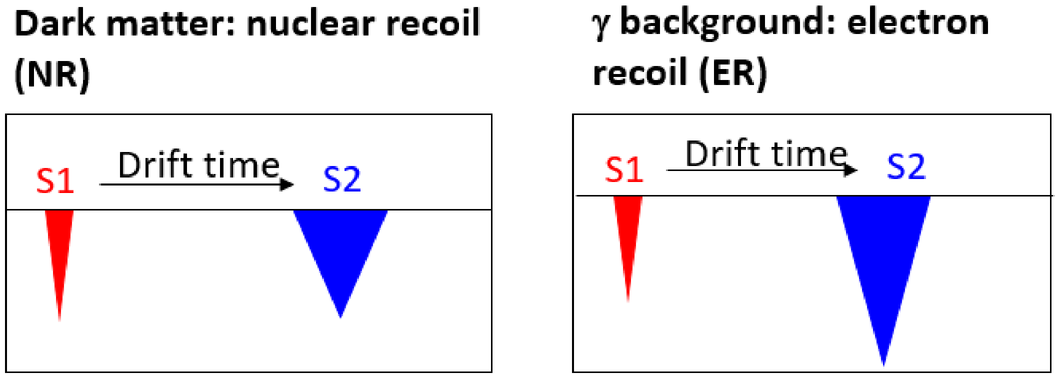
Collaboration meeting 2024 @ GuangZhou

The Two-Phase Liquid Xenon TPC



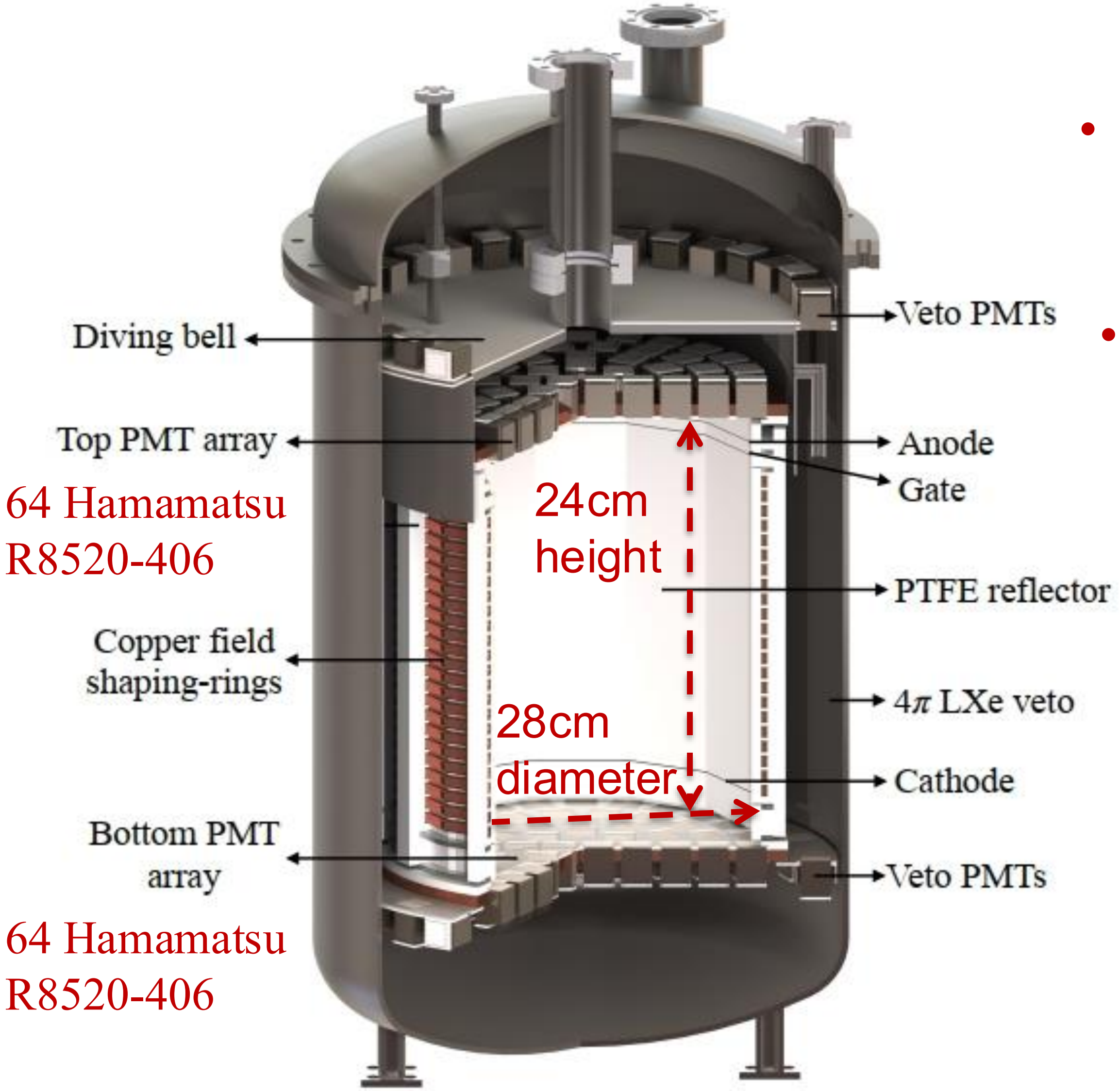


- Energy, 3D position reconstruction
- Particle interaction identification
- Low isotope background
- Low ionization energy threshold
- Used in dark matter searches

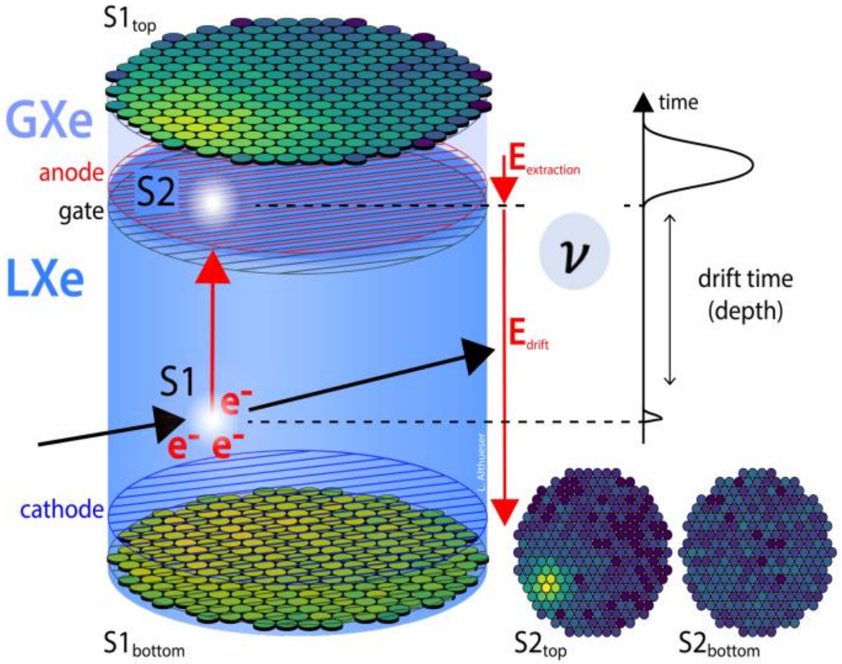


$(S2/S1)_{NR} \ll (S2/S1)_{ER}$

RELICS Detector



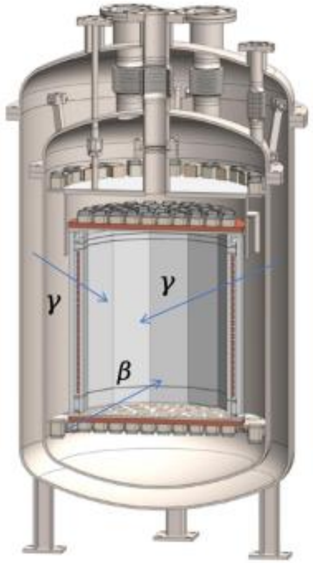
- Extraction field 10kV/cm
- drift field 500V/cm ν



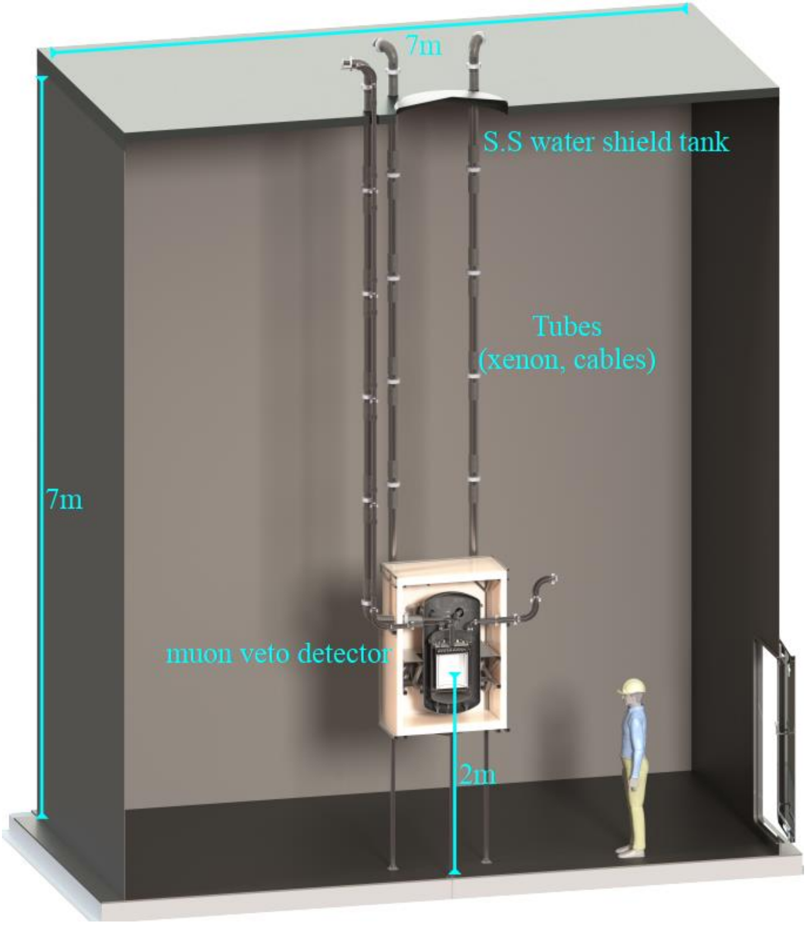
- Fiducial Mass 32 kg, 62kg LXe in total
- ROI Recoil energy: 0.3~1 keV
- S2 only-analysis(low energy threshold)

RELICS Background Source

Reactor(γ, n)

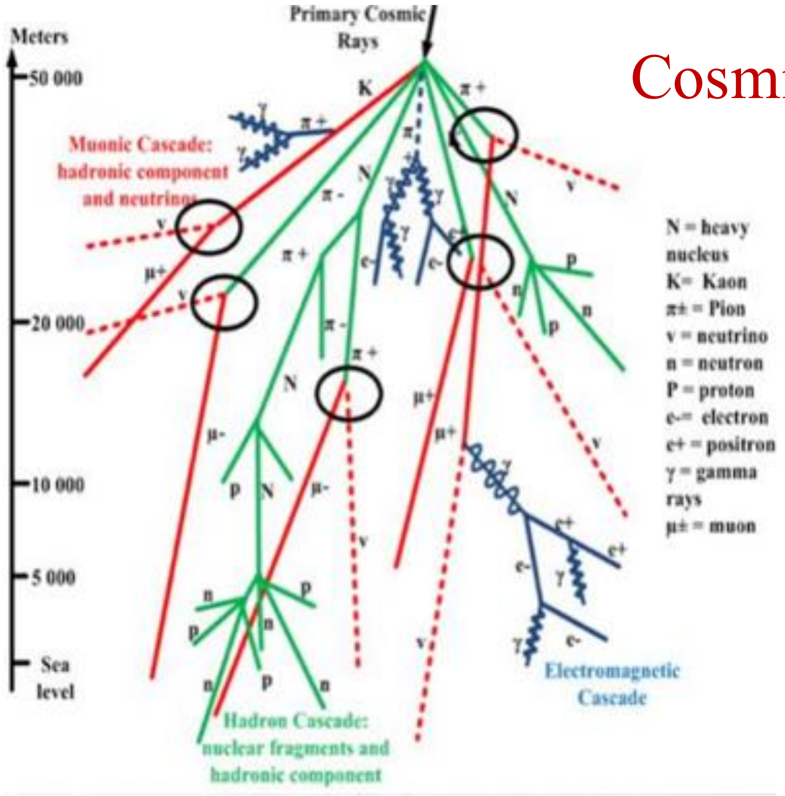


Material (γ, n)



Cosmic μ $\boldsymbol{O(10Hz)}$

Cosmic neutron



- Water shielding
- Muon veto, 99% efficiency

RELICS Background Budget

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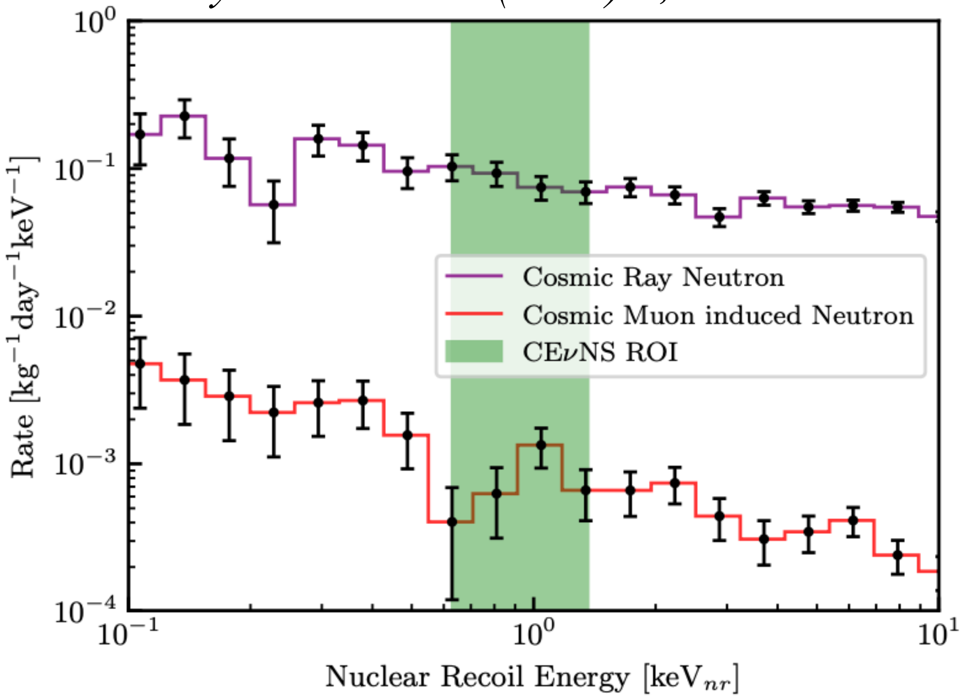
Phys. Rev. D 110 (2024) 7, 072011

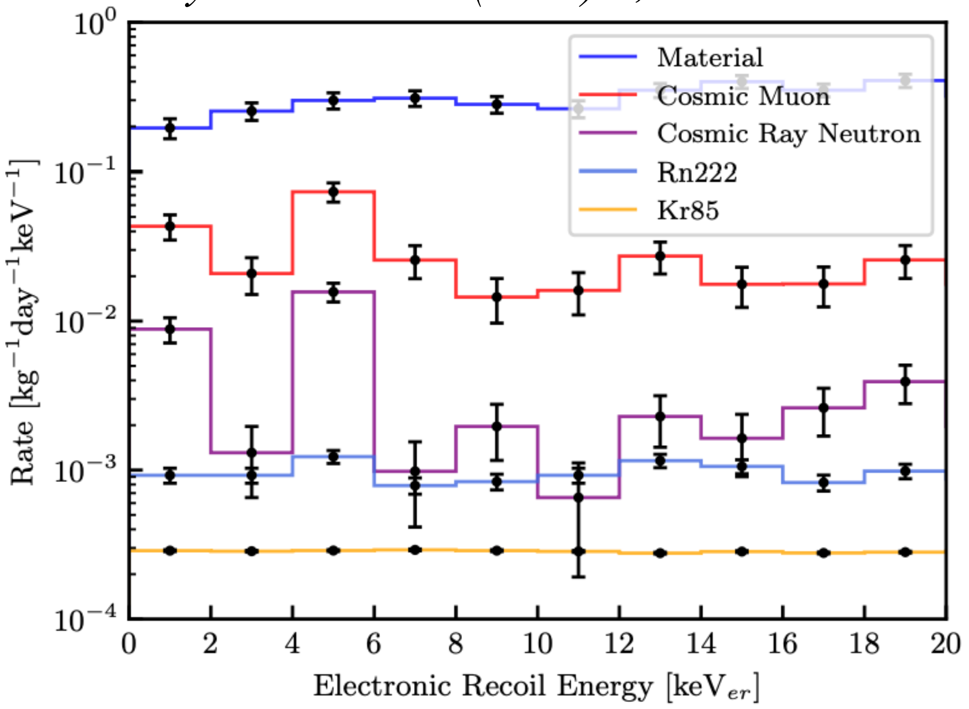


- NR background [0.63,1.36]keV_{nr} :

  $(\mathbf{6.0 \pm 0.6}) \times \mathbf{10^{-2}}\ kg^{-1} \cdot day^{-1}$

- Cosmic neutron dominant

Phys. Rev. D 110 (2024) 7, 072011



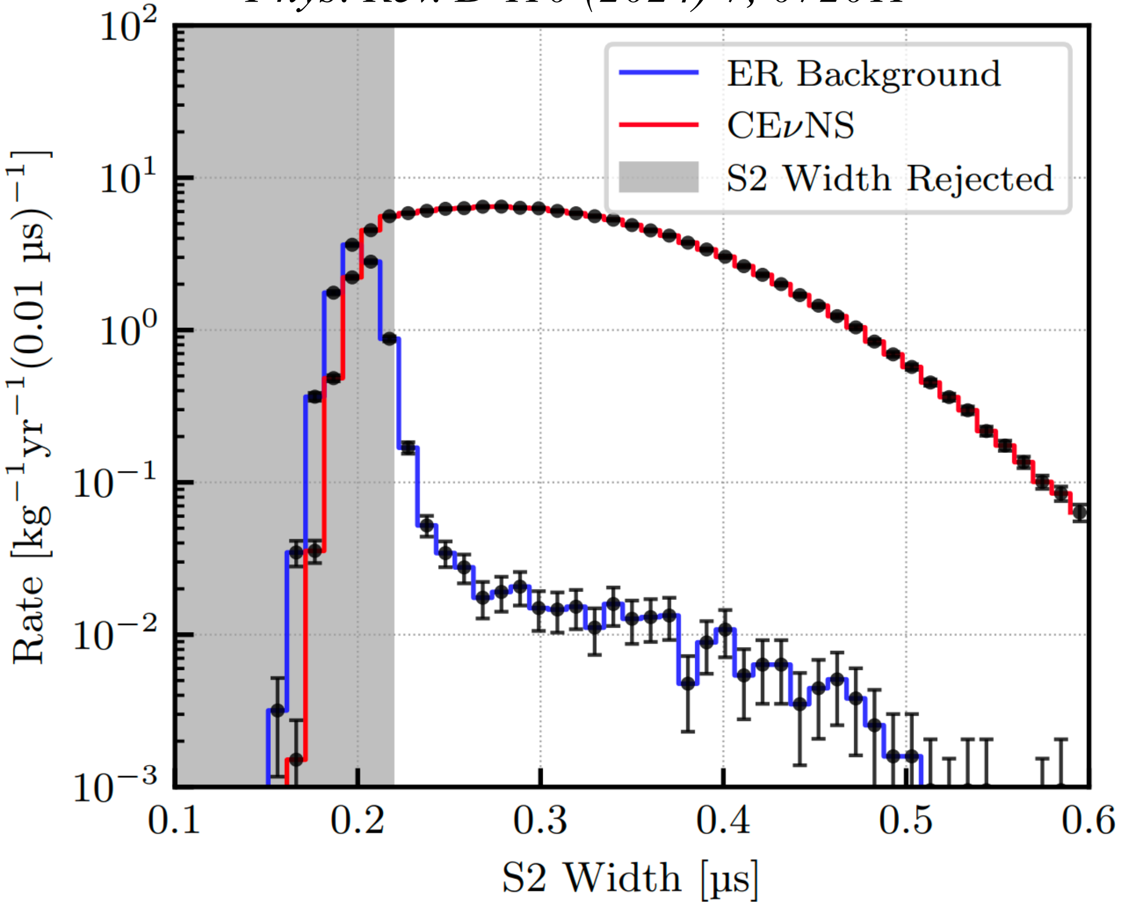
- ER background $[0, 20]keV_{er}$:

  $(\mathbf{310 \pm 10}) \times \mathbf{10^{-3}} kg^{-1} \cdot day^{-1} \cdot keV^{-1}$

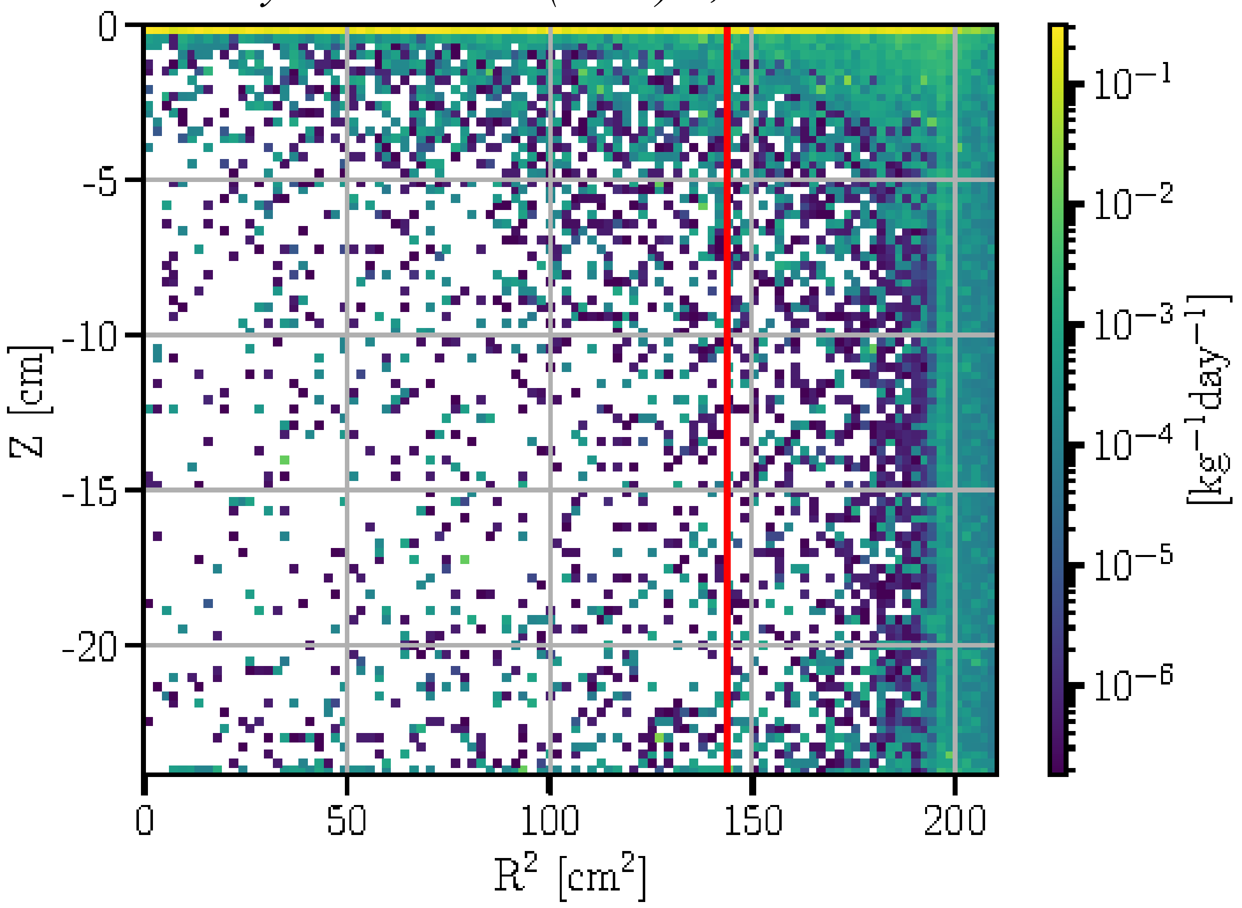
- Detector material dominant

ER Background Suppression Strategy

Phys. Rev. D 110 (2024) 7, 072011



Phys. Rev. D 110 (2024) 7, 072011



- Most of the ER background is at the top due to absence of LXe shielding
- Utilizing S2 width cut of 0.22us, **rejection 94% , 86% CEνNS survived**

Delay Electron(DE) Background

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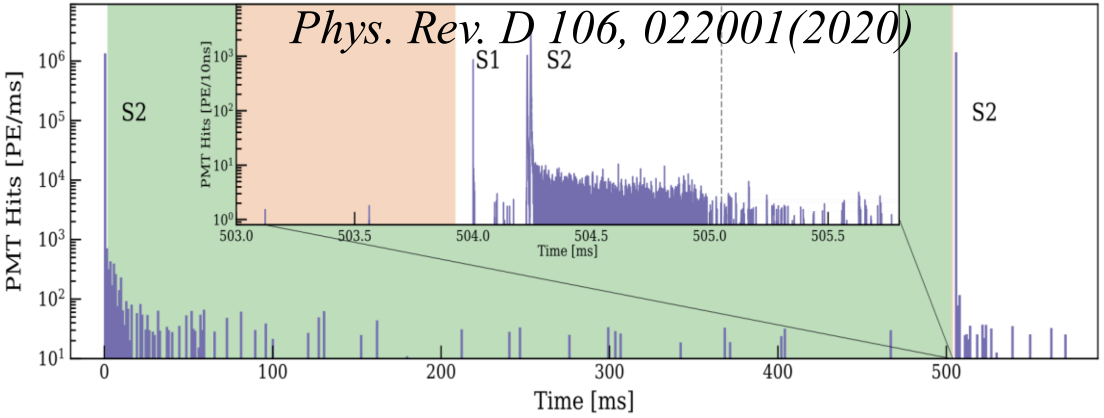
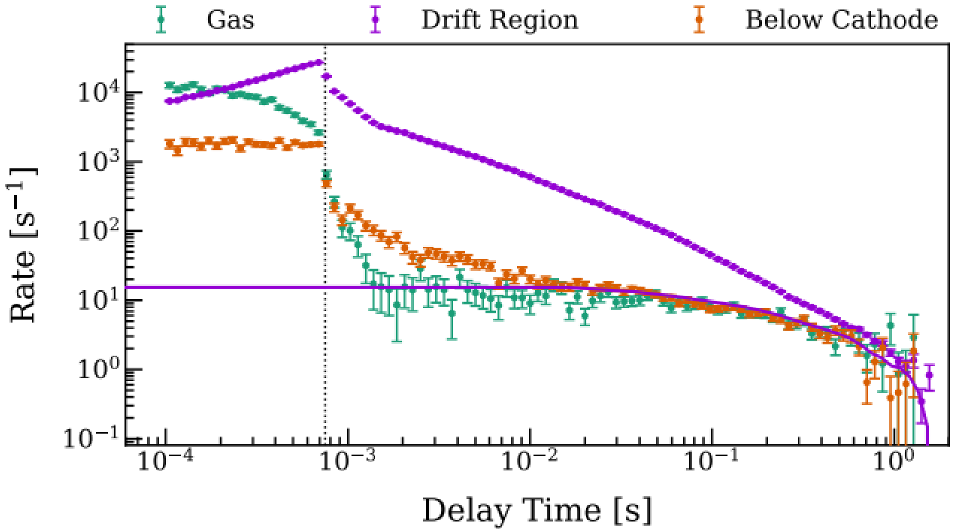
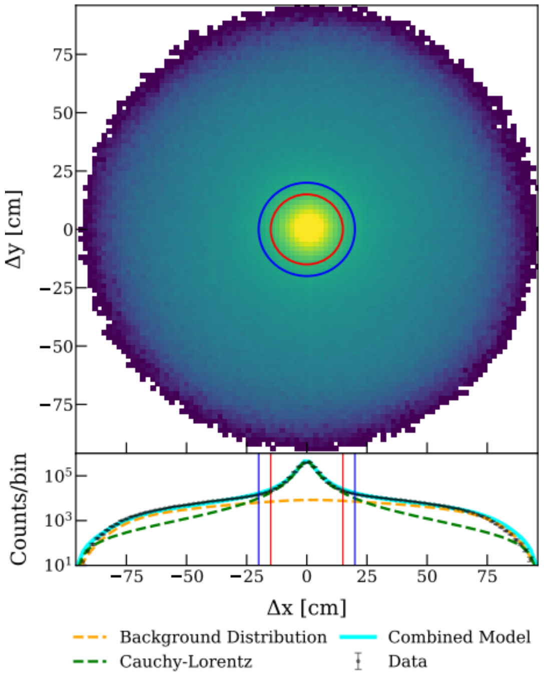
Phys. Rev. D 106, 022001(2020)





- **Exponential power law decay** in time
- Up to the **second ~*s* level**



- **Recoil positions related**

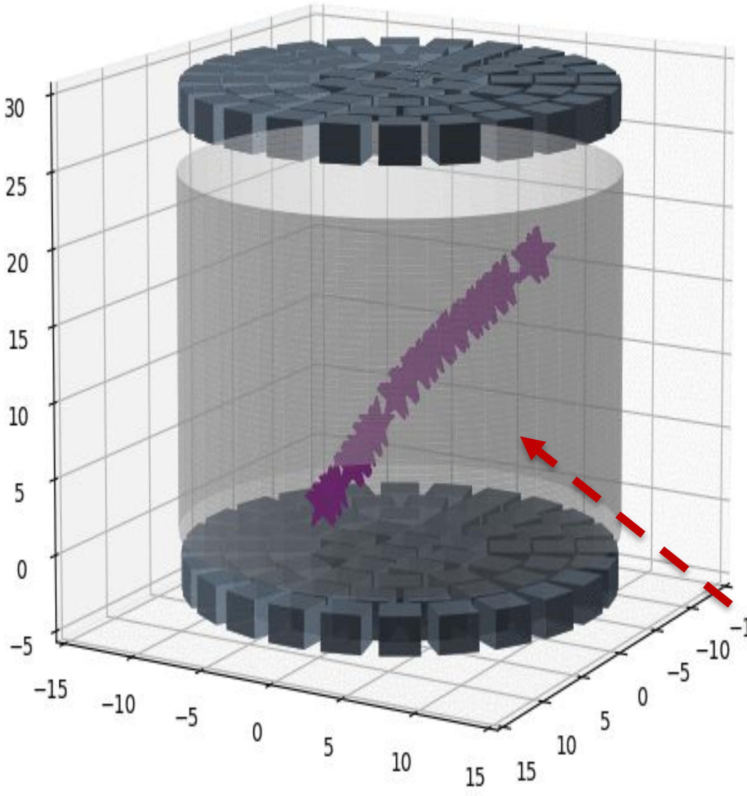
32*kg.year* exposure

Challenge !

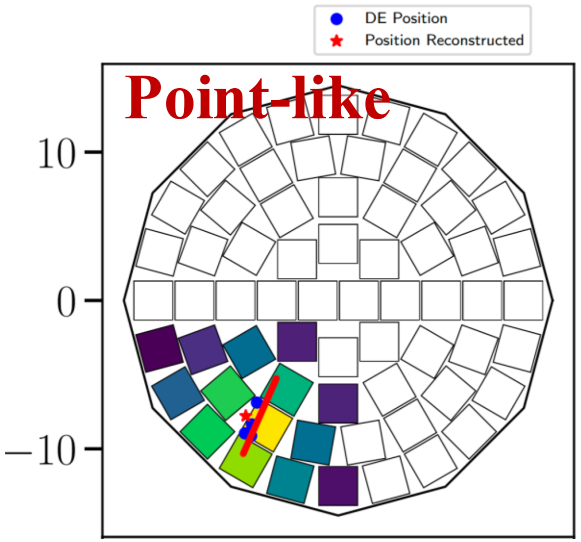
Phys. Rev. D 110 (2024) 7, 072011

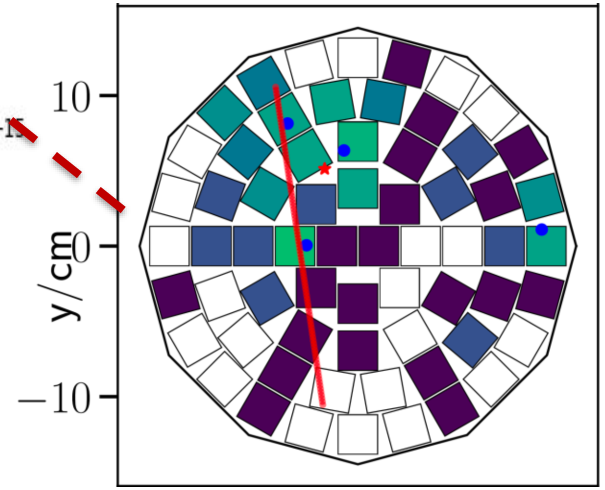
N_e	CEνNS	DE pile-up
3	3.5×10^4	9.8×10^8
4	1.5×10^4	7.3×10^6
5	6.9×10^3	6.9×10^5
6	3.2×10^3	7.5×10^4

DE Suppression Strategy



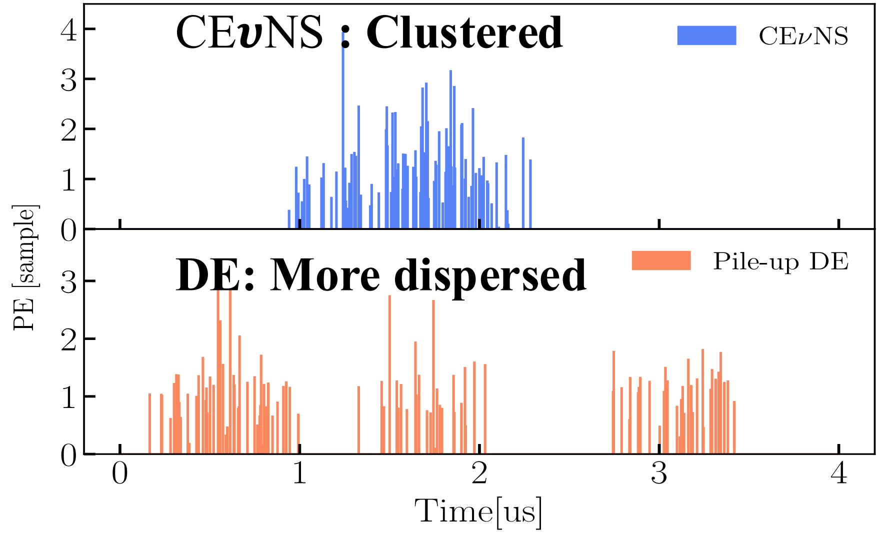
Muon scattering in TPC

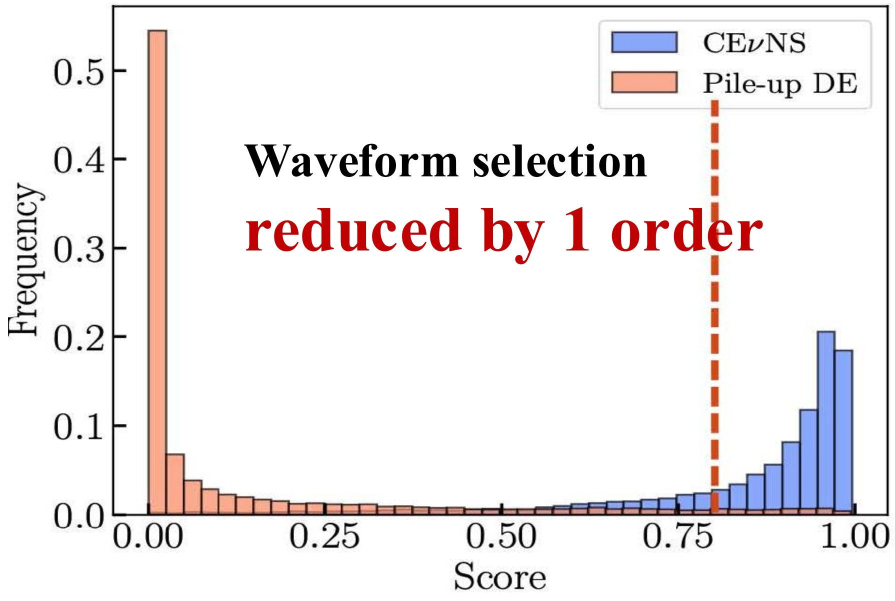




Track related

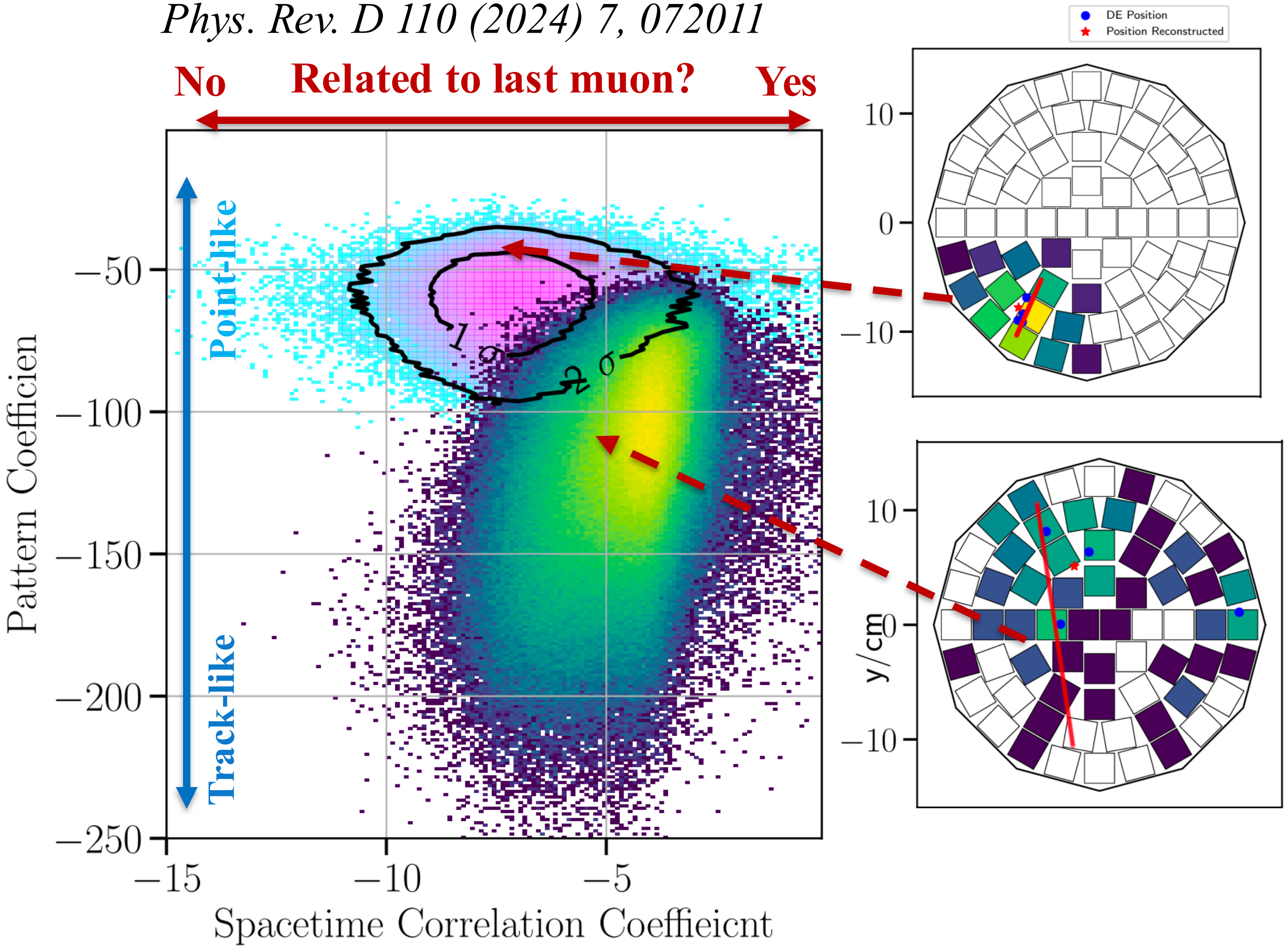
Phys. Rev. D 110 (2024) 7, 072011





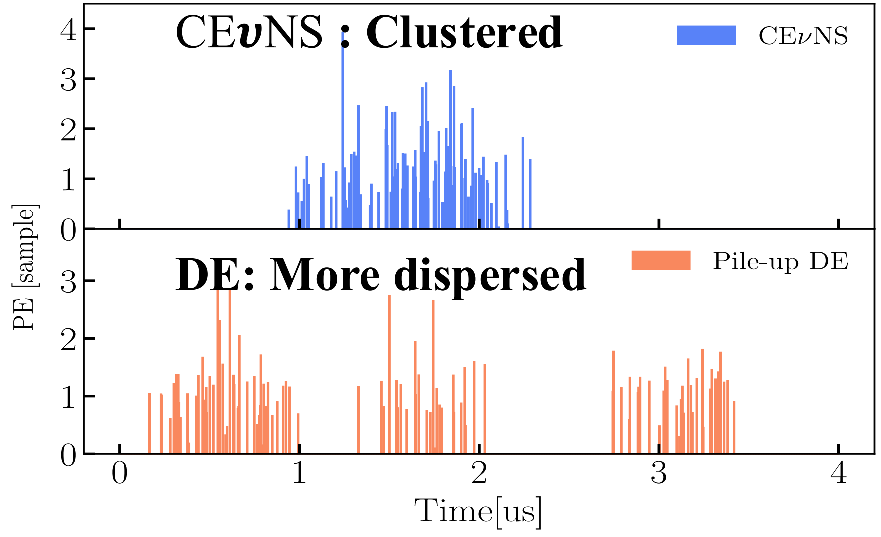
DE Suppression Strategy

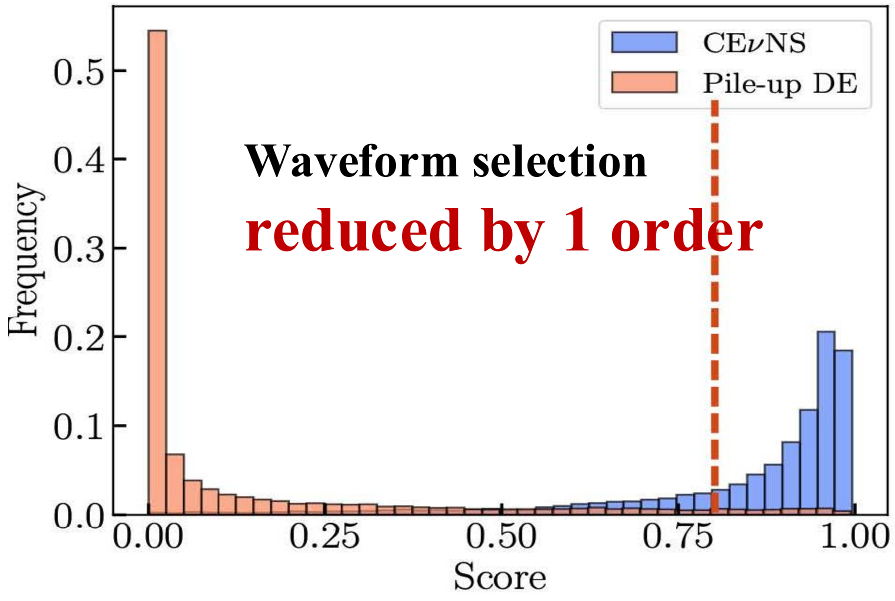
Phys. Rev. D 110 (2024) 7, 072011



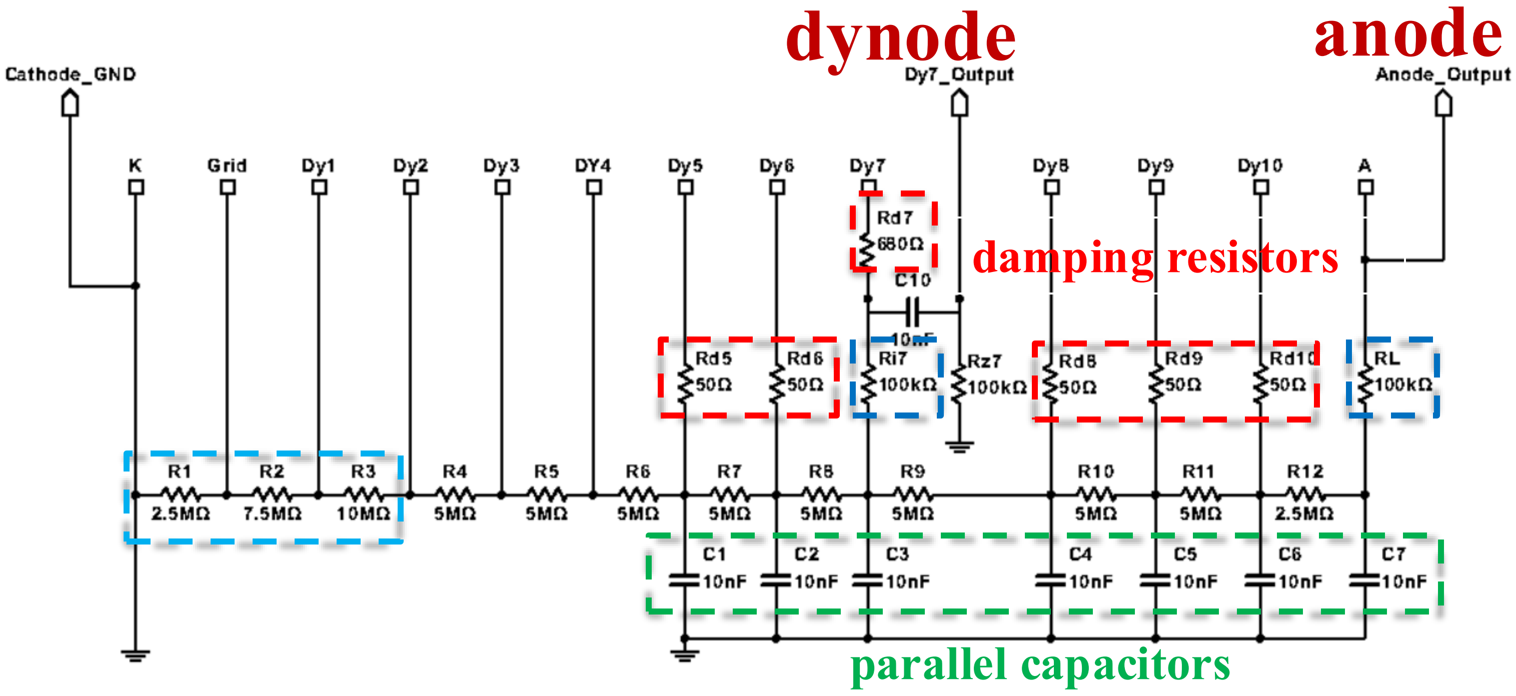
Spacetime correlation selection reduced by 4 orders

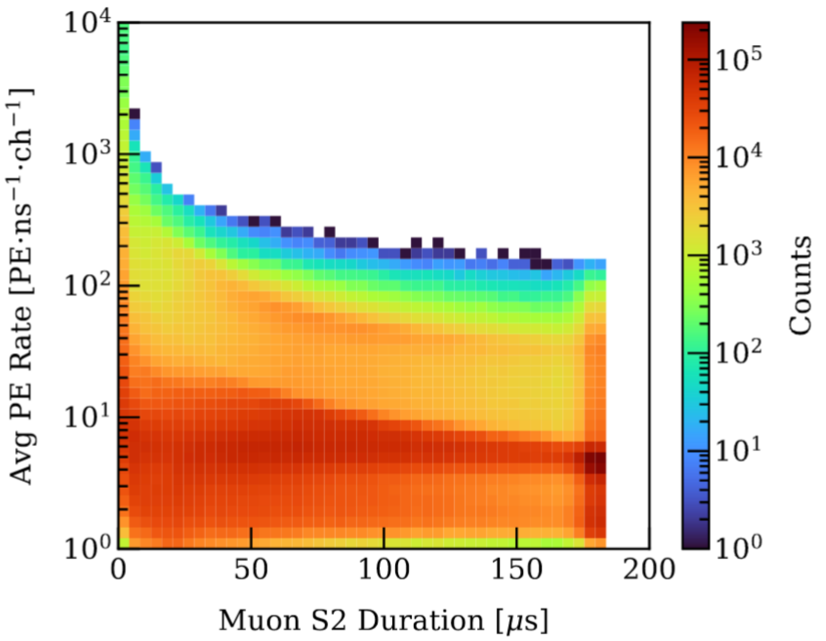
Phys. Rev. D 110 (2024) 7, 072011

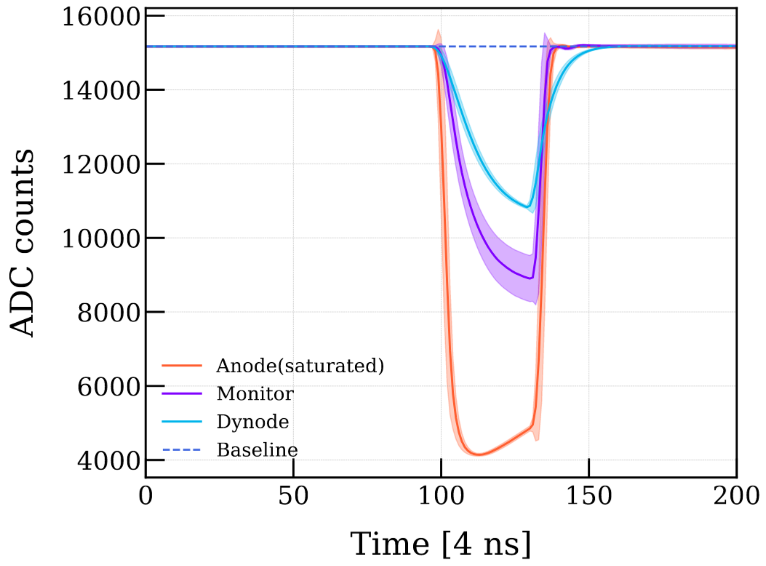




Dynamic Readout Technique

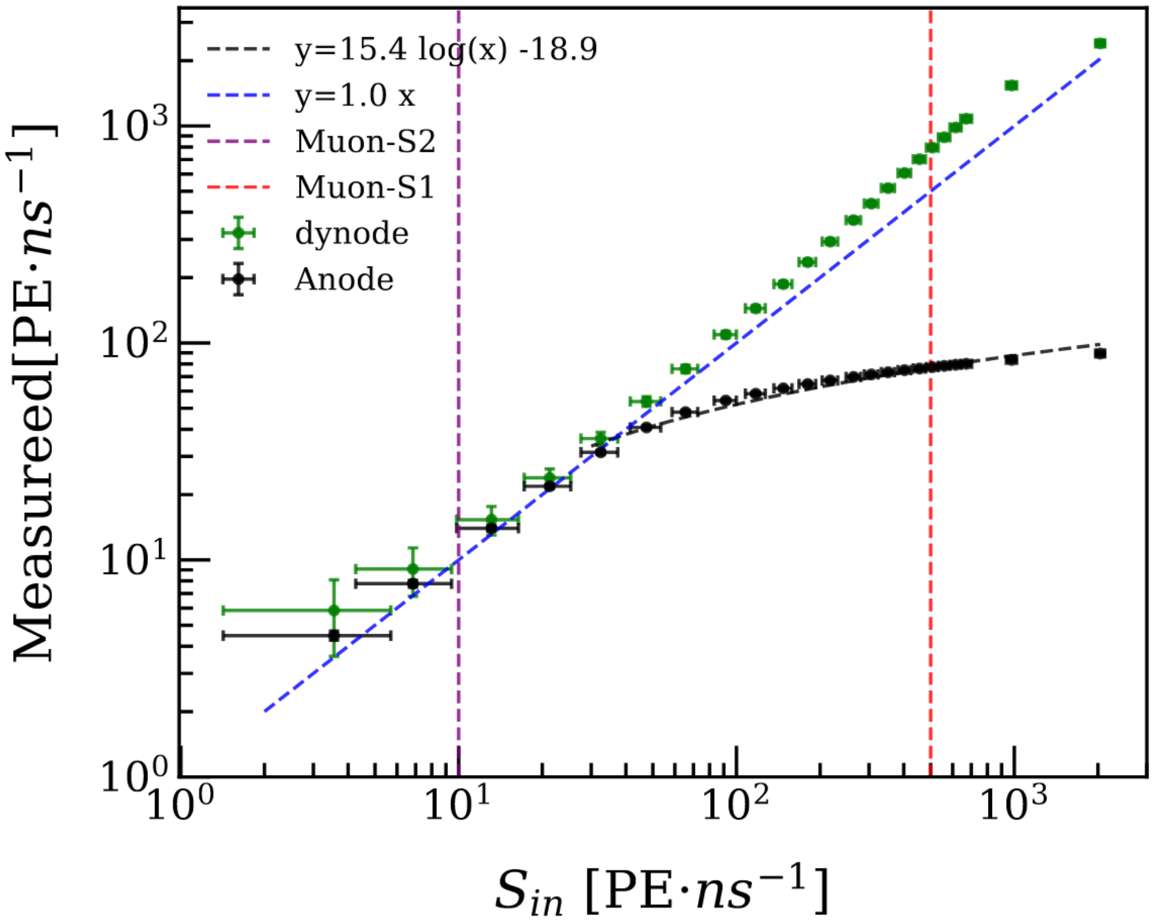


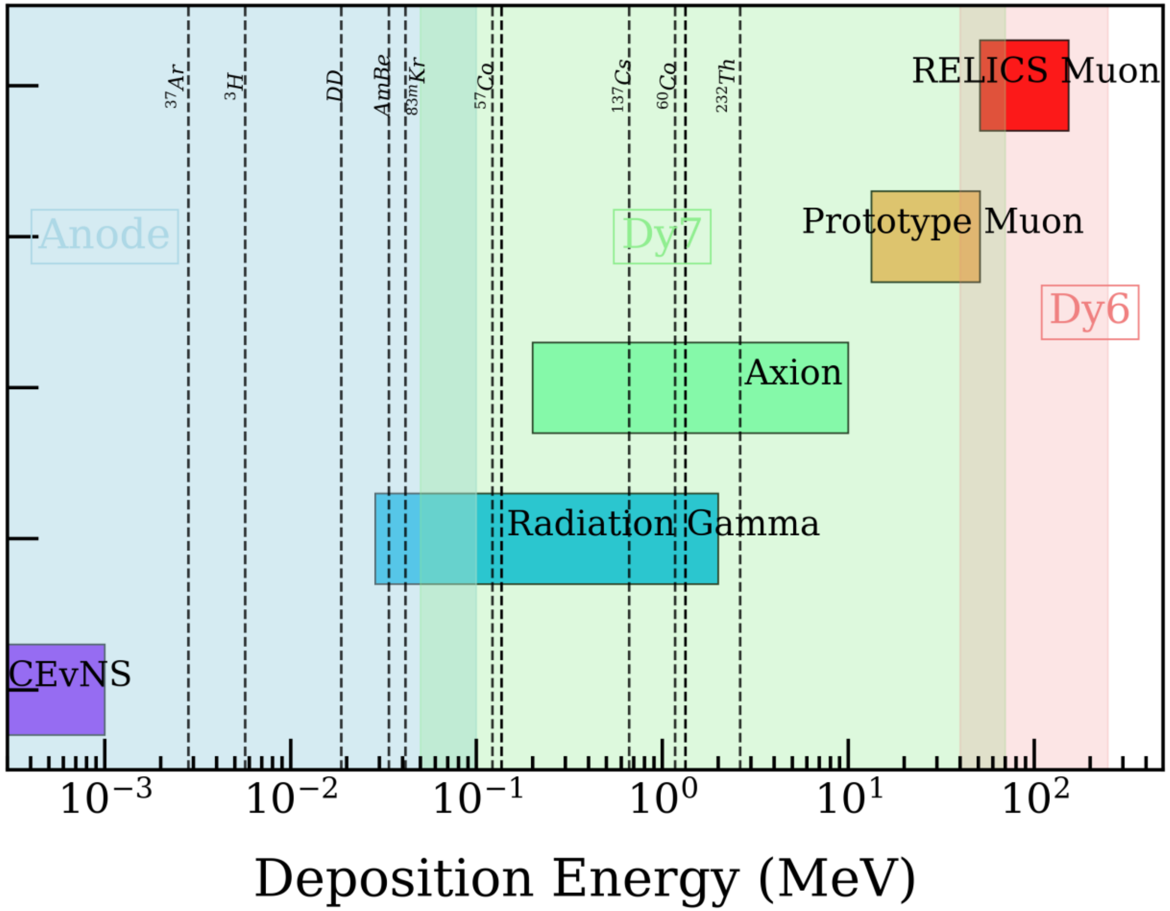




- Energy deposition at ~**MeV** saturates the PMT
- The 7th dynode readout, **anode/dynode ratio ~110**
- Muon S1: average ~**500 PE/ns**
- Muon S2: average ~**10 PE/ns**

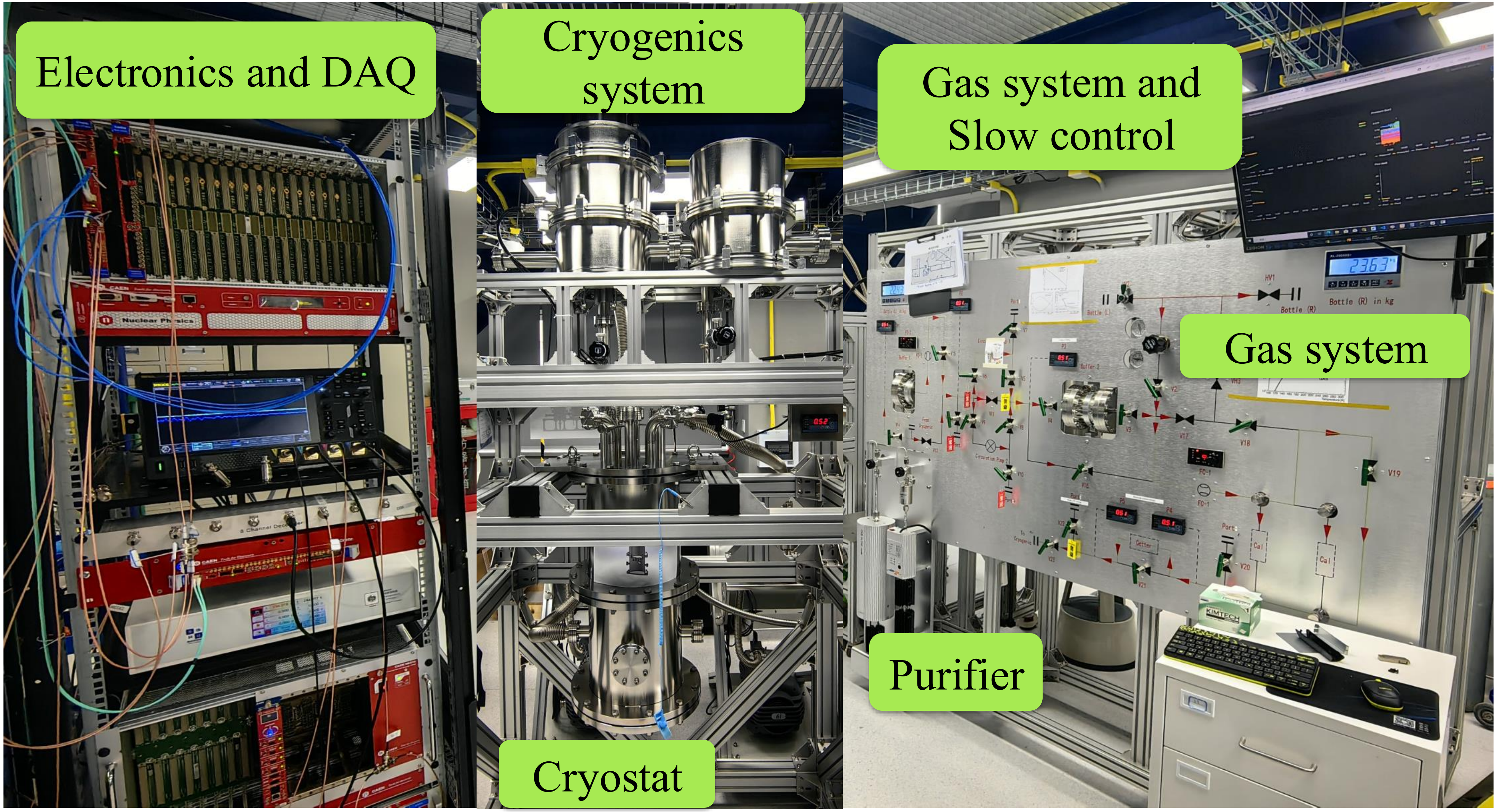
Dynamic Readout Range



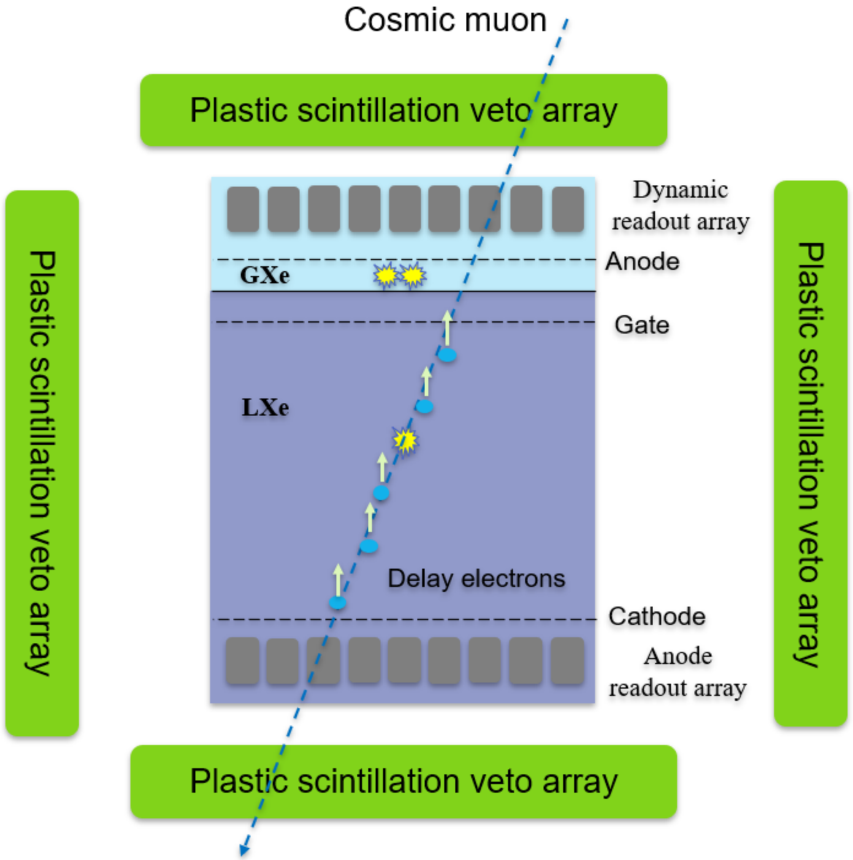


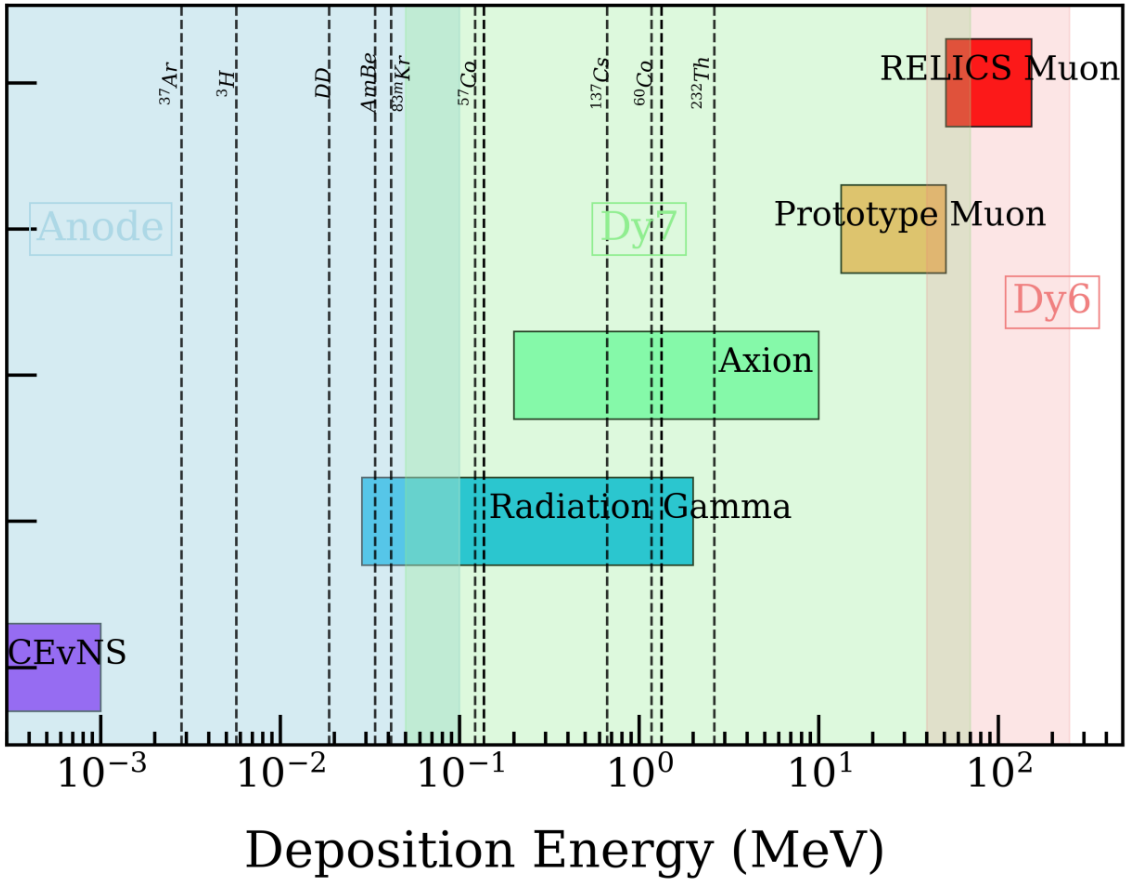
- Expanded readout range to ~**1000 PE/ns**
- **Anode saturated at ~40 PE/ns**
- **Multi-physical** detection capacity
- Both low and high-energy detection

Westlake test System



Dynamic Technique Verification on Local

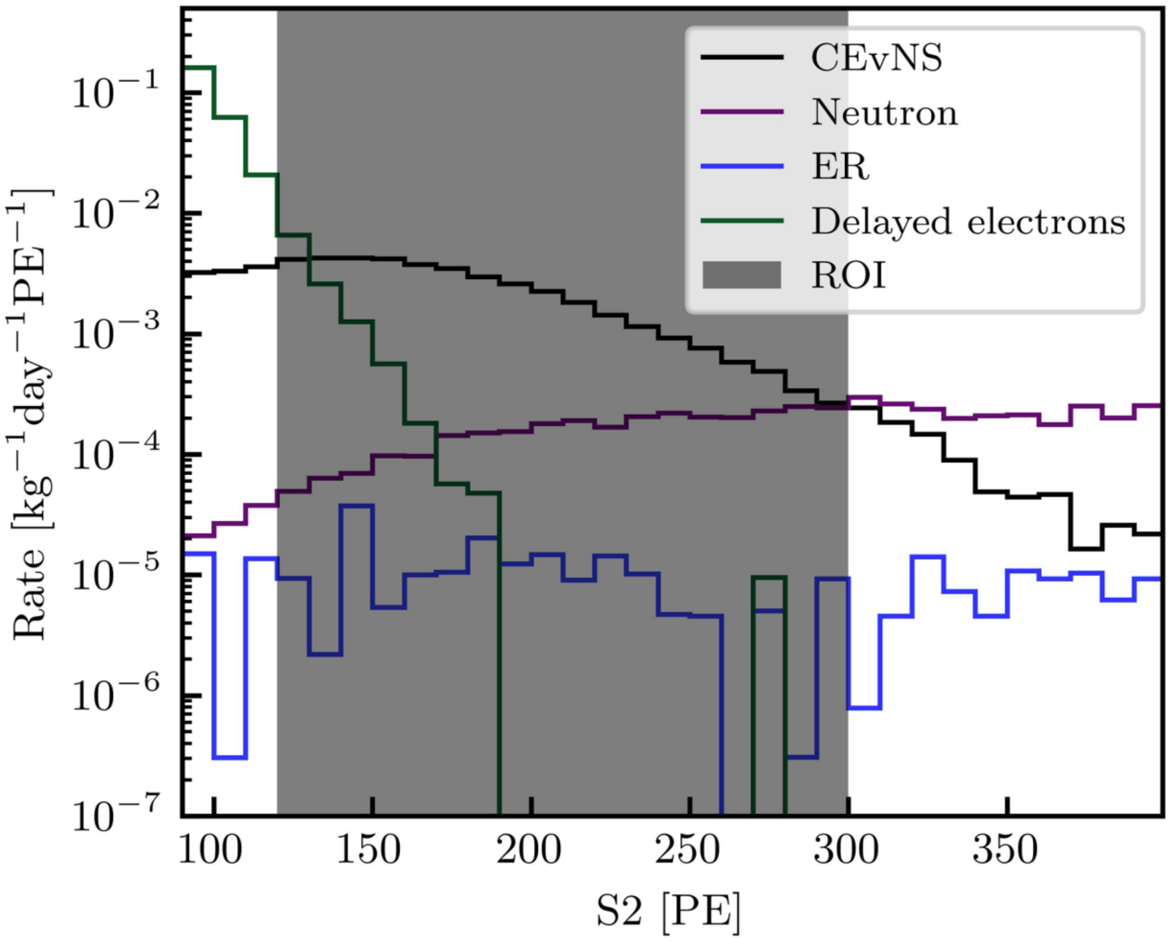




Plans

- Verification of **dynamic readout**, plastic **veto system**
- **Track reconstruction algorithm**

Total Background

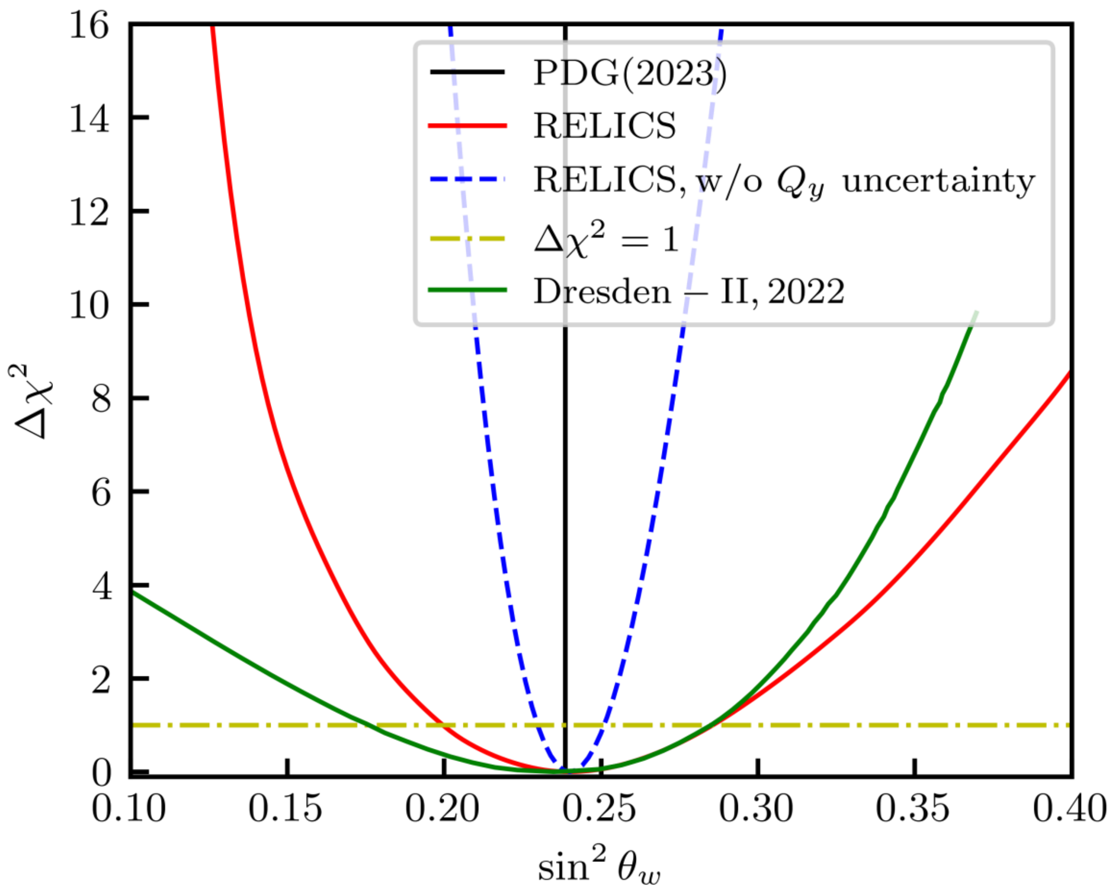


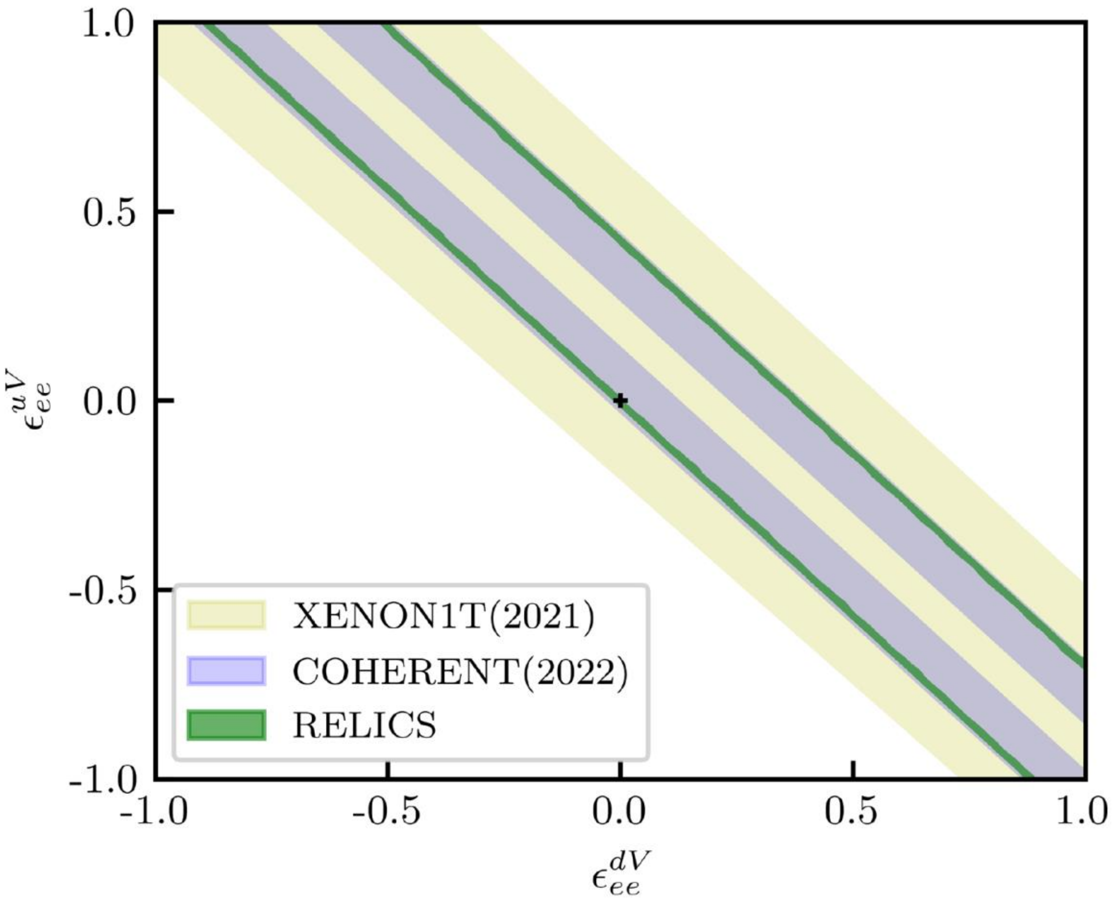
Total signal and background budget

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

- **CEvNS ROI: [120, 300] PE**

Sensitivity Estimation





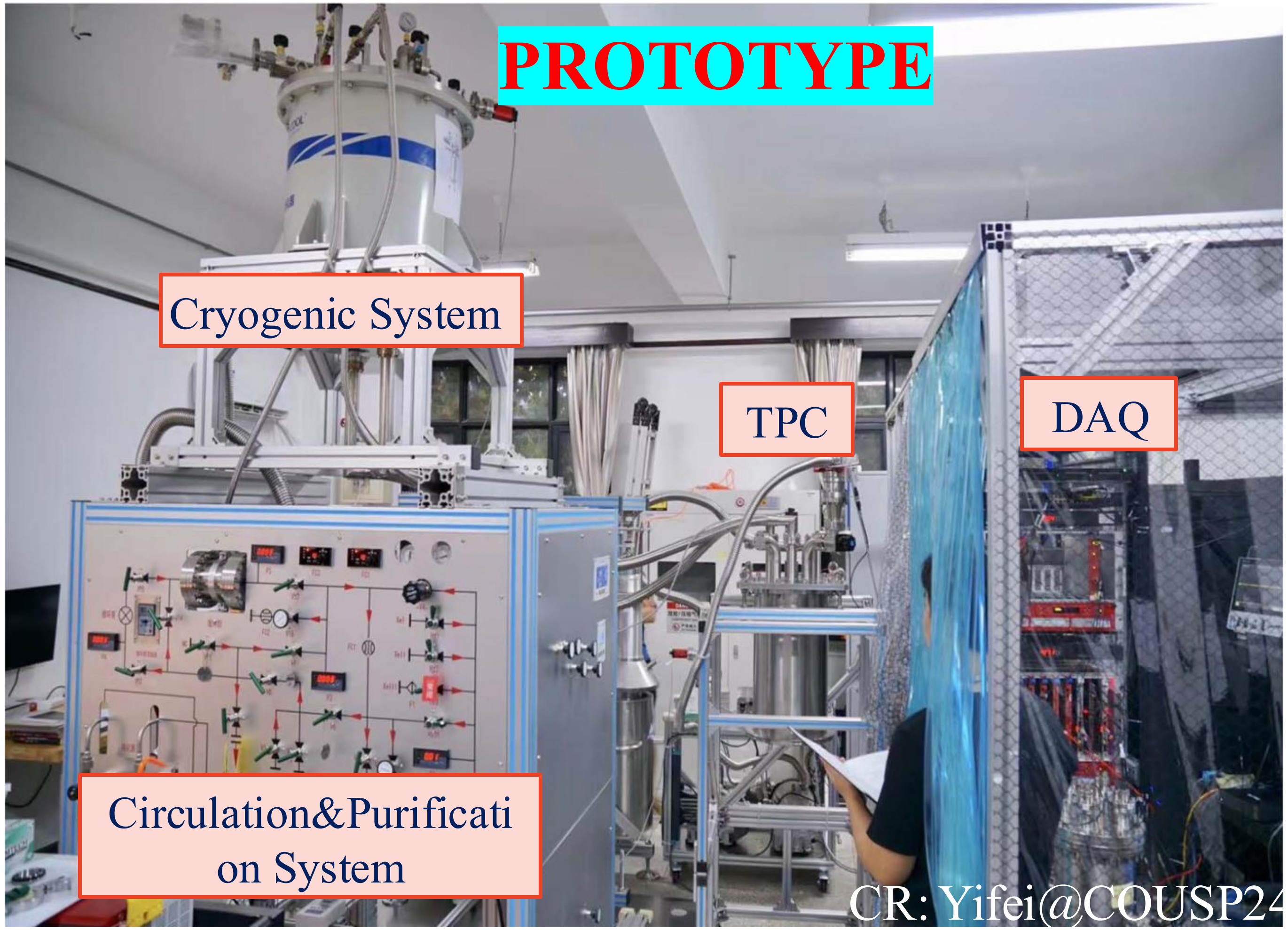
Weak Mixing Angle：

- 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.

Time Schedule 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

- RELICS is a low-threshold, low background, LXe TPC detector planned for reactor neutrinos.
- The main background sources in RELICS are **delayed electrons**, **cosmic-ray neutrons**, and detector **material**.
- RELICS will find **~4600** CEνNS events in one year of exposure
- RELICS has multi-physics potential: probing **weak mixing angle, NSI**, reactor **axions**

THANKS!

Jijun Yang

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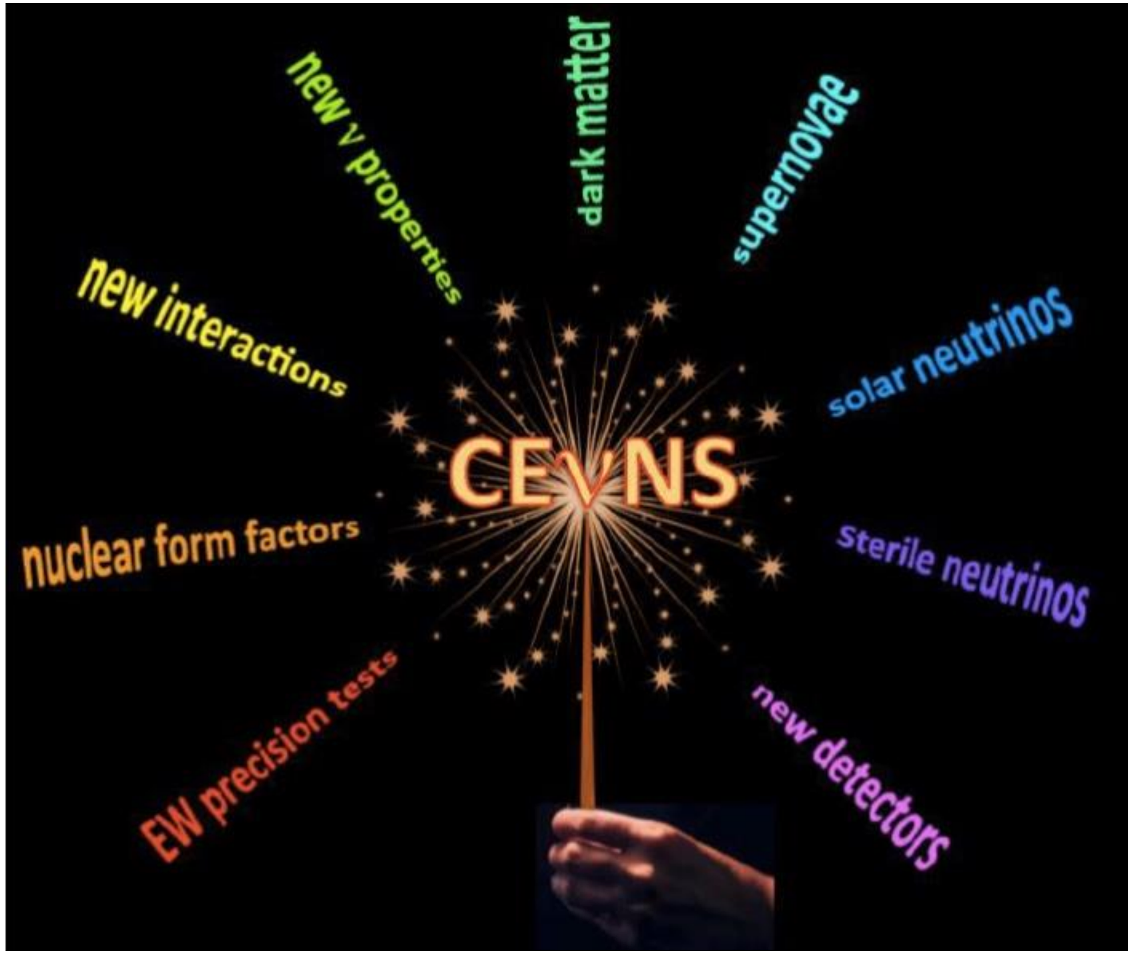
Westlake University

Backup

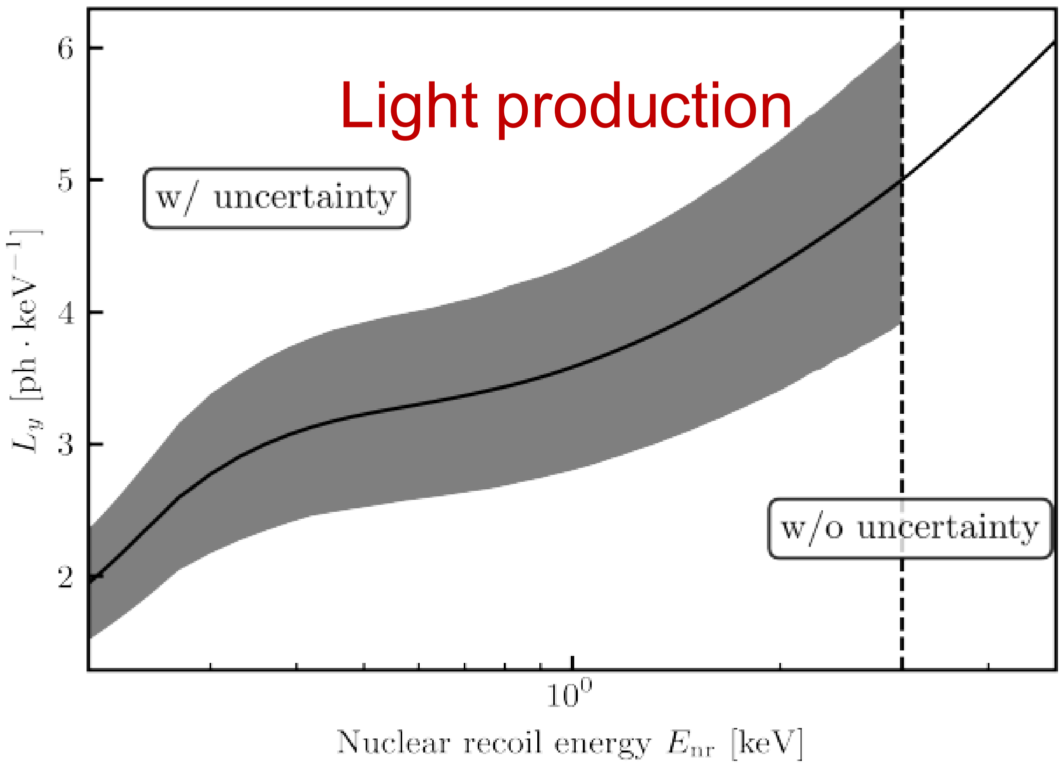
The Significance of CEυNS Research

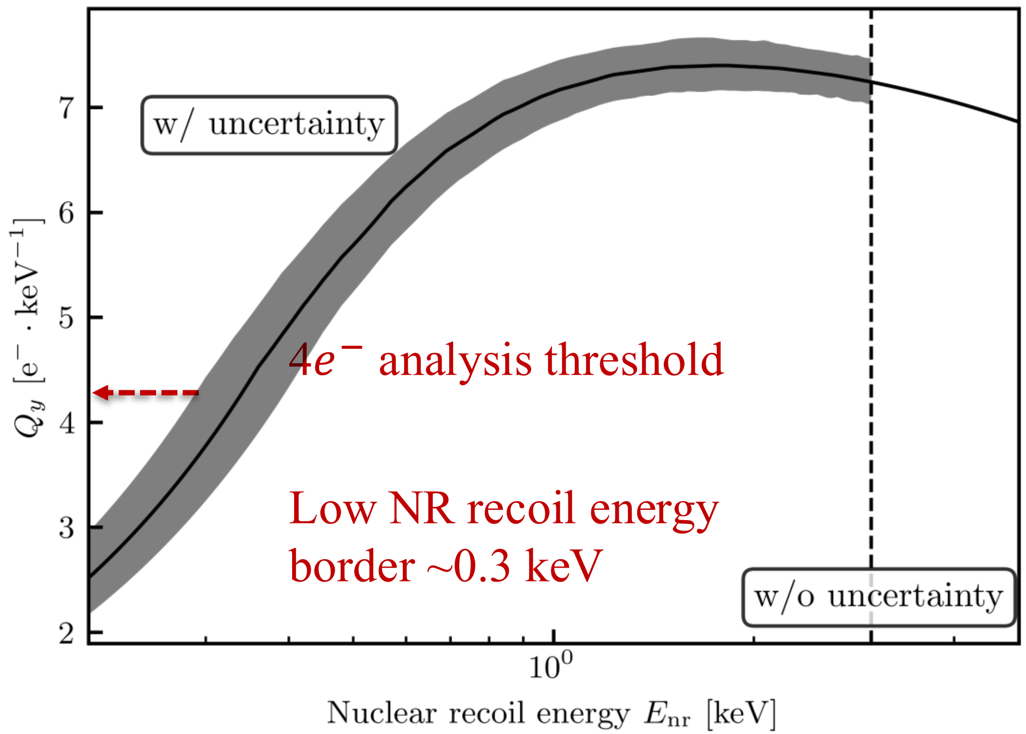
- Particle physics：
  - Weak mixing angle in low-momentum transfer
  - Non-standard neutrino interactions
  - Anomalous magnetic moments
  - Sterile neutrinos
- Astrophysics：
  - Background for dark matter detection
  - core-collapse supernova explosions
- Nuclear Physics：
  - Form factor and atomic structure



E. Lisi @Neutrino 2018

Detector Response



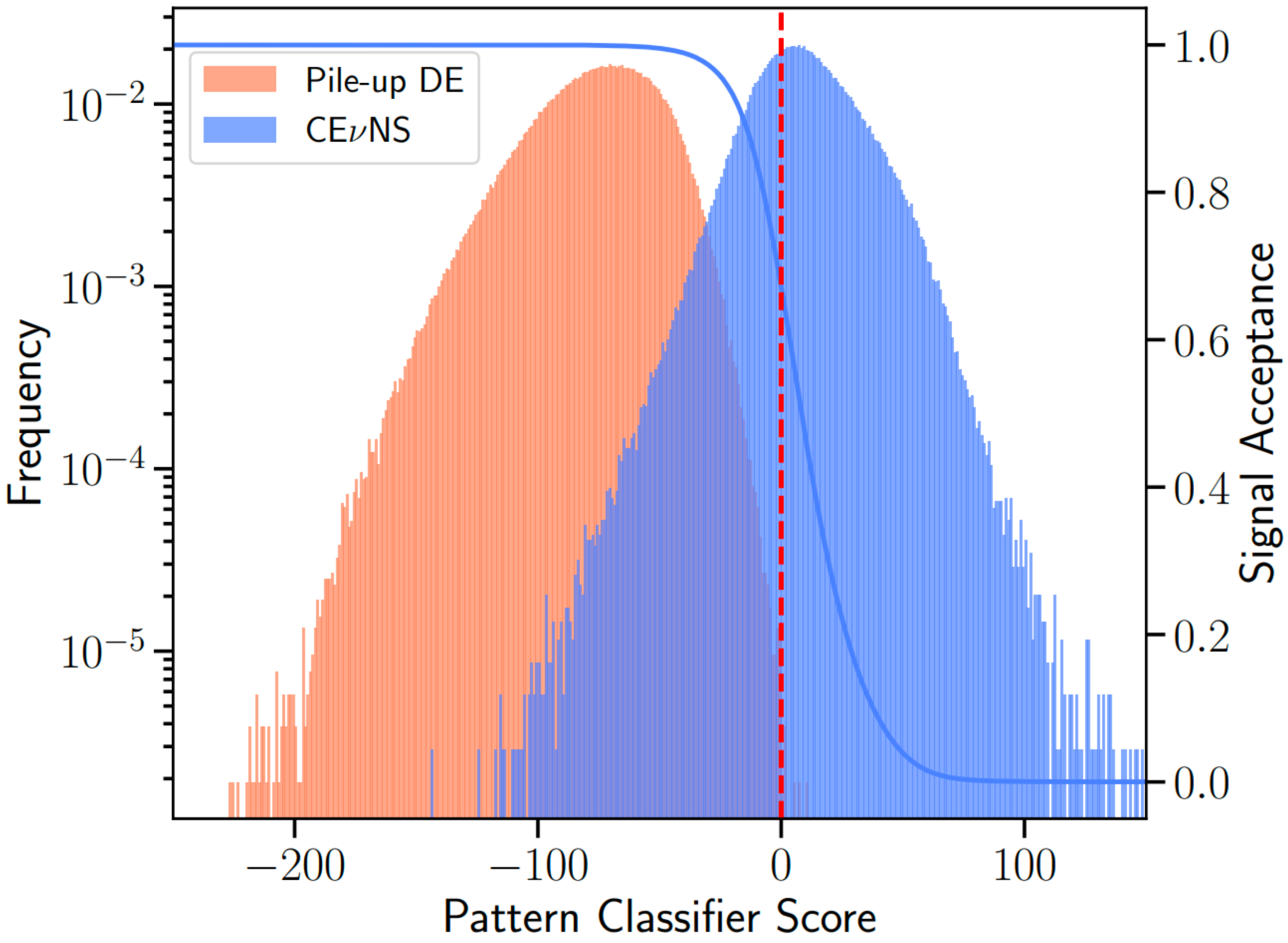


- **Low light production with low energy recoil**

$$E = 13.7\text{eV}\left(\frac{cS1}{g_1} + \frac{cS2}{g_2}\right)$$

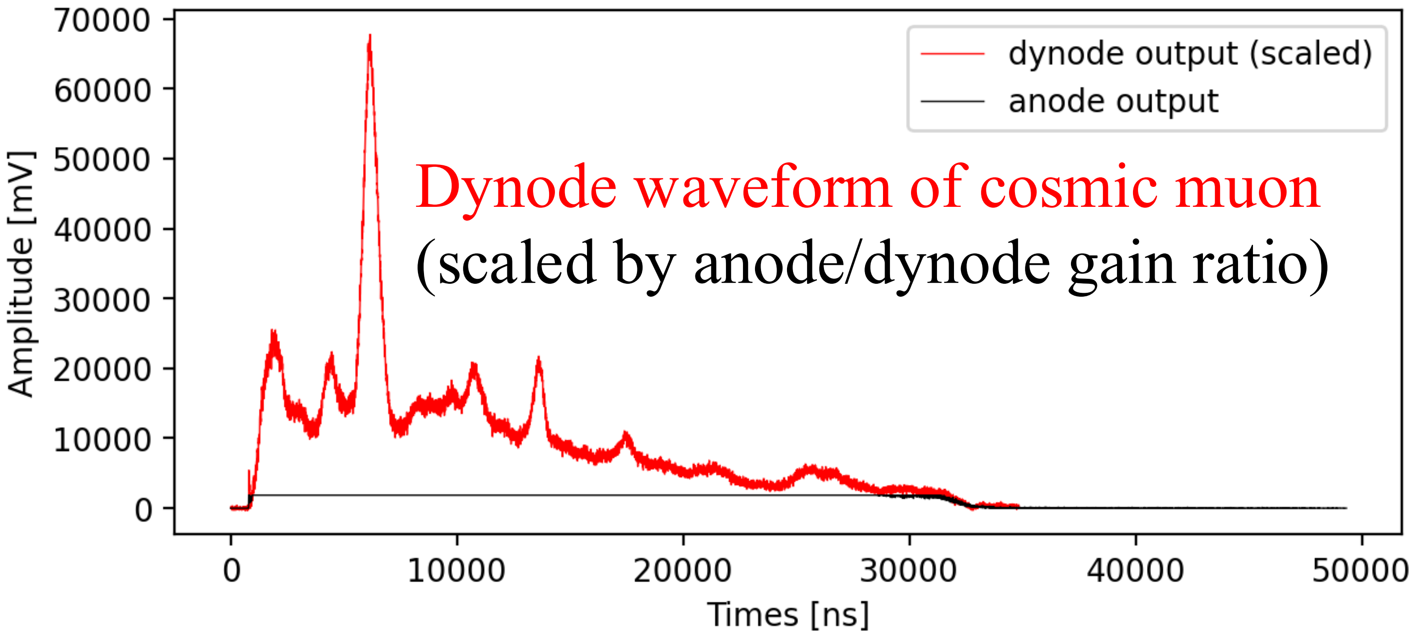
- **4 electron** detection threshold
- $g1 \sim 0.115\ PE/photon$
- $g2 \sim 30\ PE/e$;

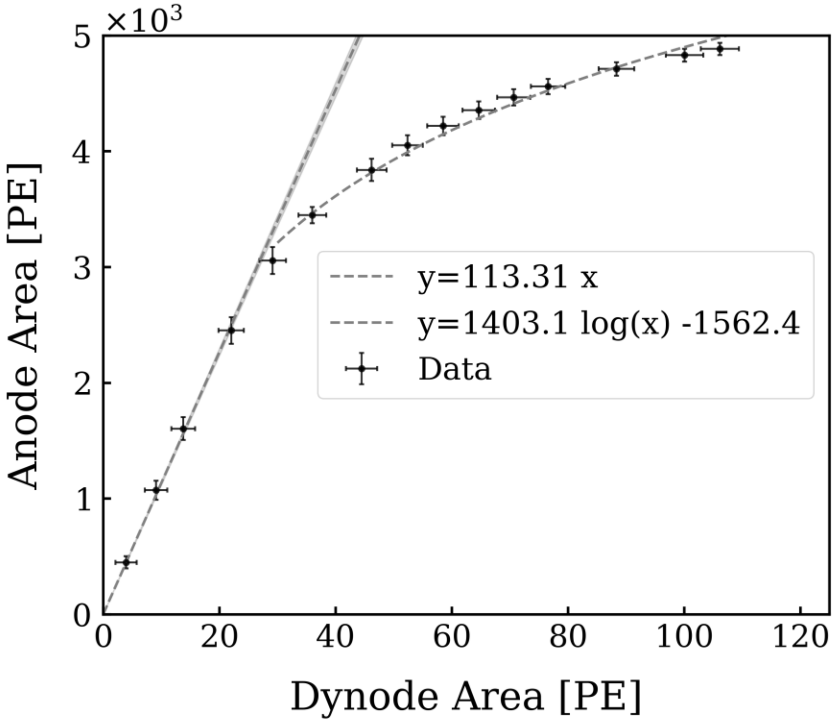
Spacetime Correlation Score



- Based on **the spacetime correlation**, distinguish CEνNS from the DE background
- Reduced by **4 orders of DE** background, with a **33% loss** of CEνNS.

Verification of Dynode Readout



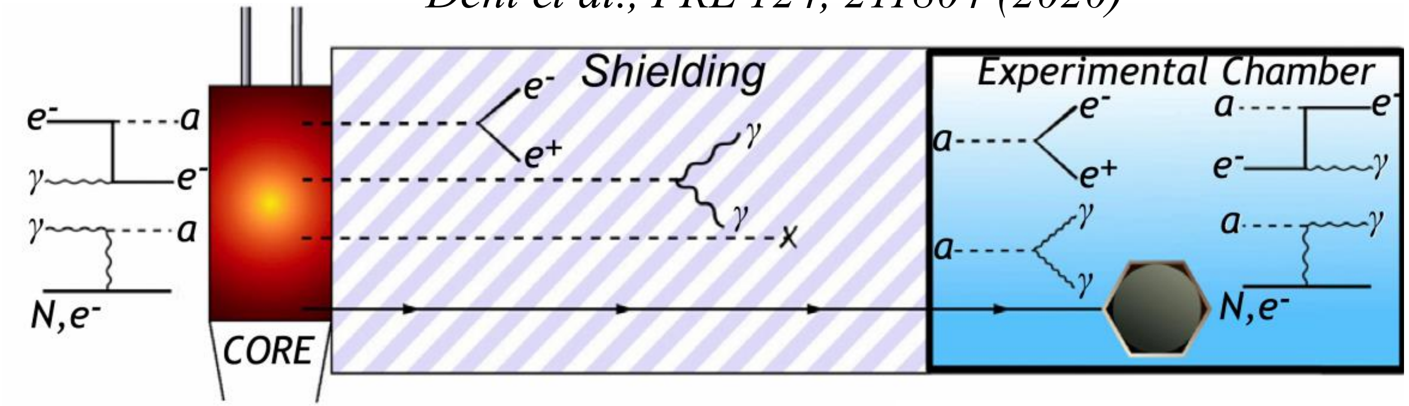


- Muon waveform observed on the prototype detector on **the dynode readout**

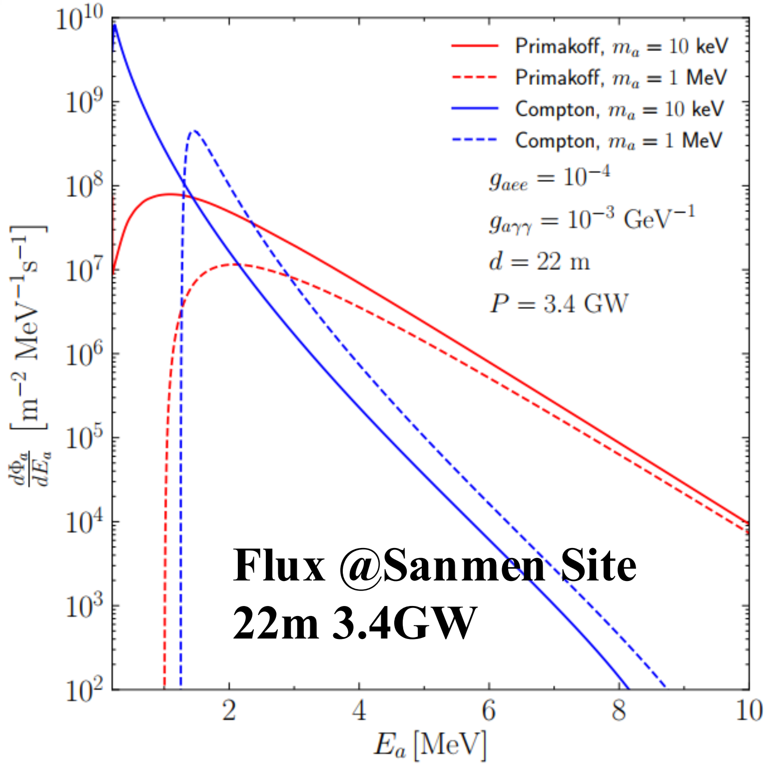
- Anode/dynode ratio fixed

Axion-Like Particle Search

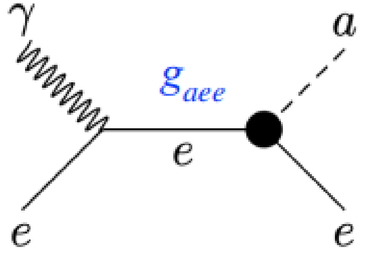
Dent et al., PRL 124, 211804 (2020)



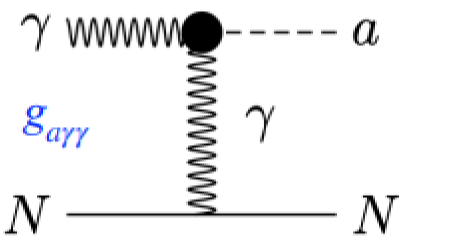
- Produced in the reactor cores due to copious photons from the fission processes.
- Reactors produce **MeV photons** (gamma), which allow for probing ALPs with MeV mass!



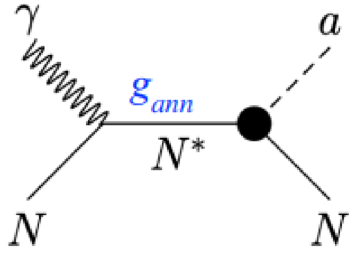
Compton-like scattering g_{aee}



Primakoff $g_{a\gamma\gamma}$



Nuclear de-excitation

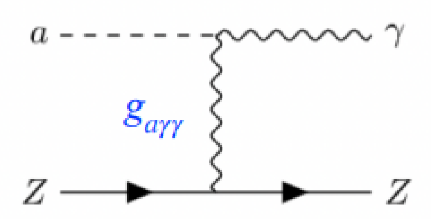


Li-7, $p(n,\gamma)d$

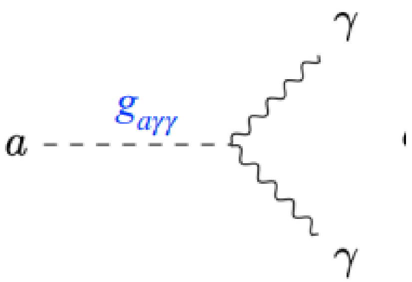
Axion-Like Particle Search

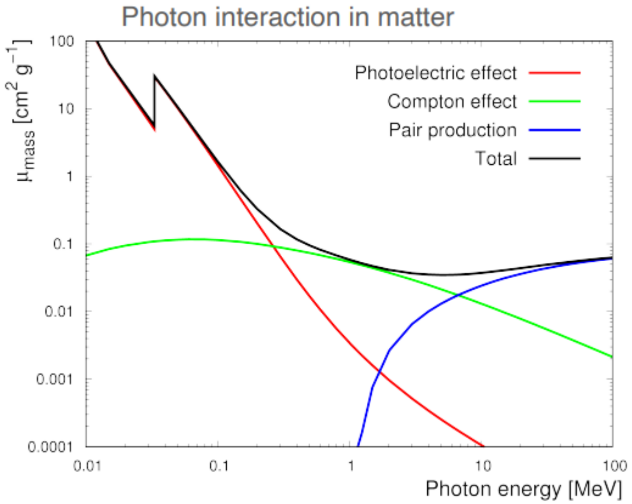
$g_{a\gamma\gamma}$

Inverse Primakoff



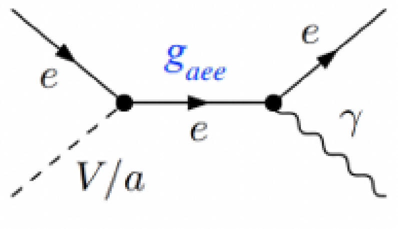
Axion decay - photon

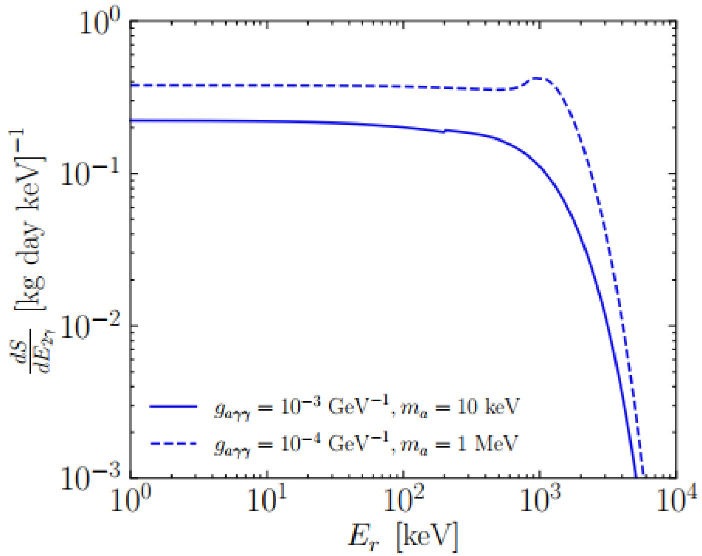


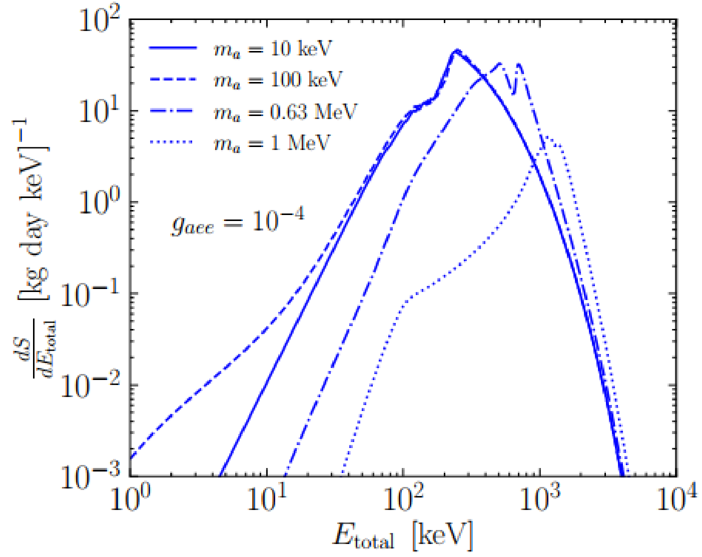


g_{aee}

Inverse Compton-like

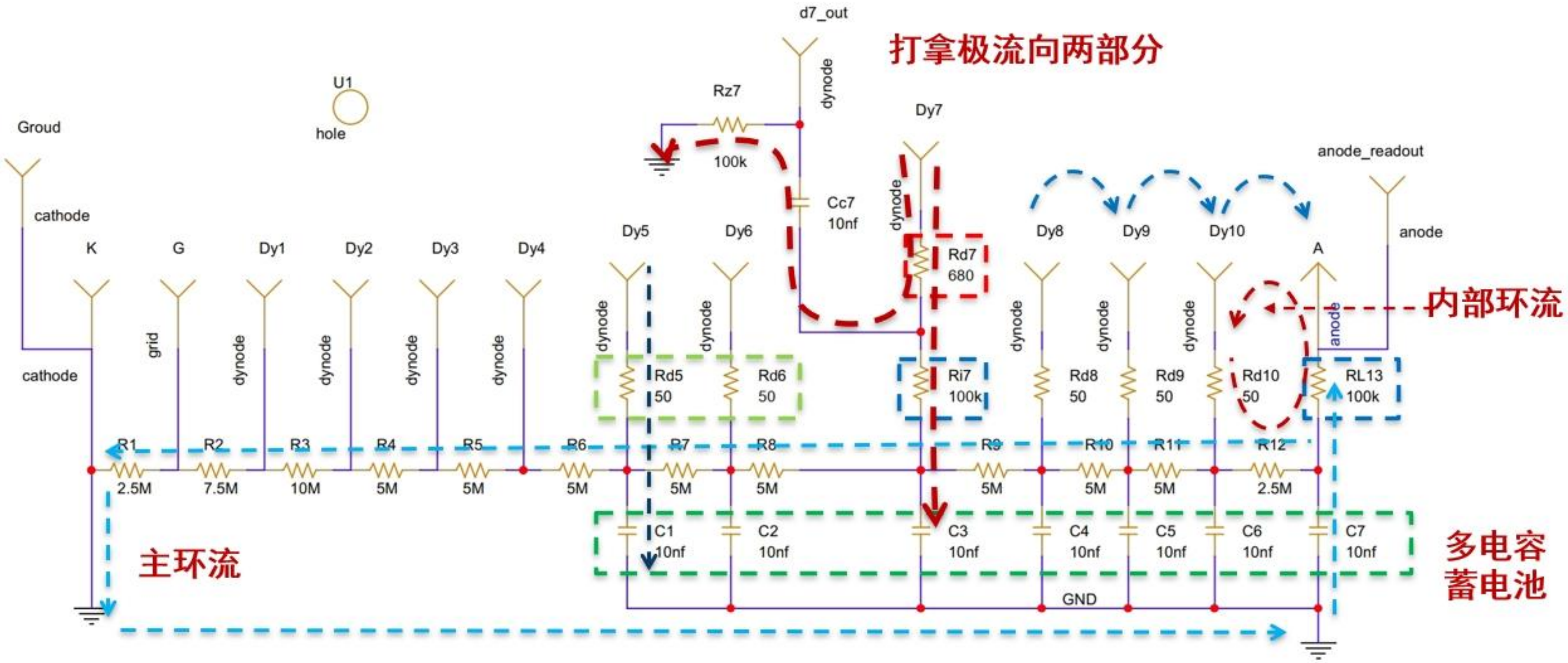






- Dynamic readout technique is potential on searching **Seb-MeV to MeV energy deposition from ALP** particle

Dynamic readout Design



- **Dynode** and **anode** readout, six **parallel capacitors,**
- Output **high impedance, damping resistors**
- **High photoelectron collection efficiency**
- **High secondary electron emission probability**

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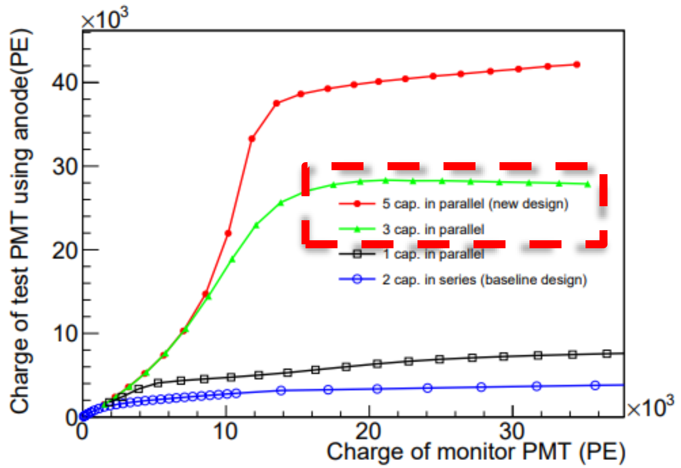
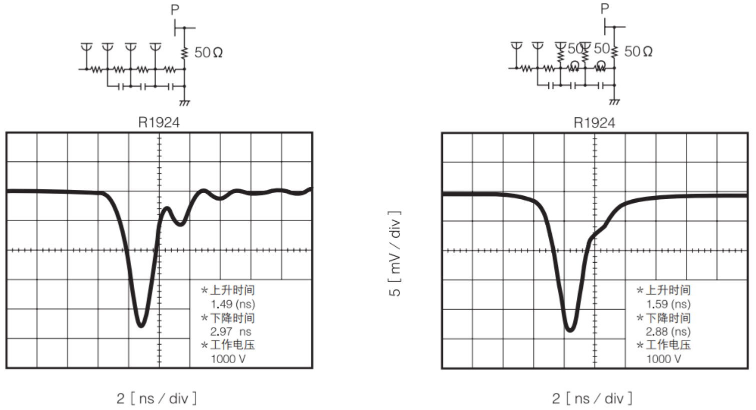
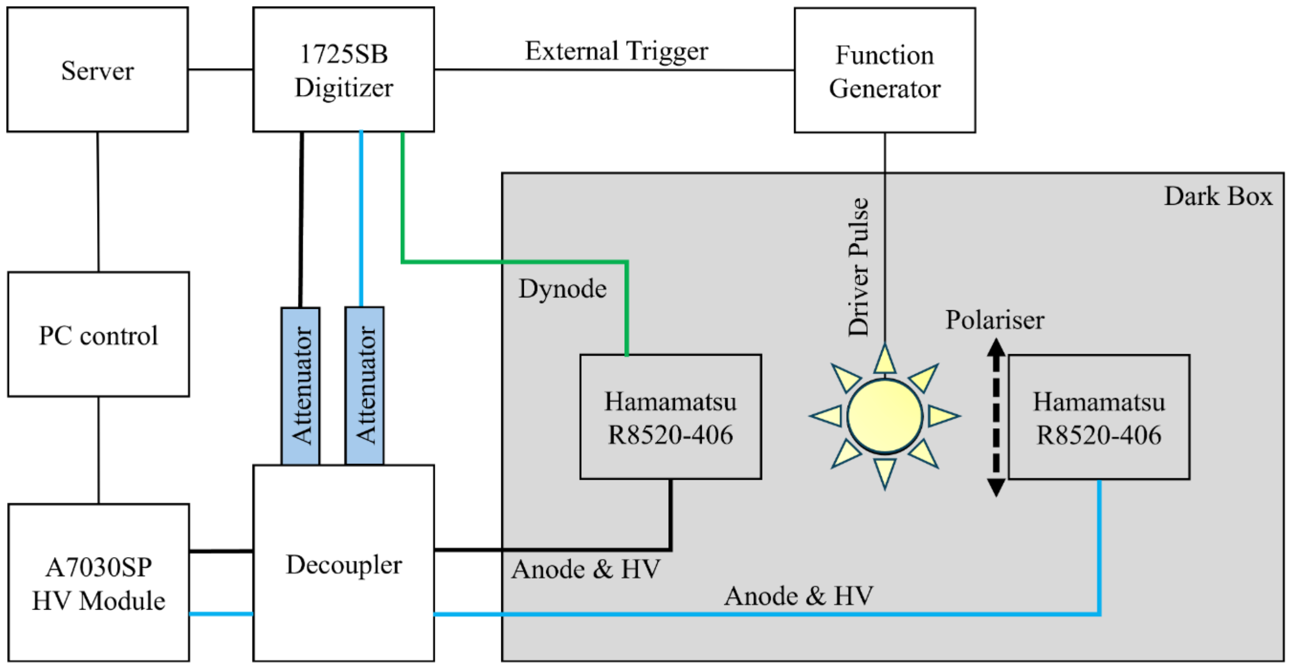




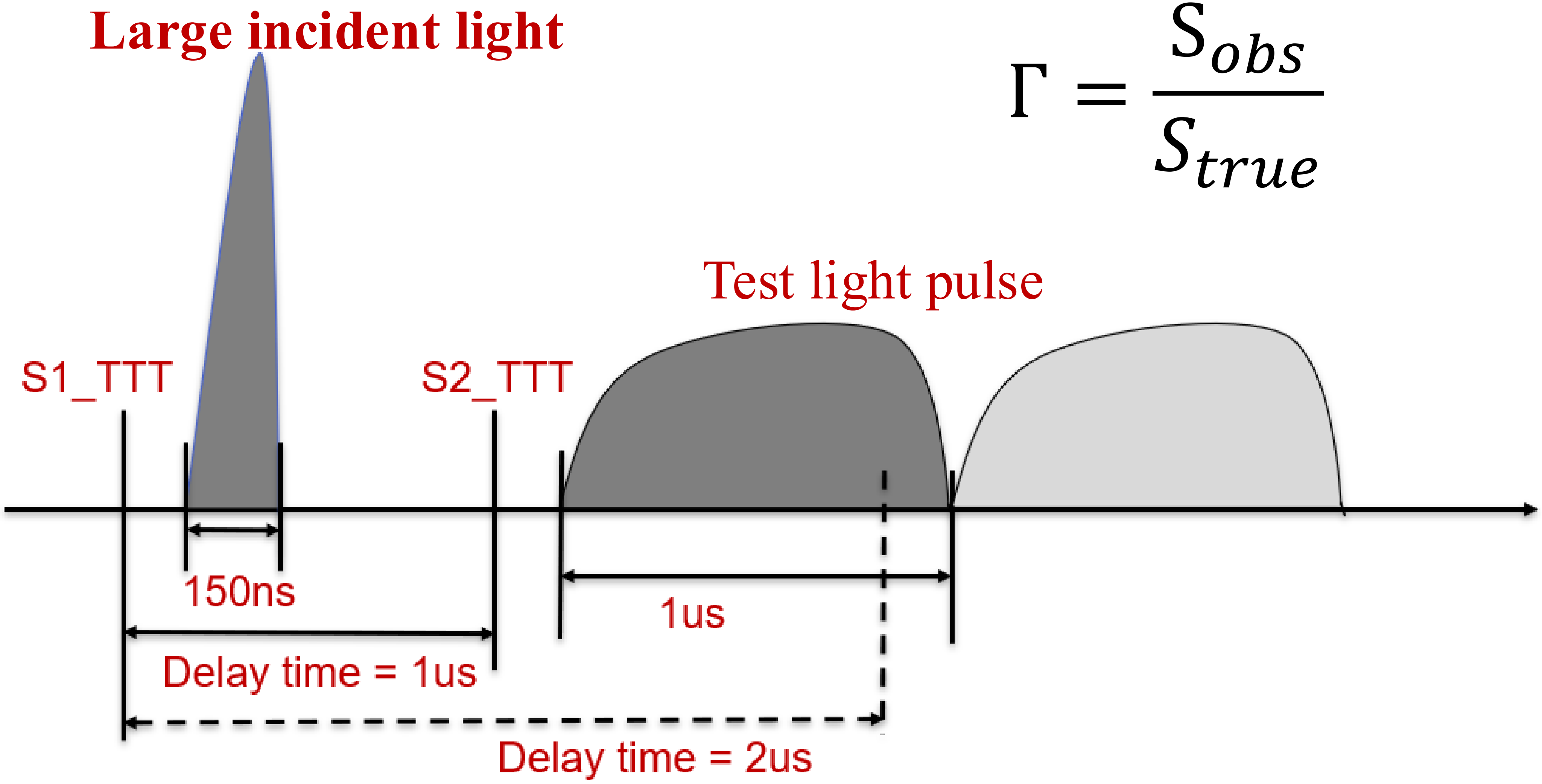
Hamamatsu handbook

Batch Test Setup



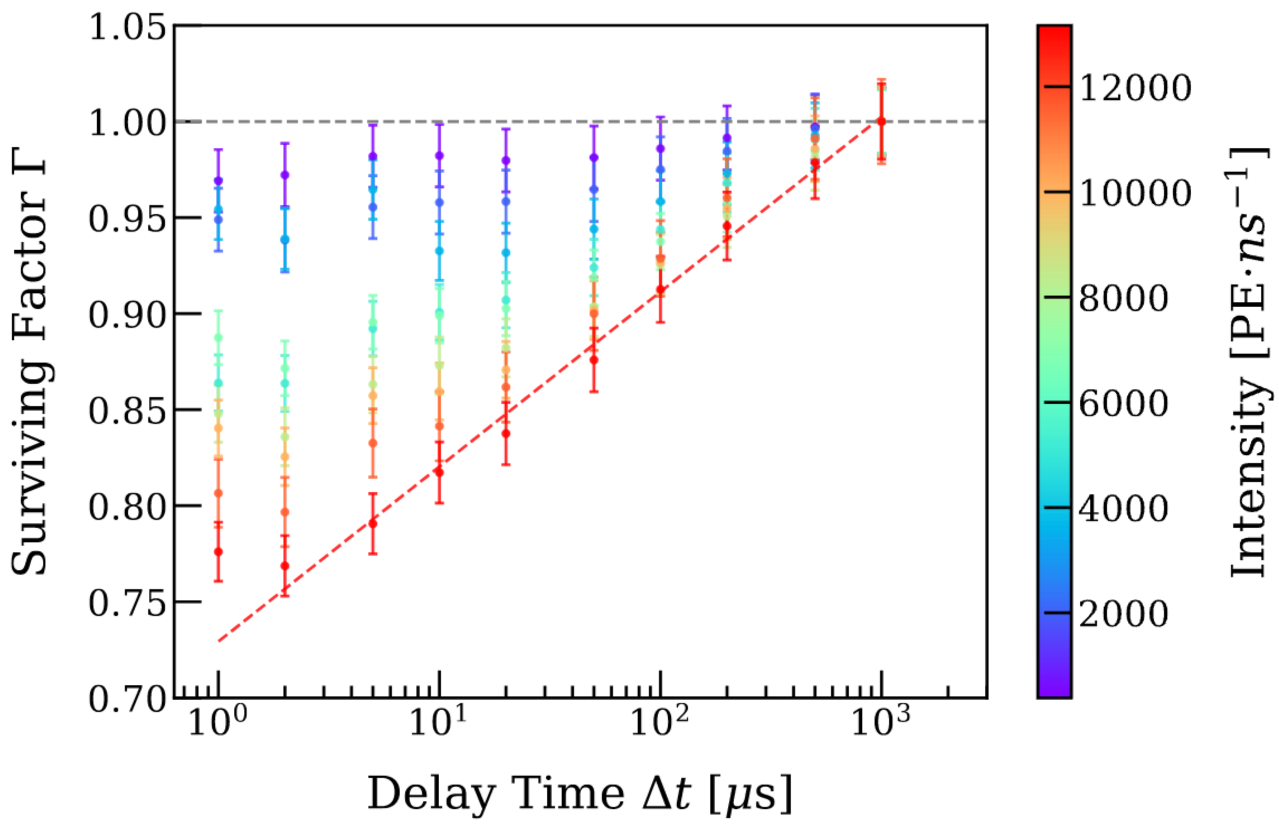
- Light source: **LED with PFTE sphere**
- Test PMT: **dual readout,** monitor PMT: **light filter**
- **Two BNC attenuators** to avoid ADC saturation
- Example waveforms

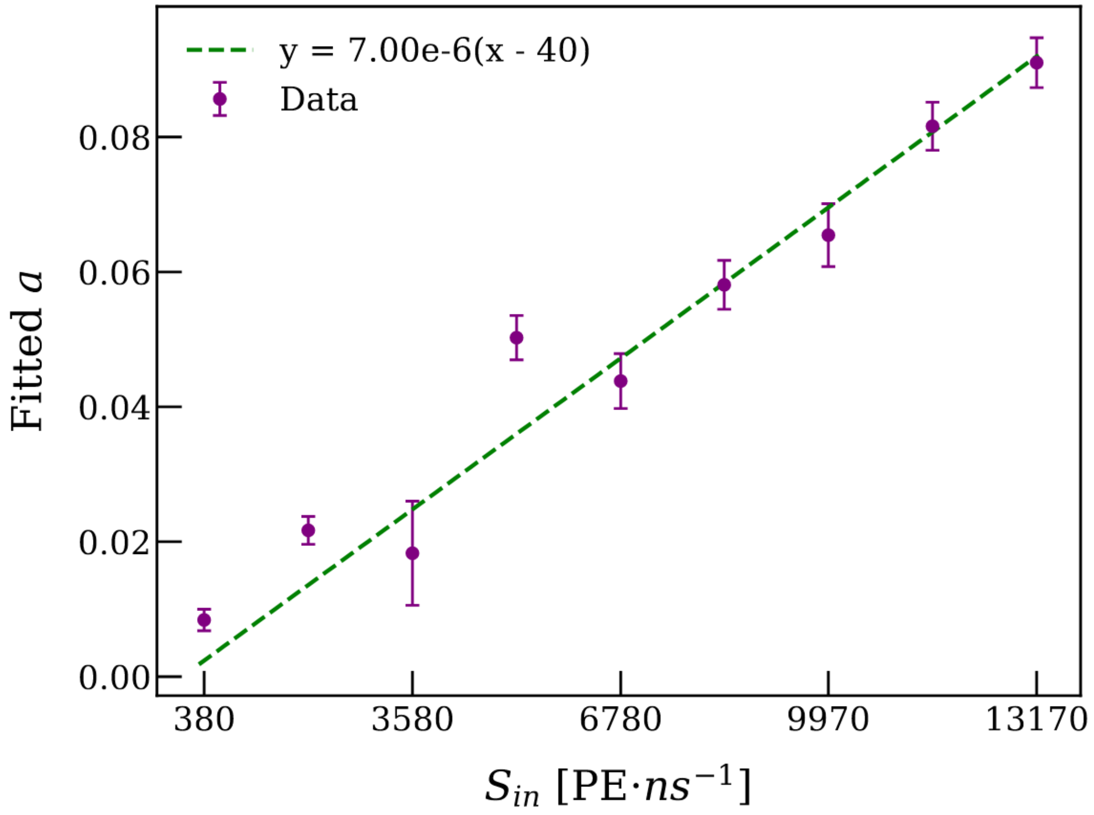
Saturation Recovery Test



$$\Gamma = \frac{S_{obs}}{S_{true}}$$

Saturation 2D Dependence





- **Linearly** related to **incident light intensity**
- Saturation recovery time ~**1ms**
- **Exponentially related to the delay time**

$$\Gamma(S_{\text{in}}, \Delta t) = a(S_{\text{in}}) \log_{10}\left(\frac{\Delta t}{\mu s}\right) + \Gamma_0(S_{\text{in}}), \qquad 2\,\mu s \le \Delta t \le 1\,\text{ms},$$