RELICS

REactor neutrino **LI**quid xenon **C**oherent elastic **S**cattering

RELICS Liquid Xenon Reactor Neutrino Experiment

魏月环 (Yuehuan Wei)

中山大学 (Sun Yat-sen University)

On behalf of the RELICS Collaboration

Oct. 25, 2025, Beijing

Neutrino Scattering: Theory, Experiment, Phenomenology (νSTEP 2025)

Coherent elastic neutrino nucleusscattering (CEνNS)

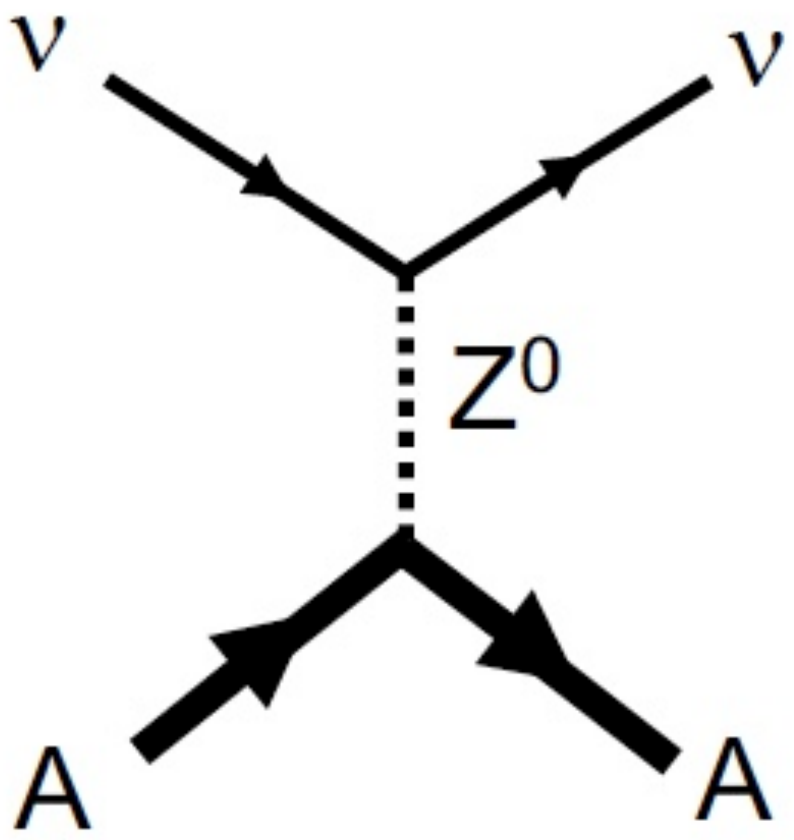
D. Freedman, PRD 9 1389 (1974)

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)



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 nucleusscattering (CEνNS)

D. Freedman, PRD 9 1389 (1974)

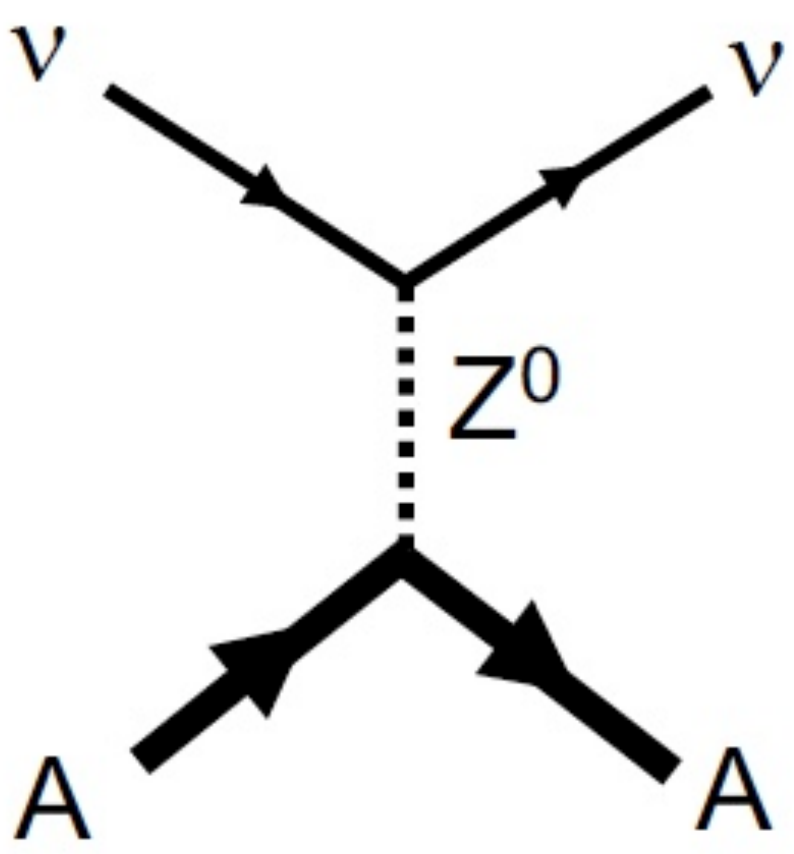
D. Akimov et al, Science 357 (2017)

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

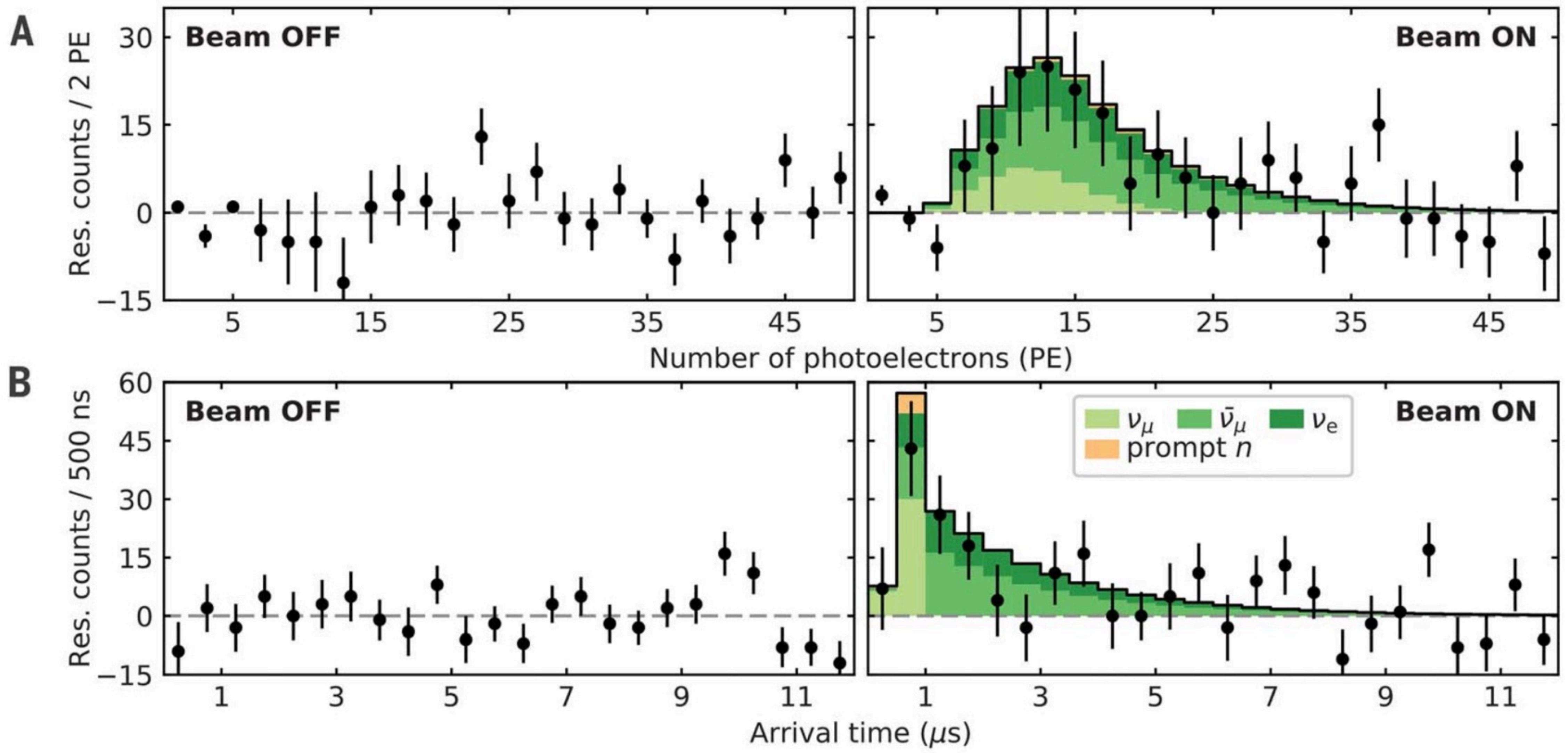
Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

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

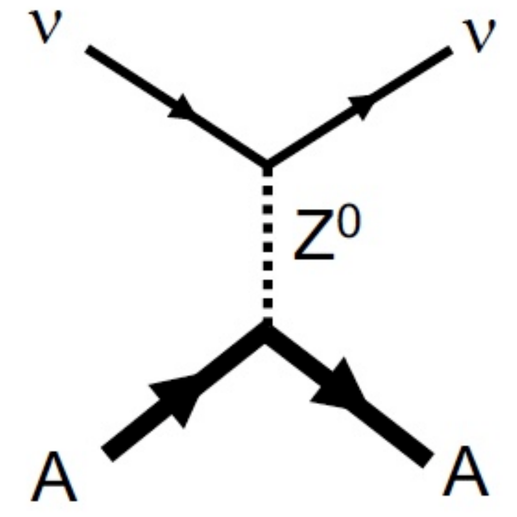


Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical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

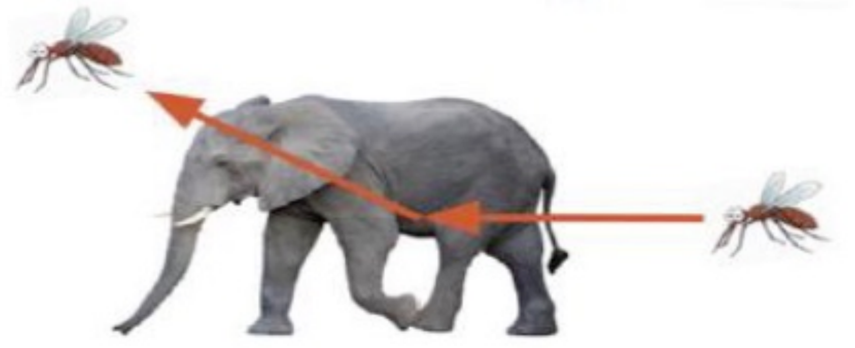
COHERENT SNS



Coherent elastic neutrino nucleusscattering (CEvNS)

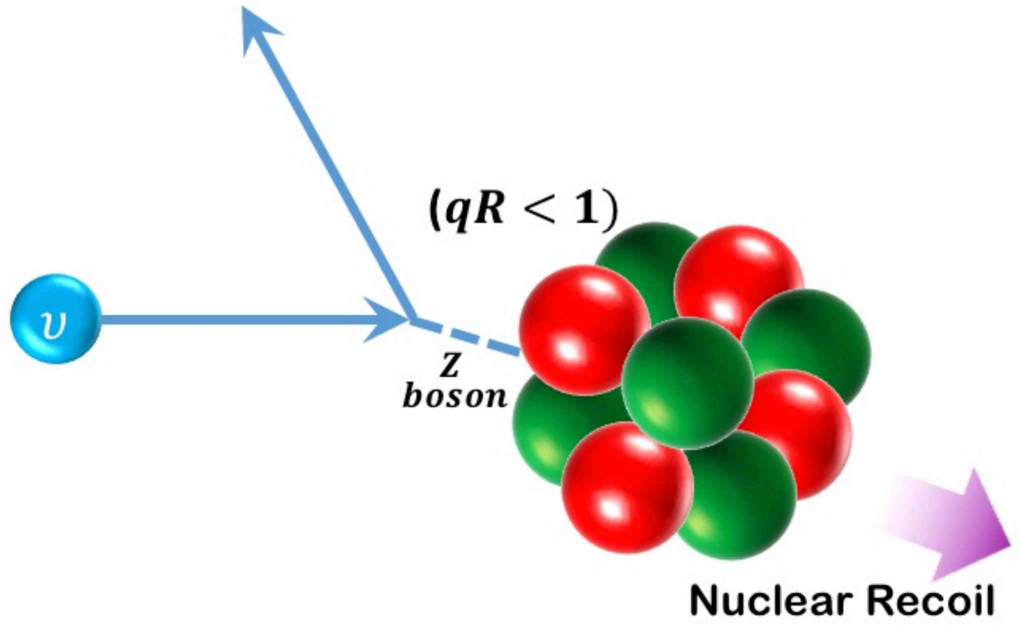


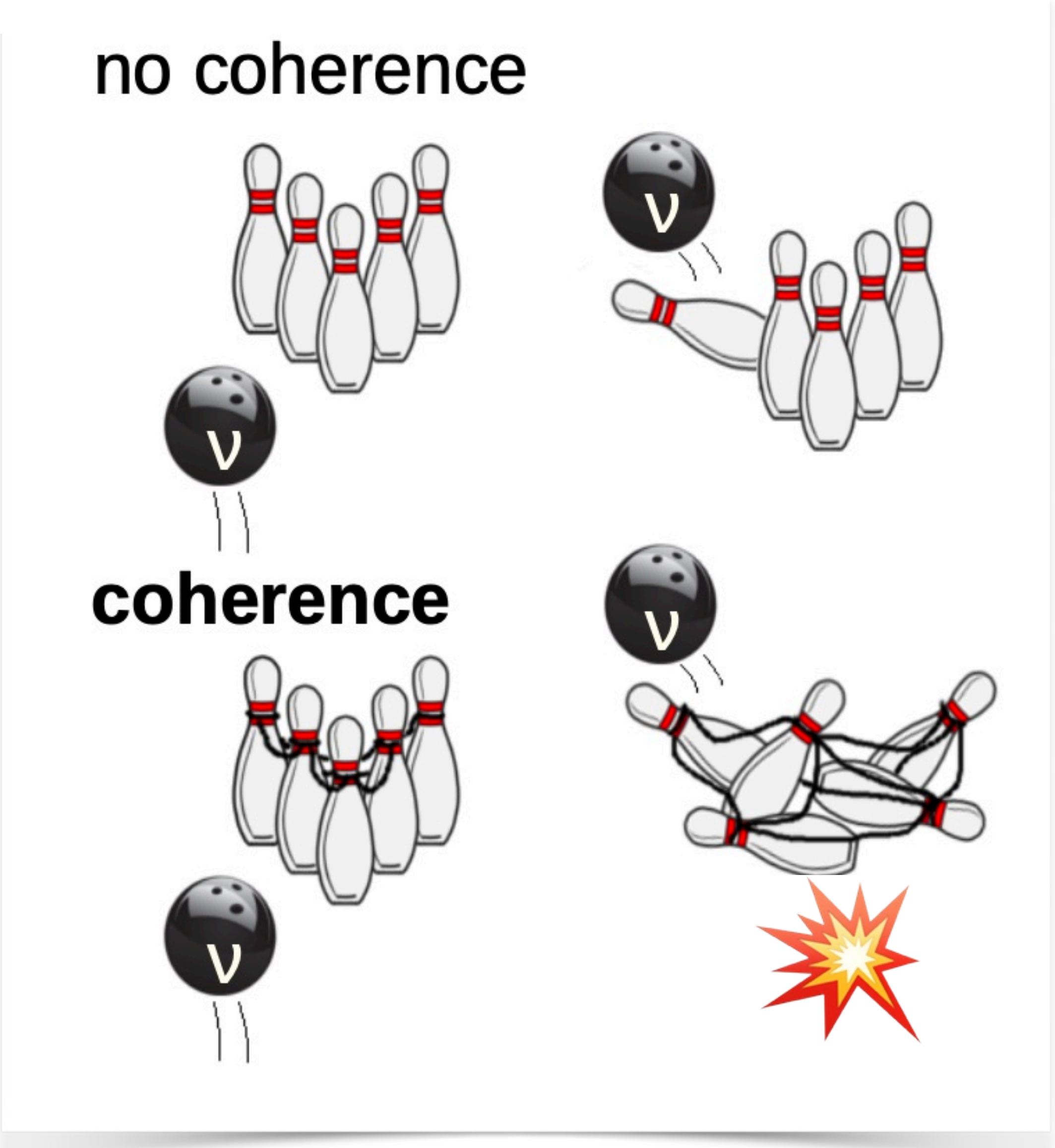
What is CEvNS?



Z-exchange of a neutrino with nucleus:

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





Neutrino wavelength larger than size of nucleus: qR<1

- q: momentum transfer
- R: nucleus size

Standard Model prediction for CEvNS differential cross section

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

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

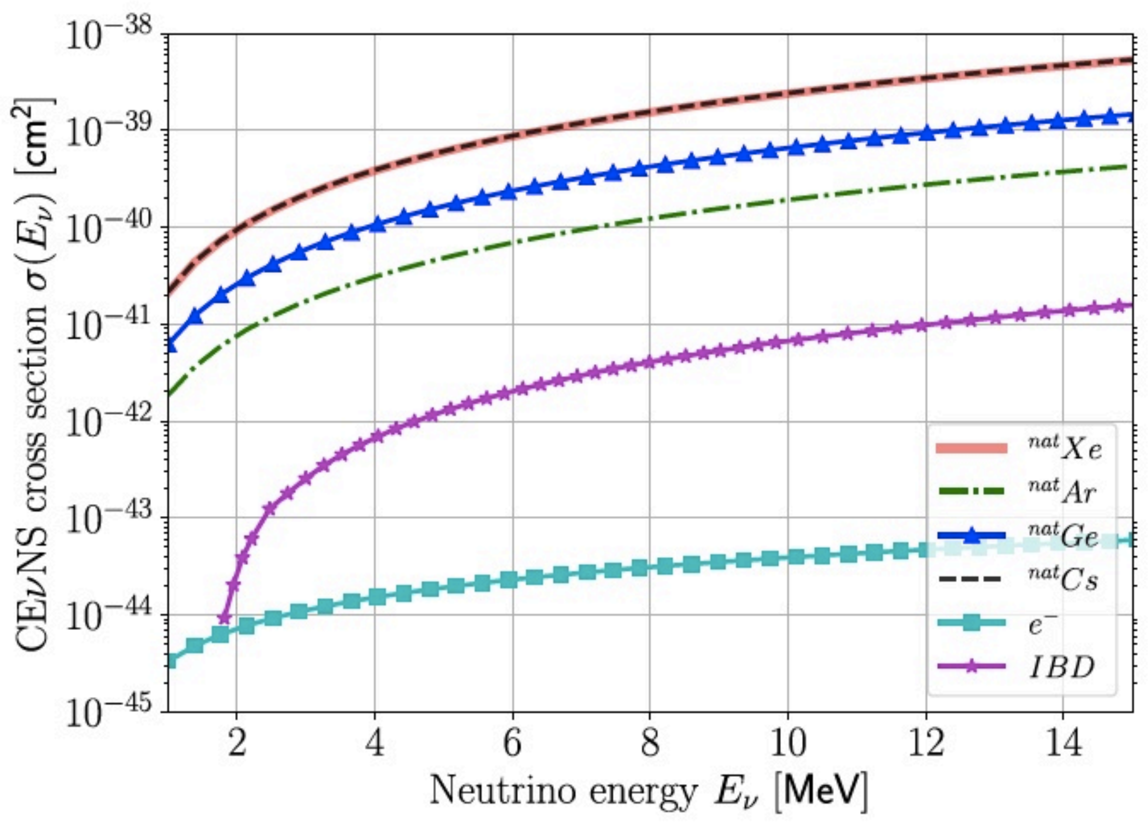
$$Q_W \propto N \Longrightarrow \boxed{\frac{d\sigma}{dT} \propto N^2}$$

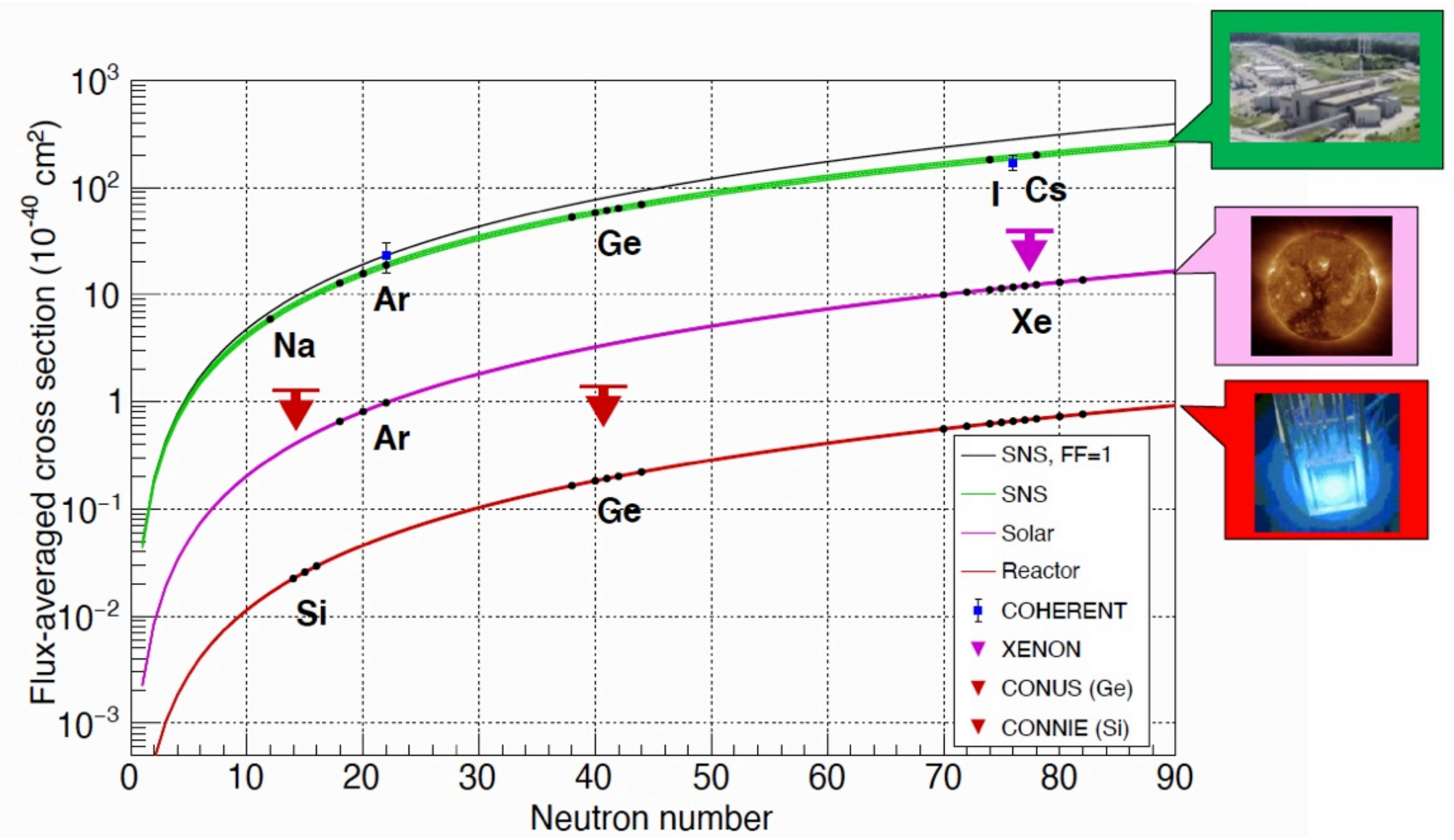
Coherent elastic neutrino nucleusscattering (CEνNS)

- **Particle Physics:**
  - Weak mixing angle at low momentum transfer
  - Non-standard effective neutrino interactions
  - Anomalous neutrino magnetic moments
  - Sterile neutrinos, etc.
- **Astrophysics:**
  - Novel methods for detecting solar neutrinos and supernova neutrinos
  - Important background for dark matter detection
- **Nuclear Physics:**
  - Nuclear form factors
- **Reactor Physics:**
  - Miniaturization of neutrino detectors
  - reactor monitoring

Coherent elastic neutrino nucleusscattering (CEvNS)

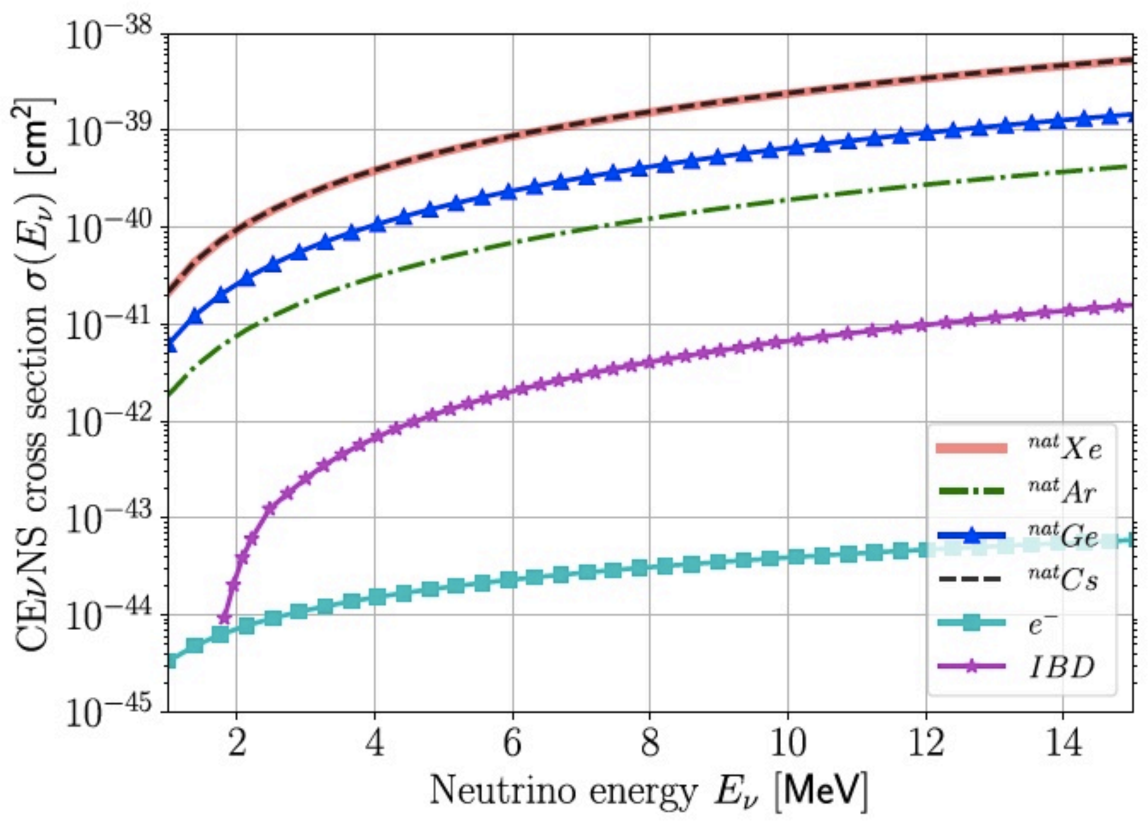
- **Particle Physics:**
  - Weak mixing angle at low momentum transfer
  - Non-standard effective neutrino interactions
  - Anomalous neutrino magnetic moments
  - Sterile neutrinos, etc.
- **Astrophysics:**
  - Novel methods for detecting solar neutrinos and supernova neutrinos
  - Important background for dark matter detection
- **Nuclear Physics:**
  - Nuclear form factors
- **Reactor Physics:**
  - Miniaturization of neutrino detectors
  - reactor monitoring

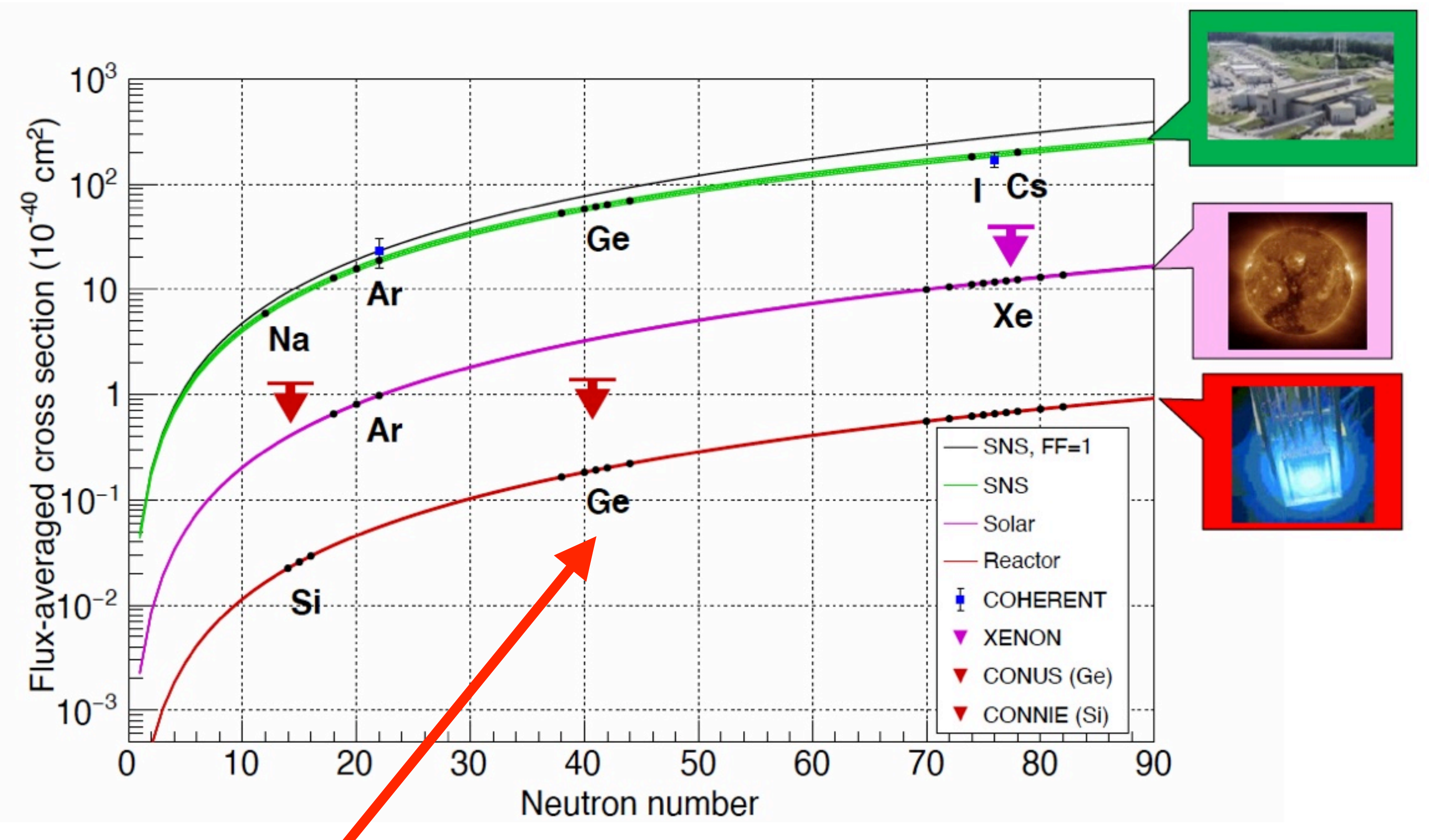




Coherent elastic neutrino nucleusscattering (CEvNS)

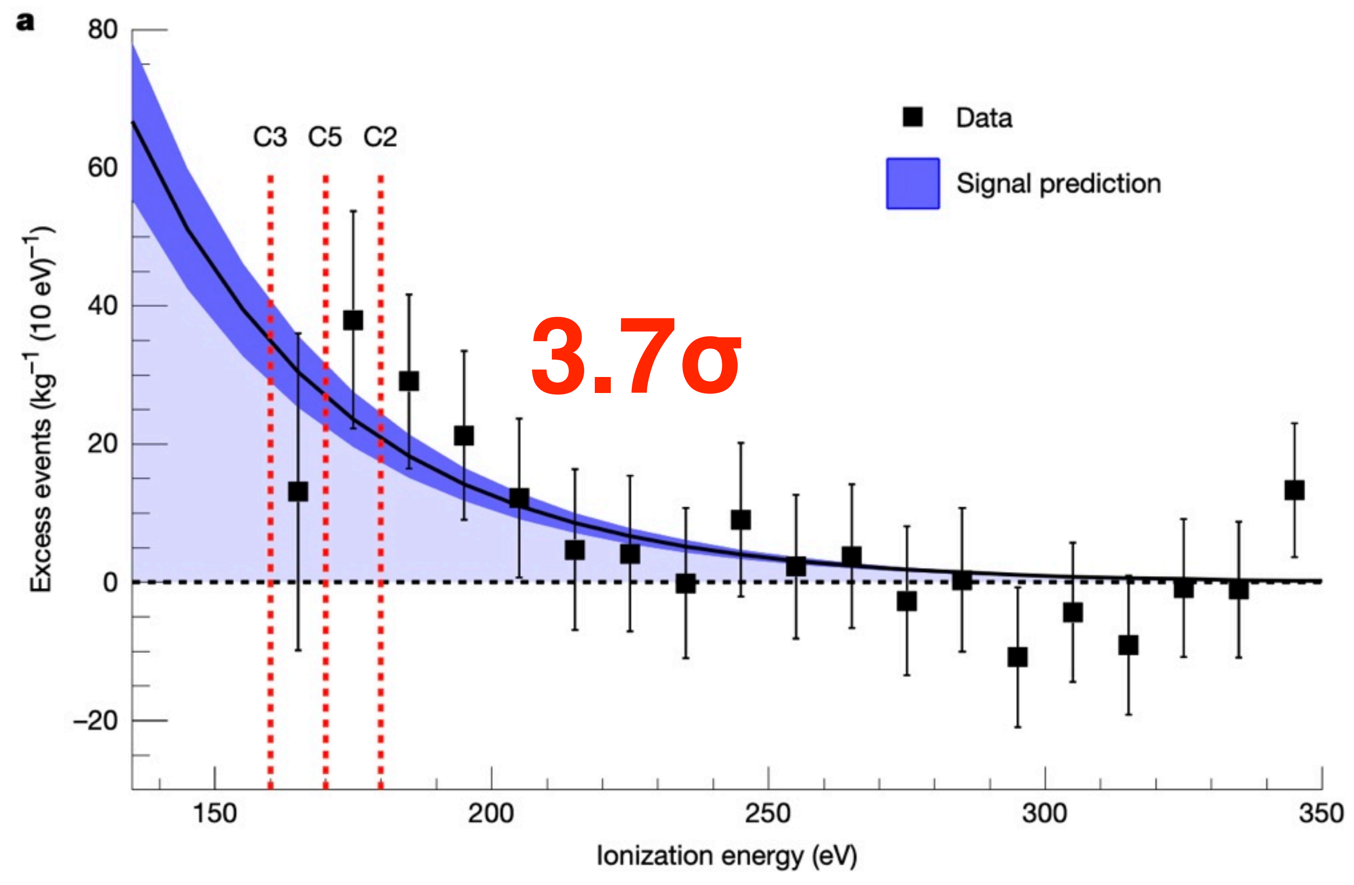
- **Particle Physics:**
  - Weak mixing angle at low momentum transfer
  - Non-standard effective neutrino interactions
  - Anomalous neutrino magnetic moments
  - Sterile neutrinos, etc.
- **Astrophysics:**
  - Novel methods for detecting solar neutrinos and supernova neutrinos
  - Important background for dark matter detection
- **Nuclear Physics:**
  - Nuclear form factors
- **Reactor Physics:**
  - Miniaturization of neutrino detectors
  - reactor monitoring





REACTOR

COνUS+

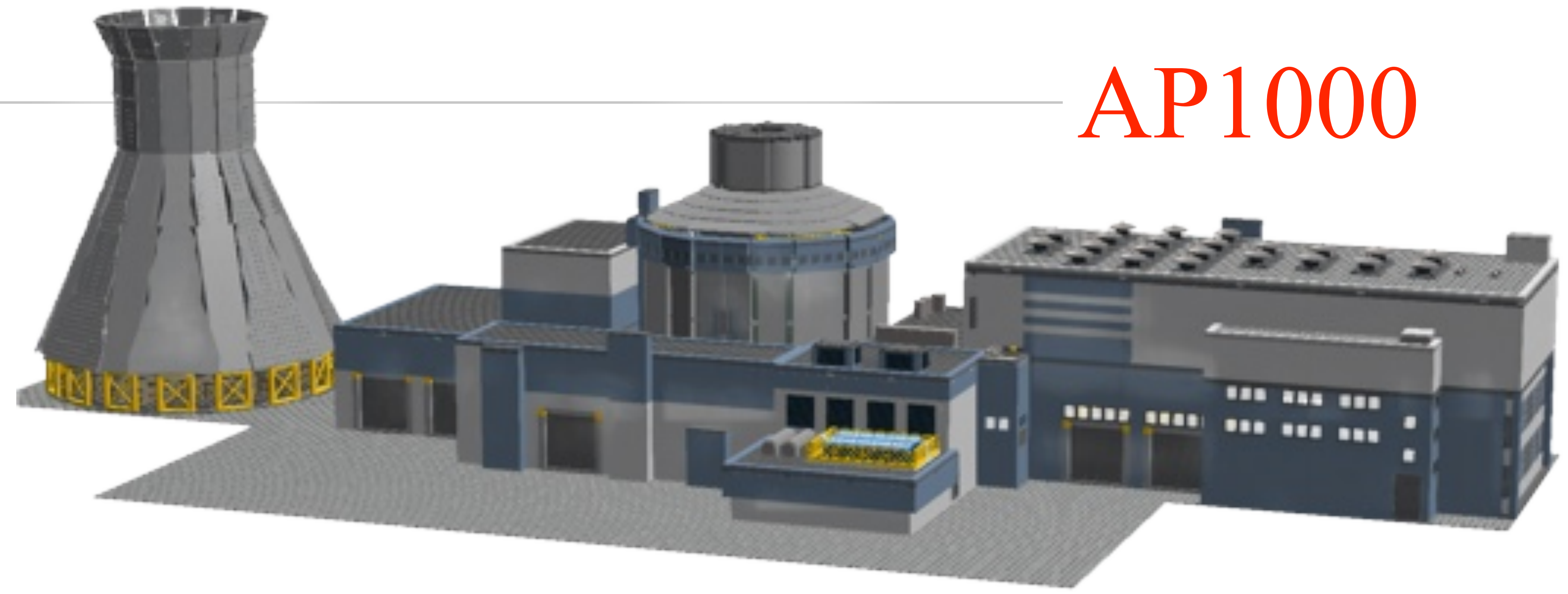


3.7σ

Nature volume 643, pages 1229–1233 (2025)

The **reactor** site of RELICS Experiment

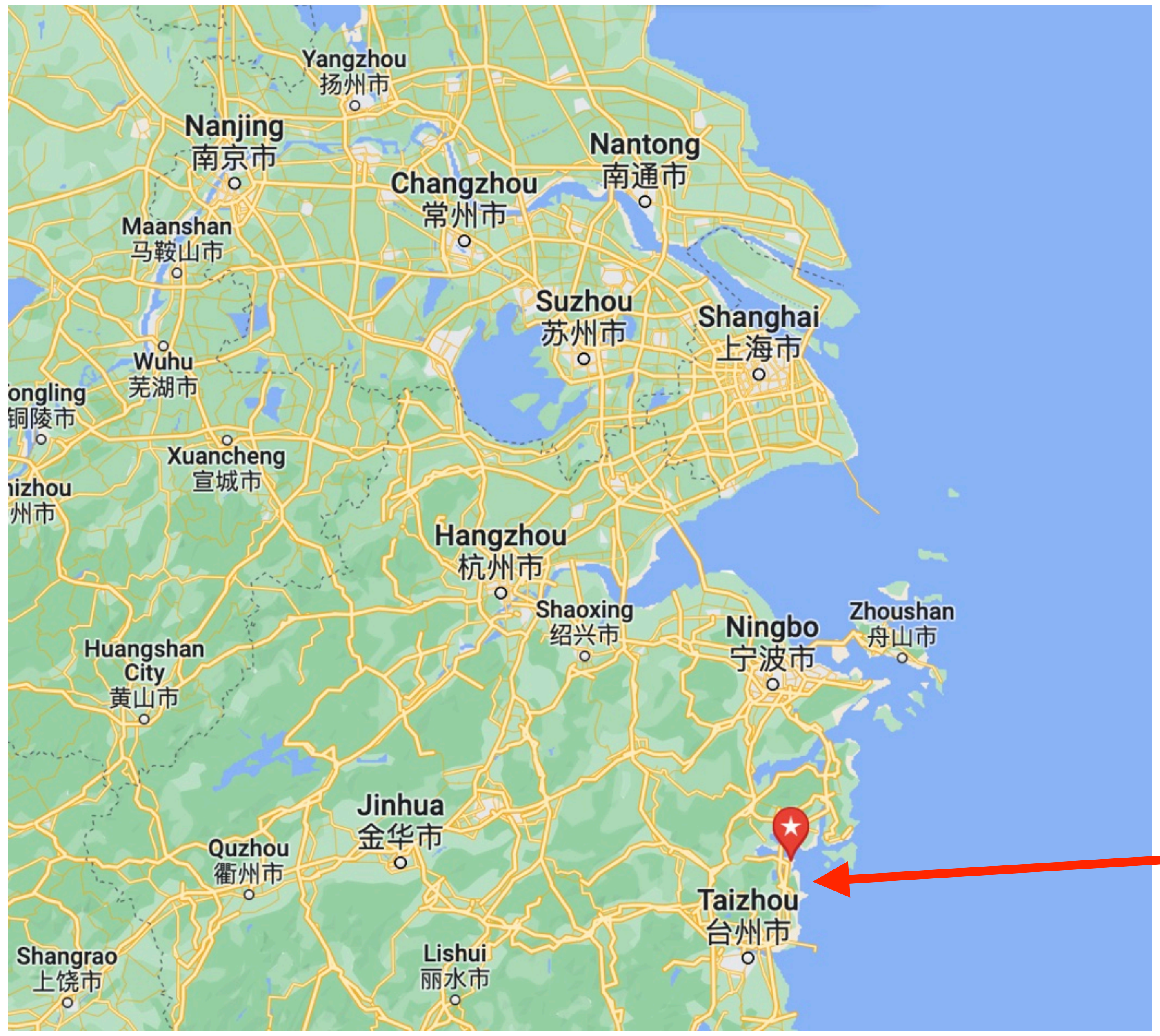
- Sanmen Nuclear Power Plant, Zhejiang Province
- Thermal Power ~3.4GW, baseline ~25m
- Neutrino flux >1e13 $\boldsymbol{\nu}$/cm^2/s

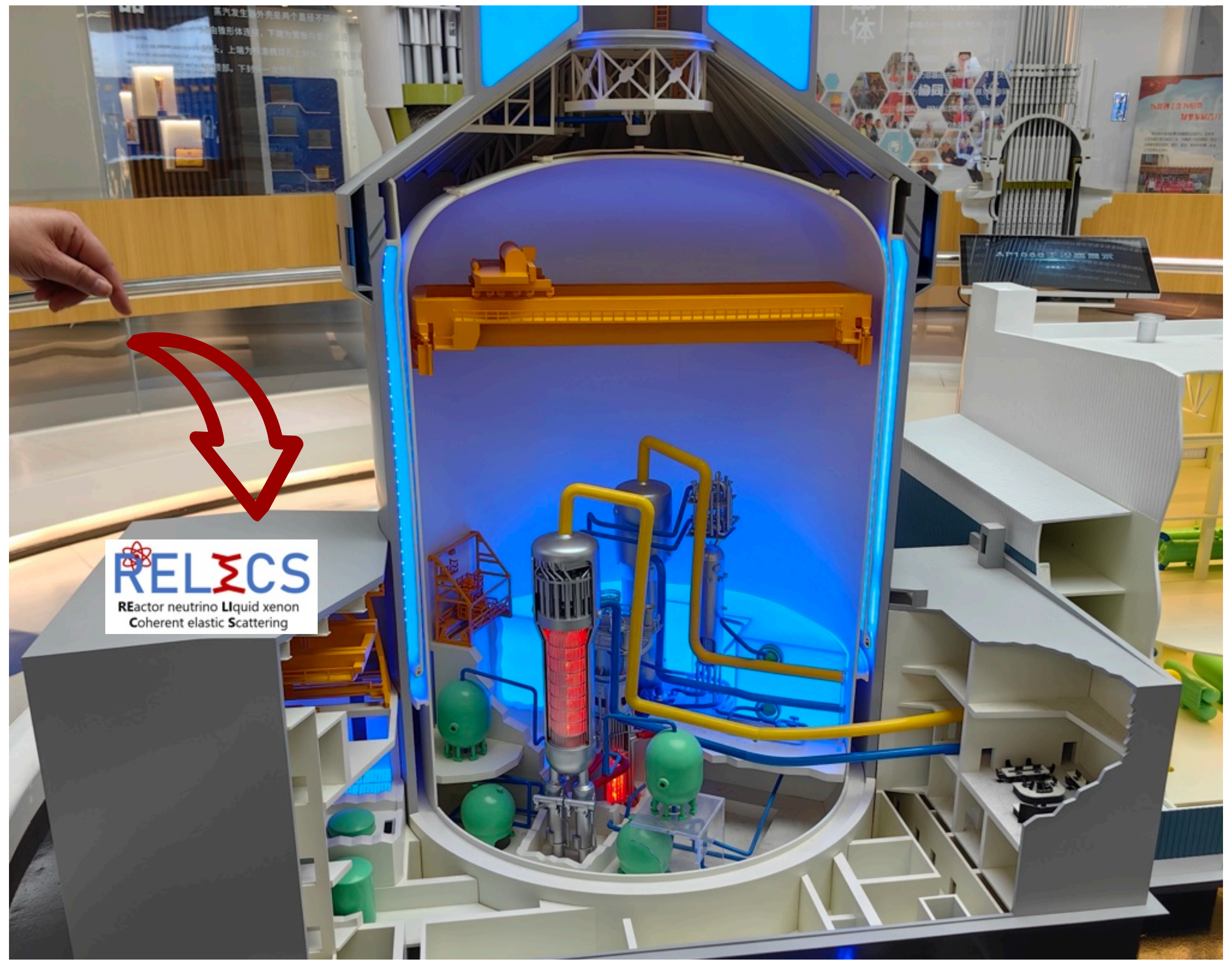


AP1000

RECODE

(LiTao's Talk)





RELICS
REactor neutrino **LI**quid xenon **C**oherent elastic **S**cattering

RELICS Collaboration

- 6 institutes
- ~40 people

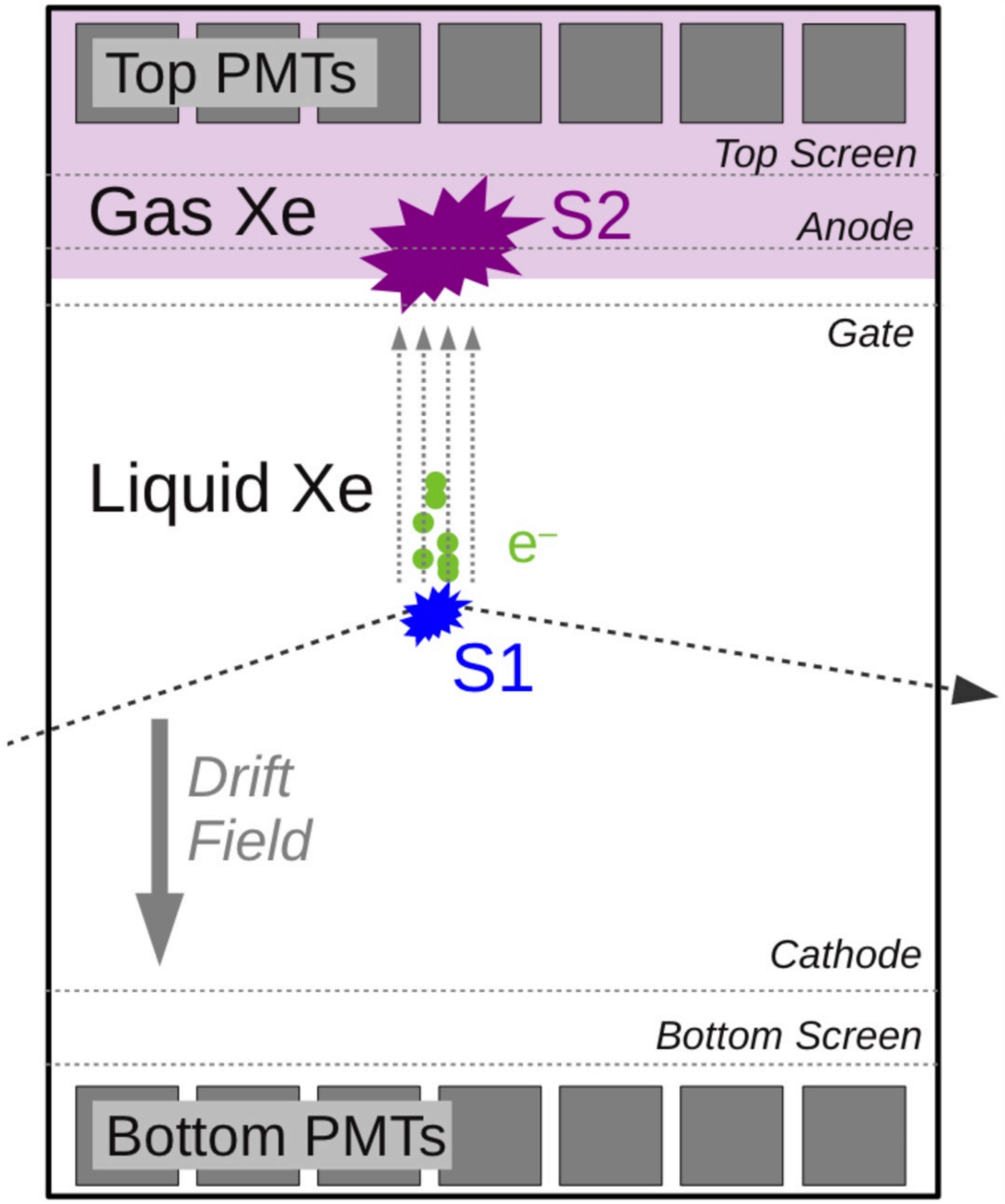
RELICS collaboration meeting, Dec 2024, SYSU

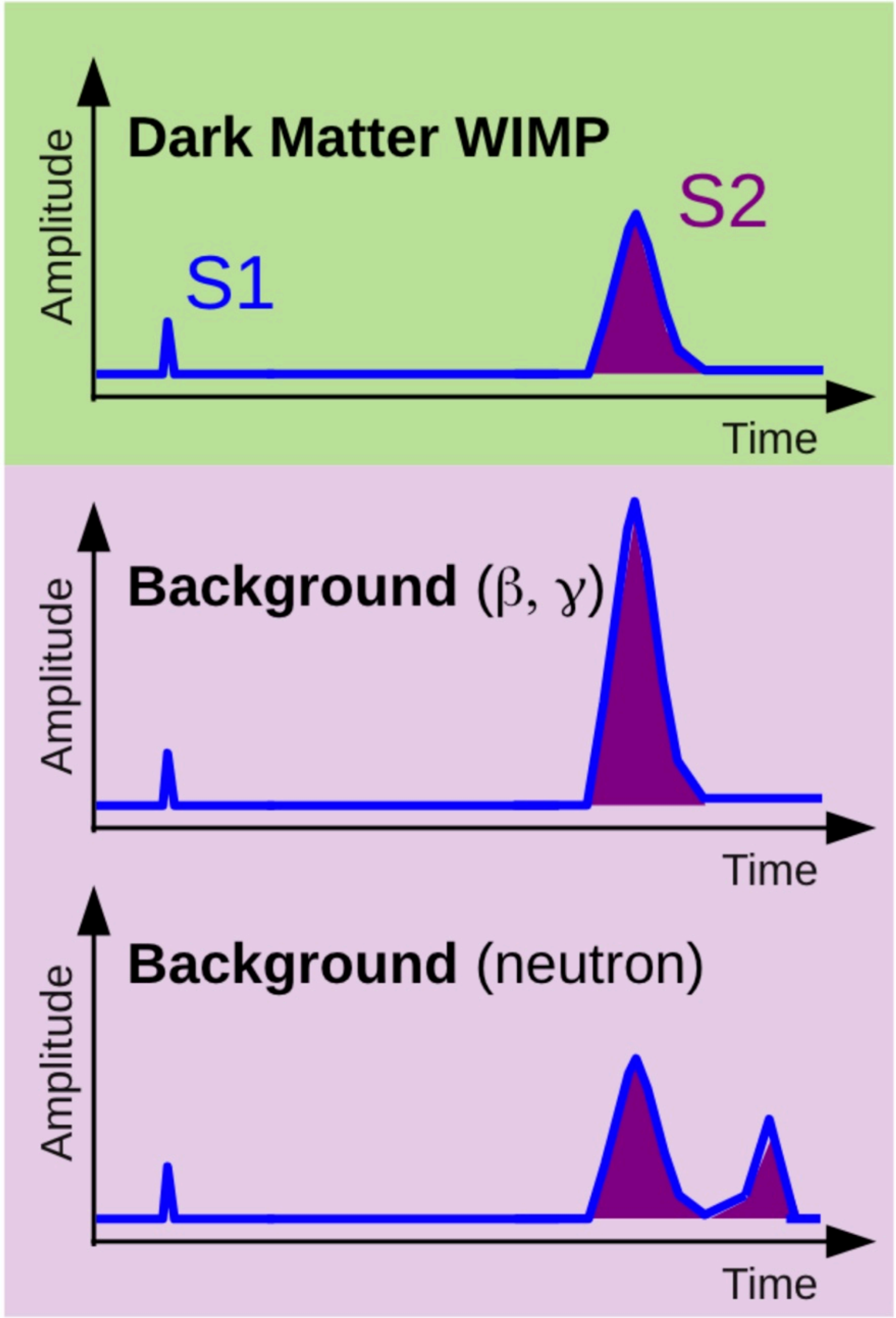
香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

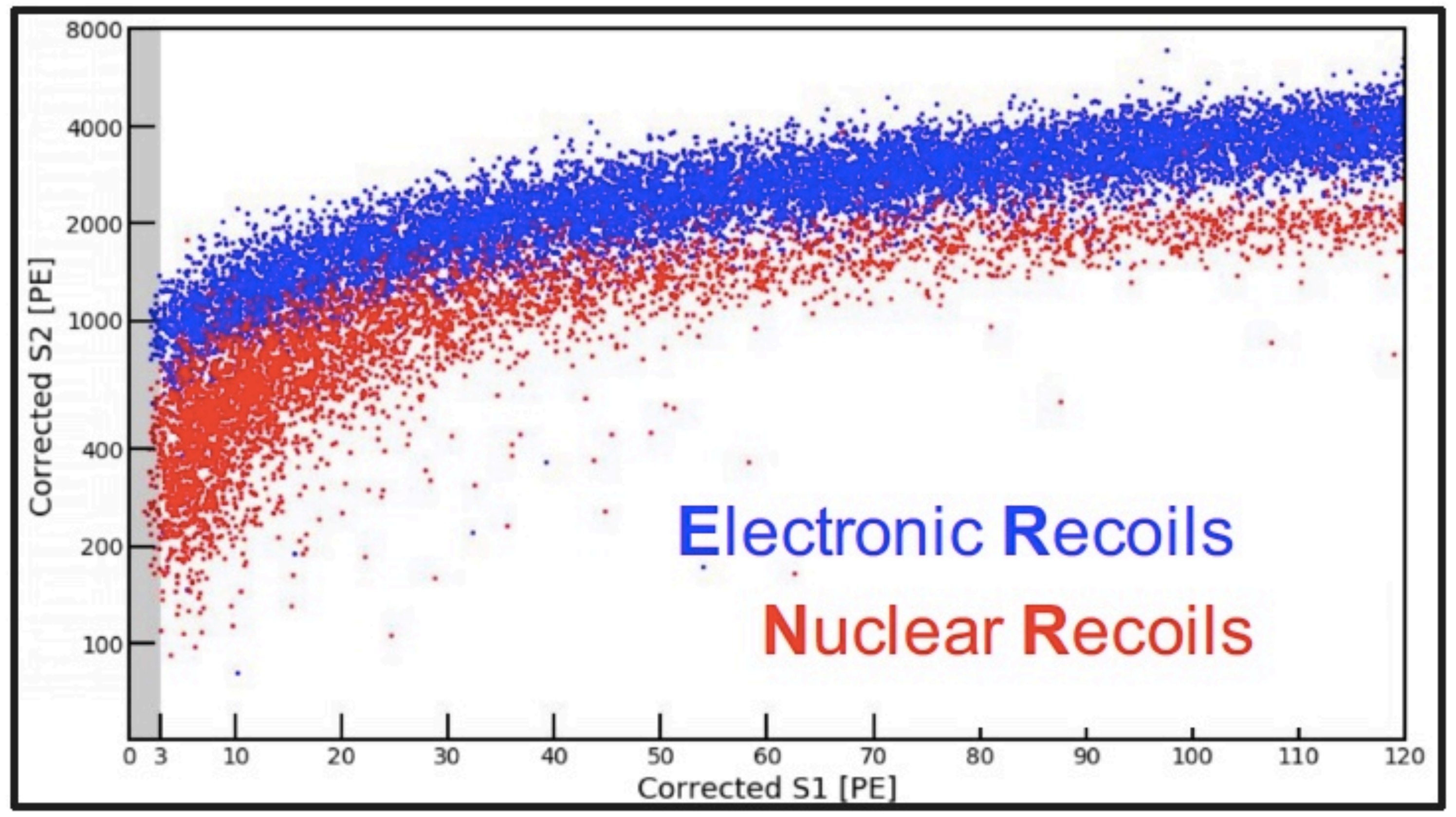
RELICS detection technology

Liquid Xenon Time Projection Chamber (LXeTPC)

Credit to XENON







✦**Low-threshold**

✦**Low-background**

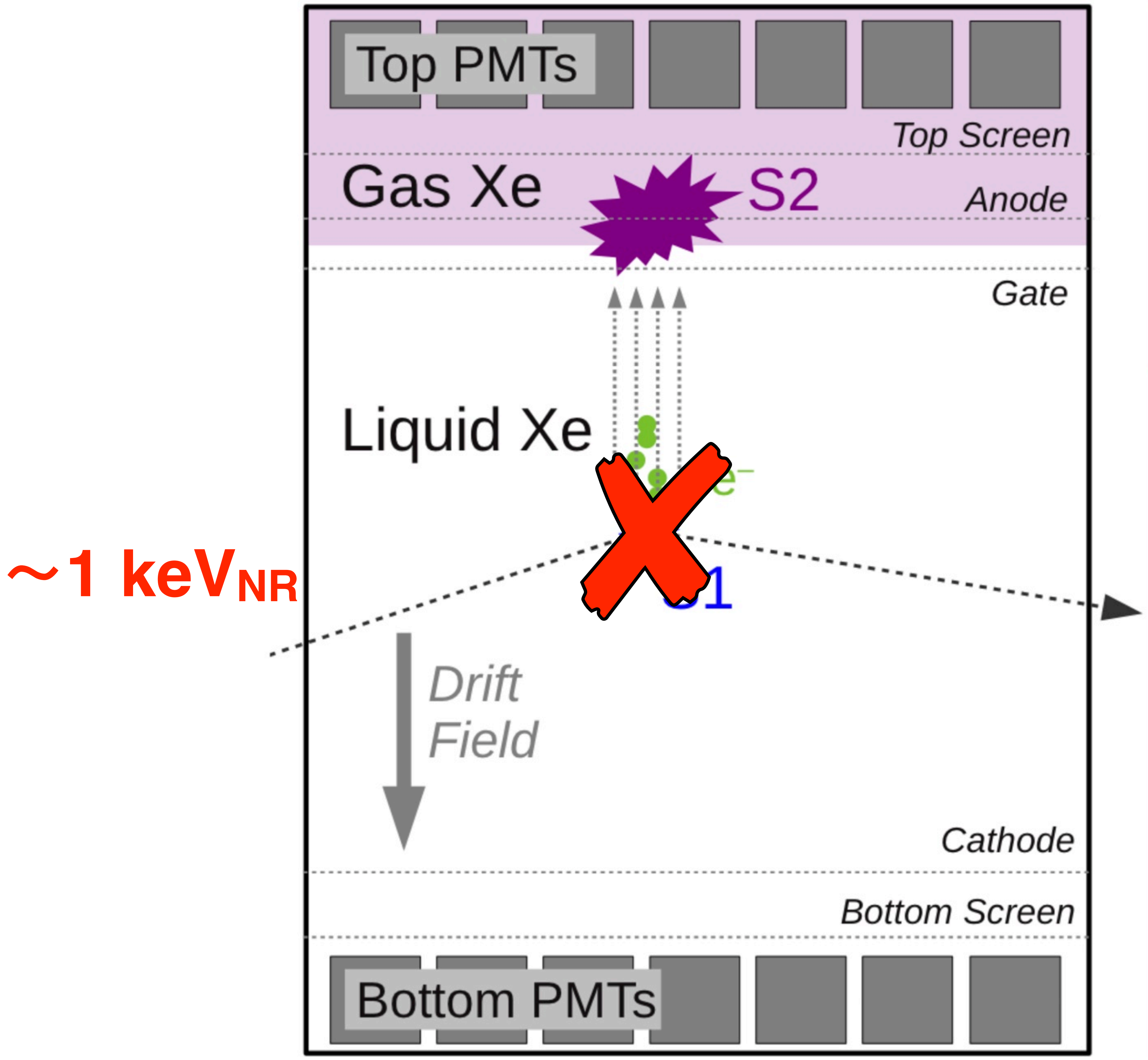
✦Large-mass

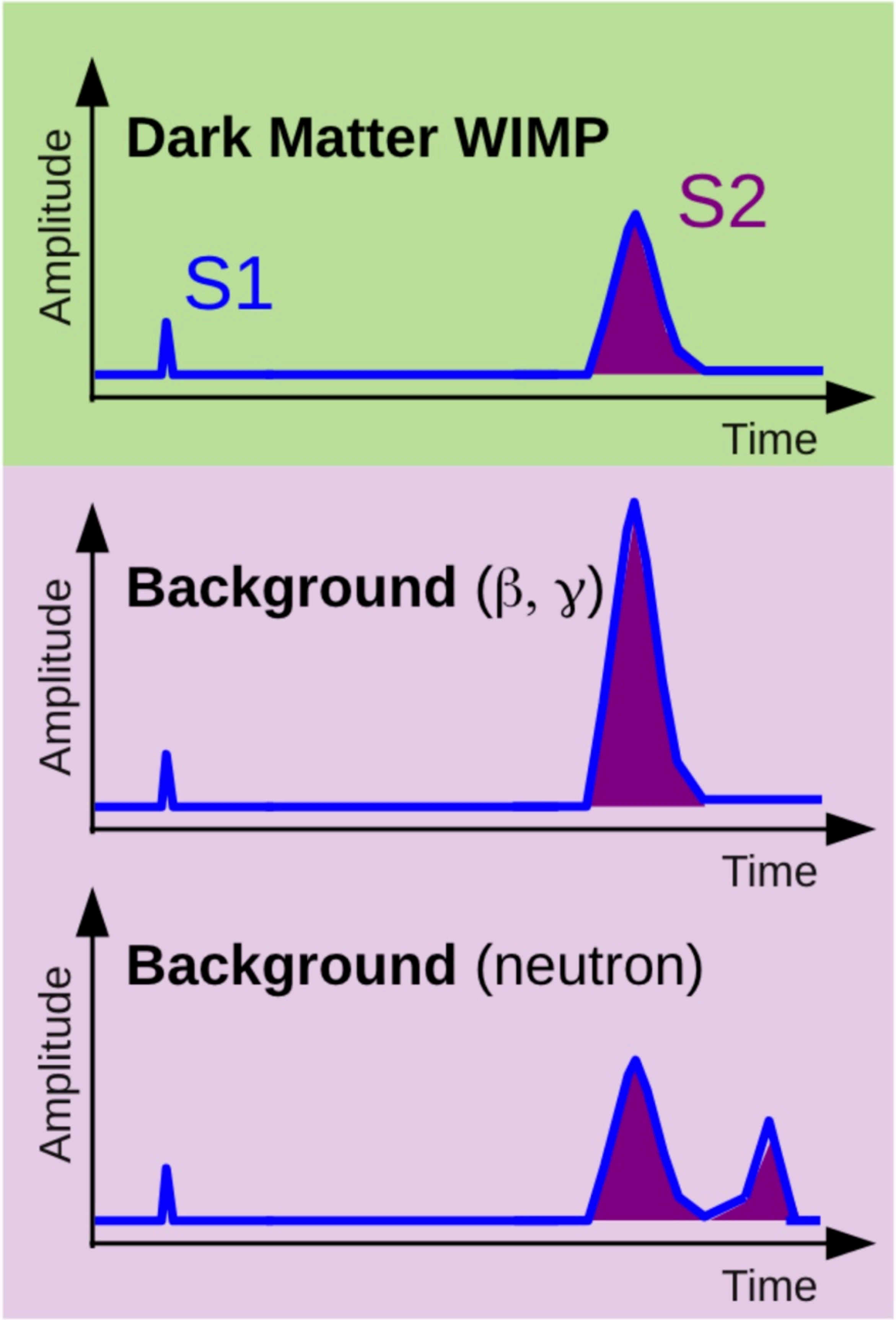
Same as the PandaX, XENON, LZ Dark Matter Experiments..

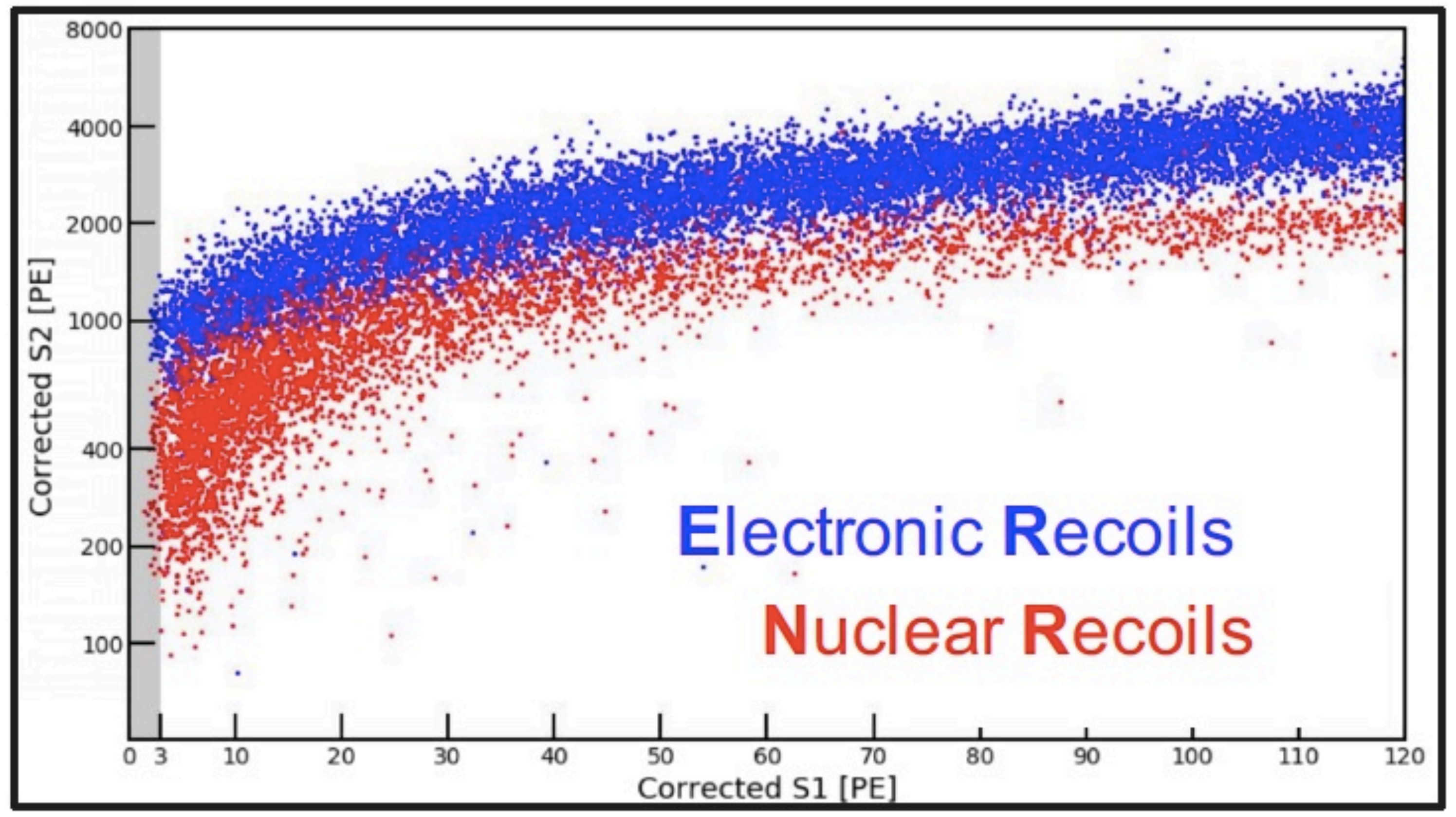
RELICS detection technology

Liquid Xenon Time Projection Chamber (LXeTPC)

Credit to XENON







✦**Low-threshold**

✦**Low-background**

✦Large-mass

Same as the PandaX, XENON, LZ Dark Matter Experiments..

Neutrino CEvNS ⇔ Neutral current for Dark Matter detection

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)

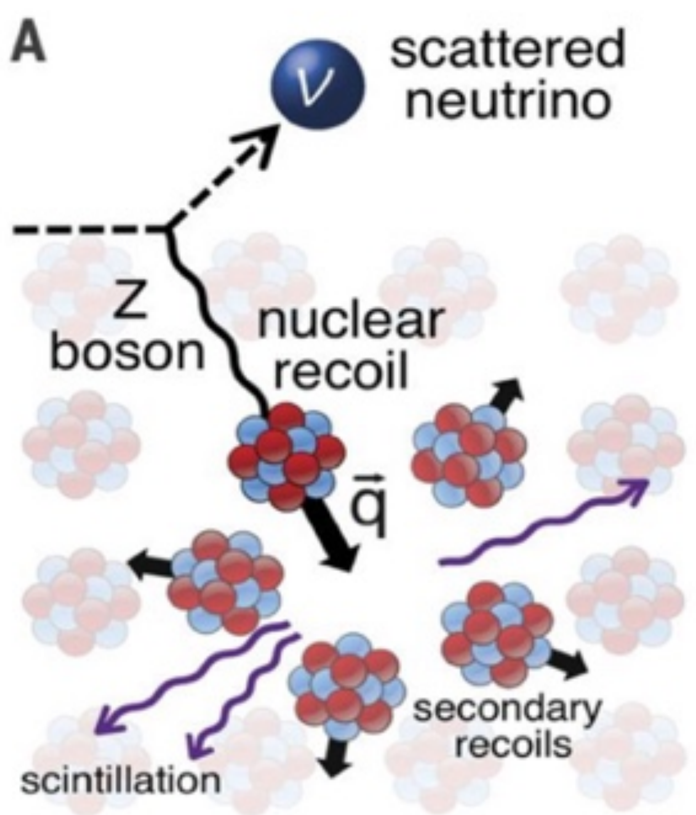
If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are 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 $\nu + A \to \nu + A^*$ 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.

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

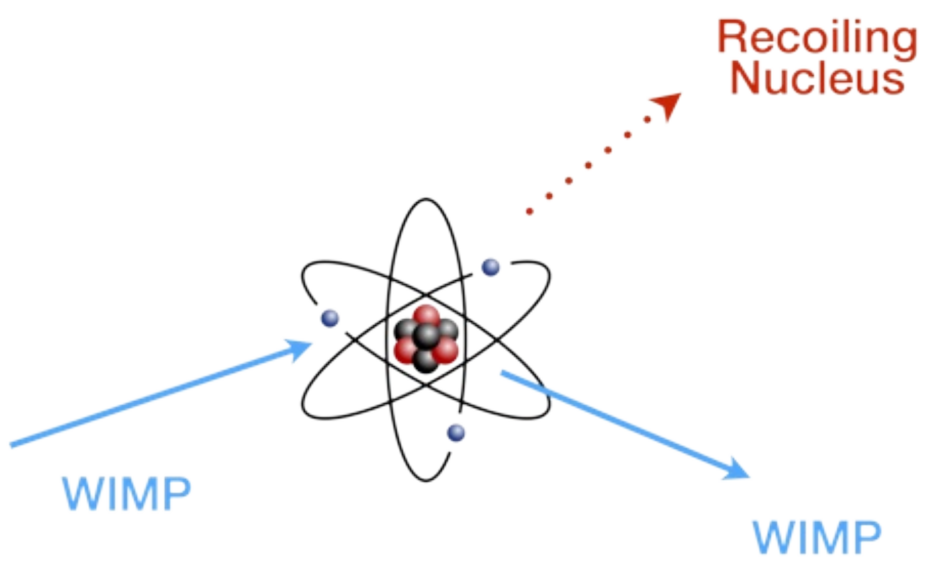
Detectability of certain dark-matter candidates

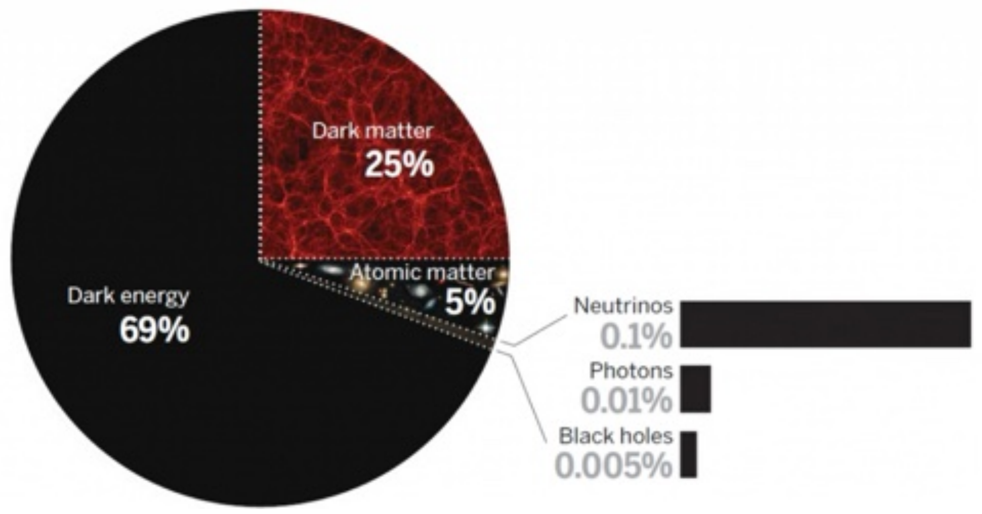
Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

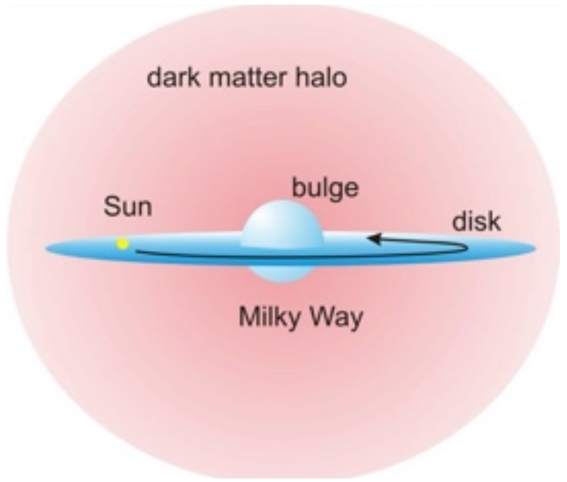
We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses 1—10^6 GeV; particles with spin-dependent interactions of typical weak strength and masses 1—10^2 GeV; or strongly interacting particles of masses 1—10^{13} GeV.

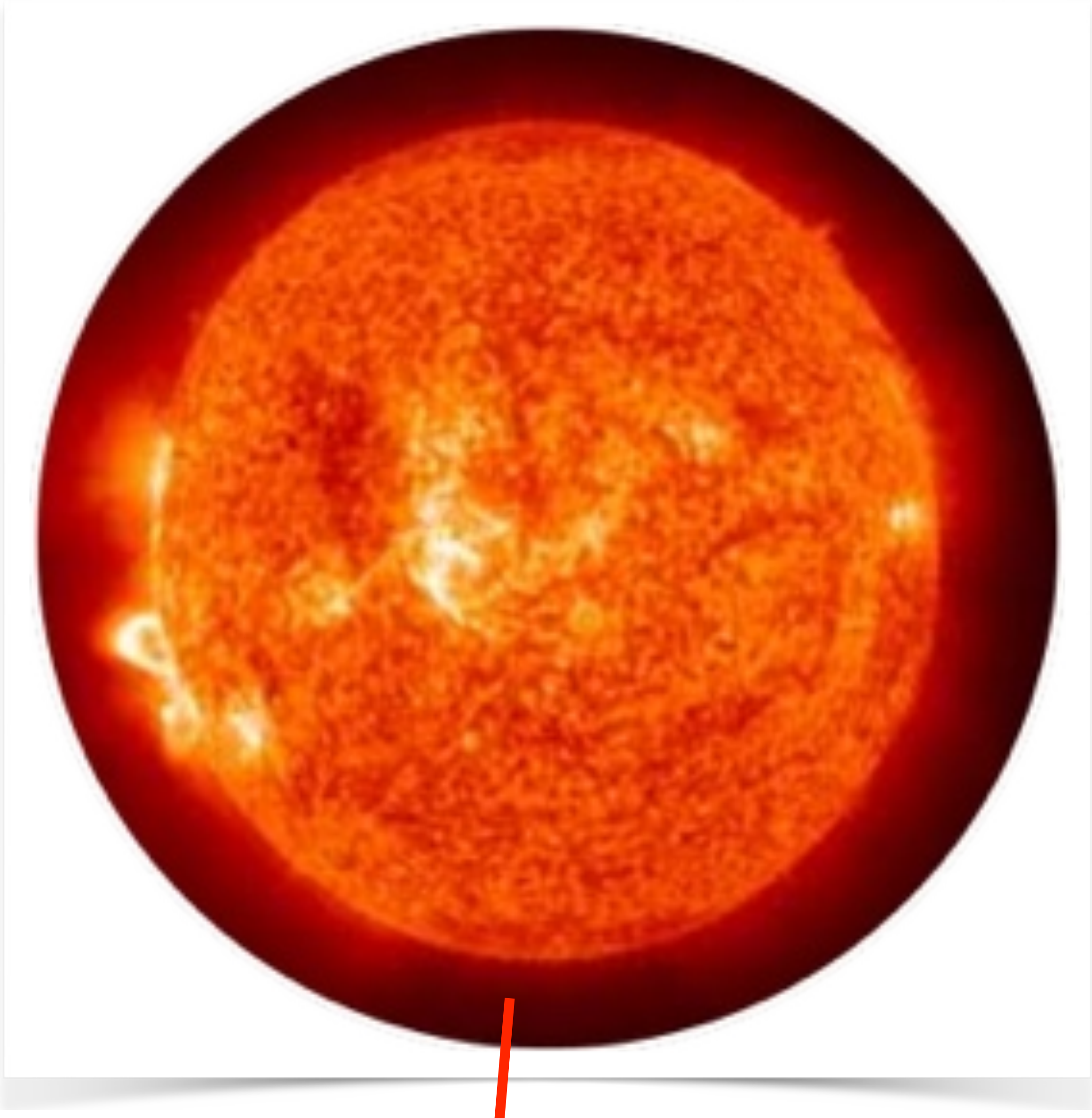


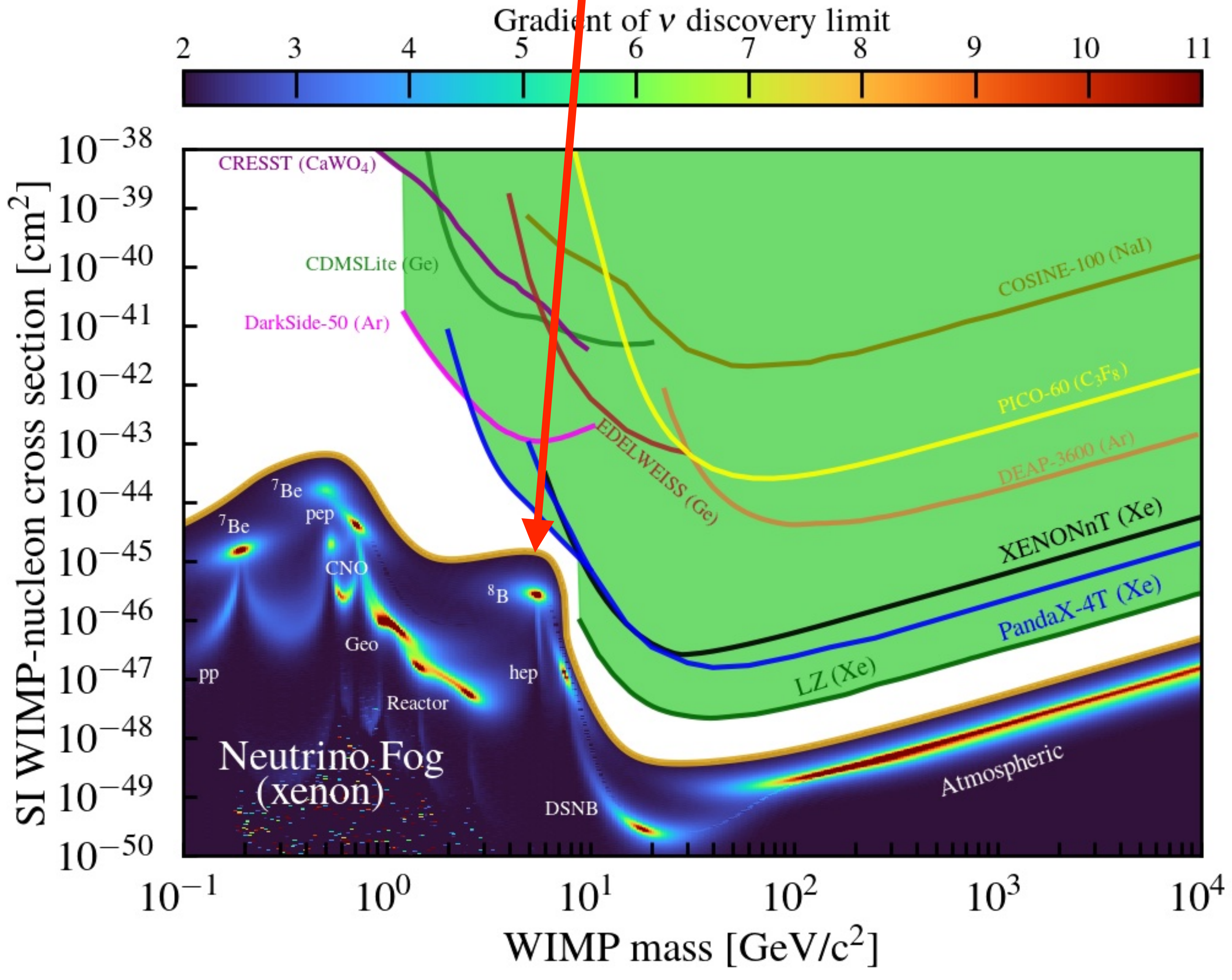
D. Akimov et al, Science 357 (2017)











PHYSICAL REVIEW LETTERS **133,** 191001 (2024)

Editors' Suggestion | Featured in Physics

First Indication of Solar ^{8}B Neutrinos through Coherent Elastic Neutrino-Nucleus Scattering in PandaX-4T

2.64σ

PHYSICAL REVIEW LETTERS **133,** 191002 (2024)

Editors' Suggestion | Featured in Physics

First Indication of Solar ^{8}B Neutrinos via Coherent Elastic Neutrino-Nucleus Scattering with XENONnT

2.73σ

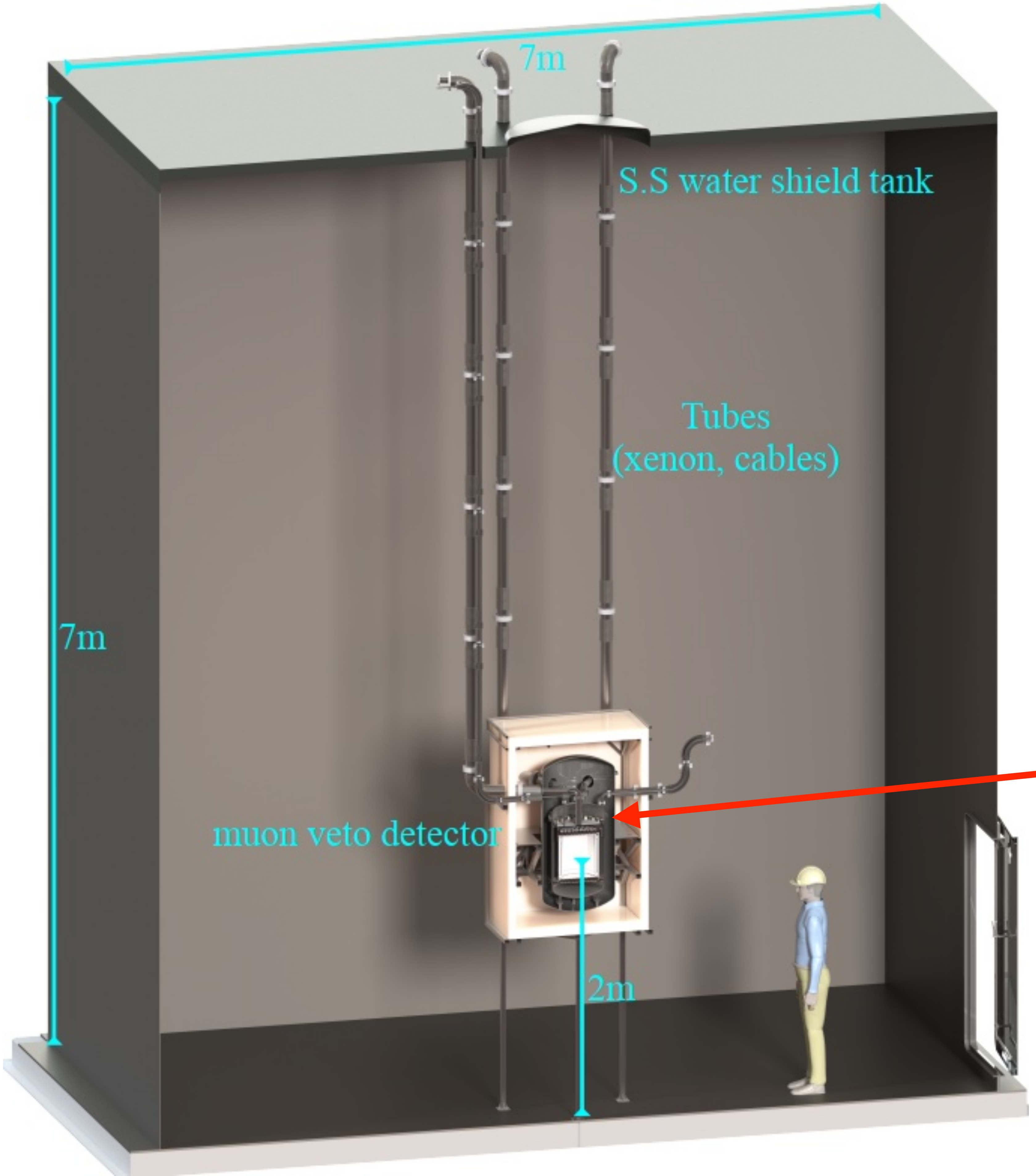
First detection of CEvNS of astrophysical neutrinos!

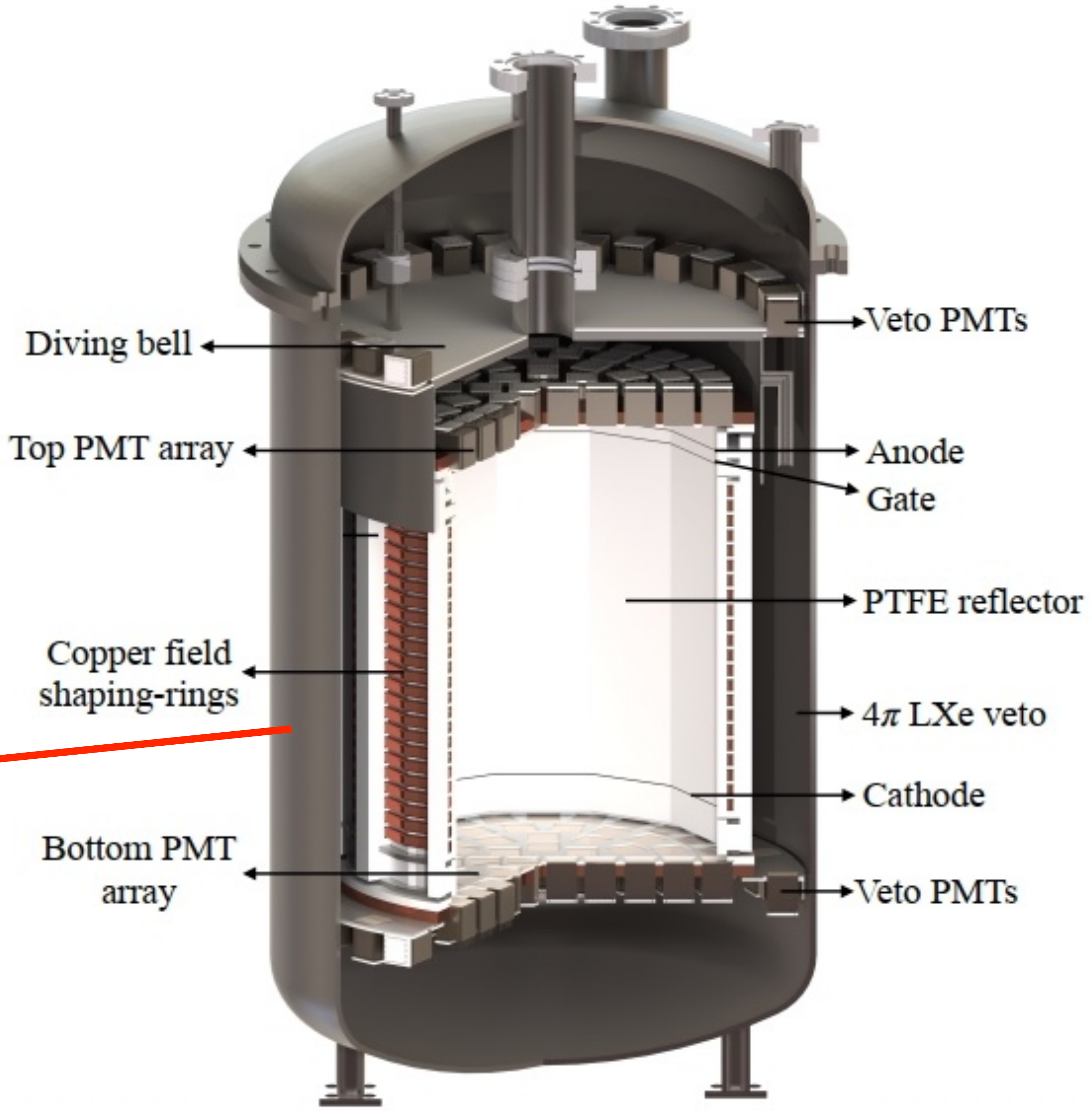
First astrophysical signal measured by a dark matter experiment!

RELICS detector

✦ 7x7x7m³ water shield to suppress cosmic-ray neutrons induced background

✦ 4π plastic scintillator muon veto detector with veto efficiency of 99%





RELICS-50

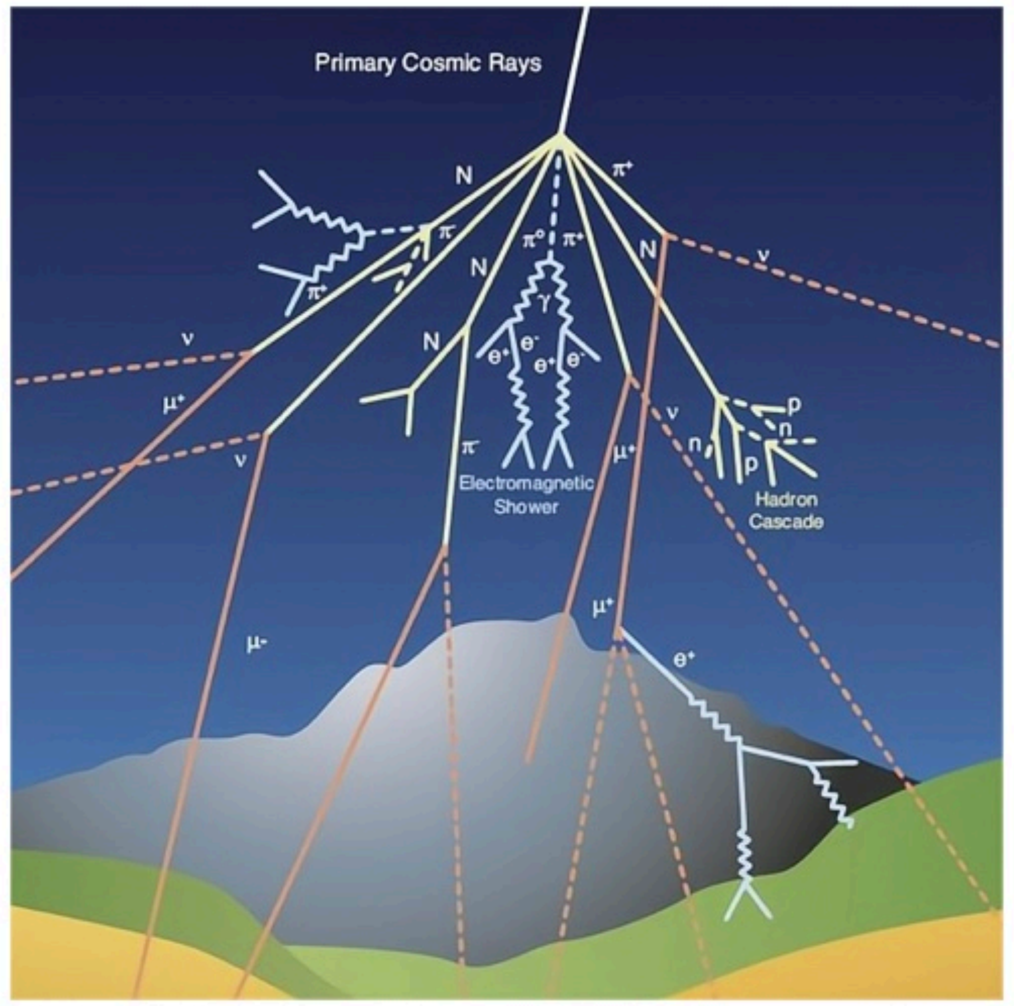
✦ TPC: 24 cm $H \times$ 28cm D

✦ 64 1-inch PMTs on top and bottom, respectively

RELICS Background

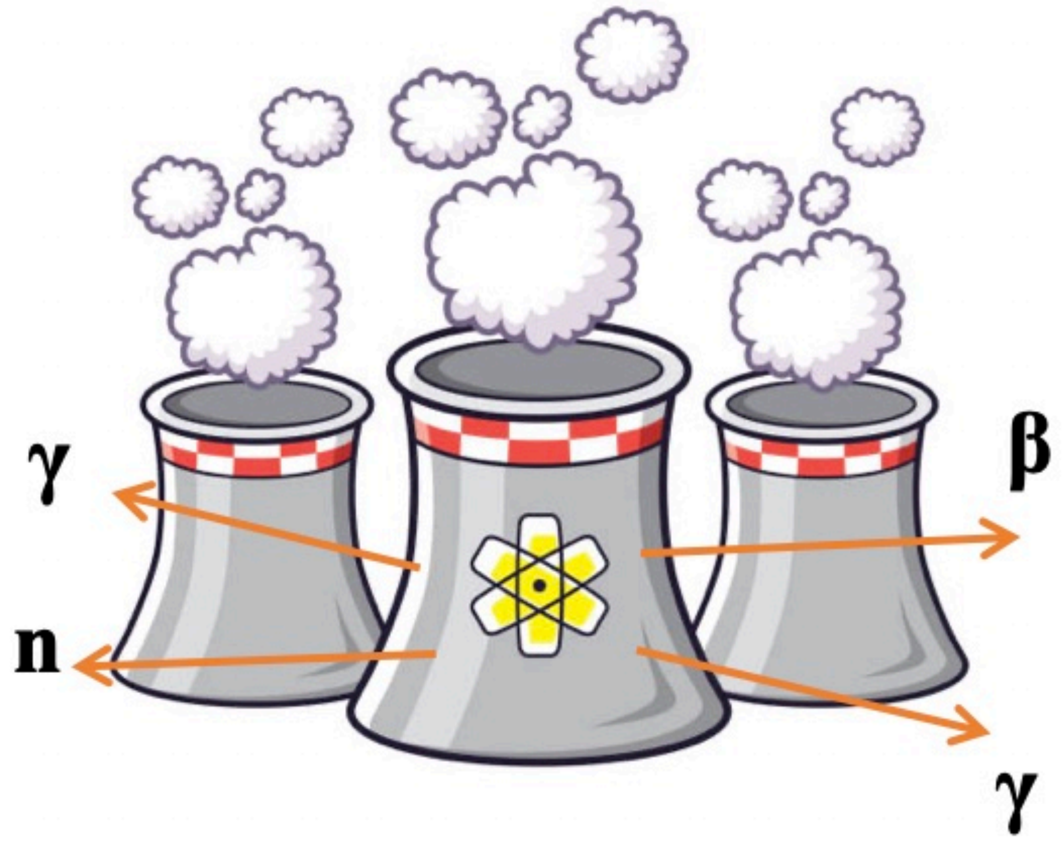
Challenges & Suppression

Cosmic Ray Particles



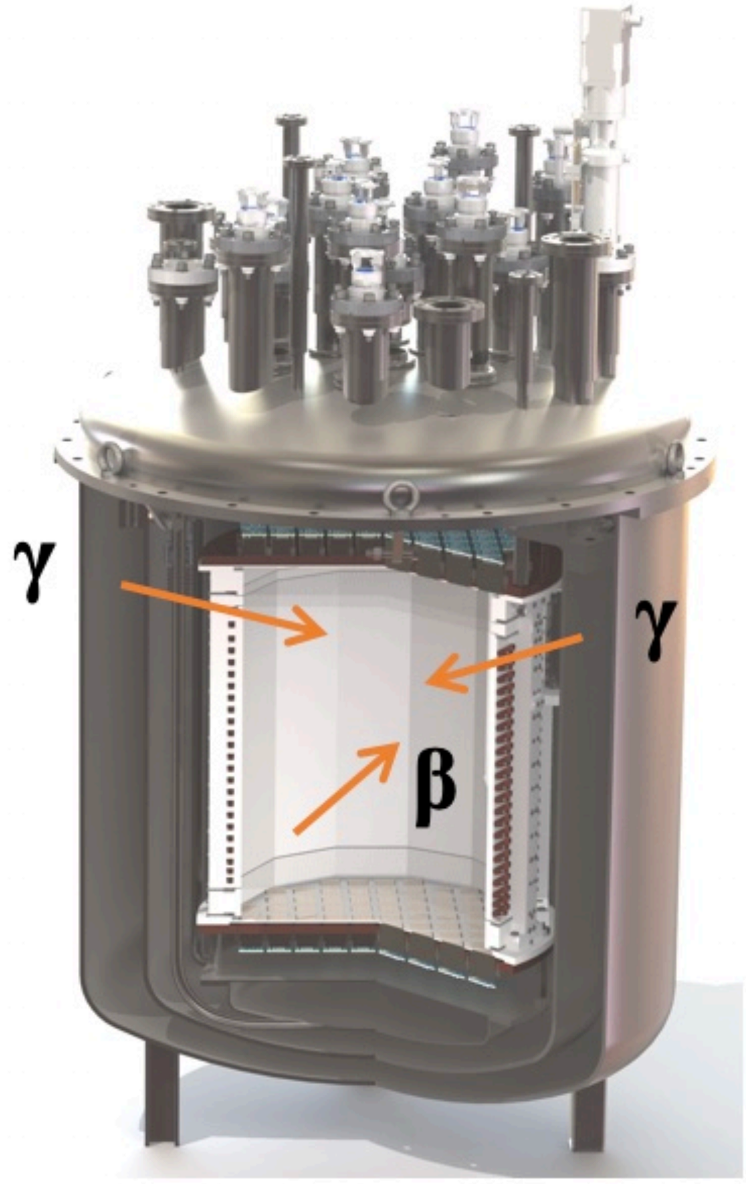
- ☐ Cosmic μ
- ☐ Cosmic neutron
- ☐ Others…

Reactor



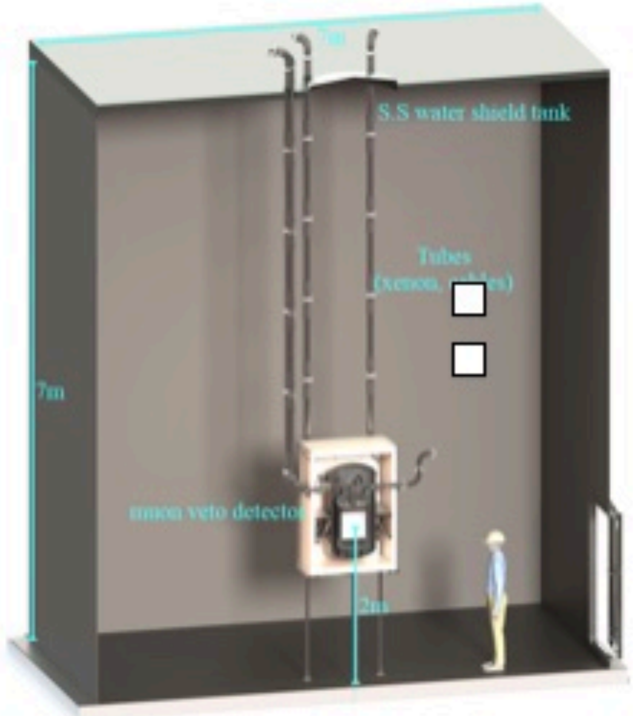
- ☐ Reactor Neutron
- ☐ Reactor γ
- ☐ Others…

Detector Material



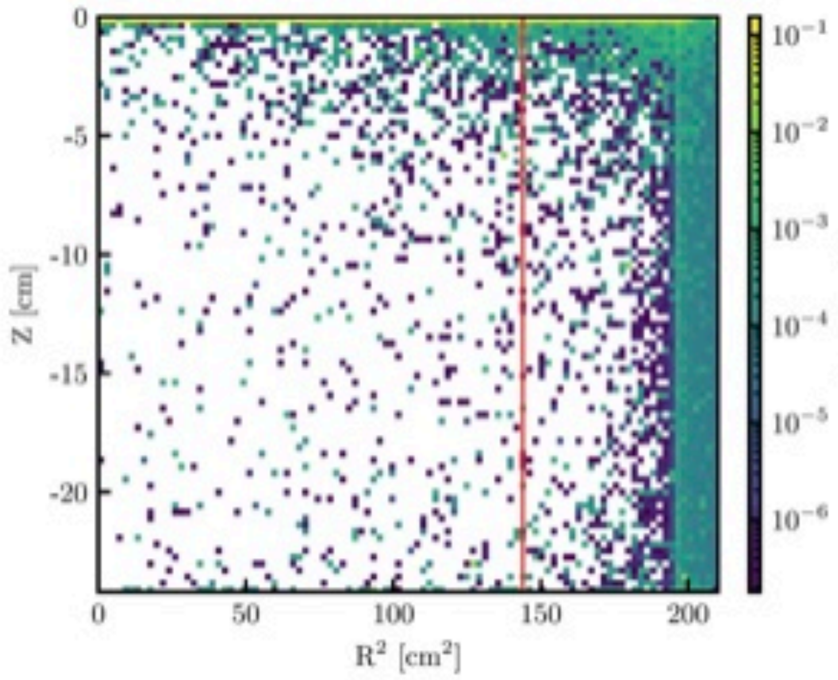
- ☐ Material γ, β
- ☐ Others…

Physics Background Simulation with Geant4

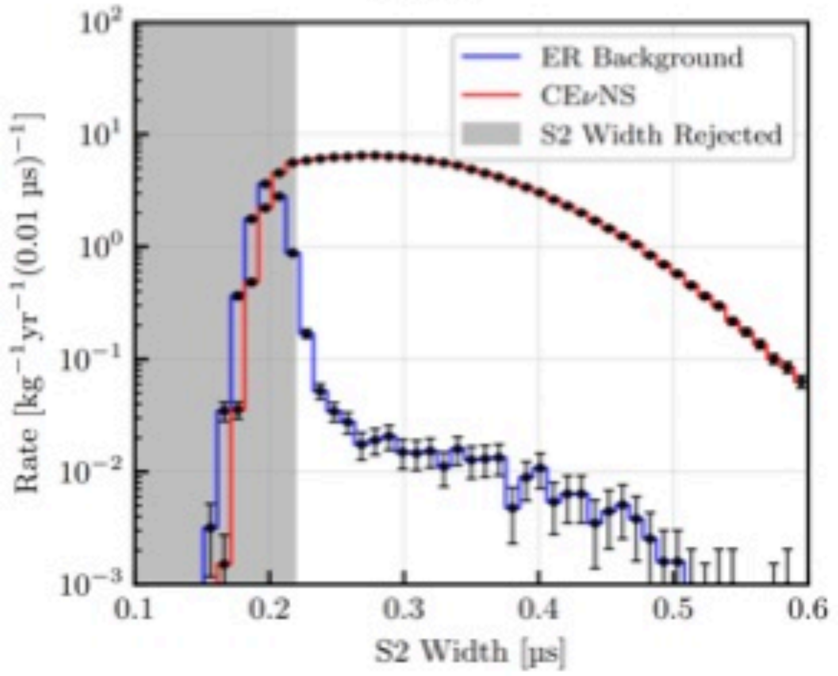


Muon veto

$> 99\%$



Fiducial Selection

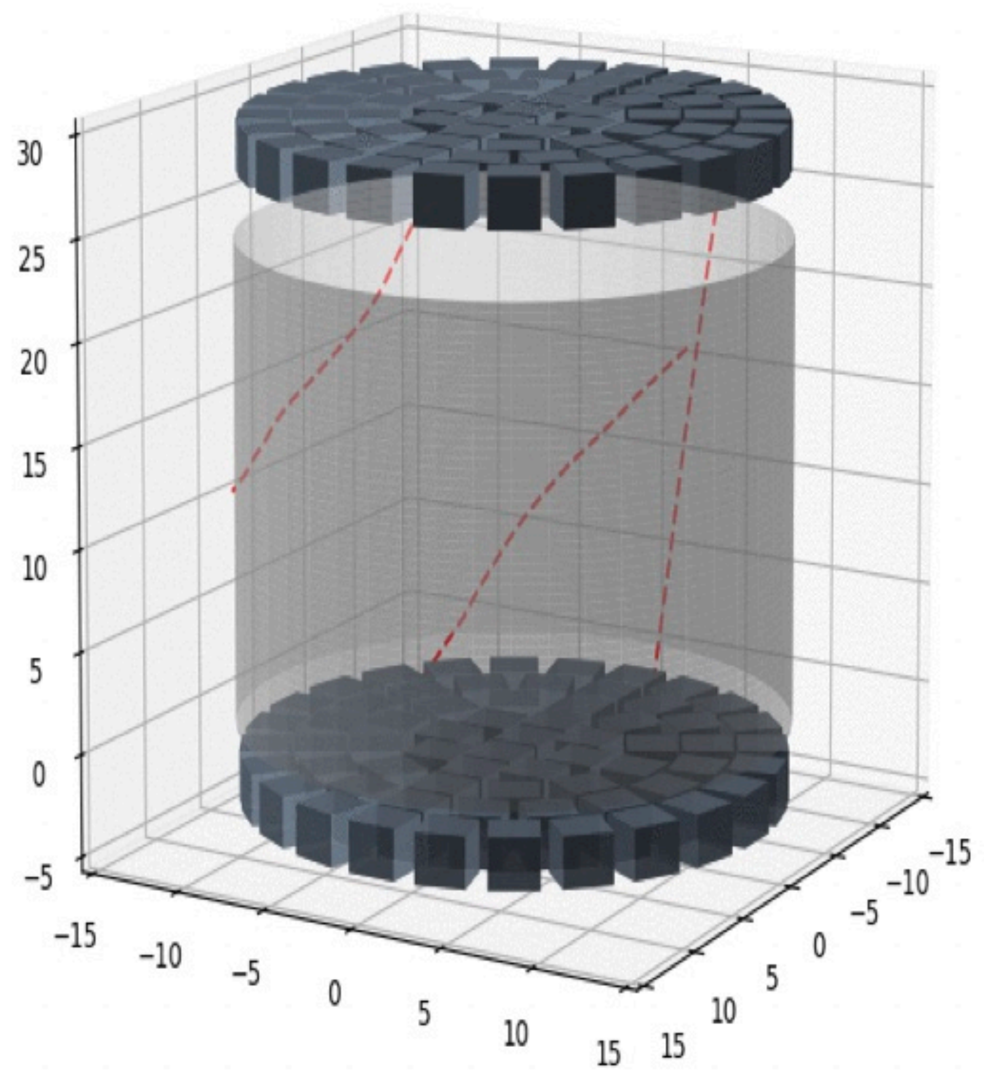


S2 Width Selection

RELICS Background

Challenges

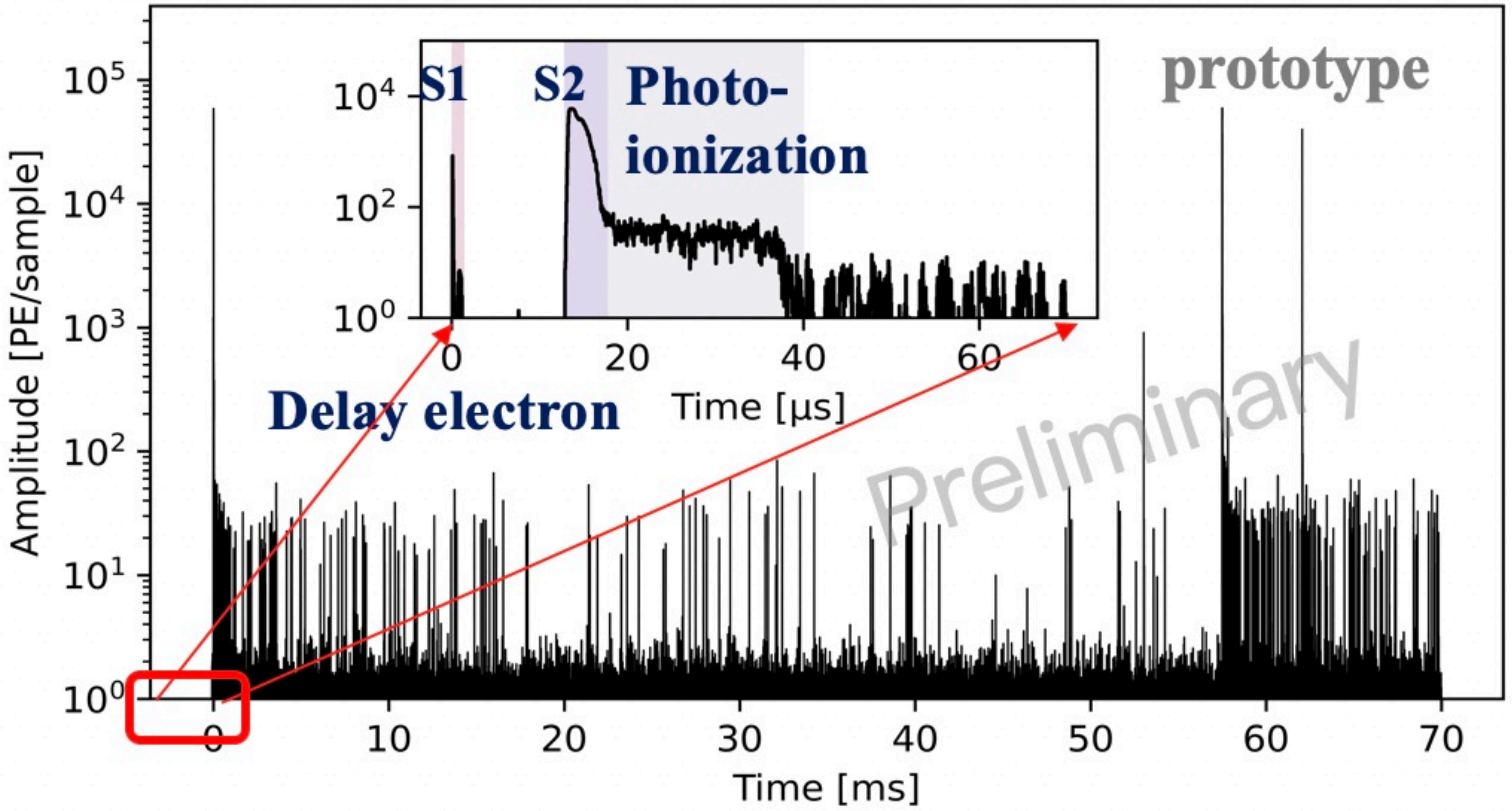
Spurious Signals



- ☐ Delayed Electrons
- ☐ Others…

Data-driven Modeling of Delayed Electron Backgrounds

Large Energy deposition



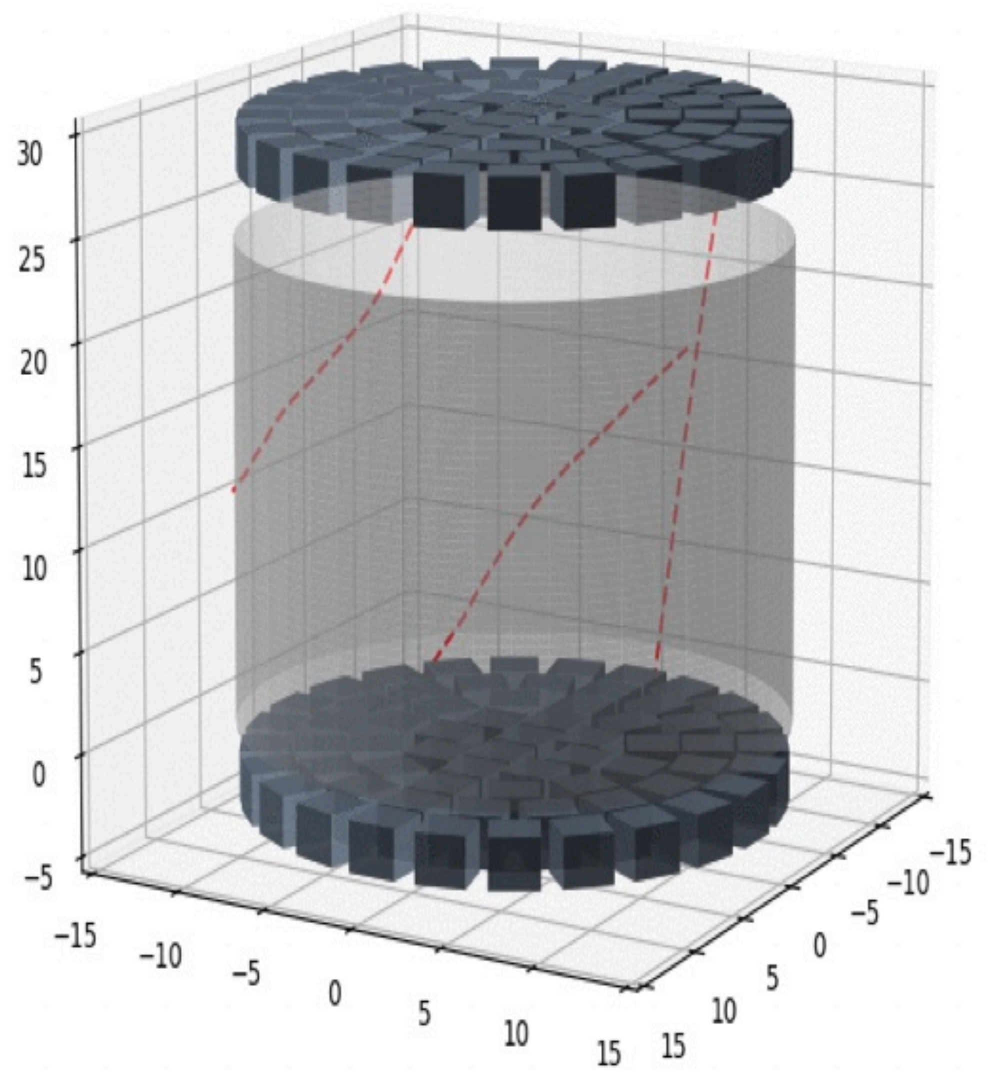
Delayed Electrons phenomenon:

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

RELICS Background

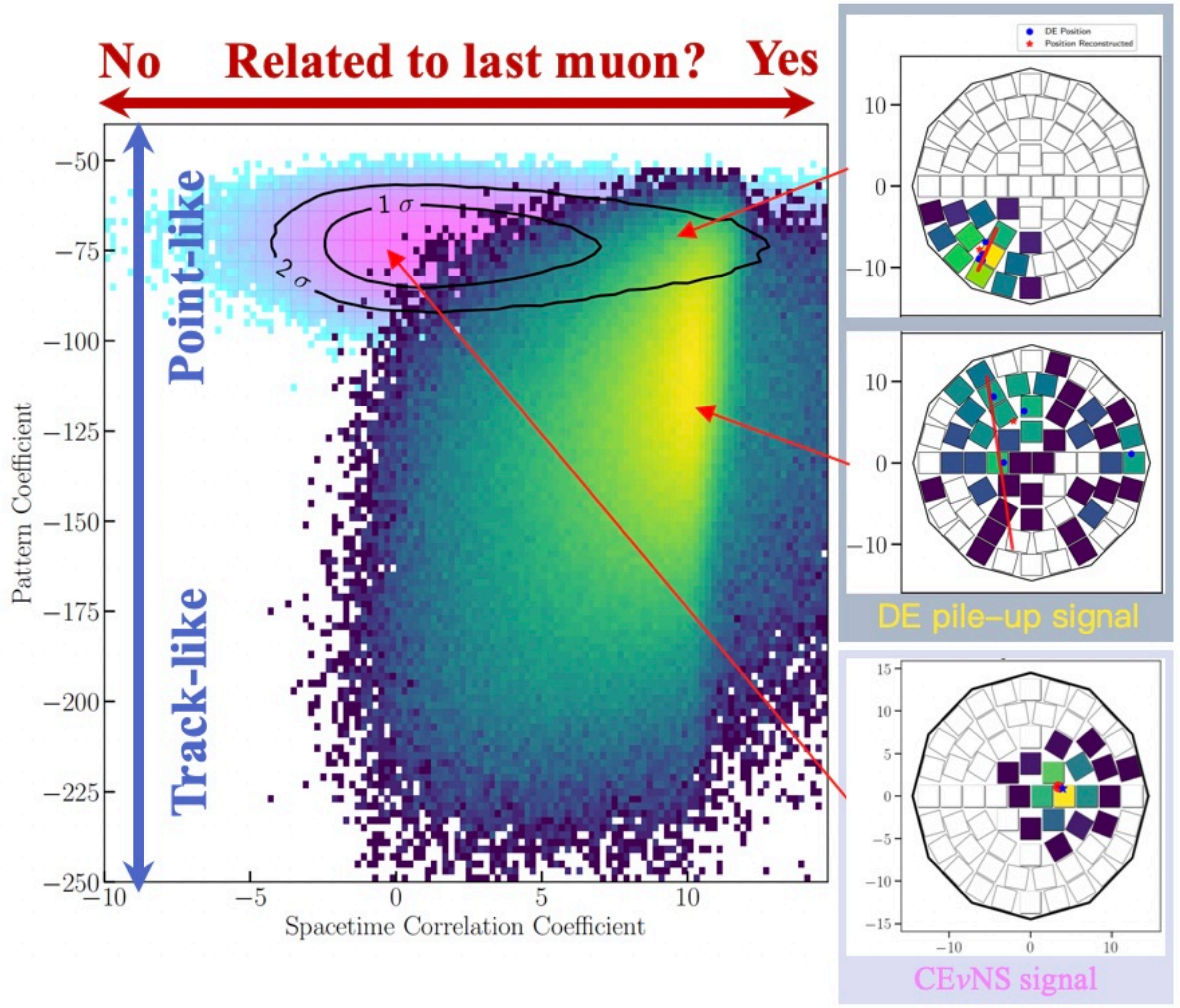
Challenges & Suppression

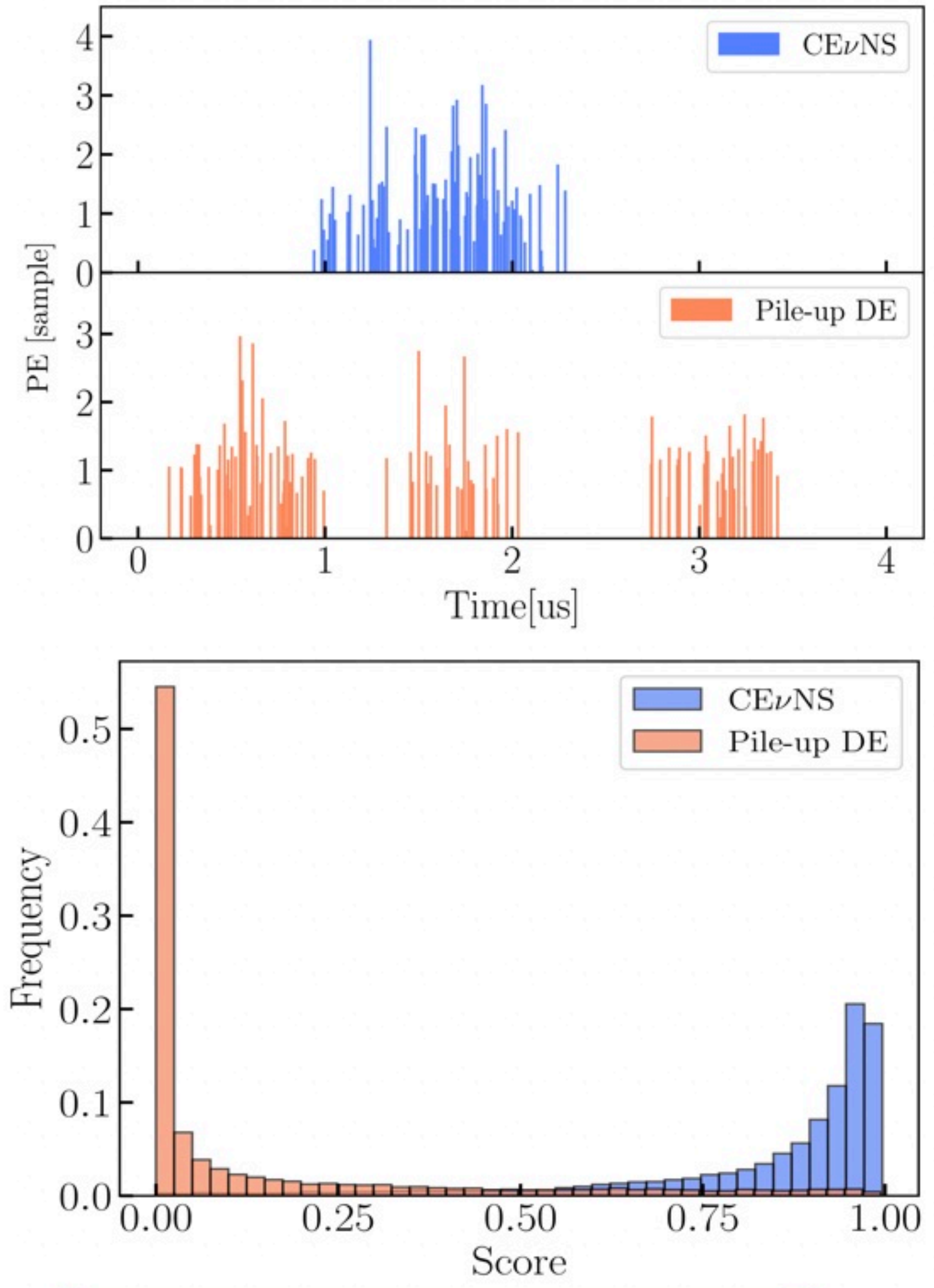
Spurious Signals



- ☐ Delayed Electrons
- ☐ Others…

Data-driven Modeling of Delayed Electron Backgrounds





Pattern + Correlation selection:

- ☐ CEvNS: Closer to single-point events
- ☐ DE: Linked to the preceding muon track

Waveform selection:

- ☐ CEvNS: Gaussian
- ☐ DE: More dispersed

RELICS background summary and sensitivity

CEvNS ROI: [120, 240] PE

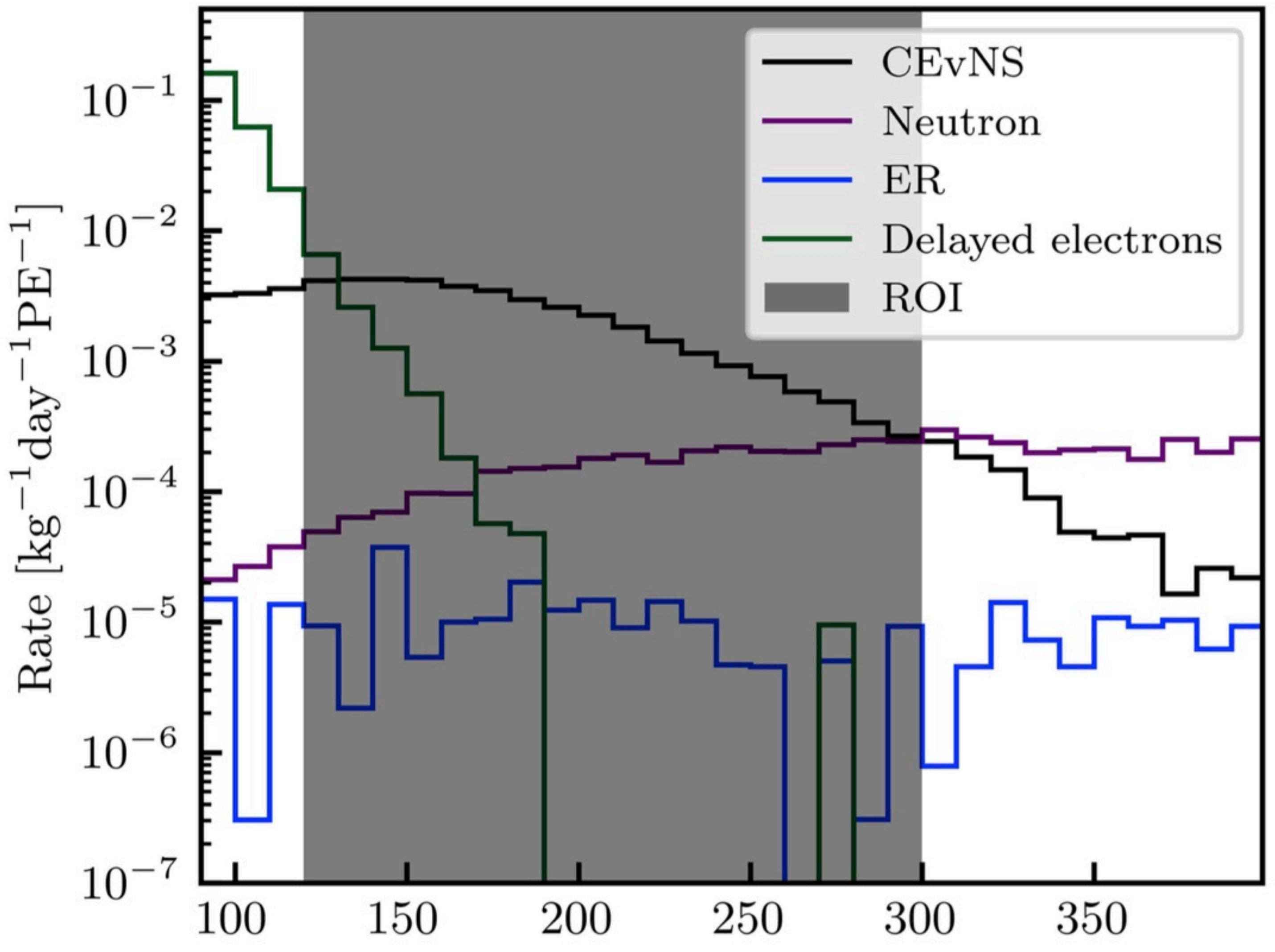
Name	Events / (32kg·year)
CEvNS	4639.7
Cosmic Ray Neutron	339.9
Muon Induced Neutron	1.7
ER	21.1
DE Pile-ups	1325.1

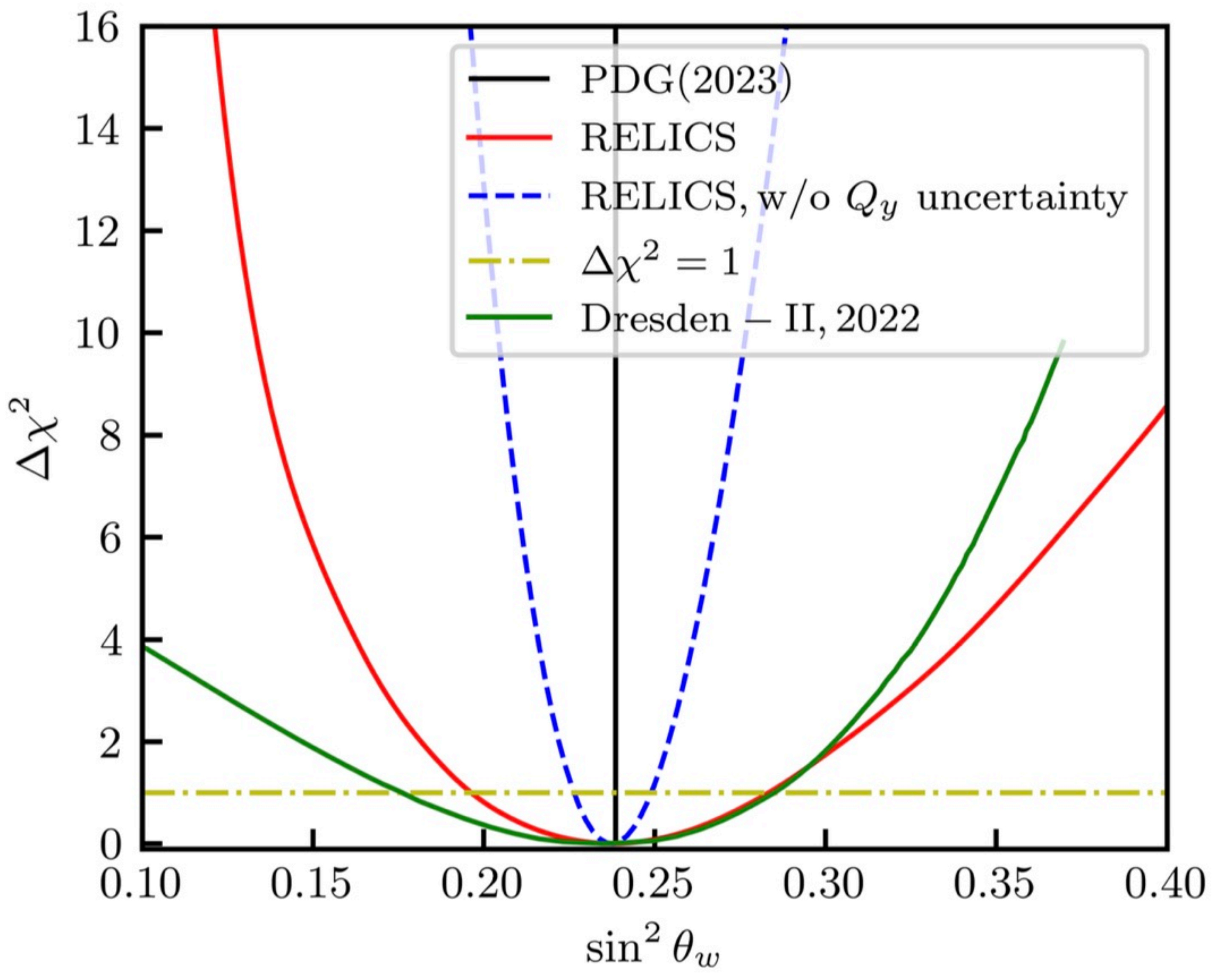
PHYSICAL REVIEW D **110,** 072011 (2024)

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,‡] Gaojun Jin,[2] Yipin Jing,[1,¶] Gaojun Ju,[2] Yang Lei,[1] Jiayi Li,[1] Kaihang Li,[1] Meng Li,[2] Minhua Li,[2] Shengchao Li,[8] Siyin Li,[8] Tao Li,[2] Qing Lin,[5,6] Jiajun Liu,[9] Minghao Liu,[1] Sheng Lv,[2] Guang Luo,[9] Jian Ma,[1] Chuanping Shen,[2] Mingzhuo Song,[1] Lijun Tong,[5,6] Xiaoyu Wang,[8] Wei Wang,[3,9] Xiaoping Wang,[4,10] Zihu Wang,[2] Yuehuan Wei,[3,†] Liming Weng,[2] Xiang Xiao,[9] Lingfeng Xie,[1] Dacheng Xu,[1,§] Jijun Yang,[8] Litao Yang,[11] Long Yang,[2] Jingqiang Ye,[7] Jiachen Yu,[5,6] Qian Yue,[11] Yuyong Yue,[3] Bingwei Zhang,[2] Shuhao Zhang,[1] Yifei Zhao,[1] and Chenhui Zhu[6]

(RELICS Collaboration)





Search for New Physics in Electronic Recoil from RELICS

- ✦ Neutrino Magnetic Moment
- ✦ Reactor Axion
- ✦ Dark Photon
- ✦ Millicharged particles
- ✦ …

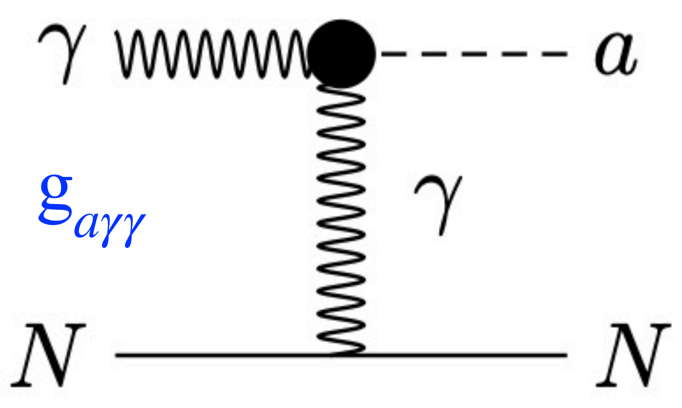
Search for New Physics in Electronic Recoil from RELICS

- Neutrino Magnetic Moment
- **Reactor Axion**
- Dark Photon
- Millicharged particles
- …

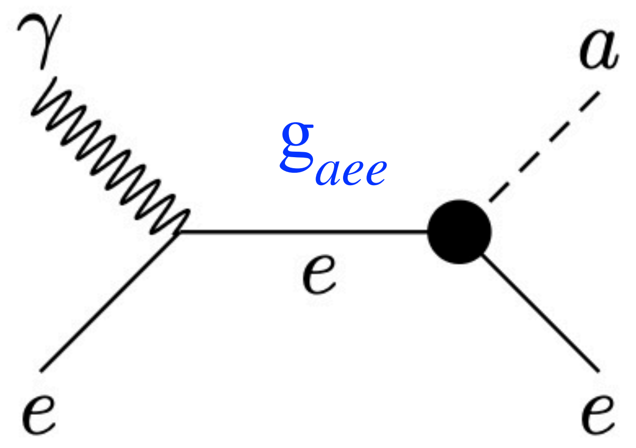
Search for New Physics in Electronic Recoil from RELICS

Reactor axion: production and detection

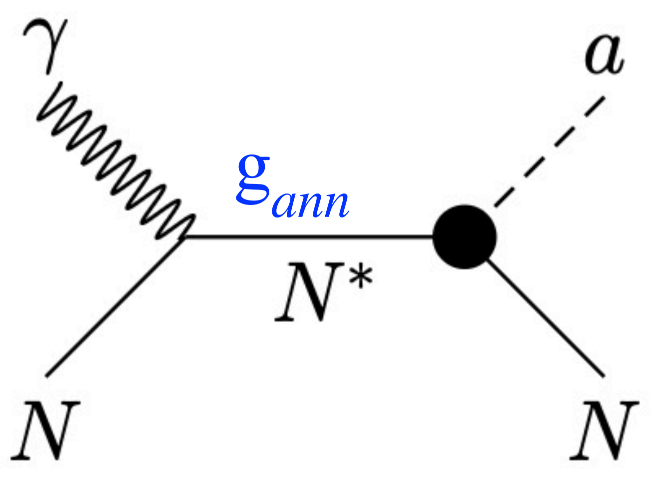
Primakoff photon-ALP conversion



Compton-like scattering

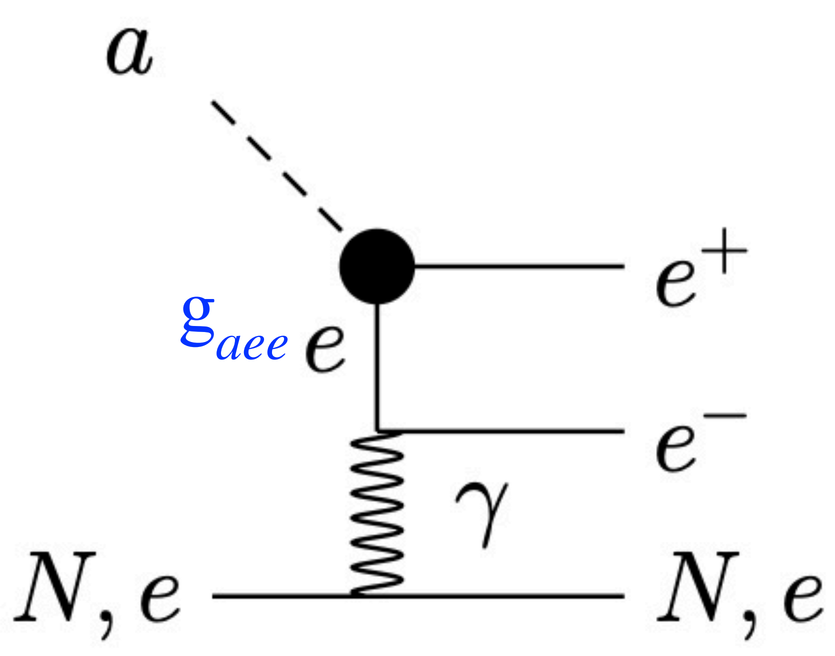


Nuclear de-excitation

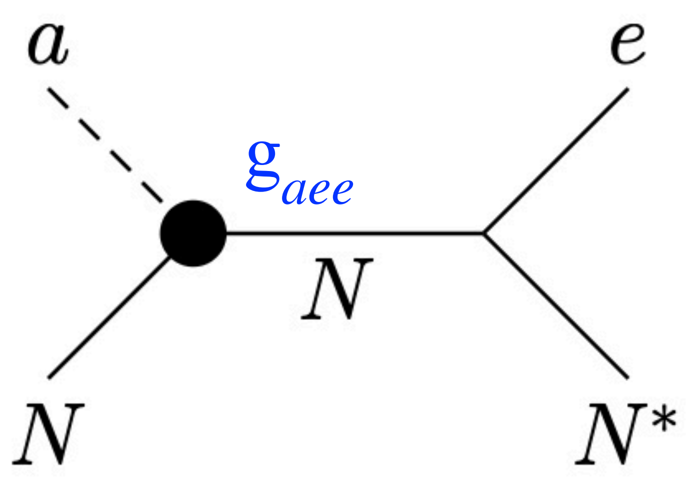


Inverse Primakoff
Inverse Compton-like
Nuclear excitation

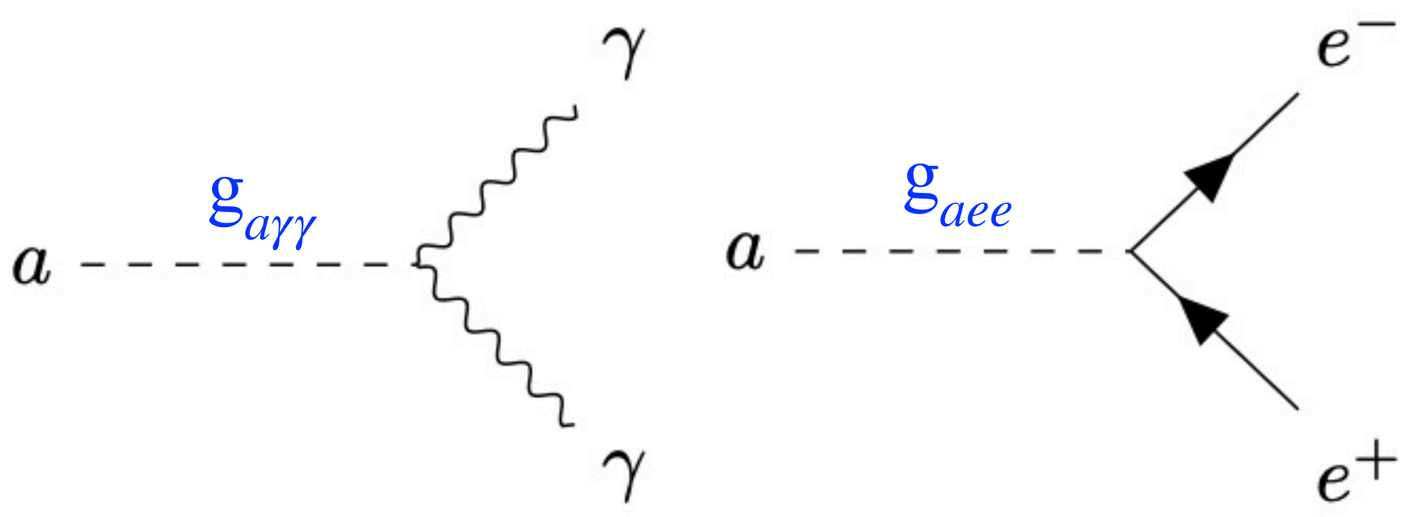
e-pair production



Axio-electric process



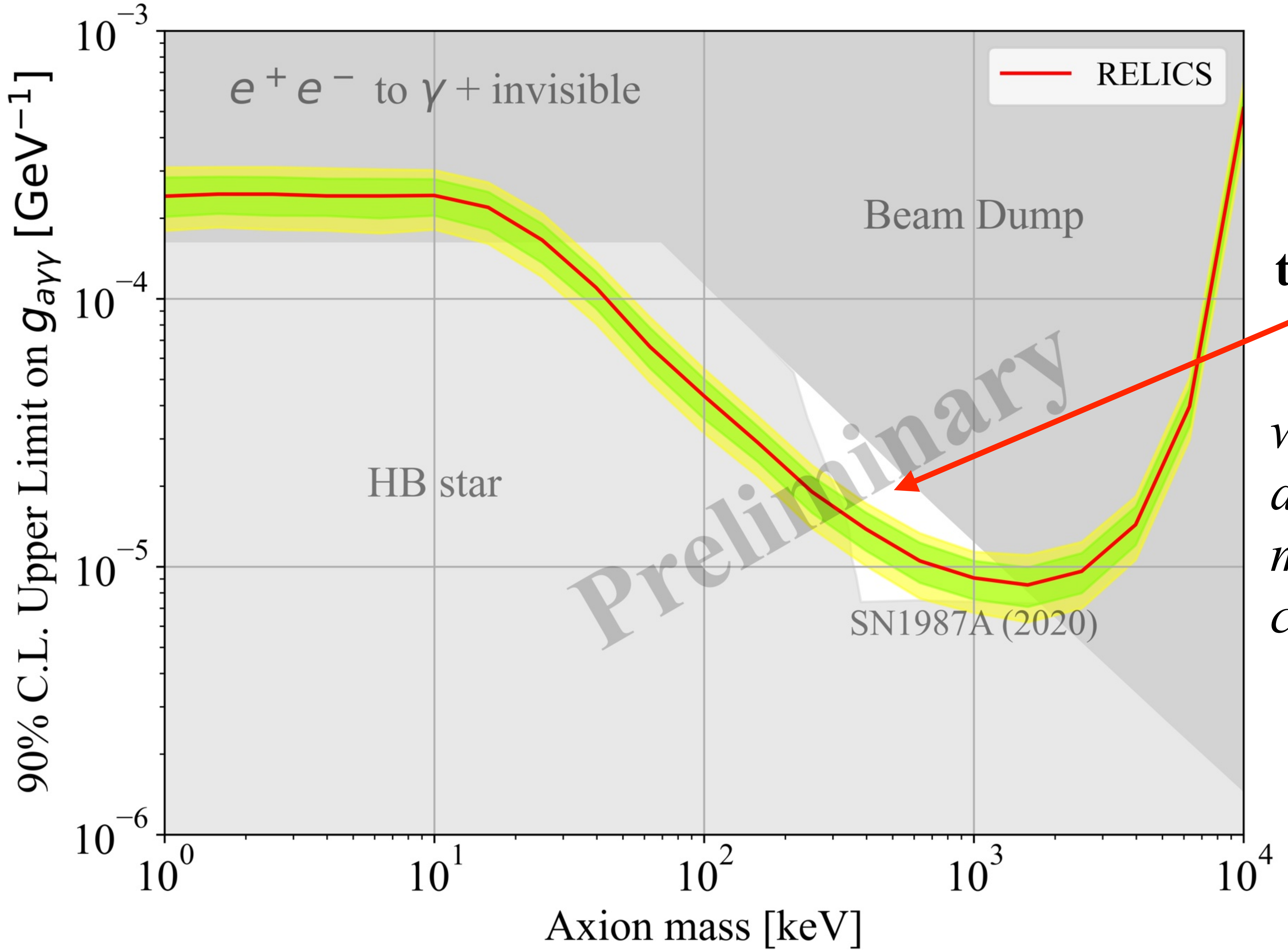
Axion decay
(photon, electrons-positron pairs)



Axion can interact with SM particles with weakly $g_{a\gamma\gamma}$, g_{aee}, g_{ann} couplings…

Search for New Physics in Electronic Recoil from RELICS

RELICS sensitivity on axion-photon coupling

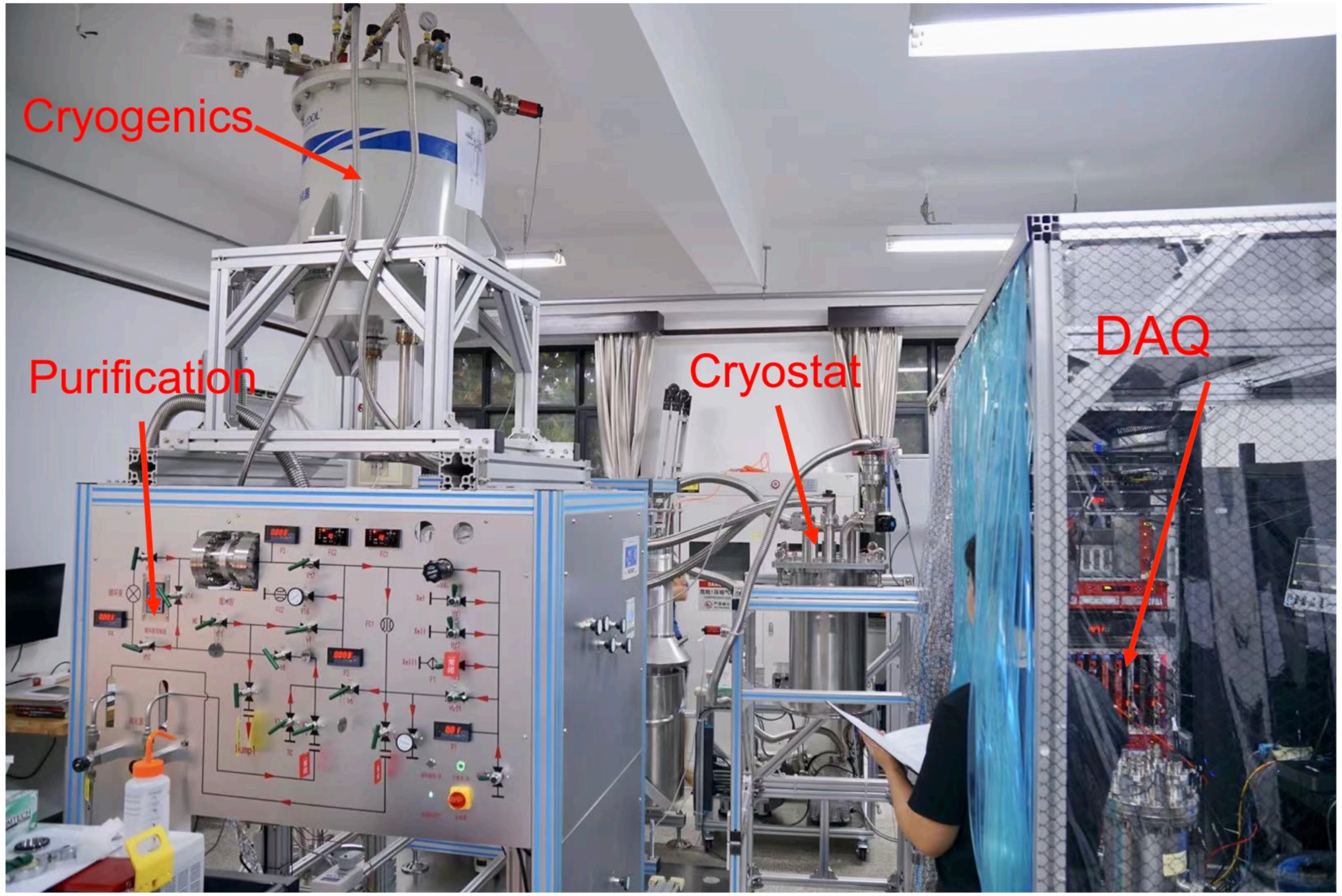


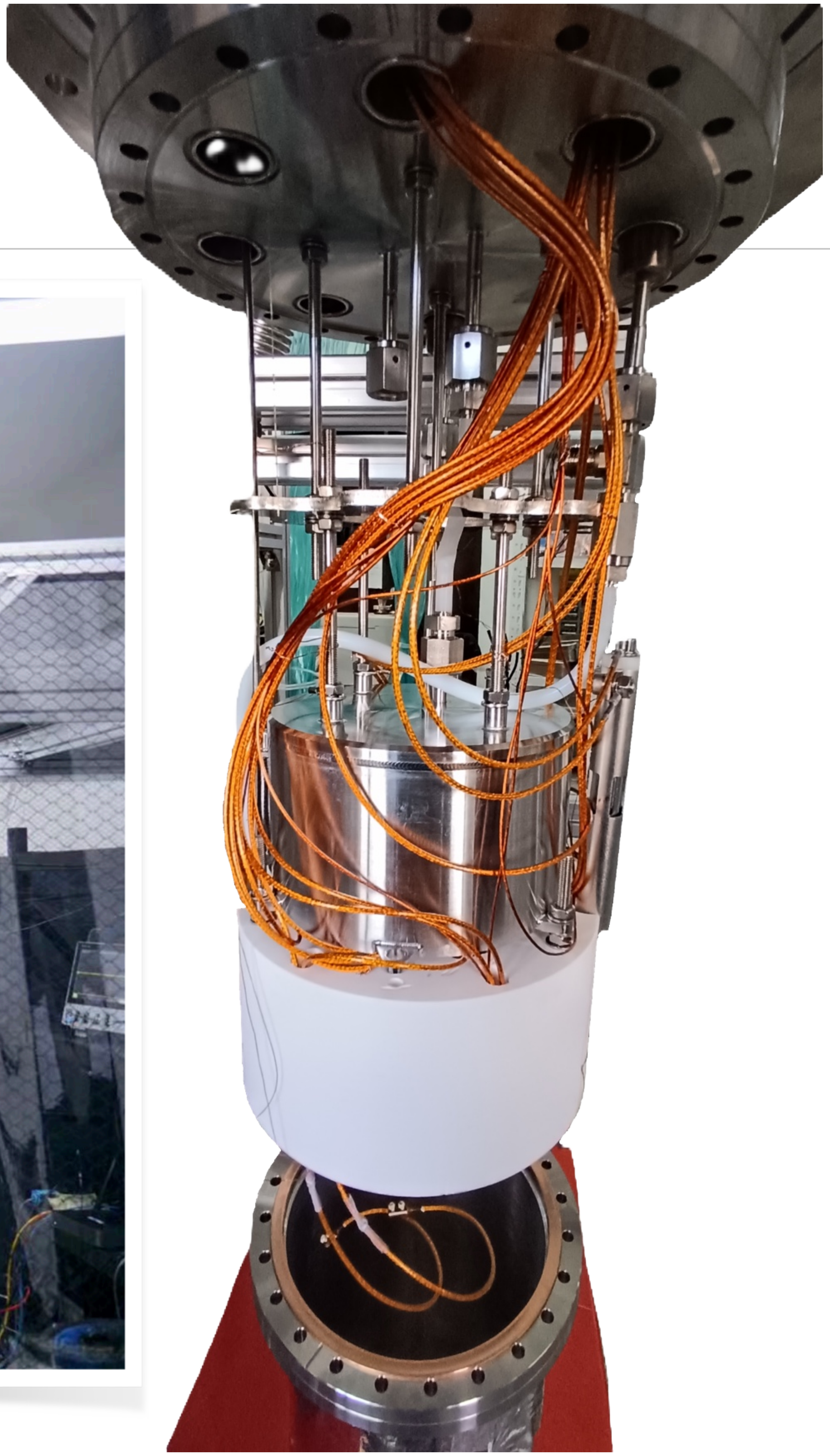
20 kg·year exposure

Exploring / Closing the Cosmological Triangle

which was previously accessible only through model-dependent cosmological arguments!

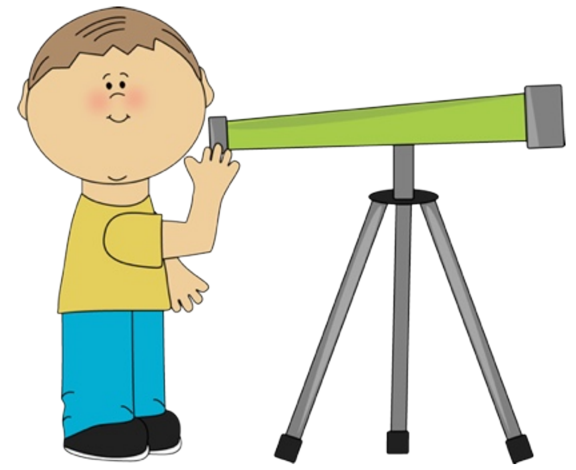
R&D of the RELICS detector development





Summary & Outlook

- RELICS is a reactor neutrino experiment with rich physics, including both CEvNS and a few ER channels.
- RELICS holds significant practical value for nuclear reactor monitoring applications.

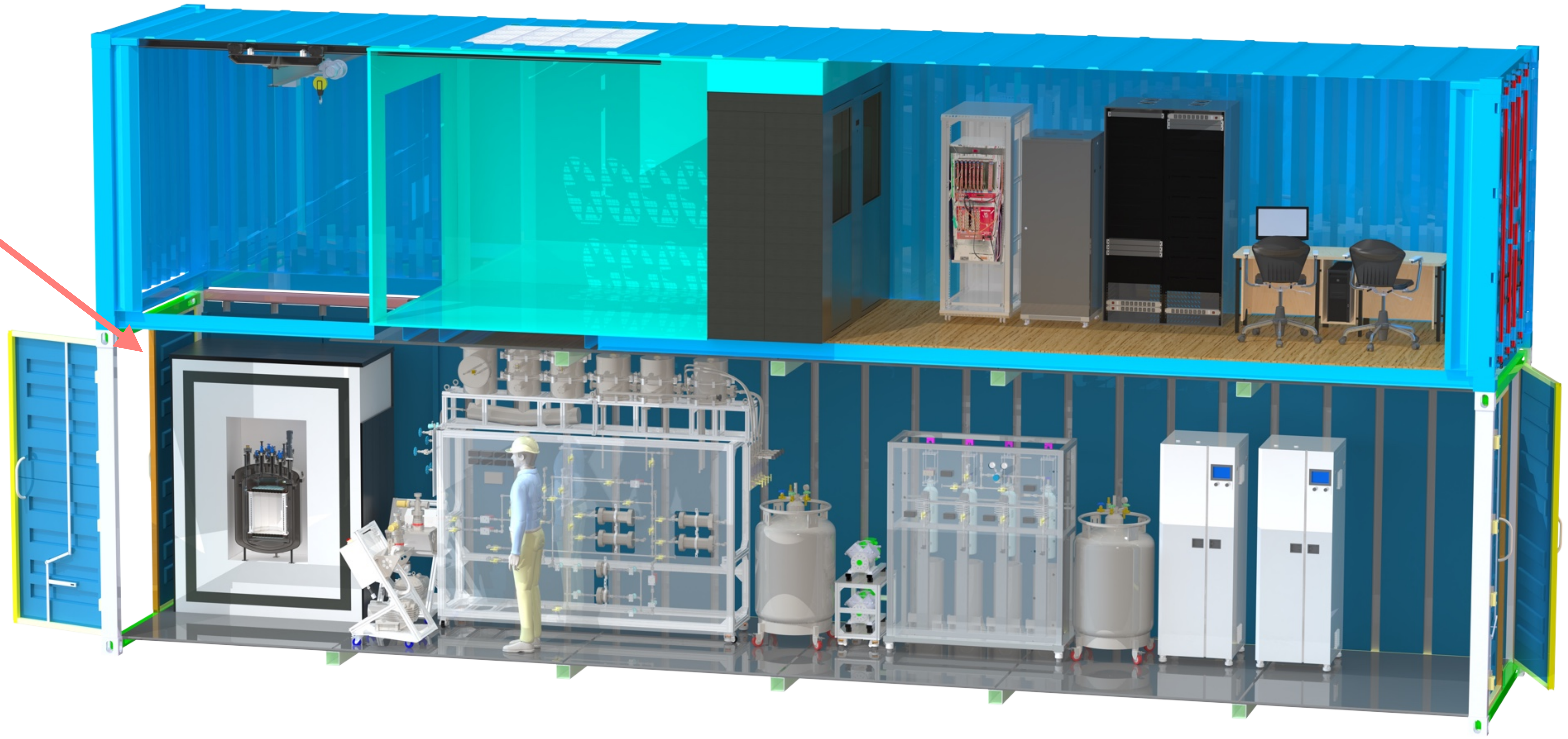


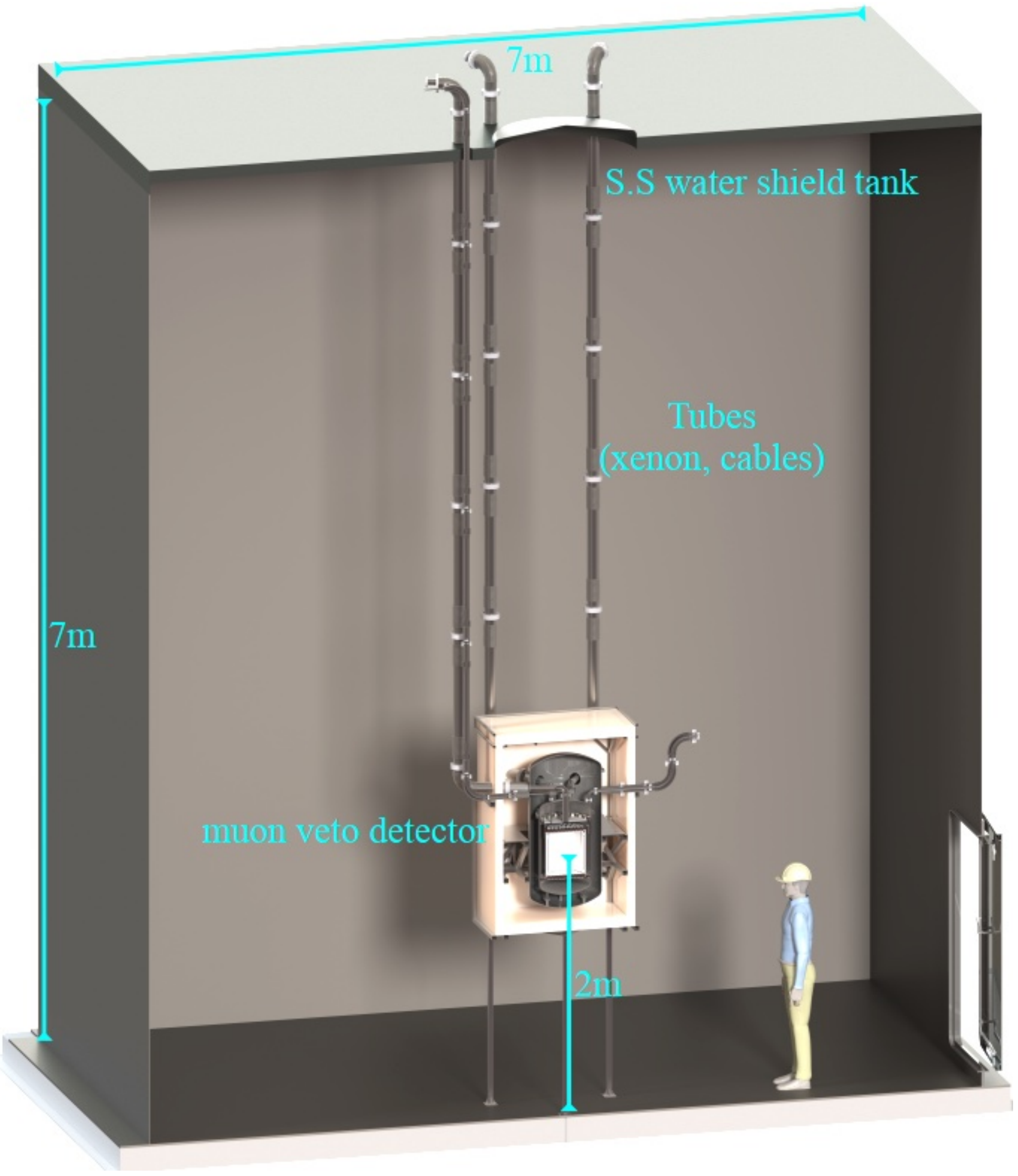
2026

RELICS 5:
- ☐ **Solid Shielding**
- ☐ **Reactor Neutrino**
- ☐ **99% Muon Veto**
- ☐ **LXe Mass ~ 5kg**
- ☐ **PMT Number ~ 38**

2028

RELICS 50:
- ☐ **Water Shielding**
- ☐ **Reactor Neutrino**
- ☐ **99% Muon Veto**
- ☐ **LXe Mass ~ 50kg**
- ☐ **PMT Number ~ 128**





Thanks