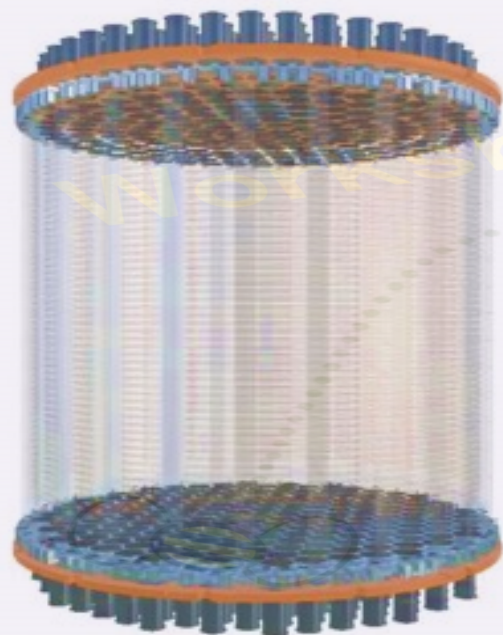


Double Beta Decay Searches in the PandaX Experiments



Tao Li (李涛)

On behalf of PandaX Collaboration

Second Workshop on Neutrinoless double beta decay
search in Xe-next-generation experiment

14th-18th Sep. 2026



PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

taoli@sjtu.edu.cn

PandaX - Particle and Astrophysical Xenon



2025年PandaX合作组春季会议

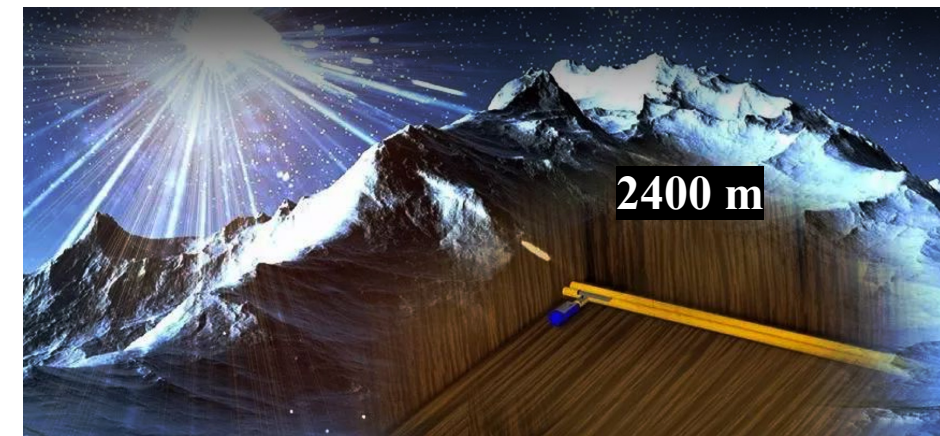
16 institutions, ~ 100 collaborators

2026/09/17

search in Xe-next-generation experiment

PandaX @ CJPL

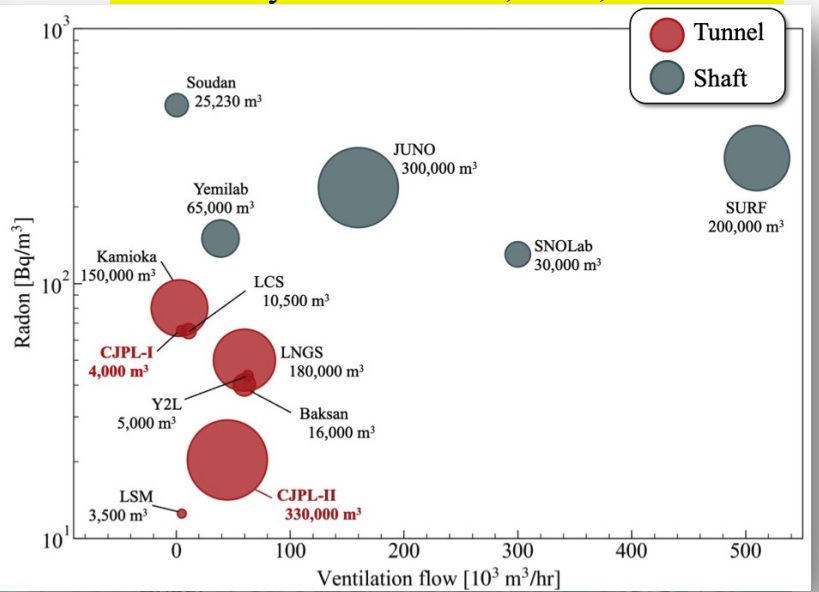
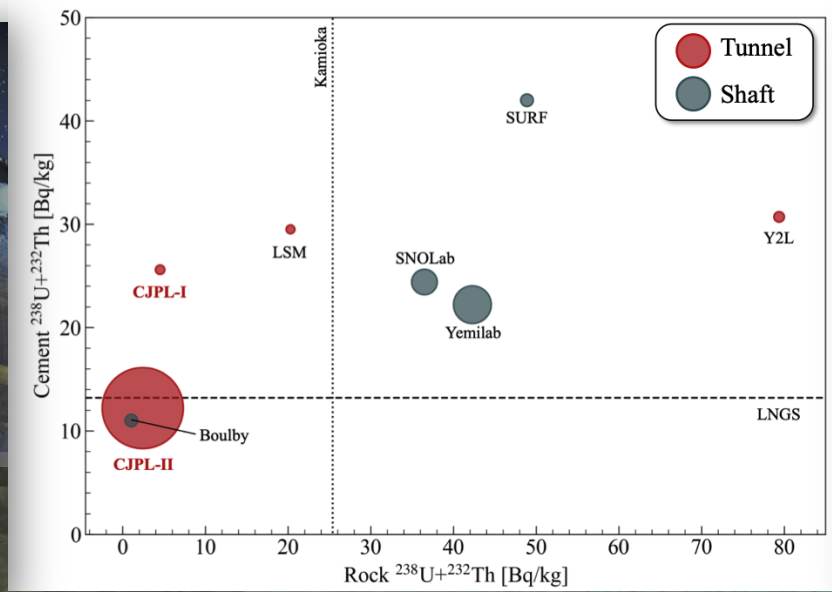
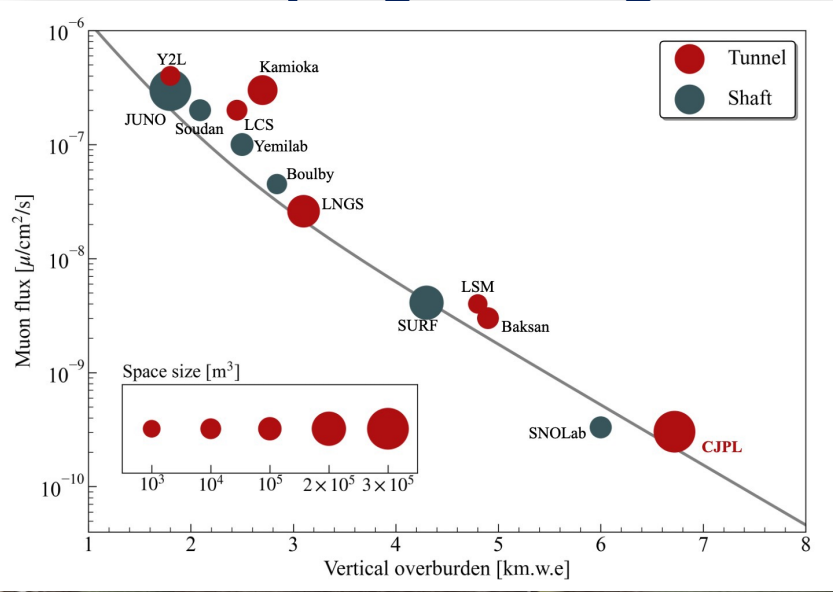
China Jinping Underground Laboratory



Co-developed by Tsinghua University
and Yalong River Hydropower Inc.



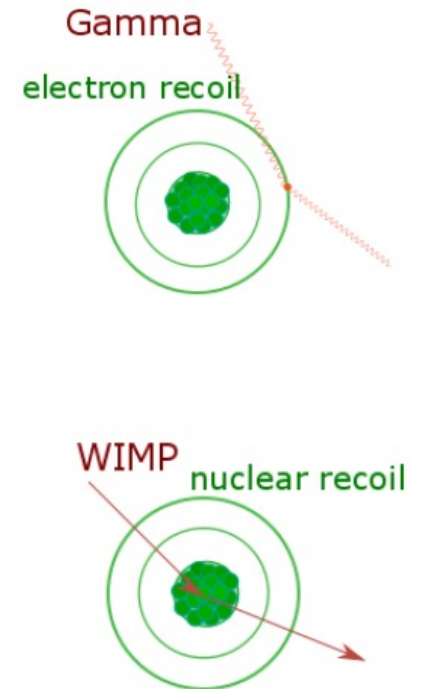
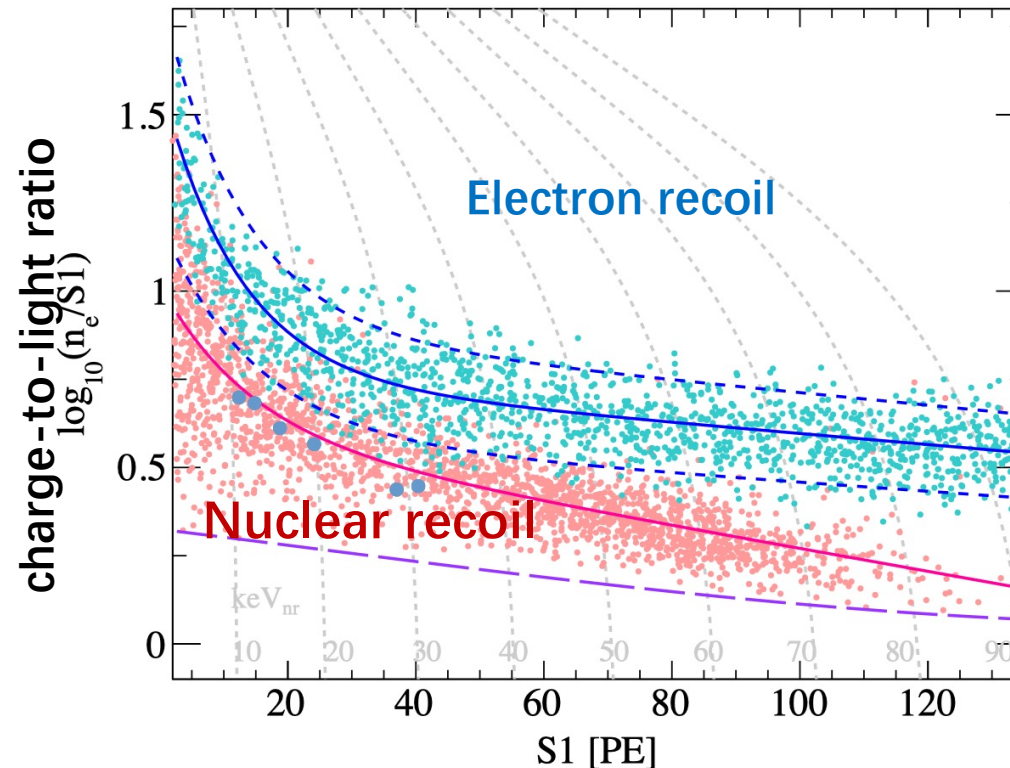
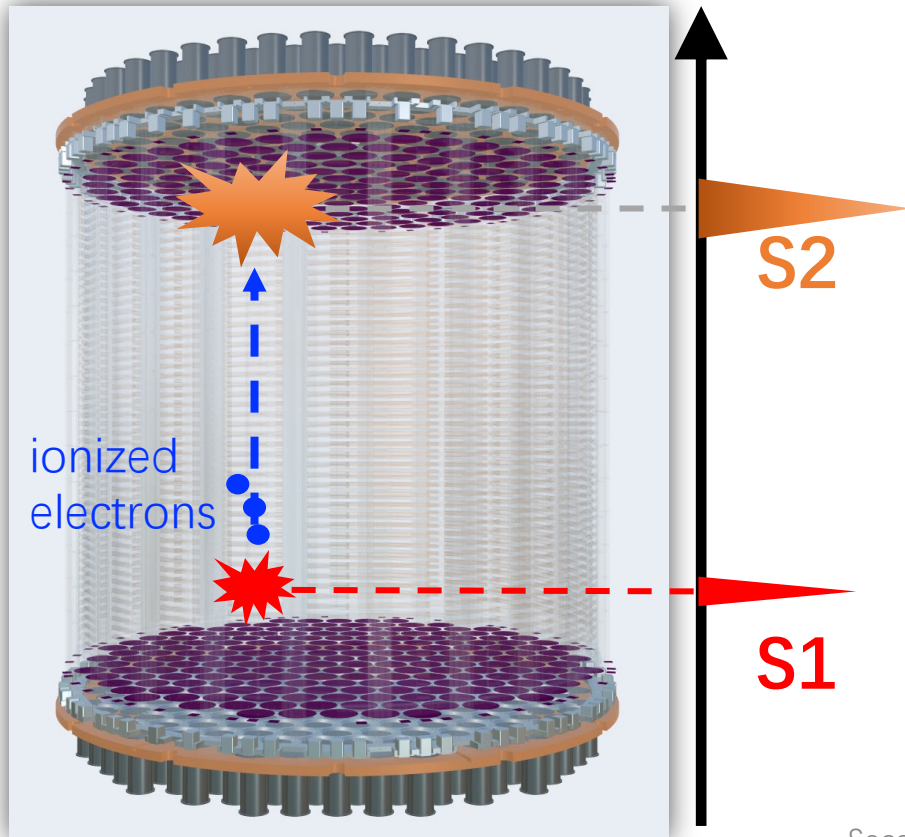
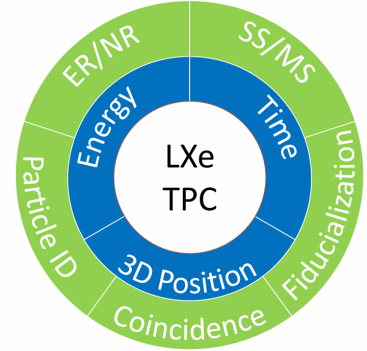
China Jinping Underground Laboratory



Sci Sin-Phys Mech Astron, 2025, 55: 111017
Sci Sin-Phys Mech Astron, 2025, 55: 111018

PandaX: Dual-phase Xe TPC

- **Paired scintillation (S1) and ionization (S2) signals**
 - Precise energy measurement and 3-D position reconstruction
 - Discrimination of nuclear recoil (NR) and electron recoil (ER) signals



PandaX Development

- Increasing the detector sensitive target volume
- Lowering the radioactive background

PandaX Start



2009

PandaX-I
120 kg



2010-2014

PandaX-II
580 kg



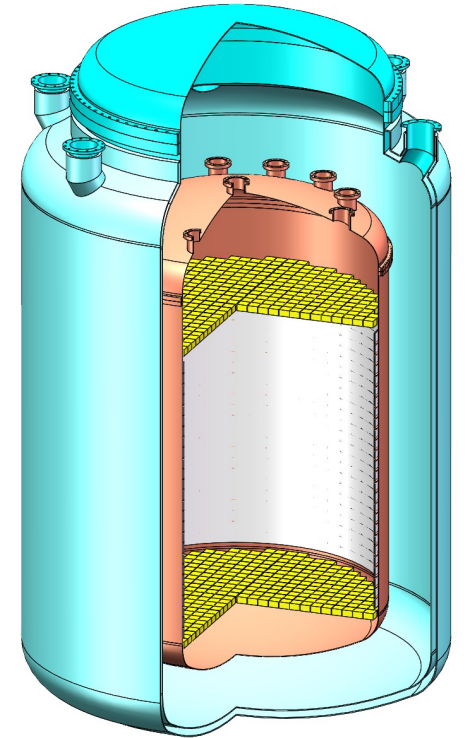
2015-2019

PandaX-4T
3.7 tonne



2021-

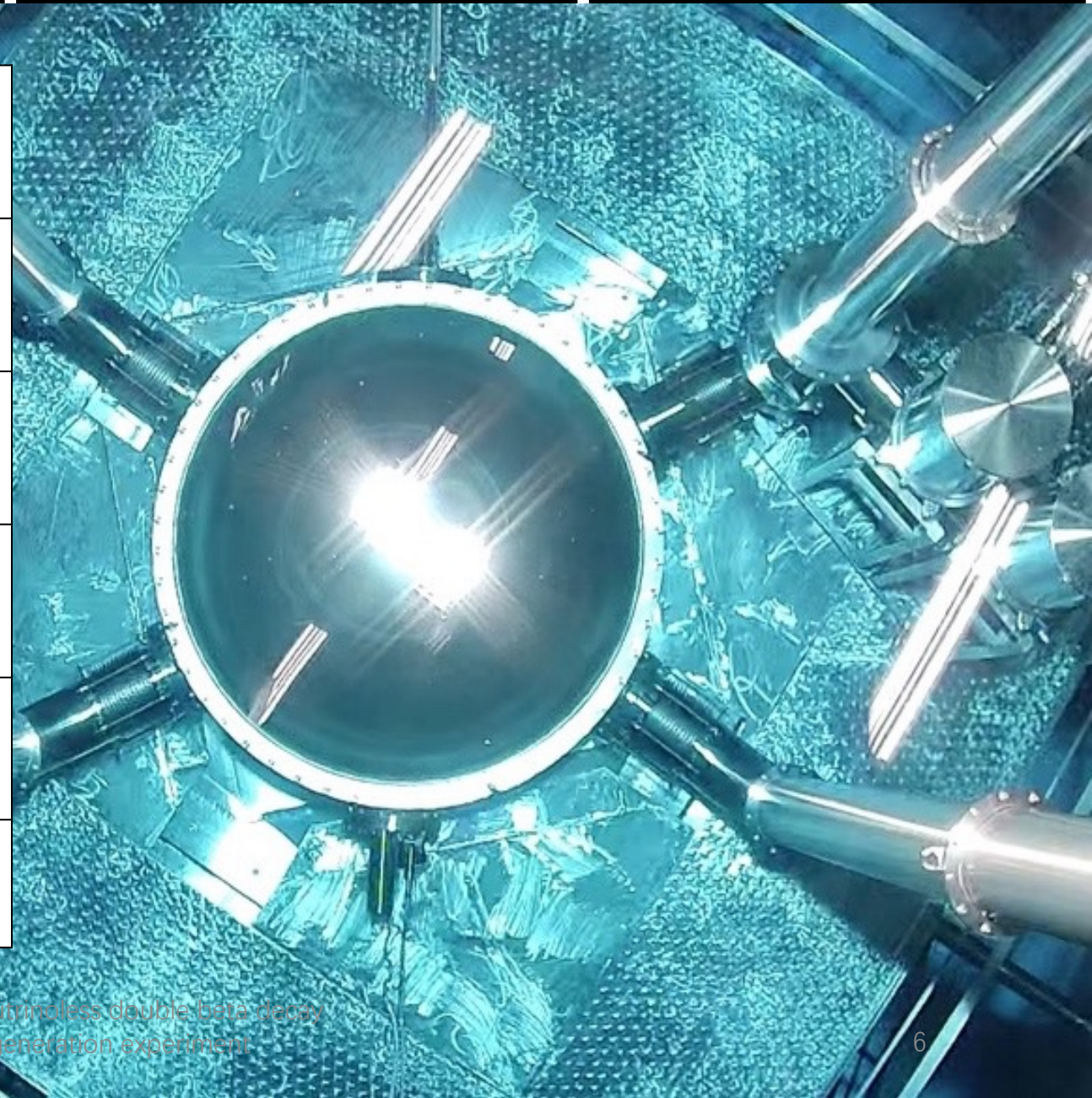
PandaX-xT



2027-

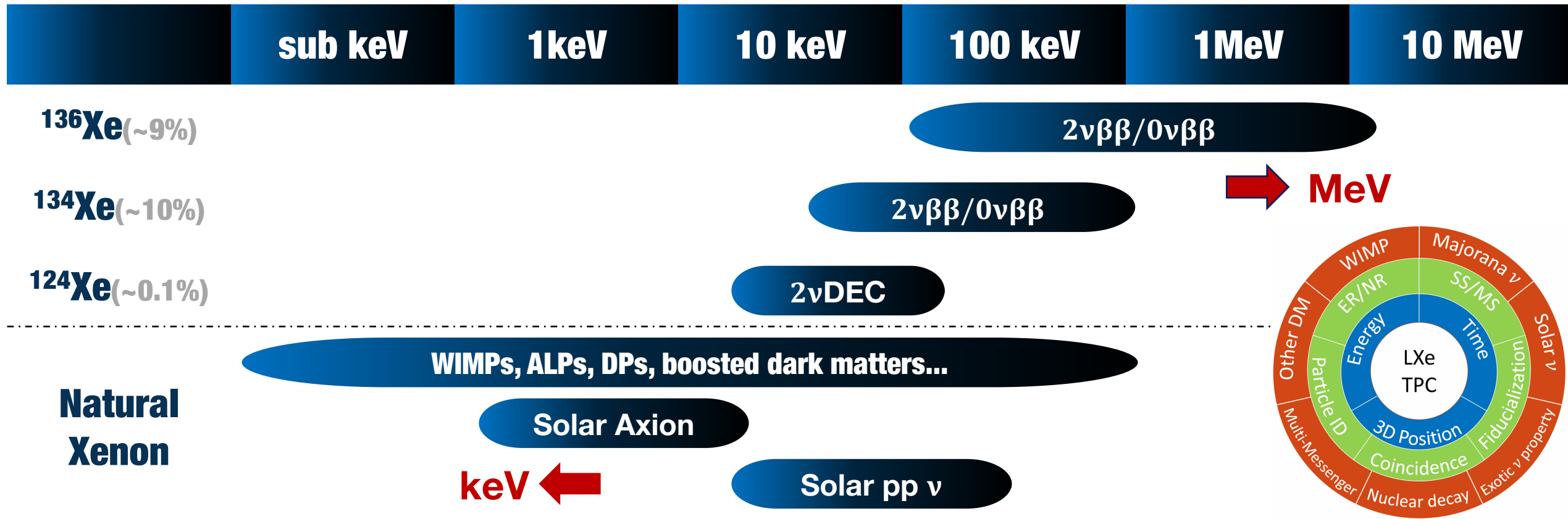
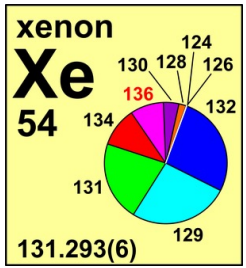
PandaX-4T: Physics Run

2020/11 – 2021/04	Commissioning (Run 0) 95 days
2021/07 – 2021/10	Tritium removal xenon distillation, gas flushing, etc.
2021/11 – 2022/05	Physics run (Run 1) 164 days
2022/09 – 2023/12	CJPL B2 hall construction xenon recuperation, detector upgrade
2024/01 – 2026/04	Physics run (Run 2) 438 days
Current Status	Shut down on Apr. 15th, 2026



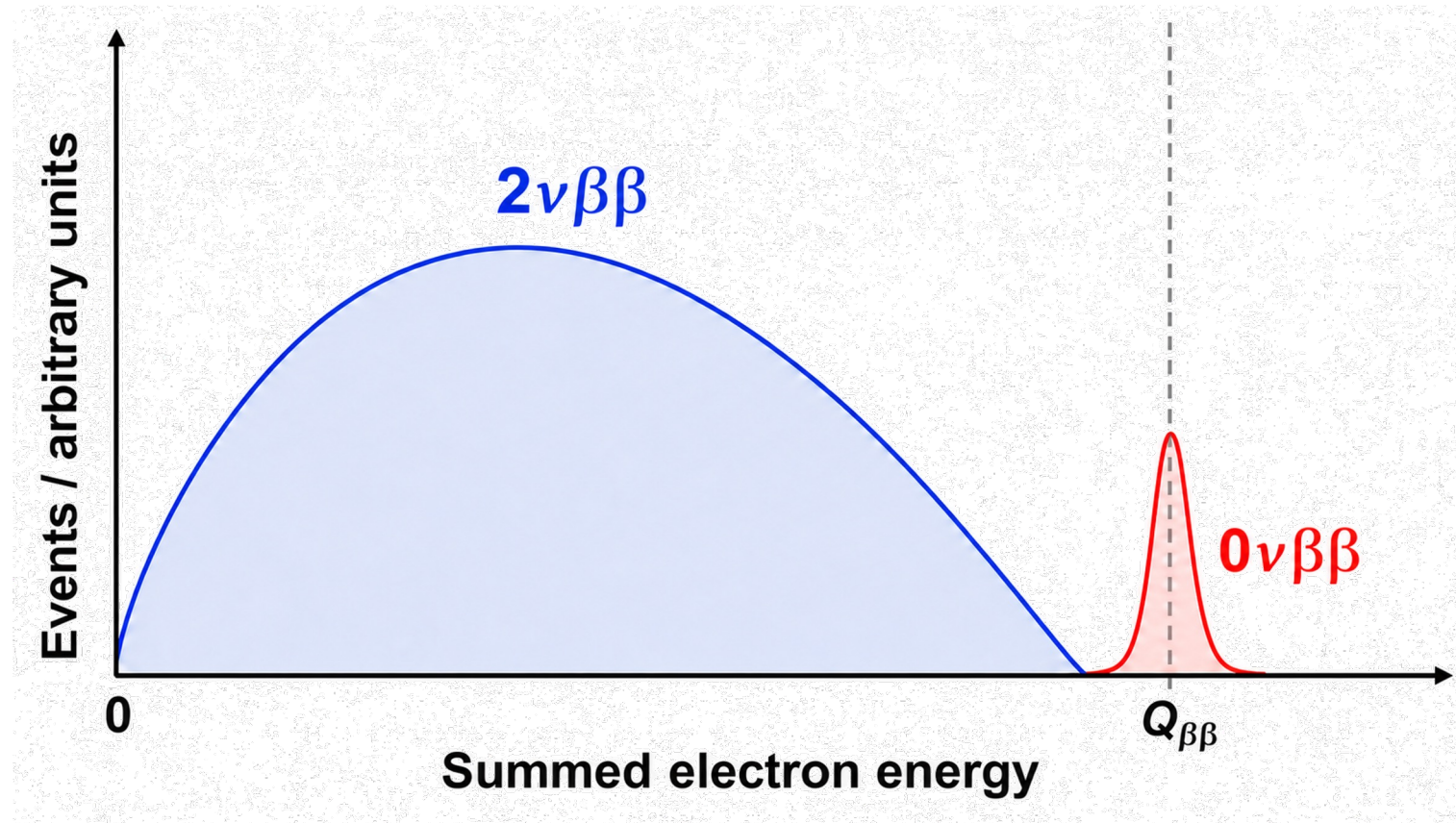
PandaX: Multi-physics Targets

- From sub keV to several MeV
- From DM to double beta decay



Neutrinoless double beta decay ($0\nu\beta\beta$)

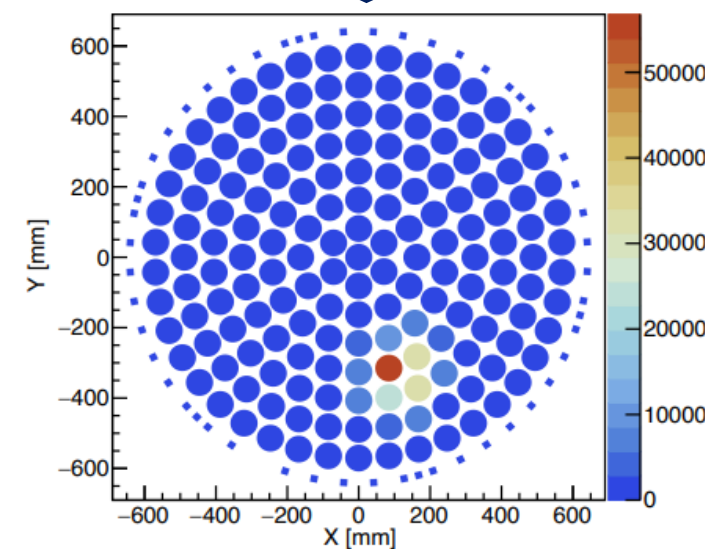
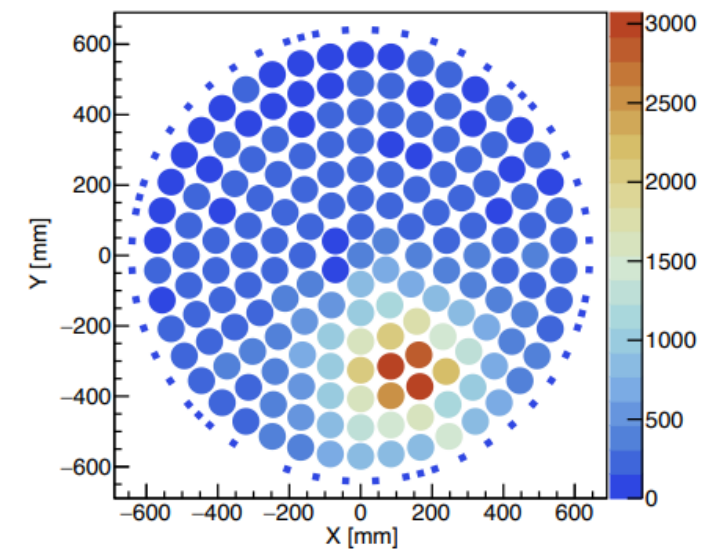
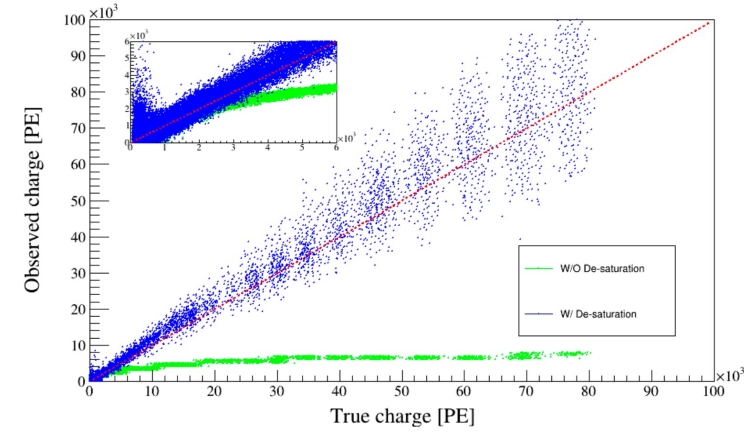
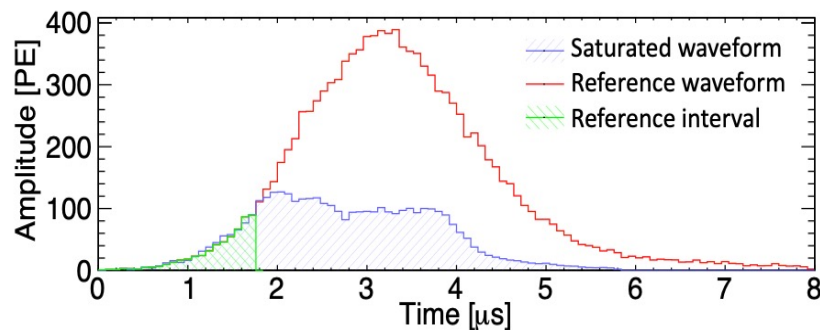
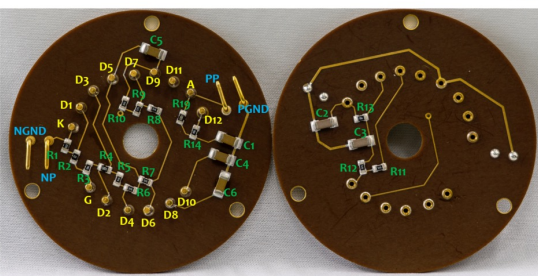
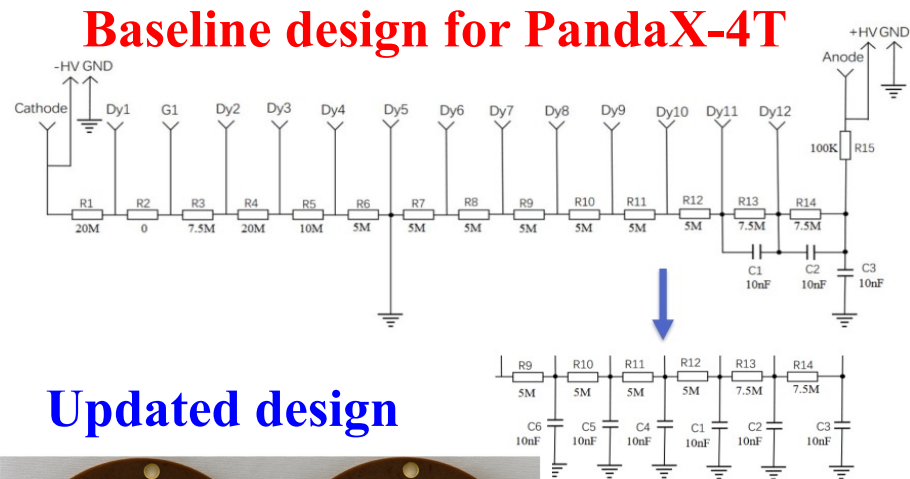
- Neutrinoless double beta decay ($0\nu\beta\beta$): Majorana fermions and lepton number violation
- SM-allowed: 2-neutrino double beta decay ($2\nu\beta\beta$)



Second Workshop on Neutrinoless double beta decay
search in Xe-next-generation experiment

Energy Region Extension

- Severe **S2 waveform saturation** at the MeV range in Run0+1, which has been solved by the updated base design in Run2.
- Recover the S2 signal area using waveform matching.



Energy Reconstruction

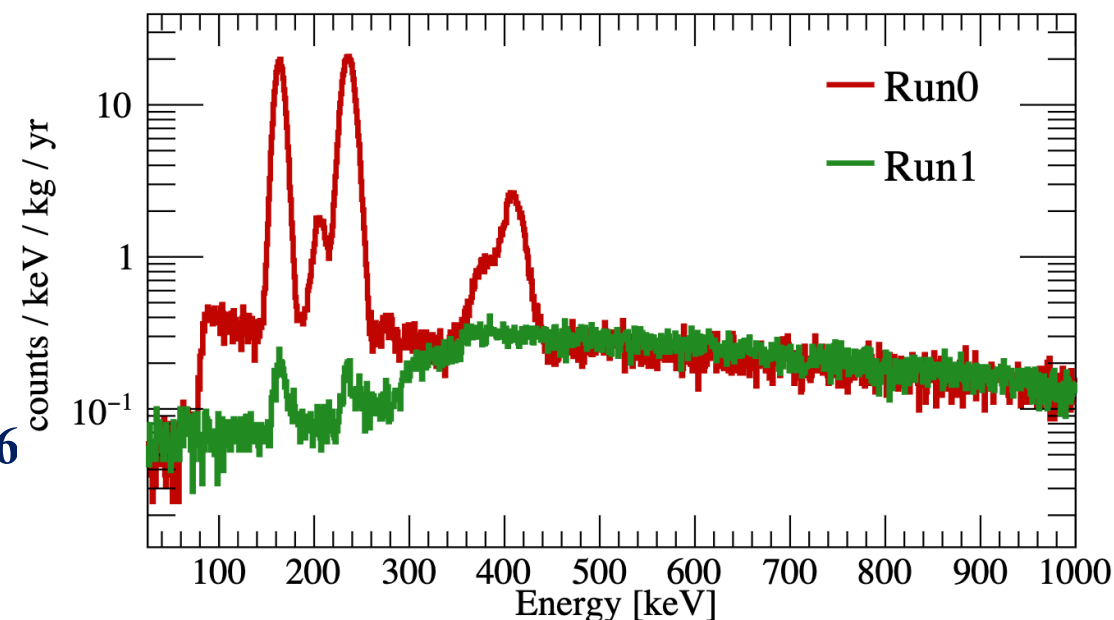
$$E = 13.7 \text{ eV} \times \left(\frac{S1}{\text{PDE}} + \frac{S2_B}{\text{EEE} \times \text{SEG}_B} \right)$$

- **Combine S1 and the bottom array S2 signals to reconstruct energy.**

(S2B avoids dead channels and strong saturation in the top array.)

- **Correct the position-dependent response using $^{83\text{m}}\text{Kr}$ calibration data.**
- **Calibrate the energy scale using peaks at 41.5, 164, 236 and 1460 keV.**

- **PDE:** photon detection efficiency
- **EEE:** electron extraction efficiency
- **SEG_B:** single-electron gain of the bottom PMT array

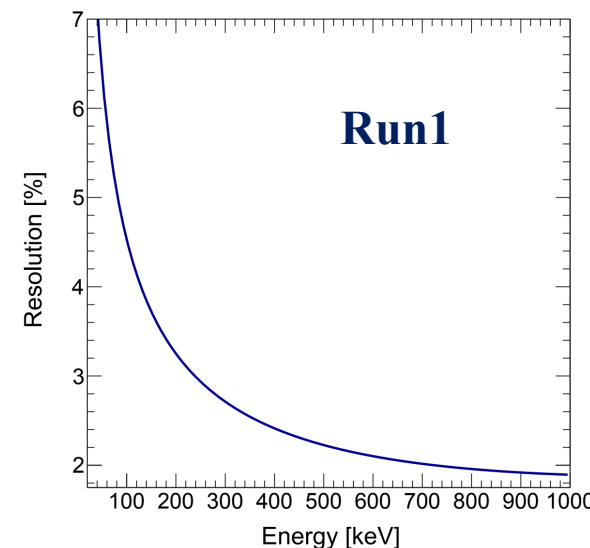
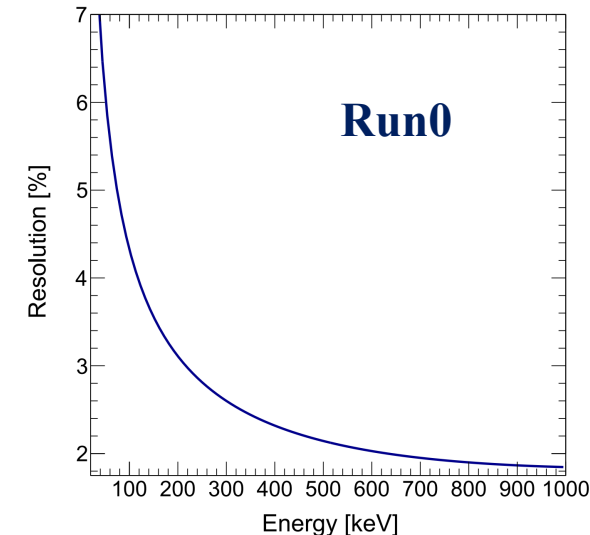


Energy Response Model

- **Energy resolution**: $\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} + b \cdot E + c$
- **Energy scale**: $E = d \cdot \hat{E} + e$
- Fit calibration peaks to determine the energy scale and resolution.
- Fold simulated spectra with the detector response.
- Constrain the five response parameters

$$\mathcal{M}_0 = (a_0, b_0, c_0, d_0, e_0)^T$$

using their fitted values and the 5x5 covariance matrix Σ_m .



Background model

➤ External γ backgrounds

- ^{60}Co , ^{40}K , ^{232}Th and ^{238}U in detector materials
- Activities constrained by HPGe screening or multiple-site spectra

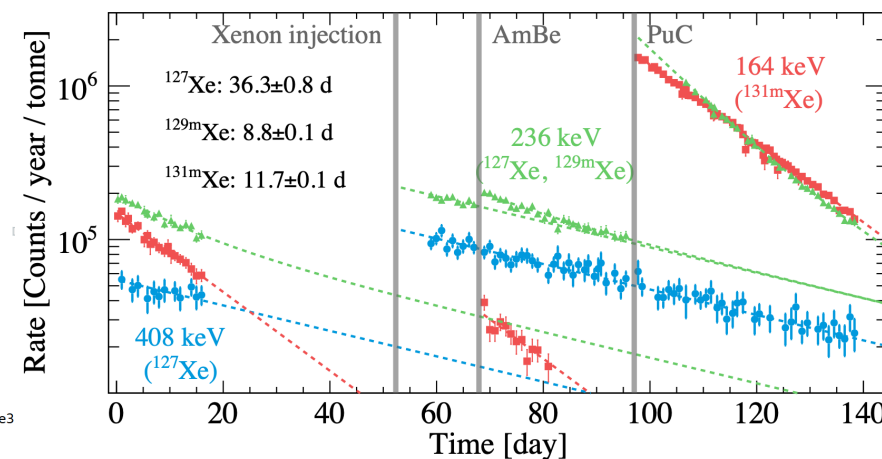
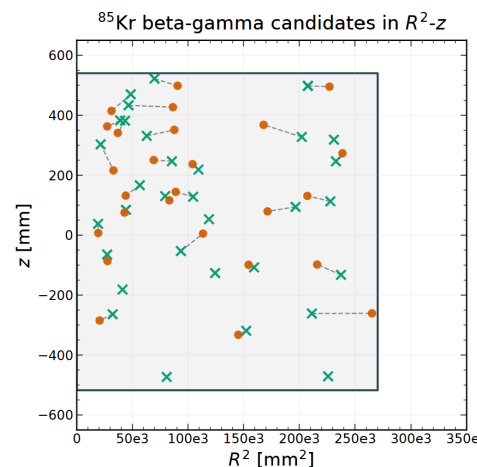
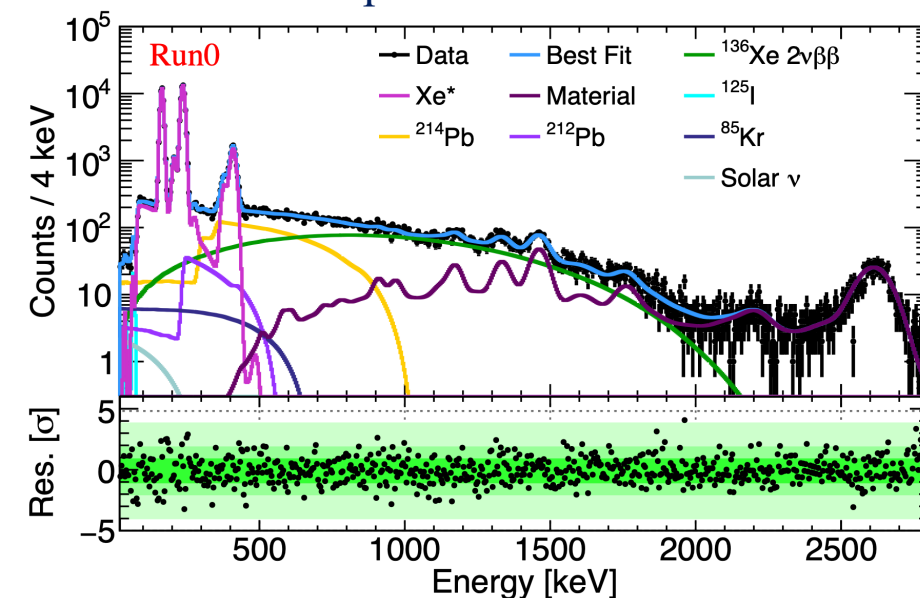
➤ Internal radioactive backgrounds

- ^{214}Pb and ^{212}Pb : decay-chain activity constraints
- ^{85}Kr : delayed coincidences
- ^{127}Xe , $^{129\text{m}}\text{Xe}$ and $^{131\text{m}}\text{Xe}$: time evolution
- Other contributions: ^{125}Xe , ^{133}Xe , ^{125}I , ...

➤ Solar neutrinos

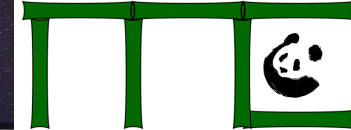
- pp and ^7Be neutrino–electron scattering

Example fit to Run 0 data

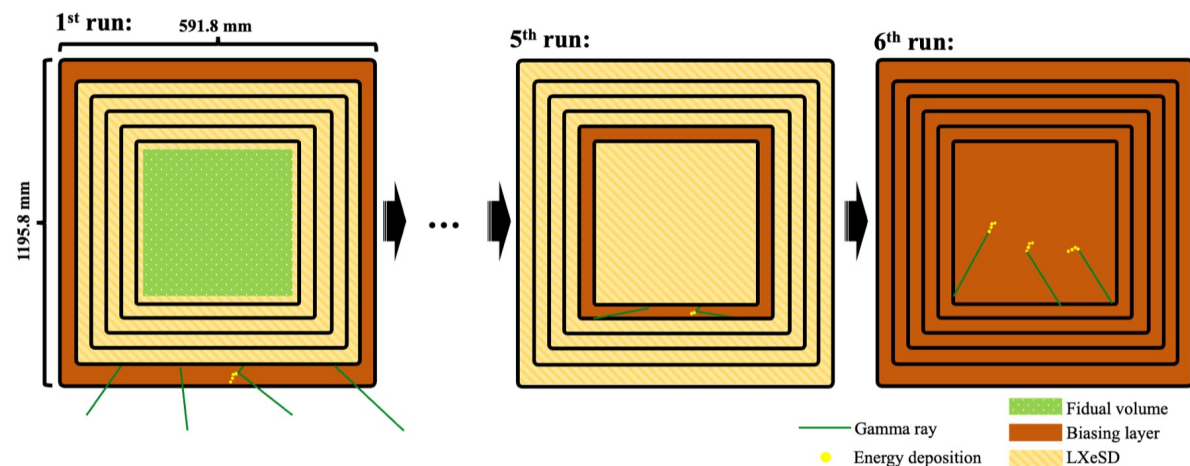


* ^{136}Xe $2\nu\beta\beta$ is the signal in the half-life measurement and a background in other searches.

Simulation Biasing in BambooMC

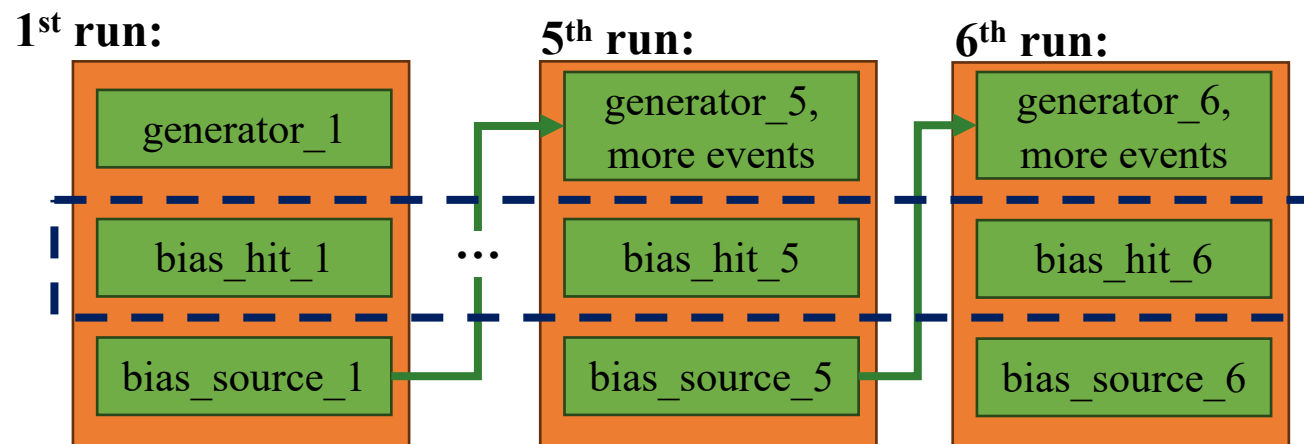


1. Divide the active volume into nested layers.
2. Record energy deposits and particles crossing each inner boundary.
3. Reuse the recorded particles as sources for the next layer.
4. Combine the energy deposits with appropriate weights.



bias hit: energy deposits

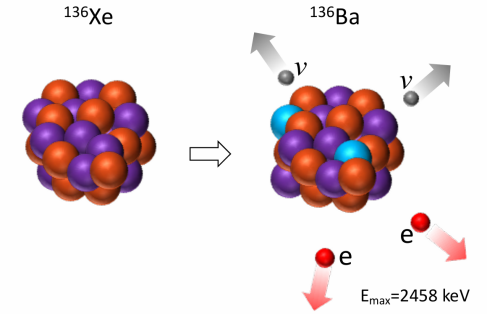
bias source: particle states at the inner boundary



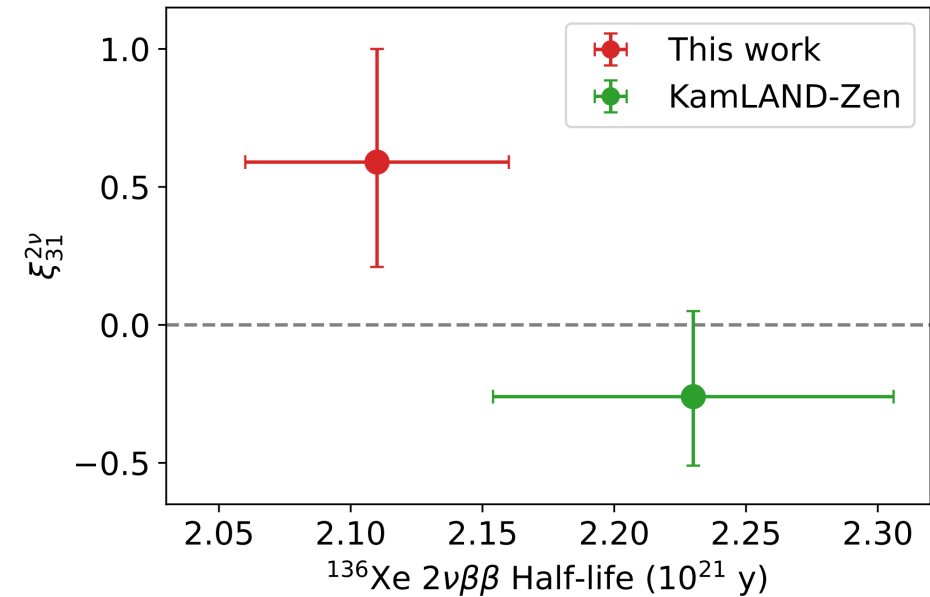
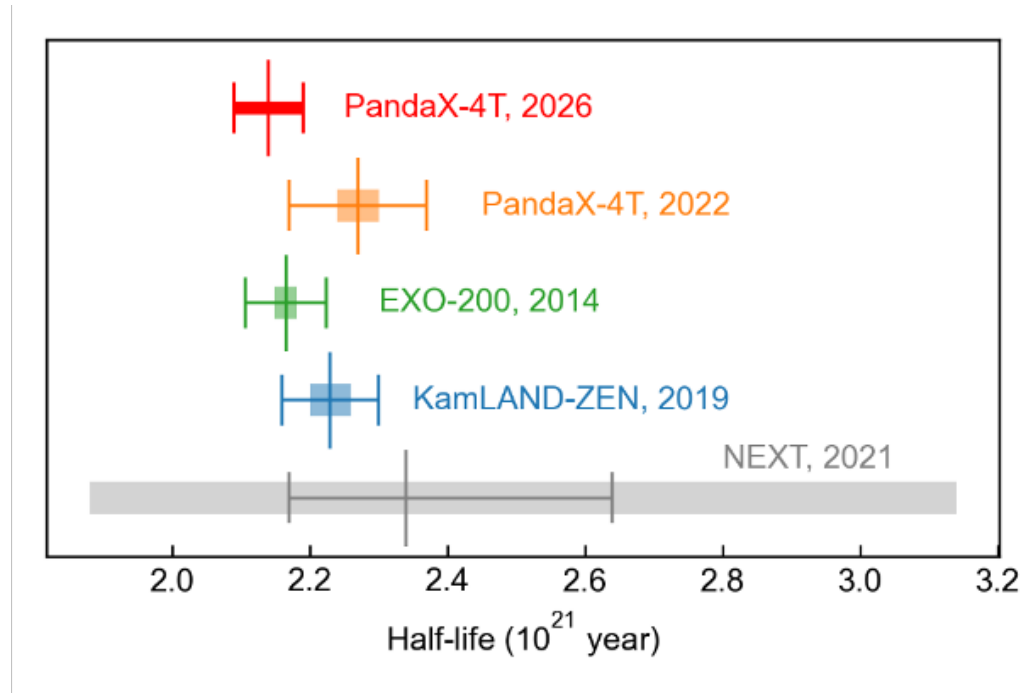
More simulated events in the inner target at a lower computing cost.

^{136}Xe $2\nu\beta\beta$ half-life measurement

- A near-complete ^{136}Xe $2\nu\beta\beta$ spectrum from 20 keV to the endpoint
- Most precise ^{136}Xe $2\nu\beta\beta$ half-life measurement: $(2.14 \pm 0.05) \times 10^{21}$ yr
- Constraints on higher-order nuclear matrix element contributions $\xi_{31}^{2\nu}$ and



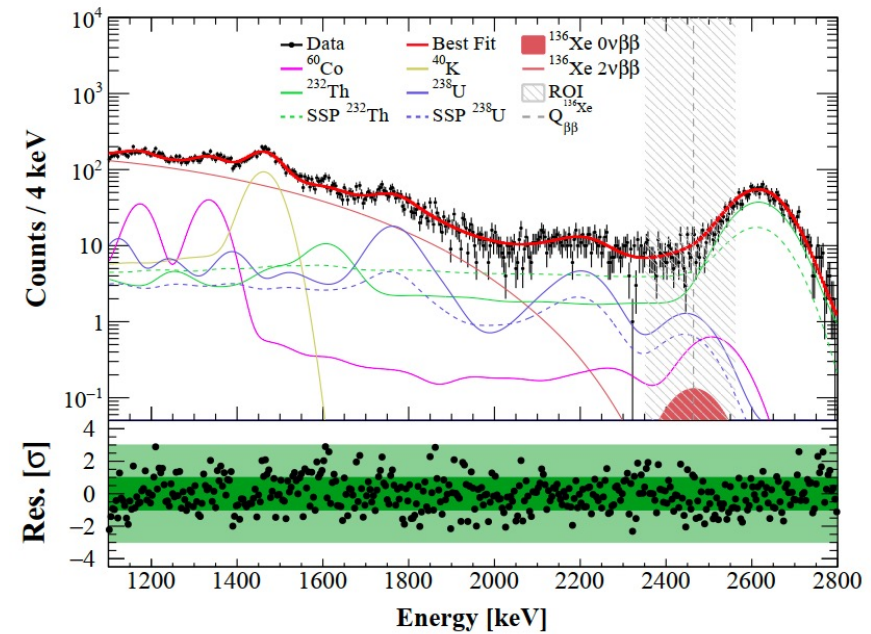
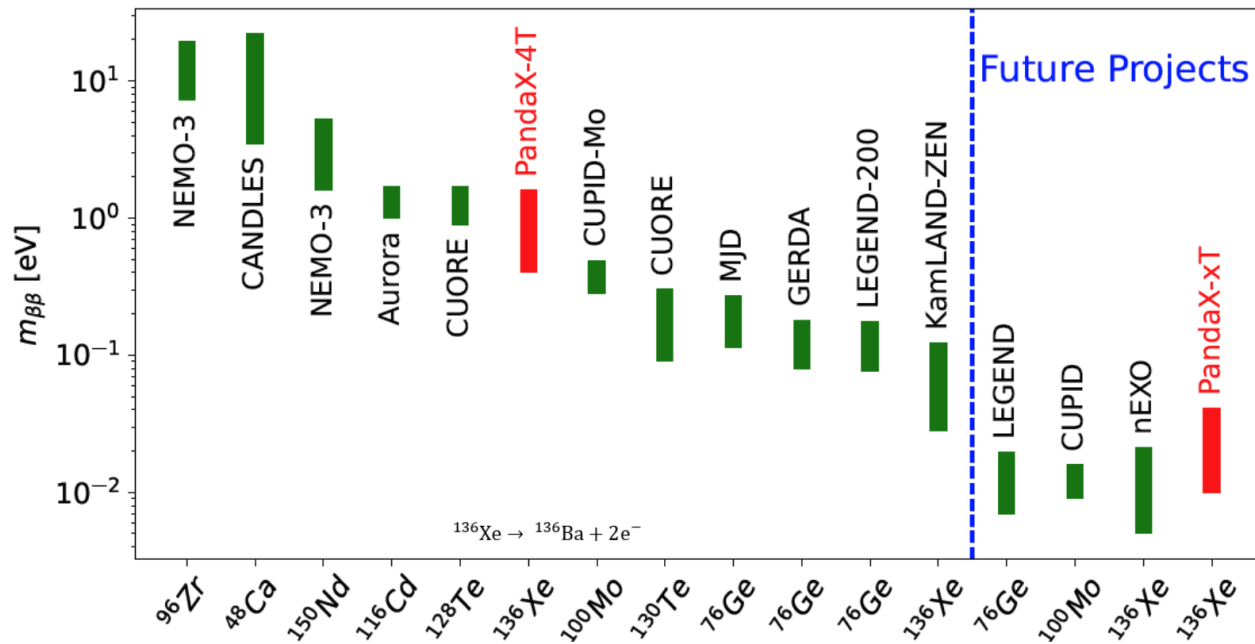
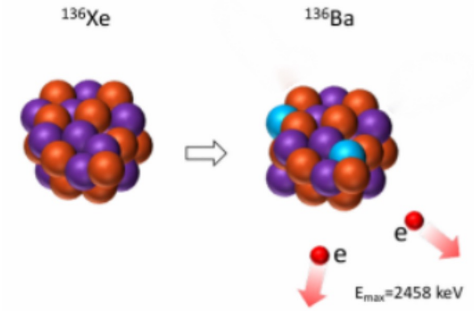
Majoron-emitting decay modes



Research 2022 (2022) 9798721
Phys.Rev.Lett. 136 (2026) 16, 162501

Search for $^{136}\text{Xe } 0\nu\beta\beta$

- Run0+Run1 (~250 days' data) blind analysis, 44.6 kg·yr isotope exposure
- Stringent half-life limit from natural xenon detector: $T_{1/2}^{0\nu\beta\beta} > 2.1 \times 10^{24} \text{ yr}$ (90% CL)
- $m_{\beta\beta} < (0.4\text{-}1.6) \text{ eV}$, assuming light Majorana neutrino exchange.

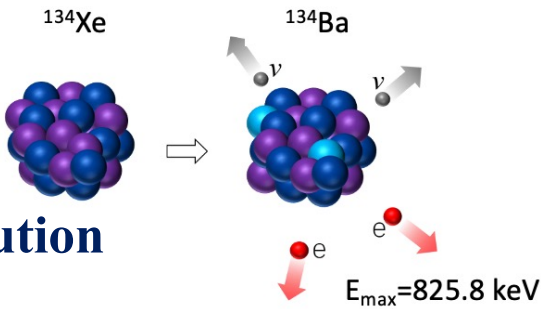


Science Bulletin 70 (2025) 1779-1785

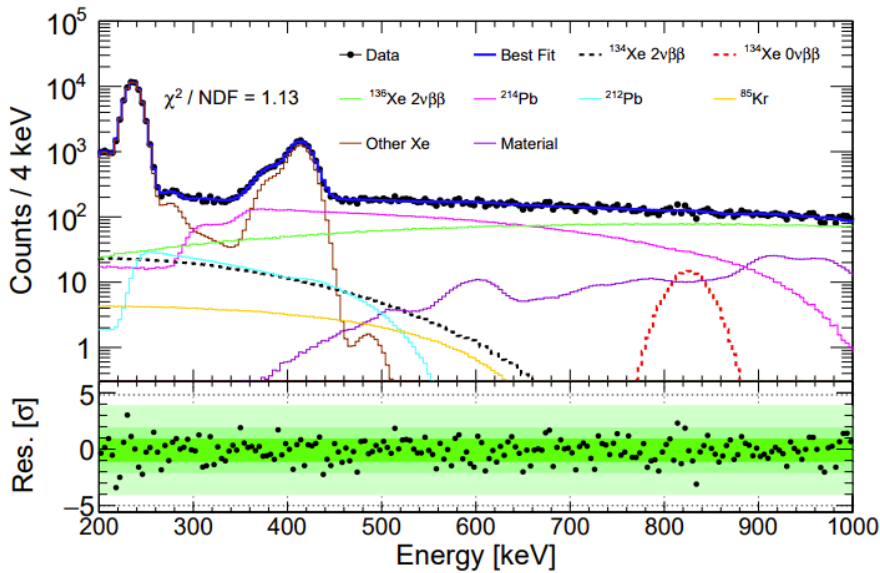
Second Workshop on Neutrinoless double beta decay
search in Xe-next-generation experiment

Searches for ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$

- $Q=826$ keV; Predicted $2\nu\beta\beta$ half-life: $10^{24}\text{--}10^{25}$ yr (has not yet been observed)
- PandaX-4T: larger ^{134}Xe mass, lower analysis threshold, and smaller ^{136}Xe contribution
- 90% CL lower limits on the half-life: $T_{1/2}^{2\nu\beta\beta} > 2.8 \times 10^{22}$ yr and $T_{1/2}^{0\nu\beta\beta} > 3.0 \times 10^{23}$ yr

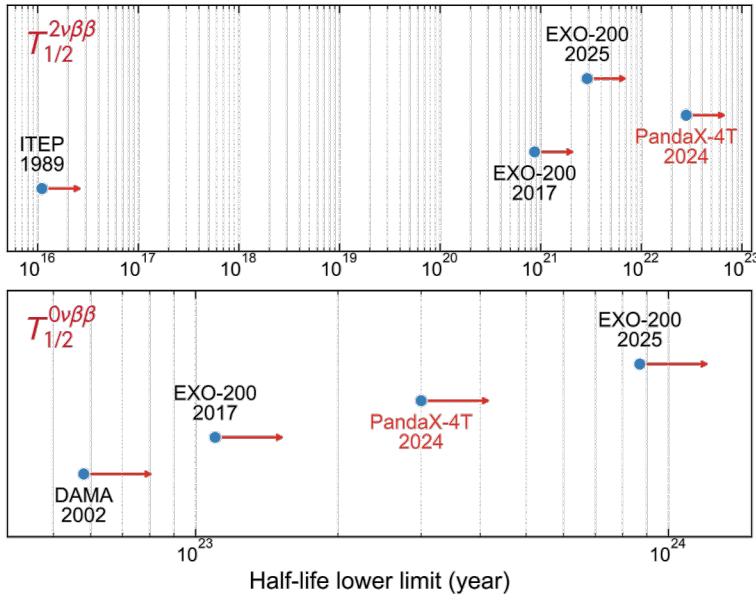


	PandaX-4T	EXO-200 (2017)
^{134}Xe mass	68.7 kg	18.1 kg
^{136}Xe abundance	8.90%	81%
Analysis threshold	200 keV	460 keV
Live Time	94.9 days	600 days



PRL 132, 152502 (2024)

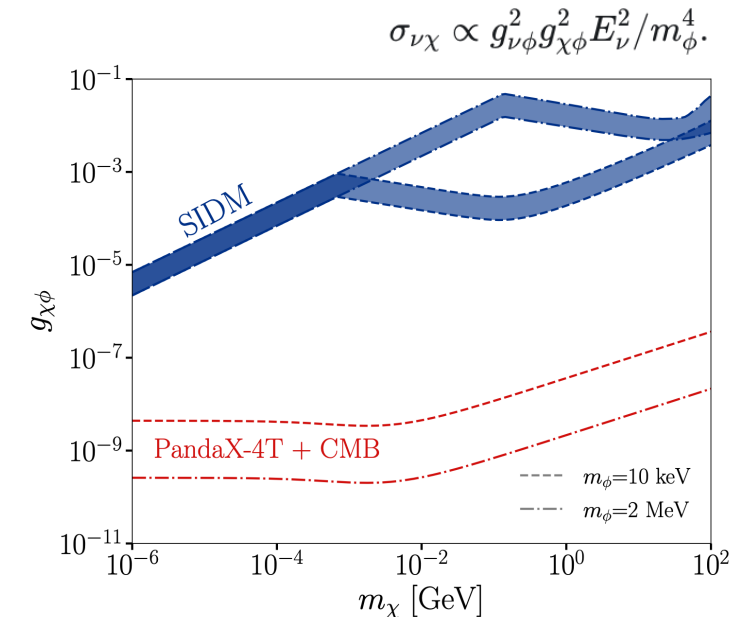
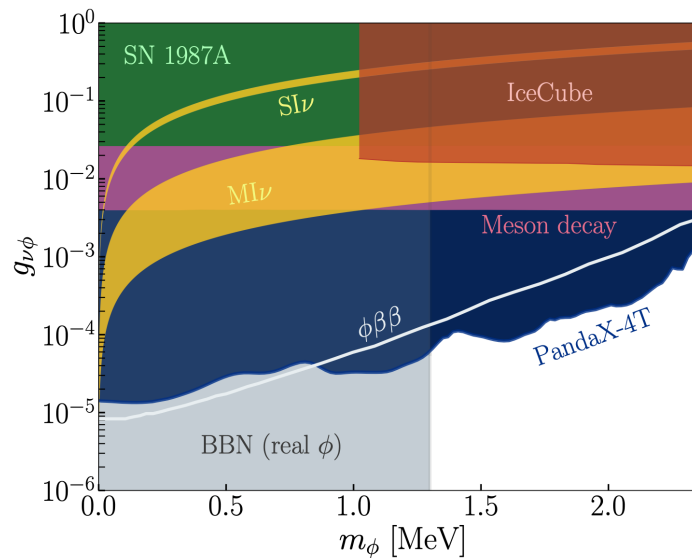
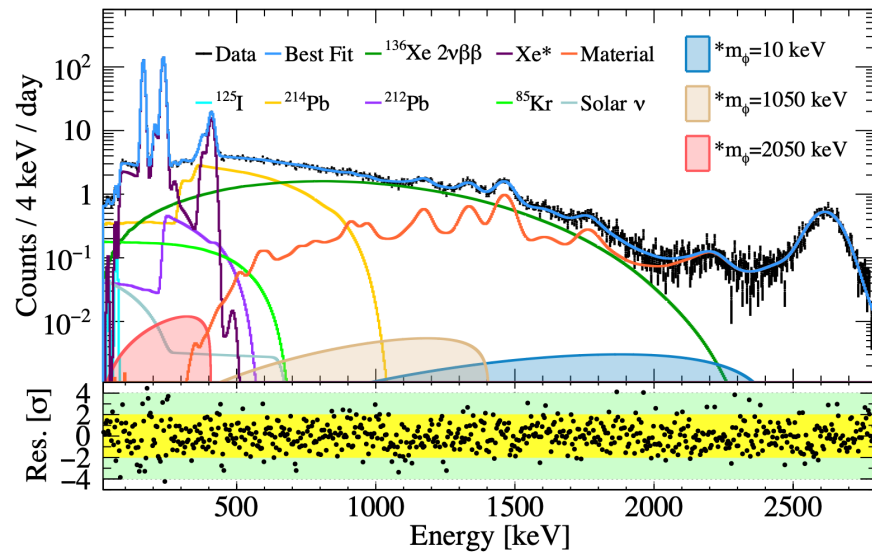
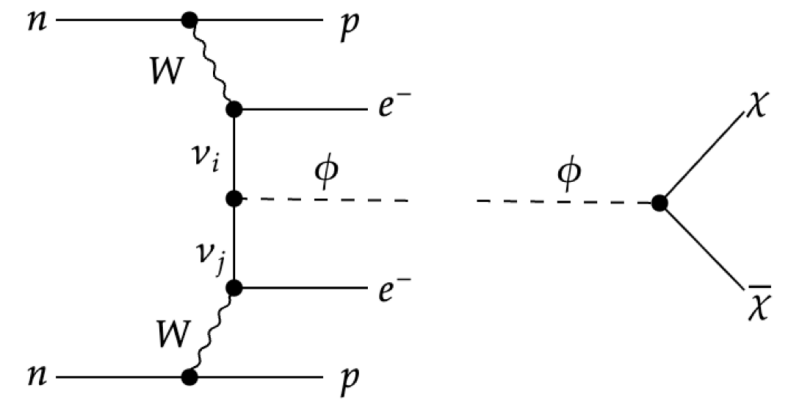
Second Workshop on Neutrinoless double beta decay
search in Xe-next-generation experiment



EXO-200: 2511.13990, PRD 96, 092001 (2017)
ITEP: PLB 223, 273 (1989); DAMA: PLB 527, 182 (2002)

Scalar-neutrino and scalar-dark-matter interactions

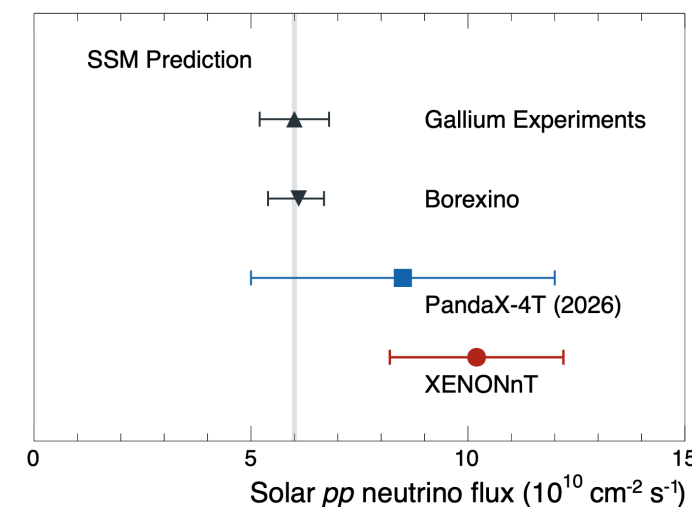
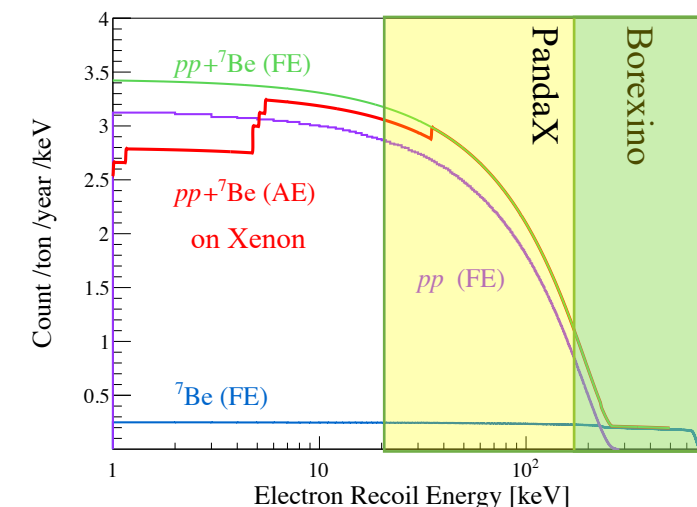
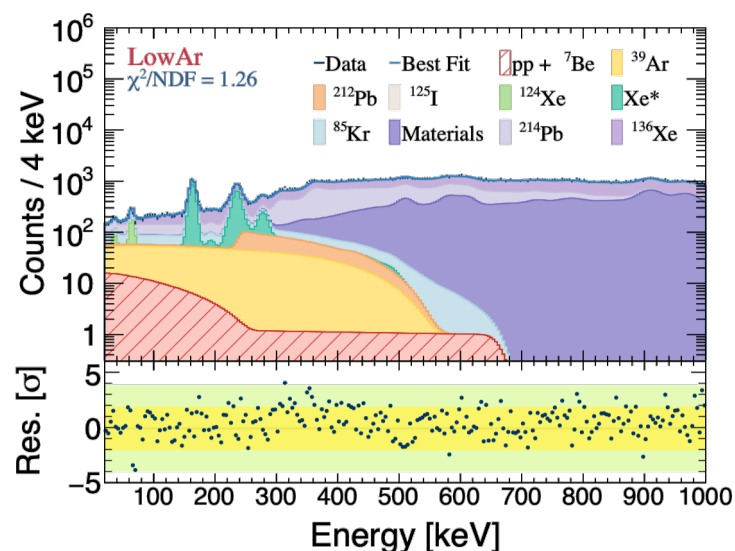
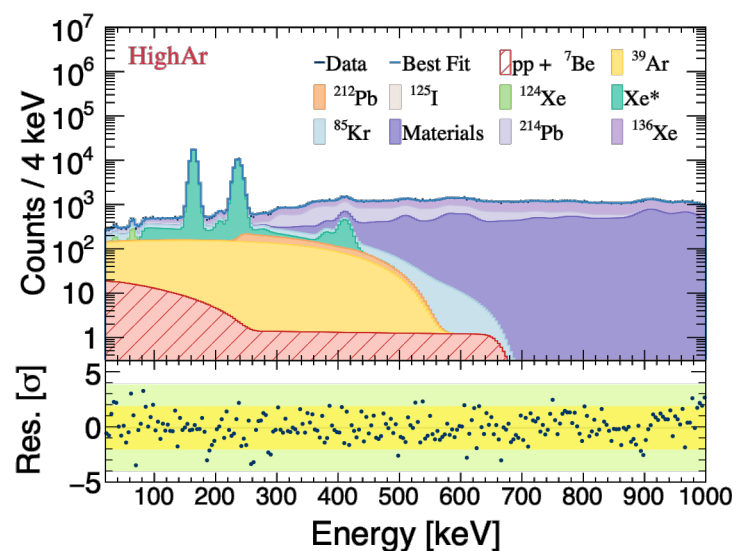
- A real scalar ϕ couples to neutrinos and may also mediate dark matter self-interactions.
- A laboratory test of neutrino self-interactions relevant to the early Universe.
- The strongest laboratory constraints on $g_{\nu\phi}$ for $m_\phi = 0.8\text{--}2\text{ MeV}/c^2$
- The dark matter interpretation also uses cosmological constraints and coupling assumptions.



PRL 136 (2026) 24, 241802

Solar pp Neutrino Flux with Run2 Data

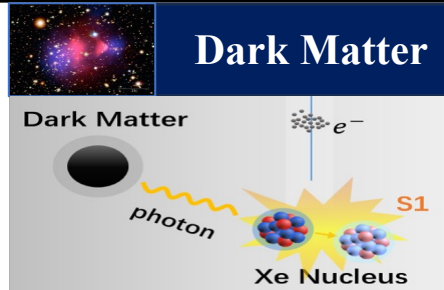
- Simultaneous fit to the high-argon and low-argon Run 2 datasets
- Combined Run 0 + Run 2: $\Phi_{pp} = (8.5 \pm 3.5) \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1} (2.2\sigma)$
- Consistent with the Standard Solar Model prediction
- XENONnT recently reported solar neutrino–electron scattering at 5.0σ



[arXiv: 2607.02405](https://arxiv.org/abs/2607.02405)

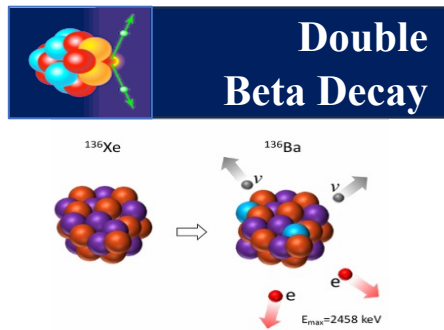
[arXiv: 2608.29450 \(XENONnT\)](https://arxiv.org/abs/2608.29450)

Fruitful Physics with PandaX-4T



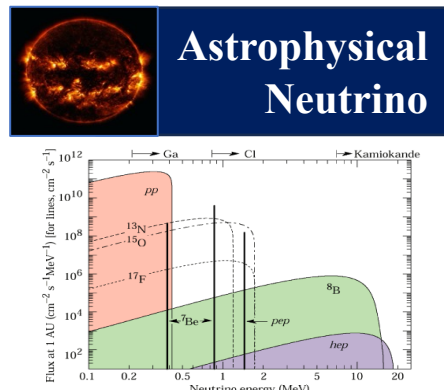
- **Dark matter and new physics searches**
 - Competitive spin-independent WIMP limits
 - Light Dark Matter searches with ionization-only / paired data
 - Leading constraints for ALP and dark photon 150keV-1MeV
 - Competitive constraints on axion, neutrino magnetic moment, etc

[PRL 134, 011805 \(2025\)](#)
[PRL 135, 211001 \(2025\)](#)
[PRL 134, 071004 \(2025\)](#)
[PRL 134, 041001 \(2025\)](#)



- **Precise ^{136}Xe Double Beta Decay Measurement**
 - half-life $(2.14 \pm 0.05) \times 10^{21}$ yr
- **Leading ^{136}Xe $0\nu\beta\beta$ constraints from natural xenon detector**
 - 90% CL limits on half-life $T_{1/2} > 2.1 \times 10^{24}$ yr
- **First ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ search from natural xenon detector**
 - 90%CL limits on half-life $T_{1/2}^{2\nu\beta\beta} > 2.8 \times 10^{22}$ yr and $T_{1/2}^{0\nu\beta\beta} > 3.0 \times 10^{23}$ yr
- **Probing scalar-neutrino and scalar-dark-matter Interactions**

[PRL 136 162501 \(2026\)](#)
[Sci. Bull. 70, 1779 \(2025\)](#)
[PRL 132, 152502 \(2024\)](#)
[PRL 136, 241802 \(2026\)](#)

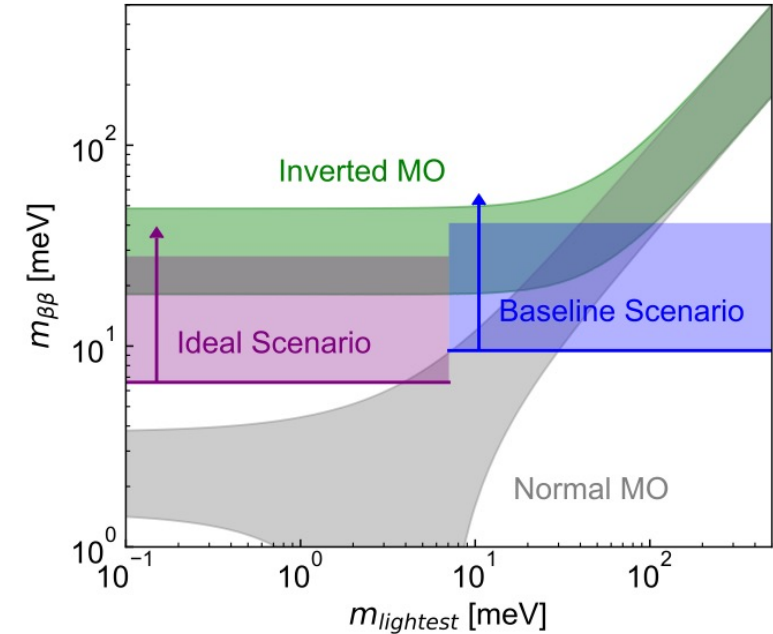
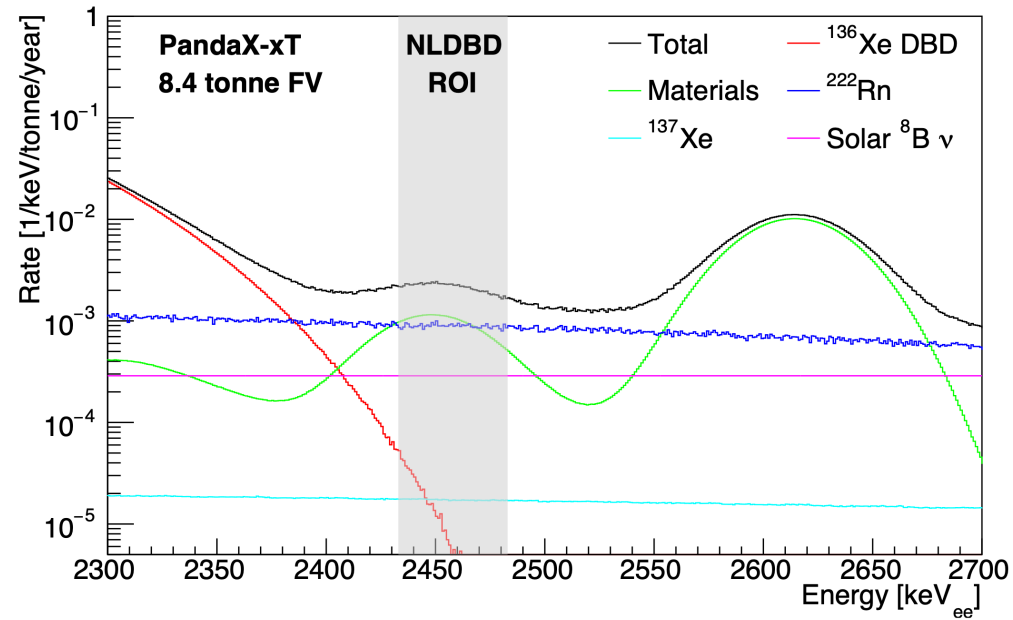
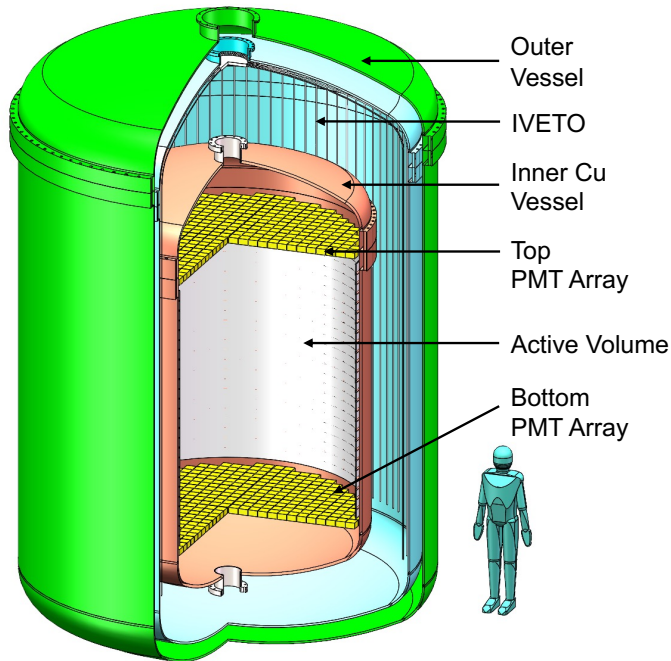


- **Measurement of solar pp neutrino flux with Run2 data**
 - pp flux: $(8.5 \pm 3.5) \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$ (2.2σ)
- **First indication of solar ^8B neutrinos through CEvNS**
 - ^8B flux: $(8.4 \pm 3.1) \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}$ (2.64σ)
- **First search for solar pp neutrinos in a xenon detector**
 - pp flux: $[8.0 \pm 3.9 \text{ (stat)} \pm 10.0 \text{ (syst)}] \times 10^{10} \text{ s}^{-1} \text{ cm}^{-2}$

[arXiv: 2607.02405](#)
[PRL 133, 191001 \(2024\)](#)
[CPC 48, 091001 \(2024\)](#)

Future Plan: PandaX-xT

- With **~40-tonne** active xenon target;
- ~4 ton of ^{136}Xe and ~4 ton of ^{134}Xe : one of the largest $0\nu\beta\beta$ experiments
- Projected ^{136}Xe $0\nu\beta\beta$ half-life sensitivity: $>10^{27}$ yr



SCPMA 68, 221011 (2025)

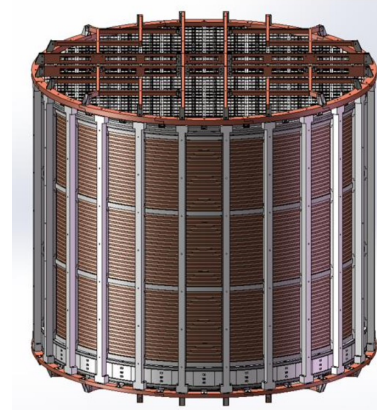
2026/09/17

Workshop on Neutrinoless double beta decay
search in Xe-next-generation experiment

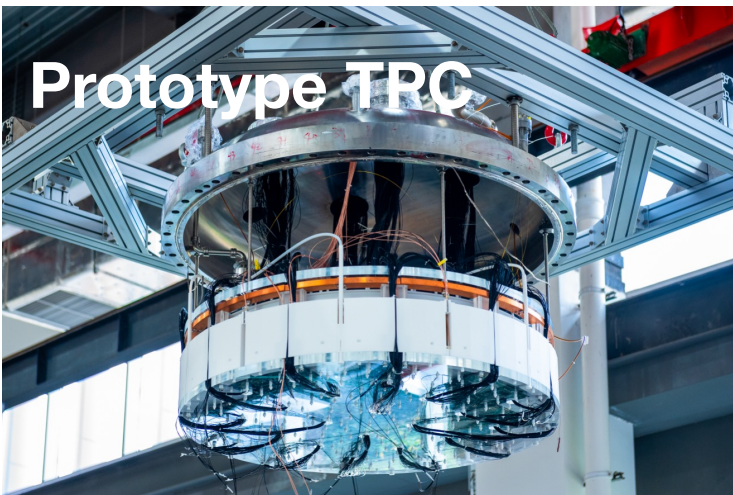
PandaX-20T: Intermediate Stage

- Multi-physics targets
 - Energy range 100eV – 10MeV
- Estimated timeline
 - **2027**: 20T is planned to get online
 - **2028**: physics data

PandaX-20T



PandaX-xT



Prototype TPC



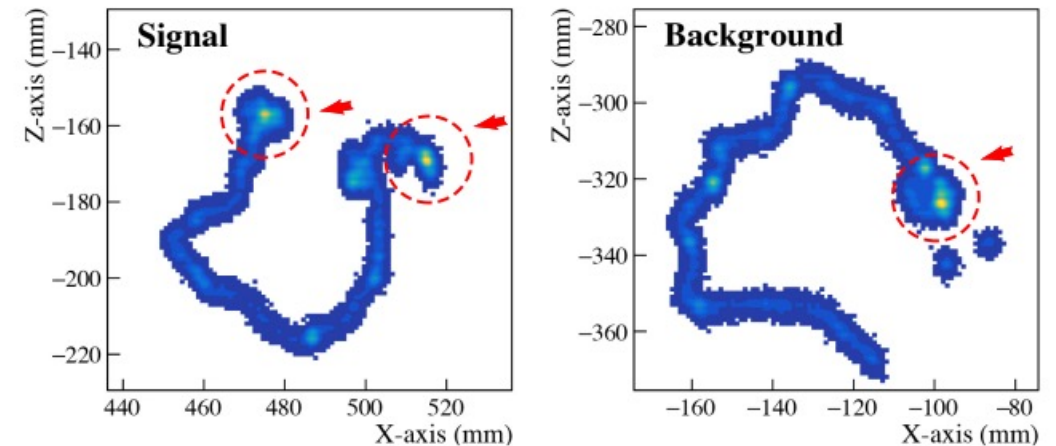
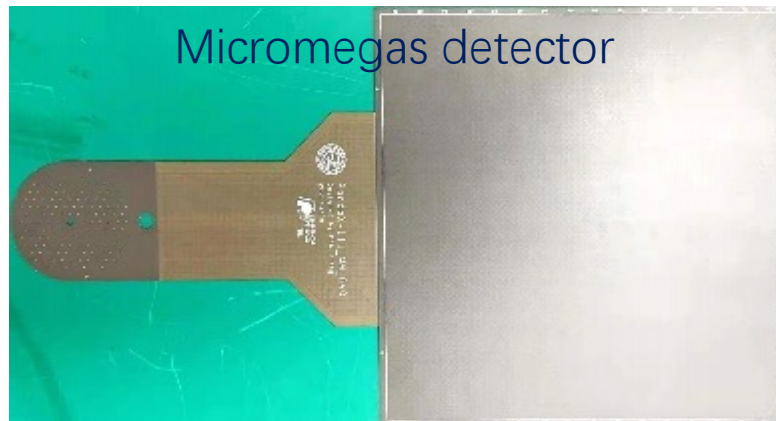
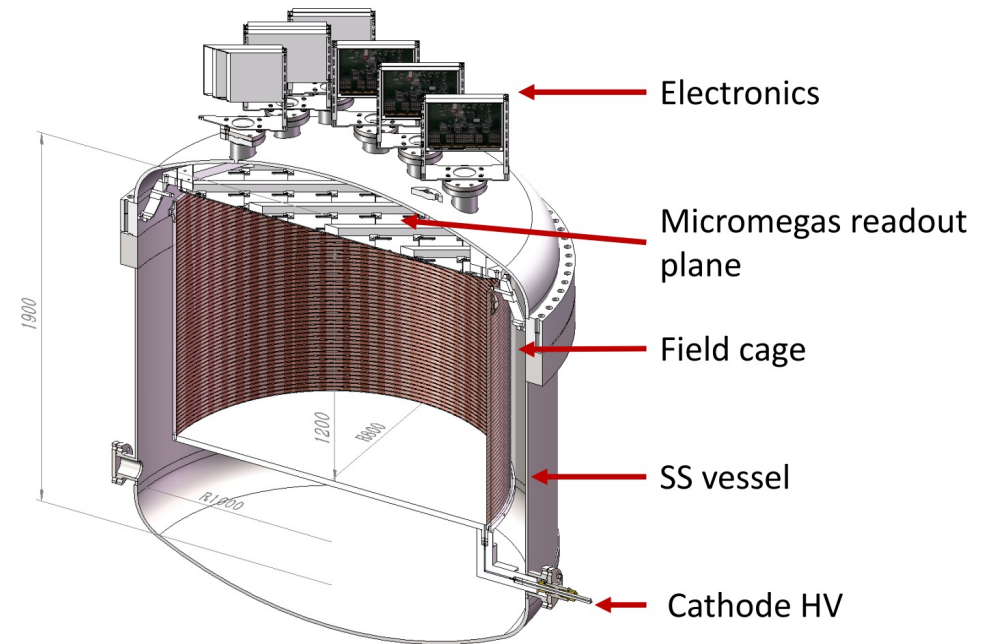
Cryogenics and recirculation



Liquid xenon storage

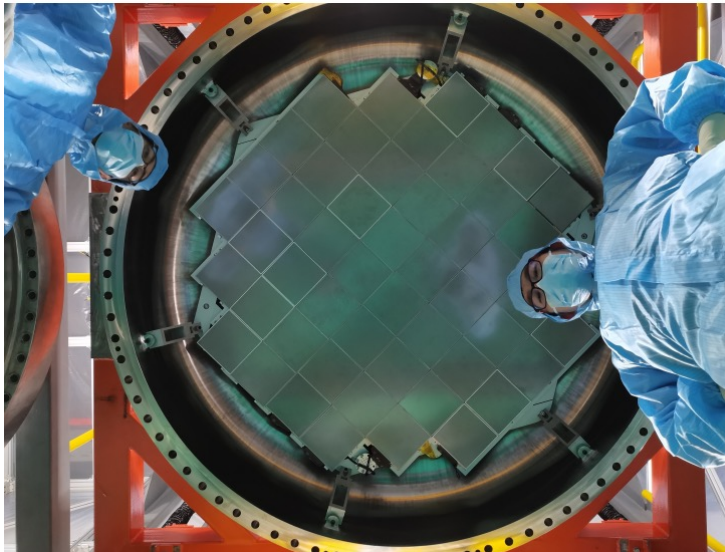
R&D towards a tracking calorimeter (PandaX-II)

- **PandaX-III:** 10 bar Xe-(1%)TMA (trimethylamine), ~100 kg xenon enriched to 90% in ^{136}Xe
- **TPC:** Single-end charge readout on the upper side; the cathode on the bottom
- **charge readout:** 52 20X20 cm² Micromegas; 2 series of strips (x, y) of 3 mm
- **Target Energy resolution:** 3% FWHM at $Q_{\beta\beta}$.



R&D towards a tracking calorimeter (PandaX-II)

- 100 kg-scale demonstrator



Second Workshop on Neutrinoless double beta decay
search in Xe-next-generation experiment

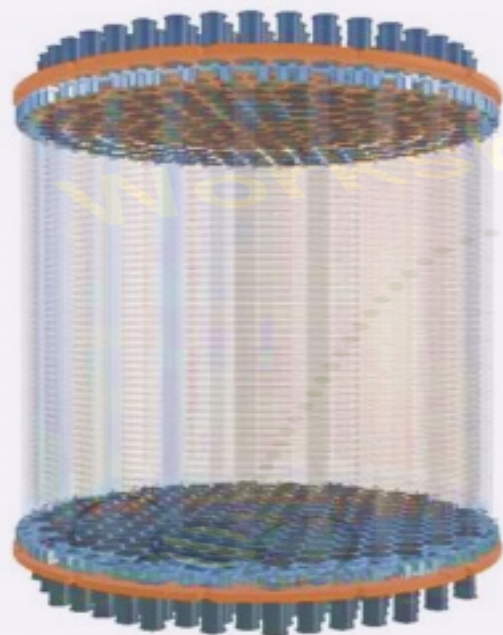
Summary

- Multi-physics goals in PandaX with an active double beta decay program
- PandaX-4T verified the feasibility and potential of a DM detector for $2\nu\beta\beta$ and $0\nu\beta\beta$ searches; competitive results for ^{136}Xe and ^{134}Xe
- Next stage: 20T detector is planned to go online in 2027; physics data in 2028



Thank You!

Backup



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On behalf of PandaX Collaboration

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14th-18th Sep. 2026



PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



上海交通大学
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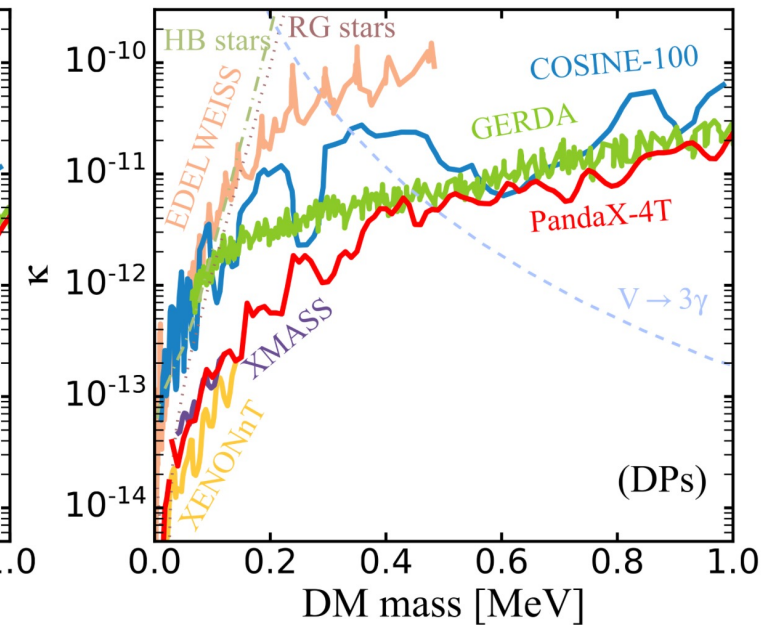
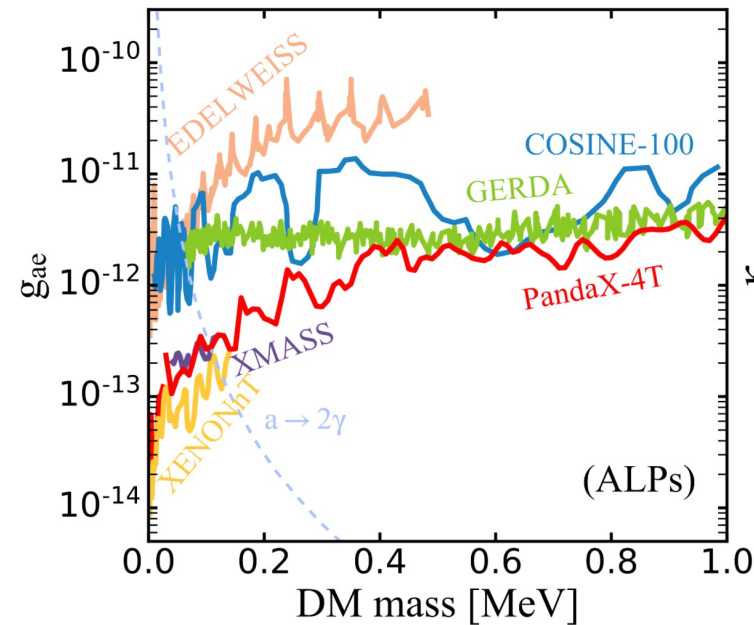
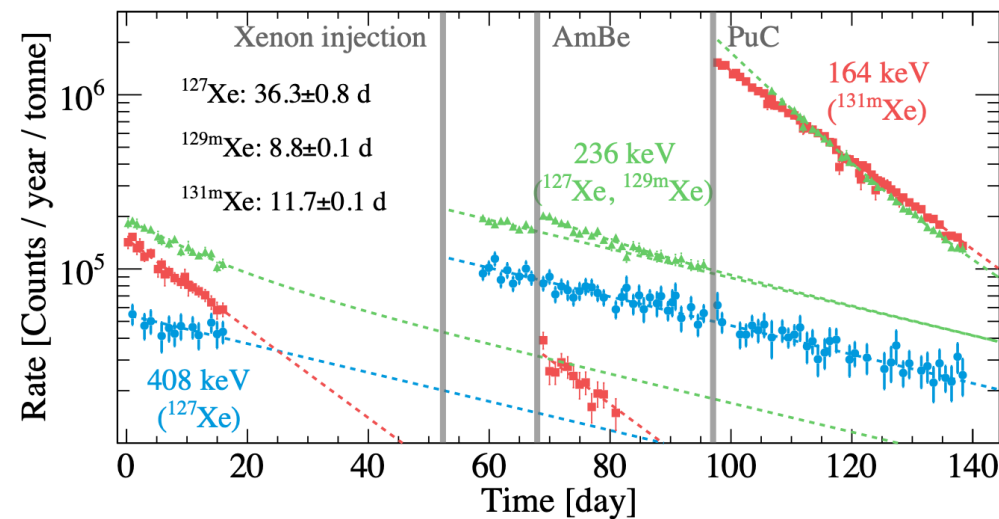
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Axion-like Particle / Dark Photon Absorption

- Absorption on bound electrons produces a peak near $E = mc^2$ when the deposited energy is fully contained
- Time-varying background (^{127}Xe , $^{129\text{m}}\text{Xe}$, $^{131\text{m}}\text{Xe}$) incorporated for the first time in PandaX-4T
- The strongest limits over most of the mass range 150 keV/c²–1 MeV/c²

$$R_{\text{ALP}} = \frac{1.47 \times 10^{19}}{A} g_{ae}^2 \cdot m_a \sigma_{pe} [\text{kg}^{-1} \text{d}^{-1}],$$

$$R_{\text{DP}} = \frac{4.7 \times 10^{23}}{A} \frac{(e\kappa)^2}{4\pi\alpha} \frac{\sigma_{pe}}{m_d} [\text{kg}^{-1} \text{d}^{-1}],$$



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