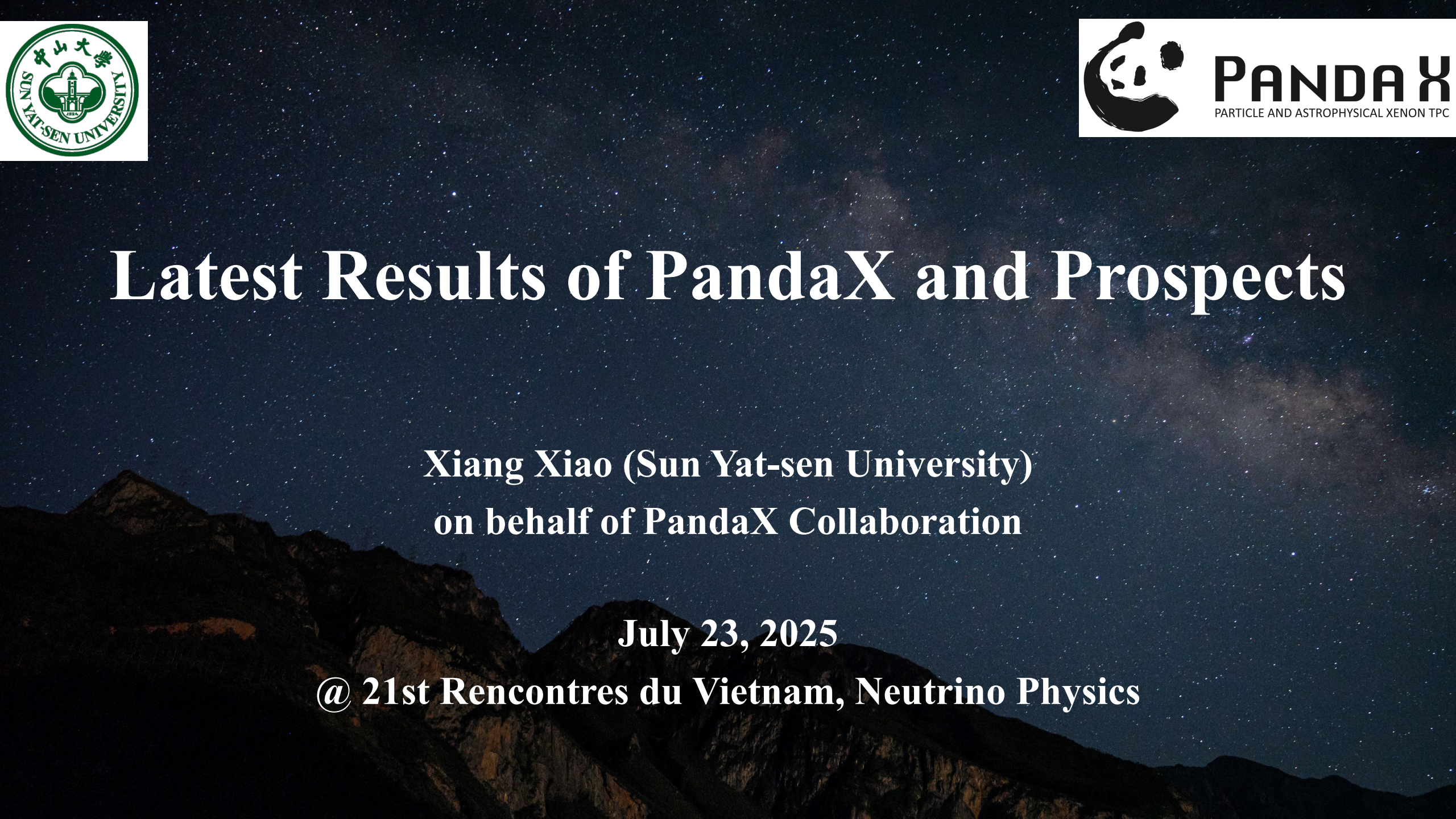


Latest Results of PandaX and Prospects

Xiang Xiao (Sun Yat-sen University)
on behalf of PandaX Collaboration

July 23, 2025

@ 21st Rencontres du Vietnam, Neutrino Physics

PandaX Collaboration

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

PandaX: Particle and Astrophysical Xenon Experiment

11 institutions, ~100 collaborators

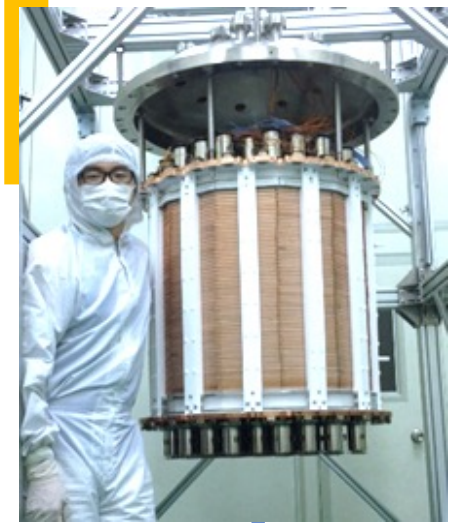
PandaX pathway

- **Increasing sensitive target volume**
- **Lowering radioactive background**

PandaX initiated

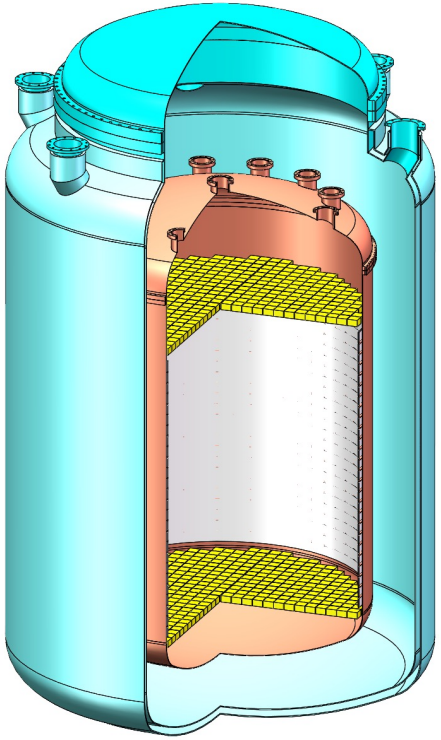
PandaX-I
120 kg

PandaX-II
580 kg



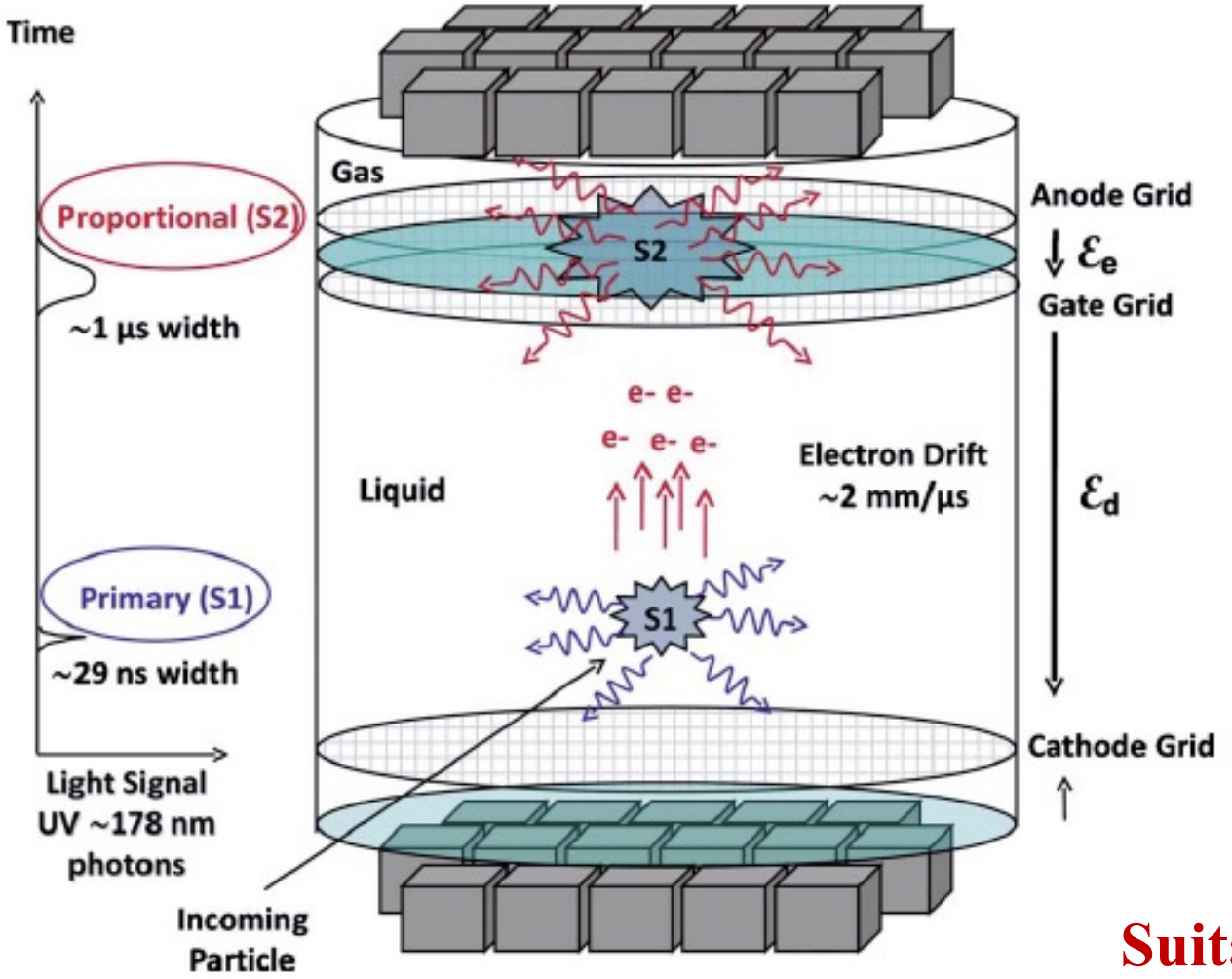
PandaX-4T
3.7 tonne

PandaX-xT
20 tonne -> 47 tonne



2009 | **2010-2014** | **2015-2019** | **2020-** | **2027-**

Dual-phase Xenon Time Projection Chamber (TPC)



- **3D position reconstruction**
  - Fiducialization
  - Single-Site (SS) and Multi-Site (MS) discrimination
- **Particle identification among α, neutron, and γ/electron**
- **Calorimeter from sub keV to a few MeV**
- **Monolithic and scalable**

↓

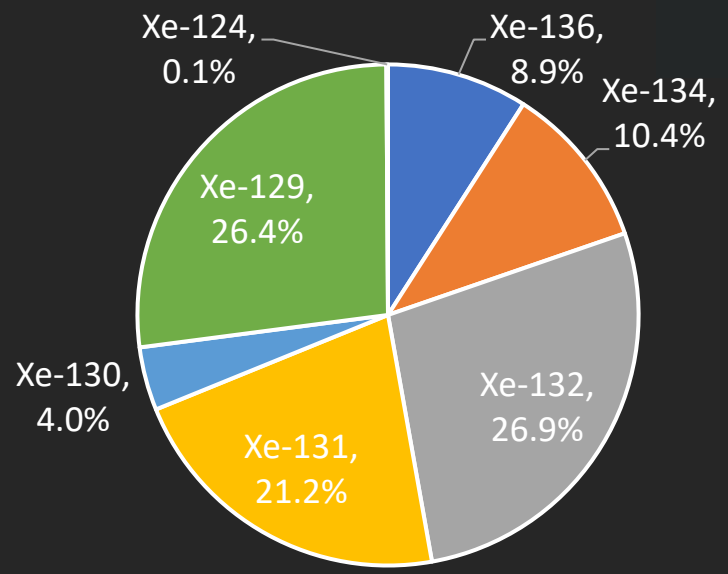
- **Low background**
- **Large target mass**
- **High detection efficiency**

↓

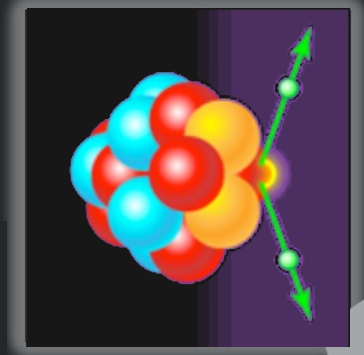
Suitable for detection of dark matter, 0νββ, and astrophysical neutrinos at the same time!

PandaX-4T as multi-physics observatory

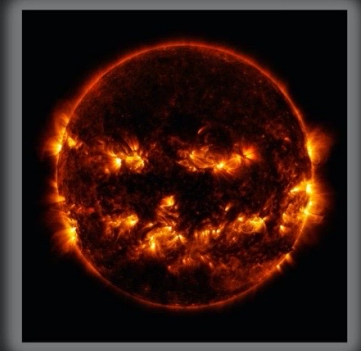
- **Wide energy range: sub keV ~ a few MeV**
- **Large volume nature xenon target**
- **Background control and mitigation**



Dark Matter
1 keV – 10 keV



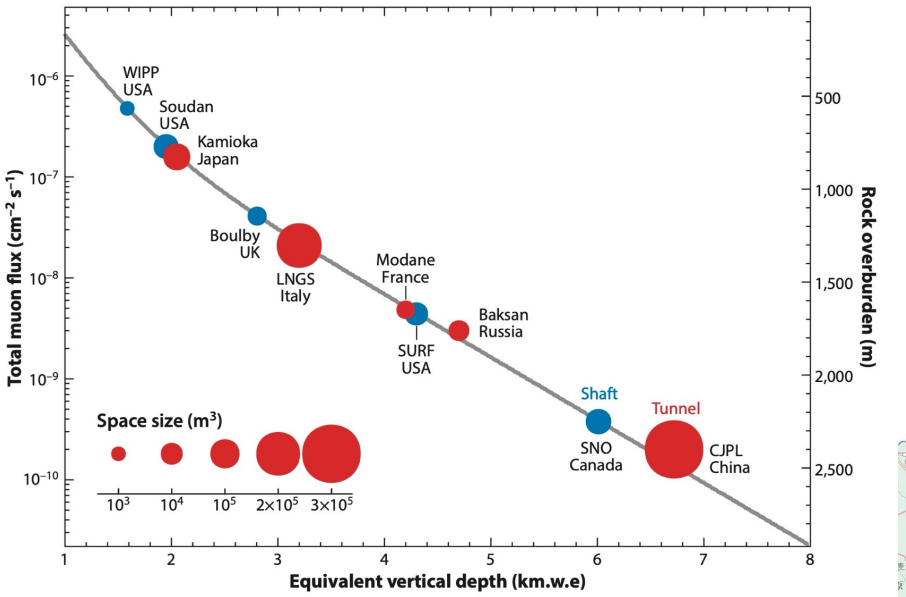
Majorana Neutrino
~2 MeV

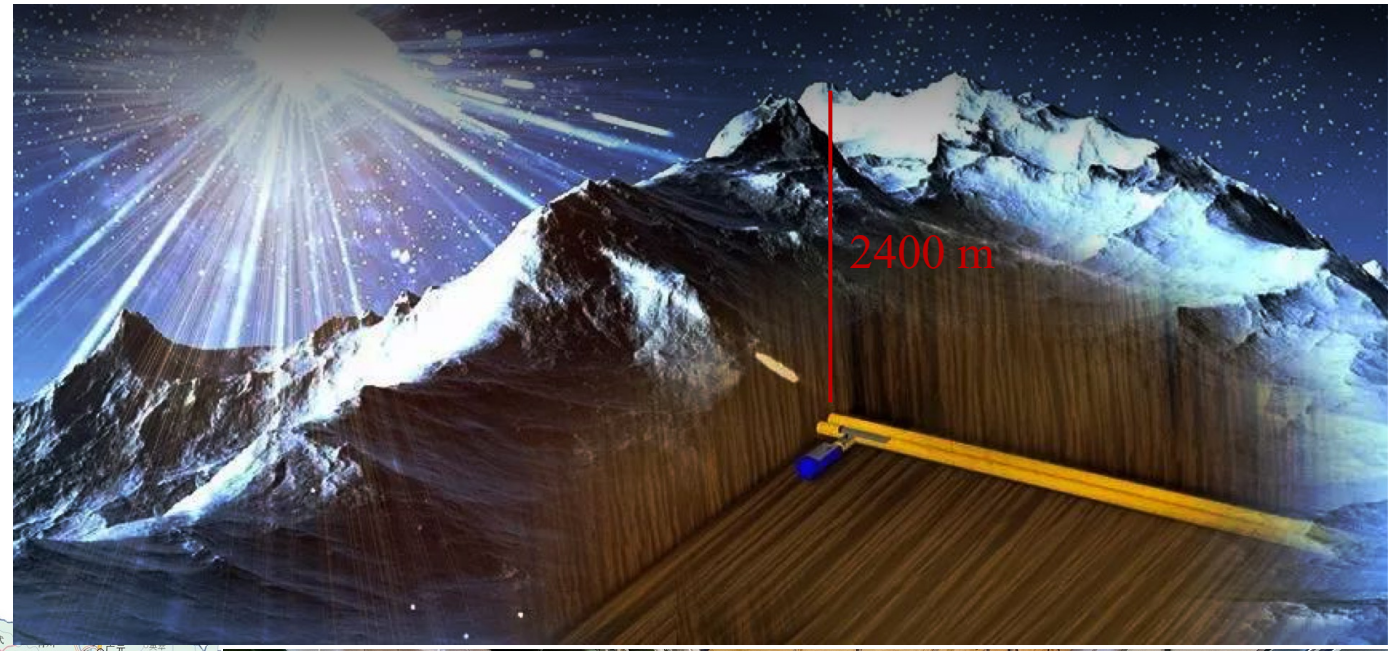


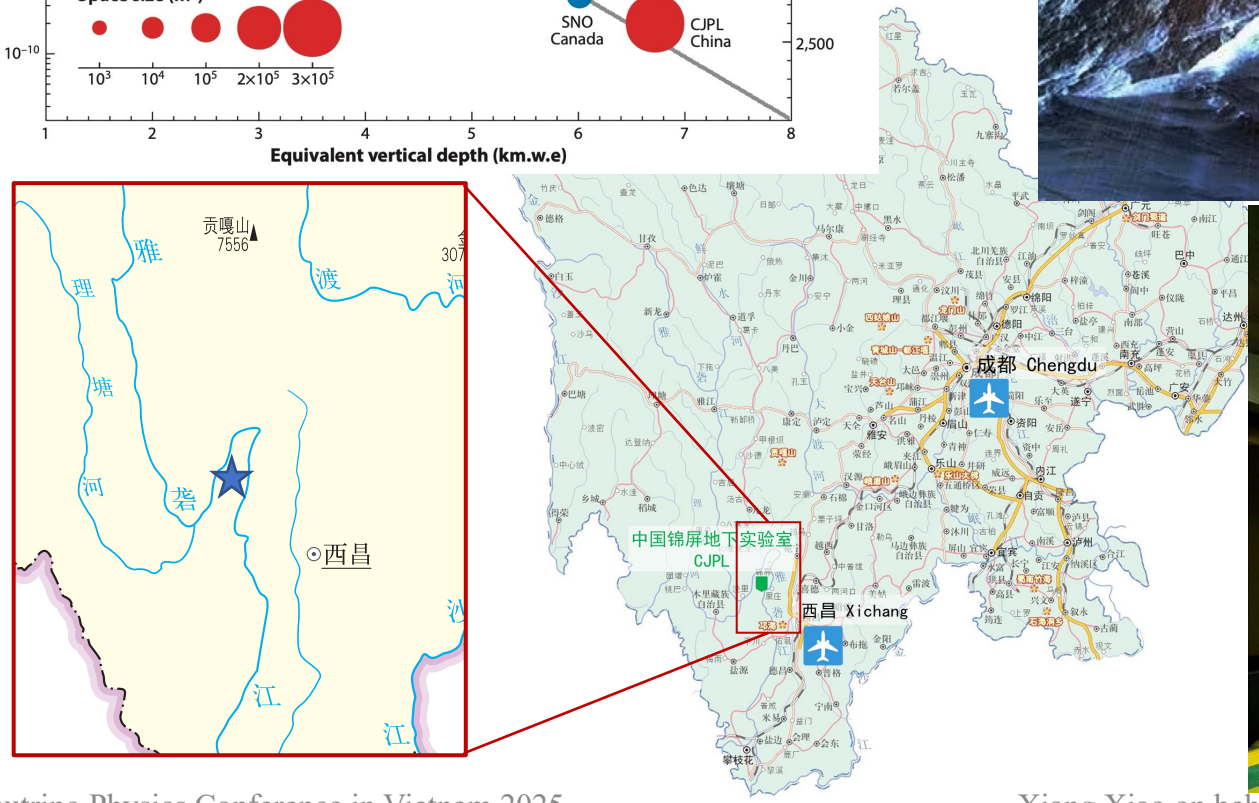
Astrophysical Neutrino
~100 keV & sub-keV

China Jinping Underground Laborotary (CJPL)

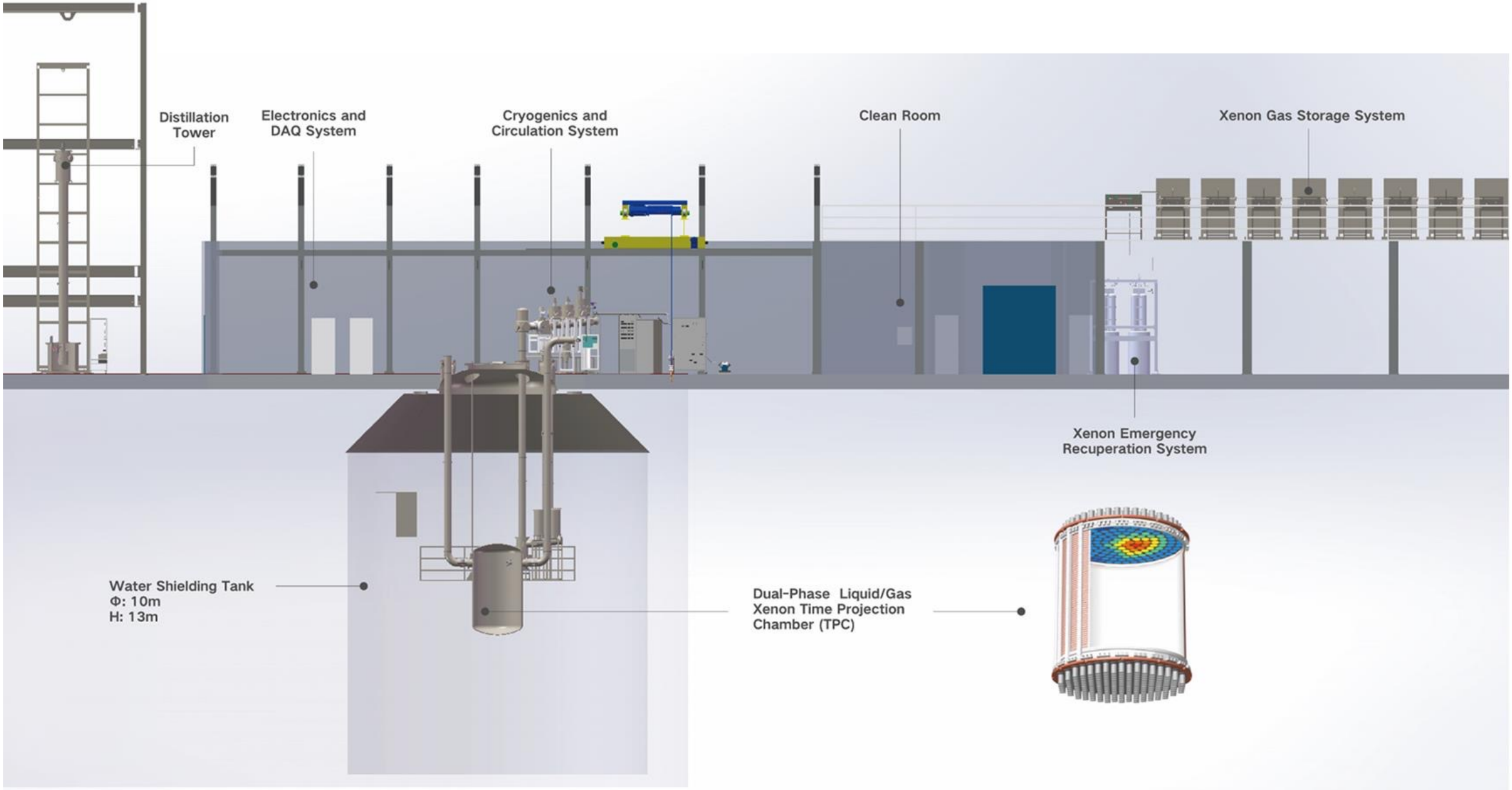
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC



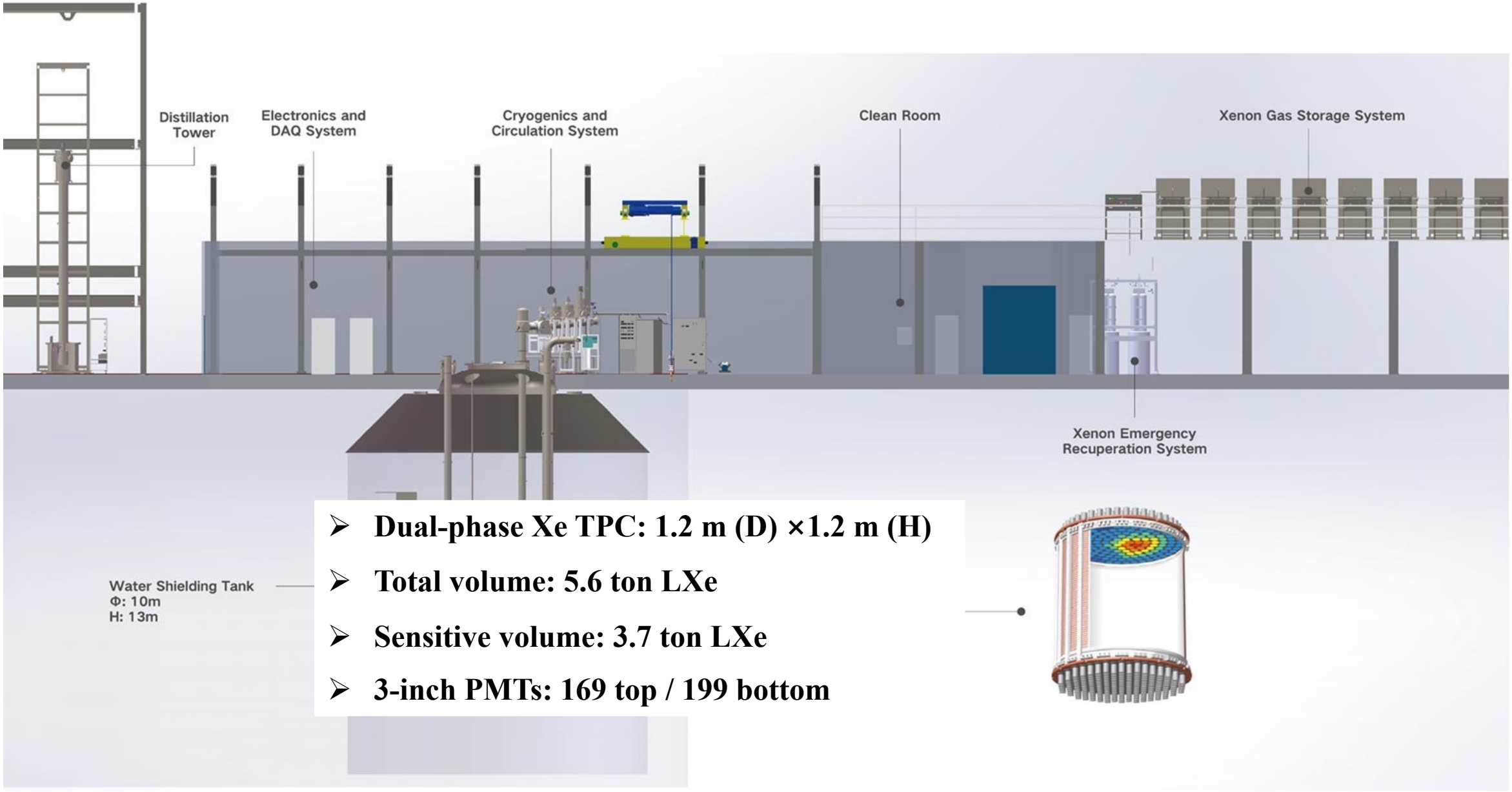




PandaX-4T @ CJPL-II B2 Hall

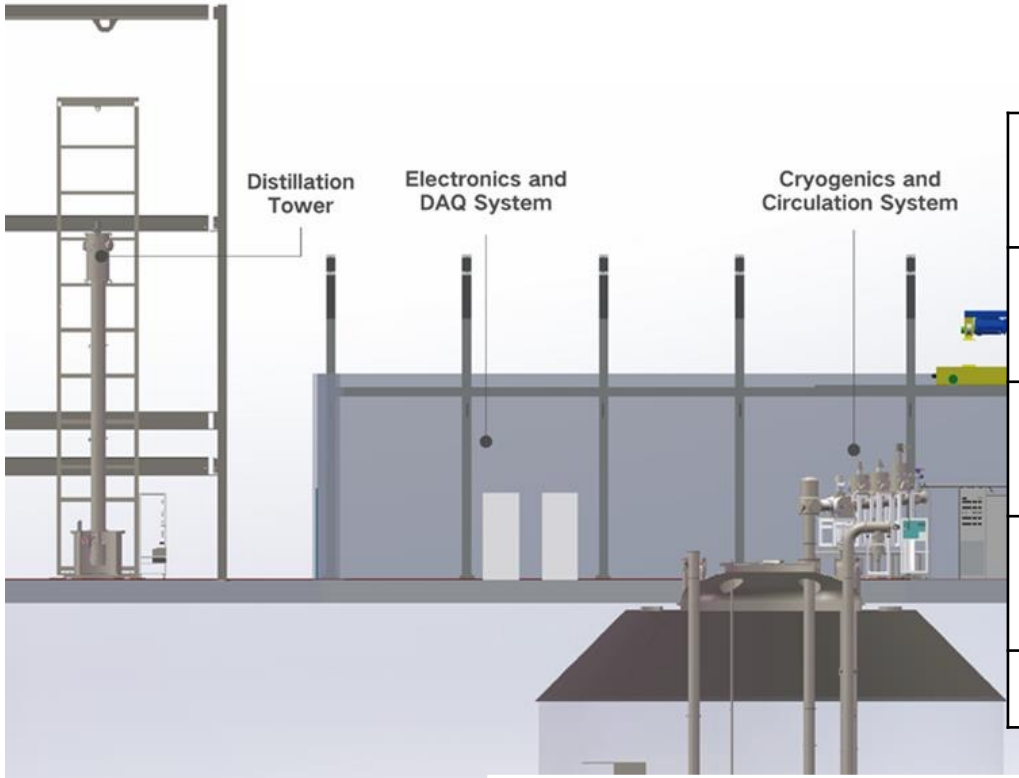


PandaX-4T @ CJPL-II B2 Hall



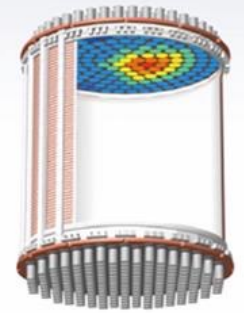
- **Dual-phase Xe TPC: 1.2 m (D) ×1.2 m (H)**
- **Total volume: 5.6 ton LXe**
- **Sensitive volume: 3.7 ton LXe**
- **3-inch PMTs: 169 top / 199 bottom**

PandaX-4T @ CJPL-II B2 Hall

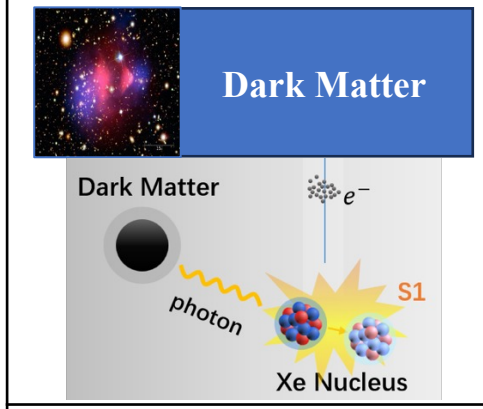


2020/11 – 2021/04	**Commissioning run (Run0)** 95 days of physics data
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc
2021/11 – 2022/05	**First science run (Run1)** 164 days of physics data
2022/09 – 2023/12	**CJPL-II B2 hall construction** xenon recuperation, detector upgrade
Resume data-taking (Run2)	

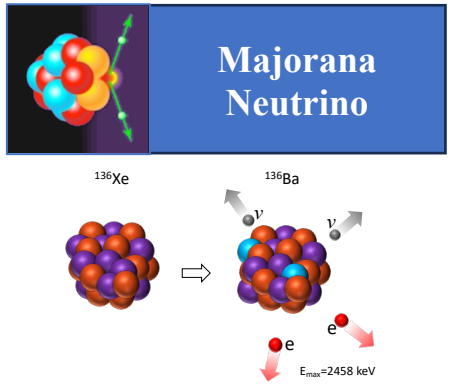
- **Dual-phase Xe TPC: 1.2 m (D) ×1.2 m (H)**
- **Total volume: 5.6 ton LXe**
- **Sensitive volume: 3.7 ton LXe**
- **3-inch PMTs: 169 top / 199 bottom**



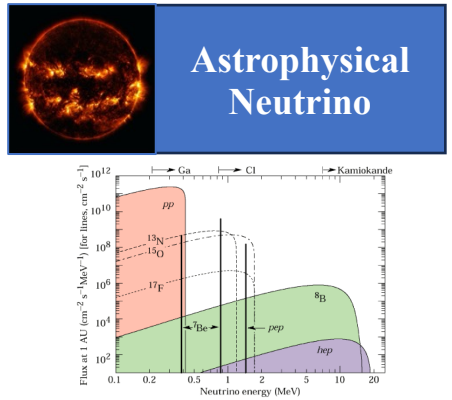
Some recent results...



- **Run0+Run1 combined 1.54 tonne-year exposure**
  - Leading constraints for WIMP mass above 100 GeV — **PRL** 134, 011805 (2025)
  - Leading constraints for ALP and dark photon 150 keV - 1 MeV — **PRL** 134, 071004 (2025)
  - Competitive constaints on axion, neutrino magnetic moment, etc — **PRL** 134, 041001 (2025)
- **Limits on the luminance of dark matter**
  - First constraints on DM charge radius — **Nature** 618, 47-50 (2023)



- **First ^{136}Xe 2νββ half-life precise measurement from natural xenon detector**
  - $T_{1/2} = 2.27 \pm 0.03(\text{stat.}) \pm 0.10(\text{syst.}) \times 10^{21}$ yr — **Research** 2022, 9798721 (2022)
- **Leading ^{136}Xe 0νββ half-life constraints from natural xenon detector**
  - 90% CL limits on half-life $T_{1/2} > 2.1 \times 10^{24}$ yr — **Science Bulletin** 70, 1779-1785 (2025)
- **Leading ^{134}Xe 2νββ and 0νββ half-life constraints**
  - 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 — **PRL** 132, 152402 (2024)

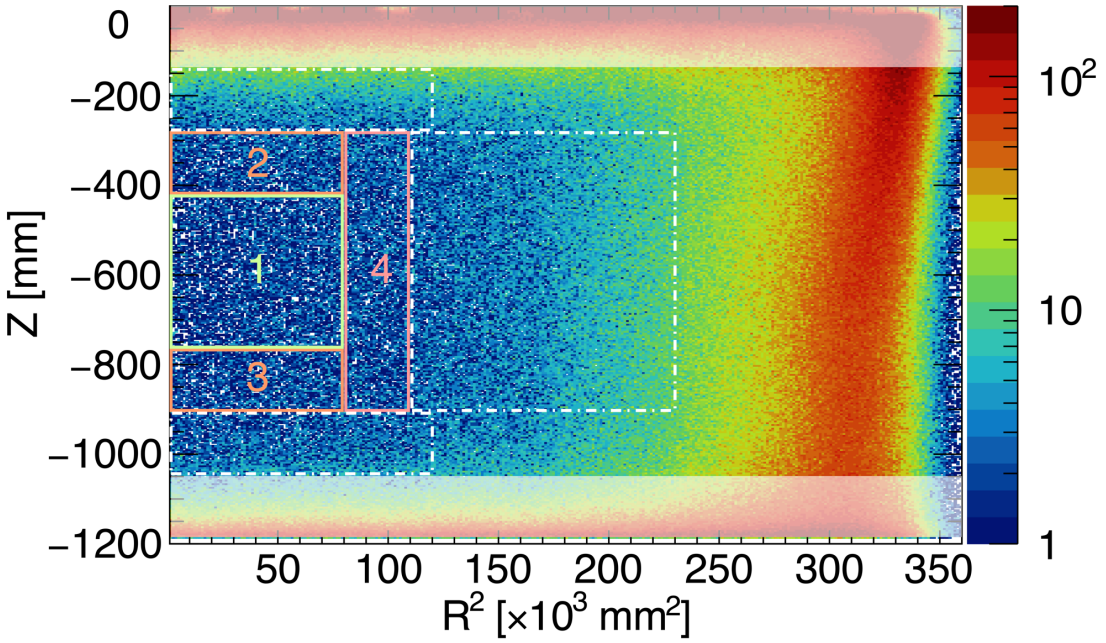


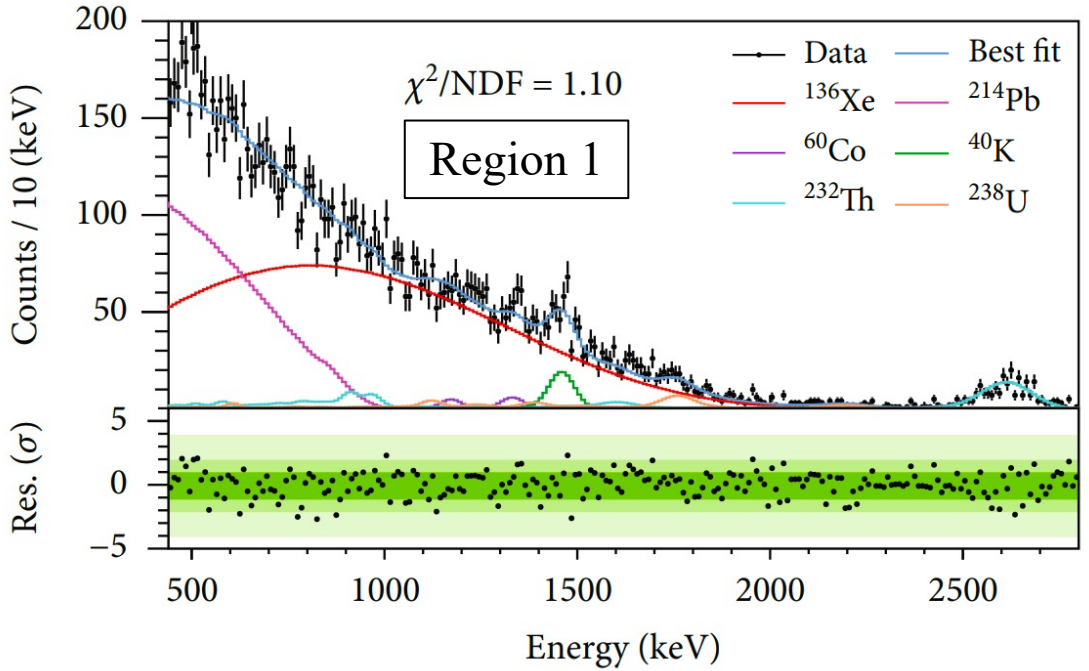
- **First indication of solar ^{8}B neutrinos through CEνNS** — **PRL** 133, 191001 (2024)
  - 2.64σ significance
  - Two ROI regions: paired (3.5±1.3 events) and S2-only (75±28 events)
- **First attempt to detect solar pp neutrinos in liquid xenon detector** — **CPC** 48, 091001 (2024)
  - Flux: $8.0 \pm 3.9(\text{stat.}) \pm 10.0(\text{syst.}) \times 10^{10}$ s^{-1} cm^{-2}

^{136}Xe 2νββ spectrum and background fitting (Run0)

- Dedicated data analysis pipeline is developed for O(10 keV) – O(MeV) energy range
- Segmented FV to partially include position information
- Binned Poisson likelihood fitting on SS energy spectrum performed simultaneously in four regions
- Outer regions to check background model, consistent at ~1%

$$L = \prod_{i=1}^{N_{\mathrm{R}}} \prod_{j=1}^{N_{\mathrm{bins}}} \frac{(N_{ij})^{N_{ij}^{\mathrm{obs}}}}{N_{ij}^{\mathrm{obs}}!} e^{-N_{ij}} \prod_{k=1}^{N_{\mathrm{bkgs}}} \frac{1}{\sqrt{2\pi}\sigma_k} e^{-\frac{1}{2}(\frac{\eta_k}{\sigma_k})^2}, \quad N_{ij} = n_{\mathrm{Xe}} S_{ij}^{\mathrm{Xe}} + \sum_{k=1}^{N_{\mathrm{bkgs}}} (1+\eta_k) n_{ij}^k B_{ij}^k$$

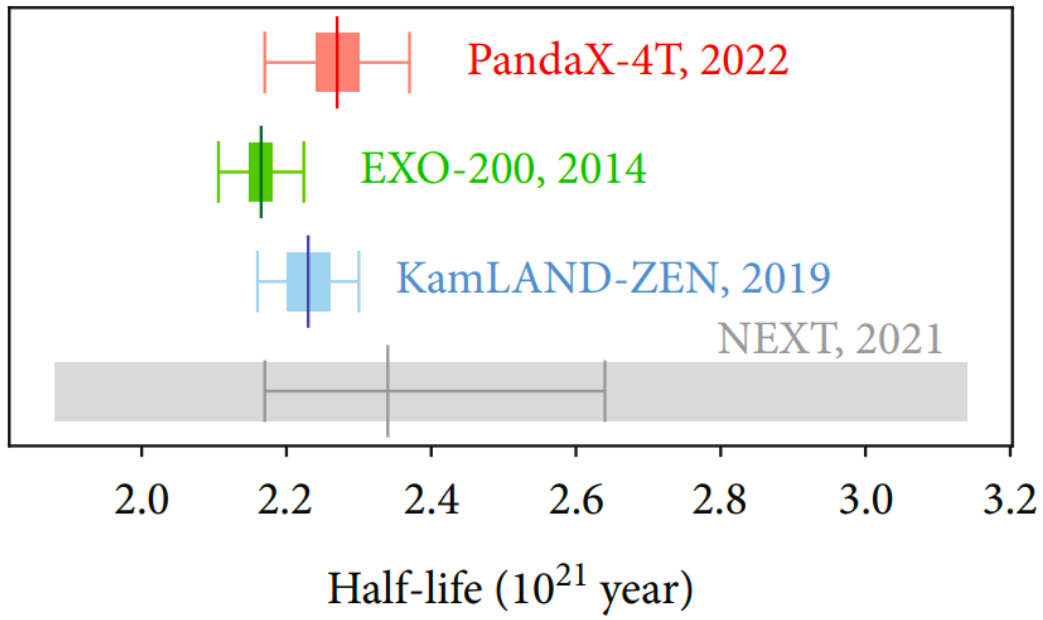




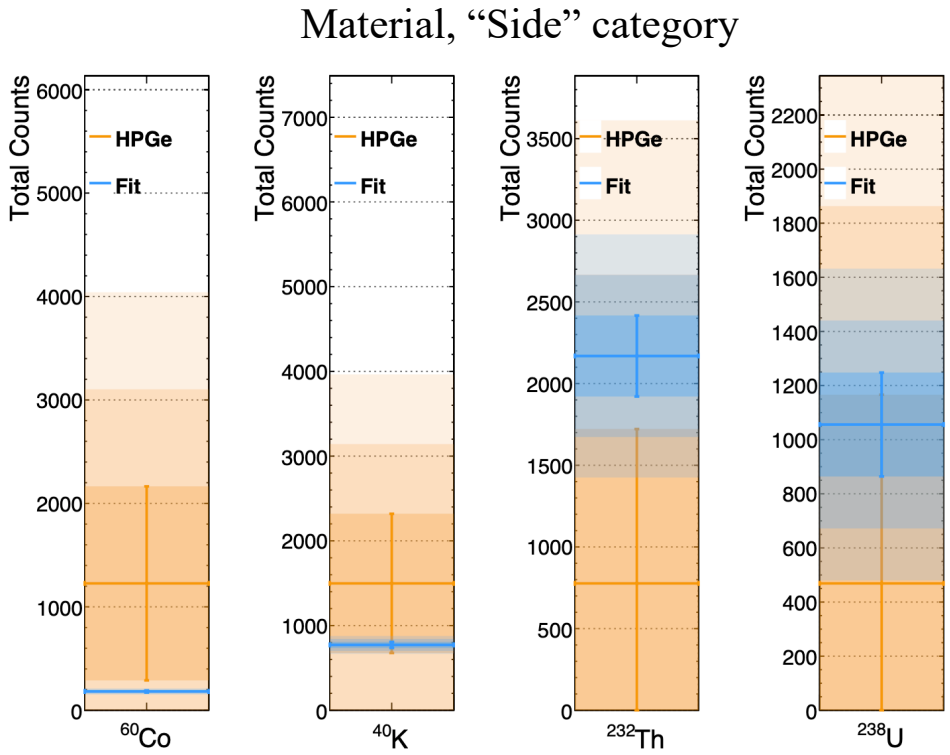
^{136}Xe 2νββ half-life and background estimation

^{136}Xe 2νββ half-life measured as: $2.27 \pm 0.03(\text{stat.}) \pm 0.10(\text{syst.}) \times 10^{21}$ year with Run0 data

- First such measurement from natural xenon detectors
- Comparable precision with dedicated ^{136}Xe-enriched 0νββ experiments
- Much lower analysis threshold compared with previous measurements
- *"in-situ"* material background fitting results compatible and more precise than HPGe assay



Research 2022, 9798721 (2022)

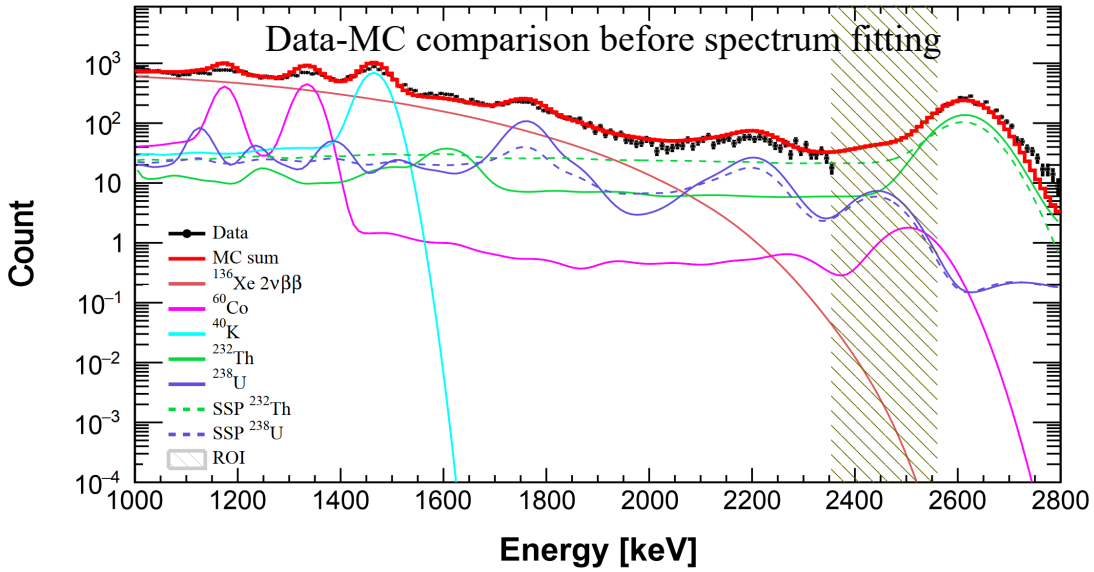


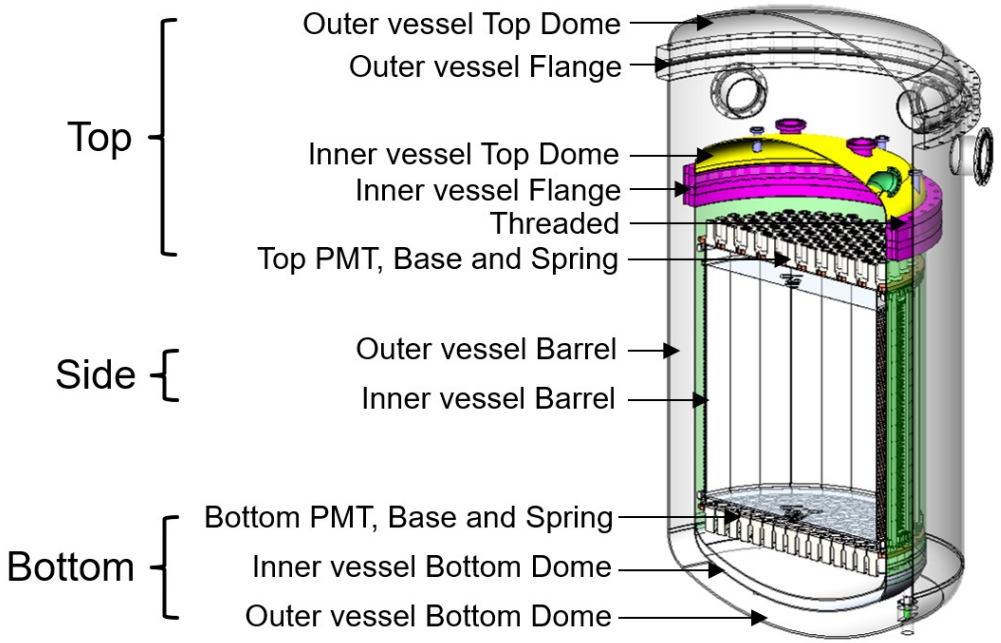
Blind analysis for ^{136}Xe 0νββ search

Unified and optimized data reconstruction for Run0+Run1

Background components:

- ^{136}Xe $2\nu\beta\beta$: from ^{136}Xe 2νββ half-life measurement)
- Detector material ^{60}Co, ^{40}K, ^{232}Th, and ^{238}U: from HPGe material assay, and grouped into top, side, and bottom parts
- Stainless steel platform (SSP): ^{232}Th, ^{238}U (from MS fitting)

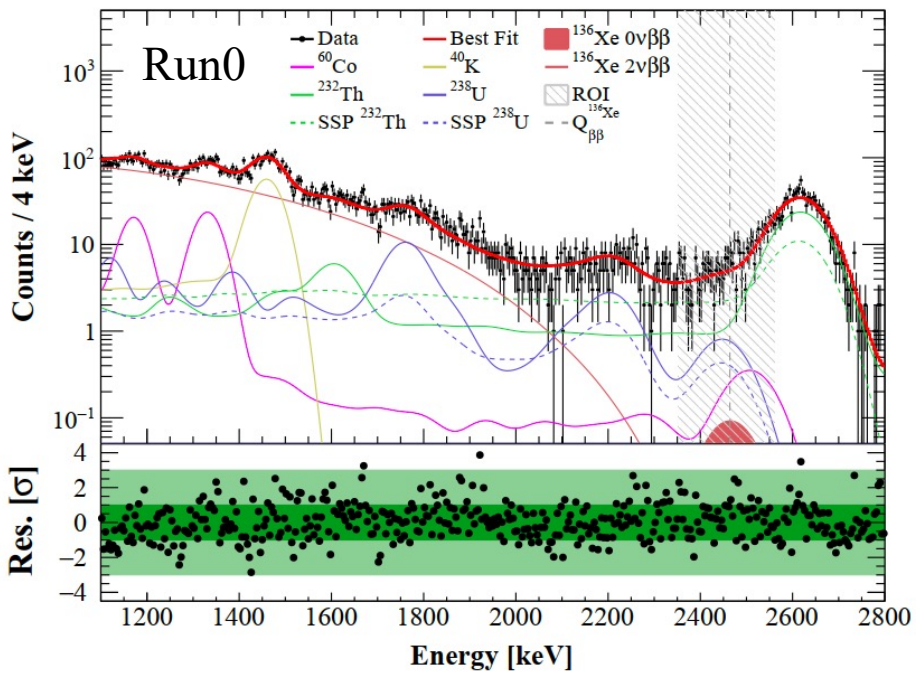


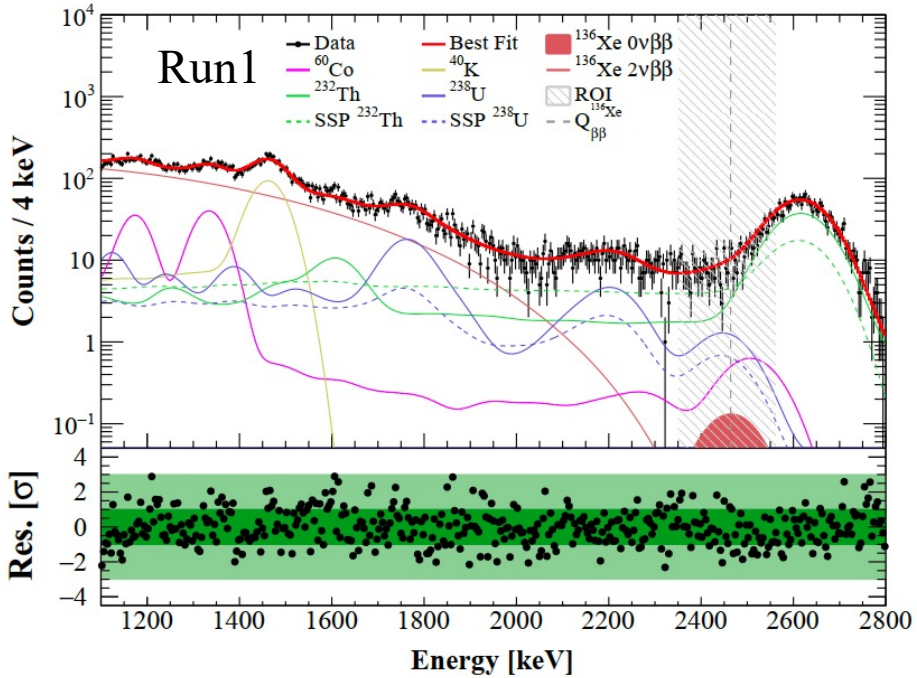


Other background components are checked:

- Residual ^{214}Bi in TPC -> negligible
- Gammas of ^{214}Bi from LXe skin region -> negligible
- 2.5 MeV peak from ^{60}Co cascade gammas -> well modelled

Unblinded fitting and results of ^{136}Xe 0νββ





^{136}Xe exposure of Run0+Run1: 44.6 kg-yr

Energy resolution @ 2615 keV in FV:
- 2.0% in Run0
- 2.3% in Run1

^{136}Xe $0\nu\beta\beta$ event rate is fitted to be $\mathbf{14 \pm 37\ t^{-1}yr^{-1}}$, with a p-value of 0.49 for null results.

$$T_{1/2}^{0\nu\beta\beta} > 2.1 \times 10^{24}\ yr \text{ at 90\% C.L.}$$

Upward fluctuation, the limit is consistent with the median sensitivity within 1.1σ.

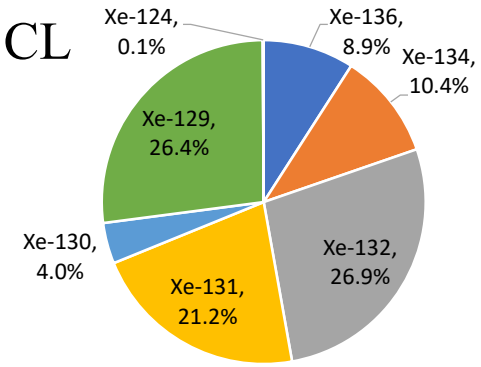
$$\langle m_{\beta\beta} \rangle = (0.4 - 1.6)\ \mathrm{eV/c^2}$$

- **Best results among natural xenon detectors so far**
- Improvement to our previous PandaX-II results by an order of magnitude and to the XENON1T results by a factor of 1.8
- Demonstrating the potential of ^{136}Xe 0νββ search with next-generation multi-ten-tonne natural xenon detectors

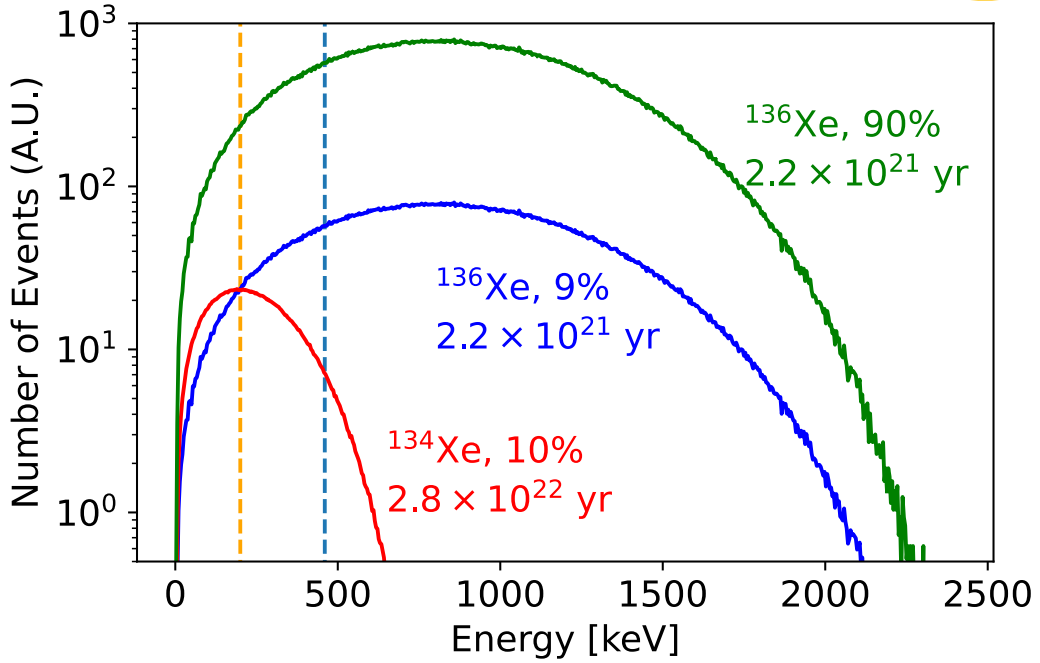
Science Bulletin 70, 1779-1785 (2025)

A blessing: ^{134}Xe 2νββ/0νββ searches

- Q=826 keV; Half-life from theoretical predictions: 10^{24}-10^{25} yr; Never been observed yet
- Previous 2νββ (0νββ) half-life limit from EXO-200: T >8.7 × 10^{20} yr (1.1 × 10^{23} yr) at 90% CL
- PandaX-4T: more ^{134}Xe; much less ^{136}Xe; wider energy range; discovery possible

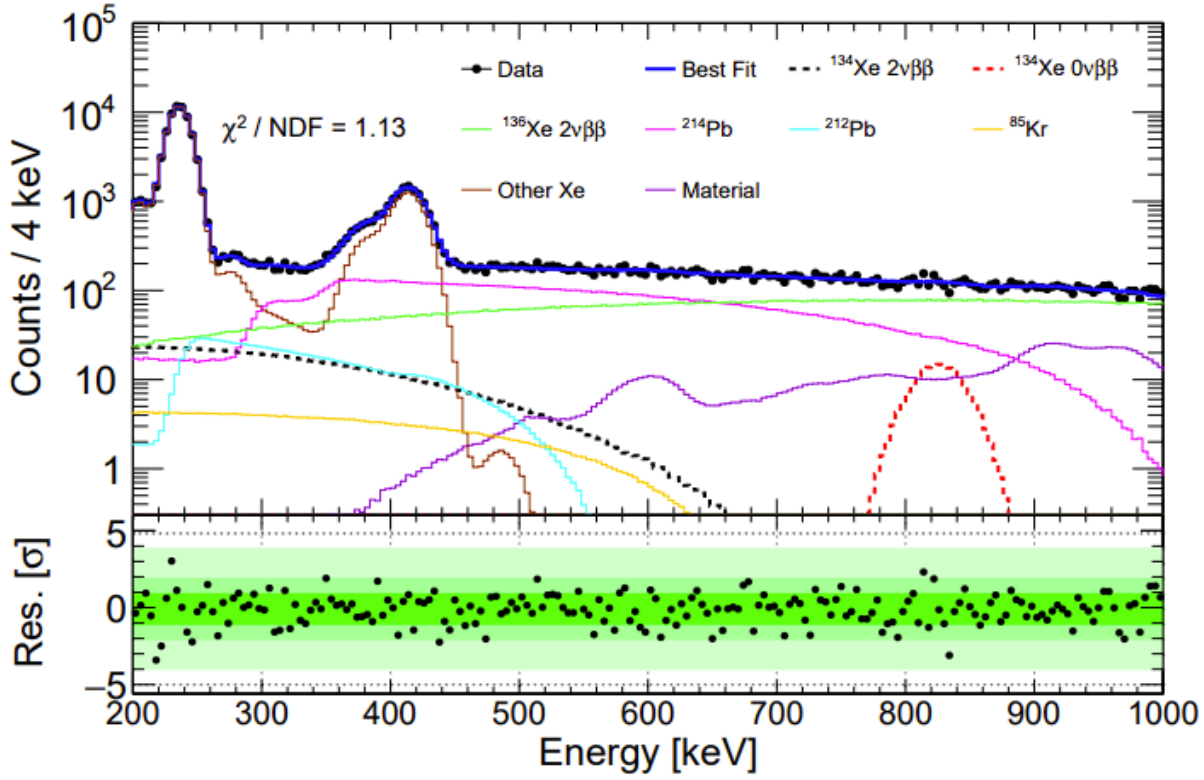


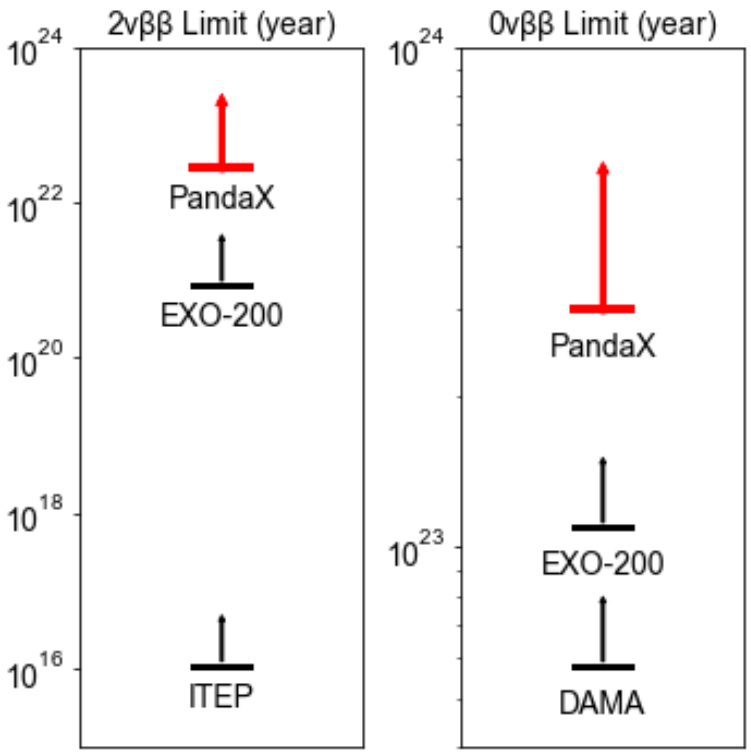
	PandaX-4T	EXO-200
^{134}Xe mass	68.7 kg	18.1 kg
^{136}Xe abundance	8.90%	81%
Analysis threshold	200 keV	460 keV
Live Time	94.9 days	600 days



^{134}Xe 2νββ/0νββ searches with Run0

- Simultaneous fit for ^{134}Xe 2νββ and 0νββ with Run0 data
- Final counts of 2νββ and 0νββ: 10±269(stat.)±680(syst.) and 105±48(stat.)±38(syst.)
- 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

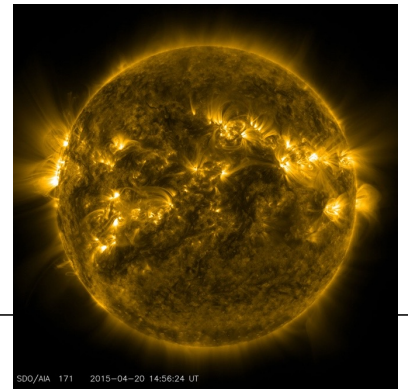


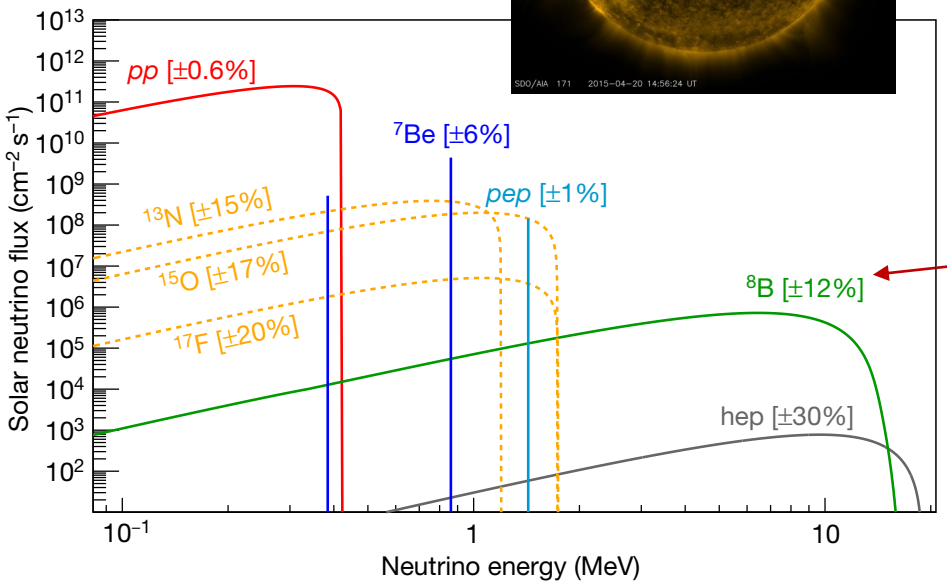


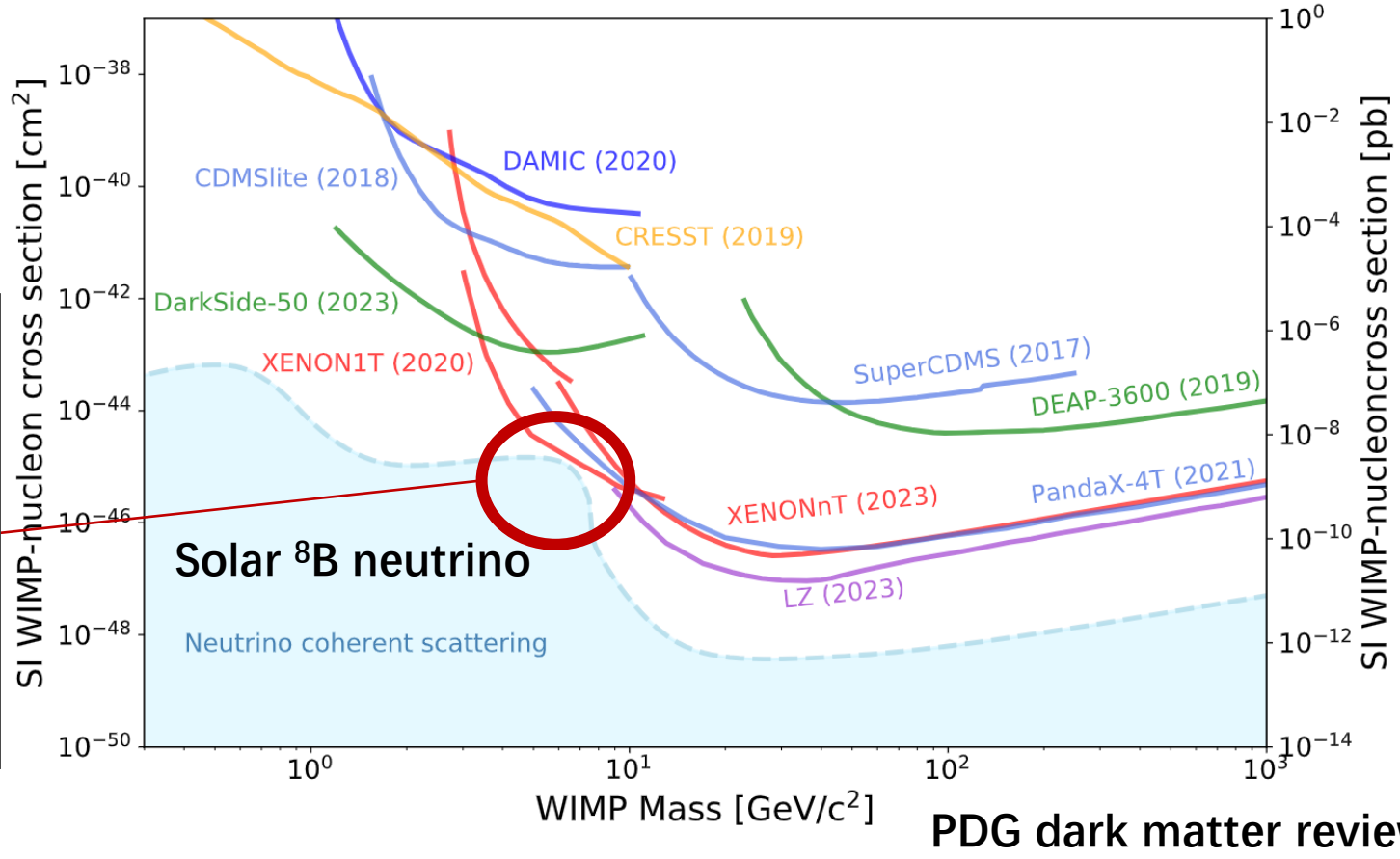
PRL 132, 152402 (2024)

Dark matte search touching neutrino fog...

- In the past decades, the DM search sensitivity improved several orders of magnitude, touching the neutrino fog at ~6 GeV DM mass
- Detecting solar ^{8}B neutrinos through CEvNS becomes feasible with a multi-tonne LXe detector





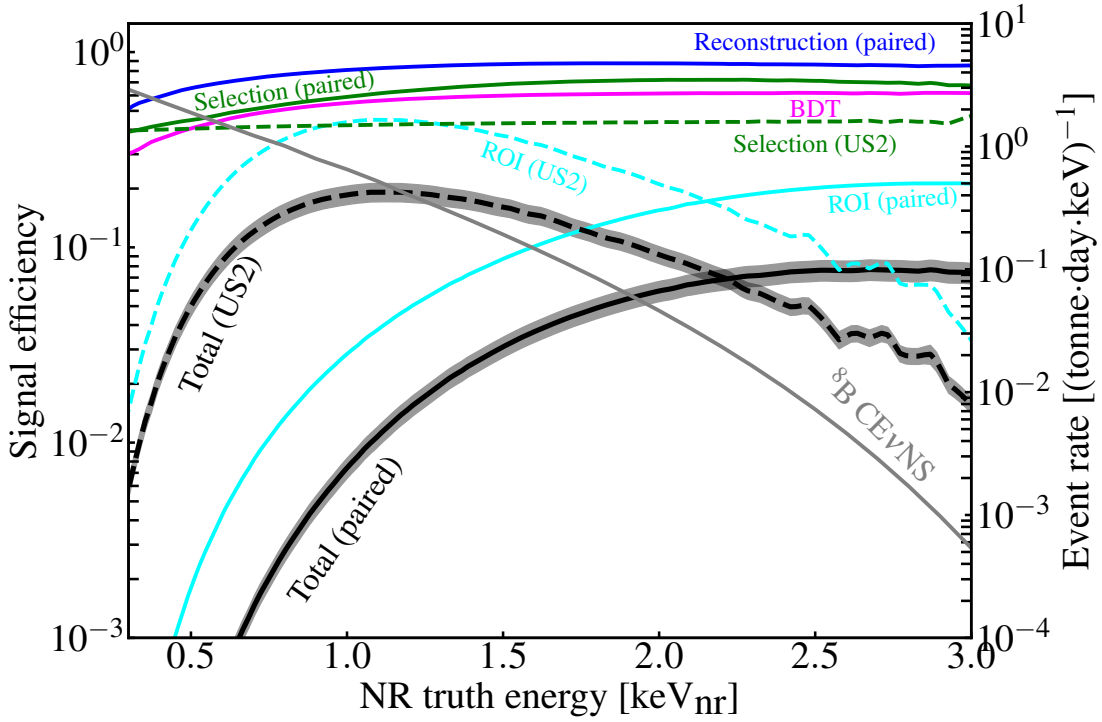


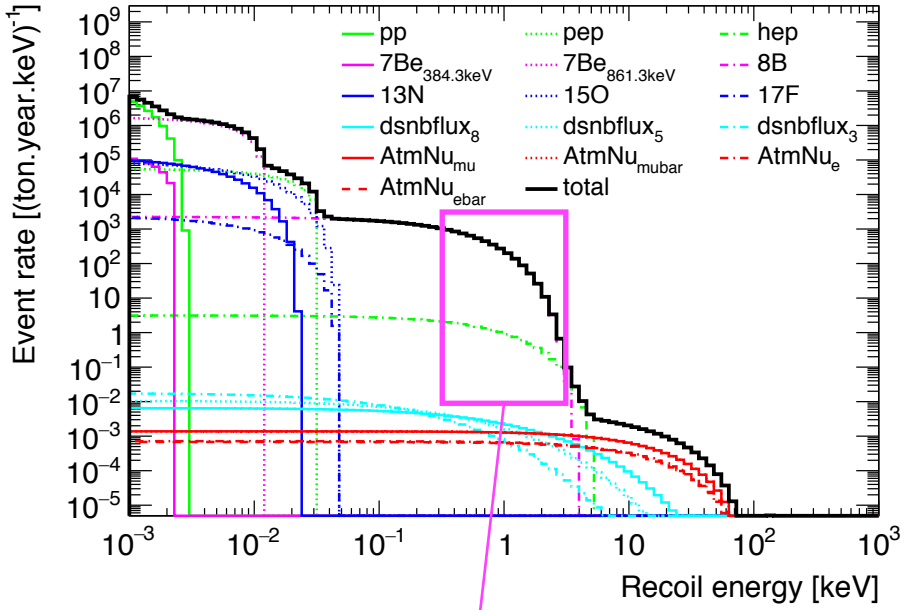
Further lowering energy threshold

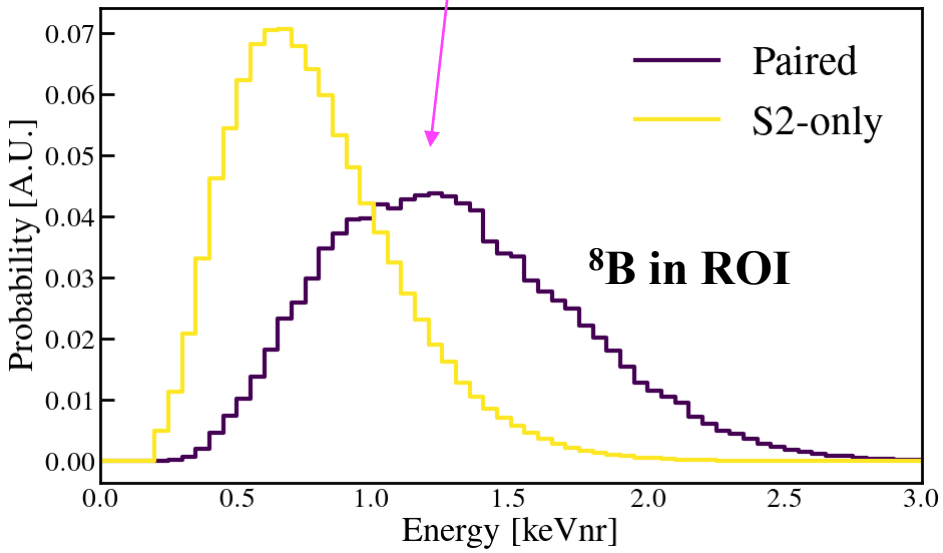
Low threshold detection mode:

- low threshold S1+S2 paired ROI (paired)
- Ionization S2-only ROI (US2)

Challenges: background control and signal model at ultralow energy



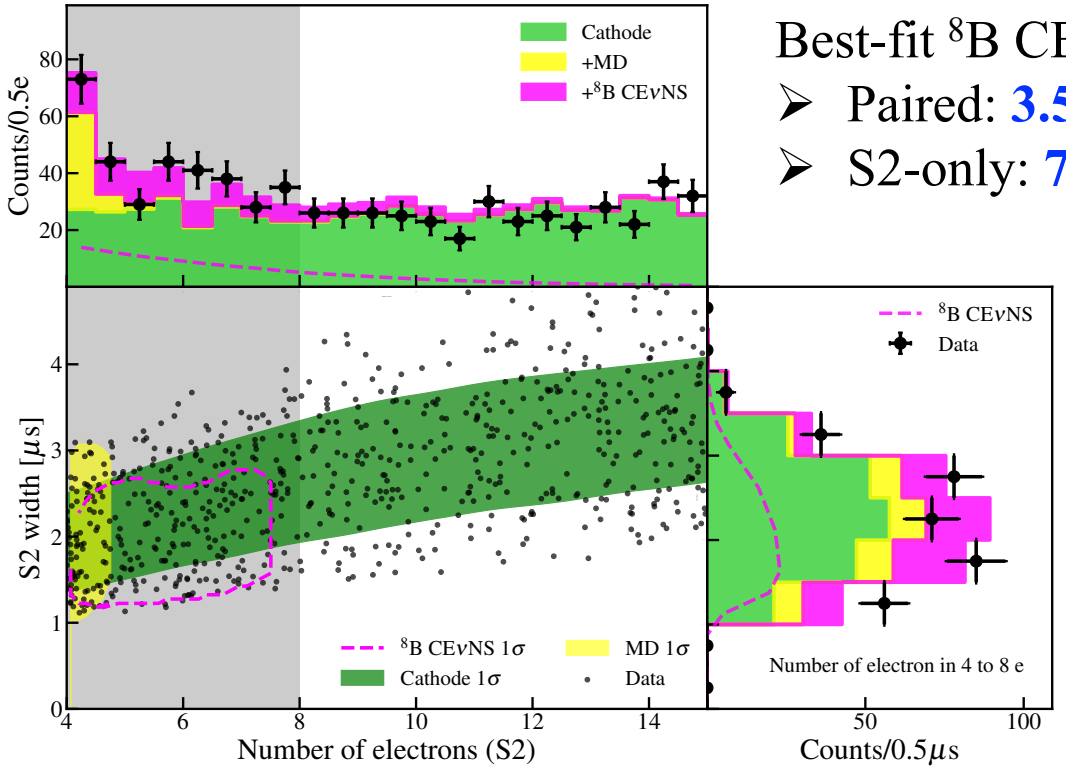




First indication of solar ^{8}B CEνNS signal

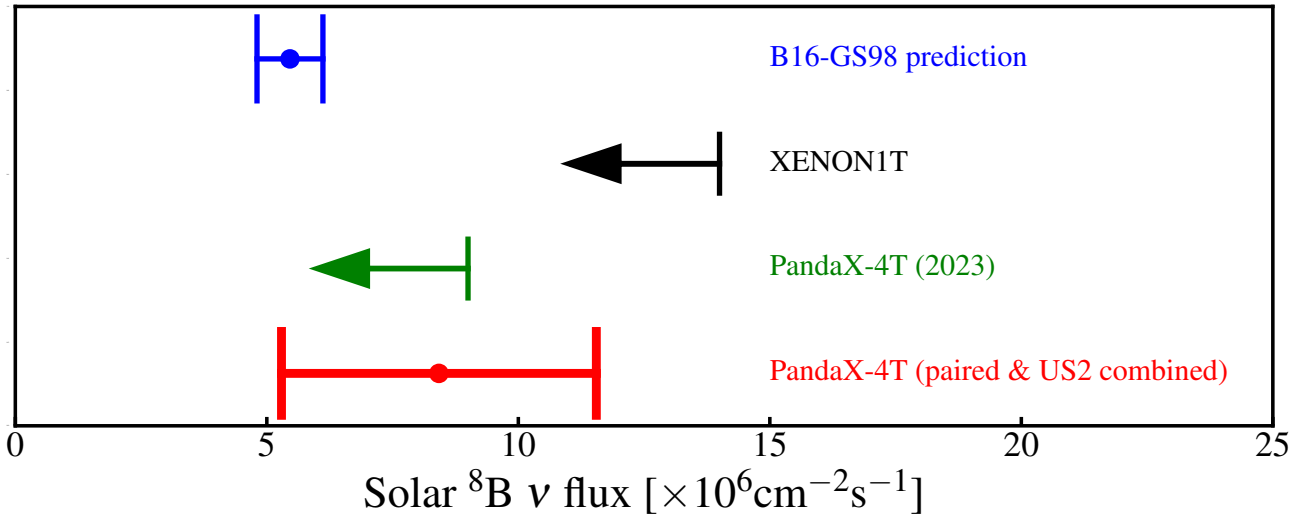
Run0 + Run1 dataset:

- Significance: 2.64σ
- Best-fit ^{8}B neutrino flux: $(8.4 \pm 3.1) \times 10^6$ cm^{-2} s^{-1}



Best-fit ^{8}B CEνNS signal:

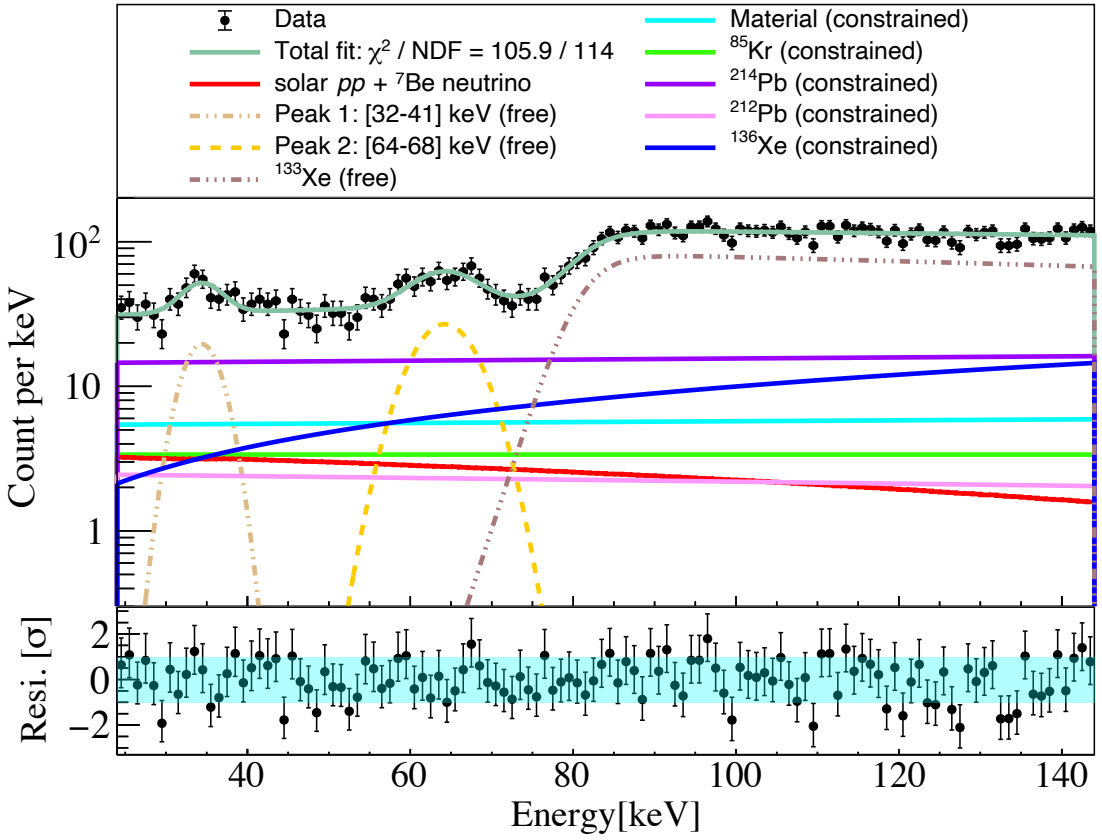
- Paired: **3.5 ± 1.3** evts
- S2-only: **75 ± 28** evts

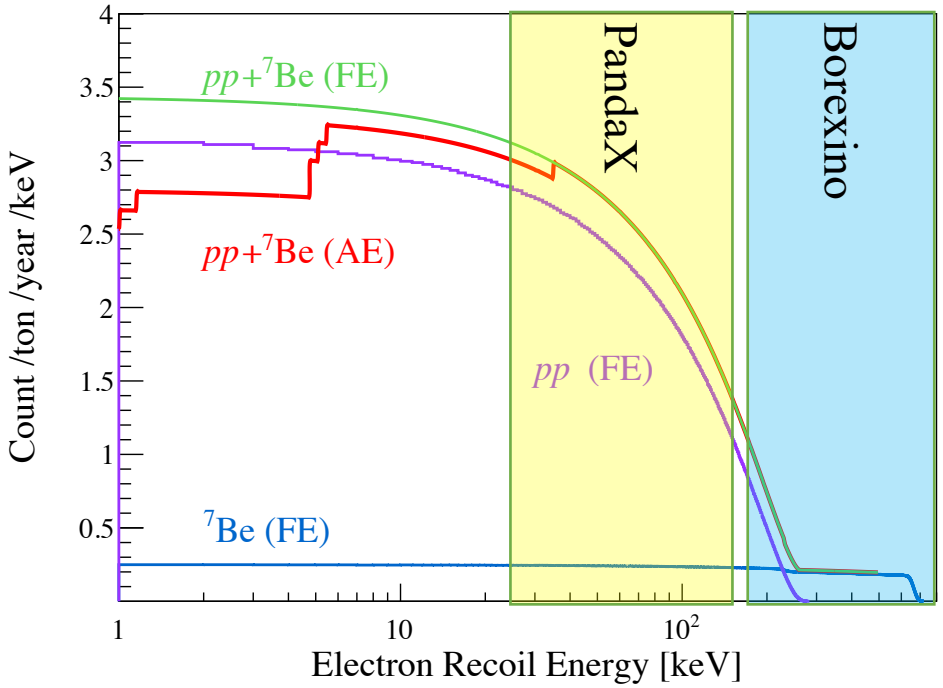


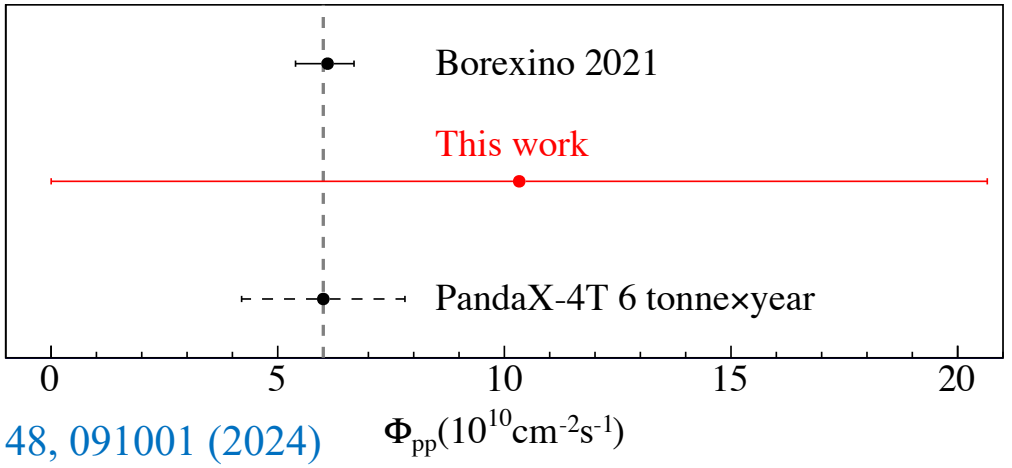
PRL 133, 191001 (2024)

An attempt: solar pp neutrino results with Run0

- World's leading result is from Borexino with a recoil energy of >165 keV
- PandaX-4T tried to measure the lower energy spectrum from 24 to 144 keV with a much smaller detector



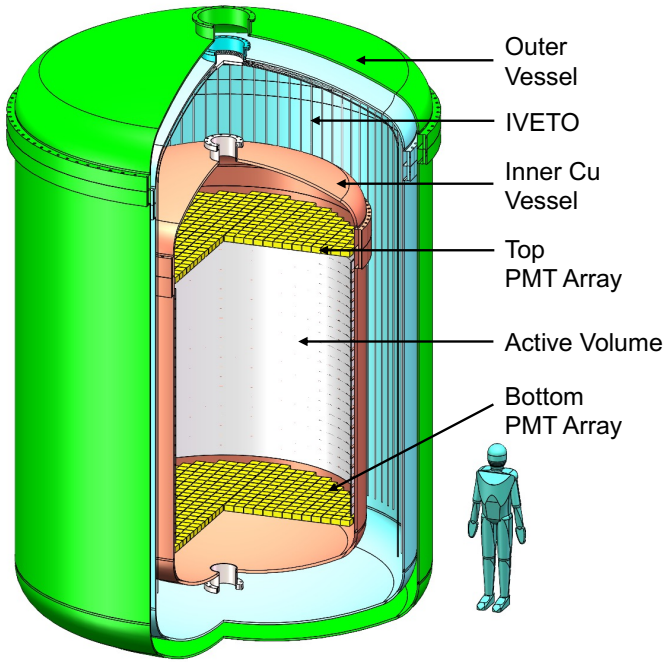


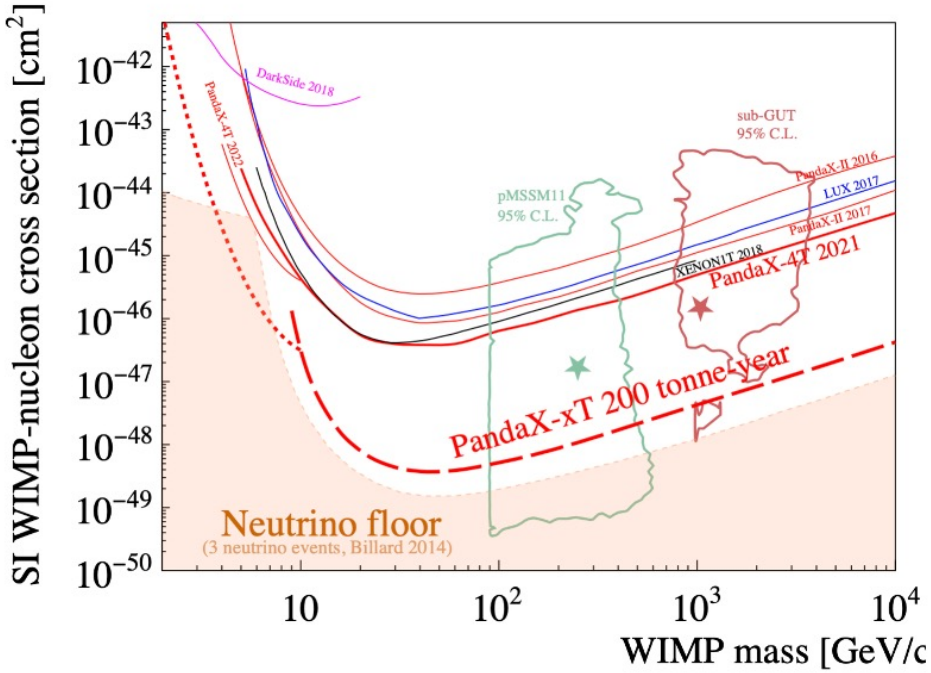


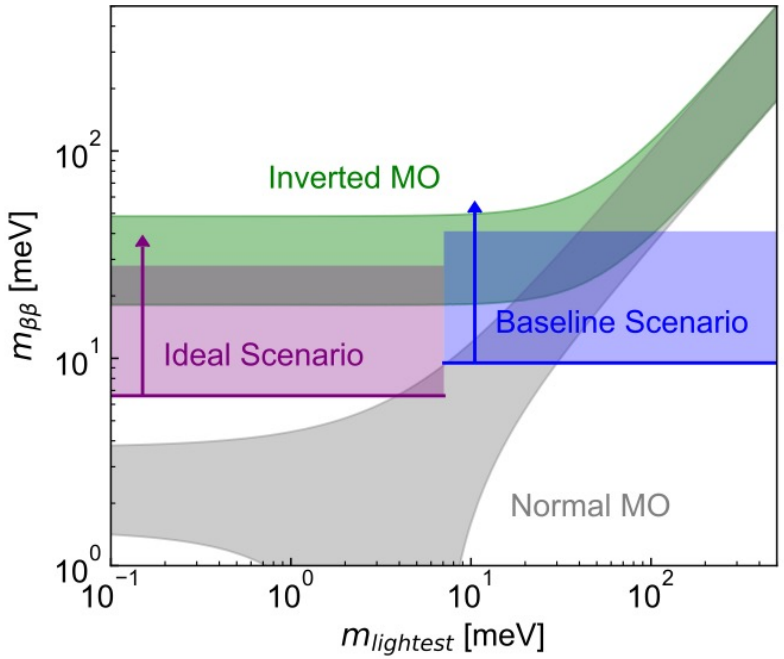
CPC 48, 091001 (2024)

Future plan: PandaX-xT

- **Staged plan, finally reaching 43 tonne natural Xe in sensitive volume**
- **Key tests on WIMP and Dirac/Majorana neutrino**





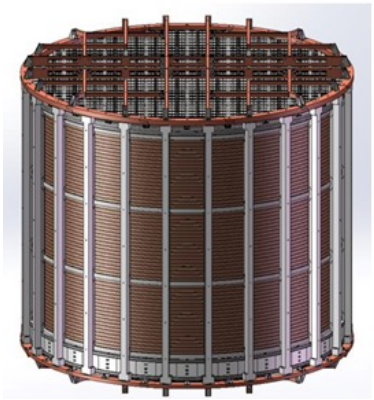


arXiv:2402.03596, **SCPMA** 68, 221011 (2025)

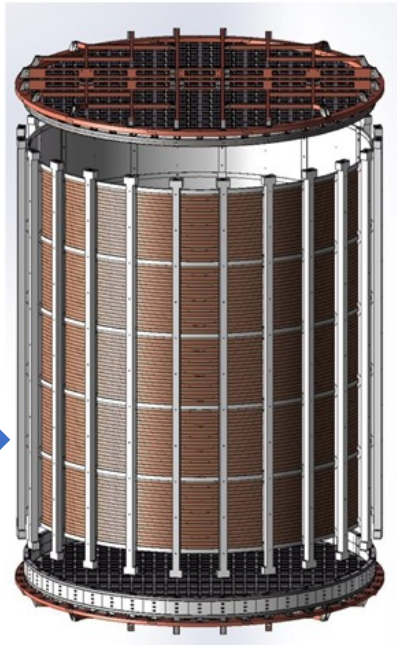
PandaX-20T: intermediate stage

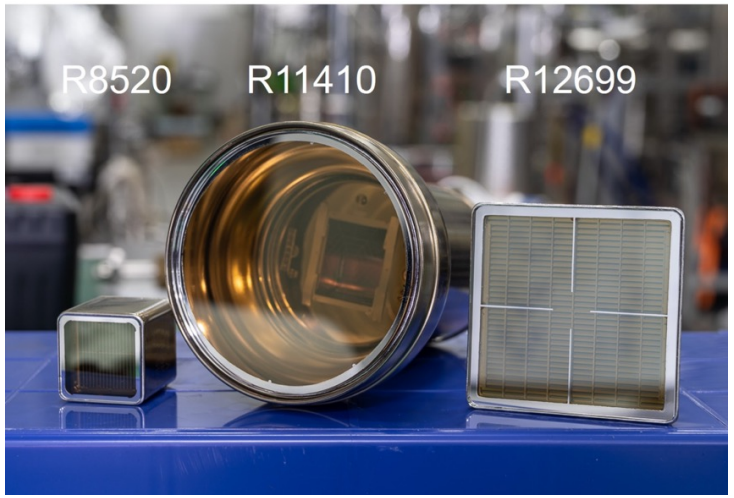
- **R&Ds already started**
- **Estimated timeline**
  - **2026: move to CJPL and assembling**
  - **2027: commissioning**

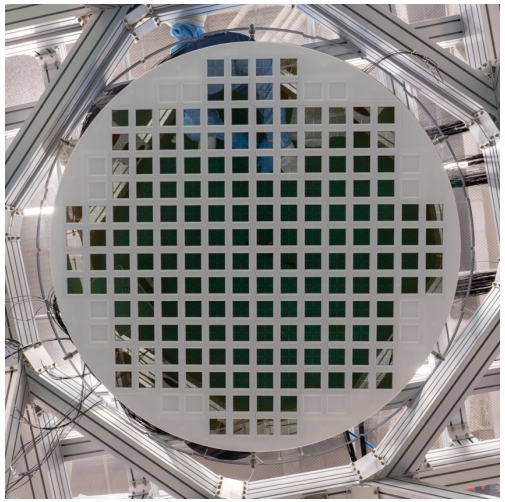
PandaX-20T

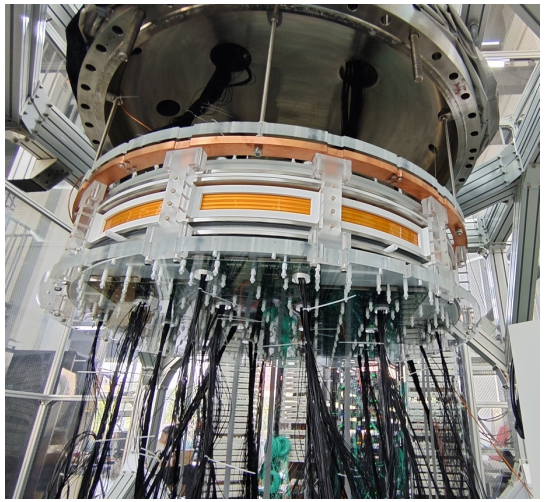


PandaX-xT

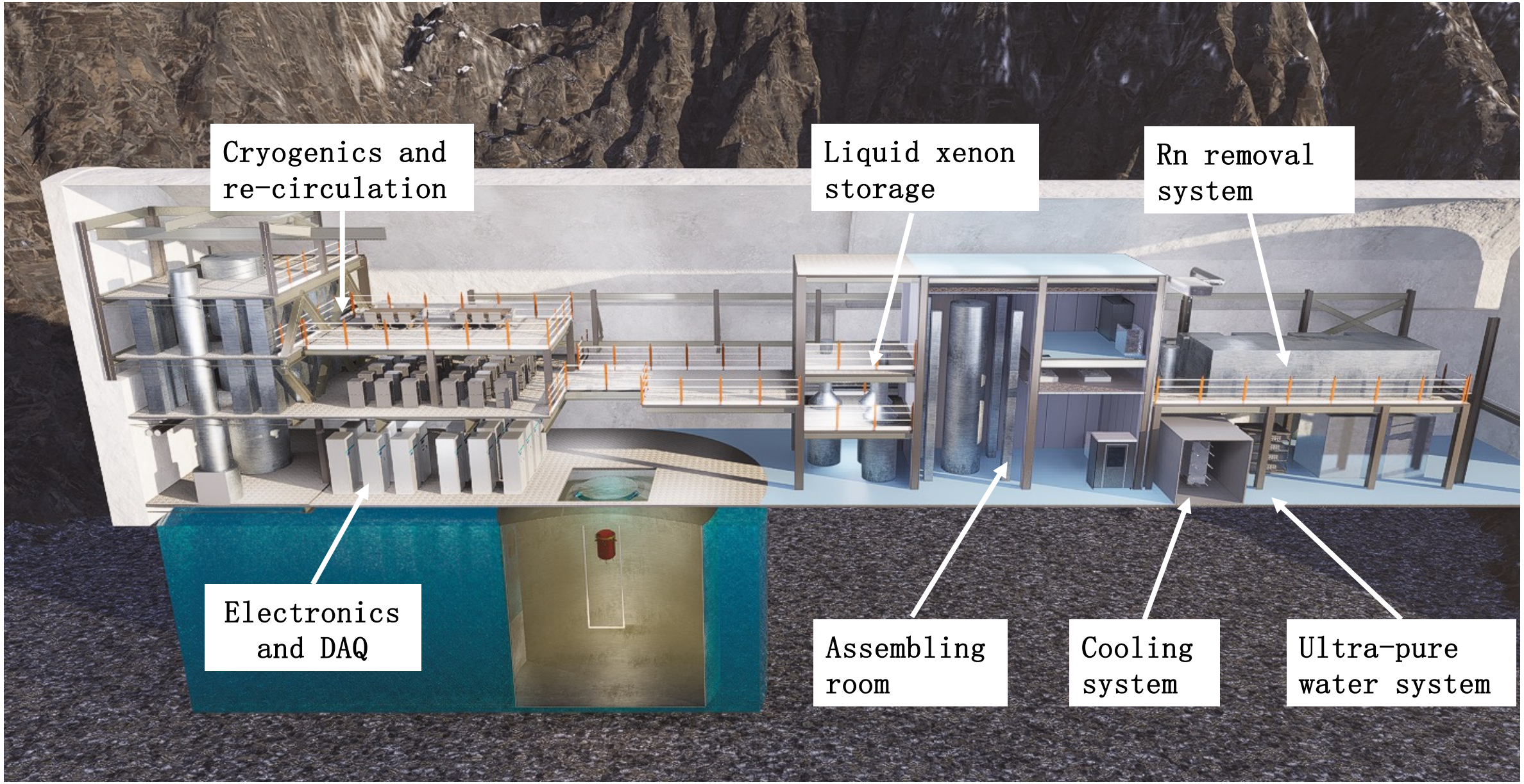








Planned layout for PandaX-xT at CJPL-II B2 Hall



PandaX-xT First Open Meeting

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

PandaX-xT First Open Meeting

Apr 10 – 11, 2025
Tsung-Dao Lee Institute
Asia/Shanghai timezone

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Summary

- Multi-physics observatory: PandaX-4T → PandaX-xT
- Continue PandaX-4T data-taking in 2025
- Next stage: PandaX-20T is planned to get online in 2027
- Highly welcome new collaborators!

Thank You !