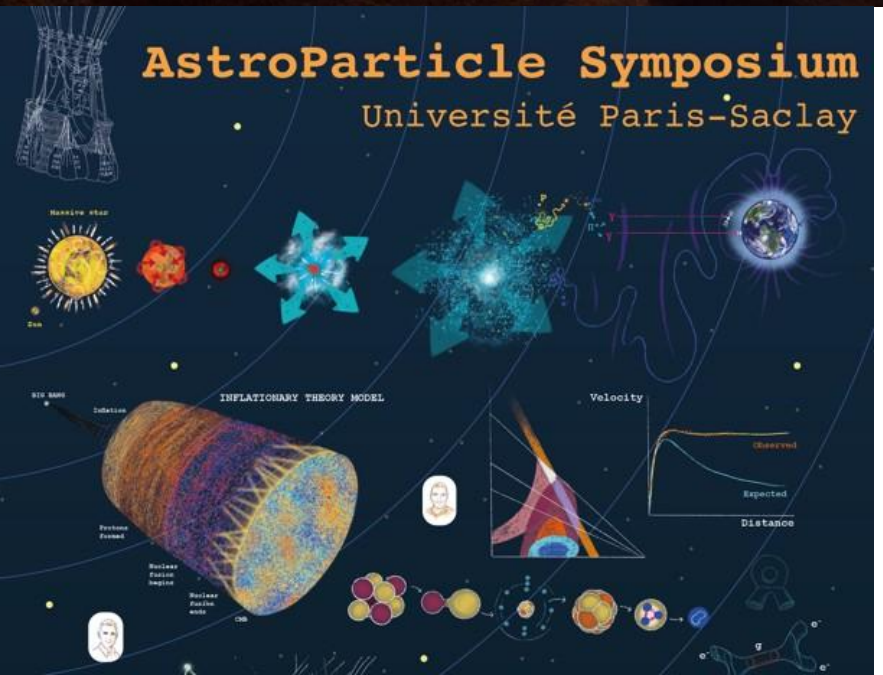
PandaX: Large Scale Underground Liquid Xenon Observatory for Dark Matter and Neutrinos



Shaobo WANG
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On behalf of the PandaX Collaboration

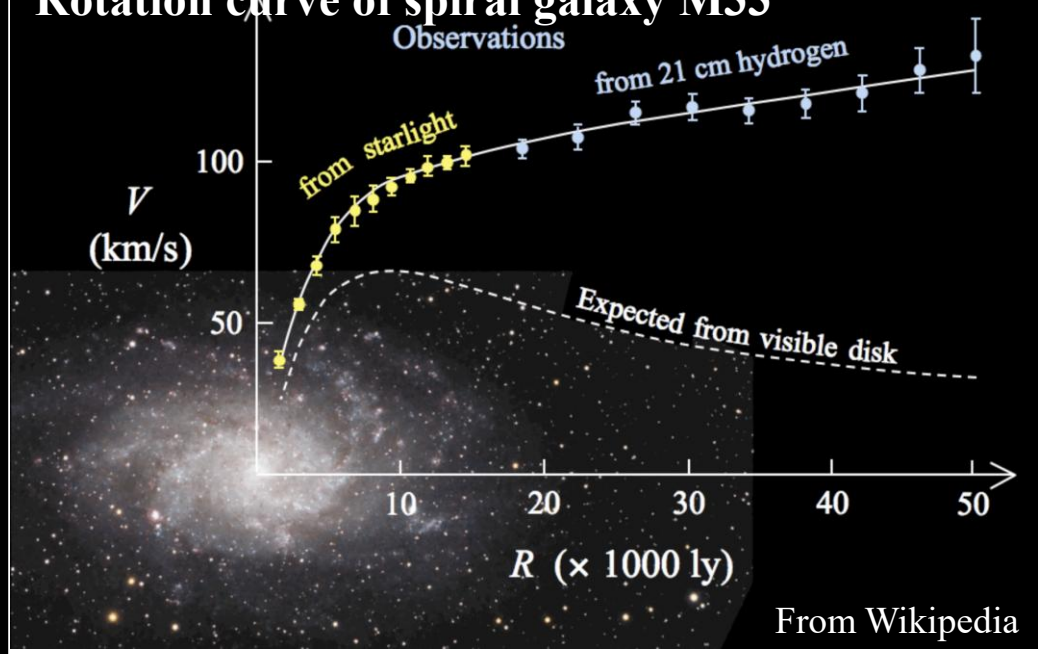
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Astroparticle Symposium 2025
2nd-7th Nov. 2025

Dark Matter

Rotation curve of spiral galaxy M33

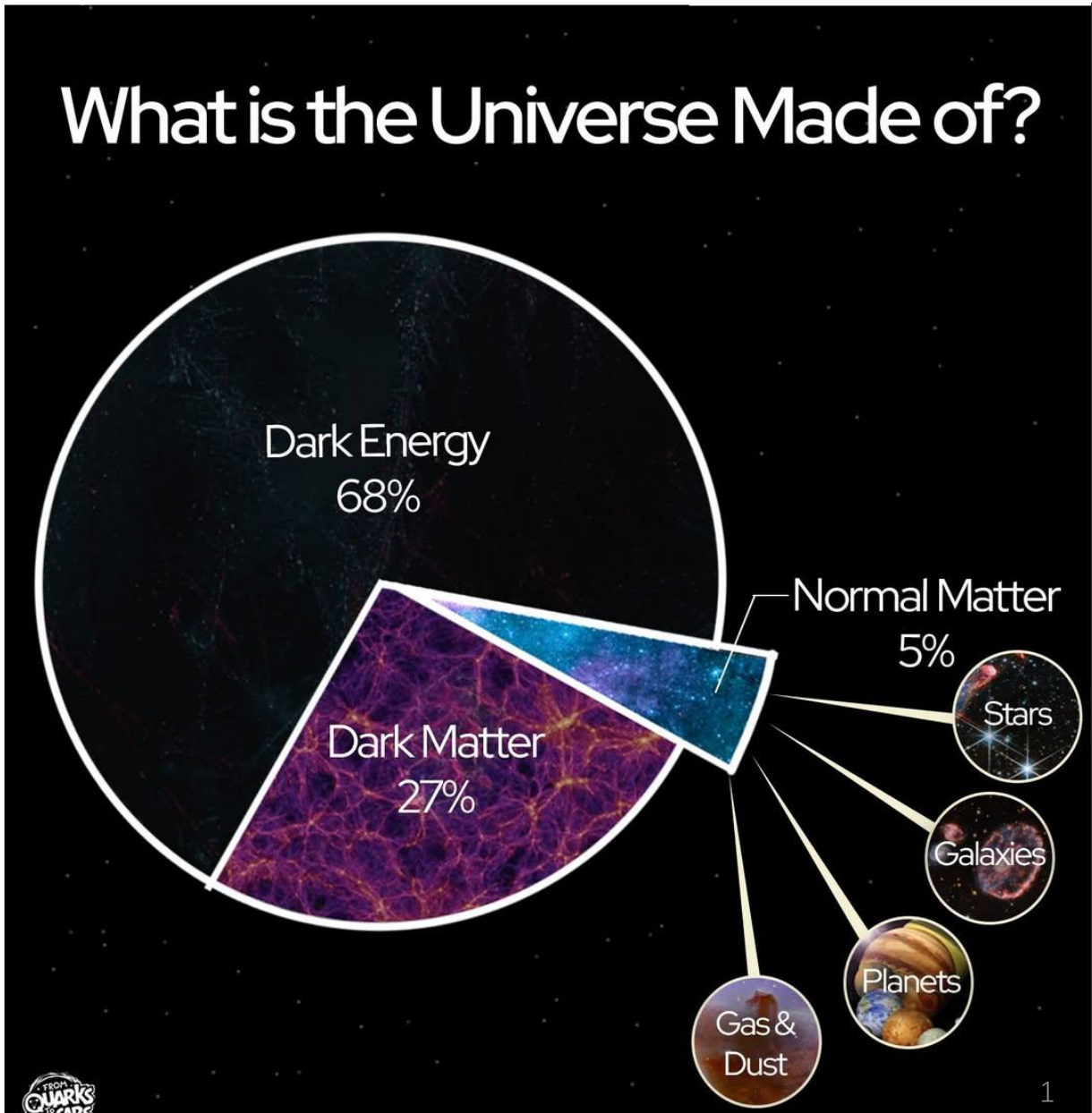


From Wikipedia

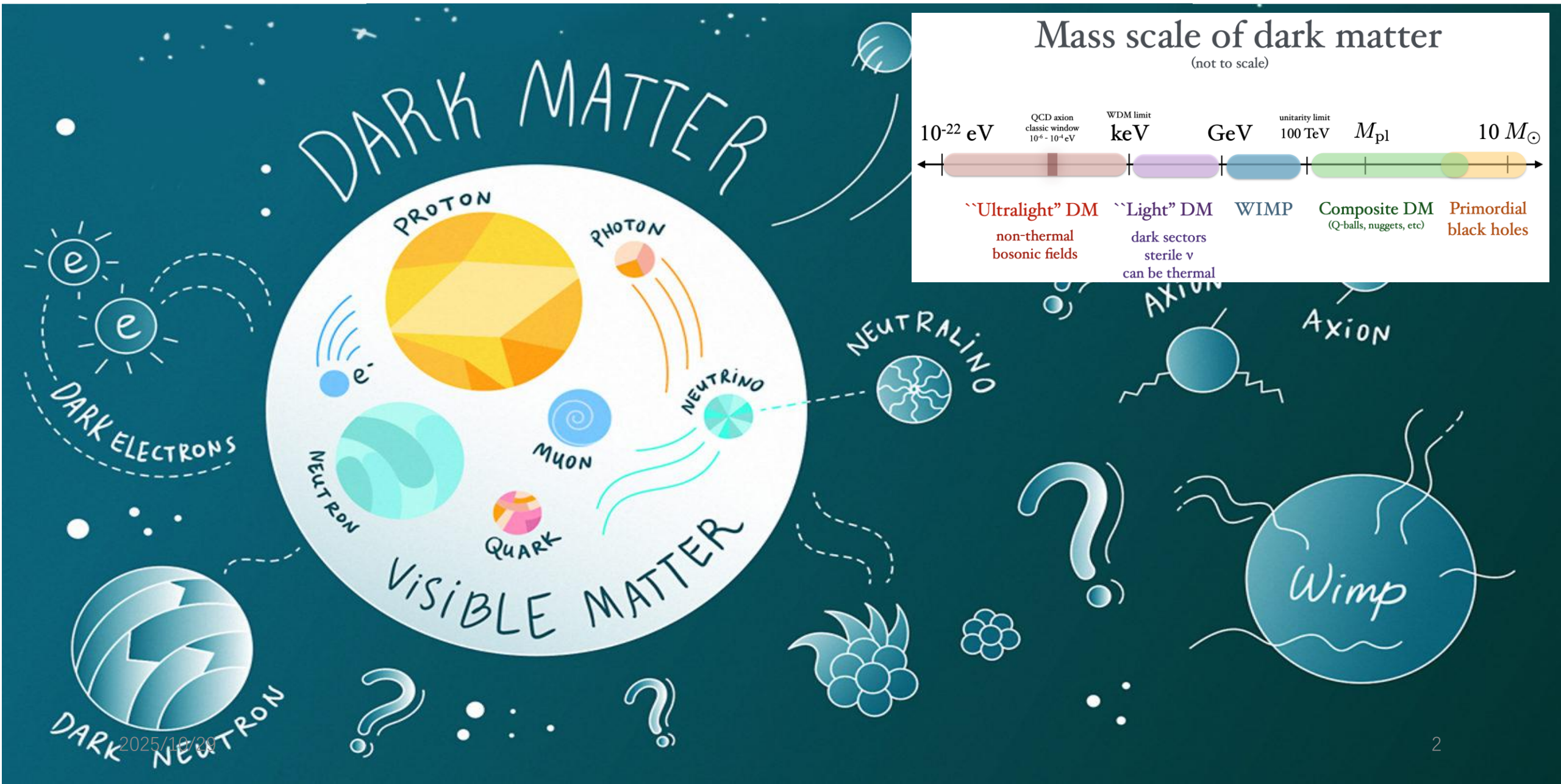
The solar system is cycling the center of galaxy with on average 220 km/s speed

Gravitational evidences suggest dark matter is the dominant form of matter in Universe!

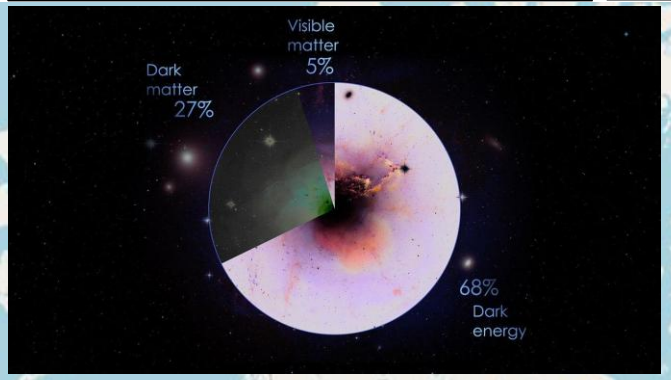
From Marc Schumann

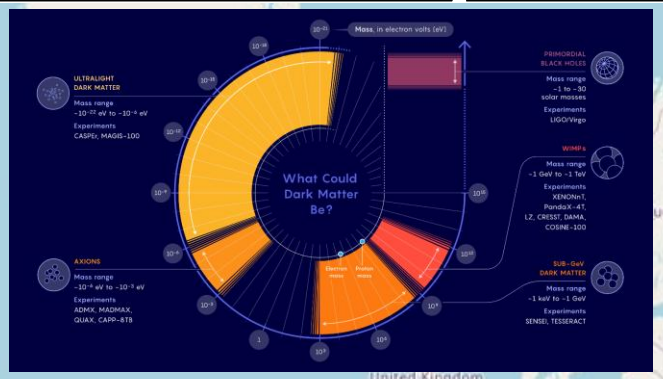


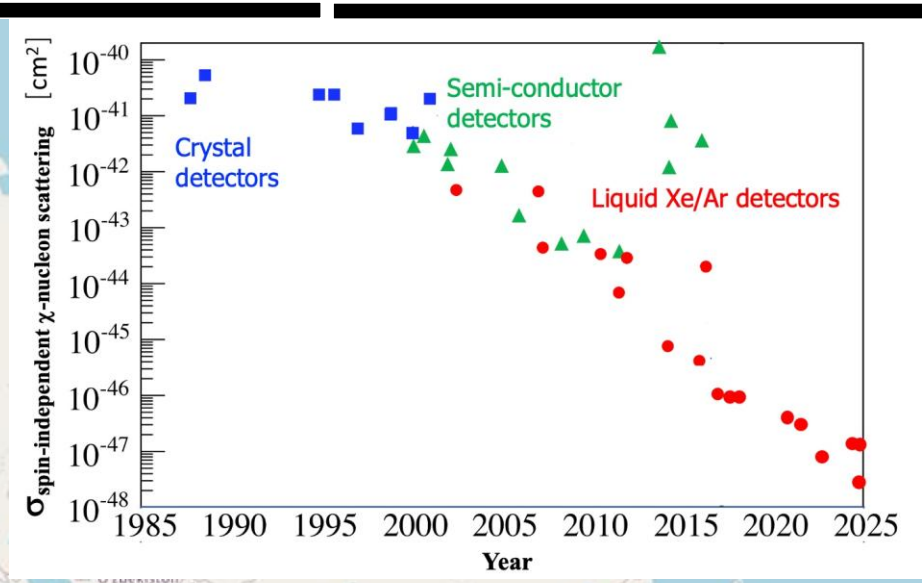
Dark Matter candidates



Liquid Xenon Experiments

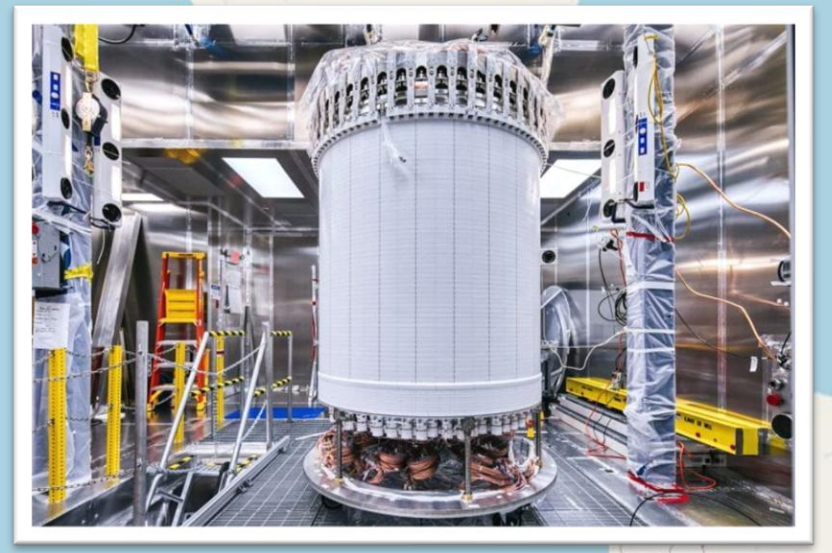






Sanford Lab, LZ

3

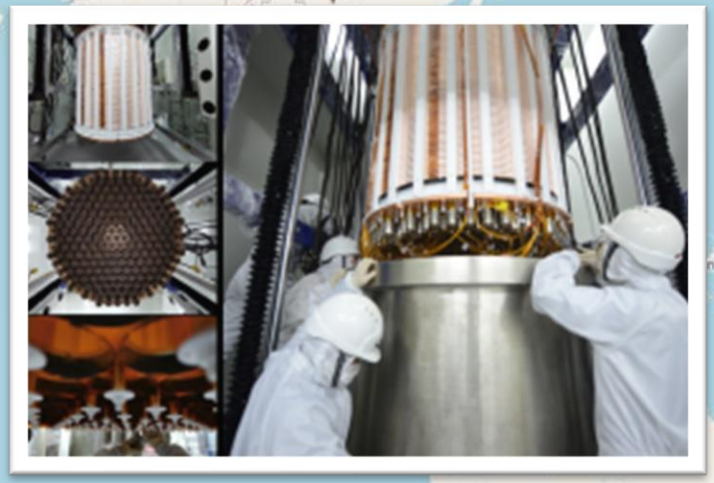


LNGS, XENONnT

2

CJPL-II, PandaX-4T

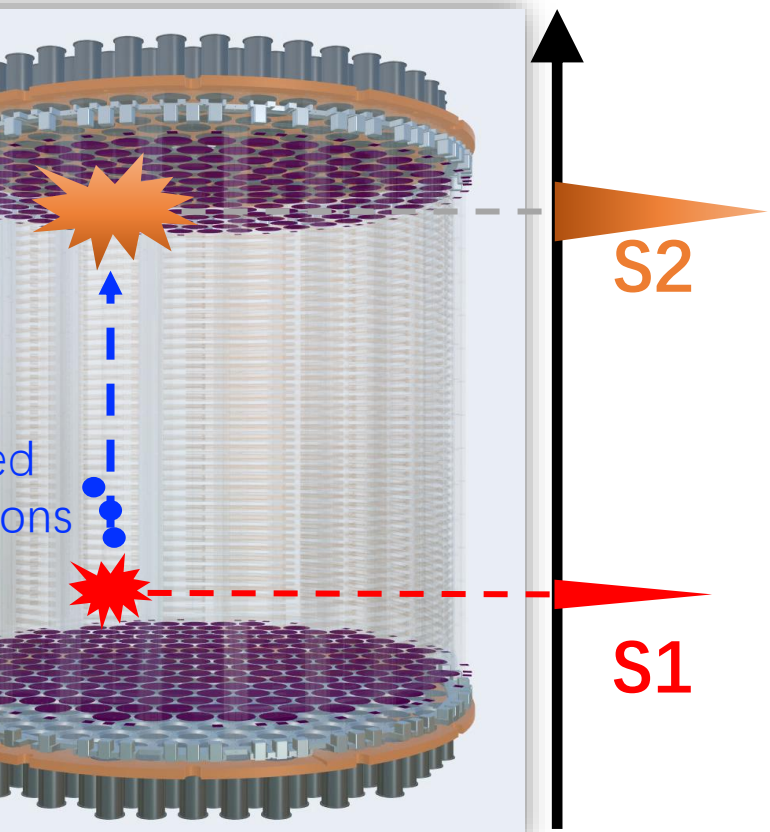
1

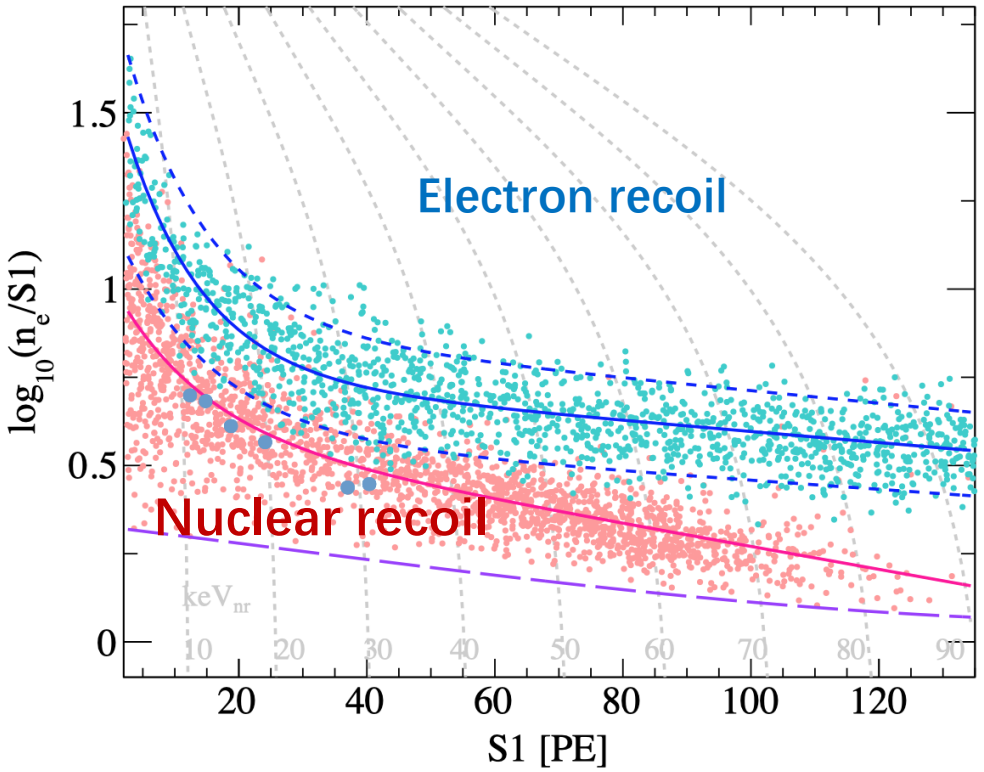


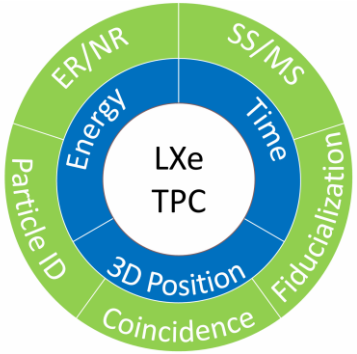
PandaX - Particle and Astrophysical Xenon

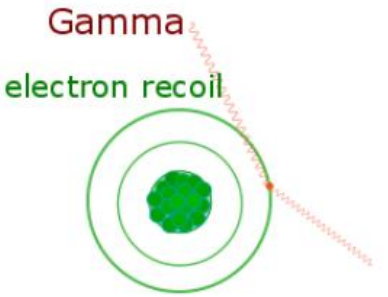
PandaX: Dual-phase Xe TPC

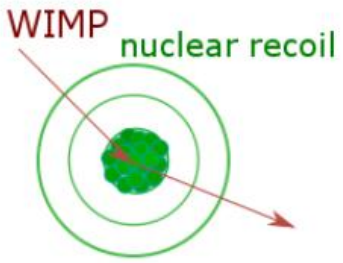
- **Paired scintillation (S1) and ionization (S2) signals**
  - Precise energy measurement and 3D position reconstruction
  - Discrimination of nuclear recoil (NR) and electron recoil (ER) signals











PandaX detectors

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

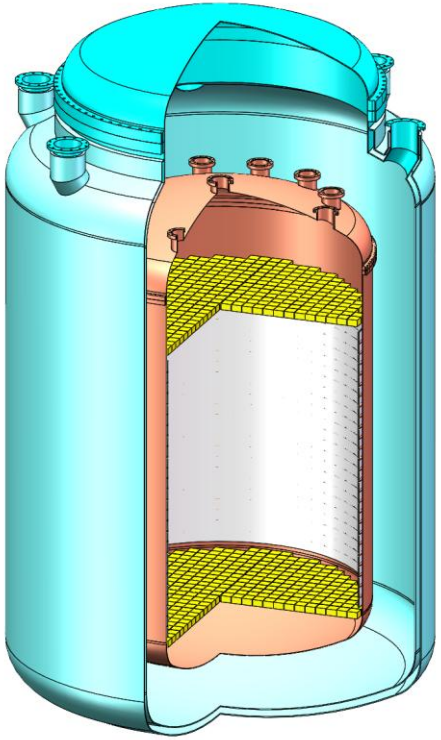
PandaX Start

PandaX-I
120 kg

PandaX-II
580 kg

PandaX-4T
3.7 tonne

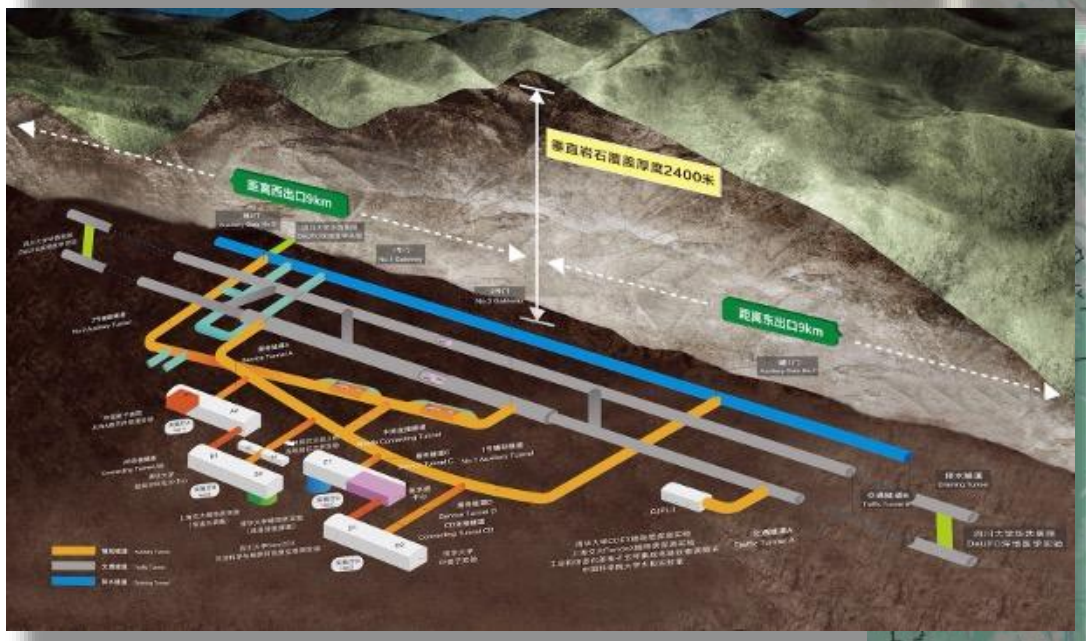
PandaX-xT



2009 | 2010-2014 | 2015-2019 | 2021- | 2027-

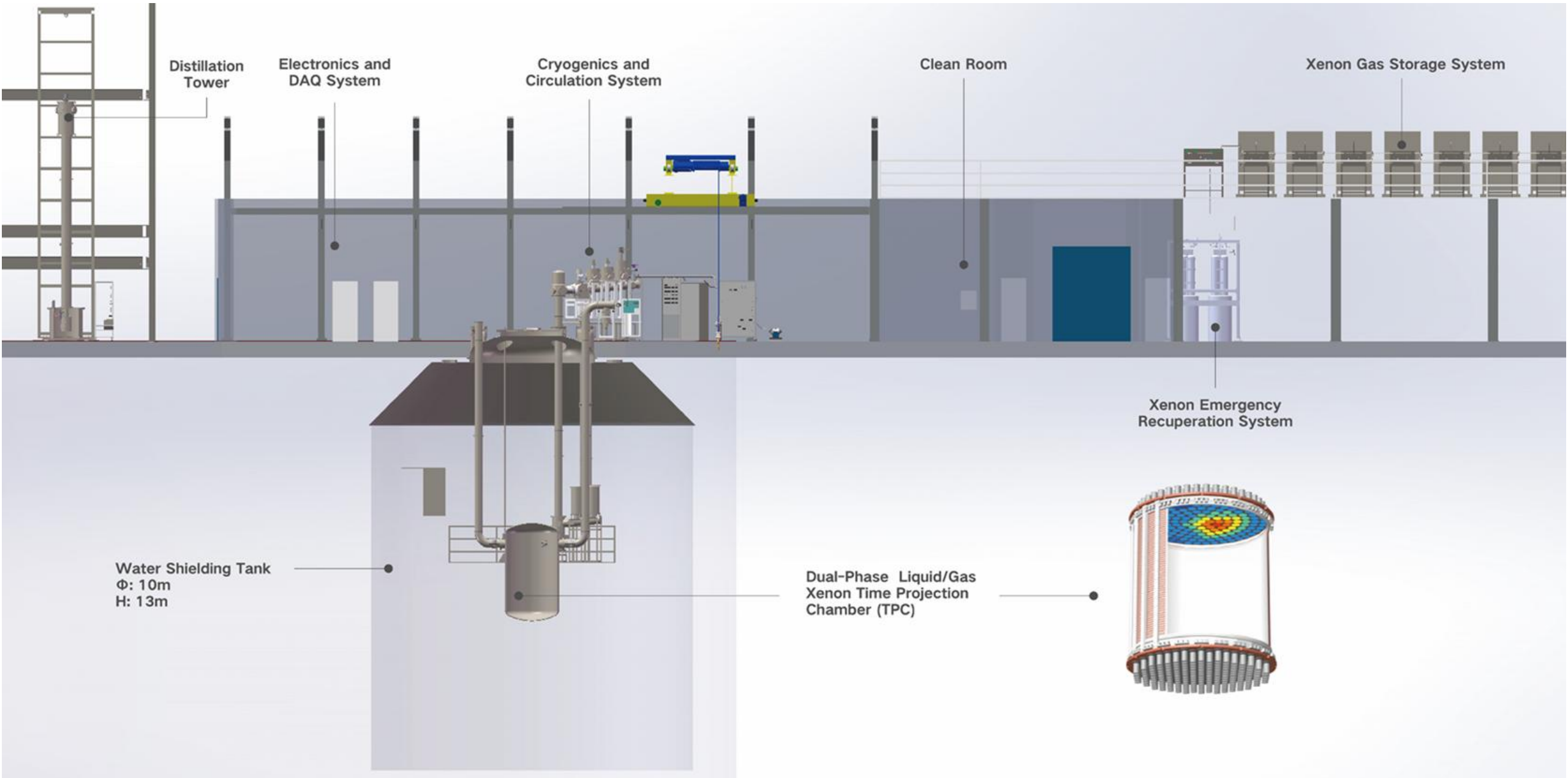
PandaX @ CJPL-II

China Jinping Underground Laboratory



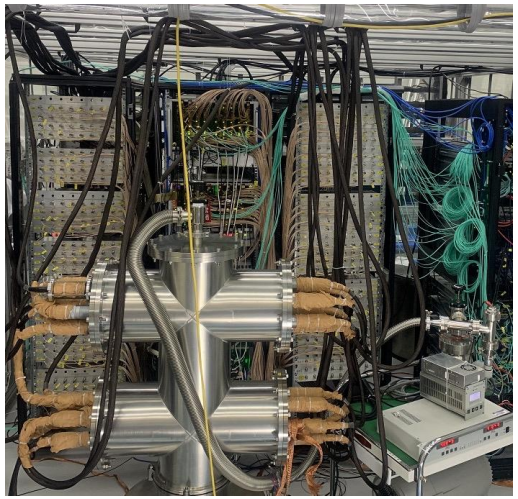
Co-developed by Tsinghua University and Yalong River Hydropower Inc.

PandaX-4T Layout



PandaX-4T @ CJPL-II B2

Distillation tower



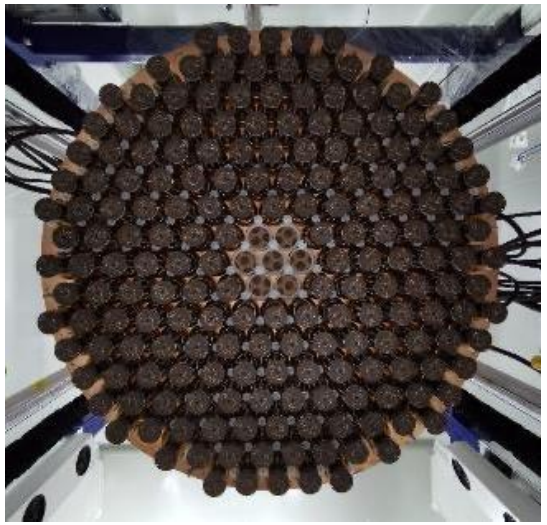
Electronics

Cryogenics system

Gas storage system

Water shielding

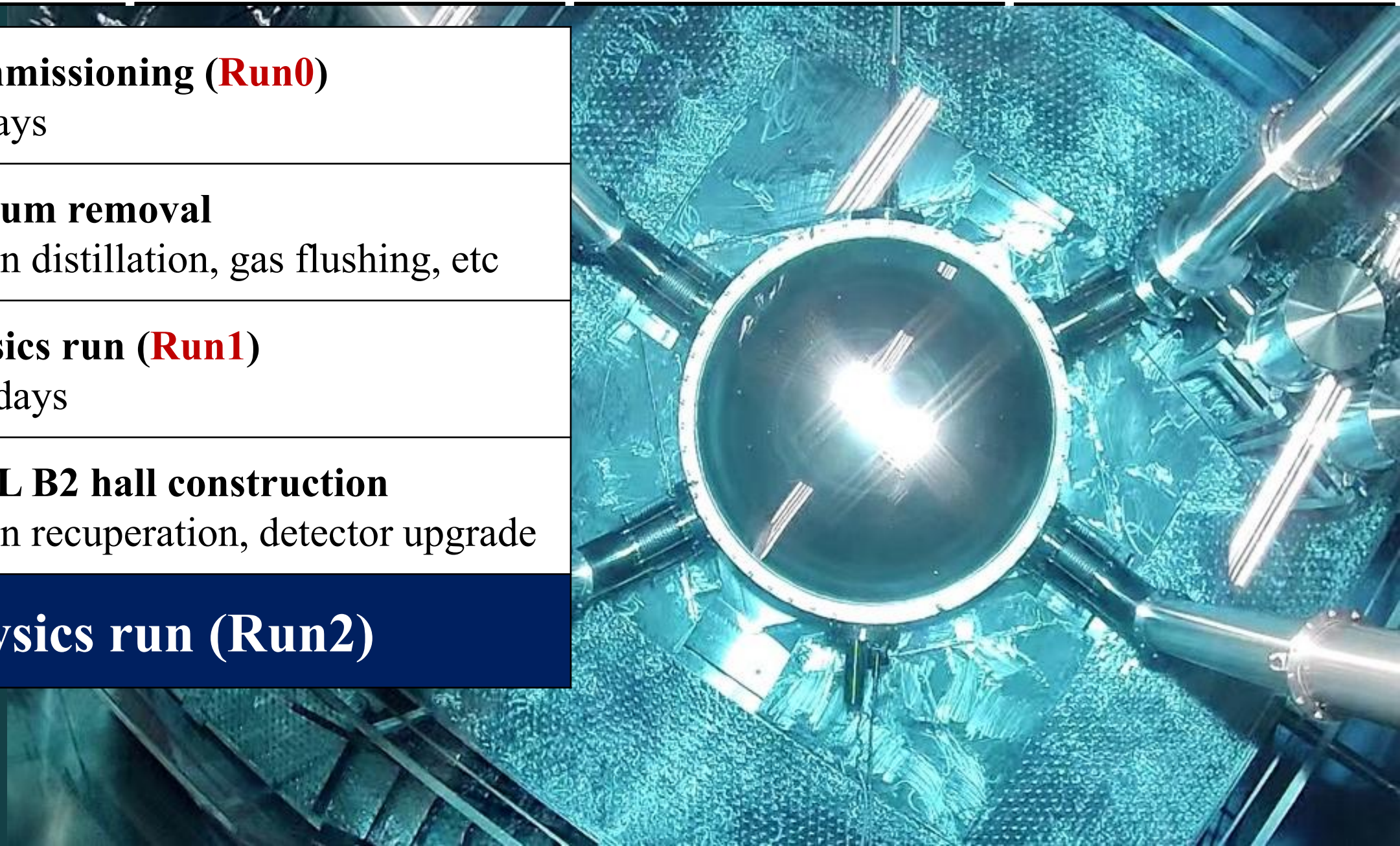
TPC



PMT array

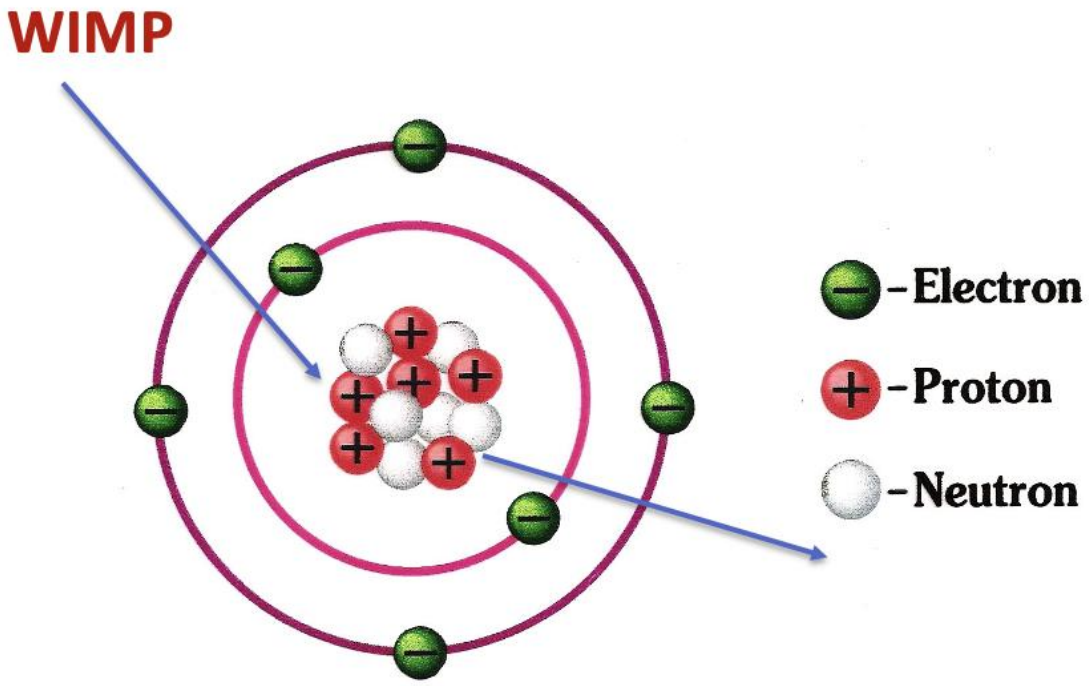
PandaX-4T Physics Run

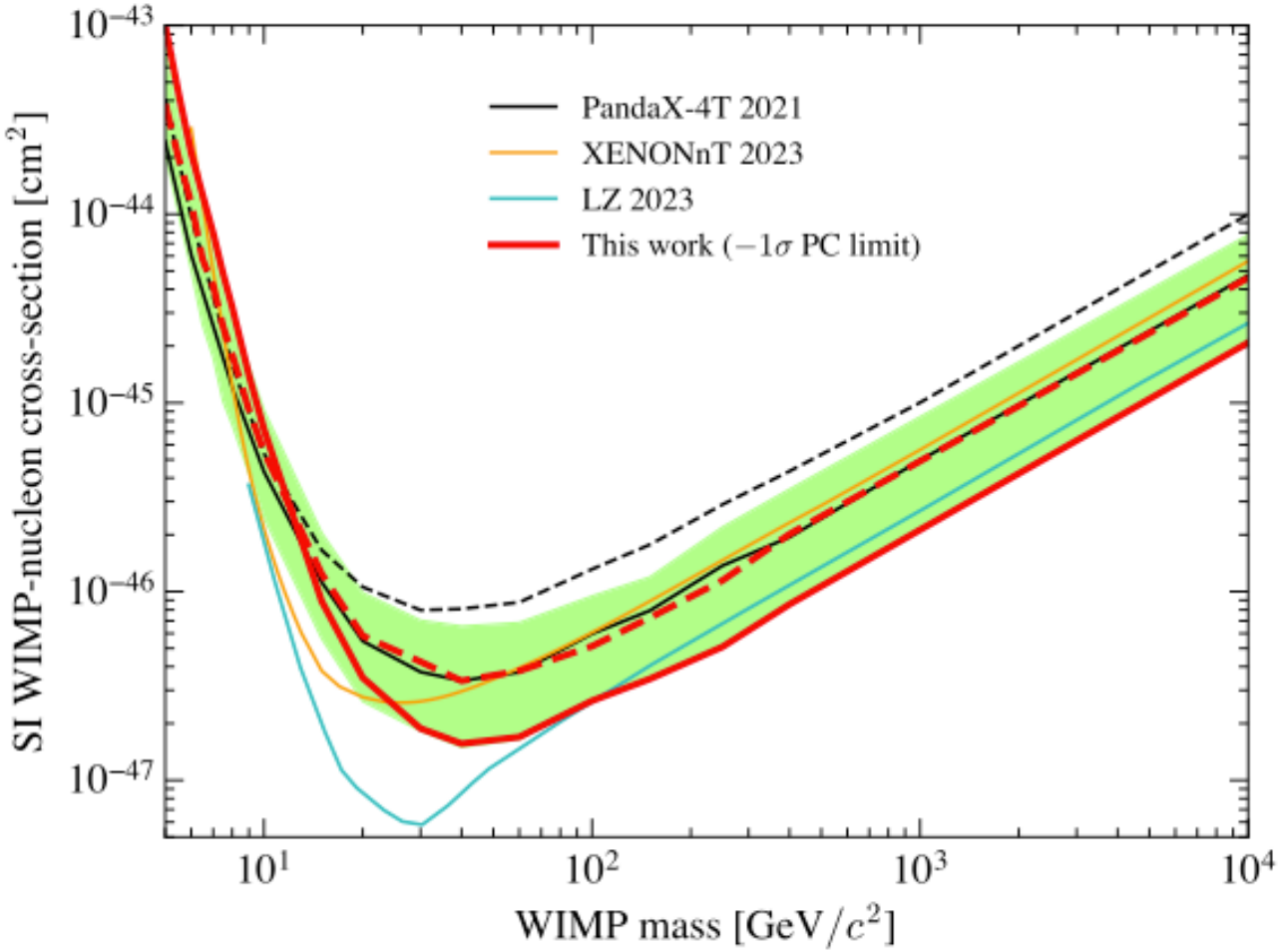
2020/11 – 2021/04	**Commissioning (Run0)** 95 days
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc
2021/11 – 2022/05	**Physics run (Run1)** 164 days
2022/09 – 2023/12	**CJPL B2 hall construction** xenon recuperation, detector upgrade
Current Status	**Physics run (Run2)**



WIMP-Nucleus Scattering

- **Cross section exclusion @ 40GeV/c^2 : 1.6×$10^{-47}$$cm^2$**
- **Leading constraints for DM mass above 100 GeV/c^2**

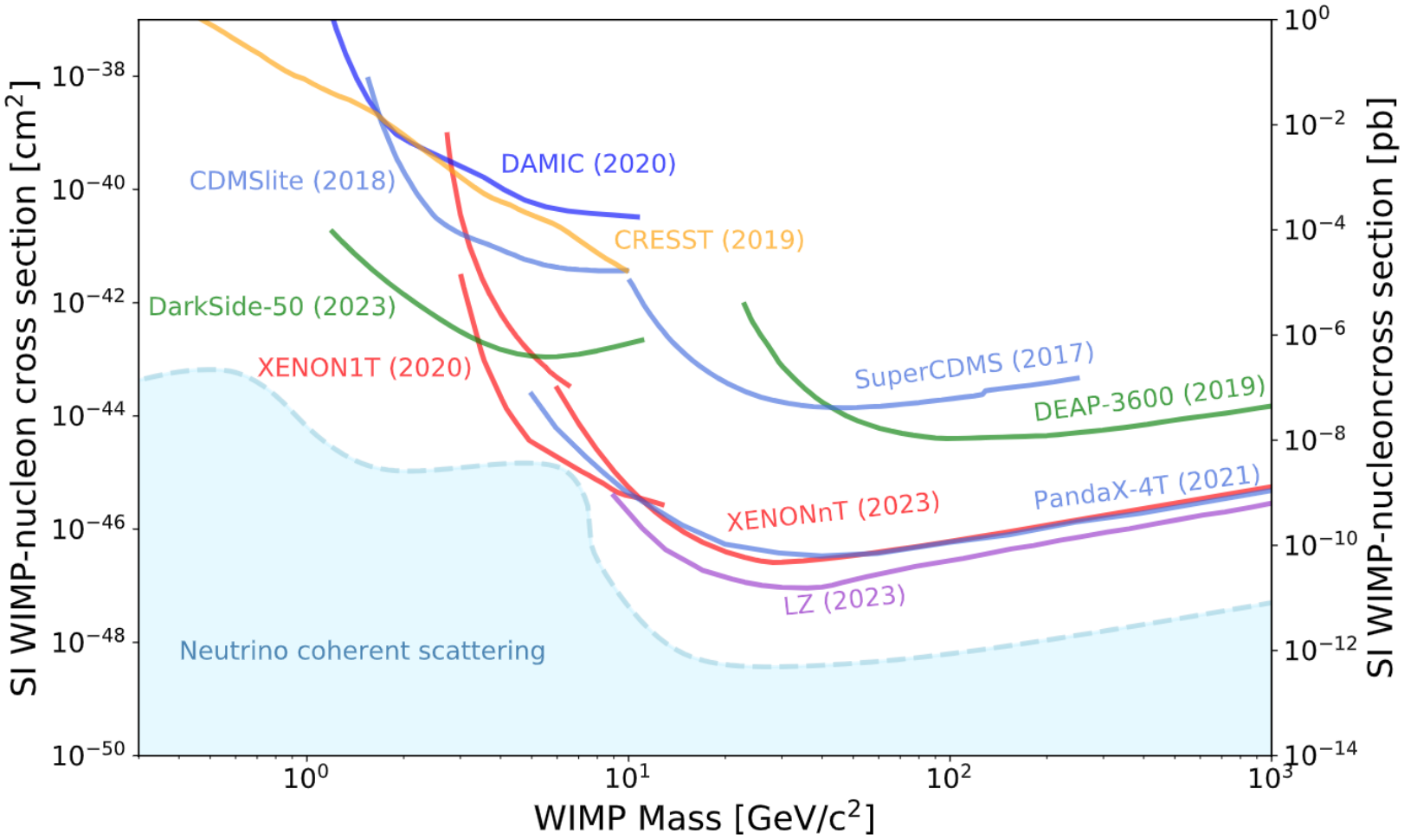




PandaX Collaboration: ***PRL*** *134, 011805 (2025)*

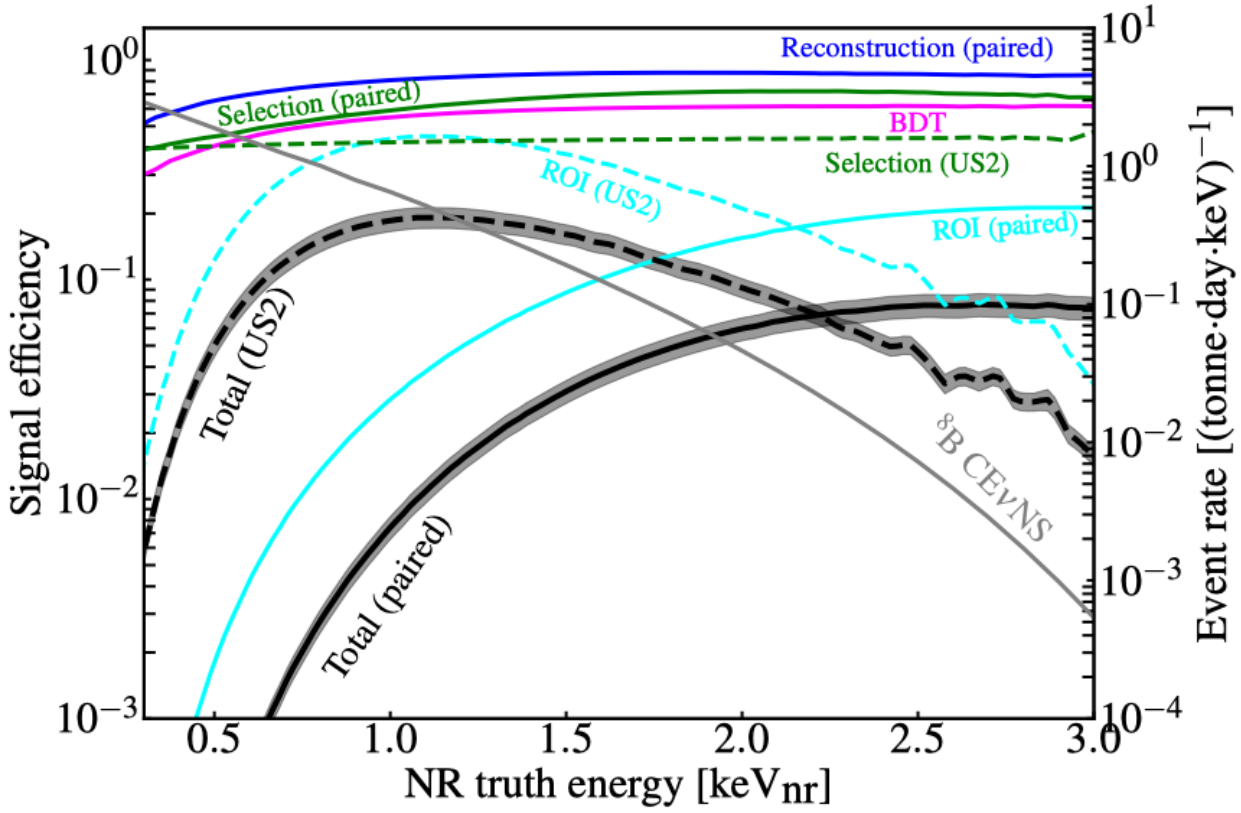
Towards Low Mass Dark Matter

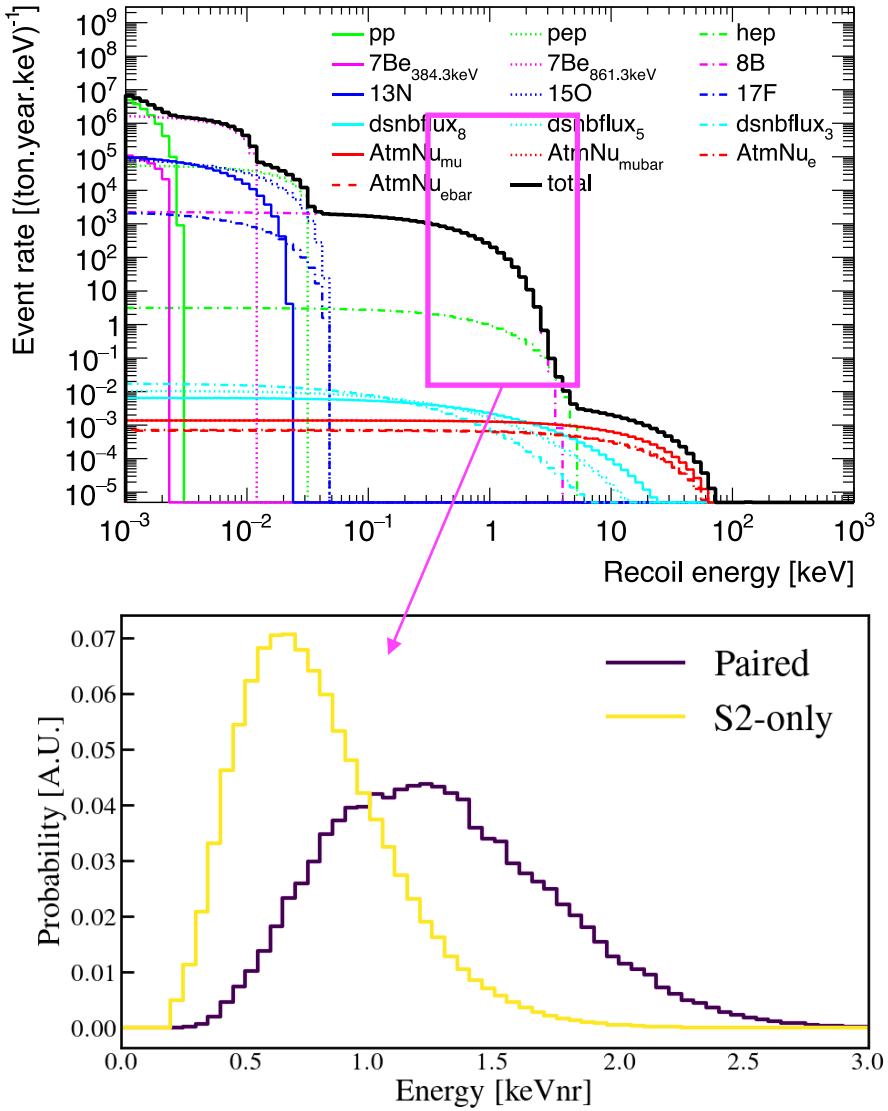
- **LXe sensitivity decreases significantly for DM mass < 10 GeV/c^2**
  - Limited by scintillation light signal detection



Low-threshold Detection

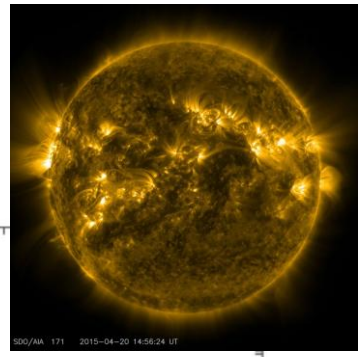
- **Low threshold detection: NR threshold ~3keV → ~0.3keV**
  - Low threshold paired ROI
  - Ionization S2-only ROI

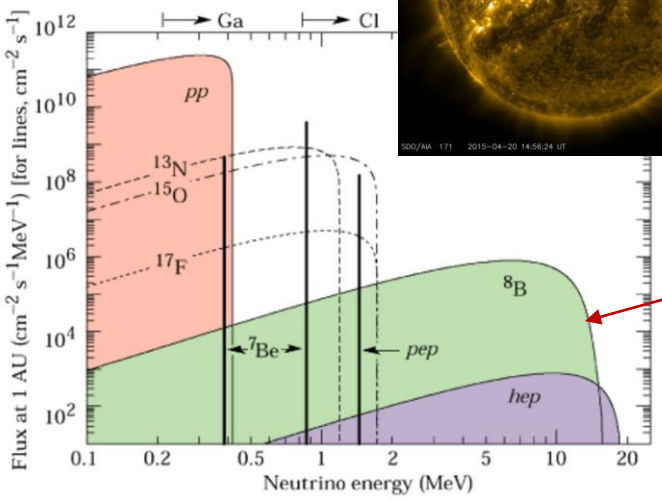


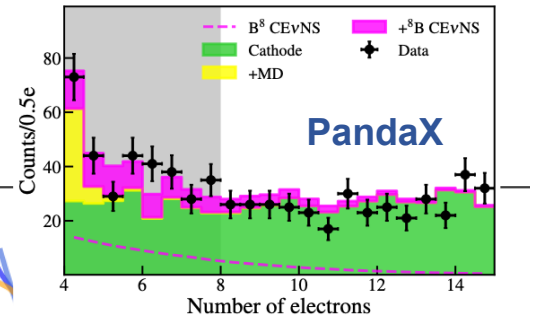


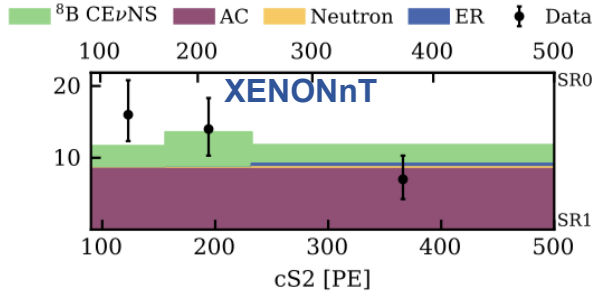
Low-threshold Detection

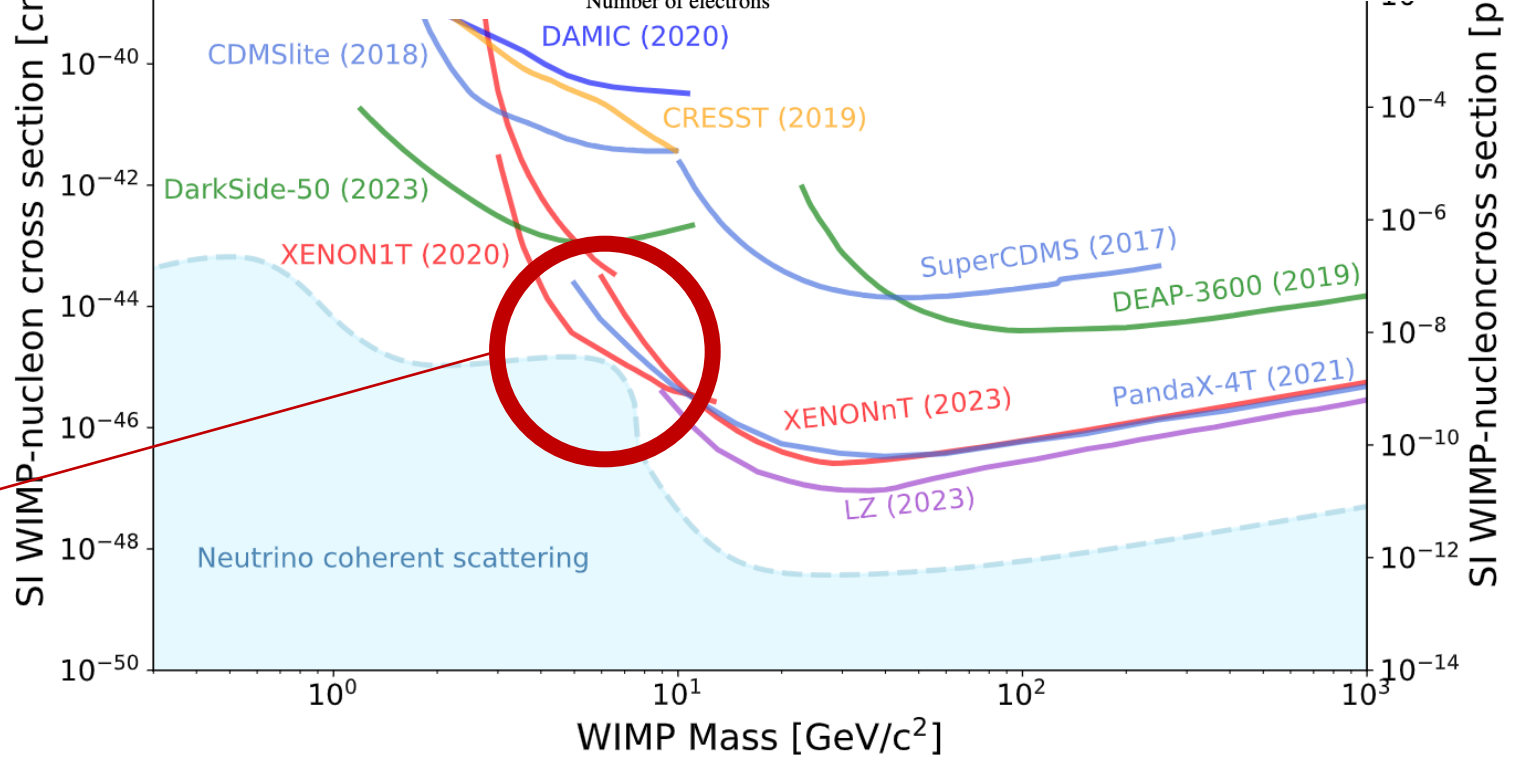
- **LXe sensitivity decreases significantly for DM mass < 10 GeV**
  - Limited by scintillation light signal detection
- **Low threshold detection**
  - Solar ^{8}B neutrino CEvNS





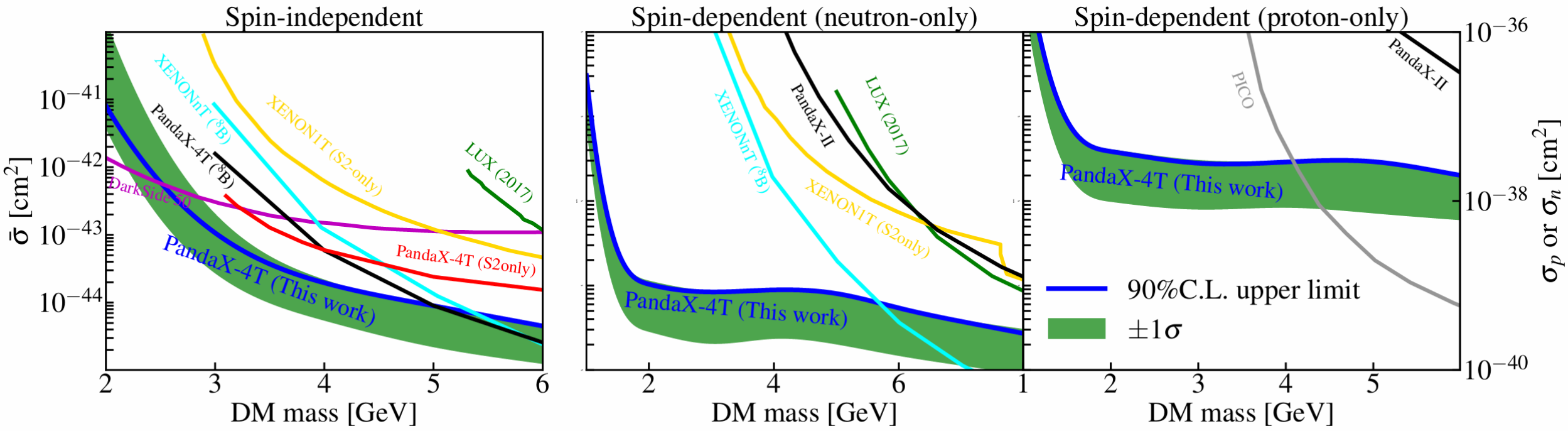






Low-threshold Detection for Low Mass

- **Extending LXe high-sensitive region to 2–6 GeV/c^2**
- **SI ~10^{-41}–10^{-44}cm^2, SD-neutron ~10^{-39}cm^2, SD-proton ~10^{-38}cm^2**



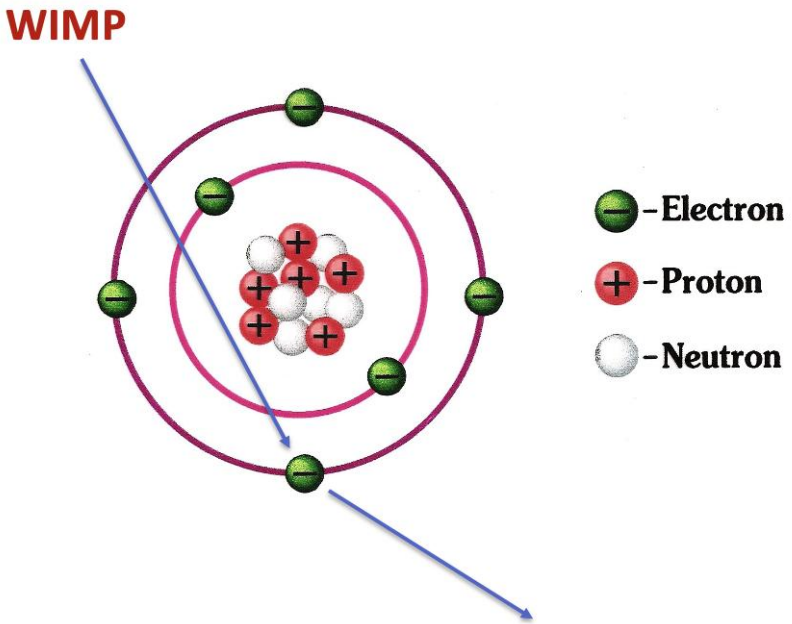
PandaX Collaboration: Arxiv 2507.11930 **(accepted by *PRL*)**

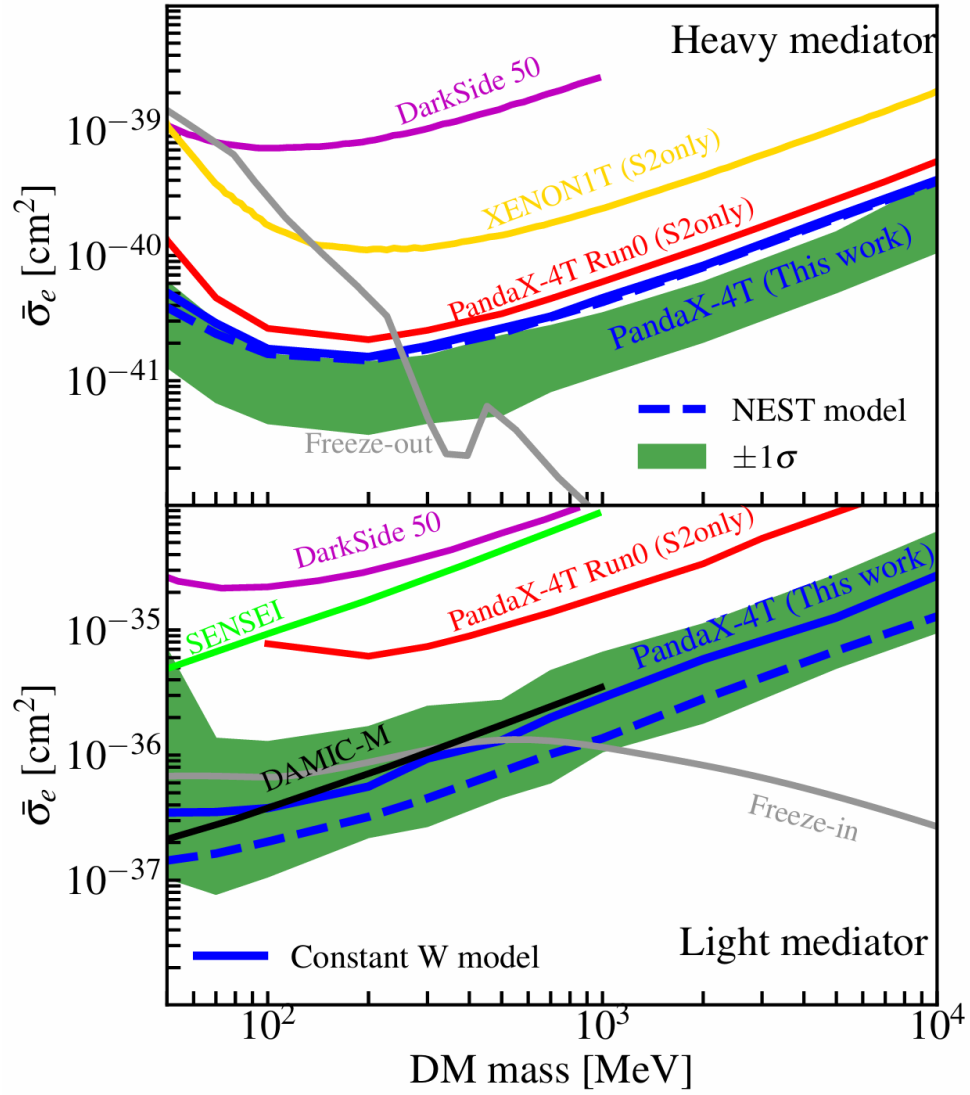
WIMP-Electron Scattering

- **Probing DM mass ~100MeV/c² in LXe**
- **Heavy mediator or light mediator**

$$\frac{dR}{d\ln E_{\rm er}} = N_T \frac{\rho_\chi}{m_\chi} \sum_{nl} \frac{d\langle \sigma^{nl}_{\rm ion} v\rangle}{d\ln E_{\rm er}}$$

$$\frac{d\langle \sigma^{nl}_{\rm ion} v\rangle}{d\ln E_{\rm er}} = \frac{\overline{\sigma}_e}{8\,\mu^2_{\chi e}} \int dq\, q\, |f^{nl}_{\rm ion}(k',q)|^2\, |F_{\rm DM}(q)|^2\, \eta(v_{\rm min})$$

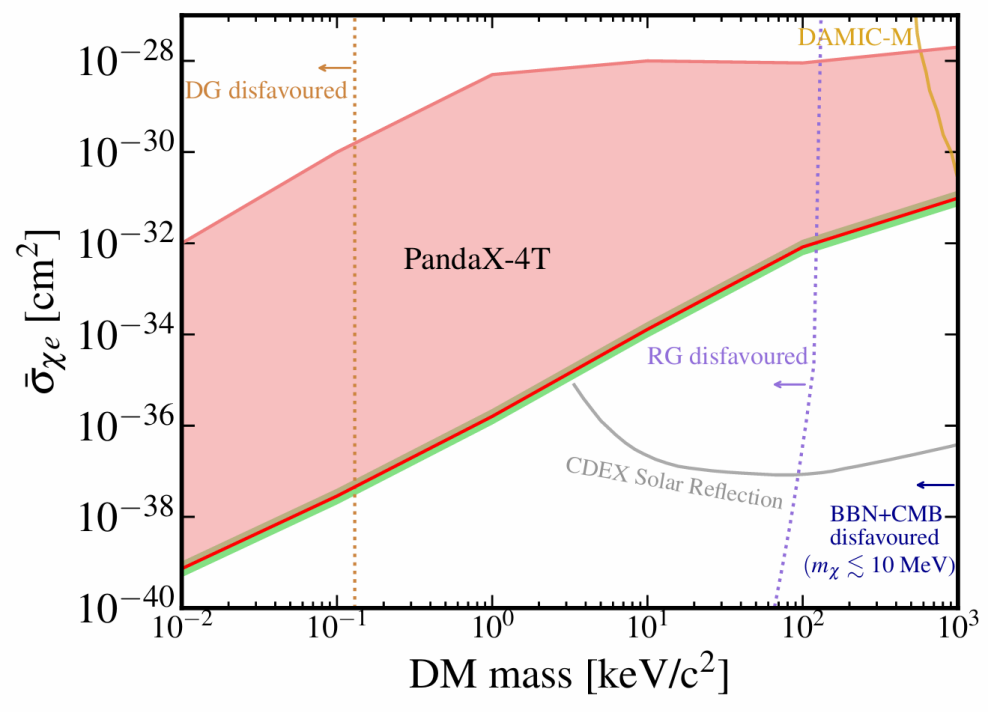




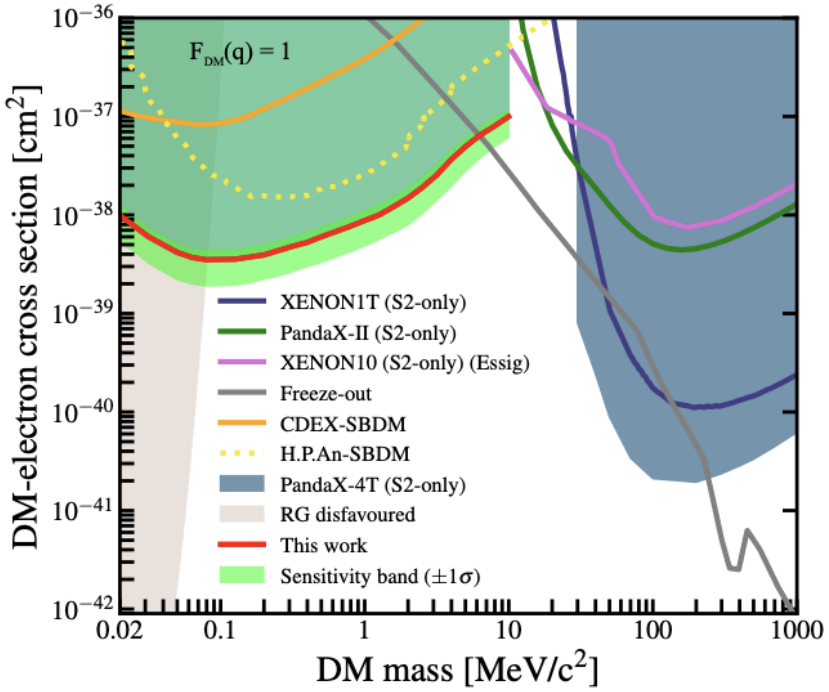
PandaX Collaboration:
Arxiv 2507.11930 **(accepted by *PRL*)**

Accelerated Low Mass DM

- **The Universe is a big accelerator，accelerating light DM based on the same interaction**
- **New constraints on the cross section for elastic scatterings between cosmic-ray boosted sub-MeV dark matter and electron**
- **Stringent constraints on solar boosted DM in [0.02, 10] MeV/c^2**



Cosmic ray electron boosted DM



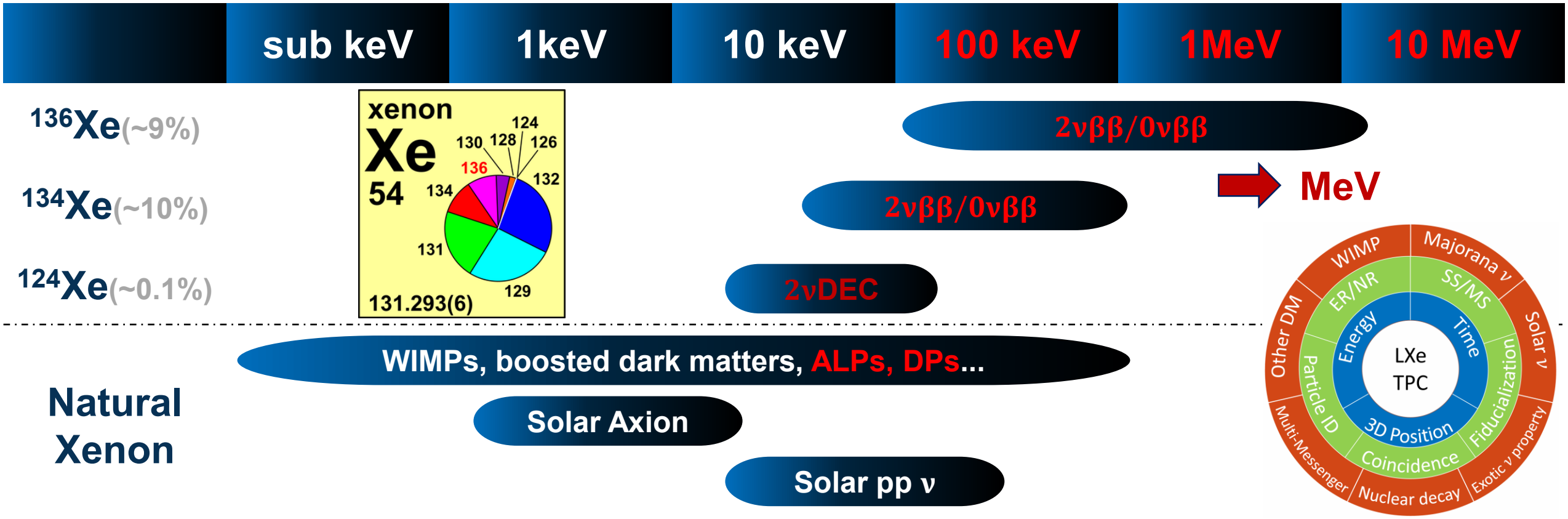
Solar boosted DM

PandaX Collaboration: *PRL* 133 (2024) 10, 101805

PandaX Collaboration: *PRL* 134 (2025) 16, 161003

Multiple physics in a wide energy range

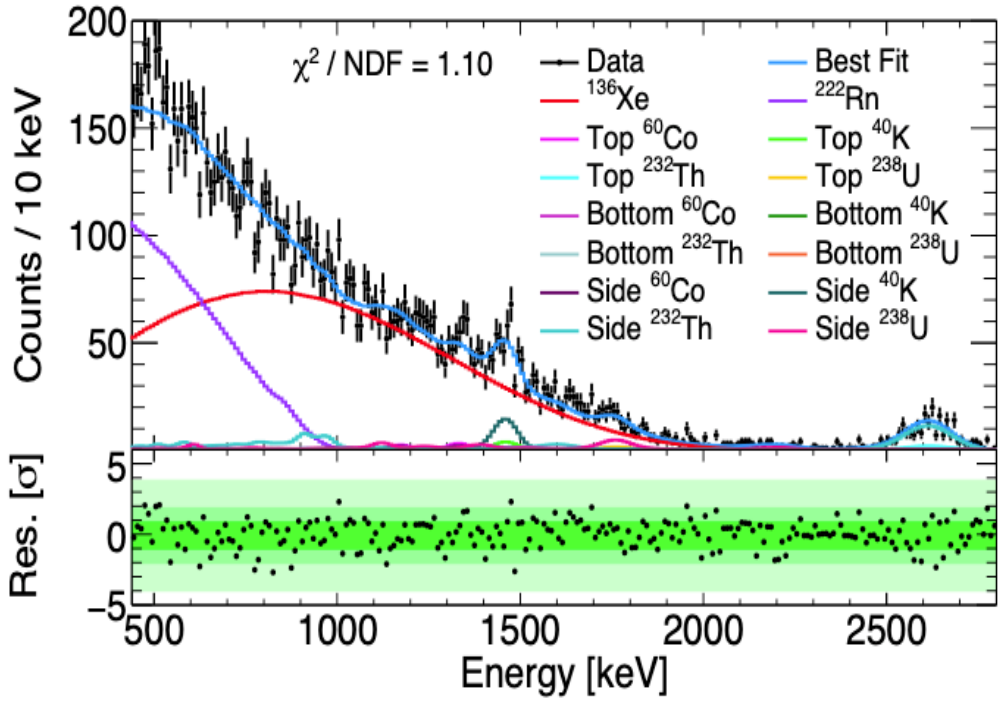
- Rare signals in wide energy range
- Natural liquid xenon: multiple double beta decay isotopes

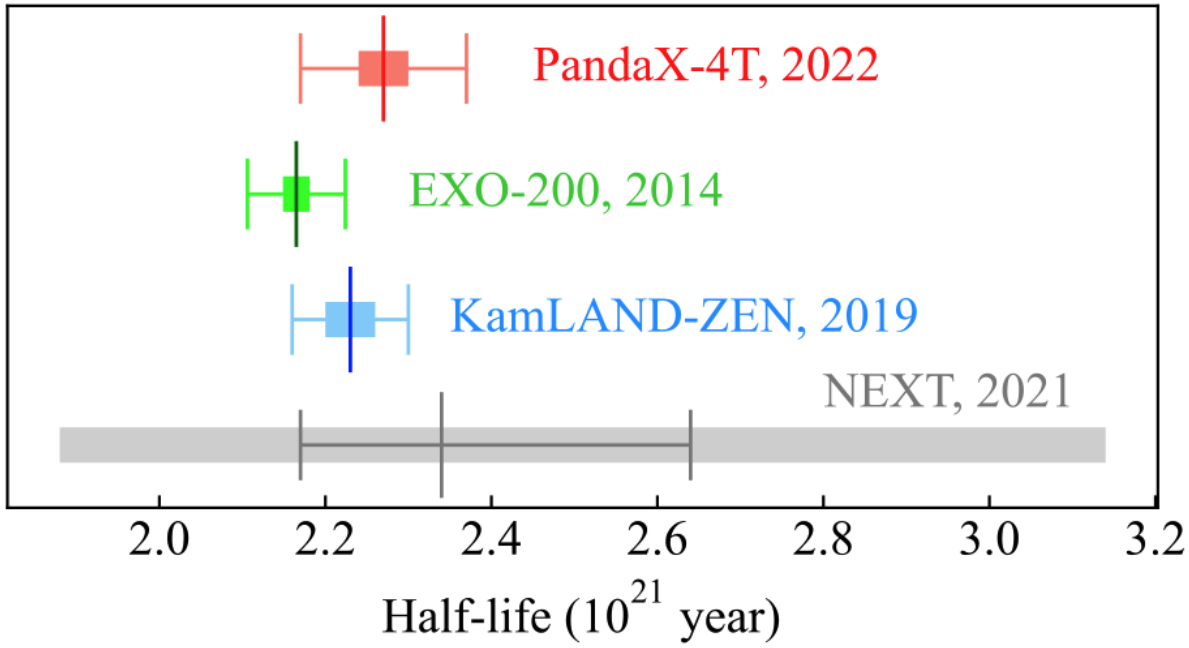


Majorana Neutrinos

- **Extended the energy range from keV to MeV**
- **First measurement of ^{136}Xe $2\nu\beta\beta$ from natural xenon detector:**

$$T_{1/2}^{2\nu\beta\beta} = 2.27 \pm 0.03(\text{stat.}) \pm 0.10(\text{syst.}) \times 10^{21}\ \text{yr}$$



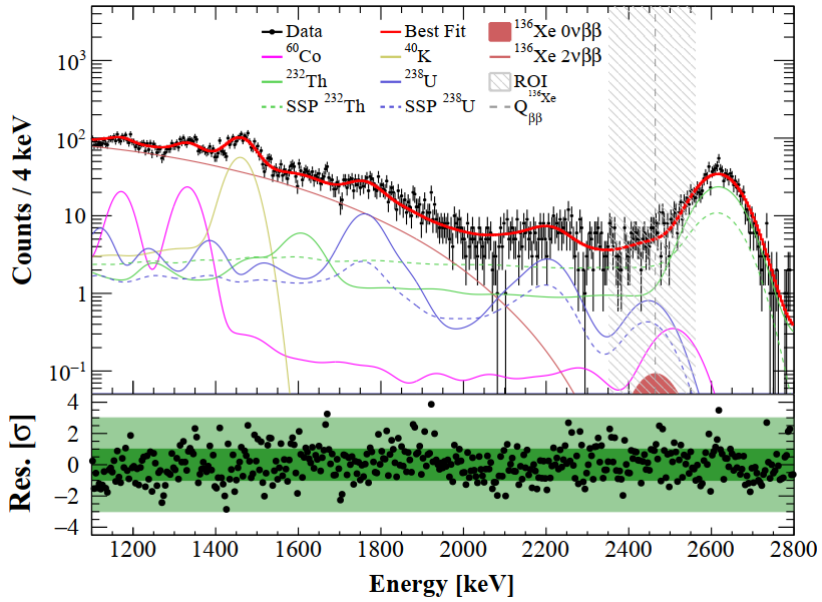


PandaX Collaboration: ***Research*** *2022 (2022) 9798721*

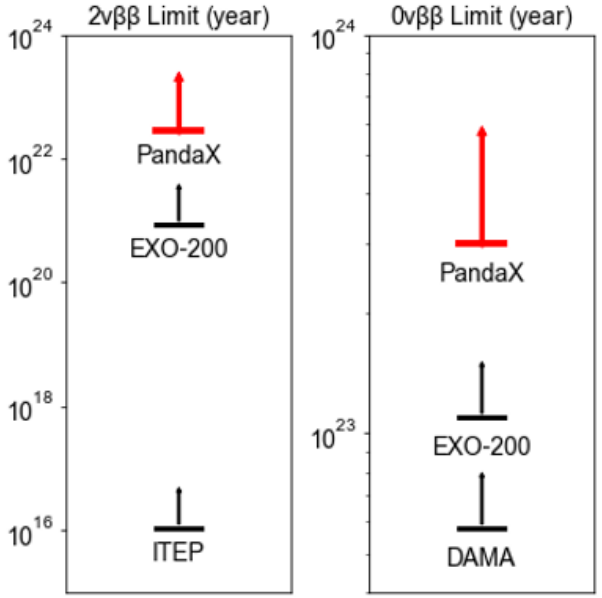
Majorana Neutrinos

- ^{136}Xe $0\nu\beta\beta$ search: $T_{1/2}^{0\nu\beta\beta} > 2.1 \cdot 10^{24}$ yr
- ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ search: $T_{1/2}^{2\nu\beta\beta} > 2.8 \cdot 10^{22}$ yr and $T_{1/2}^{0\nu\beta\beta} > 3.0 \cdot 10^{23}$ yr
- ^{124}Xe 2νECEC half-life measurement: $1.03 \pm 0.15(\text{stat.}) \pm 0.06(\text{syst.}) \times 10^{22}$ yr

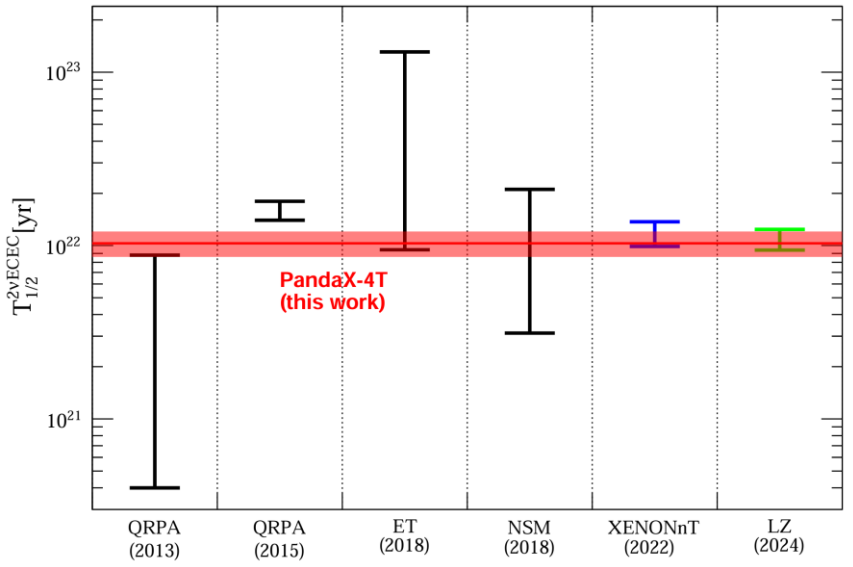
^{136}Xe $0\nu\beta\beta$



^{134}Xe $0\nu\beta\beta$ and $0\nu\beta\beta$



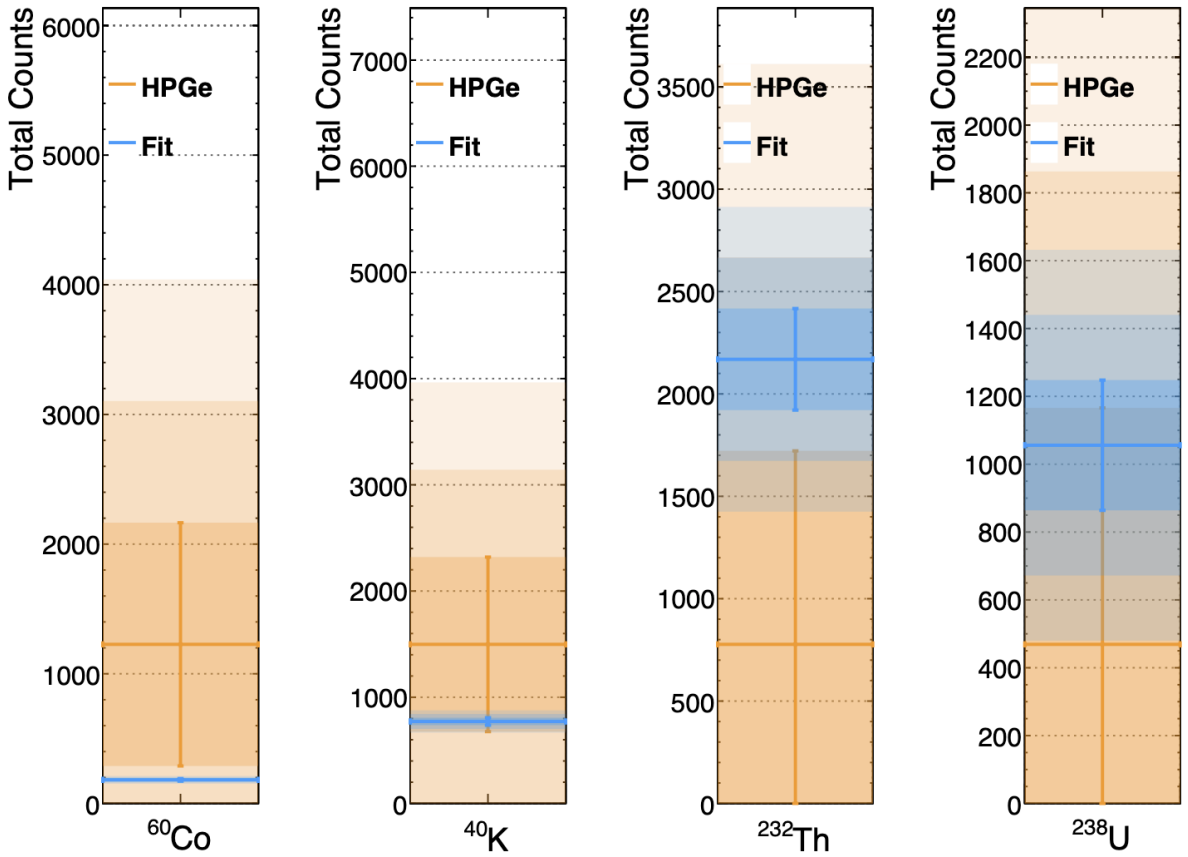
^{124}Xe 2νECEC

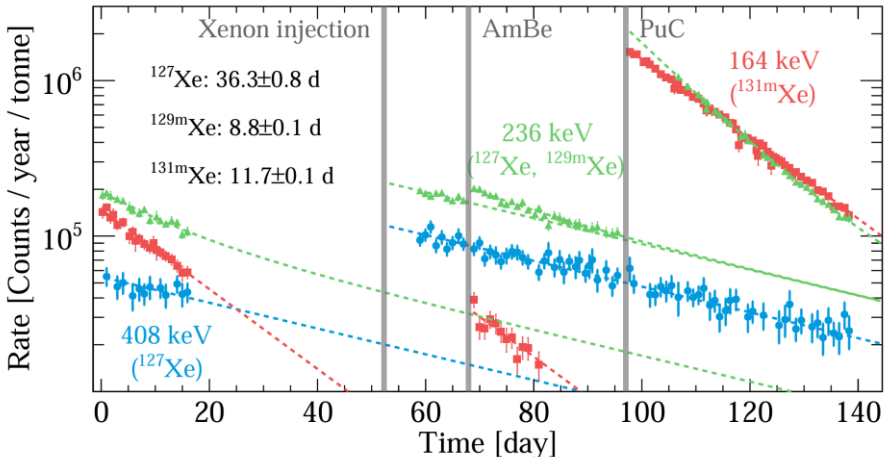


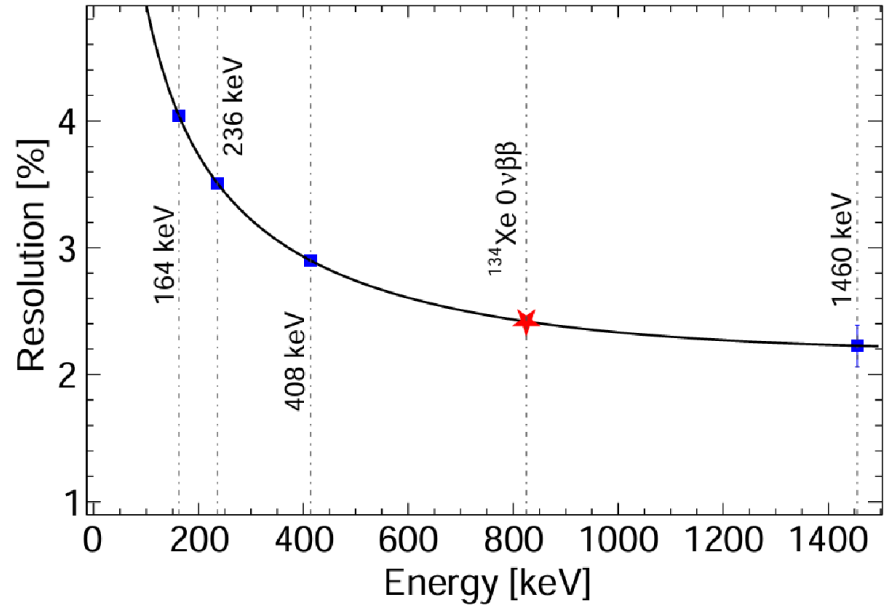
PandaX Collaboration: ***Science Bulletin*** *70 (2025) 1779-1785;* ***PRL*** *132 (2024) 15, 152502;* ***JHEP*** *05 (2025) 119*

keV-MeV Energy Range

- The detector response and background model in high energy range

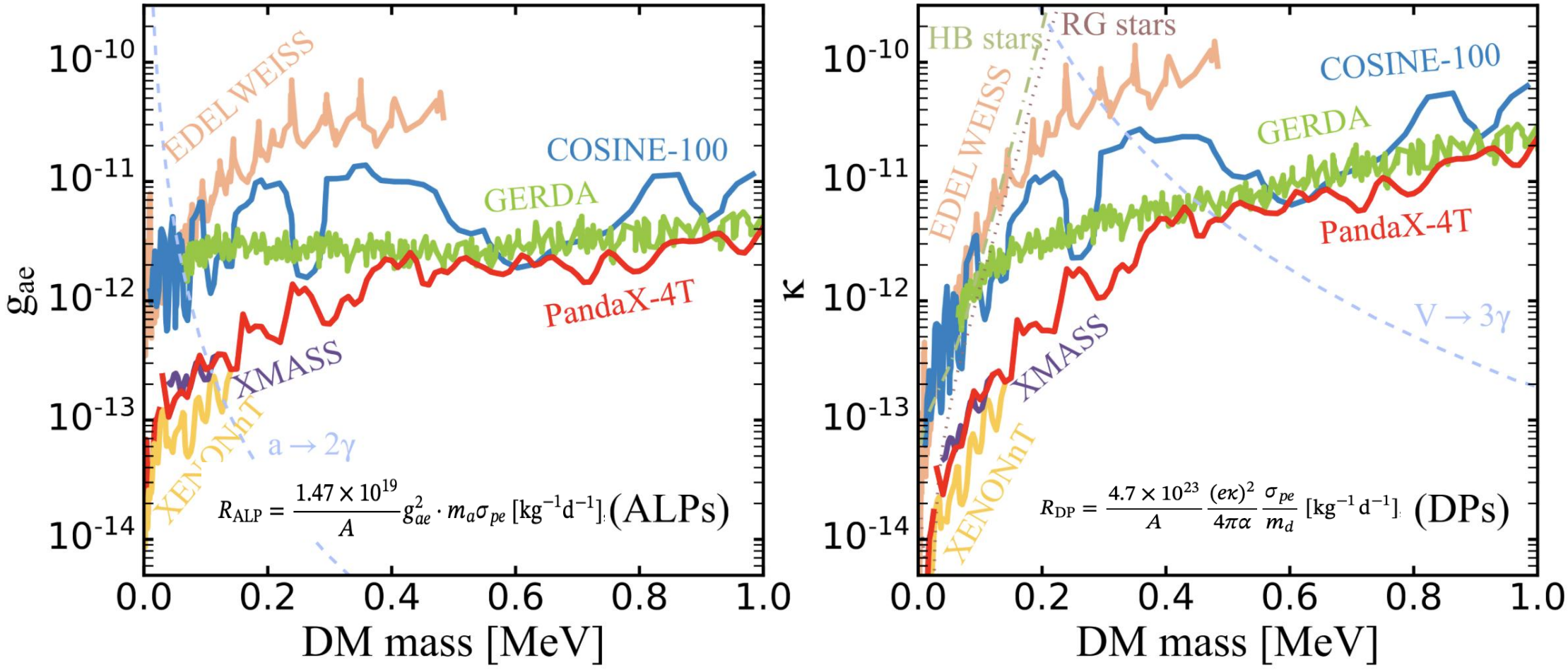






Axion-like Particle / Dark Photon

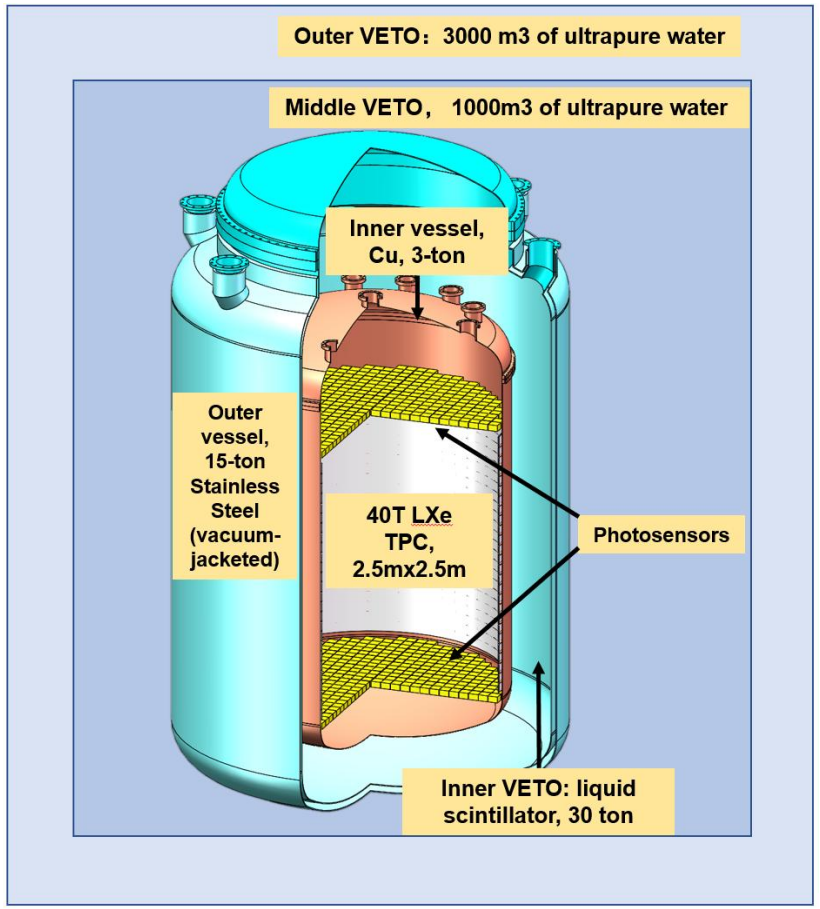
- **The stringent exclusion limits within [keV/c², 1 MeV/c²]**

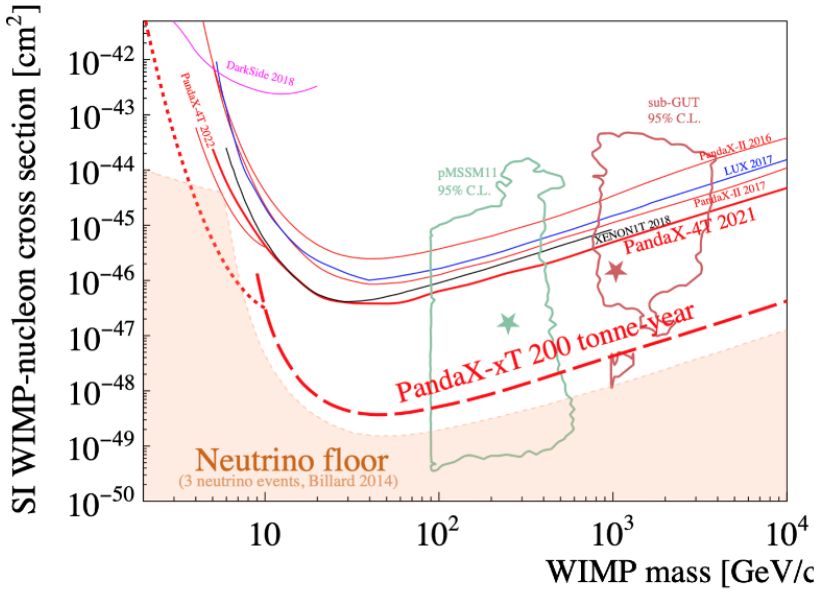


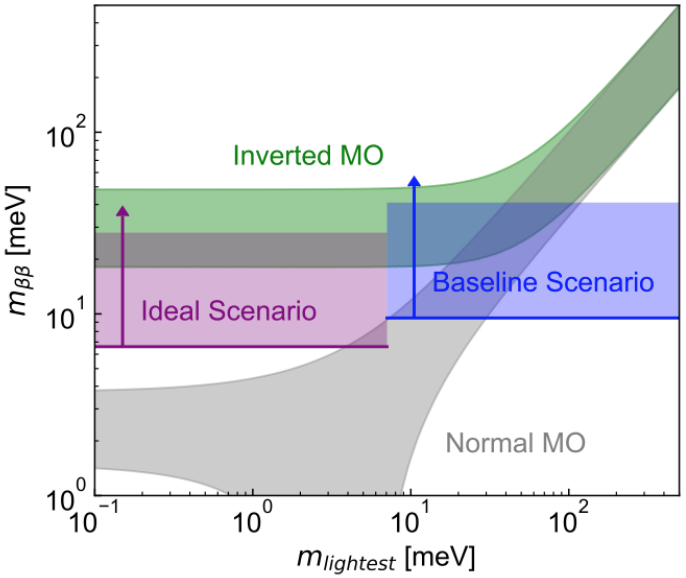
PandaX Collaboration: ***PRL*** *134 (2025) 4, 041001;* ***PRL*** *134 (2025) 7, 071004*

Future Plan: PandaX-xT

- With ~40 tonne sensitive volume
- Key tests on WIMP and Dirac/Majorana neutrino





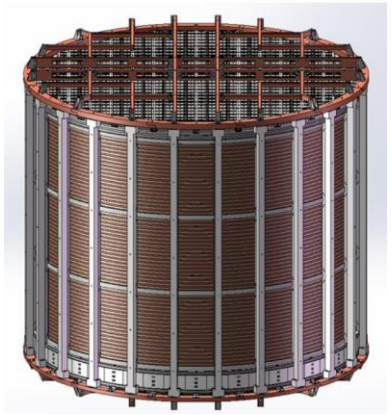


PandaX Collaboration: *SCPMA* 68, 221011 (2025)

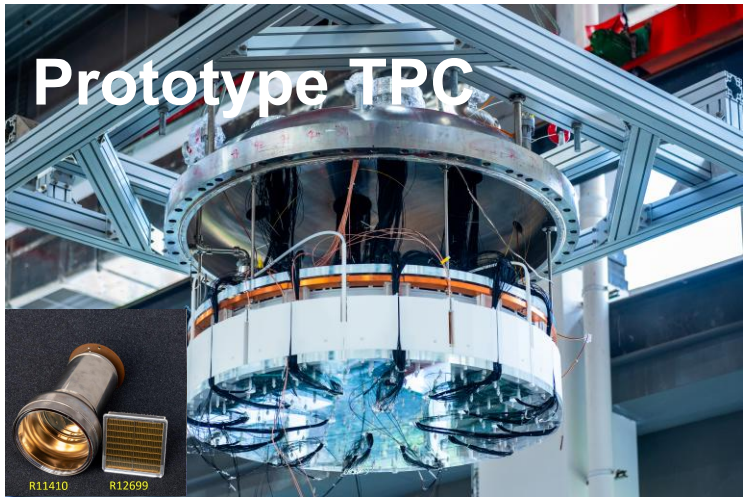
PandaX-20T: Intermediate Stage

- **Multi-physics targets**
  - Energy range 100eV – 10MeV
- **Estimated timeline**
  - 2026: move to CJPL and assembling
  - 2027: commissioning

PandaX-20T

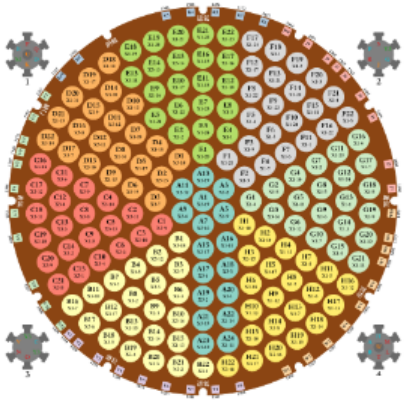


PandaX-xT

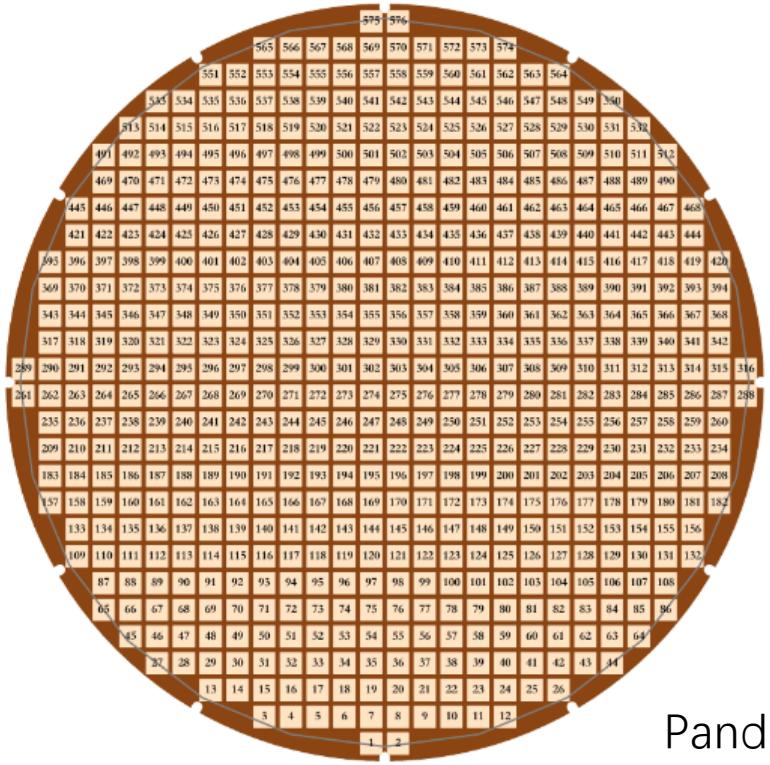


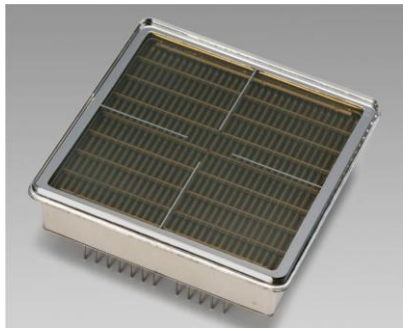
PMT Array in PandaX-20T

- **Larger area, lower background, higher spatial resolution PMT arrays**
  - 2-inch R12699 PMT



PandaX-4T： 169 3-inch R11410 PMTs in top array





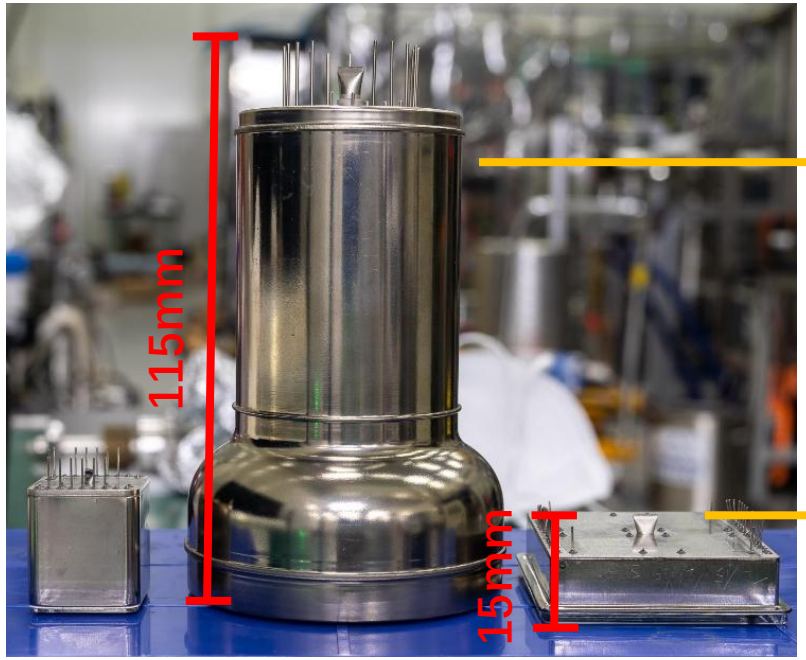
PandaX-20T： 616 2-inch R12699 PMTs in top array

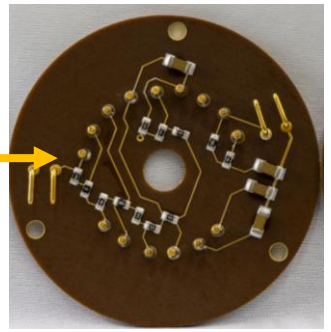
Novel 2-inch PMT: R12699

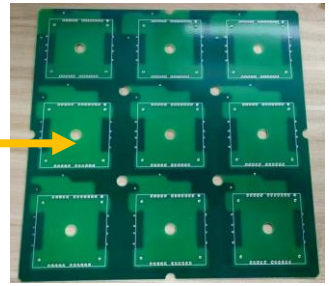
PandaX team & Hamamatsu Photonics

K.K corporation

- Low background
- Compact, high granularity, 4 individual channels
- Quick transit time and rise time

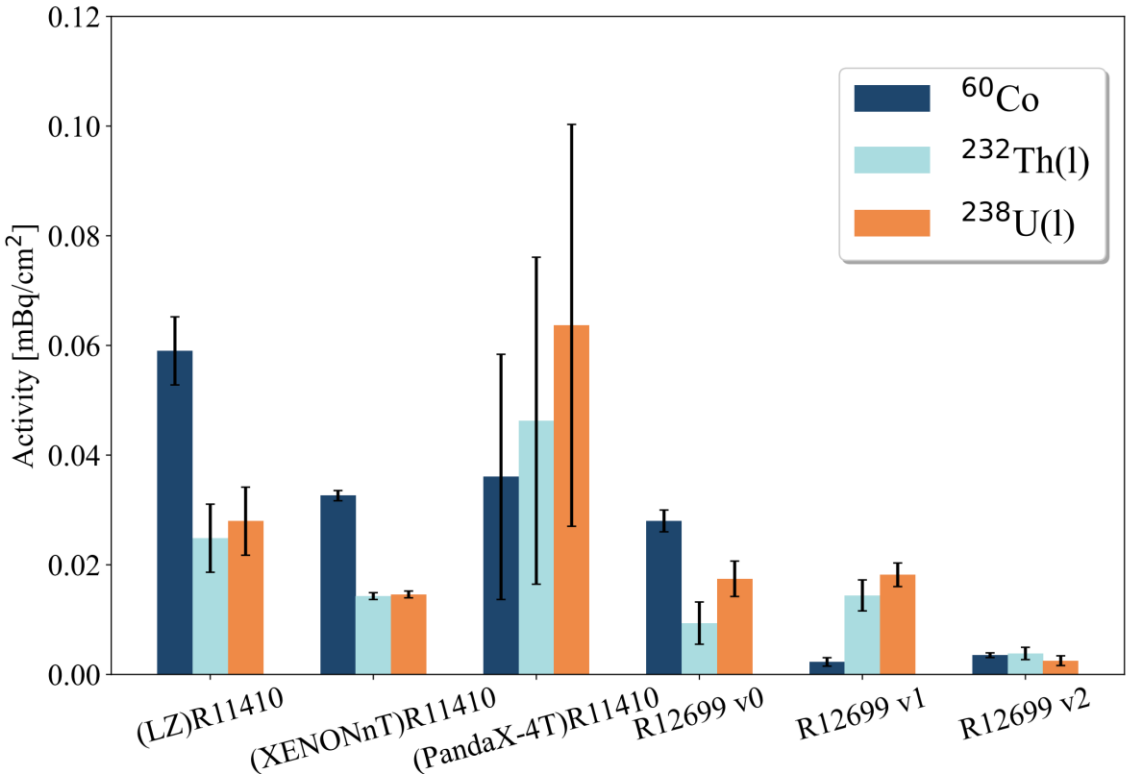






Parameter		R12699-406-M4	R11410-20	Unit
Cathode Sensitivity	Luminous (2856K)	95	90	uA/lm
	Blue Sensitivity Index	10.0	10	-
Anode Sensitivity	Luminous (2856K)	140	315	A/lm
Gain		1.5×10^6	3.5×10^6	-
Anode Dark Current (Each anode) (after 30min. storage in darkness)		1.5	10	nA
Time Response	Rise Time	1.2	5.5	ns
	Transit Time	5.9	46	ns
	Transit Time Spread (FWHM)	0.41	9	ns
Uniformity Between Each Anode		1:1.5	-	-

Novel 2-inch PMT: R12699



Nucl.Instrum.Meth.A 1073 (2025) 170290

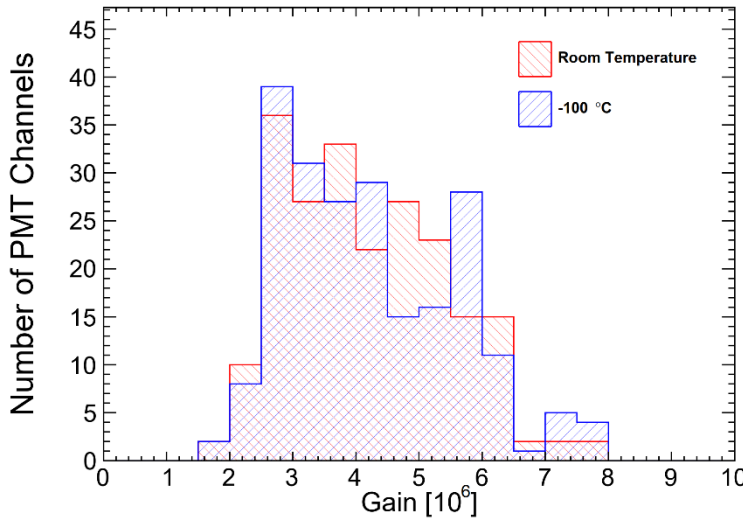
v0 Original

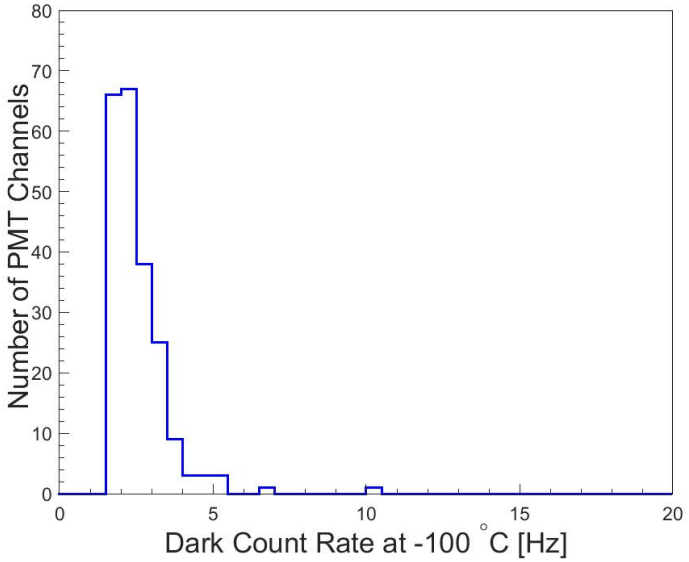
v1 Fe-Co-Ne alloy (Kovar) → Fe-Ne alloy

v2
- Glass-1 raw materials selected
- Using platinum crucible

- ^{60}Co: **1/8** of original
- ^{238}U(late): **1/4** of original
- ^{232}Th(late): **1/7** of original

R12699 electrical performance



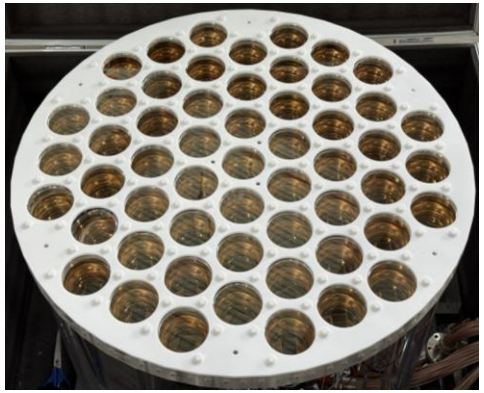
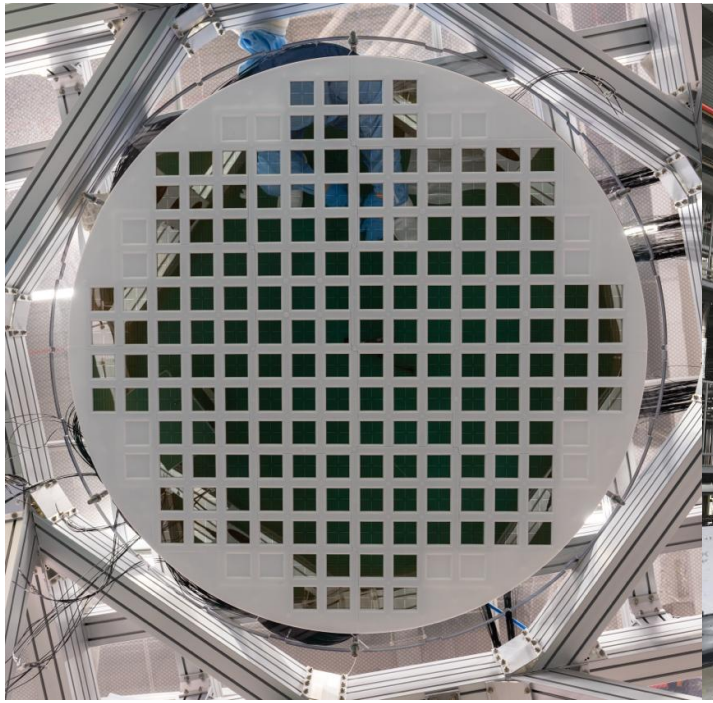


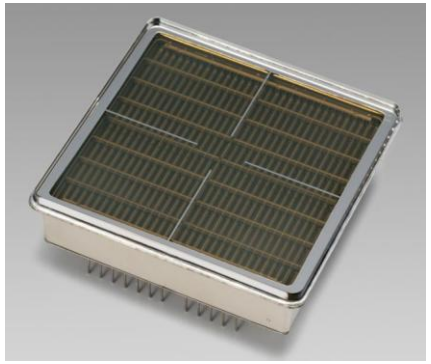
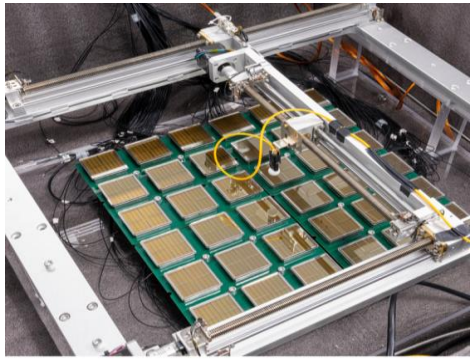
- Comparable gain and AP
- Low DCR
- Stable at -100°C

PMT models	Gain	AP probability	DCR/channel [Hz]	DCR/area [Hz/cm^2]
R11410-21 (XENON1T)	5.8×10^6 at 1500 V	1.4%	44	0.97
R11410-20/22 (LZ)	operated at 3.5×10^6	-	-	-
R11410-23 (PandaX-4T)	operated at 5×10^6	1%	20	0.44
R12699-406-M4	4.23×10^6 at -1000 V	0.5%	2.5	0.32

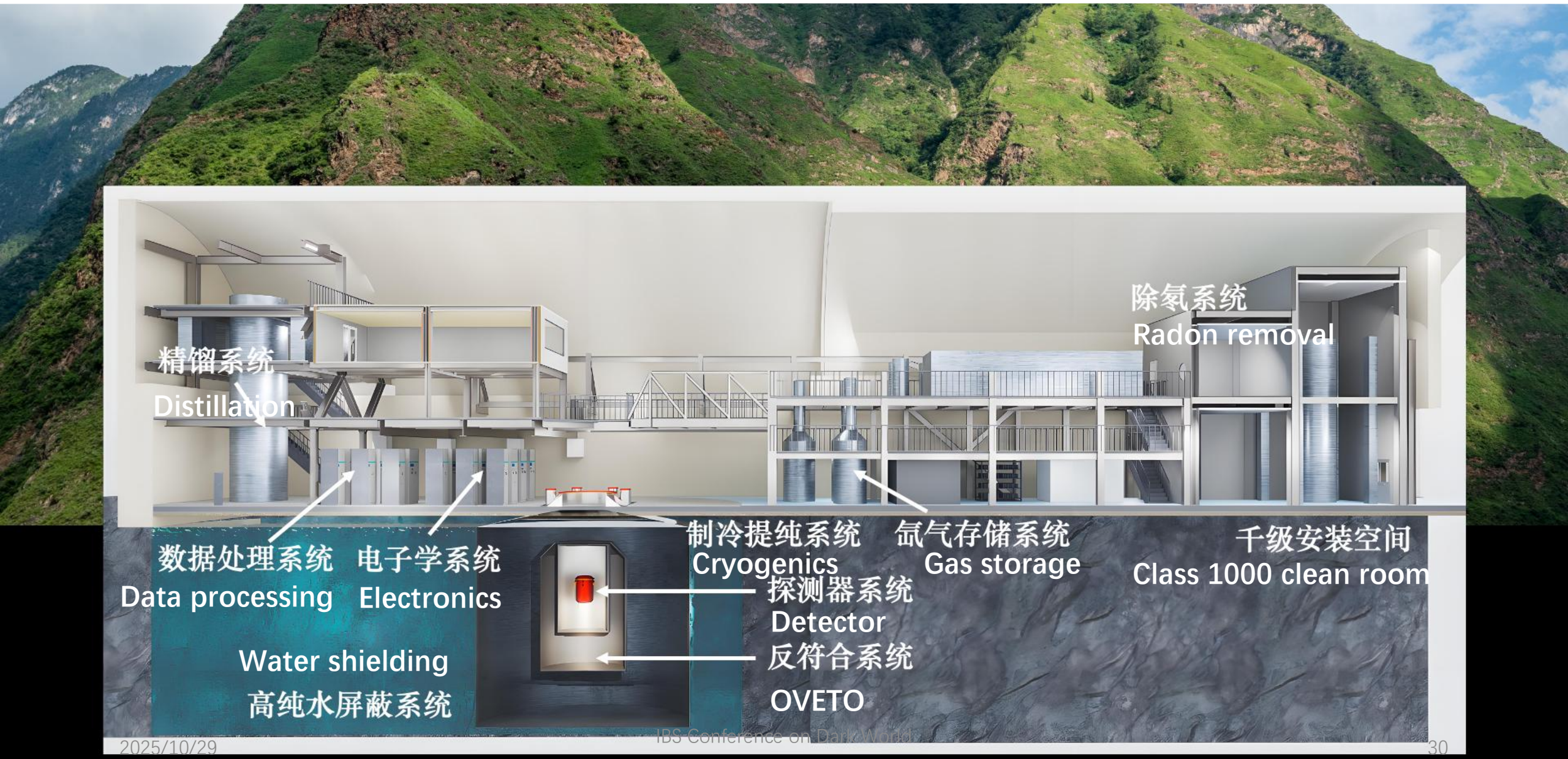
Prototype

- Position reconstruction test in a small array
- A prototype detector with 800kg liquid xenon are operating in Shanghai
- Xenon environment verification

PandaX-xT Layout @ CJPL-II B2 Hall



Summary

- PandaX: Observatory for Dark Matter and Neutrinos
- Continue PandaX-4T data-taking in 2025
- PandaX-20T is planned to get online in 2027
- Highly welcome new collaborators!

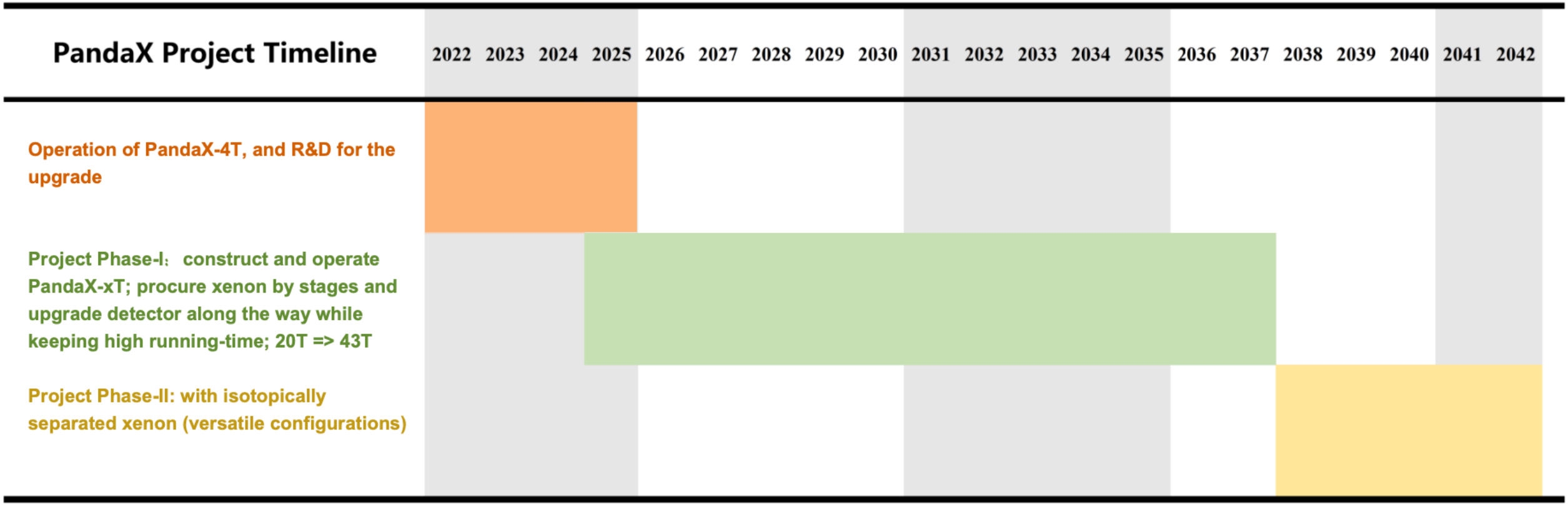
Thank You !

PandaX-xT First Open Meeting

PandaX-xT First Open Meeting

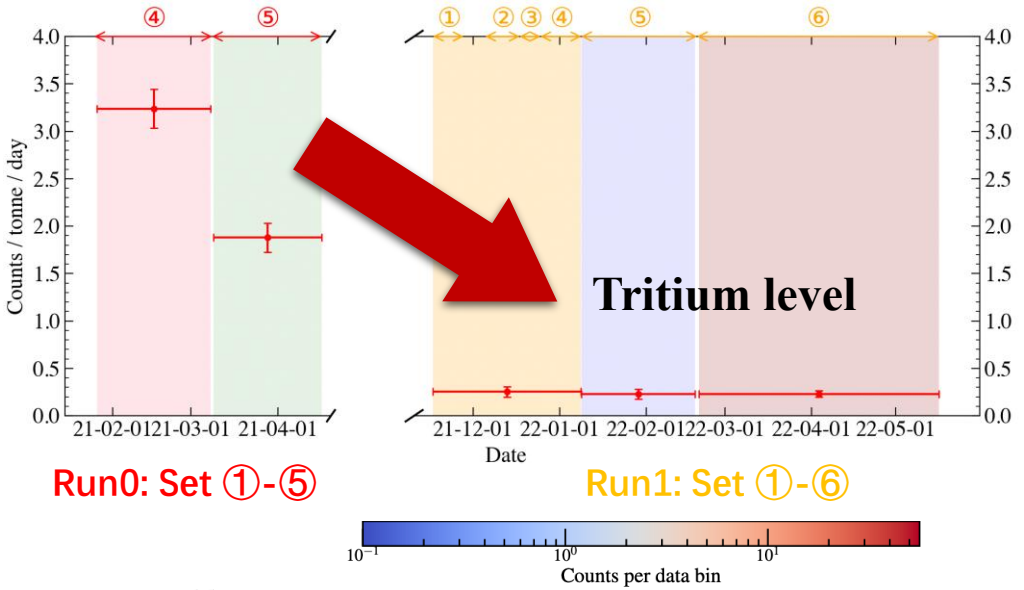
Apr 10 – 11, 2025
Tsung-Dao Lee Institute
Asia/Shanghai timezone

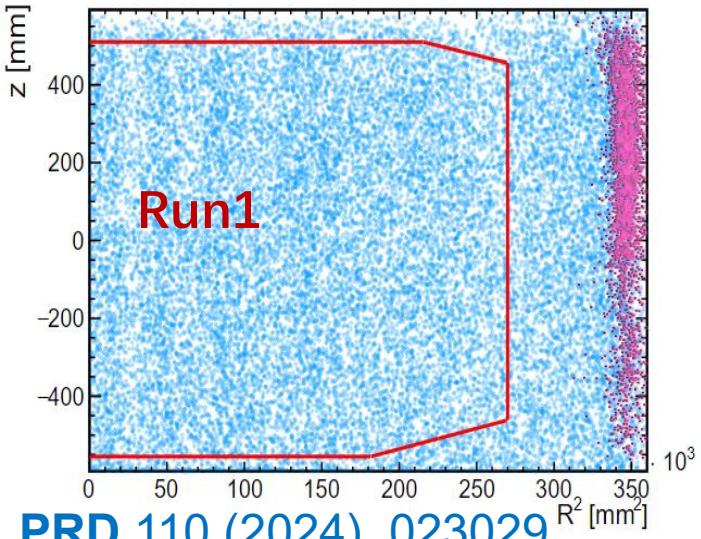
Enter your search term

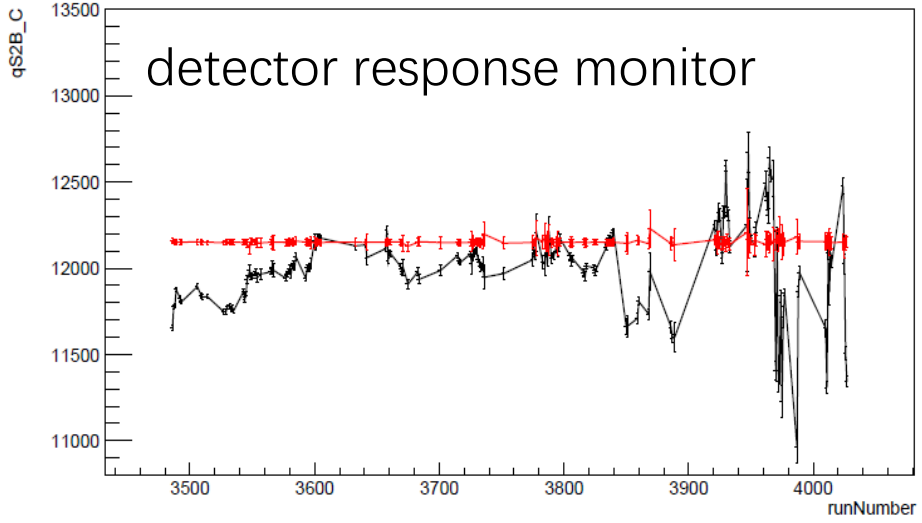


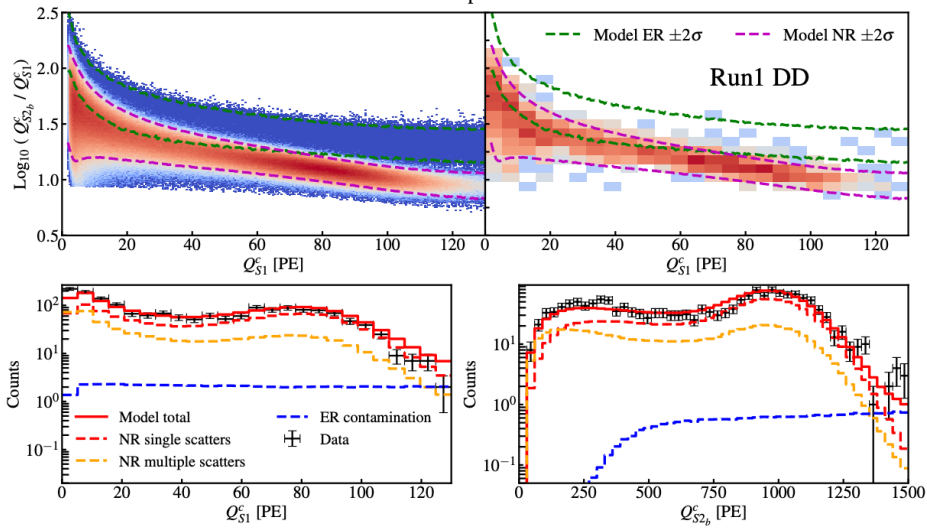
WIMP Search

- **Run0 + Run1: 1.54 tonne·year**
  - ✓ Tritium reduction from Run0 to Run1
  - ✓ More accurate detector response
  - ✓ Signal model from combined fit on Run0+Run1 calibration data









PRD 110 (2024), 023029