Neutrinoless Double beta decay with PandaX

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For the PandaX Collaboration

2025/1/14

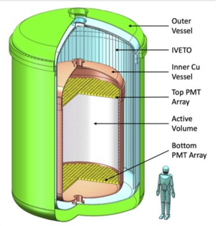
PandaX: Particle and astrophysical Xenon Experiment

PandaX detectors

PandaX-I: 120kg
LXe (2009 – 2014)

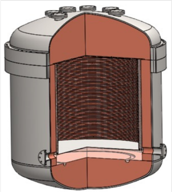
PandaX-II: 500kg
LXe (2014 – 2018)

PandaX-4T LXe
(2020-)

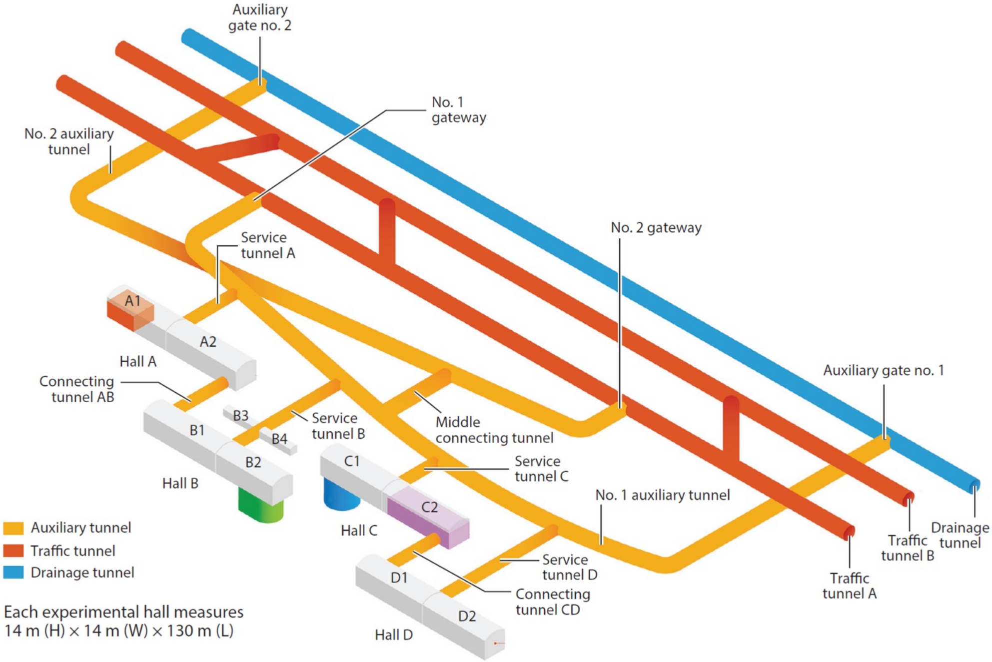


PandaX-xT LXe
(future)

PandaX-III: 100kg - 1 ton
HPXe for 0νββ (future)

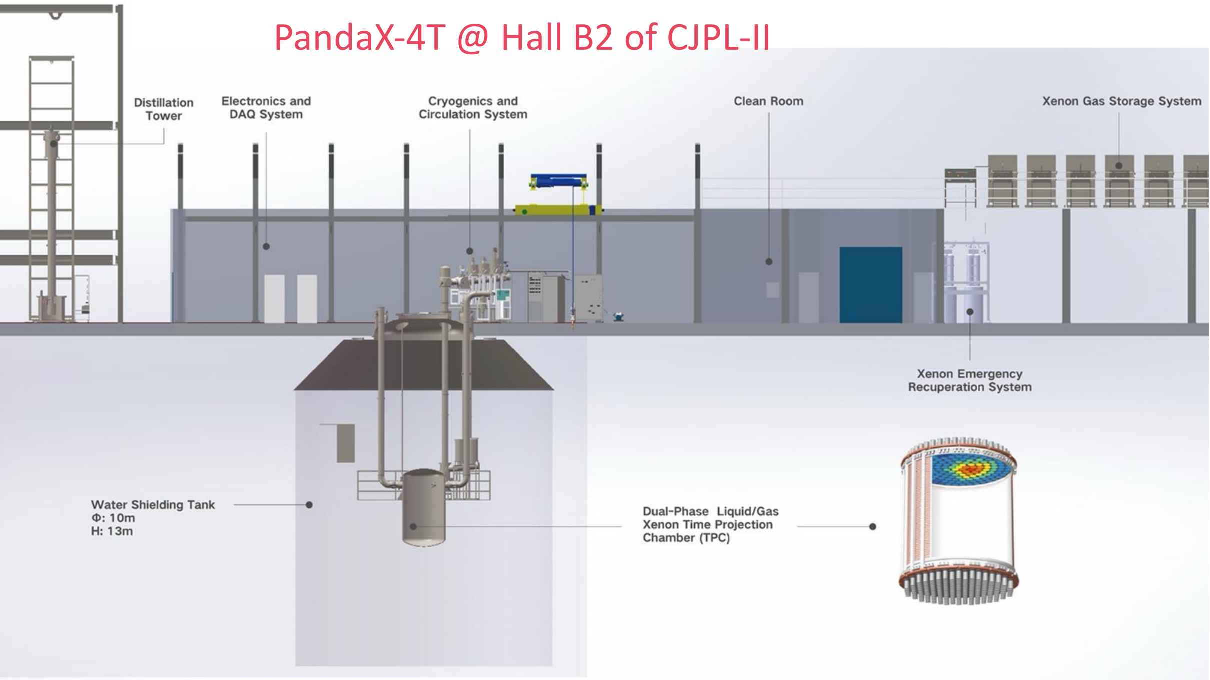


CJPL-II



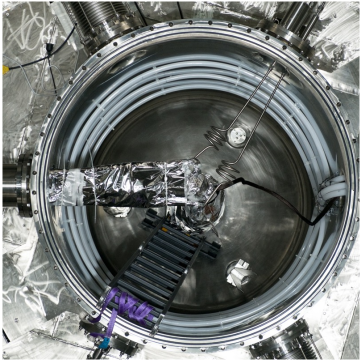
Each experimental hall measures 14 m (H) × 14 m (W) × 130 m (L)

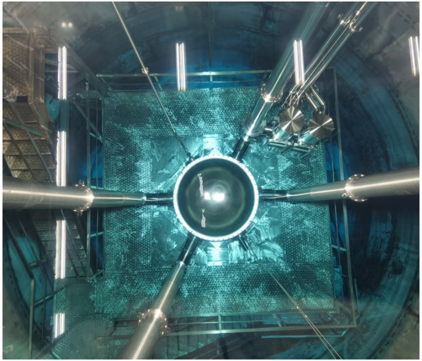
PandaX-4T @ Hall B2 of CJPL-II



PandaX-4T

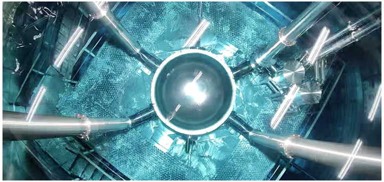
- A multi-ton dual-phase xenon TPC at B2 hall of China Jinping Underground Laboratory
- 1.2 m (D) ×1.2 m (H); Sensitive volume: 3.7-ton LXe; 3-inch PMTs: 169 top / 199 bottom
- Water shielding





PandaX-4T timeline

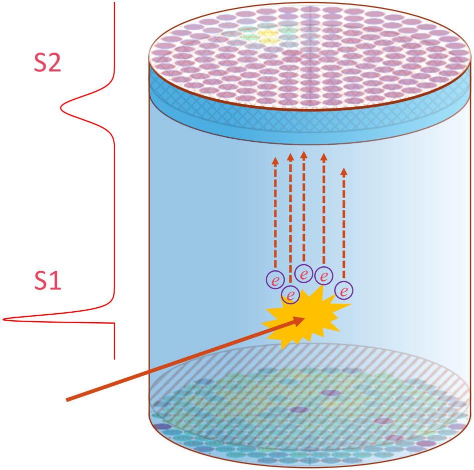
2020/11 – 2021/04	**Commissioning (Run 0)** 95 days data
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc.
2021/11 – 2022/05	**Physics run (Run 1)** 164 days data
2022/09 – 2023/12	**CJPL B2 hall construction** xenon recuperation, detector upgrade
Detector is taking Run 2 data	

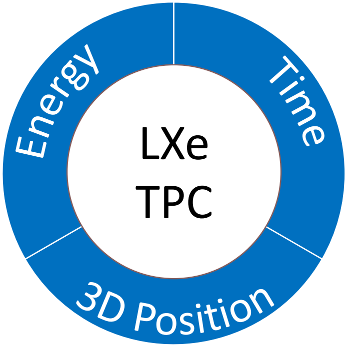


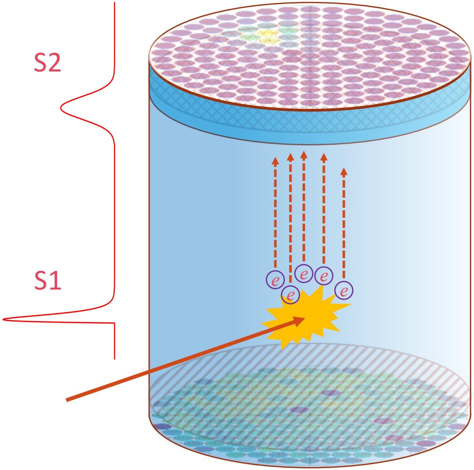
Liquid Xenon Time Projection Chamber (LXe TPC)

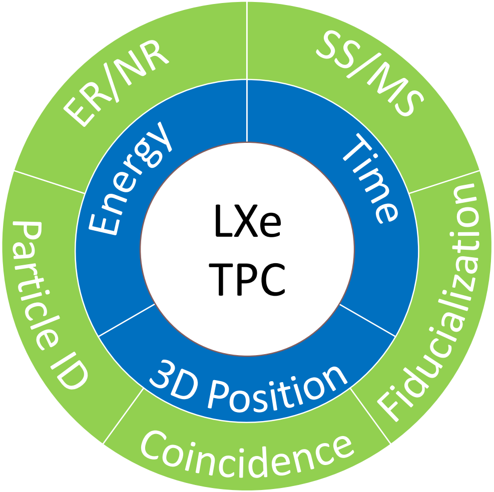
- Prompt scintillation signal (S1) followed by drift electron signal (S2)
- Measures the 3D position, energy, and time
- Nuclear Recoil (NR) and electron recoil (ER) discrimination
- Single-site (SS) and multi-site (MS) event discrimination
- Large monolithic target: High signal efficiency and effective self-shielding

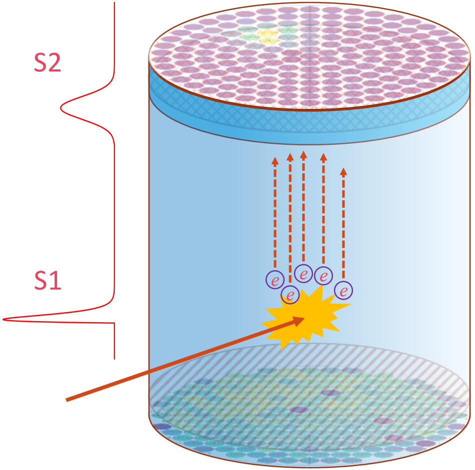
- LXe TPC as a Total-Absorption 5D Calorimeter



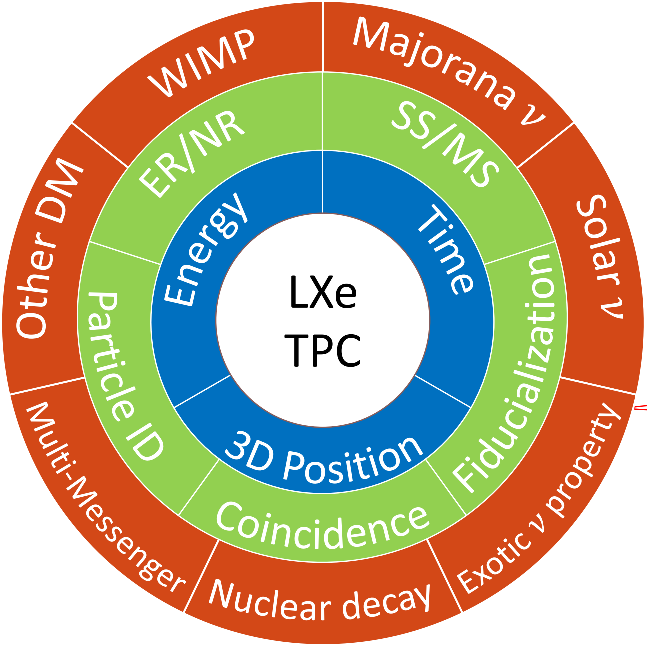

Energy
Time
3D Position
LXe
TPC

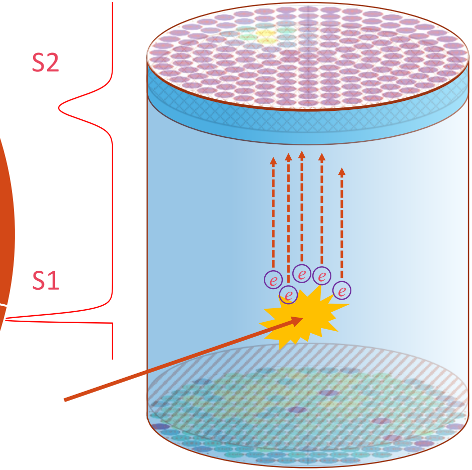

S2
S1
e
e
e
e
e





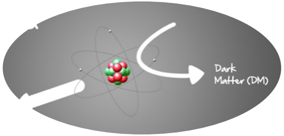
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC





PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

Multiple physics goals in one detector

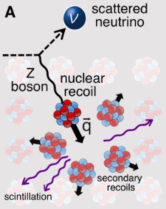


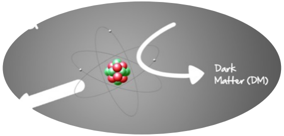
keV | 10 keV | 100 keV | 1 MeV

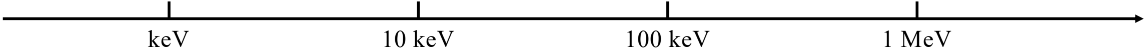
WIMP signals

- Large target mass
- Great energy threshold
- NR and ER discrimination

Multiple physics goals in one detector







CEνNS (NR)

- Large target mass
- Better energy threshold
- NR and ER discrimination

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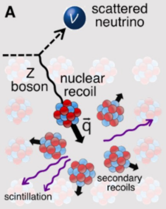
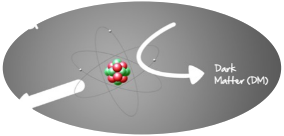
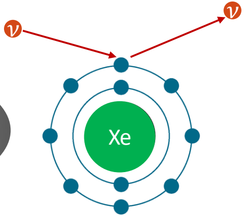
Multiple physics goals in one detector







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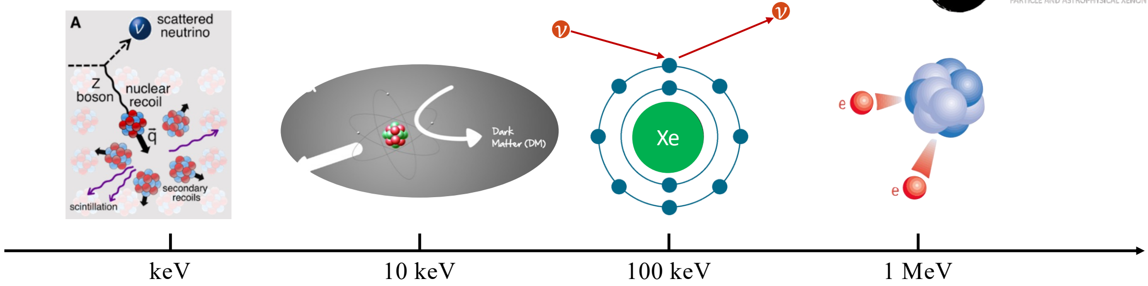
Neutrino-electron scattering

- Large target mass
- Energy threshold and resolution

Multiple physics goals in one detector



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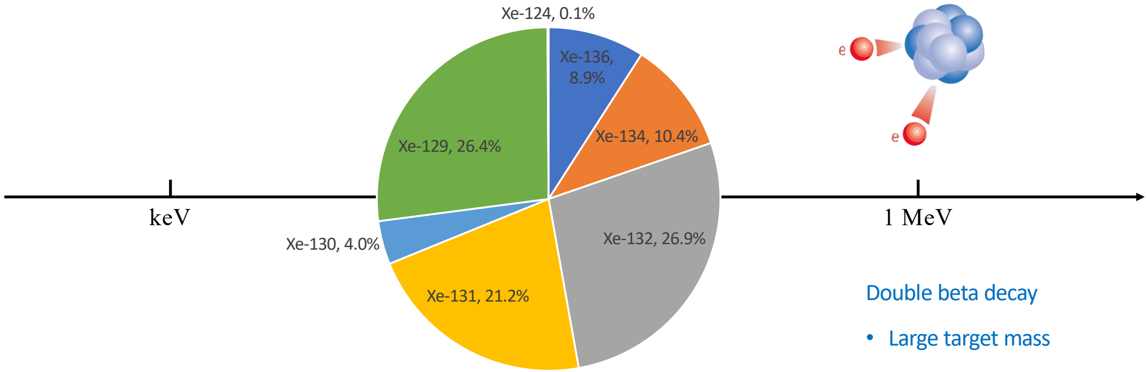
- Energy threshold and resolution

Double beta decay

- Large target mass
- Excellent energy resolution
- Single vs multiple site event

Multiple physics goals in one detector



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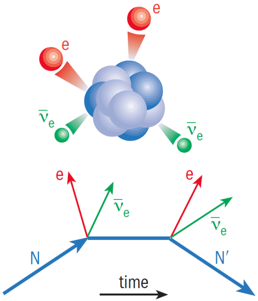
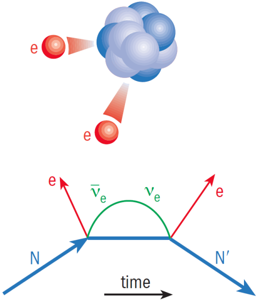
Majorana neutrino and Double beta decay



$$\bar{\nu} = \nu$$



From Physics World

1935, Goeppert-Mayer
Two-Neutrino double beta decay

1937, Majorana
Majorana Neutrino

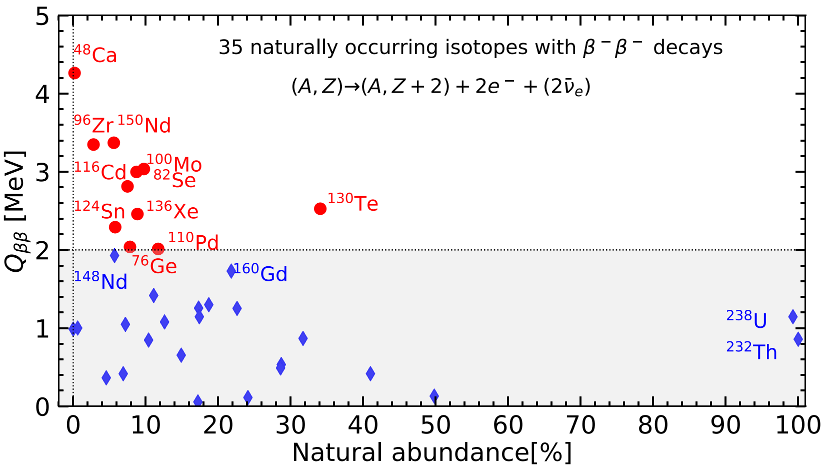
1939, Furry
Neutrinoless double beta decay

1930, Pauli
Idea of neutrino

1933, Fermi
Beta decay theory

$$^{136}_{54}Xe \rightarrow {}^{136}_{56}Ba + 2e^{-} + (2\bar{\upsilon})$$

Candidate Isotopes



- J.M. Yao, J. Meng, Y.F. Niu, P. Ring, Prog.Part.Nucl.Phys. 126 (2022), 103965

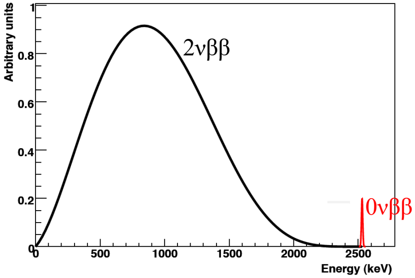
Detection of double beta decay

- Examples:

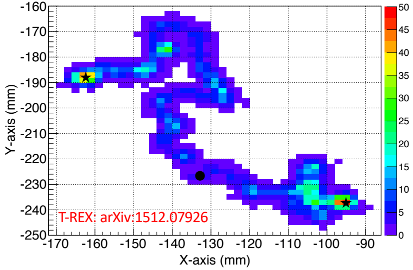
$$^{136}_{54}Xe \rightarrow ^{136}_{56}Ba + 2e^- + (2\bar{\upsilon})$$

$$^{130}_{52}Te \rightarrow ^{130}_{54}Xe + 2e^- + (2\bar{\upsilon})$$

- Measure energies of emitted electrons
- Electron tracks are a huge plus
- Daughter nuclei identification



Sum of two electrons energy



Simulated track of 0νββ in high pressure Xe

0νββ probes the nature of neutrinos

- Majorana or Dirac
- Lepton number violation
- Measures effective Majorana mass: relate 0νββ to the neutrino oscillation physics

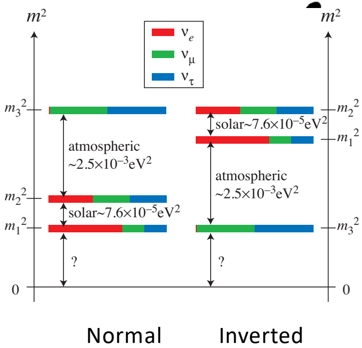
$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\ |M^{0\nu}|^2\ \frac{|\langle m_{\beta\beta}\rangle|^2}{m_e^2}$$

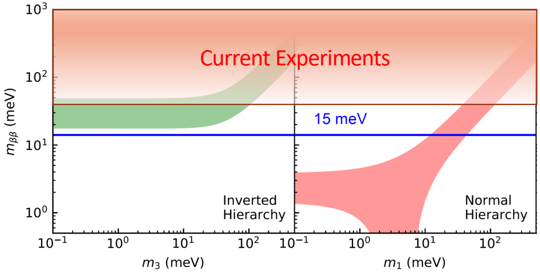
Phase space factor

Nuclear matrix element

Effective Majorana neutrino mass:

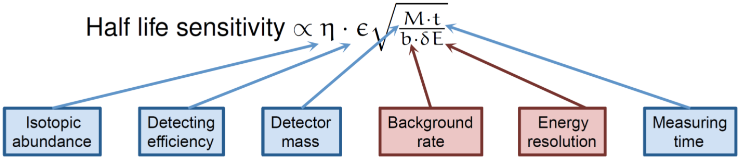
$$|\langle m_{\beta\beta}\rangle| = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$



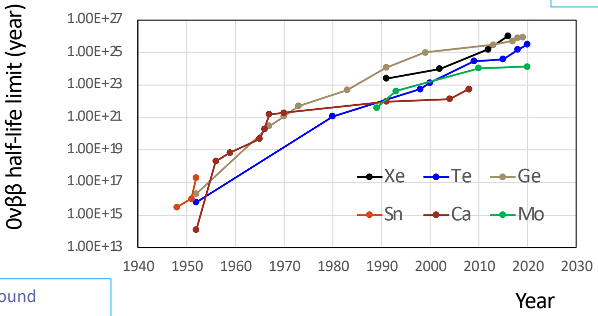


Impressive experimental progress

PandaX — PARTICLE AND ASTROPHYSICAL XENON TPC

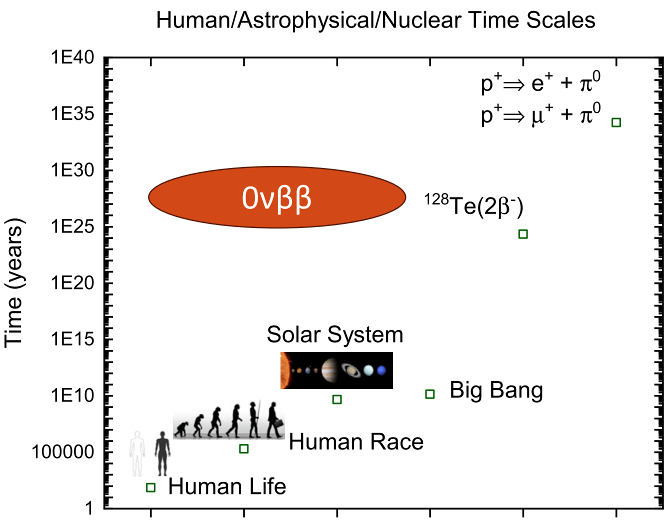


- ~100 kg of isotopes
- ~100-person collaborations
- Deep underground
- Shielding + clean detector



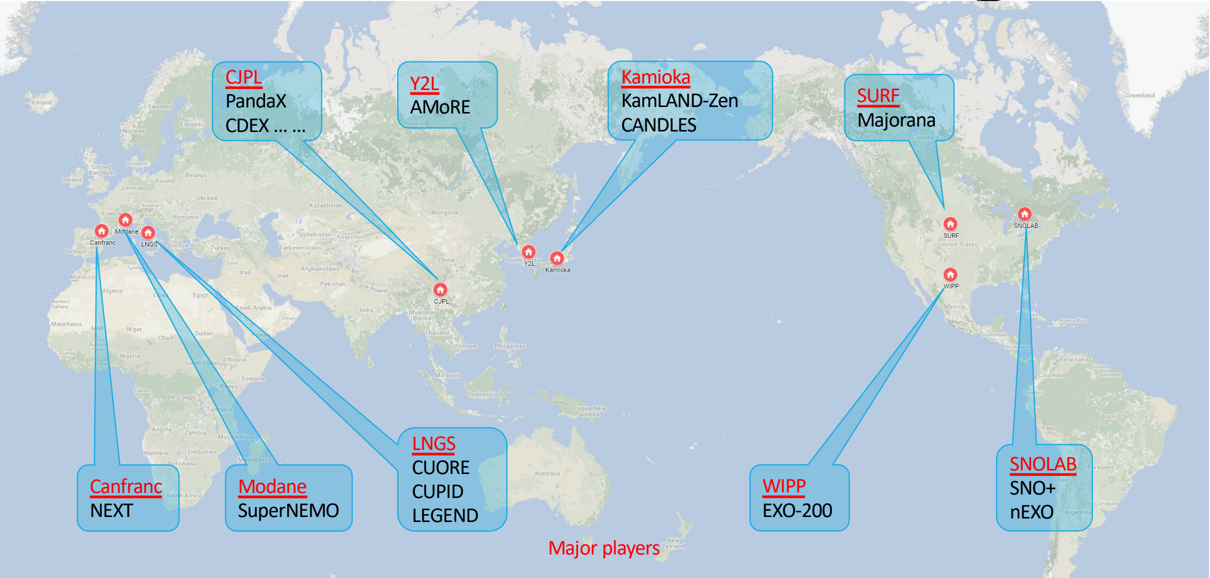
- Grams of isotopes
- Table-top experiment
- Above-ground
- Little shielding

Partial list of selected isotopes; Pre-1984 data points from review article by Haxton and Stephenson, Jr.



Nuclear Physics A 1033 (2023) 122628

Major 0νββ experiments around the world



US Nuclear Science Long-term planning

2015

RECOMMENDATION II

The excess of matter over antimatter in the universe is one of the most compelling mysteries in all of science. The observation of neutrinoless double beta decay in nuclei would immediately demonstrate that neutrinos are their own antiparticles and would have profound implications for our understanding of the matter-antimatter mystery.

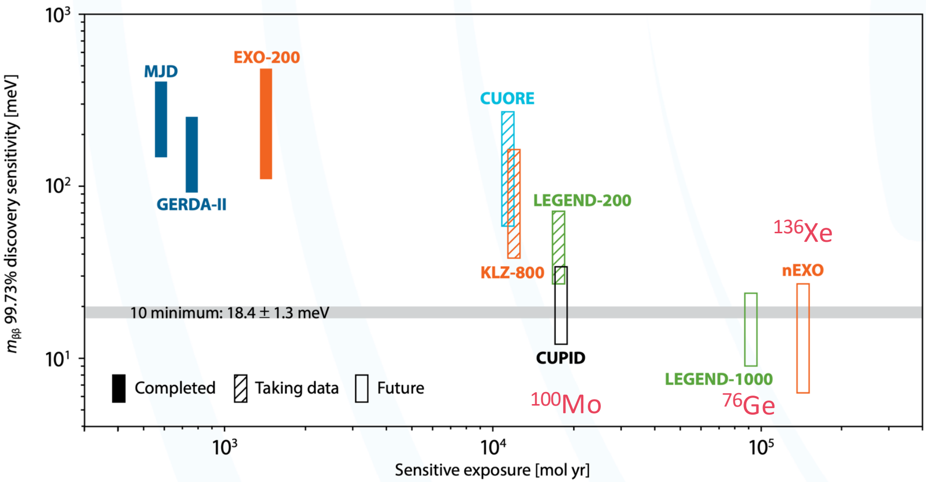
We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment.

2023

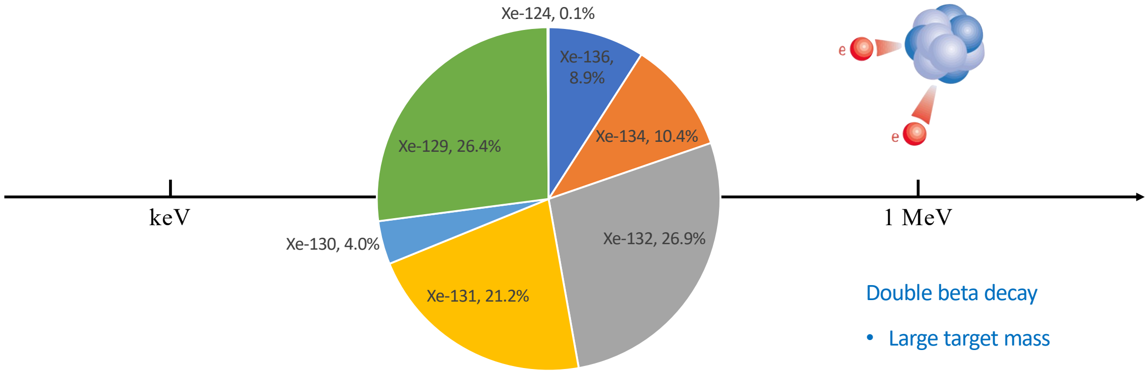
RECOMMENDATION 2

As the highest priority for new experiment construction, we recommend that the United States lead an international consortium that will undertake a neutrinoless double beta decay campaign, featuring the expeditious construction of ton-scale experiments, using different isotopes and complementary techniques.

Sensitivity comparison



Multiple physics goals in one detector



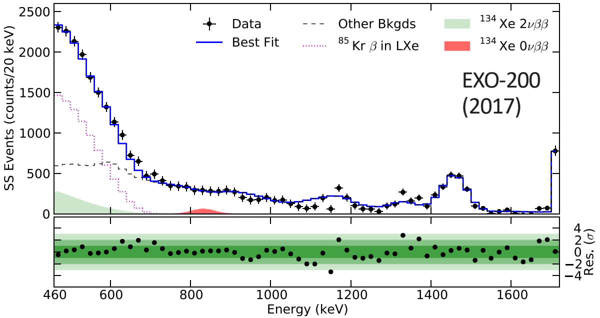
Double beta decay

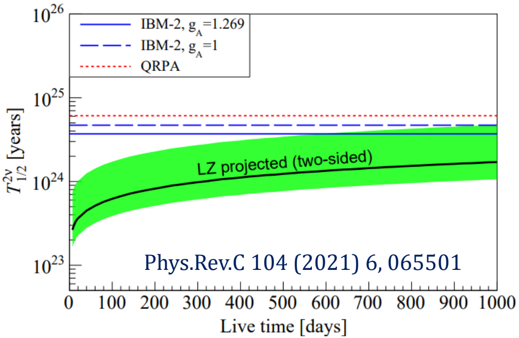
- Large target mass
- Excellent energy resolution
- Single vs multiple site event

^{134}Xe 2νββ and 0νββ

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- Q=826 keV; Half-life from theoretical predictions: 10^{24}-10^{25} yr; Never been observed
- Previous 2νββ (0νββ) half-life limit from EXO-200 : T >8.7x10^{20} yr (1.1x10^{23} yr) at 90% CL
- Discovery within reach with a natural Xe TPC





^{134}Xe (0)2νββ searches at PandaX-4T

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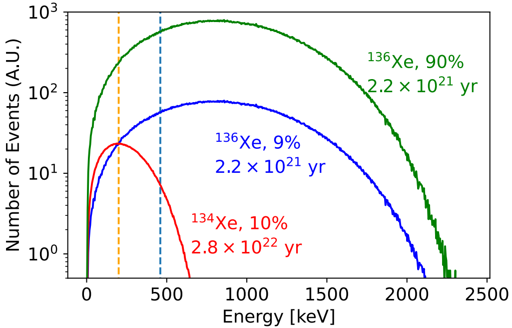
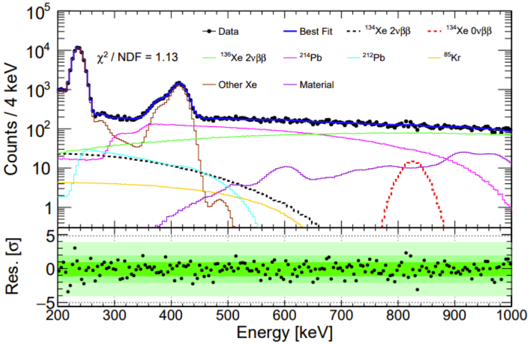
- Previous 2νββ (0νββ) half-life limit from EXO-200 : T >8.7x10^{20} yr (1.1x10^{23} yr) at 90% CL
- PandaX-4T: more ^{134}Xe; much less ^{136}Xe; wider energy range; discovery possible

	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

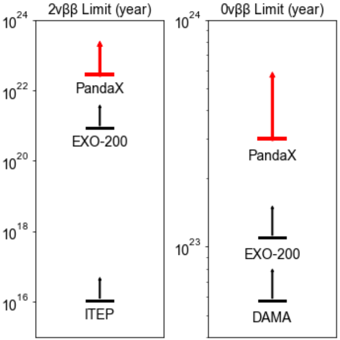


^{134}Xe half-life limits @ PandaX-4T

- Simultaneous fit for ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$
- Final counts of $2\nu\beta\beta$ and $0\nu\beta\beta$: 10±269(stat.)±680(syst.) and 105±48(stat.)±38(syst.)
- 90% CL lower limits on the half-life: $T_{1/2}^{2\nu\beta\beta} > 2.8 \cdot 10^{22}$ yr and $T_{1/2}^{0\nu\beta\beta} > 3.0 \cdot 10^{23}$ yr

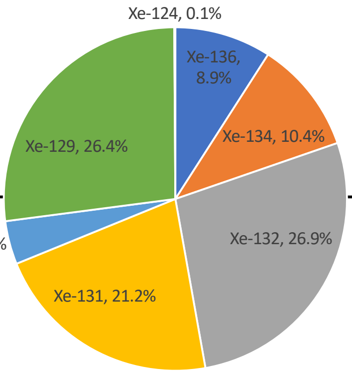


PRL 132, 152502 (2024)

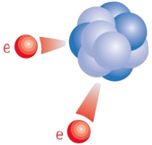


Multiple physics goals in one detector

keV



1 MeV

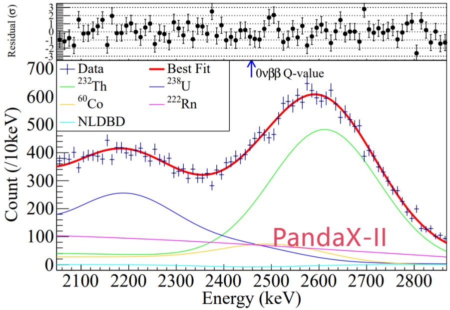


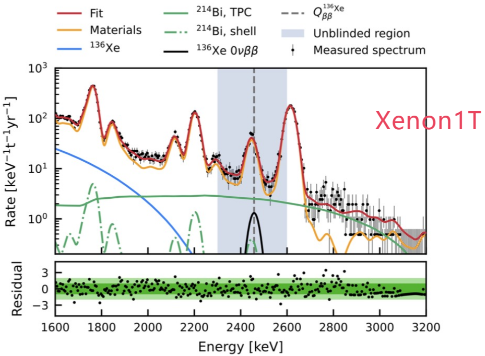
Double beta decay

- Large target mass
- Excellent energy resolution
- Single vs multiple site event

Search for ^{136}Xe 0νββ with natural Xe TPC

	Bkg rate (/keV/ton/y)	Energy resolution	FV mass (kg)	Live time	Sensitivity/Limit (90% CL, year)	Year
PandaX-II	~200	4.2%	219	403 days	2.4×10^{23}	2019
XENON1T	~20	0.8%	741	203 days	1.2×10^{24}	2022
PandaX-4T	~10	2.0-2.3%	735	258 days	2.1×10^{24}	2024

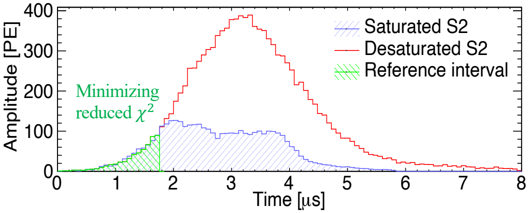


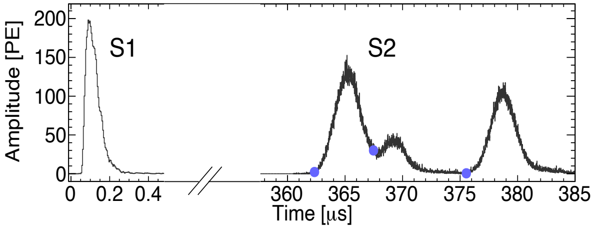


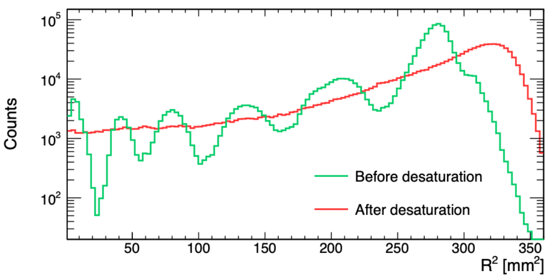
Extending energy from keV to O(100 keV) – O(MeV)

- S2 waveform slicing to improve SS and MS identification
- PMT desaturation for large S2 signals
- Improvement of X-Y position reconstruction, energy linearity and energy resolution

Research 2022 9798721 (2022)





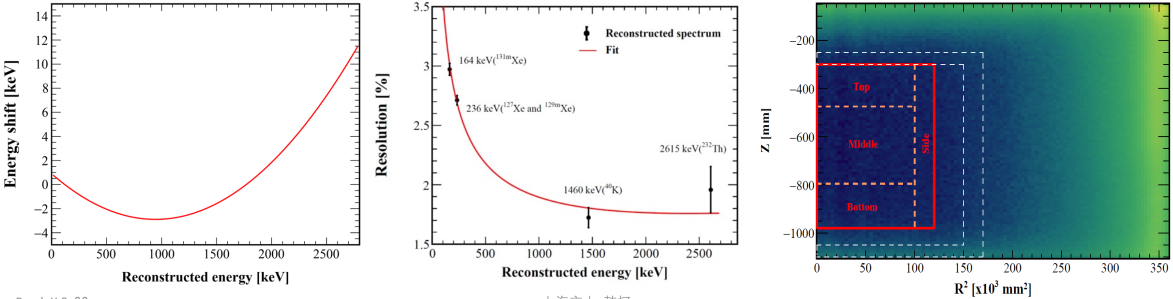


Energy Response Model

- Residual shift between simulated energy and reconstructed energy
- Energy resolution vs. reconstructed energy
- Response model from physics data in slim regions outside FV
- Model parameters naturally included in the likelihood fitting

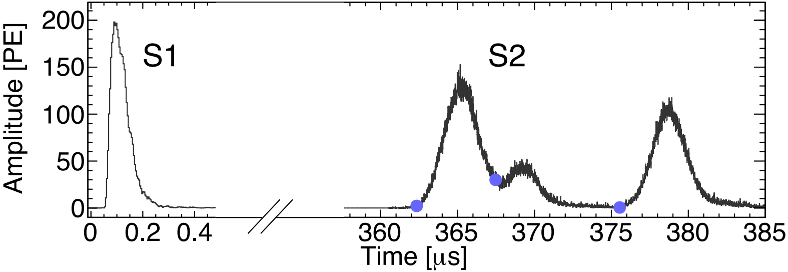
$$E = a \cdot \hat{E}^2 + b \cdot \hat{E} + c.$$

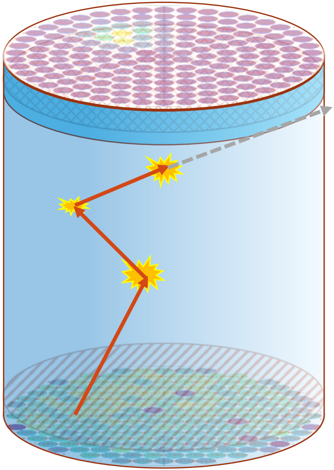
$$\frac{\sigma(E)}{E} = \frac{d}{\sqrt{E}} + e \cdot E + f.$$



SS vs. MS

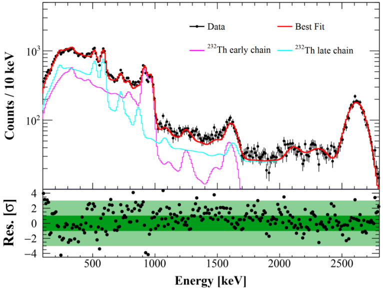
- MeV gamma events are mostly multiple-scattering events; while signals (DBD) are mostly single site (SS)
- Identifying Multi-Site (MS) events with PMT waveforms
- Width of waveforms dominated by Z (electron diffusion)

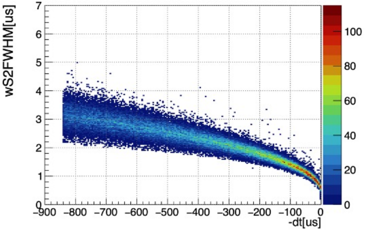


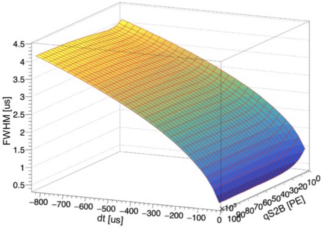


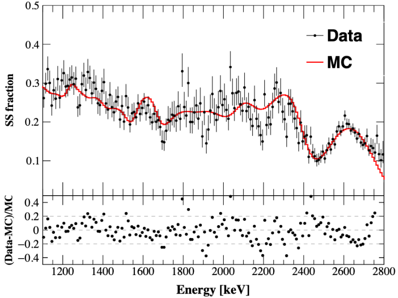
SS Fraction (SS/Total) determination

- Data-driven S2 waveform simulation + data processing
- SS fraction uncertainty is estimated by comparison MC/data of ^{232}Th calibration
- Spectrum average of the absolute bin-by-bin deviation between data and MC taken as SS fraction uncertainty



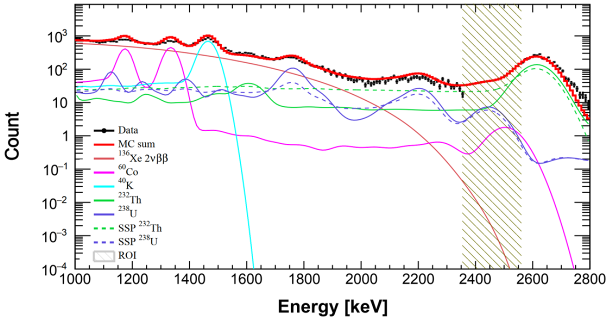


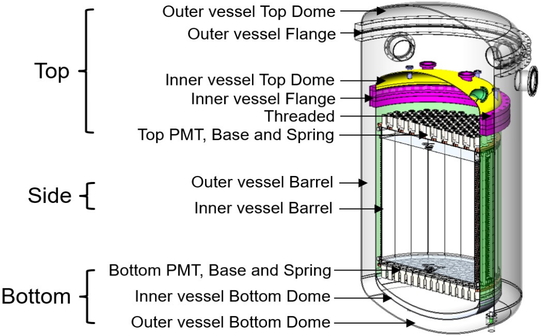




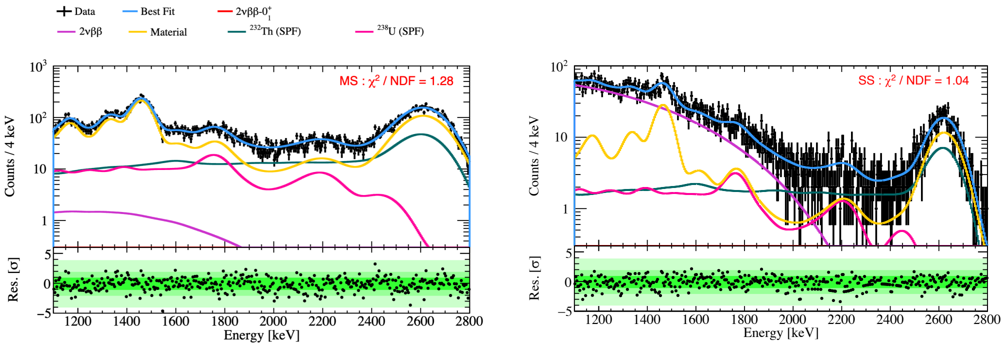
Background Model

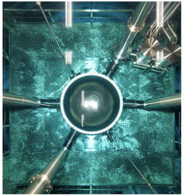
- ^{136}Xe $2\nu\beta\beta$ (from PandaX measured ^{136}Xe half-life)
- Detector material: ^{60}Co, ^{40}K, ^{232}Th, ^{238}U (from HPGe material assay), and grouped into top, side, and bottom parts
- Stainless steel platform (SSP): ^{232}Th, ^{238}U (from MS fitting)

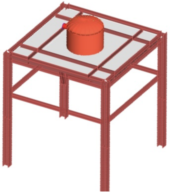




Stainless steel platform (SSP) contribution

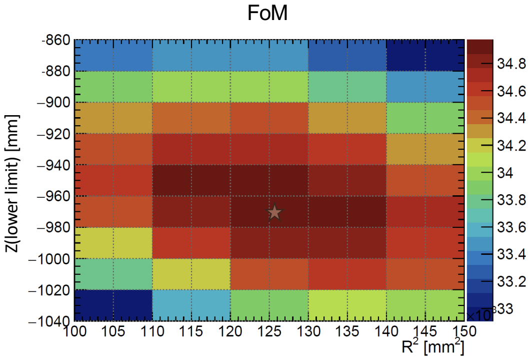


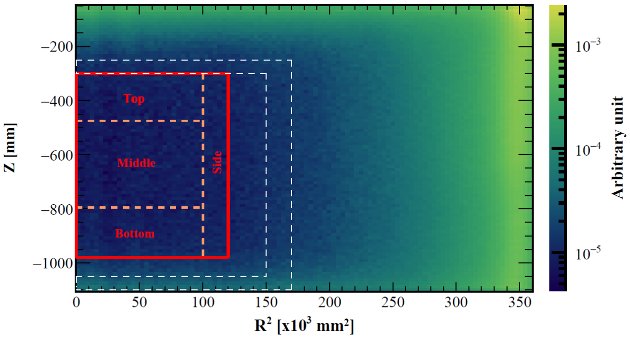




Fiducial Volume (FV)

- FV is optimized by maximizing the FoM $$FoM \propto \frac{m}{\sqrt{B}}$$
- FV is further divided into four regions to better constrain detector material background from top, side, and bottom parts





Likelihood and Systematics

- Binned Poisson likelihood with Gaussian penalty terms to constrain nuisance parameters
- Systematics include three categories: energy response, overall efficiency, ^{136}Xe mass
- ^{136}Xe mass uncertainties: abundance from RGA measurement; FV mass from the non-uniformity of ^{83m}Kr + LXe density fluctuation

$$L = \prod_{r}^{N_{run}} \prod_{i}^{N_{region}} \prod_{j}^{N_{bins}} \frac{(N_{rij})^{N_{rij}^{obs}}}{N_{rij}^{obs}!} e^{-N_{rij}}$$

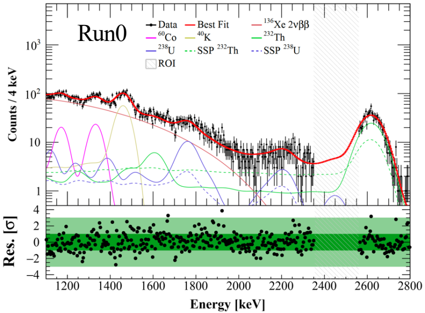
$$\cdot \prod_{r}^{N_{run}} [\mathcal{G}(\mathcal{M}_r; \mathcal{M}_r^0, \Sigma_r^{\mathcal{M}}) \cdot \prod_{k}^{N_{eff}} G(\eta_r^k; 0, \sigma_r^k)]$$

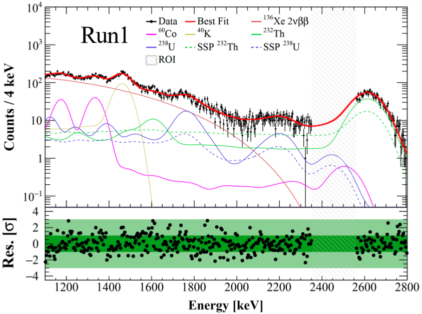
$$\cdot \prod_{b}^{N_{bkg}} G(\eta^b; 0, \sigma^b)$$

$$N_{rij} = (1 + \eta_r^o) \cdot [(1 + \eta_r^s) \cdot n_r^s \cdot S_{ijr} + \sum_{b}^{N_{bkg}} (1 + \eta^b) \cdot n_r^b \cdot B_{ijr}^b]$$

Sources		Values (Run0)	Values (Run1)
Energy response	a [keV^{-1}]	$(4.2 \pm 1.0) \times 10^{-6}$	$(1.1 \pm 1.4) \times 10^{-6}$
	b	0.992 ± 0.002	0.997 ± 0.004
	c [keV]	0.90 ± 0.32	1.4 ± 1.5
	d [$\sqrt{\text{keV}}$]	0.259 ± 0.046	0.46 ± 0.25
	e [keV^{-1}]	$(1.1 \pm 1.5) \times 10^{-6}$	$(8.8 \pm 22.2) \times 10^{-7}$
	f	$(9.7 \pm 3.5) \times 10^{-3}$	$(7.4 \pm 10.0) \times 10^{-3}$
Overall efficiency	^{136}Xe $0\nu\beta\beta$ SS fraction	$(87.1 \pm 11.3)\%$	$(87.3 \pm 7.0)\%$
	Quality cut	$(99.89 \pm 0.10)\%$	$(99.97 \pm 0.02)\%$
^{136}Xe mass	^{136}Xe abundance	$(8.58 \pm 0.11)\%$	
	FV mass [kg]	735 ± 3	735 ± 14
Background model		Table. 2	

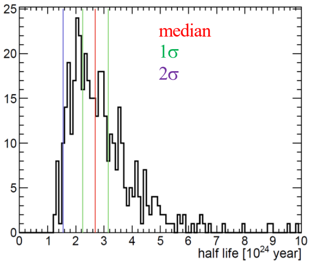
Blinded Fit and Sensitivity





Goodness-of-fit:

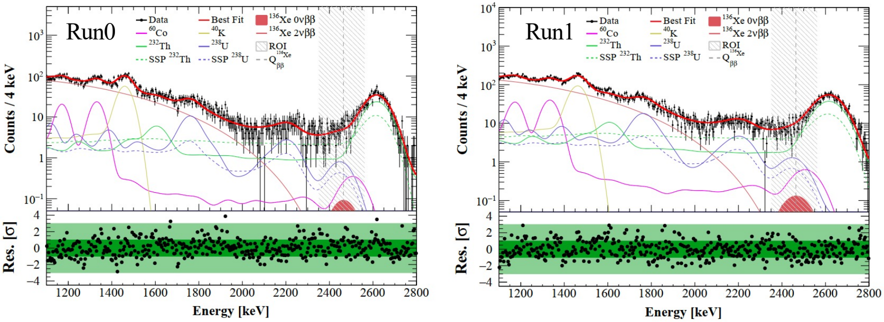
$\chi^2/\mathrm{NDF} = 1.14$



Median sensitivity is estimated by fits to toy-data, generated from background model.

$$T^{0\nu\beta\beta}_{1/2,\,sensitivity} > 2.7\times 10^{24}\ yr \text{ at 90\% C.L.}$$

Unblinded Fit and Results

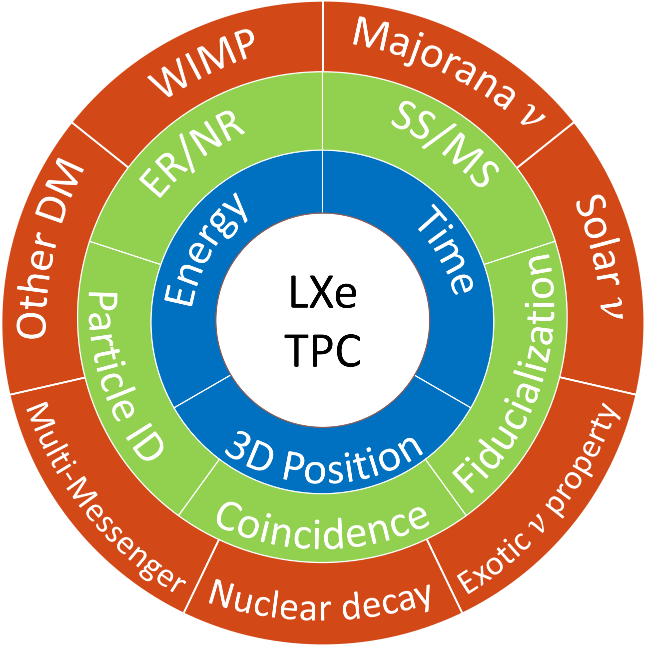


- ^{136}Xe exposure: 44.6 kg-yr
- Energy resolution @ 2615 keV: 2.0% in Run0 and 2.3% in Run1
- ^{136}Xe $0\nu\beta\beta$ event rate: $14\pm55\ t^{-1}yr^{-1}$, <111 $t^{-1}yr^{-1}$ at 90% C.L.
- $T_{1/2}^{0\nu\beta\beta} > 2.1\times 10^{24}\ yr$ at 90% C.L. $\langle m_{\beta\beta}\rangle = (0.4 - 1.6)\ \mathrm{eV/c^2}$

Search for ^{136}Xe 0νββ with natural Xe TPC

	Bkg rate (/keV/ton/y)	Energy resolution	FV mass (kg)	Live time	Sensitivity/Limit (90% CL, year)	Year
PandaX-II	~200	4.2%	219	403 days	2.4×10^{23}	2019
XENON1T	~20	0.8%	741	203 days	1.2×10^{24}	2022
PandaX-4T	~10	2.0-2.3%	735	258 days	2.1×10^{24}	2024

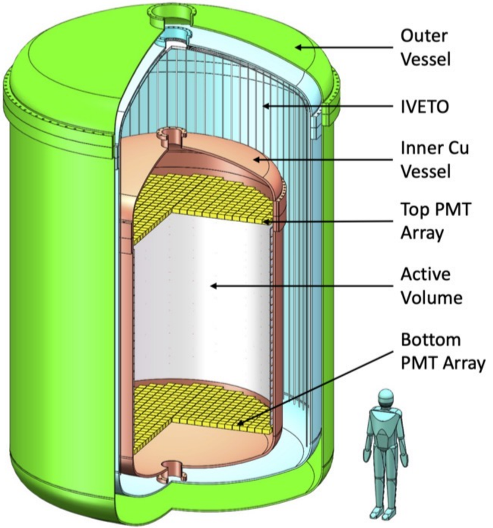
- The most stringent constraint from a natural xenon detector
- Improvement w.r.t PandaX-II by an order of magnitude and XENON1T by a factor of 1.8
- Demonstrating the potential of ^{136}Xe 0νββ search with next-generation multi-ten-tonne natural xenon detectors



+ Larger Cleaner Detector

PandaX-xT: Multi-ten-tonne Liquid Xenon Observatory

- Active target: 43 tons of Xenon
  - Test the WIMP paradigm to the neutrino floor
  - Explore the Dirac/Majorana nature of neutrino
  - Search for astrophysical or terrestrial neutrinos and other ultra-rare interactions
- Notable detector improvements:
  - High-granularity, low-background 2-in PMT array
  - Cu/Ti vessel for improved radiopurity
  - Inner liquid scintillator veto



SCPMA 68, 221011 (2025)

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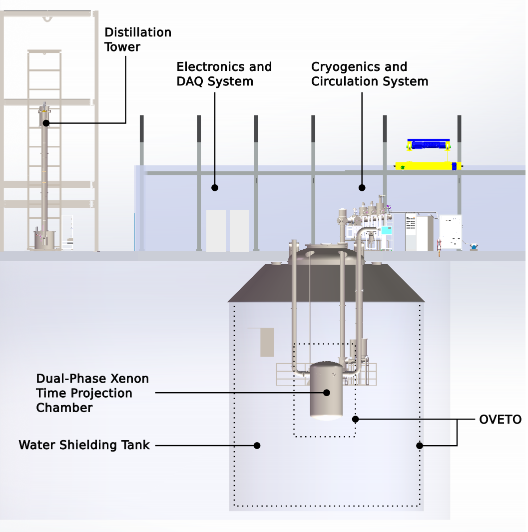
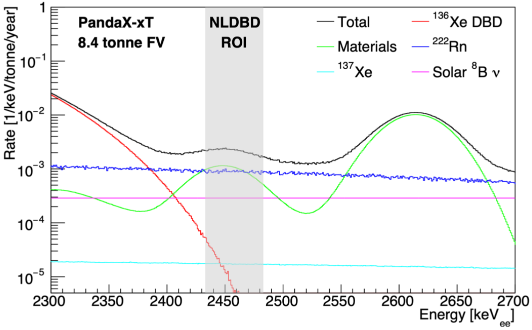


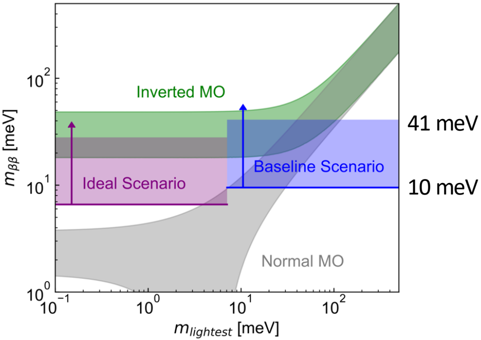
SCPMA 68, 221011 (2025)

PandaX-xT for 0νββ

- 4 ton of ^{136}Xe: one of the largest 0νββ experiments
- Effective self-shielding: Xenon-related background dominates in the 8.4-tonne center FV

	Baseline (1/tonne/year)	Ideal (1/tonne/year)
Photosensors	1.4×10^{-2}	2.8×10^{-3}
Copper vessel	3.2×10^{-2}	6.3×10^{-3}
^{222}Rn	4.5×10^{-2}	-
^{136}Xe DBD	5.2×10^{-4}	5.2×10^{-4}
^{137}Xe	8.7×10^{-4}	8.7×10^{-4}
Solar ^{8}B ν	1.4×10^{-2}	1.4×10^{-2}
Total	$\mathbf{1.1\times10^{-1}}$	$\mathbf{2.4\times10^{-2}}$





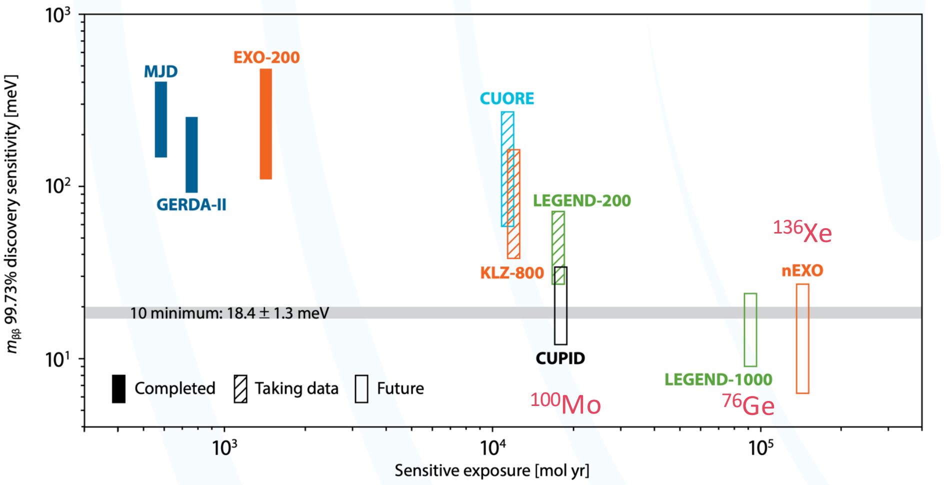
Head-to-head with other DM/0νββ experiments

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

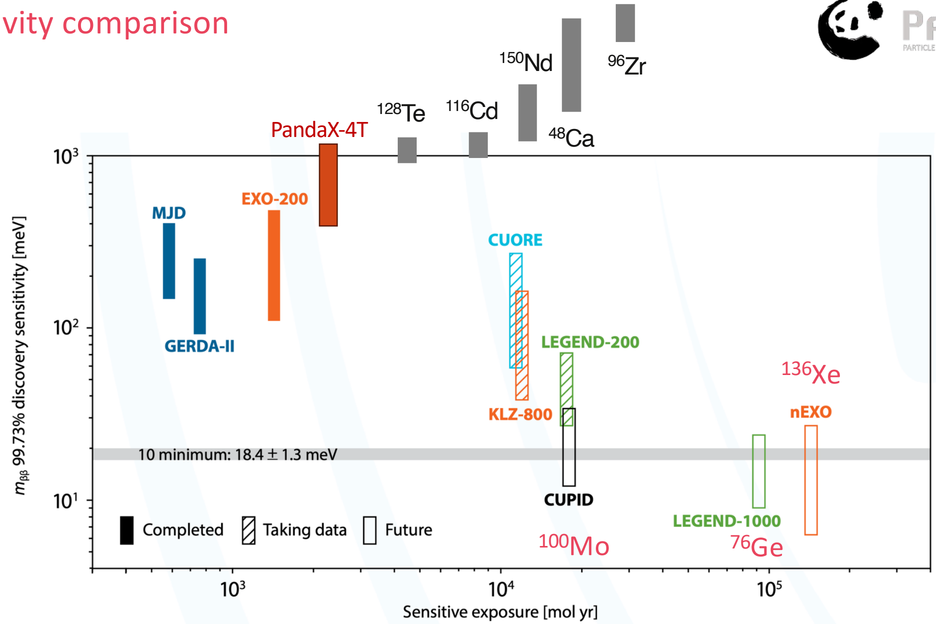
	Bkg rate (/keV/ton/y)	Energy resolution	Mass (ton)	Run time	Sensitivity/Limit (90% CL, year)
PandaX-4T	6	1.9%	4	94.9 days	$> 10^{24}$
XENONnT	1	0.8%	6	1000 days (expected)	2×10^{25}
LZ	0.3	1%	7	1000 days (expected)	1×10^{26}
KamLAND-ZEN	0.002	5%	0.8 (^{136}Xe)	1.5 years	2.3×10^{26}
nEXO	0.006	1%	5 (^{136}Xe)	10 years	1.35×10^{28} **
DARWIN	0.004*	0.8%	40	10 years	2×10^{27}
PandaX-xT	0.002*	1%	43	10 years	3×10^{27}

* Major difference from cosmogenic ^{137}Xe; ** $\frac{S}{\sqrt{B}}$ sensitivity is 6×10^{27} yr, for detector performance comparison in the table.

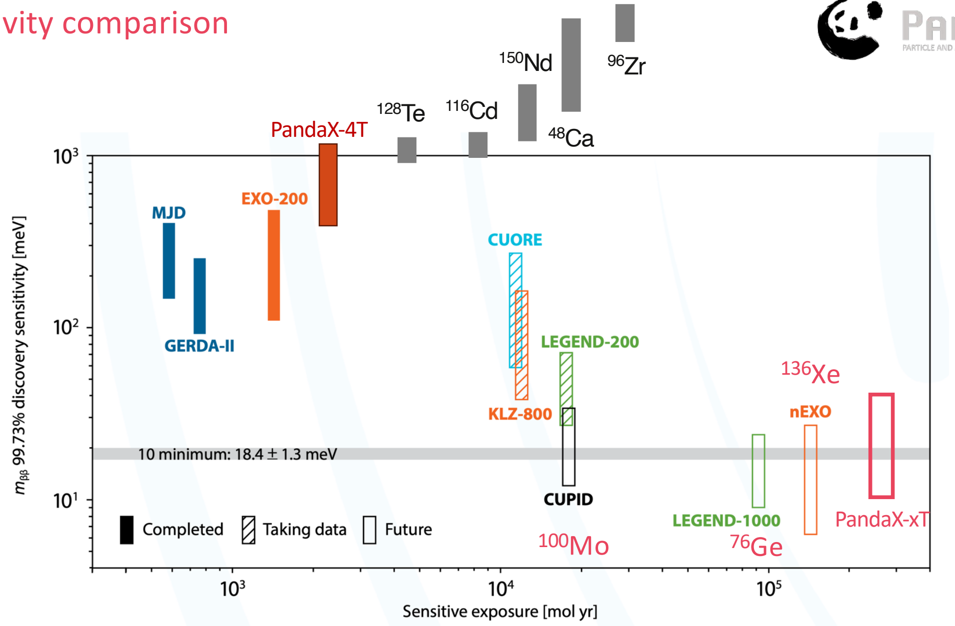
Sensitivity comparison



Sensitivity comparison

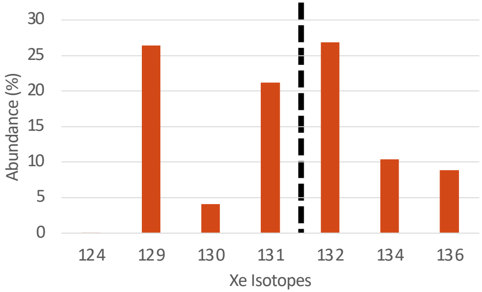


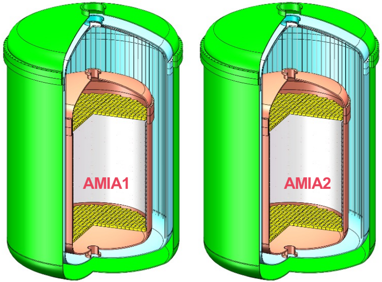
Sensitivity comparison



Possible isotope seperation/enrichment

- Xenon with artificially modified isotopic abundance (AMIA) for smoking gun discovery
  - A split of odd and even nuclei
  - Further enrichment of ^{136}Xe
  - to improve sensitivity to spin-dependence of DM-nucleon interactions and 0νββ





Neutrinoless double beta decay with PandaX

- Neutrinoless double beta decay is at the frontier of particle and nuclear physics: the Majorana nature of neutrino and beyond
- Global competition: LEGEND (US), CUPID (EU), and KamLAND2-ZEN (JP); all with enriched materials
- PandaX-4T has established the most stringent ^{136}Xe limit from a natural xenon detector
- PandaX-xT will be one of the most competitive $0\nu\beta\beta$ experiments

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

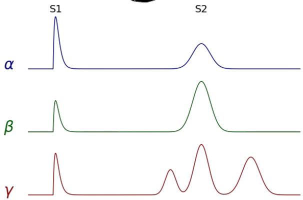
Thank you very much

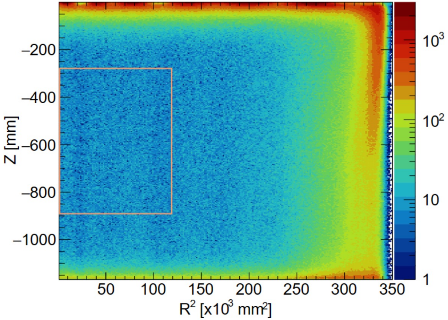
We welcome new collaborators

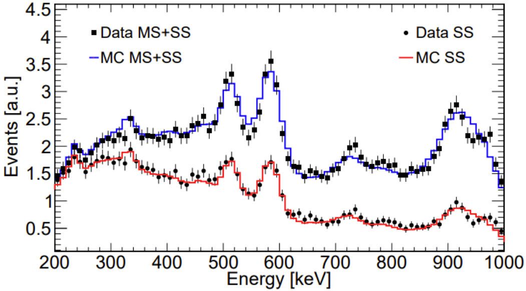
at PandaX-xT

Data selection

- An identical FV as in ^{136}Xe analysis, total isotopic exposure: 17.9 kg·yr
- Single site vs multi-site selection measured by ^{232}Th calibration data
  - Little impact to DBD signals (β SS events)





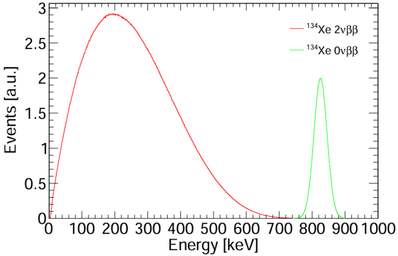


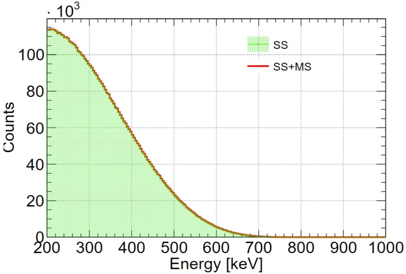
PandaX, Phys.Rev.Lett. 132 (2024) 15, 152502

Signal efficiencies

- ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ events generated with the theoretical calculation
- The signal events went through PandaX-4T simulation and data processing chain

- ROI [200,1000]keV cut:
  - $2\nu\beta\beta$: 60.56%
  - $0\nu\beta\beta$: 99.98%
- SS ratio in ROI:
  - $2\nu\beta\beta$: 99.89%
  - $0\nu\beta\beta$: 98.23%





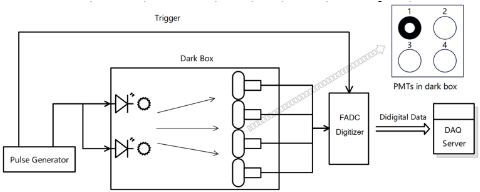
Physical Review C 85, 034316 (2012)

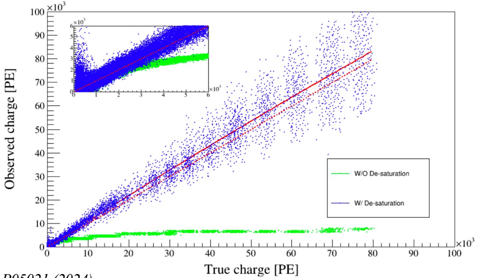
Background model

	Component	Input Counts	Constraint	
	^{60}Co	130	13%	
Materials	^{40}K	133	8%	
	^{232}Th	950	5%	Measured in ^{136}Xe $2\nu\beta\beta$ analysis
	^{238}U	274	8%	*Research* 2022 (2022) 9798721
	^{136}Xe	12372	5%	
	^{212}Pb	1012	29%	Measured by its daughter ^{212}Po alpha decay
	^{85}Kr	296	52%	Determined by β−γ emission through the metastable state ^{85m}Rb
LXe	^{133}Xe	3423	10%	Estimated the β+γ shoulder of ^{133}Xe between 90 and 120 keV
	^{214}Pb	19429	Free	Determined by ^{222}Rn
	^{125}Xe	-	Free	short-lived xenon isotopes induced by neutron calibration
	Other Xe	-	Free	^{127}Xe and ^{129m}Xe

Bench test for saturation and new PMT base design

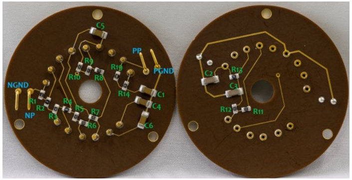
- PMT waveform saturation is studied by independent bench tests
- Desat

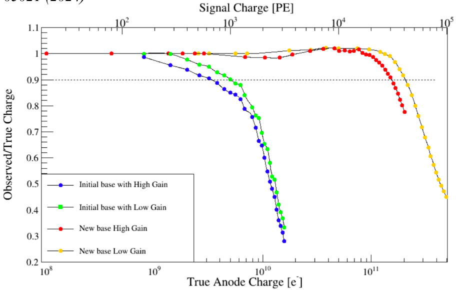




JINST 19 P05021 (2024)

- New PMT base design to increase the dynamic range
- All PMT bases have been changed in Run2

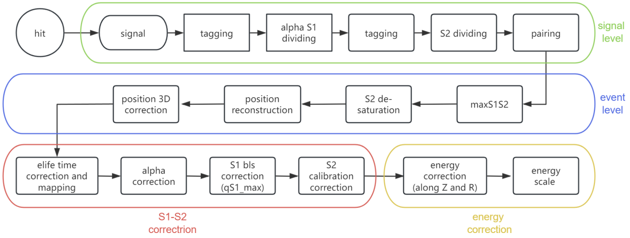




Unified Data Reconstruction Pipeline

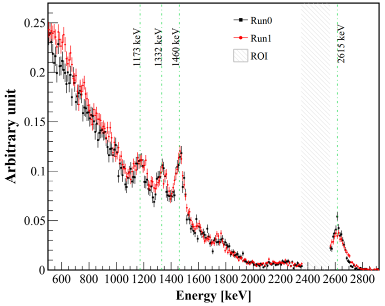
Optimizations in data processing:

- Recovered ~0.5% SS events by an improved time window cut
- S1 waveform slicing to improve alpha events reconstruction
- 3.5 ms dead-time cut before ^{214}Po events to remove isolated ^{214}Bi events: ~1% background reduction and negligible data loss
- And more...



Unified pipeline for Run0 and Run1

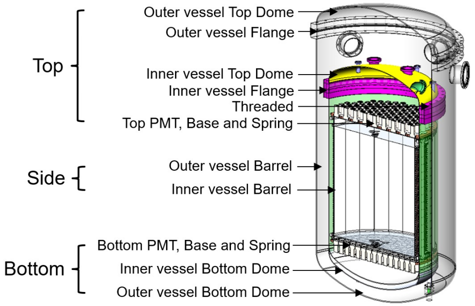
- Reconstructed spectra of Run0 and Run1 are consistent, considering the ^{222}Rn increase in Run1

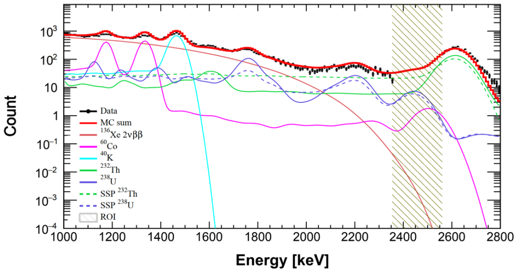


Blind analysis: ROI = [2356, 2560] keV, only SS events used

Background Model

- ^{136}Xe $2\nu\beta\beta$ (from PandaX measured ^{136}Xe half-life)
- Detector material: ^{60}Co, ^{40}K, ^{232}Th, ^{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

Likelihood and Systematics

- Binned Poisson likelihood with Gaussian penalty terms to constrain nuisance parameters
- Systematics include three categories: energy response, overall efficiency, ^{136}Xe mass
- Background model and systematics are included in likelihood fitting

$$L = \prod_{r}^{N_{run}} \prod_{i}^{N_{region}} \prod_{j}^{N_{bins}} \frac{(N_{rij})^{N_{rij}^{obs}}}{N_{rij}^{obs}!} e^{-N_{rij}}$$

$$\cdot \prod_{r}^{N_{run}} [\mathcal{G}(\mathcal{M}_r; \mathcal{M}_r^0, \Sigma_r^{\mathcal{M}}) \cdot \prod_{k}^{N_{eff}} G(\eta_r^k; 0, \sigma_r^k)]$$

$$\cdot \prod_{b}^{N_{bkg}} G(\eta^b; 0, \sigma^b)$$

$$N_{rij} = (1 + \eta_r^o) \cdot [(1 + \eta_r^s) \cdot n_r^s \cdot S_{ijr}$$

$$+ \sum_{b}^{N_{bkg}} (1 + \eta^b) \cdot n_r^b \cdot B_{ijr}^b]$$

Sources		Values	
		Run0	Run1
Energy response	a [keV^{-1}]	$(4.2 \pm 1.0) \times 10^{-6}$	$(1.1 \pm 1.4) \times 10^{-6}$
	b	0.992 ± 0.002	0.997 ± 0.004
	c [keV]	0.90 ± 0.32	1.4 ± 1.5
	d [$\sqrt{\text{keV}}$]	0.259 ± 0.046	0.46 ± 0.25
	e [keV^{-1}]	$(1.1 \pm 1.5) \times 10^{-6}$	$(8.8 \pm 22.2) \times 10^{-7}$
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Overall efficiency	^{136}Xe $0\nu\beta\beta$ SS fraction	$(87.1 \pm 11.3)\%$	$(87.3 \pm 7.0)\%$
	Quality cut	$(99.89 \pm 0.10)\%$	$(99.97 \pm 0.02)\%$
^{136}Xe mass	^{136}Xe abundance	$(8.58 \pm 0.11)\%$	
	FV mass [kg]	735 ± 3	735 ± 14
Background model		Table. 2	

- ^{136}Xe abundance is measured by RGA with xenon samples from detector
- FV mass uncertainty is estimated from the non-uniformity of ^{83m}Kr calibration data distribution, plus the LXe density fluctuation (pressure fluctuation) during data-taking

Background counts and parameter pulls

Background counts in the ROI

Background	Model expectation	Blinded fit	Unblinded fit
SSP ^{232}Th	527 ± 45	470 ± 34	458 ± 33
SSP ^{238}U	50 ± 15	38 ± 11	39 ± 11
^{232}Th	375 ± 224	510 ± 34	485 ± 31
^{238}U	78 ± 42	70 ± 9	72 ± 9
^{60}Co	18 ± 7	31 ± 3	31 ± 3
^{136}Xe	0.18 ± 0.01	0.19 ± 0.01	0.19 ± 0.01

paper on arXiv

arxiv:2412.13979

- All pulls of nuisance parameters fall within the ±2σ range
- All best-fit nuisance parameters are consistent between the blinded and unblinded fits
- Pull of top ^{60}Co reaches 1.8σ, indicating that the model expectation from the HPGe material assay might be slightly underestimated