PARTICLE AND ASTROPHYSICAL XENON TPC

Measurement of ^{136}Xe DBD Half-life with PandaX-4T

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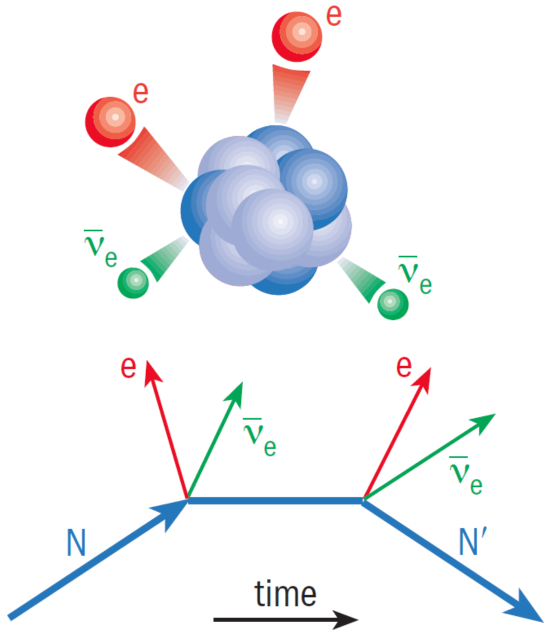
on behalf of the PandaX Collaboration

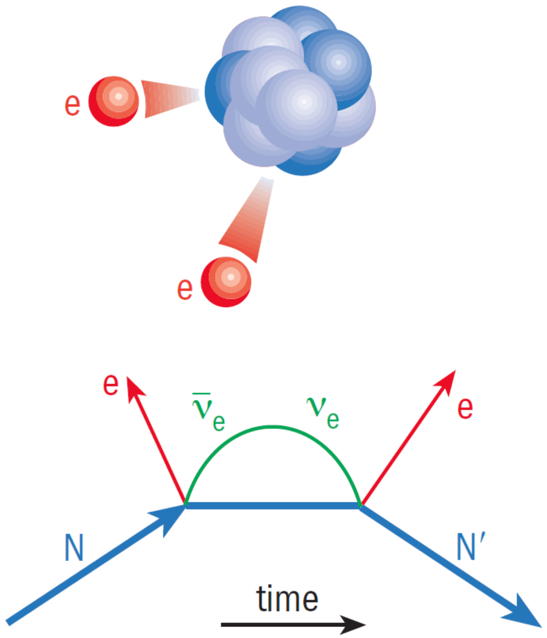
July 5, 2022

第一届“粤港澳”核物理论坛，珠海

Majorana neutrino and Double beta decay



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



From Physics World

1935, Goeppert-Mayer
Two-Neutrino double beta decay (DBD)

1937, Majorana
Majorana Neutrino

1939, Furry
Neutrinoless double beta decay (NLDBD)

1930, Pauli
Idea of neutrino

1933, Fermi
Beta decay theory

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

NLDBD probes the nature of neutrinos

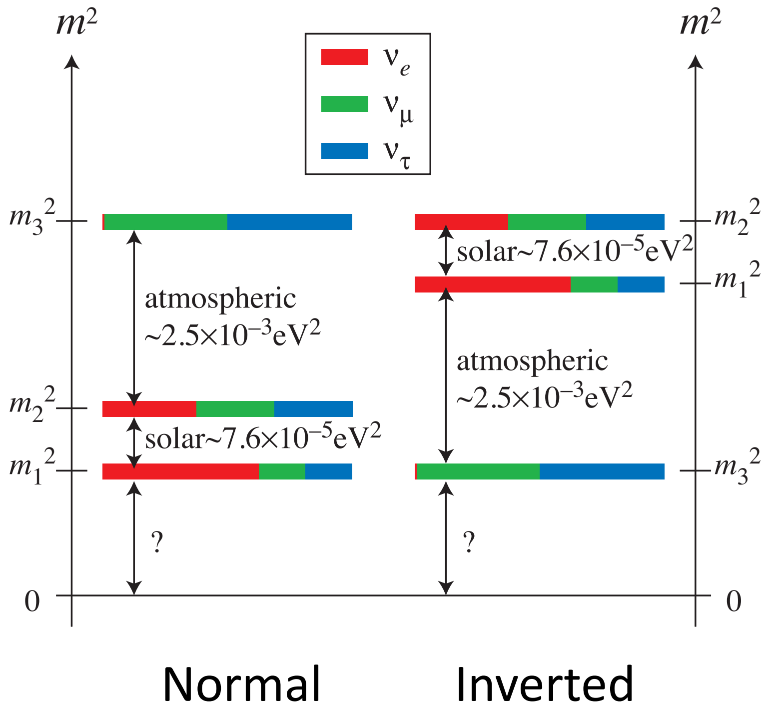
- Majorana or Dirac
- Lepton number violation
- Measures effective Majorana mass: relate 0νββ to the neutrino oscillation physics

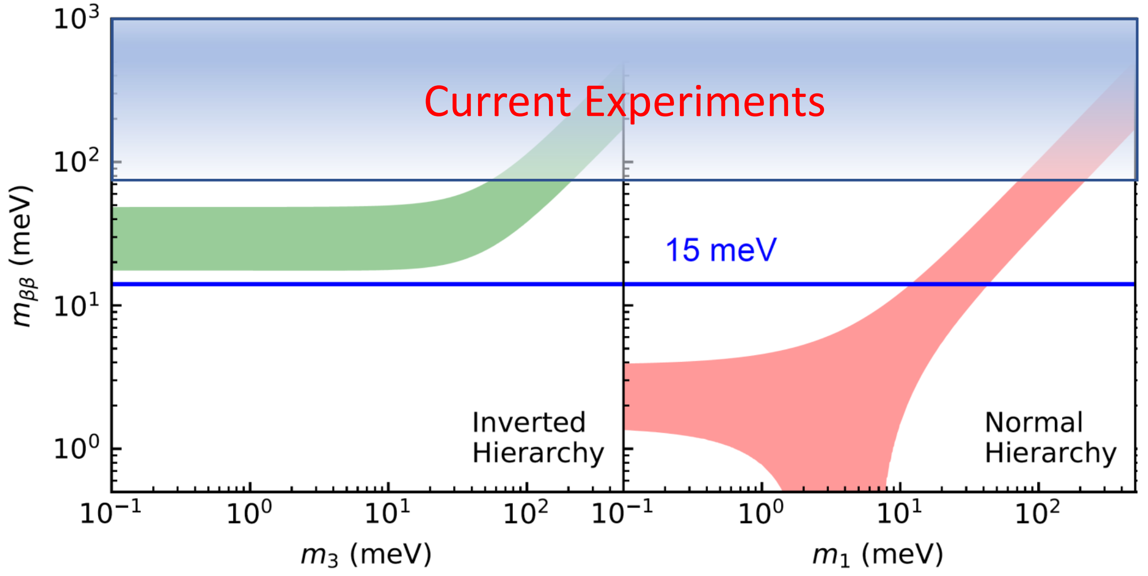
$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\ |M^{0\nu}|^2\ \frac{|\langle m_{\beta\beta}\rangle|^2}{m_e^2}$$

Phase space factor

Nuclear matrix element

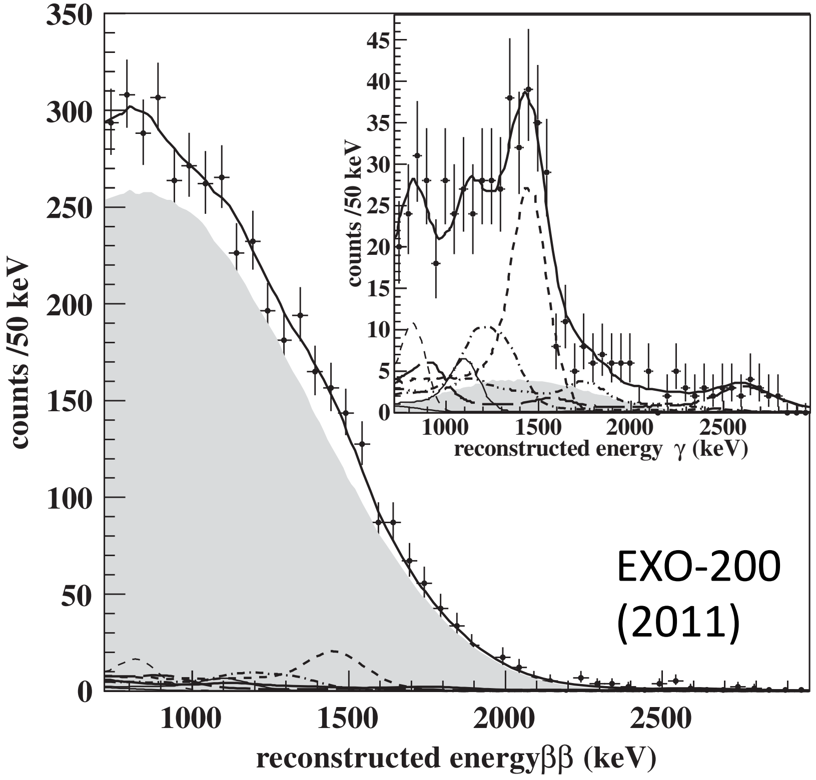
Effective Majorana neutrino mass: $|\langle m_{\beta\beta}\rangle| = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$



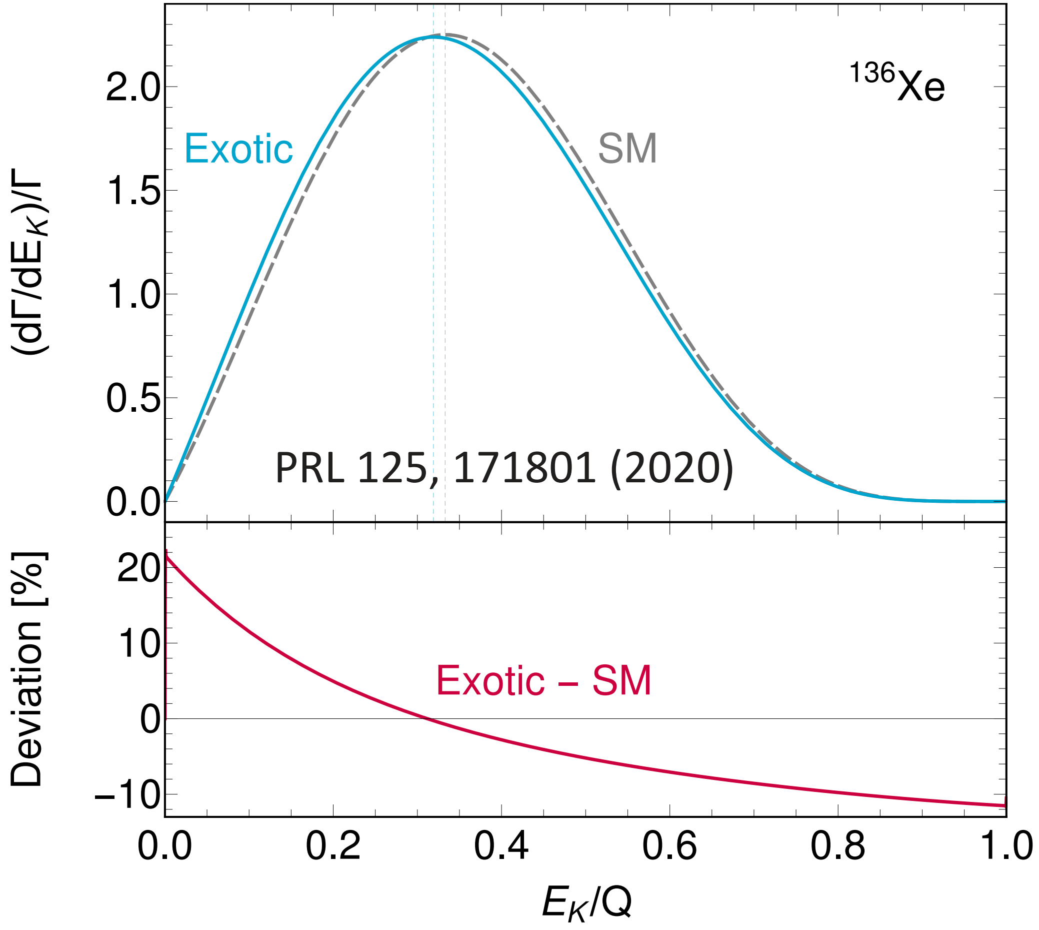


Measuring the DBD half-life

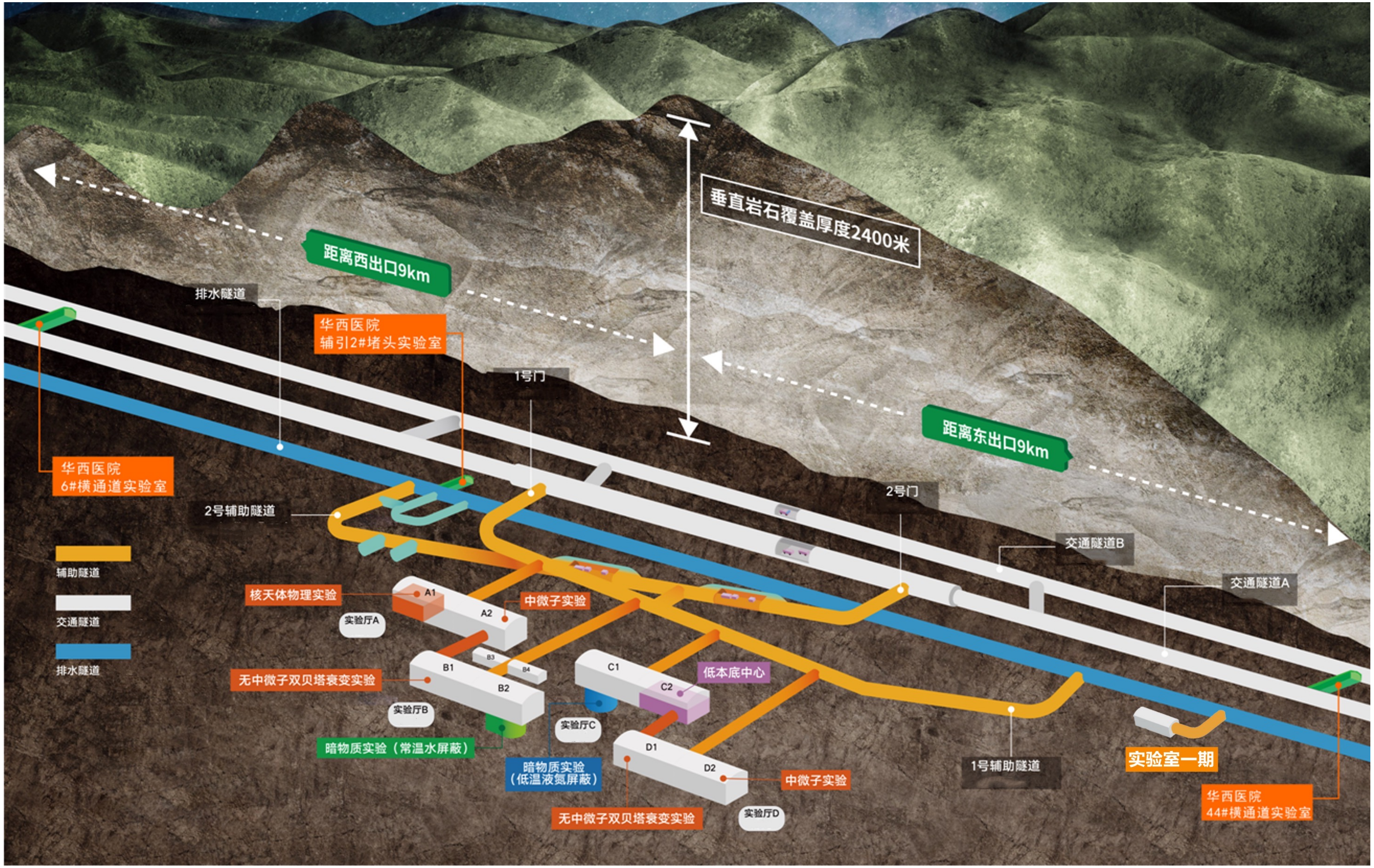
- Precision measurement of DBD is a major first step for any NLDBD experiment
- Understand better the background for more rare searches

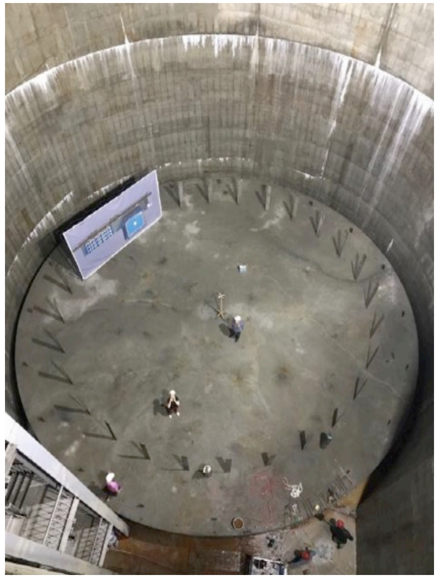


- Searching for possible shape distortion for new BSM physics



CJPL: Deepest underground lab

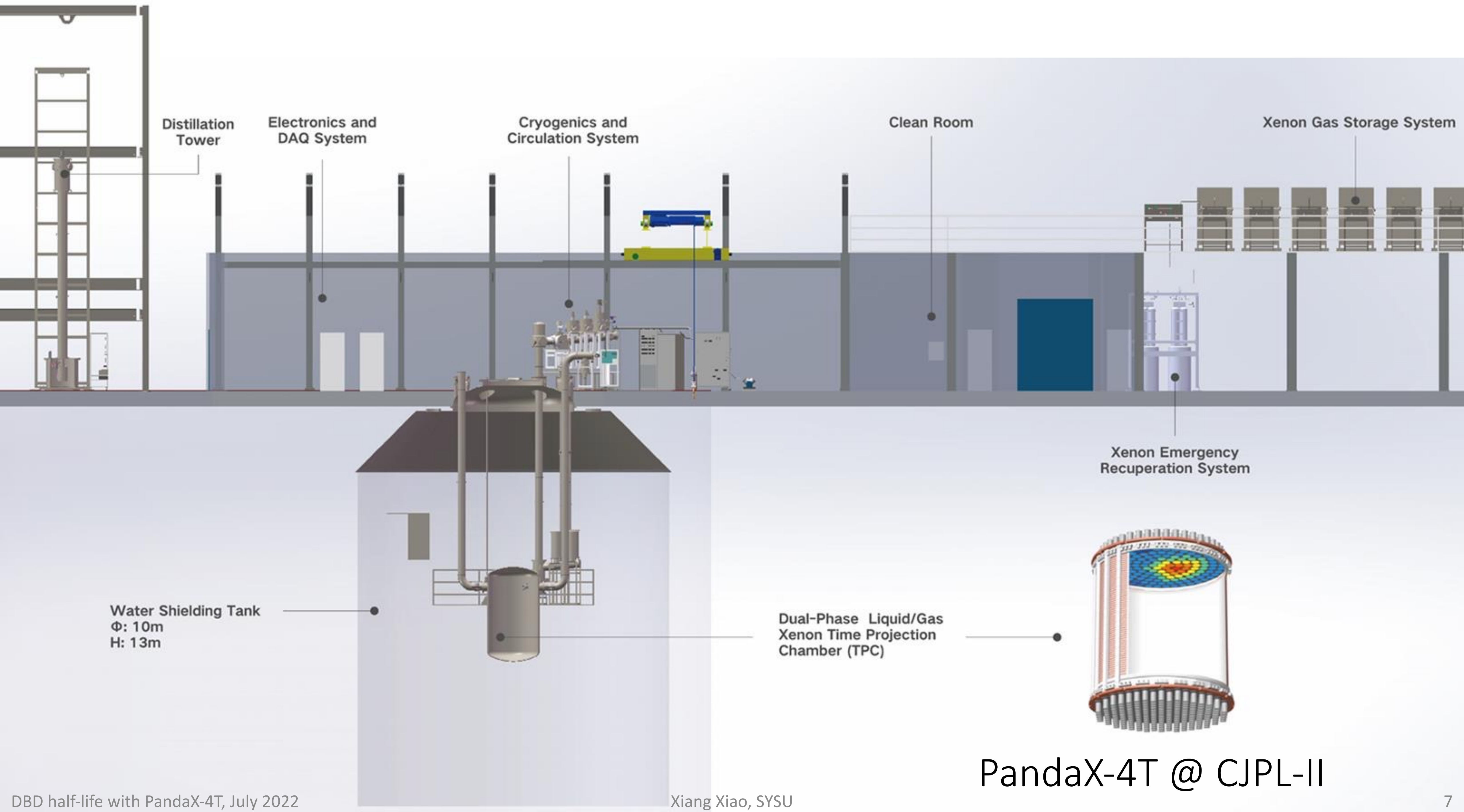




PandaX Collaboration

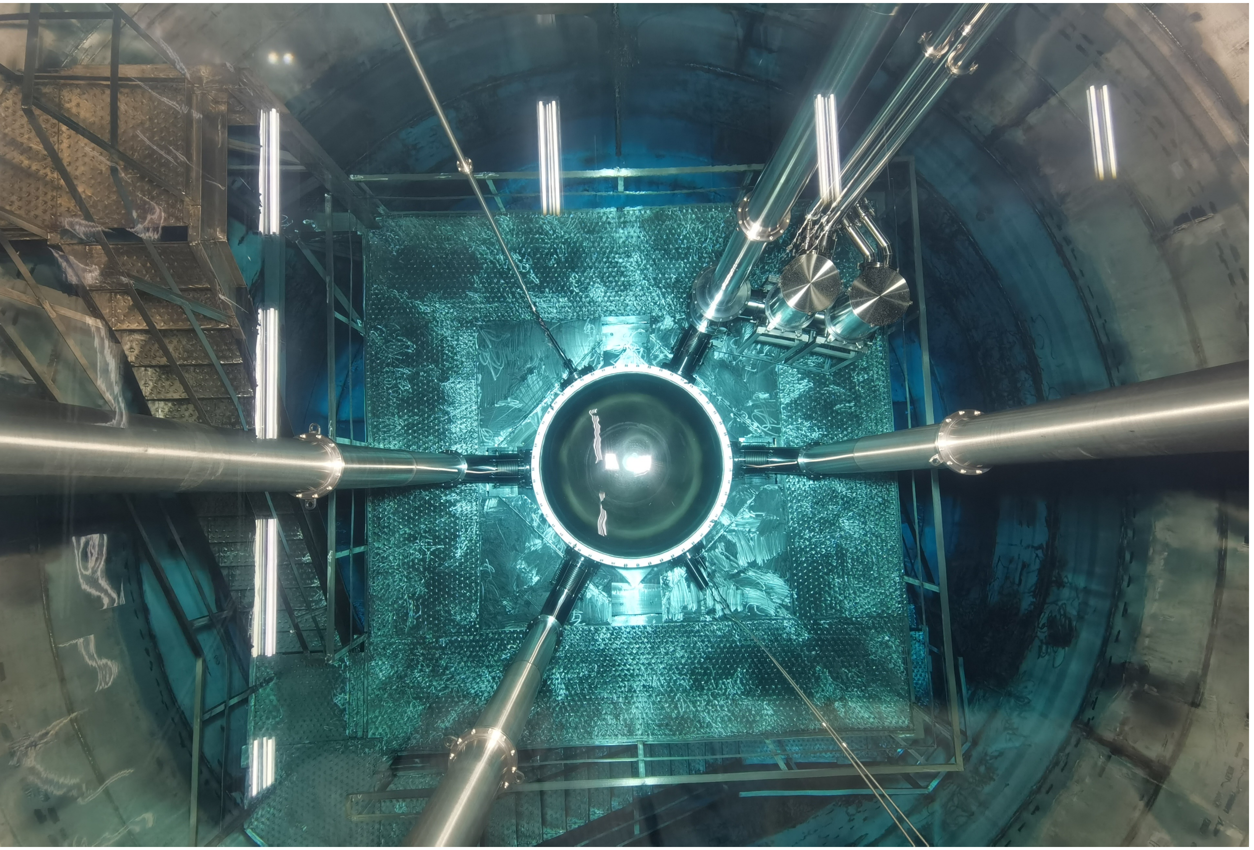
Particle and Astrophysical Xenon Experiment; started in 2009; now ~80 authors

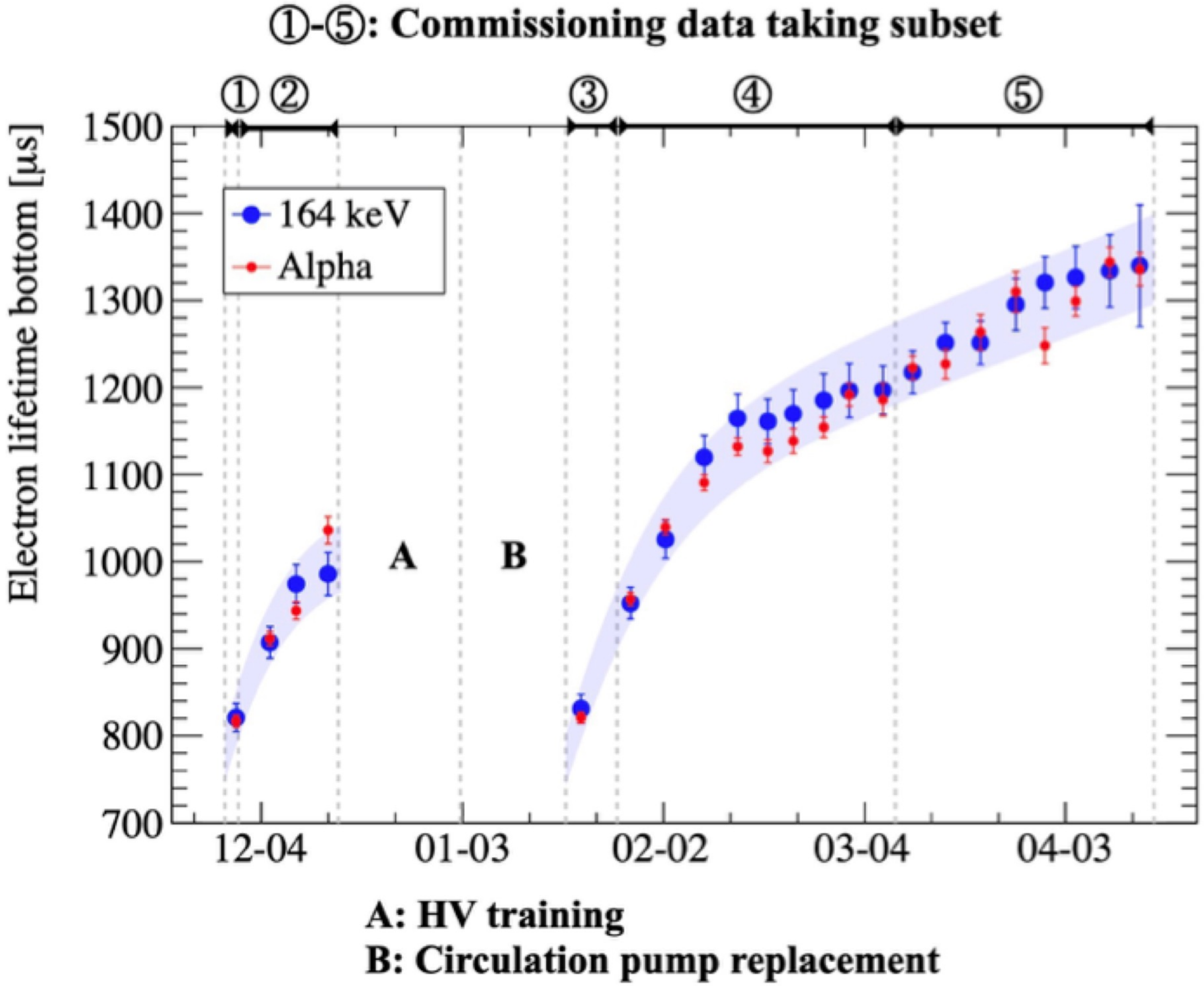
SINAP CNNC 雅砻江水电 cea Universidad Zaragoza



PandaX-4T @ CJPL-II

Stable data taking during commissioning runs: 94.9 days for DBD analysis

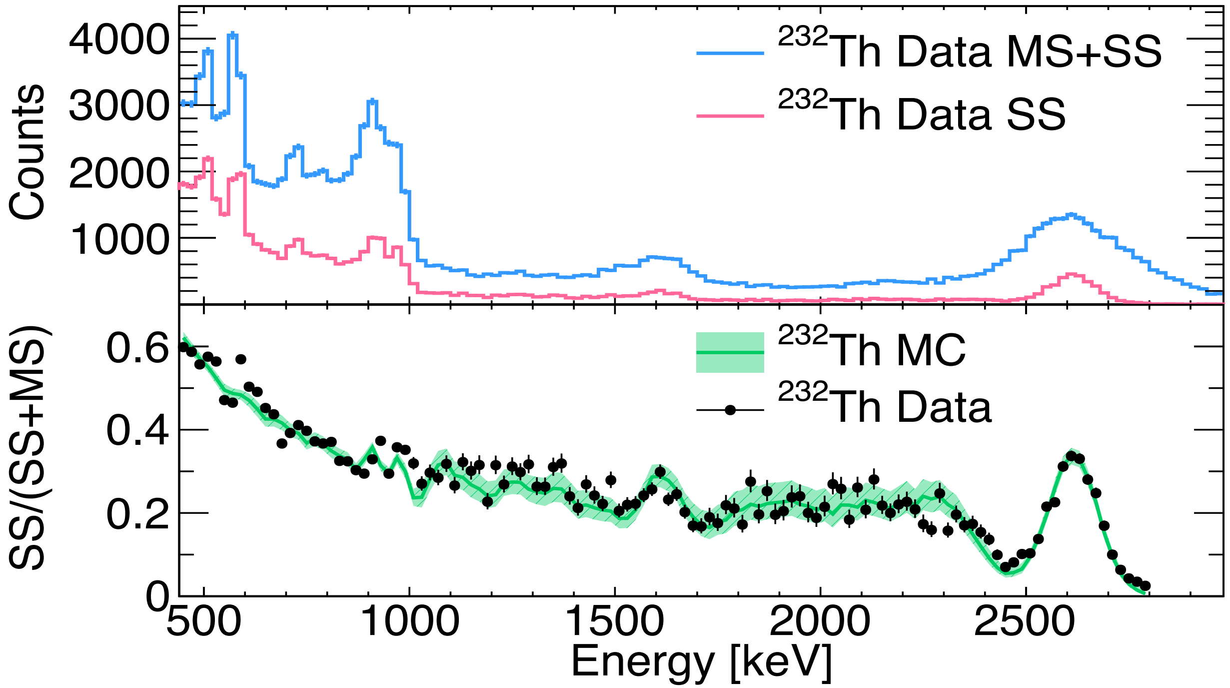


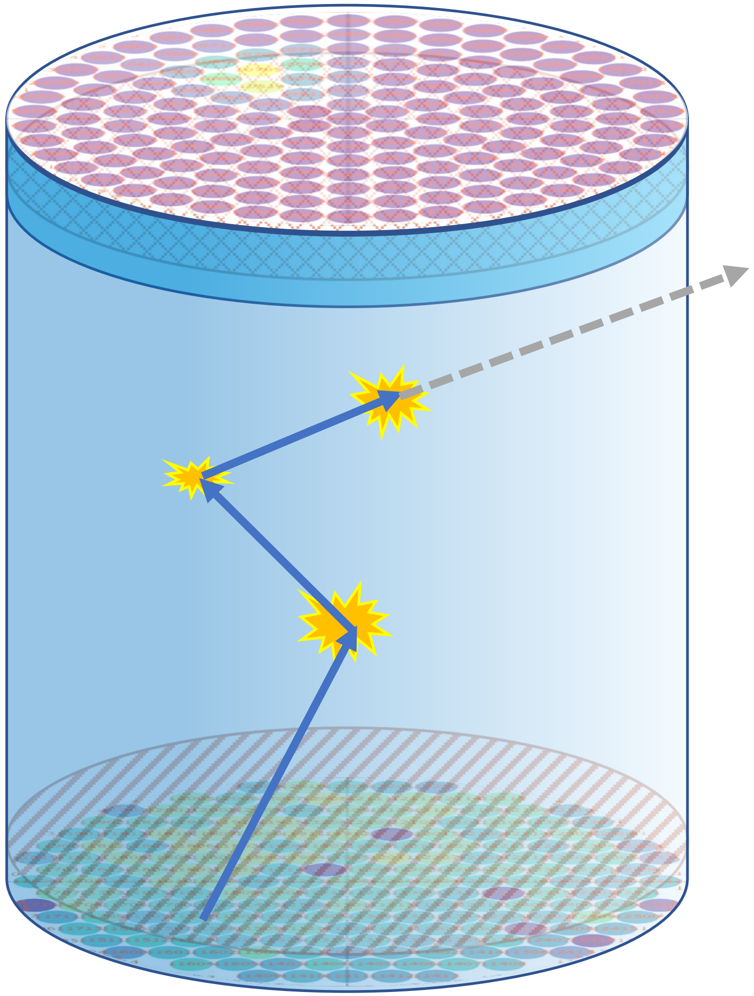


Nov. 28, 2020 to Apr. 16, 2021

Extending DM detector response to MeV range

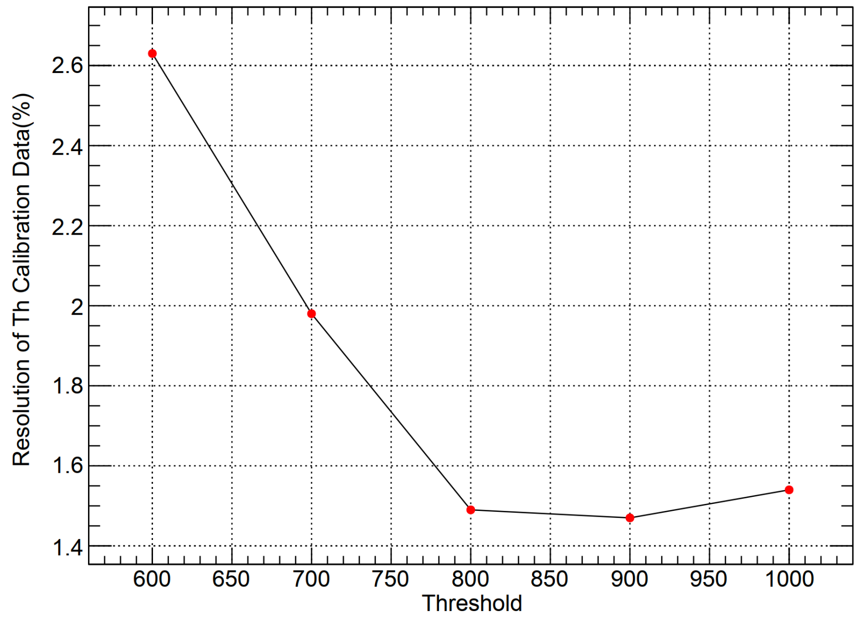
- MeV gamma events are mostly multiple-scattering events; while signals (DBD) are mostly single site (SS)
- Identifying Multi-Site (MS) events with PMT waveforms
- Width of waveforms dominated by Z (electron diffusion)



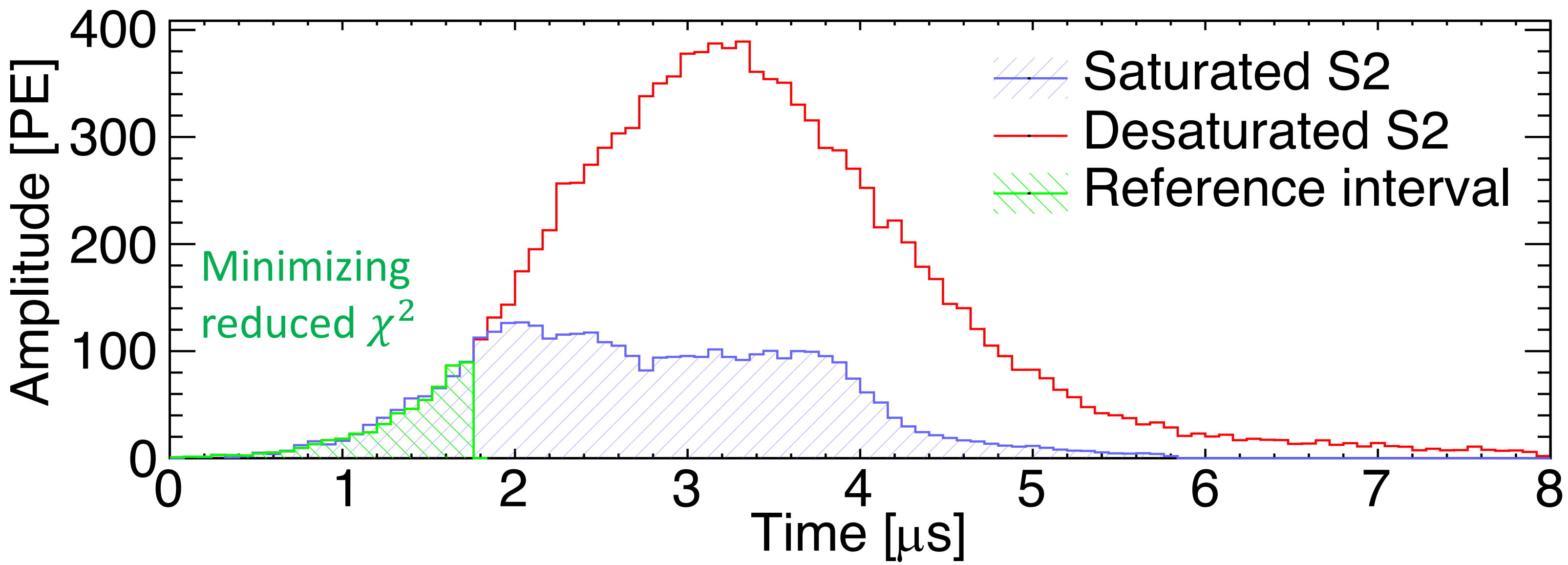


PMT pulse saturation and desaturation

- PMT bases suffer serious saturation for MeV range events
- Match the rising slope of the saturated to the non-saturated templates in the same events→ True charge collected
- For events in the energy range of 1 to 3 MeV, the average correction factor is ~3.0 for the top PMT array



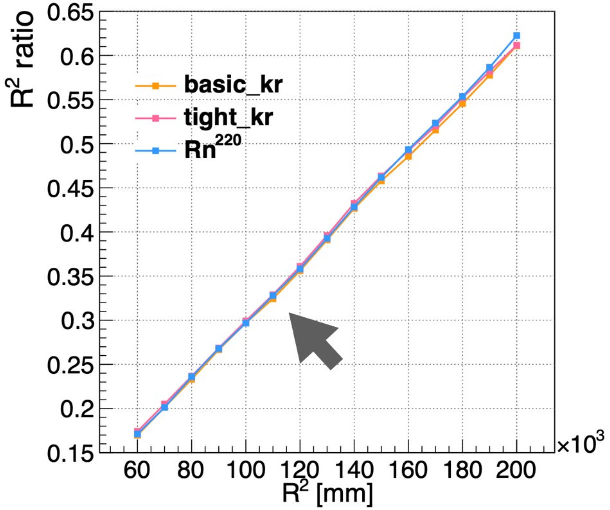
Unsaturated WFs (50-900 PE) as templates

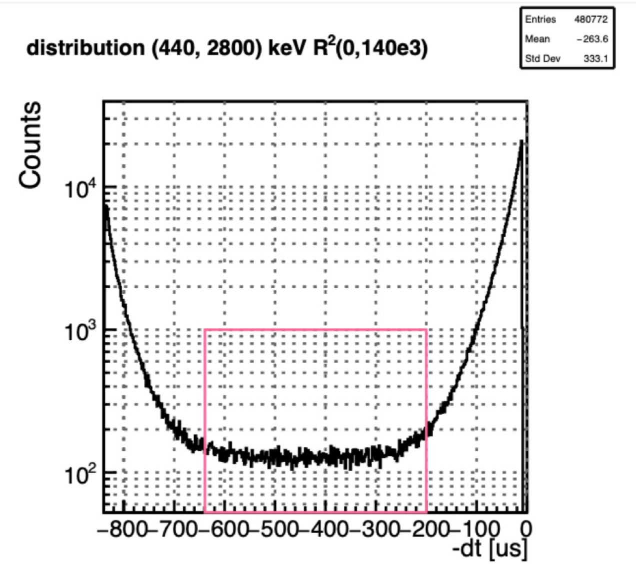


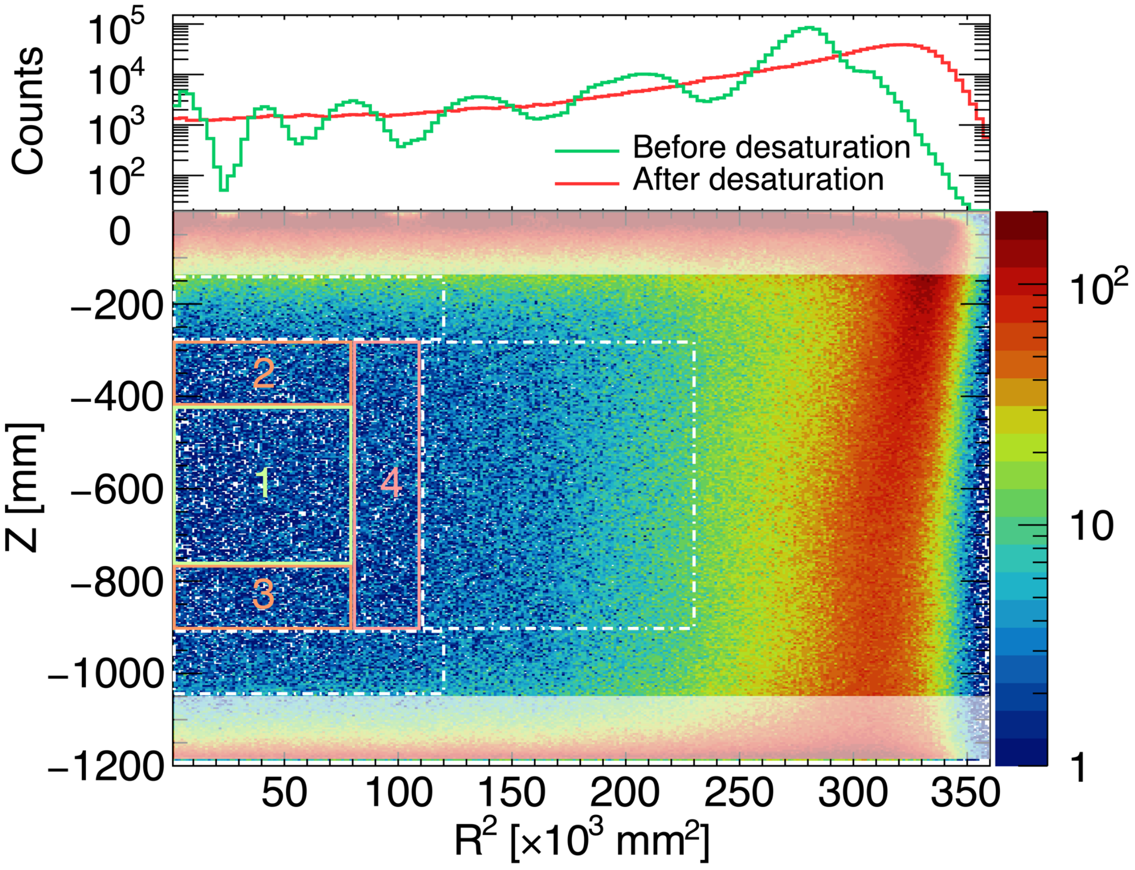
Fiducial volume

- Compare the number of events of ^{83m}Kr and ^{220}Rn with geometric volume; the non-linearity between the two <0.5% defines the cut in R direction
- Z direction: smaller background rate
- Outer (dashed) region for cross-validation

FV mass



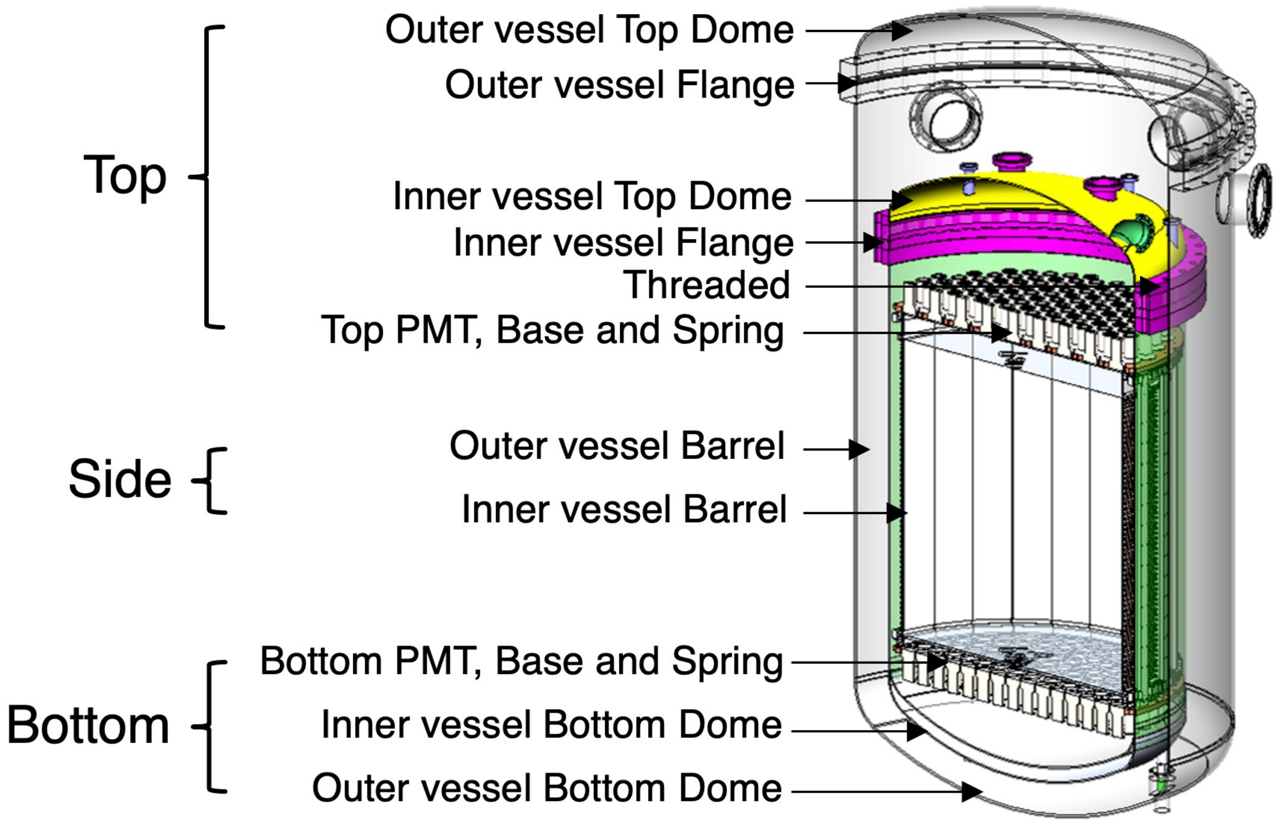




Background components

- Grouped detector components into three categories: top, bottom and side, based on weight and relative contribution to background counts in the ROI
- Input values based on HPGe assay results and high energy alpha events

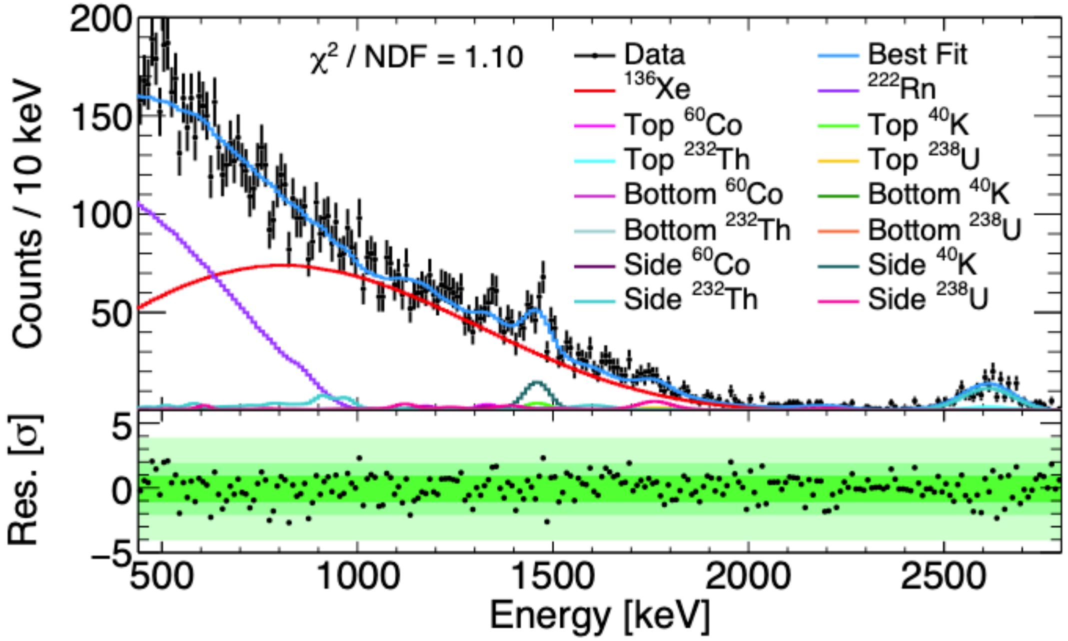
Detector part	Contamination	Expected counts
Top	^{238}U	334 ± 127
	^{232}Th	397 ± 131
	^{60}Co	322 ± 137
	^{40}K	296 ± 155
Bottom	^{238}U	143 ± 52
	^{232}Th	240 ± 120
	^{60}Co	161 ± 97
	^{40}K	90 ± 85
Side	^{238}U	469 ± 697
	^{232}Th	777 ± 945
	^{60}Co	1227 ± 938
	^{40}K	1498 ± 822
LXe	^{222}Rn	8951 ± 186



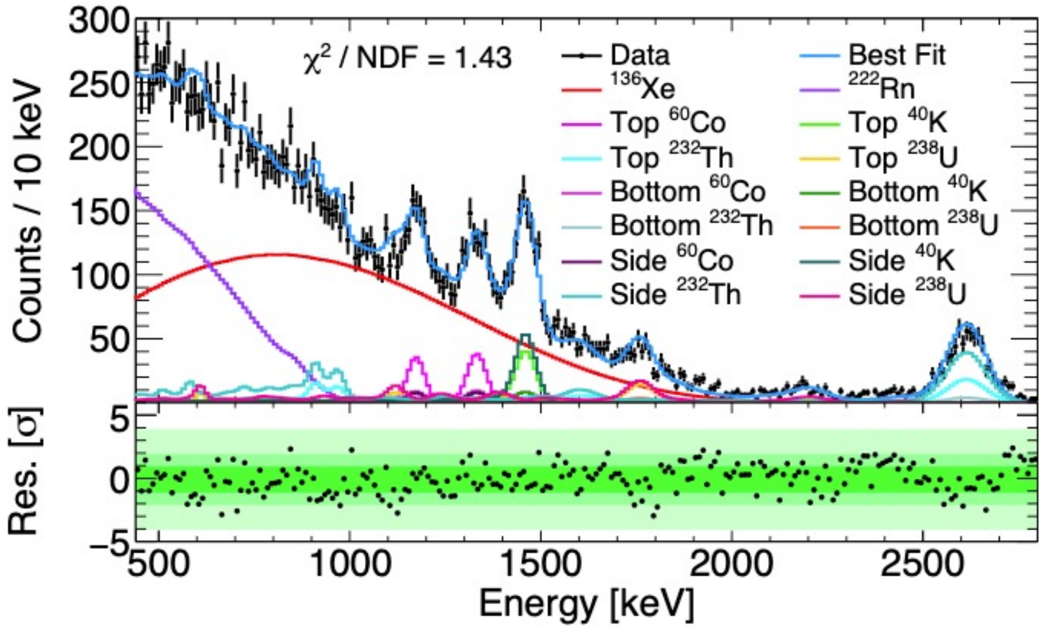
Simultaneous binned likelihood fit in four regions

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

Region 1



Region 234



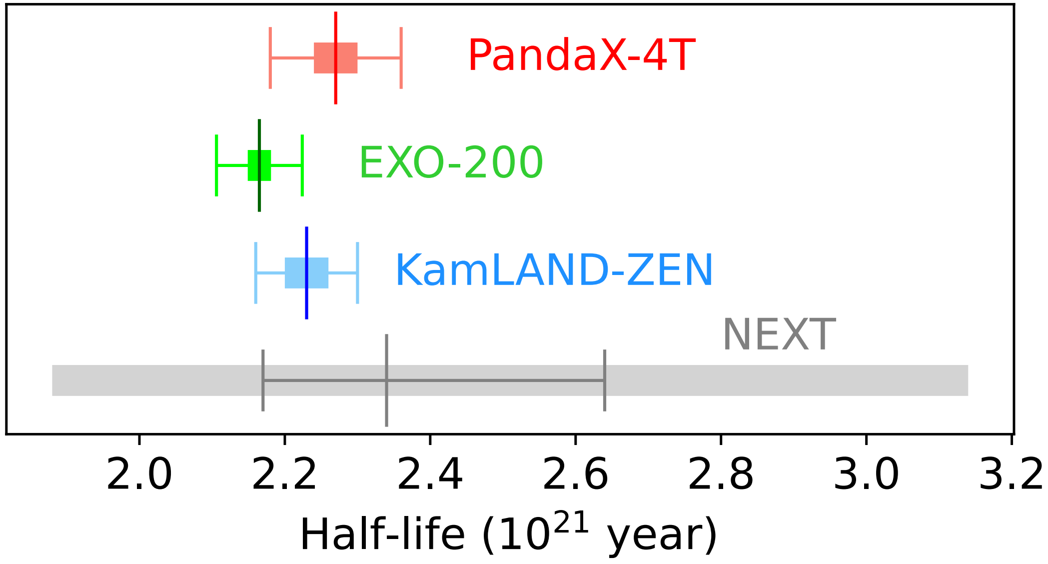
^{136}Xe fit results: 17468±243 events; 2.27 ± 0.03(stat.) ± 0.09(syst.) × 10^{21} year half-life

Cross check with RooFit likelihood fit

Final results

systematic source	Uncertainty [%]
Quality cut	0.39
FV cut	0.99
SS cut	1.75
LXe density	0.13
Pb214 spectrum	2.03
Bin size	0.05
Xe136 abundance	1.92
Energy range	1.23
Region difference	1.58
resolution	0.58
shift MC spectrum	0.26
total	4.05

- ^{136}Xe DBD half-life measured by PandaX-4T: 2.27 ± 0.03(stat.) ± 0.09(syst.) × 10^{21} year
- Comparable precision with leading results
- First such measurement from a DM detector with natural xenon
- 440 keV – 2800 keV range is the widest ROI

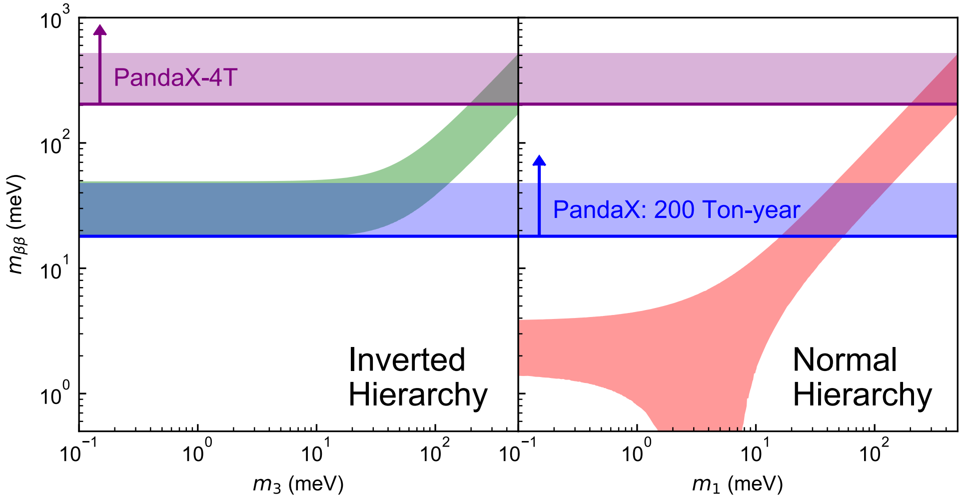


Comparison with other LXe TPC for NLDBD search

	Bkg rate (/keV/ton/y)	Energy resolution	FV mass (kg)	Run time	Sensitivity/Limit (90% CL, year)
PandaX-II	~200	4.2%	219	403.1 days	2.4×10^{23}
PandaX-4T	9	1.9%	649.7 ± 6.5	94.9 days	$> 10^{24}$
XENON1T	~20	0.8%	741 ± 9	202.7 days	1.2×10^{24}
XENONnT	~2	0.8%	1128	1000 days	2.1×10^{25}
LZ	~0.1	1%	967	1000 days	1.06×10^{26}
DARWIN	~0.004	0.8%	5000	10 years	2.4×10^{27}

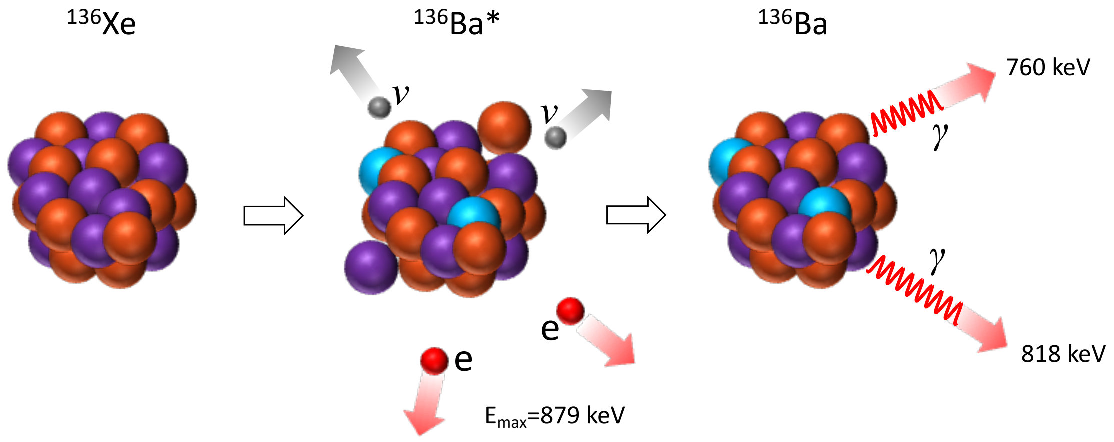
Upgrade of PandaX-4T with improved PMT bases is planned

- Better energy resolution
- Better SS/MS discrimination

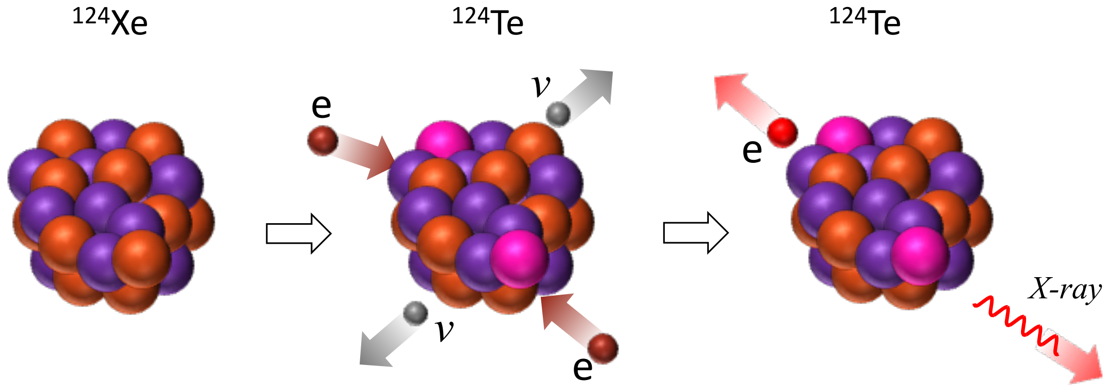


PandaX-4T for more neutrino physics

- Double beta decay to excited states of daughter nuclei
- Dual-electron + Gamma emission: clearer signature
- $^{136}Xe \rightarrow ^{136}Ba^*$ to be discovered; half-life measurement would help understand the nuclear physics of DBD



- (Neutrinoless) Double electron capture (DEC) is an equivalent 2nd-order weak process
- XENON1T recently reported the first observation of DEC of ^{124}Xe: very nice bonus feature for natural xenon detectors



Stay tuned for multi-physics program with PandaX!