PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

Determination of Double Beta Decay Half-life of ^{136}Xe with the PandaX-4T Natural Xenon Detector

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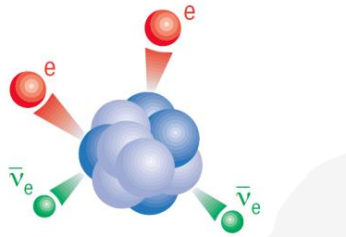
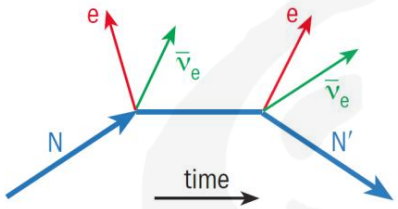
On behalf of the PandaX Collaboration

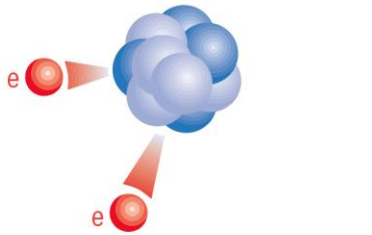
CHEP,2022/08/08-2022/08/11

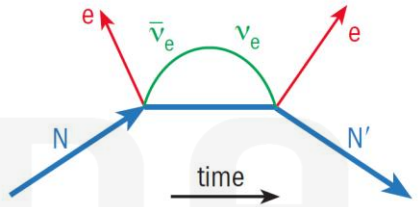
(Neutrinoless) Double beta decay





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





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

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

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

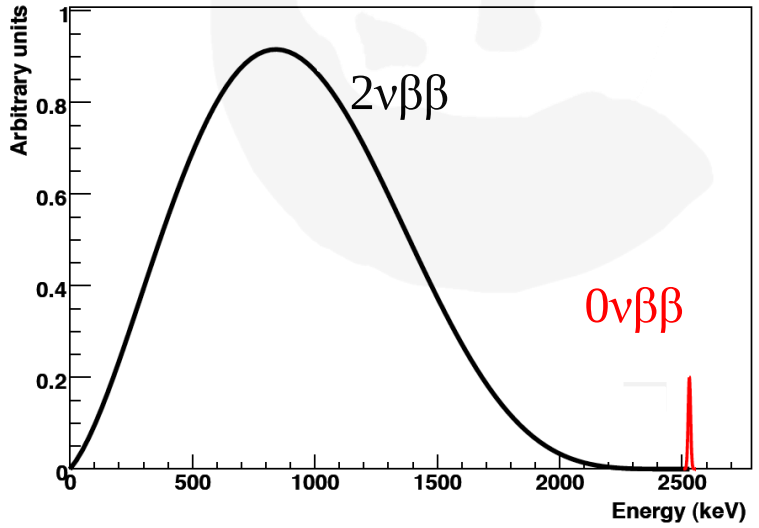
Nuclear matrix element

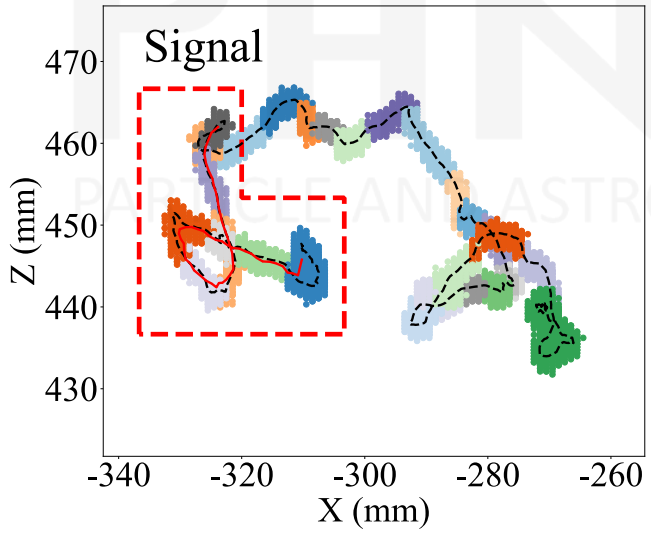
Effective Majorana neutrino mass:

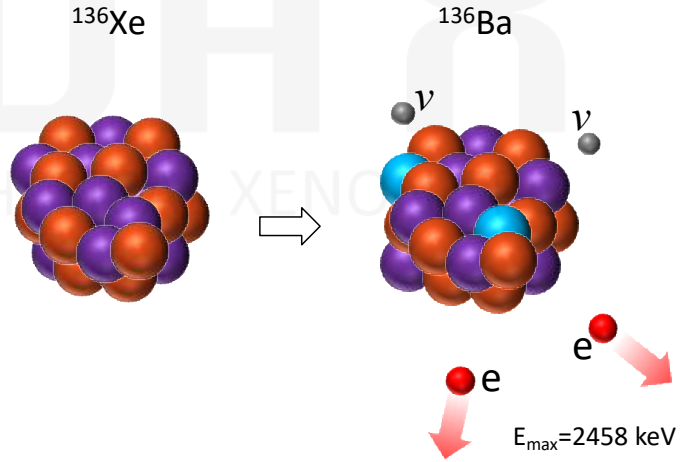
$$|\langle m_{\beta\beta}\rangle| = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$

Detection of double beta decay

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



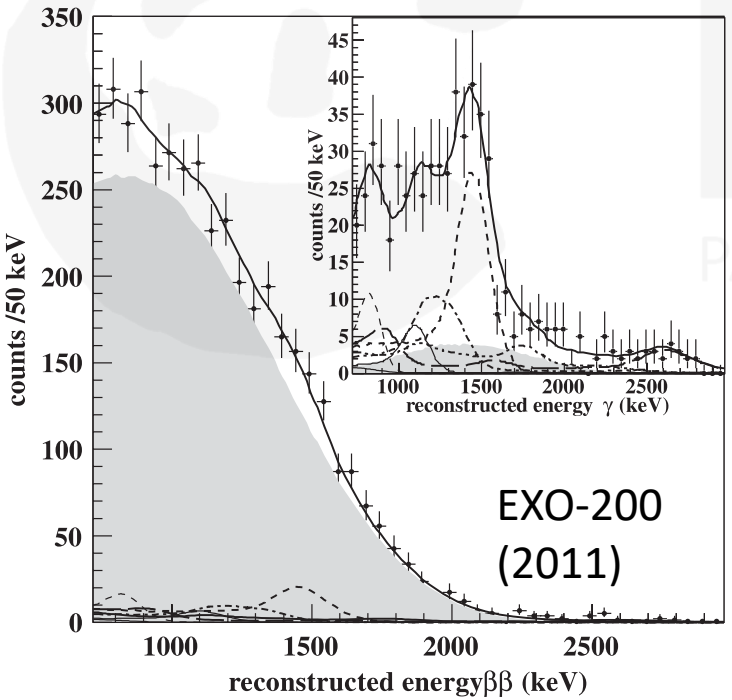




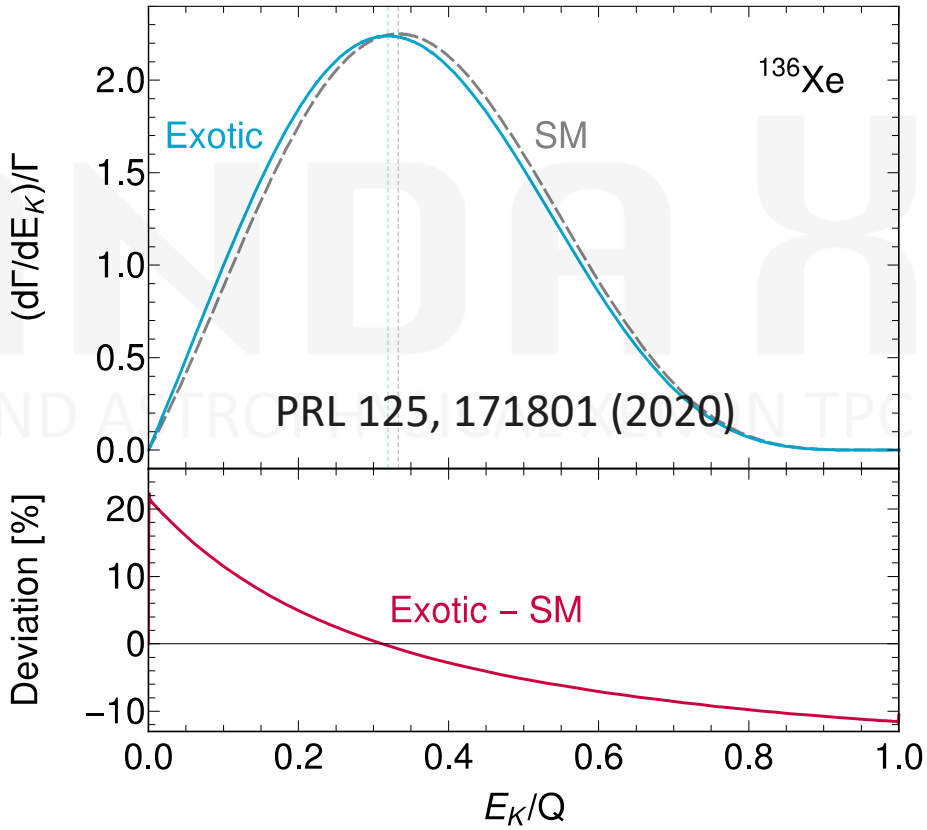
Sum of two electrons energy

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



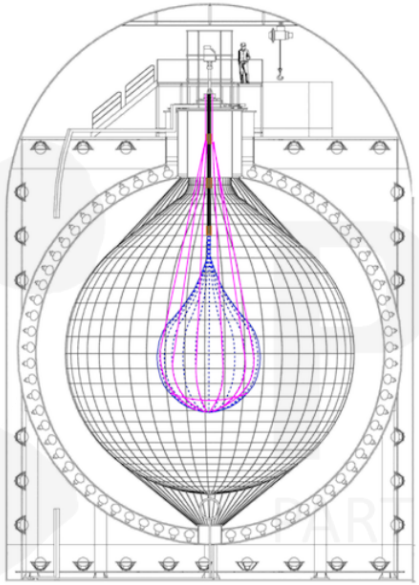
- Searching for possible shape distortion for new BSM physics



Detector techniques The big four

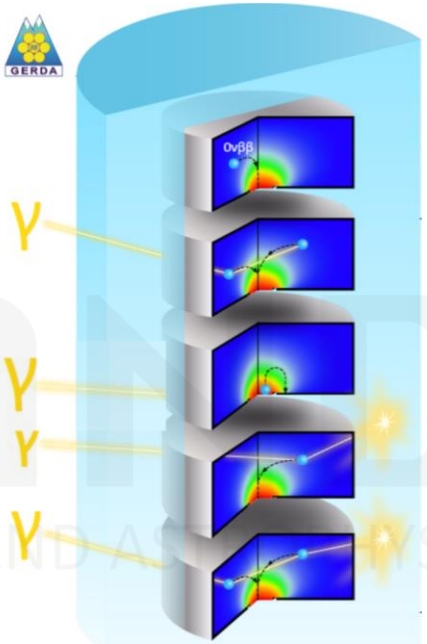
CUORE/CUPID

Bolometer



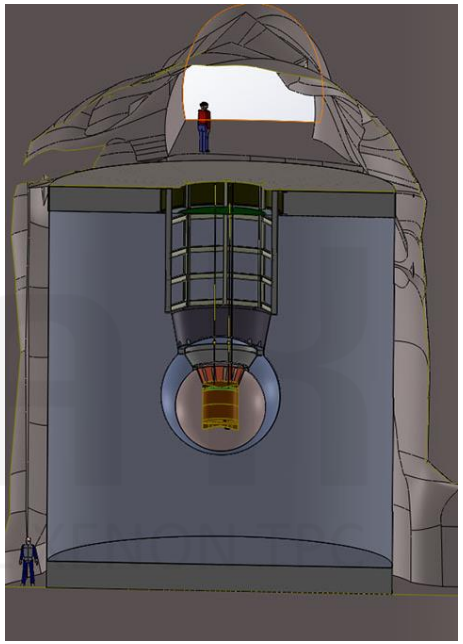
KamLAND-ZEN

Doped LS



LEGEND family

HPGe



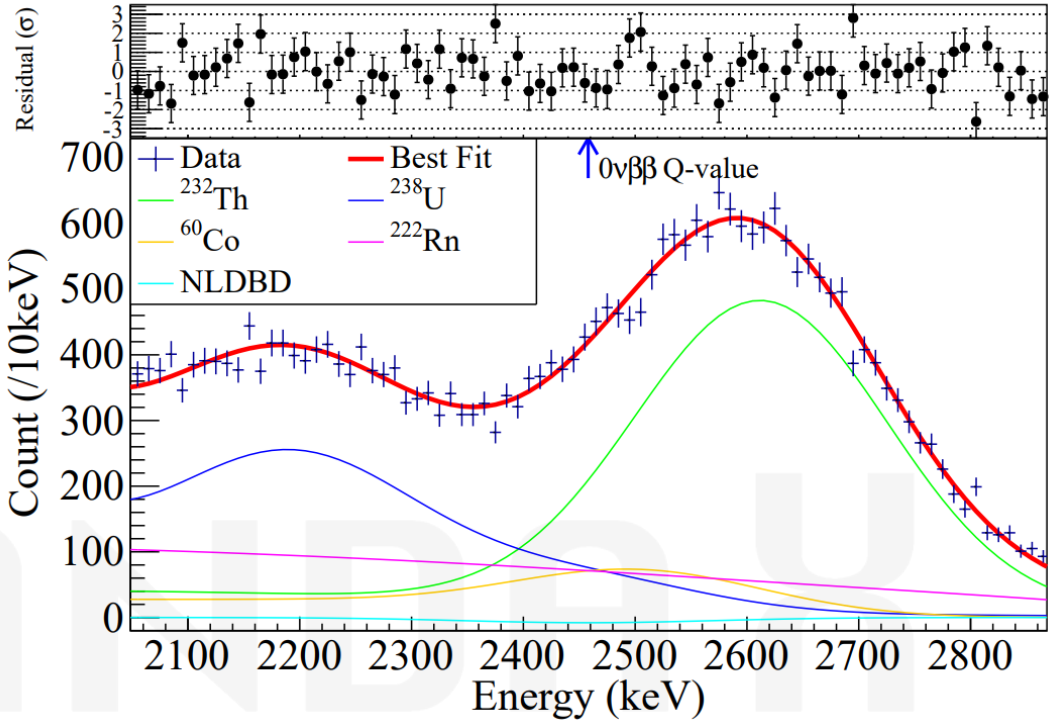
EXO/nEXO

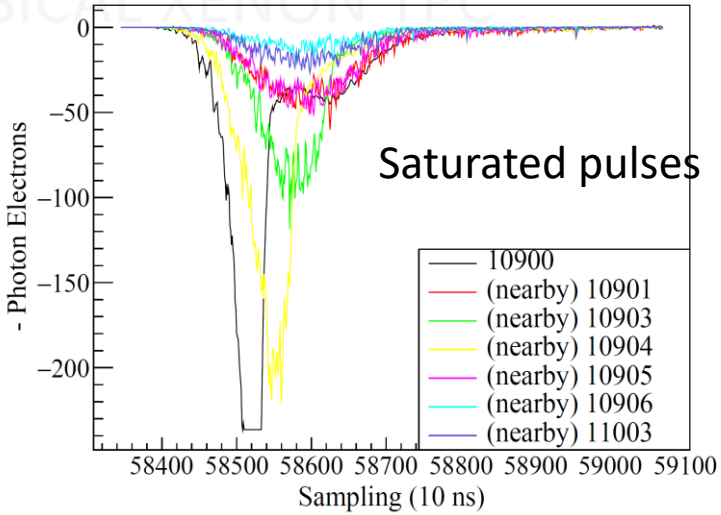
LXe TPC

PandaX detectors

NLDBD search at PandaX-II

- 580 kg natural xenon; ~50 kg of ^{136}Xe.
- 403.1 day of dark matter physics data
- Null results; Lower limit for decay half-life: 2.4×10^{23} yr at 90% CL
- Effective Majorana mass upper limit: 1.3-3.5 eV.
- First NLDBD result reported from a dual-phase xenon experiment
- Proof of Principle



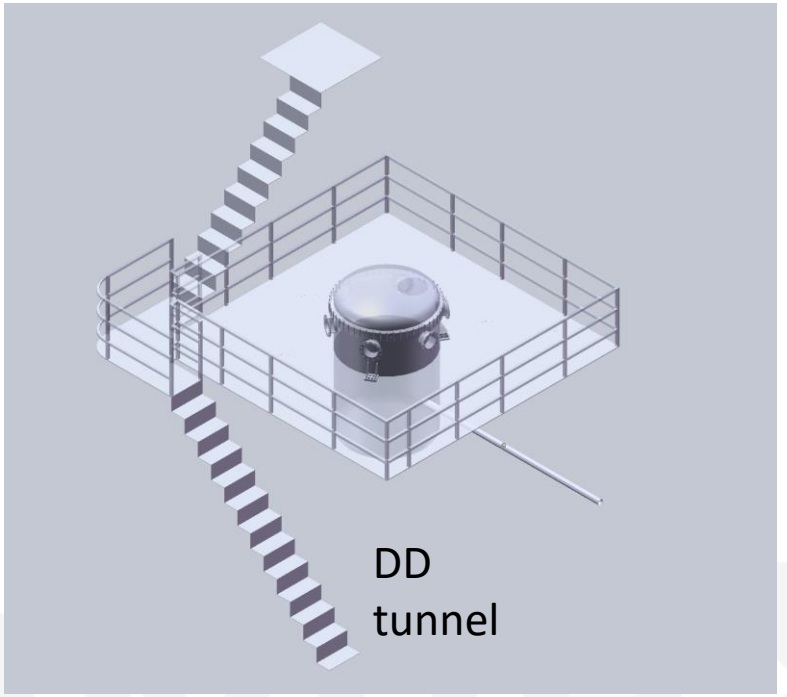


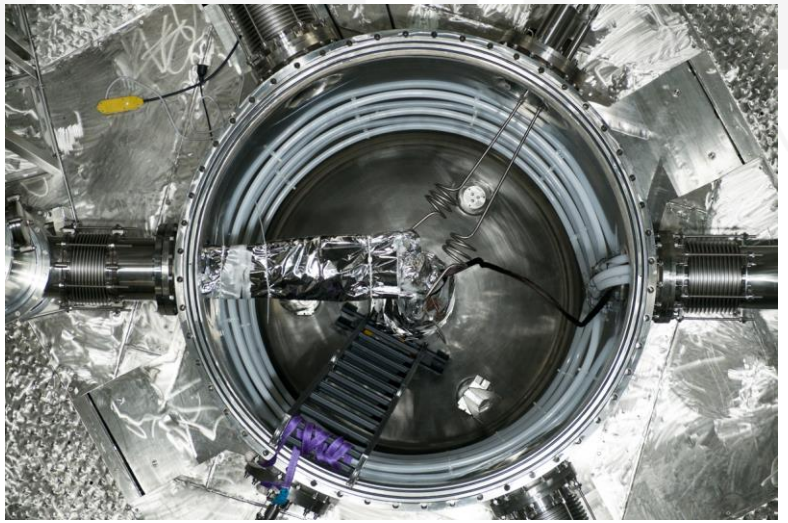
PandaX detectors

DBD search at PandaX-4T

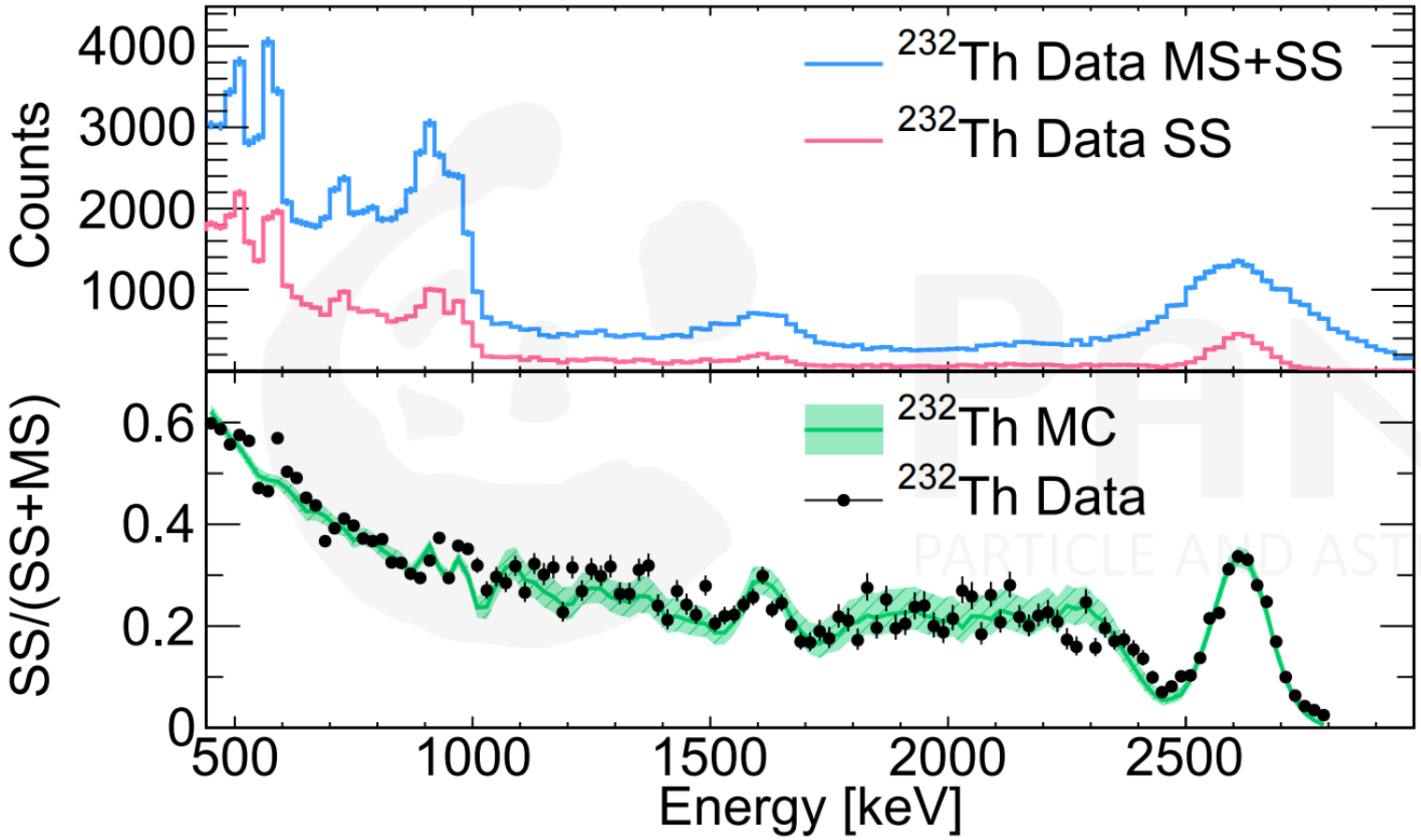
Stable data taking during commissioning runs: 94.9 days for DBD analysis

External calibration sources for high energy detector response: ^{232}Th (loops), ^{137}Cs, and ^{60}Co (DD tunnel)





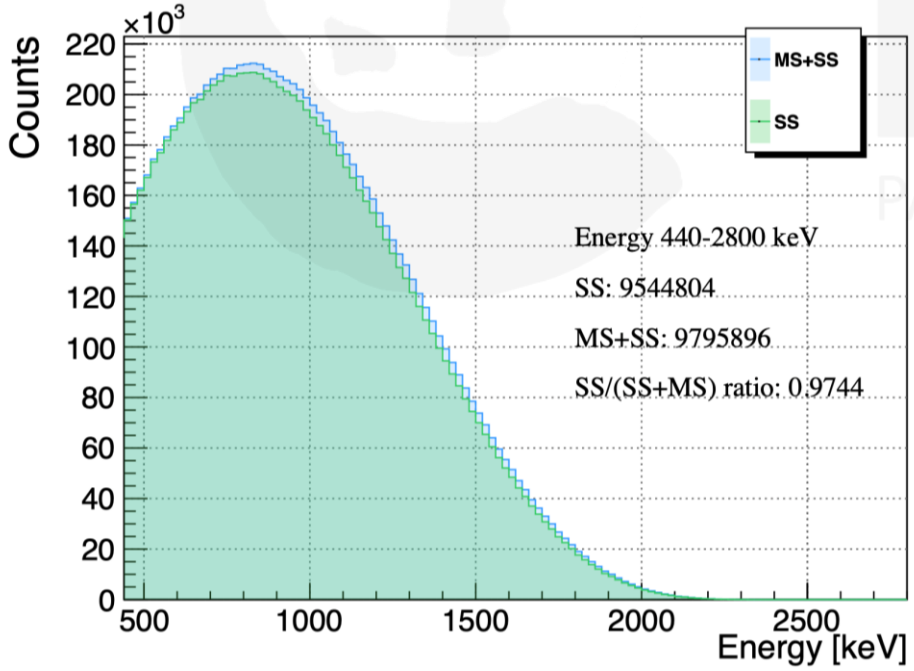
Validation with calibration data



SS MS ratio: The overall agreement is at 1.7% level, taken as systematics

Signal Efficiencies

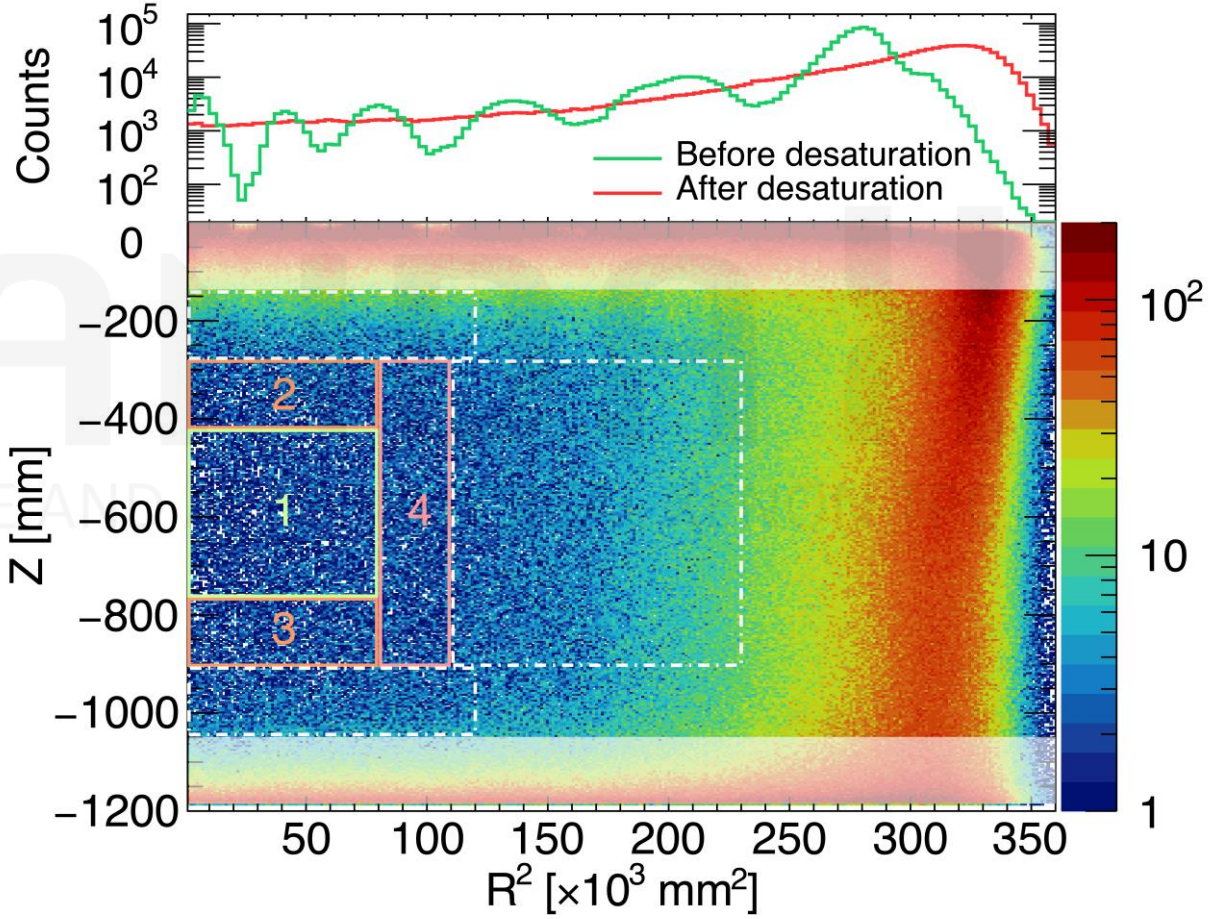
- SS efficiency: 97.4% for DBD events > 440 keV
- DBD events generated with DECAY0 package and went through PandaX-4T simulation and data processing chain.



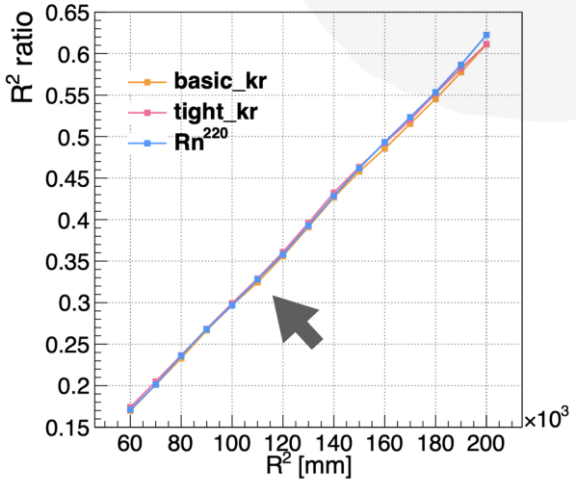
- (Very mild) Data quality cut efficiencies: (99.4 ± 0.4)%
  - S1, S2, S1/S2: remove non-electron recoil and alpha events
  - Top and bottom S1 charge asymmetry vs. drift time: reject accidental coincidence events and events originating from the gate electrode.
  - Calculated by region
- Calculated from 9.6 days of physics data; validated with full data
- Validated with 164 and 236 keV peaks

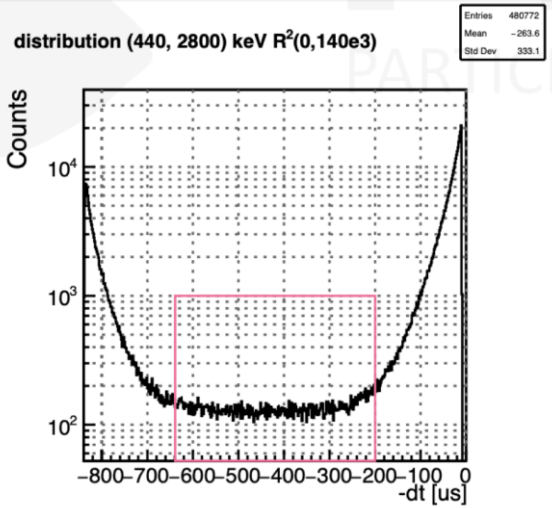
Fiducial Volume: emphasis on systematics, not statistics

- 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



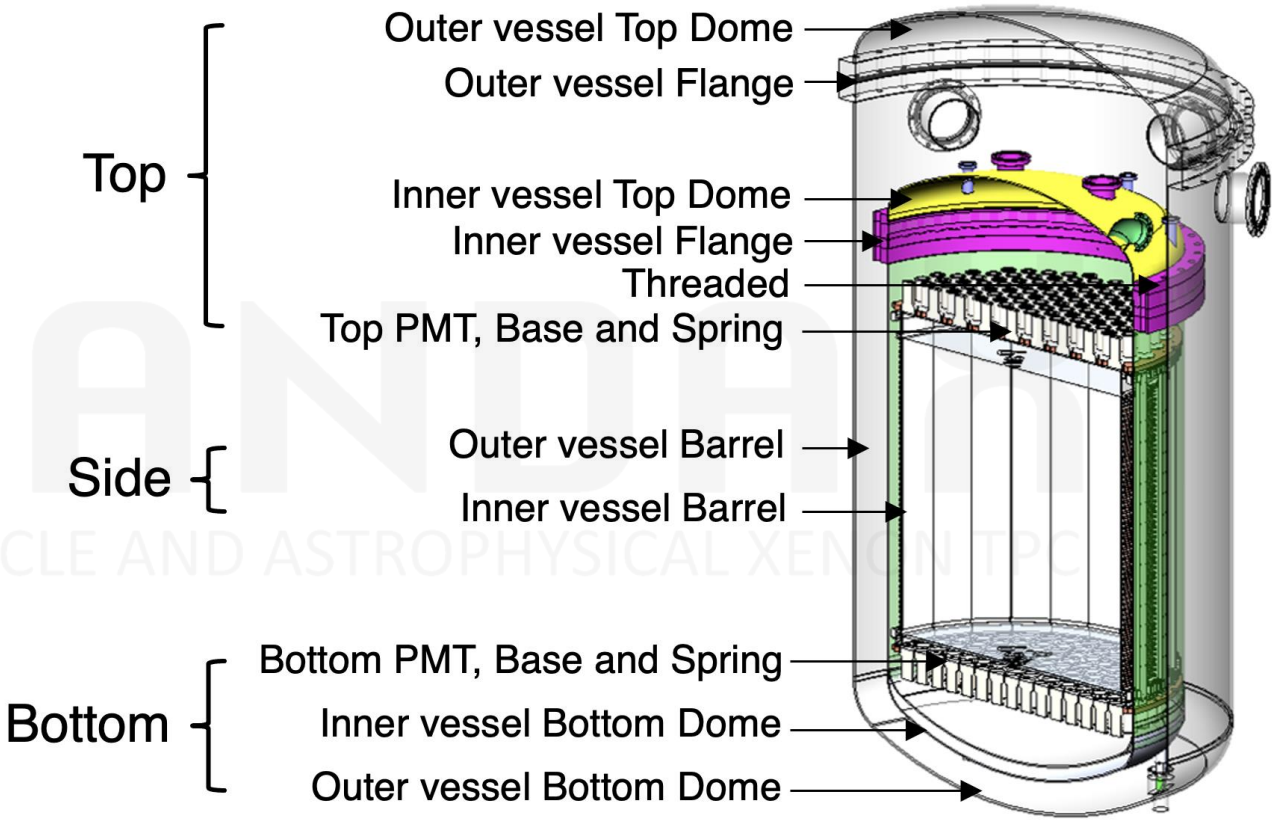
FV mass





Background components

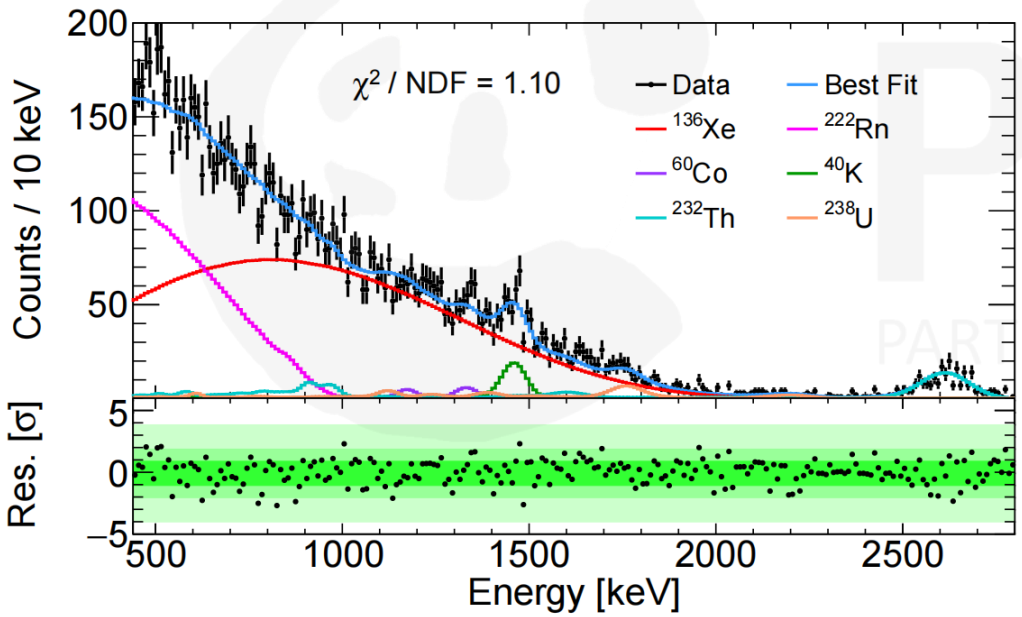
Detector part	Contamination	Expected counts
Top	^{238}U	339 ± 129
	^{232}Th	402 ± 133
	^{60}Co	327 ± 141
	^{40}K	300 ± 156
Bottom	^{238}U	141 ± 51
	^{232}Th	237 ± 119
	^{60}Co	159 ± 95
	^{40}K	89 ± 84
Side	^{238}U	475 ± 707
	^{232}Th	786 ± 959
	^{60}Co	1244 ± 945
	^{40}K	1518 ± 835
LXe	^{222}Rn	12057

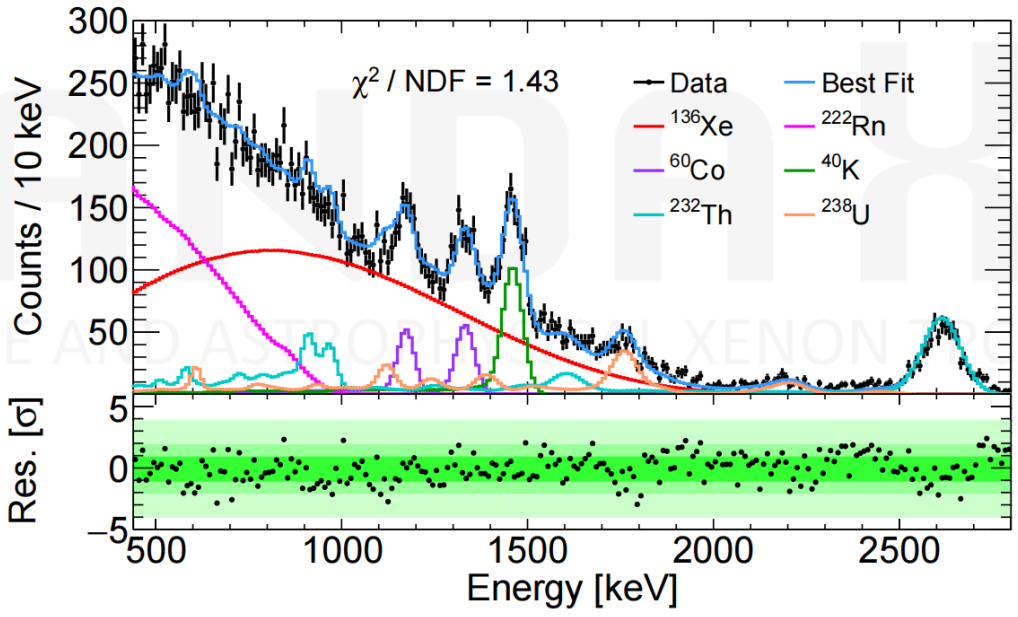


Simultaneous binned likelihood fit in four regions

$$L = \prod_{i=1}^{N_{\mathrm{R}}} \prod_{j=1}^{N_{\mathrm{bins}}} \frac{(N_{ij})^{N_{ij}^{\mathrm{obs}}}}{N_{ij}^{\mathrm{obs}}!} e^{-N_{ij}} \prod_{k=1}^{N_{\mathrm{bkgs}}} \frac{1}{\sqrt{2\pi}\sigma_k} e^{-\frac{1}{2}(\frac{\eta_k}{\sigma_k})^2}$$

$$N_{ij} = n_{\mathrm{Xe}} S_{ij}^{\mathrm{Xe}} + \sum_{k=1}^{N_{\mathrm{bkgs}}} (1+\eta_k) n_k B_{ij}^k$$

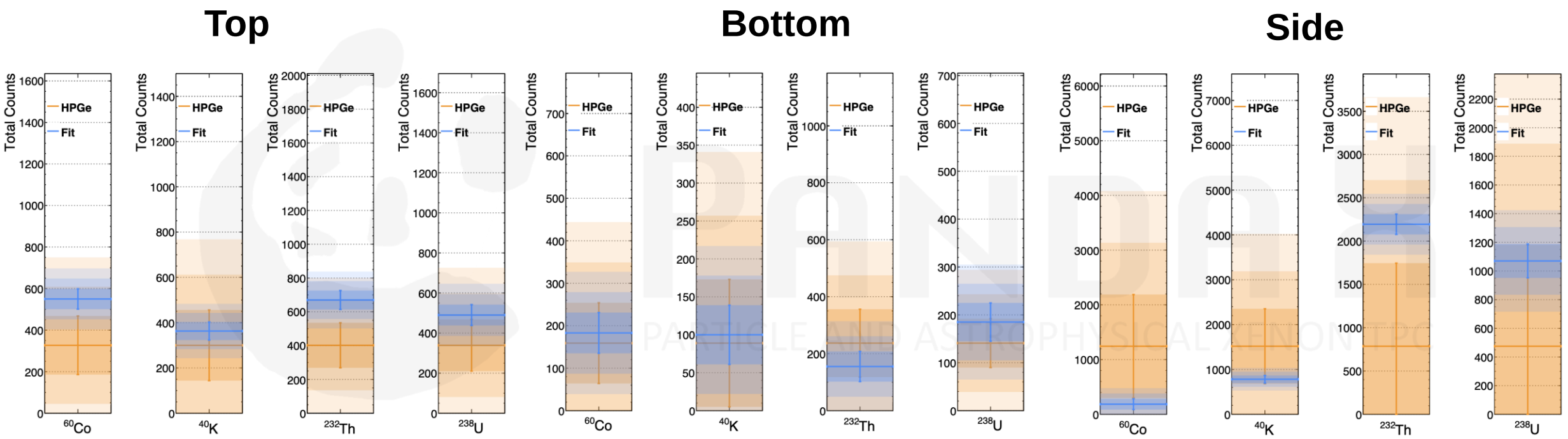




^{136}Xe fit results: 17468±257; 2.27 ± 0.03(stat.) ± 0.10(syst.) × 10^{21} year half-life

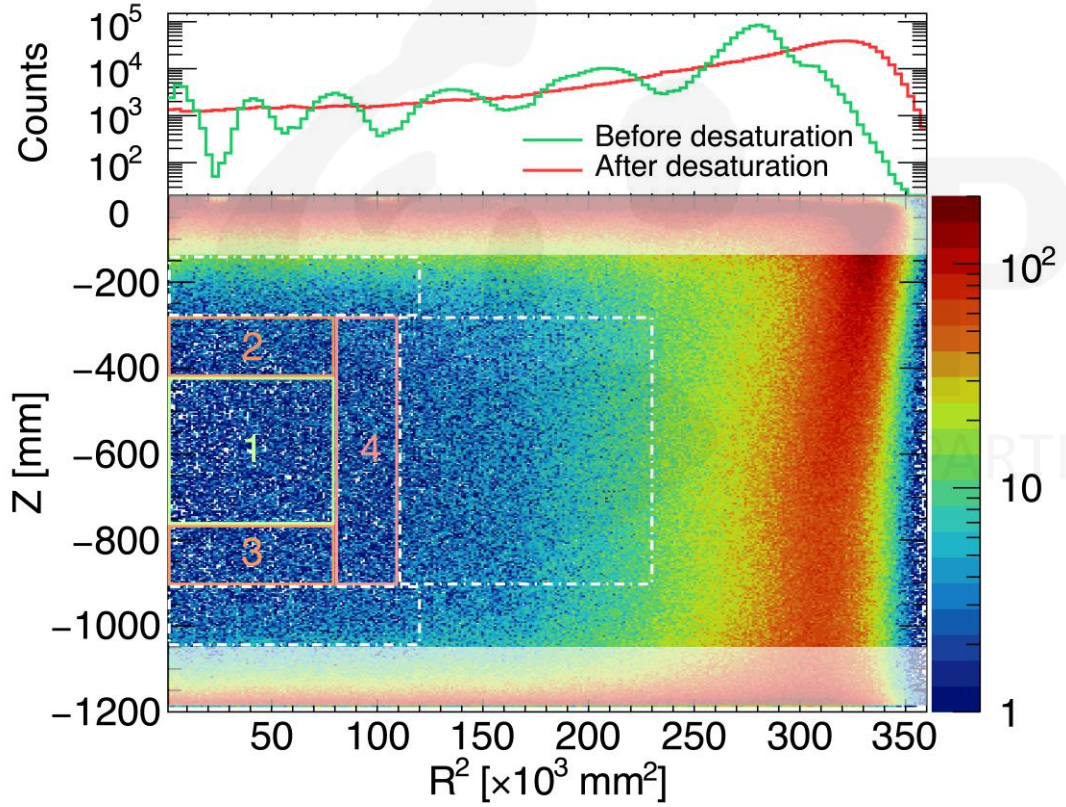
Cross check with RooFit likelihood fit

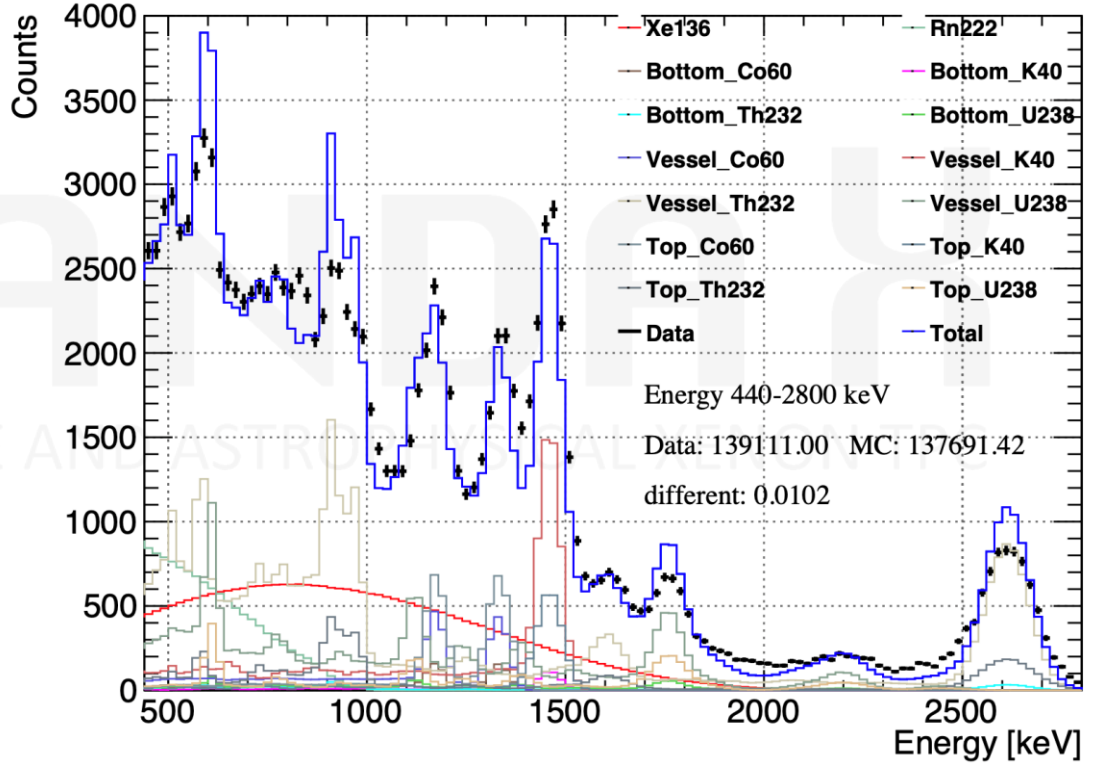
Background results



- Compatible and more precise results from PandaX-4T than HPGe

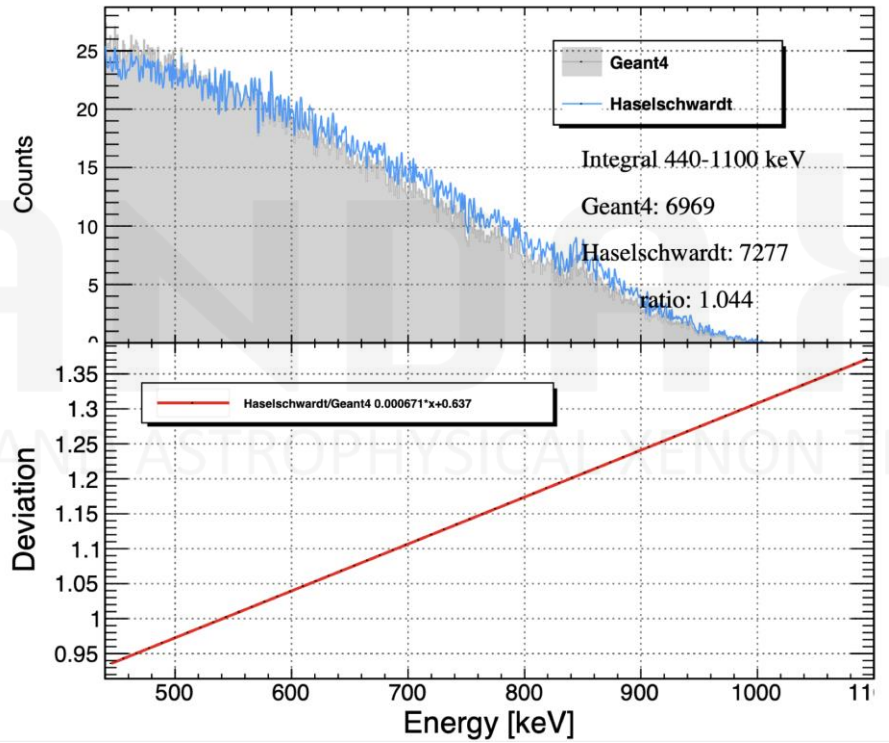
Cross validation in the outer region





Systematic uncertainties

systematic source	Uncertainty[%]
Quality cut	0.39
FV cut	0.99
SS cut	1.75
LXe density	0.13
^{214}Pb spectrum	2.03
Bin size	0.05
Xe136 abundance	1.92
Fit range	1.23
Regional weight	1.58
Energy Resolution	0.58
Energy scale	0.26
^{136}Xe spec. shape	0.36
Non-equilibrium decay chain	1.98
total	4.526



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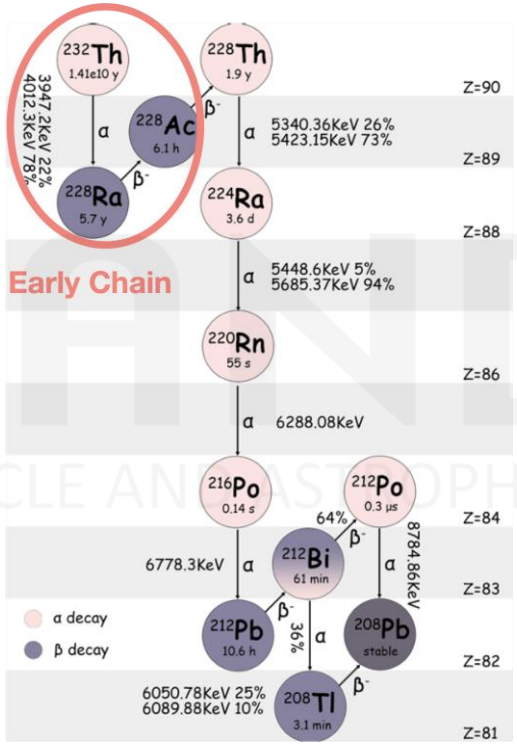

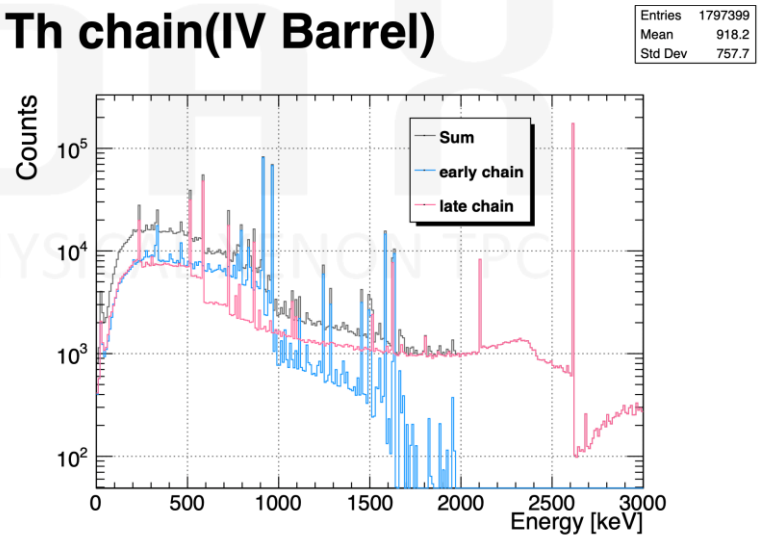

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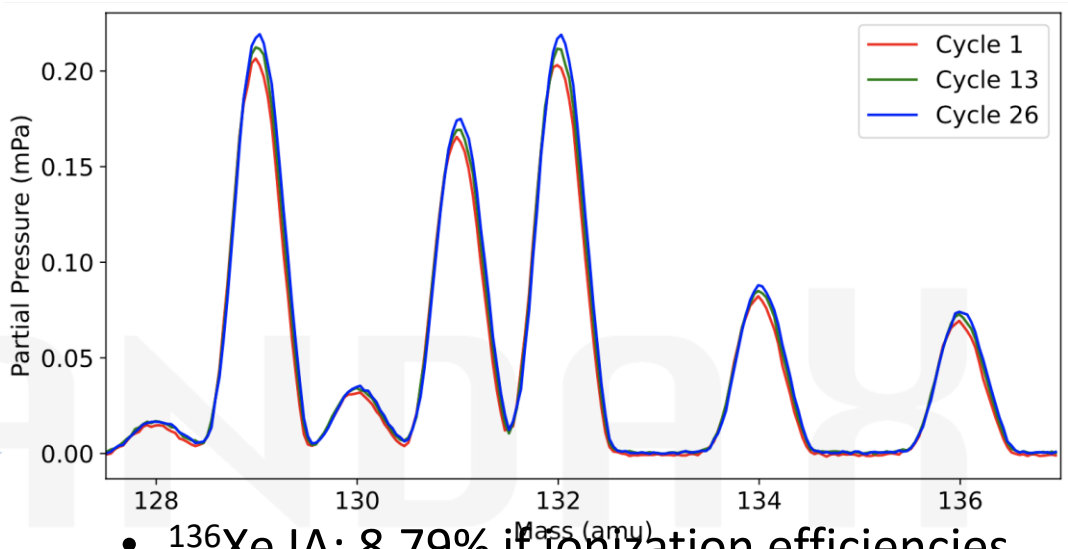

- ^{136}Xe IA: 8.79% if ionization efficiencies not corrected; 9.03% if corrected with NIST values
- Taken nominal value 8.86% as input and difference to our measurement as uncertainties

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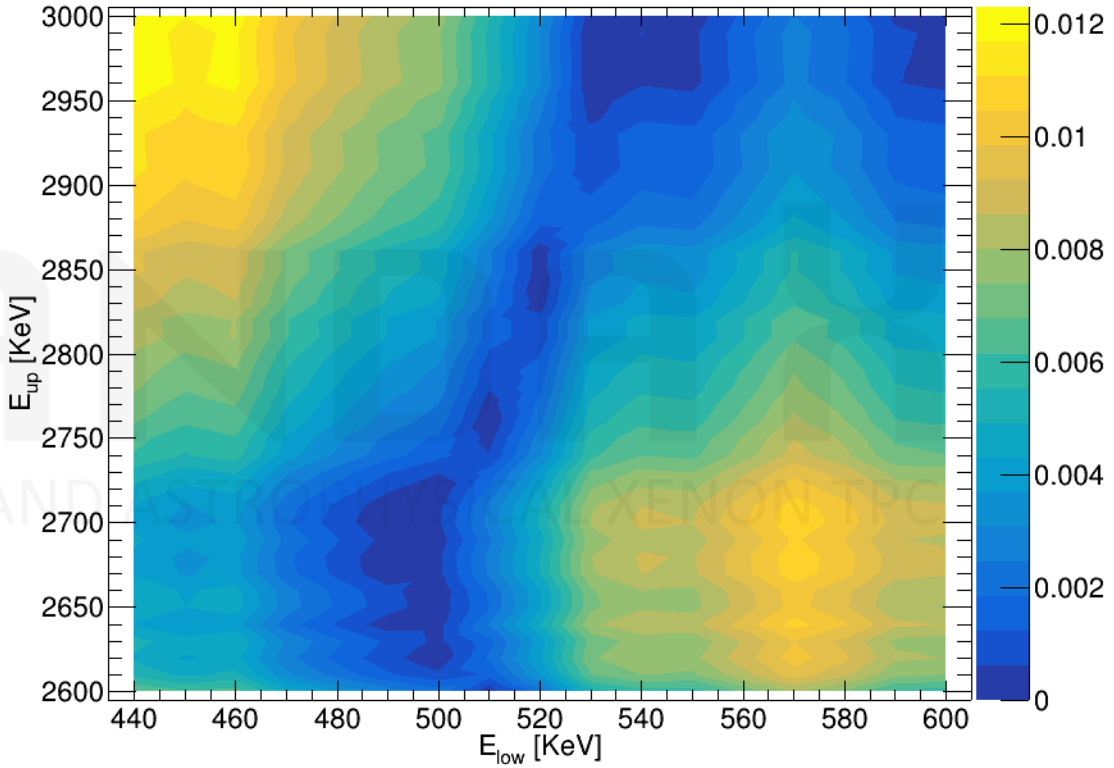
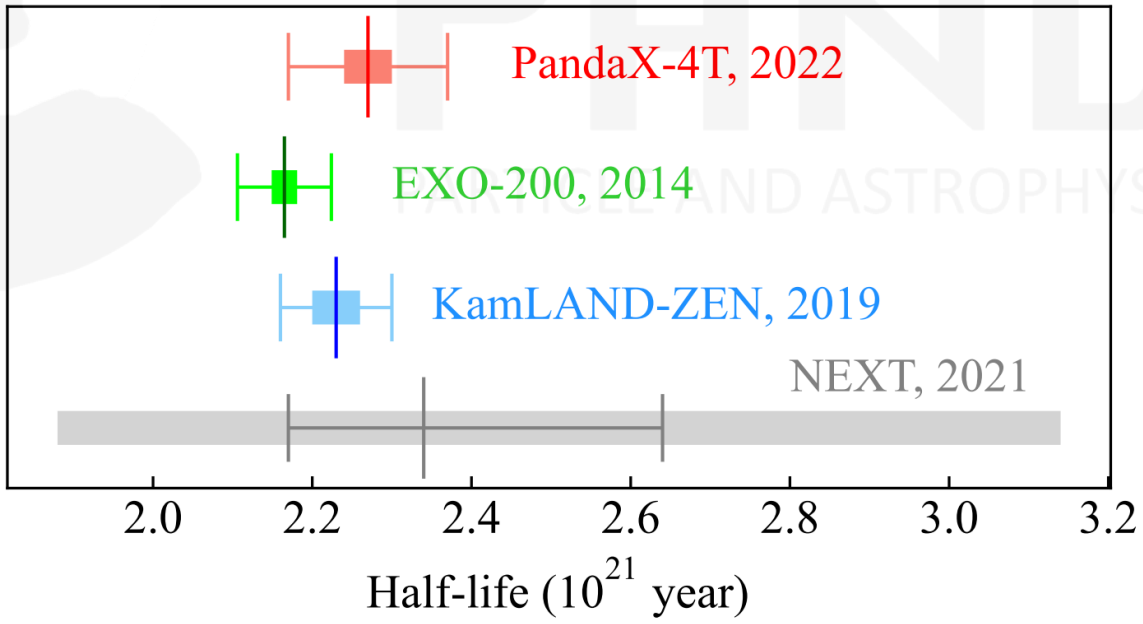


Final results

- ^{136}Xe DBD half-life measured by PandaX-4T: 2.27 ± 0.03(stat.) ± 0.10(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

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