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Neutrino Physics with PandaX-4T

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For the PandaX Collaboration

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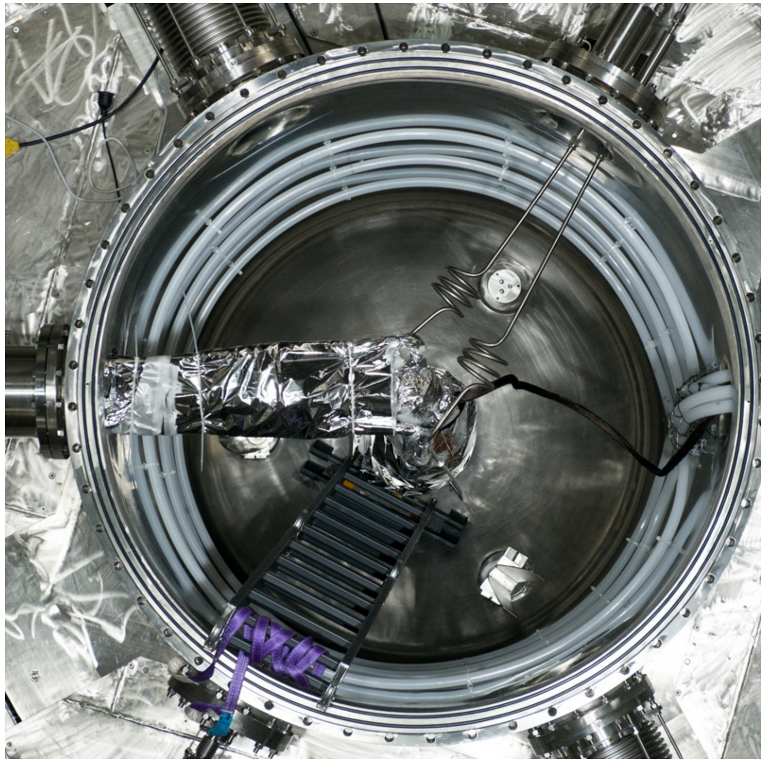
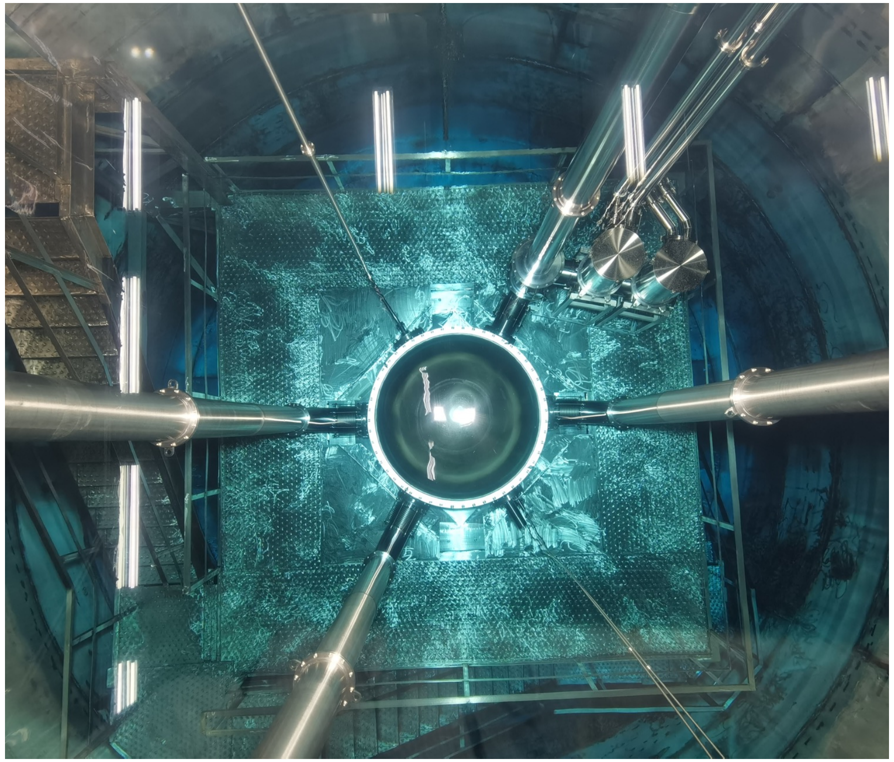
Arxiv:2205.12809

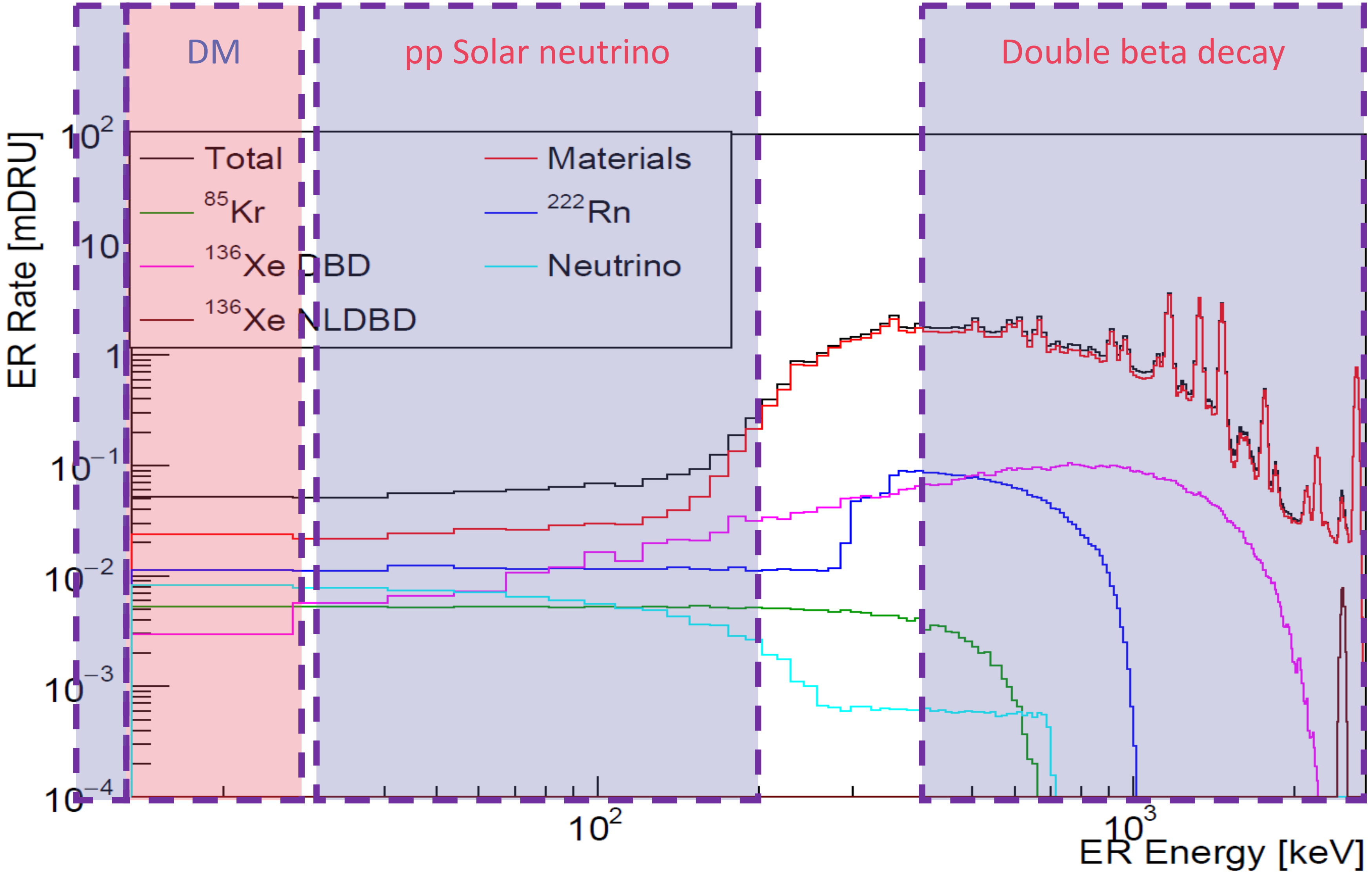
PandaX-4T

- A multi-ton dual phase xenon TPC at China Jinping Underground Laboratory
- Primary science goal: dark matter direct detection and neutrinoless double beta decay, etc
- Commissioned since late 2020. data released: Nov. 28, 2020 to Apr. 16, 2021





Expected background budget for PandaX-4T before commissioning



^{8}B Solar neutrino via coherent scattering

See more [Recent progress and plan of PandaX experiment](#)

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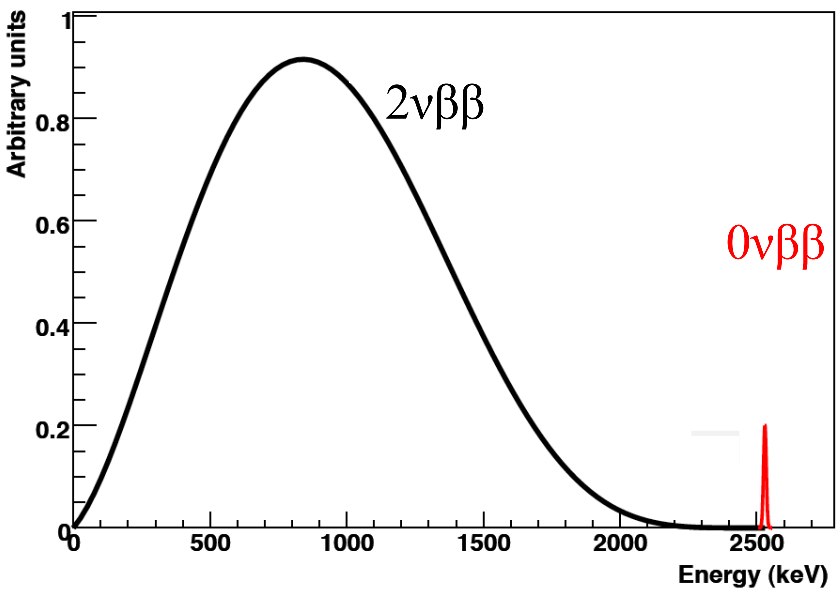
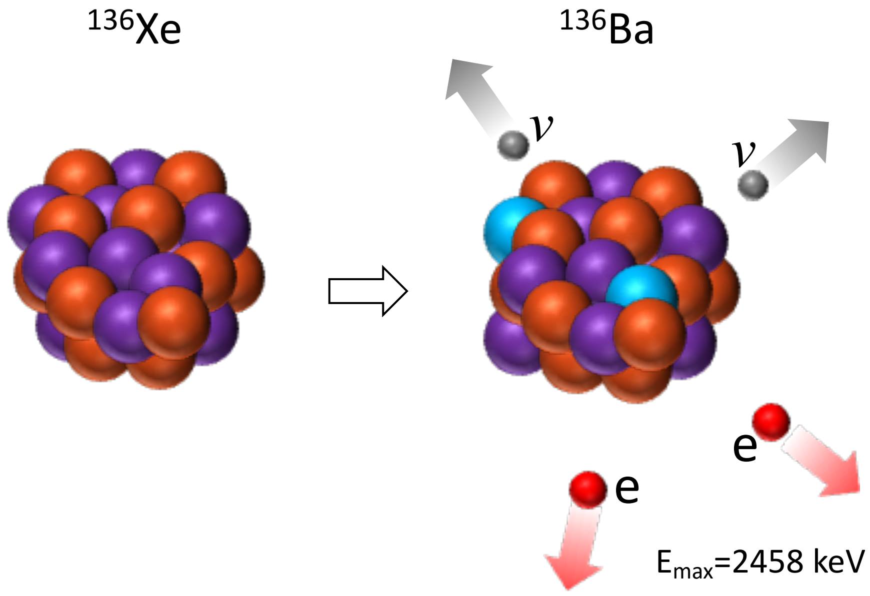
Room 11 (Magenta A)

Double beta decay

- Neutrinoless double beta decay probes the nature of neutrinos: Majorana or Dirac
- Lepton number violating process
- Measure energies of emitted electrons

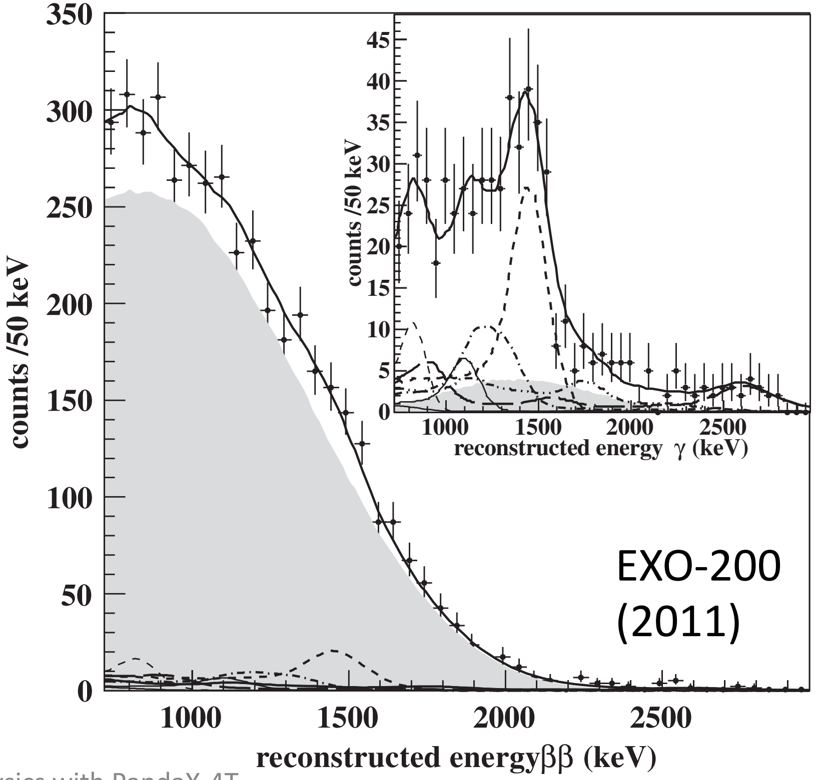


Sum of two electrons energy

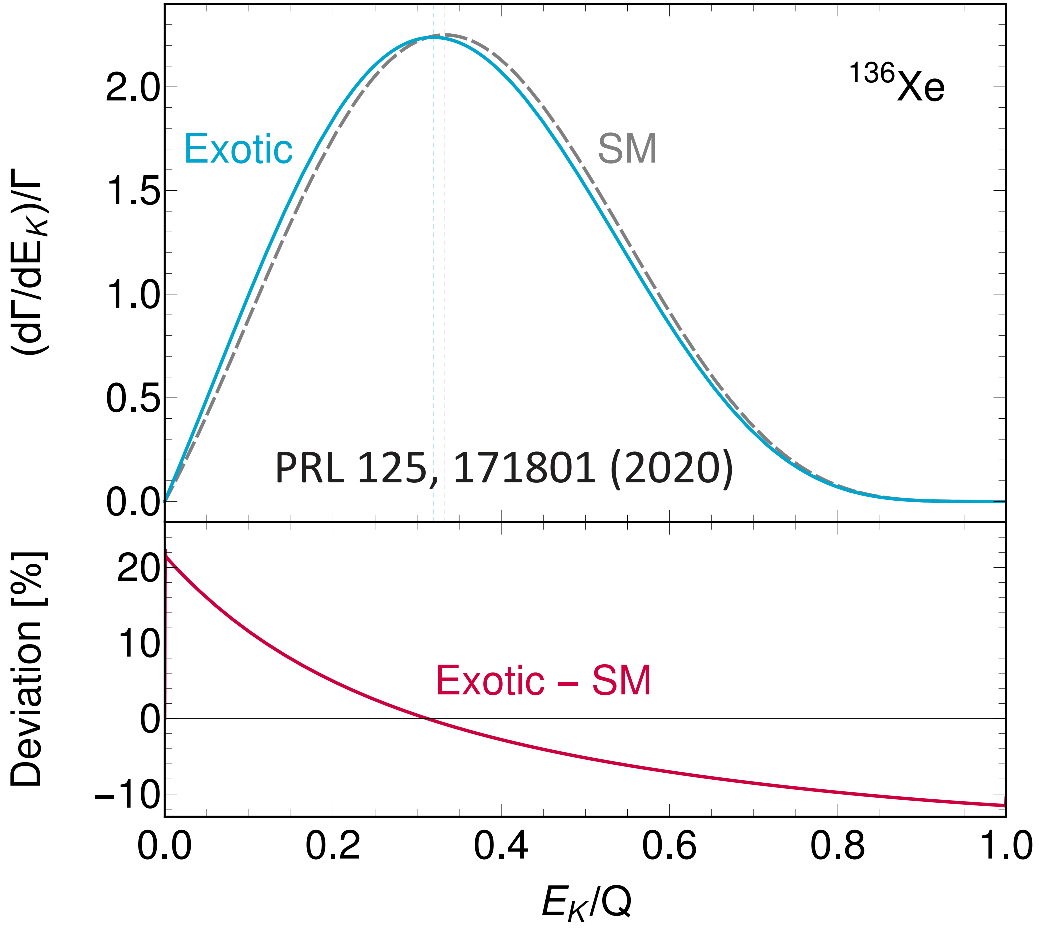


Measuring the DBD half-life

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

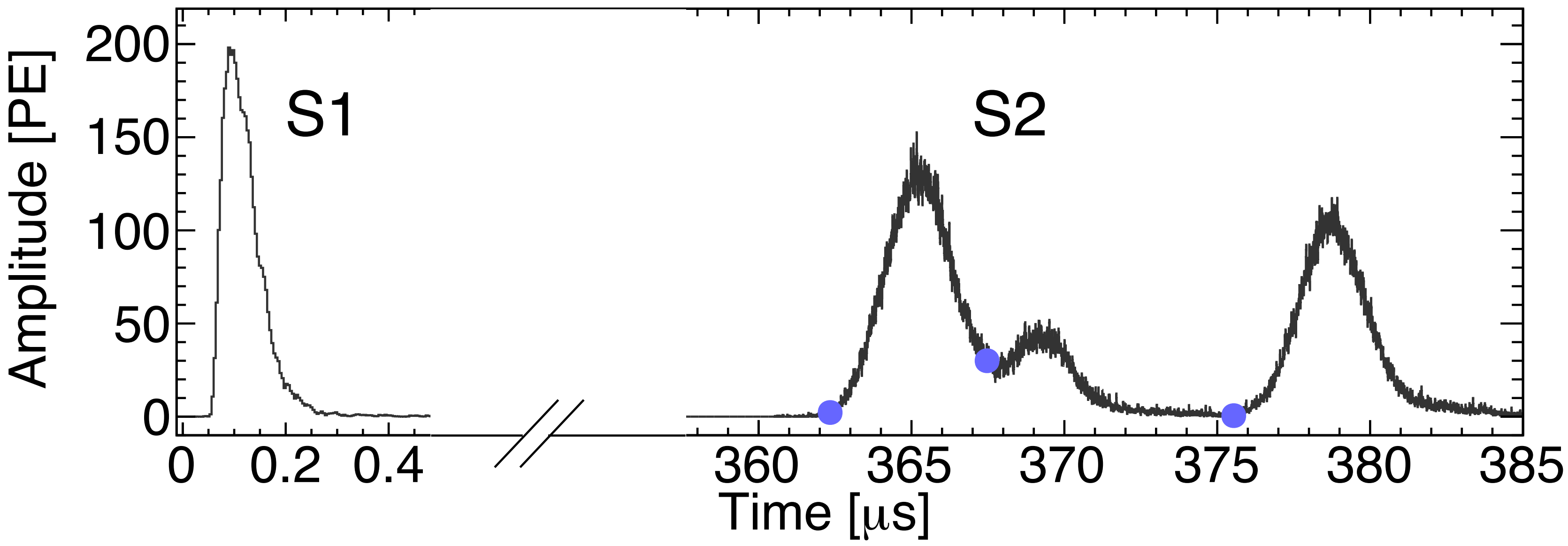


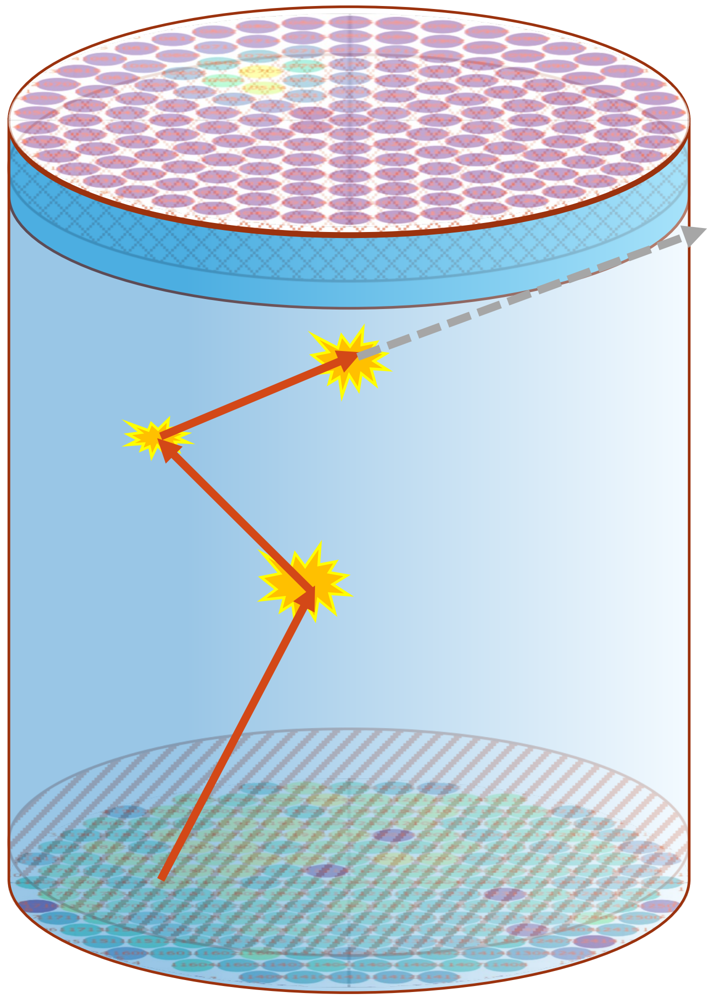
- Searching for possible shape distortion for new BSM physics



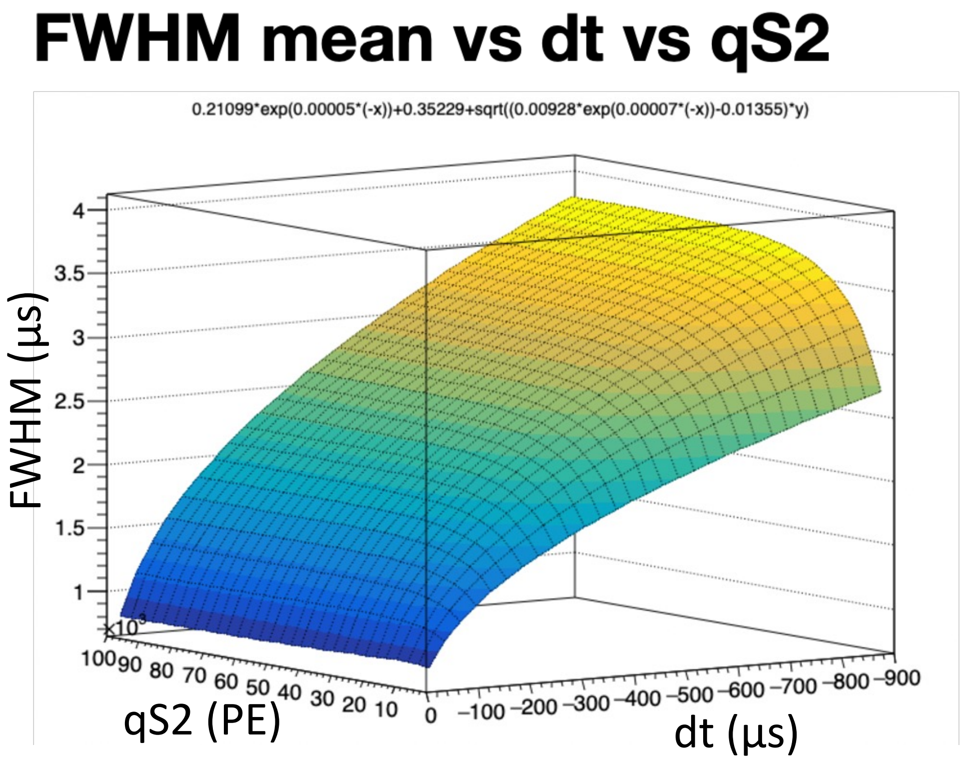
Extending DM detector response to MeV range

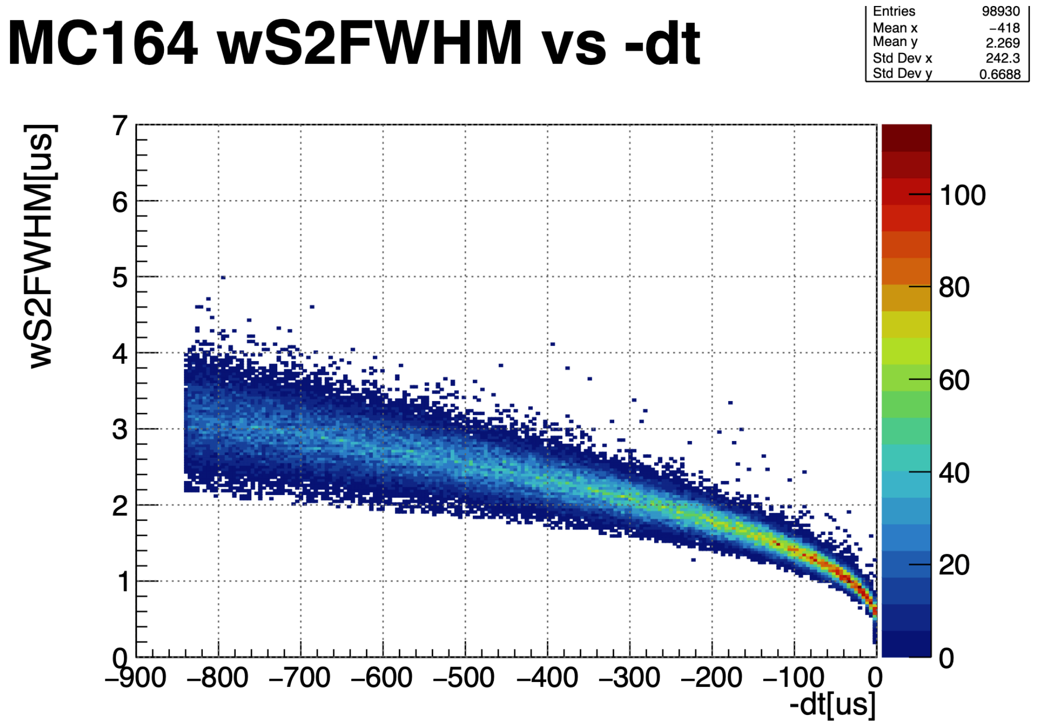
- MeV gamma events are mostly multiple-scattering events; while signals (DBD) are mostly single site (SS)
- Identifying Multi-Site (MS) events with PMT waveforms
- Width of waveforms dominated by Z (electron diffusion)





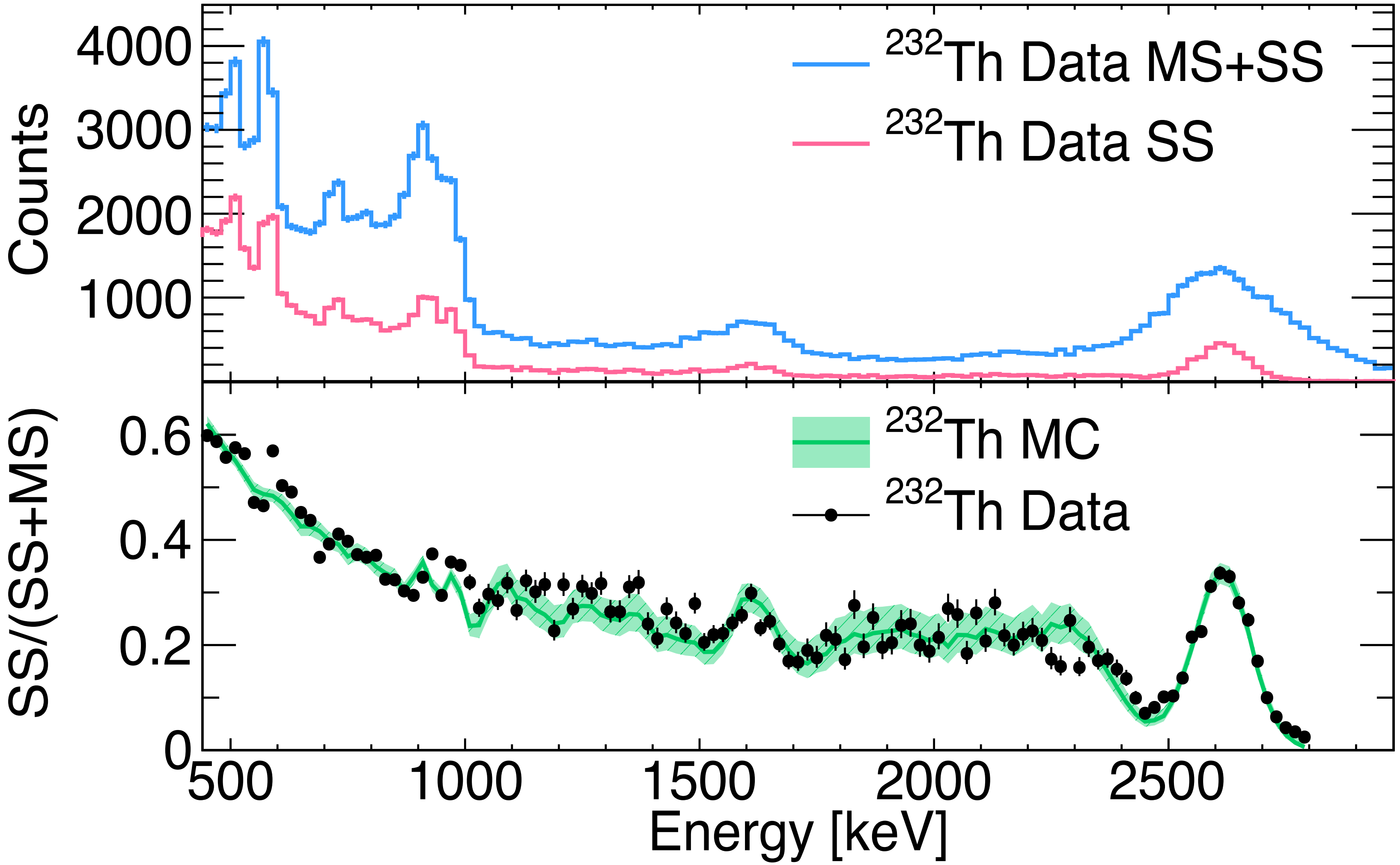
Data-driven diffusion width as input for simulation





- Pulse width of SS events are calculated from data
- Used for simualtion of waveforms after Geant4 output

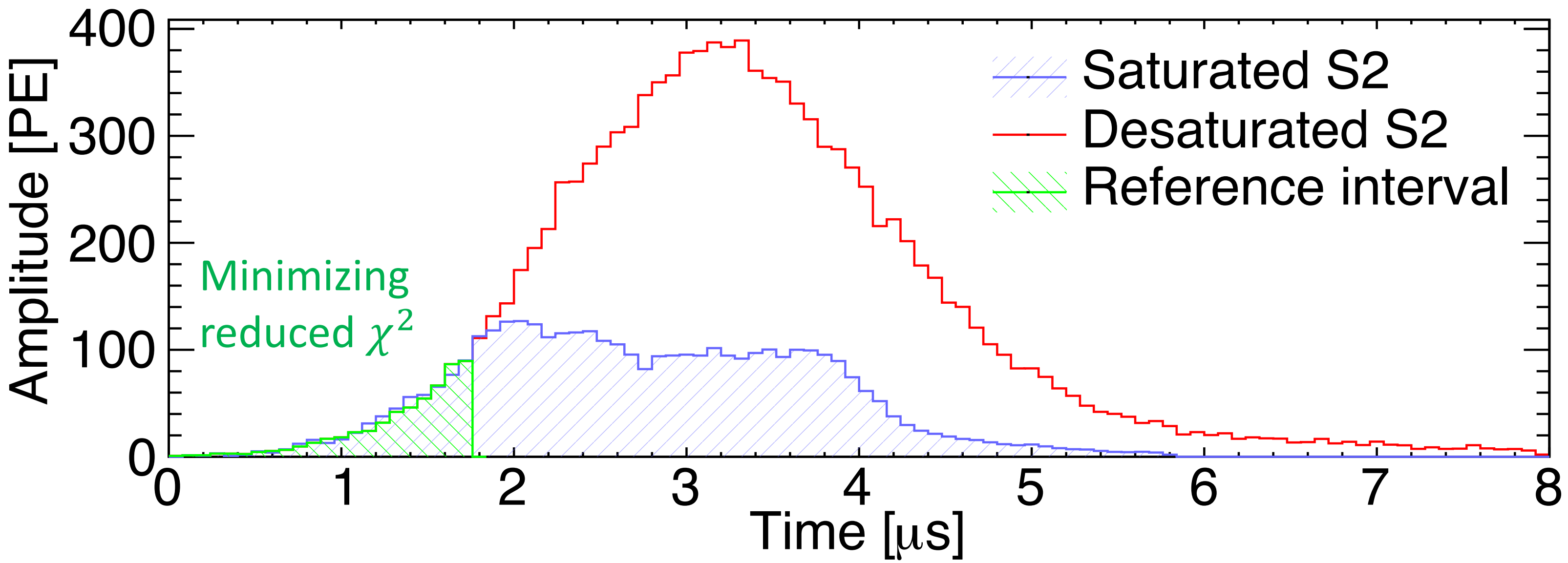
Validation with calibration data



The overall agreement is at 1.7% level, taken as systematics

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 event
- For events in the energy range of 1 to 3 MeV, the average correction factor is ~3.0 for the top PMT array
- Procedure validated with bench test. De-saturated charge used for position but not energy reconstruction

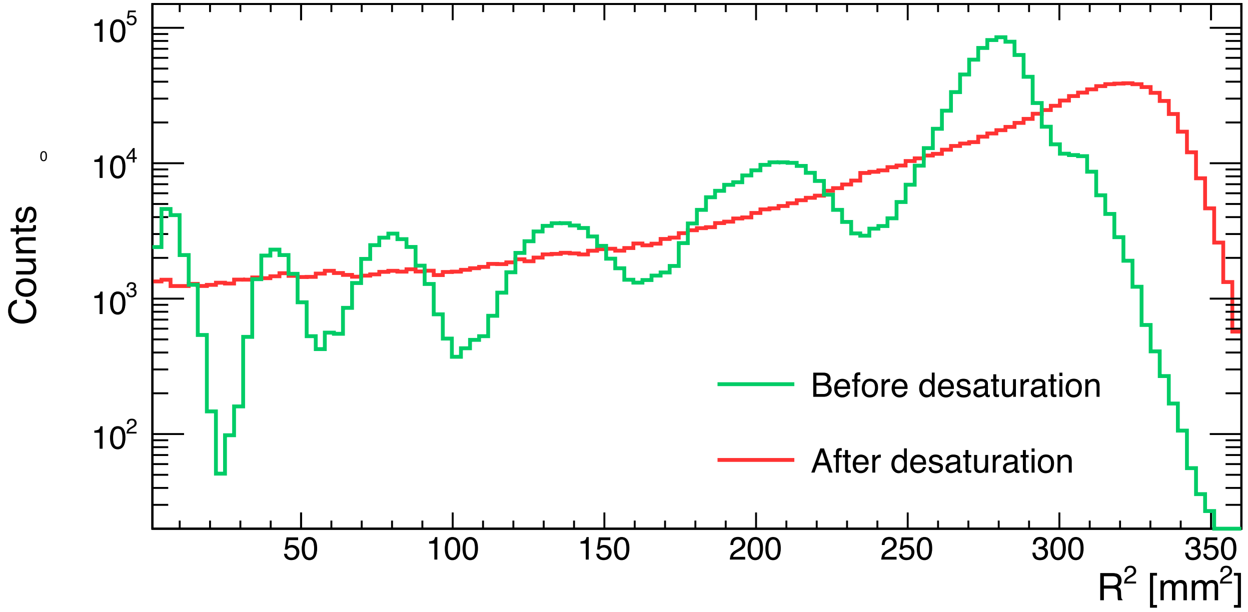


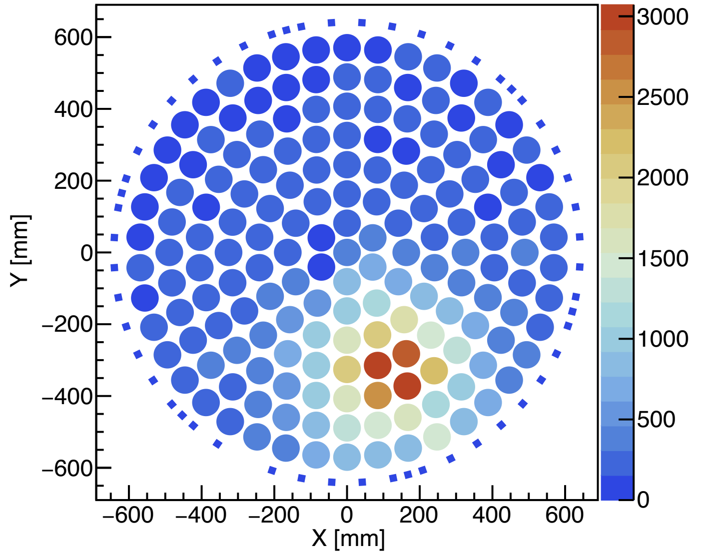
>900 PE

Unsaturated WFs (50-900 PE) as templates

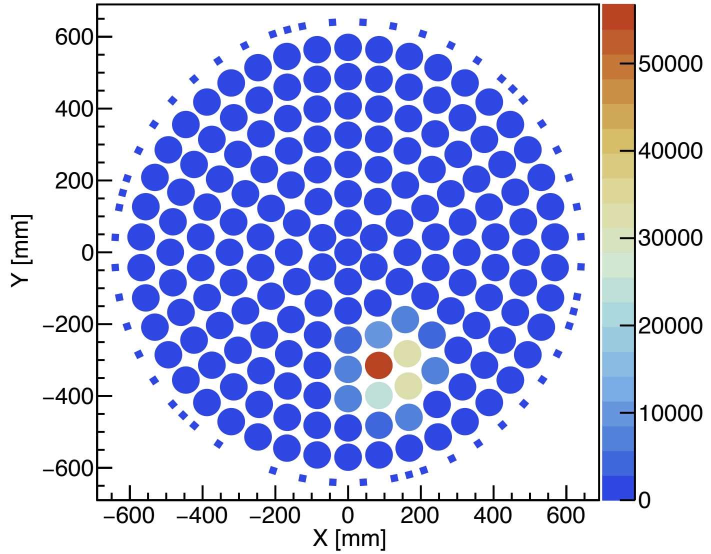
Position reconstruction improvement with desaturation

- Position reconstruction based on PAF (photon acceptance function) methods devloped in DM analysis
- Reconstruction at HE is significantly improved with desaturation
- Removed the band structure in R^2 distribution





Before



After

Energy reconstruction

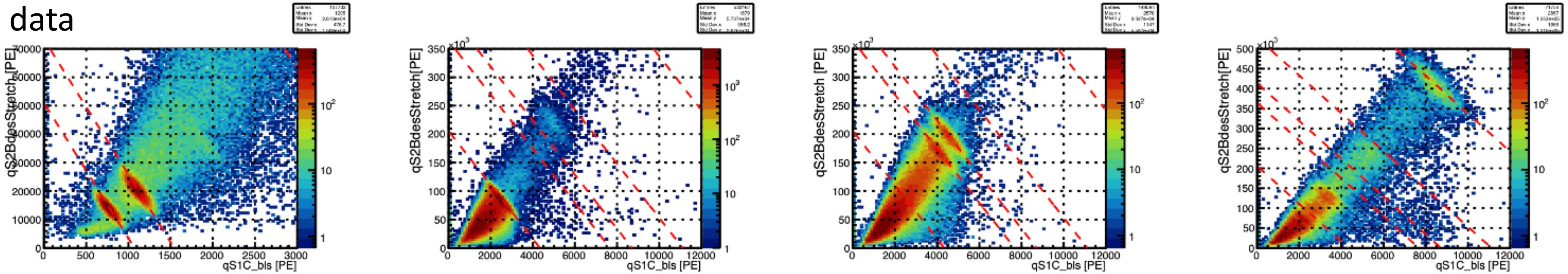
- Energy reconstruction: $E = 13.7\ \text{eV} \times (S1/PDE + S2_b/(EEE \times SEG_b))$
- High energy peak positions off by ~10% with inputs from DM analysis
- Further tune S1 and $S2_b$ vs. energy and position → deviations of peak positions to the percent level.

PDE: photon detection efficiency for S1

EEE: electron extraction efficiency

SEG_b: single-electron gain for $S2_b$

Calibration data

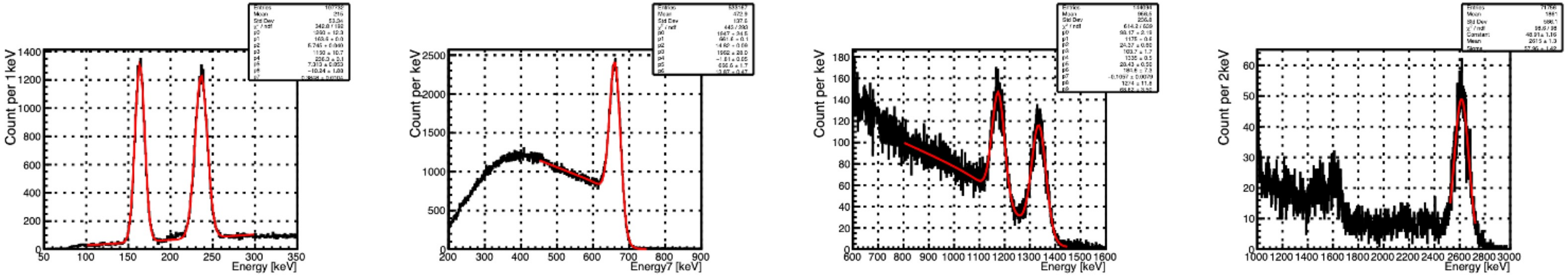


^{131m}Xe (164 keV), ^{129m}Xe (236 keV)

^{137}Cs

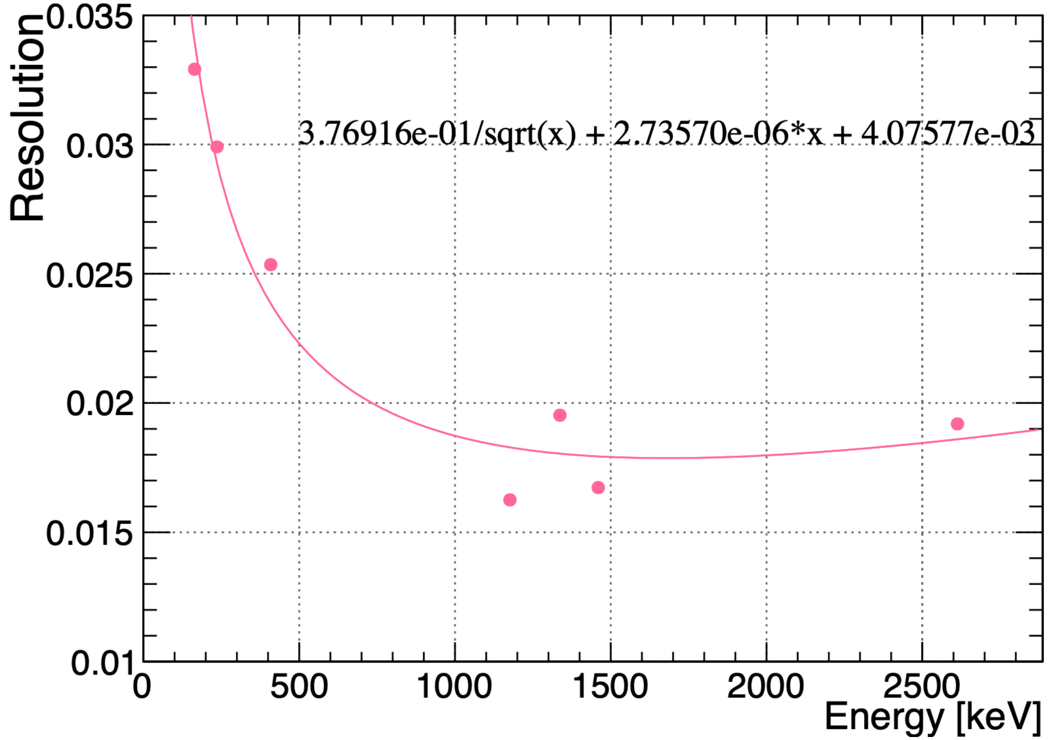
^{60}Co

^{208}Tl

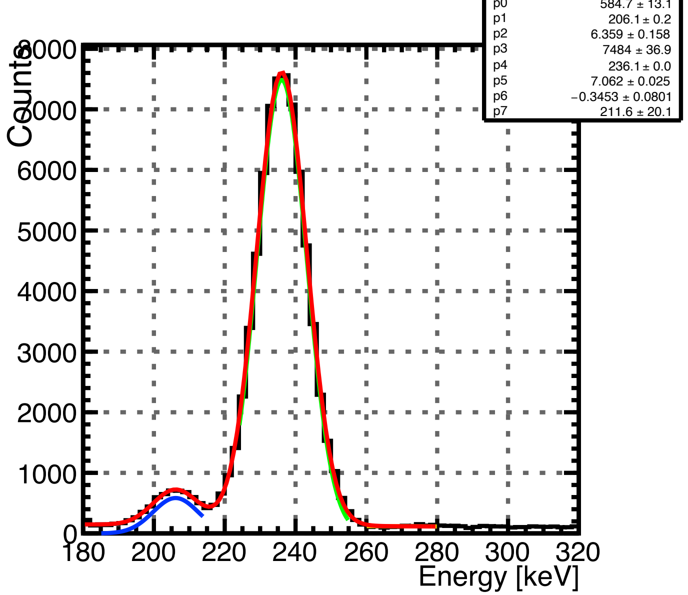


Background peaks

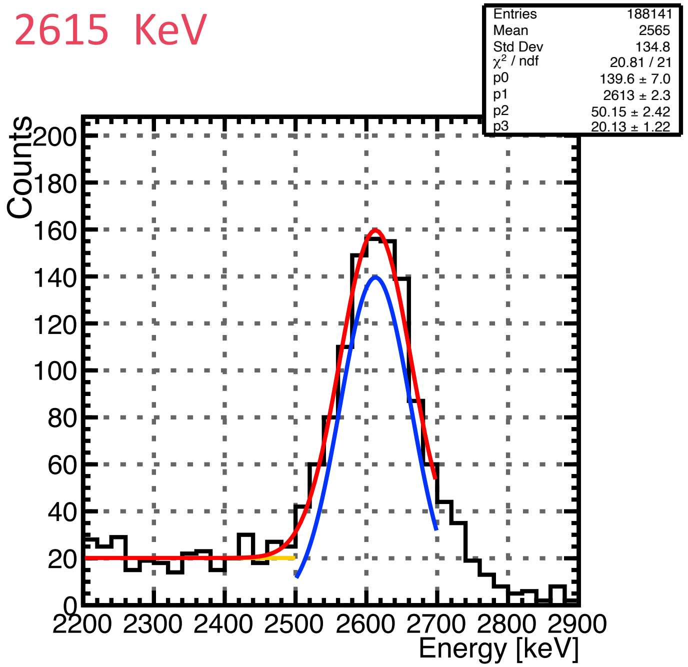
- Resolution of background data: 1.9% at 2615 keV; 3.0% at 236 keV
- Resolutions from different peaks as input for simulated spectrum



236 KeV

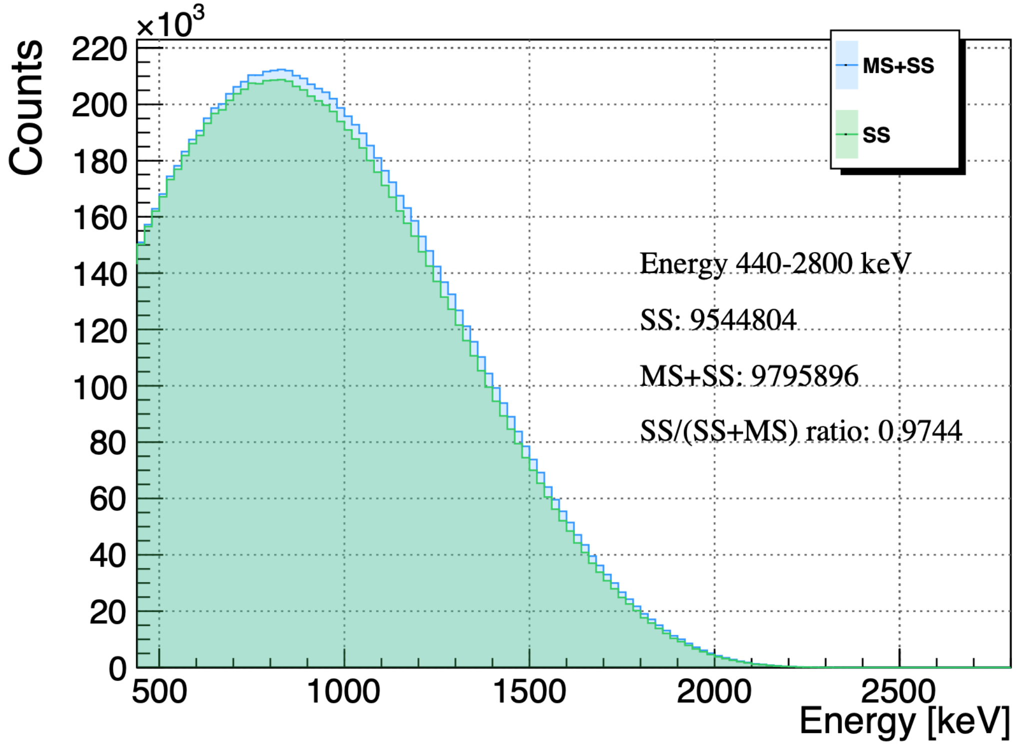


2615 KeV



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.

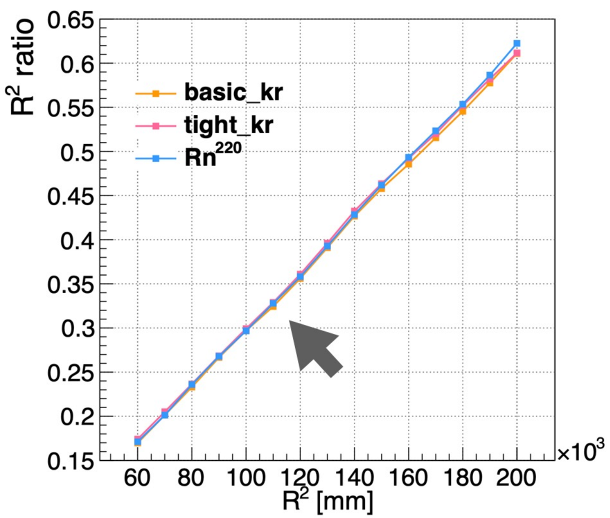


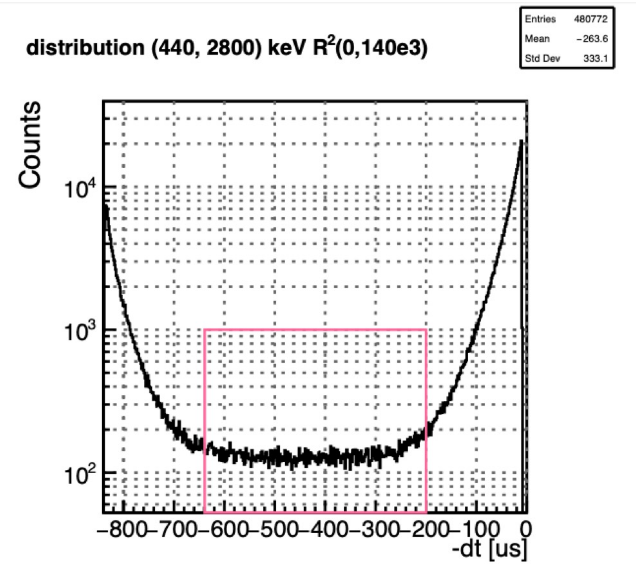
- (Very mild) Data quality cut efficiencies: (99.4 ± 0.4)%
  - S1, S2, S1/S2: remove non-electron recoil and alpha events
  - Top and bottom S1 charge asymmetry vs. drift time: reject accidental coincidence events and events originating from the gate electrode.
  - Calculated by region
- Calculated from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

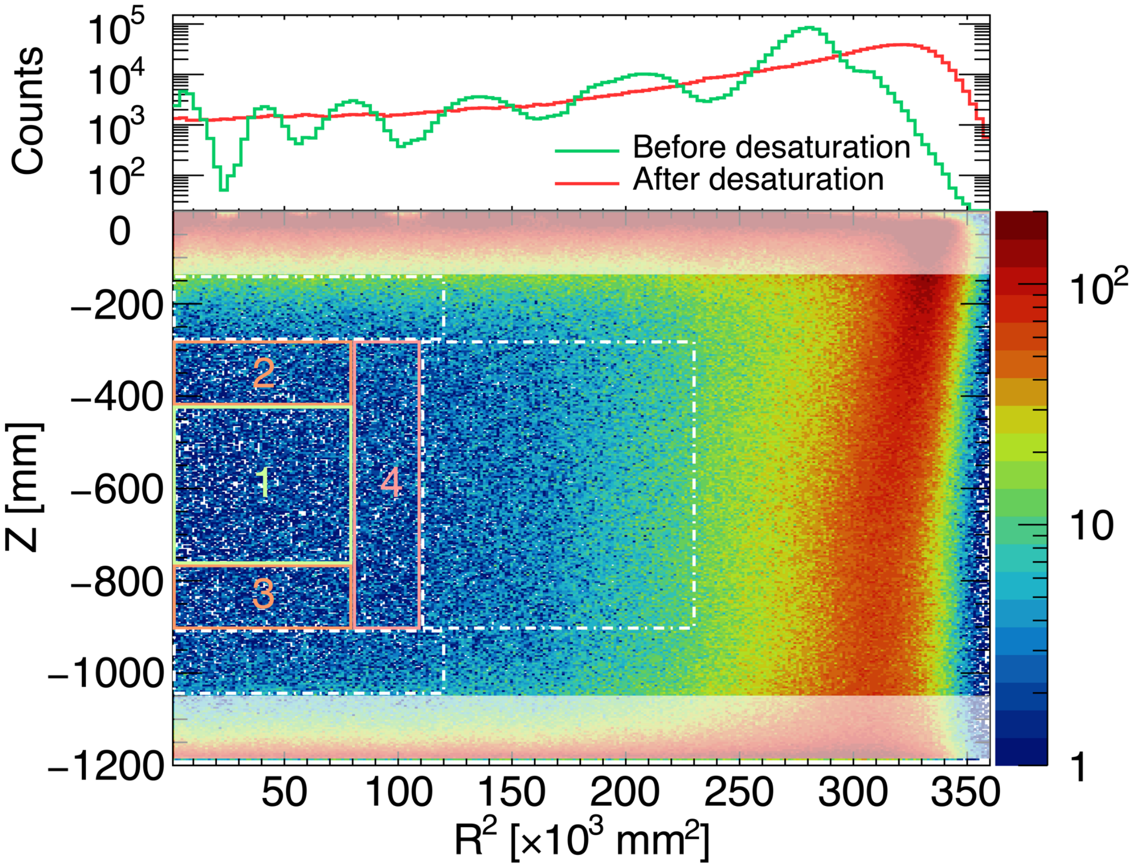
Fiducial Volume: emphasis on systematics, not statistics

- 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
- 649.7 ± 6.5 kg of xenon

FV mass



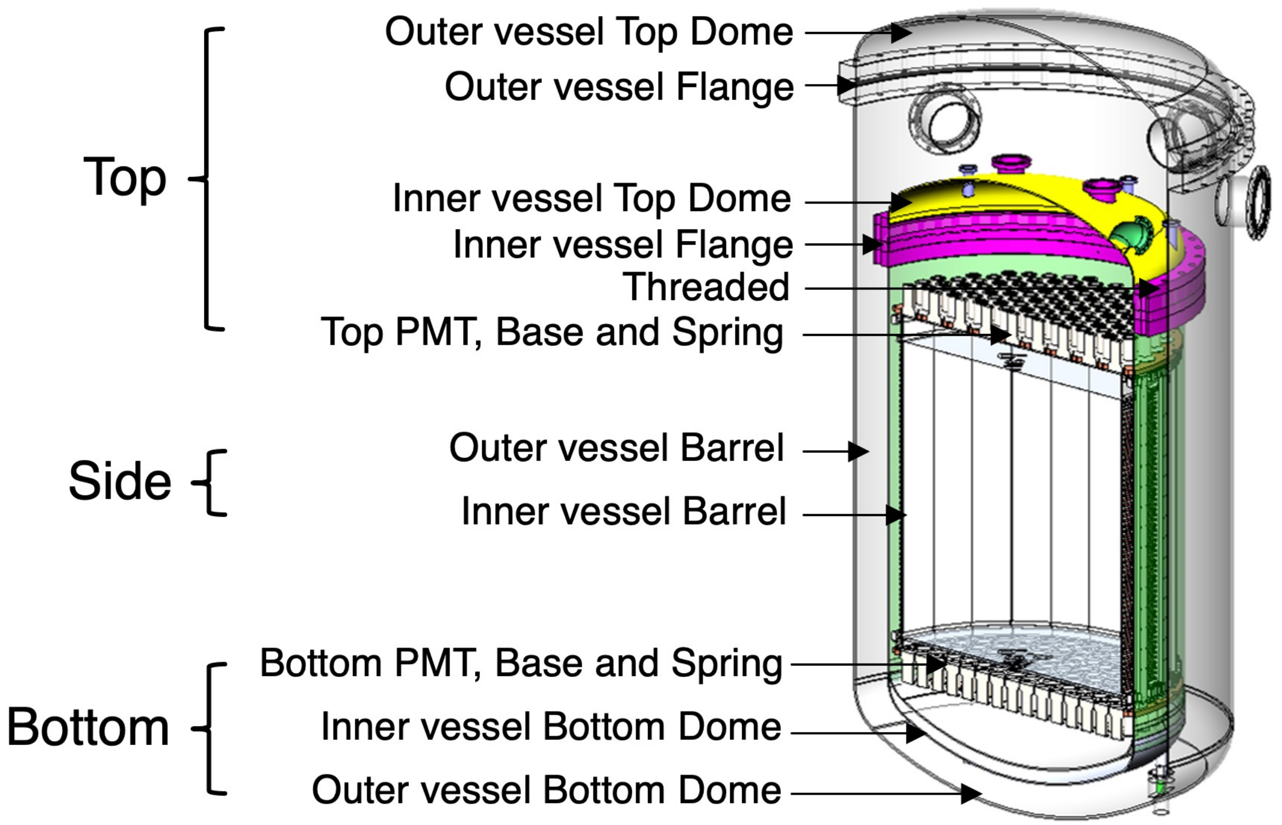




Background components

- 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

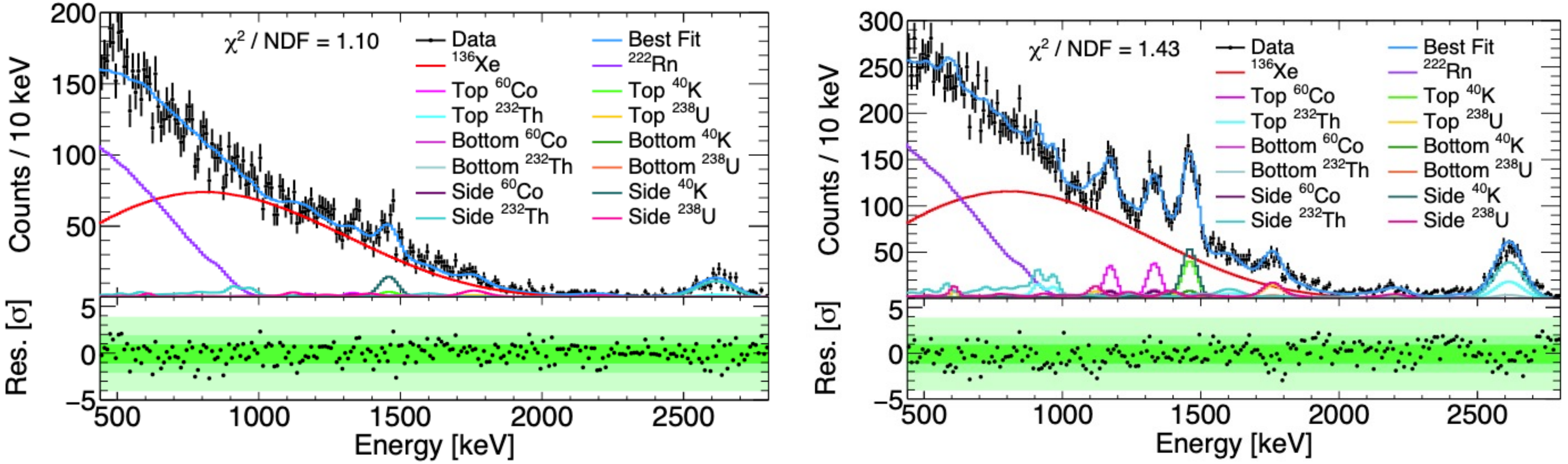


Simultaneous binned likelihood fit in four regions

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

Region 1

Region 234

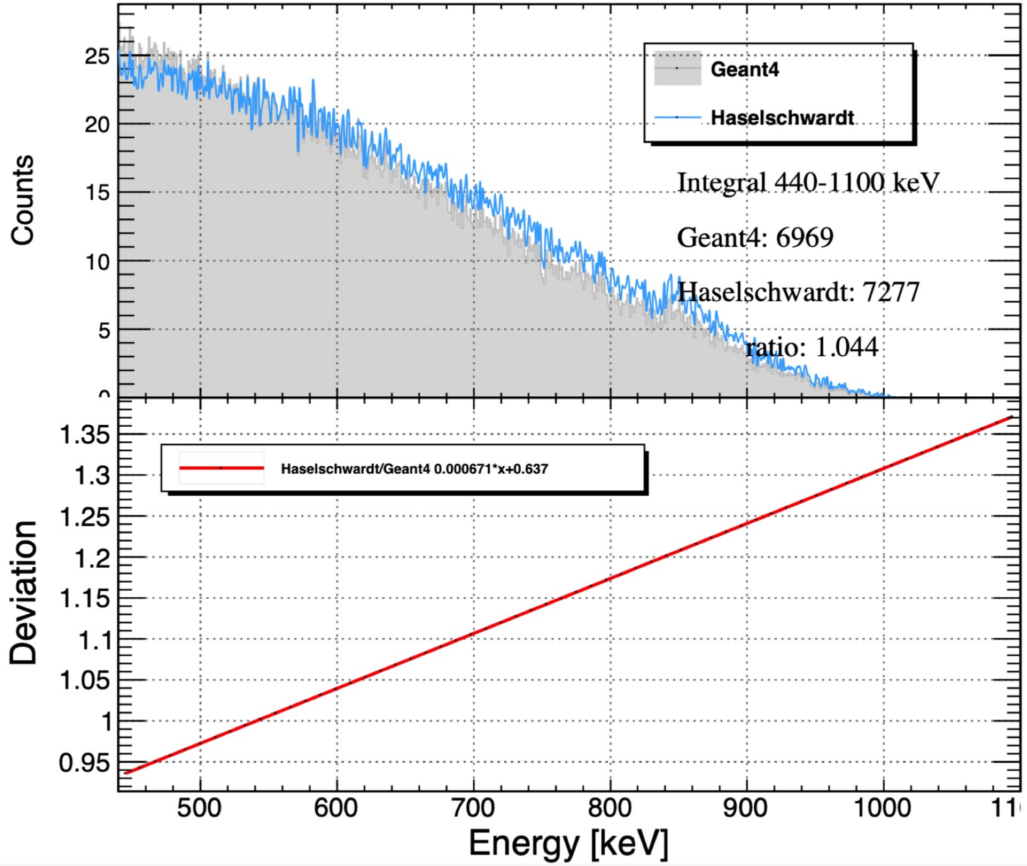


^{136}Xe fit results: 17468±243; 2.27 ± 0.03(stat.) ± 0.09(syst.) × 10^{21} year half-life

Cross check with RooFit likelihood fit

Systematic uncertainties

systematic source	Uncertainty [%]
Quality cut	0.39
FV cut	0.99
SS cut	1.75
LXe density	0.13
Pb214 spectrum correction	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



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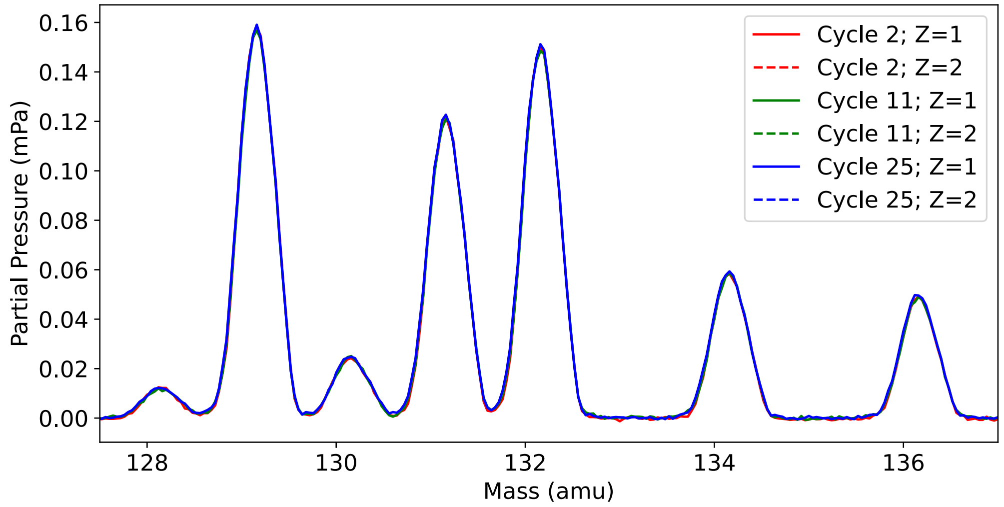
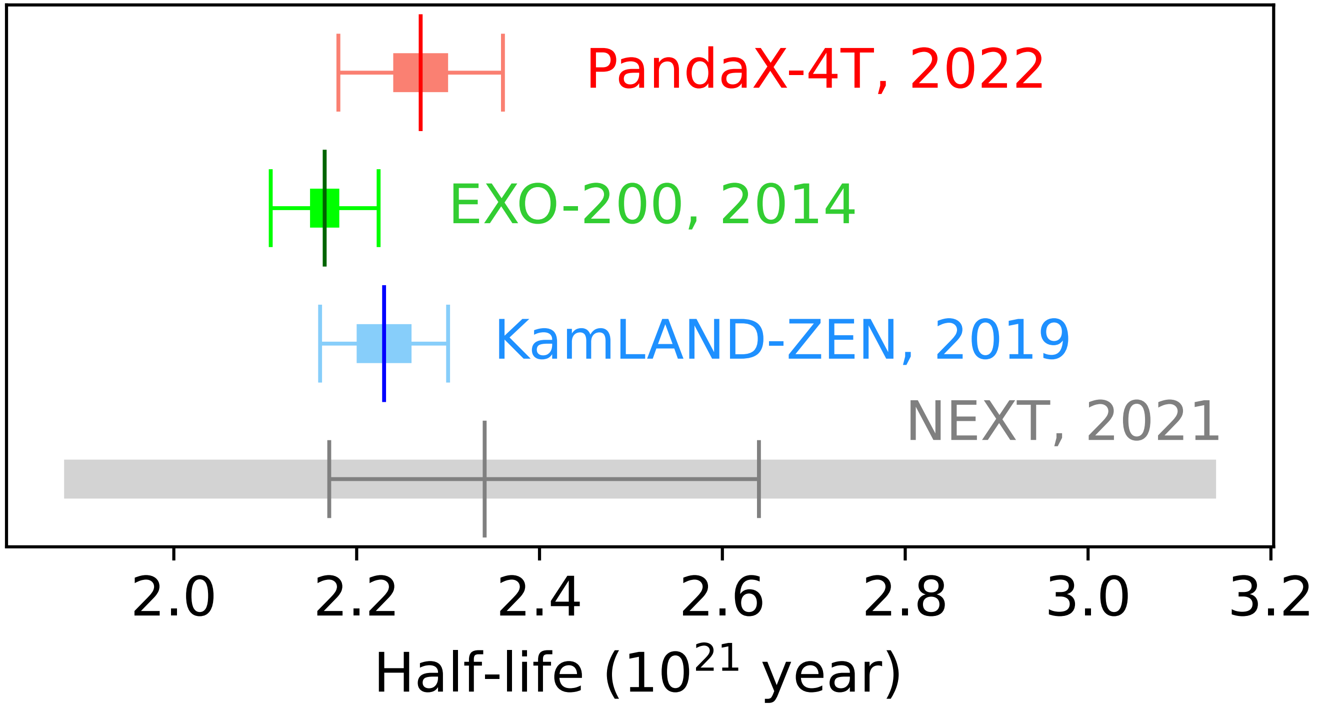


- ^{136}Xe IA: 8.79% if ionization efficiencies not corrected; 9.03% if corrected with NIST values
- Taken nominal value 8.86% as input and difference to our measurement as uncertainties

Conclusion: Final results

- ^{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



Stay tuned for multi-physics program with PandaX!