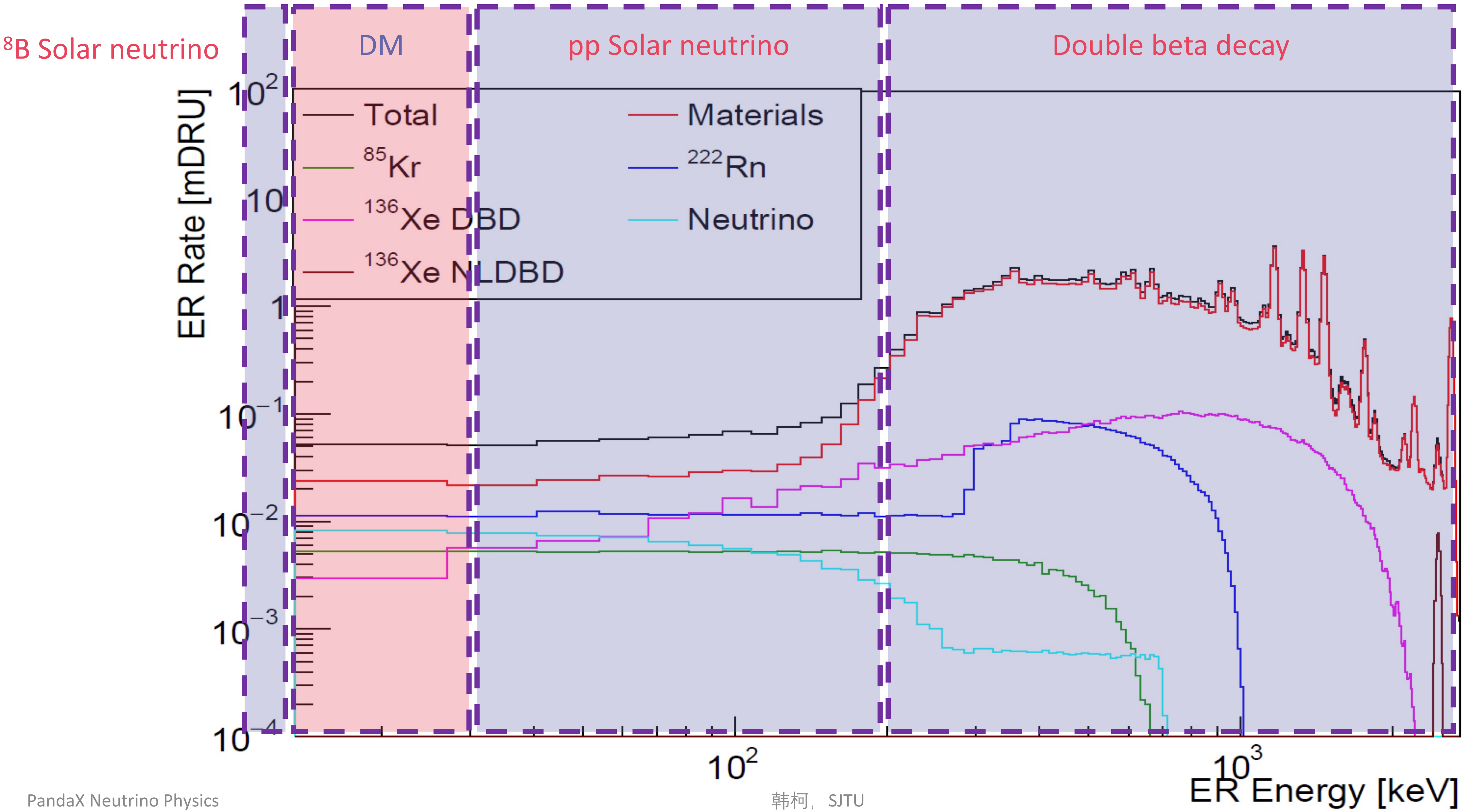
Neutrino Physics with PandaX

HAN, Ke 韩柯 (SJTU)

For the PandaX Collaboration

2023/10/2

Simulated spectrum for PandaX-4T



Wide energy range, multiple “interesting” isotopes for neutrino physics

	Sub-keV	keV	10 keV	100 keV	1 MeV	10 MeV
Xe-136 (9%)					DBD and NLDBD	
Xe-134 (10%)				DBD and NLDBD		
Xe-124 (0.1%)				Double EC		
Xe-all	^{8}B solar neutrino		WIMP and other DM signals	pp solar neutrino		alphas

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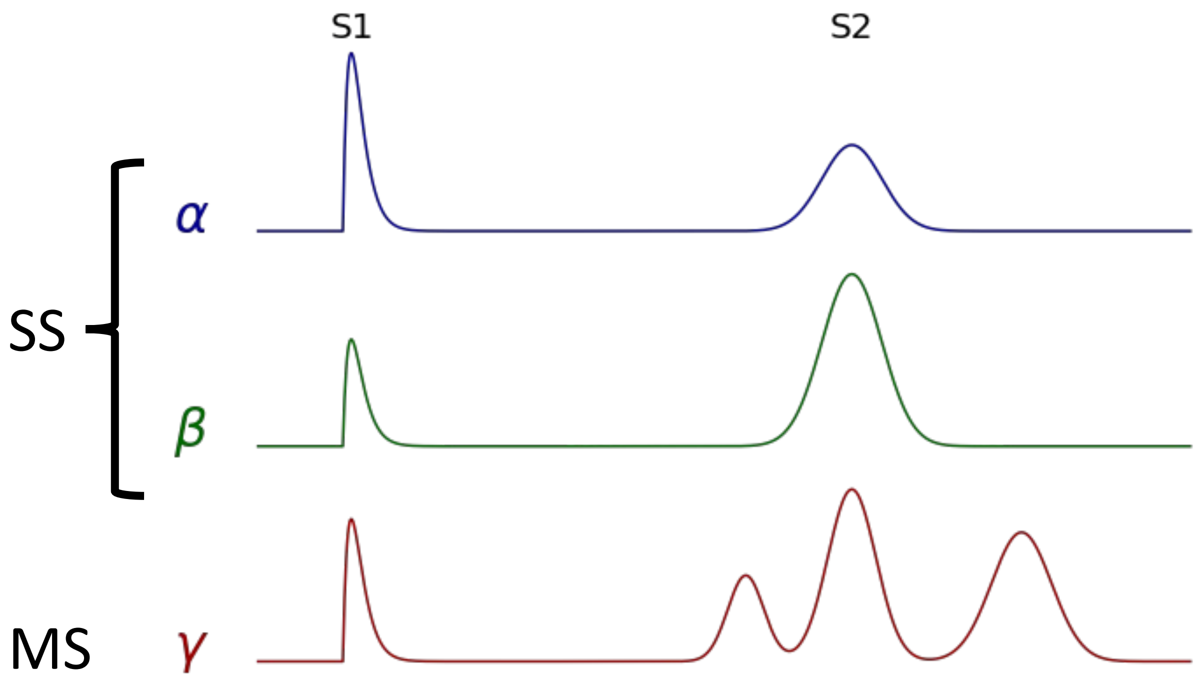
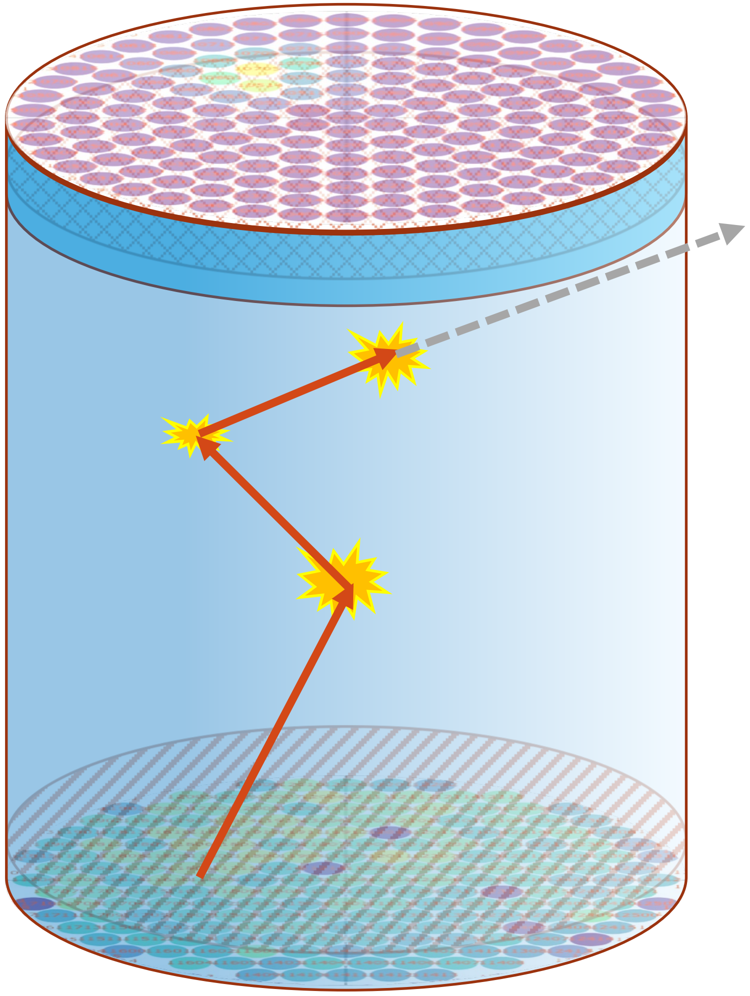
PandaX LXe TPC: Total-Absorption 5D Calorimeter

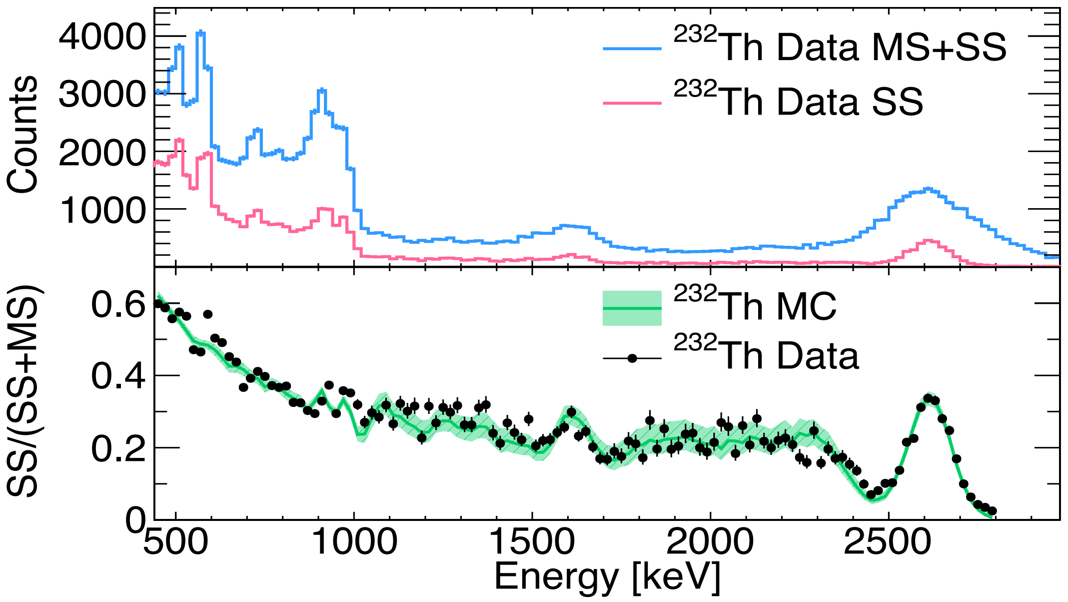
- Precisely measure 3D position, energy, and timing information in the energy range from sub-keV to 10MeV
- Large monolithic volume: total absorption; ~20 x MeV γ attenuation length
- Single-site (SS) and multi-site (MS) event for event topology and particle ID

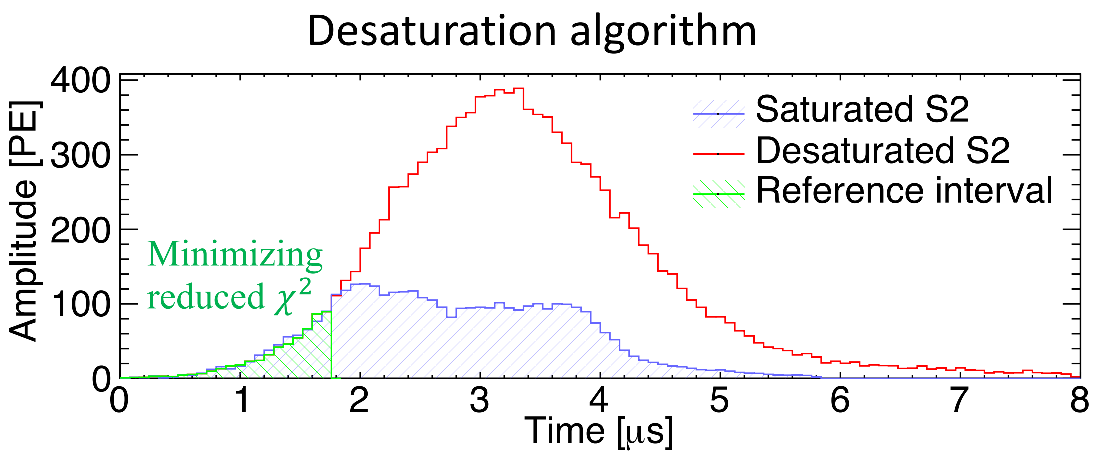


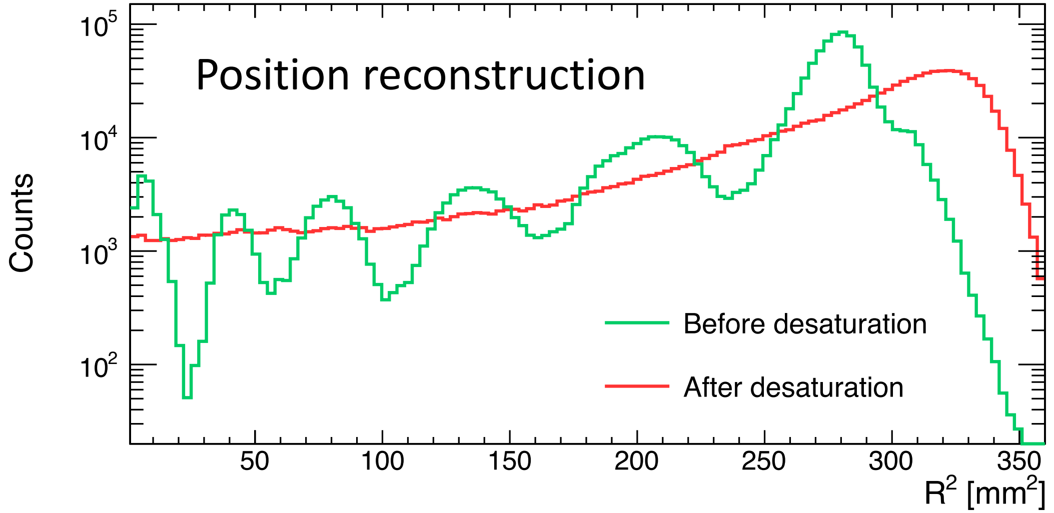


Extending from keV to MeV

- Dedicated data analysis pipeline is developed for O(100 keV) – O(MeV) energy range
- Improved SS and MS identification: calibration data/MC SS ratio consistent within 1.7%
- Desaturation algorithm: X-Y position reconstruction, energy linearity and resolution significantly improved

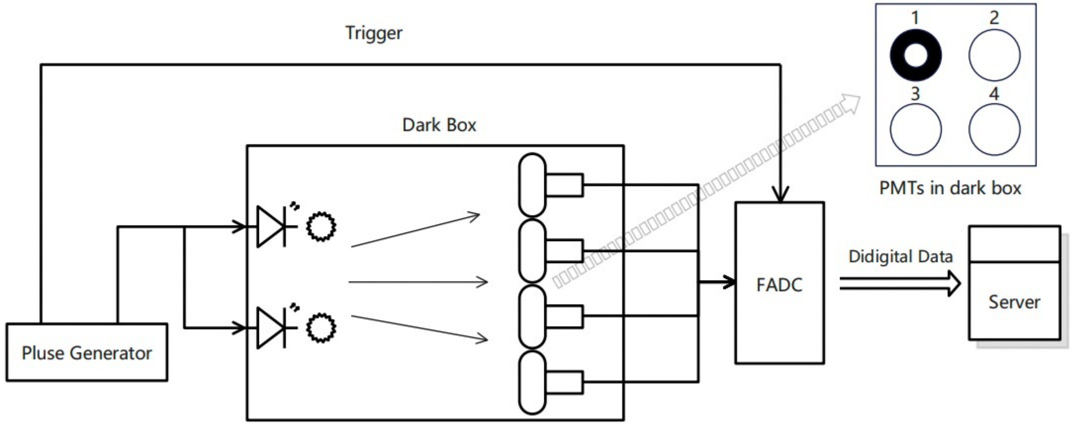


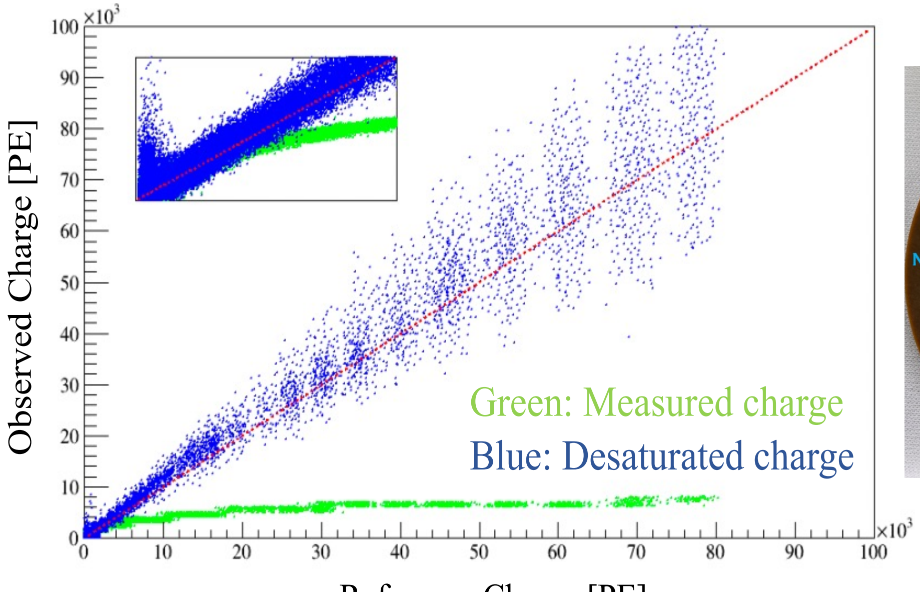


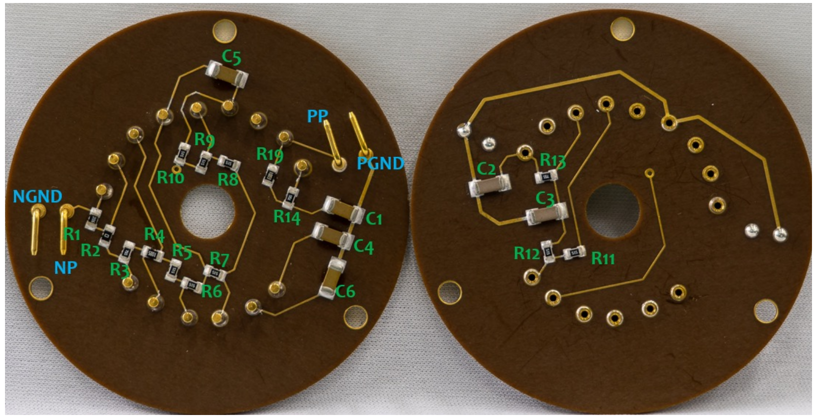


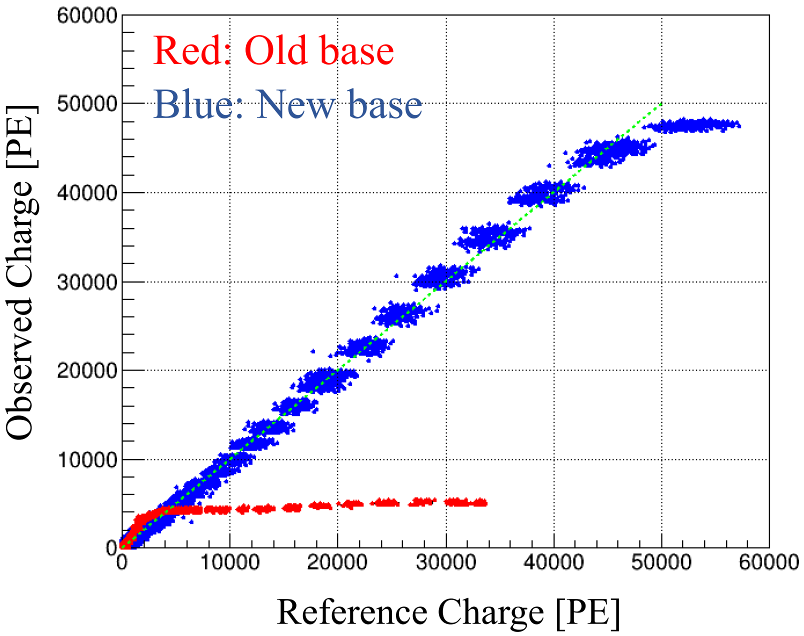
Bench test for saturation and new PMT base design

- Dedicated test bench was setup to study PMT saturation
- Desaturation algorithm verified
- New PMT base design with much improved linearity
- All new bases for the upcoming Run2



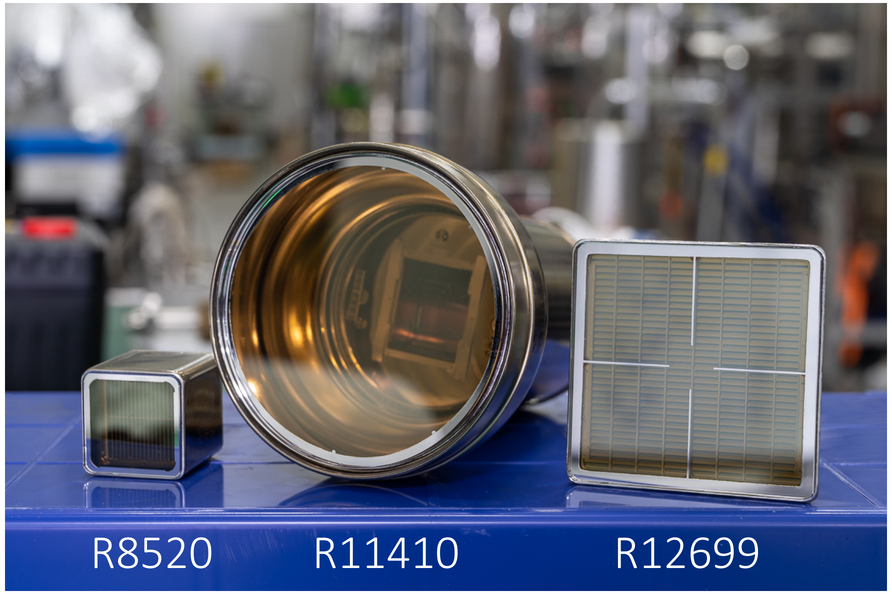


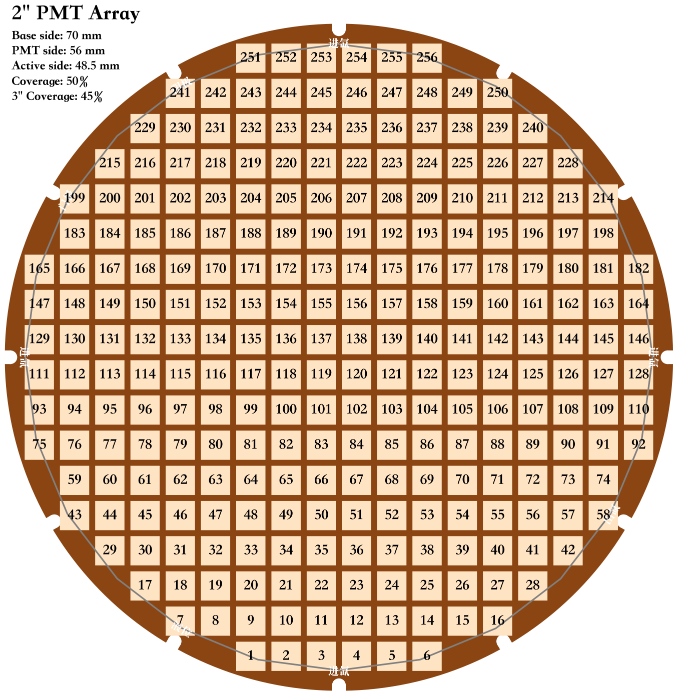




New PMTs for next generation LXe detectors

- New 2" multi-anode R12699 PMT is an attractive option for next generation multi-purpose LXe detectors
  - High granularity, fast timing, low dark noise
  - 2" array for excellent performance at keV an MeV
  - Improved position reconstruction; better event topology; less concerns for PMT saturation; higher coverage possible
- Extensive performance testing at SJTU and R&D efforts on background control is on-going together with Hamamatsu





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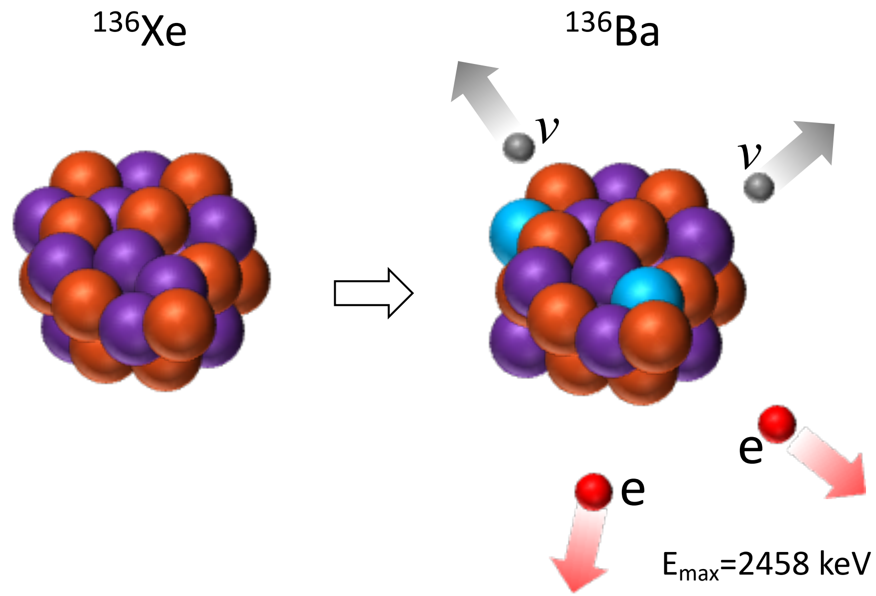
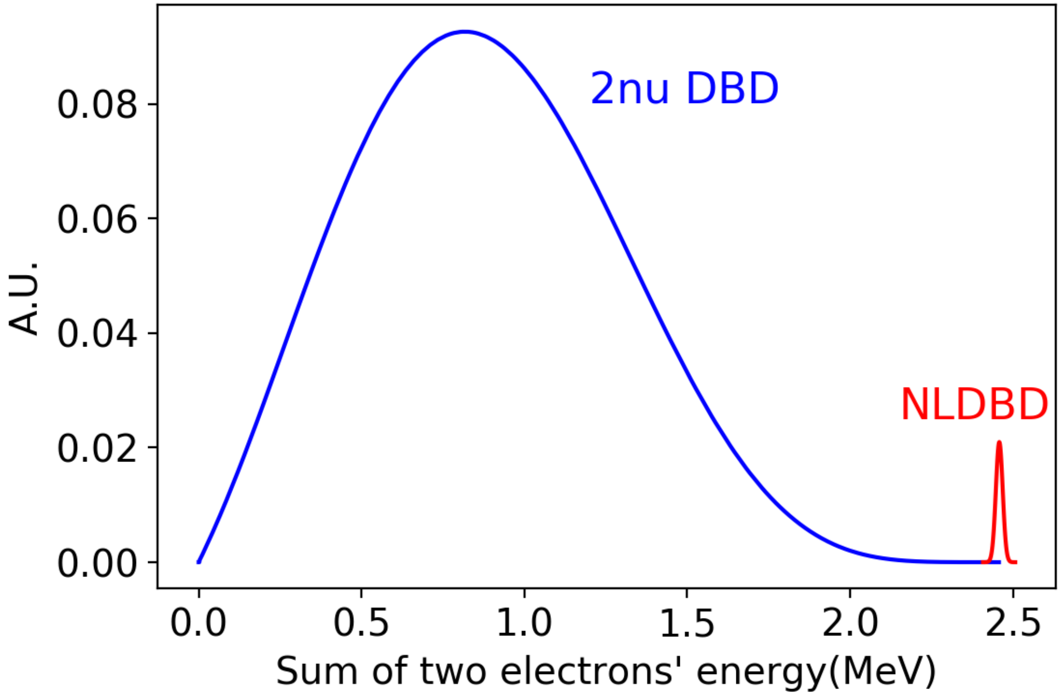
Neutrinoless Double beta decay (NLDBD)

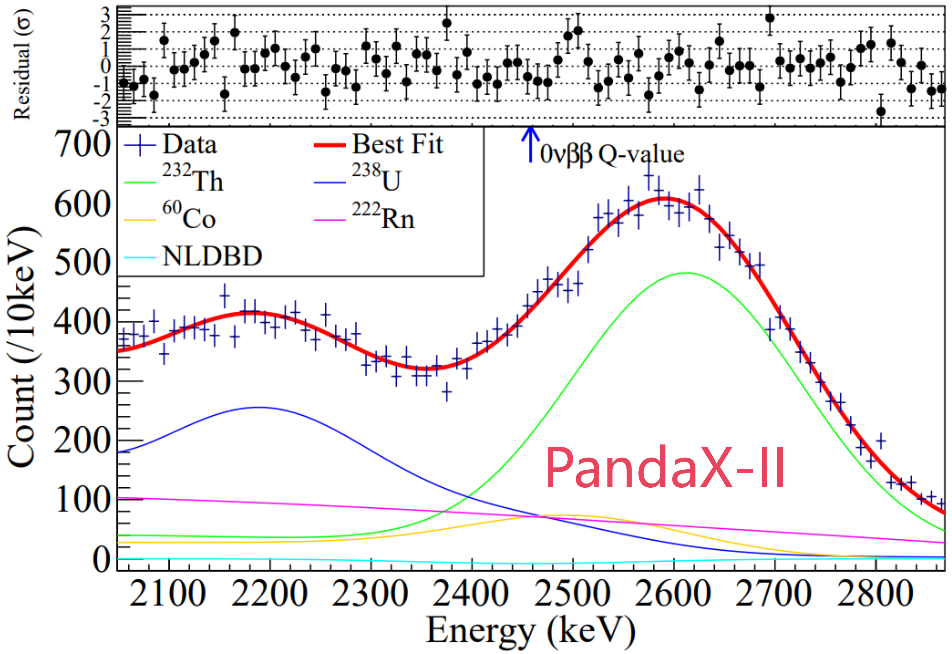
- Neutrinoless double beta decay probes the nature of neutrinos: Majorana or Dirac
- Lepton number violating process
- Measure energies of emitted electrons

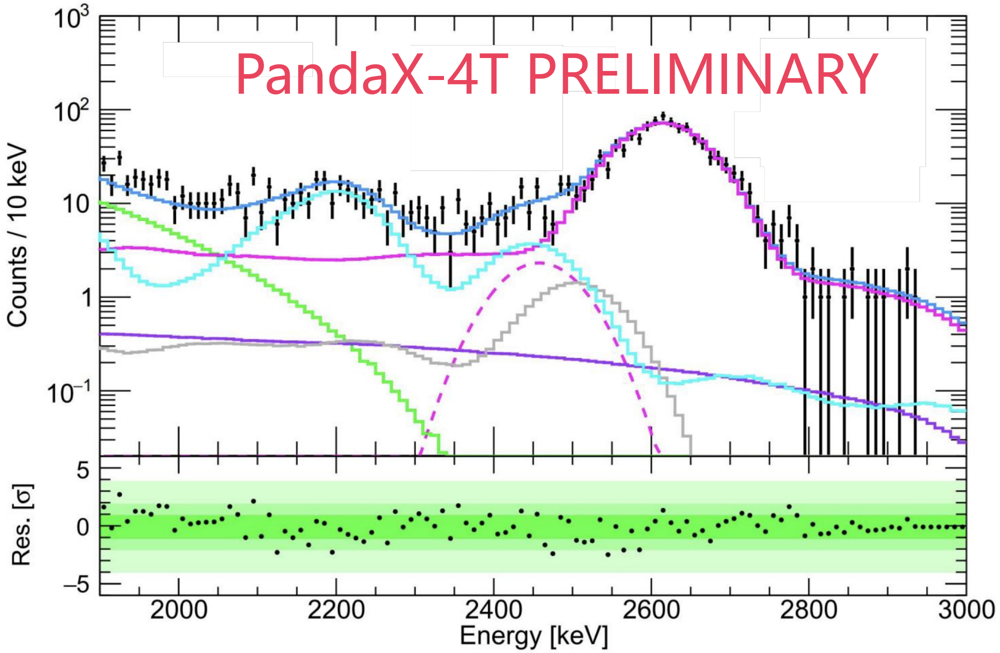




Search for ^{136}Xe NLDBD with LXe TPC

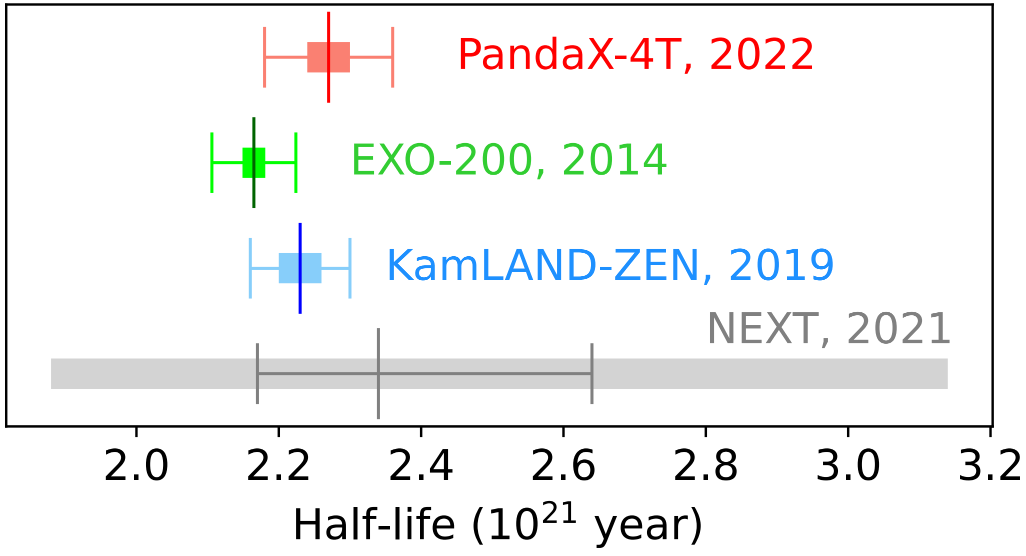
	Bkg rate (/keV/ton/y)	Energy resolution	FV mass (kg)	Run time	Sensitivity/Limit (90% CL, year)	Year
PandaX-II	~200	4.2%	219	403.1 days	2.4×10^{23}	2019
XENON1T	~20	0.8%	741	202.7 days	1.2×10^{24}	2022
PandaX-4T	6	1.9%	~650	~250 days	$> 10^{24}$	



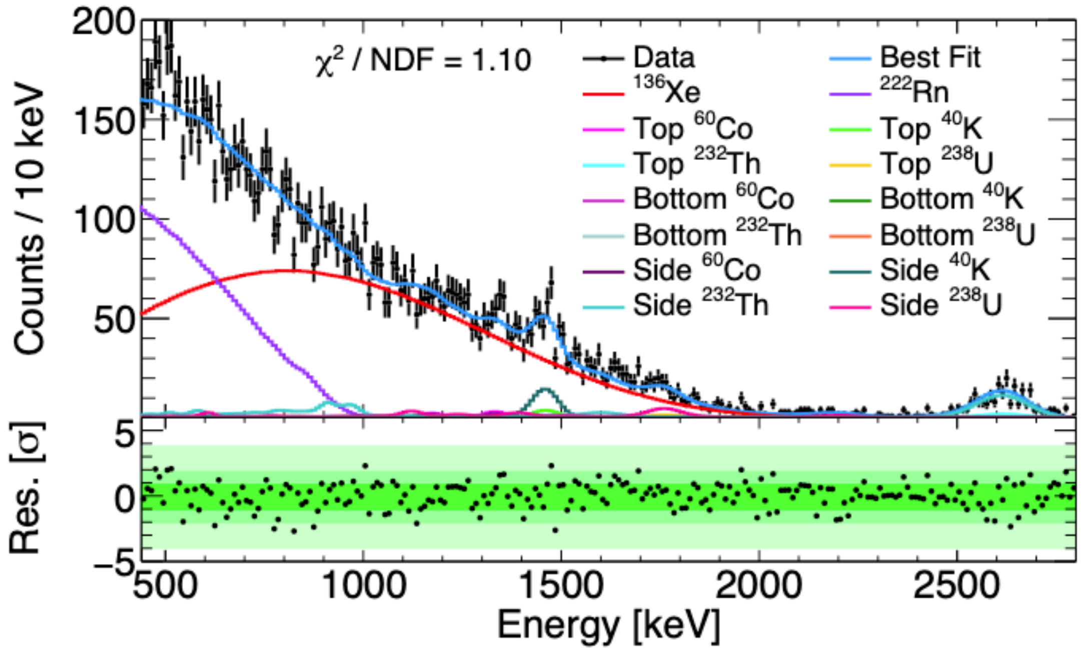


^{136}Xe DBD half-life measurement

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



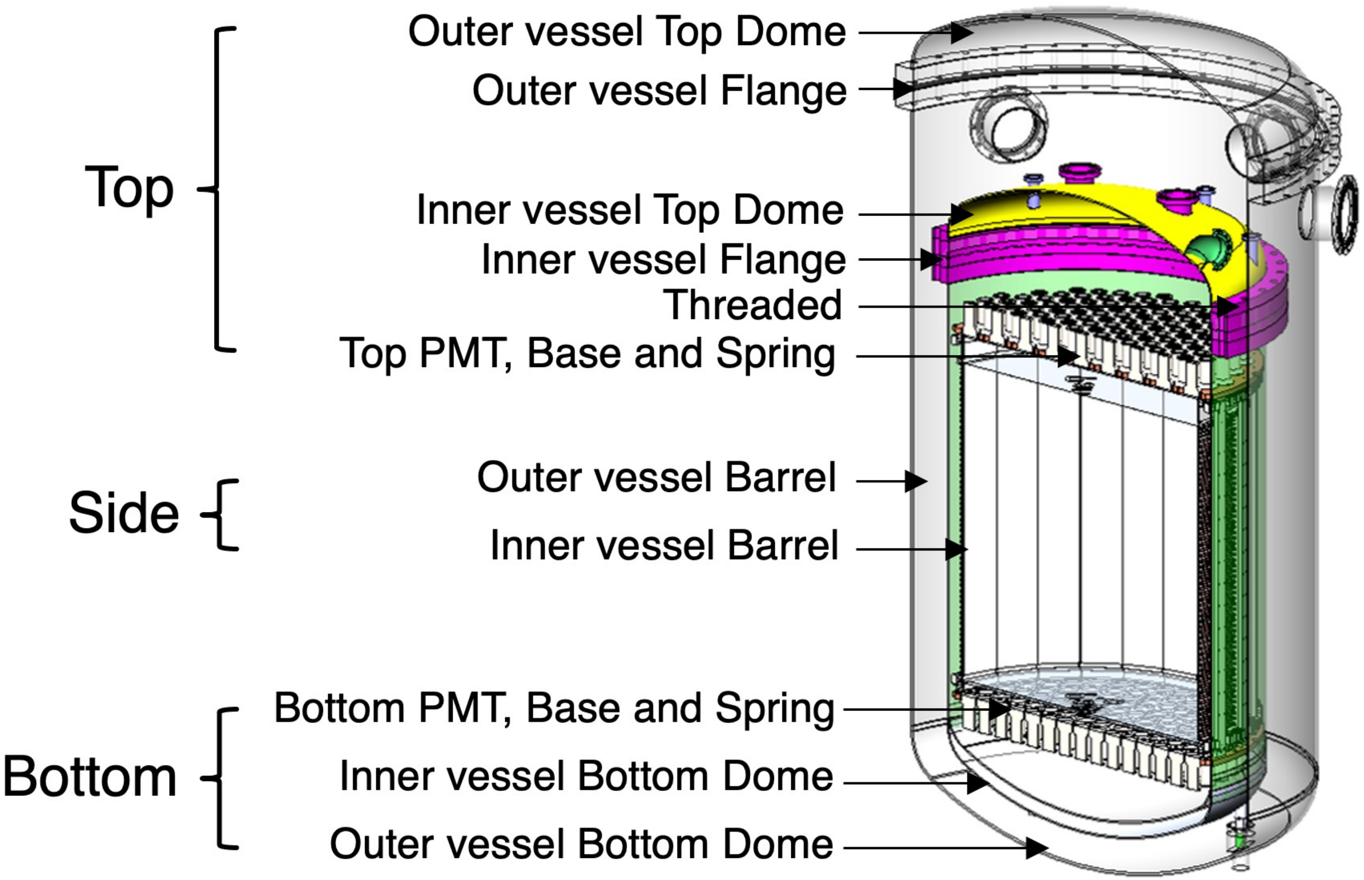
Research, 9798721 (2022)



More accurate background models

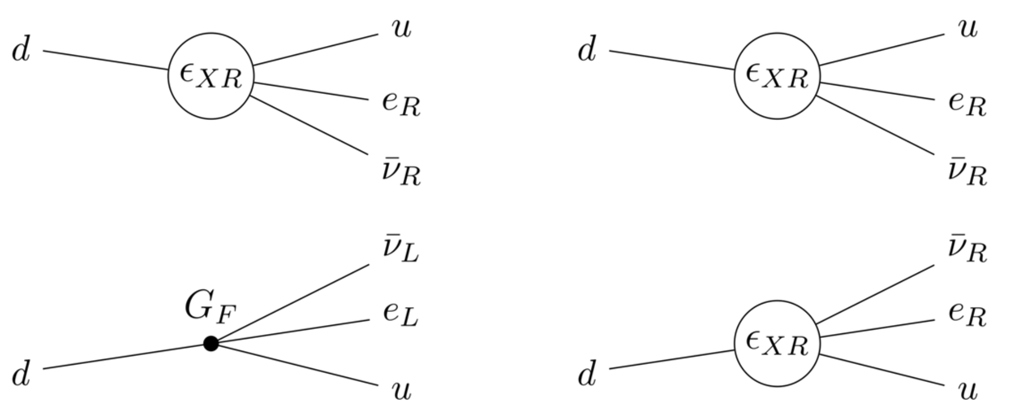
- Better than the input values based on HPGe assay results and high energy alpha events

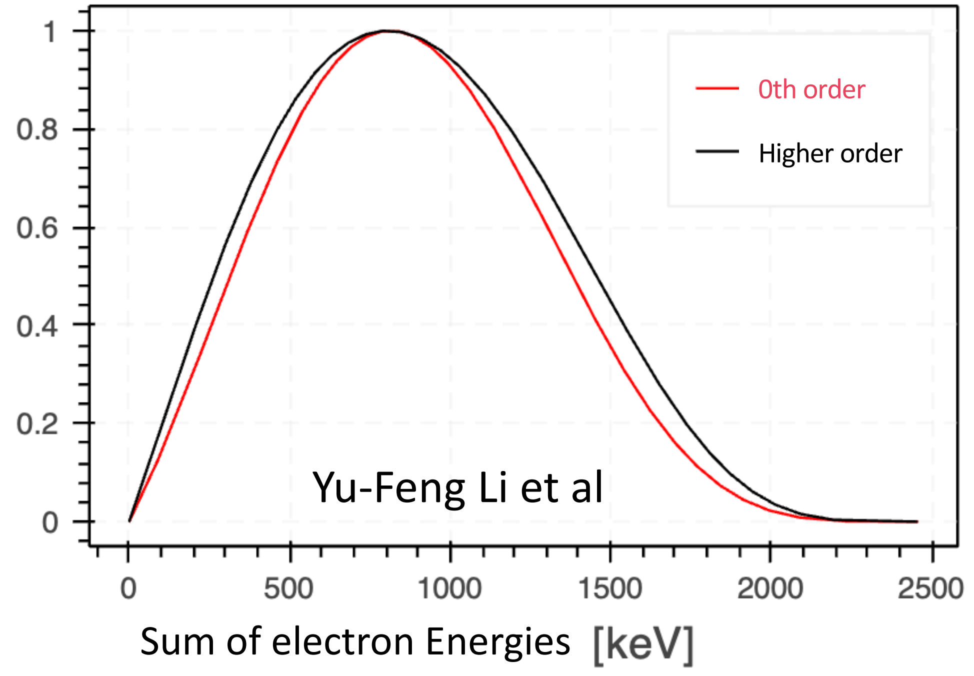
Detector part	Contamination	Expected counts	Fitted counts
Top	^{238}U	339 ± 129	490 ± 52
	^{232}Th	402 ± 133	670 ± 56
	^{60}Co	327 ± 141	550 ± 49
	^{40}K	300 ± 156	363 ± 40
Bottom	^{238}U	141 ± 51	185 ± 40
	^{232}Th	237 ± 119	155 ± 53
	^{60}Co	159 ± 95	183 ± 48
	^{40}K	89 ± 834	100 ± 39
Side	^{238}U	475 ± 707	1070 ± 118
	^{232}Th	786 ± 959	2194 ± 117
	^{60}Co	1244 ± 945	185 ± 98
	^{40}K	1518 ± 835	782 ± 84
LXe	^{214}Pb (^{222}Rn progeny)	[0,12057]	7180 ± 152

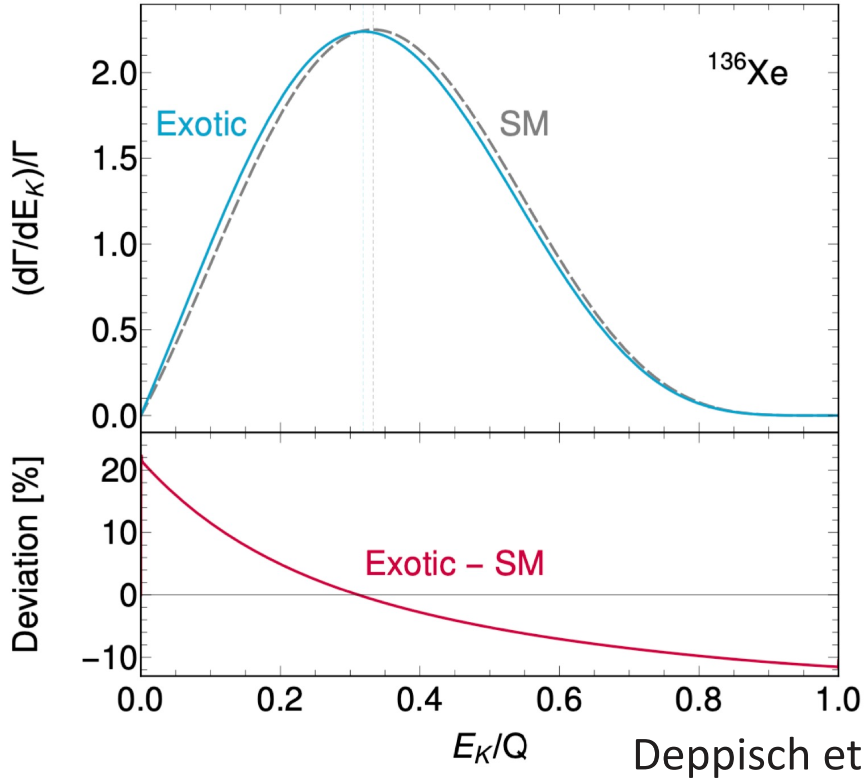


More Physics with ^{136}Xe DBD spectrum

- NME of DBD may be energy dependent and cause DBD shape change
- BSM physics, such as right-handed leptonic currents would affect the energy distribution







Deppisch et al, (2020)

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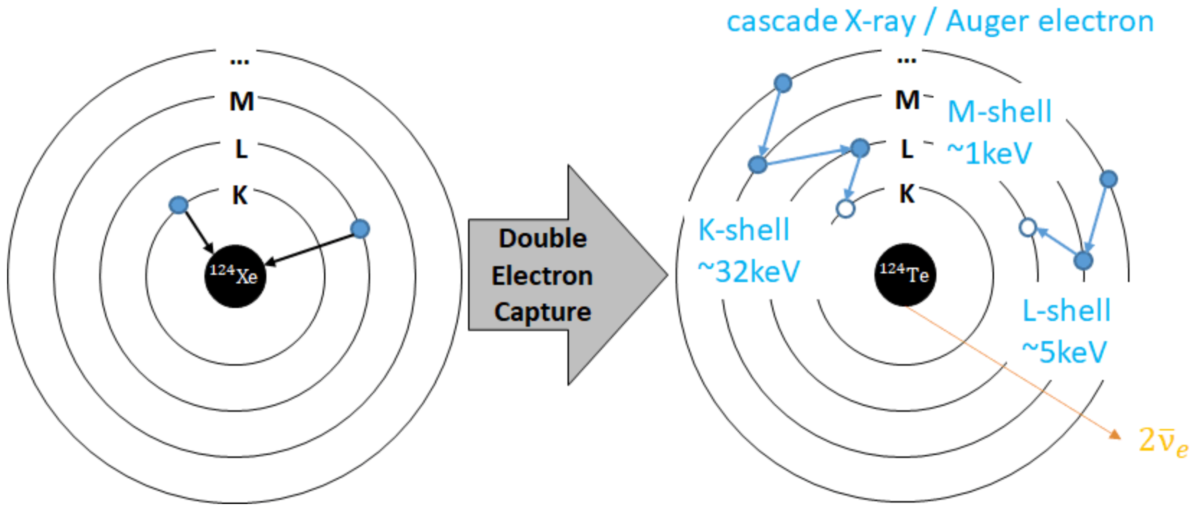
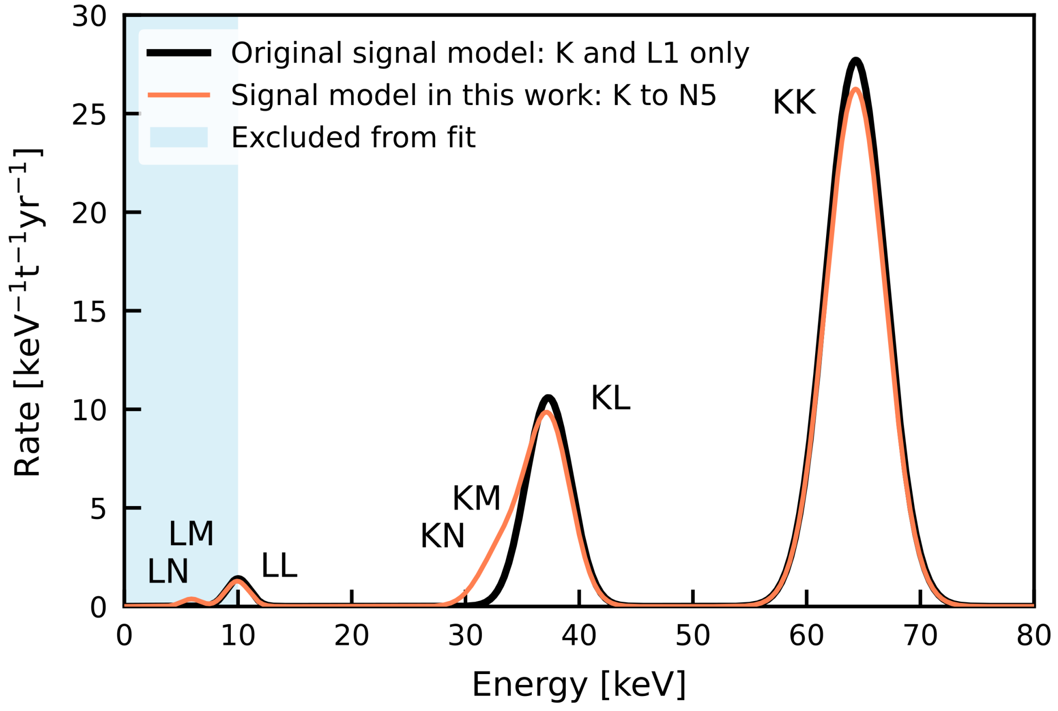
^{124}Xe double electron capture (DEC)



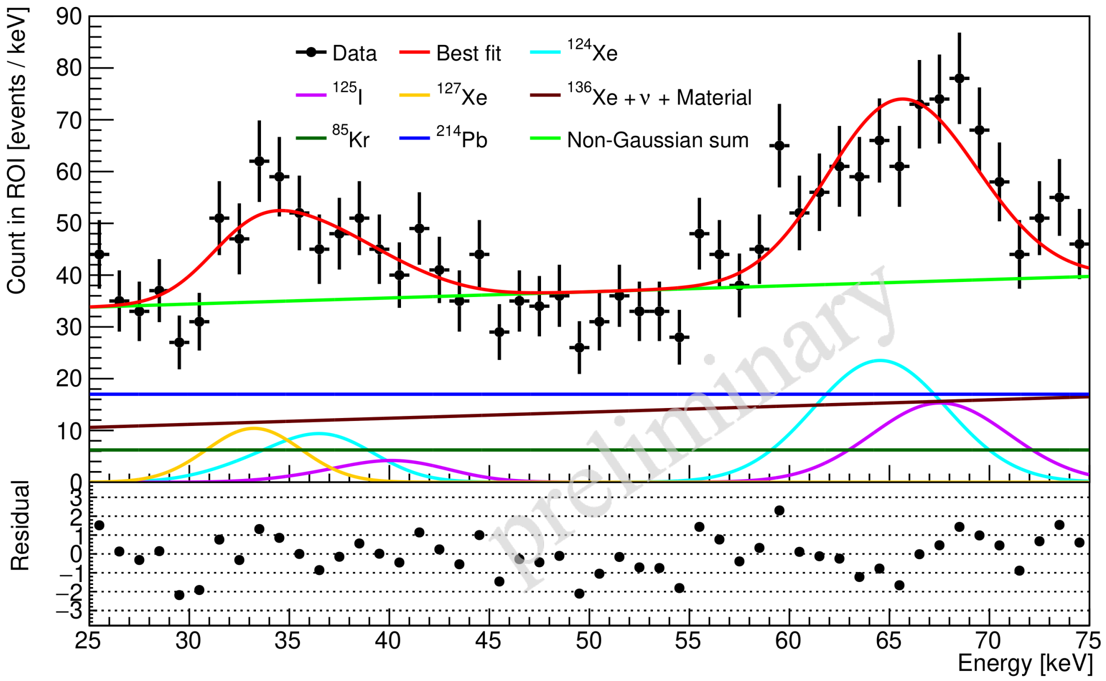
$$(A, Z) + 2e^- \rightarrow (A, Z-2) + (2\nu_e)$$

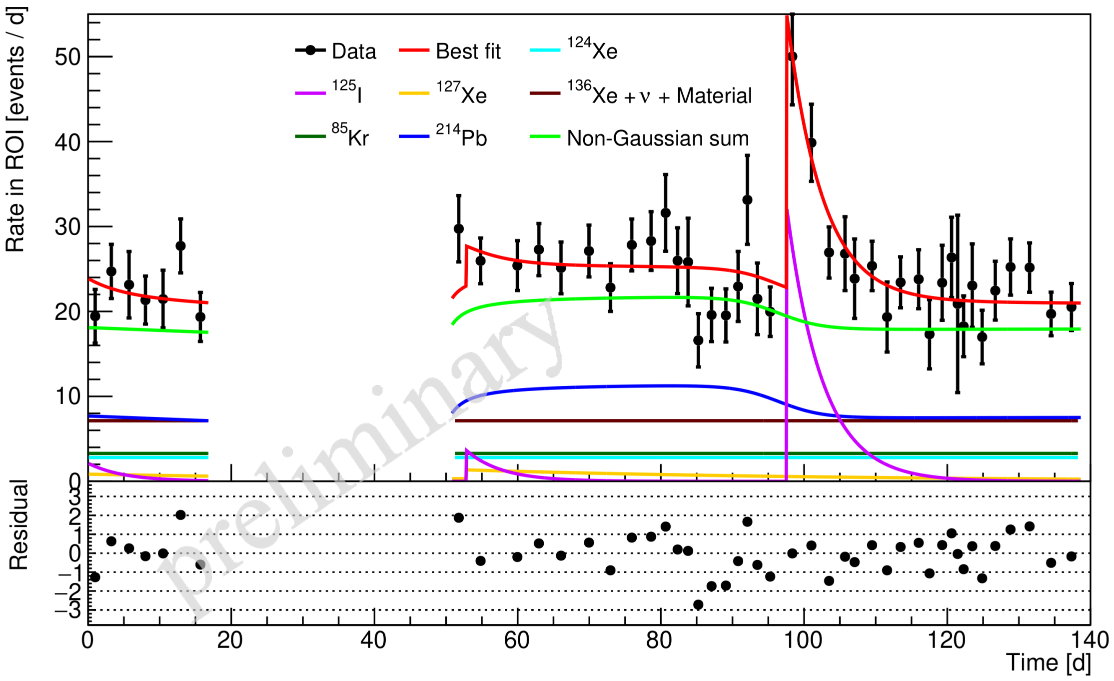


XENON1T, Physical Review C 106, 024328 (2022)

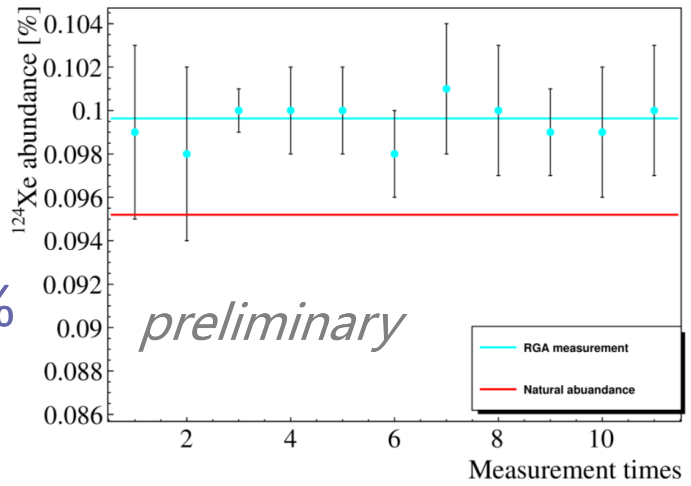
- Two-neutrino / neutrinoless double electron capture (DEC)
- 2^{nd} order weak process, $T_{1/2}=(1.18\pm0.13_{stat}\pm0.14_{sys})\times10^{22}$ yr from XENONnT

^{124}Xe DEC: spectrum fit to PandaX-4T data





- Spectral and temporal fit to data for ^{124}Xe DEC signal peak
  - Energy resolution at 64.3keV: (5.4±0.4)%
- Measurement of ^{124}Xe abundance in PandaX-4T: (0.099±0.001)%
  - 5% difference from natural abundance



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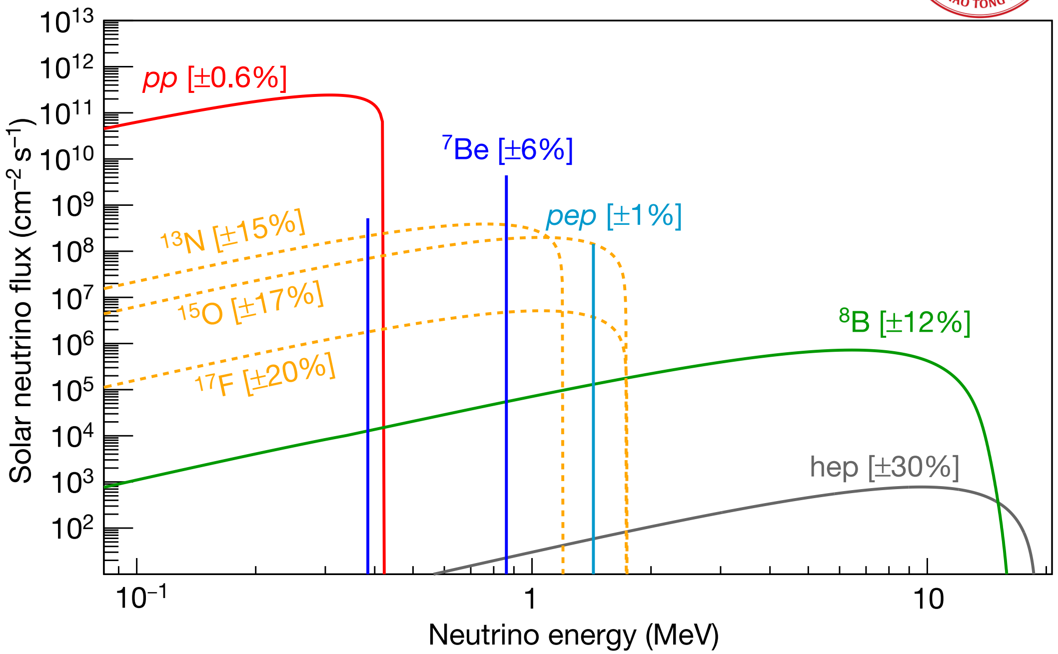
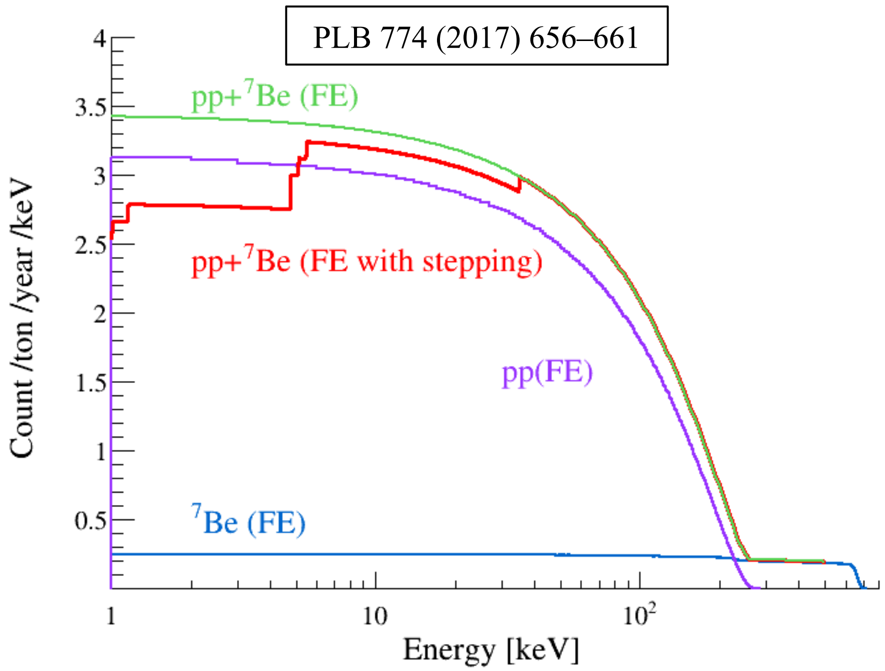
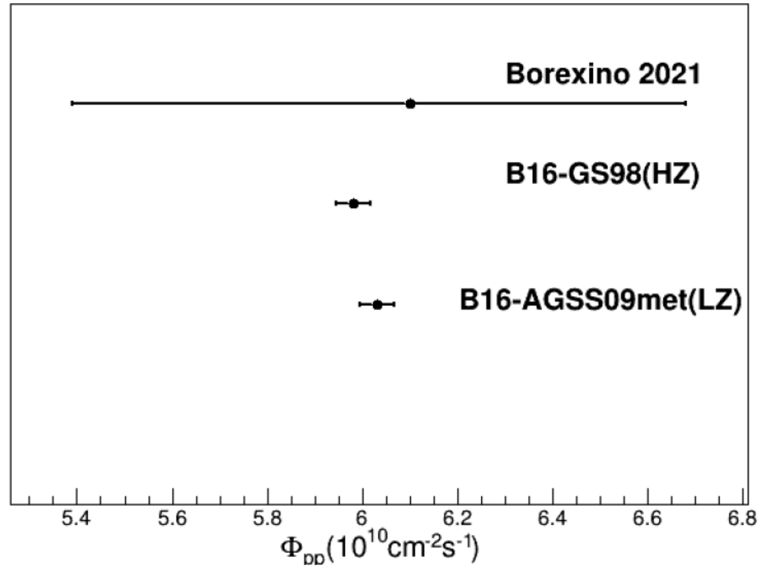
Search for solar pp + ^{7}Be neutrinos

- The world's leading direct detection result is from Borexino with a recoil energy of >165keV
- PandaX-4T aims to measure the lower energy spectrum than Borexino







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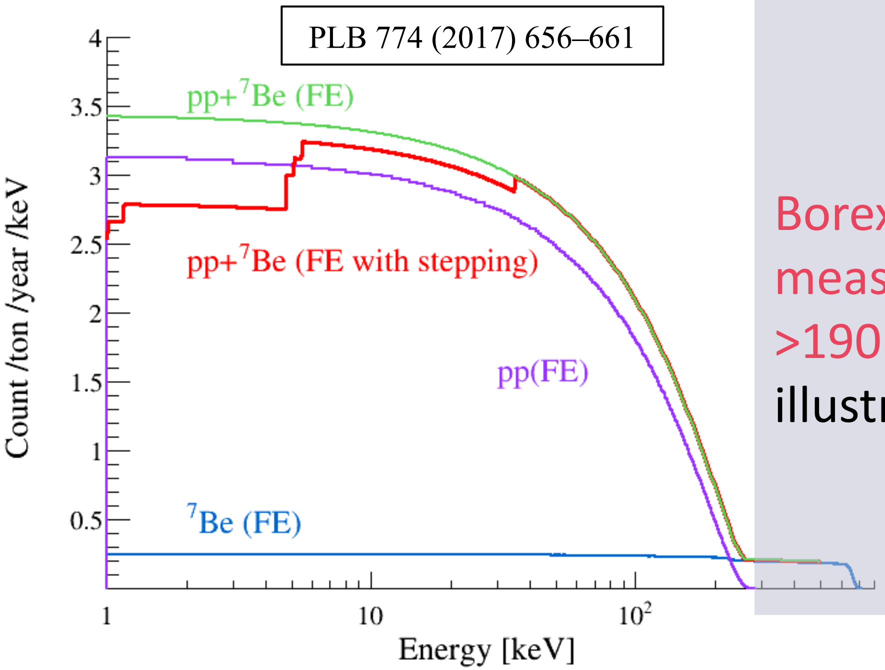
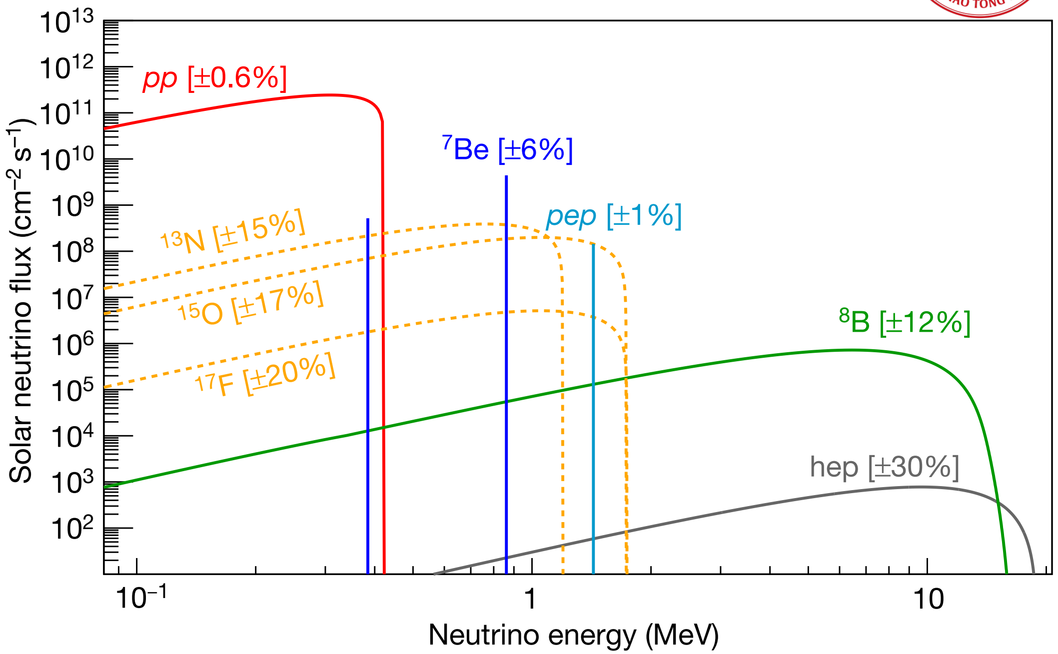
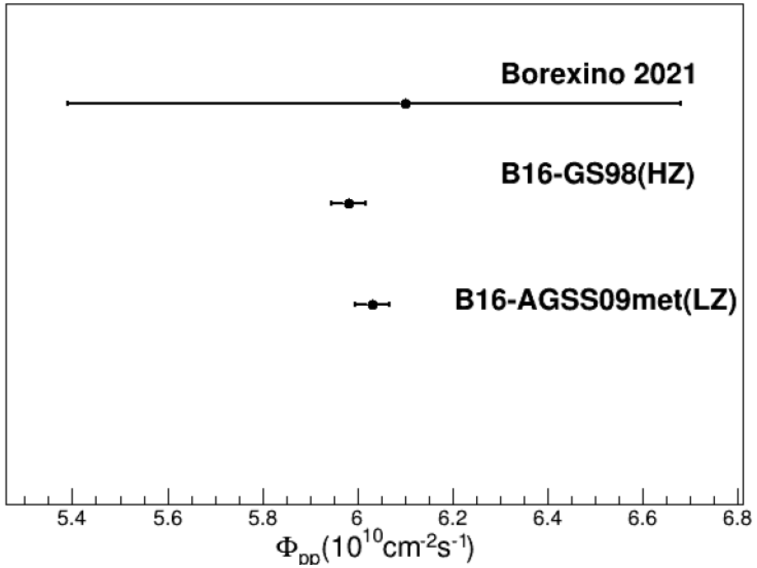


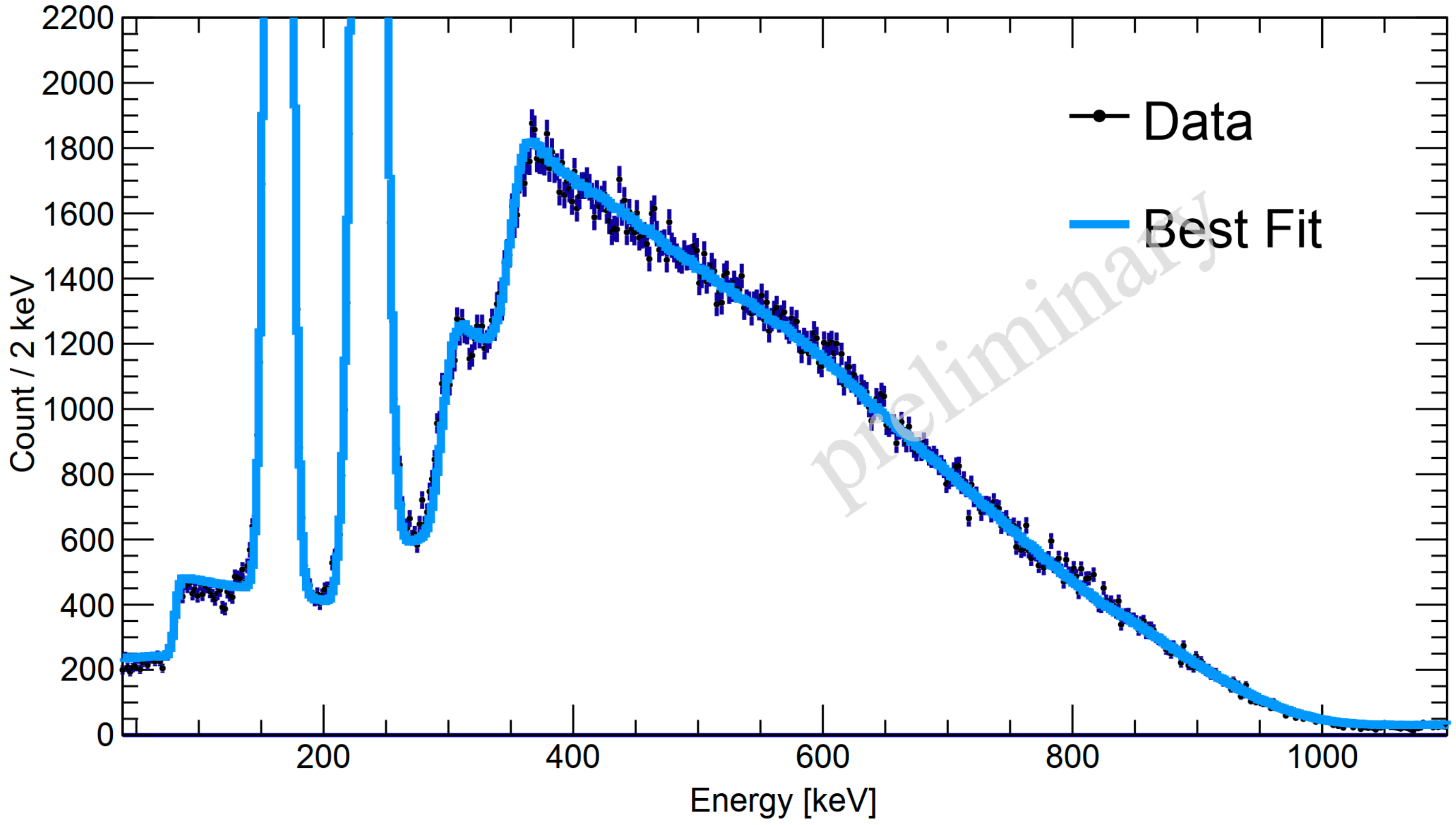
Borexino measurement >190 keV (for illustration only)





Shape of the most important background ^{214}Pb

- Dedicated ^{222}Rn calibration campaign to measure ^{214}Pb spectrum in-situ.
- ^{222}Rn activity ~1 mBq/kg, 100x higher than science data.
- Measured ^{214}Pb spectrum is then used in the fit on science data to estimate ^{214}Pb level.



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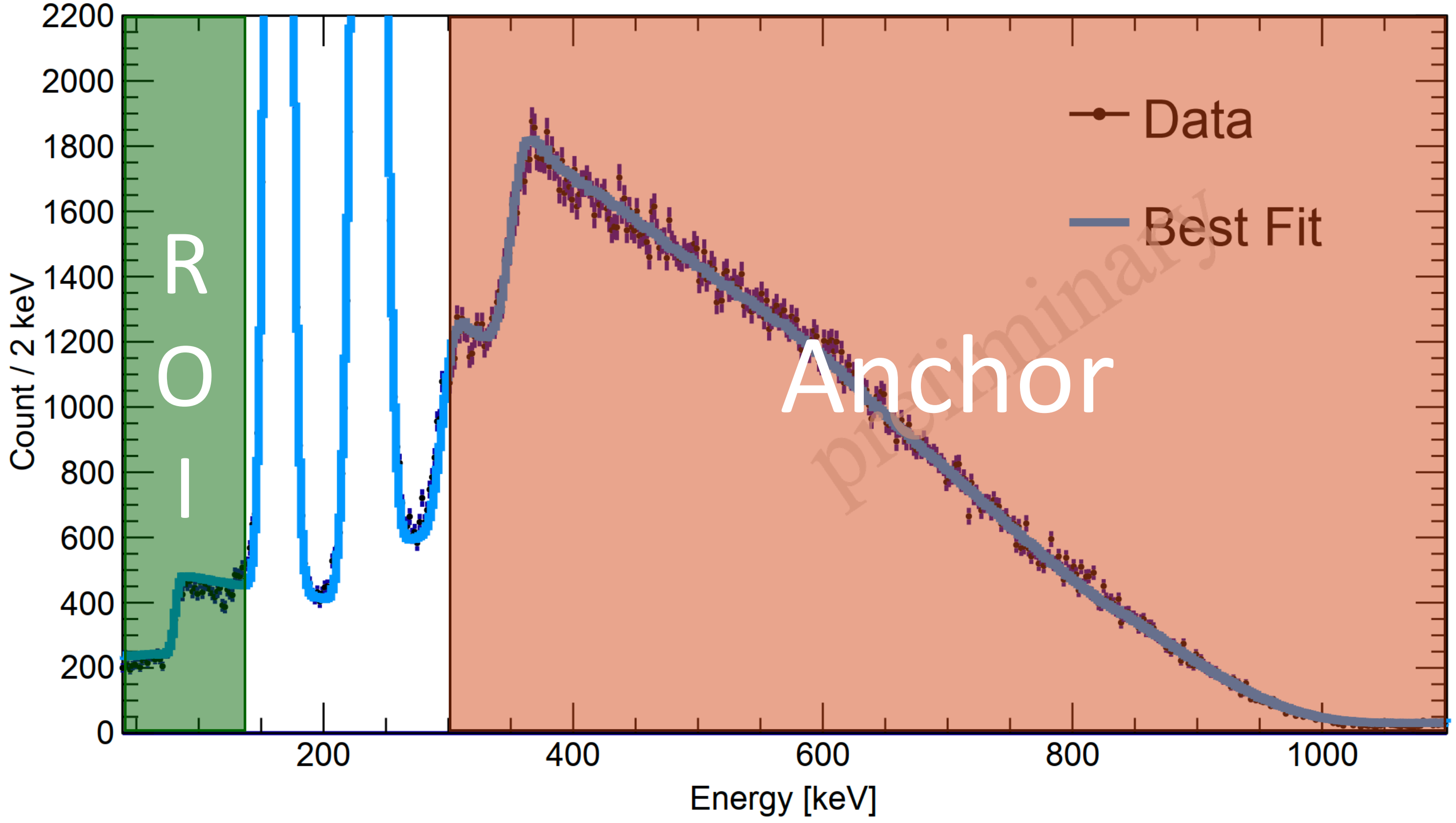
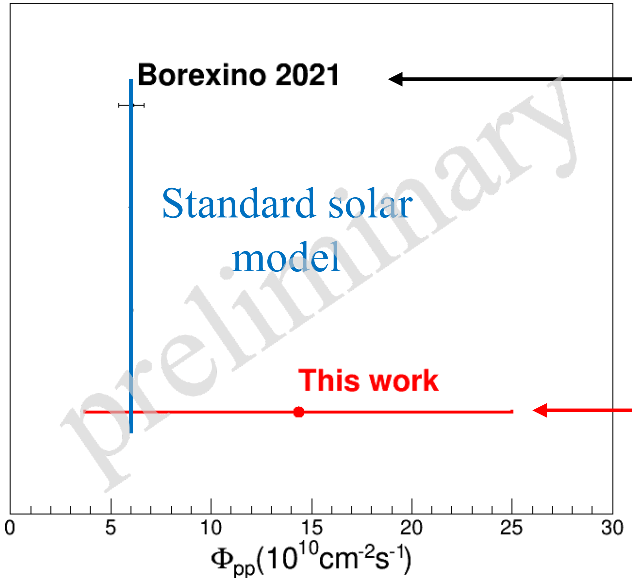


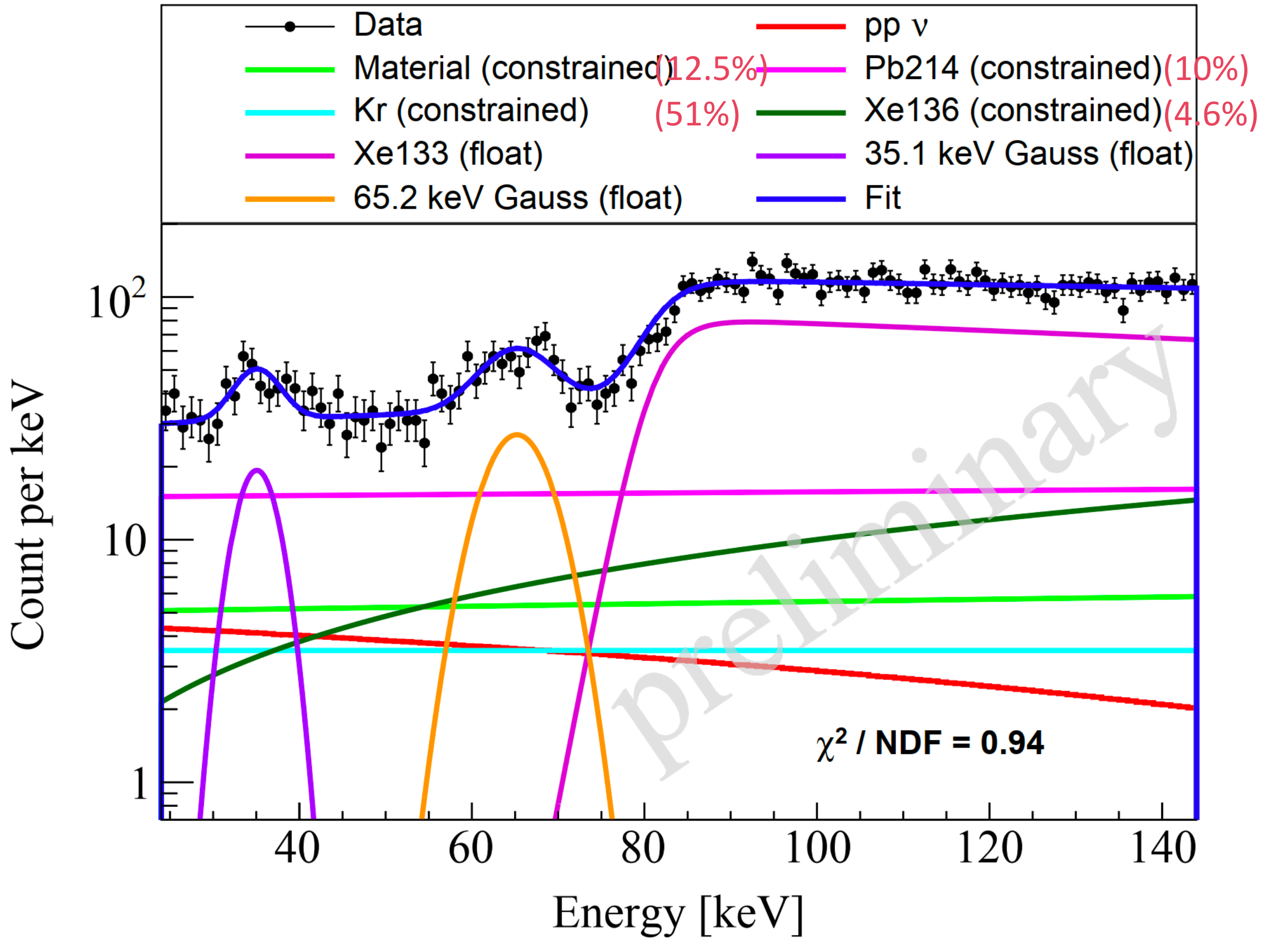
Preliminary solar pp + ^{7}Be neutrinos measurement

- Background constrained from higher energy fits or dedicated studies
- Peaks and ^{133}Xe float
- ~ 1 sigma significant signal with PandaX commission data



The current best measurement with threshold of 190 keV

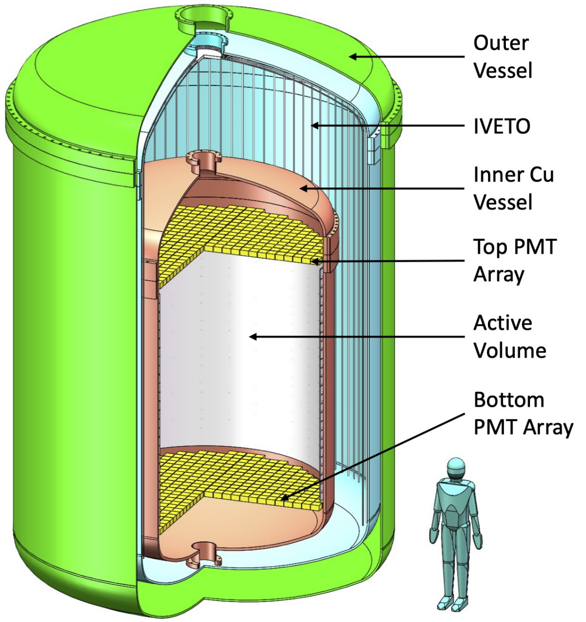
A first measurement below 190 keV

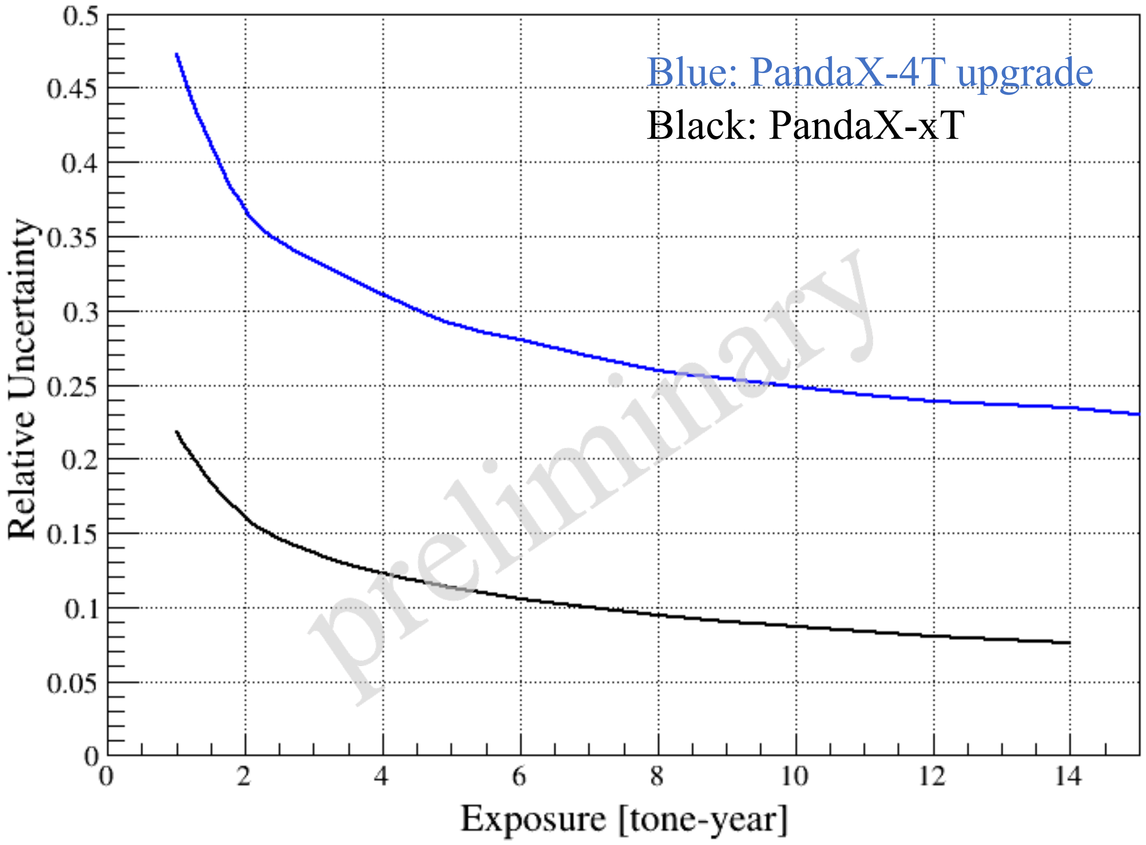


Solar pp + ^{7}Be neutrinos sensitivity in PandaX-xT

- PandaX-4T expected uncertainty: ~28% @ 6 ton·year
  - ^{222}Rn ~3.5 uBq/kg, ^{85}Kr ~0.25 ppt, with uncertainty <5%
- PandaX-xT: expected uncertainty: <10% @ 8 ton·year
  - ^{222}Rn ~0.5 uBq/kg, ^{85}Kr ~0.01 ppt, with uncertainty <2%

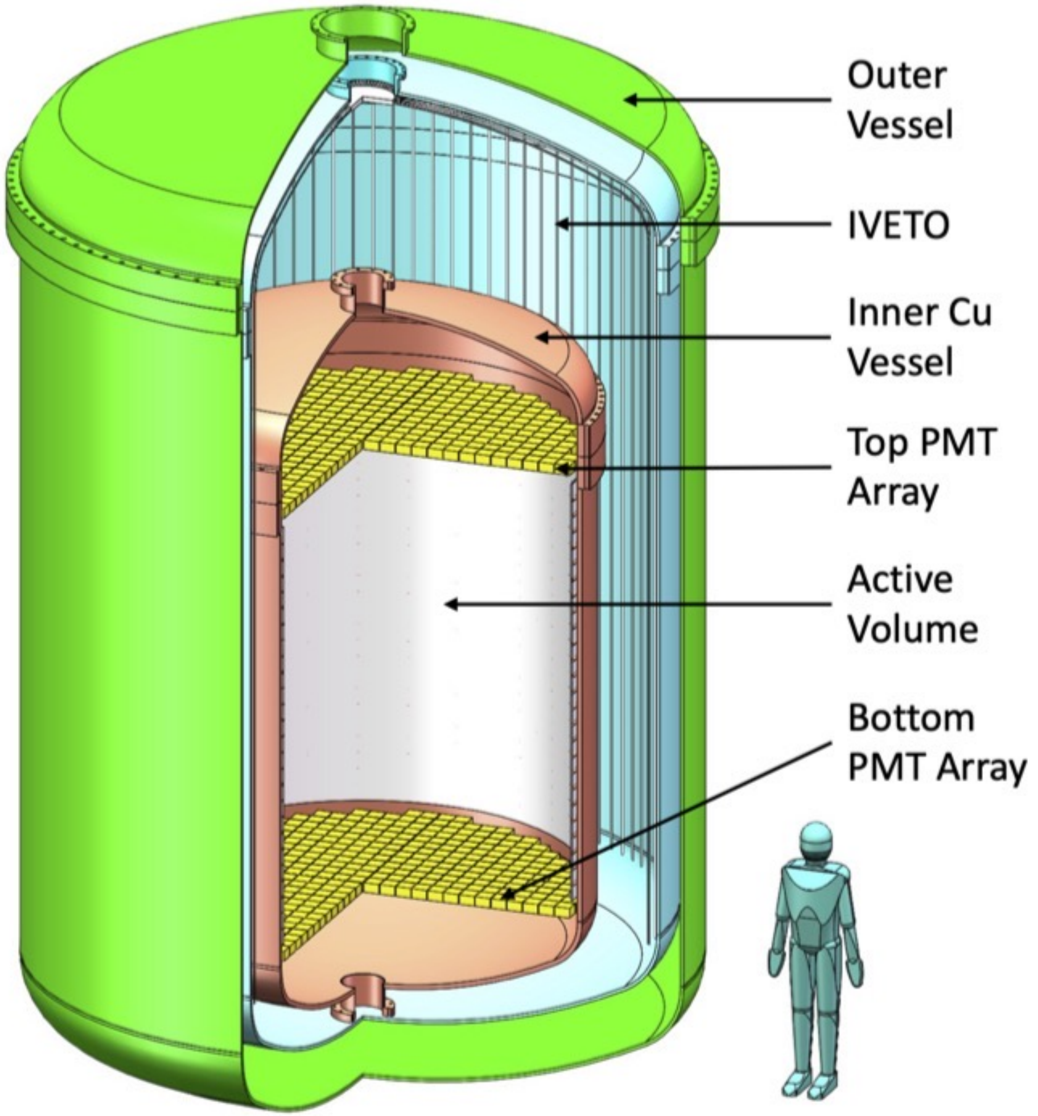
PandaX-xT:
multi-ten ton liquid
xenon project at CJPL-II





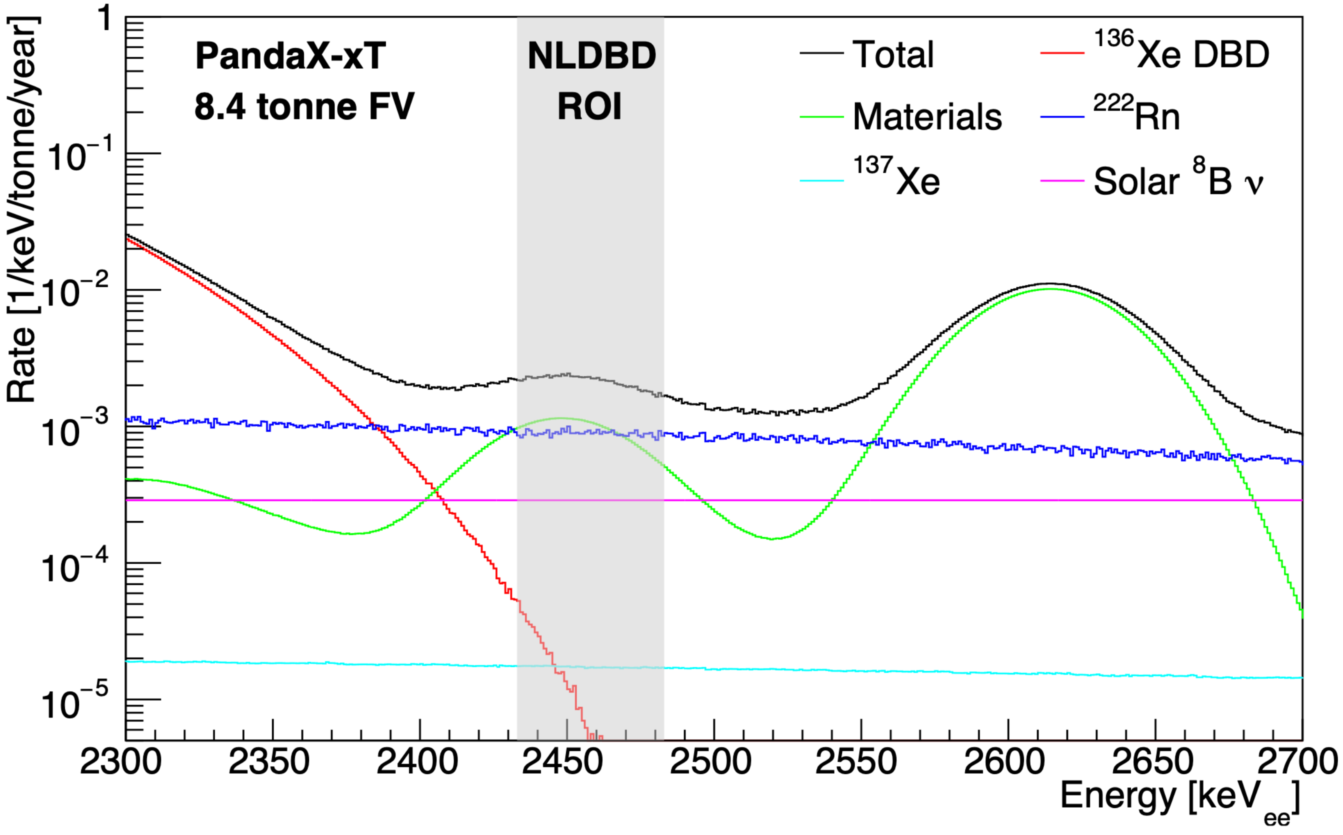
PandaX-xT: Multi-ten-tonne Liquid Xenon Observatory

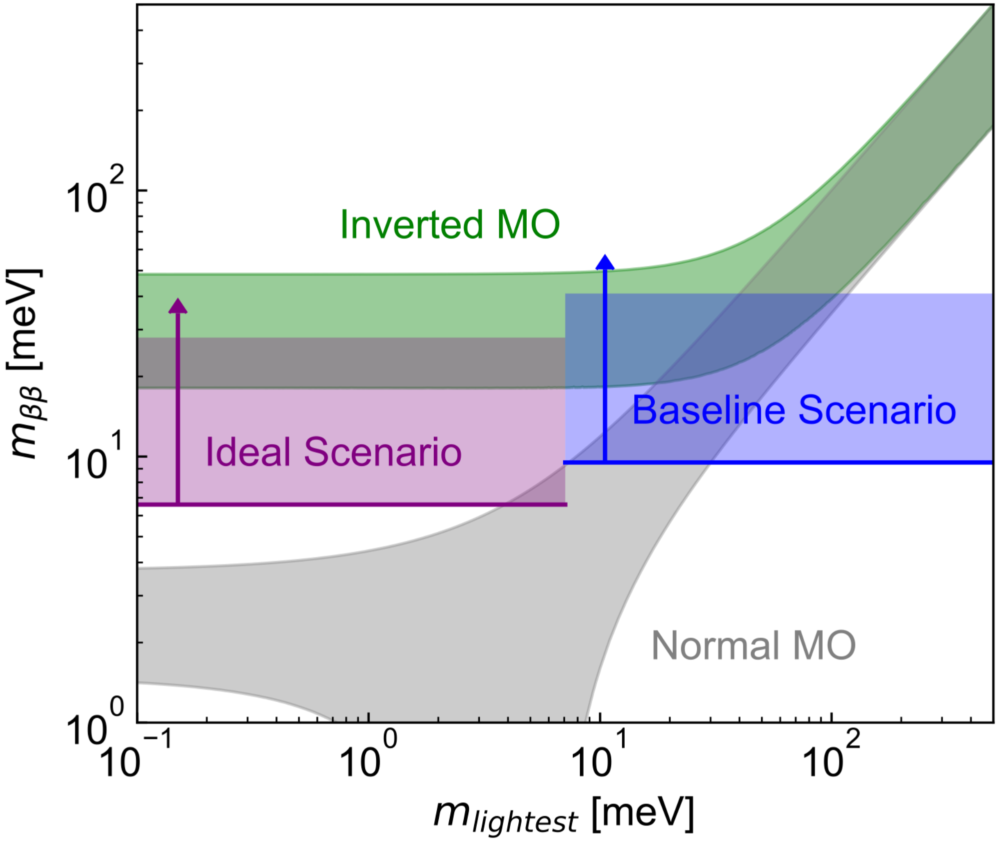
- Active target: 43 ton of Xenon
  - Decisive test to the WIMP paradigm
  - Explore the Dirac/Majorana nature of neutrino
  - Search for astrophysical or terrestrial neutrinos and other ultra-rare interactions
- Improved PMT, veto, vessel radiopurity, etc
- Staged upgrade utilizing isotopic separation on natural xenon.



PandaX-xT for NLDBD

- 4 ton of ^{136}Xe: one of the largest DBD experiments
- Effective self-shielding: Xenon-related background dominates



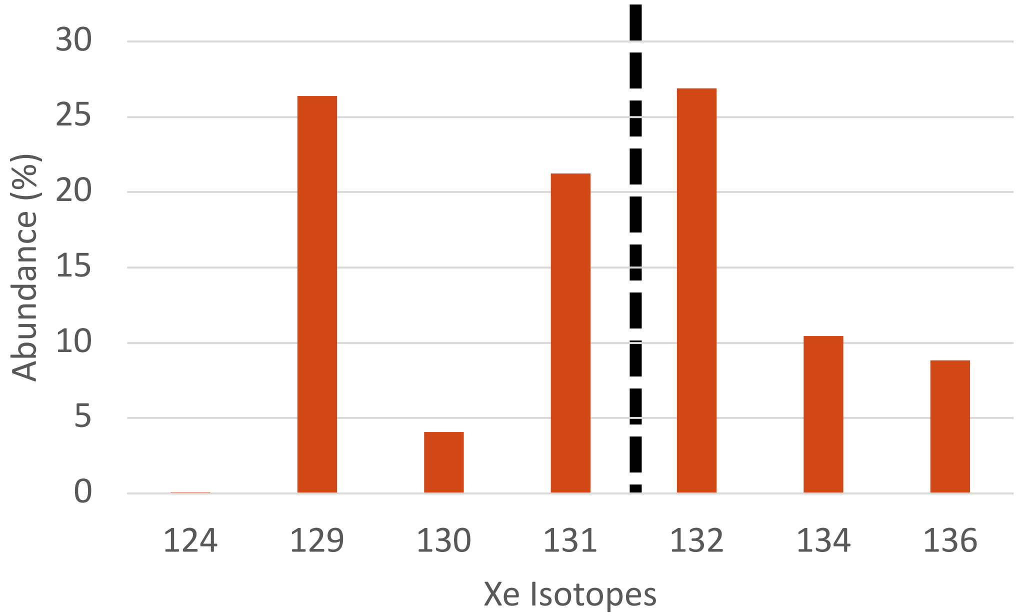


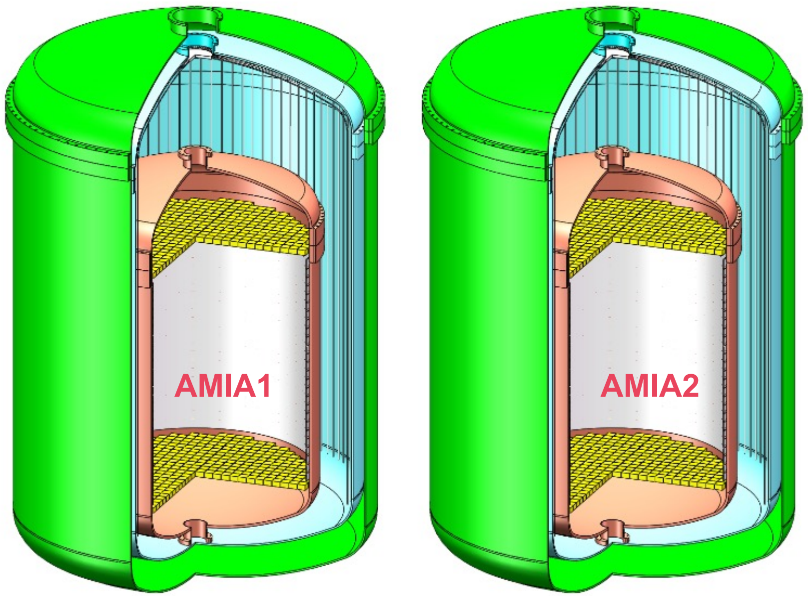
Head-to-head with other DM/DBD experiments

	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	2×10^{25}
LZ	0.3	1%	7	1000 days	1×10^{26}
KamLAND-ZEN	0.002	5%	0.8 (^{136}Xe)	1.5 years	3×10^{26}
nEXO	0.006	1%	5 (^{136}Xe)	10 years	6×10^{27}
DARWIN	0.004	0.8%	40	10 years	2×10^{27}
PandaX-xT	0.002	1%	43	10 years	3×10^{27}

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 NLDBD





Neutrino physics program at PandaX

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- Re-think the LXe TPC as a Total-Absorption 5D Calorimeter
- Fully exploit the entire energy range of LXe TPC
- Fully utilize the mulitple isotopes of natural xenon for rich physics


Thank you very much