Dark Matter Search and Neutrino Physics at the PandaX Experiment

Qiuhong Wang

Fudan University

On behalf of the PandaX Collaboration

Aug 13, 2024, SLAC

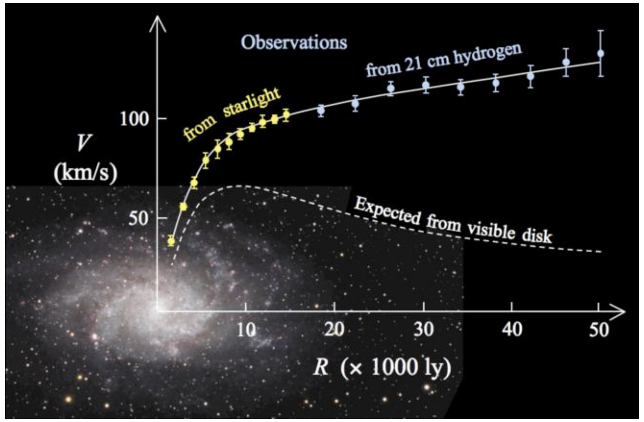
wangqiuhong@fudan.edu.cn

Outline

- Introduction
- Dark matter search in PandaX-II & PandaX-4T
  - Data analysis techniques
  - WIMP search results
- Neutrino physics in Pandax-4T
  - Extend detector response to O(MeV)
  - ^{136}Xe 2νββ/0νββ search
  - ^{124}Xe 2νECEC search
  - Solar neutrino flux measurement
- Summary

Dark matter and its evidence

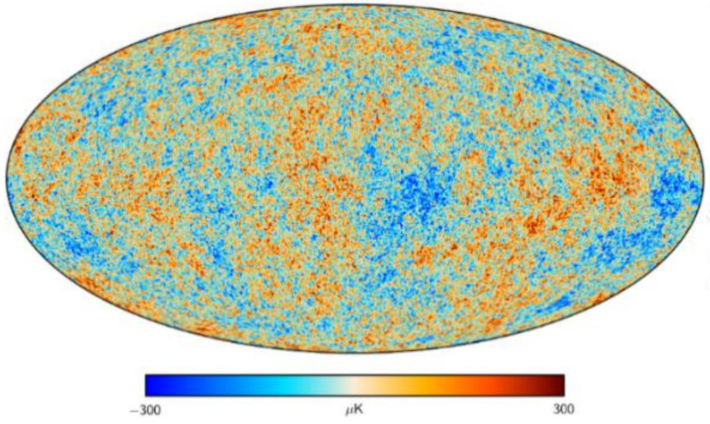
Galactic rotation curve

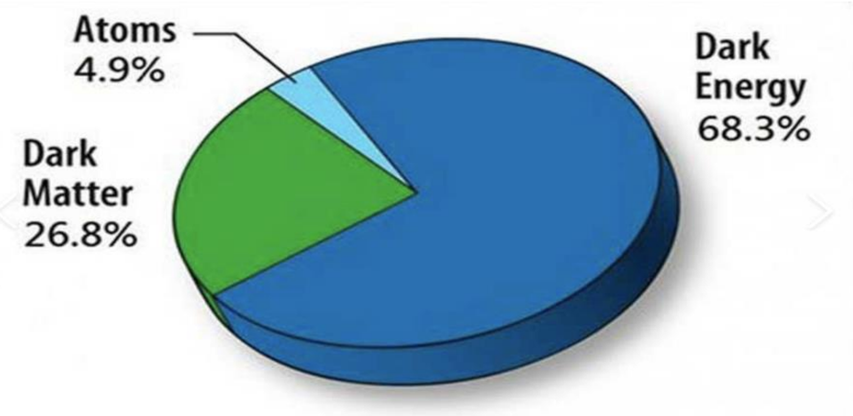


Bullet Cluster

- Gravitational evidences suggest dark matter really exists and is the dominant form of matter in Universe!

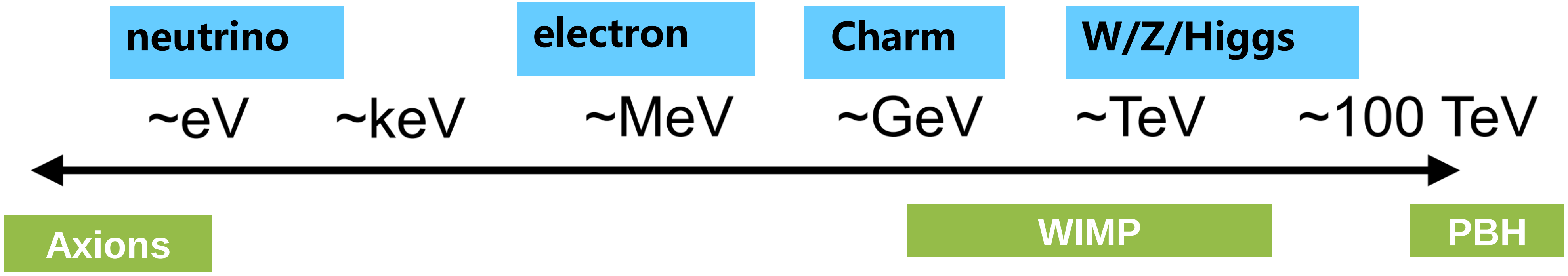
Cosmic Microwave Background





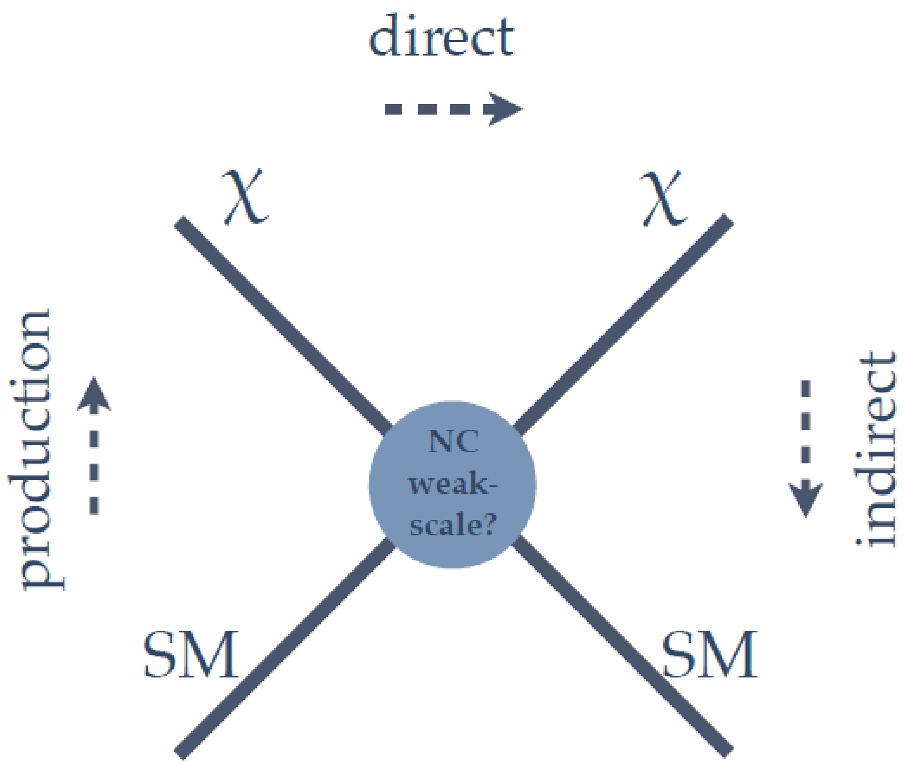
- The nature of dark matter is still a mystery: fundamental particle?

Dark matter candidates

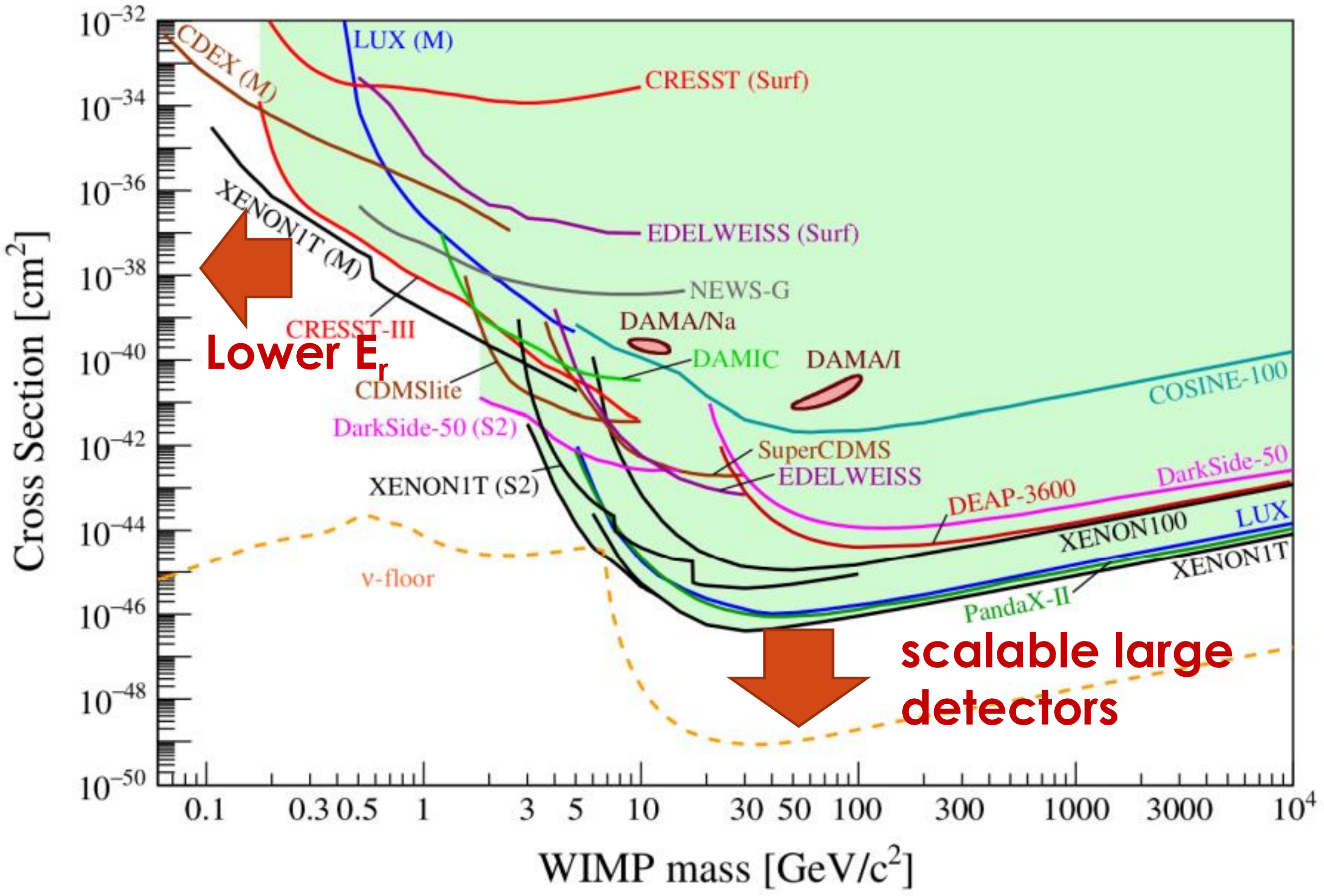


- Weakly Interacting Massive Particle (WIMP)
- mass ~ 100 GeV, “WIMP miracle”
- WIMP is one of the most promising dark matter candidates!

Dark matter detection

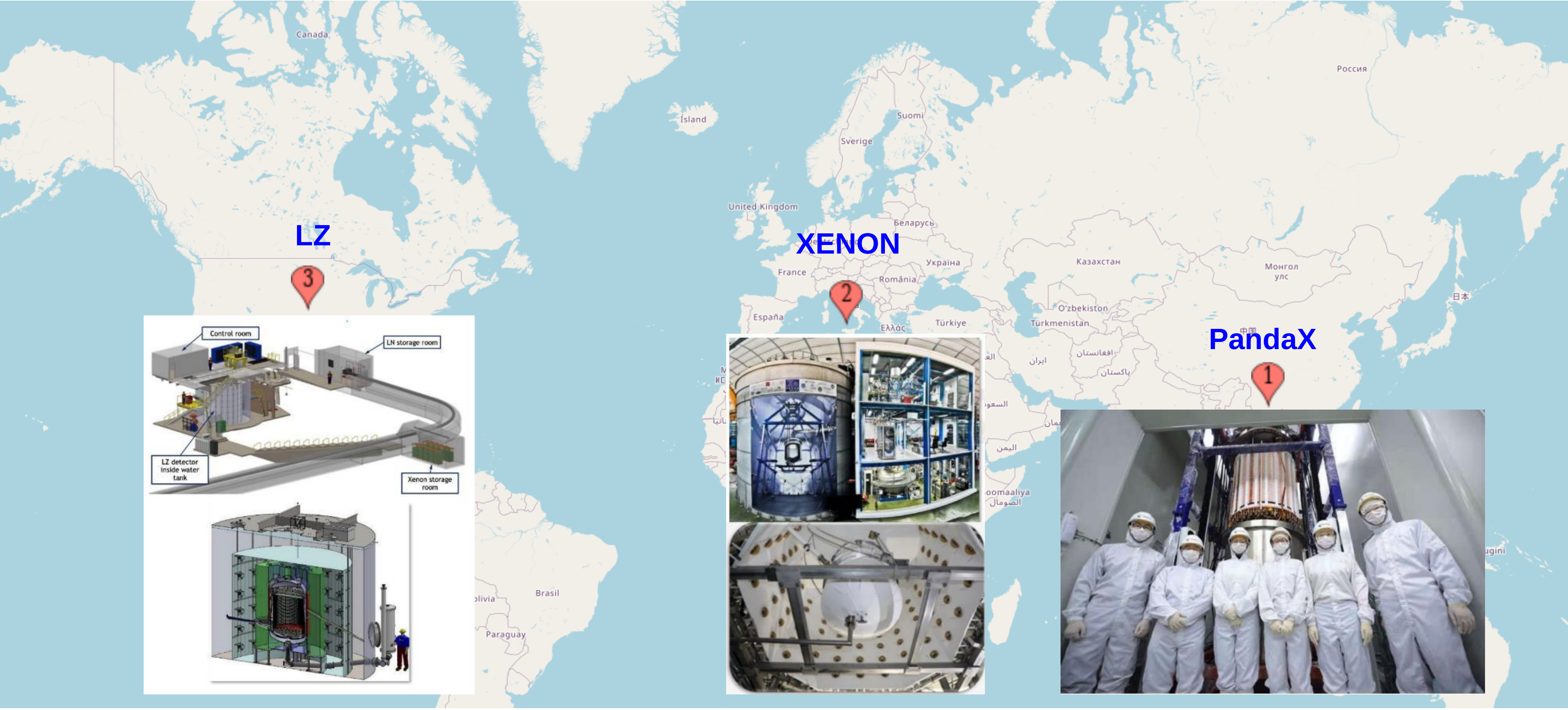


- Collider search
- Direct detection
- Indirect detection



DM: low hanging fruit?

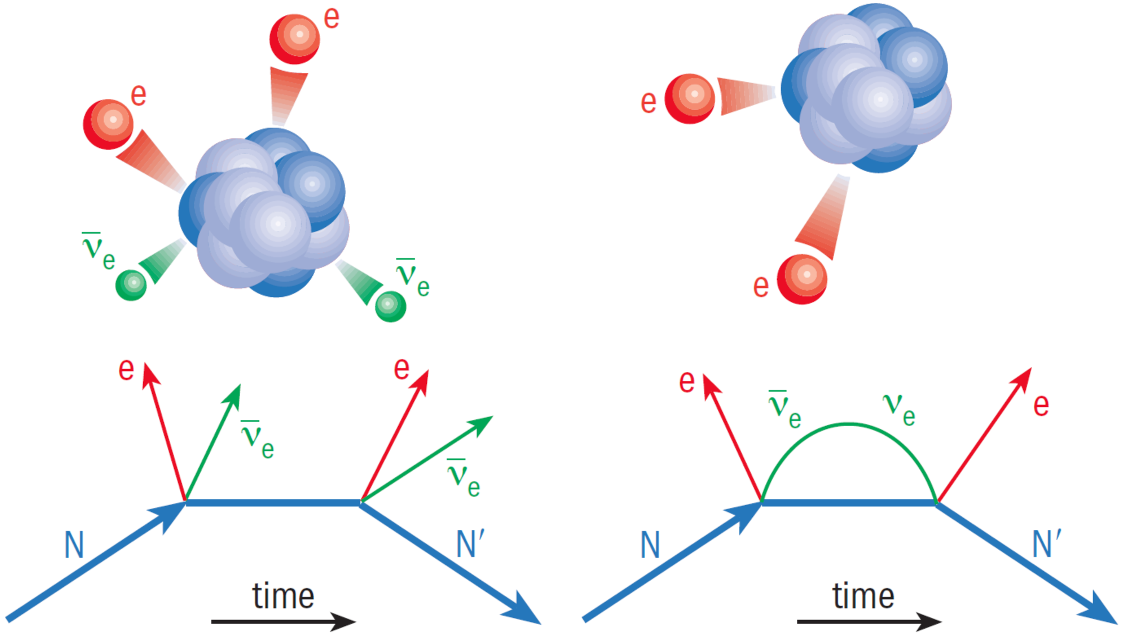
The big three xenon DM experiments



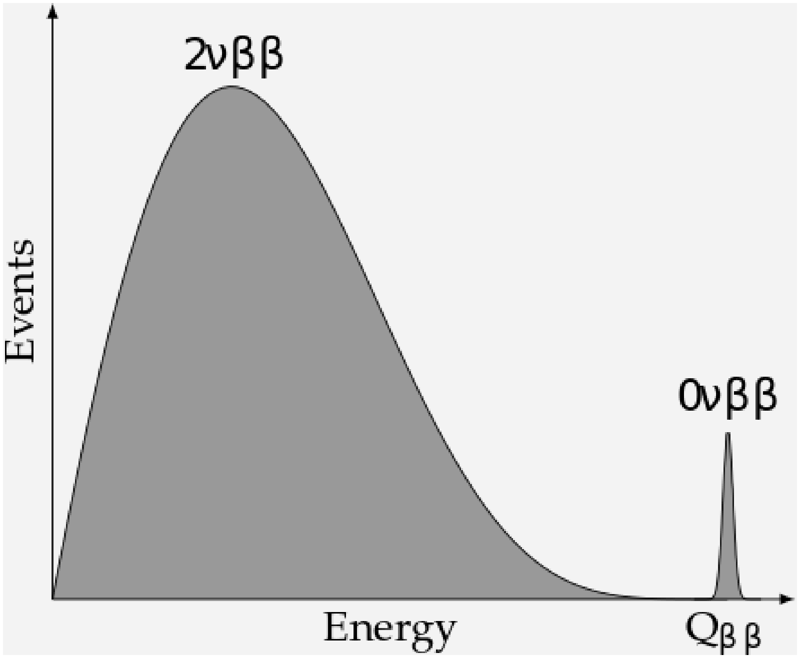
Neutrinos are Dirac or Majorana?

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

Neutrinoless double-β decay



From Physics World



- Majorana neutrino may be an important link in connecting to matter-antimatter asymmetry in our universe.

0νββ probes the nature of neutrinos

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

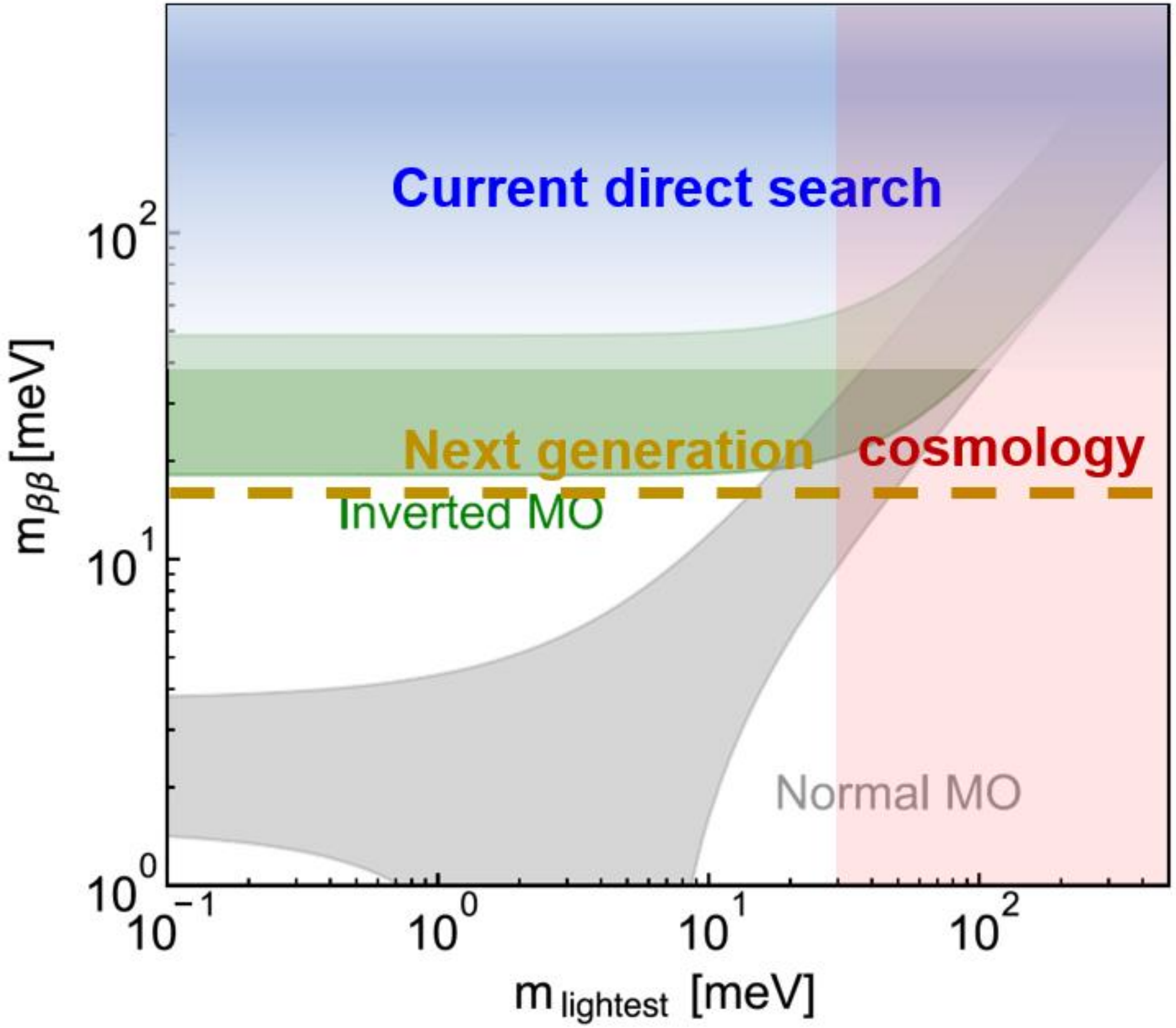
$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\ |M^{0\nu}|^2\ \frac{|\langle m_{\beta\beta}\rangle|^2}{m_e^2}$$

Phase space factor

Nuclear matrix element

Effective Majorana neutrino mass:

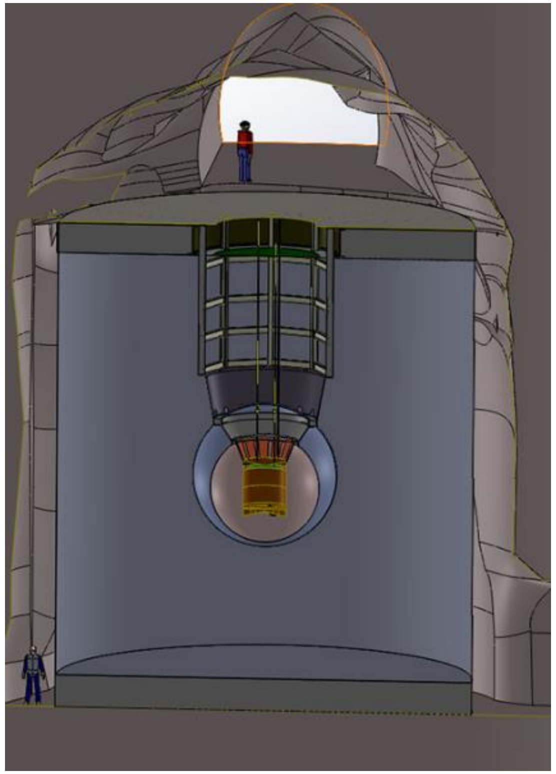
$$|\langle m_{\beta\beta}\rangle| = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$



Leading 0νββ experiments

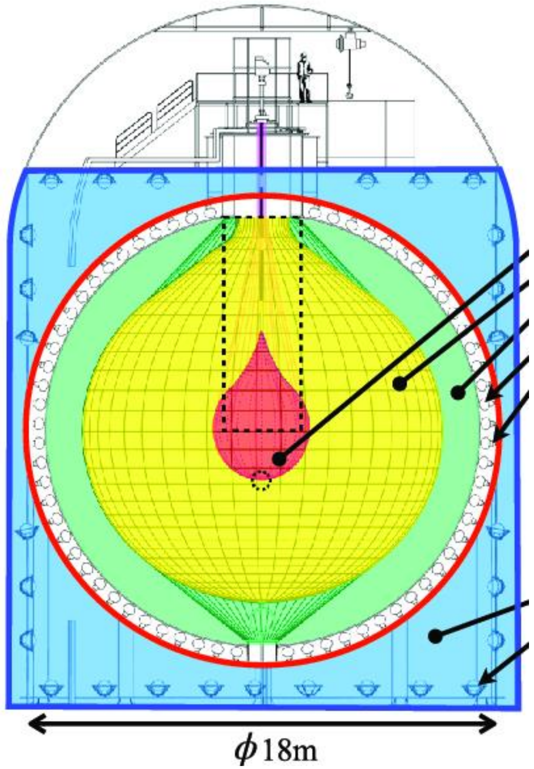
CUORE/CUPID

Bolometer



EXO/nEXO

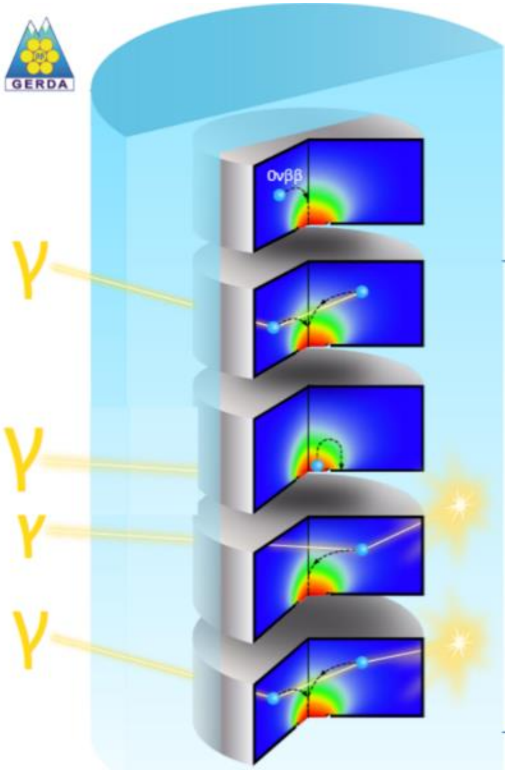
LXe TPC



KamLAND-ZEN

Doped LS

^{136}Xe



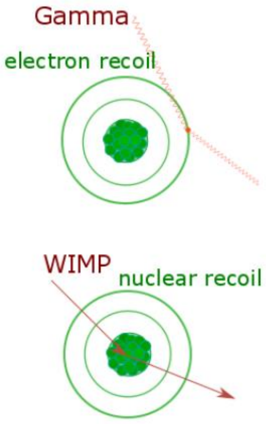
LEGEND family

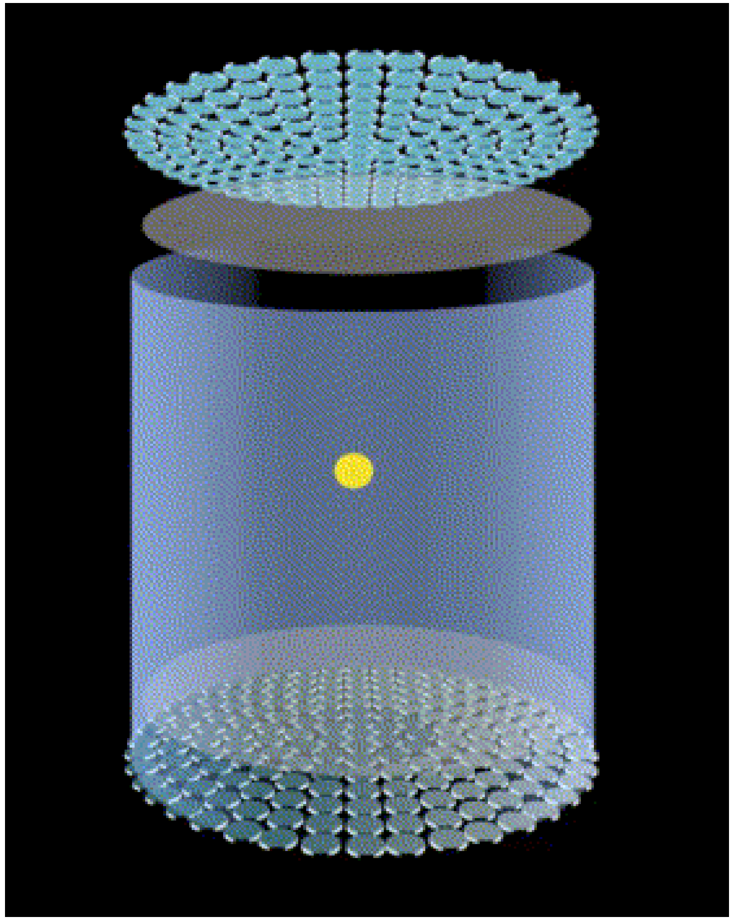
HPGe

Dual-phase xenon time projection chamber (TPC)

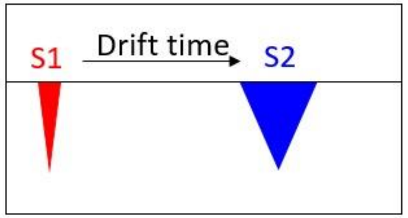
54
Xe
Xenon
131.29

- S1: prompt scintillation signal
- S2: delayed ionization signal

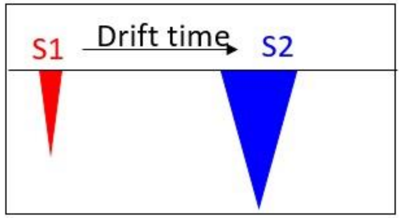




Dark matter: nuclear recoil (NR)

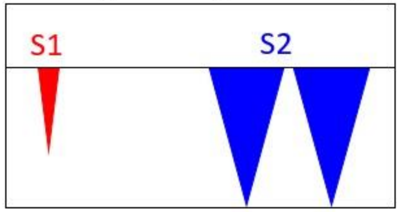


γ background: electron recoil (ER)



$$(S2/S1)_{NR} << (S2/S1)_{ER}$$

Multi-site scattering background (ER or NR)



Dual phase xenon detector capability:

- ER/NR identification
- Single / multi-site identification
- 3D reconstruction and fiducialization
- Calorimeter from sub keV to MeV

PandaX collaboration

- Particle and Astrophysical Xenon Experiment
- Now 15 institutions, ~80 authors

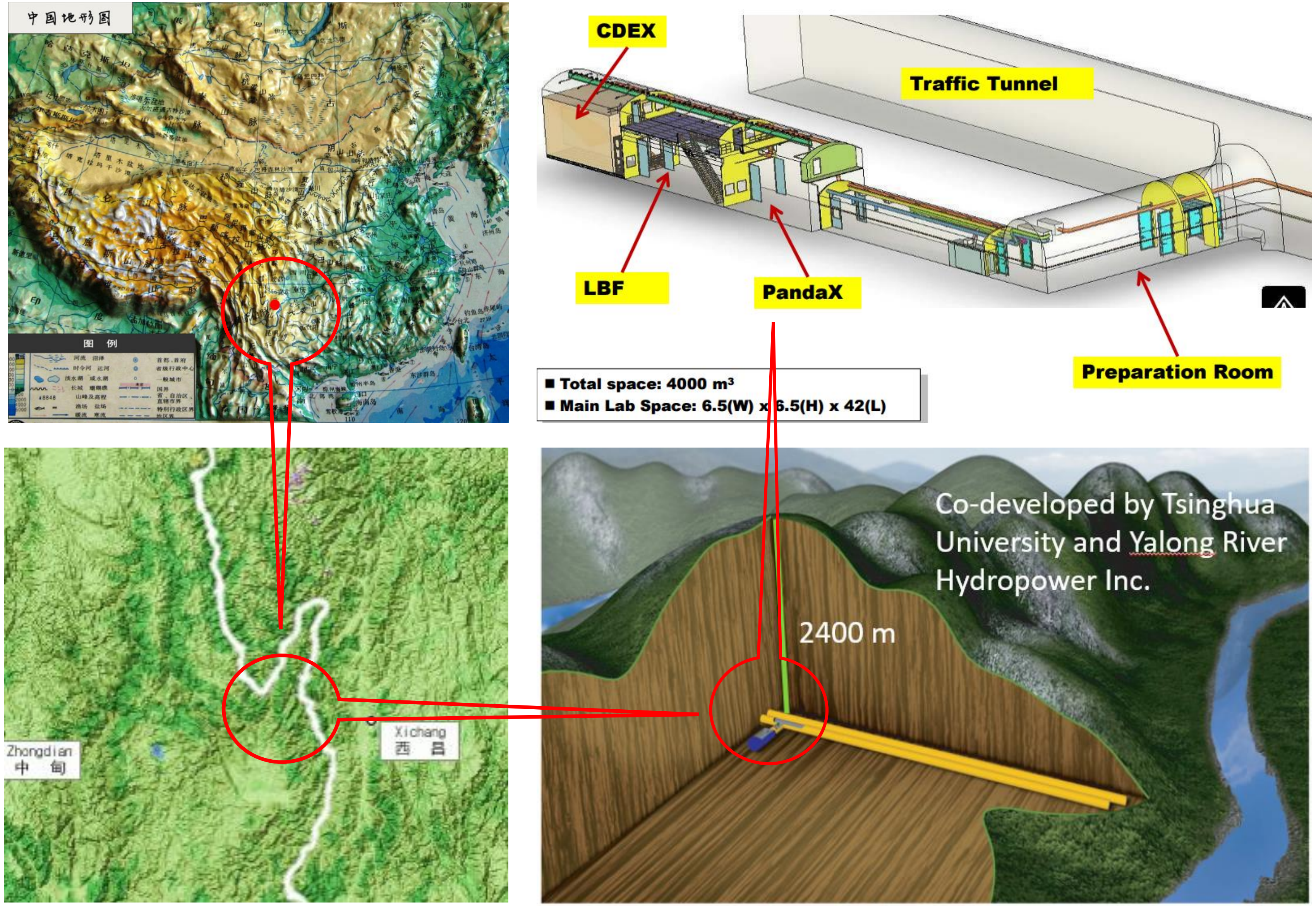
雅砻江水电

SINAP

Universidad Zaragoza

CNNC

China Jinping underground Laboratory (CJPL)



- Deepest underground lab
  - 6800 m.w.e
  - < 0.2 muons/m^2/day
- Much larger space in CJPL-II
- National key science research facility for dark matter searches, neutrino physics, and astroparticle physics, etc.

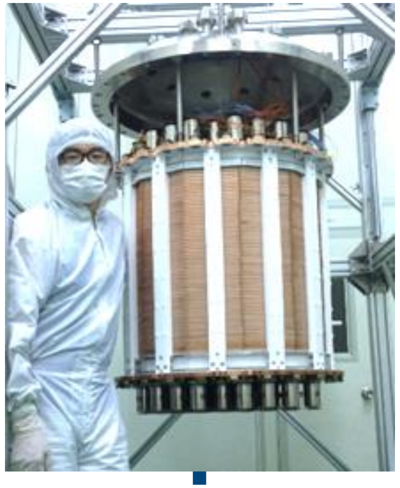
PandaX experiments

- Increasing the detector sensitive target volume
- Lowering radioactive background

PandaX start

PandaX-I
120kg

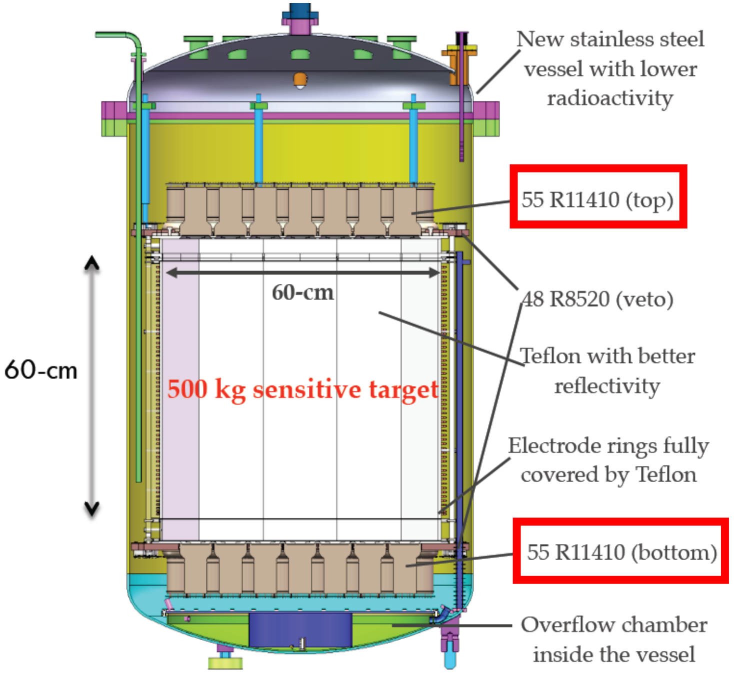
PandaX-II
580kg



PandaX-4T
(3.7 tonne)

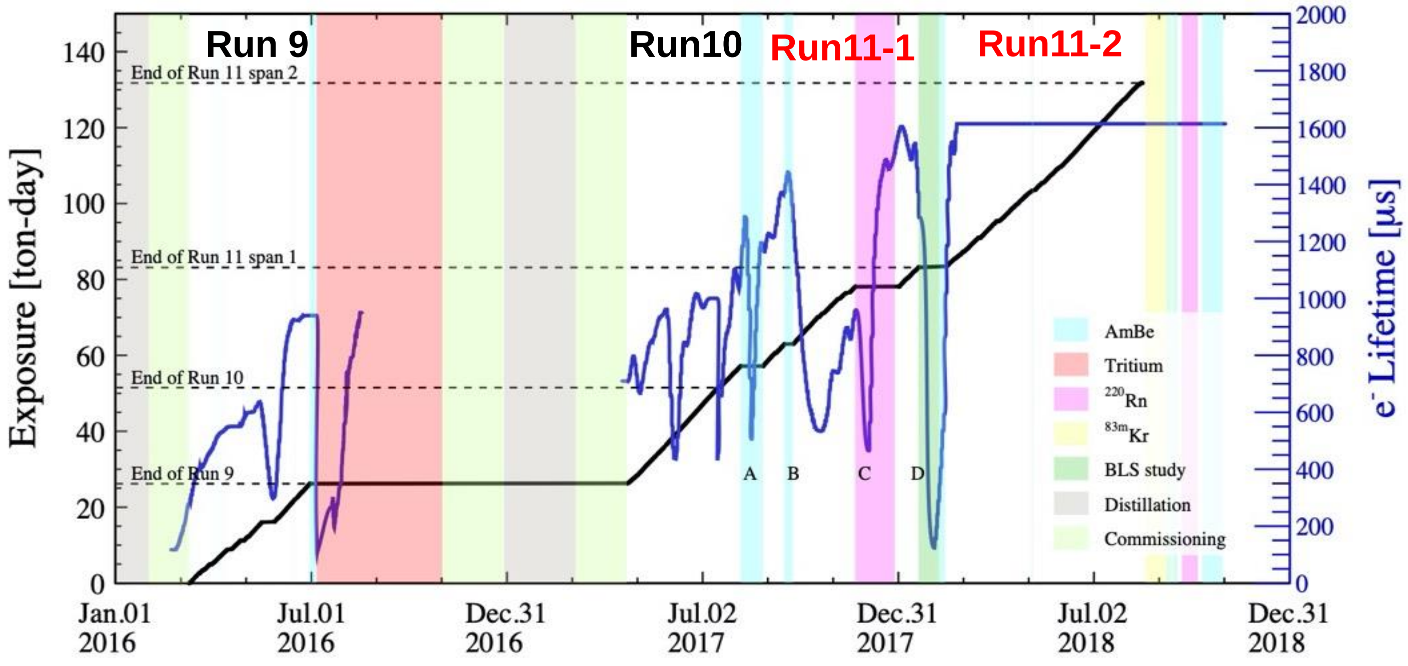
2009 | 2010-2014 | 2015-2019 | 2020-

Ph.D. work: WIMP search with PandaX-II



- PandaX-II: started the commissioning run in Nov. 2015, shut down in Jun. 2019
- Spent ~3 months per year on duty at CJPL
- Gained extensive experience in experimental particle physics and astrophysics, including detector simulation, experimental setup, commissioning and debugging, laboratory management, operation and maintenance on infrastructures and various subsystems

PandaX-II data sets

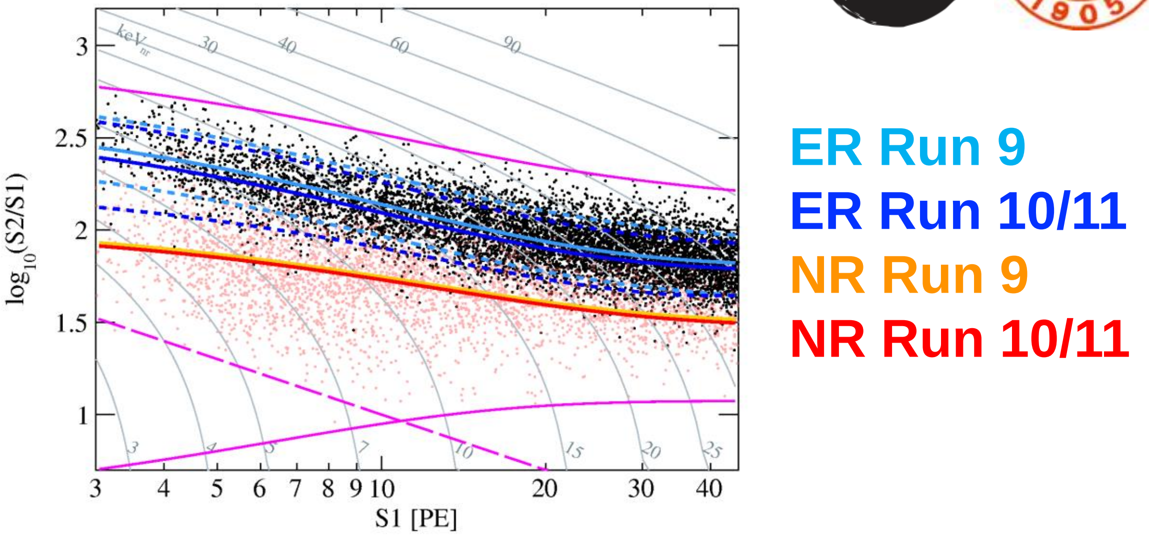


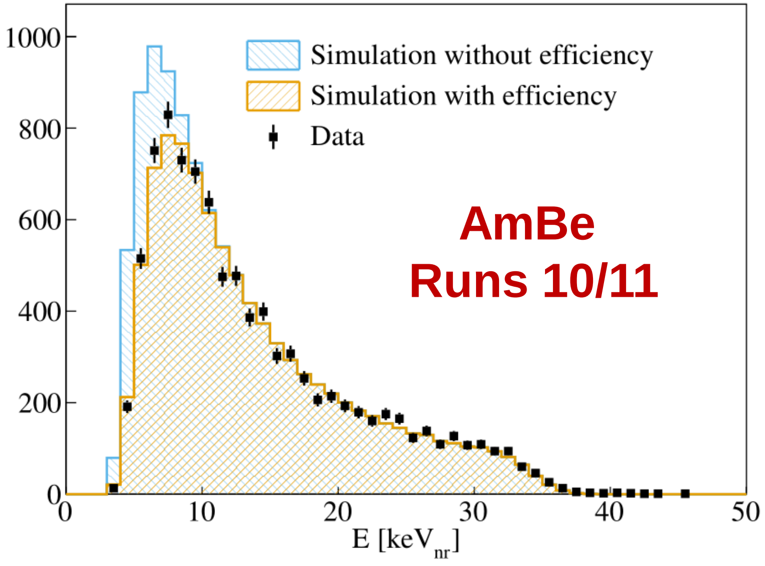
- 2019.06 "End-of-Run" completed
- Total exposure: 131.7 ton-day
  - Run 9: 79.6 days
  - Run 10: 77.1 days
  - **Run 11, span 1: 96.4 days**
  - **Run 11, span 2: 147.9 days**

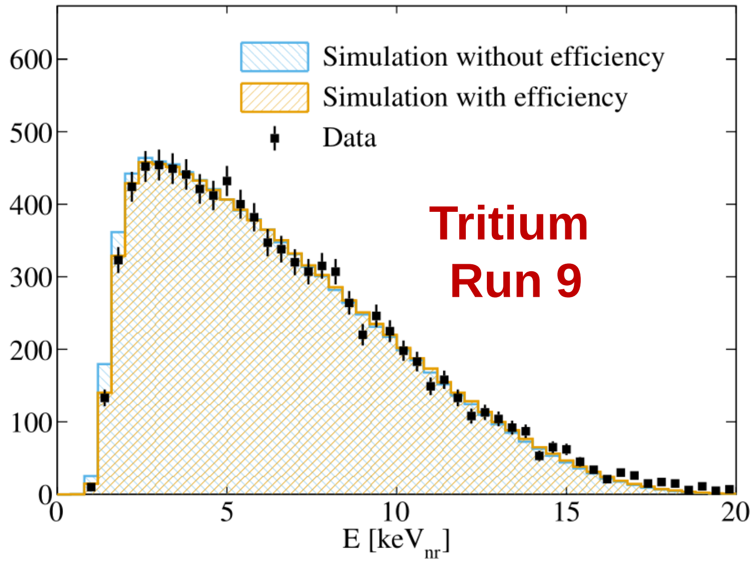
- WIMP search with commissioning, 1st, 2nd physics runs, and full exposure of PandaX-II
- Refined algorithms: (1) detector response model, (2) improved background evaluation

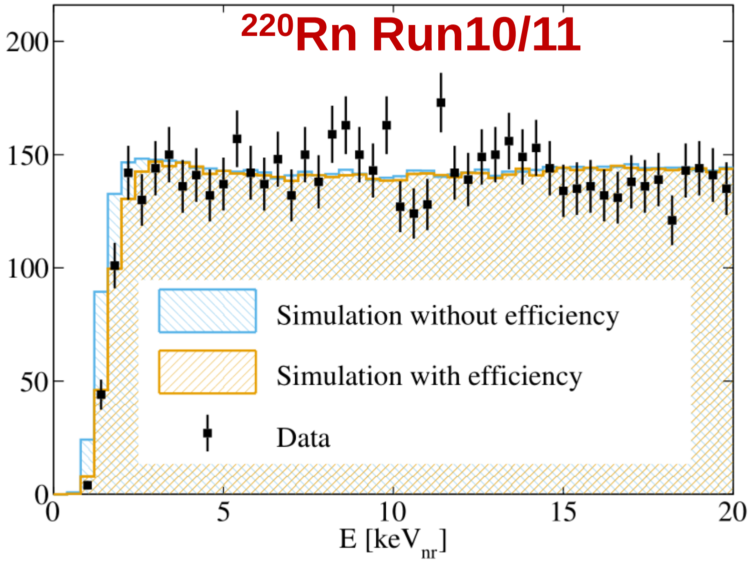
Response Model

- Calibration data
  - ER events: tritium and ^{220}Rn
  - NR events: AmBe
- NEST 2.0 based response model
  - with data quality cut efficiency









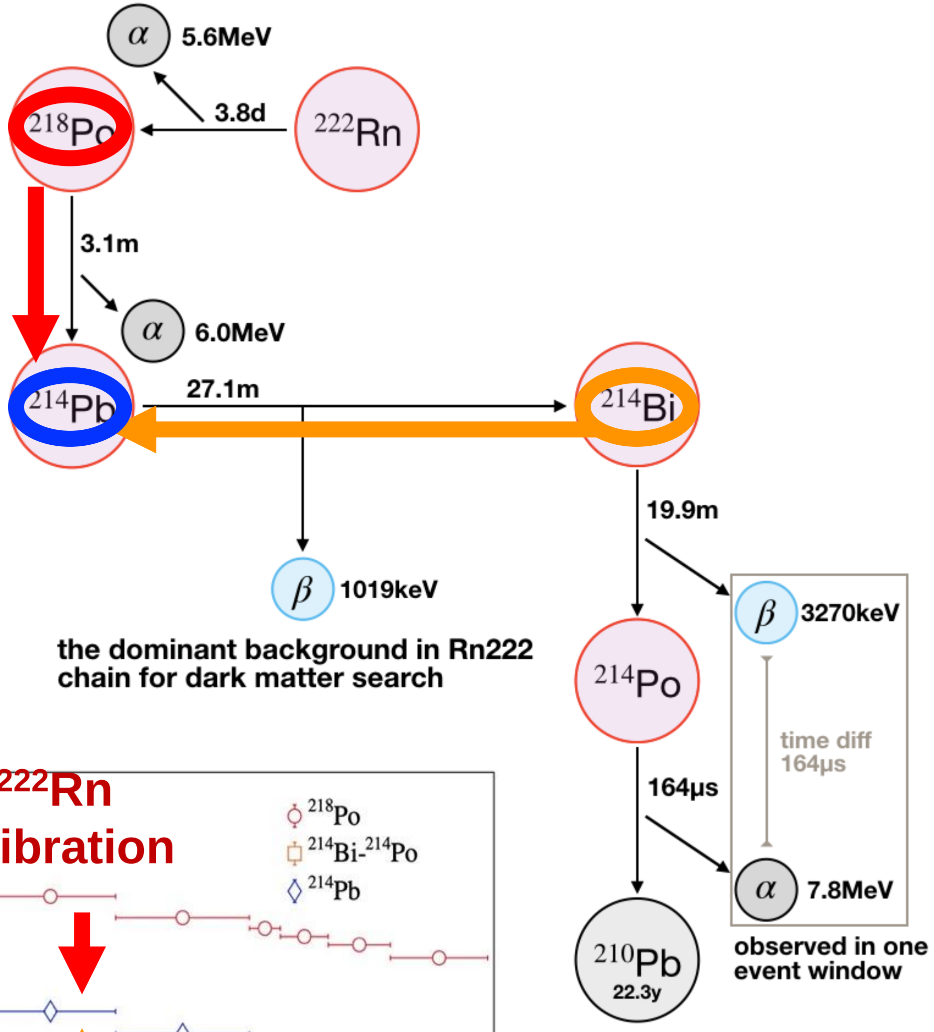
Background estimation and unblinding data

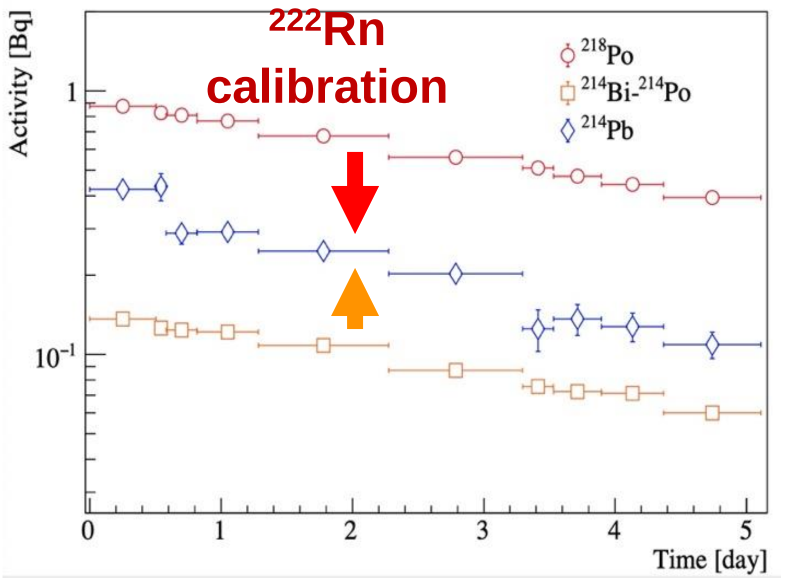
Source	Evaluation
^{127}Xe	35.5 day lifetime, decay away in Run 11
^{3}H	Introduced after Run 9, fitted from data, see later
^{214}Pb	**Depletion effect from measurement**
^{85}Kr	Not a constant due to air leakage in Run 11
neutrons	**Data-driven estimation**
surface events	Data-driven extrapolation
accidental events	Newly trained BDT discriminator

- Refined algorithms
  - New detector response model
  - **Improved background evaluation**
- Blind analysis for Run 11
- Total 1220 events, 38 below NR median
  - Consistent with background expectation (with best fit)
  - Best fit: 1217 ± 60 evts
  - Below NR median: 40.3 ± 3.1 evts

^{214}Pb background

- Major ER contribution from ^{214}Pb
  - Charged Rn progenies attracted to the cathode with negative HV
  - Less contribution in fiducial volume: "depletion effect"
- New method to evaluate ER event rate from ^{214}Pb
  - The depletion ratio measured from ^{222}Rn calibration (end-of-run)
  - Interpolation from ^{218}Po and ^{214}Bi
- PandaX-II ^{214}Pb level: 10μBq/kg





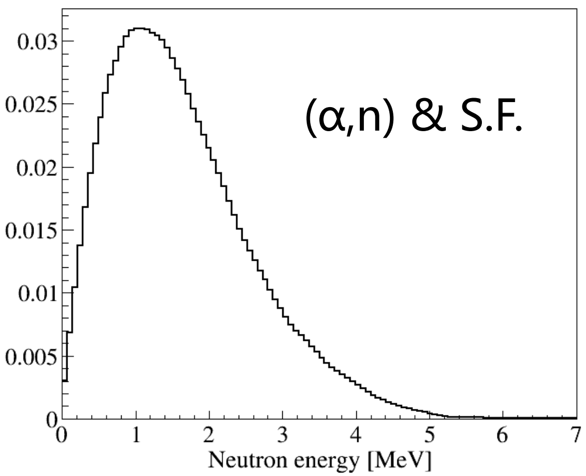
Traditional calculation for neutron background

01 Material Radioactivity ($^{238}U/^{235}U/^{232}Th$)

knowledge of the radioactivities of detector materials

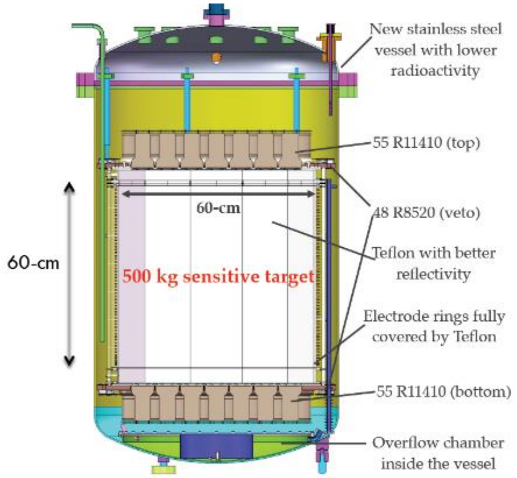
02 Neutron Generator (SOURCES4A)

a model convert material radioactivity to the number of neutrons and their energy spectrum



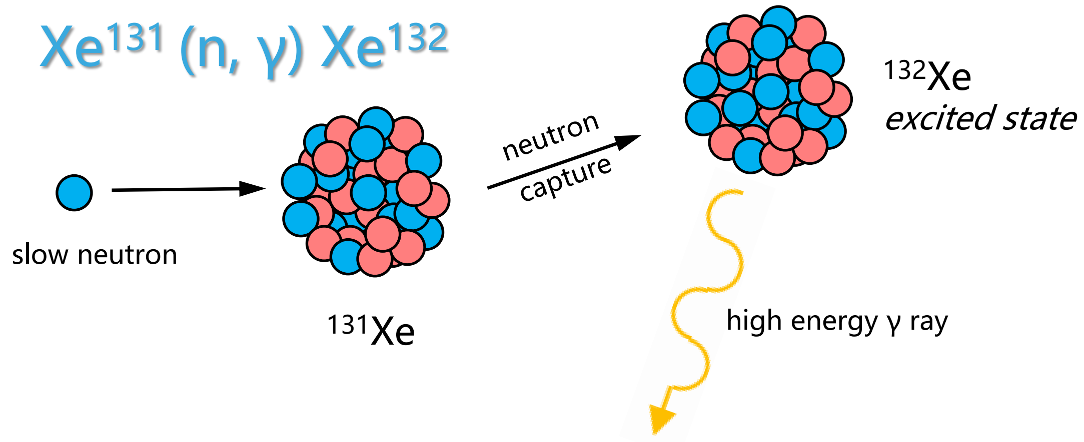
03 Detector Simulation (Geant4)

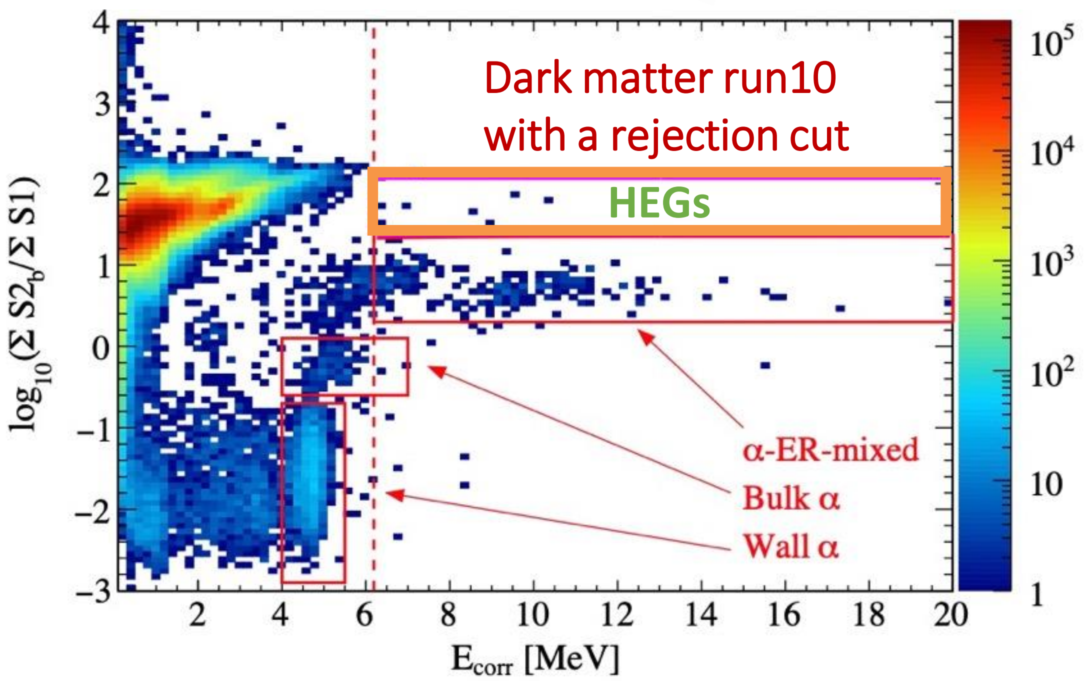
describe detailed neutron interactions in the xenon target and calculate the final DM-like background



- Measurement of material radioactivity has large uncertainty
- Fully rely on the Monte Carlo simulation

Improved estimation on neutron background

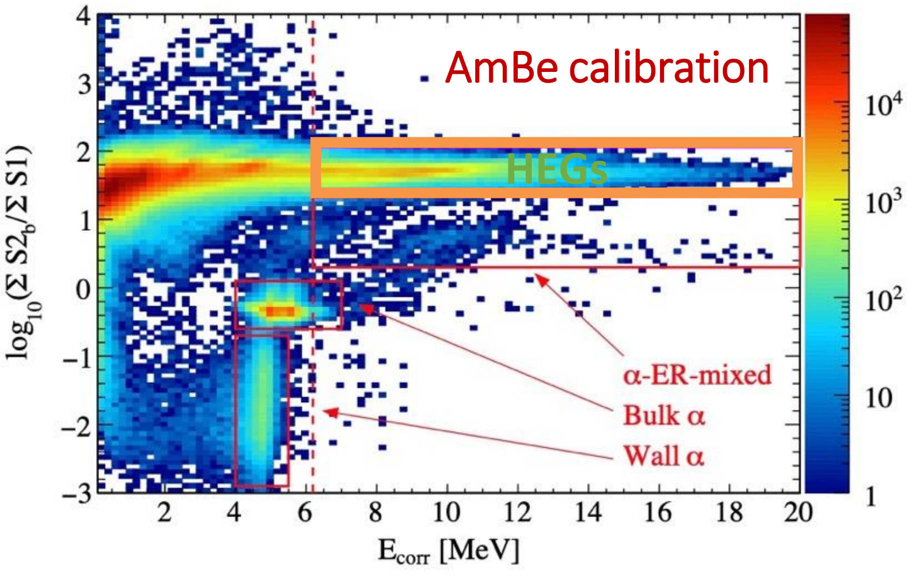


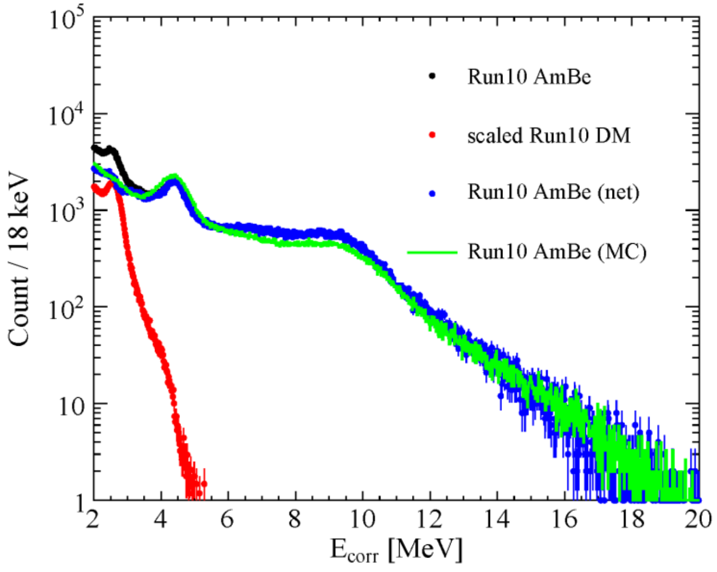


SCIENCE CHINA Physics, Mechanics & Astronomy(2019)

- Constrain low energy neutron background via neutron-induced high energy gamma (HEG) signals
- Scale factor (neutron bkg / HEGs ≈ 1 : 20) predicted by MC, benchmarked by neutron source calibration (see next page)
- More reliable estimation of neutron background with a well-controlled uncertainty of 30%-50%

Benchmarked by neutron calibration





- Compare data and MC with AmBe calibration
  - ER spectra at high energy
  - SSNR/HEG ratio

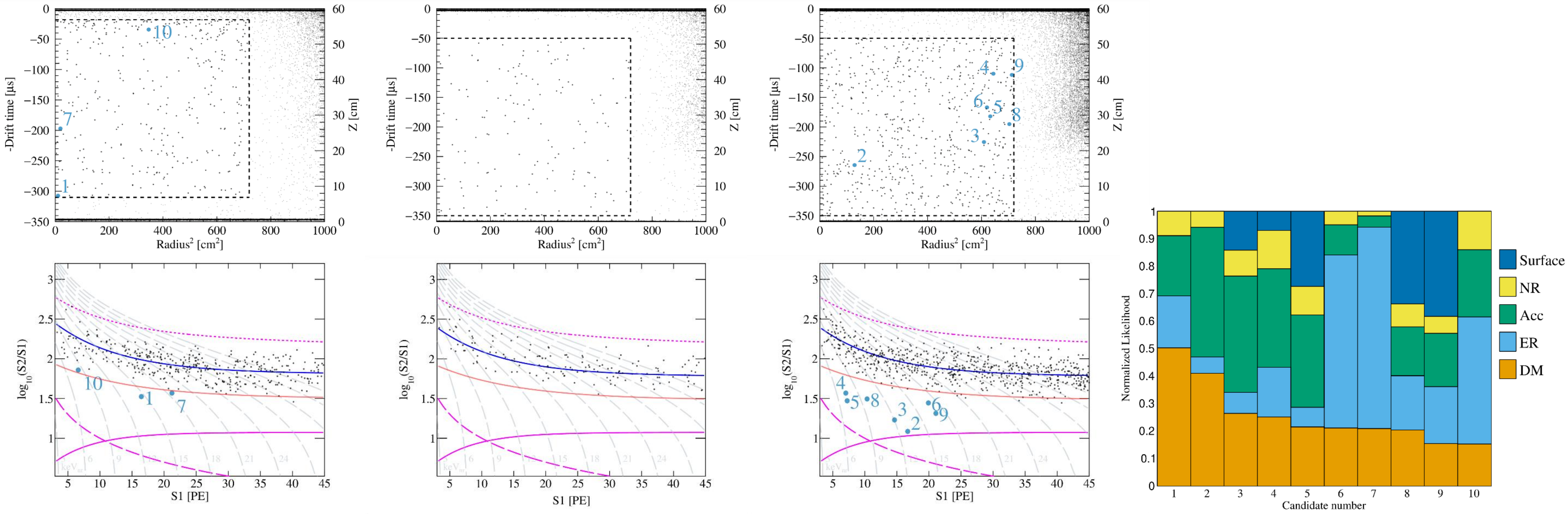
AmBe Run	Data			MC
	# SSNR	# HEG	Ratio	Ratio
Run 9	3415	49159	1/14.4	1/14.7
Run 10	10390	151783	1/14.6	1/15.2

- Difference between data and MC indicates systematic uncertainty.

Event distributions

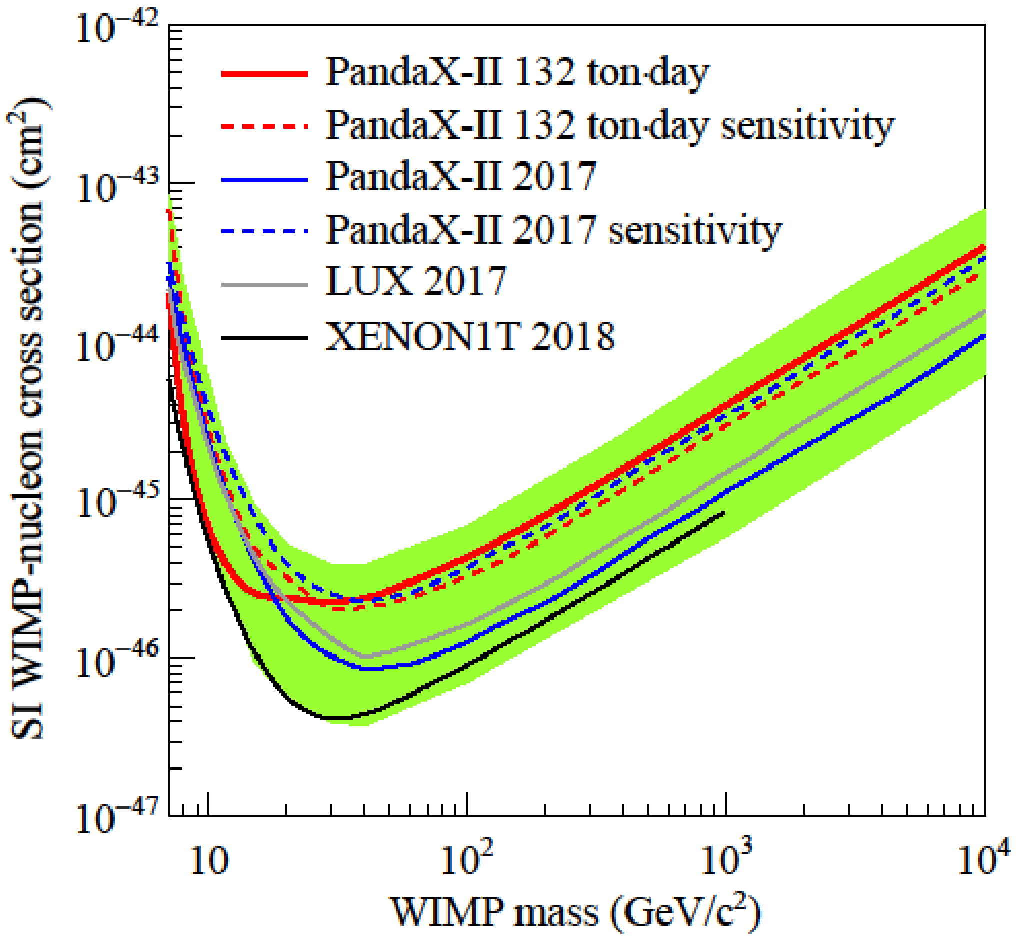
- Distribution of events with high WIMP hypothesis likelihood (400 GeV)
  - 3 events in Run 9 and 7 events in Run 11

Run 9: 26.2 ton-day **Run 10: 25.3 ton-day** **Run 11: 80.3 ton-day**

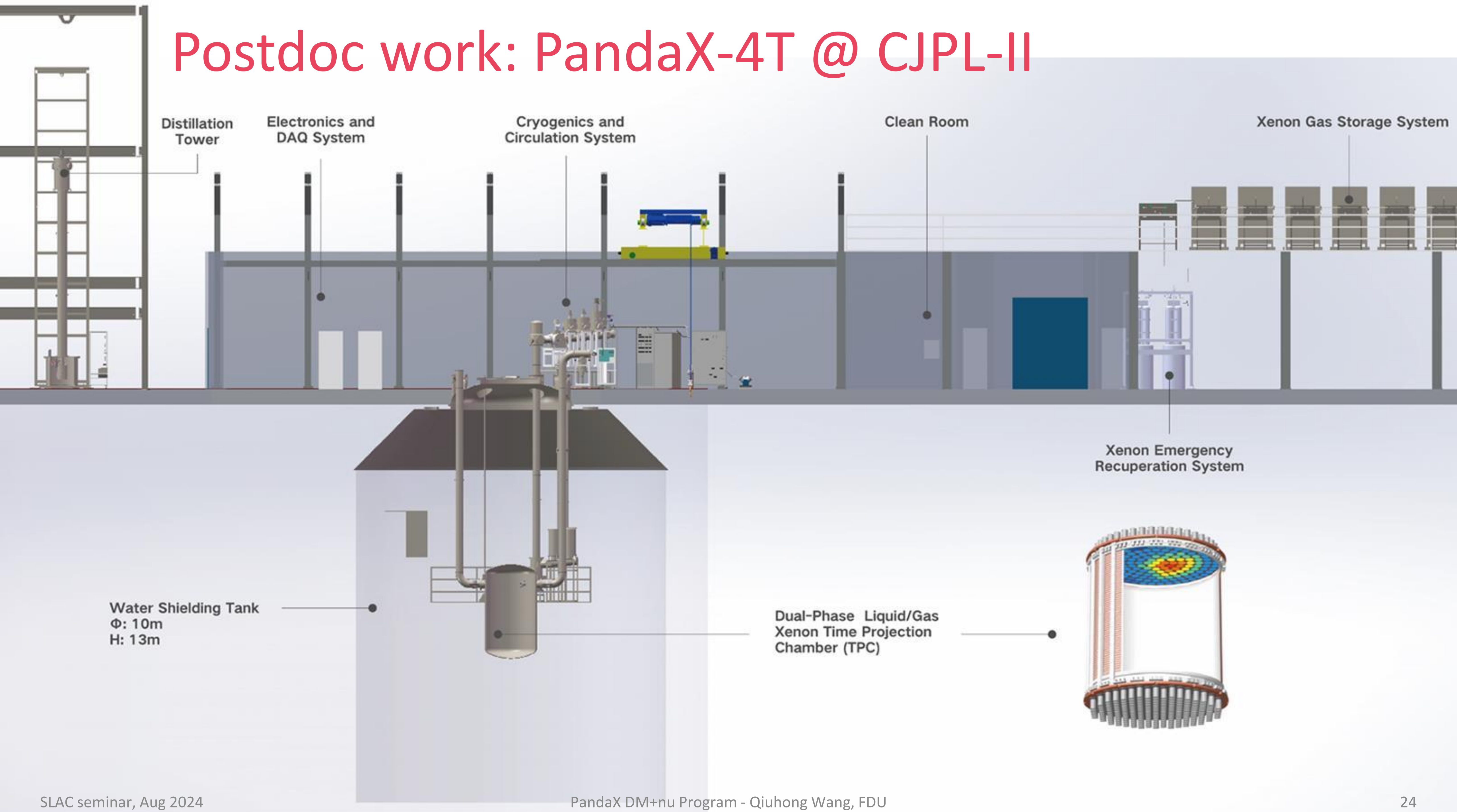


WIMP search results of PandaX-II

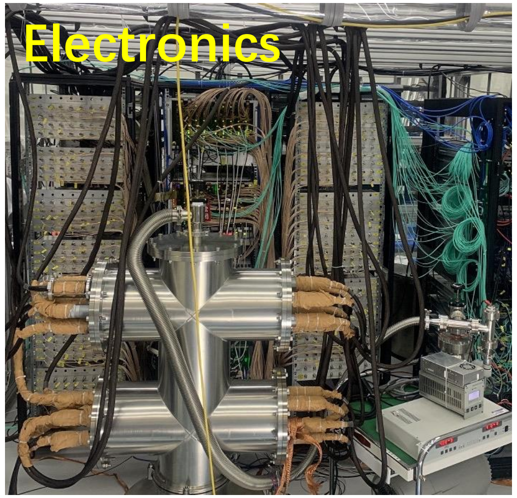
- Spin-independent Interaction
- Exclusion limits on SI
  - for 30 GeV, 2.2×10^{-46} cm^2, 1.7 WIMPs
- 54 ton-day exposure data, with downward fluctuation, generated a best constraint on WIMP model in 2017
- The long duration of the PandaX-II operation, the systematic studies performed, and the analysis techniques are all crucial for the development of the subsequent PandaX-4T

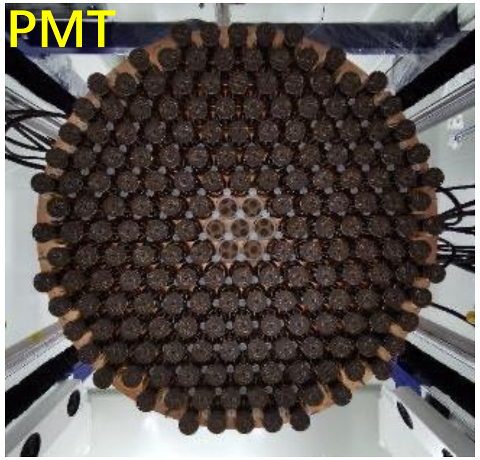


Postdoc work: PandaX-4T @ CJPL-II

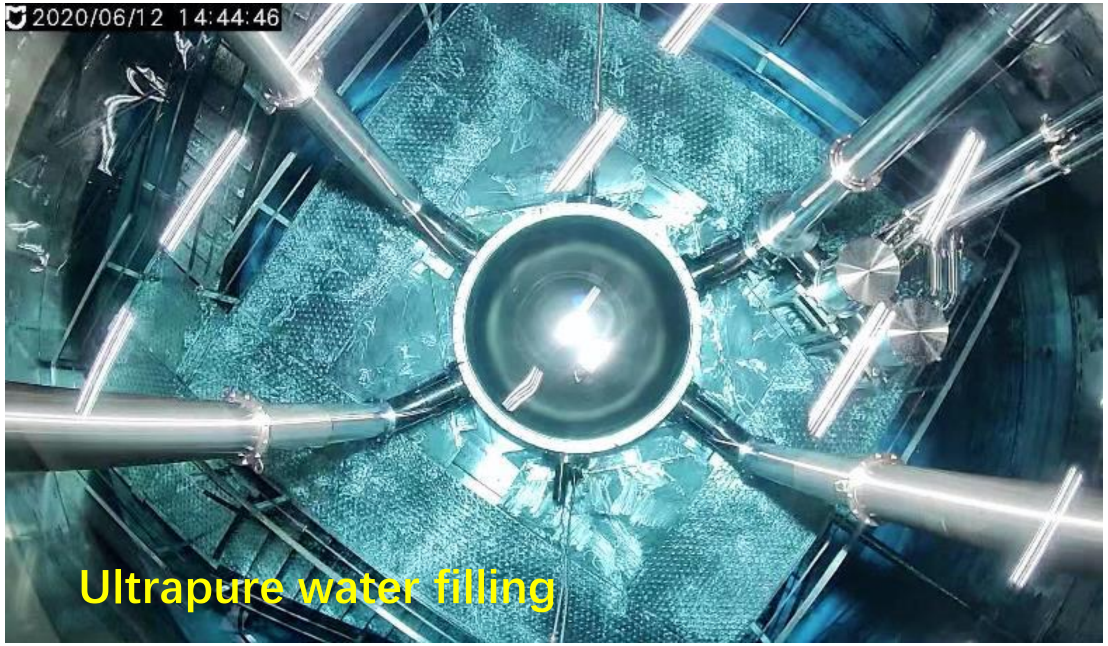


PandaX-4T subsystems





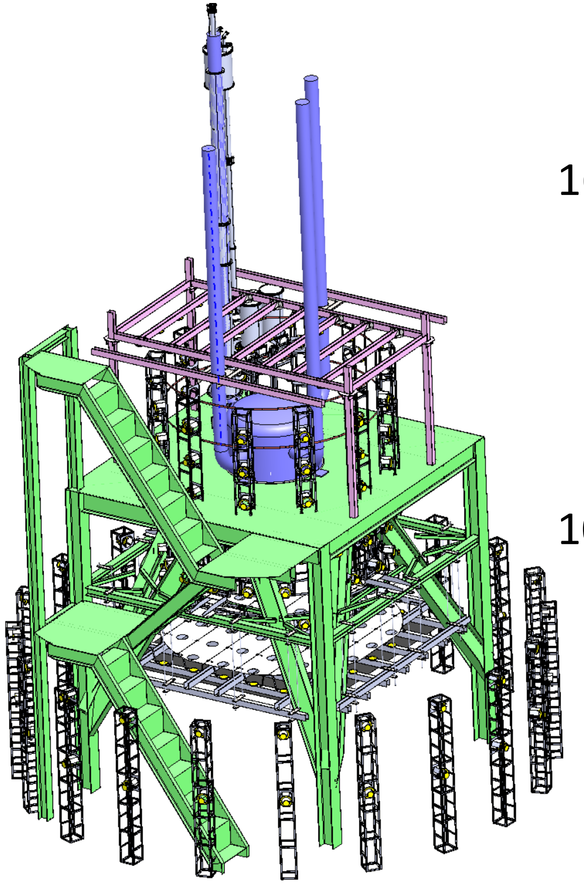
PandaX-4T subsystems



- Undertook construction and acceptance of some subsystems of PandaX-4T
- Ultrapure water system for water shielding
- Radon removal system for cleanroom

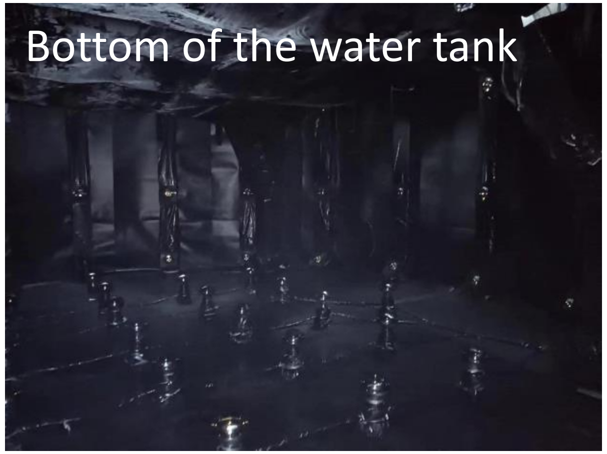
Upgrade water shielding into a veto detector

- Instrument the water shielding with 270 8-inch PMTs to form a veto for gammas, neutrons, and cosmic rays
- Contributed to installation during my time as a shift manager at CJPL



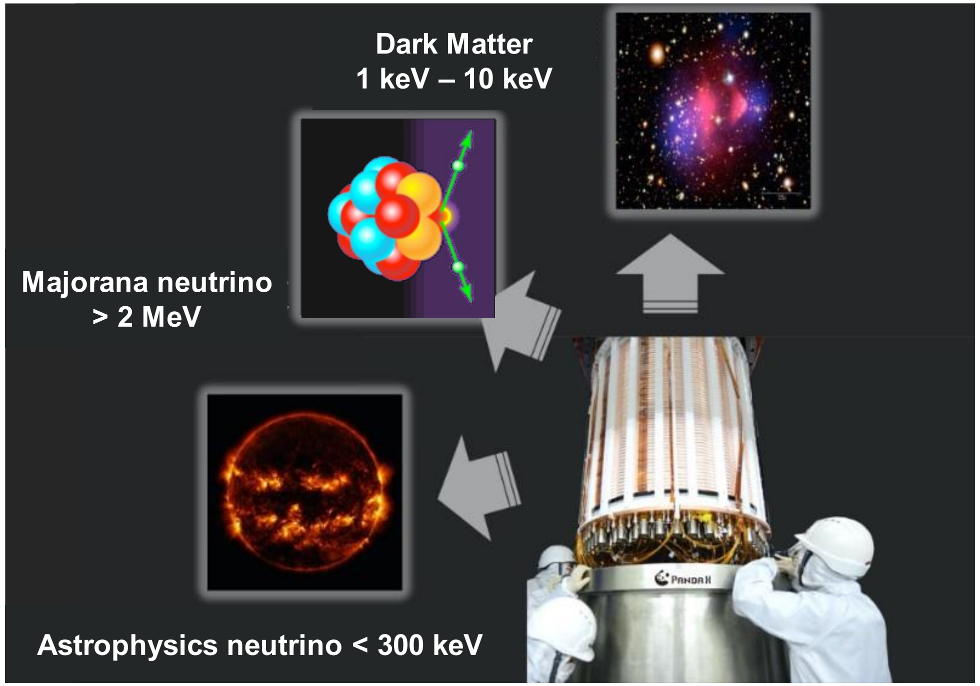
165 PMTs in the inner layer

105 PMTs in the outer layer



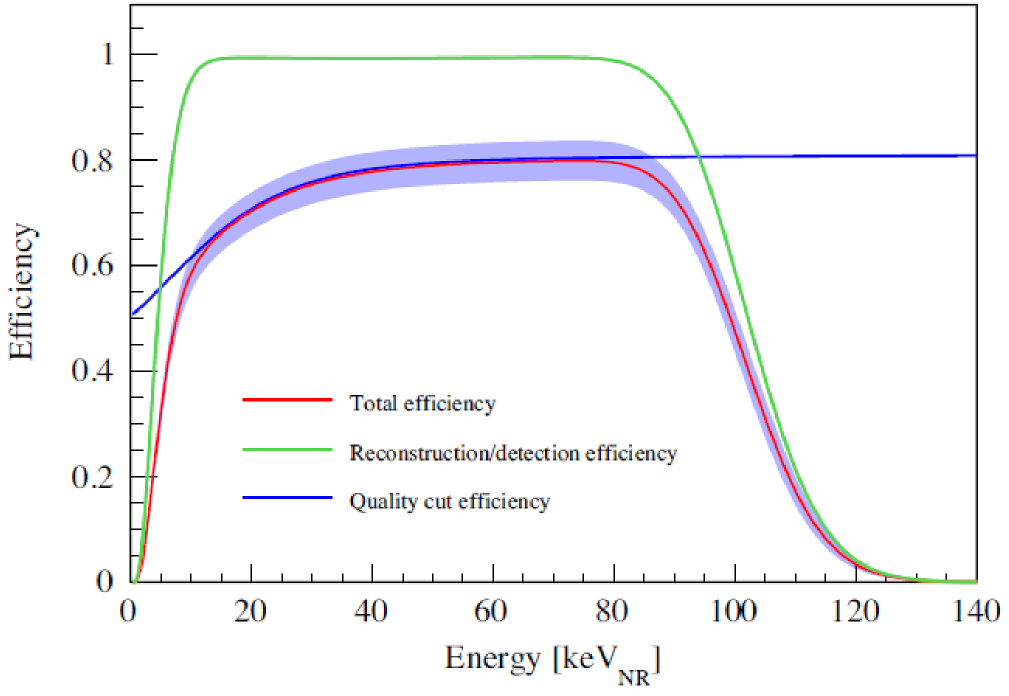
PandaX-4T runs and multiple physics topics

Commissioning (Run 0)	Calibration	Distillation	Physics Run (Run 1)	Calibration	Detector Upgrade
2020/11/28 – 2021/04/16	2021/04/17 – 2021/06/09		2021/11/15 – 2022/05/15	2022/05/16 – 2022/07/08	

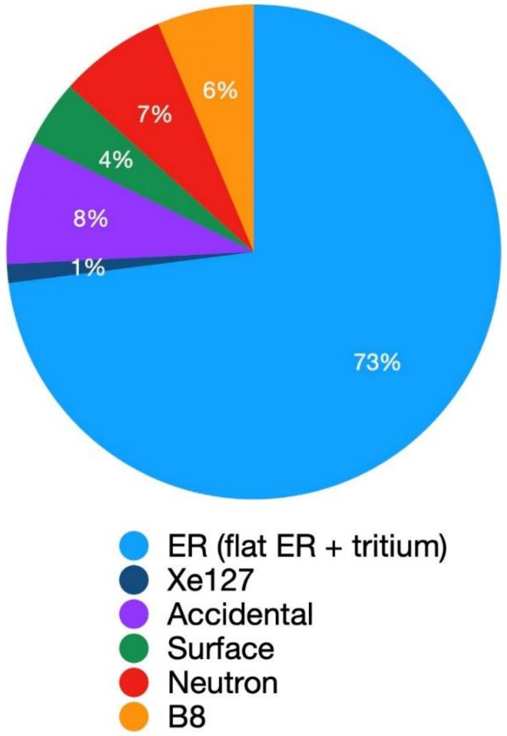


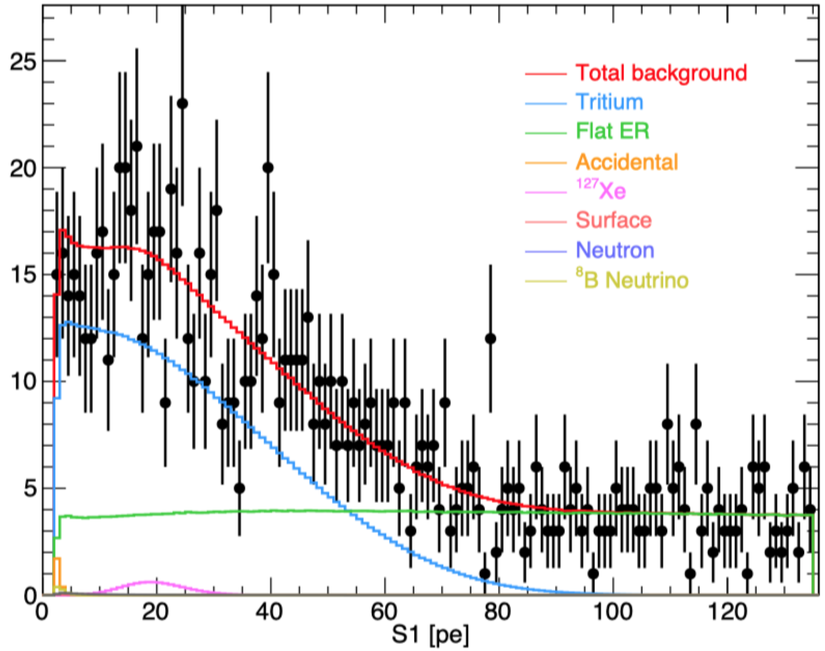
- Have completed data-taking of
  - Commissioning Run 0 (~ 95 d)
  - Physics Run 1 (~ 164 d)
- Detector upgrade and more physics runs are on-going
- Multiple physics topics are being studied now

Efficiency and background in Run0



Expected below-NR-median events: 9.8 (0.6) evts

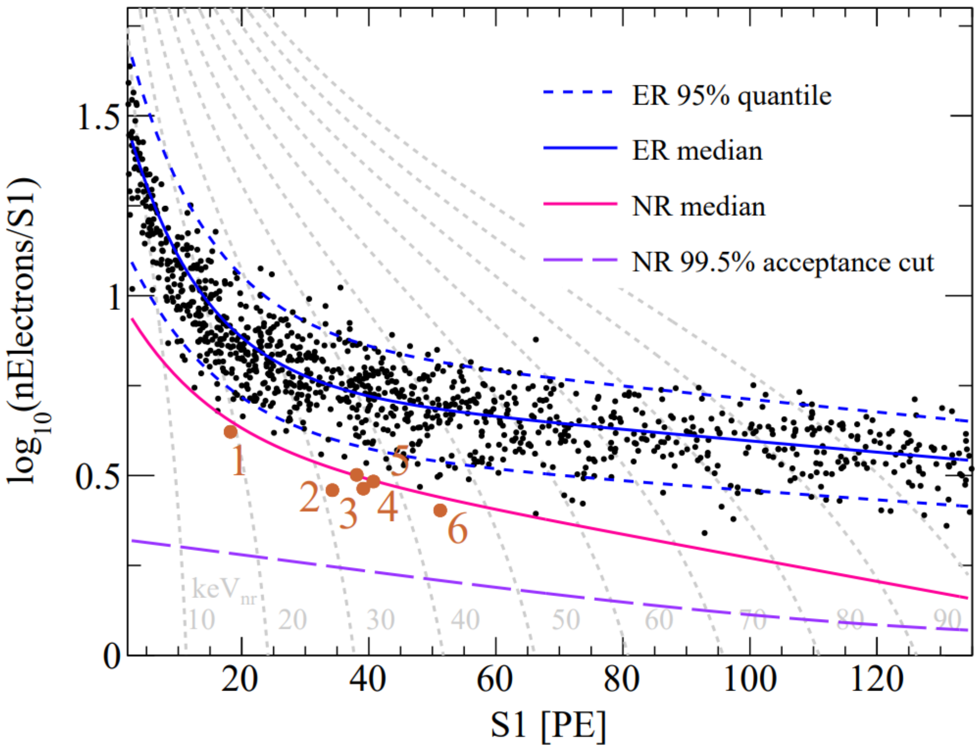




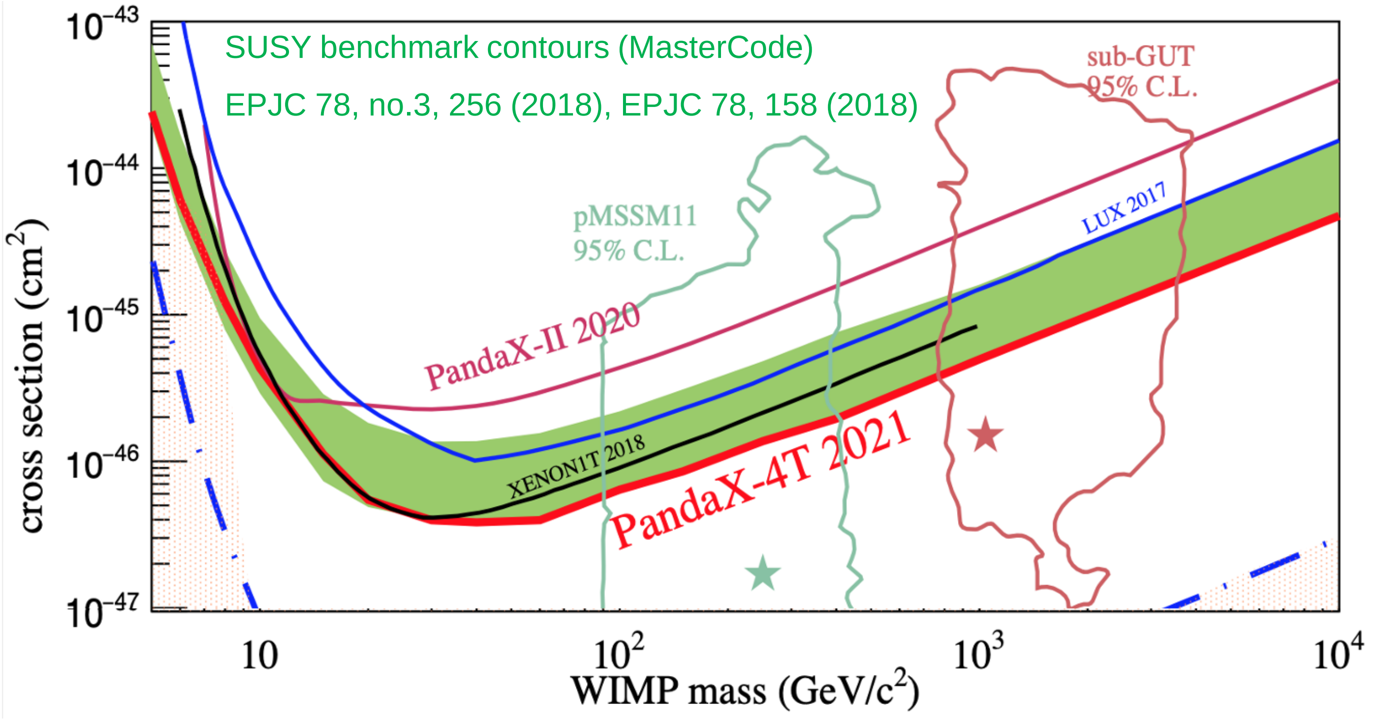
- Coordinated the efficiency calculation and several background estimations
- Background per unit target is improved from PandaX-II by 4 times (<10 keV)
- Projected S1 spectrum agrees with expected background with efficiency

WIMP search with PandaX-4T Run0

Exposure: 0.63 tonne-year

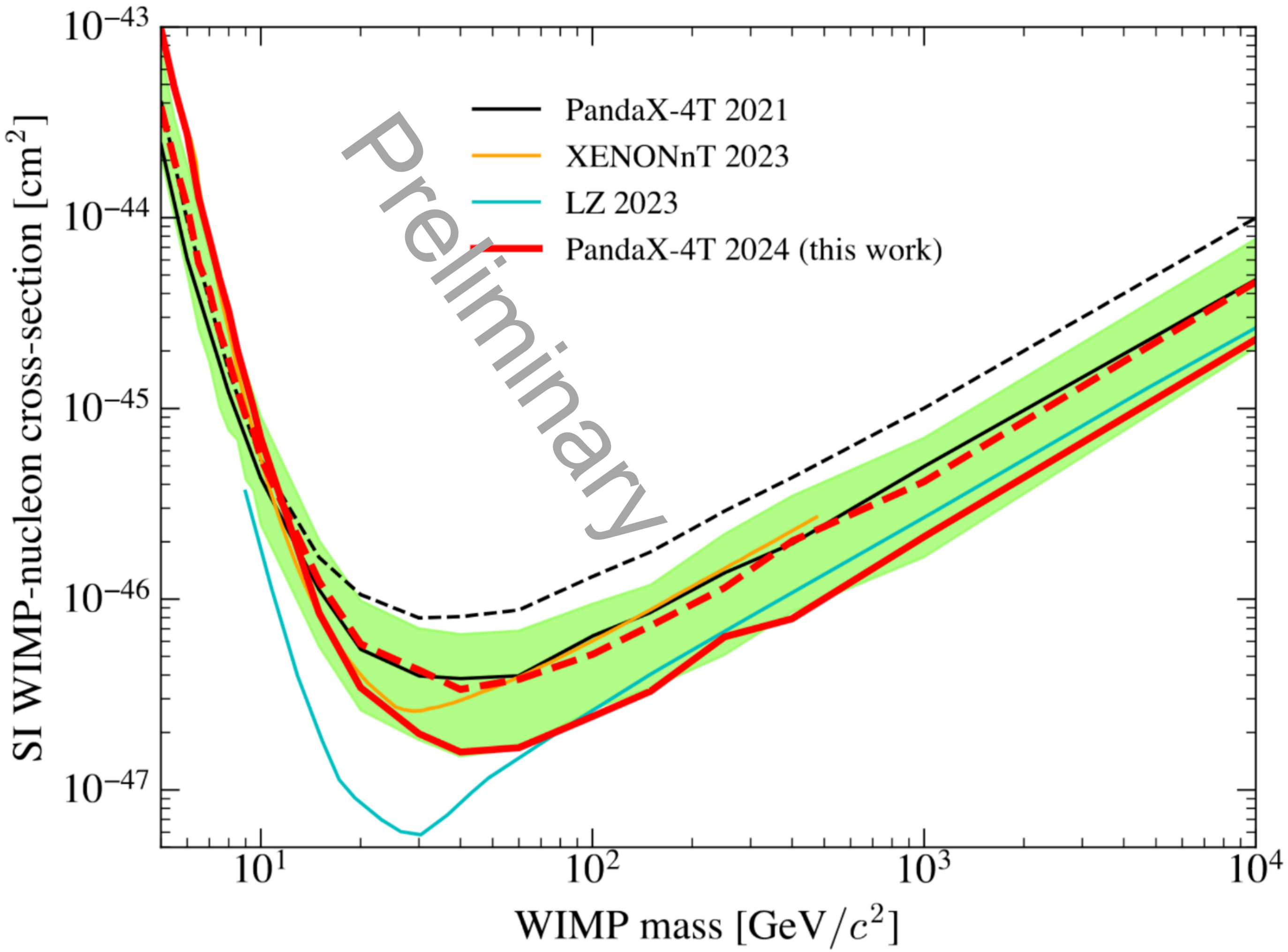


Phys. Rev. Lett. 127, 261802 (2021)



- 1058 candidates (expected 1054±39), 6 below NR median curve (expected 9.8±0.6)
- Sensitivity improved from PandaX-II final analysis by 2.9 times (30 GeV/c^2)
- Our limit is ~1.24 times stronger than XENON1T around 30 GeV/c^2

Combined WIMP search results (Run 0+1)



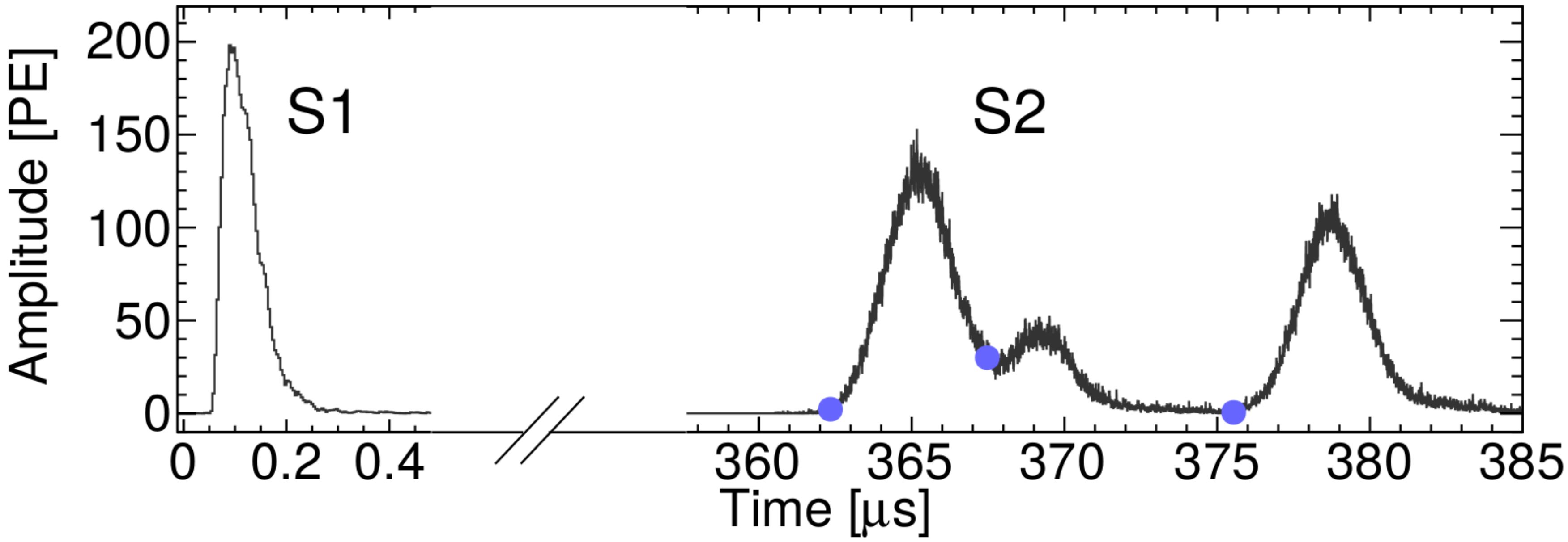
- 1.54 tonne·year
- Fully blind analysis
- Most stringent constraint for WIMP mass above 100 GeV/c

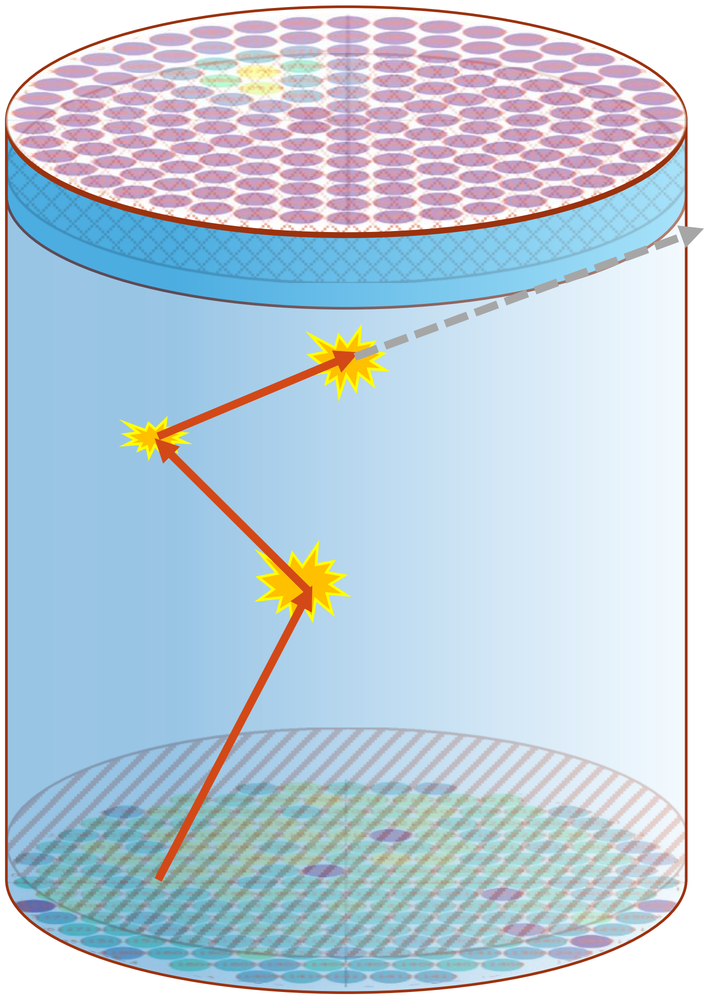
Multiple physics in a wide energy range

	Sub-keV	1 keV	10 keV	100 keV	1 MeV	10 MeV
^{136}Xe (~9%)				2νββ / 0νββ		
^{134}Xe (~10%)				2νββ / 0νββ		
^{124}Xe (~0.1%)				2νECEC		
Xe all isotopes	Solar ^{8}B ν and light DM	WIMP, other DM models, and more		Solar pp ν		Alphas, muons, and more

Identifying SS and MS

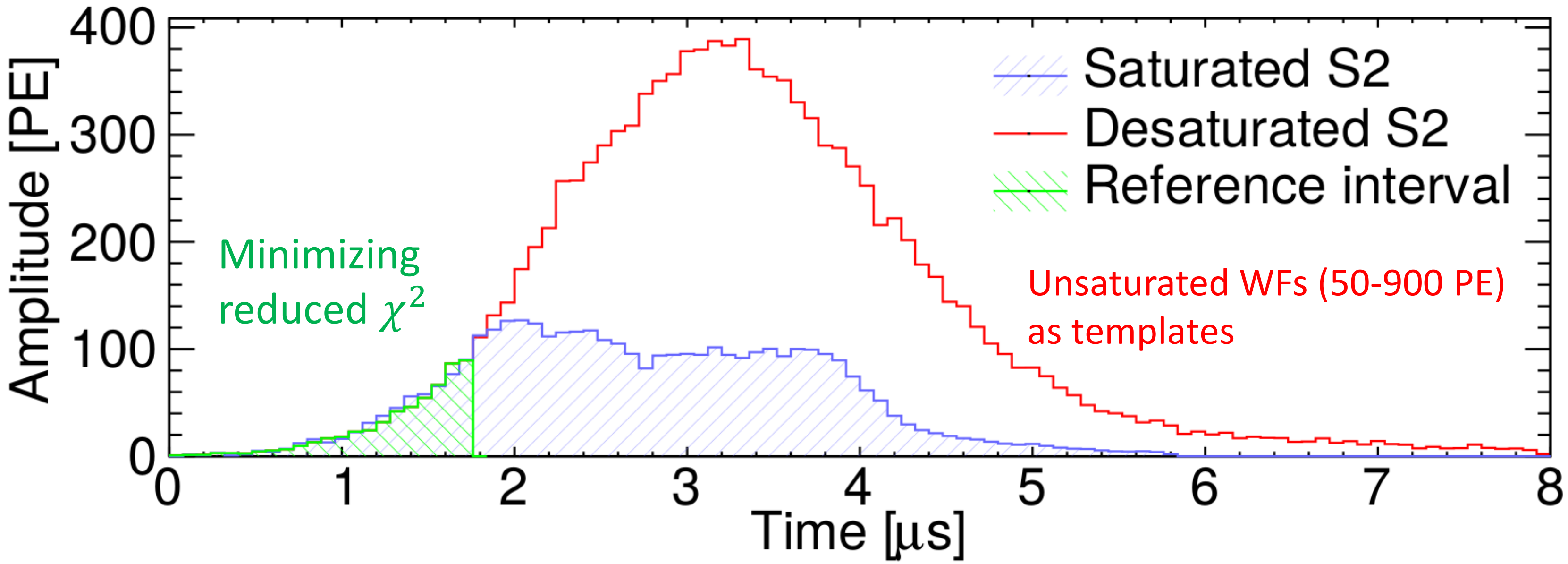
- MeV gamma-rays are mostly multi-site (MS) events; while signals (DBD) are mostly single site (SS)
- Identifying MS backgrounds with PMT waveforms





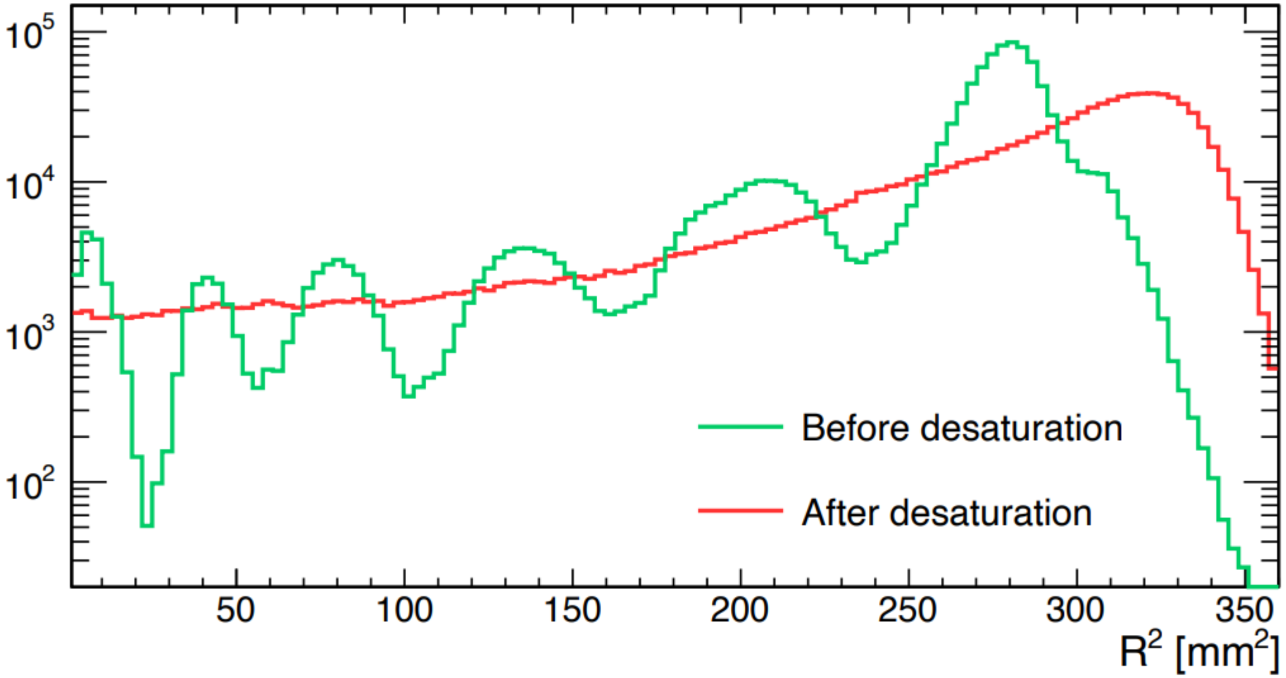
PMT pulse saturation and desaturation

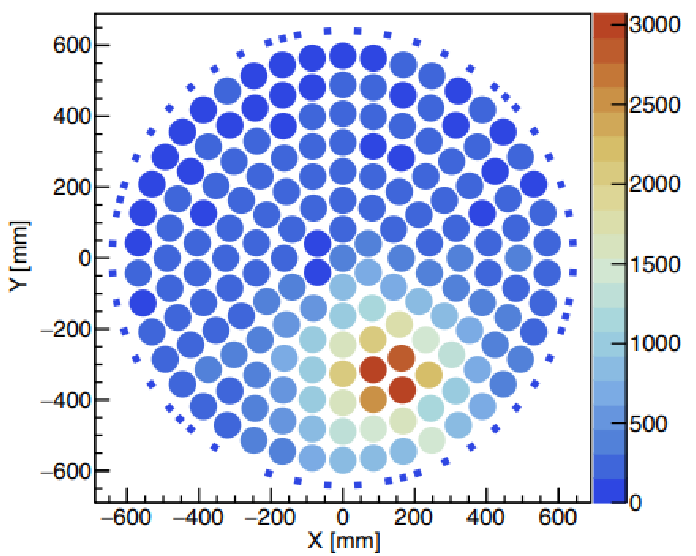
- PMT bases suffer serious saturation for MeV range events.
- Match the rising slope of the saturated to the non-saturated templates in the same events → True charge collected
- For events in the energy range of 1 to 3 MeV, the average correction factor is ~3.0 for the top PMT array



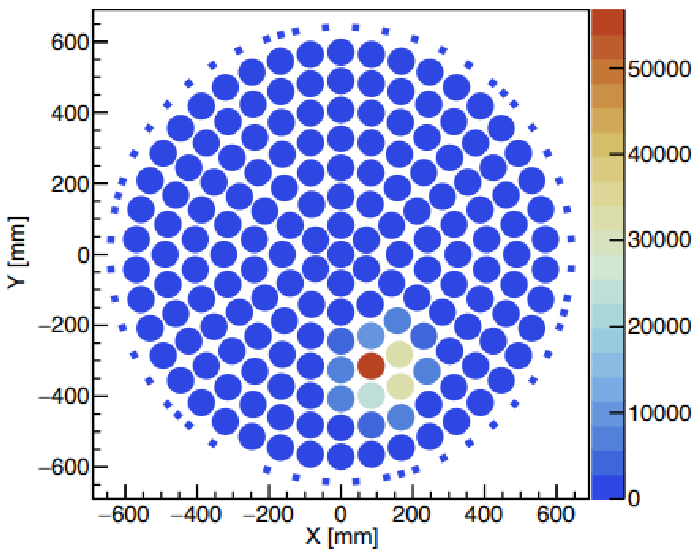
Position reconstruction improvement with desaturation

- 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

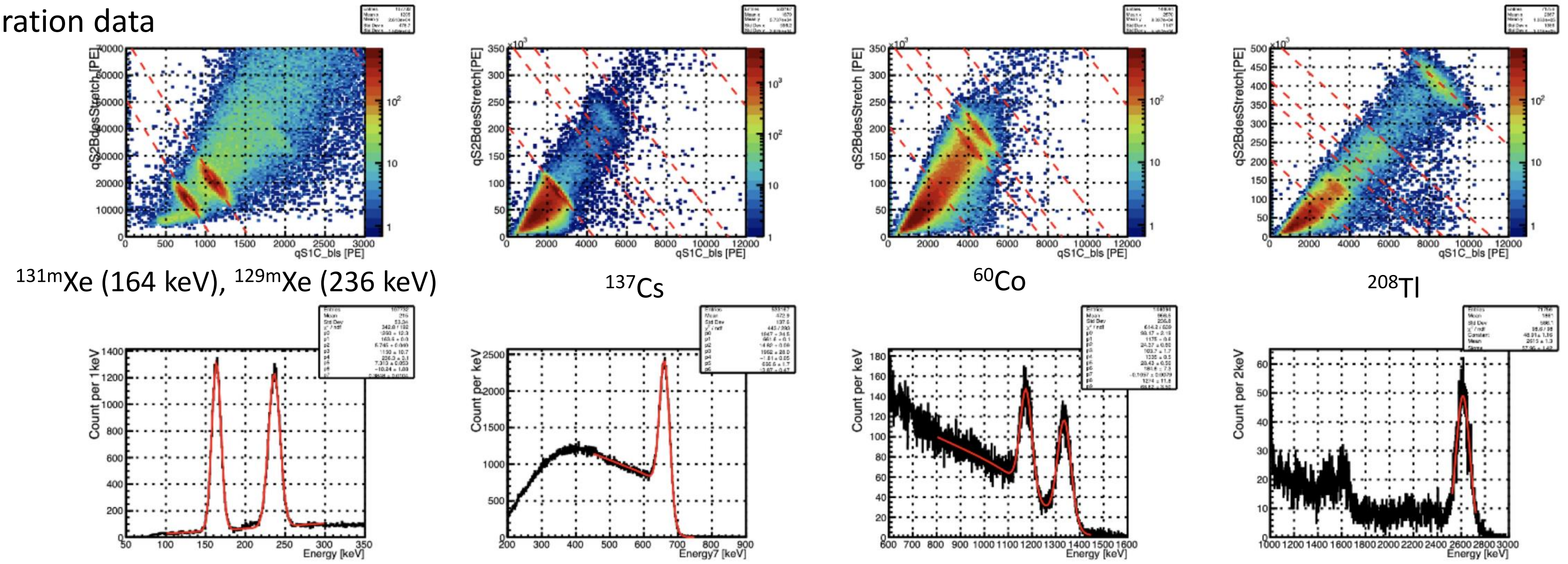
- Energy reconstruction: $E = 13.7\ \mathrm{eV} \times (S1/PDE + S2_b/(EEE \times SEG_b))$
- Further tune S1 and $S2_b$ vs. energy and position → deviations of peak positions to the percent level.

PDE: photon detection efficiency for S1

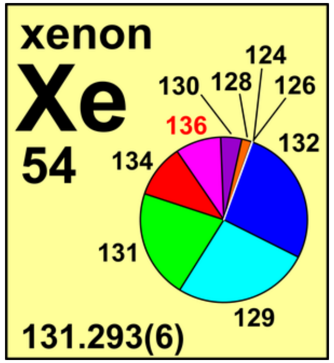
EEE: electron extraction efficiency

SEG_b: single-electron gain for $S2_b$

Calibration data

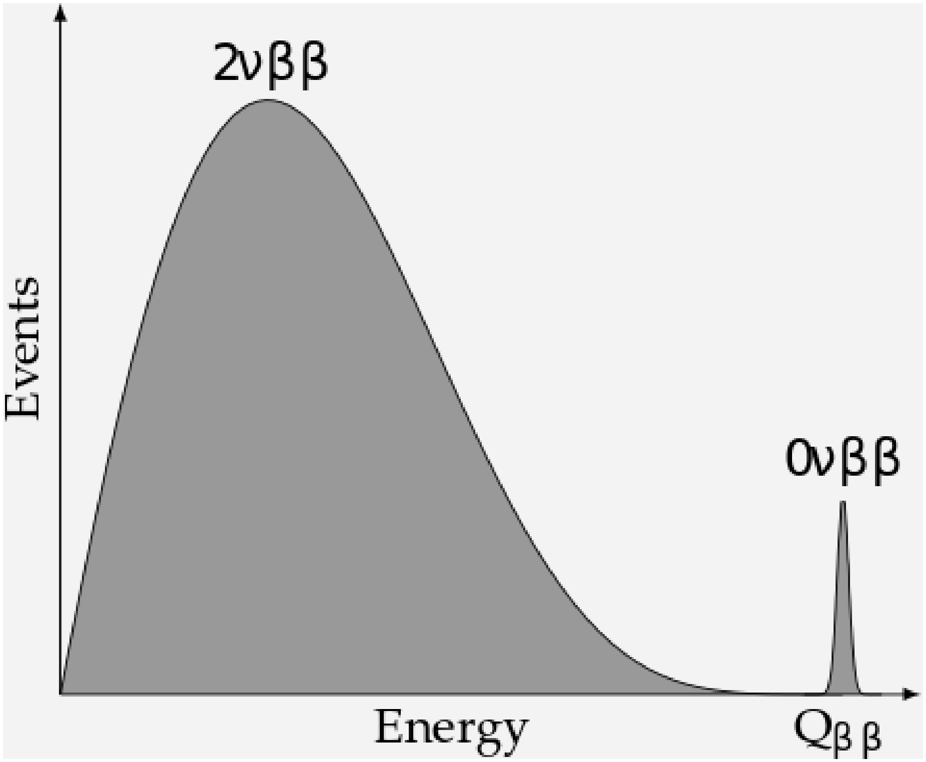


Detection of 2νββ and 0νββ



$$^{136}_{54}Xe \rightarrow {}^{136}_{56}Ba + 2e^- + (2\bar{\upsilon}), \qquad Q_{\beta\beta} = 2.46\text{MeV}$$

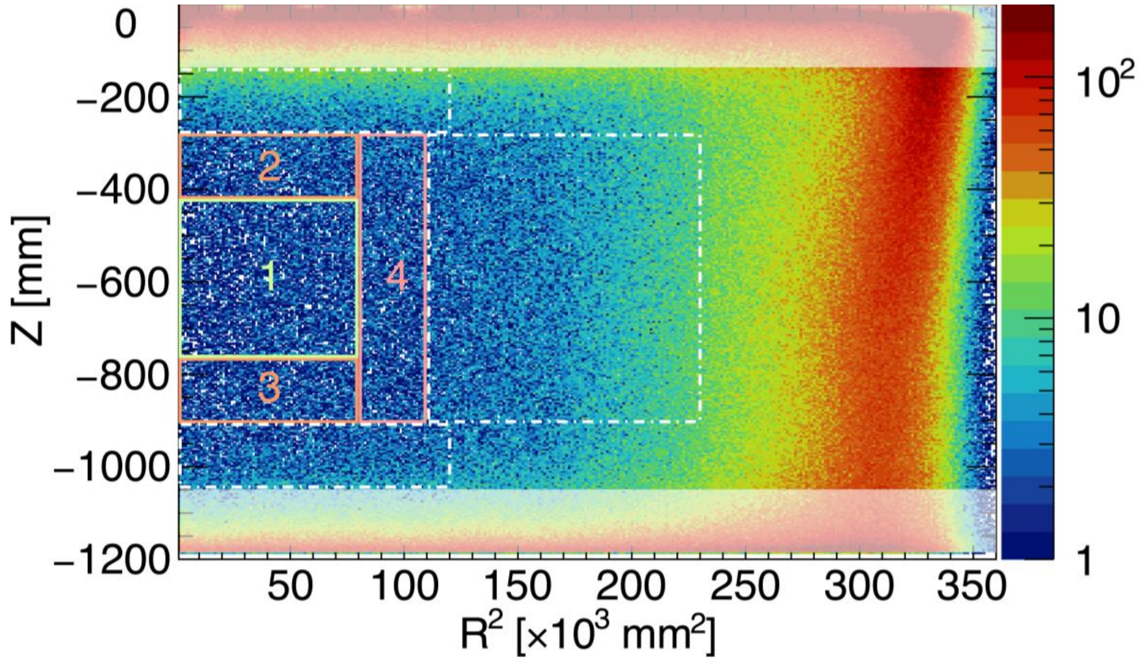
$$^{134}_{54}Xe \rightarrow {}^{134}_{56}Ba + 2e^- + (2\bar{\upsilon}), \qquad Q_{\beta\beta} = 0.83\text{MeV}$$

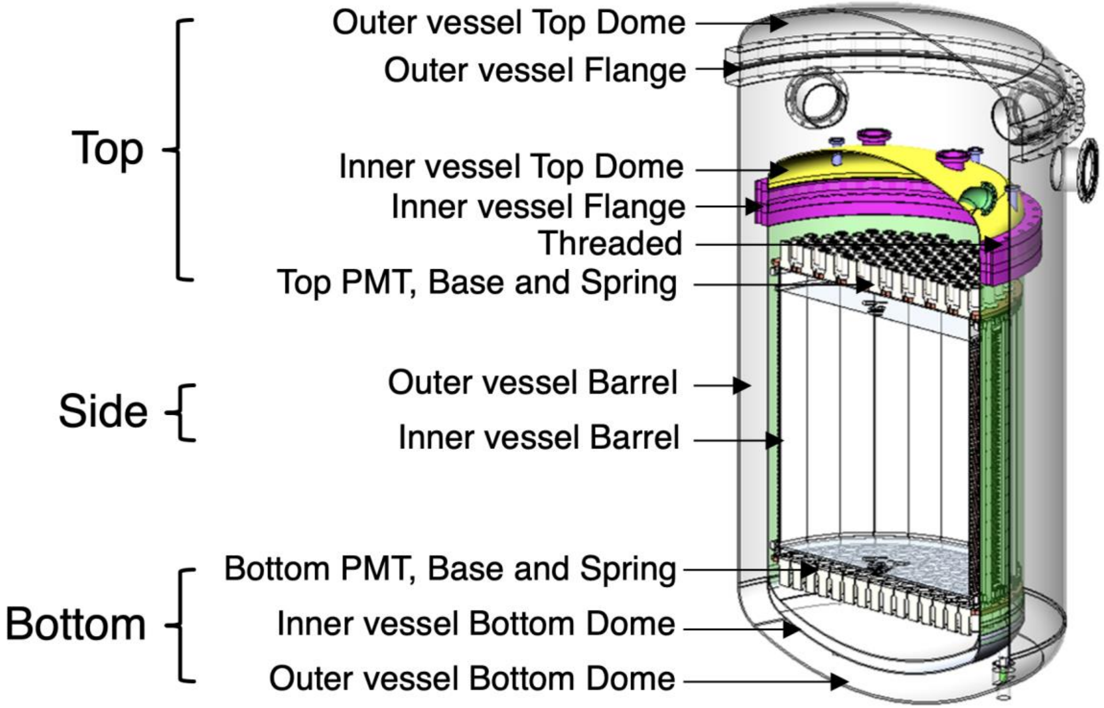


- Detect 2νββ and 0νββ through energies of emitted electrons
- Precision measurement of 2νββ is a major first step for any 0νββ experiment
  - ^{136}Xe 2νββ: discovered, $T_{1/2} = 2.2\times10^{21}$ yr
  - ^{134}Xe 2νββ: next promising, $T_{1/2} \sim 10^{24}$ yr
- Understand better the background

Accurate background model for ^{136}Xe

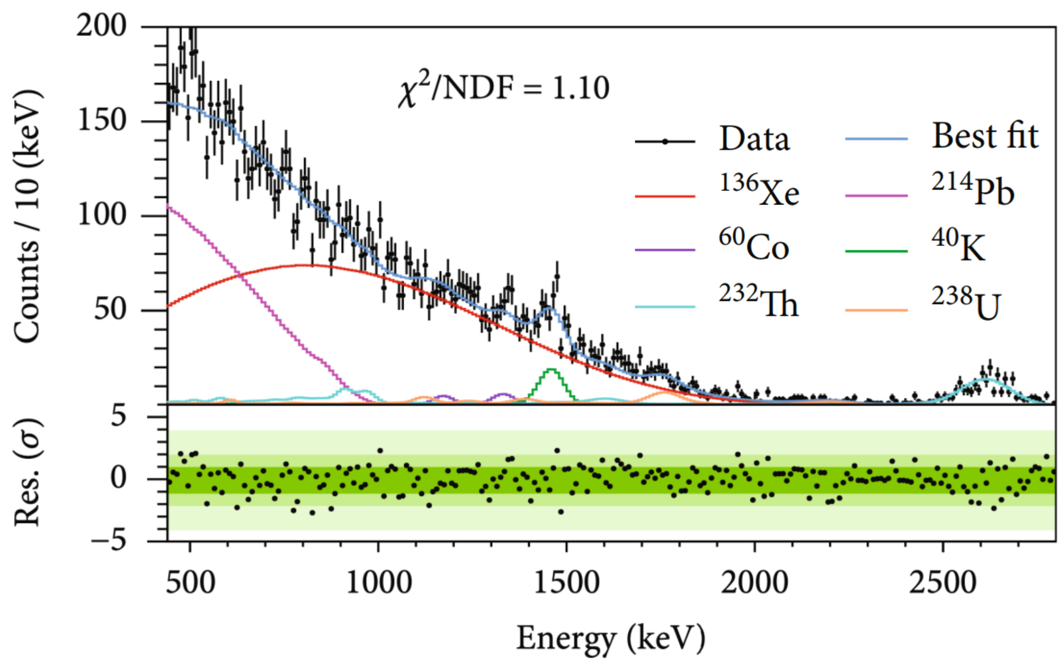
- Robust estimation of backgrounds in fiducial volume (4 regions)
  - Three categories of material backgrounds:
    - Top, bottom and side
    - Input values based on HPGe assay results
  - ^{214}Pb in ^{222}Rn chain inside LXe
    - High energy alpha events, and consider a float depletion



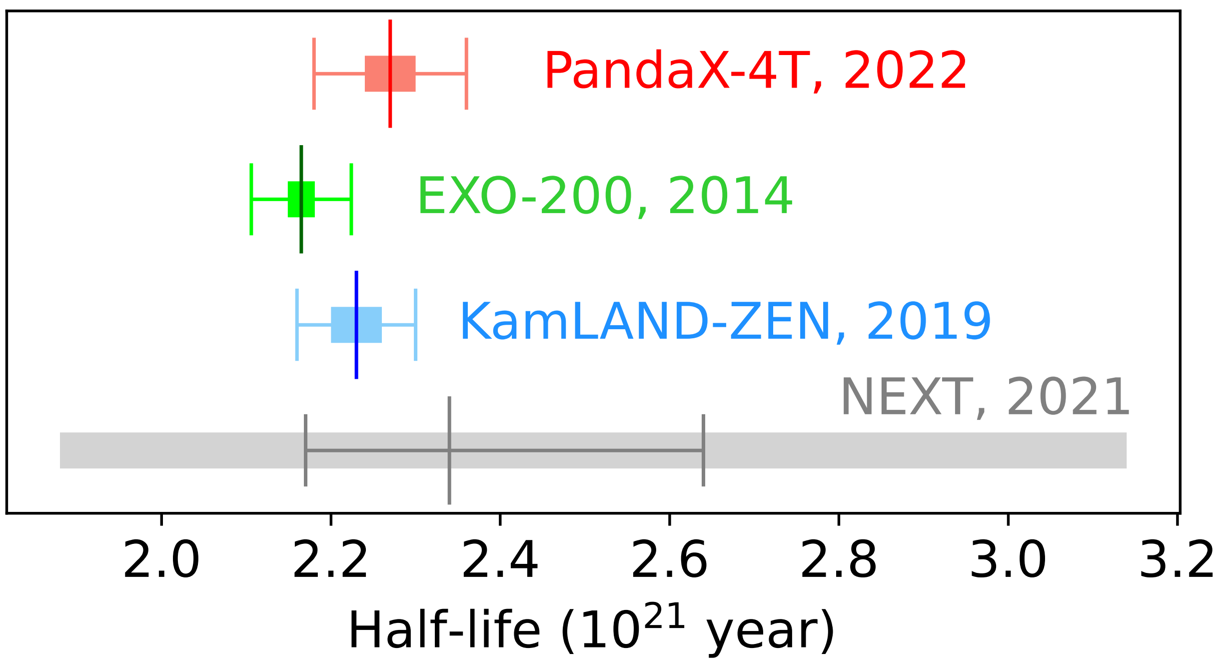


^{136}Xe 2νββ half-life measurement

FV region 1



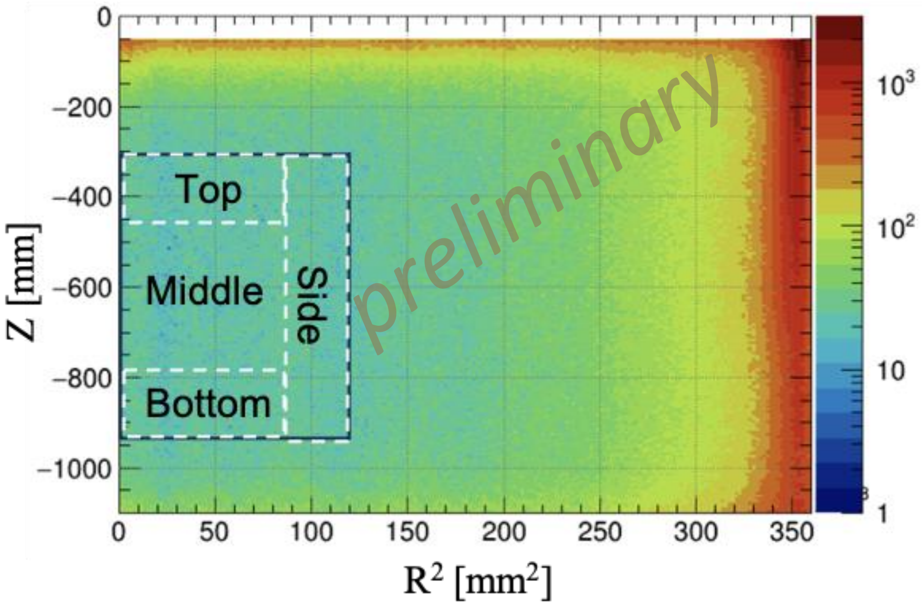
Research.10.34133/2022/979872

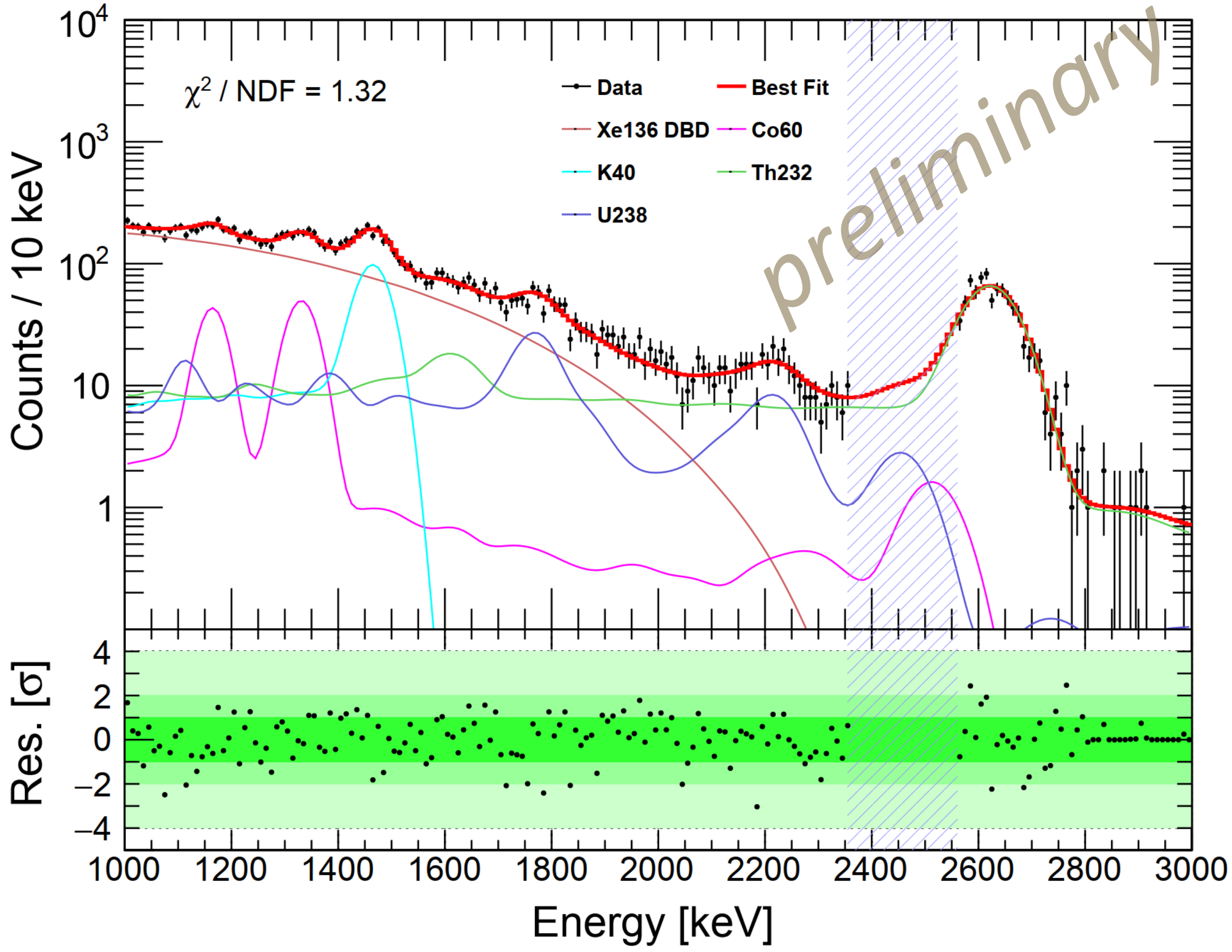


- First such result from a DM detector with natural xenon
  - ^{136}Xe 2νββ $T_{1/2}$ = 2.27 ± 0.03(stat.) ± 0.10(syst.) × 10^{21} year
  - Comparable with enriched ^{136}Xe experiments
  - The widest ROI from 440 keV to 2800 keV

Status of ^{136}Xe $0\nu\beta\beta$ search

- Run0 + Run1 blind analysis
- Improved data analysis
  - FV optimization
  - Background model from "*in-situ*" fitting
  - Detector response model from calibration data and science data
  - ...

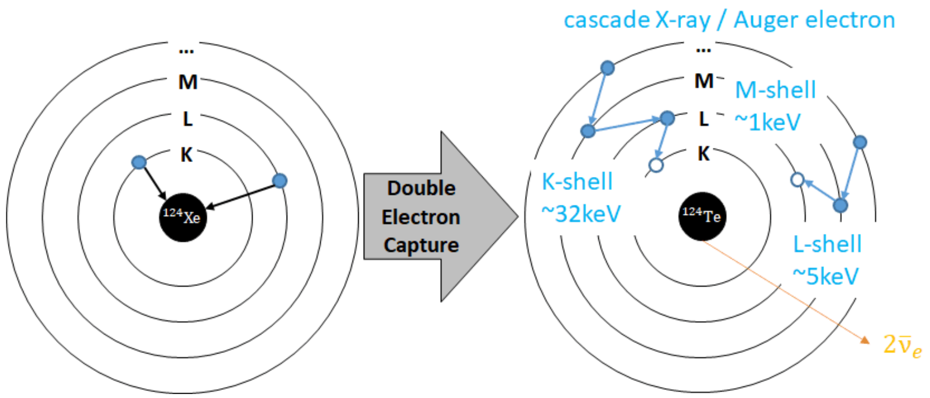


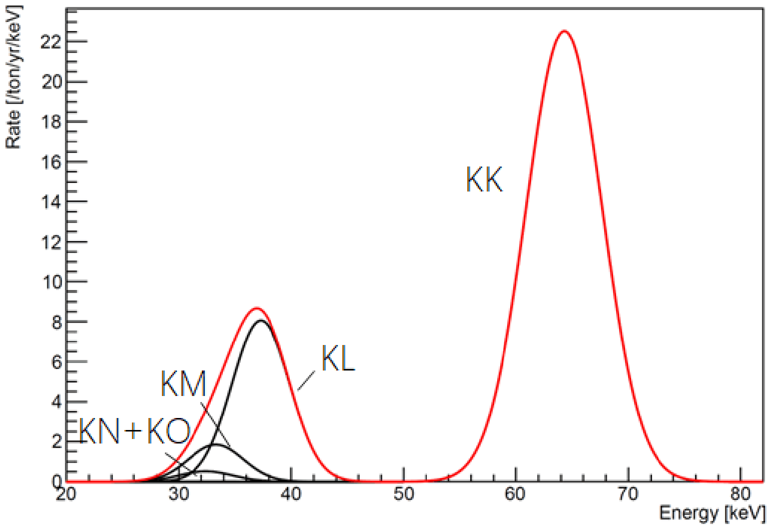


- Sensitivity of $0\nu\beta\beta$ search in PandaX-4T: 2×10^{24} yr

^{124}Xe double electron capture (DEC)

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





- 2ν/0ν ECEC
  - Q = 2857 keV
  - Auger electron & X-ray cascades SS events
- 2νECEC is a 2nd order weak process, with a longest measured half-life so far

- XENONnT: $T_{1/2} = (1.18 \pm 0.13_{stat} \pm 0.14_{sys}) \times 10^{22}$ yr

  [PRL 129, 161805 (2022)]

- LZ: $T_{1/2} = (1.1 \pm 0.1_{stat} \pm 0.2_{sys}) \times 10^{22}$ yr

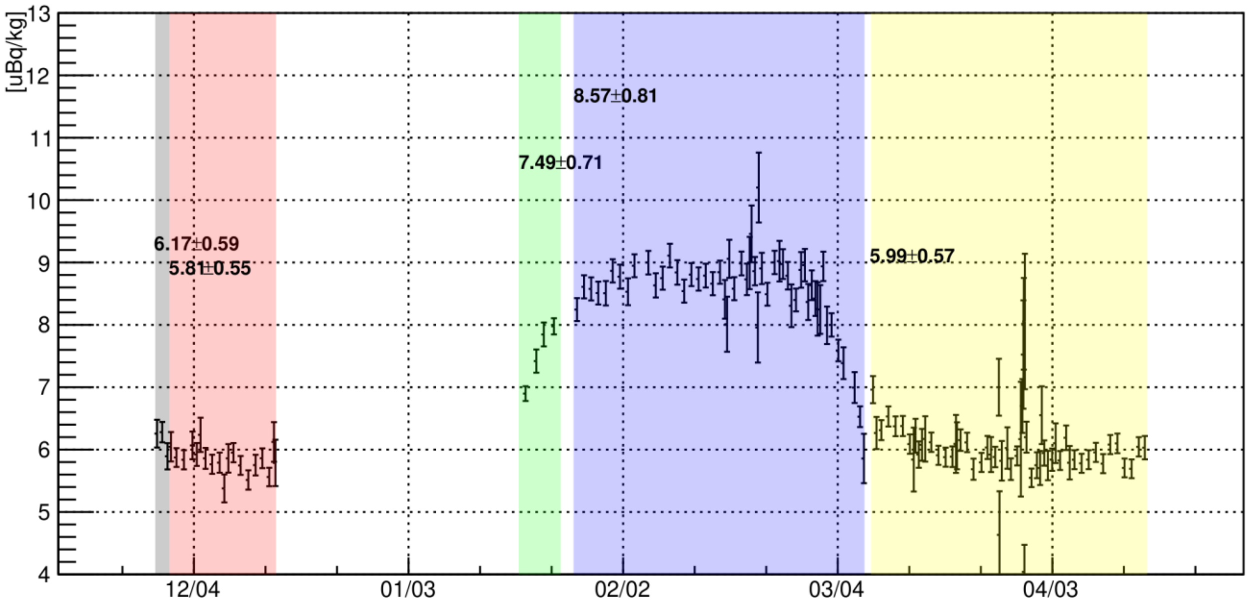
  [H. Almeida, University of Coimbra, Master Thesis (2024)]

Signal + background model for 2νECEC in PandaX-4T

- Energy ROI: [25, 75] keV
- Construct a 2D (energy × time) signal and background model in ROI

Source	Spectrum	Evolution
^{124}Xe	**Multi-Gaussian**	**Constant**
^{125}I	Multi-Gaussian	Decaying
^{127}Xe	Gaussian @33keV	
^{133}Xe	Tail into 75keV	
^{214}Pb	Flat	^{222}Rn α
^{212}Pb	Flat	Constant
^{85}Kr	Flat	
Material ER	Flat	
^{136}Xe 2νββ	Slope	
Solar ν	Slope	

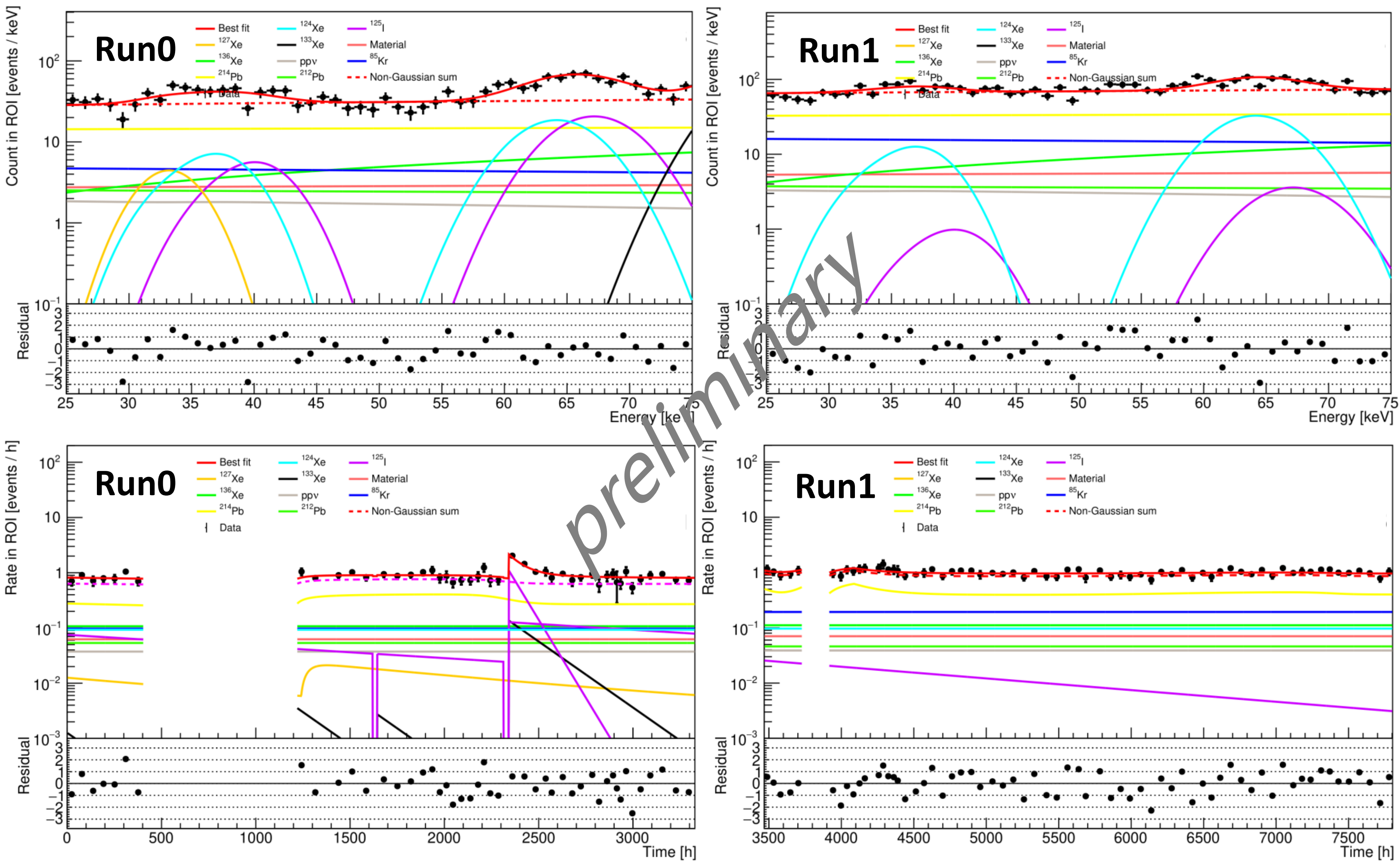
^{222}Rn rate evolution in Run0



^{124}Xe 2νECEC half-life measurement in PandaX-4T

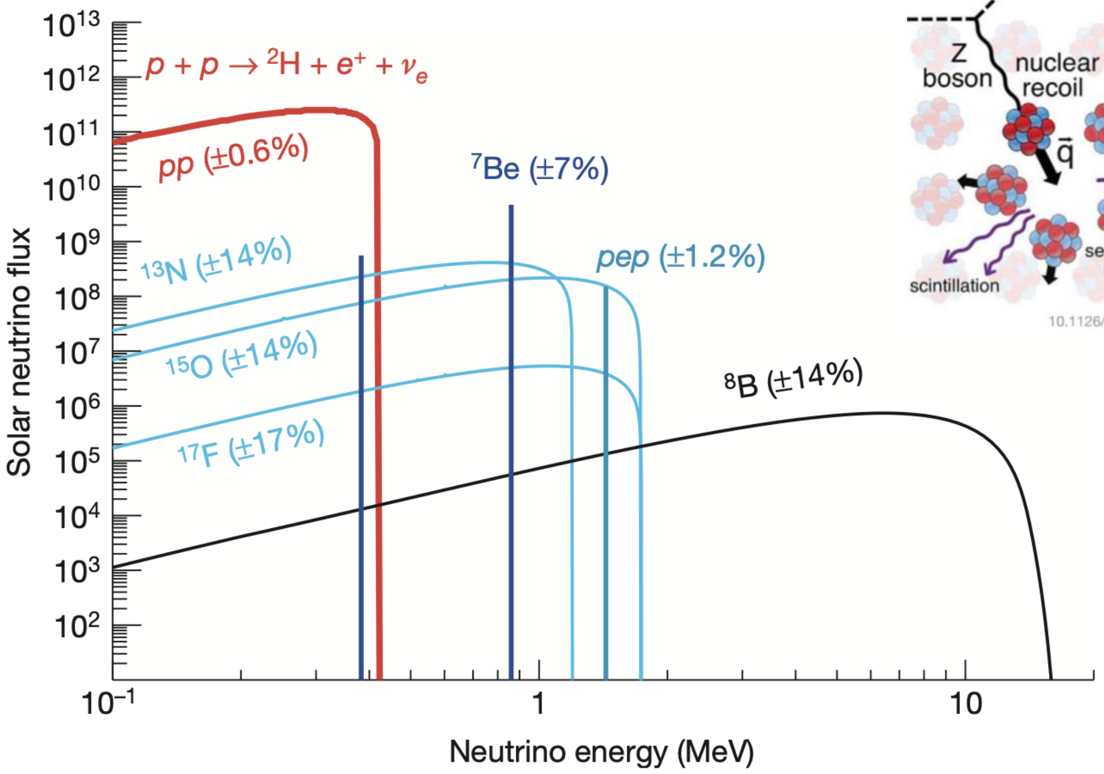
Projected spectra and time evolution

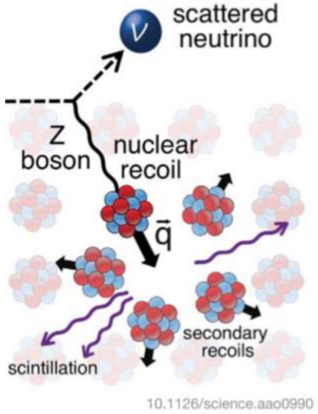
- Unbinned 2D fit to Run0+Run1 data in parameter space of (energy, time)
- Use a profile likelihood ratio (PLR) approach
- Preliminary measurement on ^{124}Xe 2νECEC half-life:
  - $9.4 \pm 0.9(\text{stat.}) \pm 1.5(\text{syst.}) \times 10^{21}$ yr

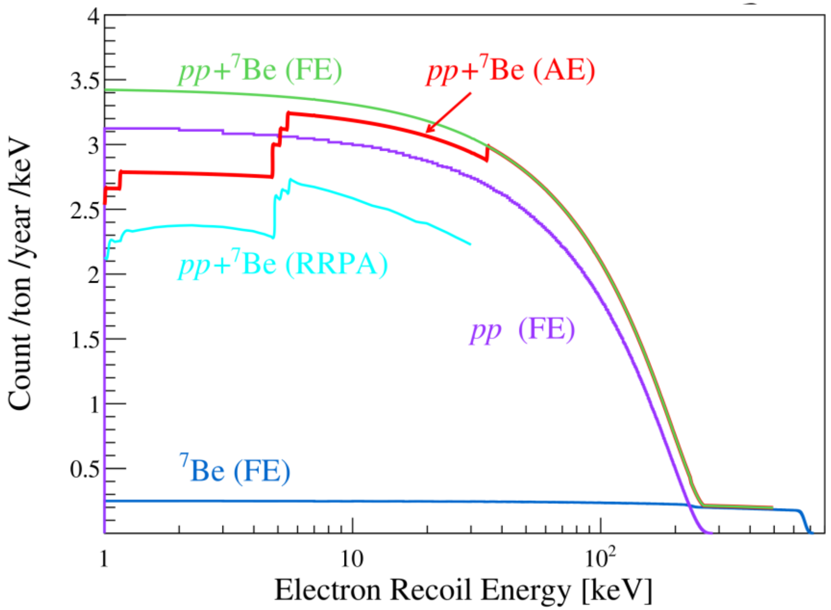


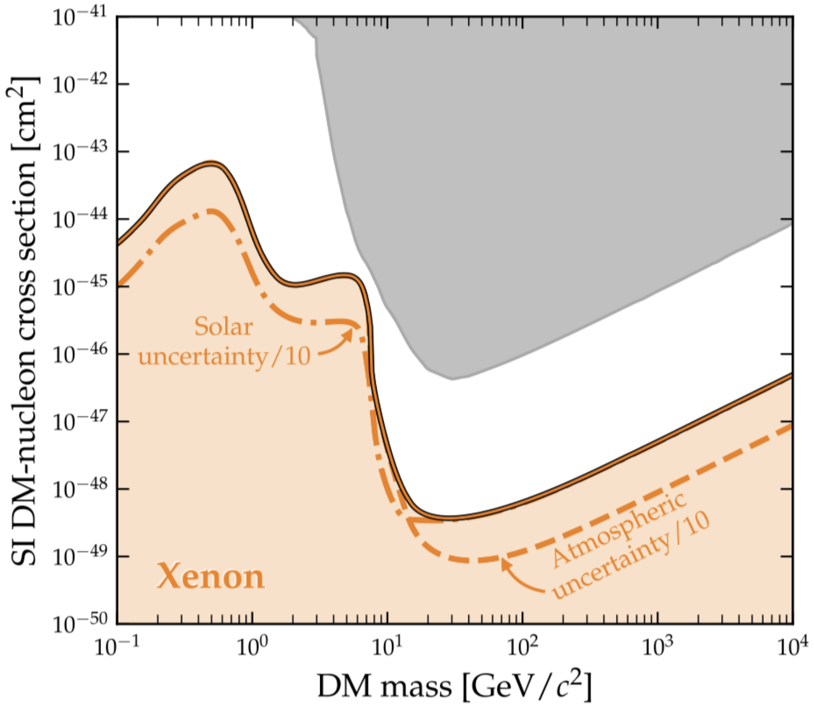
Solar neutrino flux

- Solar *pp* neutrino: neutrino-electron elastic scattering
- Solar ^{8}B neutrino: Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)



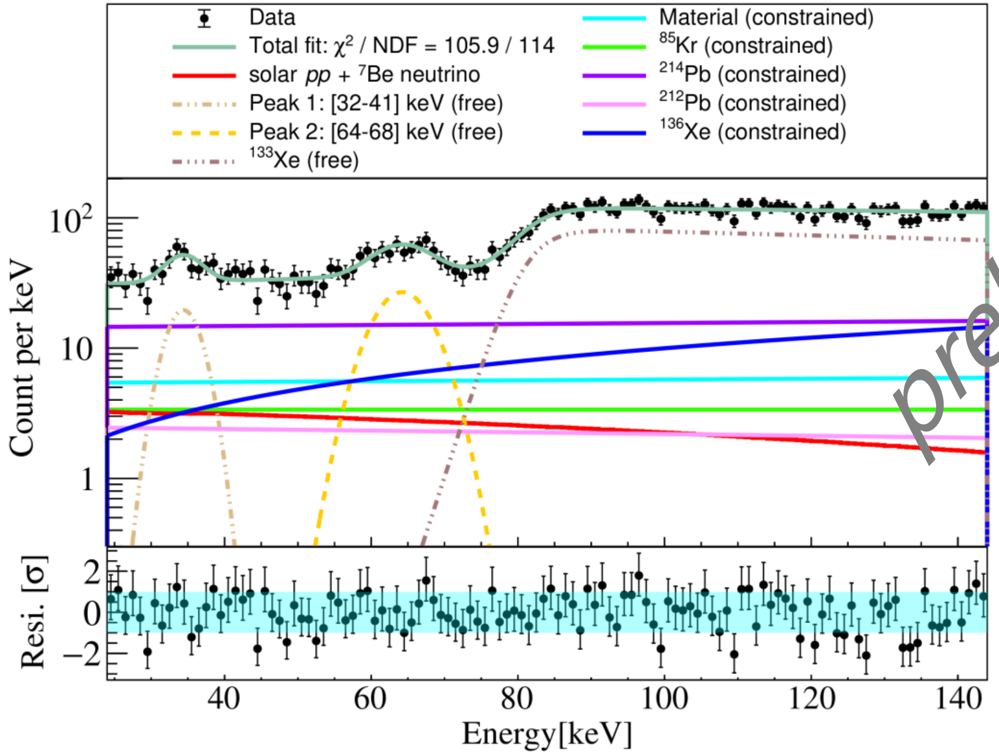




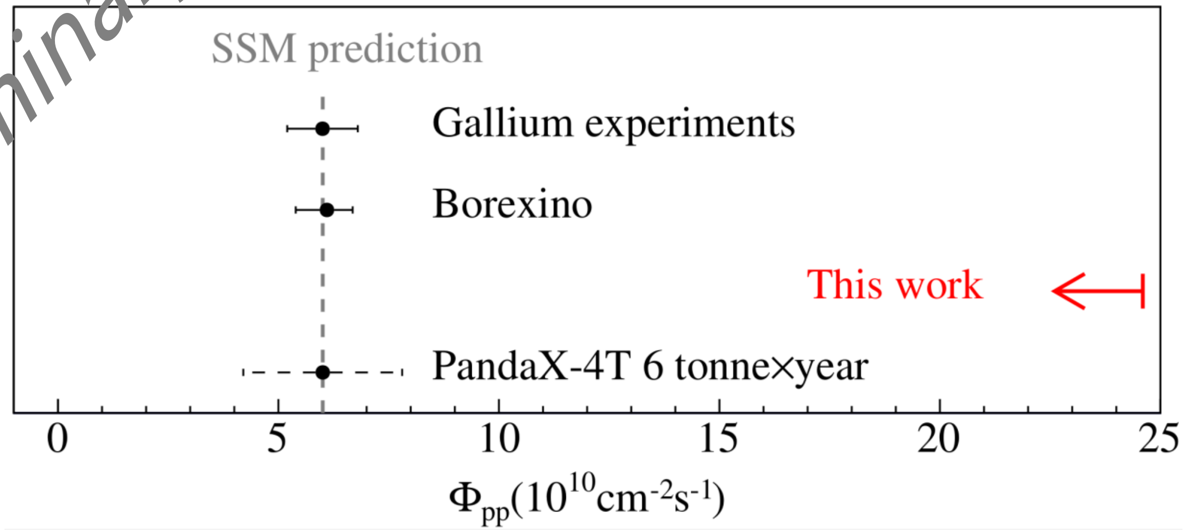


C. O'Hare PRL 127, 251802 (2021)

Measurement of solar pp ν flux in PandaX-4T



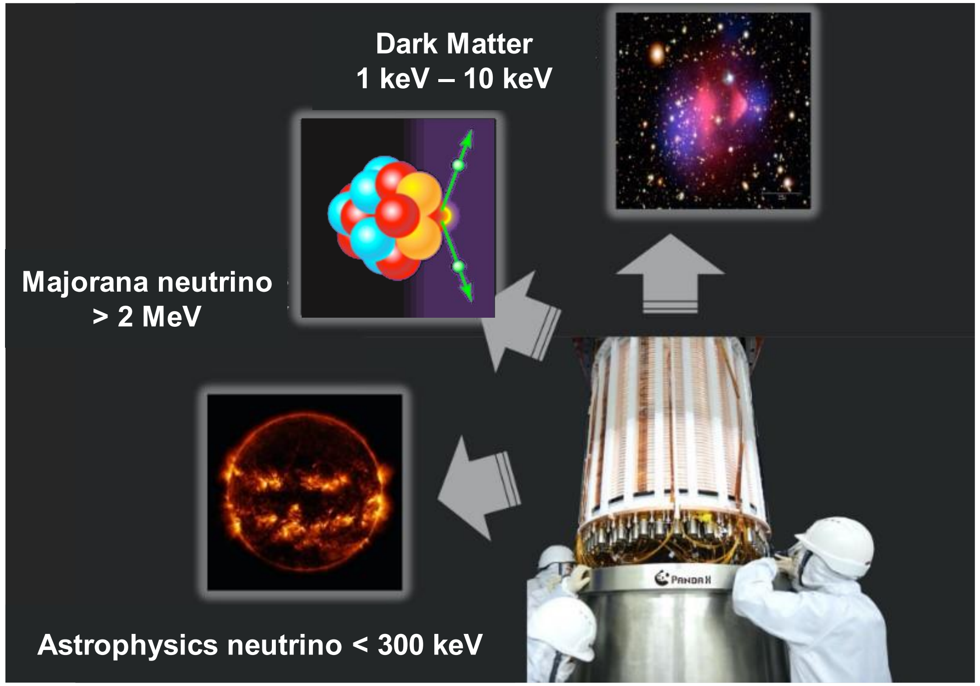
arXiv:2401.07045



- Spectrum fit to Run0 data in [24, 144] keV (0.63 tonne×year exposure)
- First direct measurement at a recoil energy below 150 keV
  - Solar pp ν flux: $(10.3 \pm 3.7_{stat.} \pm 9.7_{syst.}) \times 10^{10}$ s^{-1} cm^{-2}
  - Upper limit: 24.6×10^{10} s^{-1} cm^{-2} at 90% C.L.
- With reduced backgrounds and 6 tonne×year exposure in the future: ~30% uncertainty

Summary

- PandaX reached to the forefront of DM search and neutrino physics in recent years!
- WIMP searches with PandaX-II (Ph.D. work)
  - Extensive experience in experimental HEP
  - Comprehensive analysis of the full exposure data
- Neutrino research with PandaX-4T (Postdoc work)
  - Extend DM detector response to MeV range
  - ^{136}Xe and ^{134}Xe $2\nu\beta\beta/0\nu\beta\beta$
  - ^{124}Xe 2νECEC
  - Solar ν flux: *pp*



Thanks very much for your attention!

Backup slides

Qiuhong Wang

Fudan University

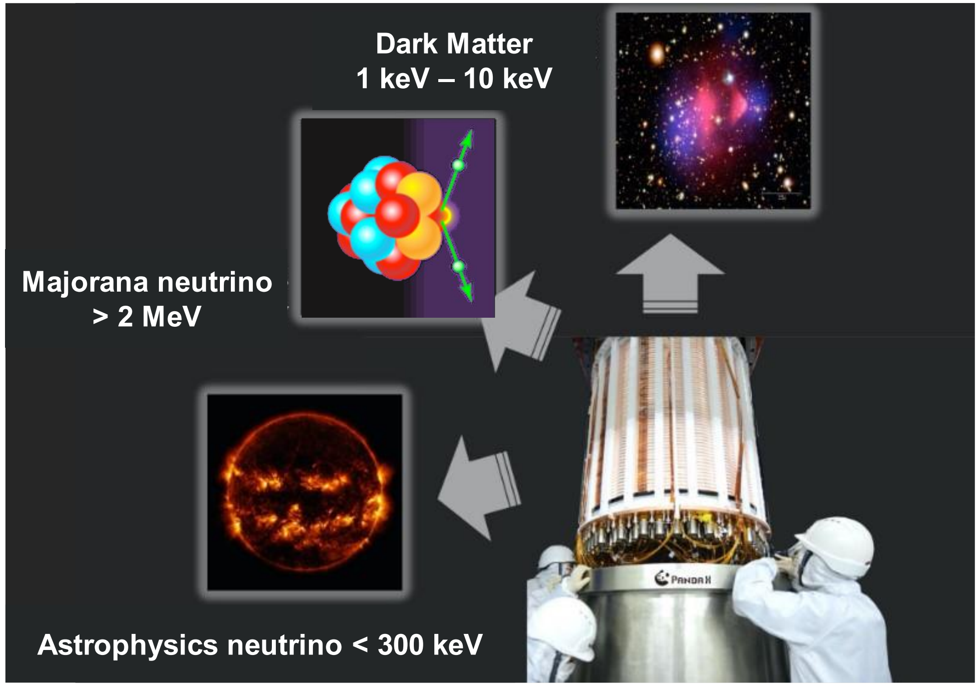
On behalf of the PandaX Collaboration

Aug 13, SLAC

wangqiuhong@fudan.edu.cn

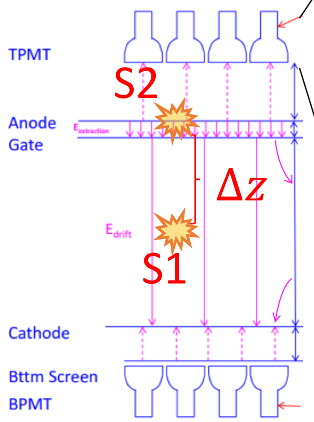
My research journey

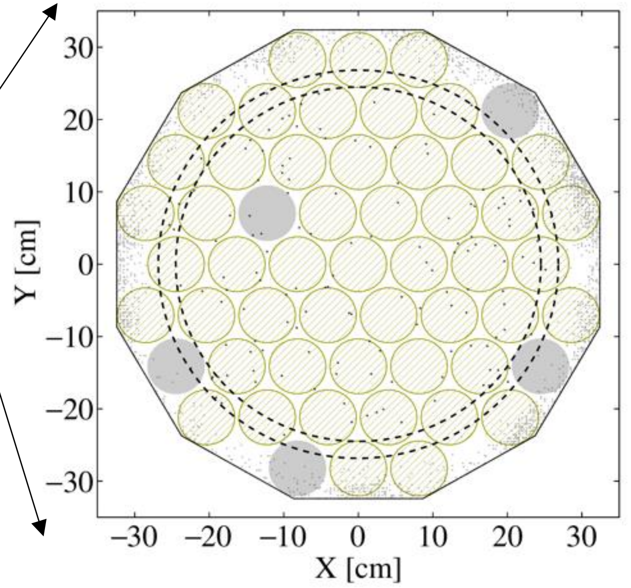
- **Dark matter search with PandaX-II (Ph.D.)**
  - **Coordinated** physical analysis of full exposure data
  - **Developed** a novel method for neutron background estimation
  - Detector R&D, simulation program, operation, and maintenance
- **Neutrino physics with PandaX-4T (Postdoc)**
  - **Undertook** construction of two subsystems, contributed to detector design, simulation, and operation
  - **Coordinated** signal reconstruction in MeV range for ^{136}Xe $2\nu\beta\beta$ search
  - **Coordinated** ^{124}Xe 2νECEC search

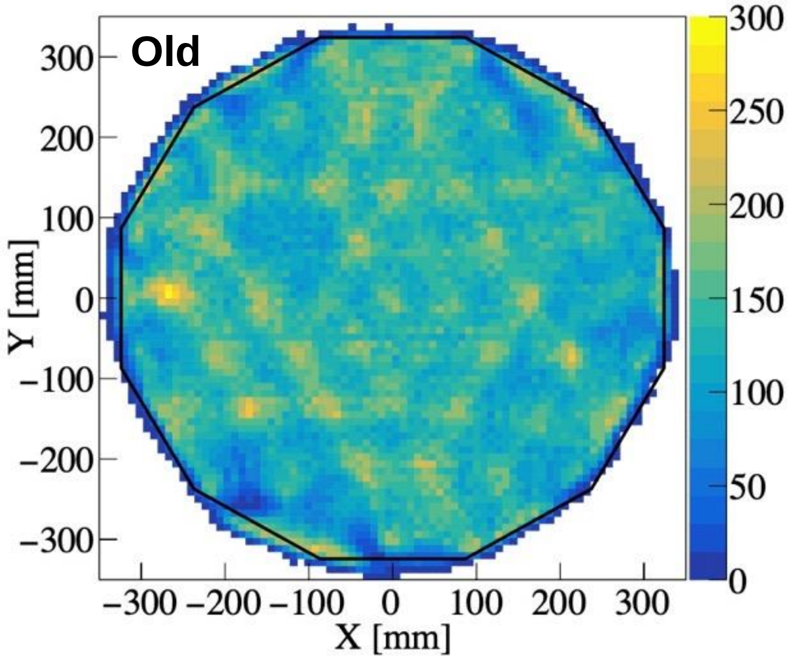


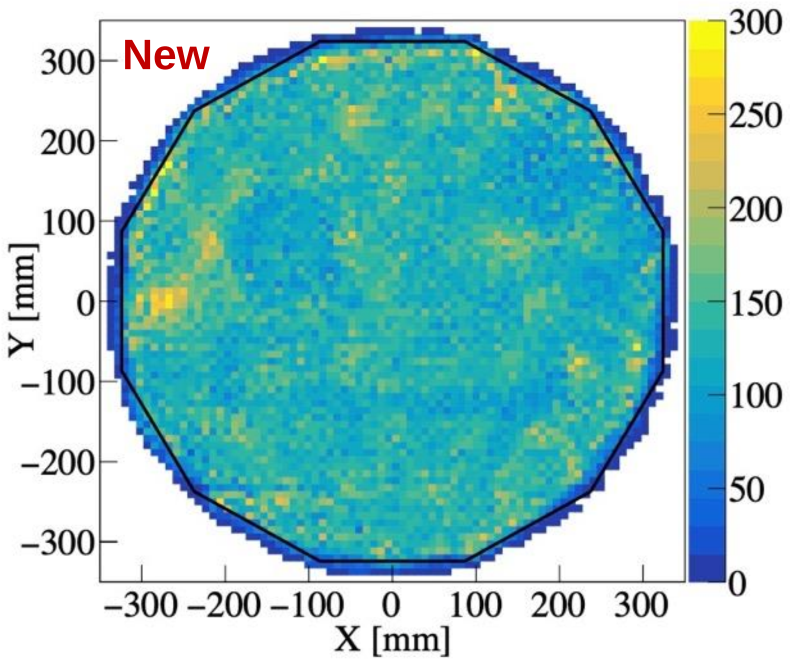
Position Reconstruction in PandaX-II

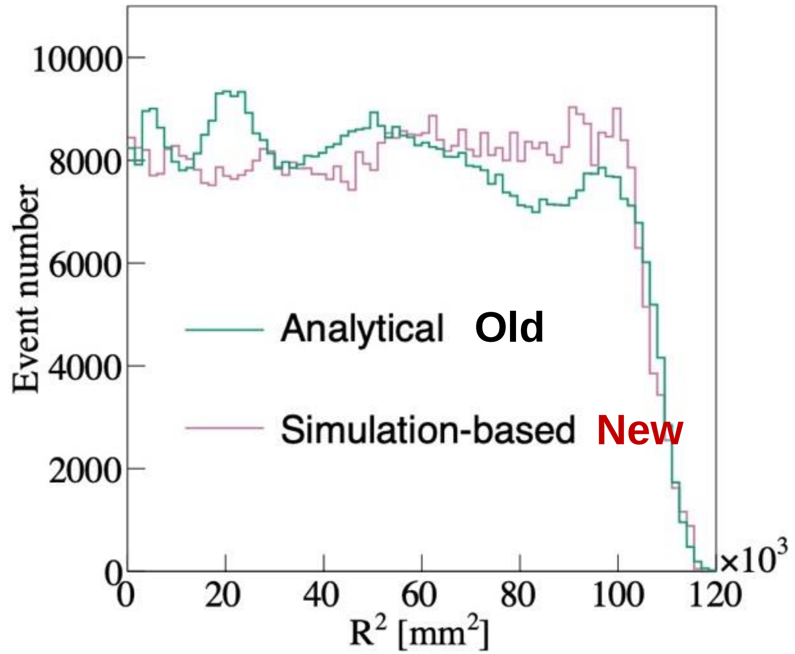
- Trained with evenly distributed ^{83m}Kr calibration events
- Turn off 7 malfunctioned PMTs
  - 5 top and 2 bottom
- Data-driven position reconstruction: photon acceptance function
  - Analytically parameterized PAF (old)
  - Simulation-based PAF: optical simulation of the detector (new)









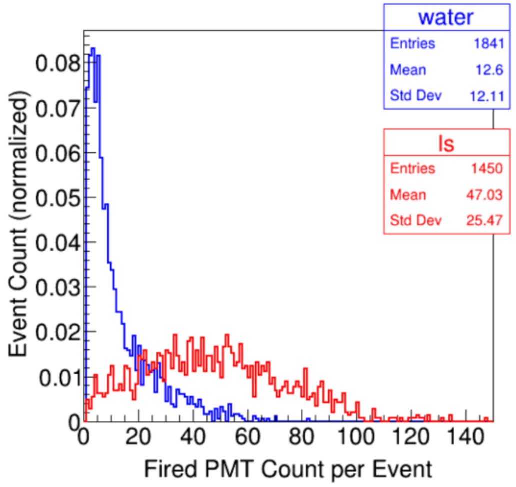


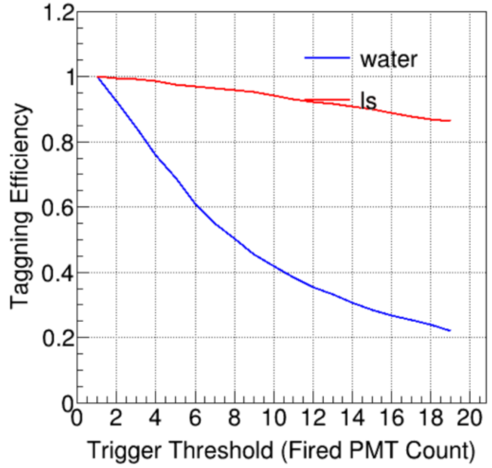
Future upgrade to veto in PandaX-4T

- Pure water veto
  - 78% (13%) for neutron (gamma) veto
- Water-based liquid scintillator
  - ~5% blending, 500 photons / MeV
  - ~100% (60%) for neutron (gamma) veto
- Gadolinium-doping water veto (XENONnT)
  - 68% -> 87% for neutron veto
- LS-based veto (LZ)
  - Chemical and fire hazards for PandaX-4T

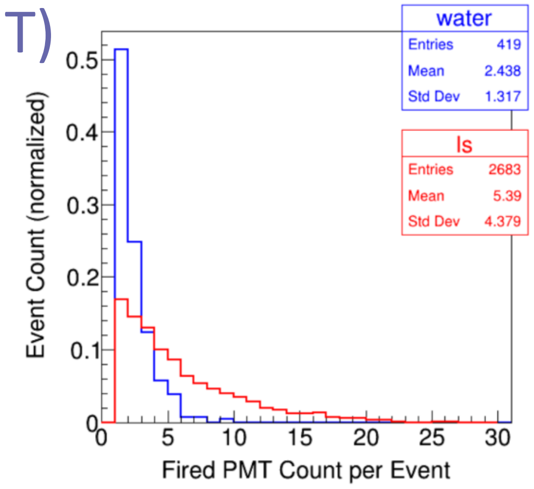
Optical Simulations in Geant4

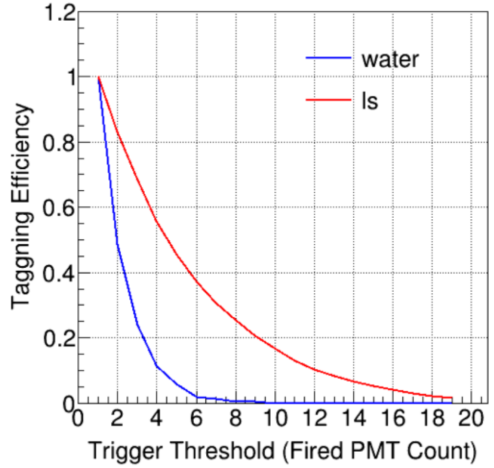
Neutron Veto Efficiency





Neutron Veto Efficiency

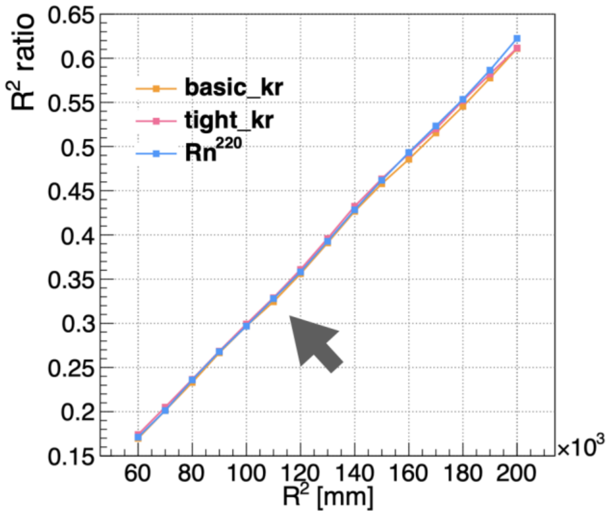


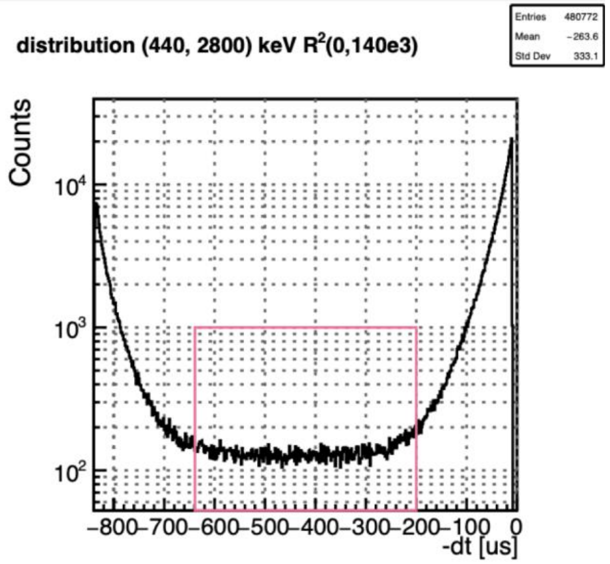


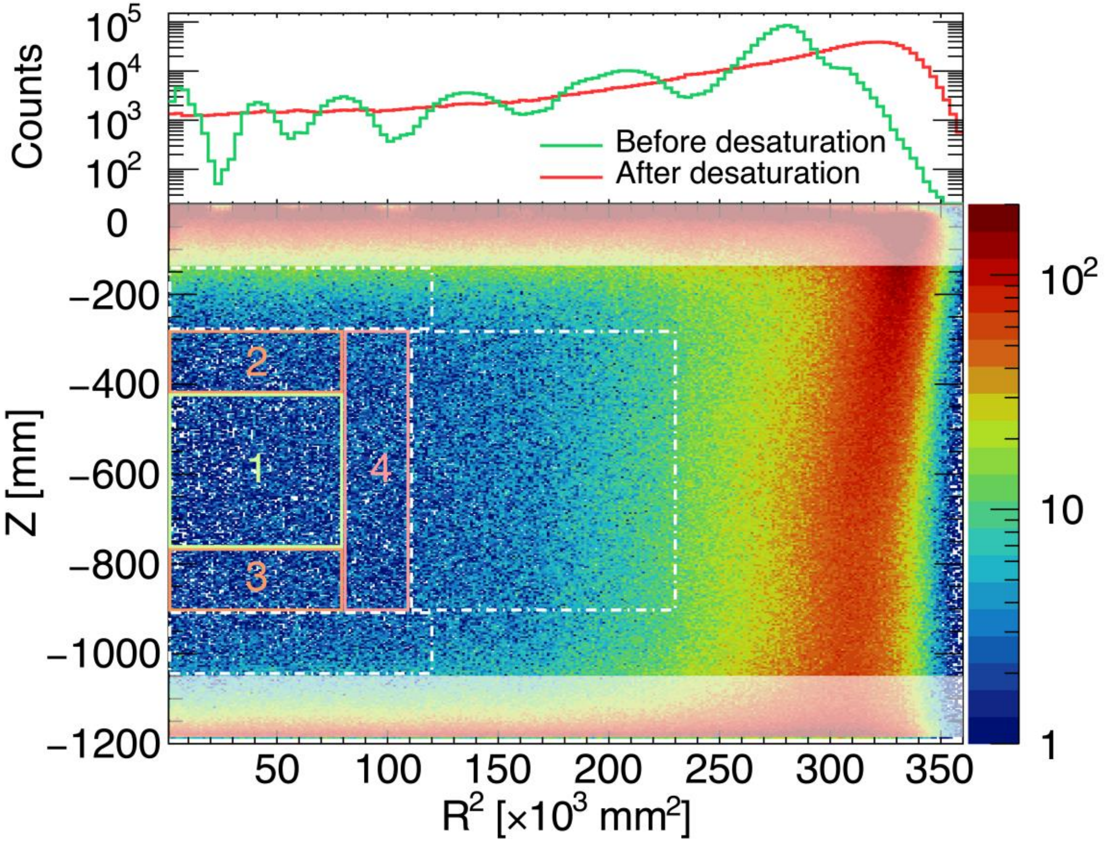
Fiducial volume for ^{136}Xe $2\nu\beta\beta$ search

- 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







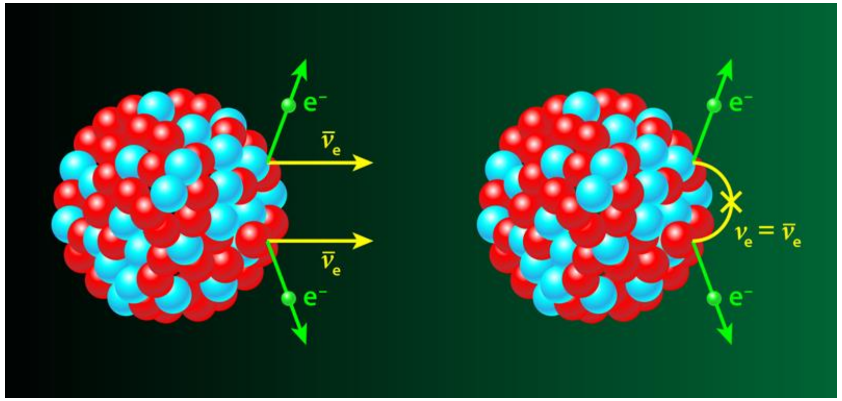
Double beta decay

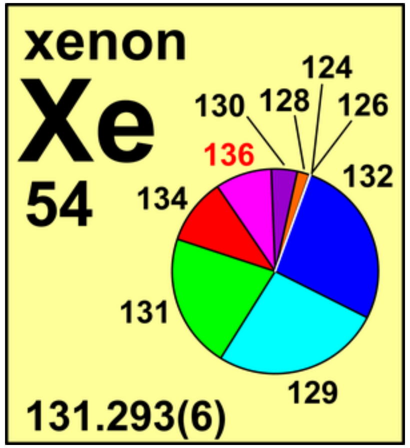
- $0\nu\beta\beta$: Golden channel for Majorana neutrino searches
- $2\nu\beta\beta$ candidate ^{134}Xe (10.4%): the next promising discoveries of $2\nu\beta\beta$

Isotope	Natural abundance[%]	$Q_{\beta\beta}$ [MeV]	$T_{1/2}^{2\nu\beta\beta}$ [yr]
^{48}Ca	0.187	4.26	4.2×10^{19}
^{76}Ge	7.8	2.04	1.5×10^{21}
^{82}Se	8.7	3.00	0.9×10^{20}
^{96}Zr	2.8	3.35	2.0×10^{19}
^{100}Mo	9.8	3.04	7.1×10^{18}
^{116}Cd	7.5	2.81	3.0×10^{19}
^{130}Te	34.1	2.53	0.9×10^{21}
^{136}Xe	8.9	2.46	2.2×10^{21}
^{150}Nd	5.6	3.37	7.8×10^{18}
^{124}Xe	0.1	2.86	1.1×10^{22}
^{134}Xe	10.4	0.83	$\sim10^{24}$
^{128}Te	31.7	0.87	$\sim10^{24}$

the next promising discoveries of $2\nu\beta\beta$

$$^{136}\mathrm{Xe} \rightarrow \ ^{136}\mathrm{Ba} + 2e^{-} + ?\,\nu$$



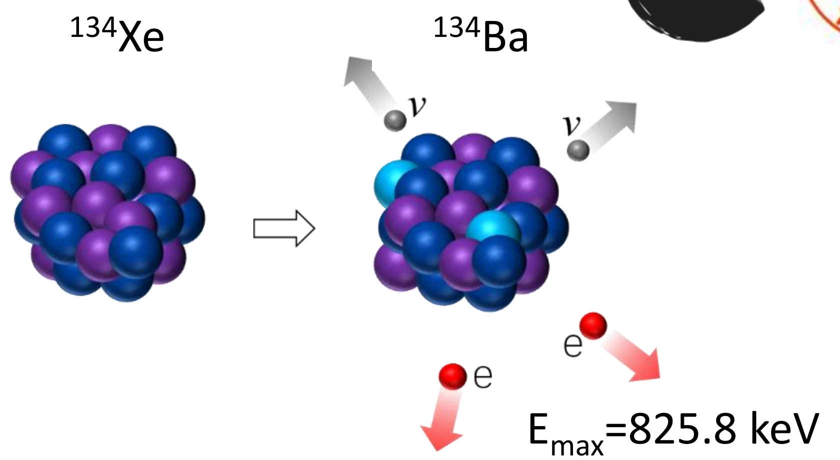


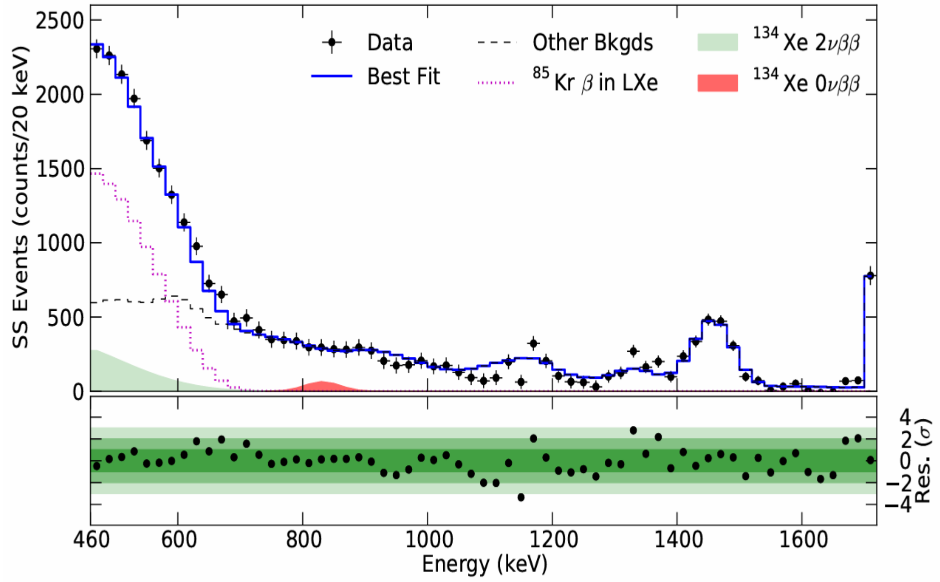
^{134}Xe 2νββ and 0νββ

- Double beta decay of ^{134}Xe into ^{134}Ba:

$$^{134}\mathrm{Xe} \rightarrow ^{134}\mathrm{Ba}^{++} + 2\,e^{-}\ (+2\,\bar{\nu}_e)$$

- Q-value is 825.8±0.9 keV
- Half-life from theoretical predictions: ~10^{24} yr
- Best experiment limits from EXO-200 with 29.6 kg·yr data of ^{134}Xe :
  - $T_{1/2}^{2\nu\beta\beta}$ >8.7·1020 yr at 90% CL
  - $T_{1/2}^{0\nu\beta\beta}$ >1.1·1023 yr at 90% CL
- Isotopic composition in EXO-200 : 80.7% 136 Xe and 19.1% ^{134}Xe
- Energy spectrum: ROI between 460 keV and 740 keV for $2\nu\beta\beta$, energy resolution σ/E=3.56% @825.8 keV

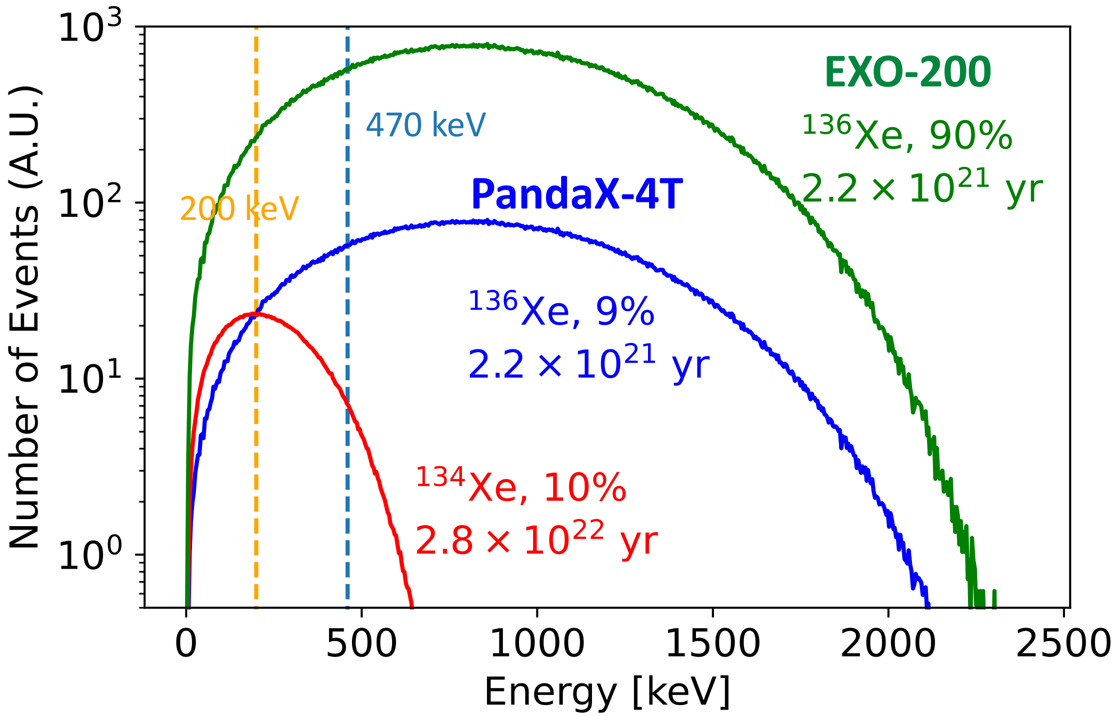




Phys.Rev.D 96 (2017) 9, 092001

Down to [200, 1000] keV for ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ search

- ^{134}Xe event fraction in ROI [200, 1000] keV
  - 60.56% ($2\nu\beta\beta$), 99.98% ($0\nu\beta\beta$)
- Compared to EXO-200, PandaX-4T has:
  - More ^{134}Xe; much less ^{136}Xe; wider energy range; better resolution;
  - Self shielding effect
  - Discovery possible



	Live Time	^{134}Xe mass	^{136}Xe abundance	Analysis threshold	Resolution @$Q_{\beta\beta}$
PandaX-4T	94.9 days	68.7 kg	8.9%	200 keV	2.4%
EXO-200	600 days	18.1 kg	81%	470 keV	3.56%

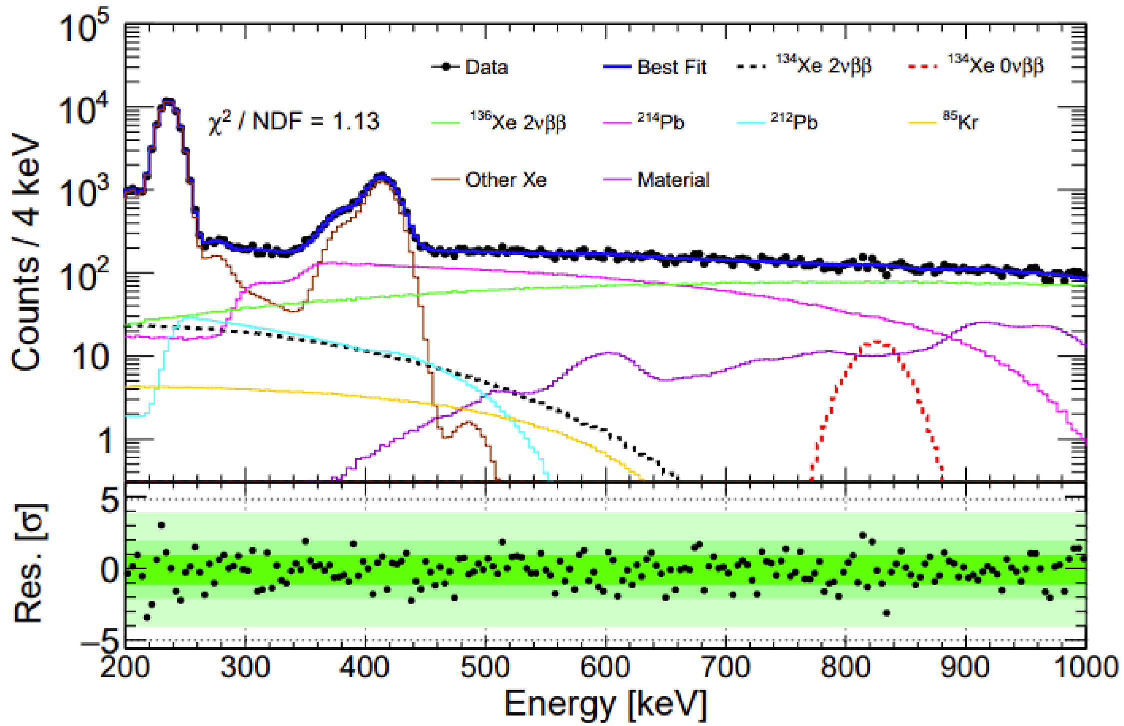
Background model for ^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ search

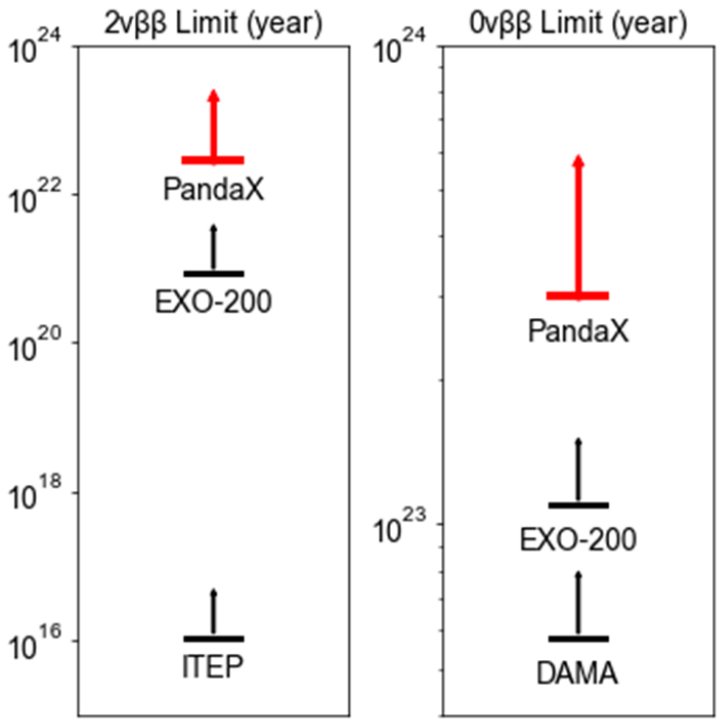
- Down to [200, 1000] keV, more backgrounds in LXe need to be considered

	Component	Input Counts	Constraint	
Materials	^{60}Co	130	13%	Measured in ^{136}Xe $2\nu\beta\beta$ analysis *Research* 2022 (2022) 9798721
	^{40}K	133	8%	
	^{232}Th	950	5%	
	^{238}U	274	8%	
LXe	^{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
	^{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

^{134}Xe $2\nu\beta\beta$ and $0\nu\beta\beta$ search in 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% C.L. lower limits on the half-life： $T_{1/2}^{2\nu\beta\beta} > 2.8\times10^{22}$ yr and $T_{1/2}^{0\nu\beta\beta} > 3.0\times10^{23}$ yr

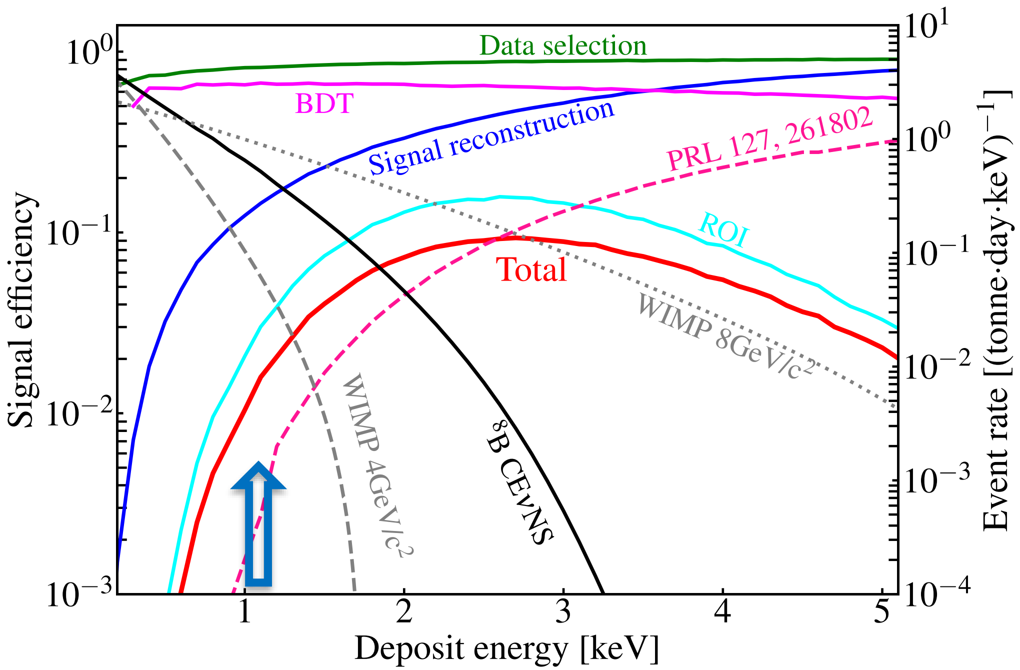


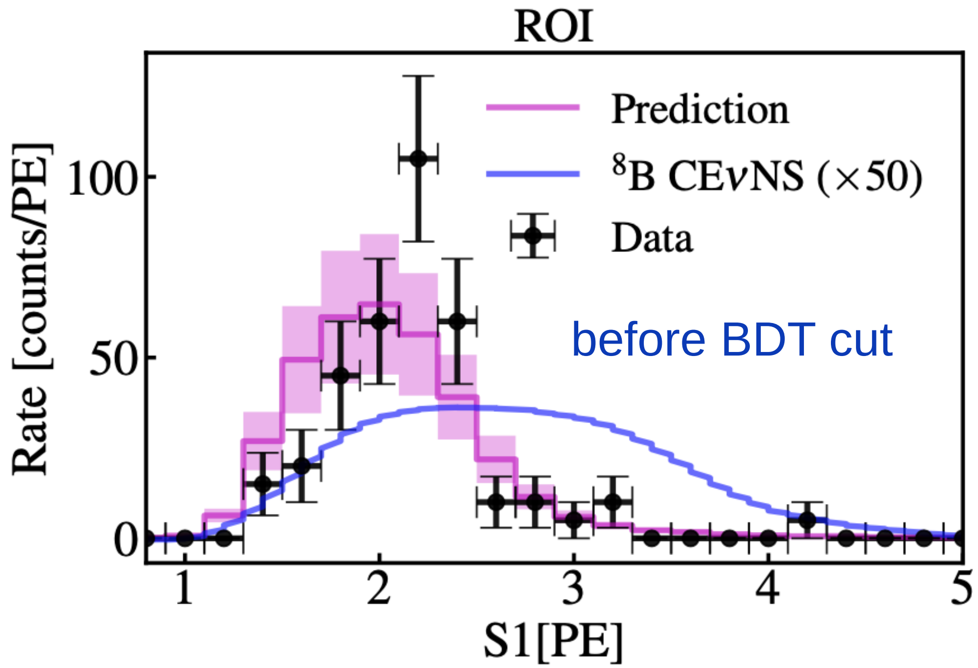


Phys. Rev. Lett. 132 (2024) 15, 152502

Towards the neutrino floor from solar ^8B

- Lowering selection threshold for solar ^8B CEvNS
  - Cut on the scintillation signal (S1) from 2 PE to 0.3 PE
  - Optimizing signal selection cuts with waveform simulation
- Accidental paired (AC) background modeling and rejection

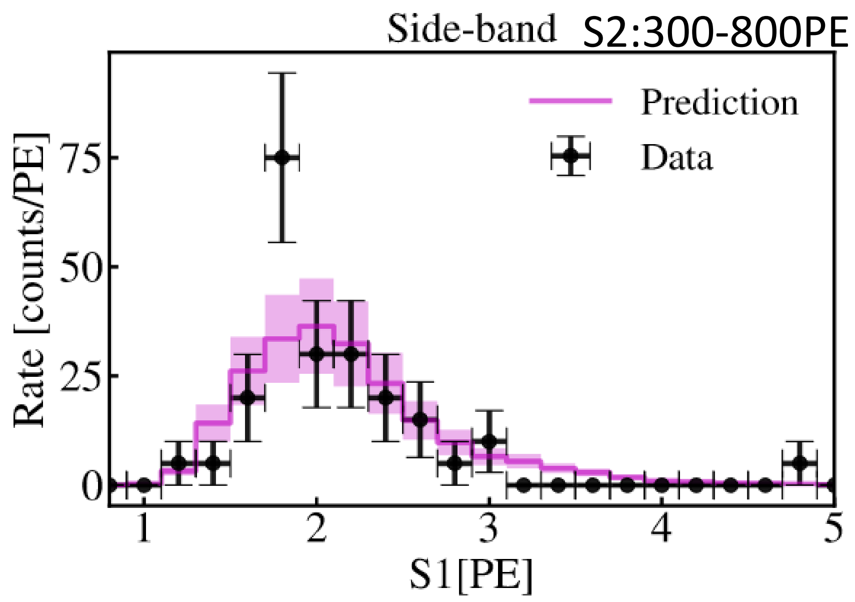


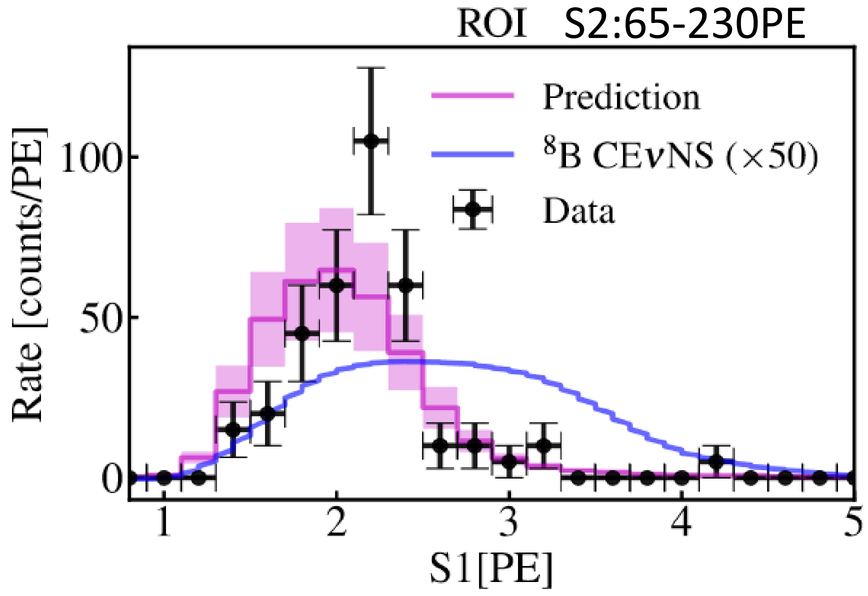


Control of accidental background in ^{8}B search

- Use "scrambled" real data to model accidental background
- A multi-variate **(BDT) algorithm** trained to suppress AC background
- Training/selection is blinded
- postBDT: N_{obs}=1, N_{bkg}=1.6, N_{sig}=1.7

N_{hit}	$S2$ range [PE]	BDT	ER	NR	Surf	AC	Total BKG	^{8}B	**Obs**
2	65-230	pre	0.04	0.10	0.14	62.43	62.71	2.32	**59**
		post	0.02	0.04	0.03	1.41	1.50	1.42	**1**
3	65-190	pre	0.01	0.05	0.08	0.79	0.93	0.42	**2**
		post	0.00	0.02	0.03	0.02	0.07	0.29	**0**



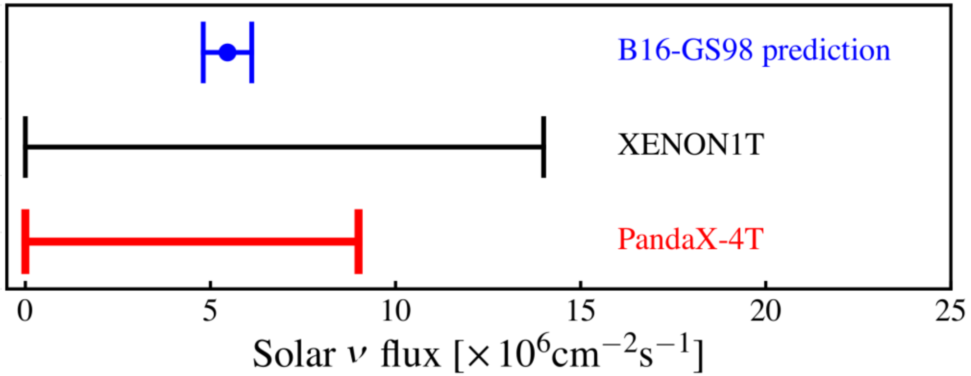


Constraints on ^{8}B neutrino

- A multi-variate (BDT) algorithm trained to suppress AC background
- Blind analysis with 0.48 tonne-year data in Run0
- Leading constraint on ^{8}B neutrino flux through CEvNS
  - Upper limit of 9.0×10^{6} cm^{-2} s^{-1}

ROI (BDT applied)

ER+NR+AC	8B	**Total prediction**	**Unblind data**
1.46	1.42	**2.88**	**1**
0.04	0.29	**0.33**	**0**



Phys. Rev. Lett. 130, 021802 (2023)