Recent Progress and Plan of PandaX Experiment

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University of Science and Technology of China

On behalf of the PandaX Collaboration

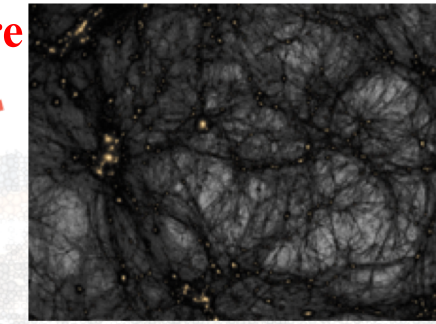
ICHEP, 2022/07/06 – 2022/07/13

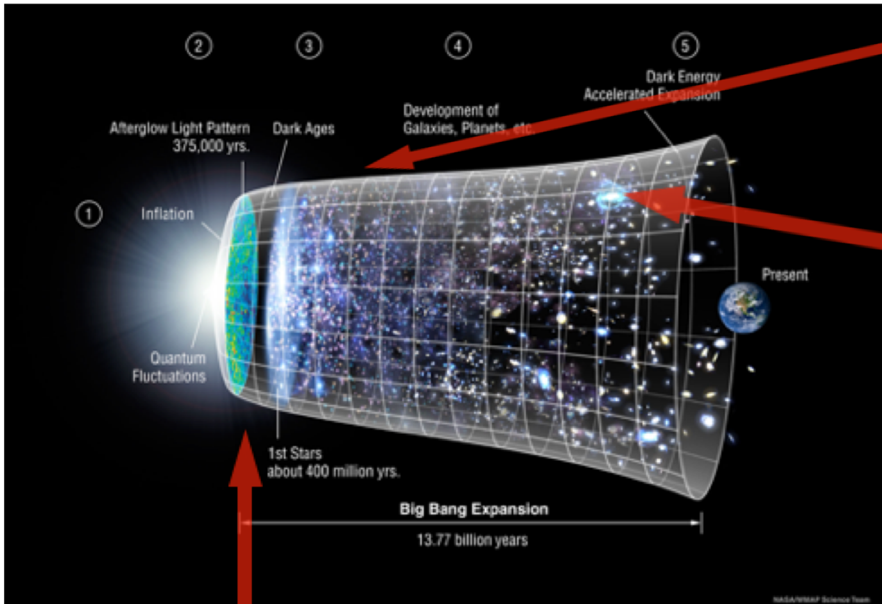
PANDA X

PARTICLE AND ASTROPHYSICAL XENON TPC

Dark Matter and its Gravitational evidence

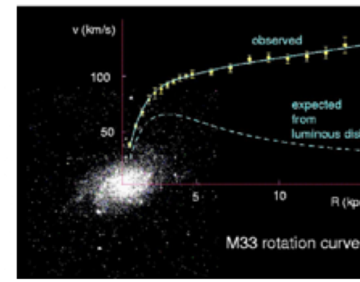
Large Structure





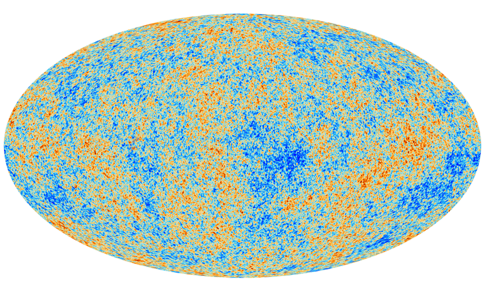
Small Structure

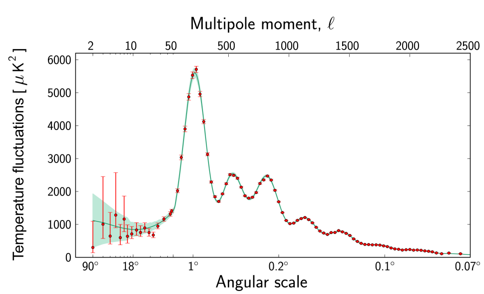
Bullet cluster collision

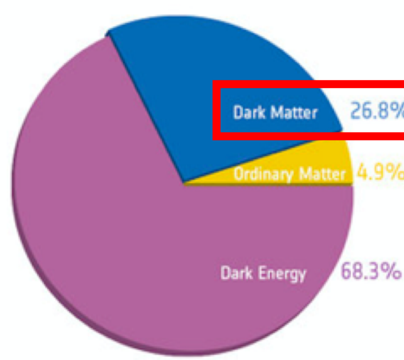


Galaxy rotation curve

Primordial Universe







Gravitational evidences suggest dark matter is the dominant form of matter in Universe!

PandaX Collaboration

PandaX

SINAP CNNC 雅砻江水电

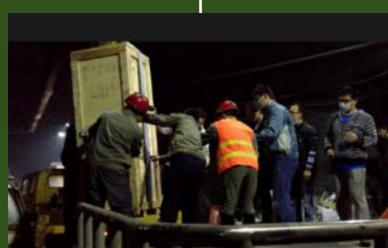
PandaX Experiments

Particle and Astrophysical Xenon Experiments

Collaboration formed

2009.3

2012.7



PandaX-I apparatus moved to Jinping

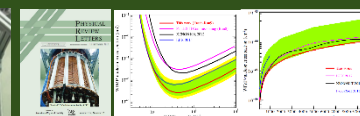
PandaX-I started

2014.3

2014.5-10

PandaX-I, 120 kg operation

PandaX-II, 580 kg operation

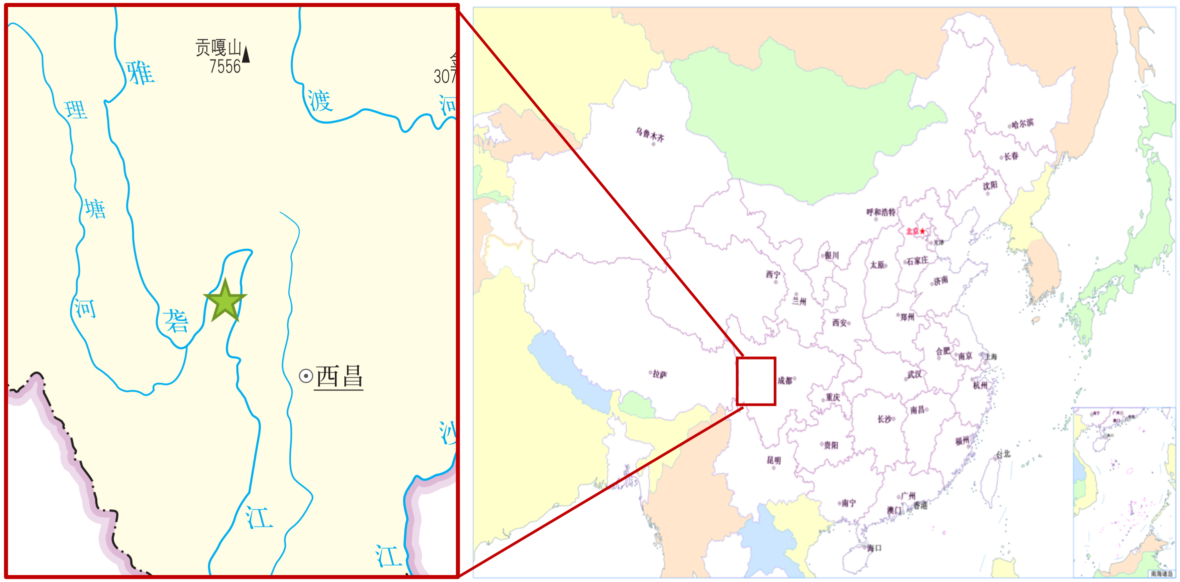


2016.7 -2019.7

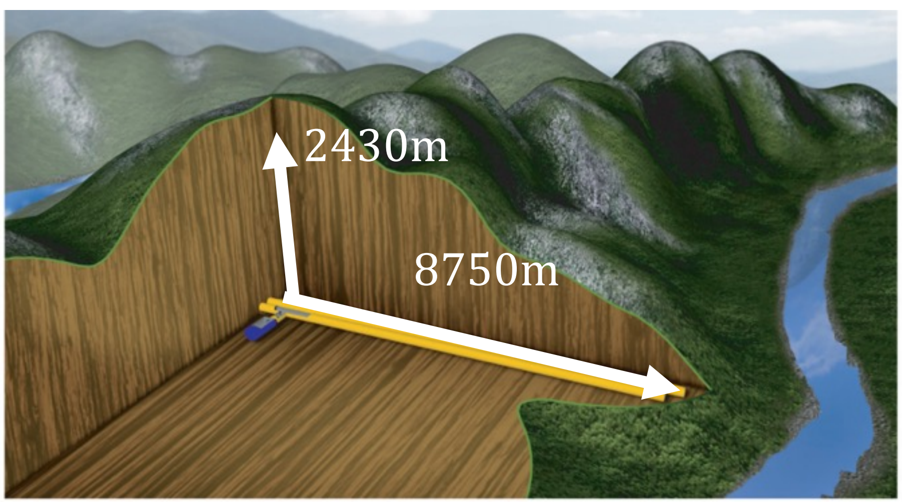
2019.8-

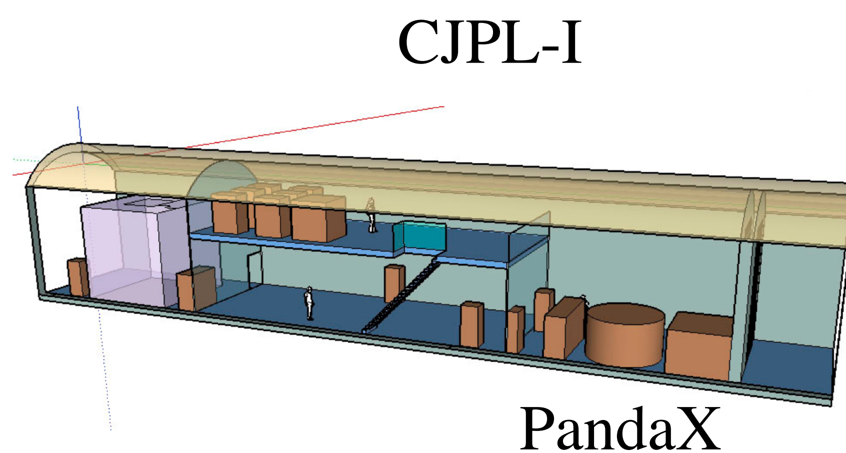
PandaX-4T moved to CJPL-II

CJPL: Deepest Underground Lab



- Deepest (6800 m.w.e): < 0.2 muons/m^2/day
- Horizontal access with ~9 km long tunnel: large truck can drive in.
- National key science research facility for dark matter searches, neutrino physics, and astroparticle physics, etc.





CJPL-II: Much Larger

PANDAX

300k m^3 with eight main halls of 14x14x64 m (4k m3 of CJPL-I)

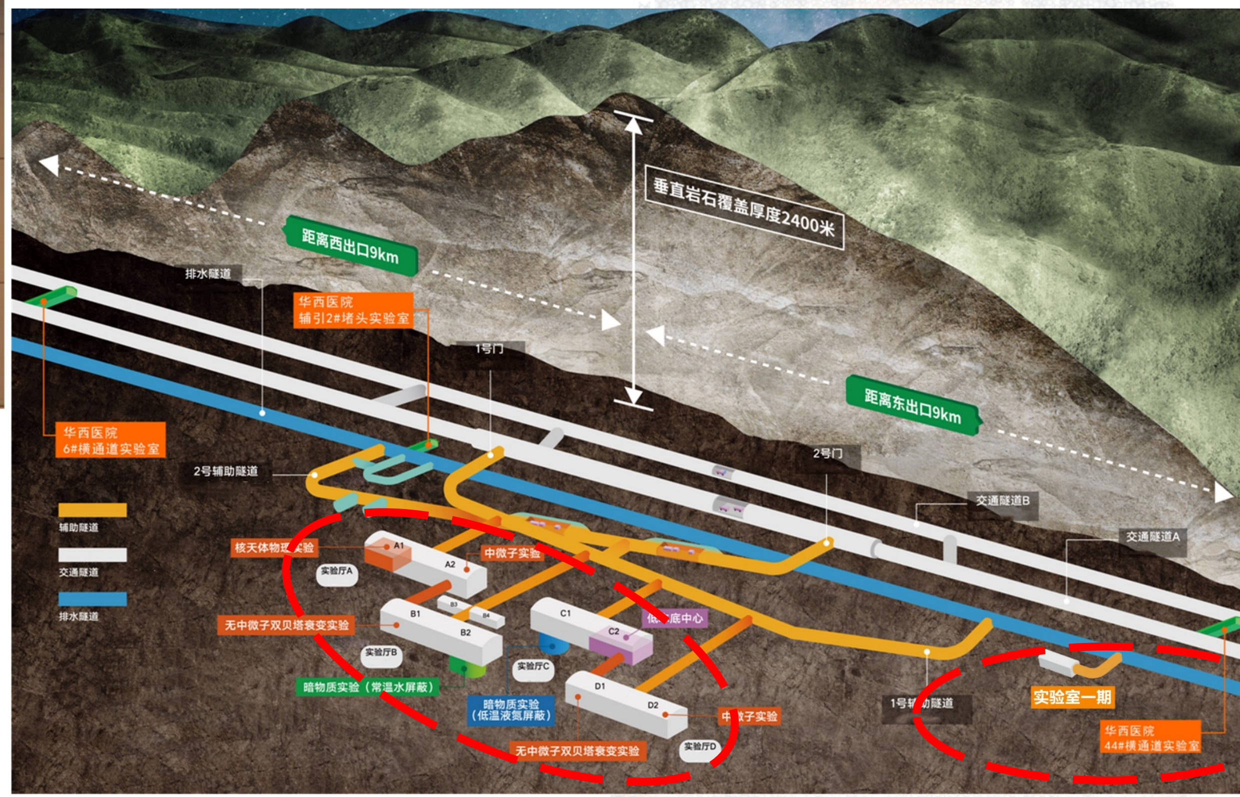
PHYSICS

China supersizes its underground physics lab

Planned expansion could pave way for "ultimate dark matter experiment"

The world's deepest physics laboratory is about to become one of its largest. Early next year, workers will start carving four cavernous experiment halls along a tunnel through Jinping Mountain in China's Sichuan province. Once the science at the China Jinping Underground Laboratory (CJPL) is scaled up as well, "it will be a milestone for Chinese physics," says Nigel Smith, director of the underground SNOLAB in Sudbury, Canada

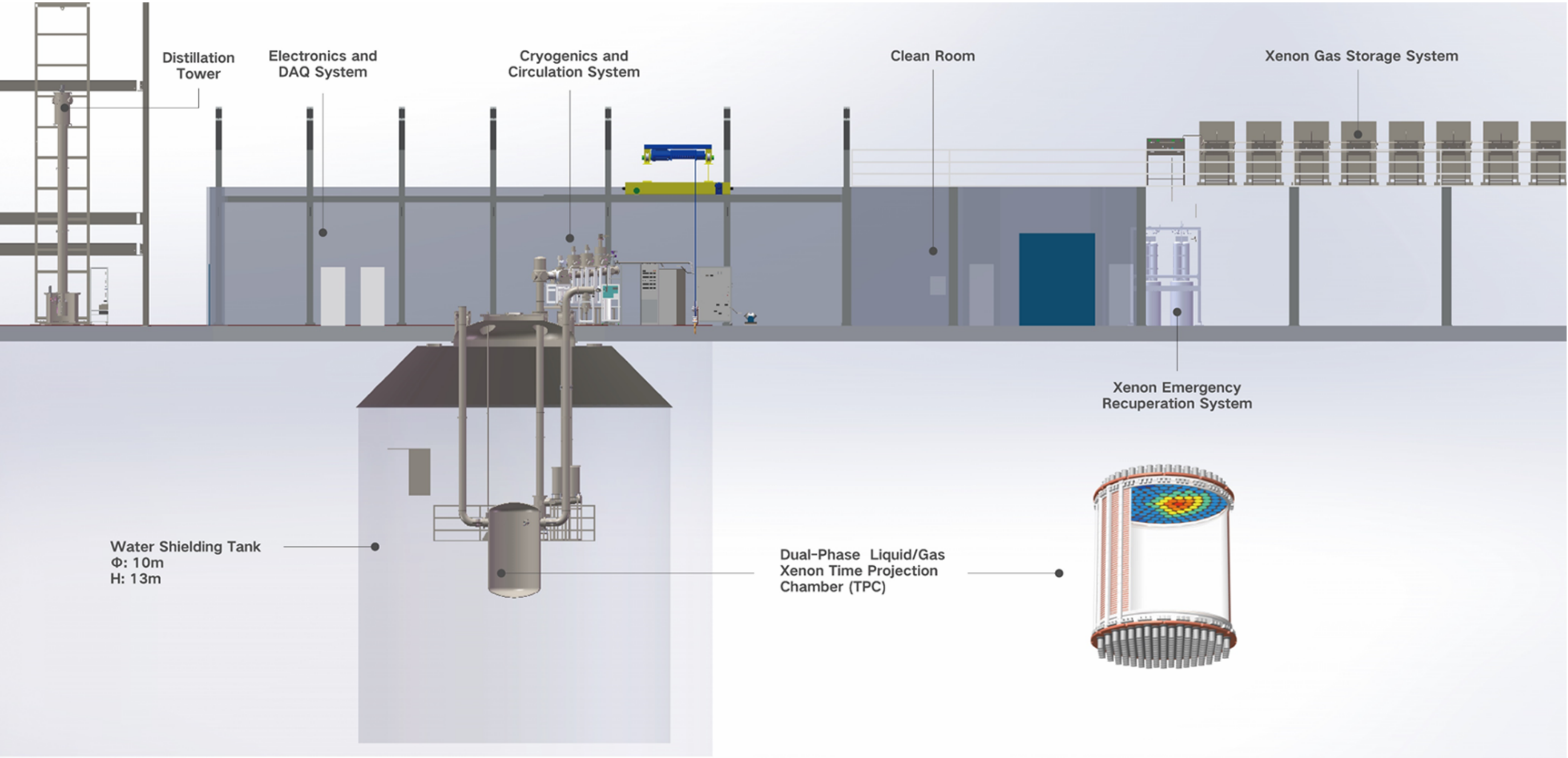
Science, Nov. 30, 2014



CJPL-II

CJPL-I

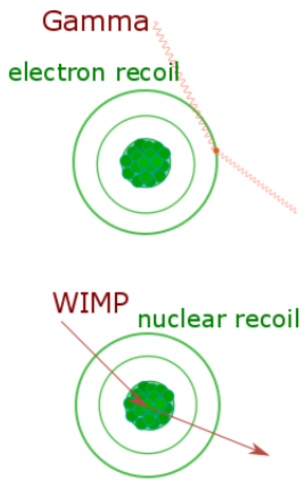
PandaX-4T overview @ CJPL-II

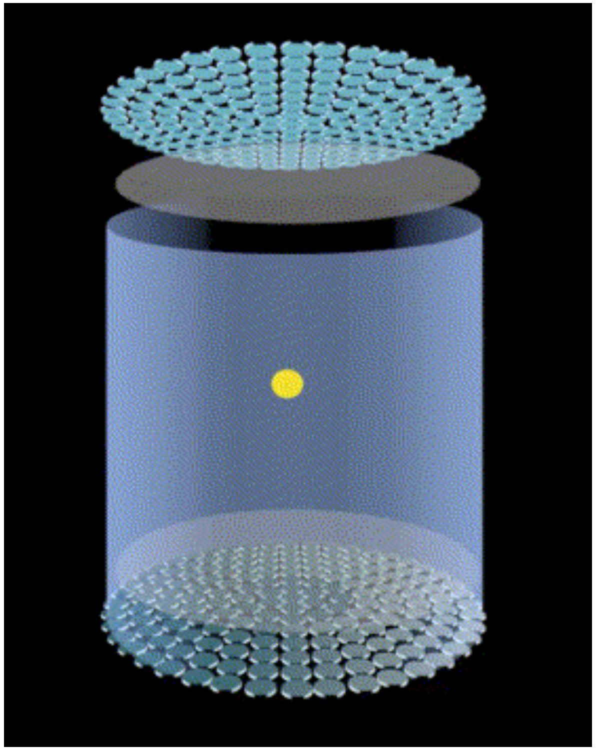


- ❑ Ultrapure water shield: 13 m (H) x 10 m (D) ~ 900 m^3
- ❑ TPC: 1.2 m (H) x 1.2 m (D)
- ❑ 3-in PMTs: 169 top/199 bottom

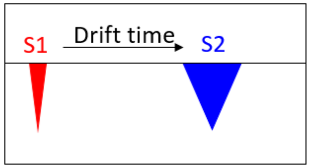
- Sensitive volume: 3.7-tonne LXe

Dual phase xenon TPC

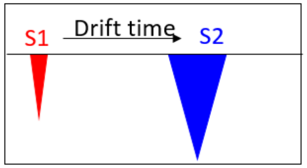




Dark matter: nuclear recoil (NR)

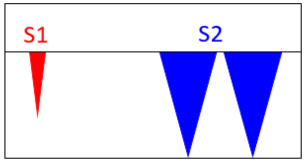


γ background: electron recoil (ER)



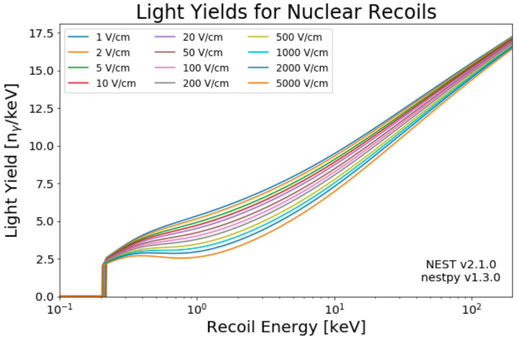
$(S2/S1)_{NR} << (S2/S1)_{ER}$

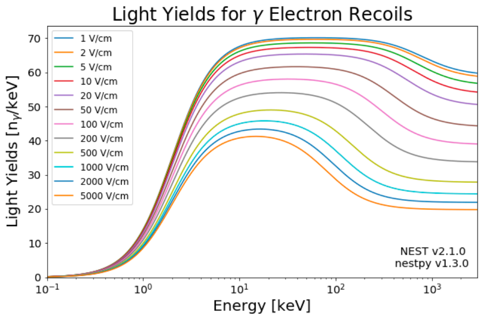
Multi-site scattering background (ER or NR)



Detector capability:

- Large monolithic target
- 3D reconstruction and fiducialization
- Good ER/NR rejection
- Calorimeter capable of seeing a couple of photons/electrons

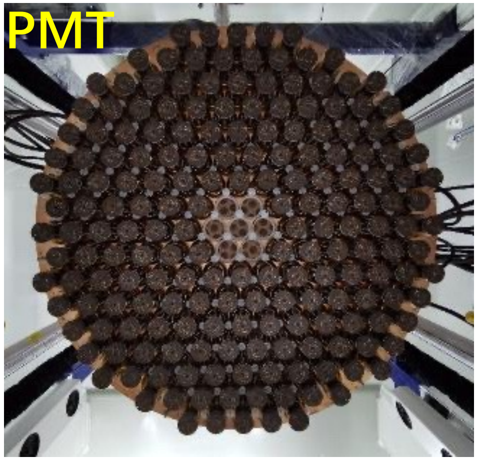


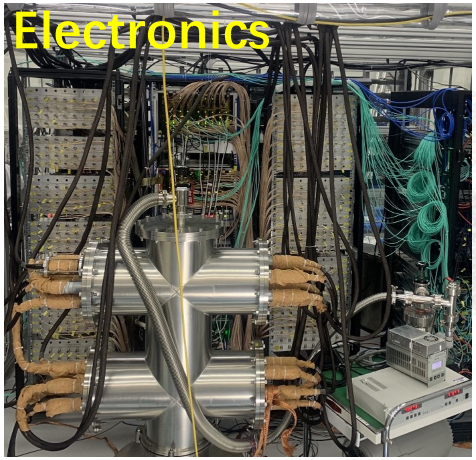


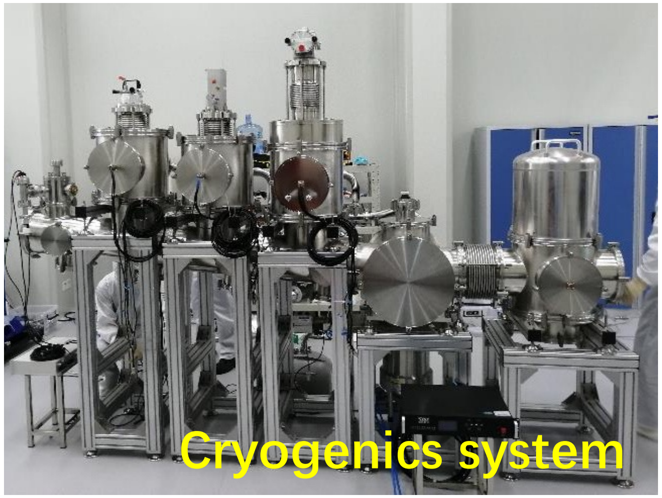
https://nest.physics.ucdavis.edu/benchmark-plots

PandaX-4T Experiment

PandaX-4T Subsystems

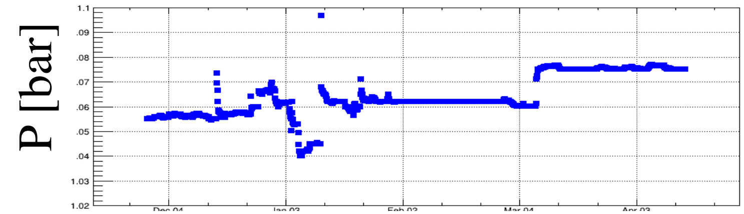


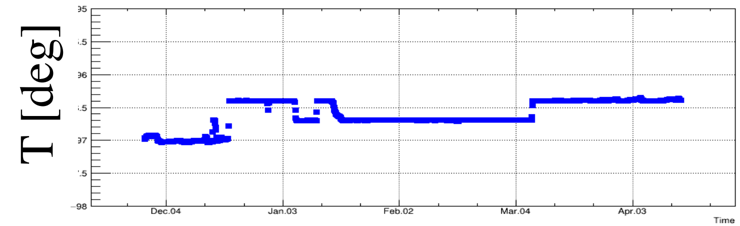


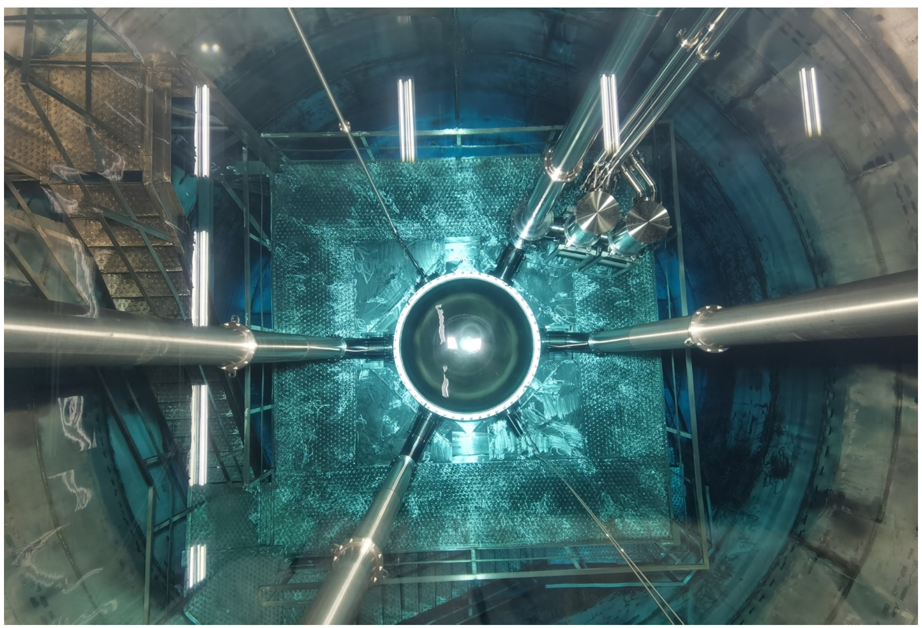


PandaX-4T Commissioning

- Electron lifetime: *in situ* S2 vertical uniformity calibration
- Ref: the maximum drift time ~ 840 μs (field dependent)
- Two gas loops for purification
- Stable data running period: 95.0 calendar days （86 days after selection)

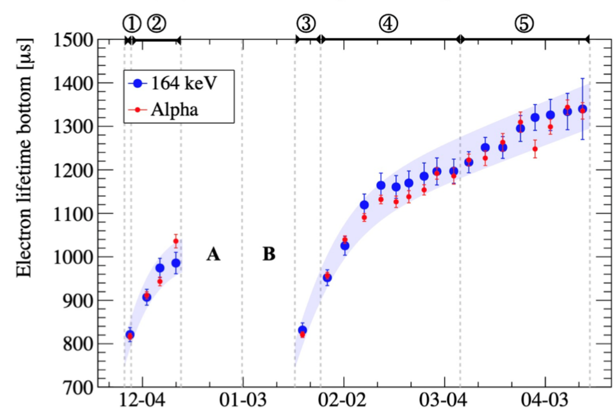






	Set 1	Set2	Set3	Set 4	Set5
Gate(kV)	-4.9		-5	-5	
Cathode (kV)	-20	-18.6	-18	-16	

①-⑤: Commissioning data taking subset



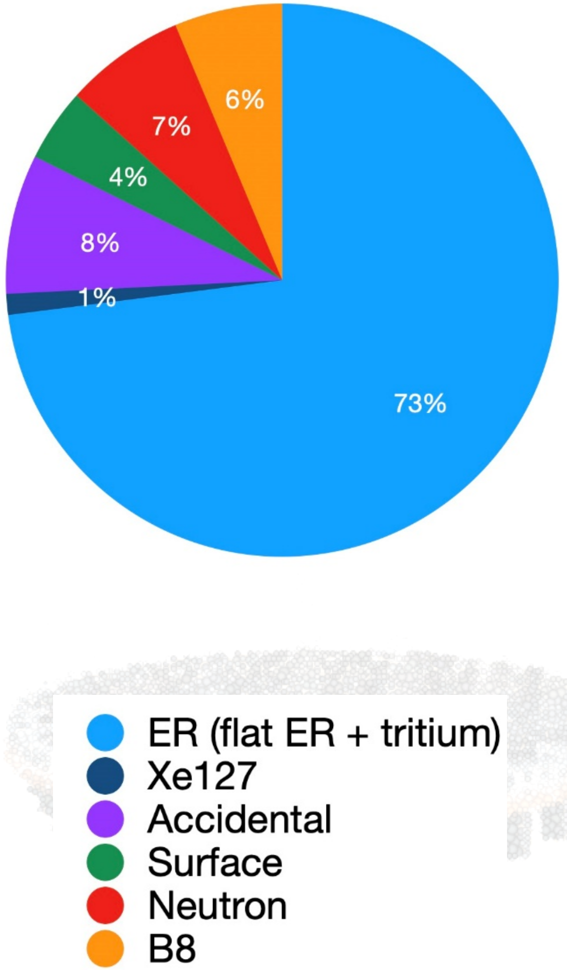
A: HV training
B: Circulation pump replacement

Background composition

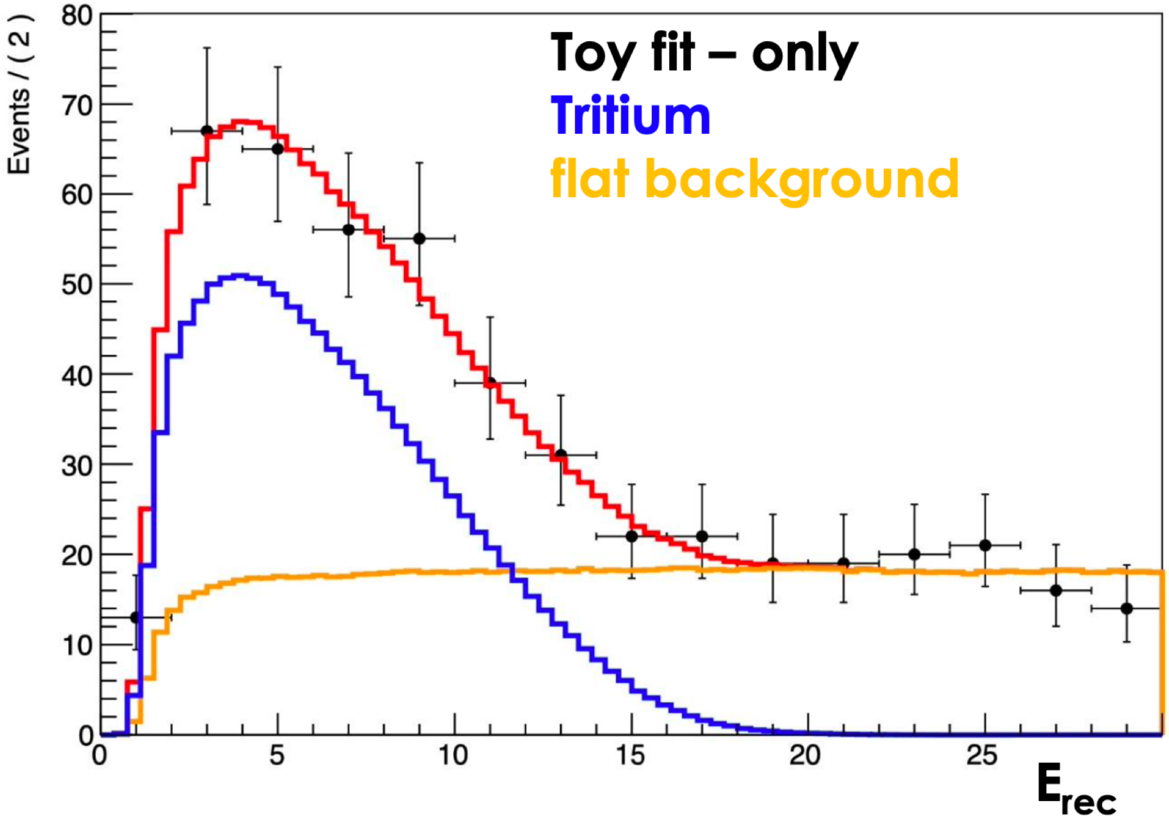
Component	Nominal (evts)
^{3}T (from fit to data)	532 (32)
Flat ER* (18-30keV side band)	492 (31)
Rn	347 (190)
Kr	53 (34)
Material	33 (4)
Xe127	8 (1)
Neutron	0.9 (0.5)
Neutron-X	0.2 (0.1)
Surface	0.5 (0.1)
Accidental	2.4 (0.5)
B8	0.6 (0.3)
Sum	1037 (45)

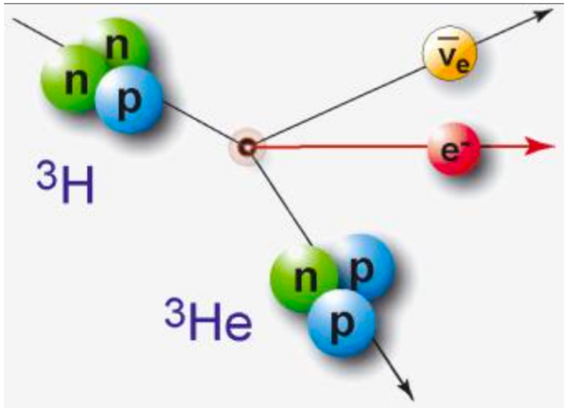
- Flat ER (Rn+Kr+Material) is determined from side band in DM data
- Background per unit target is improved from PandaX-II by 4 times (<10 keV)

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



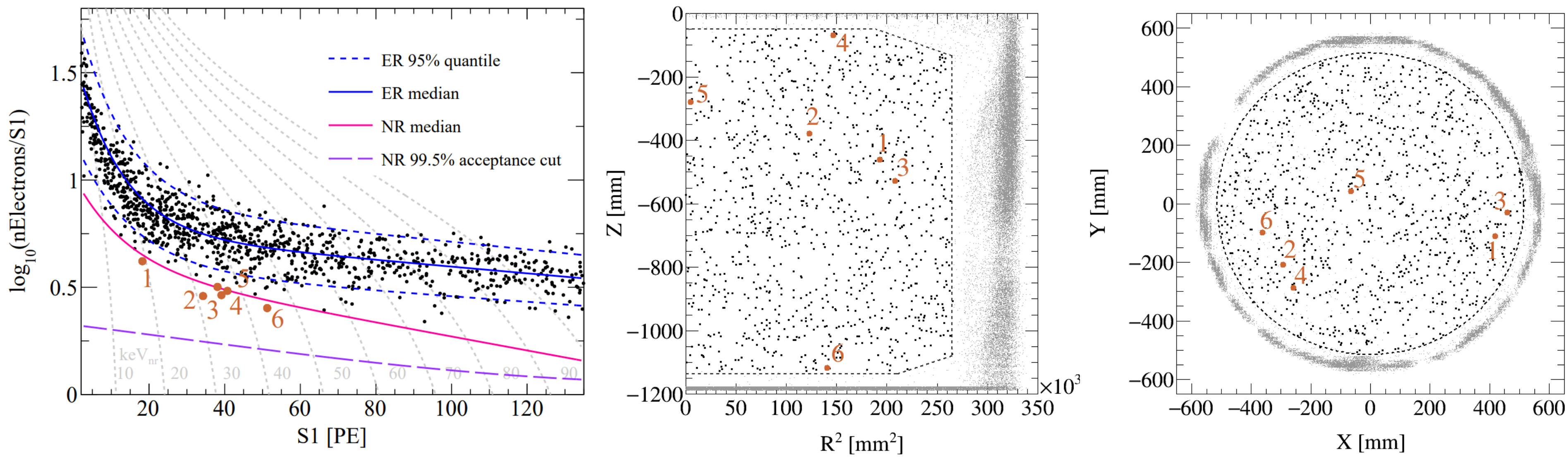
Tritium background





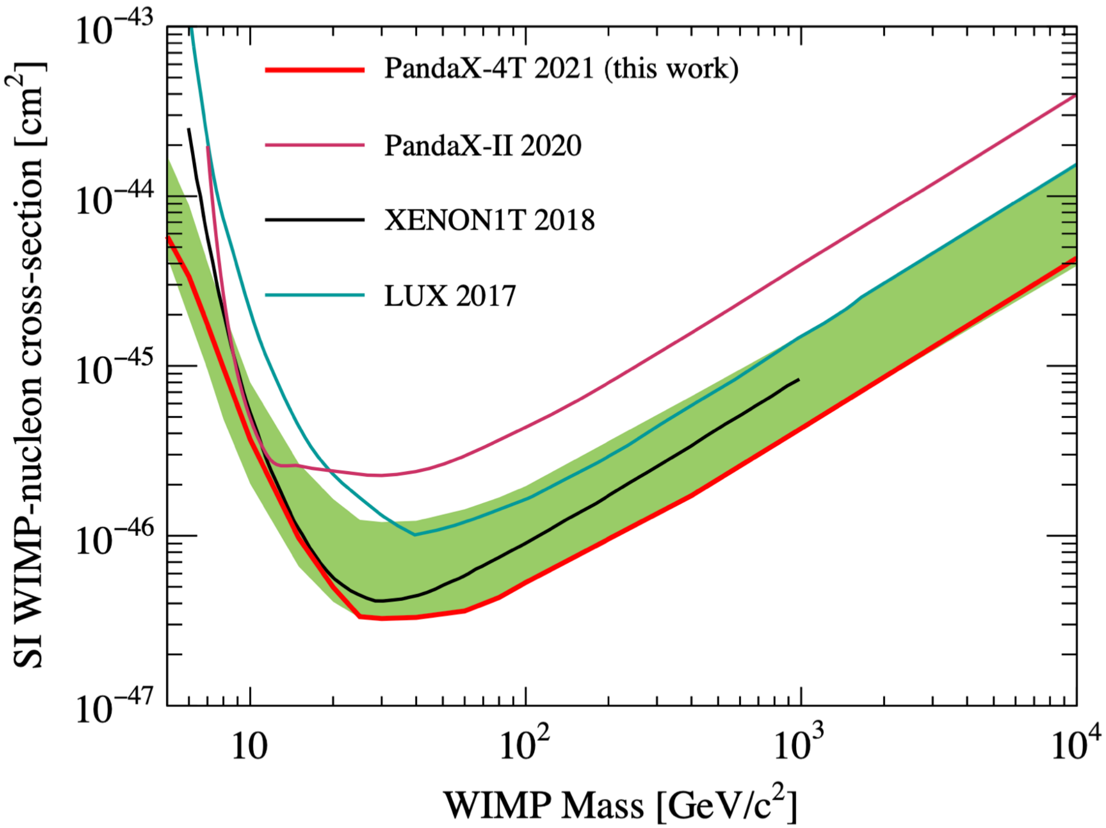
- ➢ Tritium spectrum identified in data;
- ➢ Likely originated from CH3T calibration in the end of PandaX-II;
- ➢ Rate floated in final statistical fit which obtained $5(0.3)\times10^{-24}$(mol/mol)

DM candidates & position distribution



- S1 = (2, 135) PE, $S2_{raw}$ > 80 PE, S2 < 20000
- FV = 2.67 tonne
- 1058 candidates (expected 1054±39), 6 below NR median curve (expected 9.8±0.6)
- Events uniformly distributed in the FV, as expected if dominated by tritium and radon

WIMP-nucleon SI exclusion limits



- Exposure: 0.63 tonne•year
- 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

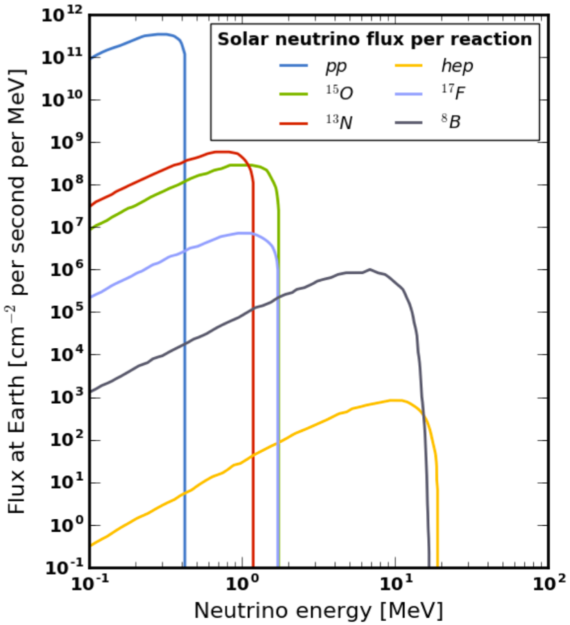
Post-WIMP Analyses

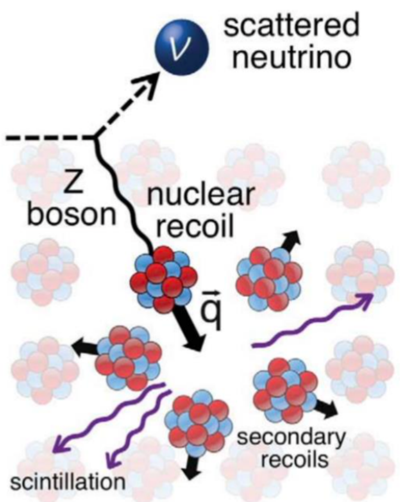
Dark Matter Energy

<keV	~ keV – 30 keV	>30 keV
B8 CEvNS; Low-mass WIMP; WIMP-electron scatter; Self-interacting DM;	Spin-dependent DM; Self-interacting DM; DM Absorption; Migdal effect Solar axion & axion-like particles; EFT; Superheavy DM;	(Neutrinoless) Double beta decay; Xe124 double electron capture; Solar pp neutrino electron scatter;

We are taking data with lowered background for more exposure.

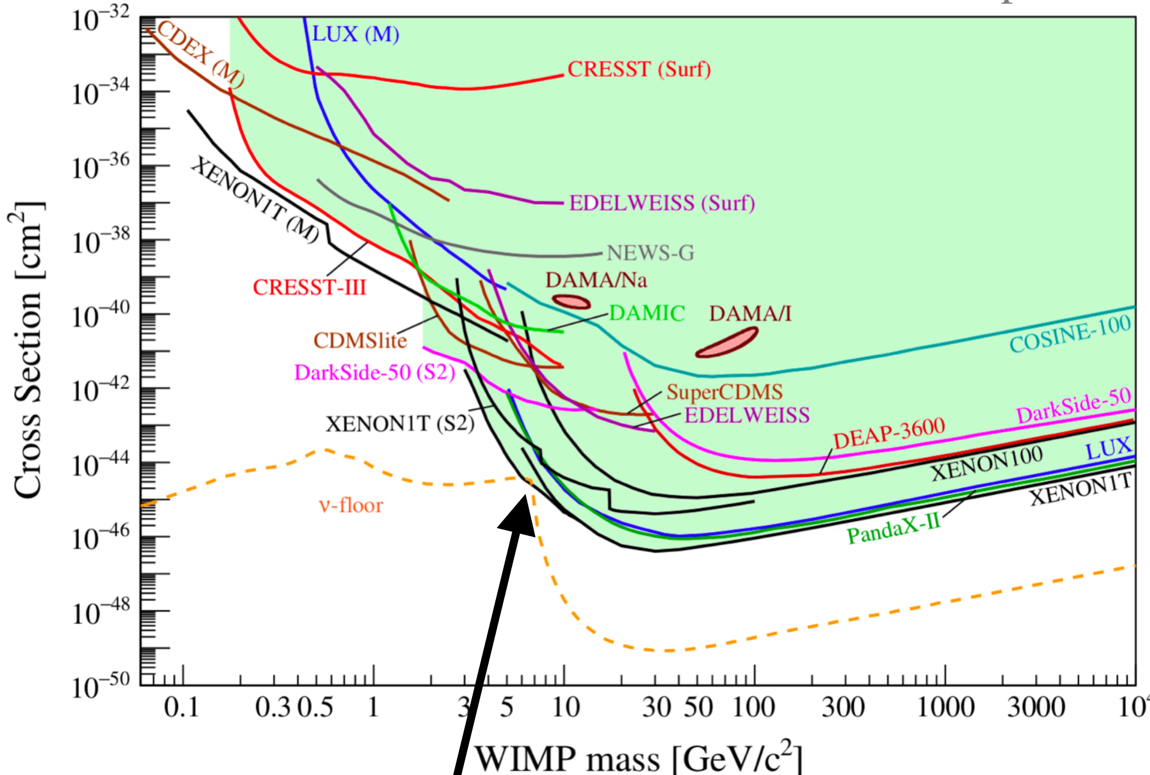
Solar B8 neutrino





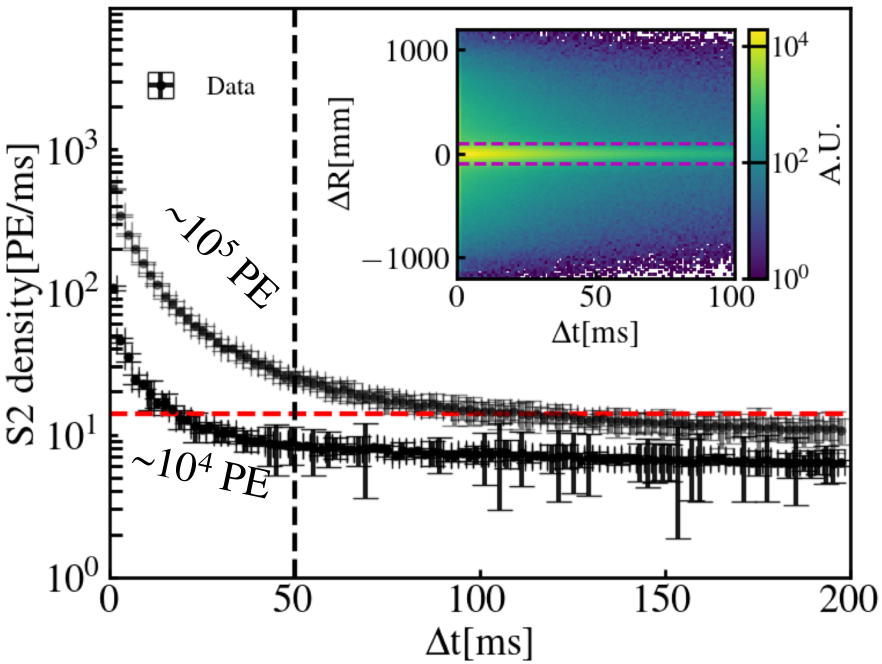
10.1126/science.aao0990

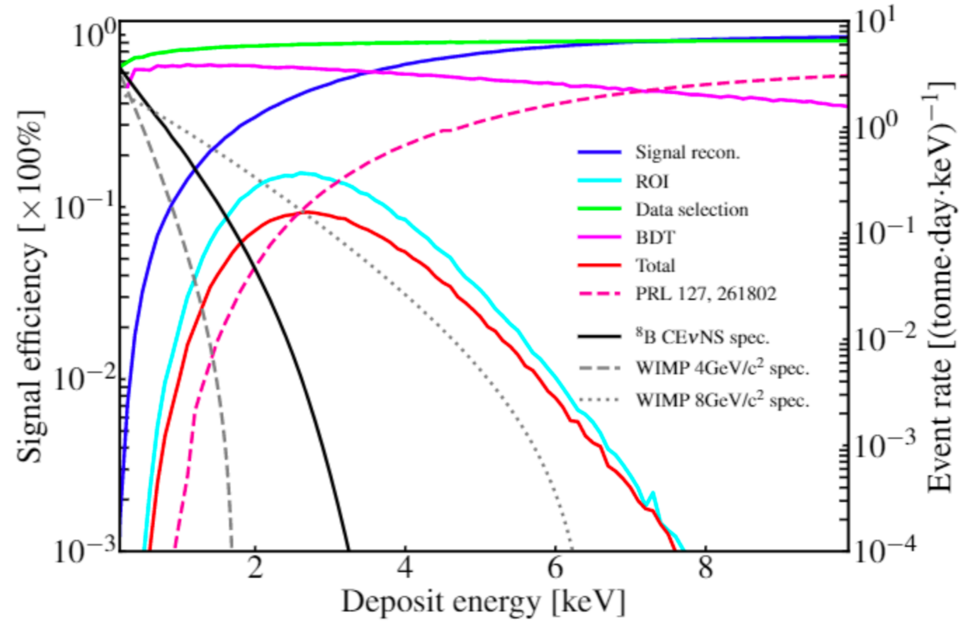
APPEC report



- DM detector start to be sensitive to B8 neutrino CEvNS;
- XENON1T (PRL 126, 091301) expects 2, sees 0.

PandaX-4T search on B8 CEvNS



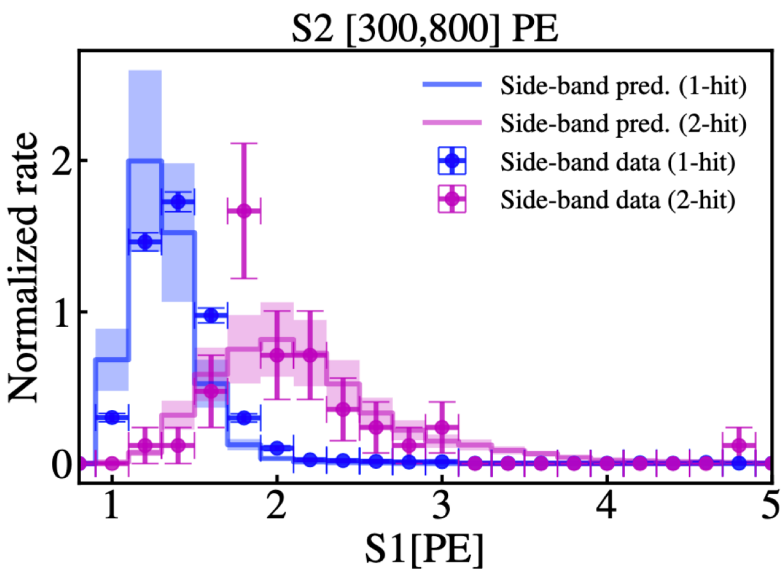


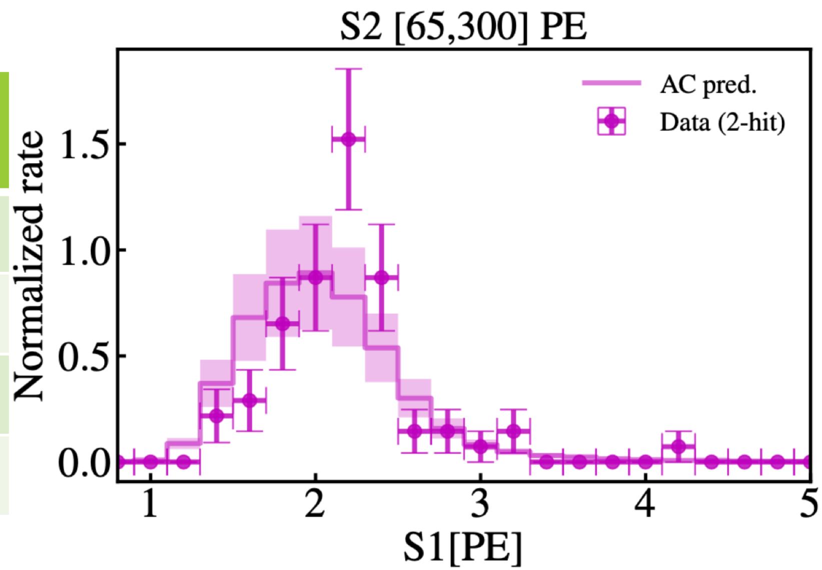
- To increase the sensitivity, lower threshold is required.
- Key difficulty: Accidental pileup emerges.
- Various techniques used: waveform simulation & boosted decision tree.
- Blind analysis is performed with 0.48 tonne-year data, which has a software veto excluding time and position with high rates.

AC background

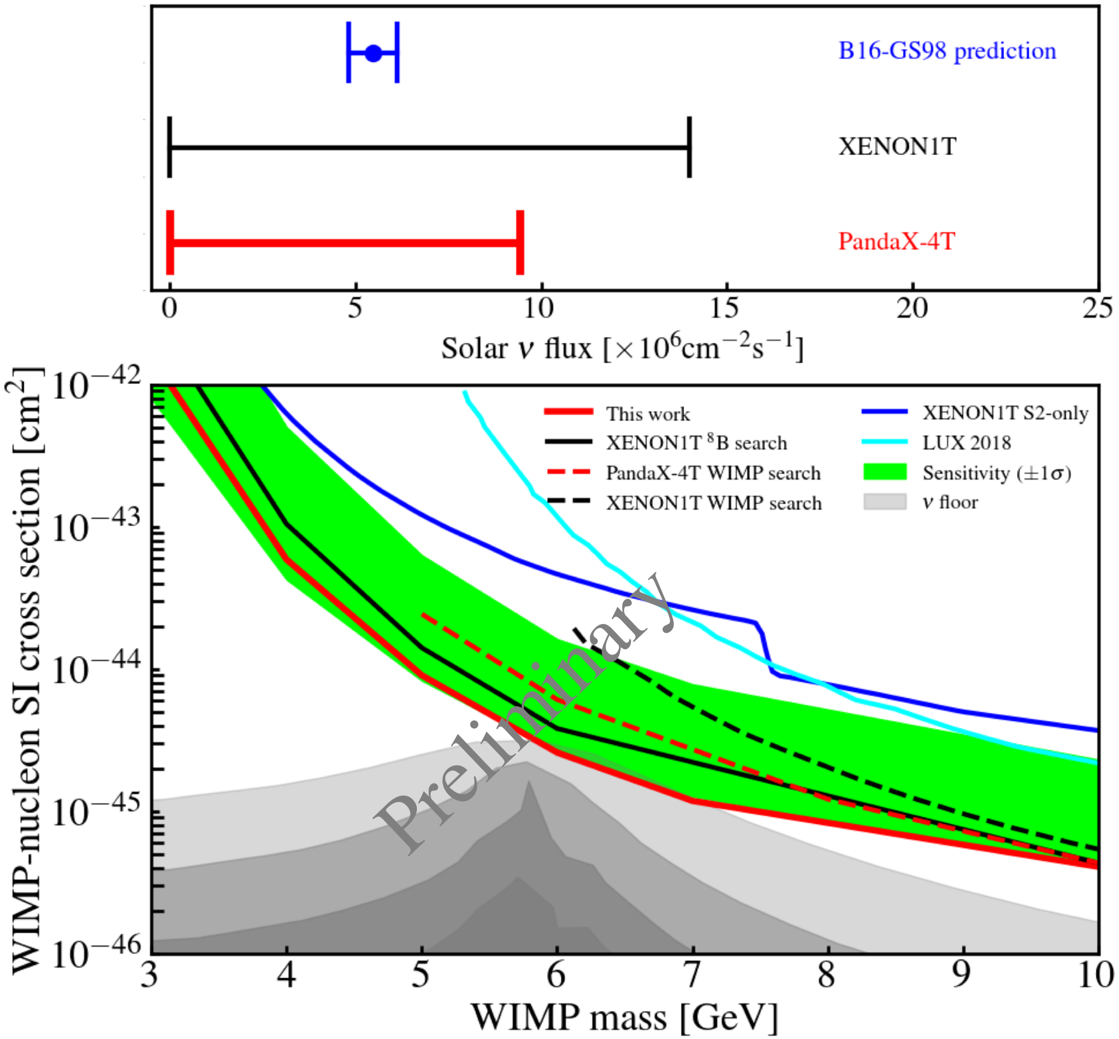
- AC samples are "scrambled" S1s & S2s.
- Boosted Decision Tree (BDT) is trained to maximize the B8-to-AC ratio.
- Trained with simulation + "scrambed" AC sample;
- Tested on neutron calibration and alternative AC samples, gaining ~25% and ~20% uncertainty for signal and background.
- Downward probability of ~20%.

Nhit	BDT	Expected bkg	Expected B8	Observed
2	off	62.6	2.3	59
	on	1.5	1.4	1
3	off	0.8	0.4	2
	on	0.04	0.3	0



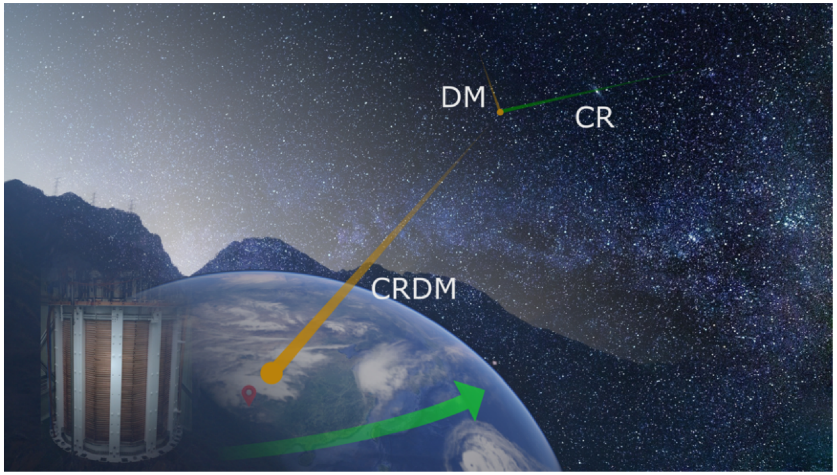


B8 search preliminary results

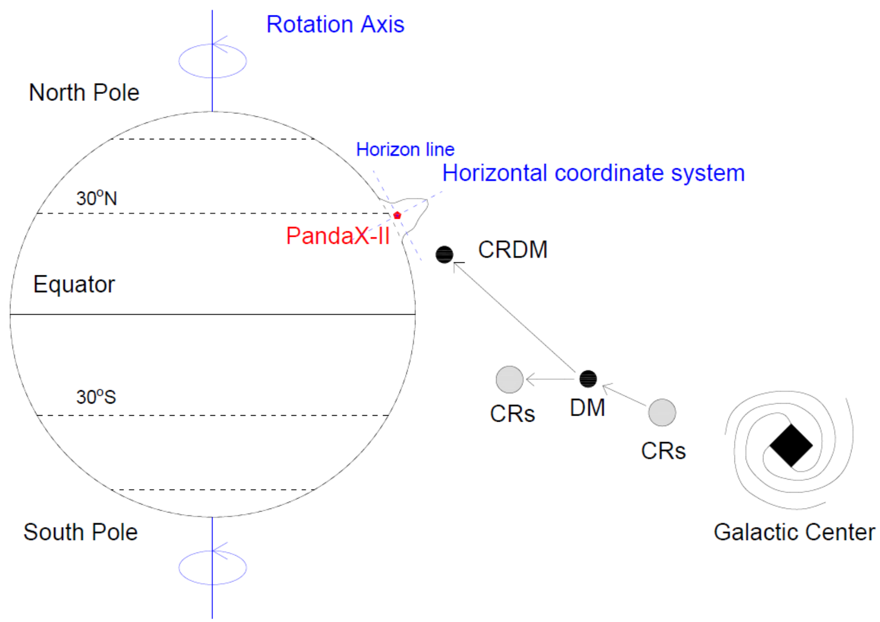


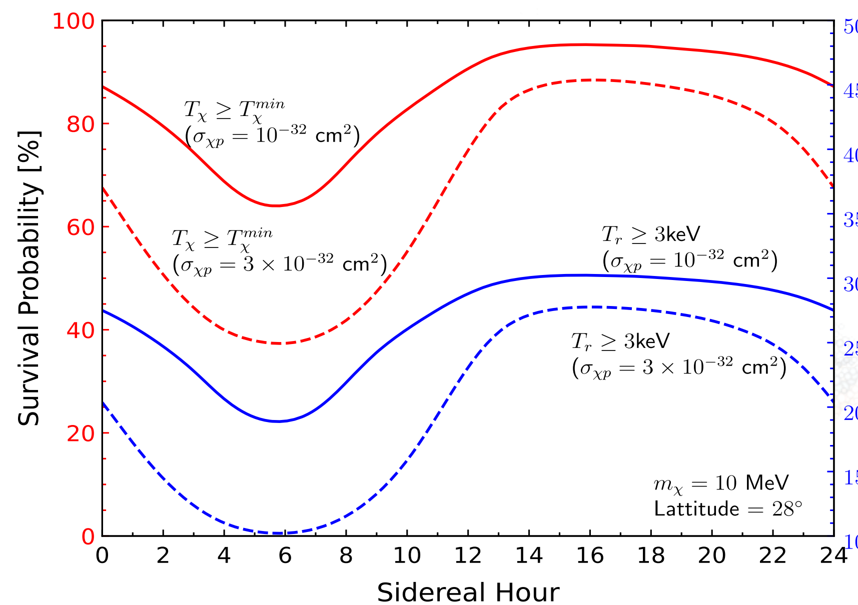
- Leading constraint on B8 neutrino flux among CEvNS detection results.
- Into sensitivity of the "neutrino floor". Can cast new insight on neutrino-nucleus interactions.
- Assuming B8 as bkg, it also gives the most stringint upperlimit for WIMP-nucleon interactions with mass from 3-10GeV.

Cosmic ray boosted Dark Matter



- Energetic cosmic ray in Galactic center scatters off low-mass dark matter, boosting it to close to higher speed.
- For low-mass DM, the attenuation of Earth may not be negligible.

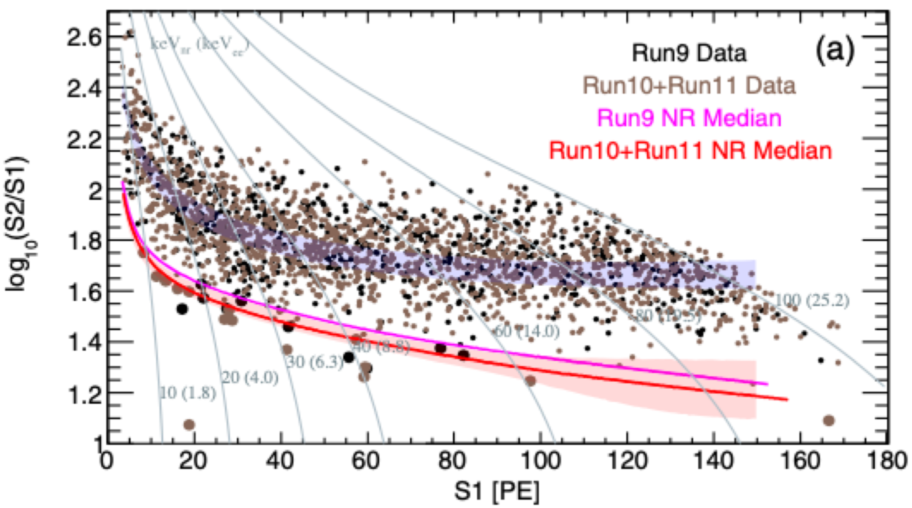


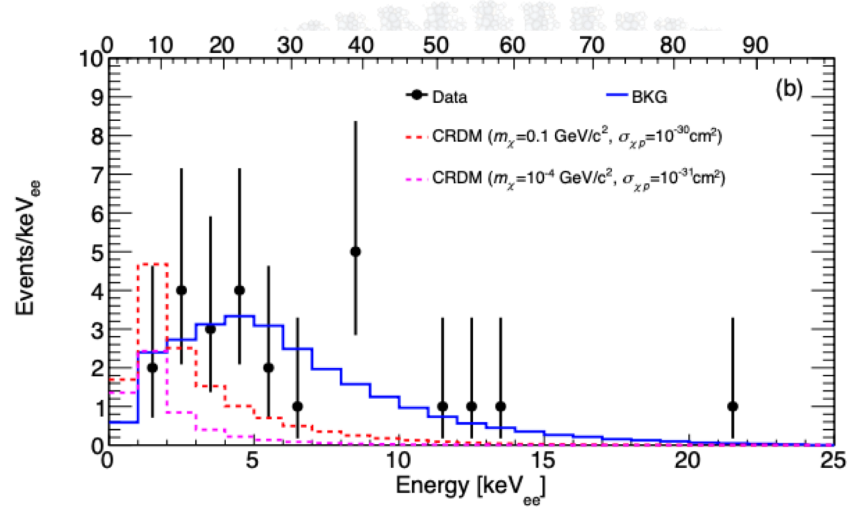


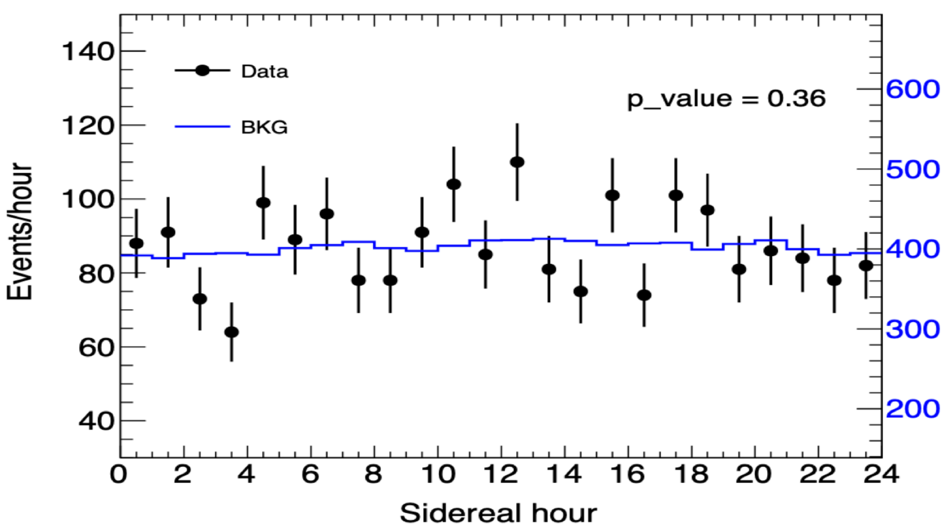
Diurnal modulation in PandaX-II

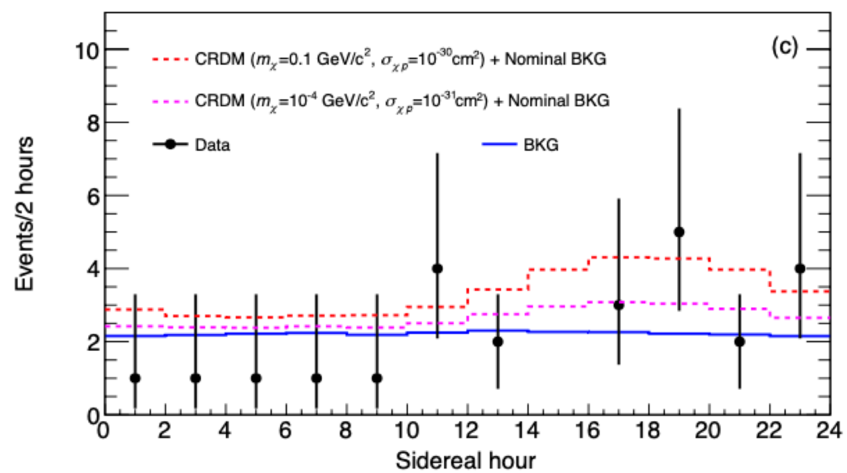
Using events below NR median

25 events (expected 26.6 background)



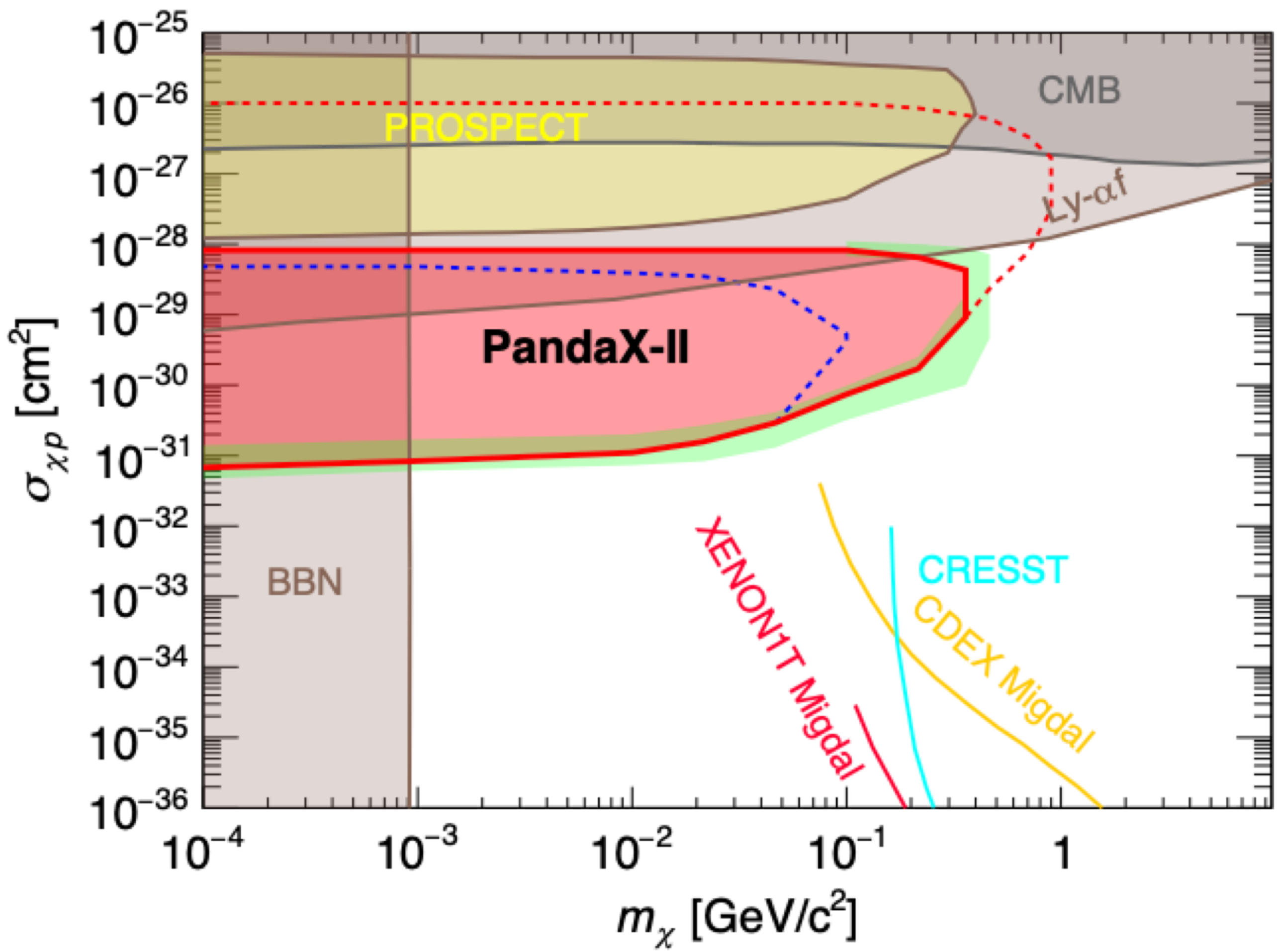






Constraint on sub-GeV DM

- Expand to the region beyond the astrophysical and cosmological probes;
- The analysis will be extended using PandaX-4T data;



PRL 128, 171801 (2022) Editors' Suggestion

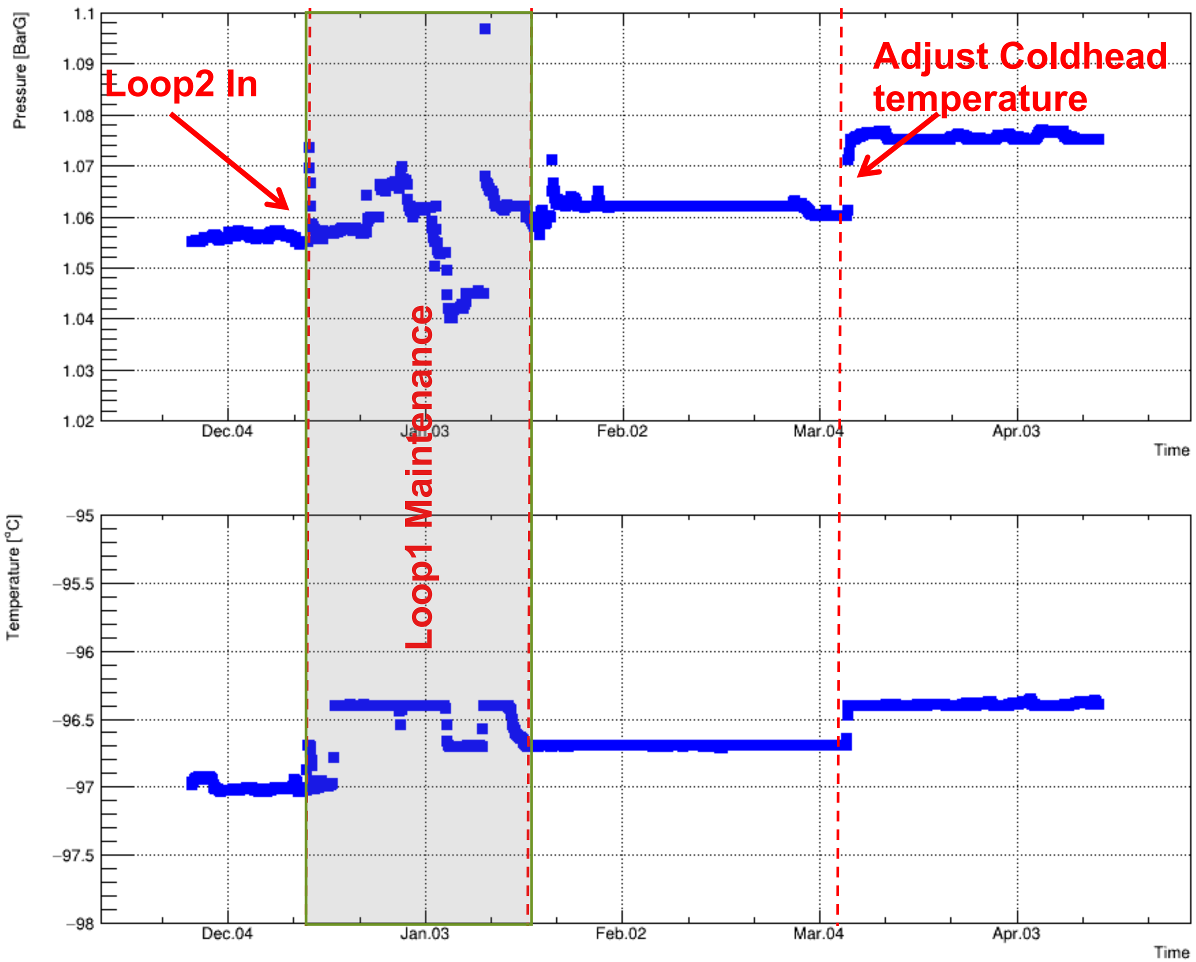
Summary

- PandaX-4T has completed its commissioning run
- With a 0.63 tonne·year exposure, PandaX-4T produced the strongest WIMP-nucleon interaction constraint at 2021.
- An offline tritium removal campaign has been performed, new physics run is on going
- PandaX-4T analysis on other physics topics, including B8 CEvNS, double beta decay, and etc.
- In parallel, the collaboration is developing the plan for the next generation experiment at CJPL, we welcome collaborators!

Thank you for listening!

Backups

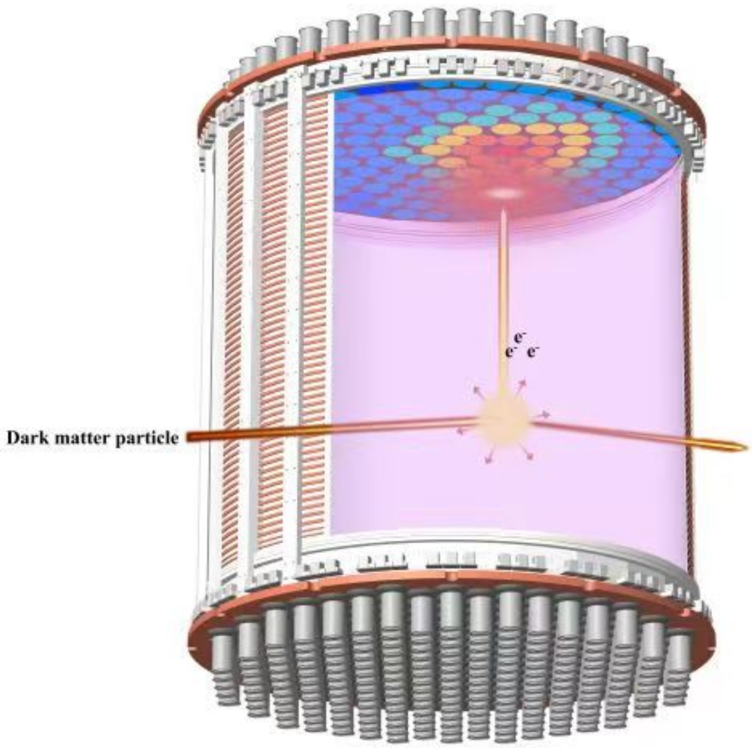
Cryogenics stability

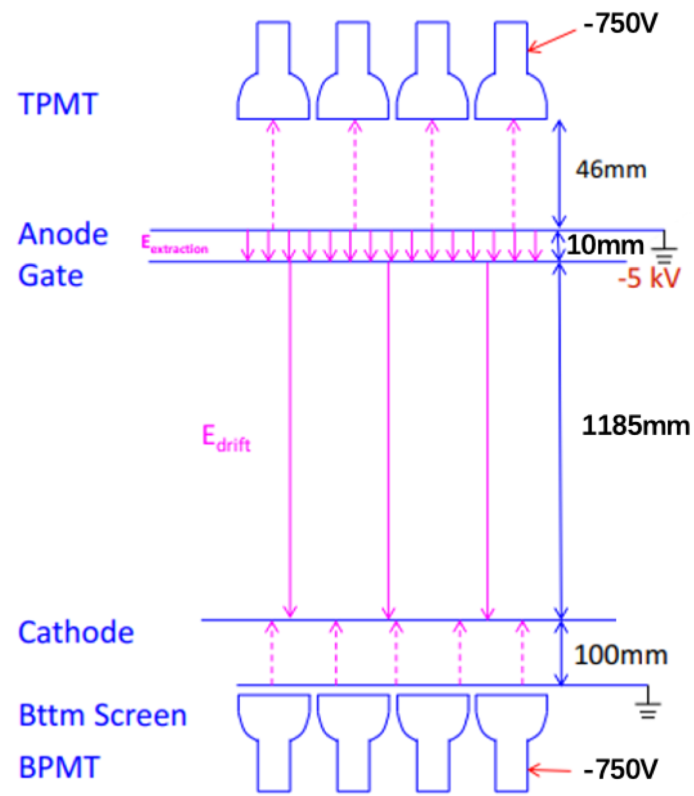


- In the stable running period, the P and T are stable within 0.5% and 0.1K, separately.

Parameters	Heating load (No purification)	Maximum Cooling Power	Purification flow rate	Outer Vacuum
Value	~50W	~580W	~110 SLPM (40 kg/h)	<2E-4Pa

TPC operation conditions

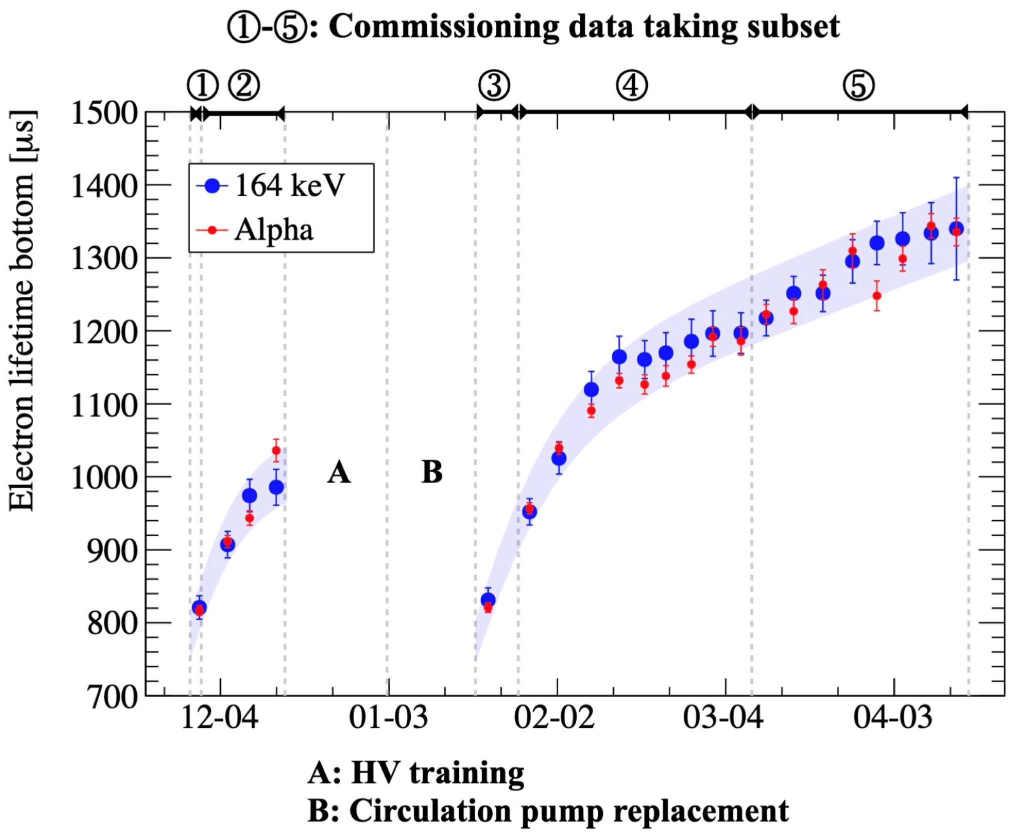




	Set1	Set2	Set3	Set4	Set5
Gate(kV)	-4.9		-5	-5	
Cathode (kV)	-20	-18.6	-18	-16	

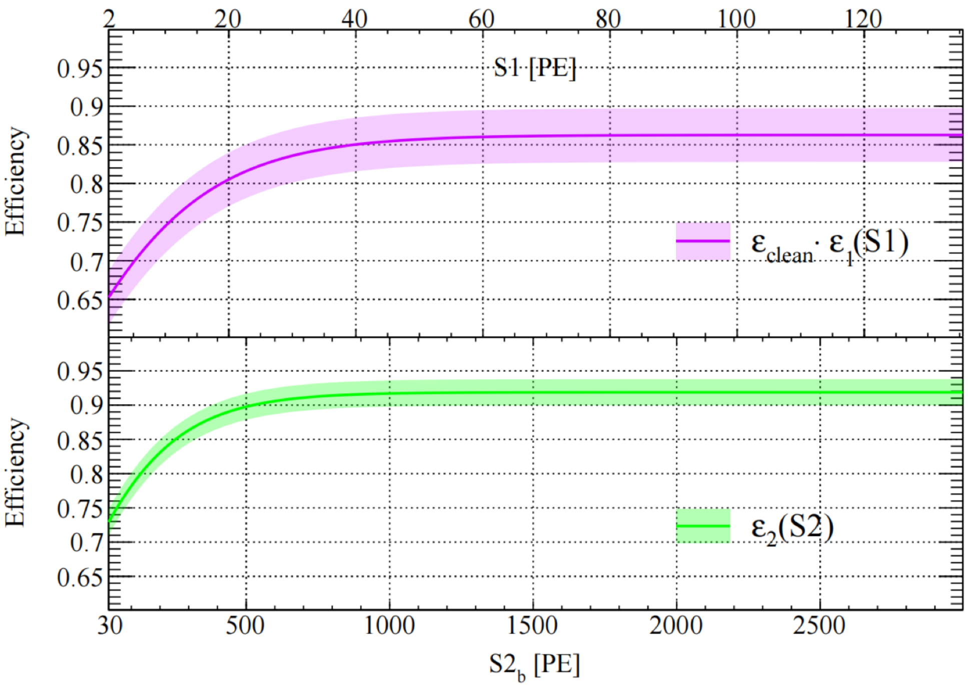
During the run, HV set at a few different values to avoid excessive discharges.

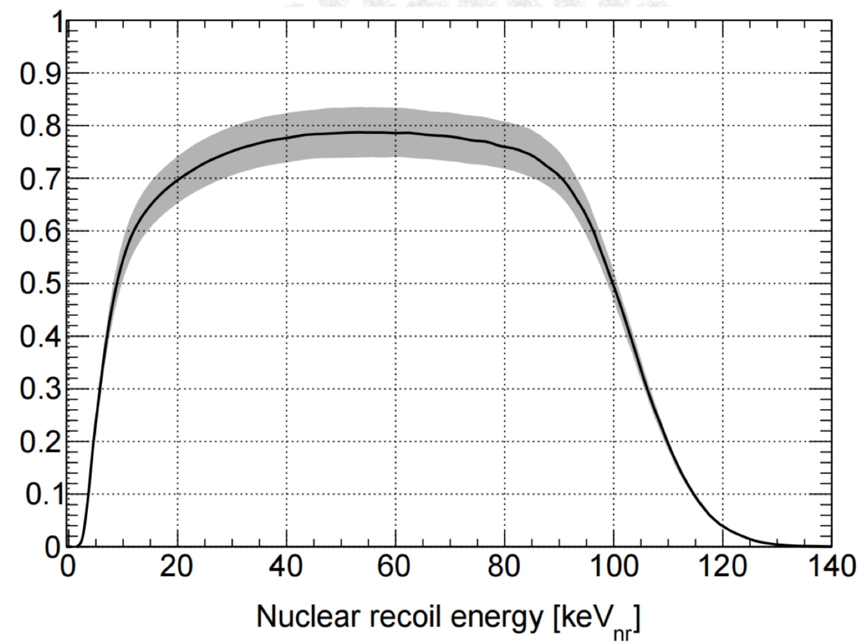
Data taking history



- Electron lifetime: *in situ* S2 vertical uniformity calibration
- Ref: the maximum drift time ~ 840 μs (field dependent)
- Two gas loops for purification
- Stable data running period: 95.0 calendar days （86 days after selection)

Efficiencies obtained from calibration data

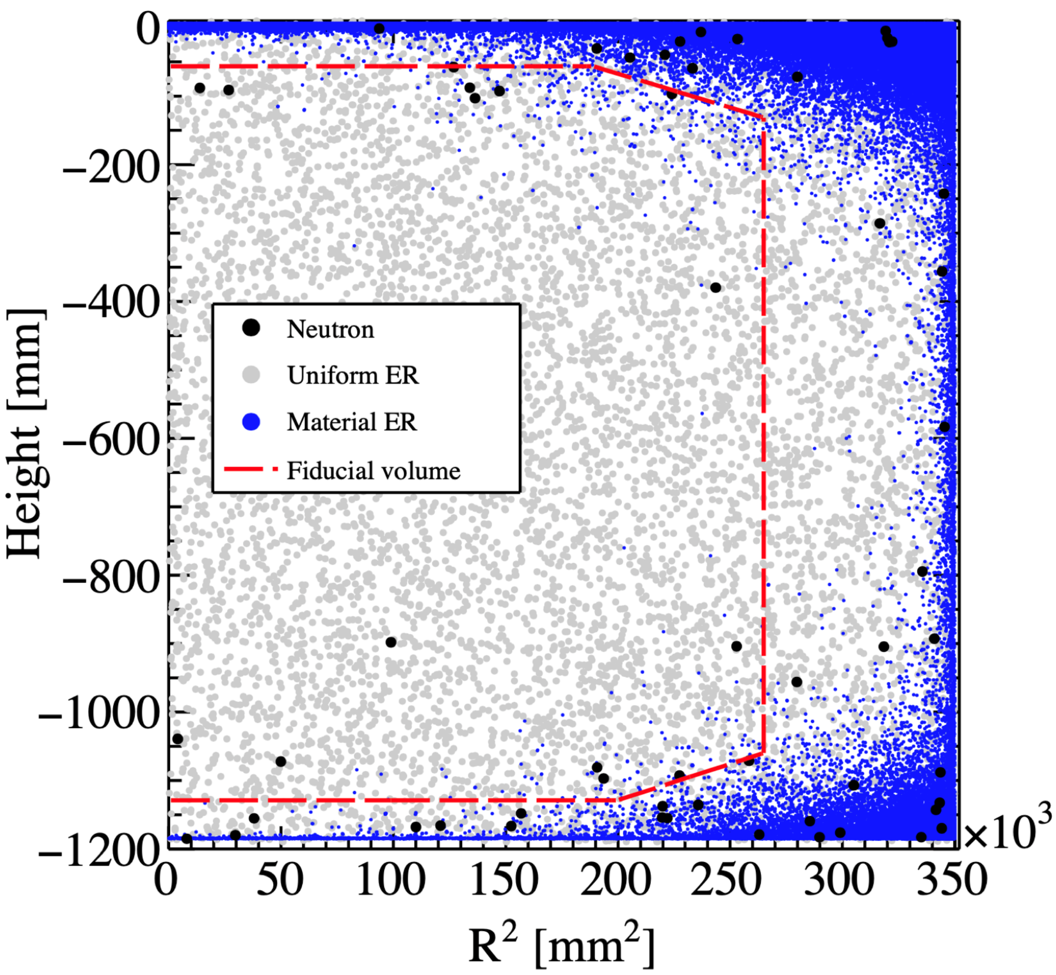




- Same S1 and S2 efficiency obtained from the ER and NR data
- Plateaued efficiency at 40 keV_{nr} ~78%.

FV determination

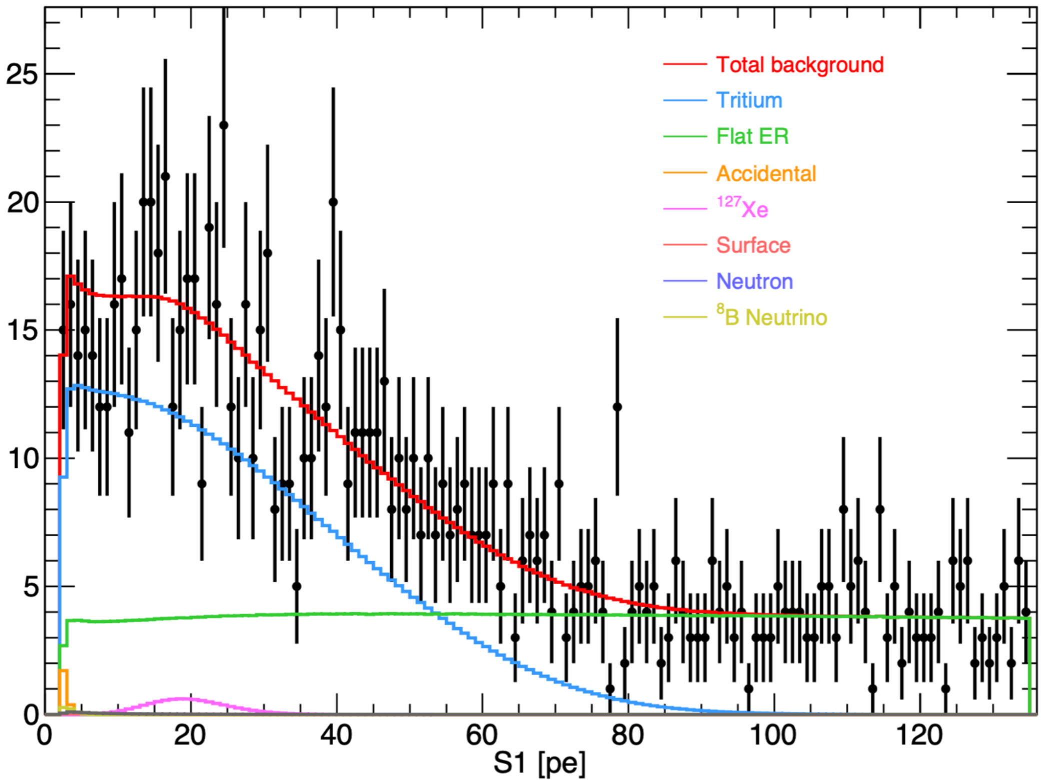
PandaX



- ❑ Based on background simulation (10 t-year)
- ❑ Uniform ER (including tritium) normalization come from data
- ❑ Define FoM = sqrt(B)/M
- ❑ Best FV = 2.67 tonne

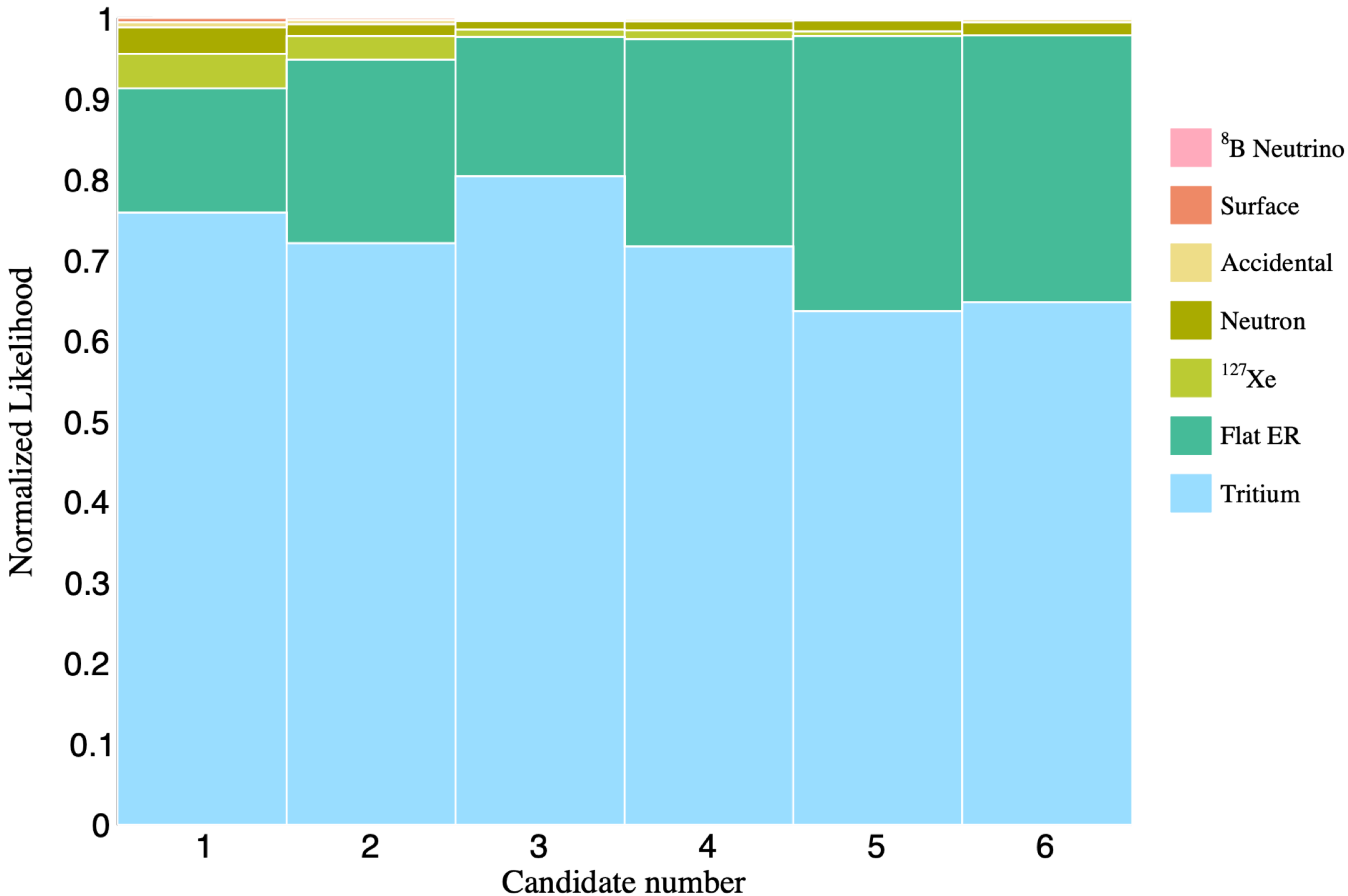
Spectral comparison

PandaX

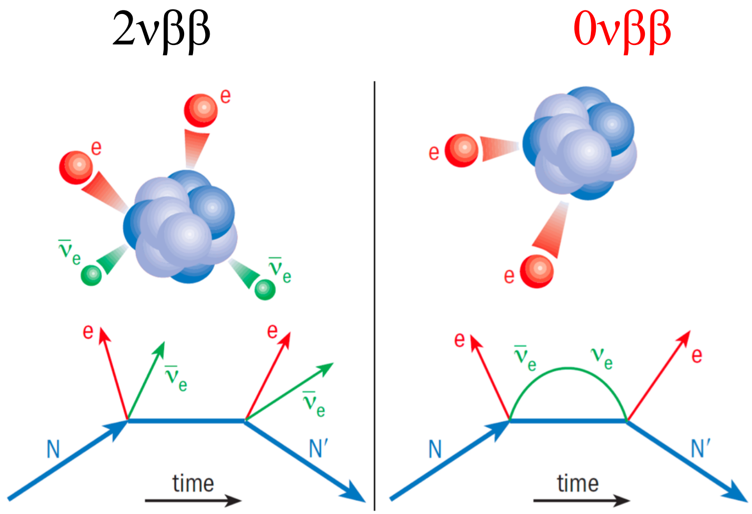


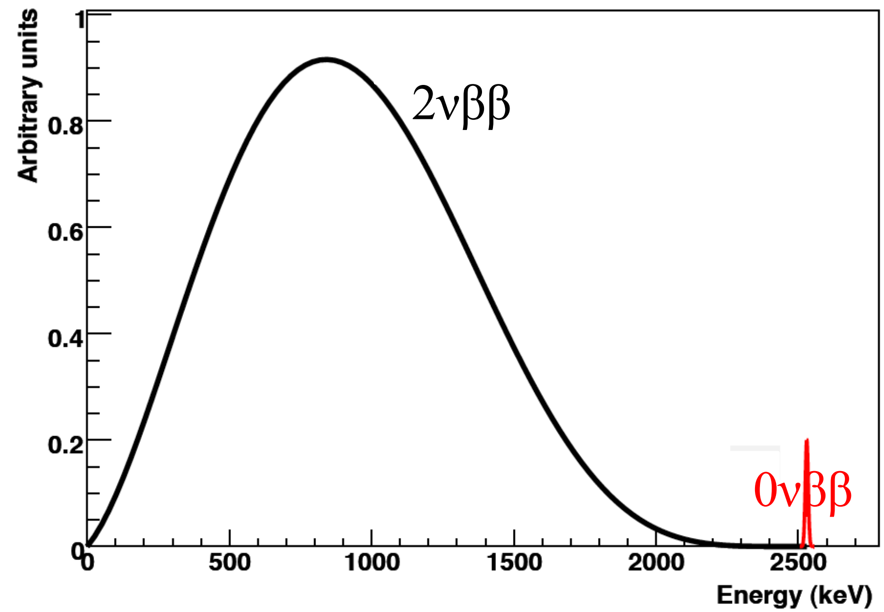
- Fit data with unbinned likelihood with all signal/background PDFs in (S1, $S2_b$)
- No excess found, background-only p-value 0.58
- Spectrum agrees with expected background

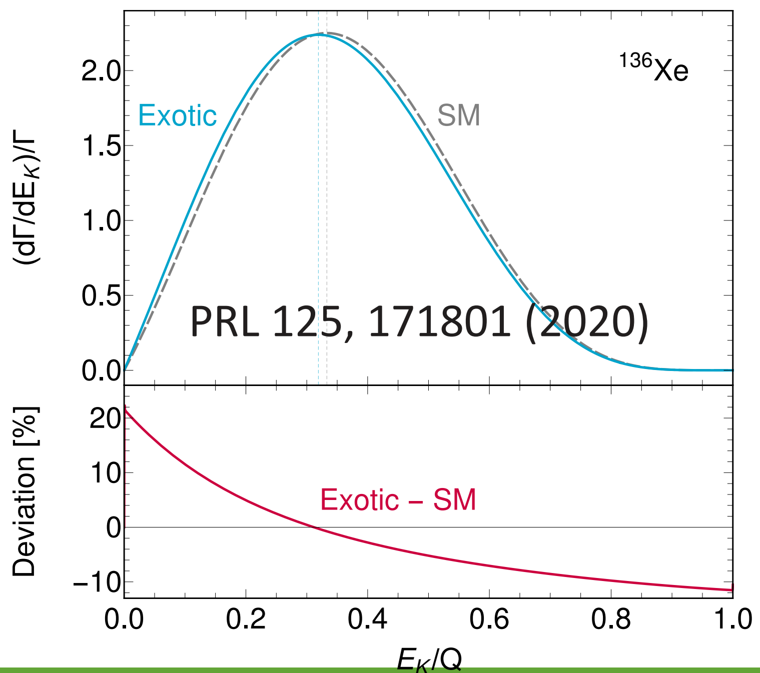
Likelihoods of the six below-NR events



Double beta decay (DBD) measurement



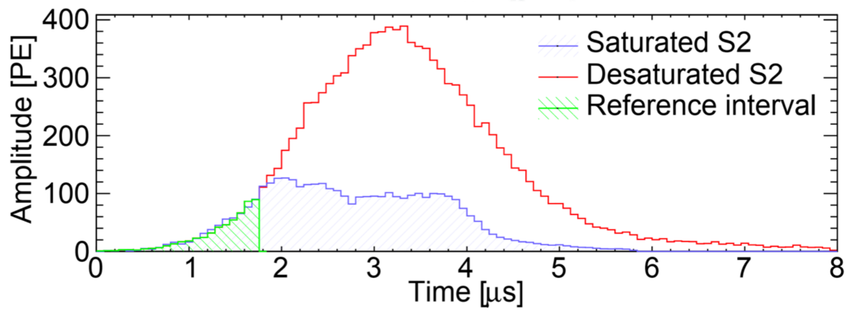


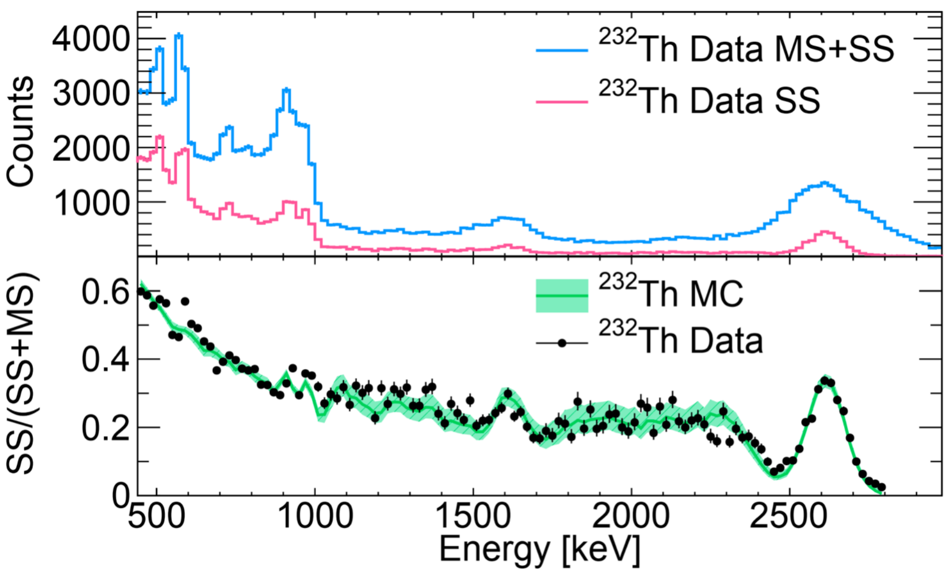


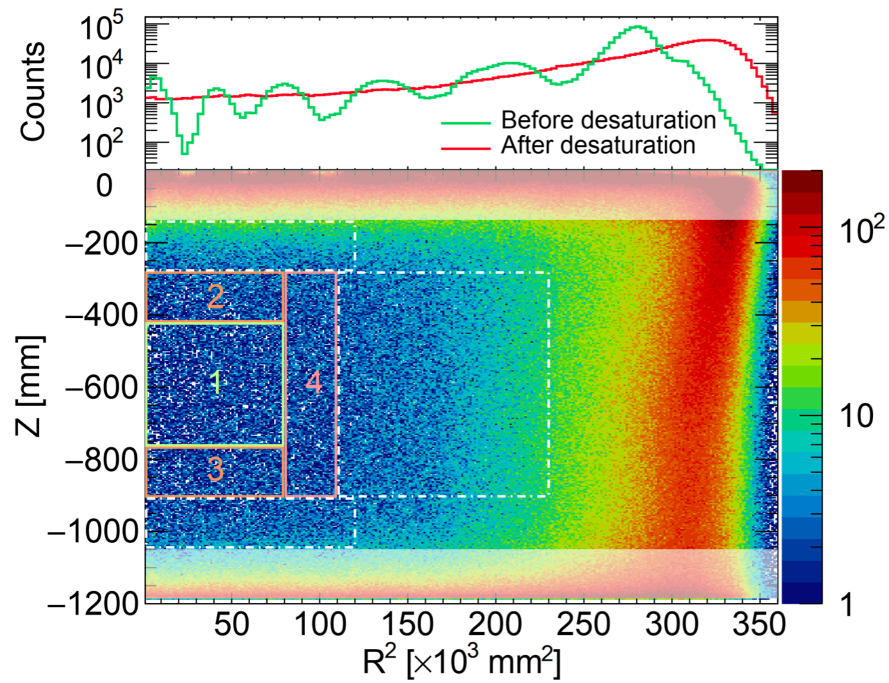
- Precise DBD measurement is essential for neutrinoless DBD, to better understand background;
- Searching for possible shape distortion, exploring beyond-standard-model physics.

Saturation correction & MC-data comparsion

- Single-site vs. Multi-site identification
  - Agreement in 2.7% in ROI
- PMT desaturation
  - Great improvement in pos. rec. of high-energy events.
- FV divided into 4 regions
  - For different bkg component constraint.



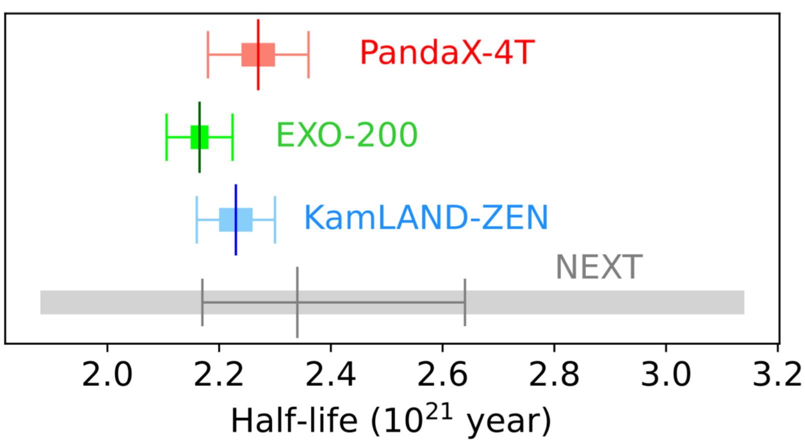




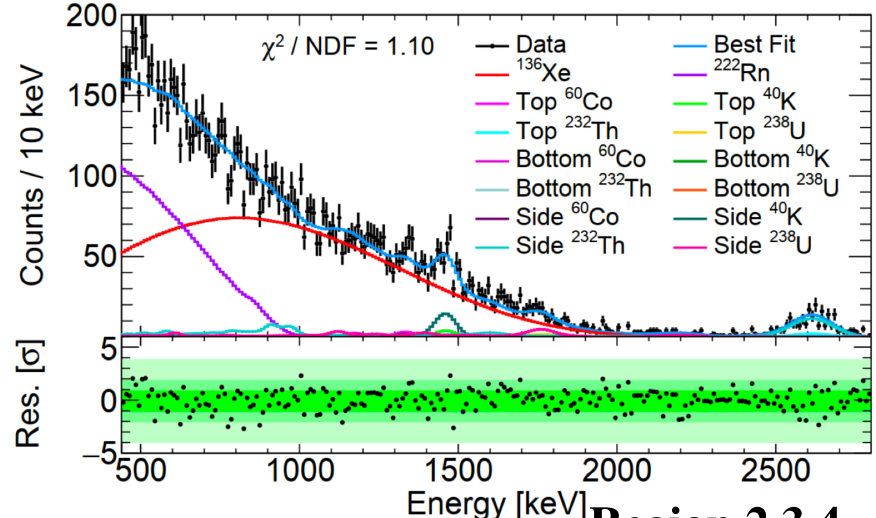
Final fit and Xe136 DBD half-life

- Simultaneous fit in 4 regions of FV
- 649.7±6.5 kg natural xenon in FV and 94.9 days of data,
  - the total fitted number of Xe-136 DBD events is 17468±243 in ROI of 440 to 2800 keV
- Xe-136 DBD half-life is measured as: $2.27 \pm 0.03(\text{stat.}) \pm 0.09(\text{syst.}) \times 10^{21}$ yr

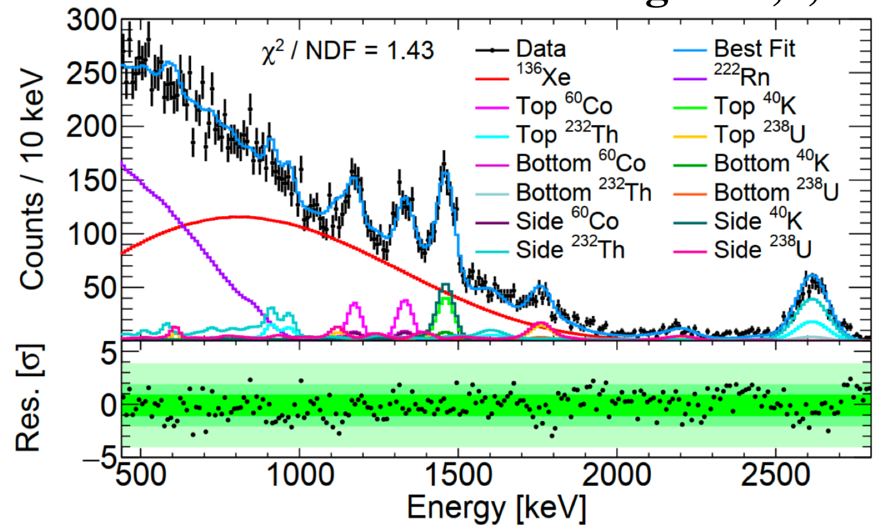
Source	Percentage	Source	Percentage
Quality cut	0.39%	SS cut	1.7%
FV cut	1.0%	Bin size	0.05%
Fit range	1.2%	Energy resolution	0.58%
Energy scale	0.26%	Regional weight	1.6%
^{214}Pb spectrum	2.0%	LXe density	0.13%
^{136}Xe abundance	1.9%	**Total**	**4.1%**



Region 1



Region 2,3,4



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