Recent Results and Progress of PandaX-4T Experiment

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(On behalf of PandaX collaboration)

University of Science and Technology of China

iDM @ L'Aquila, 2024.07.08

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Large Structure

Small Structure

Primordial Universe

Courtesy of NASA
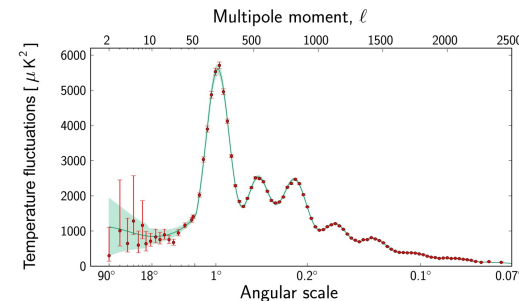
Credit: https://youtu.be/sI23cwbbNqs
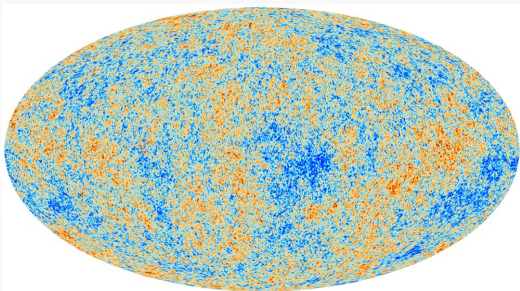
Bullet cluster collision
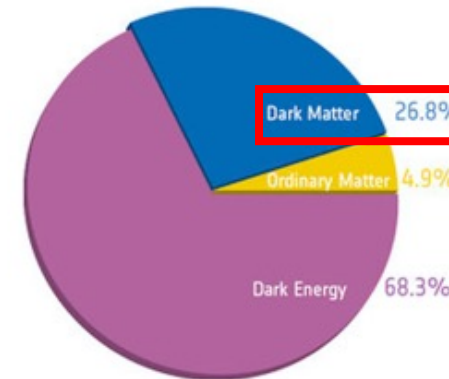
Galaxy rotation curve

Courtesy of PLANCK

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

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PandaX collaboration

- PandaX: **particle and astrophysical xenon detector**
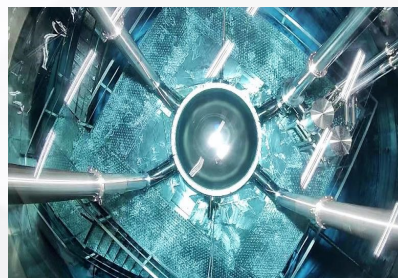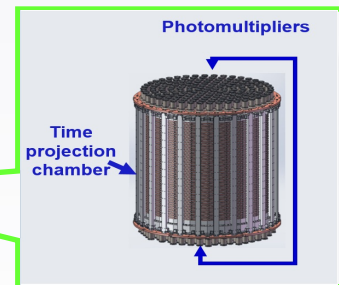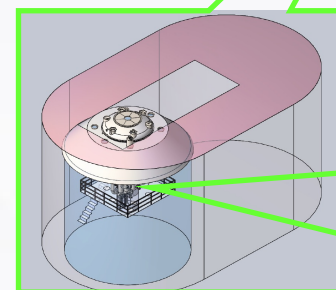 - dark matter, Majorana neutrino, astrophysical neutrino
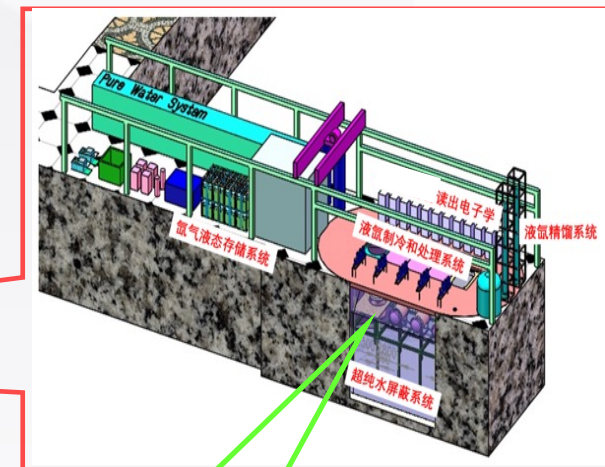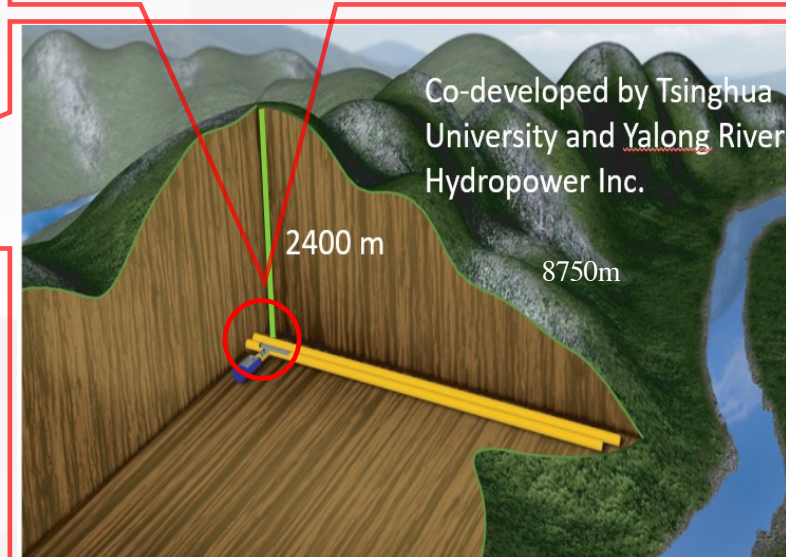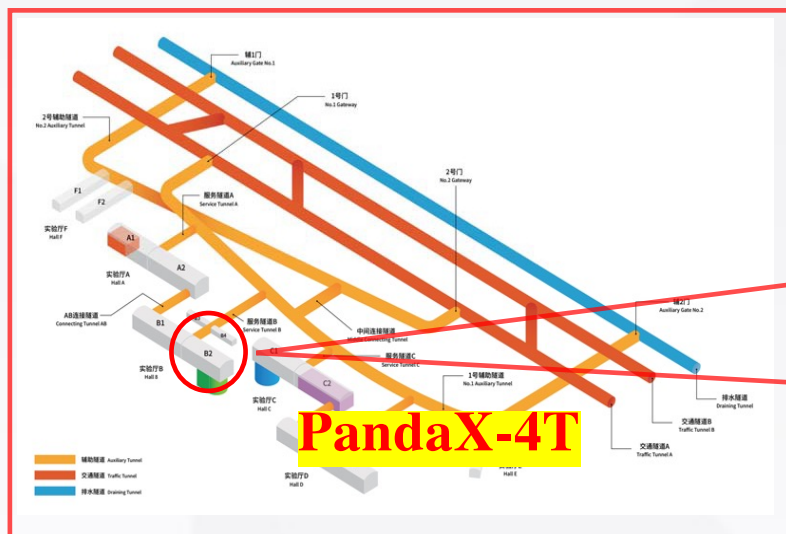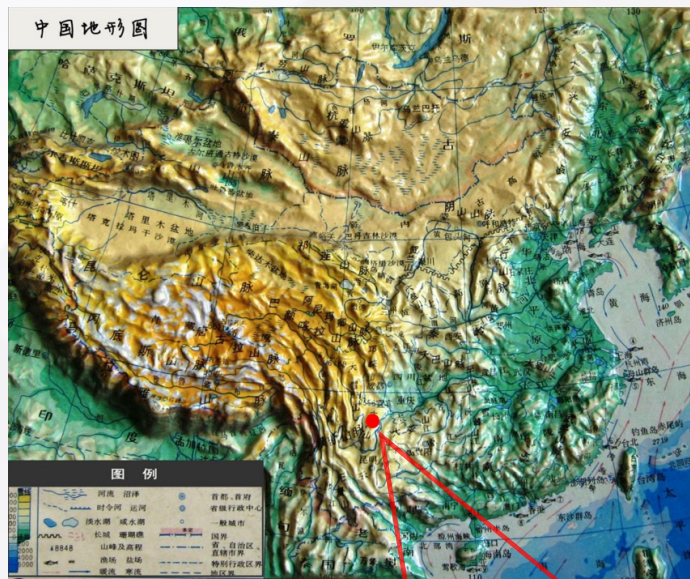
PandaX-4T

Co-developed by Tsinghua University and Yalong River Hydropower Inc.

2400 m

8750m

Photomultipliers

Time projection chamber

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Timeline of PandaX-4T Experiment

2020/11 – 2021/04	**Commissioning (Run 0)** 95 days
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc
2021/11 – 2022/05	**Physics run (Run 1)** 164 days
2022/09 – 2023/12	**CJPL B2 hall renovation** xenon recuperation, detector upgrade
Current Status	**Resuming physics data-taking**

- Electron lifetime: *in situ* S2 vertical uniformity calibration
- Stable data running period: 95.0 calendar days　(86 days after selection)
- Sensitive Volume: 3.7 tonne;
- Total exposure: 0.63 tonne-year;
- Limits on SI WIMP-nucleon cross section reach $3.8 \times 10^{-47} cm^2$

PRL 127, 261802 (2021)
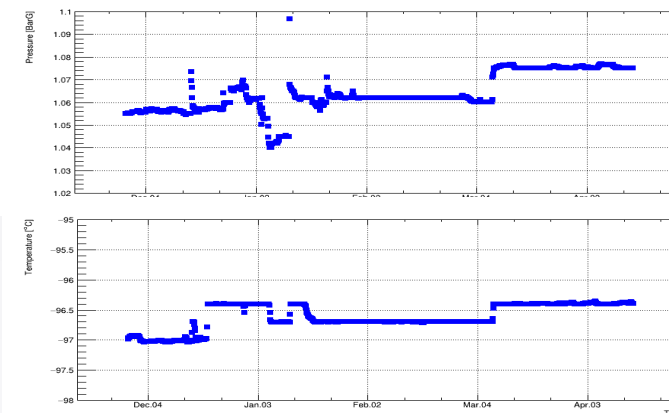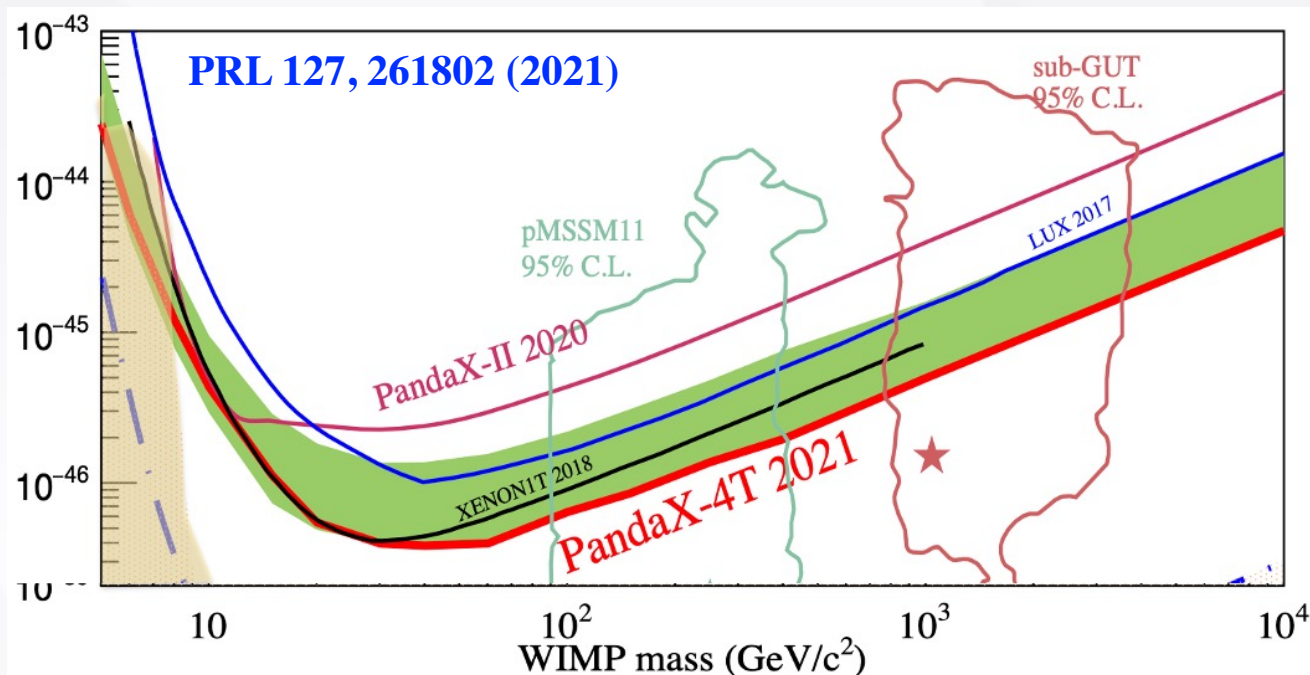
	Set1	Set2	Set3	Set4	Set5
Gate(kV)	-4.9		-5		-5
Cathode (kV)	-20	-18.6	-18		-16

①-⑤: Commissioning data taking subset

A: HV training
B: Circulation pump replacement

Electron lifetime evolution

Run0

Run1

Single electron gain evolution

Top Charge Pattern (*LOGZ*)

83mKr
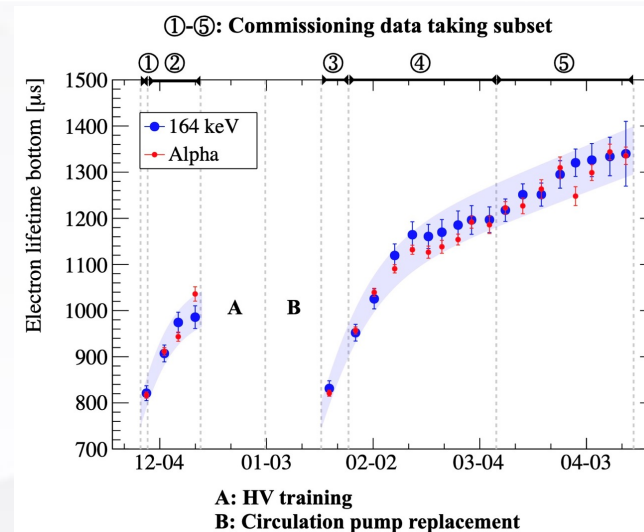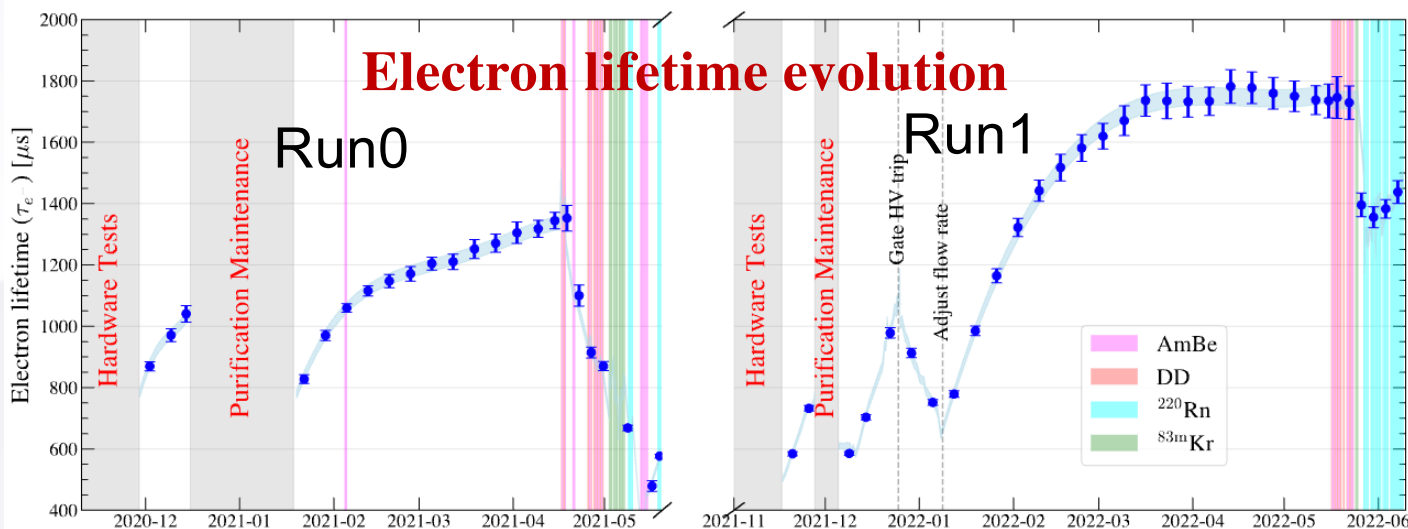
- Gate -6kV, Cathode -16kV
- E-lifetime monitoring through alpha events
  - maximum reaches 1800 us
- Failure of liquid level controlling;Dividing into 6 subsets accordingly
- Additional 10 top PMTs turned off;
- Near off-PMT region: dedicated selection cuts
  - Loosened Top/Bottom ratio, and pos. rec. quality requirement;
- Reconstruction refined (summarized in arXiv2403.04239)
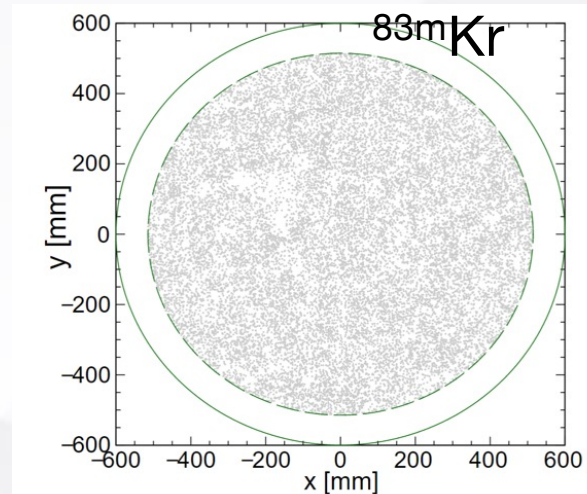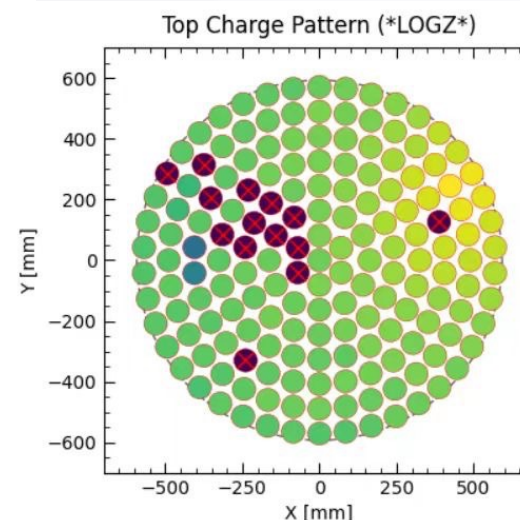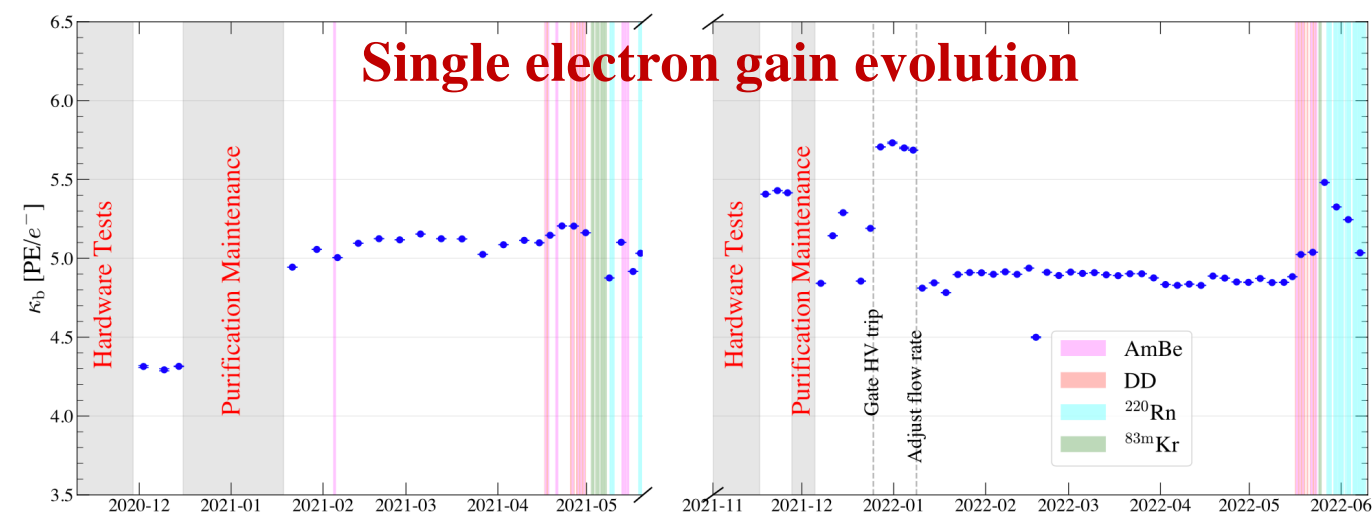
Tritium Background
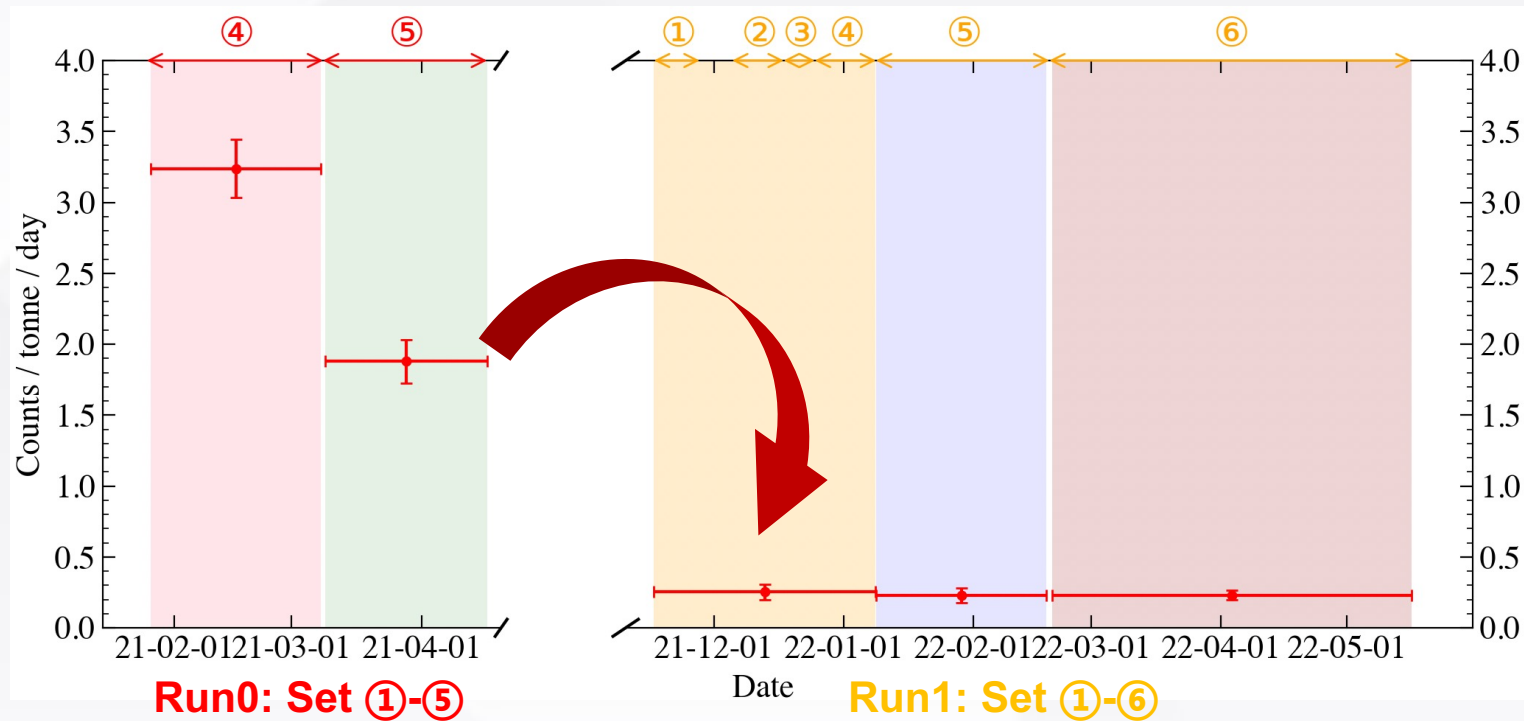
Dataset	Run0 Set4	Run0 Set5	Run1 Set1-4	Run1 Set5	Run1 Set6
Rate [/tonne/day]	3.24±0.20	1.88±0.15	0.25±0.05	0.23±0.05	0.23±0.03

Run0: Set ①-⑤

Run1: Set ①-⑥
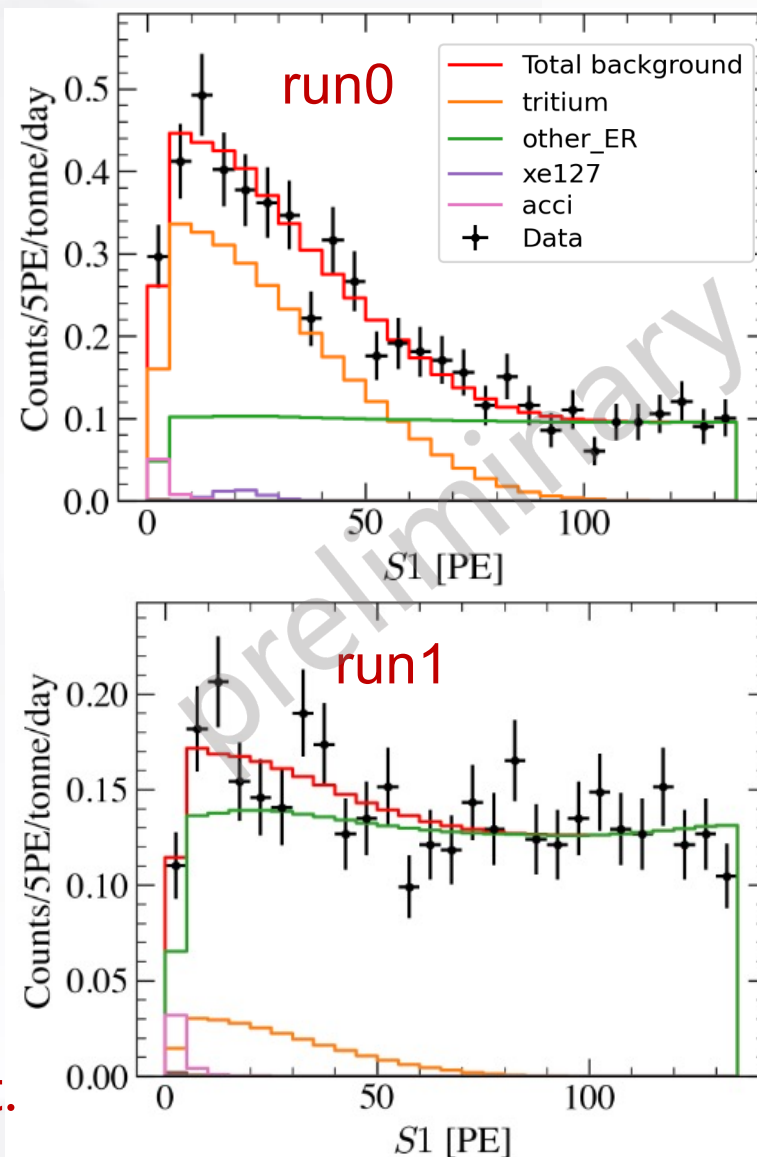
CH3T rates significantly decreased, estimated from S1 fit.

	Run0	Run1	Total	Below NR median	Best fit
^{214}Pb	281 ± 13	675 ± 35	956 ± 38	$3.6^{+0.9}_{-0.7}$	-
^{212}Pb	49 ± 13	97 ± 25	146 ± 30	$0.6^{+0.2}_{-0.2}$	-
^{85}Kr	80 ± 40	289 ± 88	369 ± 96	$1.4^{+0.5}_{-0.5}$	-
Material ER	42 ± 5	105 ± 11	147 ± 12	$0.6^{+0.2}_{-0.1}$	-
Solar ν	37.5 ± 3.8	73.7 ± 7.4	111.2 ± 8.3	$0.42^{+0.10}_{-0.08}$	-
^{136}Xe	27.8 ± 1.4	59.3 ± 3.1	87.0 ± 3.4	$0.16^{+0.05}_{-0.03}$	-
Other ER (data)	504 ± 16	1226 ± 28	1730 ± 32	$6.4^{+1.7}_{-1.2}$	1767 ± 39
CH$_3$T	556 ± 33	114 ± 33	670 ± 47	$5.2^{+1.2}_{-1.1}$	677 ± 47
^{127}Xe	7.65 ± 0.77	0.02 ± 0.00	7.67 ± 0.77	$0.10^{+0.02}_{-0.02}$	7.69 ± 0.17
^{124}Xe	2.26 ± 0.61	4.05 ± 1.09	6.31 ± 1.70	$0.03^{+0.01}_{-0.01}$	6.25 ± 1.68
Neutron	0.63 ± 0.18	1.10 ± 0.24	1.73 ± 0.30	$1.04^{+0.13}_{-0.13}$	1.75 ± 0.28
^{8}B CEνNS	0.31 ± 0.03	0.69 ± 0.07	0.99 ± 0.08	$0.98^{+0.30}_{-0.30}$	1.10 ± 0.33
Surface	0.09 ± 0.06	0.17 ± 0.11	0.26 ± 0.12	$0.26^{+0.12}_{-0.12}$	0.25 ± 0.11
Accidental	11.3 ± 3.4	12.7 ± 3.8	24.0 ± 5.1	$6.42^{+1.36}_{-1.36}$	25.7 ± 5.2
Sum	1079 ± 37	1355 ± 43	2434 ± 43	$20.5^{+2.5}_{-2.2}$	2487 ± 56
Observed	1117	1373	2490	24	-

➤ CH3T dominate in Run0;
➤ After tritium removal, Pb214 and Kr85 are the dominant bkg components in Run1;
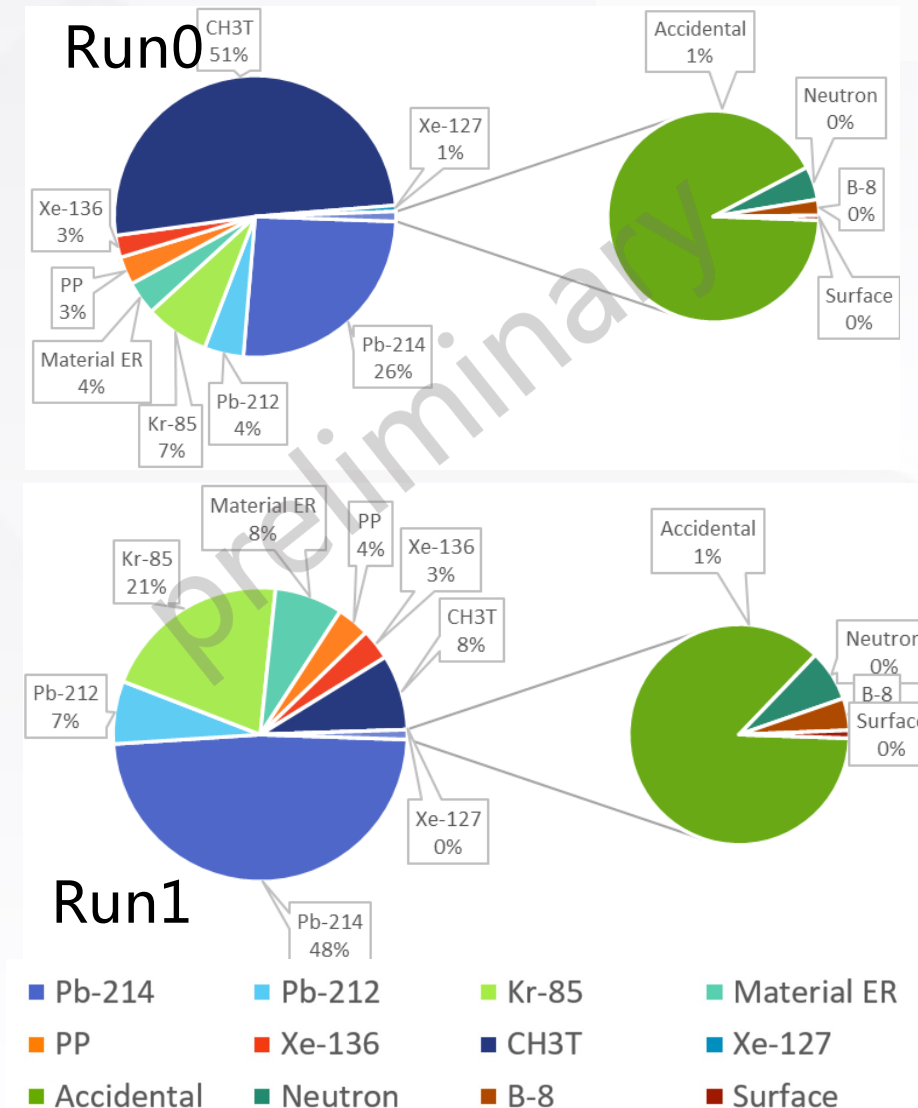
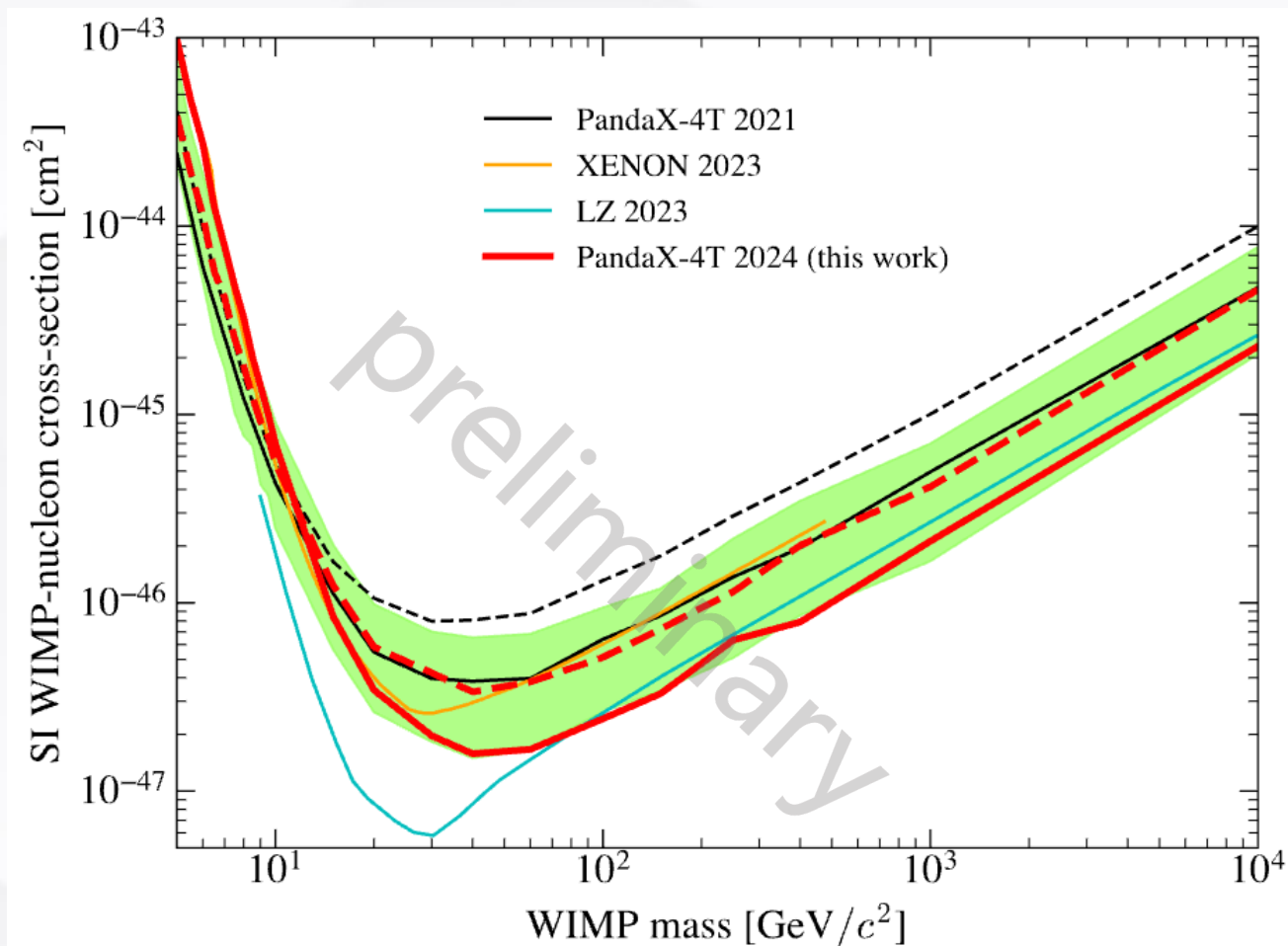▷ **24 (12+12) in Ref. region while expecting 20;**   ▷ **Spatially and Timely uniformly distributed;**
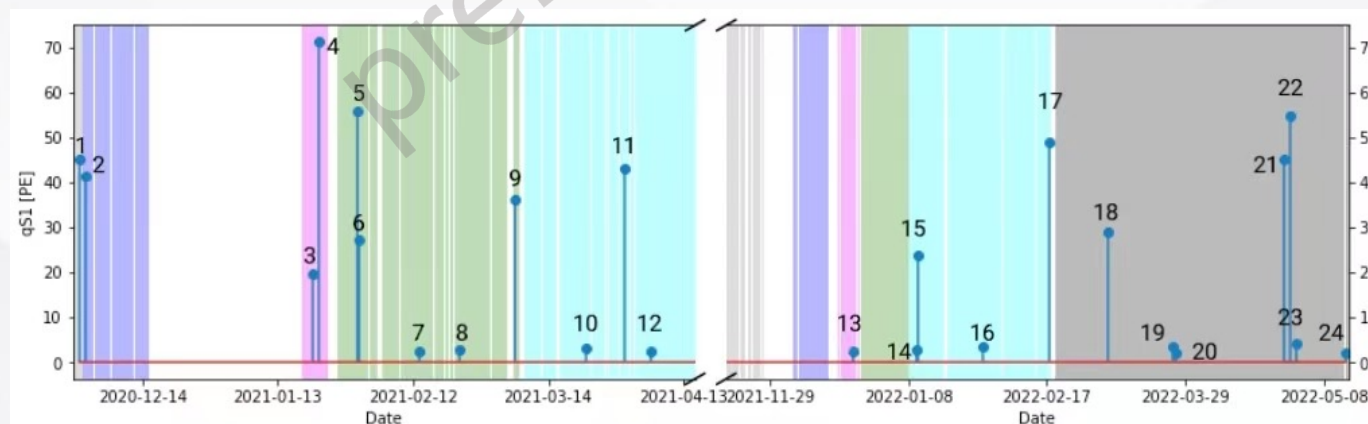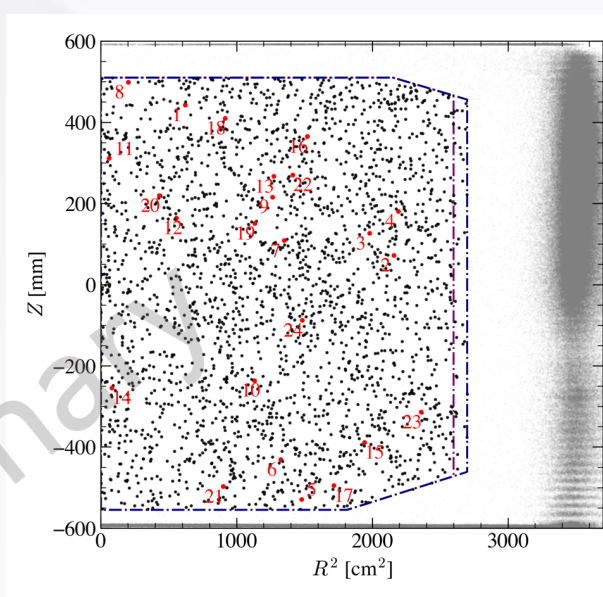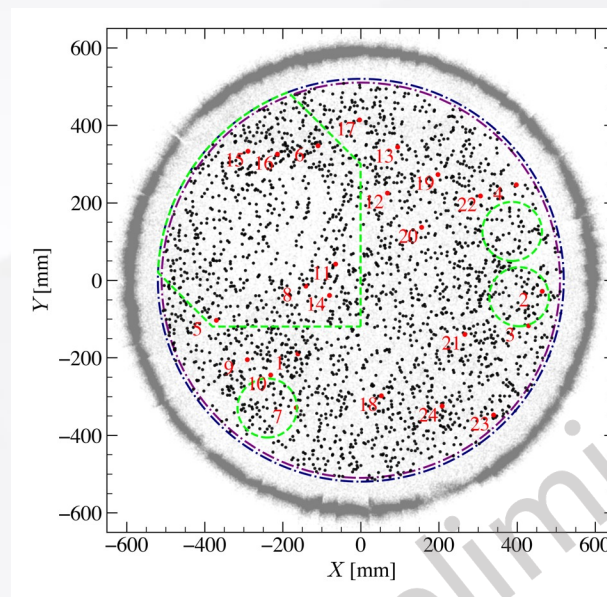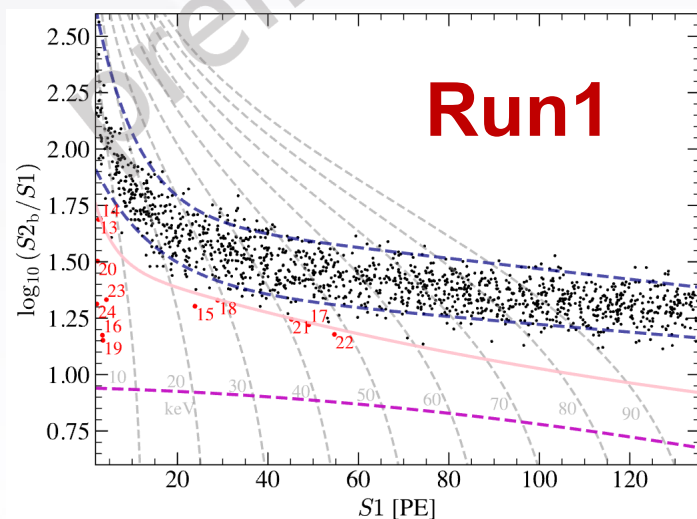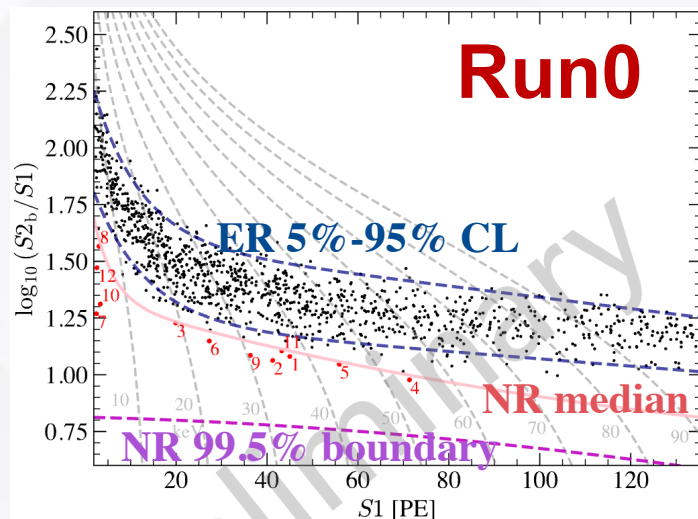
Constraint to WIMP

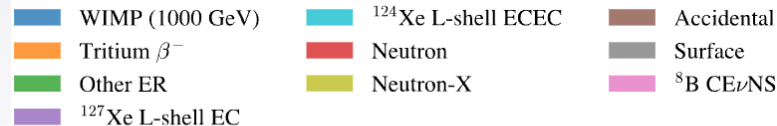- **Blind analysis using Run0+1, total exposure = 1.54 tonne-year;**
- **No significant excess;**
- **1σ upward fluctuation with <8GeV;**
- **Downward fluctuation in high-mass region;**
- **Best constraint > 100GeV;**
- **1.6e-47 cm² @ 40GeV.**

S1<5PE		AC	B8	Bkg	Obs
	Run0	2.2+-0.4	0.28+-0.02	**2.7+-0.4**	**4**
	Run1	2.8+-0.5	0.65+-0.04	**3.6+-0.5**	**7**

Below NR median	Inside 1000 GeV/c² WIMP 1σ contour		
	Expected	Observed	Toy Median
Run0	**4.531**	**5**	**4.163**
Run1	**4.716**	**3**	**4.741**

6GeV WIMP

1TeV WIMP

Legend: WIMP (1000 GeV), Tritium β^-, Other ER, ^{127}Xe L-shell EC, ^{124}Xe L-shell ECEC, Neutron, Neutron-X, Accidental, Surface, ^{8}B CEνNS
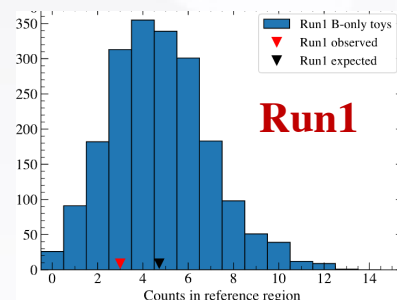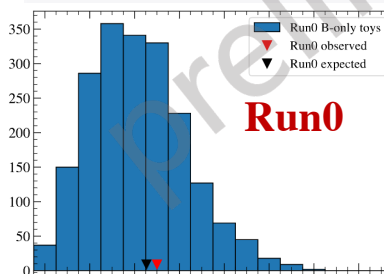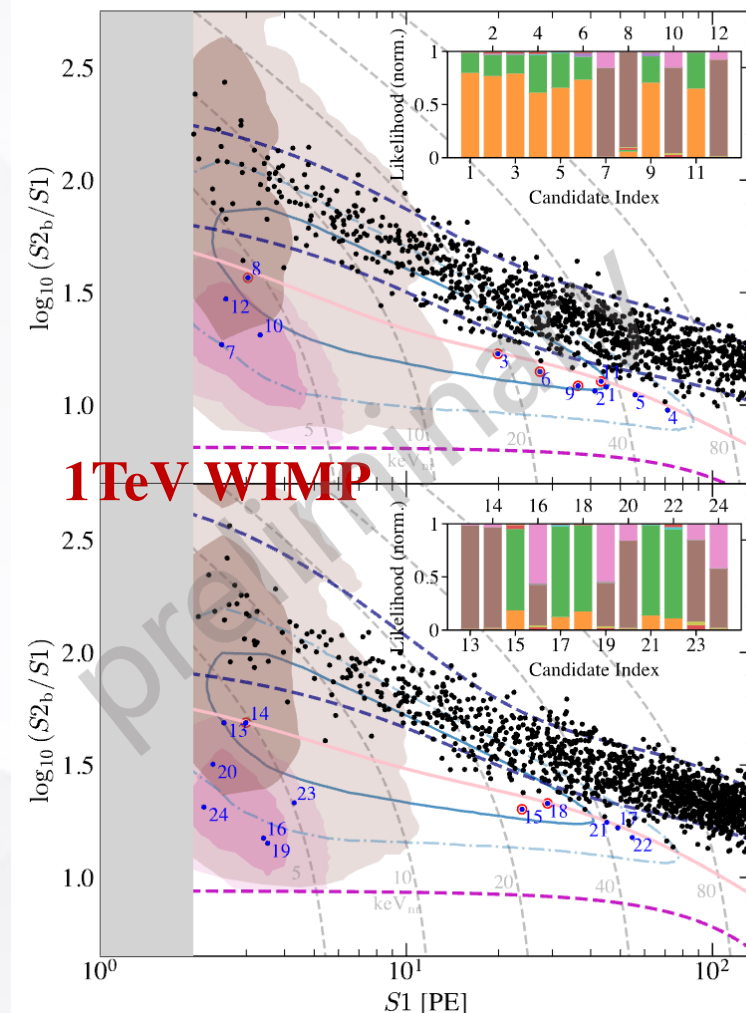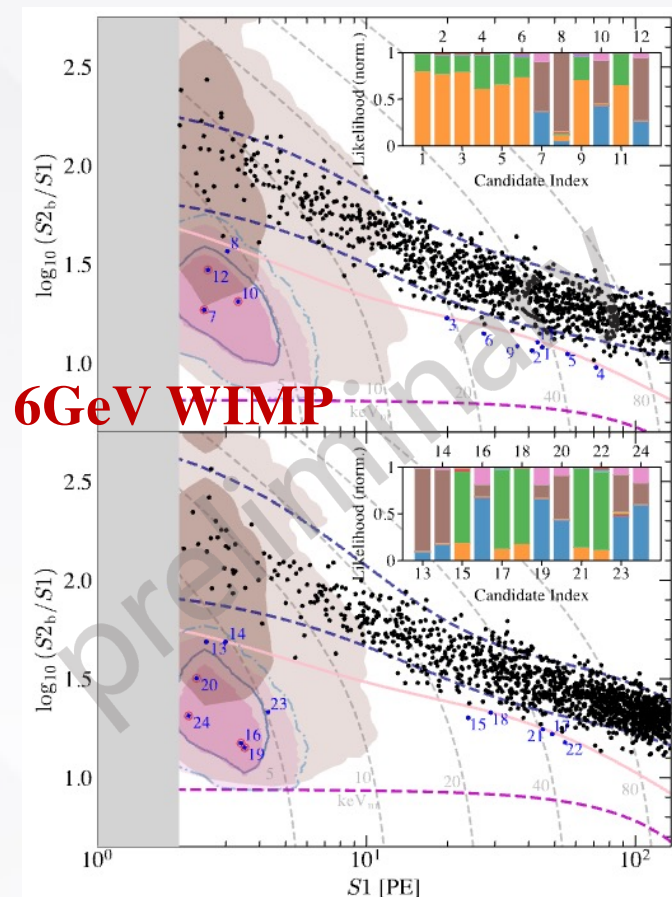
Run0

Run1

➤ In 1σ & ref. region of 1TeV WIMP, Run0 and Run1 see upward and downward, respectively;

➤ Run1 dominates the limit, the downward tendency is about 1σ, consistent with limit vs. sensitivity;

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Search for solar neutrinos

- PandaX-4T searches for solar B8 CEvNS with lowered threshold;
- Large amount of background emerged with lowered threshold;
- Two data regions used: Paired and S2-only;
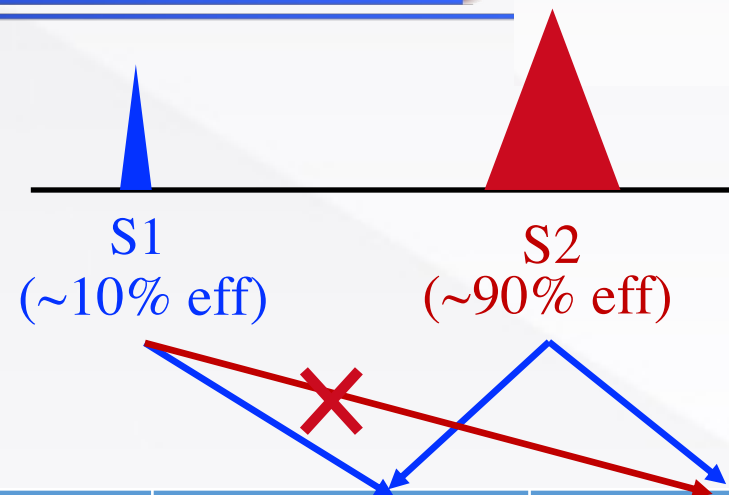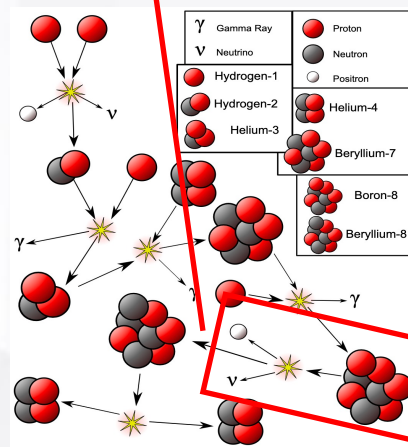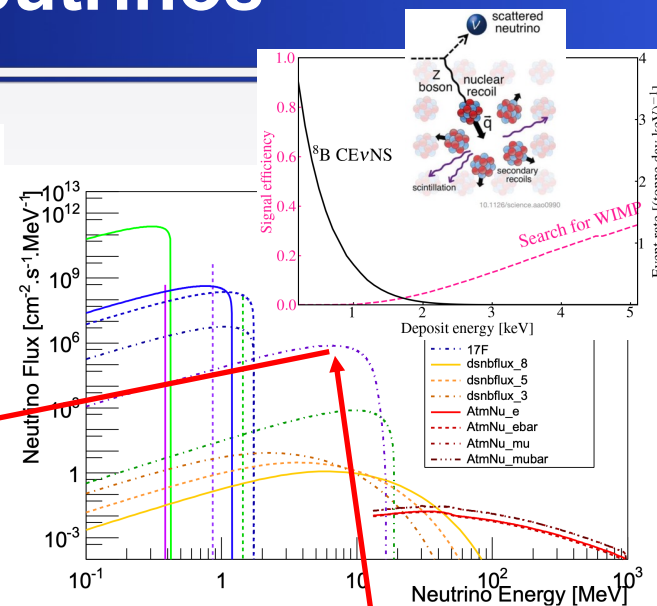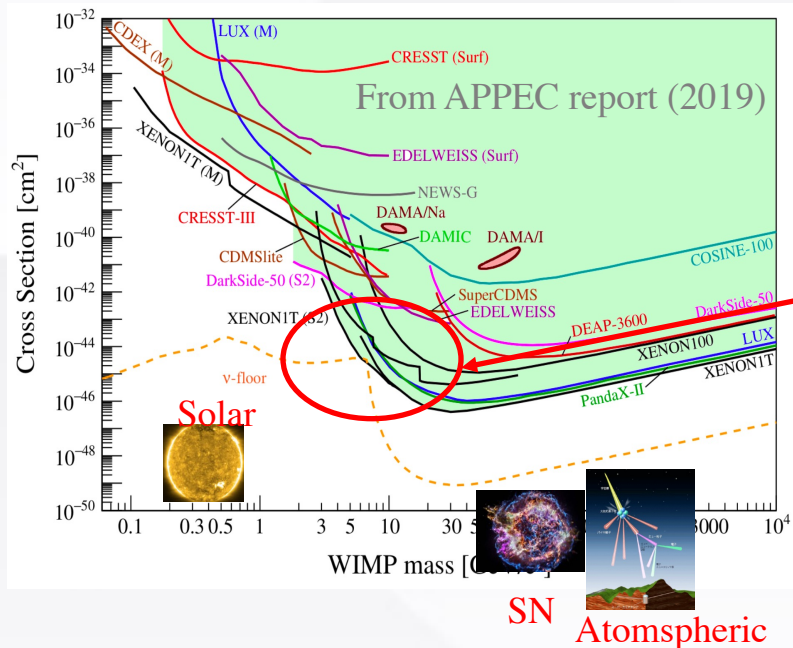
	Paired	S2only
ROI	2or3 hit, 60<S2<300PE	4-8 e-
Energy range	~0.8-1.8 keVnr	~0.4-1.2keVnr
B8 CEvNS Rate	Low	High
Bkg rate	Low	High
Effective Exposure	1.25 tonne-year	1.04 tonne-year

S1 (~10% eff)
S2 (~90% eff)

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AC background in Paired data and unblinded results

➤ Randomly pair isolated S1 and S2 waveforms as AC sample waveforms;
➤ Off-window, 10% open data (OD), and 1-hit sideband for AC validation;
➤ Off-window events are those with drift time larger than maximum allowed by the TPC height;
➤ Cut-and-count BDT selection with more variables given in BDT;

|		Run0		Run1	
		WO BDT	W. BDT	WO BDT	W. BDT
Off-window	Model	209±25	1.2±0.4	485±43	0
	Data	209	1	495	2
OD	Model	26±6	0.12±0.04	34±7	0.06±0.02
	Data	18	0	29	0
1-hit side-band	Model	17095±2564	14±4	27567±4135	15±5
	Data	17374	9	29359	17

Unblinded data

	Other (surface, ER, etc)	AC	Total bkg	B8 CEvNS	Obs.
2-hit Run0	0.08+-0.01	1.08+-0.28	1.16+-0.28	**1.17+-0.39**	**1**
3-hit Run0	0.09+-0.01	0.07+-0.02	0.16+-0.02	**0.29+-0.10**	**0**
2-hit Run1	0.07+-0.01	1.15+-0.35	1.23+-0.35	**2.21+-0.68**	**2**
3-hit Run1	0.06+-0.02	0.24+-0.08	0.30+-0.08	**0.53+-0.19**	**0**

1-hit sideband
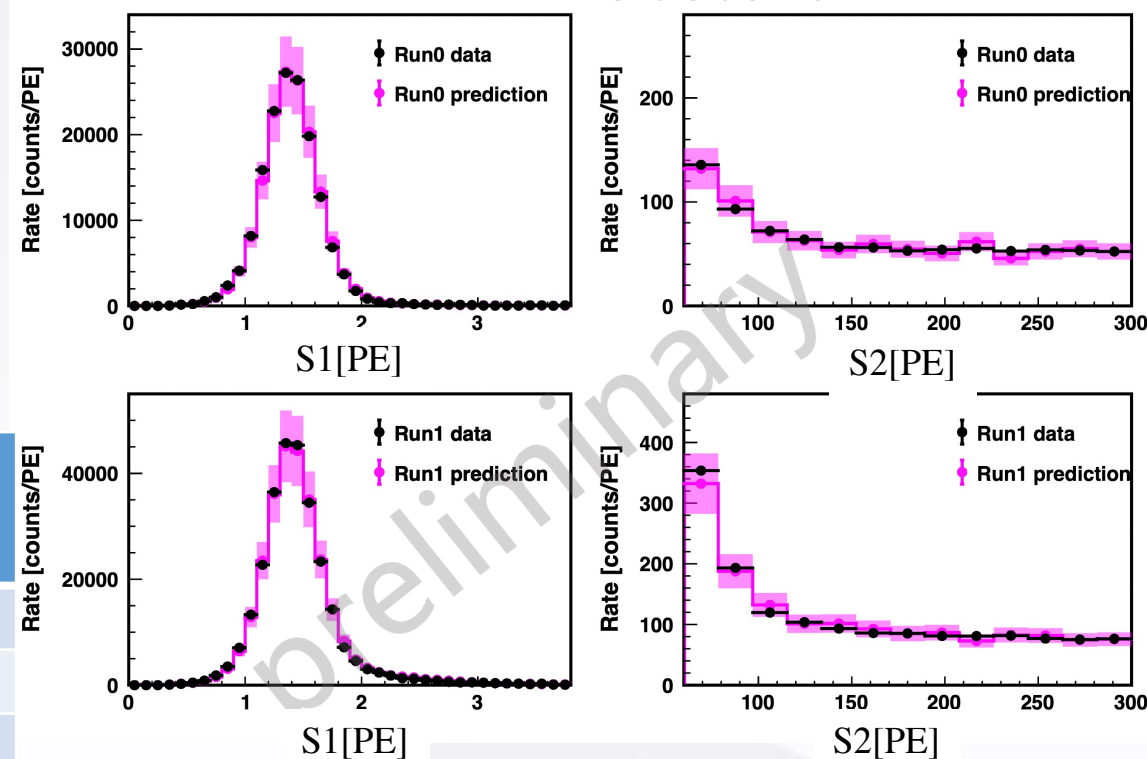
Run0 as example (PRL 130, 261001)
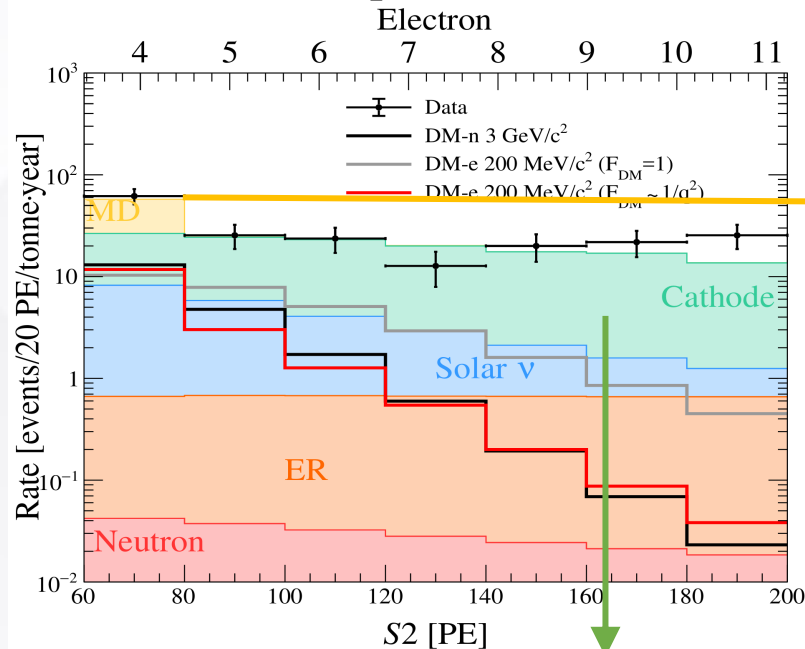
Use events with small S2 and timely close to previous large S2 as sideband

Use fixed-dt data as estimate for cathode!
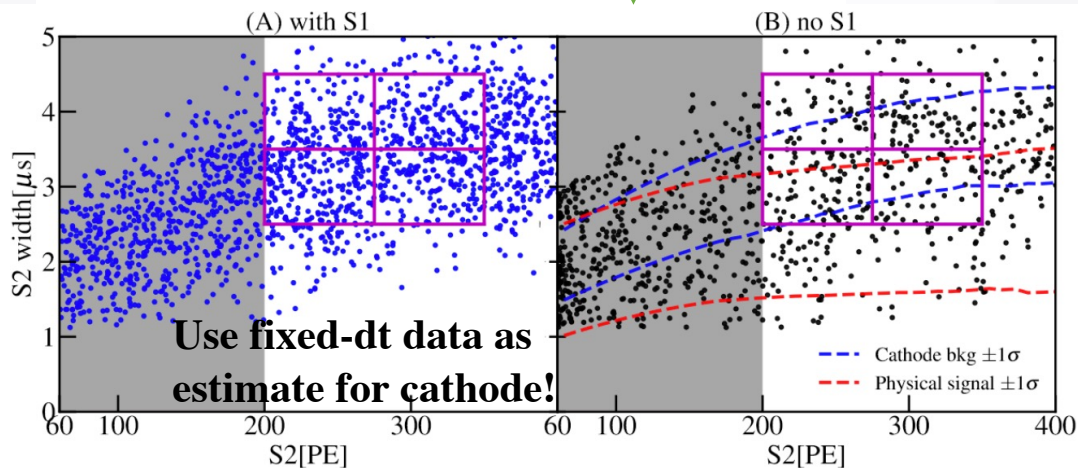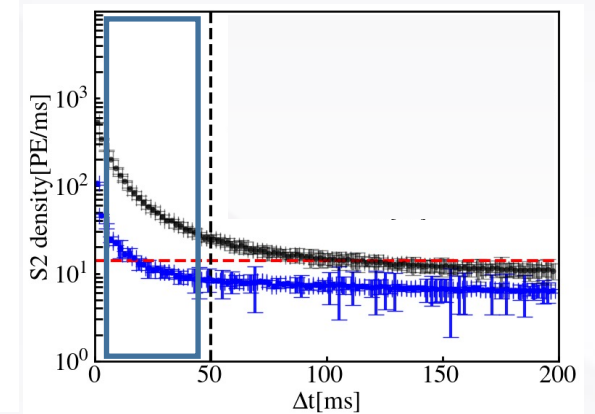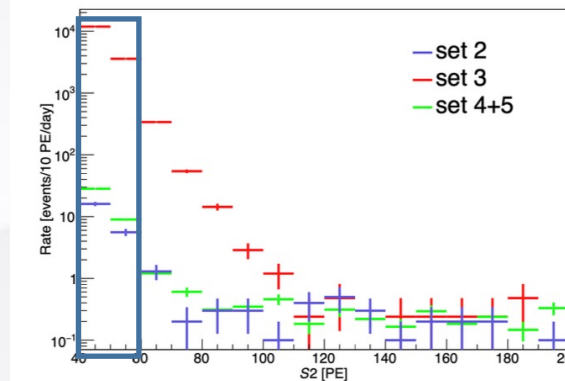
- Cathode spectral shape is estimated using cathode sample with S1, rate estimated using sideband;
- MD spectral shape is estimated using events timely close to large S2;
- MD rate is estimated using small-S2 sideband;

More details in Shuaijie Li's talk on Wednesday

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Unblind the S2-only data

- **Run0+1 seem to see an excess in S2-only data, but a downward fluctuation in paired data!**
- **S2only fit shows a best-fit B8 rate larger than expectation: mu_B8 = 1.8+-0.8;**
- **S2only background-only hypothesis p-value = 0.003;**
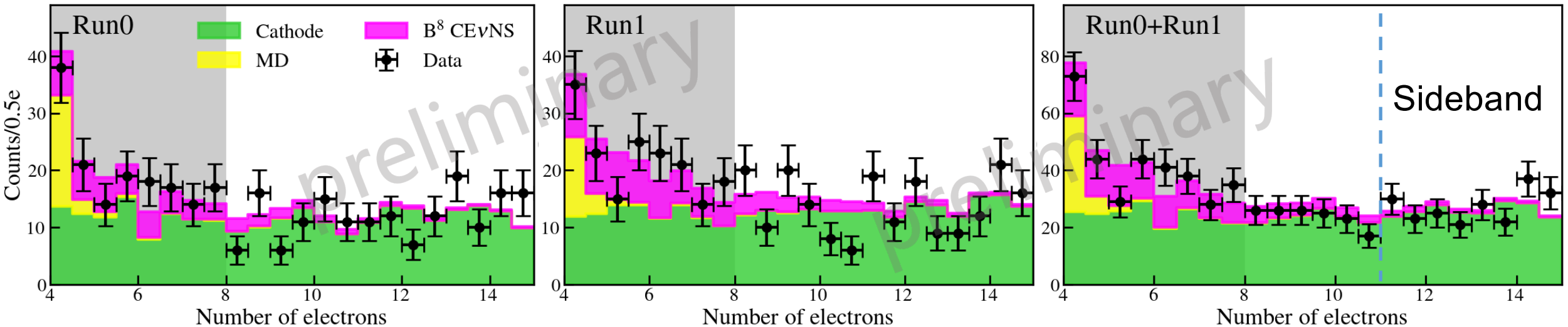
Systematic Uncertainties

	Stdev./Nominal						
	Paired				US2		
	Run0		Run1				
Nuisance parameters	2-hit	3-hit	2-hit	3-hit	Run0	Run1	Estimated by
Selection	0.10		0.10		0.11	0.17	WS vs. DS
BDT to ^{8}B CEνNS	0.17		0.11		-	-	WS vs. DS
Light/charge production	0.24	0.37	0.28	0.44	0.17	0.16	Average in ROI based on NEST
AC model	0.15		0.15		-	-	WS vs. control samples
BDT to AC	0.14		0.23		-	-	WS vs. control samples
Cathode model	-	-	-	-	0.24	0.20	Varying side-band selection
MD model	-	-	-	-	0.13	0.16	Varying side-band selection

➢ Uncertainties of selection, BDT, AC model, and LY/CY are included in paired data;

➢ Uncertainties of selection, cathode, MD, and LY/CY are included in S2only data;

➢ Uncertainties are given by MC vs real data, and varied control selection;
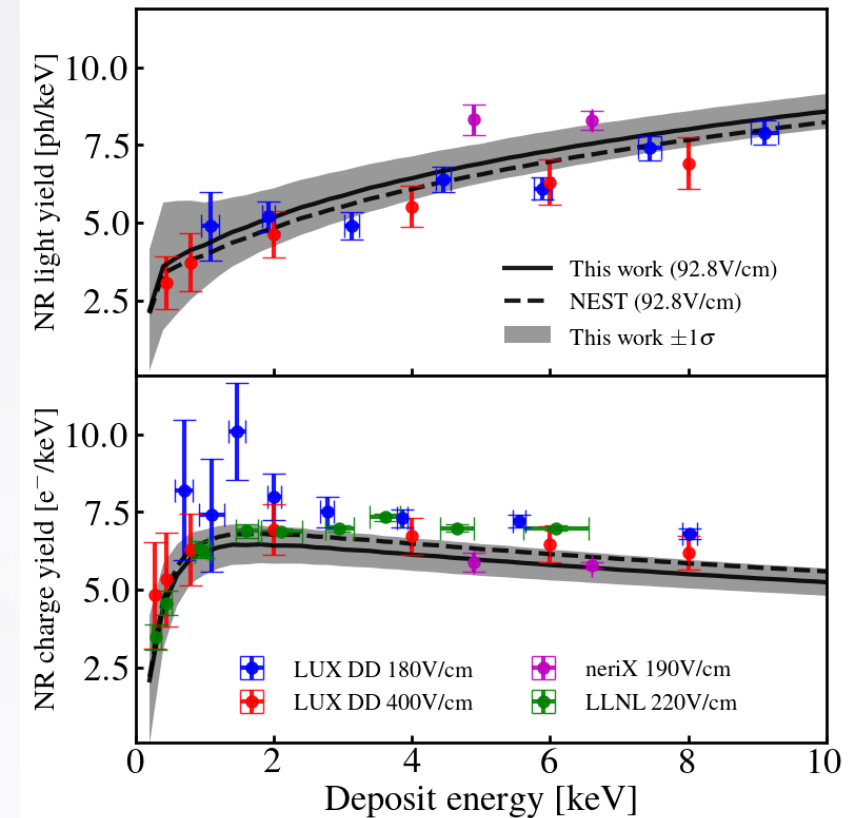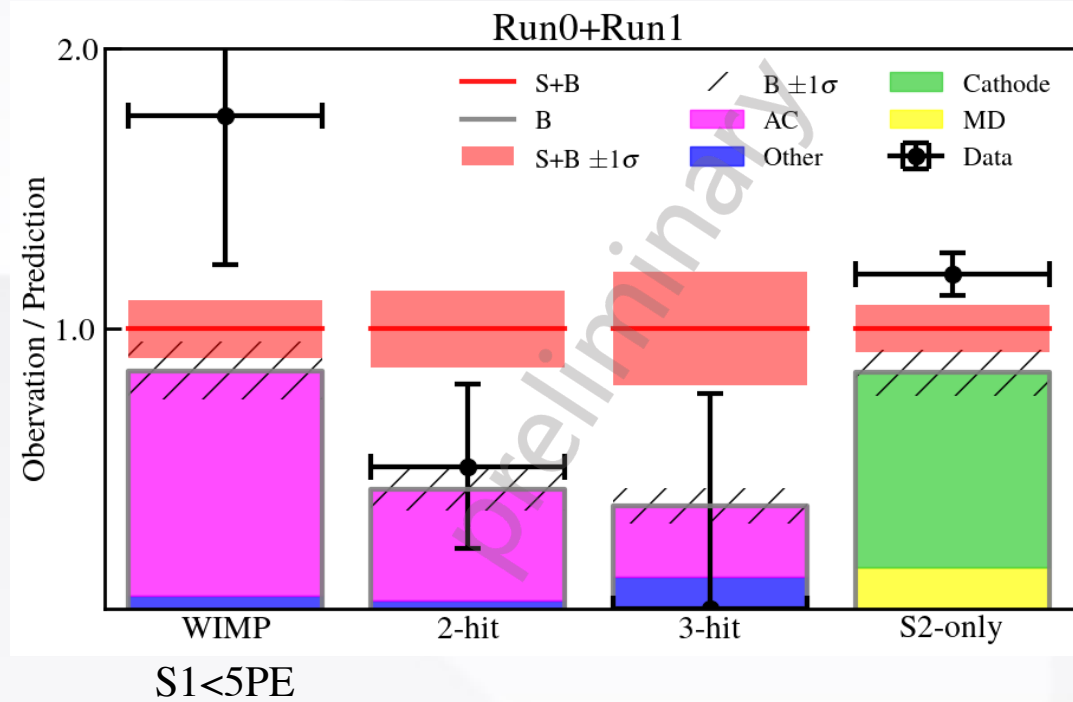
	Background-only p-value	Best-fit / Theoretical predition
S2-only	0.003	1.8+-0.8
Paired & S2only combined	0.105	0.8+-0.7

➤ 1D fitting on S2 spectra for S2-only;
➤ Signal uncertainty is assumed to be anti-correlated between paired and S2only data;
➤ **2D fitting on S2 vs width space is ongoing!**

➢ Preliminary results of blind WIMP analysis on the Run0 and Run1 combined data;

➢ Upward fluctuation in <8GeV; Best constraint for >100GeV;

➢ Preliminary results of B8 CEvNS search using Run0+1 and S1-S2 paired/S2-only combined analysis;

➢ S2-only sees slight sign of B8 signal; Energy vs width fitting is ongoing!

➢ Next stage of PandaX (PandaX-20T) is expected to be online in 2027!

Thank You for your attention !