Recent Results from the PandaX-4T Experiment

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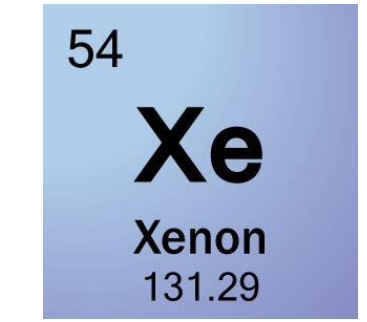
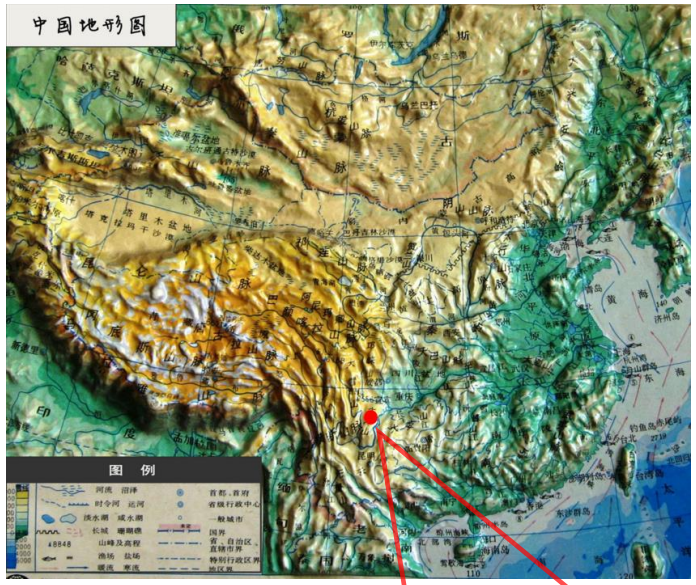
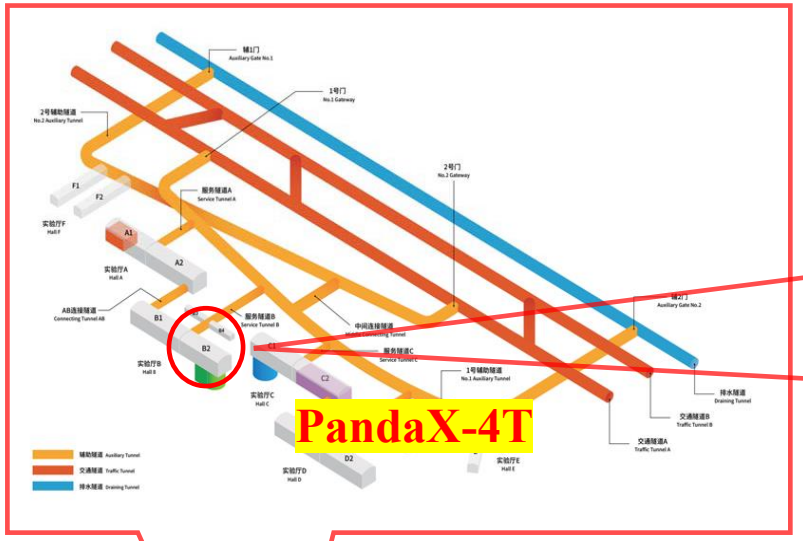
PandaX collaboration

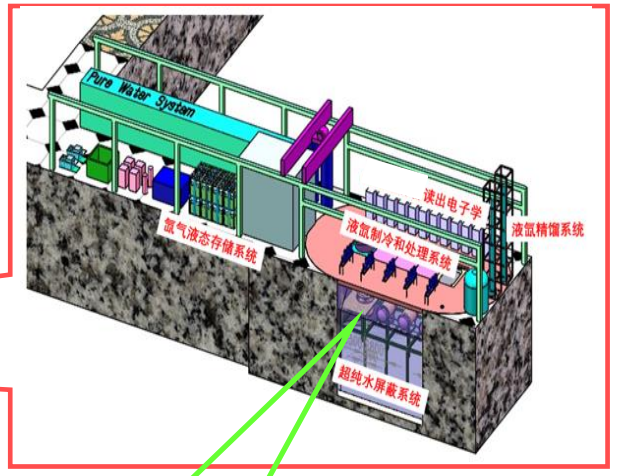
- PandaX: **particle and astrophysical xenon detector**
  - dark matter, Majorana neutrino, astrophysical neutrino

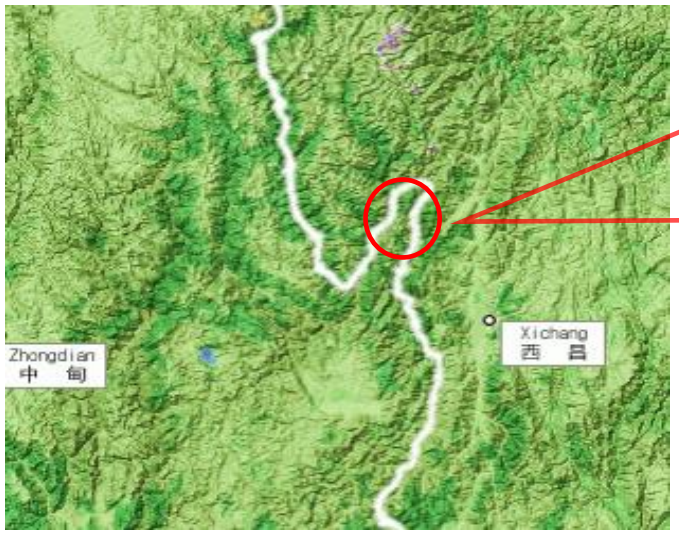


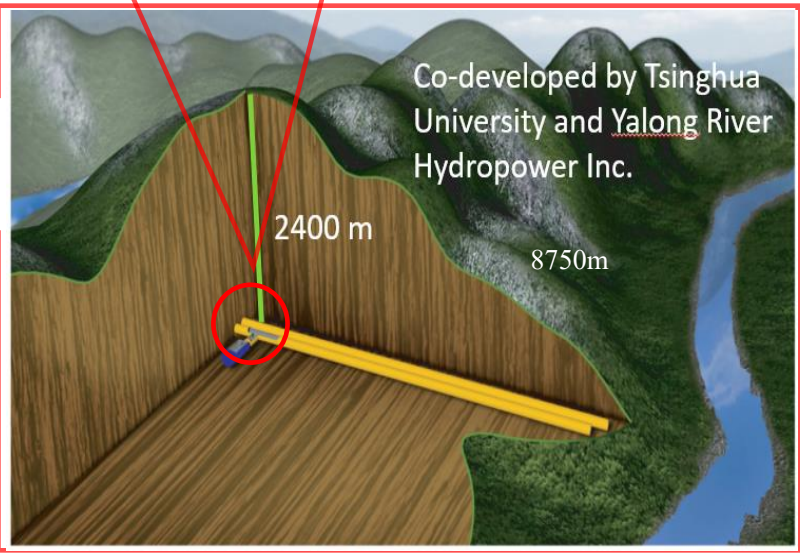
PandaX @ CJPL-II

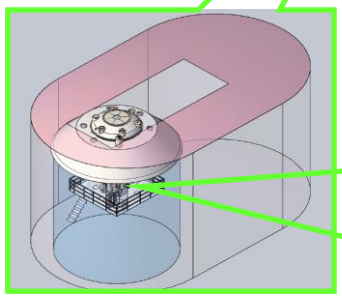


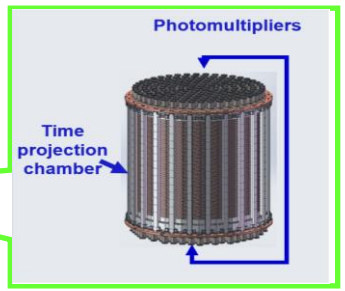


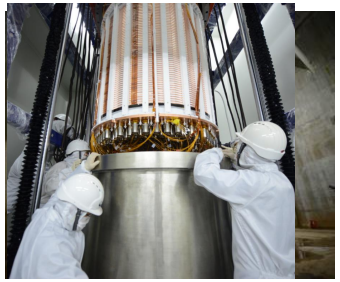


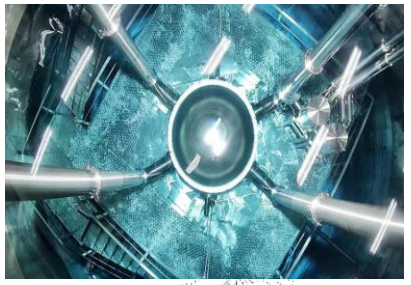










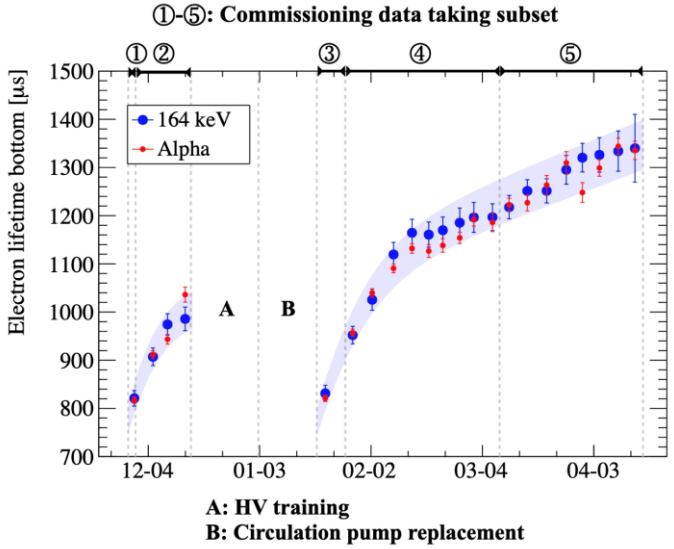


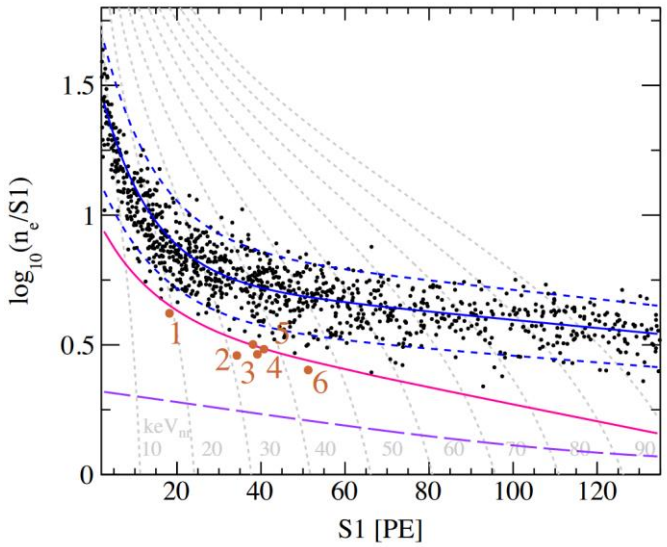
Timeline of PandaX-4T

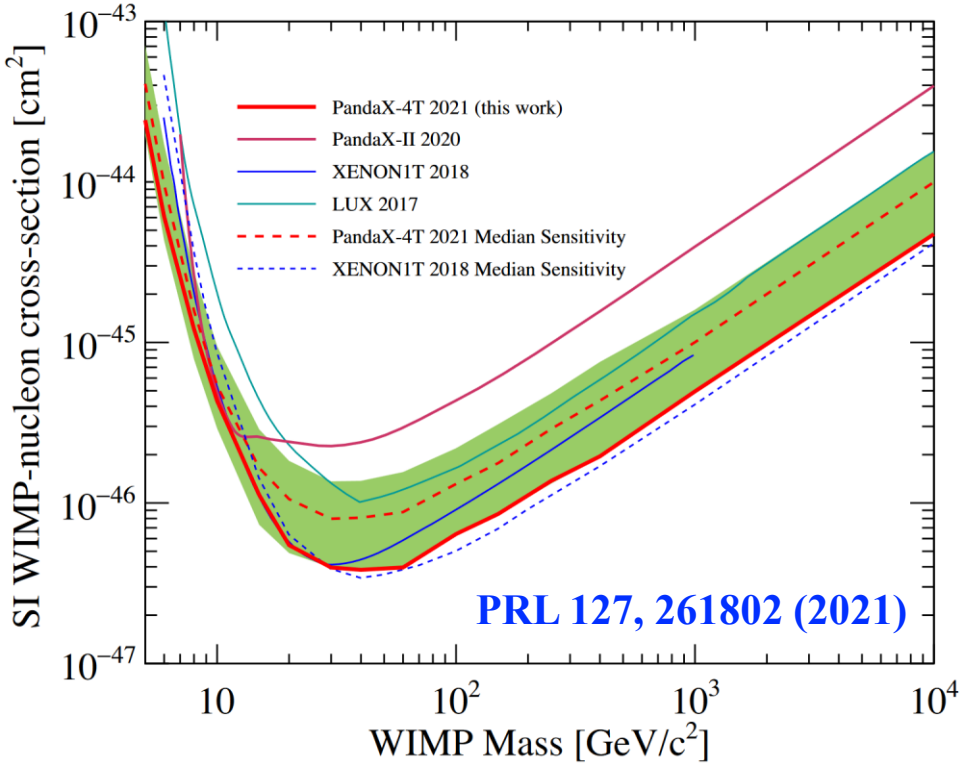
2020/11 – 2021/04	**Commissioning (Run 0)** 95 days
2021/07 – 2021/10	**Tritium removal** xenon distillation, gas flushing, etc
2021/11 – 2022/05	**Physics run (Run 1)** 164 days
2022/09 – 2023/12	**CJPL B2 hall renovation** xenon recuperation, detector upgrade
Current Status	**Resuming physics data-taking**

First WIMP result – Run0

- Stable data running period: 95 calendar days;
- Sensitive Volume: 3.7 tonne;
- Total exposure: 0.63 tonne-year;
- Limits on SI WIMP-nucleon cross section reach $3.8\times10^{-47}cm^2$;

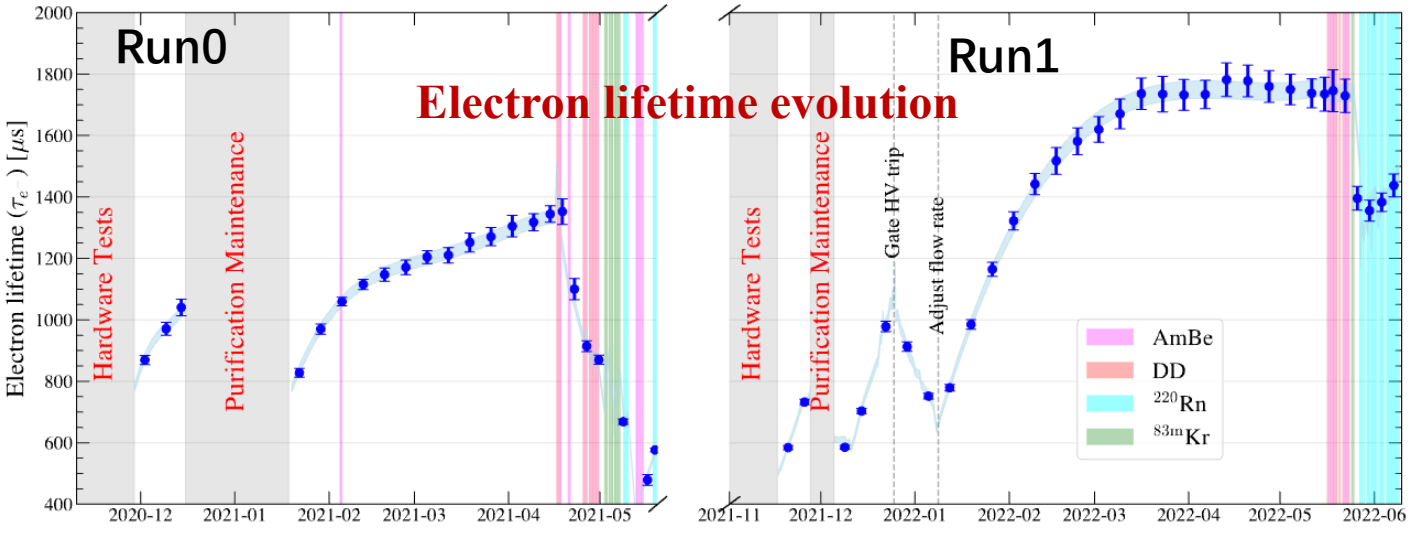






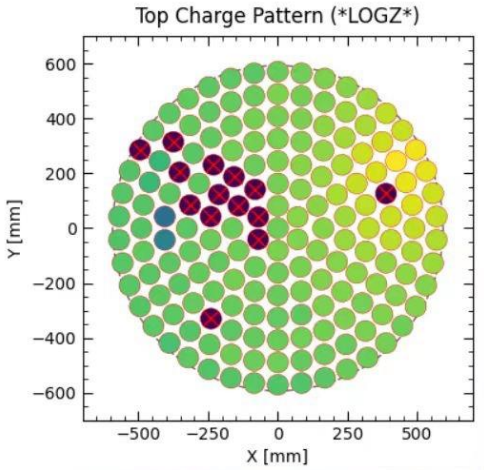
PandaX-4T detector condition

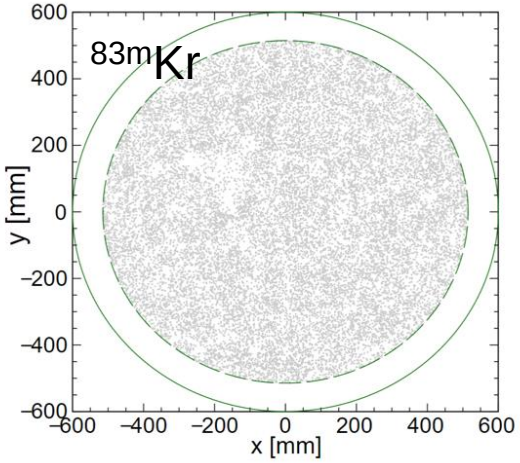
Run	Run0					Run1					
Set	1	2	3	4	5	1	2	3	4	5	6
Duration (days)	1.96	13.54	5.53	37.22	36.61	9.41	10.50	6.18	14.00	38.44	85.08
Live Time (days)	1.82	12.30	2.14	33.01	34.29	8.07	8.53	5.56	12.19	34.45	77.86
$\langle\tau_e\rangle(\mu s)$	807.2	958.1	812.5	1110.4	1275.4	631.2	642.3	975.7	831.5	1171.7	1719.6
$V_{cathode}$(-kV)	20	18.6	18	16	16	16					
V_{gate}(-kV)	4.9	4.9	5	5	5	6					
$g_1(\%)$	10.0 ± 0.5					9.1 ± 0.4					
g_{2_b}(PE/e^-)	4.1 ± 0.4					5.0 ± 0.5					



- 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 *PRD 110, 023029*);

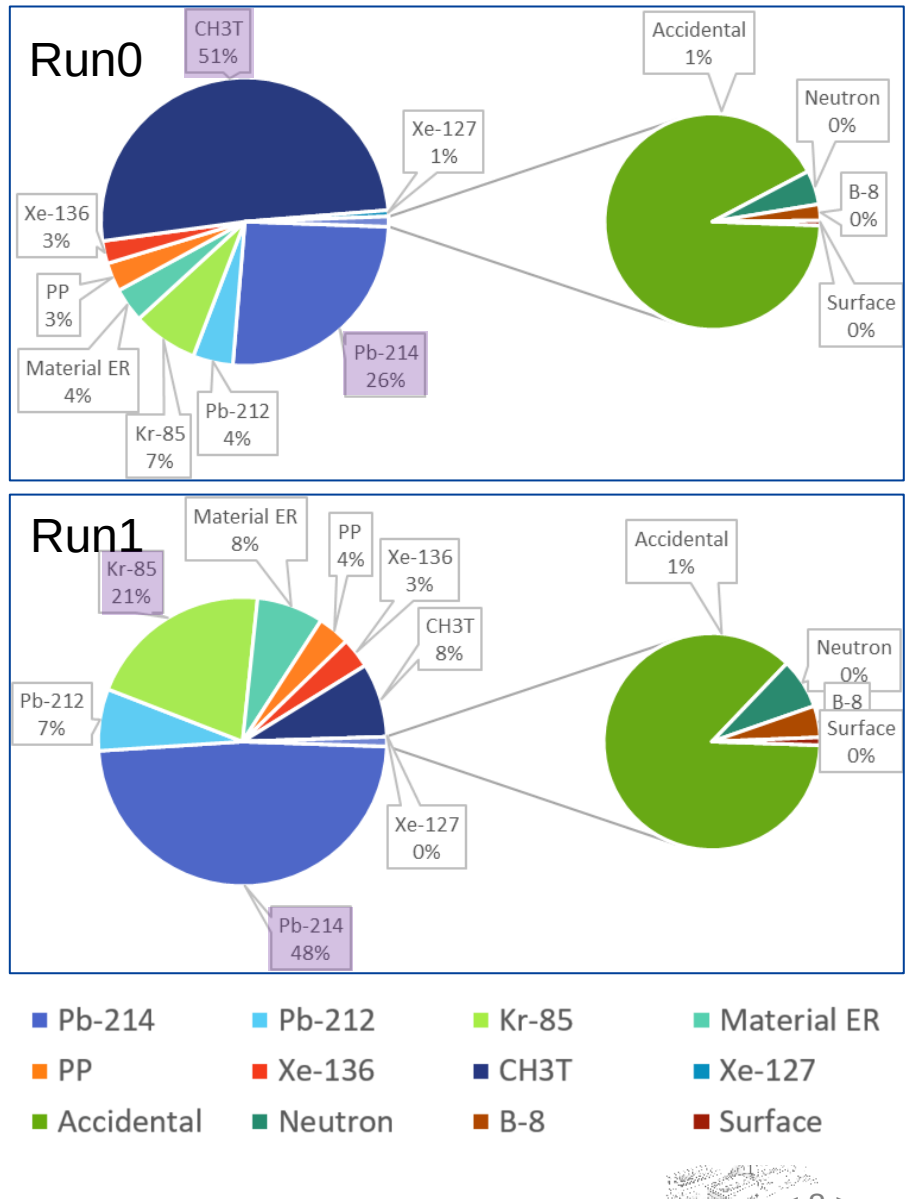




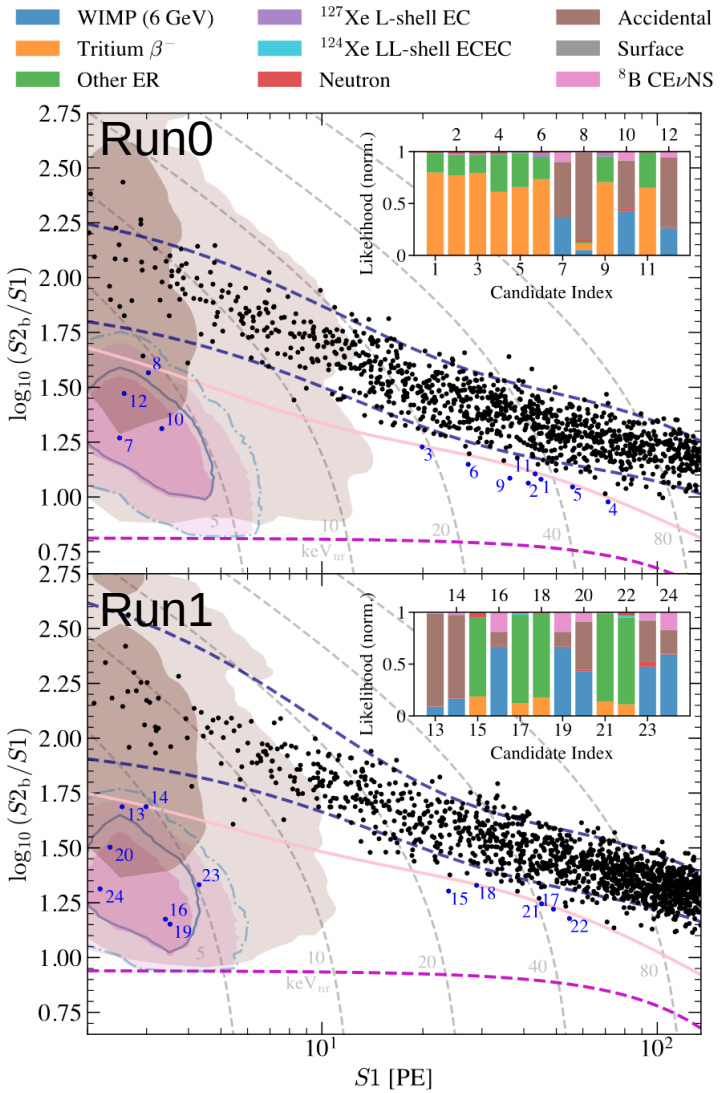
Background Composition

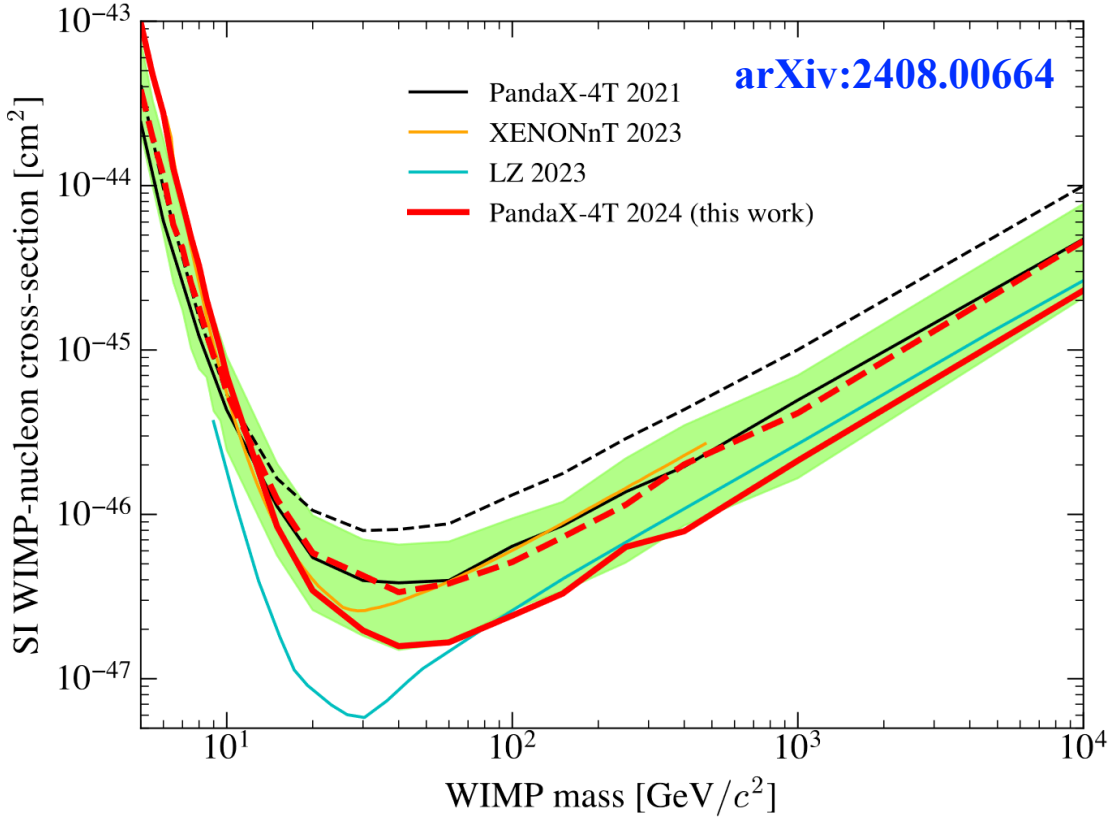
	Run0	Run1	Total	Below NR median	Best fit
^{214}Pb	281 ± 13	675 ± 35	956 ± 38	$3.6^{+0.9}_{-0.7}$	-
^{212}Pb	49 ± 13	97 ± 25	146 ± 30	$0.6^{+0.2}_{-0.2}$	-
^{85}Kr	80 ± 40	289 ± 88	369 ± 96	$1.4^{+0.5}_{-0.5}$	-
Material ER	42 ± 5	105 ± 11	147 ± 12	$0.6^{+0.2}_{-0.1}$	-
Solar ν	38 ± 4	74 ± 7	111 ± 8	$0.4^{+0.1}_{-0.1}$	-
^{136}Xe	28 ± 1	59 ± 3	87 ± 3	$0.2^{+0.1}_{-0.1}$	-
Other ER (data)	504 ± 16	1226 ± 28	1730 ± 32	$6.4^{+1.7}_{-1.2}$	1767 ± 39
CH_3T	556 ± 33	114 ± 33	670 ± 47	$5.2^{+1.2}_{-1.1}$	677 ± 47
^{127}Xe	7.7 ± 0.8	0.0 ± 0.1	7.7 ± 0.8	$0.10^{+0.02}_{-0.02}$	7.7 ± 0.2
^{124}Xe	2.3 ± 0.6	4.1 ± 1.1	6.3 ± 1.7	$0.03^{+0.01}_{-0.01}$	6.2 ± 1.7
Neutron	0.6 ± 0.2	1.1 ± 0.2	1.7 ± 0.3	$1.0^{+0.1}_{-0.1}$	1.8 ± 0.3
^{8}B CEνNS	0.3 ± 0.1	0.7 ± 0.2	1.0 ± 0.3	$1.0^{+0.3}_{-0.3}$	1.1 ± 0.3
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	13 ± 4	24 ± 5	$6.4^{+1.4}_{-1.4}$	26 ± 5
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;



Constraint to WIMP





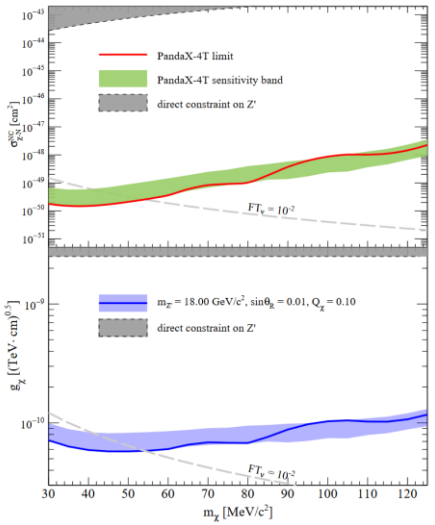
- Combined analysis using Run0+1, total exposure = 1.54 tonne-year;
- 1σ upward fluctuation with <8 GeV, while downward fluctuation in high-mass region;
- 1.6e-47 cm^2 @ 40GeV;

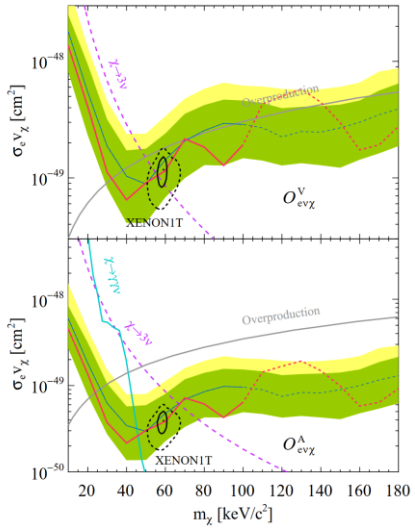
Move to light dark matter

CRDM DM-N

- Sensitive to Sub-GeV DM;
- MC simulation for Earth Attenuation;
- Time information;

2022-04-27

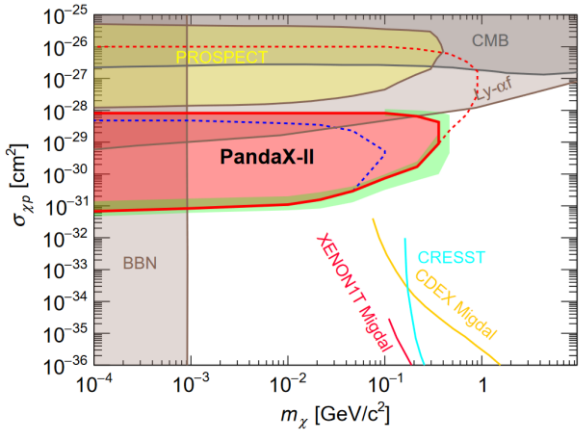




Atmospheric DM-N

- Sensitive to *O*(MeV);
- Consider QE process in Earth attenuation;
- Add flux from Earth back;

2023-01-08



Absorption DM-e

- 30-125 MeV DM;

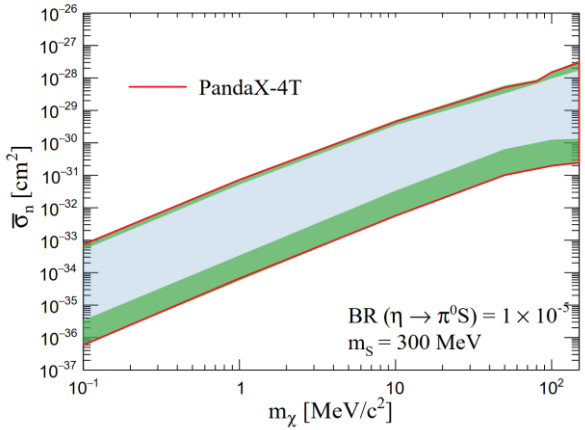
Absorption DM-N

- 10-180 keV DM;

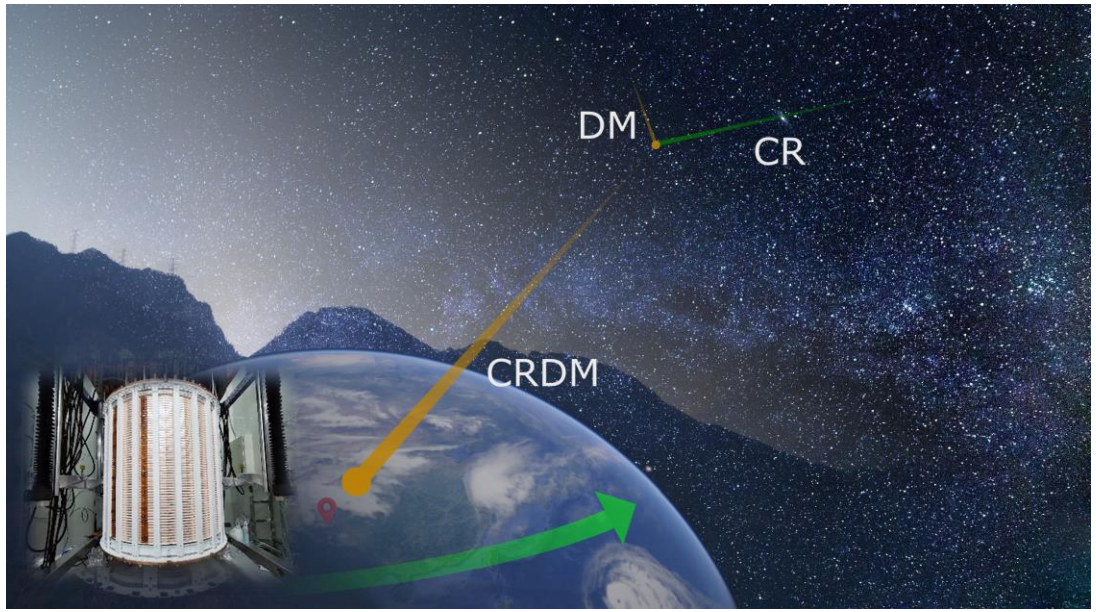
- Mono-peak signal, good energy resolution understanding by calibration data vs. MC;

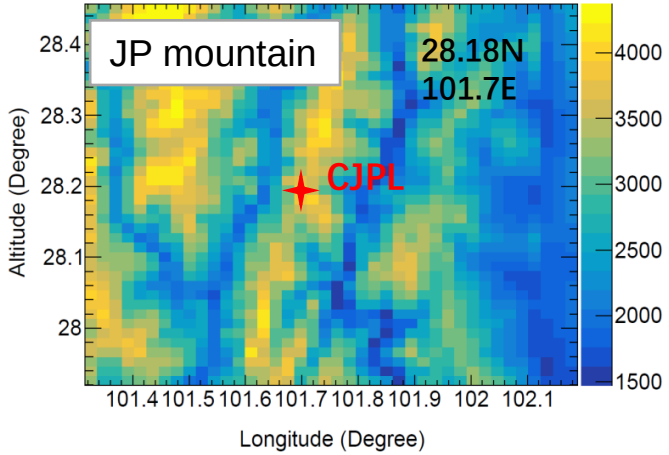
2022-06-05

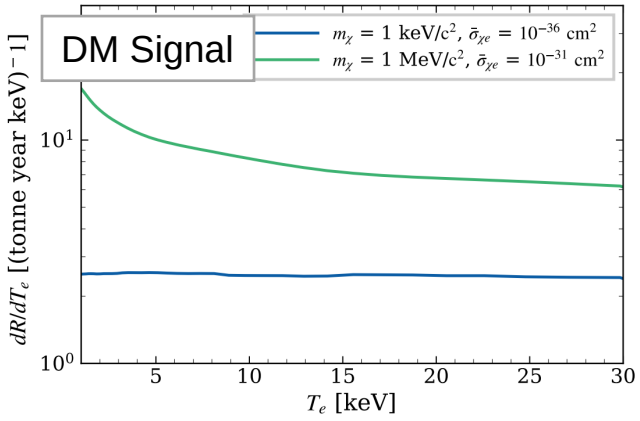
2022-10-13



Cosmic ray electron boosted dark matter (CReDM)







- **DM-e interaction scenario:**

$$\mathcal{L}_{\rm int} = G\bar{\chi}\gamma^{\mu}\chi\bar{e}\gamma_{\mu}e$$

where the χ is fermionic DM and G is the effective vector coupling constant.

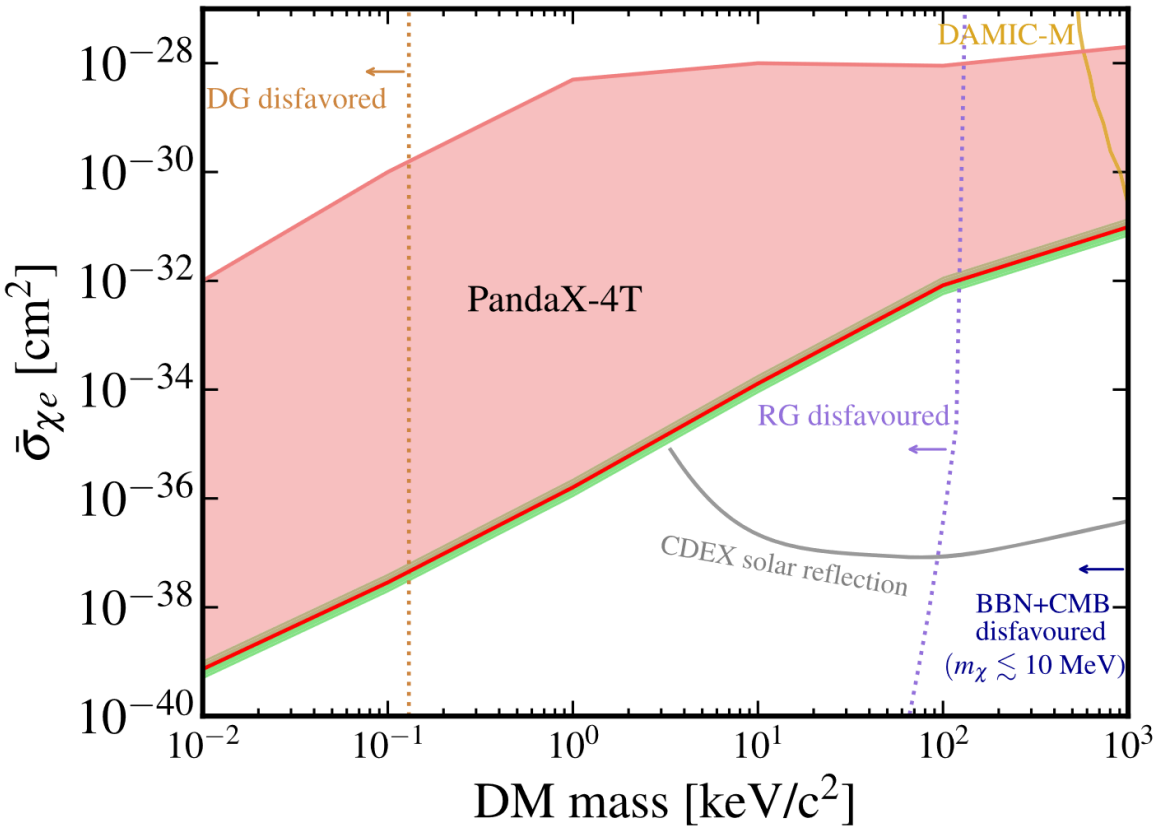
- **Differential cross section with free relativistic electrons:**

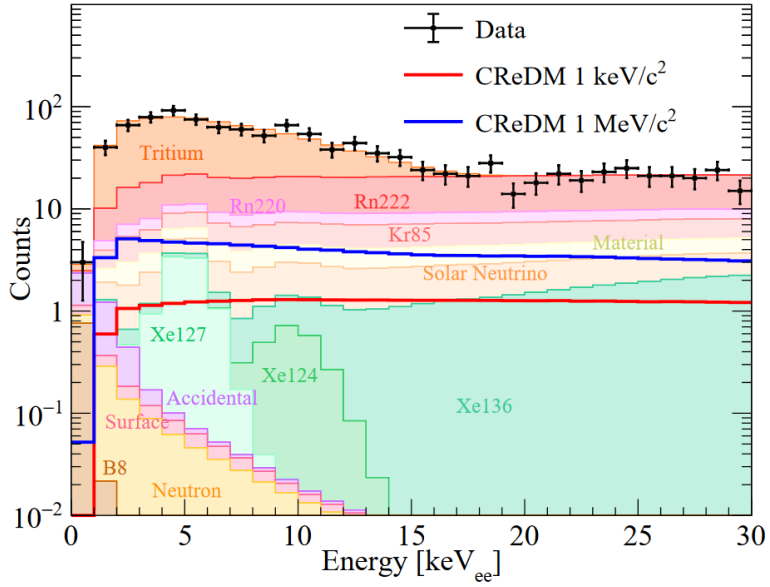
$$\frac{d\sigma_{\chi e}}{dT_\chi} = \frac{\bar{\sigma}_{\chi e}}{4\mu_{\chi e}^2 T_e^{\rm CR}(T_e^{\rm CR}+2m_e)}\Big[2m_\chi(m_e+T_e^{\rm CR})^2 - T_\chi\left(2m_\chi T_e^{\rm CR}+(m_\chi+m_e)^2\right)+m_\chi T_\chi^2\Big]$$

where the effective cross section $\bar{\sigma}_{\chi e} = G^2\mu_{\chi e}^2/\pi$.

CReDM search in PandaX-4T

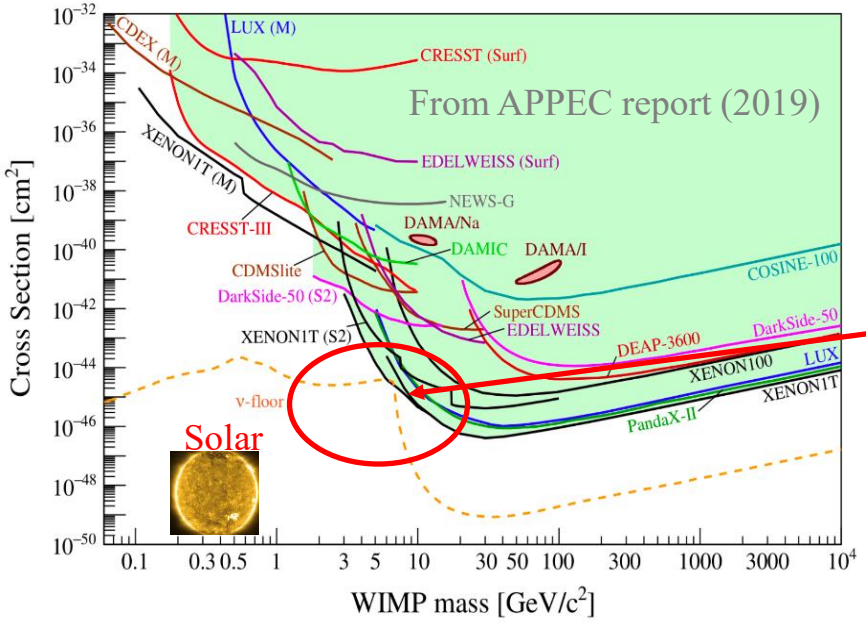
PRL 133, 101805 (2024)

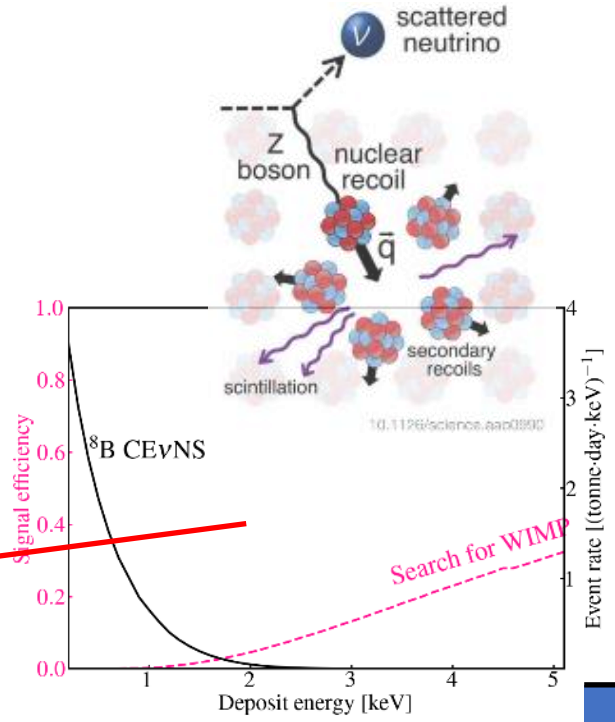


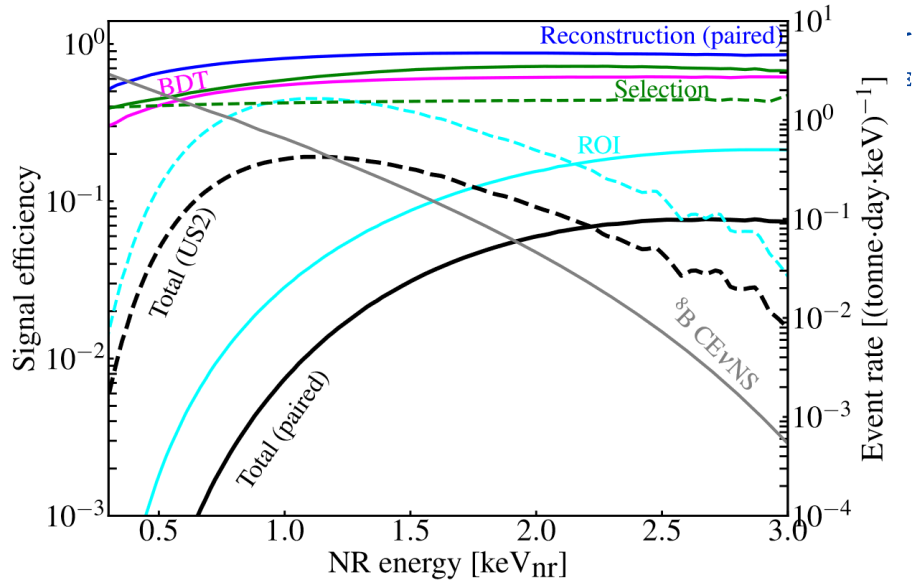


- Energy information used for the signal identification, no excess was found;
- We present constraints on DM-e cross section for DM mass below 1 MeV and sensitive for 10 eV to 3 keV;
- This result push the current mass range down by two orders of magnitude, achieve the minimum fermionic DM mass allowed by the local density;

Solar B8 Neutrino







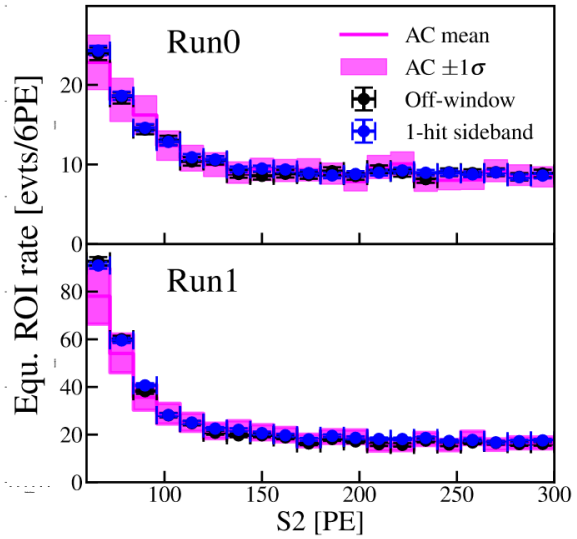
- PandaX-4T searches for solar B8 CEvNS with lowered threshold;
- Large amount of background emerged with lowered threshold;
- Two data regions used: S1-S2 Paired and S2-only (US2);

	S1-S2 Paired	S2-only
ROI	2 or3 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	1.20 tonne-year	1.04 tonne-year

Background estimation

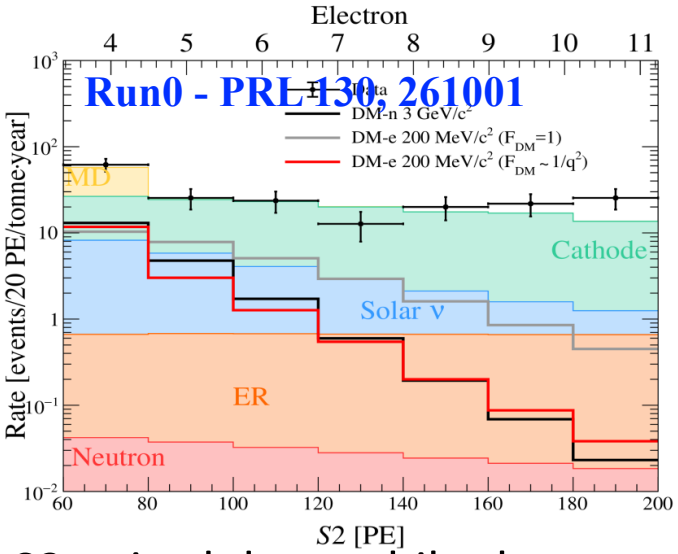
S1-S2 paired

paired ROI	Run0 2-hit	Run0 3-hit	Run1 2-hit	Run1 3-hit
Surface	0.06±0.01	0.06±0.01	0.01±0.01	0.02±0.02
ER	0.01±0.00	0.00±0.00	0.01±0.01	0.01±0.01
Neutron	0.02±0.01	0.02±0.01	0.03±0.01	0.03±0.01
AC	1.08±0.28	0.07±0.02	1.15±0.35	0.24±0.08
Total bkg.	1.16±0.28	0.15±0.02	1.21±0.35	0.30±0.08
^{8}B CEνNS	1.00±0.24	0.24±0.09	1.76±0.50	0.40±0.18
Observed	1	0	2	0



S2-only

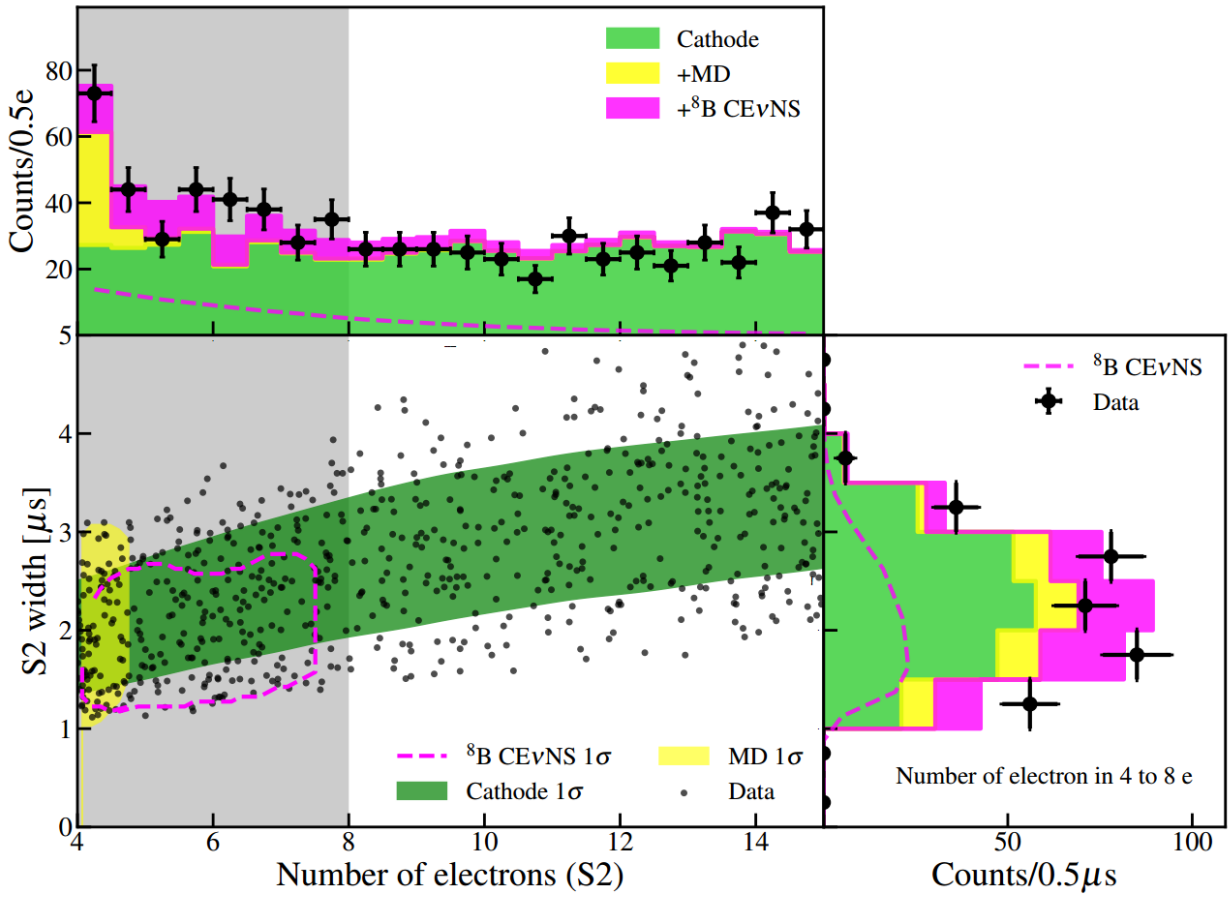
US2 ROI	Run0	Run1
Cathode	100±24	104±21
MD	25±3	20±4
ERs	1.3±0.1	0.9±0.2
Total bkg.	126±24	125±21
^{8}B CEνNS	18±4	25±6
Observed	158	174



- Accidental (AC) background dominated in the S1-S2 paired data, while the cathode & micro-charge (MD) background dominated in the S2-only data;
- Each BKG component was estimated independently by the MC and the data-driven method;
- By MC vs real data, and varied control selection, B8 signal and background uncertainties are included;

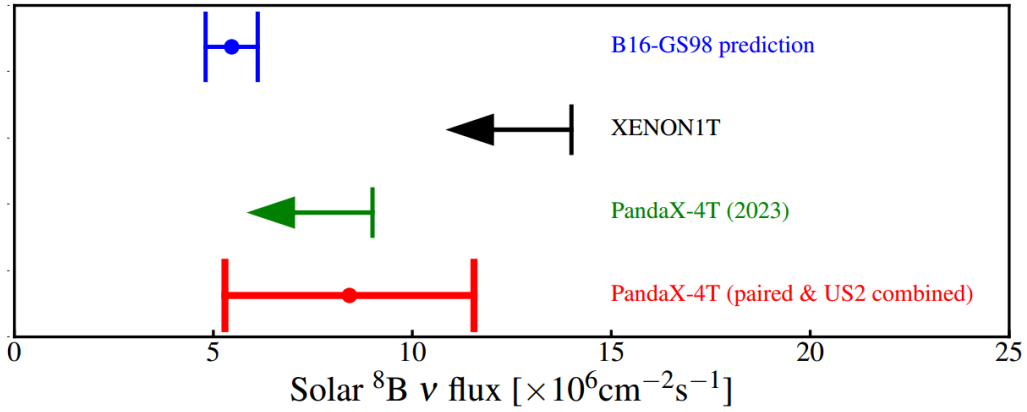
Search for B8 combining S1-S2 paired and S2-only data

Unblinded US2 in Run0&Run1



$$\mathcal{L} = \mathcal{L}_{\text{paired}} \cdot \mathcal{L}_{\text{US2}}$$

arXiv:2407.10892



- Combined statistical test with S1-S2 paired and S2-only data;
- Reject bkg-only hypothesis with significance of 2.64σ, with best-fit B8 events is 75±28 (US2) and 3.5±1.3 (paired);
- Resulting best-fit solar B8 neutrino flux is $(8.4\pm3.1)\times10^6$ cm^{-2}s^{-1};

Summary and outlook

- PandaX-4T released the WIMP result with combined Run0&Run1 data;
- By cosmic ray boosted, light dark matter can be studied in PandaX-4T;
- Measure the solar B8 neutrinos flux by S1-S2 and S2-only combined analysis;
- More physical studies are ongoing with new data, and the next stage of PandaX (20T) is on the schedule!

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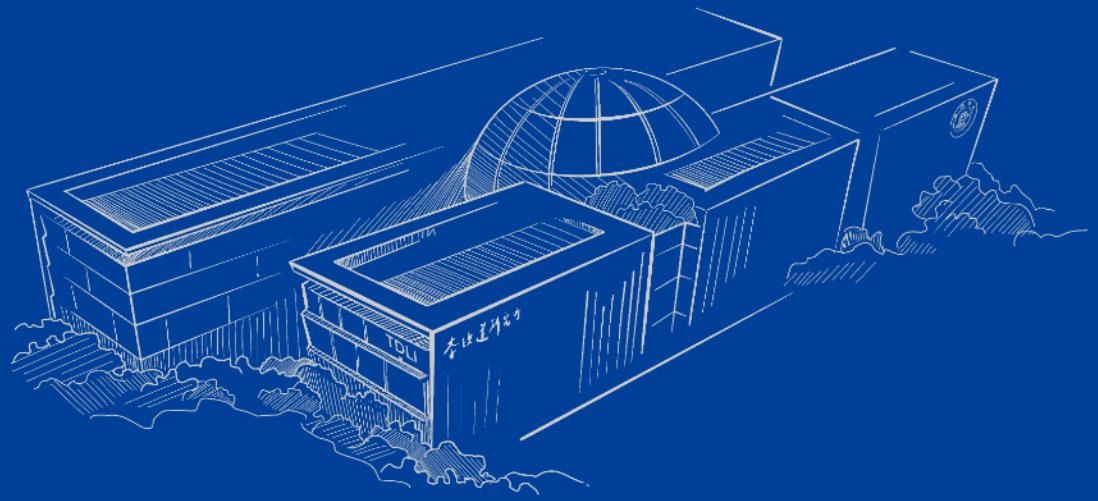
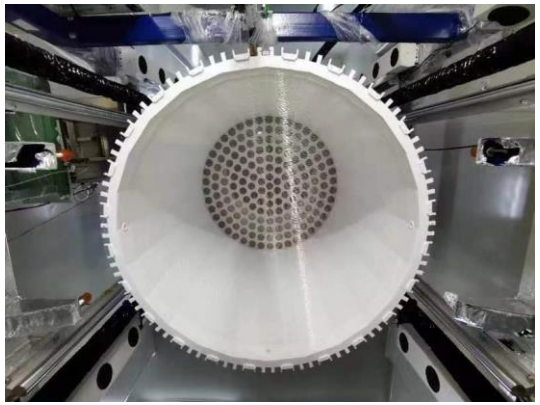
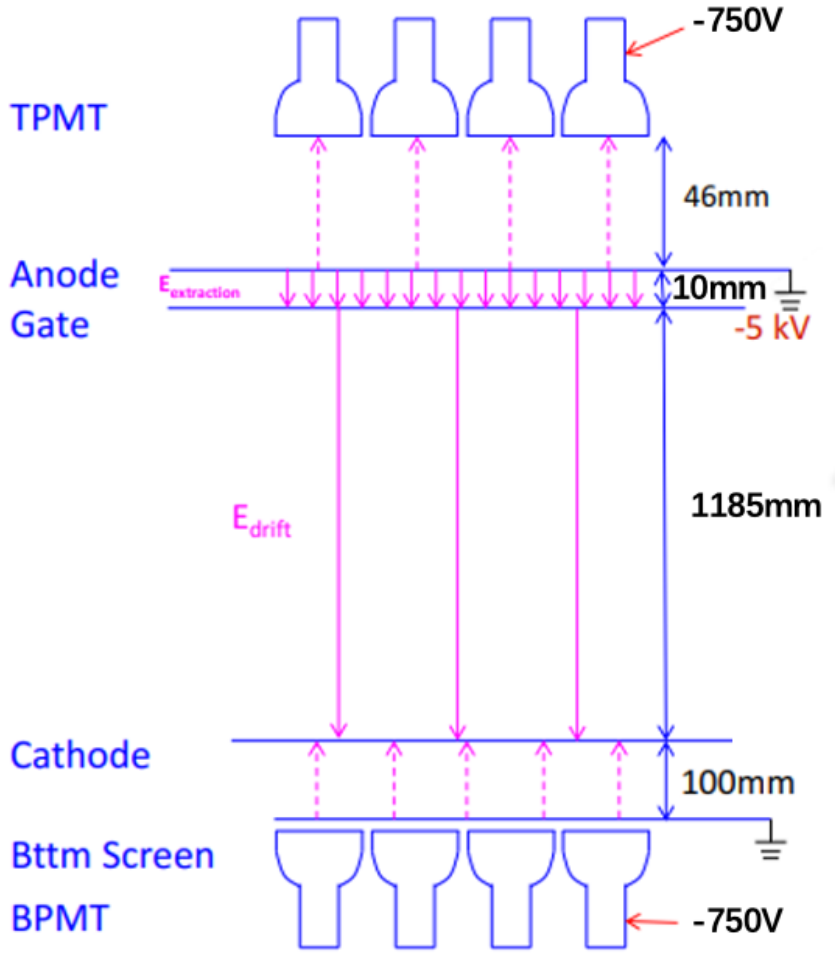
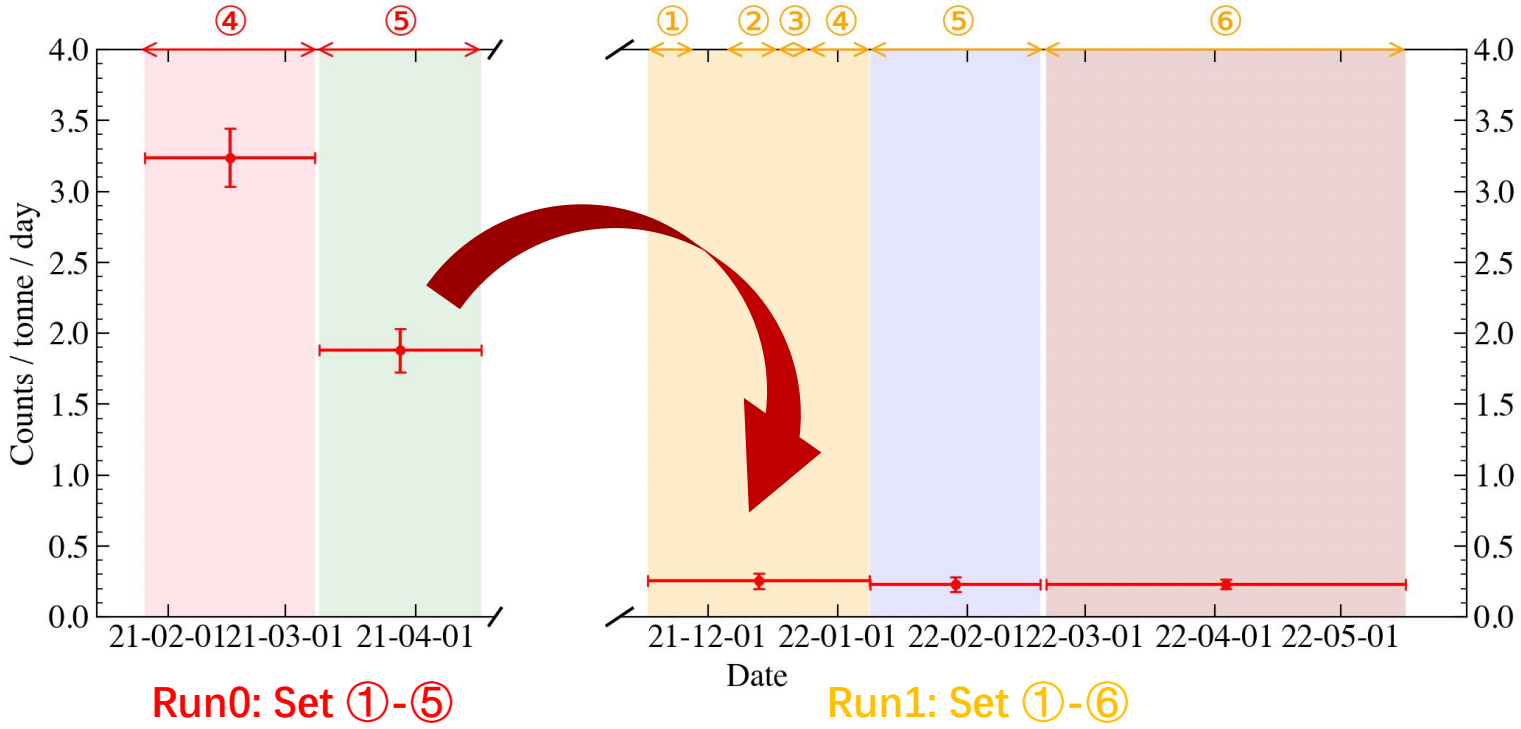


Backup - TPC




-750V
TPMT
46mm
Anode
Gate
$E_{extraction}$
10mm
-5 kV
E_{drift}
1185mm
Cathode
100mm
Bttm Screen
BPMT
-750V

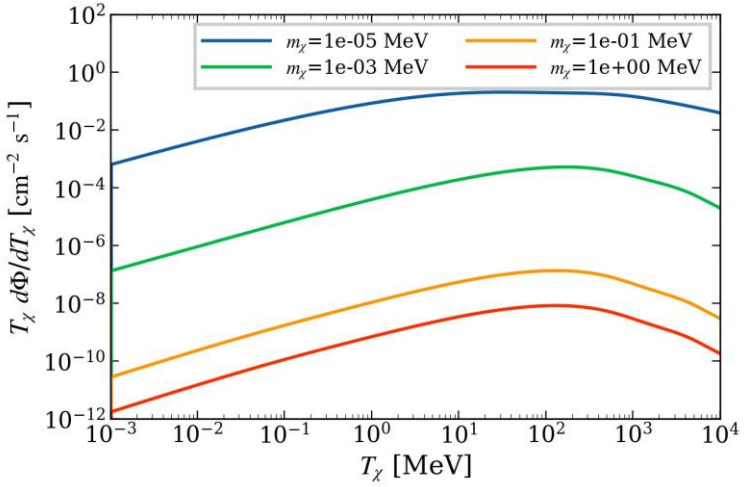
Backup - Tritium removal

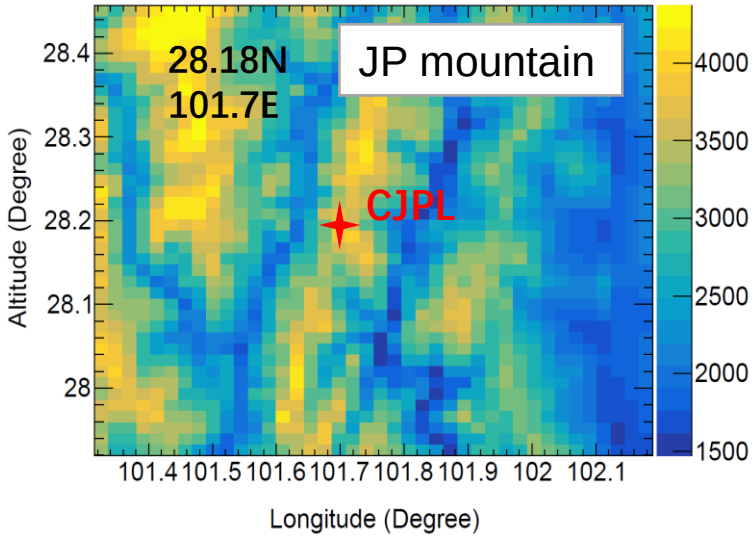


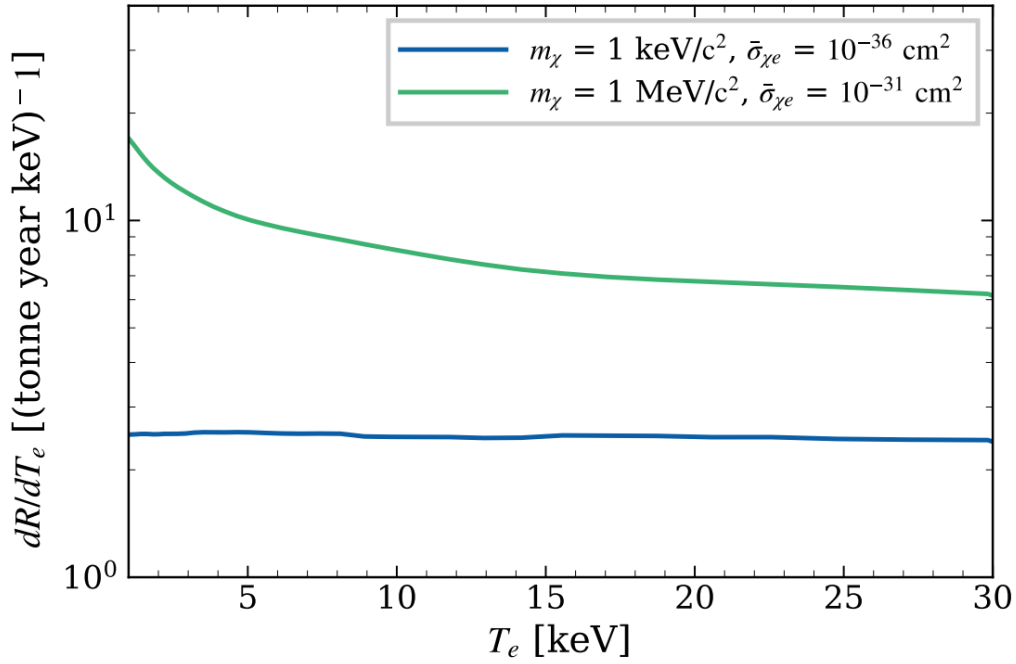
- Kr-removal distillation process applied, along with the xenon gas self-purification (hot Getter) inner the detector;
- CH3T rates significantly decreased, estimated from S1 fit;

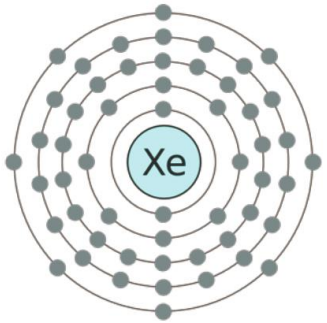
Backup - CReDM signal in PandaX

$$\frac{d\sigma^{nl}_{\chi e}}{dT_e} = \frac{\bar{\sigma}_{e\chi}}{8\mu^2_{e\chi} v^2_\chi T_e} \int_{|\mathbf{q}|_{\min}}^{|\mathbf{q}|_{\max}} d|\mathbf{q}|\,|\mathbf{q}|\,|f^{nl}_{\rm ion}(T_e,|\mathbf{q}|)|^2 \times \left(1 - \frac{\Delta E_{nl}}{E_\chi} - \frac{\mathbf{q}^2 - \Delta E^2_{nl}}{4E^2_\chi}\right),$$



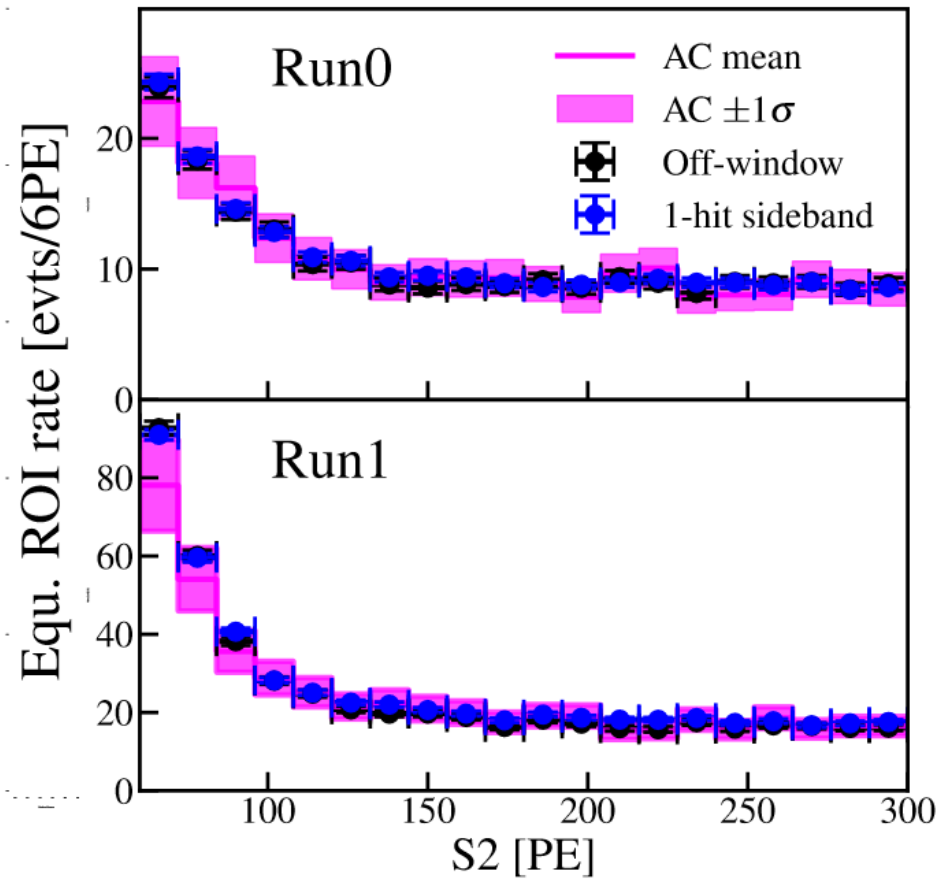






- CReDM including the CRs acceleration, Earth attenuation and deposition process in the detector;
- Relativistic effect of the DM are consistently considered in all processes;

Backup - Background estimation – S1-S2 paired



paired ROI	Run0 2-hit	Run0 3-hit	Run1 2-hit	Run1 3-hit
Surface	0.06±0.01	0.06±0.01	0.01±0.01	0.02±0.02
ER	0.01±0.00	0.00±0.00	0.01±0.01	0.01±0.01
Neutron	0.02±0.01	0.02±0.01	0.03±0.01	0.03±0.01
AC	1.08±0.28	0.07±0.02	1.15±0.35	0.24±0.08
Total bkg.	1.16±0.28	0.15±0.02	1.21±0.35	0.30±0.08
^{8}B CEνNS	1.00±0.24	0.24±0.09	1.76±0.50	0.40±0.18
Observed	1	0	2	0

- Accidental background (AC) dominated in the S1-S2 paired data;
- Randomly pair isolated S1 and S2 waveforms as AC sample waveforms, and three types of data for AC validation;
- BDT cuts with more variables are applied;

Backup - Background estimation – S2-only

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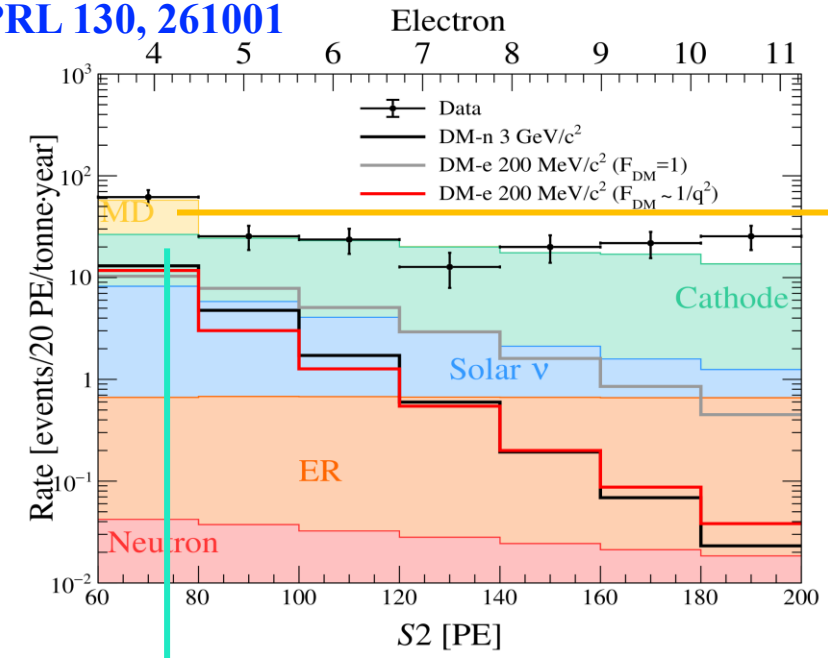
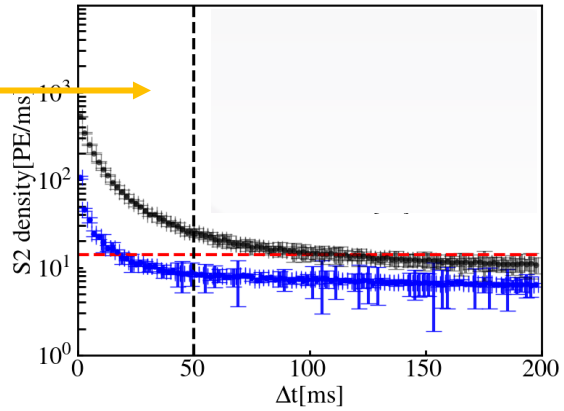
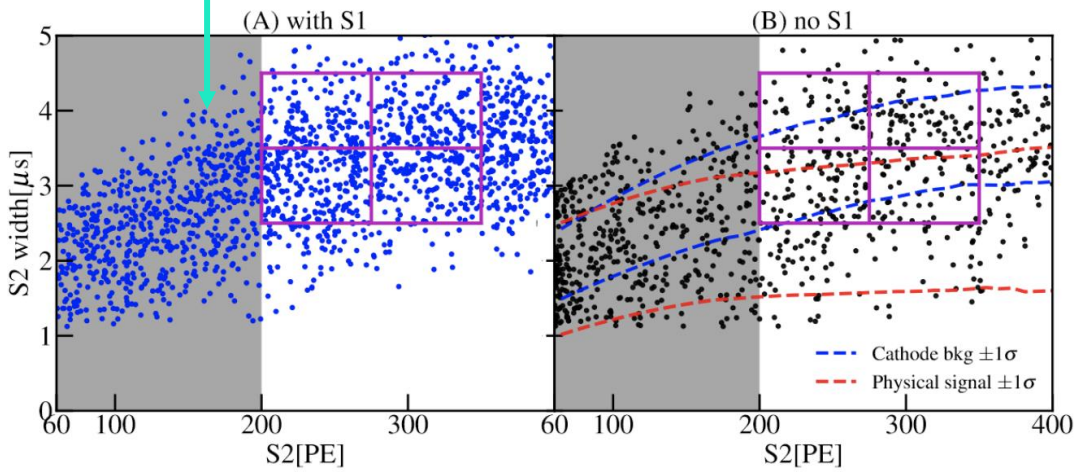




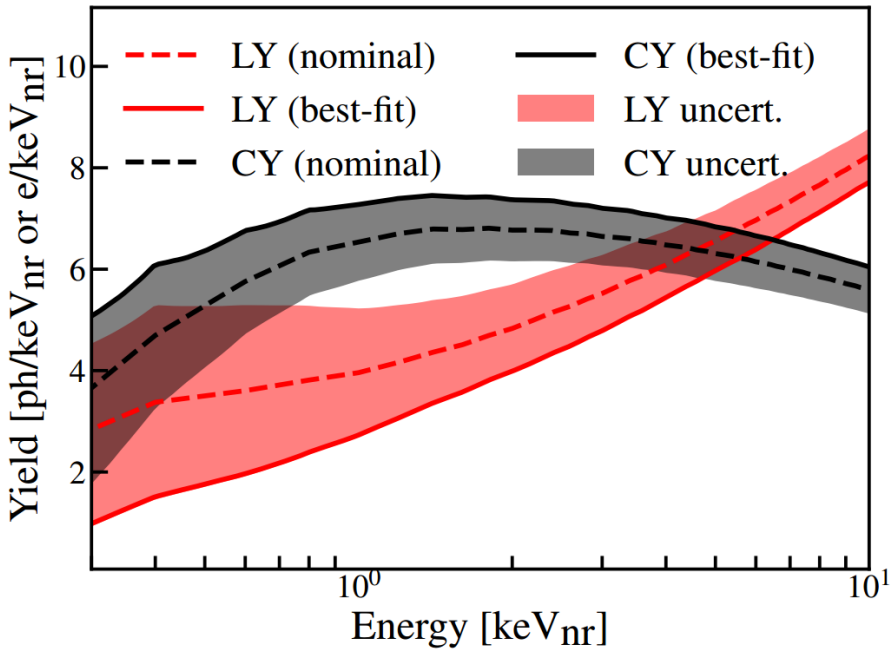


US2 ROI	Run0	Run1
Cathode	100±24	104±21
MD	25±3	20±4
ERs	1.3±0.1	0.9±0.2
Total bkg.	126±24	125±21
^{8}B CEνNS	18±4	25±6
Observed	158	174

- Cathode spectral shape is estimated using cathode sample with S1 information, rate estimated using sideband 11-15 e$^-$;
- Micro-charge (MD) shape is estimated using the events rejected by the afterflow veto, rate from the sideband 2.5-4 e$^-$;

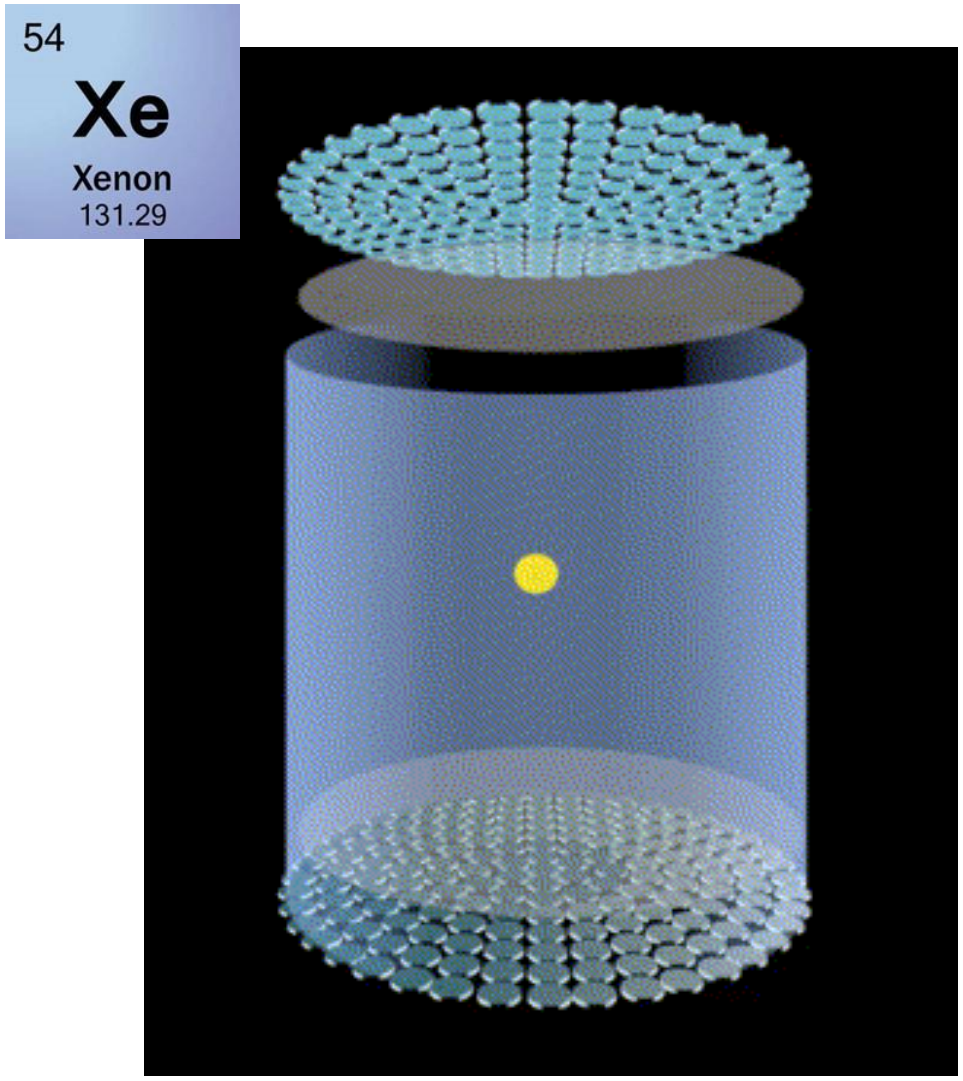
Backup - Systematic uncertainties in B8

Sources	Paired Run0 2-hit	Paired Run0 3-hit	Paired Run1 2-hit	Paired Run1 3-hit	US2 Run0	US2 Run1	Estimated by
^{8}B data selection	0.10		0.10		0.11	0.17	WS vs. DS
^{8}B model	0.24	0.37	0.28	0.44	0.17	0.16	Average in ROI based on NEST
BDT to ^{8}B	0.17		0.11		-	-	WS vs. DS
AC model	0.15		0.15		-	-	WS vs. control samples
BDT to AC	0.18		0.25		-	-	WS vs. control samples
Cathode model	-	-	-	-	0.24	0.20	Varying side-band selection
MD model	-	-	-	-	0.13	0.16	Varying side-band selection

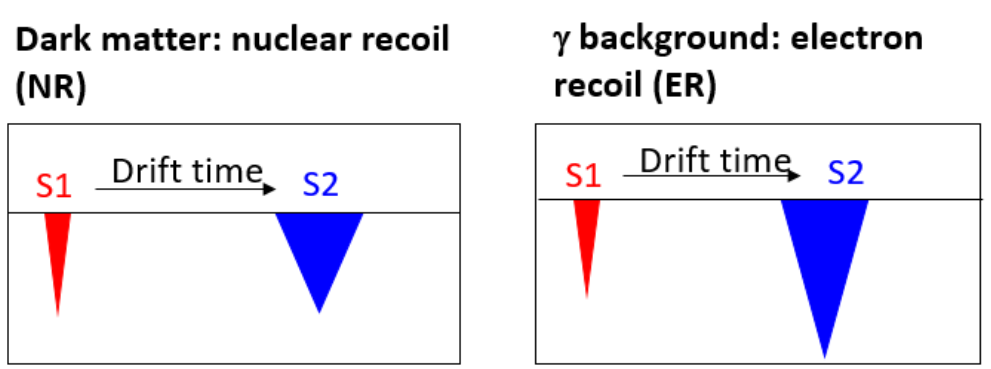


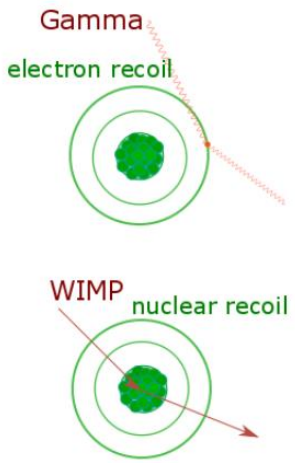
- B8 signal uncertainty including data selection, B8 model and BDT cuts are estimated;
- By MC vs real data, and varied control selection, background uncertainties are also estimated ;

Dual phase Xenon TPC



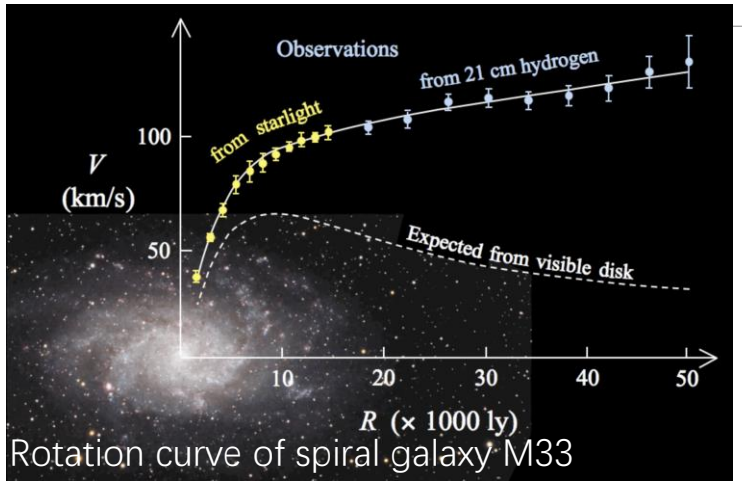
- Purity liquid xenon target, enhanced DM signals, achievable liquefication temperature, high light & charge yield
- Good ER/NR discrimination by S2/S1 ratio



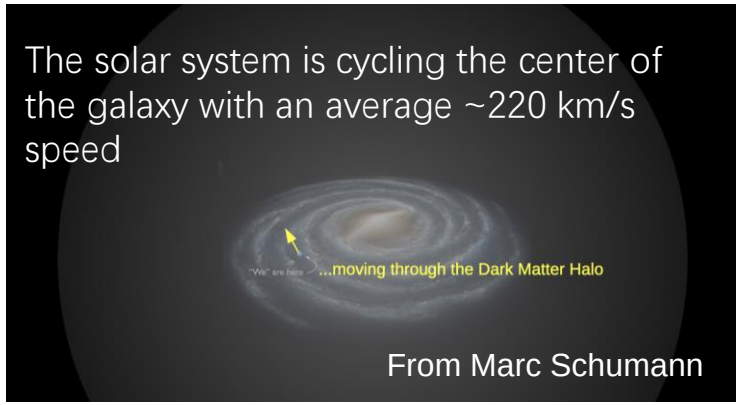


- 3D reconstruction rejects external background

Backup



Rotation curve of spiral galaxy M33



Gravitational evidence suggests dark matter is the dominant form of matter in the Universe!