Light dark matter search at PandaX

Speaker: Minzhen Zhang

On behalf of PandaX collaboration

Shanghai Jiao Tong University

2024-07-18

饮 水 思 源 • 爱 国 荣 校

Contents

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- Introduction to PandaX experiment
- Light dark matter search with commissioning run(Run0)
- Run0+Run1 combined analysis

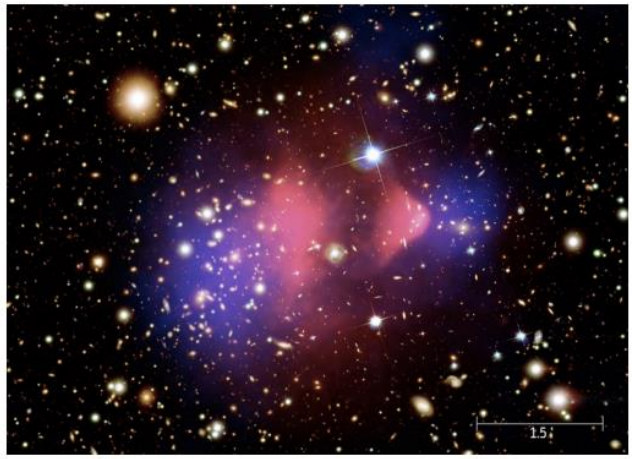
Contents

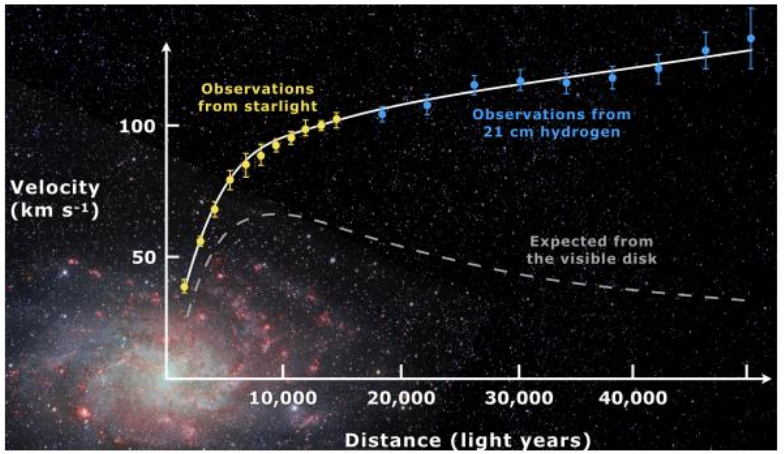
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

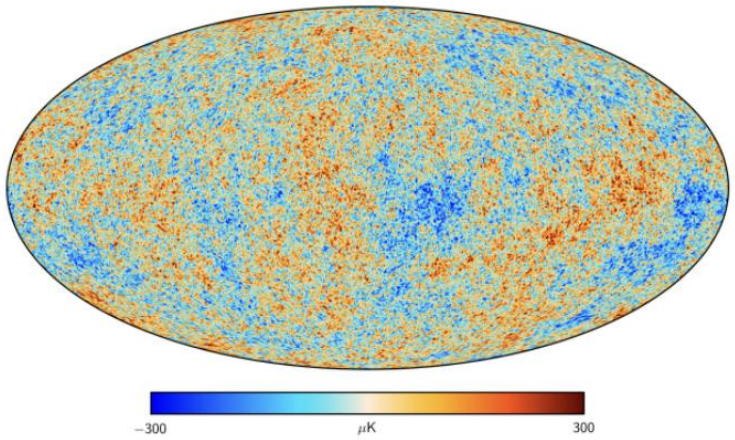
- Introduction to PandaX experiment
- Light dark matter search with commissioning run(Run0)
- Run0+Run1 combined analysis

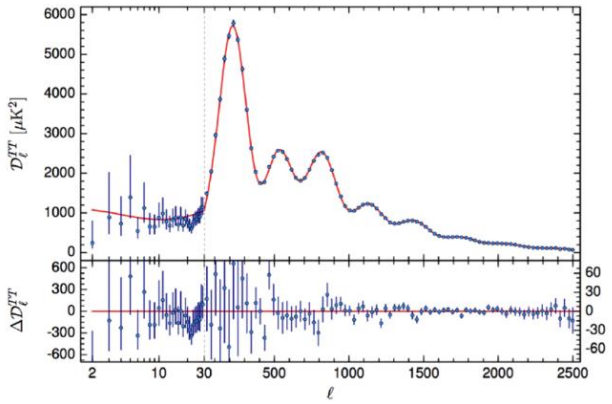
Dark matter

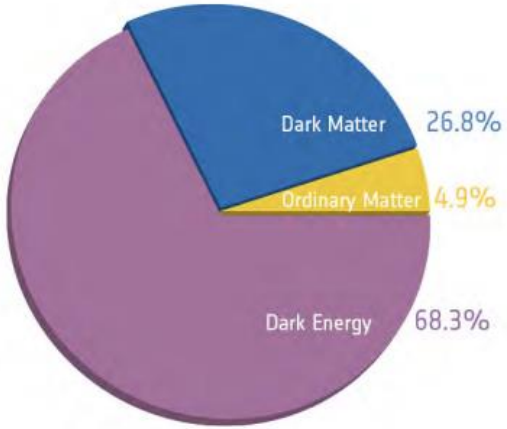
- Gravitational evidence:
  - Rotation curves
  - Gravitational lensing
  - CMB
  - ……



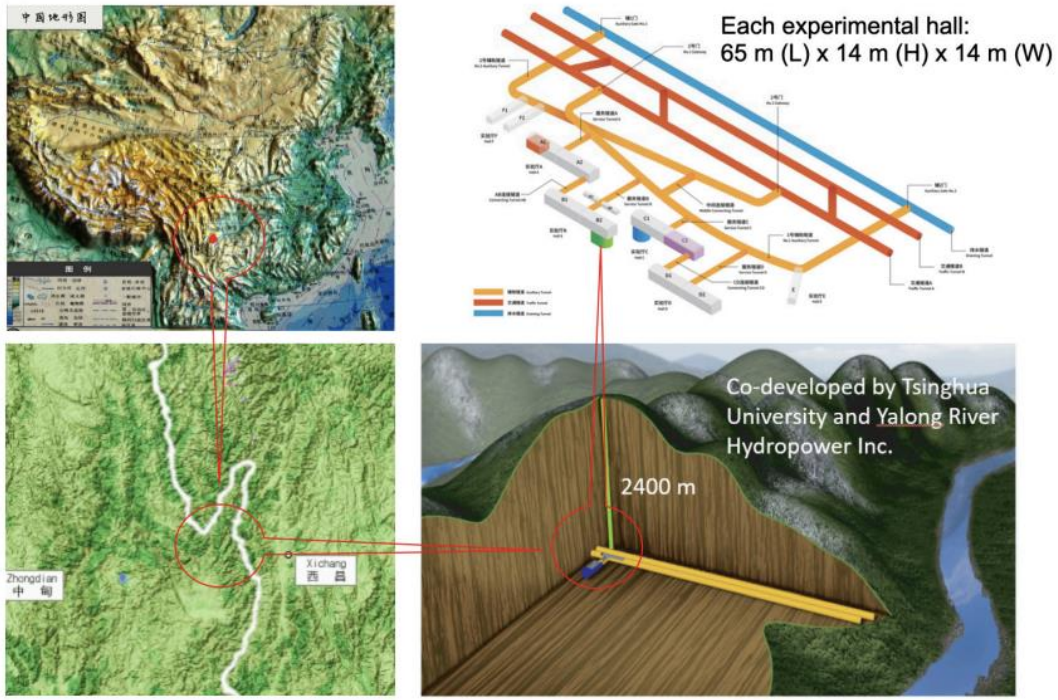


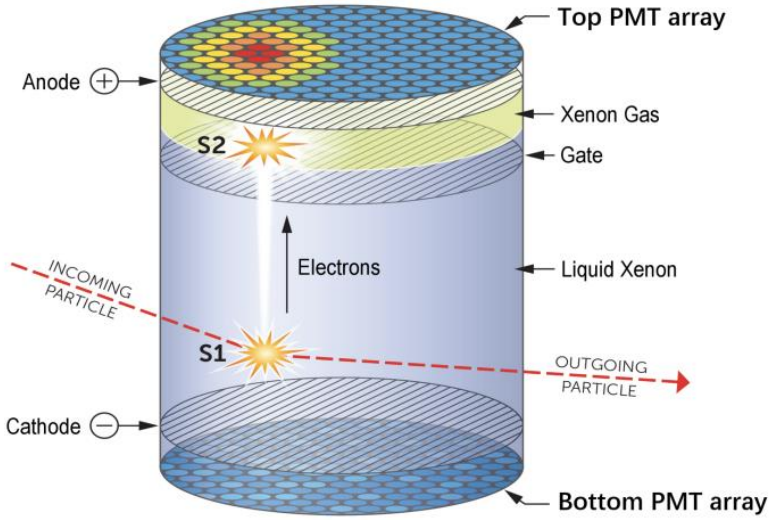


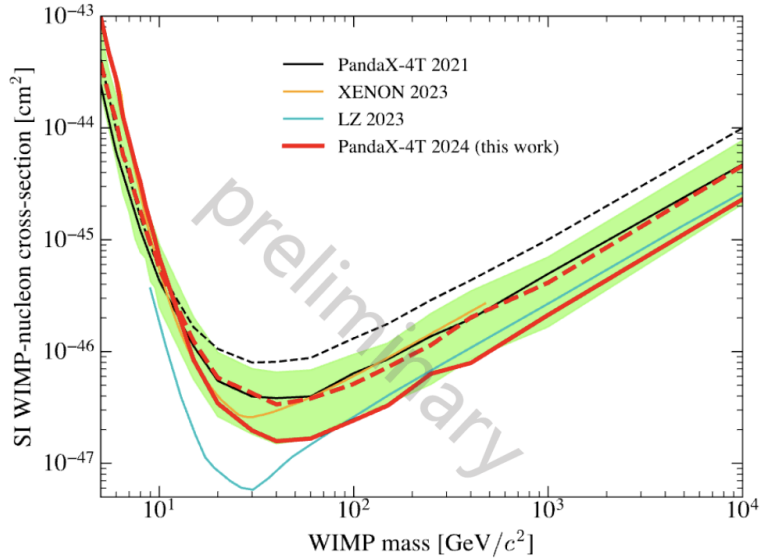




PandaX-4T experiment







- Dual phase Xe time projection chamber(TPC)
- Most sensitive at ~40 GeV WIMP dark matter mass with traditional S1-S2 analysis

Contents

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

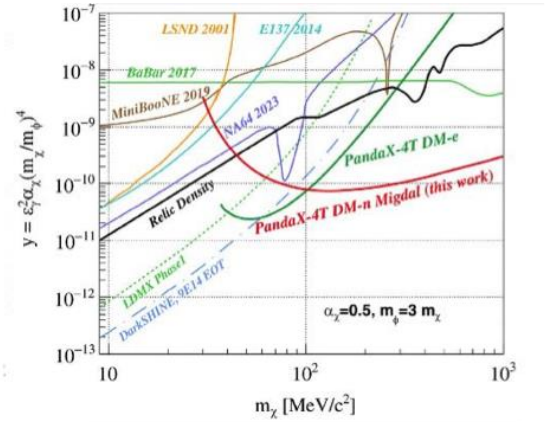
- Introduction to PandaX experiment
- Light dark matter search with commissioning run(Run0)
- Run0+Run1 combined analysis

Light Dark Matter search

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

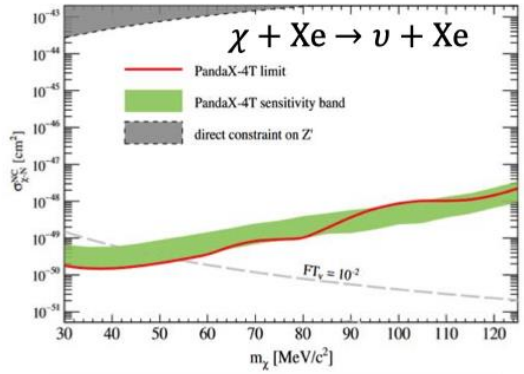
- PandaX has achieved progress in various light dark matter(LDM) interaction

DM-electron

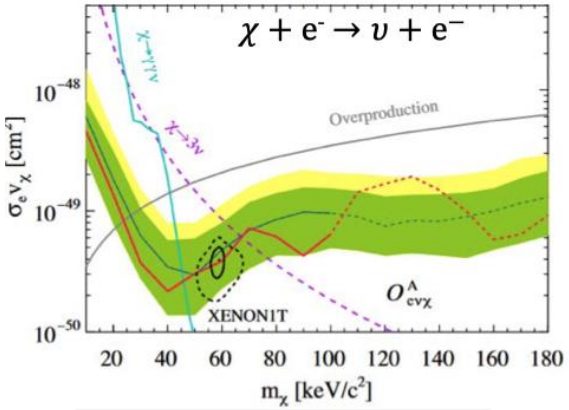


PRL 131, 191002 (2023)

DM-neutrino

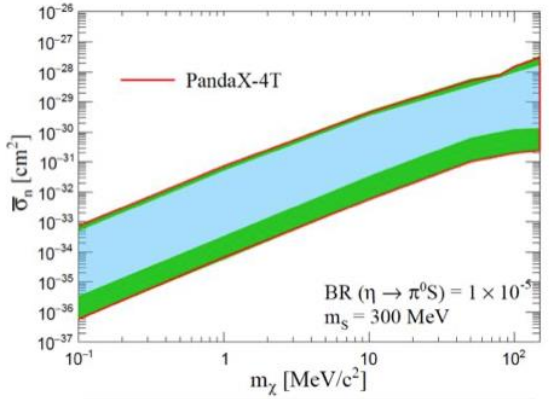


PRL 129, 161803 (2022)
Editors' Suggestion

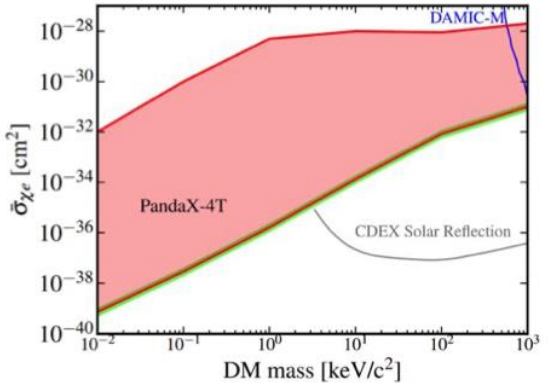


PRL 129, 161804 (2022)
Editors' Suggestion

Boosted DM



PRL 131, 041001 (2023)

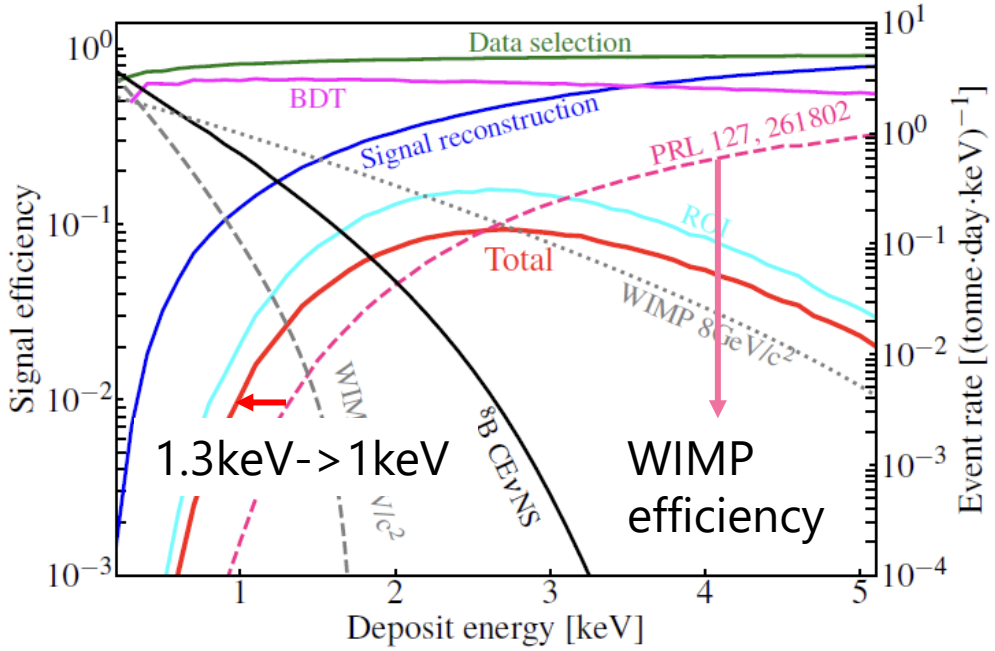


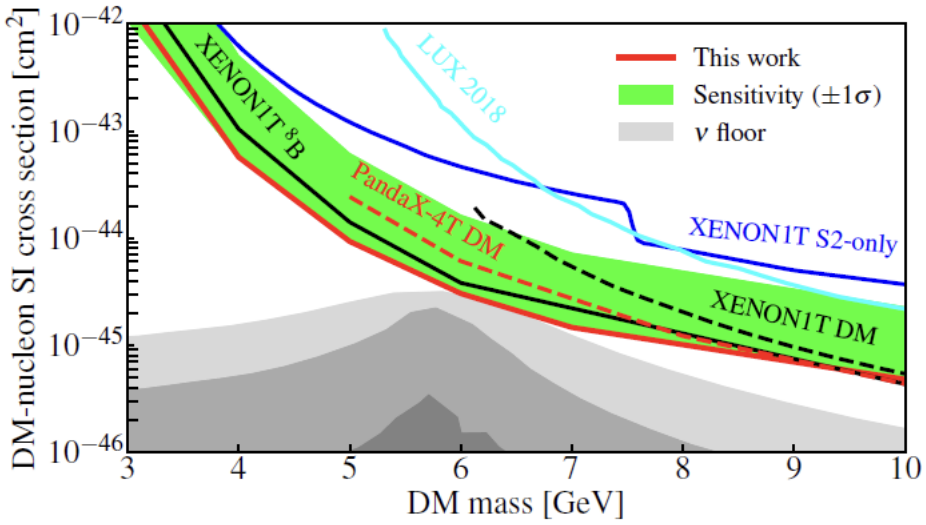
arXiv: 2403.08361

- To improve sensitivity
  - More exposure: Run1
  - Lower threshold: low energy analysis

Low energy analysis: Paired channel

- Events with very small S1(2 ~ 3 hits on PMTs)
- Lower the energy threshold to 1keV, increase the sensitivity to light dark matter





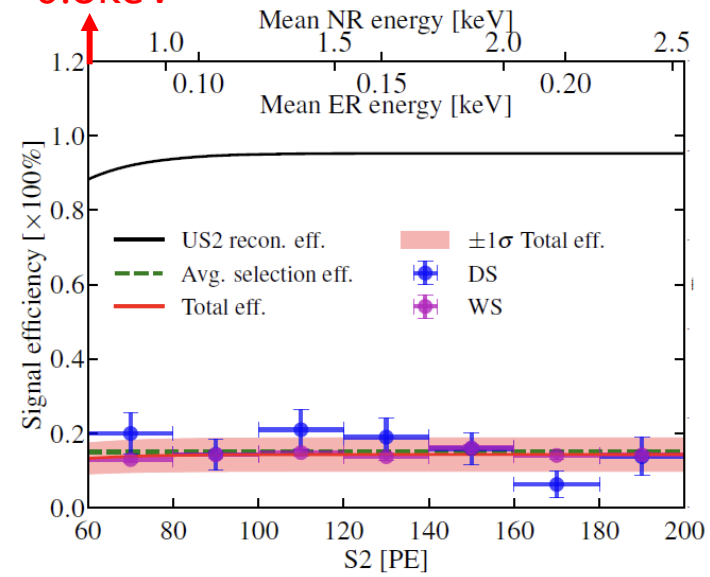
Physical Review Letters 130, 021802 (2023)

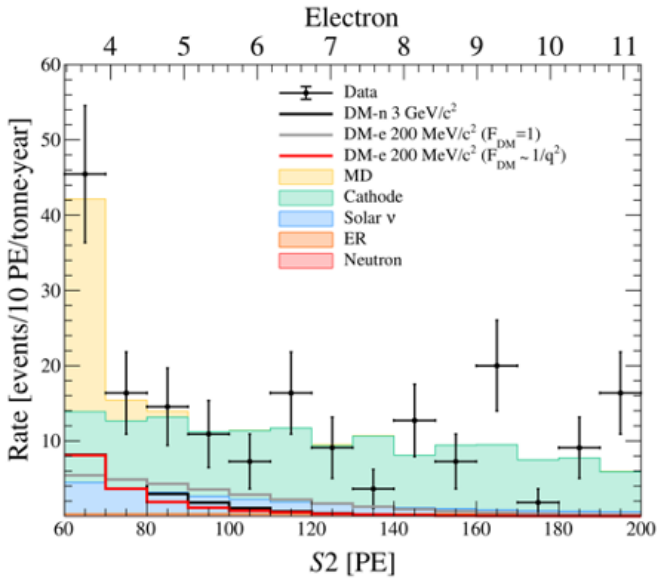
Low energy analysis: US2 channel

- Unpaired S2(US2): Events without physical S1
- The energy threshold is further lowered to ~0.8keV
- Model the backgrounds different from paired analysis, and significantly increase sensitivity to DM-electron interaction

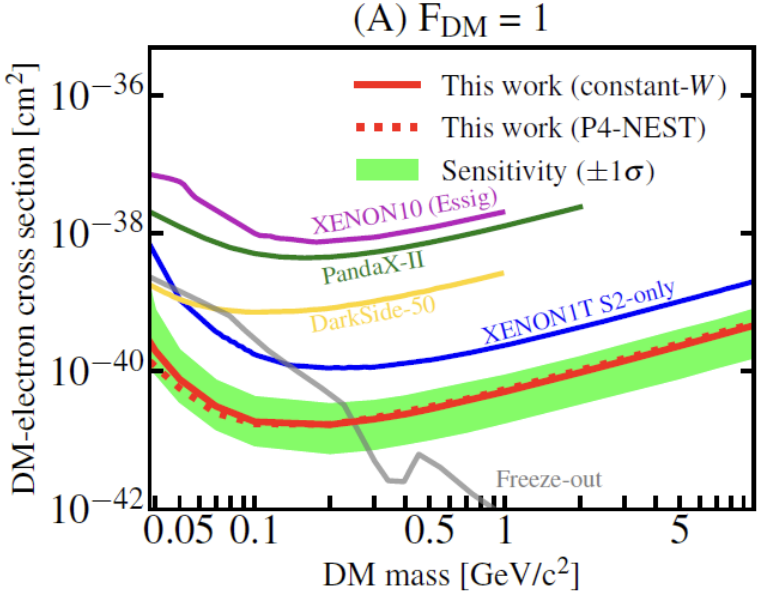
This report will focus on US2 analysis combining Run0 and Run1

~0.8keV





Phys. Rev. Lett. 130, 261001 (2023)



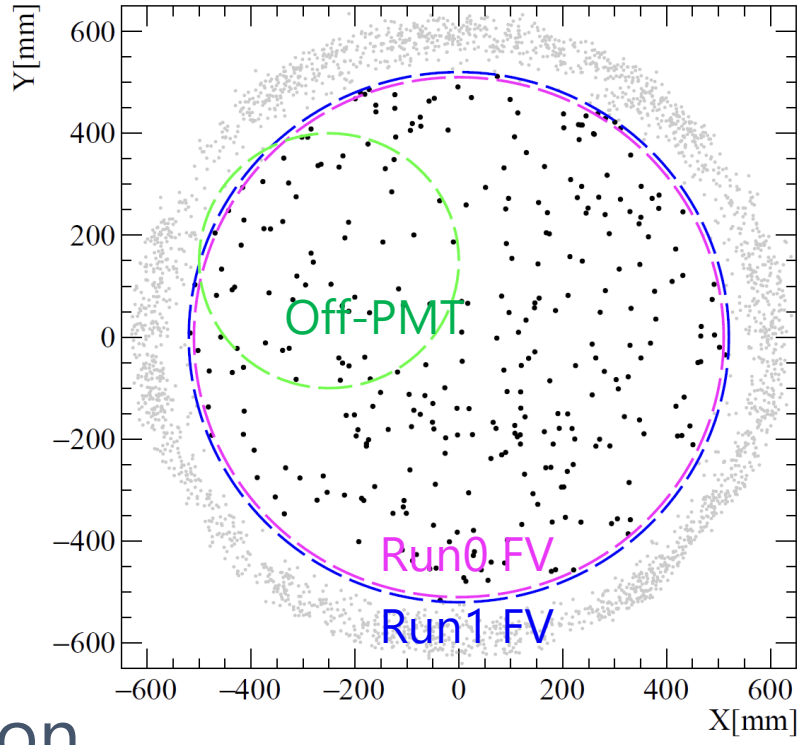
Contents

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- Introduction to PandaX experiment
- Light dark matter search with commissioning run(Run0)
- Run0+Run1 combined analysis

Data selection

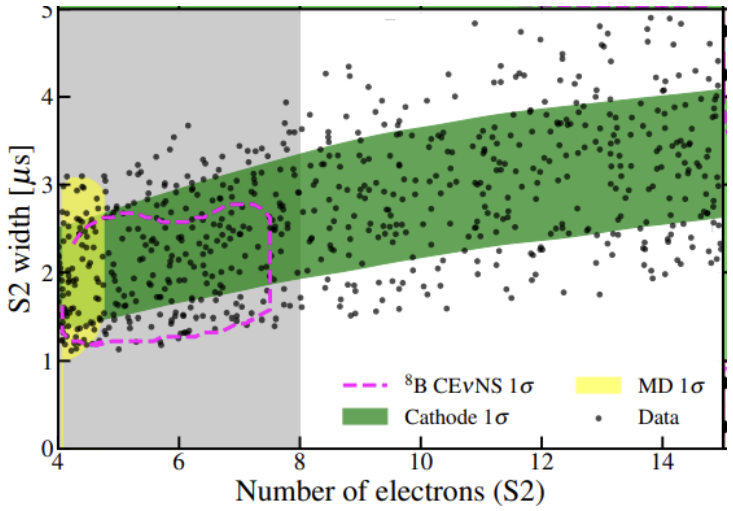
- Afterglow veto cuts:
  - remove period after large signal(deadtime)
  - remove volume near large S2
- Bad file: remove periods with high event rate or abnormal operation condition
- Fiducial Volume(FV): remove background events concentrated at edge of the detector
- Off-PMT: remove the dysfunctional PMT region

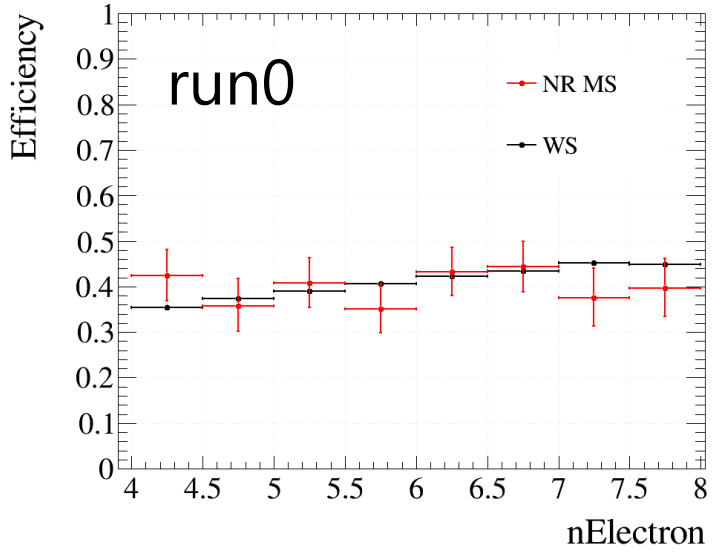


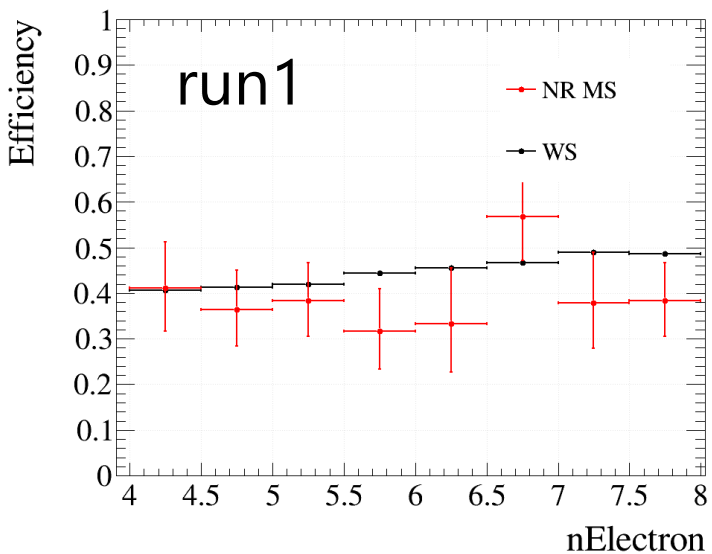
	run0	run1	Total
Livetime[days]	64.6	93.5	158.1
FV mass[ton]	2.78	2.16	/
Exposure[ton·year]	0.49	0.55	1.04

Data selection

- Region of interest: paired S1<=1hit, 4-8 electrons
- Selection cuts: based on s2 shape and position reconstruction quality, mostly follow run0 cuts, but loosened for higher signal acceptance.
- Efficiency is given by MS(multi-scatter signal from nuclear recoil calibration) and WS(waveform simulation of signals)



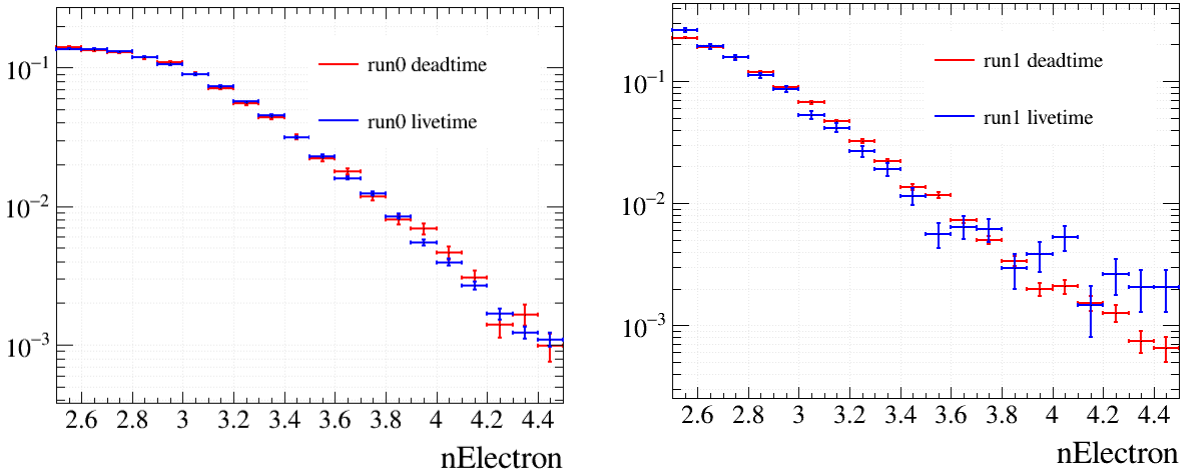




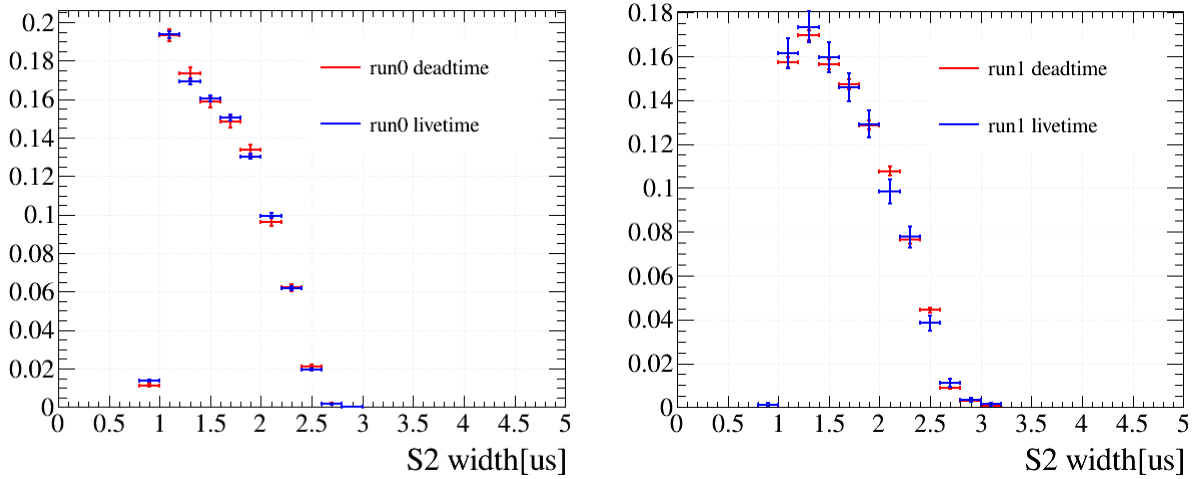
MD Estimation

MD sample

Charge distribution



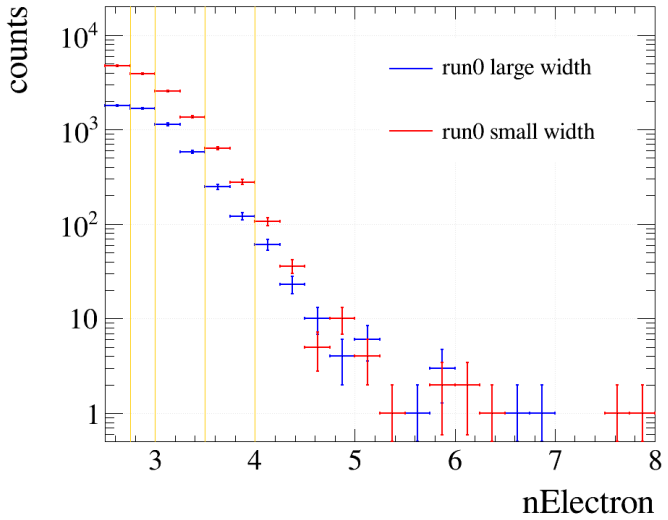
Width distribution

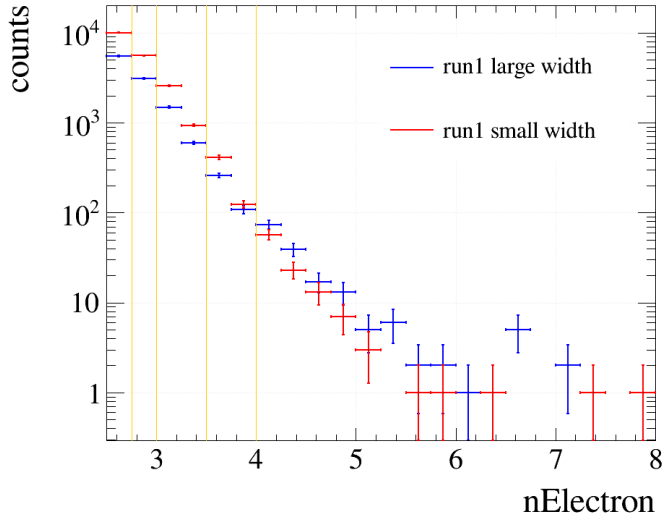


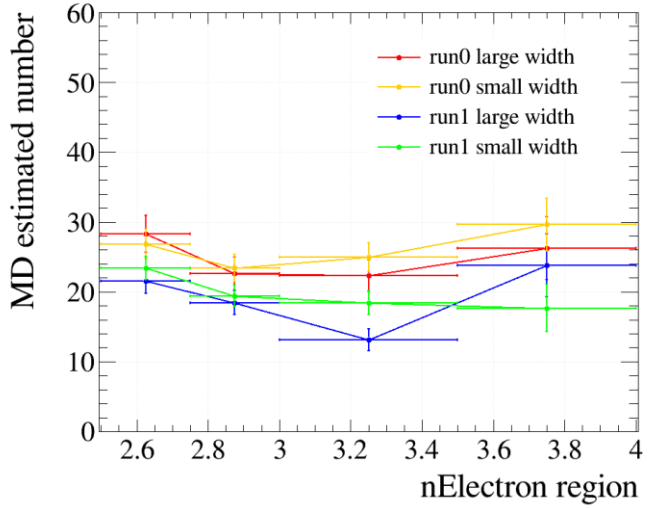
- We find that MD rate is related with single electron(SE) rate, so we get MD samples from deadtime region where SE rate is very high
- The sample in deadtime is consistent with the MD events in livetime
- MD events in livetime are from high US2(2.5-3nE) rate runs

MD Estimation

$$nominal = \frac{num\_sample\_in\_roi}{num\_sample\_in\_cr} \cdot num\_data\_in\_cr \qquad roi : \text{4-8nE} \; cr : \text{2.5-4nE}$$







- Different small control regions divided by S2 charge and width give systematic error
- Spectrum with total statistic give the nominal value and statistical error

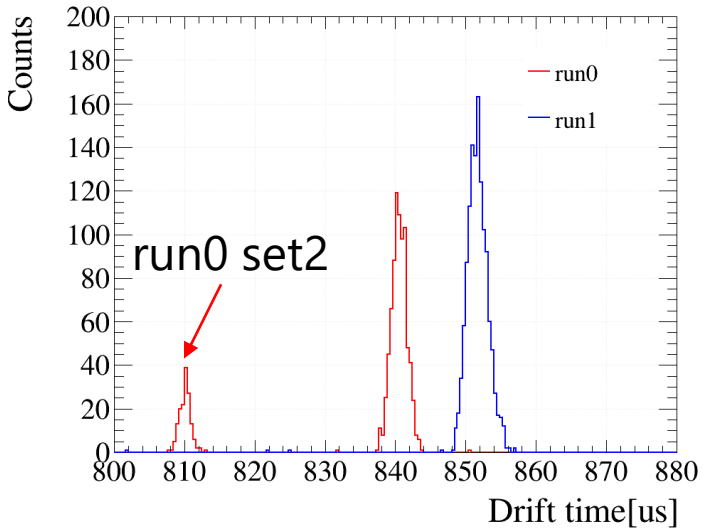
Estimation	Run0	Run1
Result	25±3	20±4
Statistical error	6.5%	6.4%
Systematic error	10.6%	16.9%

Cathode estimation

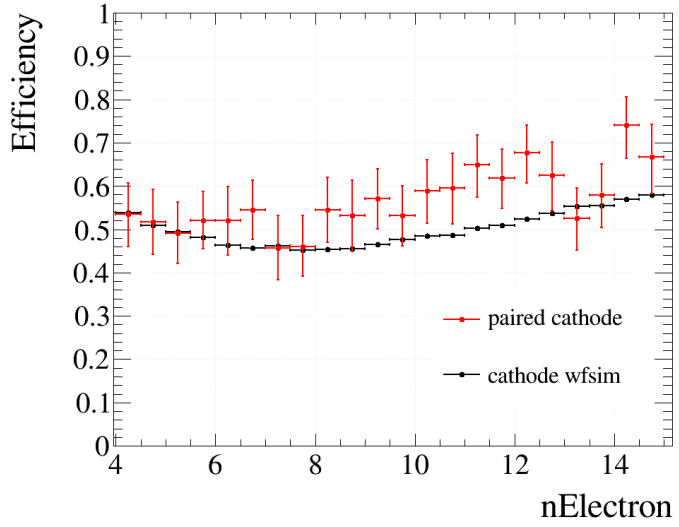
Cathode sample

Efficiency: $\frac{selection\ cut}{selection\ cut\ with\ loose\ width\ cut}$

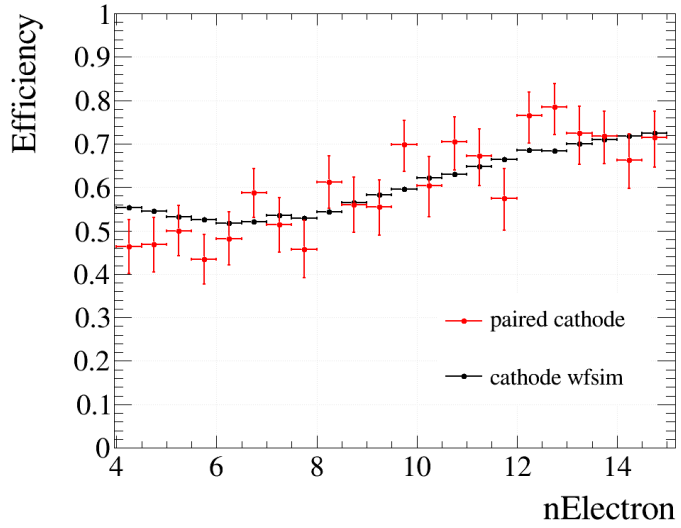
Cathode drift time distribution



Run0 efficiency



Run1 efficiency

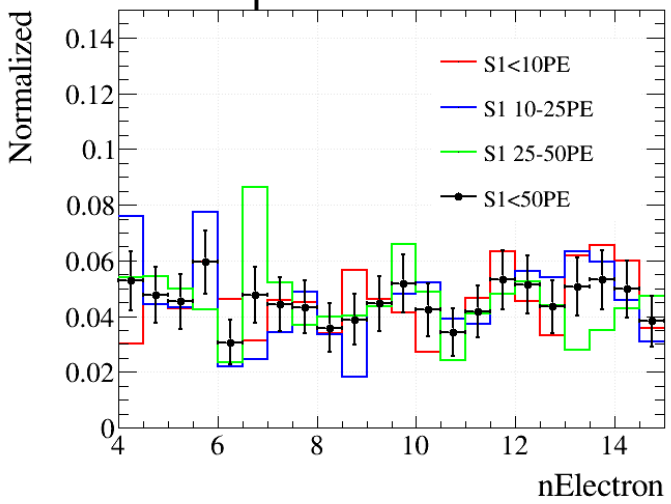


- Use paired cathode events as background sample
- Simulate physical events at the bottom of detector, these samples are consistent with paired cathode events
- To reduce spectrum statistical fluctuation, use the spectrum under a loose width cut, and then apply corresponding efficiency from waveform simulation to it

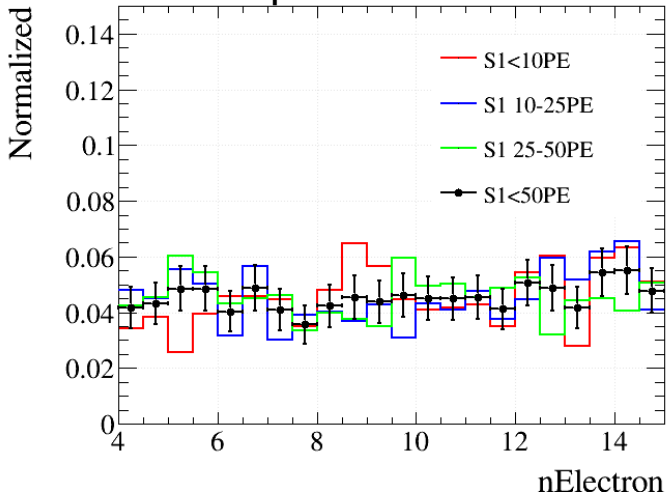
Cathode estimation

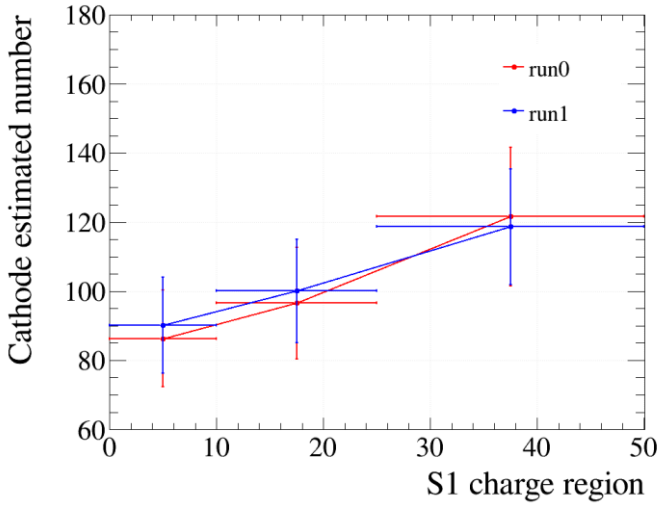
$$nominal = \frac{num\_sample\_in\_roi}{num\_sample\_in\_cr} \cdot num\_data\_in\_cr \qquad roi: \text{4-8nE} \quad cr: \text{11-15nE}$$

Run0 spectrum



Run1 spectrum



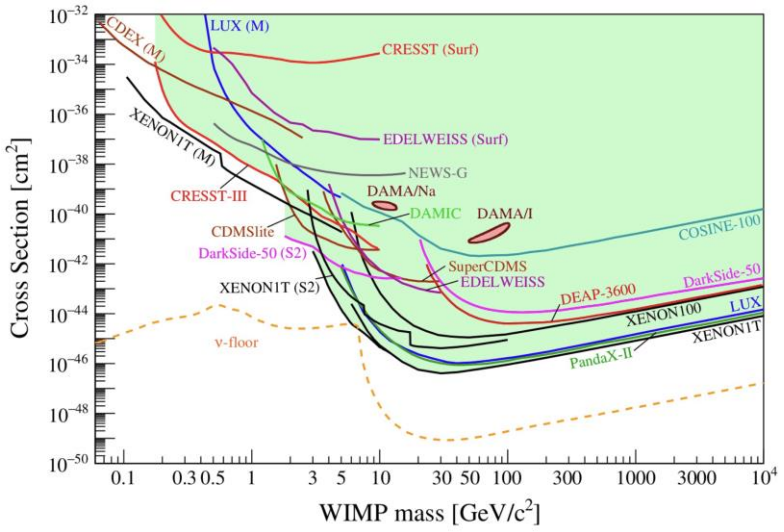


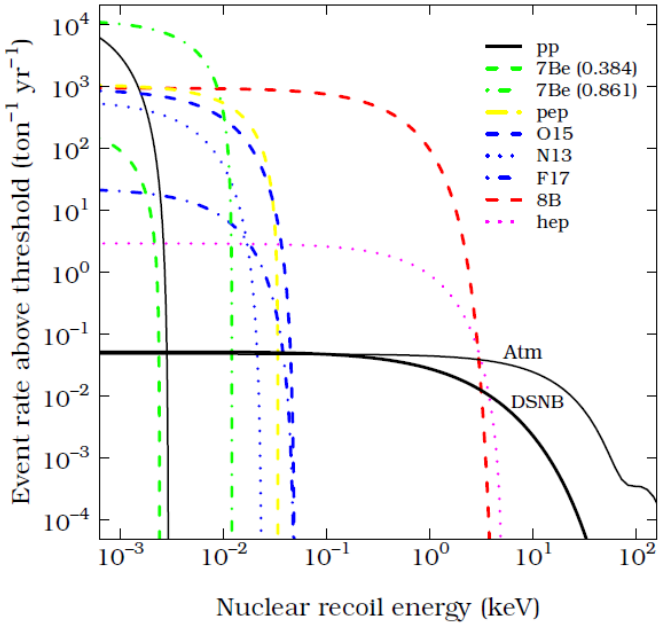
- Spectrum with different S1 range give systematic error
- Spectrum with total statistic give the nominal value and statistical error
- Difference of results given by efficiency from data and simulation give efficiency error

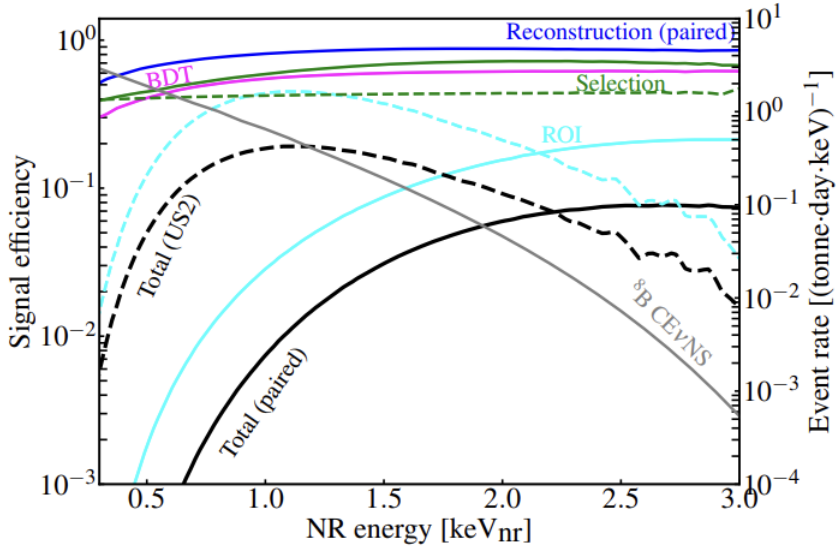
Estimation	run0	Run1
Result	100±24	104±21
Statistical error	12.4%	11.4%
Systematic error	18.1%	13.9%
Efficiency error	10.6%	9.4%

Physical events estimation

- Solar neutrino can be a background component in DM searching($\nu\ floor/fog$)
- Physical events in US2 mainly come from B8 solar neutrino coherent elastic neutrino nucleus scattering($CE\nu NS$)
- Due to loosened cuts, energy threshold is lowered to ~0.3keV, increasing B8 neutrinos

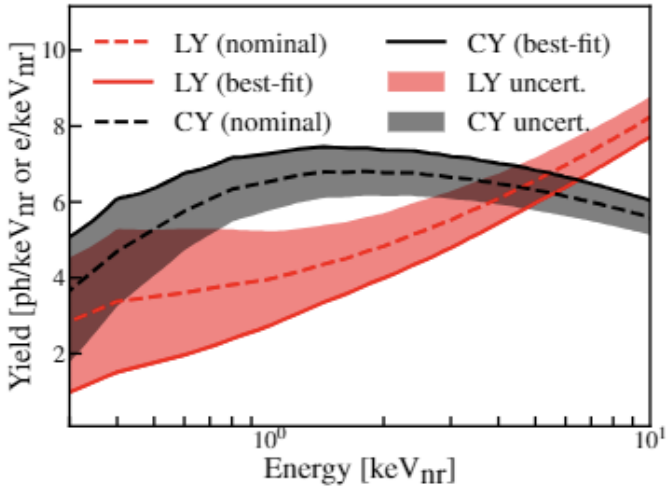


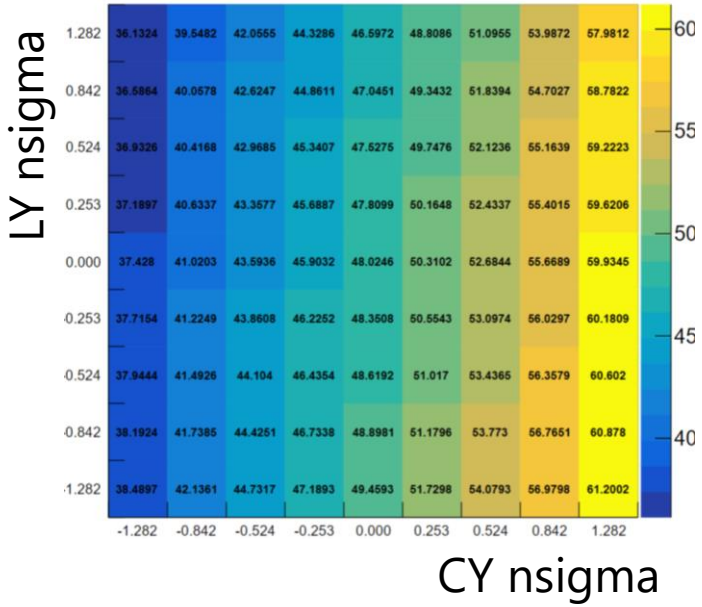




Physical events estimation

- Nominal: Apply efficiency to the spectrum given by NEST
- Uncertainty:
  - Efficiency uncertainty: difference of MS and WS
  - Light yield(LY) and charge yield(CY) uncertainty: anti-correlated floating(based on NEST 2.3.6 nominal value and uncertainty)



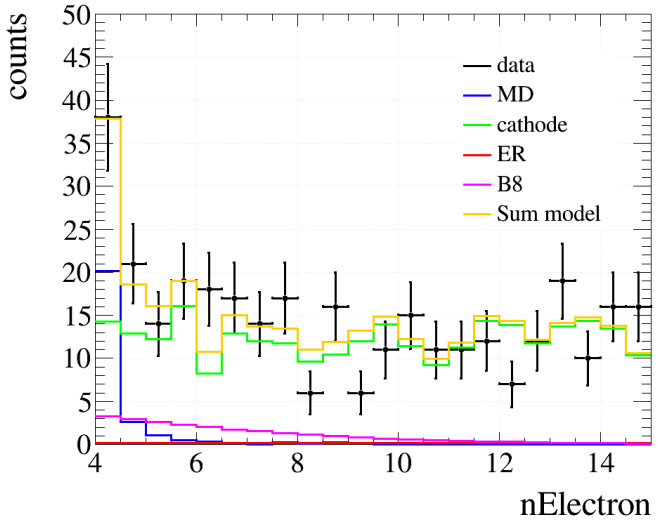


Type	Run0	Run1
B8	18±4	25±6
ER	1.3±0.1	0.9±0.2

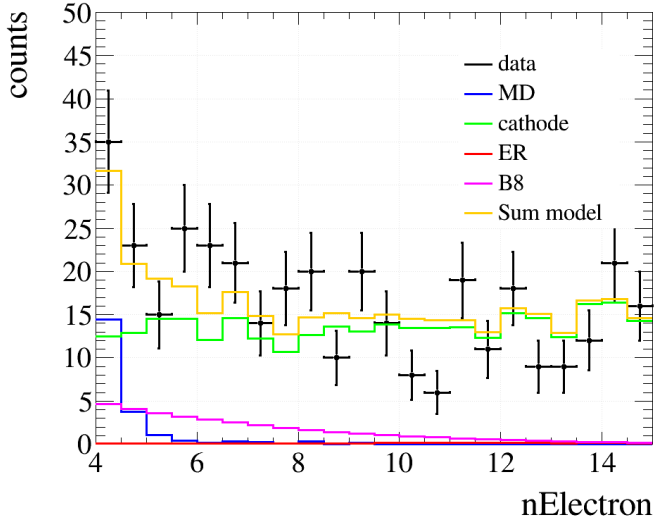
ER backgrounds are mainly Rn, Kr and tritium in detector. Other physical components like neutron are negligible

Unblind data

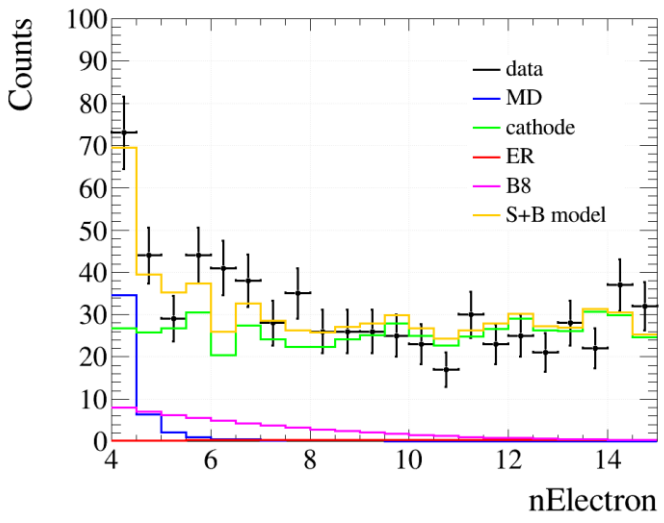
Run0



Run1



Run0+Run1



4-8nE	Run0	Run1	Run0+run1
Cathode	100±24	104±21	204±32
MD	25±3	20±4	45±5
B8	18±4	25±6	43±7
ER	1.3±0.1	0.9±0.2	2±0.2
Total	144±25	150±22	294±33
data	158	174	332

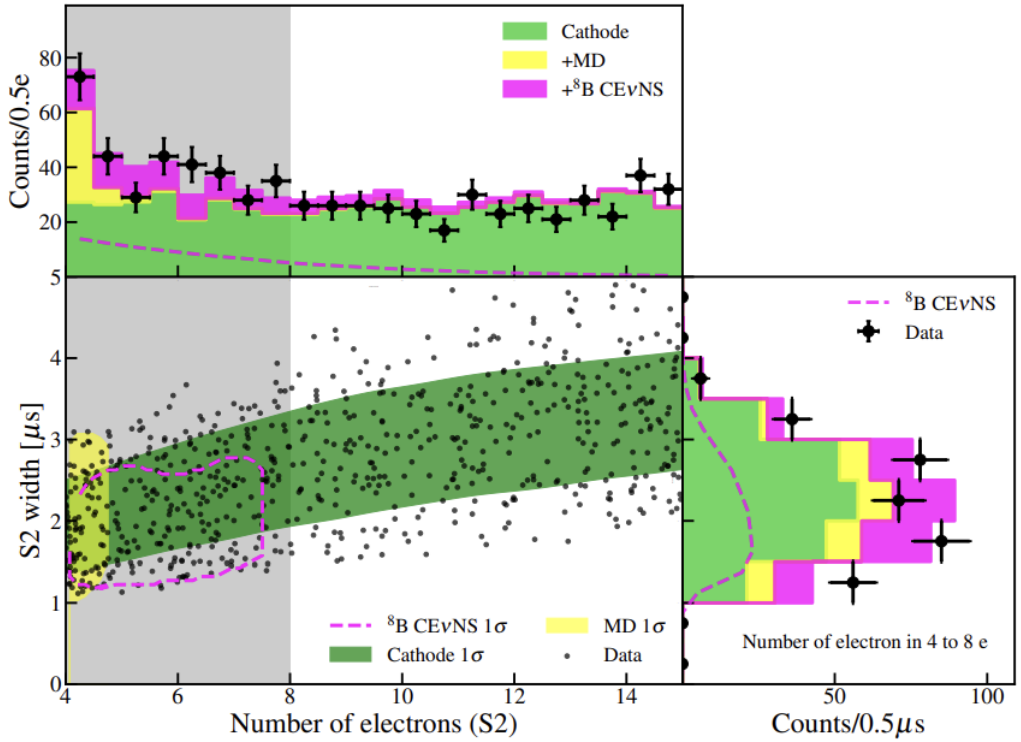
- There is no significant excess in data
- LDM fitting is ongoing
- We make a measurement of B8 solar neutrino flux combining this data and paired channel

B8 measurement

- Do profile likelihood ratio(PLR) fitting for B8, combine both channels
- For US2 channel, a 2D fitting using S2 charge and width is performed

Paired channel estimation and data

	Run0		Run1	
	2-hit	3-hit	2-hit	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

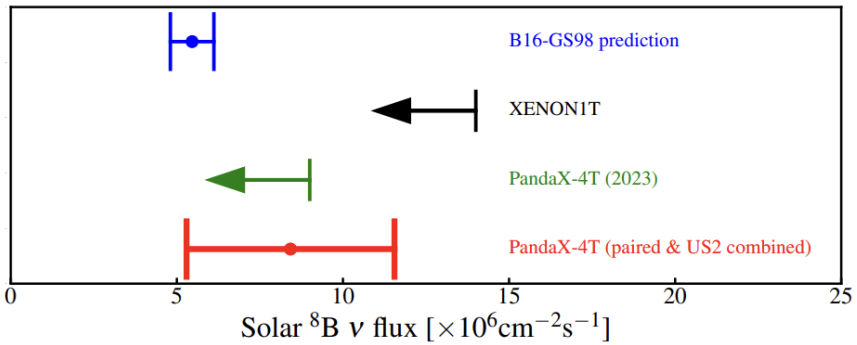


S2only best-fit spectrum

B8 measurement

- The best fit result tells that there are 75±28 B8 events in s2only channel and 3.5±1.3 in paired channel, the corresponding B8 flux is $8.4 \pm 3.1 \times 10^6 cm^{-2} s^{-1}$
- The p-value rejecting background only model is 0.004, with significance 2.64σ

Best-fit	paired	s2only
B8 number	3.5±1.3	75±28
P-value	0.004	
significance	2.64σ	



$8.4 \pm 3.1 \times 10^6 cm^{-2} s^{-1}$

This result has been submitted to arXiv:2407.10892

Summary

- US2 background model for LDM search
- Measurement of B8 solar neutrino flux through $CE\nu NS$, combining Run0 and Run1, US2 and paired channels
- LDM result is ongoing


PANDA X
Thank you
for your attention!
饮 水 思 源 爱 国 荣 校