Study of accidental coincidence background in the PandaX experiment

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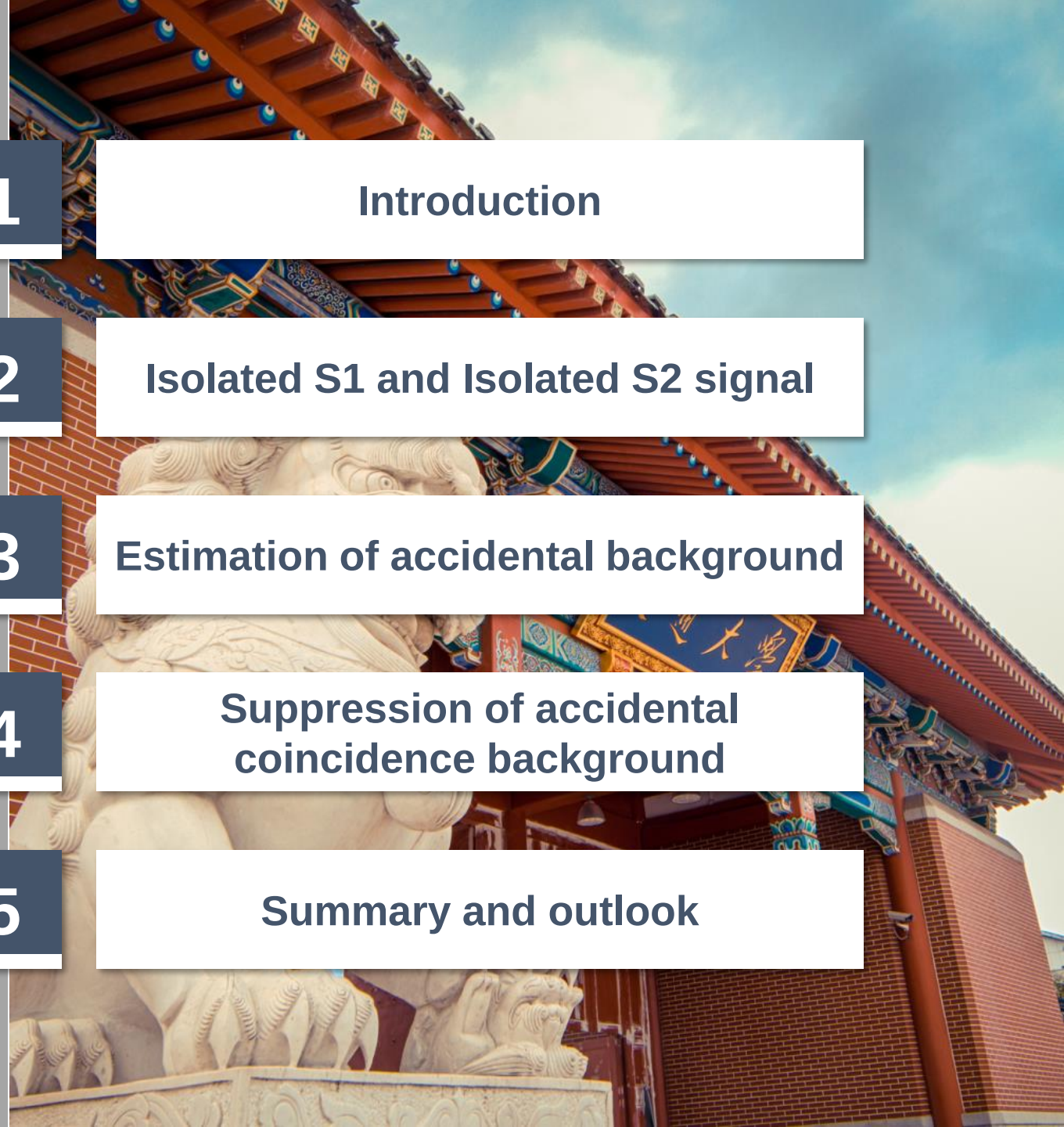
Content



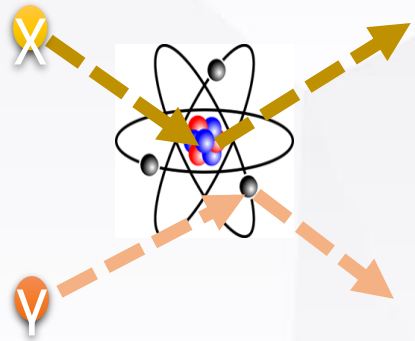
01

Introduction

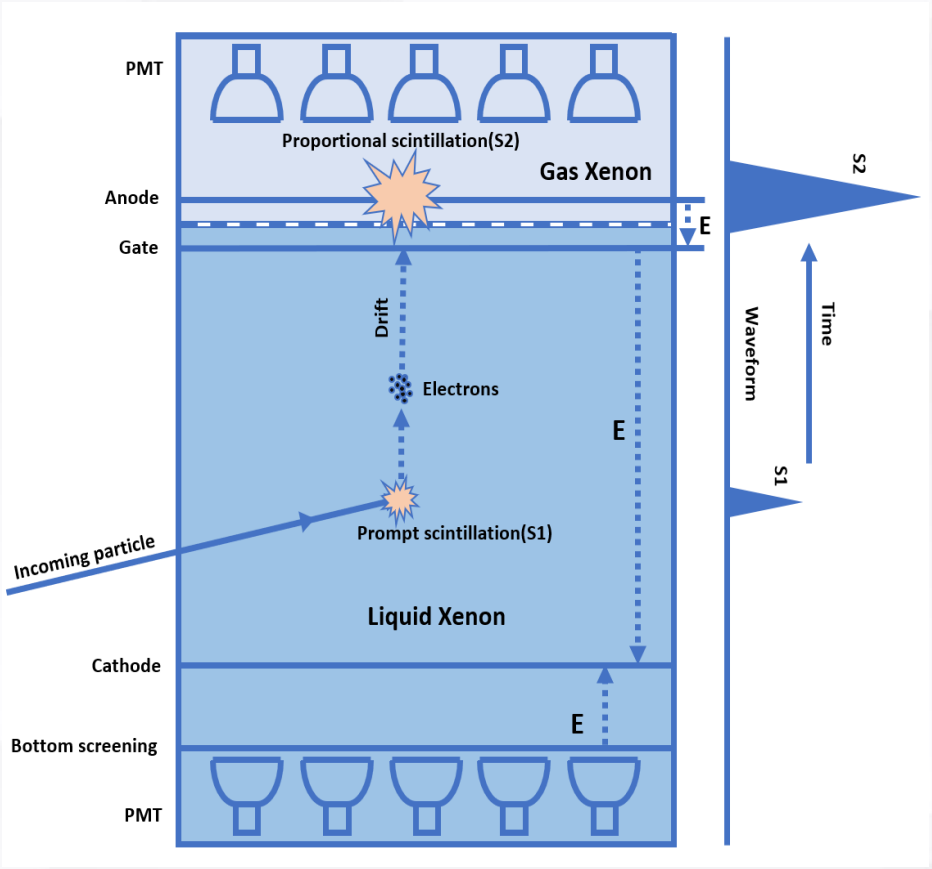
Dual phase liquid xenon time projection chamber (TPC)

- Xenon as target
  - Large atomic number
  - High density, good for self-shielding
- Produce photons(S1) and electrons(S2)
  - Electron recoil (ER): Large S2/S1
  - Nuclear recoil (NR): Small S2/S1

Nuclear recoil (WIMP)



Electron recoil (Gamma)

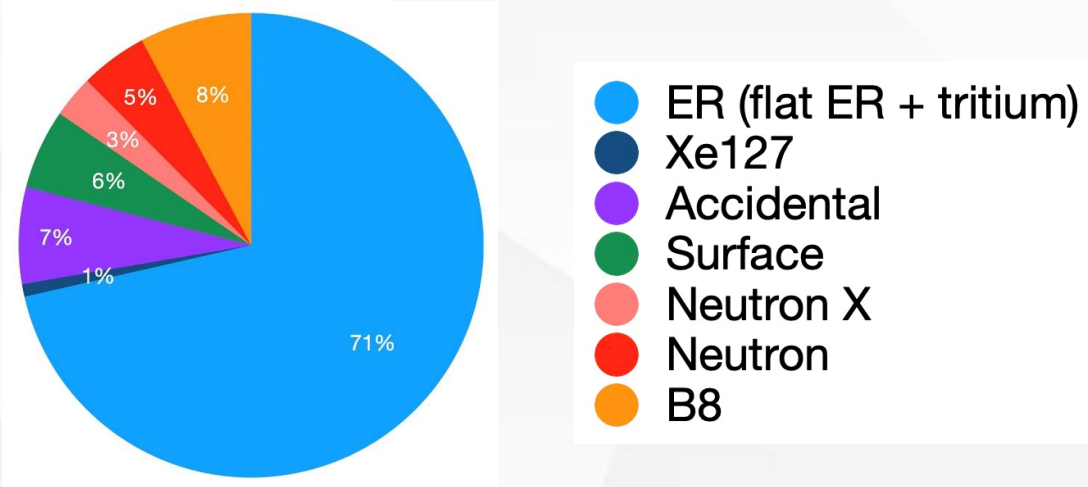


- PandaX-II (580kg), PandaX-4T (3.7T)

Main backgrounds in PandaX detector

- Electron Recoil (ER) background → Krypton, Radon, Material ER，Tritium, etc.
- Nuclear Recoil (NR) background → Materials (Neutron，B8 Neutrino).
- Surface background → Daughters of 222Rn attached on the inner surface of the TPC
- Accidental coincidence background → Non-physical Events.

- Expected events below-NR-median



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Accidental coincidence(AC) background

- Normal physical events
  - S1 and S2 are in waveform physically correlated with each other

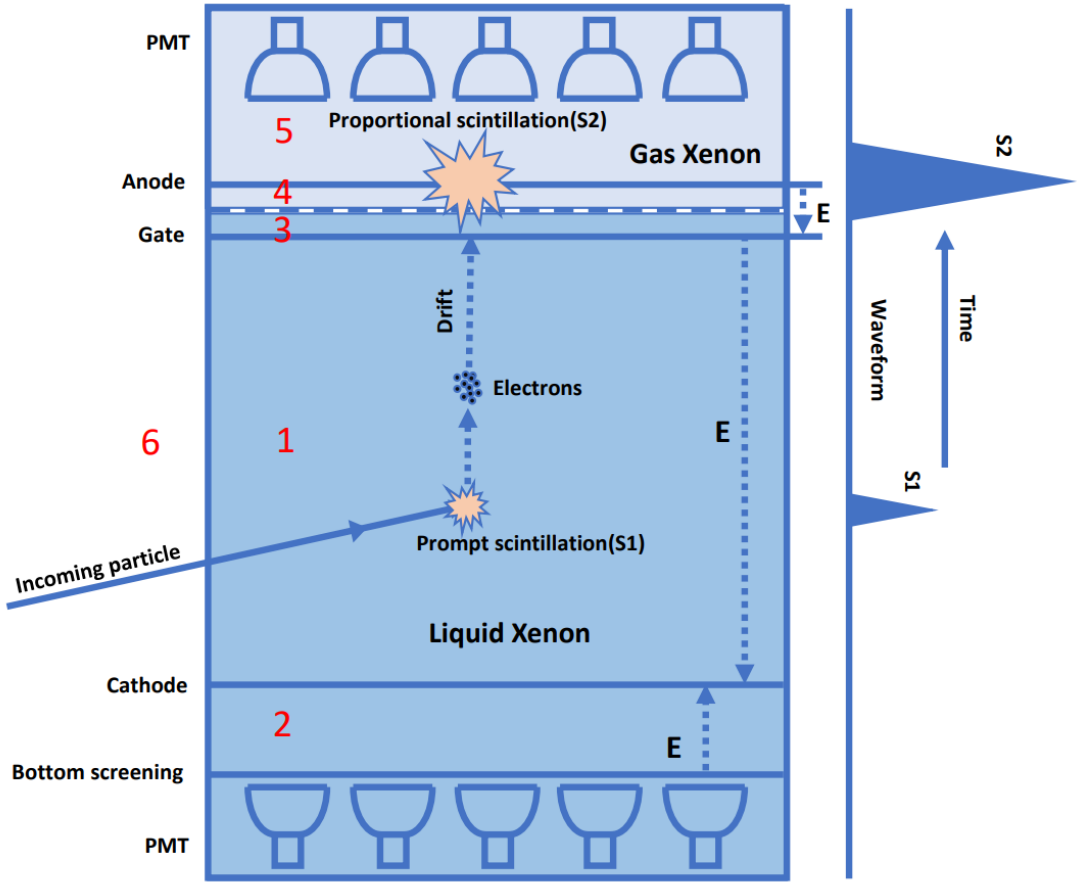
- AC events
  - S1 and S2 are in waveform physically uncorrelated, randomly coincided
  - Composed of isolated S1 isolated S2

02

Isolated S1 and Isolated S2 signal

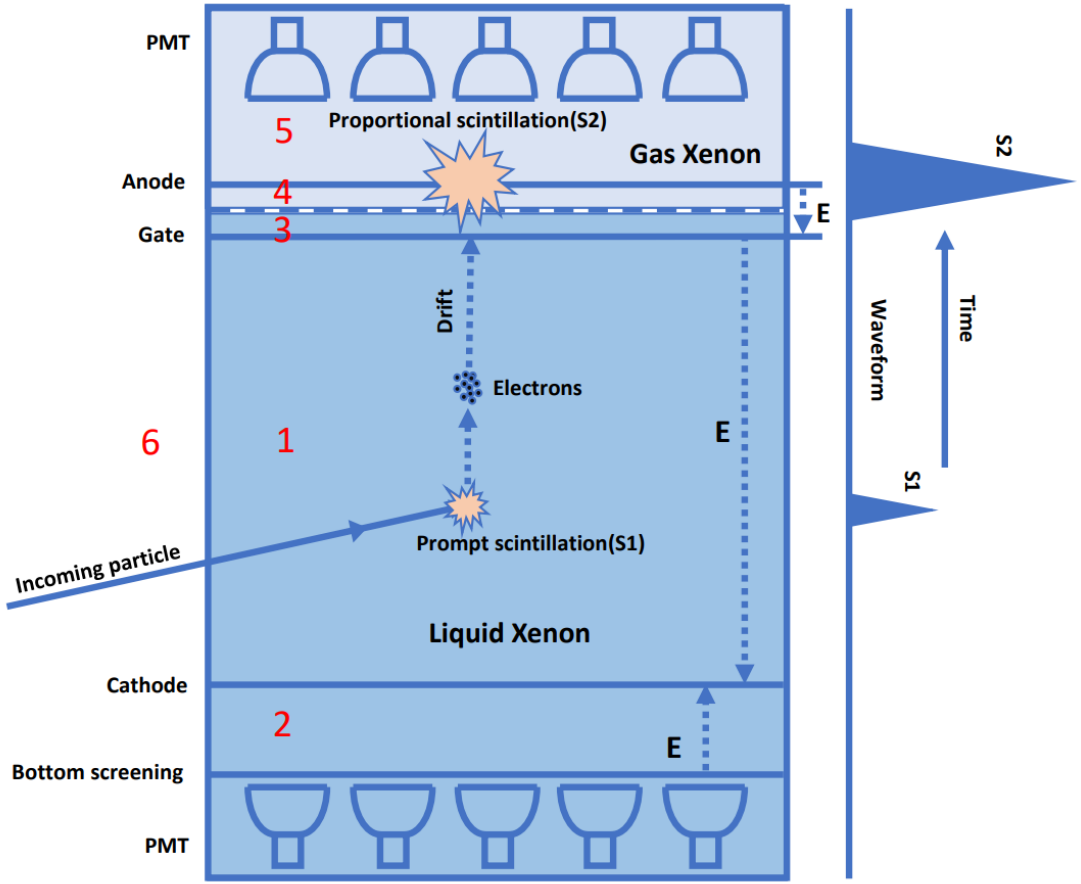
Possible origin of isolated S1

- Physical origin
  - Tiny sparks on the TPC electrode
  - Event on cathode region (region 2)
  - Events above the anode (region 5)
  - Mis-identified single electron
- Non-physical origin
  - PMT dark noise

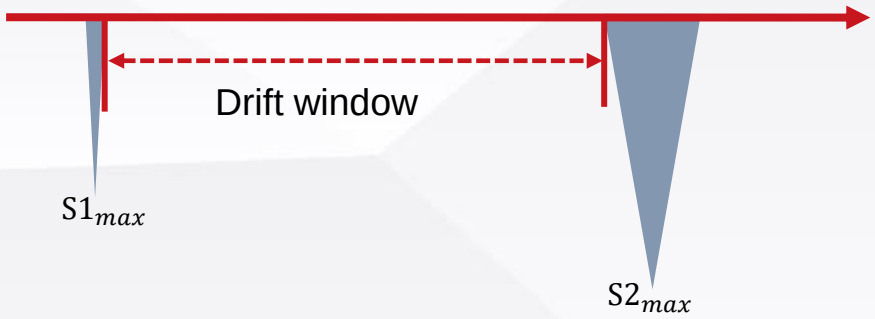


Possible origin of isolated S2

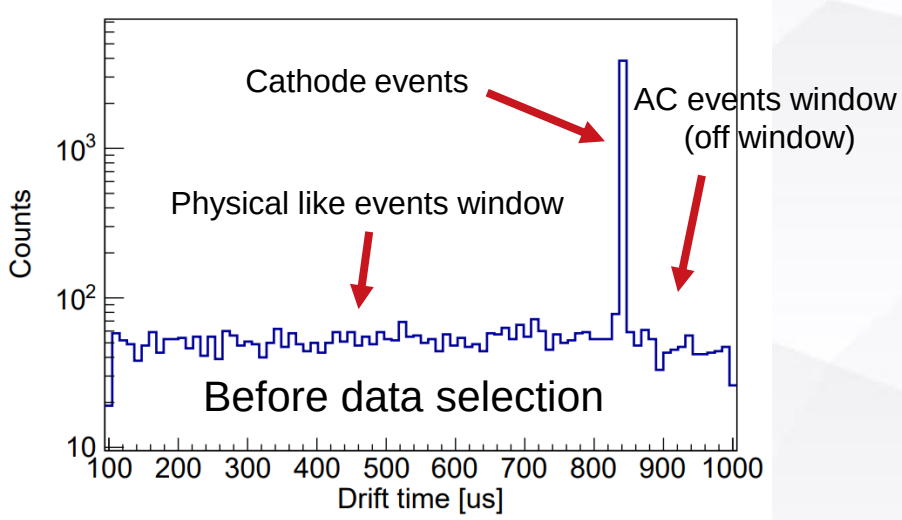
- Events with small energy deposition, S1 is not detected with low detection efficiency
- Events which is too close to the liquid surface, S1 and S2 overlapped with each other (region 3)
- Events in the region above the gate below the anode (region 3, 4)
- Delay electrons induced by large energy events

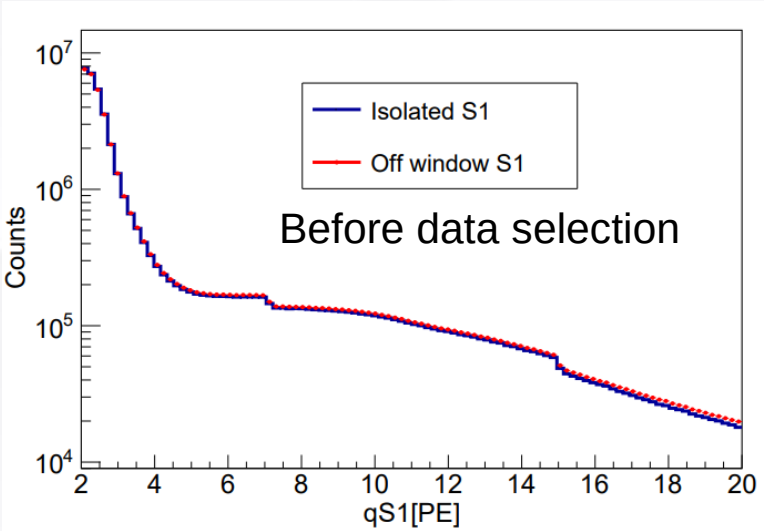


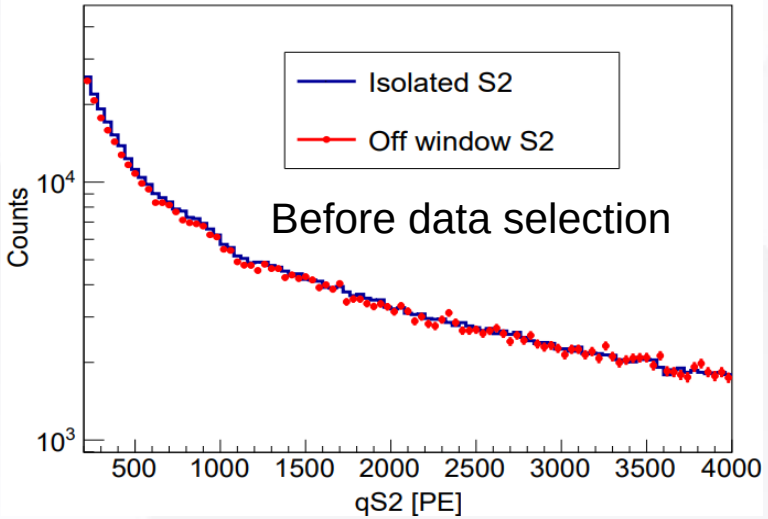
Rate of isolated S1 and isolated S2 in PandaX-4T



- Isolated S1s (S2s) are selected requiring them without main S2s (S1s).
- Spectrum shapes of isolated S1 and isolated S2 validated with the events whose time separation beyond the maximum drift time (850us).

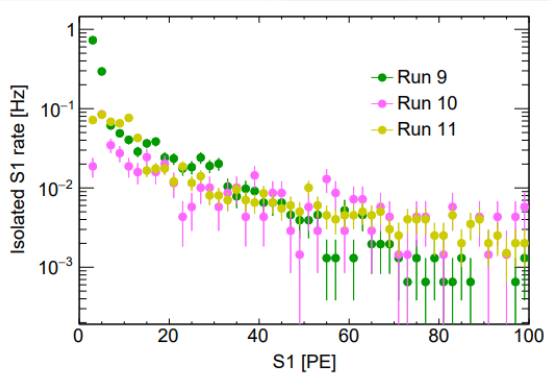


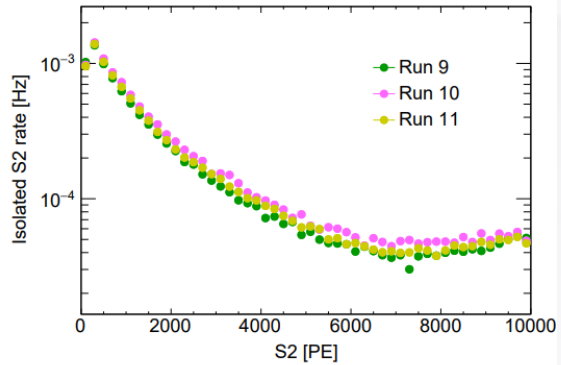




Rate of isolated S1 and isolated S2 (WIMP analysis)

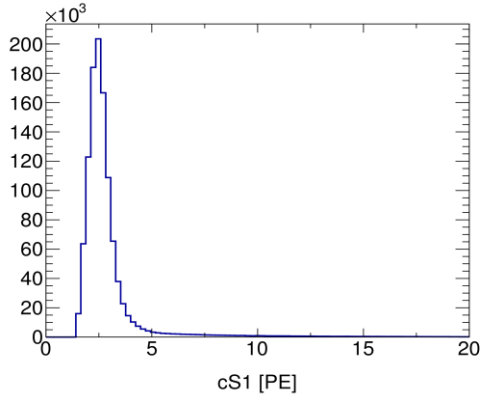
- PandaX-II

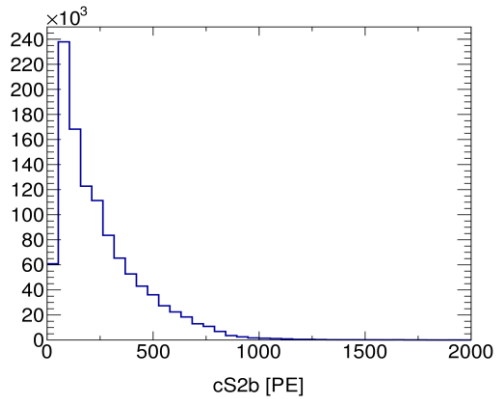




arXiv:2204.11175
(accepted by CPC)

- PandaX-4T





	Duration [Days]	Isolated S1 rate [Hz]	Isolated S2 rate [Hz]
PandaX-II(Run 9)	79.6	1.53+/-0.16	0.0121+/-0.0002
PandaX-II(Run 10)	77.1	0.47+/-0.02	0.0130+/-0.0007
PandaX-II(Run 11)	244.2	0.69+/-0.06	0.0121+/-0.0001
PandaX-4T	95	9.5+/-0.1	4.5×10^{-3} +/- 5.7×10^{-4}

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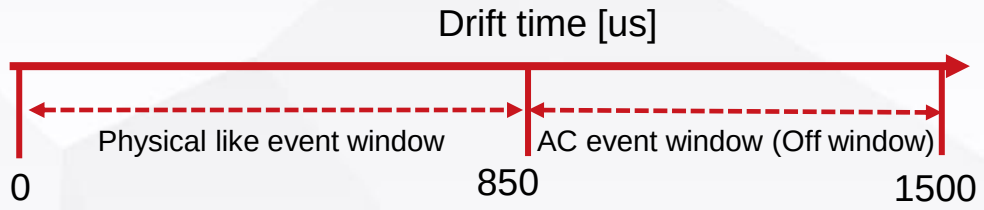
Rate of isolated S1 and isolated S2 (CEvNS analysis)

	S1 range	S2 range
WIMP analysis	[2-135] PE	[80-20000] PE
CEvNS analysis	2,3 hit	[65-300] PE



- Different region of interest
- For S1, used hit unit instead of PE.
- Lowered threshold from 1.33keV to 0.95keV

- Randomly selected 1000us waveform window
  - Rate of isolated S1 → 11.2 mHz
- Extended AC events window (Off window) to 1500us
  - Rate of isolated S2 → 11.9 mHz

arXiv:2207.04883

03

Estimation of accidental background

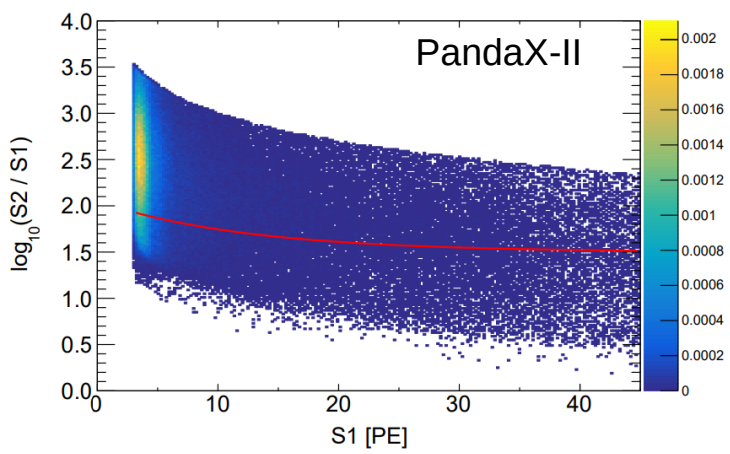
Estimation of AC background (After data quality selection)

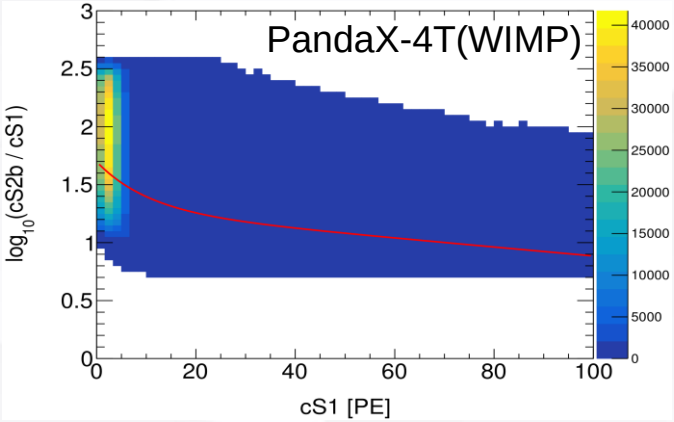
$$N_{AC} = r_{S1} \cdot r_{S2} \cdot \Delta t \cdot T \cdot \epsilon$$

PandaX-II		
Run	Duration [days]	AC counts
9	79.6	8.15 +/- 0.94
10	77.1	3.16 +/- 0.15
11	244.2	9.87 +/- 0.89

PandaX-4T		
	Duration [days]	AC counts
WIMP analysis	95	2.43 +/- 0.47

- The Isolated S1s and S2s are randomly assembled uniformly in the drift time Δt



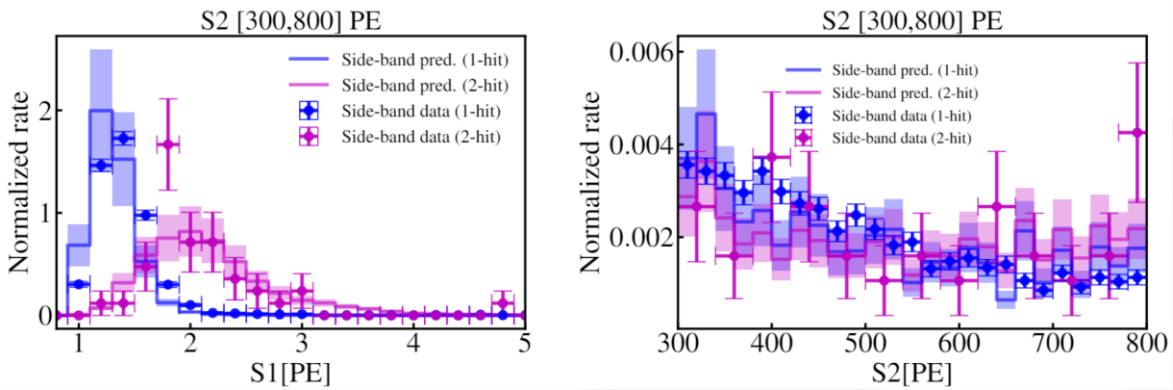


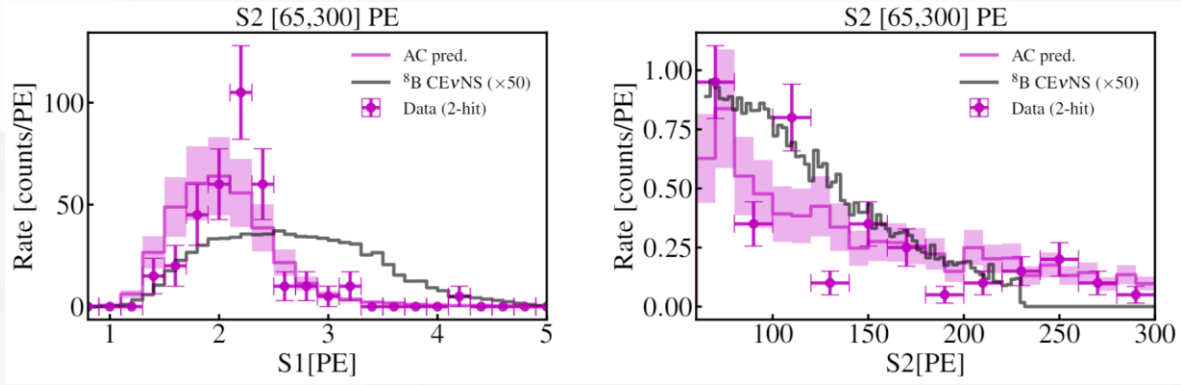
Estimation of AC background (After data quality selection)

- Side band definition: Region where adjacent to the region of interest

nHit	Side band (300-800 PE)		
	Phys counts	AC counts	Obs counts
1	9.4	2060.5	2043
2	10.1	33.8	47
3	6.9	2.2	7

nHit	S2 range(opt)	Phy counts	AC counts	Obs counts
2	[65-230] PE	2.76	62.43	59
3	[65-190] PE	0.48	0.79	2





- 30% of uncertainty was taken which is error-weighted standard deviation of S2 spectra

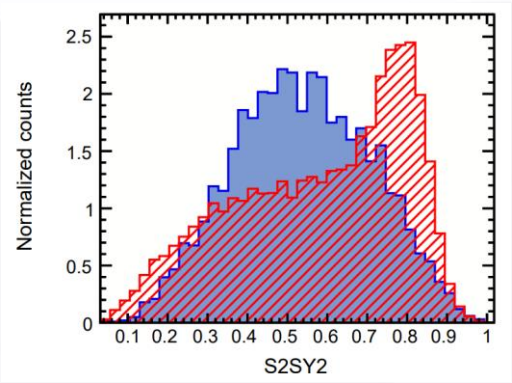
arXiv:2207.04883

04

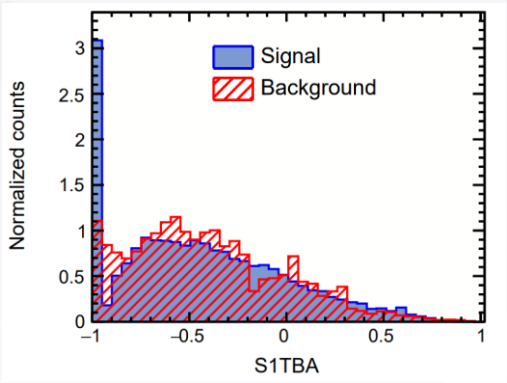
Suppression of accidental coincidence background

Further suppression of AC background (PandaX-II)

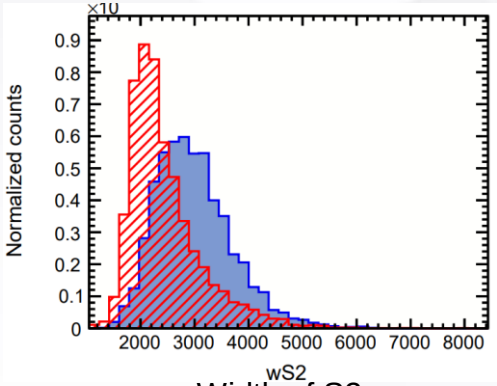
- A set of variables are exploited to search for the difference between the accidental events and the physical NR events using Boosted Decision Tree (BDT)



Waveform asymmetry of S2

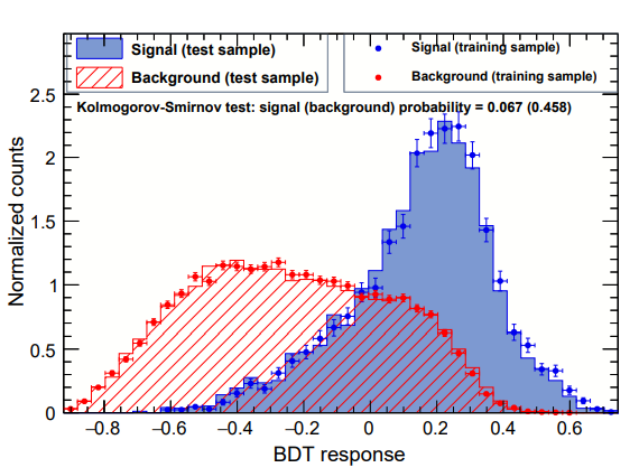


Top bottom charge asymmetry



Width of S2

- Training data set
  - Background: simulated AC sample
  - Signal: NR calibration data

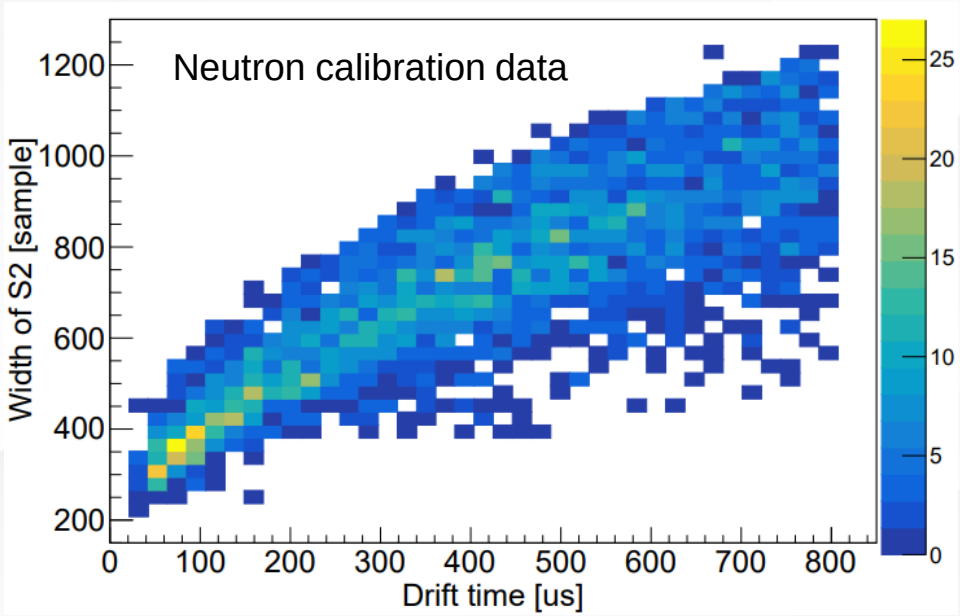


Signal efficiency of BDT	Background rejection of BDT
90%	70%

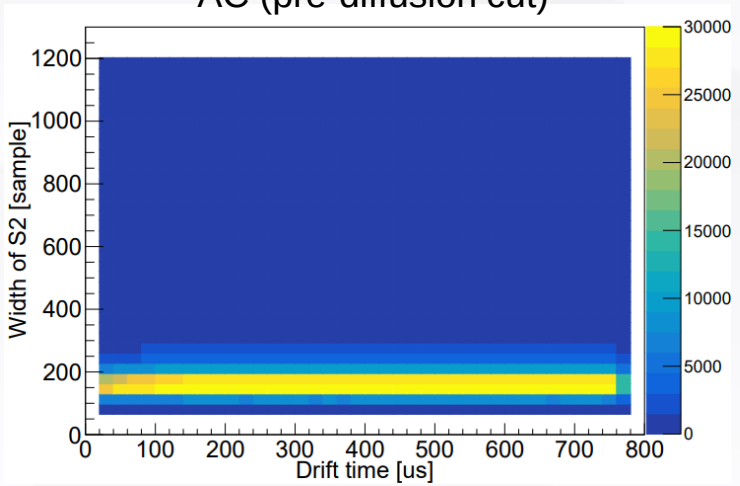
Run	AC counts (pre-BDT)	AC counts (post-BDT)
9	8.15 +/- 0.94	2.09+/-0.25
10	3.16 +/- 0.15	1.03+/-0.05
11	9.87 +/- 0.89	2.53+/-0.24

Suppression of AC background in PandaX-4T (WIMP)

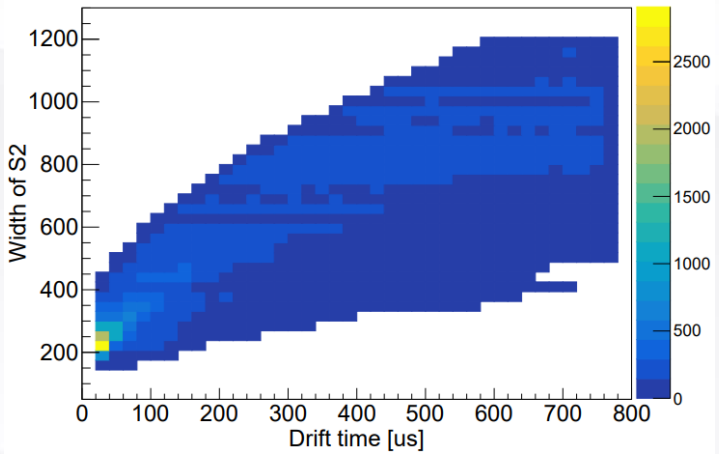
- PandaX-4T has long drift time compare to PandaX-II
- Long drift time causes diffusion effect for physical events.
- Longer drift time cause large S2 width
- A cut (diffusion cut) based on diffusion effect was developed (S2 charge, S2 width and drift time correlated 3D cut) to removed AC background



AC (pre-diffusion cut)



AC (post-diffusion cut)



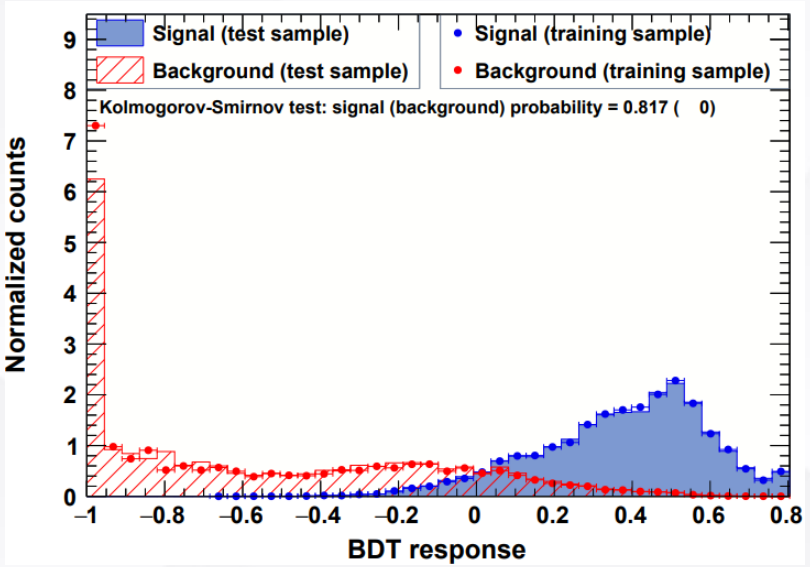
Suppression of AC background in PandaX-4T (B8)

- Diffusion cut was applied
- High level data selections are not developed.
- BDT was trained with bunch of variables

nHits	SIG acceptance (Waveform simulation)	BKG rejection (Simulated AC)
2	39%	98%
3	31%	96%

nHits	S2 range (optimized range)	AC counts (pre-BDT)	AC counts (post-BDT)
2	65-230 PE	62.43	1.42
3	65-190 PE	0.79	0.29

- Training data set
  - Background: simulated AC sample
  - Signal: waveform simulation



- BDT cut uncertainty estimated to be 20% using alternative AC sample

05

Summary

Summary

- The accidental coincidence background is an important composition of the backgrounds in the dark matter search experiments with dual phase xenon detector.
- Briefly discussed the possible origins of isolated S1 and isolated S2.
- Developed various methods to estimate the level of accidental coincidence background in PandaX-II and PandaX-4T detector.
- BDT or other data selections were developed to suppress the accidental coincidence background significantly.

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Thanks for listening

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