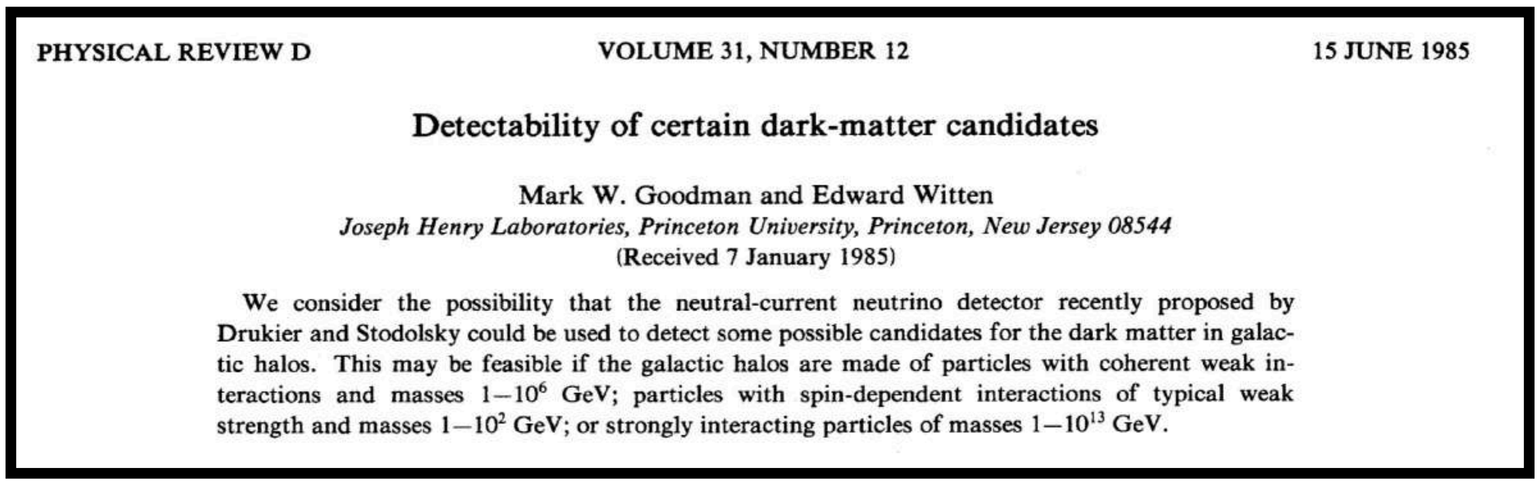
S2-only and Accidental Coincidece Backgrounds in XENON1T/nT

Fei Gao, Tsinghua University
feigao@tsinghua.edu.cn

on behalf of XENON Collaboration

Nagoya Workshop on Technology and instrumentation in Future Liquid Noble gas Detectors
Feb 14 - 16, 2024, Nagoya, Japan

Dark Matter and Neutrino Signals in LXeTPC

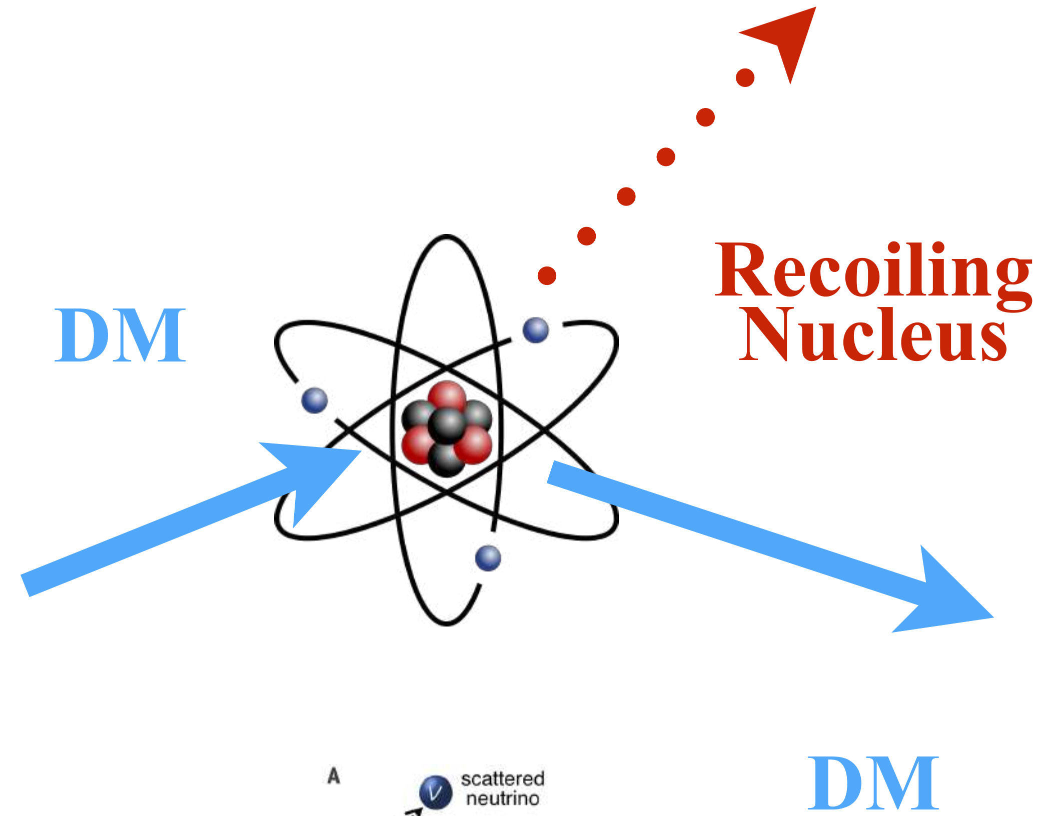


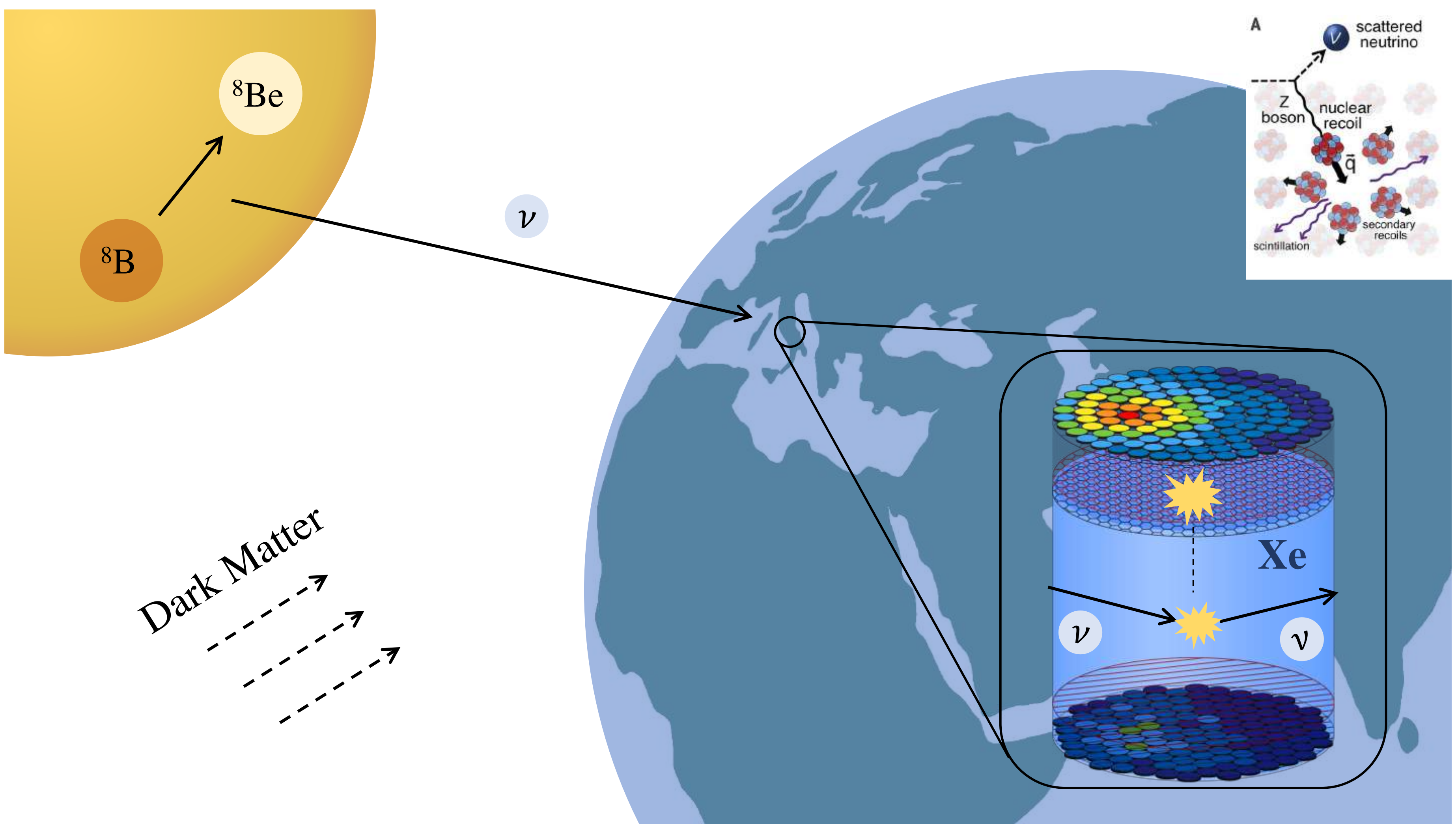
PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

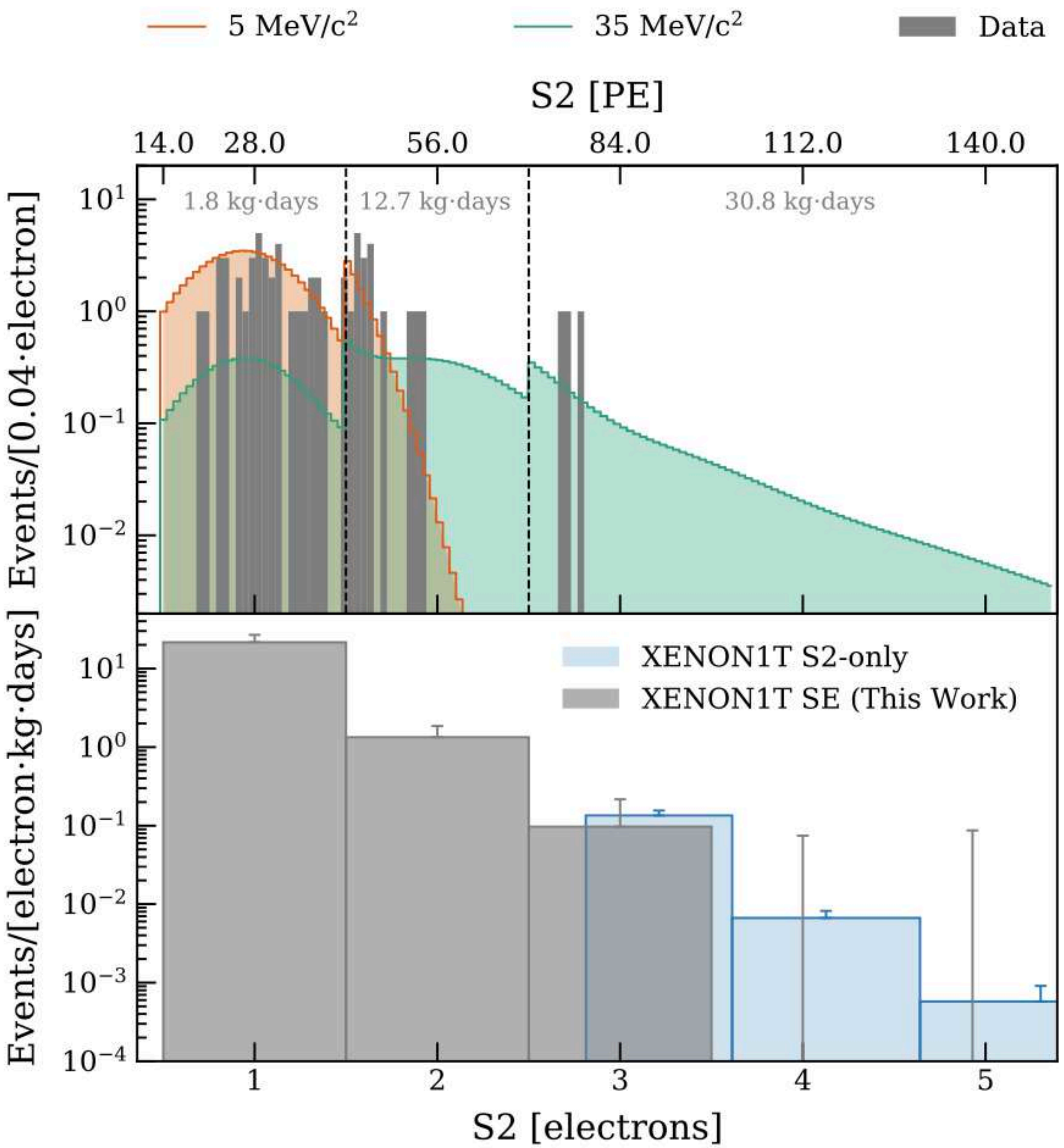
Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

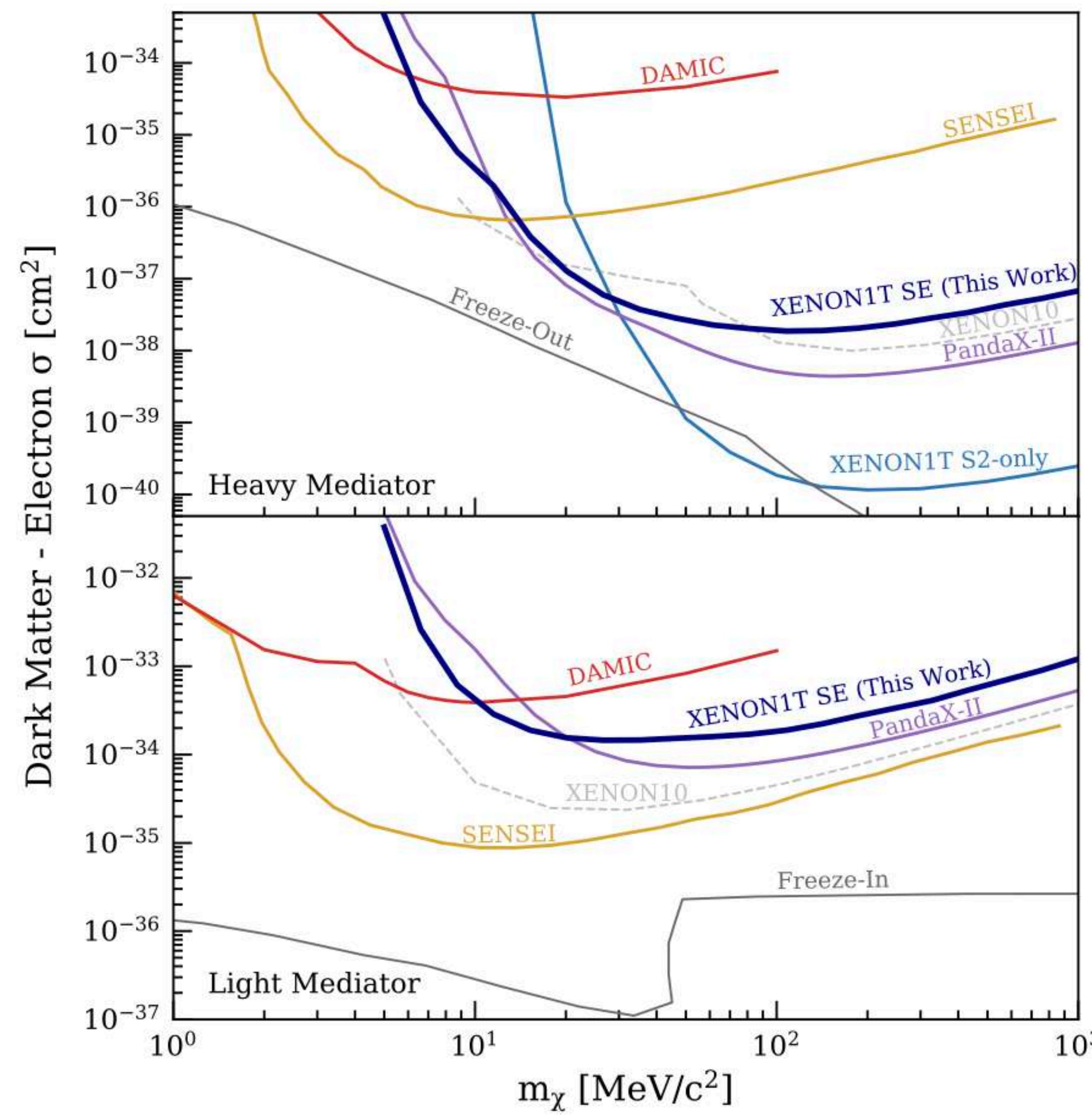
We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.





Light DM Search with Single-Electrons (SEs)

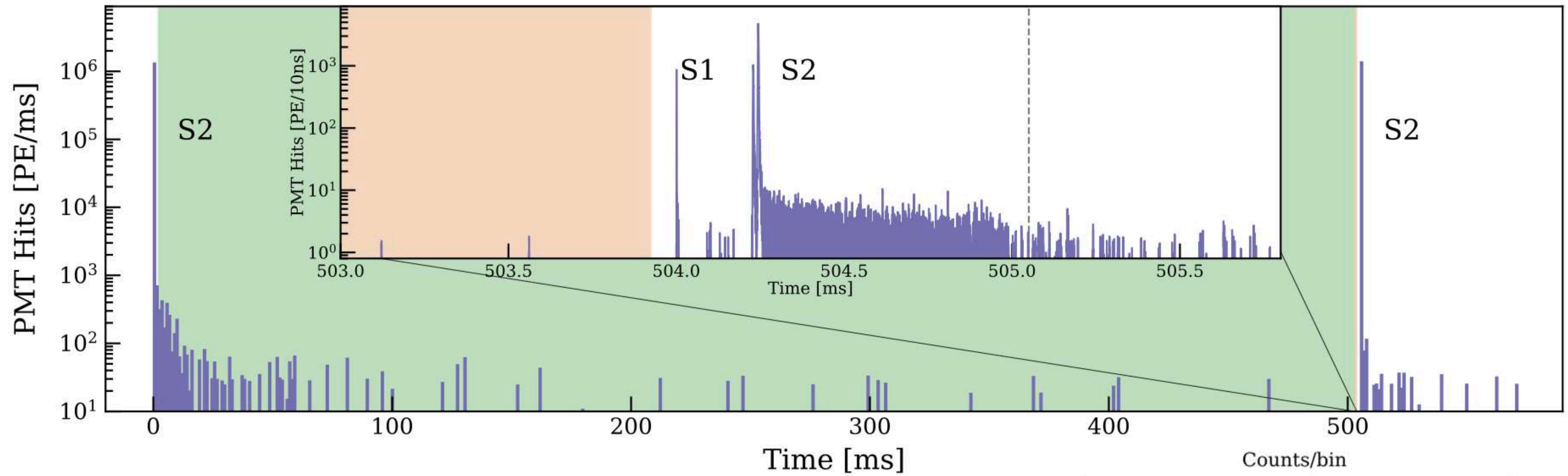


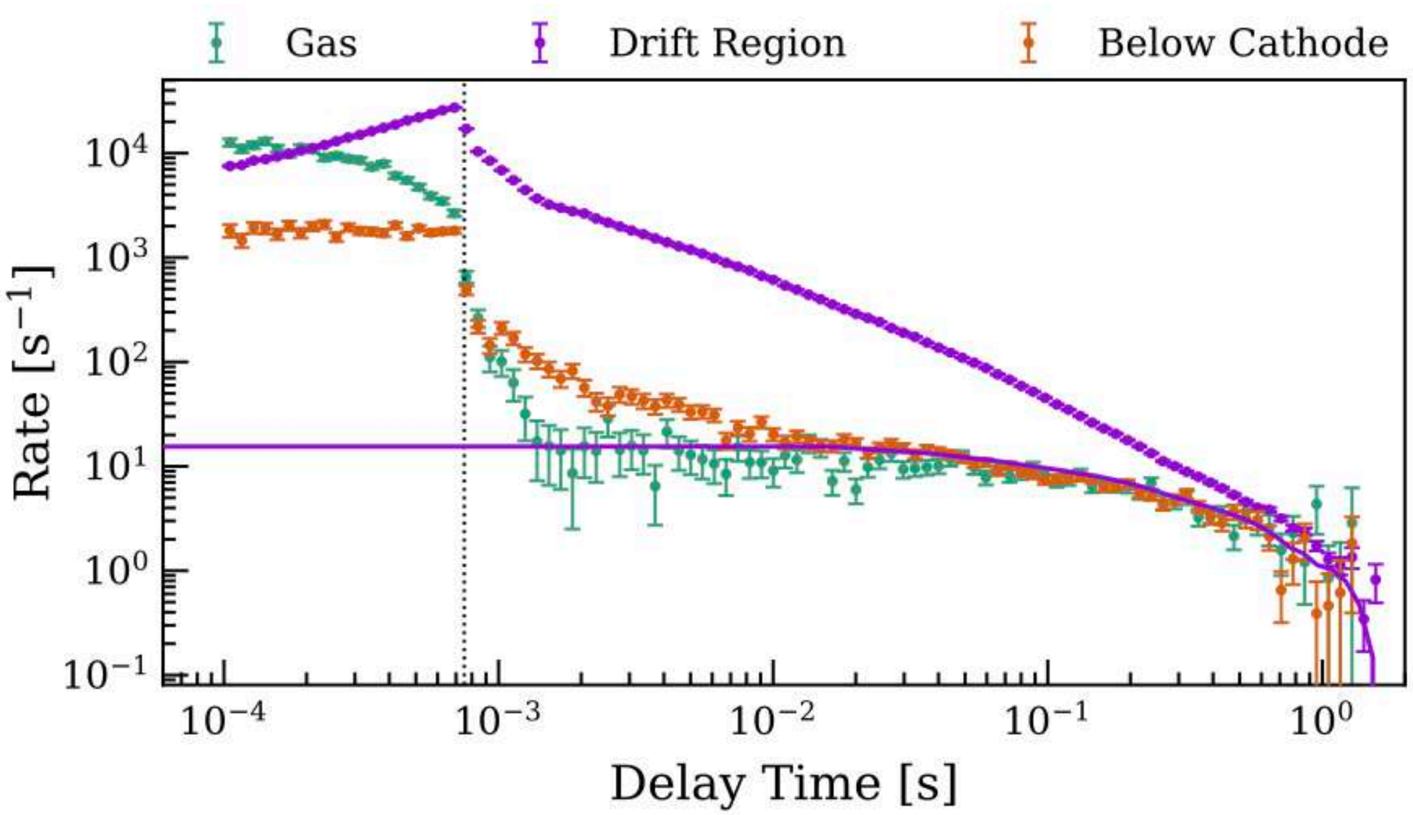


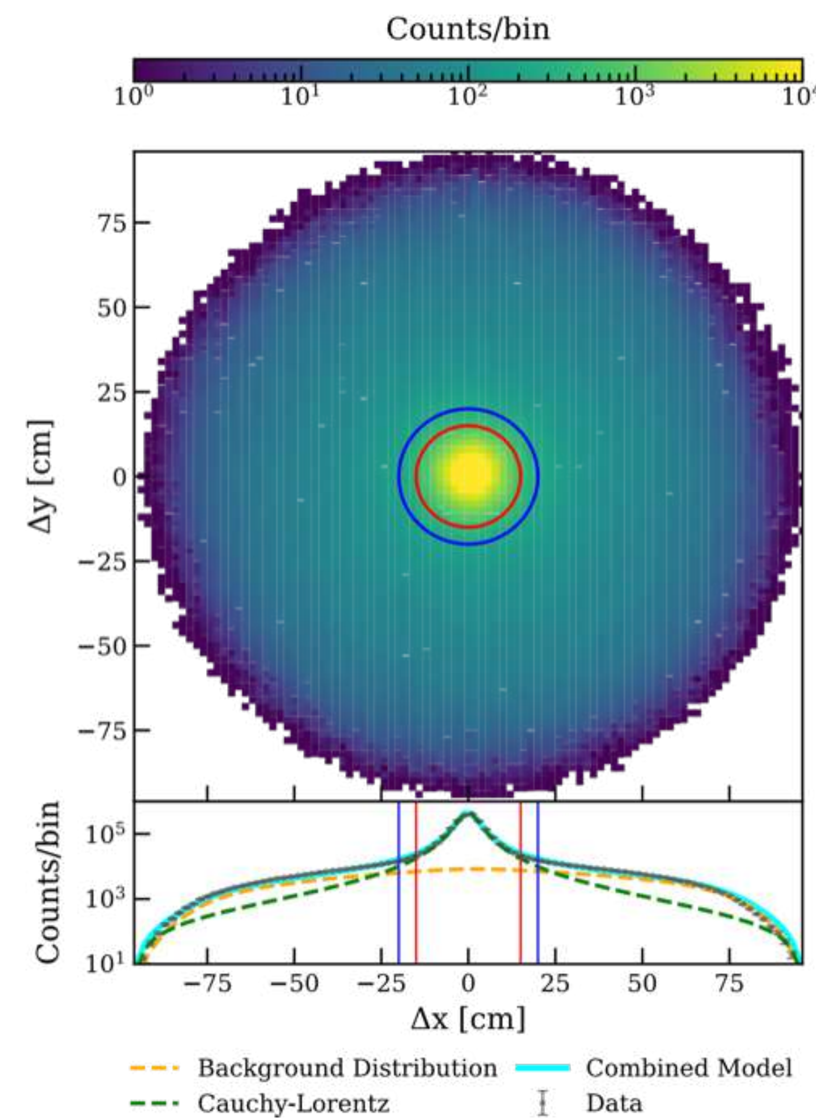
Analysis using SEs pushes the threshold down to W value

PRD 106, 022001 (2022)

SEs in XENON1T

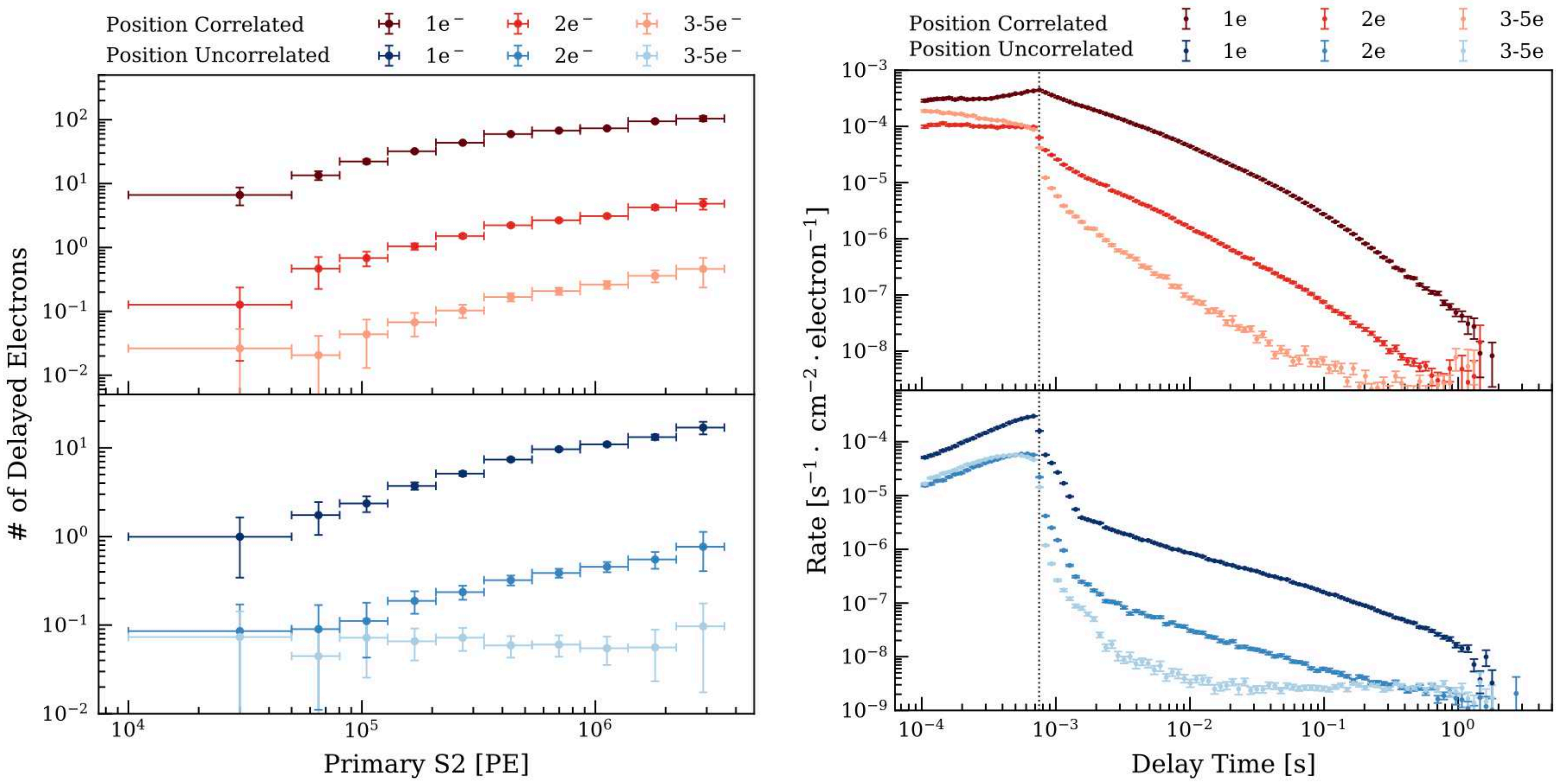






PRD 106, 022001 (2022)

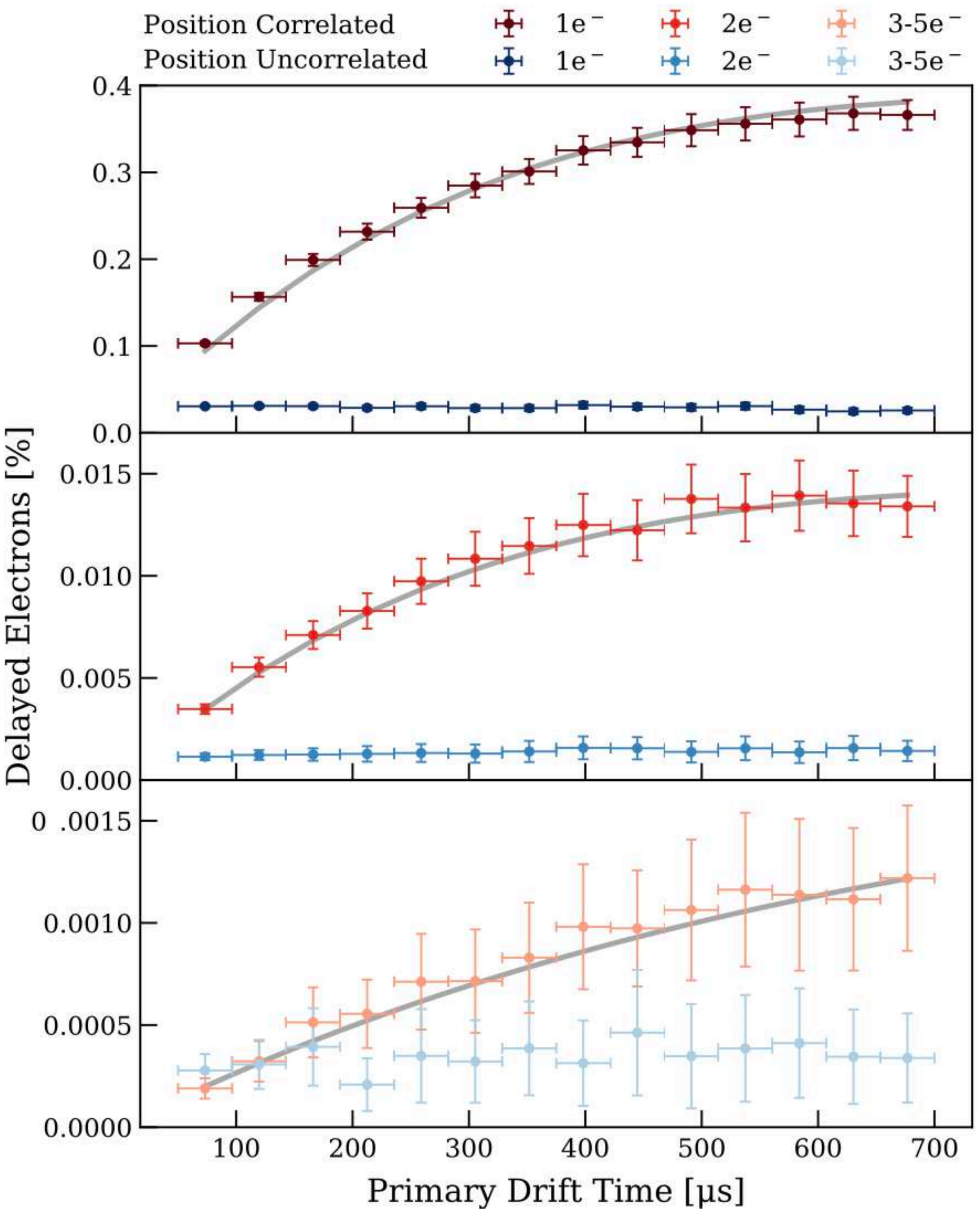
SEs in XENON1T

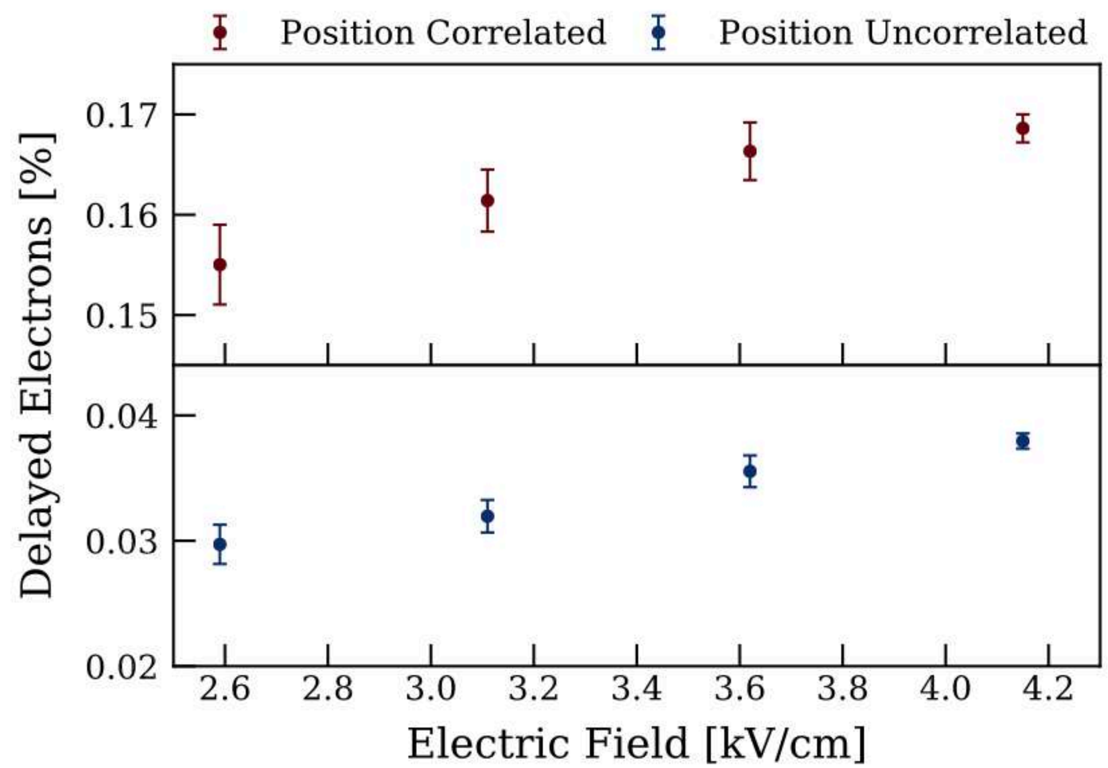


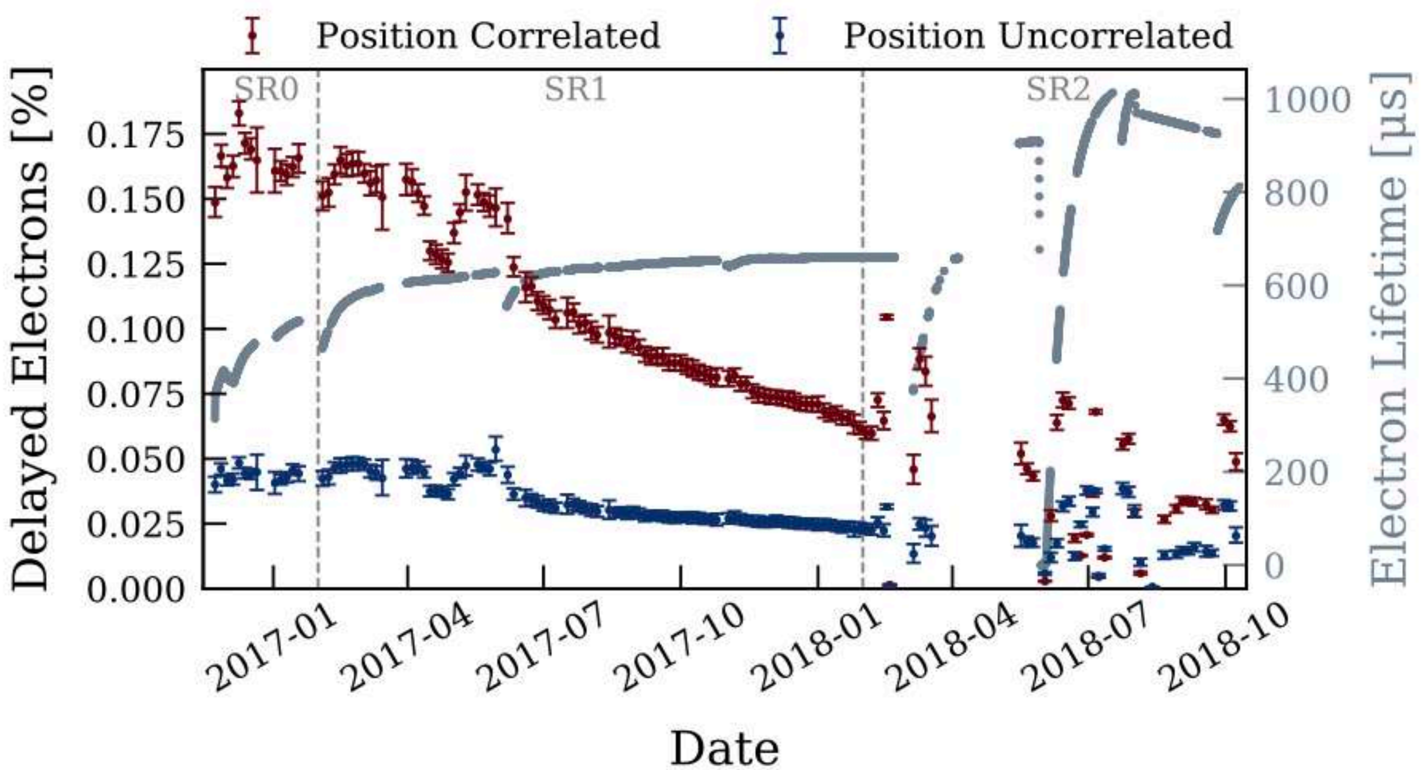
SEs are spacially and temporally corrlated with Primary S2

PRD 106, 022001 (2022)

SEs in XENON1T

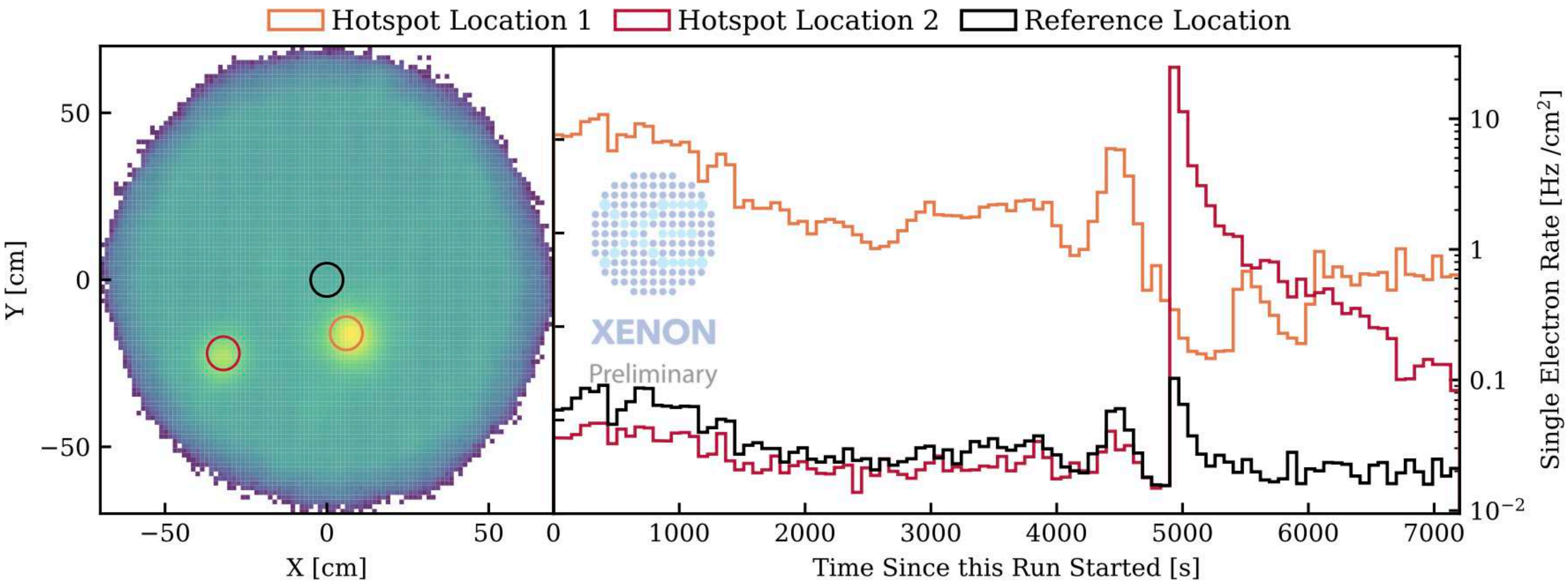


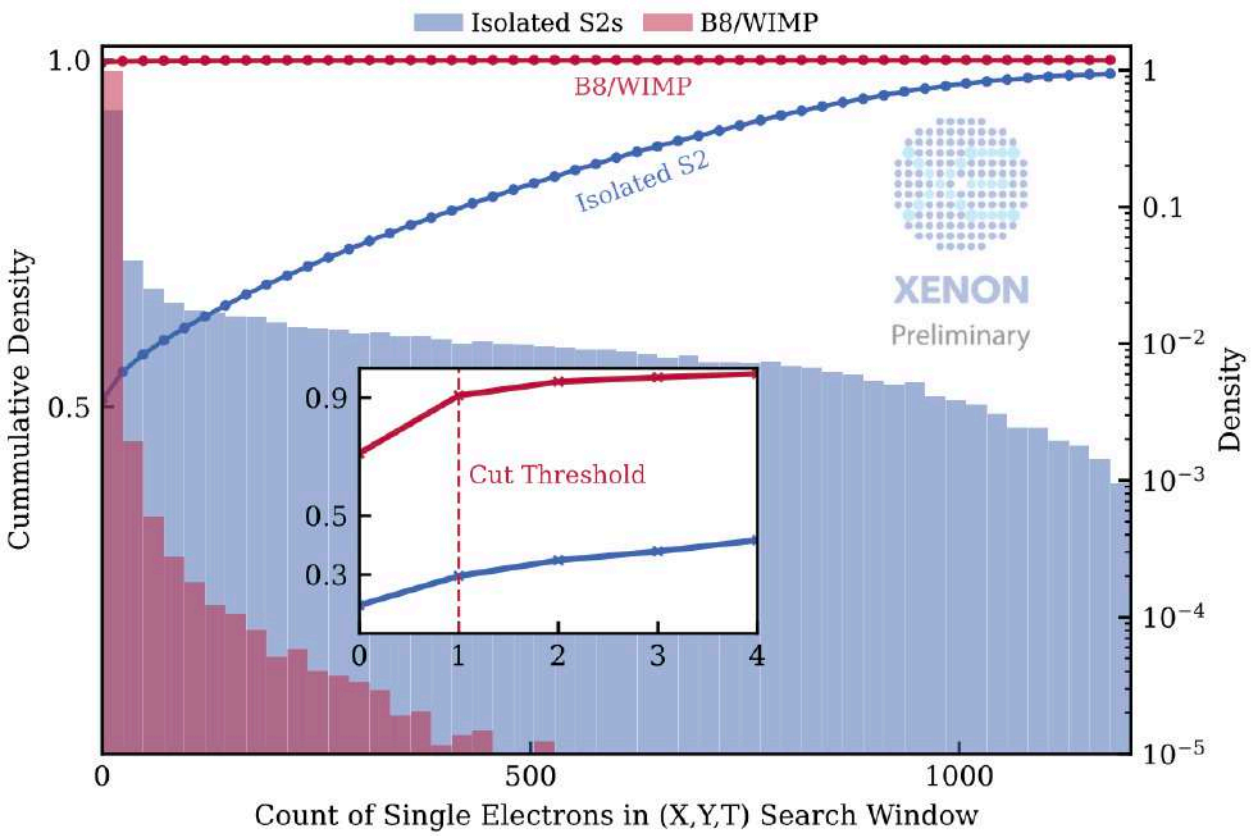




PRD 106, 022001 (2022)

Additional SE source in XENONnT

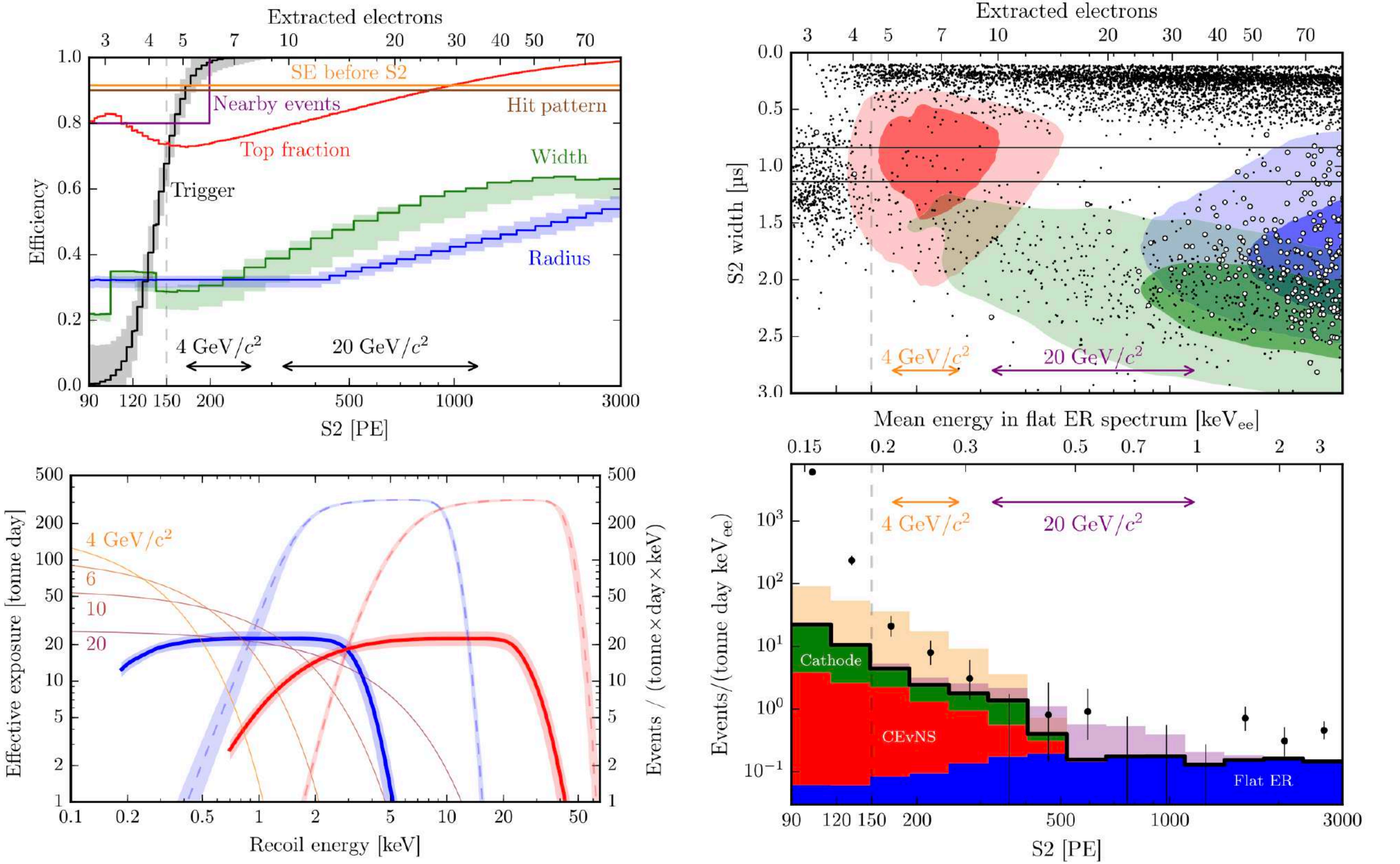




Hot spots are locations where the rate of SEs is high.

The effect of the hot spots on WIMPs/^{8}B search can be reduced via veto

Events with S2 > 4 electrons in XENON1T



We don't fully understand the background in this energy region yet

PRL 123, 251801 (2019)

A few comments on S2-only Background

The S2-only background is observed in a large energy range. Its causes include:

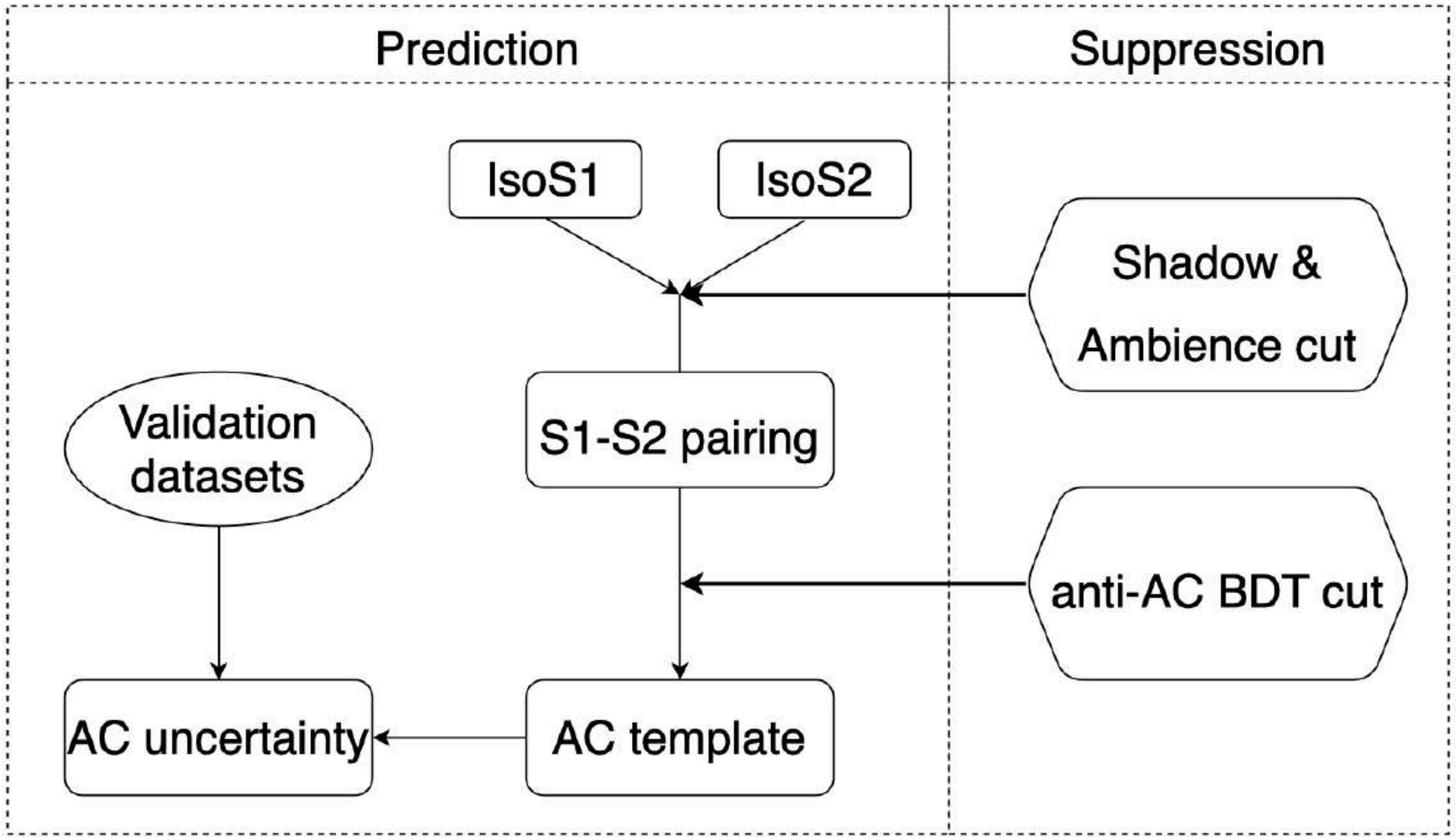
- Photon-ionization of impurities, metals, etc
- Delayed electrons from interactions in the DRIFT region
- Hot spots due to local field effects?
- Surface radioactivities on the electrodes
- …

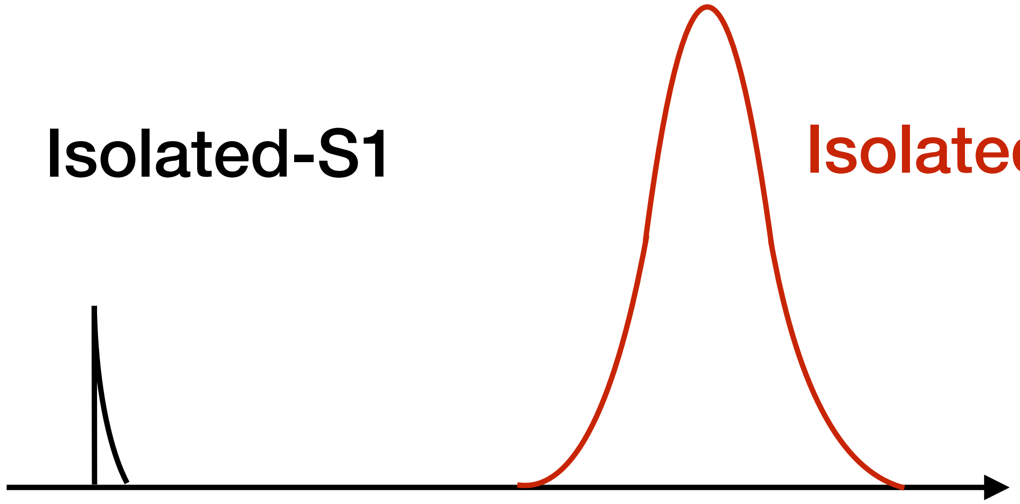
An incomplete understanding of S2-only backgrounds limits the discovery potential of LXeTPC for light DM

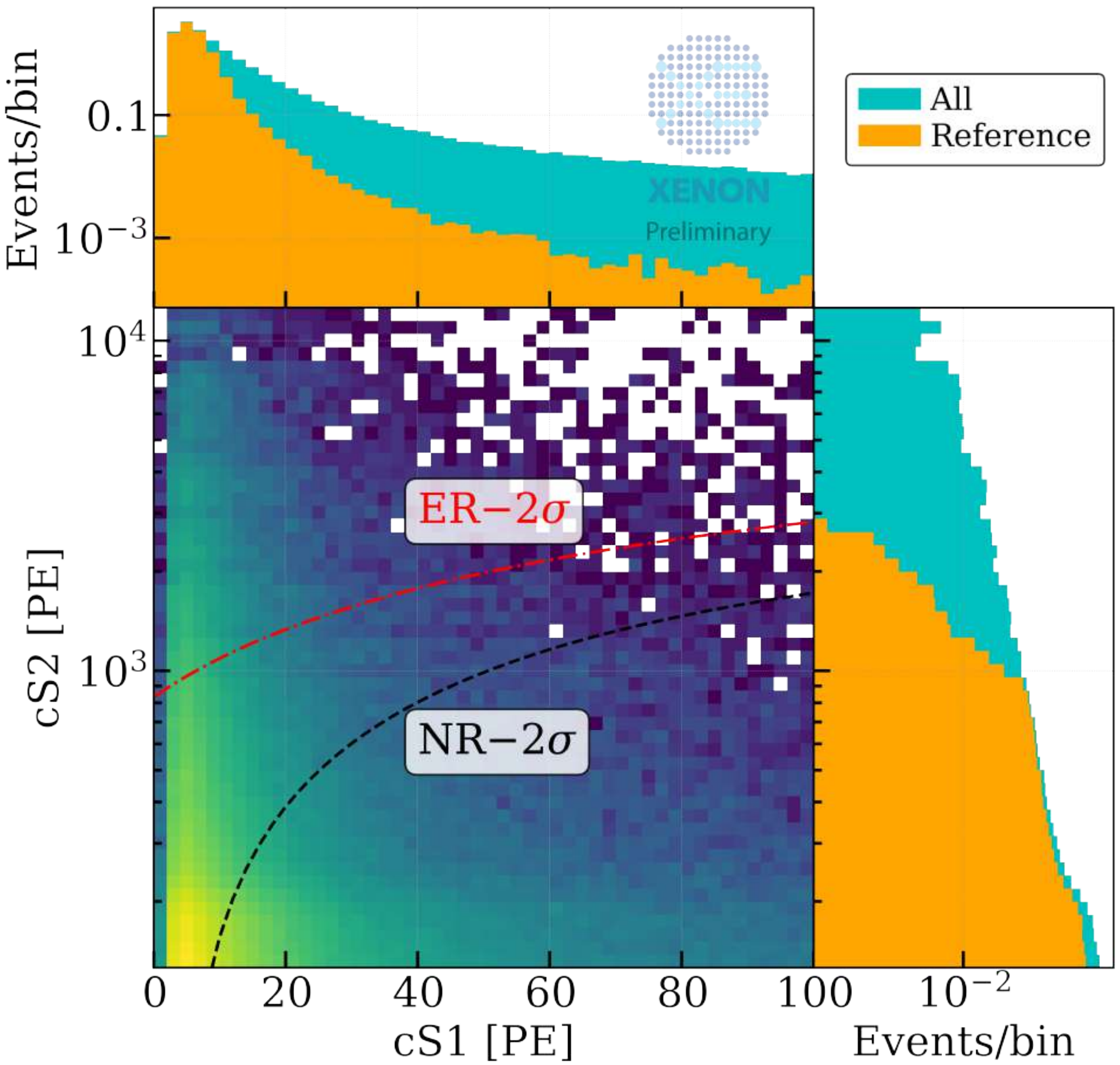
- Can hardly be predicted before an experiment is built
- Currently, attentions are paid to purity, E-fields, surface treatment

R&D effort might be especially useful!

Accidental Coincidence Background







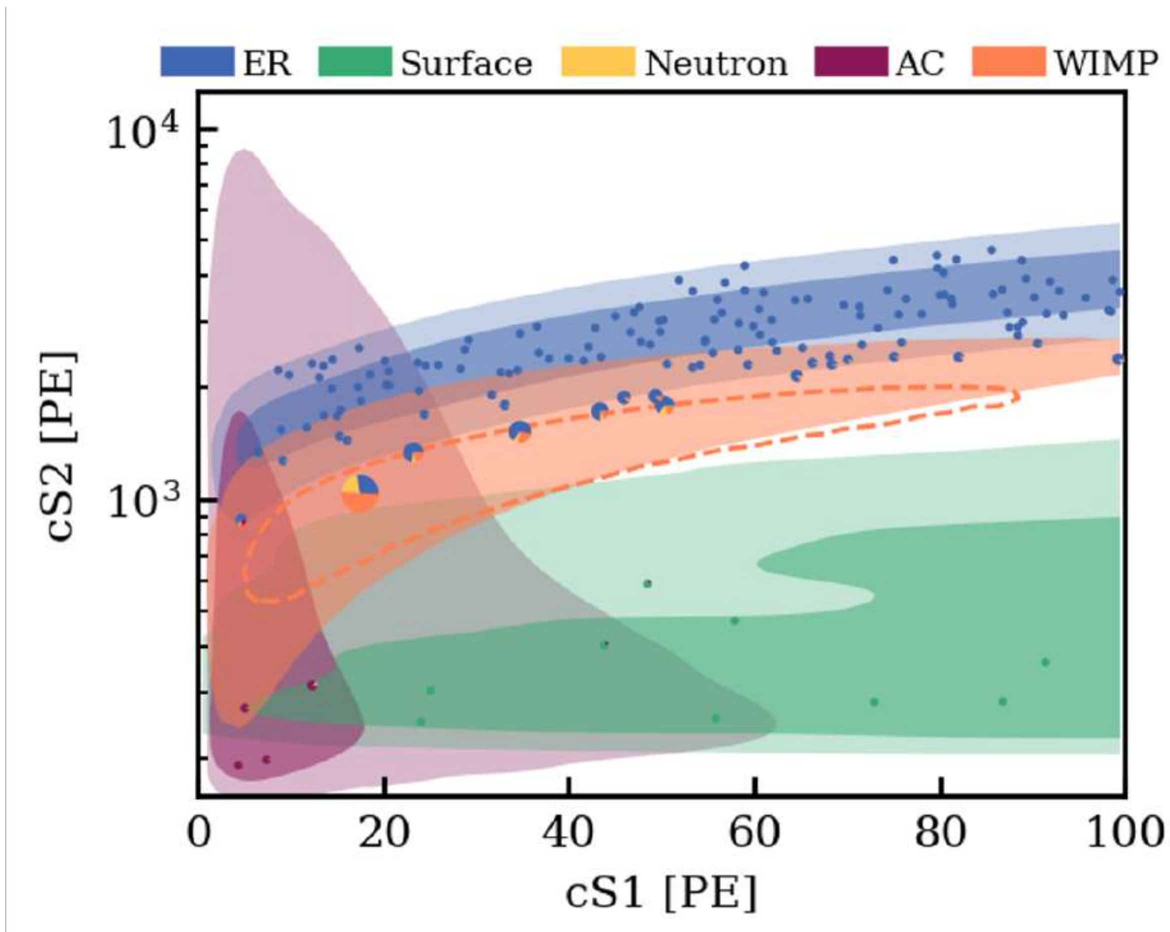
XENONnT WIMPs Search Analysis

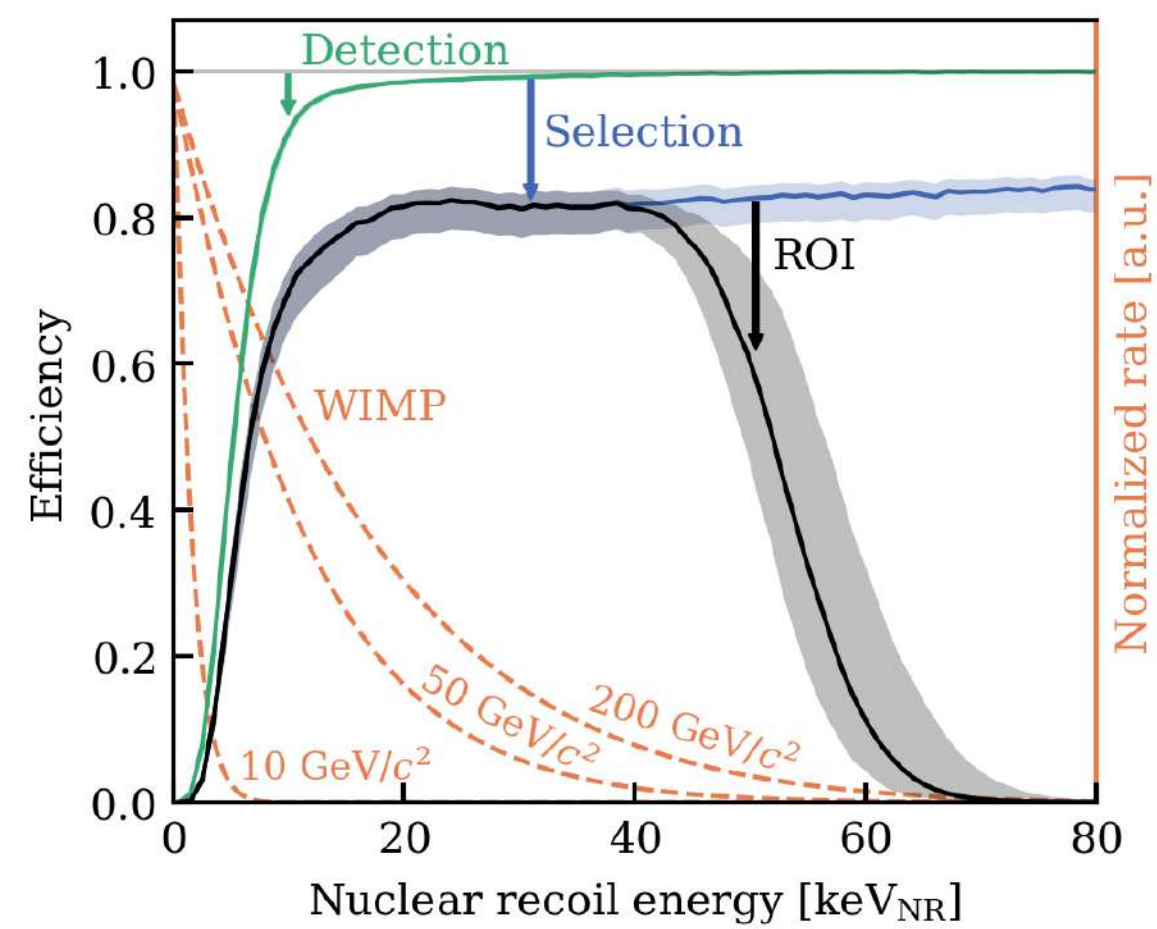
Sources	Nominal	Best Fit	
	ROI		Signal Like
ER	134	135^{+12}_{-11}	0.81±0.07
Neutron	$1.1^{+0.6}_{-0.5}$	1.1±0.4	0.42±0.20
Neutrino	0.23±0.06	0.23±0.06	0.02±0.01
AC	**4.3±0.2**	**4.3±0.2**	**0.36±0.01**
Surface	14±3	12^{+0}_{-4}	$0.34^{+0.01}_{-0.11}$
Total	154	152±12	$1.95^{+0.12}_{-0.16}$
Data		**152**	**3**

S1 threshold: 3 PMT coincidence!

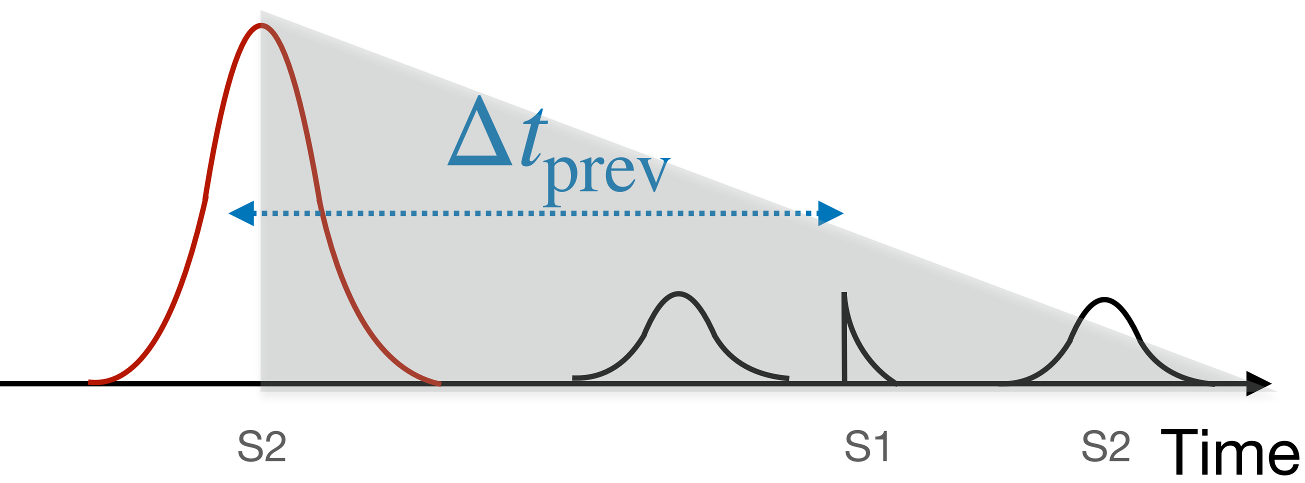
S2 threshold: 200PE (~7 electrons)

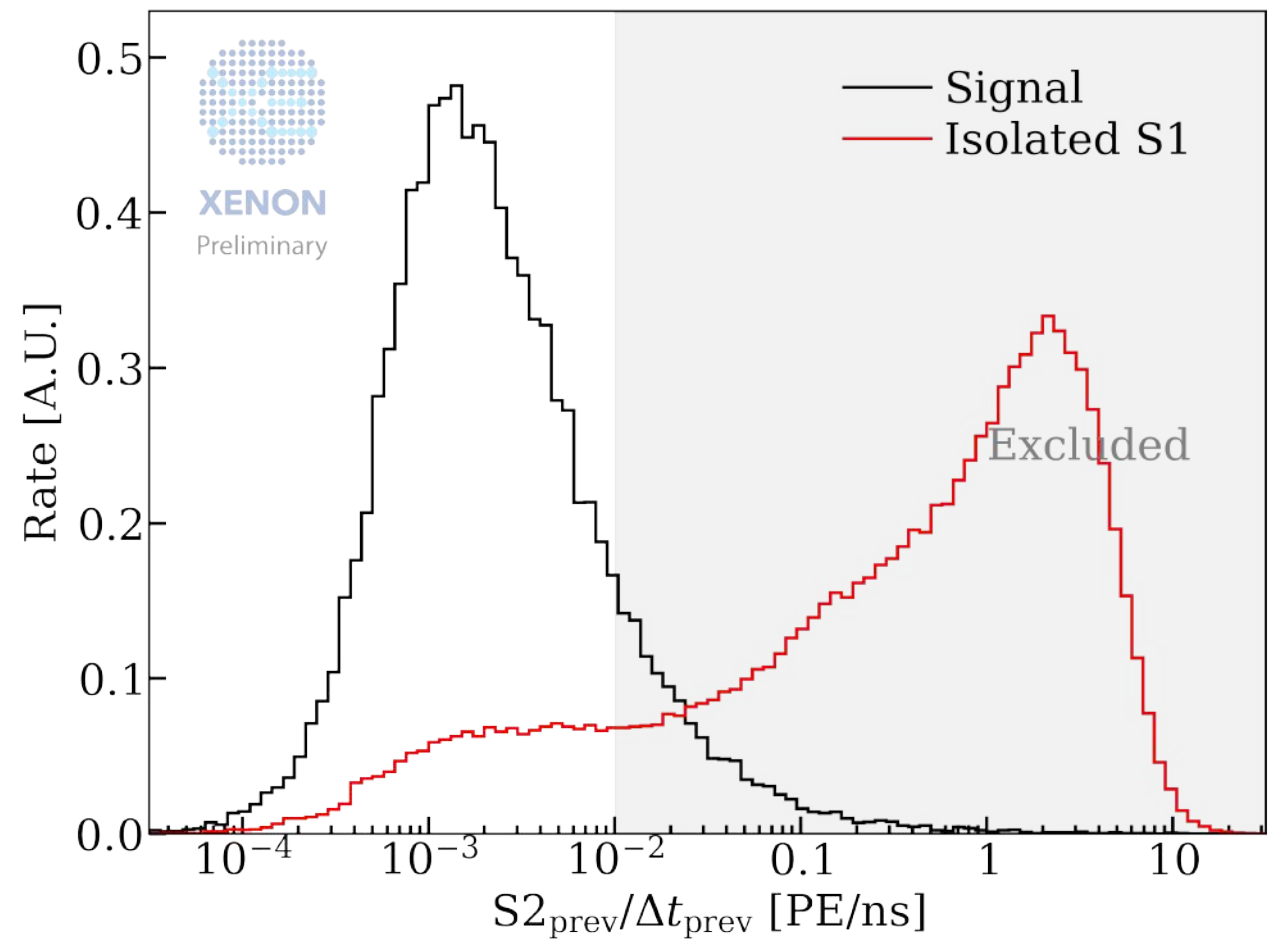
AC is highly suppressed with higher S1 and S2 threshold, but not negligible!



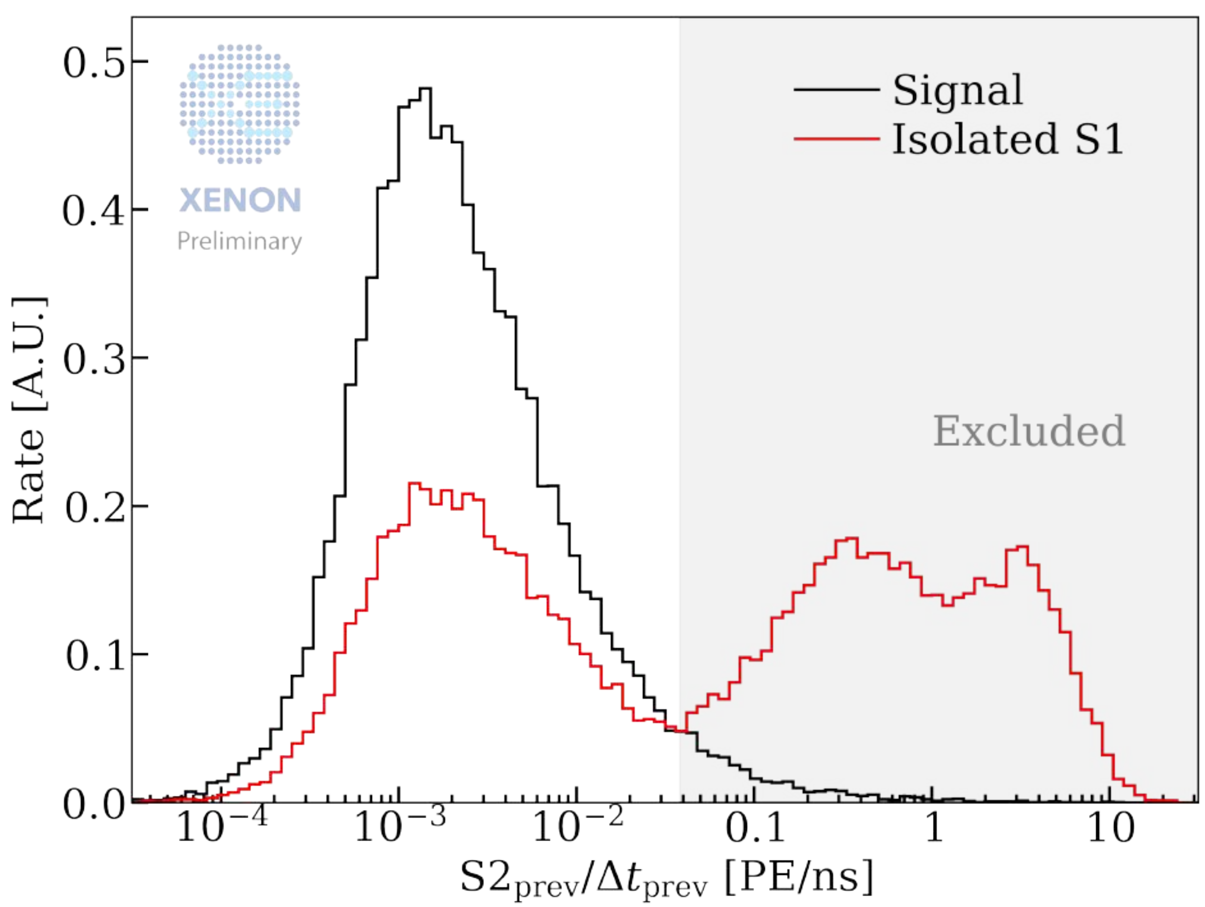


AC Suppression — Shadow Effects





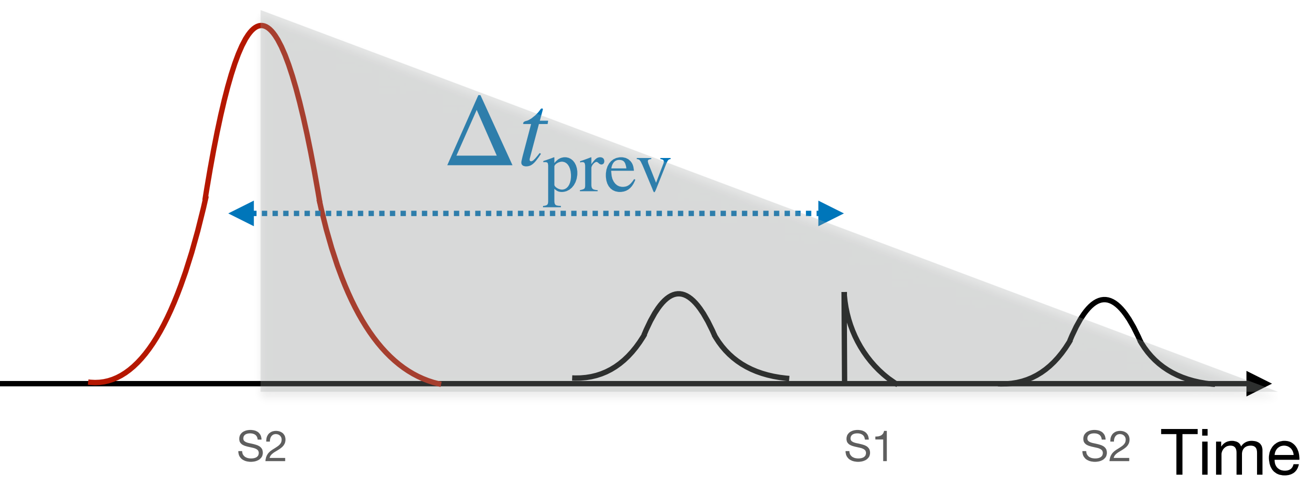
PMT Coin: 2

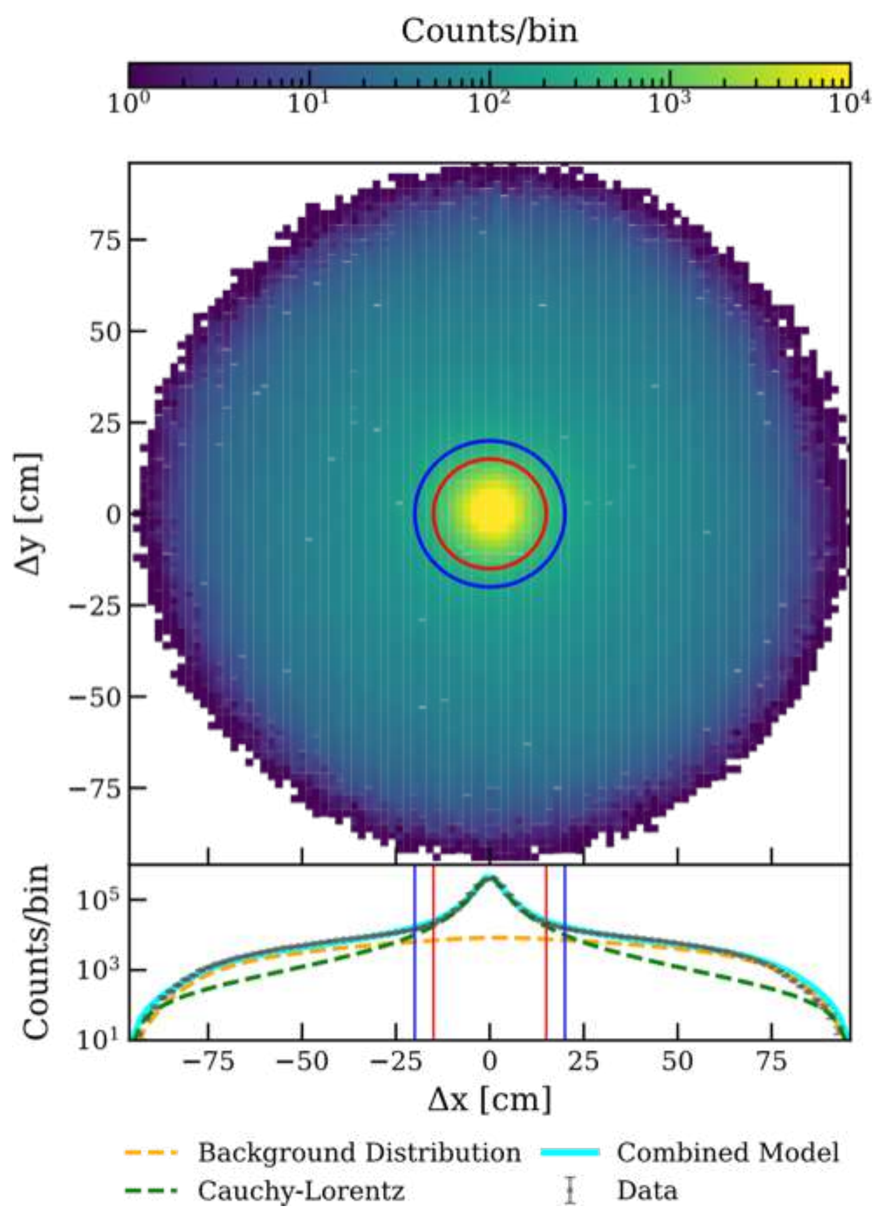


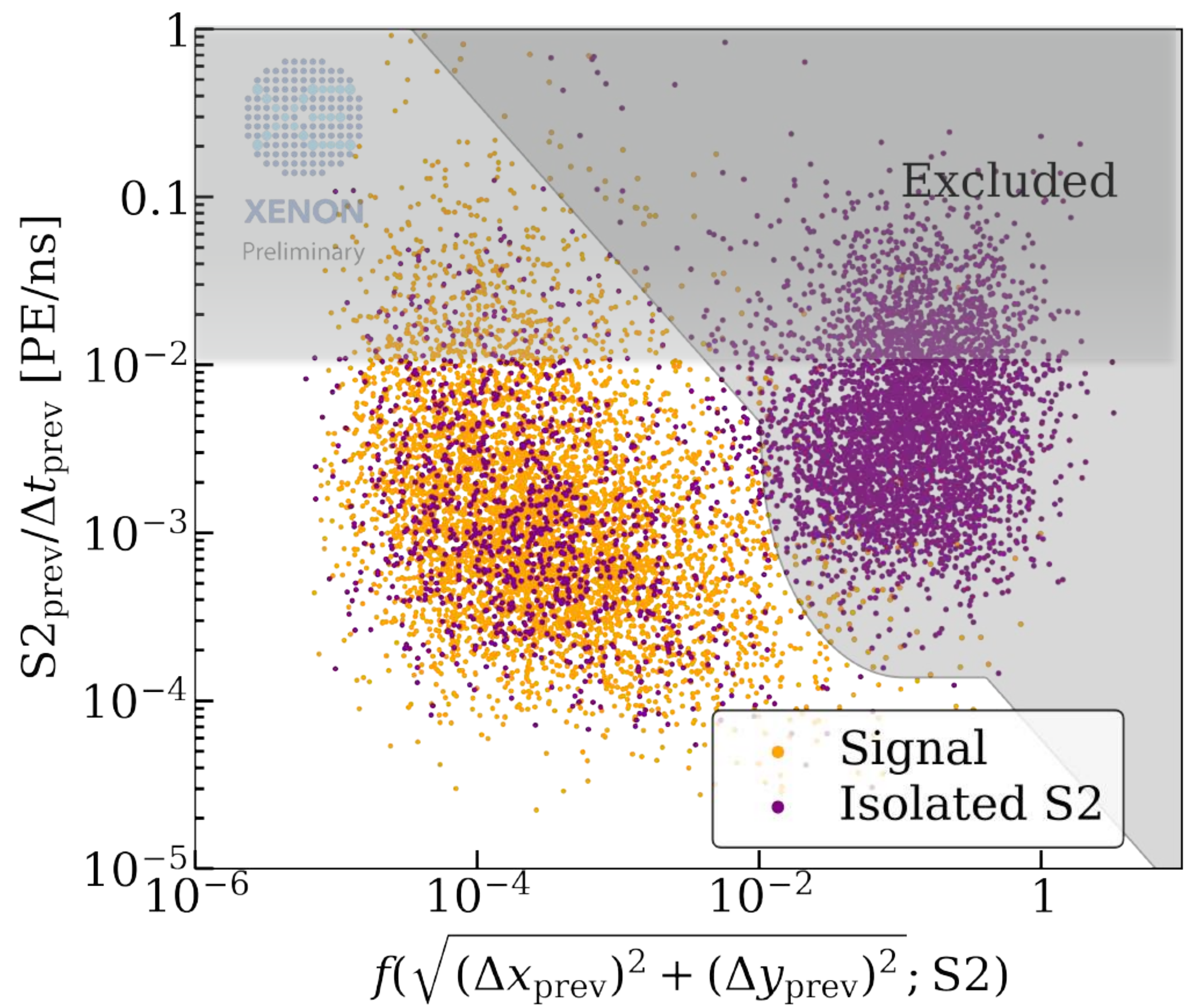
PMT Coin: 3+

Reject exposure near high energy events

AC Suppression — Shadow Effects

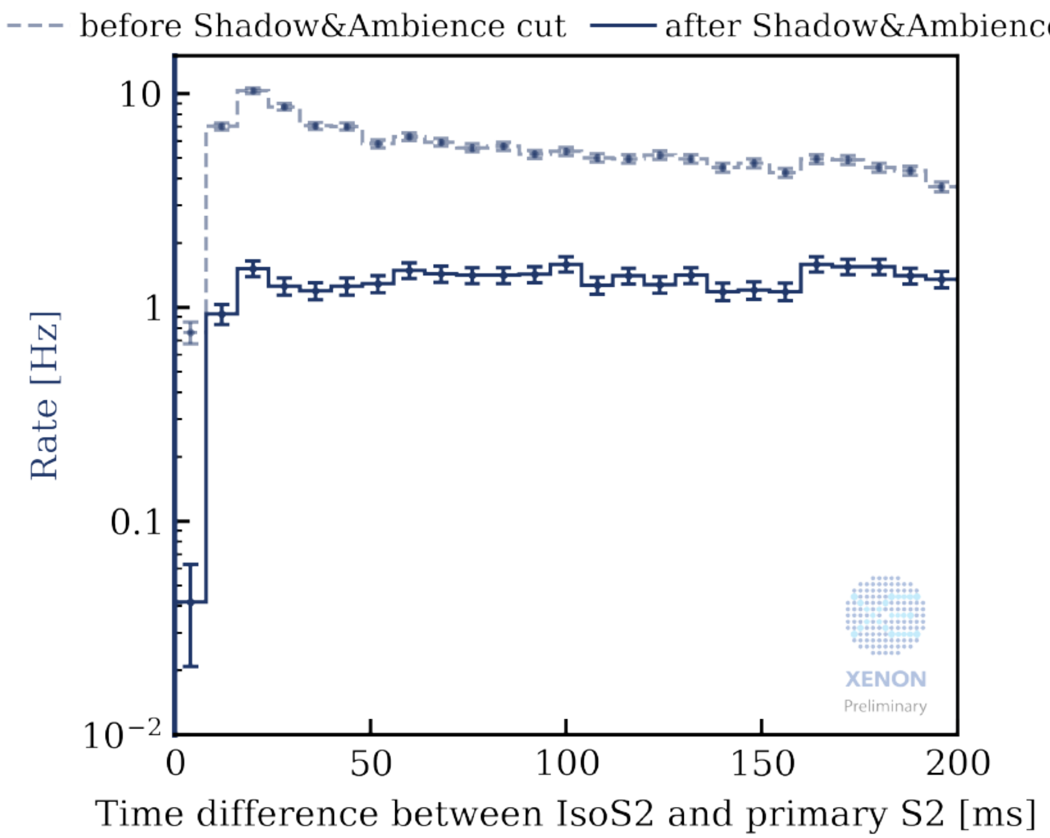


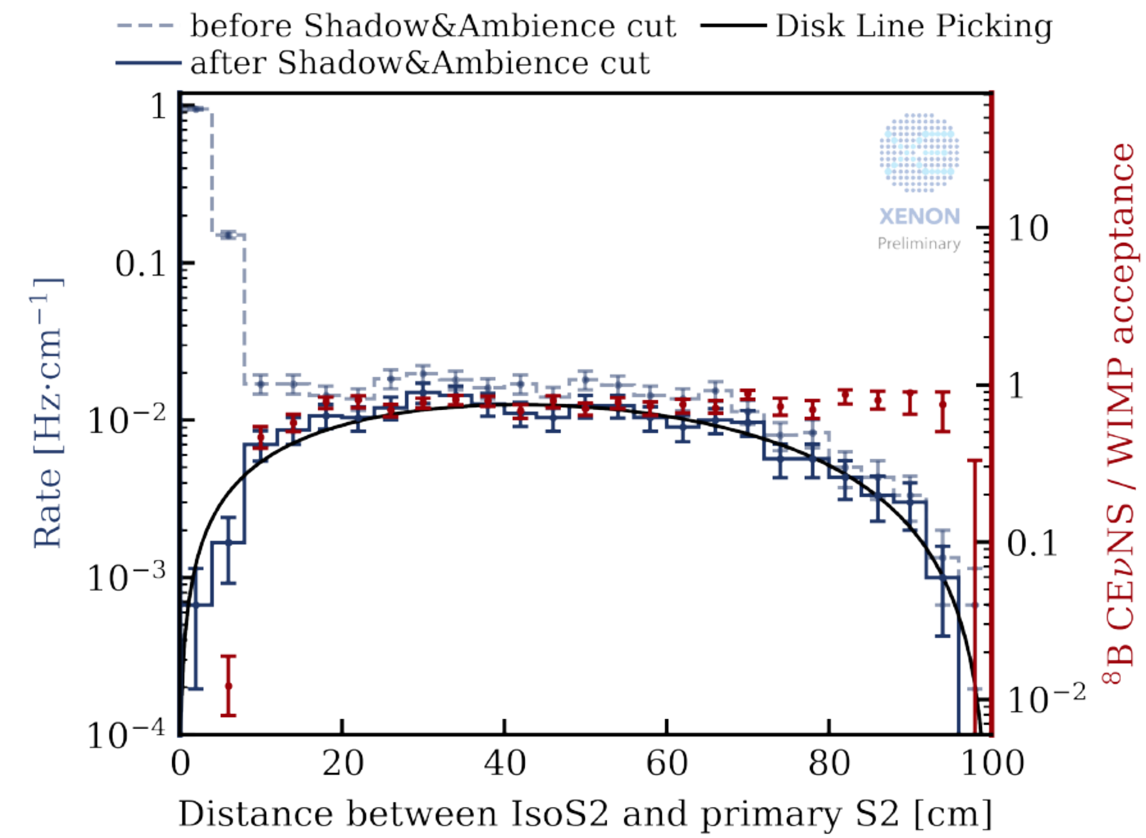


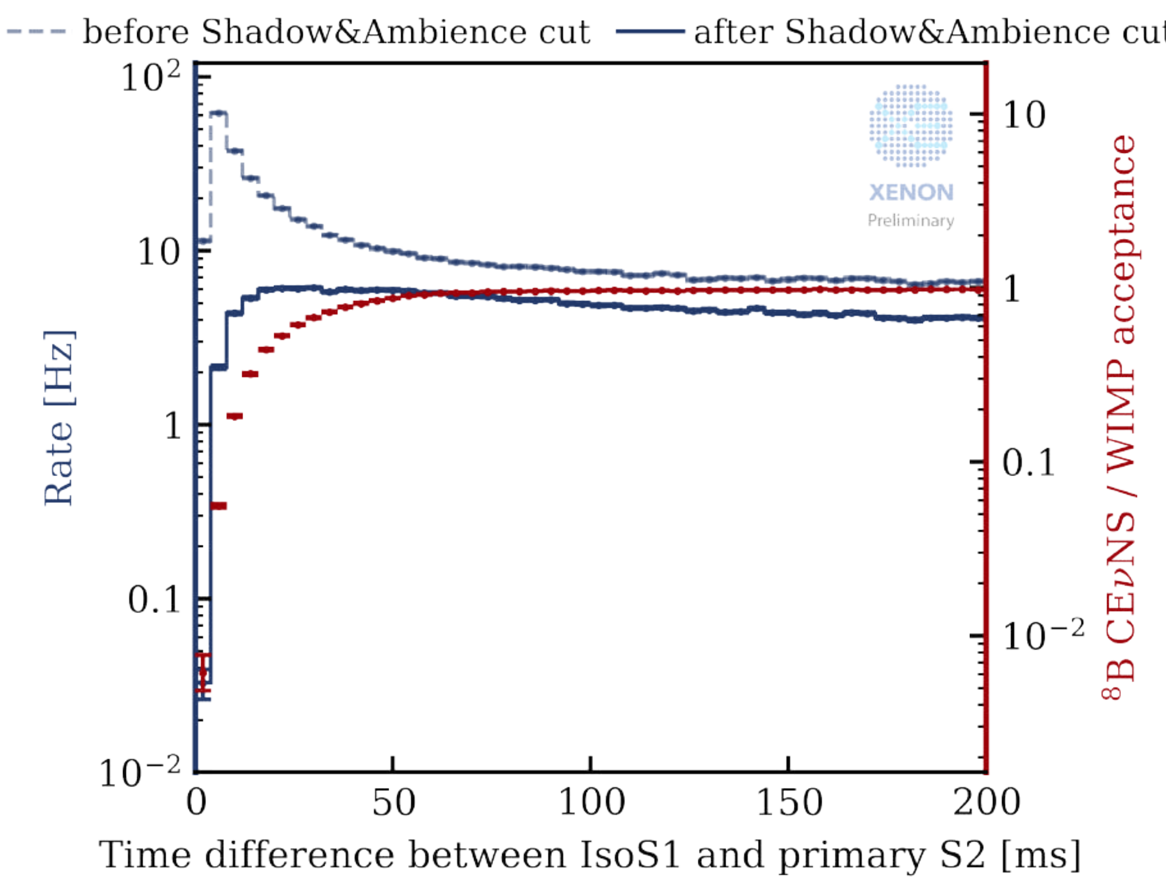


Reject exposure near high energy events

AC Suppression — Shadow Effects

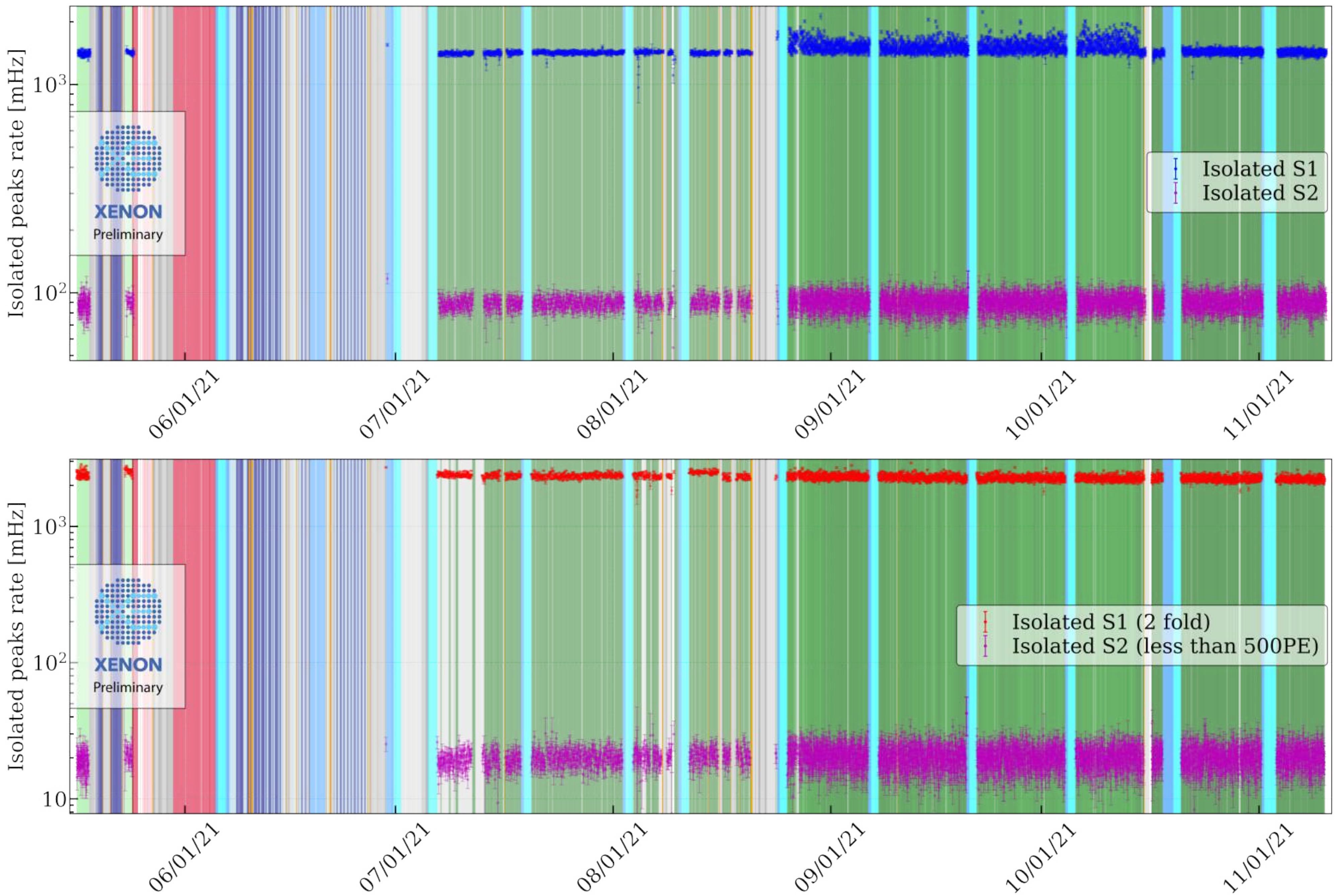






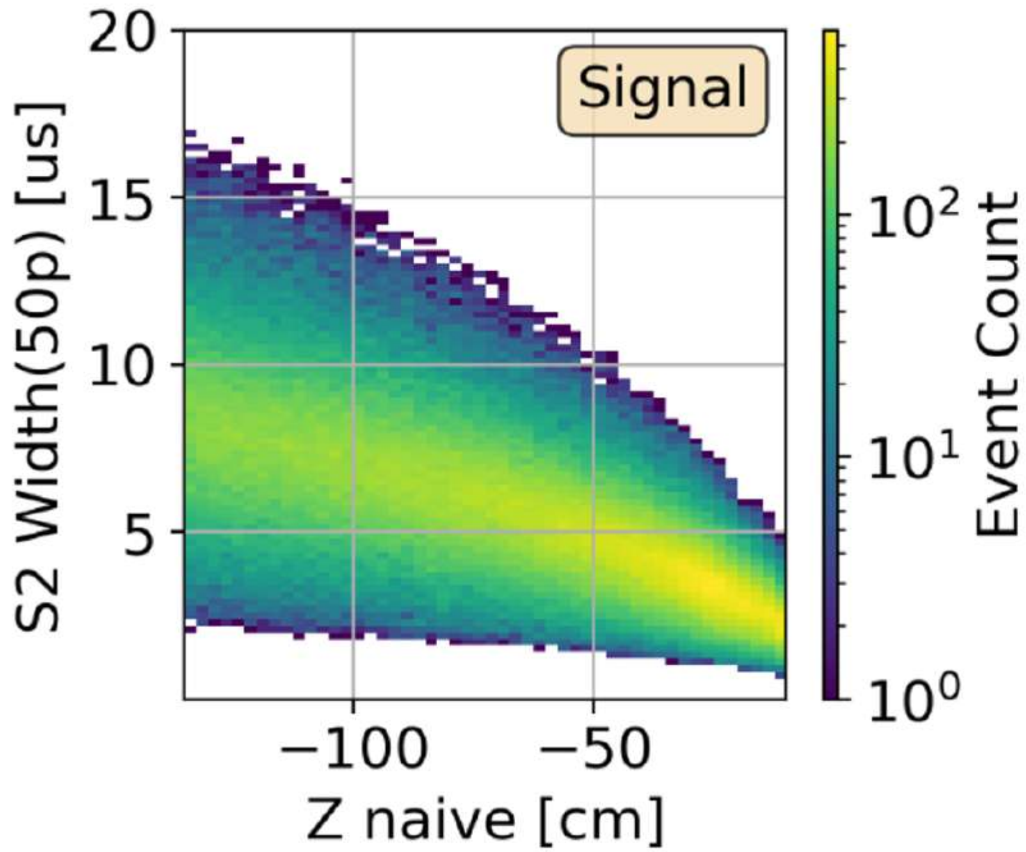
After these cuts, the isolated peaks are not as correlated to the primary S2s

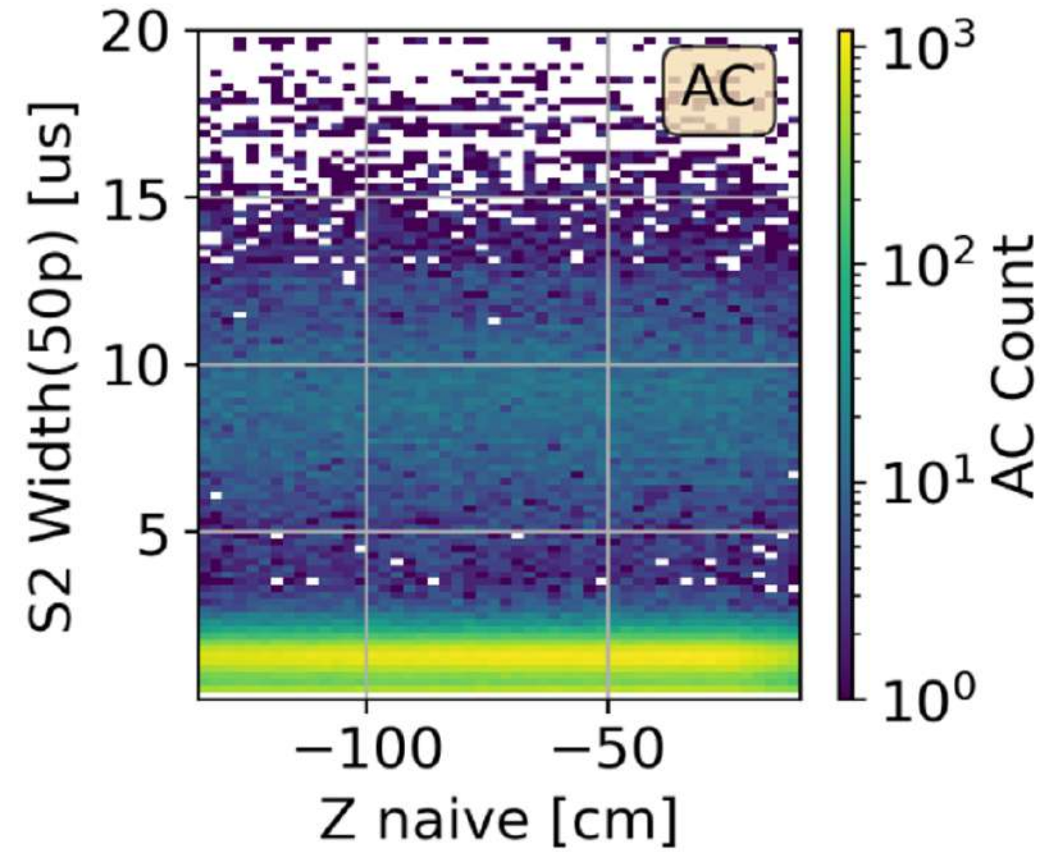
Accidental Coincidence Background

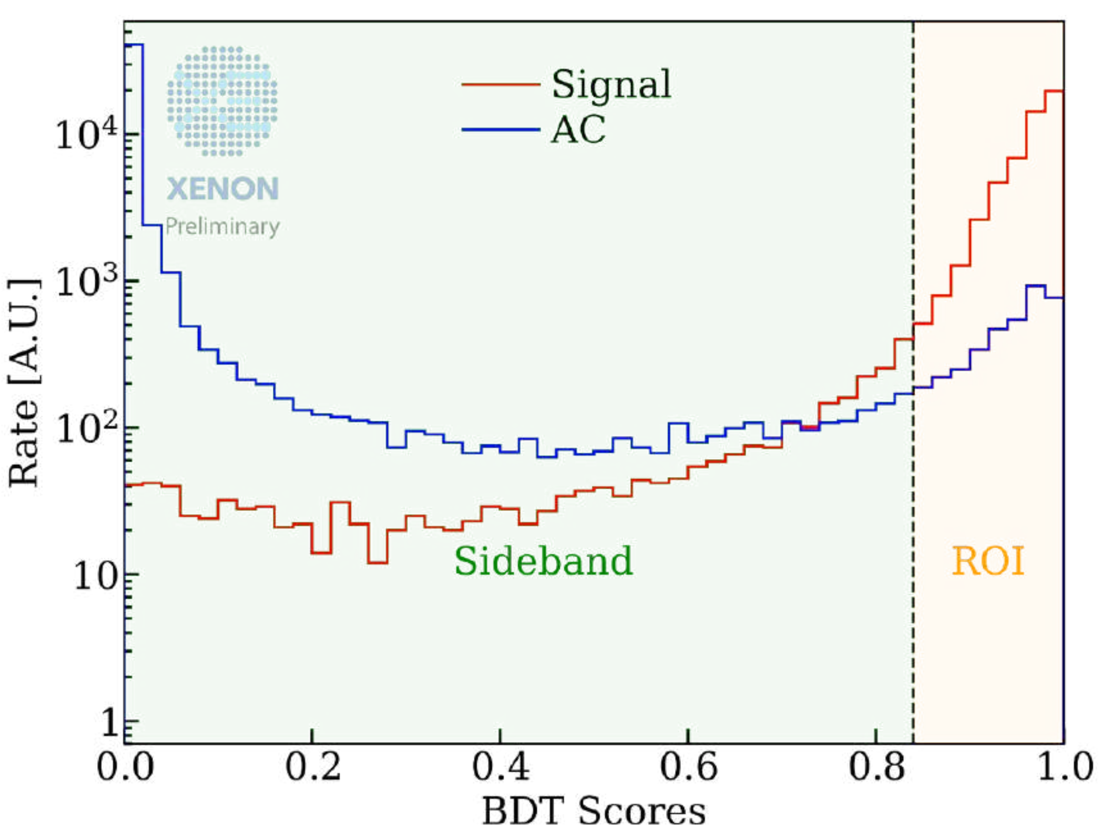


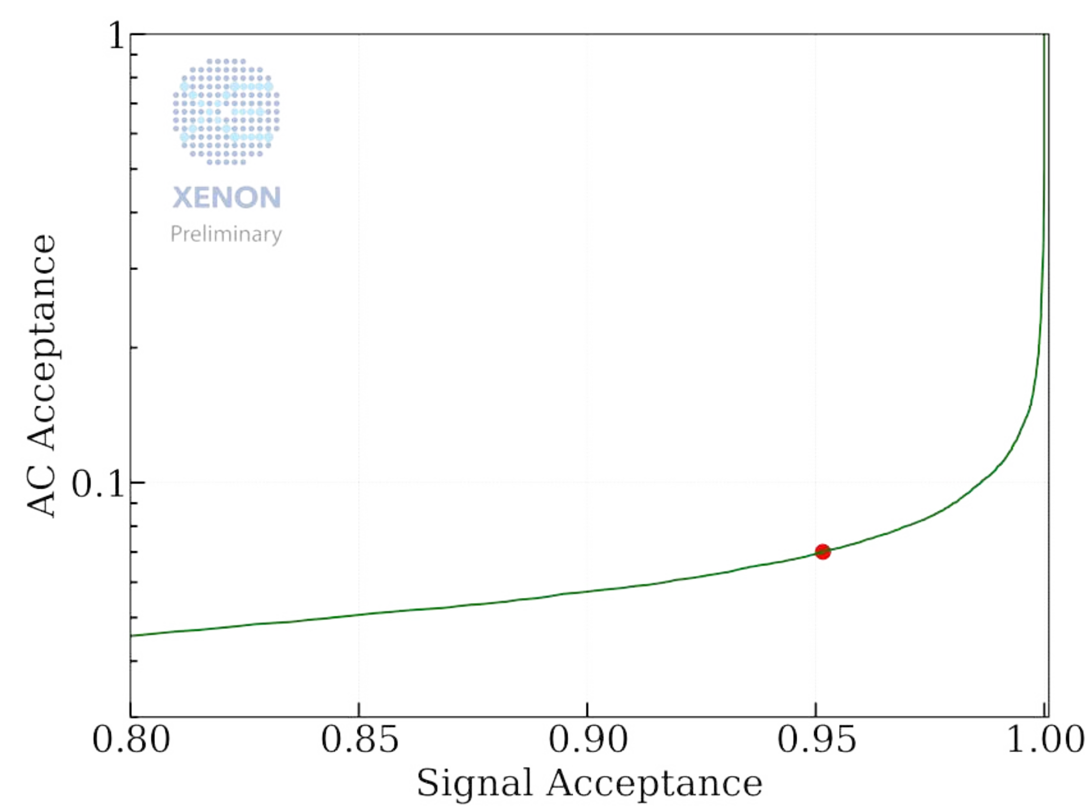
Exp	Isolated-S1 (Coin 2)	Isolated-S1 (Coin 3+)	Isolated-S2 (100-500 PE)	Max Drift	Relative Rate (Coin 2)
XENON1T	11.2 Hz	1.1 Hz	1.1 mHz	730 us	1
XENONnT	2.5 Hz	1.5 Hz	18.5 mHz	2200 us	>10

AC Suppression — S1 and S2 Correlations

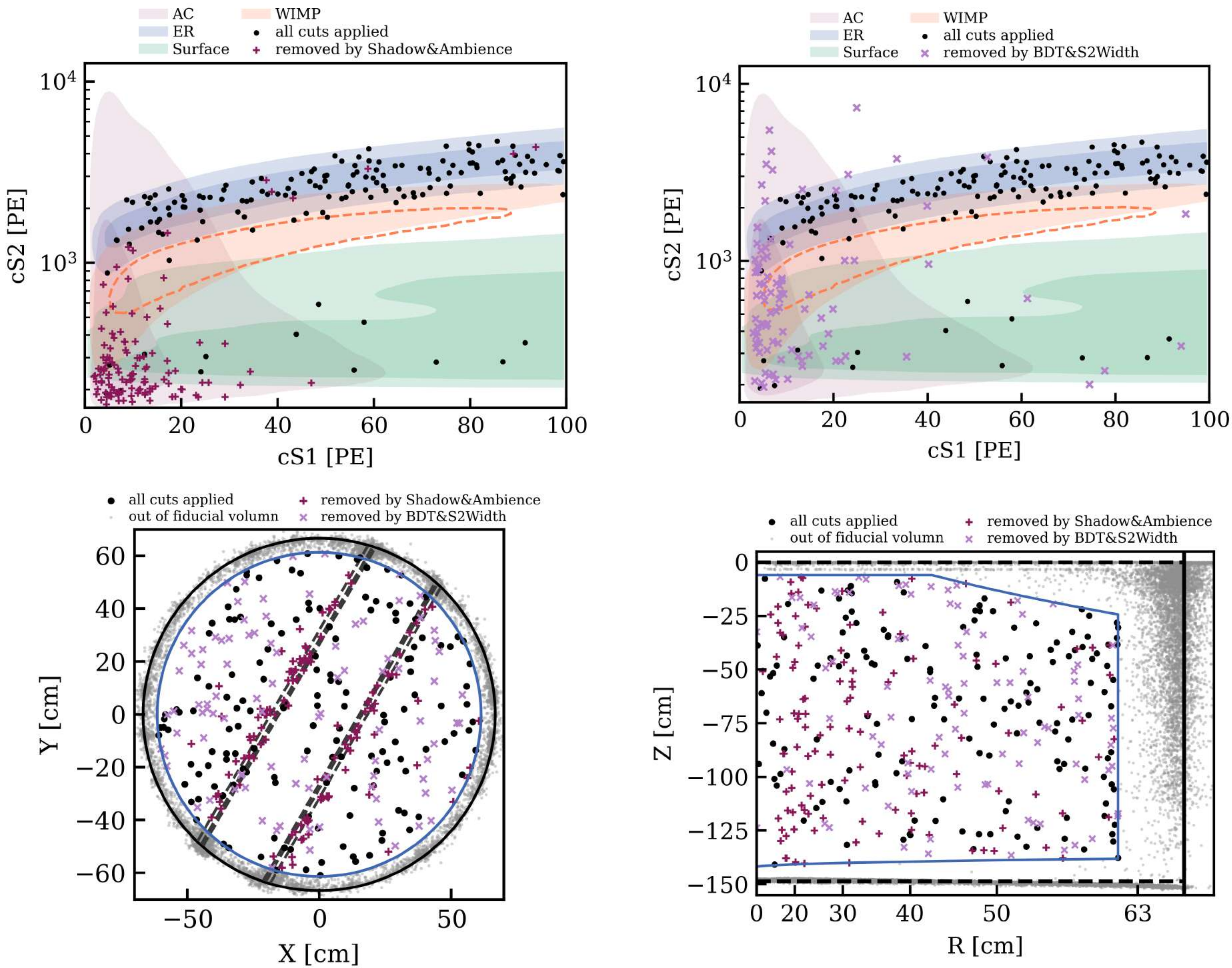




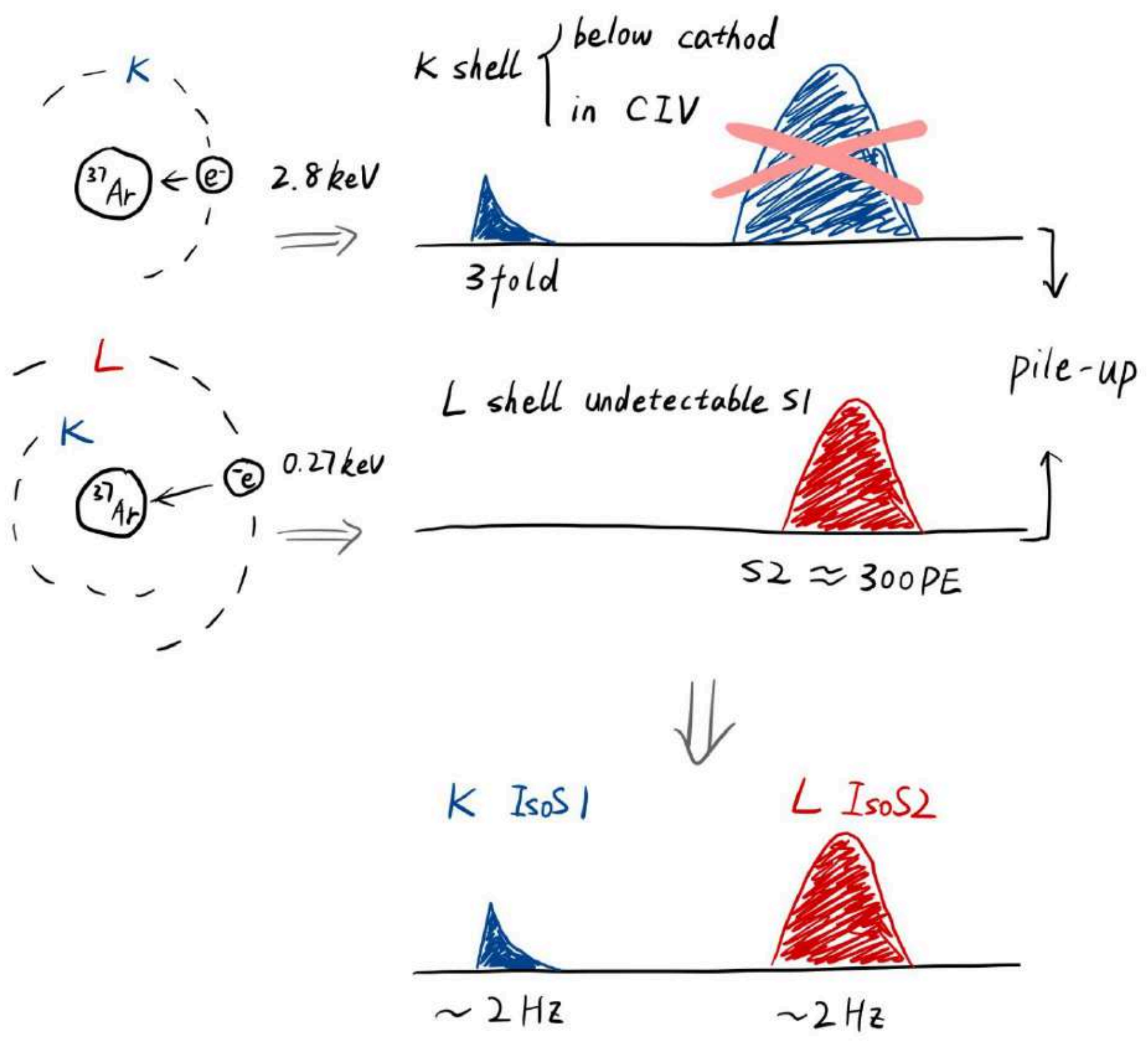




Impact of Anti-AC Cuts on WIMPs Search



Validation of AC Background



A Cartoon of an AC validation sample with ^{37}Ar calibration

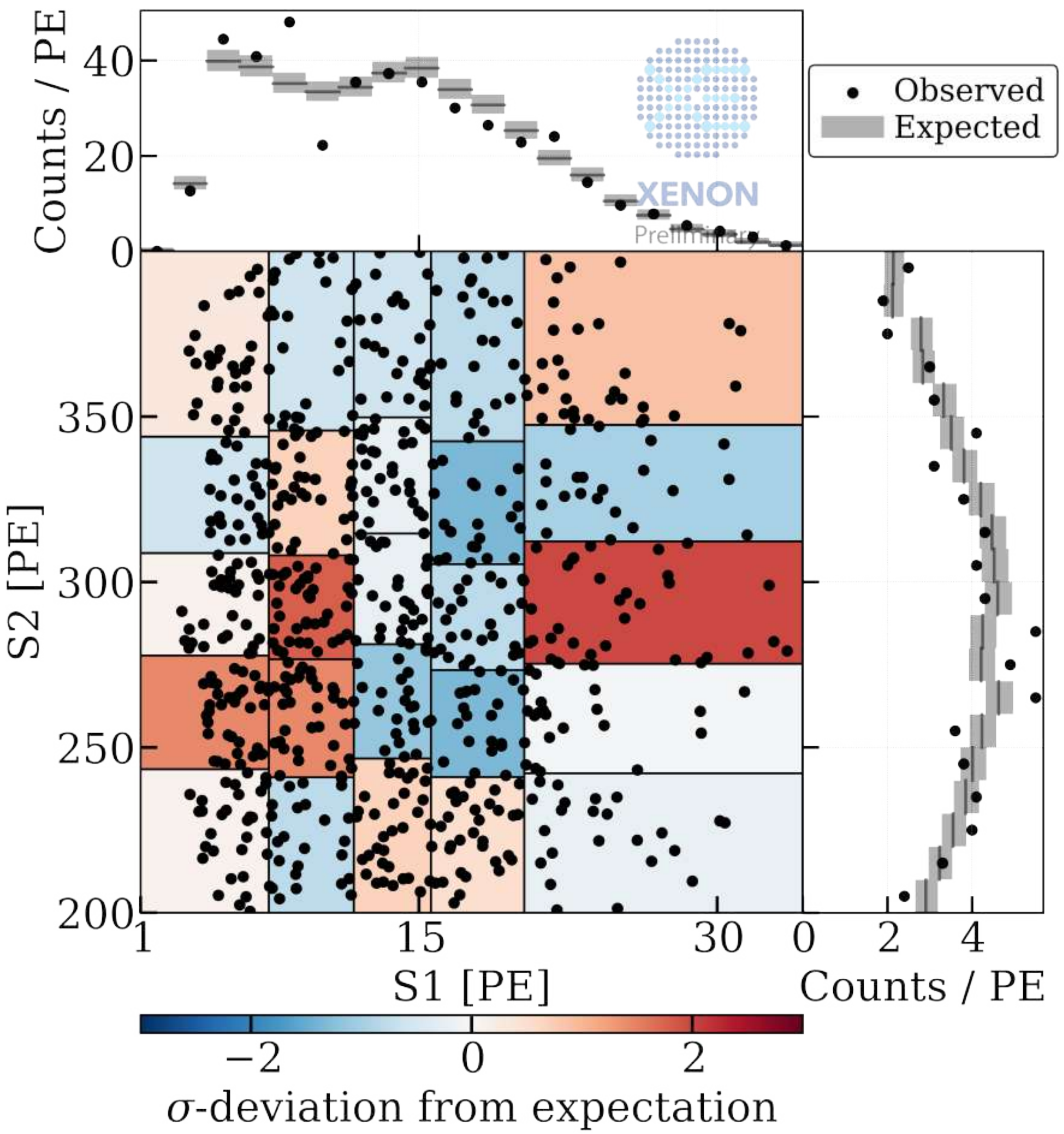
For Validation, AC background shall dominate in a data sample.

Achieved with dedicated samples:

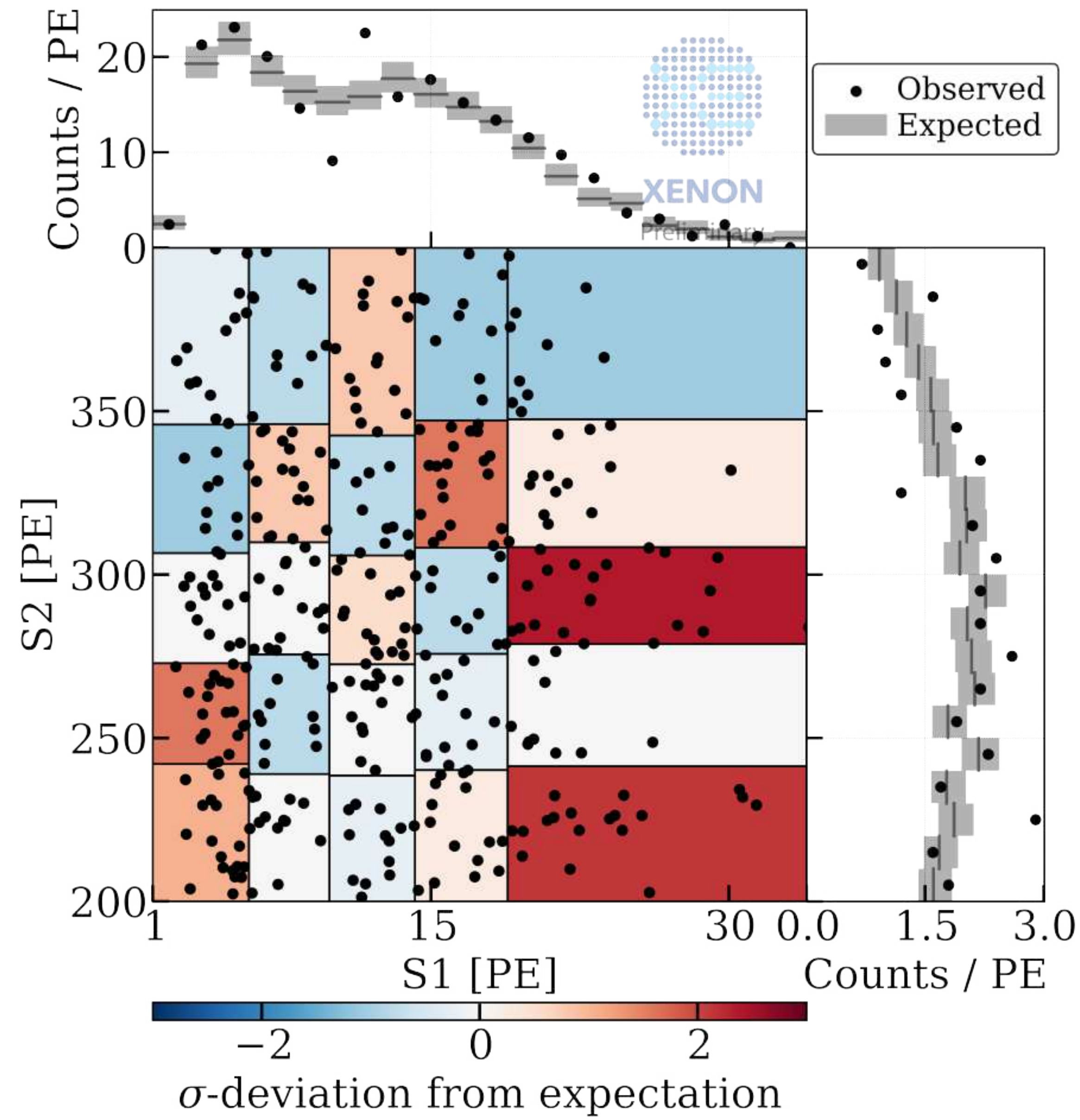
- Artificial long drift time
- S2 range (eg < 200PE)
- Events tagged by Anti-AC cuts (Sideband)
- …

Validation of AC Background (^{37}Ar)

S2 range: 200-400 PE



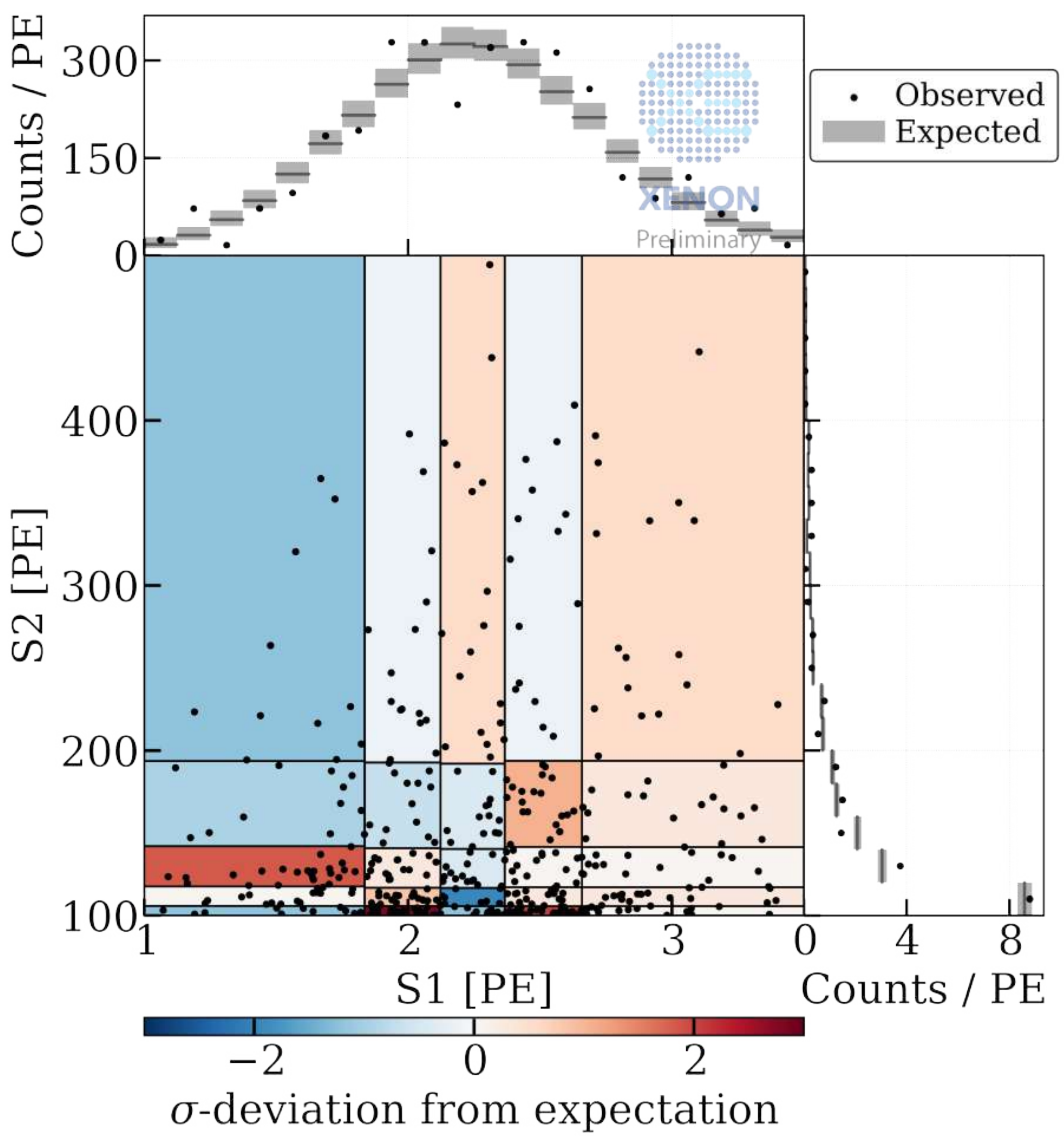
Sideband



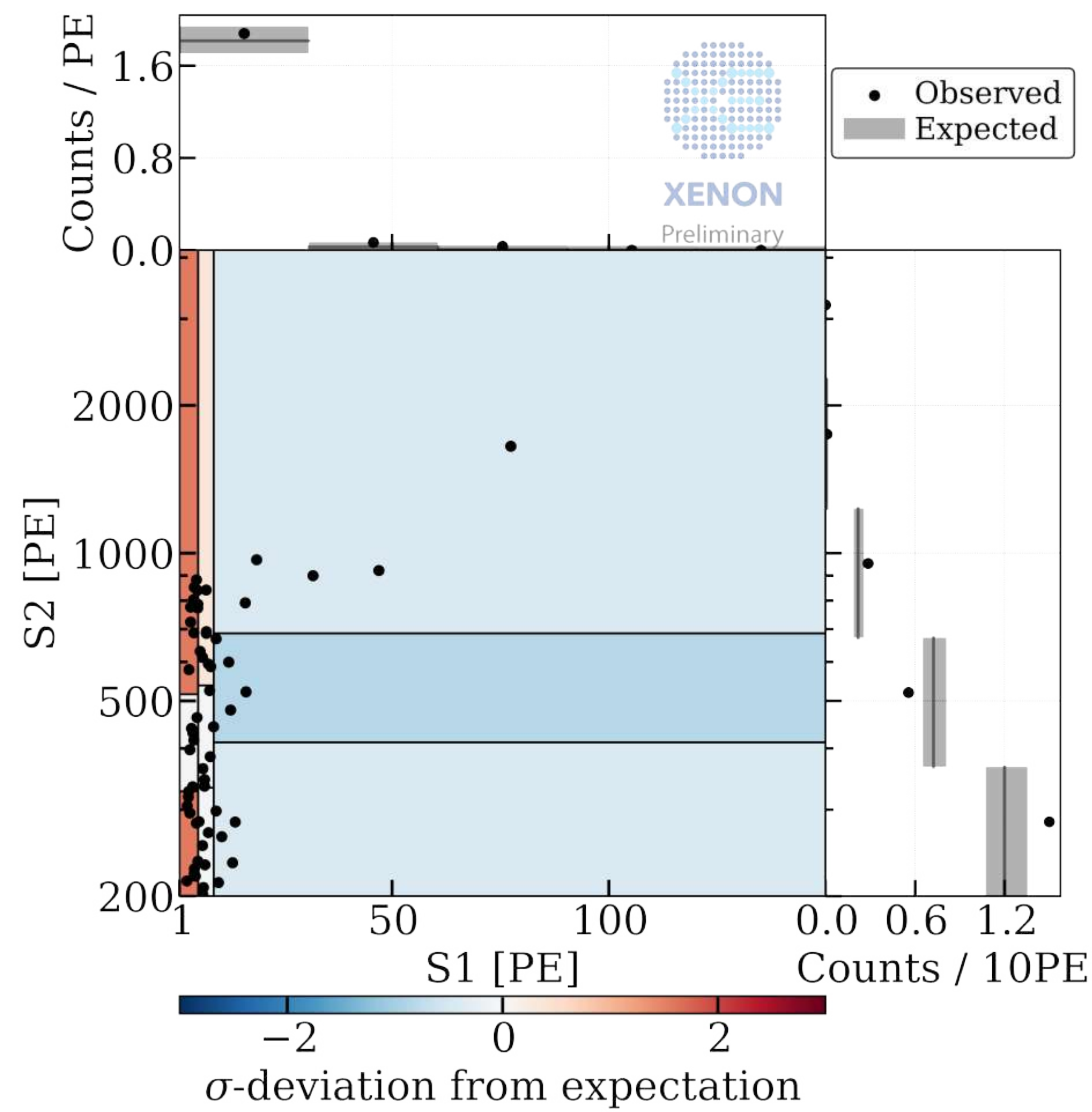
AC background prediction is validated with precission bettern than 5%!

Validation of AC Background

^{220}Rn



Background - Sideband



AC background prediction is validated with precission bettern than 20%!

A few comments on AC Background

AC background is becoming more and more complicated in large LXeTPCs.

- Complicated nature (competing peaks/environments) -> simple calculation doesn’t work, modeling is very time consupming.
- Need to understand the correlation between peaks -> Hardware high energy veto can not be applied -> data rate/storage challenge
- Hard to model when density of SEs is too high -> low background/calibration rate

AC is currently a data-driven background model.

- Needs special attention against mismodeling!
- Can hardly be predicted before experiment is built -> need to understand its origin better for a G3 LXeTPC

R&D effort might be especially difficult!

Search for ^{8}B CEνNS with XENON1T

$$R = \phi(\nu) \times \sigma_\nu \times N_{Xe} \times \text{exposure}$$
$$\simeq 600\,\text{events}/(\text{tonne} \times \text{year})$$

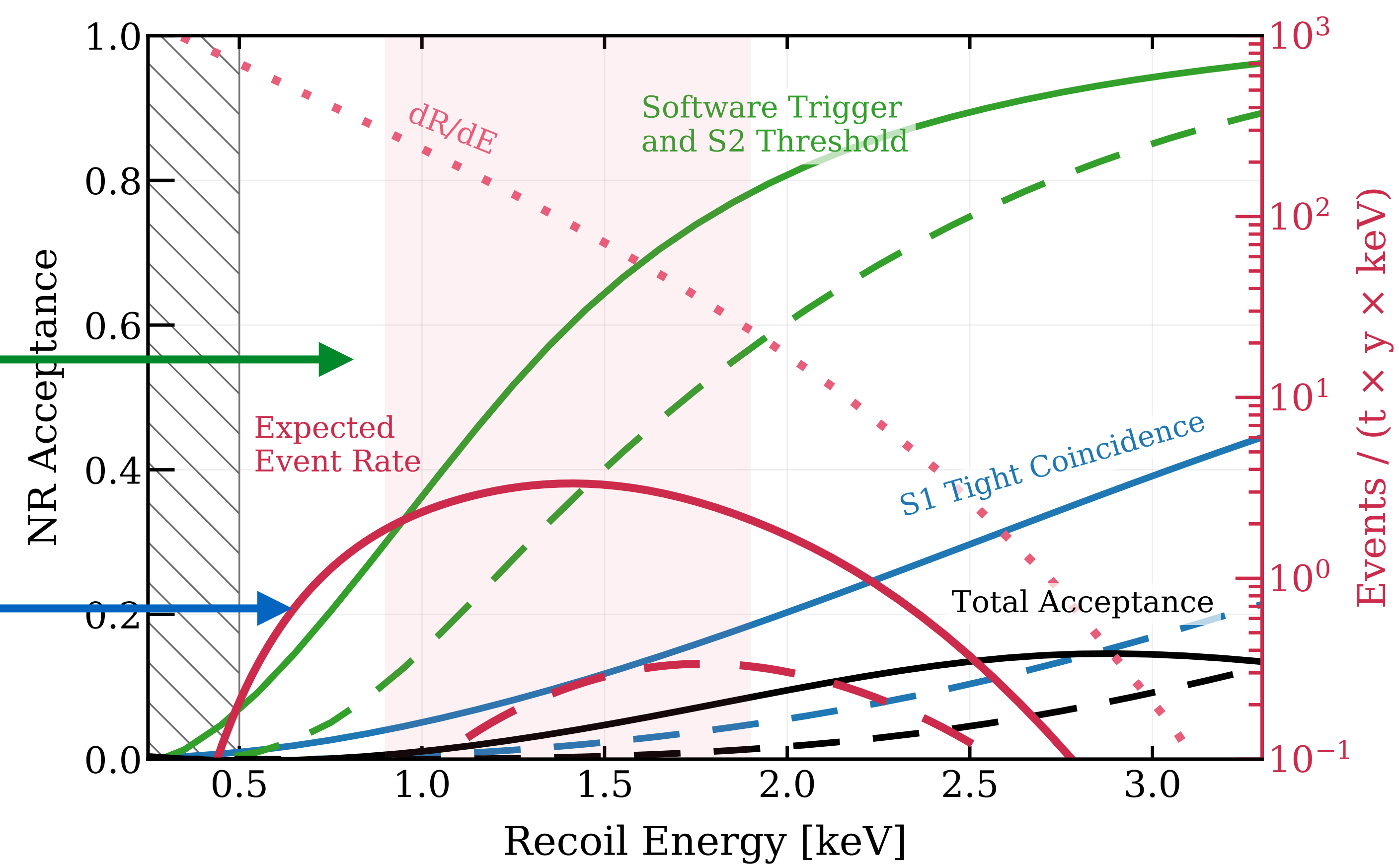
Source	1.3 t	1.3 t, NR Ref.
ER	627 ± 18	1.6 ± 0.3
Radiogenic	1.4 ± 0.7	0.8 ± 0.4
CEνNS	**0.05 ± 0.01**	0.03 ± 0.01
Accidental	$0.5\ ^{+0.3}_{-0.0}$	$0.10\ ^{+0.06}_{-0.00}$
Surface	106 ± 8	4.8 ± 0.4
Total	735 ± 20	7.4 ± 0.6

PRL 126, 091301 (2021)

Can we increase the detection efficiency to ~1%? o(5) CEνNS

S2 threshold: S2 > ~~200~~ 120PE

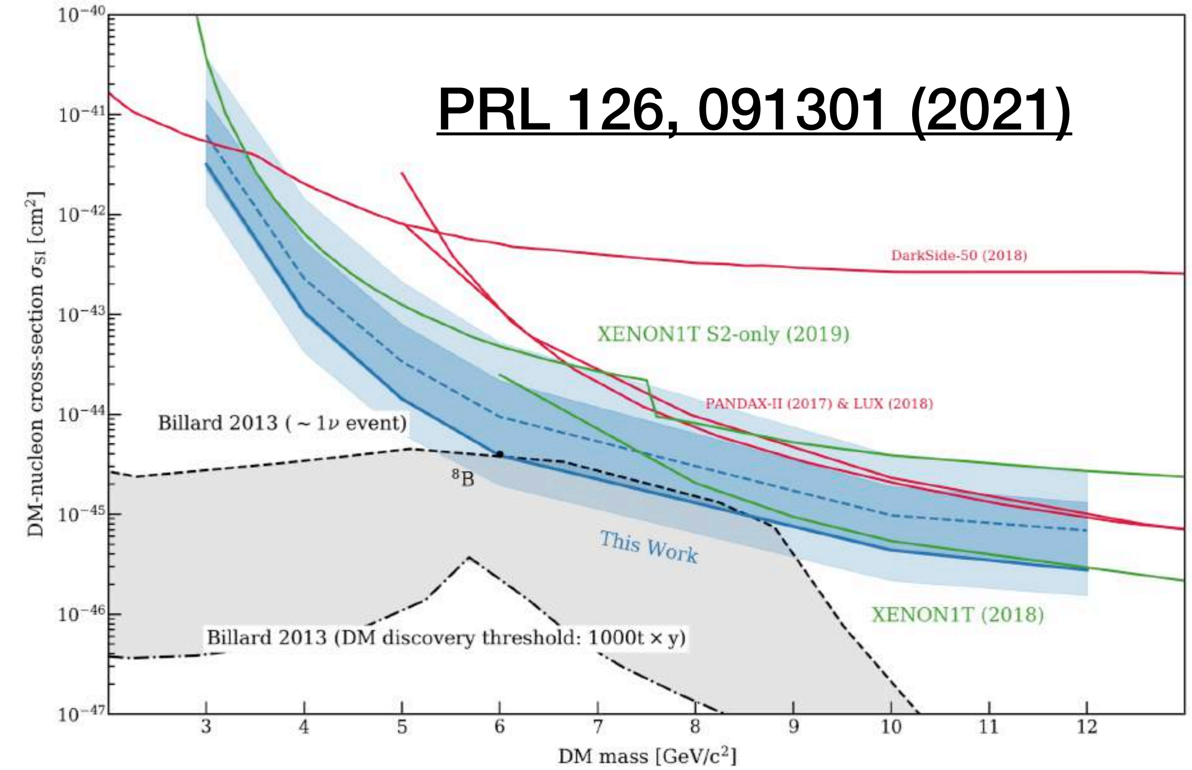
S1 threshold: ~~Three~~ Two PMTs coincidence



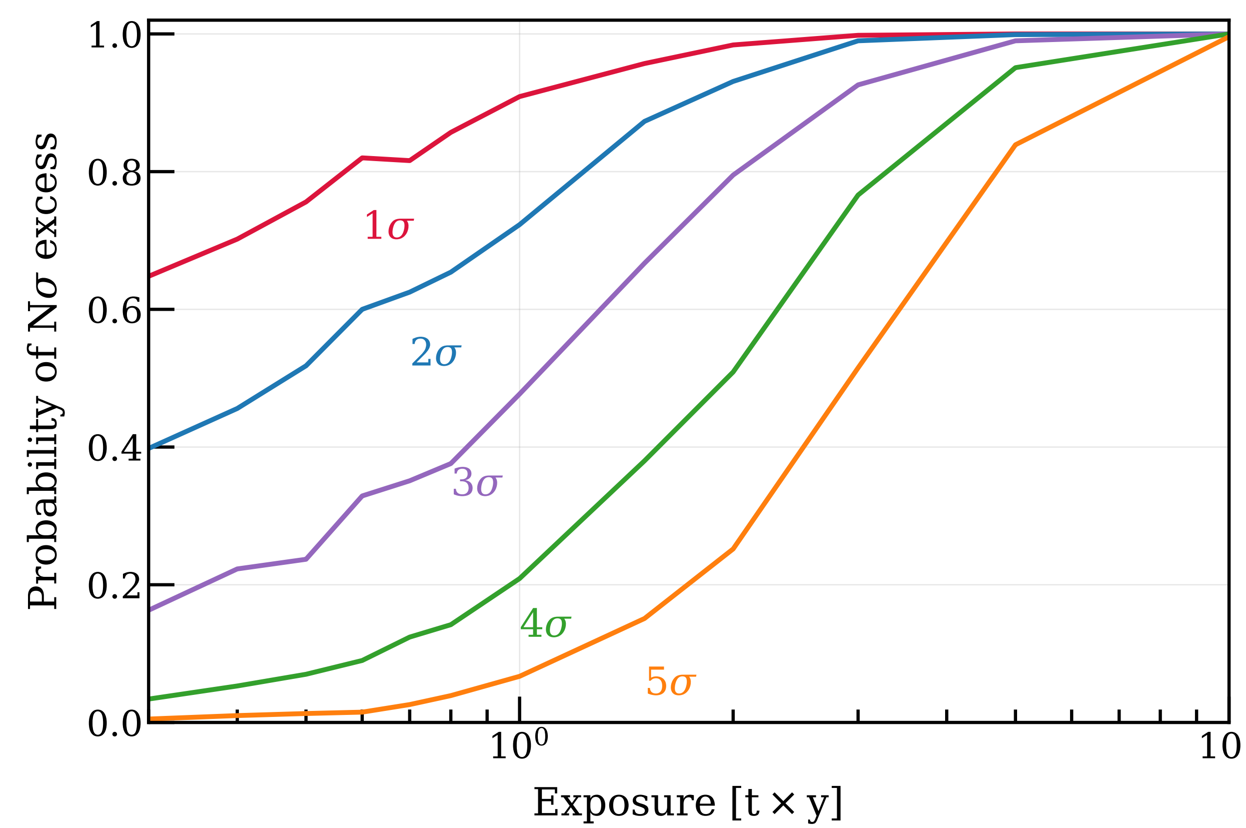
Search for ^{8}B CEvNS with XENON1T

Analysis ROI

- S1: 2 or 3 hits
- S2: 120 - 500 PE
- 0.6 t-y of exposure -> significantly improved in XENONnT



Source	Expectation
CEvNS	**2.11**
Accidental	5.14
ER	0.21
Radiogenic	0.03
Total	7.65
Observed	6



We aim to make the signal to background ratio in XENONnT comparable to XENON1T, and observe the ^{8}B CEvNS with a larger exposure!

Summary

- The S2-only background is a limiting factor for light DM search. However, we don’t have a full picture of it yet.
- The Accidental Coincidence background can be modeled well in a data-driven way but still with challenges
- The key problem is how to project these backgrounds for a G3 LXeTPC, thus we cannot assure its reduction.
- But, we cannot simply wait to see it either.

Thanks for your attention!

http://xenonexperiment.org

The XENON Collaboration

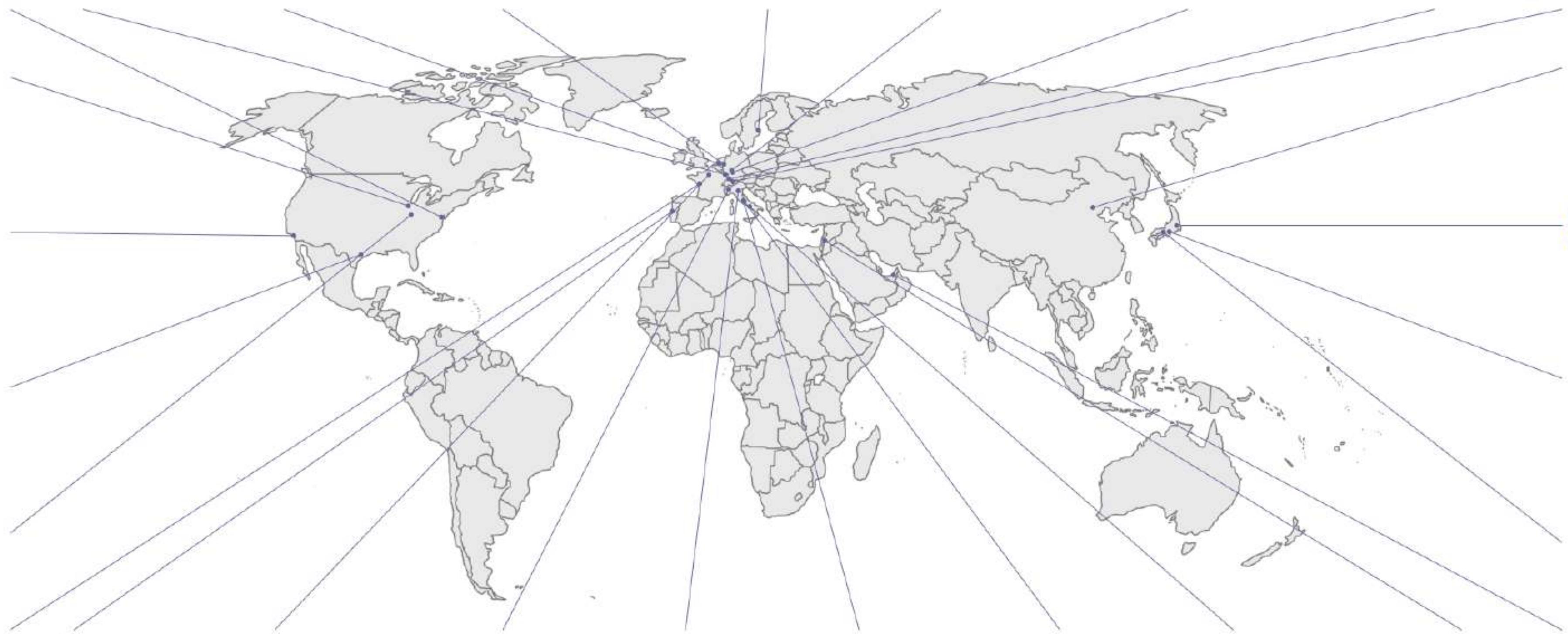
Columbia | KIT | Nikhef | Muenster | Stockholm | Mainz | MPIK, Heidelberg | Freiburg | Zurich

Chicago

Tsinghua

UCSD

Tokyo



Rice

Nagoya

Purdue

Kobe

Subatech | Coimbra | LPNHE | Torino | Bologna | L'Aquila | LNGS | Napoli | Weizmann | NYUAD