XENON

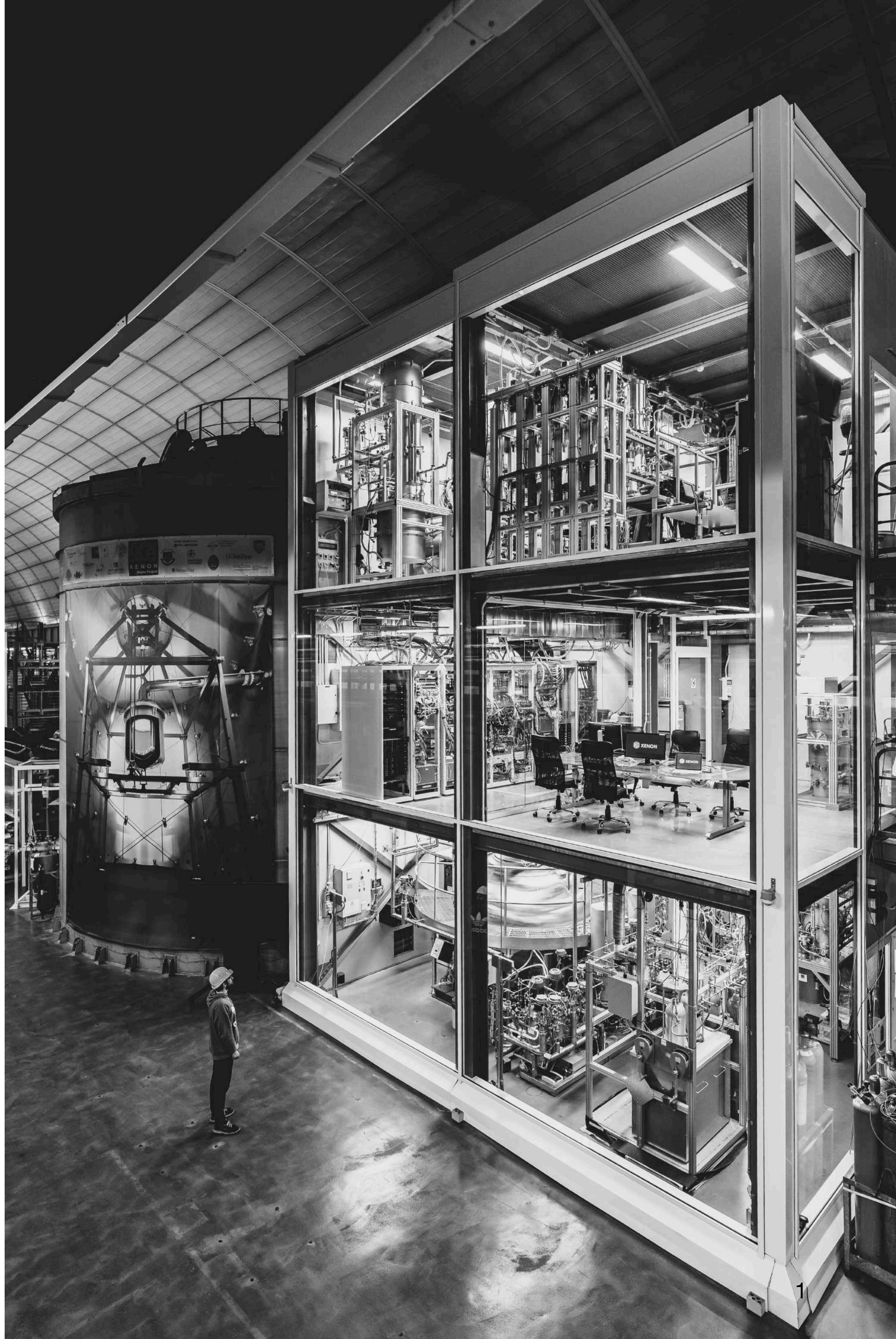
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

First Measurement of Solar ^{8}B Neutrinos via Coherent Elastic Neutrino-Nucleus Scattering with XENONnT

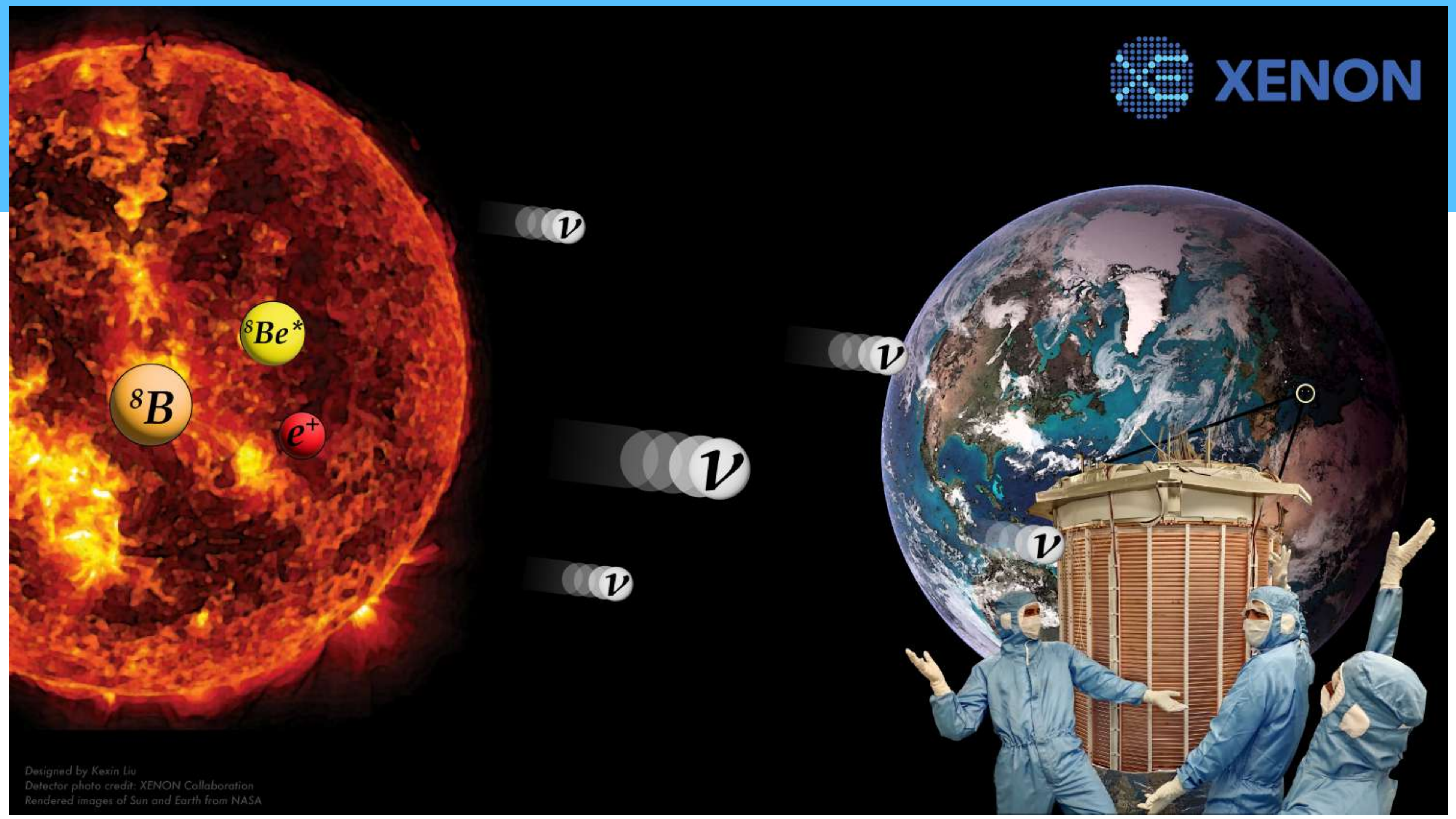
arXiv 2408.02877

Dacheng Xu
Columbia University

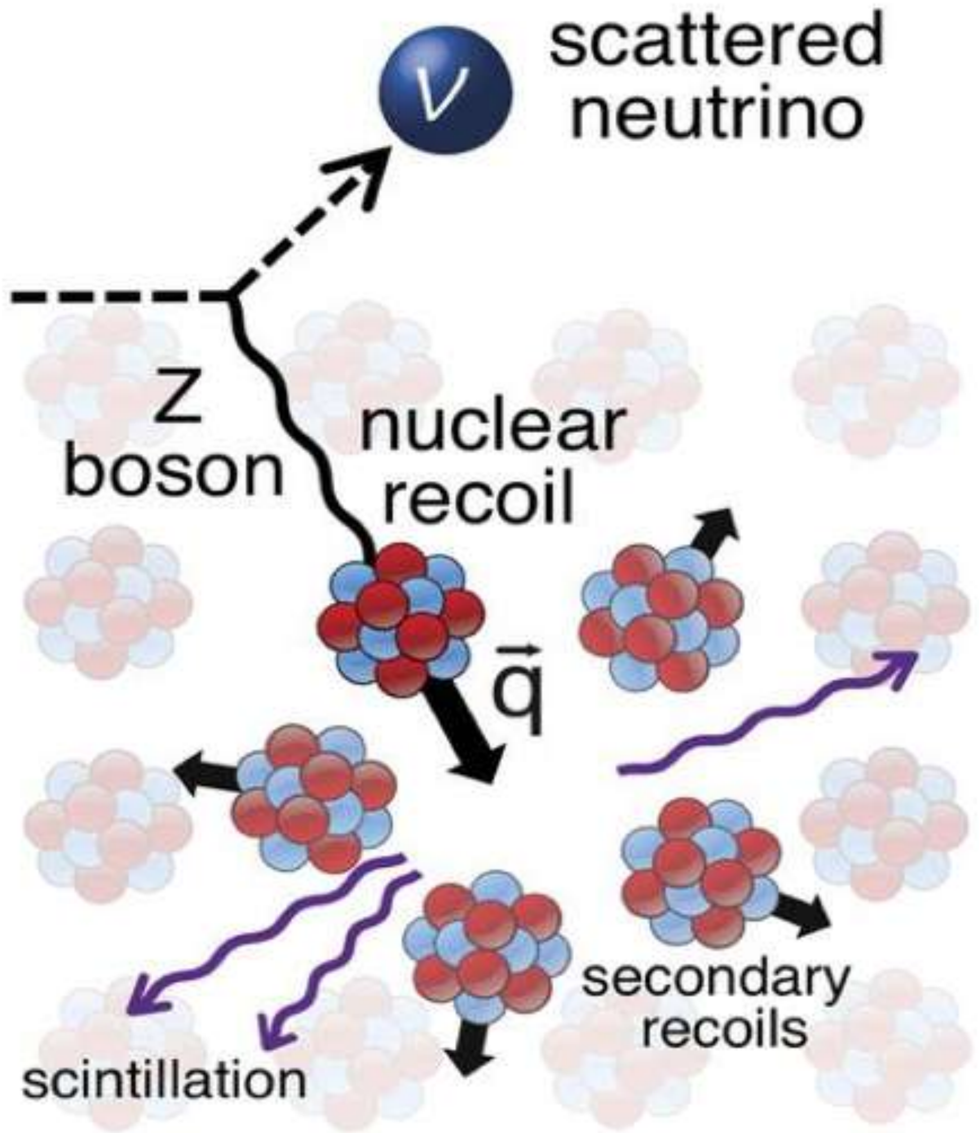
Blois 2024, October 24th



Neutrino Fog

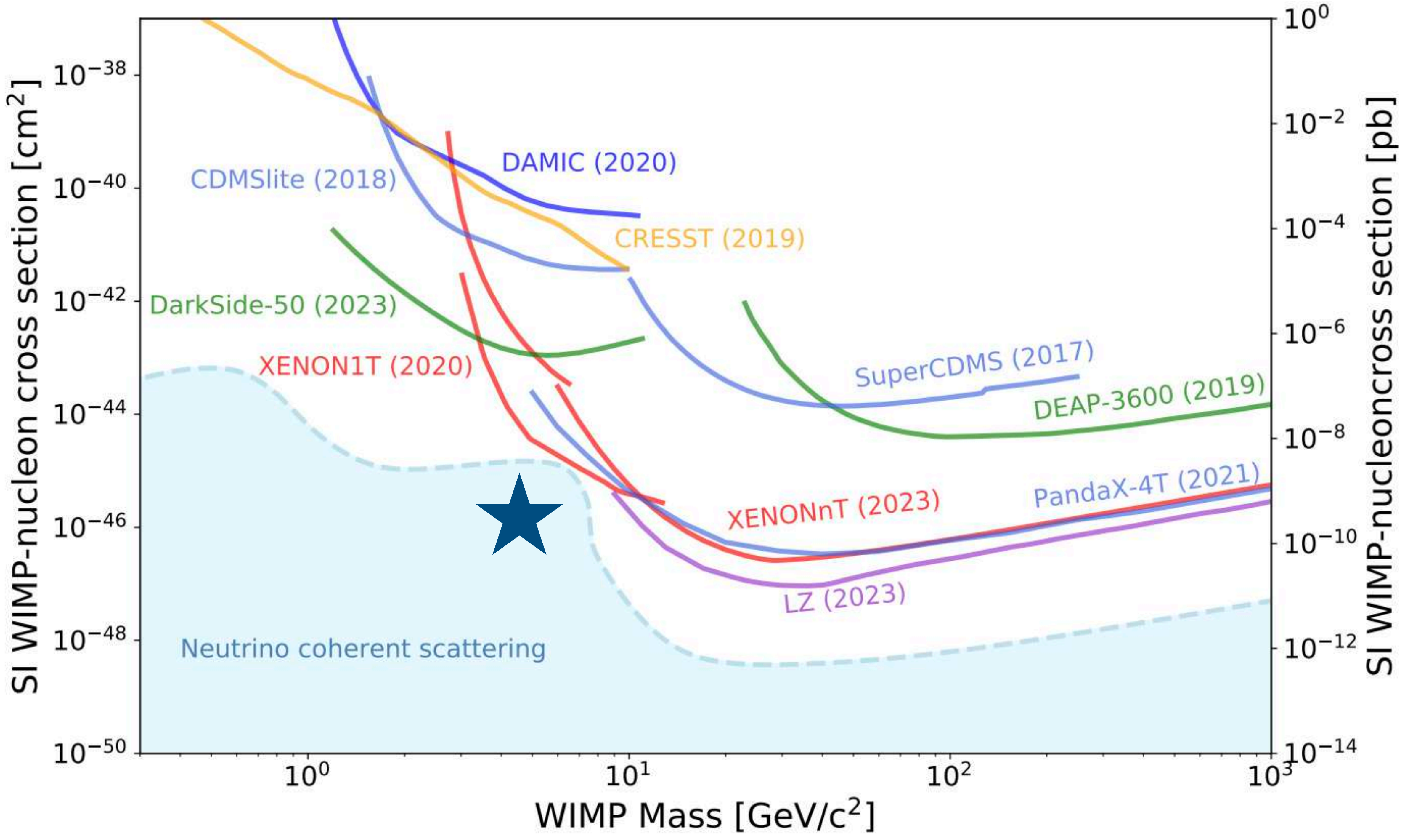


- Solar neutrino is the unavoidable background for DM
- First step into the "neutrino fog"



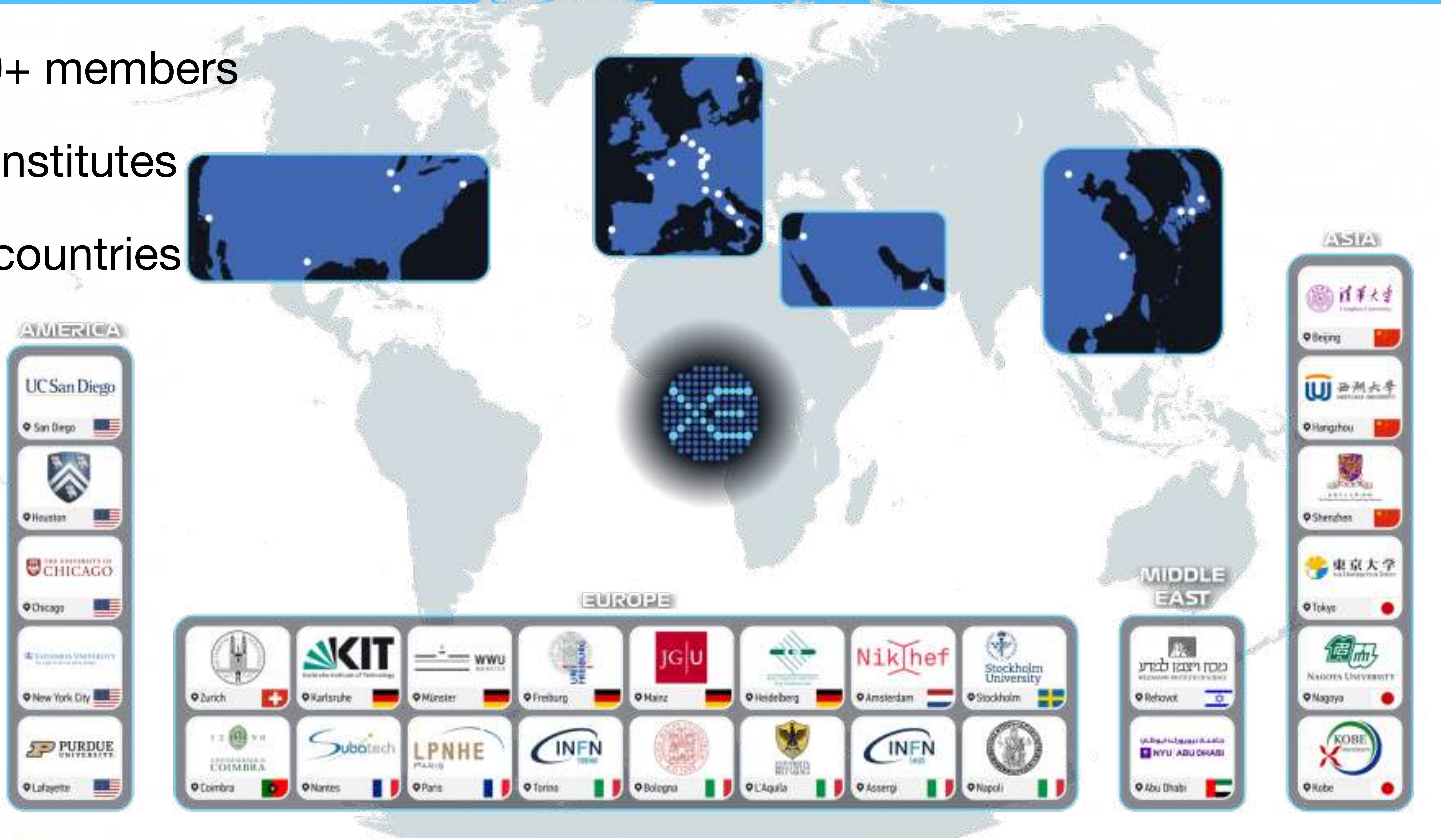
Coherent elastic neutrino-nucleus scattering (CEvNS)

D. Akimov et al, Science 357 (2017)



XENON Collaboration

- 200+ members
- 29 institutes
- 12 countries



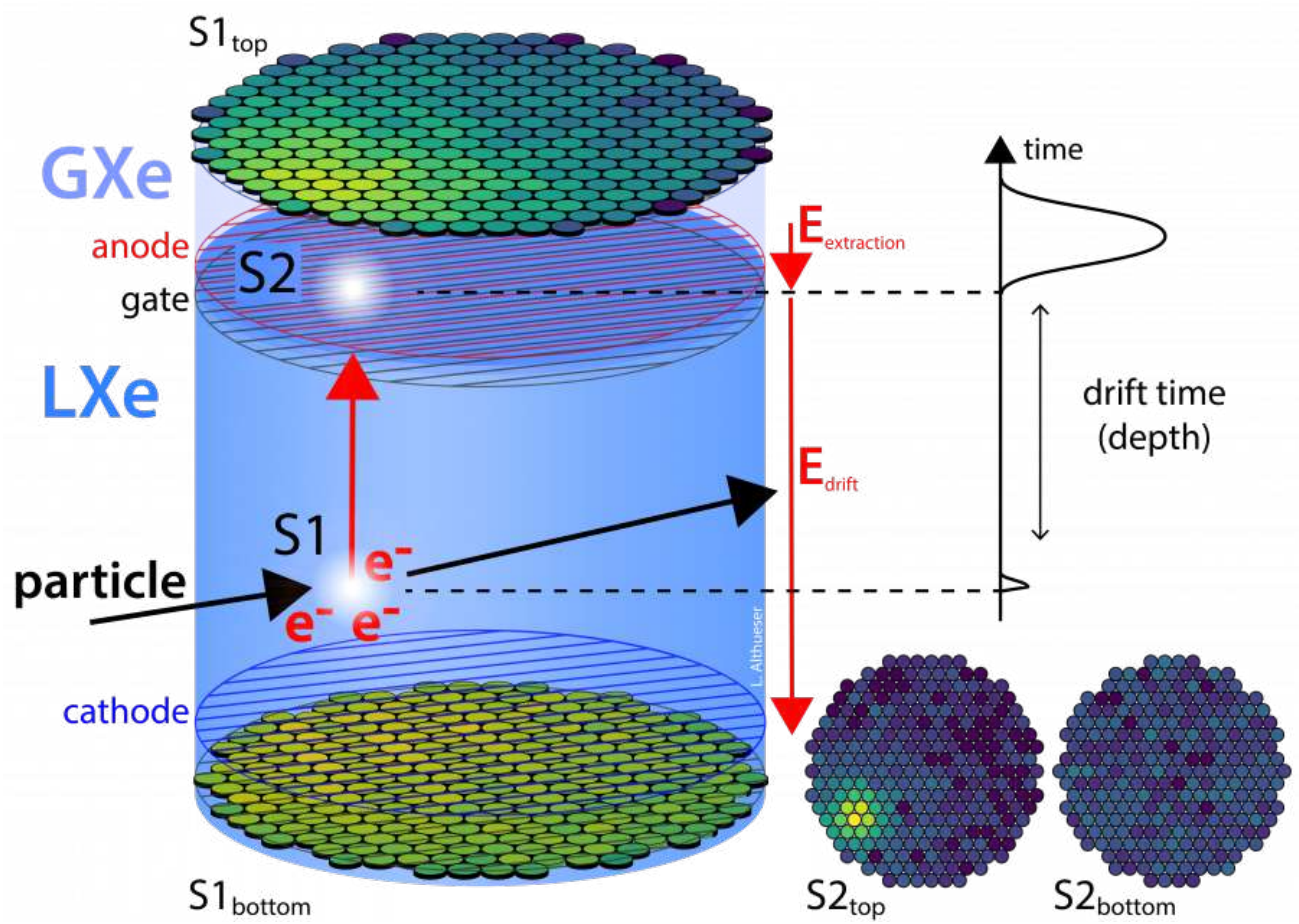
Content - Physics result & technical improvement

- Introduction
  - The XENONnT experiment, detector characteristic
- Signal & Background
  - Calibration in low energy nuclear recoil
  - Background: Accidental Coincidence, ER, Neutron, Surface
- Inference and Result

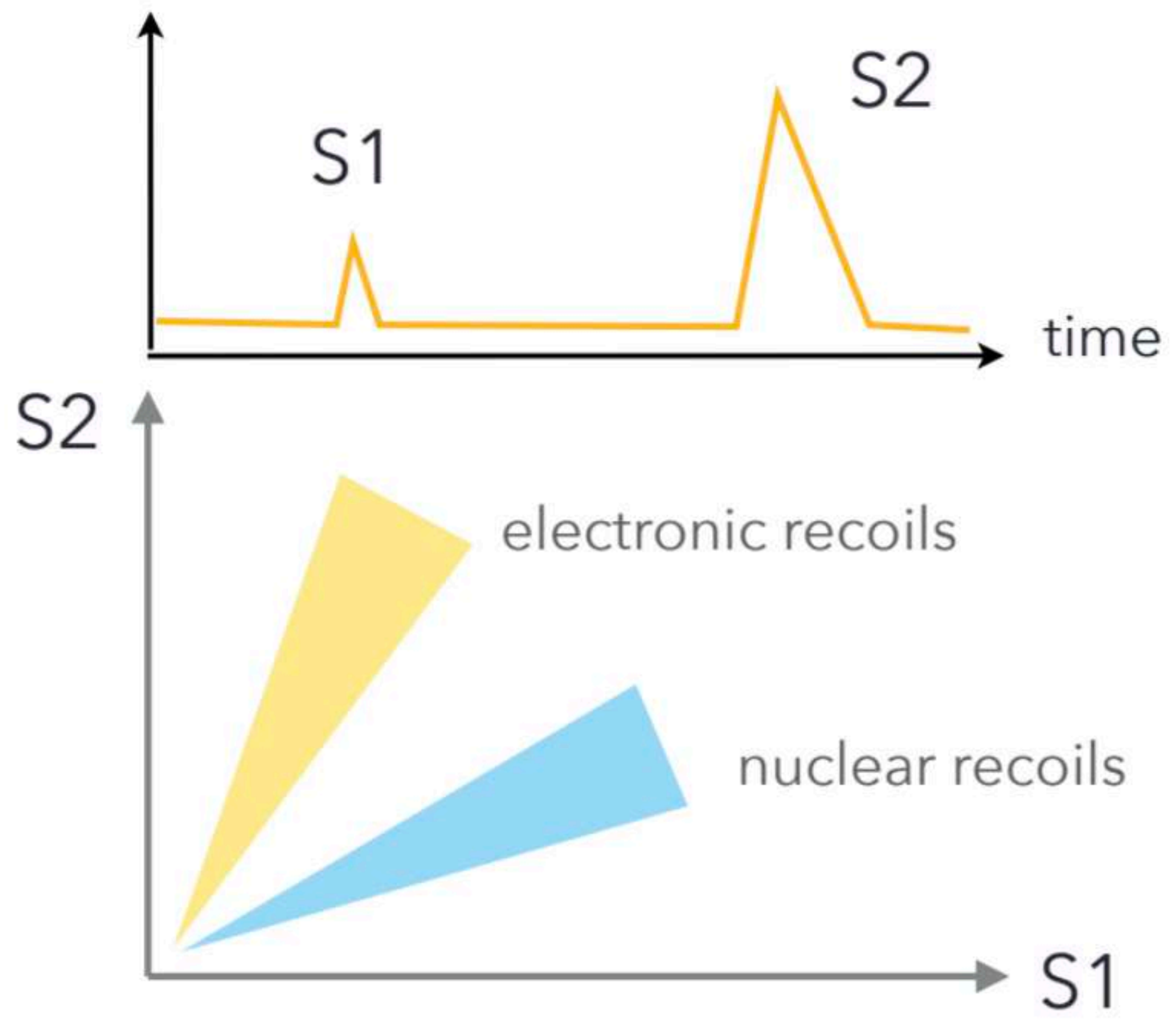
Please also see the talk by Jaron Grigat!
(https://indico.cern.ch/event/1335188/contributions/6177615/)

XENON Detector Principle

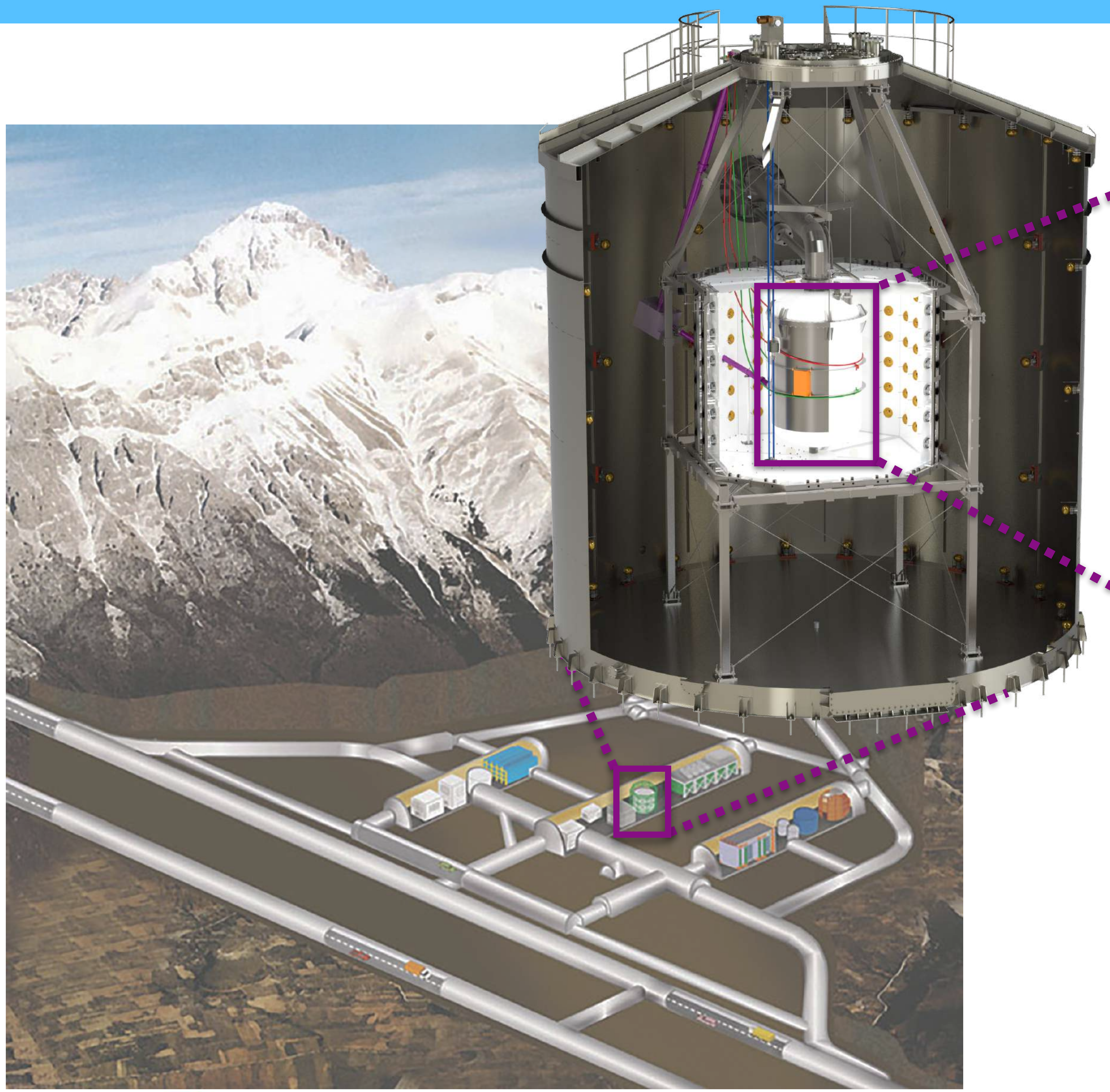
Two-Phase LXe Time Projection Chamber(TPC)



- 3D position resolution via light(S1) and charge(S2) signals
- S1/S2 depends on particle type
- Fiducialization



XENONnT Under the Gran Sasso

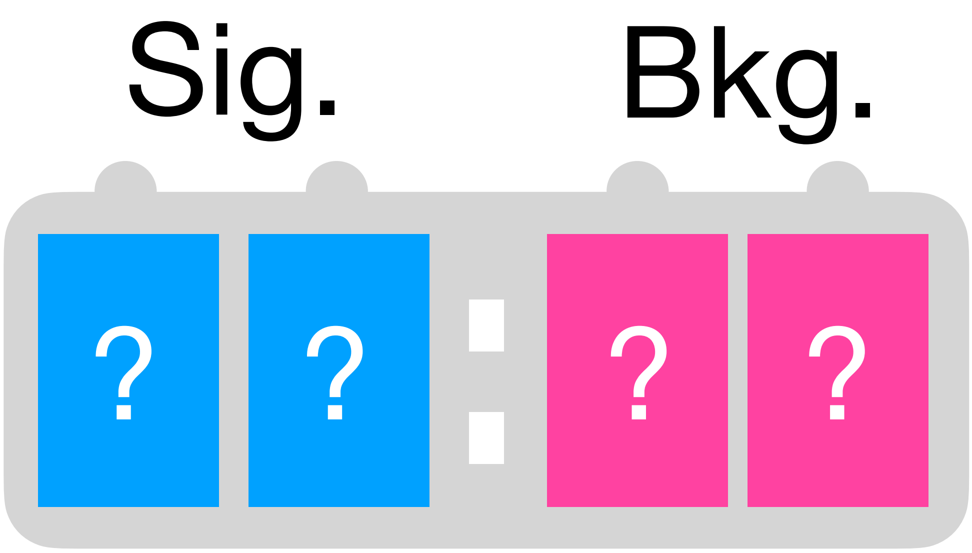


Drift Length	Diameter	Sensitive Target	Drift Field
1.5 m	1.32 m	5.9 tonne	23 V/cm

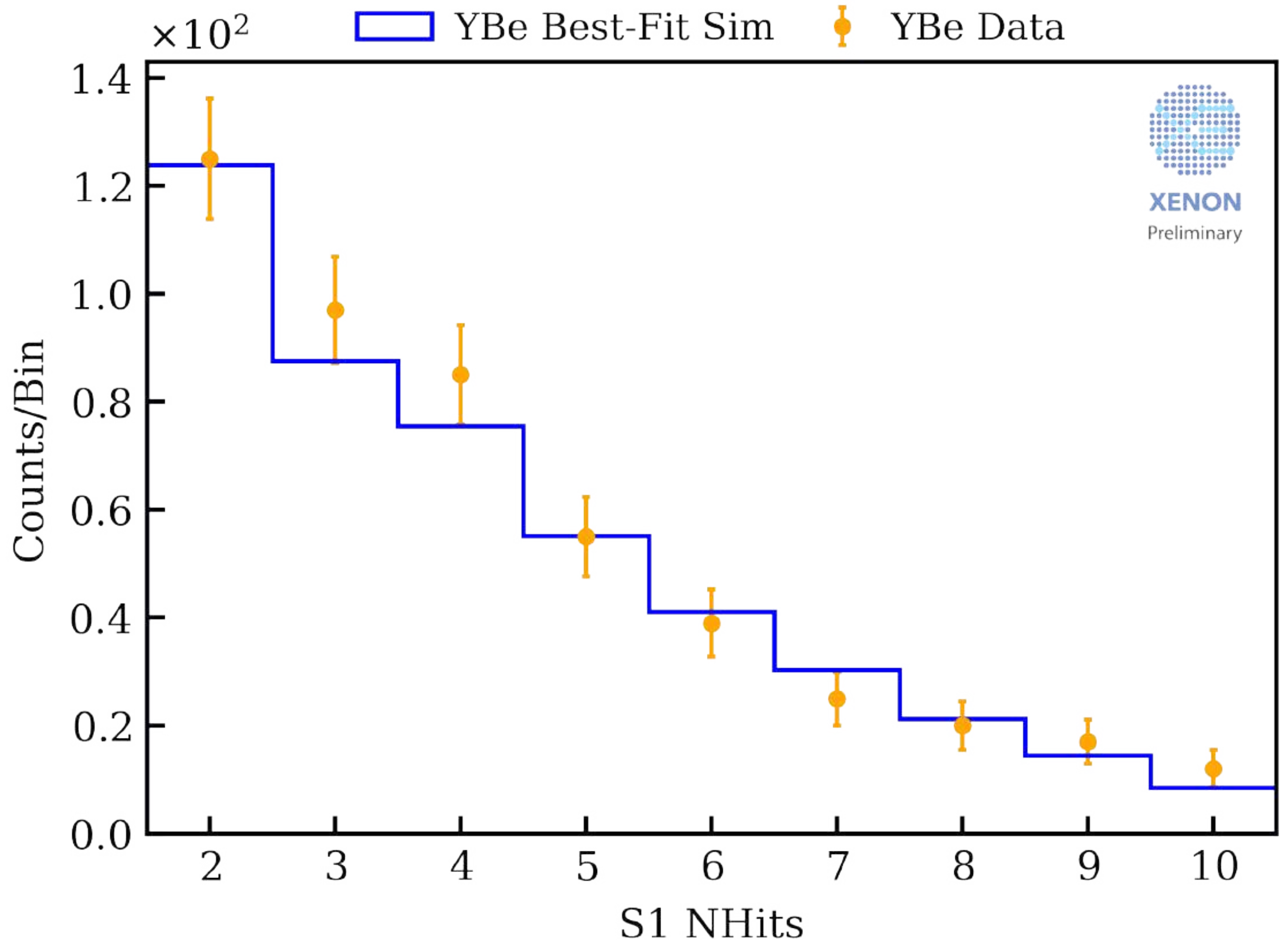
Eur. Phys. J. C 84, 784 (2024)

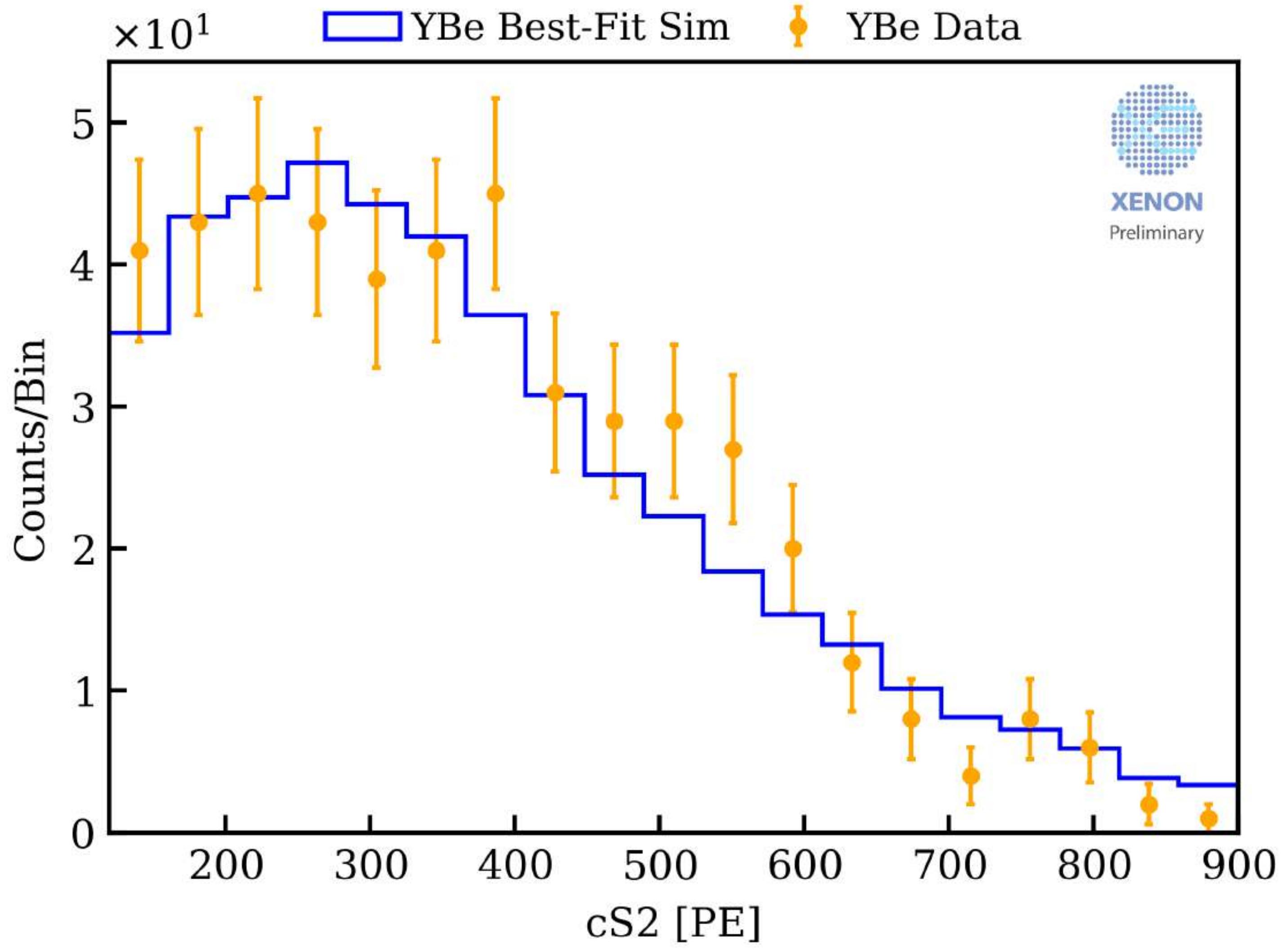
Signal & Background

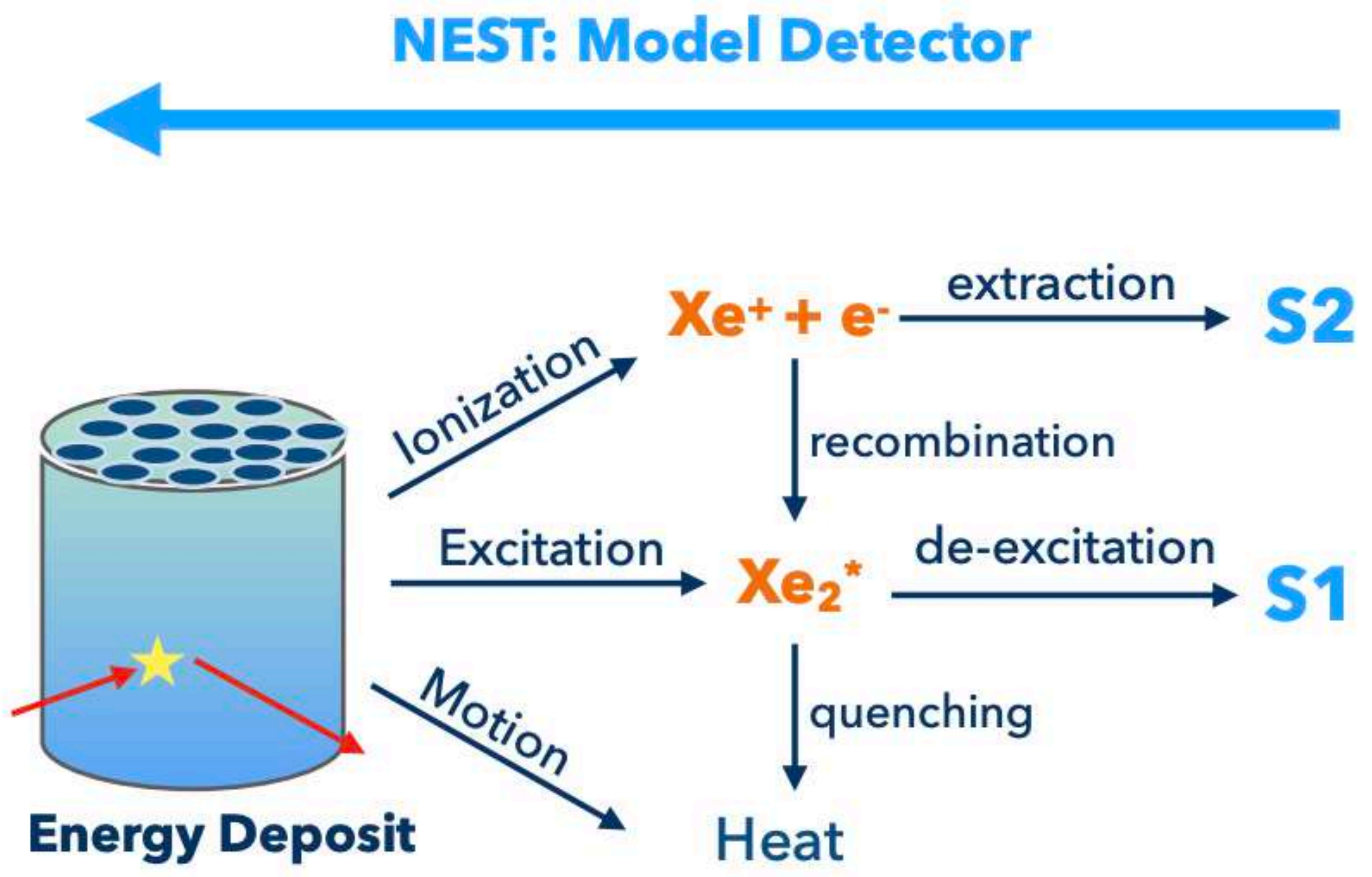
- Discovery significance ~ $S/\sqrt{B}$

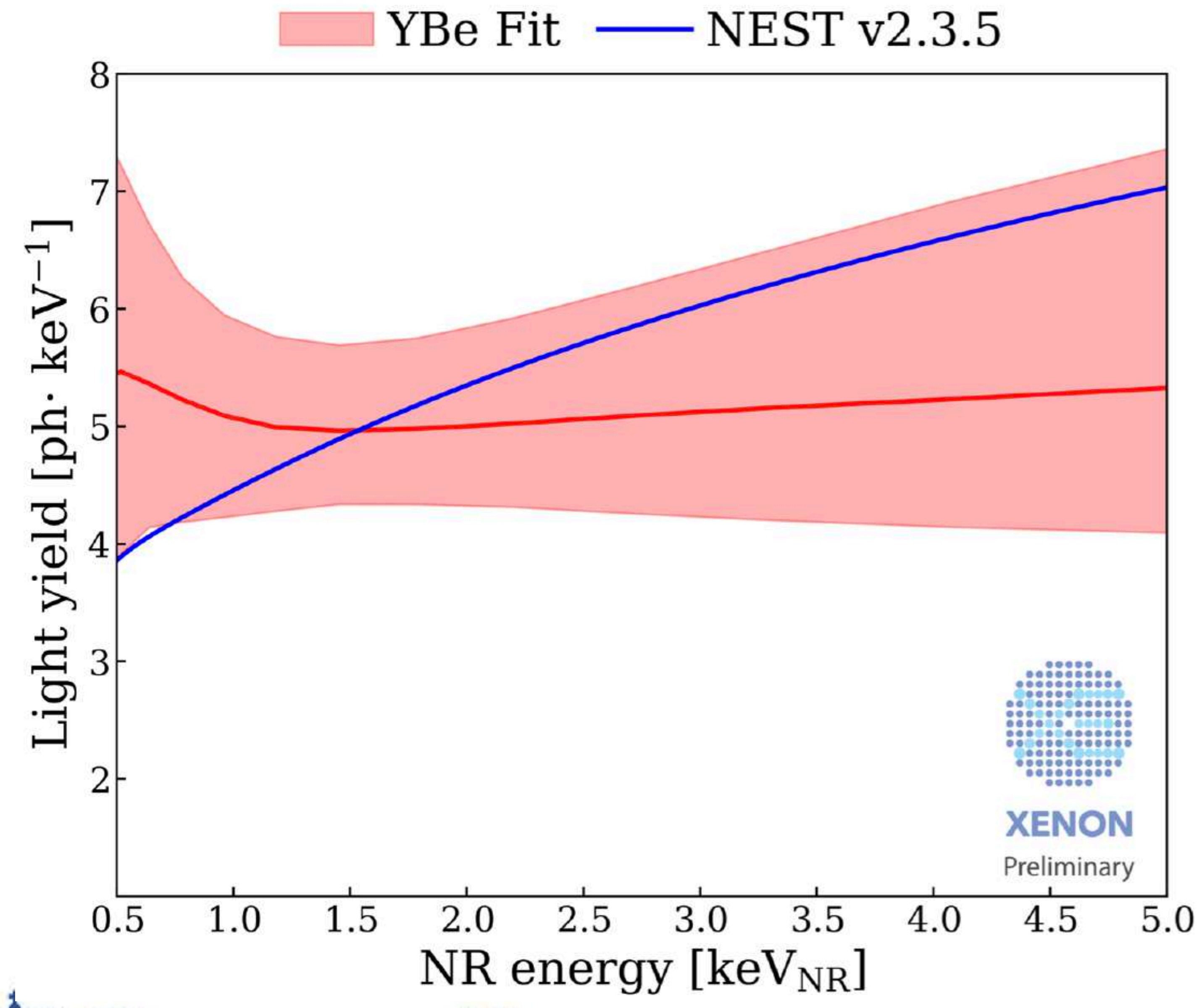


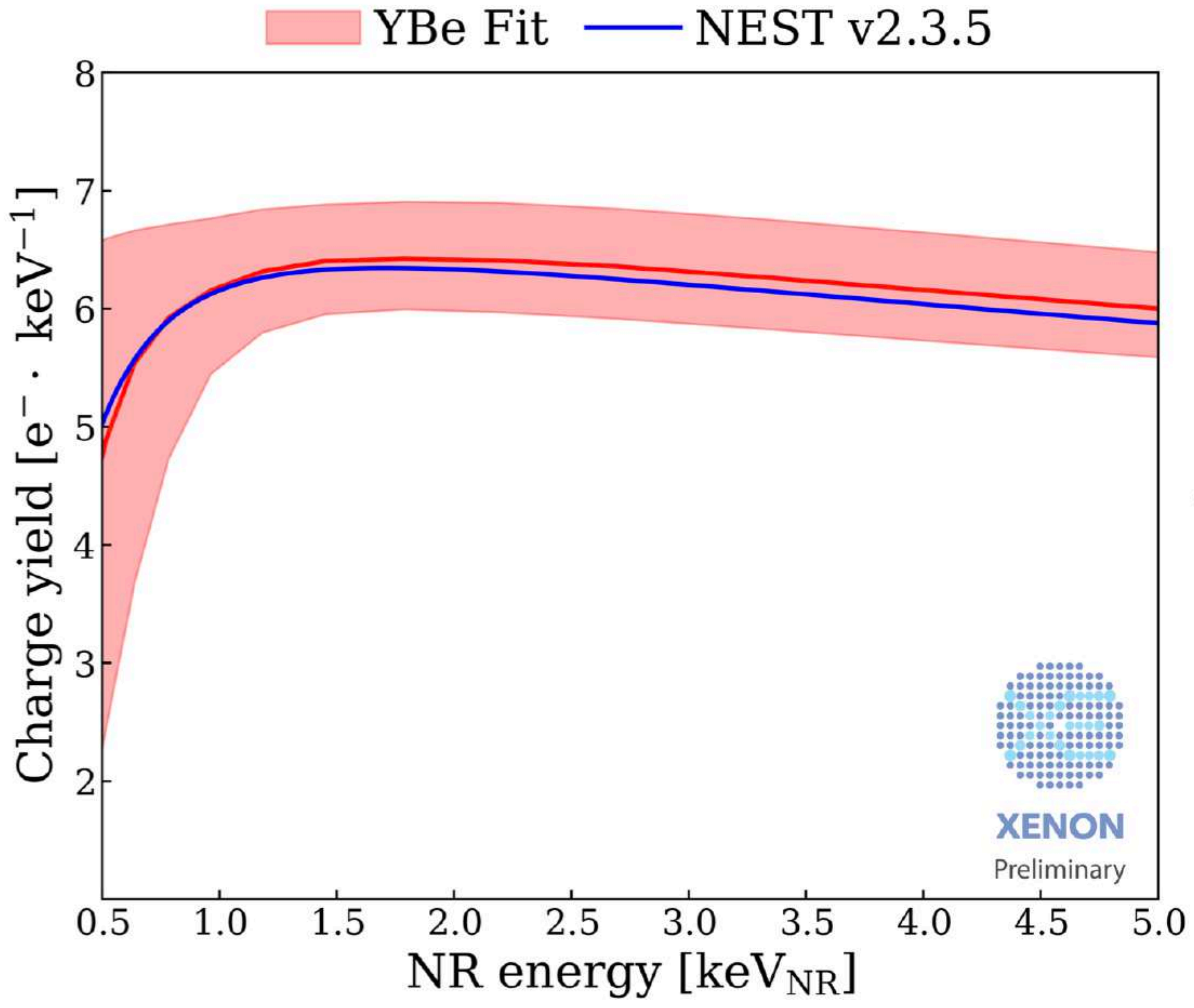
Calibration with Neutron Source: ^{88}YBe





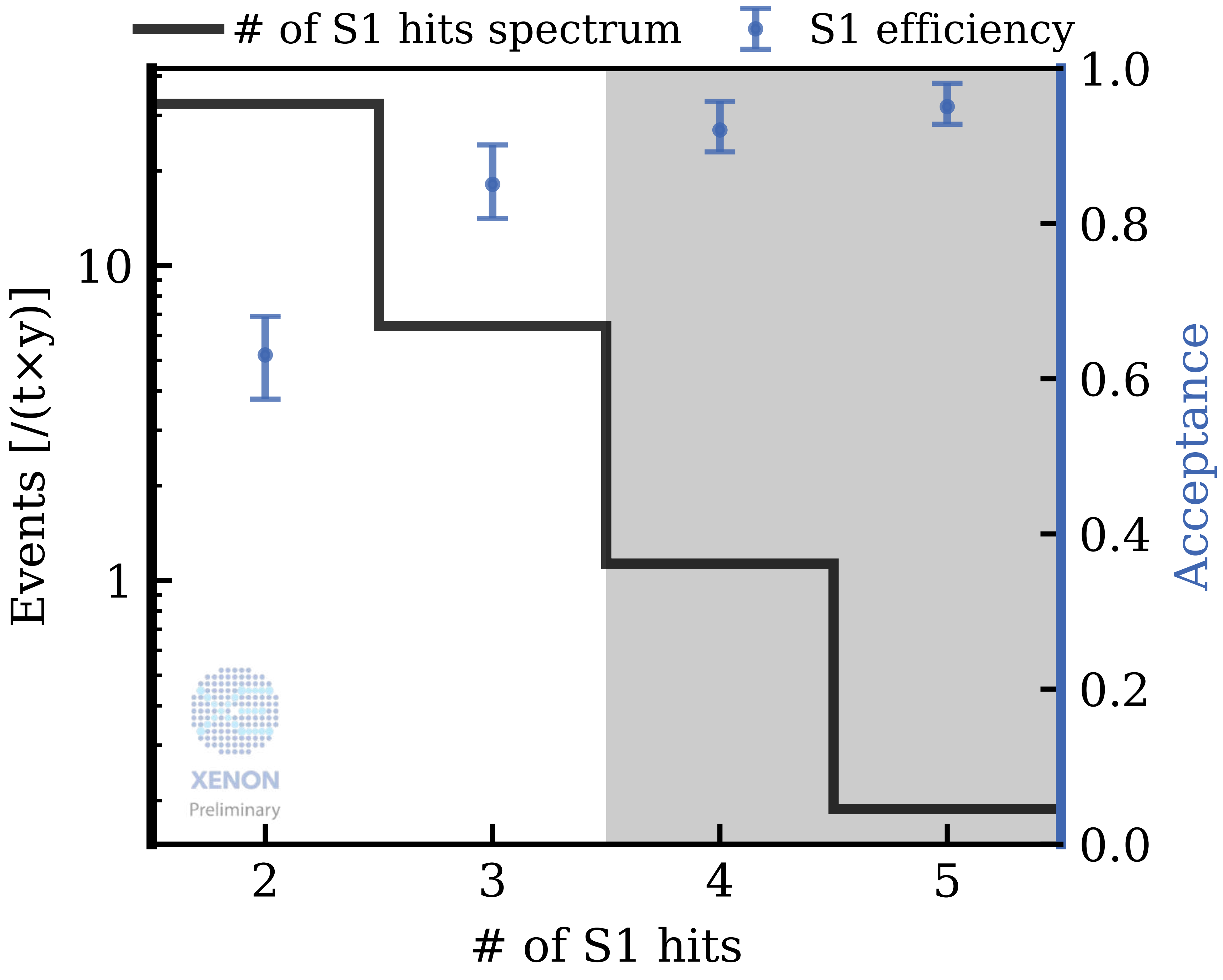


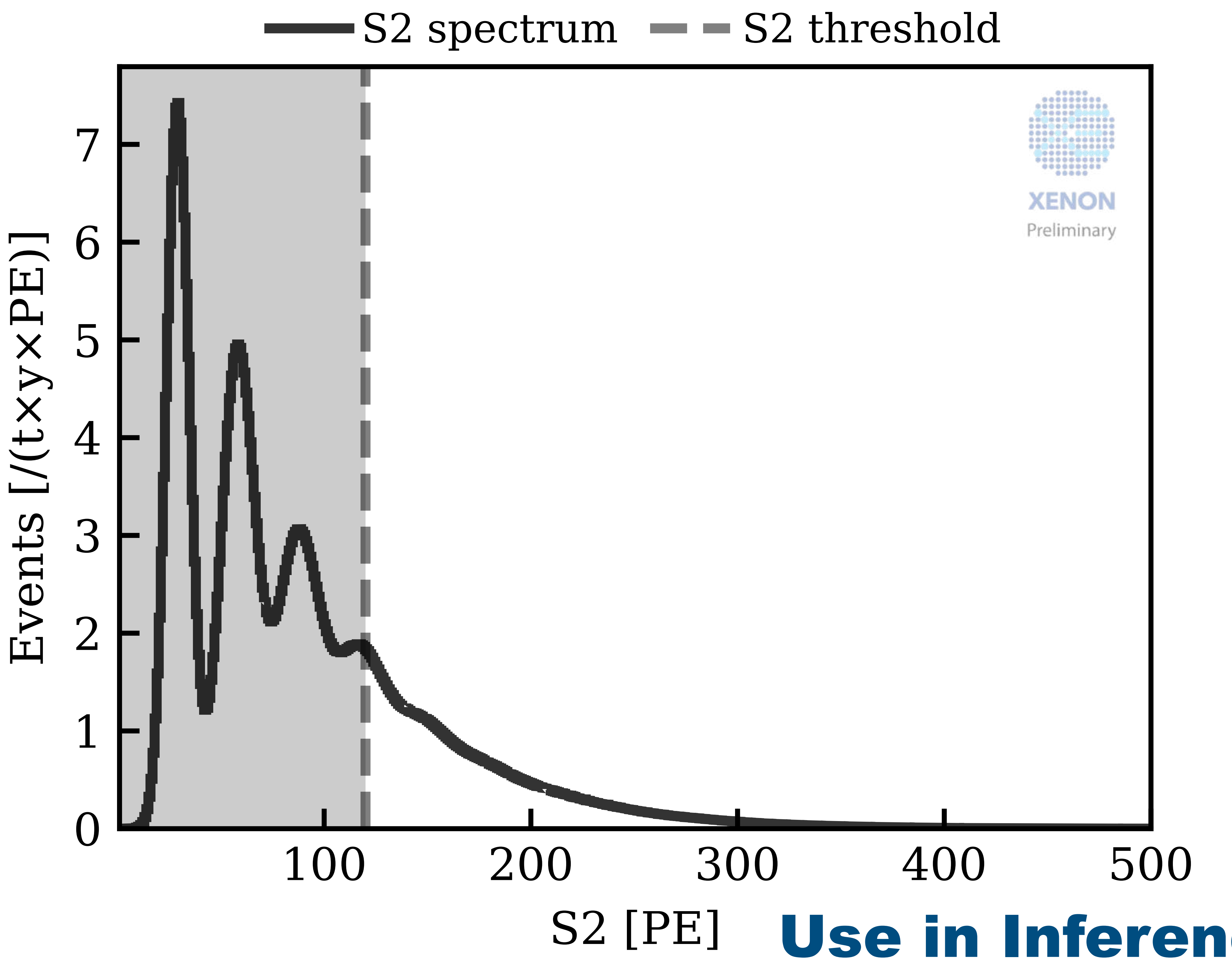




- Excellent match between data and model
- Fit the NEST model with the ^{88}YBe data to predict the light and charge yield in the ^{8}B CEvNS energy range at the XENONnT drift field

^{8}B CEvNS Signal Region of Interest





Use in Inference

S1 Range: 2 & 3 hits

- A hit usually corresponds to a photon hitting the PMT and is recorded by our DAQ and software

S2 Range: 120 - 500 PE

- S2 threshold of 120PE is used to reject high isolated S2 background

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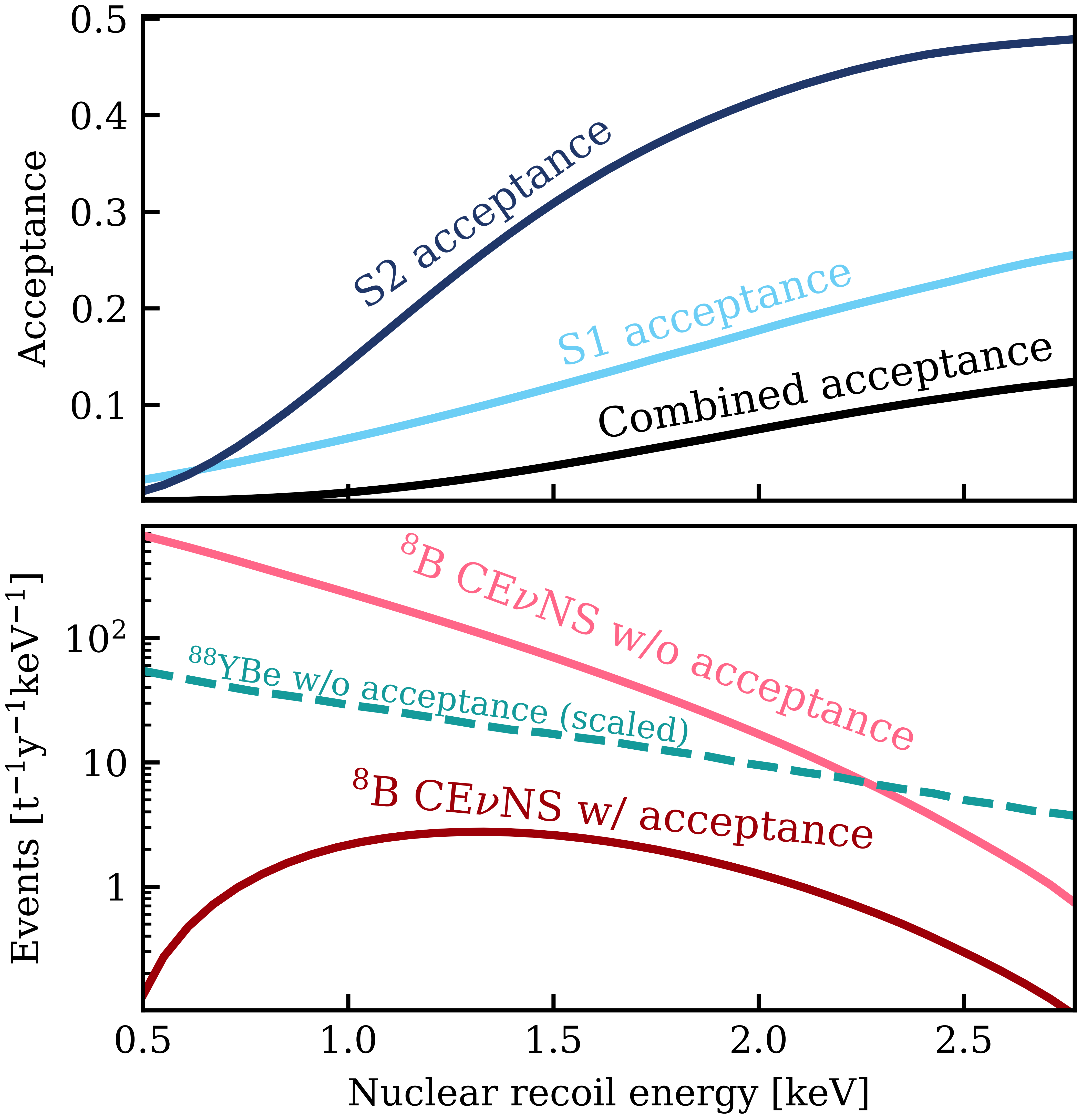
^{8}B CEvNS Signal Model



- SR0: 1.17 t·y
- SR1: 2.34 t·y

appletree 0.5.1

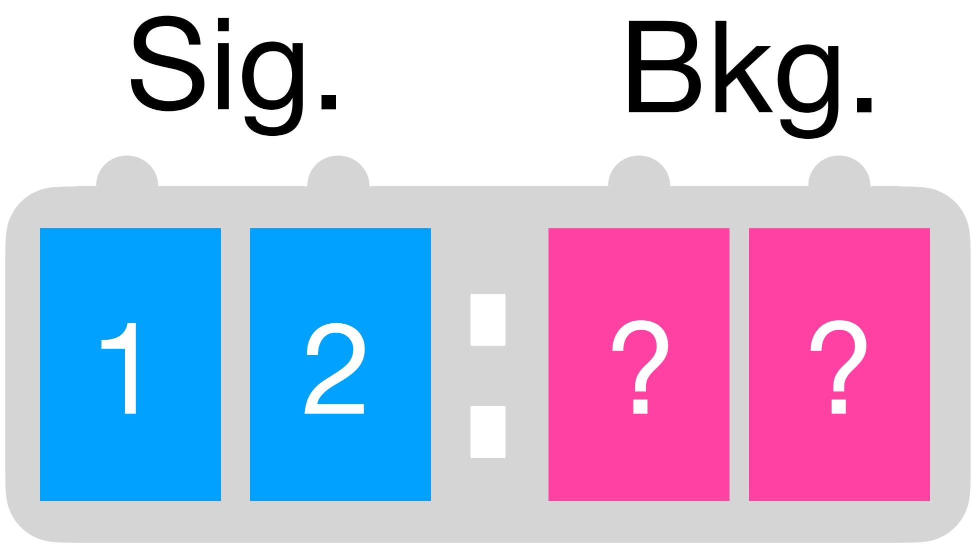
```
pip install appletree
```

Solar SM + SNO measurement

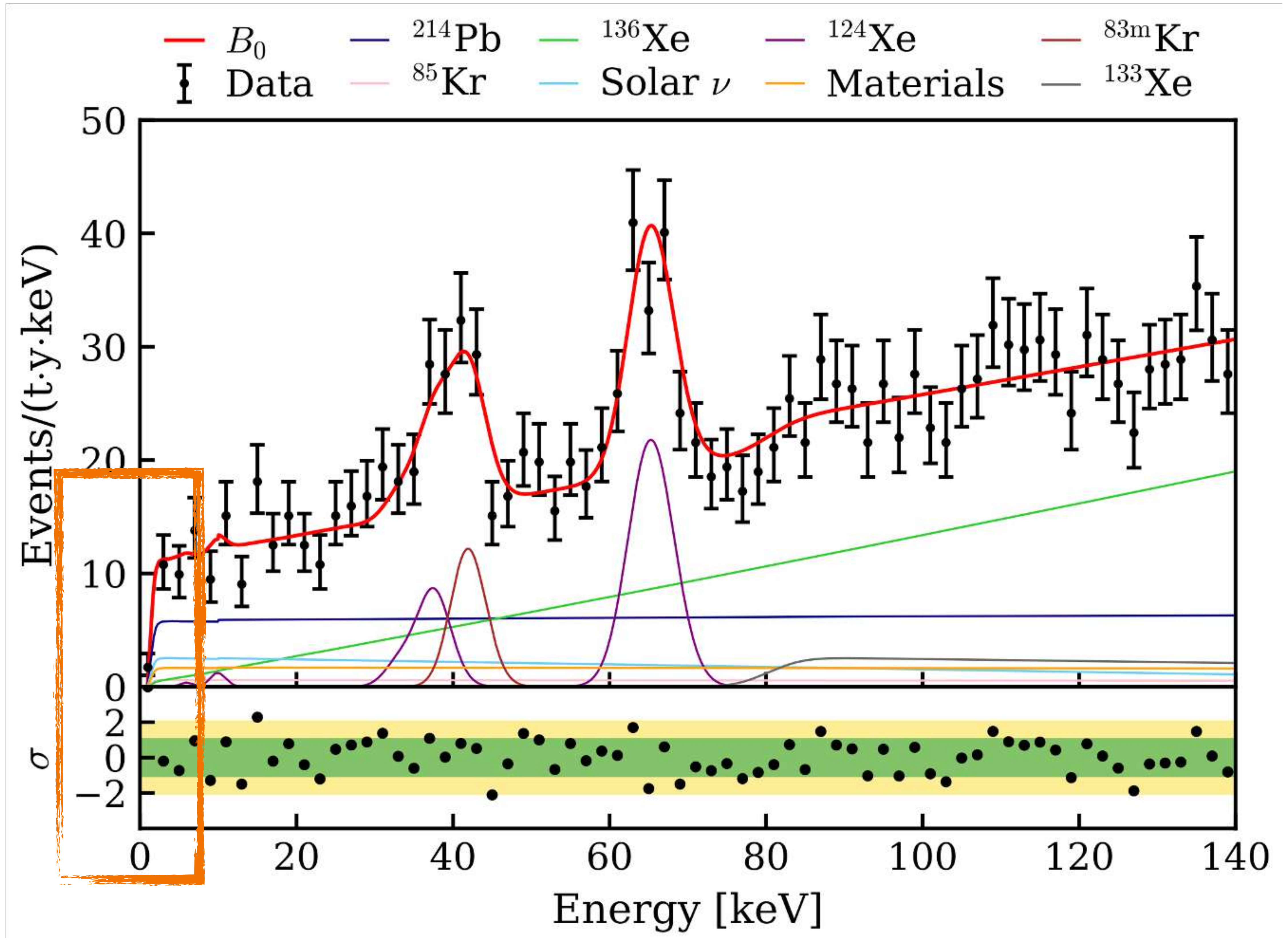
SM CEvNS cross-section

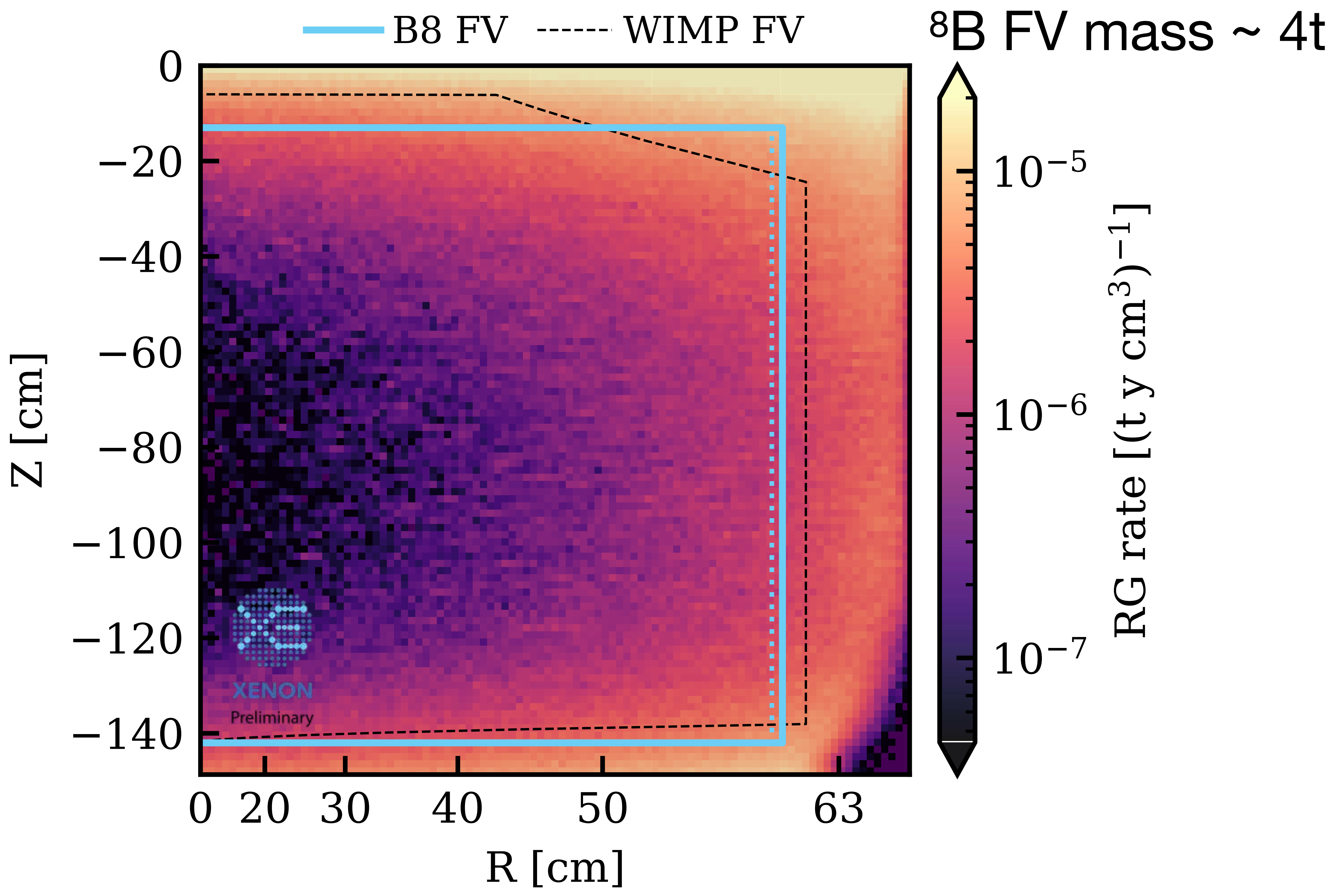
Detector Response

Efficiency



Electronic and Nuclear Recoil Background



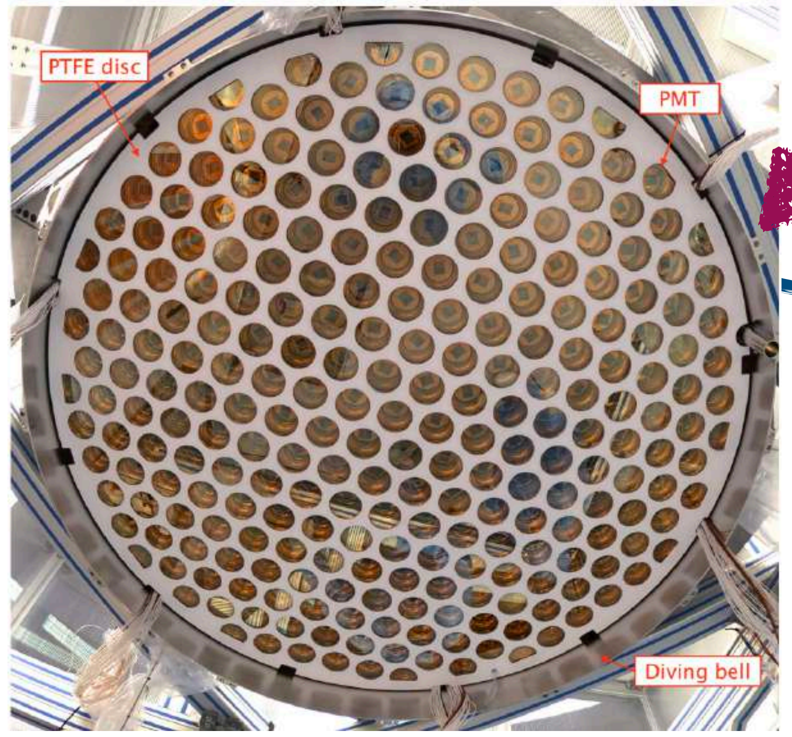


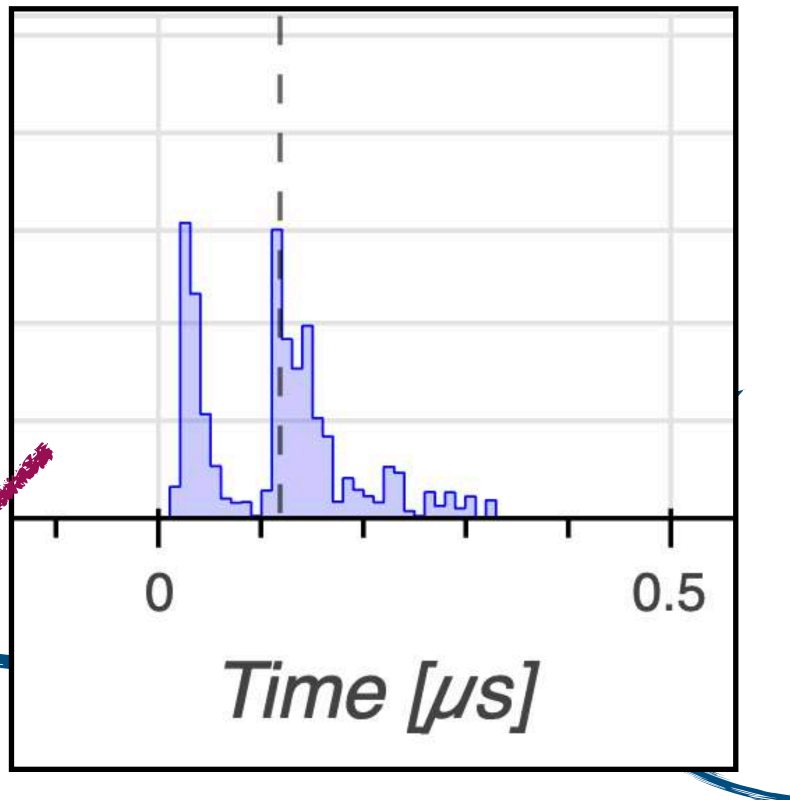
Final background prediction:
- SR0: 0.13 ± 0.13 Events
- SR1: 0.56 ± 0.56 Events

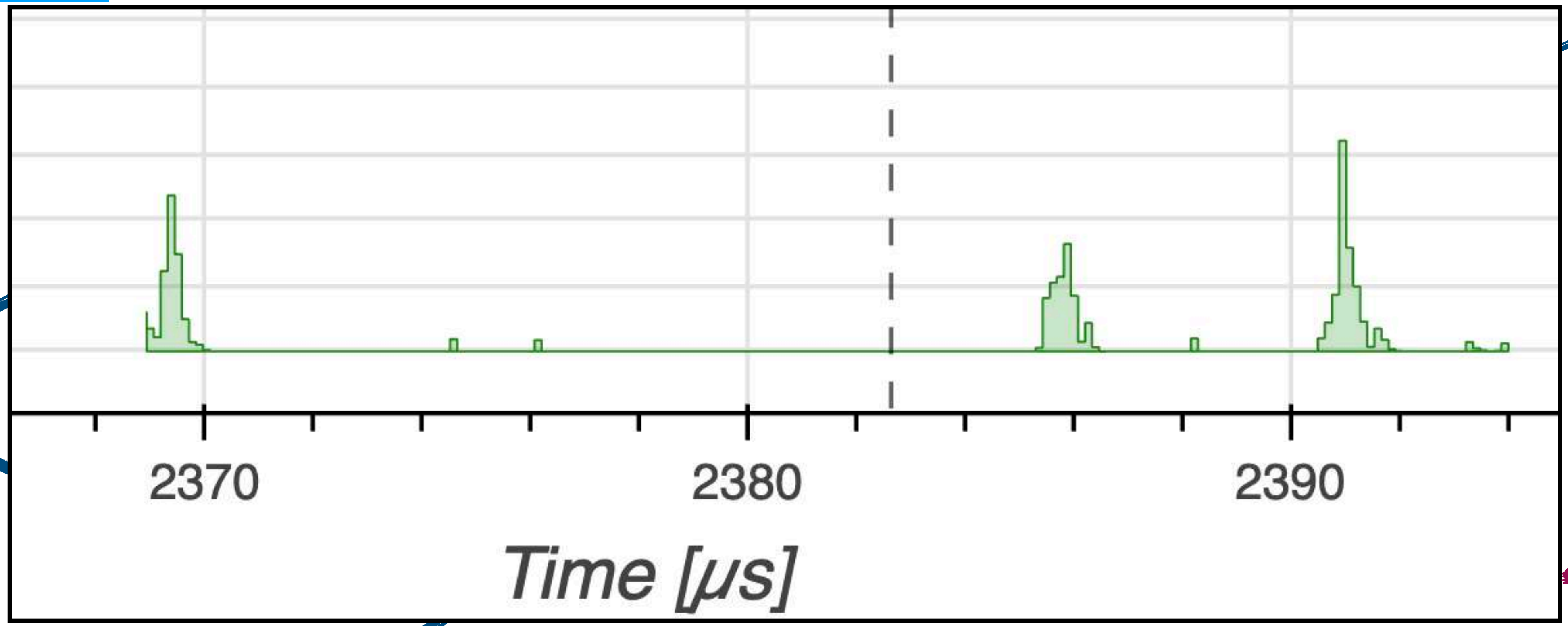
Final background prediction:
- SR0: 0.13±0.07 Events
- SR1: 0.33±0.19 Events

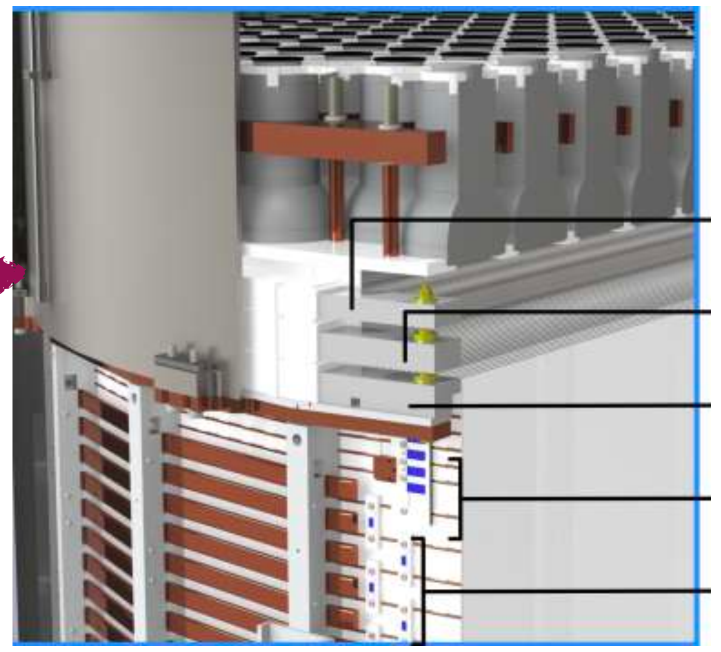
Accidental Coincidence in XENONnT

Accidentally pair S1 and S2 peaks









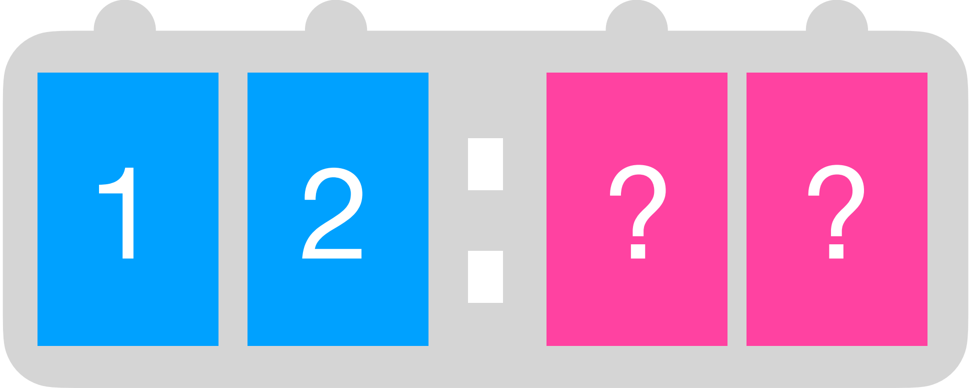
$$N_{AC} = \int_{t_0}^{t_1} R_{S1}(t) \cdot R_{S2}(t) \cdot T_{max} dt$$

In low energy NR ROI： (S1 2/3 hits, S2 from few to dozens electrons)

Iso-S1 Rate	Iso-S2 Rate	T max	Raw AC Rate
~ 15 Hz	~ 0.15 Hz	2.2 ms	5 mHz (~400/day)

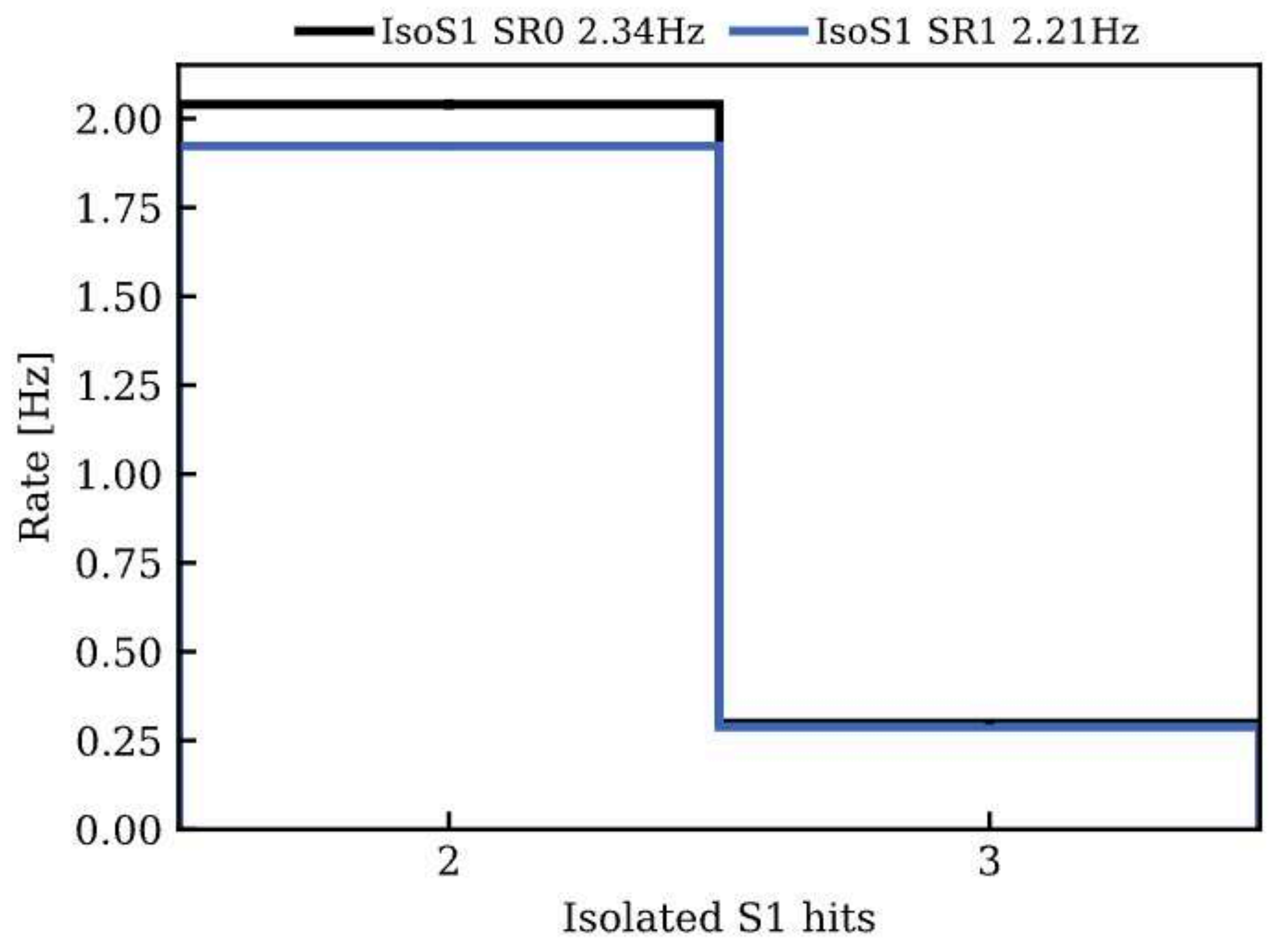
23 V/cm drift field

Sig. Bkg.

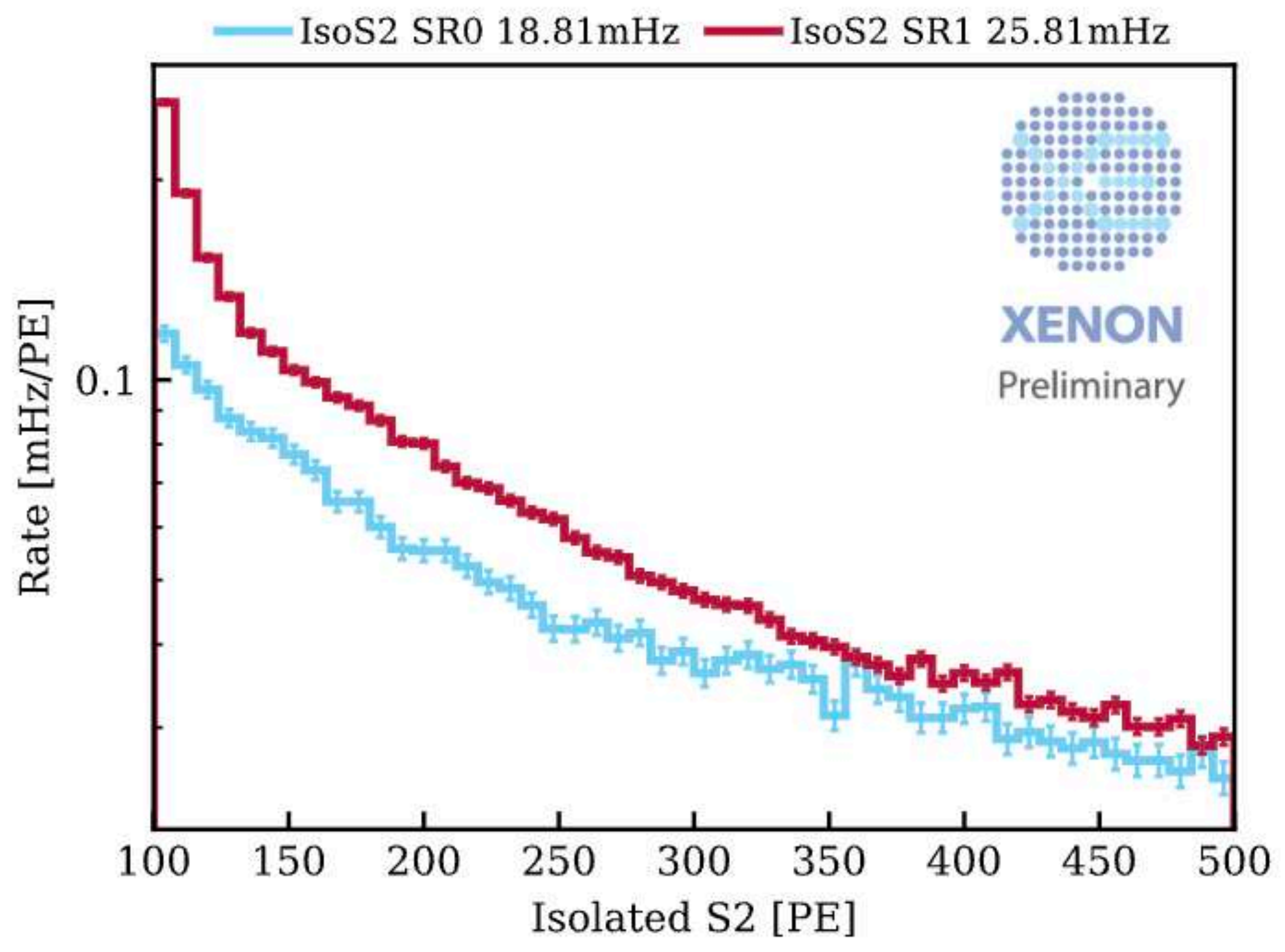


Suppress isolated peaks & Simulation

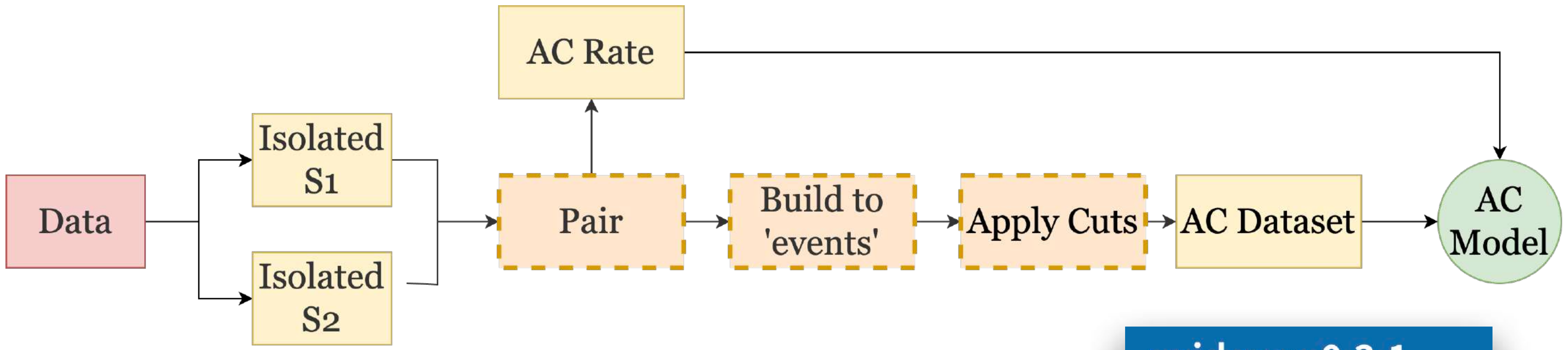
Isolated S1: 15 Hz →2.3 Hz



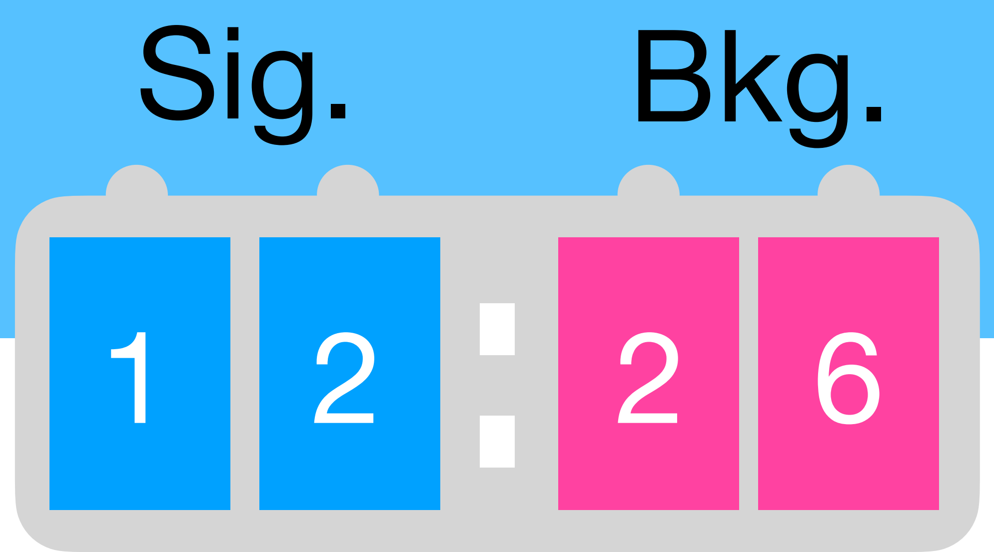
Isolated S2: 0.15 Hz → 25 mHz



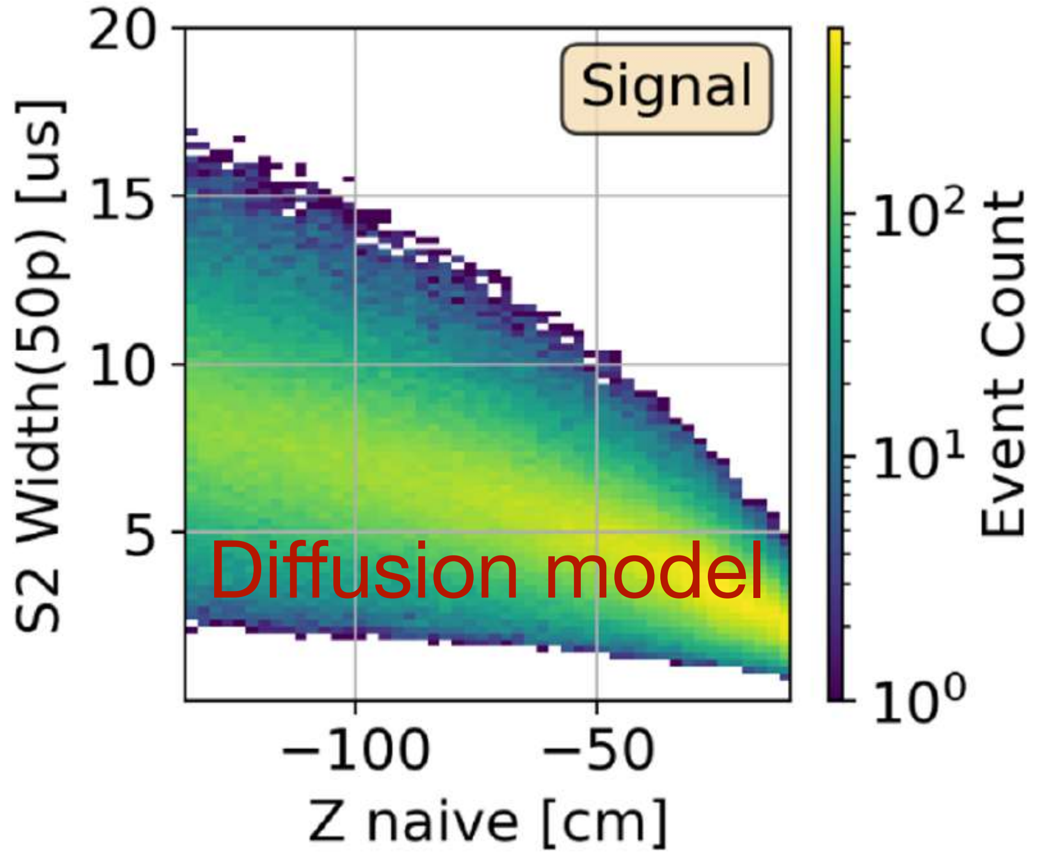
- After the time-space correlation cuts, the majority of isolated peaks is removed.
- Signal acceptance ~ 75%-85%
- Then we run Data-driven simulation to get the background prediction

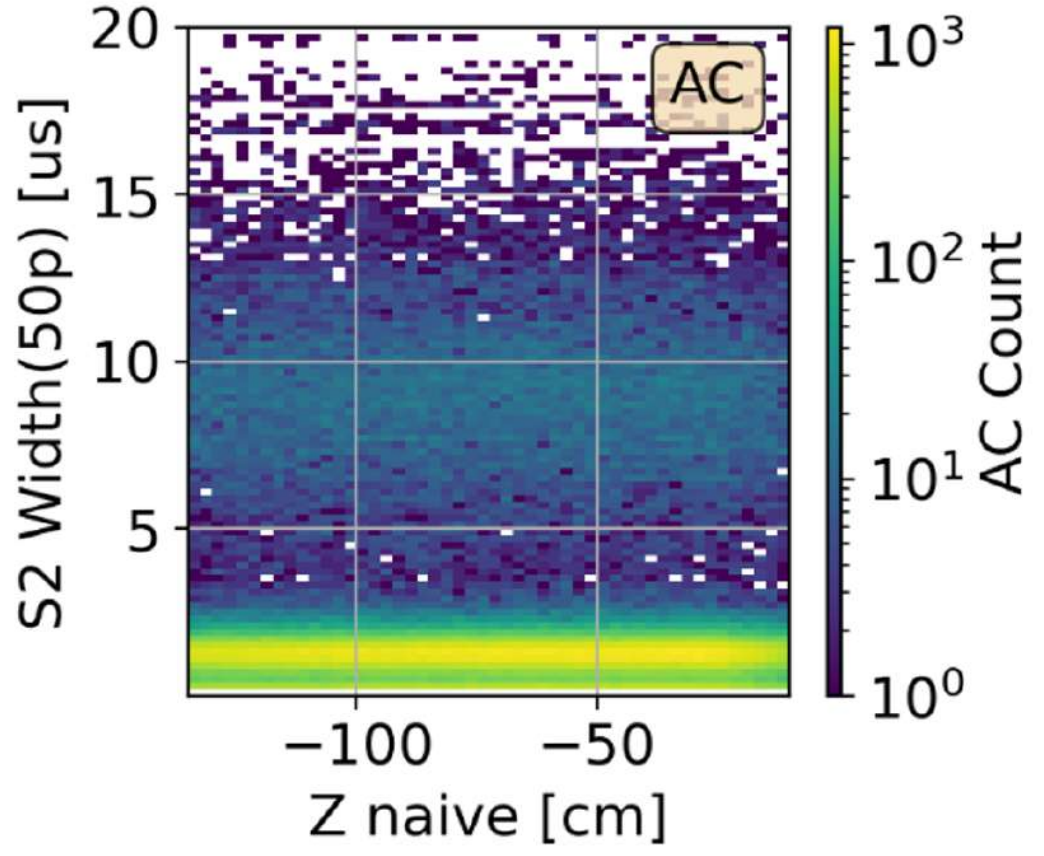


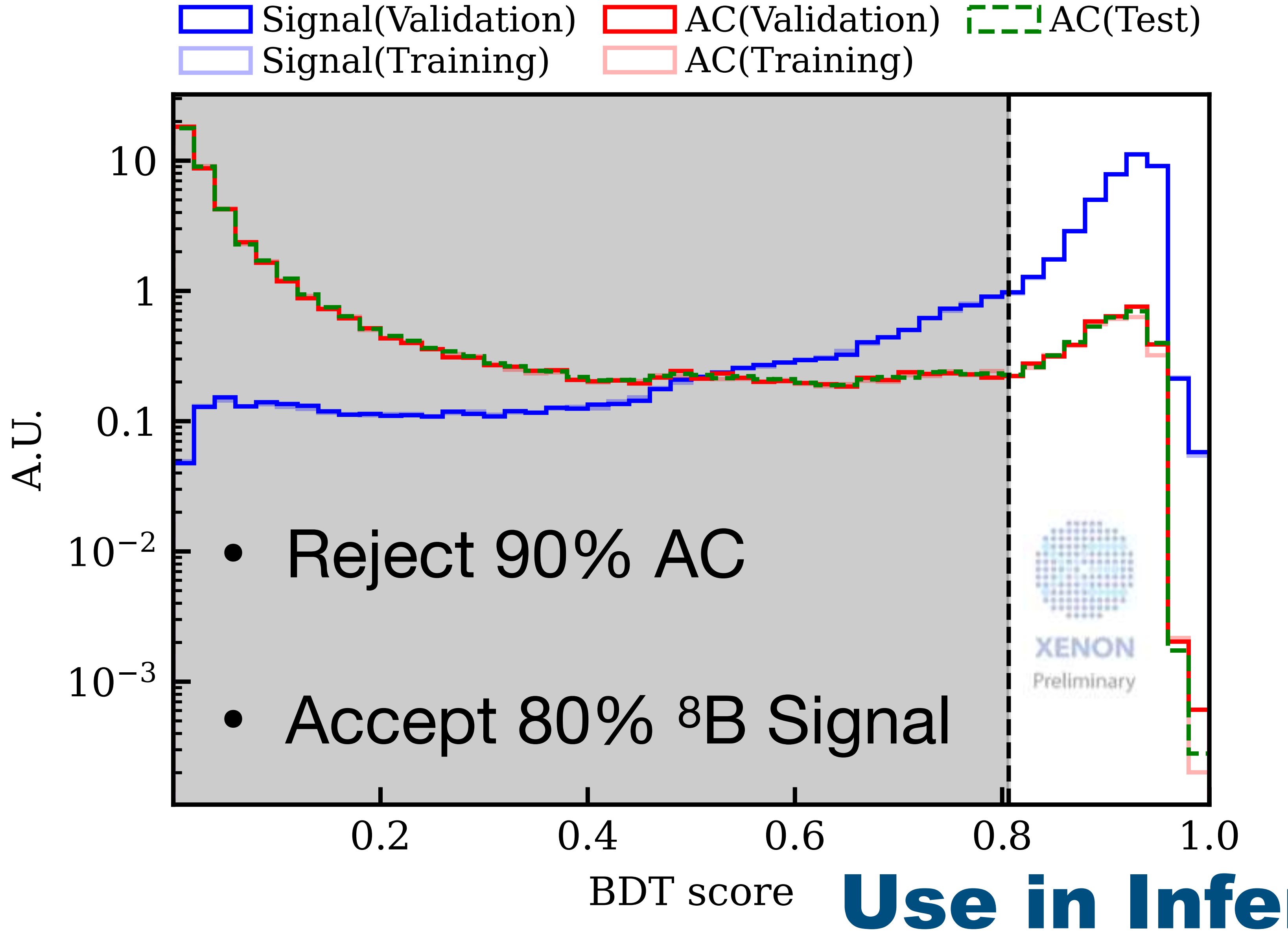
S1/S2 Pulse shape into GBDT



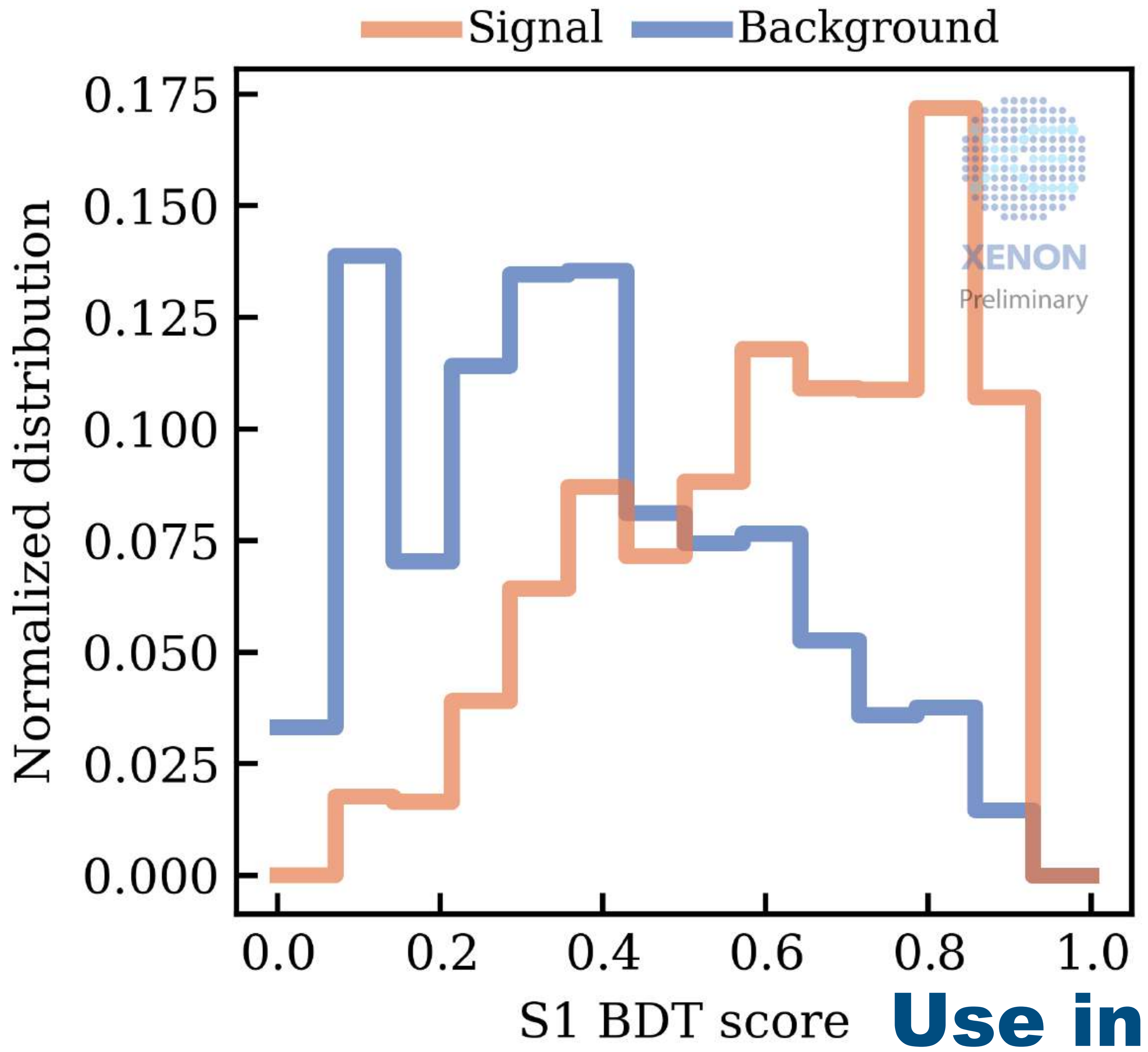
Gradient Boosting Decision Tree



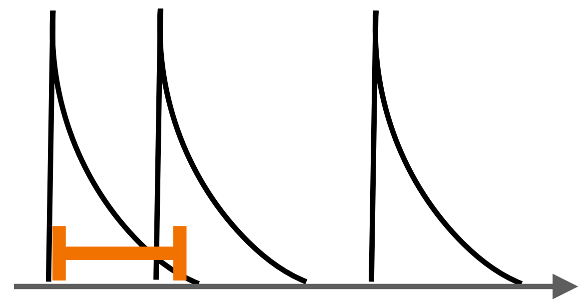




Use in Inference



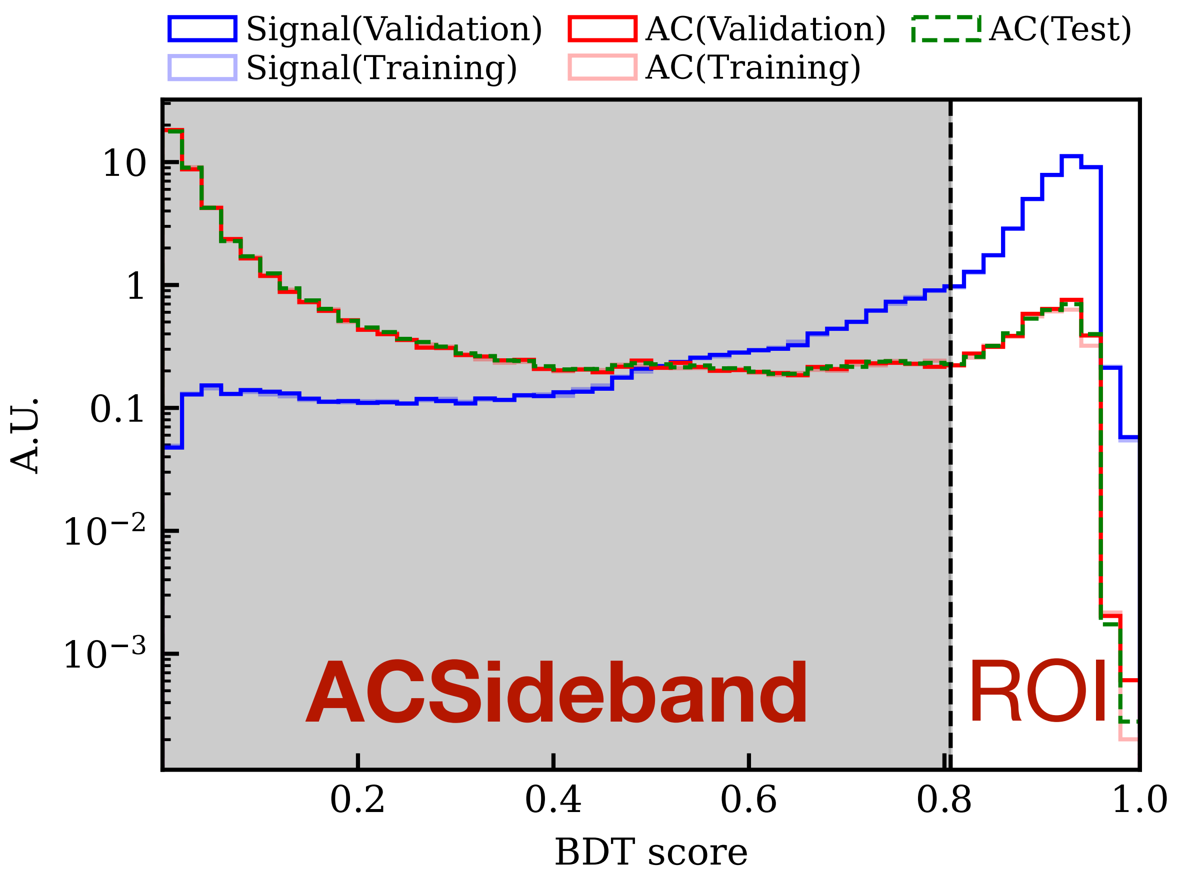
Use in Inference



- Trained with AC vs Simulated ^{8}B
- Also use the S1BDT score and S2BDT score as inference dimensions

Validation on Science data ACSideband

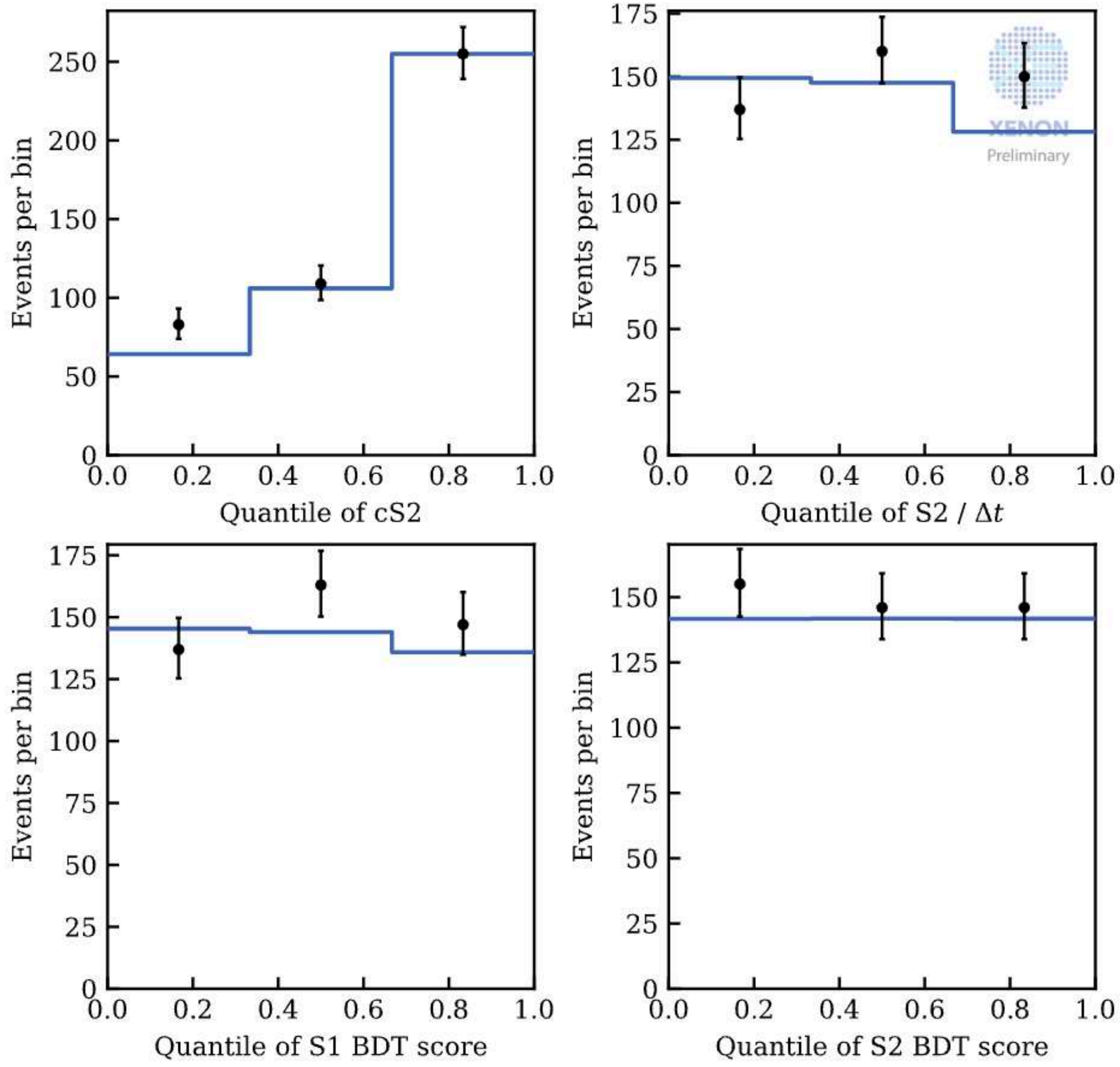
Determine Systematic Uncertainty



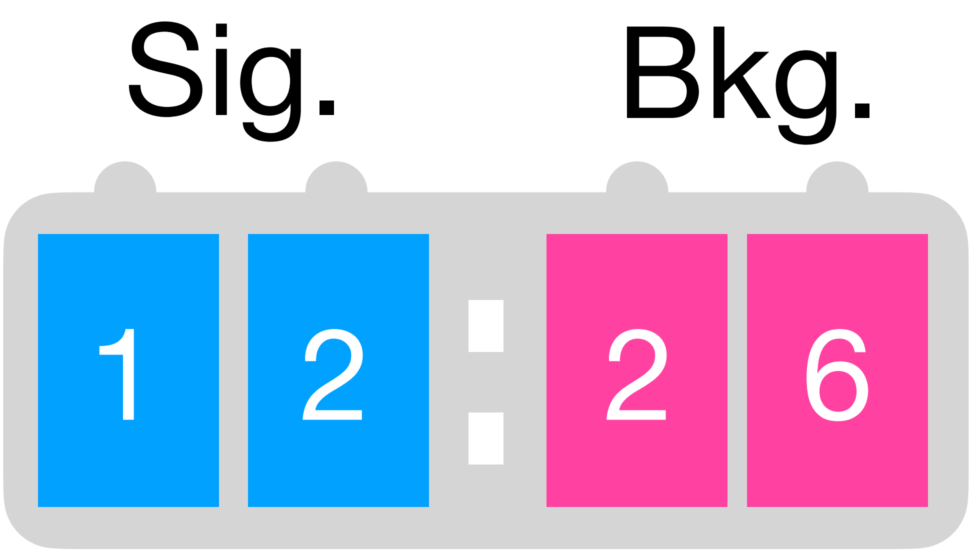
	AC Rate[/t/y]
SR0	6.37
SR1	7.58

Unblinding shows within 2-sigma, use the statistic uncertainty of ACSideband to be the systematics

Dataset	Predicted	Observed	p-value (4D)	Relative Uncertainty
SR0	122.7	121	0.33	9.0%
SR1	302.5	326	0.25	5.8%

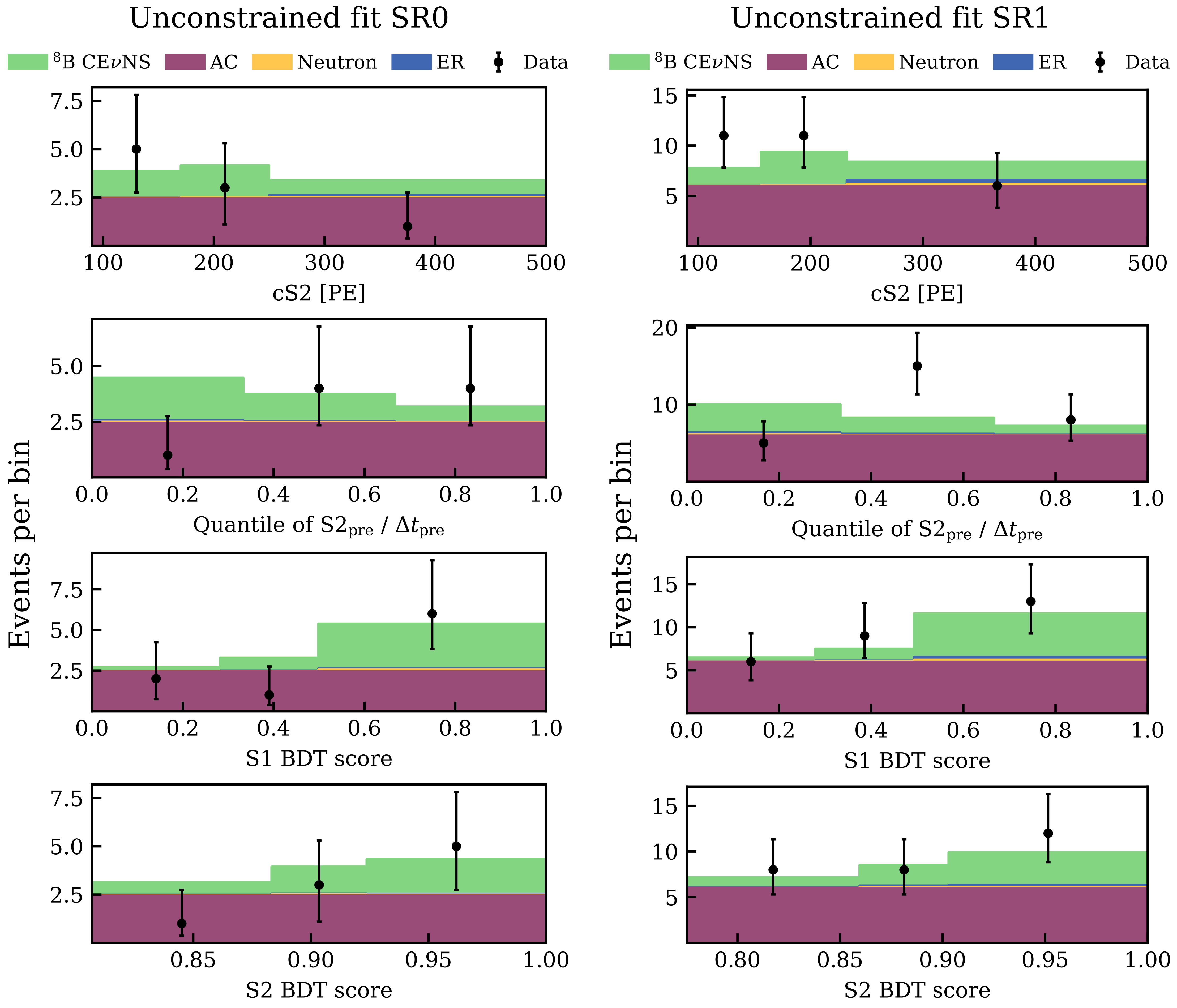


Inference and Result



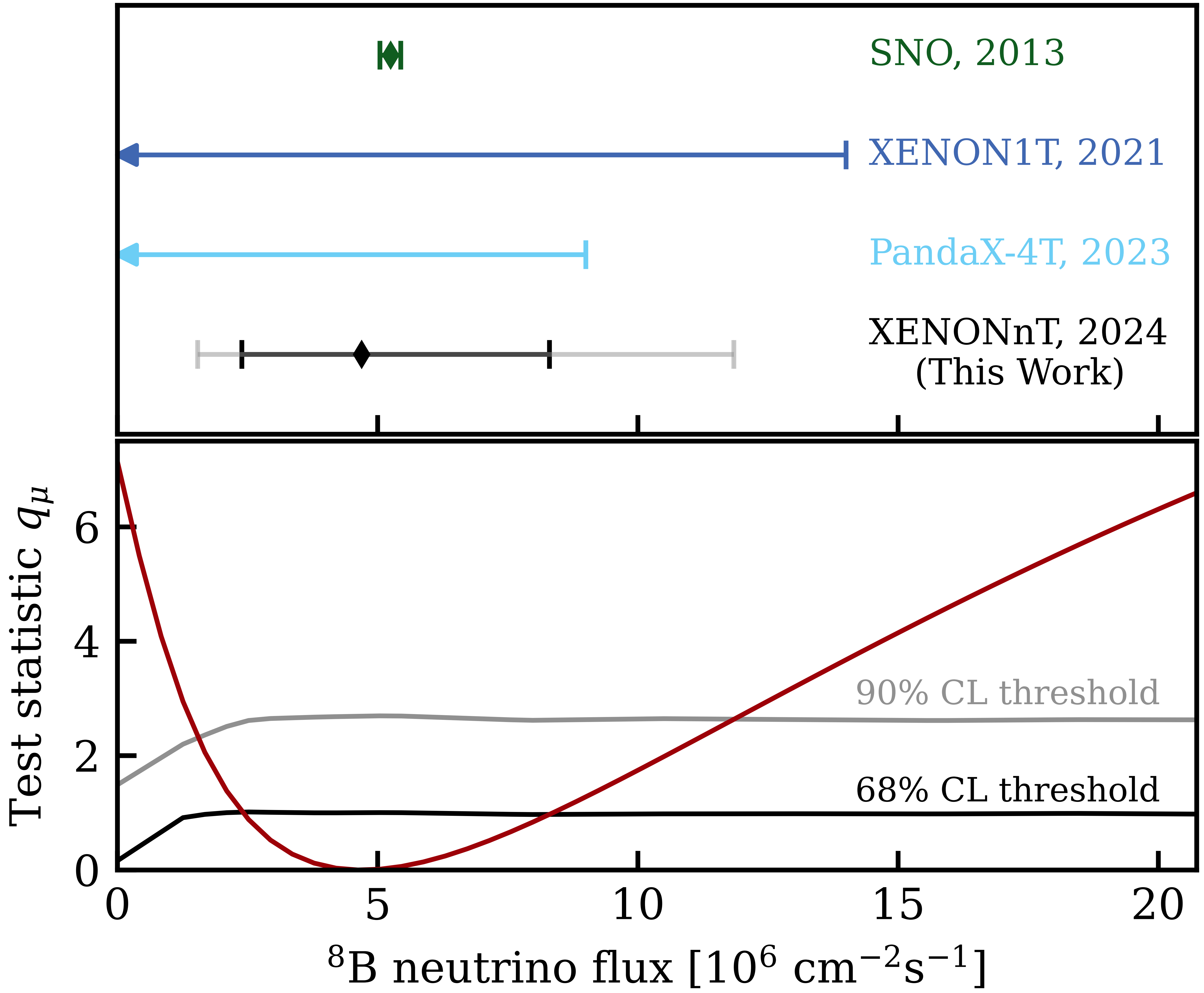
Unblind Result

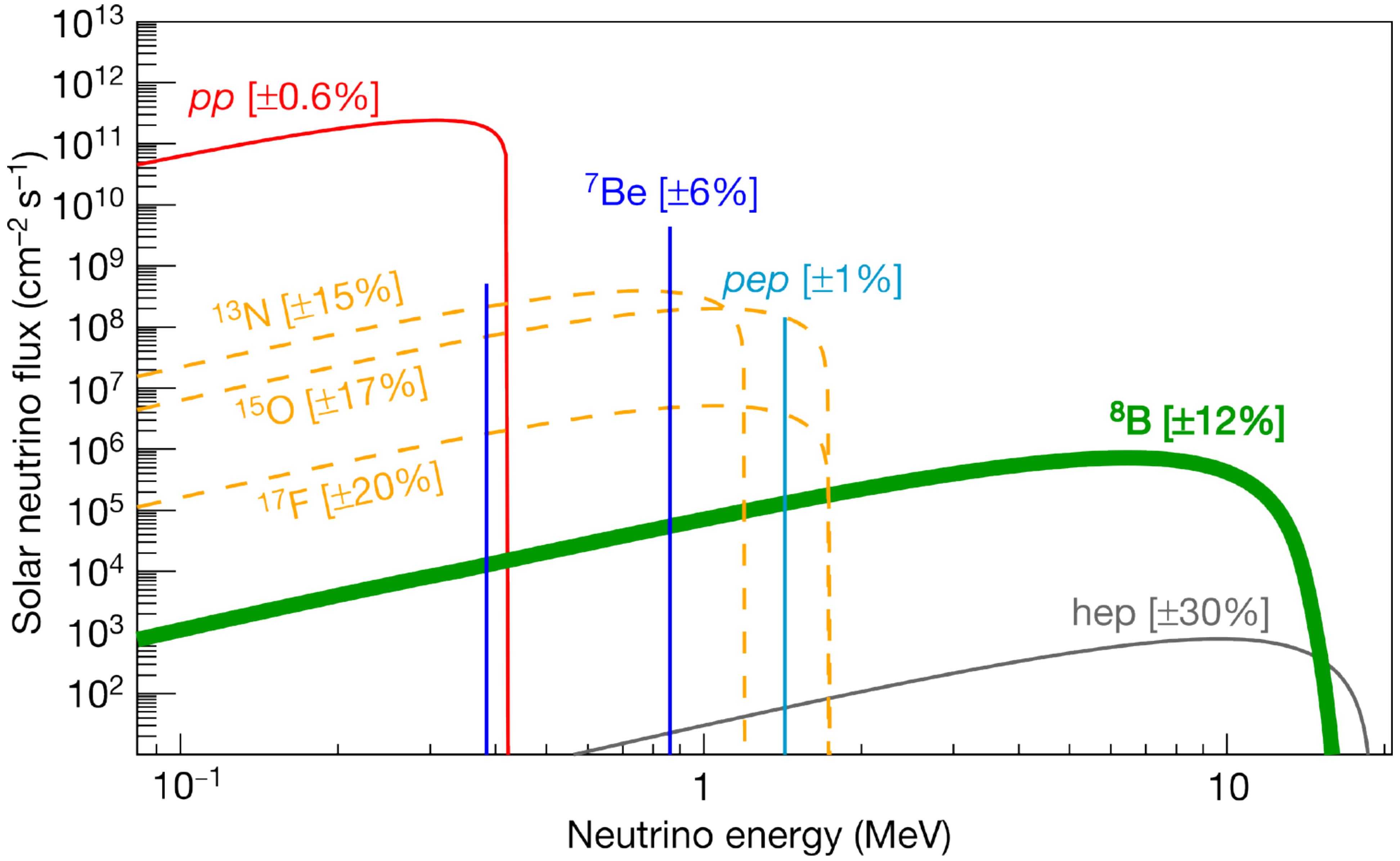
Component	Nominal Expectation	Background + ^{8}B fit
AC - SR0	7.5 ± 0.7	7.4
AC - SR1	17.8 ± 1.0	17.9
ER	0.7 ± 0.7	0.5
NR	0.5 ± 0.3	0.5
Total Background	26.4 ± 1.4	26.3
^{8}B	11.9 ± 4.5	10.7
Observed	37	



The significance of the solar ^{8}B neutrinos via CEvNS in XENONnT at 2.73σ

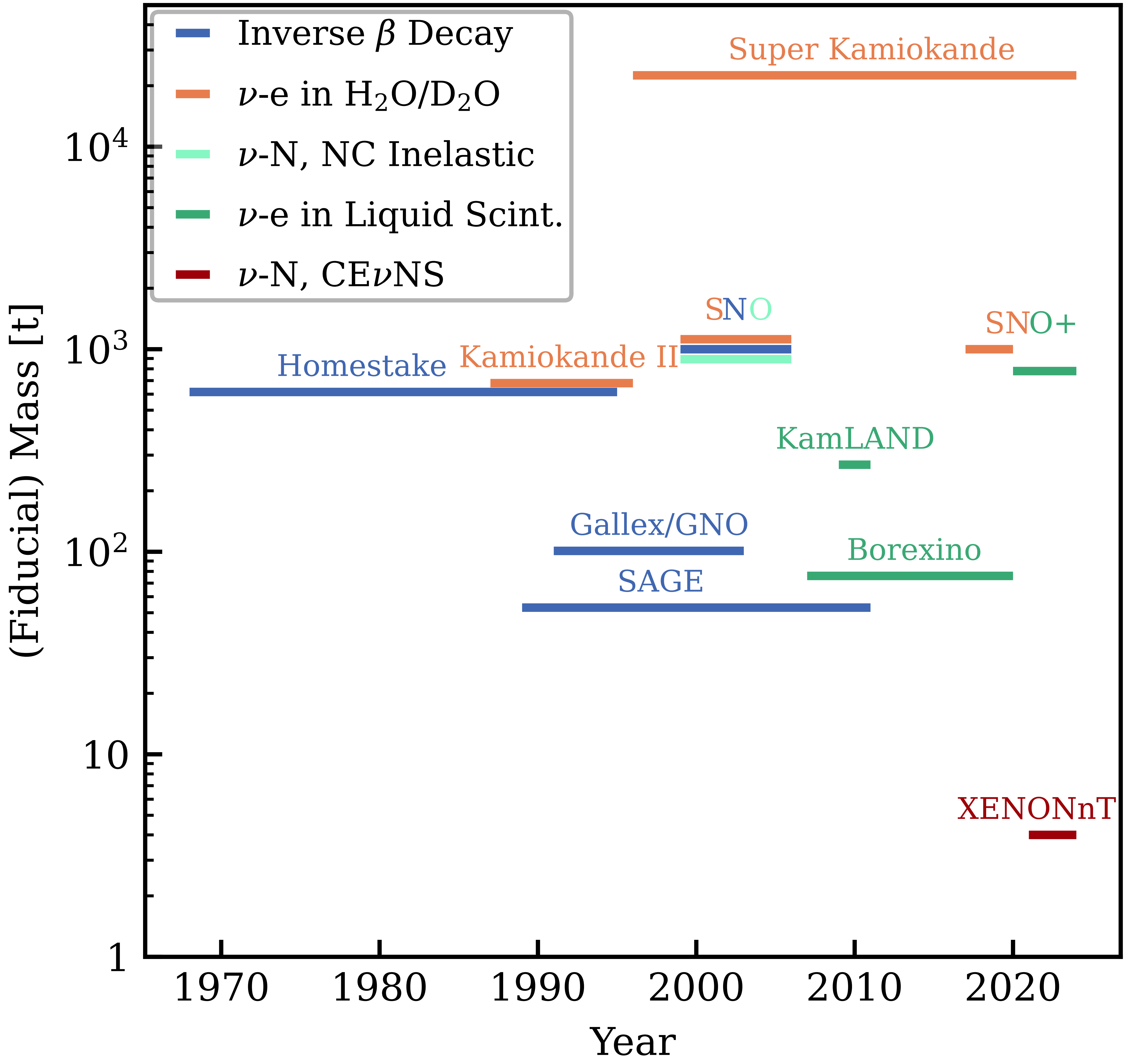
Set Constrain on solar ^{8}B neutrinos flux





- Assume the CEvNS cross-section predicted by the SM
- Constraints on the solar ^{8}B neutrino flux of $4.7^{+3.6}_{-2.3} \times 10^{6}$ cm^{-2} s^{-1}

Summary and Outlook

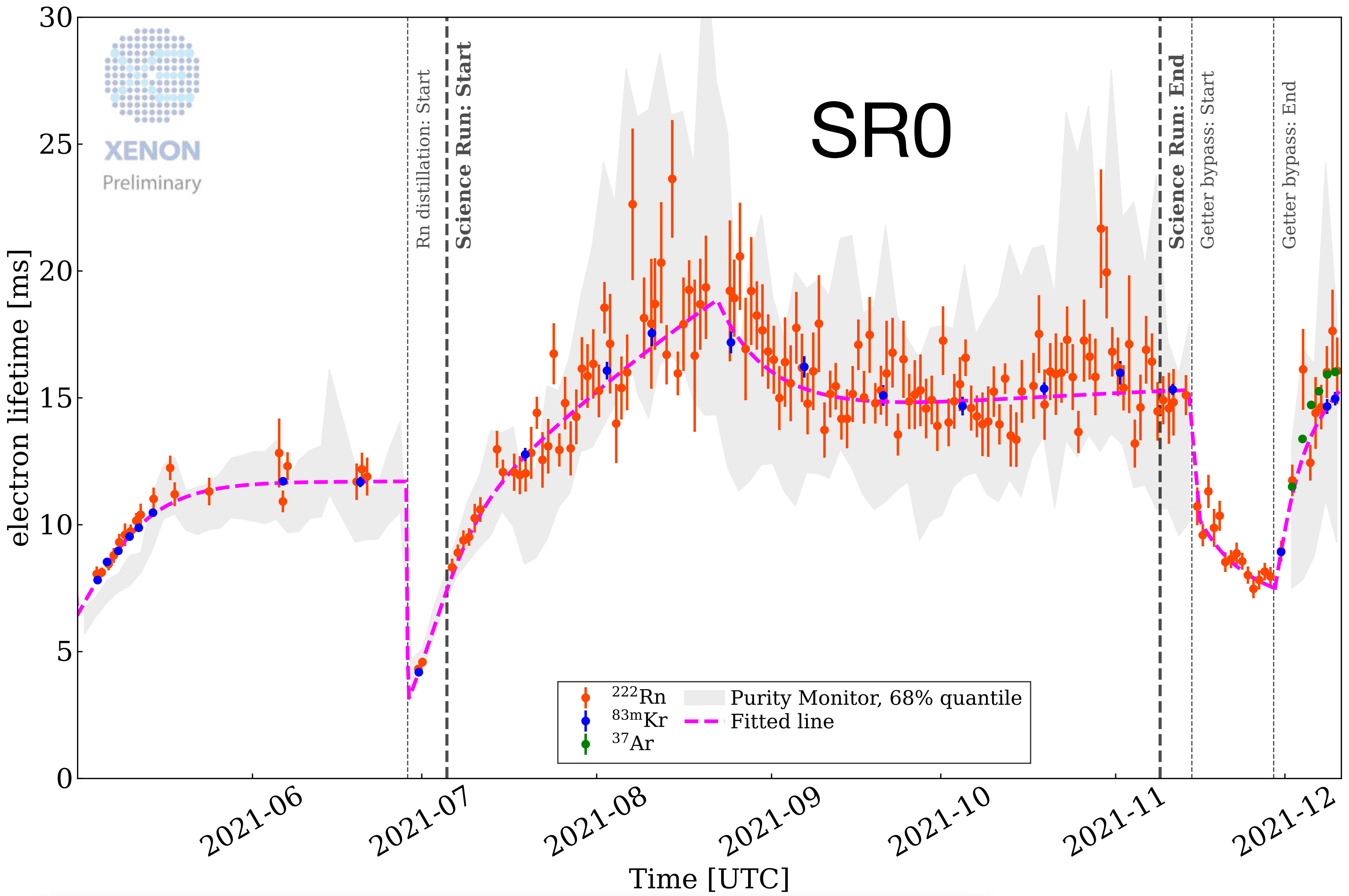


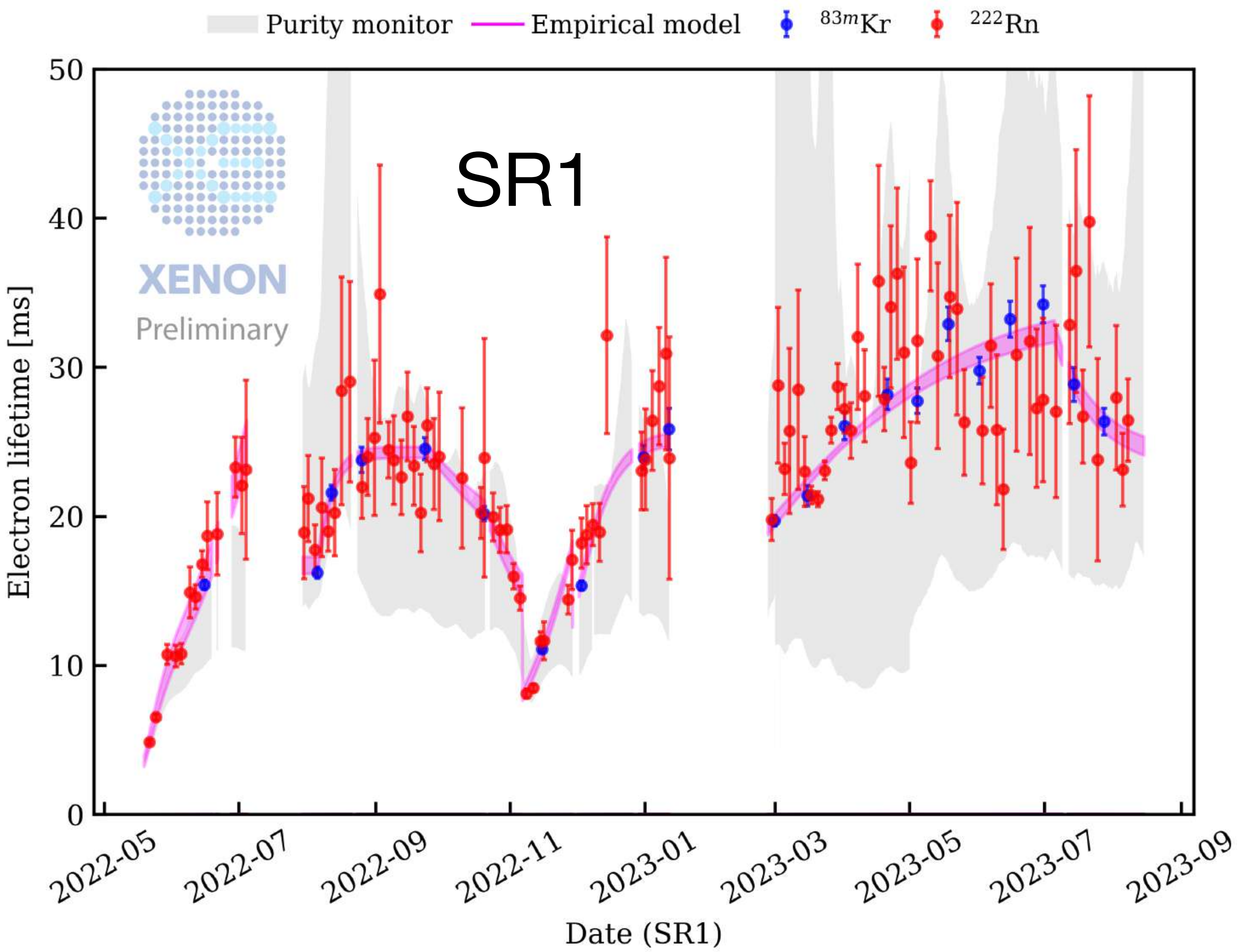
- Check our paper online:
  - arXiv: 2408.02877 accepted by PRL
- The smallest solar neutrino detector!

Thanks for listening!

Supplementary

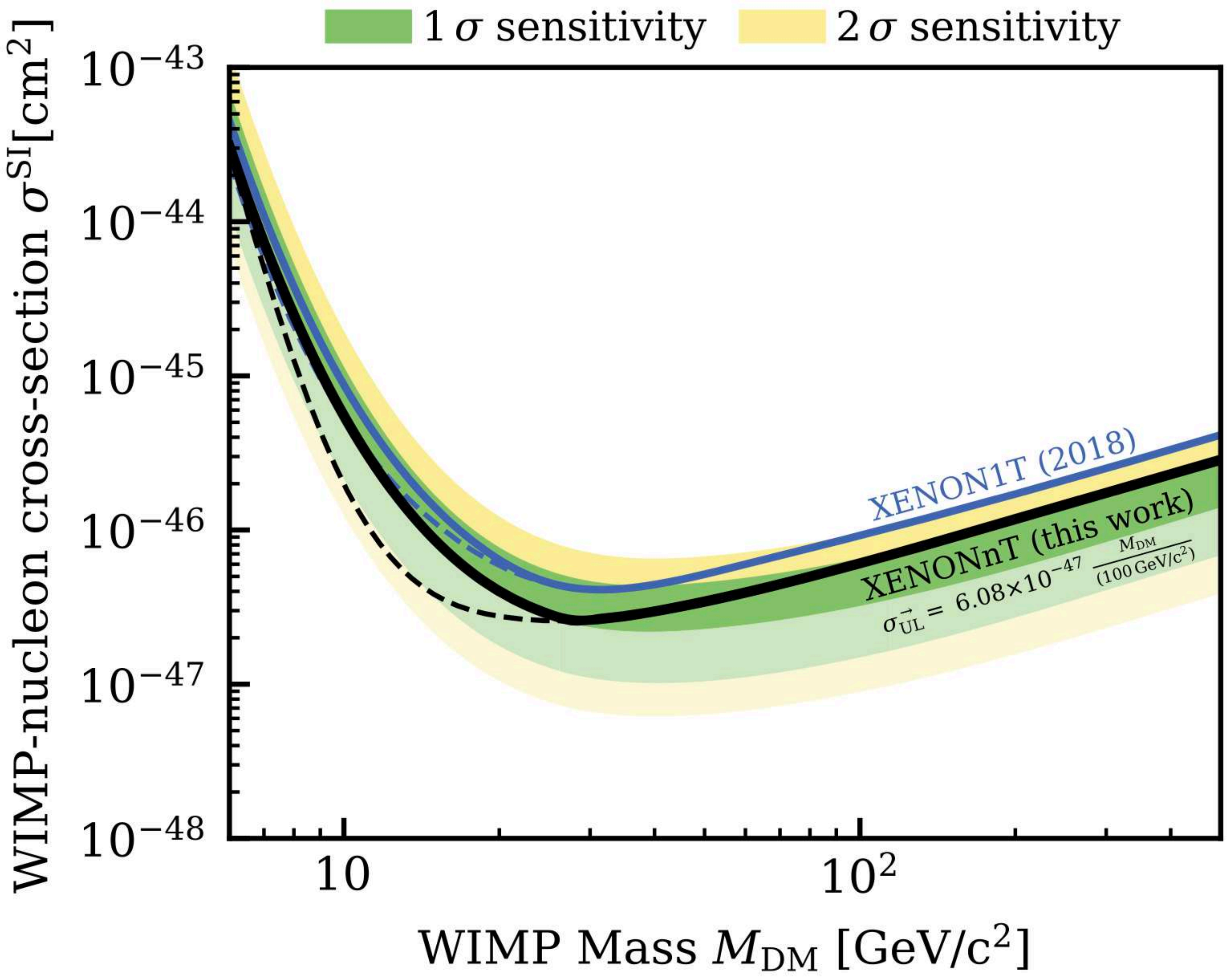
High Liquid XENON Purity

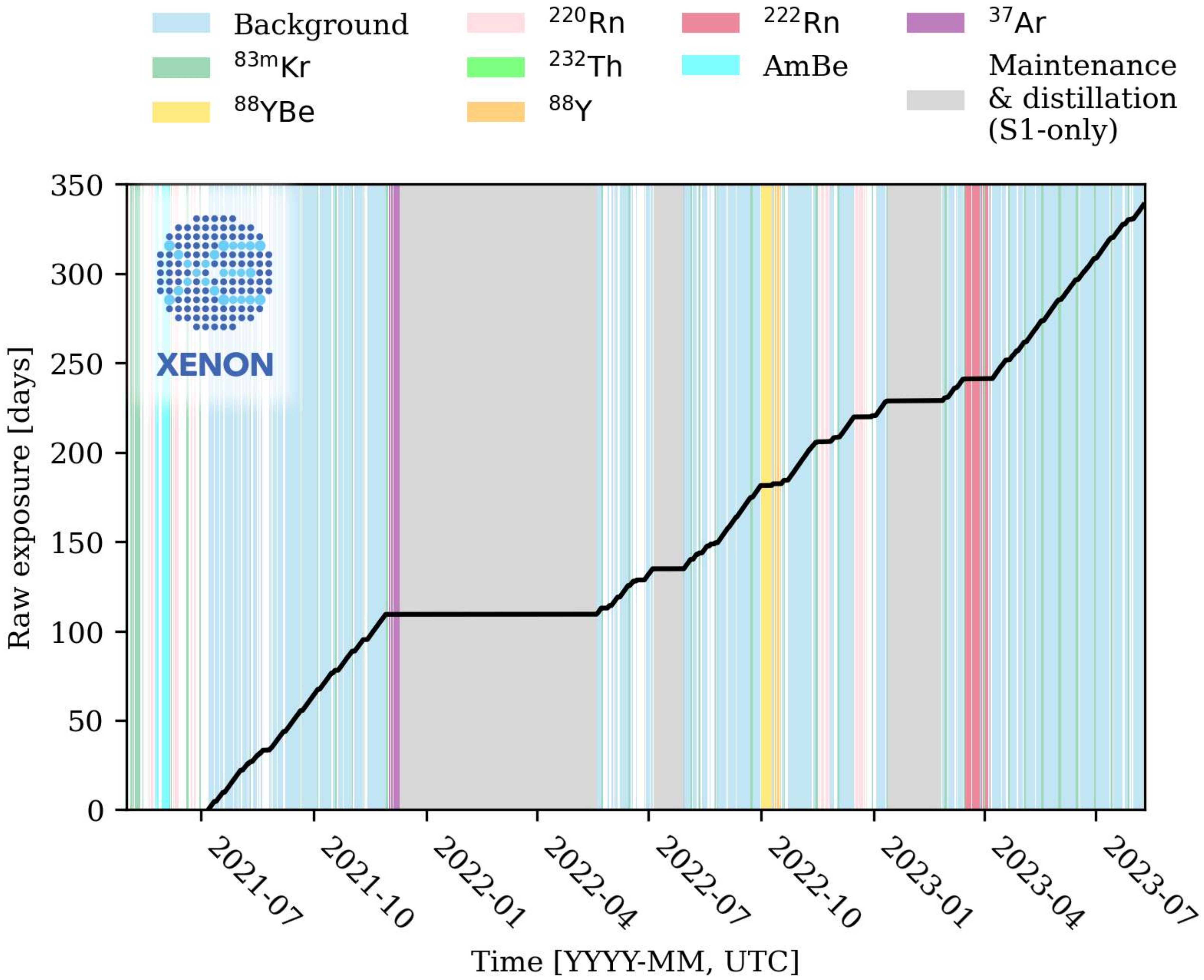




- XENONnT maintains high electron lifetime thanks to its novel liquid phase purification
- Turn-around time of 0.9 days for entire 8.6 tonnes
- About 90% of the electrons survive the full drift

XENONnT Science Data





Both SR0 and SR1 data are used to search for solar ^{8}B CEvNS and WIMPs Dark Matter, etc

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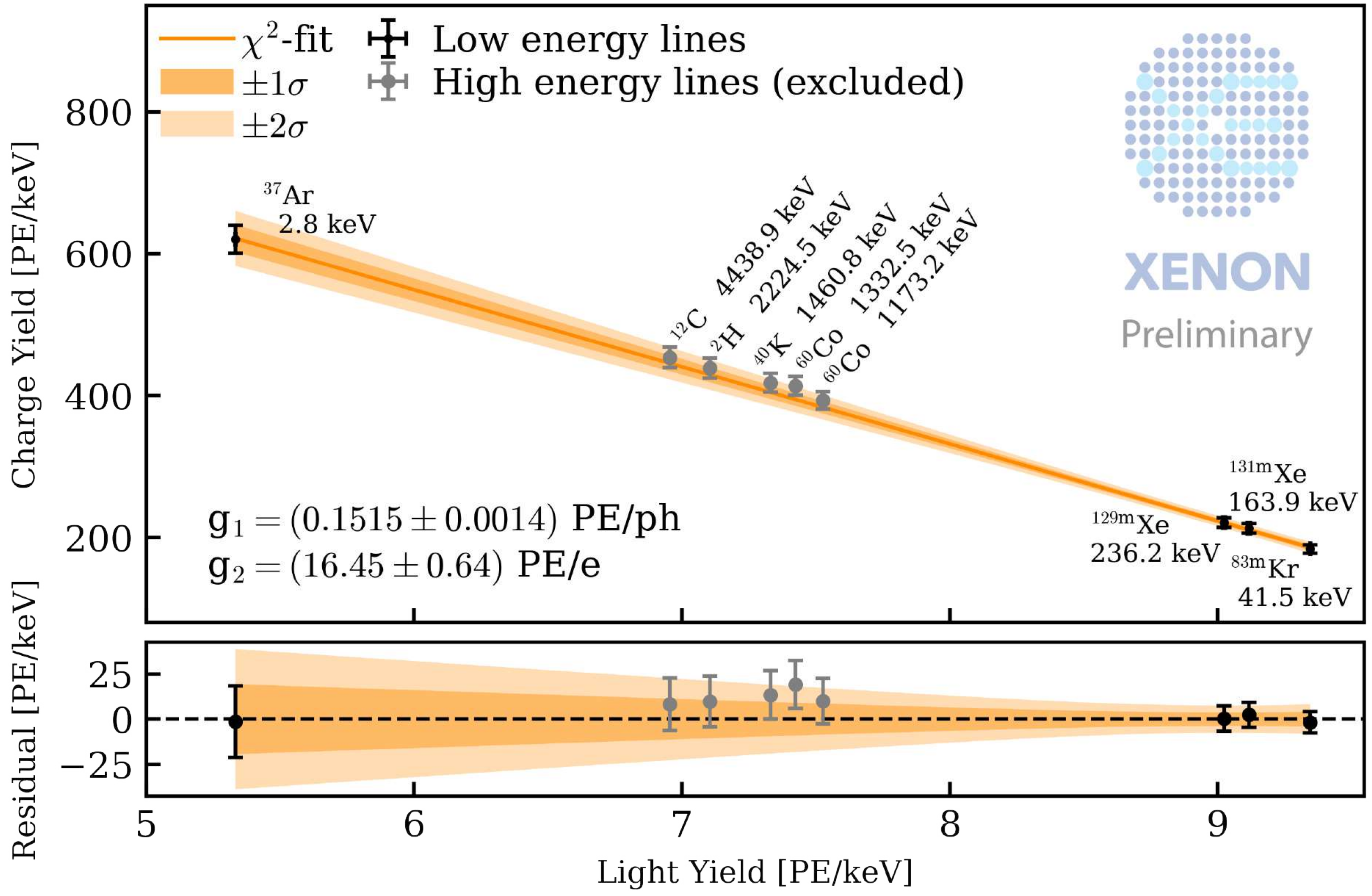
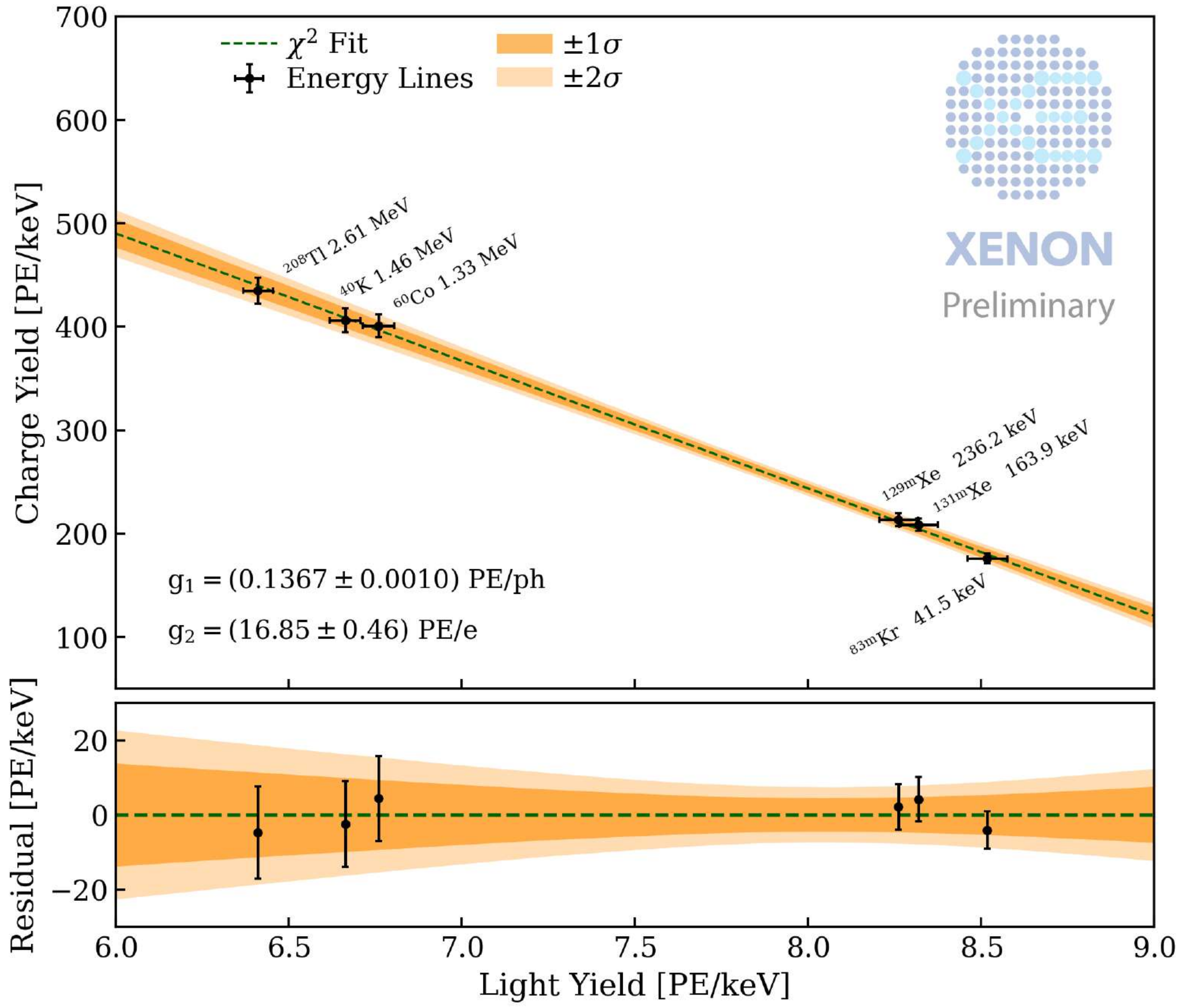
Calibration with Mono-E Electronic Recoils



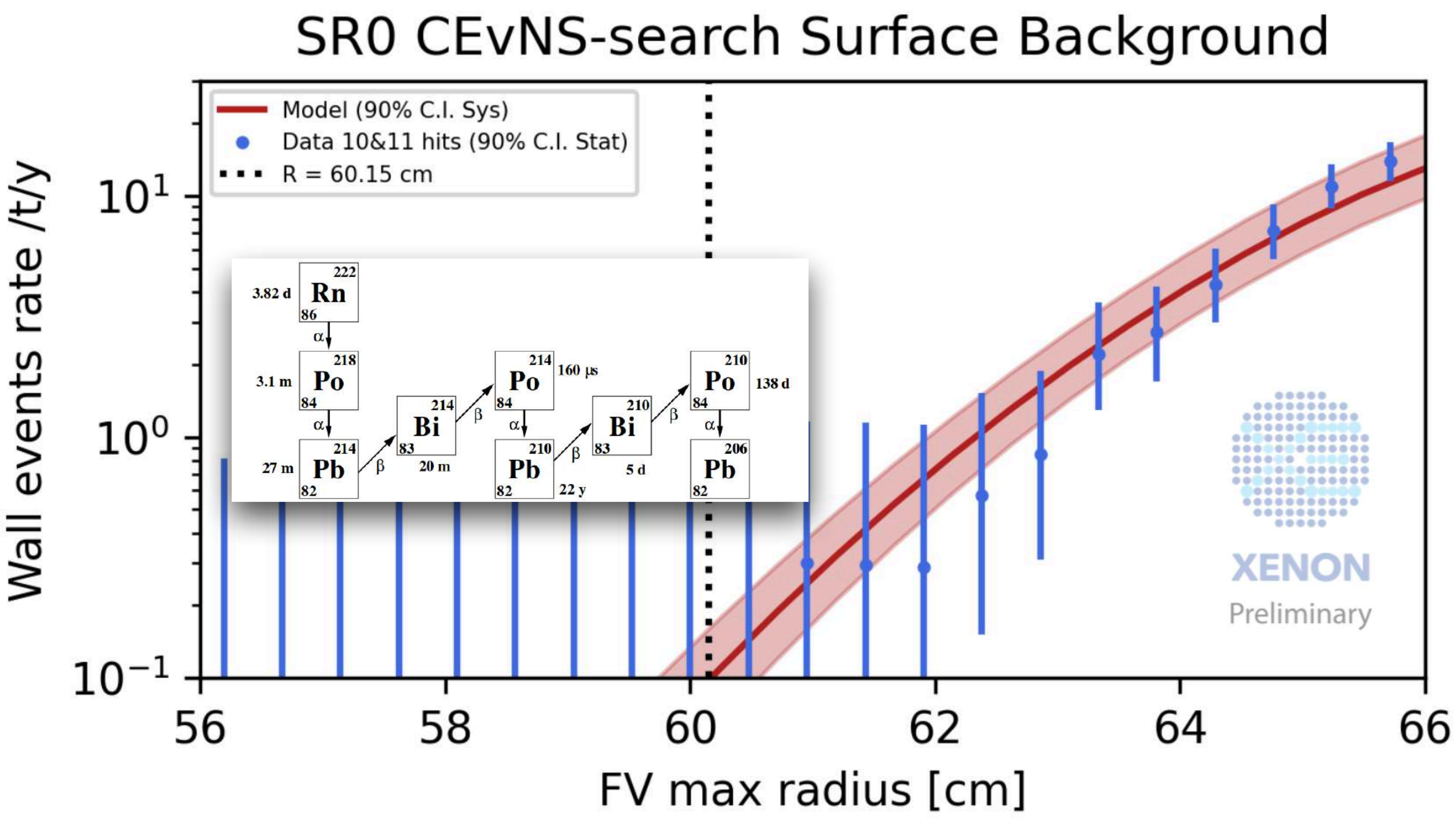


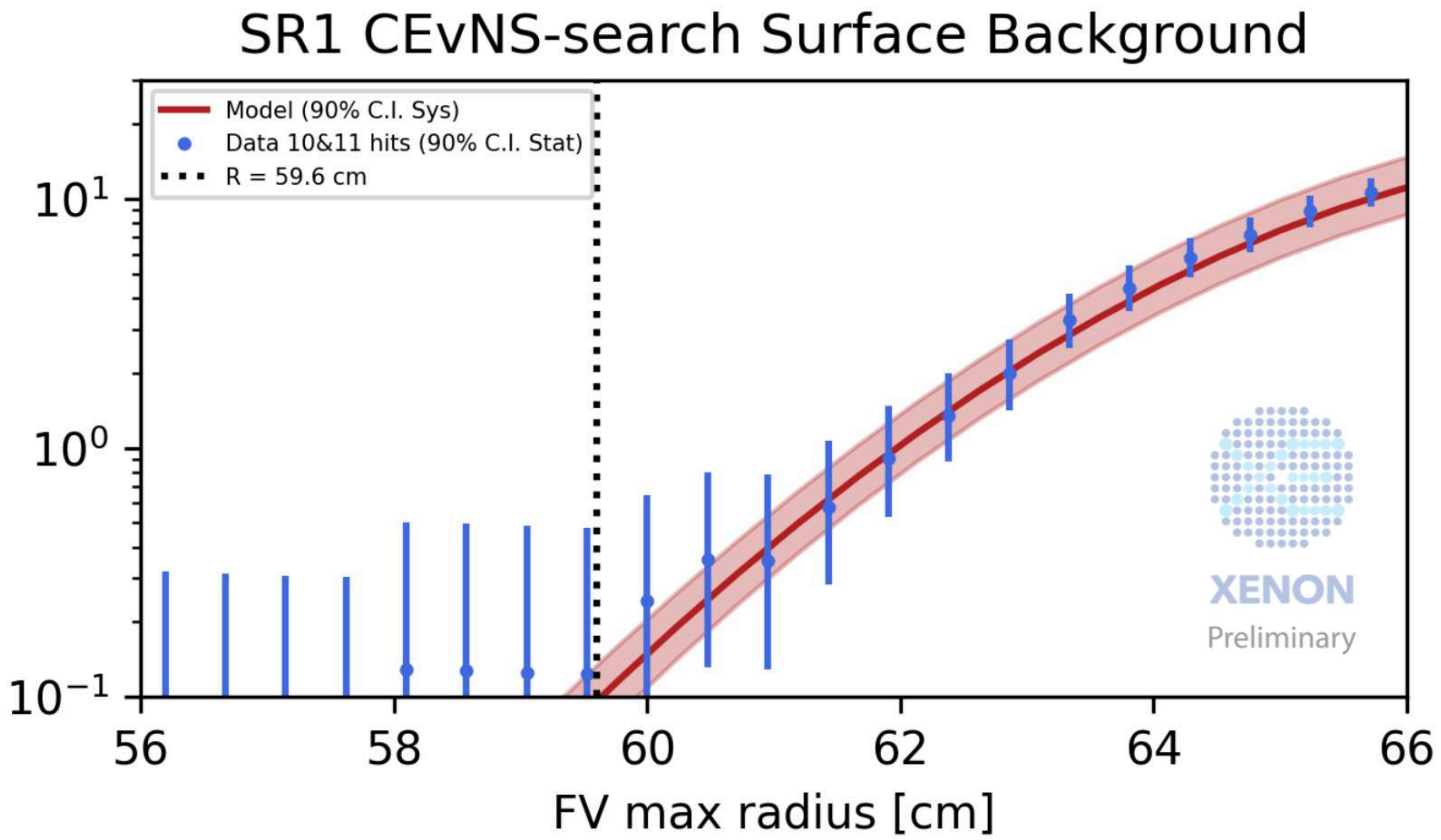
Science Run	g1 [PE/ph]	g2 [PE/e]
SR0	0.1515 ± 0.0014	16.45 ± 0.64
SR1	0.1367 ± 0.0010	16.85 ± 0.46

- $S1 = g_1 \times n_\gamma$ (photon detection efficiency)
- $S2 = g_2 \times n_e$ (charge amplification)

Surface Background

Sig. 1 2 : Bkg. 0 1





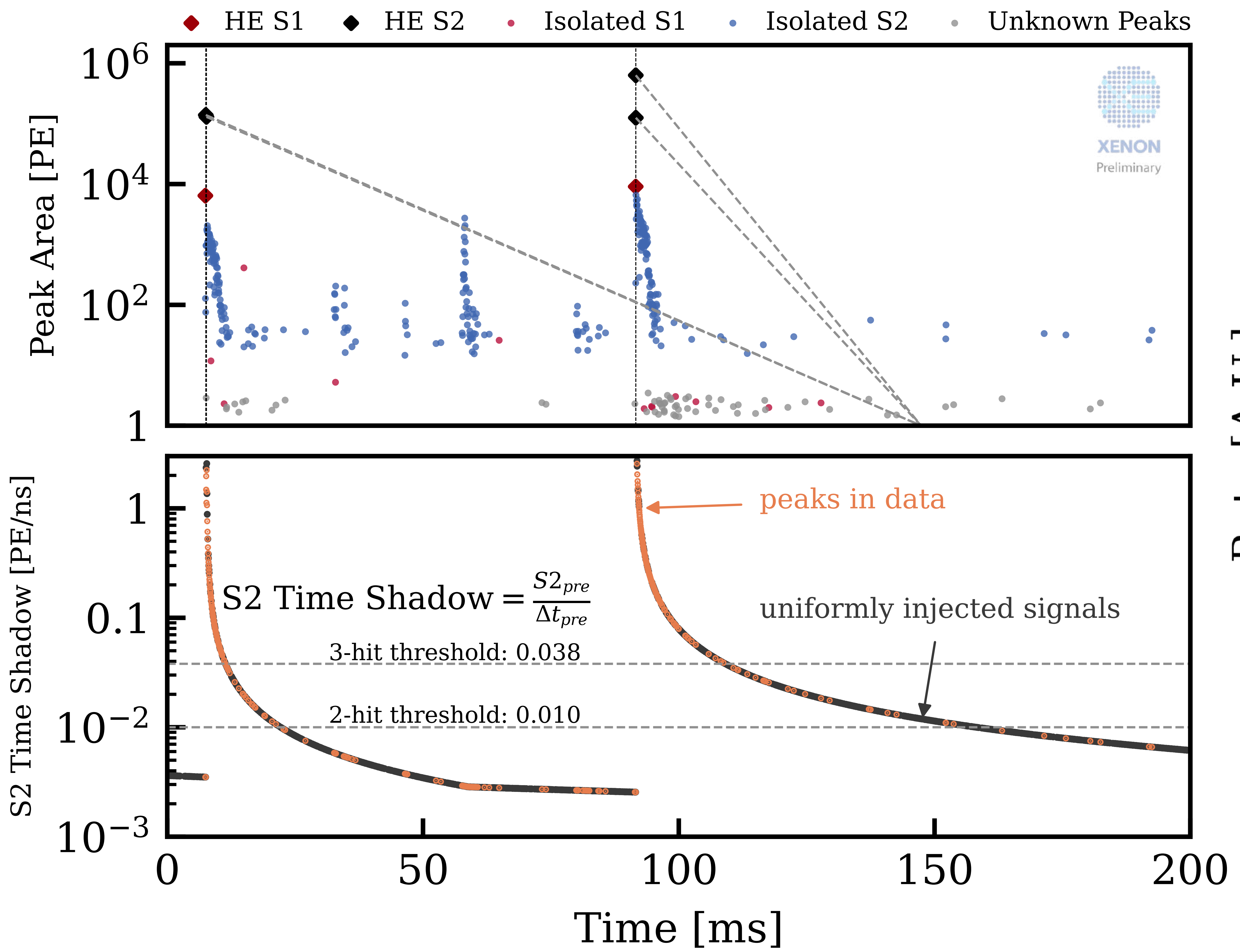
A radial cut is placed to reduce the background on the inner surface of the PTFE panels

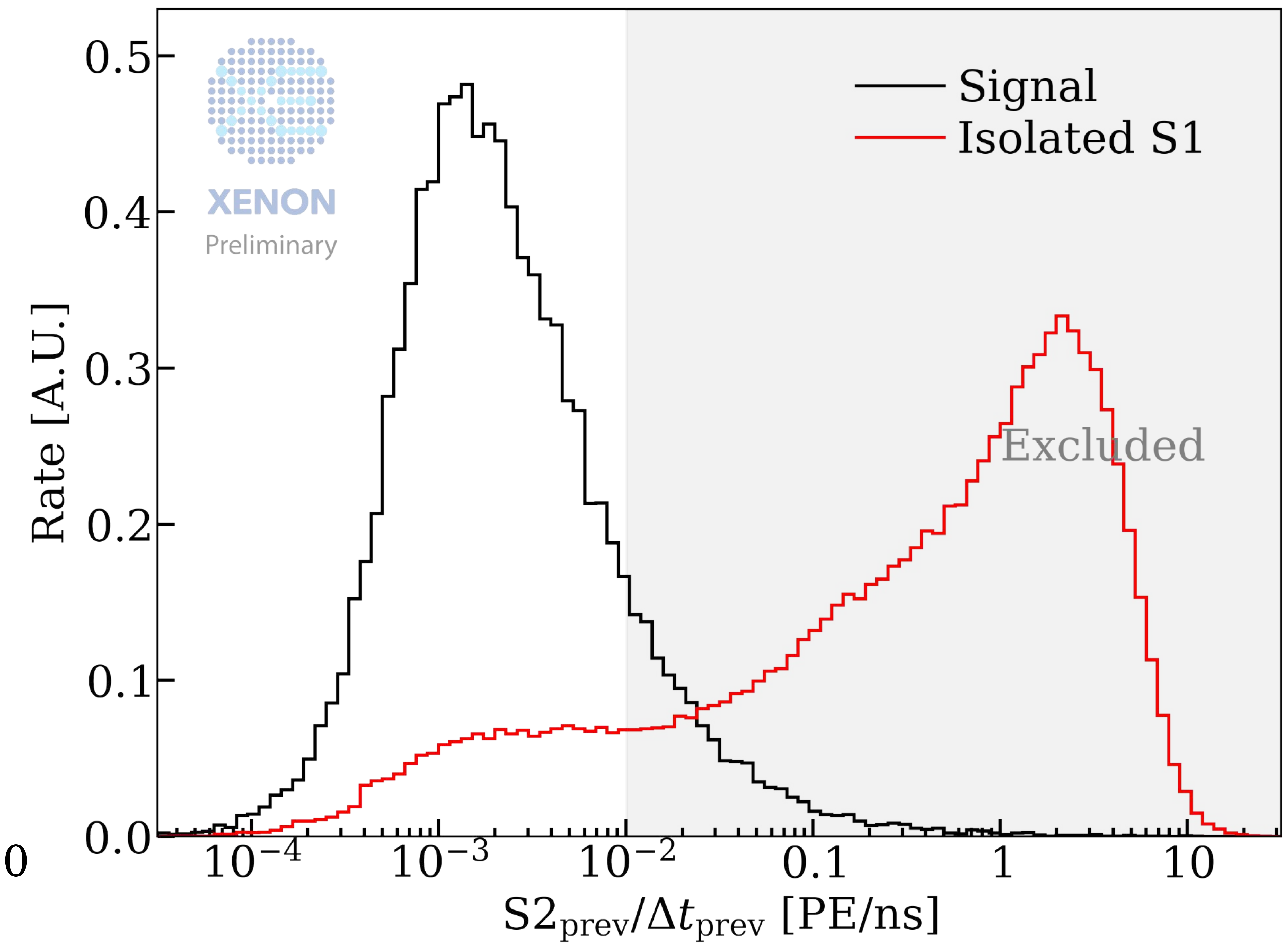
Final background prediction:

- SR0: 0 (< 0.12 Events), $R_{max} = 60.15$cm
- SR1: 0 (< 0.23 Events), $R_{max} = 59.60$cm

A negligible component in this analysis

Time Shadow - Quantify the cleanliness of the exposure

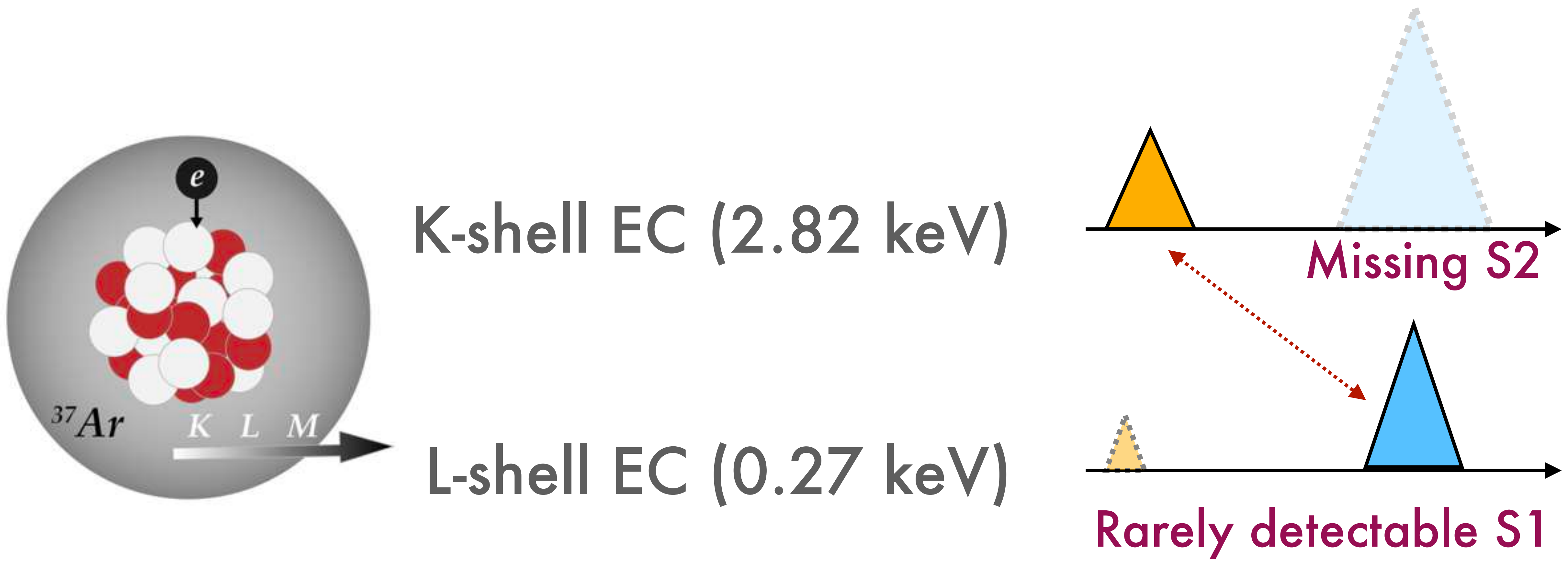




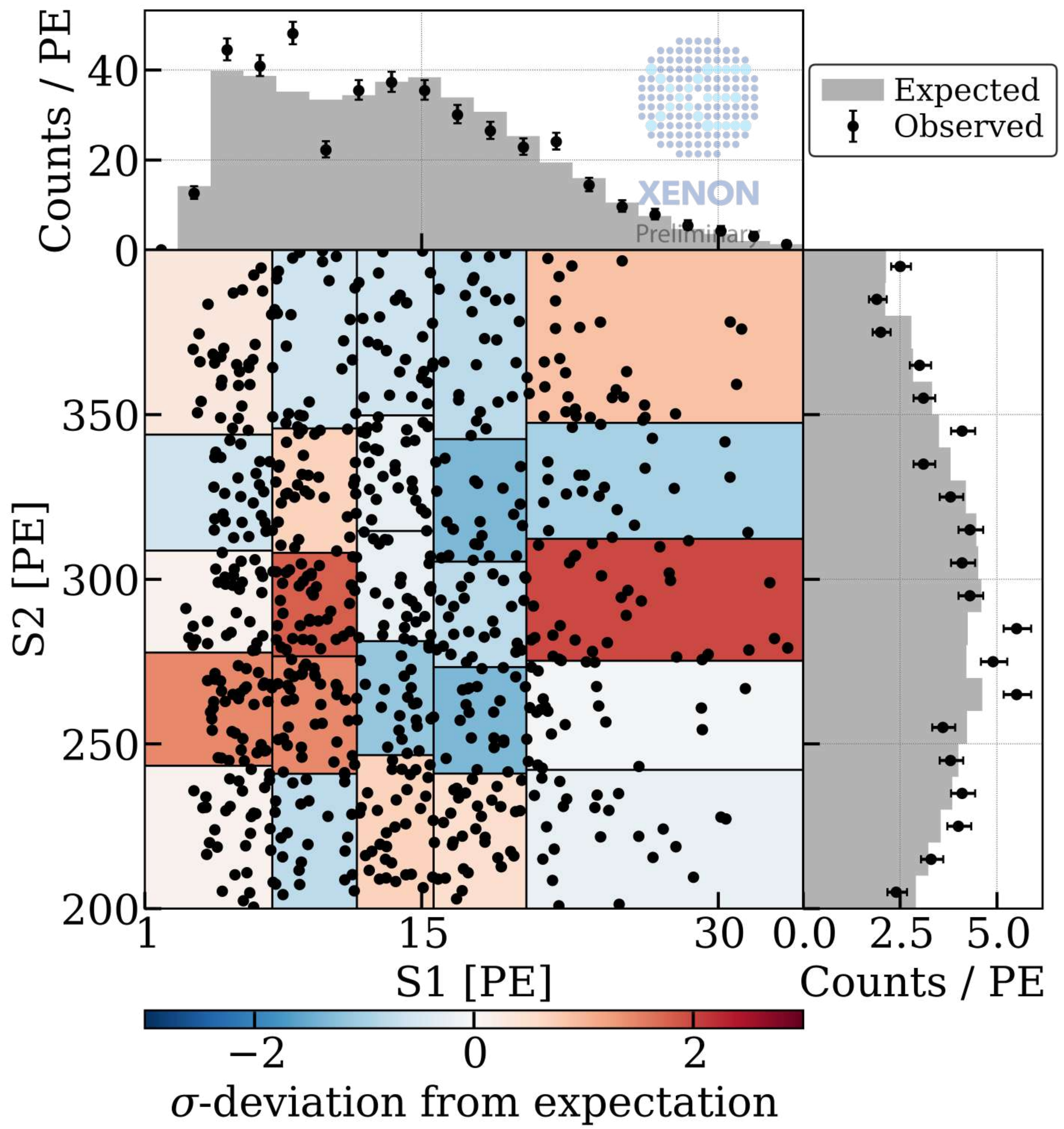
Also use Shadow as an analysis dimension in the final inference

Find AC in ^{37}Ar datasets

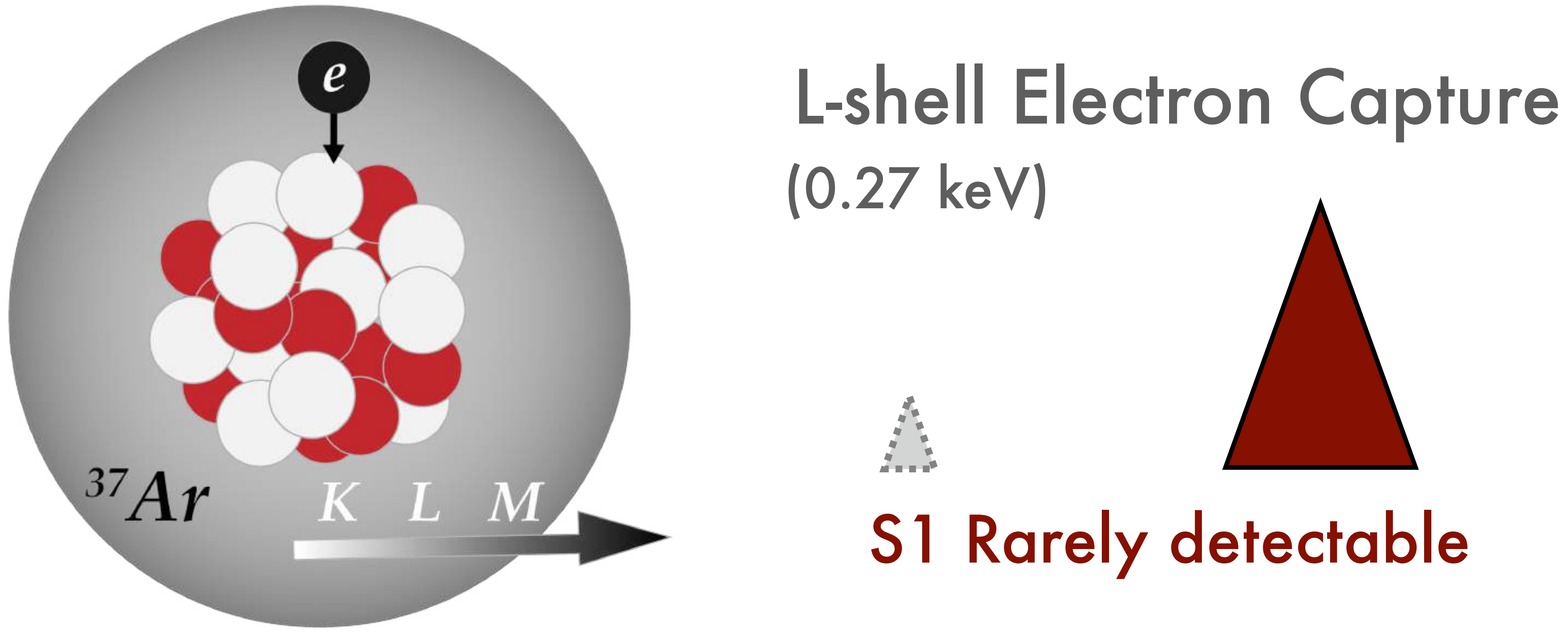
Provide High AC Counts to validate the framework

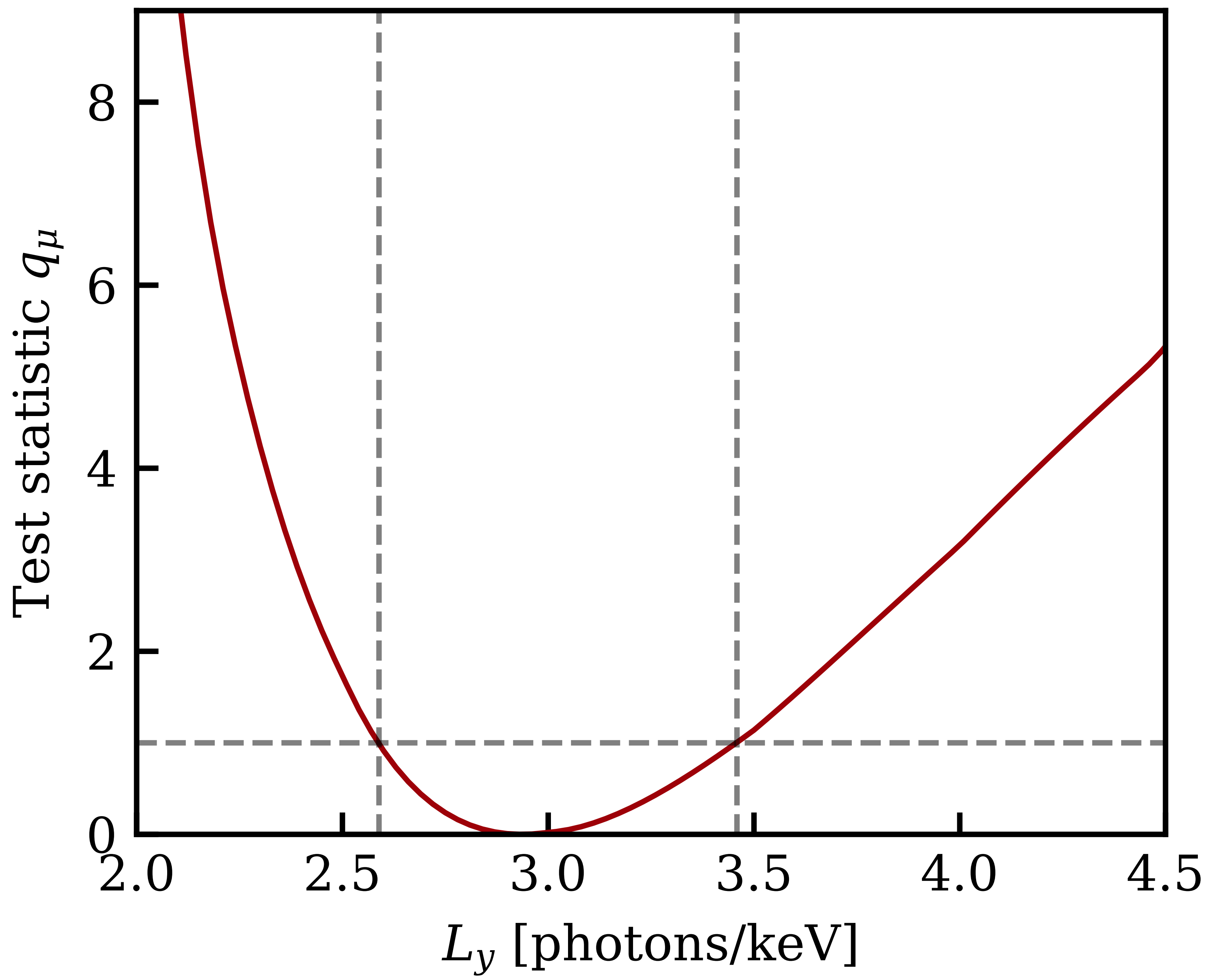


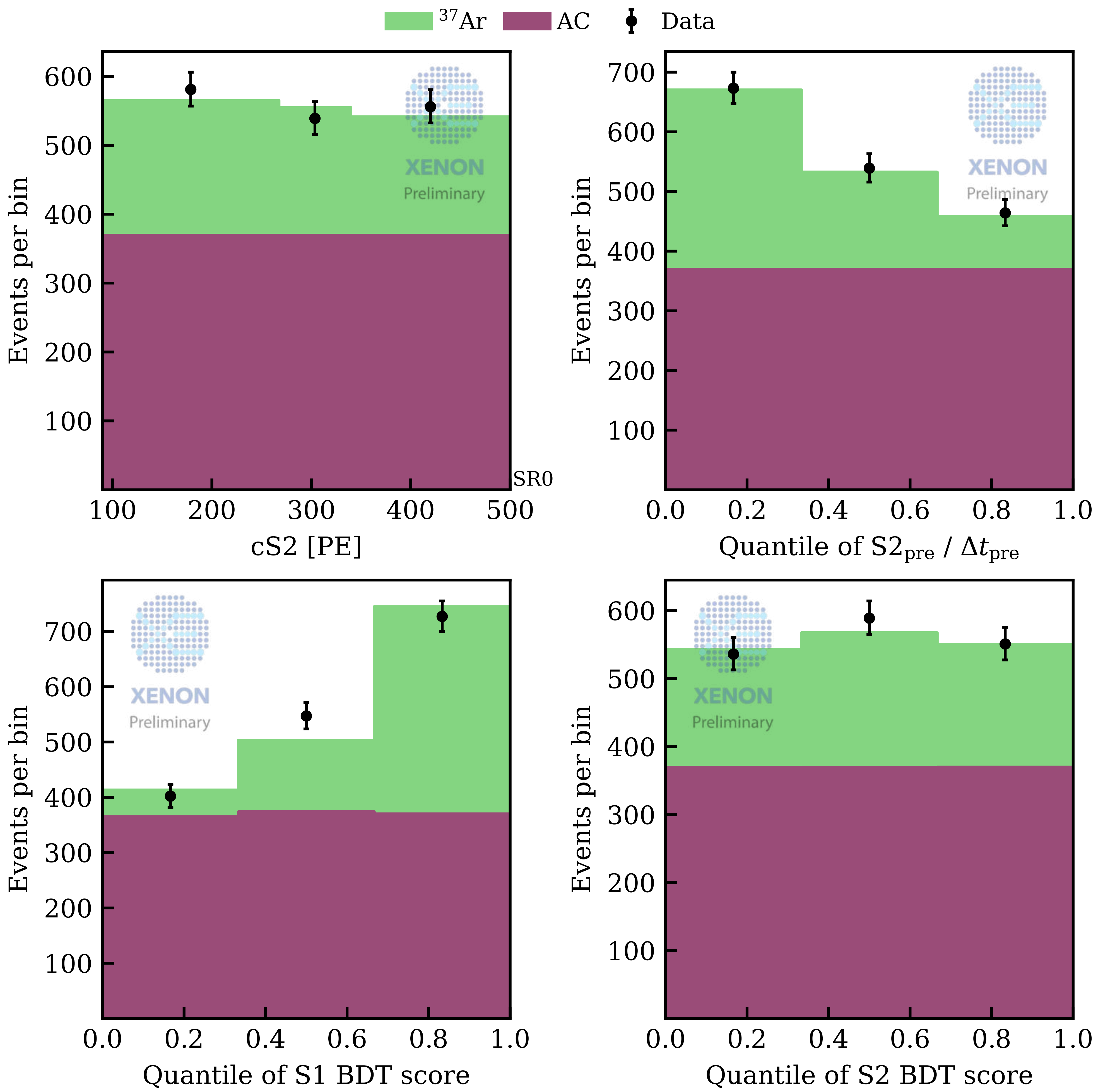
Dataset	Predicted	Observed
PureAC	1522.7	1459
In-ROI	731.6	733
ACSideband	349.7	366



Analysis Validation by Search for ^{37}Ar L-Shell





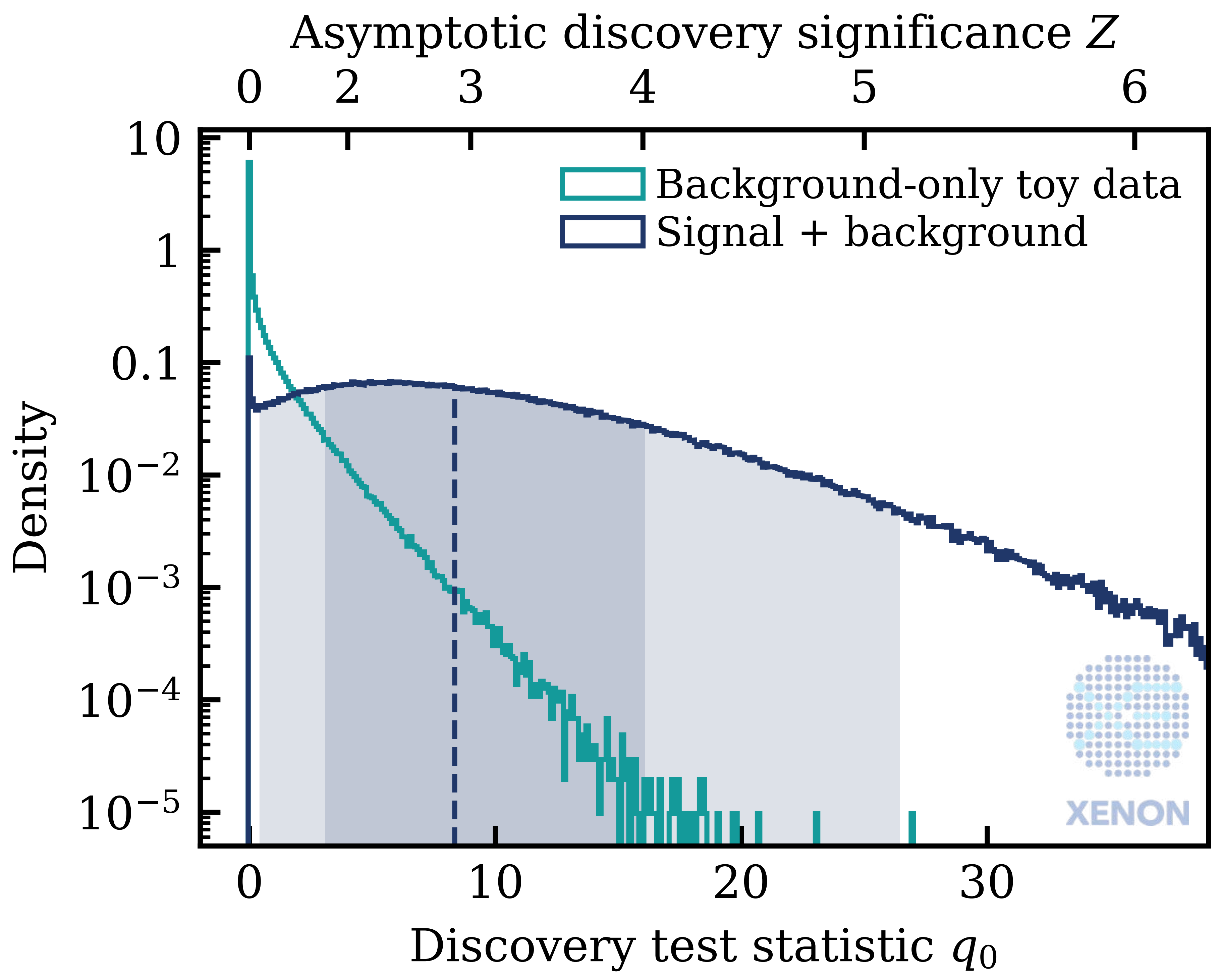


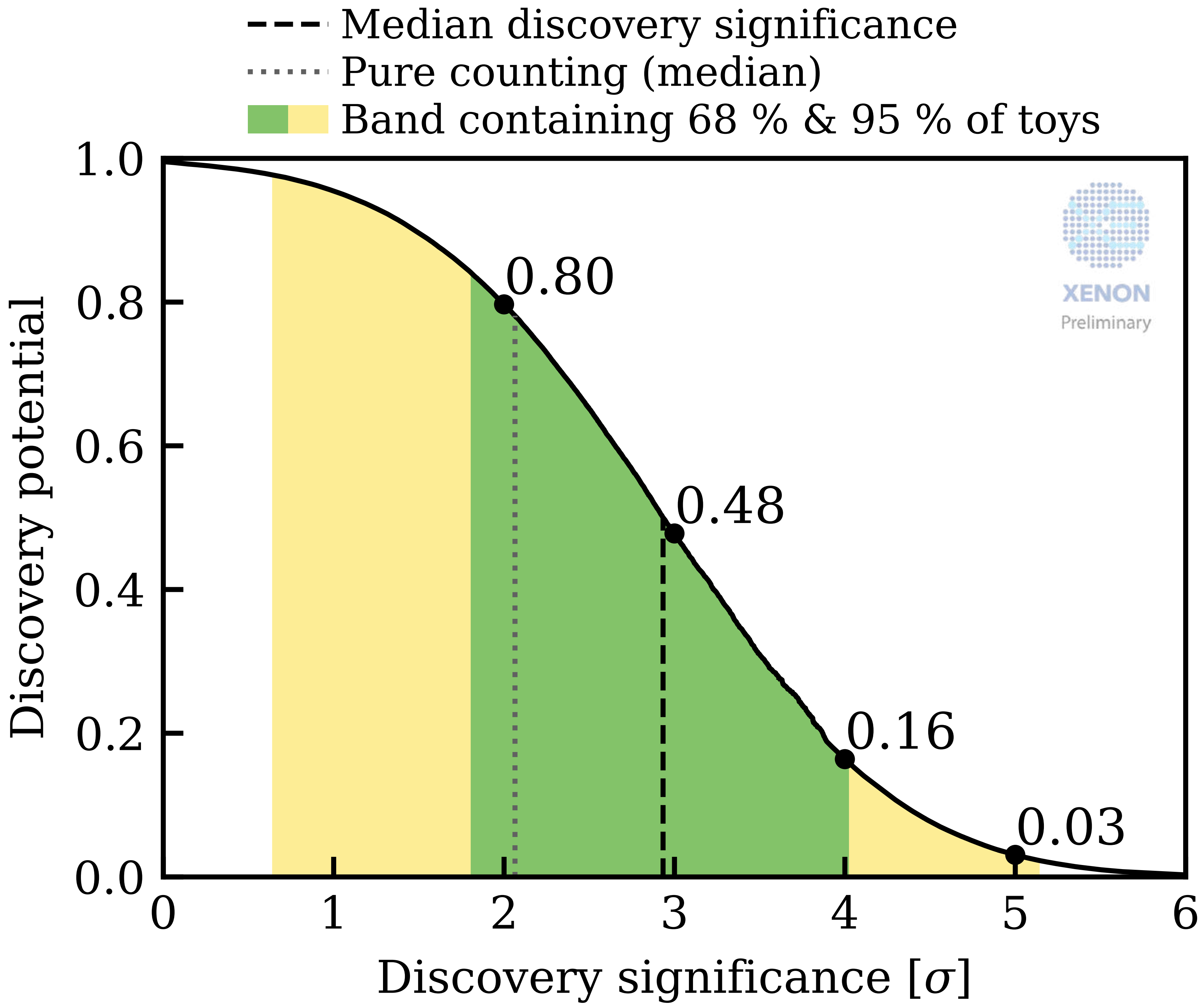
Extended binned likelihood with $3^4 = 81$ bins

4D GoF p-value: 0.7

Final Prediction & Projected Discovery Potential

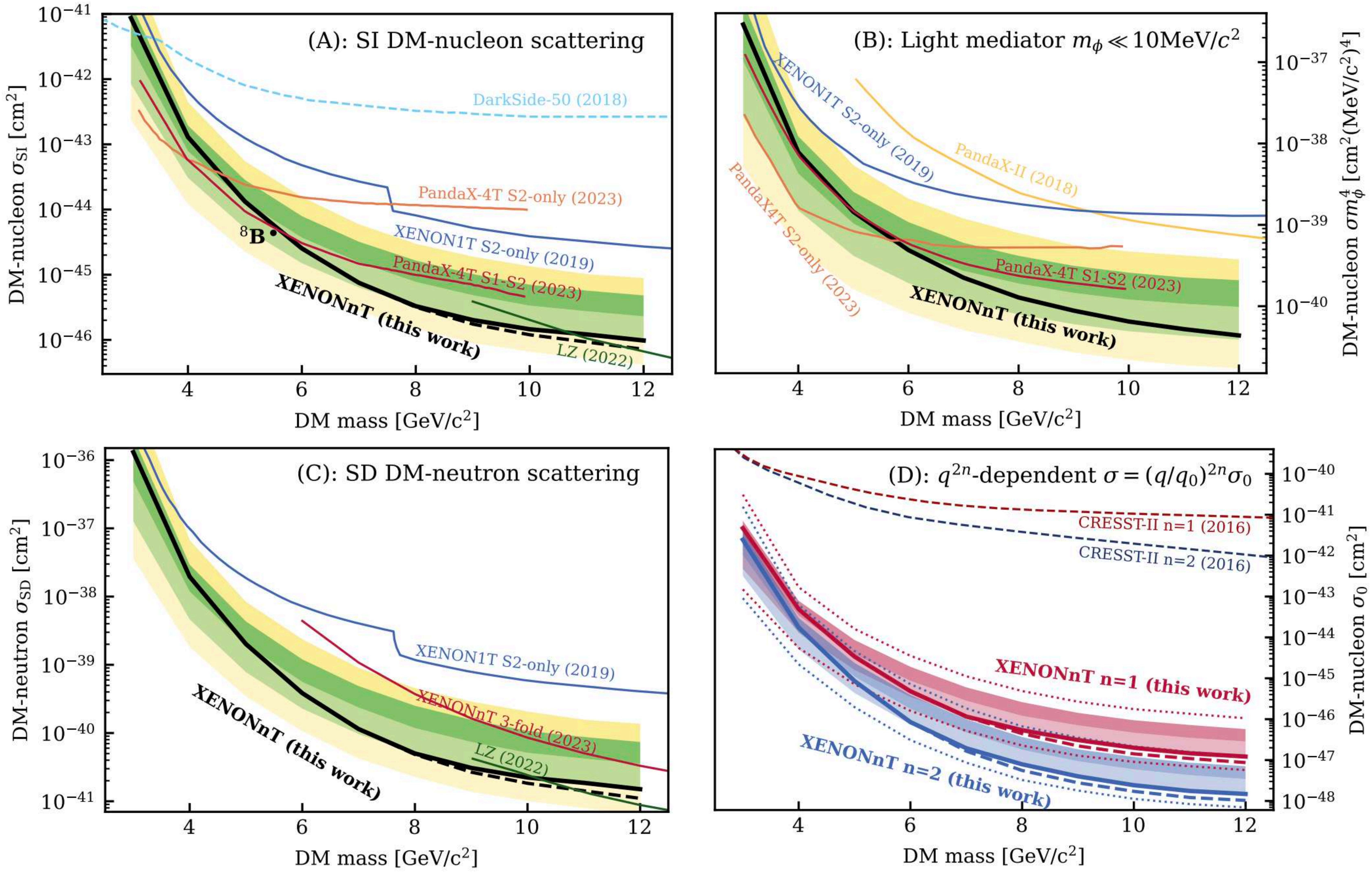
Component	Rate [Events]
AC - SR0	7.5 ± 0.7
AC - SR1	17.8 ± 1.0
ER	0.7 ± 0.7
NR	0.5 ± 0.3
Total Background	26.4 ± 1.4
^{8}B	11.9 ± 4.5





We expect to see solar ^{8}B neutrinos at $>2(3)\sigma$ significance with a probability of 0.80 (0.48), with a full 4-D analysis

First Search for Light Dark Matter in the Neutrino Fog with XENONnT



arXiv 2409.17868

Submitted to PRL