



New Dark Matter search results from XENONnT with combined science runs

Maxime Pierre

On behalf of the XENON collaboration

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UNIVERSITEIT VAN AMSTERDAM



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The XENON Program

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Timeline

2006

XENON10

25 kg LXe
58.6 livedays
BG: 600 / (t.d.keV)

2008

XENON100

160 kg LXe
477 livedays
BG: 5.3 / (t.d.keV)

2015

XENON1T

3200 kg LXe
279 livedays
BG: 0.2 / (t.d.keV)

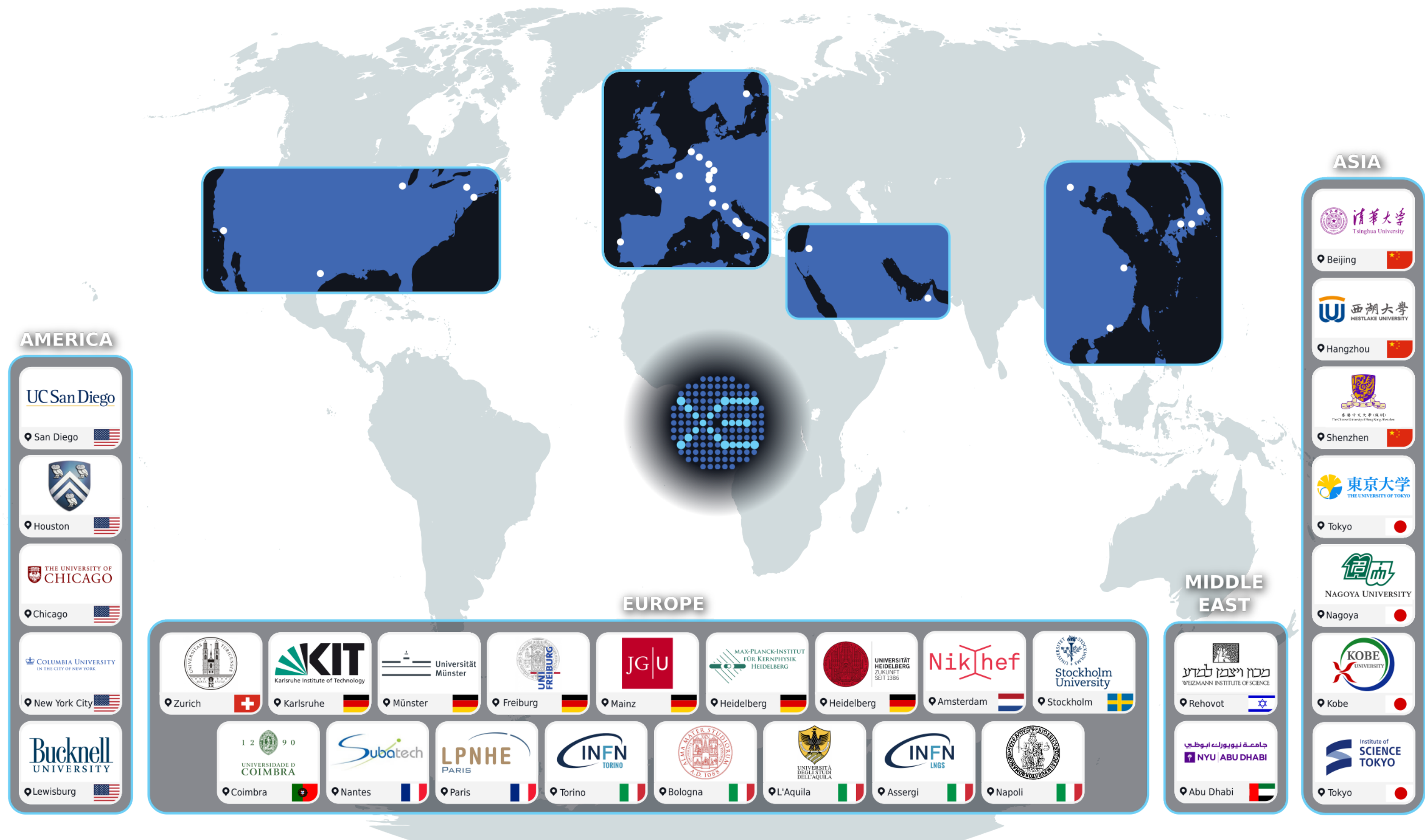
2020

XENONnT

8600 kg LXe
300+ livedays
BG: 0.04 / (t.d.keV)

(ongoing)

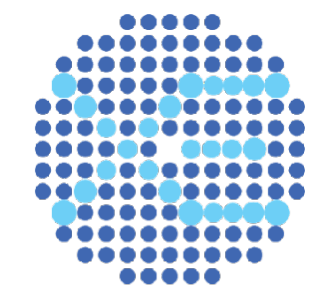
Lowest ER background level ever
achieved in LXe based experiment



200+ Scientists

31 Institutions

12 Countries



Dark Matter (DM)
direct search with
liquid xenon

Deep Underground @ INFN Laboratory
Nazionali Del Gran Sasso in Italy
1.4 km depth - 3600 mwe

3 Nested Detectors Inside 700 t Water Tank

1 Muon Veto

**Active Gd-water
Cherenkov muon veto:**
muon-induced neutrons

Passive veto: γ and n
from **natural
radioactivity**

84 8" high-QE PMTs

[JINST 9, P11006 \(2014\)](#)

2 Neutron Veto

**Active Gd-water
Cherenkov neutron
veto:** radiogenic
neutrons

33 m³ volume around
cryostat

120 8" high-QE PMTs

[Eur. Phys. J. C 85 \(2025\) 695](#)

3 Time Projection Chamber

Dual-phase Xe TPC

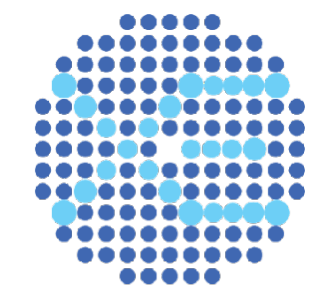
5.9 t active target,
8.6 t total mass

1.5 m drift length,
1.3 m diameter

494 3" PMTs

[Eur. Phys. J. C 84 \(2024\) 784](#)

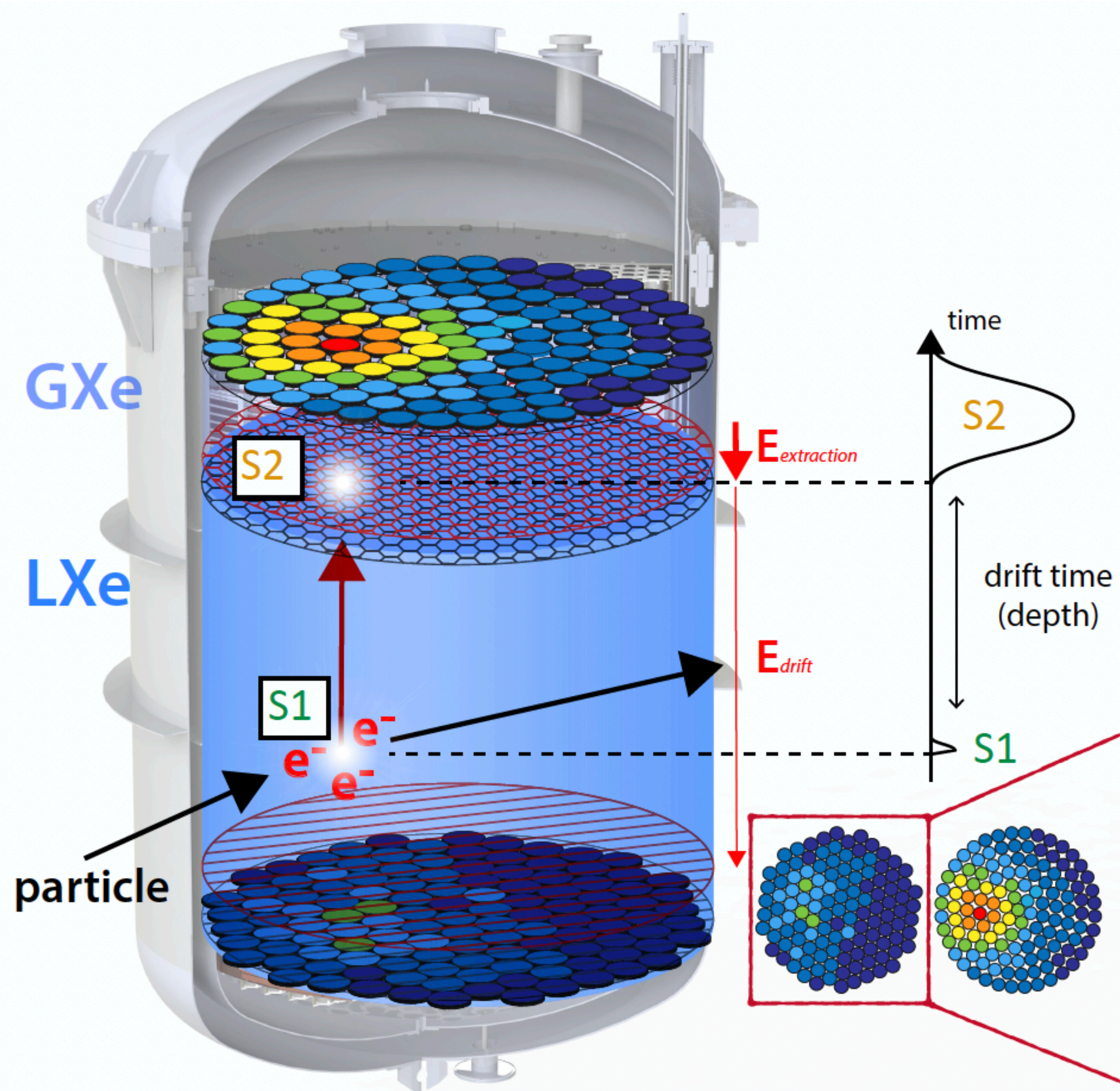




XENON TPC in a nutshell

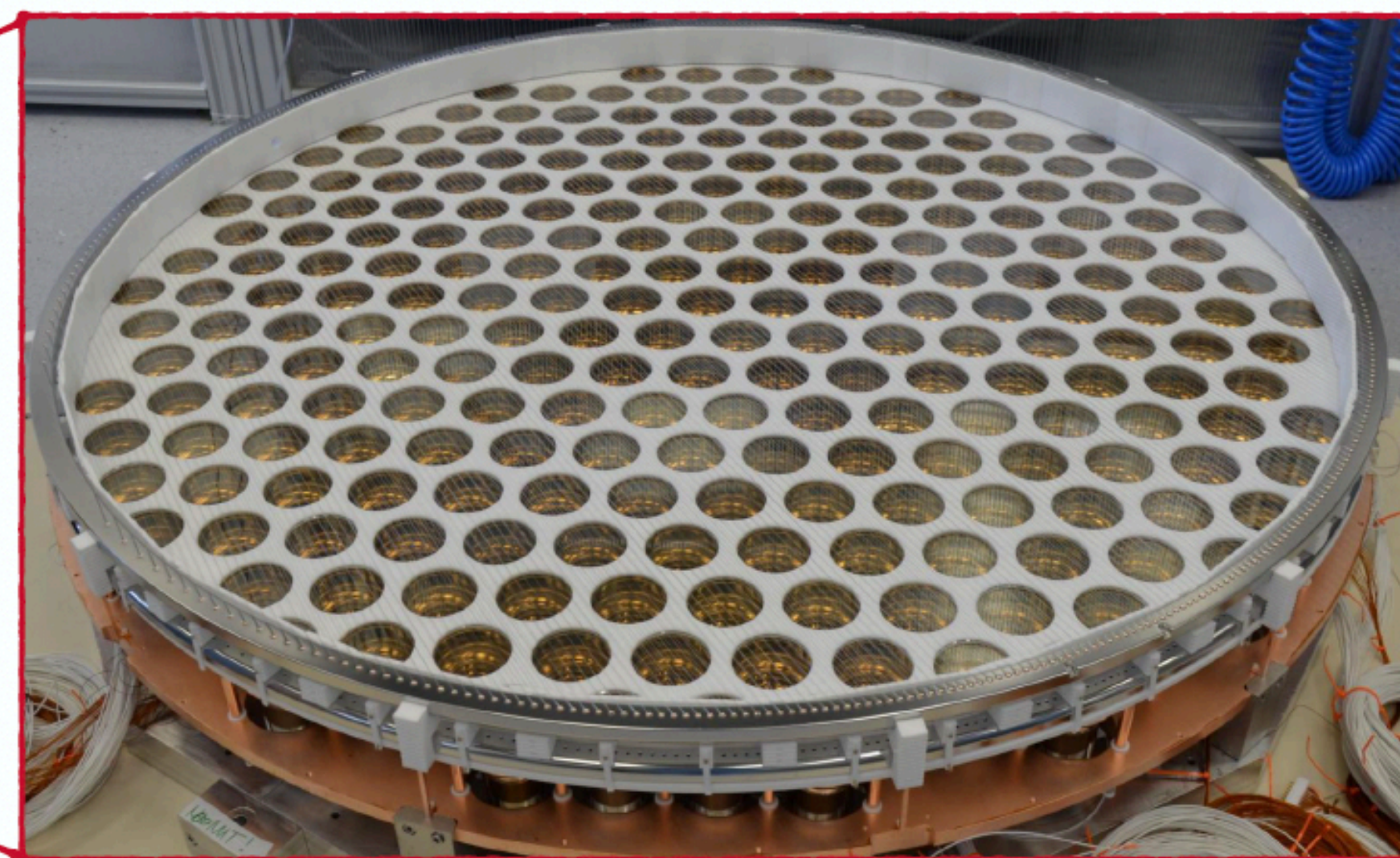
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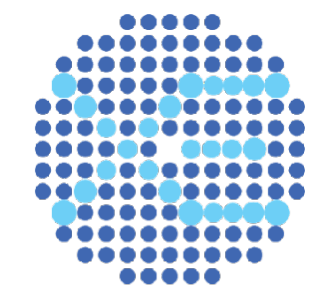
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Light and Charge readout

- Prompt scintillation signal (**S1**)
- Secondary proportional scintillation signal in GXe from drifted electrons (**S2**)



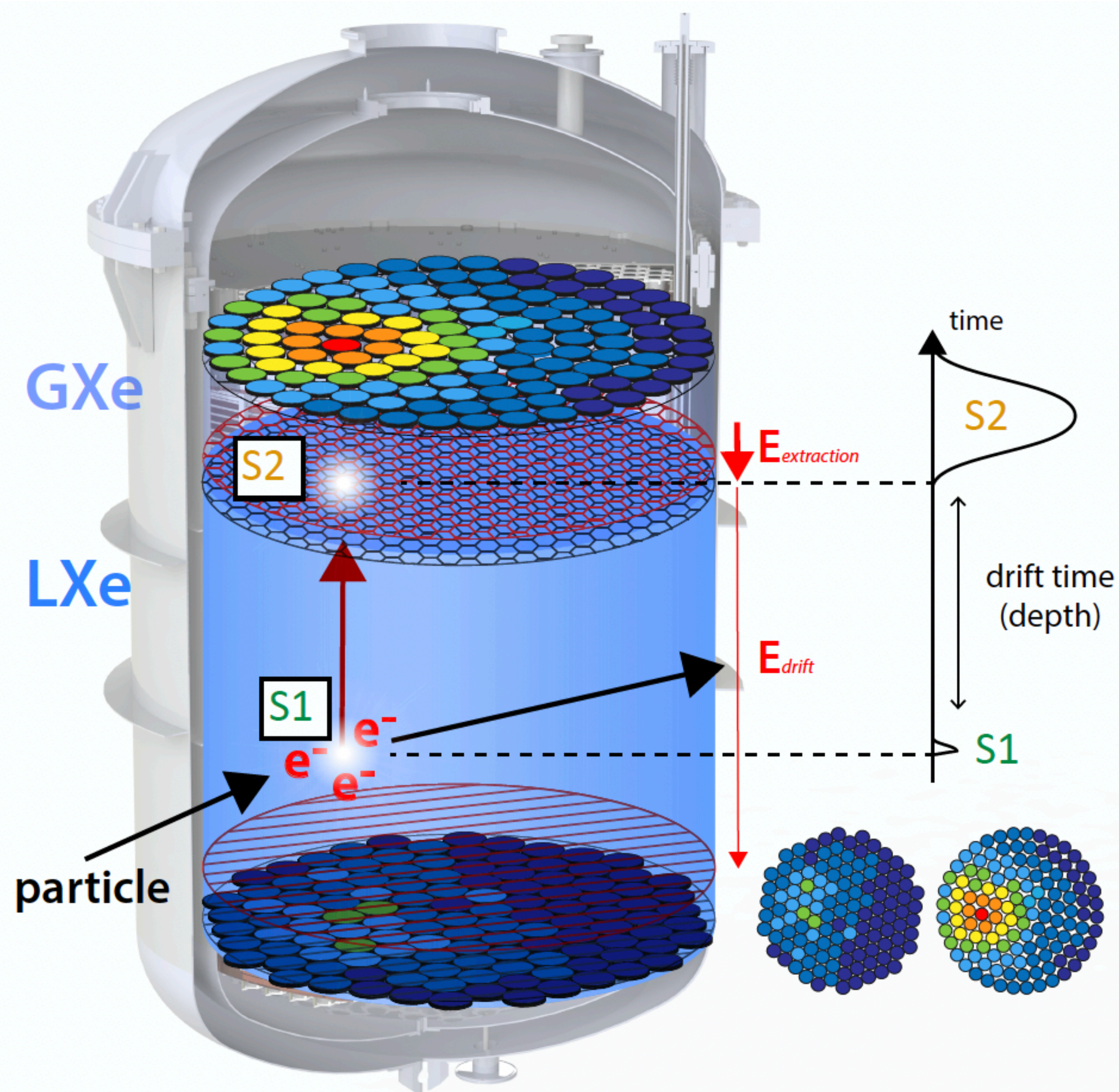


XENON TPC in a nutshell

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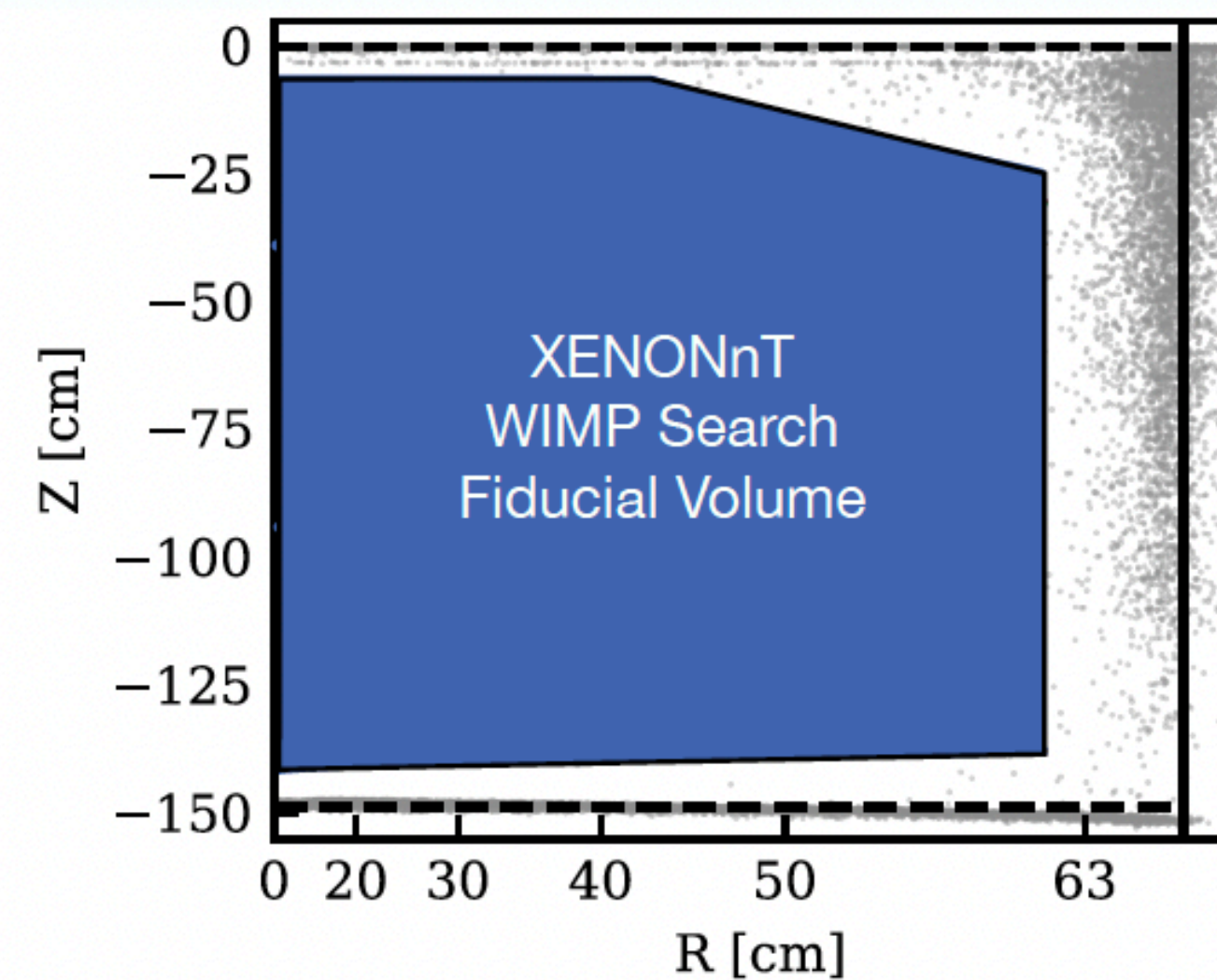


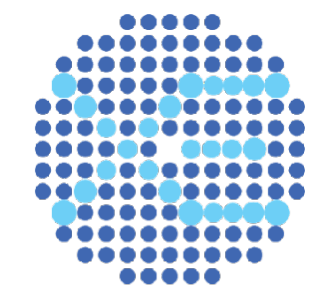
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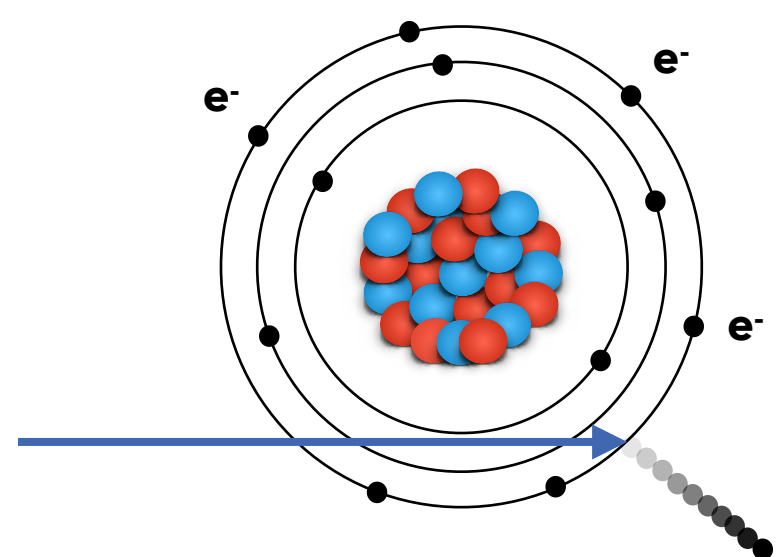
Event reconstruction

- **3D Position:**
 - Z from drift time
 - (X, Y) from PMTs hit pattern
- **Energy** → $E = W \cdot (n_{ph} + n_e)$

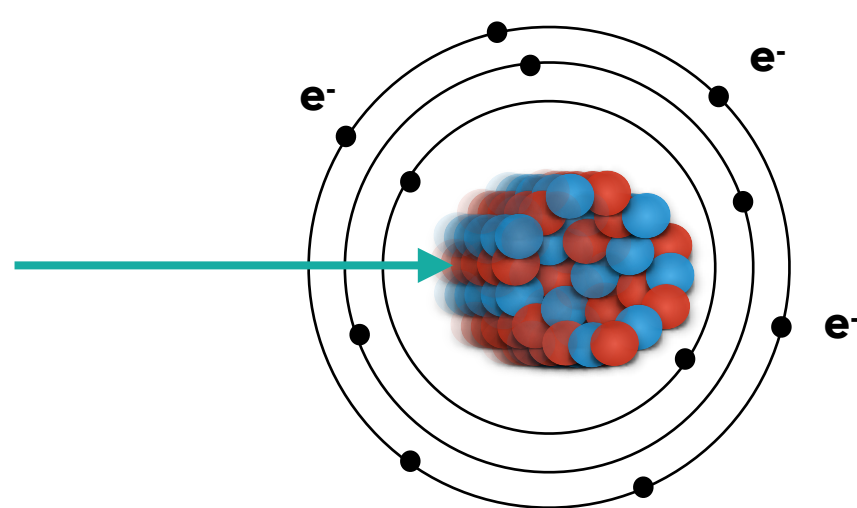




Electronic Recoil (ER)



Nuclear Recoil (NR)



ER	✗ Gamma and Beta
	✓/✗ Double Weak Decay
	✓/✗ Neutrino elastic scattering
	✓ Solar axions, ALPs

NR	✗ Neutrons
	✓/✗ Neutrinos (CEνNS)
	✓ WIMPs

✓ Signal ✗ Background

Light and Charge readout

- Prompt scintillation signal (**S1**)
- Secondary proportional scintillation signal in GXe from drifted electrons (**S2**)

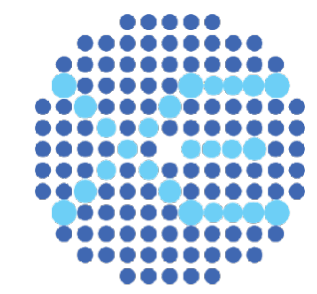
Event reconstruction

- **3D Position:**
 - Z from drift time
 - (X, Y) from PMTs hit pattern
- **Energy** → $E = W \cdot (n_{ph} + n_e)$

Particle discrimination

- Interaction type **Nuclear Recoil (NR)/Electronic Recoil (ER)** through **S1/S2** ratio

$$\left(\frac{S2}{S1} \right)_{NR} < \left(\frac{S2}{S1} \right)_{ER}$$



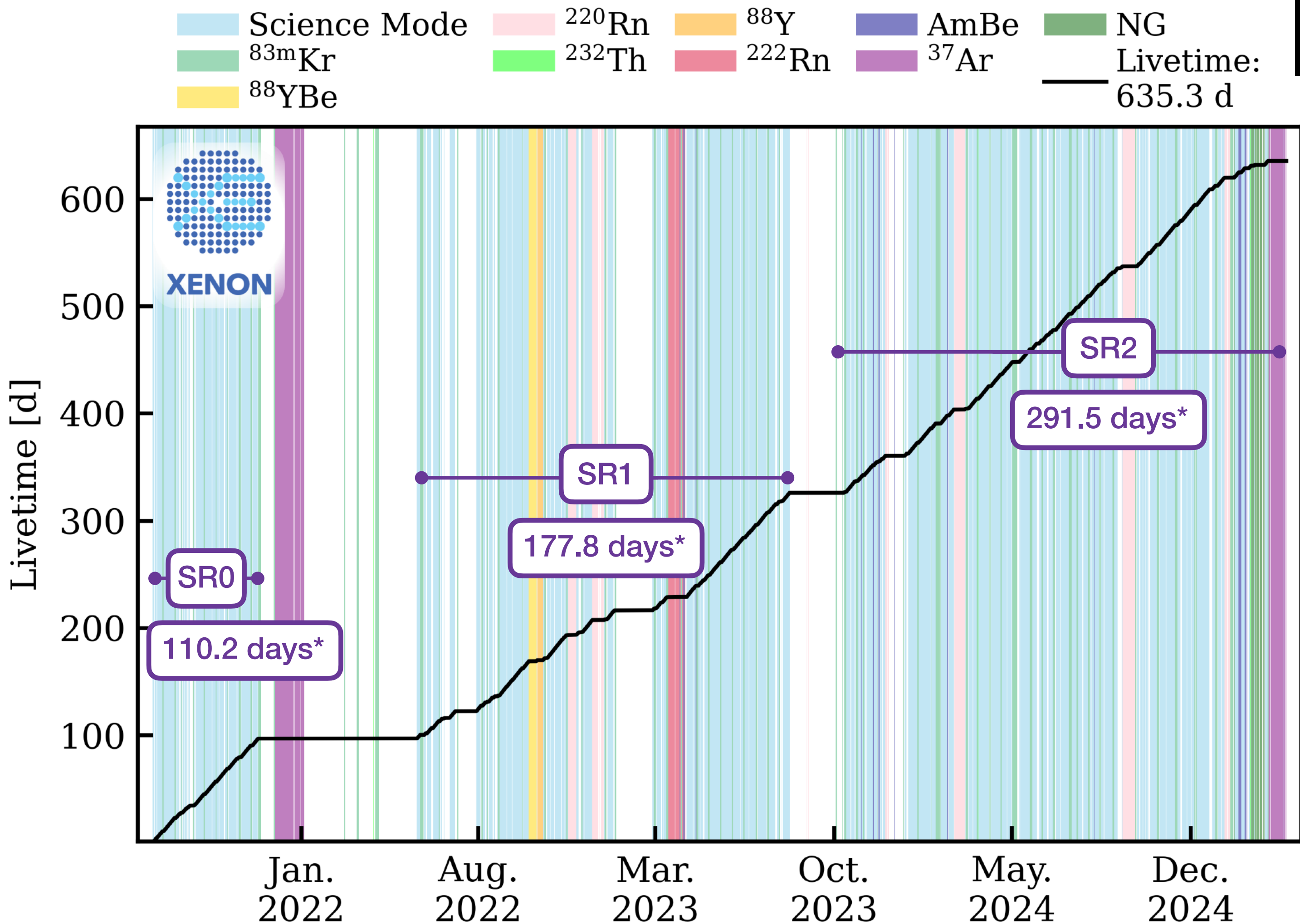
Science Data Overview

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Stable Light (Charge) Yield: variation < 1% (3%)



Continuous Rn online distillation

$^{222}\text{Rn}_{\text{SR0}}$: 1.9 $\mu\text{Bq/kg}$

$^{222}\text{Rn}_{\text{SR1}}$: **0.9 $\mu\text{Bq/kg}$**

[Eur. Phys. J. C 82 \(2022\) 1104](#)

Kr distillation

natKr/Xe concentration < **50 ppq**

[Eur. Phys. J. C 77 \(2017\) 275](#)

LXe Purification

Electron Lifetime > **10 ms**

[Eur. Phys. J. C 82 \(2022\) 860](#)

Triggerless DAQ

DAQ shared between three detectors

Improve low-energy sensitivity

[JINST 18, P07054 \(2023\)](#)

Milestones Highlights

*Used in the result presented in this talk: 579.5 days

And More! See E. Angelino Talk on neutron Veto performance



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Various DM Region Of Interest

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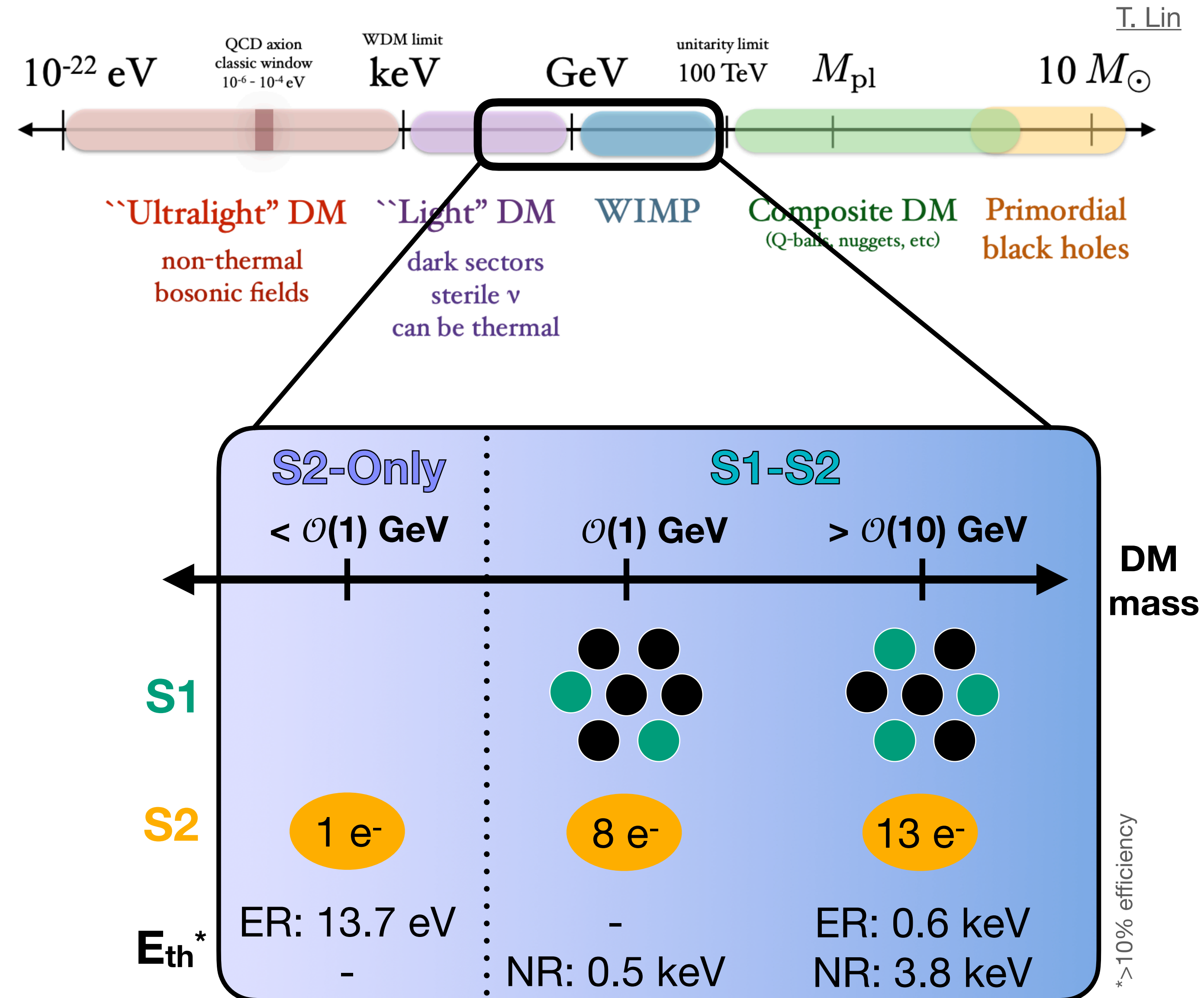
Probe lower mass DM $\rightarrow$ lower $E_{\text{threshold}}$:

- Reduce requirements on S1 signals
- Migdal

3-fold S1-S2 Standard WIMP search
- Stay tuned!

2-fold S1-S2 Light WIMP & ^8B CE ν NS
- See G. Volta Talk

S2-Only Light WIMP & Sub-GeV DM
- Focus of this talk





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S2-Only **Signal** Models

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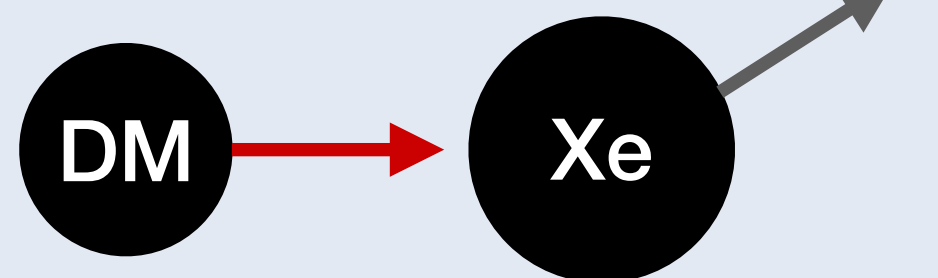
Recoil Energy Spectrum

Detector response & Efficiency

Signal Prediction

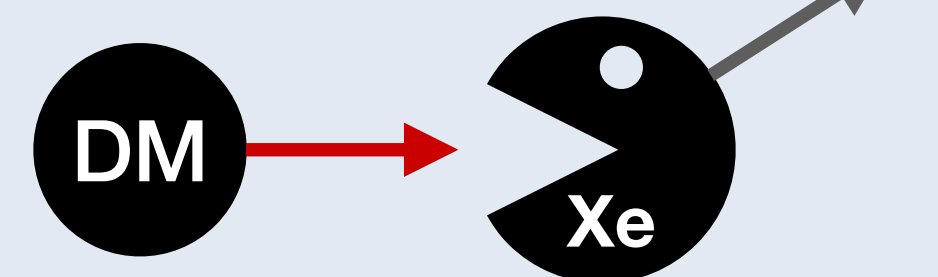
DM Candidates

Light WIMPs



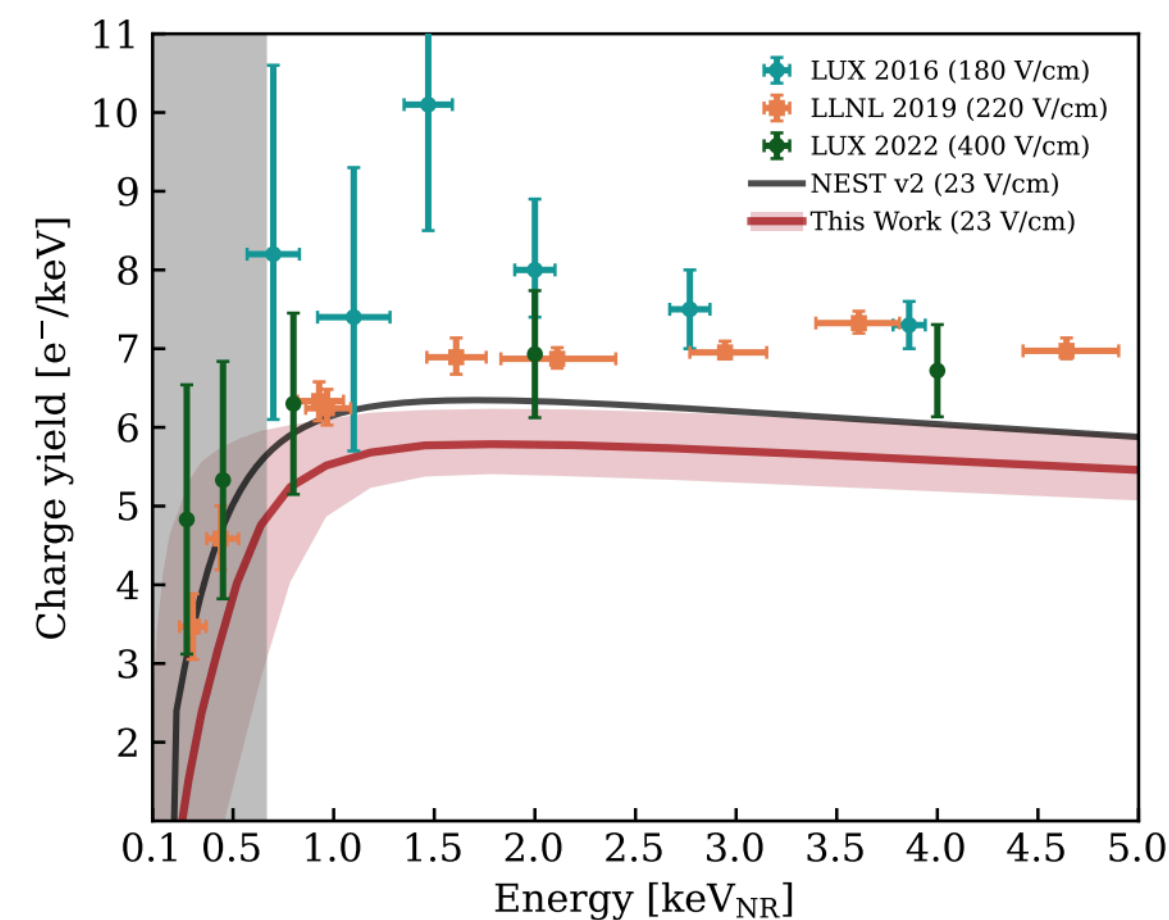
Elastic scattering

Axion-like Particle
Dark Photon

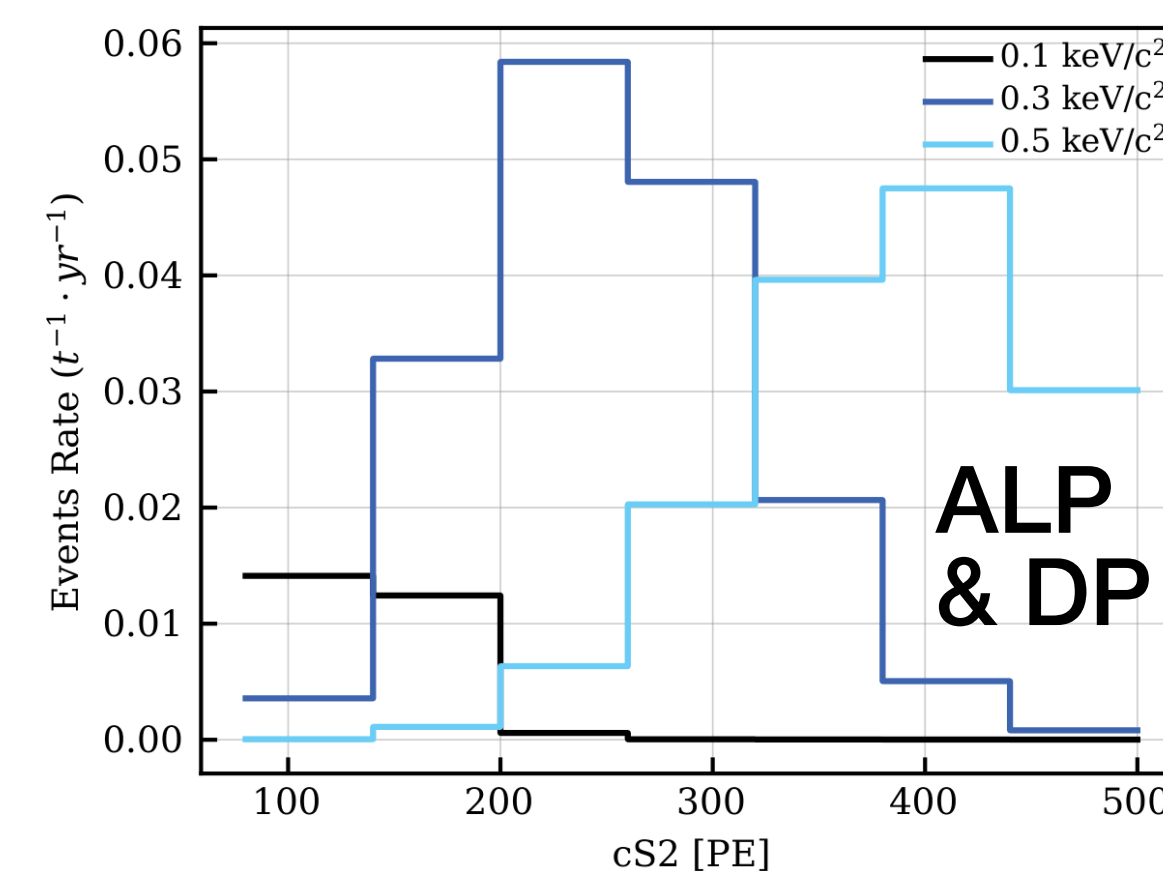
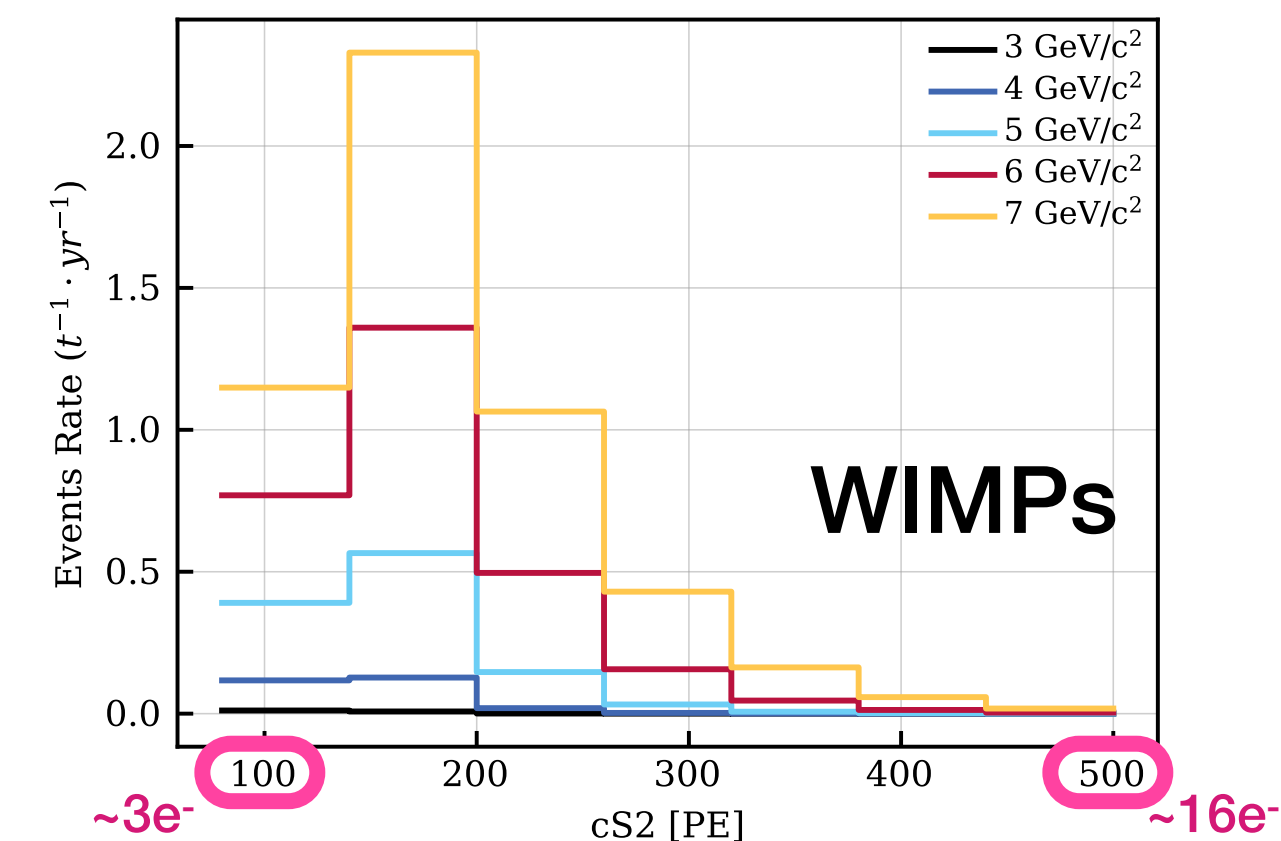
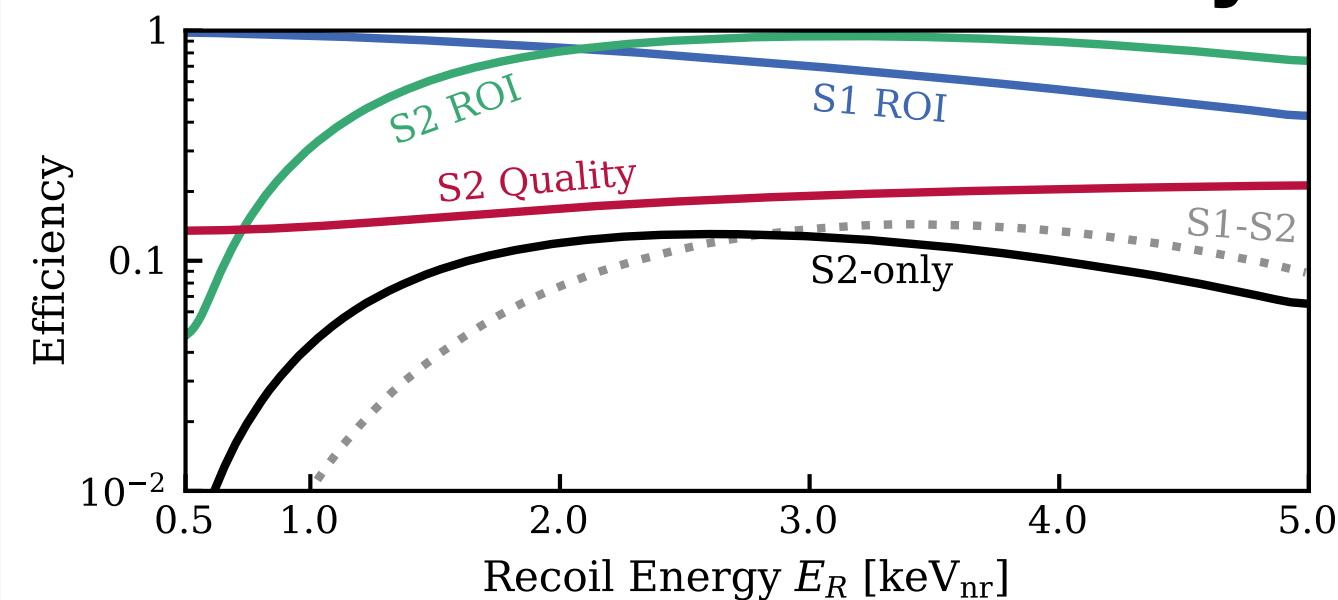


Absorption

Energy $\rightarrow$ Charge Quanta



Data Selection Efficiency





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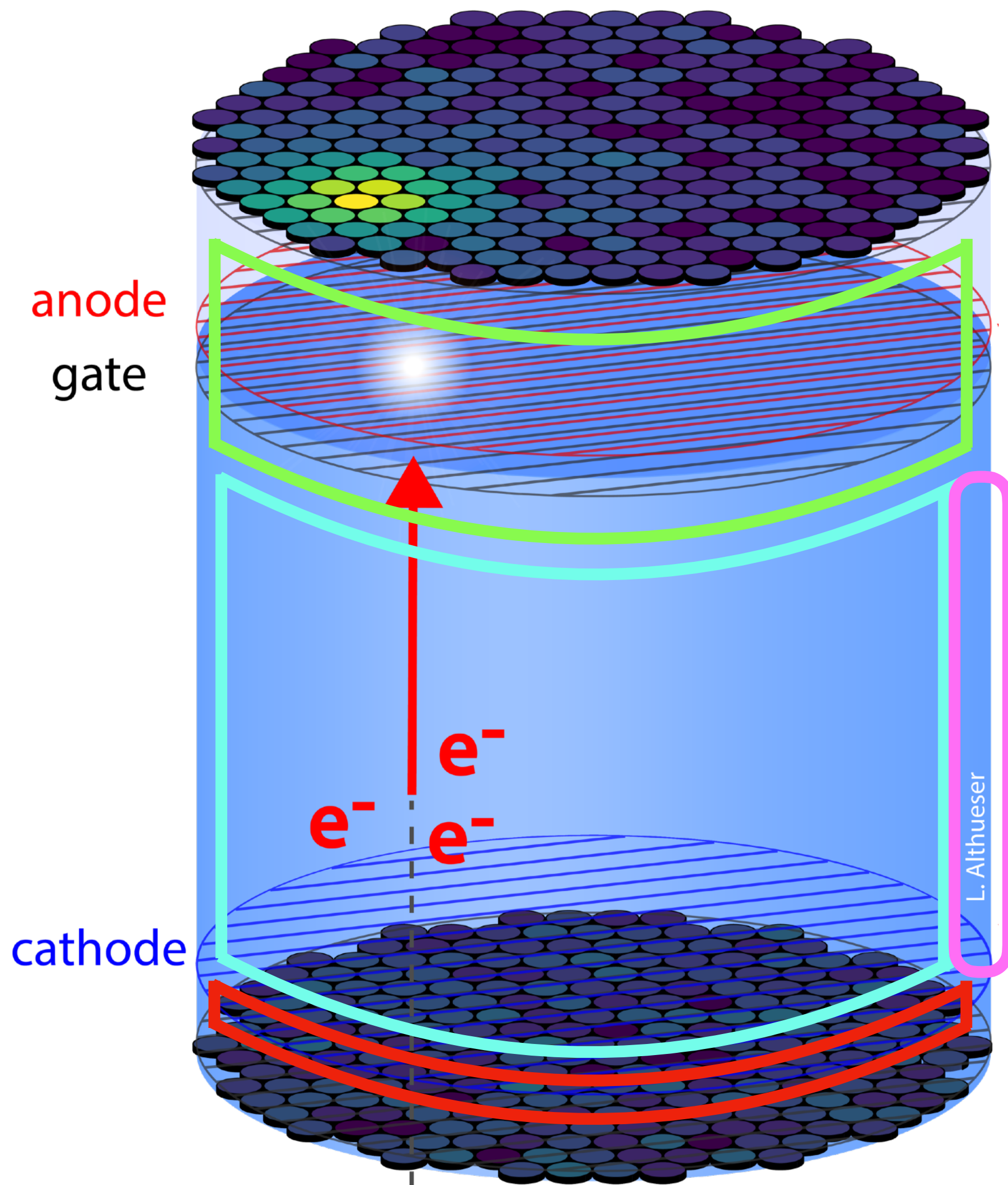
S2-Only Background Model

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Potential Background



Top electrodes + Gas region

- Radioactivity (electrodes and TPC materials)

Delayed electrons (DE) Accidental electrons (AE)

- Pile-up of electrons trapped in impurities

PTFE Wall

- Radioactivity (Plate-out on the wall)

Cathode electrodes

- Radioactivity (electrodes - ^{210}Pb)



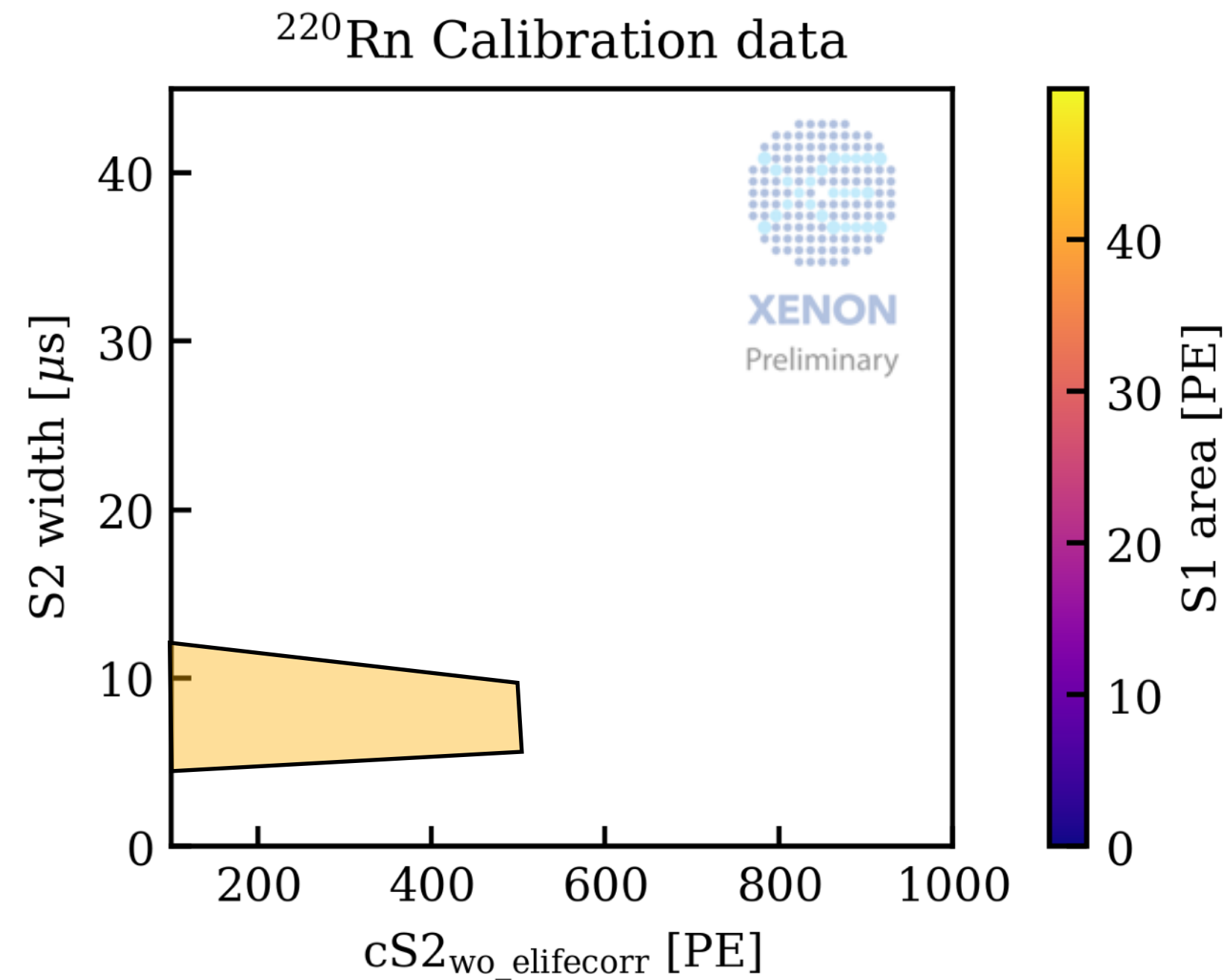
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S2-Only Background Model

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Potential Background + Mitigation Strategy



Region of Interest (ROI)

$\text{cS2} \in [100, 500] \text{ PE} \leftrightarrow [3, 16] \text{ e}^-$
 $\rightarrow [0.5, 5.0] \text{ keV}_{\text{NR}}$ and $[0.04, 0.7] \text{ keV}_{\text{ER}}$

Top electrodes + Gas region

- Radioactivity (electrodes and TPC materials)

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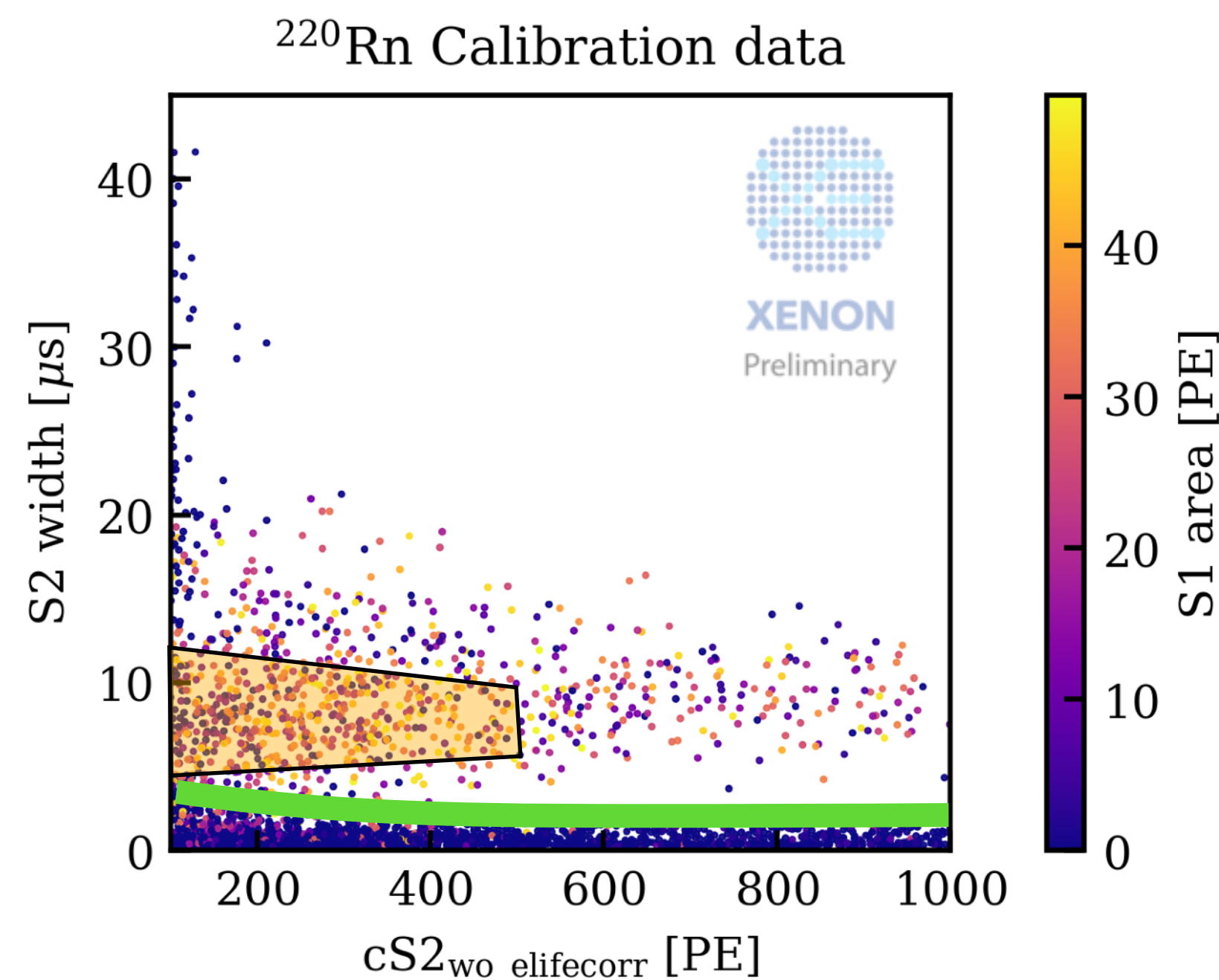
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Radial Cut

$R < 60.15 \text{ (SR0)}, 59.60 \text{ cm (SR1/2)}$

Top electrodes + Gas region



- Radioactivity (electrodes and TPC materials)
- Negligible after **width** cut

Delayed electrons (DE) Accidental electrons (AE)

- Pile-up of electrons trapped in impurities

PTFE Wall



- Radioactivity (Plate-out on the wall)
- Negligible after **radial** cut

Cathode electrodes

- Radioactivity (electrodes - ^{210}Pb)



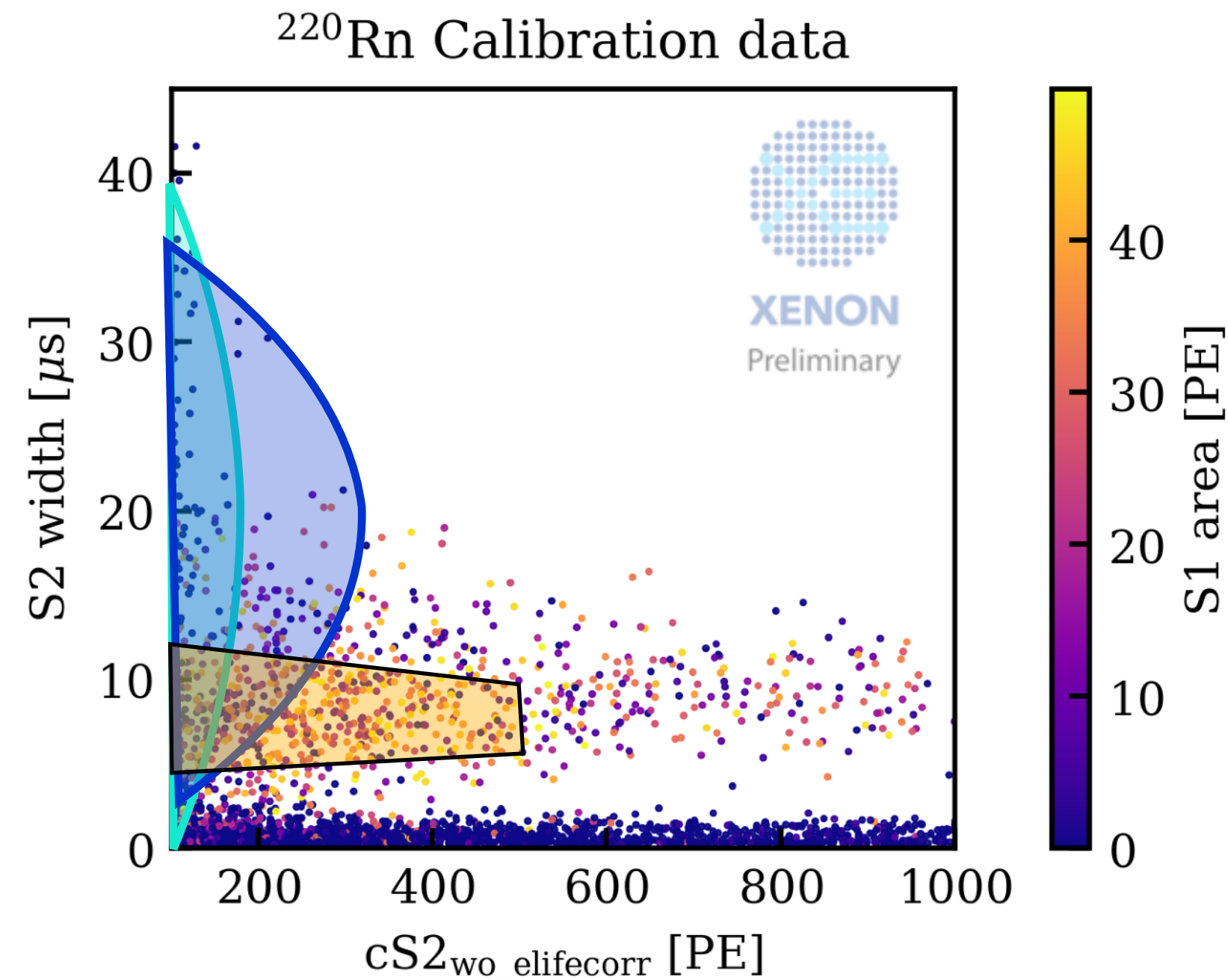
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S2-Only Background Model

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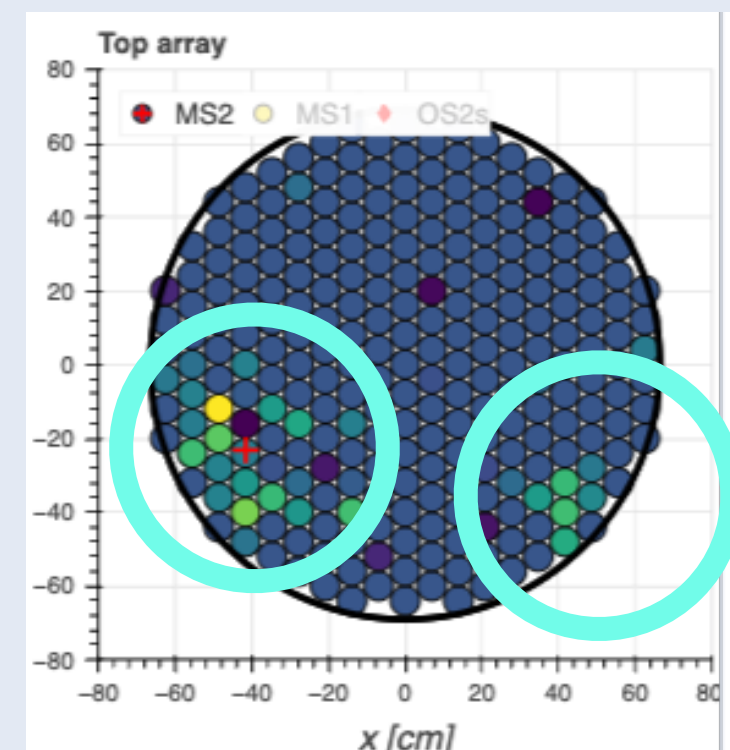
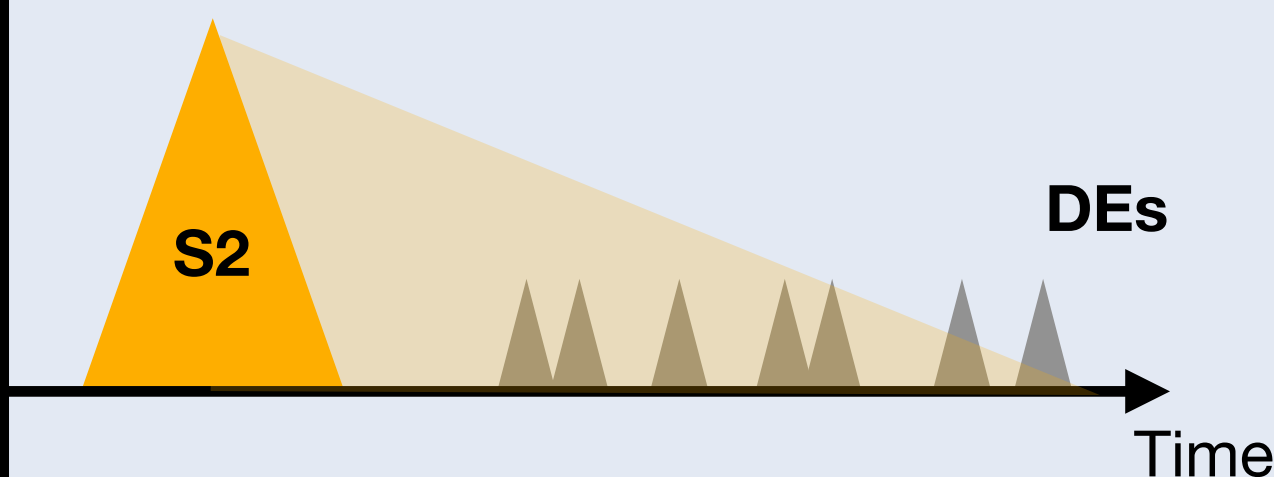
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Potential Background + Mitigation Strategy



DE: Time and Position correlated

AE: poor pile-up PMT S2 pattern



Top electrodes + Gas region



- Radioactivity (electrodes and TPC materials)
- Negligible after **width** cut

Delayed electrons (DE) Accidental electrons (AE)

- Pile-up of electrons trapped in impurities
- Correlation-based **CNF** and **BDT machine**

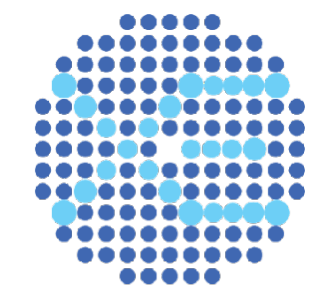
PTFE Wall



- Radioactivity (Plate-out on the wall)
- Negligible after **radial cut**

Cathode electrodes

- Radioactivity (electrodes - ^{210}Pb)



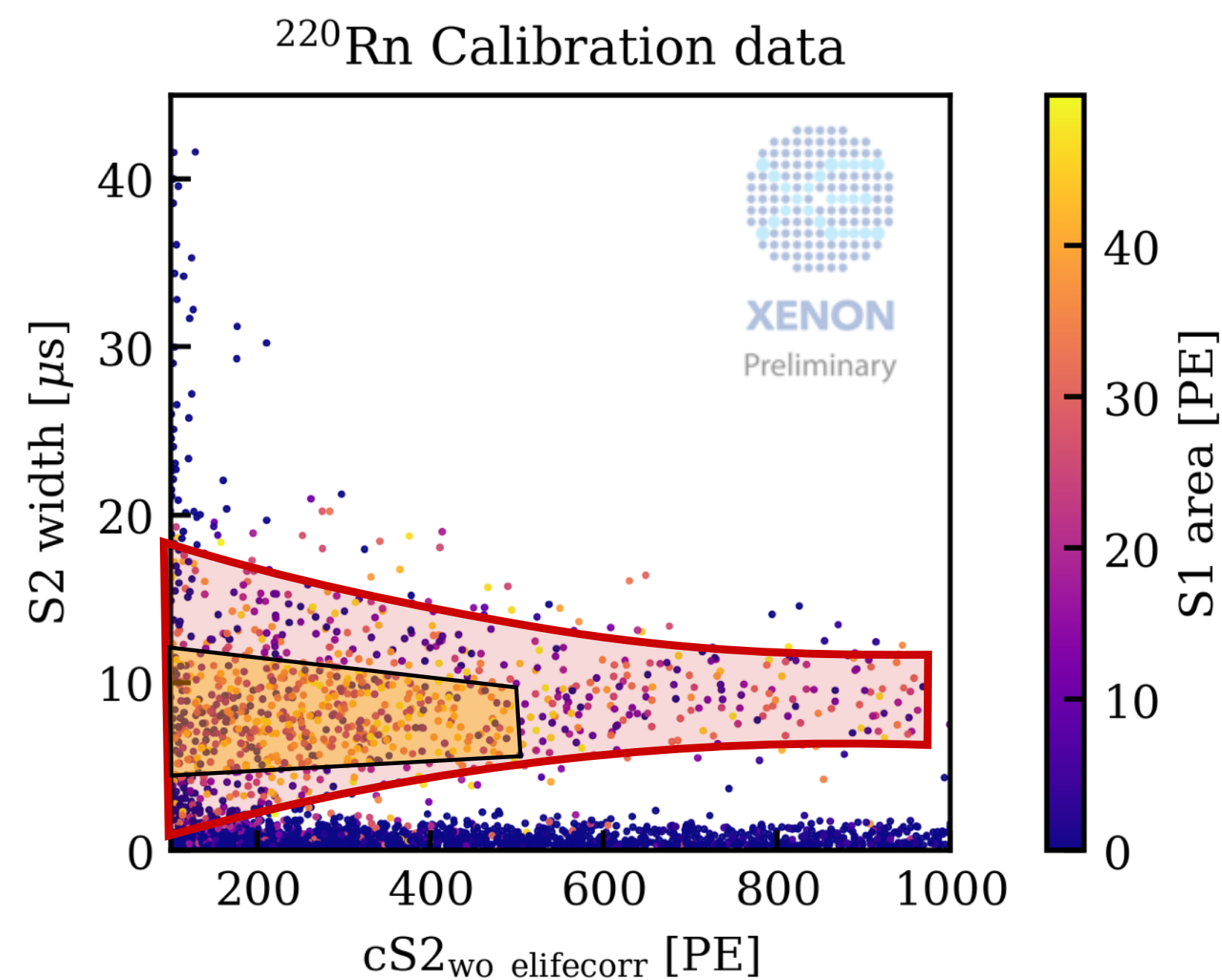
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S2-Only Background Model

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Potential Background + Mitigation Strategy



Top electrodes + Gas region



- Radioactivity (electrodes and TPC materials)
- Negligible after **width** cut

Delayed electrons (DE) Accidental electrons (AE)

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- Correlation-based **CNF** and **BDT machine**

PTFE Wall



- Radioactivity (Plate-out on the wall)
- Negligible after **radial cut**

Cathode electrodes

- Radioactivity (electrodes - ^{210}Pb)
- Waveform-based **BDT machine** developed to suppress it

Leverage the larger S2 width dimensions (width @ 50/90%, rise time), from longer diffusion time, to discriminate Cathode events from signal in LXe bulk



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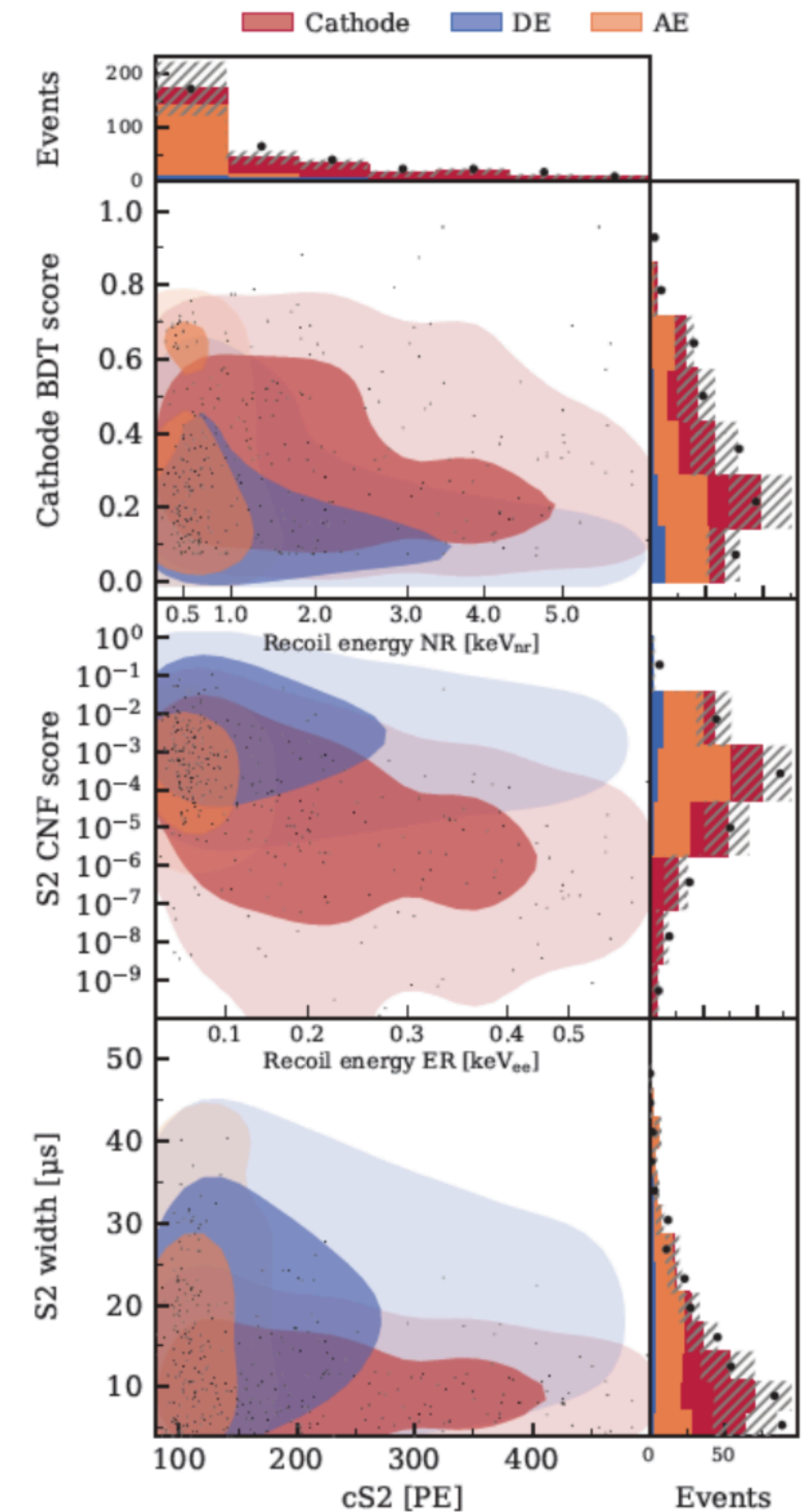
SR0+1+2 S2-Only Datasets

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- Background model validated across different dimensions with Calibration data and sideband ROI

^{220}Rn Calibration Data





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SR0+1+2 S2-Only Datasets

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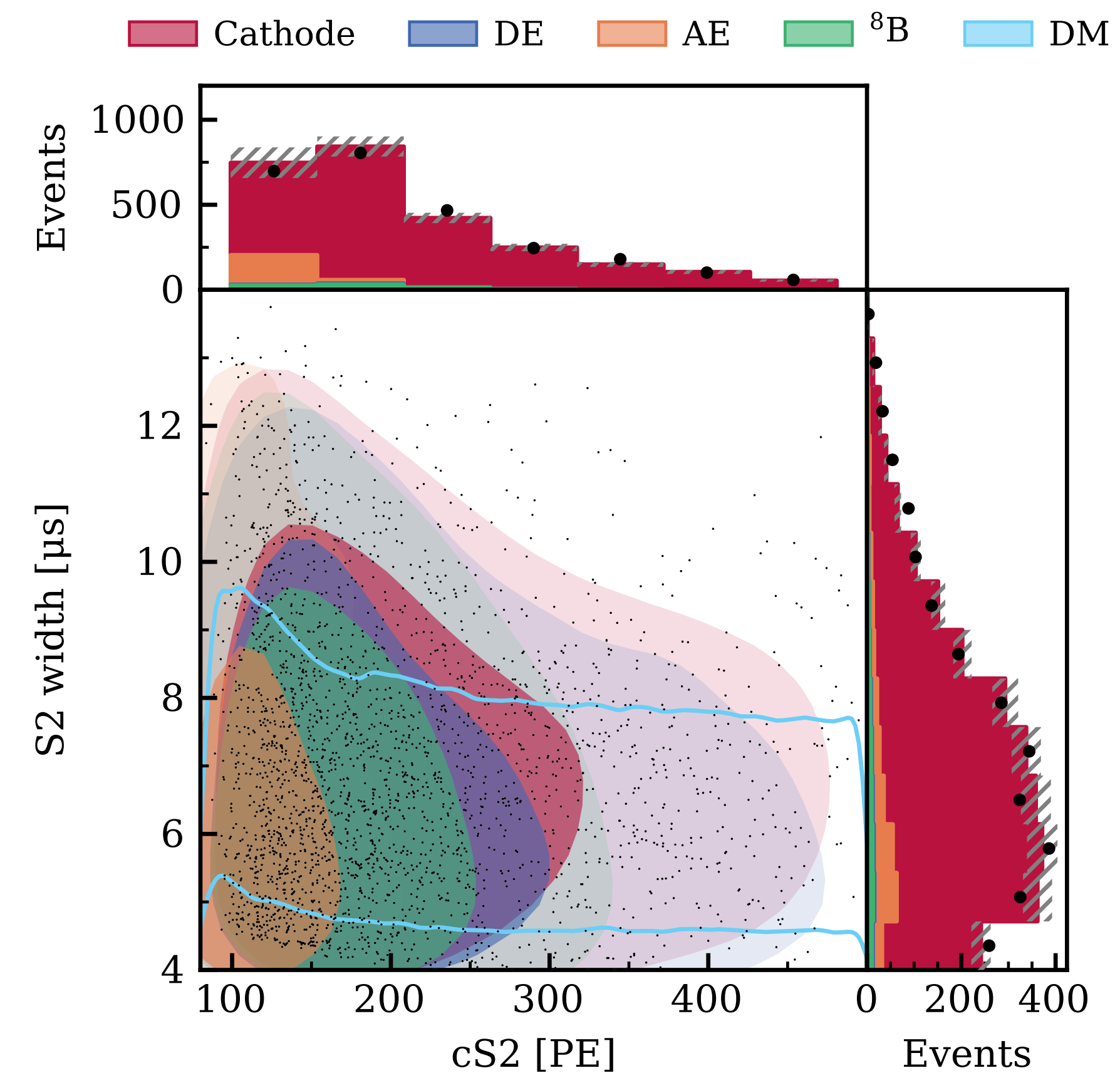
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- Background model validated across different dimensions with Calibration data and sideband ROI

Blind analysis with 7.83 tonne-year exposure

- Good agreement:** between the observed events and background model
- Cathode** background is dominant while AE primarily contribute to the lowest energy bin

No excess over background observed

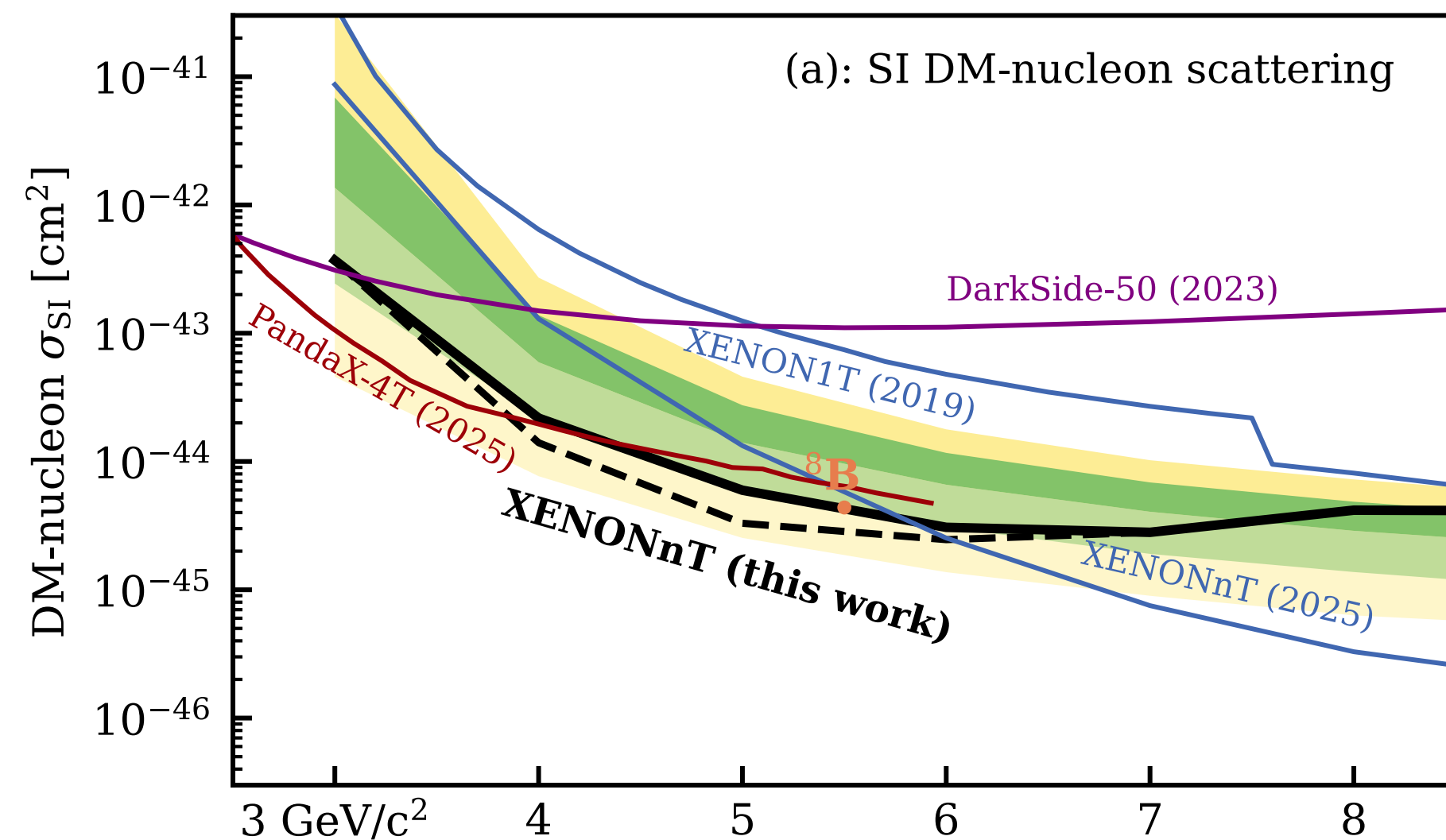




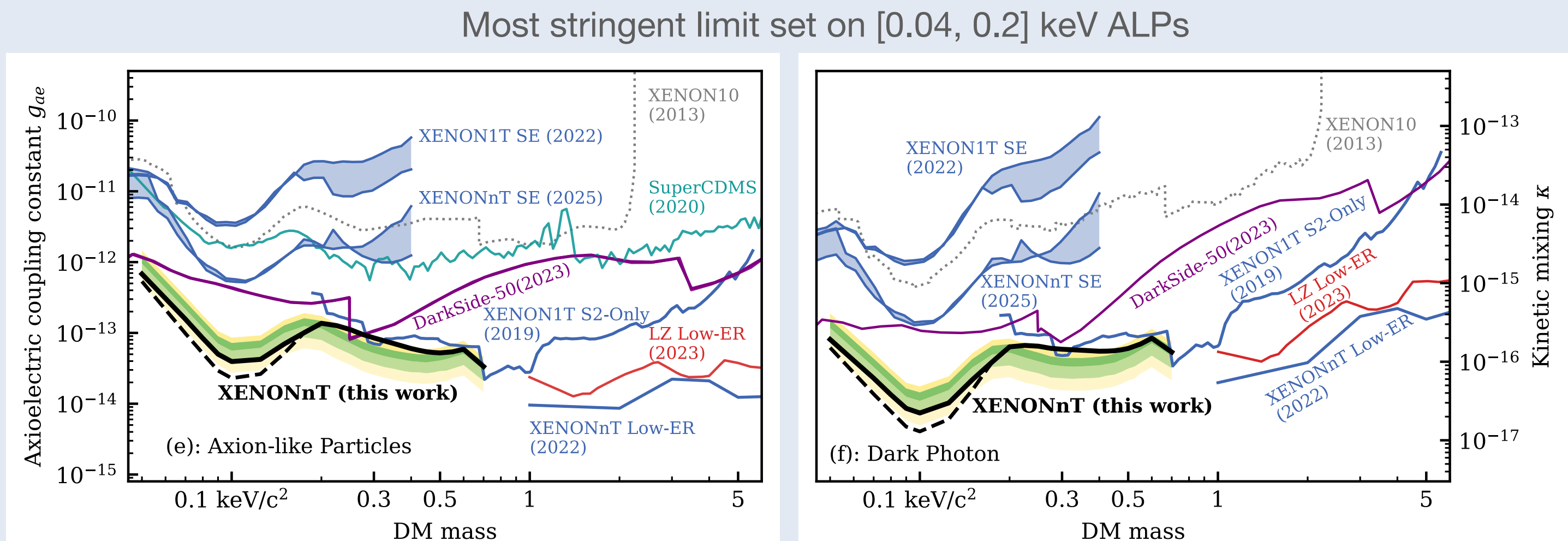
New set of limits on Light DM

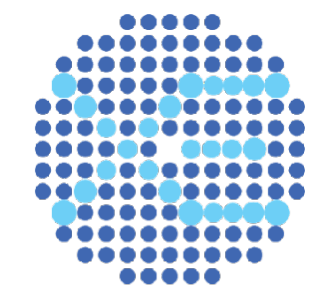
Science run (exposure)	SR0 (1.50 t · y)		SR1 (2.44 t · y)		SR2 (3.89 t · y)	
Component	Expectation	Best fit	Expectation	Best fit	Expectation	Best fit
Cathode	480 ± 70	477^{+25}_{-24}	660 ± 70	726^{+28}_{-27}	1210 ± 90	1080 ± 30
Delayed electron	1.3 ± 0.5	1.3 ± 0.5	0.34 ± 0.07	0.34 ± 0.07	17.2 ± 2.3	17.1 ± 2.3
Accidental electron	97 ± 17	89 ± 13	108 ± 8	106 ± 8	—	—
^8B CE ν NS	21 ± 5	18^{+5}_{-4}	29 ± 7	26^{+7}_{-6}	32.3 ± 8	29^{+8}_{-6}
Total background	600 ± 80	586 ± 28	800 ± 80	858^{+30}_{-29}	1260 ± 100	1130 ± 30
Observed		583		864		1107

Most stringent limit set on ~5 GeV light WIMPs



PCL applied





New Result

[arXiv:2601.11296](https://arxiv.org/abs/2601.11296)

SRO+1+2
S2-Only DM

- No excess observed
- New limits set on Light DM candidates: WIMP, ALP, DP

Future Results

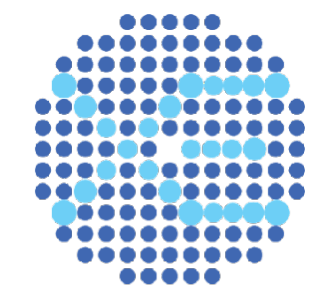
SRO+1+2
WIMP

- Stay tuned for new WIMP results with combined datasets

Other
Channels

- Broad Physics program with more results to come (DM, solar-neutrino, $2\nu/0\nu\beta\beta$, ...)

What next?



Electrodes replacement

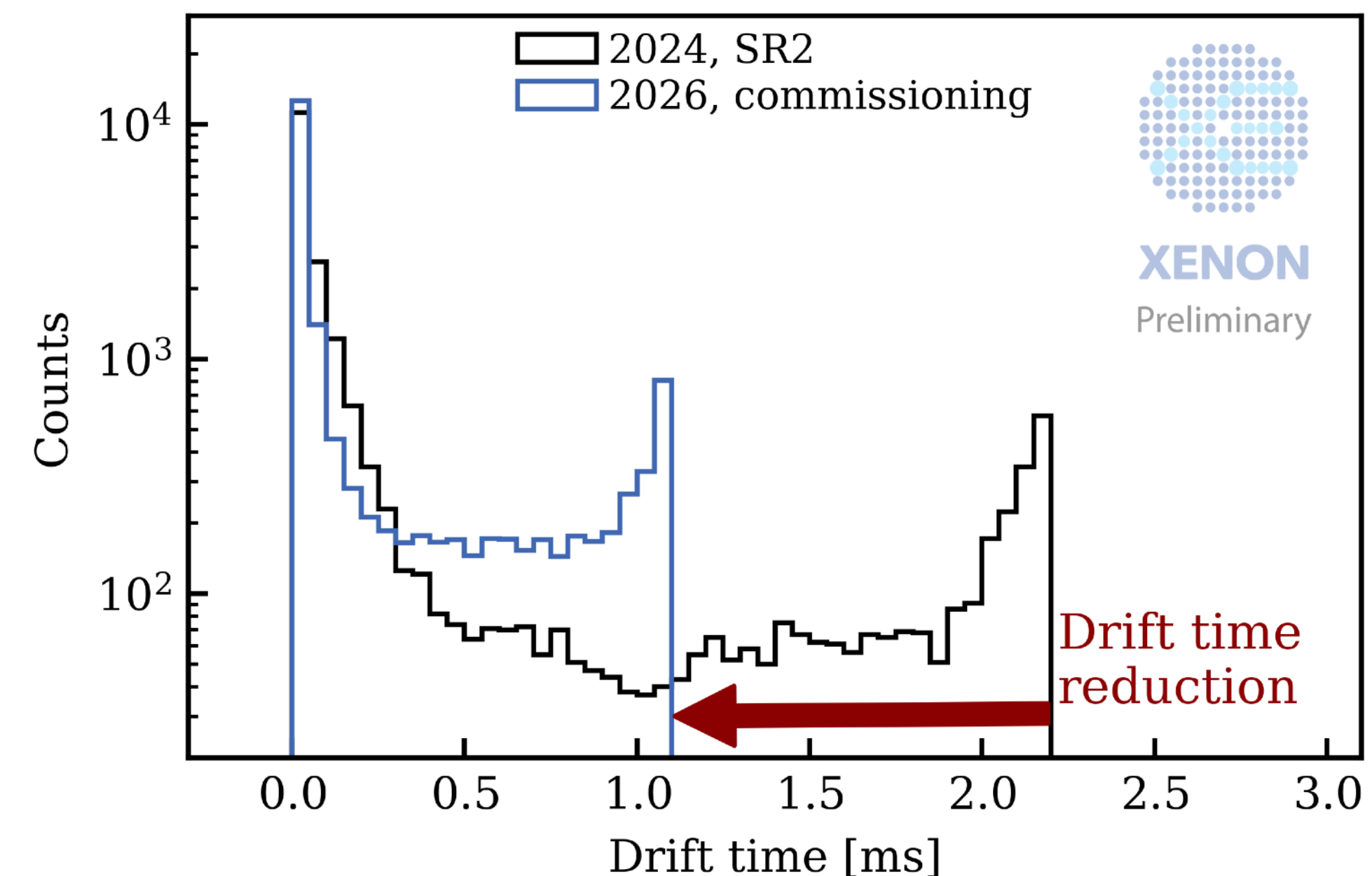
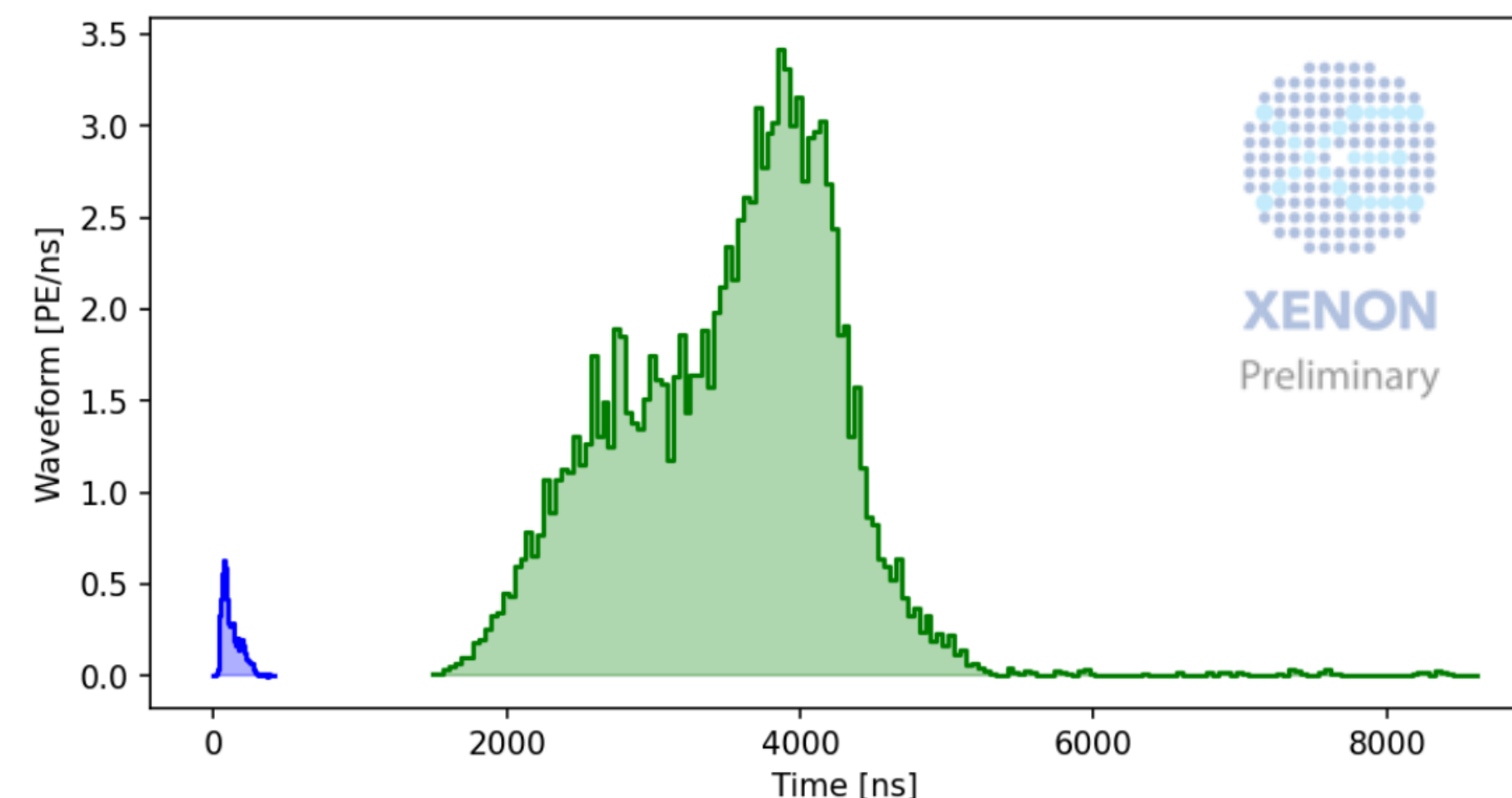
Reassembly of the TPC replacement

Filling Water tank & TPC

NOW: Commissioning of TPC & vetos

Electrodes are working (we saw our first new S1 and S2s) and field settings are being adjusted

XENONnT soon back looking for dark matter & other rare events





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Talks and Posters Advertisement

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Talks

- **Probing the neutrino fog with XENONnT: $CE\nu$ NS, light WIMPs, and BSM- ν physics with a 6.77 t x yr exposure,** *Giovanni Volta*, 2 June 11:30
- **Rare Event Searches in the Electron Recoil Channel of the XENONnT Experiment,** *Ying-Ting Lin*, 3 June 16:00
- **Performance of the Gd-loaded Water Cherenkov Neutron Veto in XENONnT,** *Emanuele Angelino*, 4 June 15:15

Posters

- **Search for Magnetic Inelastic Dark Matter with Delayed NR ER Coincidences in XENONnT,** *Tianyu Zhu*, 3 June 16:50



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Talks and Posters Advertisement

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Thank You for your attention!





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Back-Up



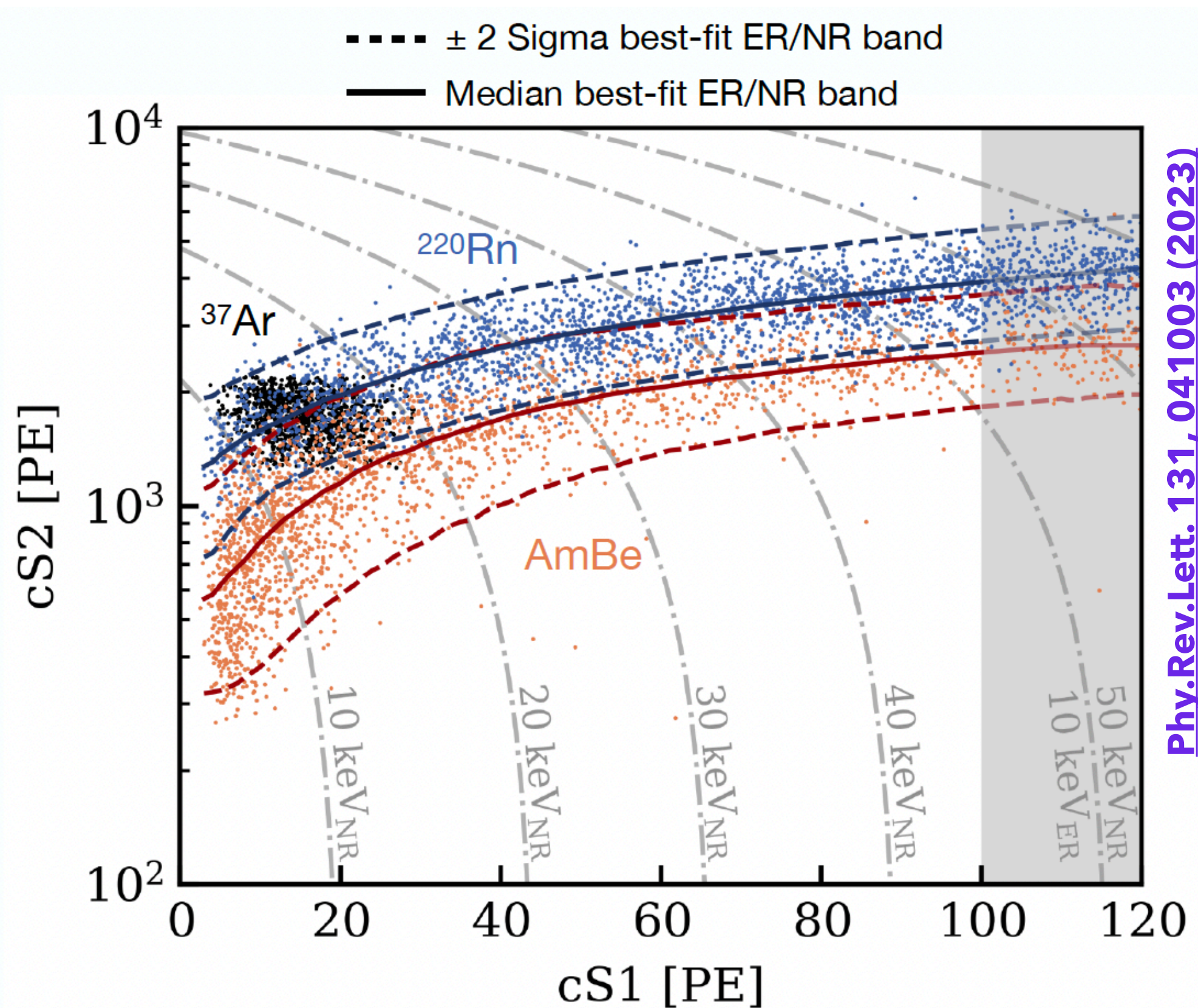


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Detector Response Modeling

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Electronic Recoil calibration:

- ^{220}Rn intrinsic calibration: $\sim$ flat β spectrum from ^{212}Pb to estimate **cut acceptances and ER response**
- ^{37}Ar intrinsic calibration: mono-energetic 2.8 keV peak to model the **low-energy response & resolution near threshold**

Nuclear Recoil calibration:

- External $^{241}\text{AmBe}$ neutron source with **clean NR selection** via **coincident** 4.4 MeV γ -ray observed in the **NV**
- External **YBe** neutron source for low-energy NR response

Other calibration sources ($^{83\text{m}}\text{Kr}$, ^{232}Th , LED, ...)

- Characterise and correct detector effects impacting our signal measurements
- Monitor detector stability

MORE INFO

Signal reconstruction, calibration and event selection

[Phys. Rev. D 111 \(2025\) 062006](#)

Signal and background modelling and statistical inference

[Phys. Rev. D 111 \(2025\) 103040](#)

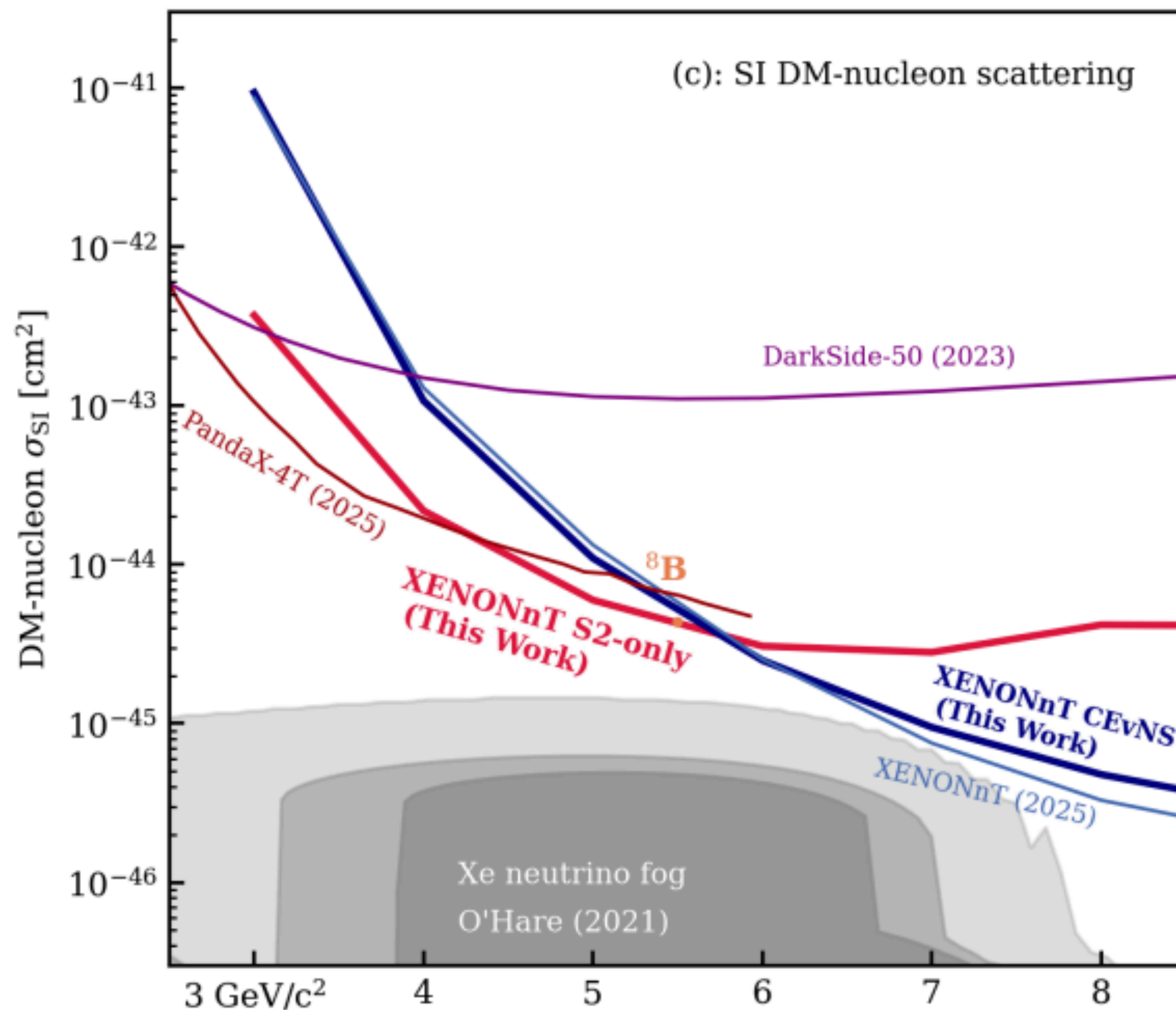


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Light WIMP results S2-Only+CE ν NS

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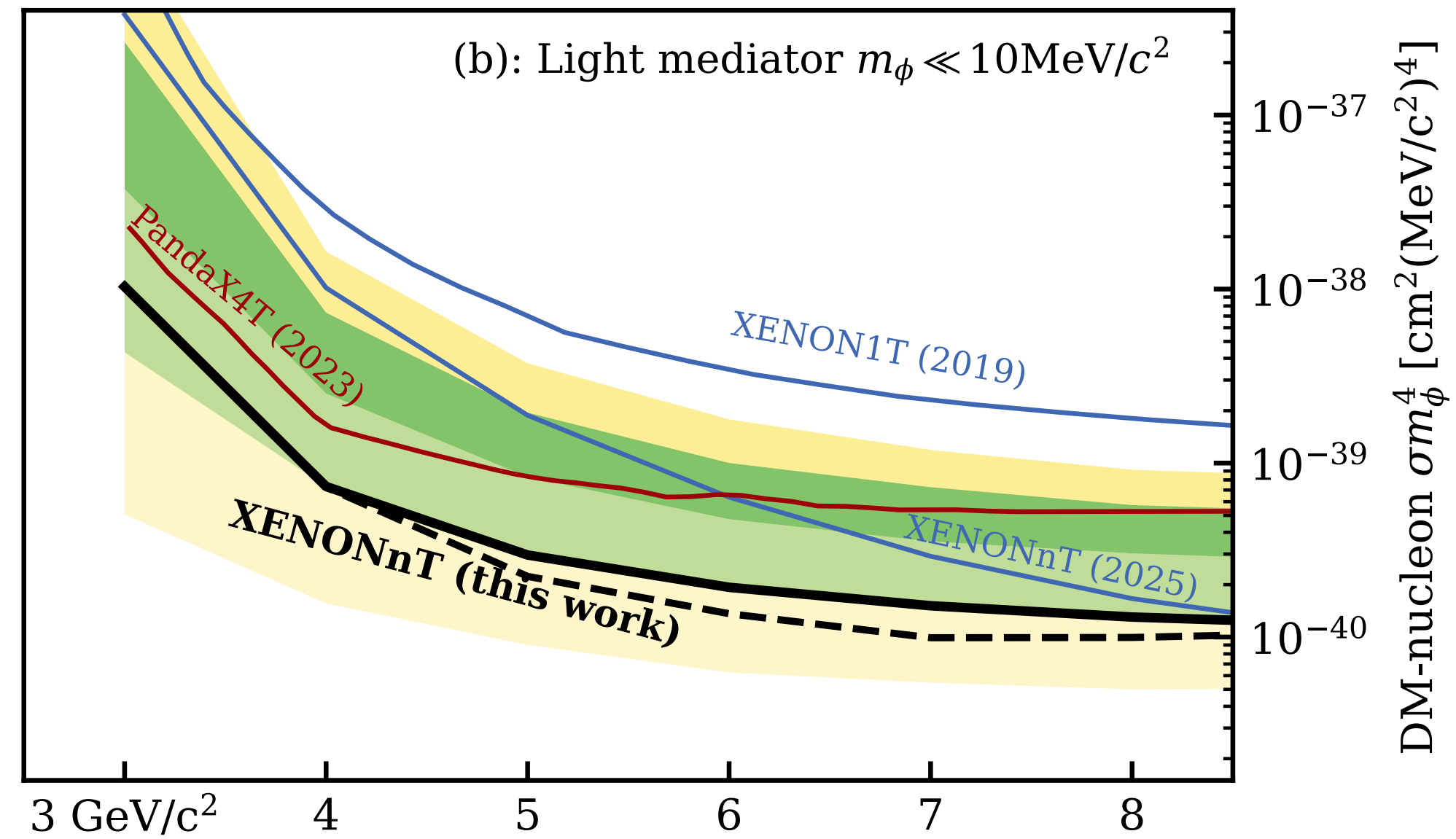
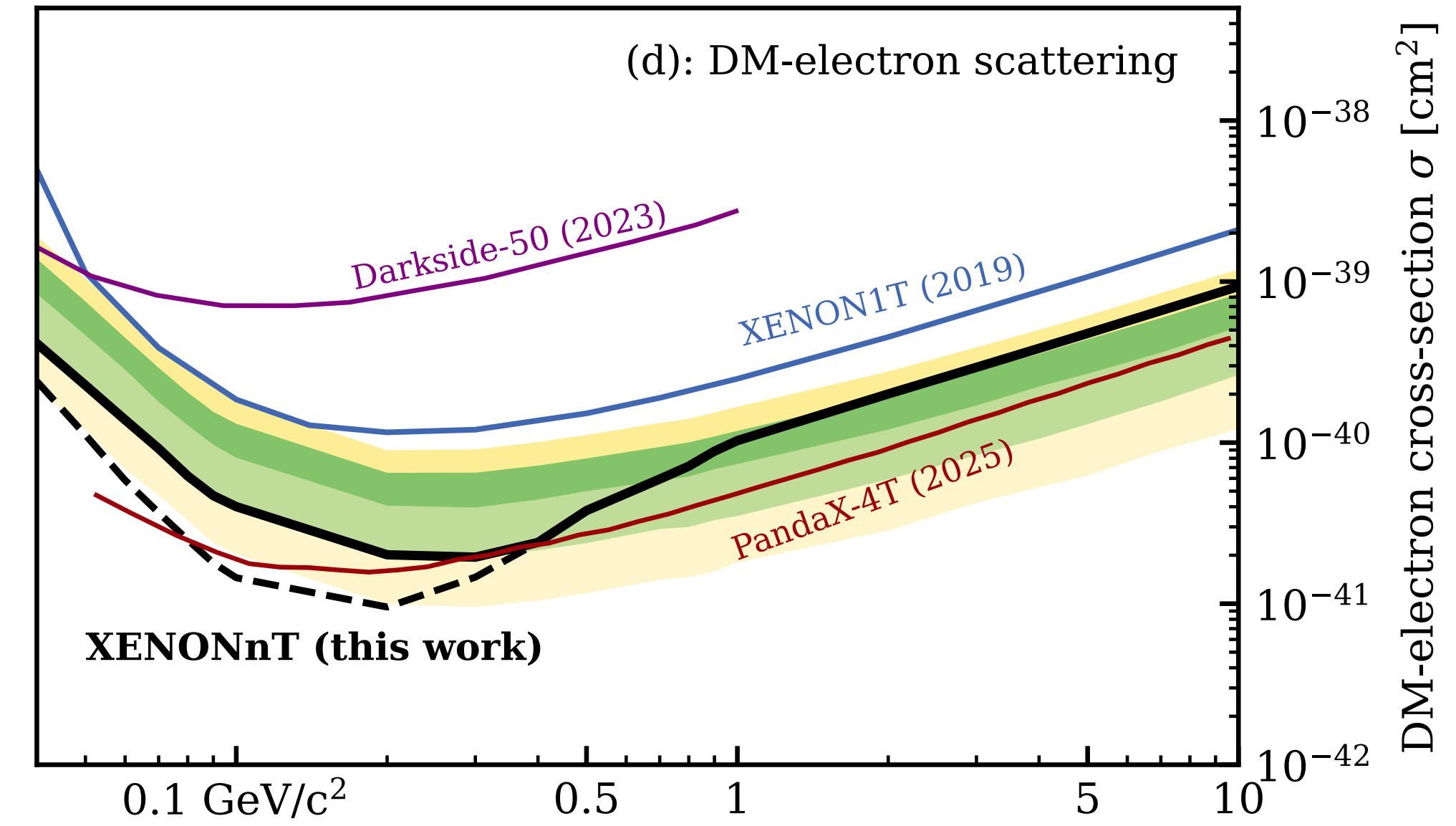
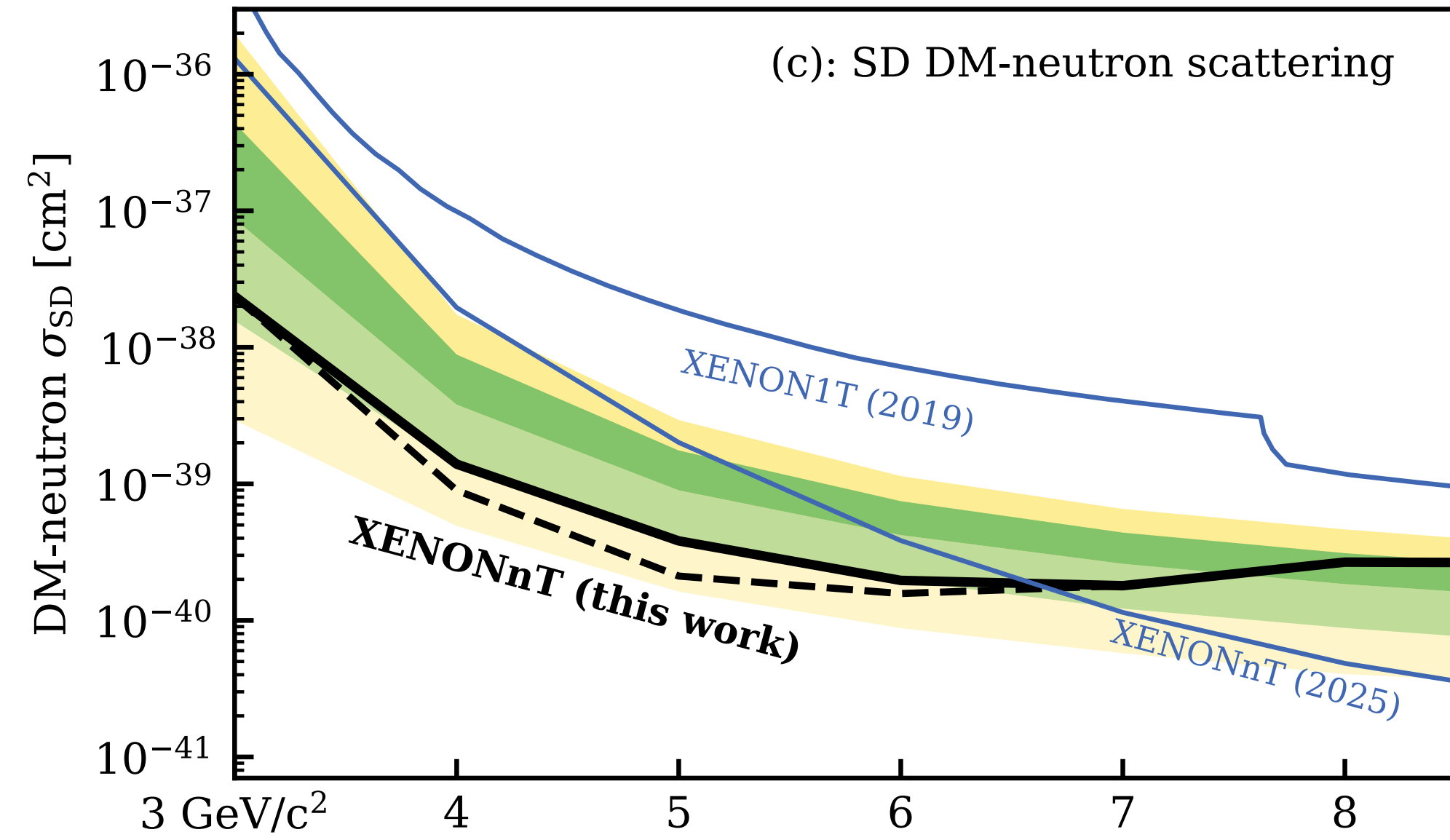


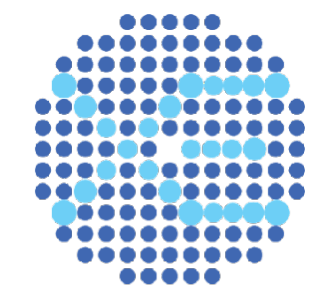
Other results

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XENON

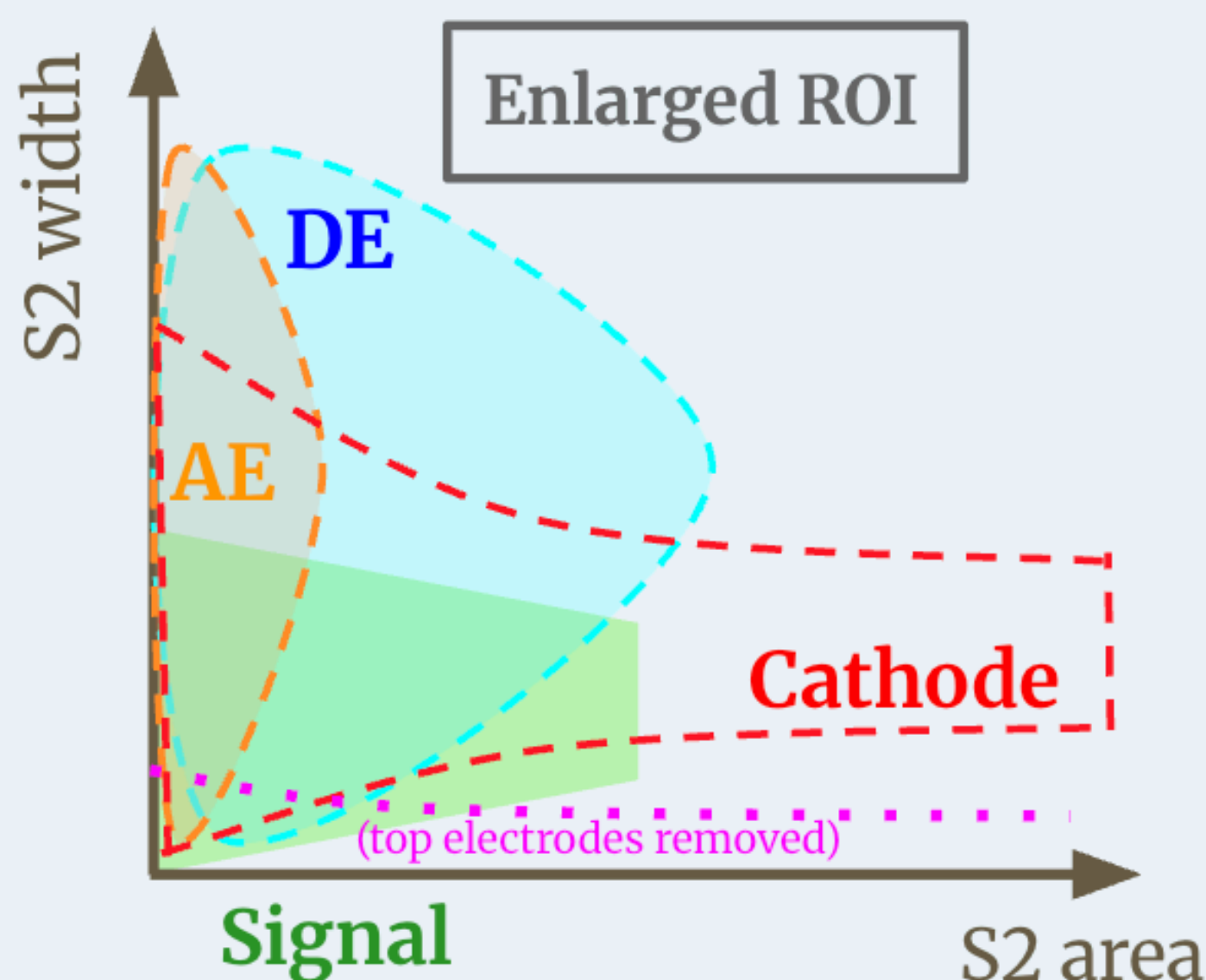
Extended ROI Validation

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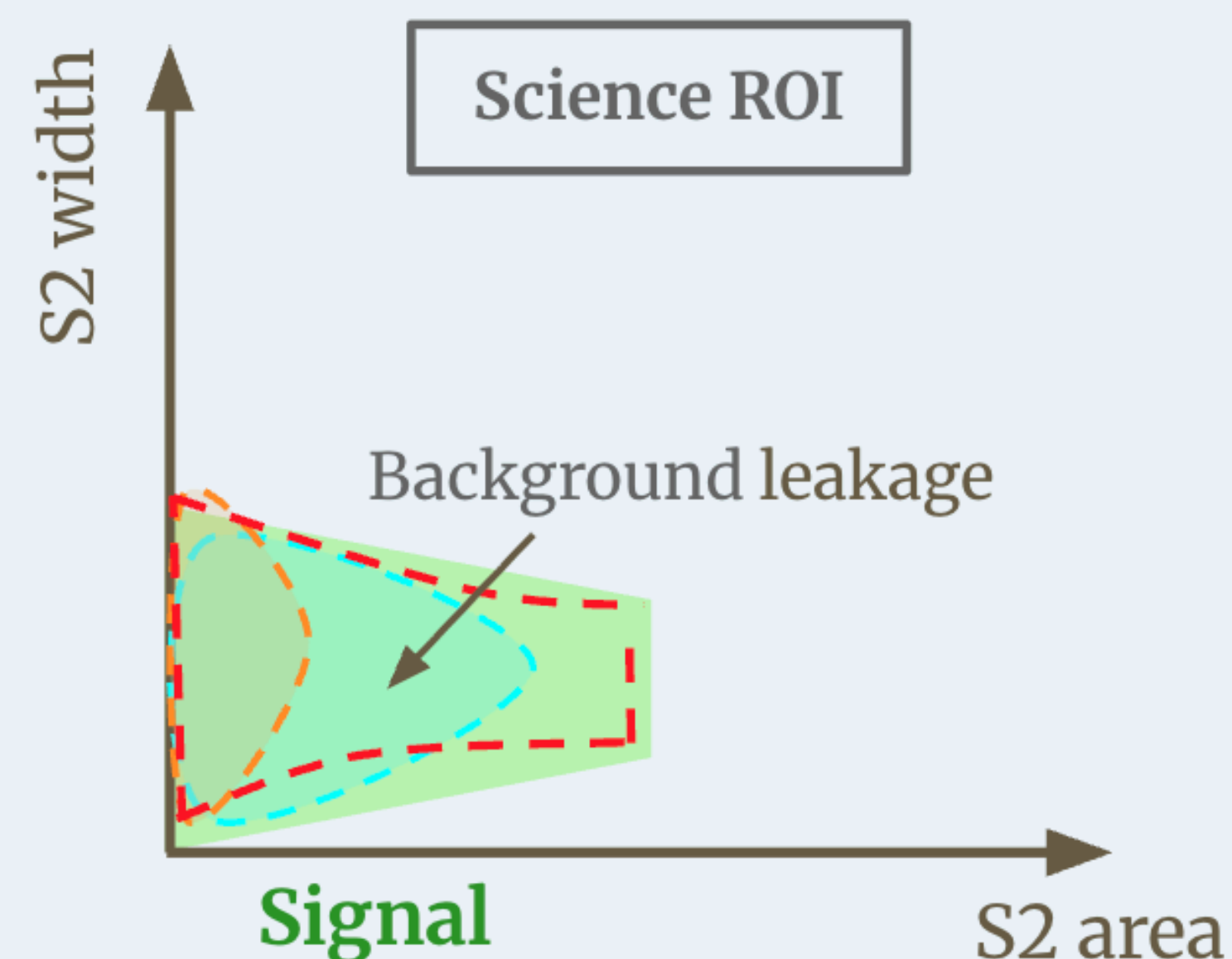
What we have now:

DE, AE, cathode background modeling in full space



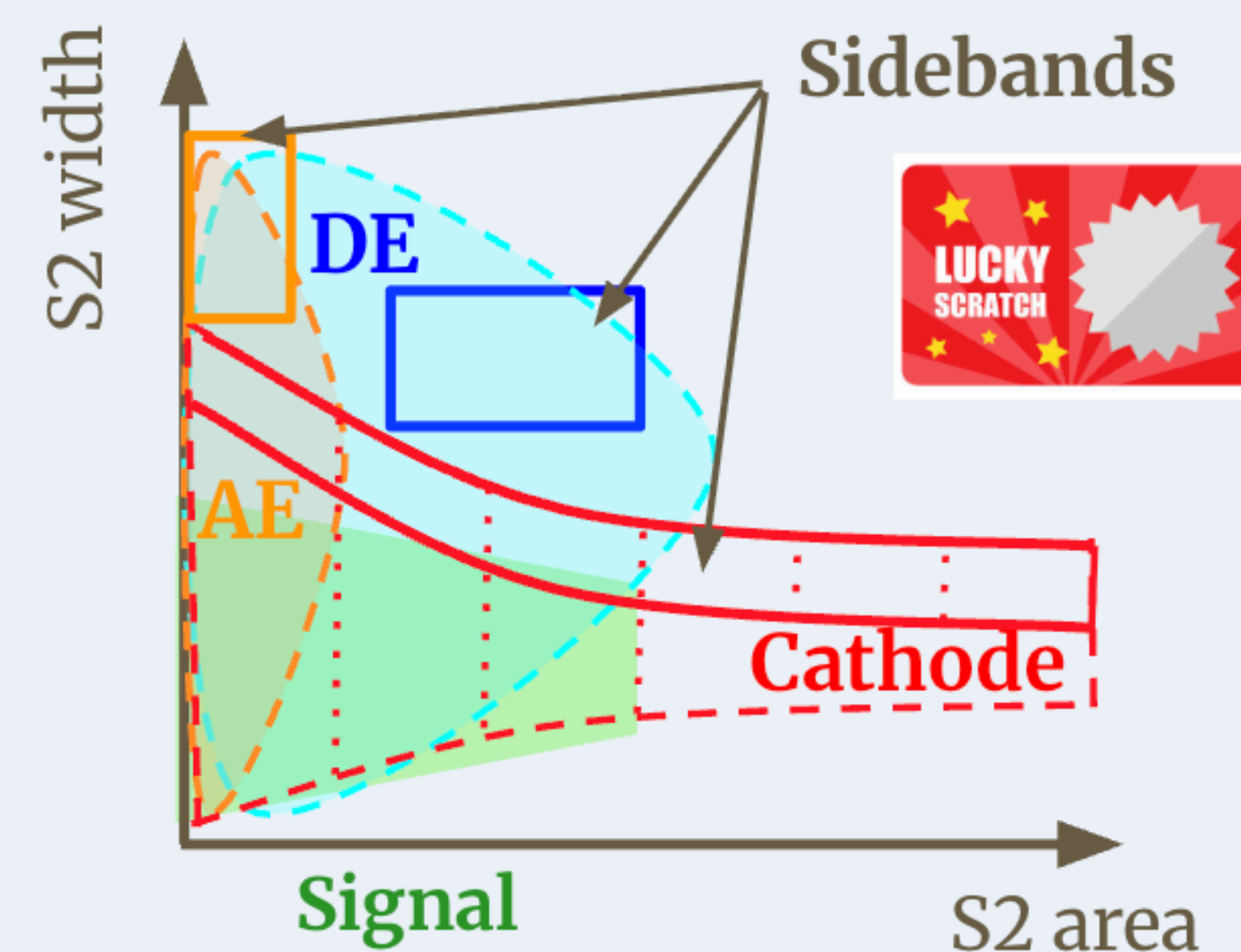
Objective:

Estimate the DE, AE, cathode background in blinded **Signal ROI**



Sideband technique:

Unblind the sideband region, correct and normalize the background modeling in **Signal ROI**.



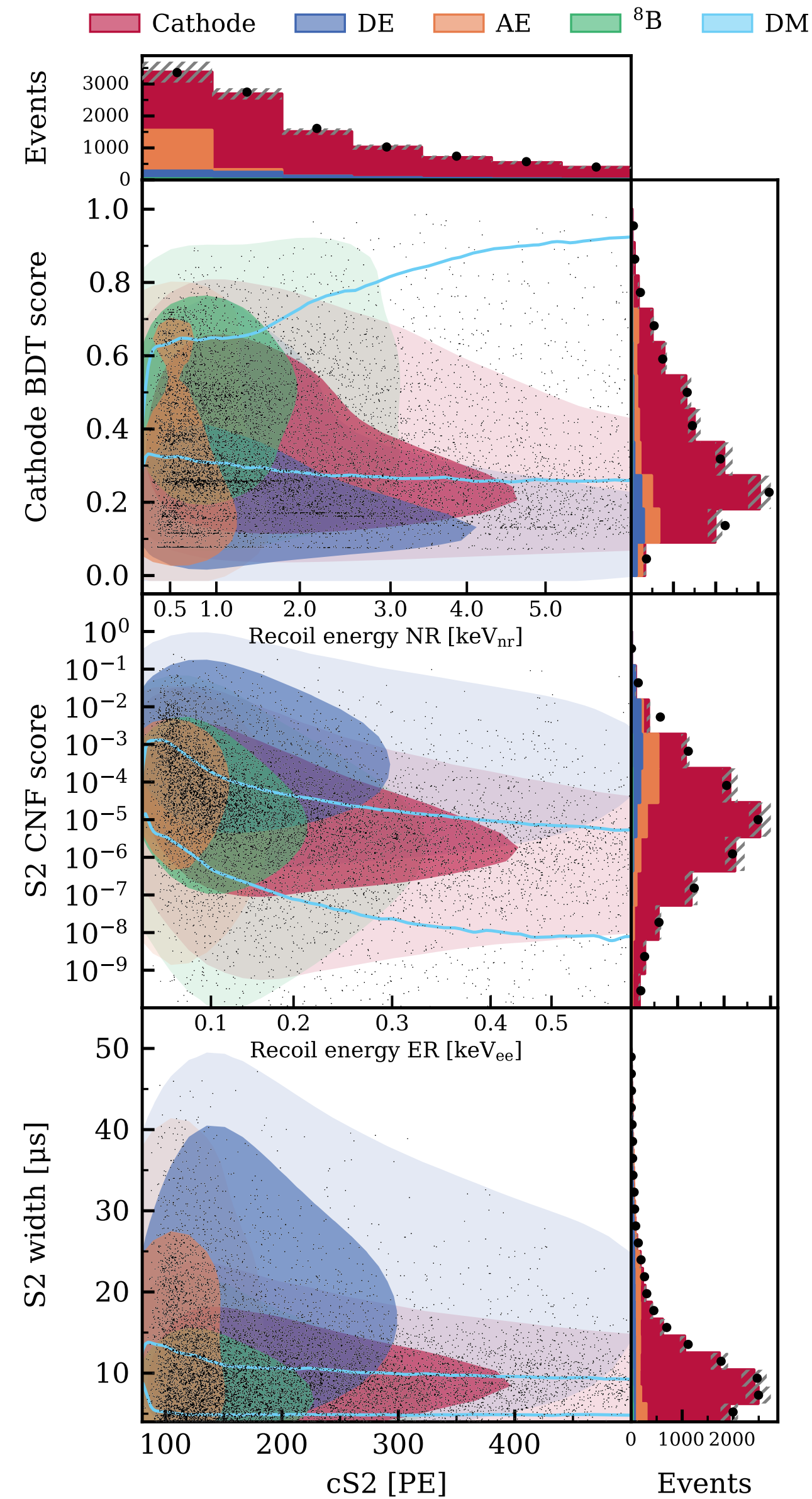


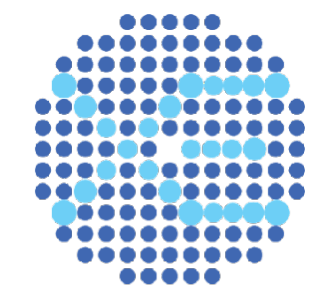
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Extended ROI Validation

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IDM 2026





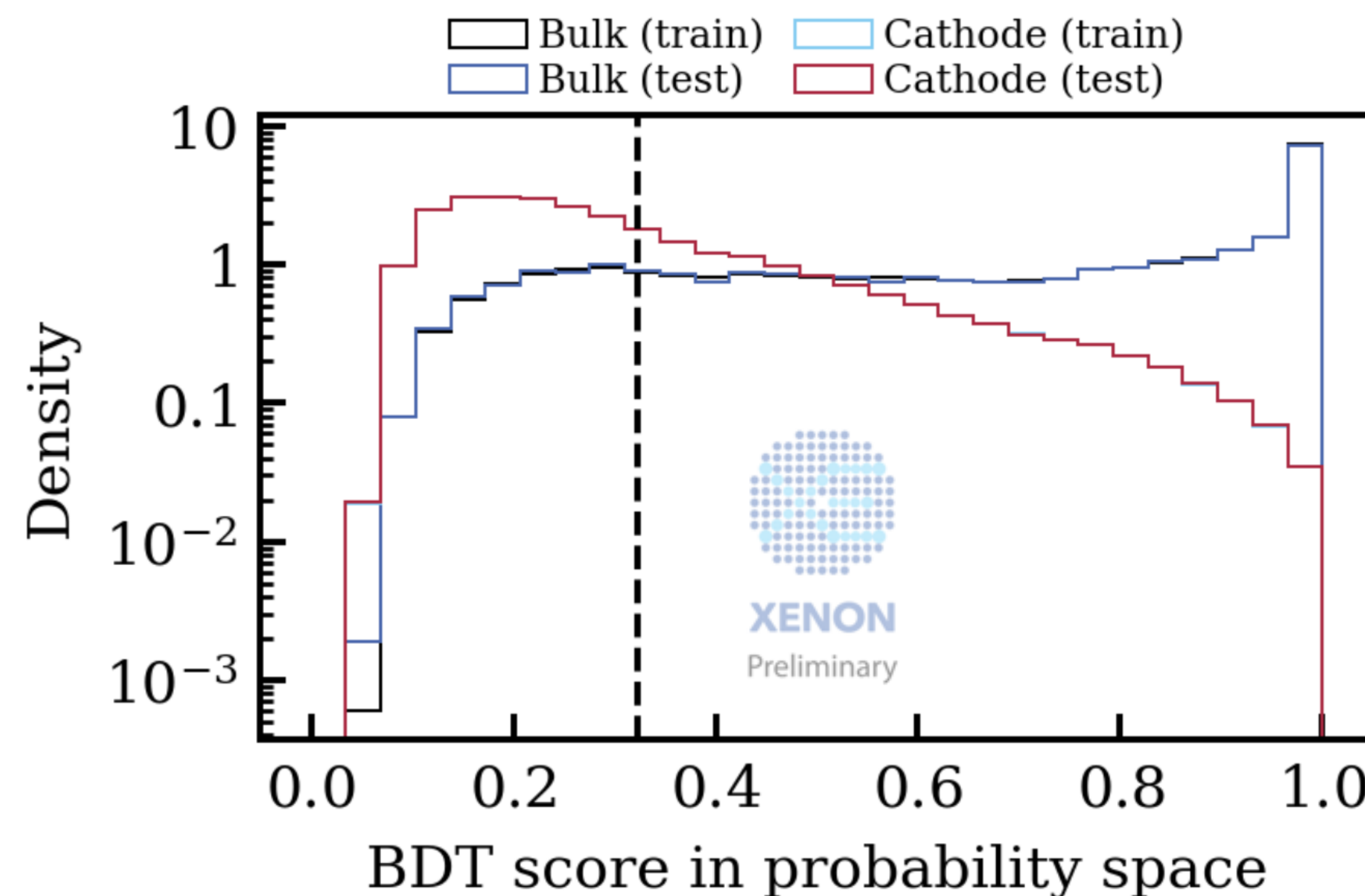
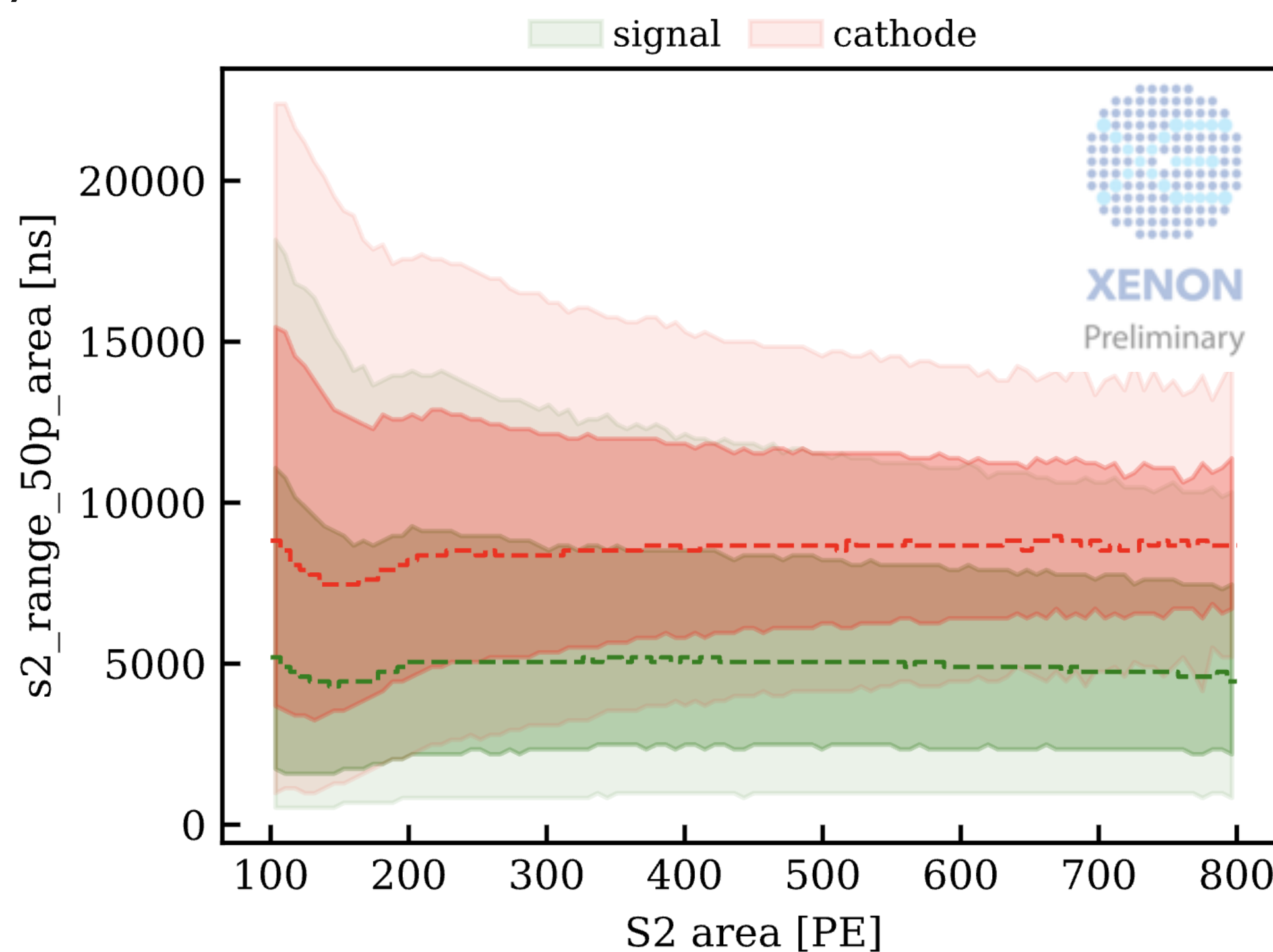
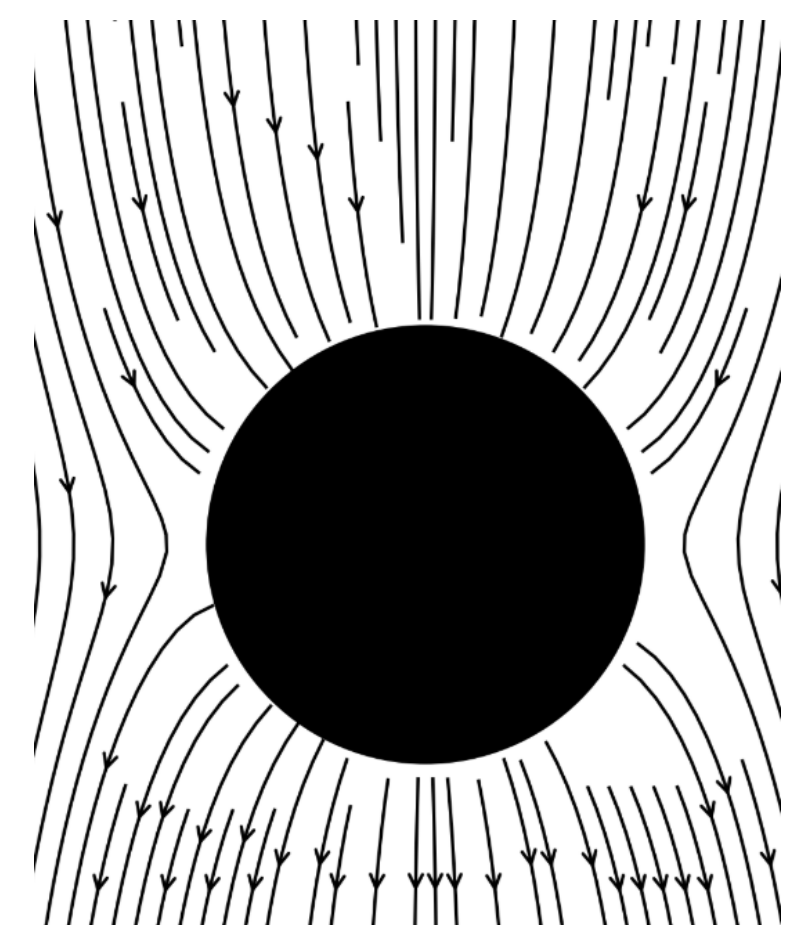
Cathode BDT

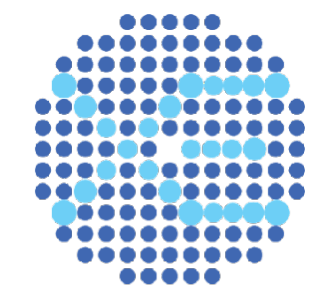
Maxime Pierre
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IDM 2026

Waveform features provide discrimination power of cathode and signal:

- S2 area
- S2 width (50p)
- S2 width (90p)
- S2 rise time



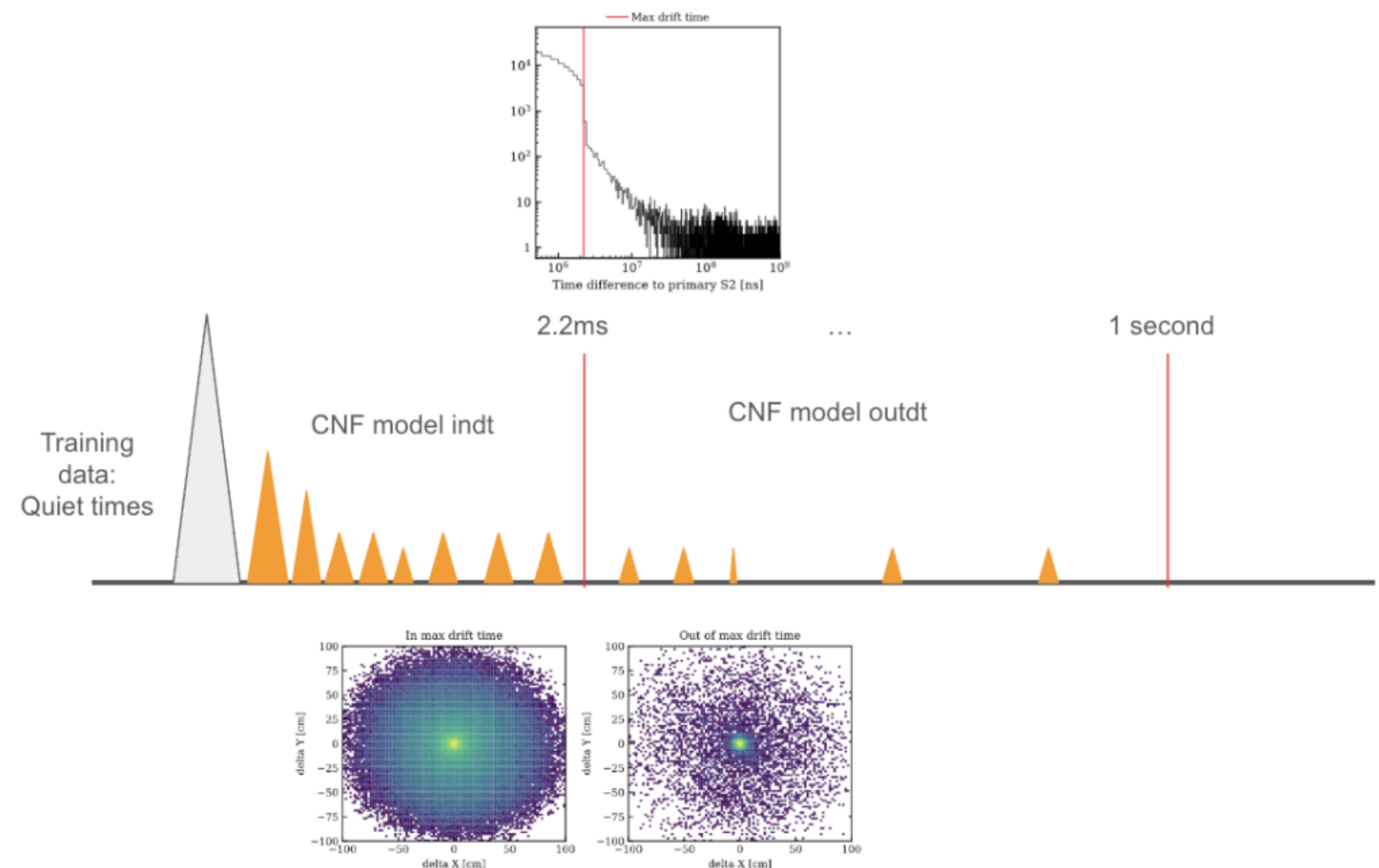


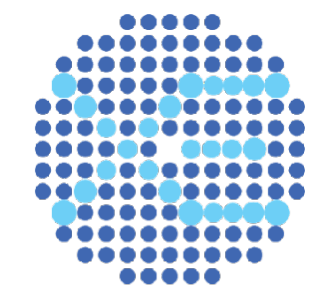
A **CNF** (conditional-normalizing-flow machine) is built to *learn the multi-dimensional correlation* between primary S2 and isolated S2.

Isolated S2s can be modeled:

- **Simulated** by feeding all primary S2s in real data, getting their S2 waveforms
- **Salted back to real data** to build delayed electron events by Straxen.
- Applying cuts to get DE **background template**

Shape determined by data-driven CNF simulation.



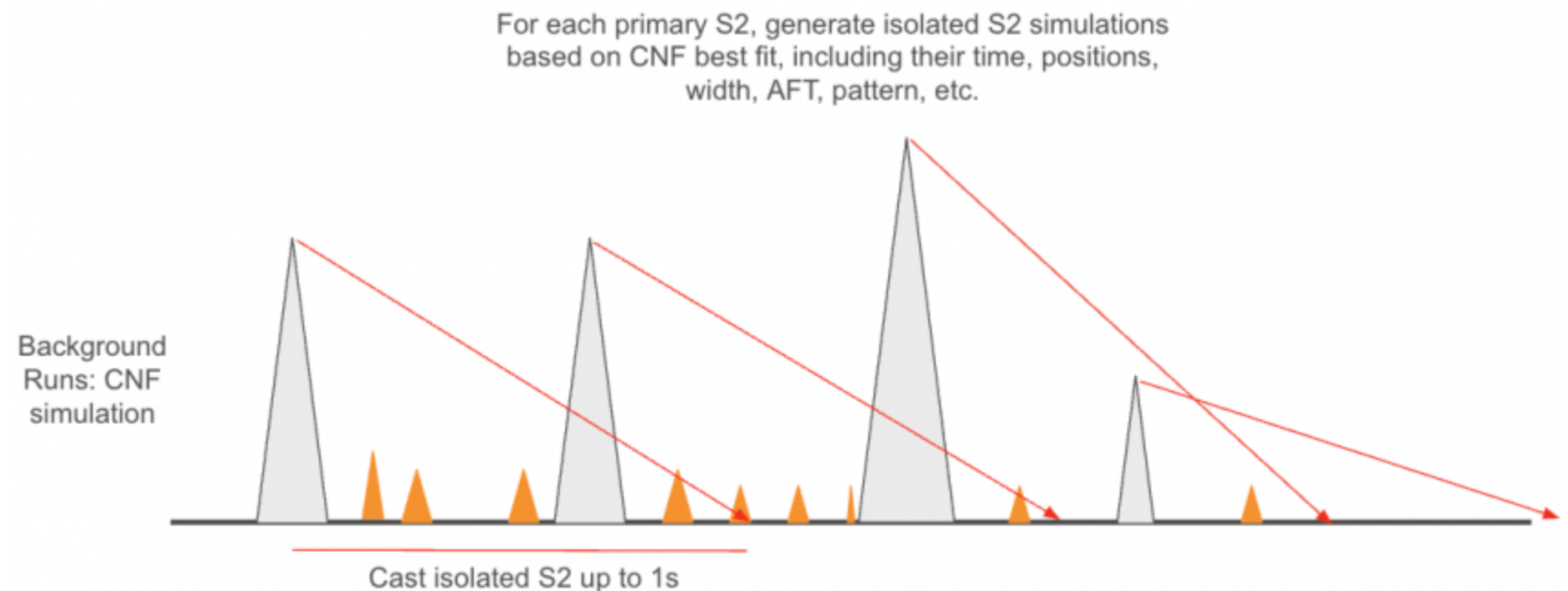


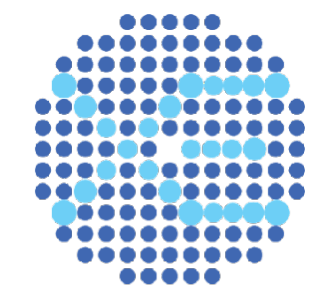
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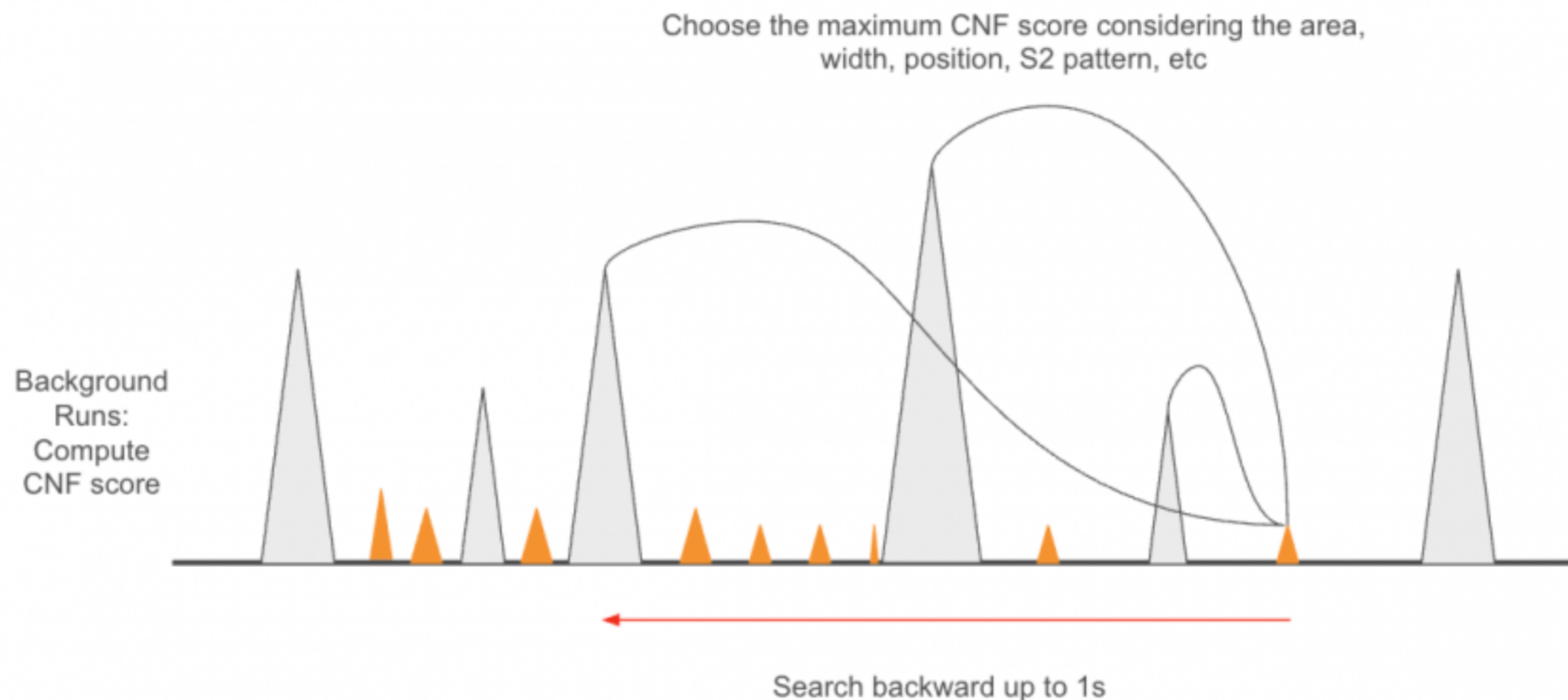


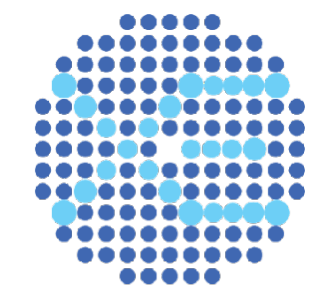
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Delayed electron BDT cut

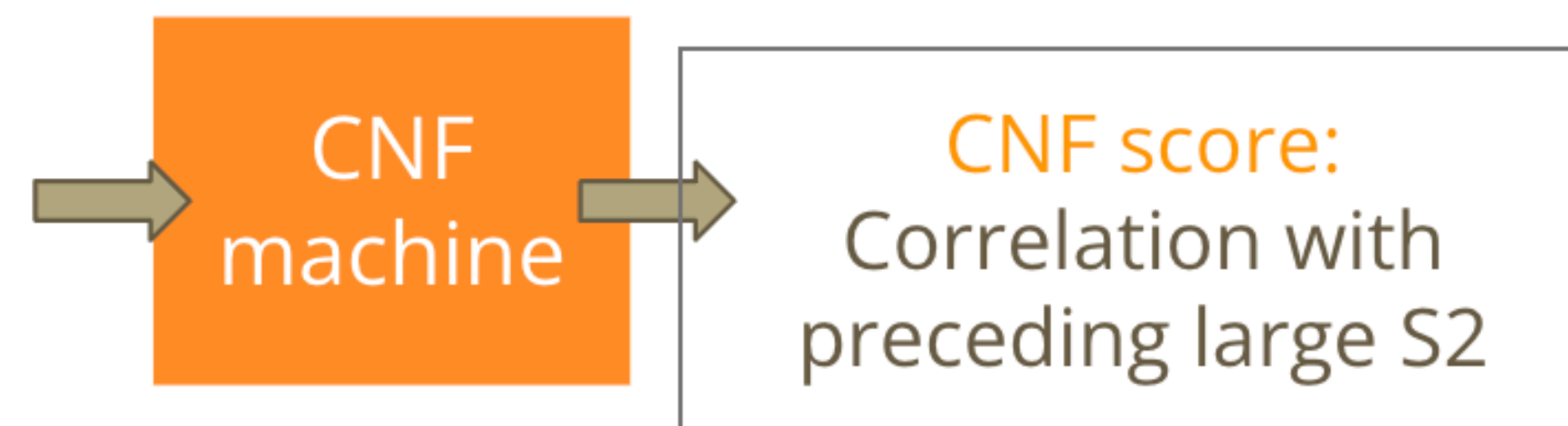
Correlation
with preceding
large S2

CNF Training dataset:

Pairing of large + DE from bkg data

CNF Feature:

- S2 area, position of large S2 and DE



BDT training dataset:

- Simulated signal from FUSE, salted in dataset
- Simulated DE from CNF

BDT features:

- CNF score
- S2 widths
- S2 area

