XENONnT

first WIMP search results

arXiv: 2303.14729

Luca Grandi - The University of Chicago

on behalf of the XENON Collaboration

Collaboration

https://xenonexperiment.org @XENONExperiment @xenonexperiment @xenon_experiment

Columbia University — Columbia

KIT Karlsruhe Institute of Technology — KIT

Nikhef — Nikhef

WWU Münster — Muenster

Stockholm University — Stockholm

JG|U — Mainz

Max-Planck-Institut für Kernphysik Heidelberg — MPIK, Heidelberg

Uni Freiburg — Freiburg

University of Zurich[UZH] — Zurich

The University of Chicago — Chicago

UC San Diego — UCSD

Rice

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清華大學 Tsinghua University — Tsinghua

東京大学 The University of Tokyo — Tokyo

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LPNHE Paris — LPNHE

INFN Torino — Torino

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INFN LNGS — LNGS

Napoli

מכון ויצמן למדע Weizmann Institute of Science — Weizmann

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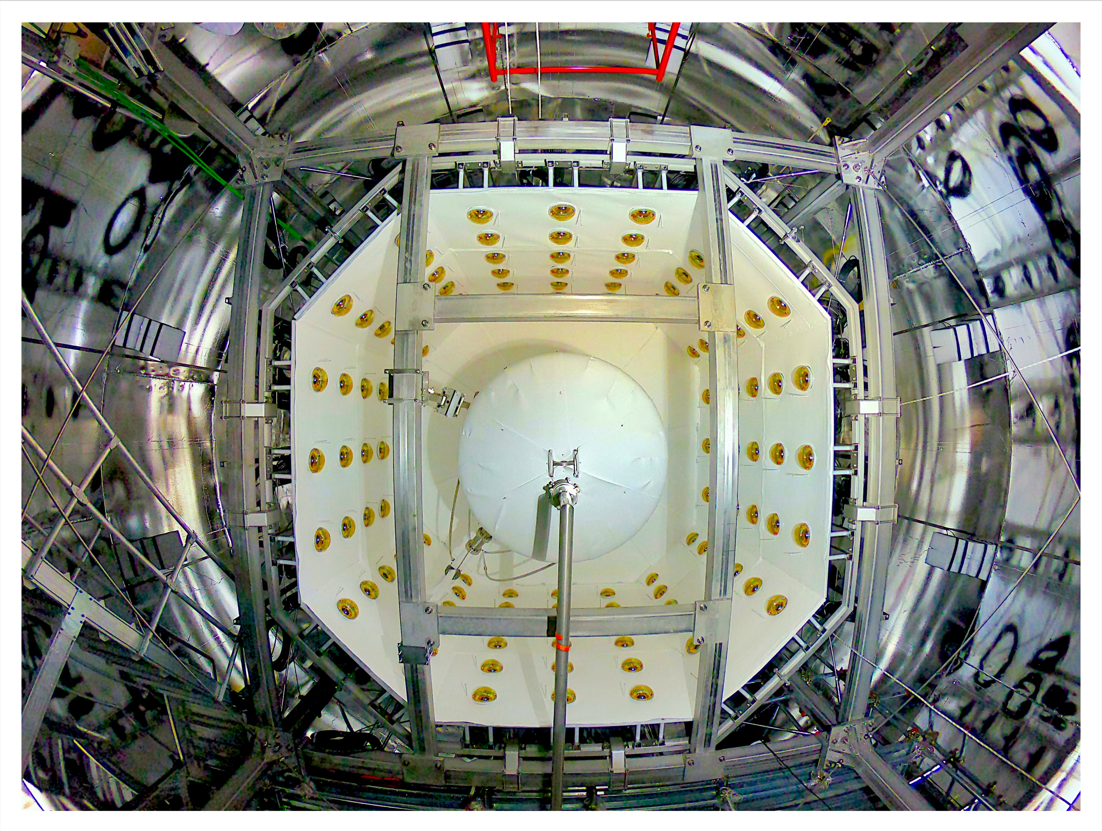
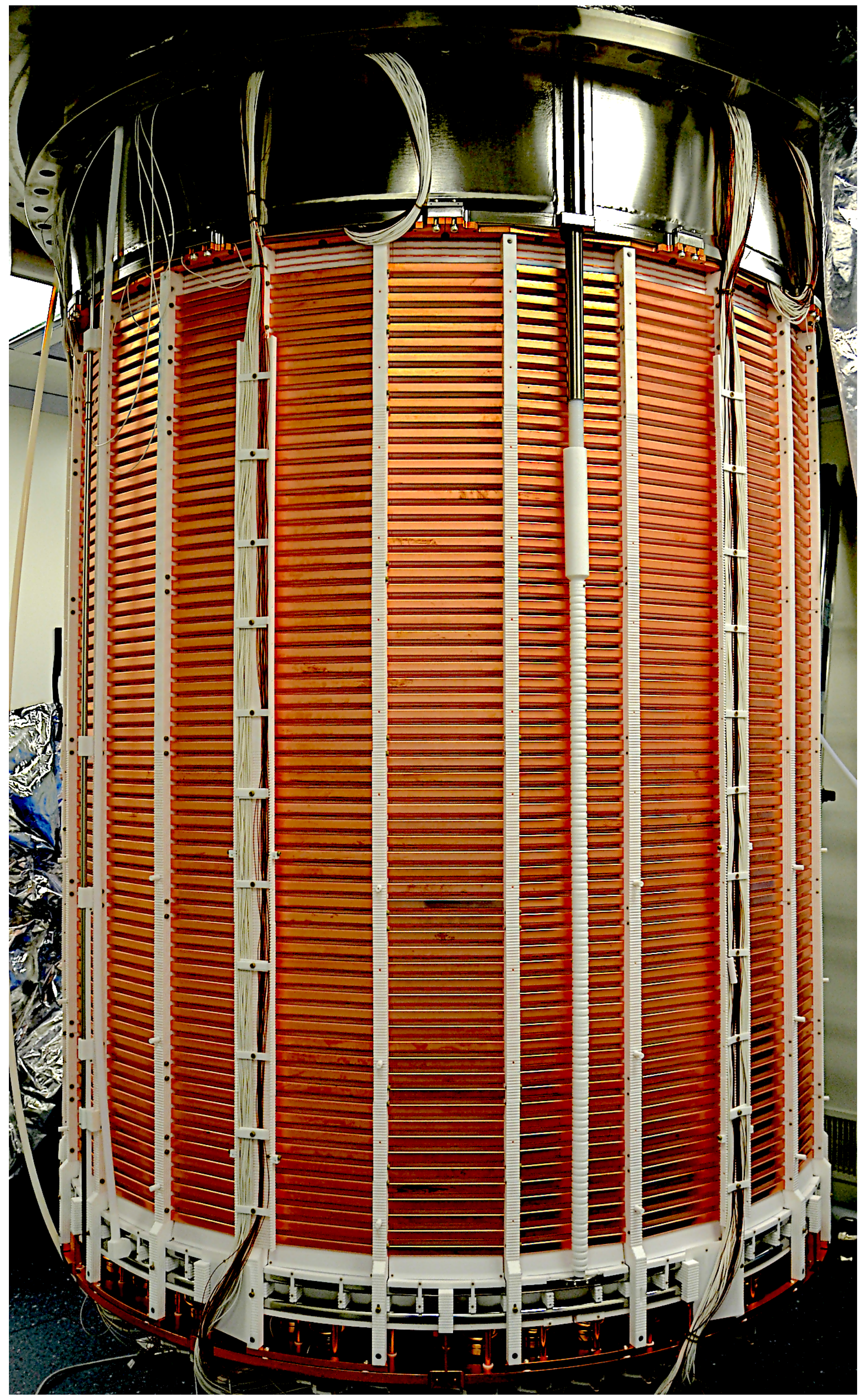


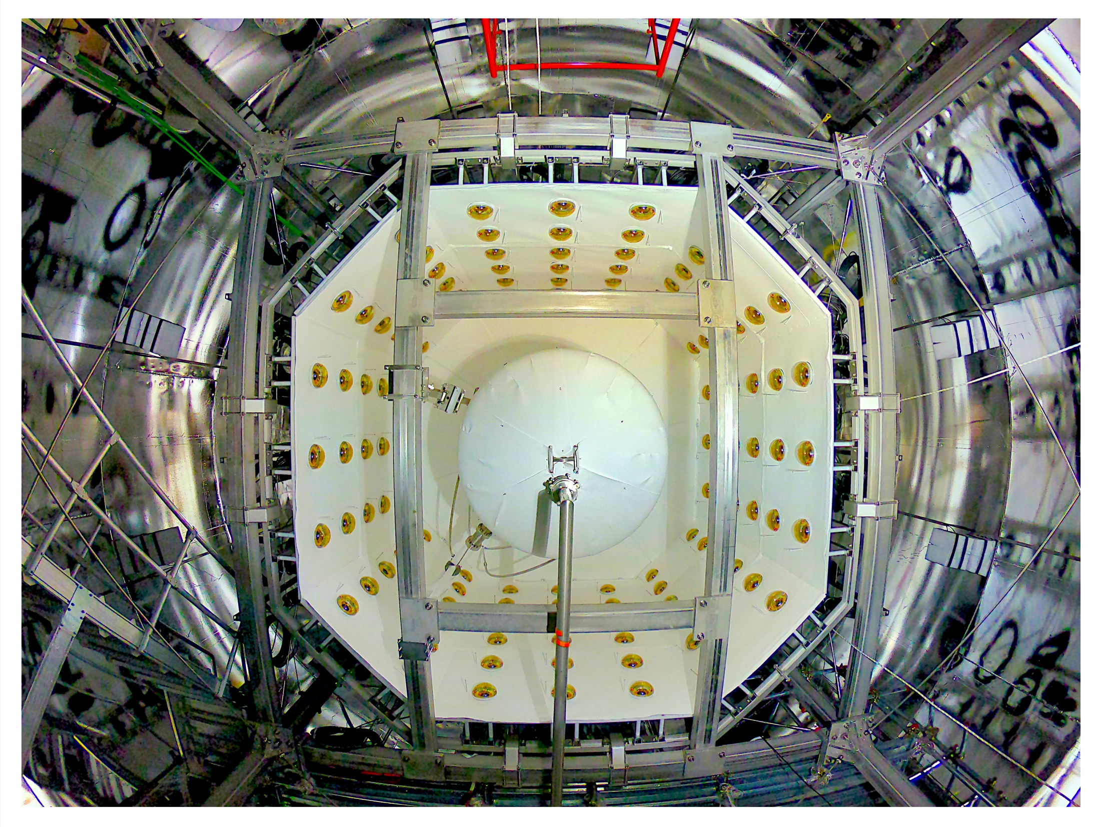
3 nested detectors



LXe Time Projection Chamber

8.6 tonnes of LXe (total)
5.9 tonnes Active Target Mass
1.5 m-long Active Target
1.3 m-diameter Active Target
494 3″ PMTs (R11410-21)

TPC



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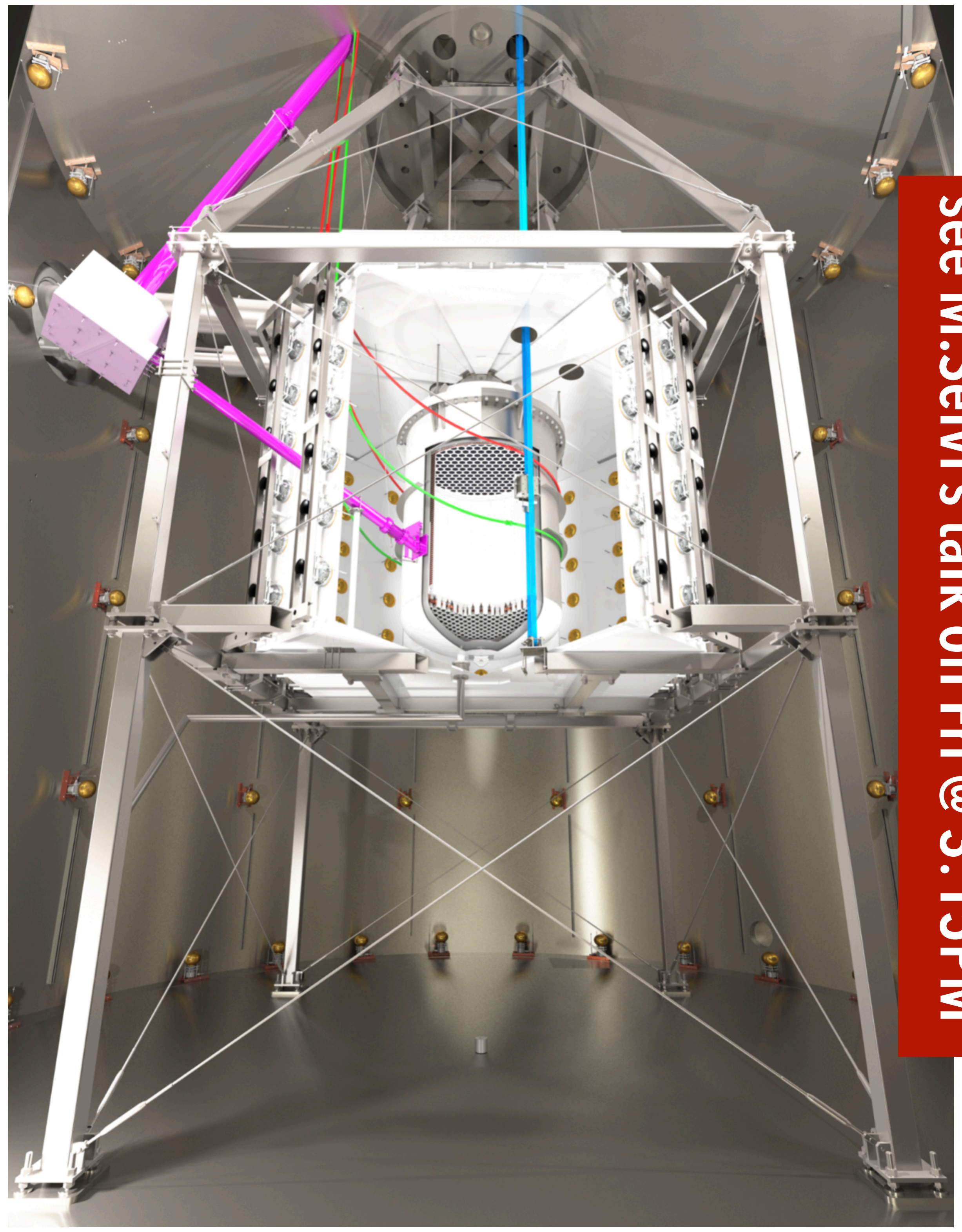


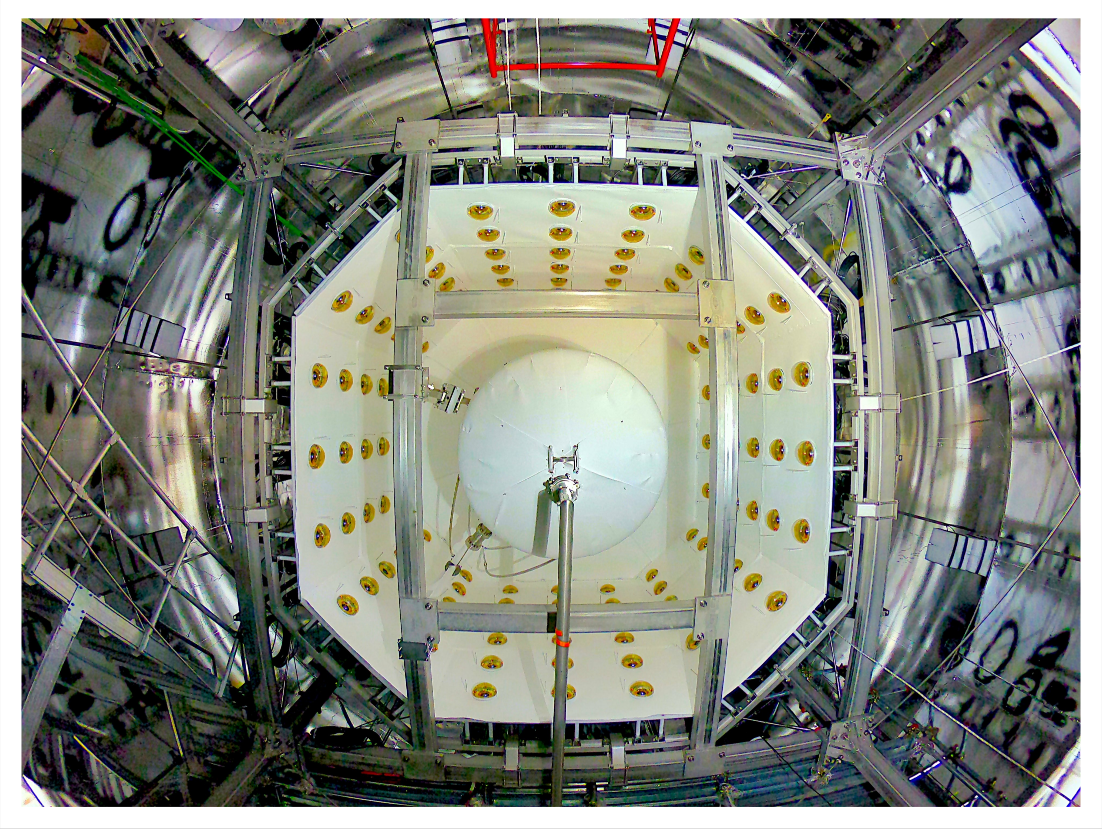
see M.Selvi's talk on Fri @ 3:15PM

Gd-doped Water Neutron Cherenkov Detector

[Operated till now with pure water]

33-m^3-volume
high-reflectivity expanded PTFE
120 8″ high-QE PMTs (R5912-100-10)

nVETO



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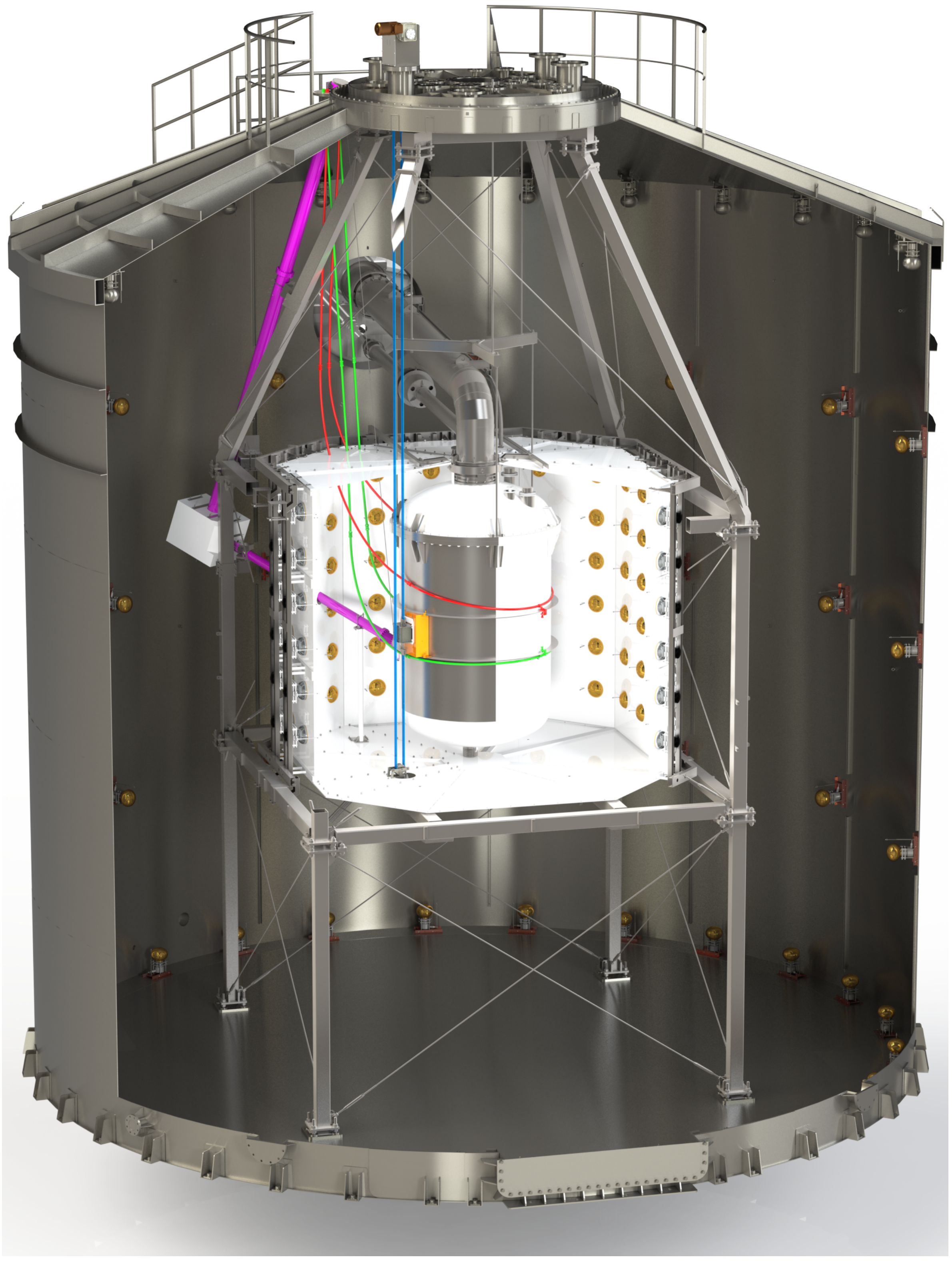


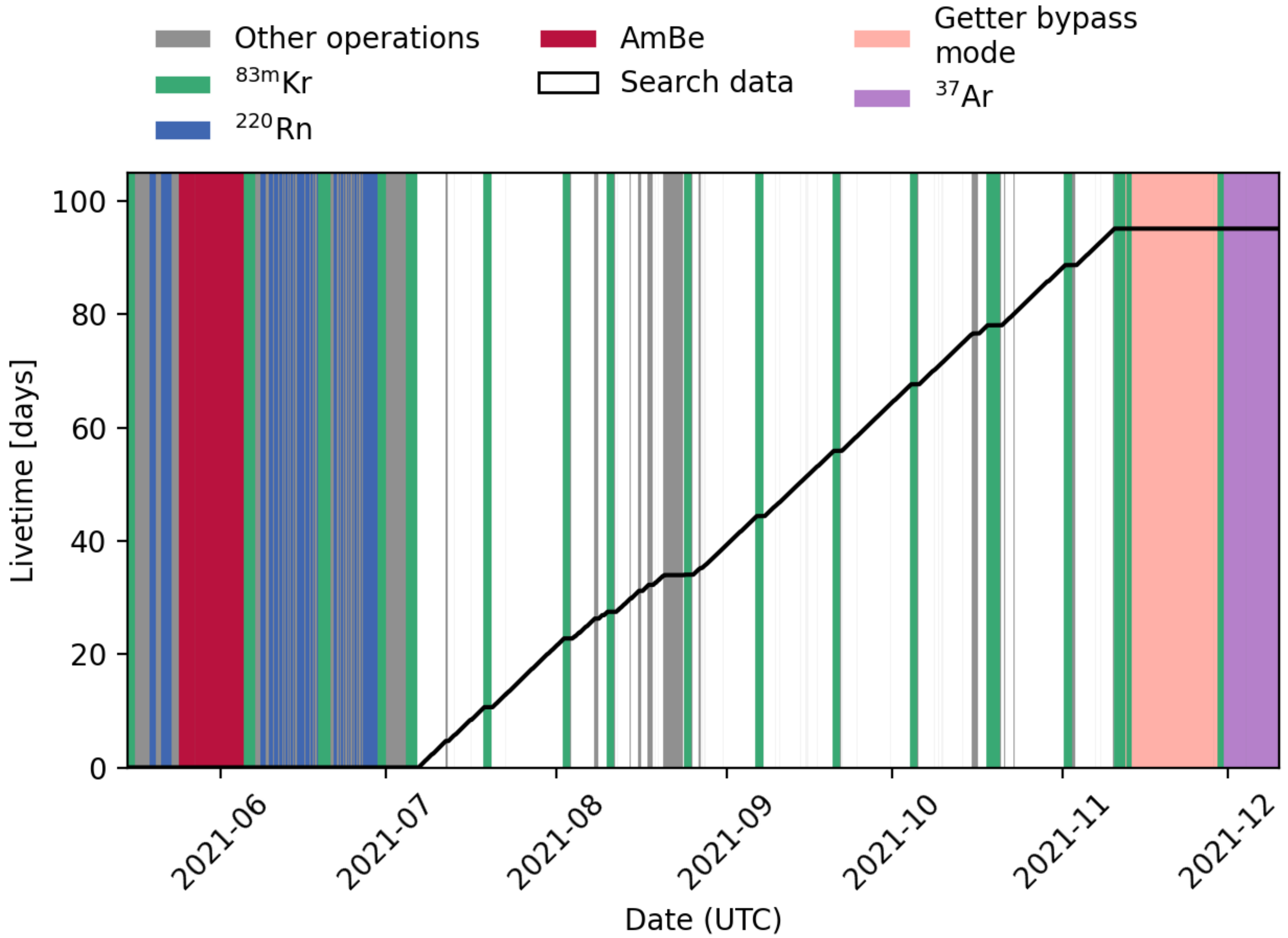
Muon Cherenkov Detector

700 tonnes of Gd-doped Water
height 10.2 m - diameter 9.6 m
high-reflectivity 3M DF2000MA
84 8" Hamamatsu R5912ASSY

µVETO

SR0 WIMP

May 2021 — **Science Run 0 - WIMP blind search** — Dec 2021



Calibration data
(AmBe, ^{220}Rn, ^{83m}Kr)

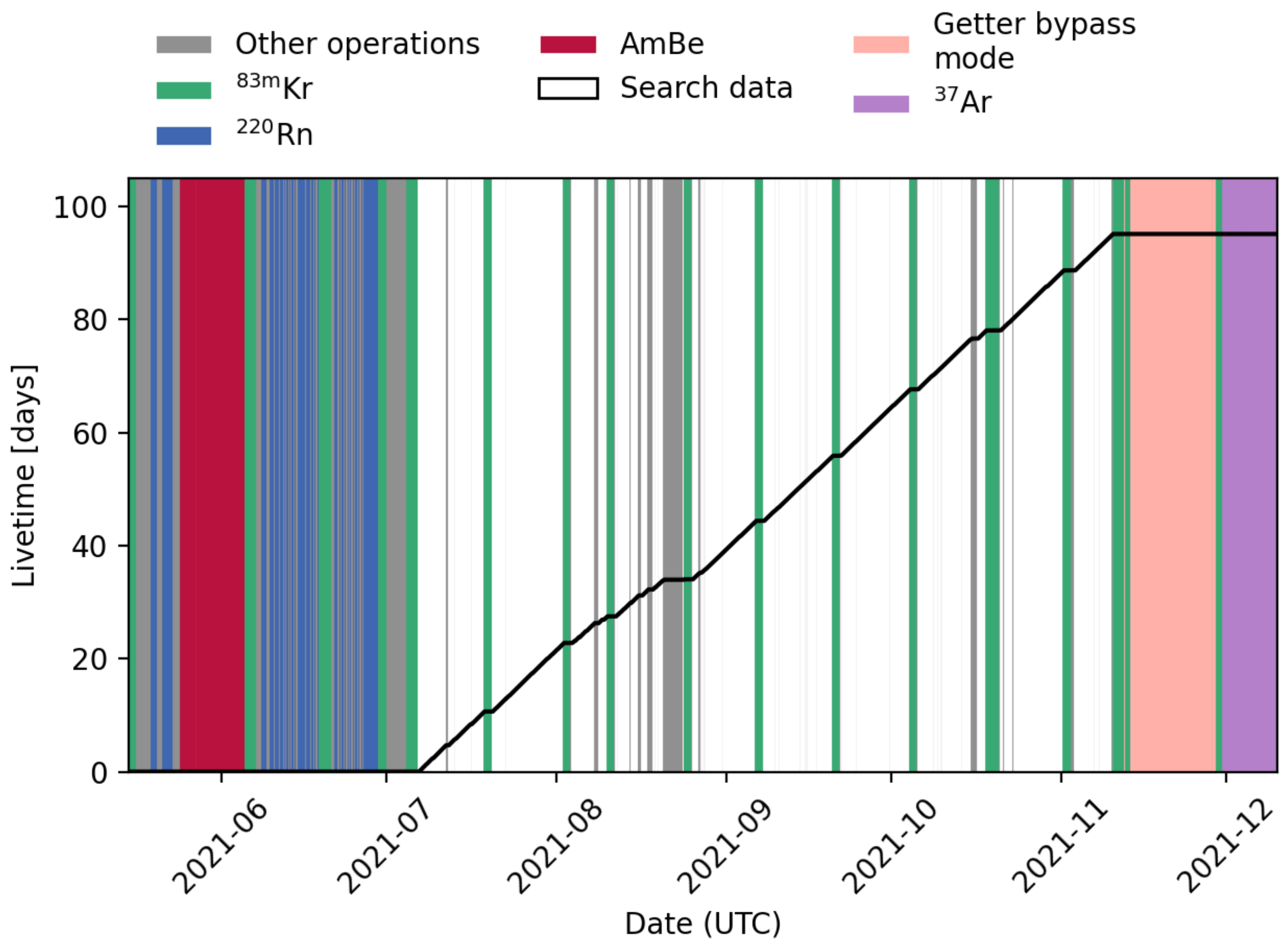
Blinded search data

95.1 live days
(For WIMP search)

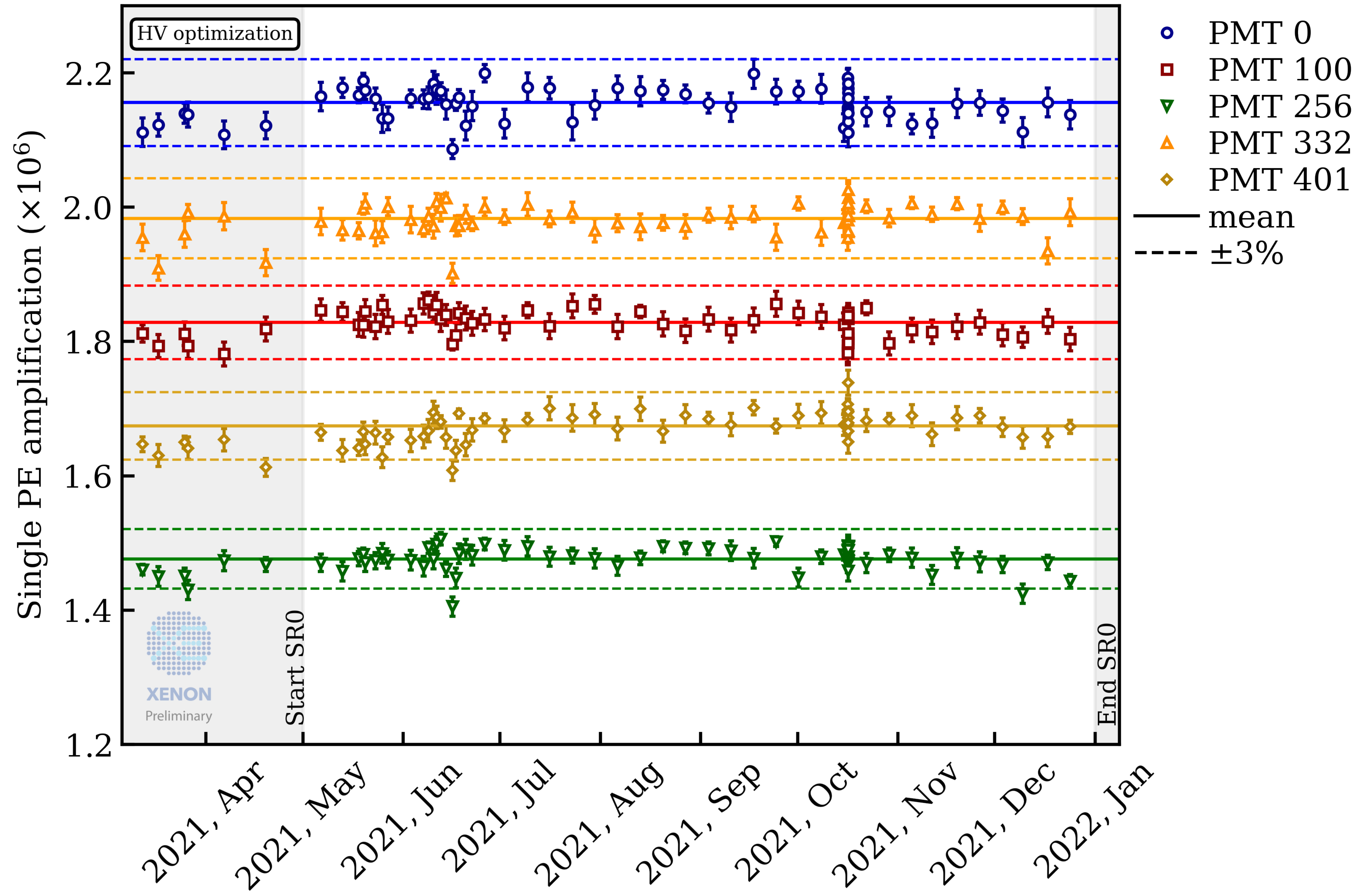
^{37}Ar Cal.

Duration optimized for Low ER Search

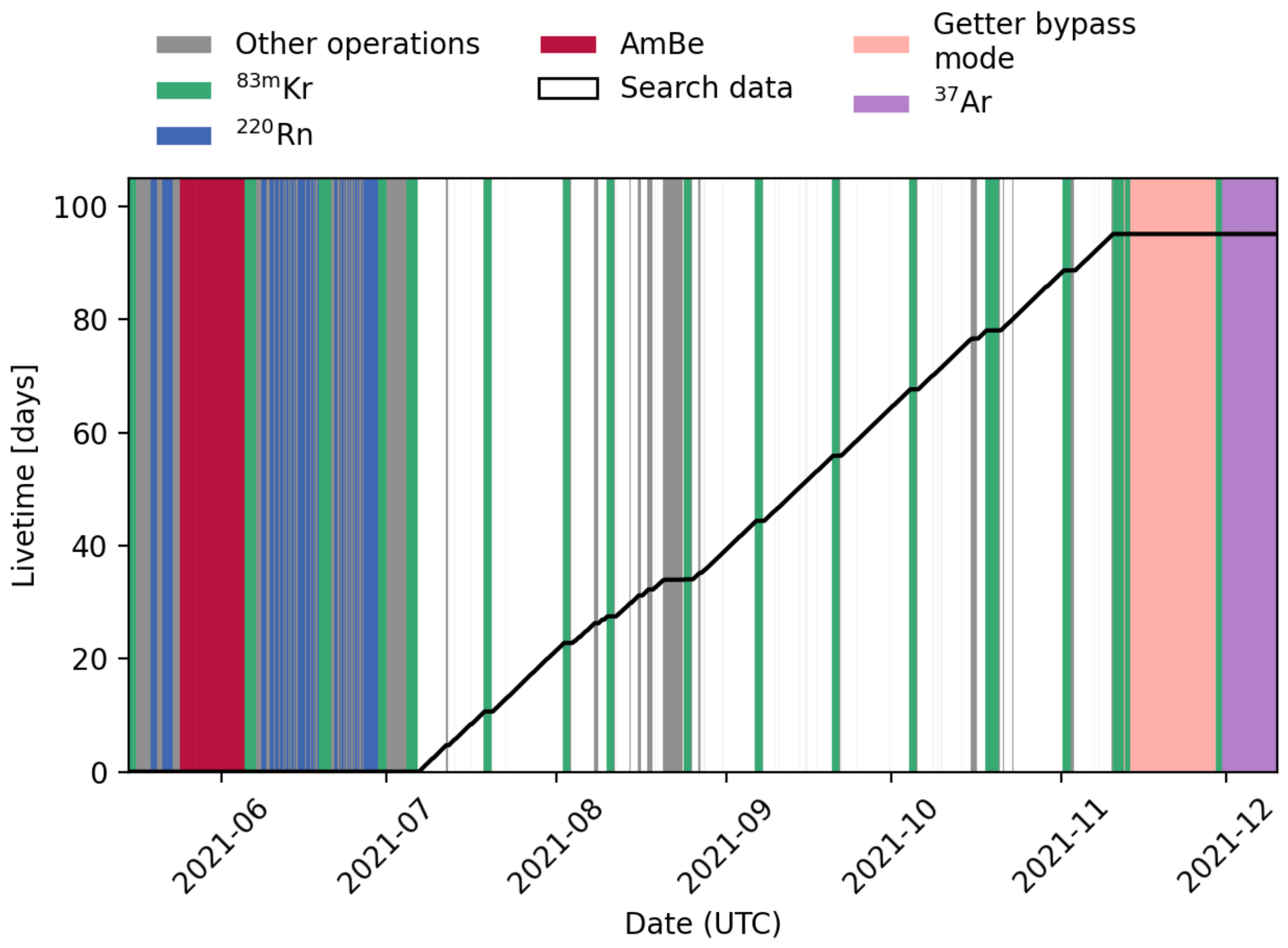
SR0 WIMP



- SR0 detector configuration:
  - Drift field: ~23 V/cm
  - Extraction field in liquid: ~2.9 kV/cm (≈50% EE)
  - 477 out of 494 PMTs working (gain stable within 3%)



SR0 WIMP



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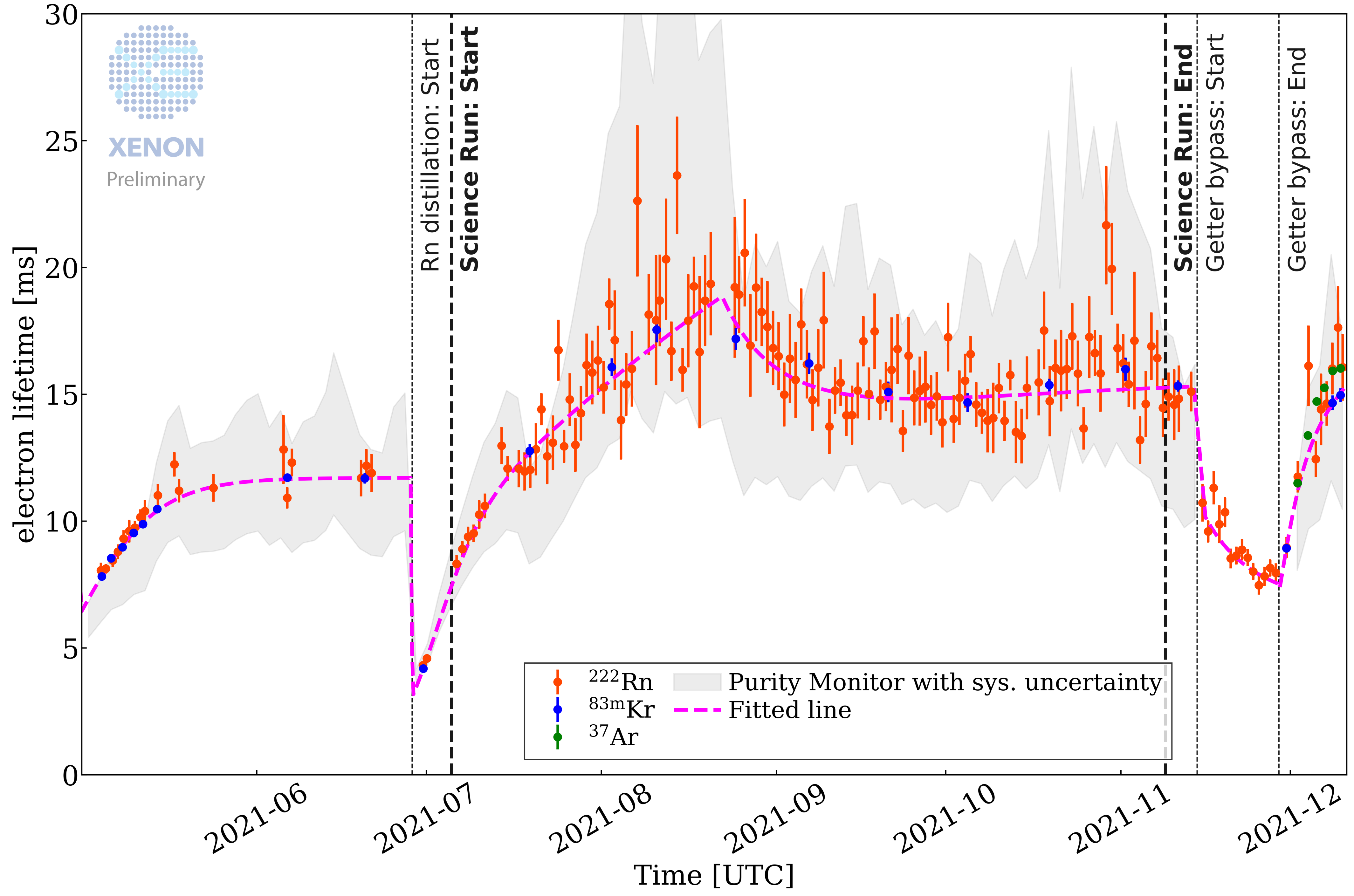
- Average **electron lifetime > 10 ms**
  - Innovative LXe Cryogenic Purification



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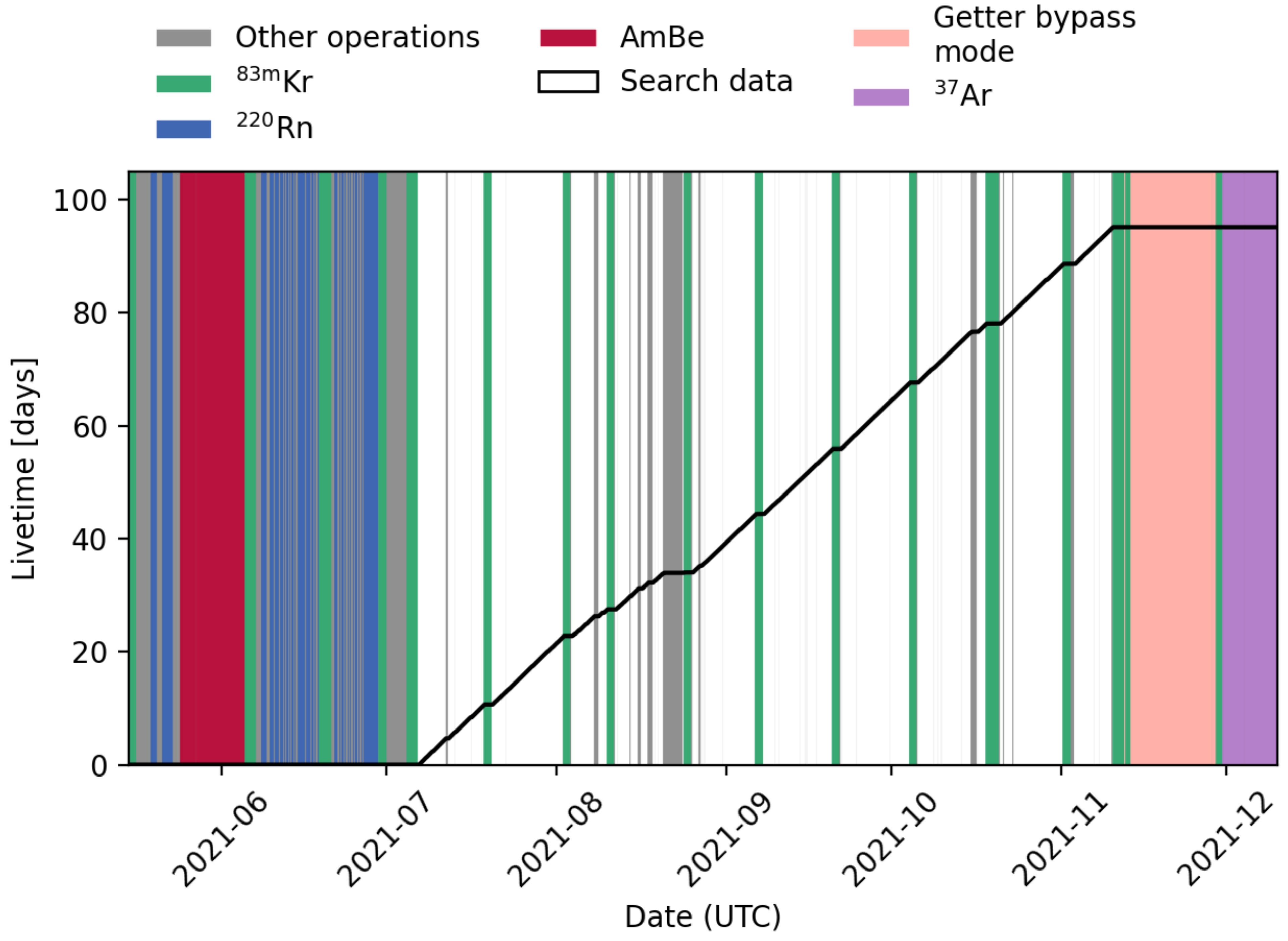

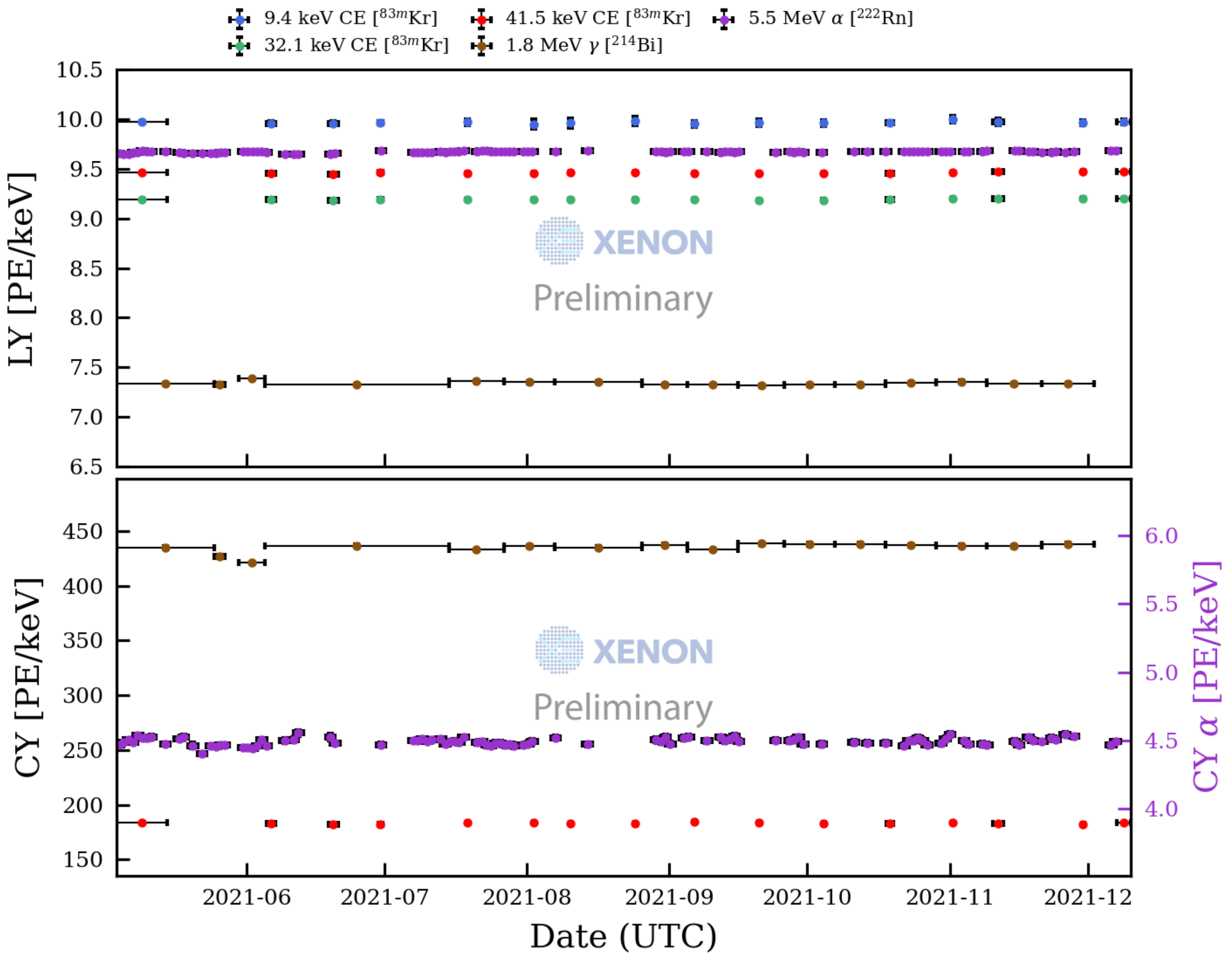

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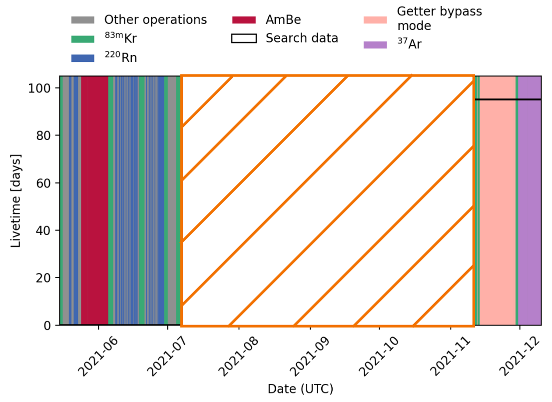
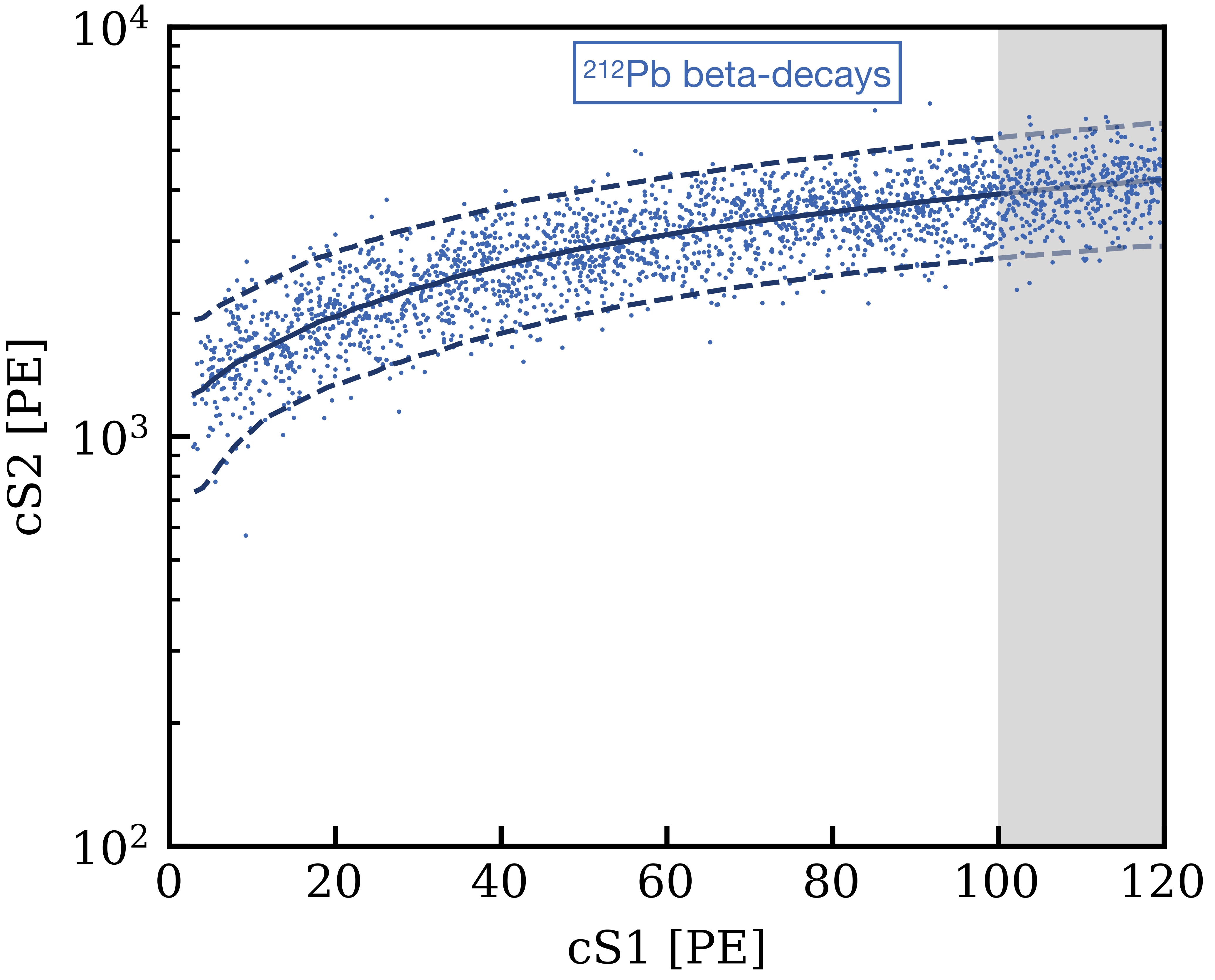
  - 477 out of 494 PMTs working (gain stable within 3%)
- Average **electron lifetime > 10 ms**
  - Innovative LXe Cryogenic Purification
- Detector **response extremely stable**
  - Light Yield (PE/keV) maximal variation ~ 1%
  - Charge Yield (PE/keV) maximal variation ~ 1.9%

SR0 WIMP

Calibration data
ER/NR response



- **ER datasets:**
  - ^{212}Pb beta-decays from injected gaseous ^{220}Rn;
    - Fitted with LXe micro-physics model to define the **cS2 vs cS1 response for ER;**
    - Used to validate **cut acceptance.**



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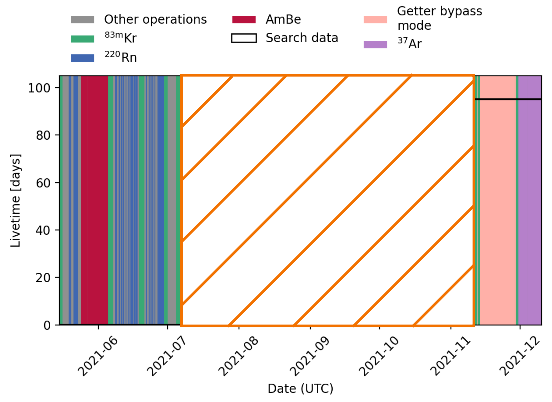

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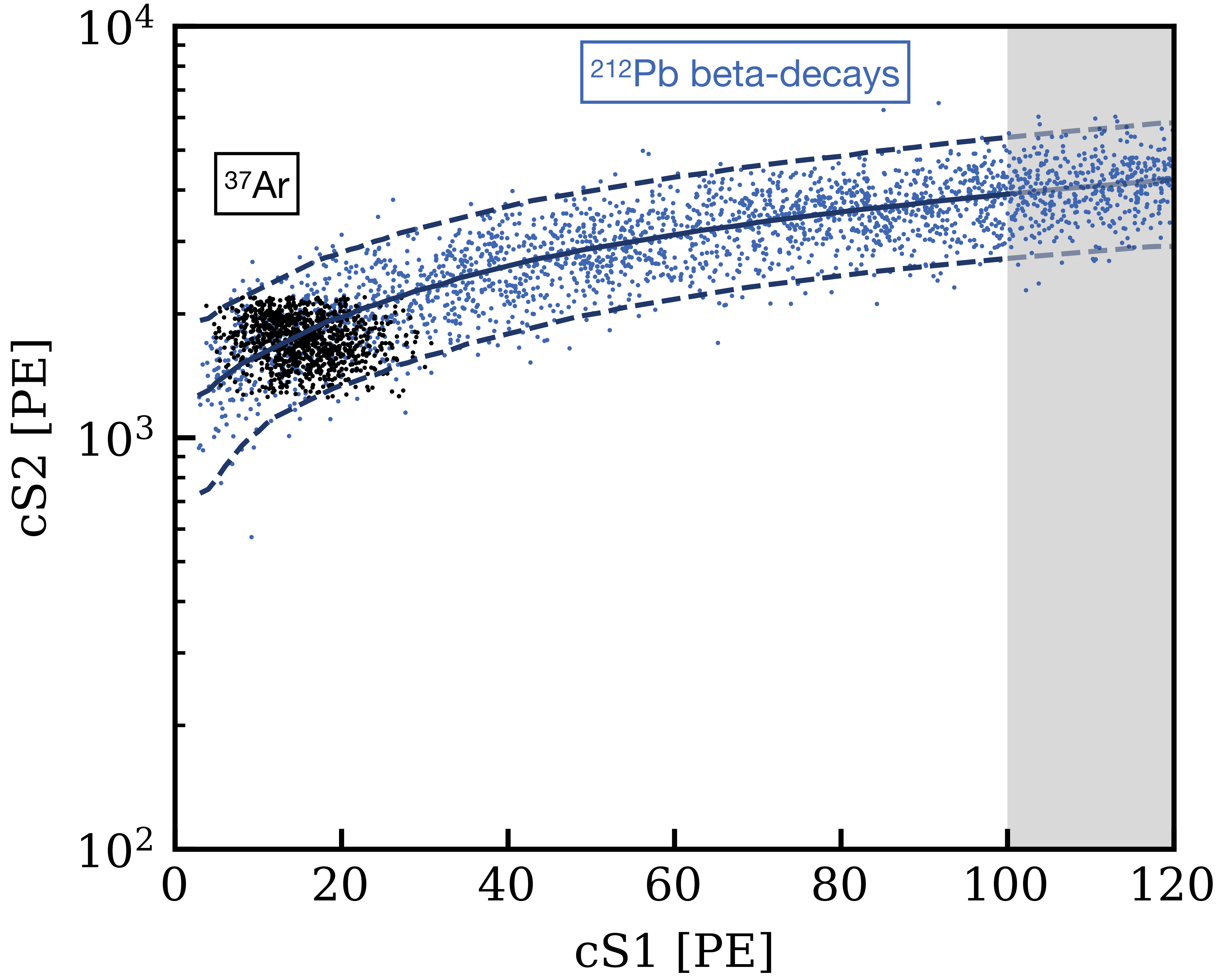
    - Used to validate **cut acceptance.**
  - ▸ ERs from injected gaseous ^{37}Ar (2.8 keV);
    - Used to validate the **low-energy ER response.**



SR0 WIMP

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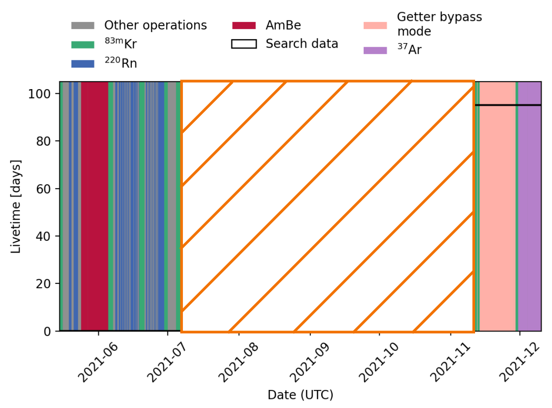
ER/NR response



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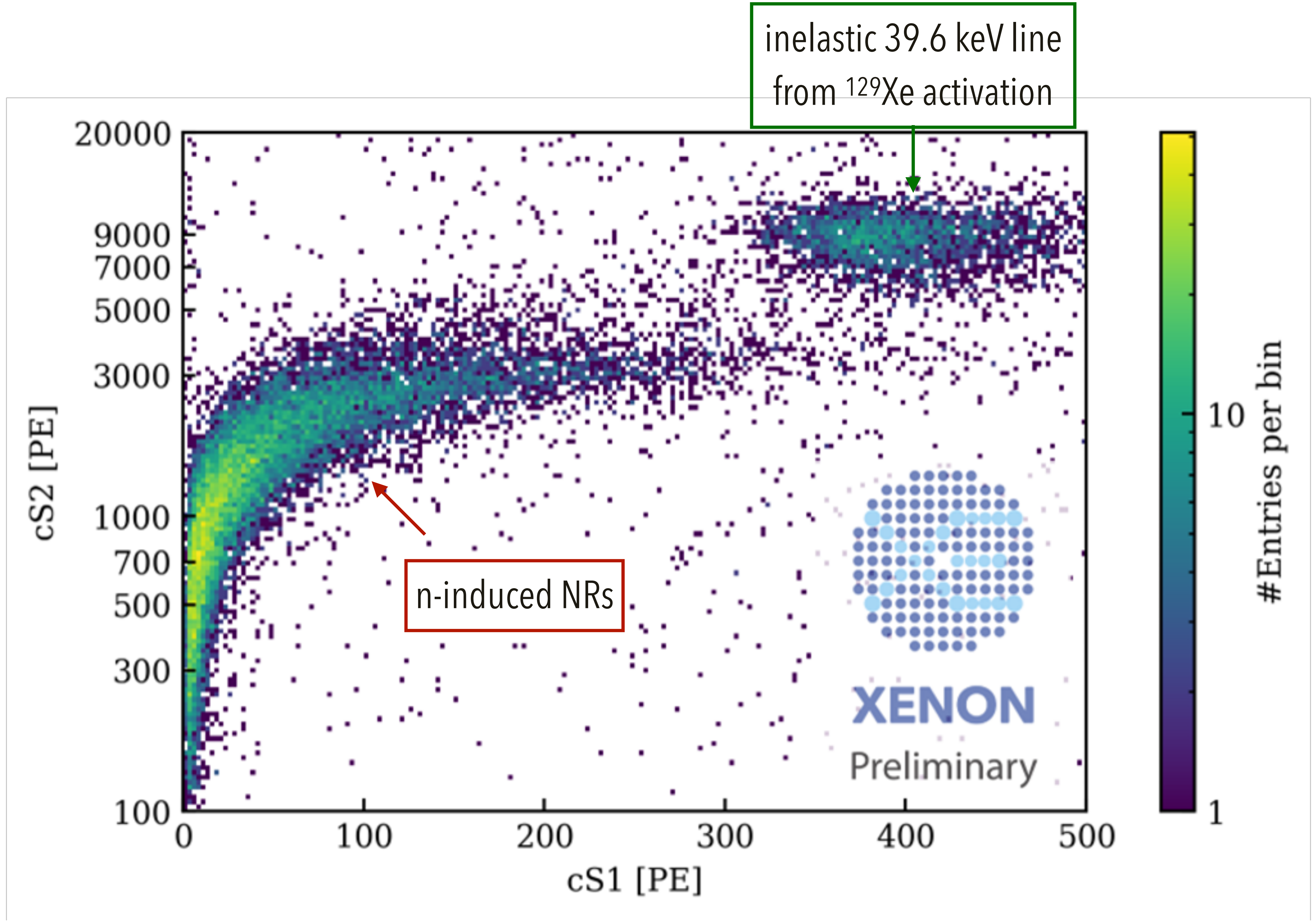
- **NR datasets:**
  - ▸ Neutron-induced NRs from **^{241}AmBe** neutron source;



SR0 WIMP

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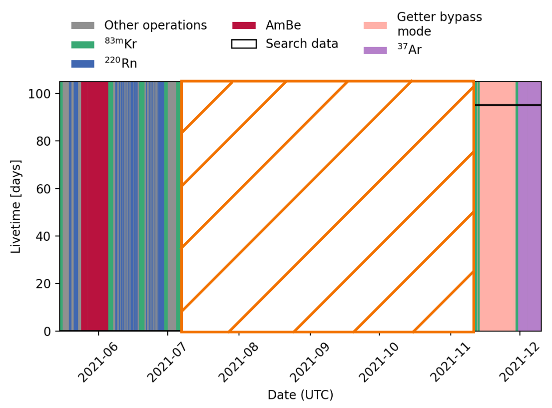

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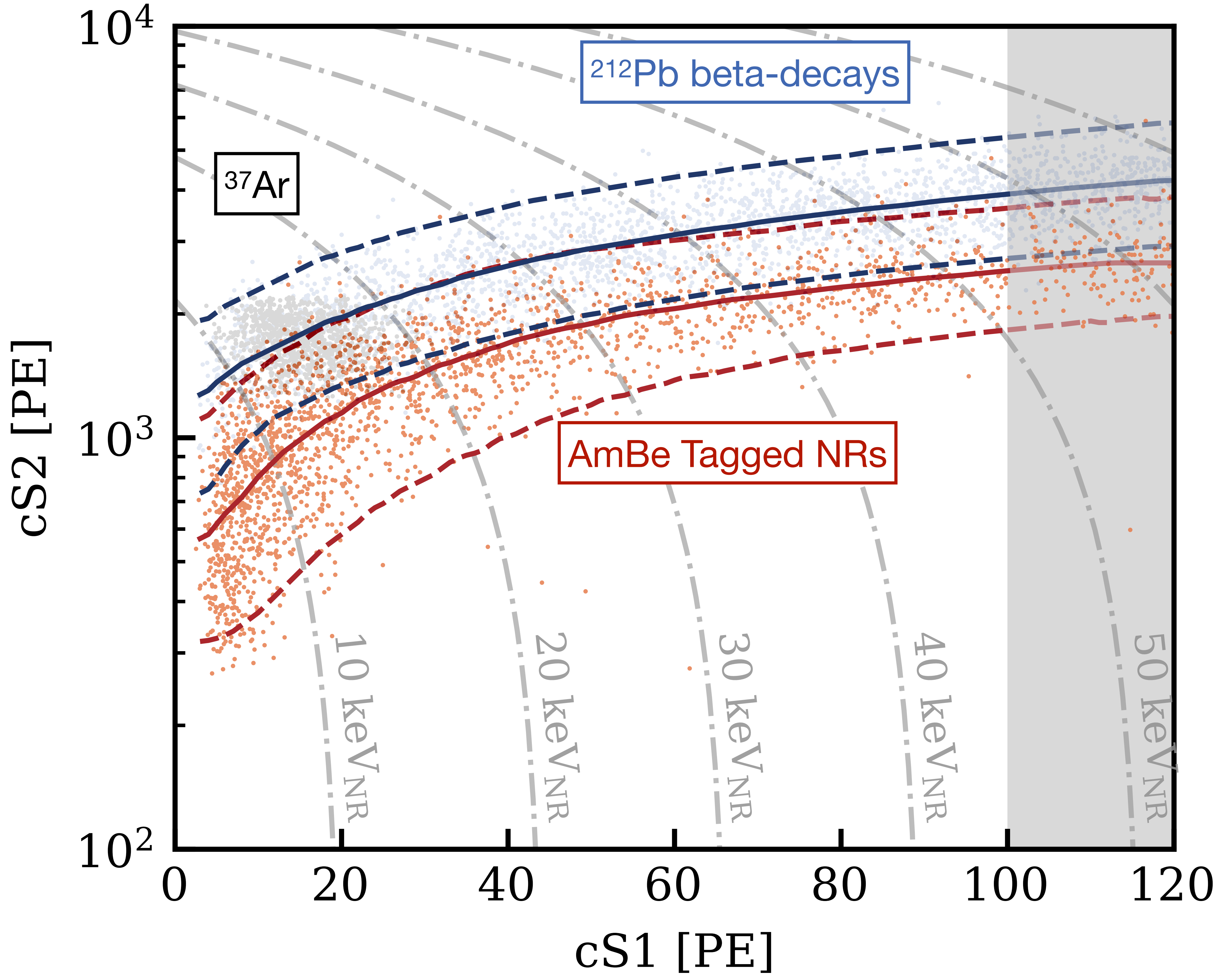
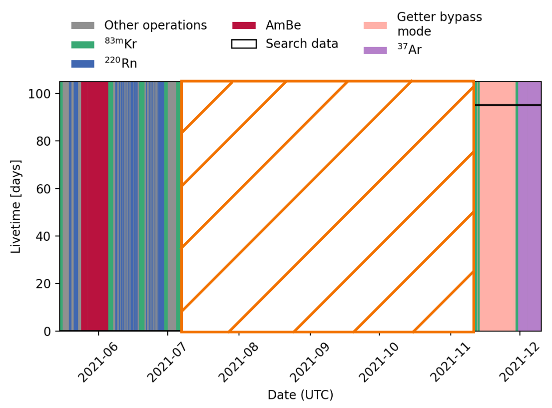
  - ▸ Neutron-induced NRs from **^{241}AmBe** neutron source;
    - Pure sample of NRs tagged by a **coincident 4.44 MeV gamma** (emitted by AmBe in 60%) detected by the nVeto;
    - Fitted with the same LXe micro-physics model to define the **cS2 vs cS1 response for NR.**



see M.Selvi's talk on Fri @ 3:15PM

SR0 WIMP

Calibration data
ER/NR response



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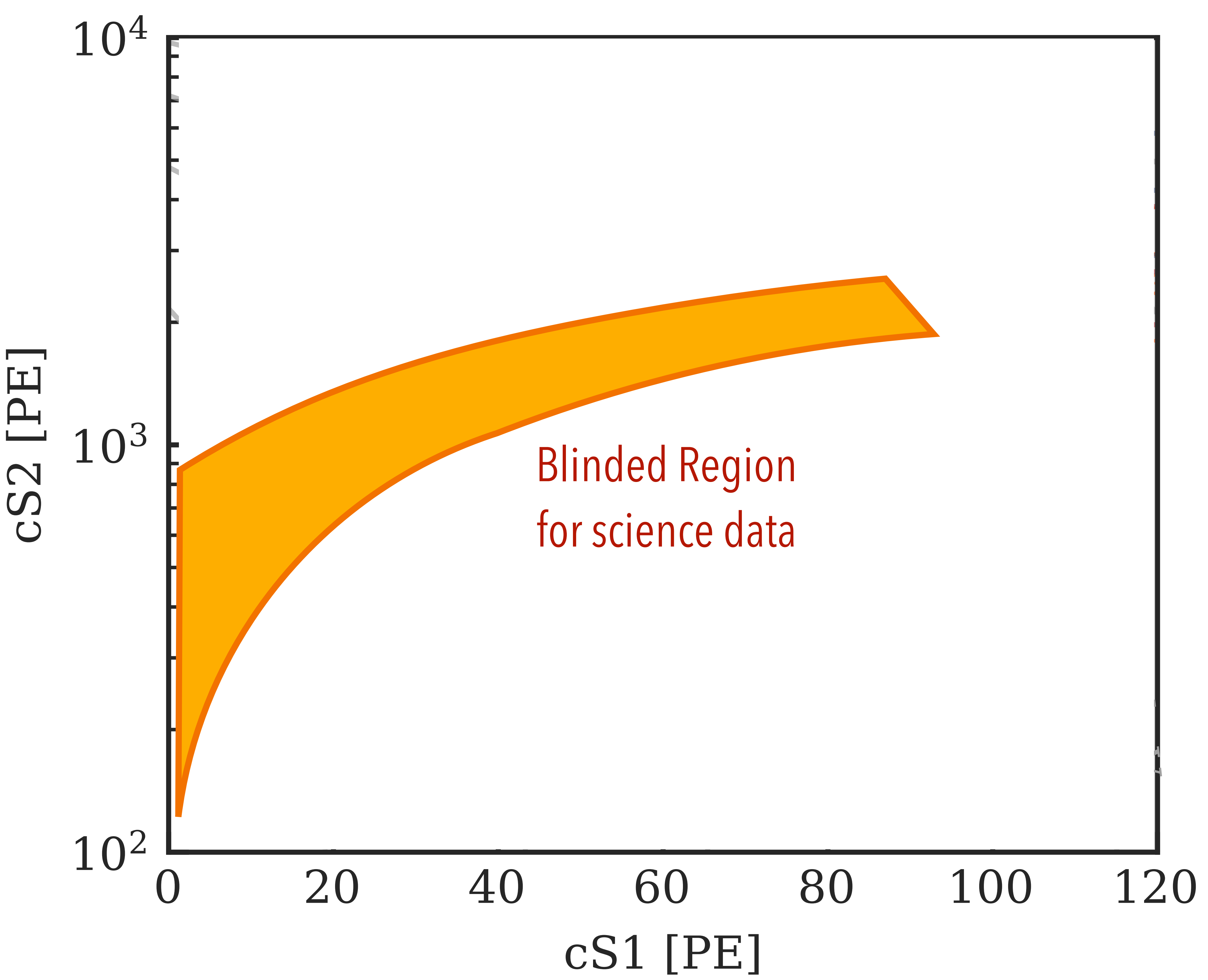
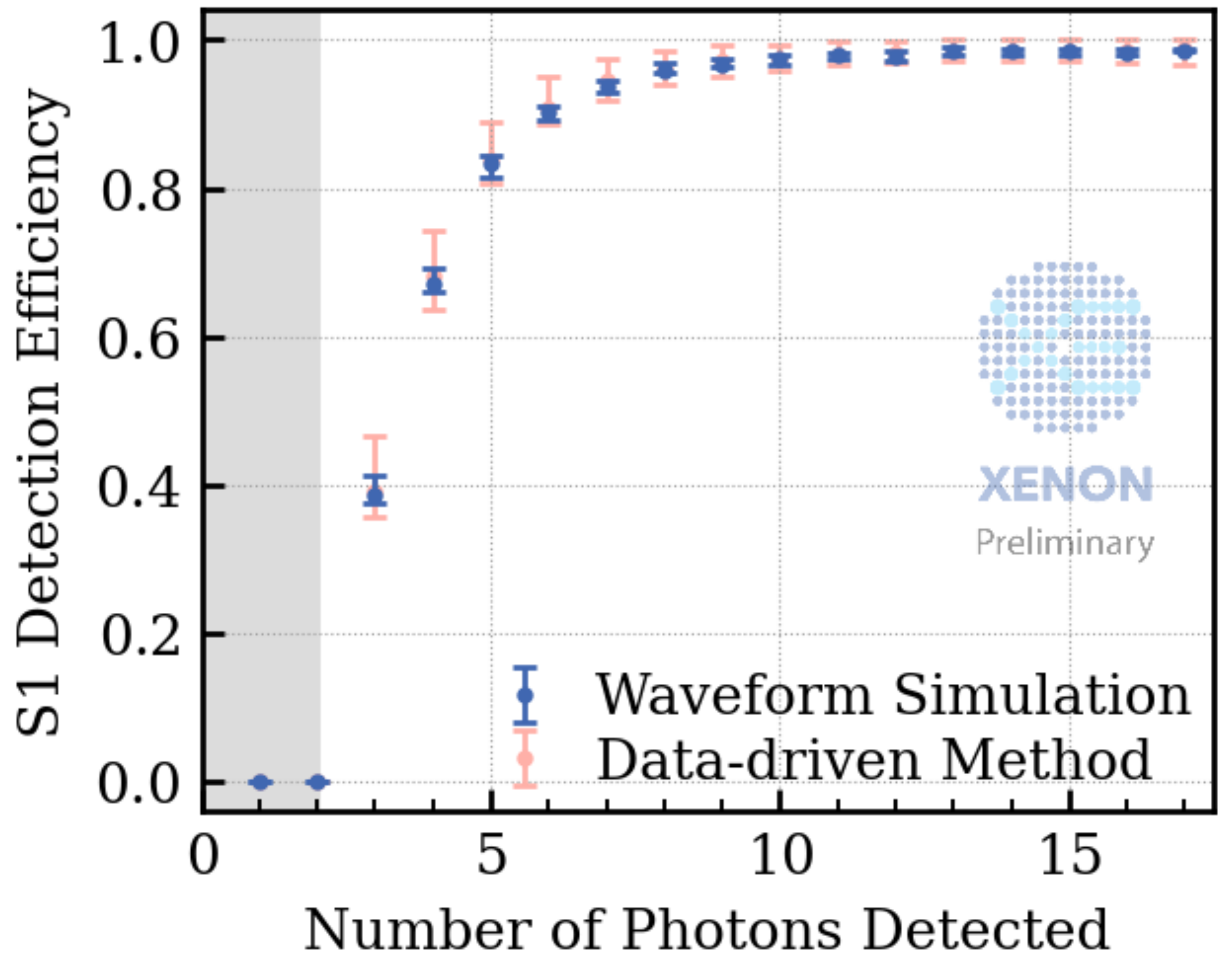
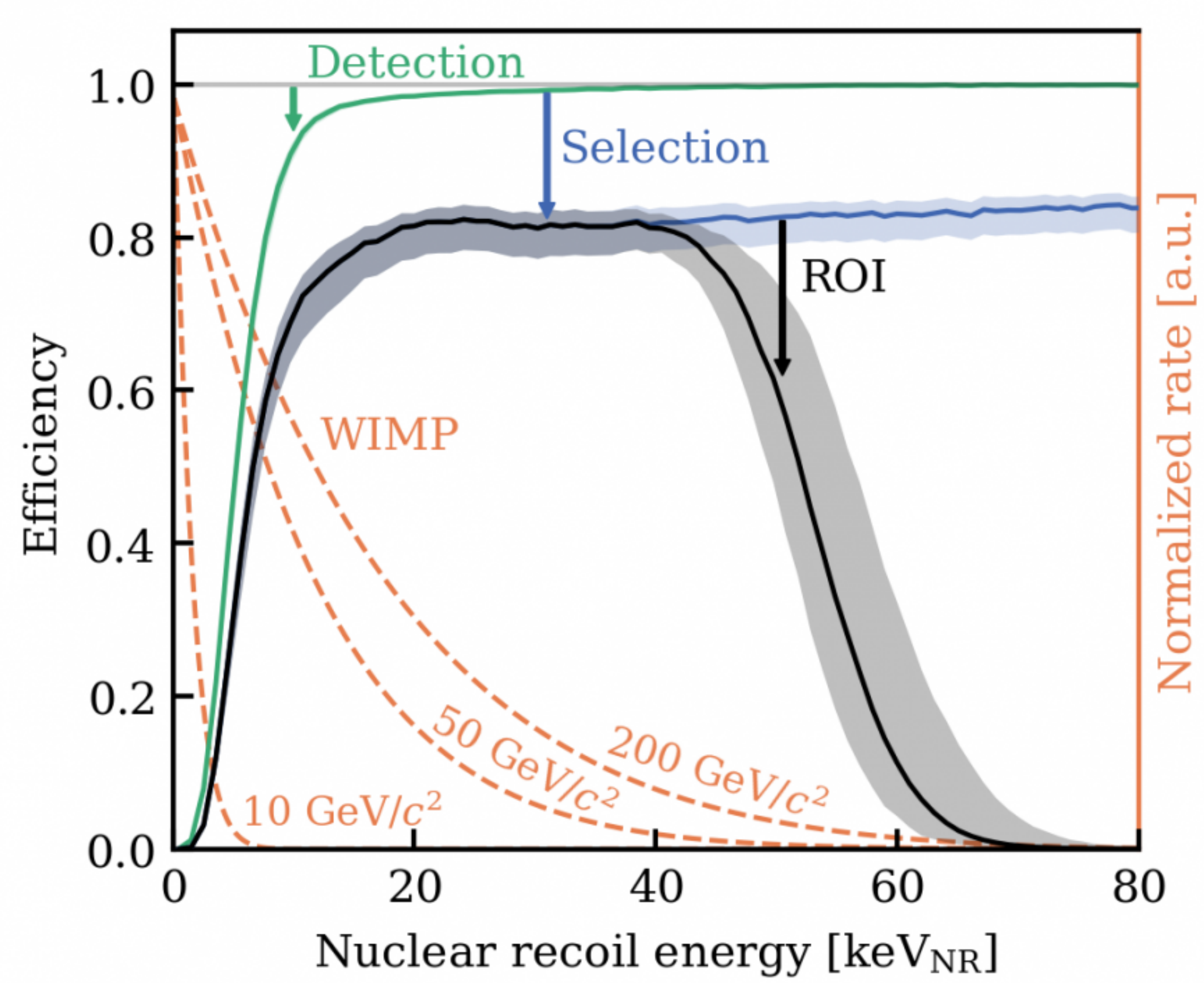


SR0 WIMP

Calibration data
efficiency and cuts

- Total efficiency for NR interaction dominated:
  - **At very low energy** by **3-fold coincidence** requirement
    - Data-driven from ^{83}Kr and ^{37}Ar (bootstrap method)
    - Full waveform simulation
  - **At intermediate energy** by **selection cut** **(plateauing @ ~80%)**
    - S1> 3-fold coincidence
    - S2>200 PE
    - Quality cuts on S1 and S2 peak parameters
    - **No associated signal in the neutron veto (250 ns after S1)** see M.Selvi's talk on Fri @ 3:15PM
  - **At high energy** by **ROI** requirement
    - cS1 $\in$ [0 PE, 100 PE]
    - cS2 $\in$ [$10^{2.1}$PE, $10^{4.1}$ PE]

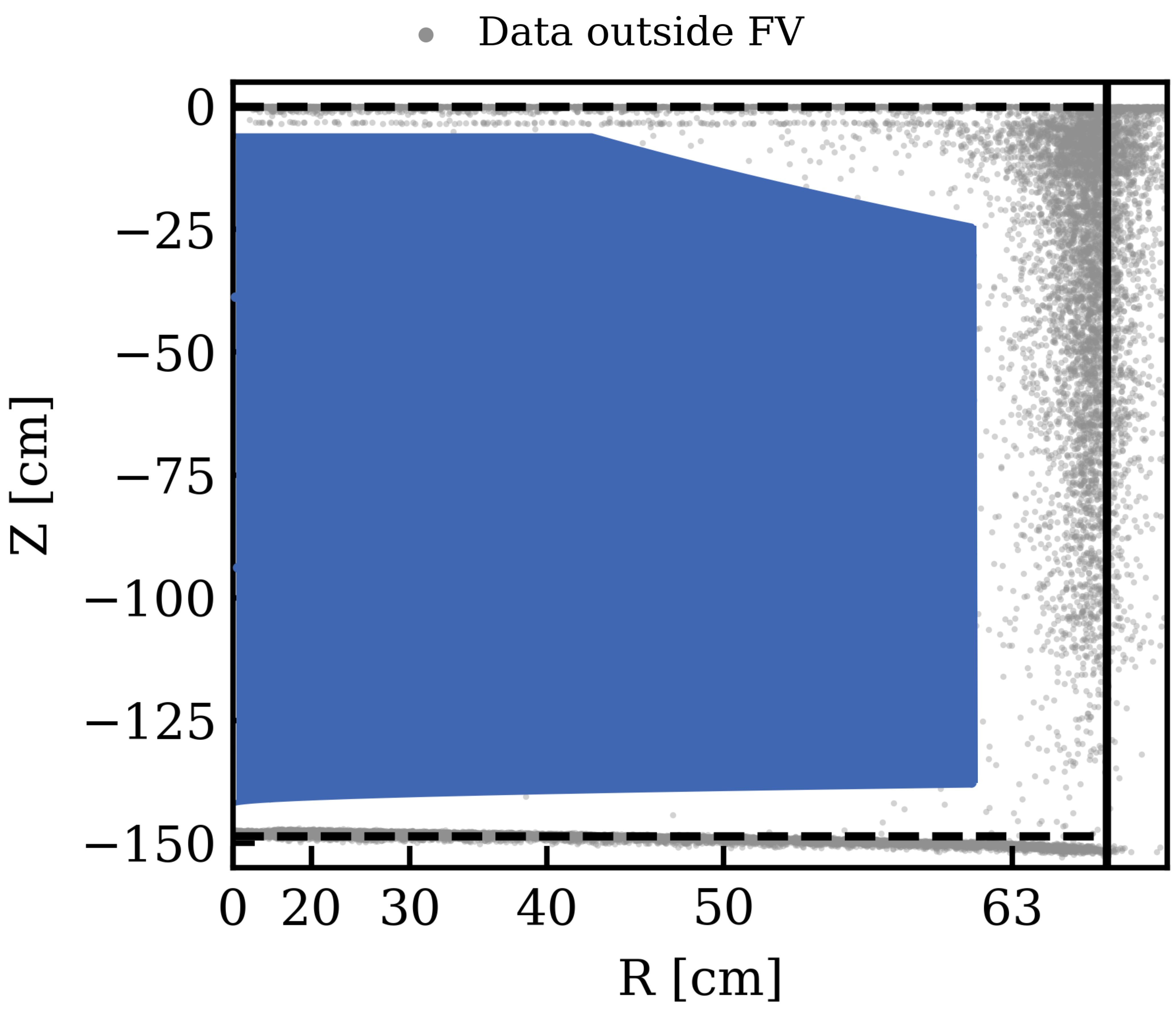




SR0 WIMP

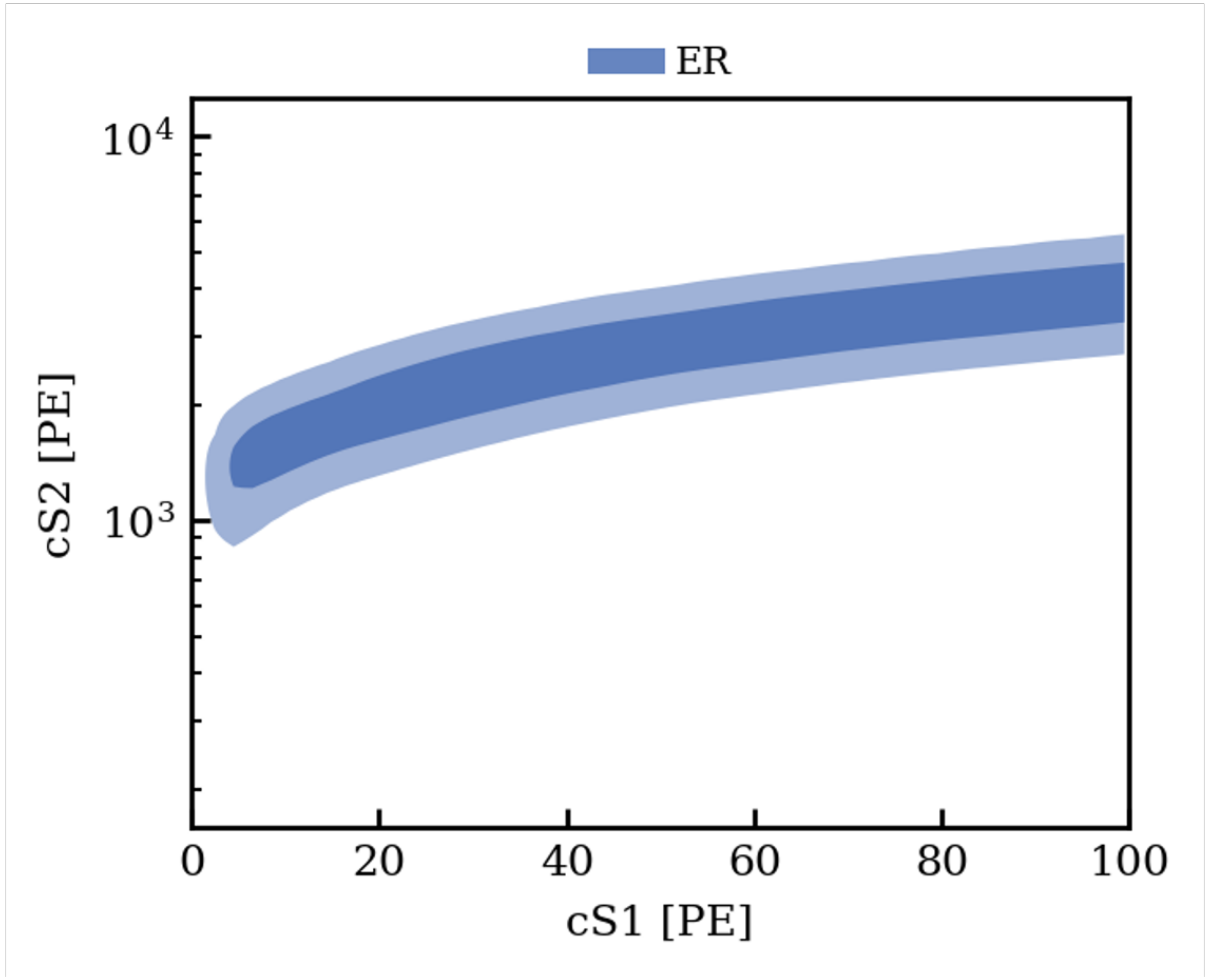
WIMP Search
fiducial volume

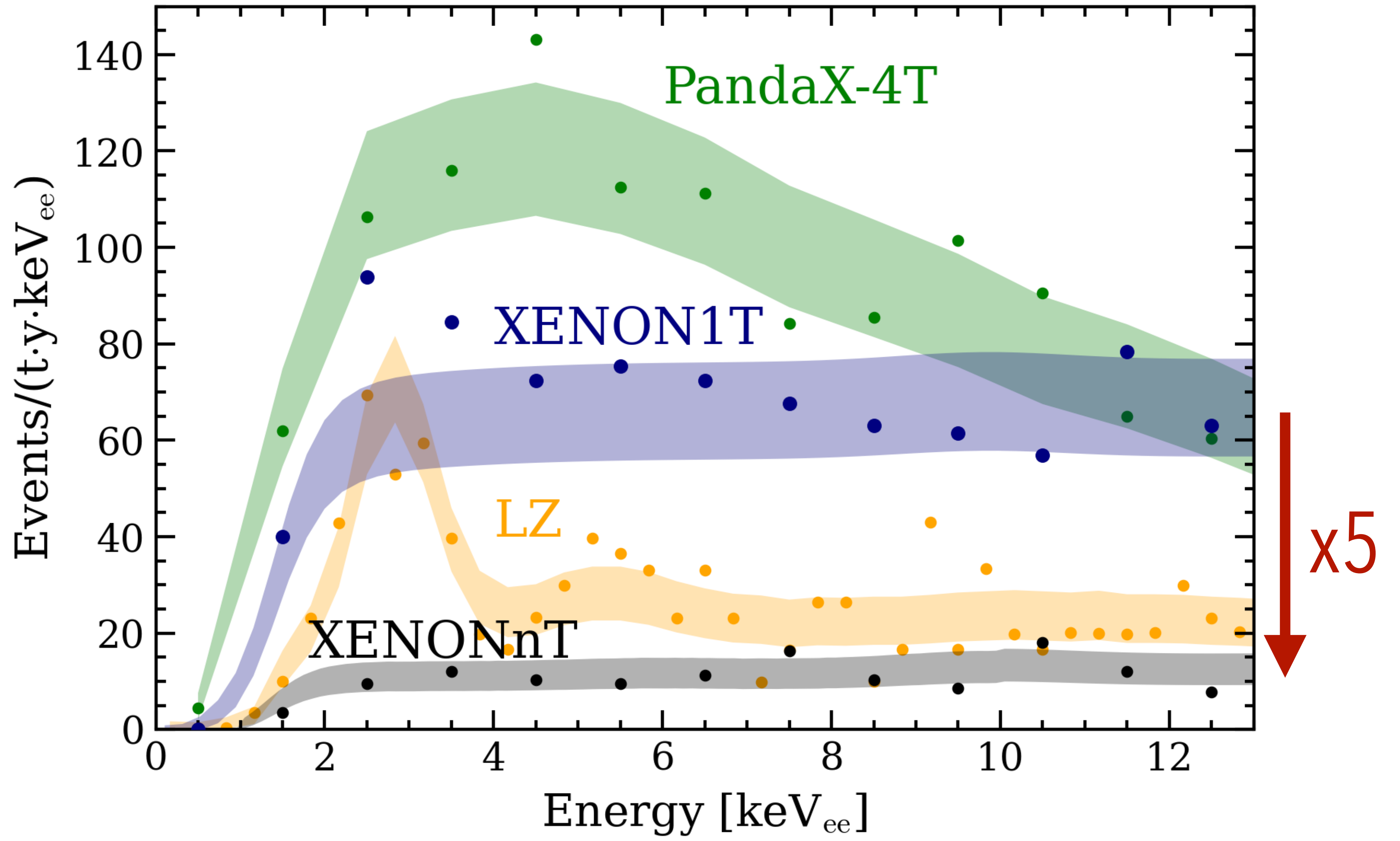
- **Fiducial Volume**
  - maximize signal/background ratio for low WIMP search
  - **M_{FV}=(4.18±0.13) tonnes**
- **Total exposure**
  - **1.1 tonnes*year**



WIMP Search
Background model

- **Low ER background**
  - **Dominated** by beta-decays from **^{214}Pb** a daughter of ^{222}Rn
  - 15.8 events/(t*y*keV) in the [1, 30] keV range (Ref. [1])





[1] E. Aprile et al, Search for New Physics in Electronic Recoil Data from XENONnT, PRL 129 (2022) 16, 161805

SR0 WIMP

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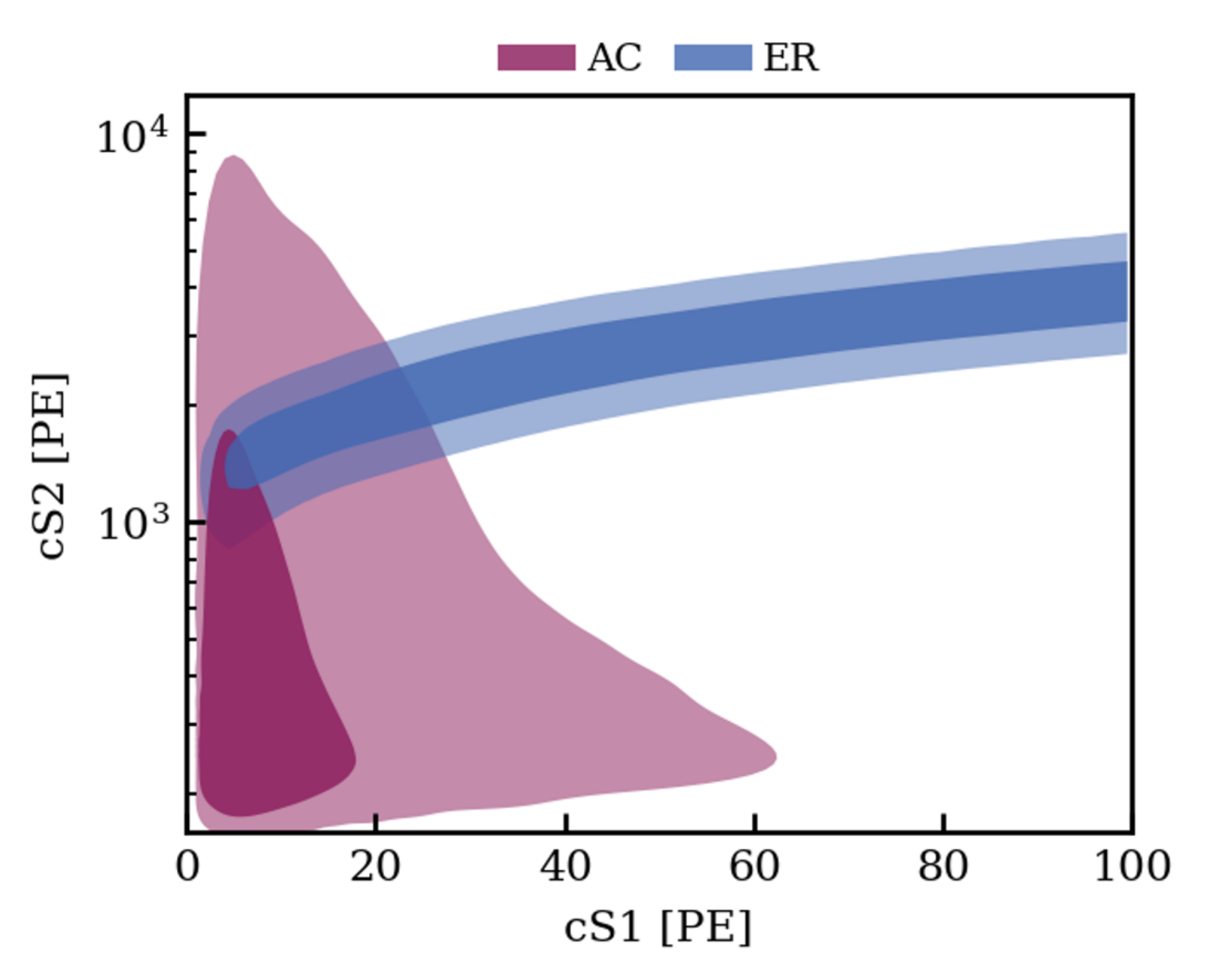
  - Random pairing of S1 and S2 lone signals
  - Suppressed by a dedicated **Gradient Boosted Decision Tree cut (GBDT)**, using S2 shape, R and Z information



see F. Gao's talk on Fri @ 2:30PM

SR0 WIMP

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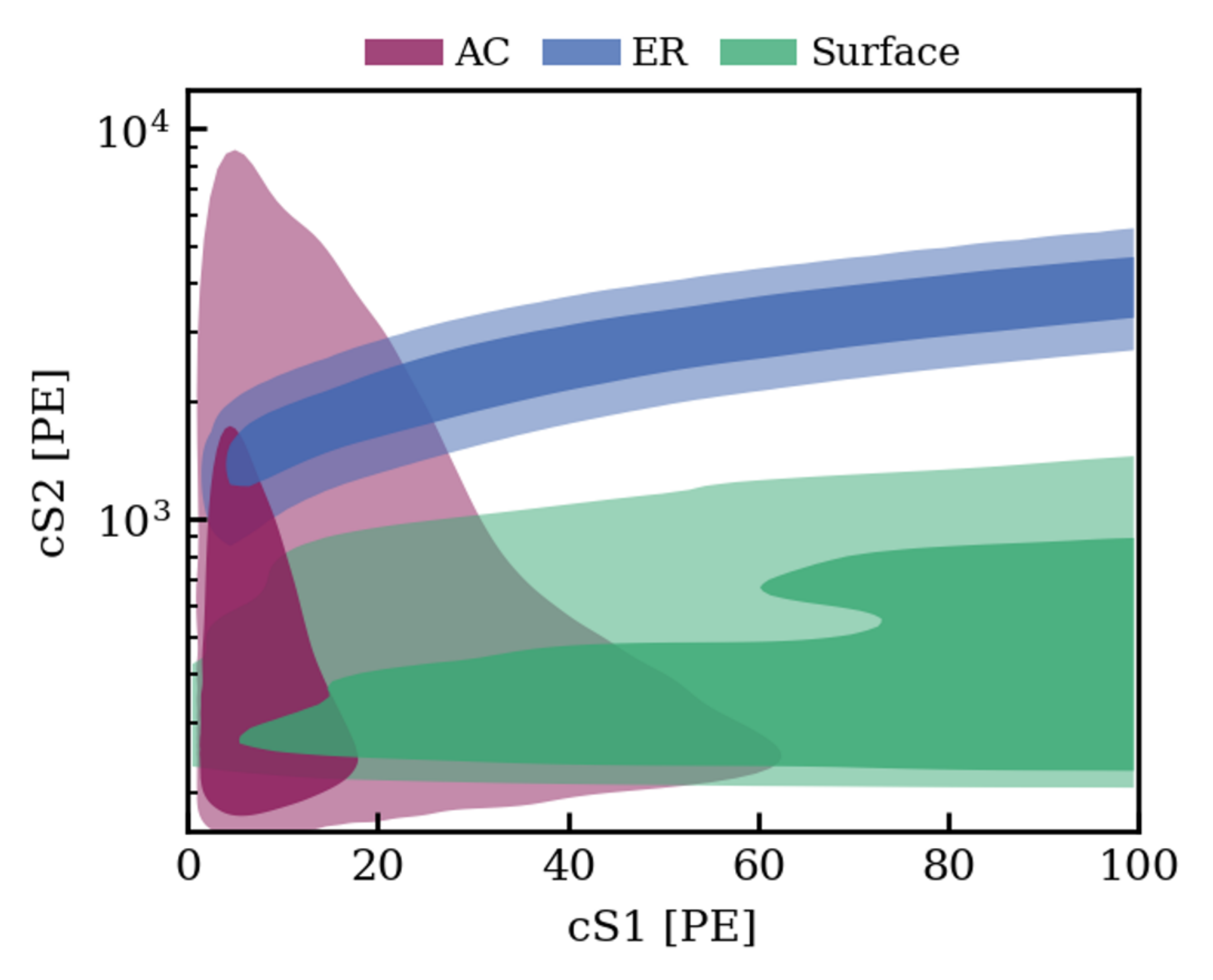
- **Surface background**
  - Due to ^{210}Pb plated out at TPC walls (beta-decay)
  - Suppressed by R_{max} < 61.35 cm of fiducial volume



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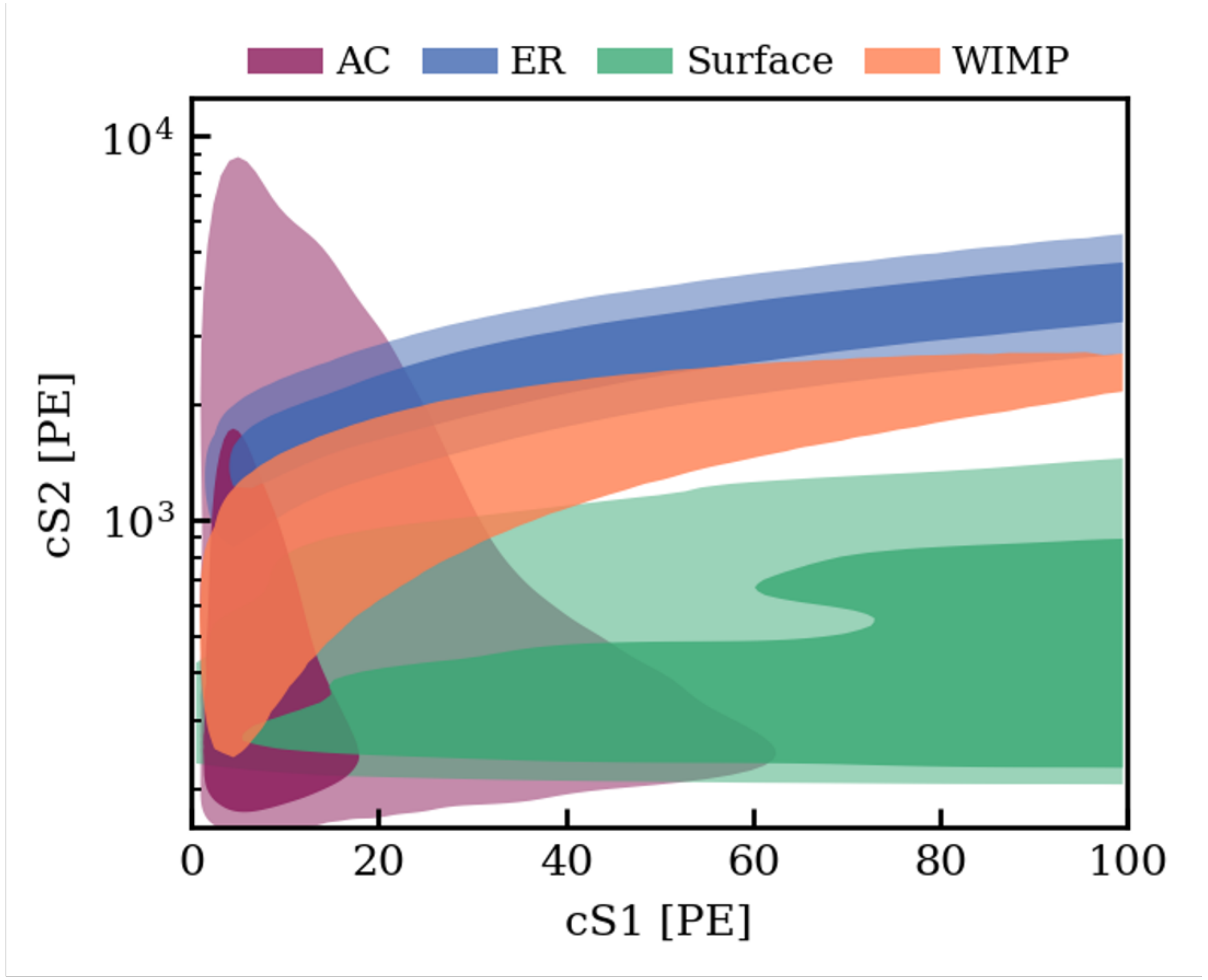
  - CEvNS



2σ contour for 200GeV/c² WIMP

SR0 WIMP

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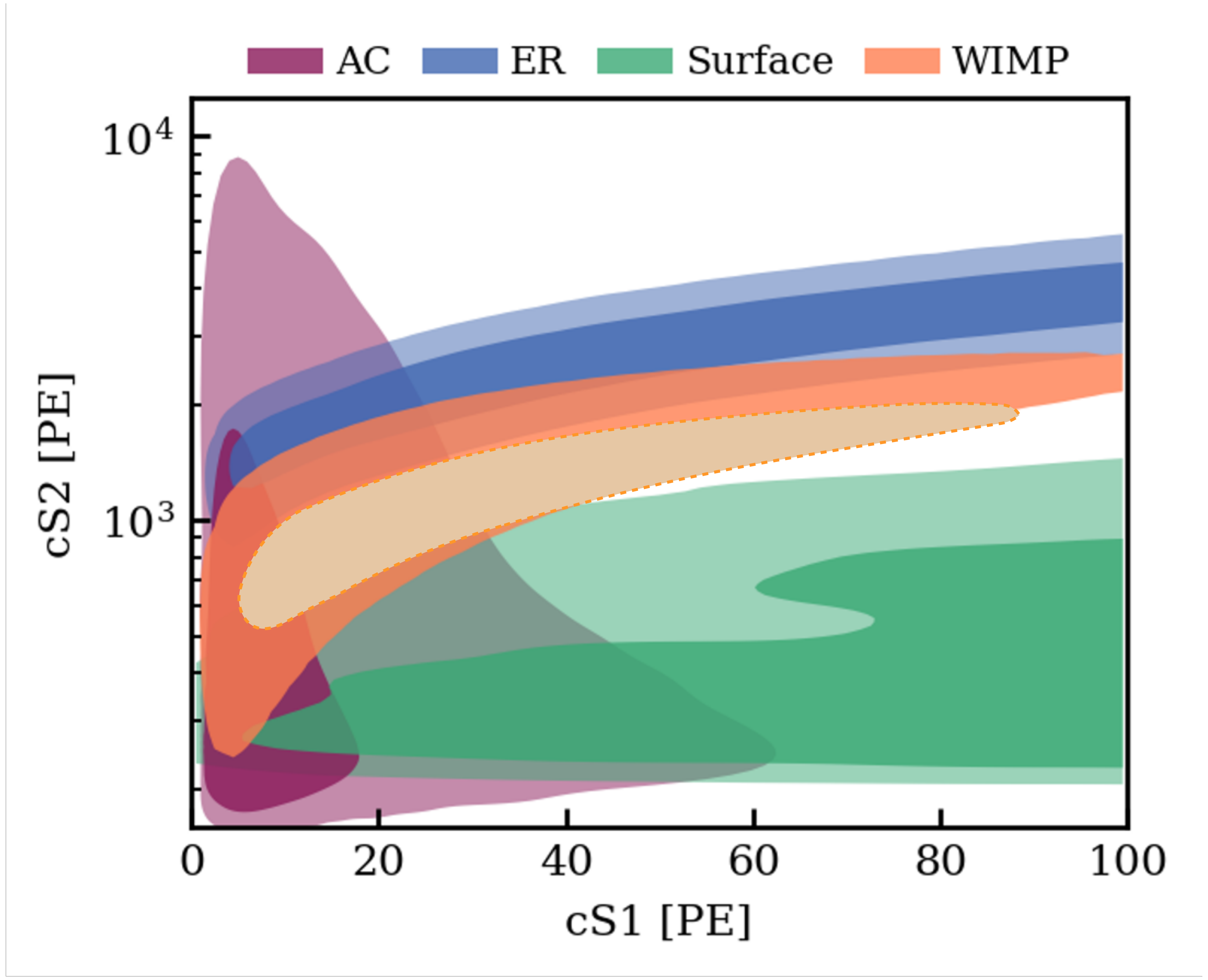


Signal-like region containing 50% of a 200GeV/c^2 WIMP signal with highest signal-to-noise ratio

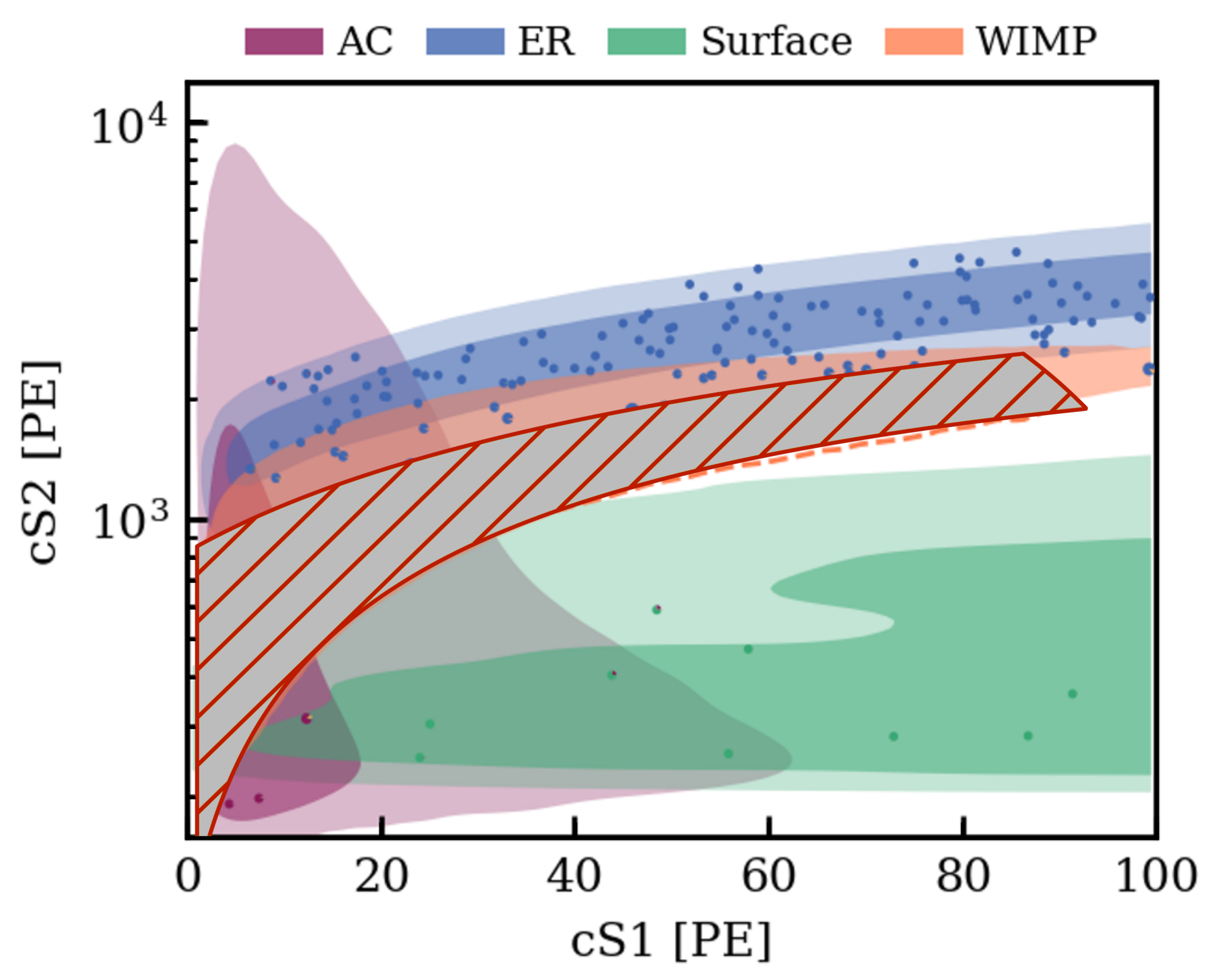
SR0 WIMP

SR0 data Unblinding

	Nominal In ROI
ER	134
Neutrons	$1.1^{+0.6}_{-0.5}$
CEvNS	0.23±0.06
AC	4.3±0.2
Surface	14±3
Total Background	154
WIMP	-
Observed:	-

Identified and fixed a bug post-unblinding.

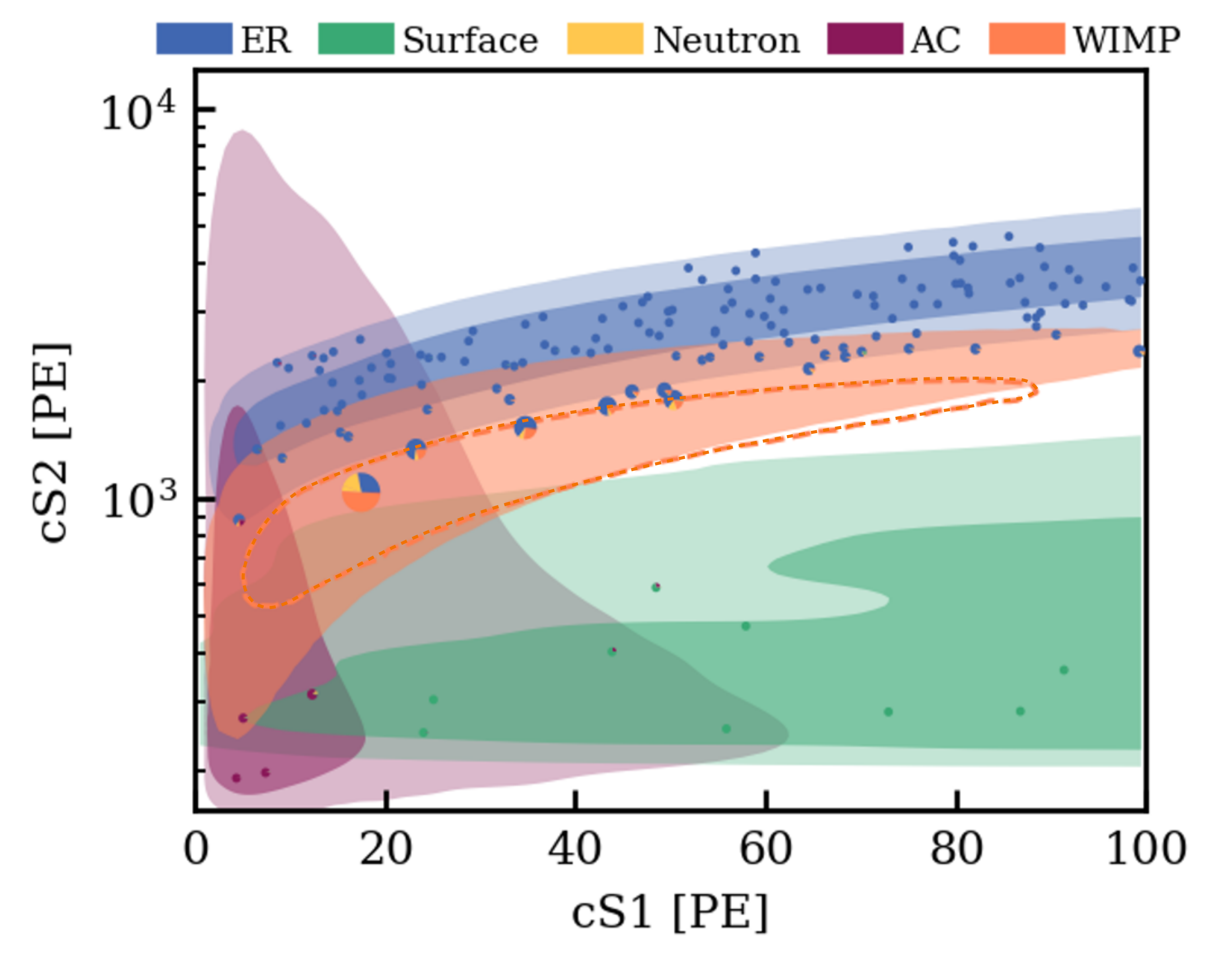
nVeto-tagged SS and MS from neutrons points to a higher than expected n-induced background

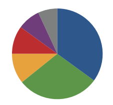


SR0 WIMP

SR0 data Unblinding

	Nominal In ROI	Best Fit In ROI	Best Fit In Signal-like
ER	134	135^{+12}_{-11}	0.81±0.07
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1±0.4	0.42±0.10
CEvNS	0.23±0.06	0.23±0.06	0.022±0.011
AC	4.3±0.2	4.32±0.15	0.363±0.013
Surface	14±3	12^{+0}_{-4}	$0.34^{+0.01}_{-0.11}$
Total Background	154	152±12	$1.95^{+0.12}_{-0.16}$
WIMP	-	2.4	1.2
Observed:	-	152	3





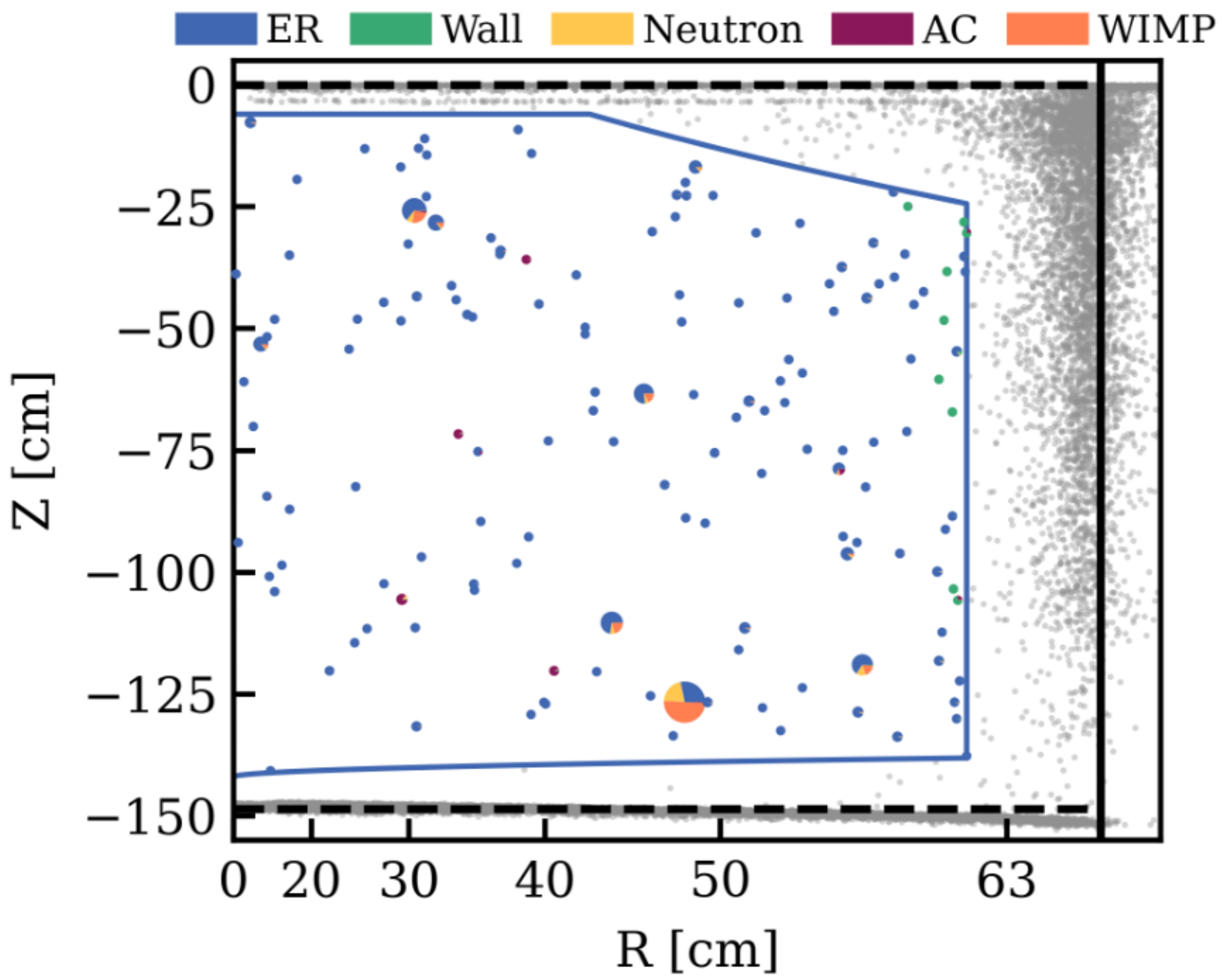
Event represented with pie-chart showing the fraction of the best-fit PDF for a 200 GeV/c² mass WIMP

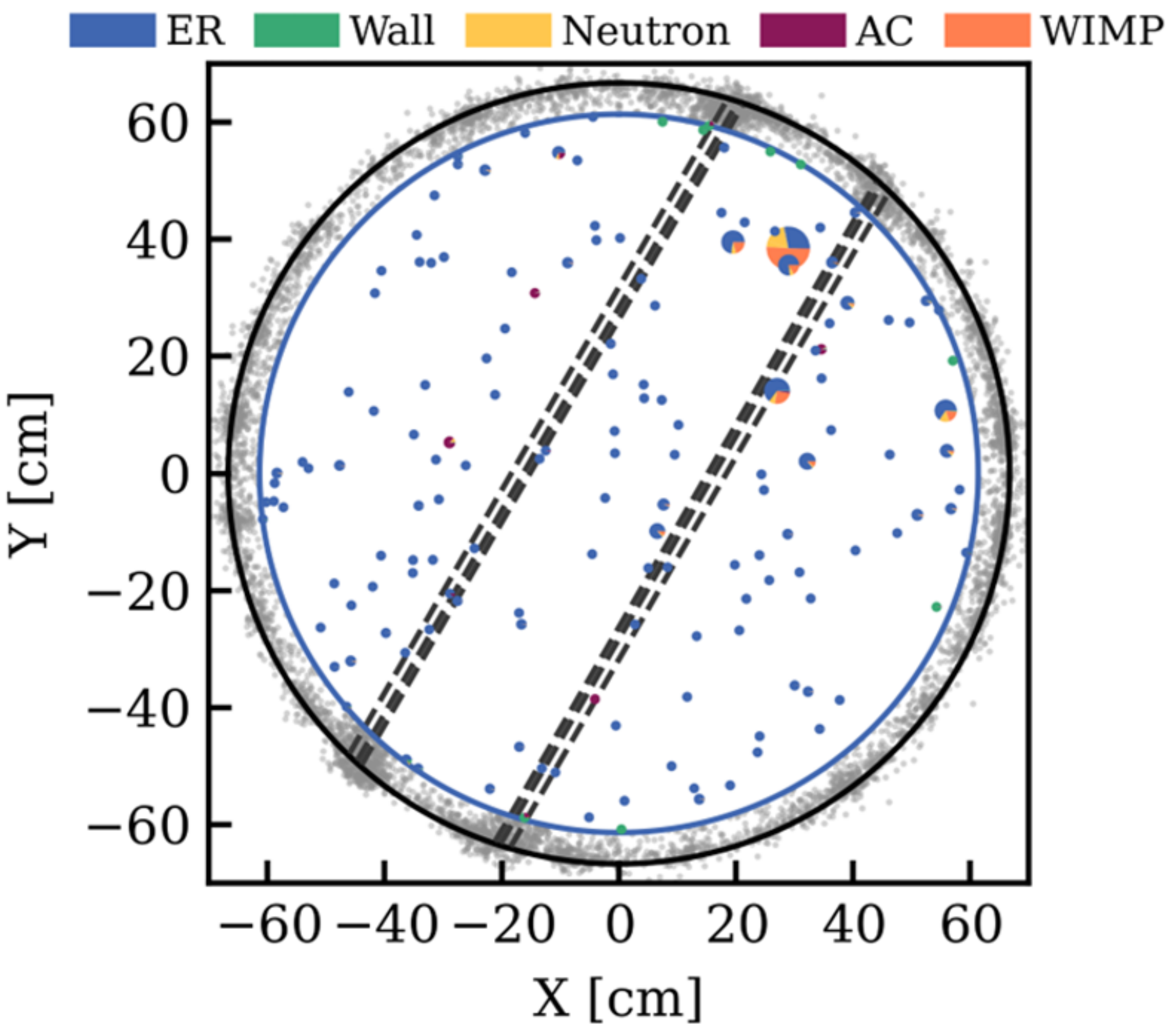
- **16 events in the blinded region** (152 events total in the ROI)
  - Best-fit indicates **no significant excess → exclusion limit**

SR0 WIMP

SR0 data Unblinding
Event spatial distribution

- Observed XY asymmetry in unblinded data (**13 events out 16** are in top quadrant)
  - But no **systematic spatial bias observed in calibration data, nor cuts and corrections**

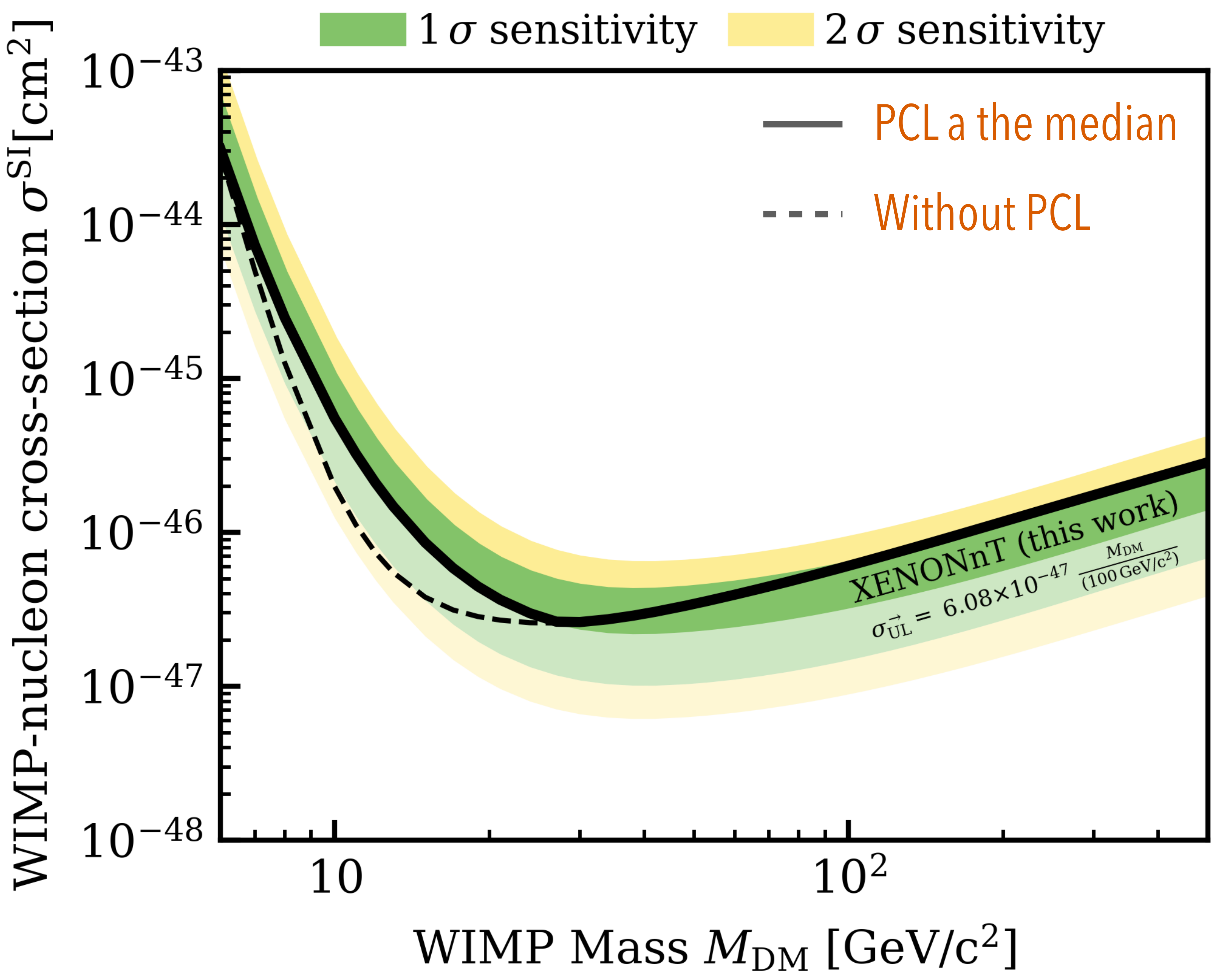




SI Interaction Result

90% CL upper limit

- Community had agreed on prescriptions for **Power-Constraint Limit** [1]
  - But Reference [1] had a wrong prescription for PCL **critical threshold (1-β_r)**, defined on discovery power instead of rejection power
  - Typically in our field PCL has been used to constrain the limit at -1σ **(1-β_r=0.16)**
  - It turns out that if **(1-β_r) is not ≫ significance level** (α=0.1 i.e. 90% limit) PCL might still allow for pathological cases
    - We dropped (1-β_r)=0.16 and picked **(1-β_r)=0.5** (median)
    - **Conservative choice** before the community re-discusses the topic extensively and agrees upon on a specific value protecting from pathologies.



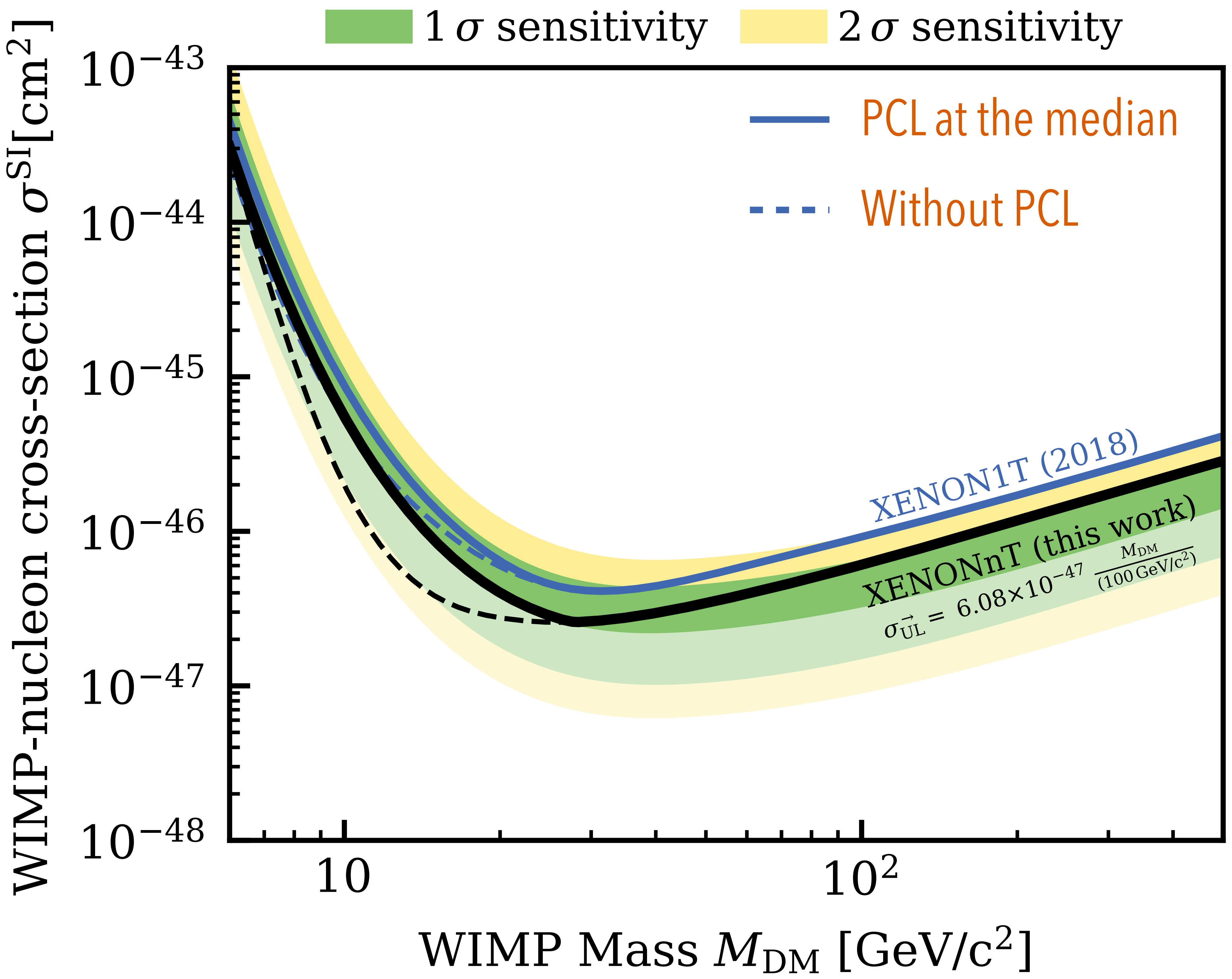
- Set also 90% CL upper limits on **Spin Dependent Interaction** (see arXiv: 2303.14729)

[1] D. Baxter, et al, "Recommended conventions for reporting results from direct dark matter searches" [EPJC 81 (2021)]

[2] G. Cowan, K. Cranmer, E. Gross, O. Vitells, "Power-Constrained Limits", arxiv:1105.3166.

SR0 WIMP

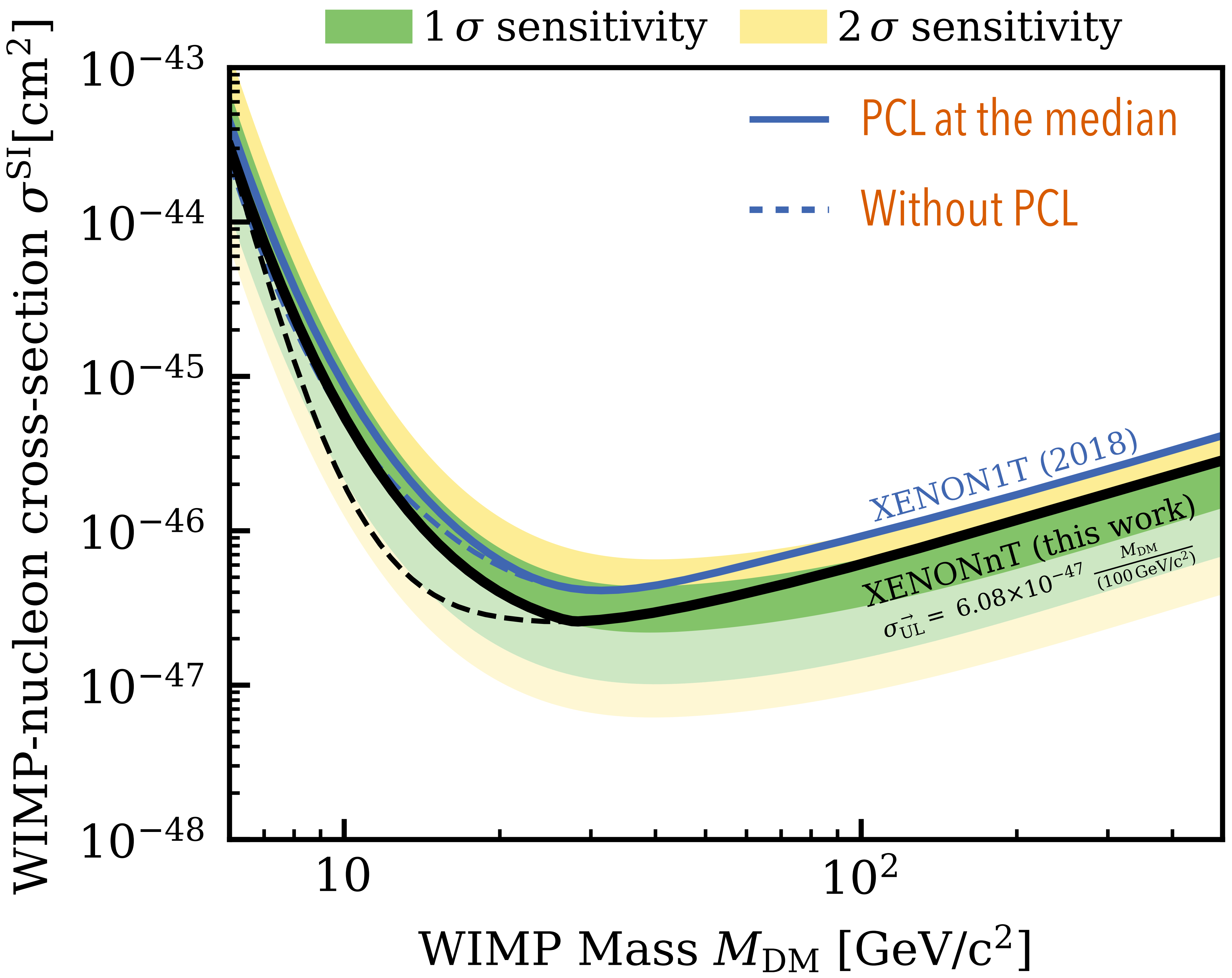
Comparison
with other results from **blinded** analyses



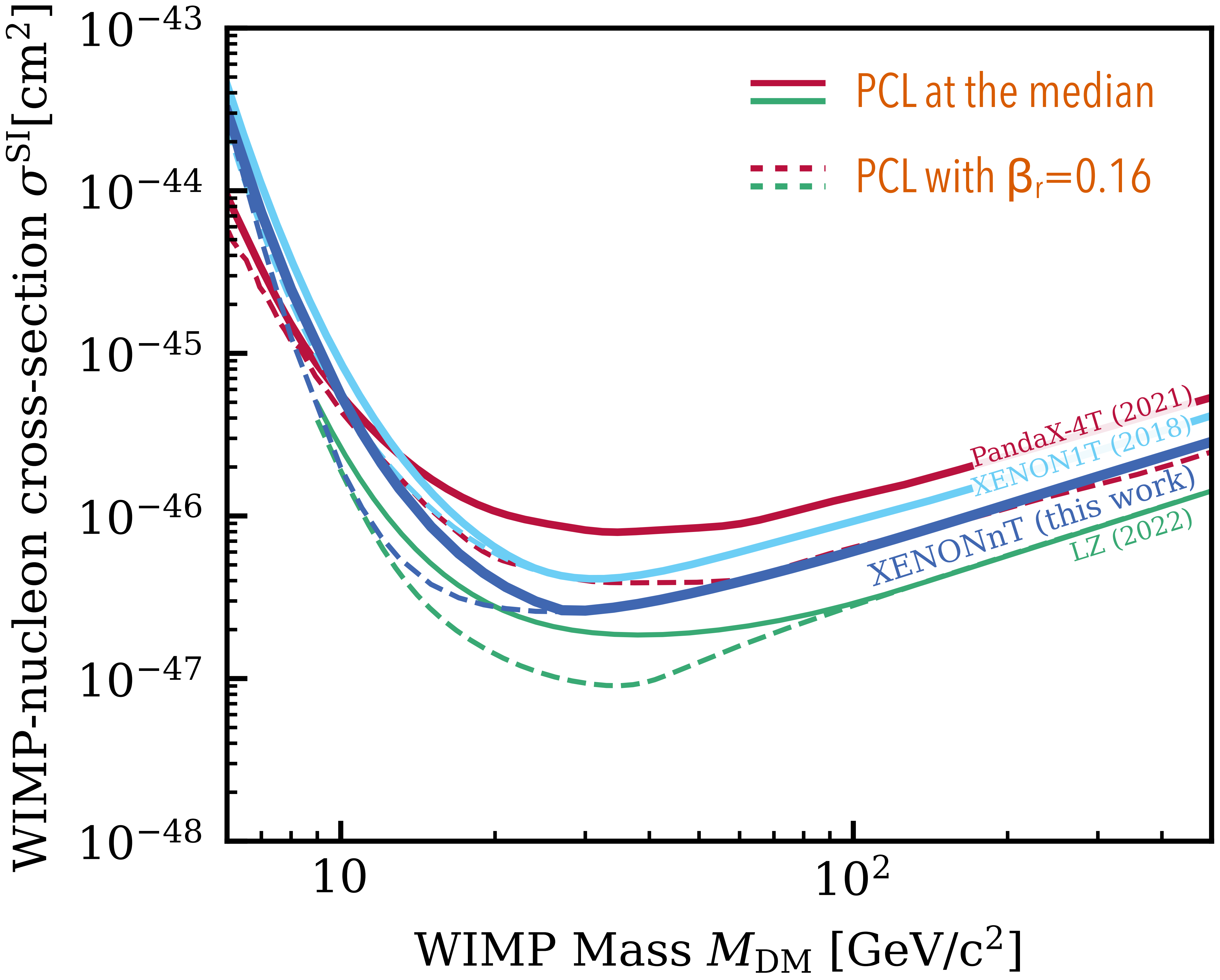
- Improved wrt XENON1T by a **factor x1.6 with a similar exposure.**

SR0 WIMP

Comparison
with other results from **blinded** analyses

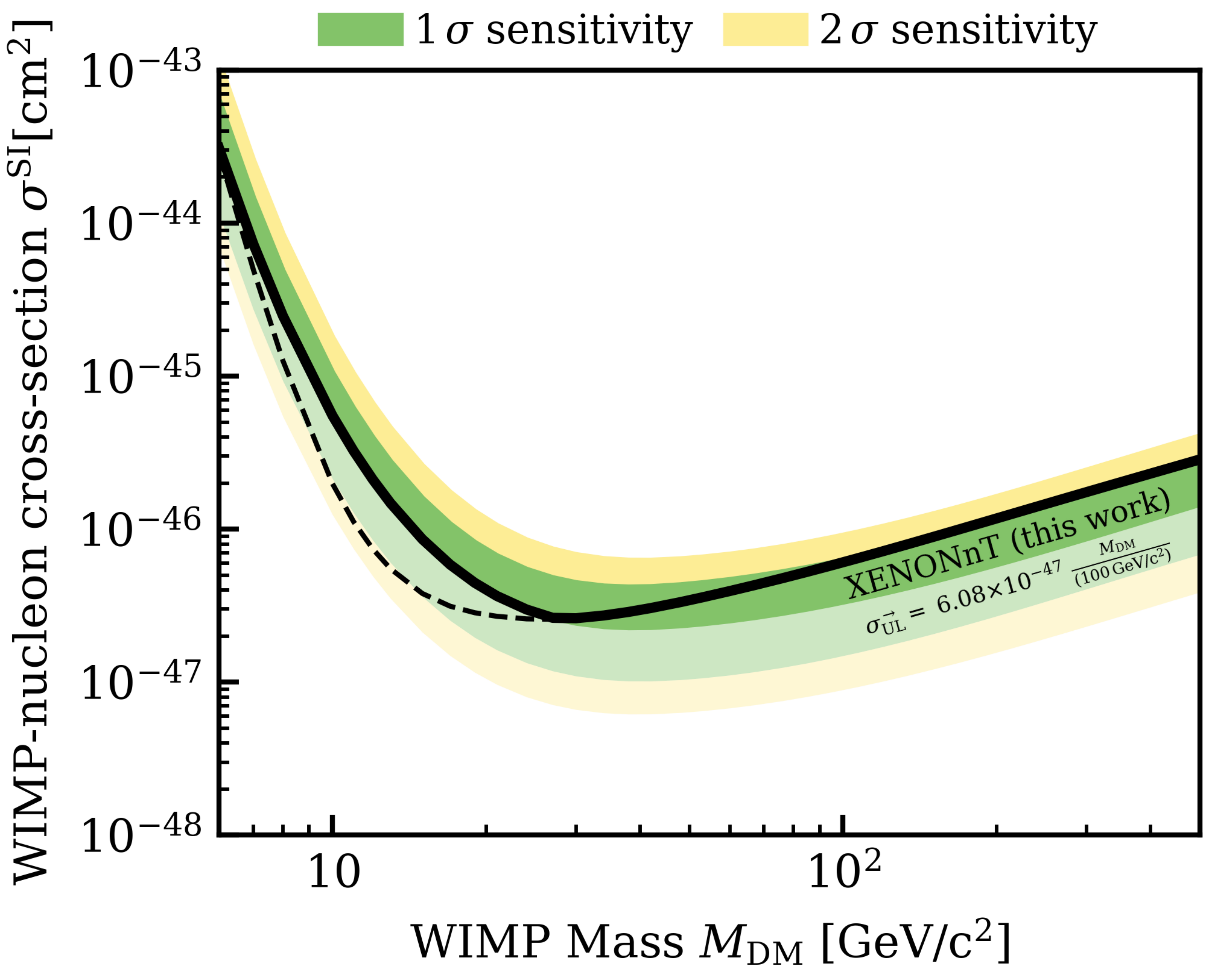


Comparison
with other results from **unblinded** analyses



Summary & Outlook

- Set **first constraints on WIMP SI and SD couplings with XENONnT** through a **blind** analysis of SR0 data (1.1 tonne-year) ;
- Unprecedented **low-energy ER background** (15.8±1.3) events/(t·y·keV);
- Measured a higher than expected **neutron background**
  - can extend **coincidence nVeto window** to improve tagging with water-only;
  - working towards **doping water with Gd-salt** to improve tagging;
  - **SS vs MS NR identification** can be likely improved in the reconstruction code;
  - **Fiducial volume definition** can be better tuned to improve signal-to-background.
- Several ongoing searches being performed on SR0 data



SR0 WIMP

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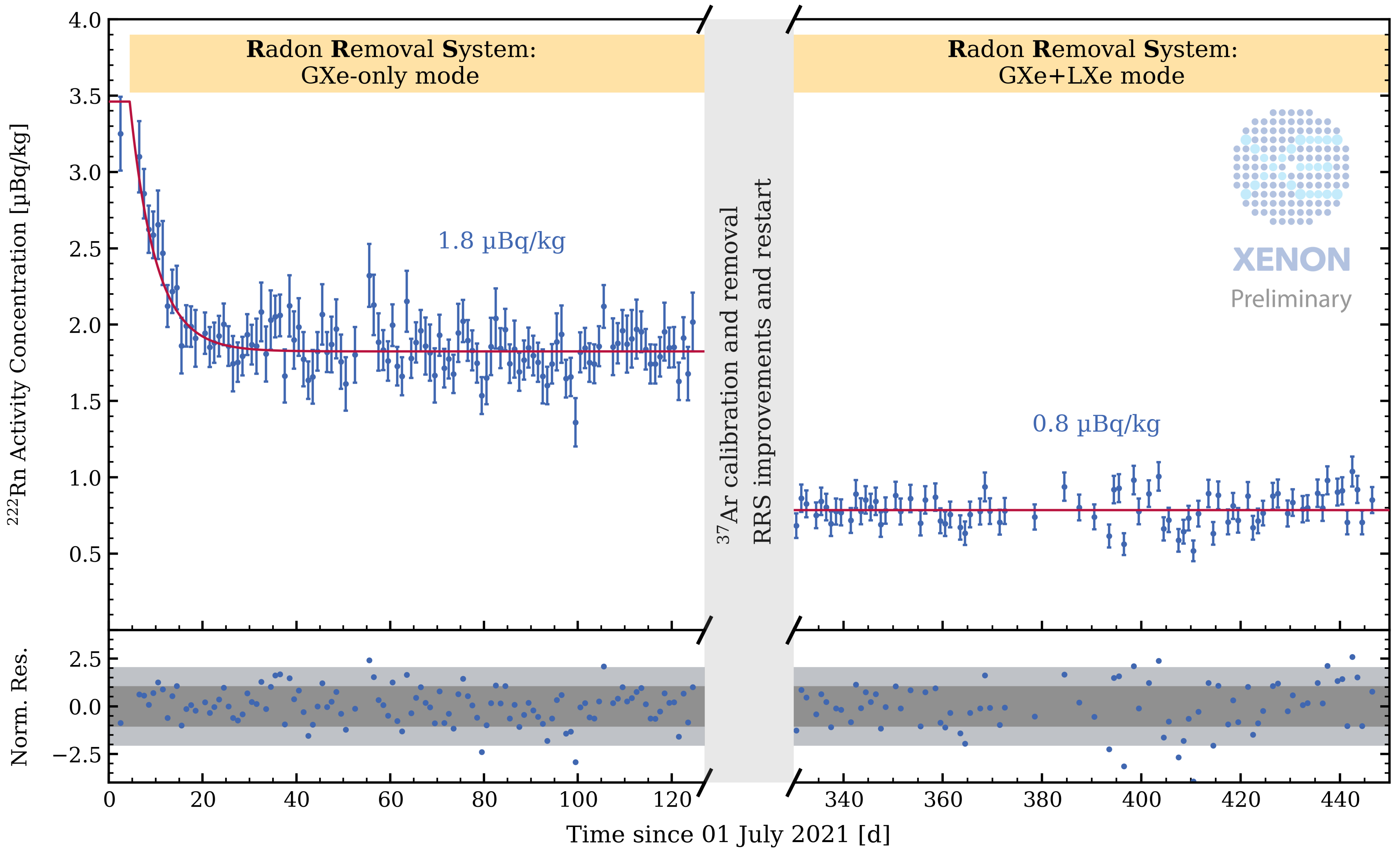
- Several ongoing searches being performed on SR0 data
- Since several months acquiring SR1 science data
  - ^{222}**Rn**, the dominant ER background in SR0, **has been further reduced**;



THANKS

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