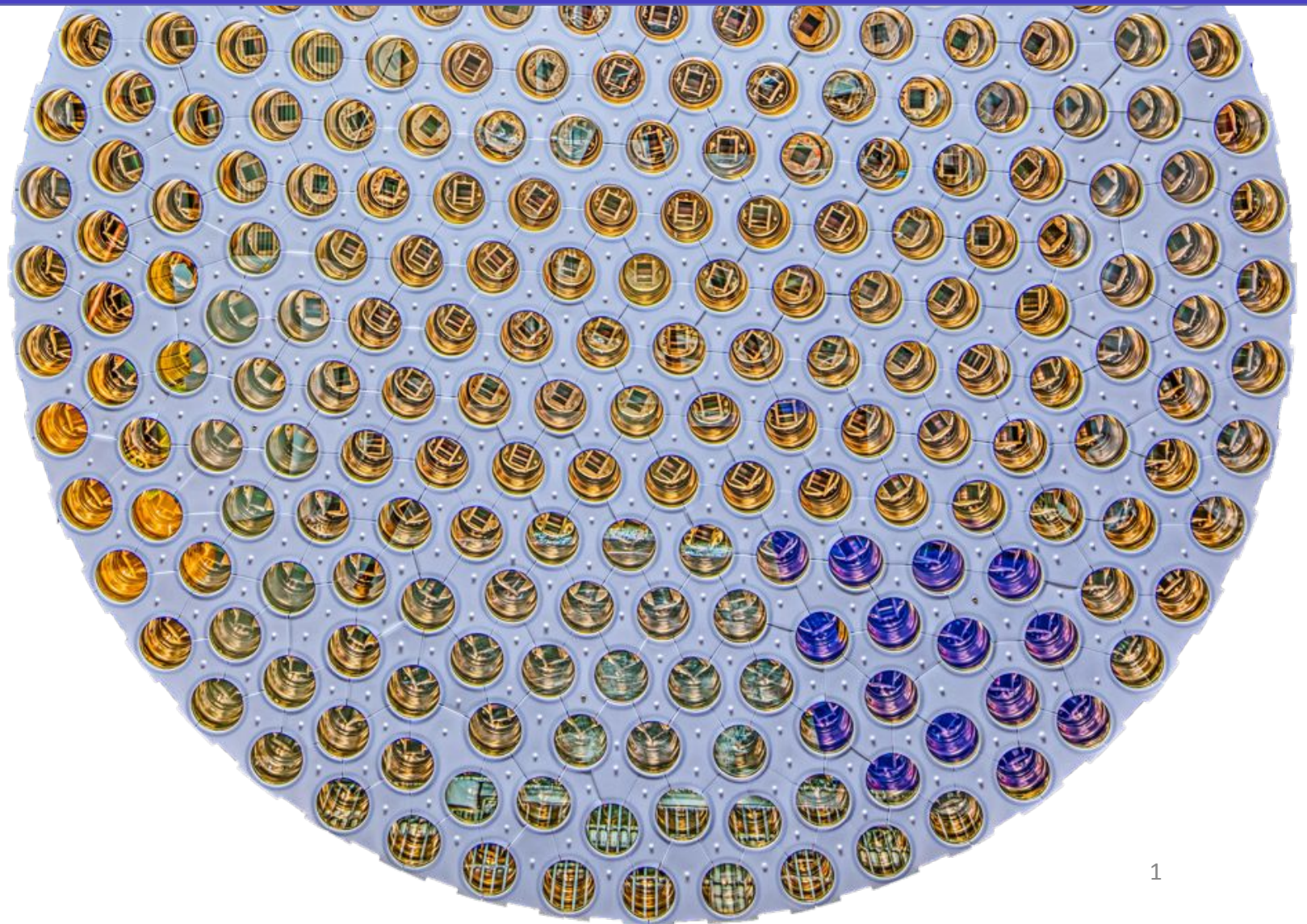
The LZ dark matter experiment

First results & status



Theresa Fruth
On behalf of the LZ collaboration

Lepton Photon 2023,
19th July 2023

THE UNIVERSITY OF SYDNEY

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

LZ collaboration - 37 Institutions: more than 250 scientists, engineers, and technical staff

Black Hills State University
Brookhaven National Laboratory
Brown University
Center for Underground Physics
Edinburgh University
Fermi National Accelerator Lab.
Imperial College London
King's College London
Lawrence Berkeley National Lab.
Lawrence Livermore National Lab.
LIP Coimbra
Northwestern University
Pennsylvania State University
Royal Holloway University of London
SLAC National Accelerator Lab.
South Dakota School of Mines & Tech
South Dakota Science & Technology Authority
STFC Rutherford Appleton Lab.
Texas A&M University
University of Albany, SUNY
University of Alabama
University of Bristol
University College London
University of California Berkeley
University of California Davis
University of California Los Angeles
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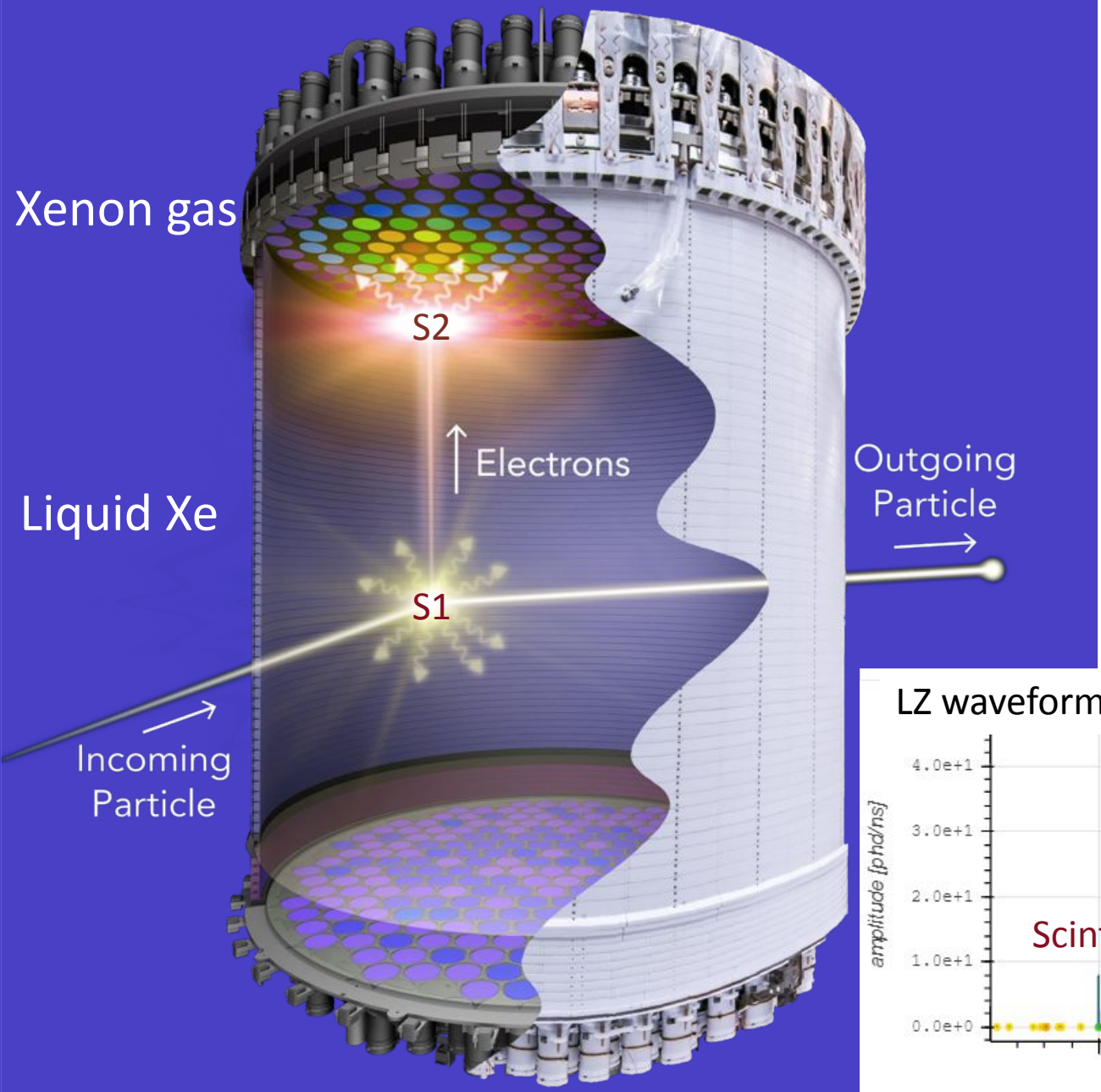
FCT Fundação para a Ciência e a Tecnologia

ibs Institute for Basic Science

Thanks to our sponsors and participating institutes!

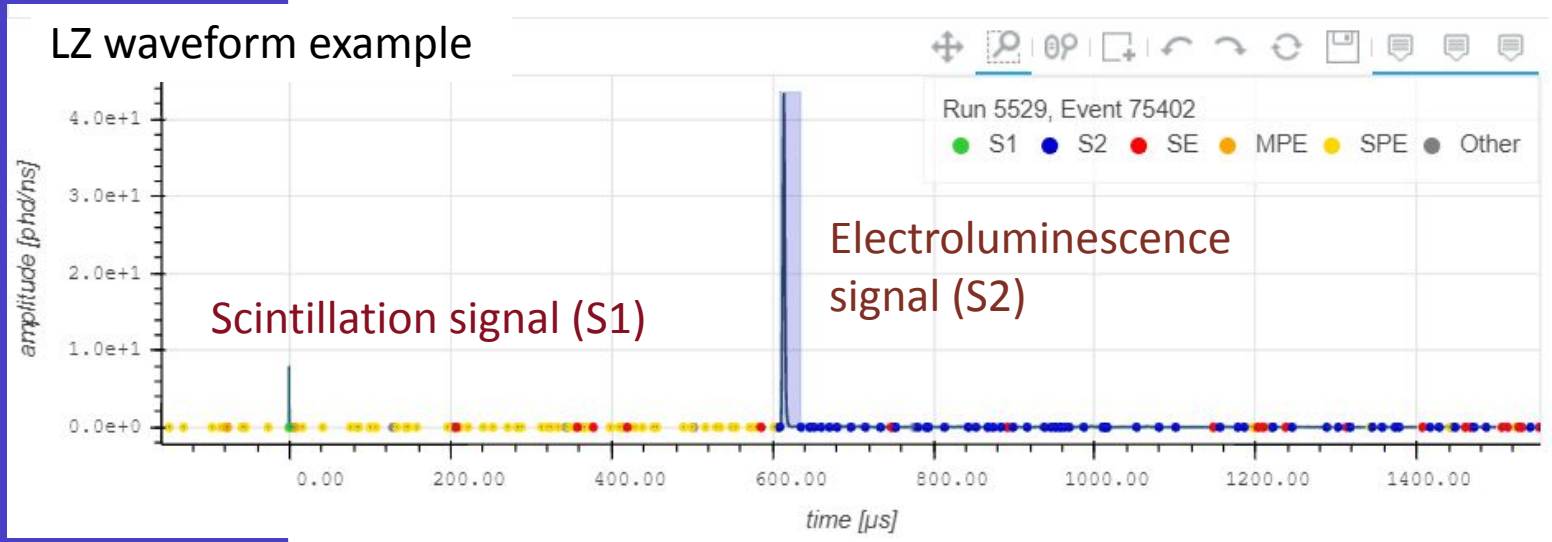


|Detector

Overview

- Principal goal: the direct detection of dark matter via nuclear recoils
- Scintillation & charge (via electroluminescence) signals
- 3D event reconstruction

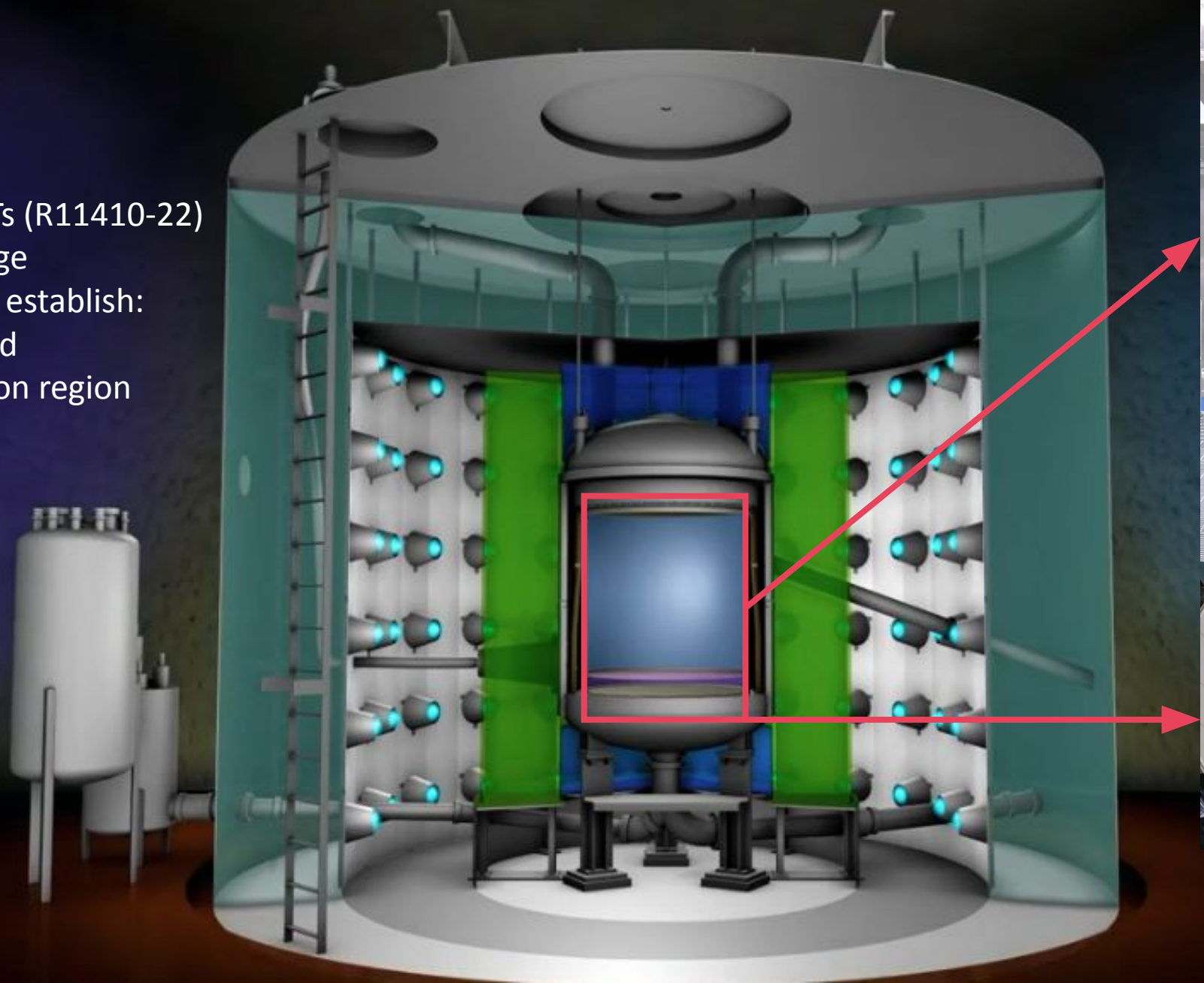
LZ waveform example

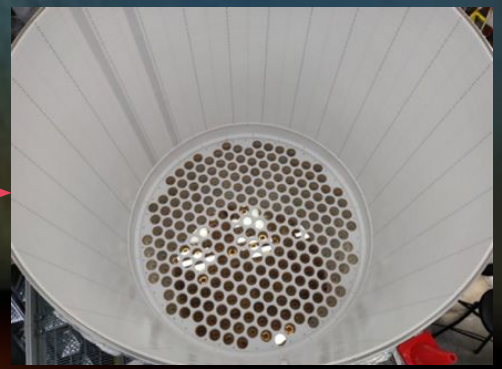


|Detector

TPC

- 494 TPC PMTs (R11410-22)
- PTFE field cage
- 4 HV grids to establish:
  - drift field
  - extraction region

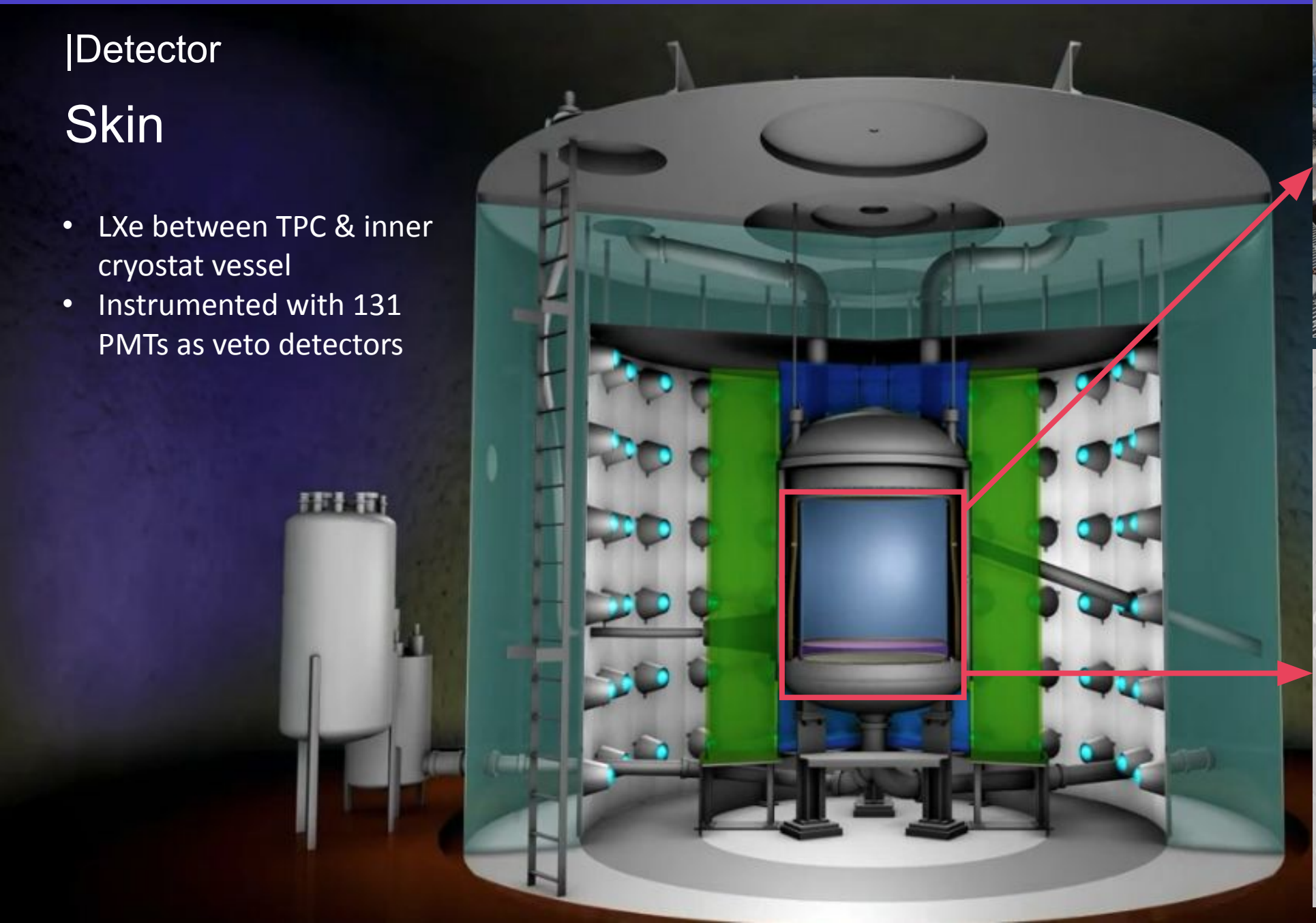


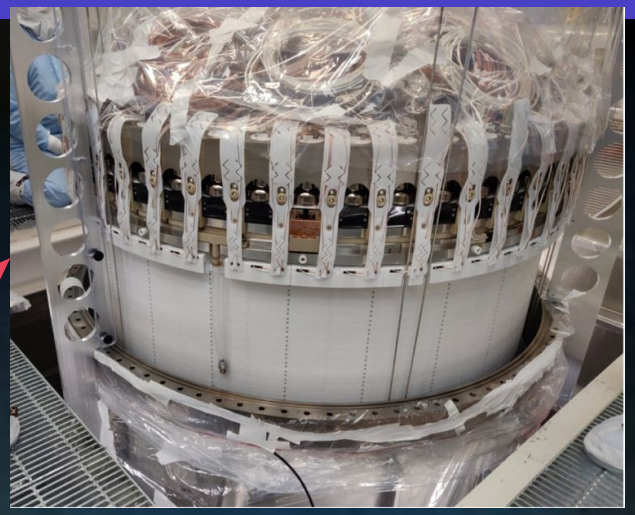


|Detector

Skin

- LXe between TPC & inner cryostat vessel
- Instrumented with 131 PMTs as veto detectors

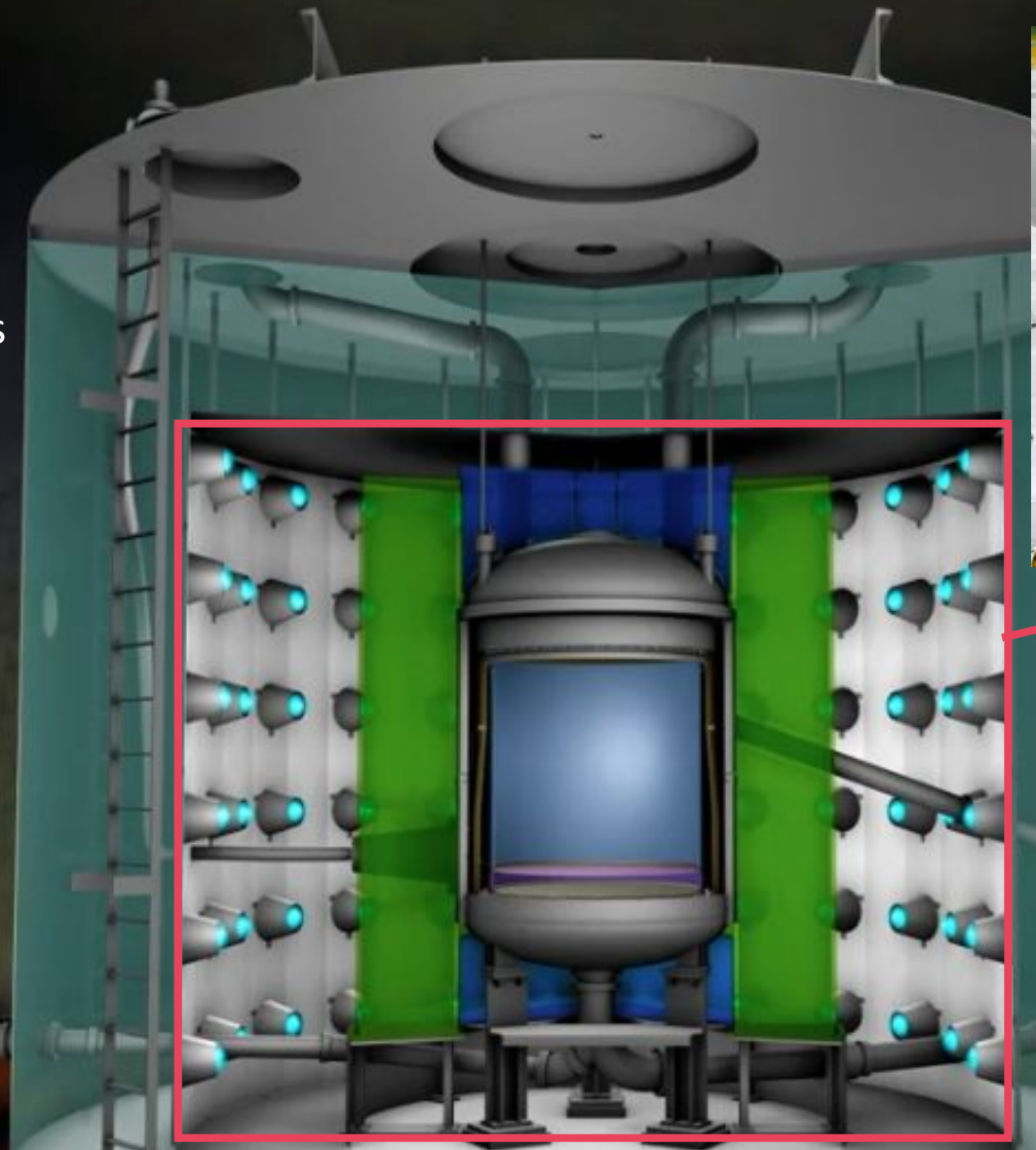


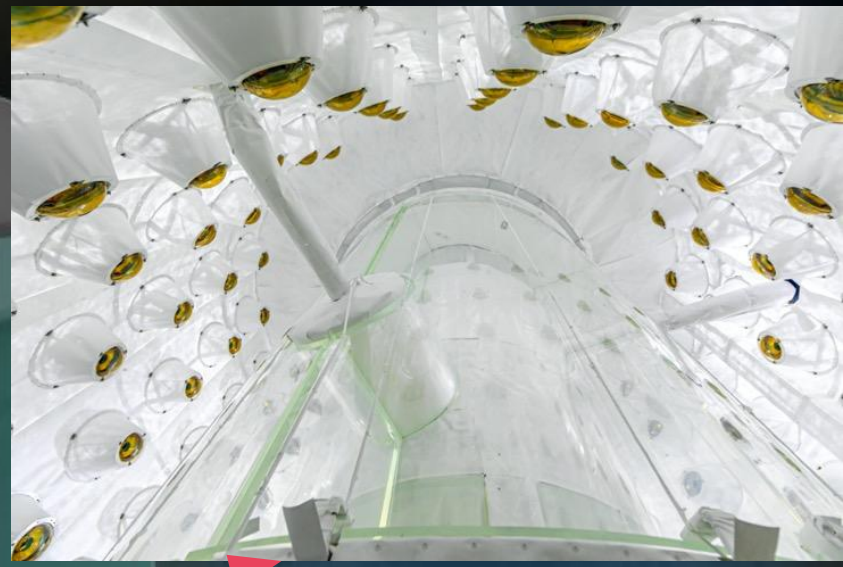


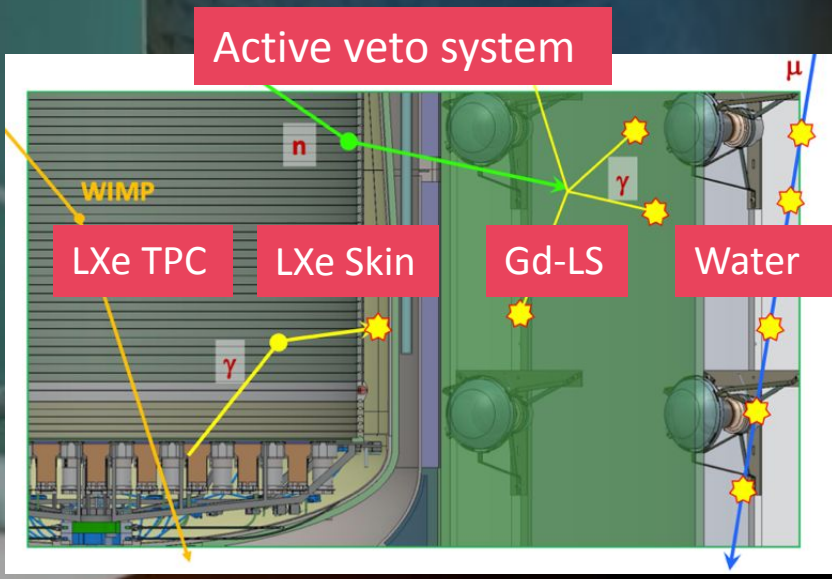
|Detector

Outer Detector

- 17 tonnes Gd-loaded liquid scintillator in acrylic vessels
- 120 8” PMTs (R5912)







Overview

Stable detector conditions:

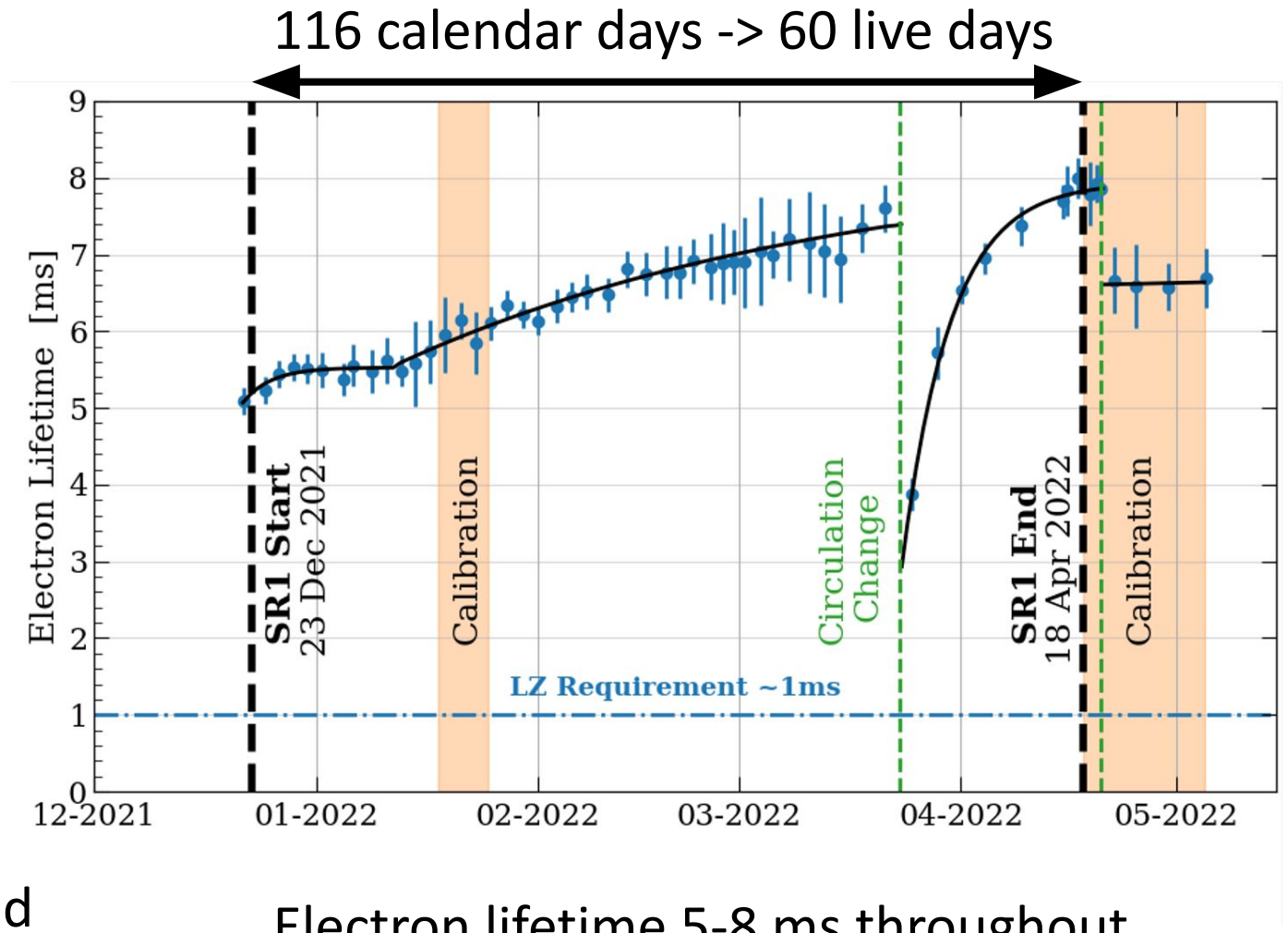
- Temperature = 174.1 K
- Gas pressure = 1.791 bar
- Drift field = 193 V/cm
- Extraction field = 7.3 kV/cm (in gas)
- >97% PMTs operational

Continuous purification:

- 3.3 t/day through hot getter system

Engineering run

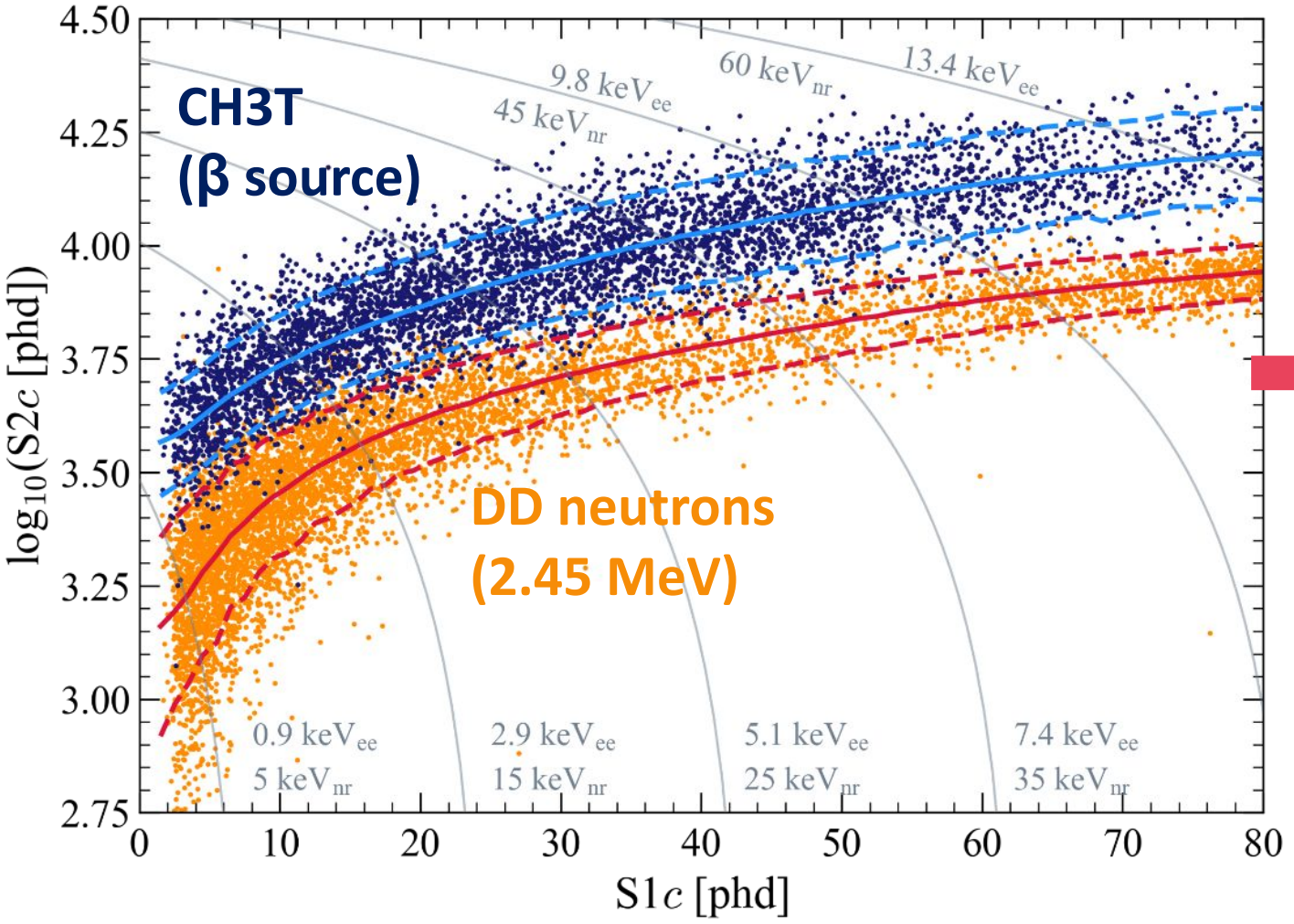
- Bias mitigation: analysis cuts developed on non-WIMP ROI background & calibration data



Electron lifetime 5-8 ms throughout

|First Science Run

TPC Calibrations



Band fits performed with NEST v2.3.7 [1]

Photon detection efficiency:
g1 = 0.114 +/- 0.002 phd/photon

Ionization channel gain:
g2 = 47.1 +/- 1.1 phd/electron

99.9% discrimination of beta backgrounds under NR band median achieved

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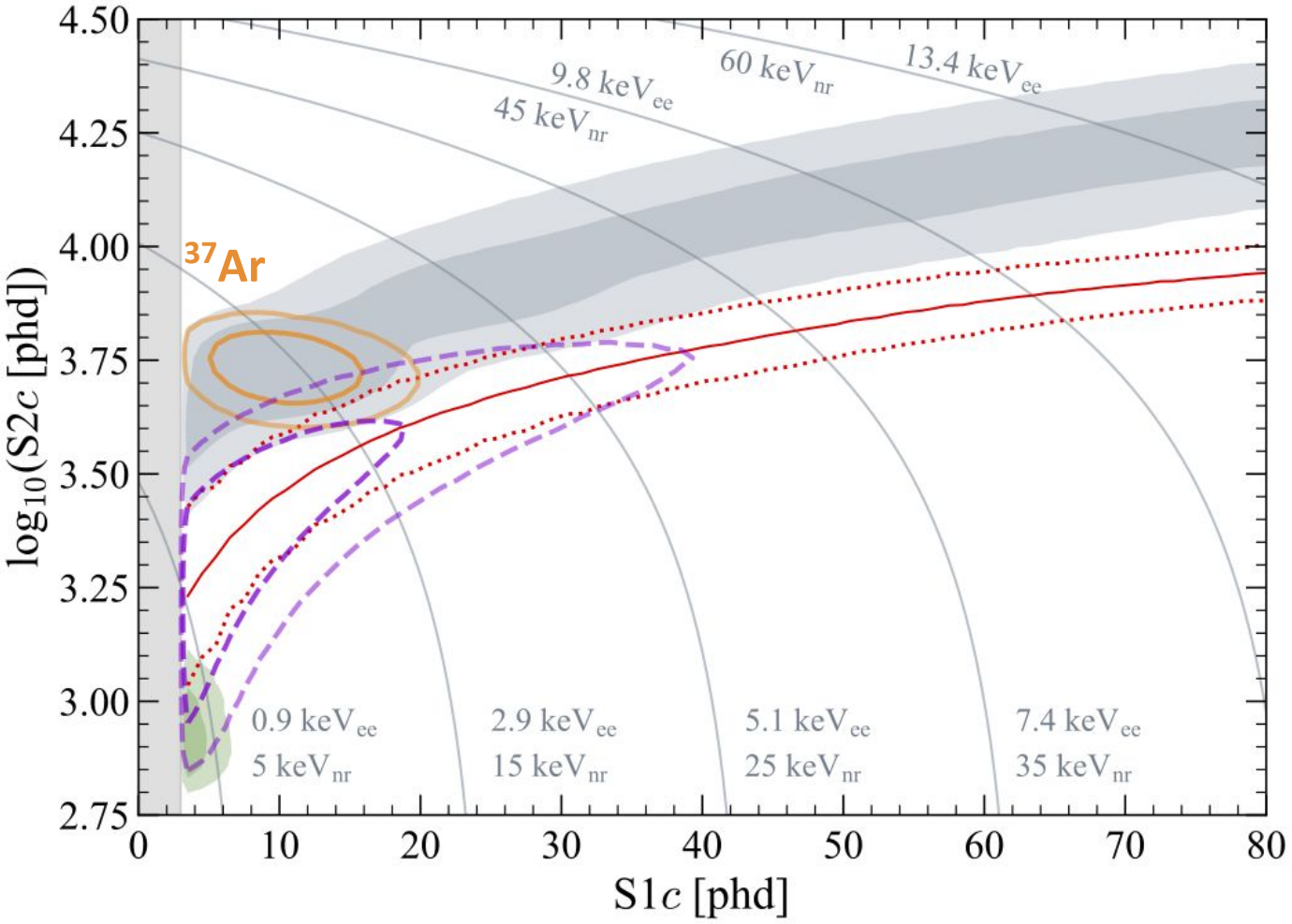
Background model



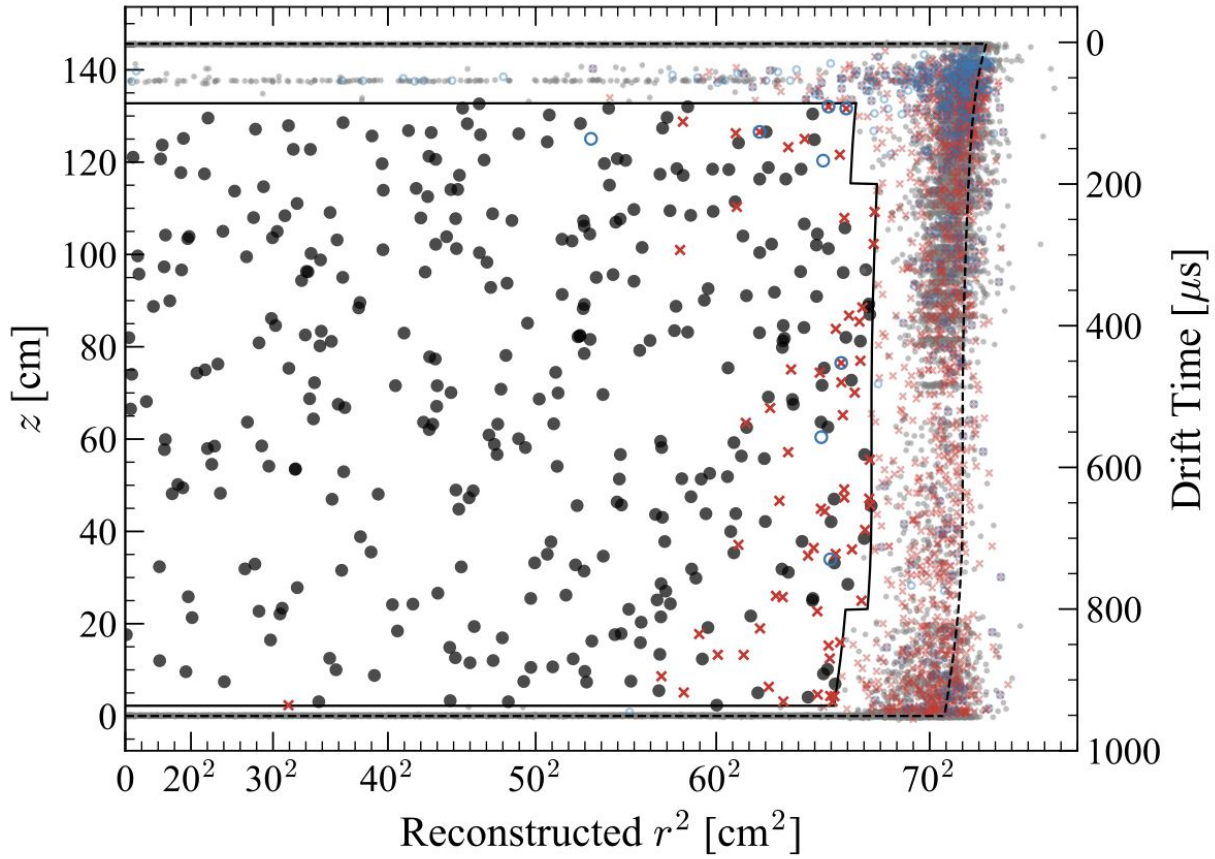
Source	Expected Events
β decays + det ER	218 ± 36
ν ER	27.3 ± 1.6
^{127}Xe	9.2 ± 0.8
^{124}Xe	5.0 ± 1.4
^{136}Xe	15.2 ± 2.4
^{8}B CEνNS	0.15 ± 0.01
Accidentals	1.2 ± 0.3
Subtotal	276 ± 36
^{37}Ar	[0, 291]
Detector neutrons	$0.0^{+0.2}$
30 GeV/c^2 WIMP	–
Total	–

Backgrounds are modelled using energy deposit
+ detector response simulations [1]

Data selection cuts

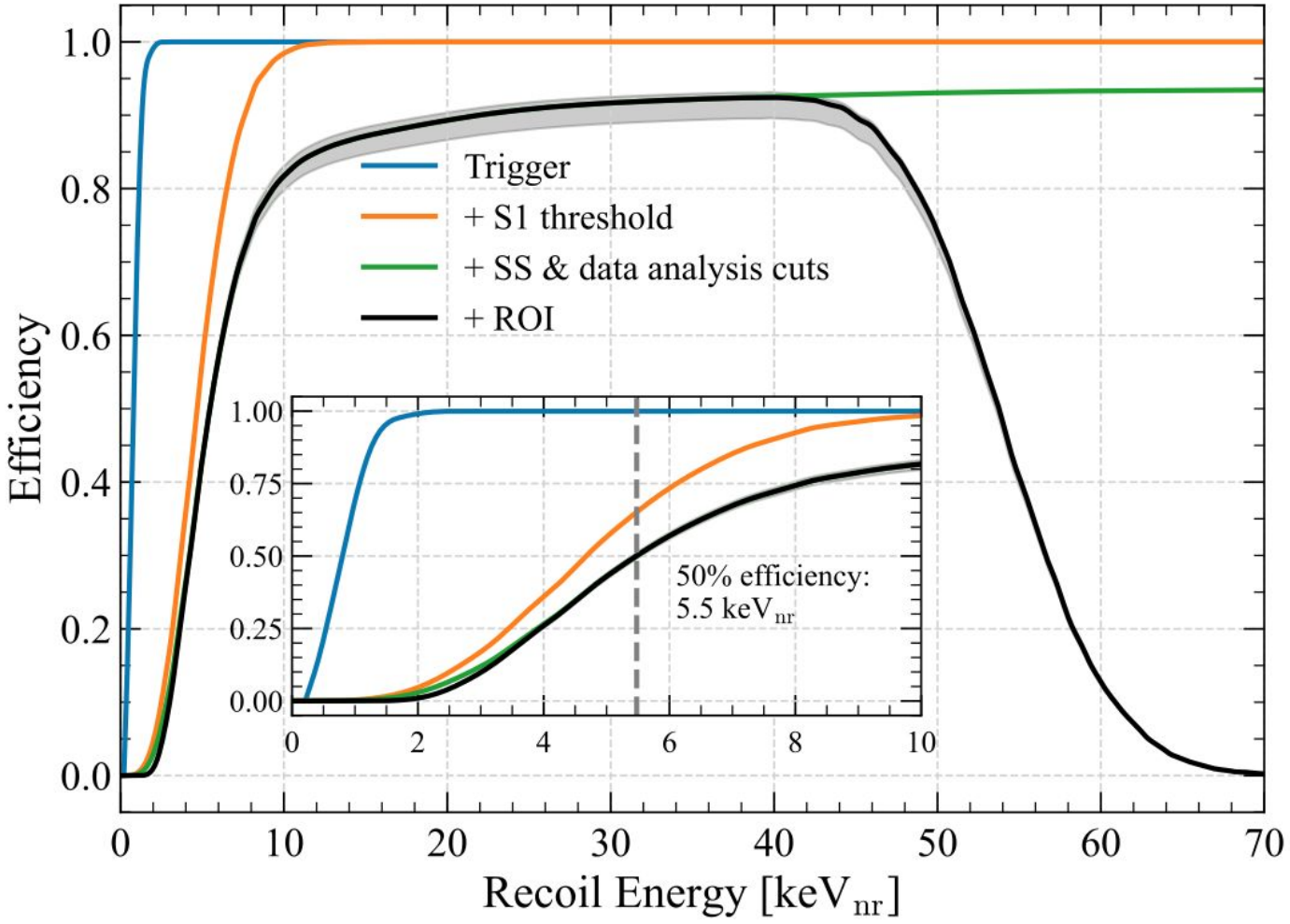
- events passing all cuts
- events outside of fiducial volume
- x events vetoed by skin (mostly ^{127}Xe)
- ○ events vetoed by OD

60 live-days, 5.5 t fiducial volume



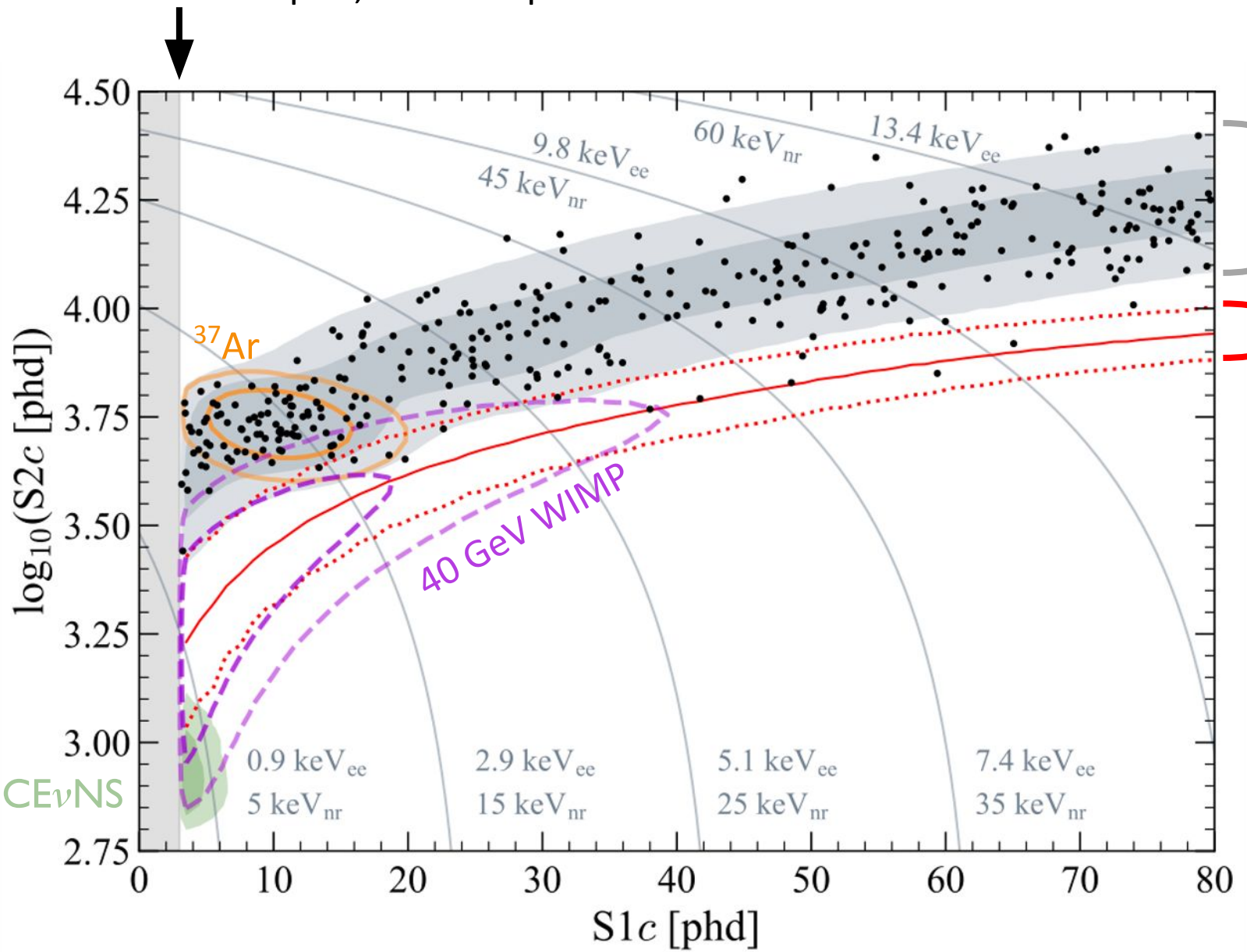
Cuts developed using calibration data and sideband regions outside the WIMP ROI

Signal acceptance



Final data set

- 335 events observed
- 60.3 ± 1.2 live days
- 5.5 ± 0.2 tonnes



Combined ER background sources

Flat NR spectrum

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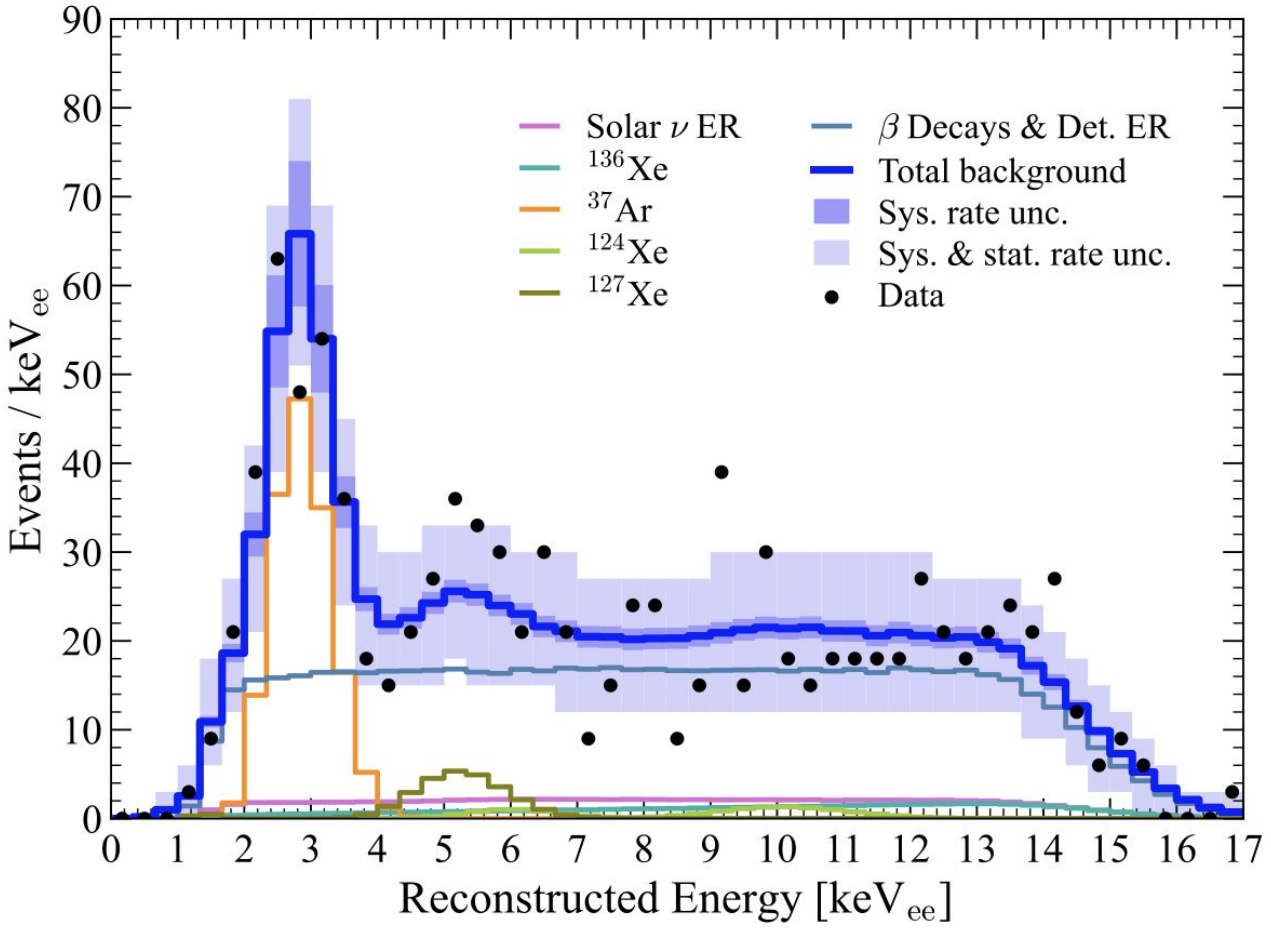
PLR fits

Source	Expected Events	Fit Result
β decays + Det. ER	215 ± 36	222 ± 16
ν ER	27.1 ± 1.6	27.2 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.1 ± 2.4	15.2 ± 2.4
^{8}B CEνNS	0.14 ± 0.01	0.15 ± 0.01
Accidentals	1.2 ± 0.3	1.2 ± 0.3
Subtotal	273 ± 36	280 ± 16
^{37}Ar	[0, 288]	$52.5^{+9.6}_{-8.9}$
Detector neutrons	$0.0^{+0.2}$	$0.0^{+0.2}$
30 GeV/c^2 WIMP	–	$0.0^{+0.6}$
Total	–	333 ± 17



Backgrounds within expectations
~25 counts/keVee/tonne/year

keV$_{ee}$ = Electron-equivalent reconstructed energy

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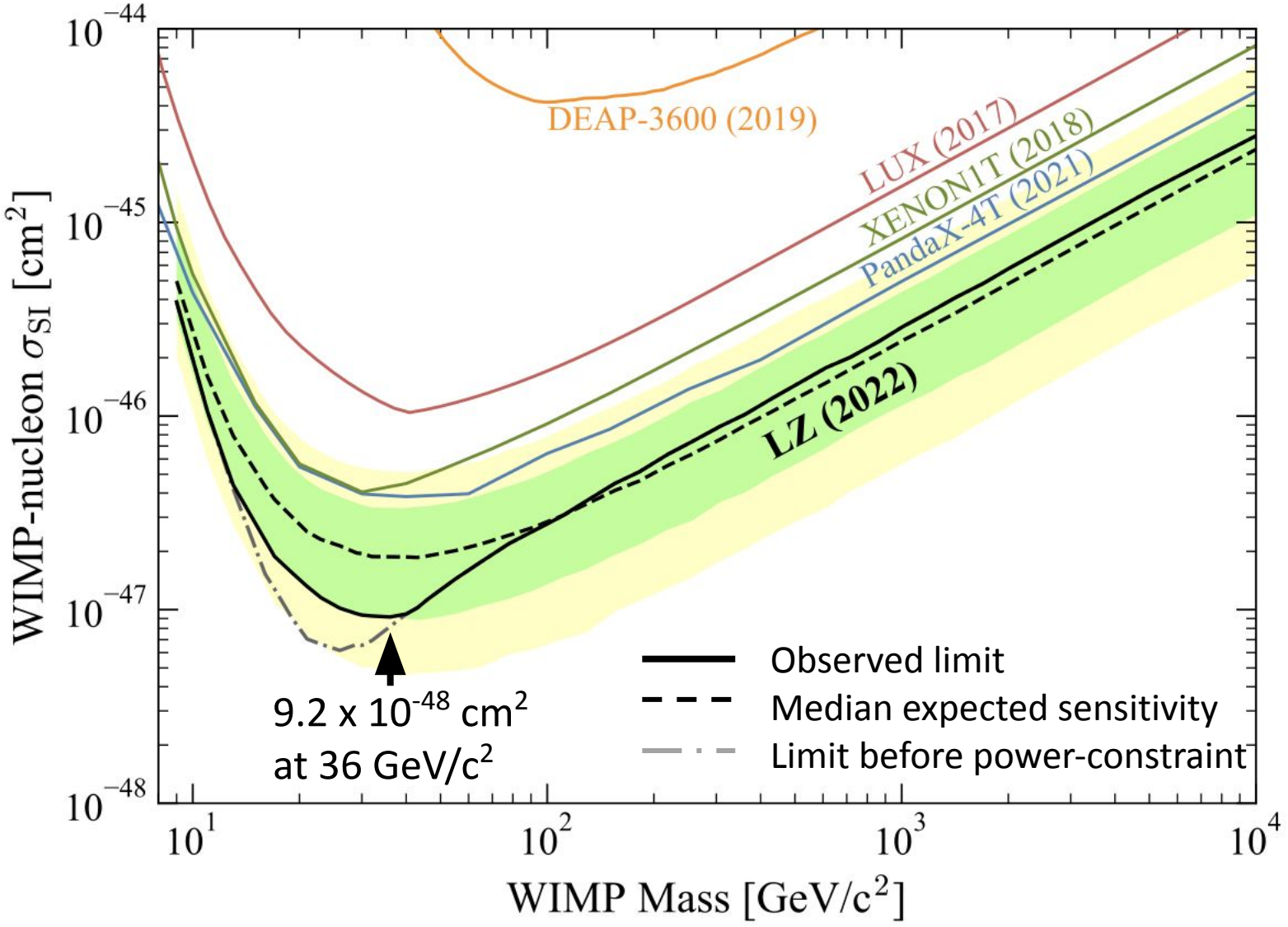
WIMP search

- Consistent with background-only hypothesis
- Two-sided PLR
  EPJC 81, 907 (2021)
- Power constraint (-1σ)
  G. Cowan et al. arxiv/1105.3166

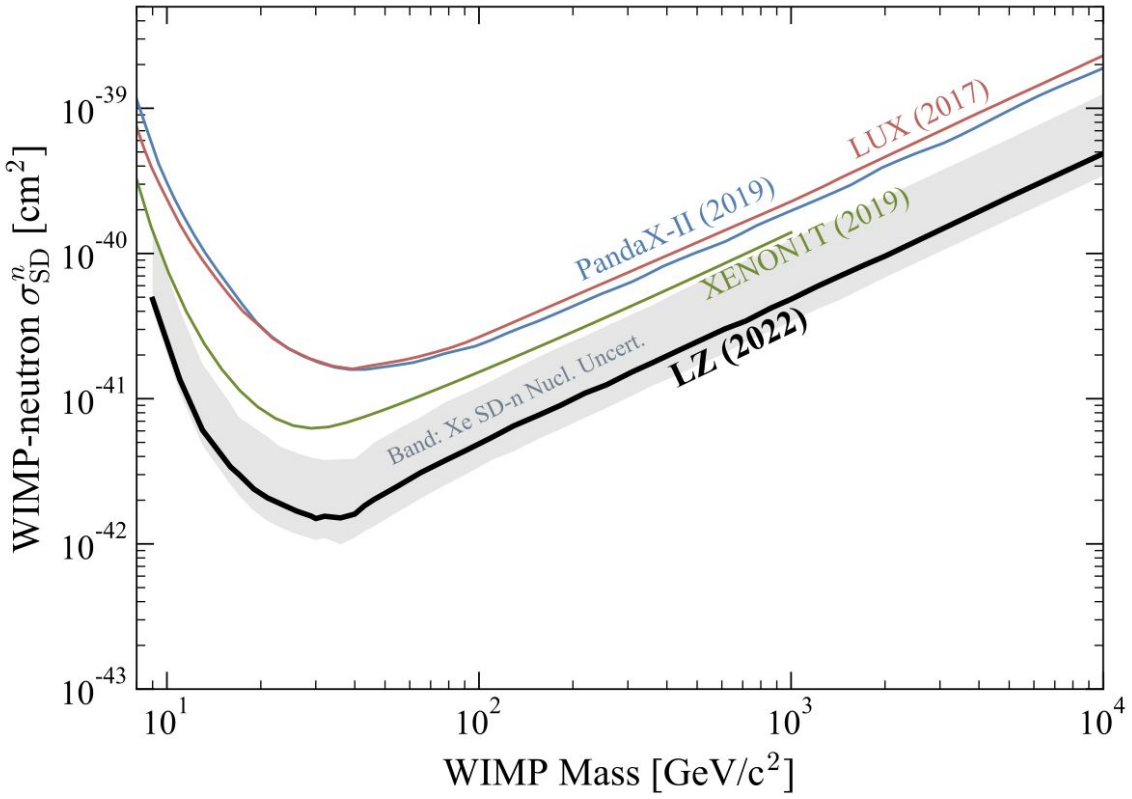


[1] P. Klos, J. Menéndez, D. Gazit, and A. Schwenk Phys. Rev. D 88, 083516 (2013)
[2] First dark matter search result from the LZ Experiment (https://arxiv.org/abs/2207.03764)

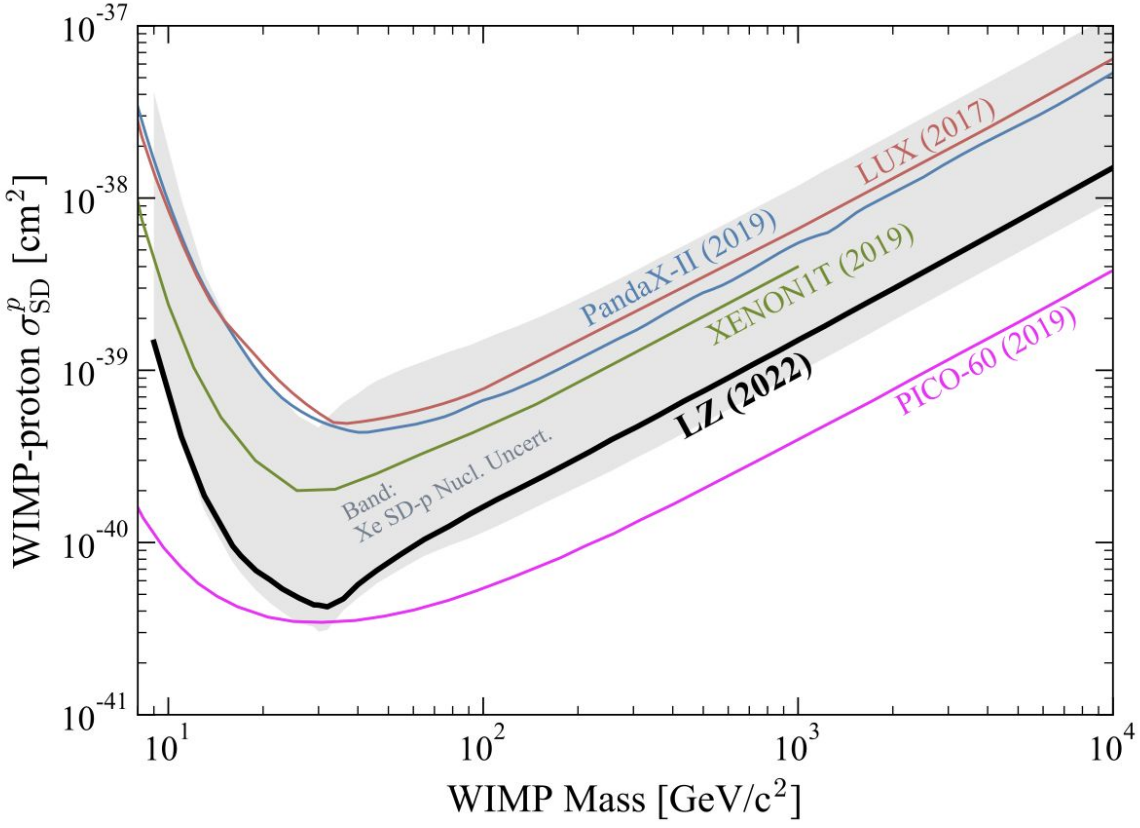
|First Science Run

WIMP search (spin-dependent)

Spin-dependent WIMP-neutron scattering



Spin-dependent WIMP-proton scattering



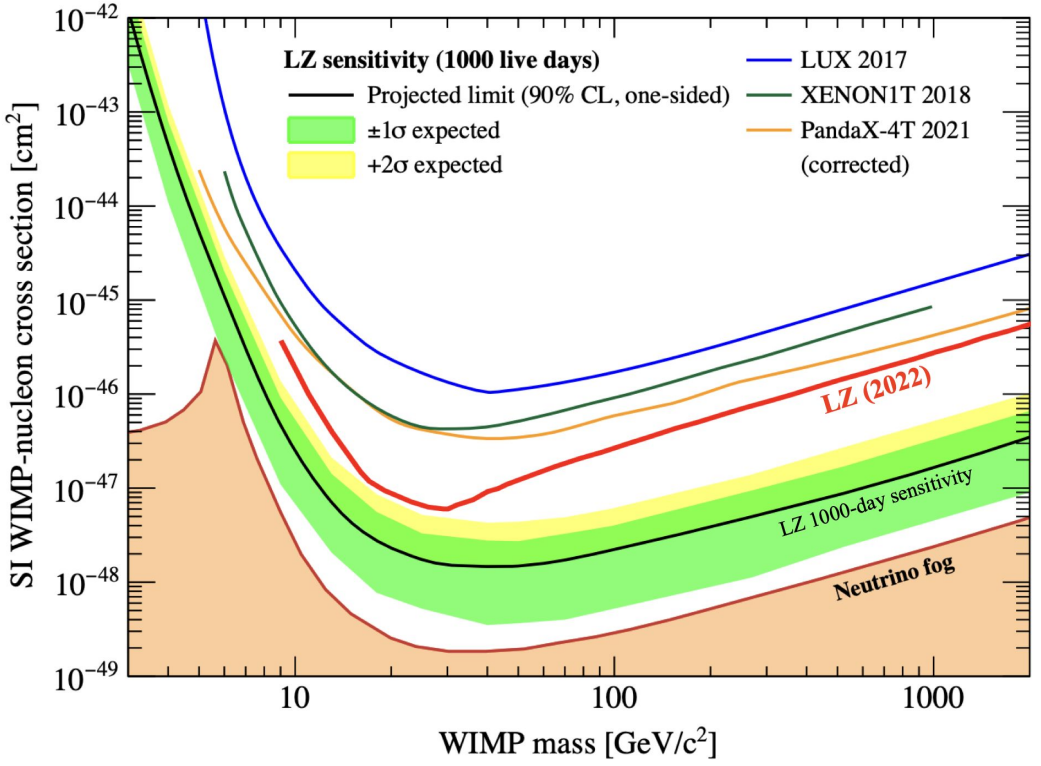
Grey uncertainty band represents uncertainty on Xe form factor [1]

What's next?

- There's much more data to come! Planning for a total 1000 live days (x 17 more exposure than SR1)
- More physics searches to look forward to, among them:
  - Enhanced sensitivity to lower WIMP masses and ^{8}B solar neutrinos (S2-only, Migdal)[2]
  - Low energy electron recoil searches for new physics (ALPs, hidden photons, mirror dark matter & more)[3]
  - Neutrinoless double-beta decay searches with ^{136}Xe & ^{124}Xe [4,5]
  - High energy EFT searches

[1]LZ WIMP search sensitivity paper: Phys. Rev. D 101, 052002 (2020)
[2]LZ S2-only and Migdal sensitivity: https://arxiv.org/abs/2101.08753 (2021)
[3]LZ low-E ER band searches sensitivity: Phys.Rev.D 104, 092009 (2021)
[4]LZ Xe136 0$\nu\beta\beta$ sensitivity: Phys. Rev. C 102, 014602 (2020)
[5]LZ Xe124 0$\nu\beta\beta$ sensitivity: Phys. Rev. C 104, 065501 (2021)

Current limit compared to projected sensitivity for 1000-day exposure[1]:



|Next Generation

Towards the ultimate LXe observatory

- MOU between LZ, XENON, DARWIN
- Two in-person meetings
  - Karlsruhe 2022
  - UCLA 2023
- https://xlzd.org/
- White paper (2203.02309)

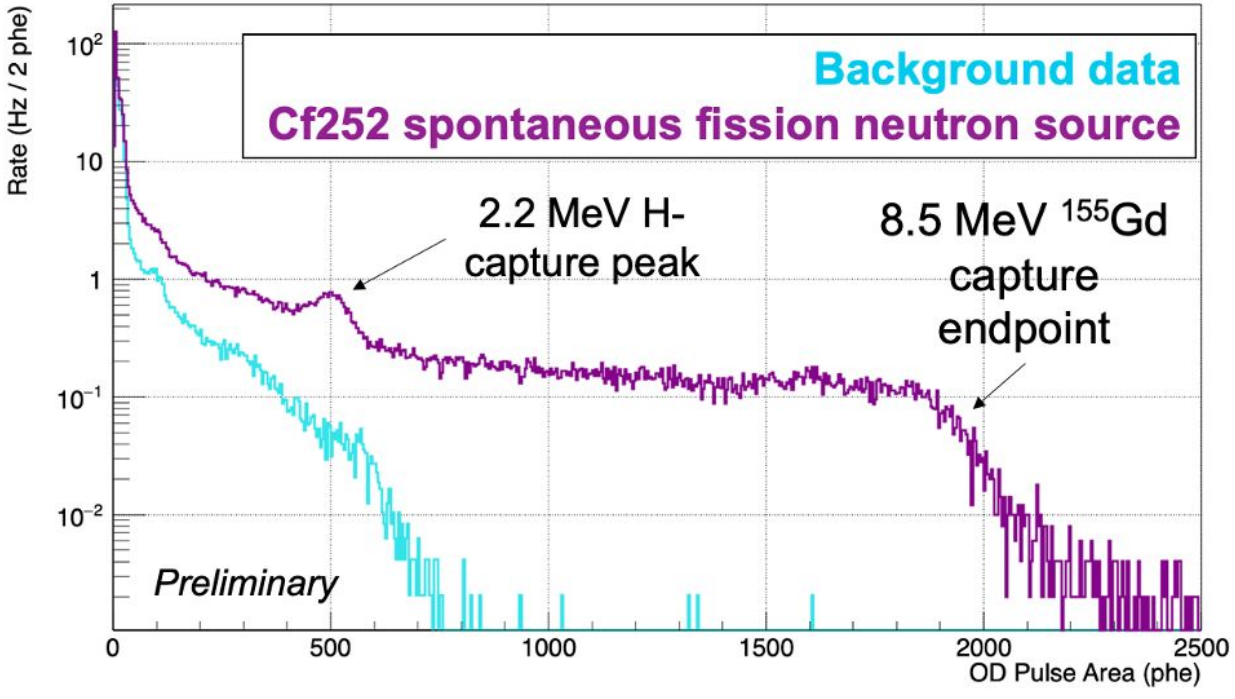
Kai Martens: *Liquid Xenon Dark Matter searches*
Thursday, 15:30

First in-person meeting June 2022

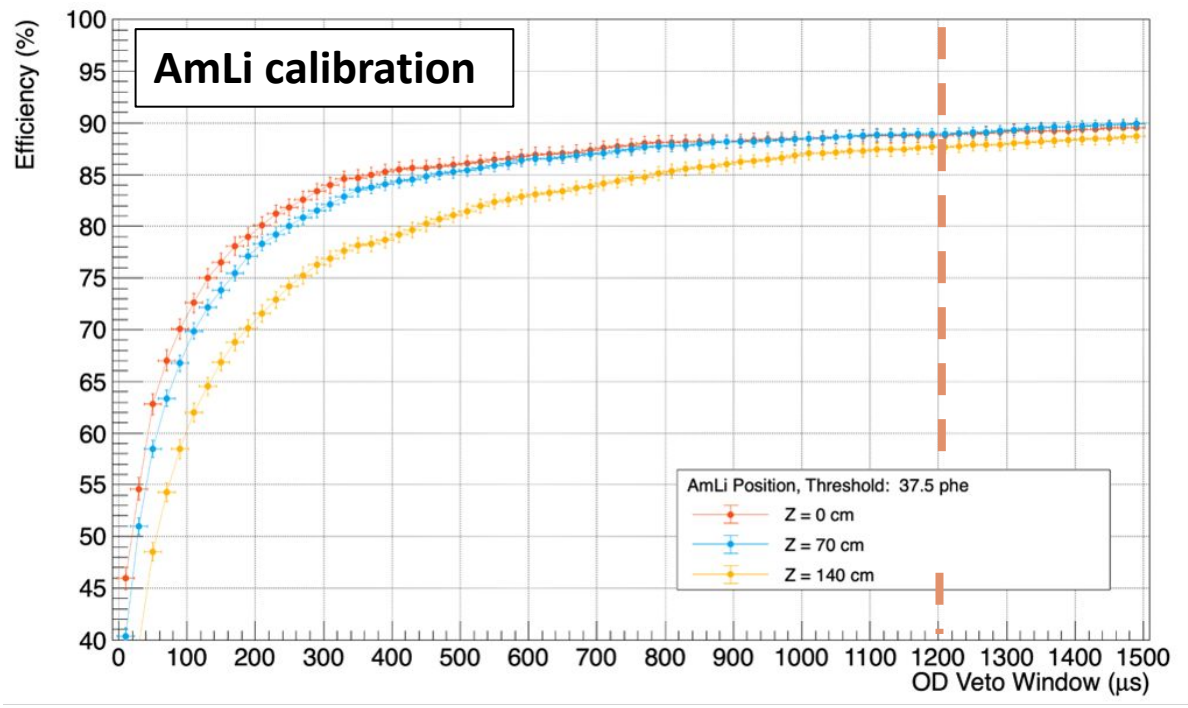
- All LZ systems are performing well and backgrounds are within expectations
- Short engineering run has produced world-leading WIMP limits!
- Much more to come for LZ:
  - Ultimately planning for 1000 live-days
  - Many more physics searches
- Beyond LZ: xenon community is uniting in XLZD consortium

|Backup

Outer detector efficiency



Single -scatter neutron tagging efficiency: 89 ± 3%



- Neutron capture on Gd produces gamma emission of up to 8.5 MeV
- Time delay between neutron scatter in LXe and capture is O(0.1-1 ms)

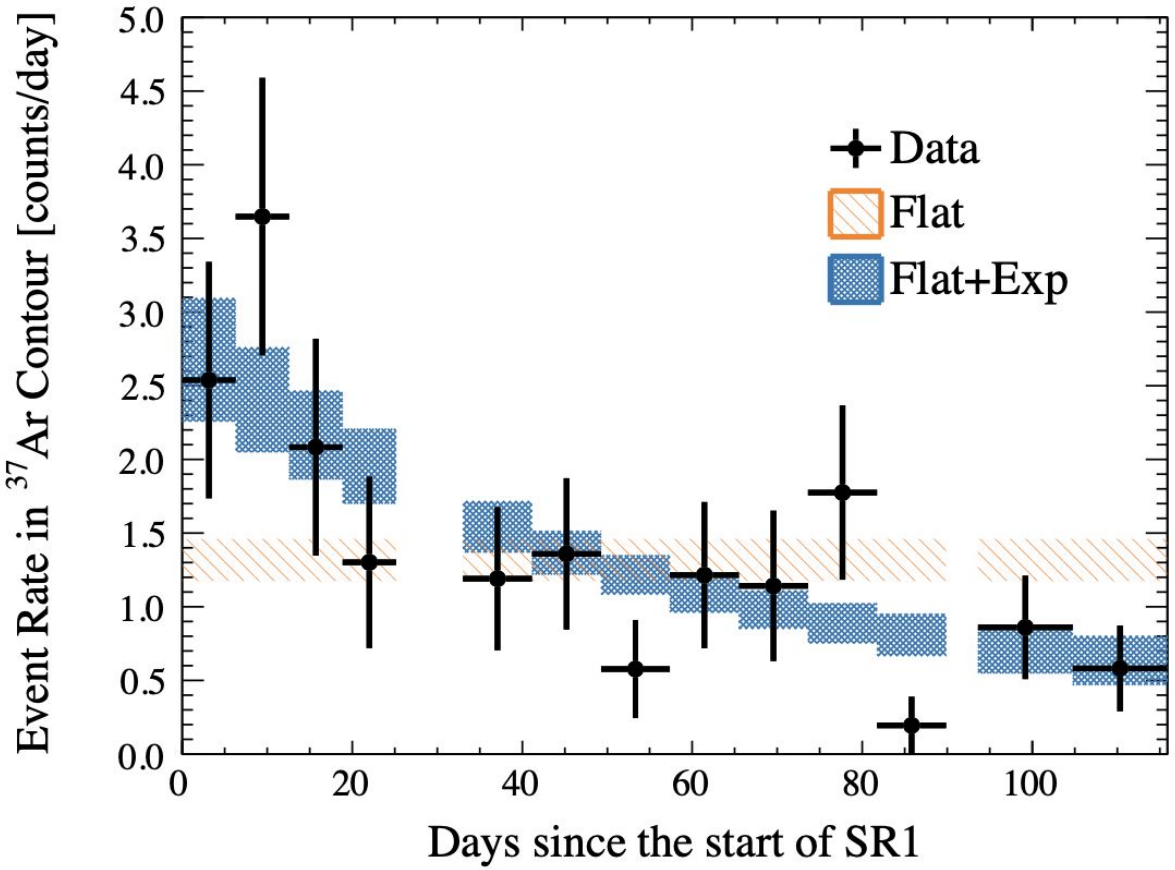
- OD neutron tagging settings
  - ≥ 200 keV
  - $\Delta t \leq 1200$ µs
- Live-time hit: 5%

|Backup

"Background Determination for the LUX-ZEPLIN (LZ) Dark Matter Experiment" (arxiv/2211.17120)

^{37}Ar

- ^{37}Ar is a significant background in early LZ data ($t_{1/2}$ = 35 d)
- Occurs naturally in atmosphere via e.g. Ca(n,α)Ar[1], but suppressed during Xe purification by charcoal chromatography
- Produced by cosmic spallation of natural xenon
- Estimating exposure during transport allows calculation of expected activity
  - ➢ We expect ~100 decays of ^{37}Ar in SR1 with a large uncertainty.[2]

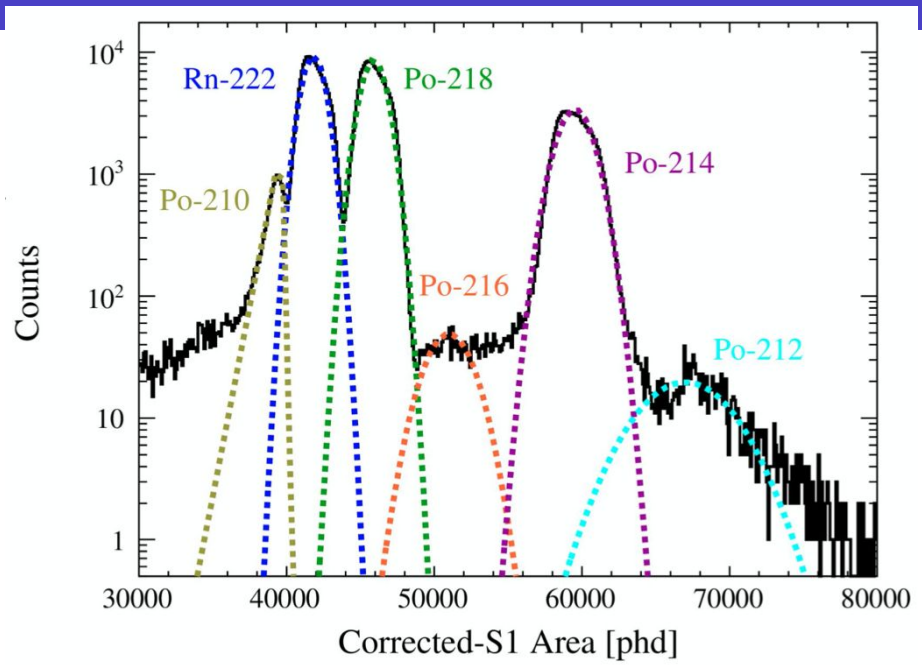


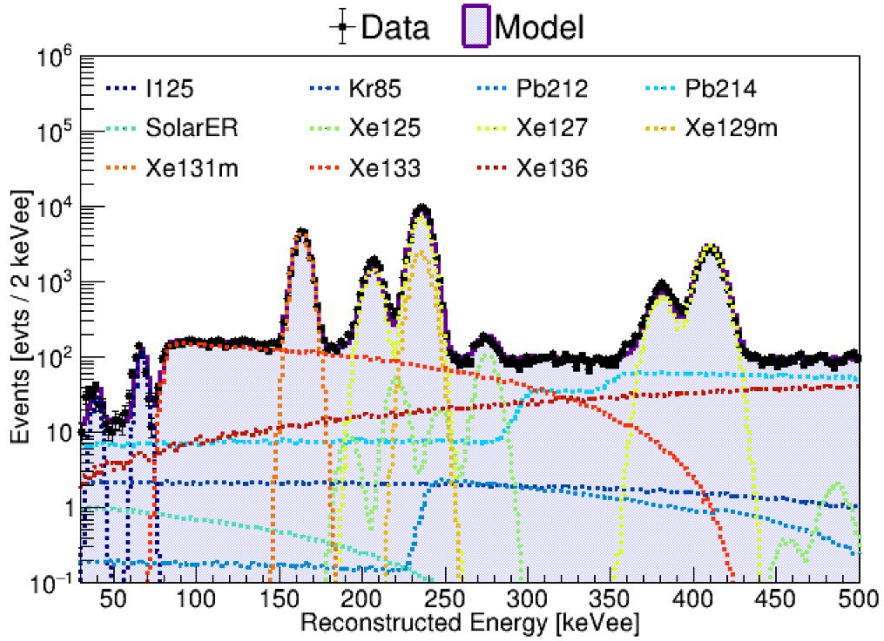
|Backup

Radon

- Naked ^{214}Pb β-decays are the **main** WIMP background
- Rn emanating from detector materials into TPC xenon
- Constrain β-decay rate with two methods:
  - Rn-chain α tagging
  - Spectral fit of all internal BGs outside of energy ROI

^{222}Rn (μBq/kg)	^{214}Pb (μBq/kg)	^{214}Po (μBq/kg)
4.37 ± 0.31 (stat)	**3.26 ± 0.13(stat) ± 0.57(sys)**	2.56 ± 0.21 (stat)

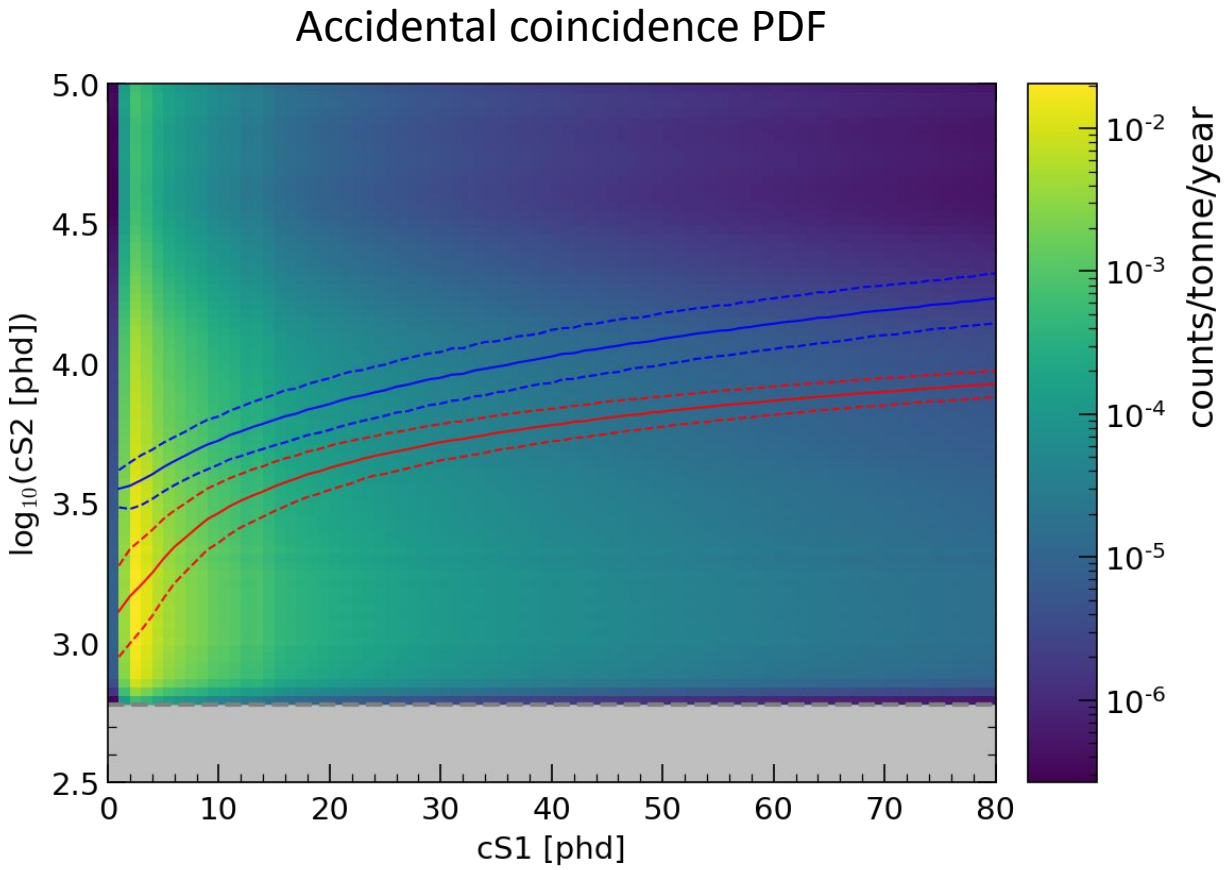




|Backup

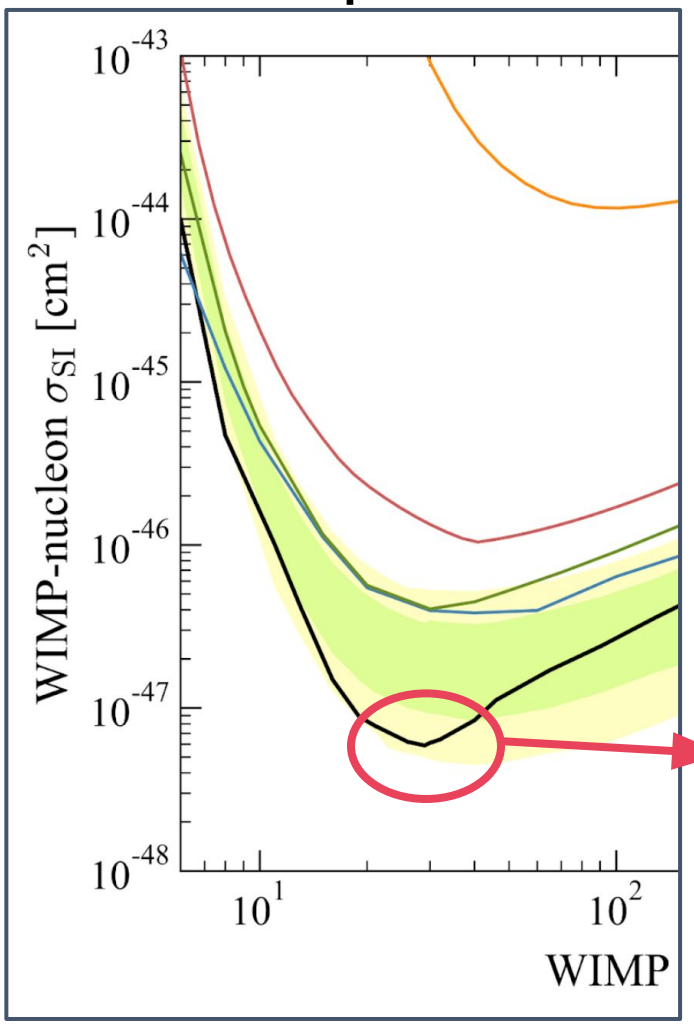
Accidental coincidences

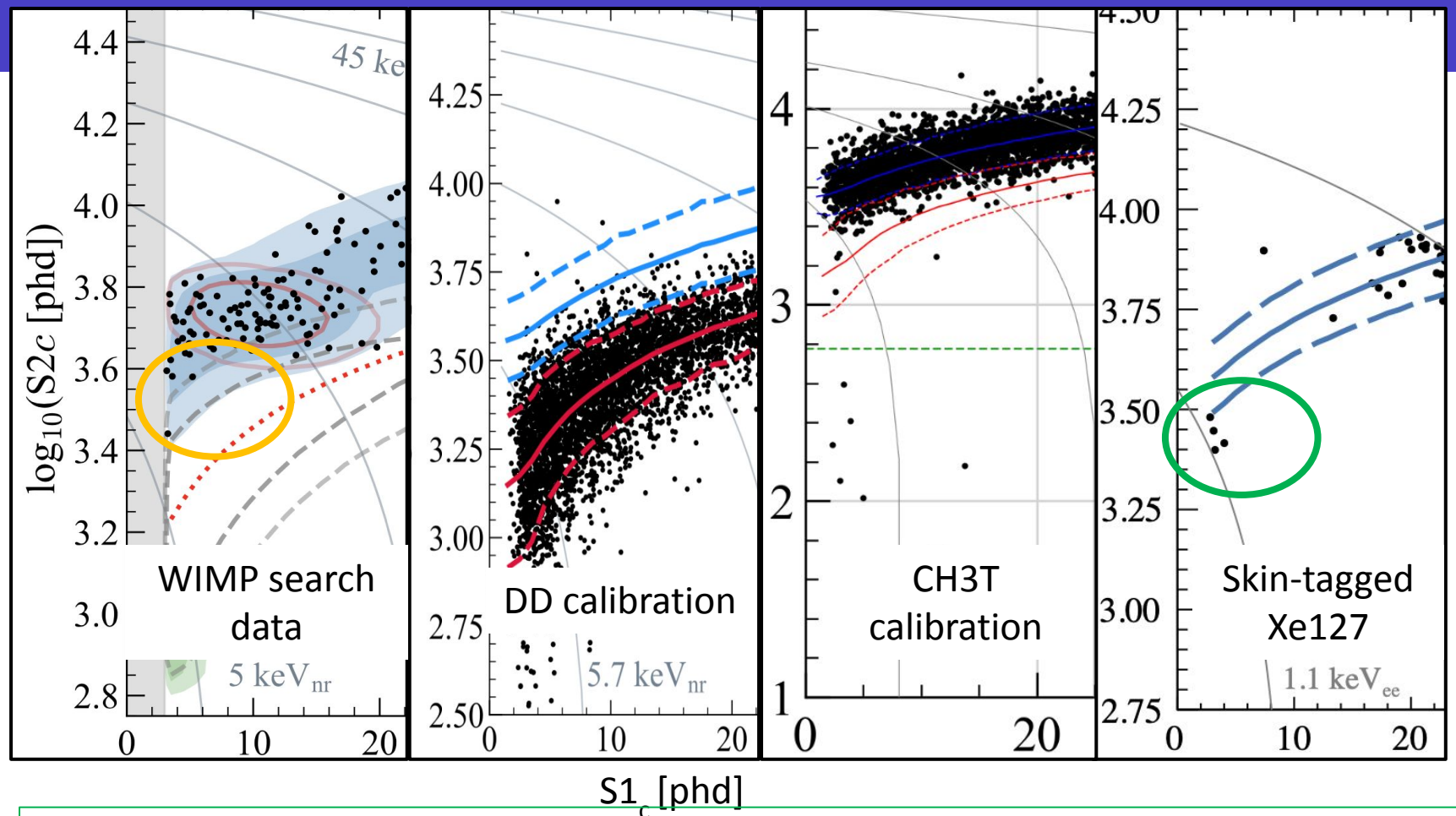
- Isolated S1s & S2s can accidentally combine to form WIMP ROI events
- Data quality cuts successfully developed to address this background
- To construct PDF, stitch isolated raw pulses together for fake events. Normalised using events with unphysical drift time (i.e. drift time > TPC height)
- Expect 1.2 ± 0.3 events in SR1



|Backup

Limit shape





Downward fluctuation in the observed upper limit (pink ellipse) is a result of the deficiency of events under the Ar-37 population (yellow ellipse).

Calibration (both DD and CH3T) and Xe127 M-shell counts (green ellipse) in this region are as expected with our signal acceptance model.

=> Deficit in WIMP search data appears consistent with under-fluctuation of background.