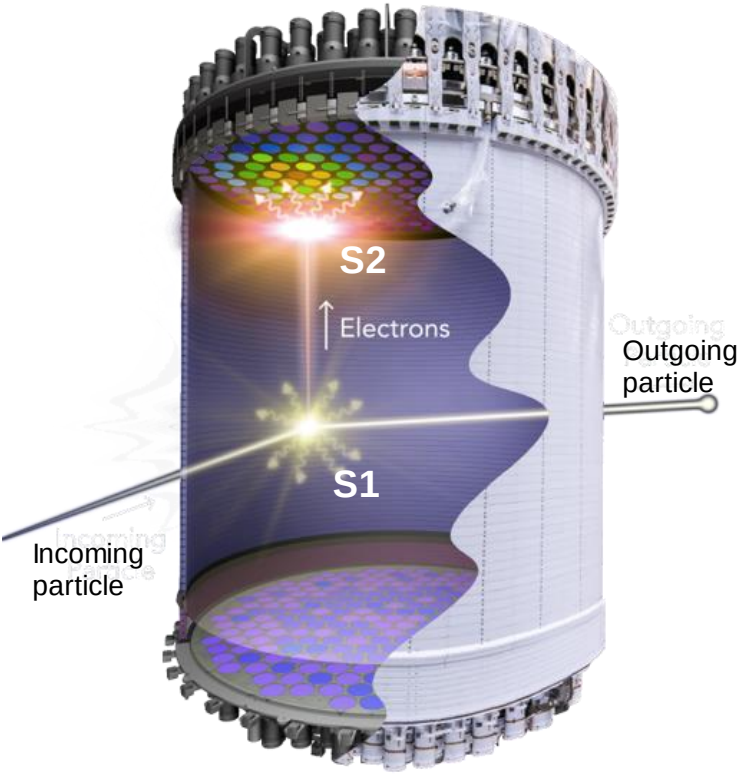
University of BRISTOL

UNIVERSITY OF MICHIGAN

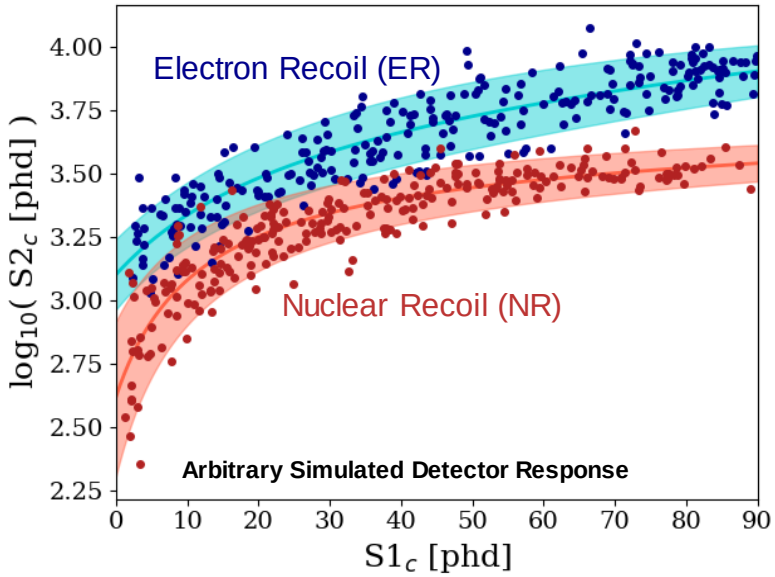
First Result of the LZ Dark Matter Experiment

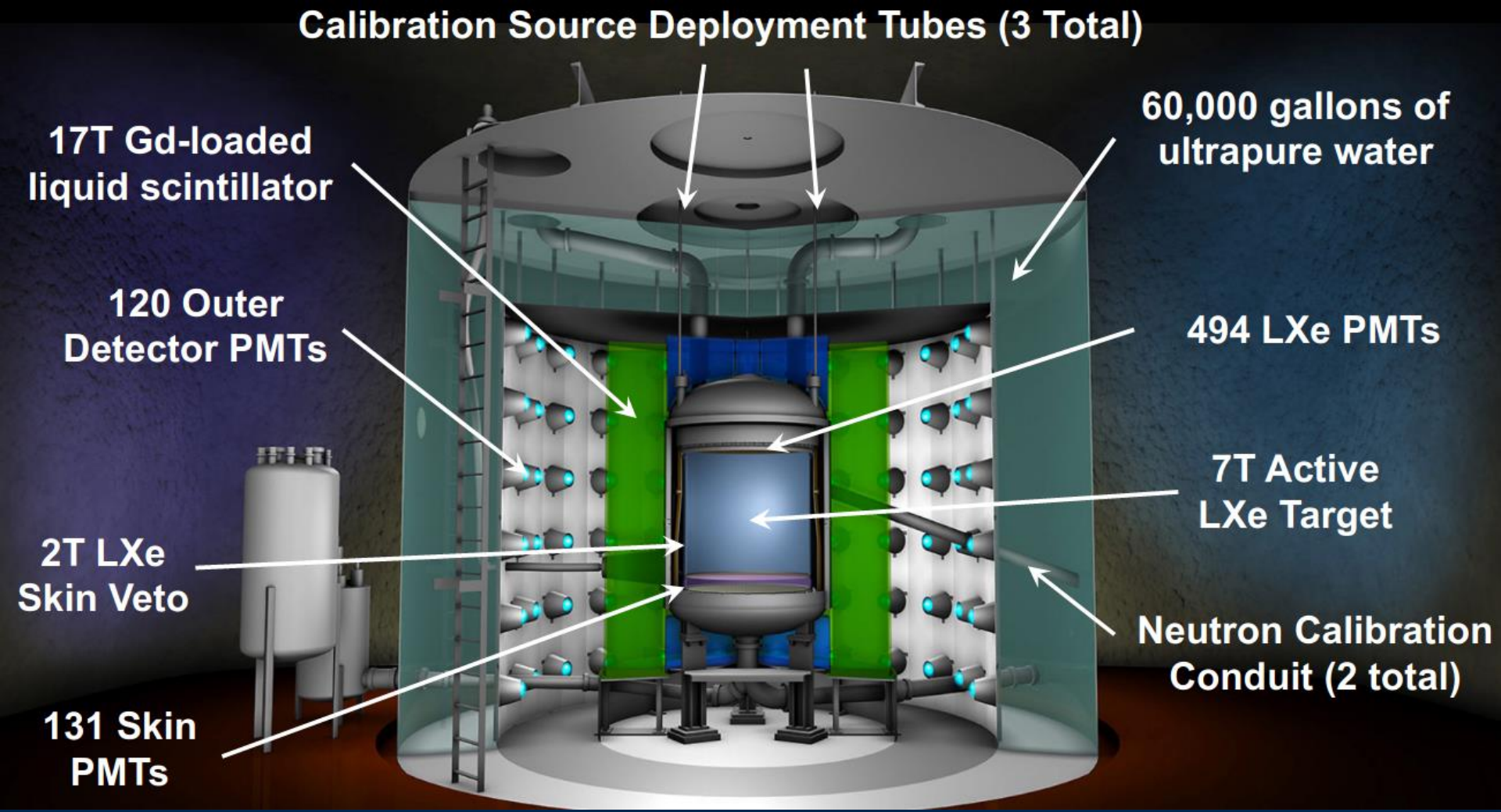
Sam Eriksen

TeVPA 2022
11th August 2022

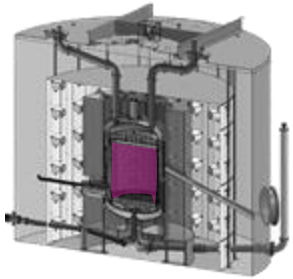


- Direct detection of dark matter via nuclear recoils
- Scintillation and charge signals
- 3D event reconstruction

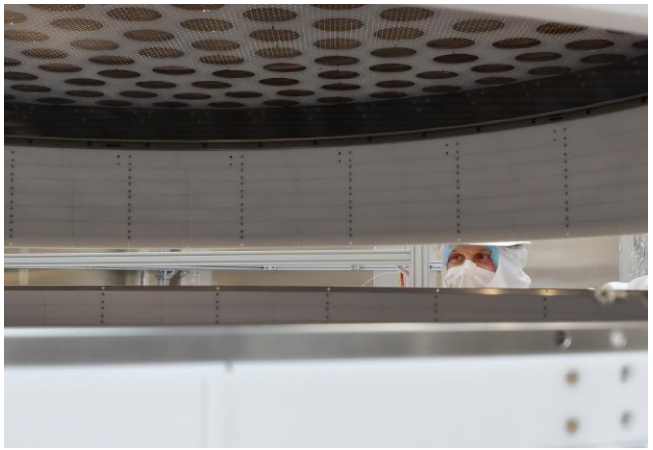



Calibration Source Deployment Tubes (3 Total)
17T Gd-loaded liquid scintillator
60,000 gallons of ultrapure water
120 Outer Detector PMTs
494 LXe PMTs
7T Active LXe Target
2T LXe Skin Veto
Neutron Calibration Conduit (2 total)
131 Skin PMTs

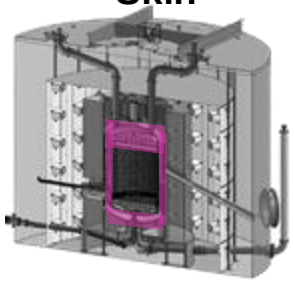
Dual-Phase Time Projection Chamber



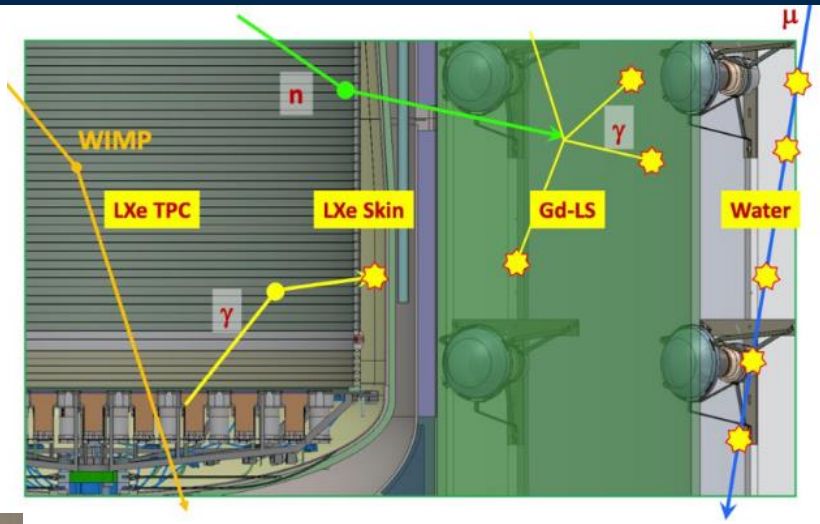
- Large Detector
  - 1.5 m diameter x 1.5 m height
  - 7 tonnes active Liquid Xenon
- High Light Collection Efficiency
  - 253 x 3" PMTs for top array
  - 241 x 3" PMTs for bottom array
  - PTFE everywhere



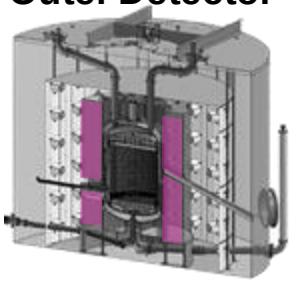
Skin



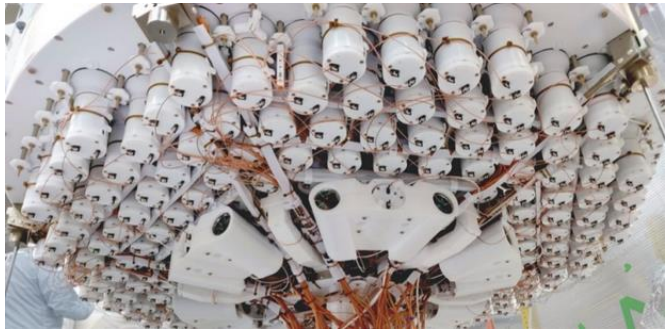
- 2 tonnes LXe
- 93x1” and 38x2” PMTs
- Anti-coincidence for *γ-ray*

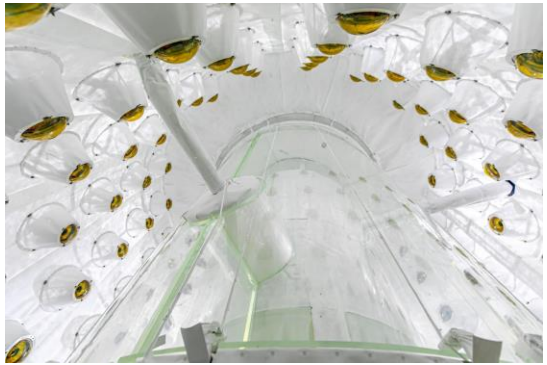


Outer Detector

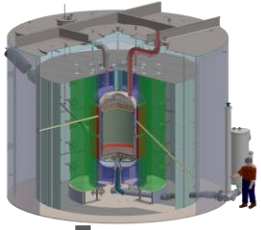


- 17 tonnes Gd-loaded scintillator
- 120 8” PMTs
- anti-coincidence for neutrons and *γ-ray*

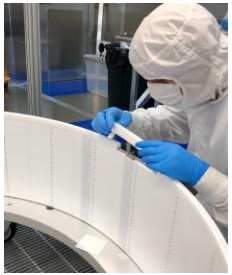




LZ timeline



March 2017
CD3 and TDR



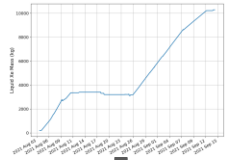
December 2018
FFR Assembly

Spring 2019
Grid Construction

October 2019
Moved Underground

Autumn 2020
Electronics
Installation

June 2021
OD Fill



August 2021
Xenon Fill

2017

2018

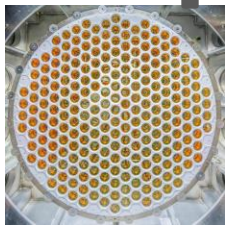
2019

2020

2021

2022
Science!

May 2018
Cryostat arrives



December 2018
January 2019
PMT arrays arrive

August 2019
TPC Complete

March 2020
HV connected

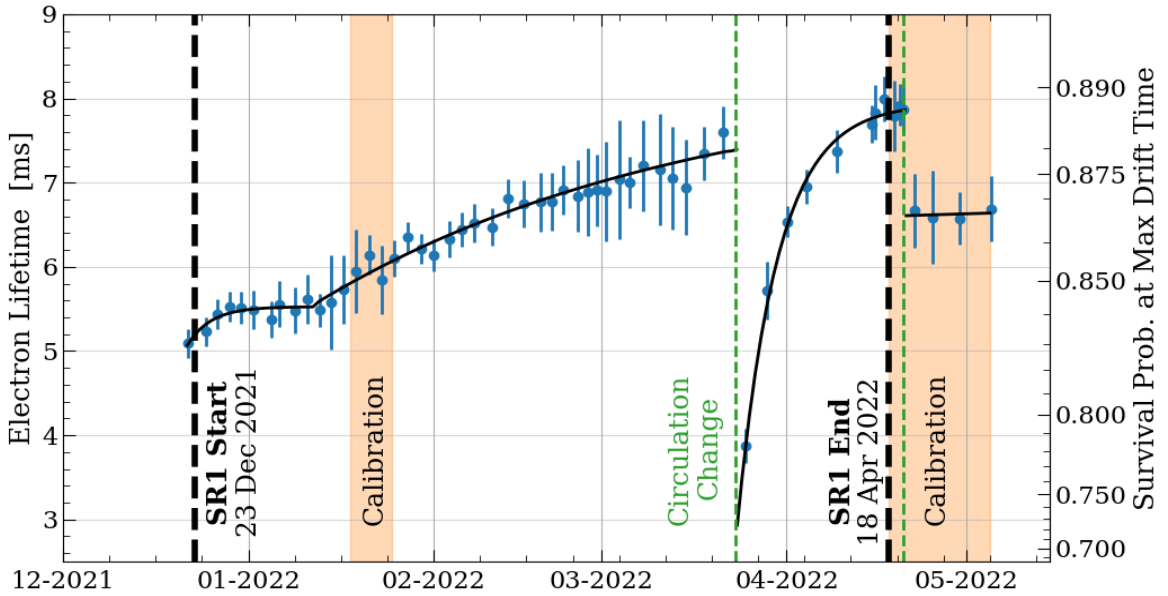
Early 2021
OD Complete

Autumn 2021
Commissioning

2021
Kr Removal

Goals for SR1

1. Demonstrate physics capability
2. Demonstrate competitive sensitivity



Key Info;

- 116 calendar days, 60 live days
- Electron drift live time 5-8ms
- Stable detector conditions:
  - Liquid temperature 174.1K (0.02%)
  - Gas circulation at 3.3t/day
  - Drift field: 193 V/cm (32kV cathode)

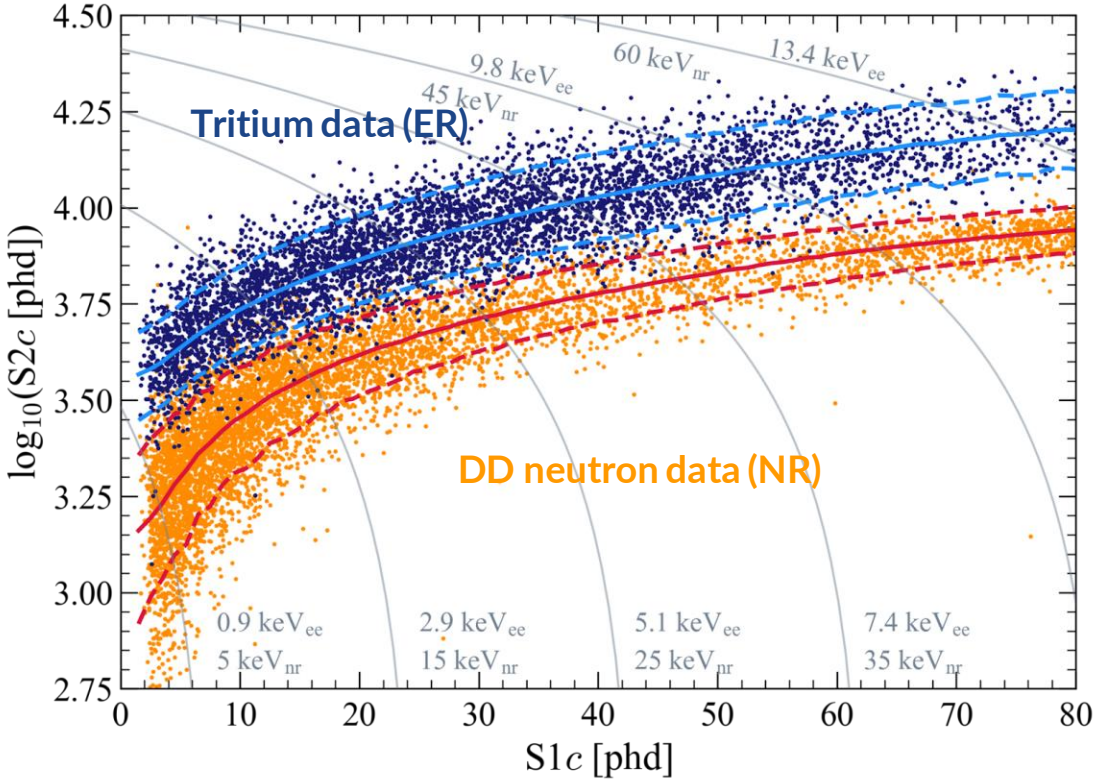
Engineering run

- Not blinded or salted
- Data cuts developed on calibrations and outside WIMP region

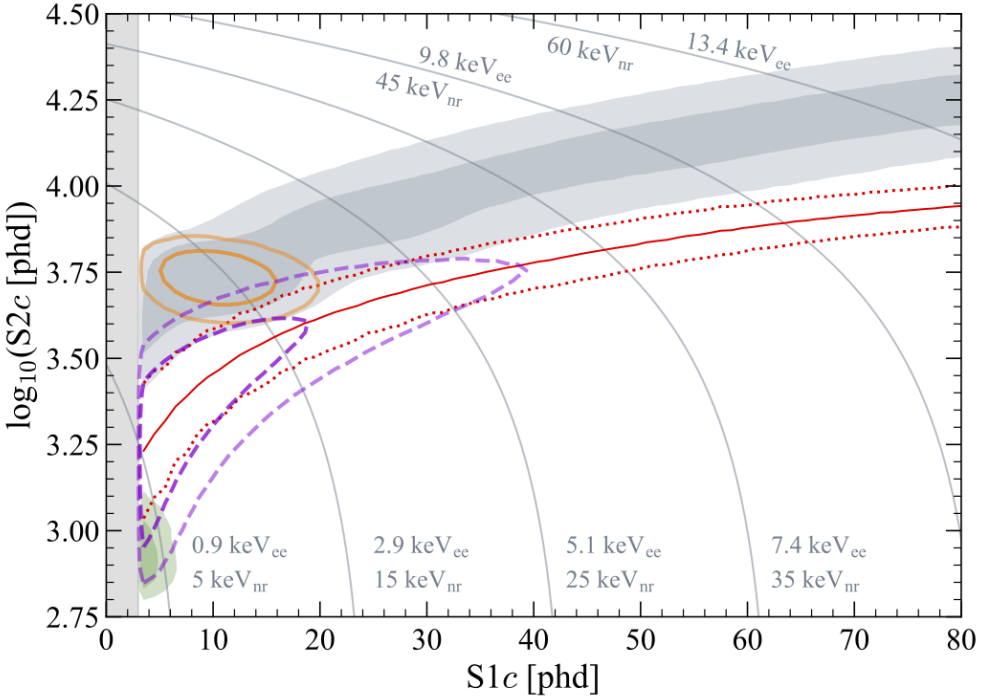
Injected tritiated methane
- Source of β ERs
- 0-18.6keV

External Deuterium-deuterium (DD)
- Monoenergetic 2.45MeV
- Up to 10^9 neutrons per second

Tuning detector response model
- Noble Element Simulation Technique (NESTv2.3.7) [1]
- $g_1 = 0.114 \pm 0.002$ phd/photon
- $g_2 = 47.1 \pm 1.1$ phd/electron
- 80.5% extraction efficiency



[1] NEST: https://nest.physics.ucdavis.edu/



ER backgrounds

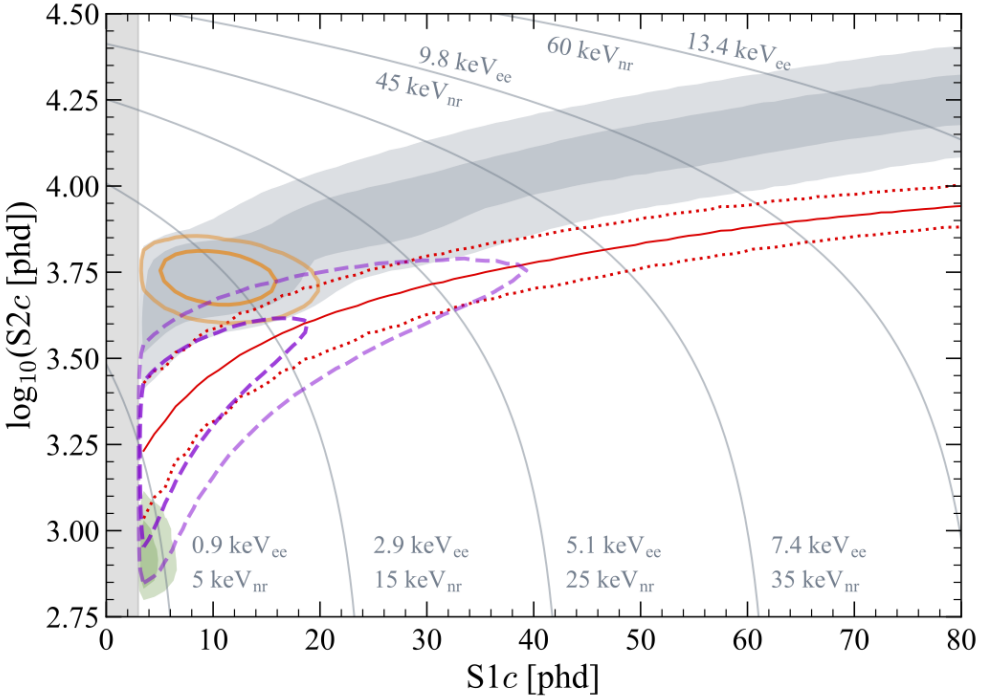
- Dissolved β-emitters
- Dissolved EC
- γ emitters
- Solar Neutrinos

NR backgrounds

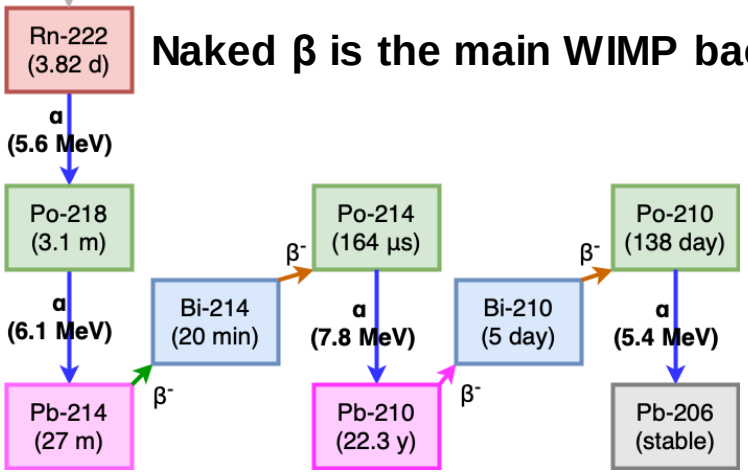
- Neutrons from (α,n) and spontaneous fission
- ^{8}B solar CEvNS

Accidentals

- Coincident S1 and S2s



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	–

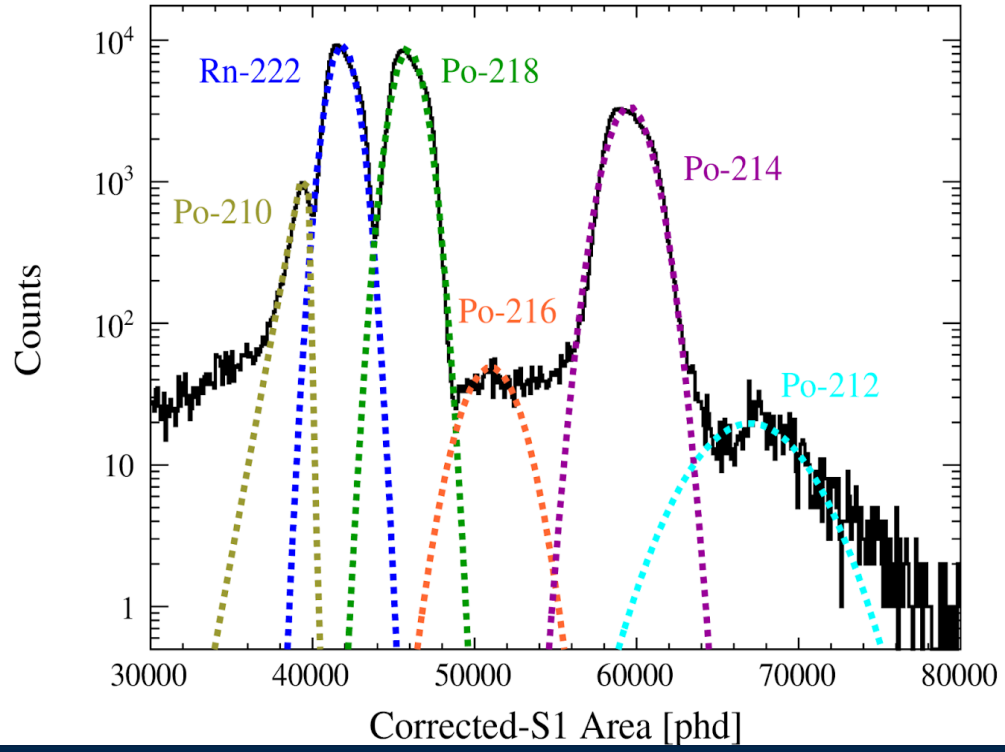


Naked β is the main WIMP background

Isotope (decay)	Activity (μBq/kg)
Rn-222 (α)	4.37 ± 0.31 (stat)
Po-218 (α)	4.51 ± 0.32 (stat)
Po-214 (α)	2.56 ± 0.21 (stat)

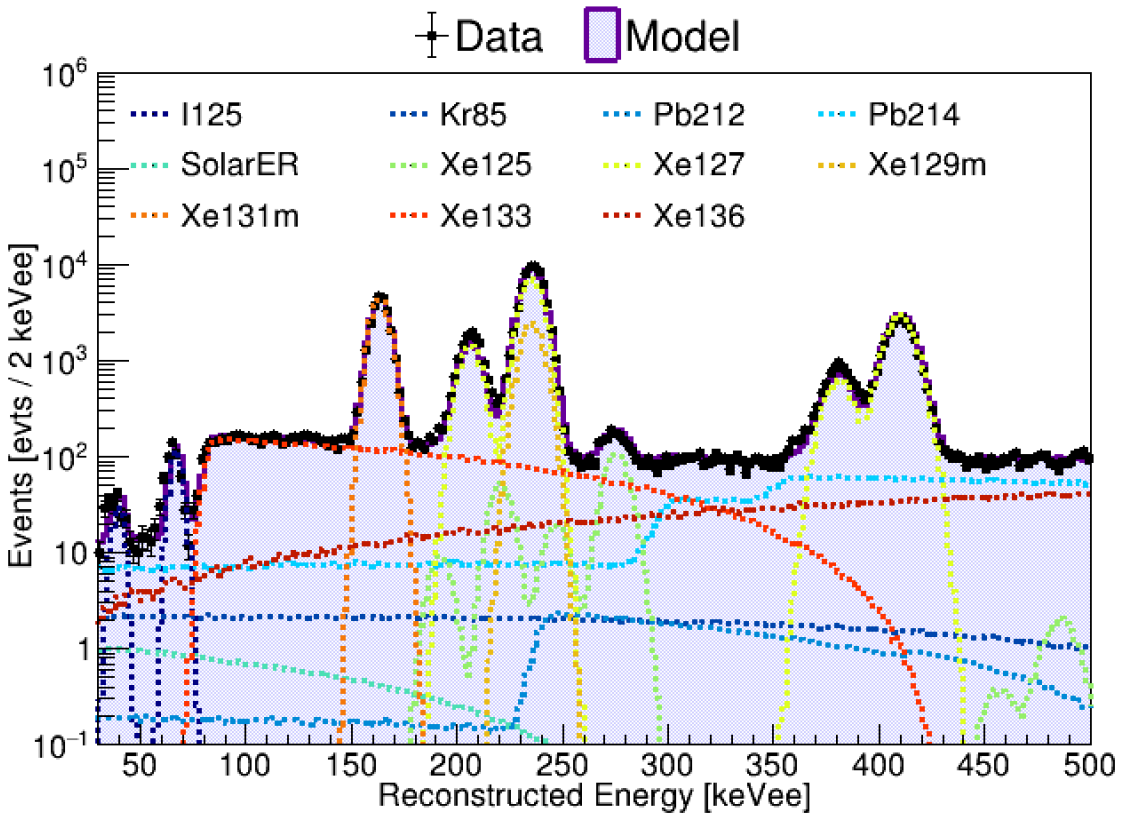
Rate constrained by:

- α tagging
- Spectral fit



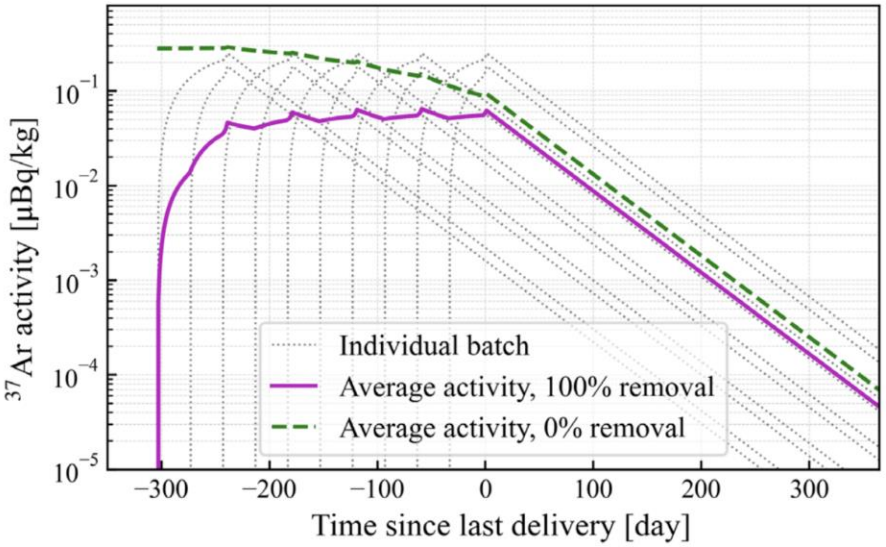
- Activated Xenon and other contaminants
- Rates informed via spectra fits above ROI

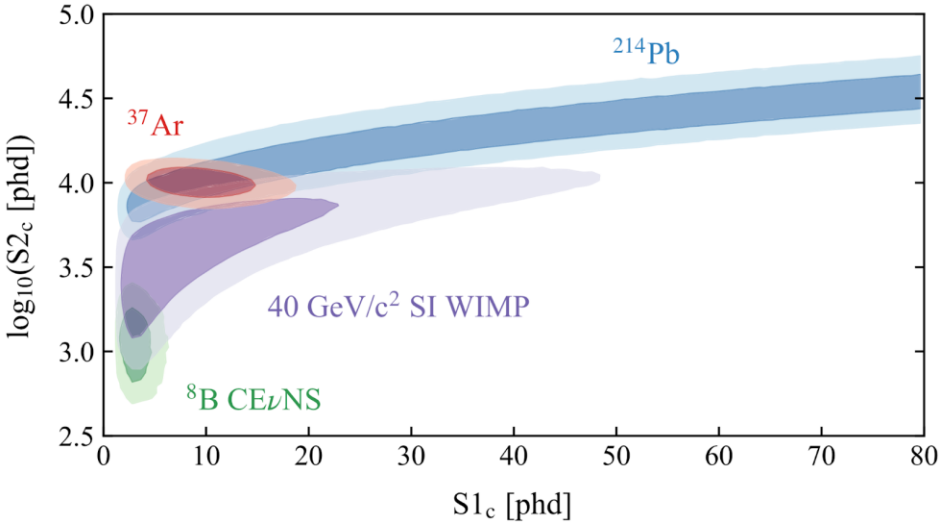
Isotope (decay)	Activity (μBq/kg)
Rn-222 (α)	4.37 ± 0.31 (stat)
Po-218 (α)	4.51 ± 0.32 (stat)
Pb-214 (β)	**3.26 ± 0.13 (stat) ± 0.57 (sys)**
Po-214(α)	2.56 ± 0.21 (stat)



- Electron capture
- Monoenergetic 2.8 keV ER
- 35 d half-life

- Naturally occurs in atmosphere
- Also by cosmic spallation of natural Xenon





- Activity constrained based on Xe delivery schedule to SURF

~100 events expected in SR1 with a large uncertainty [1]

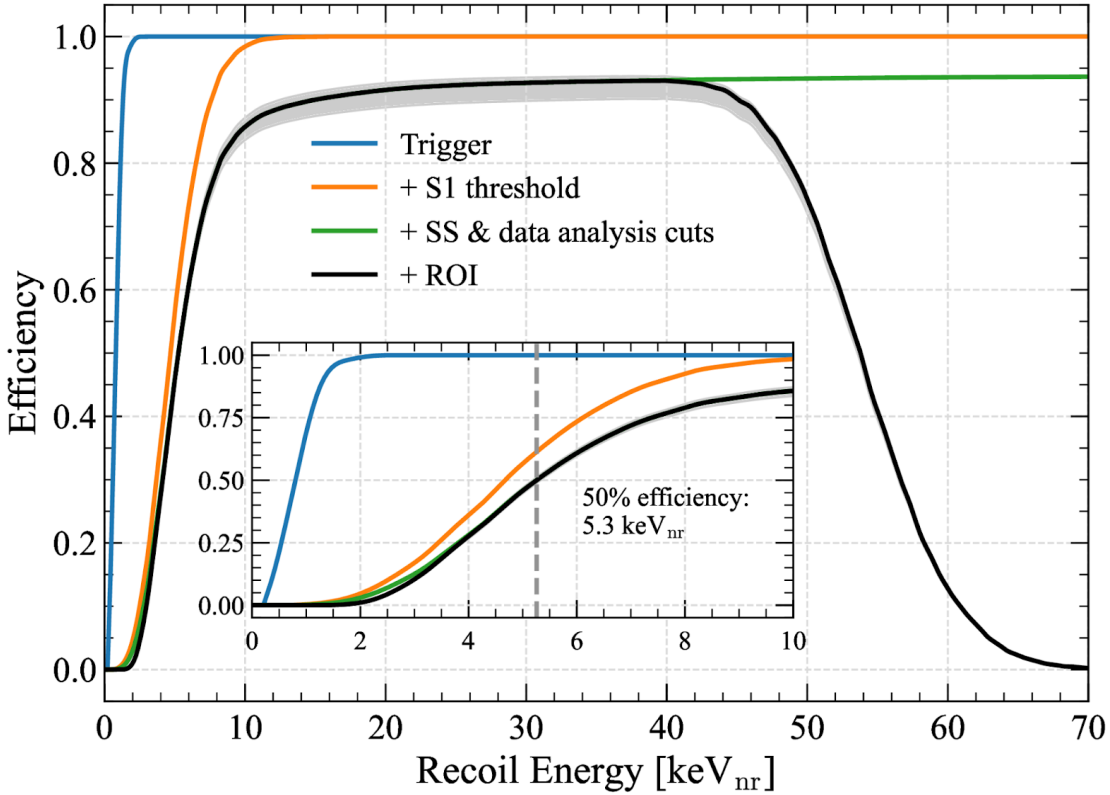
[1] LZ Collaboration, Phys. Rev. D 105, 082004 (2022), 2022.02858

Cut development
- Non-WIMP ROI
- Calibration data

Event Selection
- Single Scatter
- Fiducial Volume
- Region-of-Interest
- S1/S2 shape cuts
- Veto detector anti-coincidence

Rejection of livetime
- When detector was unstable
- High TPC rates

60.3±1.2 live days



Region of Interest

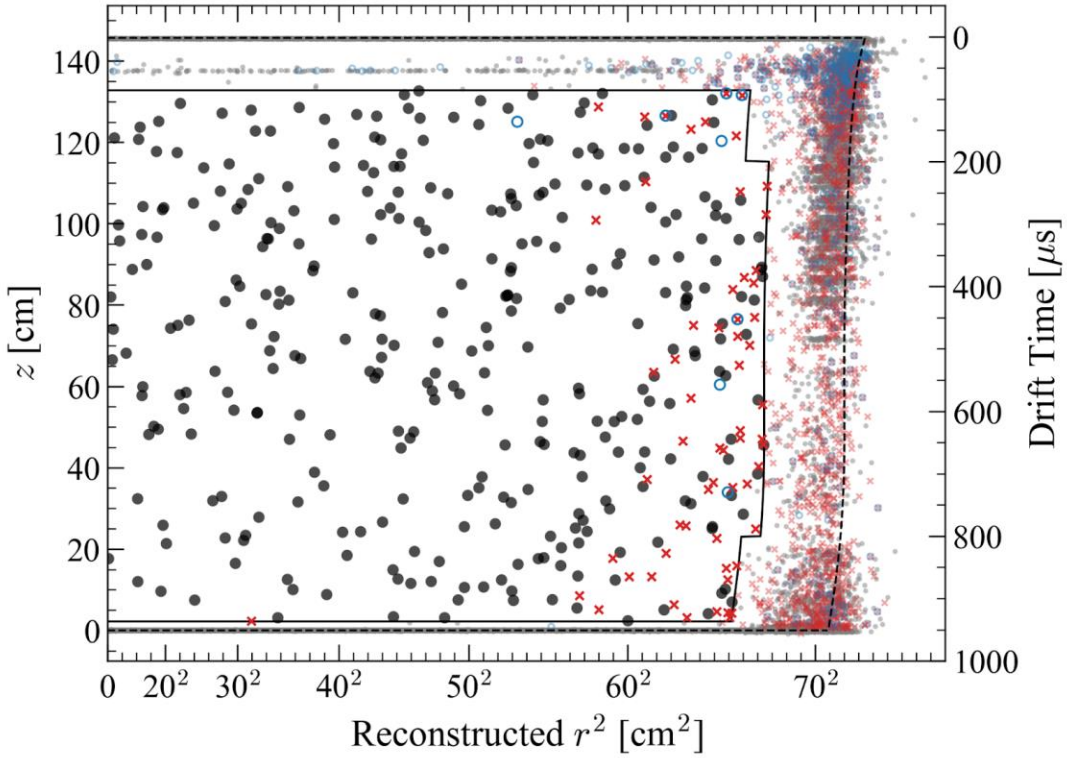
- 3 < S1c < 80 photons detected
- three-fold PMT coincidence
- S2 > 600 phd
- Log10(S2c) < 5

Fiducial Volume

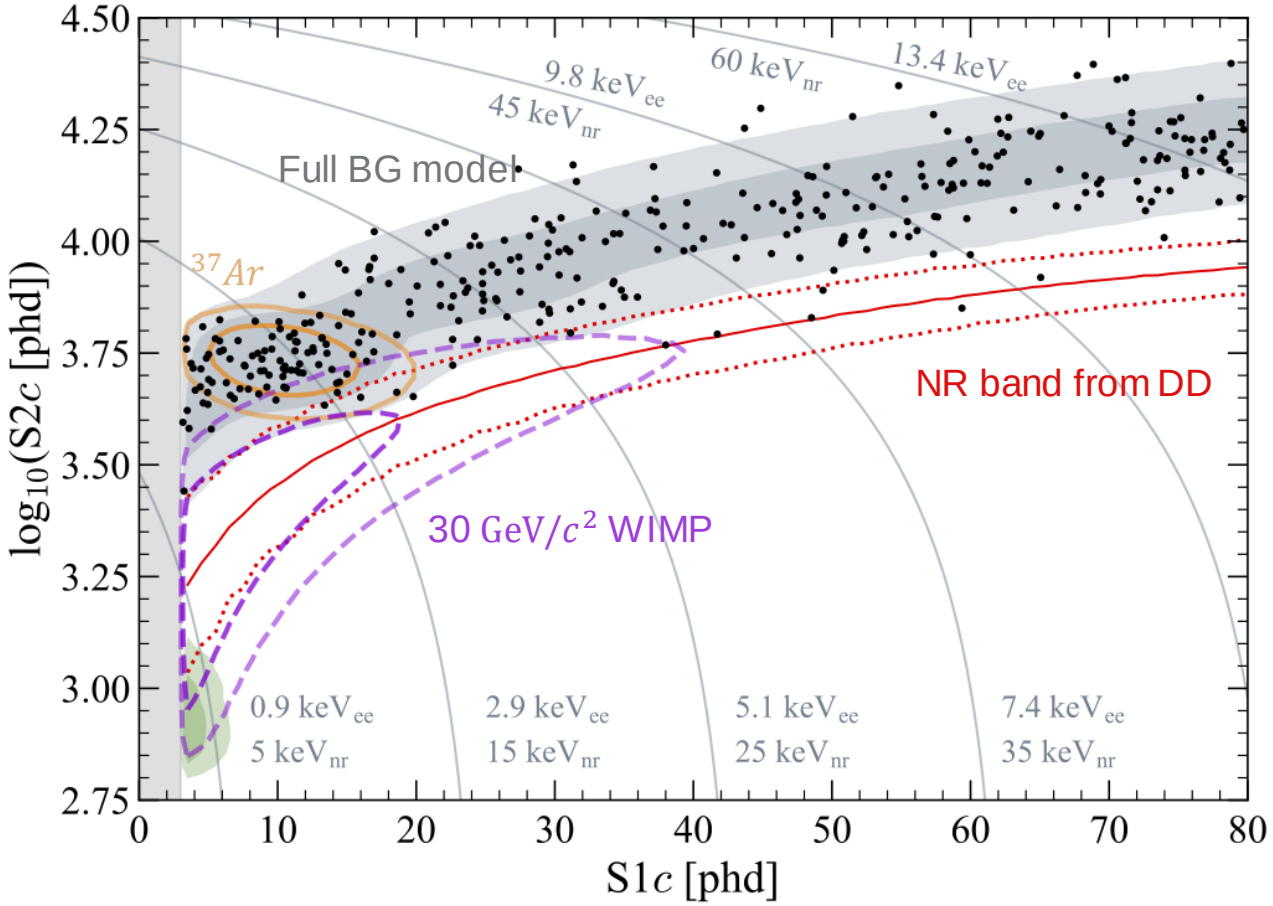
- Radial cut for <0.01 wall BGs
- 86 us < drift < 936.5 us
- wall BGs negligible
- 5.5±0.2 tonnes

Key

- Events surviving all selections
- Skin-prompt-tagged events
- OD-prompt-tagged events

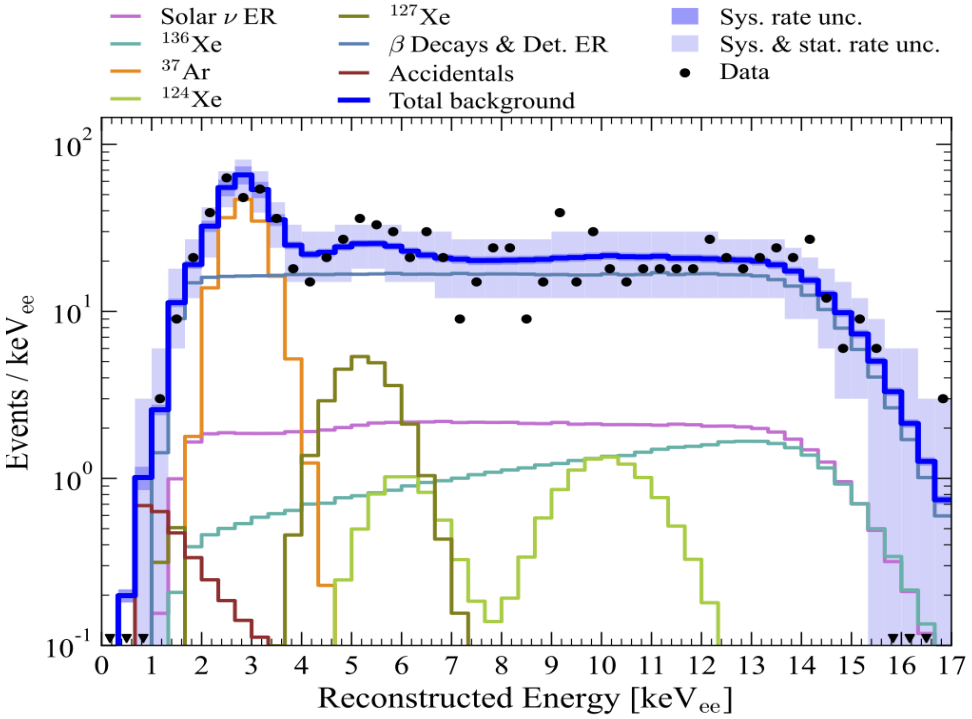


- 335 events
- PDFs created via energy deposit and detector response simulations
- Profile Likelihood Ratio analysis



Best fit is with zero WIMP events

Source	Expected Events	Best Fit
β decays + Det. ER	218 ± 36	222 ± 16
ν ER	27.3 ± 1.6	27.3 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.2 ± 2.4	15.3 ± 2.4
^{8}B CEνNS	0.15 ± 0.01	0.15 ± 0.01
Accidentals	1.2 ± 0.3	1.2 ± 0.3
Subtotal	276 ± 36	281 ± 16
^{37}Ar	[0, 291]	$52.1^{+9.6}_{-8.9}$
Detector neutrons	$0.0^{+0.2}$	$0.0^{+0.2}$
30 GeV/c^2 WIMP	–	$0.0^{+0.6}$
Total	–	333 ± 17

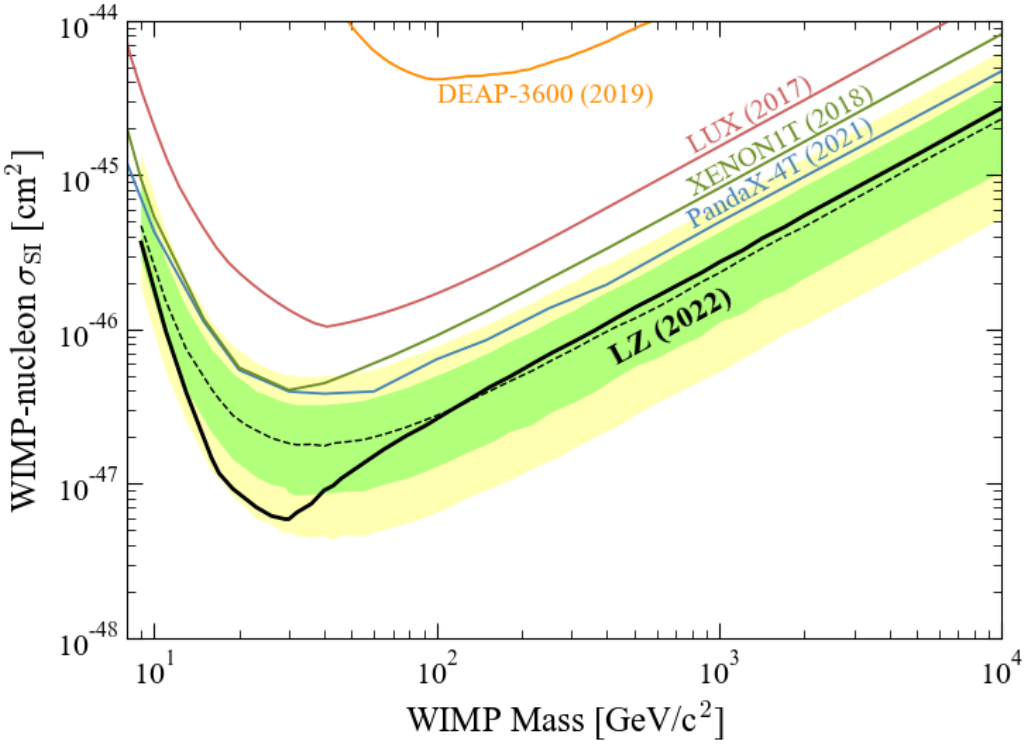


- 90% CL upper limit on WIMP-nucleon σ_{SI} at 5.9 x $10^{-48} cm^2$
- Frequentist, two-sided profile-likelihood-ratio (PLR) test statistic

Key

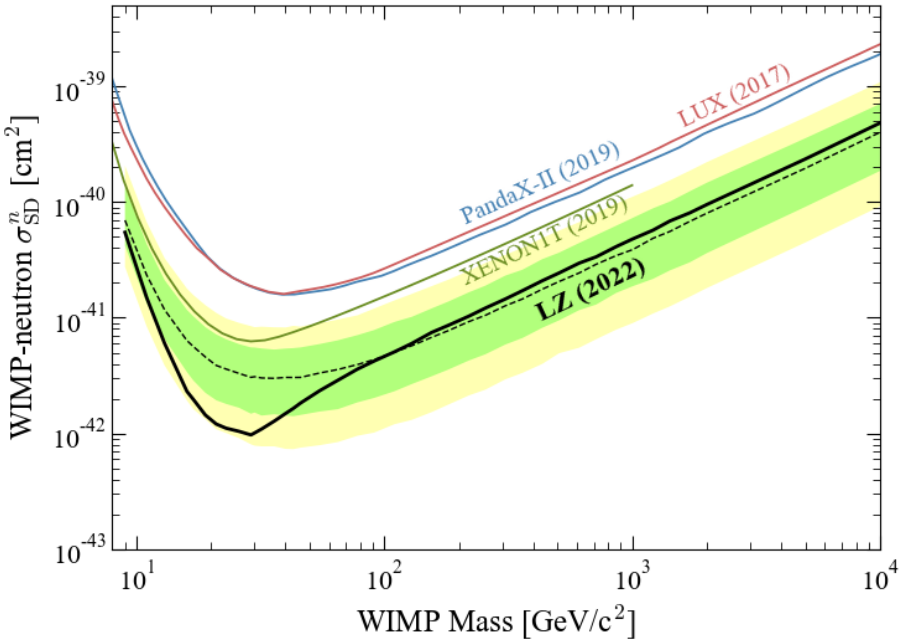
—— Observed limit

- - - Median expected sensitivity

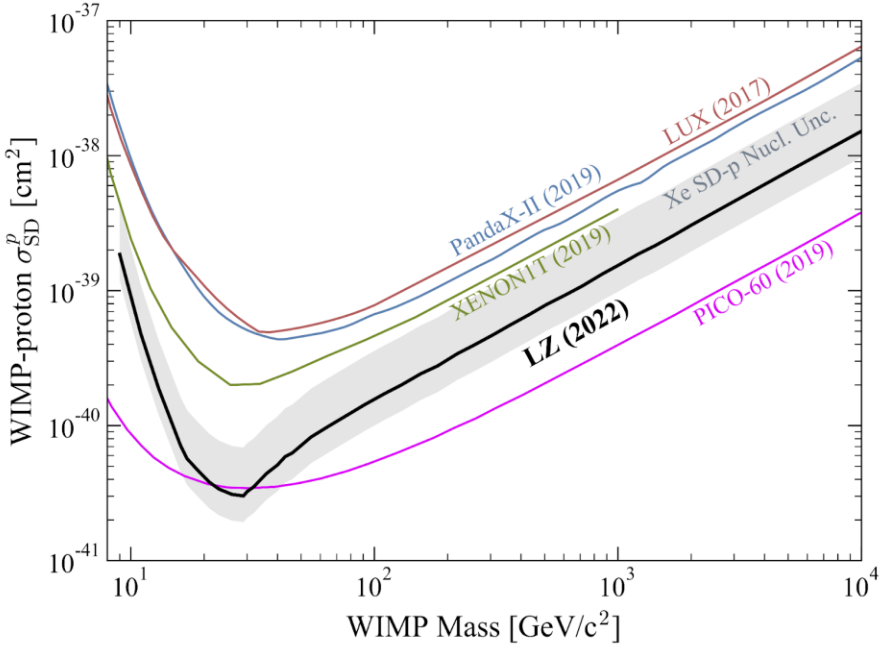


Reporting Conventions: EPJC 81, 907 (2021)

Spin-dependent WIMP-neutron scattering



Spin-dependent WIMP-proton scattering



Uncertainty band theoretical uncertainty on Xe nuclear form factor

arXiv:2207.03764

Conclusions and the future

- All LZ systems are performing well!
- World-leading WIMP sensitivity
- Preparations for year long run and eventual 1000 live days of data
- More physics to be done
  - S2-only, Migal effect, Effective Field Theory
  - Mirror DM, leptophilic DM, etc…
  - Astrophysical neutrinos
  - Rare decays; $0\upsilon\beta\beta$ from Xenon isotopes etc…

- XLZD consortium formed
  - Next-generation project
  - White paper

Thanks For Listening

35 Institutions, 250 scientists, engineers, and technicians

- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial 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
- University of California Santa Barbara
- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Wisconsin, Madison

US UK Portugal Korea

Science and Technology Facilities Council

FCT Fundação para a Ciência e a Tecnologia

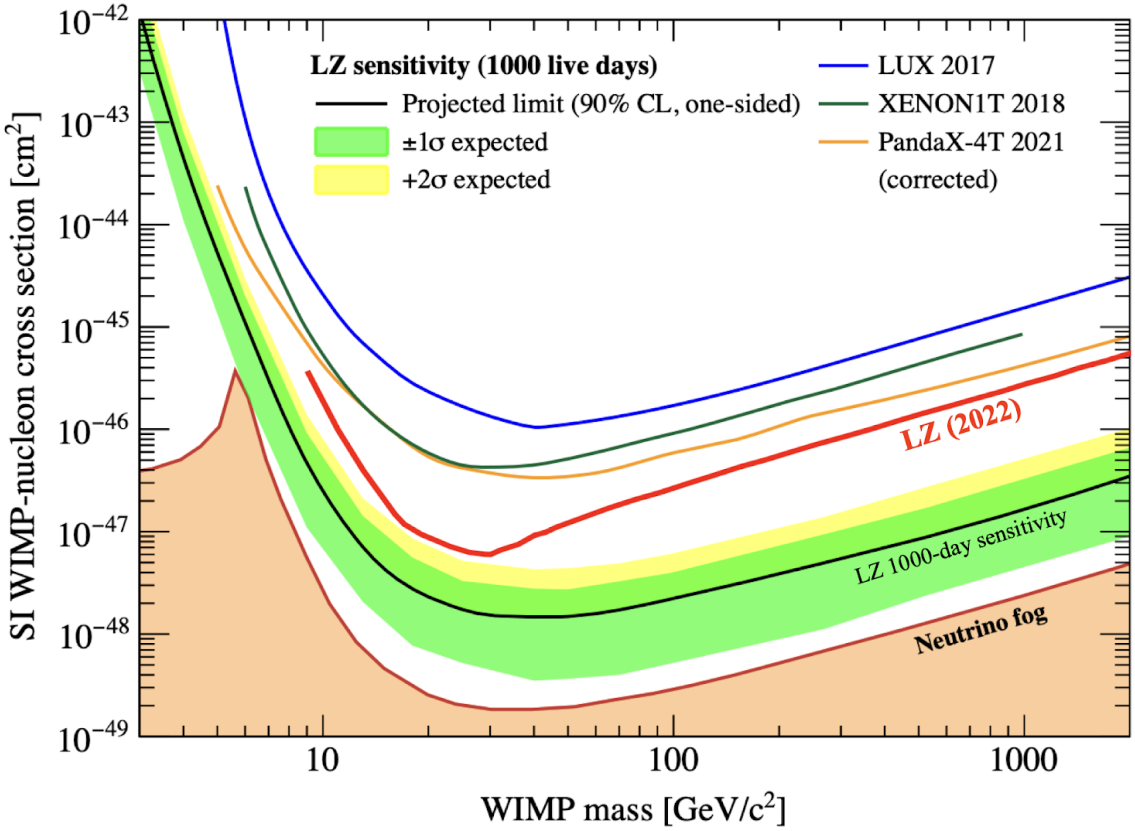
Sanford Underground Research Facility

South Dakota Science and Technology Authority

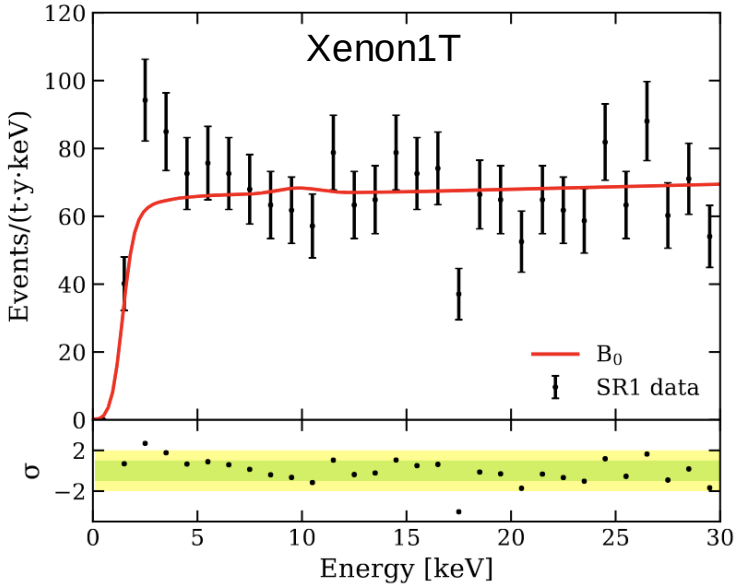
Institute for Basic Science

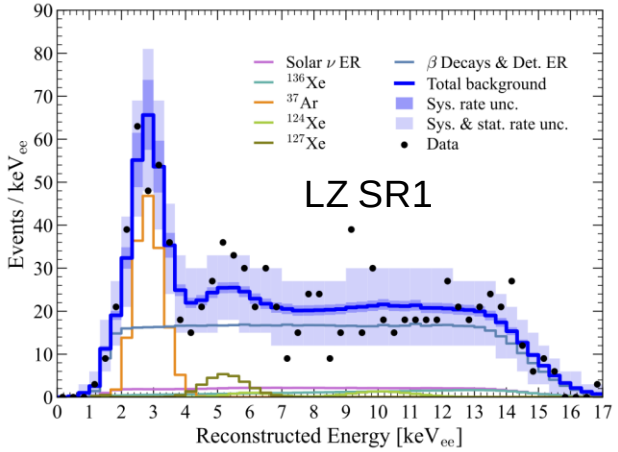

SAMSUNG

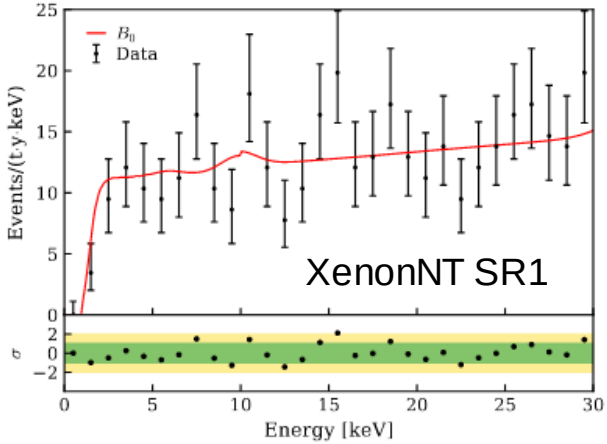
Comparison to Projected Sensitivity



Projected Sensitivity
Phys.Rev.D 101, 052002 (2020)







- XENON1T possible excess of ER at low energy
- XenonNT saw excess no excess
- LZ analysis of region ongoing

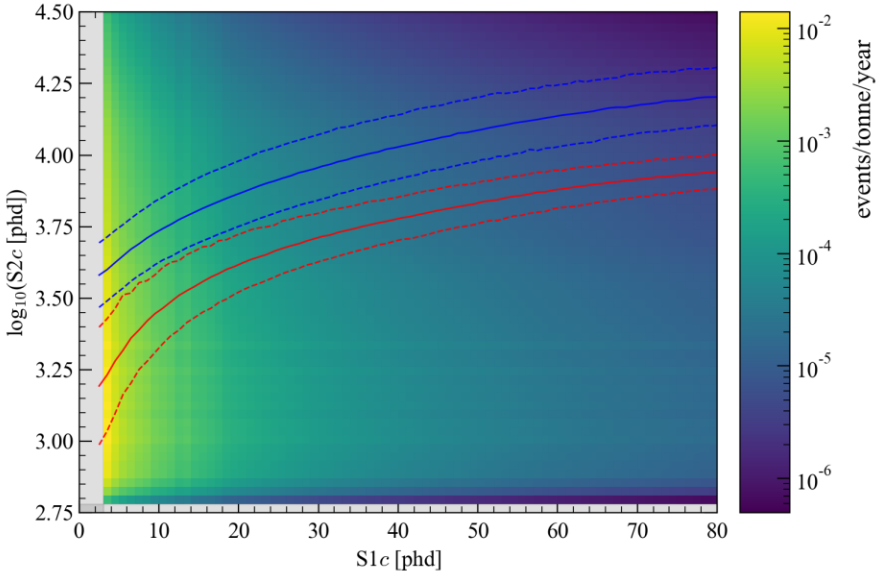
XENON1T excess

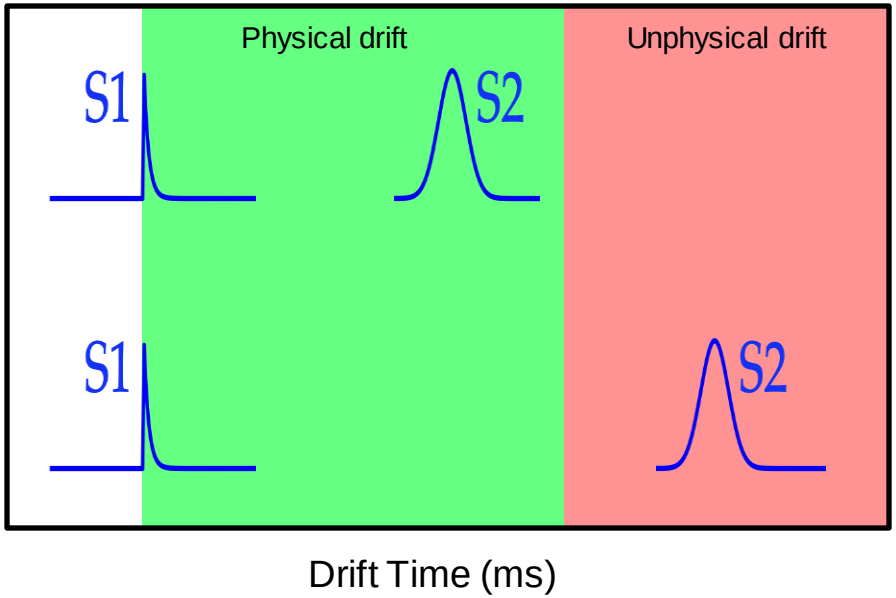
XENONNT SR1

Accidentals

- Isolated S1 pulses
- Isolated S2 pulses
- Occasionally can be within 1ms of each other

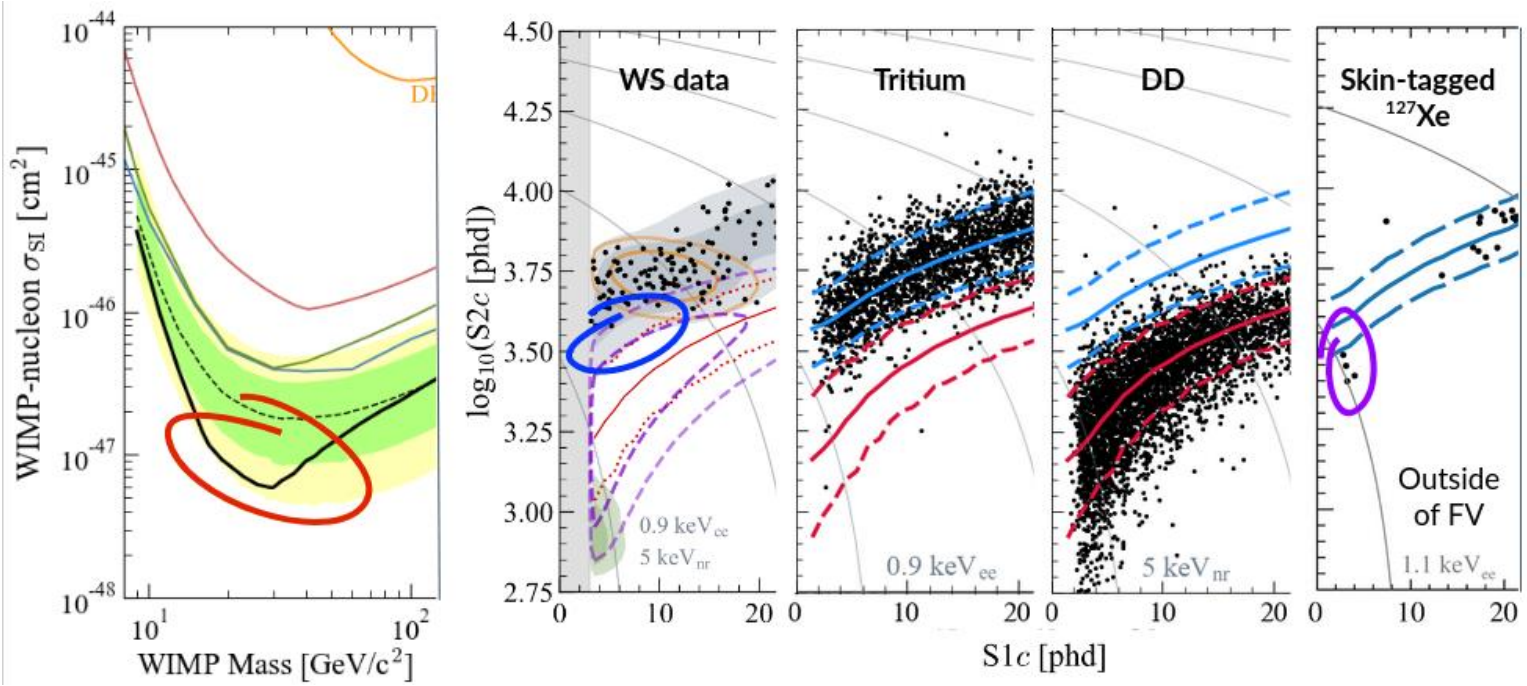
- Events with >1ms drift time are accidentals





1.2 ± 0.3 events estimated in SR1

Unusual shape



Possible reasons:

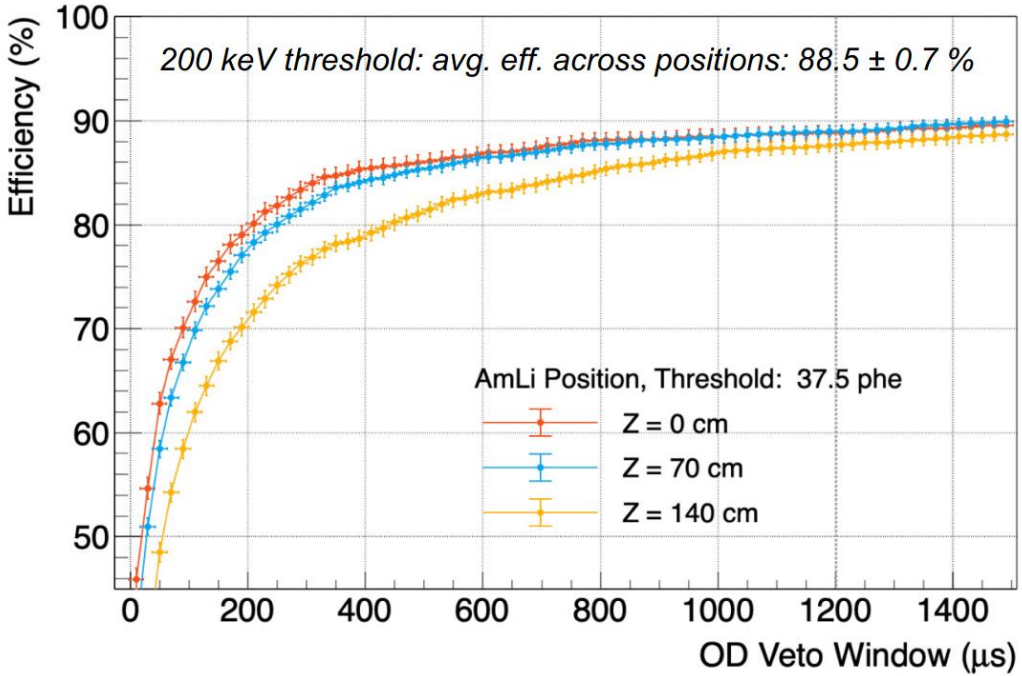
- Background under-fluctuation
- Unaccounted for signal inefficiency

- Calibrations and Xe127 M-shell counts are as expected under signal acceptance

Calibrations:
- Optical calibration system
- External γ-ray
- Neutron sources

OD Veto:
- TPC-OD veto window: 1200 μs
- OD veto threshold: 200 keV
- Neutron Veto efficiency: 89±1%

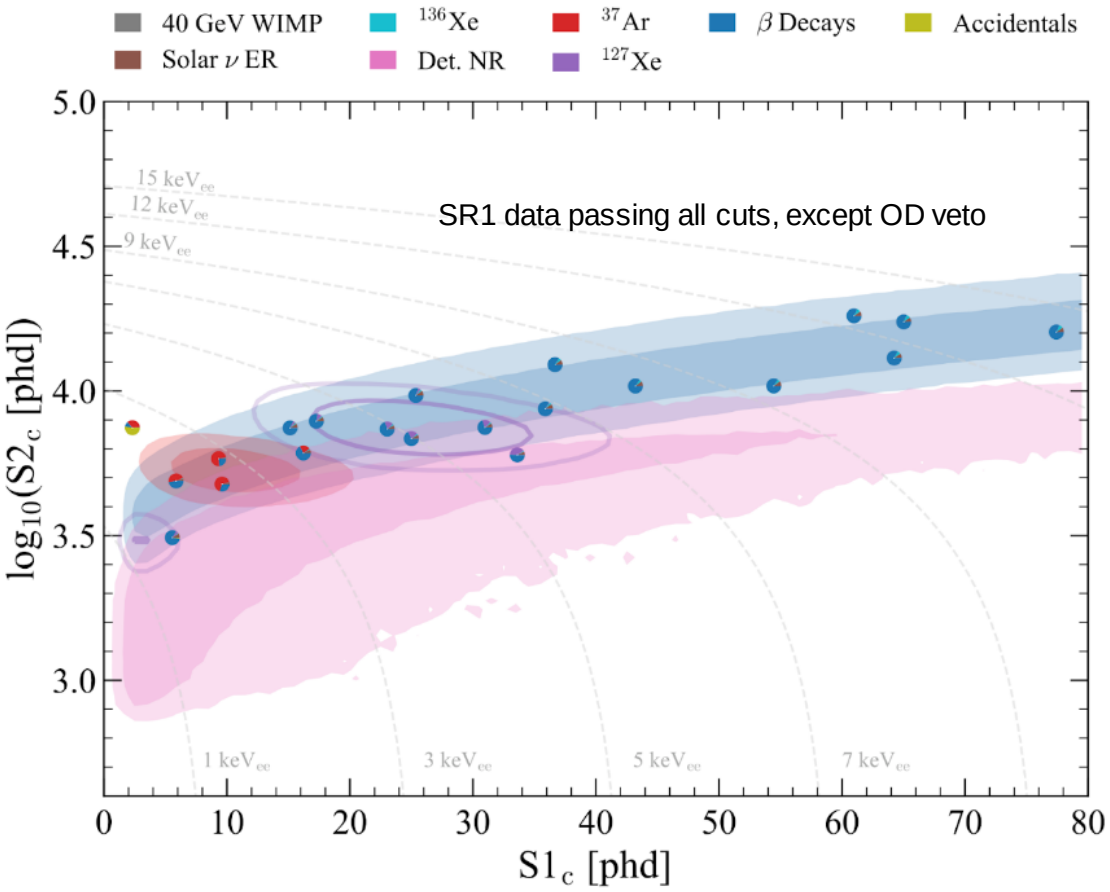
Skin Veto:
- ^{127}Xe Veto efficiency: 78±5%



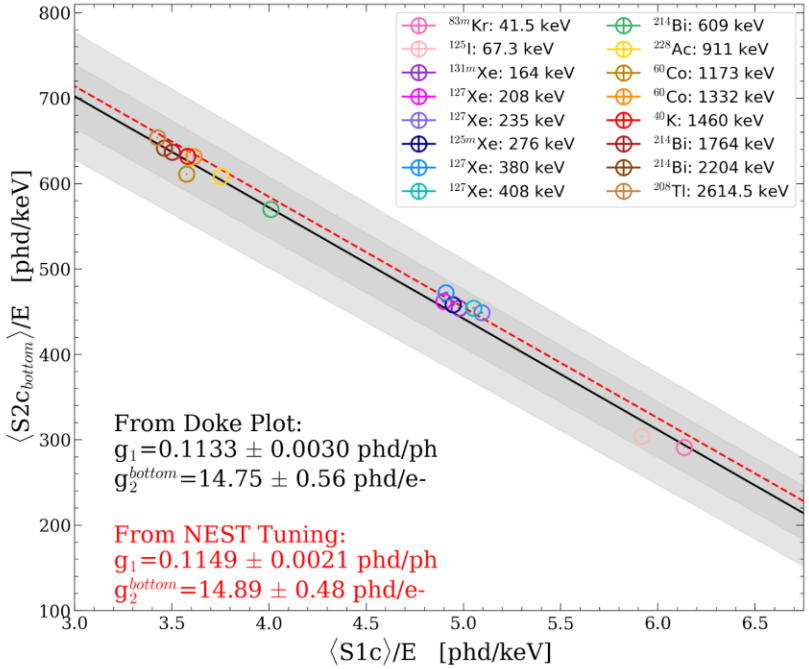
- Neutron backgrounds with OD tag are 7.75 times larger than without
- Only 5% of non-neutron backgrounds should be OD tagged
- Fit to events passing all WIMP search cuts except OD-Veto for data driven constraint on Det. NR

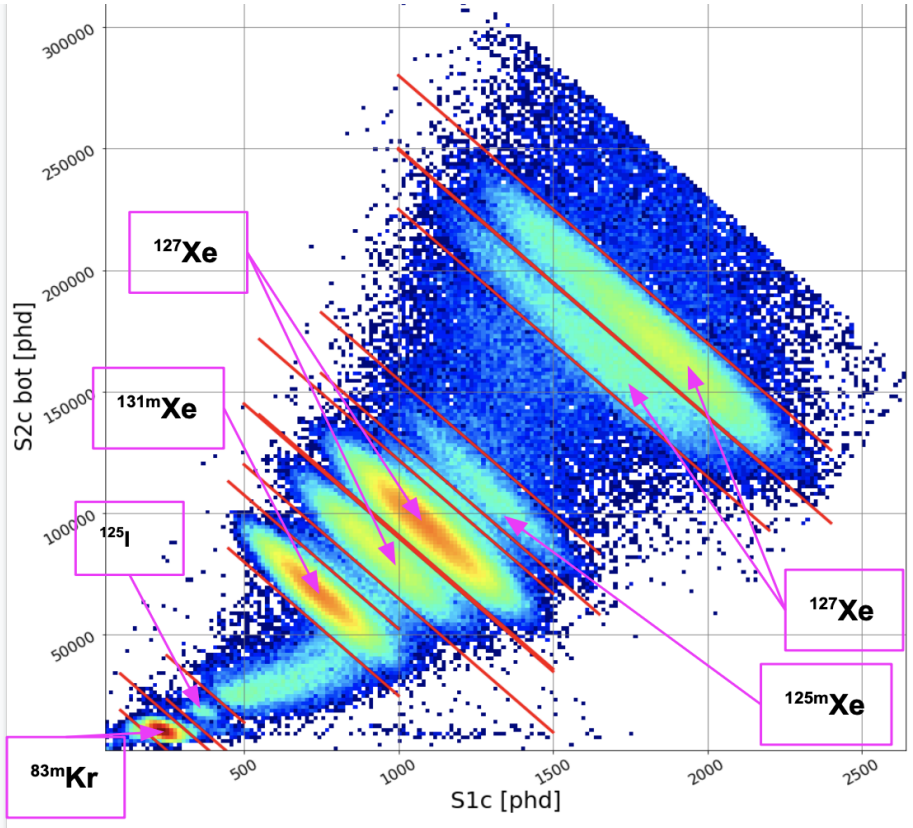
<0.2 neutrons in SR1

Consistent with simulation-derived estimate of 0.06 events in 60 live days

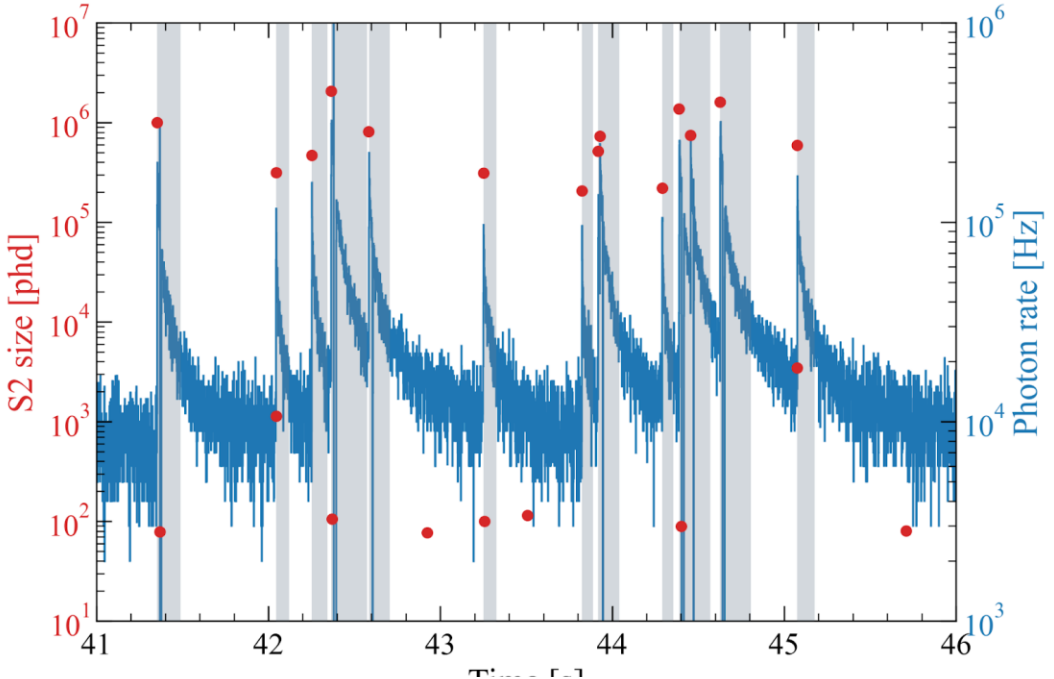


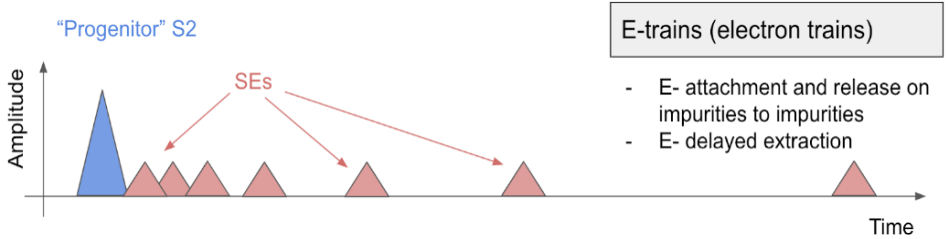
- S1 and S2 position-corrected using ^{131m}Xe and ^{83m}Kr
- Doke





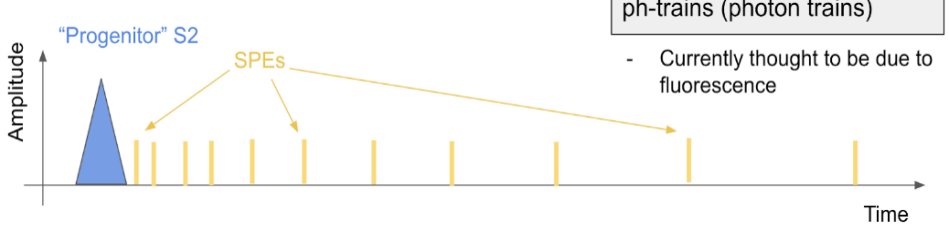
- Large S2s induce pulse trains. Longer than event window
- High pulse rates lead to pile-up. Mimic real S1s and S2s
- Remove periods after S2s. Excludes ~30% live time
- Area to optimize





E-trains (electron trains)

- E- attachment and release on impurities to impurities
- E- delayed extraction



ph-trains (photon trains)

- Currently thought to be due to fluorescence