UNIVERSITY OF LIVERPOOL

LUX-ZEPLIN

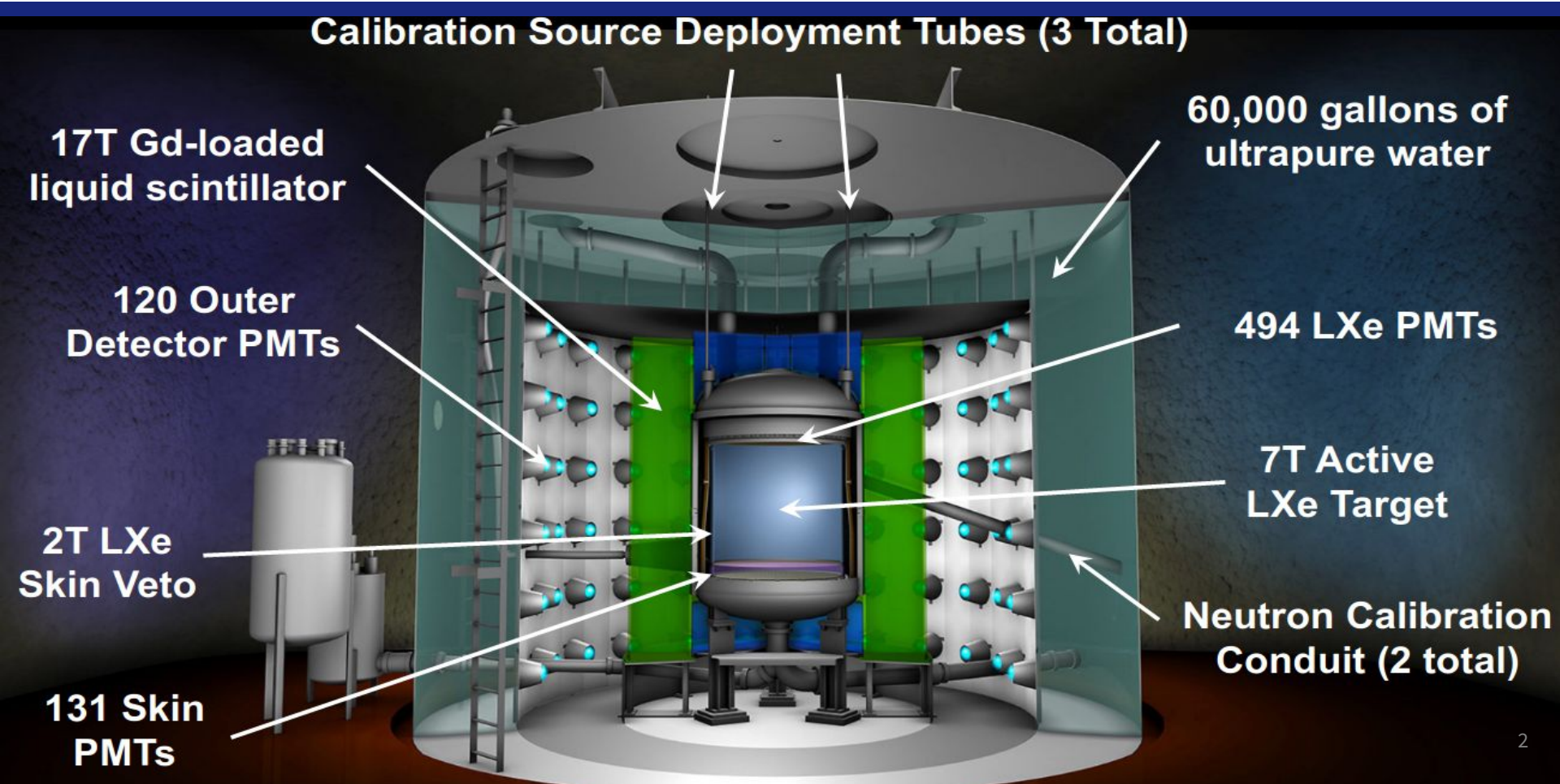
Science Run 1 WIMP Search & Liverpool Group

May 2023

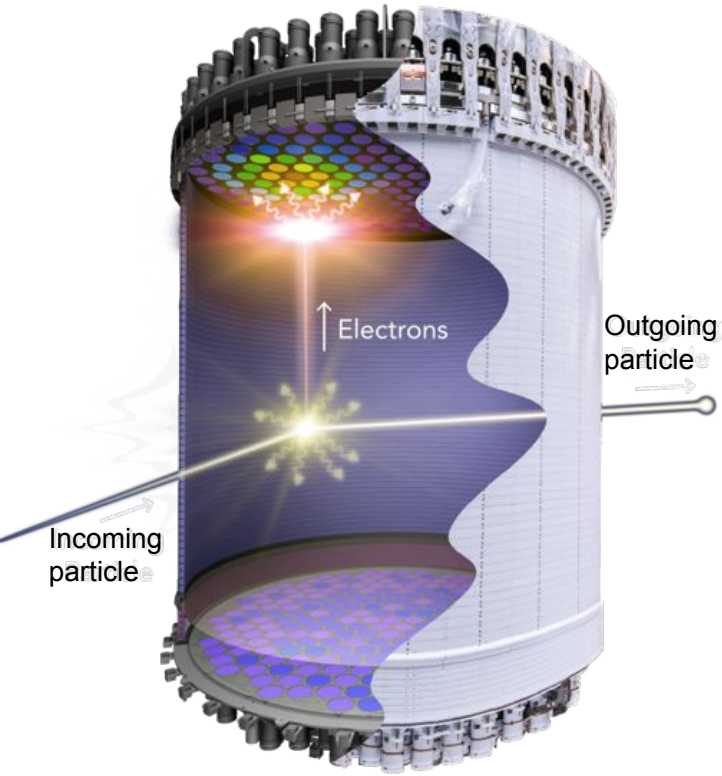
Ewan Fraser

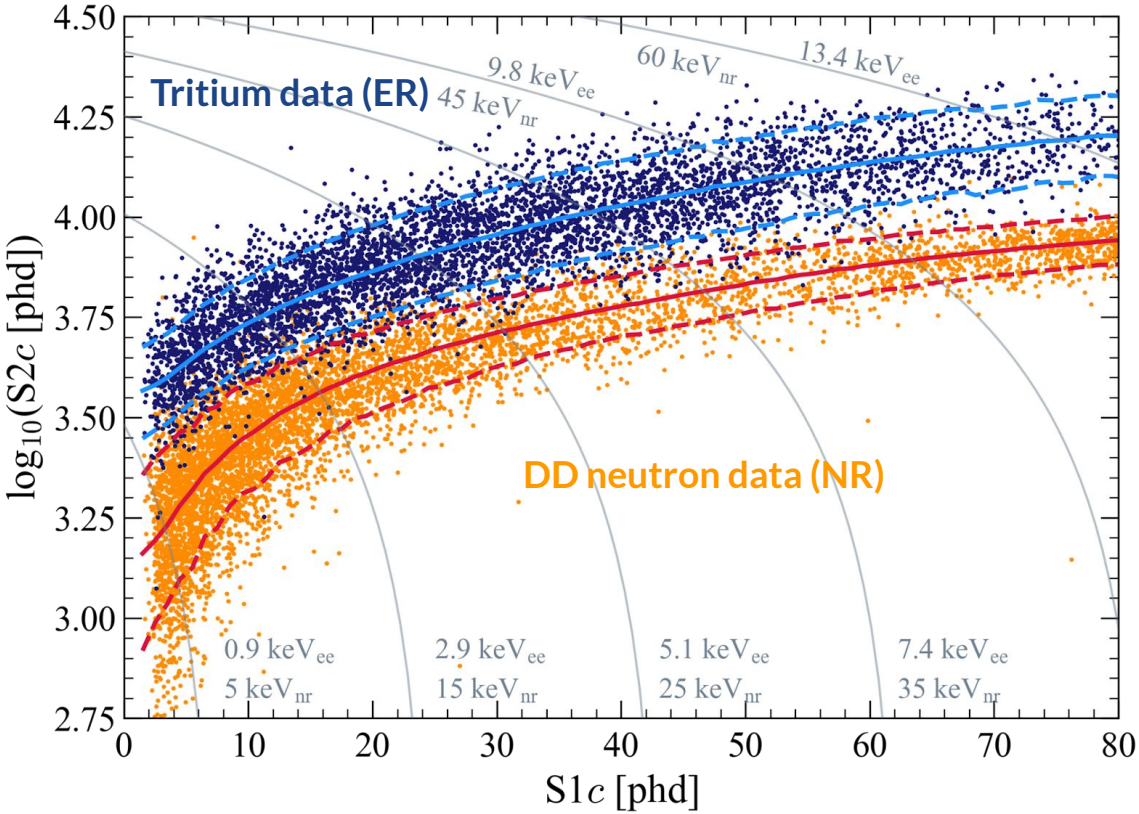
Masters student (PhD next year): Teagan Hall
PhD Students: Sam Woodford, Megan Carter
Postdoc as of Jan 2023: Ewan Fraser
Academic: Sergey Burdin

LZ - Experiment for Direct Detection of WIMP Dark Matter



TPC Principles





Electronic Recoil (ER) and Nuclear Recoil (NR) discrimination calibration

SR1 WIMP Search Analysis

SR1 Data collection: December 2021 - April 2022

Data Selection:

- ❑ Offline Data Quality Assessment ←
- ❑ Livetime impacting cuts
  - ❑ Hotspots, Muons, e^- trains

Data Analysis:

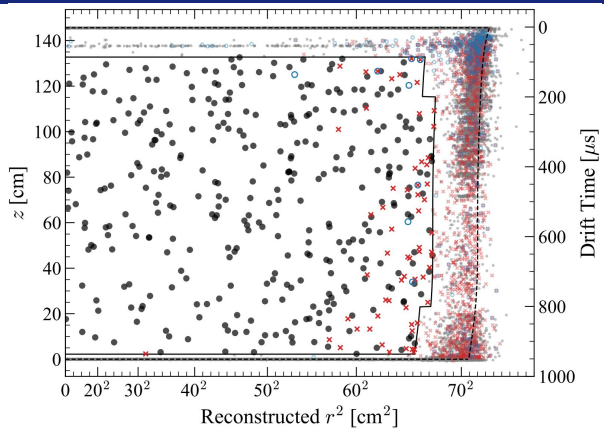
- ❑ ALPACA - LZ analysis framework

Physics cuts:

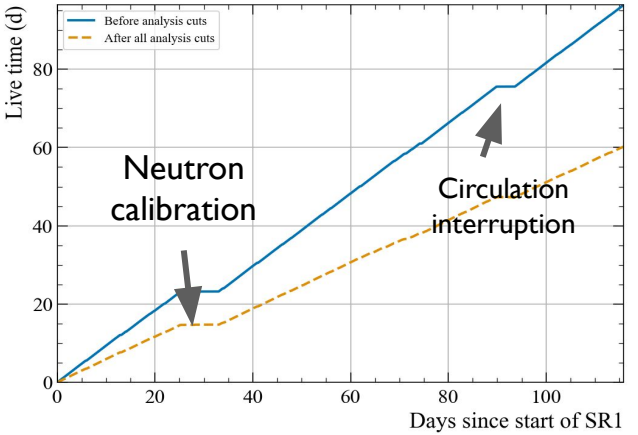
- ❑ Single Scatter
- ❑ Fiducial Volume
- ❑ Thresholds and Vetoes

Data purity:

- ❑ Cuts to remove accidental single scatters
  - ❑ Random pairing of Isolated S1s & S2s



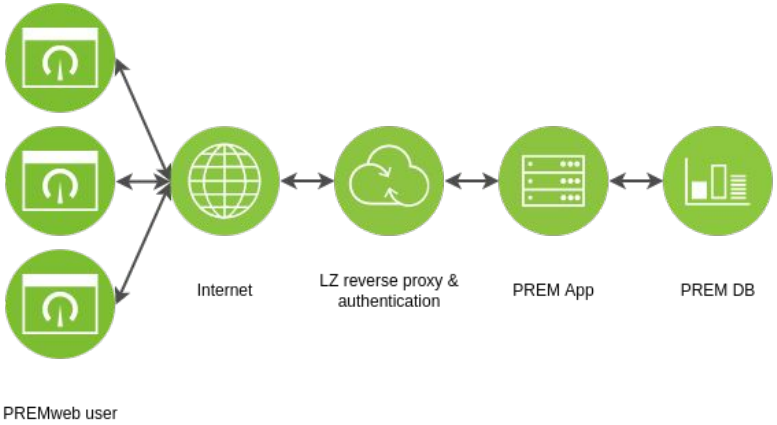
Fiducial Volume



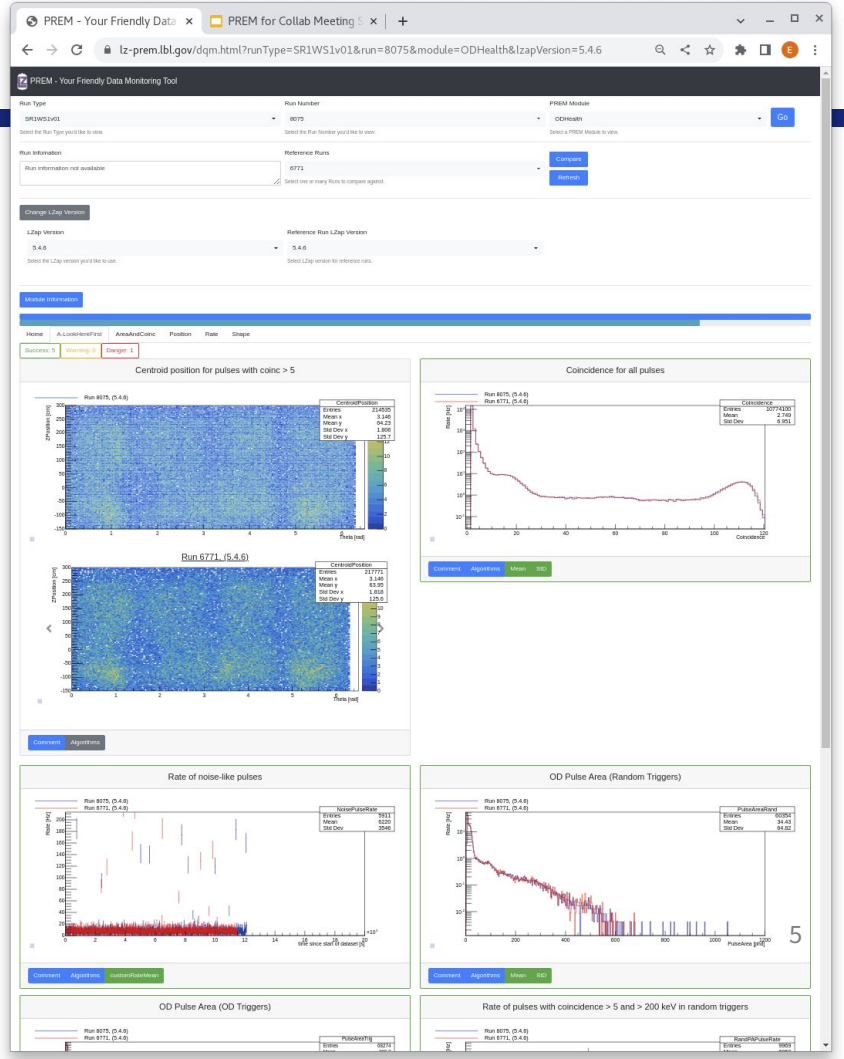
Livetime vs Calendar days

Physics Readiness Monitor

- Offline Data Quality Monitoring
- Containerised deployment on NERSC's SPIN2
  - MongoDB
  - NodeJS backend
  - Frontend using JSROOT
  - LZ Authentication + NGINX



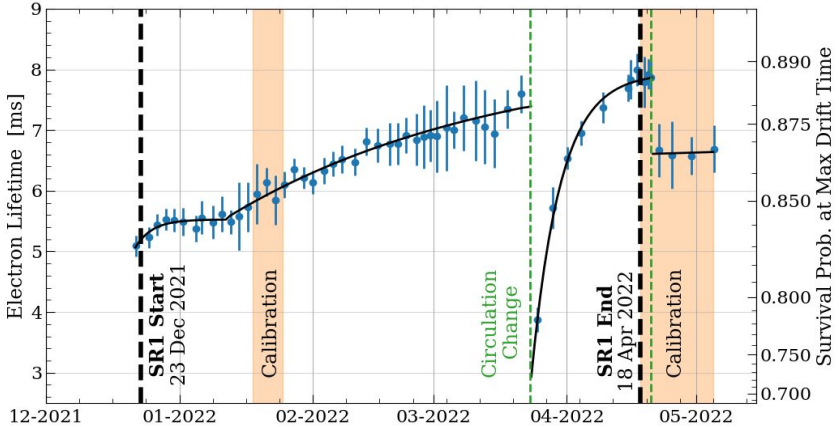
Network Diagram for Physics Readiness Monitor software stack



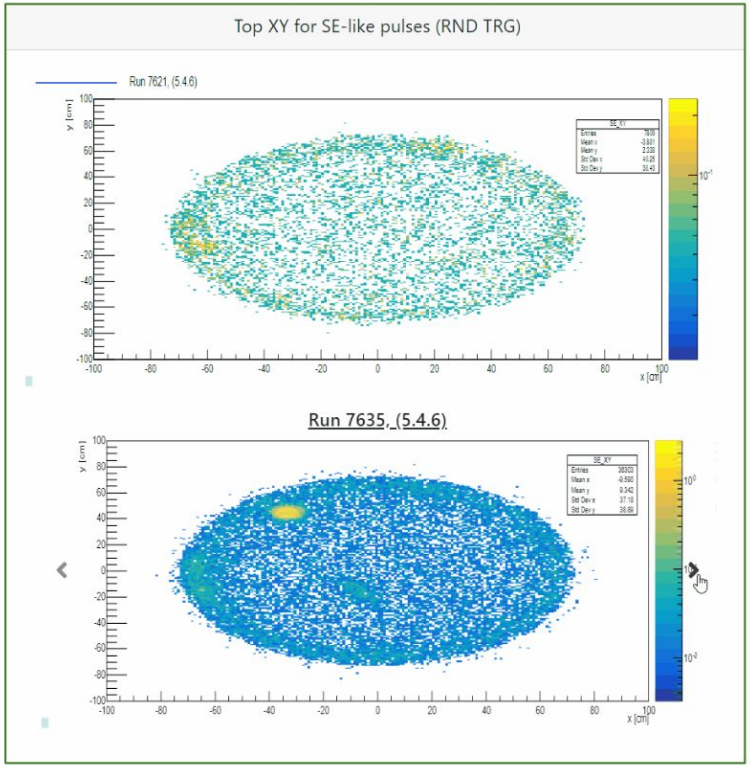
Physics Readiness Monitor

Offline Data Quality Monitoring:

- ❏ 1D and 2D comparisons to know good runs to identify and catalogue data quality defects.
- ❏ Long term trend monitoring of physical quantities.



Measure of LXe purity across SR1



TPC hotspots due to extraction region grid emission.

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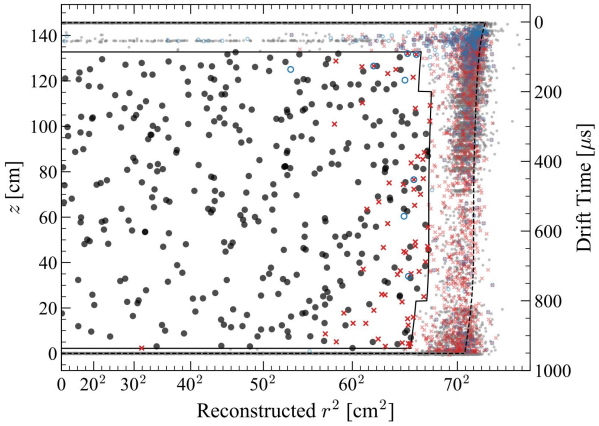
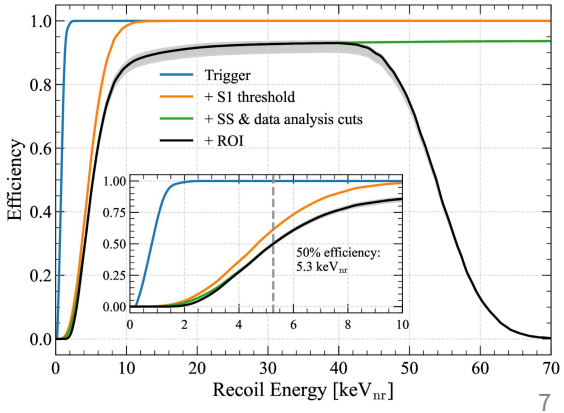


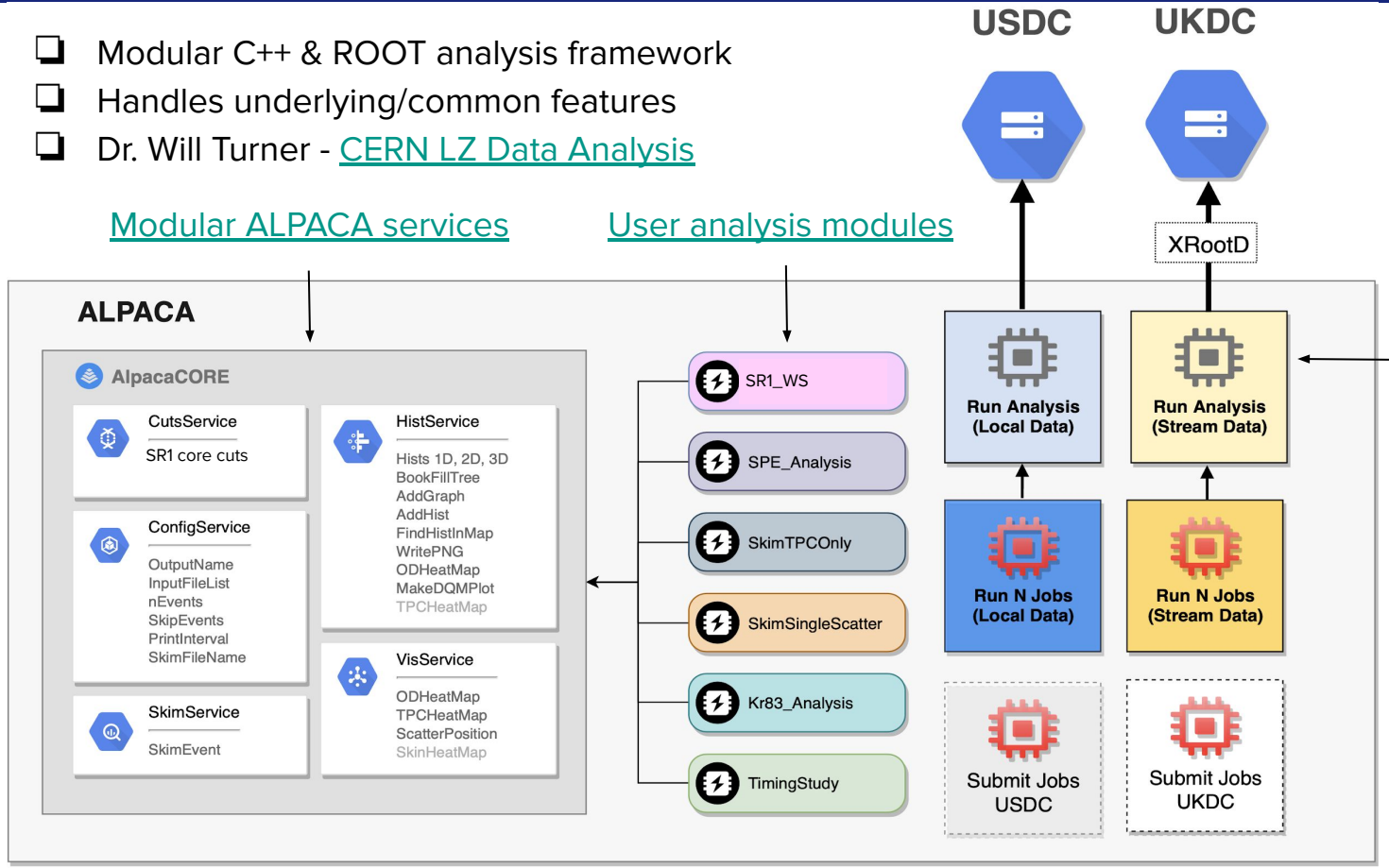
Fiducial Volume



Nuclear Recoil detection efficiency

ALPACA in Three Parts

- ❑ Modular C++ & ROOT analysis framework
- ❑ Handles underlying/common features
- ❑ Dr. Will Turner - CERN LZ Data Analysis



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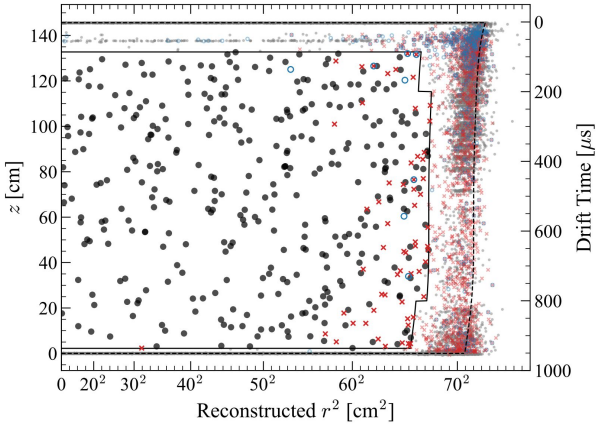

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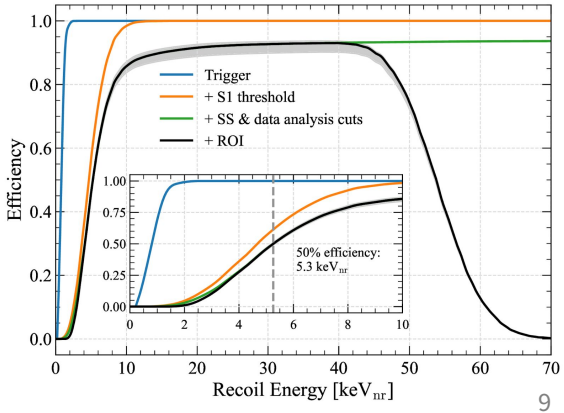
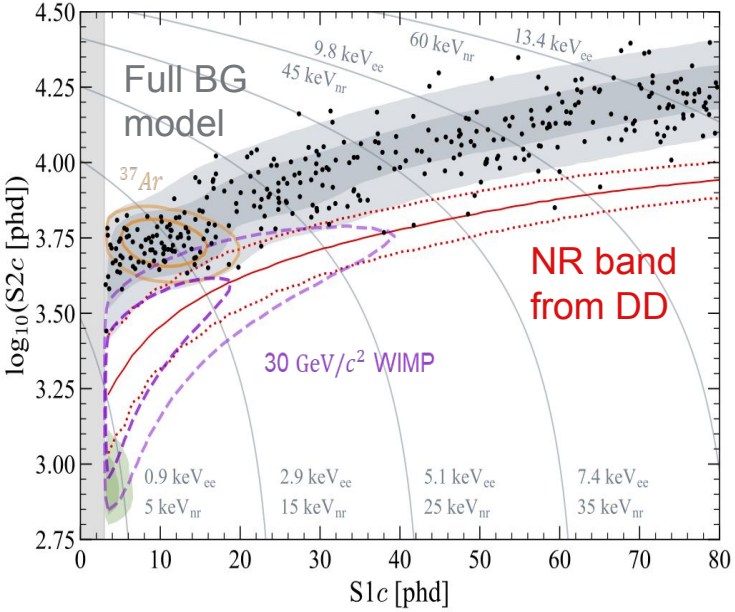


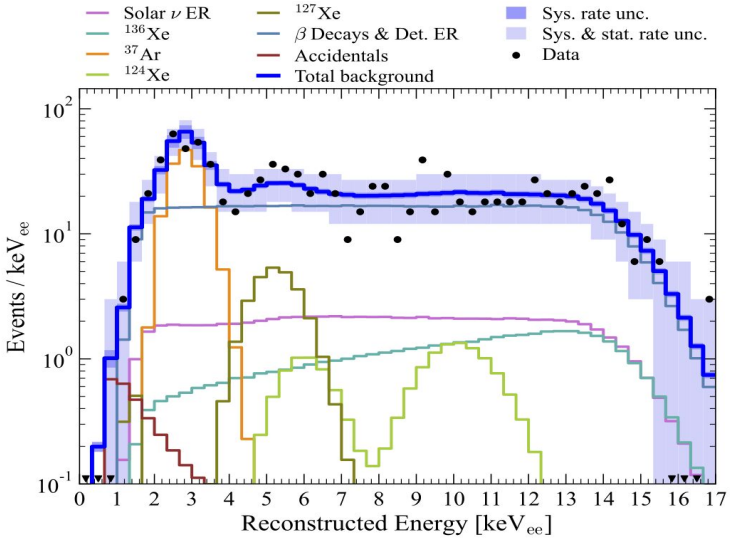
Nuclear Recoil detection efficiency

Backgrounds

To determine if a WIMP has been found:

- ❑ Simulate backgrounds due to radioactive decays.
- ❑ Initial estimates based on radiassays during detector assembly.
- ❑ Constrain background using “sideband analysis”.
- ❑ Fit simulated background PDFs to data (PLR with constraints).

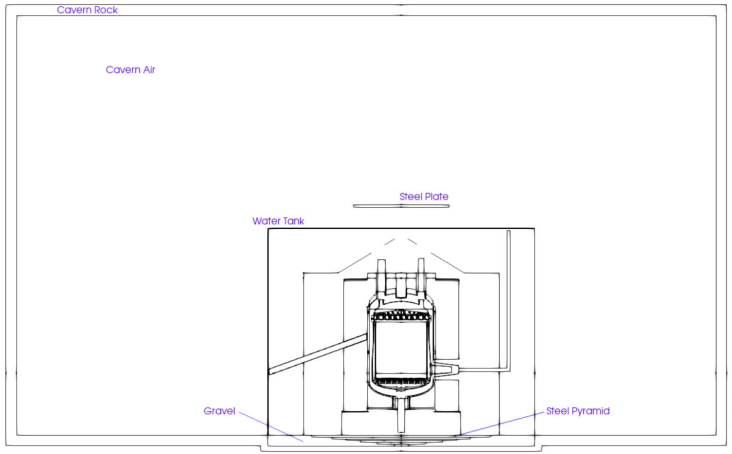




Source	Expected Events	Best Fit
β decays + Det. ER	218 ± 36	222 ± 16
ν ER	27.3 ± 1.6	27.3 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.2 ± 2.4	15.3 ± 2.4
^{8}B CEνNS	0.15 ± 0.01	0.15 ± 0.01
Accidentals	1.2 ± 0.3	1.2 ± 0.3
Subtotal	276 ± 36	281 ± 16
^{37}Ar	[0, 291]	$52.1^{+9.6}_{-8.9}$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

Constraining Cavern Rock Gamma Background

- Expect a few WS ROI Electronic Recoils from Cavern Rock Gammas over the course of LZ's lifetime.
- Important background for $0\nu\beta\beta$.
  - ~1/3 of counts in ^{136}Xe background table, significant background in ^{134}Xe.
- Measurement took place during commissioning. Empty water tank and Outer Detector.
  - Lack of shielding. kHz of rate expect from Cavern Rock Gammas (mostly low energy).
- Prior to Xe condensing, GXe target.
- GXe simulations used for signal PDFs, based on measurements of cavern rock activity.



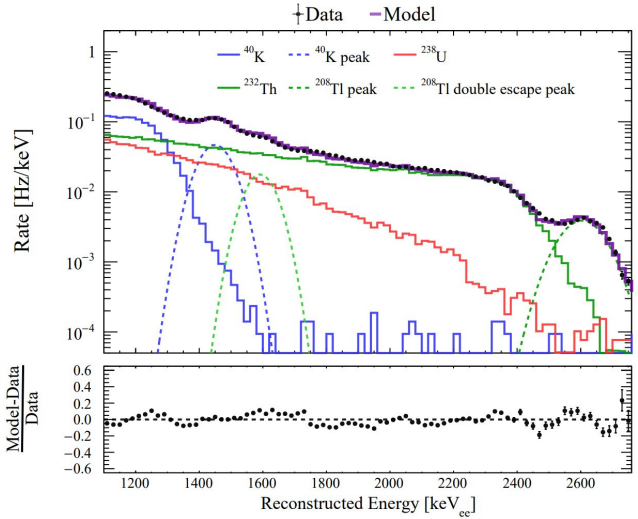


TABLE III. Fitted and predicted rates of cavern wall radioactivities, with the former derived from Figure 5.

Isotope/ Chain	Predicted Rate (Hz/keV)	Fitted Rate (Hz/keV)	Ratio (Fitted/ Predicted)
^{40}K	4.2 ± 1.1	2.79 ± 0.40	0.67 ± 0.20
^{238}U	3.9 ± 2.0	1.95 ± 0.53	0.49 ± 0.29
^{232}Th	6.1 ± 1.4	4.51 ± 0.43	0.74 ± 0.18

Found that rate predicted by simulation needed to be normalised by 0.65 ± 0.14.

Normalisation used to constrain Science Search simulations.

SR1 Backgrounds Paper.

Backgrounds

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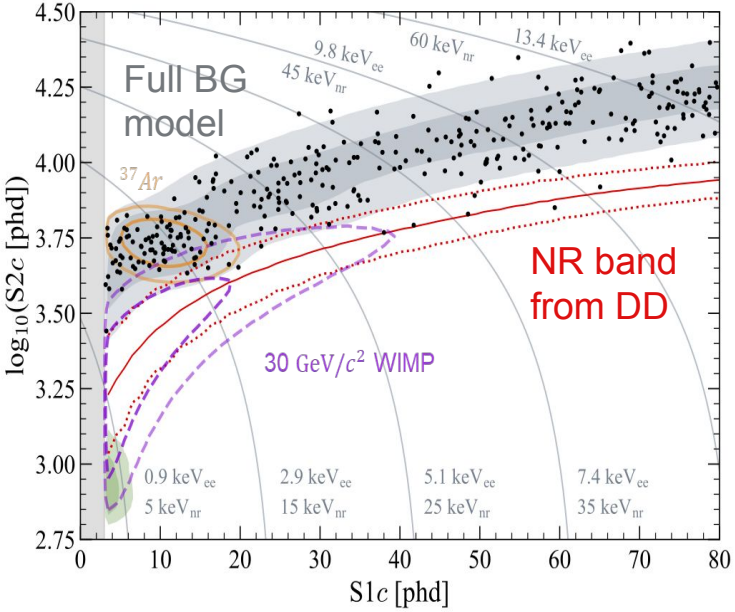

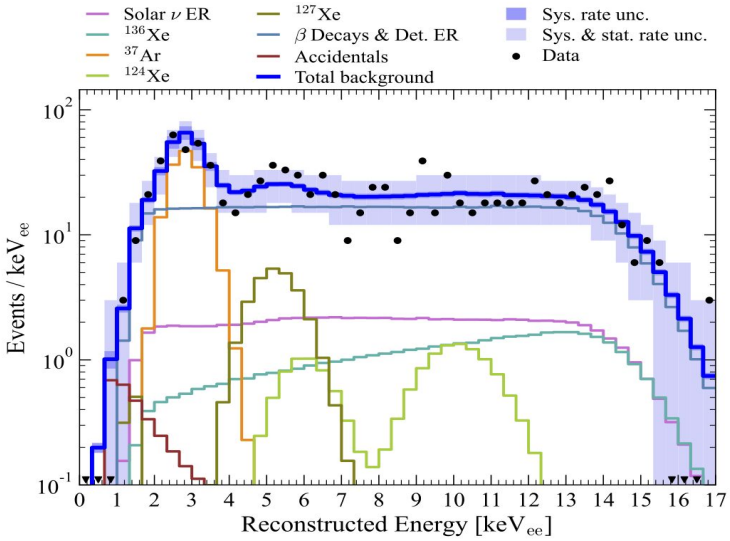

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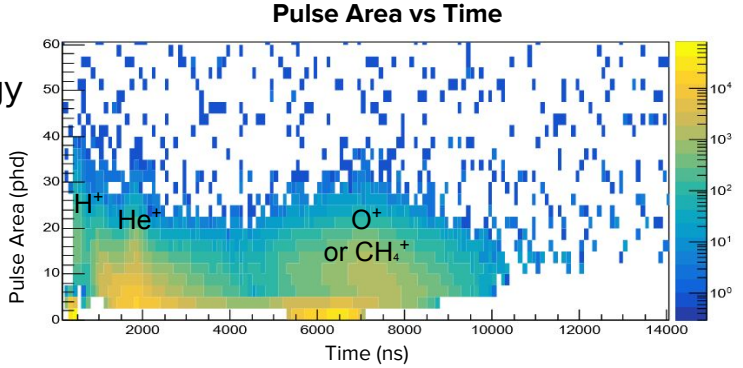
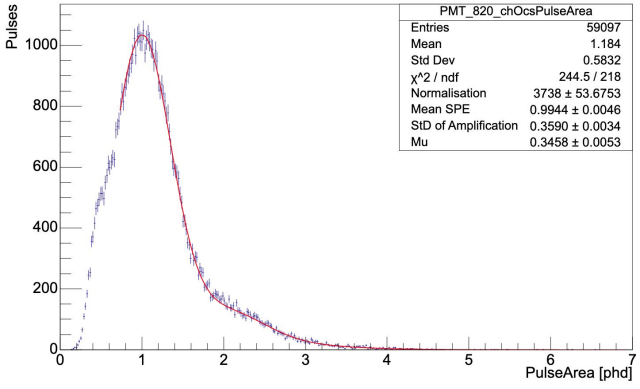
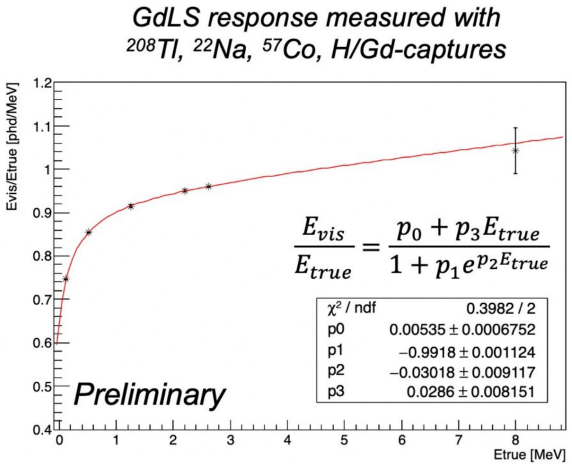
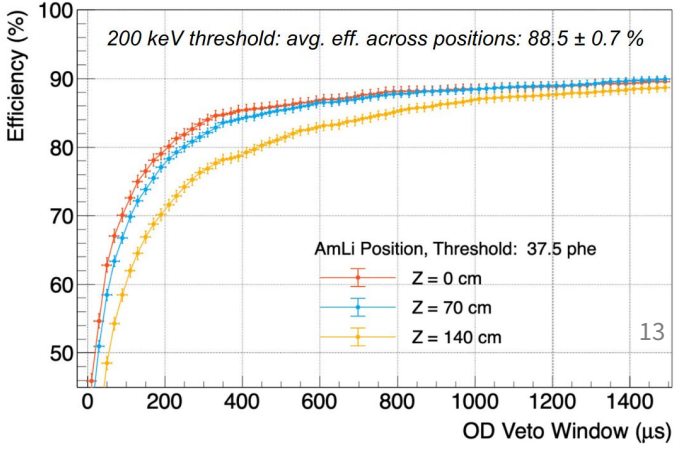
Outer Detector - Single Scatter Neutron Veto Efficiency

- Outer Detector PMT calibrations described in [LZ OD's Optical Calibration System paper]
  - Single Photoelectron calibration - how many photons does the OD see?
  - Measurement of PMT afterpulsing - PMT health
- Energy Calibration - Number of photons detected per MeV of energy
- Neutron veto efficiency:
  - How likely are we to veto a single scatter neutron?
  - Key for reducing neutron NR background WIMP search.



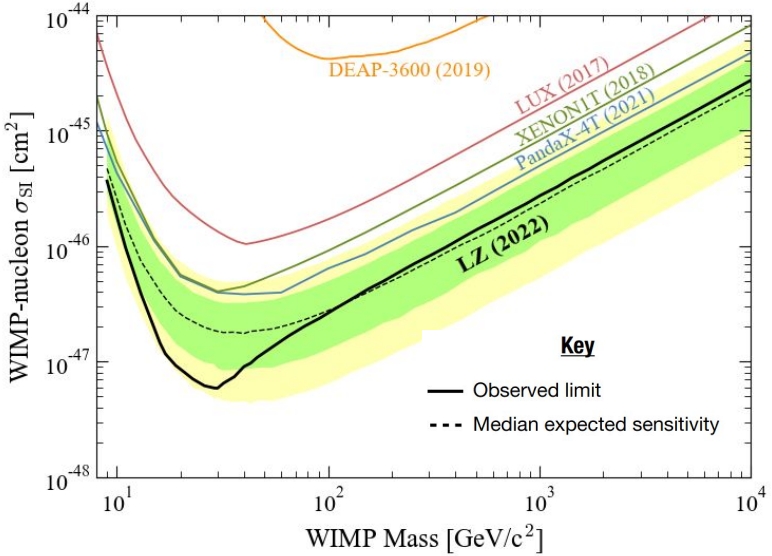


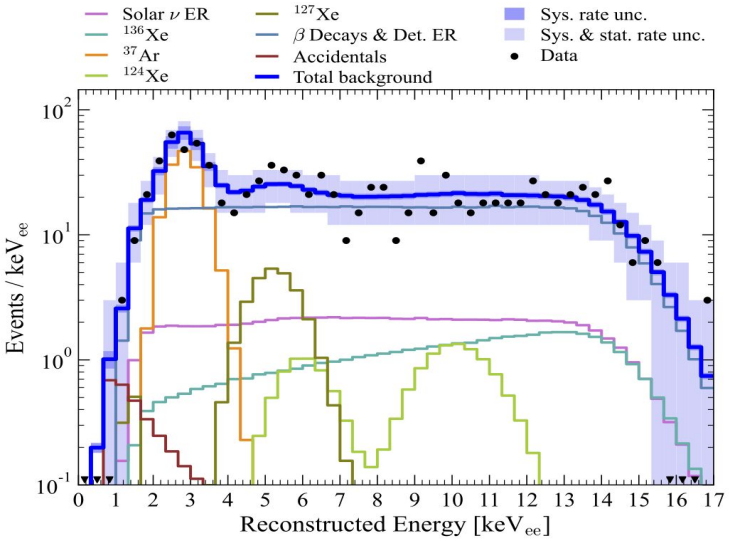




Science Run 1 - Result

- Above the smallest tested WIMP mass of 9 GeV/c^2 , the best-fit number of WIMP events is zero.
- Data are thus consistent with the background-only hypothesis.
- Excluding Spin-Independent WIMP-nucleon cross sections above 6.5 × 10^{-48} cm^2 at the 90 % confidence level.





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Summary

- ❏ LZ's construction and commissioning commissioning completed Winter 2022.
- ❏ LZ's 60 liveday Science Run 1 found no evidence of WIMPs. SR1 WIMP Search Result.
  - ❏ Excluding Spin-Independent WIMP-nucleon cross sections above 6.5×10^{-48} cm^2 at the 90 % confidence level.

University of Liverpool's LZ group responsible for/participated in:

Hardware:

- ❏ Outer Detector's Optical calibration system - OCS Paper
- ❏ PMT and Outer Detector installation

Software:

- ❏ LZ's analysis package: ALPACA - Data analysis seminar
- ❏ Offline Data quality monitoring tool: Physics Readiness Monitor

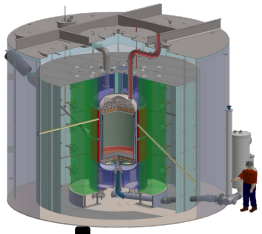
Calibration:

- ❏ Outer Detector PMT's and Energy Scale

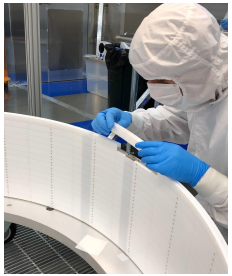
Background constraints and analysis:

- ❏ Cavern Rock Gamma ER background - SR1 Backgrounds Paper
- ❏ Neutron (NR background) Veto efficiency using Outer Detector.

LZ Timeline up to SR1



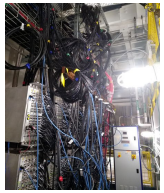
March 2017
CD3 and TDR



December 2018
FFR Assembly

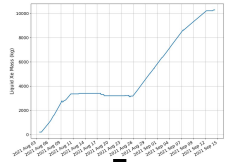
Spring 2019
Grid Construction

October 2019
Moved Underground



Autumn 2020
Electronics
Installation

June 2021
OD Fill



August 2021
Xenon Fill

2017

2018

2019

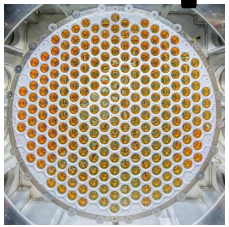
2020

2021

2022
Science!

May 2018
Cryostat arrives

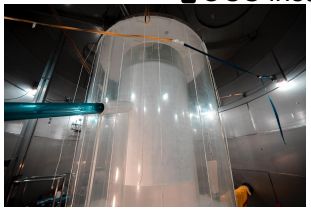
December 2018
January 2019
PMT arrays arrive



August 2019
TPC Complete

March 2020
HV connected

Early 2021
OD Complete
OCS installed



Autumn 2021
Commissioning

2021
Kr Removal

Sam!

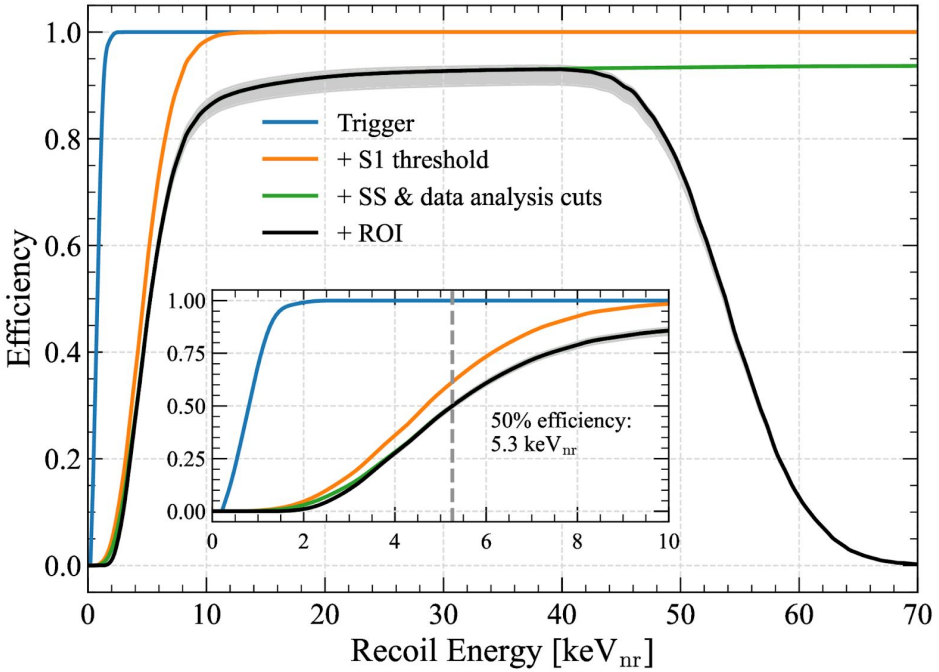
SR1 Goals and Result

Goals for SR1

1. Demonstrate physics capability
2. Demonstrate competitive sensitivity

Key Info

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



Outer Detector Neutron Tagging

- 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