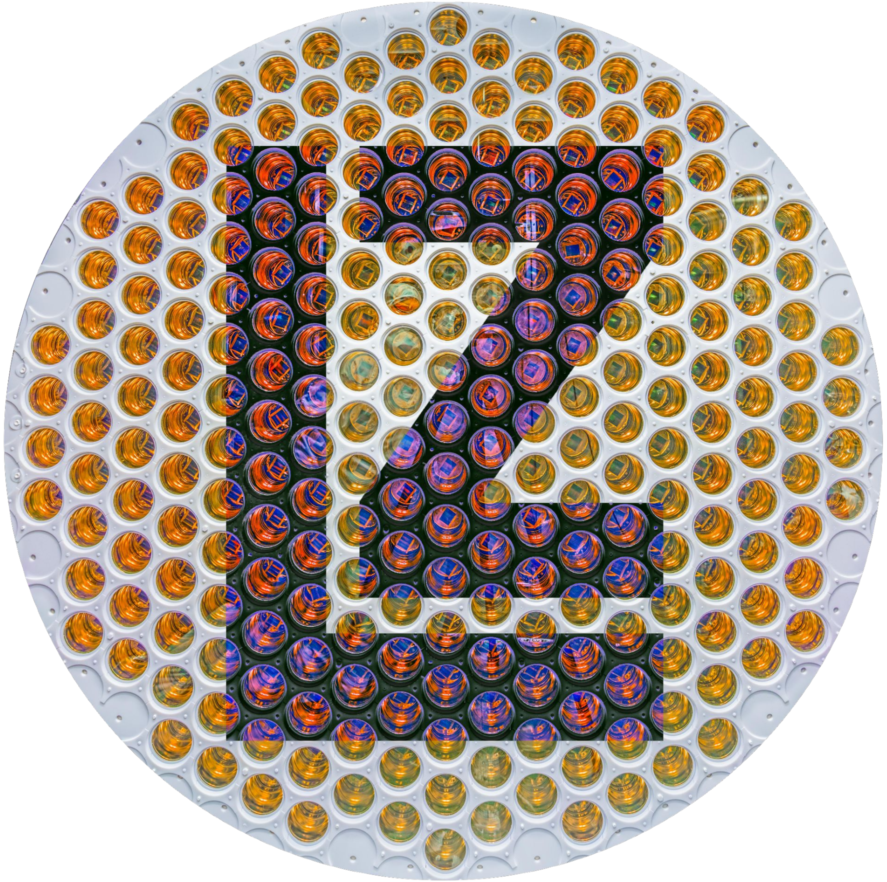
First WIMP Search Results from LZ and Outlook

Hao Chen (LBNL)

On behalf of LZ Collaboration



Dark matter

Evidence for dark matter:

- galaxy rotation curves
- cosmic microwave background
- Bullet cluster collision
- And more

All from **gravitational** and **collective** effects.

↓

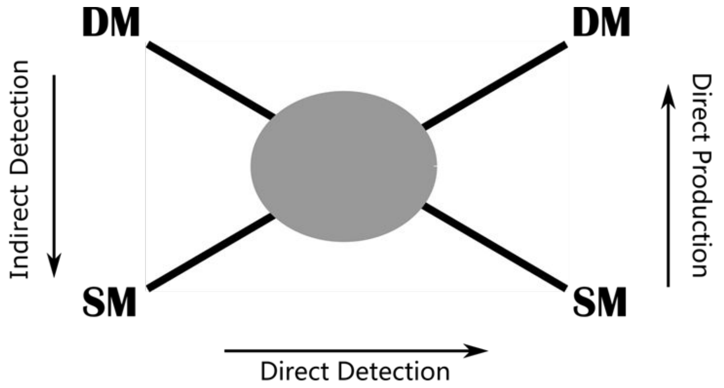
Strongest evidence for beyond standard model

↓

Many theoretic **candidates** with mass range from 10^{-22} eV to 10 times sun mass.

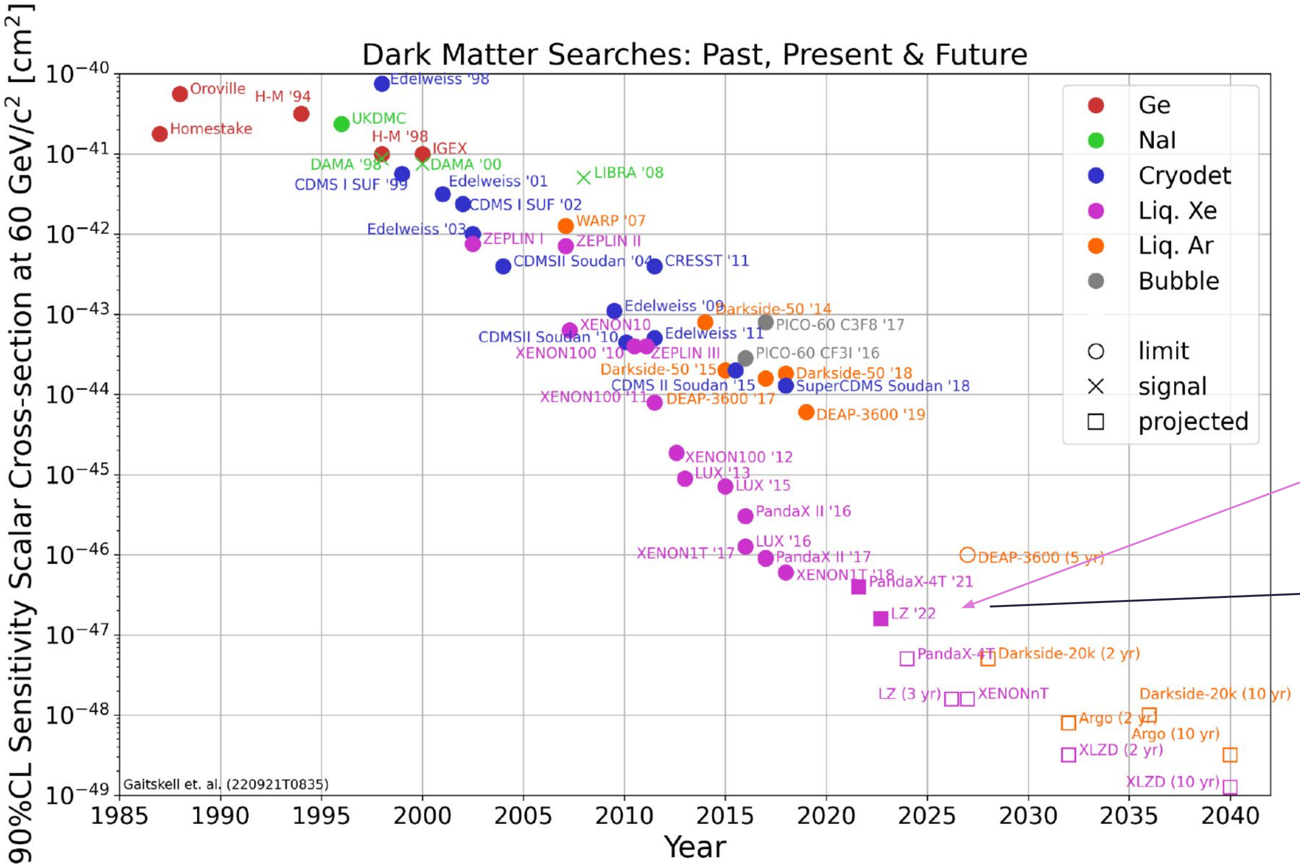
- **Weakly interacting massive particles (WIMP)** ← **LZ's main target**
- Axion
- Many others, see arXiv:2211.09978

What is it? In the sense of elementary particle



Weak interaction → Rare events search

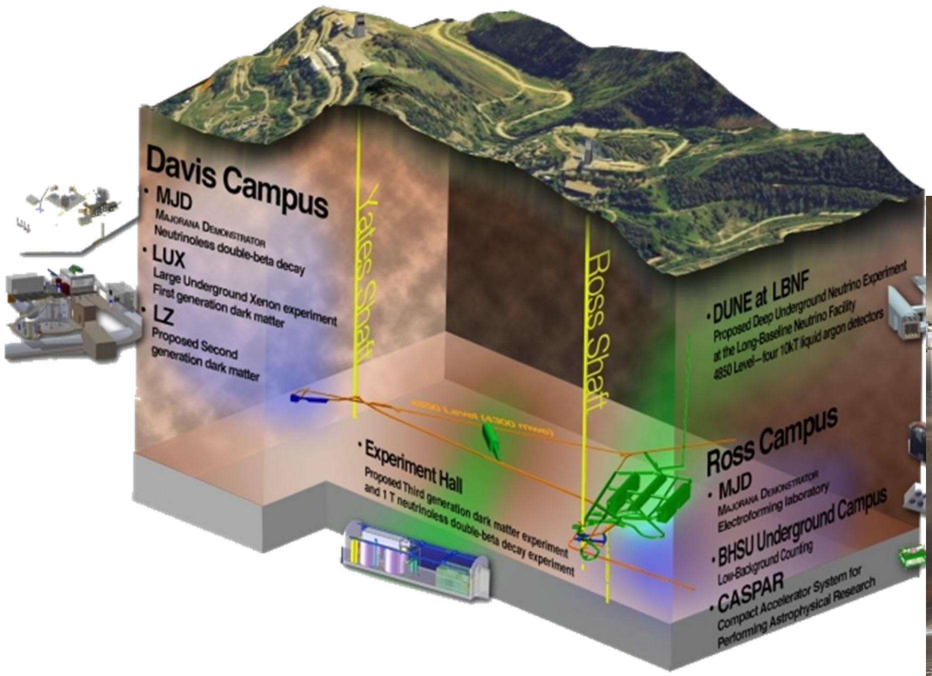
Direct detection of WIMP



This talk

1 kg xenon needs 150 years to see one 60 GeV WIMP

Sanford Underground Research Facility (SURF)



LZ at SURF in Lead, South Dakota, USA

Shielded by an overburden of 4300m water-equivalent
Muon flux reduced by O(10^6)

@lzdarkmatter

https://lz.lbl.gov/

LZ (LUX-ZEPLIN) Collaboration, 37 Institutions

- 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
- 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 Sydney
- University of Texas at Austin
- University of Wisconsin, Madison

US UK Portugal Korea Australia

250 scientists, engineers, and technical staff

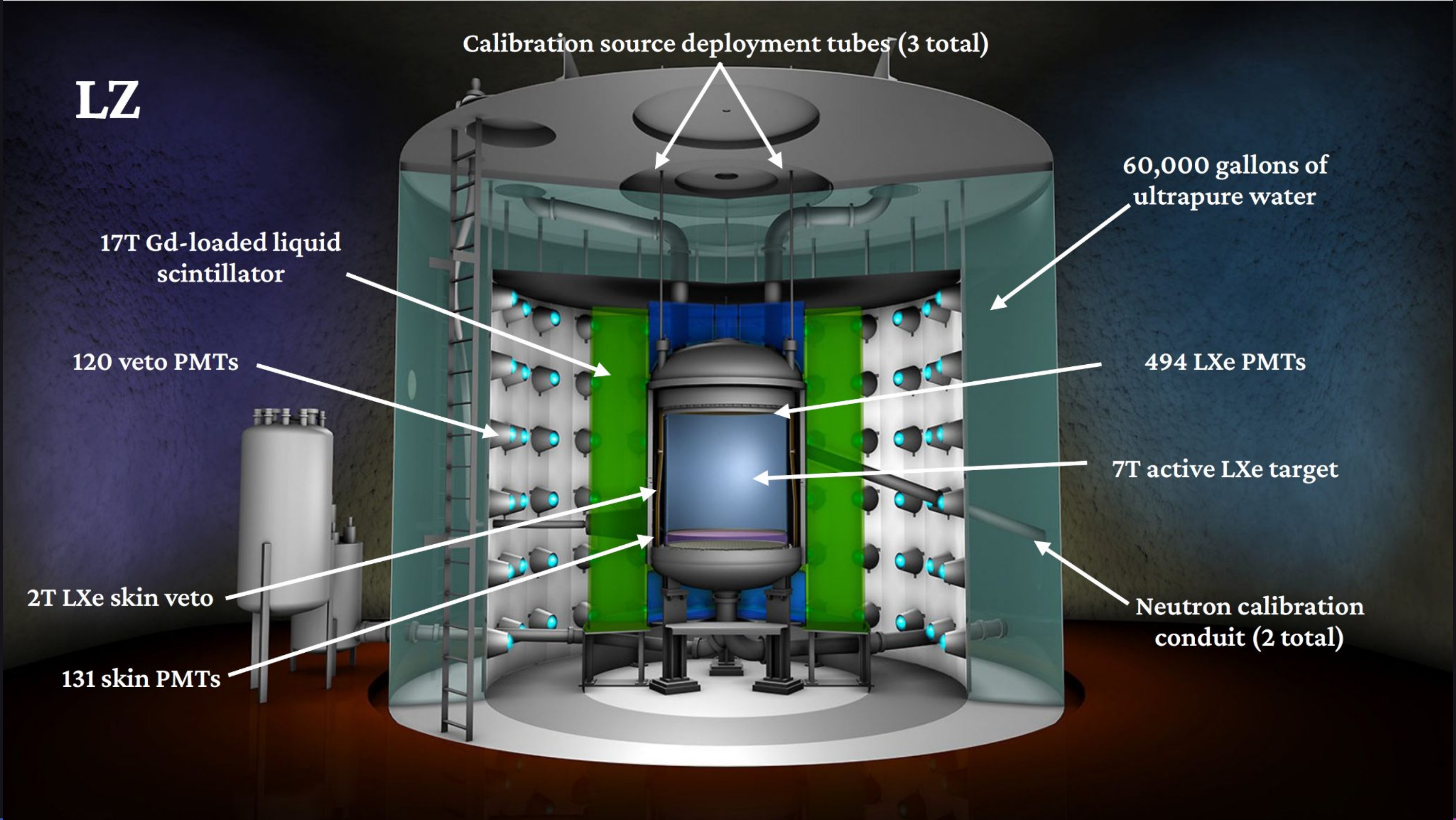
Science and Technology Facilities Council

FCT Fundação para a Ciência e a Tecnologia

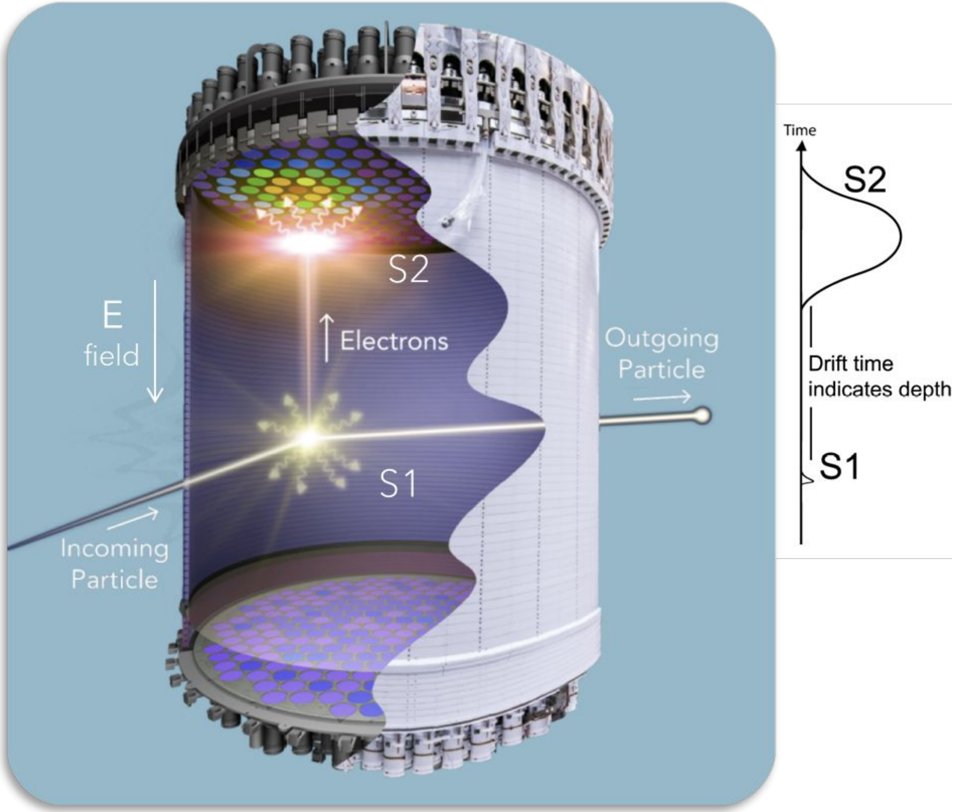
Sanford Underground Research Facility
South Dakota Science and Technology Authority

ibs Institute for Basic Science

Thanks to our sponsors and participating institutions!


LZ
Calibration source deployment tubes (3 total)
60,000 gallons of ultrapure water
17T Gd-loaded liquid scintillator
120 veto PMTs
494 LXe PMTs
7T active LXe target
2T LXe skin veto
Neutron calibration conduit (2 total)
131 skin PMTs

Main detector: the dual-phase time projection chamber

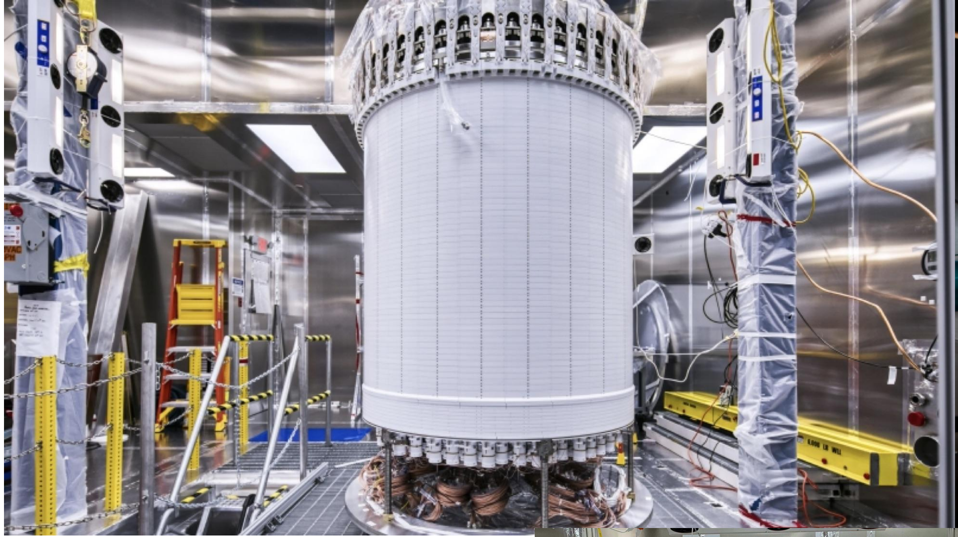


Detector mechanism:

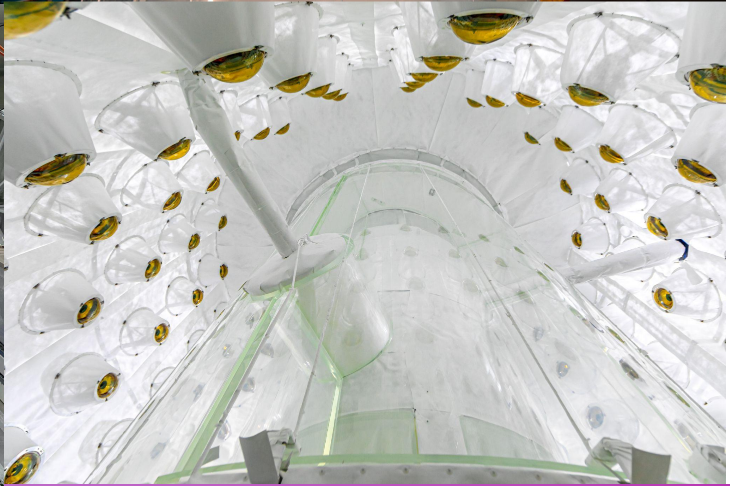
- Prompt scintillation photons→ “S1”
- Ionization→electroluminescence→ “S2”
- Energy reconstruction from S1/S2 size
- Position reconstruction from drift time and PMT hit pattern

LZ specs:

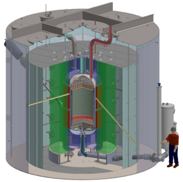
- 1.5 m in diameter and height
- 7 t active xenon (5.5 fiducial)
- 494x 3” PMTs in two arrays
- 4 wire mesh electrodes + Ti field cage for uniform electric fields



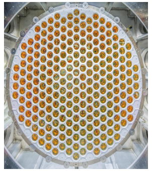

LZ for real

LZ timeline



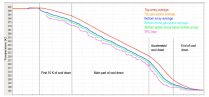
CD3 and TDR



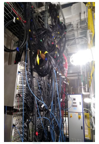
PMT arrays arrive

TPC Complete

Underground, Oct 2019

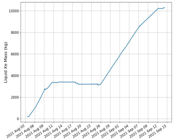


Cold gas, March 2021



Electronics Fall 2020

Kr Operation Jan-Aug 2021



Xe Fill Aug-Sep 2021

First Result

Science Running!

2017

2018

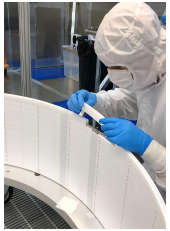
2019

2020

2021

2022

Cryostat arrives



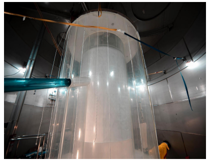
FFR Assembly

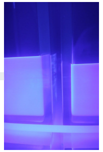
Grids

Circ Test July 2020

Sealed Up March 2020

OD Construction Winter 2020-2021





OD Fill June 2021

Commissioning Fall 2021

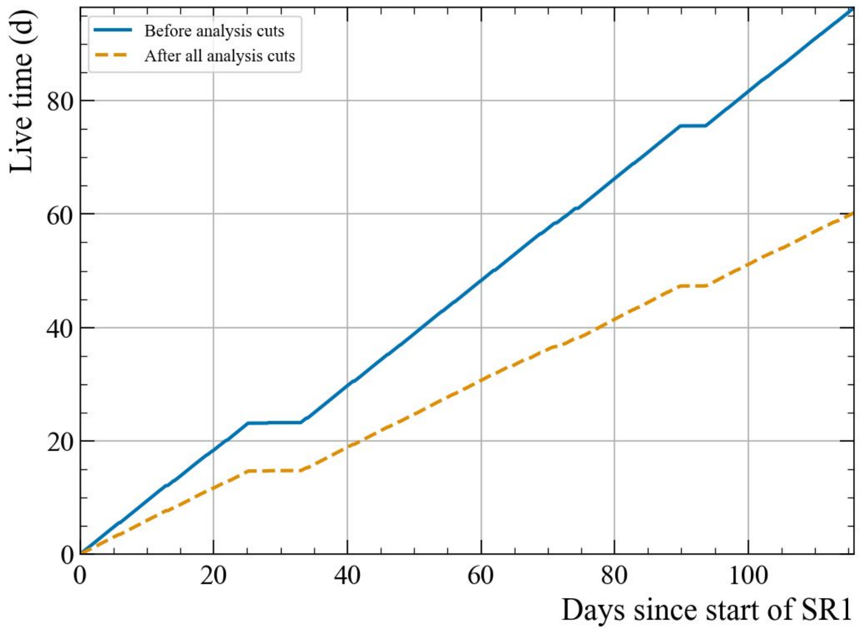
First science run (SR1)

Goal: Demonstrate physics capability of the LZ detector

Key parameters during this run:

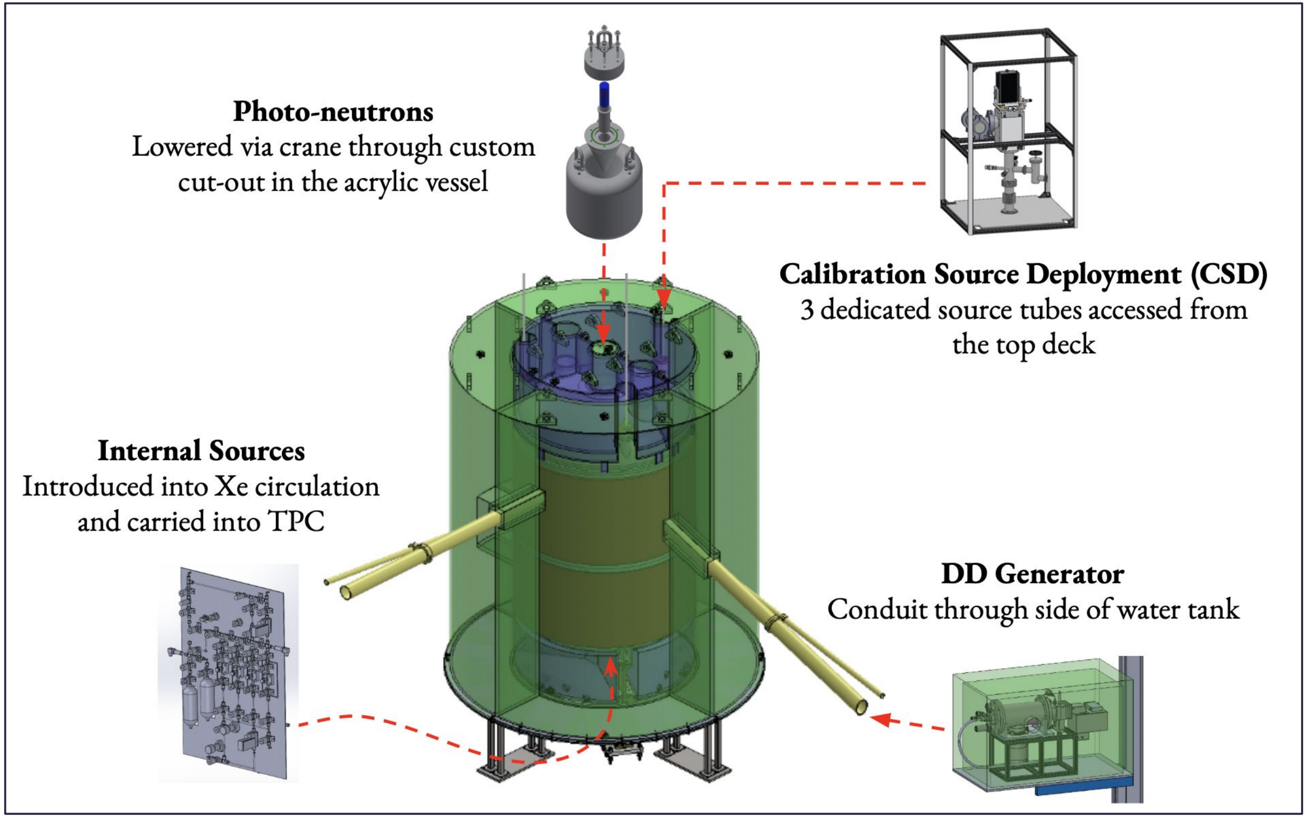
- Data taken starts 23 Dec 2021
- 5.5 t fiducial mass
- Drift field: 193 V/cm
- Gas extraction field: 7.3 kV/cm at center
- 174.1 K (at the TPC bottom) and 1.791 bar with <0.2% fluctuation
- Continuously purified at 3.3 t/day through a hot getter system
- Electron lifetime between 5000 μs and 8000 μs, much longer than the 951 μs maximum drift time in the TPC

LZ detector reached the expected condition, it was stable during SR1.

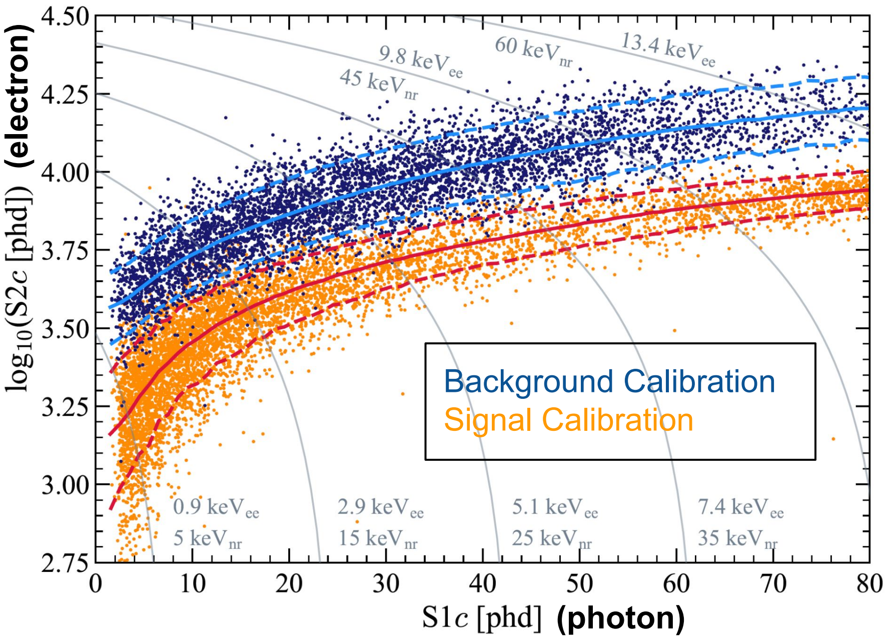


Understand the tool → calibration

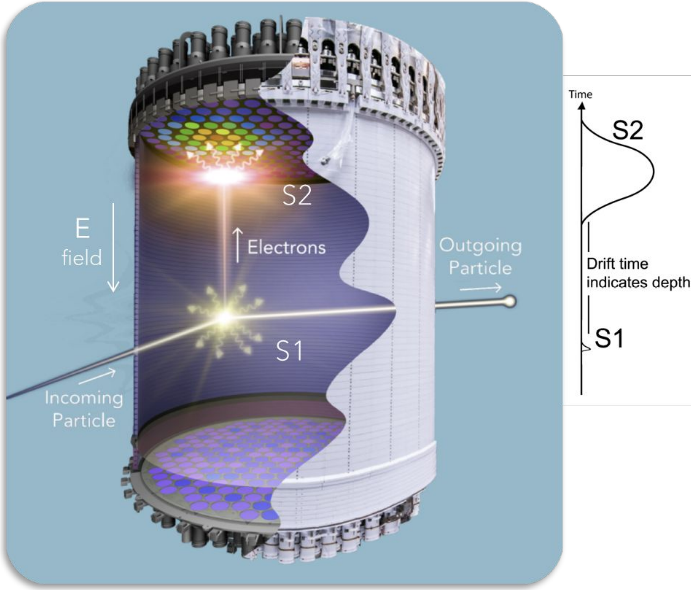
- **Neutron sources:** DD, AmLi, AmBe, YBe
- **Injected sources:** CH_3T, ^{83m}Kr, ^{131m}Xe, ^{220}Rn
- **External gamma sources:** ^{57}Co, ^{22}Na, ^{228}Th, ^{54}Mn
- Additionally, background (e.g. alphas and cosmics), used for: energy scale calibration and other purposes



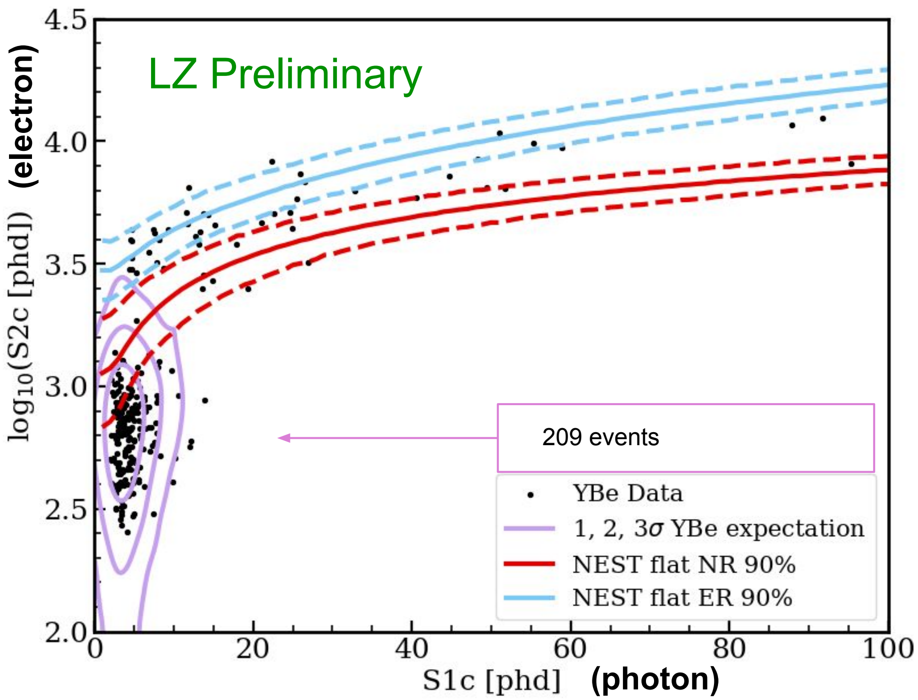
Detector response



Powerful tool to remove beta/gamma background



Low-energy signal calibration



YBe expectation based on geant 4.10.3.2 and NEST 2.3.10

Yttrium-beryllium photoneutron source:

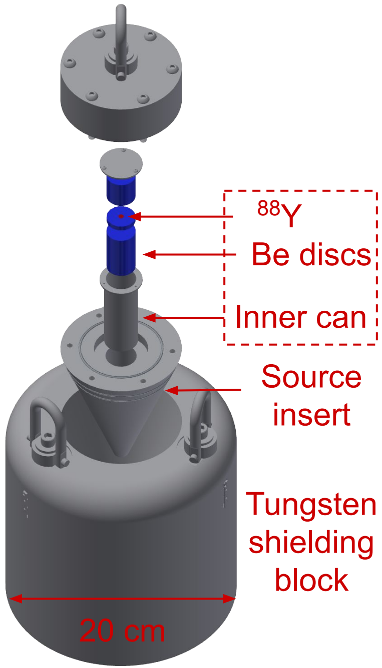
$$^{9}\text{Be} + \gamma \rightarrow {}^{8}\text{Be} + n$$

Q value = -1.667 MeV
Neutron energy: ~152 keV

Energy deposited in liquid xenon < 4.6 keV

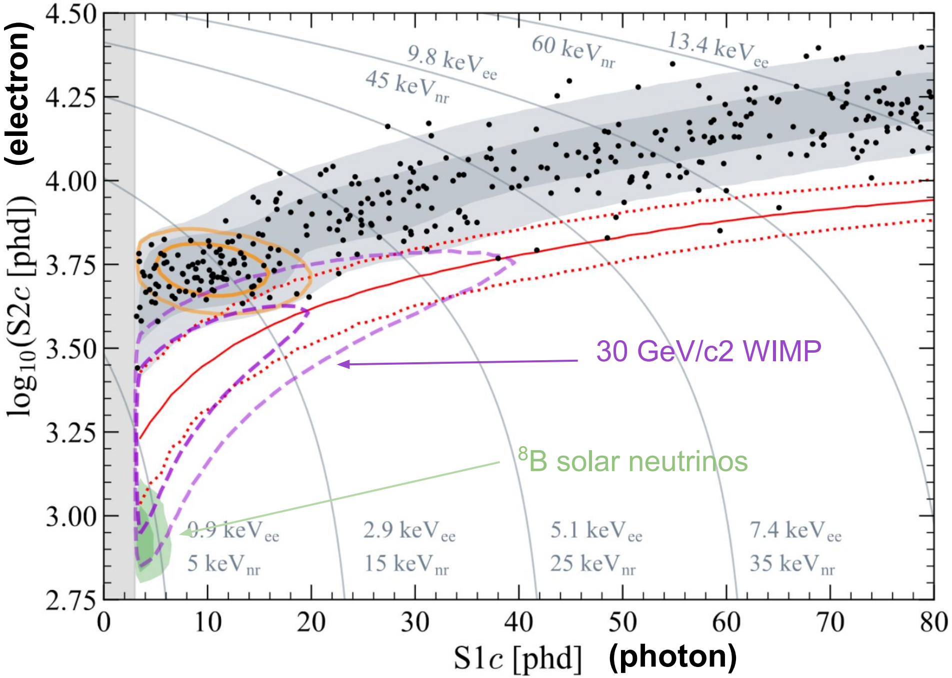
What we get:

- Demonstrate LZ's sensitivity to low energy WIMP signals.
- Calibrate the detector response for ^{8}B solar neutrinos and < 10 GeV dark matter.



WIMP-search data

WIMP-search events (black points) after all analysis cuts



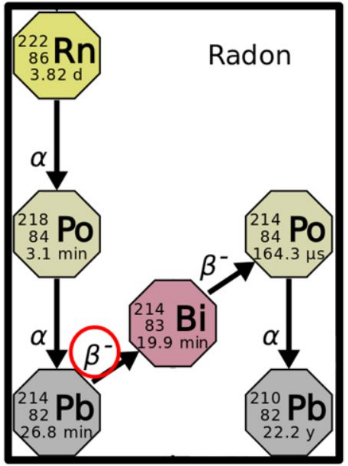
Source	Expected Events	Fit Result
^{214}Pb	164 ± 35	-
^{212}Pb	18 ± 5	-
^{85}Kr	32 ± 5	-
Det. ER	1.4 ± 0.4	-
β decays + Det. ER	215 ± 36	222 ± 16
ν ER	27.1 ± 1.6	27.2 ± 1.6
^{127}Xe	9.2 ± 0.8	9.3 ± 0.8
^{124}Xe	5.0 ± 1.4	5.2 ± 1.4
^{136}Xe	15.1 ± 2.4	15.2 ± 2.4
^{8}B CEνNS	0.14 ± 0.01	0.15 ± 0.01
Accidentals	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

"Background Determination for the LUX-ZEPLIN (LZ) Dark Matter Experiment", arXiv:2211.17120

Understand the enemy→background in SR1

Radon daughters:
- Emanate from detector material
- Hard to be tagged

Mitigation: clean, purification, discrimination



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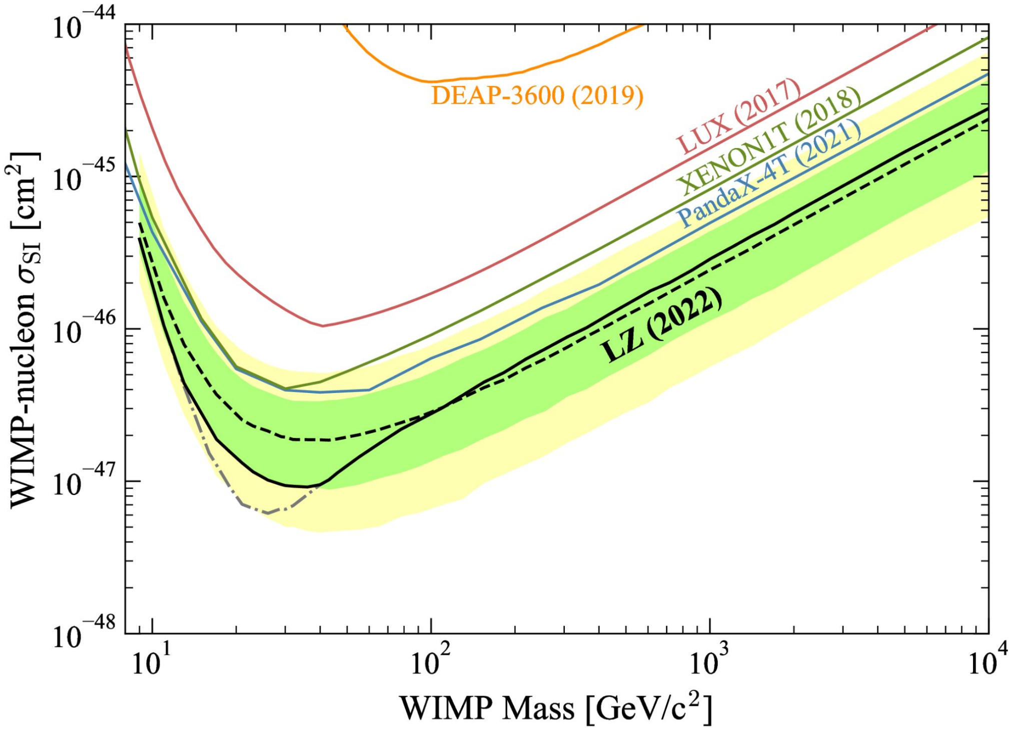
Neutron: same detector response as WIMP! <0.2 in SR1

Mitigation:
- Passive shielding
- Active neutron veto: measures 89+/-3% tagging efficiency

Other leading backgrounds: ^{85}Kr, ^{37}Ar, solar neutrinos

First WIMP search result from LZ



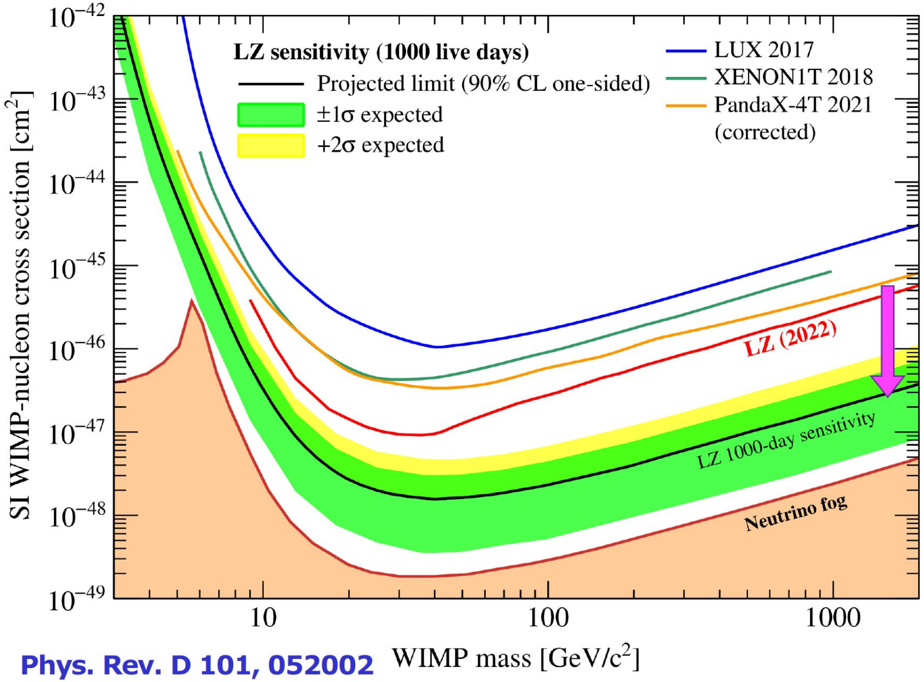
- Consistent with a background-only hypothesis,
- Setting new limits on spin-independent WIMP-nucleon for WIMP masses above 9 GeV/c^2
- arXiv:2207.03764 (accepted in PRL)

- Frequentist, two-sided profile-likelihood-ratio (PLR) test statistic
- Power constrained
- Followed conventions of Eur.Phys.J.C 81 (2021) 10, 907

The next step of LZ

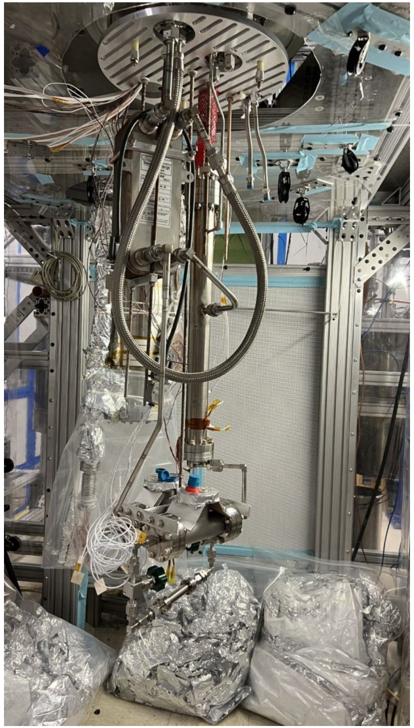
- Next science run started, with real discovery potential !
- Broad science program:
  - Low-threshold searches
  - WIMP EFT searches
  - Non-WIMP DM candidates
  - Astrophysical neutrinos
  - $0\nu\beta\beta$ of ^{136}Xe
  - And more

❏ XLZD: LZ and XENONnT formed a consortium to build the ultimate liquid xenon dark matter detector



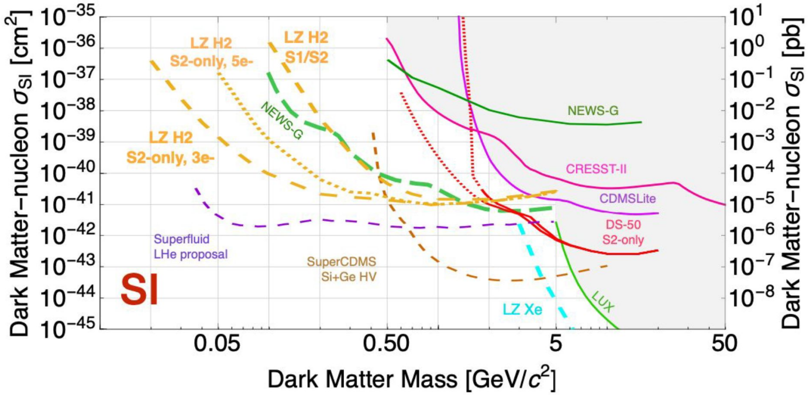
Phys. Rev. D 101, 052002

R&D for possible upgrade

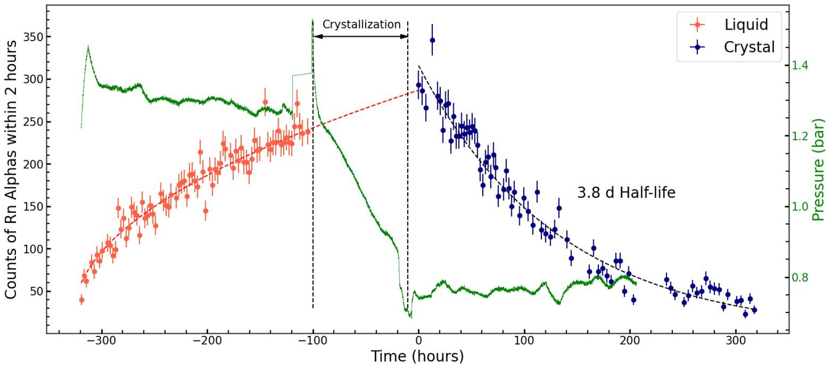


Improved Rn removal@SLAC

HydroX: H or He doped xenon for low mass detection@LBNL, SLAC and UCSB

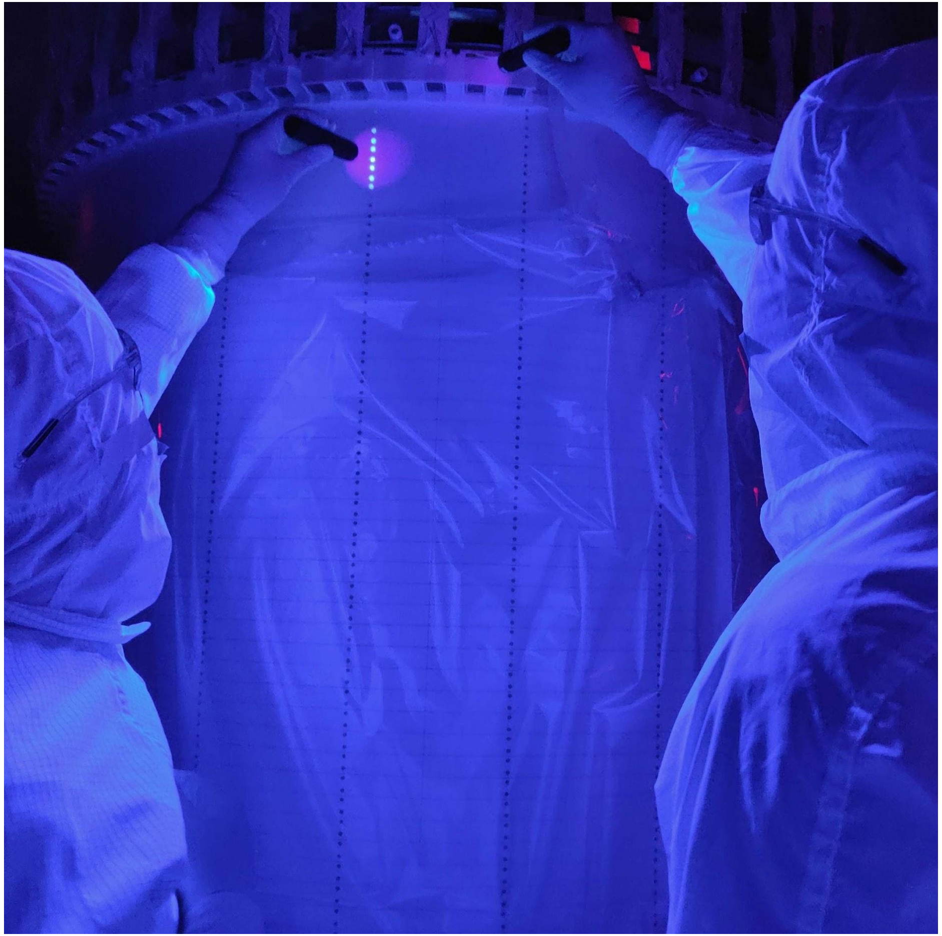


CrystaLiZe: freeze xenon to exclude radon@LBNL



Summary

- LZ is operating and taking high quality physics data
  - All detectors are performing well
  - Backgrounds are within expectation
- With its first run, LZ has achieved world-leading WIMP sensitivity
- Broad physics program still lies ahead for LZ
- Exciting R&D in progress to improve xenon dark matter searches



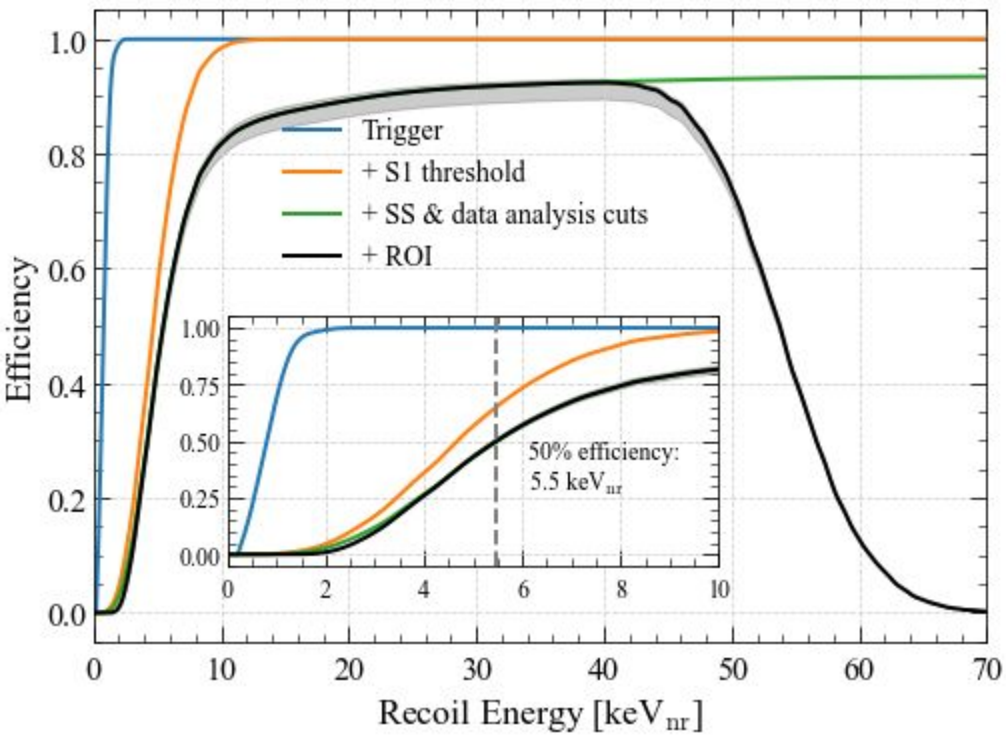
Backup

Data Selection

Single scatter: 1 S1 + 1 S2, one interaction vertex
S1 & S2 Accidentals Cuts: remove events whose S1 or S2 is not consistent with a real event (shape, timing)
S1 and S2 thresholds:

- S1c > 3 phd in at least 3 PMTs, S1c < 80 phd
- S2 > 600 phd & S2c < 10000

Fiducial Volume: remove external & wall backgrounds
Skin & OD Vetoes: remove events with corresponding signal in veto detector
Data quality: Muon holdoff, electron/photon train holdoff, hot spot exclusion, etc.

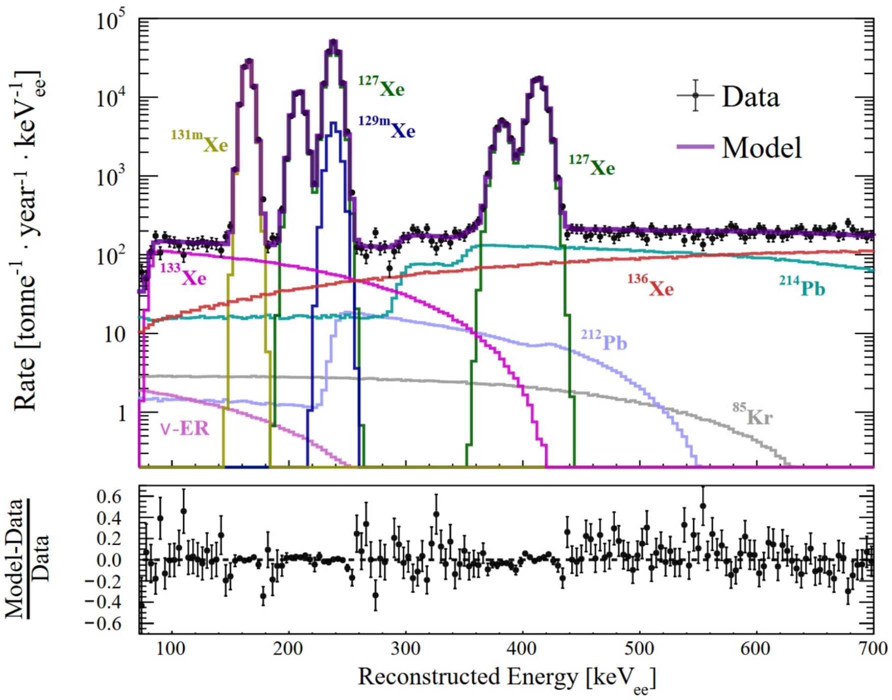


OUTLINE

- ***Dark matter search and LZ experiment***
- LZ experiment
- Results from the first science run
- Outlook

Background in LZ

- Dissolved beta emitters: ^{214}Pb (^{222}Rn daughter), ^{212}Pb (^{220}Rn daughter), ^{85}Kr, ^{136}Xe (2 beta)
- Dissolved e-captures (monoenergetic x-ray/Auger cascades): ^{127}Xe, ^{124}Xe (2 e-capture), ^{37}Ar
- Long-lived gamma emitters in detector materials: ^{238}U chain, ^{232}Th chain, ^{40}K, ^{60}Co
- Neutron emission from spontaneous fission and (α,n)
- Solar neutrinos: ^{8}B (NR), pp (ER)
- Accidental coincidences.



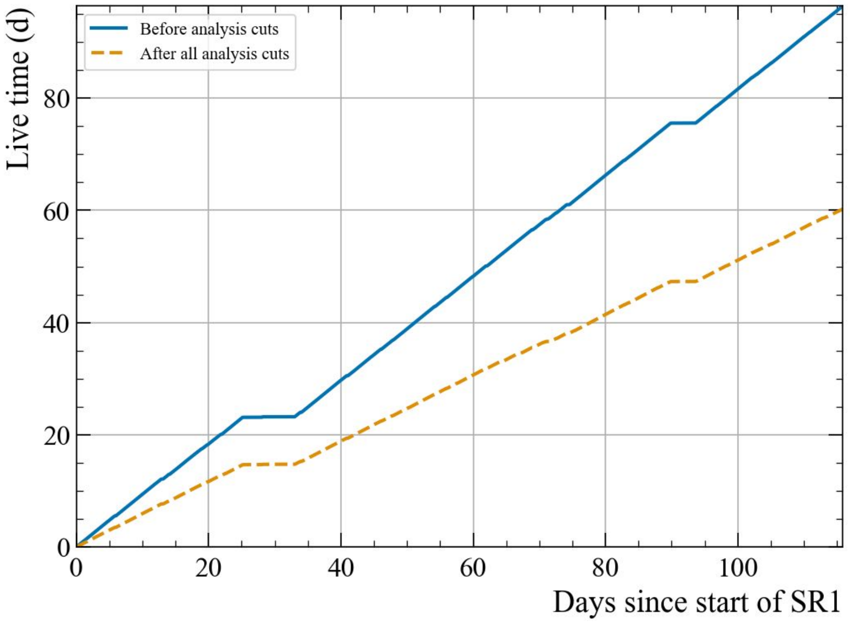
Background model

First Science Run (SR1)

Goal: Demonstrate physics capability of the LZ detector

Key parameters during this run:

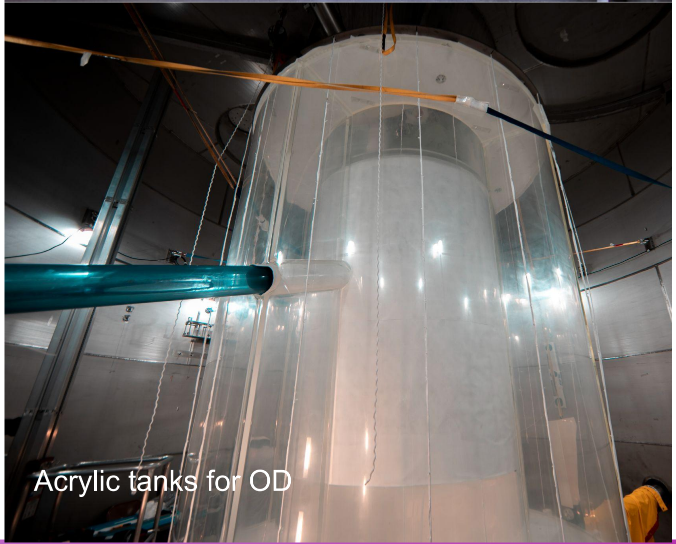
- Data taken between 23 Dec 2021 to 11 May 2022→60 live days for WIMP search
- 5.5 t fiducial mass
- Drift field: 193 V/cm
- Gas extraction field: 7.3 kV/cm at center
- 174.1 K (at the TPC bottom) and 1.791 bar with <0.2% fluctuation
- Continuously purified at 3.3 t/day through a hot getter system
- electron lifetime between 5000 μs and 8000 μs, much longer than the 951 μs maximum drift time in the TPC



Beat the enemy→Background mitigation

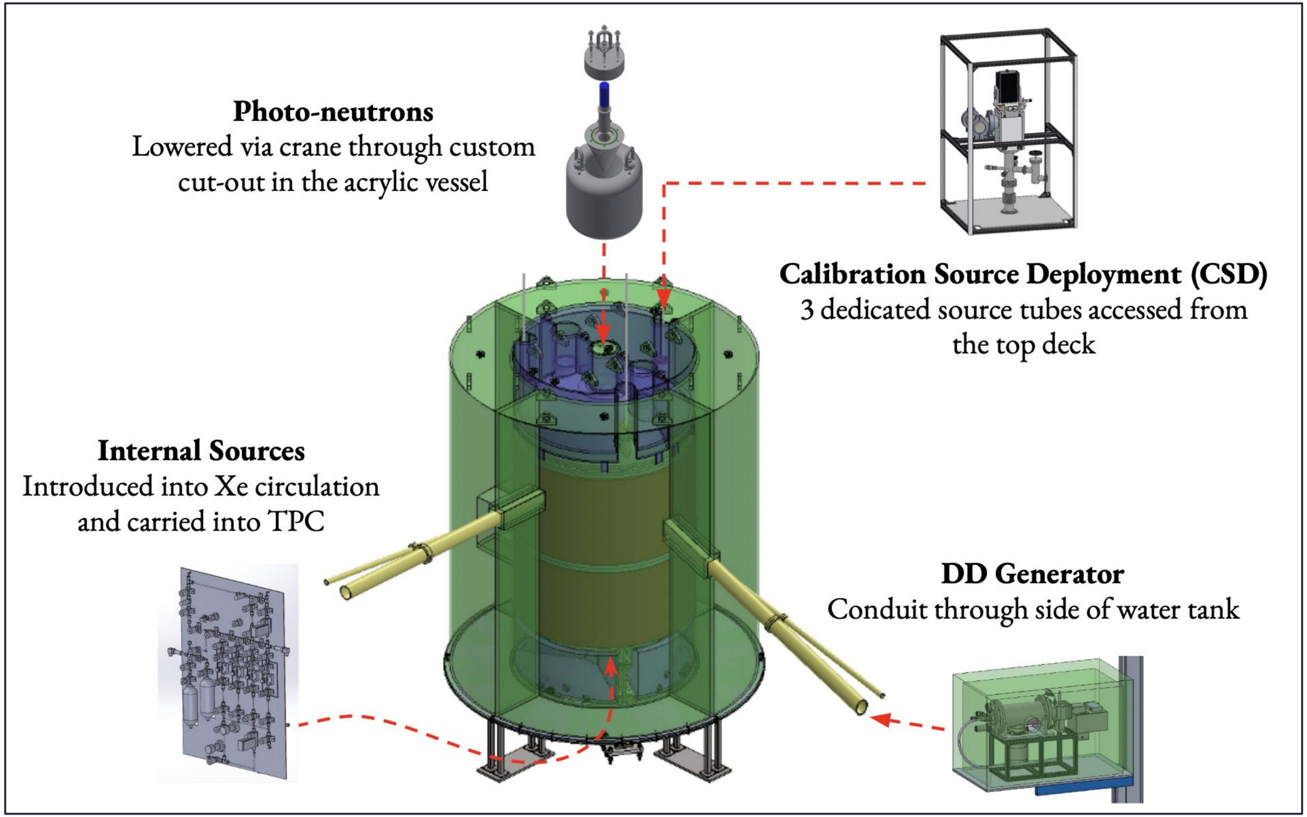
- Cleaning:
  - rigorous program of cleanliness management
  - Xenon circulation and purification
- Shielding:
  - Underground operation
  - Water tank for shielding
  - liquid xenon self-shielding
- Veto system
  - Liquid xenon skin: gamma
  - OD (gadolinium-loaded liquid scintillator (GdLS) : neutron
- Event selection:
  - 3D position reconstruction → background-light fiducial volume
  - Electronic/nuclear recoil discrimination
  - Various analysis cuts


Kr removal system at SLAC


Acrylic tanks for OD

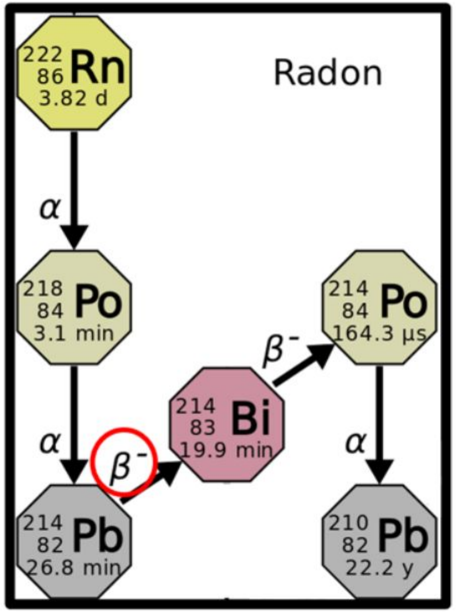
Understand the tool → Calibration

- **DD neutron generator**: 2.45 MeV neutrons, collimated, used for: NR band, trigger efficiency, S1 cut acceptance
- **Am-Li**: continuum neutrons, isotropic, used for: Outer Detector (OD), neutron-tagging efficiency, S2 cut acceptance
- **CH_3T**: continuum betas up to 18.6 keV, used for: ER band, fiducial volume, S1 cut acceptance
- **^{83m}Kr**: monoenergetic ERs, 32.1 and 9.4 keV, used for: energy scale, xy spatial corrections
- **^{131m}Xe**: monoenergetic ER, 164 keV, used for: energy scale, electron lifetime
- Additional background sources (e.g. alphas and cosmics), used for: energy scale, electron lifetime



Background in SR1

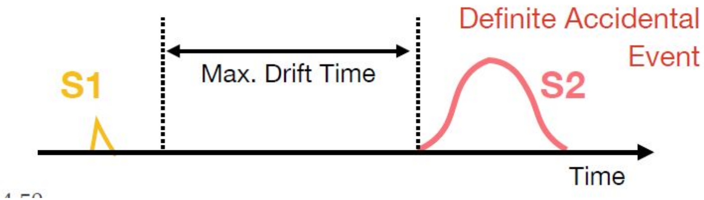
Radon daughters: ^{214}Pb, ^{212}Pb, flat band in low energy, hard to tage
Mitigation: clean, purification



Accidentals: Unrelated S1s & S2s can accidentally combine to produce single scatter events.

Analysis cuts developed to combat observed pulse/event pathologies

- >99.5% efficiency in removing accidentals
- SR1 WIMP search counts: 1.2 ± 0.3



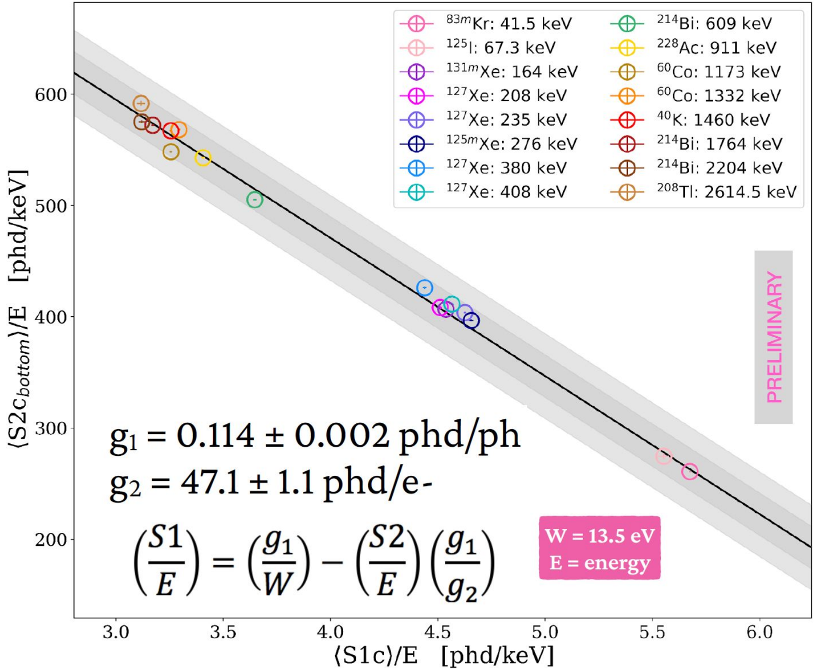
Neutron: same detector response as WIMP! <0.2 in SR1

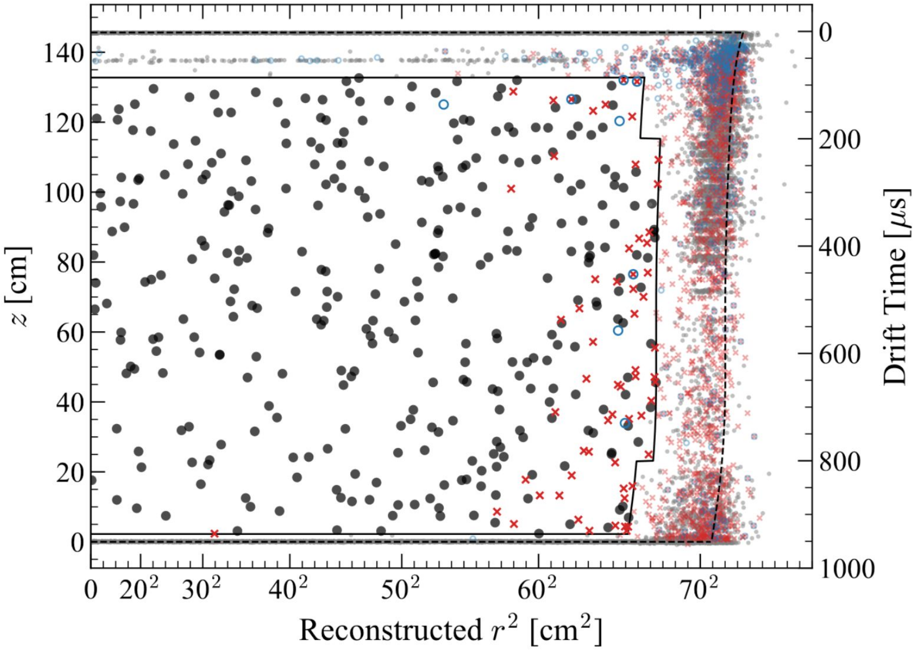
Mitigation:

- Passive shielding
- Active OD veto: measures 89+-3% tagging efficiency

Other leading backgrounds:
^{85}Kr, ^{37}Ar, solar neutrinos

Detector response





- ● Events surviving all selections
- × Skin-prompt-tagged events
- ○ OD-prompt-tagged events