Lawrence Berkeley National Laboratory

Direct dark matter searches with the LZ experiment

Update and Status

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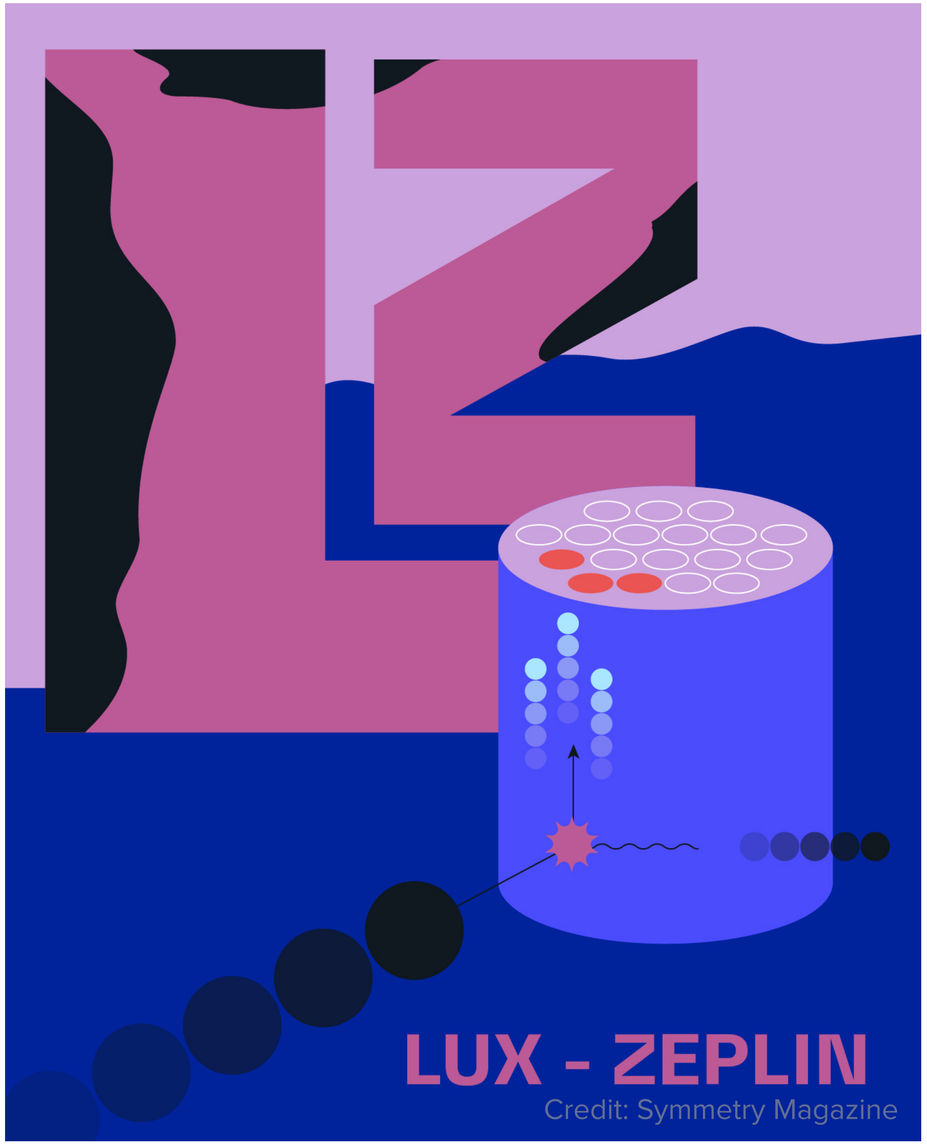
Wednesday, June 2, 2020 - GDR DUPhy

Credit: Symmetry Magazine

Liquid Xenon Time Projection Chamber



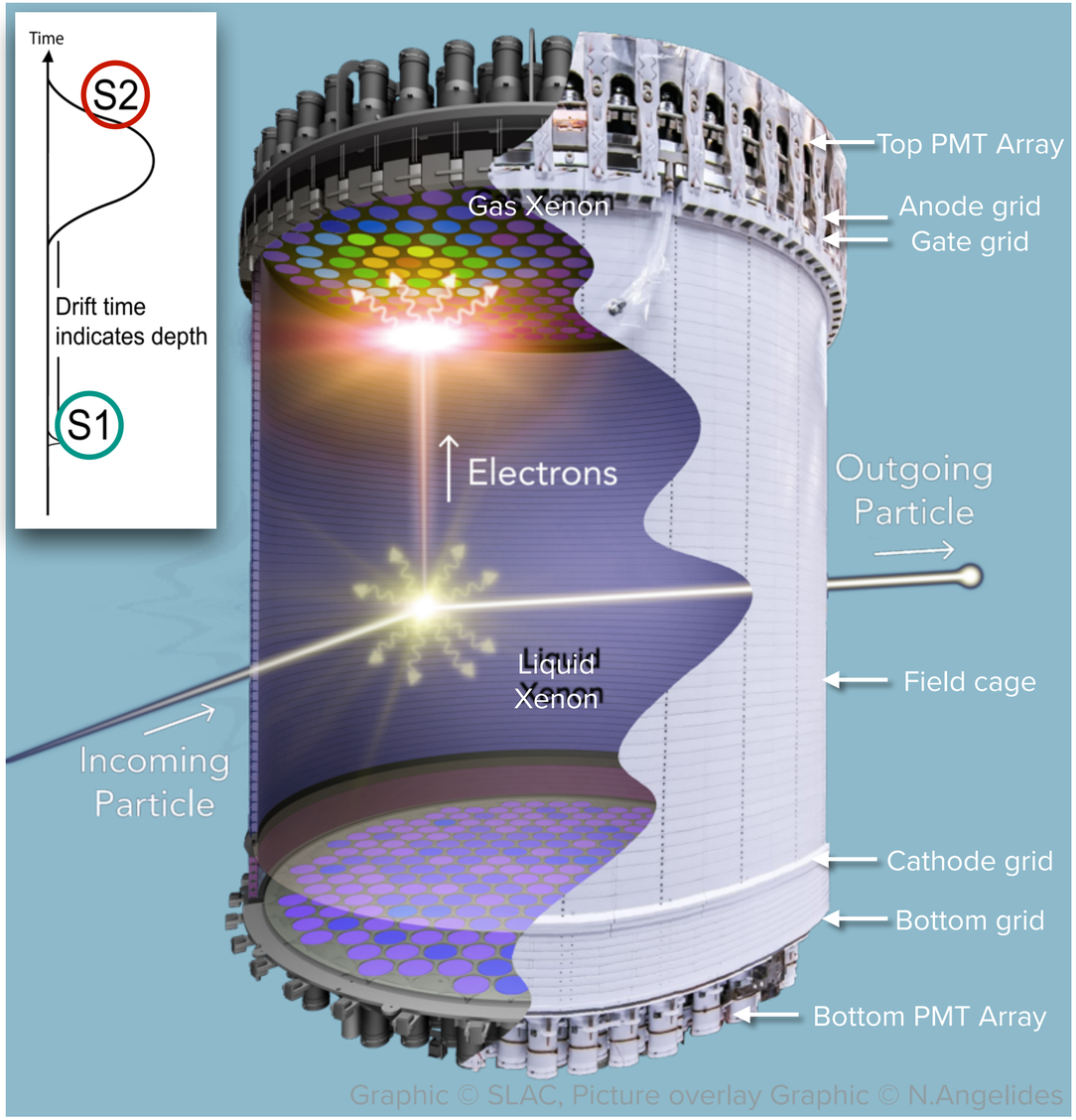
Liquid Xenon is a good target for WIMP Dark Matter searches...

- **High density**
- High ionization yield ($W \sim 13.7\,\mathrm{eV}$)
- High scintillation yield $\left(> 50{,}000\,\mathrm{photons/MeV} \right)$
- **Transparent** to its own scintillation light
- **Self-shielded**
- High intrinsic radio-purity

... but not only

- Axion Like Particles
- Exotic Dark Matter candidates (mirror dark matter, solar axions, ...)
- Neutrino physics & astrophysics
  - $0\nu\beta\beta$ search using $^{134}\mathrm{Xe}$ & $^{136}\mathrm{Xe}$

Liquid Xenon Time Projection Chamber



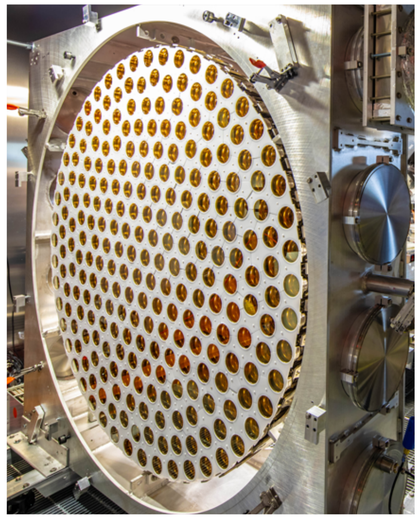
Liquid Xenon TPC

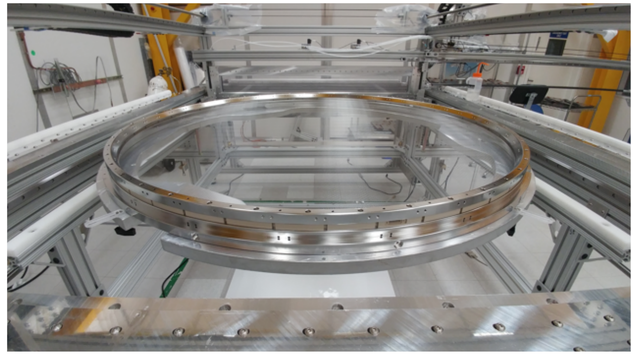
- Type of signals
  - **S1**: Primary scintillation (light)
  - **S2**: Secondary scintillation (charge)
- 3D position reconstruction
  - XY position: $\mathcal{O}(\mathrm{mm})$ from S2 light pattern
  - Z position: $\mathcal{O}(\mu\mathrm{m})$ from S1-S2 timing

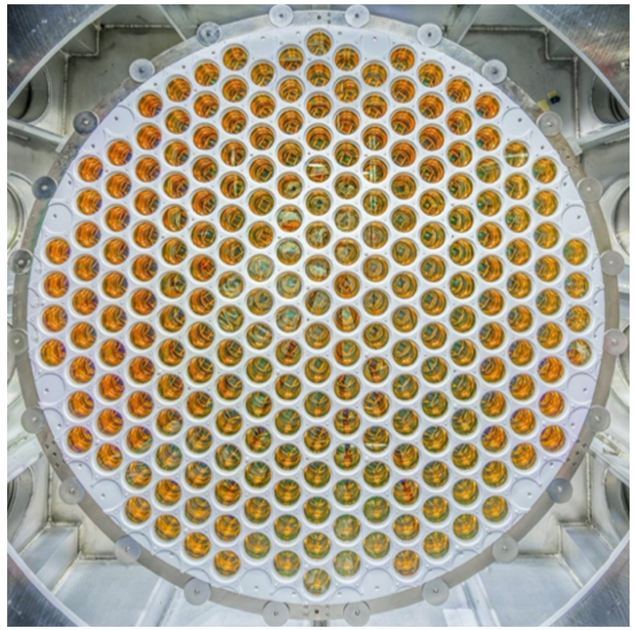
LZ TPC

- 1.5 m in diameter and height
- 10 tonnes of total mass, 7 tonnes active and **5.6 tonnes fiducial** volume
- Electric field: $300\ \mathrm{V/cm}$
- 247 (top) + 247 (bottom) PMTs to monitor the TPC

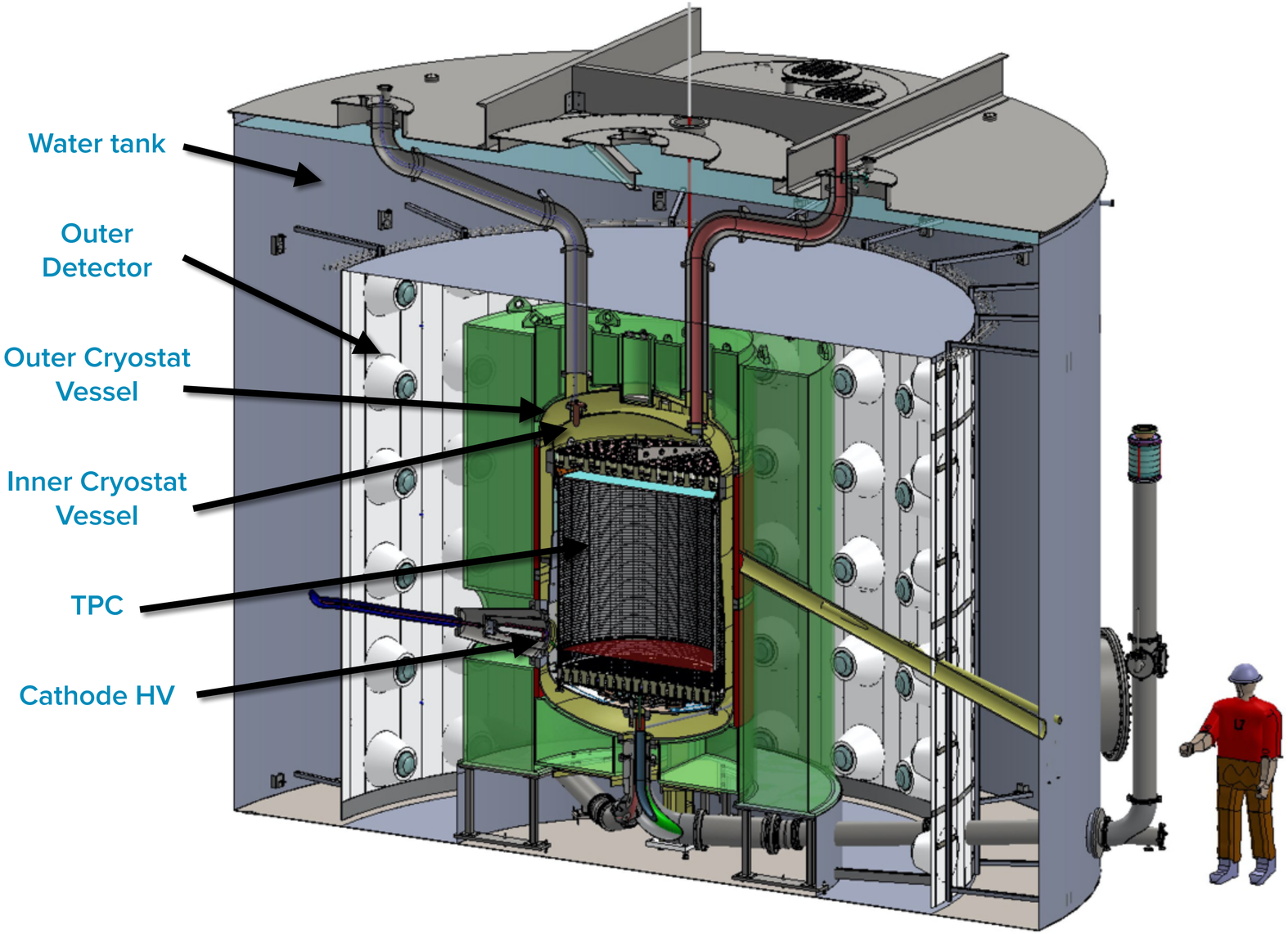
LZ Time Projection Chamber in pictures

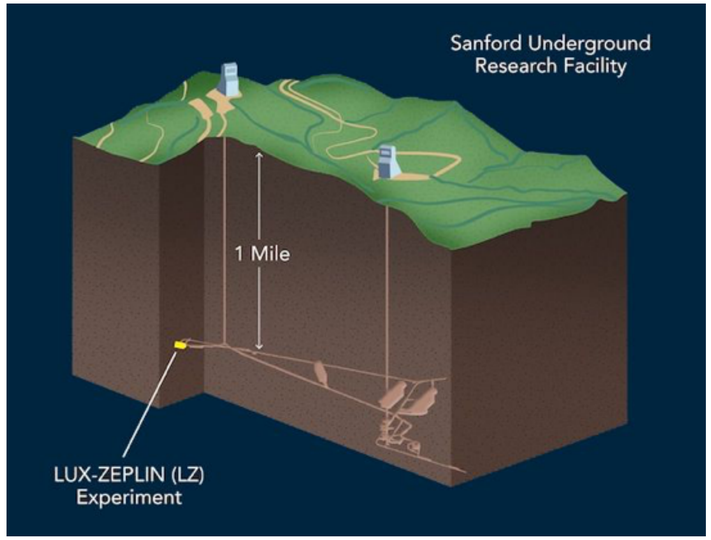






LZ Detector Systems





Location

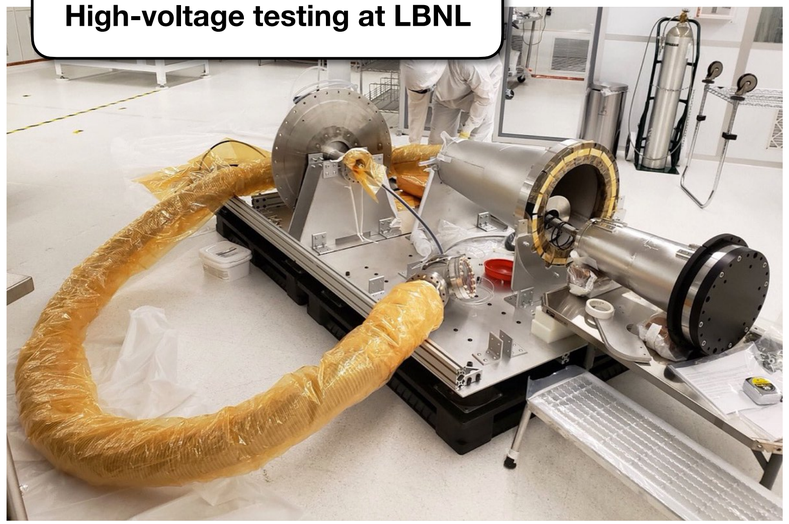
- Davis cavern of the SURF underground laboratory
- 4850 feet (1.48 km) underground
- Muon flux reduced by $\mathcal{O}\left(10^7\right)$ (@4.3 km.w.e)

More details

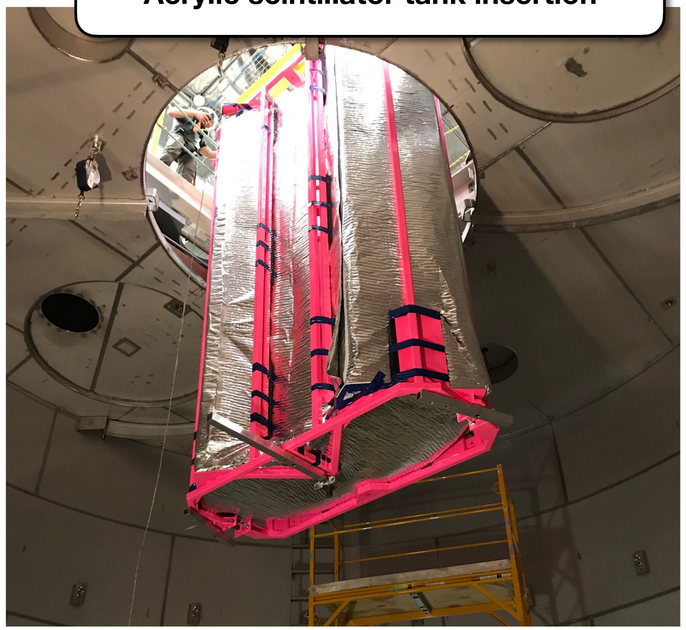
- NIMA 953 163047 (2020)
- LUX-ZEPLIN (LZ) TDR

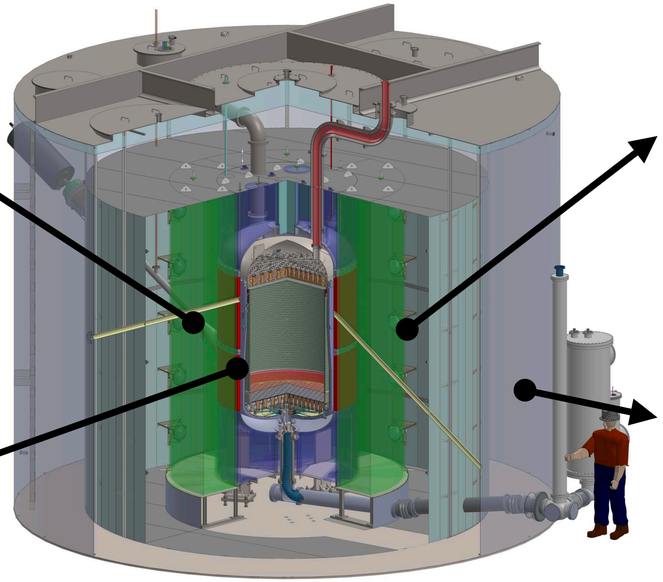
LZ Detector Systems

High-voltage testing at LBNL



Acrylic scintillator tank insertion

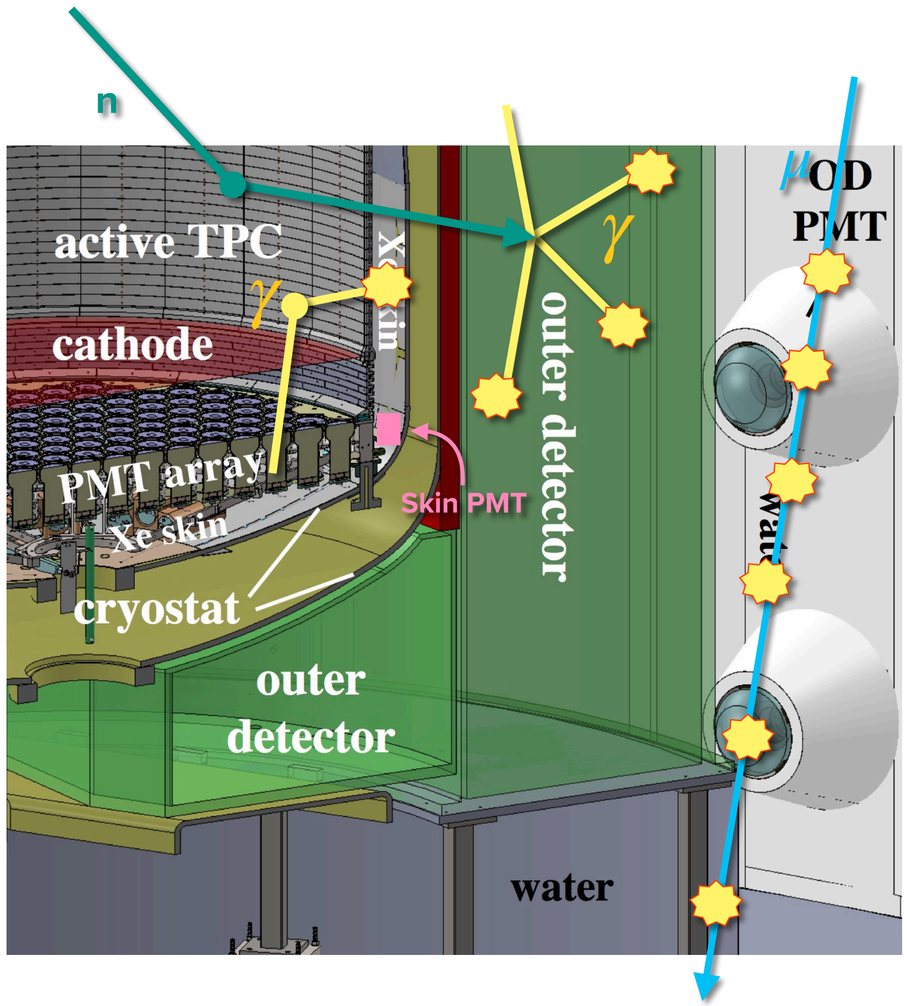




Lower inner cryostat vessel into outer cryostat vessel

Water tank in the Davis cavern at SURF

LZ Veto Systems



LZ has two veto systems

Skin

- Two tonnes of LXe surrounding the TPC
- PMTs at top and bottom of the skin region
- Lined with PTFE to maximize light collection efficiency
- Anti-coincidence detector for γ-rays

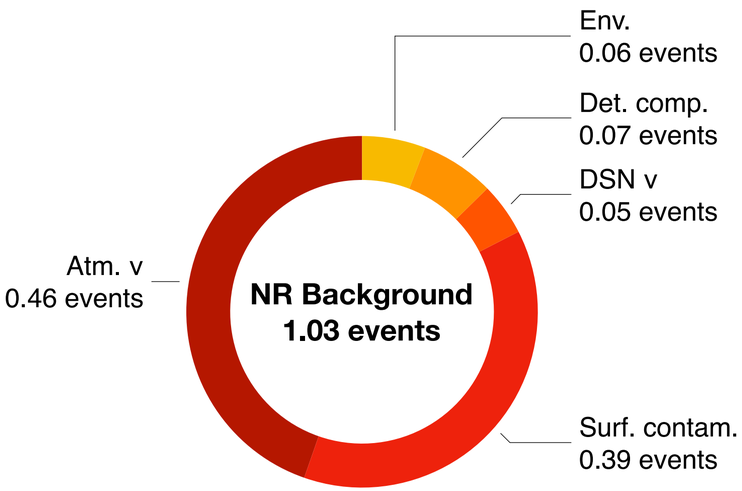
Outer Detector

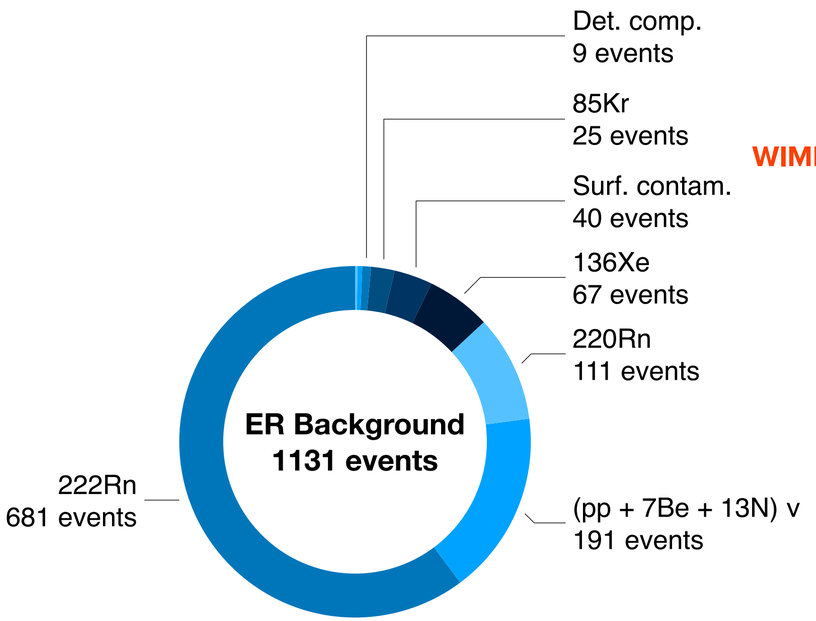
- 17 tonnes Gd-loaded liquid scintillator in acrylic vessels
- 120 8” PMTs mounted in the water tank
- Anti-coincidence detector for γ-rays and neutrons
- Observe $\sim 8\,\mathrm{MeV}$ γ-rays from thermal neutron capture

Background Budget Estimates

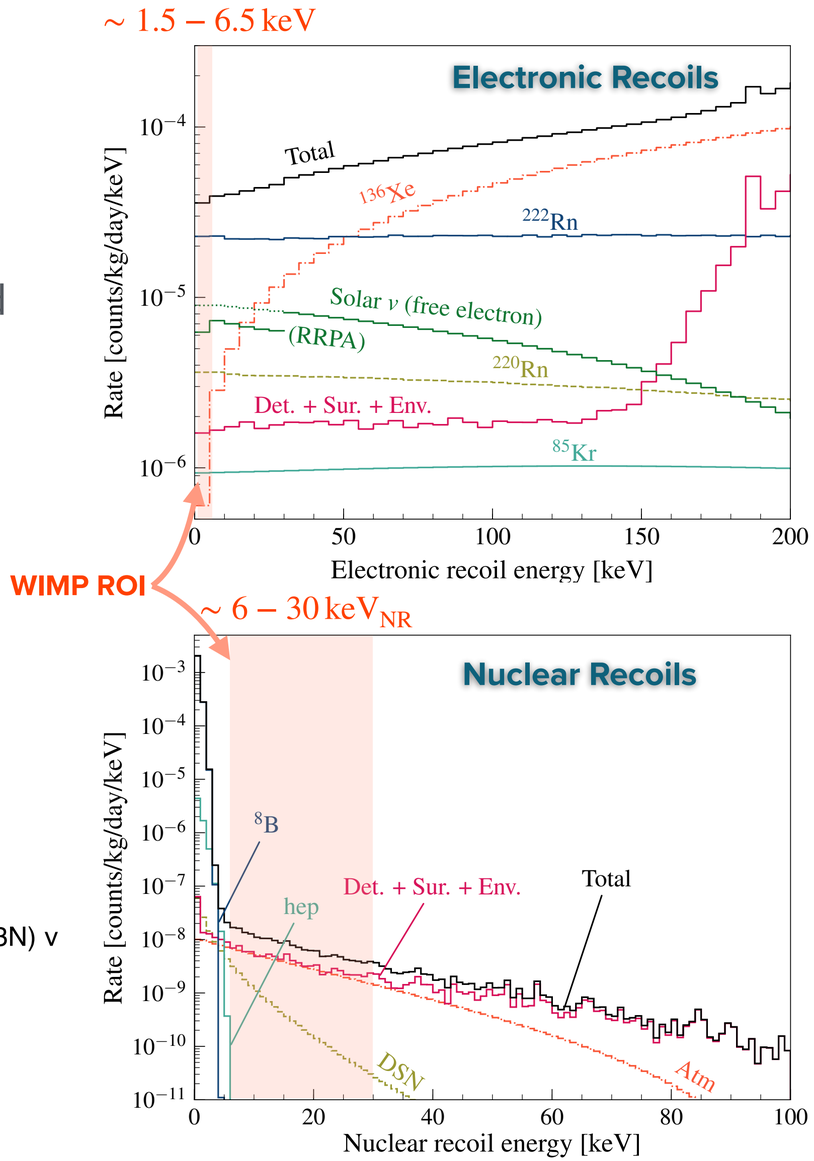
- **Geant4-based simulation** for background studies (Astro.Phys. 125 102480 (2020))
- Used to predict **LZ sensitivity** (Phys. Rev. D 101, 052002)
- **Low level of background**: multi-year campaign of material assay and acquisition of radiopure materials (EPJC 80, 1044 (2020)).

- **Background budget**





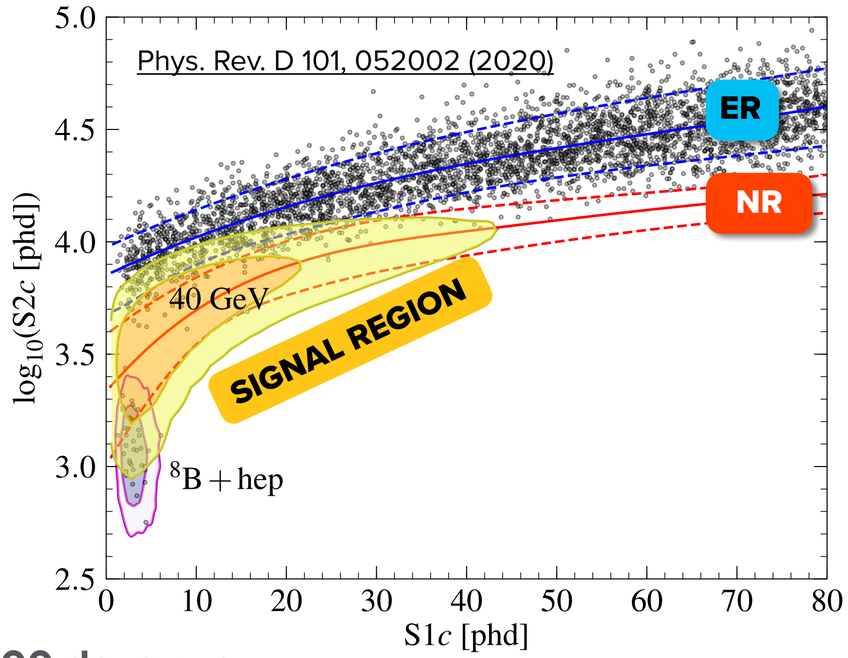
WIMP ROI for 1000 live days and 5.6 t fiducial

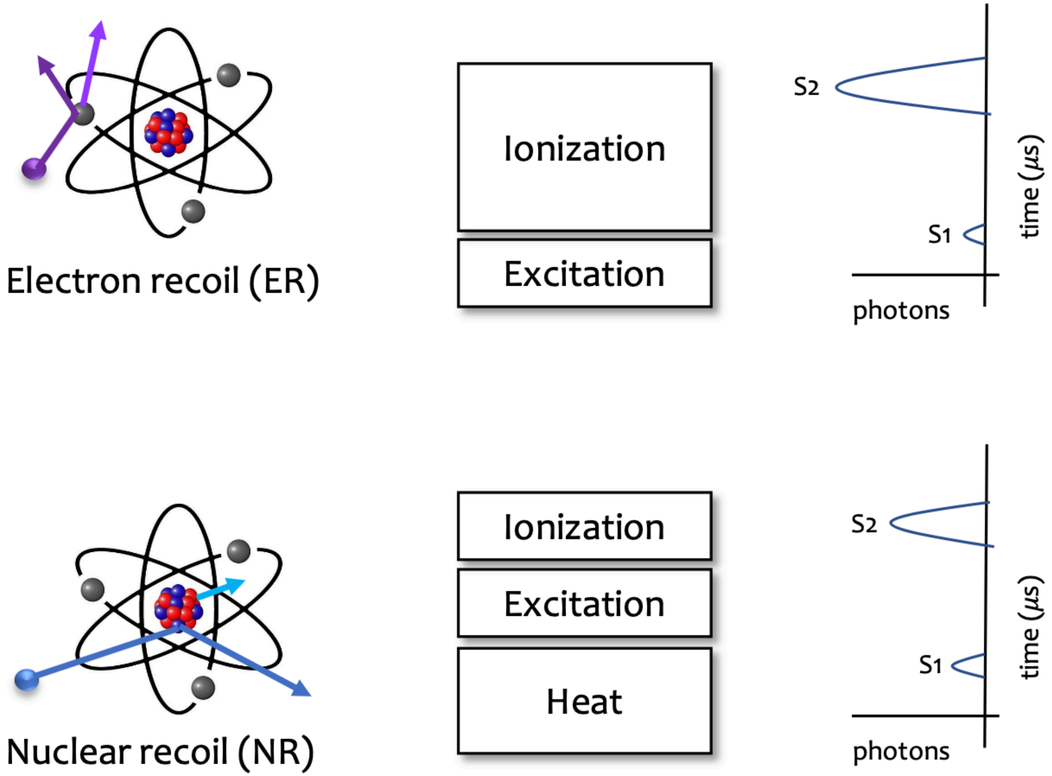


Background Reduction

Signal/Background discrimination

- ER and NR events can be distinguished from their different S2/S1 ratio



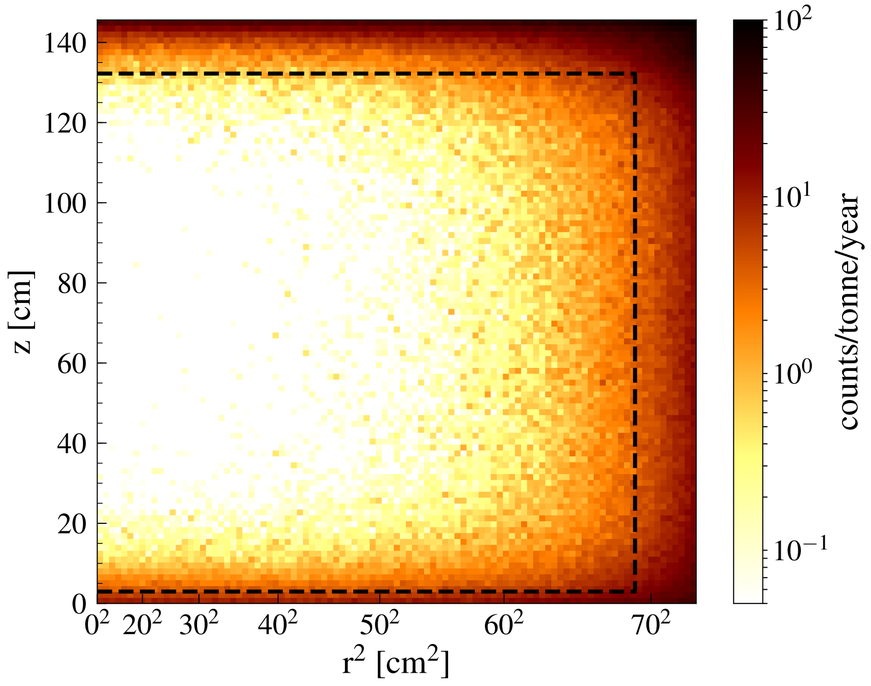


- **1000 days run**
  - **Before discrimination** 1131 ER events and 10.4 NR events
  - **After discrimination** 5.97 ER events and 0.51 NR events (with 99.5% ER discrimination, 50% NR efficiency)

Background Reduction

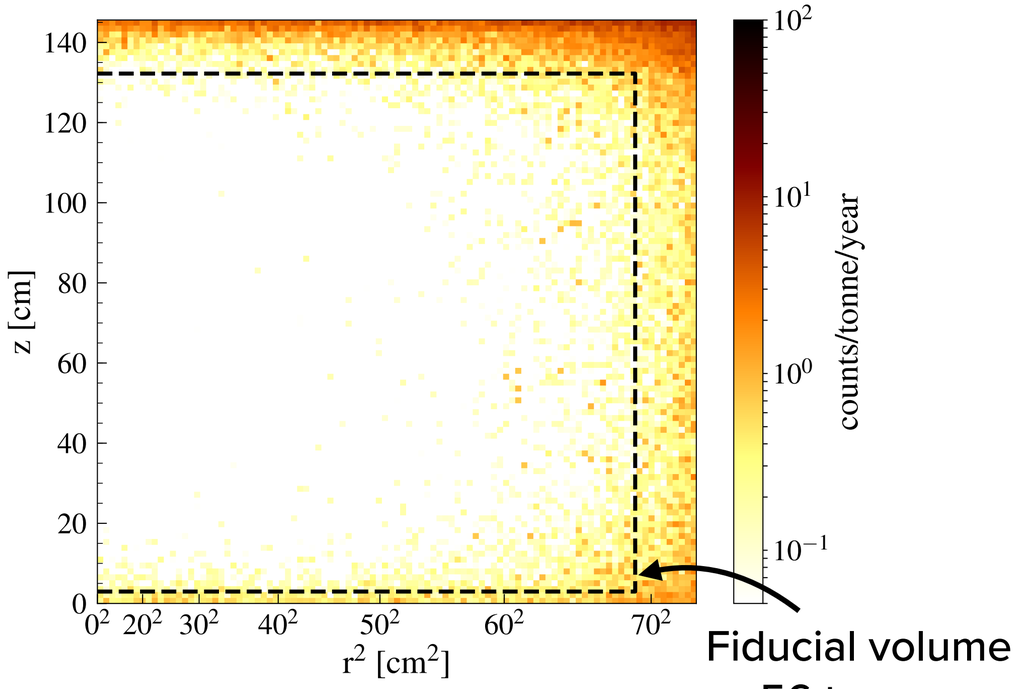
Fiducialisation and Veto cut (NR background)

Before veto cuts



12.31 cts / 1000 days

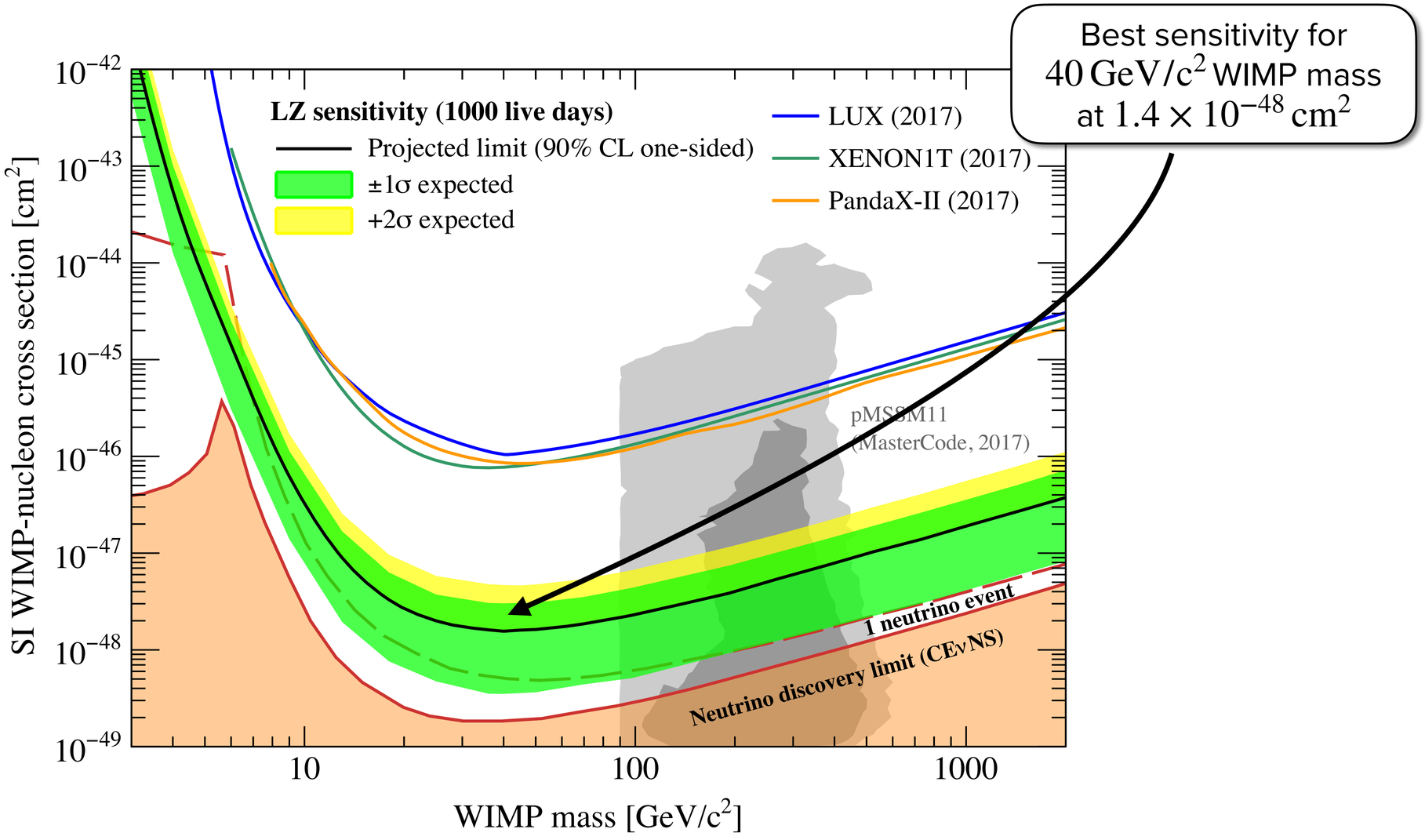
After veto cuts



Fiducial volume
56 tonnes

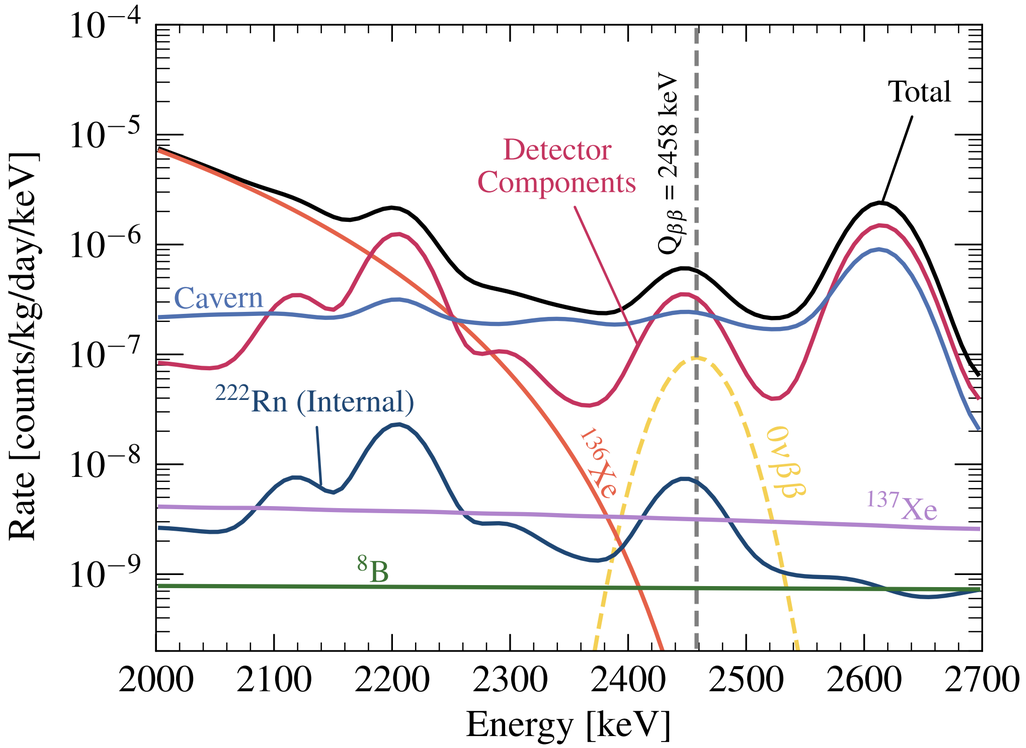
1.03 cts / 1000 days

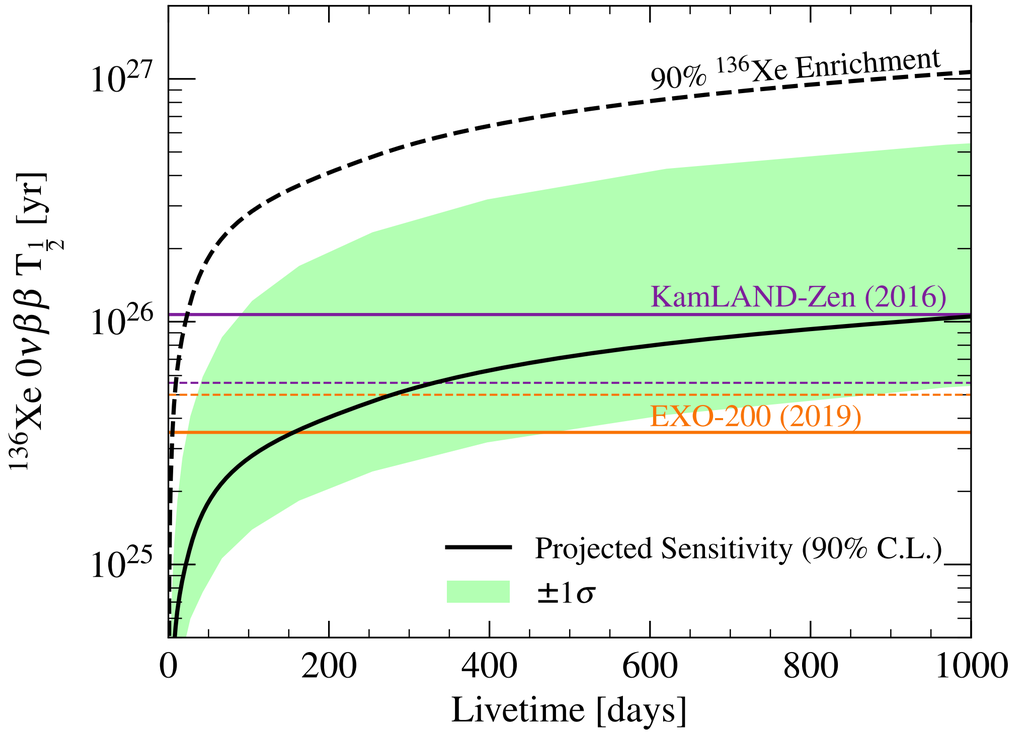
WIMP Dark Matter Projected sensitivity



LZ sensitivity Paper (Phys. Rev. D 101, 052002)

$0\nu\beta\beta$ Decay of ^{136}Xe





- **No enrichments** (8.8 %)
- ^{136}Xe $Q_{\beta\beta} = 2458\,\mathrm{keV}$
- **Fiducial volume:** 1 tonne
- $T_{1/2}\,(90\,C.L.) > 1.06 \times 10^{26}$ years in 1000 live days

Projected sensitivity to the $0\nu\beta\beta$ decay of ^{136}Xe (Phys. Rev. C 102, 014602 (2020))

SUMMARY

Good progress in assembly and integration of detector and associated systems

- **Expecting first data later this year**
- **Dark Matter detection**
  - WIMP projected sensitivity: $1.4 \times 10^{-48}\,\mathrm{cm}^2$ at $40\,\mathrm{GeV/c}^2$
  - Low mass WIMPs sensitivity (arXiV:2101.08753)
  - Sensitivity to new physics via low-energy electron recoils (arXiv:2102.11740)
- **Neutrino physics**
  - $0\nu\beta\beta$ decay of $^{136}\mathrm{Xe}$ (Phys. Rev. C 102, 014602 (2020))
  - $2\nu\beta\beta$ and $0\nu\beta\beta$ decays of $^{134}\mathrm{Xe}$ (arXiv:2104.13374)

Stay tuned!

THE LZ (LUX-ZEPLIN) COLLABORATION

@lzdarkmatter

https://lz.lbl.gov/

34 Institutions: 250 scientists, engineers, and technical staff

- 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.
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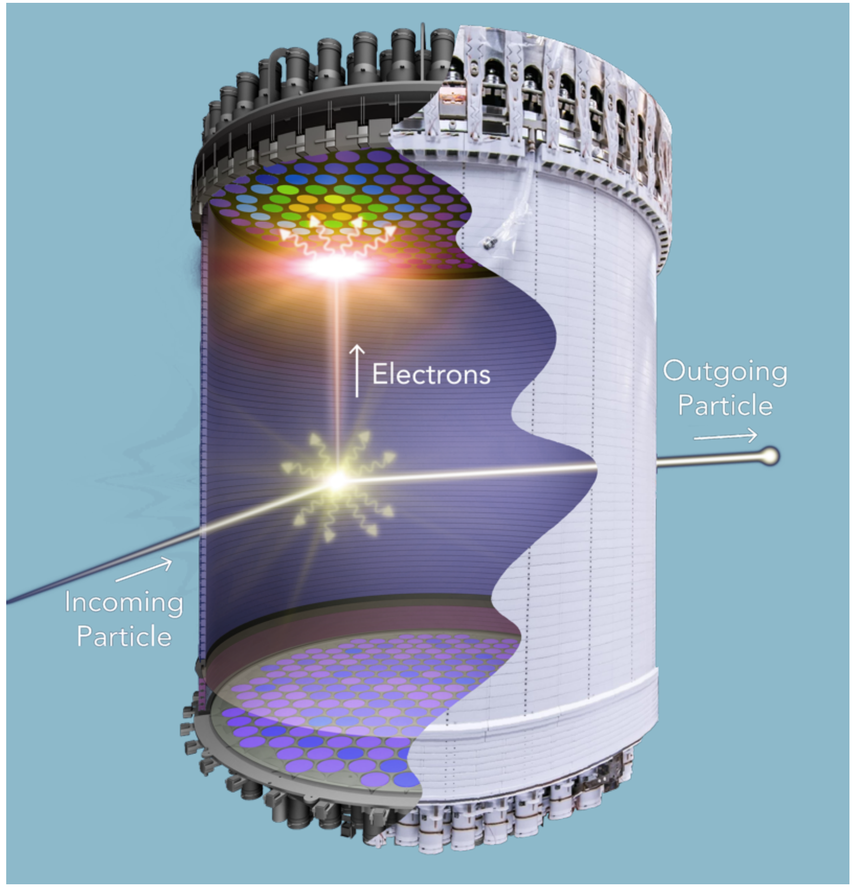

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