Overview and Status of the LUX-ZEPLIN (LZ) Experiment

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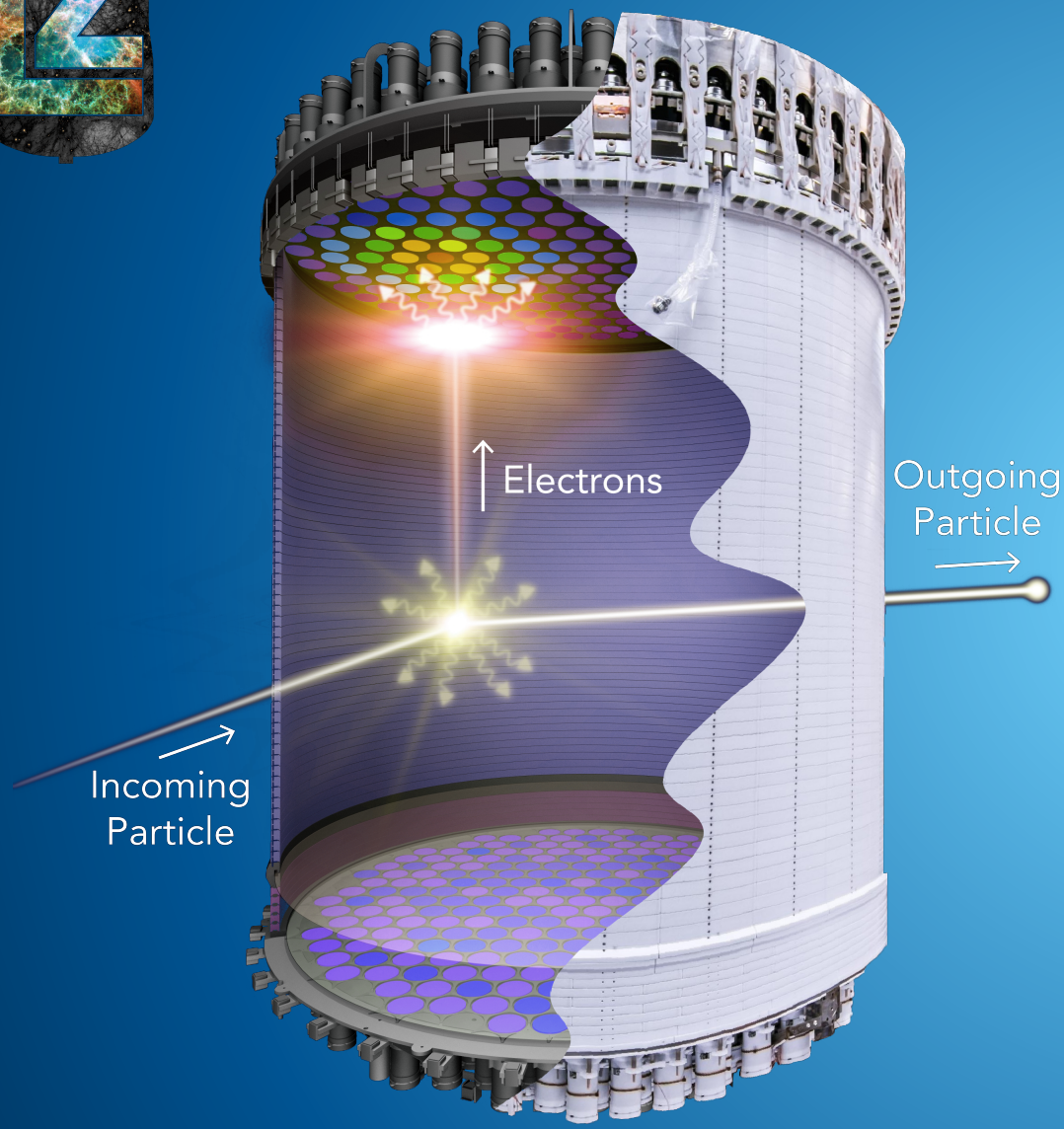
University of Oxford,
16th Patras Workshop

The Experiment



- LZ is designed to directly detect WIMPs but has *considerable* sensitivity to other new physics
- Dual phase xenon time projection chamber (TPC)
- Interactions in the xenon generate
  - Prompt scintillation (S1)
  - Charge, drifted and extracted into the gas to produce electroluminescence light (S2)
- 3D position reconstruction -> fiducialisation
- S2/S1 ratio -> discrimination between WIMPs (nuclear recoils, NRs) & γ rays (electron recoils, ERs)

The Collaboration

- 34 institutions from USA, UK, Portugal, Korea
- ~250 scientists, engineers and technical staff

UKRI Science and Technology Facilities Council

Institute for Basic Science ibs 기초과학연구원

Department of Energy United States of America

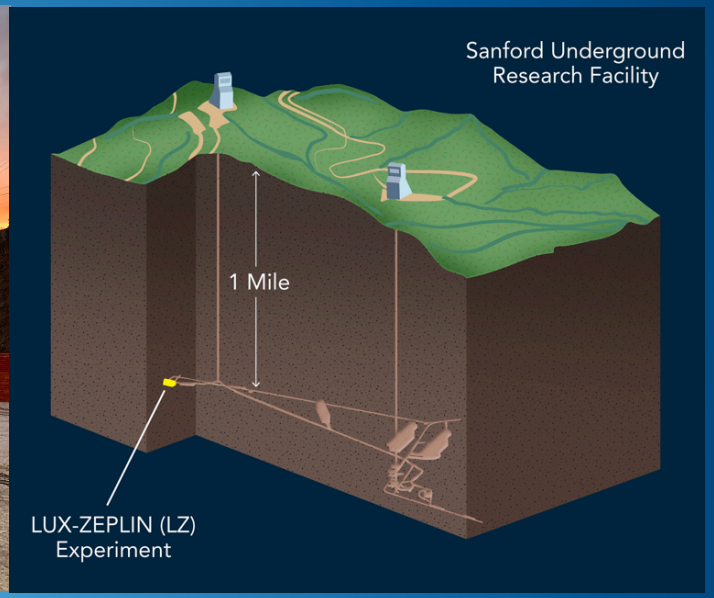
Sanford Underground Research Facility
South Dakota Science and Technology Authority

FCT Fundação para a Ciência e a Tecnologia
Ministério da Educação e Ciência

@lzdarkmatter https://lz.lbl.gov/

Oxford Physics

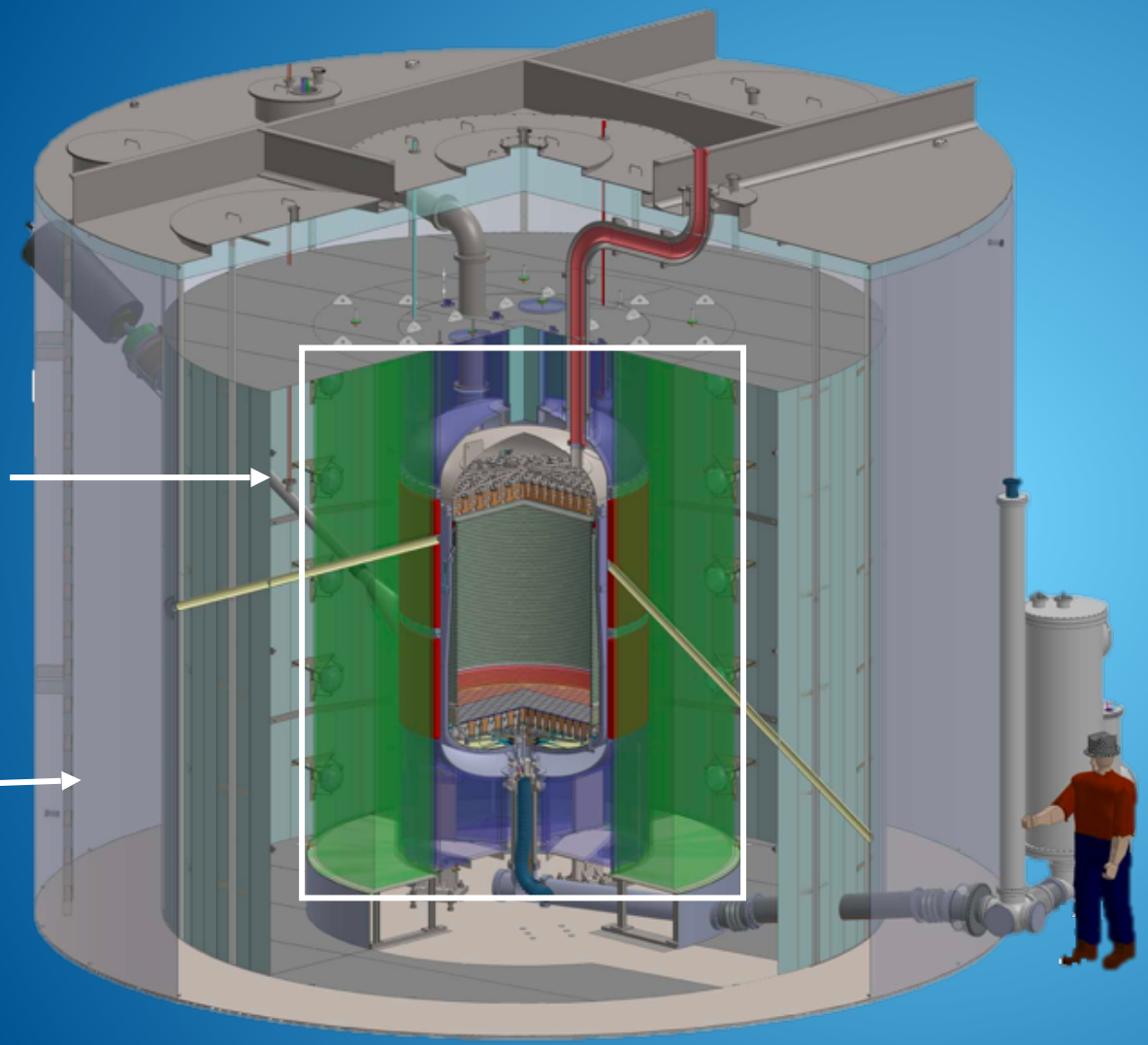
The Location



- Sanford Underground Research Facility (SURF) - Black Hills, South Dakota
- Situated in the Davis Cavern at the 4850 level (~1.5 km underground)
- 4300 metres of water equivalent overburden – reduces muon flux by ~10^6

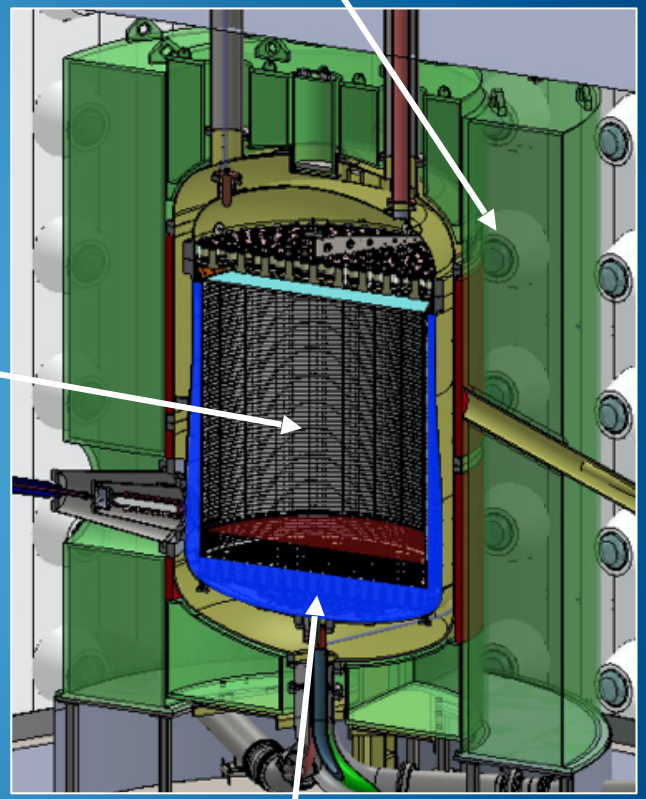
The Detectors

NIM A, 163047 (2019)



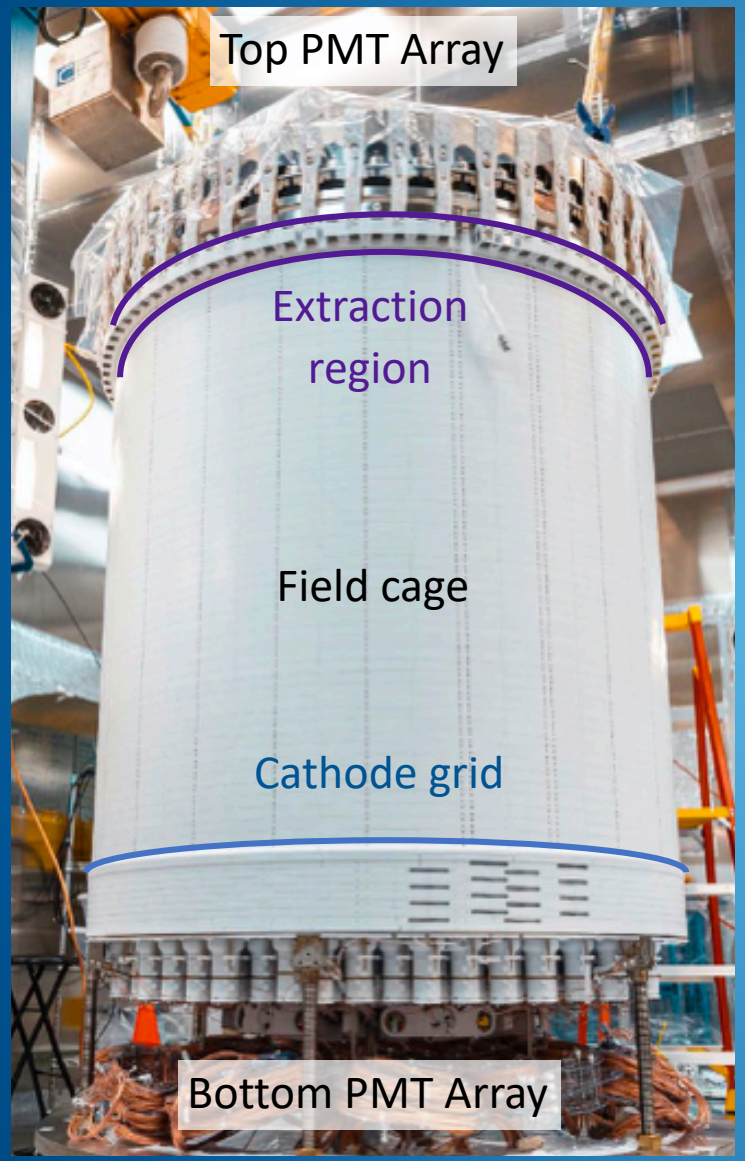
Outer veto detector: Gd-doped liquid scintillator

TPC

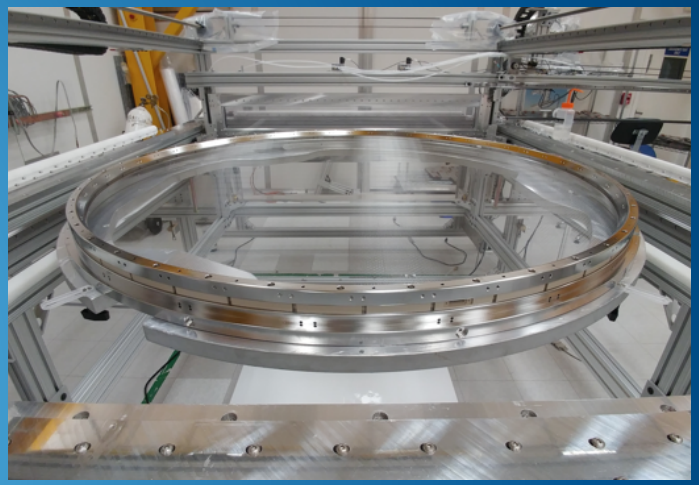


Liquid xenon “Skin” veto detector

TPC in Detail



- 7t of active xenon, viewed by 494 PMTs top & bottom



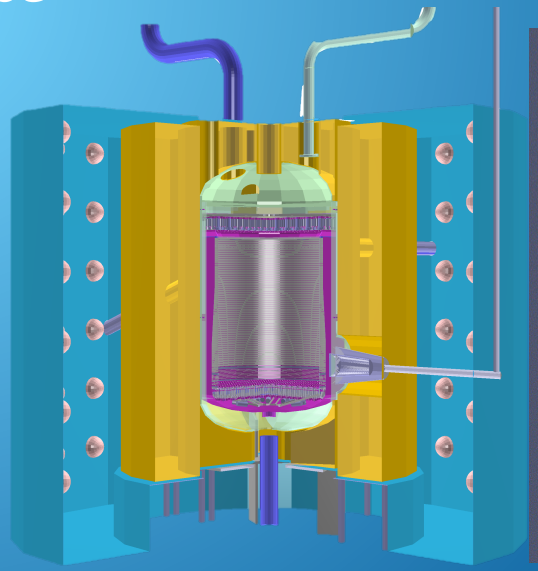
- Grid electrodes help maintain field stability
  - Cathode nominal voltage of -50 kV
  - Extraction region for S2 defined by gate and anode
- Field cage for drift field, PTFE clad for light collection

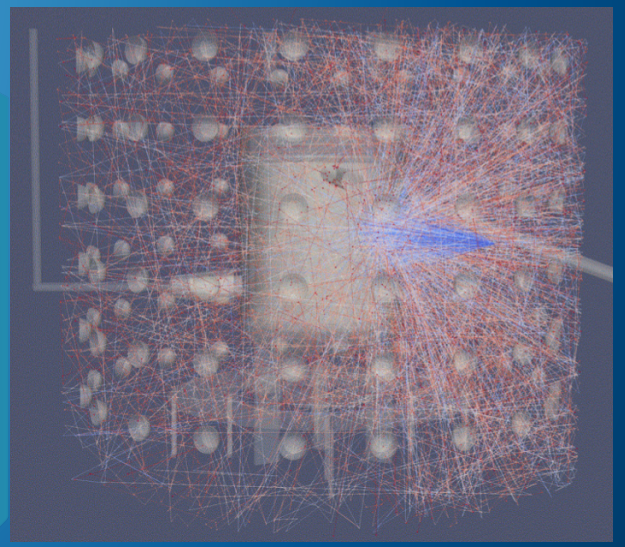
Veto Detectors in Detail

- ~2 t LXe ”Skin” detector surrounding the TPC
  - Lined with PTFE & observed by 131 PMTs
  - Anti-coincidence detector for γ rays
- 17 t Gd-loaded LAB outer detector
  - Scintillator in acrylic vessels in water tank
  - Viewed by 120 8” PMTs situated in water
  - Observe ~8.5 MeV of γ rays per thermal neutron capture

Backgrounds Control & Assessment

- Material selection based on ~2000 assays with 13 HPGe detectors, ICPMS, neutron activation analysis
- Four Rn emanation screening sites
- TPC assembly in Rn-reduced cleanroom + cleanliness limiting dust (<500 ng/cm^3), plate-out (<0.5 mBq/m^2)
- Charcoal chromatography @ SLAC to reduce xenon contaminants (^{85}Kr, ^{39}Ar)
- Online purification/radon reduction
- Geant4-based simulation framework for background & sensitivity studies



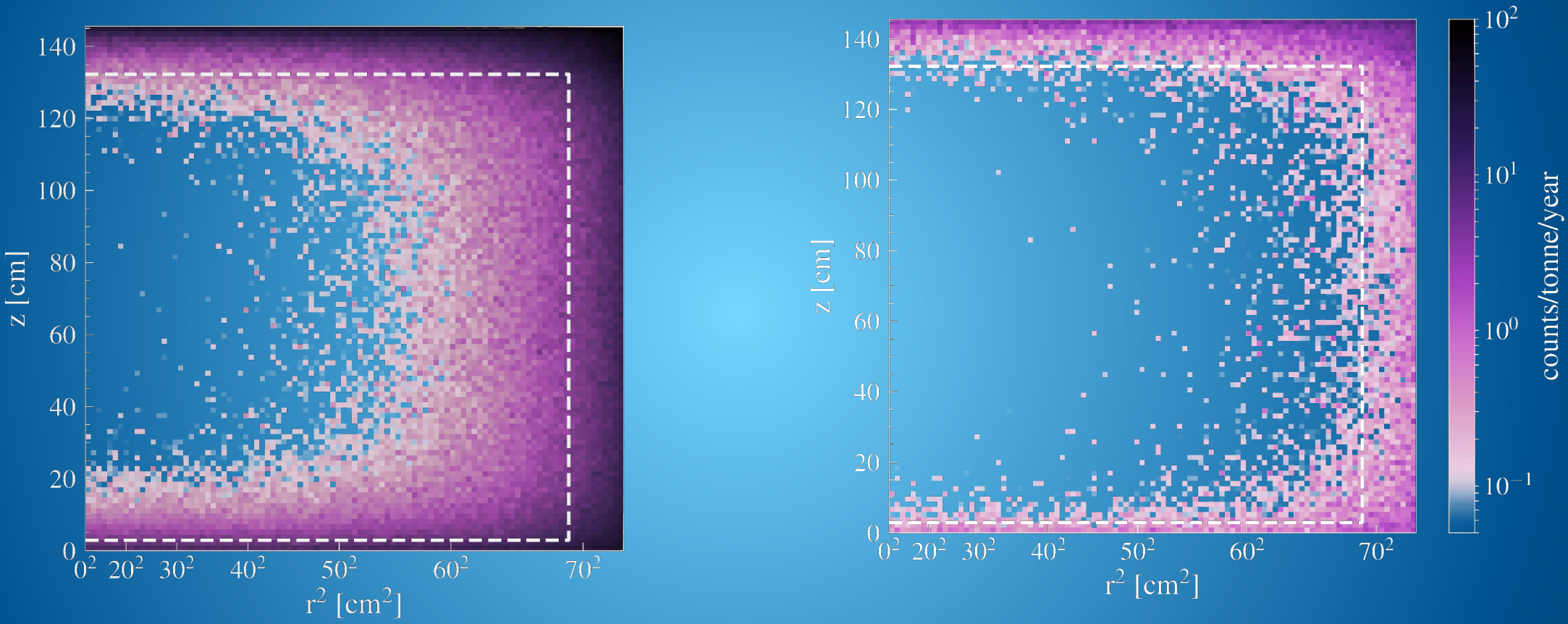


EPJC, Vol 80: 1044 (2020); j.astropartphys.2020.102480

Veto Impact on Backgrounds

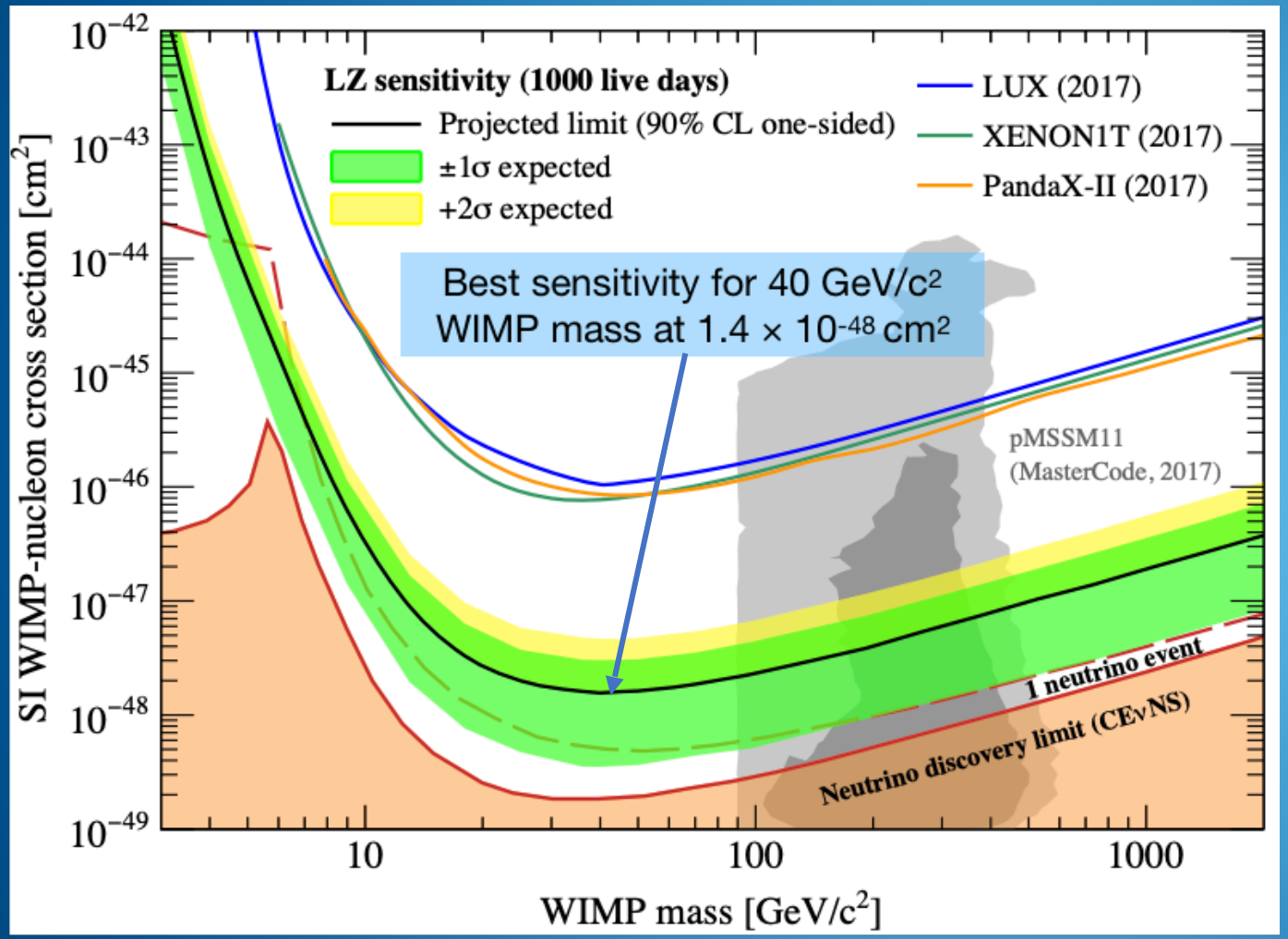
No vetoes: 10.4 NR cts/1000 days

With vetoes: 1.0 NR cts/1000 days



Combined veto system -> ~2x increase in fiducial volume to 5.6 t (80% of active volume)

WIMP Sensitivity



Background counts 1000 live days

non-vetoed single scatters
of energy 1.5-6.5 keV$_{ee}$ (6-30 keV$_{nr}$)
in 5.6 t fiducial volume

Source	ER [cts]	NR [cts]
Total	1131	1.03
+ 99.5% ER discrimination, 50% NR efficiency	**5.66**	**0.52**

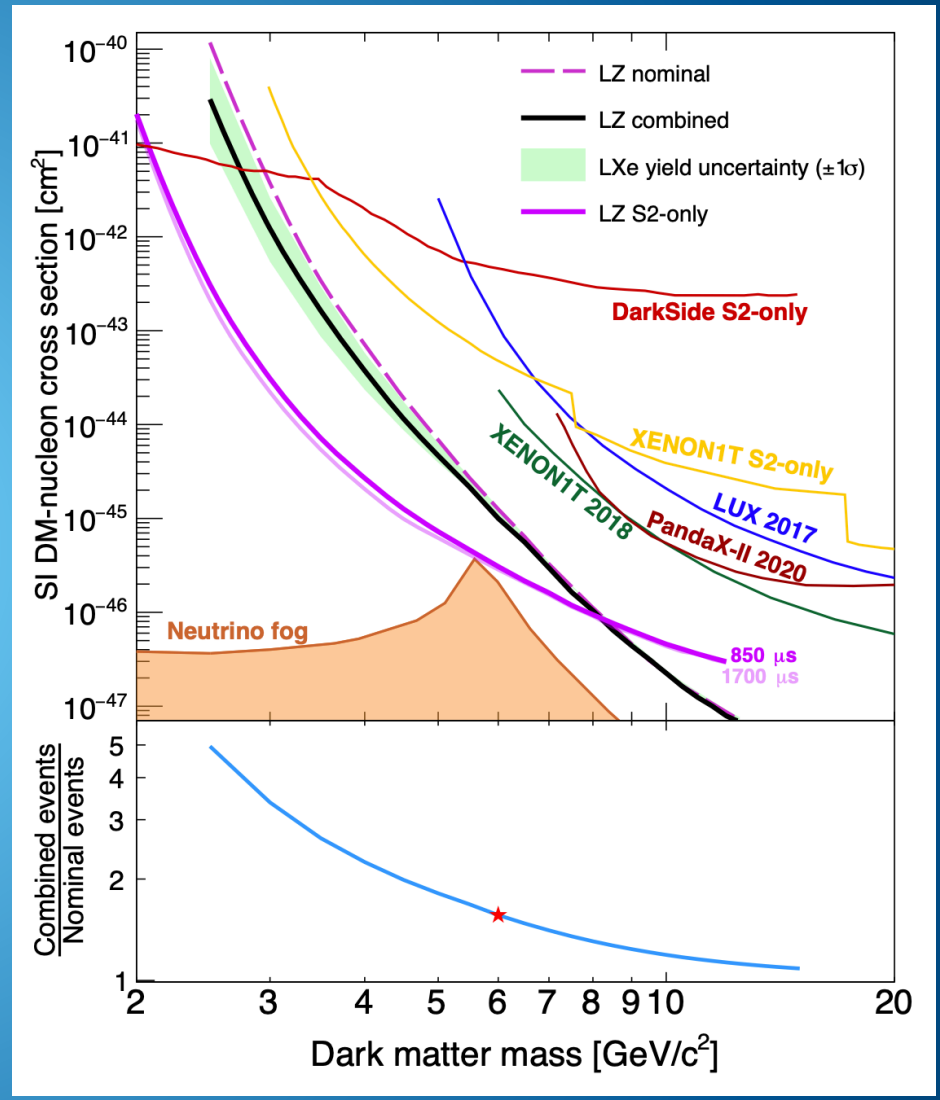
Radon comprises almost half our expected backgrounds in this region

PRD 101, 052002 (2020)

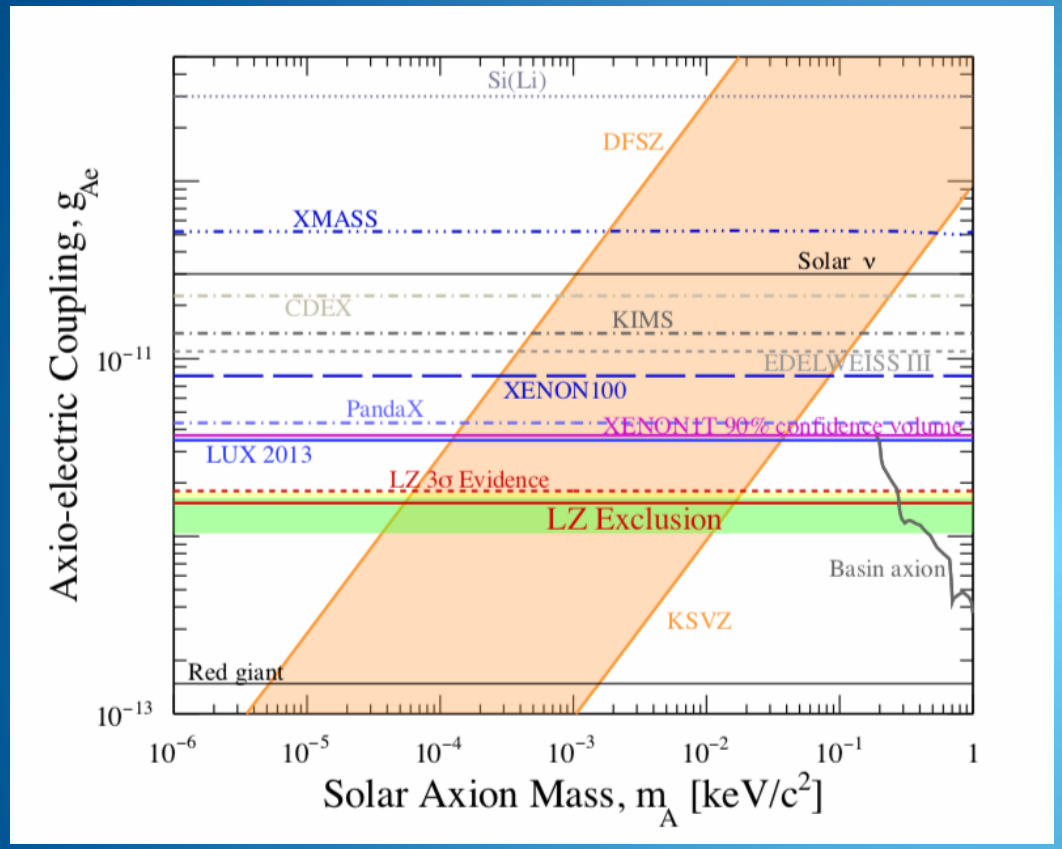
Extending to Lower Mass Candidates

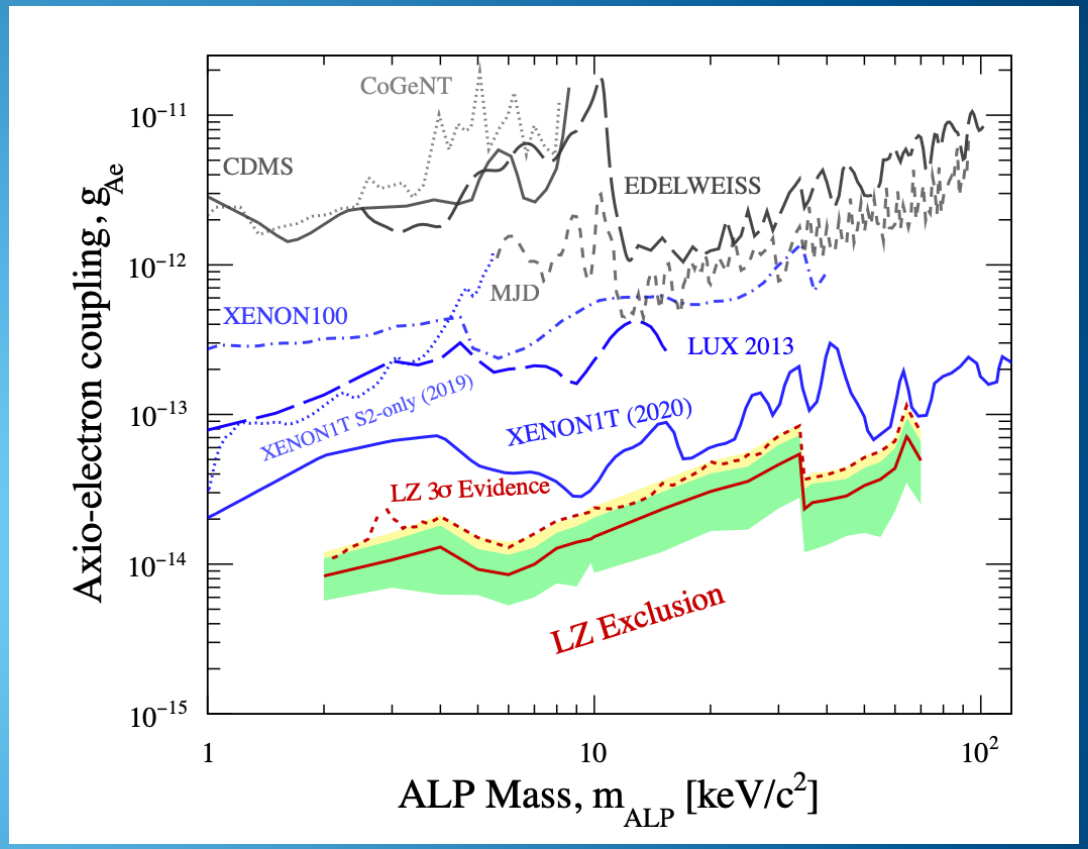
- Lower the energy threshold
  - Reduce S1 coincidence requirement from 3 to 2 (exploiting PMT double photoelectric effect)
    - ~4x improvement at 2.5 GeV/c^2
  - Conduct an S2-only search
    - Greater challenge for background discrimination -> use pulse width
- Sub-GeV masses accessible when considering Migdal electron emission

ArXiv: 2101.08753



Physics Via Low Energy Electron Recoils

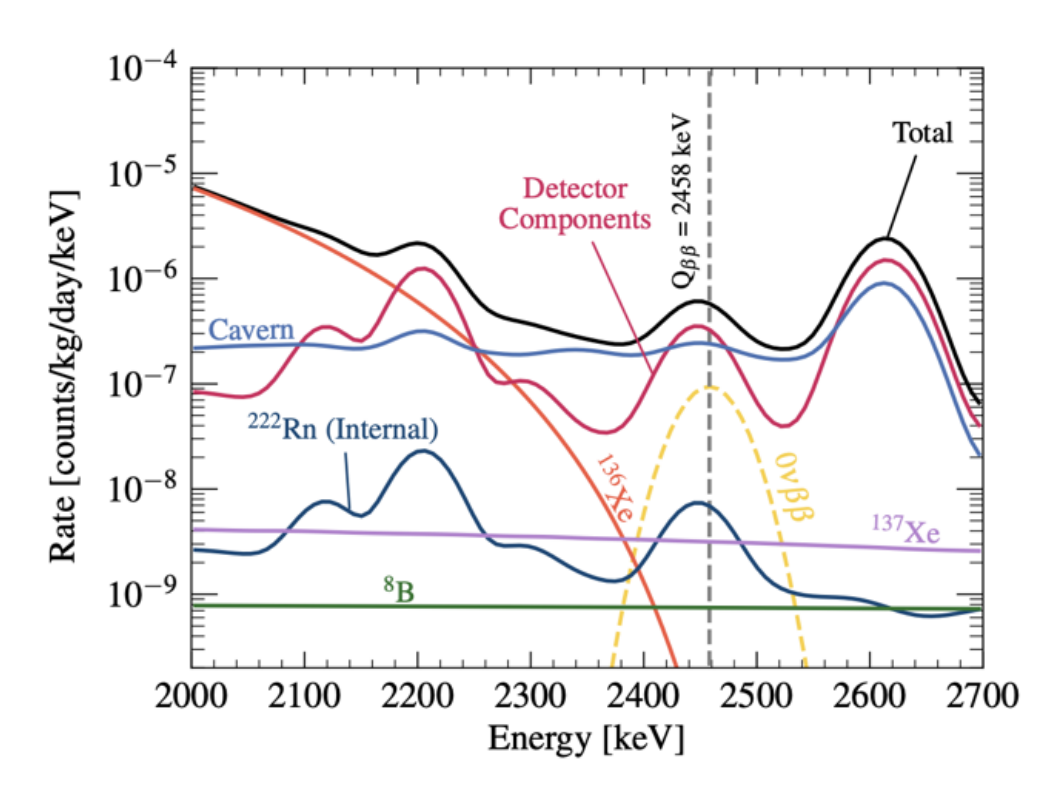


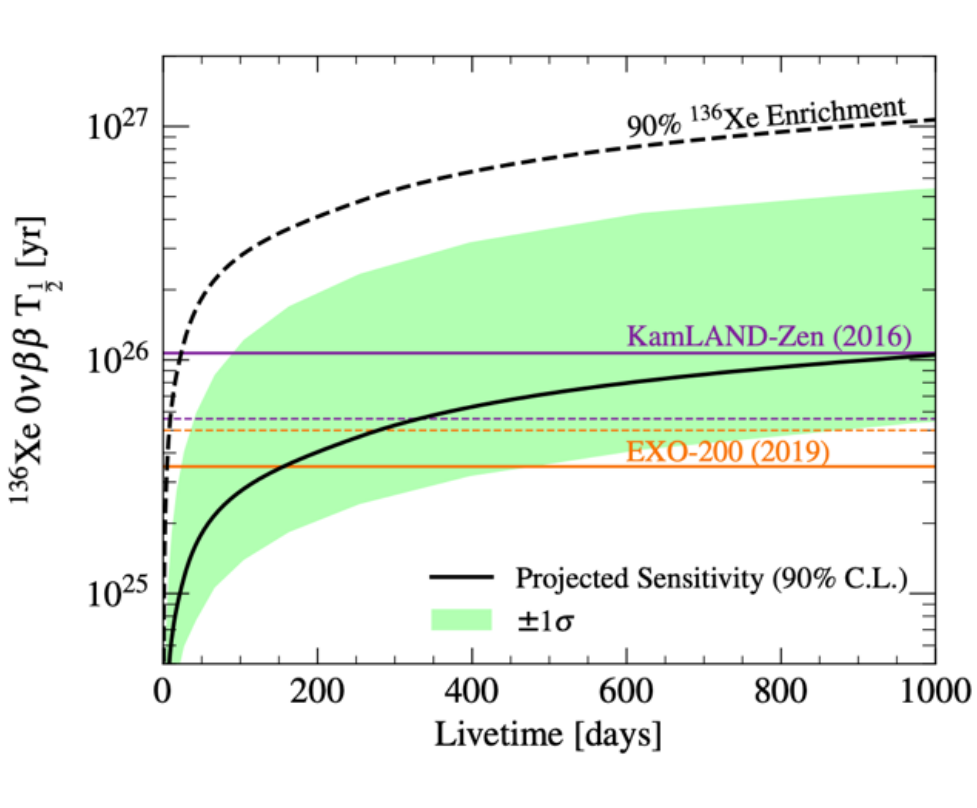


World-leading sensitivities expected to a variety of different new physics accessible via ERs e.g. solar axions, axion-like dark matter, neutrino magnetic moment

ArXiv: 2102.11740

Neutrinoless Double Beta Decay



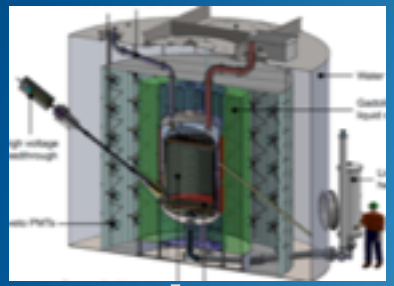


- Nominal 1% energy resolution at ^{136}Xe $Q_{\beta\beta}$ value (2458 keV)
- $T_{1/2}$ (90% C.L.) > 1 x 10^{26} years in 1000 live days in 1 t fiducial volume

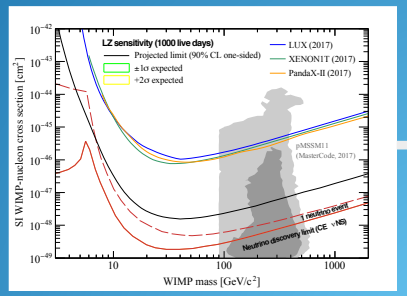
PRC 102, 014602 (2020)

Timeline

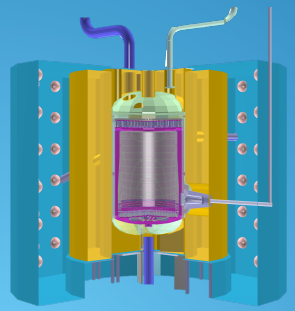
CDR Q4 2015



WIMP Sensitivity Paper Q1 2018



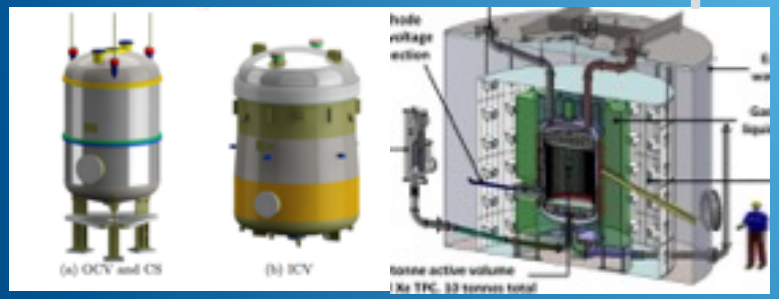
Sims, Cleanliness; ^{136}Xe 0νββ papers Q1-2 2020



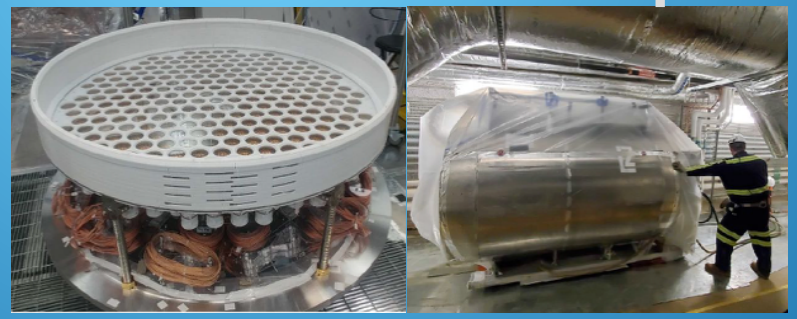
COVID-19 – Experiment in Safe Configuration

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021

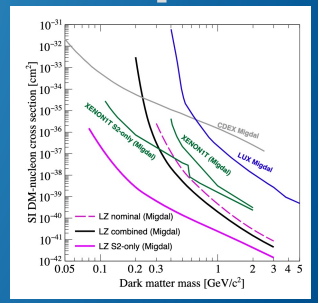
Throughout 2021: Commissioning, first science run



Titanium Paper; TDR Q1 2017

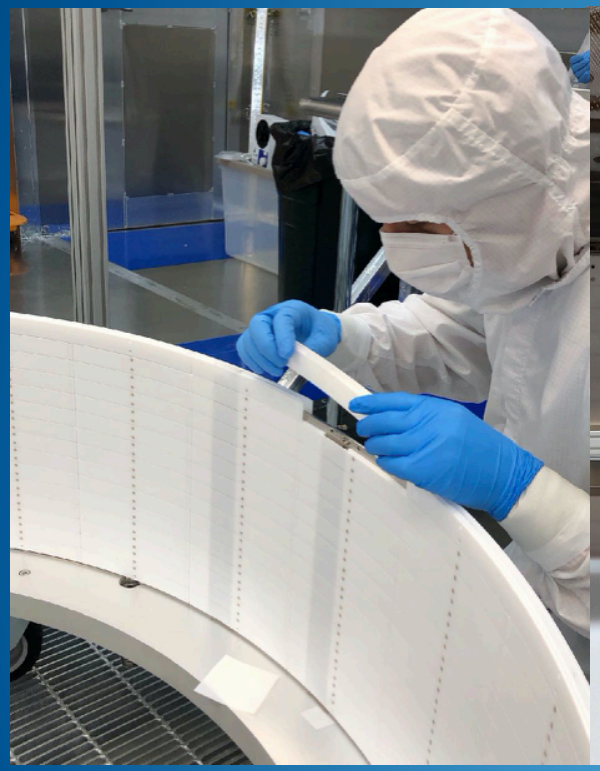


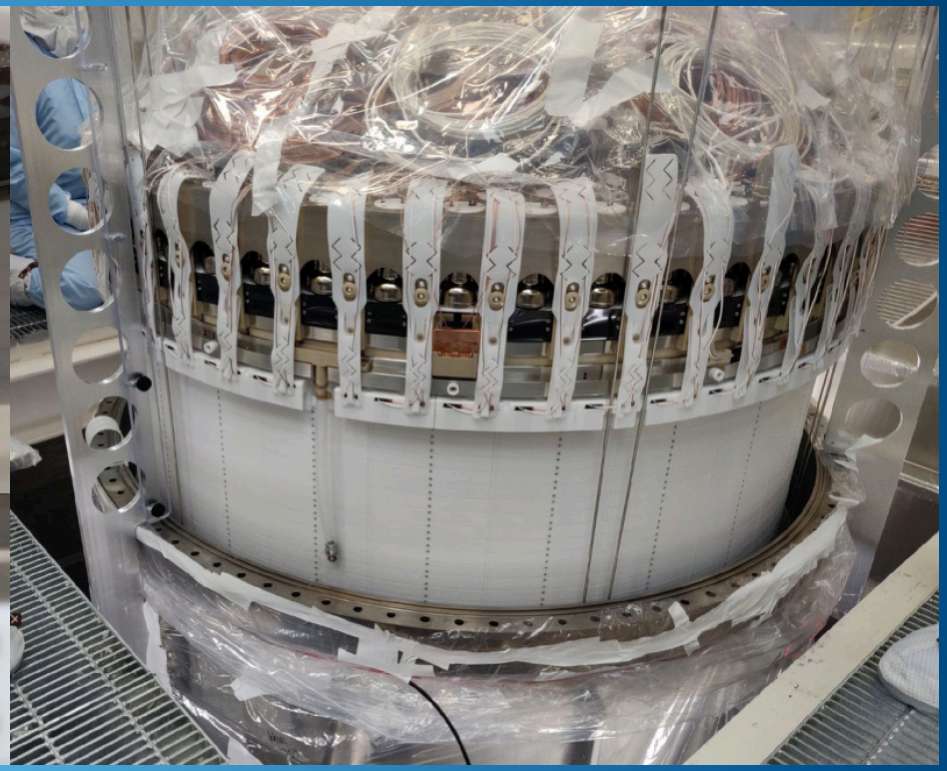
TPC Assembly Finished & Moved Underground Q3-4 2019



Low E ER, DPE & S2-only; ^{134}Xe 0νββ papers Q1-2 2021

TPC Assembly



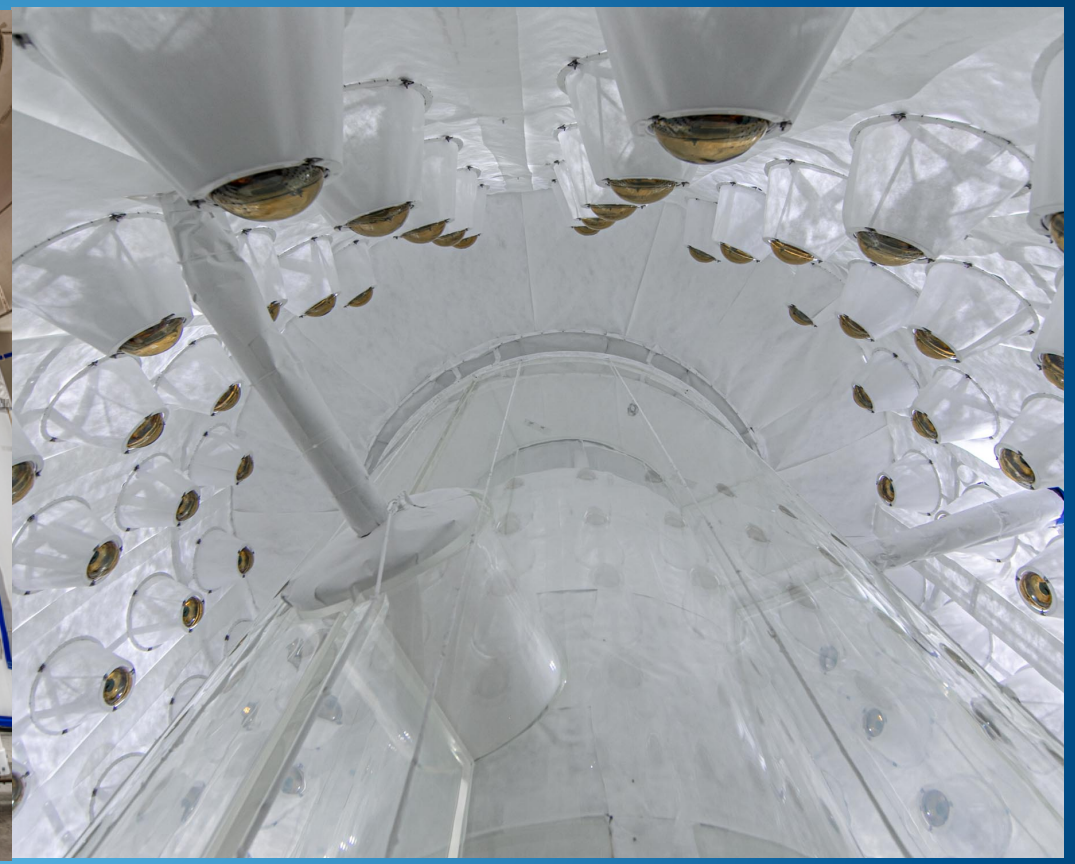


- Detector integration started in Dec. 2018 at Surface Assembly Laboratory (SURF)
- Assembled in radon reduced environment during ~13,500 working hours

TPC Underground

- Inner cryostat vessel (ICV) moved underground & inserted into outer vessel late 2019
- High voltage installed, ICV sealed and under vacuum ahead of COVID early 2020

Outer Detector Assembly

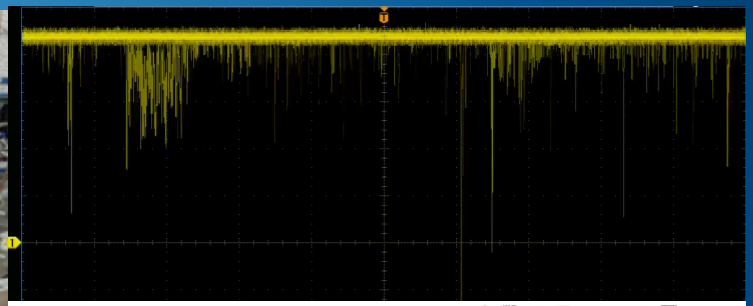


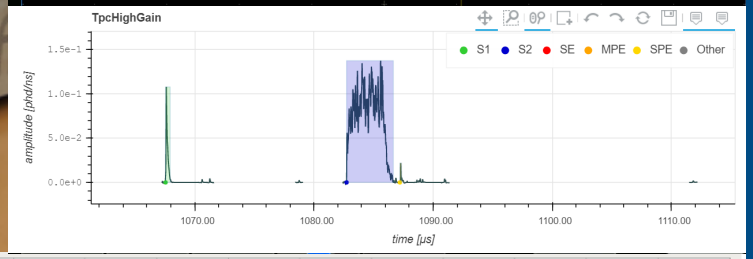
- Acrylic tanks underground early 2019; installation completed with PMT & Tyvek this year
- Optical calibration system* and liquid scintillator fill systems fully tested

*ArXiv: 2102.06281

Tests, Cooldown & Commissioning

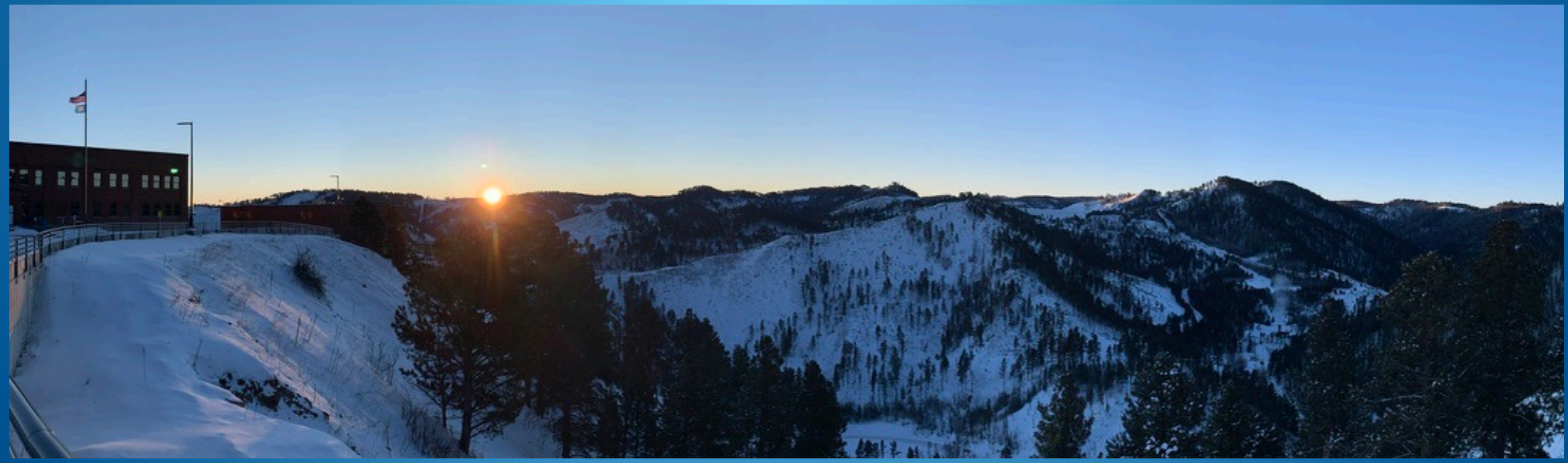
- Underground circulation commissioning completed last year in test cryostat
  - Rate of 500 SLPM - turnover full 10 t of xenon every 2.4 days
- TPC cooled down to ~185 K (cold gas close to operational temperature)
- First S2s seen from cold gas operations





Summary

- LZ is a multi-physics experiment, primed for the detection of WIMPs
- Long-term campaign for backgrounds control to ensure world-leading sensitivities
- Experiment is in its commissioning phase, with first science data expected this year
- A new chapter in dark matter physics is just on the horizon!



Back up

Backgrounds Table

Source	ER [cts]	NR [cts]
Detector Components	9	0.07
Xenon Contaminants (Rn, Kr, Ar)	819	0
Surface Contamination & Dust	40	0.39
Laboratory & Cosmogenics	5	0.06
Physics (2vBB decay, neutrinos)	258	0.51
Total	1131	1.03
After 99.5% ER discrimination, 50% NR efficiency	**5.66**	**6.18**

Oxford Physics

ER & NR Backgrounds