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

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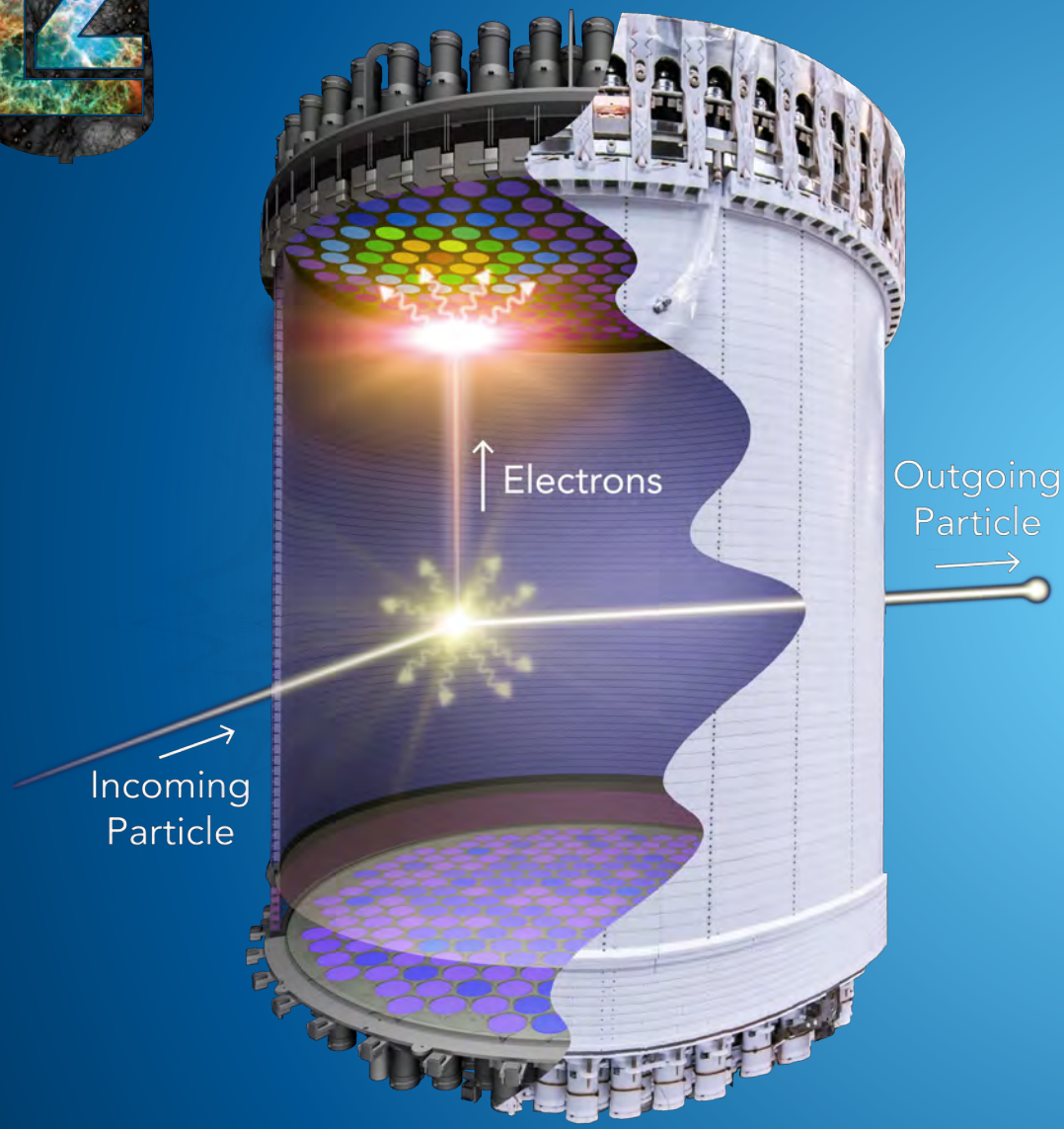
University of Oxford,
16th Patras Workshop

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

Science and Technology Facilities Council

Institute for Basic Science ibs 기초과학연구원

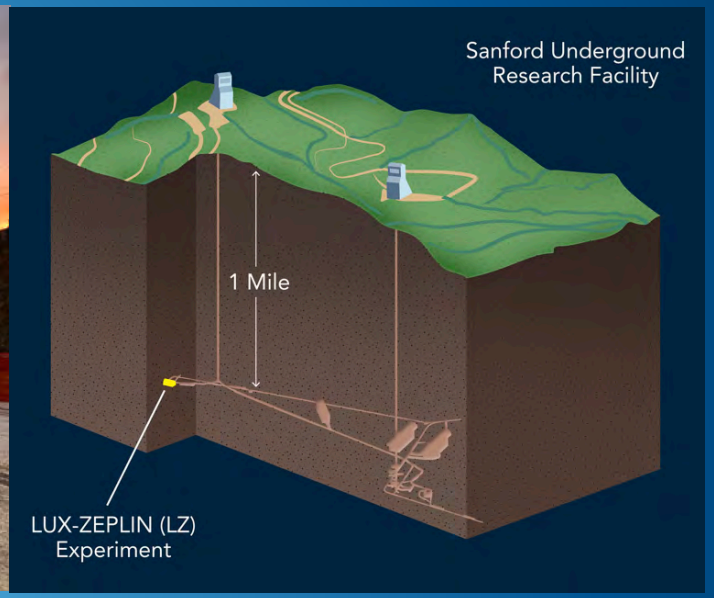
Sanford Underground Research Facility
South Dakota Science and Technology Authority

FCT Fundação para a Ciência e a Tecnologia

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

Oxford Physics

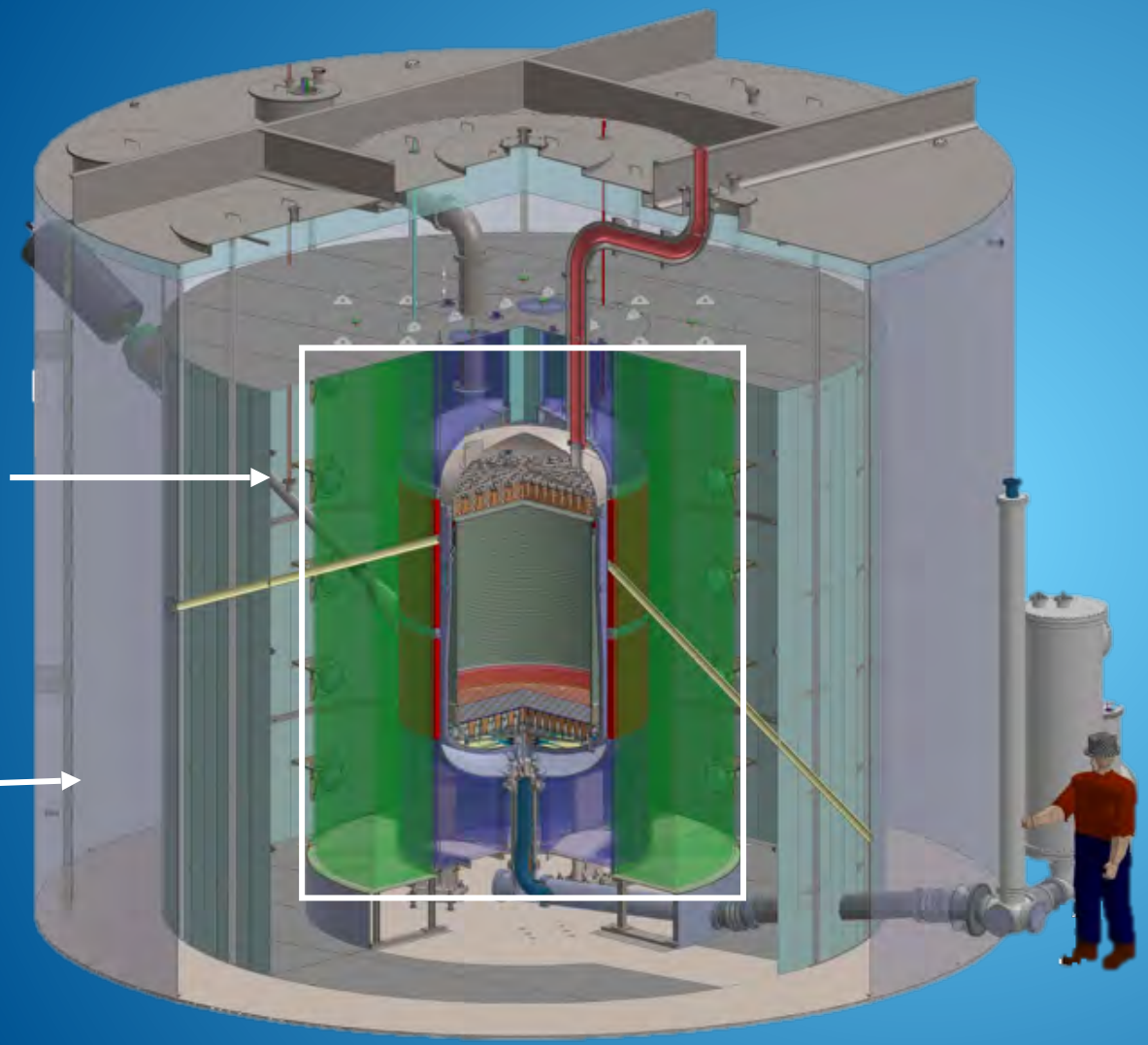
The Location

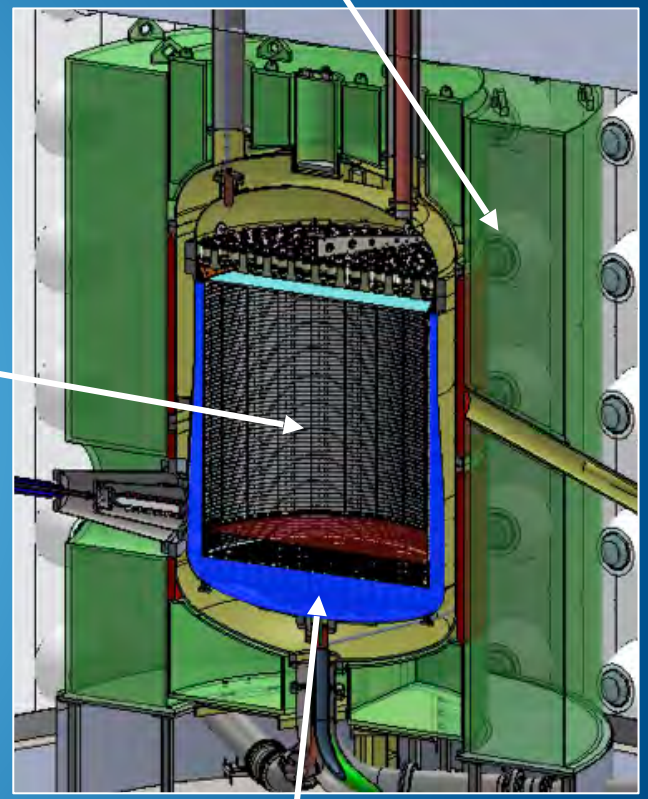


- Sanford Underground Research Facility (SURF) - Black Hills, South Dakota
- Situated in the Davis Cavern at the 4850 level (~1.5 km underground)
- 4300 metres of water equivalent overburden – reduces muon flux by ~10^6

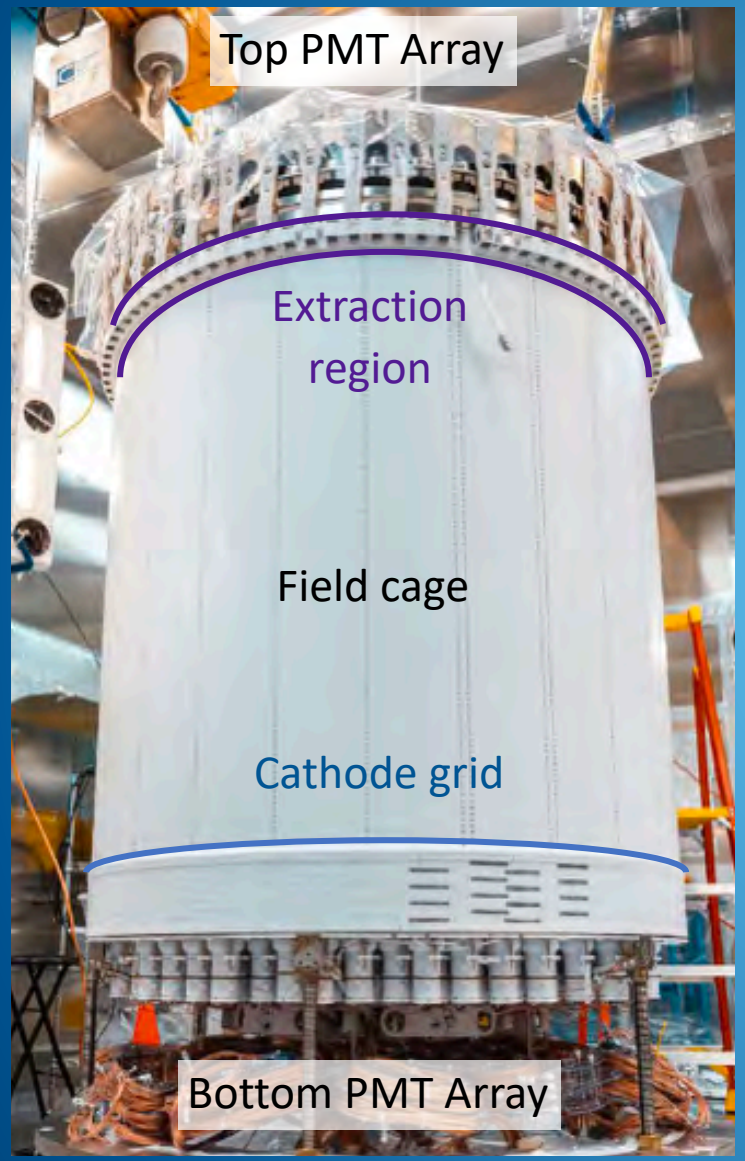
The Detectors

NIM A, 163047 (2019)

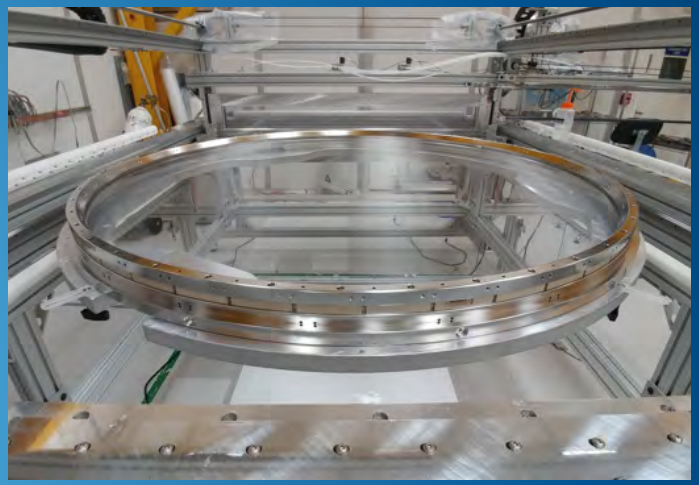




TPC in Detail



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



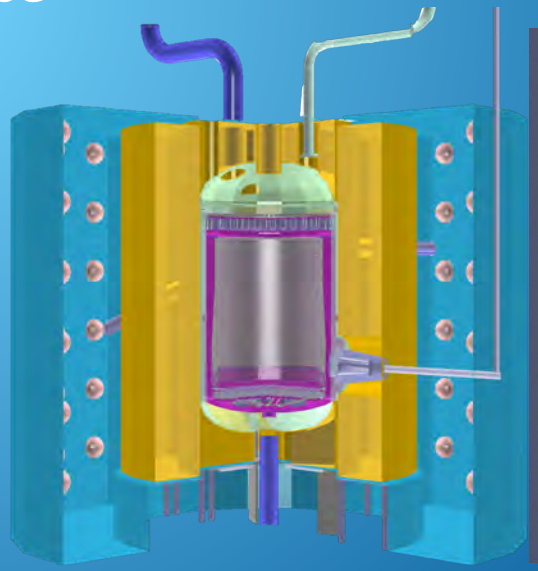
- Grid electrodes help maintain field stability
  - Cathode nominal voltage of -50 kV
  - Extraction region for S2 defined by gate and anode
- Field cage for drift field, PTFE clad for light collection

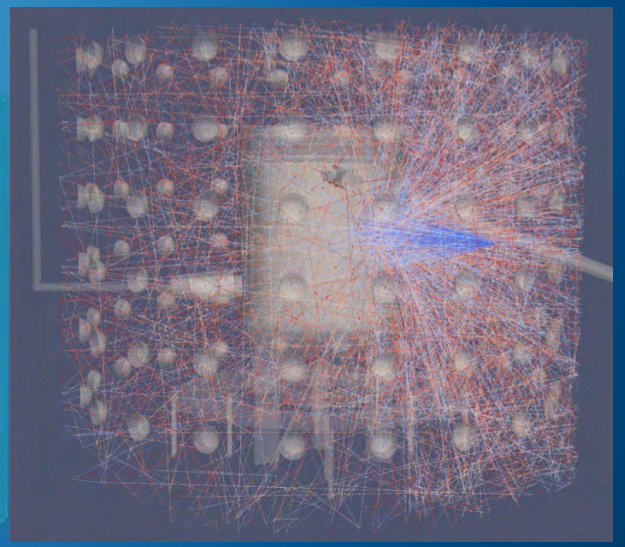
Veto Detectors in Detail

- ~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

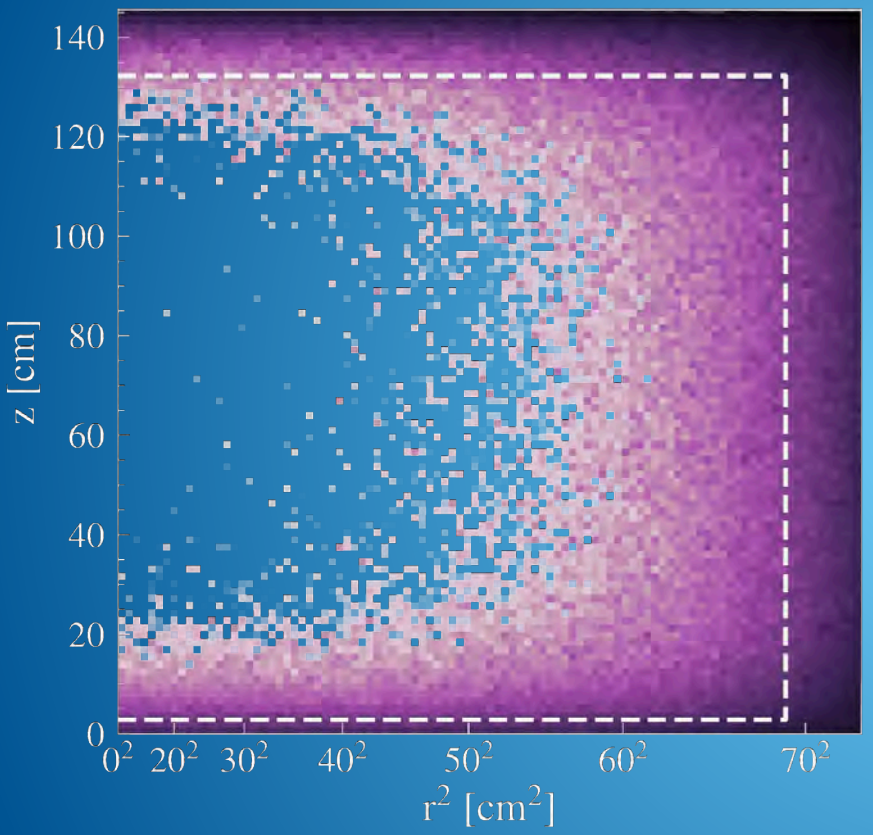




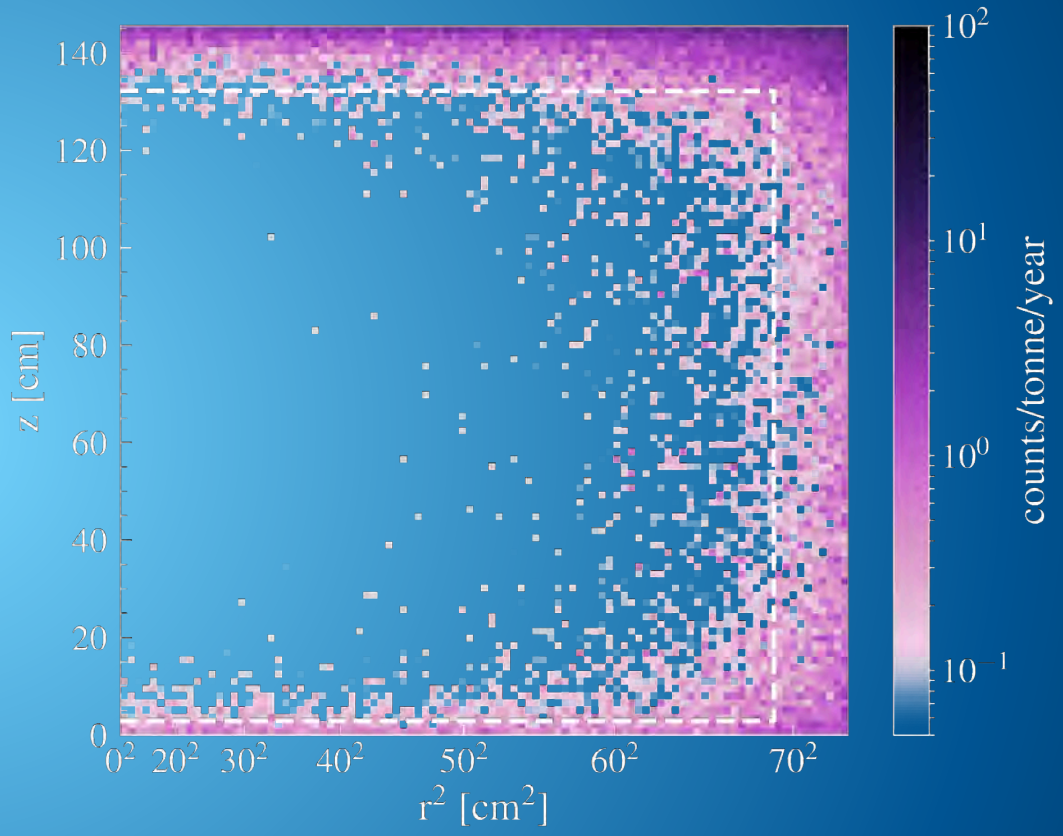
EPJC, Vol 80: 1044 (2020); j.astropartphys.2020.102480

Veto Impact on Backgrounds

No vetoes: 10.4 NR cts/1000 days

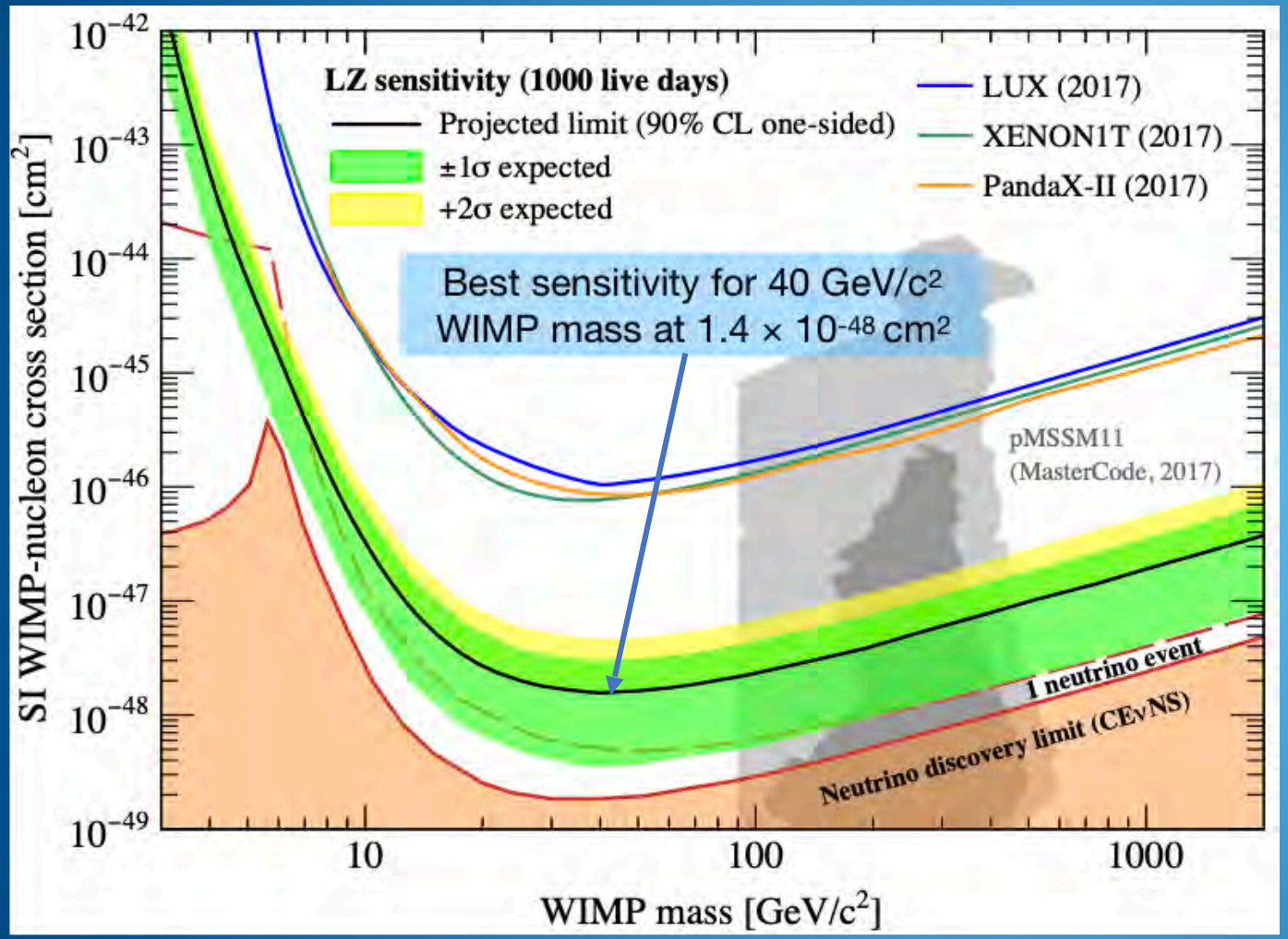


With vetoes: 1.0 NR cts/1000 days



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**

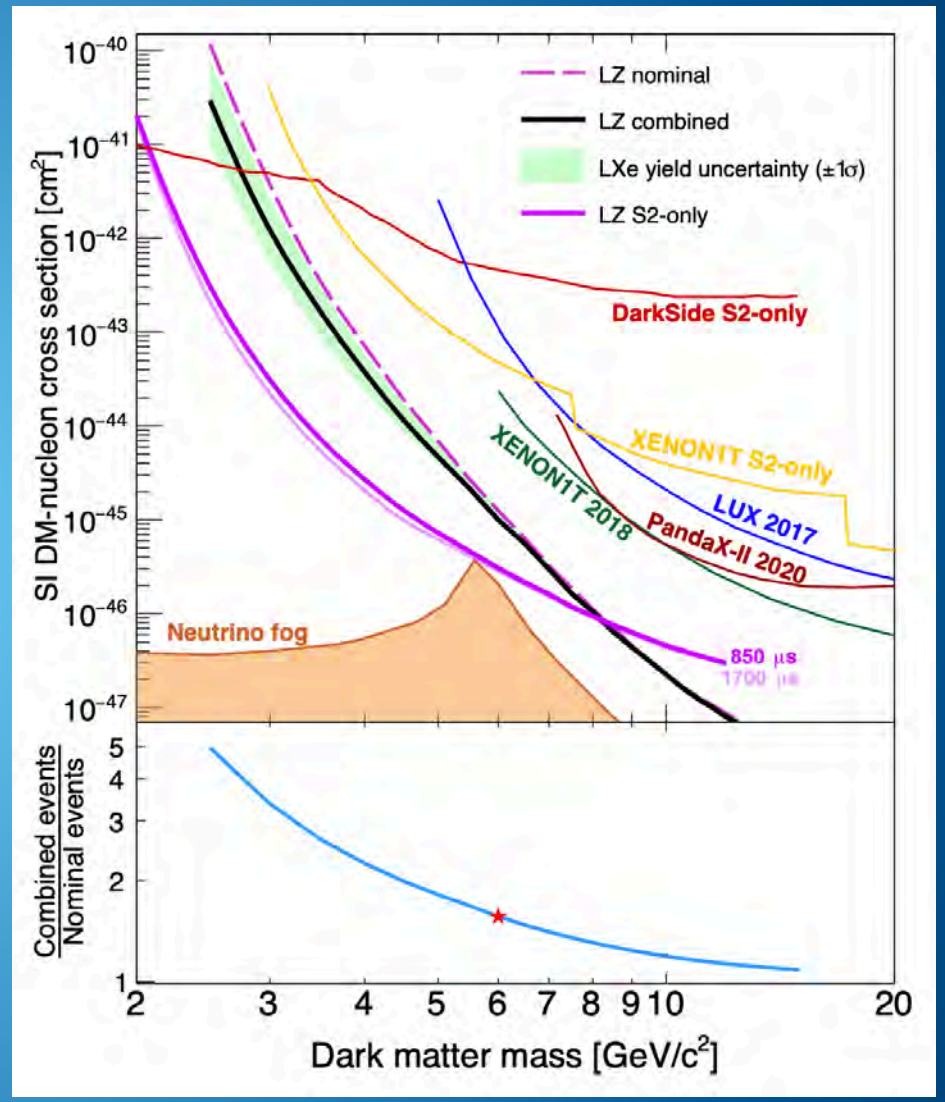
Radon comprises almost half our expected backgrounds in this region

PRD 101, 052002 (2020)

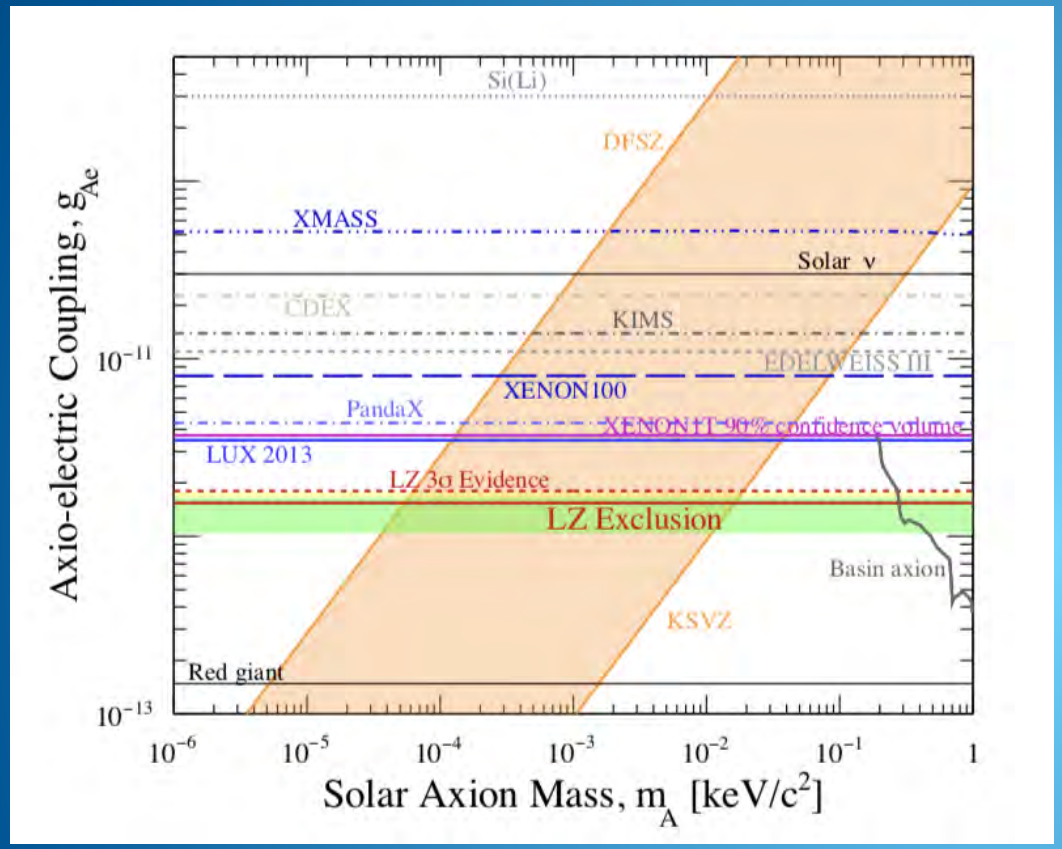
Extending to Lower Mass Candidates

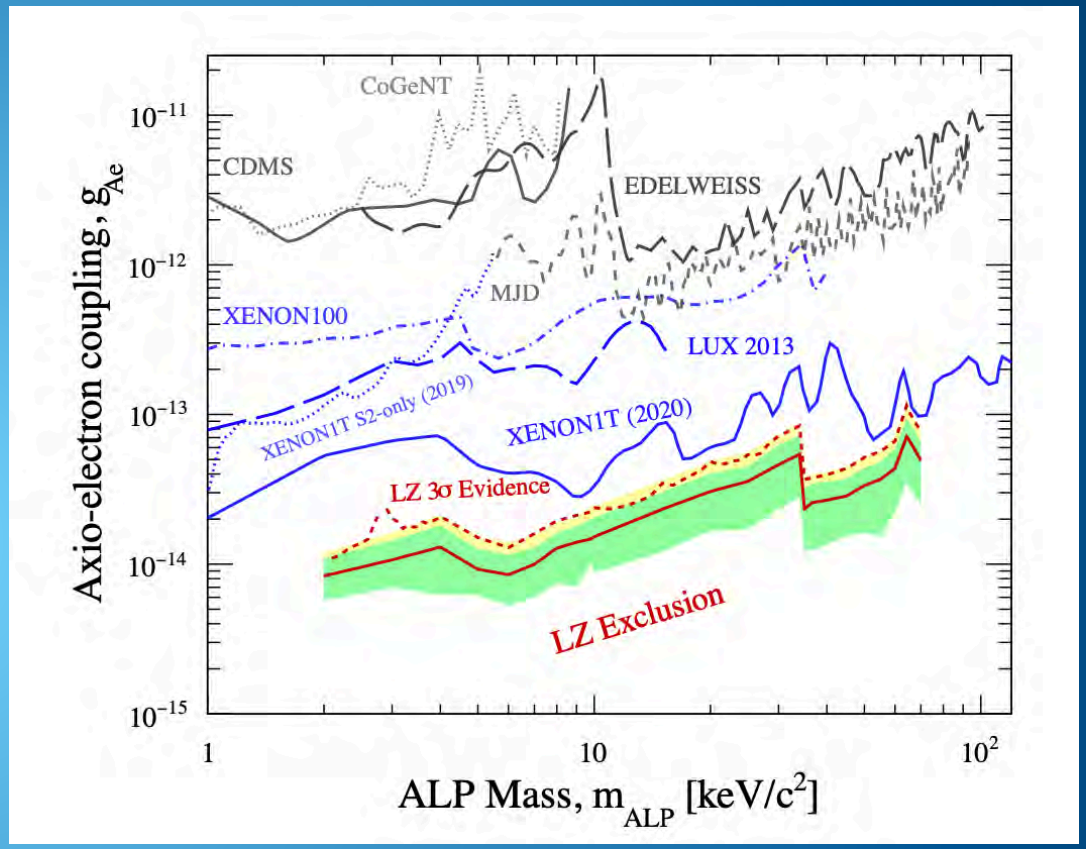
- Lower the energy threshold
  - Reduce S1 coincidence requirement from 3 to 2 (exploiting PMT double photoelectric effect)
    - ~4x improvement at 2.5 GeV/c^2
  - Conduct an S2-only search
    - Greater challenge for background discrimination -> use pulse width
- Sub-GeV masses accessible when considering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

ArXiv: 2101.08753



Physics Via Low Energy Electron Recoils

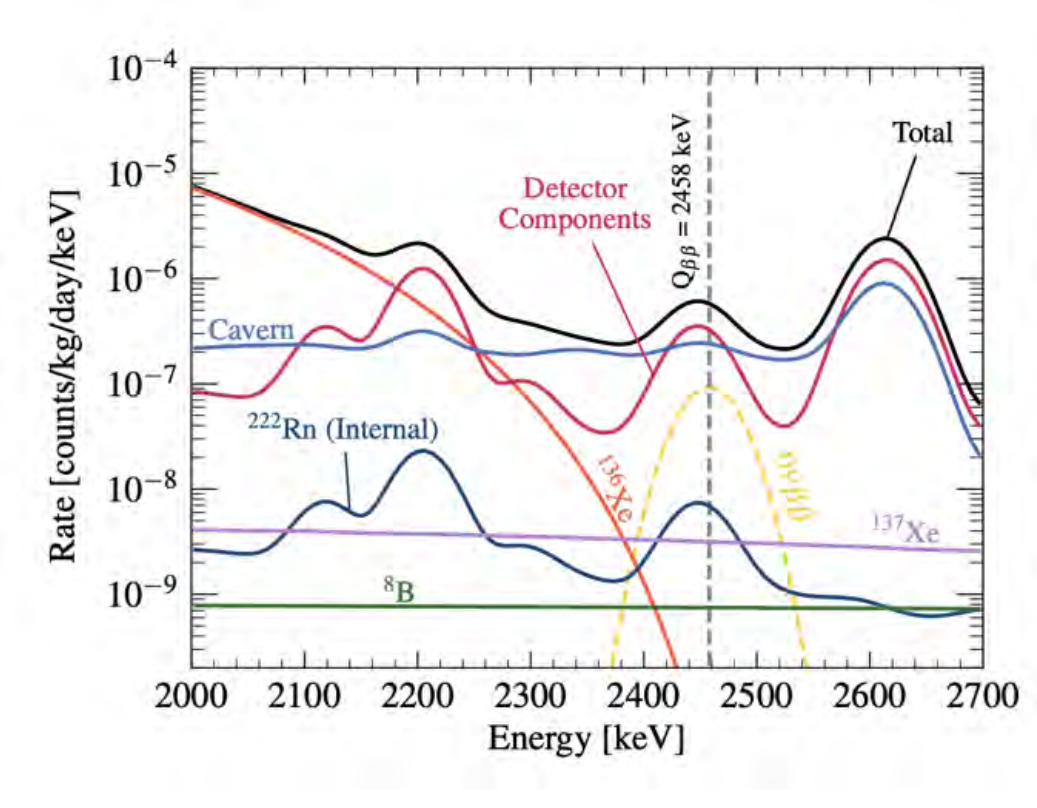


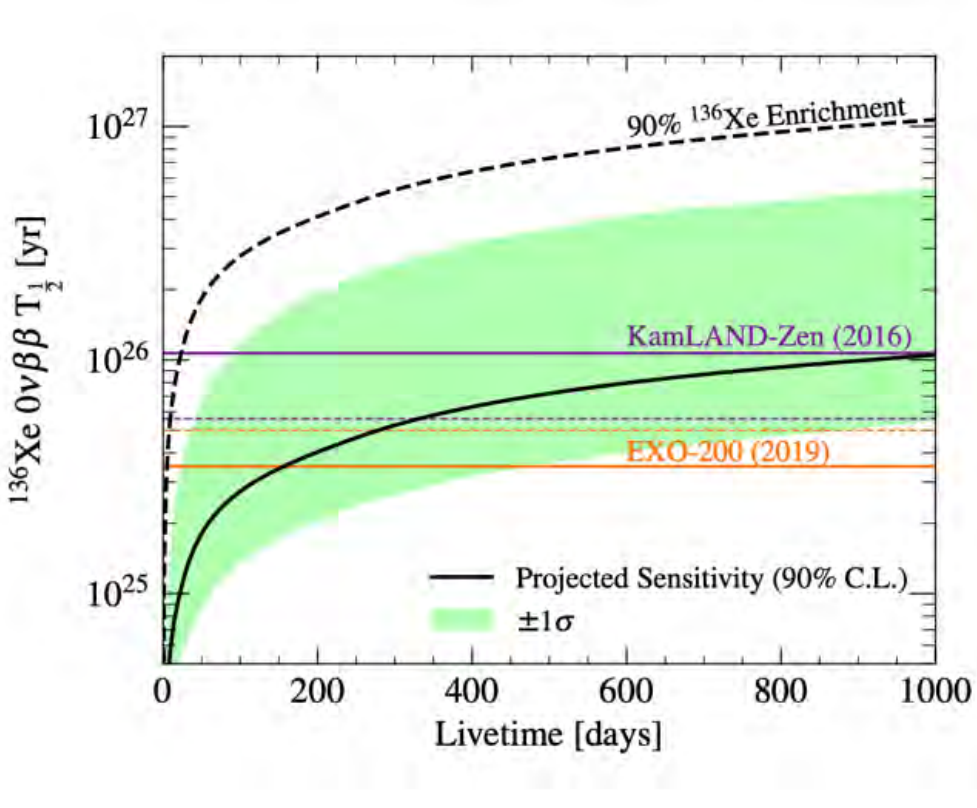


World-leading sensitivities expected to a variety of different new physics accessible via ERs e.g. solar axions, axion-like dark matter, neutrino magnetic moment

ArXiv: 2102.11740

Neutrinoless Double Beta Decay





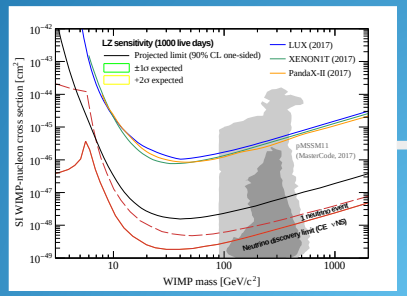
- Nominal 1% energy resolution at ^{136}Xe $Q_{\beta\beta}$ value (2458 keV)
- $T_{1/2}$ (90% C.L.) > 1 x 10^{26} years in 1000 live days in 1 t fiducial volume

PRC 102, 014602 (2020)

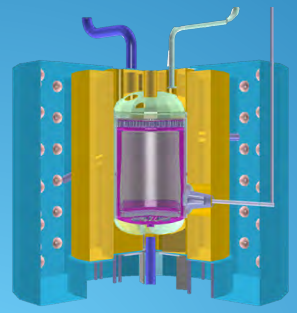
Timeline

CDR Q4 2015

WIMP Sensitivity Paper Q1 2018



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



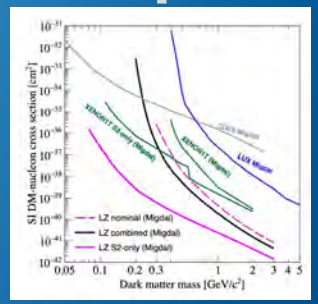
COVID-19 – Experiment in Safe Configuration

2015 2016 2017 2018 2019 2020 2021

Throughout 2021: Commissioning, first science run

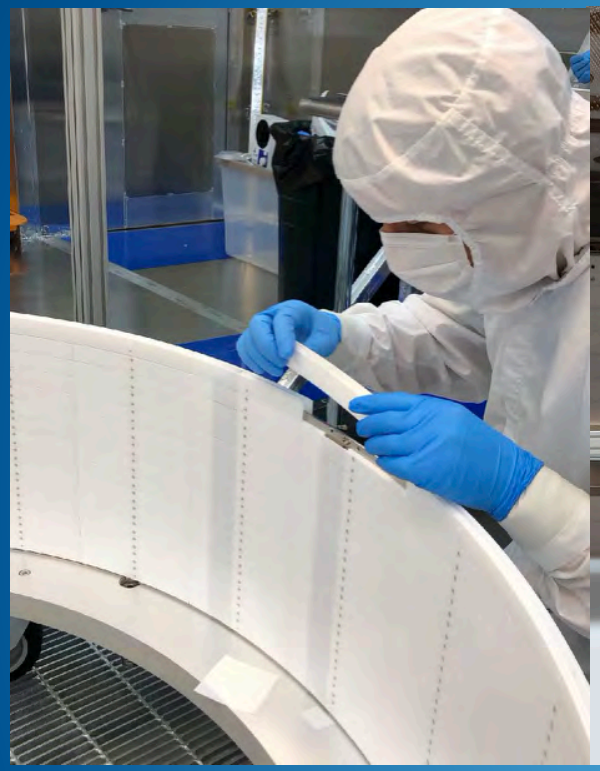
Titanium Paper; TDR Q1 2017

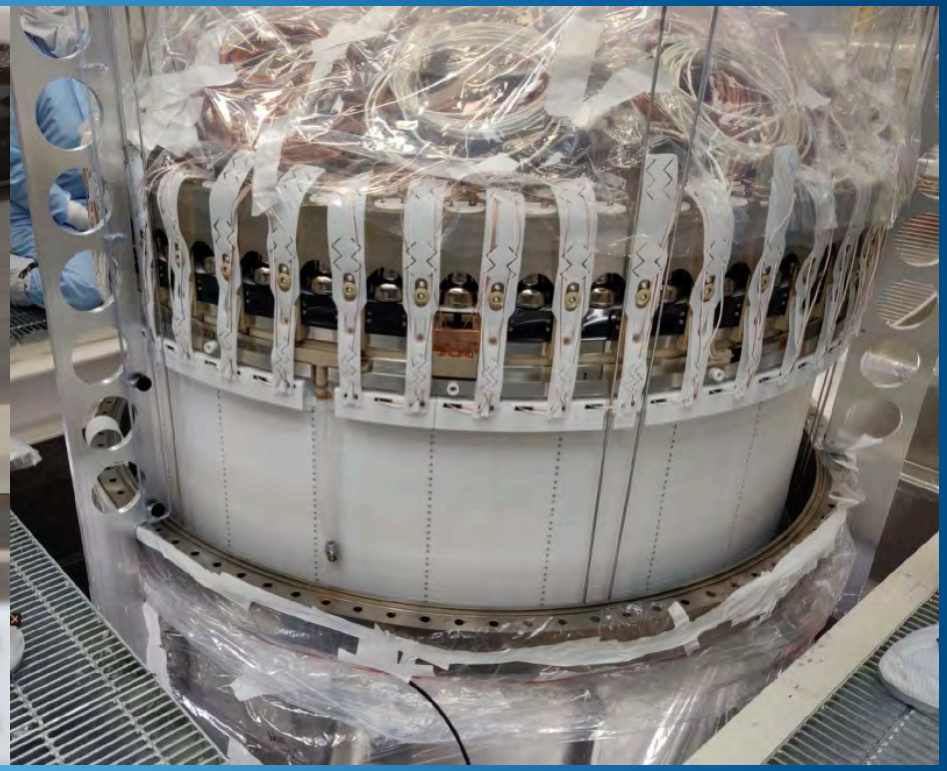
TPC Assembly Finished & Moved Underground Q3-4 2019



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

TPC Assembly



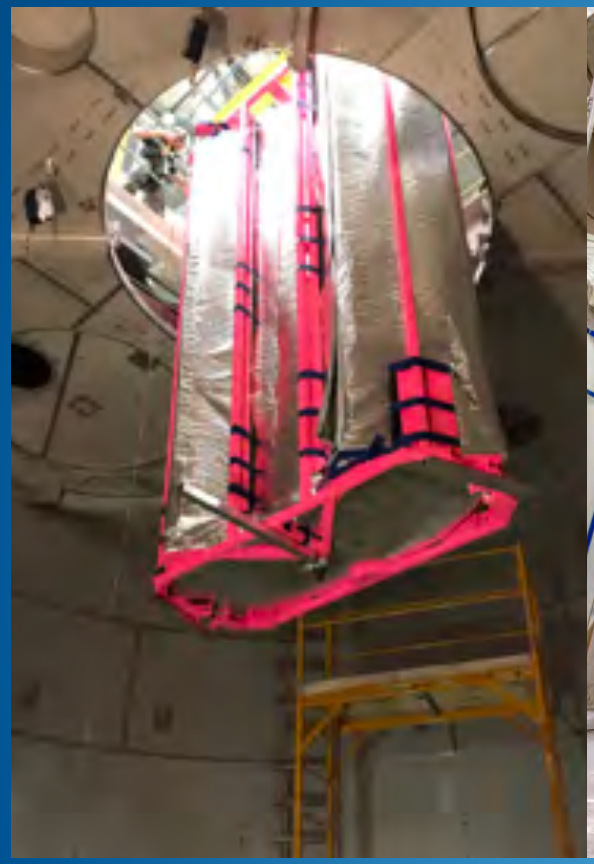


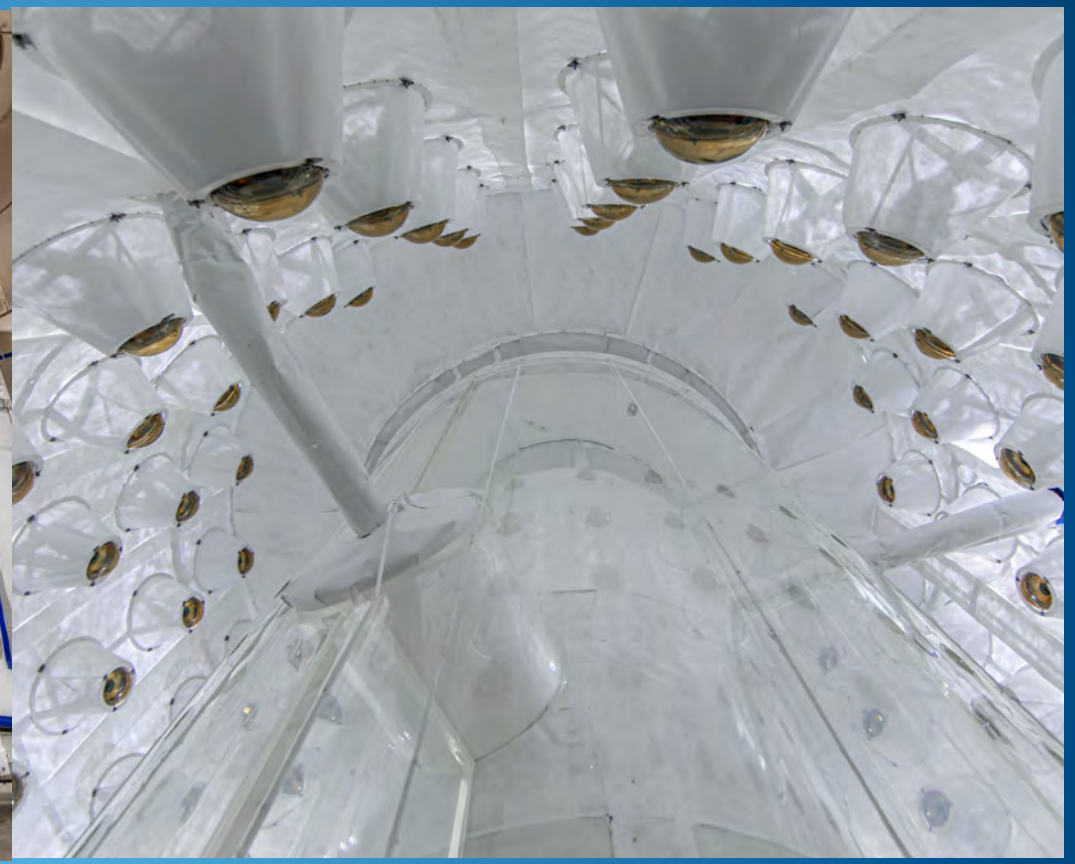
- Detector integration started in Dec. 2018 at Surface Assembly Laboratory (SURF)
- Assembled in radon reduced environment during ~13,500 working hours

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



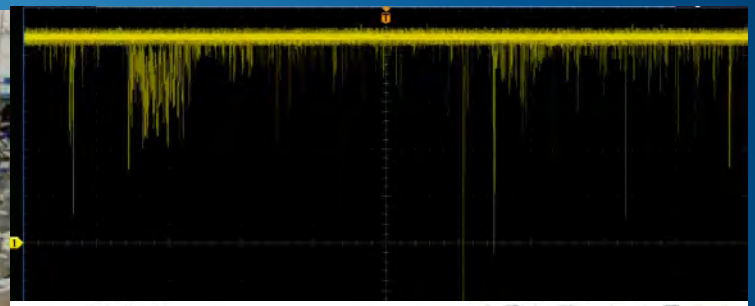


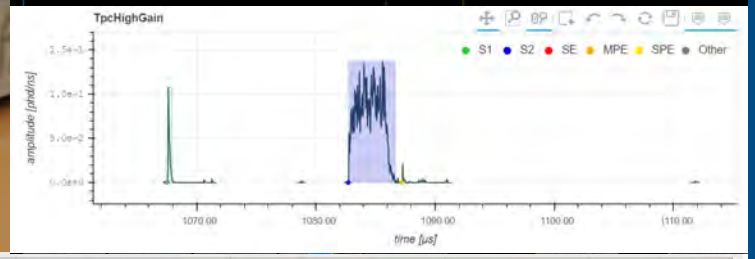
- Acrylic tanks underground early 2019; installation completed with PMT & Tyvek this year
- Optical calibration system* and liquid scintillator fill systems fully tested

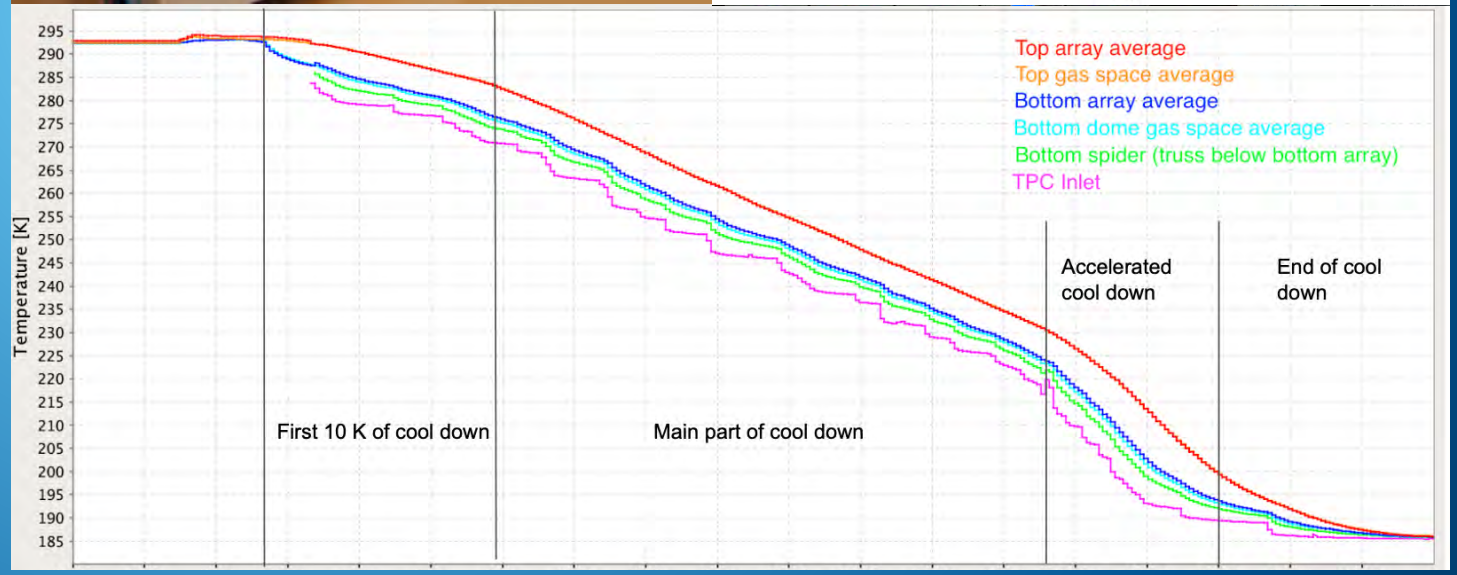
*ArXiv: 2102.06281

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

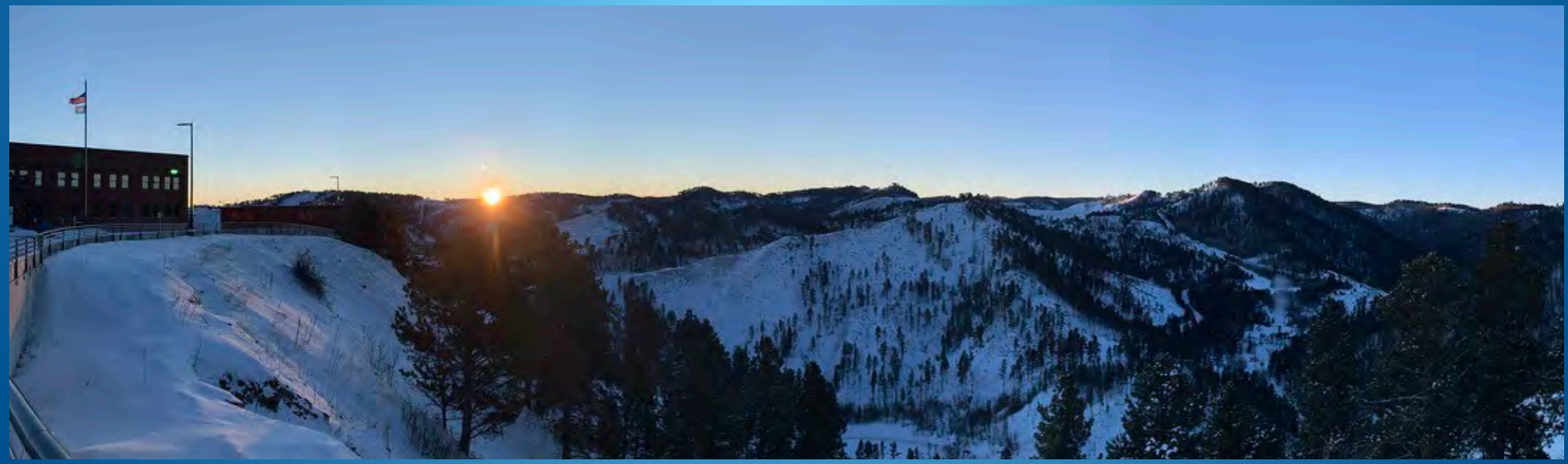


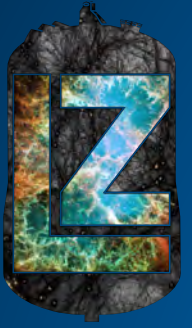




Summary

- 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**

ER & NR Backgrounds