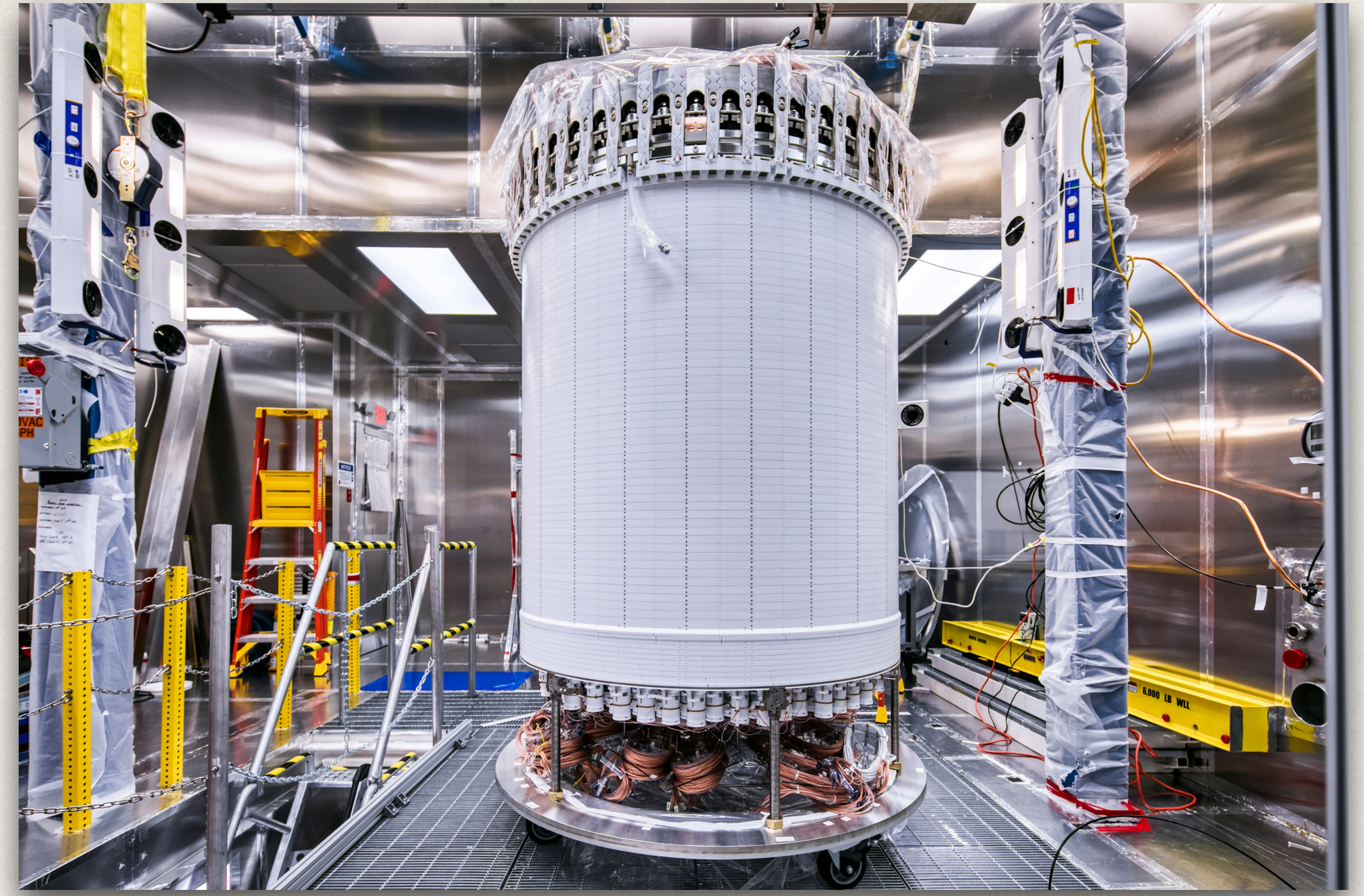



# Status of the LUX-ZEPLIN Experiment

Alexandre Lindote, for the LZ Collaboration

LIP and University of Coimbra

*May 24th 2022*

# The LUX-ZEPLIN (LZ) Collaboration

- 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.
- 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 Wisconsin, Madison

US UK Portugal Korea

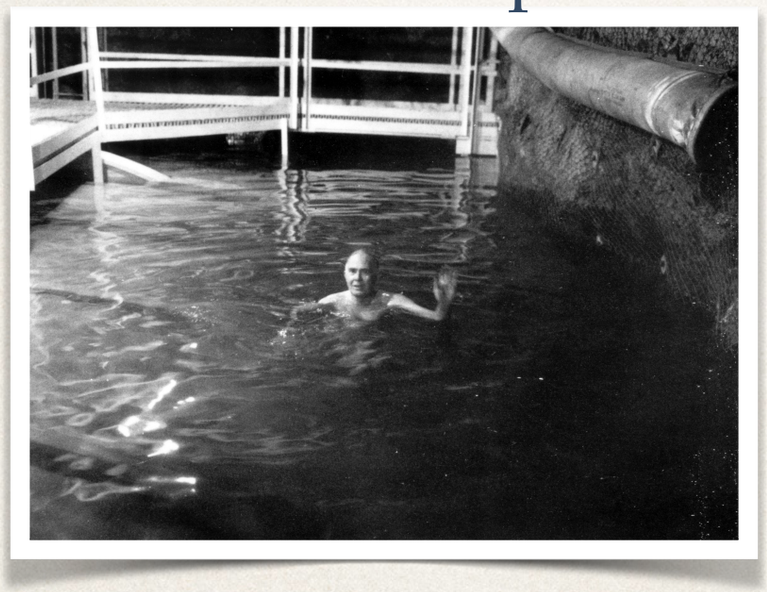

- 35 institutions
- 250 scientists, engineers and technicians

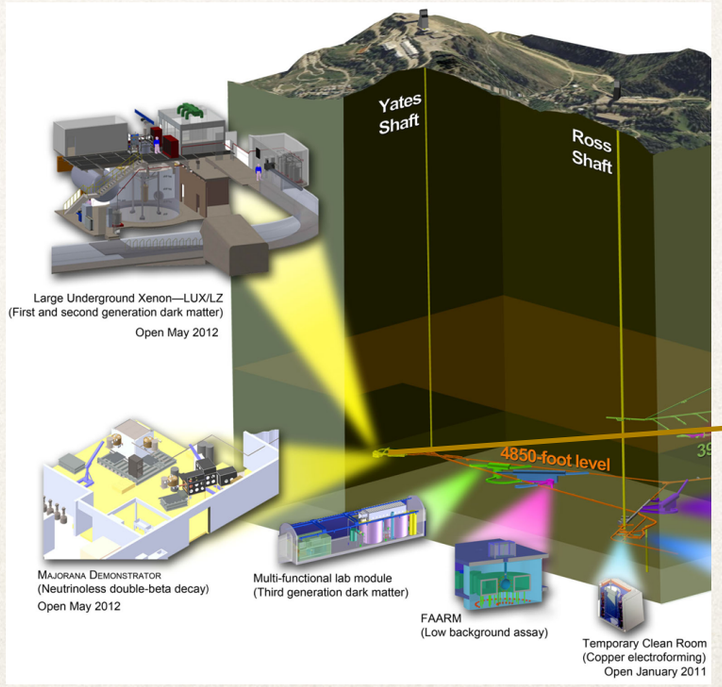
@lzdarkmatter

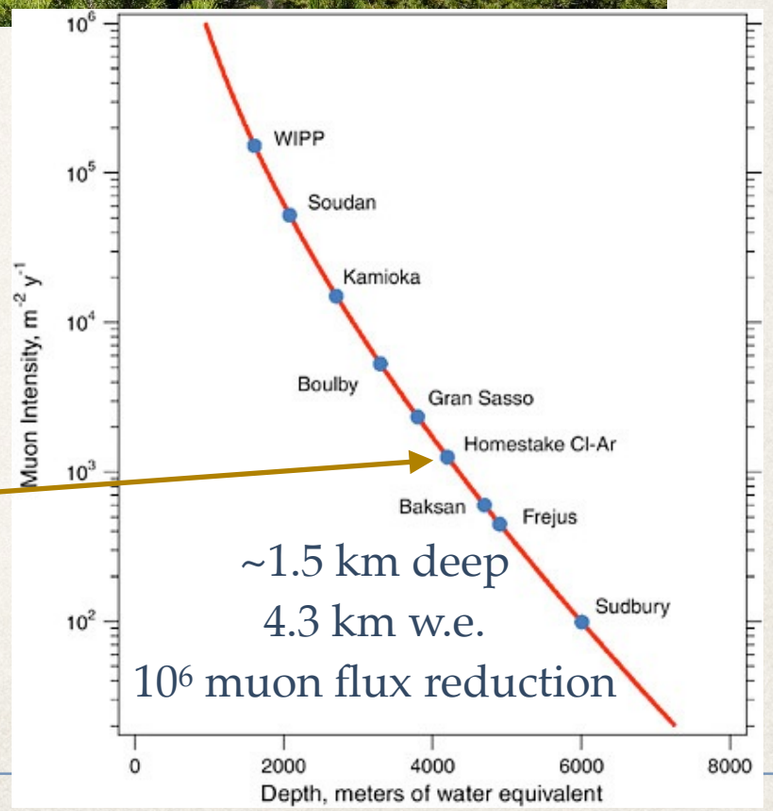
https://lz.lbl.gov/

# Sanford Underground Research Facility (SURF)


## Davis Campus





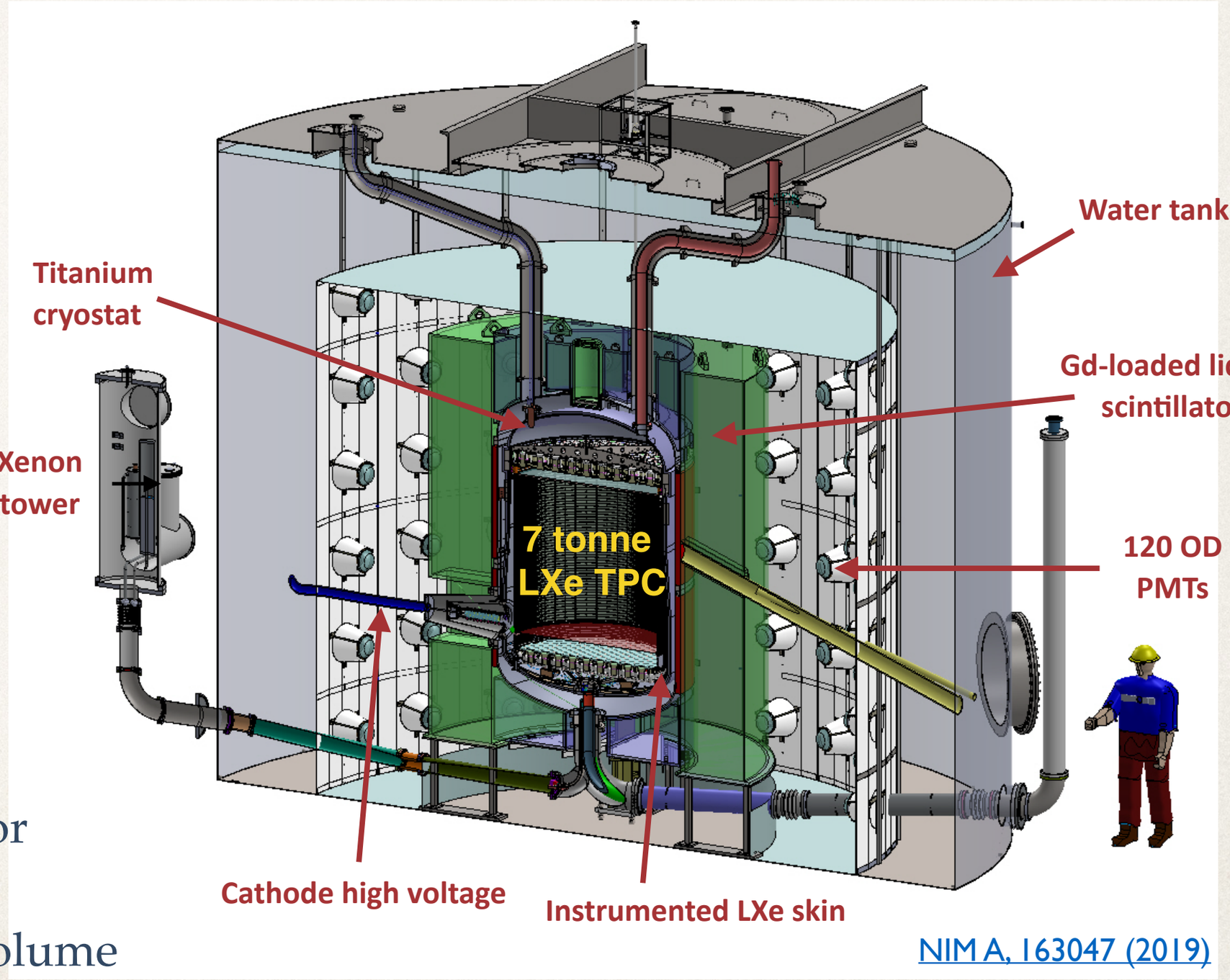
# The LZ Detector

## Xenon TPC

- 10 t total mass
- 7 t in active region

## Veto systems:

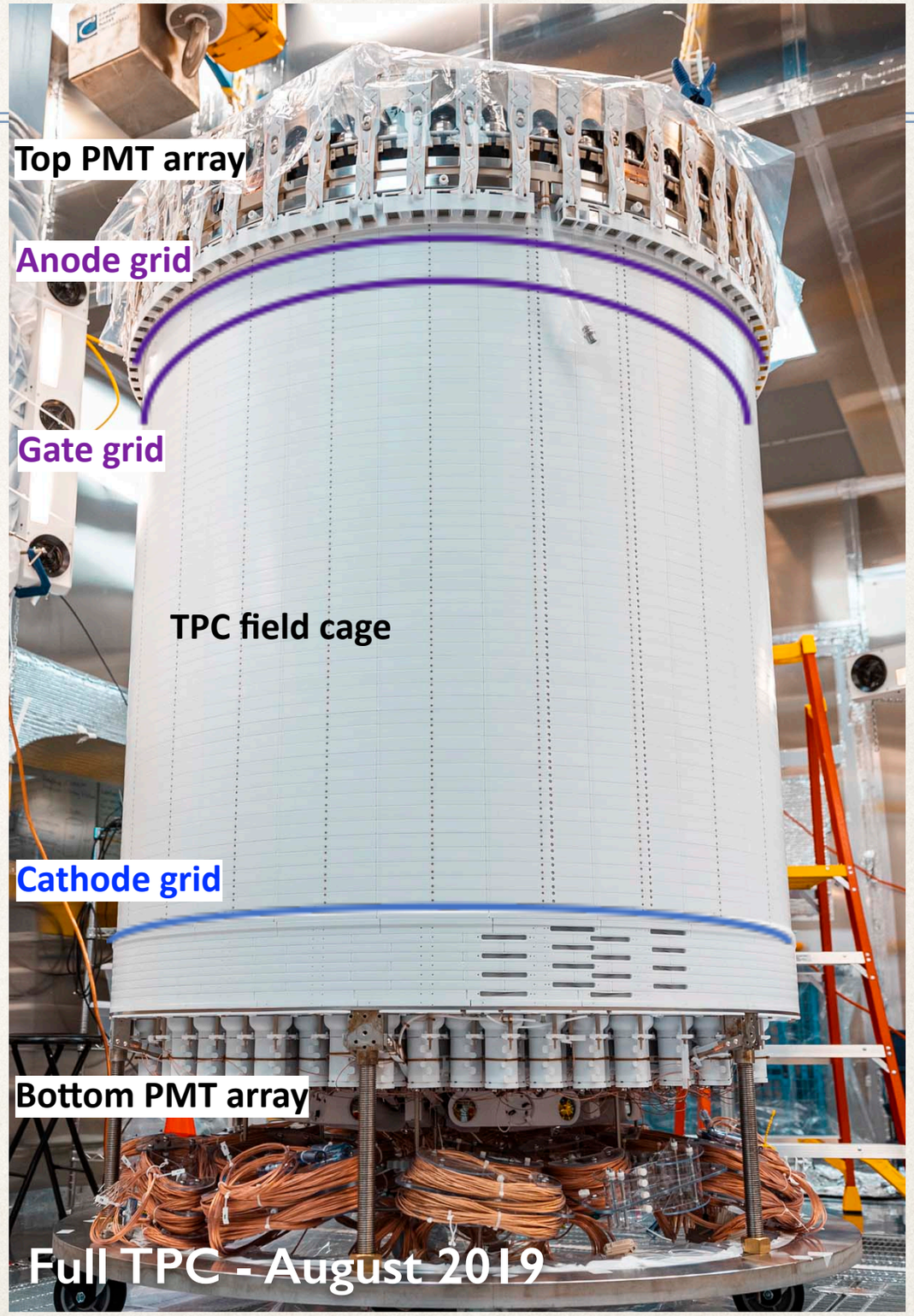
- Water tank
- Gd-loaded scintillator
- LXe skin
- Maximize fiducial volume




NIM A, 163047 (2019)

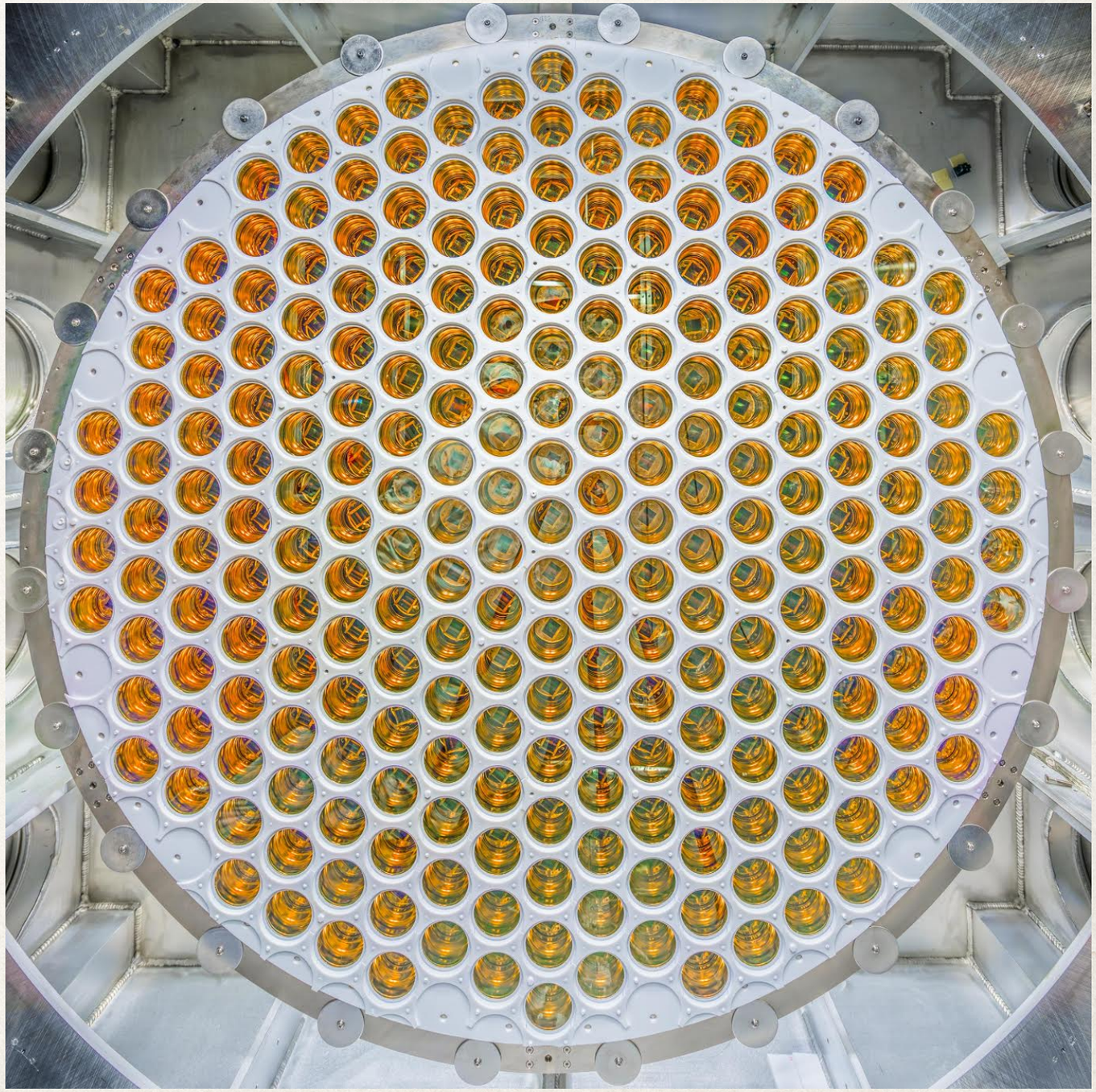
# Xenon TPC

- 7 tonnes of active mass
  - 1.5 m diameter × 1.5 m height
- 494 3″ PMTs
- Inner surfaces in PTFE



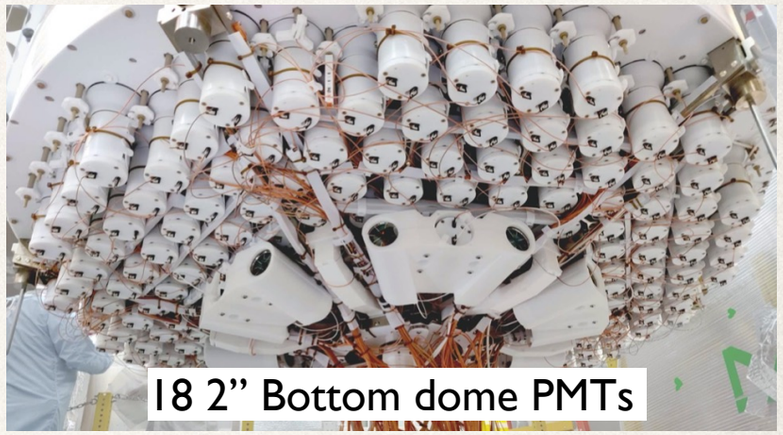
# PMT Arrays

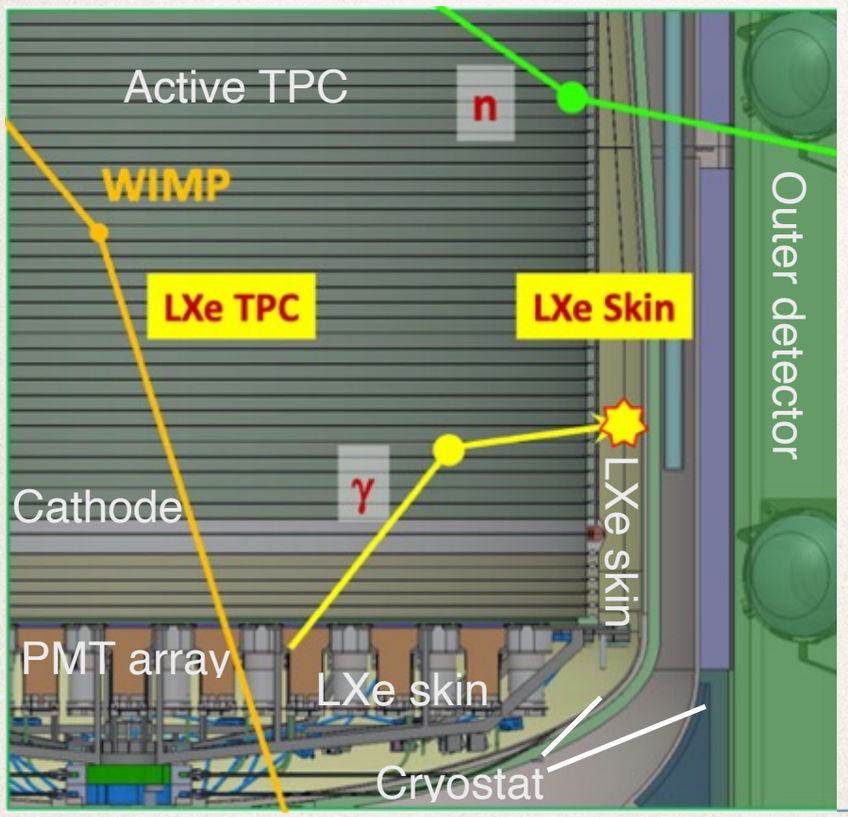
- 494 Hamamatsu R11410 (3”)
  - 253 in the top array
  - 241 in the bottom array

# The Xenon Skin

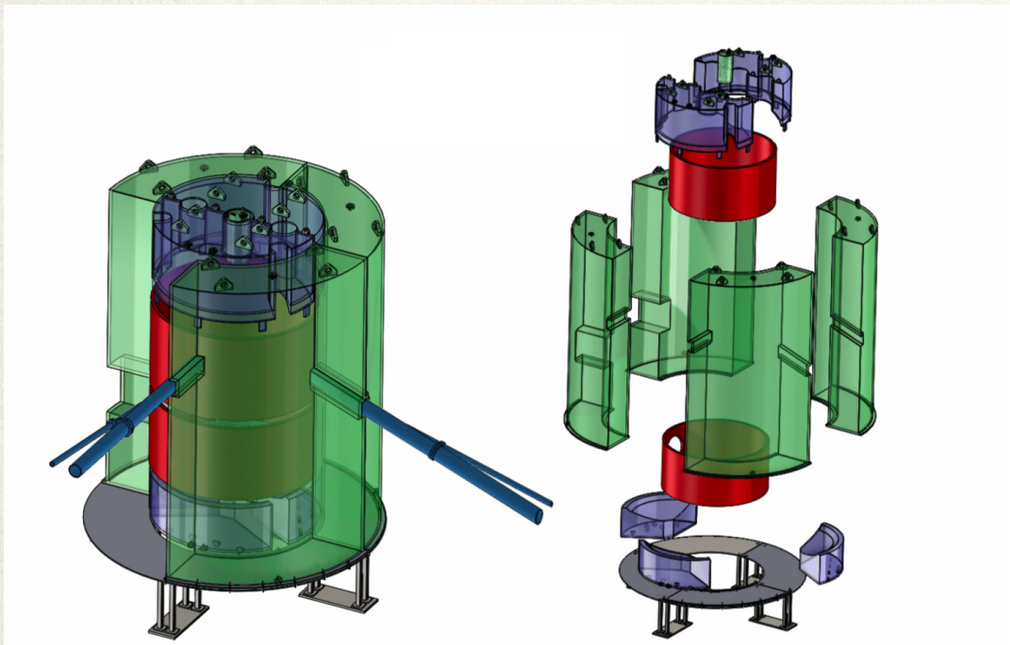
- Veto detector for $\gamma$-rays
- 2 t of LXe surrounding the TPC
- Optically isolated from the TPC
- Instrumented with 1” (side) and 2” (bottom) PMTs
- All surfaces covered in PTFE to maximize light collection

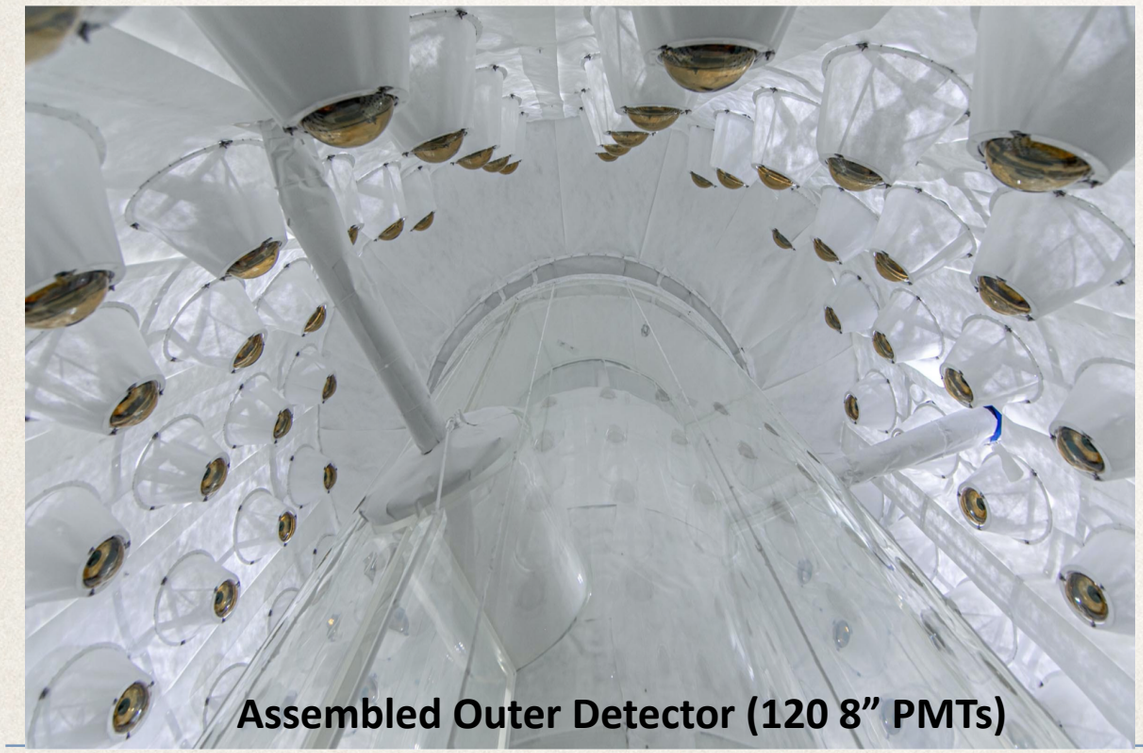





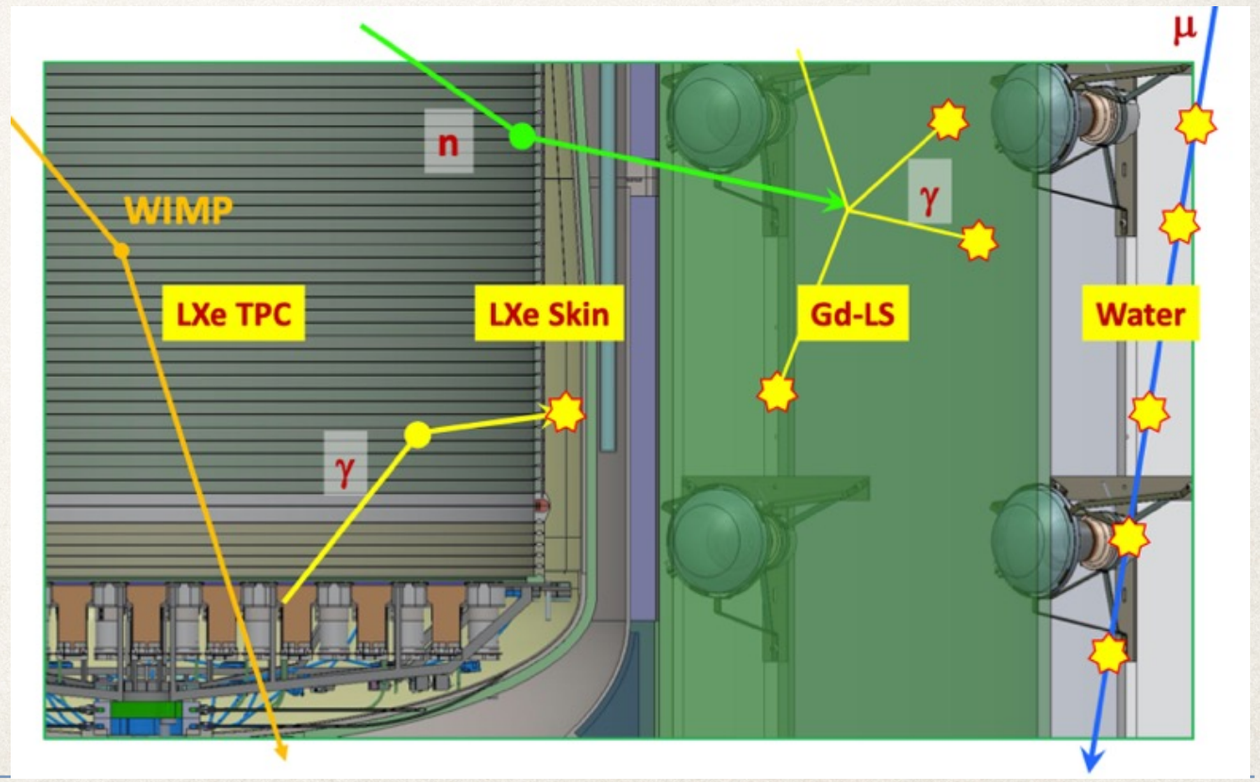
# The Outer Detector



- Suppress neutron induced background
- 17 t Gd-loaded liquid scintillator in acrylic tanks
- Surrounded by 120 8” PMTs
- ~8 MeV $\gamma$-rays following Gd neutron capture
- 95% design efficiency for tagging neutrons

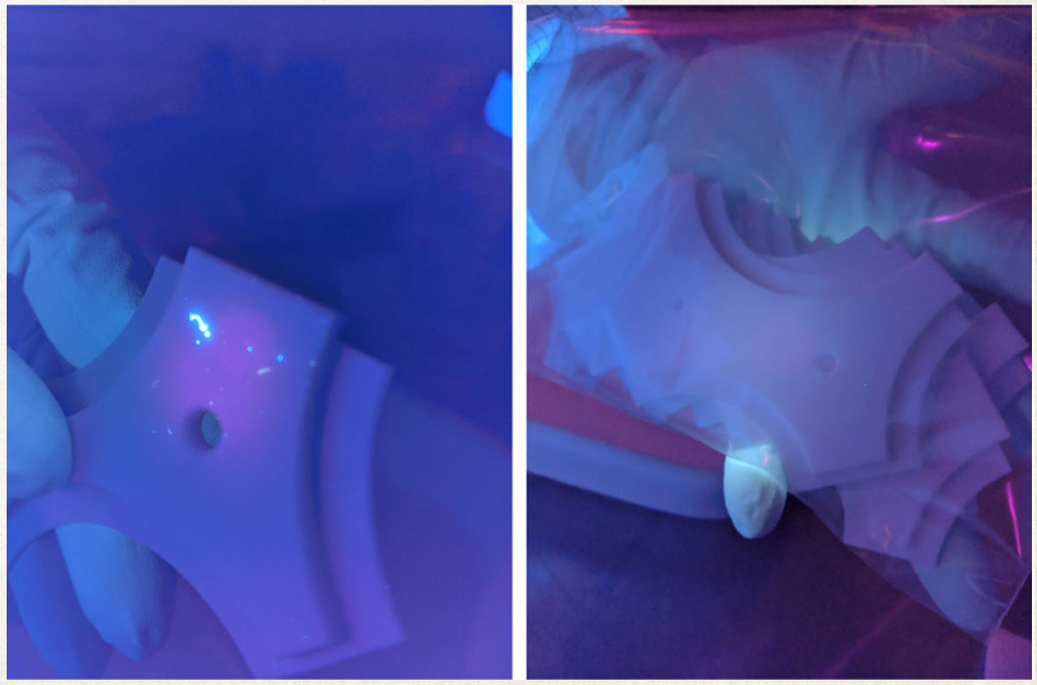


**Assembled Outer Detector (120 8” PMTs)**



# Backgrounds and Mitigation

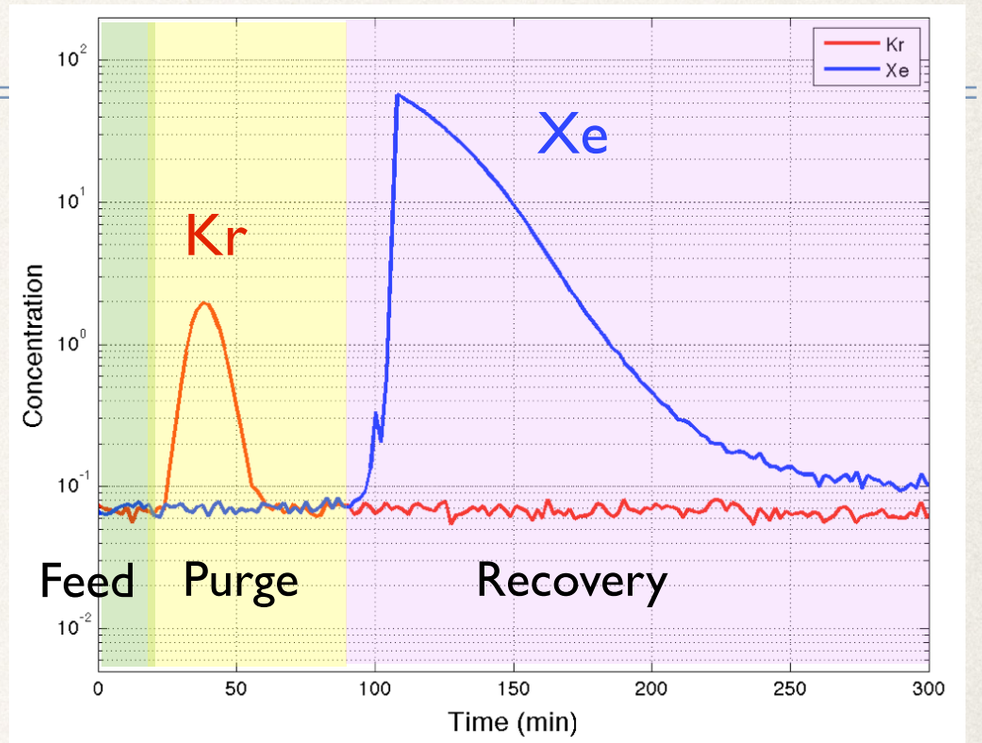
- Detector materials
  - Thorough assay campaign (~2000 assays)
  - 13 HPGe detectors, ICP-MS, neutron activation
  - All detector parts were screened!
- Rn emanation
  - Target: $< 2\ \mu$Bq/kg
  - Four screening facilities
  - All major parts assayed for emanation
- Dust and Rn daughters plate-out
  - TPC assembled in Rn-reduced cleanroom
  - Dust kept <500 ng/cm$^2$ on all wetted surfaces
  - Rn daughter plate-out on TPC walls <0.5 mBq/m$^2$
- Contaminants mixed in the Xe ($^{85}$Kr, $^{39}$Ar)
  - Highly reduced by charcoal chromatography
- Cosmogenics and environment
  - UG deployment, water tank, OD & Skin vetos

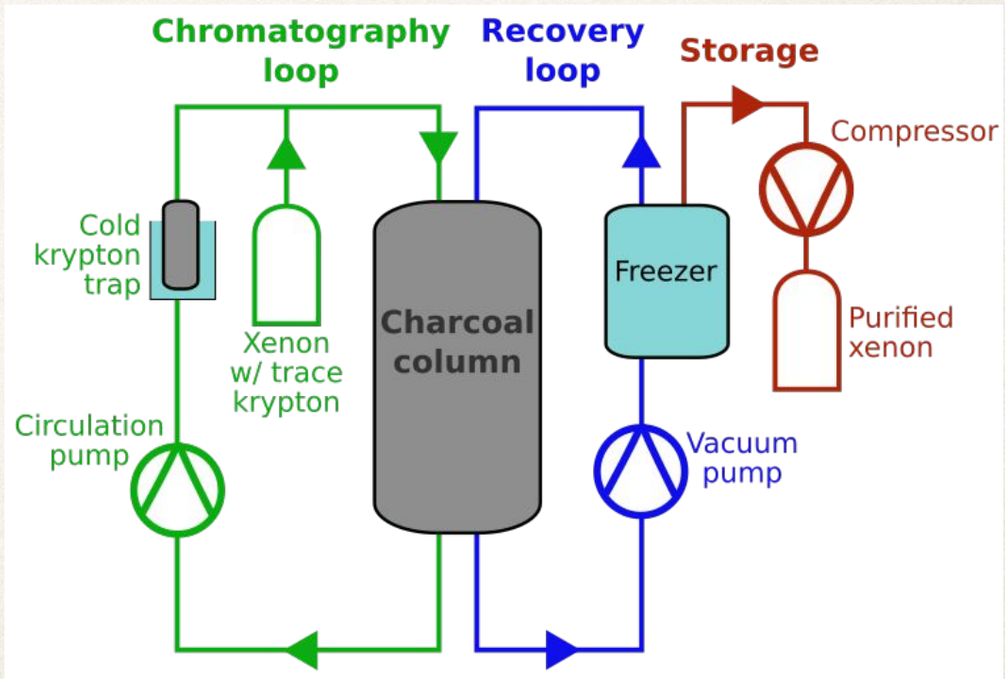



Eur. Phys. J. C, 80: 1044 (2020)

# Kr Removal

- Gas chromatography to remove Kr from Xe
  - Can reduce $^{nat}$Kr/Xe to 0.1 ppt g/g
  - $^{nat}$Ar to negligible level

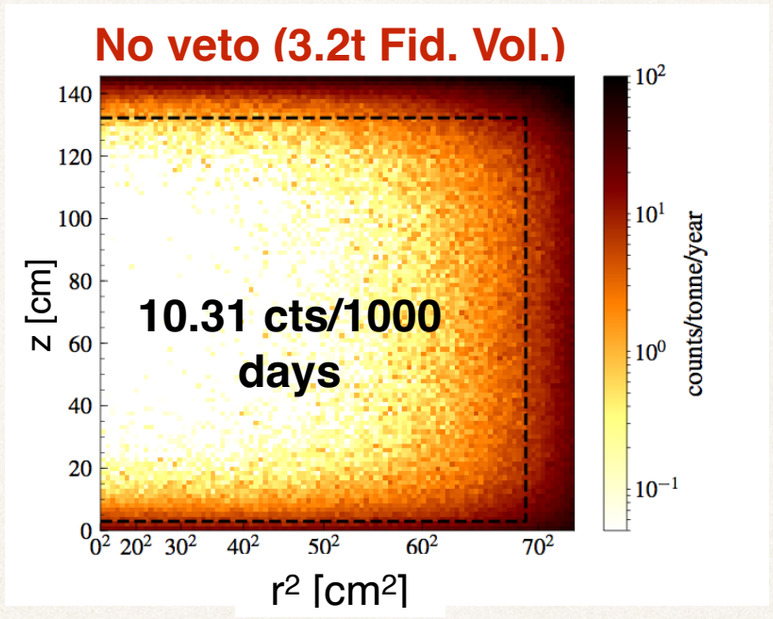



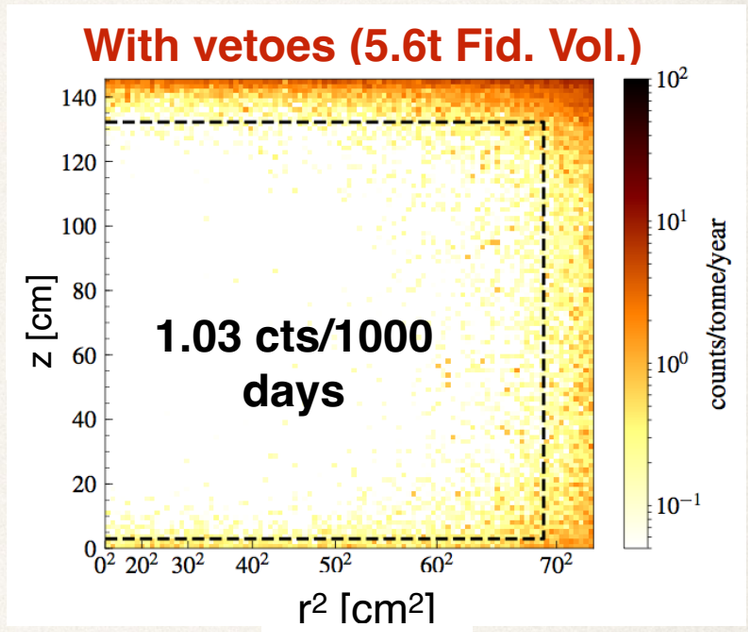
# Expected Backgrounds

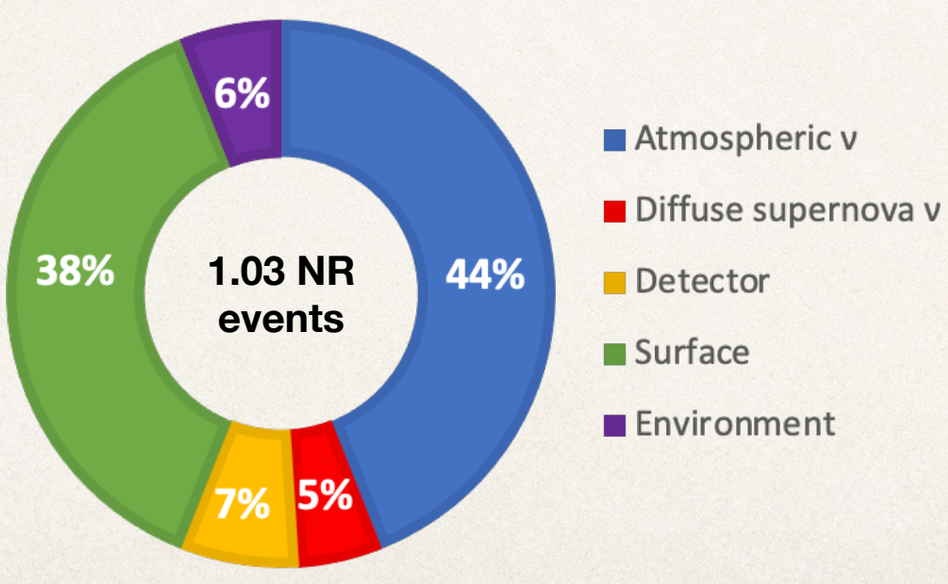
Phys. Rev. D 101, 052002 (2020)

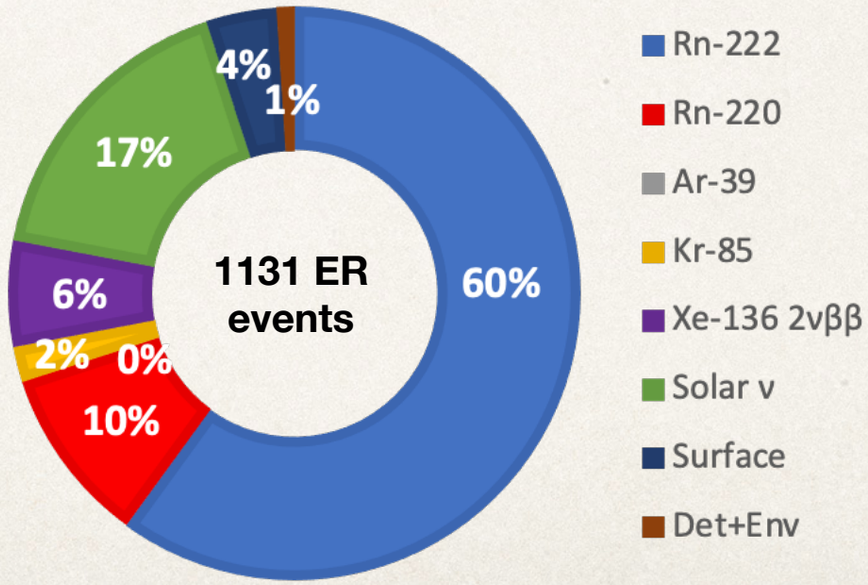
- 5.6 tonnes fiducial mass, 1000 days exposure

Simulated distribution of single scatter nuclear recoils in the ROI of a 40 GeV WIMP (6-30 keV)



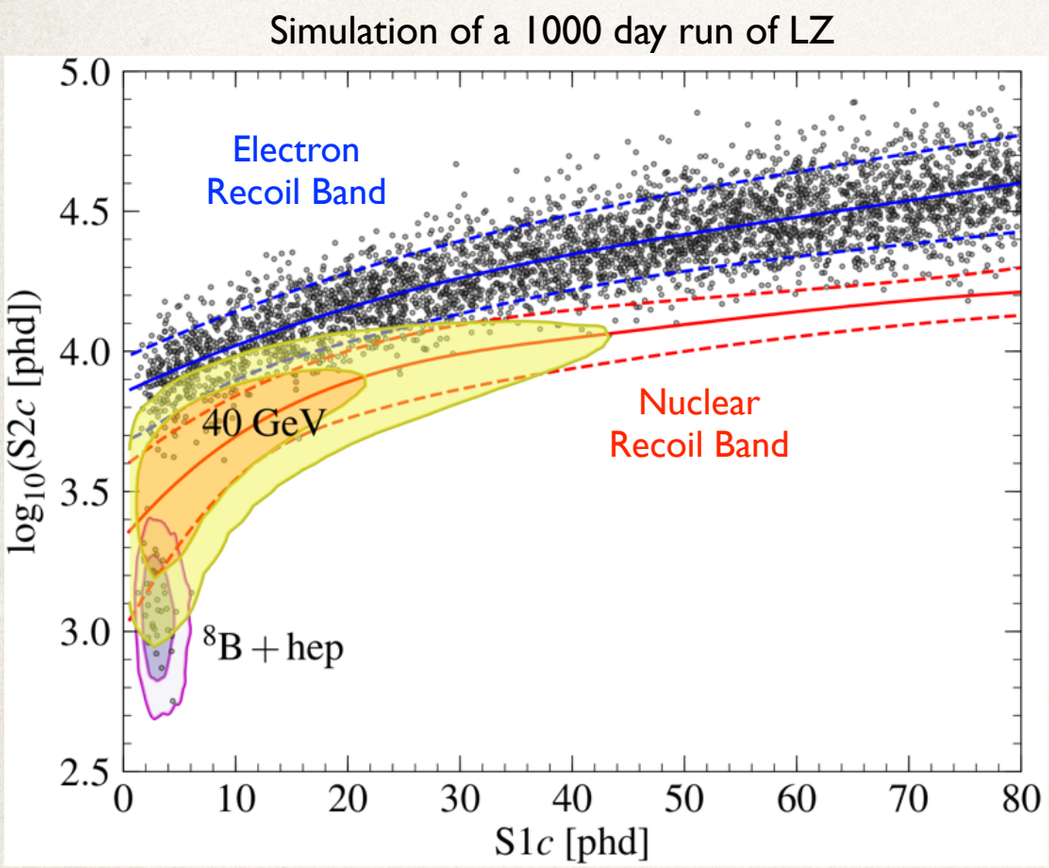



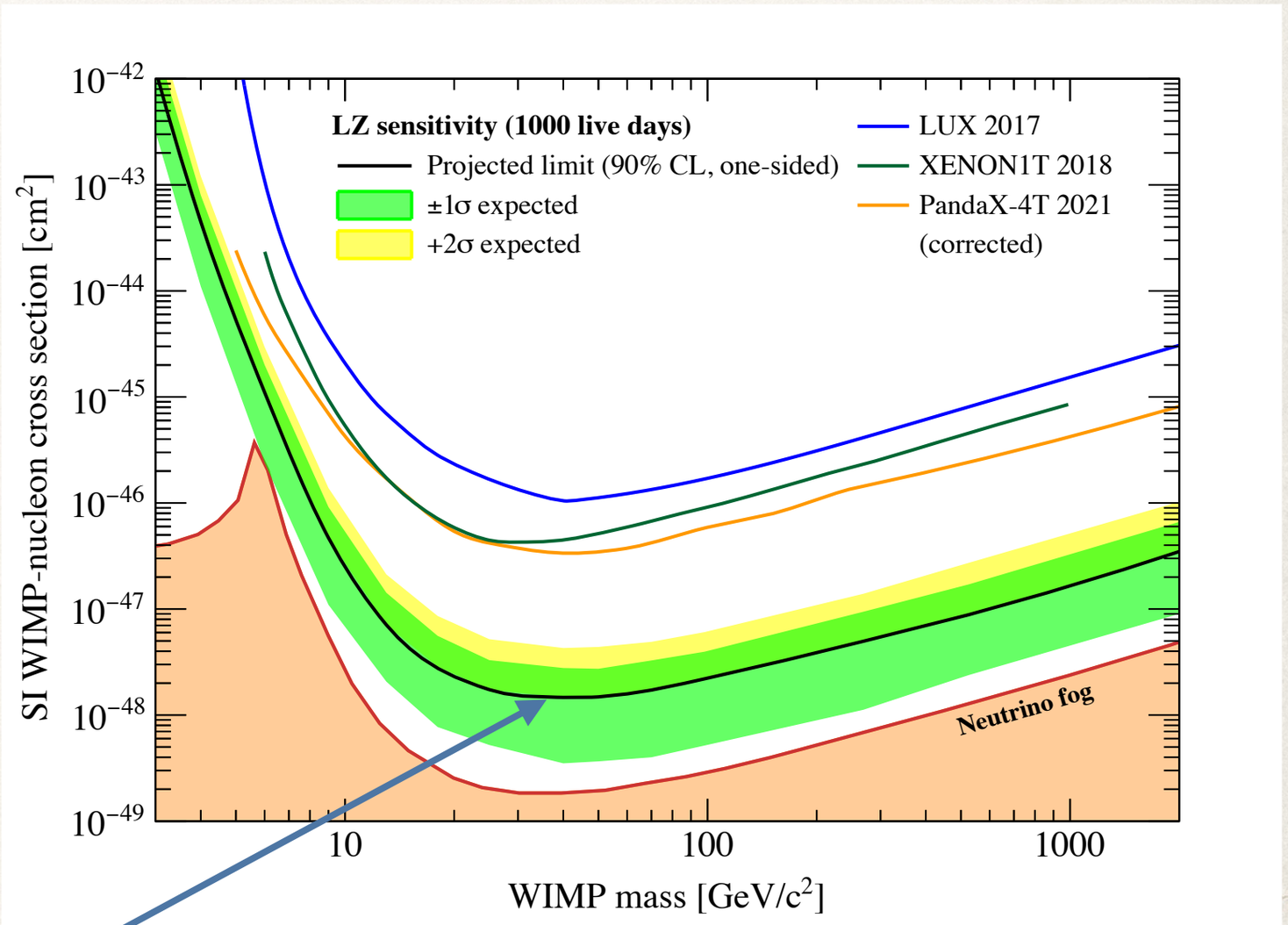



# WIMP Projected Sensitivity

Phys. Rev. D 101, 052002 (2020)

- 5.6 tonnes fiducial mass, 1000 days live-time

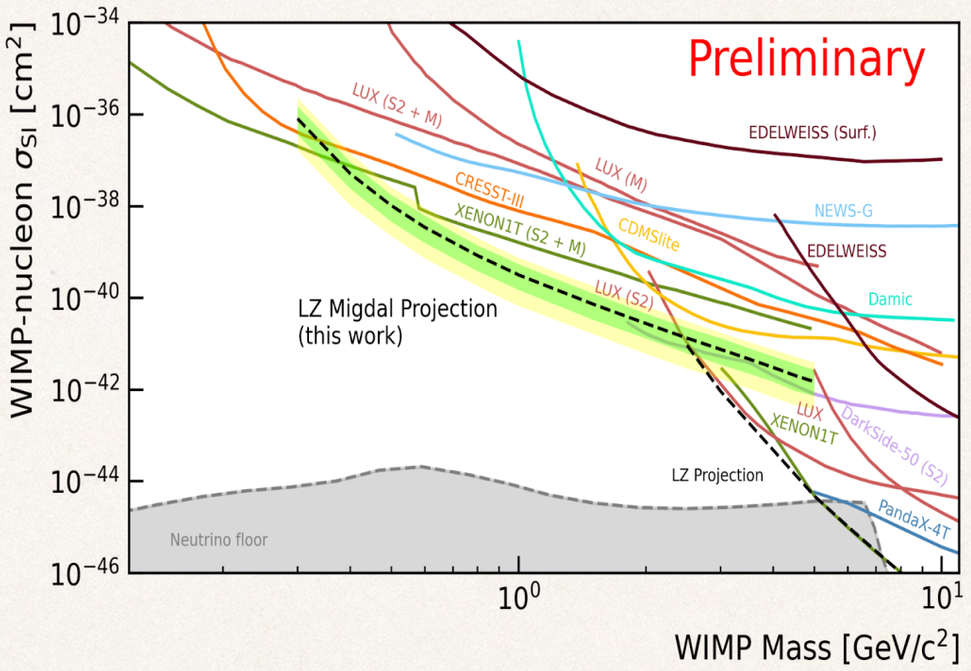


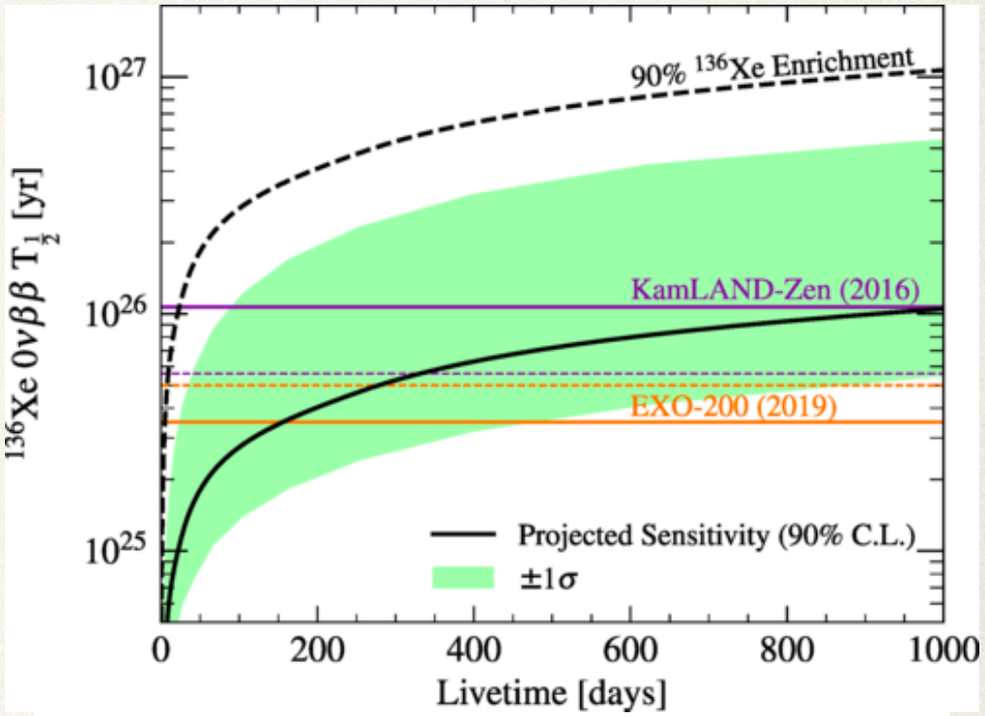



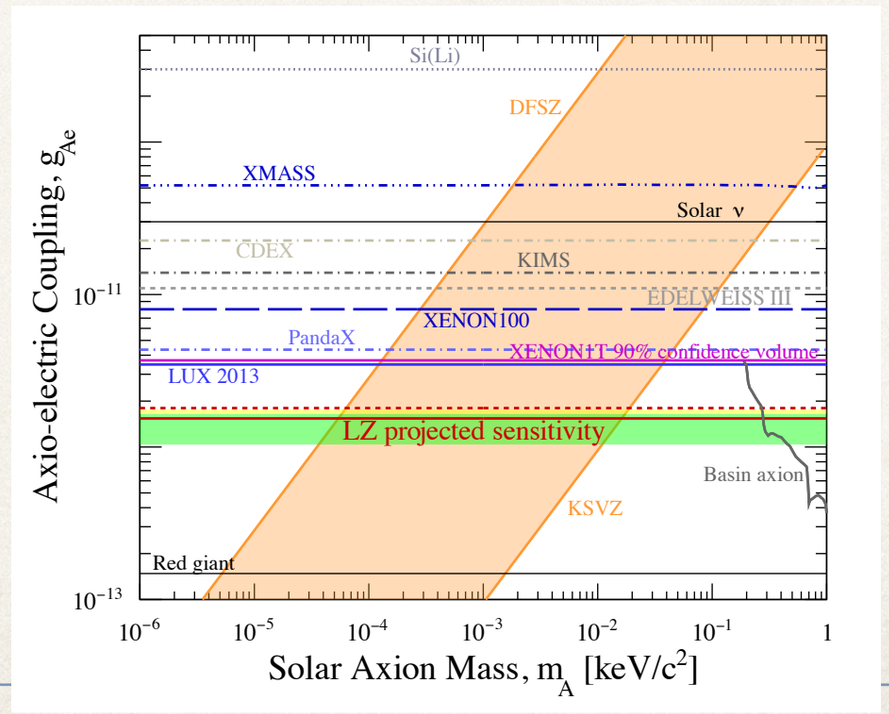

90% CL minimum of
$1.4 \times 10^{-48}$ cm$^2$ at 40 GeV / c$^2$

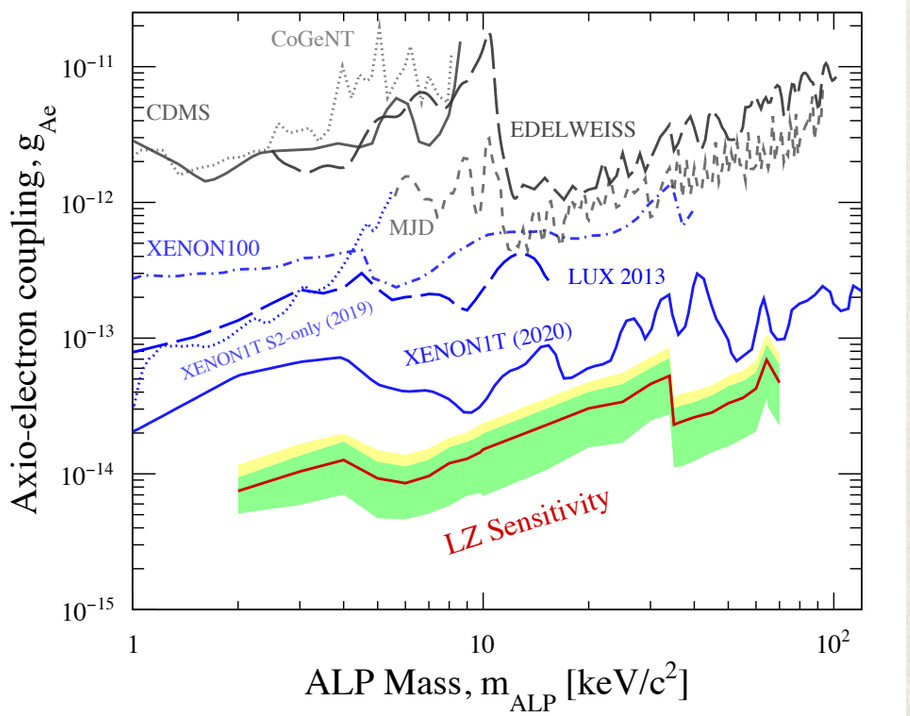
# Physics Reach Beyond WIMPs

- Low mass DM via Migdal effect
- Mirror dark matter
- 0νββ decay of $^{136}$Xe
- 2νββ and 0νββ decays of $^{134}$Xe
- Solar axions and ALPs
- CEvNS
- Neutrino magnetic moment & effective millicharge
- And more!



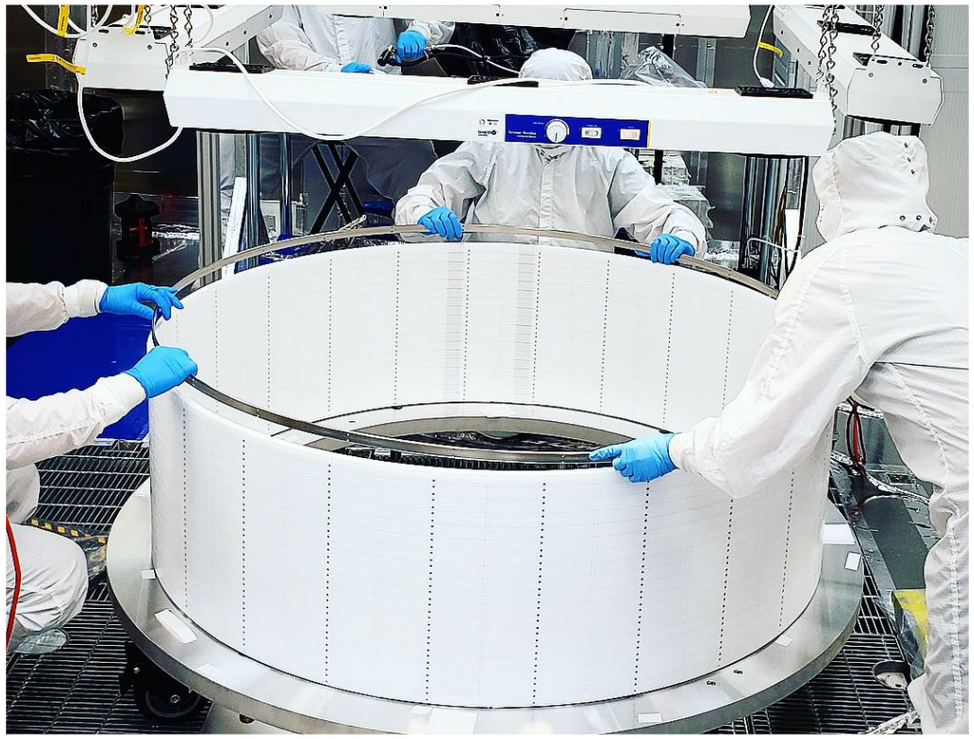





Phys. Rev. D 104, 092009 (2021)
Phys. Rev. C 104, 065501 (2021)
Phys. Rev. C 102, 014602 (2020)

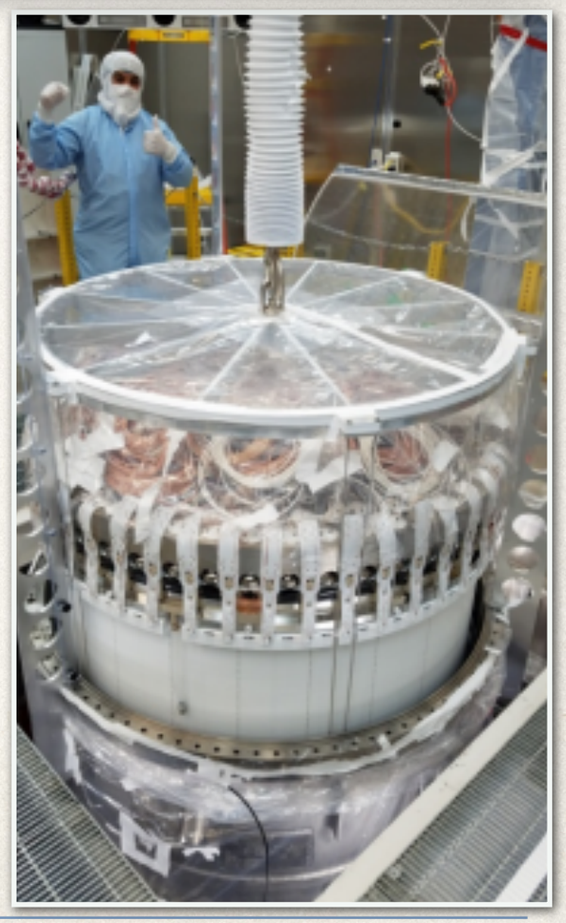
# TPC & Skin Integration



Detector integration at the SURF Surface Assembly Laboratory

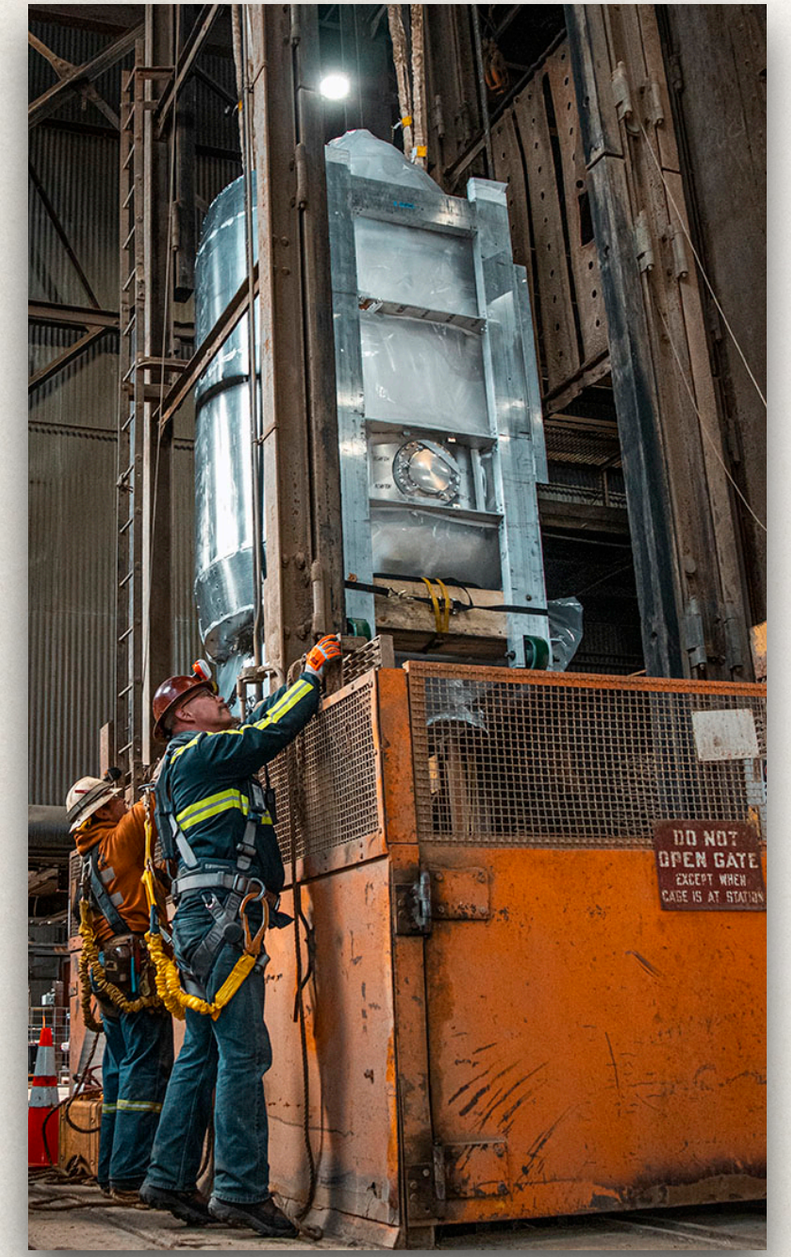
Started Dec. 2018
~13,500 working hours

TPC inserted in the inner cryostat



# Transport Underground

## October 2019




# Underground Deployment

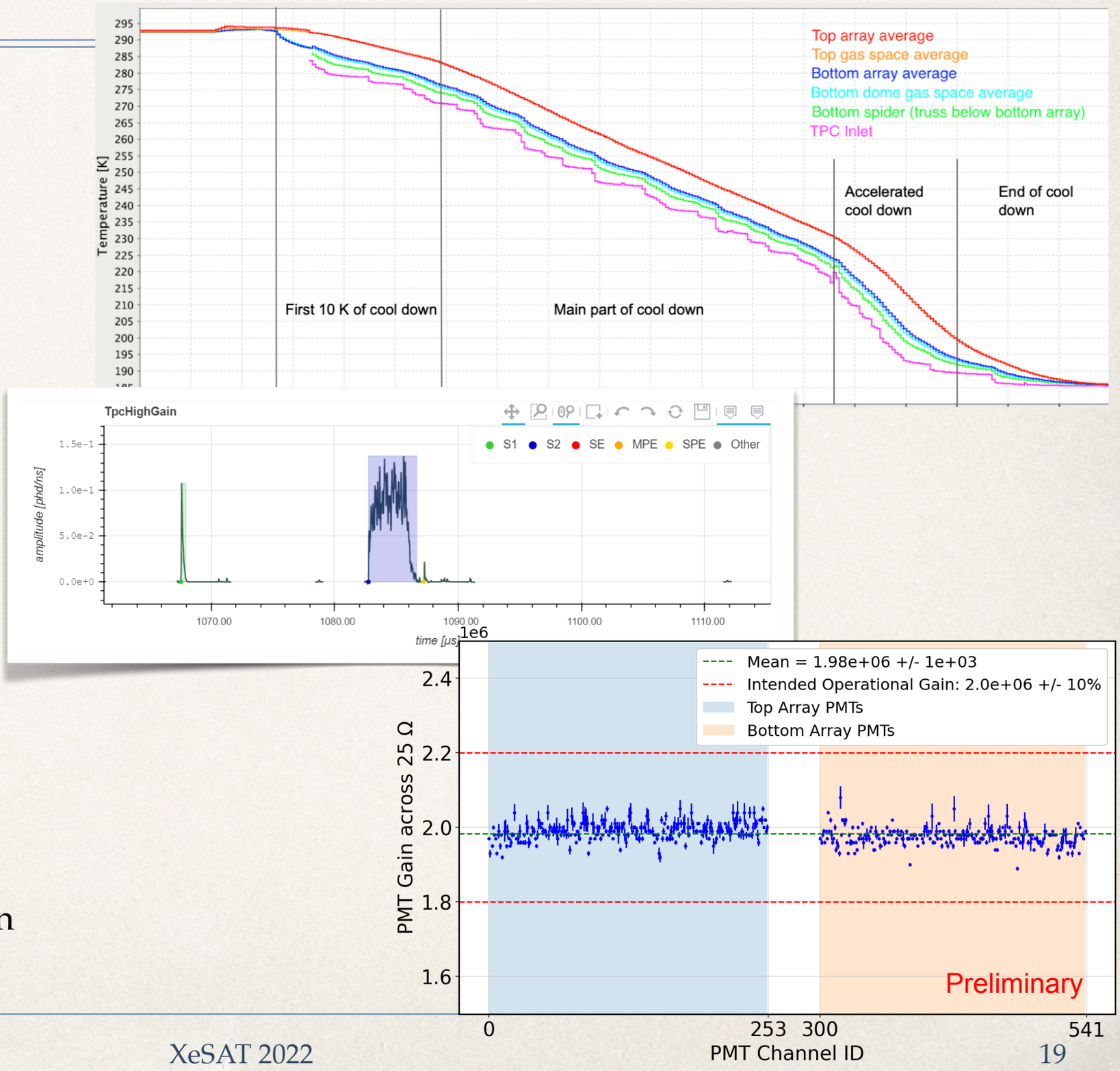


# Underground Deployment

# Underground Deployment

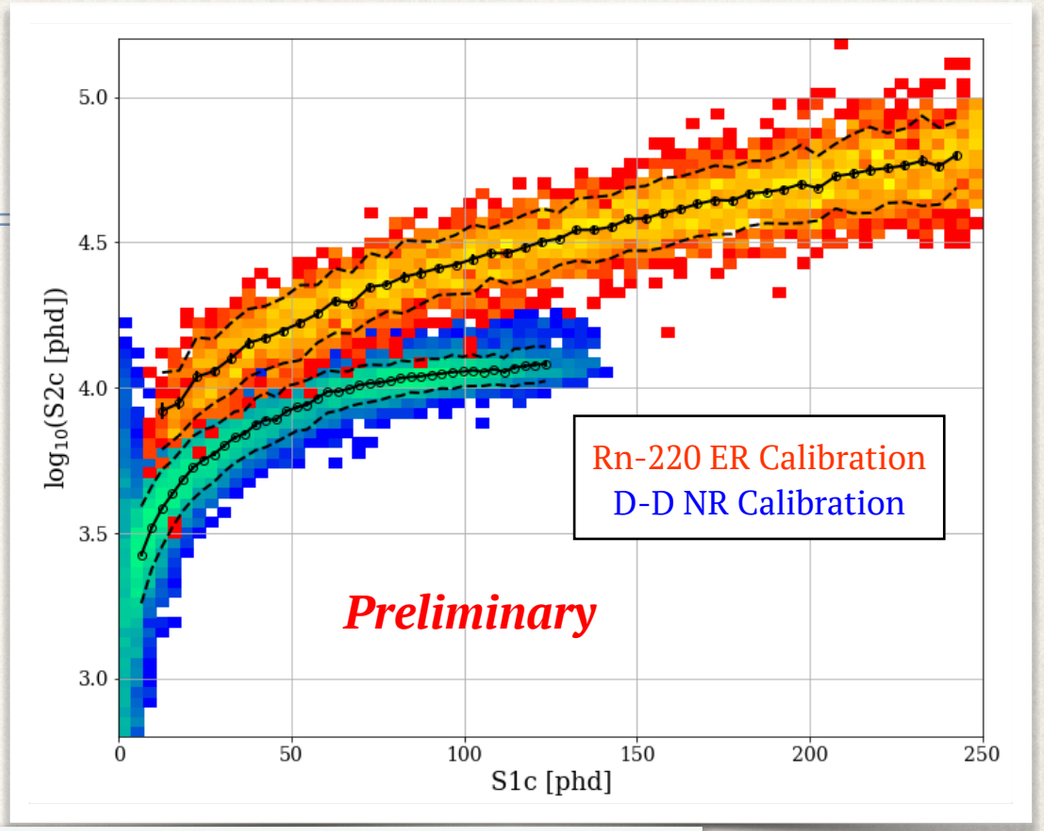
# Commissioning

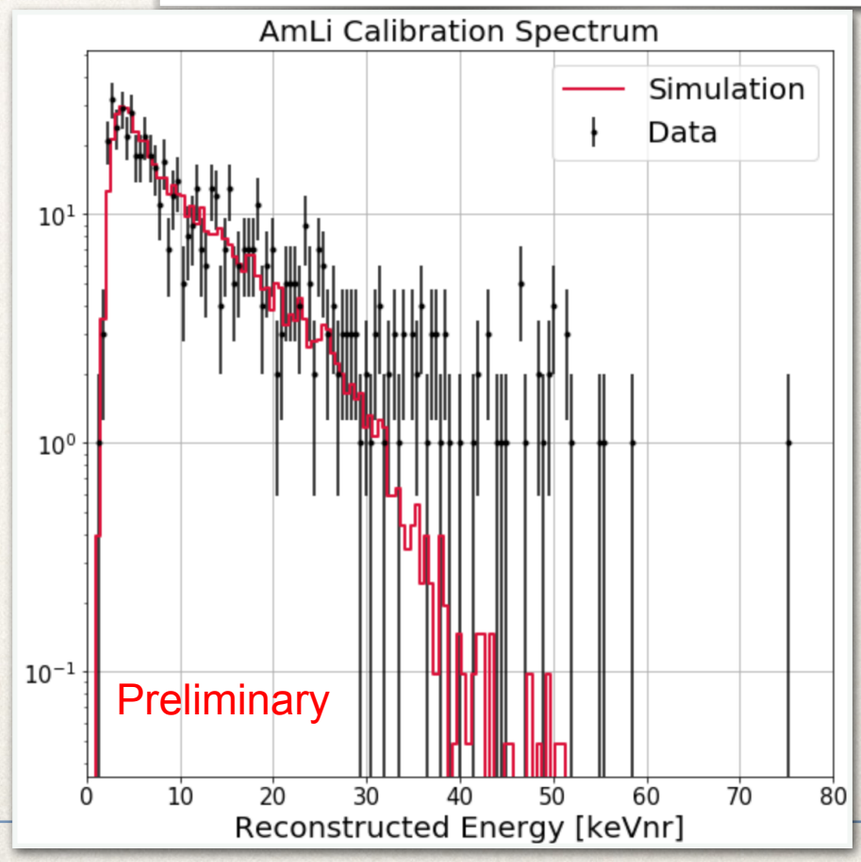
- TPC filled and levelled
- Grids biased
  - Drift field: ~190 V/cm
  - Extraction field: ~7.5 kV/cm (gas)
- First S1+S2 events!
- Data processing chain exercised
- Data acquisition & trigger settings tuned
- PMT operations & characterisation
  - LED measurements (e.g. afterpulsing and SPE studies)
  - PMT gains matched, gain drifts monitored
  - Dark count & DPE analyses
- Highly reliable event reconstruction algorithms (>95% accuracy)



# Calibrations

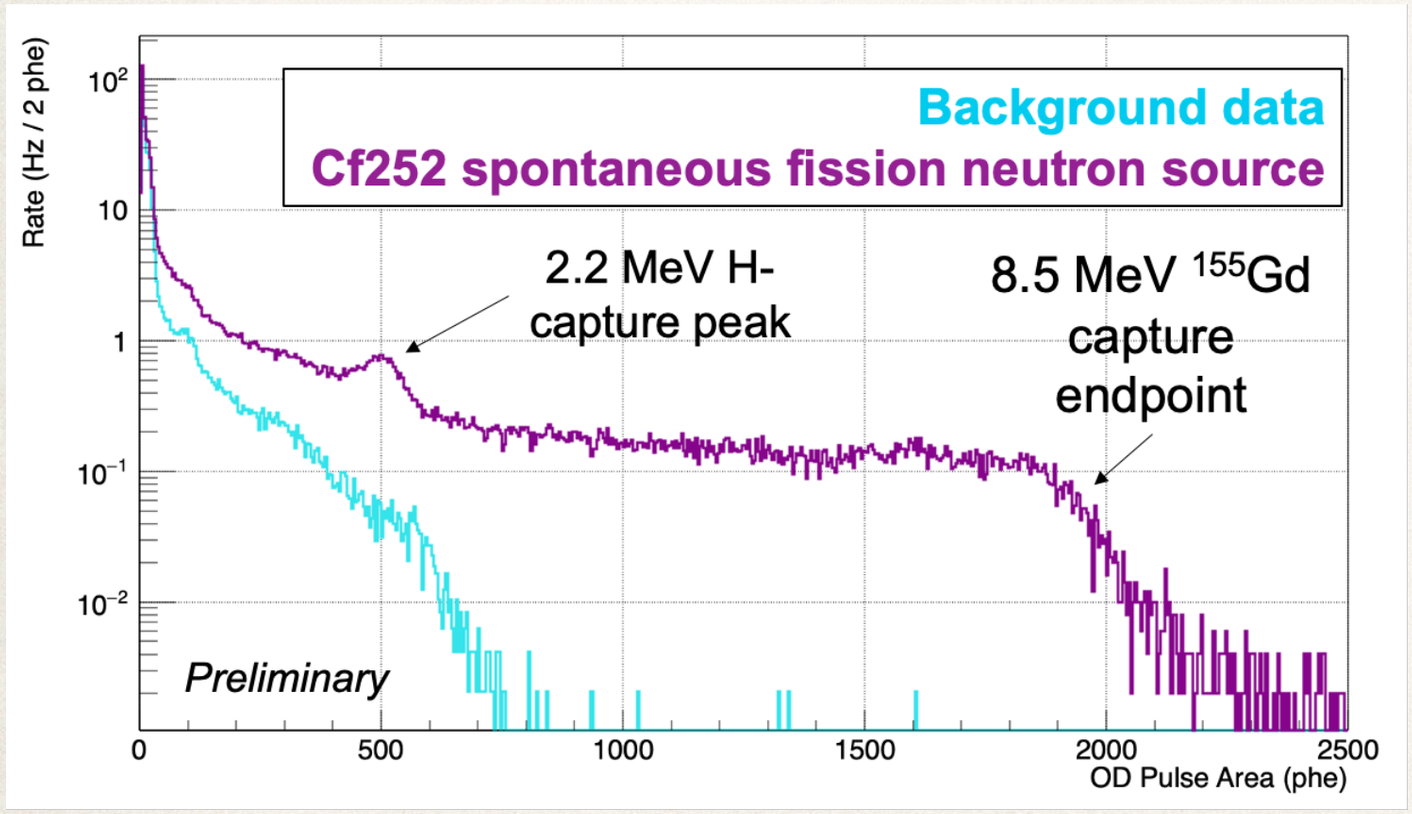
- Different deployment methods for calibration sources
  - Internal sources mixed in the xenon
  - Vertical source tubes for commercial rod sources
  - DD neutron generator
  - Photo-neutron source
- Calibrations are used to characterise
  - Energy studies in all three detectors
  - Position reconstruction
  - Inter-detector timing
  - ER & NR bands

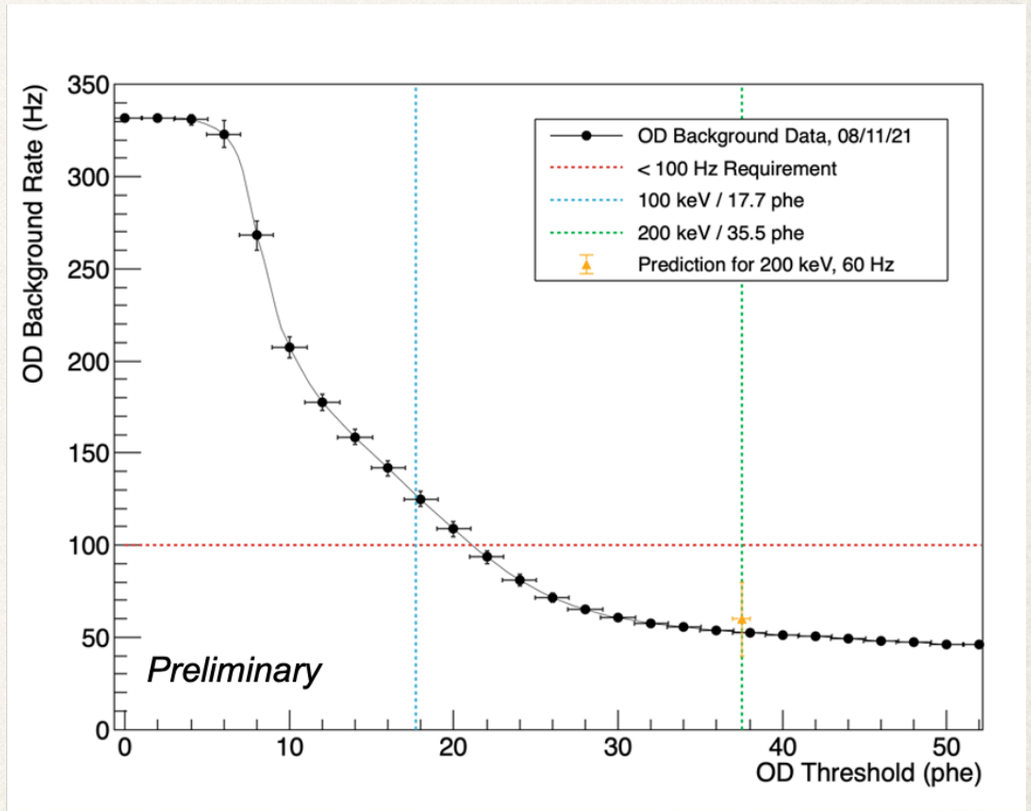


# Outer Detector Calibrations

- OD backgrounds slightly lower than expected
  - Allows a lower threshold (< 200 keV)

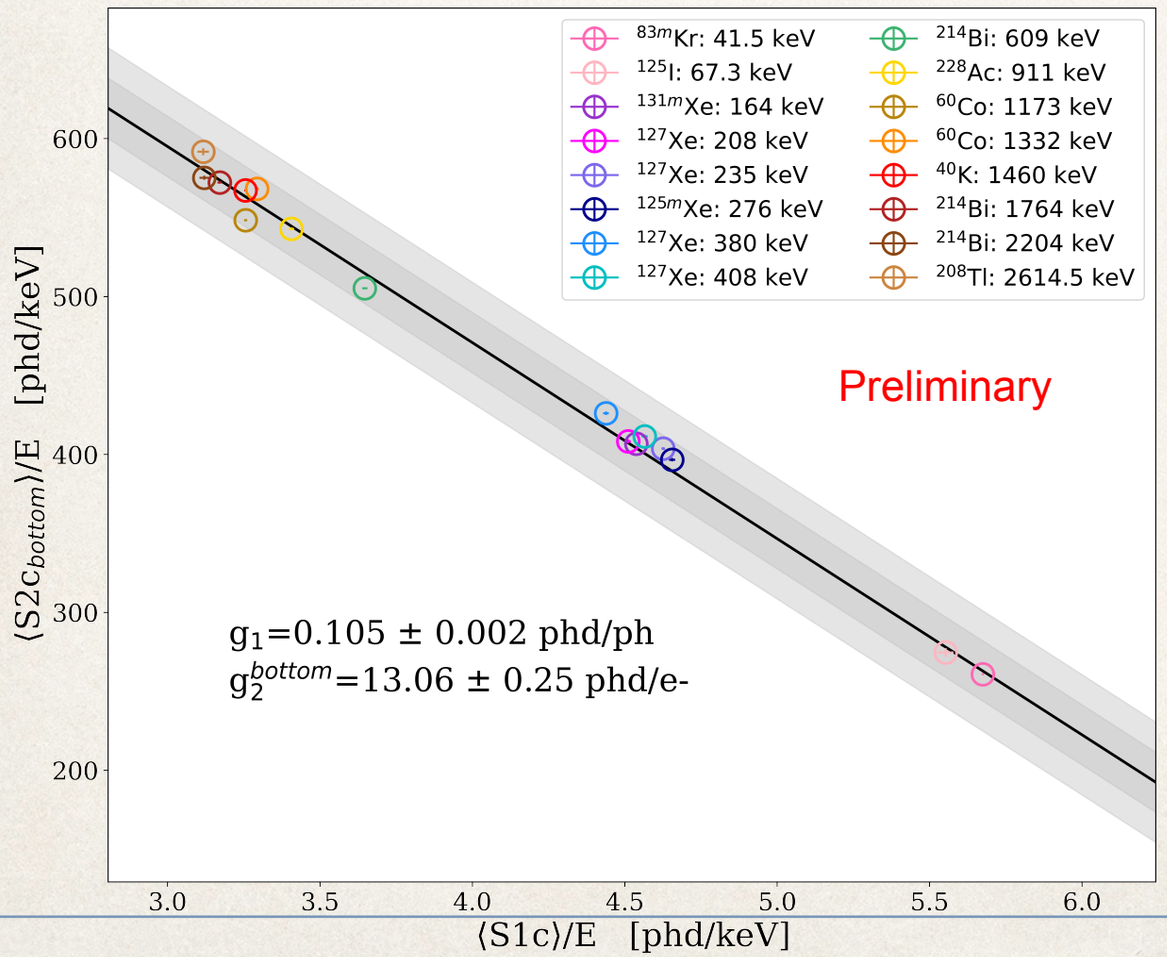


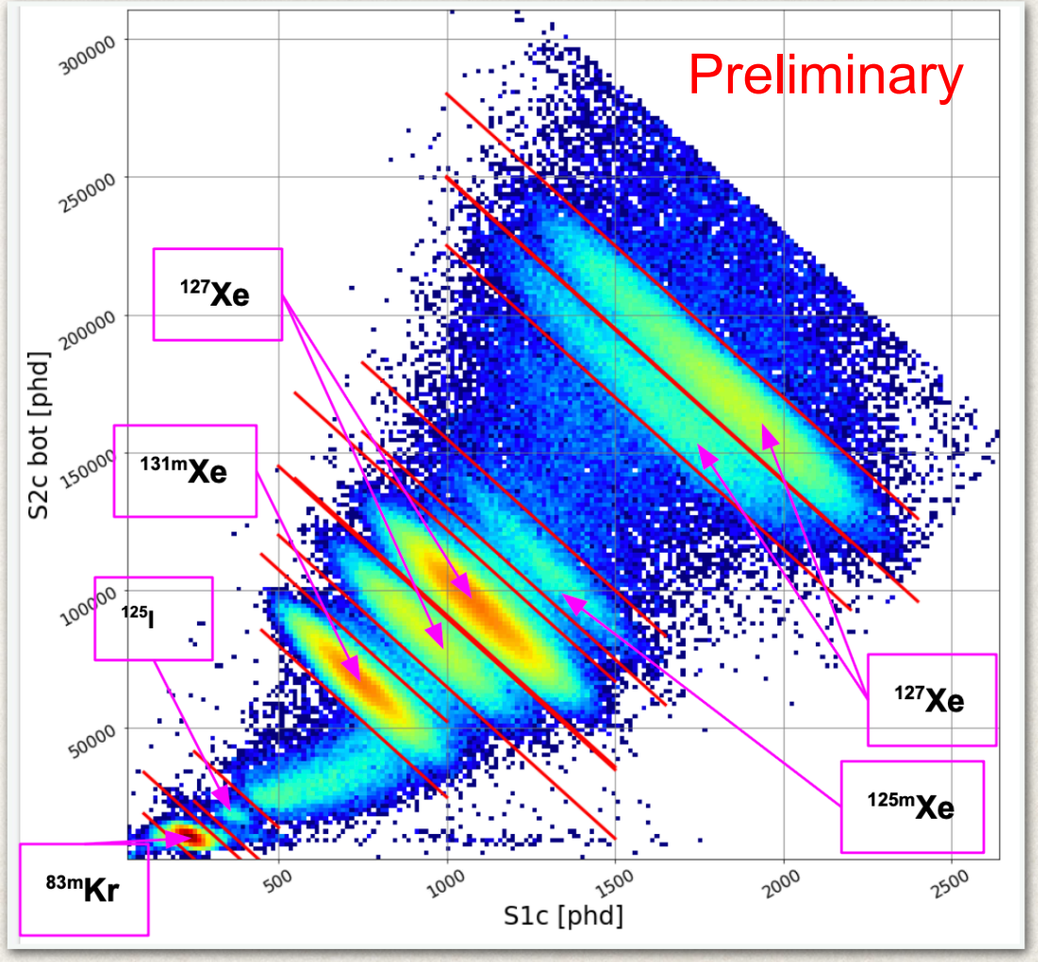



# Detector Response

- Use mono-energetic ER peaks to determine detector gains
  - g1 - detected photons (phd) per prompt scintillation photon
  - g2 - detected photons per ionisation electron

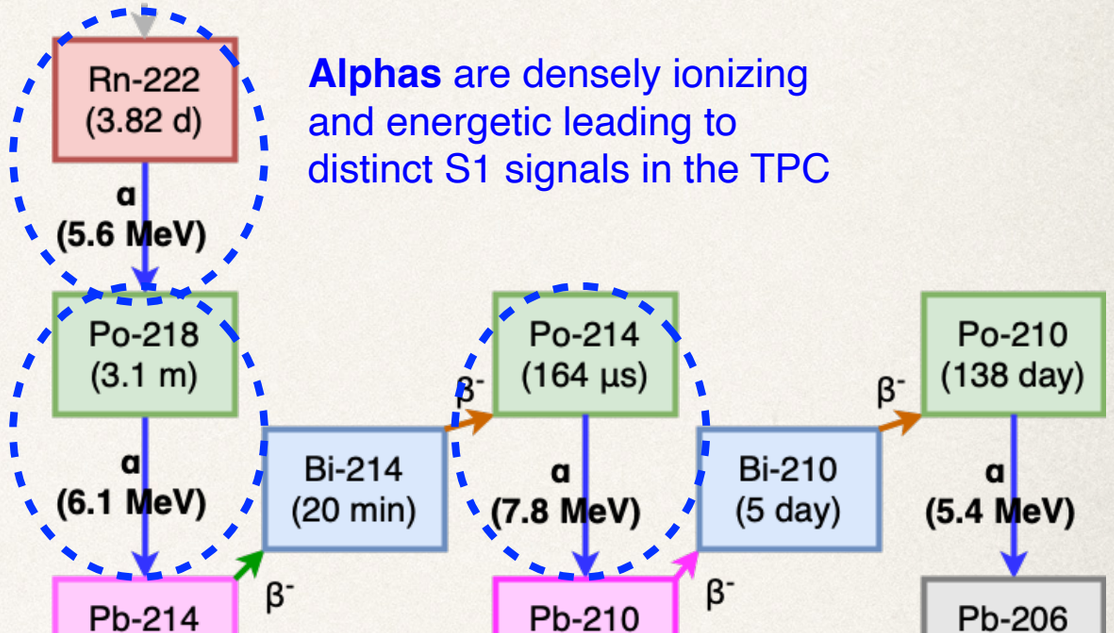
$$E = W\left(\frac{S1_c}{g_1} + \frac{S2_c}{g_2}\right)$$



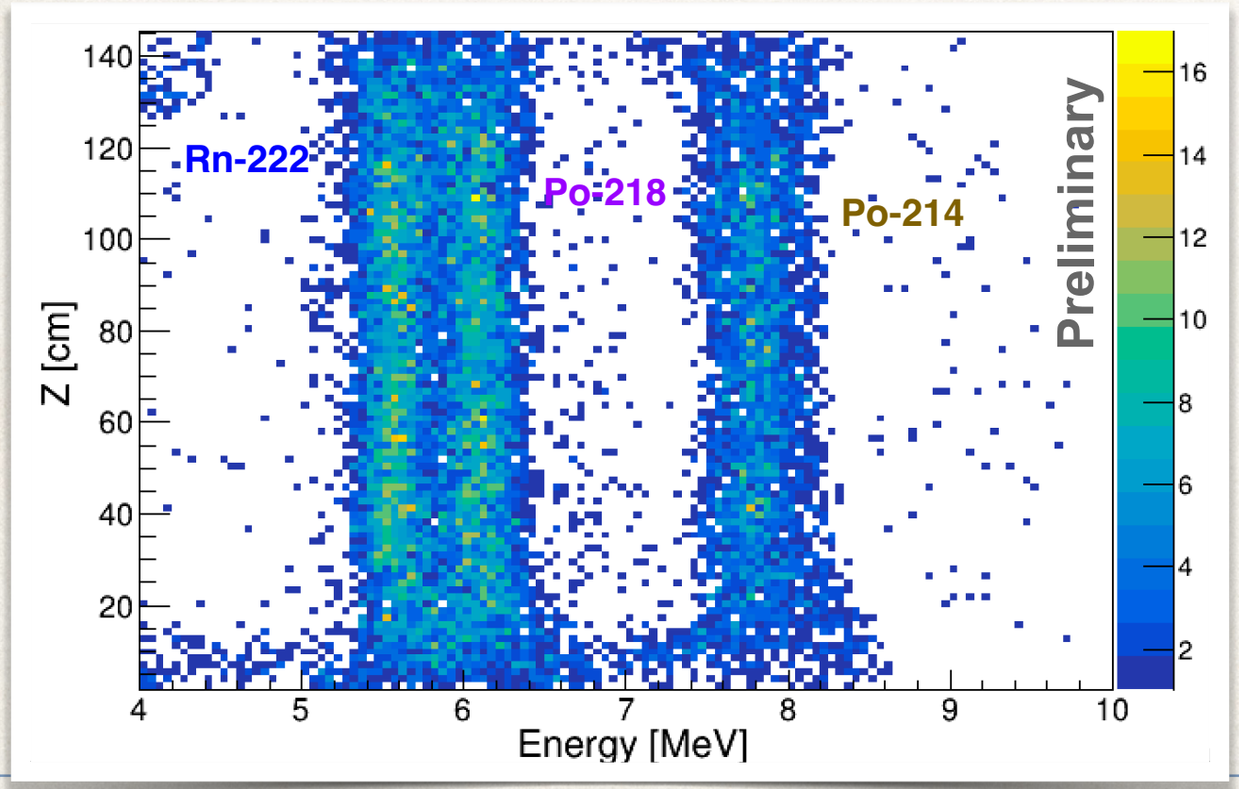



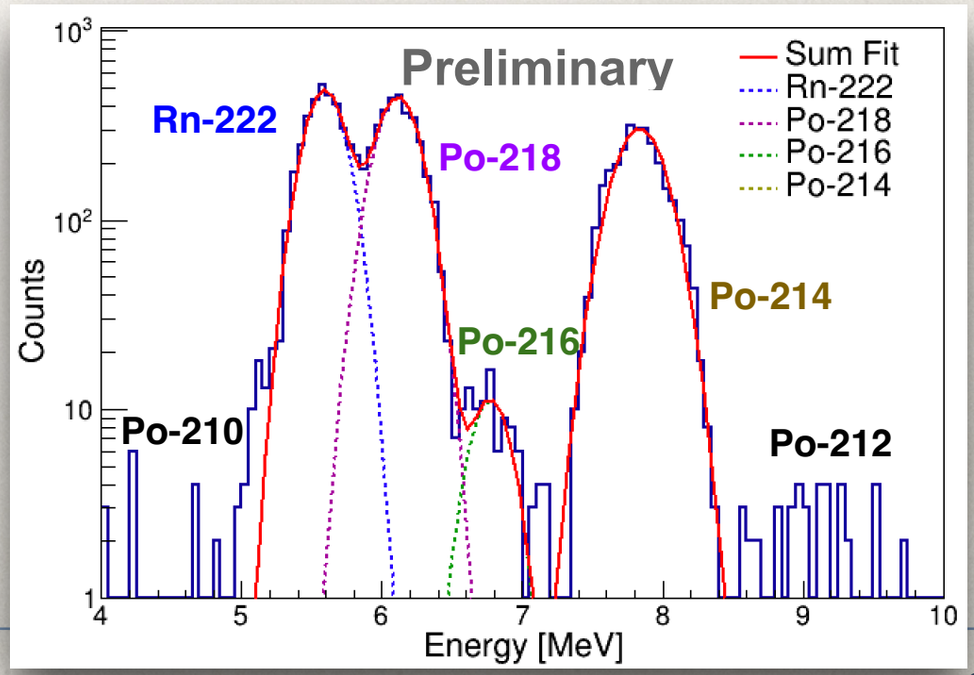
# Background Analysis: Rn chain

- Rn-222 and Rn-220 emanate from detector materials and mix with the xenon
  - Inline radon reduction system reduces radon concentration
- "Naked" betas from Pb-214 and Pb-212 are WIMP backgrounds
  - Pb-214 being the largest background in the WS region
- Preliminary analysis using alpha decays shows Rn-222 rate within expected range



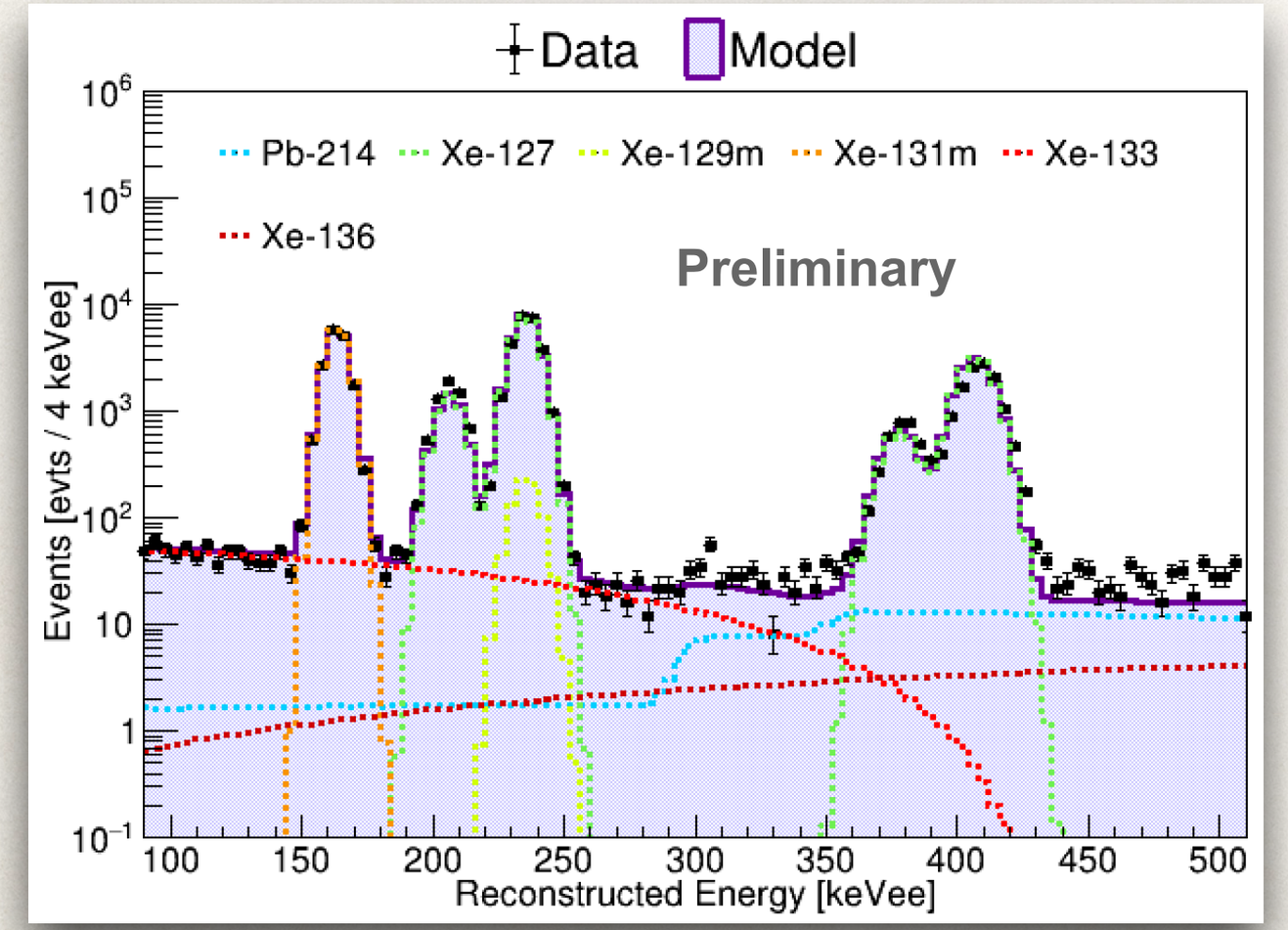

**Alphas** are densely ionizing and energetic leading to distinct S1 signals in the TPC



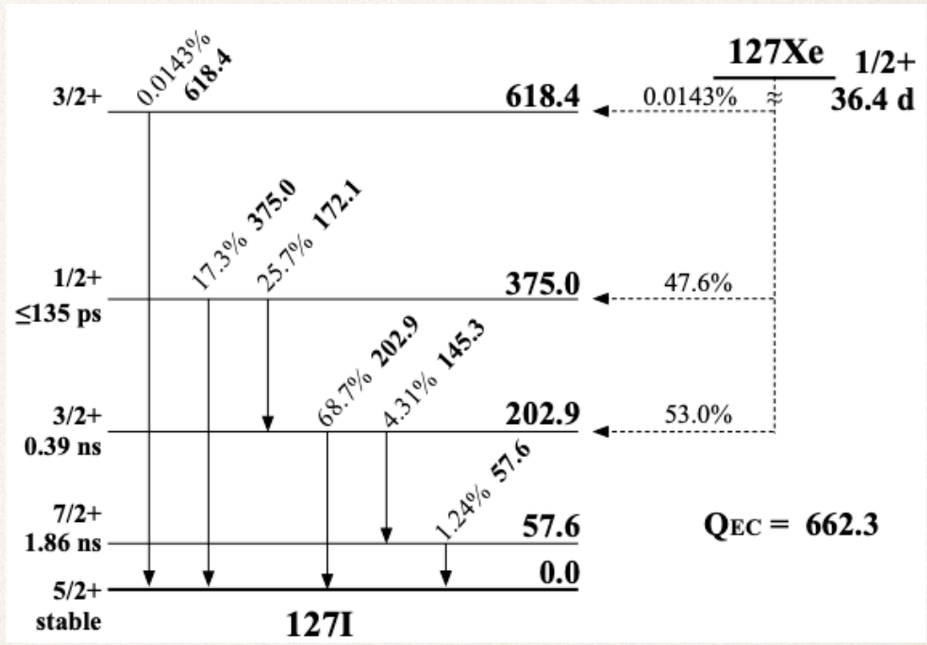



# Background Analysis: Activation

- Xenon isotopes cosmogenically produced:
  - $^{127}$Xe, $^{129m}$Xe, $^{131m}$Xe, $^{133}$Xe visible in early data
- Trial fits of background simulations to data




$^{127}$Xe is the only potential WIMP background



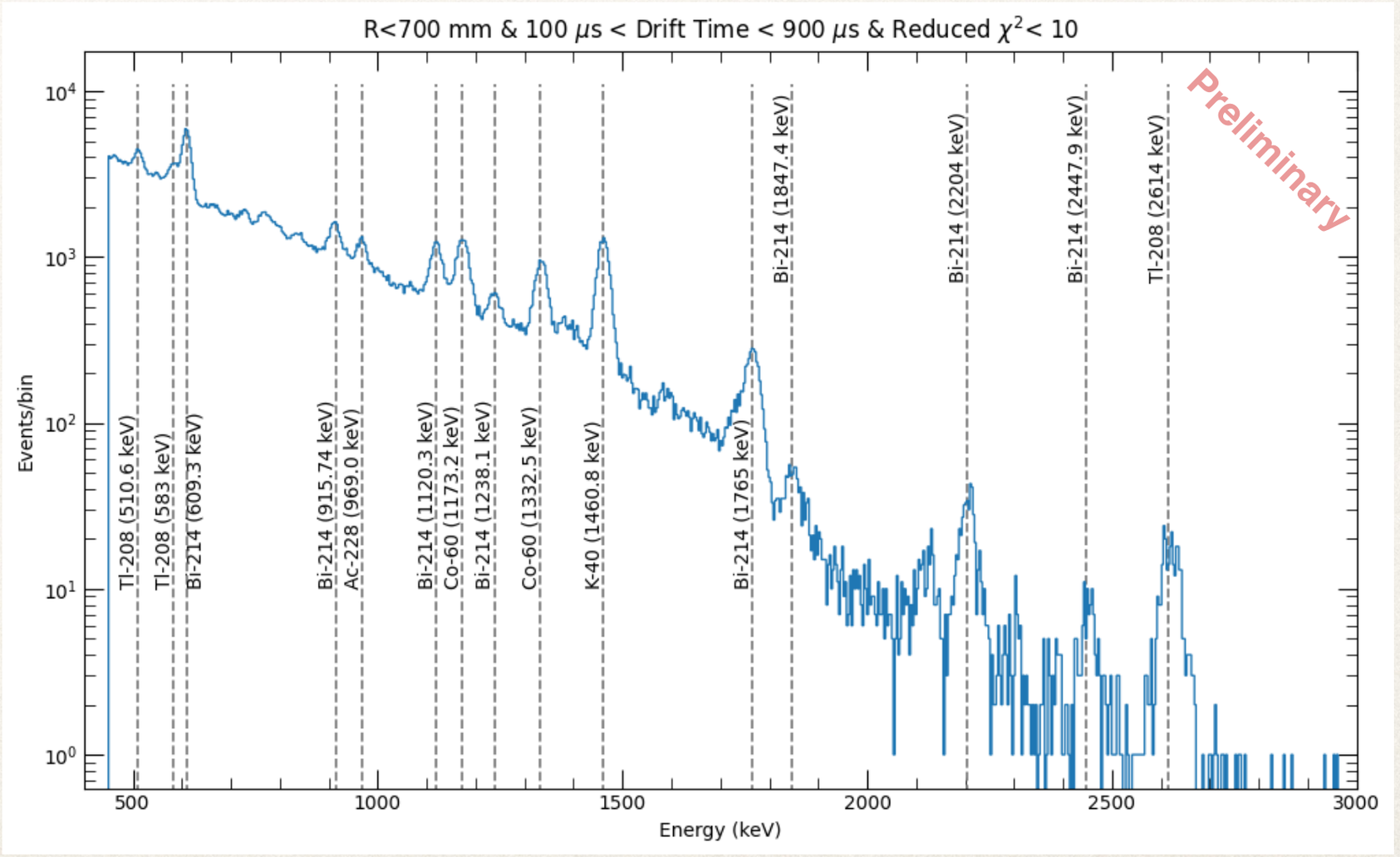

Only when the $^{127}$I gamma escapes undetected
⇒ Highly veto suppressed, position dependent

# Energy Resolution Studies

See talk by G. Pereira later today

- Optimised S1 and S2 corrections
- Determine detector gains (g1, g2) using mono-energetic ER peaks
- Reconstruct energy, determine resolution as function of energy

$$E = W\left(\frac{S1_c}{g_1} + \frac{S2_c}{g_2}\right)$$



# Summary

- LZ is a multi-physics experiment, primed for detecting WIMPs
- Commissioning completed, currently taking science data
- Extensive analyses underway
- First science results expected this year

# Thank you!

Thanks to our sponsors and
35 participating institutions!

U.S. Department of Energy
Office of Science

Science and Technology Facilities Council

Sanford Underground Research Facility
South Dakota Science and Technology Authority

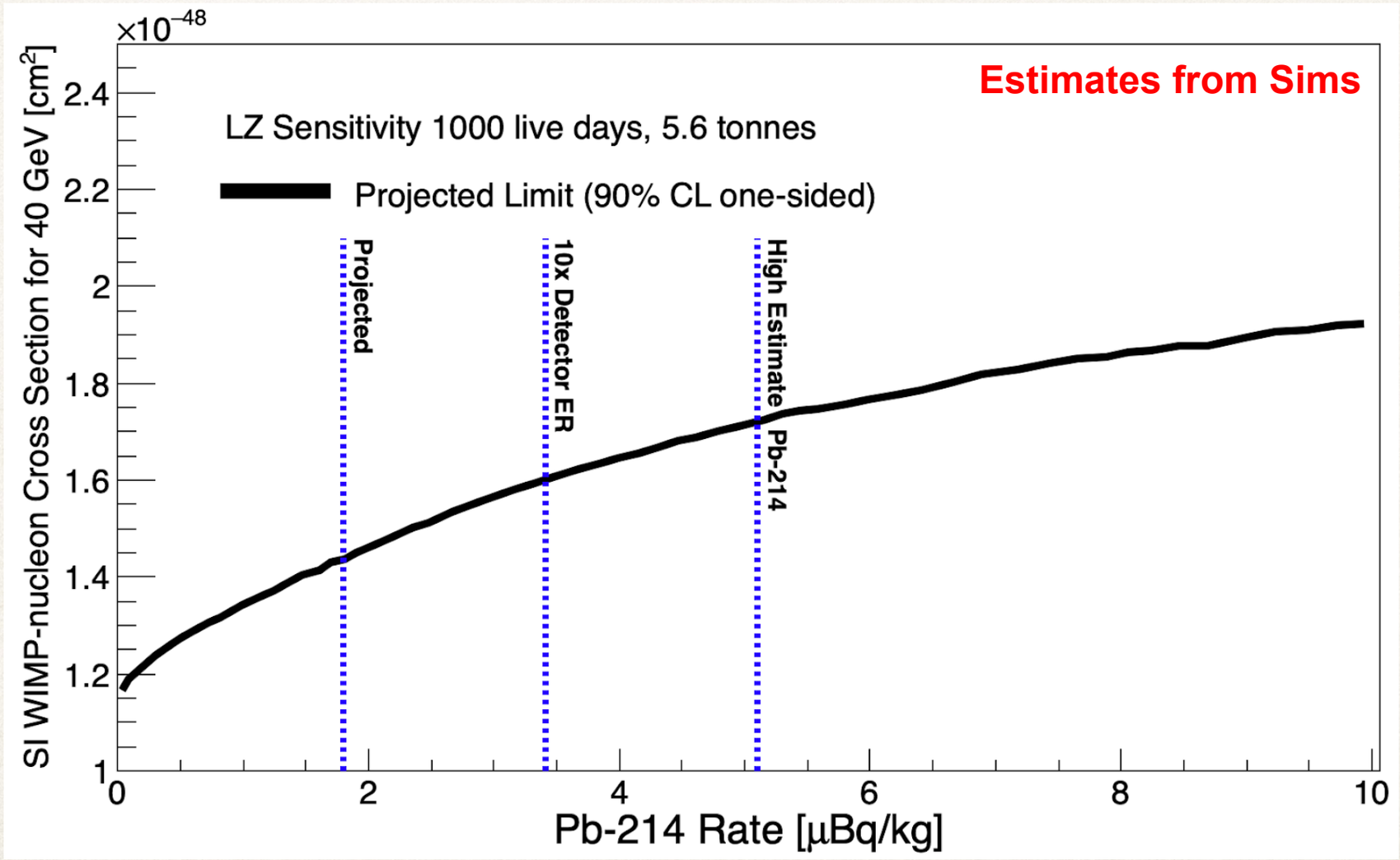
FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

ibs Institute for Basic Science

# Backup

# Sensitivity Vs $^{214}$Pb Rate

- Impact of the $^{214}$Pb rate on the sensitivity for a 40 GeV WIMP
  - Proxy for flat ER backgrounds



# Details on Expected Backgrounds

- For 5.6 t fiducial, 1000 days

| Background Source | ER (cts) | NR (cts) |
|---|---|---|
| **Detector Components** | **9** | **0.07** |
| **Surface Contamination** | **40** | **0.39** |
| **Laboratory and Cosmogenics** | **5** | **0.06** |
| **Xenon Contaminants** | **819** | **0** |
| Radon is the dominant background! — 222Rn | 681 | 0 |
| 220Rn | 111 | 0 |
| natKr (0.015 ppt g/g/) | 24.5 | 0 |
| natAr (0.45 pub g/g) | 2.5 | 0 |
| **Physics** | **258** | **0.51** |
| 136Xe 2νββ | 67 | 0 |
| Solar neutrinos (pp+7Be+13N) | 191 | 0* |
| Diffuse supernova neutrinos | 0 | 0.05 |
| Atmospheric neutrinos | 0 | 0.46 |
| **Total** | **1131** | **1.03** |
| **with 99.5% ER discrim., 50% NR eff.** | **5.66** | **0.52** |

Phys. Rev. D 101, 052002 (2020)

* using a 6 keV NR threshold

# Xenon Circulation System