Status of the LUX-ZEPLIN (LZ) Experiment

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Penn State University

May 13, 2022 - Conference on Science at SURF, SDSMT

LZ (LUX-ZEPLIN) Collaboration

35 institutions; 250 scientists, engineers, and technicians

@lzdarkmatter

https://lz.lbl.gov/

- 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

Thanks to our sponsors and participating institutions!

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FCT Fundação para a Ciência e a Tecnologia
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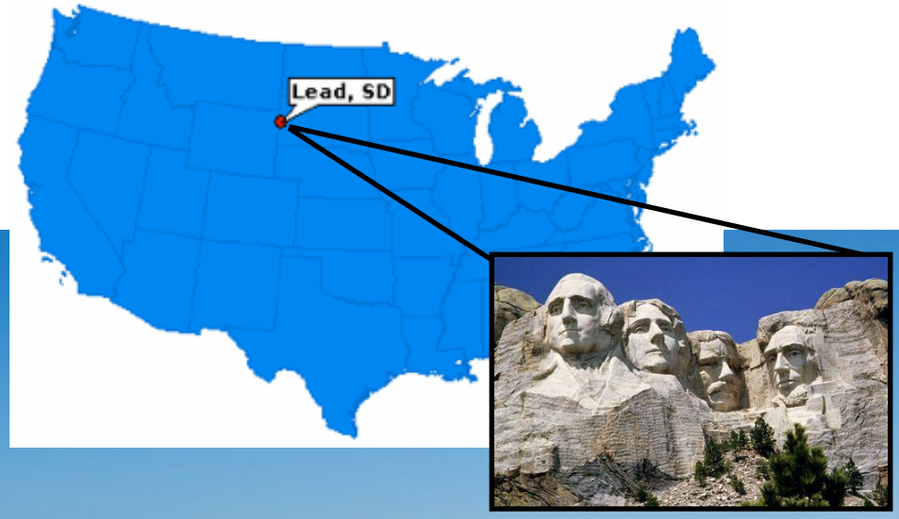
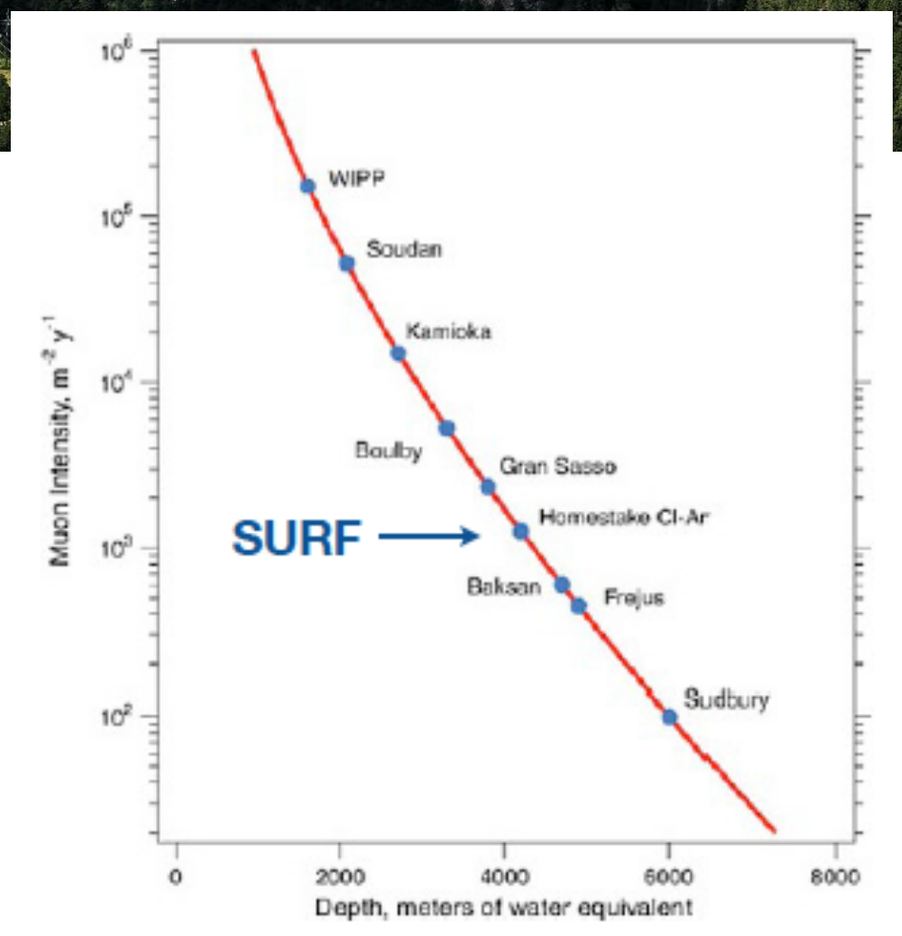
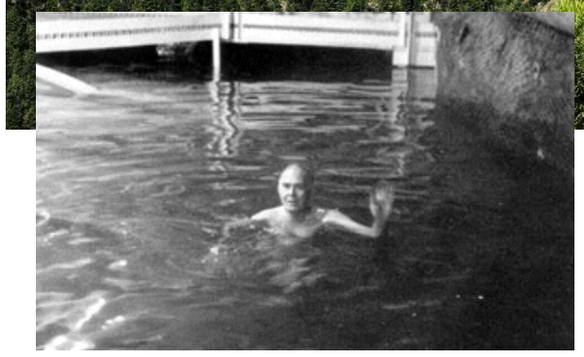
ibs Institute for Basic Science

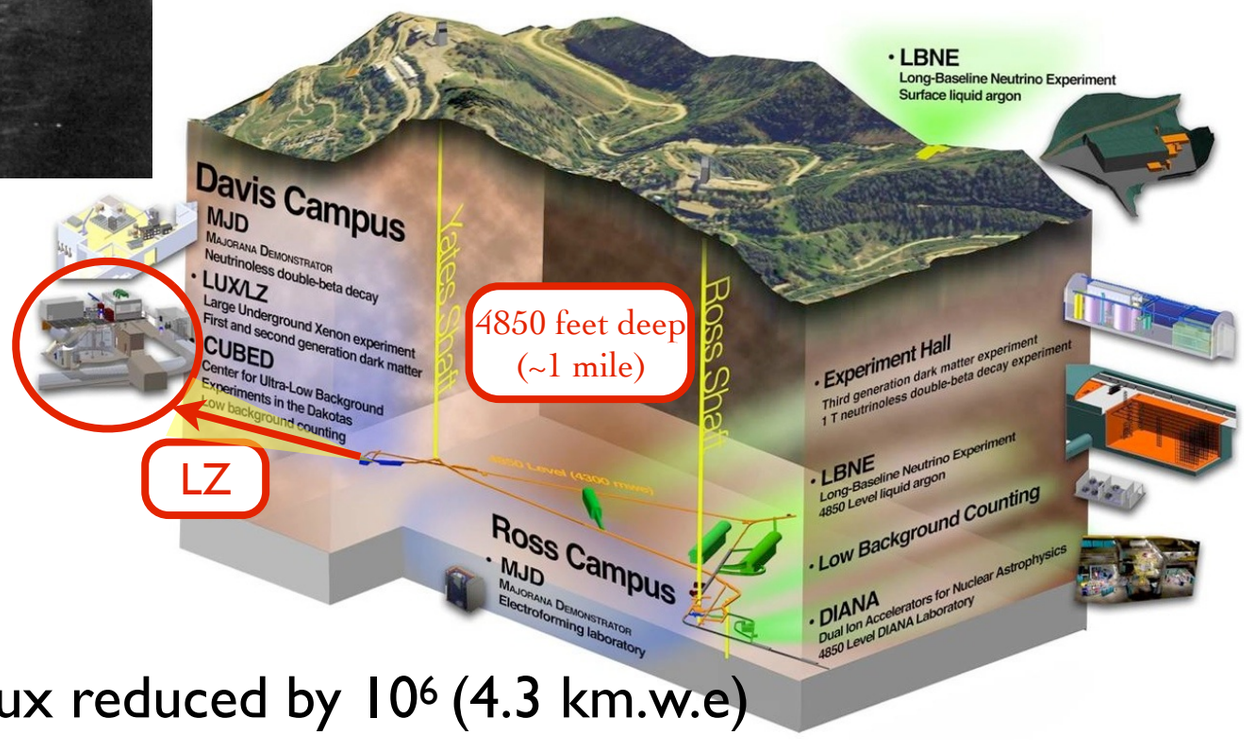
Sanford Underground Research Facility (SURF) in Lead, SD







Ray Davis, noble prize winner

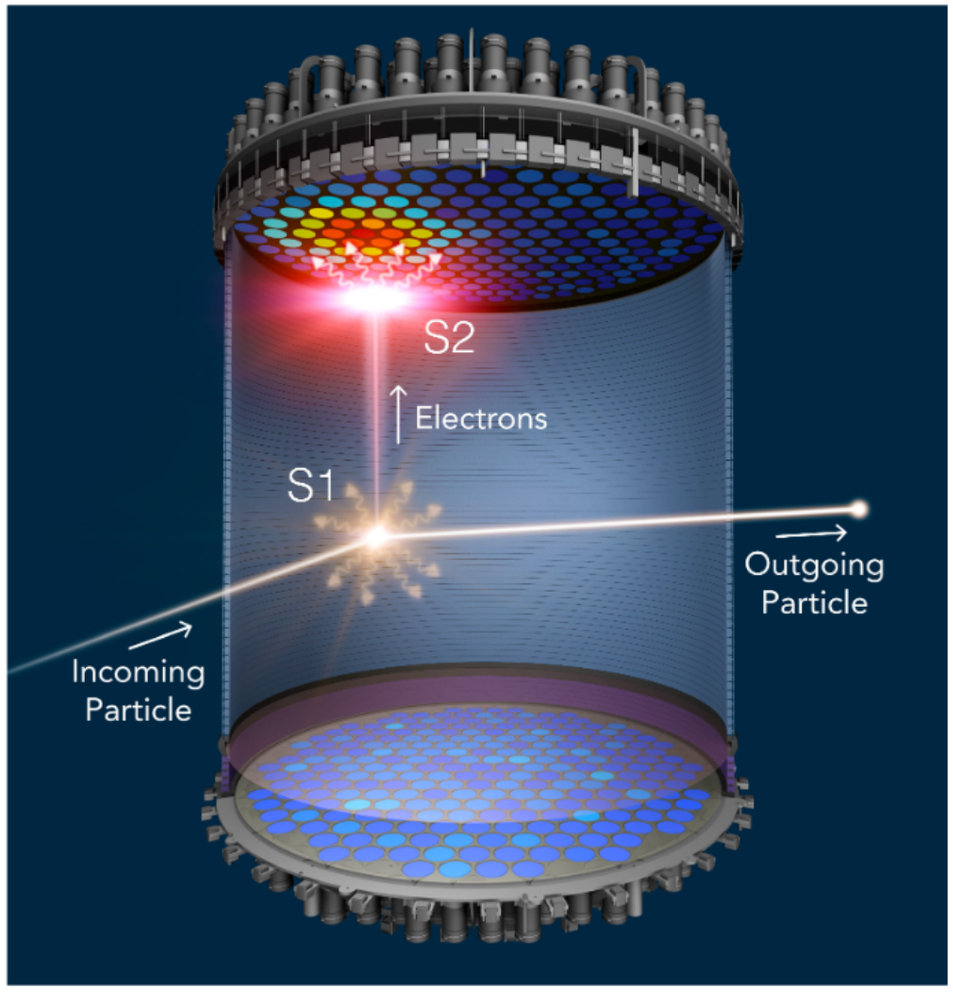


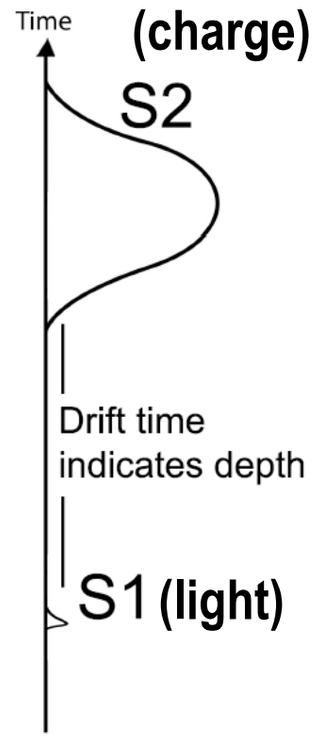
Muon flux reduced by 10^6 (4.3 km.w.e)

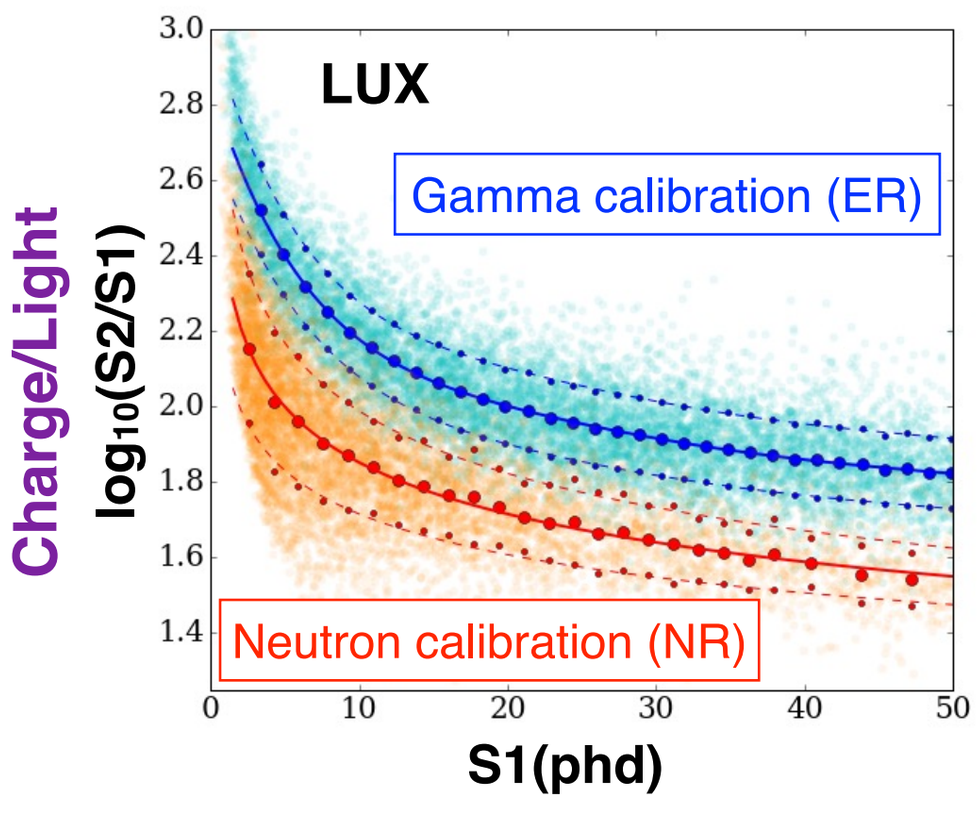
Dual Phase Noble Liquid TPC

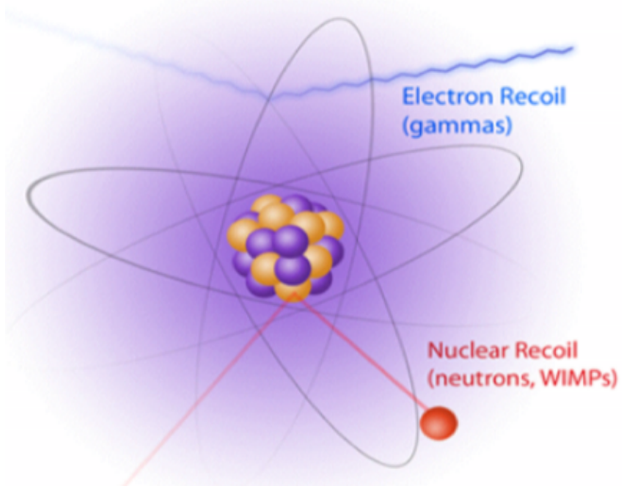
- Excellent 3D imaging capability
  - ✦ Z position from S1 - S2 timing
  - ✦ XY positions from S2 light pattern

- charge / light ratio
  => Signal vs Background discrimination





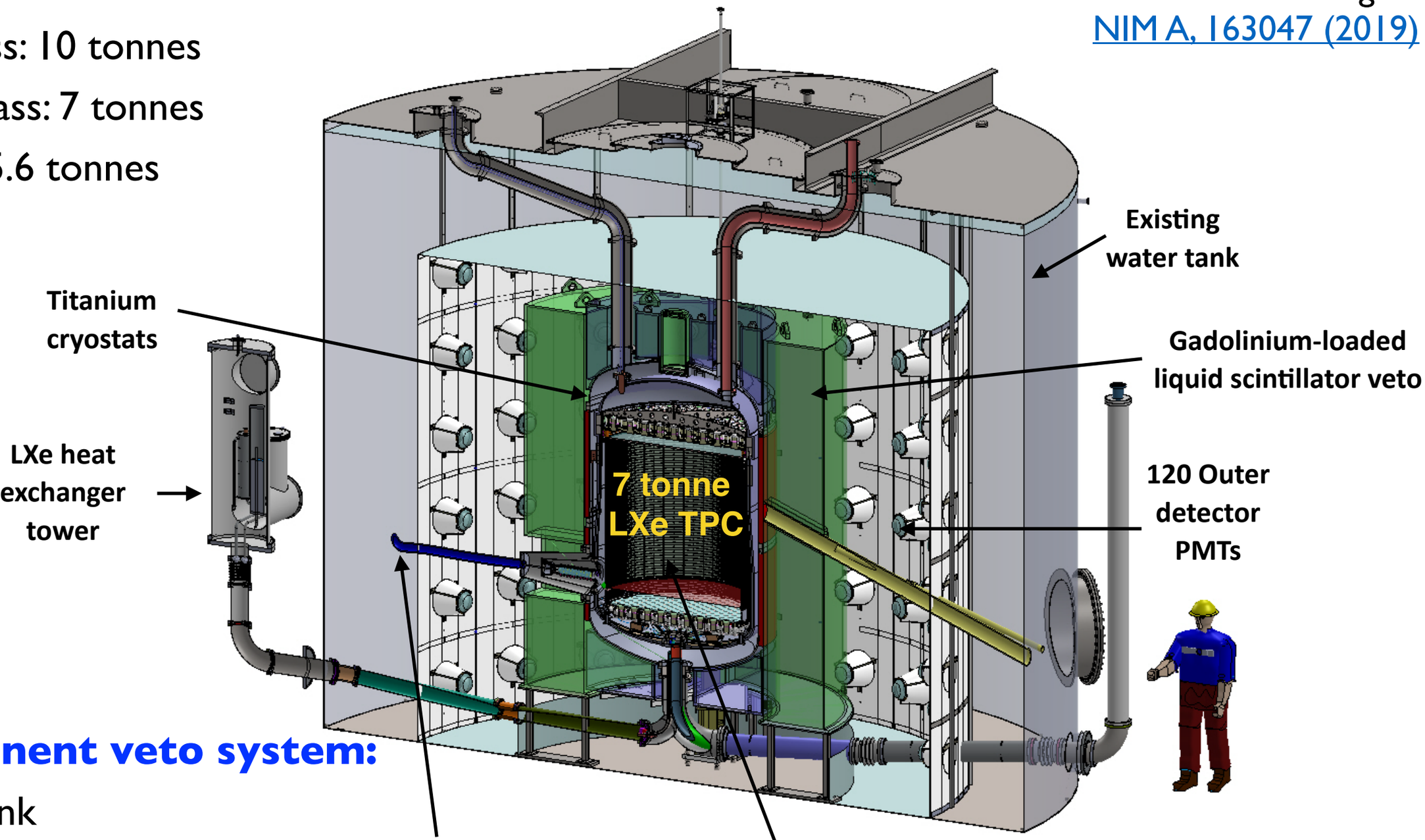




LZ Detector Overview

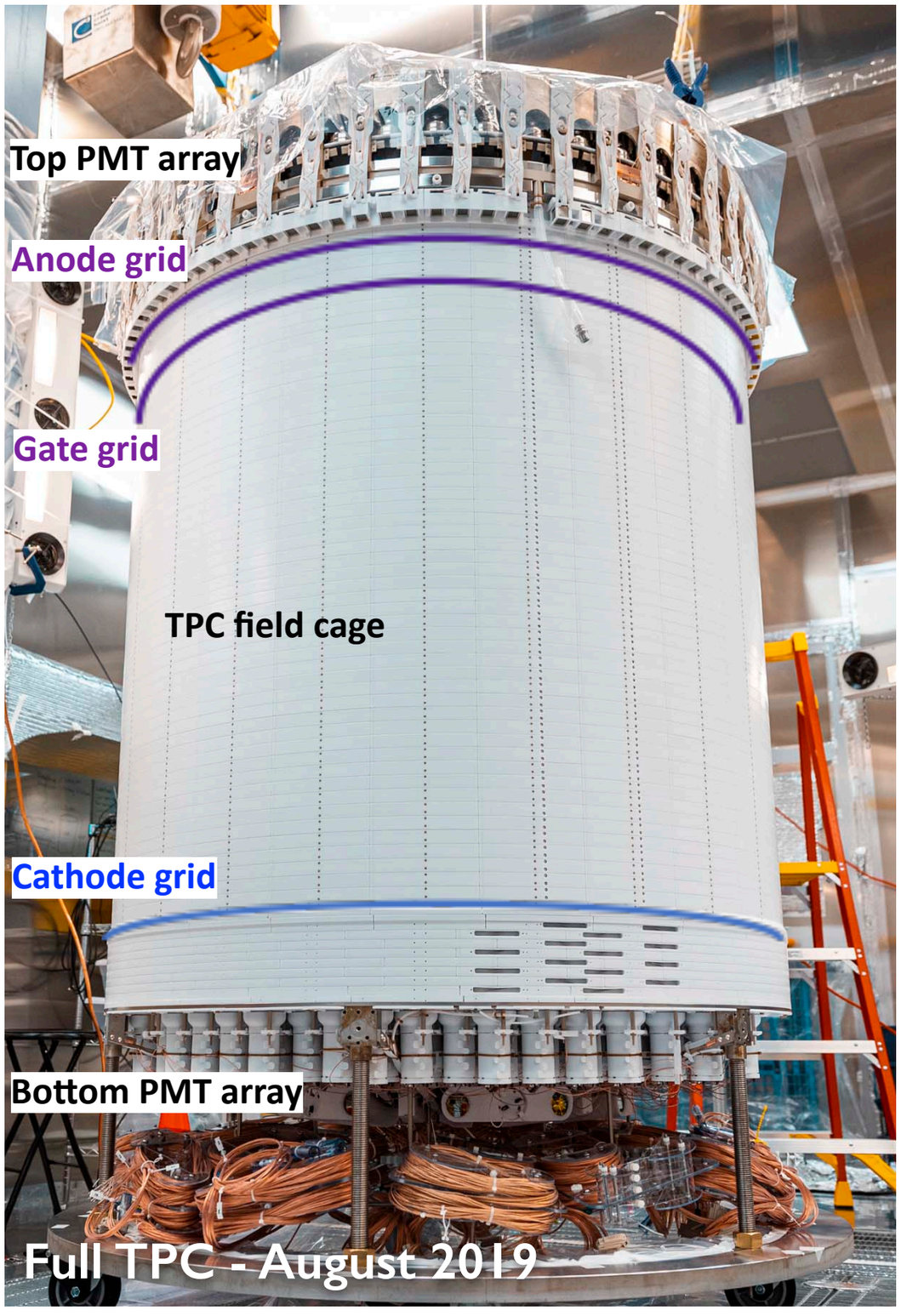
- **Xenon TPC**
  - ✦ Total mass: 10 tonnes
  - ✦ Active mass: 7 tonnes
  - ✦ Fiducial: 5.6 tonnes

LZ detector design:
NIM A, 163047 (2019)



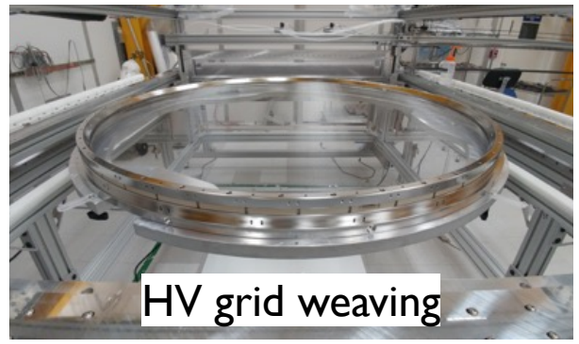
- **3-component veto system:**
  - ✦ Water tank
  - ✦ Gd-loaded scintillator
  - ✦ Instrumented LXe Skin

Xenon TPC



- 7 t of active xenon (5.6 t fiducial)
  - 1.5 m diameter x 1.5 m height
- 494x 3” PMTs
- 4 high-voltage grids for
  - Drift field
  - Extraction region

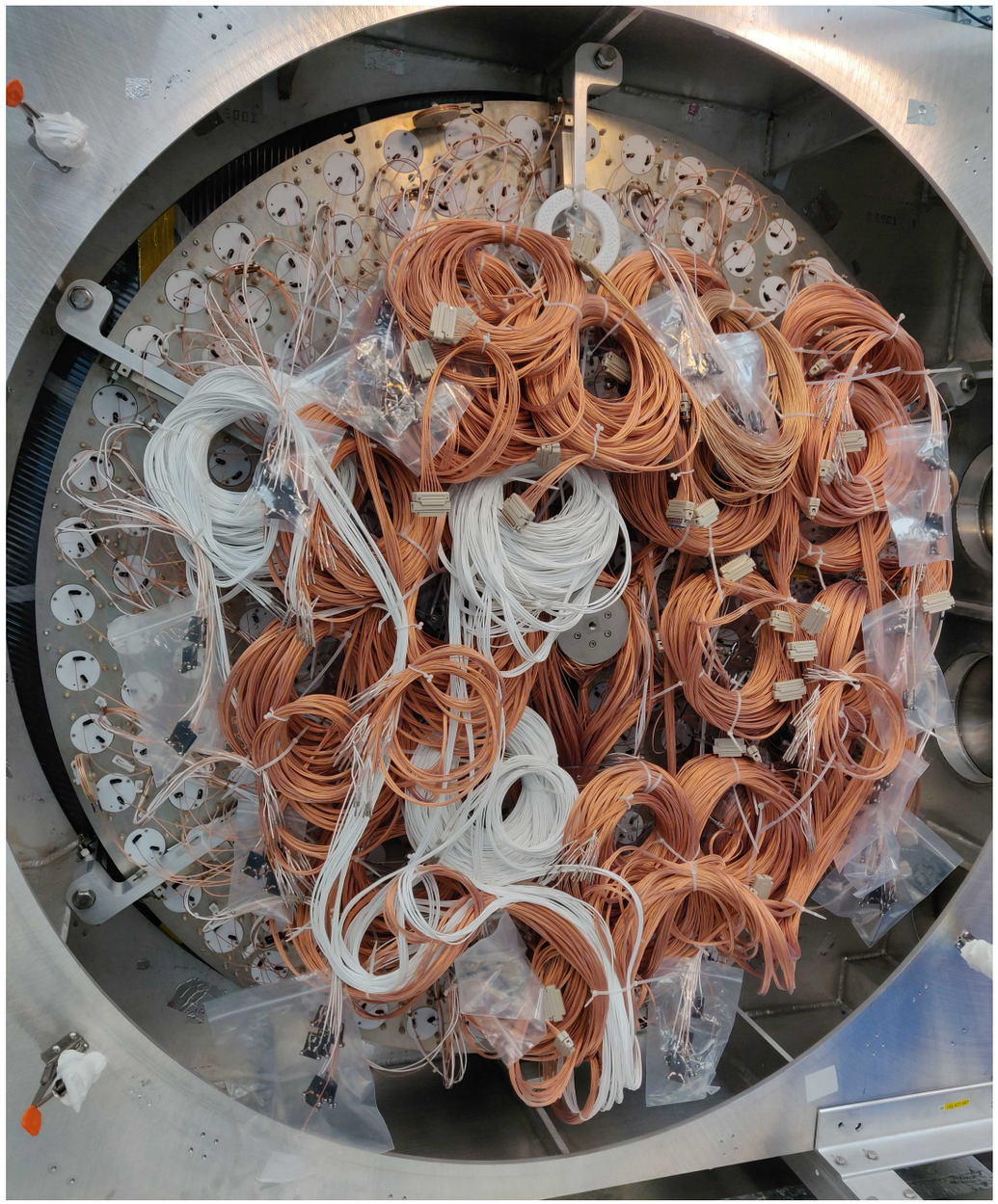
3” R11410-22 PMTs

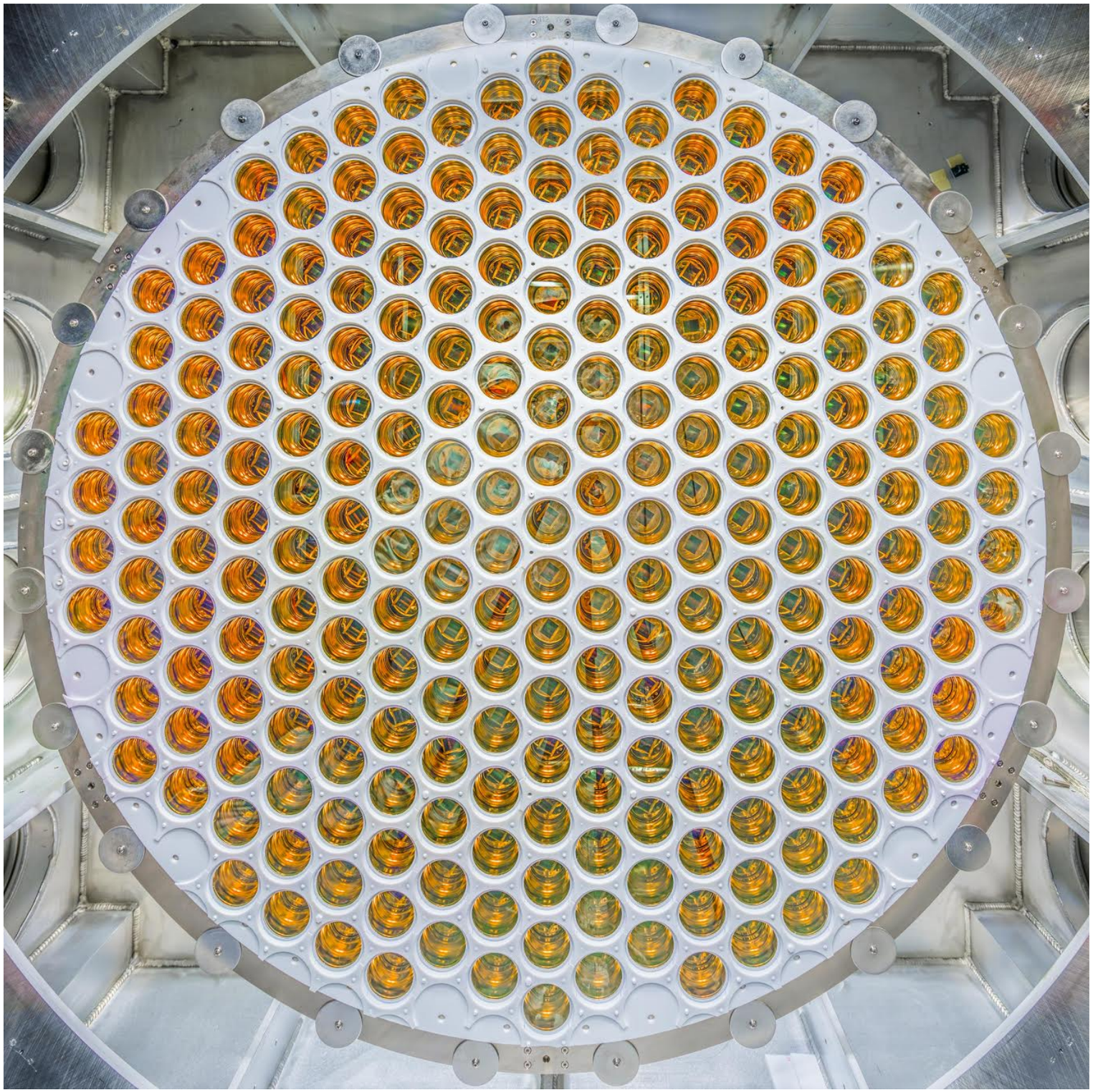

HV grid weaving

PMT arrays

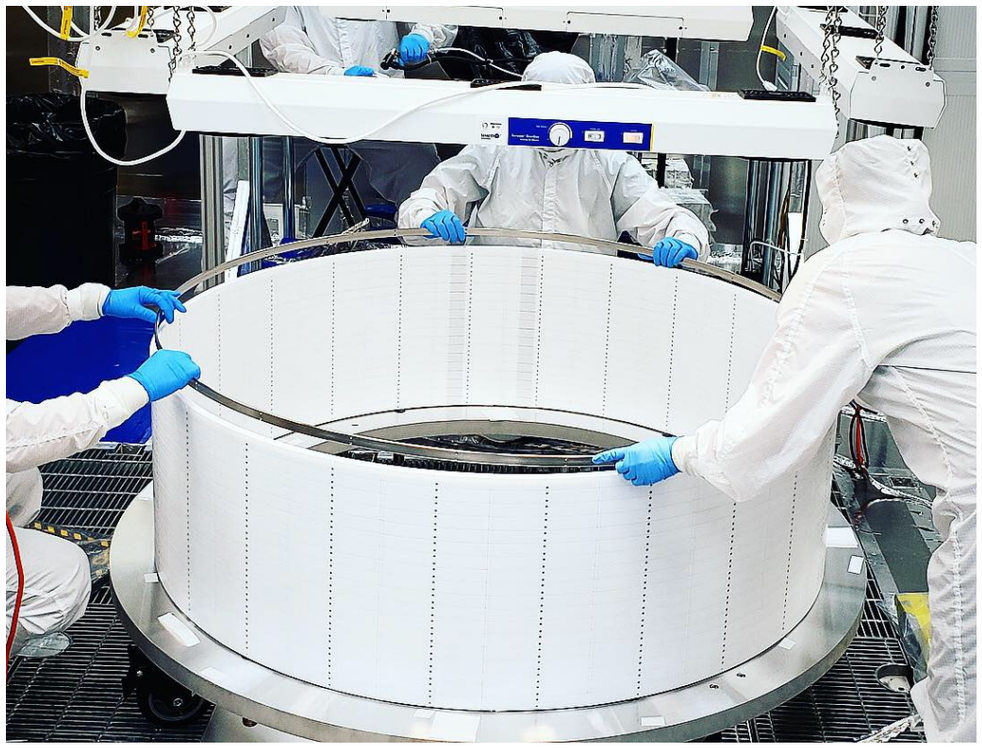
Hamamatsu R11410 (3”)

- Top array: 253 PMTs
- Bottom array: 241 PMTs

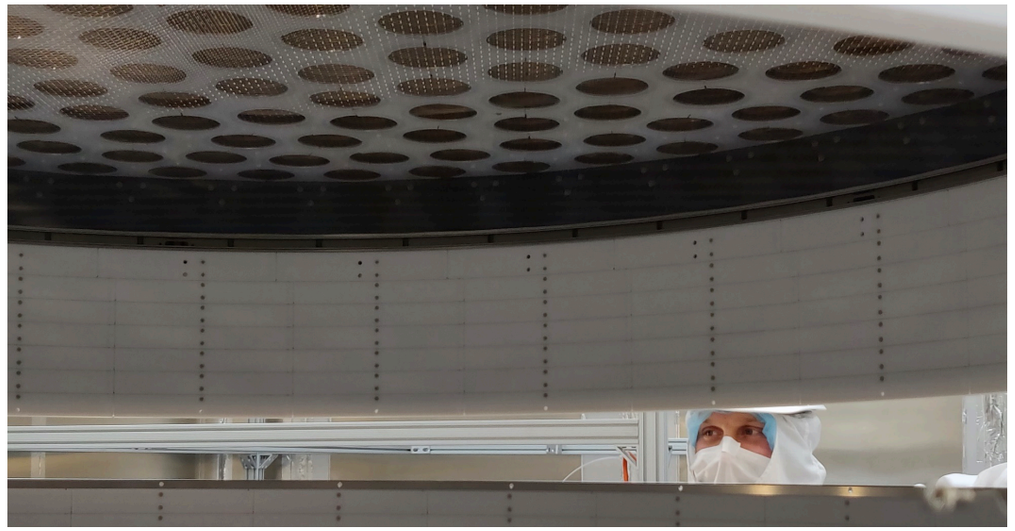


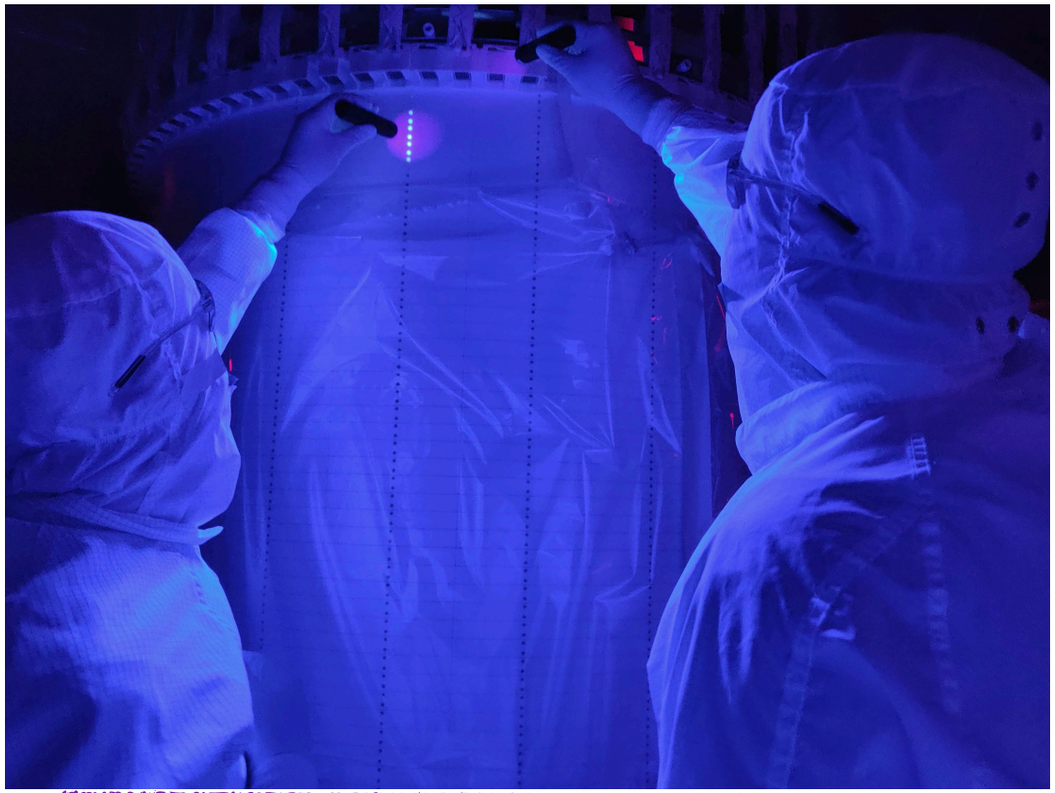


TPC & Skin Integration in the Surface Assembly Lab

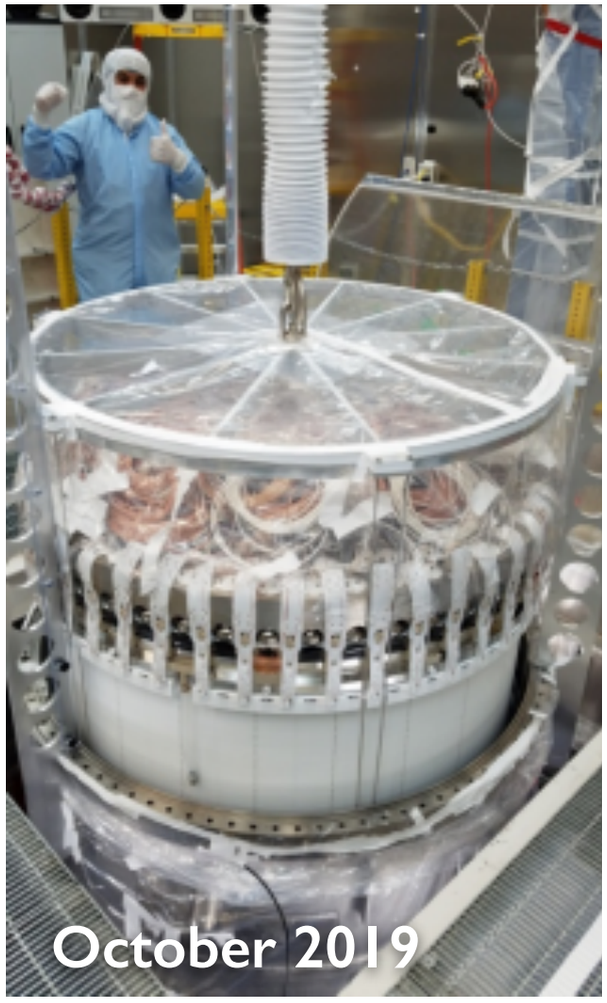


Detector integration started in December 2018 at Surface Assembly Laboratory (SURF) ~13,500 working hours



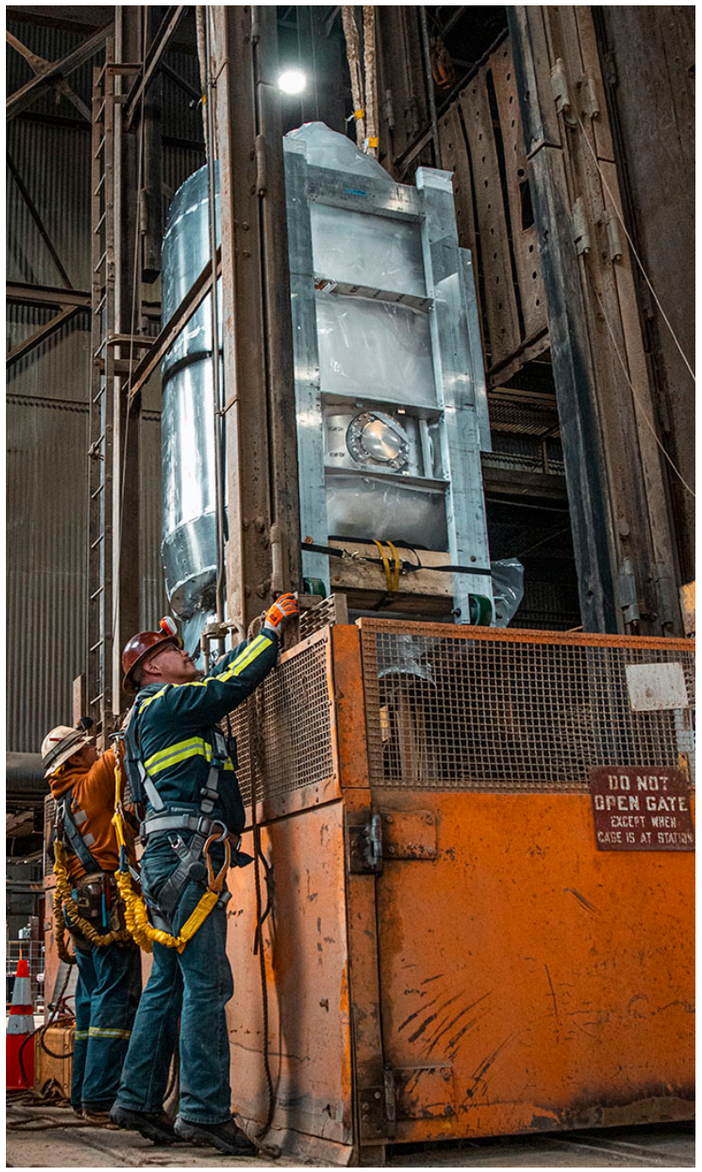


Insertion into inner cryostat vessel

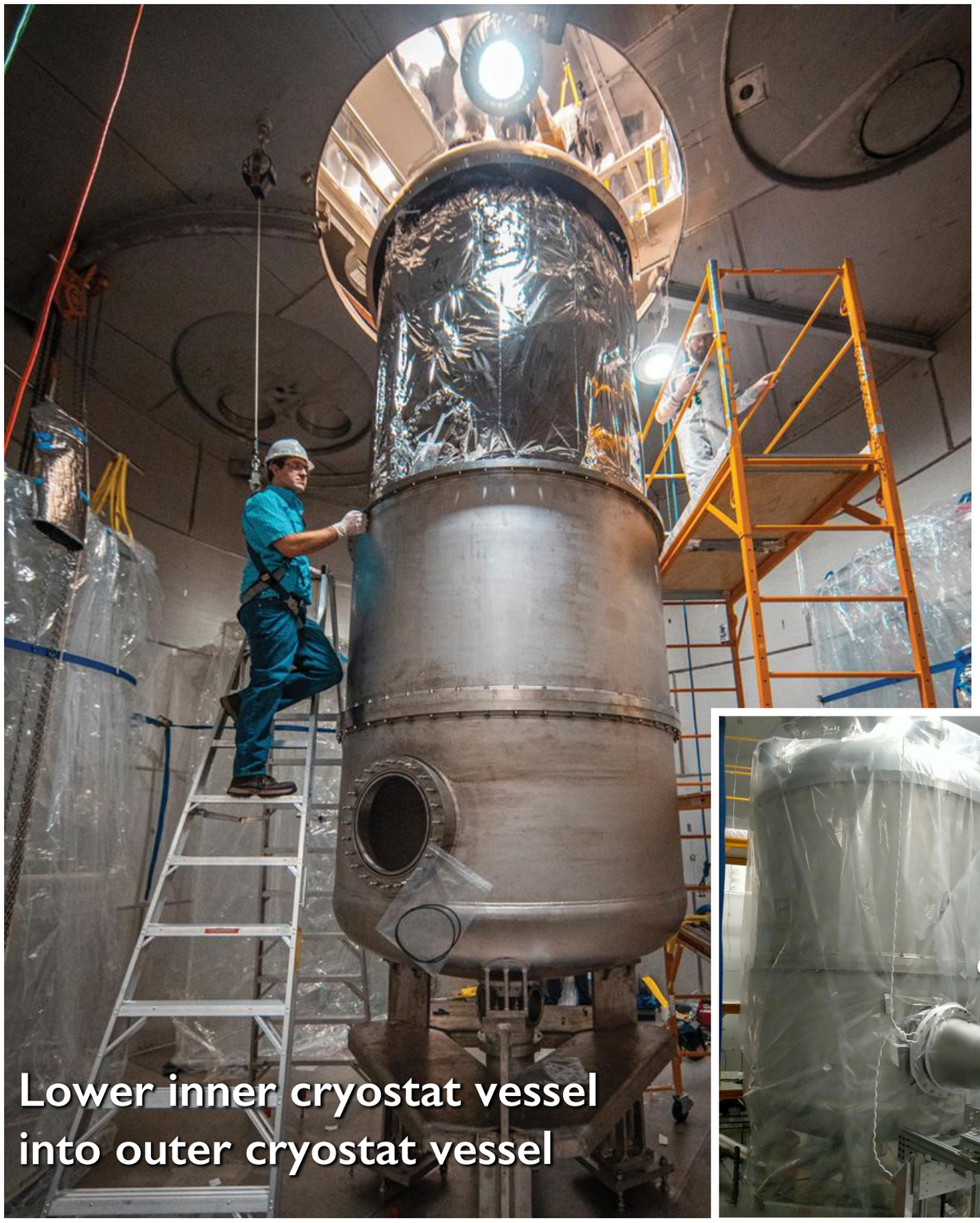


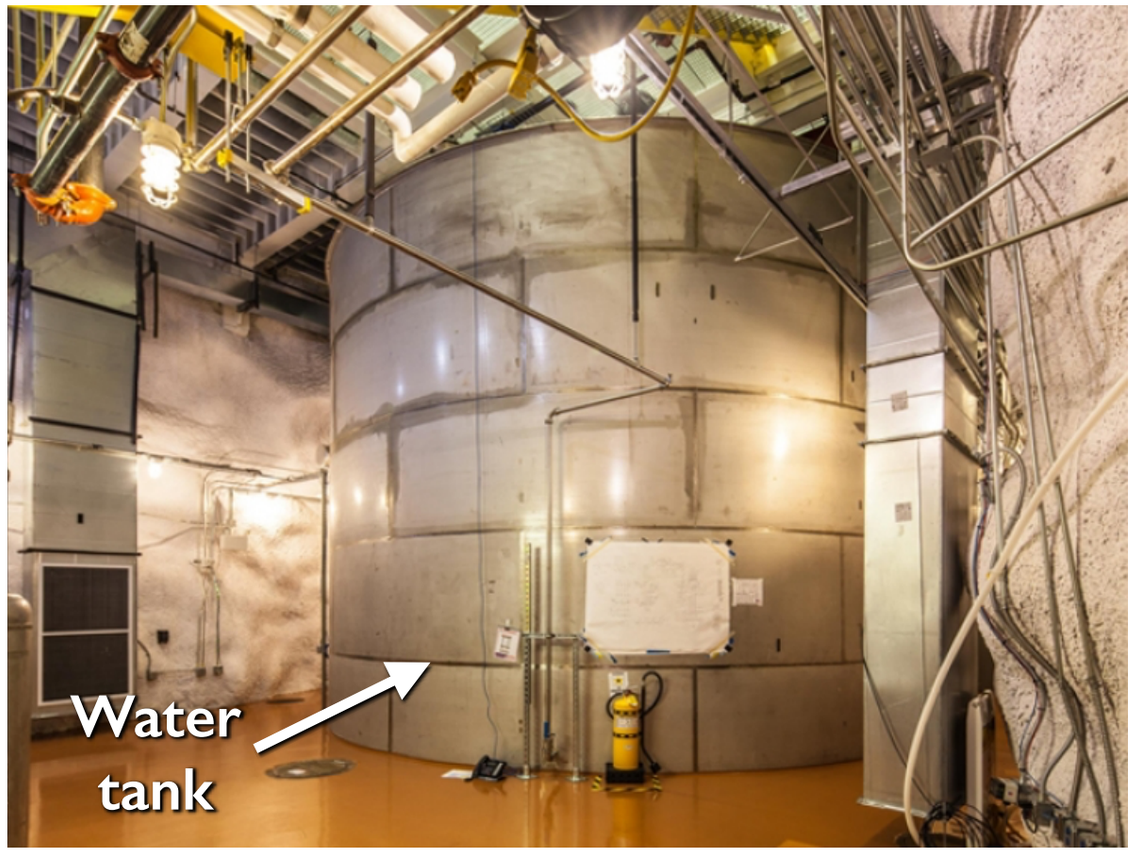
Transport of TPC Underground

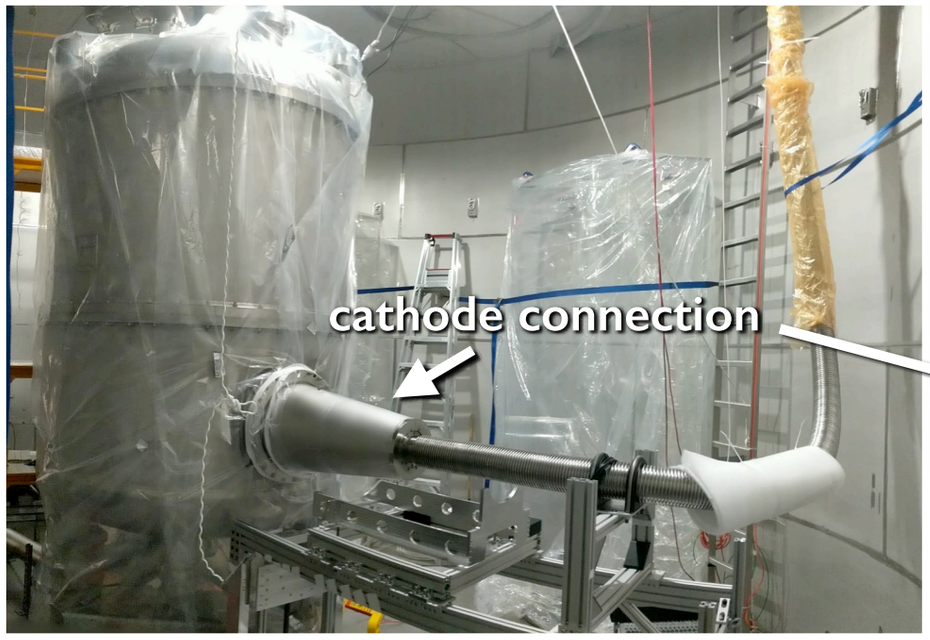
October 2019



Underground deployment I







Making up cathode connections
(under N2 purge)

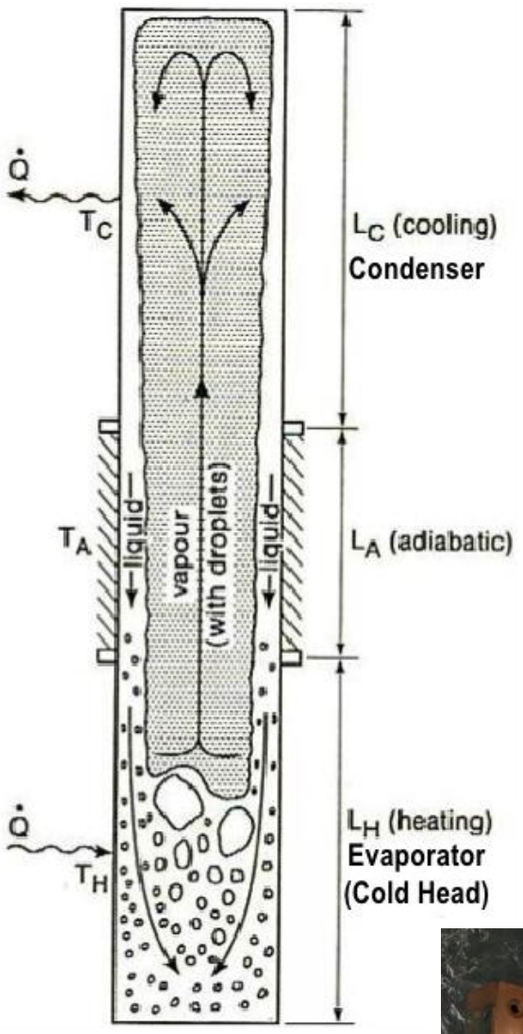
Underground deployment II

Underground deployment III

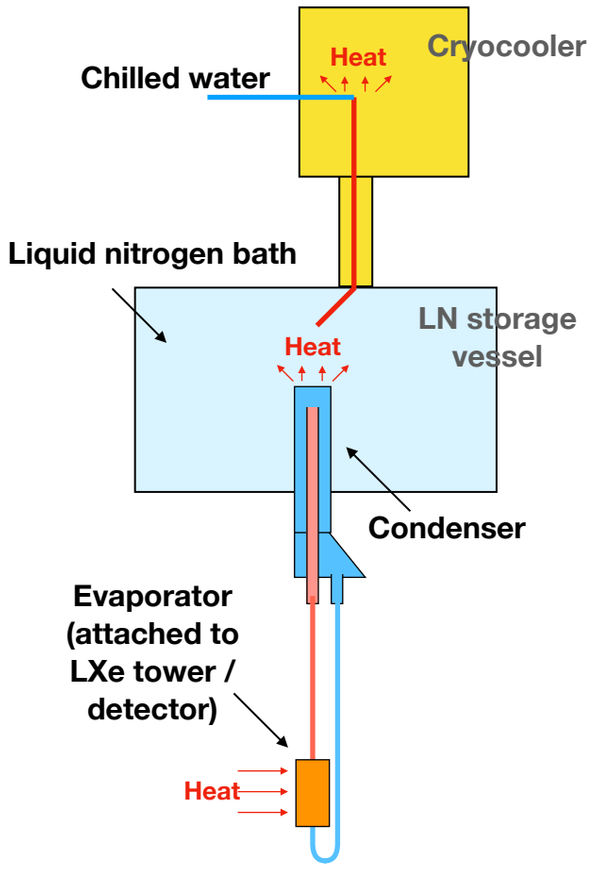
LZ Cryogenics

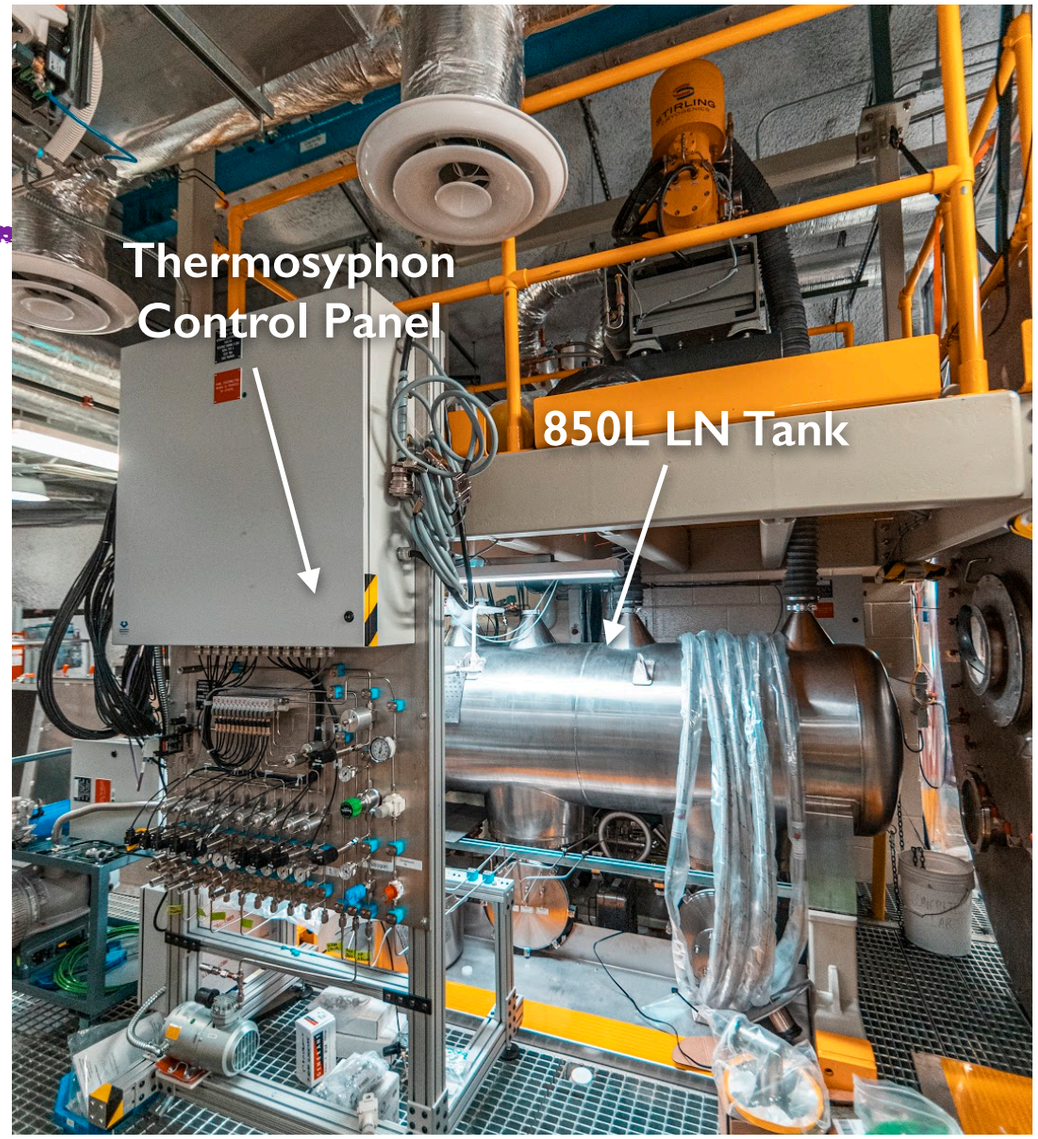
- Cooling provided by thermosyphon technology (also used in LUX)

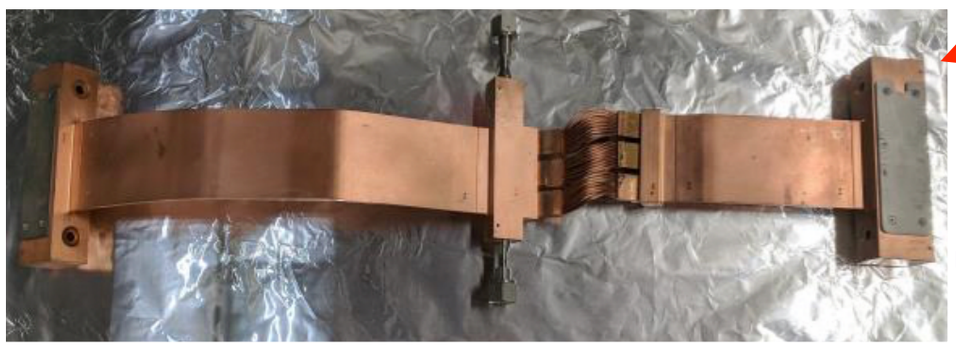
Thermosyphon principle

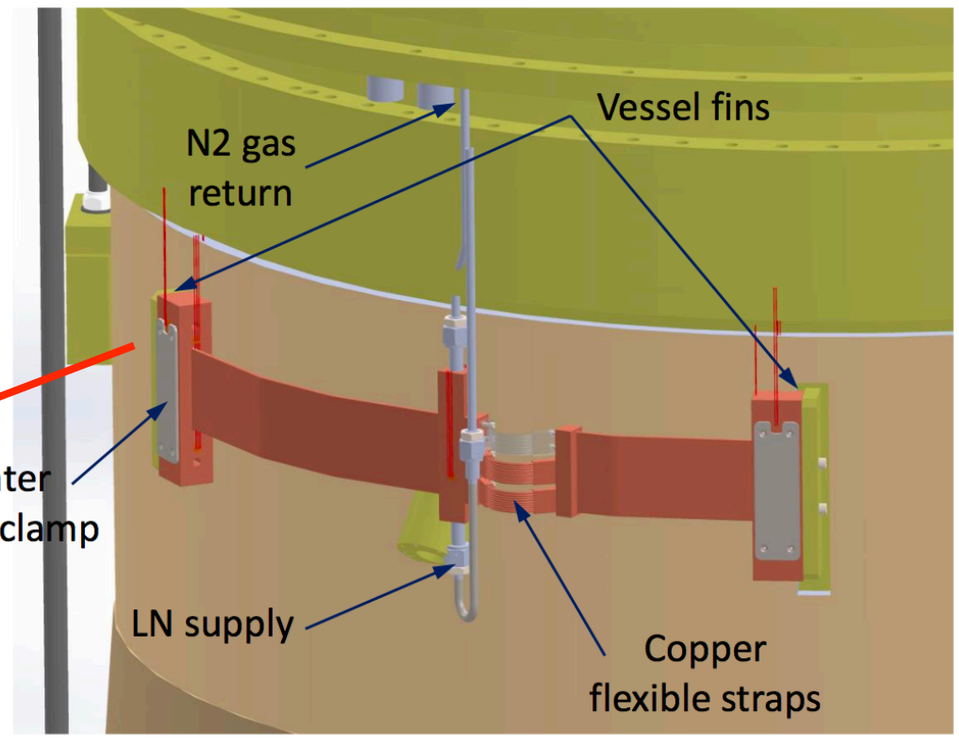


Sketch of cooling system

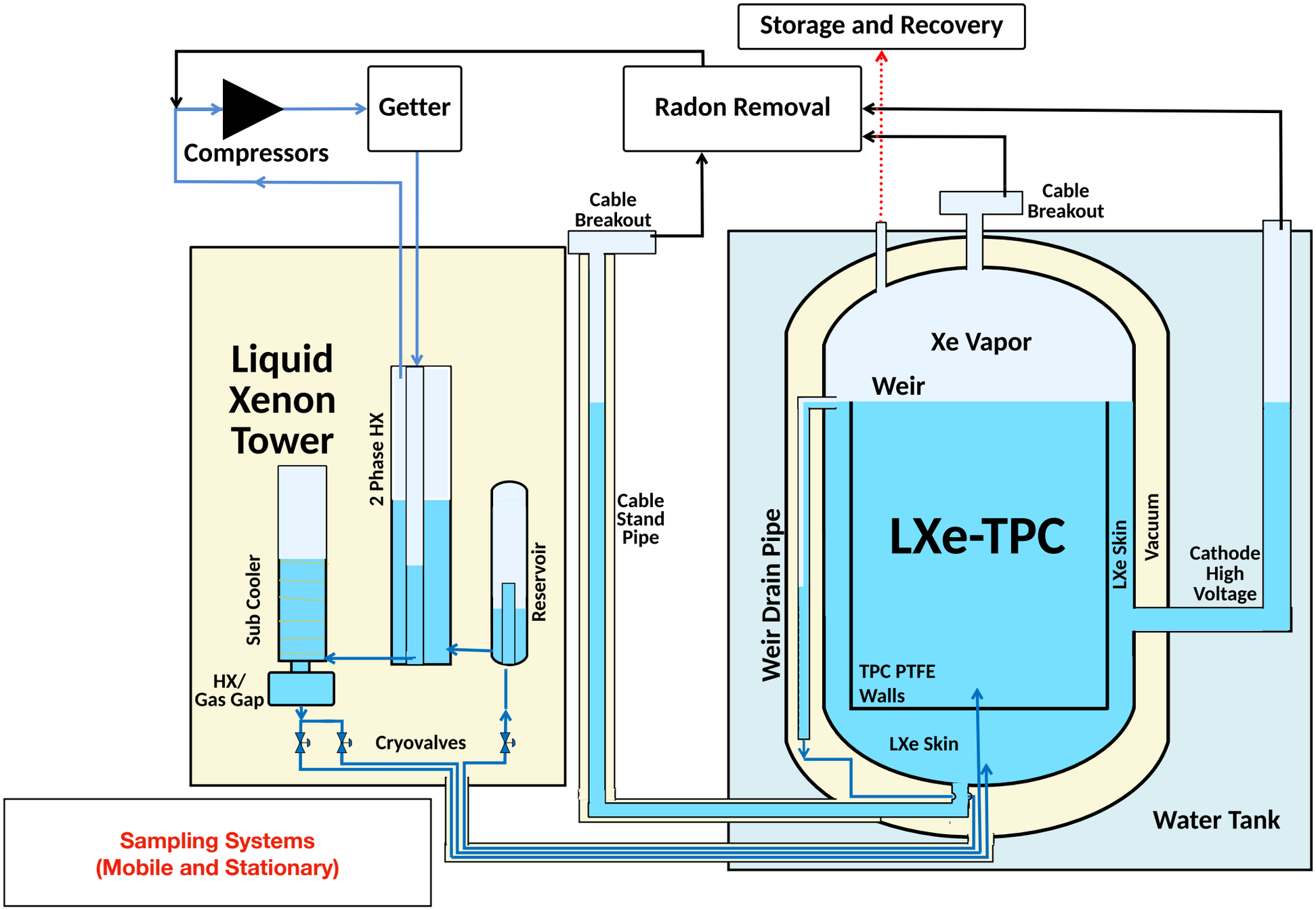






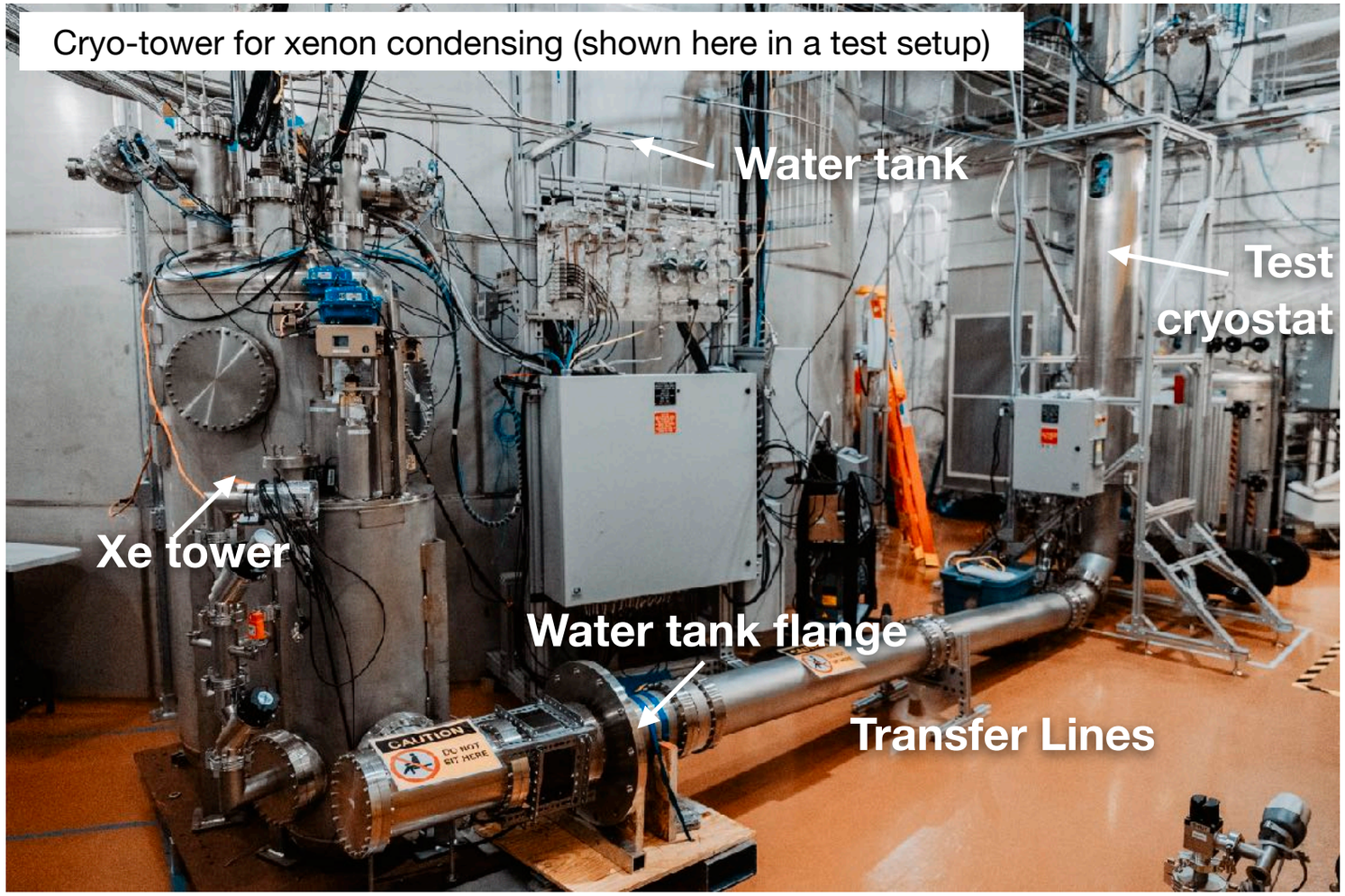


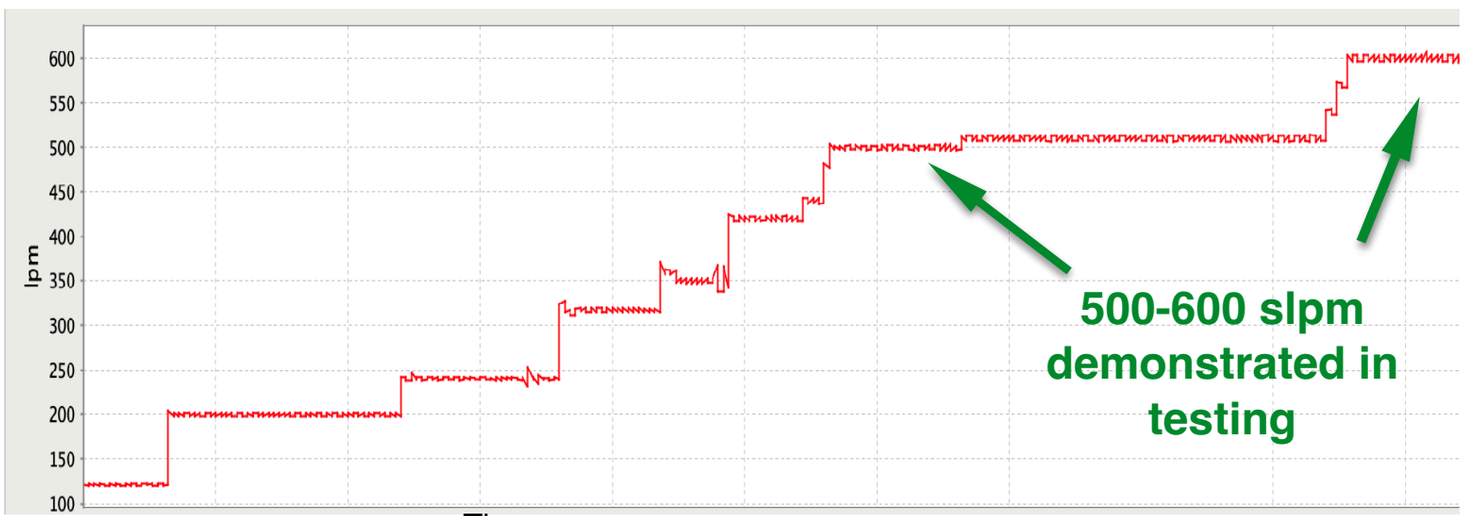
Xenon Circulation System



Xenon Circulation System & Cryogenics Commissioning

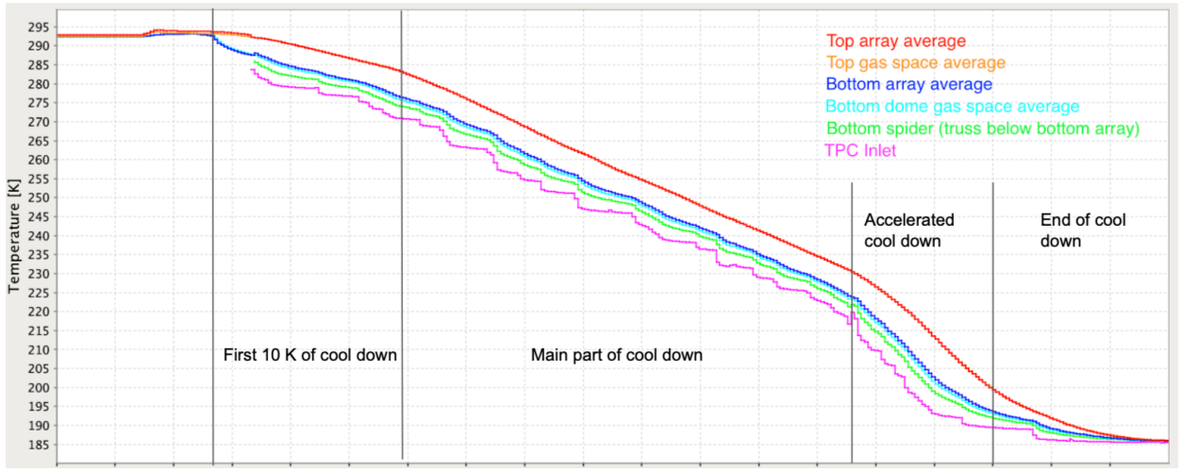
- Design gas circulation rate: 500 slpm
  - ✦ Turnover full Xe mass every 2.4 days
  - ✦ Underground commissioning completed
    - Up to 600 slpm demonstrated
- Purification using hot zirconium getter
  - ✦ Removes non-noble impurities

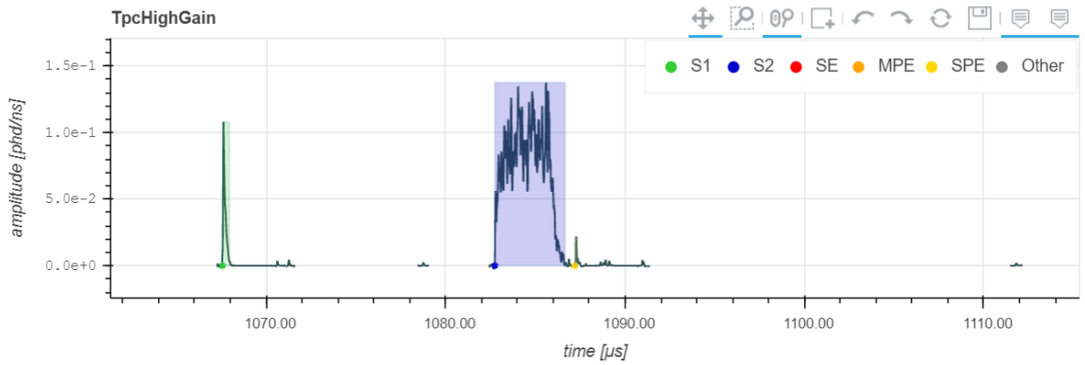


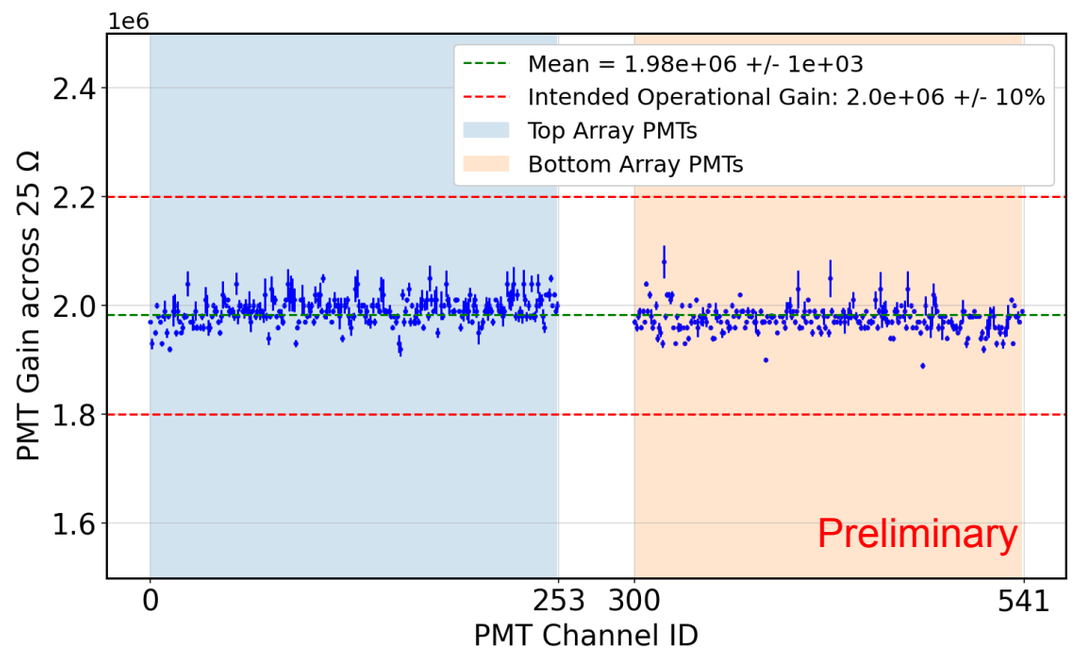


LZ Commissioning

- TPC detector filled and leveled
- Grids biassed: extraction & drift fields established
  - Drift field ~190 V/cm
  - Extraction field ~7.5 kV/cm gas
- Data processing chain exercised with first S1+S2s
- Data acquisition & trigger settings tuned
- PMT operations & characterization
  - LED measurements for after-pulsing and single photoelectron (SPE) studies
  - PMTs gain-matched and gain drifts monitored
  - Dark count & double photoelectron emission (DPE) analyses
- Event reconstruction algorithms highly reliable, with an accuracy >95%
- Bias mitigation techniques
  - See talk by D. Woodward
- Application of machine learning to find anomalous events
  - See talk by C. Amarasinghe



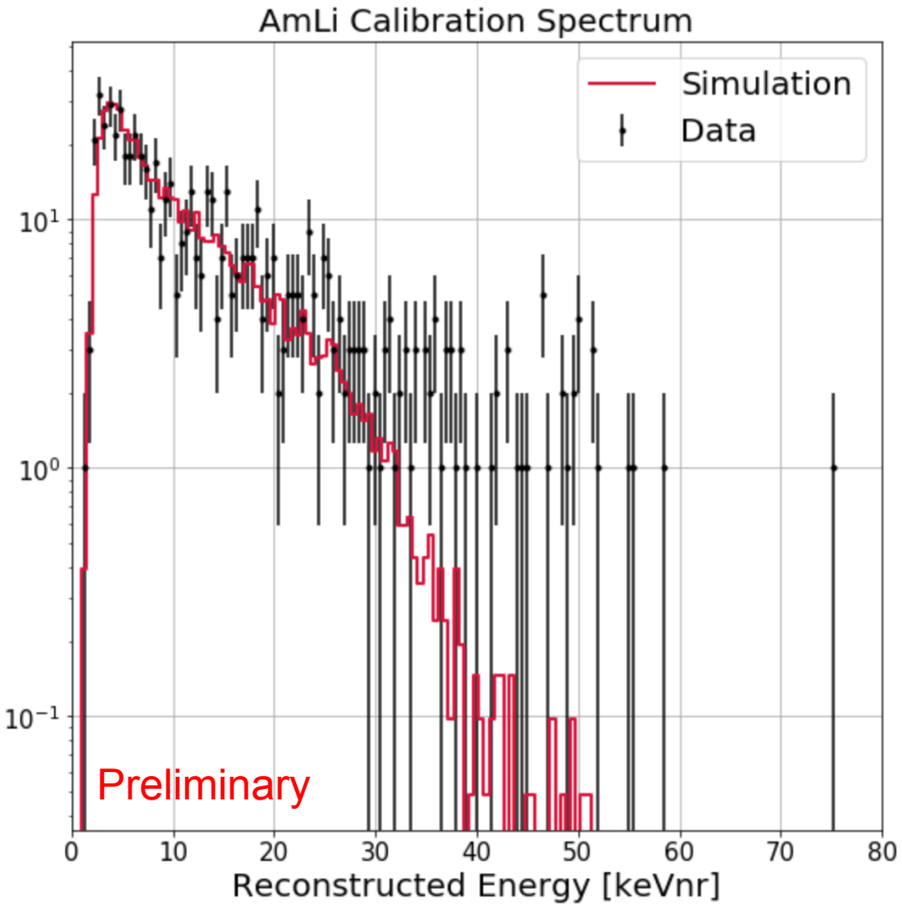


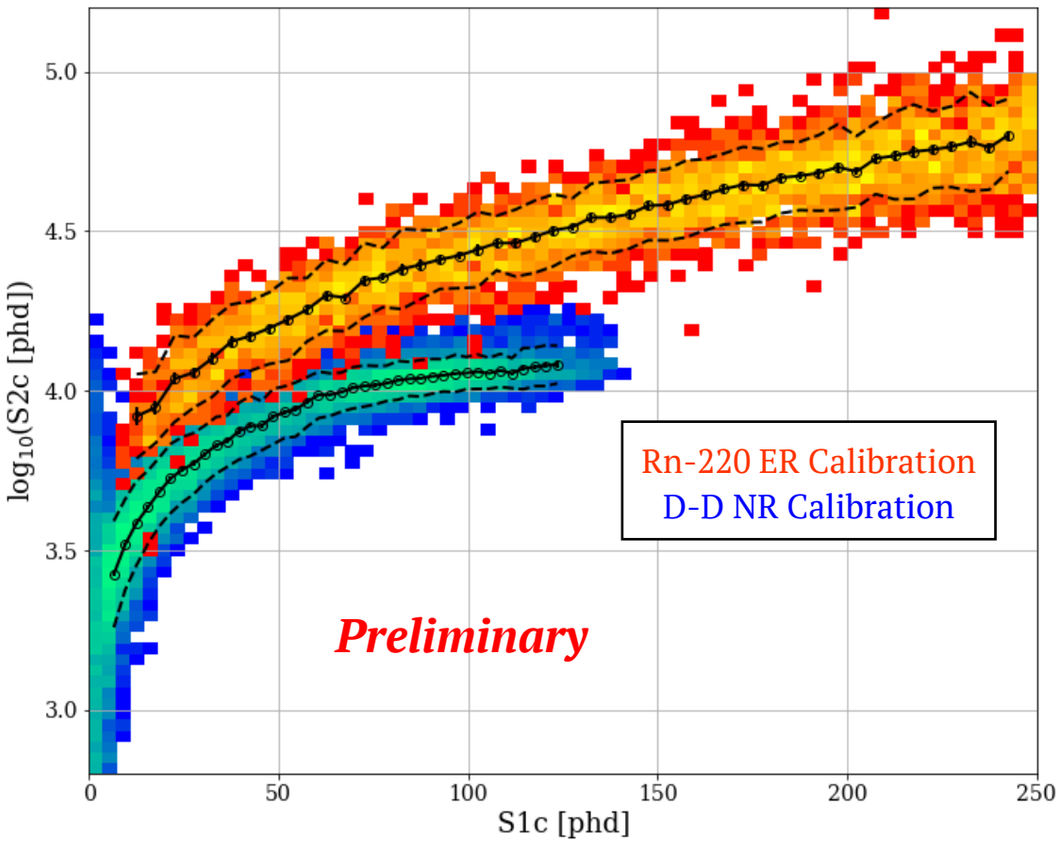


Calibrations

- Different calibration systems available
  - Internal sources
  - Commercial rod sources
  - Photo-neutrons
  - DD neutron generator
- See talk by M. Timalsina

Low energy neutron calibration source



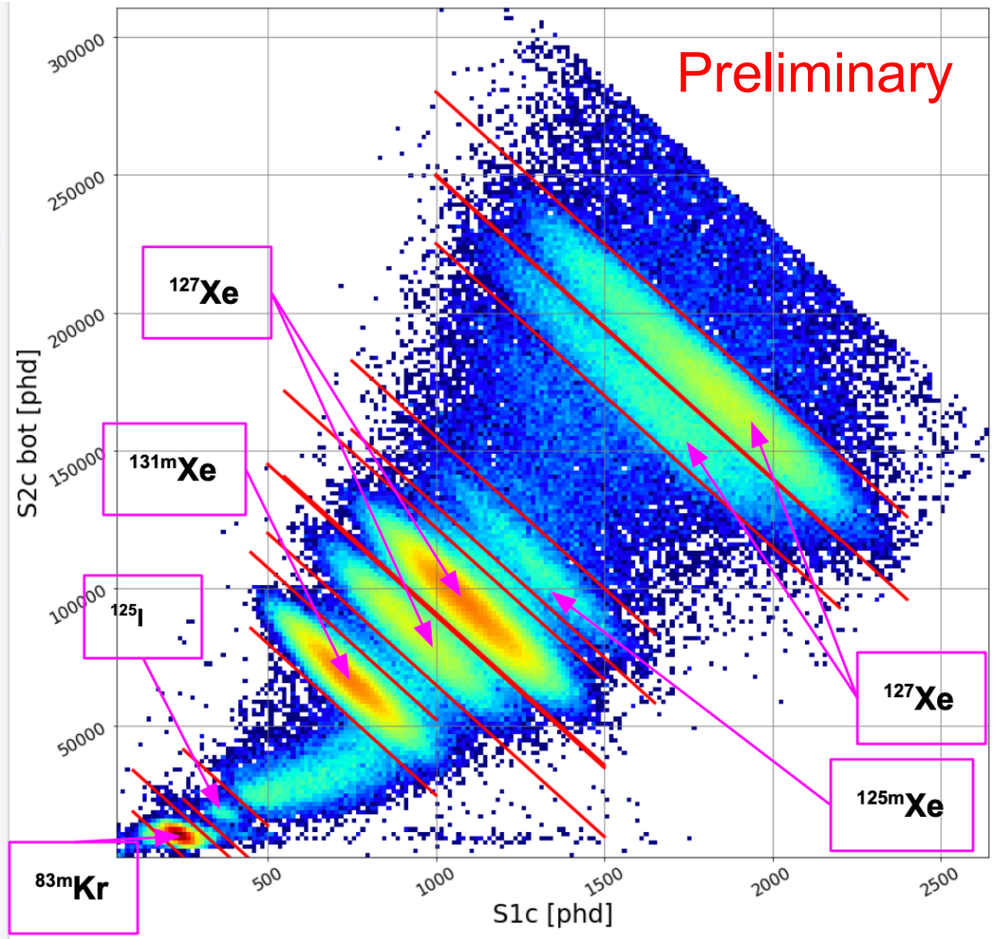


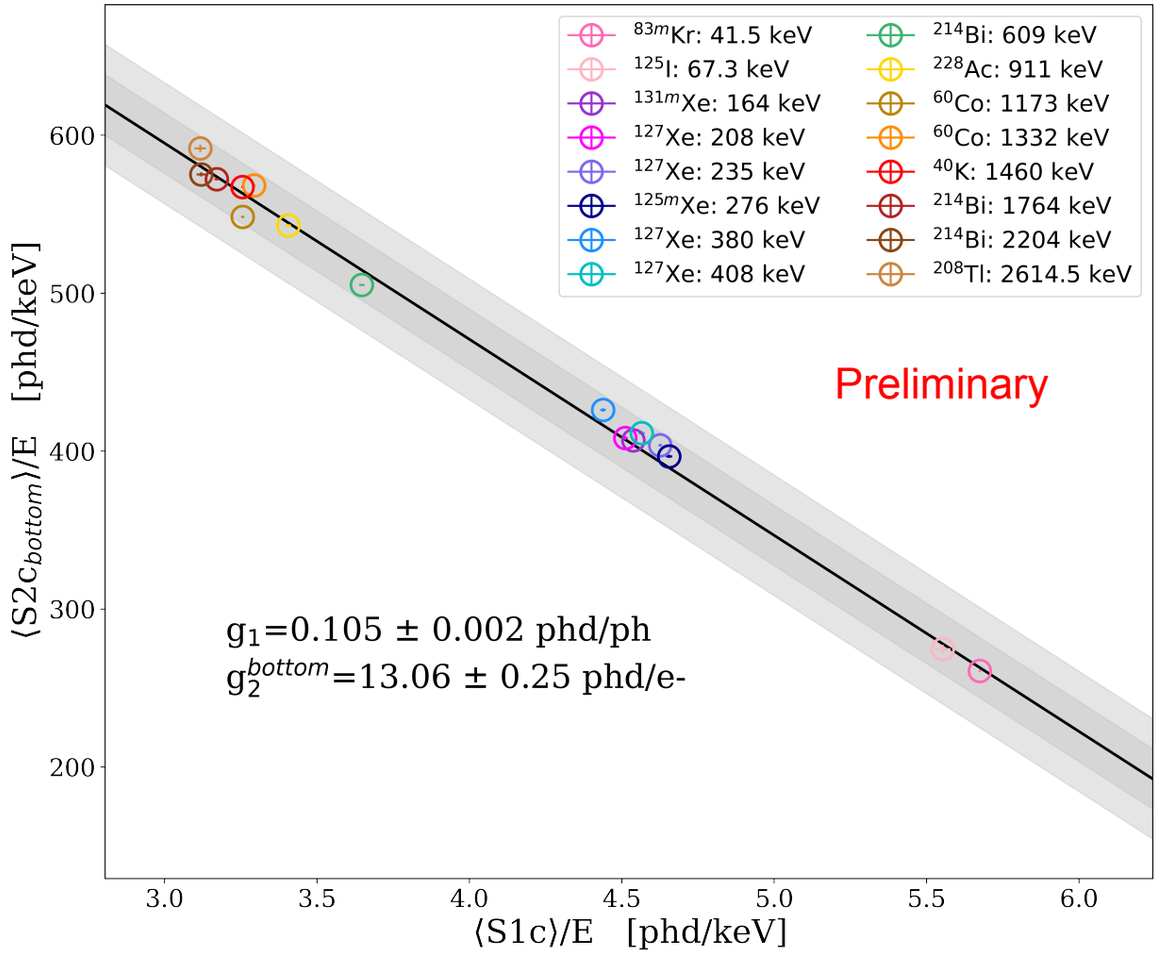
- Calibrations used to inform
  - Energy scale & thresholds in TPC, Xe skin and OD
  - Position reconstruction
  - Inter-detector timings
  - NR & ER bands in the TPC

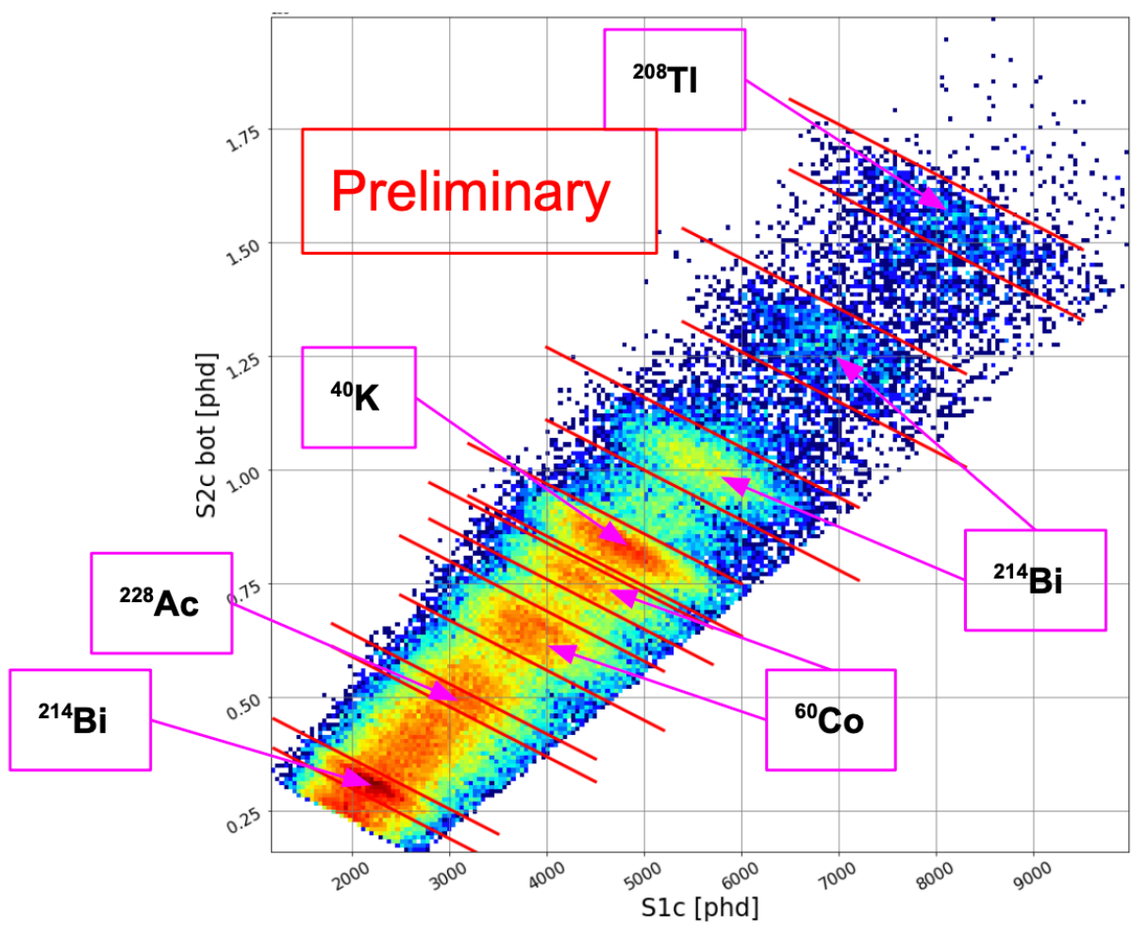
Detector Response Characterization

- Mono-energetic ER peaks used to find:
  - g1, photons detected (phd) per prompt scintillation photon
  - g2, phd per ionisation electron

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





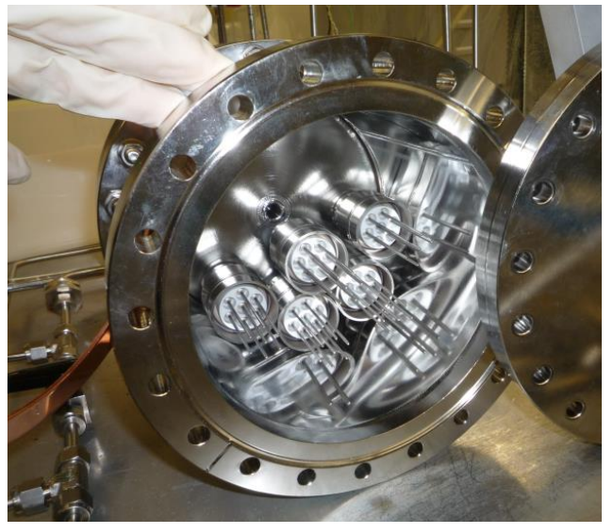


Background Sources and Mitigation

- Detector materials
  - Nothing went into the detector without screening
  - Radio-assay campaign with 13 HPGe detectors, ICPMS, neutron activation analysis
- Rn emanation
  - Four screening sites
  - All major parts emanated before assembly
- Rn daughters and dust on surfaces
  - TPC assembly in Rn-reduced cleanroom
  - Dust <500 ng/cm^2 on all LXe wetted surfaces
  - Rn-daughter plate-out on TPC walls <0.5 mBq/m^2
- Xenon contaminants — ^{85}Kr, ^{39}Ar
  - Charcoal chromatography at SLAC
- Cosmogenics and externals
  - 4300 m.w.e. underground at SURF in Lead, SD
  - Instrumented Xe skin region
  - Gd-LS outer detector
  - High purity water shield

Many sources of BG

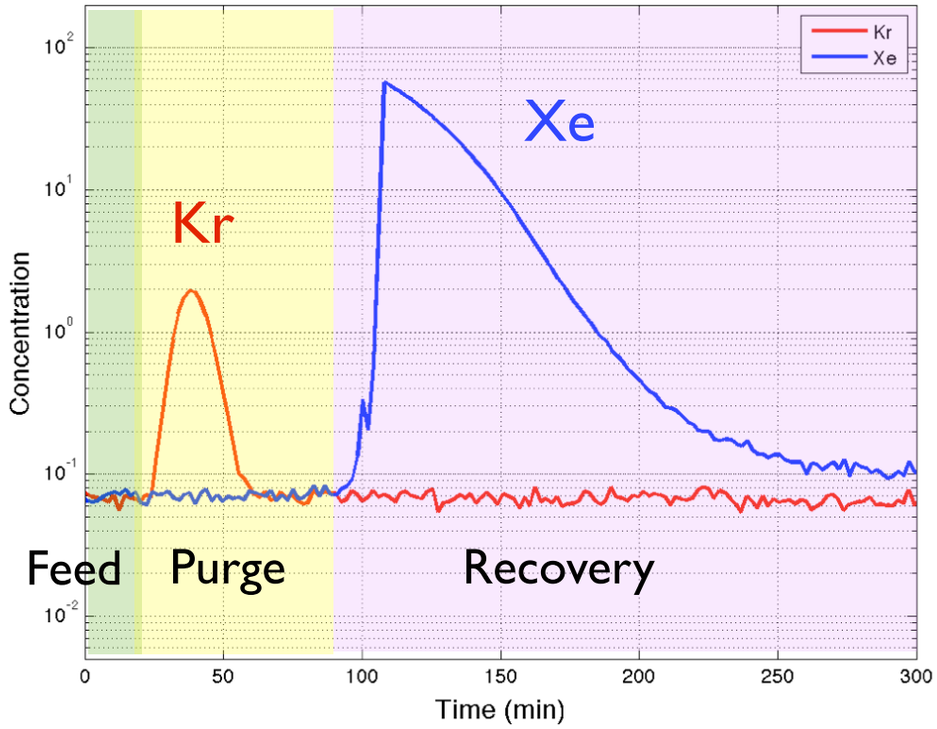
Many methods for BG mitigation

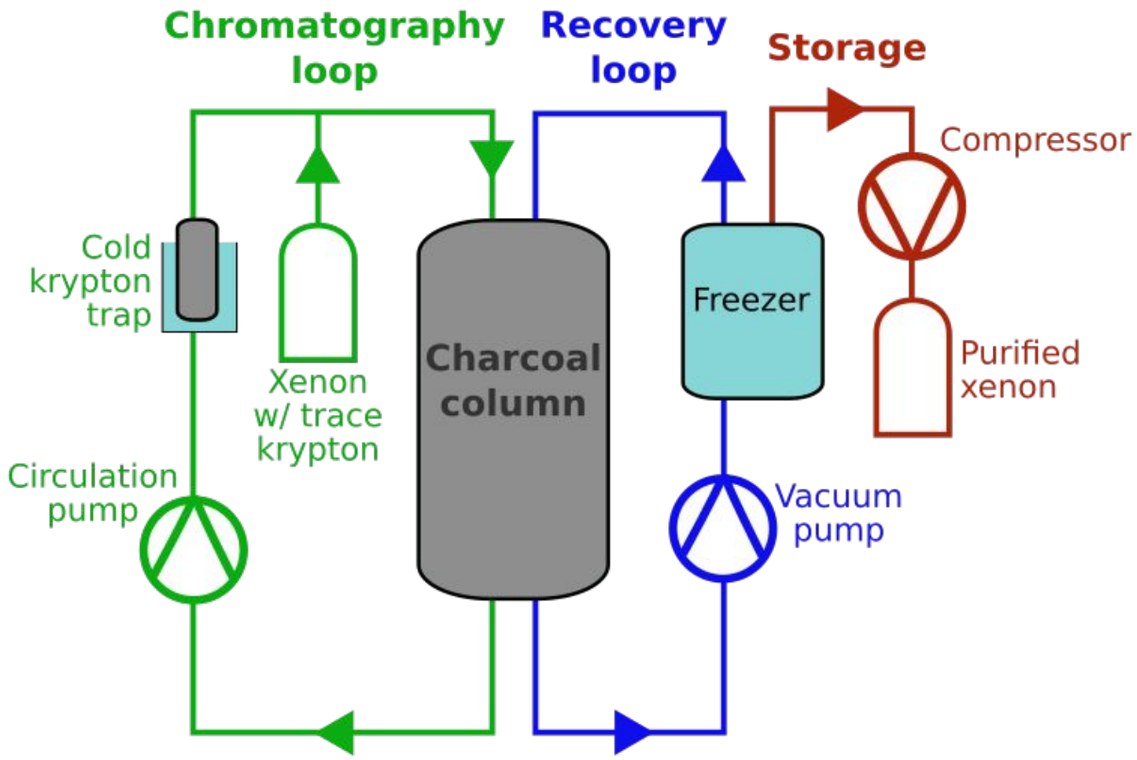


Eur. Phys. J. C, 80: 1044 (2020)

Kr Removal System

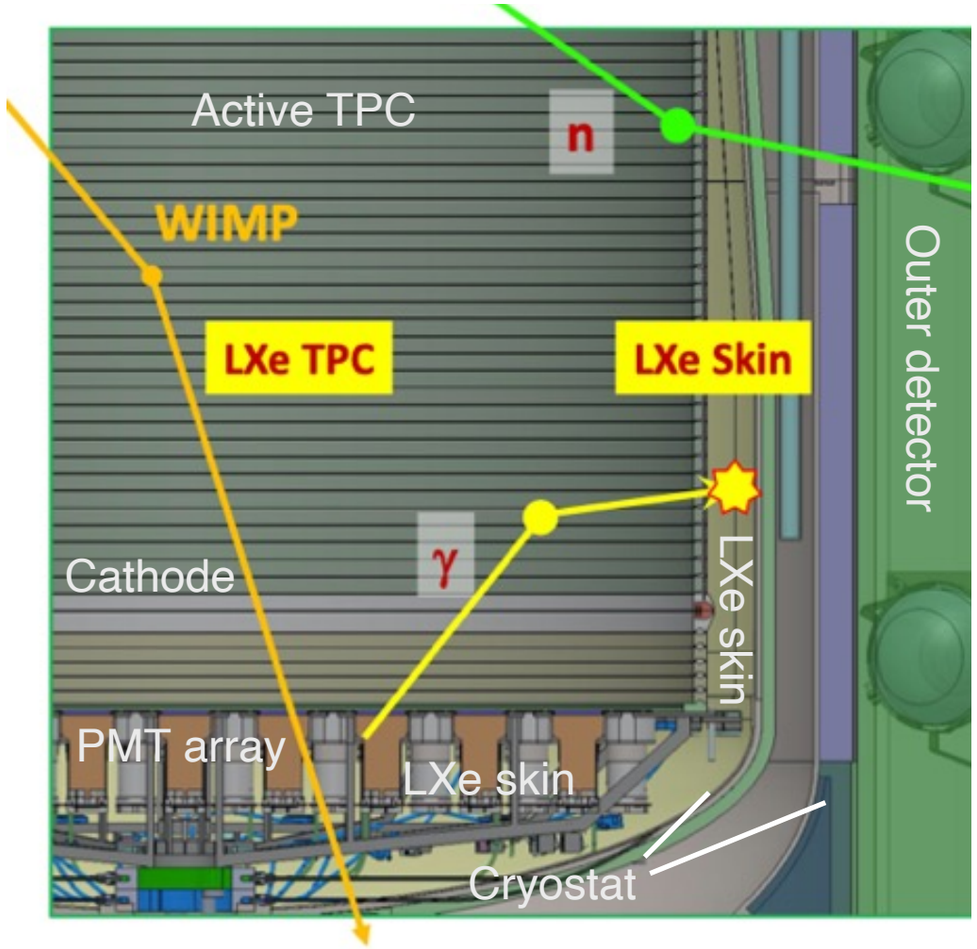
- Gas chromatography to remove Kr from Xe
  - ^{nat}Kr can be reduced to 0.1 ppt g/g ^{nat}Kr/Xe and ^{nat}Ar to a negligible level



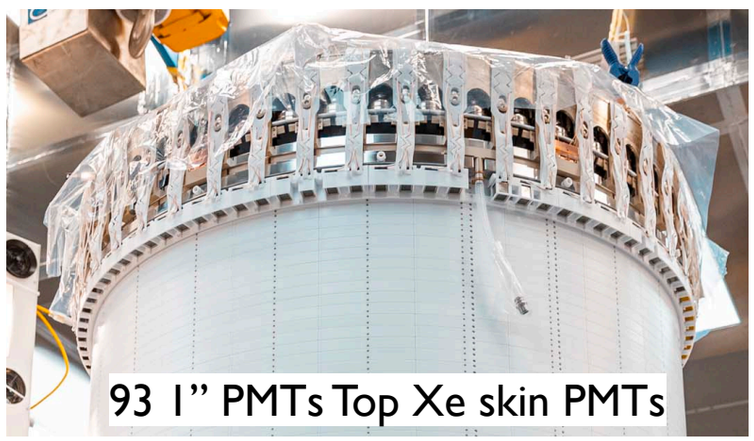


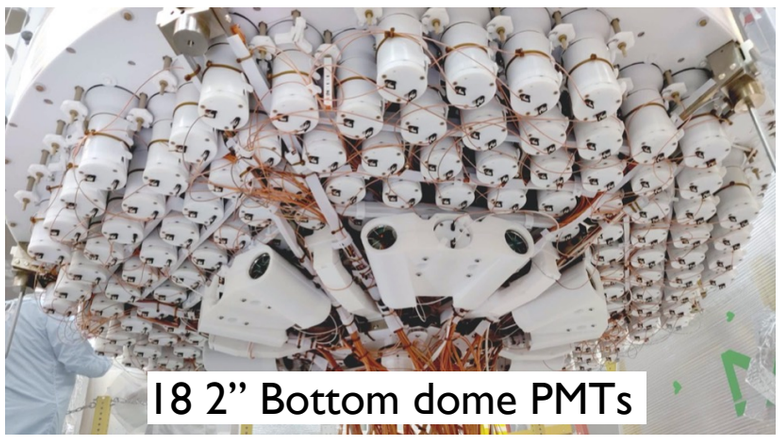
Xenon "Skin" Veto

PTFE tiling in ICV & Bottom side skin assembly



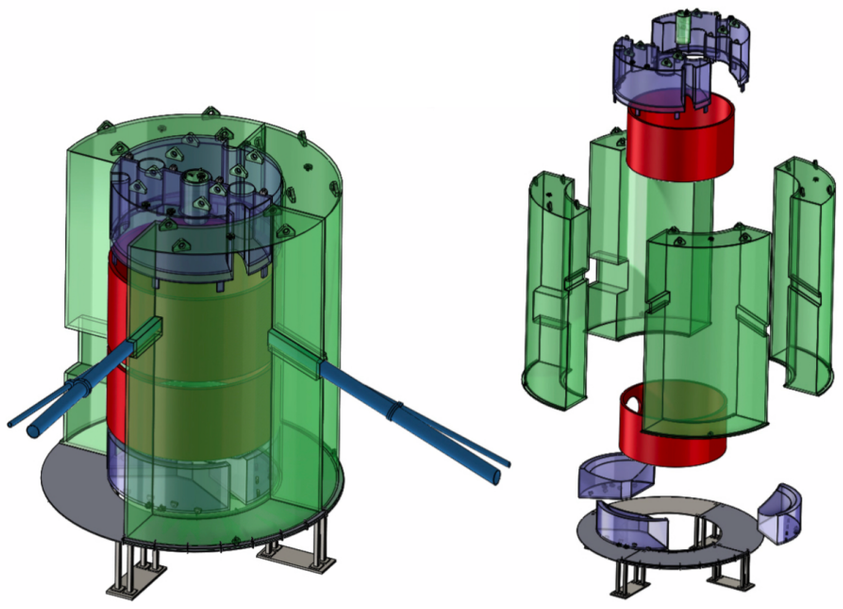
- Anti-coincidence detector for γ-rays
- 2 tonnes of LXe surrounding the TPC
- Optically isolated from the TPC
- 1" and 2" PMTs at the top and bottom
- Lined with PTFE to maximize light collection efficiency



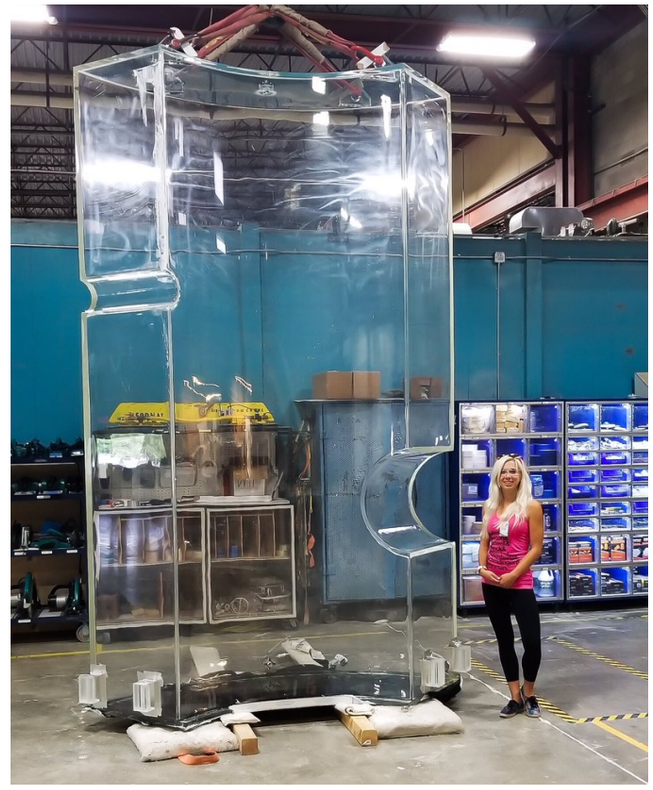


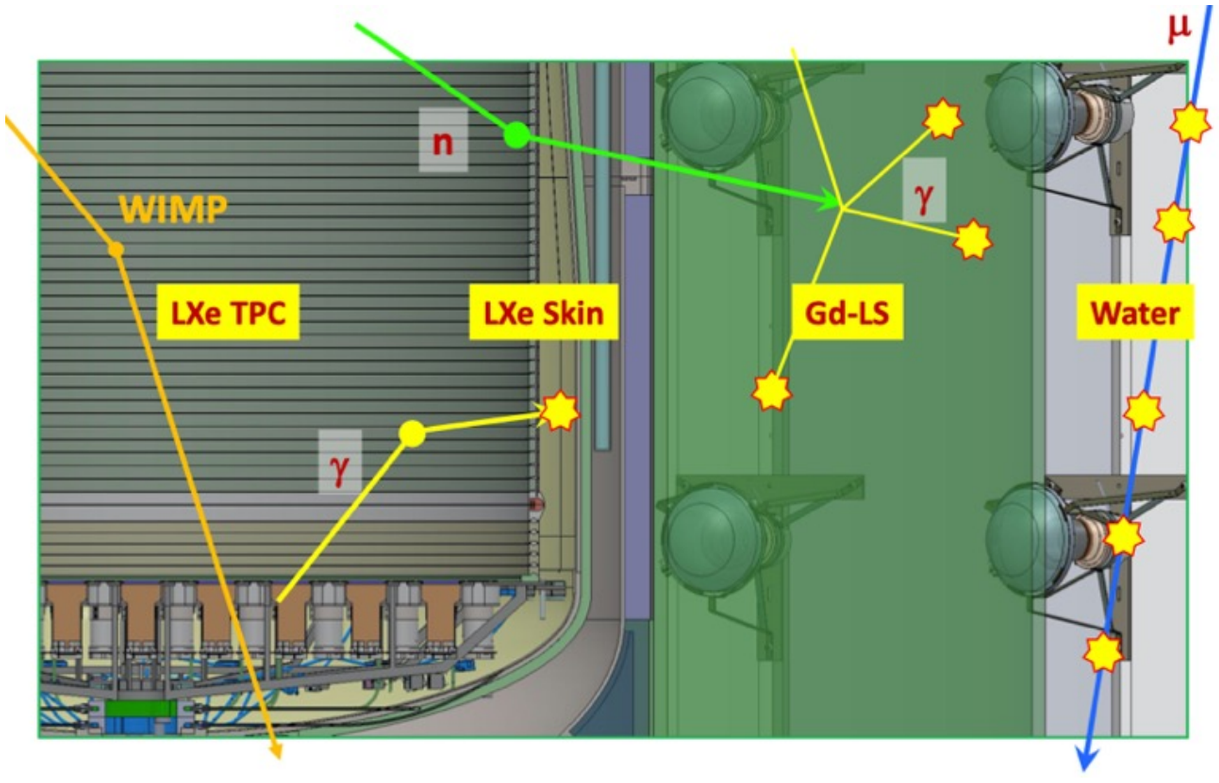
Outer Detector

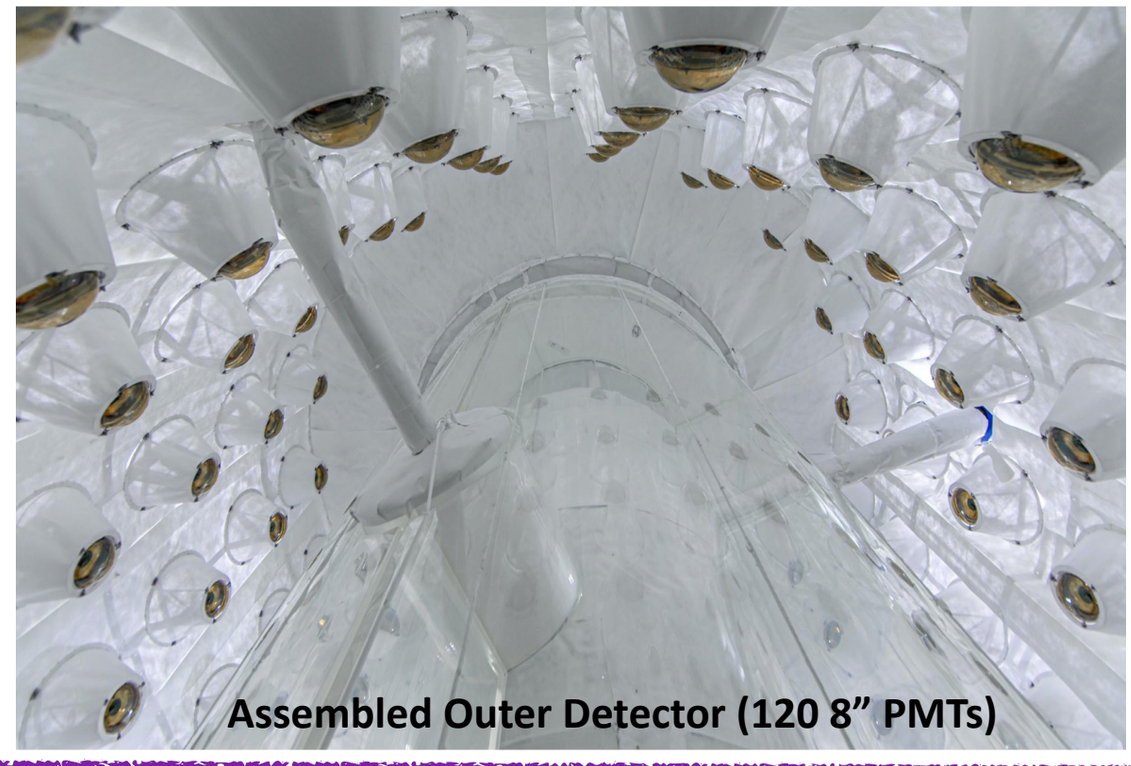
Suppression of neutron-induced nuclear recoil rate ⇒ maximize fiducial volume



- 17 tonnes Gd-loaded liquid scintillator in acrylic vessels
- 120 8” PMTs mounted in water tank
- Observe ~8 MeV γ-rays from thermal neutron capture
- 95% design efficiency for tagging neutrons



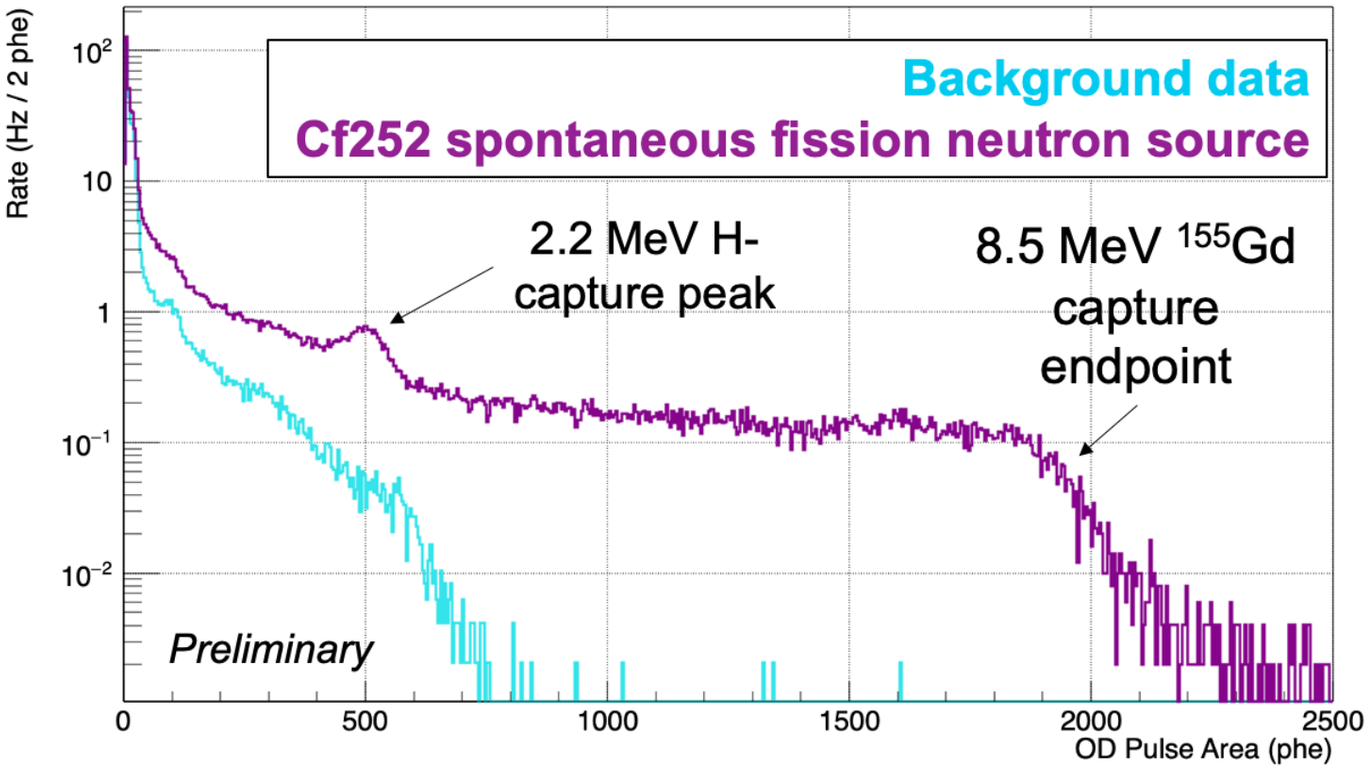


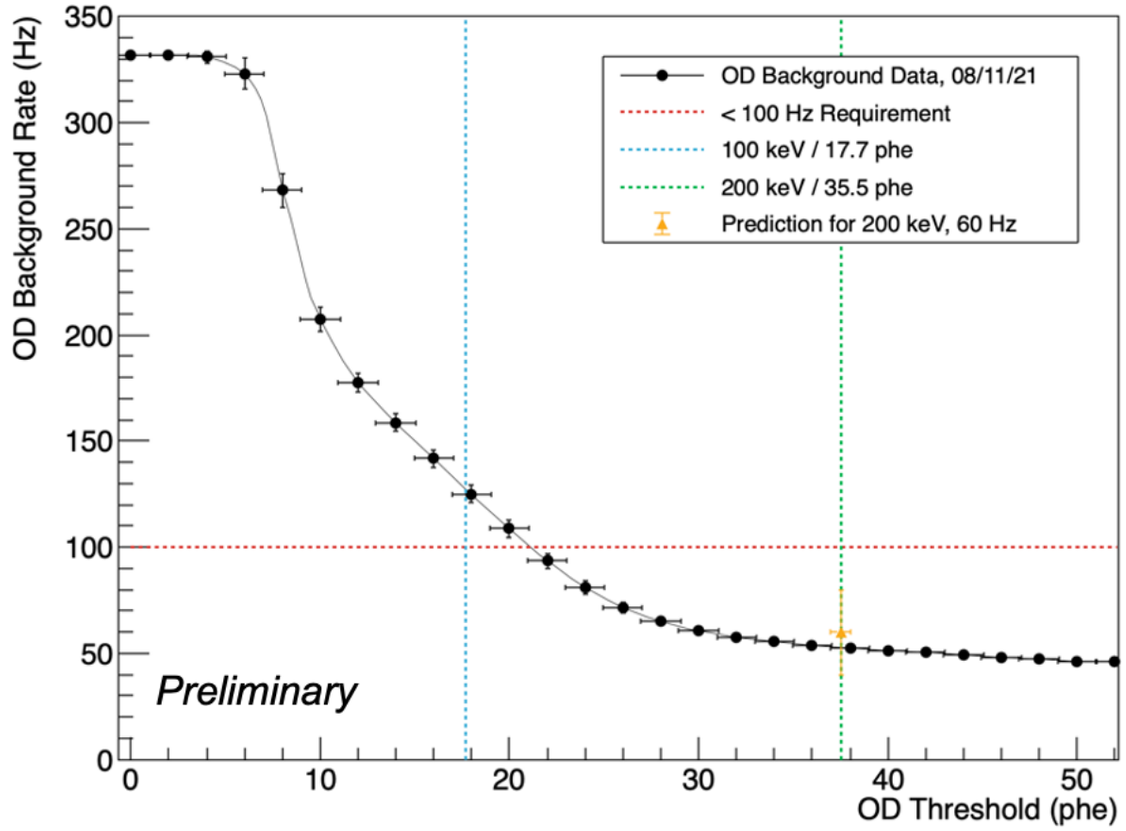


Assembled Outer Detector (120 8” PMTs)

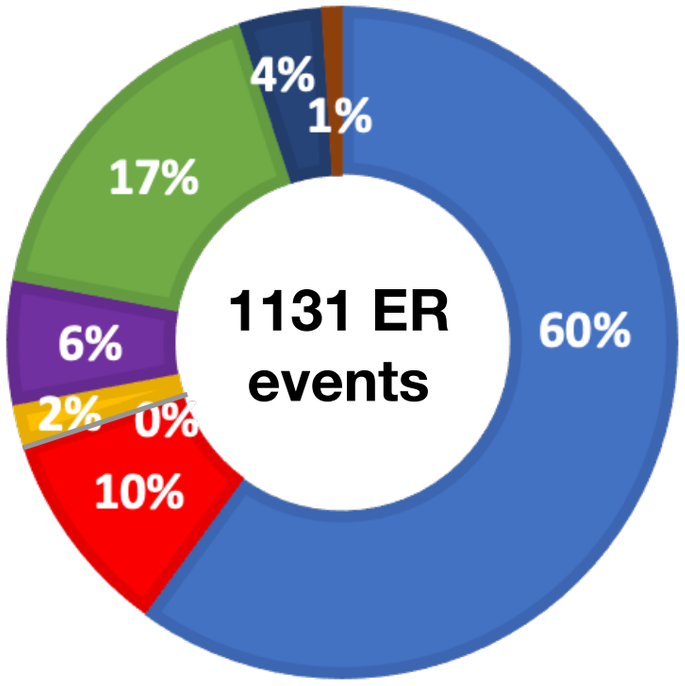
Outer Detector Calibrations

- OD backgrounds slightly lower than expected
  - ✦ Allows threshold < 200 keV

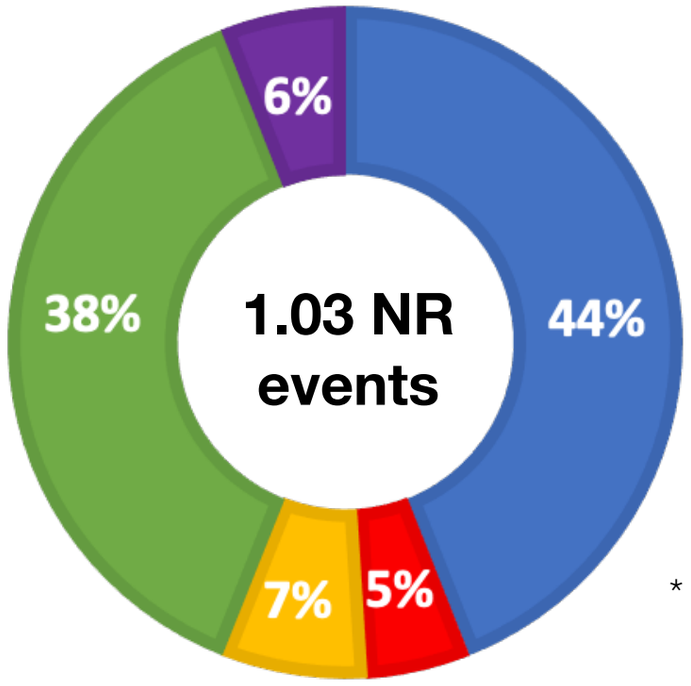




Expected backgrounds for 5.6 t fiducial - 1000 days



Rn-222
Rn-220
Ar-39
Kr-85
Xe-136 2νββ
Solar ν
Surface
Det+Env



Phys. Rev. D 101, 052002 (2020)

Atmospheric ν
Diffuse supernova ν
Detector
Surface
Environment

* Solar ν below 6 keV NR threshold used

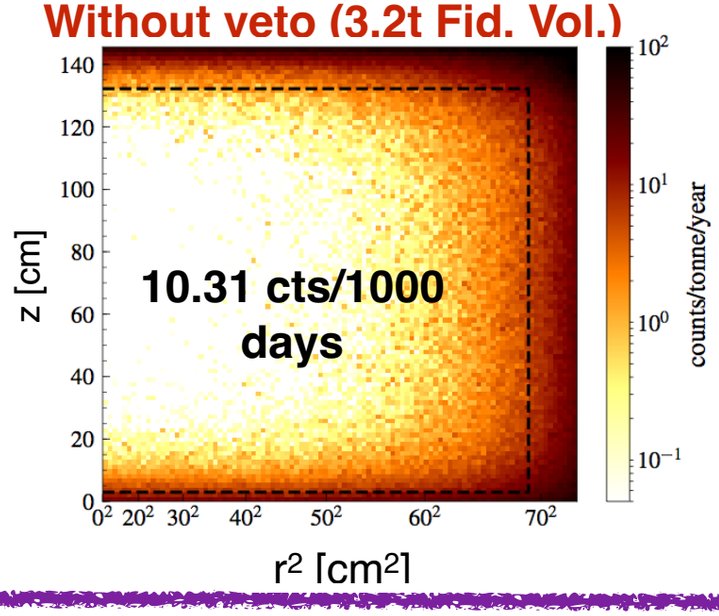
5.66 events after
99.5% ER discrimination

0.52 events after
50% NR acceptance

Distributions of single-scatter nuclear recoils in 40 Gev WIMP ROI (6-30 keV)

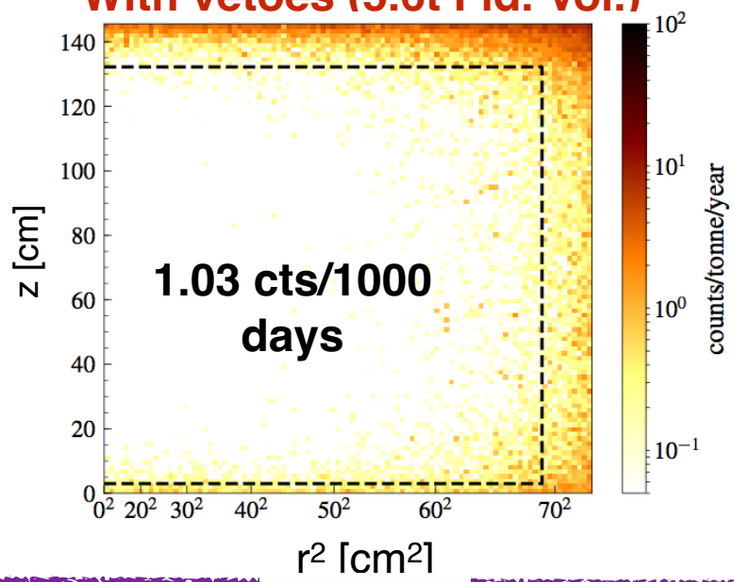
→

Without veto (3.2t Fid. Vol.)



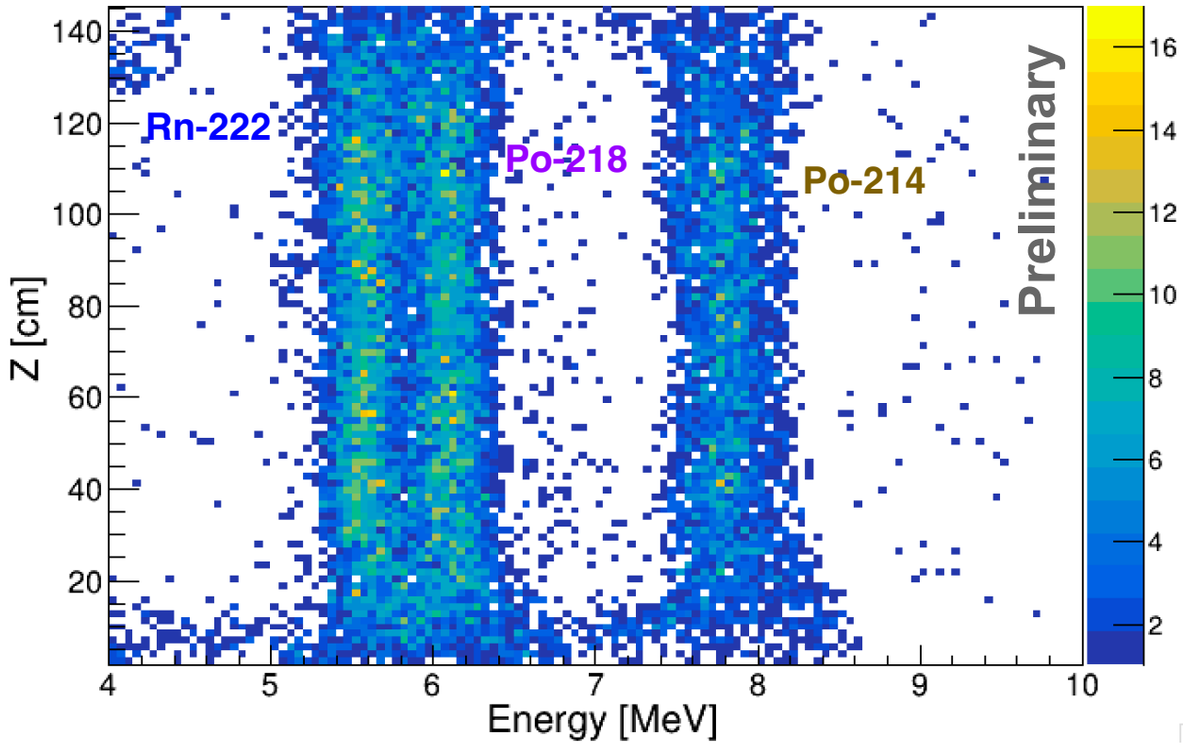
→

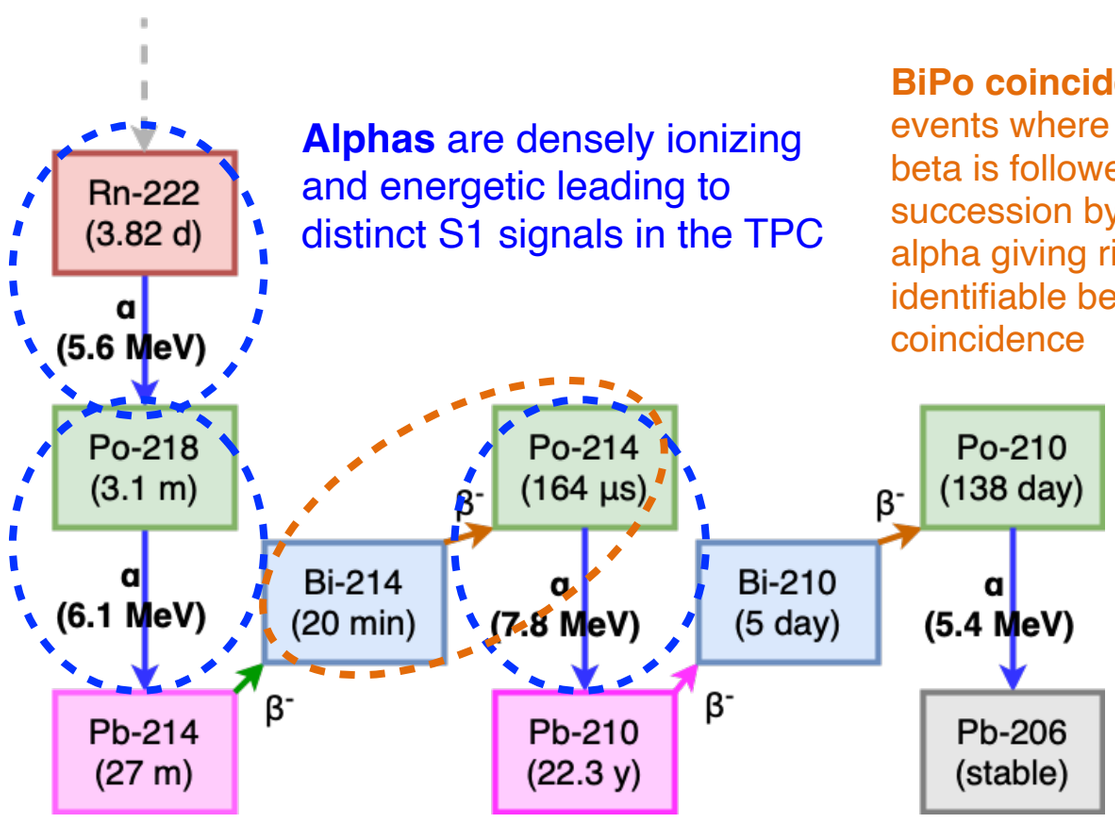
With vetoes (5.6t Fid. Vol.)



Backgrounds Analysis: Rn chain backgrounds

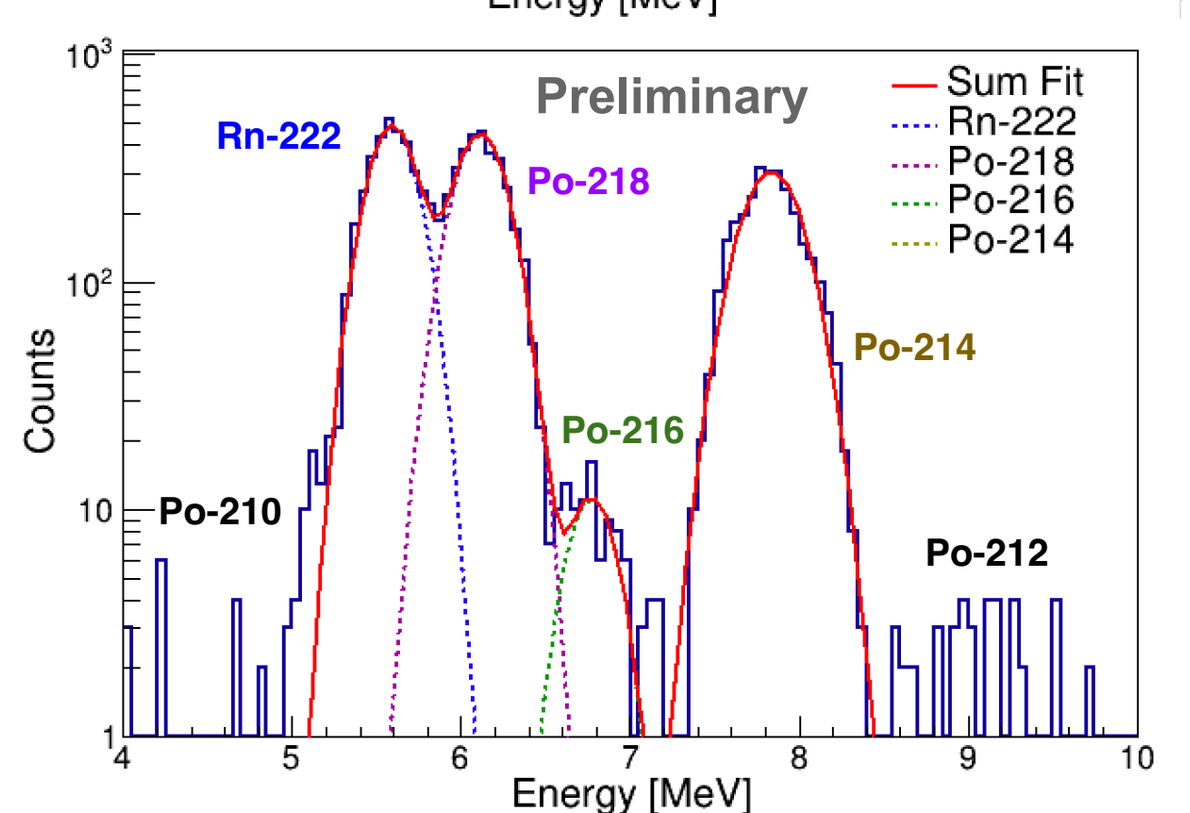
- Rn-222 and Rn-220 emanates from U-238 and Th-232 contamination in detector materials and diffuses into the Xenon
  - Inline radon reduction system further reduces radon concentration
- The "naked betas" from Pb-214/ Pb-212 are a WIMP background
  - Pb-214 is the largest background contribution
- Preliminary analysis shows Rn-222 rate within expected range





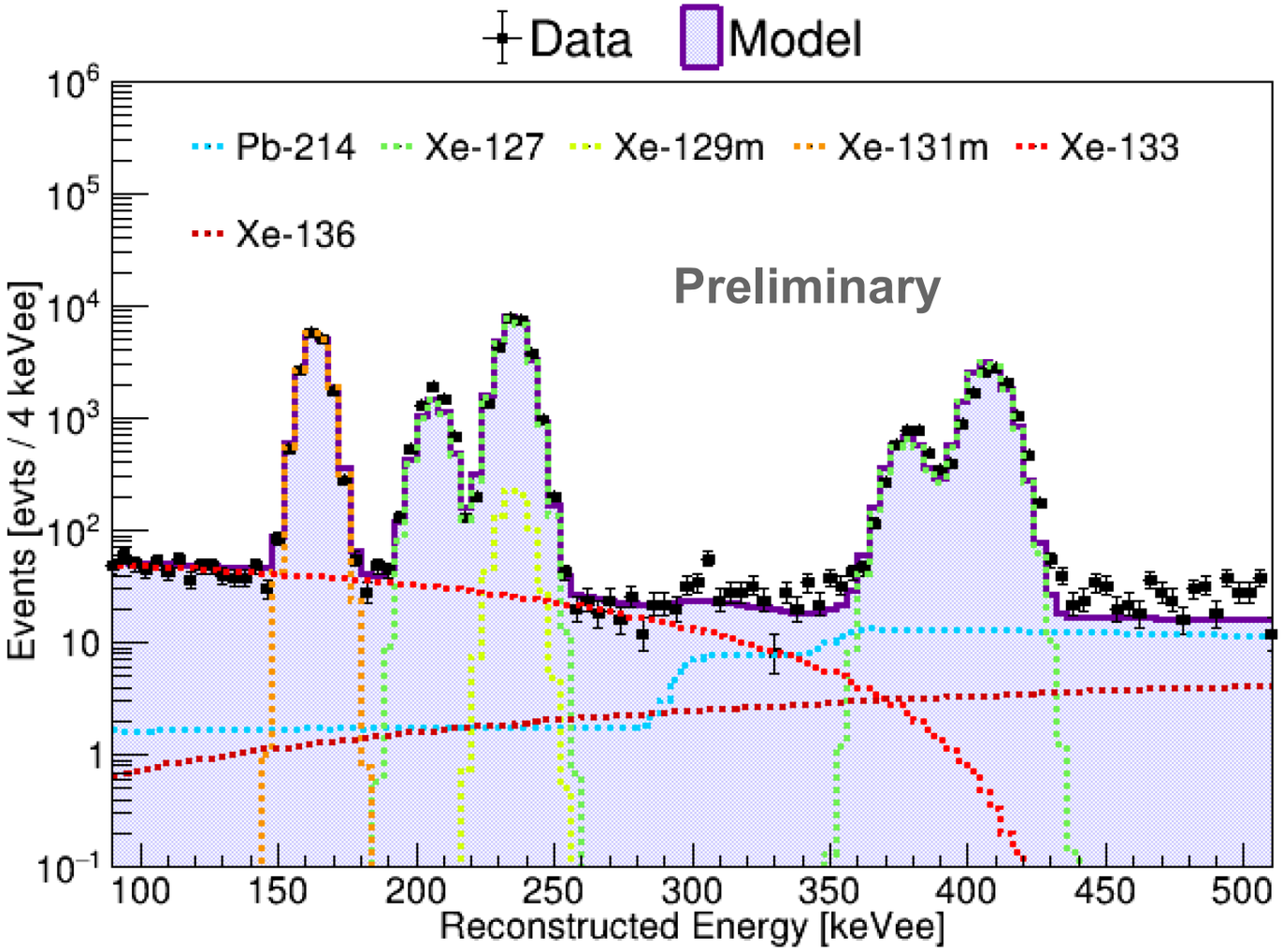
Alphas are densely ionizing and energetic leading to distinct S1 signals in the TPC

BiPo coincidences are events where the Bi-214 beta is followed in quick succession by a Po-214 alpha giving rise to an identifiable beta-alpha coincidence

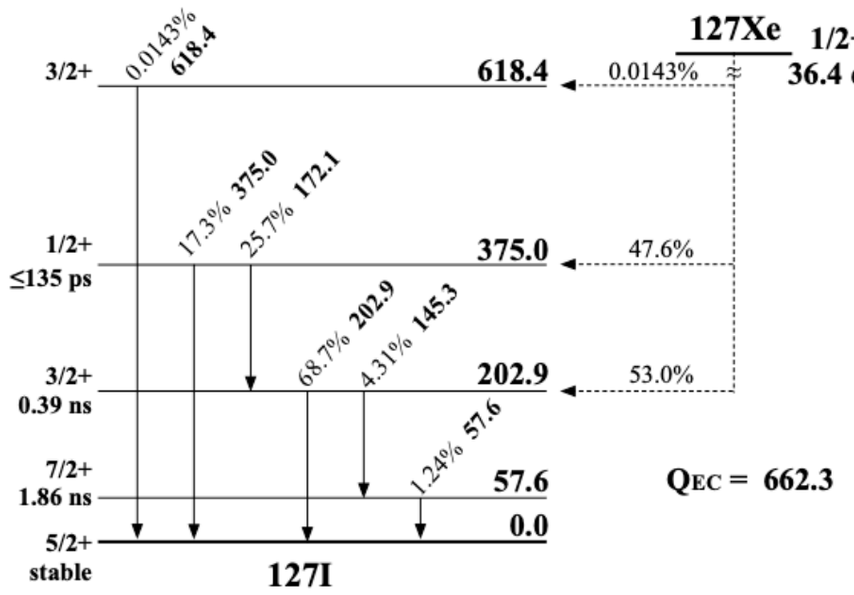


Constraining Xenon Activation Backgrounds

- Xenon can become activated by cosmogenics leading to background contributions from Xe-127, Xe-129m, Xe-131m, Xe-133 (other Xe activation products are much shorter lived)
- Activation rates can be estimated via extrapolations from LUX results and Activia calculations (open-source package for estimating activation)

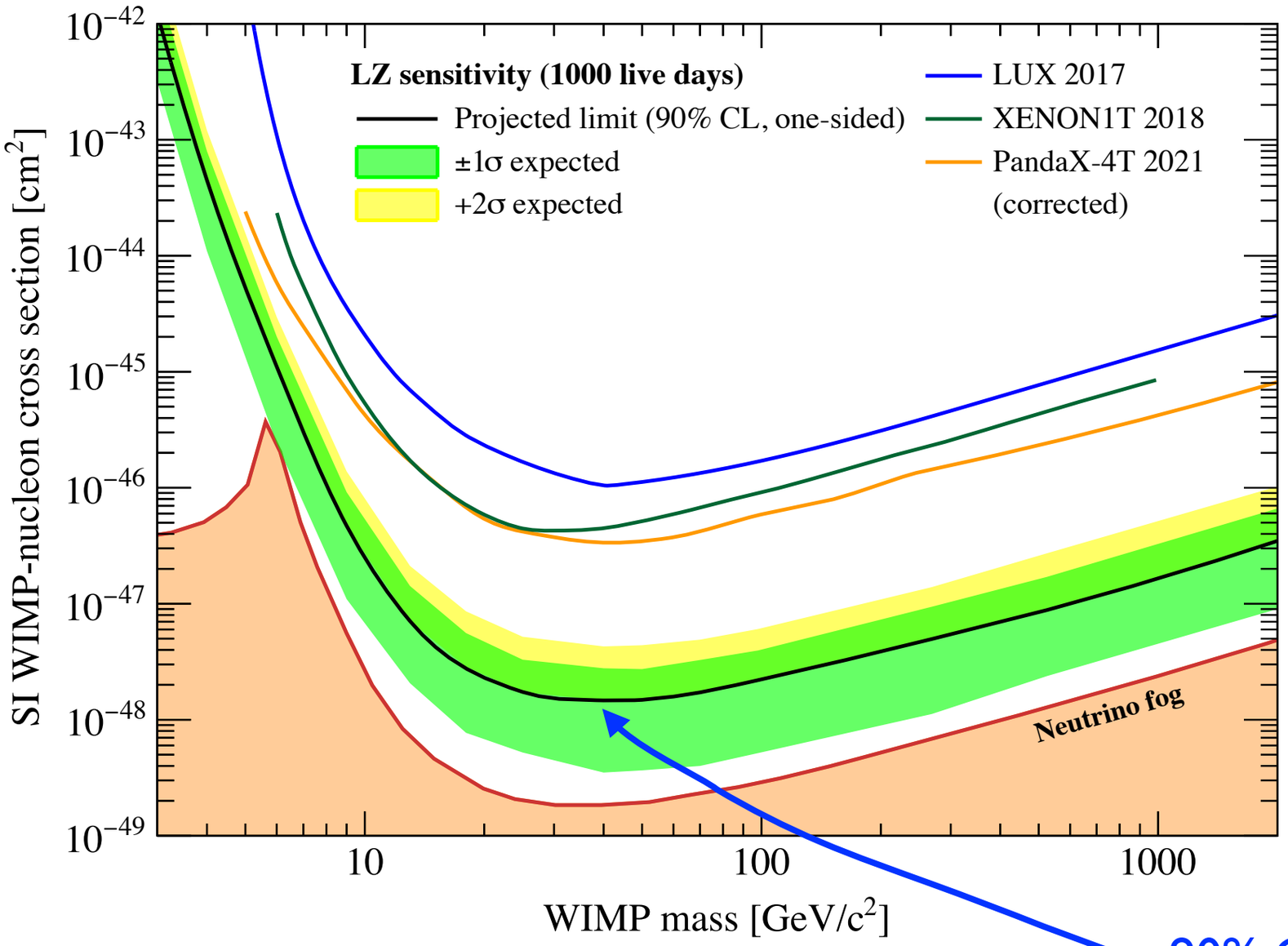


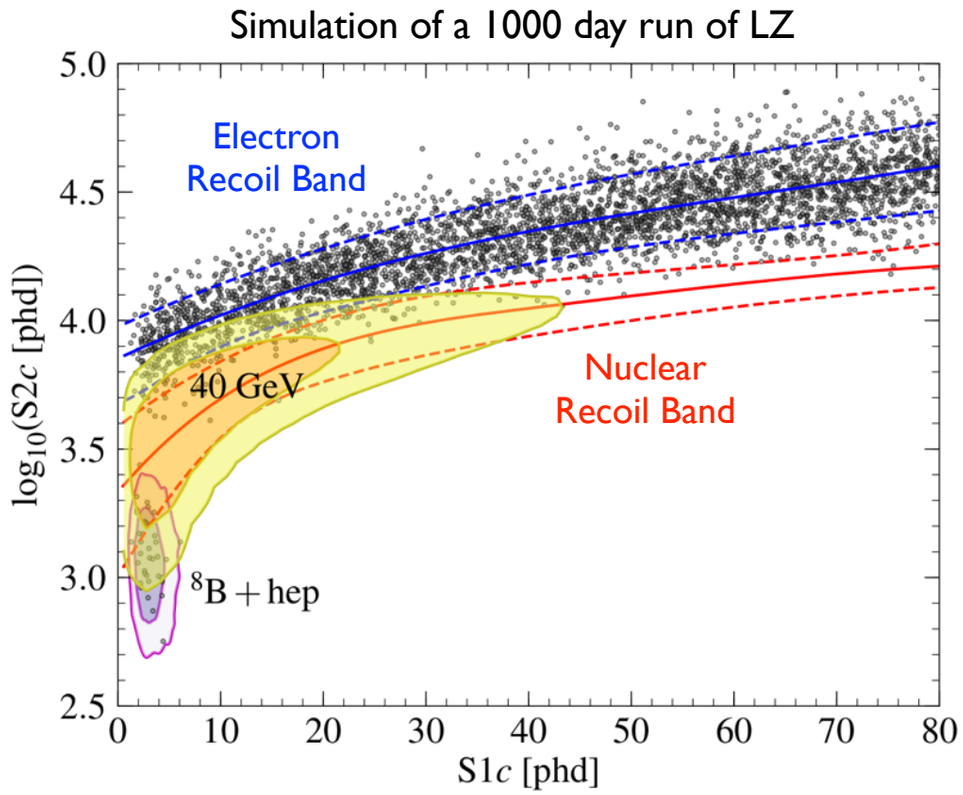
Xe-127 decays by electron capture



WIMP background arises from rare case where Xe-127 gamma escapes the TPC and low energy cascade occurs within bulk
⇒ Highly veto suppressed and strong positional dependence

Projected Sensitivity (5.6 t exposure, 1000 live days)





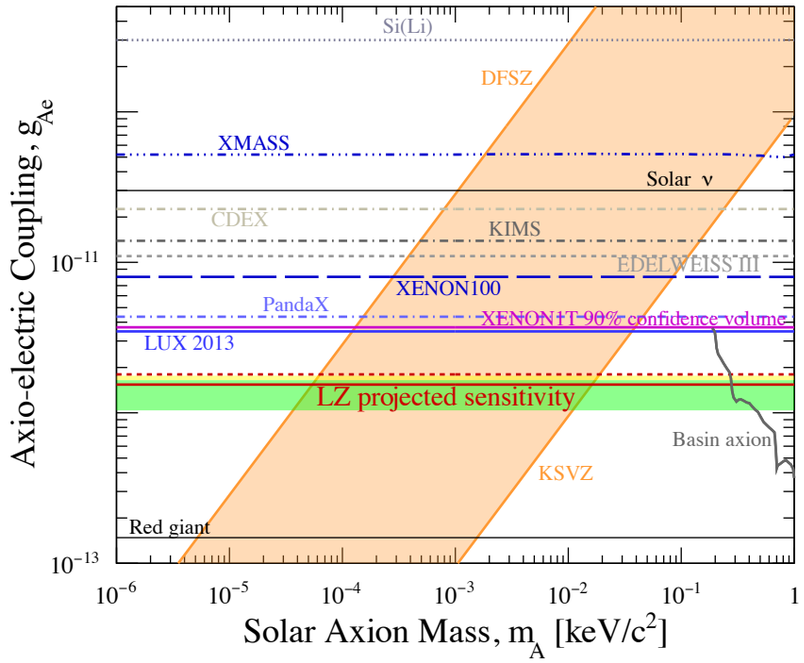
90% CL minimum of
1.4 x 10^{-48} cm^2 at 40 GeV/c^2

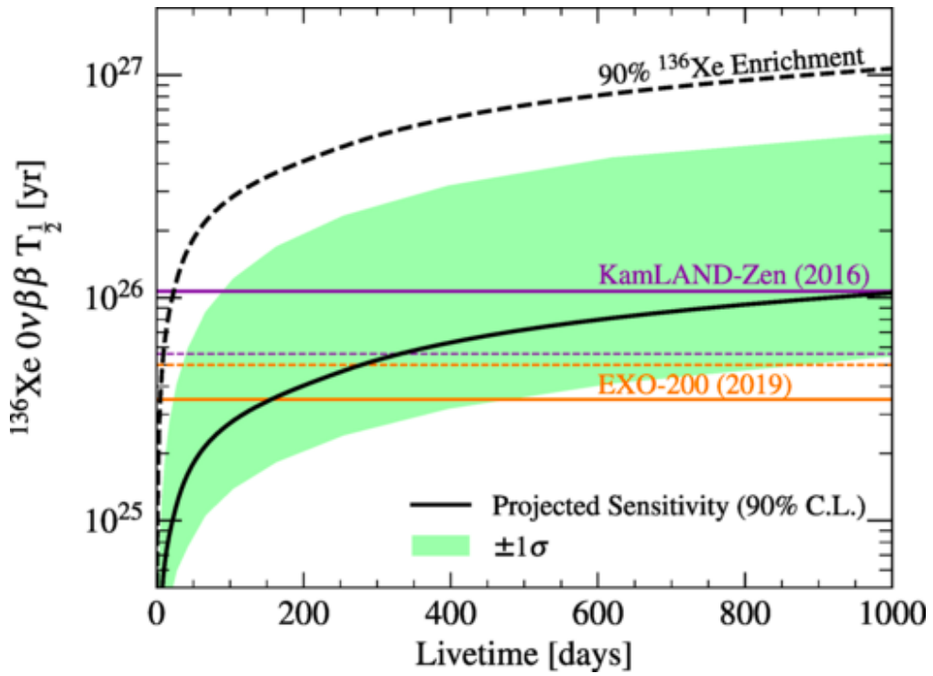
Phys. Rev. D 101, 052002 (2020)

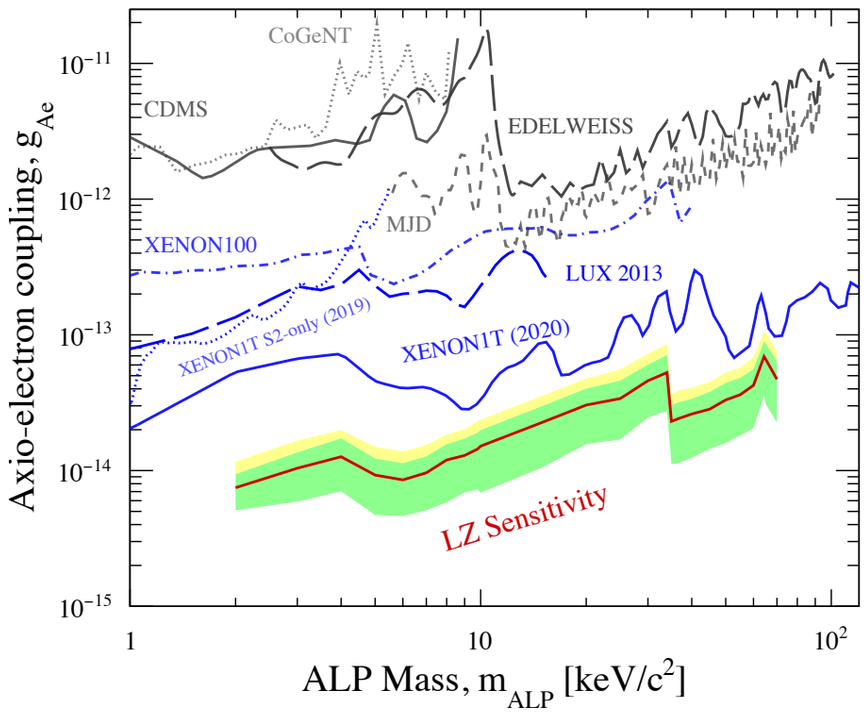
LZ Physics Reach

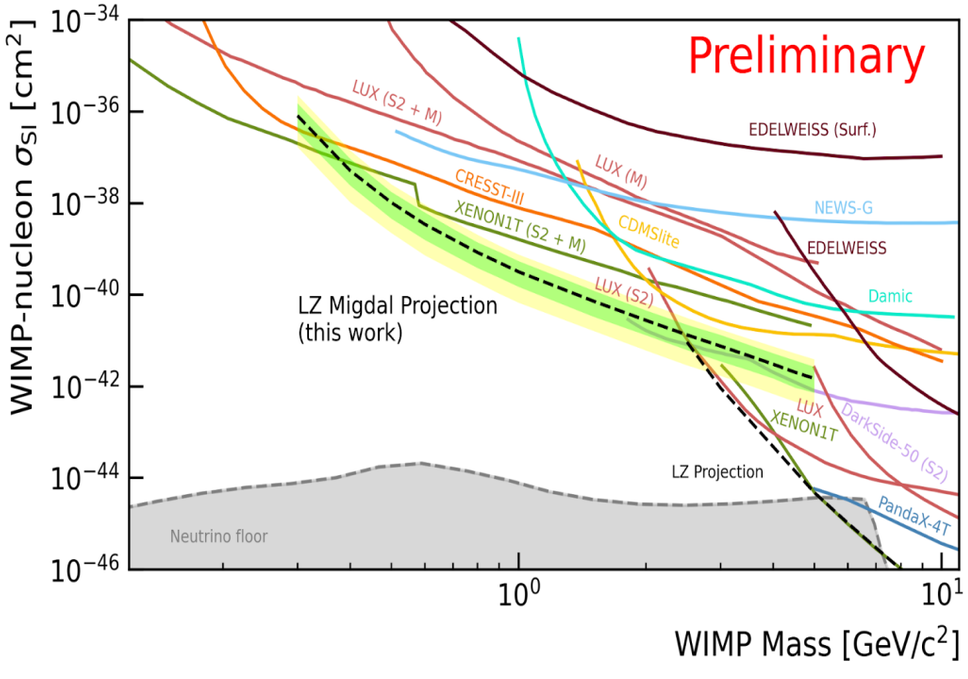
LZ physics reach extends beyond vanilla WIMPs:

- CEvNS
  See talk by M. Szydagis
- Solar axions
- Axion-like particles (ALPs)
- Leptophilic dark matter
- Neutrino magnetic moment
- Mirror dark matter
- DM-EFT Couplings
- 2νββ of ^{134}Xe with competitive sensitivity to 0νββ
- Sensitivity to the 0νββ decay of ^{136}Xe
- Enhanced sensitivity to low mass DM through Migdal effect
- Annual rate modulations
  See poster by J. Genovesi
- And more!









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

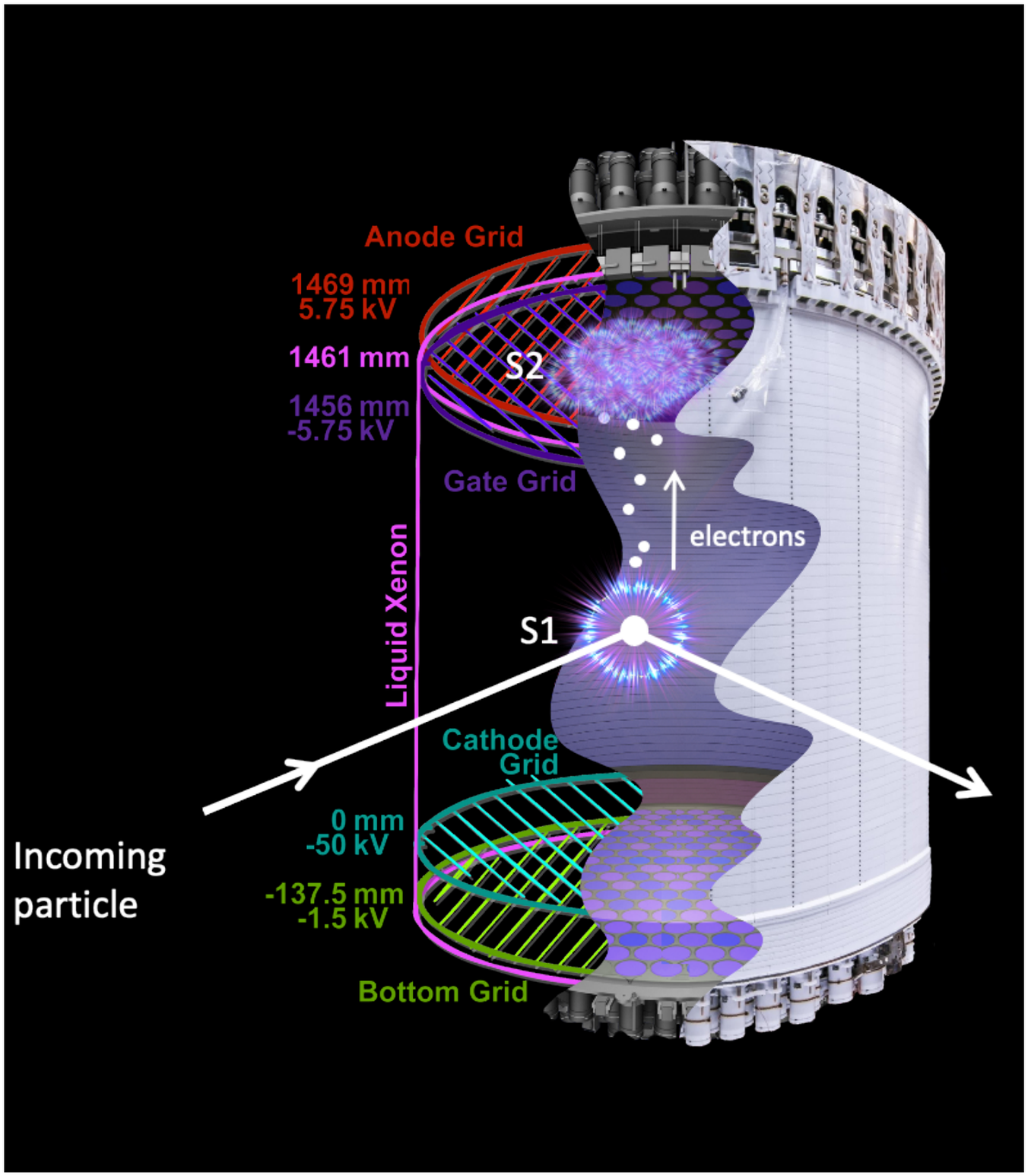
Outlook

- LZ is a multi-physics experiment, primed for detection of WIMPs
- Commissioning completed, currently taking science data, and extensive analyses underway
- First Science Results expected this year

2022 will be an exciting year for LZ!

Stay Tuned!

Thank You!



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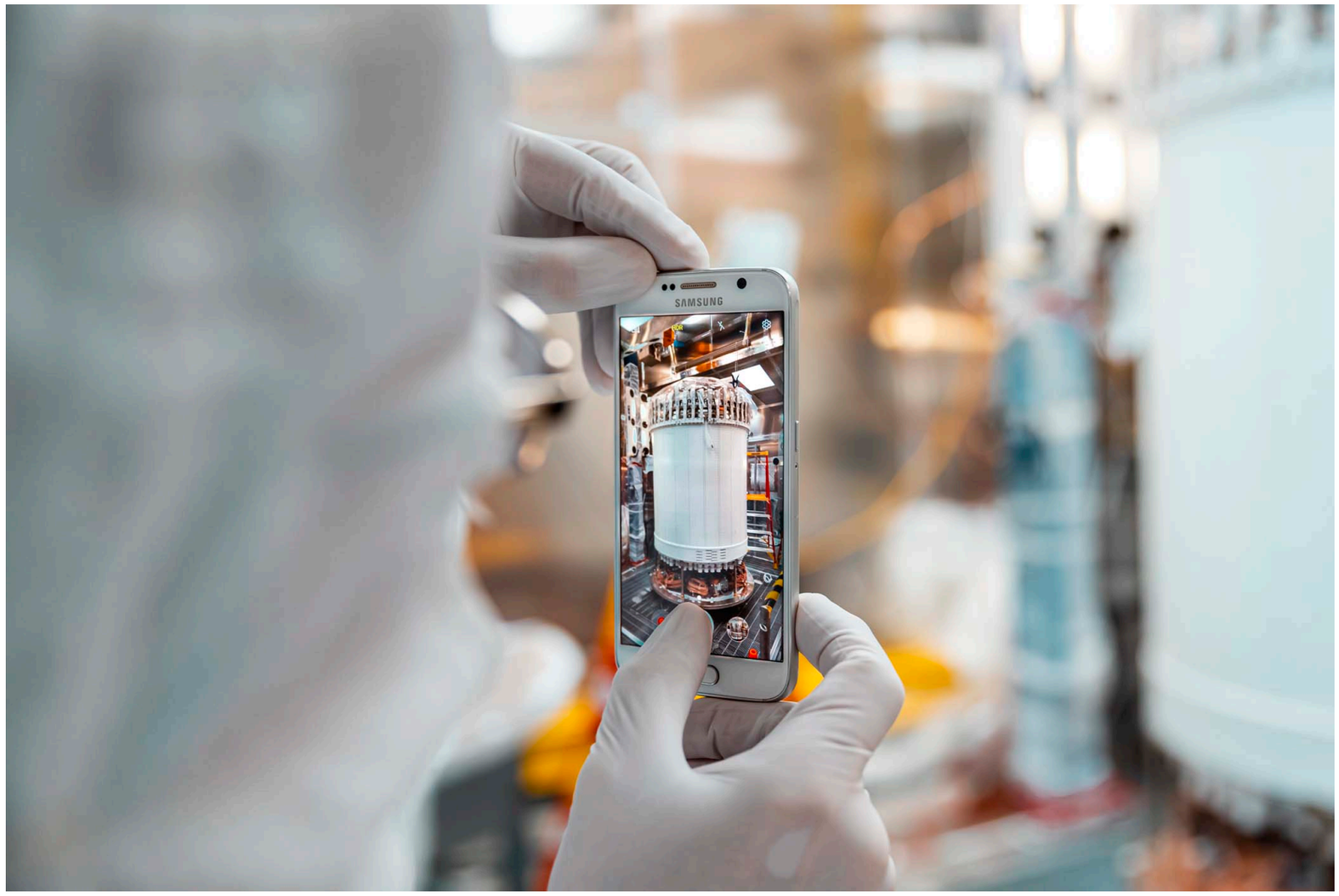
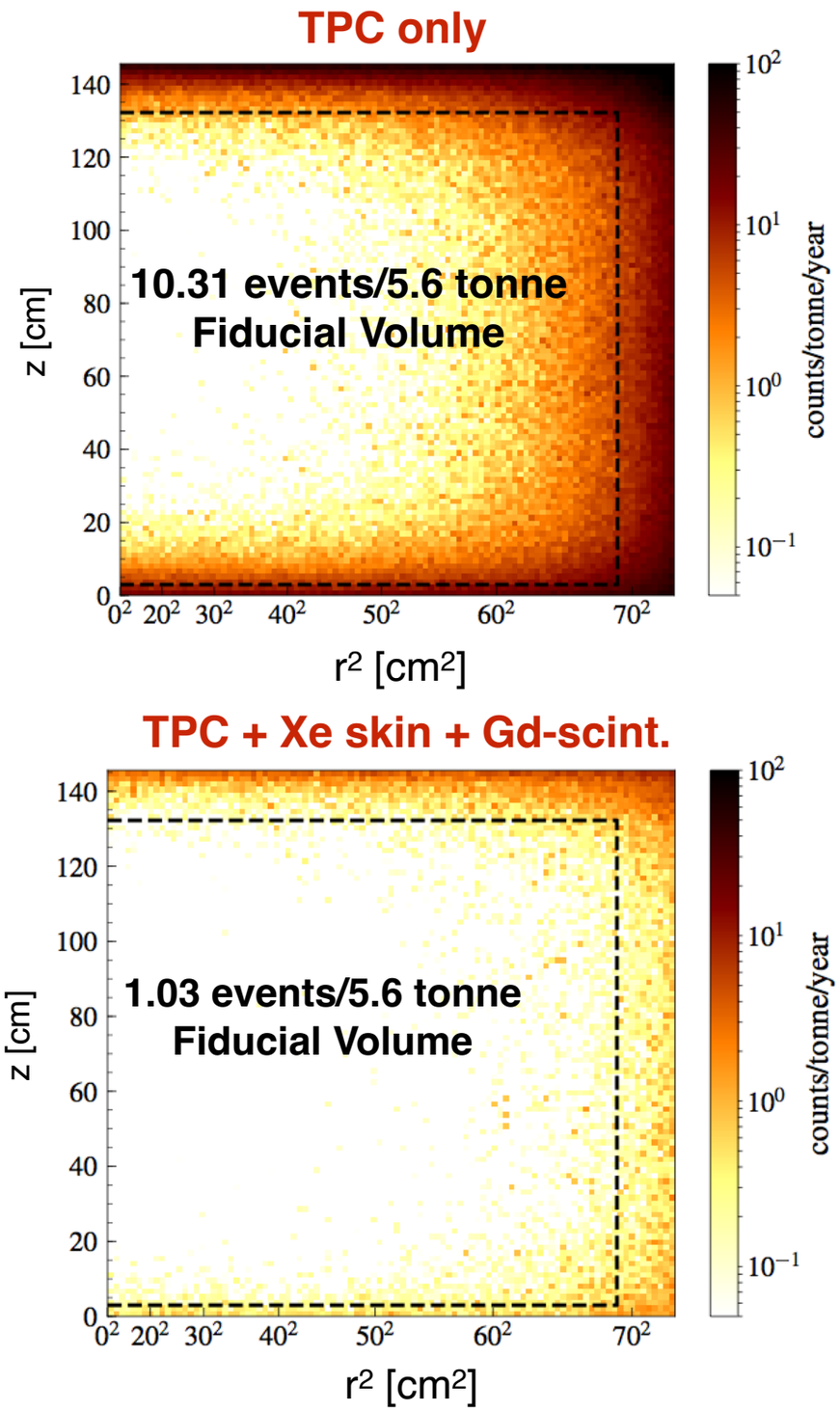


Backup Slides

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**



* 6 keV NR threshold used

D.S. Akerib et al (LZ collaboration) Phys. Rev. D 101, 052002 (2020)

Sensitivity reach vs Pb-214 rate

Impact on 40 GeV WIMP sensitivity with increasing Pb-214 rate, as a proxy for increasing flat ER backgrounds