The LUX-ZEPLIN Dark Matter Experiment

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for the LZ collaboration

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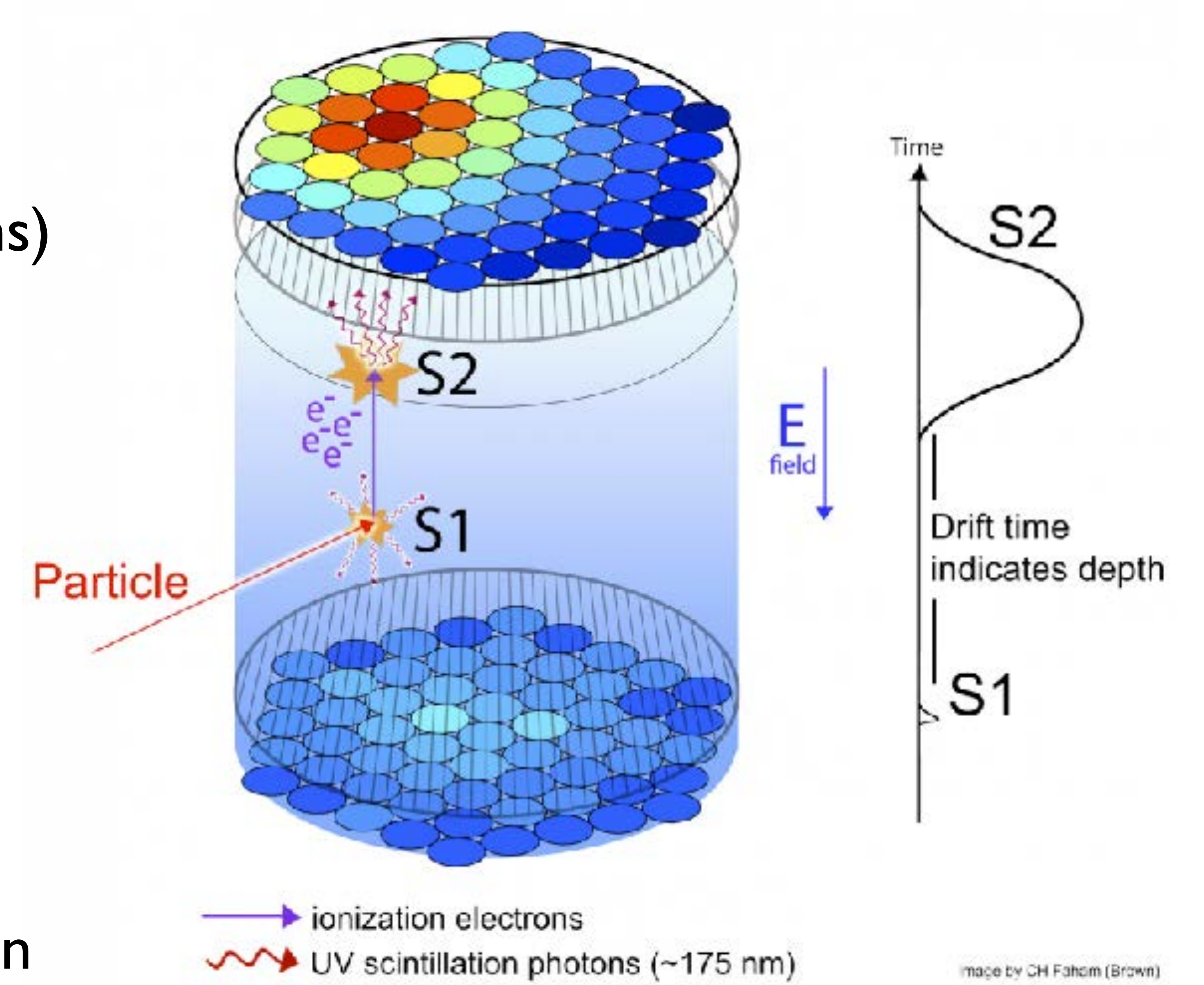
ICHEP 2020

~36 institutions, 250 scientists, engineers, technicians

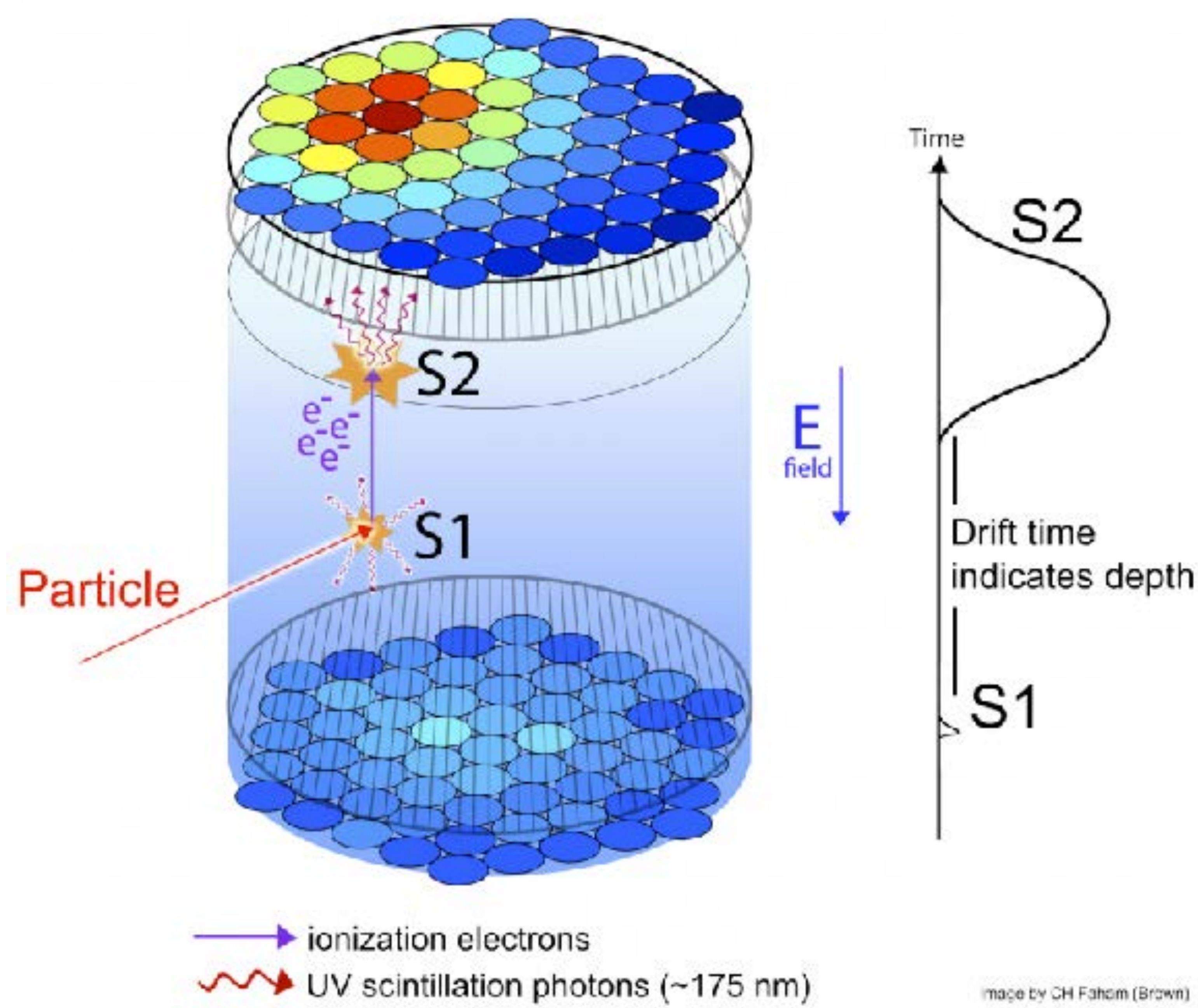
Two phase Xenon Detectors

- Interaction in the xenon creates:
  - Scintillation light (~10 ns) - called S1
  - Ionization electrons
- Electrons drift through electric field to liquid/gas surface
  - Extracted into gas and accelerated creating proportional scintillation light - called S2



Two phase Xenon Detectors

- Excellent 3D reconstruction (~mm)
  - Z position from S1-S2 timing
  - XY position from hit pattern of S2 light
  - Allows for self shielding, rejection of edge events
- Ratio of charge (S2) to light (S1) gives particle ID
  - Better than 99.5% rejection of electron recoil events

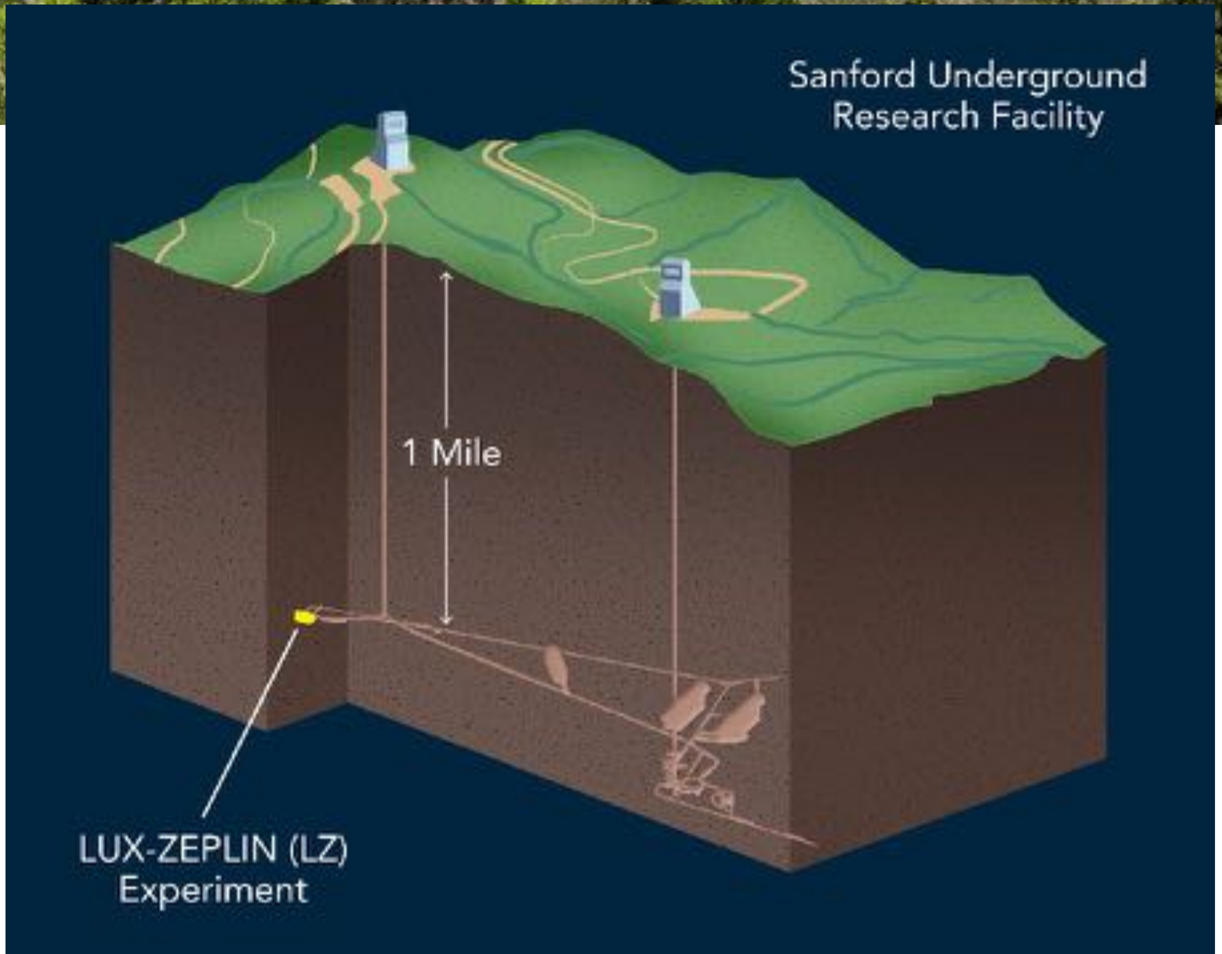


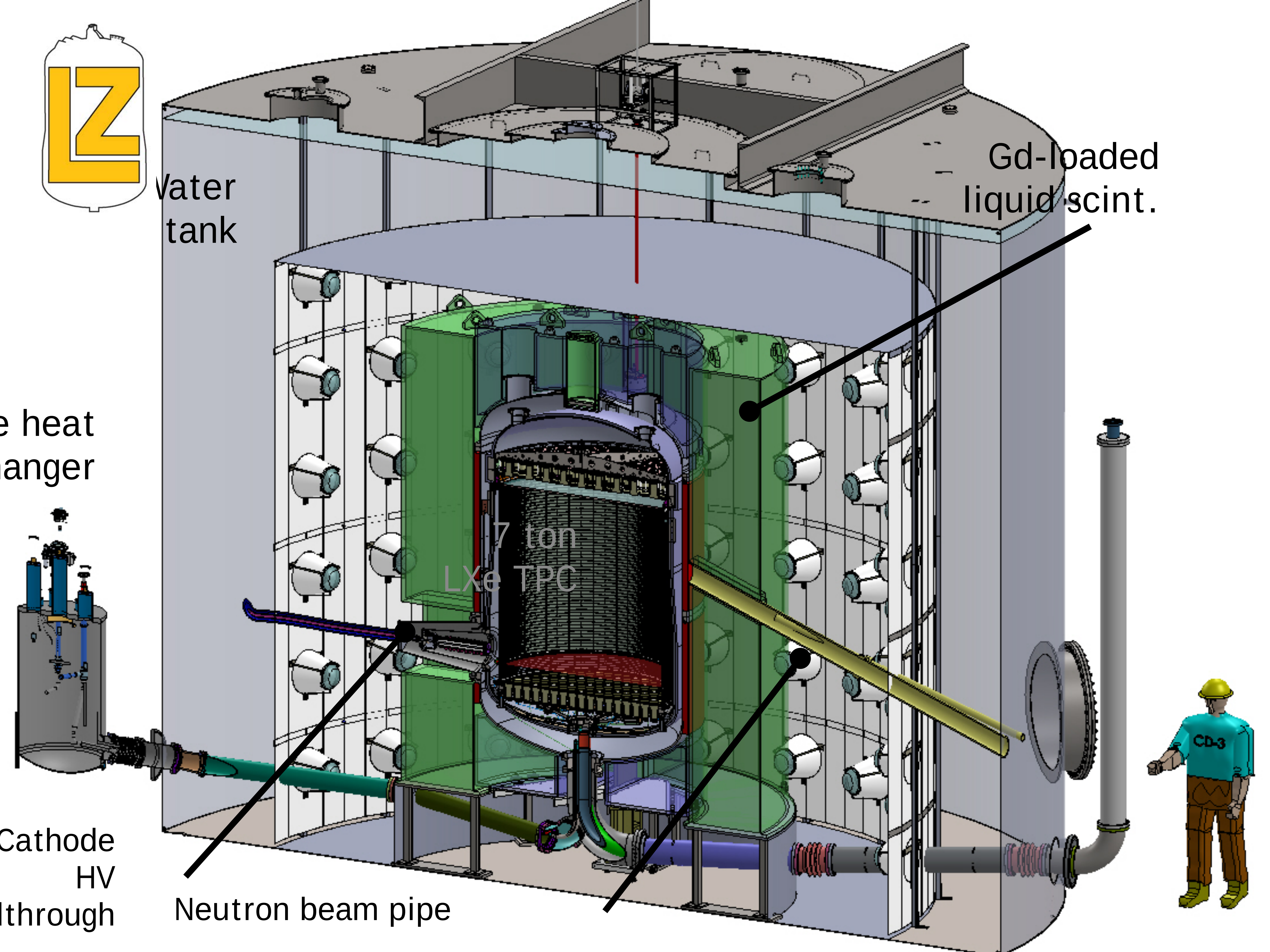
LXe as Dark Matter Target

Problem	Solution	Liquid Xenon
Extremely rare	Large mass	Very dense - 3 tonnes in 1 m^3
Energy depositions of ~10 keV or below	Low energy thresholds	~60-70 electrons + photons / keV
Backgrounds - Impurities	Purification	Noble gases are (mostly) easy to purify
Backgrounds - Detector	Self shielding	Low mean free path for ionizing radiation
Backgrounds - Internal/Detector	Discrimination	Charge to light ratio gives particle ID

Sanford Underground Research Facility

- Located in Lead, SD (USA) in the Black Hills
- LZ located at the 4850 level (~1.5 km underground)
- 4300 m.w.e. overburden
- Muon flux reduced by O(10^7)





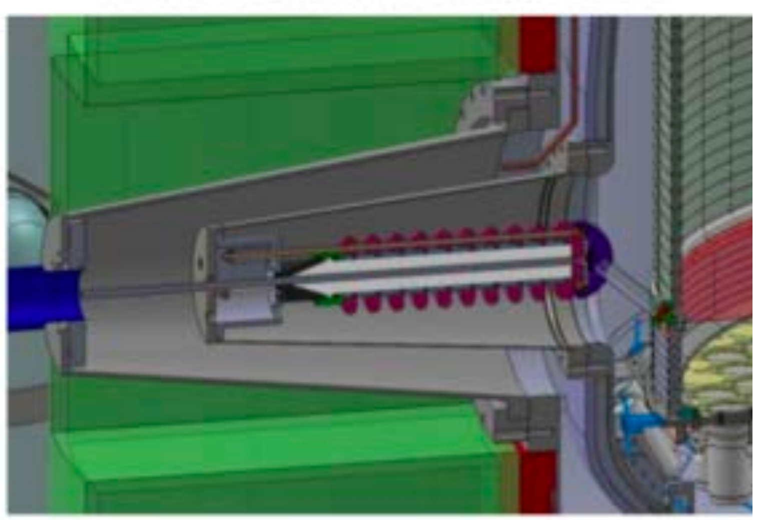
Water tank
Gd-loaded liquid scint.
e heat anger
7 ton LXe TPC
Cathode HV lthrough
Neutron beam pipe
CD-3

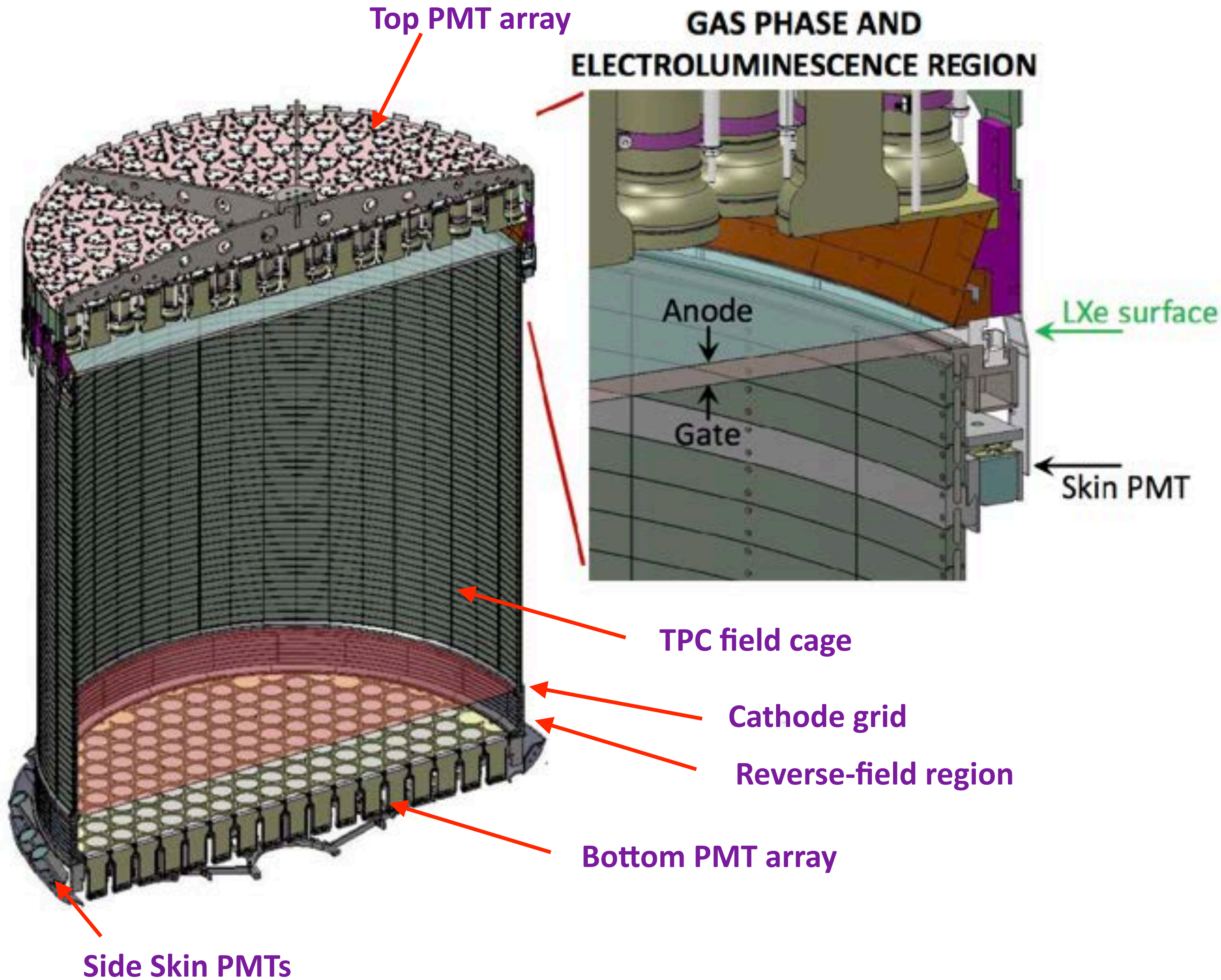
LZ design notes - TPC

NIM A, 163047 (2019)

- 1.5 m diameter x 1.5 m height
- 7T active LXe (5.6T fiducial)
  - x50 more than LUX, x6 XENON1T
- 494x 3" PMTs
- 50 kV cathode HV

HV CONNECTION TO CATHODE



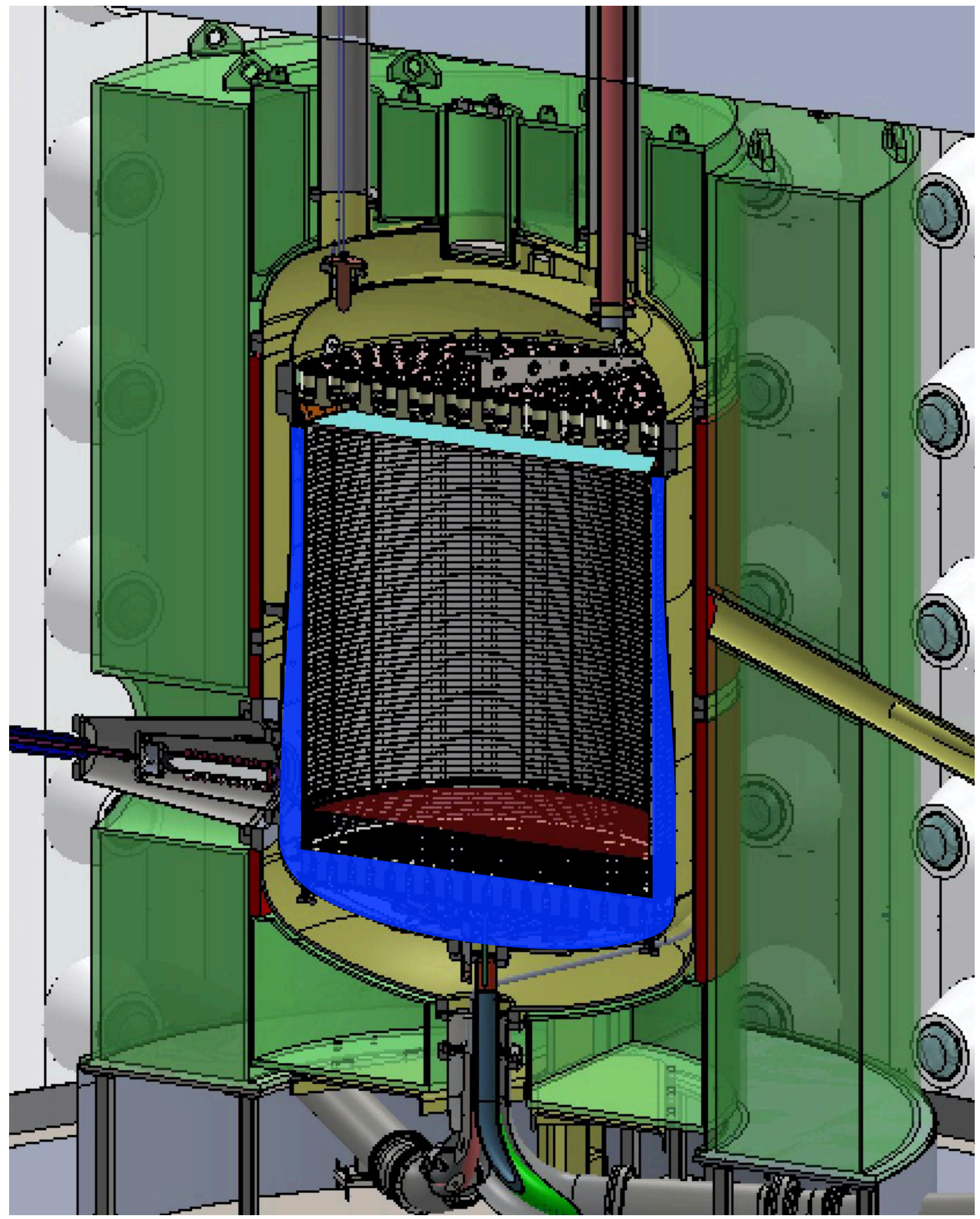


LZ design notes - the Veto

NIM A, 163047 (2019)

The OD

- 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 ~8 MeV γ-rays from thermal neutron capture
- Draw on experience from Daya Bay



The Skin

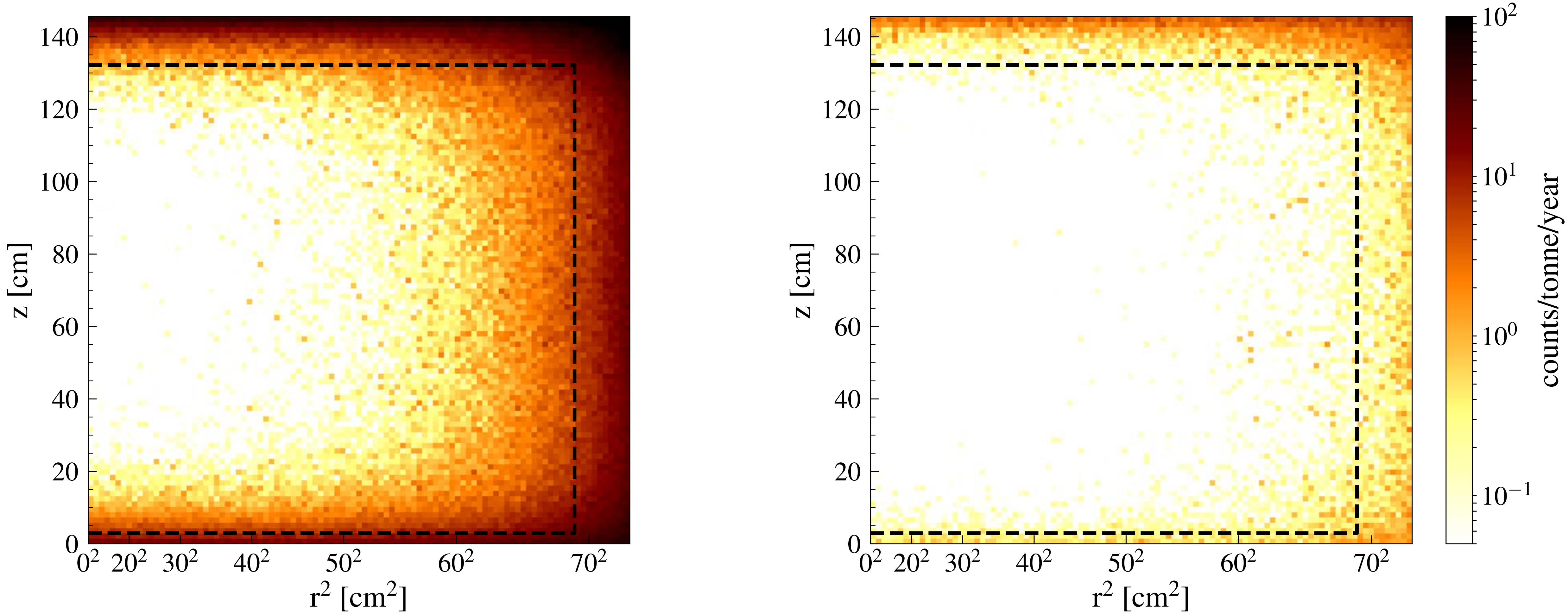
- 2 tonnes of LXe surrounding the TPC
- 1” and 2” PMTs at the top and bottom of the skin region
- Lined with PTFE to maximize light collection efficiency
- Anti-coincidence detector for γ-rays

- **Tag individual neutrons and γ-rays**
  - **>95% efficiency for tagging neutrons**
- **Characterize BGs in situ**

→Enables discovery potential

LZ design notes - the Veto

No veto   Xe skin & OD veto

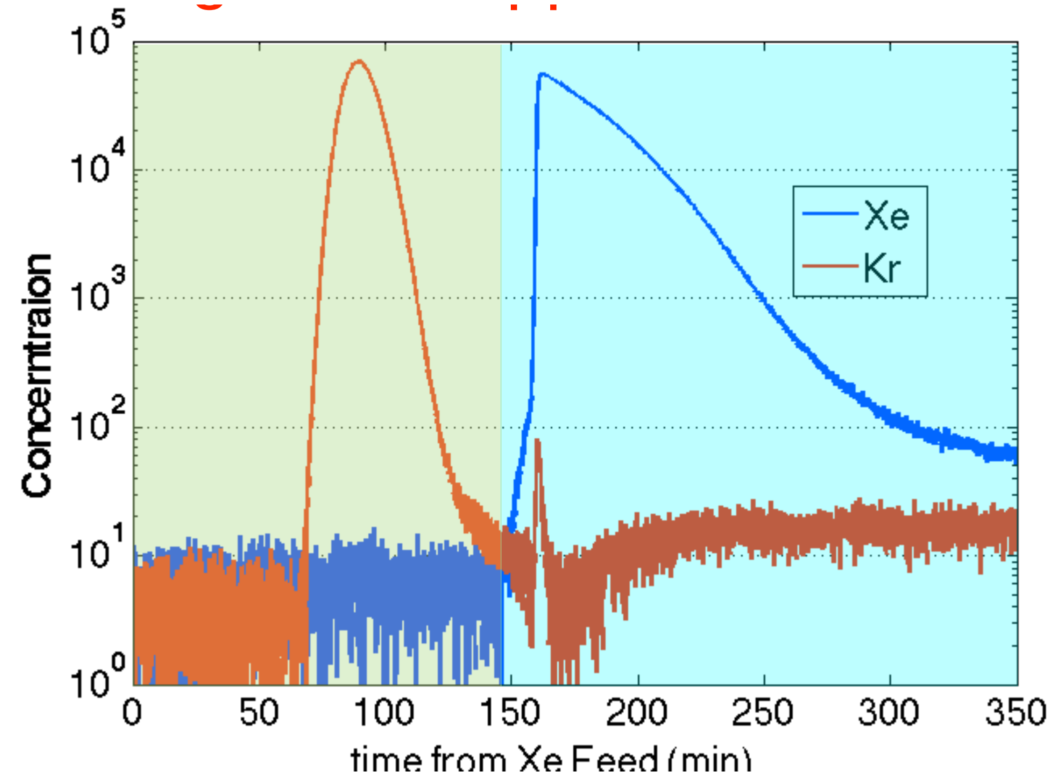


- Combined veto system allows to define a fiducial volume of 80% of active volume
  - Alternatively, takes fiducial volume from 3.2 tonnes on left to 5.6 on right

LZ design notes - Purification

NIM A, 163047 (2019)

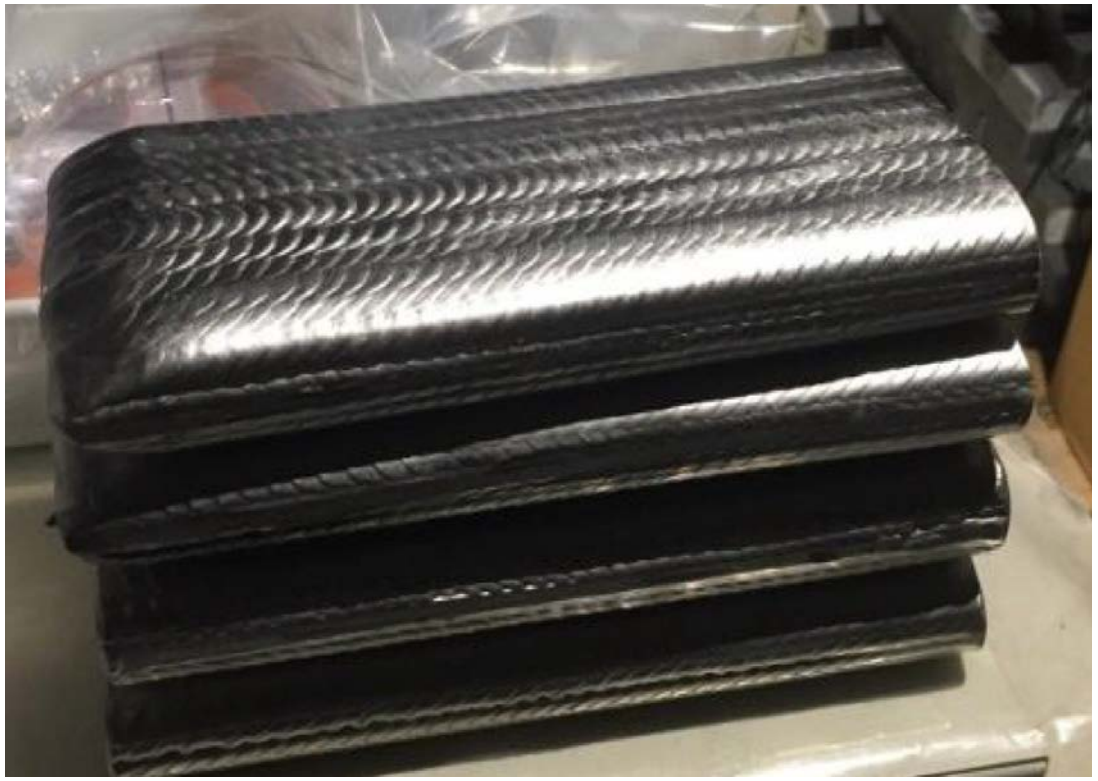
- Krypton removal via chromatography at SLAC
  - 75 ppq demonstrated in R&D
- Gas purification at 500 slpm
  - Turn over full volume every ~2.5 days
  - Up to 600 slpm now demonstrated



Detector Backgrounds

arXiv:2006.02506

- Nothing went into the detector without screening
  - ~2000 assays with 13 HPGe detectors, ICPMS, neutron activation analysis
  - E.g. cryostat made of the most radiopure titanium in the world: < 0.05 counts in 1000 days after cuts
- Supported by QA campaign during fabrication/construction
  - Caught and resolved major issues, e.g. early welds on cryostat were with wrong welding tips (color code from supplier was missing)

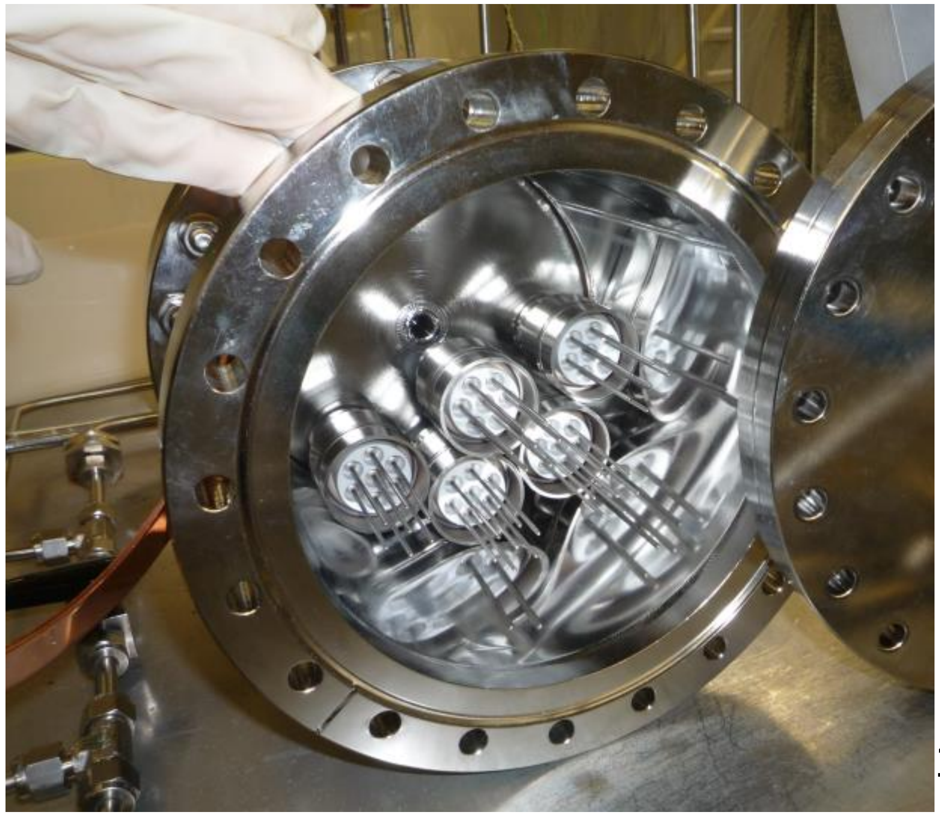


Central part (1) Weld (2) Weld (3)

Detector Backgrounds

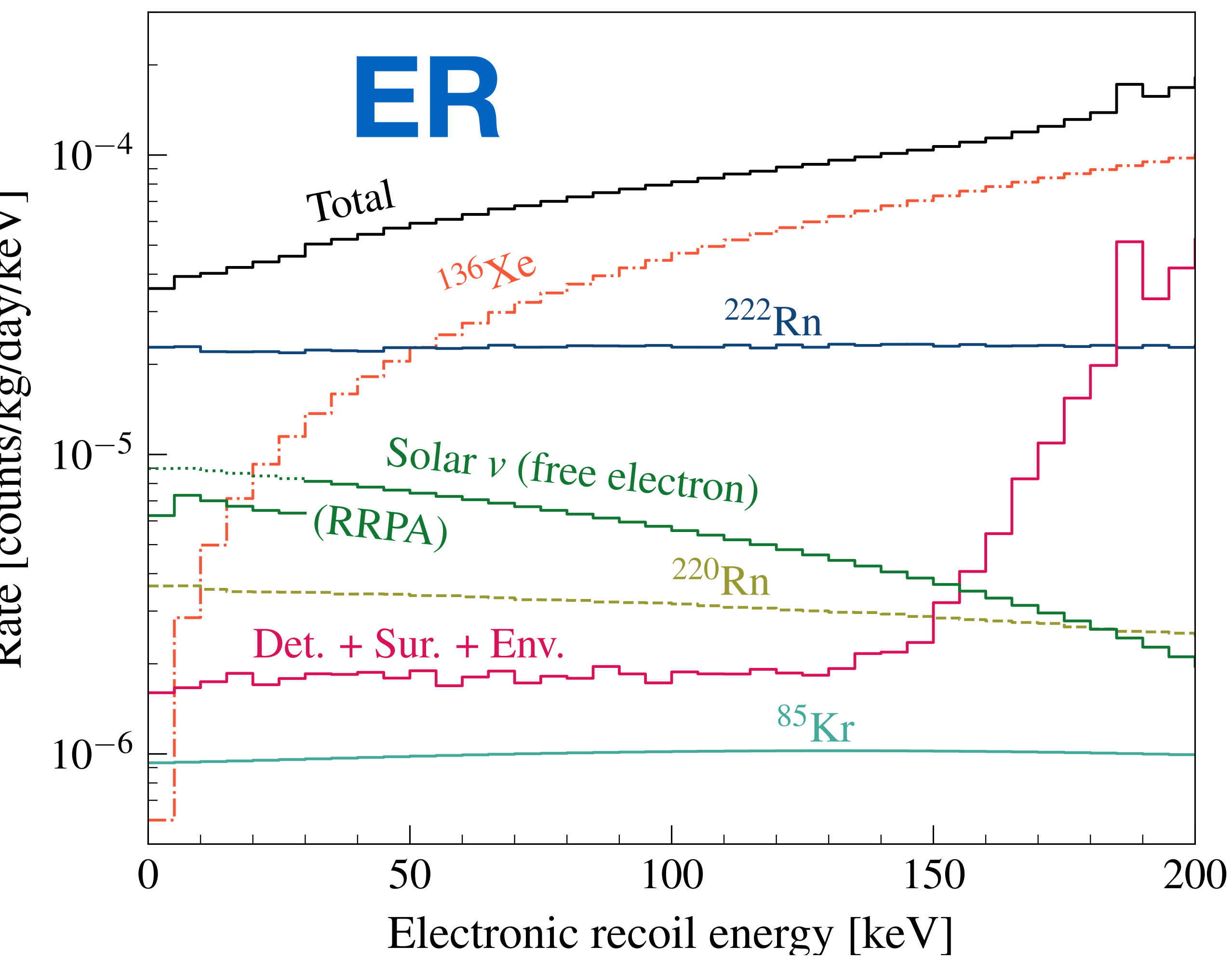
arXiv:2006.02506

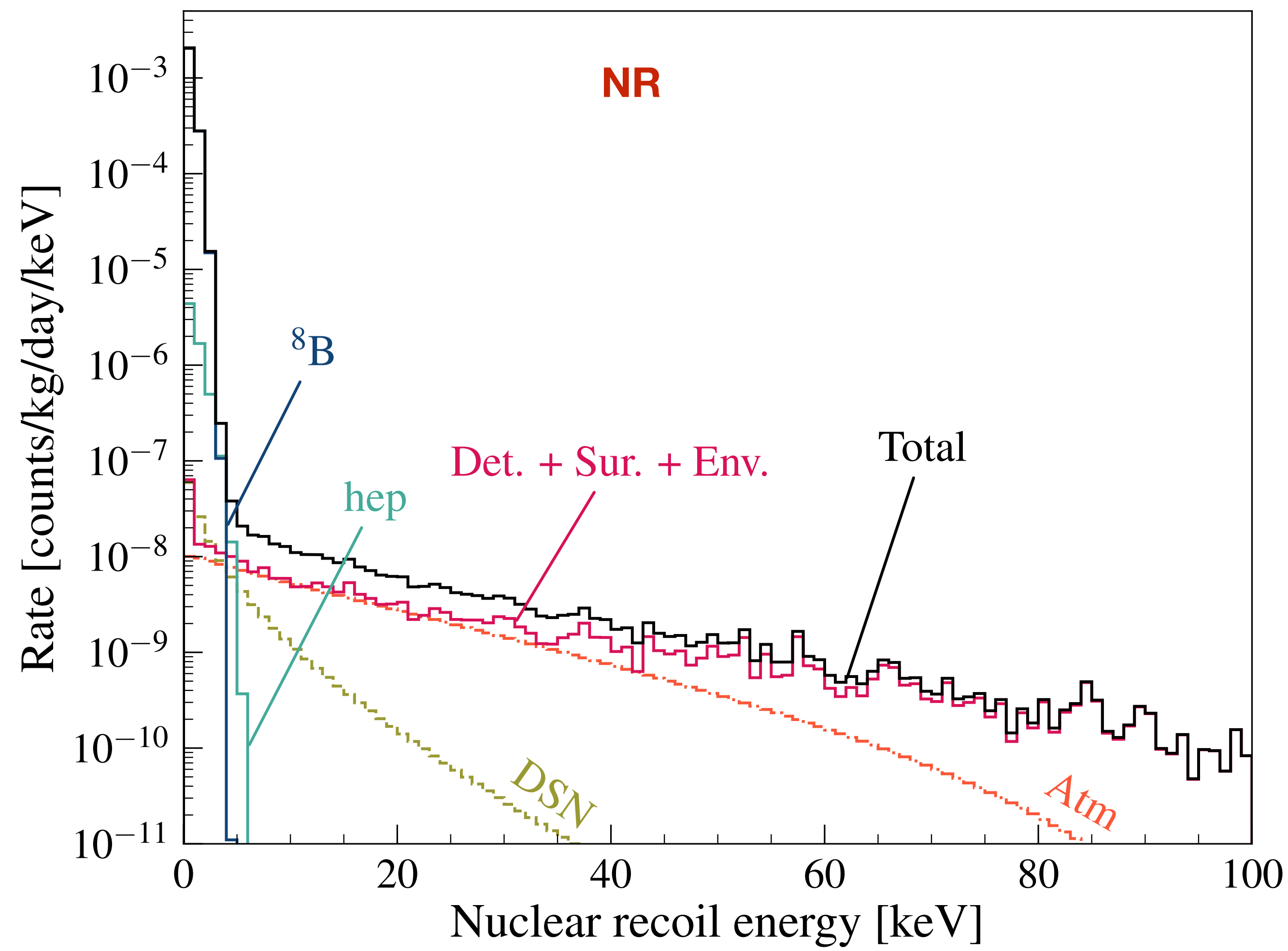
- TPC assembly in Rn-reduced cleanroom
  - Dust < 500 ng/cm^2 on all LXe wetted surfaces
  - Plateout on walls <0.5 mBq/m^2
- Radon emanation
  - Four screening sites
  - All major parts emanated before assembly



Expected Backgrounds in 1000 days

Phys. Rev. D 101, 052002 (2020)

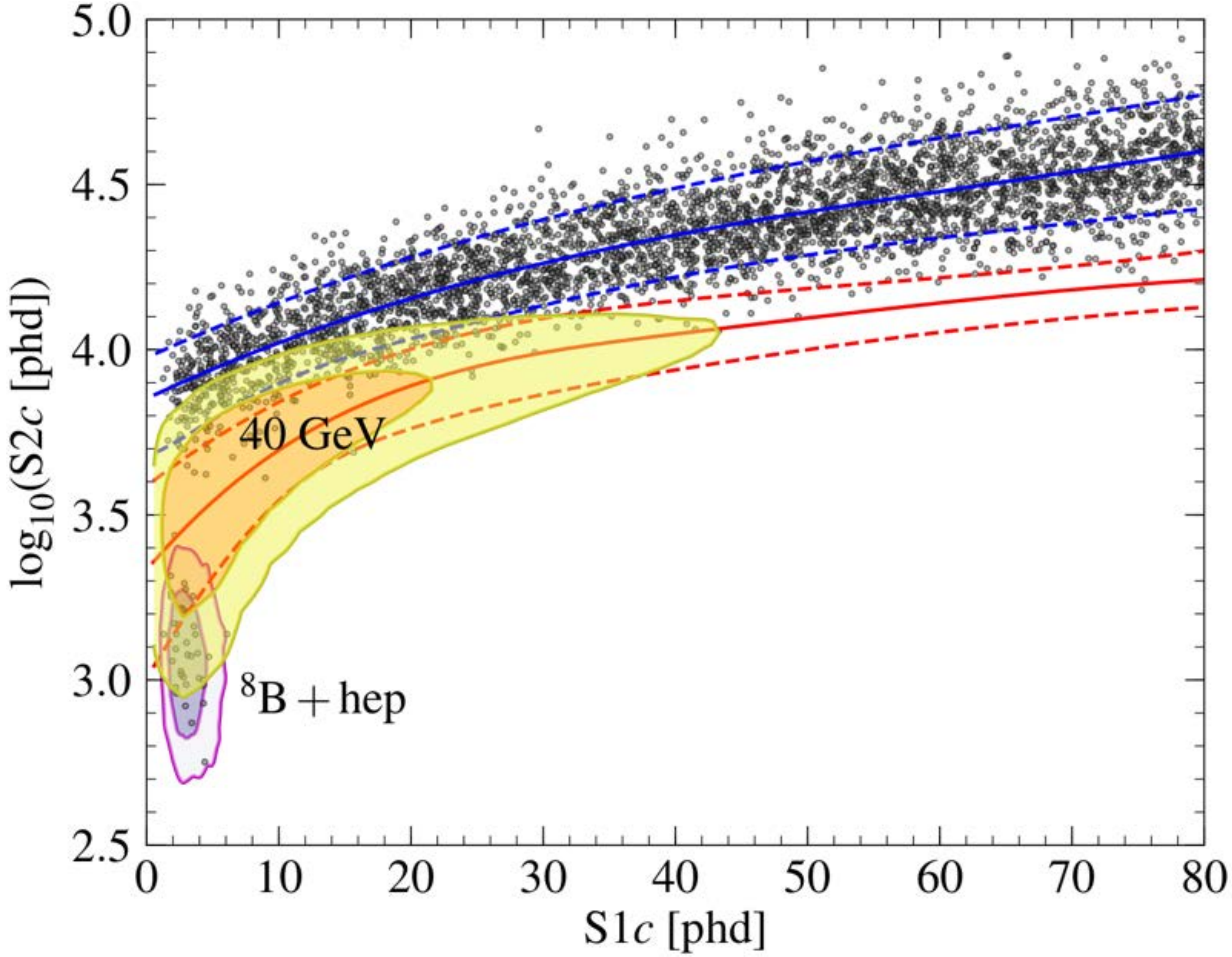




Backgrounds in full exposure	ER (cts)	NR (cts)
Total Counts	1131	1.03
with 99.5% ER discrim., 50% NR eff.	5.66	0.52

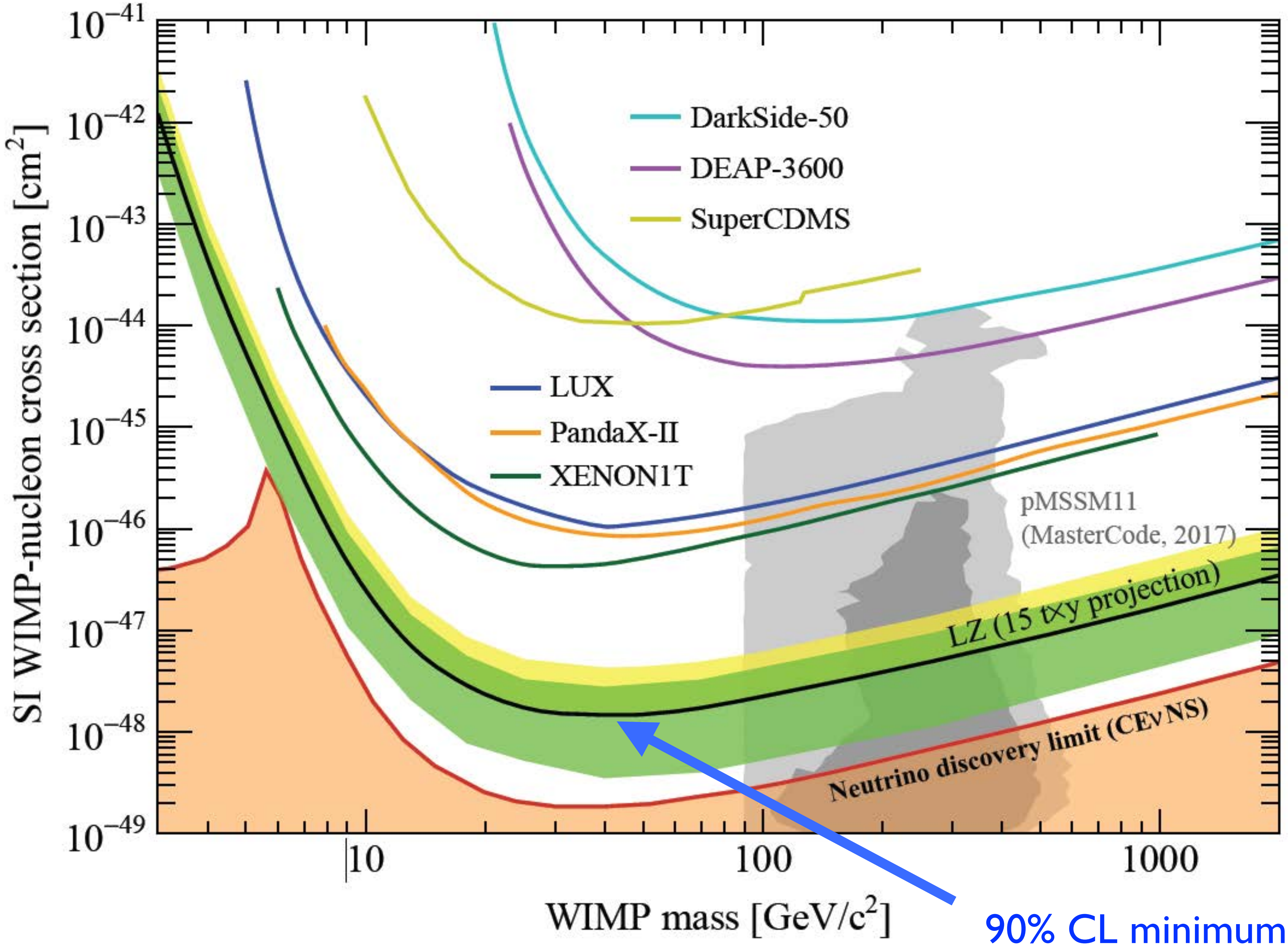
Expected Backgrounds in 1000 days

Simulation of a 1000 day run of LZ



Phys. Rev. D 101, 052002 (2020)

Sensitivity in 1000 days

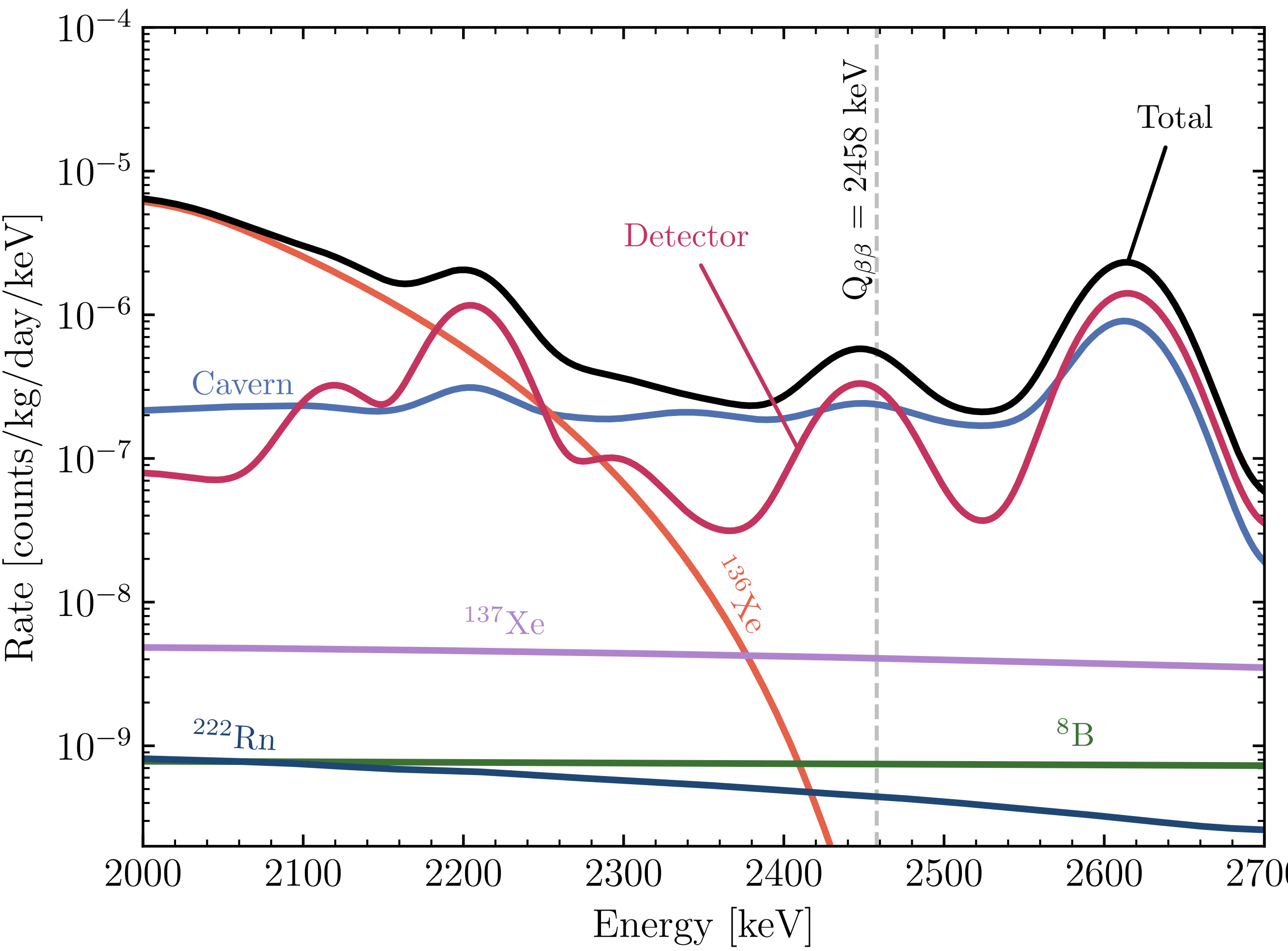


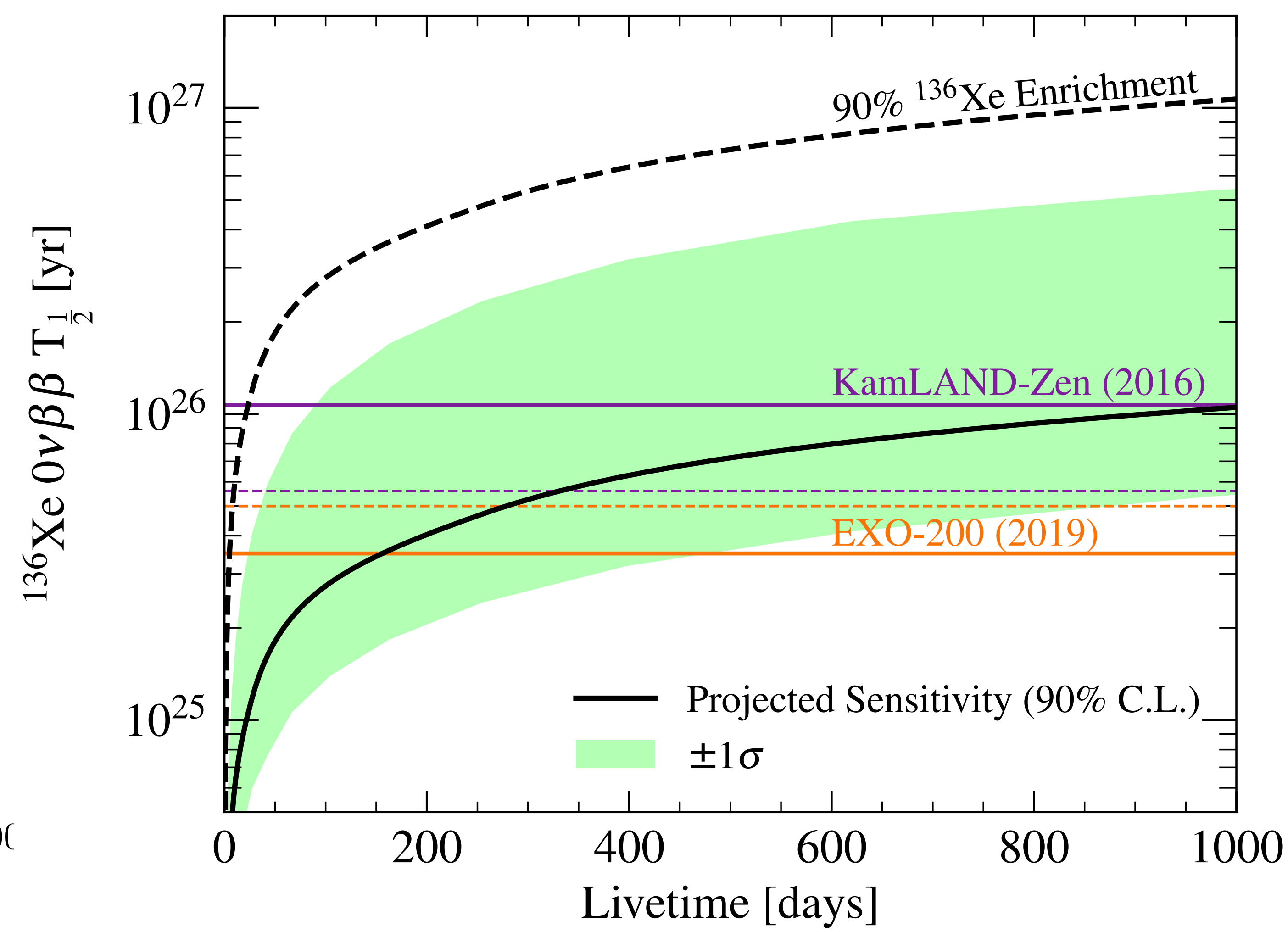
90% CL minimum of 1.6 x 10^{-48} cm^2 at 40 GeV/c^2

Phys. Rev. D 101, 052002 (2020)

Non-WIMP sensitivity - 0vBB

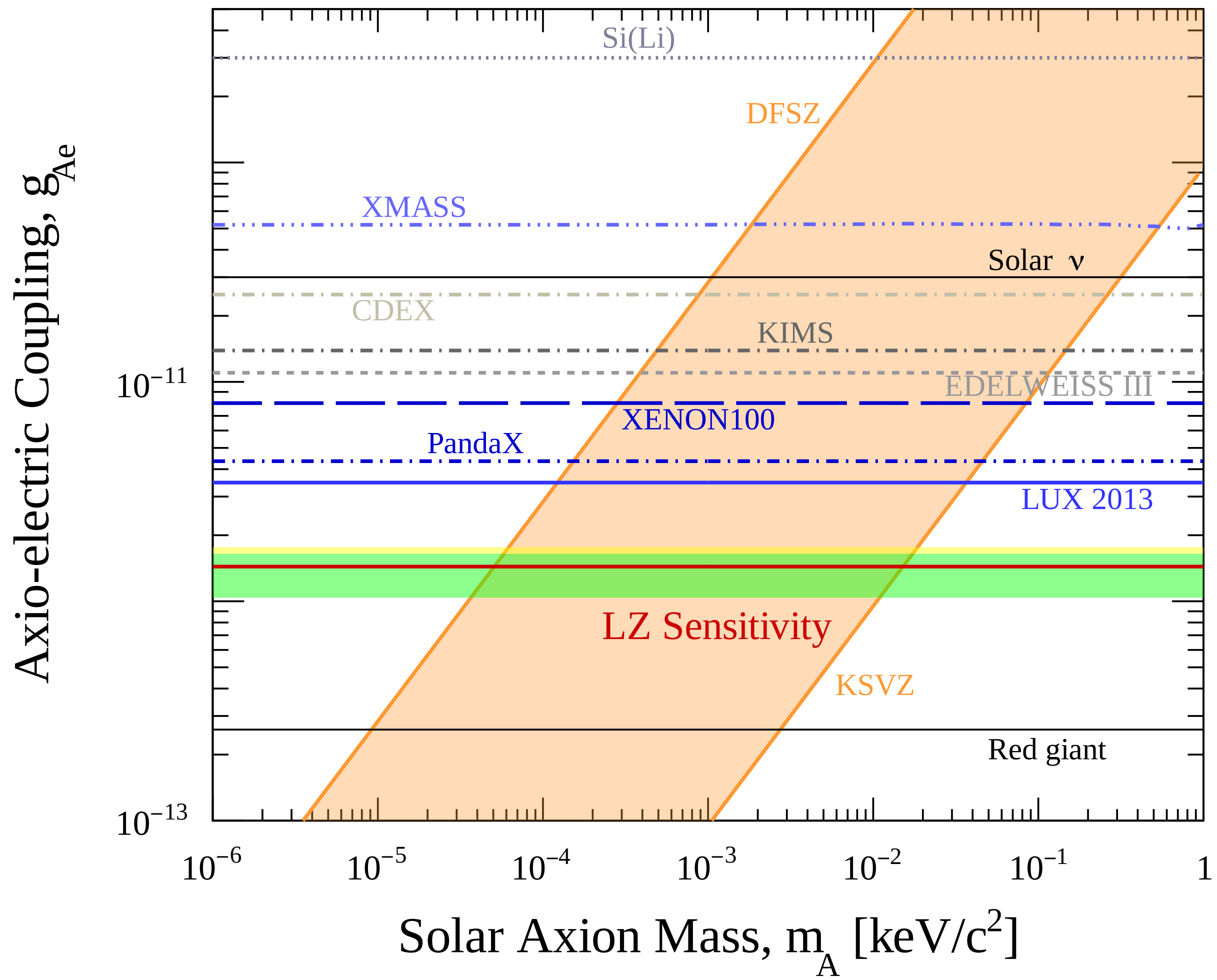
Phys. Rev. C 102, 014602 (2020)





- ^{136}Xe Q value at 2458 keV
- Nominal 1% energy resolution at Q value
- $T_{1/2}$ (90% C.L.) > 1 x 10^{26} years in 1000 live days, inner 1 tonne fiducial mass

ER searches



Recent XENON1T result (arXiv: 2006.09721) consistent with g_{Ae} of ~3e-12, among other interpretations

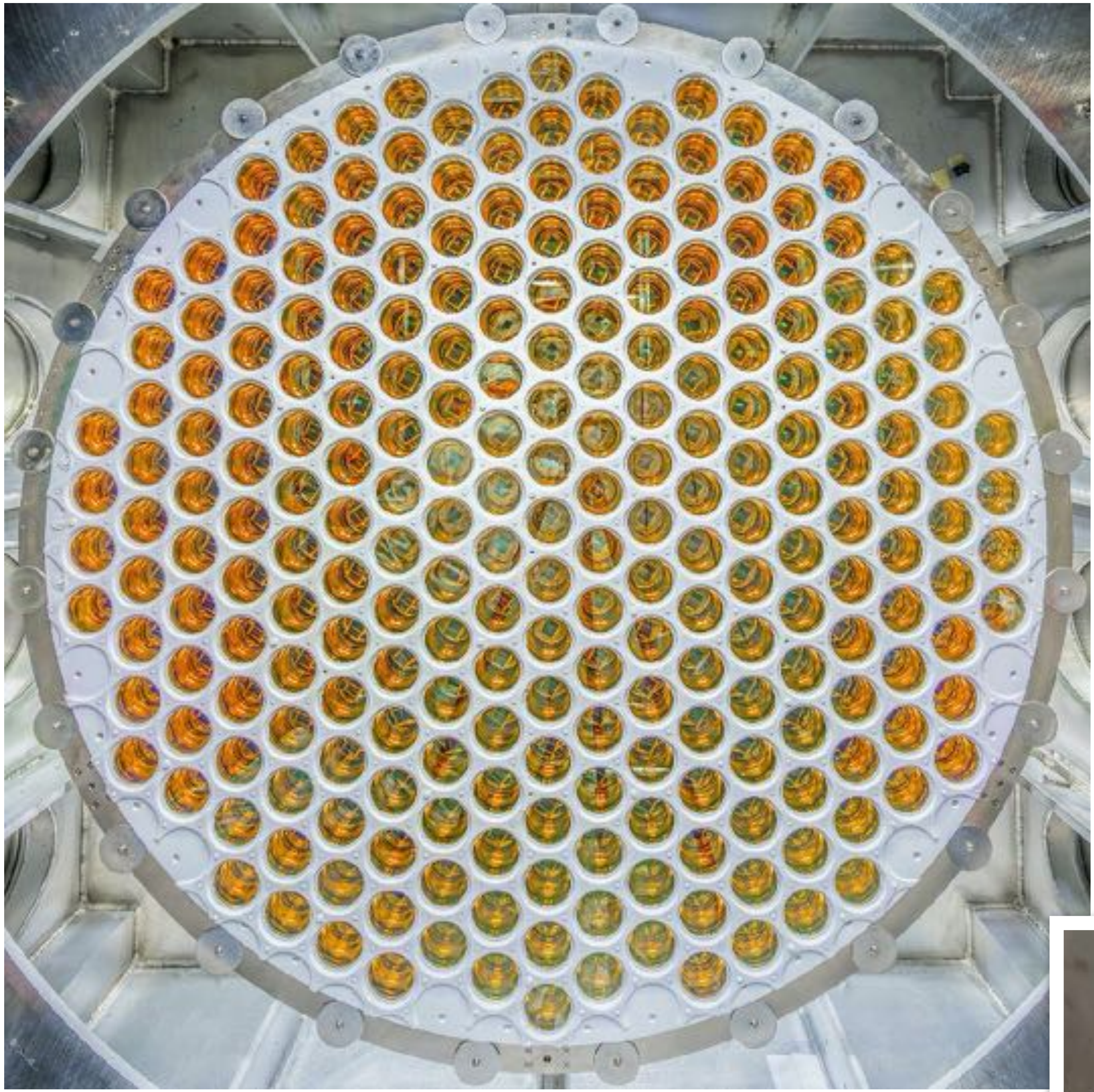
- Sensitive to electron recoils from many types of new physics including
  - Neutrino magnetic moment
  - Solar axions (axio-electric effect)
  - Axion like particles
- Paper in preparation describing LZ sensitivity to these signals
- Recent XENON1T results have highlighted importance of low energy ER backgrounds like ^3H and ^{37}Ar

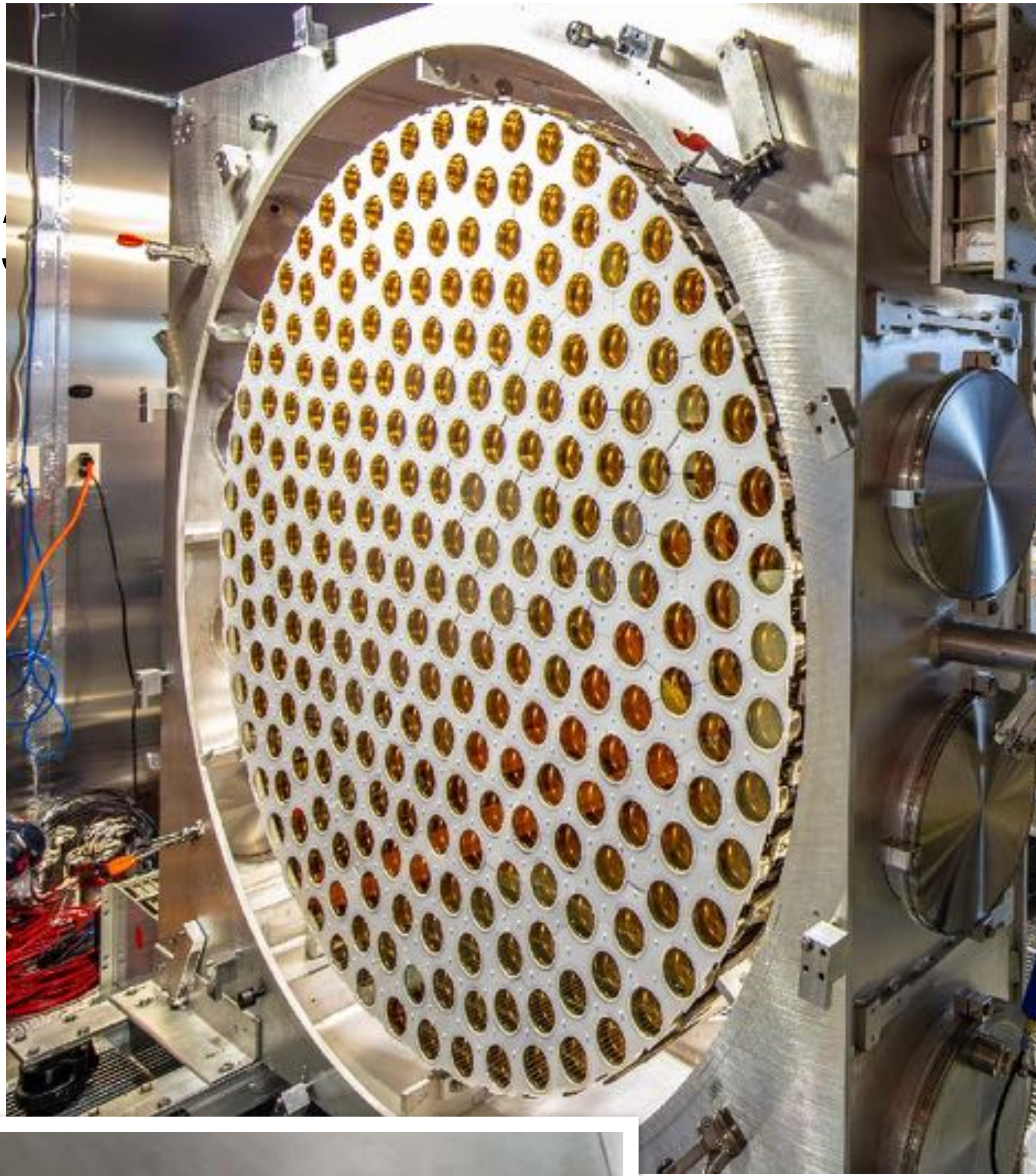
The Picture Round!

Outer Detector

DETECTOR ASSEMBLY

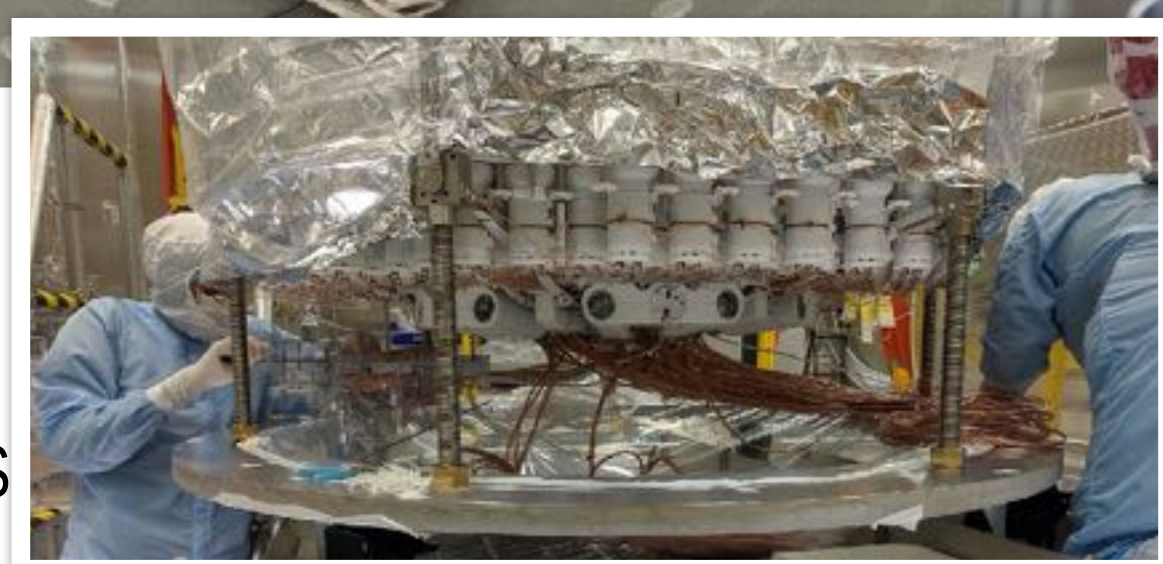
- Detector integration started in December 2018 at Surface Assembly Laboratory (SURF)
- 13,500 working hours
  - Class 1000 CR – but performing much better
  - Reduced radon environment
- Bringing tens of thousands of ultra-clean, low-background components together





SKIN DETECTOR

TOP SKIN:
93 1” PMTS



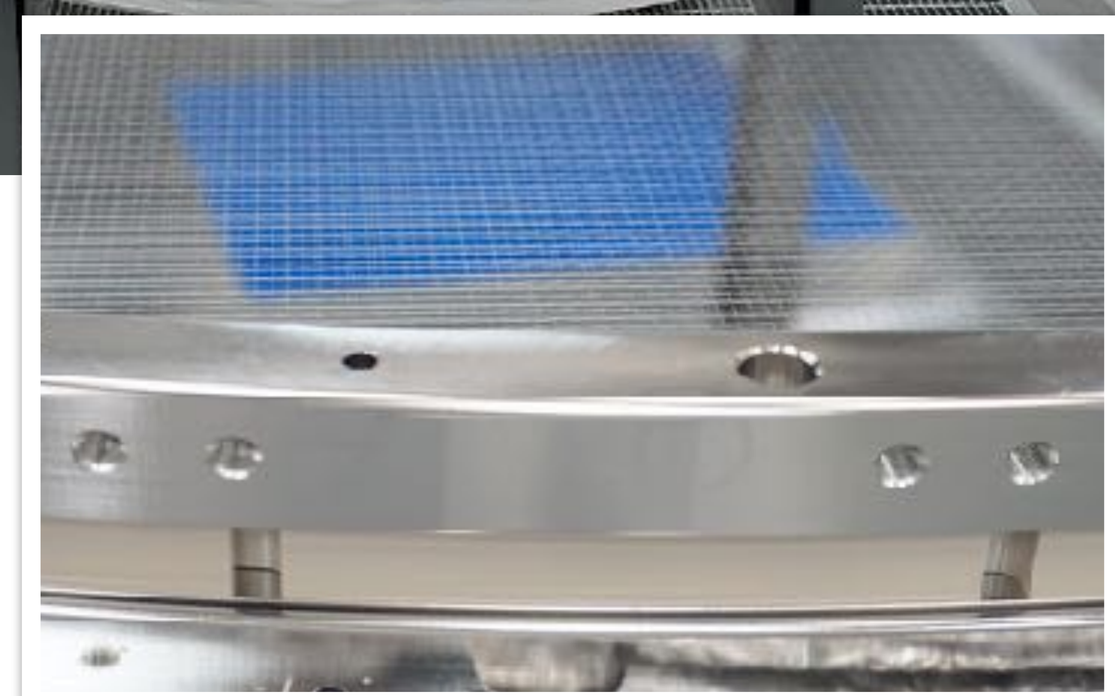
BOTTOM SKIN:
20+18 2” PMTS

ELECTRODE GRID WEAVING

- 4 meshes using 75/100 µm wire, woven using automated loom,
- epoxied to holding rings
- Major QA program for mechanical & electrical resilience, and for cleanliness
- Probably the most challenging components in the experiment

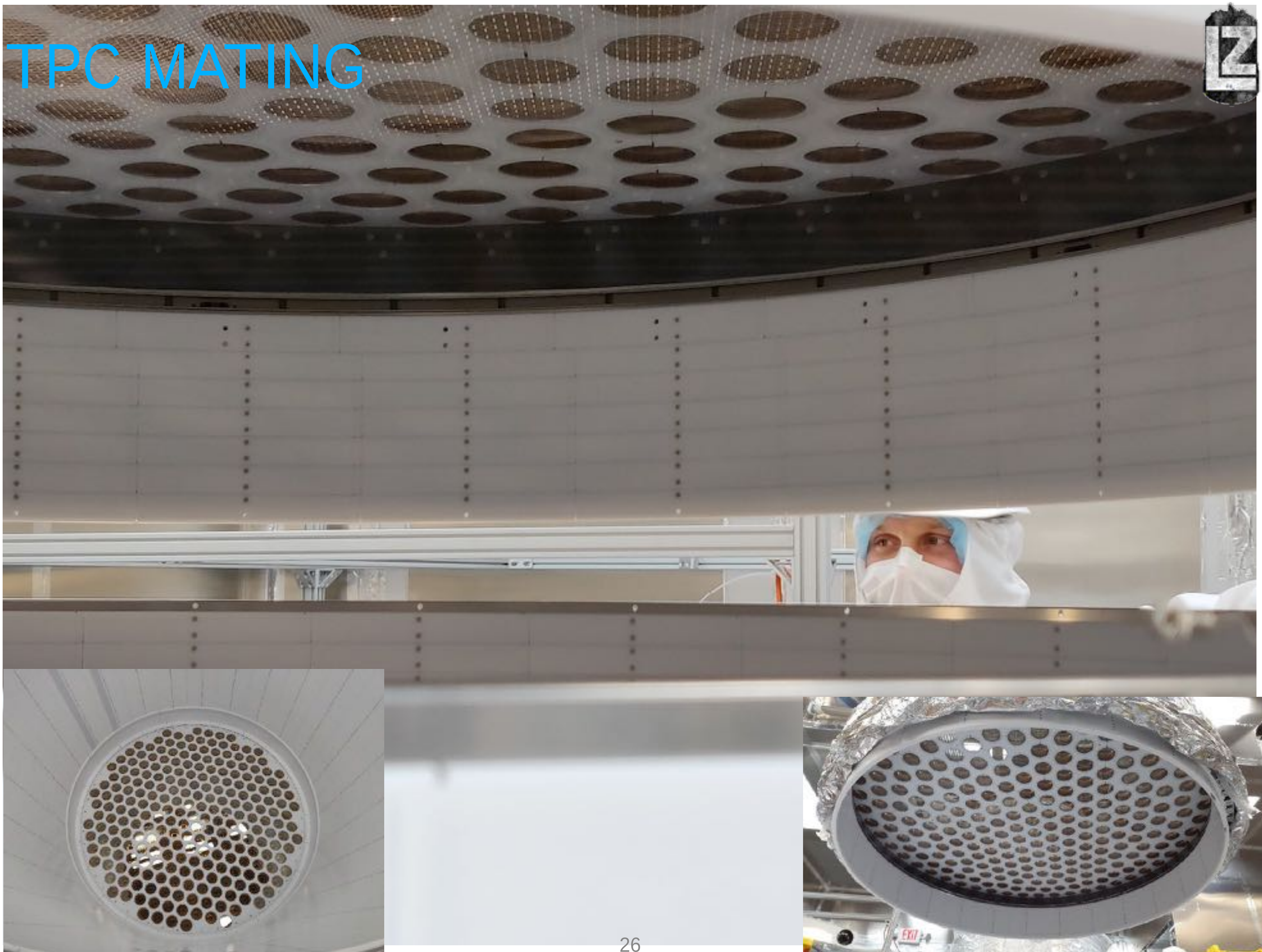
TPC FIELDCAGE & REVERSE-FIELD REGION

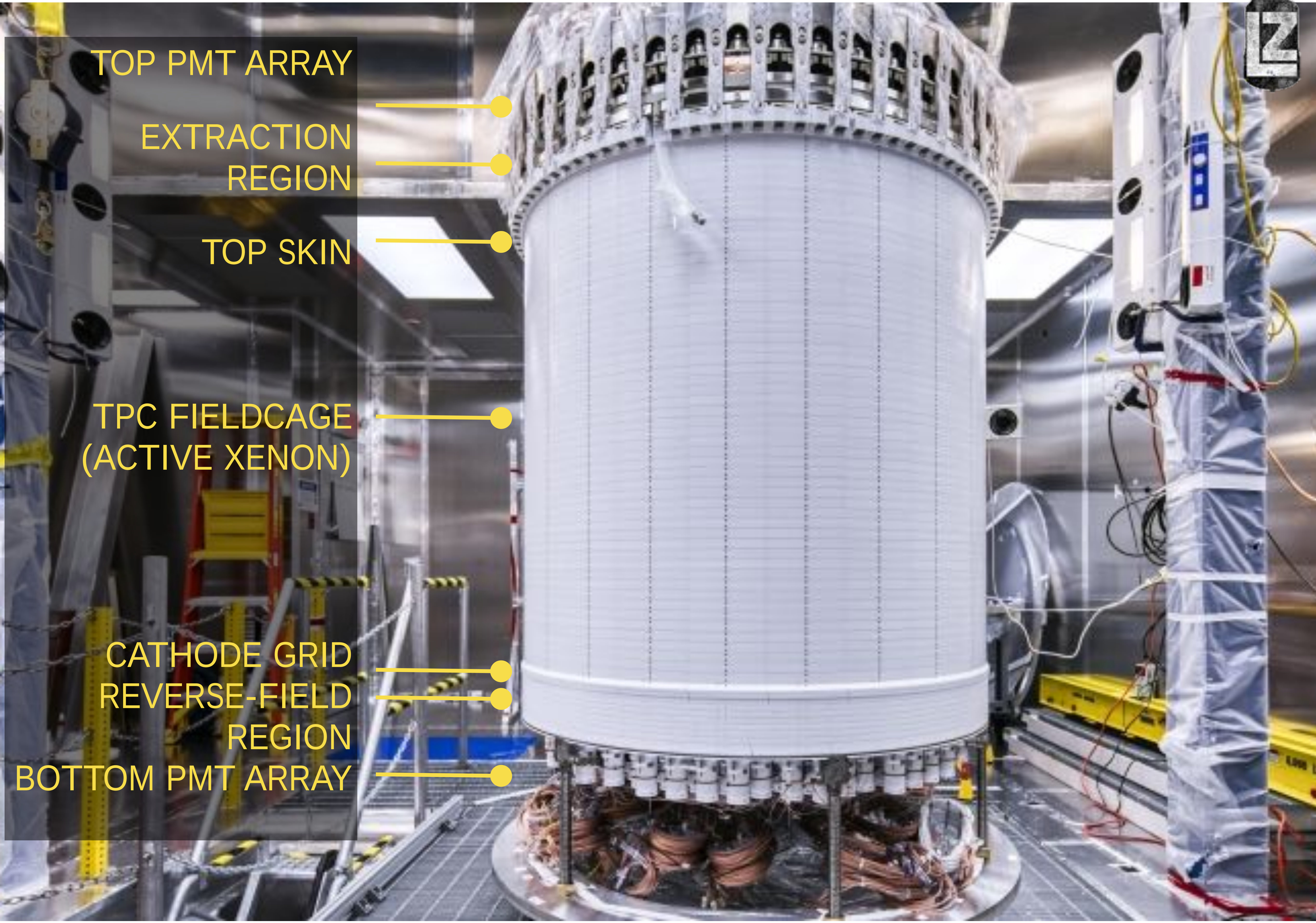
EXTRACTION REGION



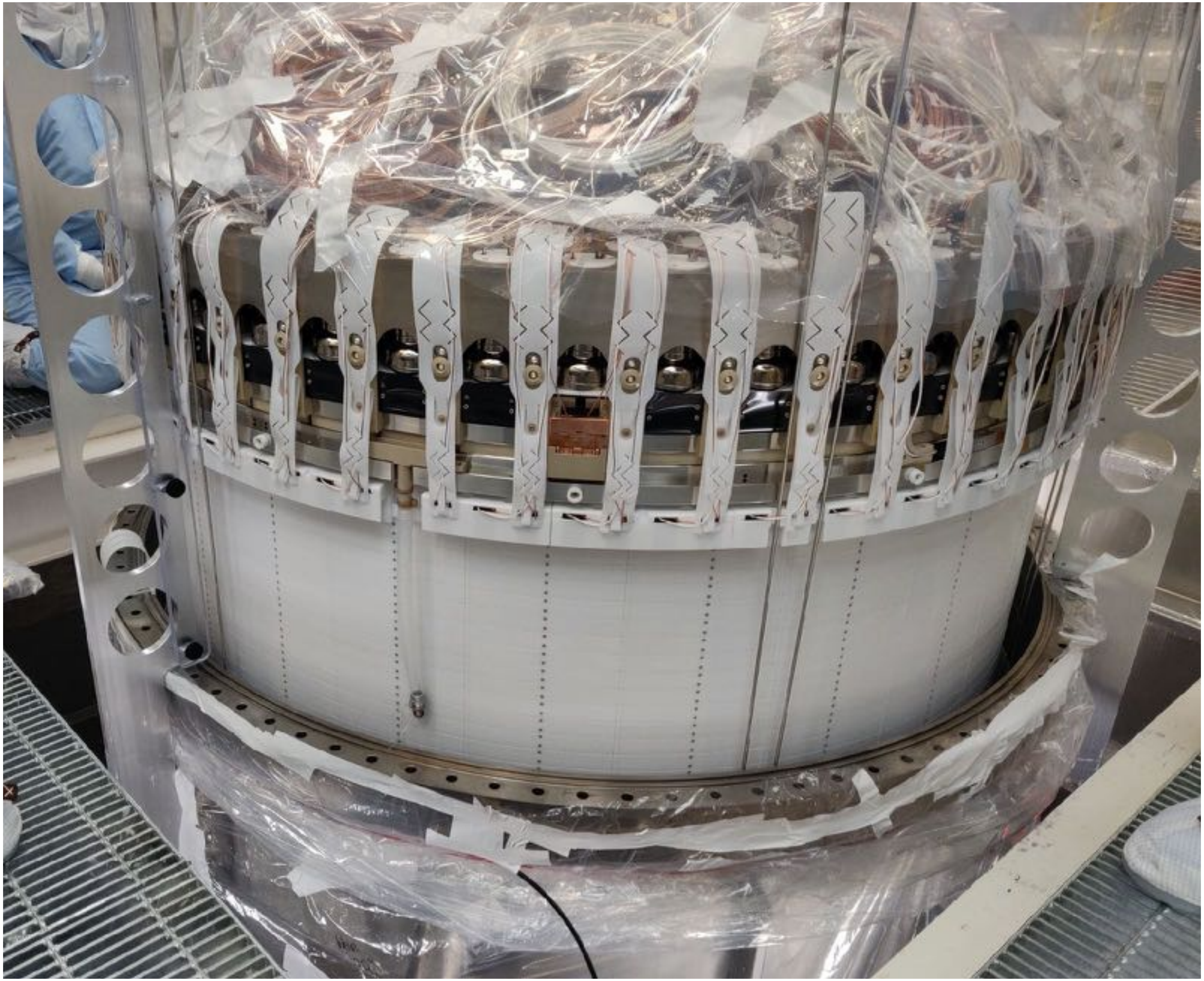
Ti: 1702.02646
PTFE: 1612.07965, 1608.01717

TPC MATING




TOP PMT ARRAY
EXTRACTION REGION
TOP SKIN
TPC FIELDCAGE (ACTIVE XENON)
CATHODE GRID
REVERSE-FIELD REGION
BOTTOM PMT ARRAY
LZ

Insertion into inner cryostat vessel



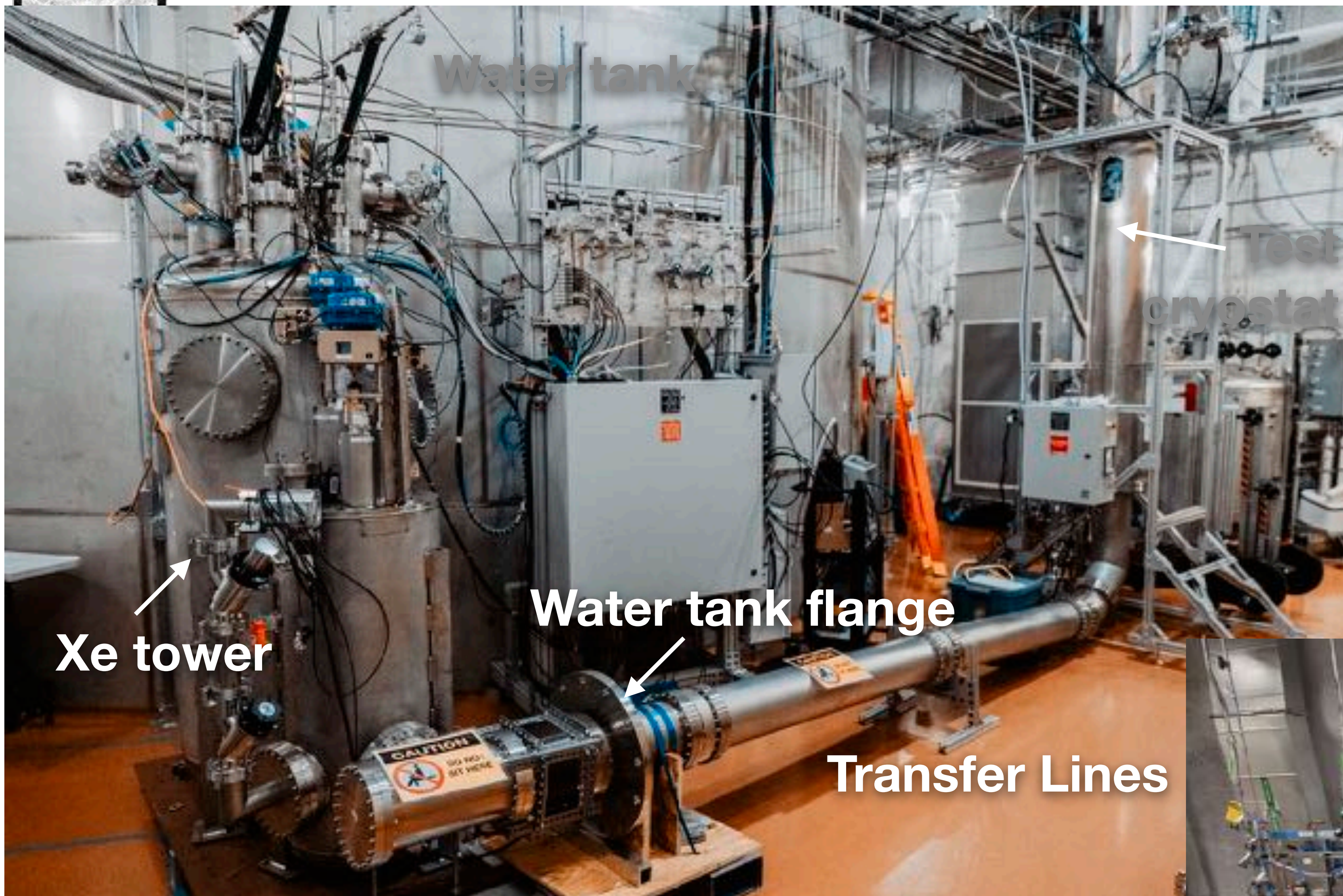
Transport Underground (Oct 2019)

Cathode Connections

Making up cathode connections (under N2 purge)

Cryostat in water tank with cathode connection (OD tanks in background)

Circulation System



Cryocooler LN Tank

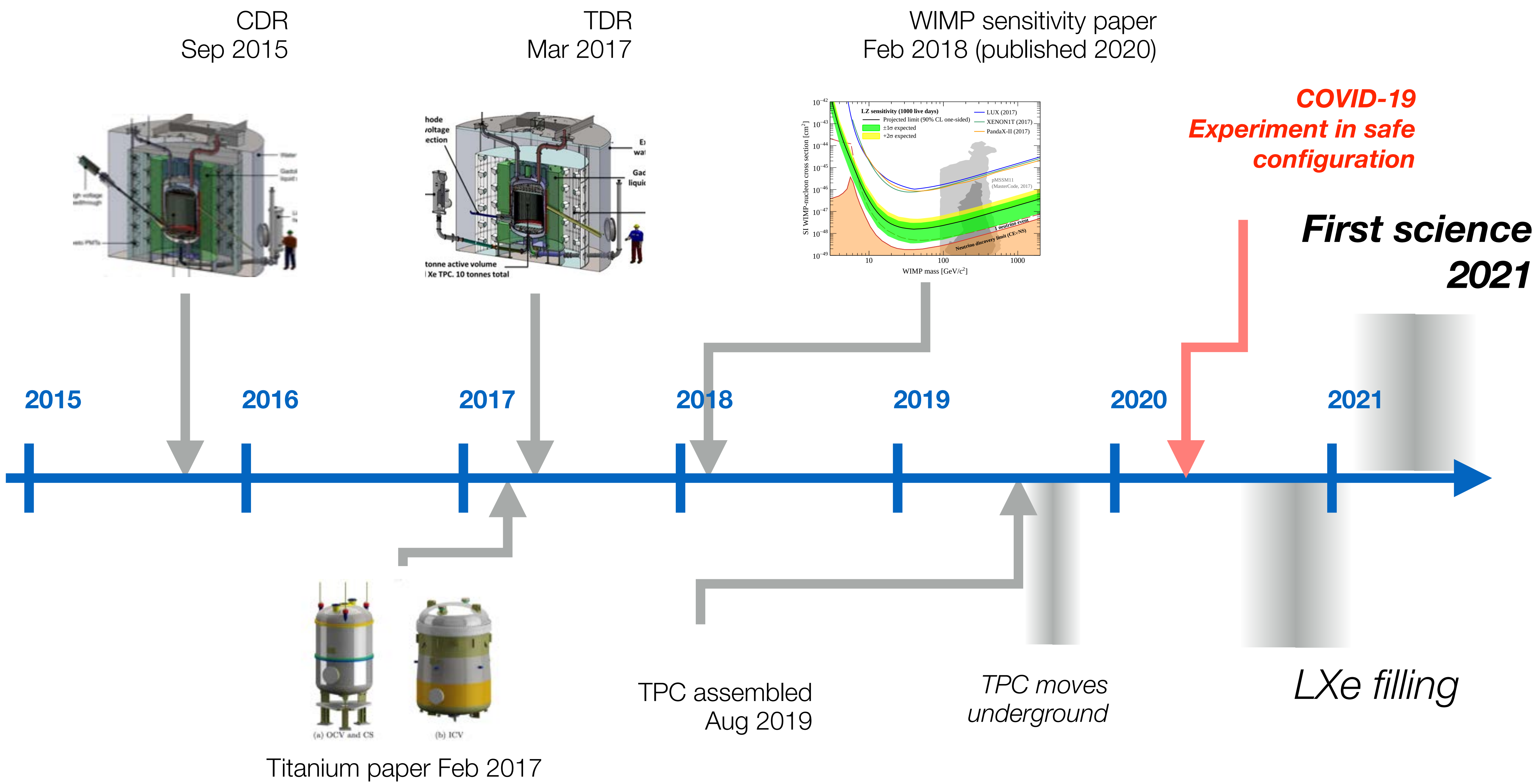
Thermosyphon panel

Krypton Removal

Current Status

- Significant progress in the assembly of the TPC and associated systems.
  - TPC complete, moved underground and currently at vacuum
  - HV cathode connection installed
  - Circulation testing complete
- SARS-CoV-2…
  - Mostly shut down in mid-March
  - Re-opening at somewhat reduced capacity starting in May-June
- Ramping back up as much as possible while following institutional, local, and national guidelines

Current Status

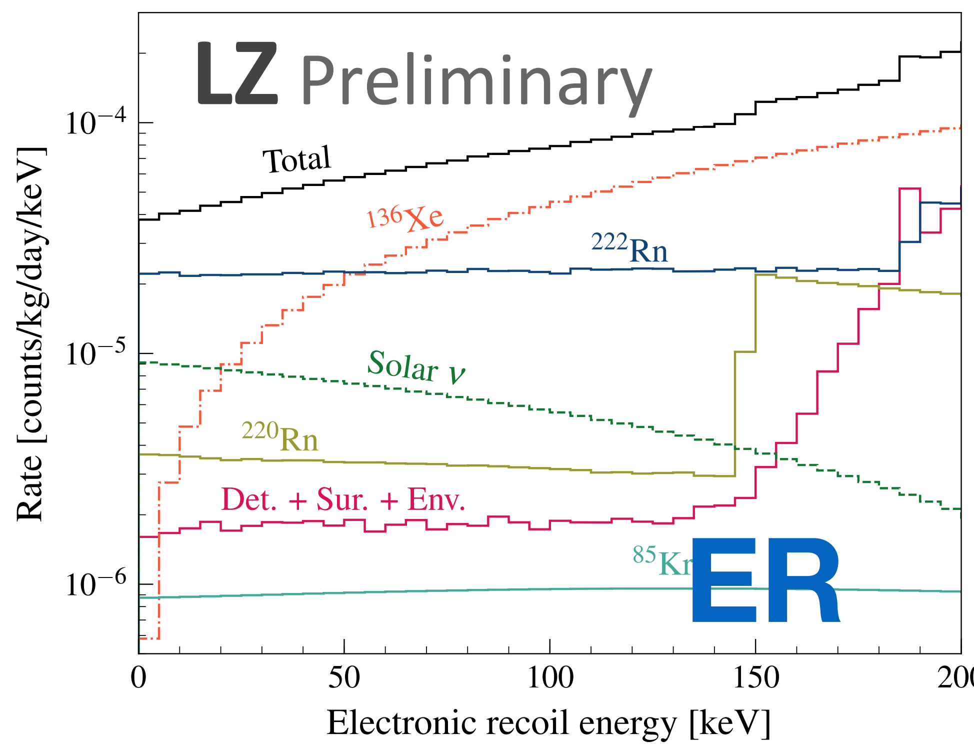


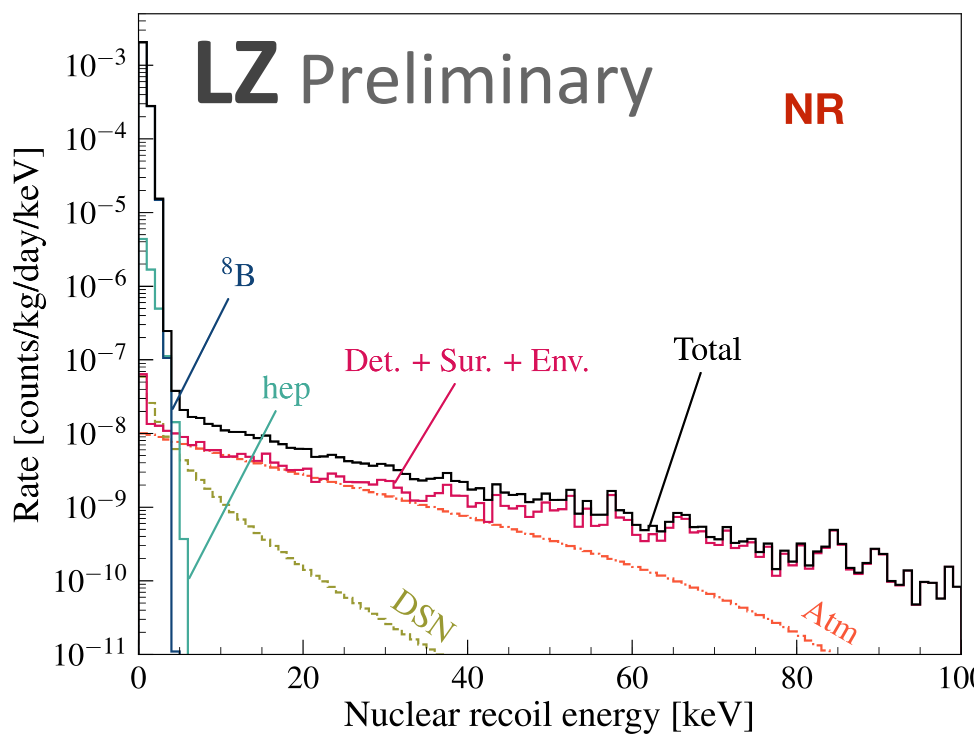
- LZ construction almost complete
  - TPC underground, final connections being made
    - Expected 5.6 tonnes fiducial volume
    - Integrated outer detector veto for background rejection/characterization
- Factor of ~40 improvement in sensitivity on current best limits
  - Discovery potential
  - Including wide variety of non-WIMP physics
- 2021 will be an exciting year for direct detection

Expected Backgrounds in 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**
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)





*Not including ^{8}B or hep