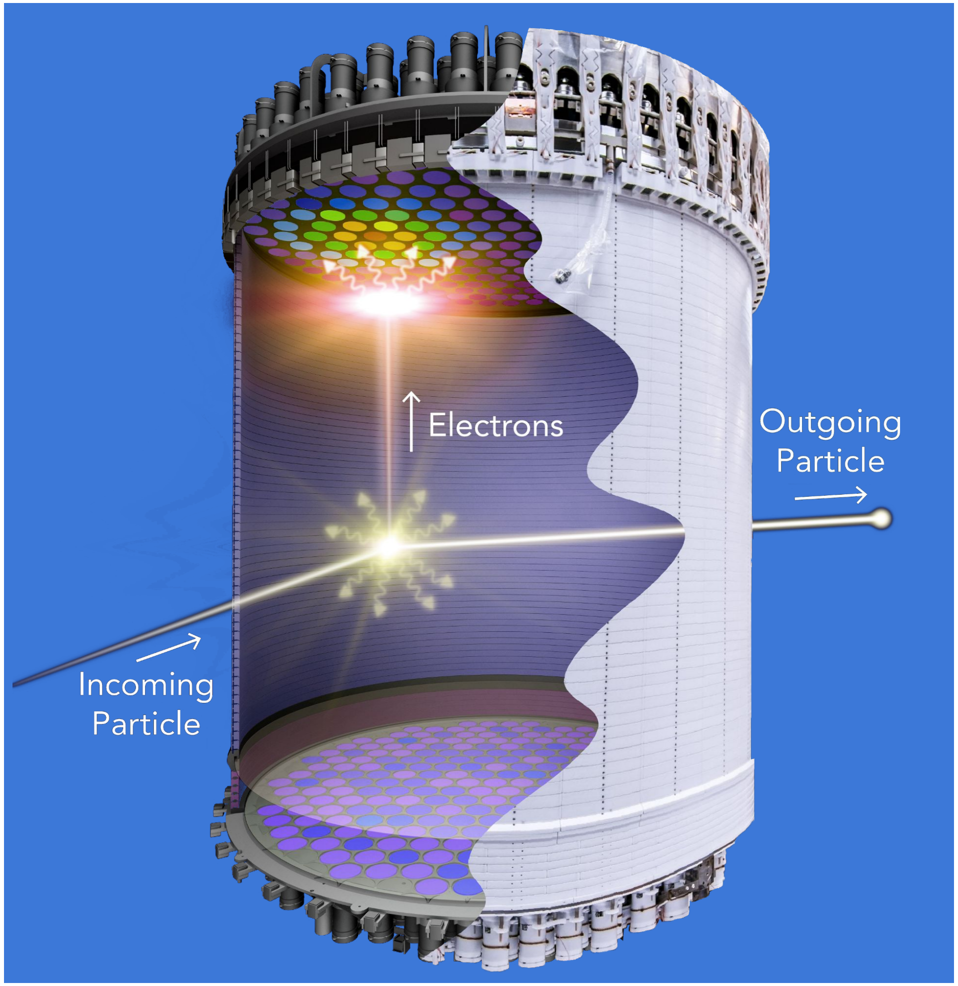
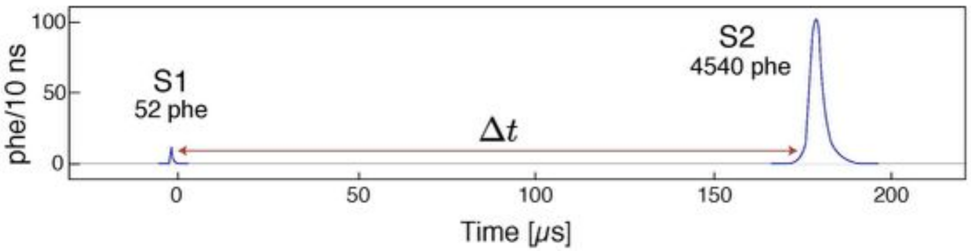
Status of the LUX-Zeplin Experiment

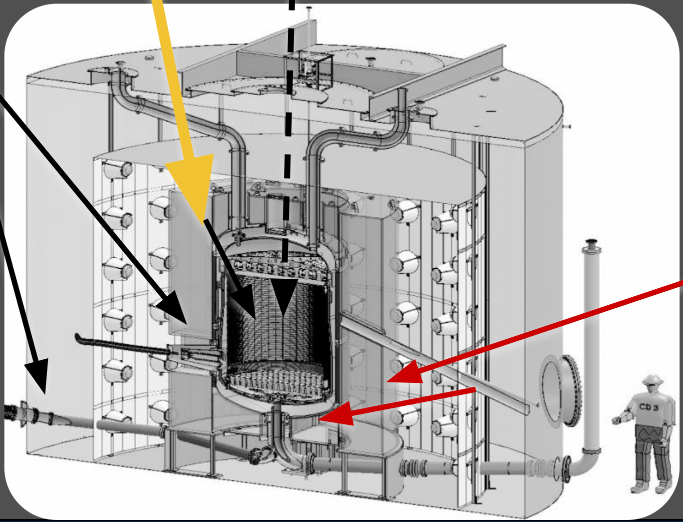
- LXe based experiments demonstrated to be most sensitive to WIMP type DM
- Dual phase **TPC with 7 T of LXe** (5.6T fiducial), two signals:
  - Prompt scintillation light (S1)
  - Prop. charge signal amplified in gas (S2)
- Signal ratio allows to discriminate particle
  - Electron scatter tend to produce (relatively) more charge
  - Neutron scatter create (relatively) more light
- Depth (z) from time difference between S1/S2 and light pattern (x, y) allows fiducialization
- LZ will be the the most sensitive DM detector w.r.t to target mass, energy threshold and discrimination power
- The TPC is surrounded by **active veto detectors**
- **Background free** experiment allows to be sensitive to a wide range of exciting physics





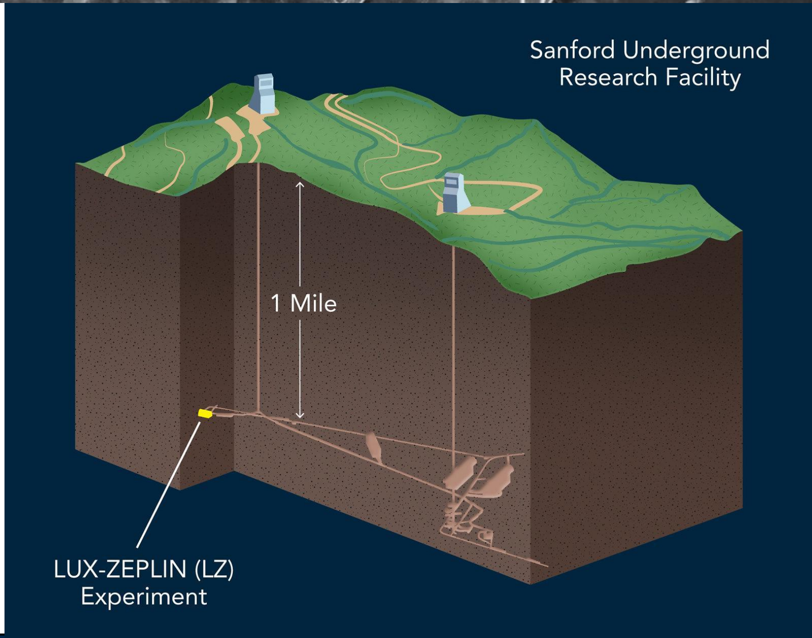
- **External sources**
  - Cosmogenics
  - Radiation from rock
  - Neutrinos

- **Internal sources**
  - Rad. impurities in material
  - Rn emanation from components
  - Dust on surfaces
  - Xe contaminants



Background Mitigation (External)

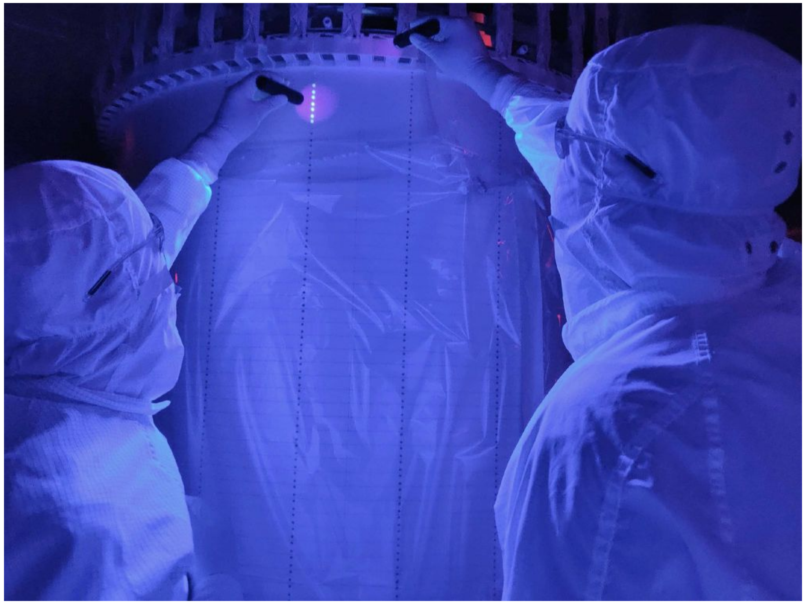
- Cosmogenic backgrounds:
  - Go deep! 1 mile underground (4850 feet)
  - Reduces muon flux by 10^7
- Sanford Underground Research Facility (SURF) in former gold mine
  - Also DUNE, CASPAR, SigmaV, ...



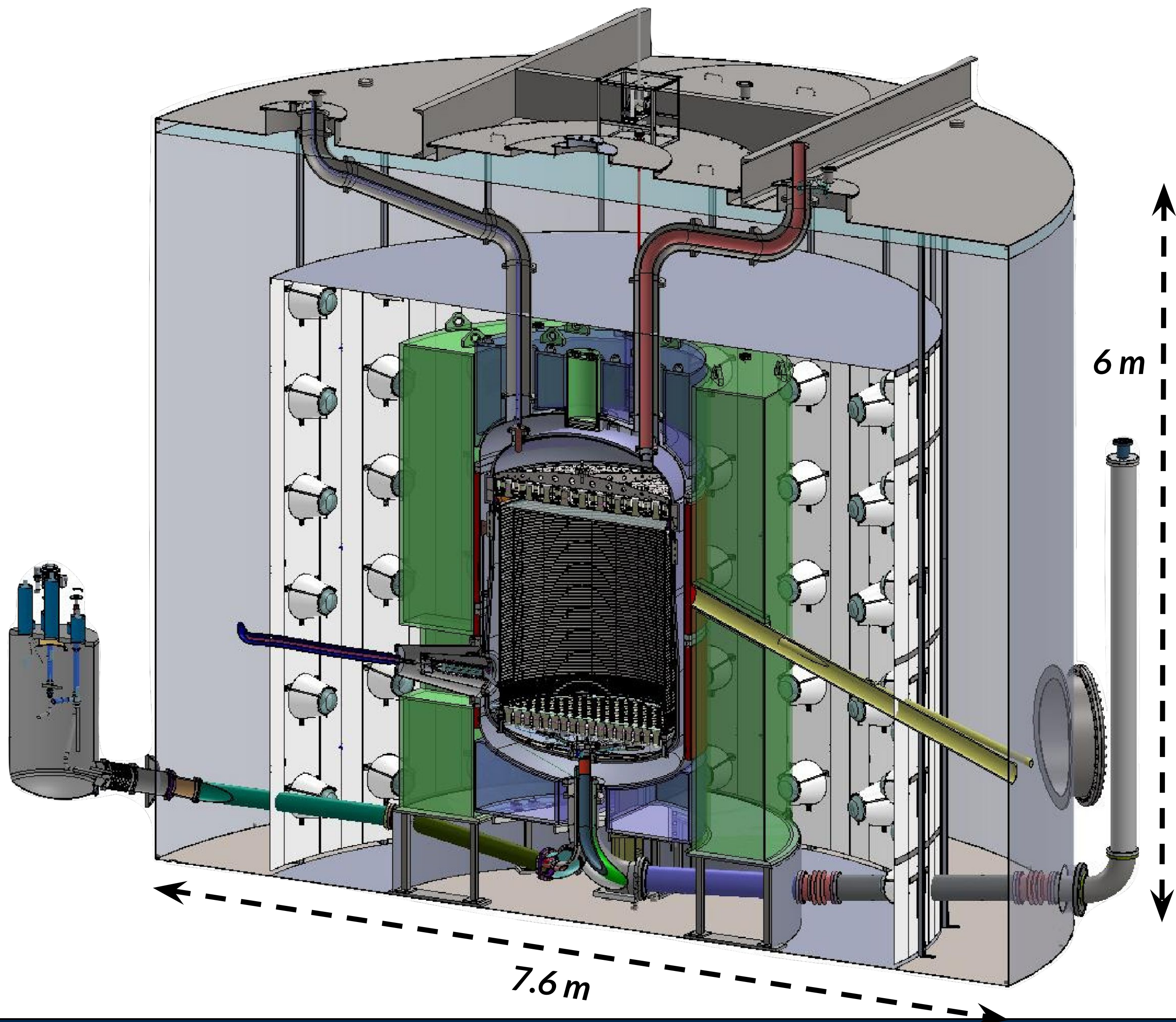
1 Banana = 15 Bq

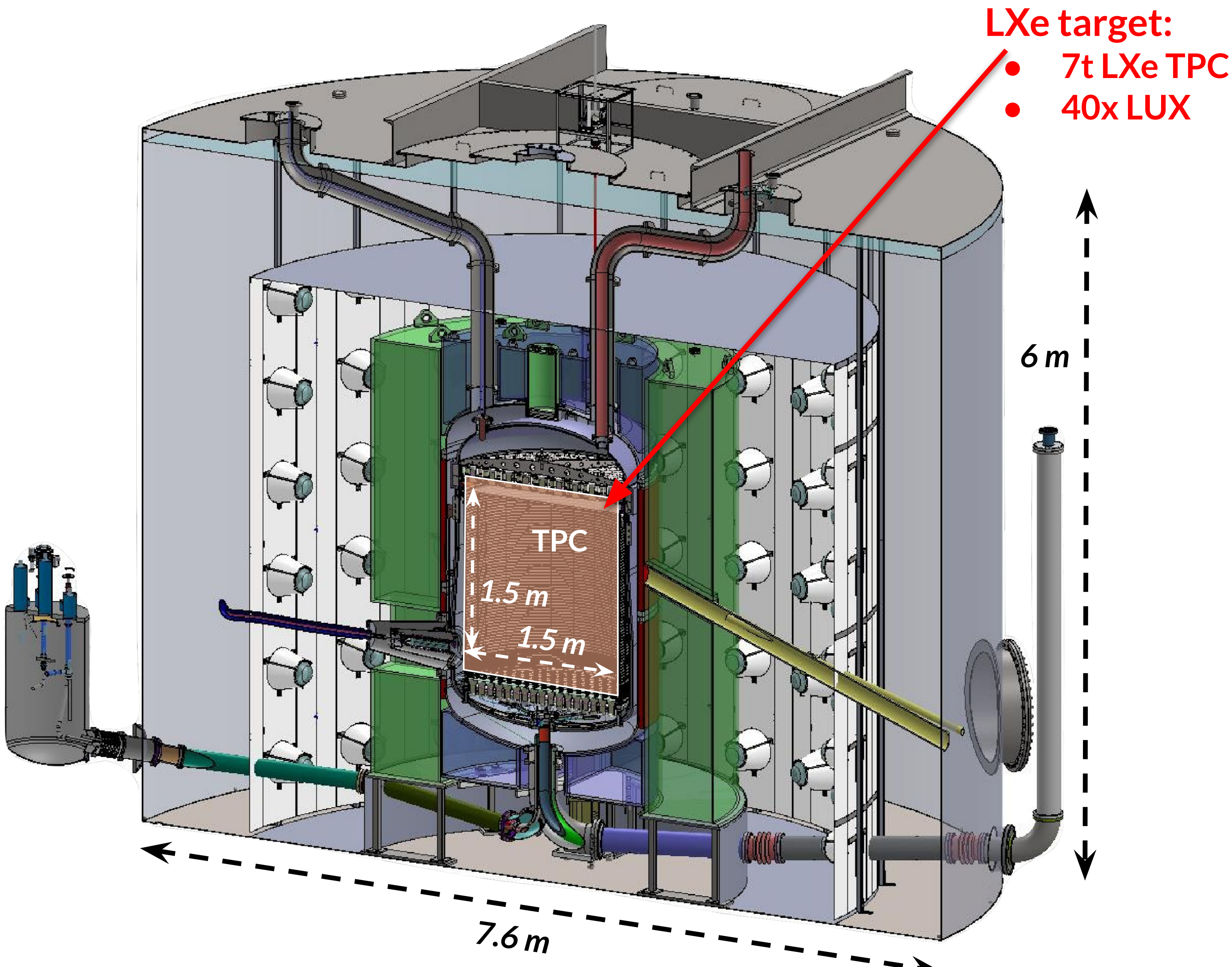
- **Detector materials:**
  - Use purest materials obtainable, screen all
  - Target activity: **O(mBq/kg) - 1/15,000 Bananas**
- **Radon emanation:**
  - Four screening sites and two portable assays
  - Reduce Rn from warm components by > x10
  - Target activity: **2 μBq/kg - 1/750,000 Bananas**

- **Radon 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 - 1/30,000 Bananas**
- Reduce Xenon contaminants to **O(0.015 ppt)**
- Cleaning, cleaning, cleaning, cleaning!



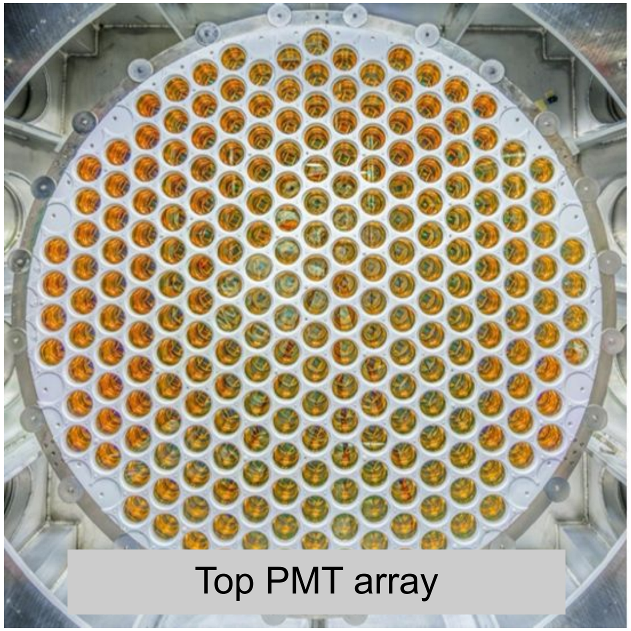
The Experiment


6 m
7.6 m

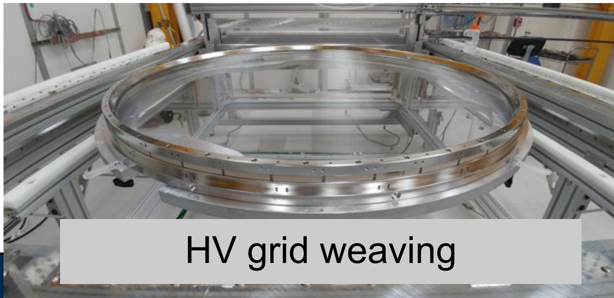

LXe target:
• 7t LXe TPC
• 40x LUX
TPC
1.5 m
1.5 m
6 m
7.6 m

Assembled TPC (July 2019)

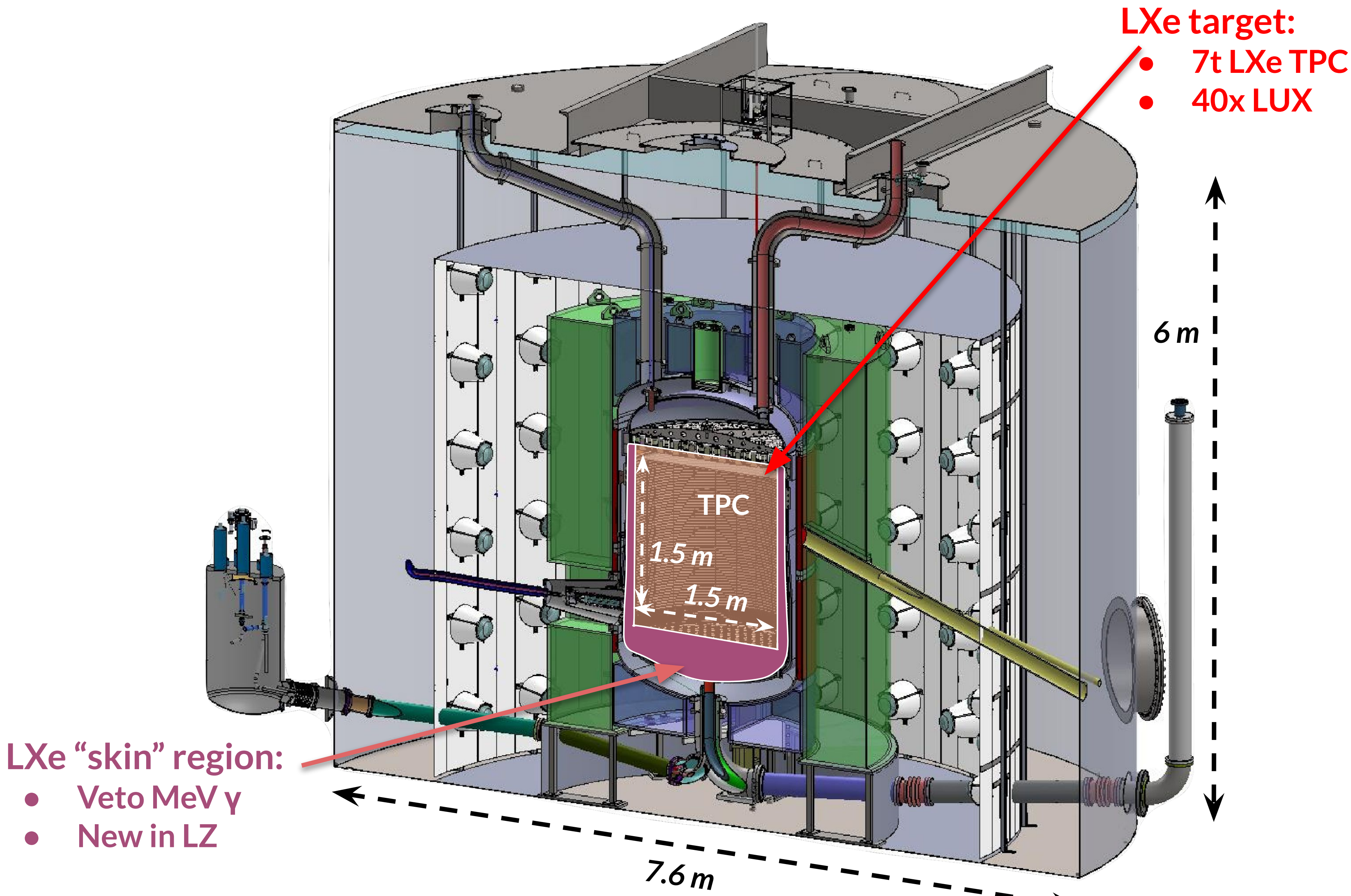
Bottom PMT array with field cage



Top PMT array

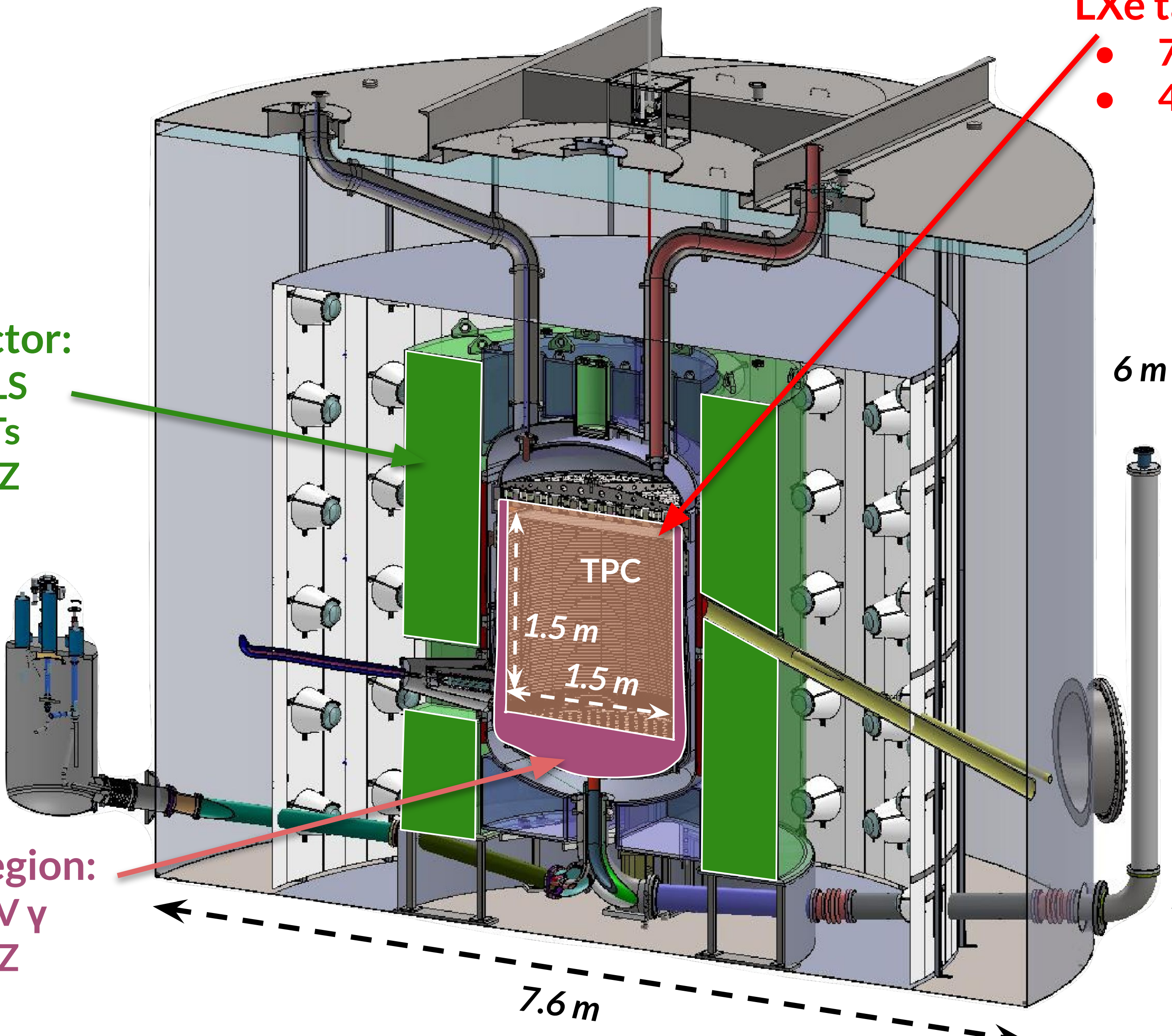


HV grid weaving

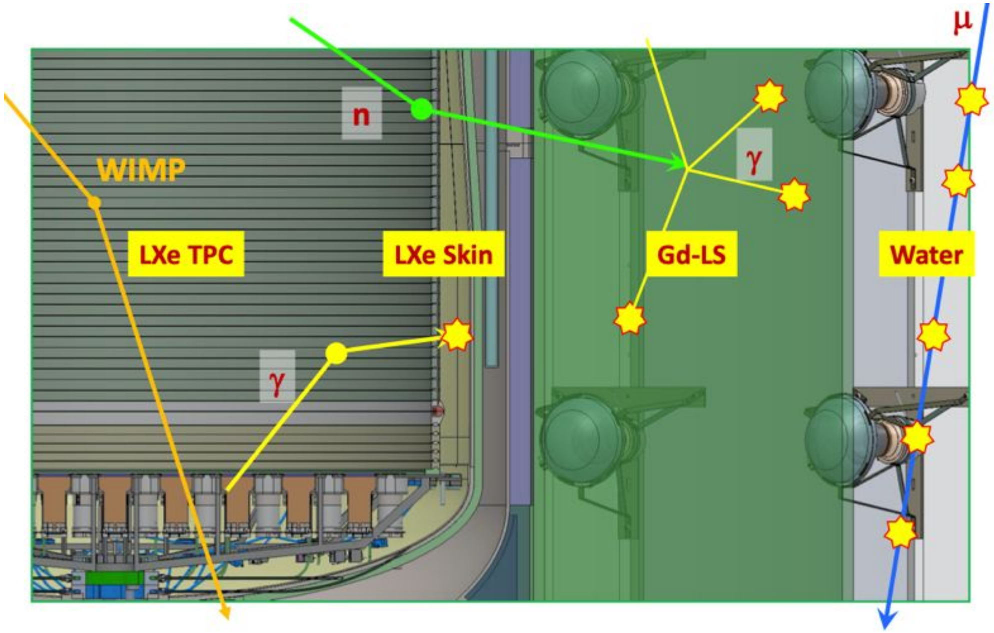

LXe target:
• 7t LXe TPC
• 40x LUX
6 m
TPC
1.5 m
1.5 m
7.6 m
LXe "skin" region:
• Veto MeV γ
• New in LZ

LXe target:
- 7t LXe TPC
- 40x LUX

Outer Detector:
- 17 t Gd-LS
- 120 PMTs
- New in LZ



LXe "skin" region:
- Veto MeV γ
- New in LZ



Skin:

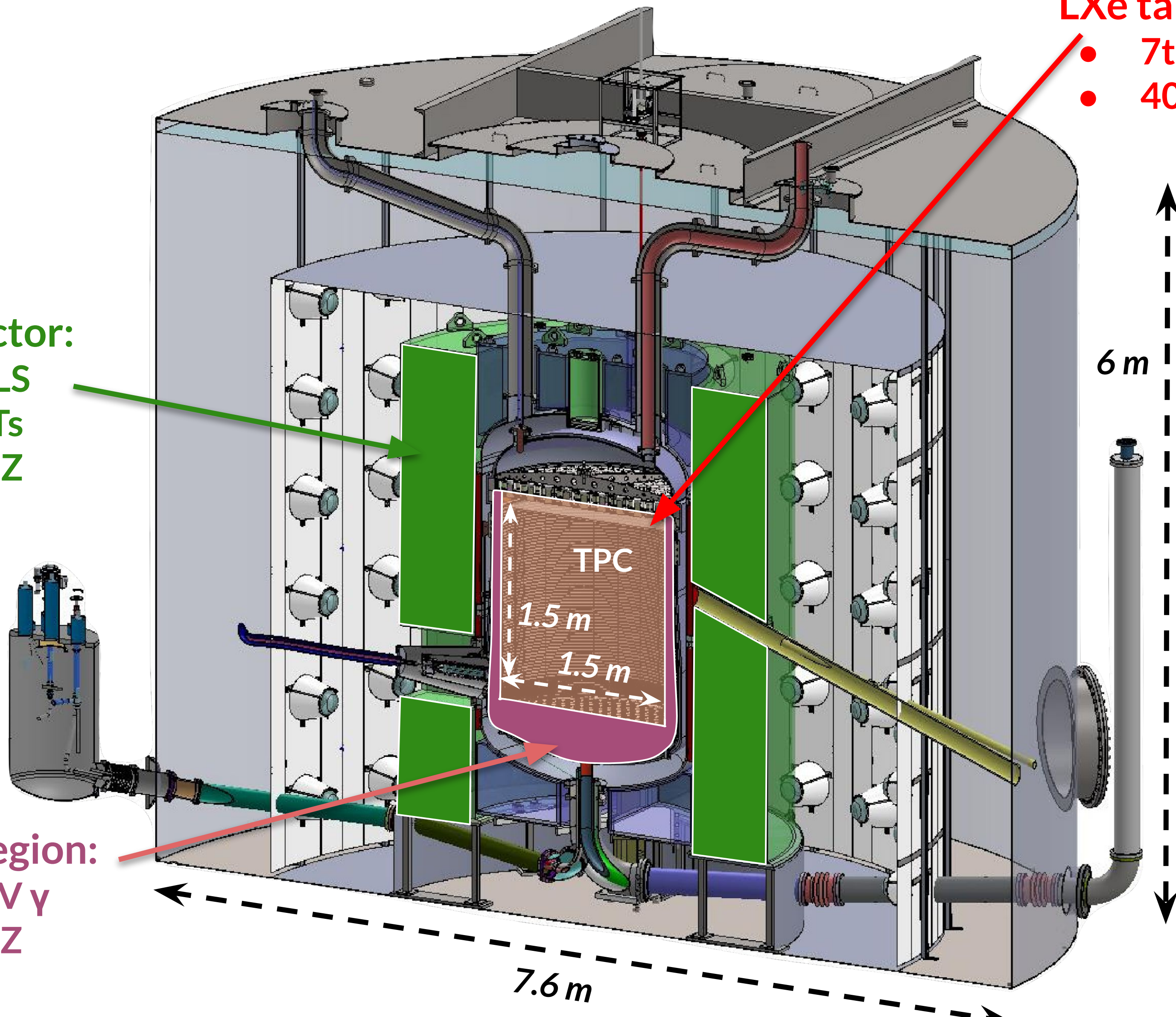
- 2 T of LXe surrounding the TPC
- Lined with PTFE to maximize light collection efficiency
- Anti-coincidence detector for MeV level γ-rays

Outer Detector:

- 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
- 95% eff of neutrons of 200 keV and above

LXe target:
- 7t LXe TPC
- 40x LUX

Outer Detector:
- 17 t Gd-LS
- 120 PMTs
- New in LZ



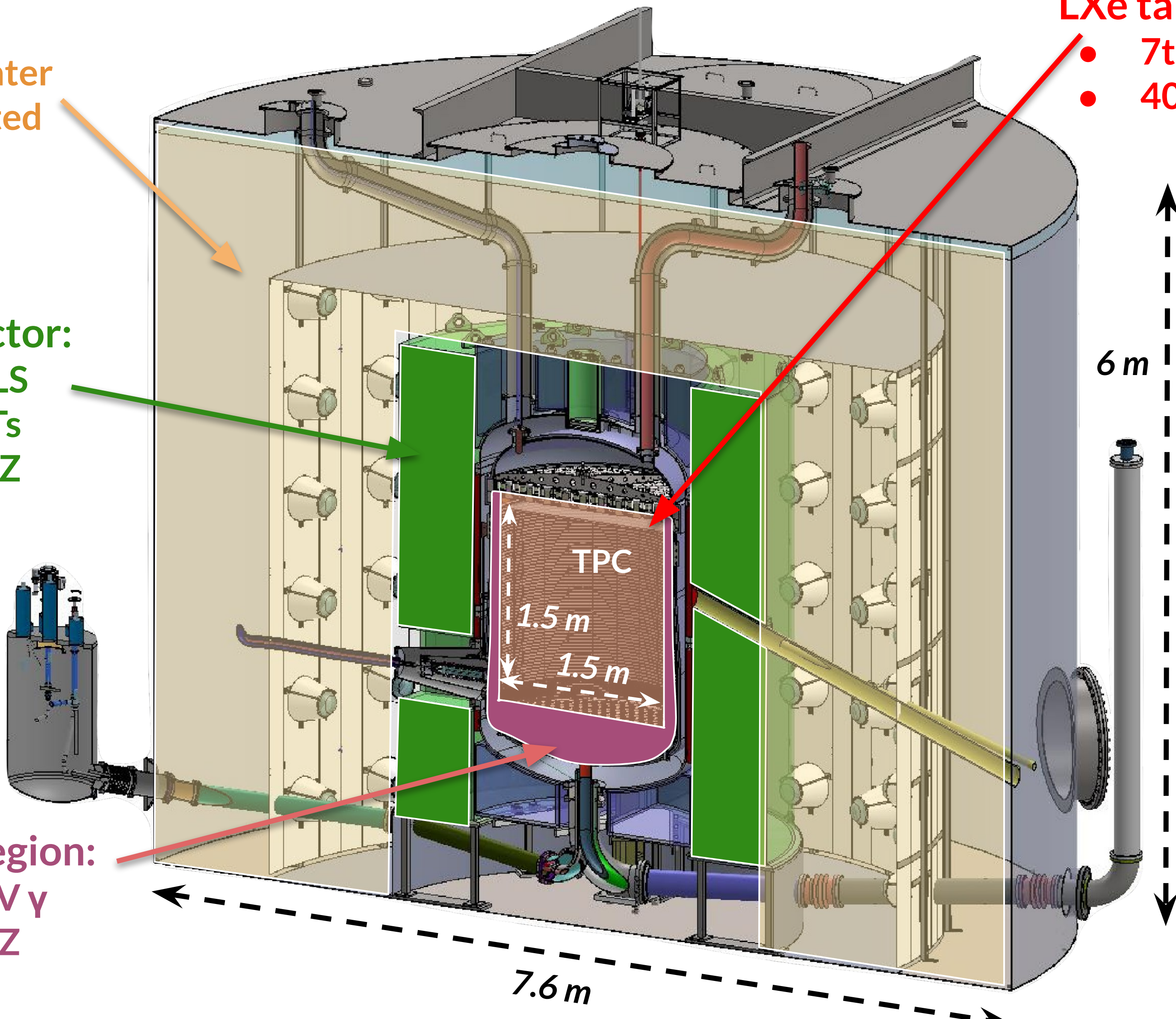
LXe "skin" region:
- Veto MeV γ
- New in LZ

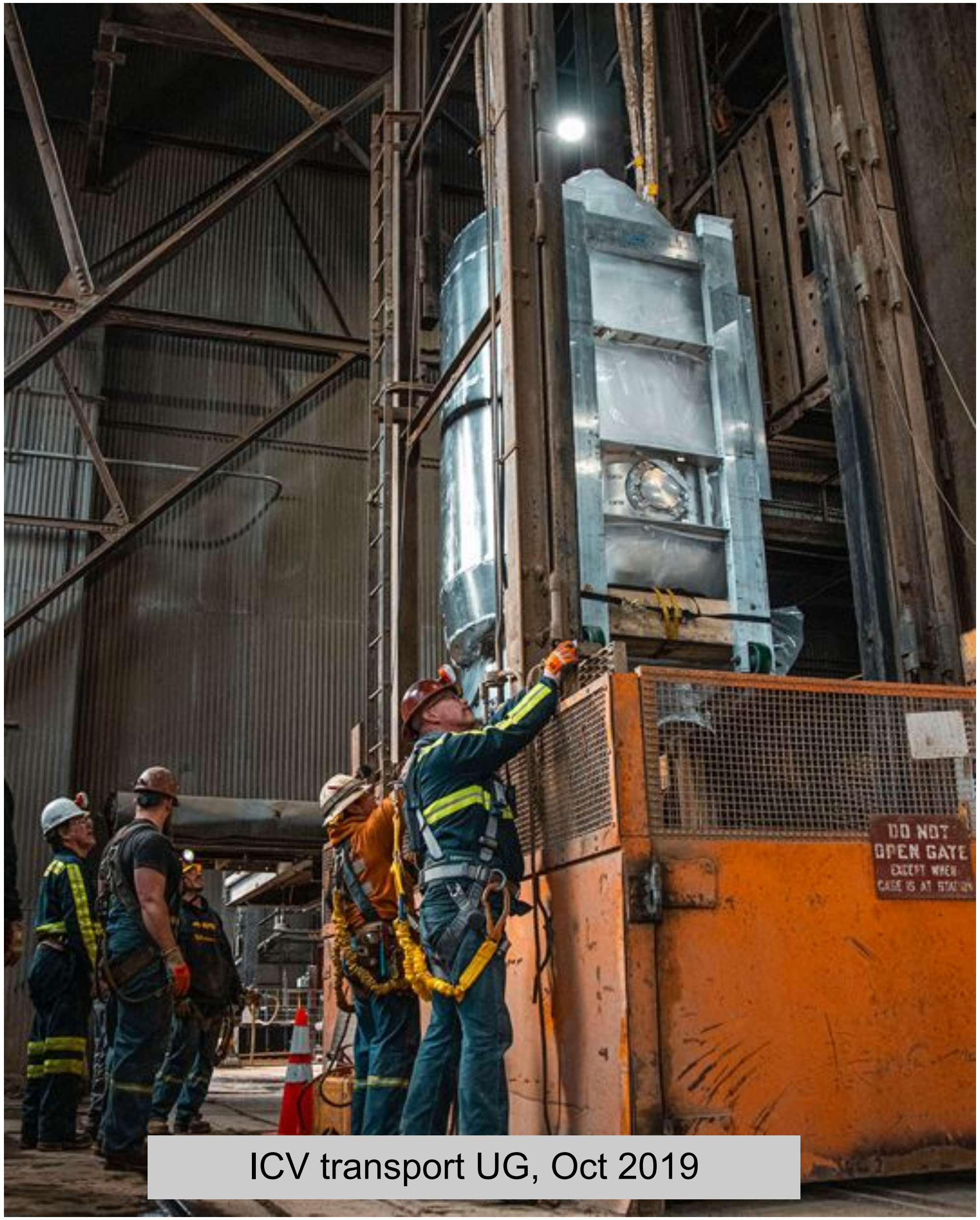
Water shield:
- 230 t DI water
- Instrumented

Outer Detector:
- 17 t Gd-LS
- 120 PMTs
- New in LZ

LXe "skin" region:
- Veto MeV γ
- New in LZ

LXe target:
- 7t LXe TPC
- 40x LUX





ICV transport UG, Oct 2019

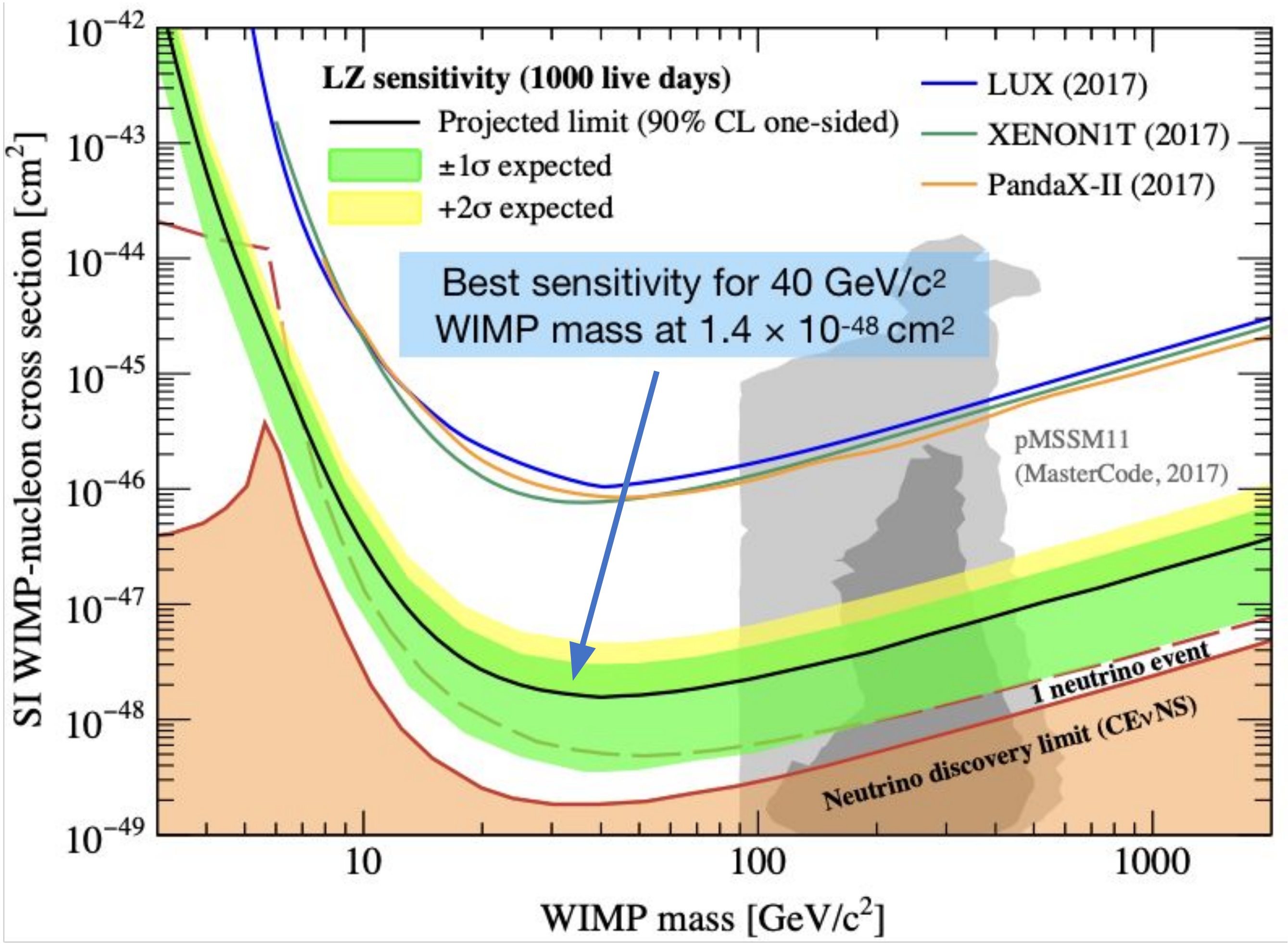
ICV insertion into OCV, Dec 2019

CHV delivery installation & Cryostat sealed, March 2020

OD installed, Summer 2021

LZ Physics

PRD 101, 052002 (2020)

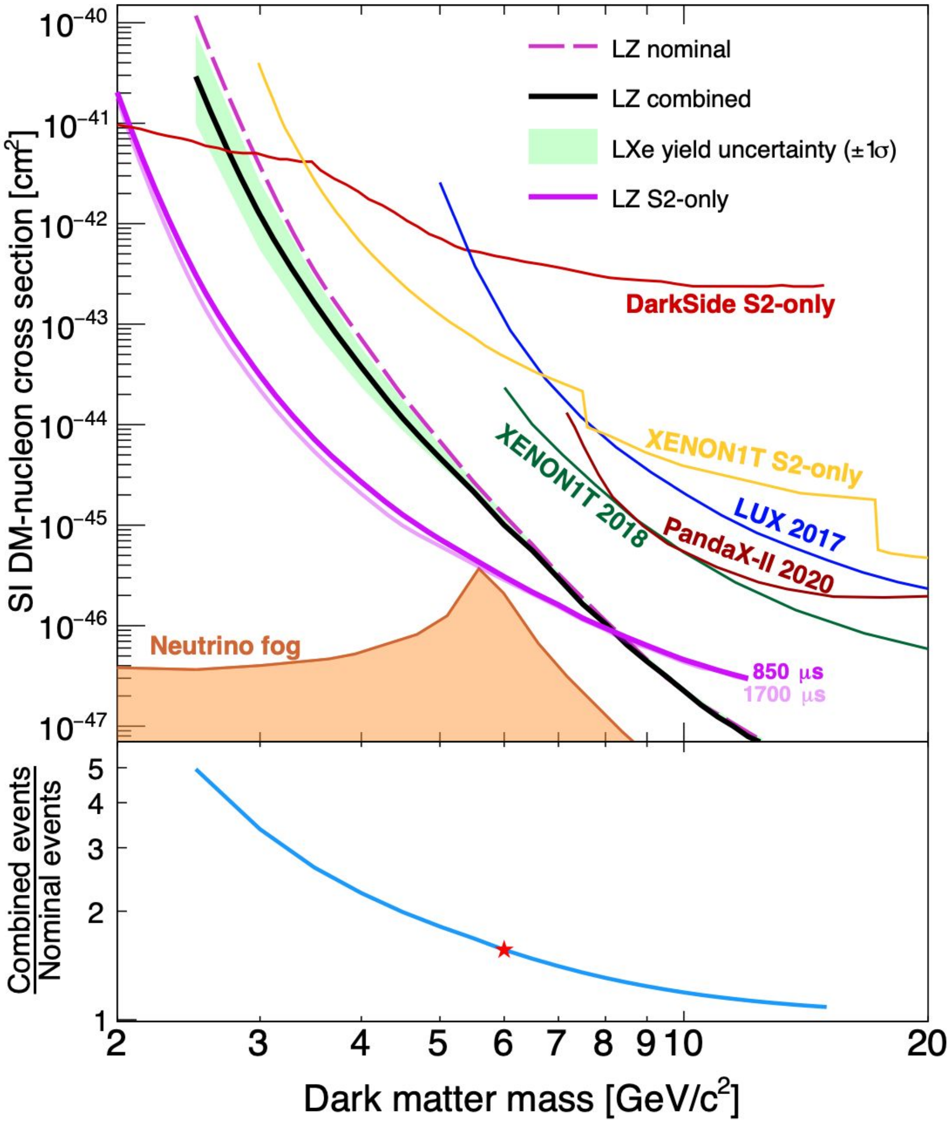


Source	ER [cts]	NR [cts]
Total	1131	1.03
99.5% ER discr., 50% NR eff.	5.66	0.52

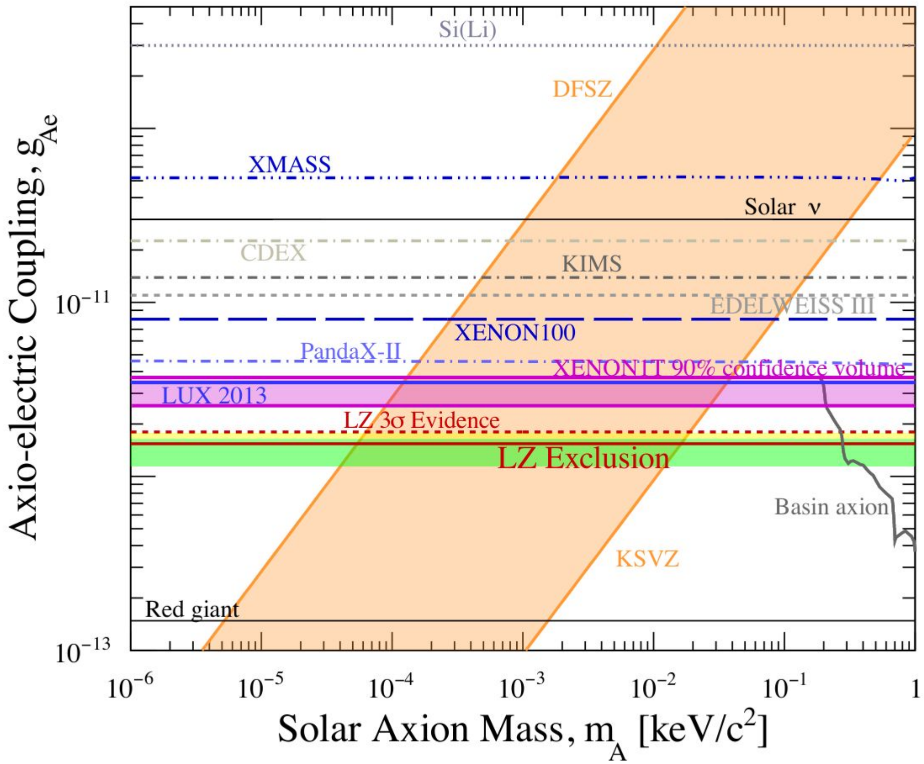
Radon comprises almost half our expected backgrounds

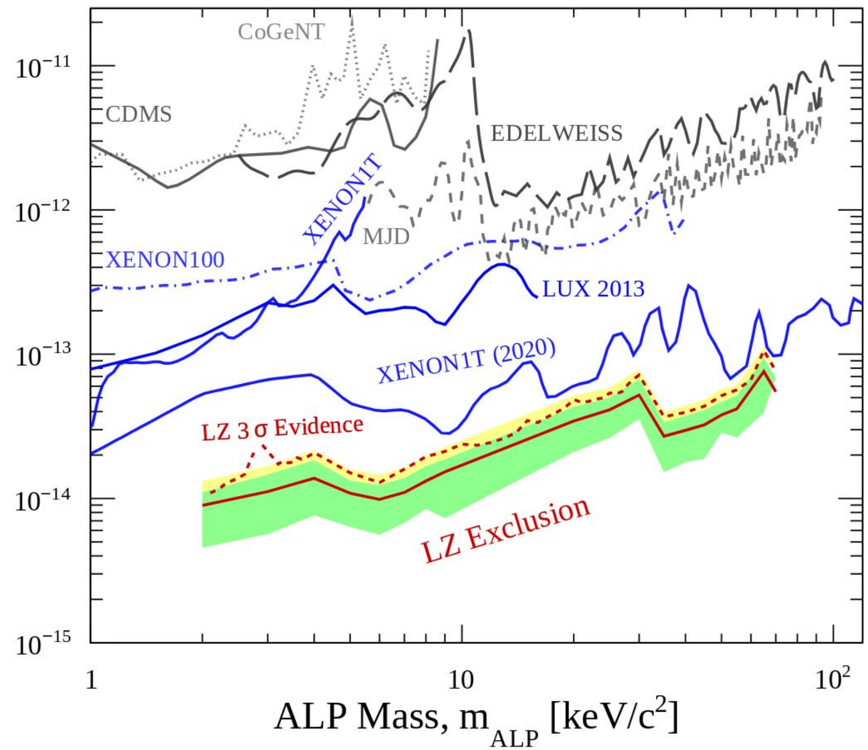
- Non-vetoed single scatters of 1.5-6.5 keV_{ee} (6-30 keV_{nr}) in 5.6 t fiducial volume: 6.18 background counts after 1000 live days arXiv: 2101.08753

- Lower the energy threshold
  - Reduce S1 coincidence requirement from 3 to 2 (exploiting PMT double photoelectric effect)
    - About 4 x improvement at 2.5 GeV/c^2
  - Conduct an S2-only search
    - Greater challenge for background discrimination
    - Employ pulse width
    - Two orders of magnitude improvement
- Sub-GeV masses accessible via Migdal effect



arXiv:2102.11740

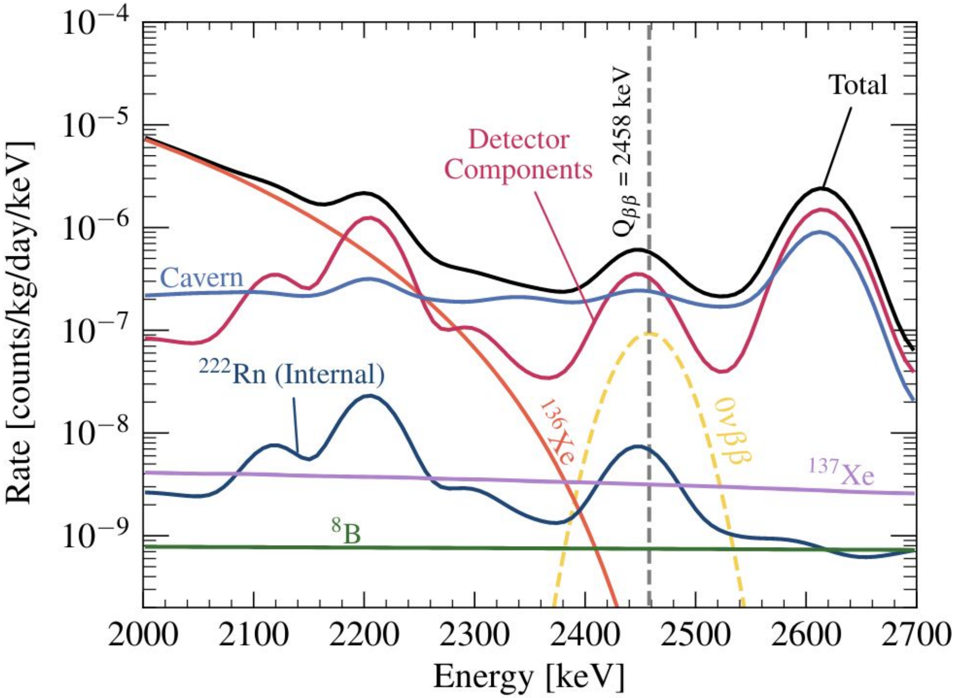


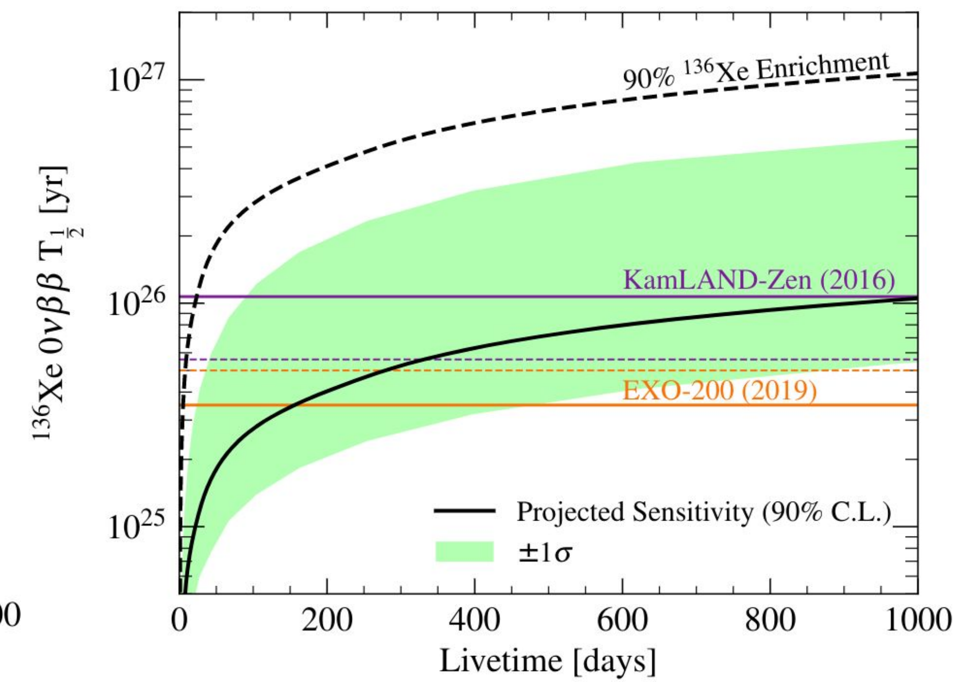


- Explore range of novel model accessible via pure electron recoils
- Backgrounds dominated by ^{222}Rn and ^{124}Xe νvββ
- Studies seven model, amon gothers: Solar axions, axion-like dark matter, neutrino magnetic moment etc
- In all LZ is able to reach world leading sensitivities

Neutrinoless Double Beta Decay

[Phys. Rev. C 102, 014602 (2020)](https://doi.org/10.1103/PhysRevC.102.014602)





- Neutrioless 0νββ only allowed if Neutrino is its own anti-particle (Majorana)
- 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

- LZ is an **multi-purpose observatory** capable of exploring a plethora of rare-event phenomena
- **World-leading sensitivities** due to ultra-low bkgd, bkd discrimination, large target mass and an excellent energy resolution.
- Experiment is in its **commissioning phase**

- **Outlook**
  - Good progress in assembly and integration of detector and associated systems
  - Expecting first data later this year
  - Expected WIMP sensitivity of 1.4 x 10-48 cm2 at 40 GeV/c2
  - Also sensitive to a range of non-WIMP physics
  - A new chapter in dark matter physics is just on the horizon!

34 Institutions: 250 scientists, engineers, and technical staff

@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
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Thanks to our sponsors and participating institutions!

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South Dakota Science and Technology Authority

FCT Fundação para a Ciência e a Tecnologia

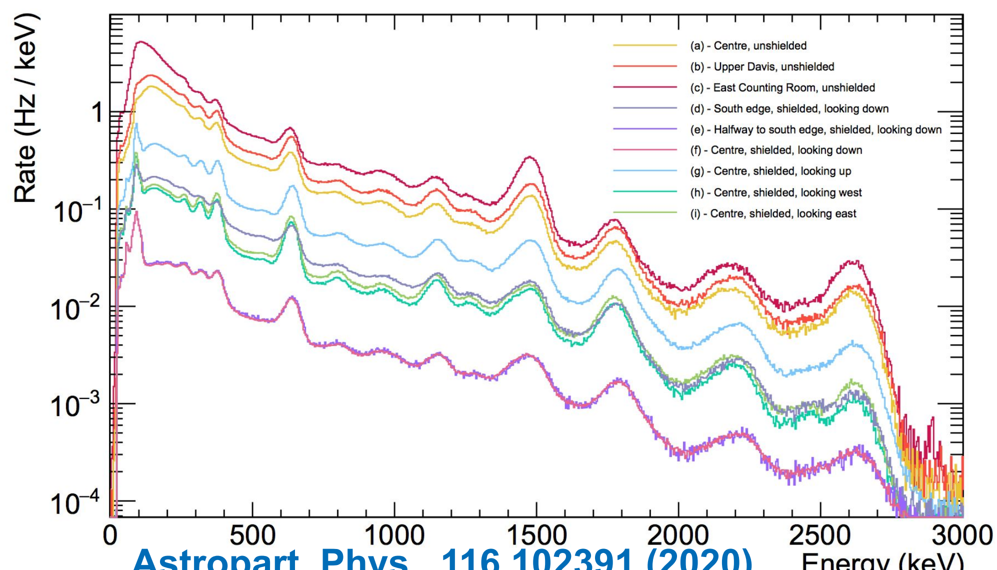
Institute for Basic Science

Backup

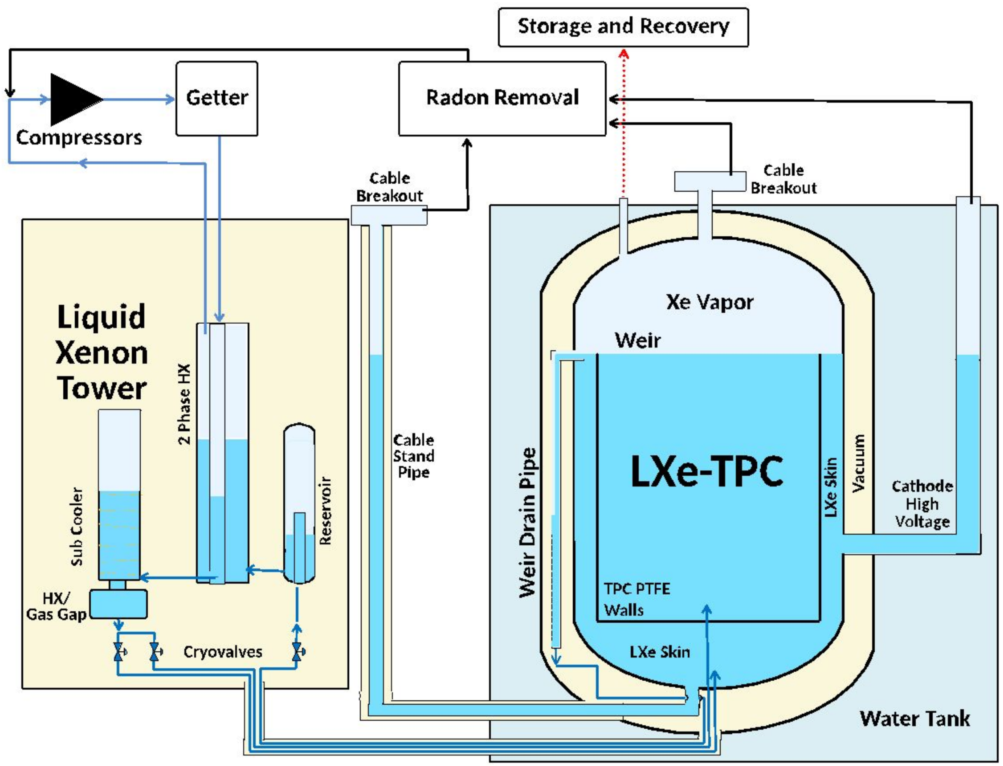
Cavern Backgrounds

Background	***Rate (Hz)***
PMTs	0.9
TPC	0.5
Cryostat	2.5
Outer Detector	13.9
Cavern γ-rays	27
Total	**45**

- Used NaI detector to measure γ-ray flux in different locations in Davis Cavern
- Initial simulations suggested cavern was dominant background in OD, with large uncertainty from γ-ray rate.
- Measurement of ^{40}K, ^{238}U and ^{232}Th concentrations in rock
- Used to normalize γ-flux simulation with previously large uncertainties

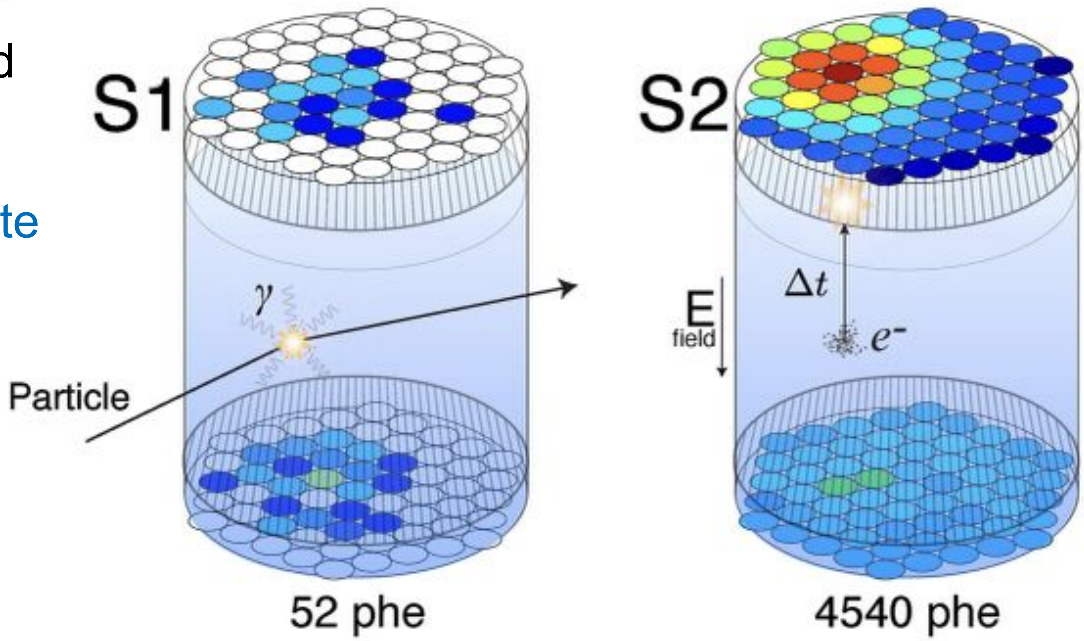


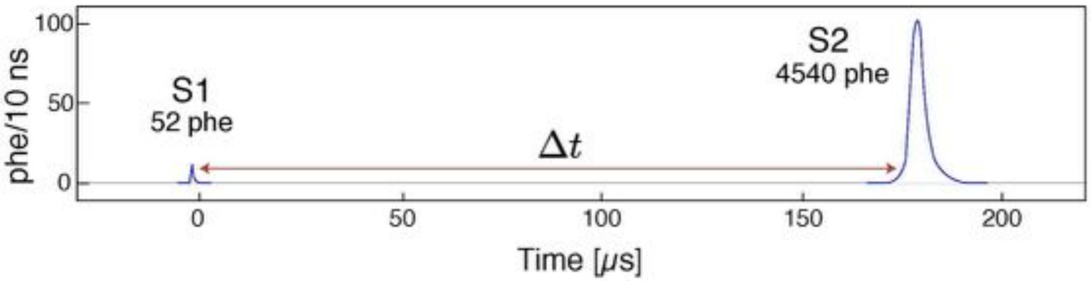
Astropart. Phys., 116,102391 (2020)

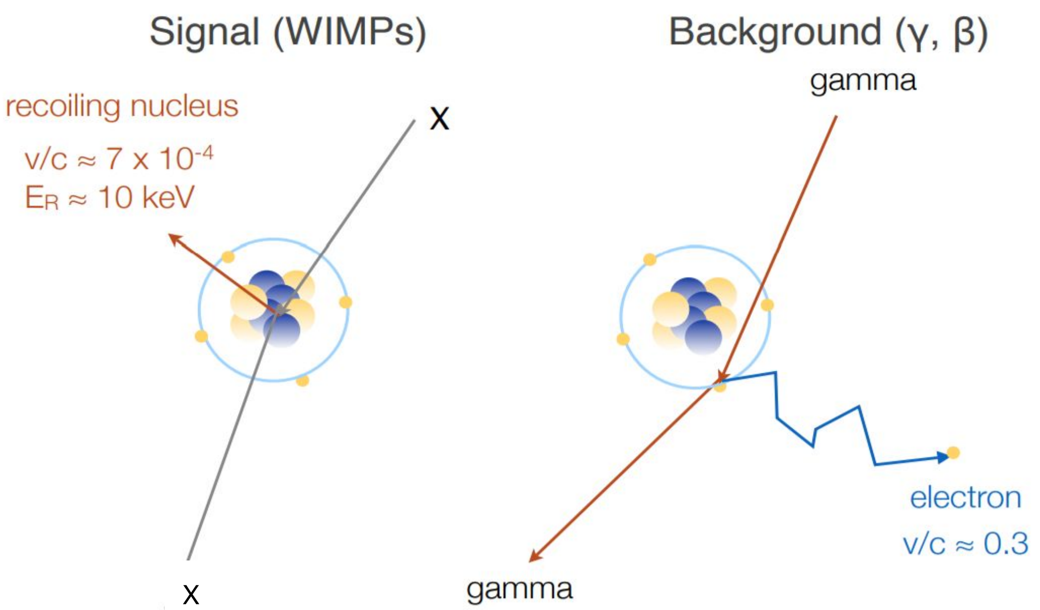


NIM A953 (2020)163047

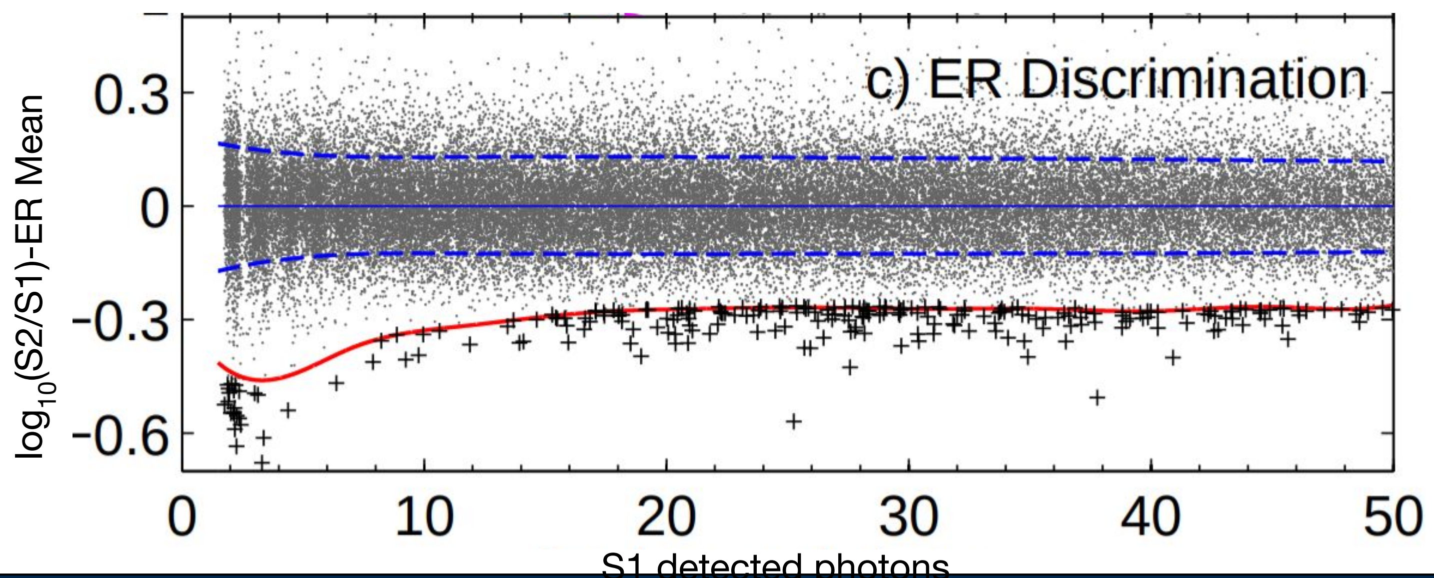
- Dual phase TPC, two signals
  - Prompt scintillation light (S1)
  - Prop. charge signal amplified in gas (S2)
- Signal ratio allows to discriminate particle
  - Electron scatter tend to produce more charge
  - Neutron scatter create more light
- Depth (z) from time difference between S1/S2 and light pattern (x, y)







- Ionization/excitation (charge/light) depends on dE/dx
- Excellent discrimination of signal (WIMPS → NR) and most backgrounds (γ → ER)
- 99.5% separation before statistical methods



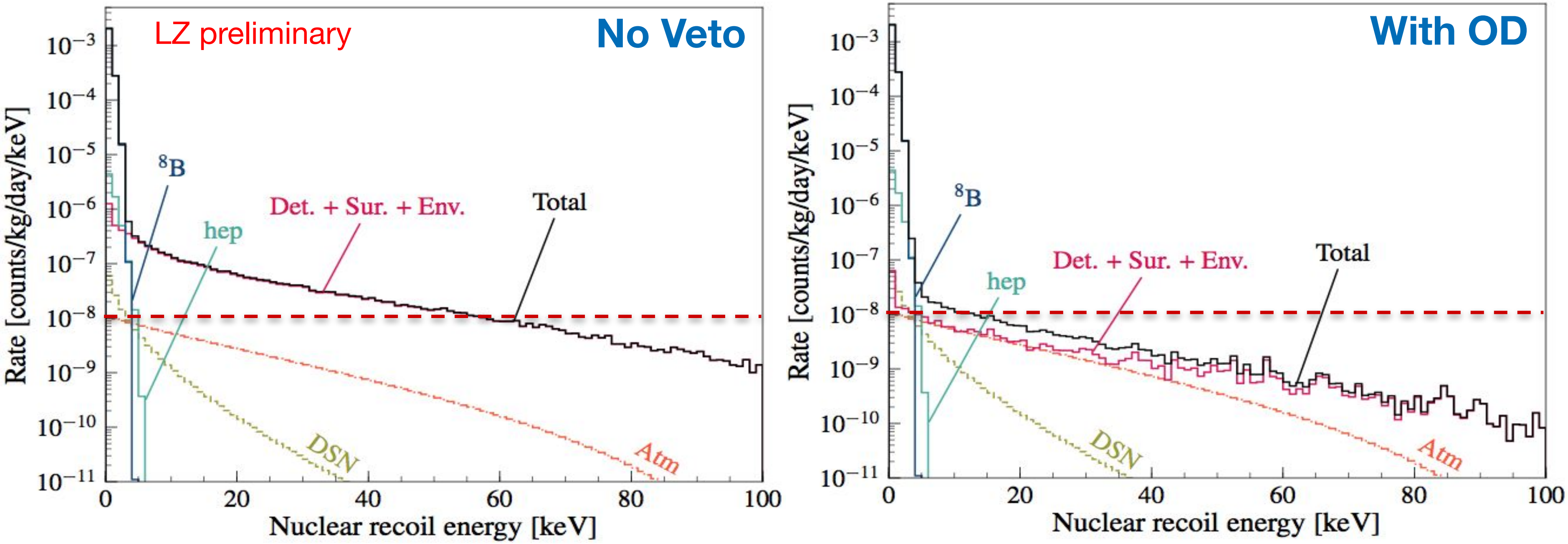
Background Overview

TABLE III. Estimated backgrounds from all significant sources in the LZ 1000 day WIMP search exposure. Counts are for a region of interest relevant to a 40 GeV/c^2 WIMP: approximately 1.5–6.5 keV for ERs and 6–30 keV for NRs; and after application of the single scatter, skin and OD veto, and 5.6 tonne fiducial volume cuts. Mass-weighted average activities are shown for composite materials and the ^{238}U and ^{232}Th chains are split into contributions from early- and late-chain, with the latter defined as those coming from isotopes below and including ^{226}Ra and ^{224}Ra, respectively.

Background Source	**Mass (kg)**	**^{238}U$_e$**	**^{238}U$_l$**	**^{232}Th$_e$**	**^{232}Th$_l$**	**^{60}Co**	**^{40}K**	**n/yr**	**ER (cts)**	**NR (cts)**
		mBq/kg								
Detector Components										
PMT systems	308	31.2	5.20	2.32	2.29	1.46	18.6	248	2.82	0.027
TPC systems	373	3.28	1.01	0.84	0.76	2.58	7.80	79.9	4.33	0.022
Cryostat	2778	2.88	0.63	0.48	0.51	0.31	2.62	323	1.27	0.018
Outer detector (OD)	22950	6.13	4.74	3.78	3.71	0.33	13.8	8061	0.62	0.001
All else	358	3.61	1.25	0.55	0.65	1.31	2.64	39.1	0.11	0.003
								subtotal	**9**	**0.07**
Surface Contamination										
Dust (intrinsic activity, 500 ng/cm^2)									0.2	0.05
Plate-out (PTFE panels, 50 nBq/cm^2)									-	0.05
^{210}Bi mobility (0.1 µBq/kg LXe)									40.0	-
Ion misreconstruction (50 nBq/cm^2)									-	0.16
^{210}Pb (in bulk PTFE, 10 mBq/kg PTFE)									-	0.12
								subtotal	**40**	**0.39**
Xenon contaminants										
^{222}Rn (1.8 µBq/kg)									681	-
^{220}Rn (0.09 µBq/kg)									111	-
^{nat}Kr (0.015 ppt g/g)									24.5	-
^{nat}Ar (0.45 ppb g/g)									2.5	-
								subtotal	**819**	**0**
Laboratory and Cosmogenics										
Laboratory rock walls									4.6	0.00
Muon induced neutrons									-	0.06
Cosmogenic activation									0.2	-
								subtotal	**5**	**0.06**
Physics										
^{136}Xe $2\nu\beta\beta$									67	-
Solar neutrinos: pp+^{7}Be+^{13}N, ^{8}B+hep									191	0*
Diffuse supernova neutrinos (DSN)									-	0.05
Atmospheric neutrinos (Atm)									-	0.46
								subtotal	**258**	**0.51**
Total									1131	1.03
Total (with 99.5% ER discrimination, 50% NR efficiency)									5.66	0.52
Sum of ER and NR in LZ for 1000 days, 5.6 tonne FV, with all analysis cuts									**6.18**	

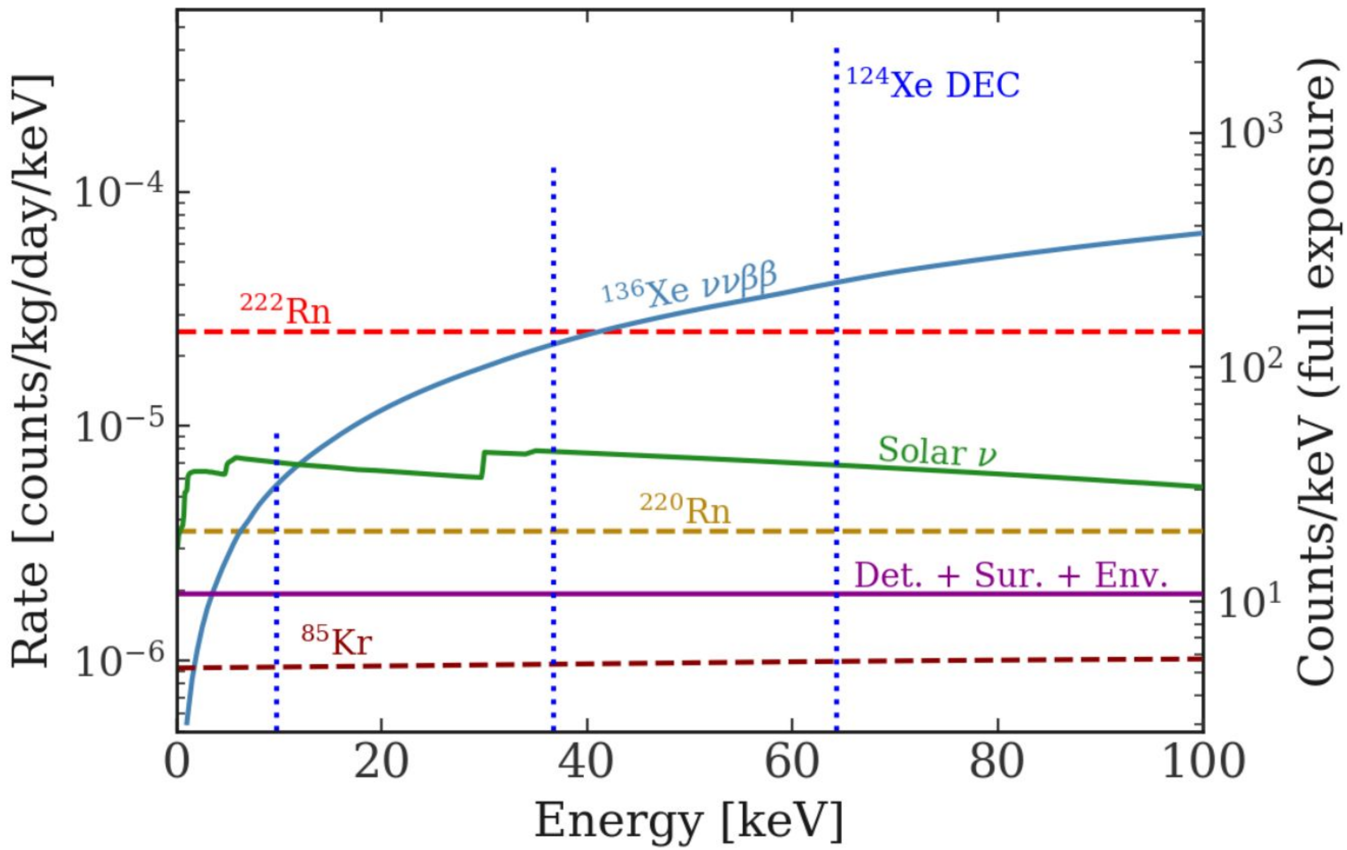
* Below the 6 keV NR threshold used here.

- 5.6 t fiducial volume, 1000 live-days and selection for 40 GeV WIMP: 1 bkgd event exp
  - NR backgrounds mostly from neutrons coming from (α,n) on PTFE surfaces
  - ER backgrounds mostly from radon daughters



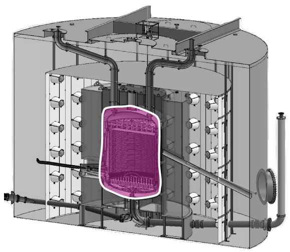
- At 200 keV, 500 μs after S1 scatter the OD will veto 96.5% of all neutrons
- Veto reduces bkgds from 12 counts to 1 count for 1000 live-days
- OD almost doubles the fiducial LXe volume and additional information to constrain the NR background in the PLR

arXiv:2102.11740



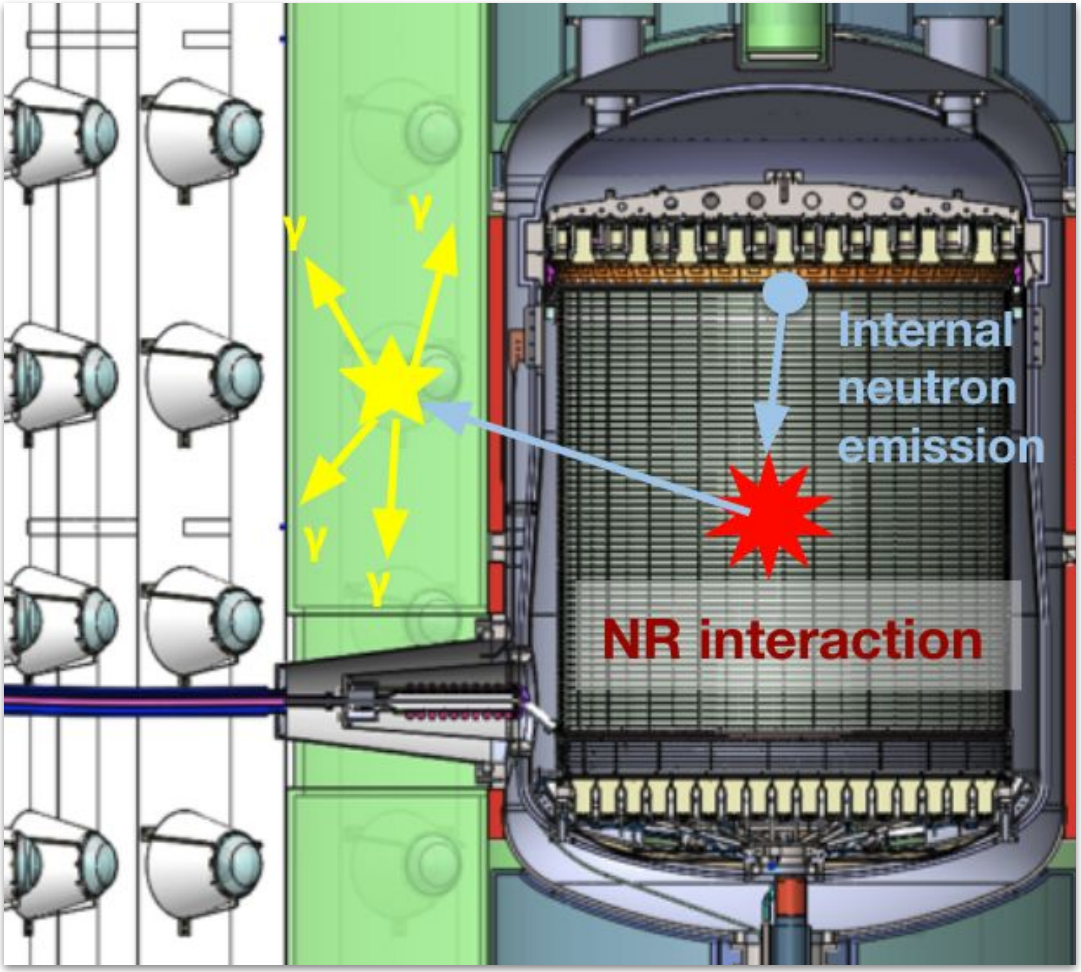
- Backgrounds dominated by ^{222}Rn and ^{124}Xe vvββ

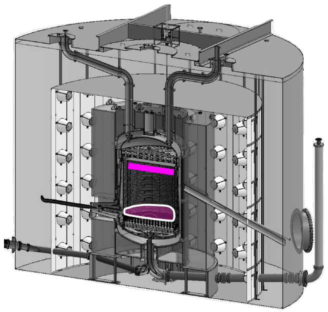
Cryostat



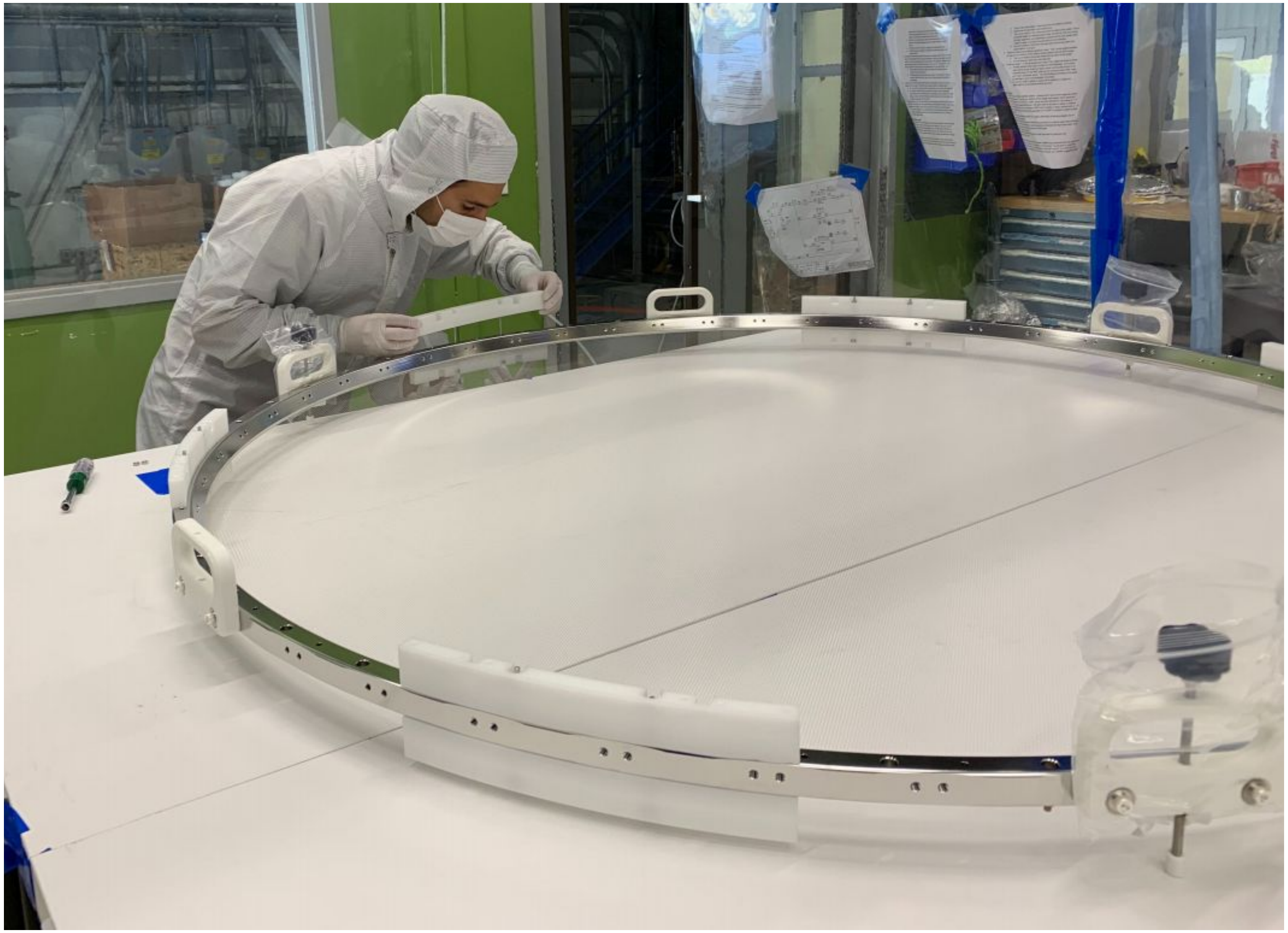
- Two cryostats, inner and outer made from low activity titanium
- Outer cryostat vessel (OCV) underground
- Inner cryostat vessel (ICV), lined with PTFE, holds TPC

- Capture remaining external and internal backgrounds
- Central TPC surrounded with three active veto detectors:
  - Xe 'skin' to veto γ-rays,
  - Outer Detector to veto neutrons in Gd-LS
  - Muons in water
- Increases the usable active (fiducial) volume by 70%
- In case of discovery to be able to demonstrate a possible DM signal is not induced by neutrons

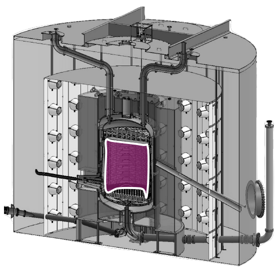




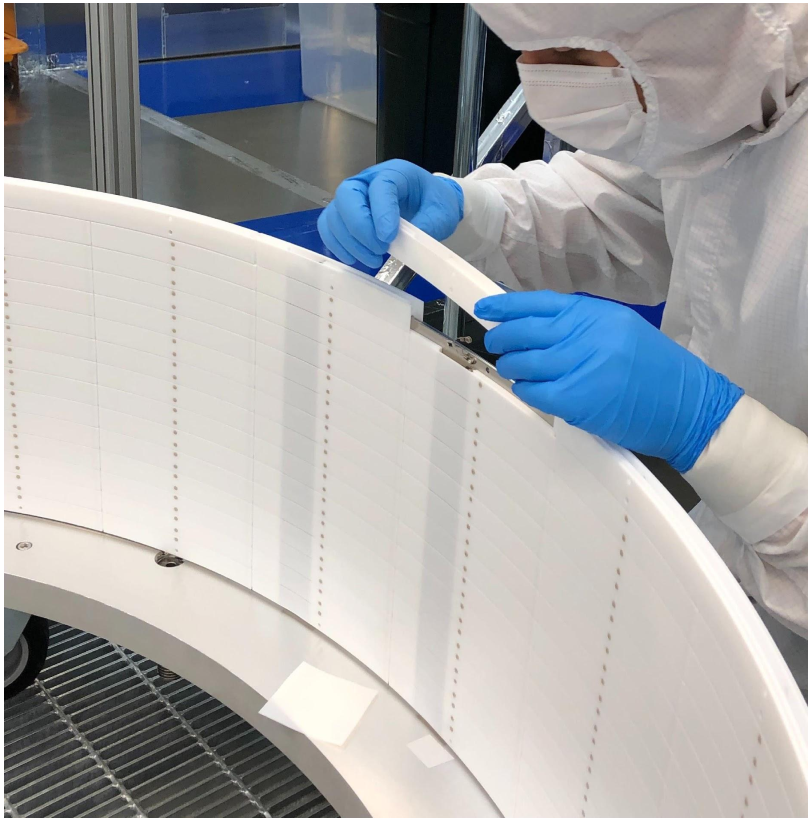
- Multiple HV grids for 3D reconstruction and ER/NR discrimination
  - High mechanical strength
  - 97% optical transparency
  - Background free (photo emission, others)



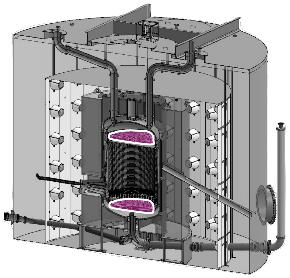
https://www.youtube.com/watch?v=yNycDcMQkss



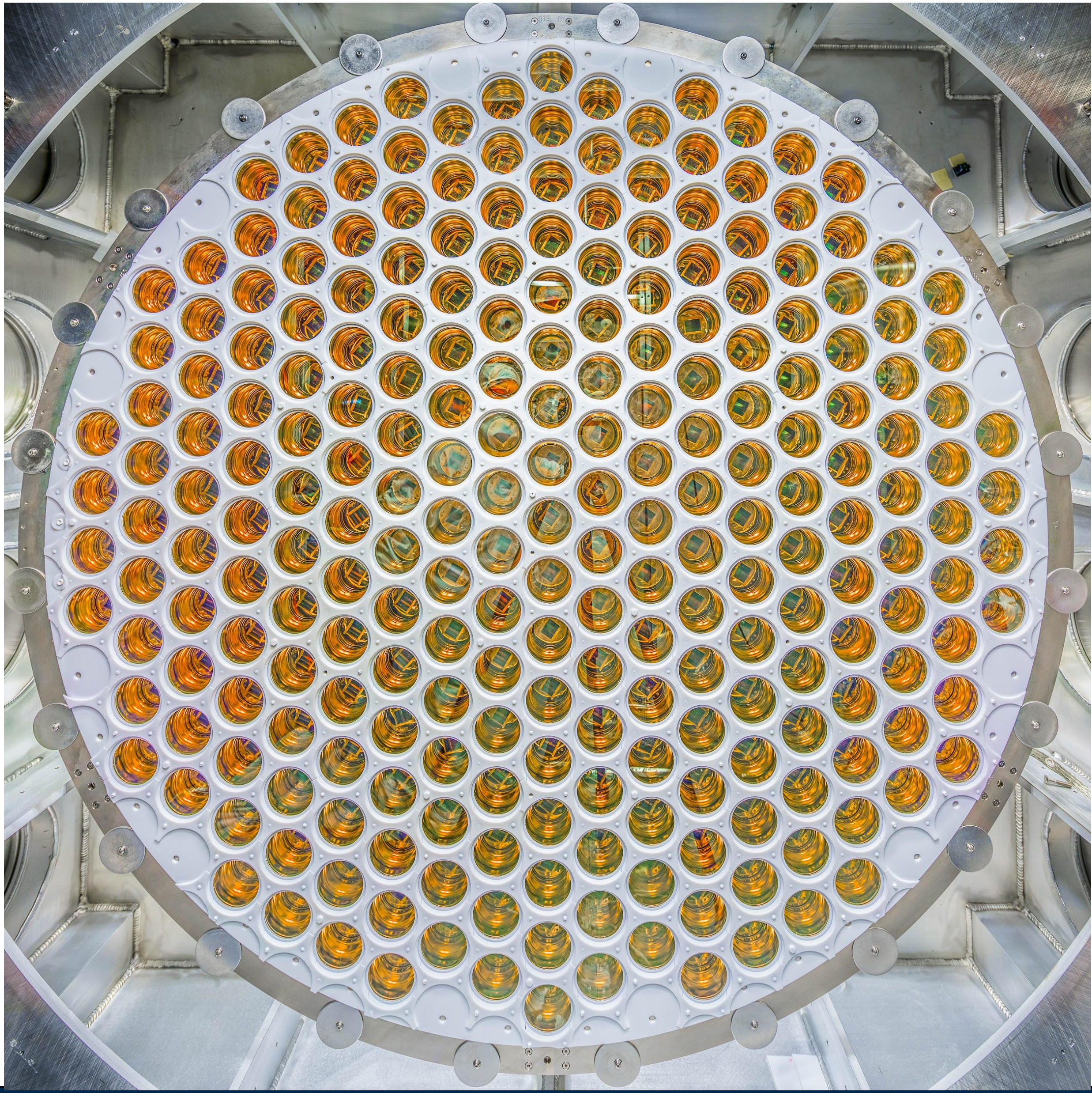
- 57 titanium field shaping rings
- PTFE for reflectivity and stability
- Completed December 2018



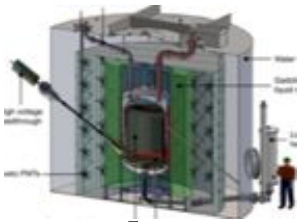
LXe PMTs



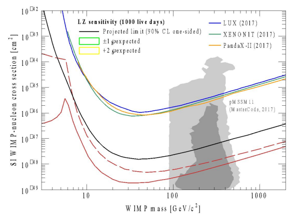
- 625 PMTs:
  - 253 x 3” top array
  - 241 x 3” bottom array
  - 93 x1” and 38 x2” skin



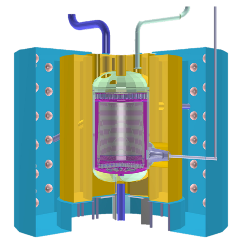
CDR Q4 2015



WIMP Sensitivity Paper Q1 2018



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



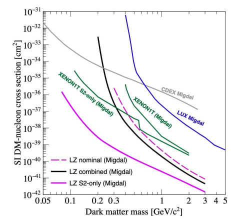
COVID-19 – Experiment in Safe Configuration

Throughout 2021: Commissioning, first science run

2015 2016 2017 2018 2019 2020 2021

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