Direct search for WIMP Dark Matter particles with the LUX-ZEPLIN (LZ) detector

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on behalf of the LZ collaboration

14th Pisa meeting on Advanced Detectors,
May 27 – June 2, 2018

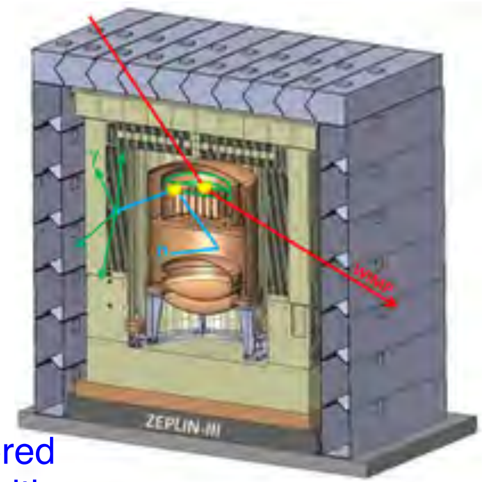
The LZ collaboration

April, 2018

(250 scientists, engineers and technicians; 37 institutions)

LZ = LUX + ZEPLIN

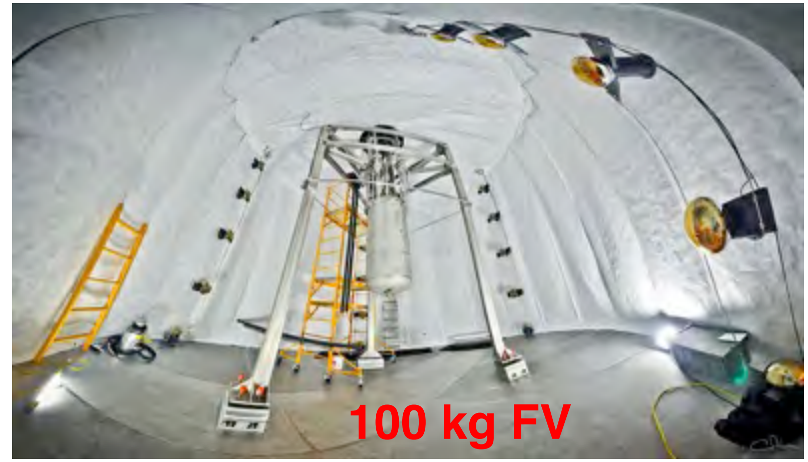
ZEPLIN-III (UK, Boulby)



ZEPLIN pioneered WIMP-search with two-phase Xe
3.9×10^{-44} cm^2

6 kg fiducial volume (FV)

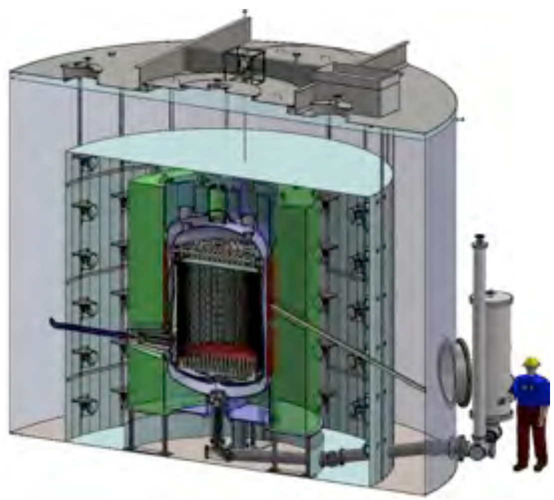
LUX (USA, SURF)



100 kg FV

1.1×10^{-46} cm^2
at 50 GeV/c^2
(decommissioned in early 2017)

LZ
5,600 kg FV

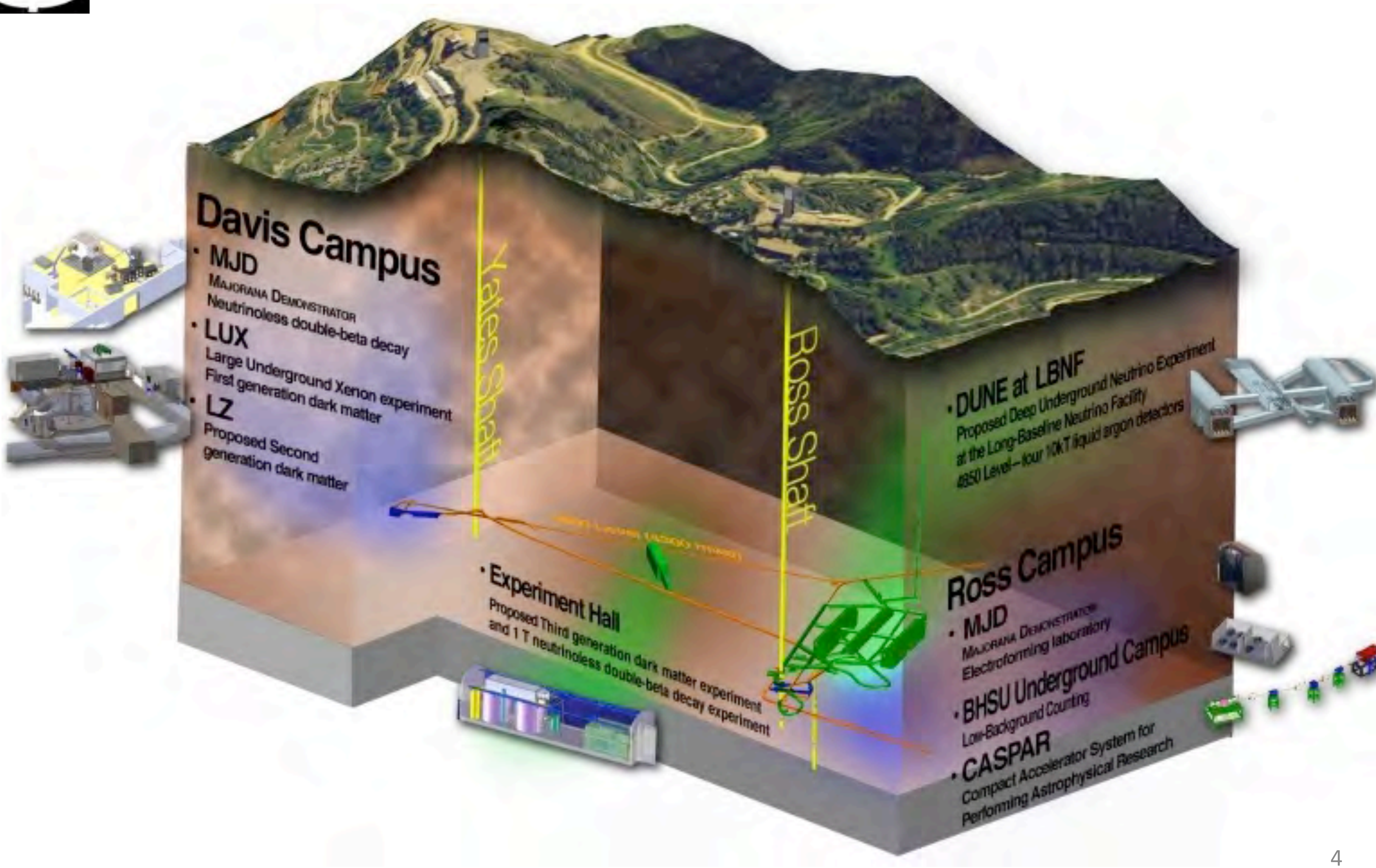


Scale-up using demonstrated technology and experience for low-risk but aggressive program:

- Very low internal background strategy
- Infrastructure inherited from LUX
- **LZ expected sensitivity: 1.6×10^{-48} cm^2 in 1000 days**

D. Akerib et al., "Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment", arXiv:1802.06039v1 [astro-ph.IM]

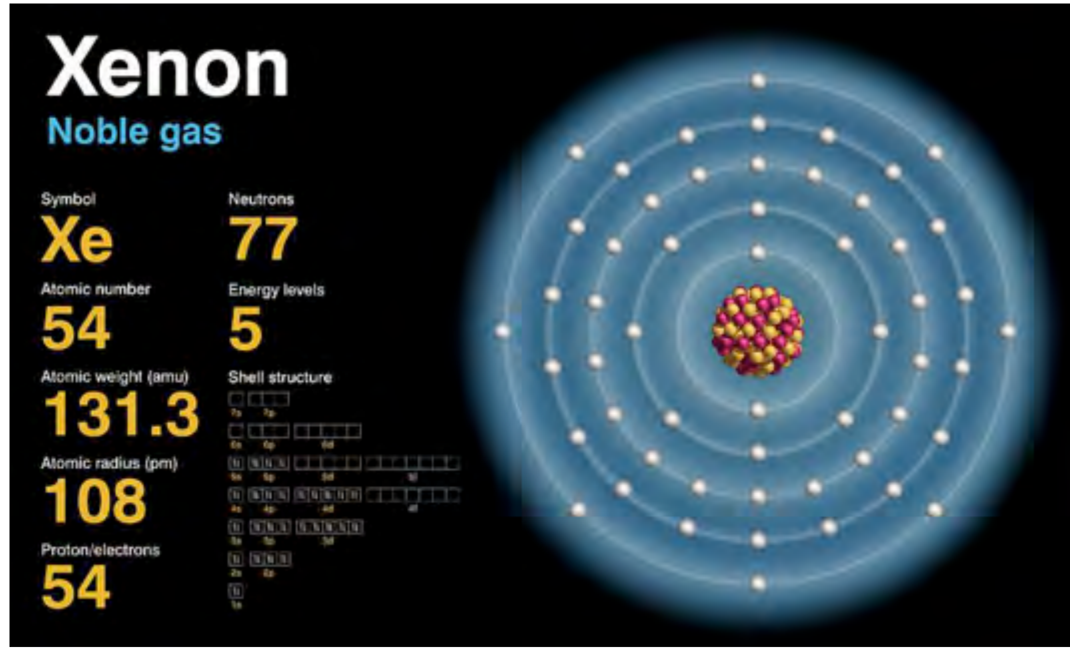
Sanford Underground Research Facility (Lead, South Dakota)



Why LXe is suitable for Dark Matter search

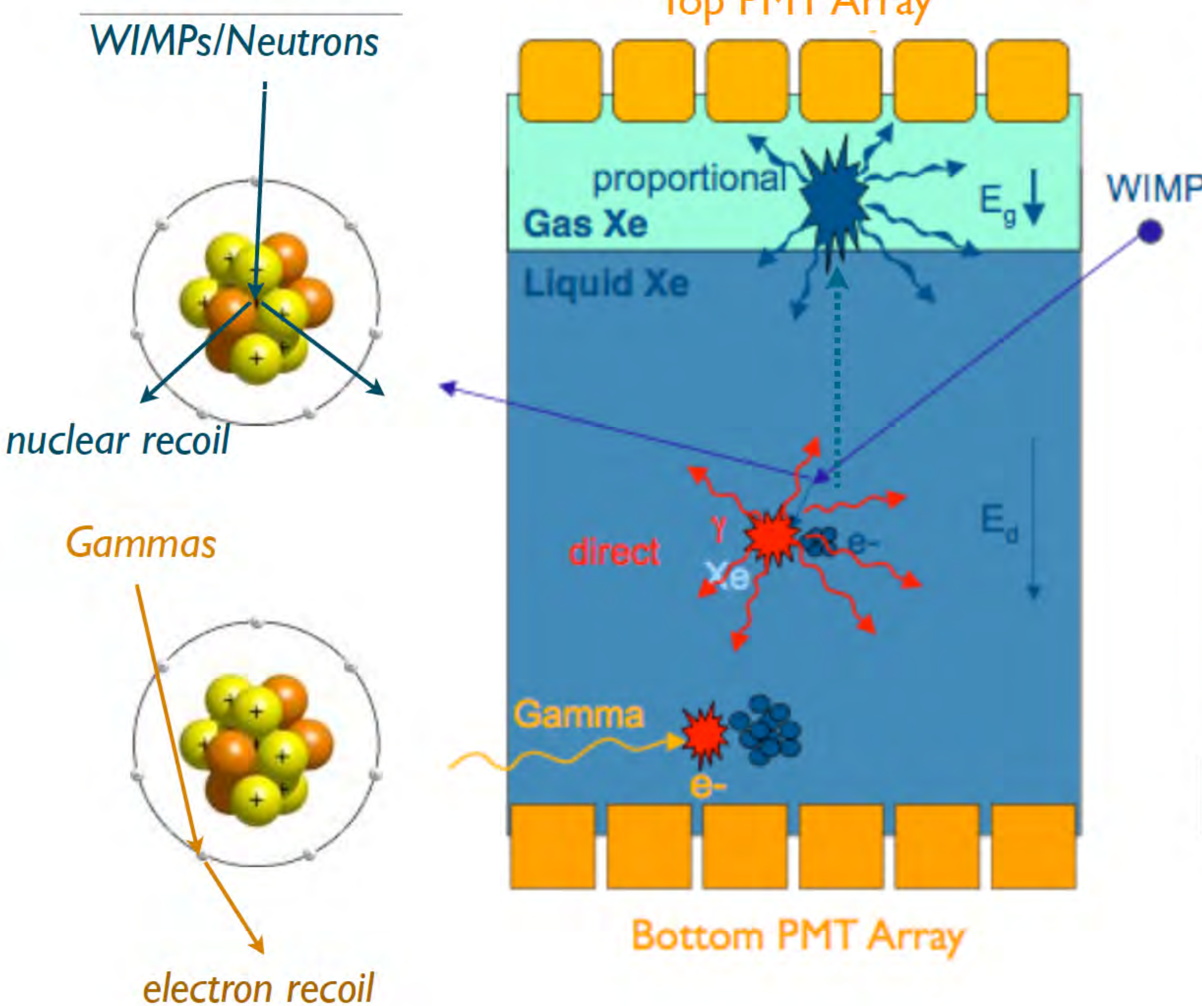
Properties of Xenon

Atomic Number (Z):	54
Mass number (A):	131.30
Number of electrons per energy level:	2, 8, 18, 18, 8
Density STP:	5.894 g/L
Melting point:	161.4 K
Boiling point:	165.1 K
Triple point:	161.405 K

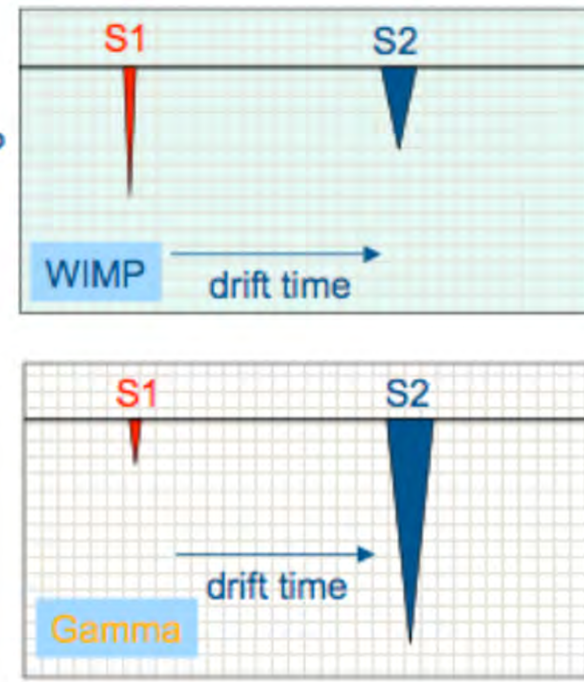


- Dense liquid (3 g/cm^3) for a massive WIMP target at modest cost (~2000 USD/kg) and scale.
- No intrinsic radioactivity other than ^{85}Kr and ^{222}Rn which both can be significantly removed using certain techniques (cryogenic distillation and radon reduction using gas chromatography).
- High sensitivity to spin-independent (SI) WIMP interactions due to its high atomic mass (acts coherently on the entire nucleus and scales as A^2).
- For spin-dependent coupling, the cross-section depends on the nuclear spin factor. Does not scale with nuclear size (^{129}Xe and ^{131}Xe).

Two phase time-projection chamber



S1 – primary scintillation **S2 – electroluminescence**



$(S2/S1)_{WIMP} < (S2/S1)_{gamma}$

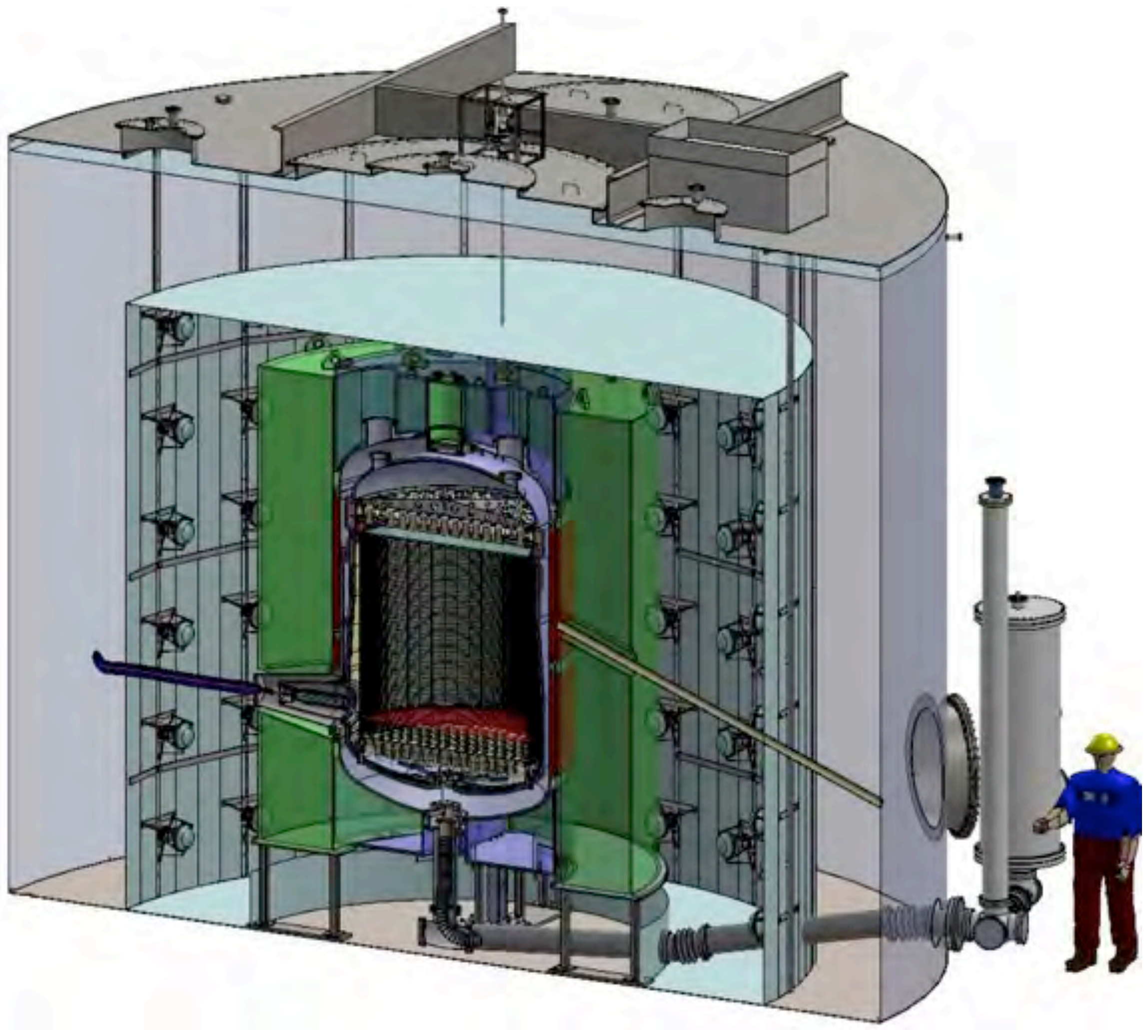
LZ (LUX-ZEPLIN)

- LXe TPC: 50 times larger than LUX
- 1.6 km underground (4300 m.w.e.), SURF, Davis Campus
- **Underground installation will start in fall 2018**
- **Physics data taking will start in 2020**

LZ
Total mass: 10 T
WIMP active mass: 7 T
WIMP fiducial mass: 5.6 T

Engineering model of the LZ detector

- 494 Hamamatsu PMTs, R11410-22, 3” (low radioactive)
- TPC walls are covered with highly VUV light reflective PTFE
- Nominal cathode operating voltage ≈50 kV, E≈310 V/cm
- ~2 T of LXe in the skin veto region (93 Hamamatsu, R8520 PMTs and further 38 Hamamatsu R8778 PMTs)
- The second veto system contains liquid scintillator – Gadolinium (17.3 T) to tag neutrons.
- 120 Hamamatsu R5912 PMTs mounted in water tank



Radioactive background strategy

◆ **Xenon purification from ^{85}Kr and ^{39}Ar**

- Distillation system at SLAC based on LUX R&D
- Final ^{84}Kr/Xe ~ 0.015 ppt (g/g)

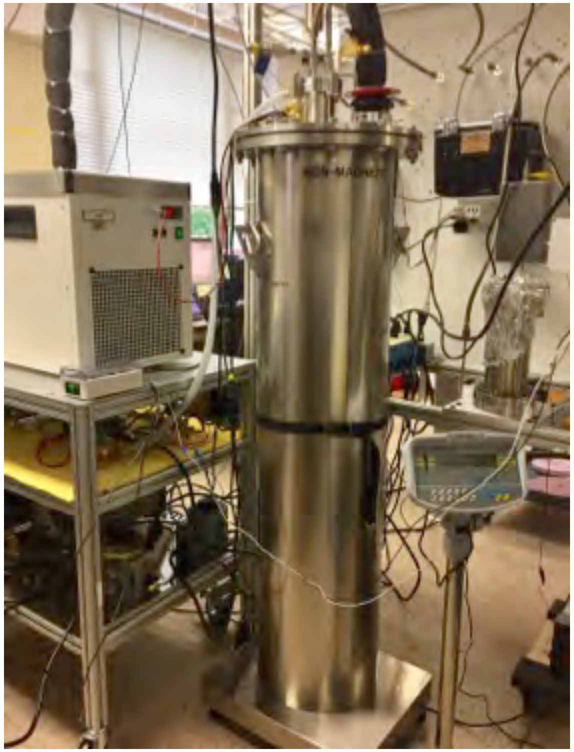
◆ **Extensive radioactive assay of detector materials**

- Gamma screening with inductively coupled plasma mass-spectrometry (ICP-MS), neutron activation analysis (NAA)
- Comprehensive radon emanation measurements

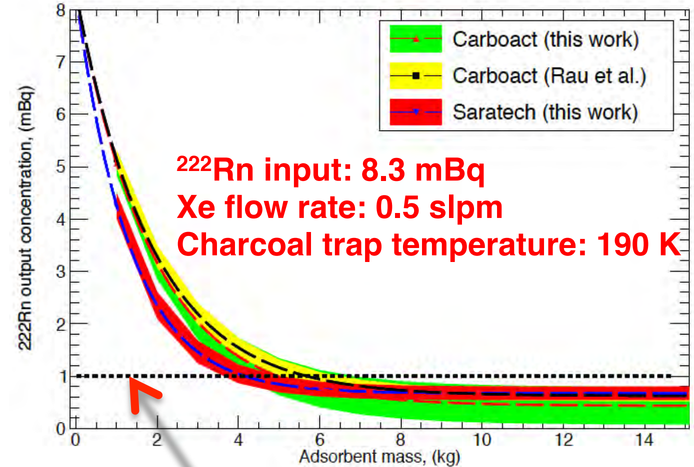
◆ **Strict surface cleanliness protocols**

- Detector assembly in ^{222}Rn reduced clean rooms
- Dust control, < 500 ng/cm^2 on all LXe wetted surfaces
- Rn-daughters plate on TPC walls <0.5 mBq/m^2

^{222}Rn reduction system for LZ
(designed and constructed at the University of Michigan)

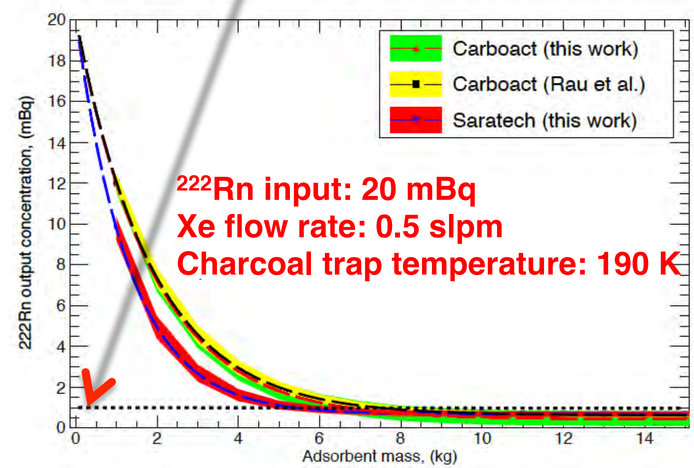


Vacuum-jacketed cryostat with 11 kg of HNO_3 etched Saratech adsorbent



(a)

1 mBq threshold, LZ's goal



(b)

Total ^{222}Rn concentration reduction output from the LZ detector vs mass of adsorbent (Xe flow rate 0.5 SLPM)

^{222}Rn emanation from some charcoals (the list is not complete, read the article)

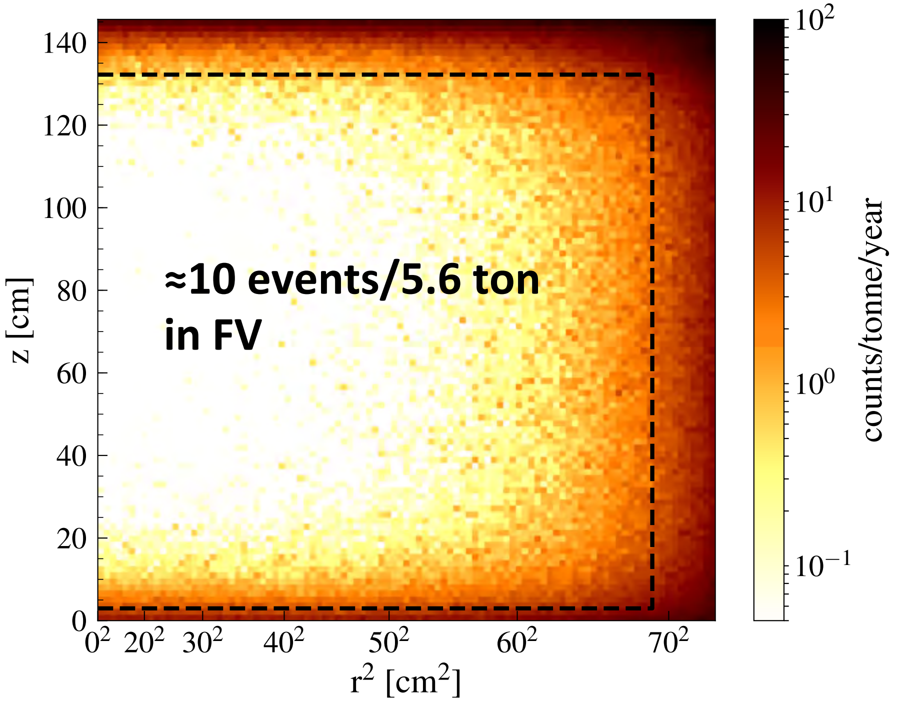
- Carboact: (0.23±0.19) mBq/kg
- Regular Saratech: (1.71±0.20) mBq/kg
- HNO_3 etched Saratech: (0.51±0.09) mBq/kg

K. Pushkin et al., "Study of radon reduction in gases for rare event search experiments", submitted to NIM A and arXiv:1805.11306v1 [physics.ins-det].

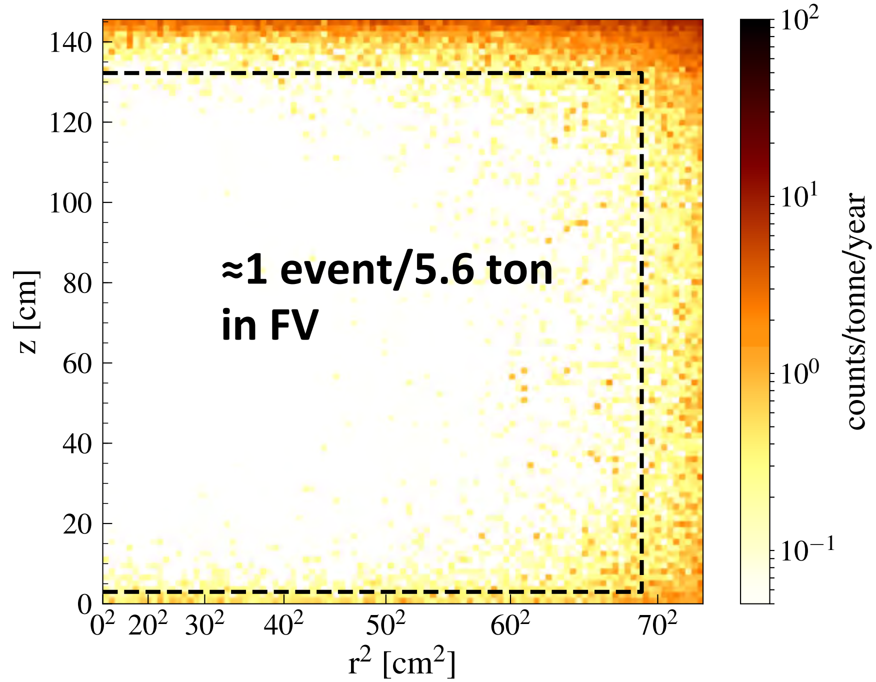
Veto system performance

- WIMP-like nuclear recoil backgrounds in 6-30 keV region of interest
- Before and after application of outer detector plus skin veto

Before veto



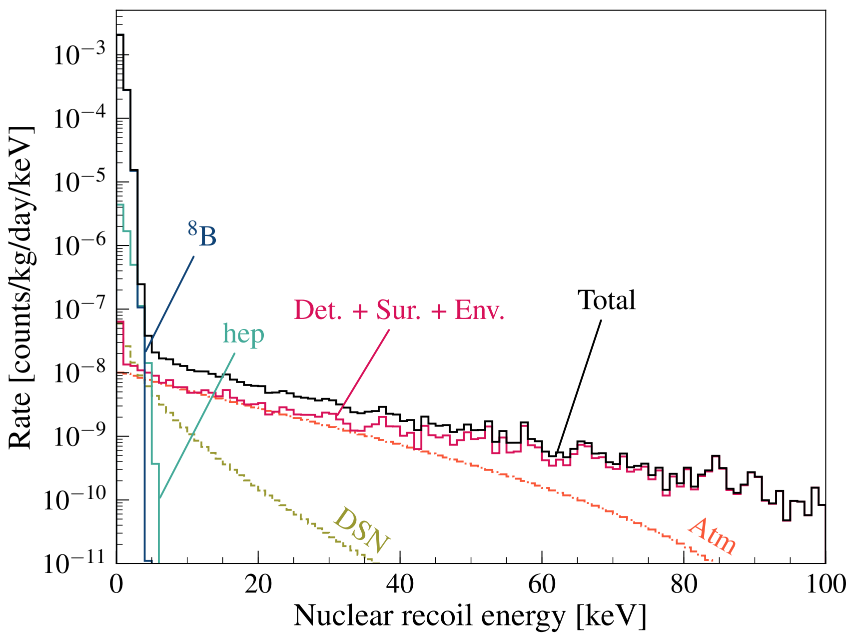
After veto



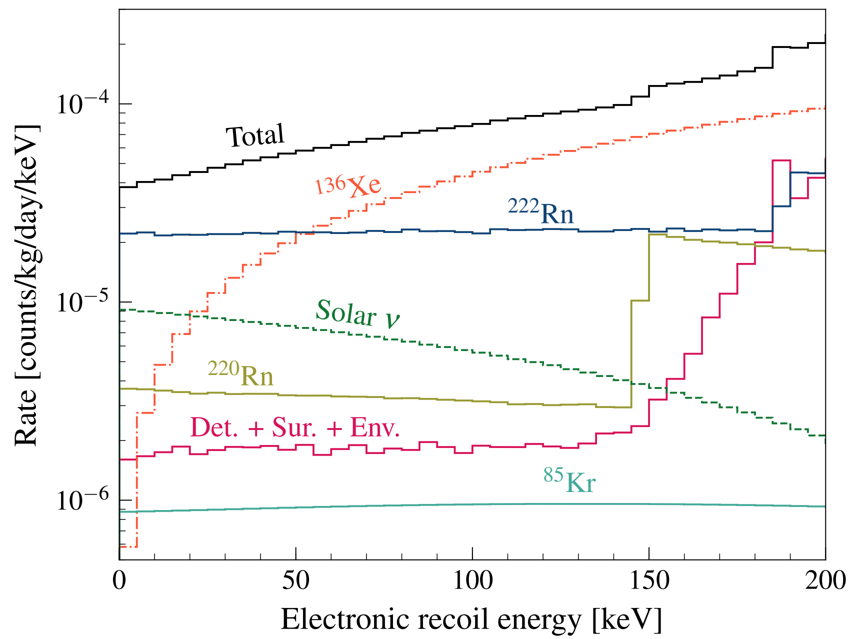
Projected background rates

- Counts/kg/day/keV in 5.6 ton fiducial volume
- Signal scatter events with no veto signal

Nuclear recoils



Electron recoils



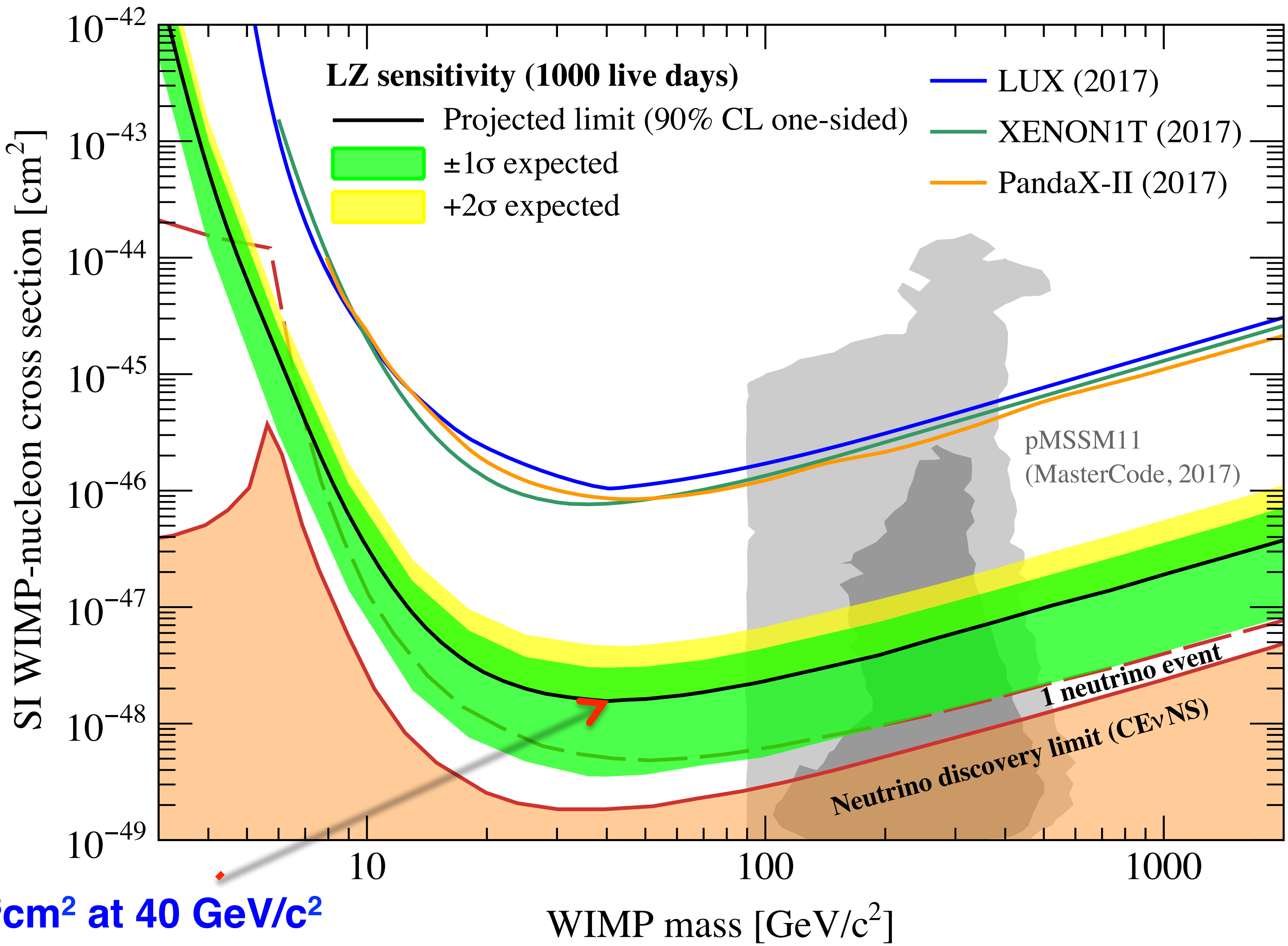
Counts/1000 days: WIMP search region-of-interest (ROI)

LZ 1000 day exposure; Counts for a 40 GeV/c^2 WIMP ROI

Background Source	ERs	NRs
Detector Components	9	0.07
Dispersed Radionuclides — Rn, Kr, Ar	816	—
Laboratory and Cosmogenics	5	0.06
Surface Contamination and Dust	40	0.39
Physics Backgrounds — 2β decay, neutrinos*	322	0.51

Total sum of ER and NR with 99.5% ER discrimination and 50% NR efficiency: 6.49 events

Projected LZ sensitivity, spin-independent, (5.6 ton FV, 1000 live-days)



1.6×10^{-48} cm^2 at 40 GeV/c^2

D. Akerib et al., "Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment", arXiv:1802.06039v1 [astro-ph.IM]

LZ schedule

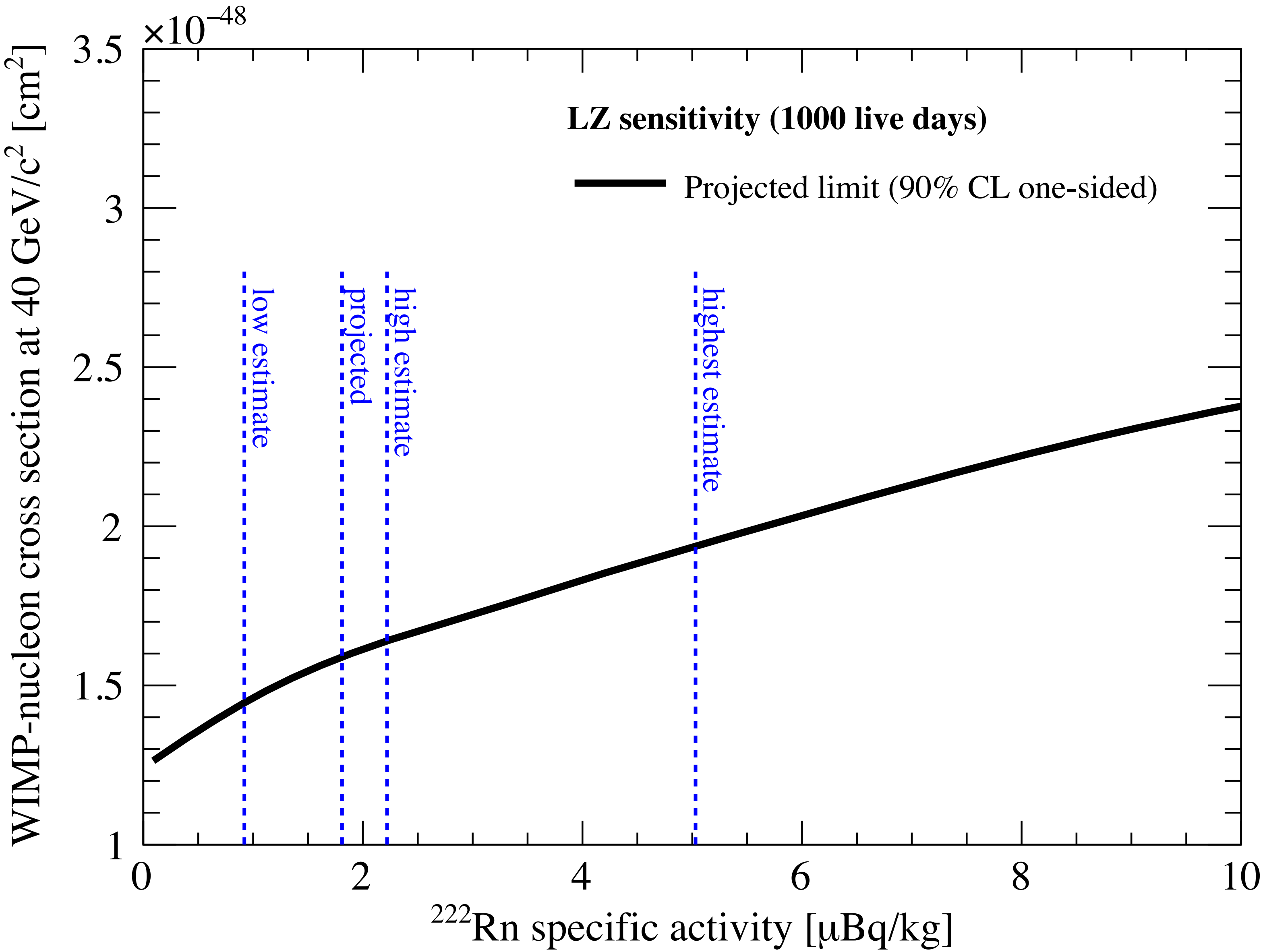
- Critical decision, step 1 – (CD1) Review – March 2015
- CD2 Review – April 2016
- CD3 Review – February 2017 construction can start in earnest
- Cryostat fabrication has recently been completed
- PMT array assembly began in March of 2018
- Xenon handling installation and commissioning starts this fall
- TPC installation will start in Spring-Summer of 2019
- Xe liquefaction will start in winter of 2019
- First physics data are expected in Spring of 2020

Summary

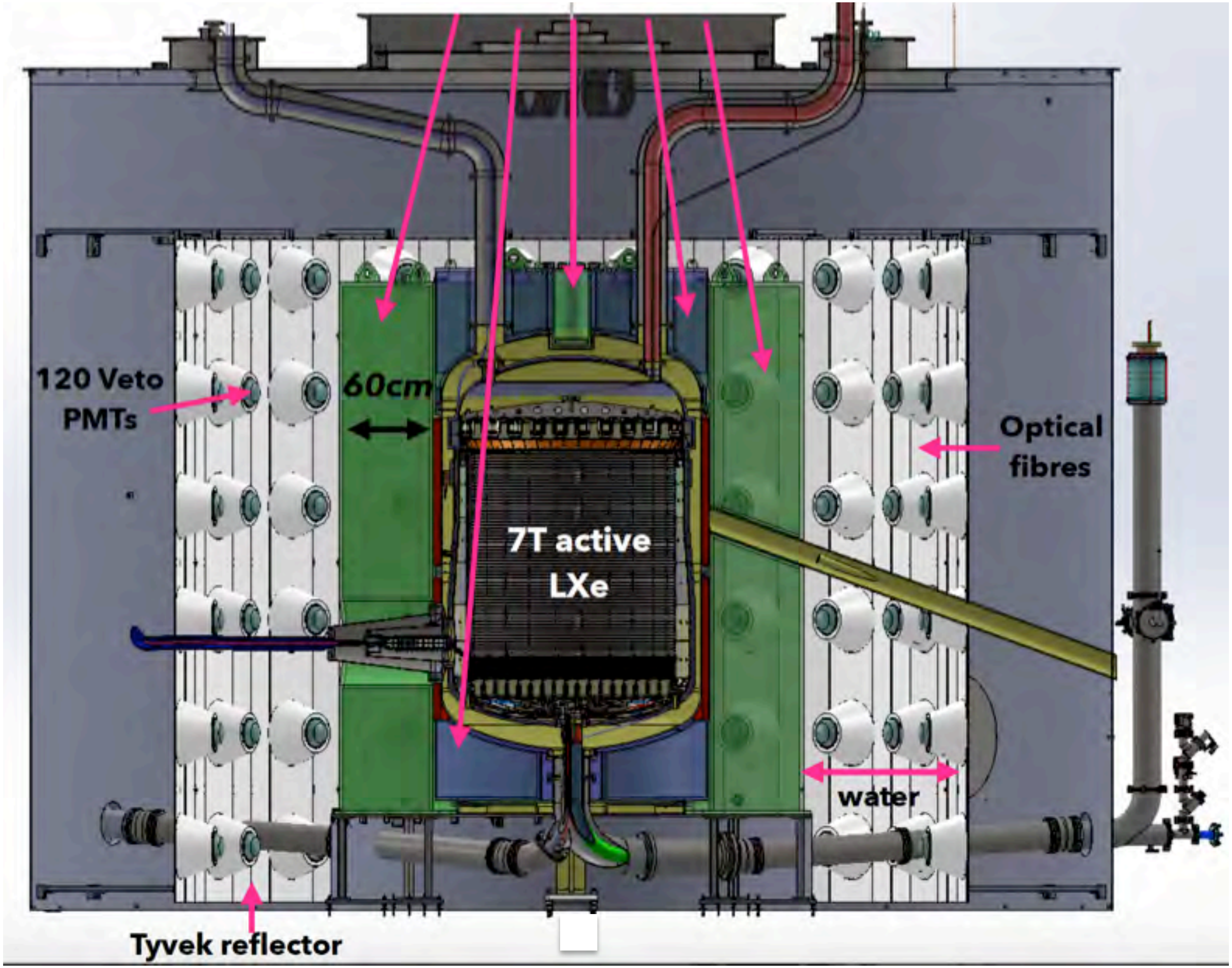
- The LZ detector will be the largest dual-phase Xe detector in the world with an active mass of 7 tons optimized for a potential discovery of WIMPs.
- The detector's components are carefully selected and meticulously assayed for the presence of radioactive background.
- The active veto system will help to suppress NR background.
- The LZ detector will have an order of magnitude sensitivity improvement compared to the currently running LXe experiments.
- The underground installation will begin this fall and data taking will start in 2020.

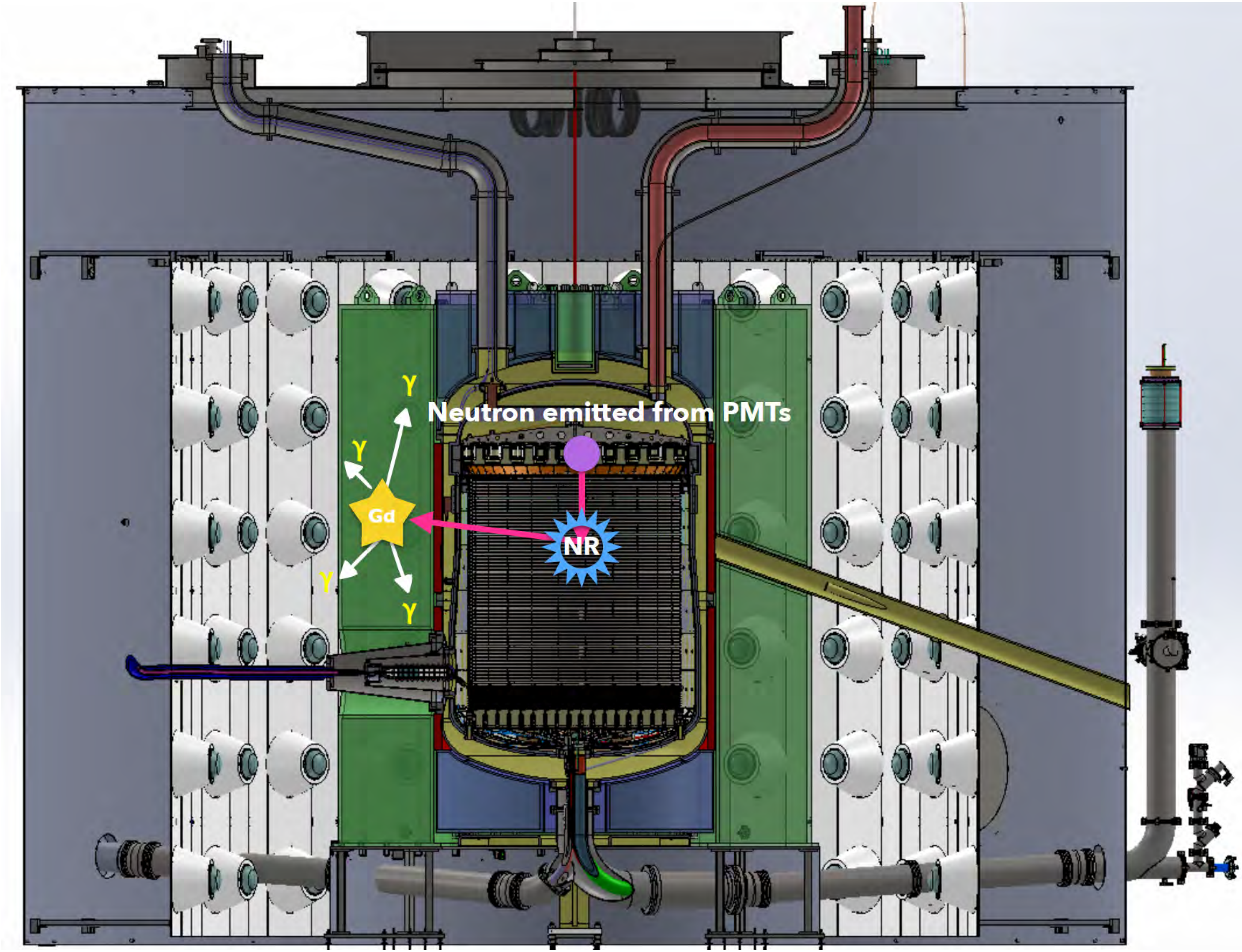
Backups

LZ sensitivity vs ^{222}Rn level



17 T gadolinium loaded liquid scintillator GdLS




Neutron emitted from PMTs
γ
γ
Gd
NR
γ
γ