A XENON DETECTOR
FOR THE LZ EXPERIMENT

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on behalf of the LZ Collaboration

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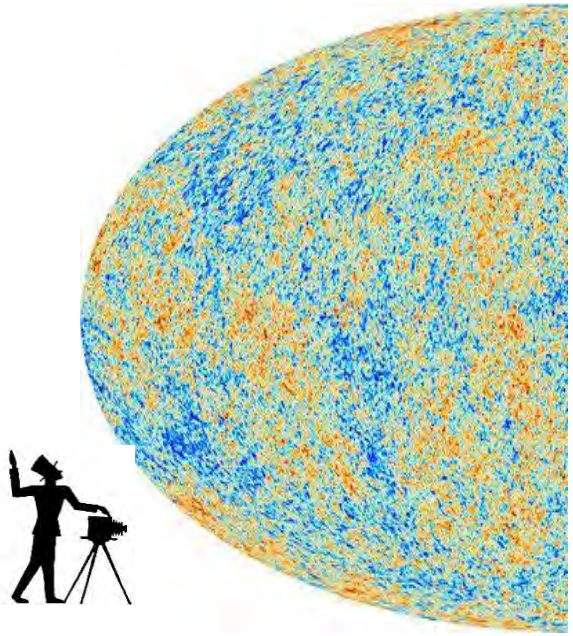
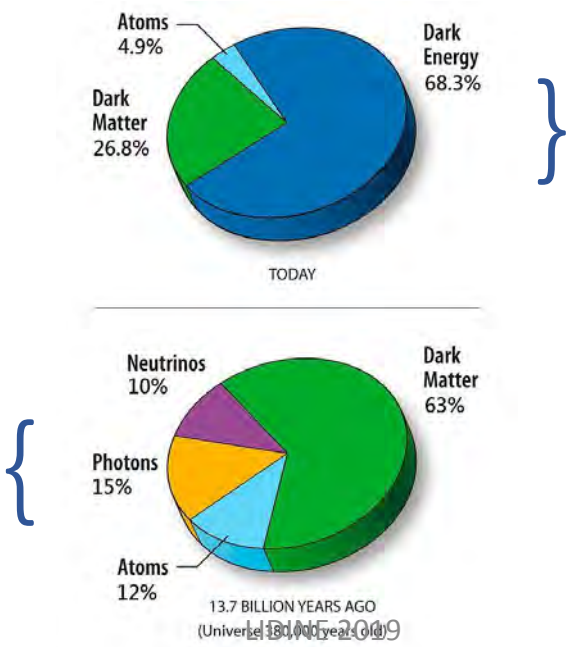
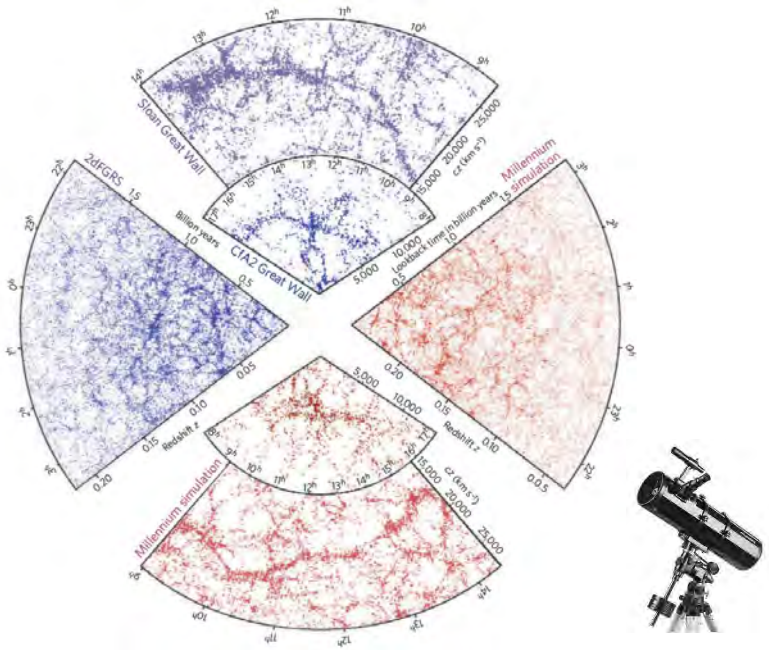
LIDINE-2019
Manchester,
Aug. 28-30, 2019

A DARK UNIVERSE

- Λ-CDM cosmology is a remarkably successful model
  - Initial conditions photographed at the surface of last scatters (CMB radiation)
    - Left to evolve for 13.7 Gyr under two dark ‘fluids’ – DE and DM
      - To produce what we see today – normal matter (almost) doesn’t matter

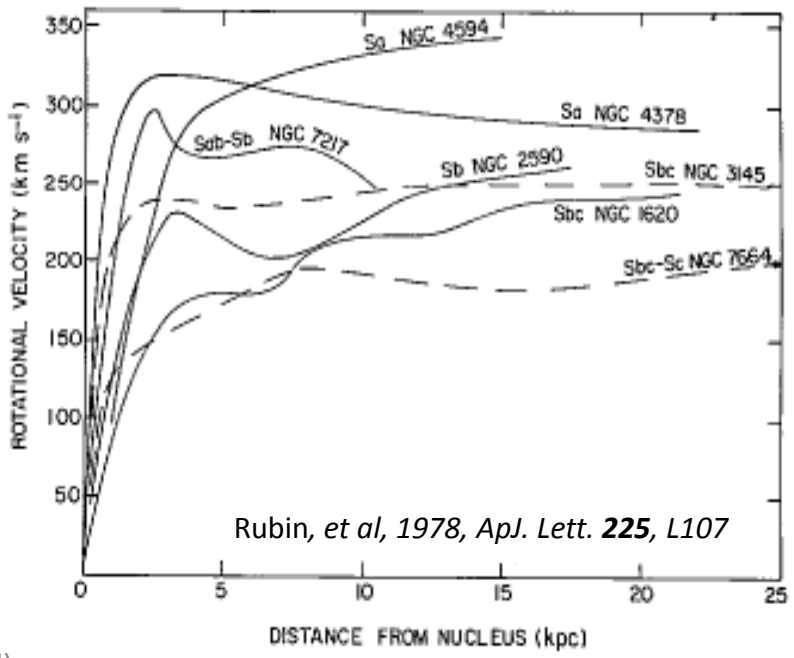




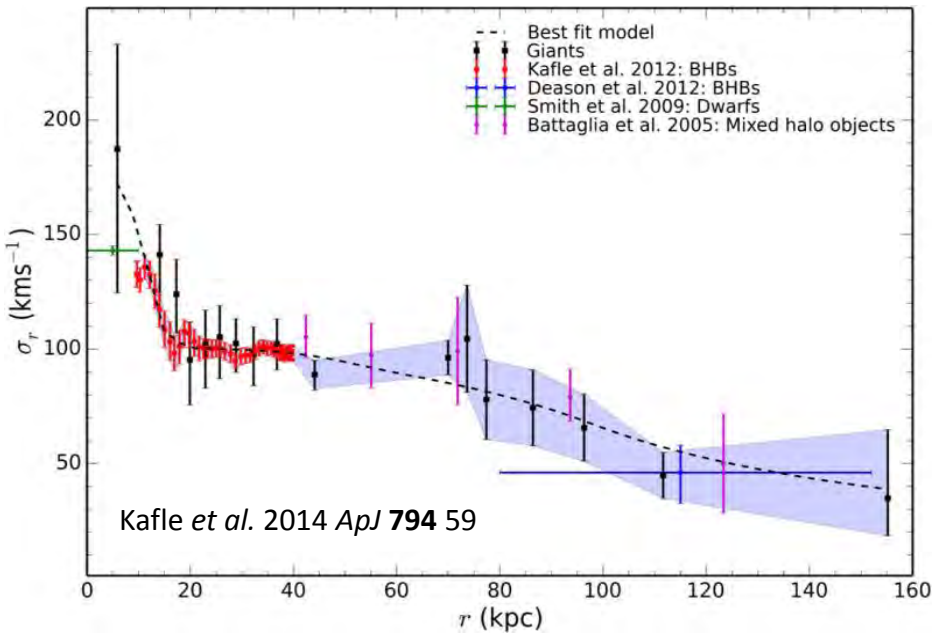


OUR DARK MILKY WAY

- Spiral galaxies ‘spin’ too quickly for their observed ‘luminous’ mass
  - Our Milky Way is no exception: we too are immersed in a DM halo
  - Density near Sun ~0.3 GeV/cm^3, mean particle speed $v \sim$ 300 km/s (0.001c)
  - Direct search experiments probe our galactic DM via elastic scattering

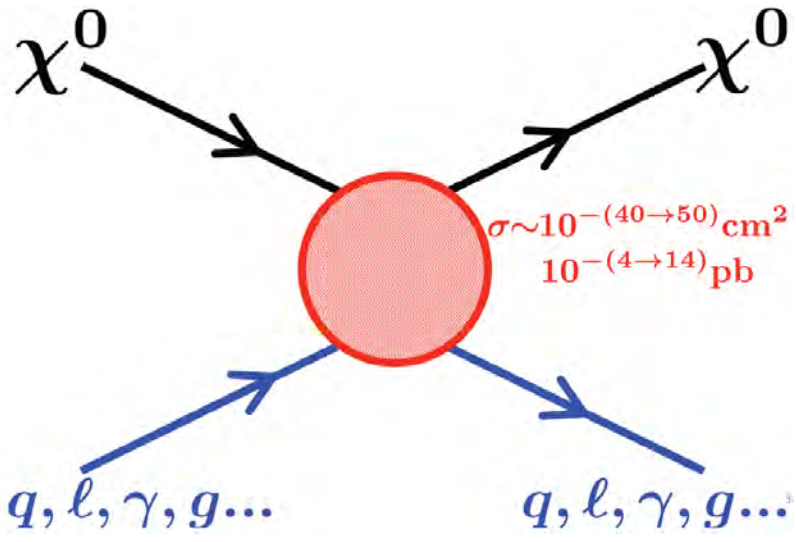


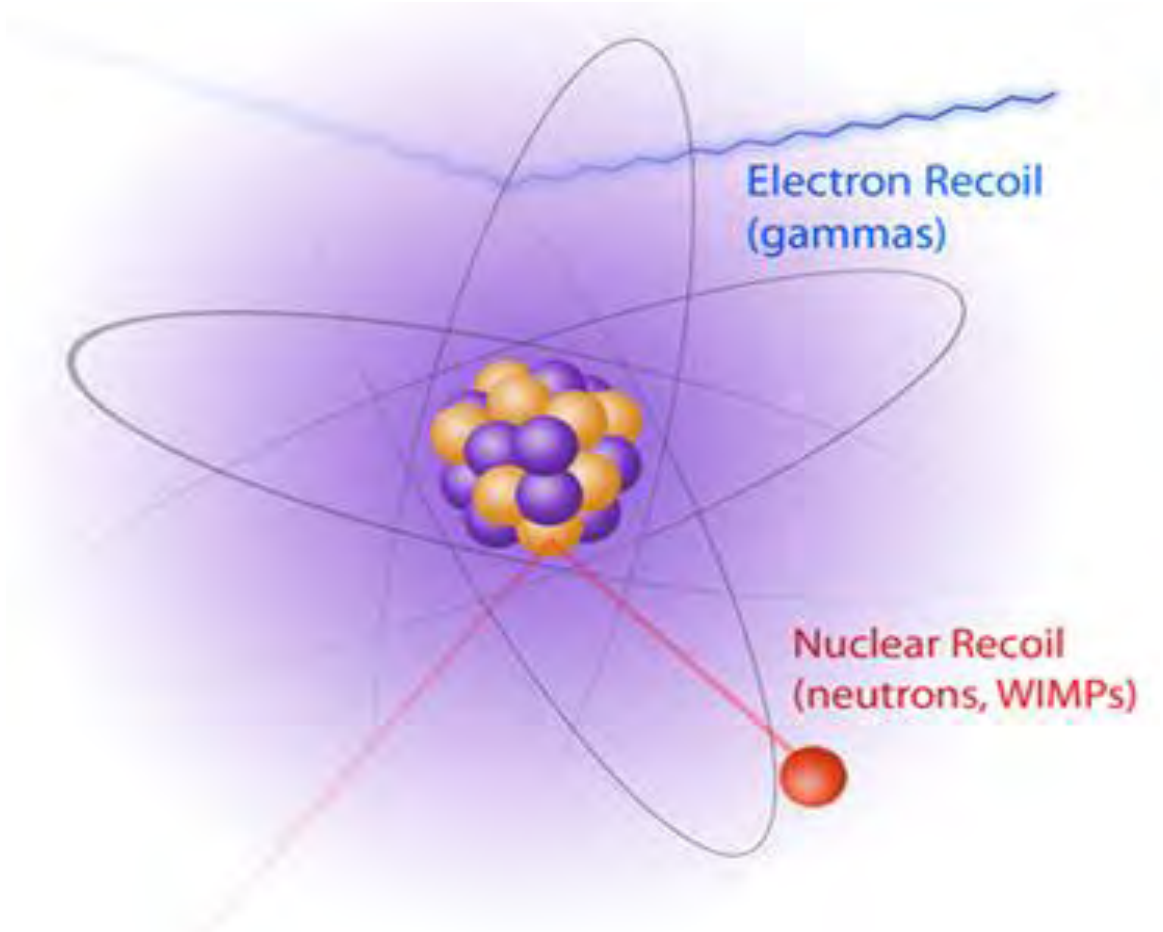
Rubin, *et al, 1978, ApJ. Lett.* ***225****, L107*



Kafle *et al.* 2014 *ApJ* **794** 59

WEAKLY INTERACTING MASSIVE PARTICLES





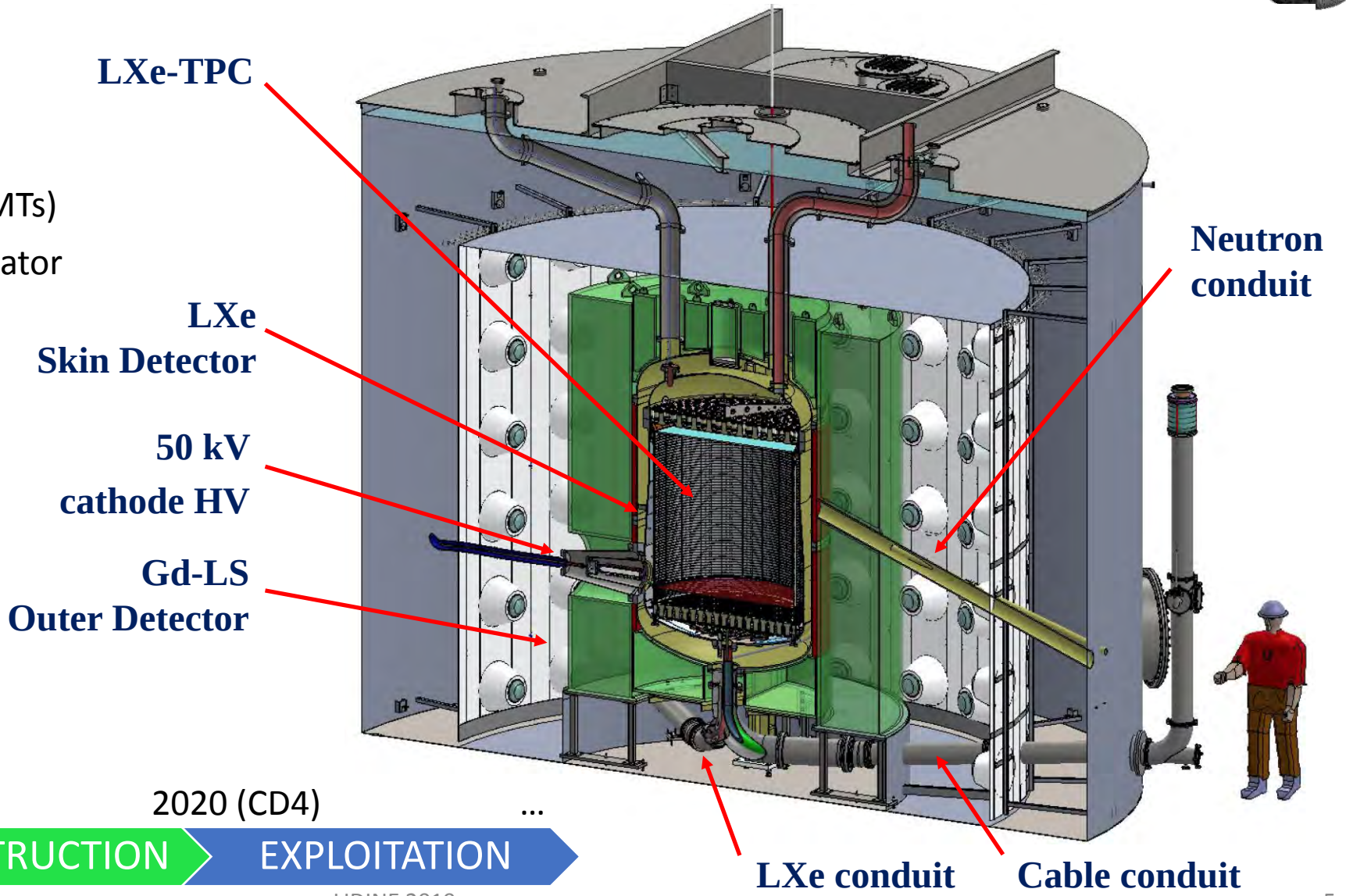
Main observable:
O(keV) nuclear recoils from elastic WIMP-nucleus scattering (or any other particle!)

THE LUX-ZEPLIN (LZ) EXPERIMENT

LZ detector(s)

- 7-T LXe-TPC (494 PMTs)
- 2-T LXe Skin Detector (131 PMTs)
- 17-T Gd-loaded Liquid Scintillator Outer Detector (120 PMTs)

100x more sensitive than LUX



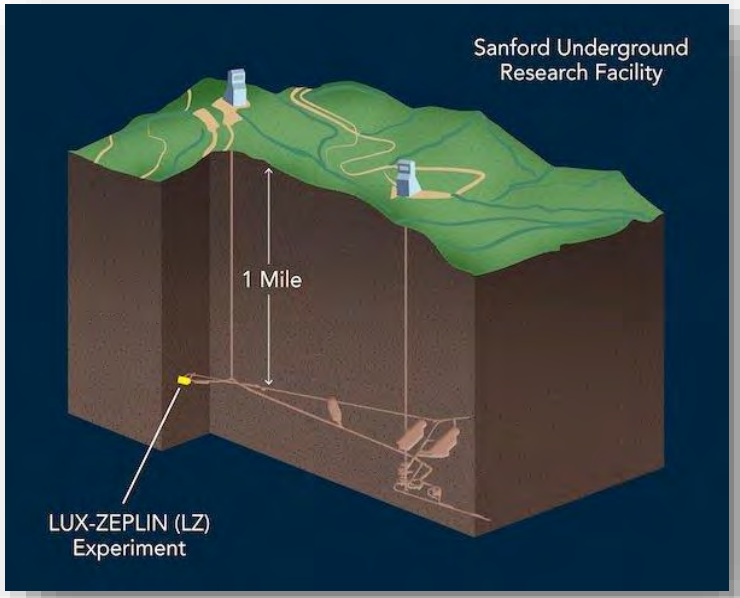
LZ Technical Design Report: arXiv:1703.09144
LZ Sensitivity: arXiv:1802.06039

2012 — 2015 (CD1) — 2020 (CD4) — …

DESIGN → CONSTRUCTION → EXPLOITATION

SANFORD UNDERGROUND RESEARCH FACILITY

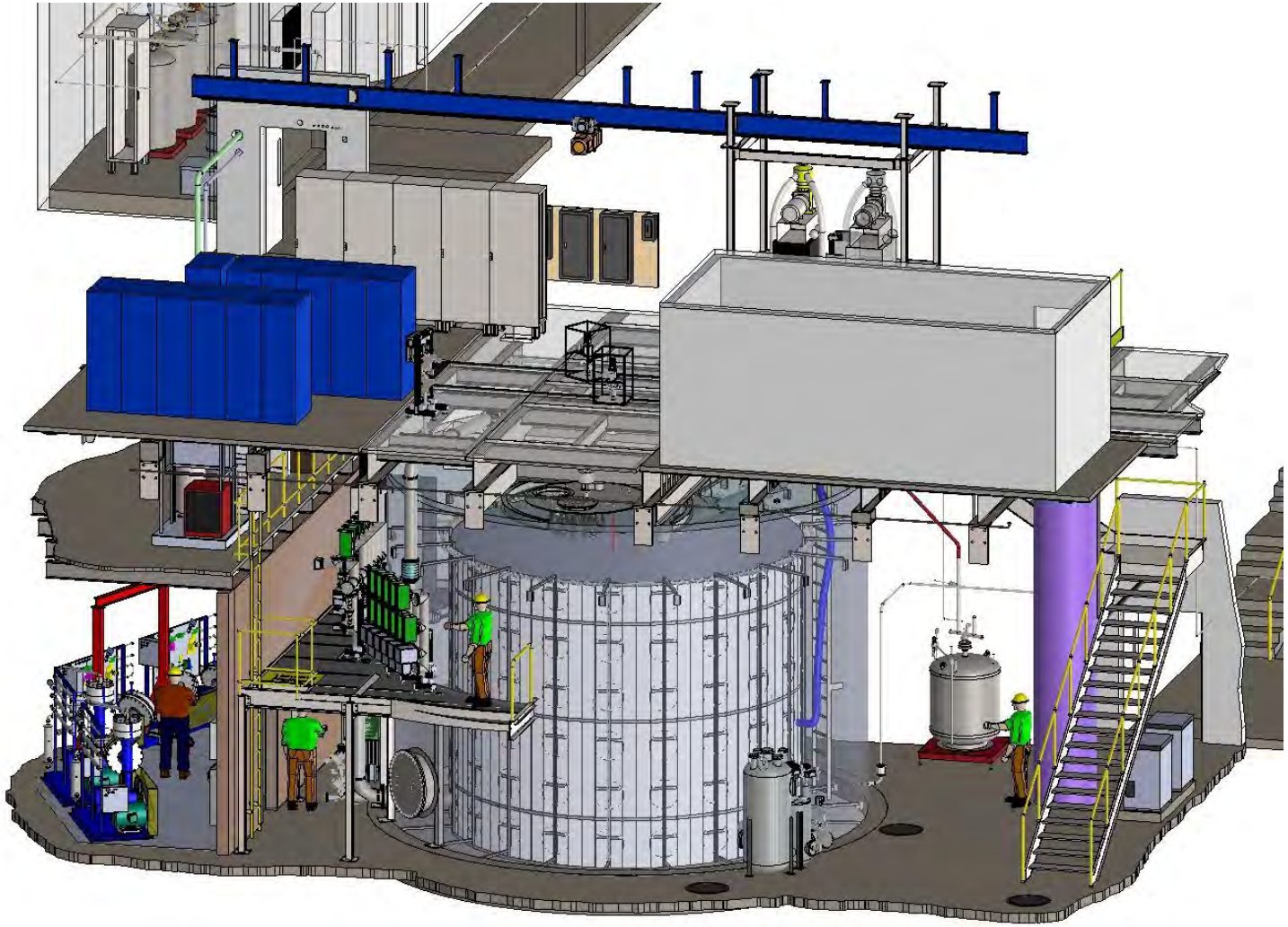
Lead, in the beautiful Black Hills of South Dakota



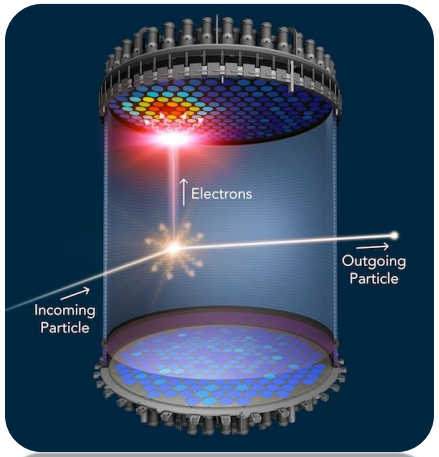
Lead and the Open Cut

Sturgis Rally

DAVIS CAMPUS @4850’ LEVEL U/G



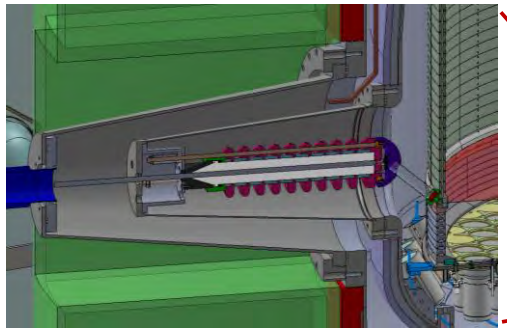
THE LZ XENON DETECTOR

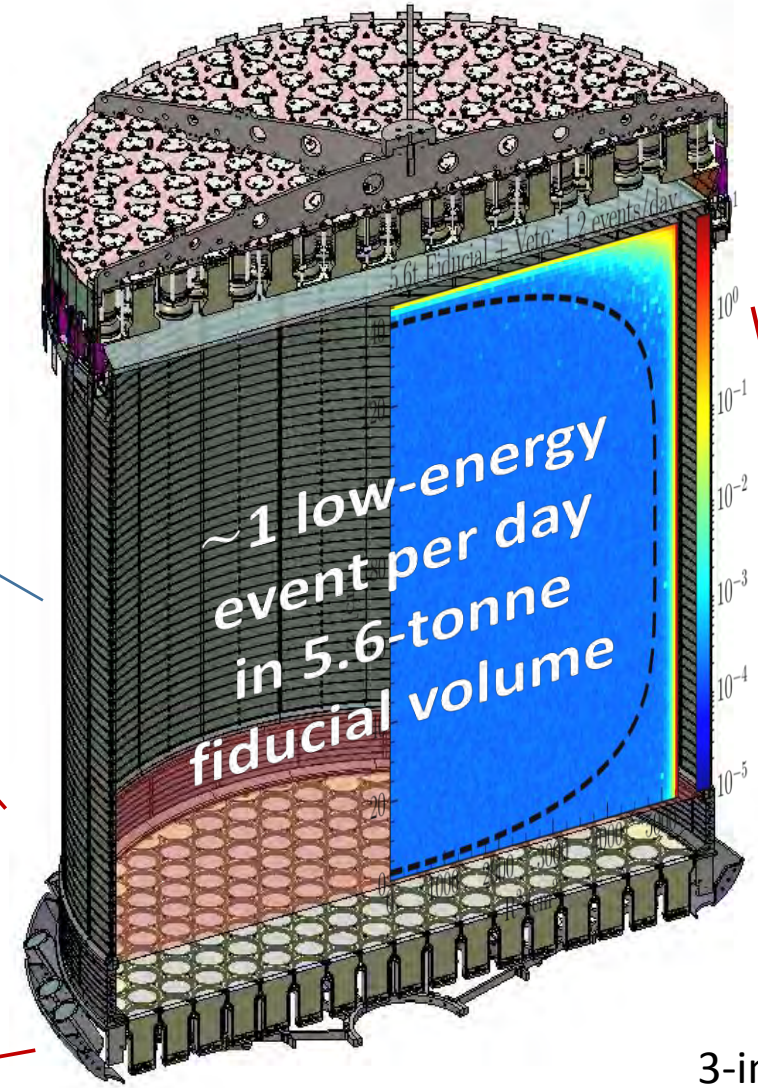


LXe-TPC (dual-phase)

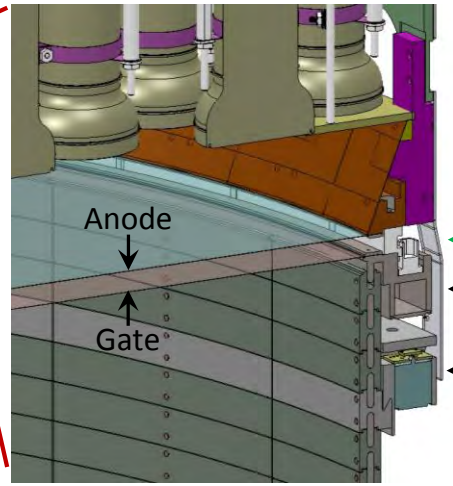
Main observables:
S1, S2, x, y, z

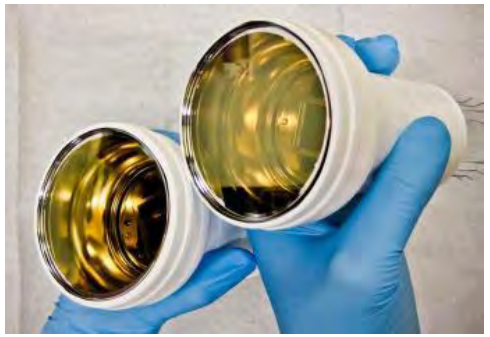
HV CONNECTION TO CATHODE





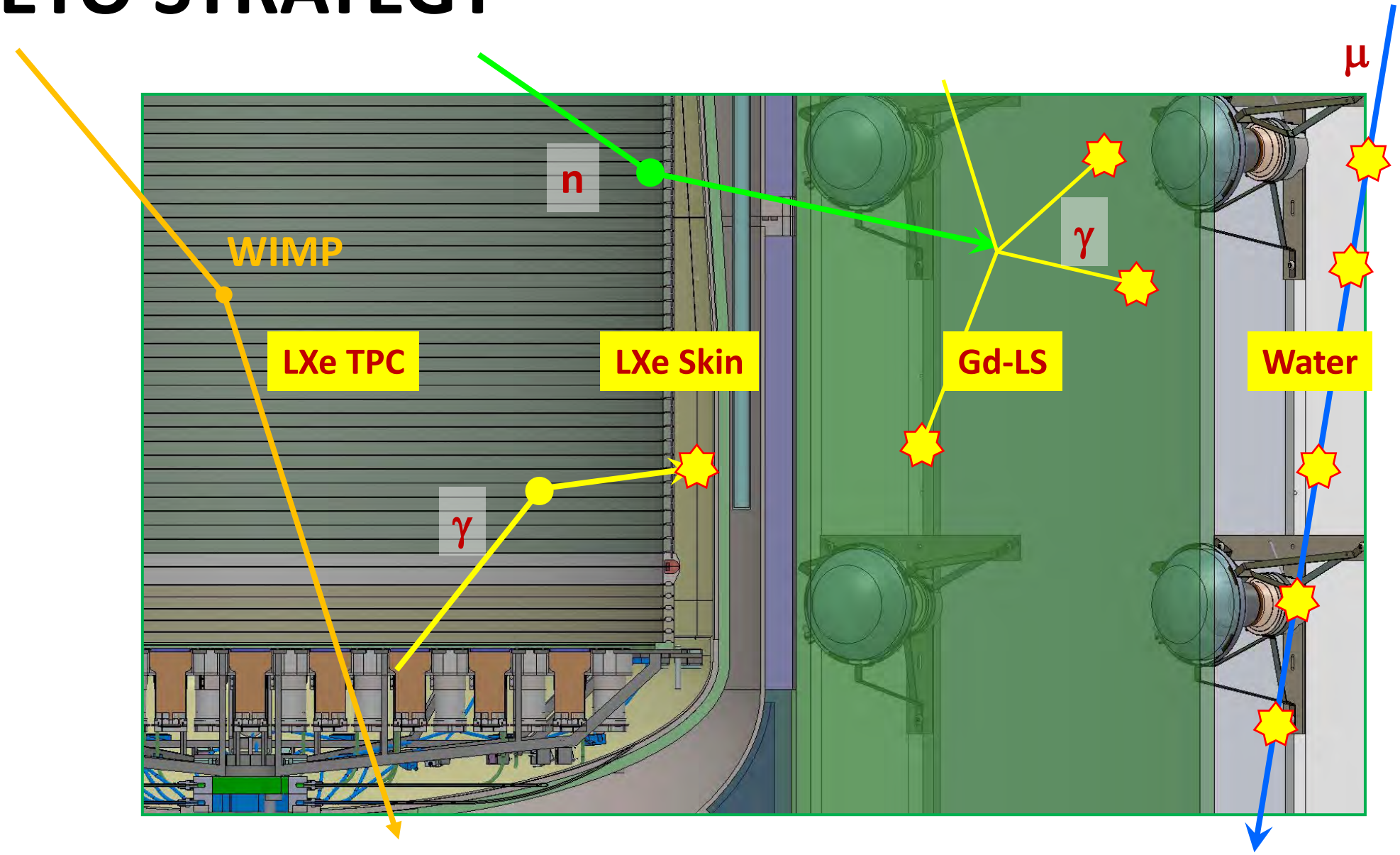
GAS PHASE AND ELECTROLUMINESCENCE REGION





3-inch Hamamatsu R11410-22 PMTs

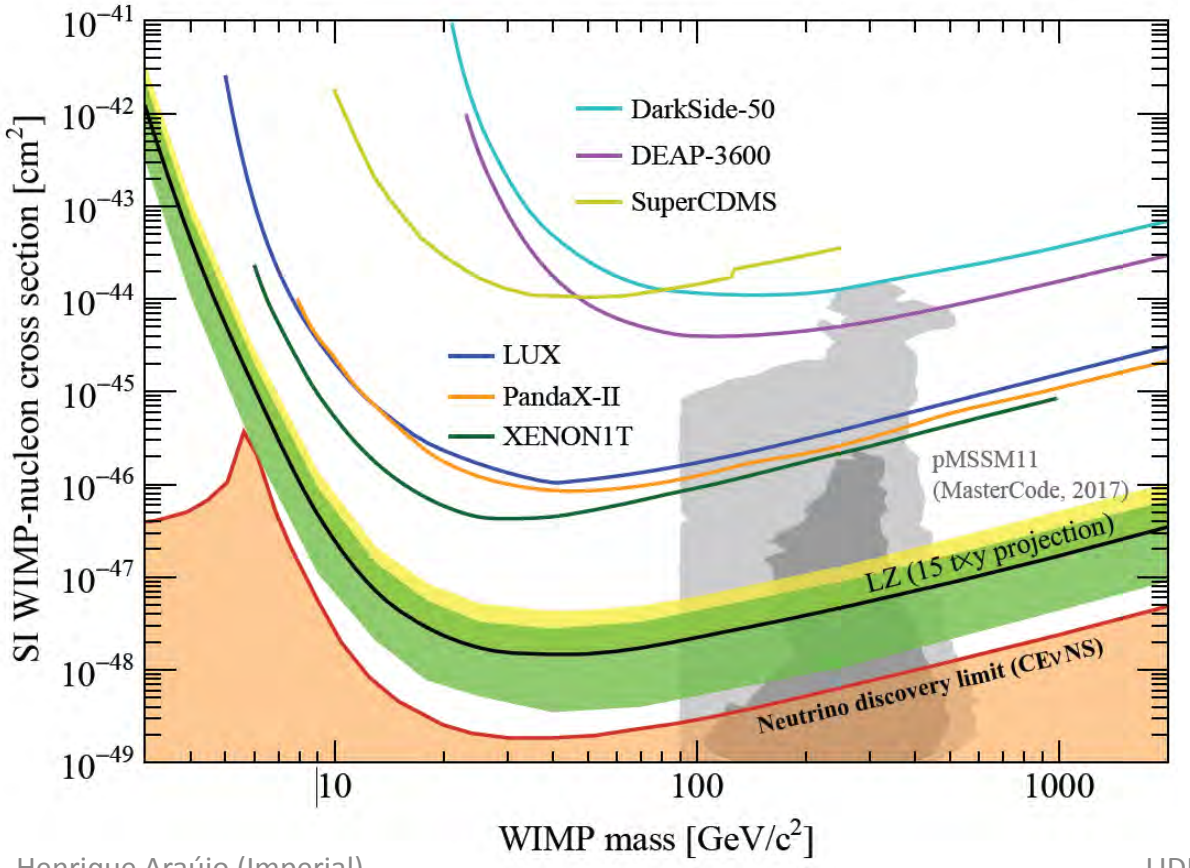
VETO STRATEGY

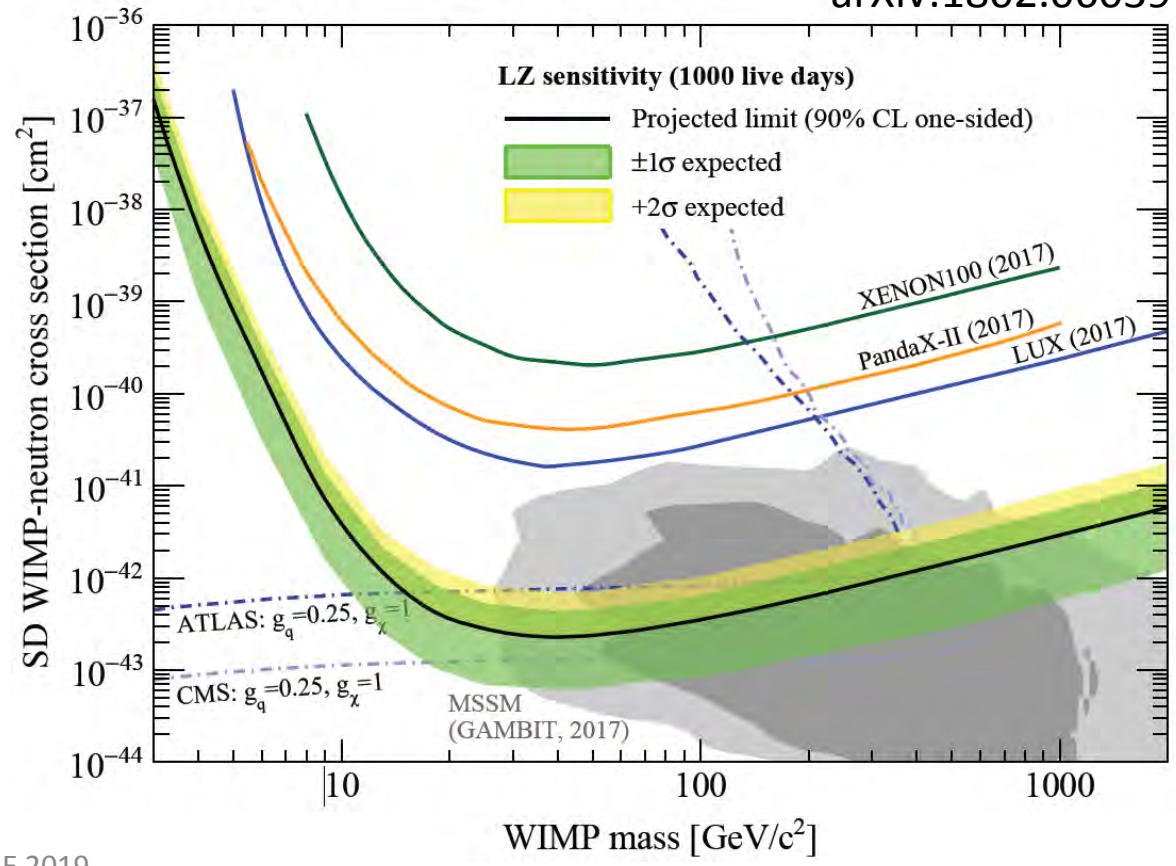


PHYSICS SENSITIVITY HIGHLIGHTS: WIMPS

- Aiming for leading SI sensitivity above a few GeV, 1.6×10^{-48} cm^2 @ 40 GeV
- Also WIMP-n and WIMP-p SD sensitivity, plus more exotic EFT operators

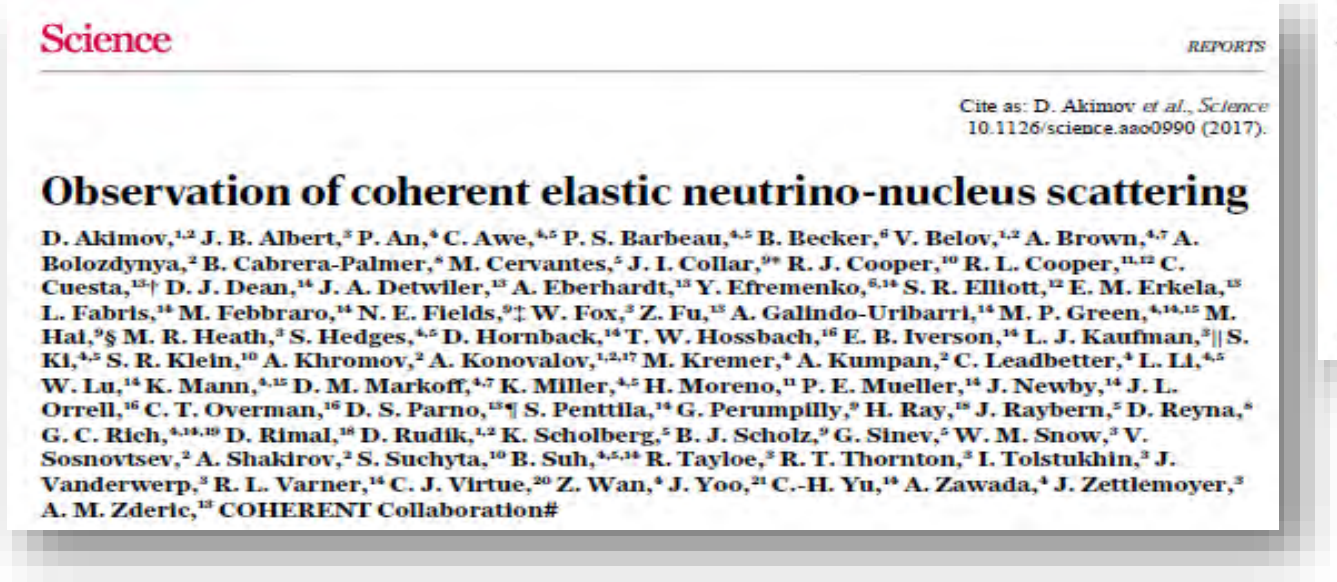
arXiv:1802.06039





PHYSICS SENSITIVITY HIGHLIGHTS: CEνNS

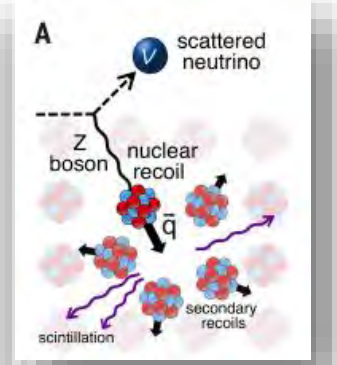
- CEνNS first observed in 2017 by COHERENT $(\nu + A \longrightarrow \nu + A)$
- Several astro-neutrino fluxes able to produce these very soft nuclear recoil spectra
- Single scatters, uniformly distributed, NR spectrum looks like (~6 GeV) WIMPs
- LZ can detect ≳40 B-8 solar neutrinos – and hence demonstrate supernova sensitivity


Science REPORTS

Cite as: D. Akimov et al., Science 10.1126/science.aao0990 (2017).

Observation of coherent elastic neutrino-nucleus scattering

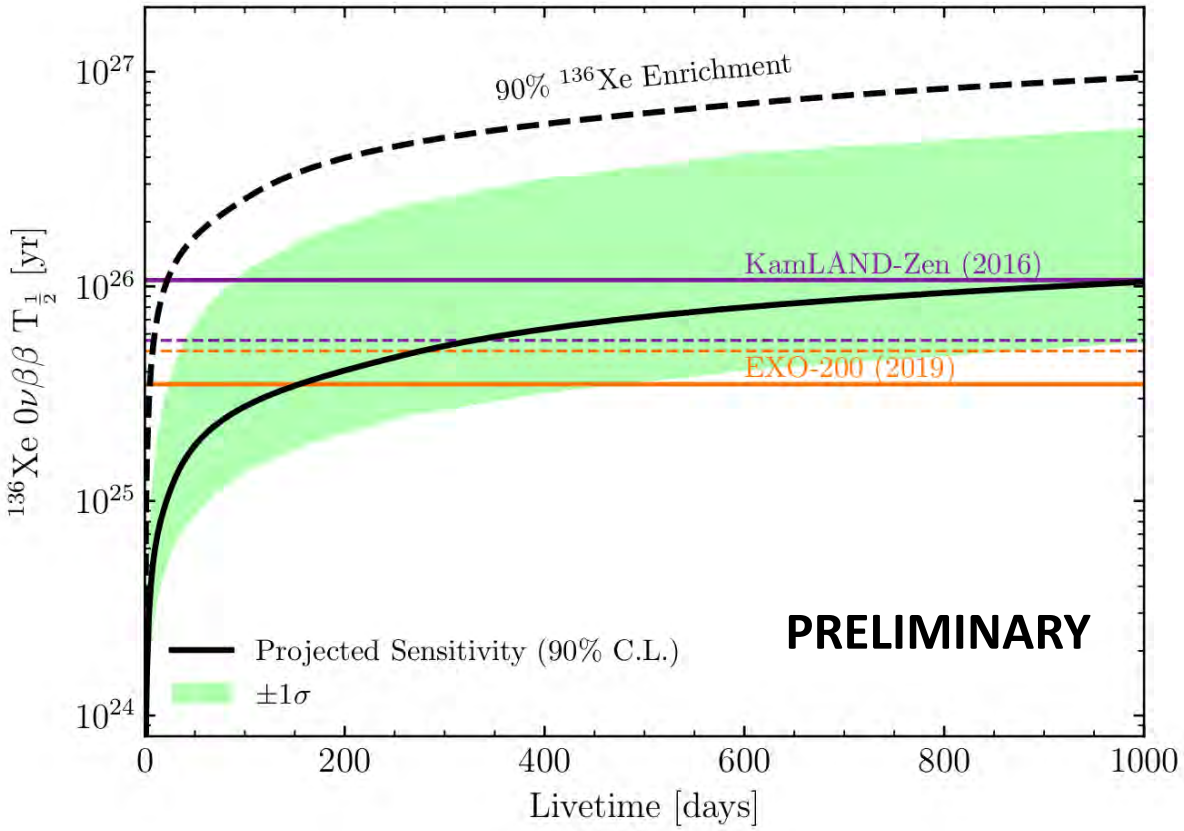
D. Akimov,[1,2] J. B. Albert,[3] P. An,[4] C. Awe,[4,5] P. S. Barbeau,[4,5] B. Becker,[6] V. Belov,[1,2] A. Brown,[4,7] A. Bolozdynya,[2] B. Cabrera-Palmer,[8] M. Cervantes,[5] J. I. Collar,[9*] R. J. Cooper,[10] R. L. Cooper,[11,12] C. Cuesta,[13†] D. J. Dean,[14] J. A. Detwiler,[15] A. Eberhardt,[15] Y. Efremenko,[6,16] S. R. Elliott,[12] E. M. Erkela,[15] L. Fabris,[14] M. Febbraro,[14] N. E. Fields,[9‡] W. Fox,[3] Z. Fu,[15] A. Galindo-Uribarri,[14] M. P. Green,[4,14,15] M. Hai,[9§] M. R. Heath,[3] S. Hedges,[4,5] D. Hornback,[14] T. W. Hossbach,[16] E. B. Iverson,[14] L. J. Kaufman,[3||] S. Ki,[4,5] S. R. Klein,[10] A. Khromov,[2] A. Konovalov,[1,2,17] M. Kremer,[4] A. Kumpan,[2] C. Leadbetter,[4] L. Li,[4,5] W. Lu,[14] K. Mann,[4,15] D. M. Markoff,[4,7] K. Miller,[4,5] H. Moreno,[11] P. E. Mueller,[14] J. Newby,[14] J. L. Orrell,[16] C. T. Overman,[16] D. S. Parno,[13¶] S. Penttila,[14] G. Perumpilly,[9] H. Ray,[18] J. Raybern,[5] D. Reyna,[8] G. C. Rich,[4,14,19] D. Rimal,[18] D. Rudik,[1,2] K. Scholberg,[5] B. J. Scholz,[9] G. Sinev,[5] W. M. Snow,[3] V. Sosnovtsev,[2] A. Shakirov,[2] S. Suchyta,[10] B. Suh,[4,5,14] R. Tayloe,[3] R. T. Thornton,[3] I. Tolstukhin,[3] J. Vanderwerp,[3] R. L. Varner,[14] C. J. Virtue,[20] Z. Wan,[4] J. Yoo,[21] C.-H. Yu,[14] A. Zawada,[4] J. Zettlemoyer,[3] A. M. Zderic,[13] COHERENT Collaboration#



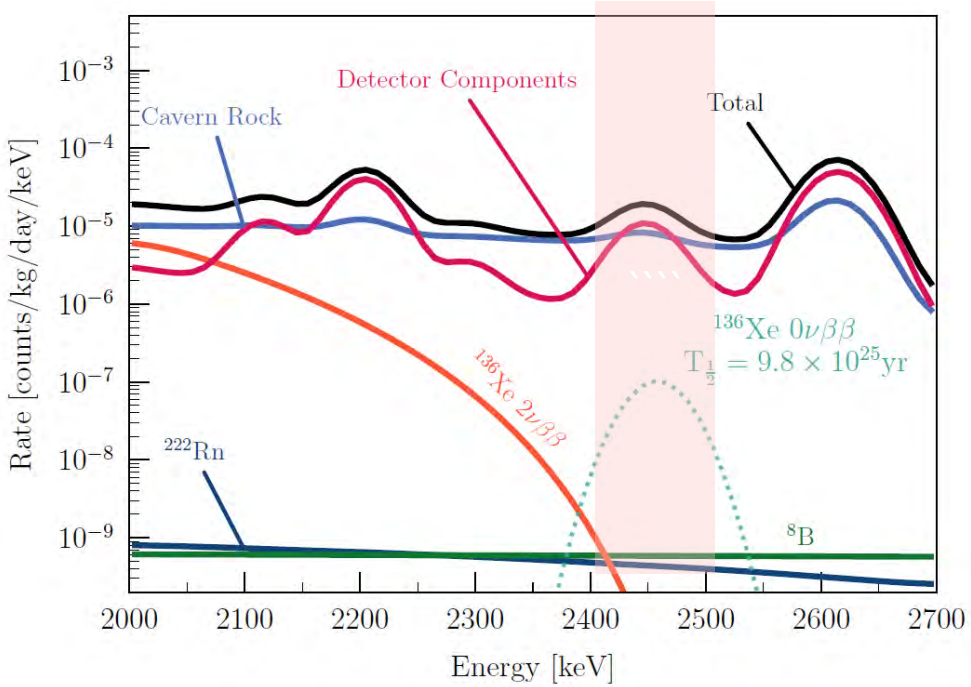
A galactic supernova at 10 kpc can produce up to ~100 events in LZ through this flavour-blind interaction

PHYSICS SENSITIVITY HIGHLIGHTS: 0νββ DECAY

- Searches for neutrinoless double beta decay in Xe-136 ($Q_{\beta\beta}$ = 2,458 keV)
- Demonstrate potential using a scalable technology



Gamma backgrounds from cavern and detector: Bi-214 (2,447 keV) and Tl-208 (2,614 keV)

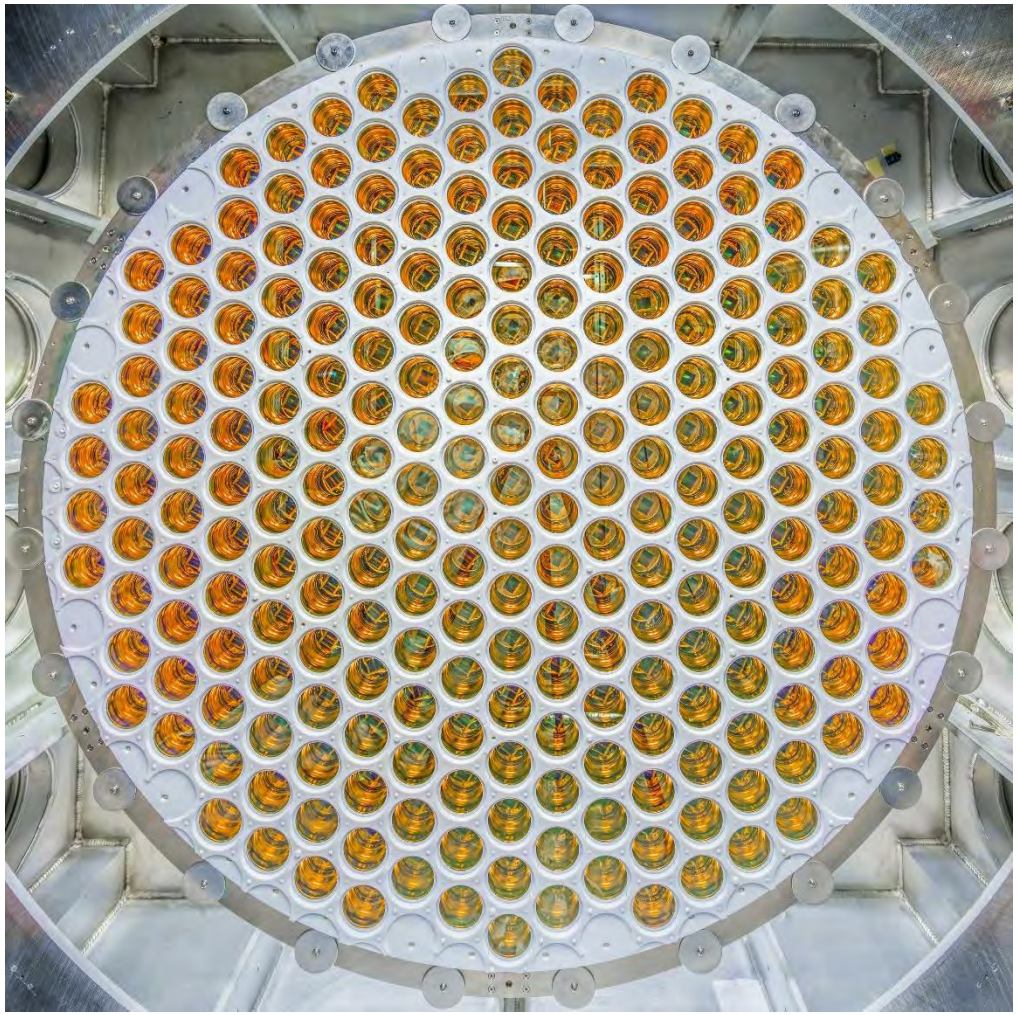


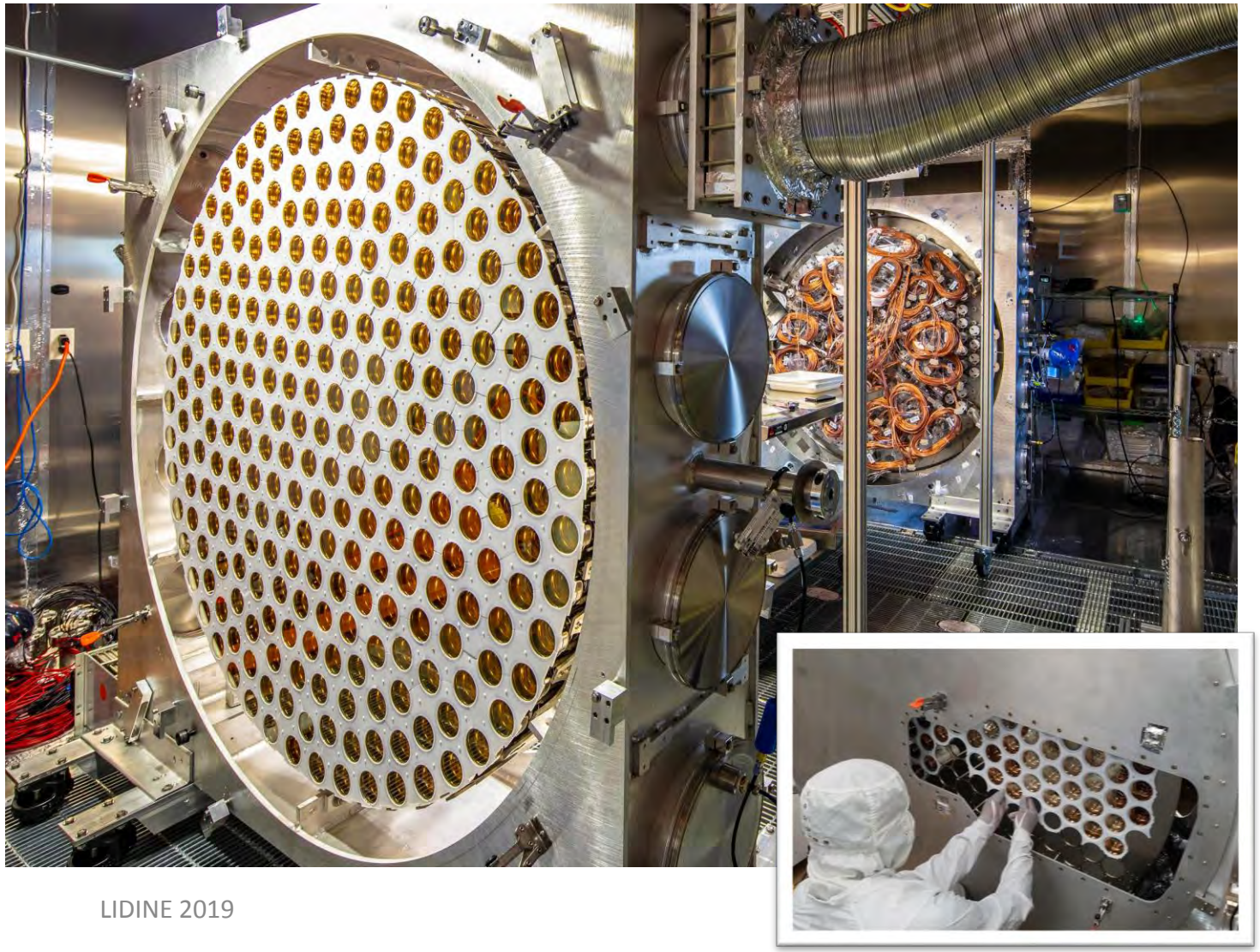
σ ~ 1% at $Q_{\beta\beta}$ demonstrated in LXe

DETECTOR ASSEMBLY

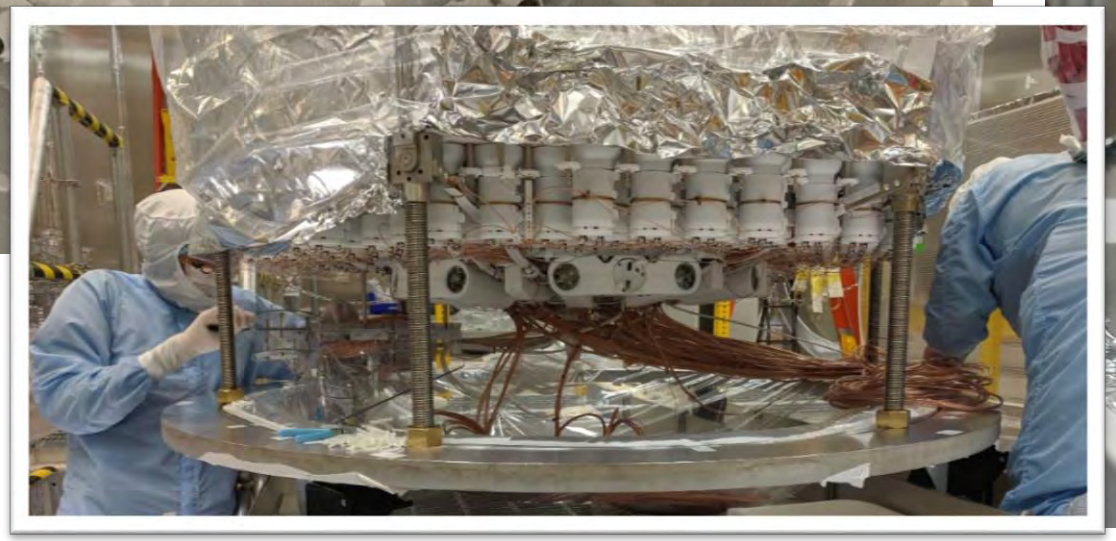
- Detector integration started in December 2018 at Surface Assembly Laboratory (SURF)
- 13,500 working hours
  - Class 1000 CR – but performing much better
  - Reduced radon environment
- Bringing tens of thousands of ultra-clean, low-background components together

PMT ARRAYS – 241+253 HAMAMATSU R11410-22





SKIN DETECTOR



BOTTOM SKIN:
20+18 2” PMTS

TOP SKIN:
93 1” PMTS

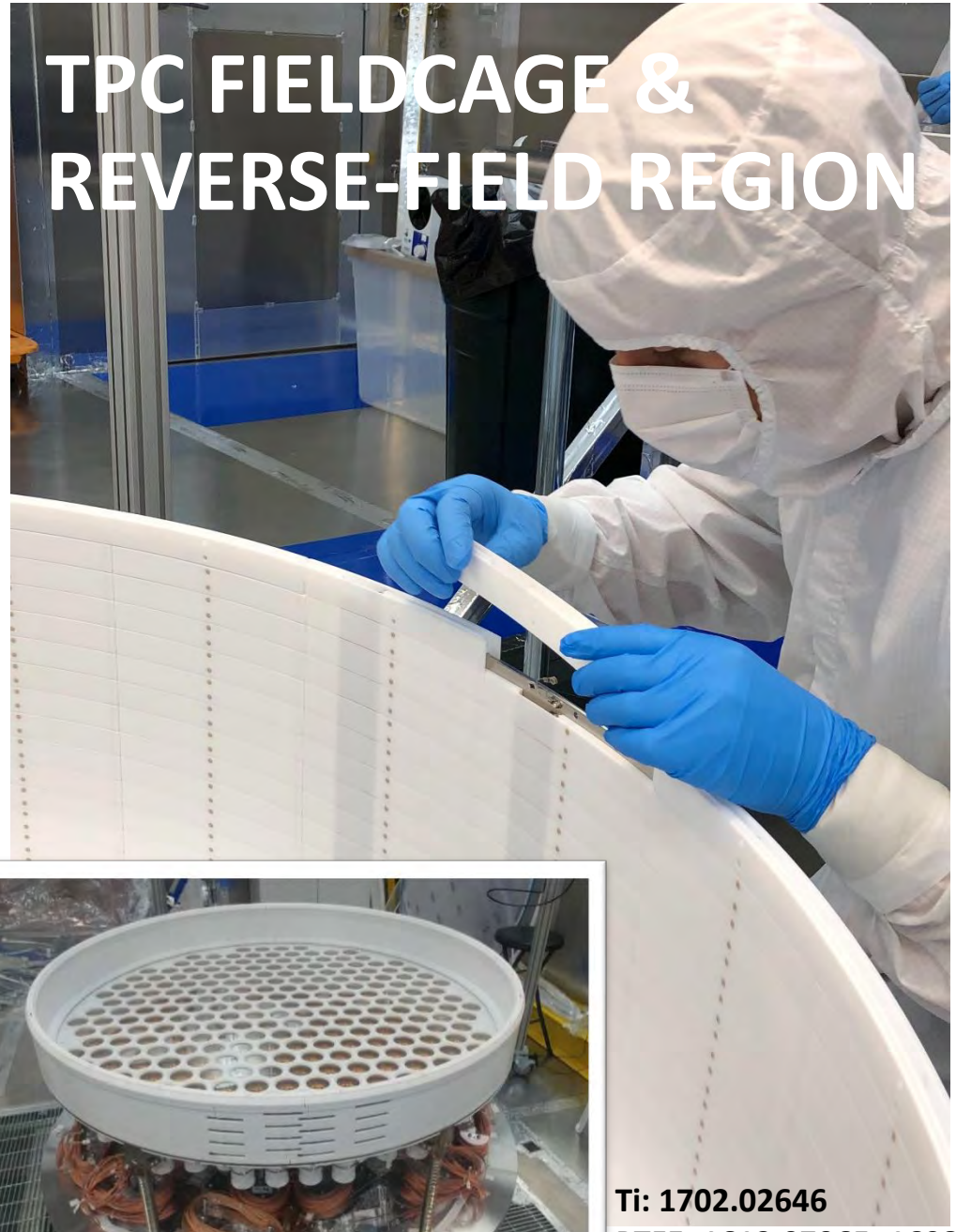
ELECTRODE GRID WEAVING

4 meshes using 75/100 μm wire, woven using automated loom, epoxied to holding rings

Major QA programme for mechanical & electrical resilience, and for cleanliness

Probably the most challenging components in the experiment

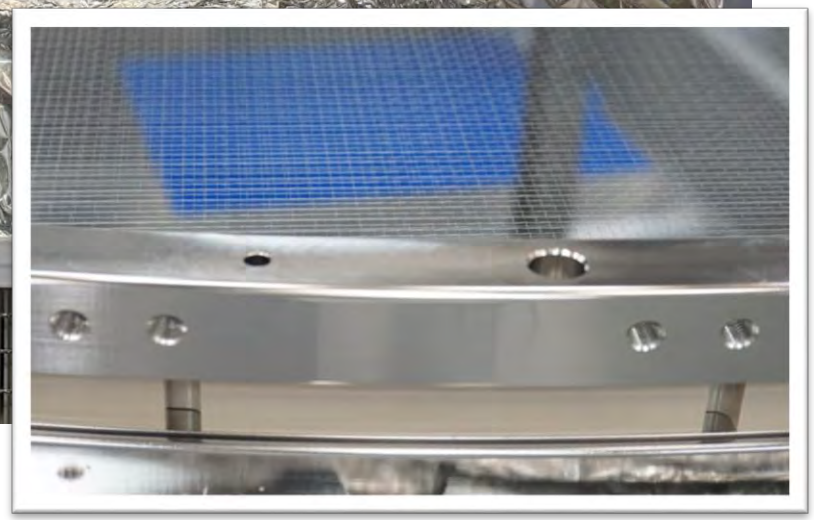
TPC FIELDCAGE & REVERSE-FIELD REGION



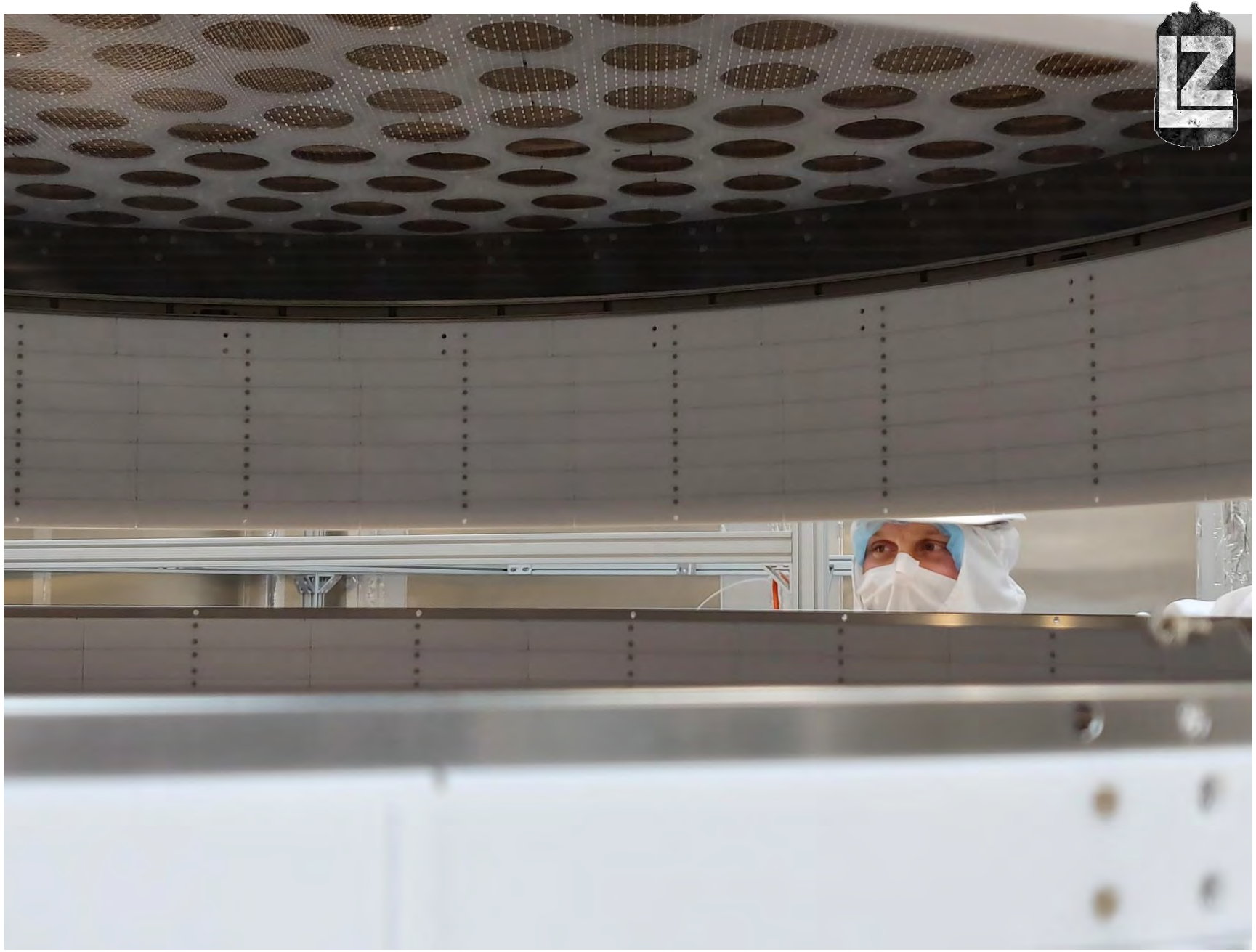
Ti: 1702.02646

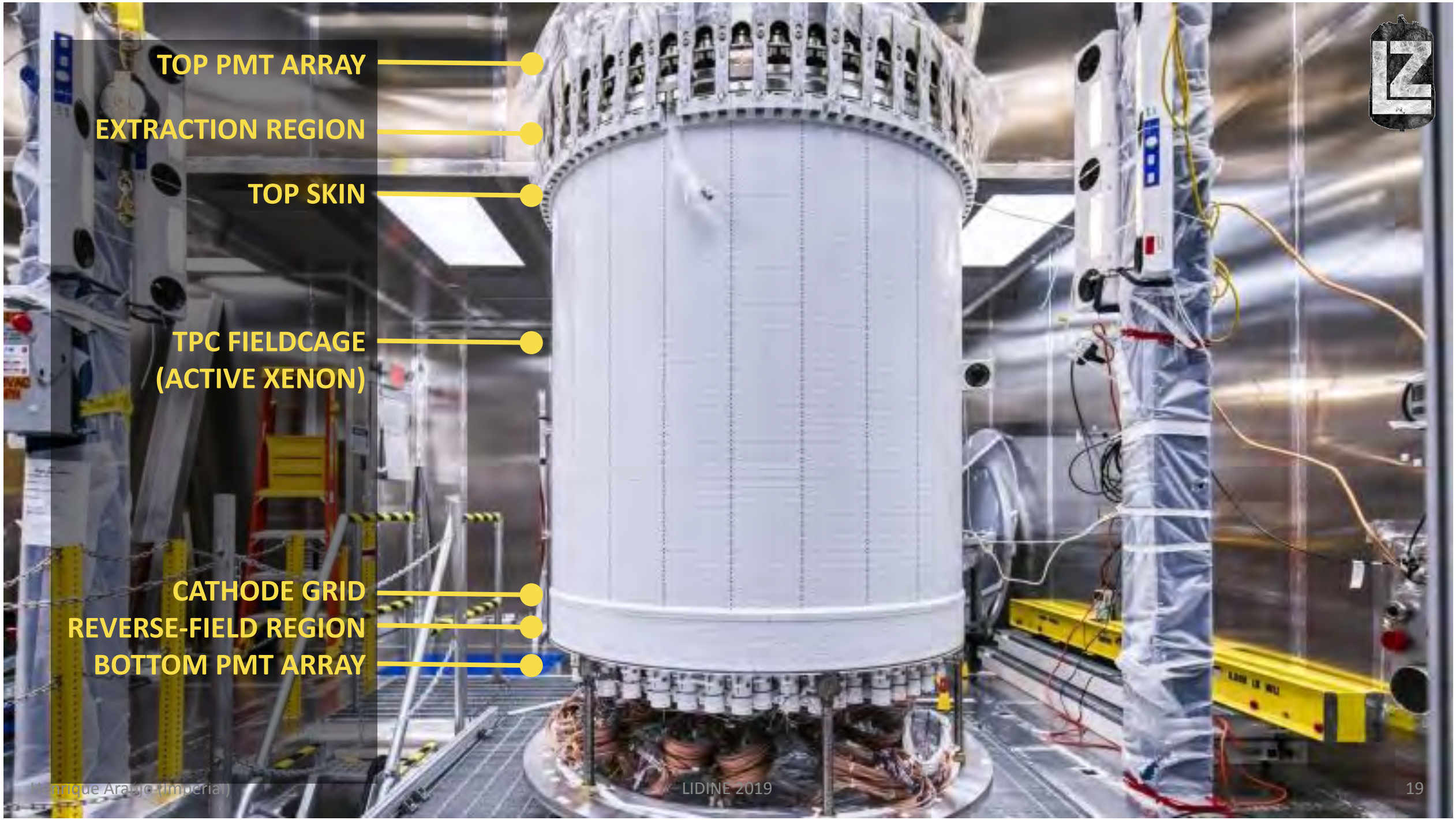
PTFE: 1612.07965, 1608.01717

EXTRACTION REGION



TPC MATING




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

QA PROGRAMME

- Rigorous Quality Plan: mechanical, electrical, radioactivity, cleanliness
- Radioassay programme
  - Fixed contaminant screening with HPGe, ICP-MS, NAA (>1,000 assays)
  - Radon emanation (>170 assays)
  - Radon removal (inline)
  - Krypton removal (prior to deployment)
  - *Comprehensive tracking system for backgrounds*
- Cleanliness programme
  - Witness coupons & tape lifts (>300 assays); UV inspection
  - Cleaning and handling procedures
  - Radon progeny plate-out
  - *Comprehensive tracking system for plate-out and dust*

SUMMARY & TIMELINE

- The LZ Xenon Detector has been assembled at SURF, following ~7 years of design and construction
- Insertion into inner cryostat vessel and checkouts ongoing, deployment underground expected within weeks
- Construction of other subsystems progressing well
- Start of physics data-taking in 2020, probing new WIMP parameter space

- LZ will be sensitive to plenty of new physics involving rare scattering and decay processes – keep an eye out in 2020!

250 scientists & engineers from 37 institutes in the US, UK, Portugal, South Korea & Russia

Black Hills State University ◊ Bristol University ◊ Brookhaven National Laboratory ◊ Brown University ◊ Center for Underground Physics, Korea ◊ Edinburgh University ◊ Fermi National Accelerator Laboratory ◊ Imperial College London ◊ Lawrence Berkeley National Laboratory ◊ Lawrence Livermore National Laboratory ◊ LIP-Coimbra, Portugal ◊ University of Liverpool ◊ MEPHI Moscow, Russia ◊ Northwestern University ◊ Oxford University ◊ Penn State University ◊ Rutherford Appleton Laboratory ◊ Royal Holloway, University of London ◊ SLAC National Accelerator Laboratory ◊ South Dakota School of Mines & Technology ◊ South Dakota Science and Technology Authority ◊ SUNY University at Albany ◊ Texas A&M University ◊ University of Alabama ◊ University of California Berkeley ◊ University of California Davis ◊ University of California Santa Barbara ◊ University College London ◊ University of Maryland ◊ University of Massachusetts ◊ University of Michigan ◊ University of Rochester ◊ University of Sheffield ◊ University of South Dakota ◊ University of Wisconsin

reserve slides

LZ BACKGROUNDS

- DETECTOR MATERIALS
  - Radioassay programme
- SURFACE CONTAMINATION
  - Cleanliness programme
- INTERNAL BACKGROUNDS
  - Rn Assay programme
  - Krypton & Radon removal
- **PHYSICS BACKGROUNDS**
  - Solar pp neutrinos (ER)
  - Atmospheric & B-8 neutrinos (NR)

TOTAL IN WIMP ROI IN 1,000 DAYS

1195 ER + 1.0 NR (before discrimination)

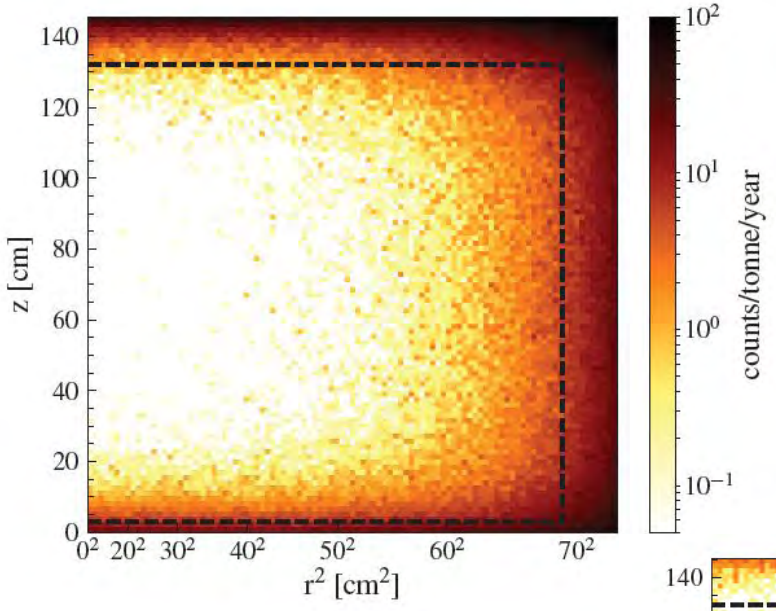
6 ER + 0.5 NR COUNTS

1802.06039

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 outer detector 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.

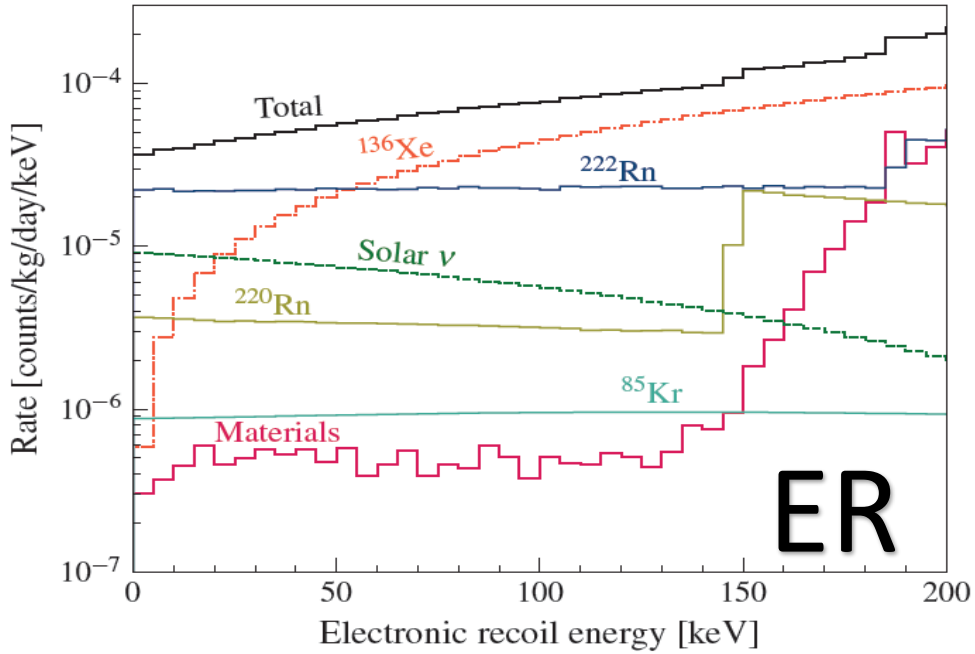
Background Source	Mass (kg)	$^{238}U_e$	$^{238}U_l$	$^{232}Th_e$	$^{232}Th_l$	^{60}Co	^{40}K	n/yr	ER (cts)	NR (cts)
		mBq/kg								
Detector Components										
PMT systems	308	31.2	5.20	2.32	2.29	1.46	18.6	248	2.82	0.027
TPC systems	373	3.28	1.01	0.84	0.76	2.58	7.80	79.9	4.33	0.022
Cryostat	2778	2.88	0.63	0.48	0.51	0.31	2.62	323	1.27	0.018
Outer detector	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 (1.81 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+^{14}N									255	-
Diffuse supernova neutrinos (DSN)									-	0.05
Atmospheric neutrinos (Atm)									-	0.46
								subtotal	**322**	**0.51**
Total									1195	1.03
Total (with 99.5% ER discrimination, 50% NR efficiency)									5.97	0.52
Sum of ER and NR in LZ for 1000 days, 5.6 tonne FV, with all analysis cuts									**6.49**	

LZ BACKGROUNDS



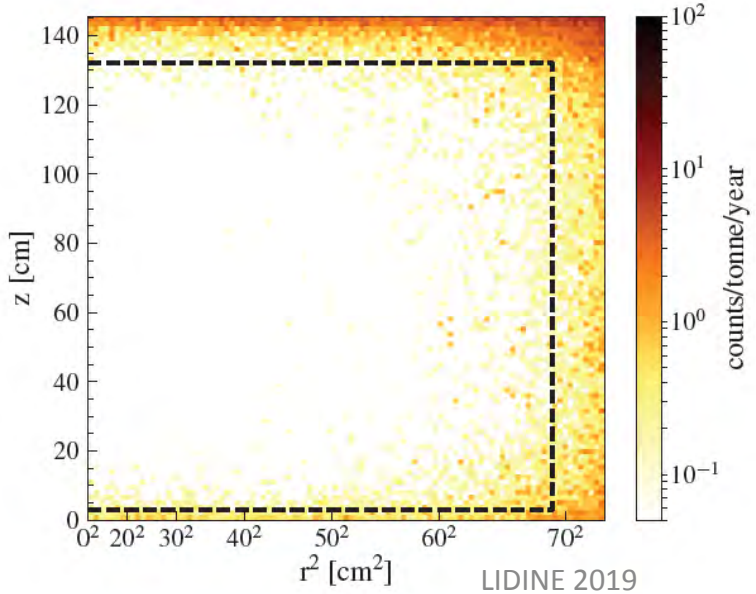
10 μDRU from solar pp ν

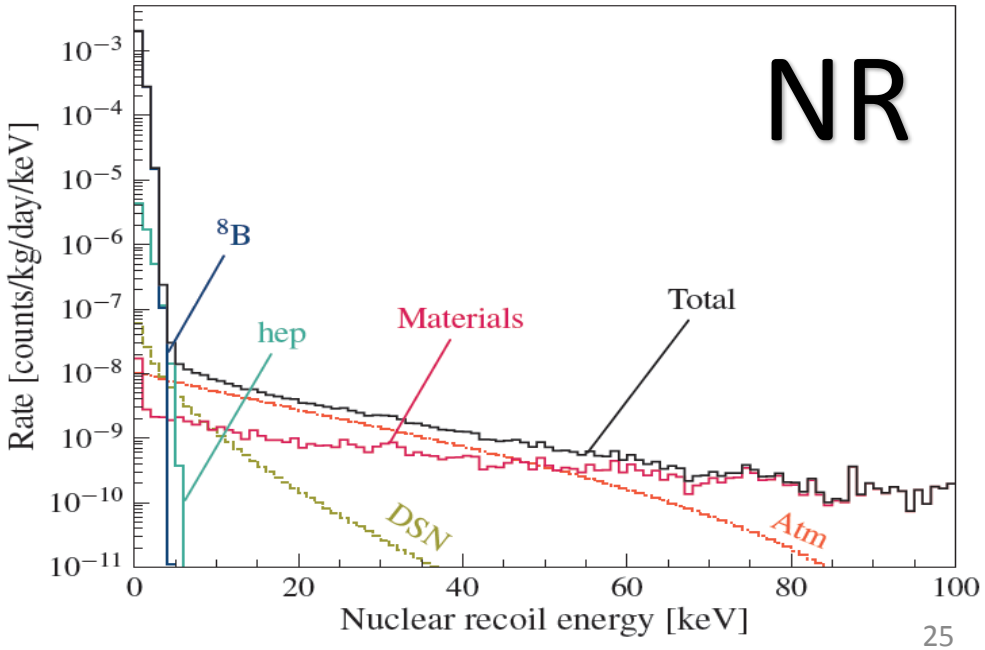
(10x10^{-6} cts/kg/day/keVee)

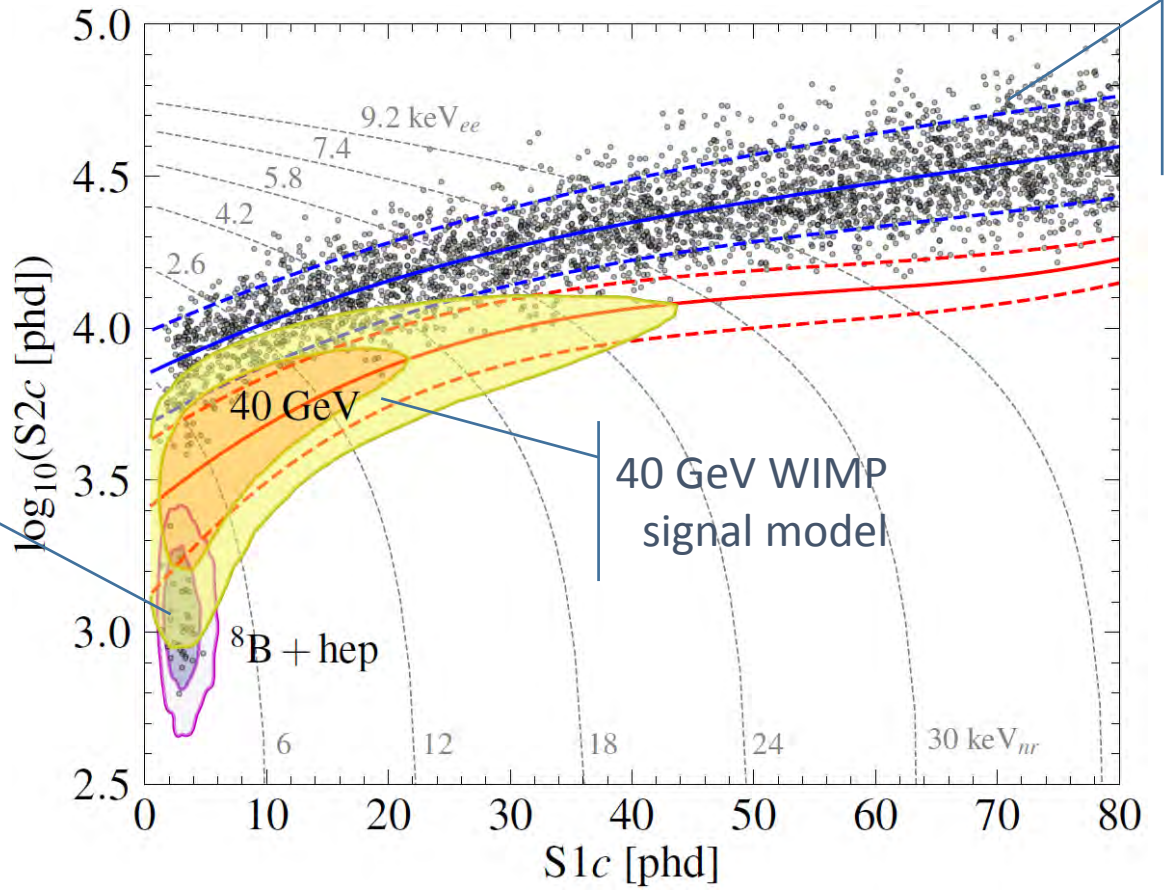


Distribution of
NR background
from detector materials

+VETOS





LZ SENSITIVITY: SIMULATED EXPOSURE

- Full LZ exposure (1,000 live days)