Projected WIMP sensitivity of the LUX-ZEPLIN dark matter experiment

UCLA DM 2018, 20-23rd February

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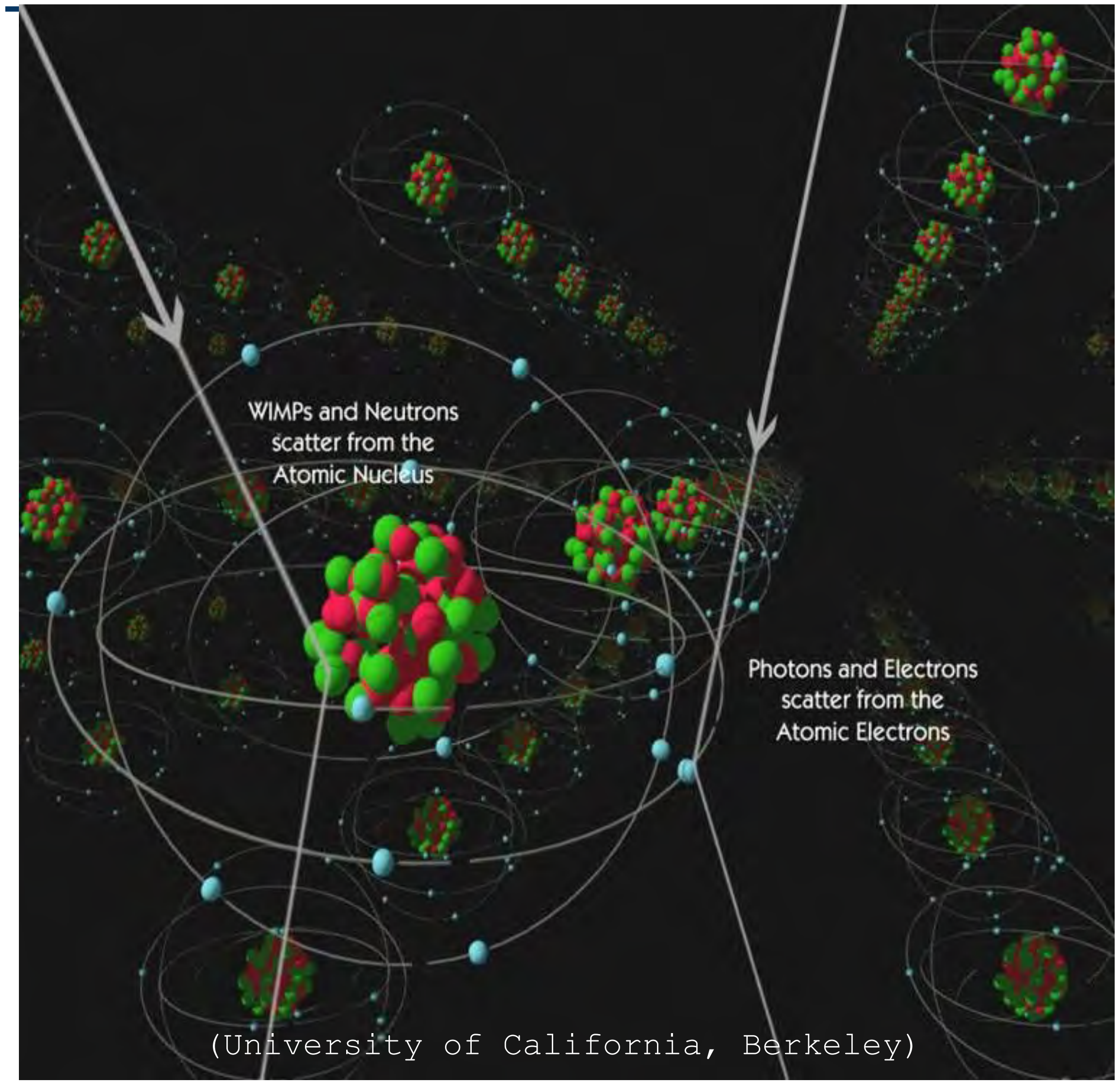
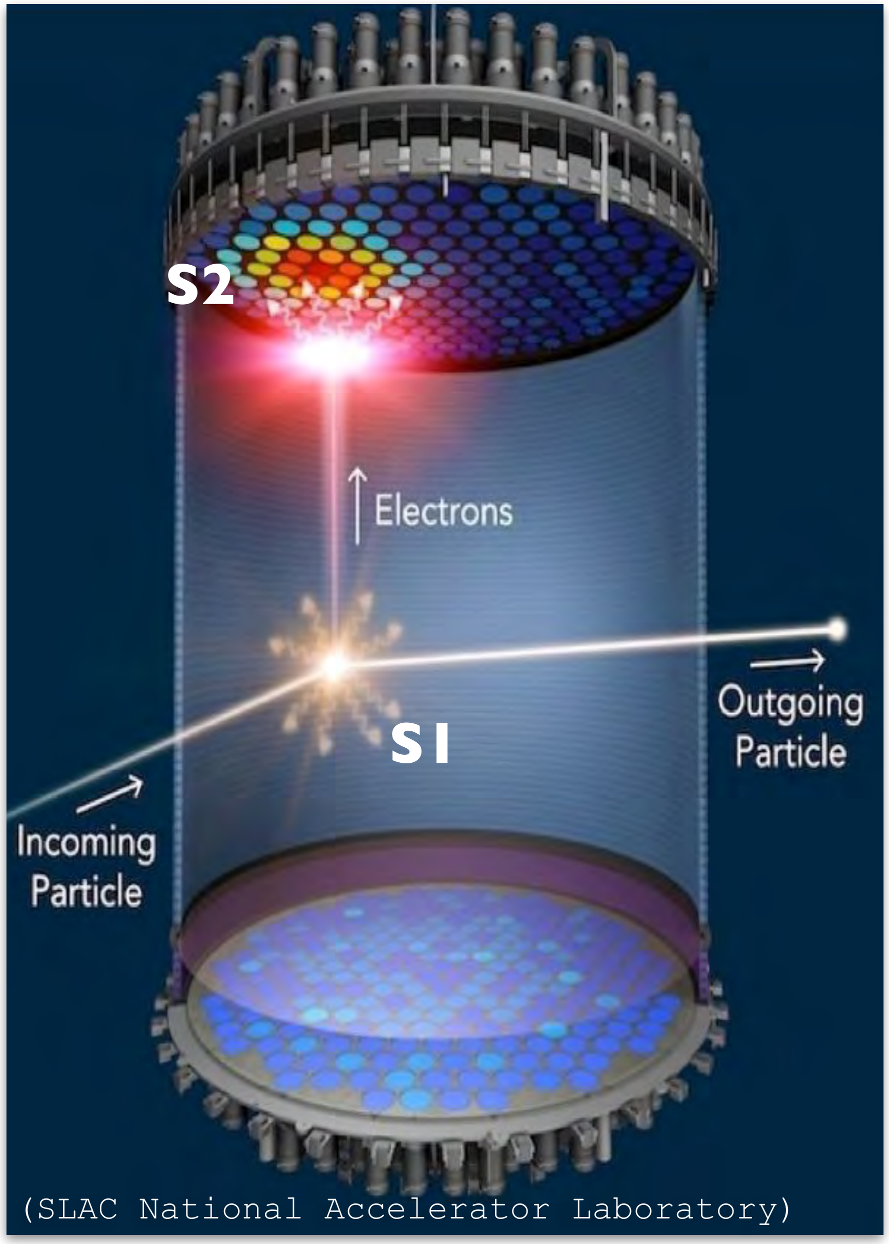
WIMP search with a LXe-TPC

Look for low energy WIMP-induced nuclear recoils





Requires: large target mass + low energy threshold + low background

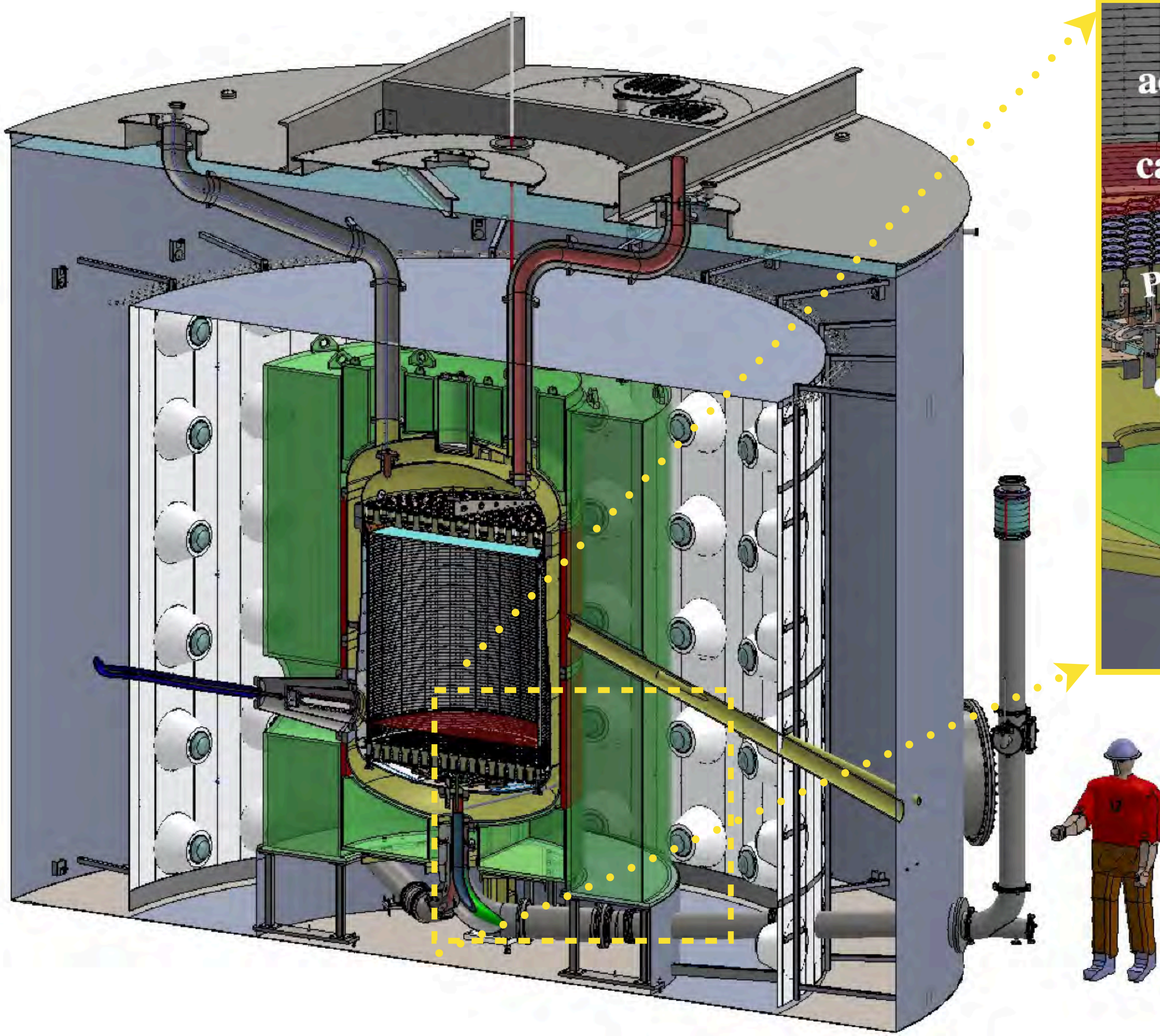
LUX-ZEPLIN (LZ)

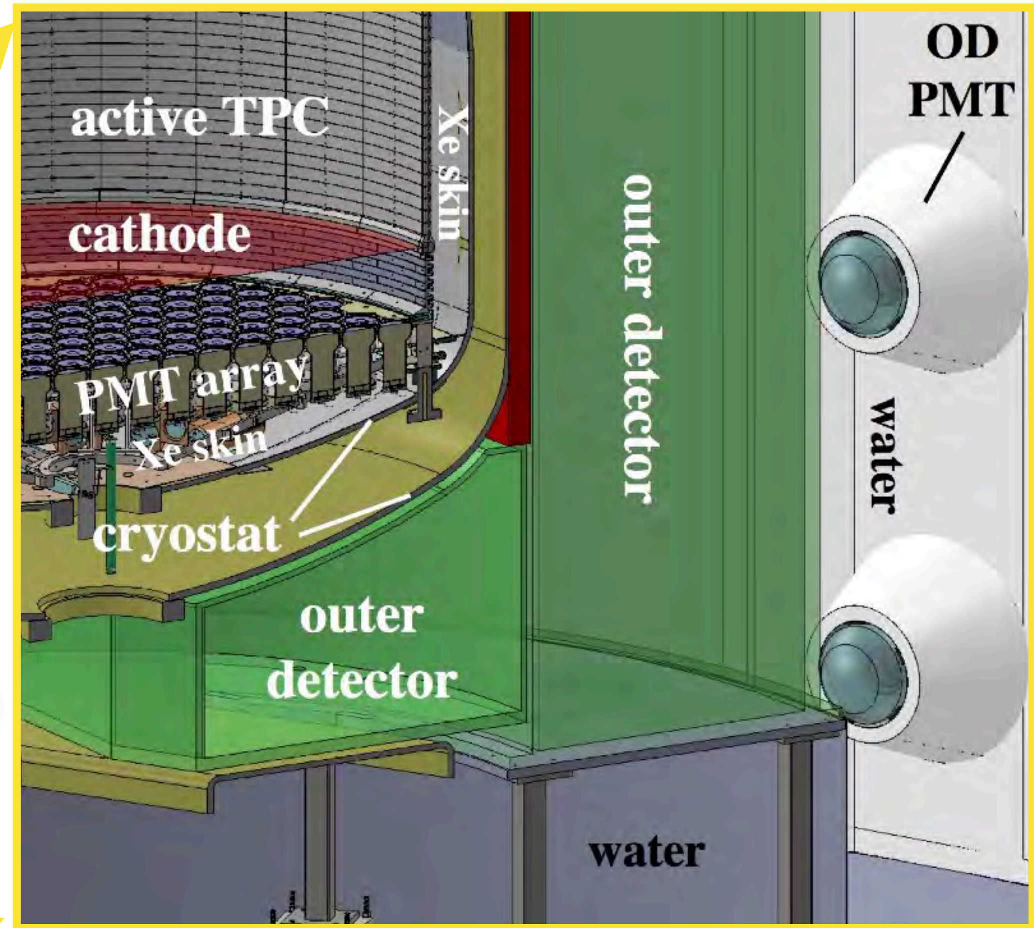
- LXe-TPC: ×50 scale up of LUX
- 1 mile underground (4300 m w.e.) at SURF
- **Underground installation 2019**
- **Physics data taking 2020**

LZ

Total mass – 10 T
WIMP Active Mass – 7 T
WIMP Fiducial Mass – 5.6 T

A discovery instrument





Background strategy

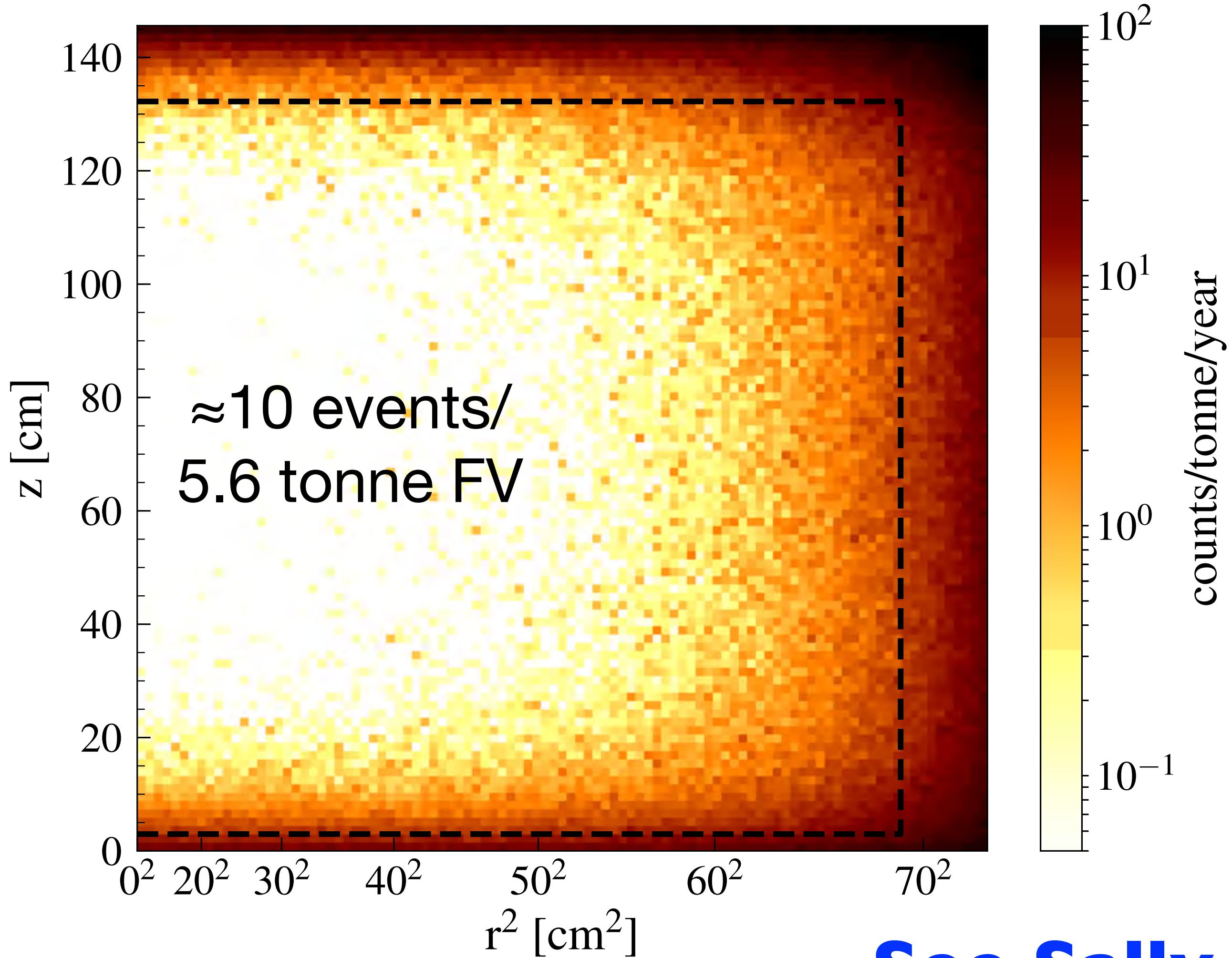
- **Xenon purification to remove ^{85}Kr and ^{39}Ar:**
  - Dedicated facility at SLAC: based on LUX demonstrated techniques
  - Final natKr/Xe 0.015 ppt (g/g)
- **Extensive radio-assay campaign for detector materials**
  - γ-screening, ICP-MS, NAA
  - ~1000 assays so far, ~1000 to go
- **Strict surface cleanliness program:**
  - Assembly in dedicated Rn-reduced cleanroom
    - Dust < 500 ng/cm^2 on all LXe wetted surfaces
    - Rn-daughter plate on TPC walls < 0.5 mBq/m^2
- **Active veto to suppress and characterise backgrounds**

See Hugh Lippincott's talk

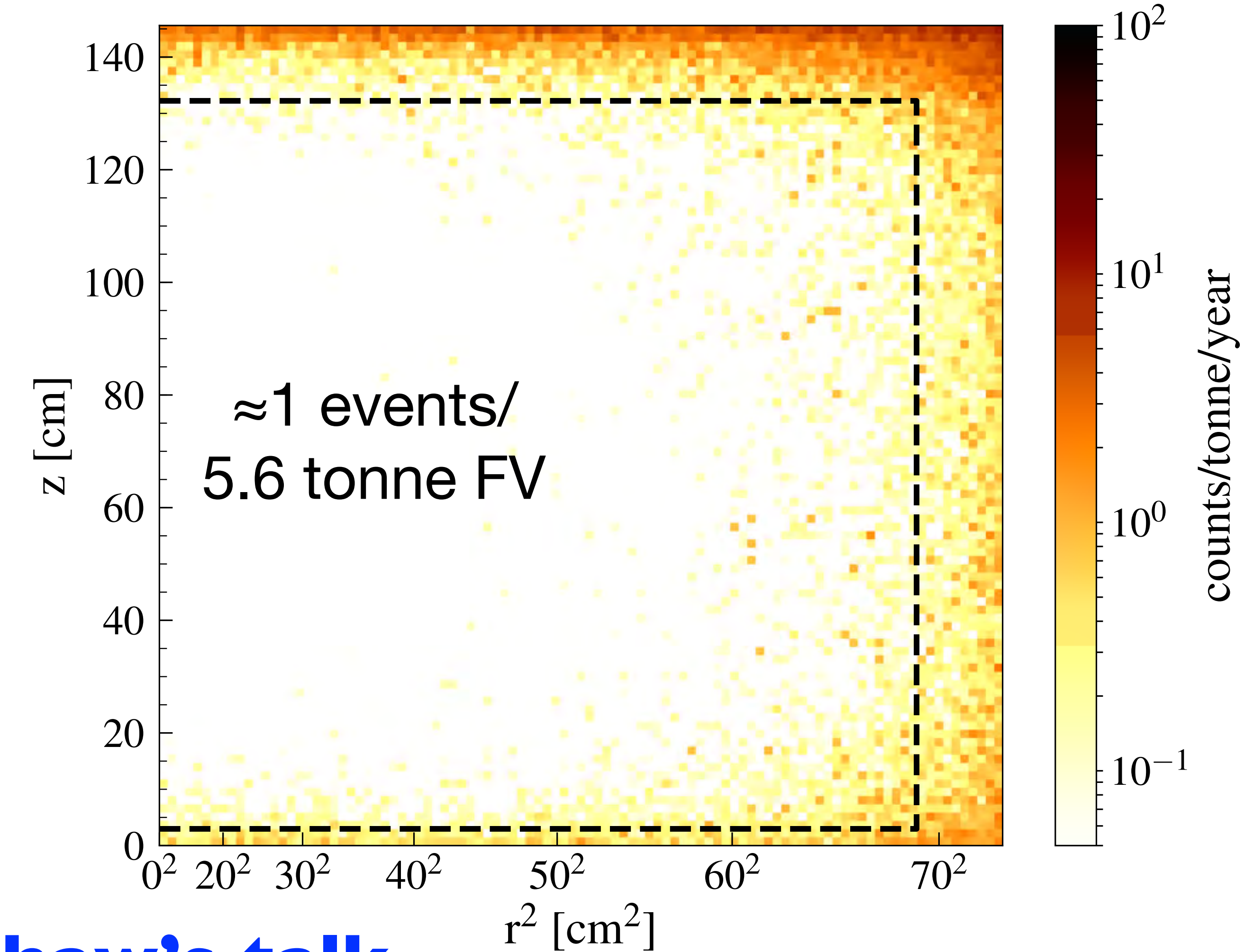
Active veto system

- WIMP-like nuclear recoil backgrounds in 6-30 keV region of interest
- Before/after application of outer detector + skin vetos

Before veto



After veto

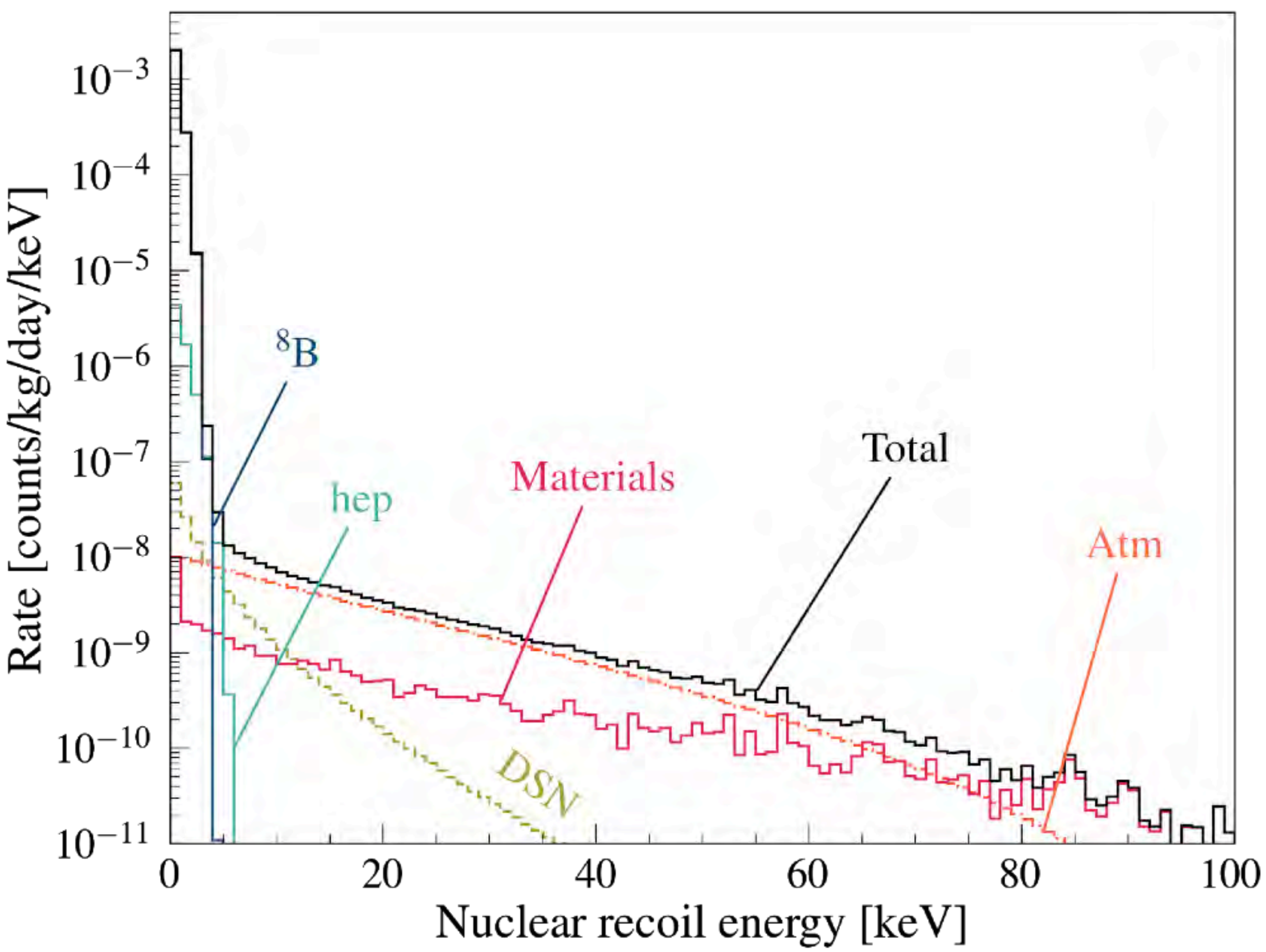


See Sally Shaw's talk

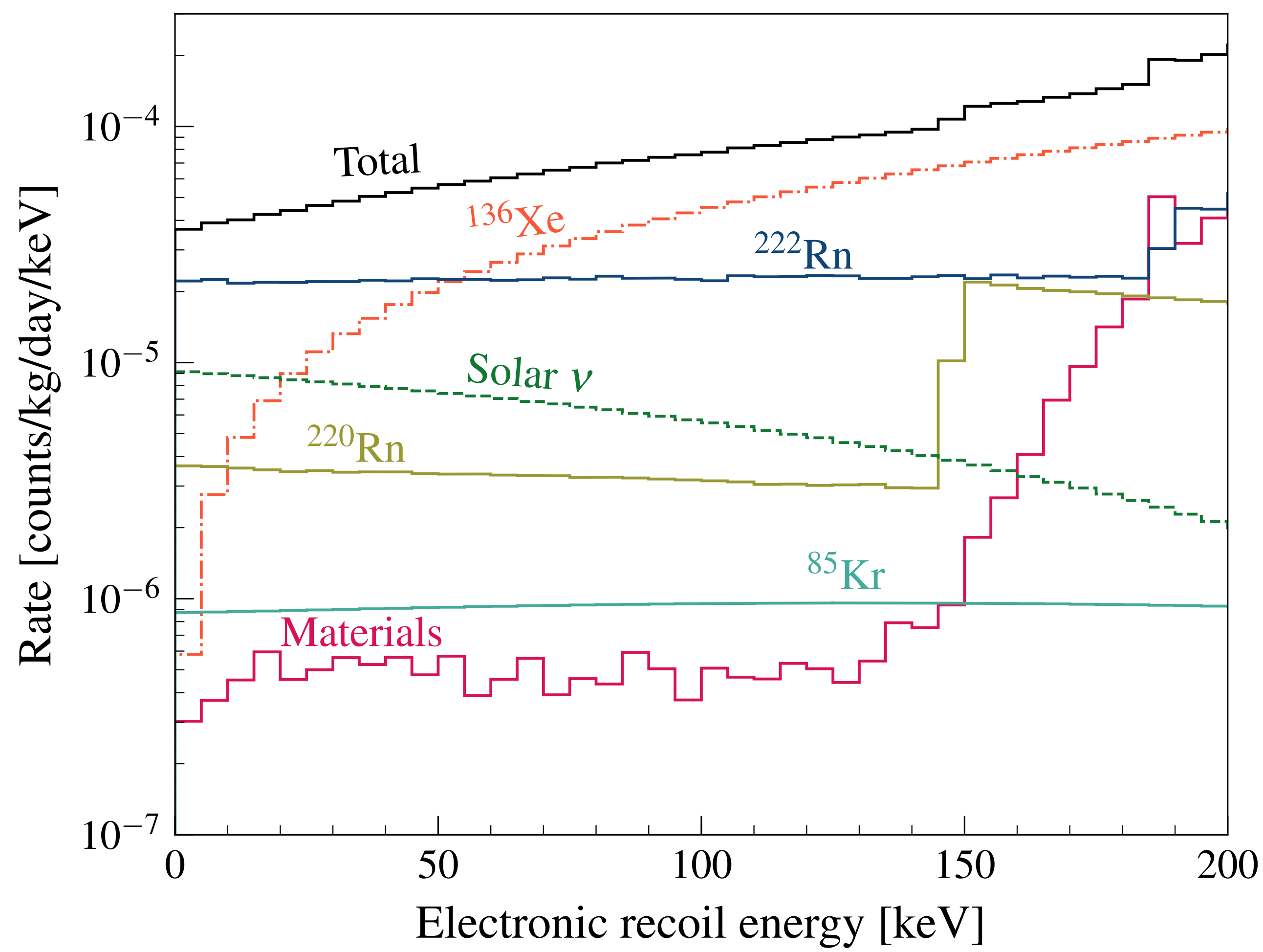
Projected background rates

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

Nuclear recoils



Electron recoils



Counts/1000 days: WIMP-search ROI

5.6 ton fiducial, 1000 live-days

~1.5 - 6.5 keV, single scatters, no coincident veto

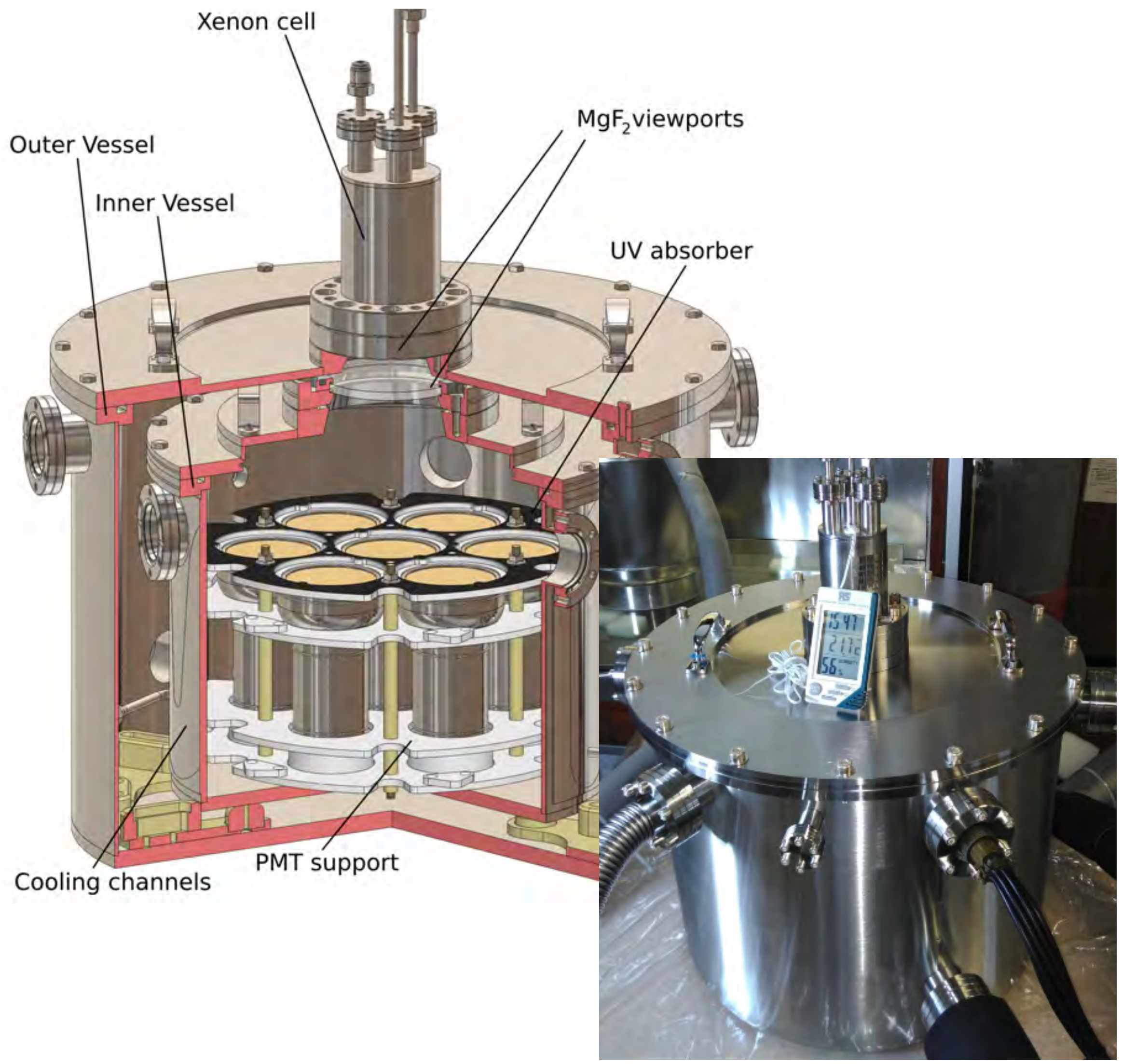
Background Source	ERs	NRs
Detector Components	9	0.07
Dispersed Radionuclides — Rn, Kr, Ar	816	—
Laboratory and Cosmogenics	5	0.06
Surface Contamination and Dust	40	0.39
Physics Backgrounds — 2β decay, neutrinos*	322	0.51
Total **(after 99.5% discrimination and 50% NR efficiency)**	**6.48**	

*** not including ^{8}B and hep**

Measurement-driven detector model

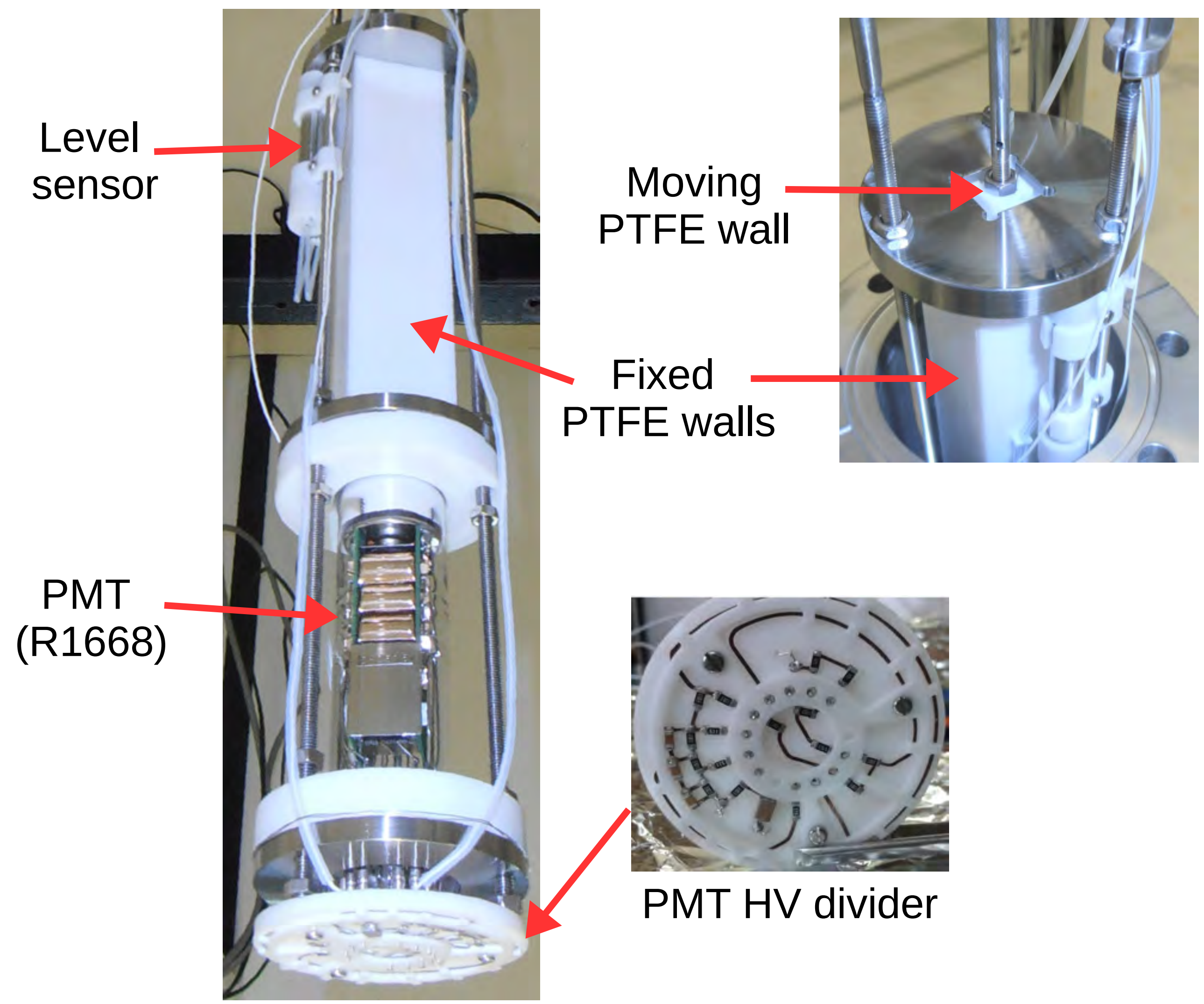
TPC light collection efficiency now 11.9% (cf. 7.5% TDR baseline)

Characterisation of LZ PMTs
@ Imperial College London



arxiv.org/abs/1801.01597

LZ PTFE reflectivity measurements
@ LIP Coimbra



arxiv.org/abs/1612.07965

Sensitivity estimates

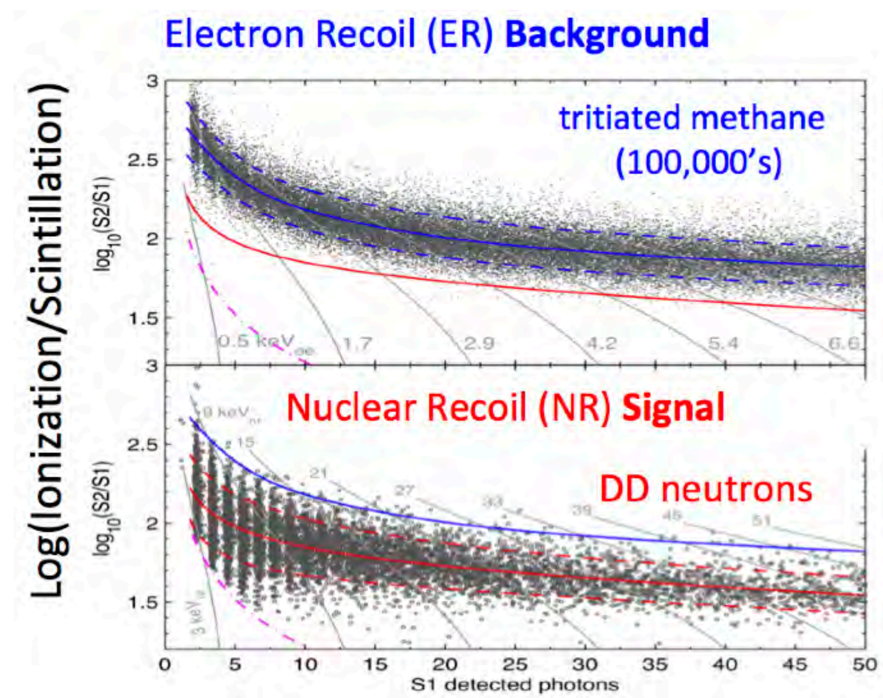
Projected background spectra → **LZ detector response + NEST**

WIMP spectra → **LZ detector response + NEST**

Based on measurements of materials/ components procured for LZ → **LZ detector response + NEST**

NEST models charge + light prod. in LXe: anchored to LUX + world data → **LZ detector response + NEST**

LZ detector response + NEST → **PDFs: (S1, S2)** → **Profile likelihood ratio (PLR)**



$$q_\sigma = -2\ln\lambda = -2\ln\left(\frac{L(\sigma,\hat{\hat{\nu}})}{L(\hat{\sigma},\hat{\nu})}\right)$$

$$L(\sigma,\boldsymbol{\nu}|\mathcal{D}_{\rm obs}) = \mathrm{Pois}(n|\mu) \times \prod_{i=1}^{n}\frac{1}{\mu}\left[n_s(\sigma)f_s(\boldsymbol{x}_i|m_\chi) + \sum_{b=1}^{N_{\rm bkg}} n_b f_b(\boldsymbol{x}_i)\right] \times \prod_{k=1}^{N_{\rm bkg}}\mathcal{N}(n_k|\mu_k,\sigma_k)$$

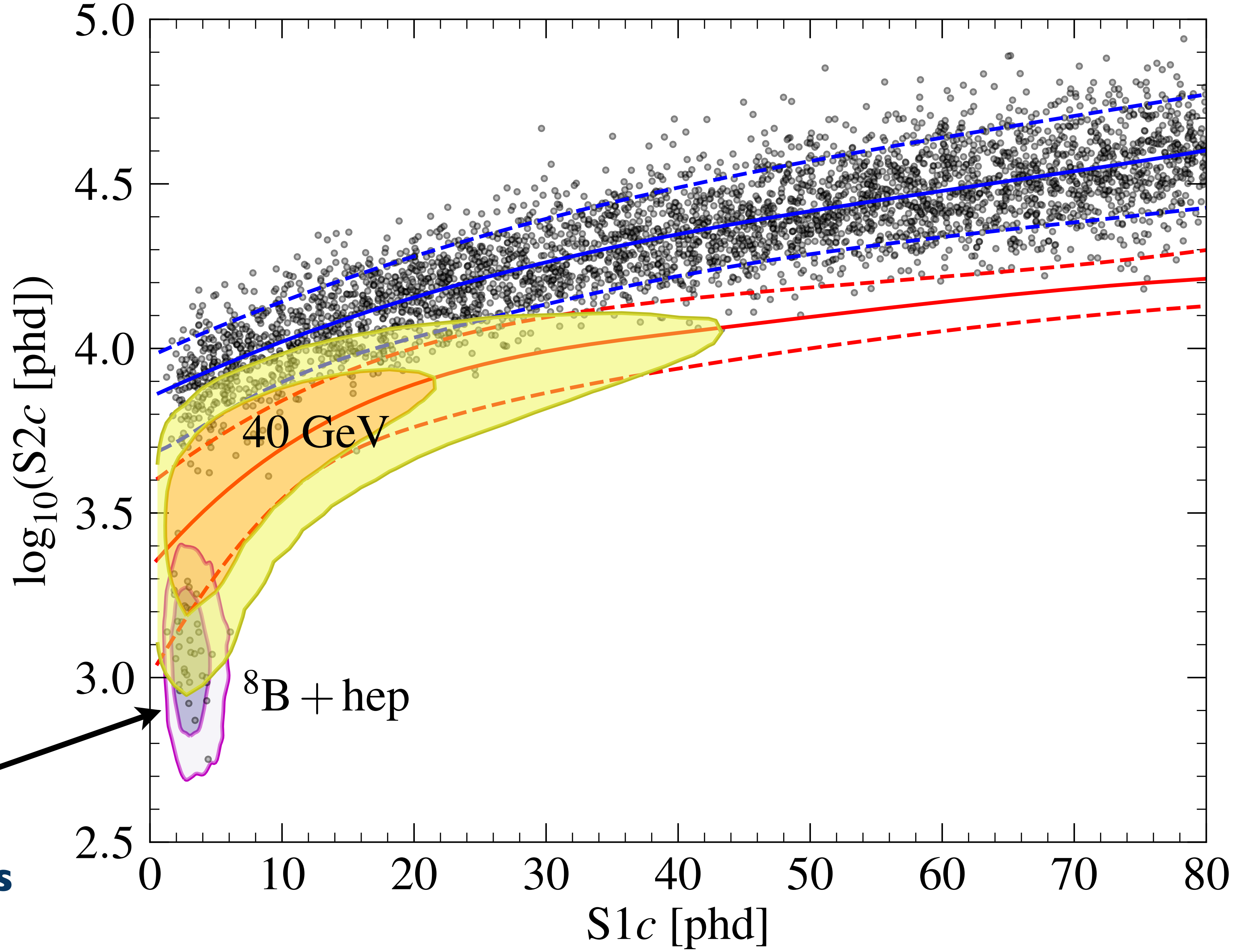
σ: parameter of interest
$\boldsymbol{\nu}$: nuisance parameters

n: observed number of data events
μ: expected number of data events
n_s: number of signal events
n_b: number of events of bkg source b

$$\mu = n_s + \sum_{b}^{N_{\rm bkg}} n_b$$

$\mathcal{N}$: Gaussian function
$N_{\rm bkg}$: number of bckg sources

Monte Carlo of 1000-day run



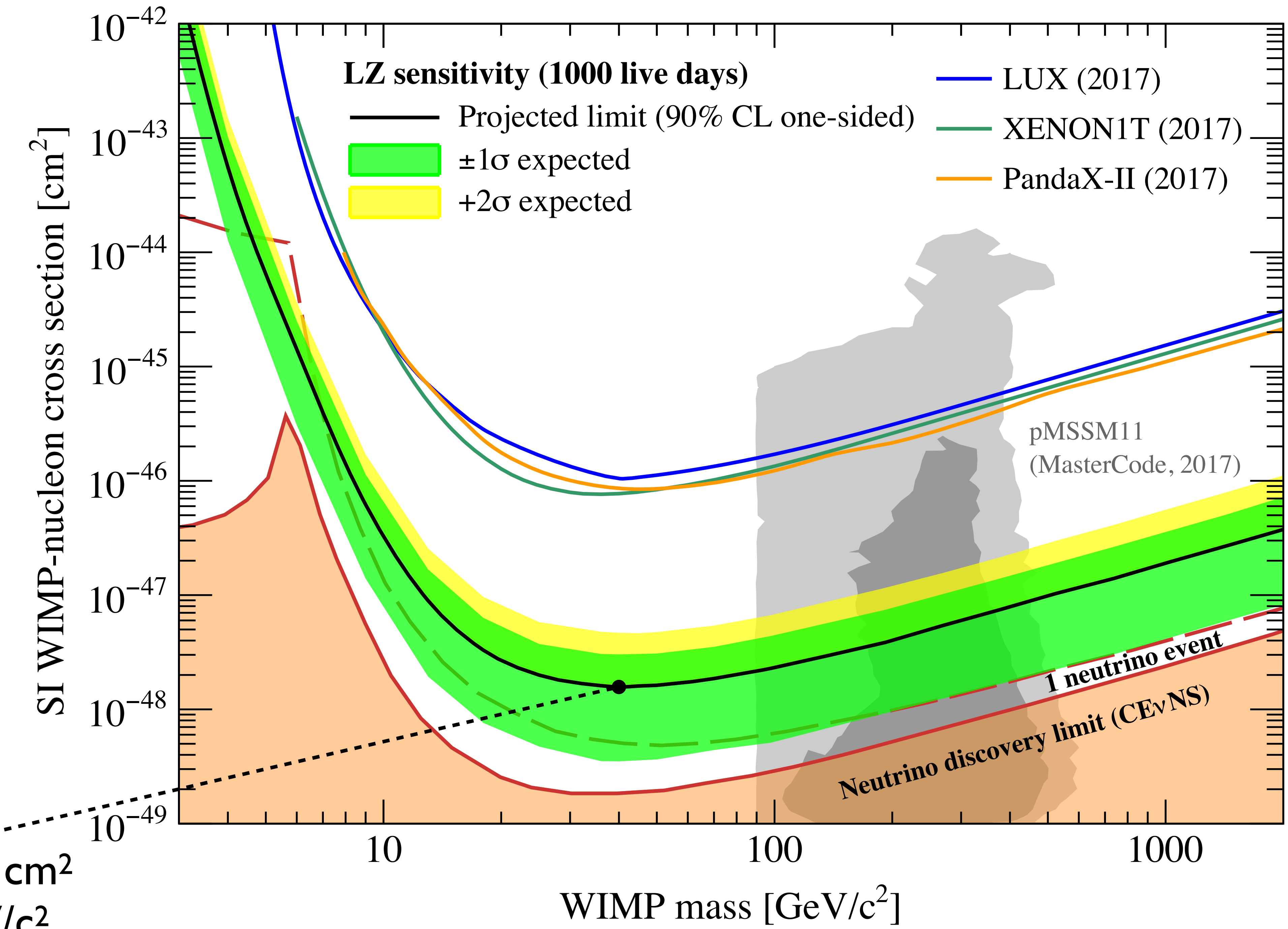
→ charge signal (S2)

→ light signal (S1)

Expect ≈36

→ low-energy NR calibrations critical

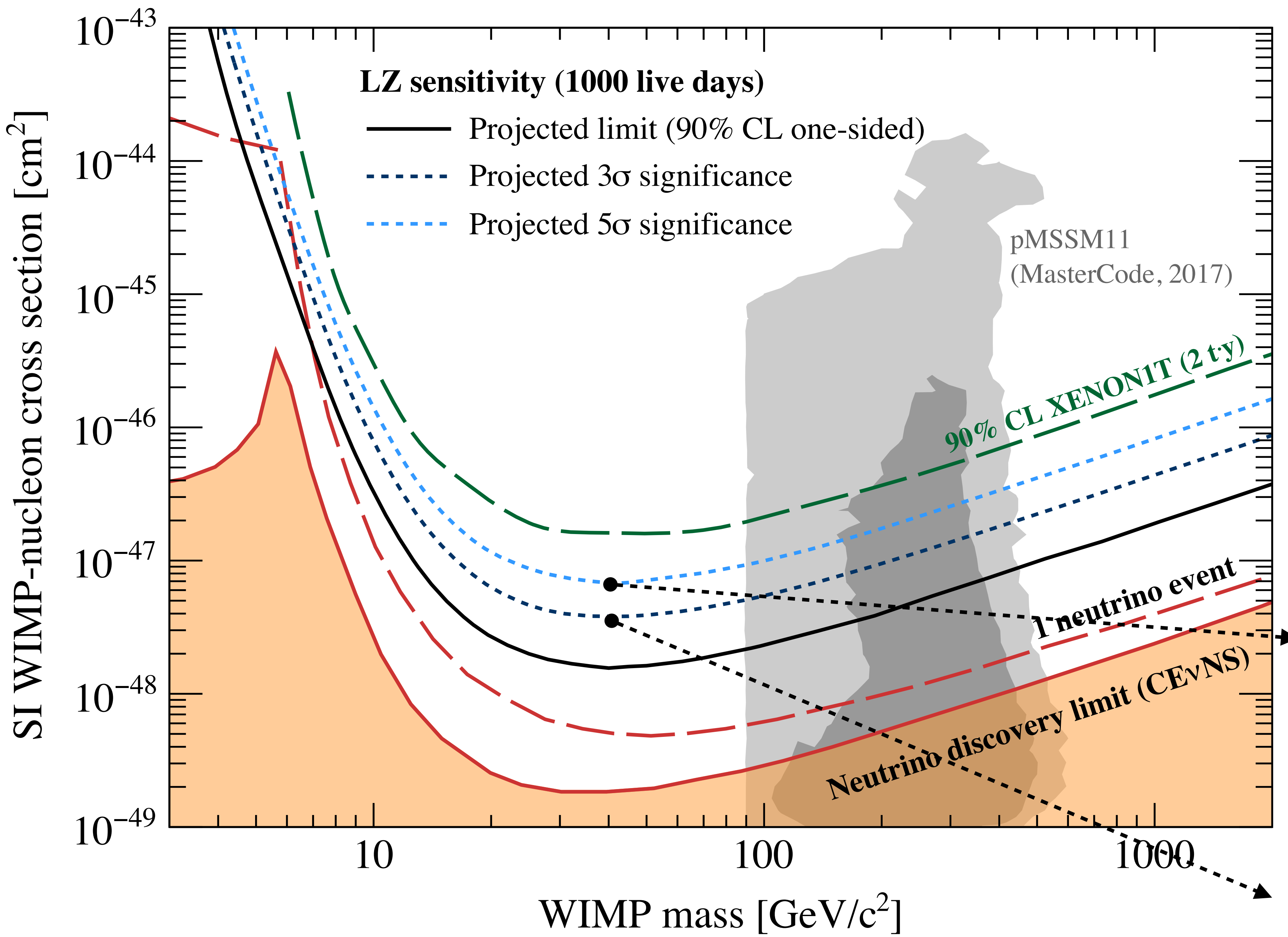
Projected WIMP sensitivity
(1000 live-days 5.6 tonne fiducial)



1.6×10^{-48} cm² @ 40 GeV/c²

3σ and 5σ discovery potential

(1000 live-days 5.6 tonne fiducial)



5σ: 6.7×10^{-48} cm²

3σ: 3.8×10^{-48} cm²

Summary

- **LZ is optimised for WIMP discovery**
  - 7-tonne active mass + low energy threshold
  - Extensive radio-assay and surface cleanliness → BG control
  - Near-hermetic active veto system suppresses remaining NR backgrounds
- **Order of magnitude sensitivity improvement beyond running experiments**
  - → exploring new WIMP parameter space
  - → 5σ discovery potential
- **Will have sensitivity to other signals:**
  - Astrophysical neutrinos, ALPs, $0\nu\beta\beta$, …
- **Underground installation 2019 → physics data 2020**

LZ projected sensitivity paper: arxiv.org/abs/1802.06039

Backups

	Background Source	Mass (kg)	U early (mBq/kg)	U late (mBq/kg)	Th early (mBq/kg)	Th late (mBq/kg)	Co60 (mBq/kg)	K40 (mBq/kg)	n/yr	ER (cts)	NR (cts)
External Backgrounds	**Detector Components**									**9**	**0.07**
	PMT Structures	122	3.89	0.95	0.72	0.65	0.23	3.28	13.6	0.31	0.002
	R11410 3" PMTs	92	71.6	3.20	3.12	2.99	2.91	15.4	81.8	1.27	0.011
	R8778 2" PMTs	6	138	59.4	16.9	16.9	16.2	413	53.0	0.05	0.006
	R8520 Skin 1" PMTs	2	62.2	5.29	4.91	4.85	24.4	337	53.7	0.02	0.005
	PMT Bases	3	359	78.0	39.1	33.4	1.06	55.4	28.9	0.28	0.002
	PMT Cabling	83	6.19	7.06	1.34	1.67	0.01	6.45	17.5	0.89	0.001
	TPC PTFE	184	0.02	0.02	0.03	0.03	0.00	0.12	22.5	0.04	0.006
	Grid Wires and Rings	96	7.39	2.76	2.49	2.28	10.0	28.0	16.3	3.64	0.005
	Field Shaping Rings	92	5.49	1.14	0.72	0.65	0.00	2.00	41.0	0.65	0.011
	TPC Sensors and Thermometers	5	21.8	5.82	2.29	1.88	1.32	61.0	6.75	0.06	0.001
	PMT Conduits, HX and Tubing	215	3.18	0.46	0.46	0.56	1.23	1.39	5.87	0.03	0.001
	HV Conduits and Cables	138	3.61	2.30	0.61	0.76	1.4	2.5	26.5	0.02	0.001
	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
	Surface Contamination									**40**	**0.39**
	Dust (intrinsic activity, 500 ng/cm2)									0.2	0.05
	Plate-out (PTFE panels, 50 nBq/cm2)									-	0.05
	210Bi mobility (0.1 μBq/kg)									40.0	-
	Ion-misreconstruction (50 nBq/cm2)									-	0.16
	210Pb (in bulk PTFE, 10 mBq/kg)									-	0.12
	Laboratory and Cosmogenics									**5**	**0.06**
	Laboratory Rock Walls									4.6	0.00
	Muon Induced Neutrons									-	0.06
	Cosmogenic Activation									0.2	-
Internal Backgrounds	**Xenon Contaminants**									**816**	**0**
	222Rn (1.81 μBq/kg)									678	-
	220Rn (0.09 μBq/kg)									111	-
	natKr (0.015 ppt g/g)									24.5	-
	natAr (0.45 ppb g/g)									2.5	-
	Physics									**322**	**0.51**
	136Xe 2νββ									67	0
	Solar neutrinos (pp+7Be+13N)									255	0
	Diffuse supernova neutrinos									0	0.05
	Atmospheric neutrinos									0	0.46
	Total									1192	1.03
	Total (with 99.5% ER discrimination, 50% NR efficiency)									5.96	0.51
										6.48	

Key detector parameters

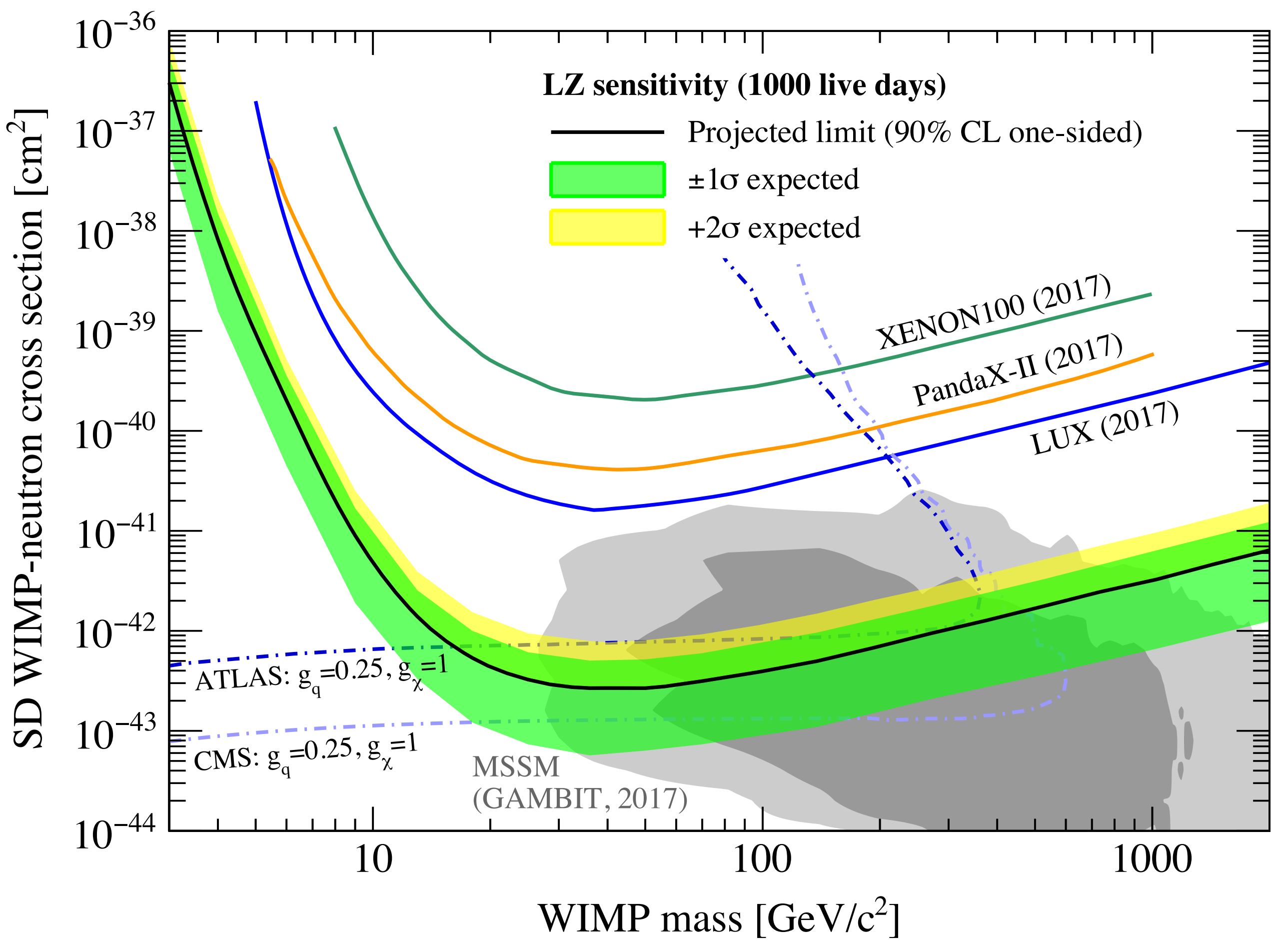
Detector Parameter	Value
Photon Detection Efficiency (PDE)	
PDE in liquid (g_1) [phd/ph]	0.119
PDE in gas ($g_{1,\mathrm{gas}}$) [phd/ph]	0.102
Single electron size [phd]	83
Effective charge gain (g_2) [phd/e]	79
PTFE-LXe reflectivity	0.977
LXe photon absorption length [m]	100
PMT efficiency at 175 nm	0.269
Other Key Parameters	
Single phe trigger efficiency	0.95
Single phe relative width (Gaussian)	0.38
S1 coincidence level	3-fold
S2 electron extraction efficiency	0.95
Drift field [$\mathrm{V\,cm^{-1}}$]	310
Electron lifetime [µs]	850

Spin-dependent sensitivity

Naturally occurring Xe: ≈50% odd neutron isotopes (26.4% ^{129}Xe and 21.2% ^{131}Xe by mass)

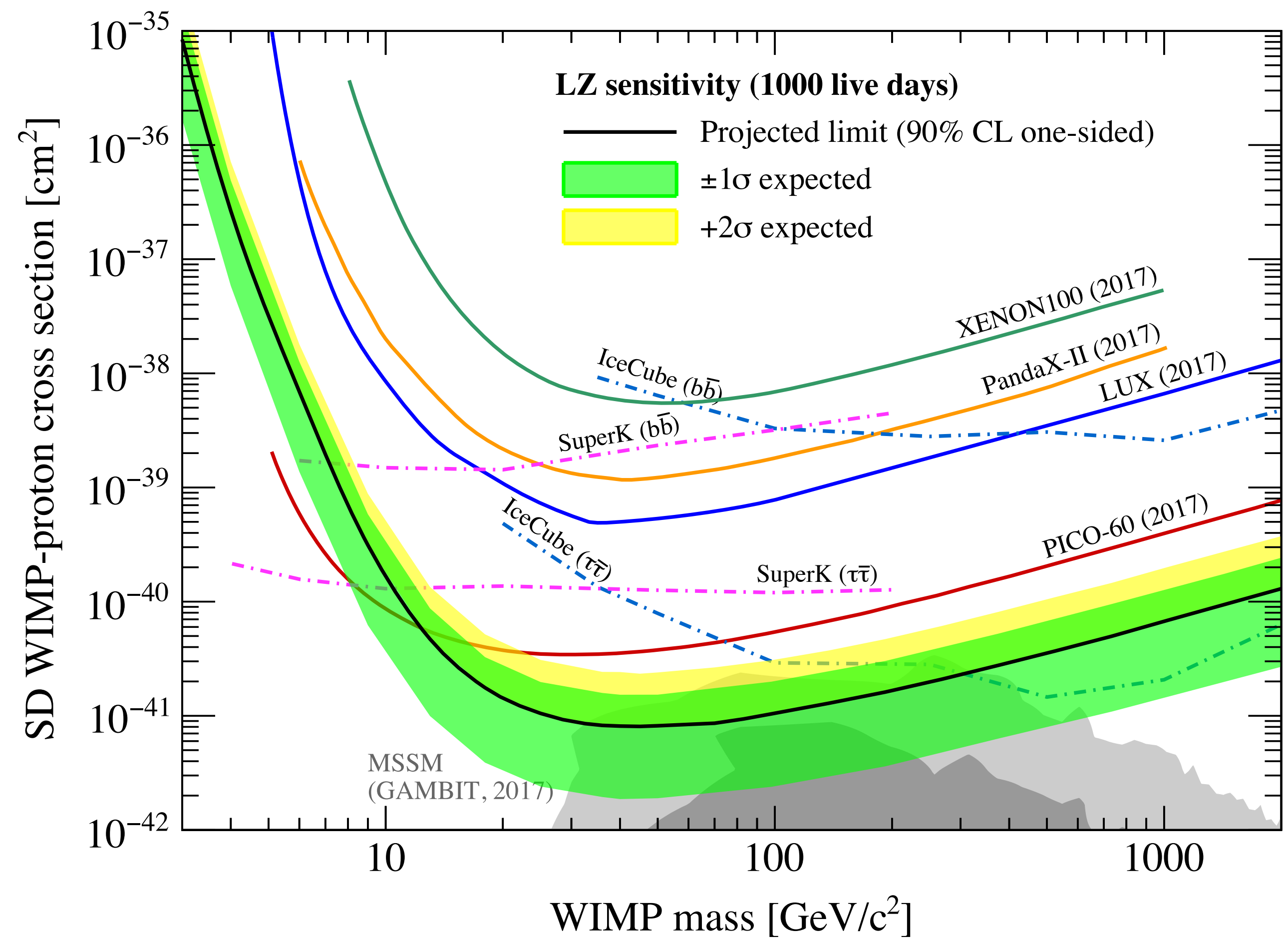
SD WIMP-neutron

2.7×10^{-43} @ 40 GeV/c^2



SD WIMP-proton

8.1×10^{-42} @ 40 GeV/c^2



Spin structure functions from Klos *et al*, Phys. Rev. D89, 029901 (2014) + SHM

Sensitivity vs Rn-level