Background Model and Science Reach of the LUX-ZEPLIN Experiment

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The LUX-ZEPLIN (LZ) Detector

- LZ is a 2-phase (liquid/gas) xenon time projection chamber (TPC) with 7 t of active mass, primarily designed to search for keV-scale nuclear recoils from WIMP interactions [1].
- It is surrounded by two veto detectors — a Gd-loaded liquid scintillator outer detector and a xenon skin —, which help to identify and reject interactions from radioactive backgrounds with high efficiency [2].
- It is installed 1 mile underground at the Sanford Underground Research Facility (SURF), and first physics data is expected later this year, in 2021.

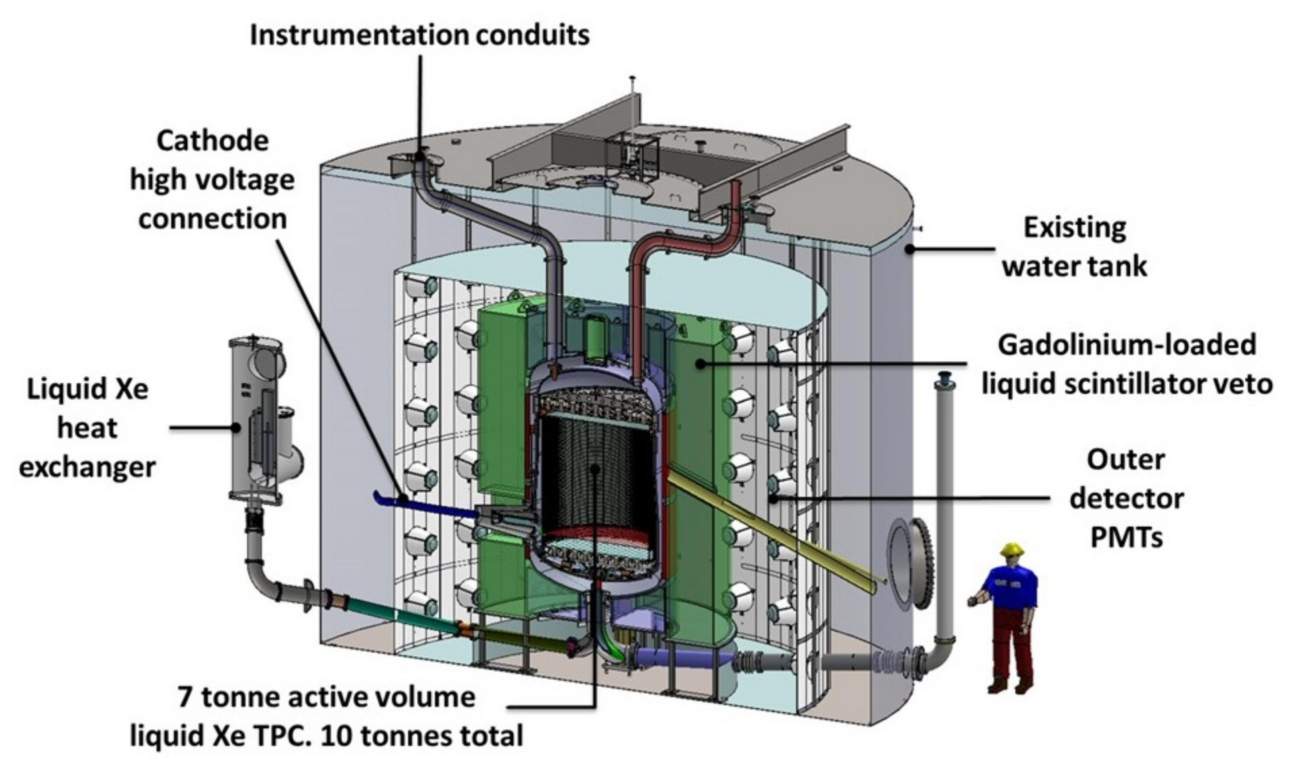

Figure 1: LZ design schematic

Operation Principle

- Interactions in the liquid xenon produce prompt scintillation (S1) and ionisation electrons. Electrons are drifted to the gas region above the liquid by an applied field, where they produce the secondary signal (S2) via electroluminescence.
- Both signals are detected by two arrays, with a total of 494 photomultipliers.
- The active region is surrounded by highly reflective PTFE panels to maximize S1 light collection.
- The deposited energy is reconstructed using both the S1 and S2 signals.
- 3D position reconstruction is achieved using the time difference between the signals (*z*) and the S2 light distribution pattern in the top array (*x,y*).
- The ratio between S1 and S2 allows to discriminate between WIMP-like nuclear recoils (NRs) and electron recoils (ERs) from beta particles and gamma-ray interactions with >99.5% efficiency.

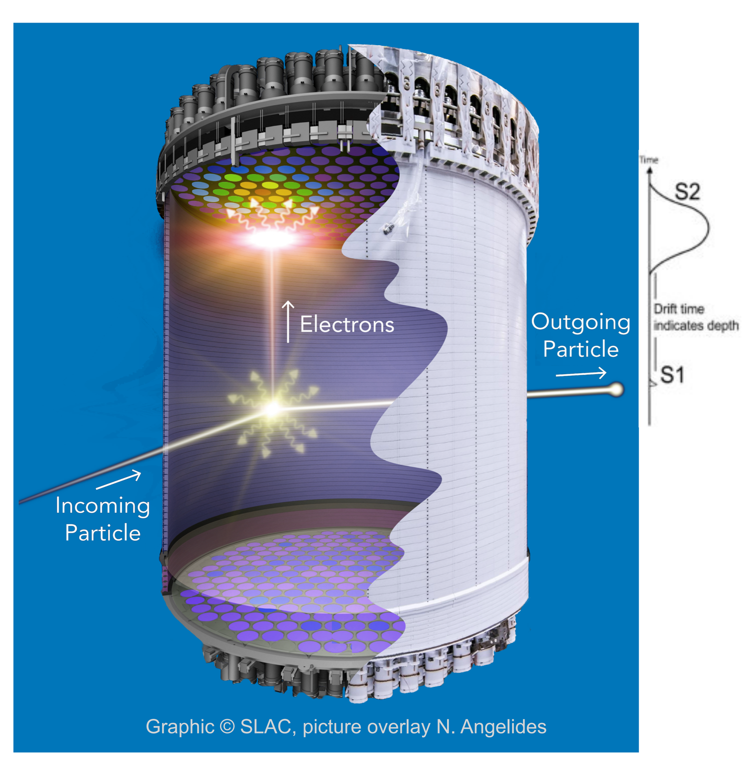

Figure 2: TPC working principle

Background Model

- The 4300 m water equivalent overburden reduces the muon flux by ~10^7.
- Installation inside a water tank, for shielding from environment backgrounds.
- Selection of radio-pure materials for detector construction based on ~2000 assays with 13 HPGe detectors, ICPMS and neutron activation analysis. Materials in contact with xenon screened for radon emanation [3].
- Taking advantage of xenon self-shielding and the veto systems multiple-scatter rejection efficiency, an optimal fiducial volume of 5.6 tonnes with much lower rate of external backgrounds can be defined in the central region of the TPC [1].

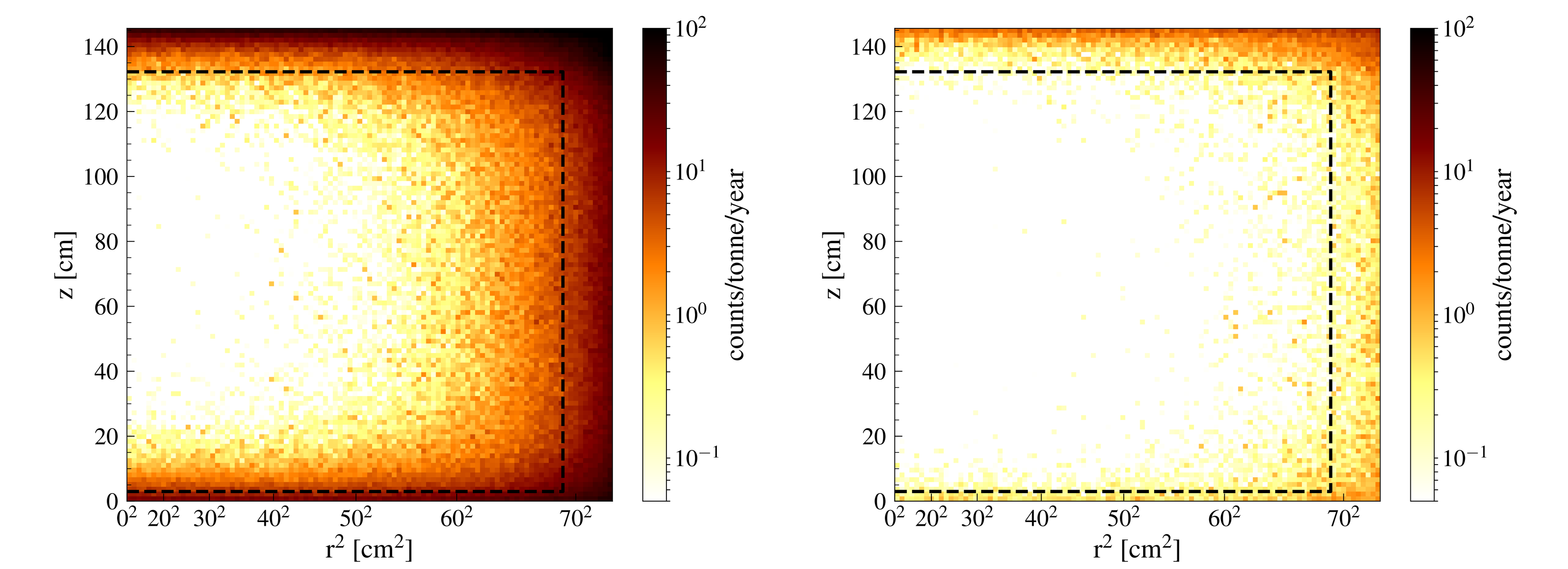

Figure 3: LZ NR backgrounds before (left) and after (right) applying vetoes. The fiducial volume, represented by the dashed lines, can be increased to 5.6 t (80% of active mass). [1]

- The background in the fiducial volume is dominated by internal xenon contaminants: (^{222}Rn, ^{220}Rn and their daughters; ^{85}Kr), double beta decay in ^{136}Xe and neutrino interactions [1].
- Background sources were simulated with the GEANT4-based BACCARAT framework and normalised with the assay results, to produce the final background model [1,4].

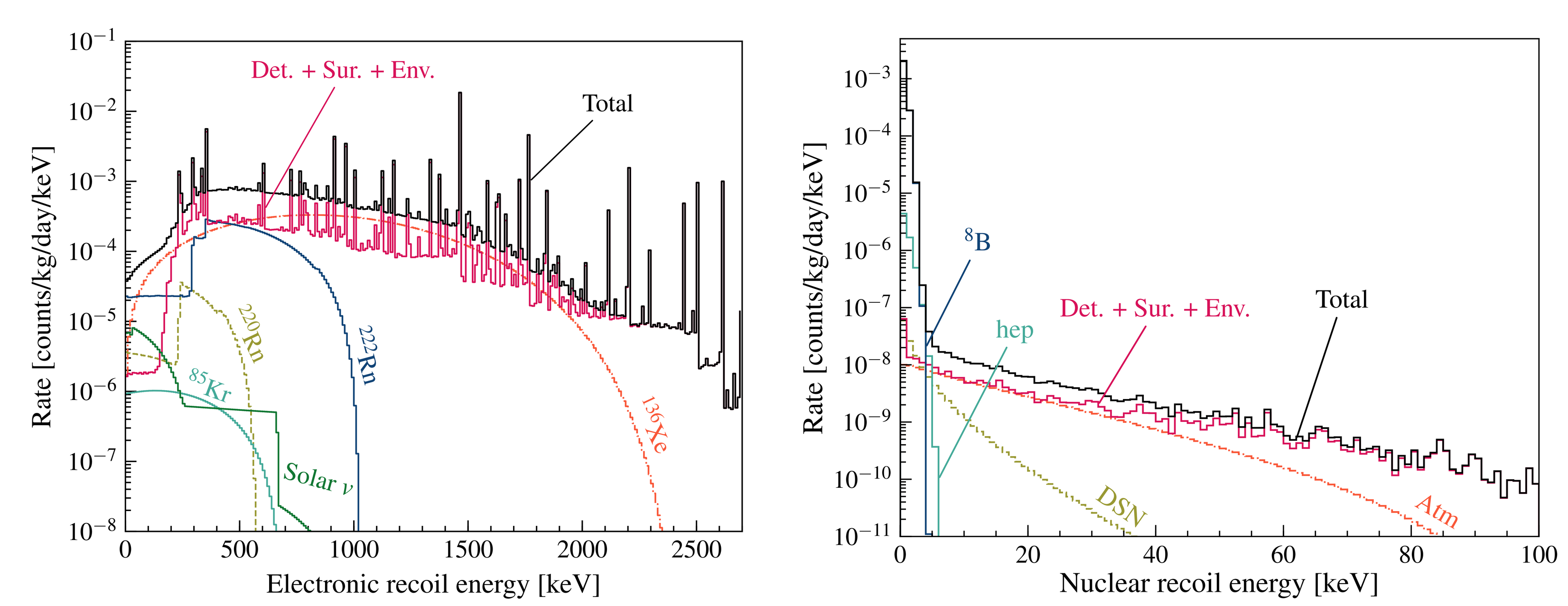

Figure 4: LZ ER and NR spectra of single scatter background events in the 5.6 tonne fiducial volume with no coincident veto signal in the xenon skin or the outer detector [1].

Background Source	ERs	NRs
Detector Materials and Environment	14	0.13
Surface Contamination and Dust	40	0.39
Dispersed Radionuclides — Rn, Kr, Ar	819	—
Physics Backgrounds — ^{136}Xe 2β decay, neutrinos*	258	0.51
Total (after 99.5% discrimination and 50% NR efficiency)	**6.18**	

* ^{8}B and hep not included

Table 1: Summary of single scatter non-vetoed backgrounds in LZ in the 5.6 t fiducial volume and in the region of interest for a 40 GeV/c² WIMP (1.5 - 6.5 keV_{ee}, 6 - 30 keV_{nr}).

Sensitivity Projections

- The background model is used in the estimate of the projected sensitivity of LZ to WIMPs, using the unbinned profile likelihood ratio (PLR) method.
- The sensitivity is calculated for a 1000-day run and the 5.6 t fiducial volume, and is defined as the median 90% CL upper limit on the WIMP-nucleon cross-section that would be obtained from a repeated set of background-only experiments.

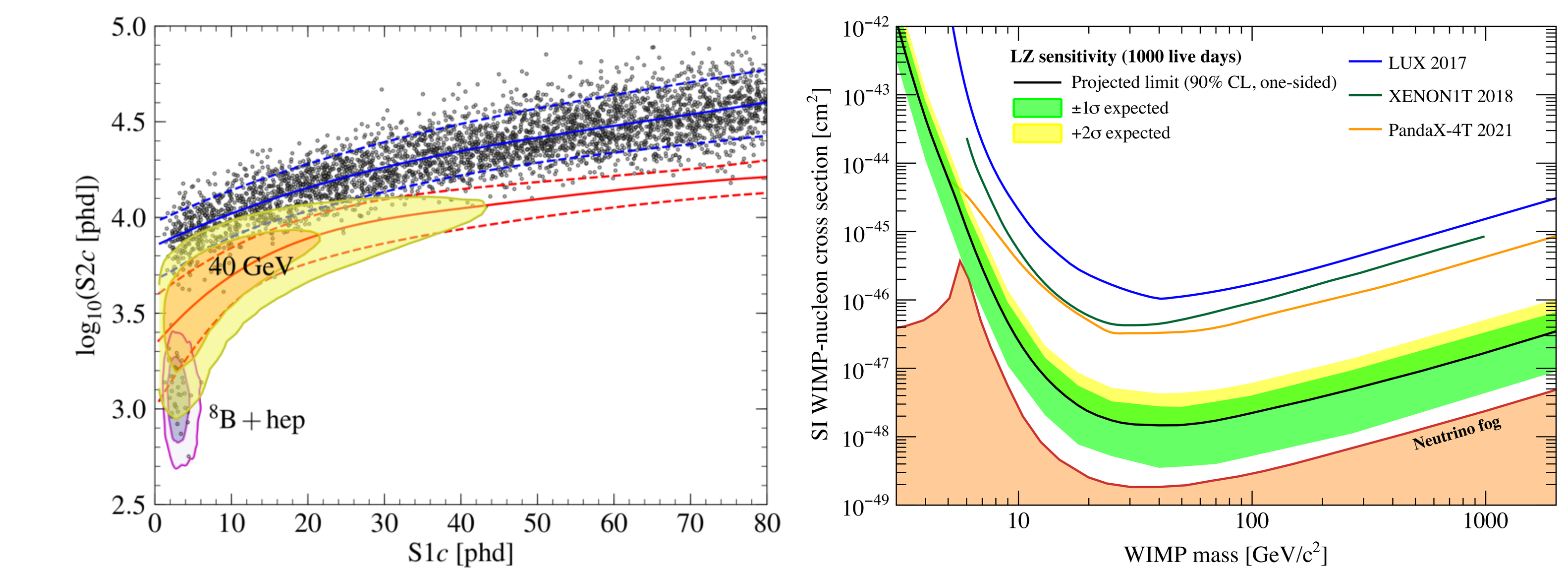

Figure 5: *Left:* simulated distribution of events in the 5.6 t fiducial volume for a 1000-day background only run of LZ, along with the 1σ and 2σ contours of the low energy ^{8}B and *hep* solar neutrino NR backgrounds and a 40 GeV/c² WIMP. *Right:* LZ projected SI sensitivity to WIMPs, with a minimum of 1.4×10^{-48} cm² for a WIMP mass of 40 GeV/c². [1]

- The model is also used to study other rare events (e.g. ^{134}Xe 2νββ decay) and search for new physics (e.g. ^{136}Xe 0νββ decay, axions and ALPs). The size and low background environment of LZ allow it to reach world-leading or competitive sensitivities in several areas beyond WIMP search.

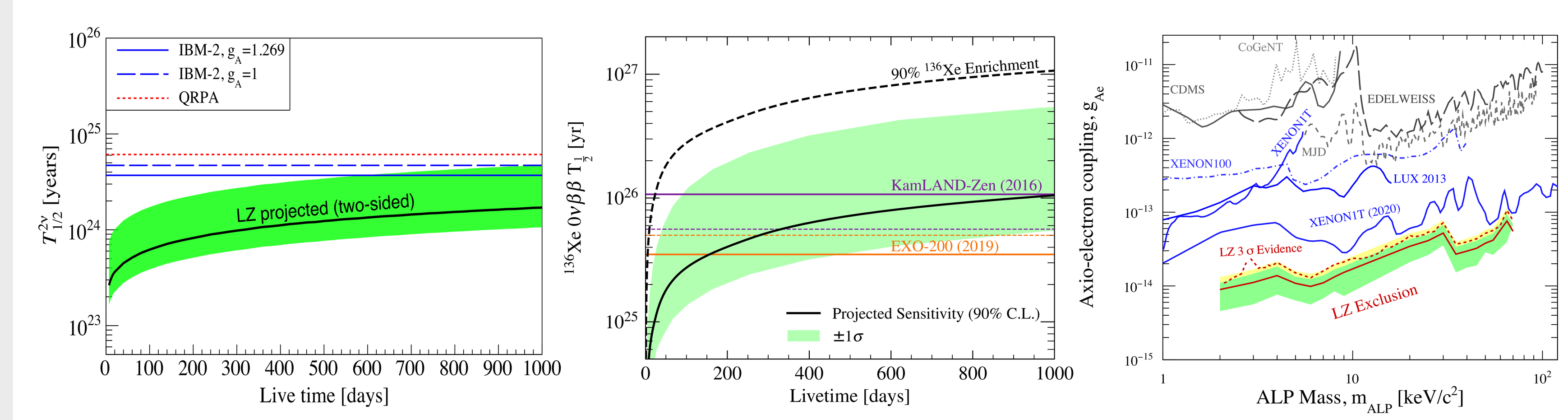

Figure 6: LZ sensitivity projections in a 1000-day run for (left to right): the half-life of 2νββ decay in ^{134}Xe [5], the half-life of 0νββ decay in ^{136}Xe [6] and the axio-electric coupling for galactic ALPs [7].

References

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Acknowledgements

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