SOLAR BORON-8 NEUTRINO DETECTION WITH THE LZ DARK MATTER EXPERIMENT

B. López Paredes, on behalf of the LZ Collaboration

Department of Physics, Imperial College London, UK

THE LUX-ZEPLIN (LZ) DARK MATTER DETECTOR

The LZ detector is a liquid xenon Time Projection Chamber (LXe-TPC). It will contain 7 tonnes of active LXe for a self-shielded 5.6-tonne fiducial volume. LZ will start operations in early 2020 in the Davis cavern at SURF, South Dakota [1].

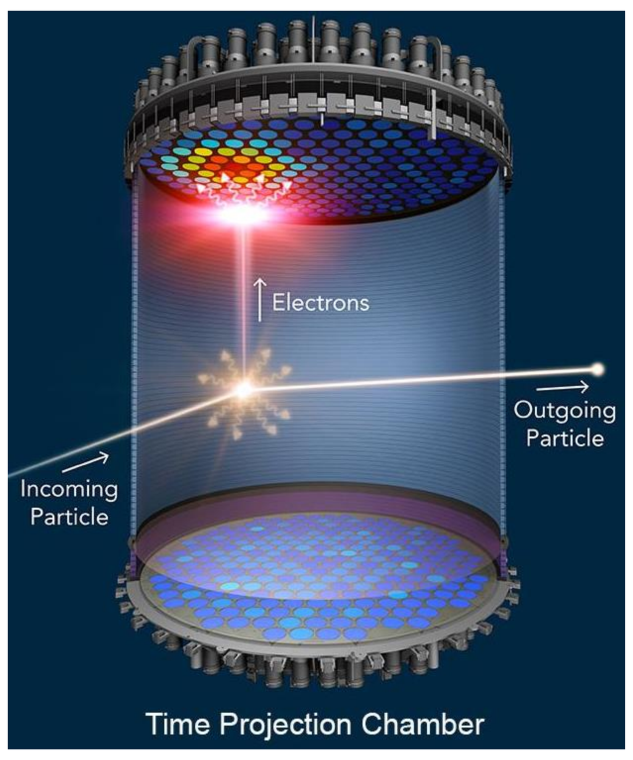

Figure 1: LXe-TPC operation principle. A particle interacting in the LXe produces a prompt scintillation signal (S1) and ionised Xe atoms. The released electrons are swept upwards by an electric field and extracted into the gas phase to produce electroluminescence (S2). These two signals are used to reconstruct both event energy and position.

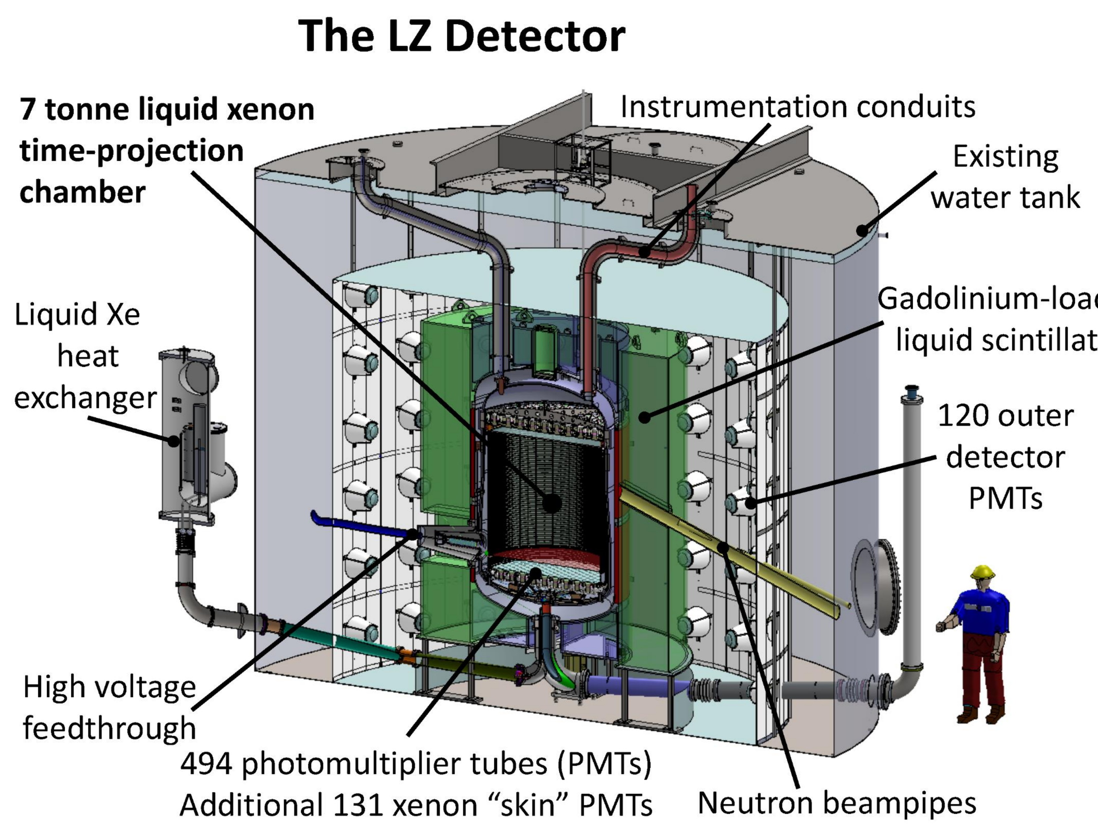

Figure 2: The LZ experiment, consisting of the LXe-TPC, viewed by top and bottom PMT arrays, plus a LXe "skin" and Outer Detector (OD) to veto gammas and neutrons.

WIMP DARK MATTER DETECTION AND BACKGROUNDS

WIMPs should scatter elastically to produce low energy Nuclear Recoils (NR) in LXe. The main NR backgrounds originate via Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) of astrophysical neutrinos. Solar ^{8}B neutrinos represent the highest contribution at low recoil energies, while atmospheric neutrinos dominate at higher energies. While it is paramount to characterise these event rates for the DM search, they also offer interesting prospects for neutrino physics.

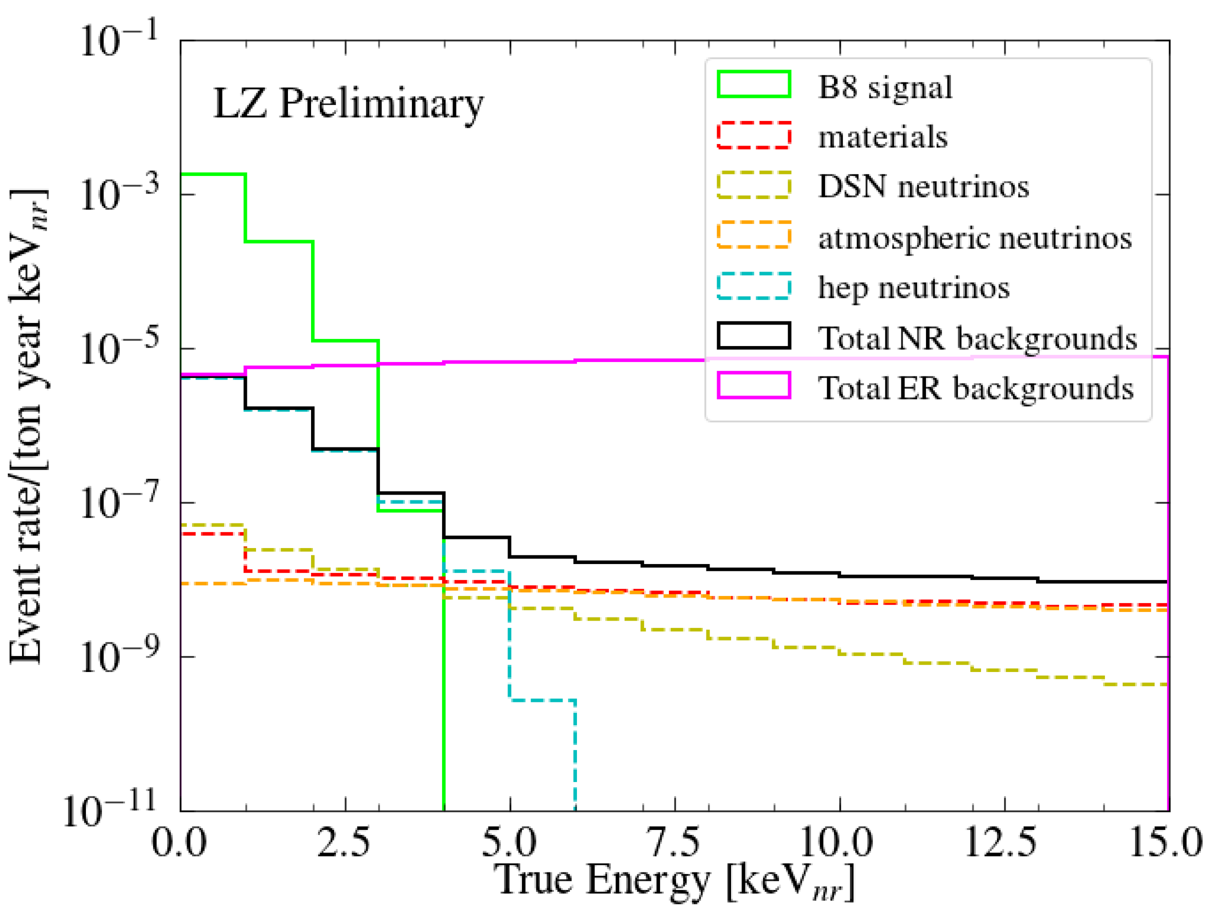

Figure 3: ER and NR background spectra for low energy recoils in the fiducial volume for unvetoed single-scatter events. No detector efficiency or analysis cuts have been applied.

^{8}B NEUTRINO MEASUREMENT WITH LZ

CEvNS is a SM process recently measured by COHERENT [2], and would enable a flavour-blind measurement of solar ^{8}B neutrinos. This $\mathcal{O}$(keV) signature would mimic a ~6 GeV WIMP, observable via upward fluctuations of the S1 response.

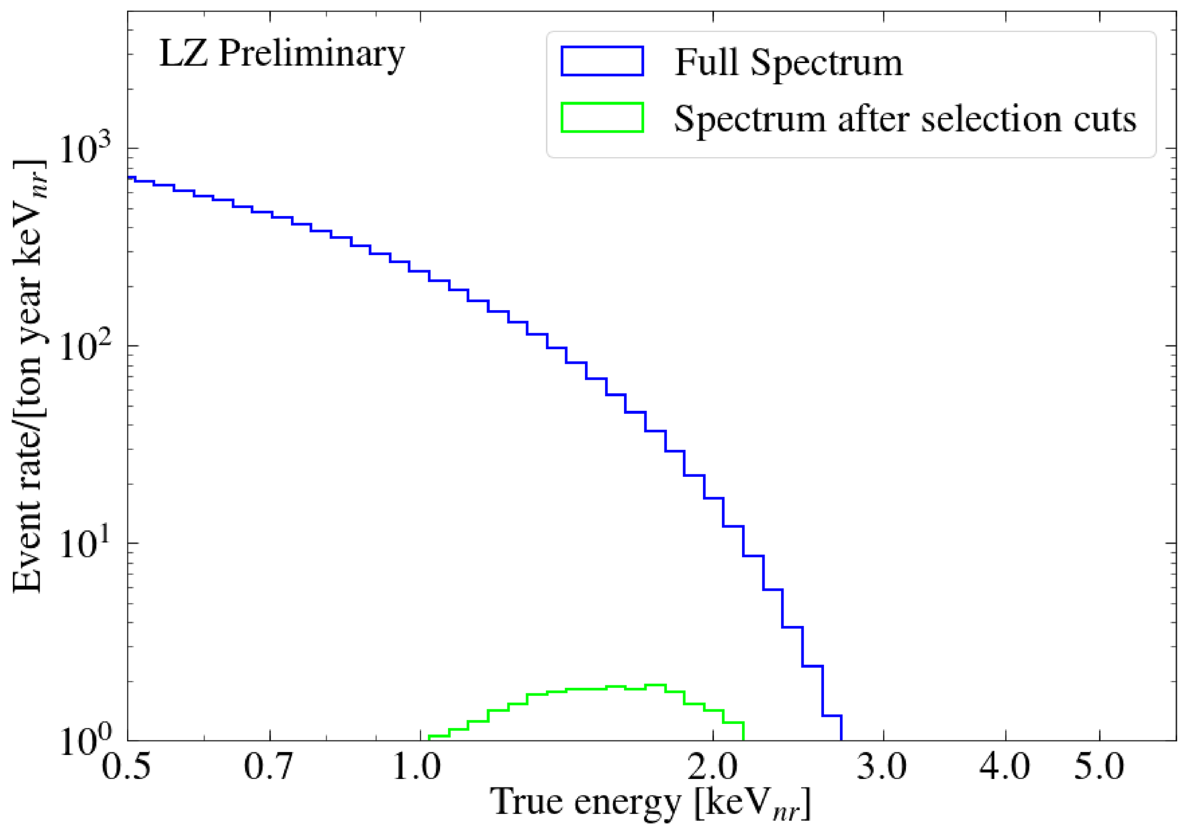

Figure 4: ^{8}B neutrino NR spectrum in LXe (blue) and detected events in LZ (green) for a 3-fold requirement on S1. See Table 1.

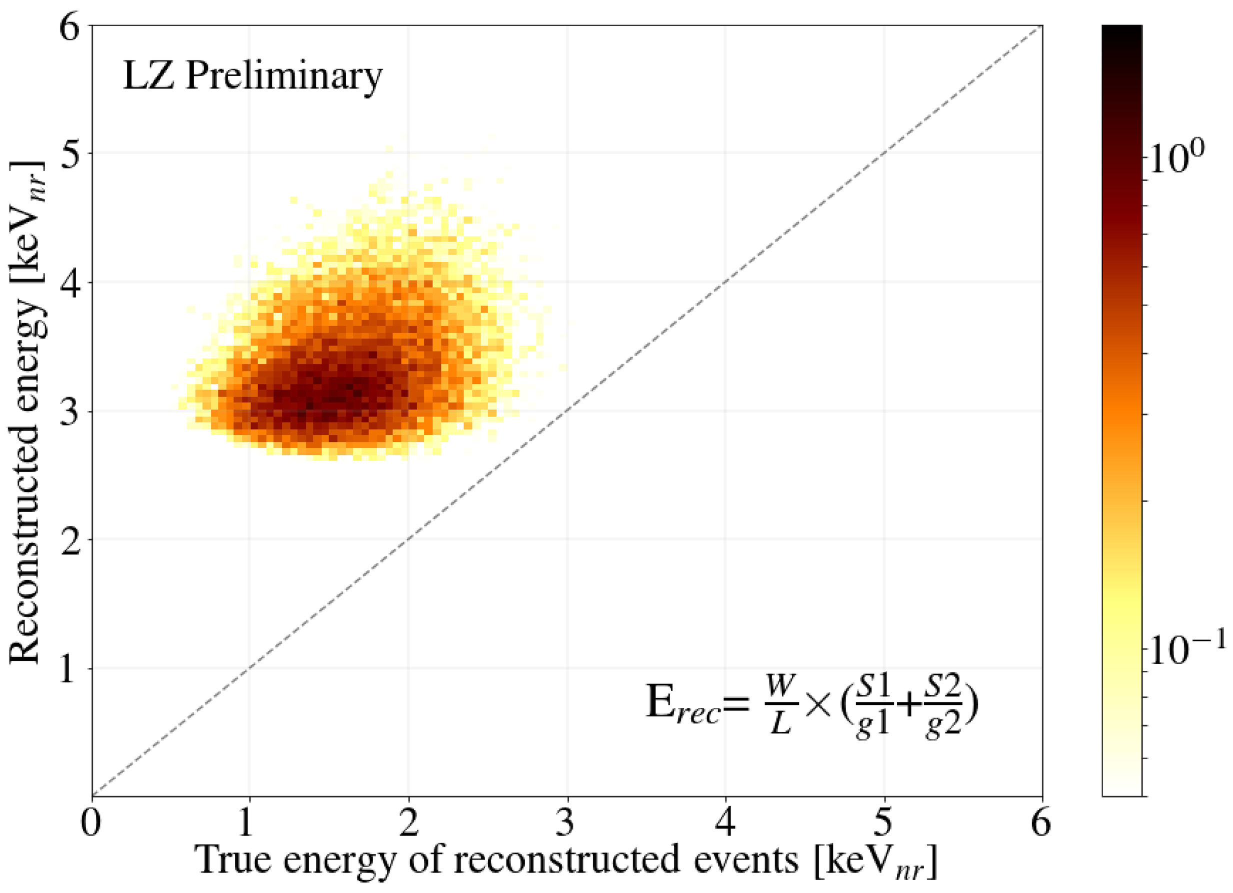

Figure 5: Upward fluctuations on the mean number of detected S1 photons bring ^{8}B neutrino interactions over the LZ threshold, highlighted here by the shift in reconstructed energy. A better reconstruction can be achieved relying more heavily on S2 [3].

A GEANT4 simulation is used to characterise signal and background. The detector electronics response is also simulated and full data reduction and analysis is performed on the simulated data samples.

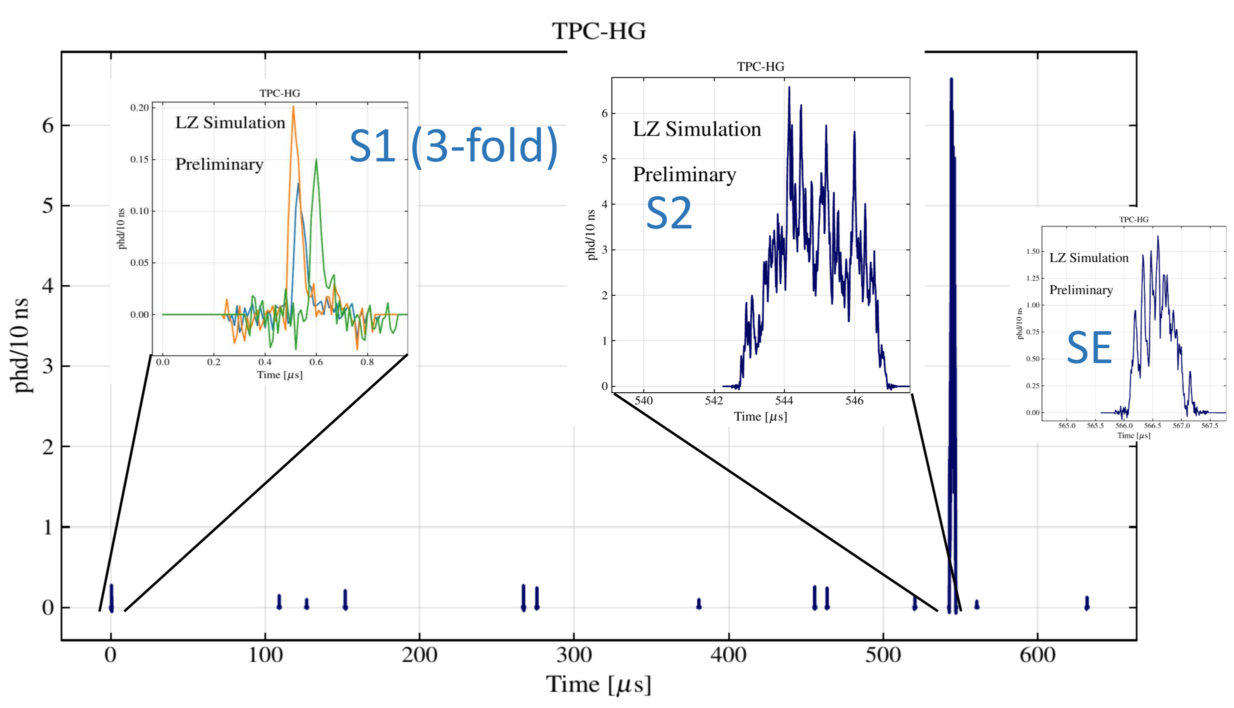

Figure 6: A simulated ^{8}B CEvNS interaction waveform. Accidental coincidences of PMT dark counts (shown between S1 and S2) are removed with the 3-fold requirement.

For the nominal LZ exposure (1000 days), 36 ^{8}B events are expected after cuts, with 95% purity. Figure 7 shows the ^{8}B signal, which appears below the background NR-band due to the upward fluctuations of its small S1.

Table 1: Event counts from Figure 7 before and after analysis cuts

	S1 cut [phd]	E cut [keV$_{nr}$]	S2 cut [phd]	Expected ^{8}B signal	ER bkg counts	NR bkg counts
All events	≥ 3	< 45	-	36	1809	2.5
^{8}B selection	≥ 3	< 5	< 3400 (*38.5 e-*)	36	1	1.0

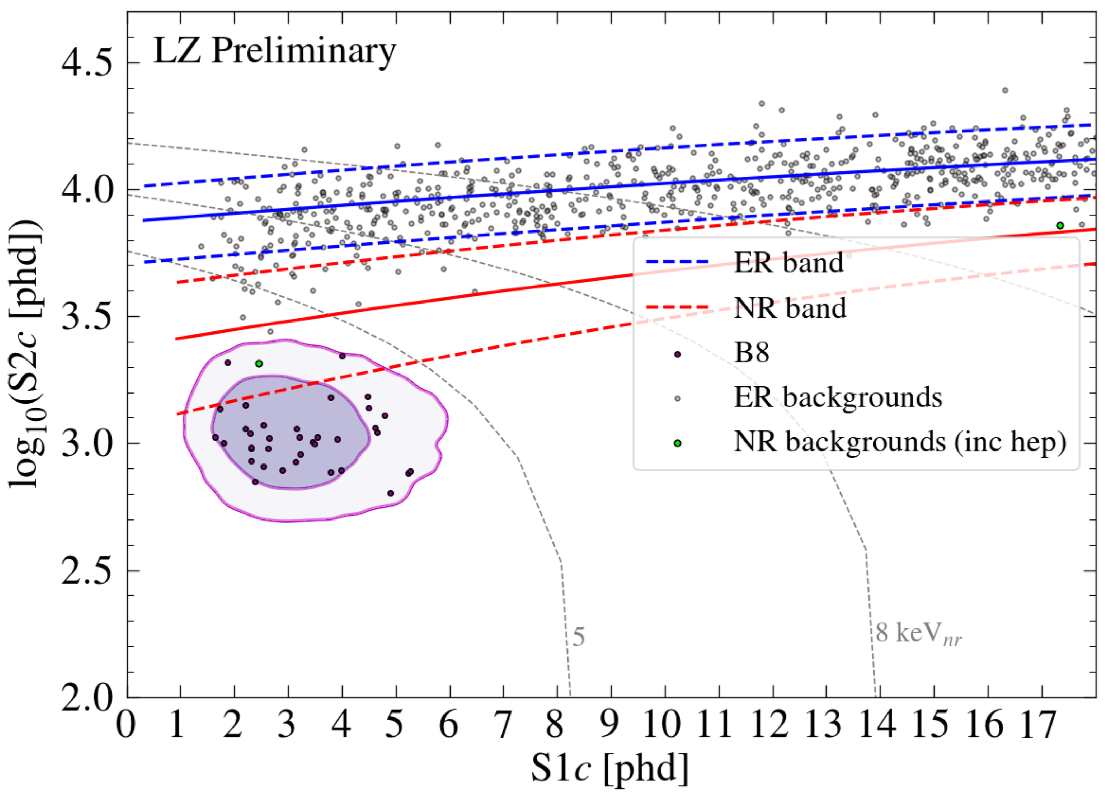

Figure 7: Simulated dataset of LZ exposure, with ^{8}B signal contours shown in violet. Signal can be selected with high purity.

The ability of LZ to make a statistically significant measurement of this signal has been evaluated as a function of livetime. This flux can easily be measured at 5-sigma during the nominal exposure of the experiment even with conservative systematic uncertainties.

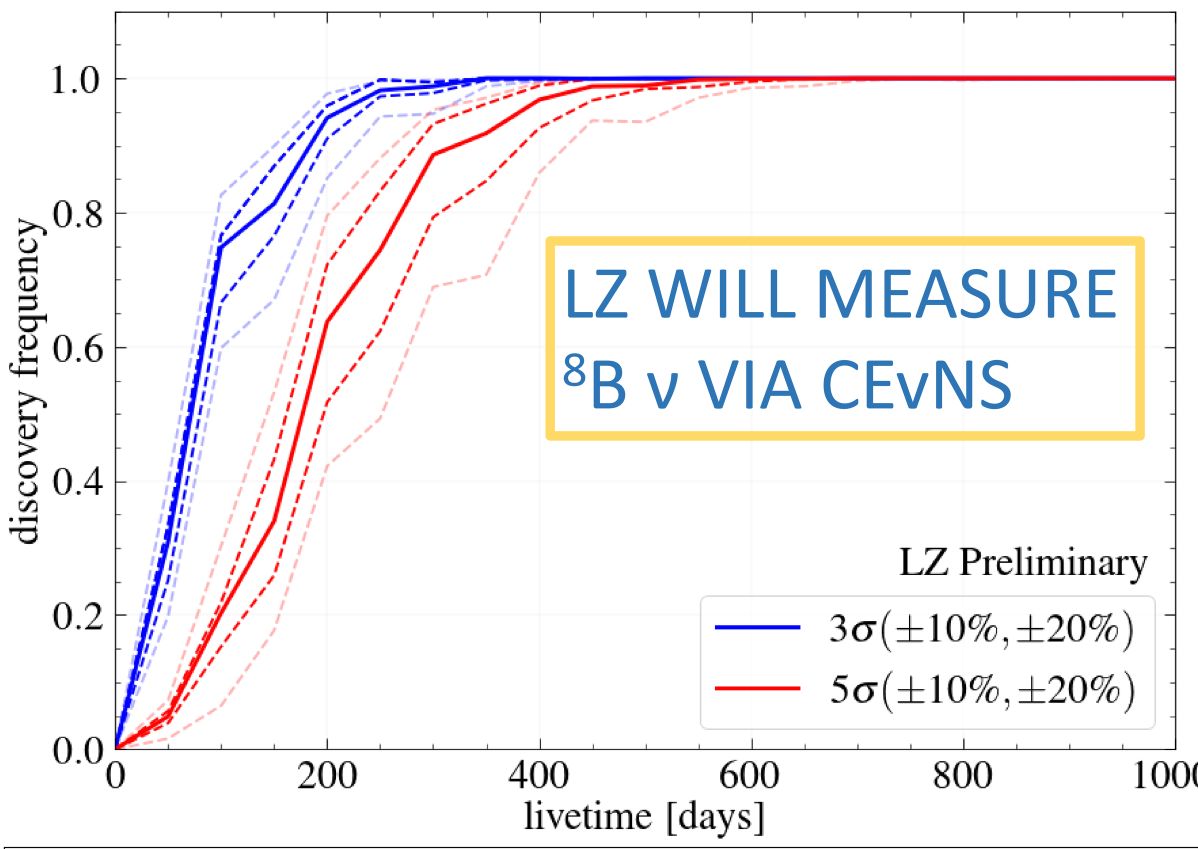

Figure 8: Discovery frequency of ^{8}B flux as a function of livetime. The dashed lines indicate a systematic flux variation of ±10% and ±20% on the 3σ and 5σ discovery significance as a first step towards a full study of uncertainties.

Table 2: ^{8}B ν events in successive DM detector generations

	Exposure	S2 Threshold	^{8}B interactions	^{8}B detections
LUX (Runs 3&4)	~100 kg·year	S2 > 200 phd (8 e$^-$)	~80	0.16 (2 fold) [4]
Current Generation	~1 tonne·year	S2 > 200 phe (6 e$^-$)	~800	~2 (3 fold)
LZ/G2	~15 tonne·year	S2 > 420 phd (5 e$^-$)	~12 000	36 (3 fold)
G3/DARWIN	~150 tonne·year	-	$\mathcal{O}(10^5)$	$\mathcal{O}(10^2)$

OTHER PHYSICS PROSPECTS

LZ may detect $\mathcal{O}$(100) neutrinos via CEvNS from a supernova explosion at 10 kpc [5]. Achieving a ^{8}B measurement via the same process will confirm sensitivity to these interactions. This measurement presents its own challenges (trigger and acquisition rate [6]) as it occurs on a short, $\mathcal{O}$(1 s), but well-defined time window, allowing for an "S2-only" analysis, down to zero S1 threshold.

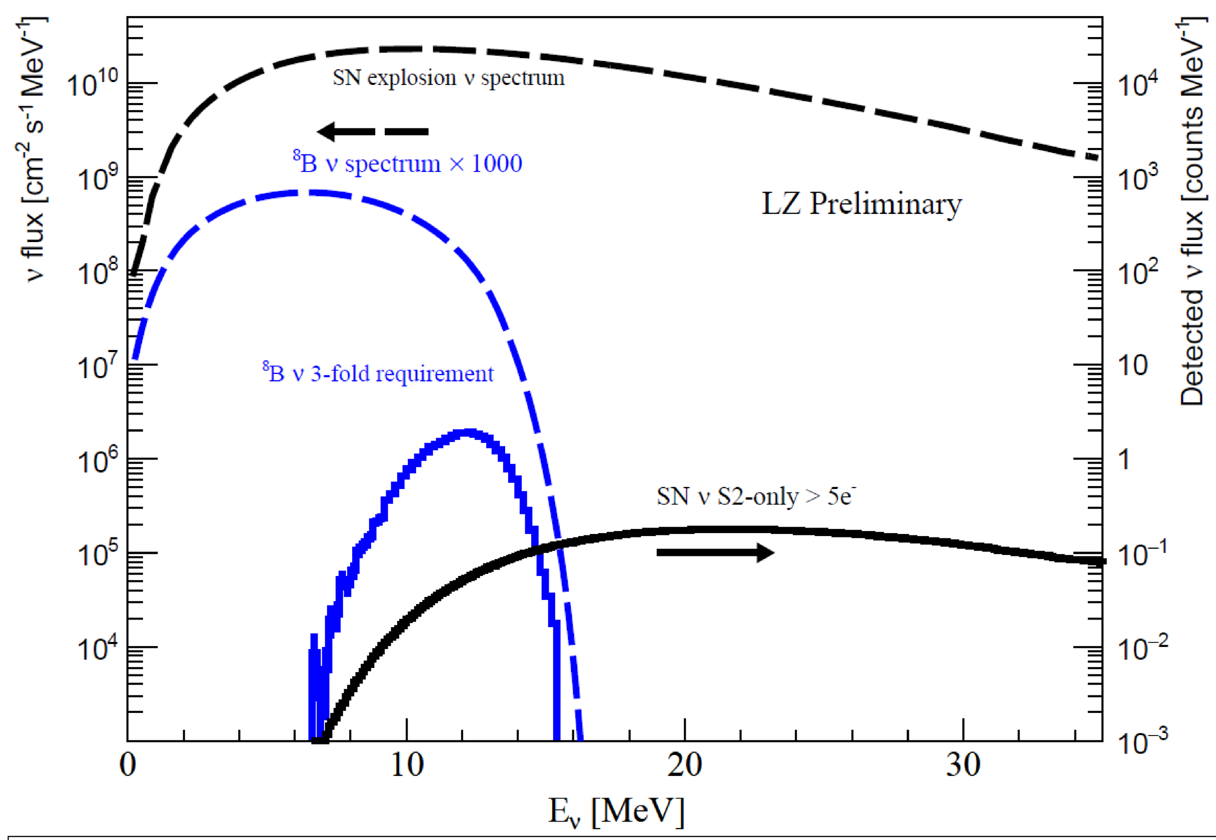

Figure 9: ^{8}B spectrum (blue dashed) and spectrum for a 27M$_{\odot}$ SN at 10 kpc (black dashed) [5]. Solid lines show the detected differential spectrum in LZ.

References:
[1] LZ Collaboration, TDR, arXiv:1703.09144
[2] COHERENT Collaboration, Science, Vol. 357, Issue 6356, pp. 1123-1126, Sep 2017
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[4] LUX Collaboration, Phys. Rev. Lett. **118**, 021303, Jan 2017
[5] R. Lang et al, Phys. Rev. D **94**, 103009, Nov 2016
[6] D. Khaitan (LZ Collaboration), *Supernova Neutrino Detection in LZ*, LIDINE 2017