Neutrino physics in LUX-ZEPLIN (LZ)

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LUX-ZEPLIN (LZ) is a time projection chamber (TPC) with an active mass of 7 tonnes of liquid xenon [1], optimized for the detection of dark matter particles. Because of its large active mass and very low background levels, LZ will be also able to conduct relevant research in neutrino physics.

The LZ experiment

The TPC is filled with liquid xenon (LXe), with a small gap at the top filled with gaseous xenon (Fig. 1). This entire volume is viewed by an array of 253 and 241 photomultiplier tubes (PMTs) mounted at the top and the bottom, respectively. In addition, four horizontal electrode grids and a series of titanium rings embedded in the TPC walls provide a nearly uniform vertical electric field in the active volume.

The TPC is surrounded by two active vetoes, used to reject background events with multiple interaction vertices, and a 228-tonne water tank for passive shielding and active muon veto. The two active vetoes are called the xenon skin and the outer detector.

LZ is located at Sanford Underground Research Facility, USA, and is expected to begin science operations in 2021.

Detection mechanism

Energy deposited in LXe by particle interactions generate a detectable prompt scintillation light (S1) and ionization electrons (Fig. 2). The ionization electrons are transported to the gaseous xenon phase at the top of the TPC by the applied electric field, where they emit detectable electroluminescence light (S2).

Detector capabilities

The delay between the S1 and S2 signals is used to reconstruct the depth of particle interactions, with an expected resolution of 2 mm. Besides, the distribution of collected light over the PMTs in the top array is used to reconstruct the radial position, with an expected resolution of 3 cm. These reconstructed coordinates allow to define an accurate fiducial volume, and to reject background events with multiple interaction vertices.

The ratio between the S2 and S1 signals (S2/S1) allows to discriminate between nuclear recoils (NRs) and electron recoils (ERs) (Fig. 3).

LZ will be able to measure both S1 and S2 with high efficiency, therefore expecting a low energy threshold (approximately 1 keV for ERs), and a good energy resolution (1.0% at the Q-value of the ^{136}Xe decay, at 2458 keV).

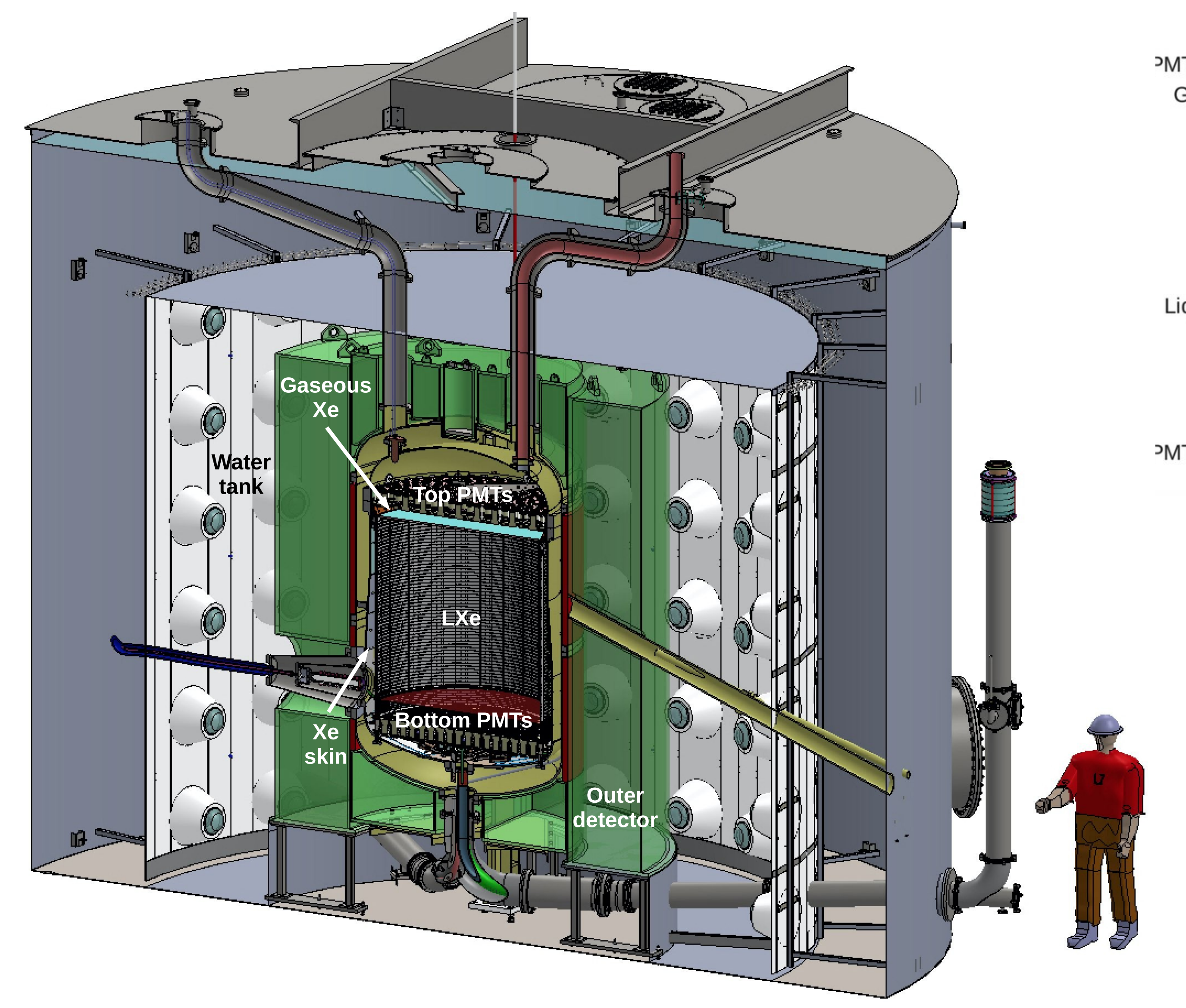

Fig. 1: the LZ experiment

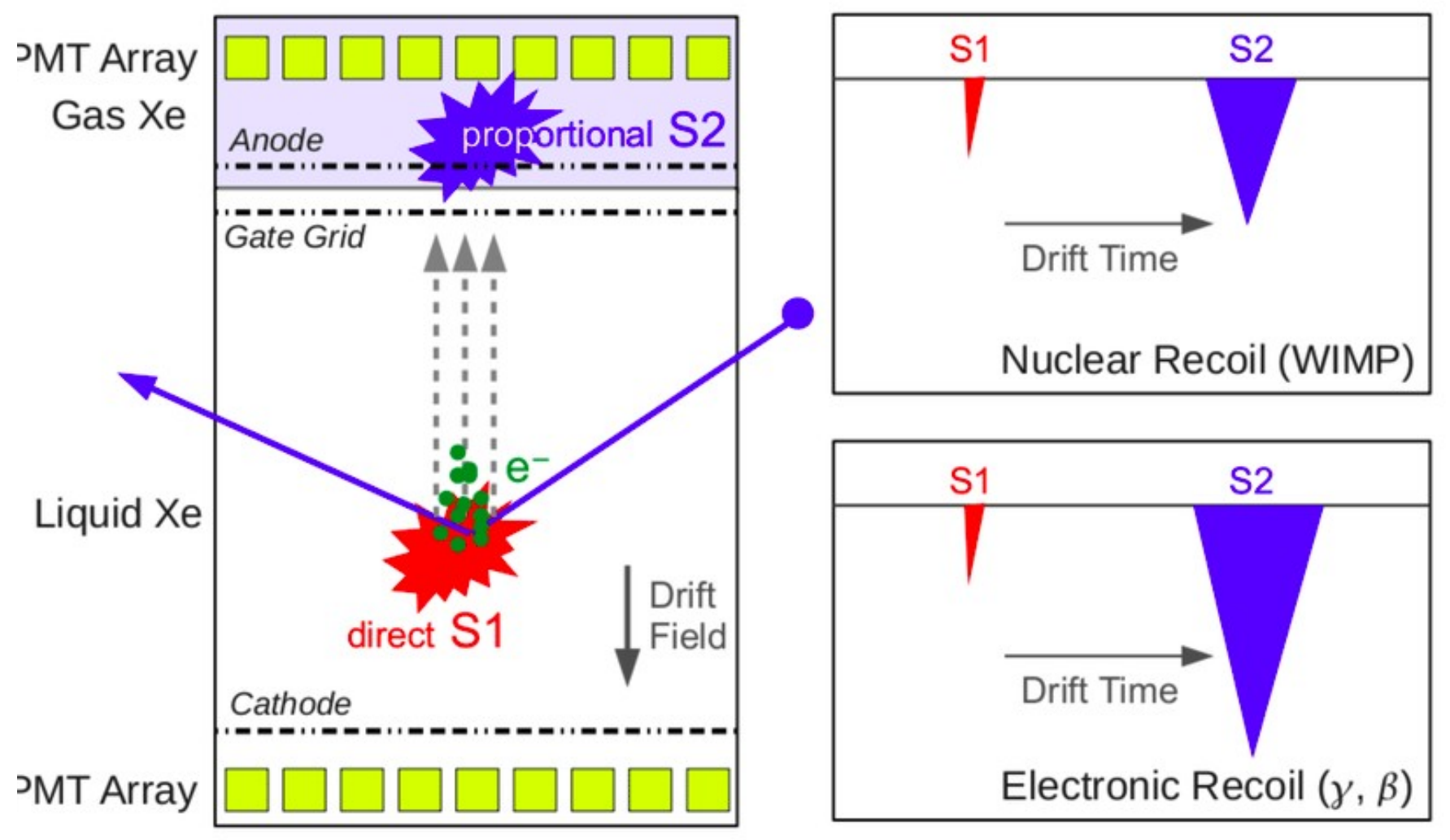

Fig. 2: dual-phase xenon TPC

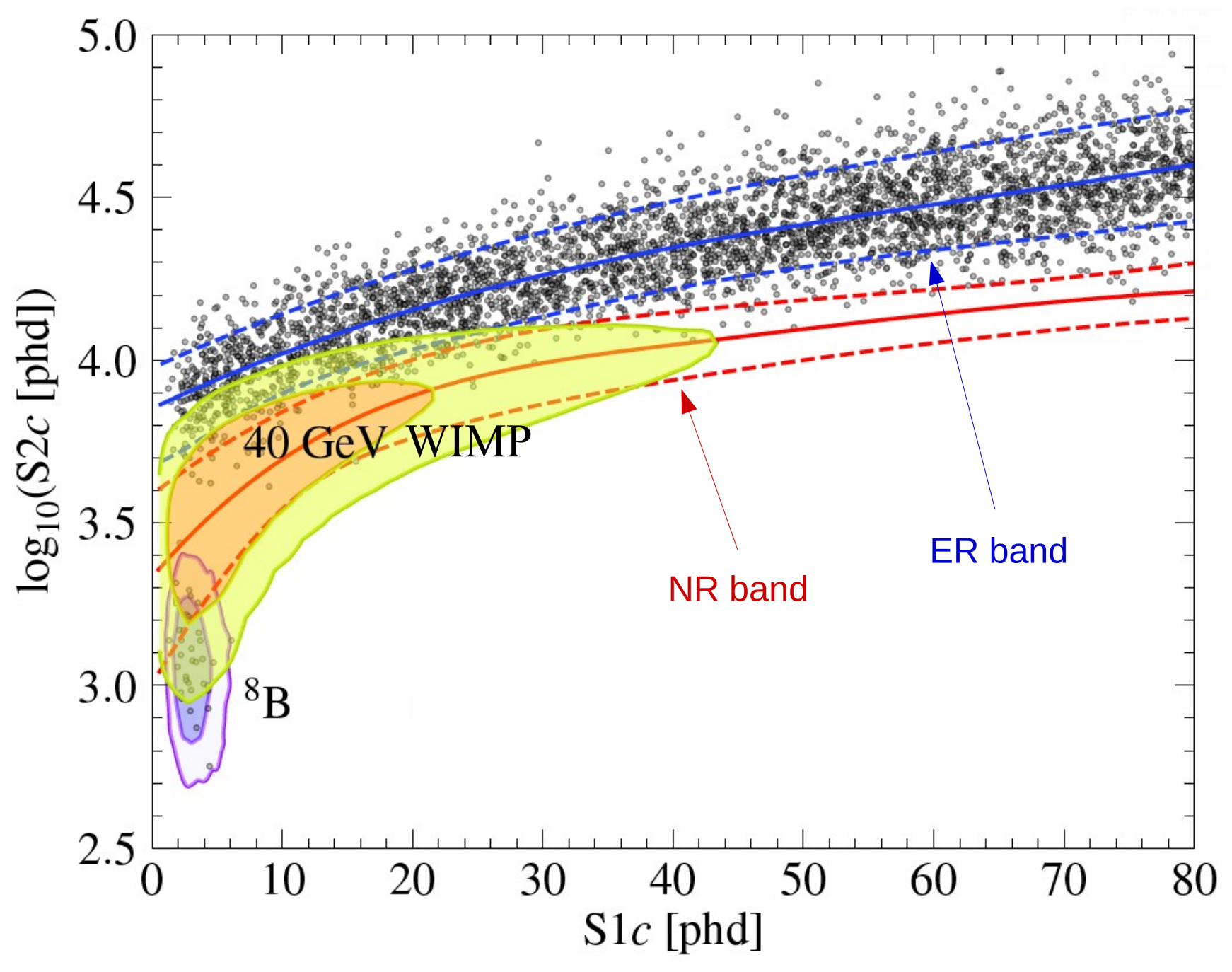

Fig. 3: simulation of background events in S1-S2 space

Sensitivity to effective neutrino magnetic moment and charge

Neutrinos are expected to manifest a small effective magnetic moment (μ_ν) and charge (q_ν) through loop contributions. The Standard Model prediction for μ_ν and q_ν is well beyond the current experimental reach, but many extensions imply important enhancements to these quantities.

An anomalous value of μ_ν or q_ν would lead to an increased rate of ERs from solar neutrinos. The predicted spectrum of this signal falls sharply with the energy of the recoiling electron (Fig. 4). Therefore, for this measurement, the relatively low energy threshold of LZ allows this experiment to compete with much larger neutrino observatories. Recently, XENON1T has reported evidence of an excess that can be interpreted as a positive observation of μ_ν [2].

Assuming 1000 live days, LZ will be able to exclude values of μ_ν and q_ν above 5.4×10^{-12} μ_B and 1.2×10^{-13} e_0, respectively, at 90% CL (Fig.5) [3], where μ_B is the Bohr magneton and e_0 is the electron charge. These projections surpass all the existing direct limits on μ_ν and q_ν, and will robustly test the XENON1T excess.

Coherent nuclear scattering of solar ^{8}B neutrinos

In addition to elastic scattering on individual atomic electrons, the coherent interaction of neutrinos with entire atomic nuclei is also possible. For solar neutrinos, only those from the β^+ decay of ^{8}B are expected to produce detectable NRs in LZ.

Actually, the S1 signal of NR from ^{8}B neutrinos in LZ would fall slightly below the detection threshold of the experiment, but upward fluctuations in this quantity could still be measured. Because S2 and S1 fluctuations are anticorrelated, this fact implies that the value of S2/S1 for the detected ^{8}B neutrino events will be systematically biased towards the lower part of the NR band (Fig. 3).

LZ has the potential to measure 36 NR events from coherent nuclear scattering of solar ^{8}B neutrinos in 1000 live days [4]. Although atmospheric neutrinos can also produce NRs above the LZ threshold, the predicted event rate is one order of magnitude below that for ^{8}B neutrinos.

Double beta decay and related processes

The large active mass and very low background levels of LZ will allow to study rare decays of xenon isotopes. This includes the search for neutrinoless decay modes, that are allowed if neutrinos are Majorana particles. In this case, the measured half lives would also constrain the absolute neutrino mass scale.

Assuming 1000 live days, the projected sensitivity of LZ to the half life of the neutrinoless double beta decay of ^{136}Xe is 10^{26} years (Fig. 6) [5]. This sensitivity could be increased to 10^{27} years if the detector is enriched to 90% in the ^{136}Xe isotope, therefore fully testing the inverted neutrino mass hierarchy (Fig. 7).

For other xenon isotopes, LZ will be able to study their decays more efficiently than dedicated neutrino experiments enriched in ^{136}Xe. LZ has the potential to detect the two-neutrino double beta decay of ^{134}Xe (Fig. 8) [6], and the two-neutrino electron capture with positron emission of ^{124}Xe [7]. These transitions have predicted half lives in the range of 10^{24} and 10^{23} years, respectively, and therefore could become the rarest processes ever measured in a laboratory.

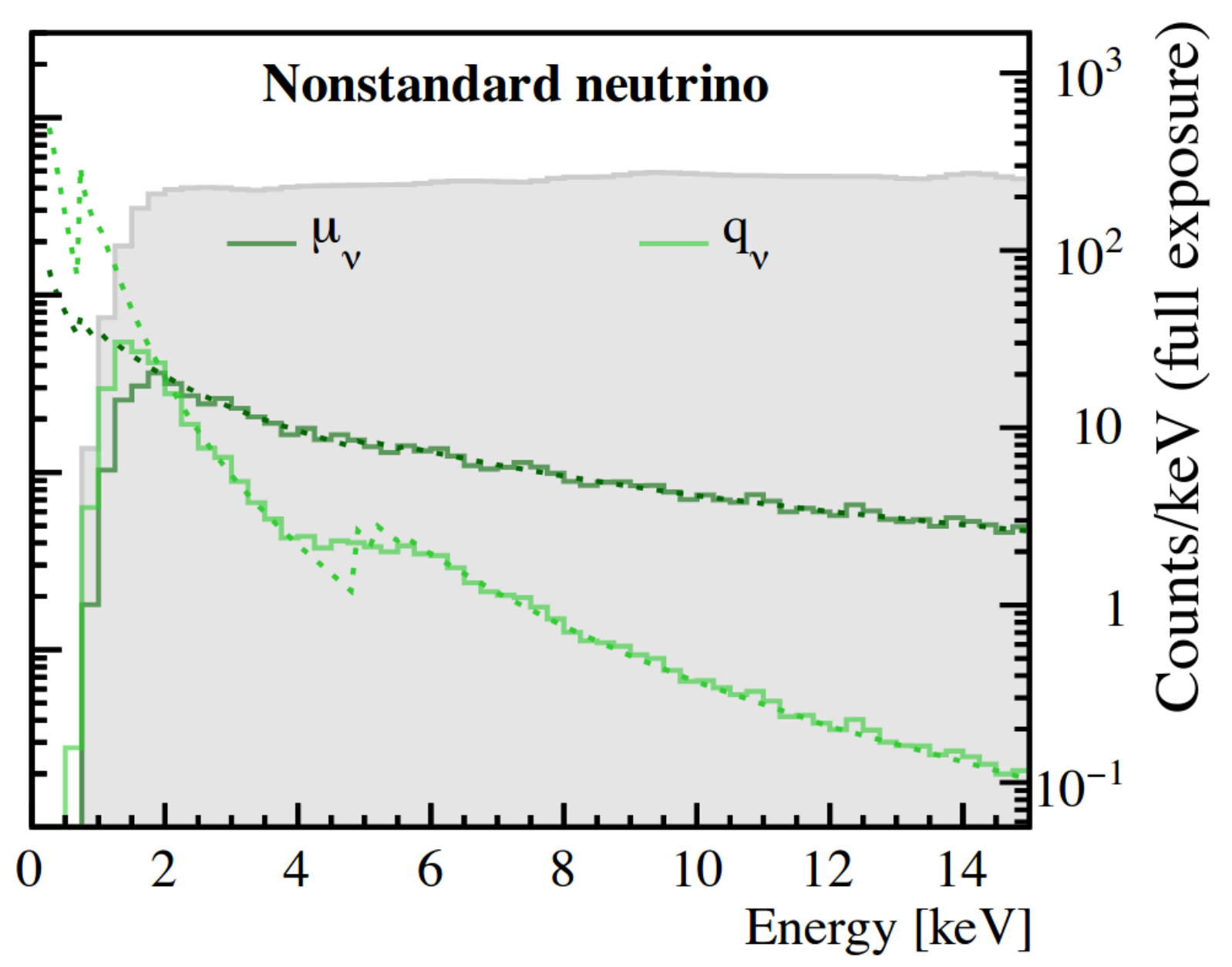

Fig. 4: spectrum from anomalous μ_ν and q_ν

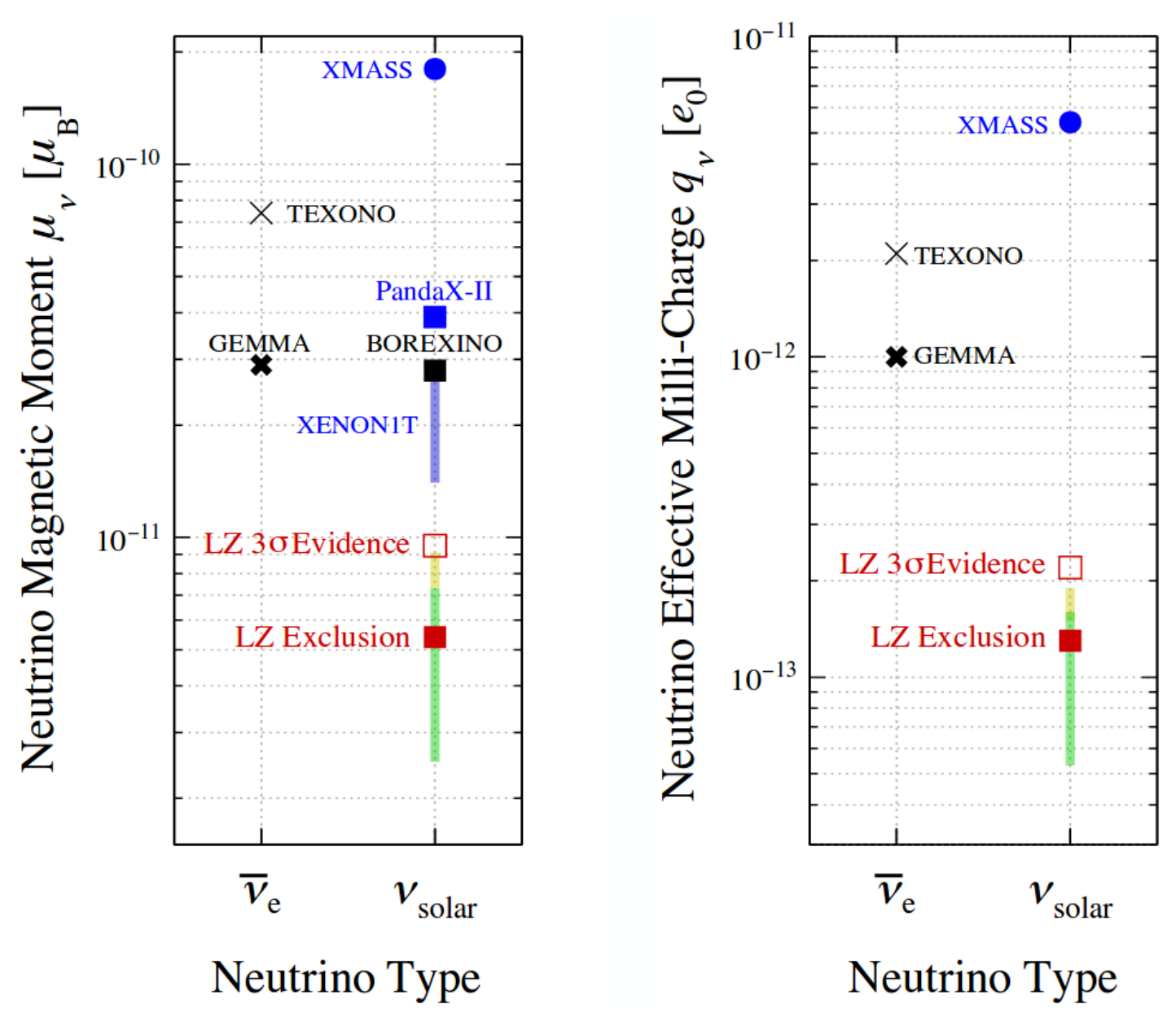

Fig. 5: sensitivity to anomalous μ_ν and q_ν

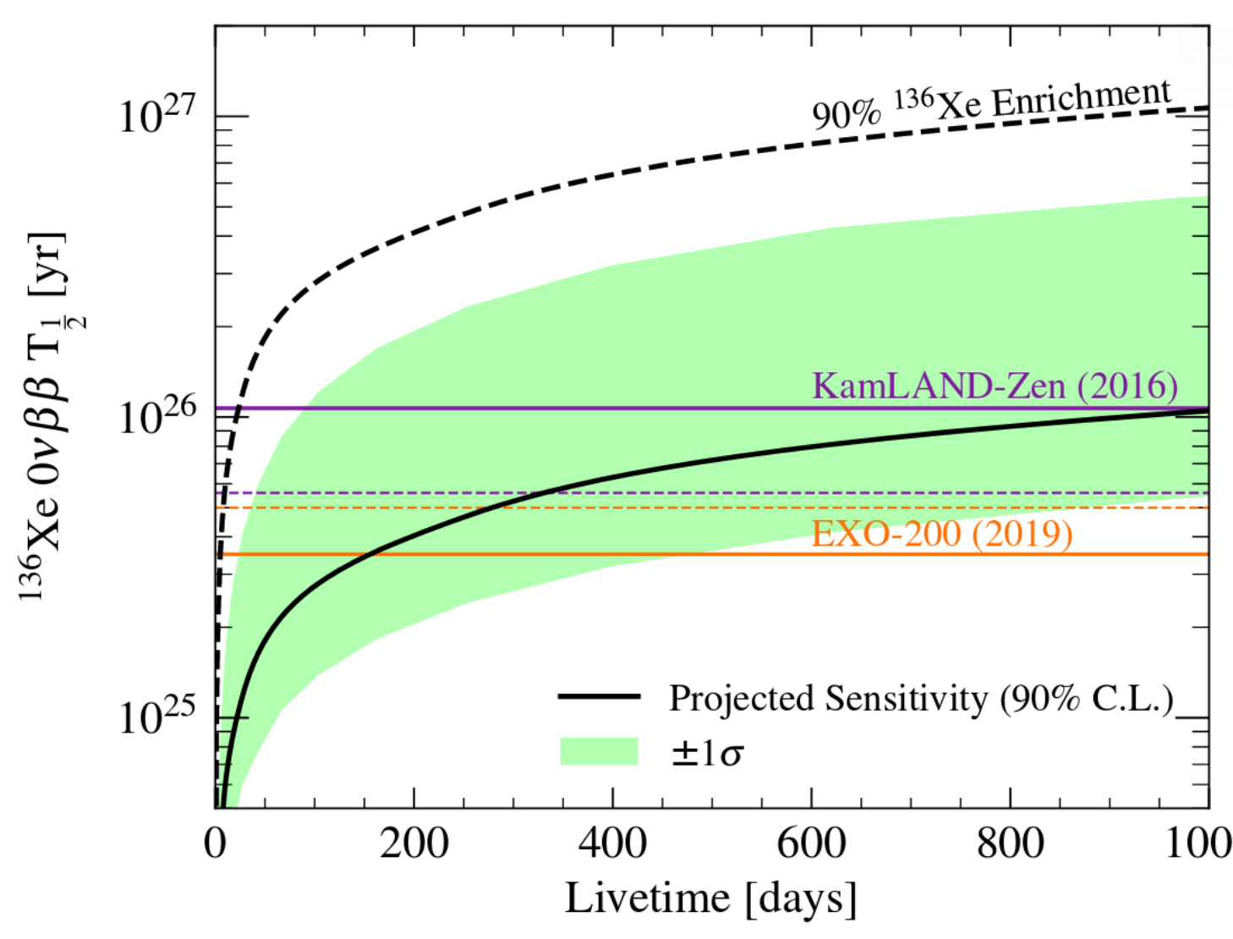

Fig. 6: sensitivity to $0\nu2\beta$ decay of ^{136}Xe

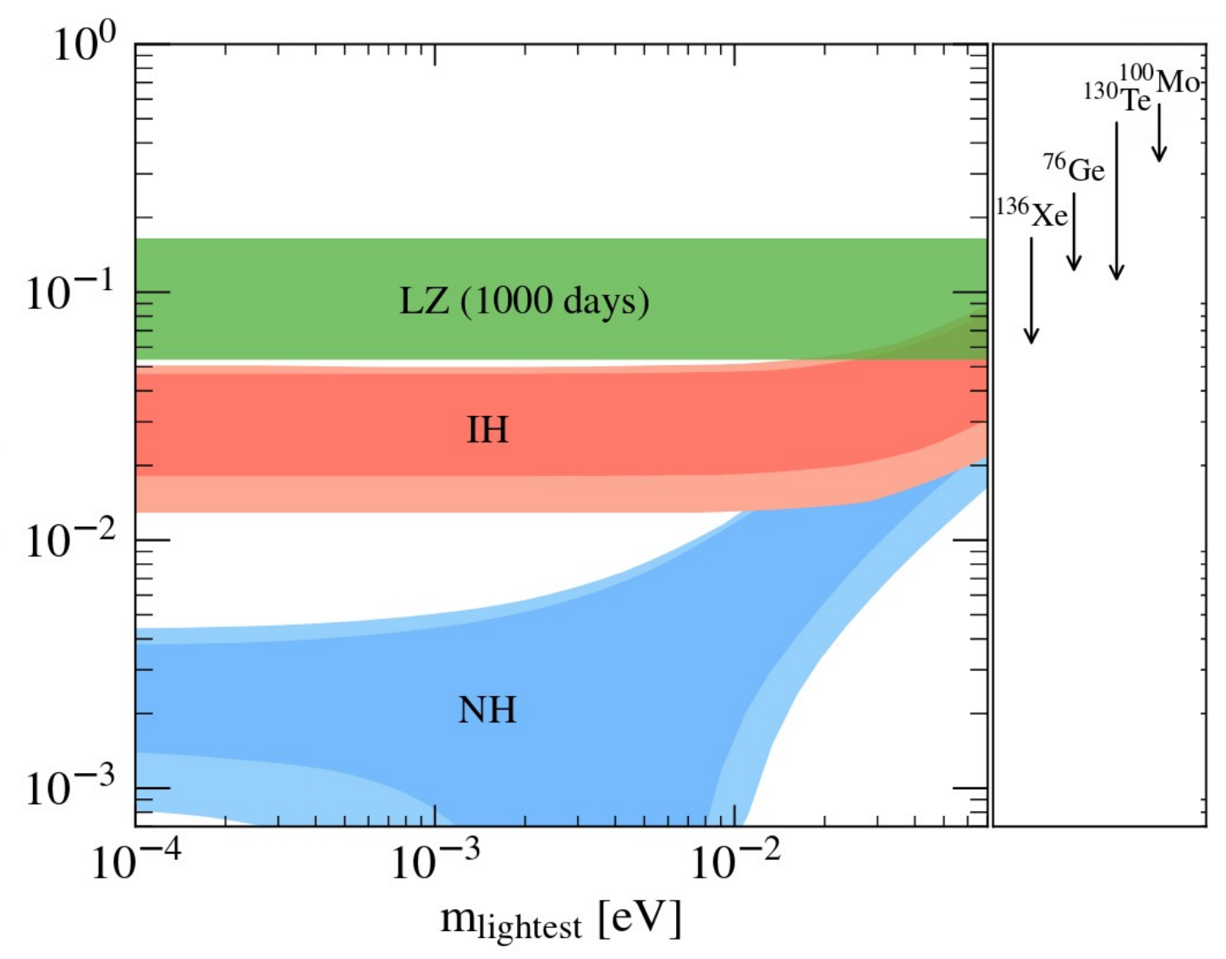

Fig. 7: sensitivity to ‹$m_{\beta\beta}$› from ^{136}Xe

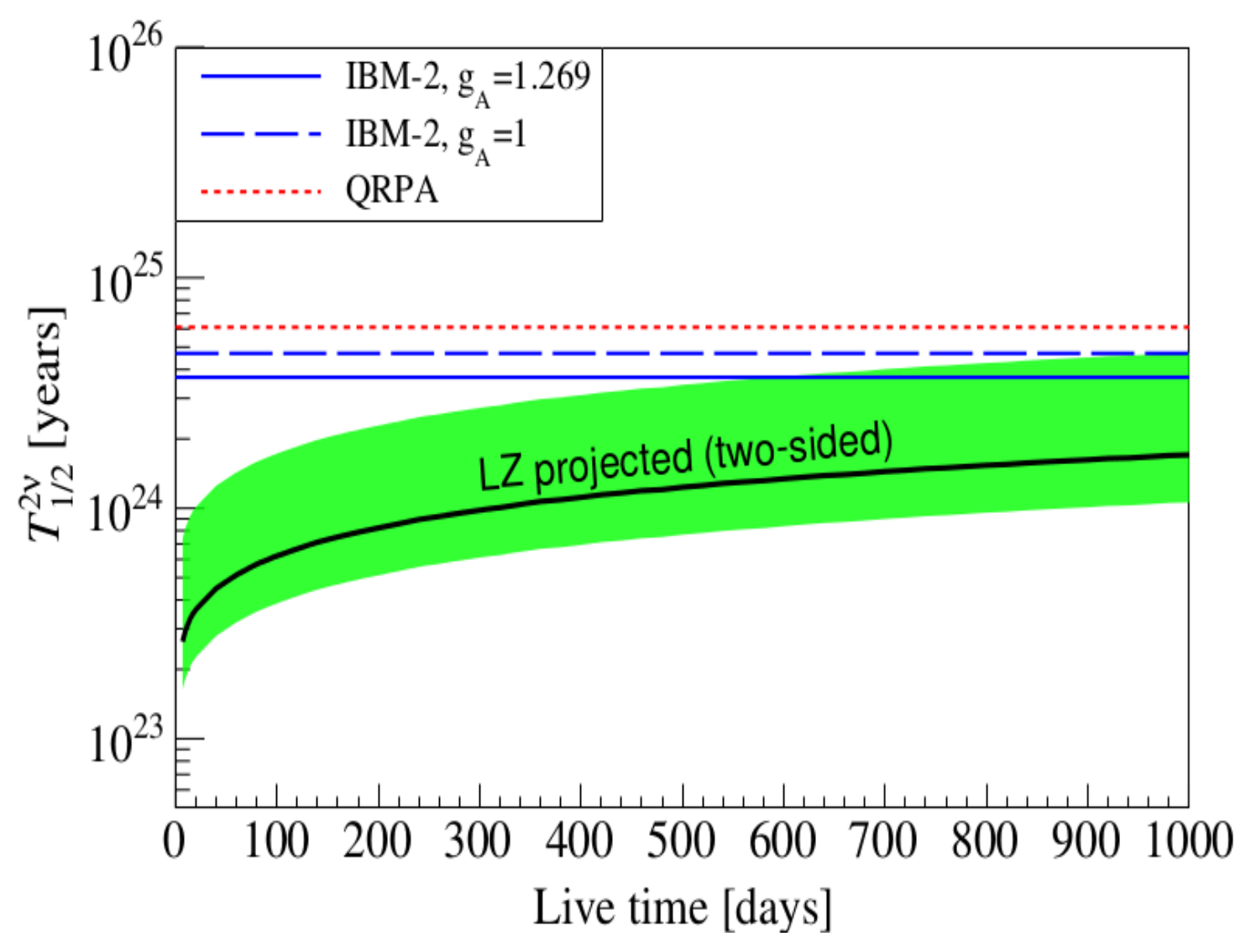

Fig. 8: sensitivity to $2\nu2\beta$ decay of ^{134}Xe

Bibliography

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