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Discovery potential of a large high pressure xenon gas TPC for neutrinoless double beta decay experiments

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Abstract. The potential of large HPXe detectors for $\beta\beta0\nu$ searches is addressed.

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Elucidating wether neutrinos are their own antiparticles is one of the major open questions in particle physics. However, neutrino oscillation experiments as well as beta decay experiments and cosmological constrains have clearly established that neutrino masses are small. A recent cosmological analysis, on the other hand, prefers nonzero neutrino masses, $\sum m_\nu = 0.32 \pm 0.11$ eV [1], suggesting that a signal could be found in the range of effective Majorana masses between 26 and 145 meV[?]. This result clearly illustrates that the next generation of $\beta\beta0\nu$ searches must be prepared to explore neutrino masses up to 20 meV, which in turn require exposures of the order of 10 ton·year, and therefore isotope (fiducial) masses in the range of the ton.

Xenon is an almost-optimal element for $\beta\beta0\nu$ searches, in particular for large detector masses, featuring many desirable properties, both as a source and as a detector. In particular xenon is a noble gas, and therefore one can build a time projection chamber (TPC) with pure xenon as detection medium. Both a liquid xenon (LXe) TPC and a (high-pressure) gas (HPXe) TPC are suitable technologies, chosen by the EXO-200[2] and the NEXT [3] experiment respectively. Being a noble gas, xenon can also be dissolved in liquid scintillator. This is the approach of the KamLAND-Zen [4] experiment.

Indeed, the field is currently dominated by xenon detectors. The combination of the recent KamLAND-Zen and EXO-200 negative results yields a limit $T^{0\nu}_{1/2}(^{136}\mathrm{Xe}) > 3.4 \times 10^{25}$ years, which essentially excludes the long-standing claim of Klapdor-Kleingrothaus and collaborators [5] [6, 7].

The NEXT experiment [3] will search for the neutrinoless double beta decay of ^{136}Xe using an asymmetric high pressure gas xenon (HPXe) TPC, filled with 100–150 kg of xenon (enriched to 91% in ^{136}Xe) gas at 15–20 bar pressure[8–10]. NEXT offers two major advantages for the search of neutrinoless double beta decay, namely: a) *excellent energy resolution*, with an intrinsic limit of about 0.3% FWHM at $Q_{\beta\beta}$ and 0.5–0.7% demonstrated by the large-scale prototypes NEXT-DBDM and NEXT-DEMO [11, 12], b) *tracking capabilities* that provide a powerful topological signature to discriminate between signal (two electron tracks with a common vertex) and background (mostly, single electrons). The topological signature, also demonstrated by the prototypes, when combined with a radio clean detector results in a very low specific background rate.

The combination of radio purity and the additional rejection power provided by the topological signature of the two electrons results in an expected background rate of $10^{-4} - -5 \times 10^{-4}$ counts/(keV · kg · y), depending of the level of background of the energy plane PMTs (there are only upper limits for those PMTs.

In order to gain a feeling of the potential of the HPXe technology is interesting to compare the experimental parameters of the three xenon experiments, which are collected in Table 1. The parameters of EXO-200 and KamLAND-Zen are those published by the collaborations [6, 13]. The resolution in NEXT corresponds to the most conservative result obtained by their prototypes [12], and the predicted background rate and efficiency comes from the full

Table 1. Experimental parameters of the three xenon-based double beta decay experiments: (a) total mass of ^{136}Xe, M; (b) enrichment fraction f; (c) signal detection efficiency, ε; (d) energy resolution, δE, at the Q value of ^{136}Xe; and background rate, b, in the region of interest around $Q_{\beta\beta}$ expressed in counts/(keV · kg · y) (shortened as ckky).

Experiment	M (kg)	f (%)	ε (%)	δE (% FWHM)	b (10^{-3} ckky)
EXO-200	110	0.81	0.56	4.0	1.5
KamLAND-Zen	330	0.91	0.42	9.9	1.0
NEXT-100	100	0.91	0.30	0.7	0.5

Table 2. Expected experimental parameters of the three xenon-based double beta decay technologies: (a) signal detection efficiency, ε; (b) energy resolution, δE, at the Q value of ^{136}Xe; and background rate, b, in the region of interest around $Q_{\beta\beta}$ expressed in counts/(keV · kg · y).

Experiment	ε (%)	δE (% FWHM)	b (10^{-3} ckky)
LXe	0.38	3.2	0.1
XeSci	0.42	6.5	0.1
HPXe	0.30	0.5	0.1

background model of the collaboration [3, 14], assuming a conservative background level for the dominant source of background (the energy–plane PMTs). Notice that the background rate of all the experiments is very good. The HPXe technology offers less efficiency than the other two but a much better resolution.

Table 2 summarises a projection [?] of the experimental parameters for the three technologies. A resolution near the practical limit for the three technologies is assumed. The quoted background rate, also near the limit achievable by the technologies, turns out to be both very small and quite similar. In exchange, the efficiencies are now closer. This is due to the fact that the only obvious way for the XeSci and LXe technologies to compensate the better rejection factor achieved by the HPXe technology is resorting to self-shielding, which in turn imposes a toll in the efficiency.

Figure 1, shows the expected performance of xenon experiments assuming the parameters described in Table 2, up to a total exposure of 10 ton·year. At the maximum exposure, the LXe and and XeSci detectors reach a draw at 40 meV, while the HPXe detector reaches 25 meV.

In practical terms, the NEXT experiment should establish the maturity of the HPXe technology and its innovative concepts (such as EL amplification and light-pixel tracking), bringing it to the same level already achieved by EXO-200 and Kamaland-ZEN. The first relevant milestone for the technology is therefore completing the construction of the detector, foreseen for 2014, and start a physics run, in 2015.

At the same time, the NEXT detector is a ∼2 m^3 HPXe TPC which incorporates all the crucial elements to be demonstrated before a larger detector can be build. In that sense a 2–3 years run will be essential not only to search for $\beta\beta0\nu$ decays but as a springboard for the next-generation HPXe detector. NEXT is an international collaboration lead by spanish and USA groups. It provides an excellent core for a future, wider collaboration.

Work towards designing such a larger device, called OSPREY has already started. The

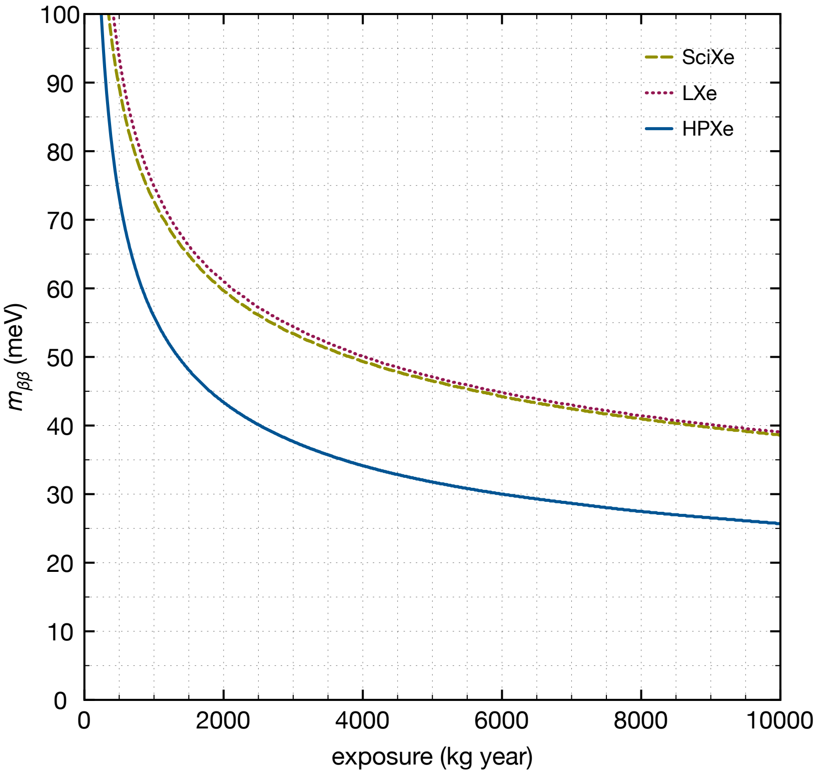

Figure 1. Sensitivity of the three technologies experiments as a function of the total exposure, assuming the parameters described in Table 2.

detector would operate at a higher pressure (20-30 bar), it would very likely be a symmetric TPC and could incorporate molecular additives such as TMA depending on the results of current R&D. The tracking plane(s) would require about 10^5 SiPMs, about one order of magnitude more than currently deployed by NEXT. A major interest of the technology is its potential to contribute, via directionality, to the next-to-next searched for WIMPs. As proposed in [**?**], a large HPXe can eventually provide the best technology for both $\beta\beta0\nu$ and DM searches.

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