High-pressure xenon gas time-projection chambers for neutrinoless double-beta decay searches

The NEXT Collaboration*

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Introduction

Understanding the origin and nature of neutrino mass is one of the most pressing questions of fundamental physics. A Majorana neutrino would provide a very interesting foundation for several theoretical models that attempt to explain the smallness of neutrino masses or the matter-antimatter imbalance in our Universe. The most sensitive known experimental method to verify whether neutrinos are Majorana particles is the search for neutrinoless double-beta ($0\nu\beta\beta$) decay. This extremely rare decay would be discovered, if neutrinos are Majorana particles, among the rare but known double beta decays that happen in a few elements.

The next step in this search is to cover the the so-called *inverted ordering region*, exploring half-lifes of the $0\nu\beta\beta$ process of the order of 10^{27}years. To explore such regions, exposures of 1 ton·year and backgrounds of 1 event per year in the region of interest are required.

To explore the largest parameter space possible, future experiments will need to develop current or future technologies much further. A promising technology is the High Pressure Xenon Gas Time Projection Chamber (HPXeGTPC) that offers unique advantages for future large scale detectors.

HPXeGTPC technology

Noble element Time Projection Chambers (TPCs) have proven to be very powerful for rare event searches allowing for very large exposures (hundreds of kg·years in the case of $0\nu\beta\beta$ and tonne·years for dark matter experiments). The NEXT collaboration has shown that the HGPXeTPC can provide very good background rejection thanks to the combination of an excellent energy resolution below 1% FWHM@Qbb [1, 2, 3] and the capacity to reconstruct the topology of the events allowing to discriminate single from double electron events [4, 5]. In addition, gas detectors allow for sufficiently low threshold for a good calibration of the total volume in the whole energy range by using a combination of different sources, including low-energy sources diluted in the gas [6].

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This technology has been lead by the NEXT collaboration with a 10 kg detector, NEXT-White (NEW) [7, 8, 9, 2] running in the last years and a 100 kg detector in construction, NEXT-100 [10], to be commissioned in 2021. The combination of radio-screening of all materials, simulations and the background rate measured in NEW indicates a background rate in the ROI of 10 events per tonne year [11, 12], one order of magnitude larger than what is needed.

Towards a tonne scale detector

Construction of detectors in the tonne scale with less than 1 event of background in the region of interest is a challenge for every technology that will force us to further develop current and new technologies. In the case of the HPGXeTPC, we propose a reduction in the total background budget and an improvement in the background rejection thanks to an improved topological reconstruction.

The first step will be to remove the most radioactive component of current generation of detectors, photomultiplier tubes, and replace them by *clean* sensors, silicon photomultipliers. This change implies large number of channels and a notable increase in the total dark current that could affect detection of the primary signal (limiting the positioning of the events inside the detector) and also the energy measurement. In order to limit such effects we are investigating the operation of the detector at low temperatures to reduce the total dark count by at least a factor 50. In addition, for the energy measurement, we are exploring the use of double-cladding optical fibers coated with TPB around the barrel to reduce the total number of channels. Such fibers would be read-out by SiPMs placed behind a thick copper plate thus further reducing the total radioactivity. In addition, we are exploring the use of gaseous mixtures to reduce the electron diffusion, improving the topological signal [13, 14]. This will require a more dense tracking plane and in-vessel electronics. The half-life sensitivity of the future NEXT tonne-scale detector is expected to be better than 10^{27} years[15].

Future plans

While pursuing the possibilities described above using different smaller detectors, the ultimate goal for the HPXeGTPC technology is to reach sensitivities covering a large phase space of the *normal neutrino mass ordering*. To achieve such sensitivity, the addition of a Ba tagging system, described in two separate LOIs [16, 17], will be essential. The HPGXeTPC with barium tagging can offer a technology with excellent energy resolution, capable to provide a background free environment, thus allowing to explore this region.

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