nEXO

The EXO Collaboration

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The Scientific Case The experimental discovery of neutrino oscillations, at various energy and lengths scales, yields compelling evidence for non-zero neutrino masses. Within the three-flavor paradigm precise data fits are now available for the squared neutrino mass differences and mixing parameters. The current picture does not yet define the mass hierarchy, the existence of non-trivial CP-phases, the overall mass scale, and the possible particle-anti-particle identity of the neutrinos. The investigation of neutrinoless double beta decay ($0\nu\beta\beta$) is currently the most sensitive test for the Majorana nature of neutrinos. In case neutrinos are Majorana particles, the investigation of double beta decay further provides the most stringent constraint on their mass.

The possible discovery of a Majorana nature of neutrinos, via an unambiguous observation of double beta decay, is the strongest and model independent science driver. The proportionality of the decay rate to the squared effective Majorana neutrino mass introduces a quantitative, yet model dependent, element. Theoretically computed nuclear matrix elements are needed to exploit it. Different nuclear model calculations show a rather large spread among each other. This uncertainty is one of the cost drivers as it impacts experiment planning. Nevertheless, even taking this spread into account, the $0\nu\beta\beta$ decay constraints on the the neutrino mass are among the most stringent in the field and the discovery of 2-component Majorana Fermions would substantially alter our understanding of the natural world.

Assuming that $0\nu\beta\beta$-decay is driven by the exchange of light neutrinos, the oscillation-derived neutrino data defines three mass scenarios: degenerate, inverse, and normal. The current generation of $0\nu\beta\beta$ decay experiments is designed to cover the degenerate case. nEXO will address Majorana neutrinos in the inversely hierarchical mass scheme, i.e. the neutrino mass scale defined by $\sqrt{\Delta m^2_{atm}}$, using well proven technology and may start approaching the normal hierarchical mass scheme with a subsequent upgrade.

Many national and international panels identified double beta decay as one essential area of research for the future of Particle Physics.

EXO-200 The EXO collaboration developed, built, and is now operating a TPC-based low background tracking detector, utilizing 200 kg of xenon enriched to 80% ^{136}Xe, of which 100 kg are active. The Xe is used in liquid phase (LXe) to produce a compact detector. EXO-200 has been taking low background data since June 2011, it is located at the Waste Isolation Pilot Plant near Carlsbad NM, in the USA, at a depth of about 1600 m.w.e. The US-led EXO collaboration currently comprises 18 institutions from 7 countries.
Simultaneous readout of ionization and scintillation results in an an energy resolution of $\frac{\sigma}{Q_{\beta\beta}} = 1.67\%$. The excellent tracking capability of the device results in a background around the Q-value

of $B = 1.5 \times 10^{-3}\ keV^{-1}kg^{-1}yr^{-1}$, the lowest in the field. Data collected with the EXO-200 detector provided the first measurement of $2\nu\beta\beta$-decay of ^{136}Xe, yielding $T_{1/2}^{2\nu\beta\beta} = (2.11 \pm 0.04^{stat} \pm 0.21^{syst}) \times 10^{21}\ yr$ [1]. EXO-200 further published one of the most restrictive bounds on the Majorana neutrino mass of: $\langle m_{\beta\beta} \rangle < 140 - 380\ meV$ using a range of nuclear matrix elements [2]. This measurement was the first to address the evidence claimed for the observation of $0\nu\beta\beta$-decay in ^{76}Ge and, in fact, shows considerable tension with it. By now experiments using ^{136}Xe as source have surpassed those utilizing ^{76}Ge as the most sensitive test for Majorana neutrino masses.

EXO-200 was the first "next" generation detector to come on line, after a a decade long "dry spell". The technical soundness of this approach is demonstrated by the fact that EXO-200 has been taking data for almost two years. In particular EXO-200 has proven that the simultaneous read out of scintillation and ionization provides energy resolution sufficient for a large scale double beta decay experiment and that the tracking capability of a homogeneous LXe TPC when combined with a rigorous materials screening program, results in extraordinarily low backgrounds, the current standard of the field. The ability of the TPC to discriminate gammas from electrons proved to be an invaluable tool for achieving this extremely low background.

nEXO Building on the successful EXO-200 experiment, the collaboration has now started planning for a new, larger experiment that, being based on EXO-200 technology, can use this very successful detector as a direct prototype. The new detector is called nEXO and will use 5000 kg of isotopically enriched LXe. It should be pointed out that the noble gas xenon is one of the most economical $\beta\beta$-emitters to enrich by ultra-centrifugation. Initial estimates indicate a cost advantage of about a factor 7 per unit mass when compared, for example, to ^{76}Ge. This and the lack of the need for crystal growing lends excellent scalability to a xenon-based approach. In addition ^{136}Xe offers a particularly favorable matrix element-phasespace combination.

The collaboration is working on a full Monte Carlo simulation of such a scaled-up EXO detector, using the analysis results from EXO-200 as input and hence providing robust results. Although the Monte Carlo effort is ongoing, initial results indicate that a Majorana neutrino mass sensitivity of $\langle m_{\beta\beta} \rangle < 11 - 30\ meV$ (using the most extreme range of nuclear matrix elements) could be reached within 10 years of detector live time. The most restrictive mass limit, based on a recent GCM model calculation [3], would cover the inverted hierarchy completely, using a detector built with well proven technology.

The EXO collaboration has an active R&D program to investigate the possibility of retrieving and tagging the final state atomic species (Ba) of the double-beta decay of ^{136}Xe. While a technical solution to this problem is still not available (and not needed for the nEXO detector outlined above), the success of this R&D would provide an upgrade path for nEXO that will be designed with ports through which the Ba-tagging system could operate. This upgraded nEXO detector would reach Majorana mass sensitivities of 4-10 meV, covering the inverted hierarchy for all matrix elements and accessing some of the normal hierarchy for the most favorable ones.

References

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[3] T.R. Rodriguez and G. Martinez-Pinedo, PRL 105 (2010) 252503.

[4] A. Staudt, K. Muto, and H.V. Klapdor-Kleingrothaus, EPL B 13 (1990) 31.