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Latest results from EXO-200

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Summary. — The Enriched Xenon Observatory (EXO) is an experimental program searching for neutrino-less double beta decay in xenon-136. The first stage of this program, EXO-200, has been in operation since early 2011. I present here the latest physics results from the experiment.

Neutrino-less double-beta decay ($0\nu\beta\beta$) is an hypothetical process that can happen only if neutrinos are Majorana particles. The signature for this decay is a peak in counts at the end point of the two-neutrino double-beta ($2\nu\beta\beta$) decay spectrum, an energy value dependent on the isotope. The half-life of this process is linked to the neutrino Majorana effective mass [1].

The search for $0\nu\beta\beta$ decay can be performed in those isotopes subject to $2\nu\beta\beta$ decay. One of these isotopes is xenon-136, and it has been the focus of the Enriched Xenon Observatory (EXO) experimental program. EXO-200, the first stage of the program, is located in the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, at 650 m depth. It features a time projection chamber (TPC) filled with about 175 kg liquid xenon (LXe). The energy resolution in xenon improves if both the charge and the scintillation signal produced by a decay event are measured. To do so each side of the TPC is equipped with large area avalanche photodiodes (LAAPDs) and two sets of wires (to sense the induction signal and to collect the charge) crossing at an angle. For a detailed description of the experiment see Ref. [2].

Since the beginning of operations (early 2011) EXO-200 has measured for the first time the $2\nu\beta\beta$ decay in Xe^{136} [3] and has improved the limit on the rate of $0\nu\beta\beta$ decay [4]. Recently, the most precise measurement for the $2\nu\beta\beta$ decay half-life has been published [5]. Between the first and the second measurement several improvements to the system were implemented, both in hardware and analysis. We completed the external lead wall, which shields the EXO TPC from background (BG) radiation, we improved the front-end electronics, and we obtained a reduction of the amount of electronegative impurities in xenon thanks to higher recirculation rate and more efficient purification. We also built a sophisticated suite of software tools to perform simulation and data analysis.

Our Monte Carlo (MC) simulation is realized in GEANT4 from most of the real system's 3-D CAD drawings for TPC, HFE, cryostat and lead wall. Some details are simplified, but the total mass for each material closely matches the mass of the same material in the real system. We simulate charge collection and induction signals assuming a 2-D simplified model for the electric field – this has been validated by comparing distributions of relevant waveform parameters in simulation and in real data. We also have a light response function (generated by MC simulation) to determine the amount of light hitting an APD plane for a certain charge deposition at a particular location in the detector.

Once signals are produced, they undergo the same full processing chain as real data. The first step of this chain is the reconstruction of the event. We first look for signals applying matched filters which are specifically designed for each channel type. We then deconvolve the signals and fit them to models to extract a set of waveform parameters which we use to eliminate mis-reconstructed or mis-identified events. All the events passing the cuts are then scanned for time coincidences: if more signals belong to the same energy deposition event, they are bundled in a cluster. At this point we classify events by topology, location, and energy. To assign the topology, we look at the distribution of energy deposition for each event. An energy deposit is single-site (SS) if it is confined within 3 mm; this is expected to be the case for most β decay events in LXe. Most of the penetrating γ radiation on the other hand causes multiple energy deposits at well separated locations, therefore called multi-site (MS). To determine the location of an event we measure the 3-D coordinates; we then evaluate the distance from the edges (standoff distance). Since most BG events originate outside the TPC or on TPC walls, their distribution falls moving towards the center of the LXe volume. In opposition, β events are distributed uniformly in the TPC. We discard events outside our fiducial volume.

To measure accurately the energy of an event, we need to calibrate our energy scale. Every few months we deploy different sources (^{137}Cs, ^{60}Co, ^{228}Th) featuring γ emission peaks in the whole energy range of interest. We deploy ^{228}Th every other day to measure the electron lifetime; we use this information to select high purity data. We also need to apply corrections to take into account electronics gain variations. Each wire gain is measured daily with an internal pulser and using ^{228}Th data. A light map is generated using multiple source runs to correct for the illumination of the APDs, which depends on the energy deposition location. Once both charge and scintillations are corrected, the Th energy spectrum is fitted to determine the time dependent rotation angle which gives the optimal energy resolution. We apply this energy correction to all the low BG physics data.

We compare source data and simulation to check for agreement in rate, shape, and fraction of single site events. With this we validate the probability density functions (PDFs) and estimate the systematic uncertainties which we use as input in the maximum likelihood fit of the physics data; every BG which could be present is represented and fitted. Well-defined cuts are used to select data for this analysis [5]. To perform the fit, we let float all the parameters (normalization, SS fraction, number of events for each PDF) and we maximize the likelihood to find the best fit for the number of events in the $2\nu\beta\beta$ PDF. We perform a profile likelihood scan to determine the error on this parameter. Given the total ^{136}Xe exposure of our data set and the detection efficiency, we obtain a half life of $T_{1/2}^{2\nu\beta\beta} = 2.165 \pm 0.016(stat) \pm 0.059(sys) \cdot 10^{21}$ yr. This is the longest and also most precise $2\nu\beta\beta$ half-life ever measured.

A much larger data set is currently being analyzed to search for $0\nu\beta\beta$ decay. In parallel, the future 5-ton detector, called nEXO, is being designed.

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