5 DARWIN: dark matter WIMP search in noble liquids

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DARWIN Consortium

DARk Matter WImp search with Noble Liquids (DARWIN) is an initiative to build the ultimate, multi-ton dark matter detector[1]. The project unites the ample expertise in Europe on liquid noble gas detectors, low-background techniques, cryogenic and underground infrastructures and on the physics issues related to direct dark matter and neutrino detection.

DARWIN's primary goal is to probe the spin-independent WIMP-nucleon scattering cross section for ~50 GeV/c^2 WIMPs down to 10^{-49} cm^2 where irreducible neutrino backgrounds set in. Two other major physics goals are the search for the neutrinoless double beta decay of ^{136}Xe and the first real-time observation of solar pp-neutrinos with high statistics. The pp- and ^{7}Be-neutrinos together account for more than 98% of the total neutrino flux and the real-time measurement of pp-neutrinos would test the main heat production mechanism in the Sun. The flux of ^{7}Be-neutrinos, measured by the Borexino experiment, is $(2.78 \pm 0.13) \times 10^9\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [3] assuming pure ν_e neutrinos. However, the most robust predictions of the Standard Solar Model are for the pp-neutrino flux, which is heavily constrained by the solar luminosity and an accurate measurement of the pp-neutrino flux will allow to distinguish between different neutrino oscillation scenarios.

In its baseline scenario, DARWIN would operate a cylindrical ~2.1 m × 2.1 m liquid xenon time-projection chamber (TPC) in a low-background cryostat, installed in the water shield of the XENON1T and XENONnT at LNGS. Improved external shielding is possible by adding a liquid scintillator veto shield around the cryostat inside the water. To achieve the required drift field (0.5 - 1.0 kV/cm), the cathode on the bottom of the TPC will be biased with voltages around or beyond -100 kV, and the field homogeneity will be optimized by using massive field shaping rings made from oxygen-free high-conductivity (OFHC) copper. The primary scintillation (S1), as well as the proportional scintillation signal from the charge (S2) are detected by two arrays of photosensors installed above and below the liquid xenon target.

Assuming 14 t LXe fiducial mass and an energy window of 2–30 keV, about 5900 pp-neutrinos are expected in DARWIN after 5 years of data collection. The upper energy boundary is motivated by the energy at which the solar neutrino induced electron recoil spectrum and the two-electron spectrum from the $2\nu\beta\beta$-decay of ^{136}Xe intersect.

A detailed study of the DARWIN sensitivity to low-energy solar neutrinos, to coherent neutrino-nucleus scattering and to neutrinoless double beta decay has been performed by our group [2]. The overall background spectrum from the various detector materials including the radioactivity intrinsic to the liquid xenon, such as the $2\nu\beta\beta$-decay of ^{136}Xe with $T_{1/2} = 2.11\times10^{21}$ yr [4], is shown in Fig. 5.1. The intrinsic background to xenon as a detection medium poses strong requirements on internal radio-activity levels: a contamination of the liquid xenon with natural krypton of about 0.1 ppt and a radon level in the liquid of about 0.1 μBq/kg are to be ensured. This can be achieved by purifying the noble gas with krypton-distillation columns and with ultra-clean, charcoal-based radon filters, and by the use of materials with low radon

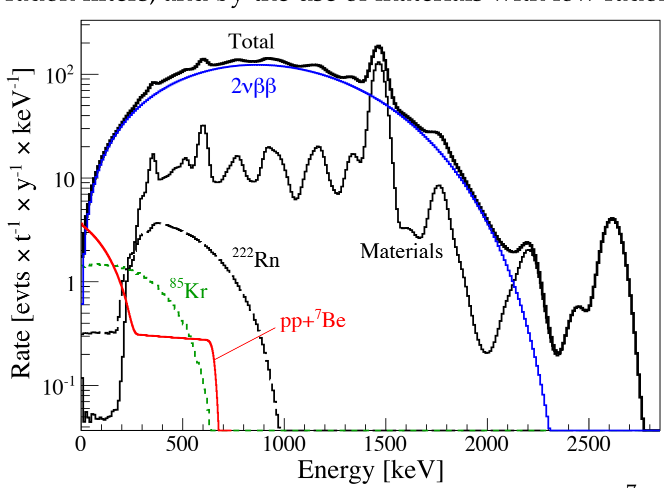

FIG. 5.1 – Total neutrino energy spectrum from pp and ^{7}Be, for a central 14 t region of the detector, compared to the predicted background from detector construction materials and internal contaminations. The background components from 0.1 ppt of natural krypton, 0.1 μBq/kg ^{222}Rn decays and ^{136}Xe $2\nu\beta\beta$-decays are shown separately.

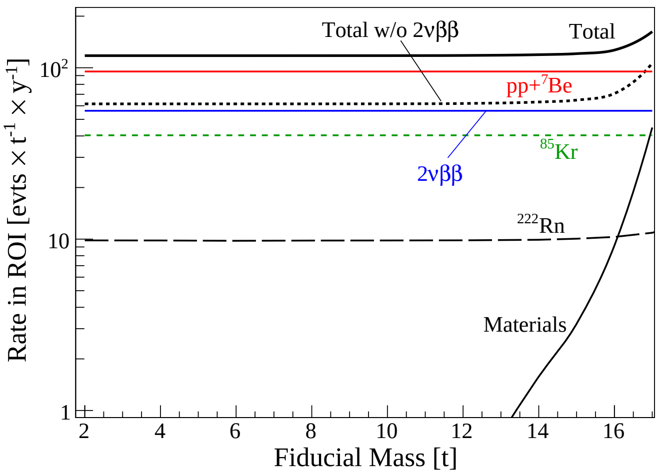

FIG. 5.2 – Predicted signal and background rates in the 2–30 keV energy region versus fiducial liquid xenon mass.

emanation. With 99.8% rejection of ^{214}Bi events using the ^{214}Bi-^{214}Po coincidence [2], the radon-induced background drops about 30% at low energies. The predicted internal background amounts to ~700 events/yr in the region 2–30 keV and, assuming 99.5% rejection of electronic recoils, about 1 event/yr in the region 2–10 keV. This rate is comparable to the ^{136}Xe $2\nu\beta\beta$ background.

External background varies with the fiducial xenon mass (see Fig. 5.2) and we define the central 14 t of LXe as detector region. The external background is dominated by the photosensors, followed by the cryostat, the TPC and the diving bell. In the range 2–30 keV without electronic recoil rejection, DARWIN would observe 19 background events per year. Assuming 99.5% rejection of electronic recoils in the region 2–10 keV, relevant for the dark matter search, this rate drops to 3×10^{-2} events/yr.

The $Q-$value of the double beta decay of ^{136}Xe is (2458.7±0.6) keV [5]. Employing as energy measure a linear combination of the charge and light signals, which

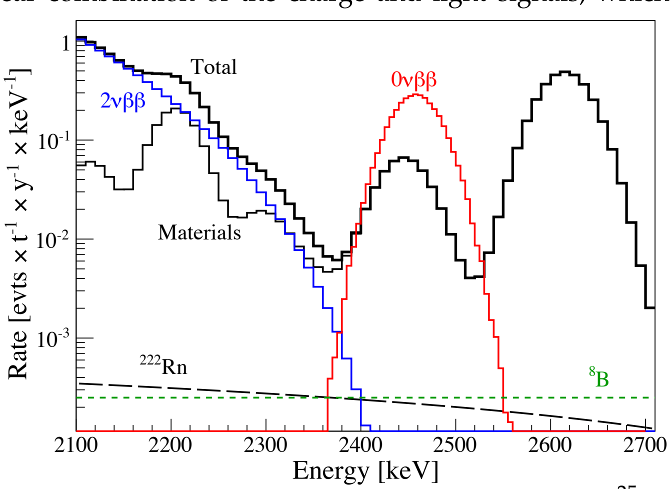

FIG. 5.3 – Hypothetical $0\nu\beta\beta$ signal for $T_{1/2}$=1.6×10^{25} yr and predicted background for 6 t fiducial mass. The background is completely dominated by detector materials with small contributions from 0.1 μBq/kg of ^{222}Rn in the LXe, ^{8}B neutrino scatters and $2\nu\beta\beta$-decays.

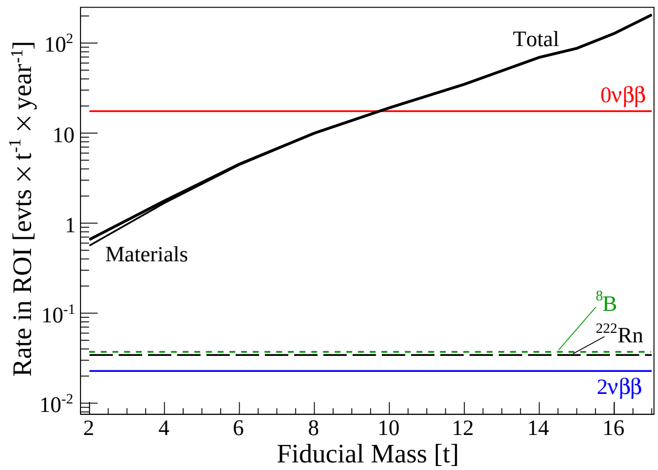

FIG. 5.4 – Integral background rate in $\pm3\sigma$ energy region around the $Q-$value (2385–2533 keV) as a function of fiducial LXe mass.

are anti-correlated in liquid xenon TPCs [6], the energy resolution is $\sigma/E \approx 1\%$. Hypothetical signal and expected background are shown in Fig. 5.3.

As illustrated in Fig. 5.4, at double beta decay energy the fiducial volume cut is less effective in reducing material backgrounds which results from the much longer mean free path of photons in this energy region. Hence, for this search we consider a reduced fiducial LXe mass of 6 t which contains 534 kg of ^{136}Xe for the natural abundance of 8.9%. The materials background is dominated by ^{214}Bi and ^{208}Tl decays in the photosensors and the cryostat which can only be further reduced by selecting materials with lower ^{226}Ra and ^{228}Th concentrations. The background contribution from internal radon can be efficiently rejected by so-called ^{214}Bi-^{214}Po tagging. It exploits the fact that the ^{214}Bi β-decay (Q_β= 3.3 MeV) and the ^{214}Po α-decay (Q_α= 7.8 MeV) occur close in time, given the ^{214}Po lifetime of 237 μs. We assume a tagging efficiency of 99.8%, as achieved in EXO-200 [7] and confirmed by us in a Monte Carlo simulation, assuming that ^{214}Po decays can be detected up to 1 ms after the initial ^{214}Bi decay.

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