Dark Matter Search with DARWIN

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DARWIN (DARk matter WImp search with Noble liquids) is a future multi-ton scale detector for the direct detection of Weakly Interacting Massive Particles (WIMPs). The detector will be based on a xenon dual-phase time projection chamber (TPC) with simultaneous charge and light readout. The goal is to build the ultimate detector for WIMP masses $\gtrsim$5 GeV/c^2, whose sensitivity will only be limited by the irreducible neutrino background. This work focuses on the physics reach and backgrounds related to DARWIN.

1 Setup

The DARWIN detector [1] will employ a dual-phase TPC with a 40 t liquid xenon (LXe) target. The TPC consists of PTFE reflectors, OFHC Cu field shaping rings and is housed in a stainless steel or titanium cryostat. In the baseline design, the LXe scintillation light will be detected by two arrays of photomultiplier tubes ($\sim$1800$\times$ 3 inches or $\sim$1000$\times$ 4 inches). Alternative light detectors like gaseous photomultipliers (GPMs) or silicon photomultipliers (SiPMs) are the subject of ongoing R&D [9]. The cryostat is housed in a water Cherenkov shield with 14 m diameter (see Fig. 1). An additional liquid scintillator shield is under study.

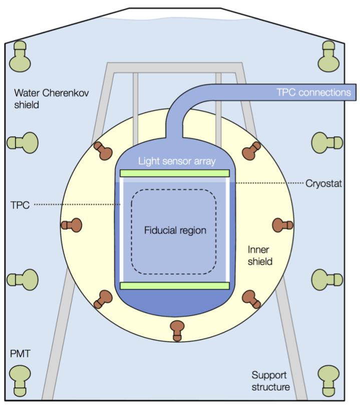

Figure 1: Sketch of the DARWIN detector. The cryostat containing the LXe target is housed inside a water Cherenkov shield. The optional inner shield contains liquid scintillator.

2 WIMP Physics

The primary goal of DARWIN is the detection of galactic WIMPs via scattering off the xenon target nuclei. In Fig. 2 we show the projected sensitivity for spin-independent and spin-dependent WIMP-nucleus scattering. The study assumes a 99.98% electron recoil (ER) rejection at 30% nuclear recoil (NR) acceptance for a 30 t fiducial volume (FV). With an exposure of 200 t y, a spin-independent sensitivity of $2.5 \times 10^{-49}\,\mathrm{cm}^2$ can be reached at a WIMP mass of $40\,\mathrm{GeV/c}^2$. For spin-dependent WIMP-neutron couplings and WIMP masses up to $\sim 1\,\mathrm{TeV/c}^2$, DARWIN will be complementary to the searches conducted by the future high-luminosity LHC, at 14 TeV center-of-mass energy [2].

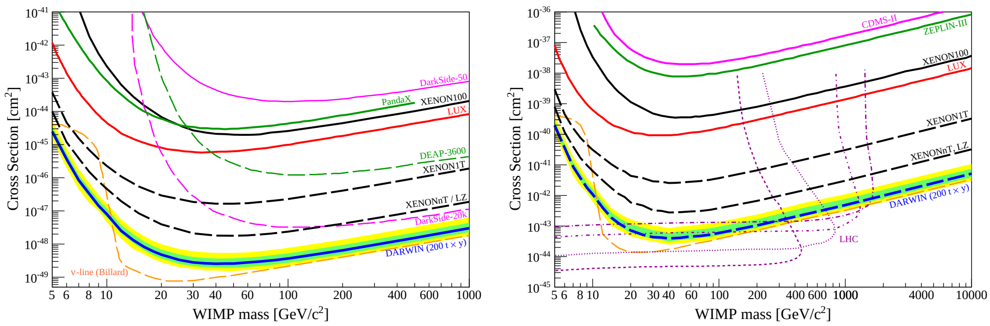

Figure 2: Projected sensitivity of DARWIN for spin-independent (left) and spin-dependent (right) WIMP-nucleus scattering.

3 Backgrounds

The primary backgrounds of DARWIN include ER background from internal contamination and solar neutrinos as well as NR background from radiogenic neutrons and coherent neutrino nucleus scattering (CNNS) of solar and atmospheric neutrinos.

The expected single-scatter nuclear recoil rate from radiogenic neutrons is about $3.8 \times 10^{-5}\,\mathrm{t}^{-1}\,\mathrm{y}^{-1}\,\mathrm{keV}^{-1}$. To reach this background level, the radioactivity of current detector materials like PTFE and PMTs has to be improved by a factor of 2-5 [3].

CNNS of solar and atmospheric neutrinos poses as an unavoidable background that will ultimately limit the sensitivity of any non-directional WIMP search experiment. For low-mass WIMPs ($\lesssim 8\,\mathrm{GeV/c}^2$) the main background comes from ^{8}B solar neutrinos with a steep exponential spectrum which depends highly on the achievable threshold and energy resolution. At higher energies the background is dominated by atmospheric neutrinos with a fairly flat spectrum and a rate of $\sim 10^{-3}\mathrm{t}^{-1}\,\mathrm{y}^{-1}\,\mathrm{keV}^{-1}$.

The ER background in DARWIN will be dominated by neutrino-electron scattering of solar pp-neutrinos and ^{7}Be neutrinos at the level of $\sim 26\,\mathrm{t}^{-1}\,\mathrm{y}^{-1}$ in the low-energy, dark matter signal region of the detector [4]. Other ER backgrounds come from intrinsic contamination with ^{85}Kr and ^{222}Rn. For the sensitivity study shown in Fig. 2 a ^{nat}Kr concentration of 0.1 ppt has been assumed. Even lower concentrations have been already achieved by the Kr removal apparatus of XENON1T [5]. The biggest challenge is the ^{222}Rn contamination which has to be reduced to 0.1 µBq/kg. This is about a factor of 40 lower than the lowest concentration achieved so far in LXe by the EXO experiment [6].

4 Other Rare Event Searches

As a large scale low-background detector DARWIN will also be suited for other rare event searches in the field of neutrino and axion physics.

Because of its low ER background DARWIN can search for solar axions and galactic axion like particles (ALPs) via the axio-electric effect. For solar axions, the estimated sensitivity for the axion-electron coupling is $g_{Ae} < 10^{-12}$ for axion masses $10^{-5} - 1\,\mathrm{keV/c^2}$. For galactic ALPs a sensitivity of $g_{Ae} < 10^{-14}$ for axion masses $1 - 40\,\mathrm{keV/c^2}$ can be reached.

The first real-time measurement of the solar pp-neutrino flux has recently been achieved by the BOREXINO experiment [7]. A precision measurement of the pp-neutrino flux would test the main energy production mechanism in the sun. DARWIN will be able to measure the solar pp-neutrino flux through elastic neutrino-electron scattering with a precision of 1% after 5 years.

Studying neutrinoless double beta decay can be used to investigate the neutrino mass hierarchy and determine whether neutrinos are Majorana particles. The isotope ^{136}Xe is interesting candidate for neutrinoless double beta decay with a natural abundance of 8.9%. Even without isotopic enrichment DARWIN will be able to reach a half-life limit $T_{1/2} > 8.5 \times 10^{27}$ y with an exposure of 140 t y.

Another interesting physics case would be the detection of neutrinos from a galactic supernova. A possible detection channel is via CNNS which provides sensitivity to all neutrino flavors. Due to the short burst time of a supernova the expected background is negligible. For a $27\mathrm{M}_{\odot}$ supernova at 10 kpc distance approximately 700 neutrinos can be detected by DARWIN [8].

5 Conclusion

The goal of the DARWIN collaboration is to build the ultimate WIMP detector. After an exposure of 200 t y it will provide a sensitivity for the spin-independent WIMP-nucleon scattering cross section of $2.5 \times 10^{-49}\,\mathrm{cm}^2$ at a WIMP mass of $40\,\mathrm{GeV/c^2}$. DARWIN will also provide important results for many other rare event searches like the neutrinoless double beta decay of ^{136}Xe or solar axions and galactic ALPs. It will also provide a real-time precision measurement of the solar neutrino flux and serve as neutrino detector for a galactic supernova.

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