# 5 DARWIN: Dark matter WIMP search with noble liquids

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The rates of WIMP interactions with target nuclei are below one event per kilogram and year, and momentum transfers are around 10-100 MeV [1, 2]. Thus, searches for these hypothetical particles require large target masses and low energy thresholds and detectors are situated deep underground where background can be low. Sensitivities of $\sim 10^{-45}$ cm$^2$ have been achieved for spin-independent WIMP-nucleon scattering cross sections in xenon [3, 4] and argon [5]. The near-future ton-scale experiments [6, 7] will probe the region down to $\sim 5\times 10^{-47}$ cm$^2$. Nevertheless, in order to eventually measure WIMP properties such as mass, scattering cross section and possibly spin [8], significantly larger detectors are required.

Fig. 5.1 – A CAD model of the 20 t LXe DARWIN TPC.

Dark matter WIMP search with noble liquids (DARWIN) is an R&D and design study for a multi-ton dark matter detector [9]. Its primary design goal is to probe the spin-independent scattering cross section down to $10^{-48}$ cm$^2$ and, in case WIMPs are discovered, to perform a high-statistics measurement of the WIMP-induced nuclear recoil spectrum, which would allow to constrain the WIMP mass and scattering cross section [8]. Besides WIMP search other physics goals are the search for neutrinoless double beta decay in $^{136}$Xe, and the real-time detection of pp-neutrinos from the sun.

DARWIN will be based on a large, unsegmented target mass capable of reducing the fiducial volume by utilizing the time projection chamber (TPC) technique. The TPC will detect the prompt scintillation light from primary particle interactions in the active detector volume, and the delayed proportional scintillation signal, produced by ionization electrons drifting towards the gas phase. A simplified CAD model of the DARWIN TPC is shown in Fig. 5.1. The background originating from cosmic muons will be suppressed to negligible levels by a large water Cherenkov shield, surrounding the noble liquid cryostats (see Fig. 5.2).

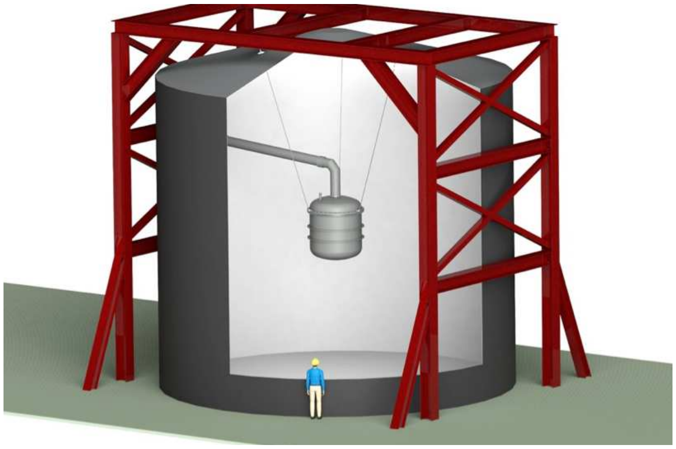

Fig. 5.2 – Schematic view of the DARWIN experiment.

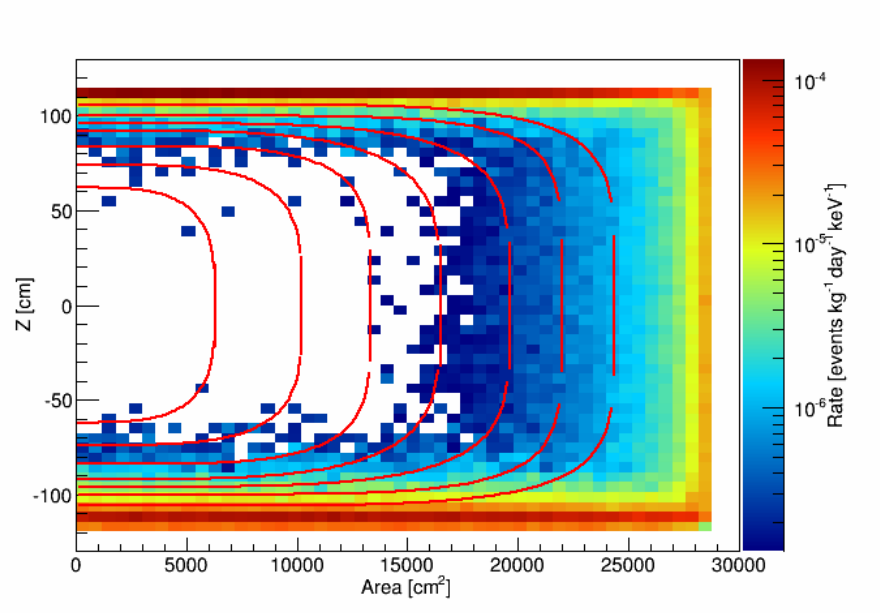

FIG. 5.3 – Spatial distribution of background events in the 2404.6−2553.4 keV $2\beta$-energy region of interest for the $^{136}$Xe $0\nu\beta\beta$ decay search. The red contours indicate fiducial volumes of 14, 12, 10, 8, 6, 4 and 2 t.

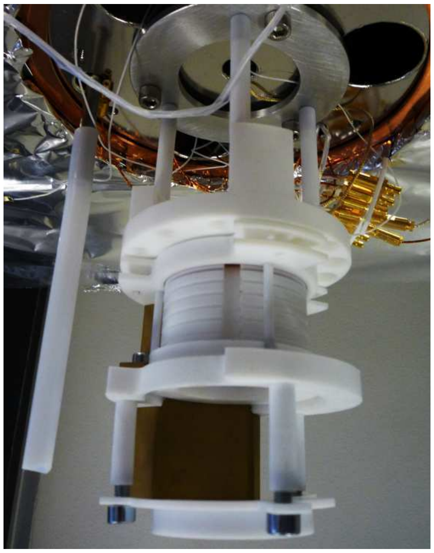

FIG. 5.4 – The new *Zürich II* detector will be used to measure light and charge yields in LXe for low-energy nuclear recoils.

Our group is a leading member of the DARWIN Consortium, involved in TPC design, Monte Carlo simulations of the electronic and nuclear recoil backgrounds, new light read-out schemes and tests of light sensors in noble liquids, material screening, and measurements of charge and light yield of low-energy nuclear recoils.

We have performed GEANT4 simulations of the potential electromagnetic and neutron backgrounds associated with the natural radioactivity ($^{238}$U, $^{232}$Th, $^{60}$Co, $^{40}$K) in the construction materials. The background as a function of fiducial detector volume was studied for the low-energy region (<100 keV), relevant for the dark matter and solar neutrino detection, and for the high-energy region (around 2.5 MeV), relevant for the neutrinoless double beta decay search in $^{136}$Xe. As an example, we show in Fig. 5.3 the background rates in the energy region 2404.6−2553.4 keV which corresponds to a $\pm 3\sigma$ window around $Q_{\beta\beta}$ = (2457.83±0.37) keV for the assumed detector resolution $\sigma$ = 1%. As illustrated the background falls rapidly when moving away from the detector boundaries.

For the study of the light yield from electronic and nuclear recoils at low energies, we have designed and built a small dual-phase LXe TPC (*Xürich II*, see Fig. 5.4) which will be exposed to the 2.45 MeV neutron beam provided by the UZH *D-D* fusion neutron generator. Its predecessor, *Xürich I*, was used to measure the light yield of low-energy electronic recoils in LXe, down to 1.5 keV [10]. Those results are relevant for the analysis of the electronic recoil spectrum of XENON100 regarding the observed annual modulation signal by the DAMA/LIBRA experiment in the region around 2-5 keV [11], as well as to non-WIMP dark-matter candidates that might interact with electrons.

The detector design is based on extensive electric field simulations aimed at optimizing the field uniformity within this small volume [12]. Fig. 5.5 shows the simulated field distribution. The vertical box located at

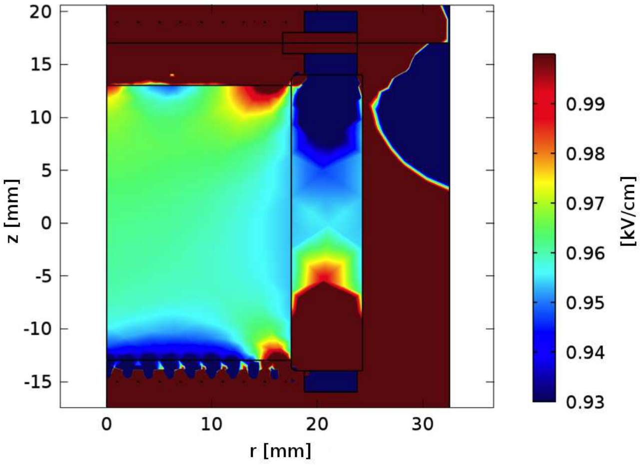

FIG. 5.5 –
The simulated electric field map for *Xürich II*. The active region of the detector extends to $r = 17.5$ mm. Note the color scale expanded to the upper 7% only.

$r \simeq 20$ mm indicates the polytetrafluoroethylene (PTFE) ring that marks the boundary of the active region. This particular simulation investigates the use of a special type of PTFE that has the resistance that results in a uniformly varying electric potential at the surface. As a result, the variation in field strength is below 4% which is essential for collecting all emitted charges.

The *Xürich II* detector is currently being assembled and tested in our laboratory. After initial characterization and calibration runs with electron ($^{83m}$Kr), gamma ($^{57}$Co) and neutron ($^{241}$AmBe, $^{88}$YBe) sources, it will be operated in coincidence with two liquid scintillator neutron detectors in the neutron generator beam.

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