XENON100

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The XENON100 Dark Matter experiment, installed in the Laboratory Nazionali del Gran Sasso (LNGS, Italy), is searching for WIMP type Dark Matter particles scattering off a 62 kg liquid xenon target in a dual phase (liquid/gas) time projection chamber. The analysis of 11.2 live days of background data taken during a commissioning run in fall 2009 leads to the first science result of XENON100: No events are observed in a pre-defined fiducial volume of 40 kg mass, excluding spin-independent WIMP-nucleon scattering cross sections above 3.4×10^{-44} cm^2 (at 100 GeV/c^2). Below 80 GeV/c^2, this is the most sensitive exclusion limit so far, constraining the interpretation of DAMA and CoGeNT being due to spin-independent, elastic interactions of light mass WIMPs.

1 Introduction

Indirect astronomical observations at all cosmological length scales suggest that a large amount of the matter content of the Universe is dark, i.e. invisible over the whole electromagnetic spectrum [1]. There are strong indications that this Dark Matter is made up from yet-unknown, heavy, non-relativistic (cold) particles that build large scale cosmological structures. A well motivated candidate is the WIMP (Weakly Interacting Massive Particle), a stable particle arising naturally in many theories beyond the Standard Model, such as supersymmetry or theories with extra dimensions [2].

In experiments, WIMPs are expected to interact with the target nuclei (nuclear recoil interactions) because they are neutral, whereas the main background comes from electromagnetic interactions of gammas and electrons with the atomic electrons (electronic recoil interactions). From the assumed WIMP mass and velocity distribution one expects to measure a steeply falling, featureless nuclear recoil spectrum at energies of a few keV only. The predicted rates are tiny, much less than one interaction per kg and day of exposure. Therefore, the experiments have to reduce their background as much as possible in order to be sensitive to WIMPs.

2 XENON100

The XENON collaboration uses liquid xenon (LXe) as target material. Xenon is a heavy target ($A \sim 131$) which enhances the sensitivity for spin-independent WIMP-nucleon scattering. Being an efficient scintillator ($\lambda = 178$ nm), xenon also serves as detector material. It's high density ($\rho \sim 3$ g/cm^3) allows to build compact detectors with excellent self shielding capabilities. Furthermore, xenon has no long-lived radioactive isotopes, and small admixtures of the

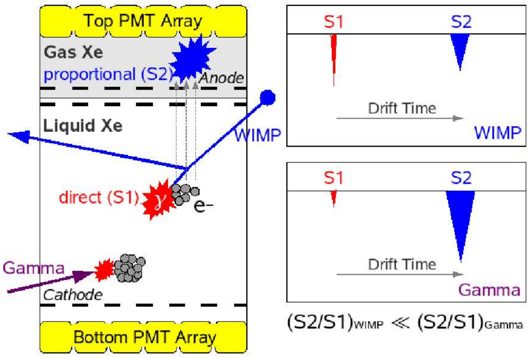

Figure 1: Double-phase LXe TPC: An interaction generates prompt scintillation light (S1) and ionizes the target. The ionization electrons are drifted upwards and extracted into the gas phase where they generate proportional scintillation (S2). The S2 light pattern, together with the drift time of the electron cloud, is used to reconstruct the event vertex. The S2/S1 ratio differs for nuclear and electronic recoil interactions and is used for signal/background discrimination.

radioactive ^{85}Kr can be removed to the ppt level [3].

Liquid xenon detectors provide 3-dimensional interaction vertex reconstruction and signal to background discrimination when operated as a dual-phase (liquid/gas) time projection chamber (TPC), see Fig. 1: An interaction in the LXe generates prompt scintillation light (the S1 signal) and ionizes the target. The ionization electrons are drifted towards the liquid gas interface by a strong electric field. Here, the electrons are extracted into the gas phase and accelerated towards the anode while generating proportional scintillation light (S2). Both signals, S1 and S2, are detected by two arrays of photosensors, one immersed in the liquid for optimal light collection, and one located in the gas phase above the target. The position of the interaction can be reconstructed using the S2 signal distribution on the top array (x, y) and the time difference between prompt S1 and delayed S2 signal (z). Due to their different track densities in the medium, the ratio S2/S1 can be used to discriminate between signal (nuclear recoil interactions) and background (electronic recoils).

XENON100 is the current detector at the 100 kg scale within the phased program of the XENON collaboration. It follows the XENON10 phase which has proven that liquid xenon detectors are able to deliver very competitive results [4]. XENON100 has a total mass of 161 kg of LXe, out of which 62 kg are in the cylindrical target volume which is viewed by two arrays of Hamamatsu R8520 photomultipliers from above (98 PMTs) and below (80 PMTs). The remaining 99 kg of LXe are surrounding the target in 4π. This volume is instrumented with another 64 PMTs and acts as an active veto. The whole detector is installed inside a passive shield in order to reduce the background from ambient gamma rays and neutrons.

Background All materials considered for XENON100 were screened with high purity germanium spectrometers in order to determine their intrinsic radioactivity. Only materials with a reasonable radioactivity were accepted for the detector construction. All measured radioactivity values are used as input parameters for a detailed Monte Carlo model of the detector and the result of the simulation agrees remarkably well with the measured background spectrum over the full energy range [6]. In a fiducial volume of 30 kg mass, XENON100's background rate in the low energy range is 5.3×10^{-3} events keVee^{-1}kg^{-1}day^{-1} (electron recoil equivalent energy) when the active LXe veto is employed. This is a factor 100 lower than XENON10, thus achieving one of the design goals of XENON100. In fact, XENON100 is currently the experiment with the lowest background level of all running dark matter detectors, more than two orders of magnitude below any other experiment at low energies.

Data Analysis and Result XENON100 is installed underground at Laboratori Nazionali del Gran Sasso (LNGS, Italy) since spring 2008. After extensive calibrations and studies to characterize the detector response, first science data has been taken in fall 2009. This article summarizes the results of this run, which have been published in [5].

In order to use the $\log_{10}(\mathrm{S2/S1})$ parameter to discriminate between electronic and nuclear recoils, the low energy response of the detector to these interactions was calibrated using the Compton continuum of ^{60}Co and elastic neutron interactions from an ^{241}AmBe source, respectively. The two populations are well separated and lead to a discrimination of $> 99\%$ at 50% nuclear recoil acceptance.

Based on the cut acceptance and the expected recoil spectrum from WIMPs, the energy region of interest for the first Dark Matter analysis has been chosen from 4–20 PE (S1 signal). This region has to be converted to a nuclear recoil equivalent energy scale (given in keVnr) which takes into account the reduced scintillation yield for nuclear recoil interactions ("quenching"). This conversion is based on the measurement $\mathcal{L}_{\mathrm{eff}}$(keVnr) of the scintillation efficiency of nuclear recoils relative to interaction of 122 keV gamma rays, measured by various groups in dedicated experiments. However, at low energies the results differ more than expected from the stated error bars. For a recent discussion of the systematics of these measurements, see [7]. Therefore, we have chosen to employ a statistical approach to this data to derive a best fit description (with a flat extrapolation below 5 keVnr) and a lower 90% CL-contour (with a conservative logarithmic extrapolation). We give our results for both cases in order to reflect the current uncertainties.

The data leading to the first XENON100 results were taken in stable conditions in October and November 2009. Altogether 11.2 life days of data have been used for the analysis. The data has not been blinded, however, the analysis has been performed in a quasi-blind way and all cuts and selections were developed on calibration data only.

The WIMP search region between 4 and 20 PE corresponds to 8.7–32.6 keVnr (best fit $\mathcal{L}_{\mathrm{eff}}$).

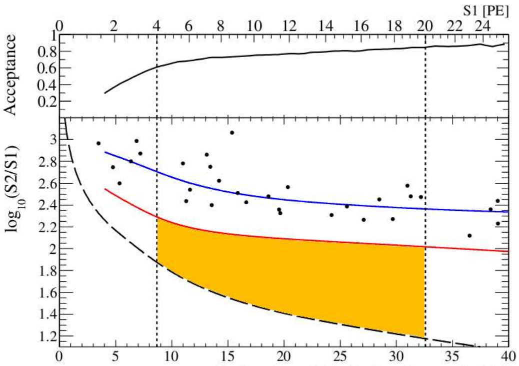

Figure 2: In $\log_{10}(\mathrm{S2/S1})$ space, used for discrimination between signal and background, all remaining events are well above the nuclear recoil median (red). No event falls in the predefined WIMP search region (yellow).

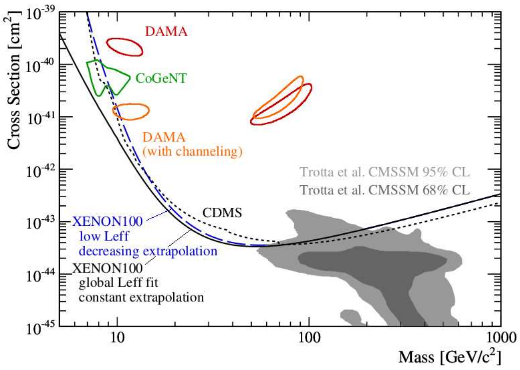

Figure 3: The limit on the spin independent WIMP-nucleon cross section derived from the first XENON100 data. The exclusion plot shows the 90% CL exclusion contours for the two $\mathcal{L}_{\mathrm{eff}}$ cases described in the text.

The upper bound in $\log_{10}$(S2/S1) space was the median of the nuclear recoil band from the neutron calibration, the lower bound a software threshold of S2 $>$ 300 PE. A simple cylindrical fiducial volume with 40 kg of xenon was chosen for this analysis, and < 0.2 background events were expected in this volume for the given exposure.

Only events with a single S2 peak (single scatter events) were selected for the WIMP analysis, since the interaction probability of WIMPs is far too small to scatter in the detector twice.

The positions of the events remaining in the fiducial volume in $\log_{10}$(S2/S1) space are shown in Fig. 2. All events are well separated from the WIMP search region. This figure is the most remarkable result of this analysis: It demonstrates that LXe detectors can be indeed used for background-free WIMP searches. The upper part of Fig. 2 gives the energy dependent acceptance function not taking into account the 50% acceptance from $\log_{10}$(S2/S1)-based electronic recoil discrimination.

Fig. 3 shows the limits from this analysis, calculated for the two choices of $\mathcal{L}_{\mathrm{eff}}$ as discussed above, assuming an isothermal WIMP halo. The acceptance-corrected exposure, weighted by a spectrum of a 100 GeV/c^2 WIMP, is 172 kg×days. For WIMP masses below 80 GeV/c^2, this result places the lowest limit so far. At light WIMP masses, DAMA [8] and CoGeNT [9] are constrained even assuming the conservative $\mathcal{L}_{\mathrm{eff}}$.

3 Outlook

The previous section summarized the first Dark Matter results of XENON100, derived from 11.2 life days of data taken during a commissioning run in fall 2009 [5]. In the meantime, about 10× more science data has been acquired and a blind analysis is ongoing. The ultimate sensitivity of XENON100 for spin-independent WIMP-nucleon scattering, based on the background predictions from Monte Carlo simulations, is $\sigma = 2 \times 10^{-45}$ cm^2 (at 100 GeV/c^2) for an exposure of 200 life days and a fiducial mass of 30 kg.

The XENON collaboration is already in the design phase for XENON1T: This future detector will employ a LXe double-phase TPC with a fiducial mass of 1000 kg in a large water Cherencov muon veto to achieve a sensitivity of a few 10^{-47} cm^2. A large fiducial volume cut, together with careful material selection and LXe purification, will further decrease the background by a factor 100 in order to explore the WIMP parameter space down to lower cross sections than XENON100, or to confirm a possible WIMP detection.

References

[1] K. Nakamura et al. (Particle Data Group), *J. Phys.* **G 37**, 075021 (2010) and references therein.

[2] G. Bertone G (ed.), *Particle Dark Matter*, Cambridge University Press, Cambride (2010).

[3] K. Abe et al. (XMASS), *Astropart. Phys.* **31**, 290 (2009).

[4] J. Angle et al. (XENON10), *Phys. Rev. Lett.* **100**, 021303 (2008);
J. Angle et al. (XENON10), *Phys. Rev. Lett.* **101**, 091301 (2008).

[5] E. Aprile et al. (XENON100), *Phys. Rev. Lett.* **105**, 131302 (2010),

[6] E. Aprile et al. (XENON100), `arXiv:1101.3866` (2011).

[7] A. Manalaysay, `arXiv:1007.3746` (2010).

[8] C. Savage et al., *J. Cosmol. Astropart. Phys.* **4**, 10 (2009).

[9] C.E. Aalseth et al. (CoGeNT) `arXiv:1002.4703` (2010).