Status of XENON100

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Abstract. XENON100 is a two-phase time projection chamber with a 62 kg liquid xenon target to search for Dark Matter interactions. Both scintillation and ionization signals are recorded to allow interaction vertex reconstruction in three dimensions. Fiducialization of the target volume results in the lowest background level of any running Dark Matter search experiment. In a 48 kg fiducial target and 100.9 days of live time, no evidence for Dark Matter is found. This leads to the strongest limit on elastic spin-independent WIMP-nucleon interactions for WIMP masses above $\sim 10 \text{ GeV}/c^2$. Also, this data excludes inelastic Dark Matter scattering off sodium or iodine as an explanation of the DAMA modulation.

1. Introduction

Various astrophysical observations at all cosmological length scales suggest that the vast majority of the content of the Universe is non-baryonic [1]. While the presence of large quantities of Dark Matter is well established, its nature is still unknown. Weakly Interacting Massive Particles (WIMPs) are well-motivated particle candidates [2], and a variety of experiments search for signals from WIMPs scattering off a target in a laboratory setting.

2. XENON100

The XENON100 Dark Matter experiment is installed underground at the Laboratory Nazionali del Gran Sasso of INFN, Italy. A 62 kg liquid xenon target is operated as a dual phase (liquid/gas) time projection chamber to search for WIMP interactions. A schematic is shown in figure 1: an interaction in the target generates scintillation light which is recorded as a prompt S1 signal by two arrays of photomultiplier tubes at the top and bottom of the chamber. In addition, each interaction liberates electrons, which are drifted by an electric field to the liquid-gas interface with a speed of about 2 mm/µs. There, a strong electric field extracts the electrons and generates proportional scintillation which is recorded by the same photomultiplier arrays as a delayed S2 signal. The time difference between these two signals gives the depth of the interaction in the time-projection chamber with a resolution of 0.3 mm ($1\sigma$). The hit pattern of the S2 signal on the top array allows to reconstruct the horizontal position of the interaction vertex with a resolution $<3$ mm ($1\sigma$). Taken together, XENON100 is able to precisely localize events in all three coordinates. This enables the fiducialization of the target, yielding a dramatic reduction of external radioactive backgrounds due to the self-shielding capability of liquid xenon. In addition, the ratio S2/S1 allows to discriminate electronic recoils, which are the dominant background, from nuclear recoils, which are expected from Dark Matter interactions. Details of the experimental setup can be found in [3].

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Figure 1. The principle of the two-phase liquid noble gas detector XENON100: the prompt scintillation signal (S1) is recorded by photomultiplier arrays in the liquid and the gas phase. Electrons are liberated in the interaction and drifted to the liquid/gas interface by an electric field. An electric field in the gas phase creates proportional scintillation light (S2) from these electrons, which is also recorded. The depth of the interaction is reconstructed from time difference between the two signals, and the horizontal position is reconstructed from the hit pattern of the S2 signal on the top photomultiplier array.

3. Spring 2010 Data
The Dark Matter search data presented here was acquired between January 13 and June 8, 2010 and represents a total live time of 100.9 days [4]. The WIMP search is restricted to the energy window 4 – 30 photoelectrons, which in nuclear recoil equivalent energy corresponds to 8.4 – 44.6 keV$_{nr}$. The dominant background from electronic recoils is discriminated from the expected nuclear recoil signal by the parameter $\log_{10}(S2_b/S1)$, where $S2_b$ is the S2 signal summed over the photomultipliers in the bottom array. The electronic recoil background of this data set is affected by a relatively high contamination with $^{85}$Kr of (700 ± 100) ppt, higher than in both the data acquired before [5] as well as after this particular run (see below). As a consequence, the optimum sensitivity to Dark Matter interactions is achieved for a relatively large fiducial volume with a mass of 48 kg.

The expected electronic recoil background of $< 22 \times 10^{-3}$ events/(keV$_{ee}$·kg·day)$^{-1}$ before S2/S1 discrimination [6] is lower than that from other direct Dark Matter detection experiments by more than an order of magnitude. The electronic recoil band in $\log_{10}(S2_b/S1)$-energy-space is flattened by subtracting its mean, which was inferred from $^{60}$Co Compton calibration data. The resulting low-energy event distribution is shown in figure 2.

Indeed, this distribution is consistent with a sum of three expected background contributions. First, a Gaussian component that is dominated by the $^{85}$Kr background. Second, non-Gaussian tails to the electronic recoil band from double-scattered gamma events, where only one interaction happens between the anode and cathode grids of the TPC. The second interaction then adds to the S1 of this event, but not to the S2, thus reducing its S2/S1 ratio. This background has been estimated using $^{60}$Co calibration data, normalized to the exposure and taking into account the amount of $^{85}$Kr events which can not contribute to such event topologies. Third, nuclear recoils are expected from neutron interactions and are estimated by Monte Carlo
simulations using the detailed detector and shield geometry as well as measured radioactivity concentrations [7]. This third population contributes \((0.31^{+0.22}_{-0.31})\) single scatter nuclear recoils in the fiducial volume and the above energy range. The combined background expectation has been verified with the high energy sideband from \(30 - 130\) photoelectrons.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Observed event distribution using the discrimination parameter \(\log_{10}(S2/S1)\) as a function of nuclear recoil equivalent energy. Gray points indicate the nuclear recoil distribution that has been measured with an \(^{241}\)AmBe neutron source, thus simulating a Dark Matter signal. The energy window as well as the software threshold \(S2 > 300\) photoelectrons are indicated as blue dashed lines and define the WIMP search region. Together with the green dashed lines they define a benchmark region in which \((1.8 \pm 0.6)\) events are expected from background, and 3 events observed, as indicated by the red circles. The observed distribution is consistent with the background expectation.}
\end{figure}

4. Dark Matter Limits
The above background expectation has been used for a Profile Likelihood analysis [8] of this data set [4]. The resulting \(p\)-value of the background-only hypothesis is 31\%, i.e., there is no significant signal excess. The corresponding limit on the spin-independent WIMP-nucleon elastic scattering cross-section \(\sigma\) is calculated under standard assumptions of the Dark Matter halo [4]. It is shown in figure 3 at 90\% confidence level together with the expected sensitivity, that is, the 1\(\sigma\) and 2\(\sigma\) region where the limit should be expected in the absence of any Dark Matter signal, solely due to the expected background. As can be seen, this represents the strongest limit on elastic spin-independent WIMP-nucleon interactions for WIMP masses above \(\sim 10\) GeV/c\(^2\) and cuts into expectations from constrained minimal supersymmetric models. The same data set has also been used to exclude the possibility that the observed DAMA modulation [9] could be due to inelastic Dark Matter [10] scattering off sodium or iodine [11].
5. Ongoing Data Taking
After the data presented here was taken, the xenon has been re-processed through a dedicated cryogenic distillation column. This processing reduced the amount of krypton at least to the lower level already reported in [5]. Electronegative impurities have also been removed from the xenon, and the improved purity results in a larger S2 signal for a given energy. In addition, the hardware S2 trigger threshold was lowered to improve the acceptance of the detector at low nuclear recoil energies. Data taking under these improved conditions is ongoing, and the live time of this upgraded run now exceeds the live time of the data discussed above. Analysis of this data is also ongoing and results are expected in the near future.

6. References
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