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XENON1T results from 1 tonne×year WIMP search

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Astronomical and cosmological observations indicate that a large amount of the energy content of the Universe is made of dark matter. The most promising dark matter candidates are the so-called WIMPs (Weakly Interacting Massive Particles). The XENON project, at the INFN Laboratori Nazionali del Gran Sasso, consists of a double-phase Time Projection Chamber (TPC) using ultra-pure liquid xenon as both target and detection medium for dark matter particle interactions. WIMPs can be indeed detected via their elastic scattering off xenon nuclei. The XENON collaboration is now running the XENON1T experiment, the first tonne-scale liquid xenon based TPC, with an active mass inside the TPC of about 2 t. Data were collected in a live time of 279 days of dark matter search up to February 2018. The detector featured the lowest electronic recoil background ever obtained in a dark matter experiment: $(82^{+5}_{-3}(sys) \pm 3(stat))$ events/(t × yr × keV$_{ee}$). The results allowed to set the most stringent exclusion limits on the spin-independent WIMP-nucleon interaction cross section for WIMP masses above 6 GeV/c^2, with a minimum of 4.1×10^{-47} cm^2 for 30 GeV/c^2 WIMP mass at 90% confidence level.

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1. Introduction

Astrophysical and cosmological observations indicate that a considerable amount of the energy content of the Universe is made of dark matter (DM). DM candidates, usually identified under the generic name of Weakly Interacting Massive Particles (WIMPs), arise in many theories beyond the Standard Model. WIMPs are non-baryonic DM candidates, they are non-relativistic (i.e. cold), stable (created in thermal equilibrium in the early Universe) and interact weakly with standard particles.

The XENON project is devoted to the direct detection of dark matter in the form of WIMPs. The XENON detector is based on a Time Projection Chamber (TPC) which uses liquid xenon (LXe) as both WIMP target and detection medium, with simultaneous measurement of the ionization and scintillation signals produced by particle interactions in the active volume.

After the successful results obtained by the XENON10 and XENON100 detectors, the XENON collaboration is now operating the XENON1T detector at the INFN Laboratori Nazionali del Gran Sasso (LNGS); the increase in target mass, its successful purification via distillation, the careful selection of radiopure materials and the use of an active muon veto water shield, allowed to increase the sensitivity to spin-independent WIMP-nucleon interaction by more than an order of magnitude with respect to XENON100 [1]. To improve further, a new detector is already planned with increased LXe active mass (6 t) and decreased background: XENONnT will be constructed and commissioned by the end of 2019 at LNGS.

2. The XENON1T detector

The detectors of the XENON program are based on similar designs and detection principles [2]. The innermost part of the detector is a Time Projection Chamber containing xenon in liquid (LXe) and gaseous (GXe) phase. A stainless steel double-wall cryostat hosts the TPC and keeps it insulated from the environment.

As shown in figure 1 (left), a particle that interacts with the LXe produces a prompt scintillation signal (S1) through excitation, and ionization electrons. The electrons can recombine, enhancing the S1 signal, or can be drifted by an appropriate electric field towards the liquid-gas interface where they are extracted into the GXe producing the secondary scintillation signal (S2). Two arrays of photomultipliers (PMTs), one on the top and one on the bottom of the TPC, are used to detect the S1 and S2 signals. From the hit pattern of the top PMTs it is possible to reconstruct the X-Y coordinate of the interaction vertex, while from the delay between S1 and S2 we can infer the Z coordinate of the event, for a full 3D vertex reconstruction. This capability is crucial since it allows to select an inner region of the LXe, usually called fiducial volume. Thanks to the self-shielding properties of the xenon, the fiducial volume is characterized by a very low background level, a mandatory requirement for an experiment that looks for very rare events such as DM interactions. The S2/S1 ratio is different for electronic recoil (ER) and nuclear recoil (NR), which provide signal-background discrimination since WIMPs are expected to induce single scatter NR in the TPC.

The XENON1T experiment [2], located at an average depth of 3600 m water-equivalent in Hall B of LNGS, is the largest Xe based detector to date. It contains 3.2 t of ultra-pure LXe, with 2 t employed as the target material in the active volume. The TPC, with a diameter of 96 cm and height

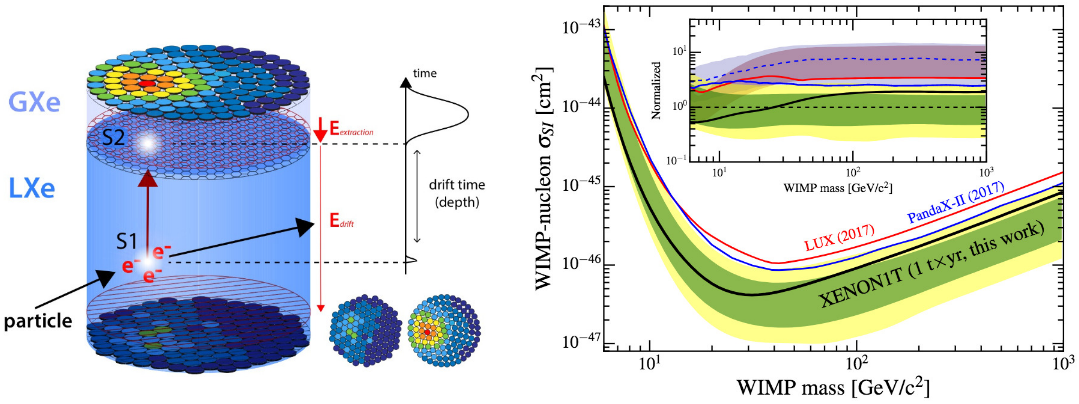

Figure 1: Left: Working principle of the XENON1T TPC. Right: XENON1T 90% confidence level upper limit on σ_{SI}(thick black line) with the 1 σ (green) and 2 σ (yellow) sensitivity bands. Results from LUX and PandaX-II are shown for comparison. The inset shows these limits and corresponding ± 1 σ bands normalized to the median of this work's sensitivity band. The normalized median of the PandaX-II sensitivity band is shown as a dotted line.

of 97 cm, is instrumented above and below by arrays of 127 and 121 Hamamatsu R11410-21 3" PMTs [3]. The detector is surrounded by an active water Cherenkov muon veto system [4].

3. Data analysis and results

The results here reported refer to data collected during two science runs which spanned from November 22, 2016 to January 18, 2017 (SR0) and from February 2, 2017 to February 8, 2018 (SR1), with a brief interruption due to an earthquake. The resulting livetime is 32.1 days and 246.7 days for SR0 and SR1, respectively. Detector operational parameters, such as liquid xenon level or gaseuos xenon pressure, have been continuously monitored and found to be stable with fluctuations $< 0.02\%$ RMS.

Several internal and external radioactive sources were regularly used to calibrate the detector: ^{83m}Kr [5] to monitor various detector parameters, an internal ^{220}Rn source for low-energy ERs calibrations [6]. NR calibration is performed with an external ^{241}AmBe source and with a D-D fusion neutron generator [7]. PMT gain and single photoelectron acceptance is monitored with dedicated LED calibrations and have been stable within $1-2\%$ throughout each science run.

S1 and S2 signals are corrected to take into account light collection efficiency (LCE) due to geometric effects and electron lifetime (which increased from 380 μs at the beginning of SR0 to a plateau of 650 μs at the end of SR1), leading to the corrected cS1 and cS2 signals. Ultimately the bottom PMT array (cS2b) is used for S2 energy reconstruction.

The DM search data were blinded in the signal region above the S2 threshold of 200 photoelectrons (PE) and below the -2σ quantile of the ER background distribution in (cS1, cS2b) space, before the definition of event selection criteria and signal and background models. Data quality criteria are imposed to include only well-reconstructed events and to suppress known backgrounds. All events must contain a valid S1 and S2 pair with S1s containing coincident signals from at least 3 PMTs within 100 ns. The energy region of interest (ROI) is defined by cS1 between 3 and 70 PE, corresponding to an average [1.4, 10.6] keV$_{ee}$ (ER energy) or [4.9, 40.9] keV$_{nr}$ (NR energy). The analysis is performed in the space of cS1, cS2b, R, and Z. Each background component and the WIMP NR signal are modelled as a probability density function of all analysis observables, see [8] for details.

The data in the whole 1.3 t fiducial mass is interpreted using an unbinned extended likelihood, profiling out the nuisance parameters [8]. SR0 and SR1 are simultaneously fitted by assuming only the following parameters are correlated: electron-ion recombination in ER, neutron rate, WIMP mass and σ_{SI}. After unblinding, the number of events in the NR reference region is consistent with background expectations. The profile likelihood analysis indicates no significant excesses at any WIMP mass. A p-value calculation based on the likelihood ratio of the best-fit including signal to that of background-only gives $p = 0.28,\ 0.41$, and 0.22 at $6,\ 50$, and 200 GeV/c^2 WIMP masses, respectively. In figure 1 (right) we show the resulting 90% confidence level upper limit on σ_{SI}: the median sensitivity of this search is ~ 7 times better than previous experiments at WIMP masses > 50 GeV/c^2.

In conclusion, the XENON1T experiment performed a DM search using an exposure of 278.8 days × 1.3 t = 1.0 t × yr, with an ER background rate of $(82^{+5}_{-3}(sys) \pm 3(stat))$ events/(t × yr × keV$_{ee}$), the lowest ever achieved in a DM search experiment. No significant excess above background has been observed and we set an upper limit on the WIMP-nucleon spin-independent elastic scattering cross-section σ_{SI} at 4.1×10^{-47} cm^2 for a mass of 30 GeV/c^2, the most stringent limit to date for WIMP masses above 6 GeV/c^2.

The detector upgrade, XENONnT, which is foreseen to start commissioning in 2019, will increase the target mass to ~ 6 t. The sensitivity will improve upon the current result by one order of magnitude in 20 tonne × year exposure.

References

[1] E. Aprile *et al.* (XENON Collaboration), JCAP **1604**, no. 04, 027 (2016).

[2] E. Aprile *et al.* (XENON Collaboration), Eur. Phys. J. C **77**, 881 (2017).

[3] E. Aprile *et al.* (XENON Collaboration), Eur. Phys. J. C **75**, 546 (2015).

[4] E. Aprile *et al.* (XENON Collaboration), JINST **9** (2014) P11006.

[5] L. W. Kastens, S. B. Cahn, A. Manzur, and D. N. McKinsey, Phys. Rev. C **80**, 045809 (2009).

[6] E. Aprile *et al.* (XENON Collaboration), Phys. Rev. D **95**, 072008 (2017).

[7] R. F. Lang *et al.*, Nucl. Inst. and Meth. A **879**, 31 (2018).

[8] E. Aprile *et al.* (XENON Collaboration), Phys. Rev. Lett. 121, 111302 (2018).