Status of the XENON Experiments

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The XENON experiments search for weakly interacting massive particles (WIMPs) using dual-phase xenon time projection chambers. While the XENON100 experiment completed its science program, the next ton-scale experiment, XENON1T, is fully installed and moving towards science data-taking. The most recent results of the collaboration are presented: from XENON100 latest analysis on low mass WIMPs to XENON1T status and its projected sensitivity, that has been evaluated to reach a minimum cross section of 1.6×10^{-47} cm^2 at a WIMP mass of 50 GeV/c^2 after 2 years exposure with 1 ton of fiducial volume.

1 Introduction

Understanding the nature of the dark matter is one of the most fundamental questions in particle and astrophysics. The XENON dark matter search experiments aim at the direct detection of dark matter in the form of weakly interacting massive particles (WIMPs). In the XENON time projection chambers (TPCs), liquid xenon (LXe) is target and detection medium with the further property of being an excellent self-shielding for background reduction. The WIMP elastic scattering off Xe nuclei would produce low energy nuclear recoils at extremely low interaction rates.

2 The XENON dark matter search experiments

The working principle of the XENON detectors is shown schematically in Fig. 1. Photomultiplier tube (PMT) arrays are placed on top and bottom of the TPC. Cathode, gate, and anode grids define electric fields in the TPC. When a particle interacts with Xe in the LXe volume, the interaction creates the excitation and ionization of Xe. Direct scintillation (S1) from the excitation and electron-ion recombination is detected by the PMTs immediately after the interaction. By the applied electric field, the electrons which escaped from the recombination drift towards the anode. Those electrons are extracted into the gas phase by a high electric field between the gate and the anode, and then accelerated in GXe. This creates proportional scintillation in the GXe, which is recorded as a secondary signal (S2) with a time difference to the S1 depending on the drift velocity of the electrons as well as on the depth of interaction. The three-dimensional interaction position is reconstructed using the drift time and the S2 hit pattern on the top PMT array for the depth and the position in horizontal plane estimations, respectively. From the position reconstruction, it becomes possible to reject background events in outer volume from the detector materials or events with multiple scatterings. The ratio S2/S1 is different for electronic recoils (ERs) and nuclear recoils (NRs), which provides background discrimination in addition to the position selection. More details of the detector are described in [1]. Since 2006, the XENON detectors have been operating at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy at an average depth of 3600 m water equivalent. It has started with XENON10 [2] and continued with XENON100 [3]. The multi-ton scale next phase of the project, XENON1T, is fully installed and the data-taking is ongoing.

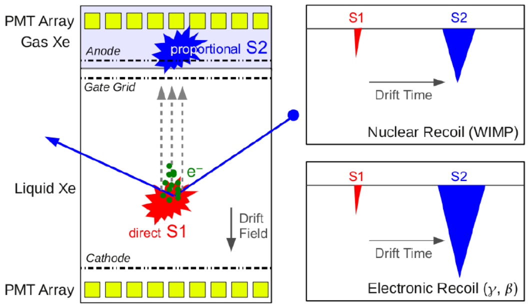

Figure 1: Left: working principle of the XENON dual-phase TPC. Right: sketch of the waveforms of nuclear recoils (WIMPs or neutrons) and electronic recoils (γ or β background), showing the different ratio of the charge (S2) and light (S1) signals for the two types of events.

3 Low mass WIMP search in XENON100

A dedicated analysis has been performed to improve sensitivity on low mass WIMPs [4], using its 225 live days of the XENON100 data. In order to explore the low energy region, the threshold of the detector is lowered by dropping the requirement of an existing S1 and focusing only on single S2 signals. This way a NR threshold of 0.7 keV was achieved, which is significantly lower than the standard analysis of 6.6 keV [3]. Therefore the energy scale was obtained from NR calibration using the S2 signal only, which is also different to the standard analysis, which used only the S1 signal. Because of a difficulty to estimate background without the S1, the analysis assumes every event passing selection criteria could be WIMP signal, which leads to conservative estimation of cross section limit. Figure 2 shows the observed S2 spectrum together with an expected spectrum from WIMP signal of 6 GeV/c^2 at spin-independent (SI) cross section of 1.5×10^{-41} cm^2 (left), and WIMP exclusion limit on the SI WIMP-nucleon scattering cross section at 90% C.L. (right). This analysis improves the result of the previous XENON100 result [3] below ~7.4 GeV/c^2.

4 The XENON1T detector and its expected sensitivity

Following the successful operation of XENON100, XENON1T is the first ton scale liquid xenon detector. XENON1T is expected to have a sensitivity to SI WIMP-nucleon cross section about a factor 100 higher than XENON100. The TPC is 96 cm height and 96 cm diameter, filled with 2 tons of LXe. Total 248 low-radioactive PMTs (Hamamatsu R11410-21 [5]) are distributed at the top and bottom of the TPC. The detector is surrounded by a water tank with a height and diameter of 10 m. This water tank not only acts a shield for external radiation, but also

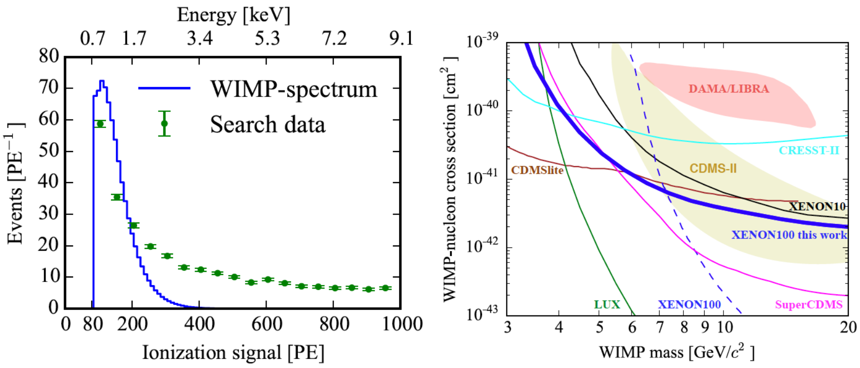

Figure 2: Left: observed S2 spectrum together with an expected S2 spectrum from WIMP signal of 6 GeV/c^2 at a SI WIMP-nucleon scattering cross section of 1.5×10^{-41} cm^2. Right: WIMP exclusion limit on the SI WIMP-nucleon scattering cross section at 90% C.L. Significant improvement from the standard analysis can be seen at WIMP mass below about 7 GeV/c^2.

is operated as an active veto for cosmic muons, since it is equipped with 84 PMTs, which are able to detect Cherenkov light produced by the muons [6].

Figure 3: Left picture shows the water tank and the service building of XENON1T. Right picture shows the installed XENON1T TPC. The copper field shaping rings and the bottom PMT array are visible.

A dedicated Geant4-based Monte Carlo simulation of the XENON1T detector has been developed, including radioactivities of all detector materials, and conversion of energy deposition into S1 and S2 signals. Figure 4 shows an expected S1 spectrum of signals from all contribution background sources as well as a selection of possible WIMP signals (left), and the projected sensitivity to SI WIMP-nucleon interaction (right). The expected XENON1T 90% C.L. SI WIMP-nucleon cross section upper limit reaches 1.6×10^{-47} cm^2 at WIMP mass of 50 GeV/c^2 with 2 ton·year exposure [7].

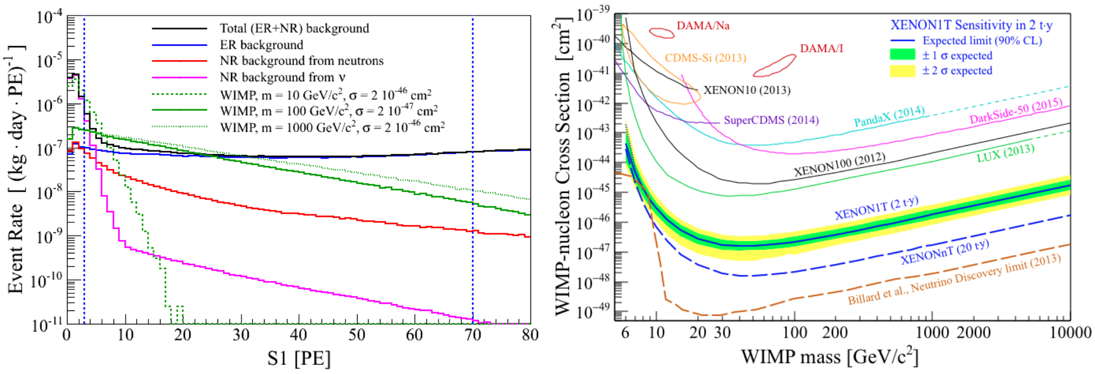

Figure 4: Left: Simulated S1 spectra of backgrounds and WIMP signals. The vertical dashed blue lines delimit the S1 region used in the sensitivity calculation. Only events with S2 > 150 PE are selected, and a 99.75% ER rejection with a flat 40% NR acceptance are assumed. Right: XENON1T sensitivity at 90% C.L. to SI WIMP-nucleon interaction.

5 Summary

The XENON collaboration aims to detect dark matter particle directly with a dual-phase time projection chamber. After the great achievement of XENON100, the next generation XENON1T is the first experiment to use LXe TPC at the ton scale. Its projected sensitivity is two orders of magnitude higher than XENON100. The first science run of XENON1T is expected to start this year.

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