XENON100 Results on WIMP and non-WIMP Searches

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XENON100 is the second phase of the XENON direct Dark Matter search program. It consists of an ultra-low background double phase (liquid-gas) xenon filled time projection chamber, and is installed at the Laboratori Nazionali del Gran Sasso. The results from the 224.6 live days of data taken between March 2011 and April 2012 are reported. The experiment sets one of the most stringent limits on the WIMP-nucleon spin-independent cross section, and the most stringent limit on the spin-dependent WIMP-neutron interaction. With the same dataset, XENON100 sets the best limit to date on the axion coupling to electrons for solar and for galactic axions.

1 Introduction

The Λ-Cold Dark Matter model states that only 5% of the energy of our universe comes from Baryonic matter. The remaining is split into *Dark Energy* (≈68%) and non-Baryonic *Dark Matter* (≈ 27%).

The nature of Dark Matter (DM) is still unknown, and possible candidates arise naturally in several extensions of the Standard Model of particle physics. Weakly Interacting Massive Particles (WIMPs) are the most prominent ones since they are cold, neutral, and can produce the correct relic density of DM observed today. Another prominent class of candidates are Axion-Like Particles (ALPs) generated in a non-thermal production mechanism in the early universe.

The several phases of underground detectors that constitute the XENON program is located at the Laboratori Nazionali del Gran Sasso (LNGS), Italy, at an average depth of 3600 m water equivalent. The ever growing detectors search for DM by detecting its scattering off a liquid xenon (LXe) atom, that leaves both ionization and excitation traces in the liquid. The current phase, XENON100, has been successfully operating since 2009 and achieved unprecedented sensitivity on WIMP-nucleon cross section [1], and on axion-electron coupling [2]. The next phase of the program, XENON1T, is a ton scale detector. XENON1T is in an advanced construction phase, and will become operational in the near future.

2 XENON100

The operational principle of XENON100 is depicted in Fig. 1. The detector is a double-phase time projection chamber (TPC), filled with 62 kg of LXe. A total of 178 low radioactivity, UV-sensitive photomultiplier tubes (PMTs) measure signals induced by particles interacting in the sensitive volume. An interaction in the detector produces both scintillation photons and ionization electrons. The electrons, moved from the interaction point by a 530 V/cm electric, are extracted from the liquid and accelerated in the gas by a 12 kV/cm field, producing proportional scintillation light. The direct scintillation signal ($S1$) and the amplified charge signal ($S2$) are detected by the PMTs. The time difference between the $S1$ and the $S2$ signals is used to estimate the z-coordinate of the interaction, while the $S2$-hit-pattern on the PMTs is employed to estimate the (x, y) - coordinate. In addition, the $S2/S1$ ratio, serves as a separator between the expected WIMP-induced nuclear recoil events (NR) and the electromagnetic induced events (ER). A detailed description of the instrument is given in [3].

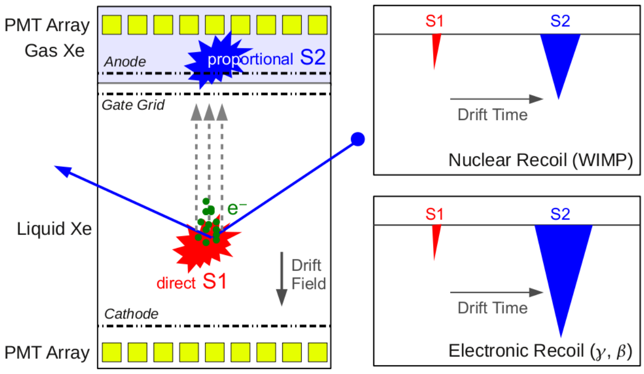

Figure 1: Operational principle of the XENON TPC. The ratio S2/S1 provides separation between nuclear and electromagnetic recoils.

3 WIMP search

The XENON100 data presented here, includes 34 kg fiducial mass and 224.6 live days, collected between March 2011 and April 2012. Compared to the previous data set, this run has a longer exposure, a significantly lower intrinsic ^{85}Kr contamination, an improved electronic noise condition and a lower trigger threshold.

The expected background comes from the leakage of ER events (originating from the detector materials and from intrinsic radioactivity), and by NRs induced by neutrons. The ER background is estimated from calibration data, while the NR background is determined by a detailed Monte Carlo simulation.

A Profile Likelihood (PL) approach is used to test the background-only and signal hypotheses. The systematic uncertainties in the energy scale and in the background expectation are treated as nuisance parameters and represented in the limit. Poisson fluctuations in the number of PEs dominate the S1 energy resolution and are also taken into account along with the single

PE resolution of the PMTs. For the signal model, we assume an isothermal halo with a local density of 0.3 GeV/cm^3, a local circular velocity of 220 km/s, and a Galactic escape velocity of 544 km/s.

WIMPs in the halo of our Galaxy are non-relativistic and their interactions with nuclei can be characterized in terms of scalar (or spin-independent, SI) and axial-vector (or spin-dependent, SD) couplings. This led to the 90% confidence level (CL) limits shown in Fig. 2 for spin-independent, and in Fig. 3 for spin-dependent interactions. The $1\sigma(2\sigma)$ uncertainty on the sensitivity of this run is shown as a green(yellow) band.

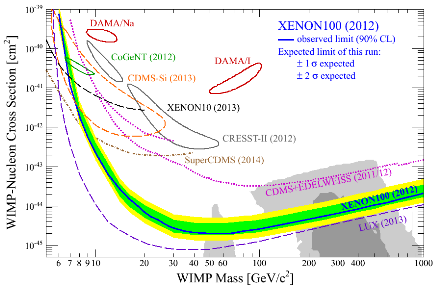

Figure 2: Spin-independent WIMP-nucleon cross section exclusion limit (90% CL) [1].

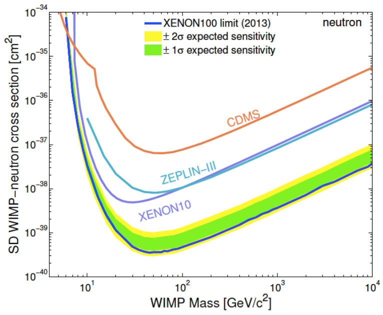

Figure 3: Spin-dependent WIMP-neutron cross section exclusion limit (90% CL) [4].

4 Axion searches

Axions were introduced in the Peccei-Quinn solution of the strong CP problem as pseudo-Nambu-Goldstone bosons emerging from the breaking of a global U(1) symmetry. Although this original model has been ruled out, “invisible” axions (arising from a higher symmetry-breaking energy scale) are still allowed, as described, for example, in the DFSZ and KSVZ models. In addition to QCD axions, axion-like particles (ALPs) are pseudoscalars that do not necessarily solve the strong CP problem, but which have been introduced by many extensions of the Standard Model of particle physics. Axions as well as ALPs are well motivated cold dark matter candidates.

The Sun is an intense source of axions and ALPs, where they can be produced via Bremsstrahlung, Compton scattering, axio-recombination and axio-deexcitation [5] (referred to as solar axions). Additionally, searches can be conducted for ALPs that may have been generated via a non-thermal production mechanism in the early universe and which now constitute the dark matter in our galaxy (referred to as galactic ALPs).

Axions and ALPs may give rise to observable signatures in XENON100 through their coupling to electrons. The coupling g_{Ae}, may be tested via scattering off the electron of a target, through the axio-electric effect [6]. This process is the analogue of the photo-electric effect with the absorption of an axion instead of a photon.

We report on the first axion searches performed with the XENON100 detector, using the same data set used for the WIMP-searches, with an exposure of 224.6 live days and 34 kg fiducial mass. The expected interaction rate is obtained by the convolution of the flux and the axio-electric cross section. The solar axion flux has recently been recalculated in [5]. This incorporates four production mechanisms that depend upon g_{Ae}: Bremsstrahlung, Compton scattering, atomic recombination, and atomic deexcitation. For ALPs in the galaxy, assuming that they constitute the whole dark matter halo density ($\rho_{DM} \sim 0.3$ GeV/cm^3), the total flux is given by $\phi_{\mathrm{ALP}} = c\beta_A \times \rho_{DM}/m_A$, where m_A is the ALP mass.

Fig.4 shows the new XENON100 exclusion limit on g_{Ae}, at 90% CL [2]. The sensitivity is shown by the green/yellow band ($1\sigma/2\sigma$). For comparison, we also present recent experimental constraints. Astrophysical bounds and theoretical benchmark models are also shown. For solar axions with masses below 1 keV/c^2, XENON100 is able to set the strongest constraint on the coupling to electrons, excluding values of g_{Ae} larger than 7.7×10^{-12} (90% CL).

Fig.5 shows the XENON100 90% CL exclusion limit [2]. The XENON100 result is shown compared to other experimental constraints. Astrophysical bounds and a theoretical benchmark model are also presented. The expected sensitivity is shown by the green/yellow bands ($1\sigma/2\sigma$). In the 5 - 10 keV/c^2 mass range, XENON100 sets the best upper limit, excluding an axion-electron coupling $g_{Ae} > 1 \times 10^{-12}$ at the 90% CL, assuming that ALPs constitute all of the galactic dark matter.

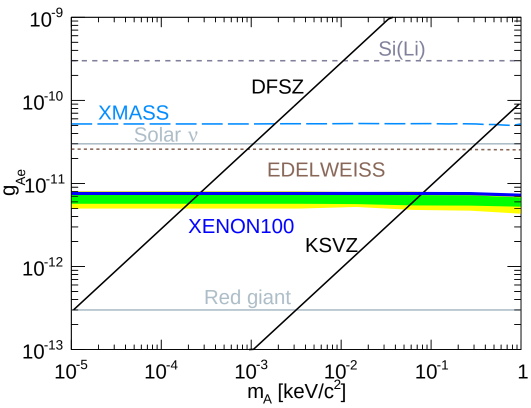

Figure 4: XENON100 limit (90% CL) on solar axions [2].

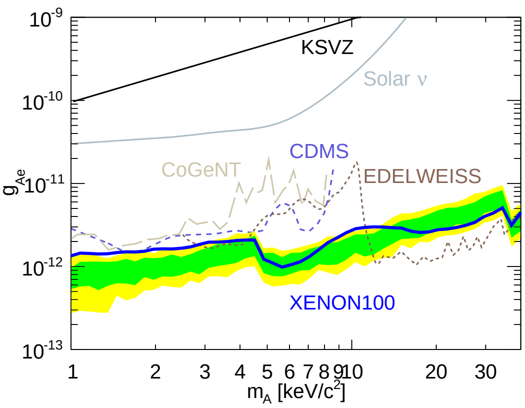

Figure 5: XENON100 limit (90% CL) on galactic ALPs [2].

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