XENON100 and XENON1T
Dark Matter Search with Liquid Xenon

Gaudenz Kessler on behalf of the XENON collaboration
Physics Department, University of Zurich

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The XENON100 detector is a dual-phase (liquid-gas) xenon time-projection chamber for dark matter particle detection containing 161 kg liquid xenon and 242 photomultiplier tubes to detect the scintillation light produced by particle interactions with xenon nuclei.

XENON1T, the next generation dark matter experiment, is being under construction and will house a total amount of 3.2 t of xenon. The designed background level is 100 times lower than that in XENON100. It is surrounded by a water tank that acts as an active muon veto. It is planned to upgrade the experiment to XENONnT with 7 t of liquid xenon.

1 Particle Detection with a Dual-Phase Time-Projection Chamber

The XENON project aims to detect Weakly Interactive Massive Particles (WIMPs) with a dual-phase time-projection chamber (TPC) filled with liquid and gaseous xenon. There are two types of particle interaction with the xenon inside the TPC. Charged particles (like electrons or muons) or γ would interact electromagnetically with an electron of the xenon atom shell. This kind of interaction is referred to as electronic recoil (ER). WIMPs would scatter off the xenon nuclei and cause a nuclear recoil (NR). Neutrons as well interact via nuclear recoil.

Figure 1 shows a schematic description of particle detection in such a detector. An energy deposition due to a particle interaction inside the TPC causes both direct scintillation light and ionisation of the xenon atoms. The direct scintillation light (S1) is promptly detected by two arrays of photomultiplier tubes (PMTs) that are located at the top and at the bottom of the TPC. The ionised electrons are extracted upwards by an electric field. They drift with a constant velocity upwards until they reach the liquid-gas surface. After being extracted into the gas phase of the TPC they produce scintillation light (S2) that is proportional to the number of extracted electrons. Since the electron extraction into the gas phase is very close to the top PMT array, the xy position can be reconstructed using the hit-pattern of photons on the top PMTs. The z coordinate of the interaction can be calculated from the drift time between the S1 and the S2 signals. This allows for a full 3D event position reconstruction. Because the ionisation density is higher for NRs than for ERs, the recombination is stronger for NR. This leads to a different ratio between S2/S1 for NRs and ERs and can be used to discriminate between these types of interaction.

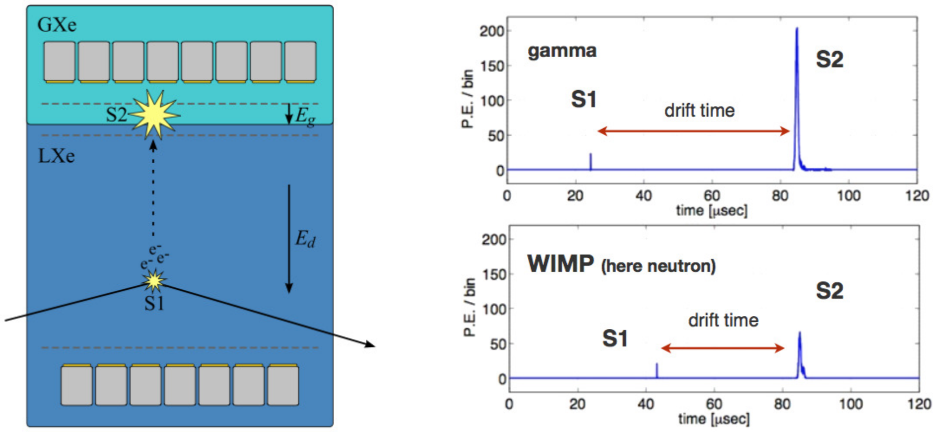

Figure 1: Working principle of a dual-phase time-projection chamber. Left: a particle interaction in the liquid xenon causes direct scintillation light (S1) and free electrons that drift to the gas phase and produce electroluminescence signal (S2). Right: the ratio between S1 and S2 is used to discriminate between ERs (electromagnetic background) and NRs (WIMPs or neutrons). The drift time between S1 and S2 peaks is used to determine the z position of the interaction.

2 XENON100

The XENON100 experiment is located at the Laboratori Nazionali del Gran Sasso (LNGS) in Italy, in which the flux of cosmic muons is reduced by a factor of 10^6 by 1400 meters of rock. The experiment consists of dual-phase time-projection chamber filled with 62 kg of liquid xenon (30 cm height $\times$ 30 diameter). The TPC is surrounded by other 99 kg of liquid xenon that act as an active veto. There are two arrays of PMTs on the top (in the gas phase) and the bottom of the TPC (242 in total). The drift field inside the liquid xenon is 530 V/cm and the field to extract drifting electrons into the gas phase is 12 kV/cm [1]

To probe the recoil behaviour of the background and signal high statistic calibrations have been performed. A ^{60}Co and a ^{232}Th source was used for the ER and an AmBe neutron source for the NR. For a good understanding of the background appearing in the experiment all components of the detector were screened for their radioactivity with high-purity Ge detectors. The obtained data was used to perform a full Monte Carlo simulation of all radioactive materials in all components of the experiment. The energy spectrum obtained in the Monte Carlo simulation fits very well to the background spectrum measured in the detector [2]. At the time of the publication, XENON100 is one of the experiments with the lowest background. The expected background rate in the signal region was determined to be only 1.0 ± 0.2 events for 224.6 live days, 0.79 ± 0.16 of which coming from γ events leaking to lower (S2/S1) values and $0.17^{+0.12}_{-0.07}$ coming from neutrons [3, 4]. In the signal region two events were observed, which means that there is no significant excess about the expected background due to a signal in the XENON100 data. There is a 26.4 % probability that the background fluctuates to two events. This result lead to the most stringent limit for the elastic spin-independent WIMP-nucleon cross-section at that time above 8 GeV/c^2, with a minimum of 2×10^{-45} cm^2 at 55 GeV/c^2 at 90% confidence

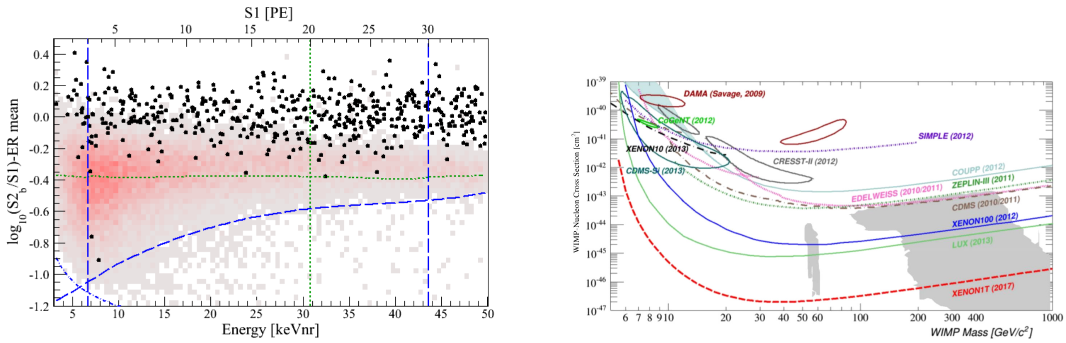

Figure 2: Left: event distribution observed during 224.6 live days using $\log_{10}(S2_b/S1)$ flattened by subtracting the ER band mean, as a function of NR energy. There are two events in the signal region, Right: exclusion limit on the WIMP-nucleon cross section obtained by XENON100 and expected sensitivity of XENON1T.

level [4]. Figure 2 shows the event distribution measured during 224.6 live days (left) and the limit for spin-independent WIMP-nucleon scattering that as achieved with XENON100 (right). 50% of the xenon nuclei have a non-zero spin. The natural abundance of ^{129}Xe and ^{131}Xe is 26.4% and 21.3%, respectively. XENON100 contains 26.2% ^{129}Xe and 21.8% ^{131}Xe. Hence also the spin-dependent elastic interaction was studied and XENON100 still holds the most stringent limit on the spin-dependent WIMP-neutron cross-section [5].

A search for axions and axion-like particles has been performed with the XENON100 data of 224.6 live days $\times$ 34 kg exposure. The axion-electric coupling constant, g_{Ae}, could be rejected for values larger than 7.7×10^{-12} (90% C.L.) [6].

An alternative way to directly detect Dark Matter is to observe inelastic WIMP-nucleus scattering, in which the nuclear recoil excites the nucleus to a low-level excited state [7]. There are two xenon isotopes for which this process is possible: ^{129}Xe has an excitation energy of 39.6 keV to the lowest-lying state, the excitation energy of ^{131}Xe is 80.3 keV. In the analysis of inelastic events ^{129}Xe is considered. The excited state has a lifetime of 0.97 ns which is too short for the nuclear recoil and the photon emission from the deexcitation to be distinguished in time. Hence the expected signal is a nuclear recoil simultaneous with a 40 keV photon. The expected sensitivity in the XENON100 detector is 5×10^{-38} cm^2 for a mass of 100 GeV/c^2 at 90% confidence level.

An annual modulation analysis and low-mass WIMP search are being performed. At the moment 154 live days of new data is available that will be unblinded soon. Currently the XENON100 detector is used to probe the recoil behaviour with various calibration sources.

3 XENON1T

The next generation detector, XENON1T, is currently under construction in Hall B of the Gran Sasso Underground Laboratory. It will house a total amount of 3.2 tons of liquid xenon with 2 tons inside the sensitive region of the TPC. The TPC is a cylinder of 1 meter diameter and 1 meter height and contains in total 248 3-inch PMTs that are designed to have an especially low radioactivity and to operate in liquid xenon environment [8] The experiment will have 100 times lower background than its predecessor XENON100. Therefore it is embedded inside a 10 meter diameter water shield that is instrumented with 84 8-inch PMTs and acts as a Cherenkov muon veto [9]. The sensitive volume is shielded by 10 cm of liquid xenon. The required level of ^{85}Kr will be below 0.5 ppt (a few ppt in XENON100), and the contamination of ^{222}Rn will be only 1 μBq/kg whereas it was 65 μBq/kg in XENON100. The goal is to achieve only 0.5 events per ton per year. The operation is planned to start in 2015. The expected sensitivity is 2×10^{-47} cm^2 for 55 GeV/c^2.

After two years of operation it is planned to upgrade XENON1T to XENONnT, the next stage with a total mass of 7 tons of liquid xenon, which would allow to increase the sensitivity by another order of magnitude. For a fast upgrade most of the systems XENON1T will be reused.

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