

1. Introduction

There is overwhelming observational evidence that about 23% of the matter and energy in the universe consists of cold dark matter, whose nature is still unknown and the subject of many investigations. Weakly Interacting Massive Particles (WIMPs) are a well-motivated class of dark matter candidates. They might be observed in terrestrial experiments, sensitive enough to measure the low-energy nuclear recoil resulting from the scattering of a WIMP with a nucleus [1]. The XENON dark matter project searches for nuclear recoils from WIMPs scattering off xenon nuclei. In a phased approach, experiments with increasingly larger mass and lower background are being operated underground, at the INFN Laboratori Nazionali del Gran Sasso (LNGS) in Italy [2], to probe WIMP-nucleon scattering cross-sections predicted by favored SUSY models [5]. The extraordinary sensitivity of XENON to dark matter is due to the combination of a large, homogeneous volume of ultra pure liquid xenon (LXe) as WIMP target, in a detector which measures not only the energy, but also the three spatial coordinates of each event occurring within the active target. Given the rapidly falling recoil energy spectrum from WIMP interactions, and the very low interaction cross sections predicted, the challenges for XENON, as for all direct detection experiments, are to achieve a very low radioactive background and energy threshold. The XENON detectors are two-phase (liquid - gas) time projection chambers (TPCs), with simultaneous detection of the Xe scintillation light (S1) at the few keVee level (keV electron equivalent [3]), and ionization (S2) at the single electron level. For a recent review of the properties of LXe as scintillator and ionizer we refer to [12] and references therein. The ratio S2/S1 produced by a WIMP (or neutron) interaction is different from that produced by an electromagnetic interaction, allowing a rejection of the majority of the gamma and beta particle background with an efficiency around 99.5% at 50% nuclear recoil acceptance. The event localization with millimeter spatial resolution and the self-shielding capability of the LXe enable further background suppression by selection of a fiducial volume. To demonstrate the XENON detector concept, the R&D phase [3] culminated with a 10 kg scale TPC prototype (XENON10), operated at LNGS from 2006/2007 [6], which achieved some of the best limits on WIMP dark matter. In order to increase the sensitivity to the WIMP-nucleon scattering cross section by more than one order of magnitude with respect to the state-of-the-art in 2007, a new TPC with a factor of 10 more mass and a factor of 100 less electromagnetic background was designed to fit inside the improved passive shield built at LNGS for XENON10. By focusing on the detectors performance, the goal of a fast realization of the new and improved XENON100 experiment was successfully achieved. Initial results [7] from XENON100, obtained from only 11 days of data acquired during the commissioning period at the end of 2009, have demonstrated [8] a background rate which is indeed a factor 100 less than that of XENON10. This was accomplished by careful selection of all detector materials regarding intrinsic radioactivity [9], a xenon target with lower ^{85}Kr contamination, a novel detector design leaving only low radioactive components close to the target, and

by improving the passive shield. Finally, XENON100 features an active LXe veto and allows for tighter fiducial volume cuts while still retaining a sizeable target mass. XENON100 has set the most stringent limit for a very large range of WIMP masses [10] and is currently the only LXe TPC in operation with a sensitivity reach of 2cm^{-2} at 100 GeV within 2012, and with a realistic WIMP discovery potential.

While the XENON100 detector is still running, the Collaboration has already designed the next generation detector, XENON1T, with a fiducial mass of about 1t and a total mass of 2.5t. XENON1T will be installed in the Hall B of the Gran Sasso Laboratory. In this paper I will briefly describe the design of XENON100 and then move to the description of XENON1T.

2. Principle of the XENON two-phase TPC

A schematic of the XENON two-phase (liquidgas) time projection chamber (TPC) is shown in Fig. 1. A particle interaction in the liquid xenon (LXe) produces direct scintillation photons and ionization electrons. An electric field is applied across the LXe volume with appropriate potentials on a series of electrodes, drifting ionization electrons away from the interaction site. Electrons which reach the liquidgas interface are extracted into the Xe gas, where the process of proportional scintillation takes place [11]. Both the direct (S1) and the proportional (S2) scintillation light, with 178 nm wavelength, are detected by photomultiplier tubes (PMTs) with optimized response in the vacuum ultraviolet (VUV) regime. The electric field in the LXe volume is produced between a cathode at negative potential and a grounded gate grid, a few mm below the liquidgas interface. A stronger electric field in the Xe gas above the liquid is produced between the gate grid and an anode grid placed a few mm above the liquidgas interface. For a field larger than 10 kV/cm in the Xe gas, the electron extraction yield is close to 100% [12]. The time difference between the S1 and the S2 signals, caused by the finite electron drift velocity in LXe at the given drift field [13] is proportional to the z-coordinate (measured along the drift field direction) of the interaction vertex. The x- and y-coordinates can be inferred from the proportional scintillation hit pattern on the PMTs placed in the gas (top array). Thus, the XENON TPC provides full 3-dimensional vertex reconstruction on an event-by-event basis allowing for the fiducialization of the target to reduce radioactive backgrounds. The different S2/S1 ratio of signals produced by electronic recoils (from gamma and beta background events) and by nuclear recoils (from WIMPs and neutrons) provides additional background discrimination [14].

3. The XENON100 detector

The almost cylindrical XENON100 TPC of 30.5 cm height and of 15.3 cm radius contains the 62 kg LXe target (see Fig. 2). The walls delineating the cylindrical volume and separating it from an active LXe veto shield, which is surrounding the target, are made of 24 interlocking panels of polytetrafluorethylen (PTFE, Teflon). The TPC is closed on the bottom by the cathode, and on the top by the gate grid. The gas phase layer is obtained by a diving bell design which allows a precise control of

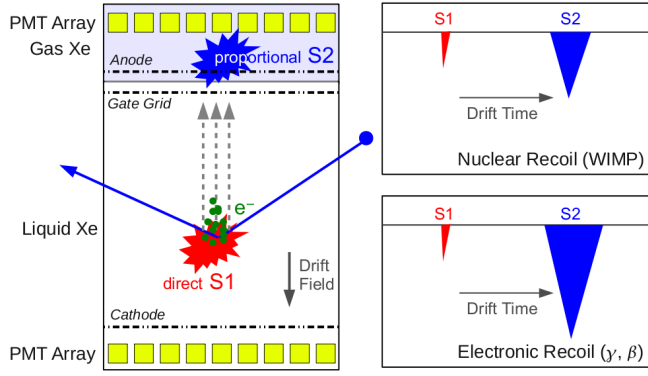


Figure 1: (Left) Working principle of the XENON two-phase liquidgas time projection chamber (TPC). See text for details. (Right) Sketch of the waveforms of two type of events. The different ratio of the charge (S2) and the light (S1) signal allows for the discrimination between nuclear recoils from WIMPs and neutrons and electronic recoils from gamma- and beta-background.

the liquid level, and the same time allowing a 4π coverage of the TPC with the surrounding LXe veto. Two arrays of Hamamatsu R8520-06-A1 1 square photomultiplier tubes (PMTs), specially selected for low radioactivity [15], detect the light in the TPC: 98 PMTs are located above the target in the gas phase, arranged in concentric circles. The energy threshold and hence the sensitivity of the detector is determined by the S1 signal which is mostly detected by the second PMT array, located below the cathode, immersed in the LXe. Here, 80 PMTs provide optimal area coverage (in average 52% useful PMT photocathode coverage) for efficient S1light collection. The bottom PMTs have a higher quantum efficiency compared to the top PMTs. A LXe layer of about 4 cm thickness surrounds the TPC on all sides and is observed by 64 PMTs, of the same type as used for the TPC readout. In total, this volume contains 99 kg of LXe. The presence of this LXe veto, operated in anti-coincidence mode, is very effective for background reduction [8]. The TPC is mounted in a double-walled 316Ti stainless steel cryostat, selected for its low activity. Since the radioactive contamination of the cryogenics system, ceramic feedthroughs, etc. cannot be lowered easily, the detector is cooled remotely and all parts with a known high radioactive contamination are installed away from the detector itself, outside the passive shield. The connection to the outside of the shield is established via three stainless steel pipes, one double-walled to the cooling system, the others single-walled to the PMT feedthroughs and pumping ports. To bias the cathode and the anode, custom-made hermetic HV feedthroughs, are used. The XENON100 experiment is installed underground at LNGS, in the so called "interferometer" tunnel away from the main experimental halls. Under about 1500 m of rock coverage, the surface muon flux is reduced by a factor 10^6 [38]. In order to reduce the background from the radioactivity in the experiments environment, in the laboratory walls, etc. additional passive shielding is needed. The detector is surrounded (from inside to outside) by 5 cm of OFHC copper, followed by 20 cm of polyethylene, and 20 cm of lead, where the innermost 5 cm consist of lead with a low 210Pb contami-

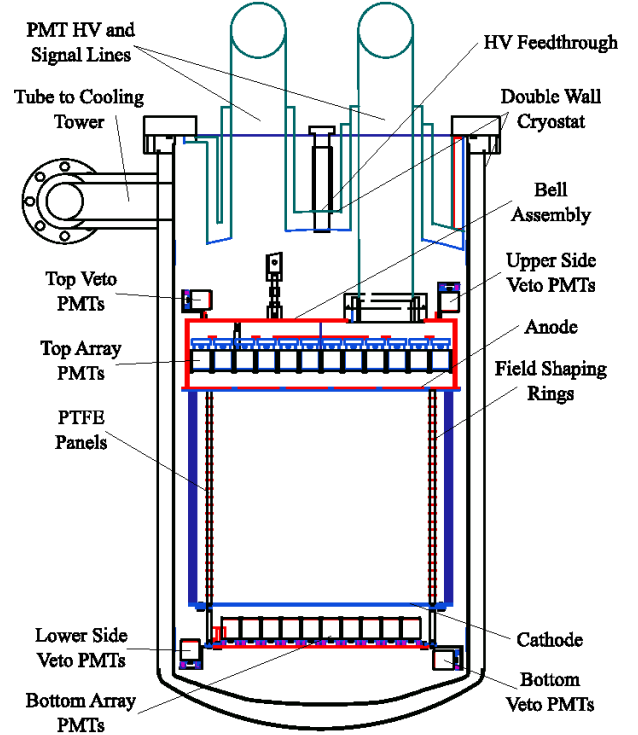


Figure 2: Drawing of the XENON100 dark matter detector: the inner TPC contains 62 kg of liquid xenon as target and is surrounded on all sides by an active liquid xenon veto of 99 kg. The diving bell assembly allows for keeping the liquidgas interface at a precise level, while enabling to fill LXe in the vessel to a height above the bell.

nation of (26 ± 6) Bq/kg [15]. The entire shield rests on a 25 cm thick slab of polyethylene. An additional outer layer of 20 cm of water or polyethylene has been added on top and on three sides of the shield to reduce the neutron background further.

4. The XENON1T detector

The technology used for XENON100 is mature enough to be scaled up by a factor of 10. The concept of the next generation XENON detector, XENON1T is to have a fiducial mass of about 1t using a total mass of about 2.5t. The goal is to have ten times more of fiducial mass and at the same time reducing the background by a factor of 100. By so doing, the sensitivity for a 50 GeV WIMP will go down to 10^{-48} cm^{-2} , exploring almost completely the region allowed by MSSM models [5]. At the time of writing the detector and infrastructures are 90% fully designed, and construction in the underground Gran Sasso Laboratory will begin in Fall 2012. XENON1T will be built in the Hall B of LNGS, between the WArP and ICARUS T600 experiment. An overall view of the installation is shown in Fig. 3, while an inner view of the cryostat and TPC is shown in Fig ?? In the following paragraphs I will shortly describe some of the key components of the detector starting from the outside.

4.1. The muon veto and water shield

The water tank of 9.60 m diameter will contain about 650 t of water. A purification system, On the walls, 84 photomul-

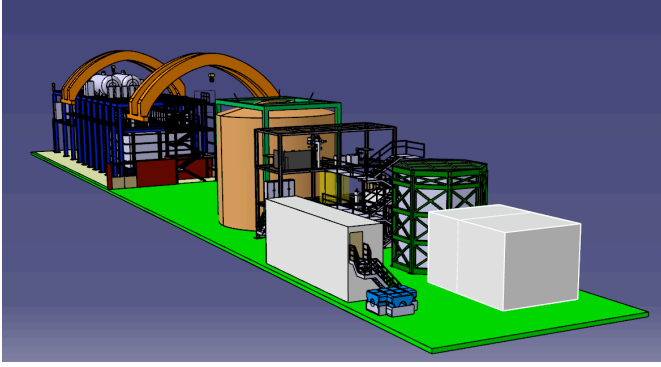


Figure 3: View of the Hall B of the Gran Sasso laboratories. In the center, the water tank of XENON1T is visible, along with the service building

tipliers Hamamatsu R5912assy will be installed. The whole inner surface will be lined with a reflector foil. The system has been designed to be 99% efficient in tagging crossing muons and 78% for showering events. For additional details about the veto system see [16]

4.2. Cryostat and TPC

The 2.5 t of xenon of the XENON1T detector will be contained in a double walled titanium cryostat. The cryostat will be supported by an hexapod structure bolted to the floor of the tank and equipped with actuators that, through a specially designed device, will be able to level the detector with the precision of 0.1 mm. The total heat loss of the cryostat will be less than 50 W. The TPC will be very much similar to the one of XENON100, except in the dimensions. The sensitive volume is a cylinder of 1 m diameter and 1 m height. The photosensors will be standard PMTs Hamamatsu R11410-10 (3-inch), with a QE of 35% at the Xe scintillating wavelength (178 nm). An array of about 120 PMTs will cover the bottom of the TPC, while about 130 will be placed in the gas phase. The drift volume is defined and divided by a series of meshes. A grounded screen mesh is placed just above the bottom PMT array, closely followed by the cathode mesh. A third mesh (grid) is placed few mm below the liquid level, closing the main volume with uniform electric field (1kV/cm). Few mm above the liquid there is the anode mesh, which will be placed at a higherfor the extraction. The TPC volume is closed laterally by 24 interlocking panels of PTFE.

4.3. The cryogenic infrastructure and gas handling system

A key aspect of the whole experiment is represented by the systems used handle the xenon and namely: 1) the storage system, 2) the purification system and 3) the distillation column. The storage system, called Restox (Recovery and Storage system of Xenon1T) will be used to store the Xenon when the TPC will be empty. The Restox is able to keep about 3 t of xenon, while cooling and recirculating it through a standard getter. For safety reasons, the cooling will be done passively by a liquid nitrogen cold head. The Restox will be in any case able to hold the xenon in gas phase and therefore to withstand a pressure of about 60 bar. A double walled, vacuum insulated pipe will

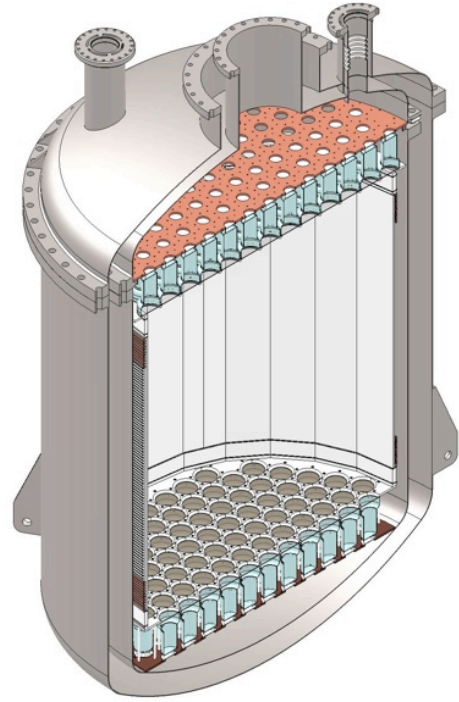


Figure 4: Artist's view of the cryostat and the TPC, with the top and bottom PMT arrays

connect the ReStox to the detector cooling system and to the cryostat.

Commercial xenon contains traces of Kr at the ppm level, and ^{85}Kr whose β decay with and point at ? may affect. To achieve the design background level of XENON1T, it has been estimated that the content of Krypton must be below 1 ppt. To achieve such a huge reduction factor the xenon will go through a distillation process, a technique that has already proven successful with XENON100. The distillation column designed for XENON1T is 4.5 m high and able to process 3 kg/h of xenon, while the present one is limited to about 0.5 Kg/h. The Xe/Kr separation factor is between 10^4 and 10^5 and the final content of Kr will be below 1 ppt

5. Schedule

References

- [1] M.W. Goodman, E. Witten, Phys. Rev. D 31 (1985) 3059.
- [2] <http://www.lngs.infn.it>.
- [3] E. Aprile et al., Phys. Rev. Lett. 97 (2006) 081302
- [4] M. C. Altunbas, et al., Construction, test and commissioning of the triple-GEM tracking detector for COMPASS, Nucl. Instrum. Meth. A490 (2002) 177–203.
- [5] O. Buchmueller et al., Eur. Phys. J. C 71 (2011) 1634.
- [6] E. Aprile et al., XENON10 Collaboration, Astropart. Phys. 34 (2011) 679
- [7] E. Aprile et al., XENON100 Collaboration, Phys. Rev. D 84 (2011) 052003.
- [8] E. Aprile et al., XENON100 Collaboration, Phys. Rev. D 83 (2011) 082001.
- [9] E. Aprile et al., XENON100 Collaboration, Astropart. Phys. 35 (2011) 43.

- [10] E. Aprile et al., XENON100 Collaboration, Phys. Rev. Lett. 107 (2011) 131302.
- [11] B.A. Dolgoshein, V.N. Lebedenko, B.U. Rodionov, JETP Lett. 11 (1970) 513.
- [12] E.M. Gushchin et al., Sov. Phys. JETP 45 (1979) 5
- [13] L.S. Miller, S. Howe, W.E. Spear, Phys. Rev. 166 (1968) 871.
- [14] E. Aprile et al., Phys. Rev. Lett. 97 (2006) 081302.
- [15] E. Aprile et al., XENON100 Collaboration, Astropart. Phys. 35 (2011) 43
E. Aprile et al., XENON100 Collaboration, Phys. Rev. D 83 (2011) 082001
- [16] S. Fattori, for the XENON Collaboration, these proceedings.