The XENON100 Dark Matter Experiment

D. Aharonov1,2, E. Aprile1 (spokesperson), K. Arisaka3,2, F. Areedo2, A. Askin1, L. Bandi2, J. M. D. Cardoso1, B. Choi3, D. B. Clin3, L. C. C. Coelho1,3, S. Fatemi2, A. D. Fert1, L. M. P. Fernandes1, K. L. Gibson1, A. Koh1, K. Lim1, J. A. M. Lopes1, Y. Mei4, K. Ni1, U. Oberlack2, G. Plante1, D. Rabini, R. Samorìll1,2,1, M. F. dos Santos2, M. Schuman4, P. Shagie1, E. Traizet1, H. Wang

1Department of Physics, Columbia University, New York, USA
2INFN Laboratori Nazionali del Gran Sasso, Assergi, Italy
3Physics Institute, University of Zurich, Zurich, Switzerland
4Department of Physics, University of California, Los Angeles, USA

Liquid Xenon to Detect Dark Matter WIMPs

The advantages of using liquid xenon (LXe) for dark matter direct detection are numerous: its high stopping power (\(E^2 \times \rho = 3 \times 10^5 \text{cm}^{-1}\)) allows for a compact self-shielding geometry, its large \(A\) (\(\sim 131\)) makes it attractive for spin independent interactions (\(A \sim A\)) and the presence of \(<50\%\) odd isotopes (\(^{129}\)Xe) also makes it good for spin dependent interactions, it has no long lived radioactive isotopes, and it is also an efficient and fast scintillator with a wavelength (~175 nm) that enables direct readout by PMTs.

The XENON Project

The XENON project aims to detect Galactic WIMPs through their elastic scattering with Xe nuclei in a 1-ton scale liquid xenon detector (XENON101) placed deep underground, with a sensitivity to both spin independent and spin dependent WIMP-nucleon coupling.

The detector is a Time Projection Chamber (TPC) operated in dual phase (liquid/gas), self-shielded by an active veto of pure LXe scintillator with event-by-event discrimination provided by the simultaneous measurement of ionization and scintillation. 3D event localization and adequate shielding further reduce the background. The first prototype detector (XENON10) was deployed and upgraded, at the Gran Sasso National Laboratory (LNGS) during 2006. With 136 kg days exposure, this first experiment reported in 2007 the best sensitivity to WIMP-nucleon spin independent cross-section.

The current phase of the project involves a new detector (XENON100), currently under commissioning at LNGS. The projected background rate, based on careful materials screening, and the expected exposure will allow to reach a sensitivity of \(\sim 1 \times 10^{-45} \text{cm}^2\).

XENON100

Like XENON10, the new XENON100 experiment is located underground in the Gran Sasso National Laboratory (LNGS) in Italy. The average rock coverage of 1.4 km (3100 mwe) provides a factor of 10\(^6\) reduction of the surface muon flux.

Design

The XENON100 detector is an evolution of the first prototype, aiming at a dramatic improvement in sensitivity through a factor of 100 reduction in gamma-background and a factor of 10\(^4\) decrease in fiducial mass.

The XENON100 cryostat was designed to fit in the existing XENON10 passive shield, to enable a rapid deployment of the experiment, paying however attention to the requirement for low background.

To this end, XENON100 uses a novel cryogenics design with the pulse tube refrigerator (PTR) located far from the detector and outside its shielded cavity, along with shielded and high voltage feed-throughs, eliminating their contribution to the background.

For effective background reduction, XENON100 also uses an active LXe shield for a total of 15 kg viewed by 64 PMTs, surrounding the inner target with 65 kg of Xe. The TPC is instrumented with 178 PMTs. The PMTs are of the same type developed for XENON10, but with lower radioactivity and higher quantum efficiency (QE).

PMTs

The top array is composed of 98 tubes (QE\(<\sim 23\%\)) disposed in circular patterns to enable good X\(Y\) position resolution while minimizing the number of tubes required. The bottom array is composed of 80 high QE (\(<\sim 3\%\)) tubes arranged on a square grid to maximize light collection. The top (bottom) shield arrays each have 32 tubes arranged in alternating inward and down (up) directions to allow them to view simultaneously the top, bottom and side portions of the active LXe shield.

TPC & Meshes

The XENON100 TPC, defined by 24 interlocking PTFE panels, has a radius of 15 cm and a drift length of 50 cm. The uniformity of the drift field is ensured by a set of 40 field shaping wires, mounted inside and outside the PTFE structure. The spectoscopic performance of different mesh designs has been simulated and the final detector will be equipped with hexagonal meshes for the proportional scintillation region.

Data Acquisition

The XENON100 data acquisition system is composed of 31 CAEN V1724 14 bit 100 MHz flash ADCs to digitize the 242 PMTs signals. The V1724 permits operation in deadtime-less mode where data is written to a circular buffer and where multiple events can be stored before they are read via the VME bus. The digitized signals are “zero length encoded” by the V1724 FPGA, i.e. only the relevant signal portions are transferred from the ADCs to the data acquisition computer, to allow faster event transfer rates (> 60 Hz).

Screening Facility

A dedicated facility for screening materials used in the construction of XENON100 has been built and consists of an ultra-low background, 100% efficient (2 kg) HPGe spectrometer enclosed in a 0.5 cm DFP Cu and 20 cm Pb outer layer shield. The LNGS screening facility has also been used for many of the XENON100 samples essaying.

Background Estimate and Sensitivity Reach

Based on the measured activity of the materials used to build the detector, a detailed simulation of the gamma and neutron backgrounds has been carried out. The expected gamma background in a 50 kg fiducial volume is predicted to be less than 0.01 events/kg/kg/day while the neutron background is expected to be less than 0.5 counts/kg. Assuming the same background rejection power and threshold as XENON10, the new detector should be background free for about 2 months, corresponding to a sensitivity reach of \(\sim 2 \times 10^{-45} \text{cm}^2\) for a 100 GeV WIMP.

XENON100 top PMT array XENON100 bottom PMT array XENON100 bottom shield array

XENON100 cryostat in the shield

XENON100 DMQ

XENON100 projected sensitivity