The XENON100 Dark Matter Experiment

Xe
XENON
Dark Matter Project

D. Aharoni[6], E. Aprile[1] (spokesperson), K. Arisaka[6], F. Arneodo[2], A. Askin[3], L. Baudis[3], J. M. R. Cardoso[4], B. Choi[1], D. B. Cline[6], L. C. C. Coelho[4], S. Fattori[2], A. D. Ferella[3], L. M. P. Fernandes[4], K. L. Giboni[1], A. Kish[3], K. Lim[1], J. A. M. Lopes[4], Y. Mei[5], K. Ni[1], U. Oberlack[5], G. Plante[1], D. Rubin[1], R. Santorelli[3], J. M. F. dos Santos[4], M. Schumann[5], P. Shagin[5], E. Tziaferi[3], H. Wang[6]

[1]*Department of Physics, Columbia University, New York, USA* [2]*INFN Laboratori Nazionali del Gran Sasso, Assergi, Italy*
[3]*Physics Institute, University of Zürich, Zürich, Switzerland* [4]*Department of Physics, University of Coimbra, Coimbra, Portugal*
[5]*Department of Physics and Astronomy, Rice University, Houston, USA* [6]*Department 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 ($Z = 54$, $\rho = 3\text{g/cm}^3$) allows for a compact self-shielding geometry, its large A ($\sim$131) makes it attractive for spin independent interactions ($\sigma \sim A^2$) and the presence of $\sim$50% odd isotopes ($^{129}_{54}$Xe, $^{131}_{54}$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 ($\sim$175 nm) that enables direct readout by PMTs.

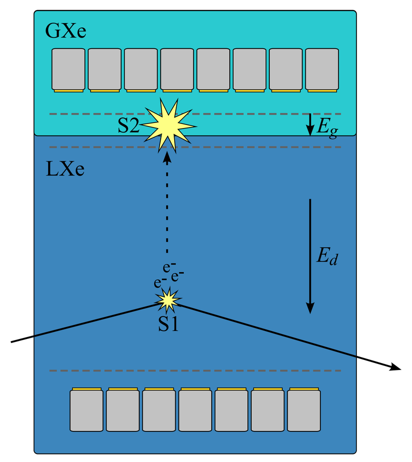
The XENON Project

The XENON project aims to detect Galactic WIMPs through their elastic scattering with Xe nuclei in a 1-ton scale liquid xenon detector (XENON1T) 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 underground, 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 $\sim 2 \times 10^{-45}$ cm^2.

XENON10



The XENON10 TPC had a total active mass of 15 kg of LXe. To detect the direct and proportional scintillation light, compact, metal channel 1” square PMTs (Hamamatsu R8520-06-Al). An array of 41 PMTs was located below the cathode, fully immersed in LXe, to efficiently detect the direct scintillation light while an array of 48 PMTs, in the gas, were used to detect the proportional light and provided the X-Y event location in the active volume, with a precision of a few millimeters. The drift time measurement provided the Z-coordinate, with a precision of a few hundred microns.

From October 6th 2006 until February 20th 2007, the XENON10 detector was operated in WIMP-search mode at the Gran Sasso underground laboratory and recorded about 1800 events in the 4.5 to 29.6 keVr energy range, a priori designated as the signal region. Out of these 1800 events, 10 were observed in the WIMP window after all cuts. By considering all ten observed events, with no background subtraction, and using the “maximum gap” method [Phys. Rev. D 66, 032005 (2002)], the experiment placed in 2007 the best limit on the spin independent WIMP-nucleon cross-section.

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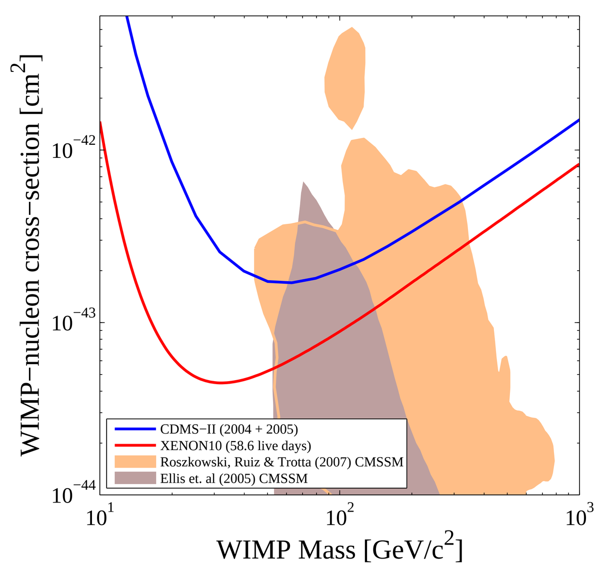
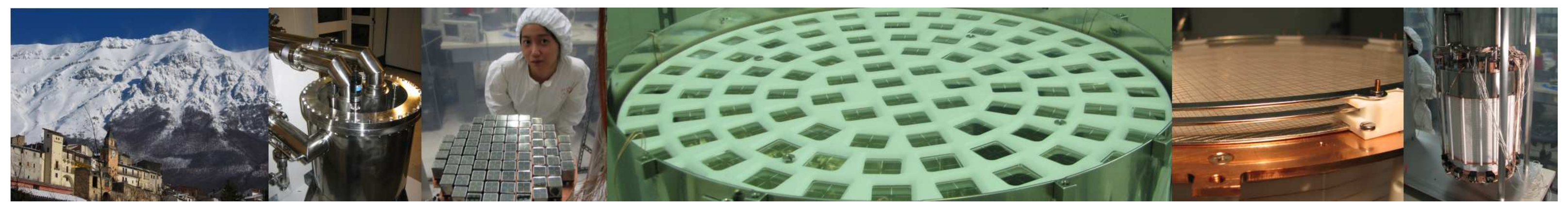
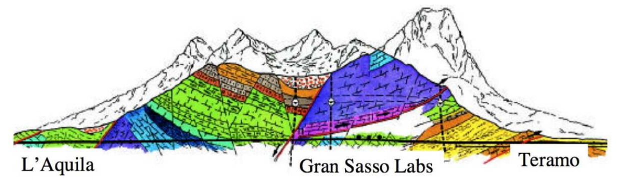


XENON100

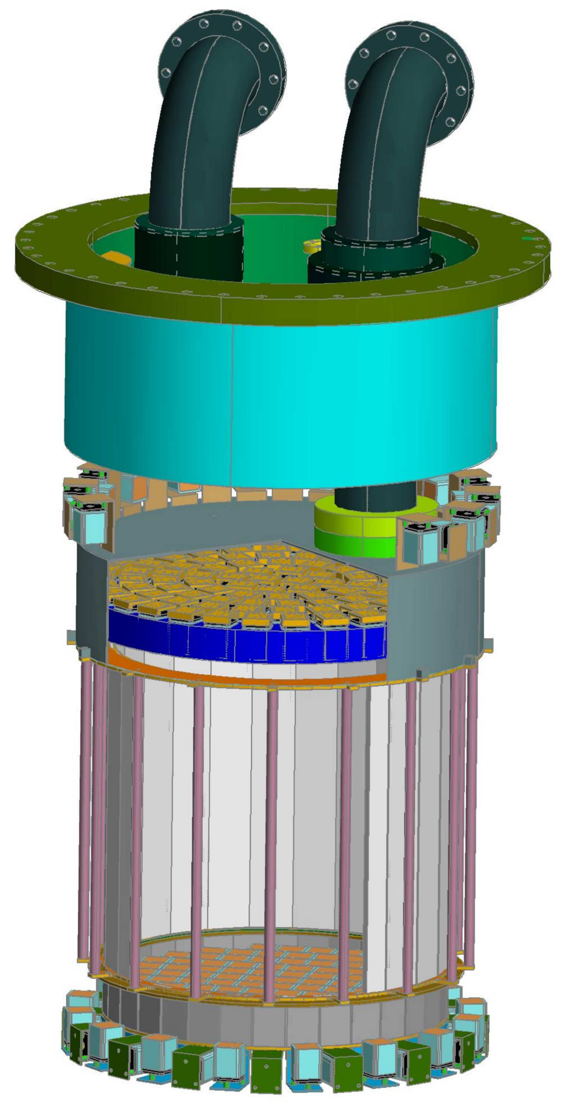


Laboratori Nazionali del Gran Sasso

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.

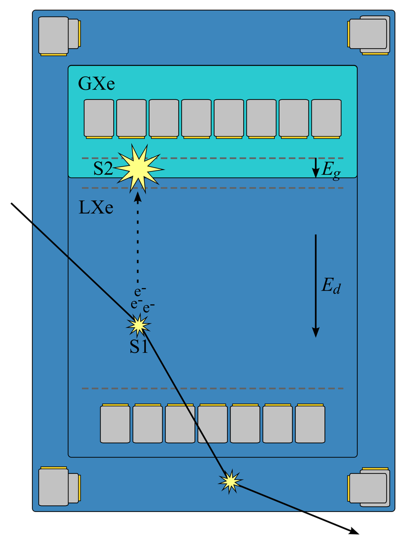


Design



The XENON100 detector

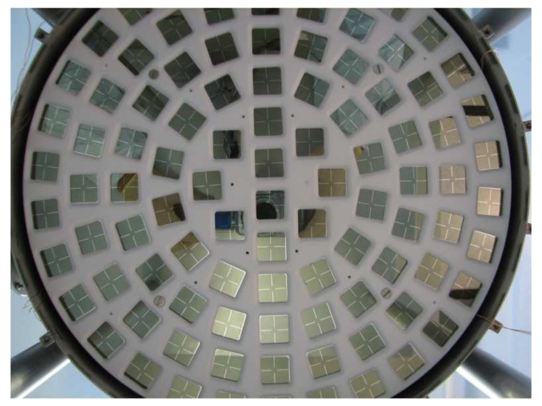
The XENON100 detector is an evolution of the first prototype, aiming at a dramatic improvement in sensitivity through a factor of 100 reduction in gamma-background and a factor of 10 increase in fiducial mass. The XENON100 cryostat was designed to fit in the existing XENON10 passive shield, to enable 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 signal and high-voltage feedthroughs, eliminating their contribution to the background.



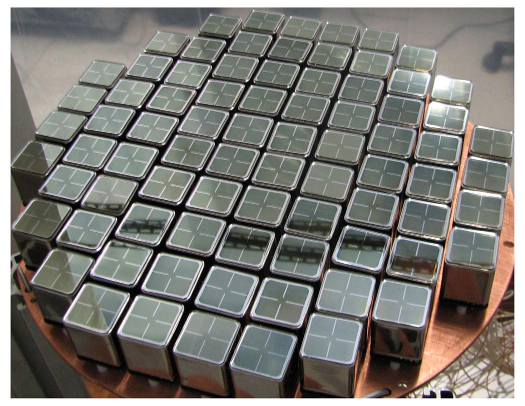
For effective background reduction, XENON100 also uses an active LXe shield for a total of 105 kg viewed by 64 PMTs, surrounding the inner target with 65 kg of Xe. The TPC is instrumented with 178 PMTs. The PMTs are of the same type developed for XENON10, but with lower radioactivity and higher quantum efficiency (QE).

PMTs

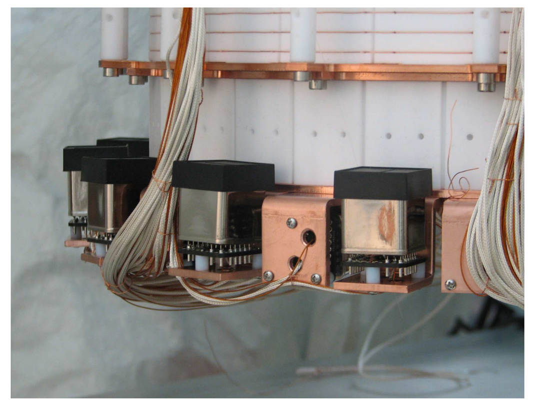
The top array is composed of 98 tubes (QE $\sim$23%) disposed in circular patterns to enable good XY position resolution while minimizing the number of tubes required. The bottom array is composed of 80 high QE ($\sim$33%) tubes arranged on a square grid to maximize light collection. The top (bottom) 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.



XENON100 top PMT array

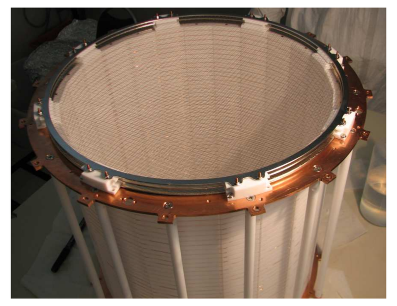


XENON100 bottom PMT array

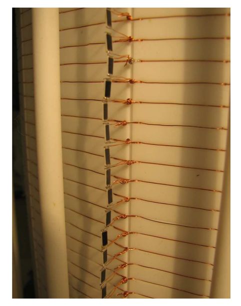


XENON100 bottom shield array

TPC & Meshes



XENON100 TPC

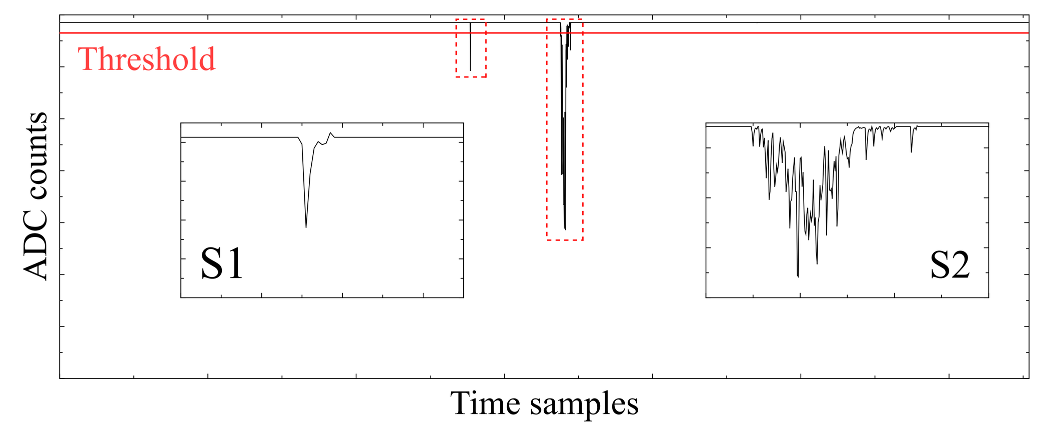


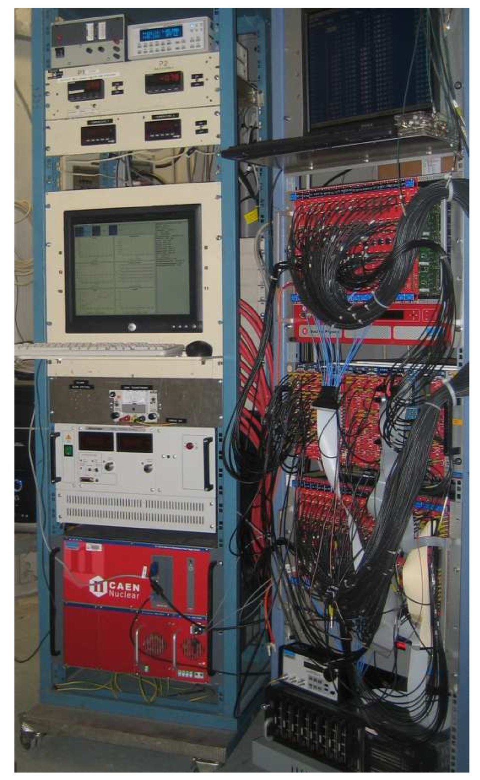
Resistors

The inner volume of the XENON100 TPC, defined by 24 interlocking PTFE panels, has a radius of 15 cm and a drift length of 30 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 spectroscopic 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

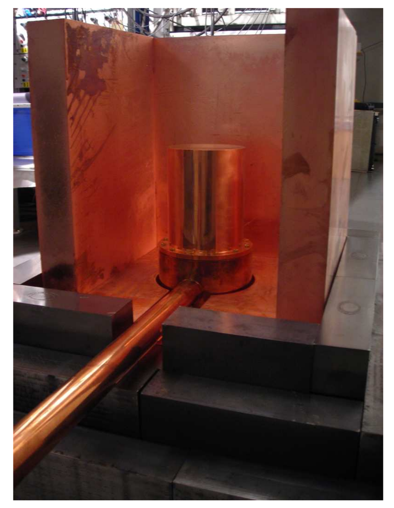
The XENON100 data acquisition system is composed of 31 CAEN V1724 14 bit 100 MHz flash ADCs to digitize the 242 PMTs signals. The V1724 permits operation in deadtime-less mode where data is written to a circular buffer and where multiple events can be stored before they are read via the VME bus. The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





XENON100 DAQ

Screening Facility



Gator HPGe detector

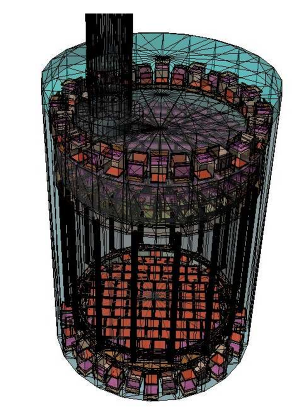
A dedicated facility for screening materials used in the construction of XENON100 has been built and consists of an ultra-low background, 100% efficient (2 kg) HPGe spectrometer enclosed in a 5 cm OFRP Cu and 20 cm Pb outer layer shield. The LNGS screening facility has also been used for many of the XENON100 samples essaying.

Shield

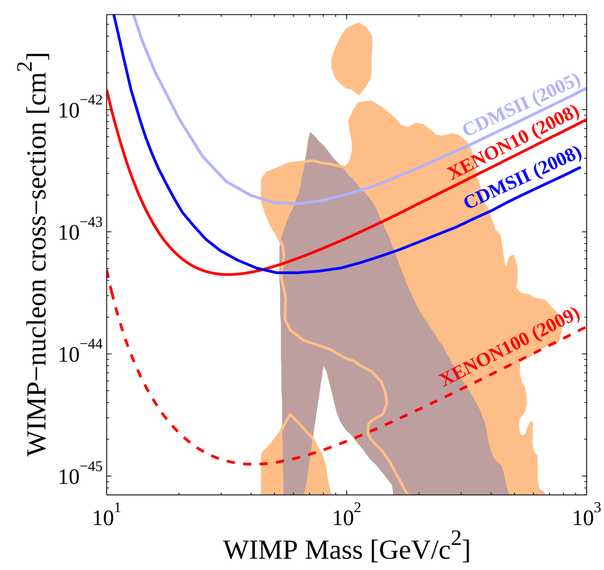
XENON100 cryostat in the shield

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 estimated to be less than 0.01 events/keV/kg/day while the neutron background is expected to be less than 0.9 n/year. 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 $\sim 2 \times 10^{-45}$ cm^2 for a 100 GeV WIMP.



Geant4 model



XENON100 projected sensitivity