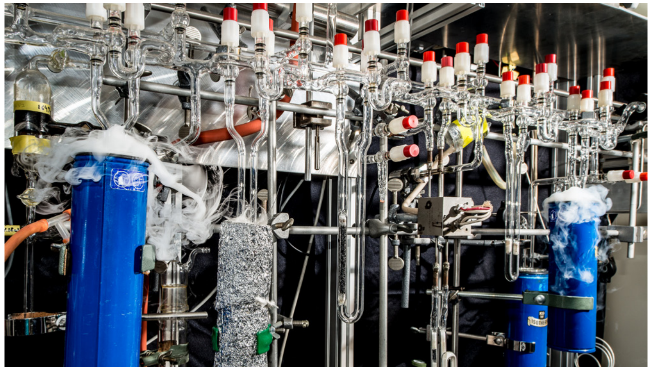

Apparatus for the determination of radon emanation rates.

Radioactive Impurities

The most critical background radiation comes from radioactive noble-gas isotopes (radon and krypton) dissolved in xenon. The content of krypton in xenon must be reduced to a level below 0.1 ppt. For this purpose, xenon is purified over a distillation column. The highly sensitive detection of krypton in xenon by means of a dedicated noble-gas mass spectrometer at the MPIK is a key technology for this process.

To select materials of highest purity, radiation detectors have been developed at the MPIK that are capable of detecting minimal traces of residual radioactivity. Besides the most sensitive gamma-radiation detectors world-wide, we operate detectors reaching for radon a lower detection limit of a few atoms. Thus, MPIK is among the few institutes able to select materials according to their radon emanation rate. Nevertheless, single radon atoms do reach the inner detector; that's why the MPIK continues to develop highly efficient radon removal methods for xenon.

Light Sensors

Also crucial for the experiment are highly sensitive photosensors which can be operated reliably over a long time at around −96 °C. These requirements are best met by dedicated photomultiplier tubes (PMTs) made from selected materials with very low intrinsic radioactivity. These have been developed by the MPIK together with the manufacturer. The PMTs for XENON1T and XENONnT were tested with respect to purity, cryo-compatibility and long-term stability, before they were mounted into the two array support plates.

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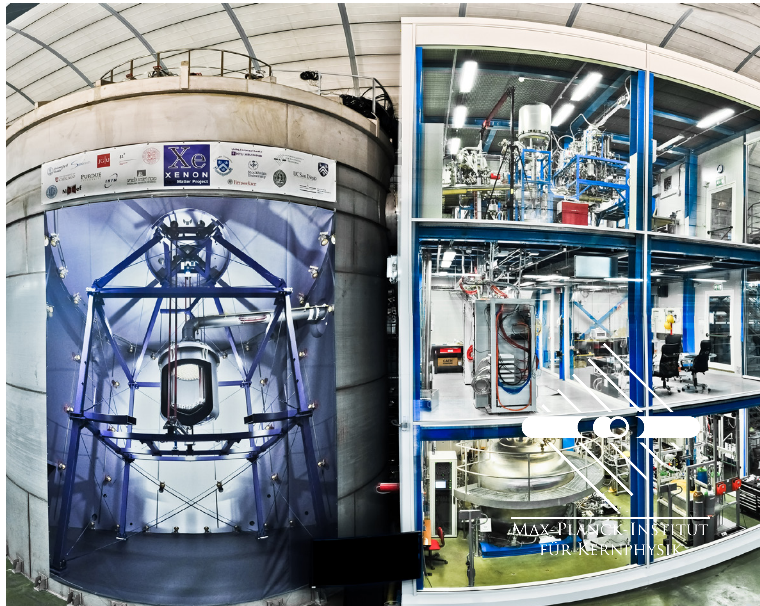
XENON Dark Matter Project

The XENON Project

Enlightening the Dark



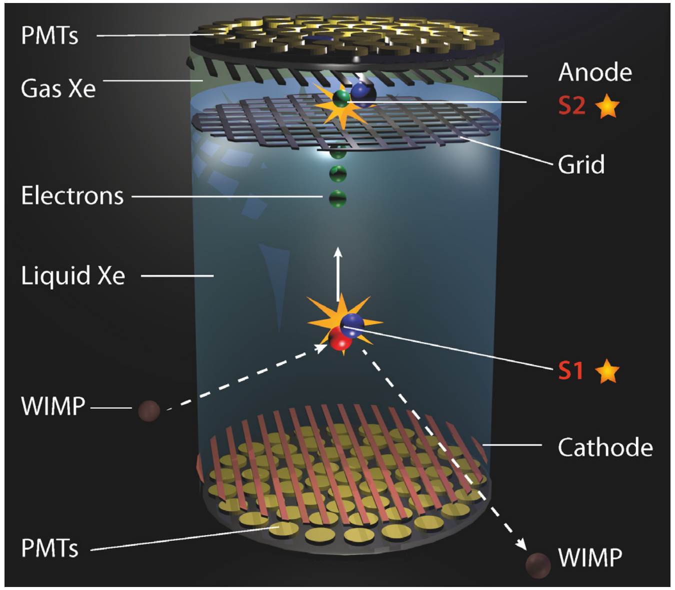
The XENON Project:

Enlightening the Dark

Looking into our Universe, many astrophysical and cosmological observations cannot be explained by our present knowledge of matter. Rotation curves of galaxies, galaxy clusters with gravitational lensing effects and the cosmic microwave background strongly suggest the existence of a so far undiscovered matter component which makes up about 85% of the entire cosmic matter content. It is called "dark matter" because it does not emit photons and interacts only very weakly with ordinary matter if at all.

Detection Principle

From a theoretical point of view, hypothetical heavy elementary particles called weakly interacting massive particles (WIMPs) are among the most promising candidates for dark matter, because calculations suggest that such particles have been produced in the early Universe with a cosmic abundance matching observation. The members of the international



Construction and operating mode of the time projection chamber; PMTs: photosensors (photomultiplier tubes).

XENON collaboration are aiming to discover such WIMPs using a xenon-filled time projection chamber. If WIMPs really do exist, the XENON experiment can detect them by their rare interaction with xenon nuclei.

Such an interaction in cryogenic liquid xenon is expected to produce both a prompt light signal (S1) and a slightly delayed ionisation charge signal (S2). The technology employed allows particle identification, a crucial property to reject background interactions. In addition to the deposited-energy measurement, the location of interactions can be reconstructed in all three dimensions.

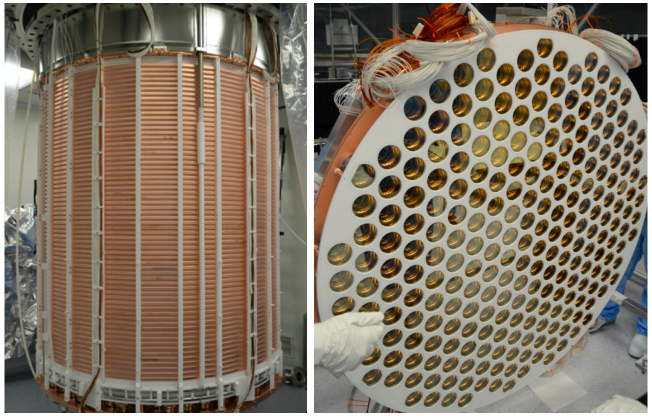
The latter is extremely important since it is necessary to select the innermost volume of the detector for WIMP searches. Although the detector consists of materials of highest purity, it nevertheless contains minimal traces of radioactivity. Despite being a million times weaker than the ubiquitous environmental radioactivity, this produces undesirable background signals particularly in the outer volume of the detector.

The XENON Project

XENON is a collaborative project (xenon1t.org) involving about 160 researchers from Europe, the US and Asia. The detector XENON1T, 100 times more sensitive successor of XENON100, acquired data from 2016 until end of 2018. Thereafter, the experiment has been upgraded to XENONnT. With the threefold active detector mass of 5.9 tonnes xenon and a further reduced radioactive impurity level, it will be about ten times more sensitive. The measurement phase of XENONnT starts in 2020.

The prompt light signal in the detector and the charge signal converted to light (see the sketch to the left) are both observed by overall 494 sensitive photosensors at the top and the bottom, capable of detecting even single photons. Reflecting teflon plates ensure that as many light as possible reaches them. Together with the electrodes generating the electric field and the cryogenic liquid xenon, all this is enclosed by a big vacuum-insulated double-wall cryostat. The xenon gas is cooled down and continuously purified in the three-story high building next to the huge water tank (see the cover picture). Two big stainless-steel tanks can accommodate the overall 8.4 tonnes of xenon used in XENONnT both in liquid and gaseous form.

The instrument is installed in the Gran Sasso underground laboratory in Italy, and is surrounded by about 700 tonnes of water as an active veto. This suppresses any remaining cosmic radiation and shields the instrument against natural radioactivity from the rock. Now, part of the water is loaded with gadolinium in order to additionally detect interfering neutrons from radioactive decays – also by means of light signals in an optically separated volume surrounding the detector.



The time projection chamber of XENONnT (diameter 1,3 m, height 1,5 m) and one of the two PMT arrays.

Results of XENON1T

Despite XENON1T didn't find dark matter, it has set the world's strongest limits on WIMP-nucleon interactions. This extraordinarily high sensitivity made it possible to successfully search for various new particles and so far unobserved processes.

Billions of years appear as a blink of an eye compared to an extremely slow processes that could be detected. The half-life of the previously not directly observed transformation of xenon-124 to tellurium-124 by double electron capture with emission of two neutrinos is for unimaginably long 1.8×10^{22} years.

Studying the electronic recoil data to search for other rare-physics process, an excess was found. The source of this surprising signal, which is not attributable to WIMP interactions remains puzzling: It might result from a tiny residual amount of radioactive tritium, but could also be a sign of the existence of a new particle, the theoretically predicted solar axion or the indication of previously unknown properties of neutrinos. Data of XENONnT will hopefully resolve this puzzle.

The MPIK is substantially involved in XENON1T/nT; in the following details about two contributions: