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First Results of the LUX Dark Matter Experiment

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Abstract

LUX (Large Underground Xenon) is a dark matter direct detection experiment deployed at the 4850' level of the Sanford Underground Research Facility (SURF) in Lead, SD, operating a 370 kg dual-phase xenon TPC. Results of the first WIMP search run were presented in late 2013, for the analysis of 85.3 live-days with a fiducial volume of 118 kg, taken during the period of April to August 2013. The experiment exhibited a sensitivity to spin-independent WIMP-nucleon elastic scattering with a minimum upper limit on the cross section of 7.6×10^{-46} cm^2 at a WIMP mass of 33 GeV/c^2, becoming the world's leading WIMP search result, in conflict with several previous claimed hints of discovery.

Keywords: dark matter, WIMP, liquid xenon, time projection chamber

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1. Introduction

The observational evidence for the existence of dark matter is overwhelming, mainly due to its gravitational effects. A wide variety of cosmological observations support the existence of non-baryonic cold dark matter: galactic rotation curves, the precise measurements of the cosmic microwave background, the study of supernovae and the mapping of large scale structures [1]. Despite this progress, the identity of dark matter remains a mystery. One of the leading candidates for dark matter in the universe are Weakly Interacting Massive Particles (WIMPs), and there are currently many experiments attempting to detect them. Direct search detectors aim to observe nuclear recoils produced by dark matter particles scattering off target nuclei. Direct dark matter search experiments look for an excess of nuclear recoil signals in a low-background underground environment. The energy deposition associated with the nuclear recoil of WIMPs is on the ~keV scale, and massive detectors with low energy threshold and high background discrimination capabilities are vital. There are different methods that can be used to detect nuclear recoils, including collecting ionization, scintillation, or thermal energy deposition data. In this framework, dual-phase liquid xenon detectors are a powerful technology for the direct detection of dark matter [2, 3, 4].

2. The LUX detector

The LUX (Large Underground Xenon) detector is a two-phase xenon time-projection chamber (TPC), containing 370 kg of xenon, operating 1.5 km underground (4300 m.w.e.) in the Sanford Underground Research Facility (SURF) in Lead, South Dakota, USA [5]. The TPC is monitored by two arrays of 61 photomultiplier tubes (PMT) each, located above and below the active liquid xenon (LXe) region. Events in the LXe target produce direct scintillation light (S1), while electrons escaping recombination at the event site are drifted to the liquid surface and extracted into the gas phase by applied electric fields, where they create proportional scintillation light (S2). Both signals are measured by the arrays of PMTs. Most of the S1 signal is measured by the bottom PMT array, while the top array is used mainly to reconstruct the x-y position of the event. The drift time between the S1 and S2 signals gives the event depth, providing this technology with excellent 3D imaging capabilities. In this type of detector, the discrimination between electron recoils (ER) from background radioactivity and nuclear recoils (NR) from neutrons and the potential WIMP-nucleon interaction is based on the ratio of S2 to S1. The background rejection is also enhanced by the strong self-shielding capability of this dense liquid (LXe) combined with the precise 3D event position determination, and it has been demonstrated in LUX to be $\sim$ 99.6 % in the energy range of interest for the WIMP signal search.

The detector design is characterized by the use of low radioactivity detector materials, like PMTs and Ti cryostats [6, 7], and by very high light collection, which is crucial for the sensitivity to low-energy events. The photon detection efficiency for events at the center of LUX is measured to be 14% [8]. The active region is a dodecagonal structure with a maximum drift distance of 48 cm (height), and a diameter of 47 cm. The walls of the barrel consist of twelve reflector panels of polytetrafluoroethylene (PTFE), which has very high reflectivity in liquid xenon (>95%). This active region is observed by 122 Hamamatsu R8778 2-inch diameter PMTs that have an average quantum efficiency (QE) of 33% at the xenon scintillation wavelength of 175 nm.

A unique cryogenic system is used to efficiently and economically cool the LUX detector, based on thermosyphon technology [9]. Each thermosyphon consists of a sealed tube, filled with a variable amount of gaseous nitrogen, and comprised of three regions: at the top, a condenser which is immersed in a bath of liquid nitrogen (LN); at the bottom, an evaporator which is attached to the detector; and a passive length made of stainless steel connecting the two active sections. The whole system is oriented vertically since it works with gravity, and is closed and pressurized with N_2. The thermosyphon thermal conductivity was measured to be ~ 55 kW/K $\cdot$ m, much higher than metals, such as copper.

The detector is housed in an 8 m diameter (300 tonne) water tank that shields it against the neutrons from cavern radioactivity and the very high-energy tail of neutrons from muon interactions in the cavern walls. The water tank provides a reduction of the external backgrounds to a level that is subdominant to the internal backgrounds from detector components. Also, the water shield is instrumented with a set of 20 eight-inch PMTs and can be used as a Cherenkov veto for muons.

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