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The XENON dark matter search: status of XENON10

E Aprile^{1*}, K L Giboni¹, S Kamat¹, K Ni¹, B K Singh¹, M Yamashita¹, R J Gaitskell², P Sorensen², L de Viveiros², R Gomez³, U Oberlack³, P Shagin³, A Bolozdynya⁴, E Dahl⁴, J Kwong⁴, T Shutt⁴, J Angle⁵, L Baudis⁵, A Manalaysay⁵, J Orboeck⁵, R Hasty⁶, A Manzur⁶, D McKinsey⁶, A Bernstein⁷, N Madden⁷, C Winant⁷, F Arneodo⁸, A Ferella⁸, J A Matias Lopes⁹ and J Santos⁹

¹Physics Department and Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027.

²Department of Physics, Brown University, Providence, RI 02912.

³Department of Physics, Rice University, Houston, TX, 77251.

⁴Department of Physics, Case Western Reserve University, Cleveland, OH, 44106.

⁵Department of Physics, University of Florida, Gainesville, FL, 32611.

⁶Department of Physics, Yale University, New Haven, Connecticut 06520.

⁷Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550.

⁸Gran Sasso National Laboratory, 67010 Assergi L'Aquila, Italy.

⁹Physics Department, University of Coimbra, R. Larga, 3004-516, Coimbra, Portugal.

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E-mail: age@astro.columbia.edu

Abstract. The XENON experiment searches for dark matter particles called WIMPs using liquid xenon (LXe) as the active target. The detector is a 3D position sensitive Time Projection Chamber optimized to simultaneously measure the ionization and scintillation produced by a recoil event of energy as low as 16 keV. The distinct ratio of the two signals for nuclear recoils arising from WIMPs and neutrons and for electron recoils from the dominant gamma-ray background determines its event-by-event discrimination. With 1 ton of LXe distributed in ten identical modules, the proposed XENON1T experiment will achieve a sensitivity more than a factor of thousand beyond current limits. A phased program will test a 10 kg detector (XENON10) followed by a 100 kg (XENON100) one as unit module for the XENON1T scale experiment. We review the progress of the XENON R&D phase before presenting the status of XENON10. The experiment will be based at the Gran Sasso Underground Laboratory and is expected to start data taking in early 2006.

1. Introduction

Weakly Interacting Massive Particles (WIMPs) populating the halo of our galaxy can be detected directly, via their interactions with nuclei in terrestrial detectors, or indirectly, via their annihilation products in the galactic center, halo, or sun [1]. XENON is a new generation dark matter experiment with the aim of observing the small energy released after a WIMP scatters off a Xenon nucleus [1,2]. Using a target mass of 1 ton, it proposes to reach a sensitivity of 10^{-46} cm² for spin-independent cross sections, which is several orders of magnitude below the current best limit of 1.6×10^{-43} [3].

Discrimination of signal and background is based on the distinct ratio of the ionization and scintillation signals produced in LXe by nuclear (from WIMPs and neutrons) and electron (from gamma, beta and alpha backgrounds) recoil events [4]. The challenge is to achieve this event-by-event

discrimination down to 16 keV nuclear recoil energy in a large volume detector. The background will be further suppressed by passive gamma and neutron shields and the detector's 3-D position resolution.

To verify achievable threshold, background rejection power and sensitivity, a 10 kg prototype (XENON10) is being developed for deployment at the Gran Sasso Underground Laboratory (3500 mwe). XENON10 aims to reach a sensitivity of 2 dark matter events/10 kg/months, without a muon veto for fast neutrons. It will pave the way to design a 100 kg detector. With 3 months of operation underground, at a background below 1×10^{-5} cts/keVee/kg/day after rejection, XENON100 will achieve a sensitivity of 10^{-45} cm² (see Fig. 1). XENON1T will be made with ten XENON100 modules.

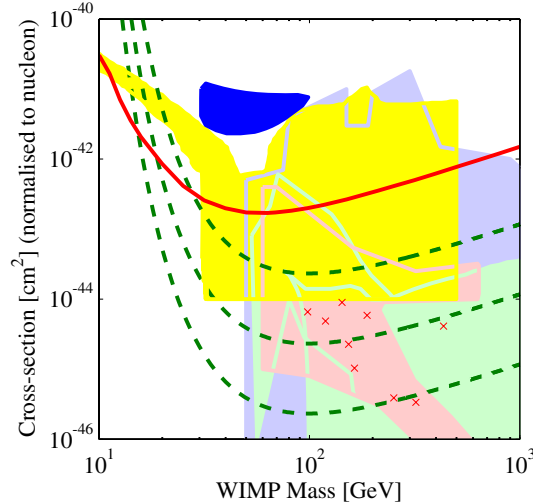


Figure 1. Theoretical predictions [6] and current best sensitivities for WIMP dark matter direct detection. The dark region shows the DAMA 3- σ signal region [5] while the plain line is the current limit [3]. The dotted lines are projected sensitivities for XENON10, XENON100 and XENON1T [2]. Figures generated with limit plotter [7].

2. Results from various prototype dual phase detectors

Several prototypes, with Xe mass ranging from a few hundred grams to a few kilograms, have been

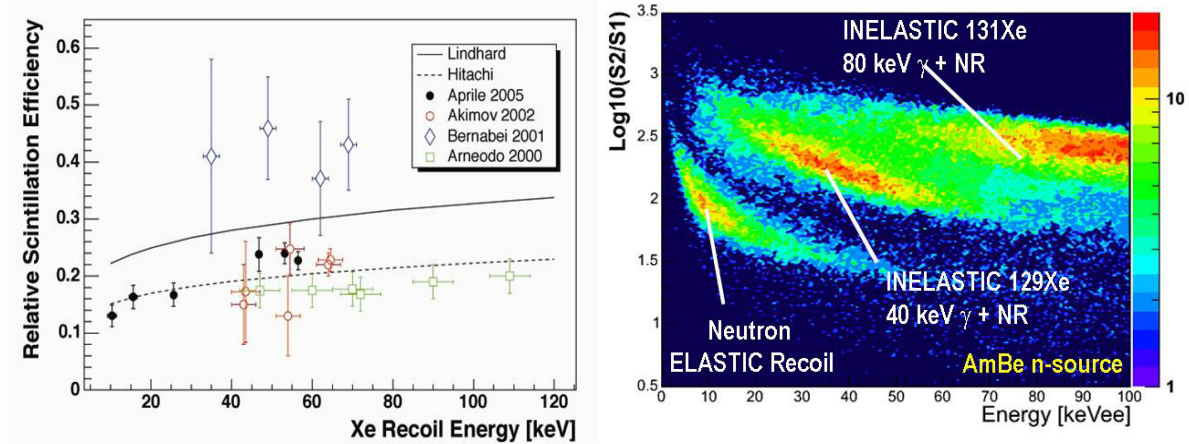


Figure 2. Studies of the (a) scintillation yield and (b) discrimination power of low energy nuclear recoils using small prototypes.

designed to test the feasibility of the concept and measure detector characteristics such as energy threshold, background discrimination as well as the scintillation and ionization efficiency of nuclear recoils in liquid Xe. Some results from this R&D work have been previously reported [8]. A xenon

chamber with 2 Hamamatsu R9288 PMTs optimized for Xe light was built to study the scintillation efficiency of Xe recoils as a function of energy and electric field. The scintillation yield for recoils of energies between 10.4 to 56.5 keV (see Fig.2, left panel), and for applied fields up to 4 kV/cm was measured with a nearly mono-energetic neutron beam with an average energy of 2.4 MeV [9]. The ionization yield of low energy nuclear recoils in LXe and the background rejection power (see Fig. 2, right panel) of a dual phase xenon chamber, was studied with a detector equipped with one PMT in the liquid and one in the gas, irradiated with a 5 Ci AmBe neutron source. The absolute number of ionization electrons from nuclear recoils was measured in the energy range of 10-100 keV. Contrary to expectation, the charge yield of nuclear recoils in LXe was found to be surprisingly high and with weak electric field dependence. Even more surprising, the yield increases with decreasing recoil energy. Results from these experiments are being finalized for publication.

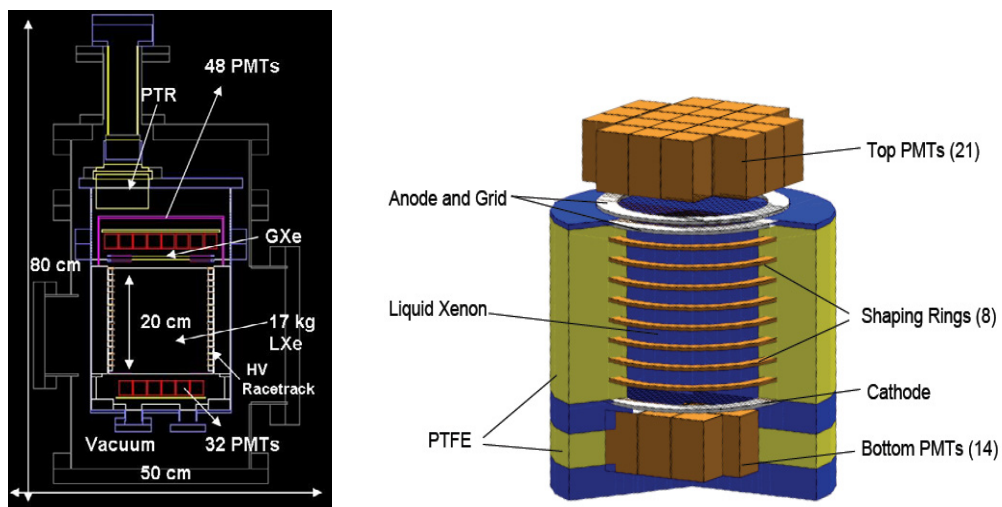


Figure 3. Representations of the (a) XENON10 and (b) XENON3 detector modules.

Fig 3. (a) shows the design of the XENON10 detector and its vacuum cryostat. It is a dual phase TPC, with an active mass of 10 kg and with drift region in the liquid of 20 cm length. Two arrays of VUV sensitive, 1 inch square metal channel photomultipliers (PMTs) with low radioactivity (Hamamatsu R8520-AL), 48 in the gas and 32 in the liquid, detect both primary and secondary scintillation light produced by an event in the active LXe. Since the secondary proportional light is produced in a small spot with the same X-Y coordinates as the primary interaction site, 2-D localization with better than 1 cm position resolution is possible. The third coordinate, or event depth in the liquid, is inferred from the drift time measurement. Thus the detector provides full 3-D event localization, allowing background reduction via fiducial volume cuts. The 3-D position sensitivity of a dual phase XeTPC has been demonstrated with a prototype of 3 kg active mass (XENON3), of very similar design as the larger XENON10. The detector, with 10 cm drift gap, is equipped with 21 PMTs in the gas and 14 PMTs in the liquid, as shown schematically in Fig 3. (b). Studies with this detector, irradiated with Cf-252 neutrons and 2.5 MeV neutrons from a D-D generator, have been recently carried out and analysis of these data is ongoing. Preliminary results show excellent discrimination power down to a threshold of 10 keV recoil energy.

At present, the XENON10 cryostat, the gas handling, purification and cryogenics systems and the data acquisition are being tested with the 21/14 PMTs detector. Construction of the larger detector with 48/32 PMTs of the same type as in XENON3 is under way. It is expected that the experiment will be installed in the Gran Sasso Laboratory at the beginning of 2006. The use of a CsI photocathode in place of the PMTs array, as in the original XENON baseline detector concept, is still being investigated given its advantages of lower radioactivity, lower cost and larger sensitive area compared to PMTs. Results from recent tests with various CsI photocathodes [10] have confirmed earlier

findings [11] of high quantum efficiency in LXe and the use of a HV switching unit has shown reliable control of the expected photon feedback in dual phase operation.

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