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Recent Progress from the MiniCLEAN Dark Matter Experiment

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Abstract. The MiniCLEAN dark matter direct detection experiment is a single-phase liquid argon detector, instrumented with photomultiplier tubes to observe scintillation light from a 150kg fiducial mass. This detector design strategy emphasizes scalability to target masses of order 10 tons or more. The projected light yield is 6 photo-electrons per keV, which allows pulse shape discrimination to separate the electron background from a WIMP-induced nuclear recoil signal. MiniCLEAN is also designed for a liquid neon target which, in the event of a positive signal in argon, will enable an independent verification of backgrounds and provide a unique test of the expected A^2 dependence of the WIMP interaction rate. This talk will review the experimental technique and current status of MiniCLEAN.

1. Introduction

The nature of dark matter is one of the fundamental questions about the universe today, at the forefront of experimental and theoretical physics research. From a variety of astrophysical measurements we now know that dark matter makes up approximately 23% of the energy density of the universe [1]. However, the properties of dark matter particles are unknown. A leading dark matter particle candidate is the hypothesized lightest super-symmetric particle, which is predicted to interact weakly with atomic nuclei, with a mass in the range of 10 to 10^4 GeV/c^2, and a cross section in the range of 10^{-42} to 10^{-48} cm^2 [2]. Current direct detection dark matter searches have excluded spin-independent cross sections above 4×10^{-44} cm^2 [3]. In the past few years there have also been several experimental results that are consistent with a dark matter signal, from both direct and indirect searches, although none are yet confirmed independently [4] [5] [6]. The field may be on the brink of discovery, or, finding new sources of background.

Current experimental limits indicate that the dark matter interaction cross section is at or below the scale of the solar neutrino interaction cross section. Solar neutrino experiments like SNO have 10 kilo-tonne fiducial mass, and observe roughly 1 solar neutrino interaction per tonne of detector fiducial mass [7]. Dark matter direct detection experiments will need to be at similar scales to measure appreciable numbers of events. Current experiments are at the 10-100 kg scale, and therefore demonstrating scalability of detector technology to the multi-tonne scale is of crucial importance. This is the primary goal of the MiniCLEAN experiment.

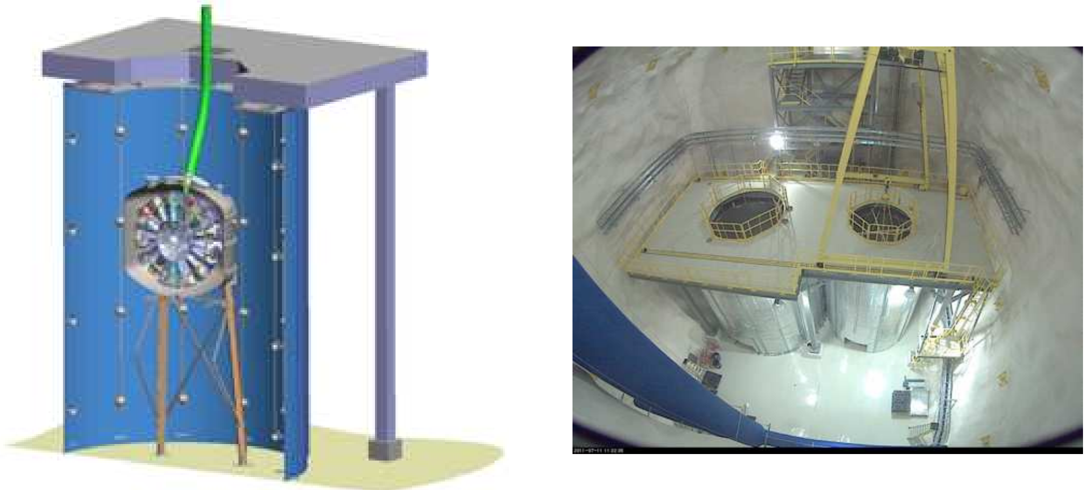

Figure 1. Left: MiniCLEAN detector assembly drawing, showing the water-filled veto tank instrumented with PMTs surrounding the outer cryostat containing the LAr detector and calibration source access port. Right: veto tanks for MiniCLEAN (right) and DEAP3600 (left) in the experiment hall at SNOLab.

2. Experiment Overview

The DEAP/CLEAN collaboration is engaged in a staged program to demonstrate the feasibility of very large single-phase LAr detectors with low energy thresholds and very low background levels. The detector design approach follows that of many successful, large neutrino experiments, emphasizing scale and simplicity.

The LAr target is chosen because of the potential for scalability to kilo-tonne masses while preserving excellent discrimination between signal and background. The dark matter detection concept is that WIMP-argon scattering produces recoiling argon nuclei, which deposit their kinetic energy in the detector. This produces single and triplet excited states of the ar detector atoms, which have 2 ns and 1.6μs lifetimes respectively [8]. The ratio of singlet to triplet excitation, which determines the number of scintillation photons produced vs. time, depends on the ionization density along the recoil track, and therefore is different for nuclear vs. electron recoils [8]. Exploiting this difference in the fraction of prompt light very effectively differentiates between these, demonstrated at the level of 3×10^{-8} at 90% confidence level [9]. A simple statistical model fit to this data projects that this rejection is sufficient to eliminate gamma and electron backgrounds for tonne-scale LAr dark matter detectors [10]. Other appealing properties of LAr include the relative ease of purification and resulting high light yield of 5-8 detected photo-electrons (p.e.) per keV of energy deposited through ionization channels [11], and relatively low cost.

The drawback of LAr as a dark matter target is the ^{39}Ar contamination, which has a beta decay with a 565 keV endpoint, at a rate of 1/s/kg [12]. A few percent of the decay electrons populate the energy window of interest for dark matter searches. This high rate imposes stringent requirements for distinguishing electron backgrounds from nuclear recoil signals, and poses a limitation to time-projection chamber readout of LAr dark matter detectors because of the ms-timescales of drifting ionization electrons leading to pile-up. However, recent progress on extracting sources of ^{39}Ar depleted-argon from underground has demonstrated reduction of the ^{39}Ar by a factor of 20, and further gains may be possible [13]. With the factor of 20 reduction, the projected maximum detector mass for dual-phase detectors is several tons. To defeat the pile-up limitation development of LAr scintillation-only dark matter detectors, several efforts

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using liquid targets only with no electric field ("single phase") are underway [10, 17, 14].

Since 2001, the DEAP/CLEAN collaboration has built a number of single-phase prototypes, miniDEAP (1 kg), microCLEAN (4 kg), DEAP-1 (7 kg), and the current detectors are MiniCLEAN (360 kg) (Mini Cryogenic Low Energy Astrophysics with Noble liquids) and DEAP-3600 (3600 kg). The MiniCLEAN detector is under construction now, and installation in SNOLab will begin in 2012, with the dark matter run beginning early in 2013. With an energy threshold of 50 keVr, fiducial mass of 150 kg, and <1 background event in 1 year of operation, MiniCLEAN's projected sensitivity to the WIMP-nucleon scattering cross section is 2×20^{-45} cm^2, at 90% confidence level for a 100 GeV WIMP mass [15]. DEAP-3600 construction will begin in 2012, and the dark matter run will begin in mid-2013, with dark matter sensitivity of 10^{-46} cm^2 [9]. The goal of the DEAP/CLEAN program is a 100 tonne-scale detector [17]. This scale would enable detailed study of the properties of WIMP dark matter, investigating predicted properties of neutrinos and the existing paradigm of neutrino oscillations, and testing the basic tenets of stellar evolution in our nearest star [16]. In addition, it would be sensitive to neutrinos from core-collapse supernovae and, in particular, to ν_μ and ν_τ flavors. This would be highly complementary to water detectors (such as Super-Kamiokande or future very larget detectors for proton decay and neutron oscillations) that will measure the $\overline{\nu_e}$ flux [17, 16].

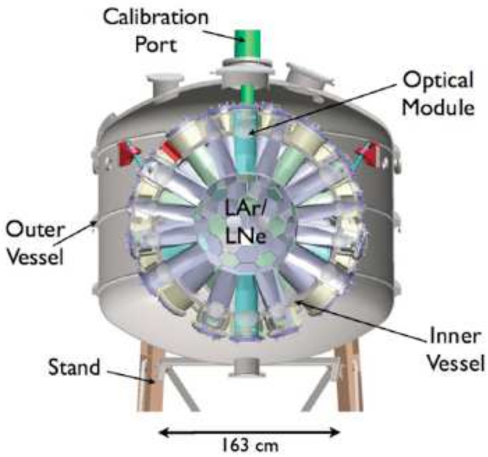

Figure 2. Left: MiniCLEAN LAr detector assembly drawing, showing the cryostat containing inner vacuum vessel, which is composed of 93 optical cassettes surrounding the LAr target volume. Right: the outer cryostat under vacuum testing at the manufacturer.

The MiniCLEAN detector design is an open target volume of 360 kg of LAr, with no electric field, viewed by a sphere of PMTs, inside a water-filled veto insttumented with PMTs. The detector assembly and current status of the experimental hall at SNOLab are shown in Figure 1. Scintillation light from dark-matter induced recoils is detected at the PMT sphere at 85 cm radius. The central target of liquid cryogen is contained in a low-background stainless steel vessel, with ports to 92 optical cassettes viewing the LAr through light guides filled with LAr and acrylic. A schematic of the LAr detector assembly and the outer cryostat are shown in Figure 2. The front faces of these light guides form a 4π wavelength-shifting sphere viewing the target volume at a radius of 45 cm. The wavelength shifting sphere is coated with TPB to shift the UV LAr scintillation light to 420 nm, where it can be detected by the array of 92 Hamamatsu R5912mod 8" PMTs. Each PMT is optically isolated from its neighbors in an optical cassette, and the fiducial volume is shielded from radioactivity from the PMT by a 10 cm acrylic plug. The optical cassette design and prototype test stand are shown in Figure 3. The PMT signals are read out at 250 MHz via CAEN V1720 waveform digitizing electronics.

The The process systems of the MiniCLEAN detector are designed for operation with a liquid neon (LNe) target as well, which gives unique sensitivity to verify the expected A^2 dependence of the WIMP-nucleon cross-section in the event that a candidate dark matter signal is found.

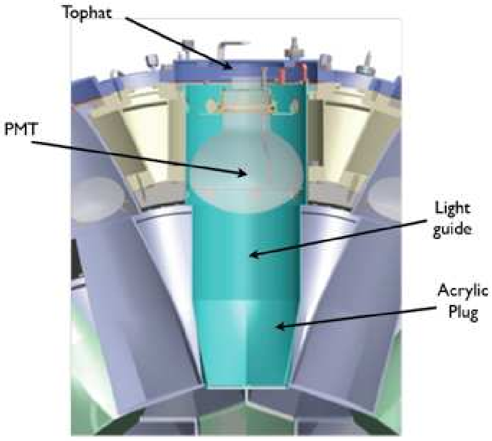

Figure 3. Left: MiniCLEAN optical casette assembly drawing, showing the R5912mod PMT, reflector, light guide, acrylic plug, and TPB-coated acrylic plate forming the wavelength-shifting sphere. Right: optical casette prototype test stand at LANL, which is used to characterize the optical casette components.

3. Conclusions and Outlook

The nature of dark matter is one of the fundamental questions about the universe today. Conclusive discovery of dark matter will require multiple technologies and targets. MiniCLEAN is unique in the global program with the ability to exchange the LAr for LNe target, in order to verify the expected A^2 dependence of a candidate dark matter signal. The ultimate goal of dark matter experiments is to measure particle properties, e.g. the mass and the interaction cross section, which requires hundreds to thousands of events. LAr has great promise as the target for future multi-tonne detectors, and the DEAP/CLEAN program will explore the scalability of the single-phase approach. The MiniCLEAN and DEAP-3600 detectors are under construction, and will begin operations at SNOLab from 2013.

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