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Neutrino detection with CLEAN

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Abstract

This article describes CLEAN, an approach to the detection of low-energy solar neutrinos and neutrinos released from supernovae. The CLEAN concept is based on the detection of elastic scattering events (neutrino–electron scattering and neutrino–nuclear scattering) in liquified noble gases such as liquid helium, liquid neon, and liquid xenon, all of which scintillate brightly in the ultraviolet. Key to the CLEAN technique is the use of a thin film of wavelength-shifting fluor to convert the ultraviolet scintillation light to the visible, thereby allowing detection by conventional photomultipliers.

Liquid neon is a particularly promising medium for CLEAN. Because liquid neon has a high scintillation yield, has no long-lived radioactive isotopes, and can be easily purified by use of cold traps, it is an ideal medium for the detection of rare nuclear events. In addition, neon is inexpensive, dense, and transparent to its own scintillation light, making it practical for use in a large self-shielding apparatus. The central region of a full-sized detector would be a stainless steel tank holding approximately 135 metric tons of liquid neon. Inside the tank and suspended in the liquid neon would be several thousand photomultipliers.

Monte Carlo simulations of gamma ray backgrounds have been performed assuming liquid neon as both shielding and detection medium. Gamma ray events occur with high probability in the outer parts of the detector. In contrast, neutrino scattering events occur uniformly throughout the detector. We discriminate background gamma ray events from events of interest based on a spatial maximum likelihood method estimate of event location. Background estimates for CLEAN are presented, as well as an evaluation of the sensitivity of the detector for p–p neutrinos. Given these simulations, the physics potential of the CLEAN approach is evaluated.

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1. CLEAN

Just as new physics can be learned by building accelerators with high collision energies, new physics can also be learned by building underground detectors with high sensitivity to rare events, such as neutrino interactions, scattering of dark matter particles, and double beta decay.

This latter field is now the source of great excitement, as the recent results of the Super-Kamiokande, SNO, and KamLAND neutrino detectors have proven that neutrinos have mass [1–3]. This is the first substantial change in the Standard Model of particle physics in the last 20 years. In addition, new highly sensitive dark matter detectors, such as CDMS, EDELWEISS, and ZEPLIN, have driven down the limits on dark matter scattering cross-sections, bringing us significantly closer to theoretical predictions for supersymmetric dark matter, and therefore closer to testing this explanation for the missing matter of the universe [4–6]. In our quest to learn more about neutrinos and other weakly interacting particles, it would be extremely valuable to have a better detector technology than is currently available. Ideally, this detector technology would simultaneously provide low radioactive backgrounds, a low energy threshold, and large detector mass at reasonable cost.

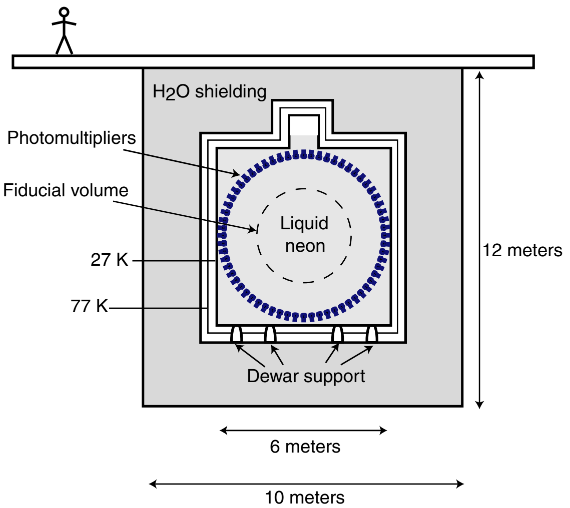

Fig. 1. A conceptual sketch of the full-sized CLEAN apparatus.

1.1. Experimental design

The following is a description of a scheme that meets all of these requirements, in which liquid neon is used as a detection medium. It is called CLEAN, standing for Cryogenic Low Energy Astrophysics with Noble gases.

In a CLEAN detector, neutrino–electron scattering events

$$\nu + e^- \to \nu + e^-$$

and neutrino-nucleus scattering events

$$\nu + \mathrm{Ne} \to \nu + \mathrm{Ne}$$

would be detected using liquid neon as a scintillator. [1] The CLEAN concept was first proposed several years ago [7], and in the years following the basic approach has undergone some revision as new ideas have surfaced. Our current concept of the final CLEAN detector is shown in Fig. 1.

In this design, the central detector consists of a stainless steel tank filled with liquid neon. Supported by a spherical geodesic structure would be about two thousand photomultipliers facing the center of the tank. In front of the face of each photomultiplier would be attached a quartz or acrylic window. Each window would be coated (on the surface facing the center of the detector) with a thin layer of organic fluor material, which would convert the extreme-ultraviolet (80 nm) neon scintillation light to the visible. Only the central "fiducial volume" of the neon would be used for detecting neutrinos; the outer "shielding volume" would prevent gamma rays from the photomultipliers and tank from reaching the fiducial volume. Around the assembly would be a tank of water serving as gamma-ray shielding, neutron shielding, and muon veto.

[1] While the CLEAN concept might be used with liquid helium or liquid xenon instead, this paper will concentrate on the liquid neon version. Liquid neon is significantly denser than liquid helium, while being easier to purify than liquid xenon, making it (in our view) especially promising for detection of rare events.