A Super Beam to the LANNDD Detector at the Carlsbad Underground Laboratory

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We describe the possible physics reach of a super beam to the LANNDD 70KT magnetized liquid argon detector proposed for the Carlsbad Underground Laboratory. The recent results of the ICARUST600 detector are shown as well. We consider super beams from LANL and FNAL for this detector.

1. The LANNDD Physics Research

In Figure 1 we show the possible location of LANNDD at the Carlsbad Underground Laboratory site (CUL). Note that the ease of construction and the exhaust pipe are key motivations for this site. Safety would be accomplished by walling off the detector from the rest of the lab. Excavation is relatively inexpensive at this site due to the salt structure.

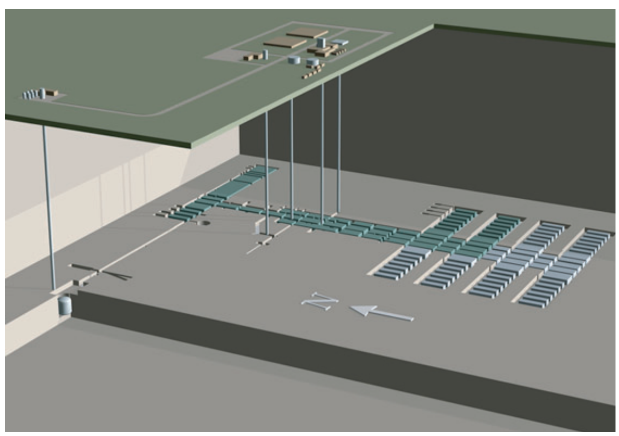

Figure 1: Liquid Argon neutrino and Nuclear Decay Detector at the CUL site.

Much of the scientific studies to be done with LANNDD follow the success of the ICARUS detector program [1, 2, 3]. The main exception is for the use of the detector at a neutrino factory where it will be essential to measure the energy and charge of the $\mu^{\pm}$ products of the neutrino interaction. We will soon propose an R&D program to study the effects of the magnetic field possibilities for LANNDD.

1.1. Search for proton decay to 10^{35} years

The detection of $p \to K^{+} + \overline{\nu_{\mu}}$ would seem to be the key channel for any SUSY-GUT model. This channel is very clean in liquid argon due to the measurement of the range and detection of the decay products. We expect very small background at even 10^{35} nucleon years exposure for this mode (refer to ICARUS studies).

1.2. Solar neutrinos and supernova neutrinos studies

The major solar neutrino process detected in liquid argon is:

$$\nu_e +^{40}\mathrm{Ar} \rightarrow^{40}\mathrm{K}^* + e^-$$

with K* de-excitation giving photons with subsequent Compton events. The same process is useful for supernova ν_e detection—the expected rate for the solar neutrinos is ~123,000 per year. For a supernova in the center of the galaxy with full mixing there would be ~3000 events—no other detectors would have this many clean ν_e events.

1.3. Use of LANNDD in a neutrino factor or super beam

Because of the large mass and nearly isotropic event response, LANNDD could observe neutrinos from any of the possible neutrino factories: BNL, FNAL, CERN or JHF in Japan. There are two approximate distances $(2\text{–}3) \times 10^3$ km and $(7 - 8)9 \times 10^3$ km for these neutrino factories. We assume the more distant neutrino factories operate at 50 GeV $\mu^\pm$ energy. For a neutrino factory that produces 10–20$\mu^\pm$ per year at FNAL/BNL and expect ~50,000 per year of right sign μ (i.e. $\mu^+ \rightarrow e^+\nu_e + \overline{\nu_\mu}$: the $\overline{\nu}_\mu$ gave μ^+ as right-sign muons.

The number of wrong sign muons will depend on the mixing angle θ_{13} (the wrong sign muon is $\mu^+ \rightarrow e^+\nu_e + \overline{\nu_\mu}$; $\nu_e \rightarrow \nu_\mu, \nu_\mu \rightarrow \mu^-$; the μ^- is the wrong sign muon)—there could be as many as 5000 wrong sign events/year.

For the farther distances (CERN in Japan) these numbers would be about the same due to the higher energy $\mu^\pm$ (50 Gev) with the rate increasing like the E_μ to the 3rd power.

2. Recent Results of the ICARUS T600 Detector at Pavia

In June the T600 detector started operation. Extremely clean cosmic ray events were observed, proving the technique works very well. We consider this a strong motivation to:

1. Complete the ICARUS detector program at the LANL
2. Design a much larger detector to advance the search for proton decay to 10^{35} years and to use for a neutrino factory or super beam.

3. The LANNDD Detector

The aim is to build a 70 kT active volume liquid argon TPC immersed in magnetic field. The geometric shape of the detector is mainly decided by the minimization of the surface-to-volume ratio S/V, directly connected to the heat input and to the argon contamination. Spherical (diameter = D), cubic (side = D) or cylindrical (diameter = height = D) shapes have all the minimum S/V (= 6/D). As compromise between easy construction and mechanical stability, the cylindrical shape has been preferred. Adding to the S/V criterion the need of minimizing the number of readout wires (= electronic channels) and of maximizing the fiducial-to-active volume ratio, a single module configuration appears definitely advantageous with respect to multi-module array configuration. The more difficult mechanical design for the single volume configuration appears fully justified by the larger fiducial volume, the lower number of channels, the lower heat input and contamination and then lower construction and operating costs.

The internal structure of the detector is mainly relied to the maximum usable drift distance. This parameter depends on the acceptable attenuation and space diffusion of the drifting charges. Acceptable working conditions are obtained with an electric field of 0.5 kV/cm, a drifting electron lifetime of $5 \div 10$ ms and a maximum drift of 5m. The detector appears then as sliced into 8 drift volumes, 5 m thick, each confined between a cathode plane and a wire chamber. Each wire chamber is made of two readout planes (u, v) with wires oriented at $+45°$ and $-45°$ with respect to the horizontal plane. A 5 mm wire pitch gives a sufficiently detailed imaging of ionizing tracks in the drift volumes. The magnetic field is vertically oriented and is obtained with a solenoid around the cryostat containing the liquid argon. With such an orientation the maximum bending

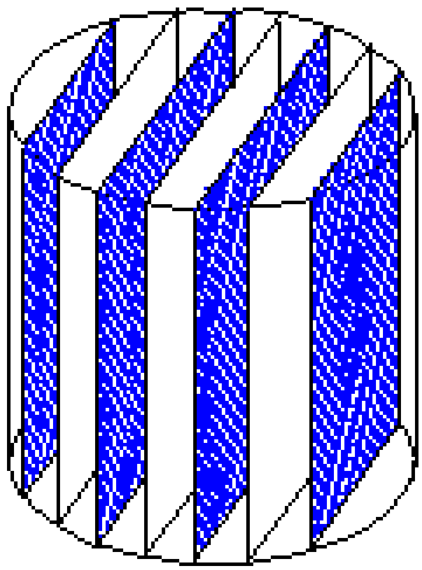

Figure 2: Schematic layout of chamber (hatched regions) and cathodes planes (white regions).

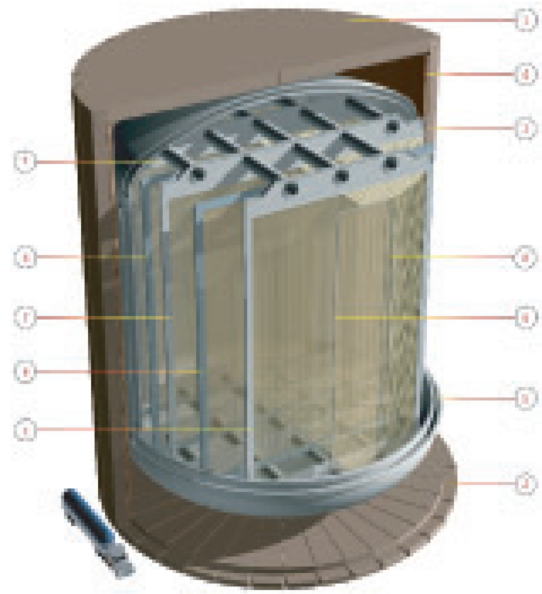

Figure 3: Artistic view of the preliminary sketch for the LANNDD detector: 1) Top end cap iron yoke; 2) Bottom end cap iron yoke; 3) Barrel iron return yoke; 4) Coil; 5) Cryostat; 6) Cathodes; 7) Wire chamber frames; 8) Field shaping electrodes.

for a charged particle is obtained in a horizontal plane and appears in the imaging as an arc in each of the planes (u, t) and (v, t).

The detector is foreseen as located underground (Figure 1), at a depth of 655 m (2150 ft) in a housing equipped with an emergency liquid argon pool and with argon vapor exhaust ducts. Forced fresh air inlet, liquid/vapor nitrogen in/out ducts, assembling hall with crane and elevator complete the basic organization of the underground cave. The magnetic field is vertically oriented and is obtained with a solenoid around the cryostat containing the liquid argon. With such an orientation the maximum bending for a charged particle is obtained in a horizontal plane and appears in the imaging as an arc in each of the planes (u, t) and (v, t). For the full project definition a preliminary activity is required to study a) the imaging in a magnetized liquid argon TPC, b) the operation in conditions of high hydrostatic pressure, c) drift path of ≥ 5 m.

4. A super beam to LANNDD at the Carlsbad Underground Laboratories

The current study of LANNDD is for location at the Carlsbad Underground Laboratory. The CUL team headed by Roger Nelson and Dennis Hofer are studying the key safety issues. This is the key to construction of LANNDD.

We can imagine two super beams for LANNDD [5]:

1. A high energy neutrino beam from FNAL; this would be unique in the world

2. A low energy beam from an upgrade LANL-LAMPF.

Either of these possibilities could lead to the eventual use of LANNDD for a neutrino factory anywhere in the world.

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References

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[3] F. Arneodo et al. [ICARUS and NOE Collaboration], “ICANOE: Imagine and calorimetric neutrino oscillation experiment,” LNGS-P21/99, INFN/AE-99-17, CERN/SPSC 99-25, SPSC/p314; see also A. Rubbia [ICARUS collaboration], hep-ex/0001052. Updated information can be found at http://pcnometh/cern/ch.

[4] This work is adapted from the LANNDD paper, Astro-PH 0105442.

[5] V. Barger, D. Marfatia, K. Whisnat, “Nautrino Superbeam Scenarios at the Peak,” contributed talk at Snowmass 2001.