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A UNIQUE DETECTOR FOR PROTON DECAY AND NEUTRINO OSCILLATIONS STUDY (LANNDD) FOR A USA DUSEL[a]

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ABSTRACT

We discuss the major scientific issues of the search for proton decay to 10^{35} years lifetime and search for CP violation with a VLBL superbeam (2000 km distance). The 100 kT LANNDD liquid Argon TPC is well matched to these goals. We describe the progress in the R&D program for the detector as well as the possible location in an underground laboratory in the USA called DUSEL.

1. Outline

1. The DUSEL concept
2. The development of the ICARUS liquid Argon detector
3. The LANNDD detector concept and current worldwide R&D effort
4. Sensitivity to proton decay and VLBL neutrino beam CP violation with $\nu_\tau \rightarrow \nu_e$
5. Safety issues at DUSEL for LANNDD
6. Summary

2. Introduction

The major scientific issues of elementary particle physics may be partially solved with the CMS and Atlas detector operation at the LHC. Other problems such as the nature of dark energy and dark matter are under investigation around the world (see the proceedings of The 6th Symposium on the Sources and Detection of Dark Matter and Dark Energy in the Universe, Marina Del Rey, California, 2005, in press).

Other equally fundamental questions involve the possibility of proton decay and CP violation in the neutrino sector. Until now these areas of science have been dominated by the use of water Cherenkov detectors such as Super K and IMB. However, with the successful development of the ICARUS liquid Argon TPC for the Gran Sasso Laboratory a new very powerful detector technique has entered the field.

In order to mount a new method to search for proton instability (mainly $p \rightarrow k^+\overline{\nu}$ a new very large underground laboratory is needed. It is possible that such a

[a]Invited talk at the XI Neutrino Telescope Conference, February 2005, Venice, Italy; parts of this paper are from a white paper submitted to SAGENAP, http://www.physics.ucla.edu/hep/whitepaper/wp.pdf.

laboratory will be developed in the USA called DUSEL (Deep Underground Science and Engineering Laboratory) by the U.S. National Science Foundation. In this report we discuss the progress to develop a 100 kT liquid Argon detector called LANNDD [1][2]. This detector is well matched to the size and scope of DUSEL and a possible super neutrino beam produced either by BNL or FNAL. A powerful R&D program for LANNDD is in progress that we will describe.

3. The DUSEL Concept

In the USA there is a plan to develop a deep laboratory for large modules (proton decay detector) and small modules (double beta detectors). Eight proposals have been to NSF. UCLA is the principal investigator for Carlsbad proposal. There are five co-PIs including the author. A key concept is the use of a neutrino beam from BNL or FNAL VLB to one of these sites (to be discussed later). The sites are shown in Figure 1 [3].

4. The Status if the ICARUS Liquid Argon Detector

The ICARUS LAR detector has made great progress recently [4].

(a) The T600 has now moved to the LNGS Hall B

(b) Work is starting to construct the next T1800 module

(c) The CNGS neutrino beam will be sent to the LNGS mid-2006; ICARUS will detect.

With about 2 kT of detector and the R & D program discussed here the time is ripe to plan a larger $\approx$ 100 kT detector. LANNDD is a major candidate for this detector and it could be located in DUSEL.

5. The LANNDD Concept: Possible application of this technology in the USA

One option for a next generation nucleon decay search instrument is a fine-grained detector, which can resolve kaons as well as background from cosmic ray neutrinos that are below the threshold for water Cerenkov detectors such as Super-Kamiokande (SK). Such a detector can make progress beyond the few $\times 10^{33}$ year limits from SK for SUSY favored modes because the reach improves linearly with the time and not as the square root of exposure as in SK. It will be possible to discover nucleon decay up to about $\approx 10^{35}$ year lifetime/branching ratio with an instrument of $\approx$ 70 kT mass in liquid argon, as the one studied in the LANNDD project after a few years of exposure [5].

A second major goal for such an instrument, as demonstrated in a spectacular example of synergy in the last two generations of underground detectors, is the study of neutrino interactions and oscillations [6]. Such a detector can make neutrino oscillation studies using the cosmic ray neutrinos alone (being able to resolve muon neutrino regeneration, detect tau's and tighten measurements of Δm^2 search for other mixing than $\nu_\tau \rightarrow \nu_e$. But coupled with a neutrino factory, this detector, outfitted with a large magnet, offers the advantage of being able to discriminate the sign not only of muon events, but of electron events as well. Given the bubble-chamber-like ability to resolve reaction product trajectories, including energy/momentum measurement and excellent particle identification up to a few GeV, this instrument will permit the study of the neutrino MNS matrix in a manner that is without peer. The LANNDD detector is shown in Figure 3.

One may question whether such a marvelous instrument is affordable, by which we mean buildable at a cost comparable or less than the neutrino source cost. It is indicated, by simple scaling from existing experience with ICARUS, that such an instrument will cost out in the class of a large collider detector instrument and represents a straightforward extrapolation of existing technology.

As expected for such a large, isotropically sensitive, general-purpose detector, there are many ancillary physics goals that can be pursued. This device would allow exploration of subjects ranging from the temporal variation of the solar neutrino flux (above a threshold of perhaps 10 MeV), to searches for neutrinos from individual or the sum of all supernovae and other cataclysmic events (e.g. GRBs), to cosmic ray research (composition, where the WIPP depth is advantageous), dark matter searches (via annihilation neutrinos), searches for cosmic exotic particles (quark nuggets, glueballs, monopoles, free quarks), and point source neutrino astronomy. In all these instances, we can go beyond SK by virtue of lower energy threshold, better energy loss rate resolution, momentum, angle, sign and event topology resolution.

6. Sensitivity to Proton Decay etc.

Much of the scientific studies that are being done with LANNDD follow the success of the ICARUS detector program. 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 m products of the neutrino interaction [3]. We will soon propose an R&D program to study the effects of the magnetic field possibilities for LANNDD.

6.1. Search for Proton Decay to 10^{35} *Years*

The detection of $p \rightarrow k^+\overline{\nu}_\mu$ would seem to be the key channel for any SUSY model. This channel is very clear in liquid argon due to the measurement of the range and detection of the decay products. We expect very small background events at 10^{35}

nucleon years for this mode (refer to ICARUS studies) [6].

6.2. Solar Neutrinos and Supernova Neutrinos Studies

The major solar neutrino process detected in liquid argon is $\nu_e + ^{40}Ar \rightarrow ^{40}Ar^* + e^-$, with Ar^* 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 $\approx$ 123,000 per year. For a supernova in the center of the galaxy with full mixing there would be 3000 events - no other detection would have this many clear ν_e events.

6.3. Atmospheric Neutrino Studies

By the time LANNDD is constructed it is not clear which atmospheric neutrino process will remain to be studied. However this detector will have excellent muon, hadron and electron identification as well as the sign of $\mu\pm$ charge. This would be unique in atmospheric neutrino studies. The rate of atmospheric neutrinos in LANNDD will be (50 kT fiducial volume):

CC ν_e events: 4800/year

CC ν_μ events: 39002800/year (depending on the neutrino mixing).

There would also be about 5000 NC ν events/year. We would expect about 25 detected ν_τ events/year that all would go upward in the detector.

6.4. Use of LANNDD in a VLBL Beam

Because of the large mass and nearly isotropic event response, LANNDD could observe neutrinos from any of the possible neutrino beam: BNL, FNAL. The LANNDD detector could be useful for the search for CP violation from any BNL or FNAL beam. This will depend on the value of the mixing angle θ_{13} and the magnitude of the CP violation. Figure 1 shows the distance to all the DUSEL sites.

7. Safety Issues for LANNDD at DUSEL

The safe installation and operation of the proposed Large Liquid Argon Detector, with tens of thousands tons of oxygen replacing liquid argon at cryogenic temperatures, will require significant safety engineering considerations. Siting a facility such as the LANNDD in a hard rock location, where mining is difficult and slow, could add significantly to the overall cost of supplying suitable egress and suitable venting systems in the event of major disruptions of containment. By contrast, the low cost of mining, shaft installation, and material removal in a salt mine provides a cost-effective solution to the safety implications posed by installation and operation of LANNDD in an underground environment. Multiple emergency air dumps and sources, along with multiple egress options, can be simply created at reasonable cost.

The safety installations described above can be obviously applied also to other underground locations, with some specific adaptations and modifications of the solutions to the local and environmental conditions.

The WIPP facility has a long history of safe operation; it can claim to be the safest underground operation in the U.S. today and has already won numerous safety awards.

The safety study will include the following items (for a more detailed description of these items see the SAGENAP report web site on the first page. Engineering Feasibility and Safety Study for LANNDD and Other Particle Detectors at WIPP):

8. R&D effort: 5m Drift Experiment (this section prepared with Franco Sergiampietri, Pisa

8.1. Introduction

Aimed to the fields of neutrino physics and of nucleon decay, a preliminary study was started, in the year 2000, for identifying the main configuration criteria, the critical items and the related required tests for a 50-100 kTon detector, configured as liquid argon TPC, eventually fitted out with magnetic field. This study pointed out general thoughts, dictated by detection efficiency, mechanical stability, feasibility, underground operation, safety and costs, for the choice of:

- shape
- modularity
- detector parameters
- cryostat parameters
- magnet parameters
- site parameters.

The results, presented at NuFact'01, Tsukuba , describe a possible future detector named LANNDD (Liquid Argon Neutrino and Nucleon Decay Detector), sited at the WIPP site, Carlsbad, NM. A huge-scale detector, as the conceived one, requires a preliminary R&D activity for directly verifying all a series of design parameters, peculiar of its large scale, beyond the indications obtainable from extrapolation from much smaller size detectors or from Monte Carlo simulations. In particular:

- long electron drift (4-8 m)
- track reconstruction in magnetic field (e.m. shower sign discrimination, muon momentum resolution),
- electron drift velocity at different (high) hydrostatic pressures should be considered as first priority tests.

In the present article we propose an experimental set-up for the first of these tests.

8.2. Long Electron Drift in Liquid Argon

In order to decrease the complexity and the cost of a large scale detector it is important minimizing the number of electron collection wire planes. The purpose of the test is to experimentally verify the limits set on the maximum drift length by diffusion and attenuation of the drifting charge, by measuring the electron collection efficiency with a 5m (or greater) drift path. For a long drift space the problems to be faced are:

- Use of high voltages for the drift in the range $V_d \approx 200-400kV$. For a drift field $E_d = 0.5kV/cm$ and a drift space $d = 5m$, $V_d = 250kV$ is required. The maximum drift time is $T_d = 3.1ms$. Every detail of the high voltage system should be carefully designed for a safe operation in a low noise environment as the liquid argon TPC.

8.3. Experimental Methods

We plan to measure attenuation and diffusion effects for ionized tracks along a 5-m long drift space. A first method is based on recording tracks induced by vertical cosmic ray, selected at different distance along the drift by a pair of scintillator counters in coincidence. After each trigger from the counters, data are acquired during a time window corresponding to the maximum drift time. The dependence on the counter position of the peak of the pulse height distribution in the collection wires will show the attenuation along the drift. The time duration of signals is related to the diffusion along the drift direction.

A second method is based on recording single long tracks, slightly inclined with respect to the drift direction, from a muon test beam (p 10 GeV/c). Portions of the track originated at different distance from the collection wire plane are collected in different wires and their pulse height distribution gives immediately the exponential behavior due to the attenuation.

8.4. The Detector

The detector is configured as a time projection chamber with cylindrical drift volume. The drift volume, 5m long, is bounded by a cathode, at one end, and by a wire chamber, at the opposite end. The electric field generated between cathode and wire chamber, is kept uniform by mean of a stack of uniformly spaced metallic rings (field shaping electrodes), biased at voltages linearly decreasing from the cathode voltage to the wire chamber voltage.

In a first configuration, the wire chamber is made by two wire planes. The first plane, with grounded horizontal wires, works as grid (Fisher type) for screening the second wire plane (collection plane) from the drift volume and then avoiding position dependent signals. The collection wires are vertically oriented and individually connected by signal lines to a low voltage multi-contact feedthrough and, from there, to the outer front-end electronics (charge sensitive preamplifiers, amplifiers, ADC's).

The current collaboration is between Pisa, Granada and UCLA.

9. Acknowledgements

I wish to thank Franco Sergiampietri for help and E. Fenyves for the Safety Study and all members of the WIPP/DUSEL team for help and discussion.

10. References

1) The following papers are available in PDF format at http://www.physics.ucla.edu/hep/whitepaper: A very sensitive measurement of $\sin^2 2\theta_{13}$ using a liquid argon detector in the NuMI off-axis beam, J. Phys. G 29 (2003) 1893-1898; LANNDD - a massive liquid argon detector for proton decay, supernova and solar neutrino studies and a neutrino factory detector, Nucl. Instrum. Meth. A 503 (2003) 136-140;A super beam to the LANNDD detector at Carlsbad Underground Laboratory; LANNDD: liquid argon neutrino and nucleon decay detector, submitted to the National Research Council (April 23, 2002); Mini-LANNDD T40: a detector to measure the neutrino argon corss-section and the ν_e contamination in the off-axis NuMI beam.
2) For example: FLARE discussion, see http://home.fnal.gov∼para/Liquid-argon.ppt.
3) Private communication from C.K. Jung.
4) Status of ICARUS, see http://pcnometh4.cern.ch/.
5) For a discussion if the use of LANNDD in the NuMI Beam at FNAL see D.B. Cline, S. Otwinowski and F. Sergiampietri, Mini-LANNDD: A very sensitive neutrino detector to measure $\sin^2(2\theta_{13})$, astro-ph/0206124, talk given by D.B. Cline at the New Initiative Workshop, FNAL, May 2002.
6) A recent meeting at UCLA gives a good overview: http://www.physics.ucla.edu/hep/proton/proton.htm.

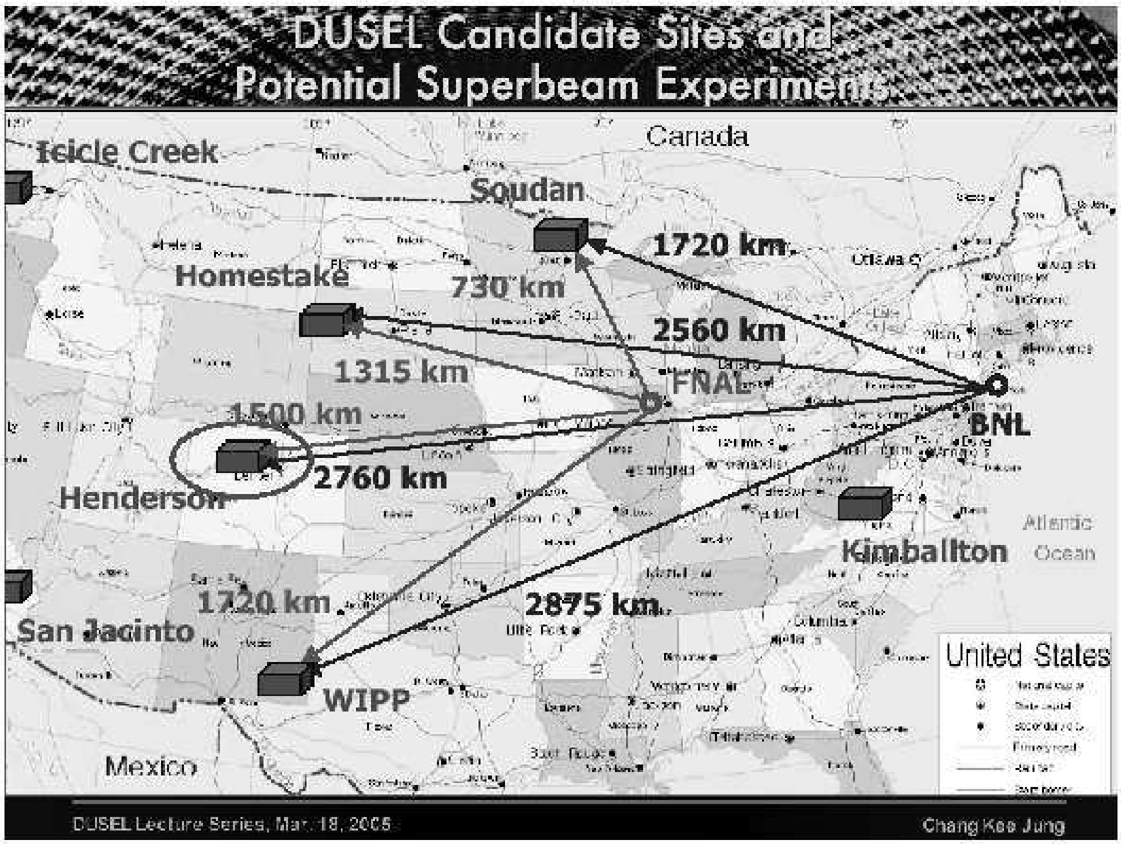

Figure 1: DUSEL candidate sites.

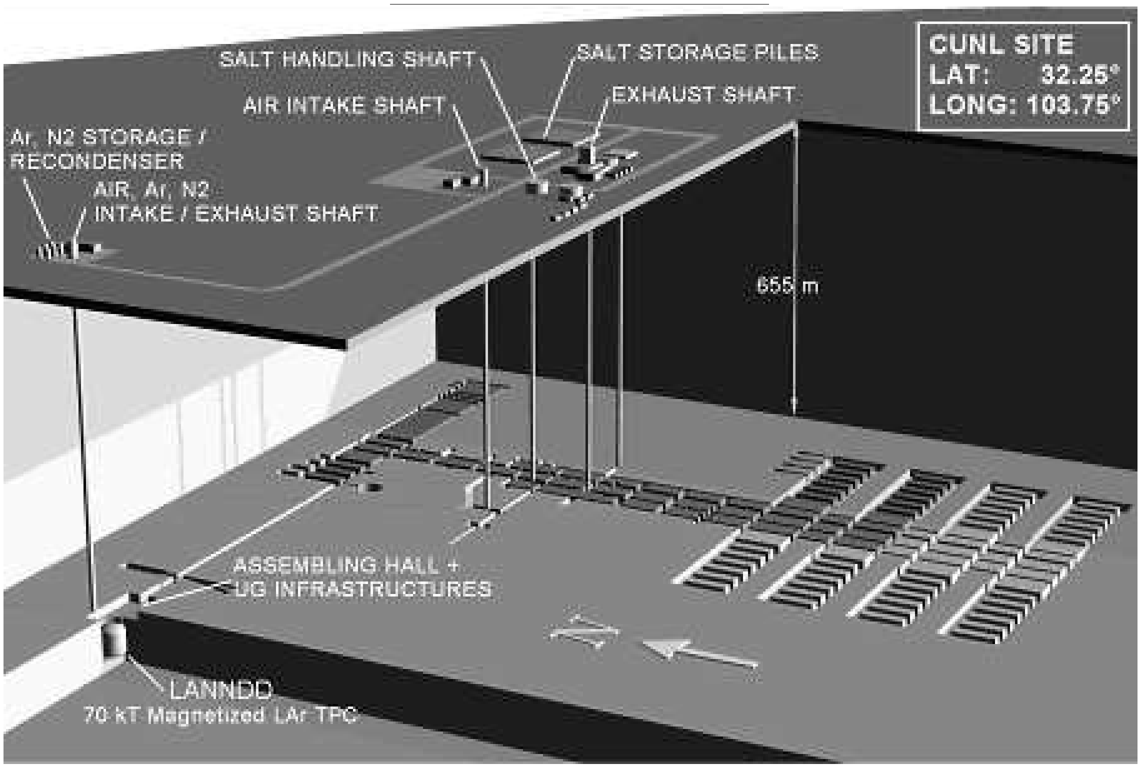

Figure 2: LANNDD at the WIPP site.

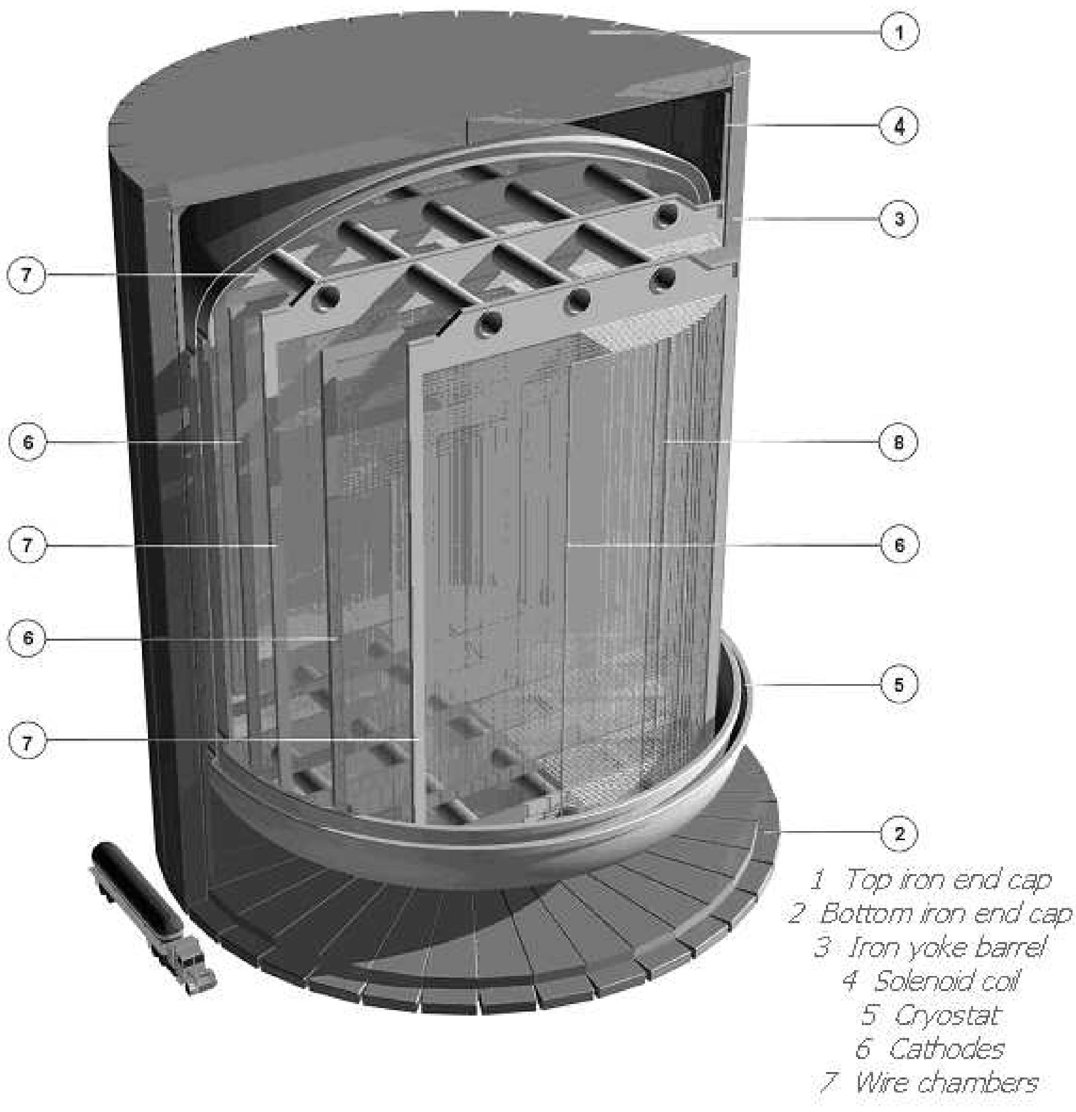

Figure 3: Cutaway view of the LANNDD detector.

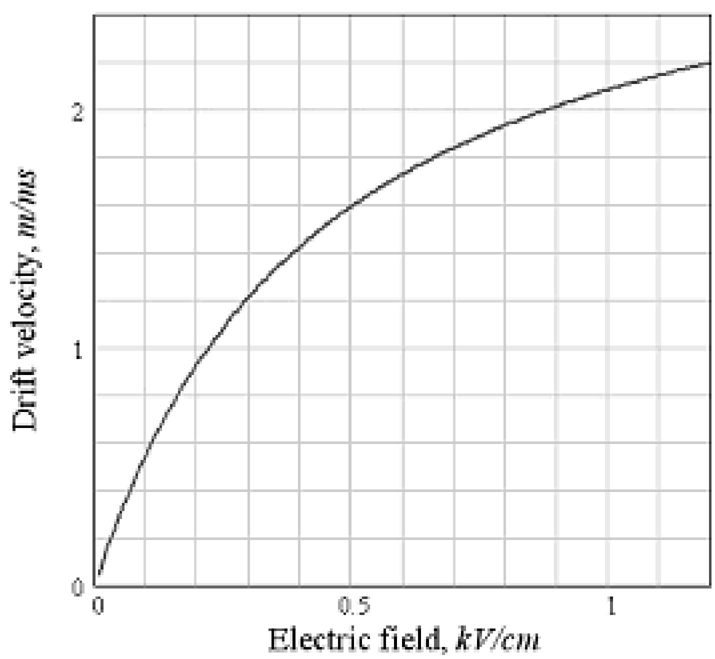

Figure 4: Drift velocity versus electric field in liquid Argon.

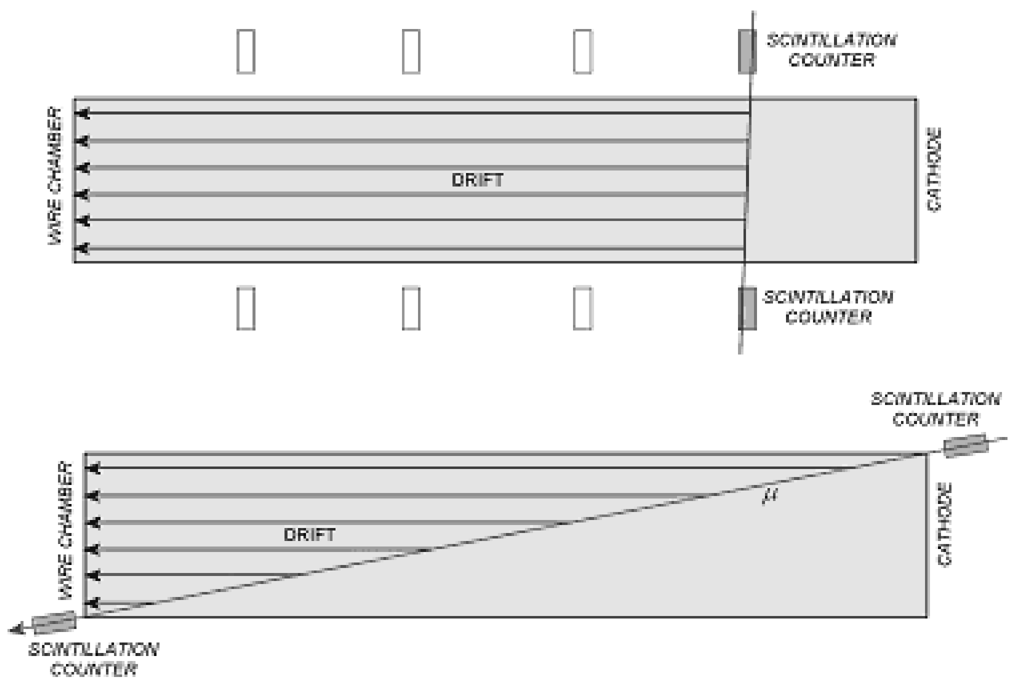

Figure 5: Collecting event with vertical cosmic ray trigger (top) and Collecting event with muon beam inclined with respect to the drift direction (bottom).

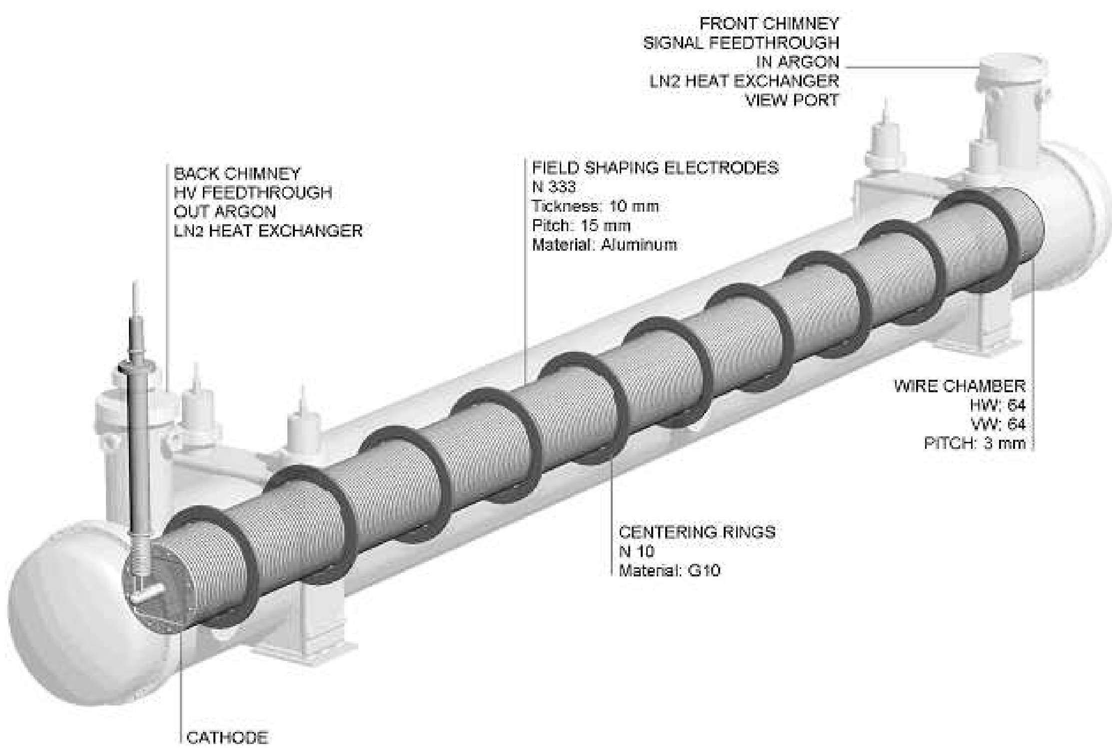

Figure 6: The 5-m drift time projection chamber.