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Mini-LANNDD: a very sensitive neutrino detector to measure $\sin^2(2\theta_{13})$*

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Abstract

The ICARUS detector at the LGNS will carry out a sensitive search for $\sin^2(2\theta_{13})$. We describe a smaller version of the LANNDD proton decay detector (70 kT liquid argon) to measure $\nu_\mu \rightarrow \nu_e$ in a low energy or off-axis neutrino beam. We find an optimal detector of size 5 kT and at a distance of about 700 km from a high-energy neutrino source. This detector uses the ICARUS method.

1. Introduction

The ICARUS detector concept is now well tested and plans for a 3 kt detector at the LGNS by 2005–2006 are in place [1]. This detector with the CNGS neutrino beam will provide the most sensitive search for $\nu_\mu \rightarrow \nu_e$ that is currently planned. To go beyond this sensitivity, a new detector will be required in a different (lower energy or off-axis) beam. In this paper we discuss a possible 5 kT detector based on the ICARUS method, and a smaller version of the proposed LANNDD detector. LANNDD (Liquid Argon and Neutrino and Nuclear Decay Detector) is a 70 kT magnetized detector for the WIPP Site at Carlsbad, New Mexico. Figure 1 shows a schematic of LANNDD and figure 2 shows a schematic of the detector located at the WIPP Site [2].

In this paper we provide a brief discussion of Mini-LANNDD, a 5 kT detector based on the LANNDD concept. We emphasize here the use to search for $\nu_\mu \rightarrow \nu_e$ beyond the ICARUS [3] range to the level of $\sin^2(2\theta_{13})$ of 0.005.

2. Reach of ICARUS T3000

The ICARUS T600 will be installed soon in the LNGS, most likely in Hall B. A proposal has been submitted to INFN and the USA DOE to construct an additional 2400 tons of ICARUS [4].

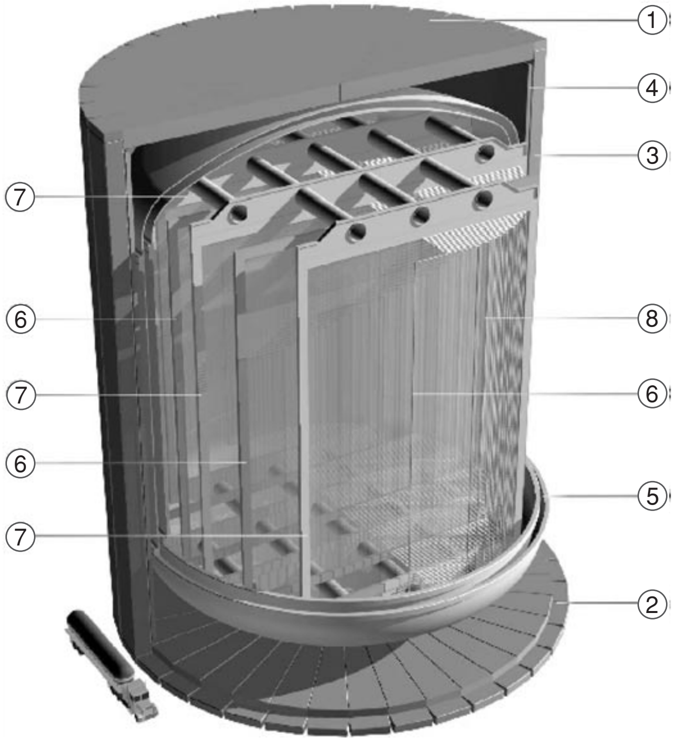

Figure 1. LANNDD: 70 000 Tons magnetized liquid argon time projection chamber. Preliminary sketch: (1) top iron end cap; (2) bottom iron end cap; (3) iron yoke barrel; (4) solenoid coil; (5) cryostat; (6) cathode planes; (7) wire chambers; (8) drift field electrodes.

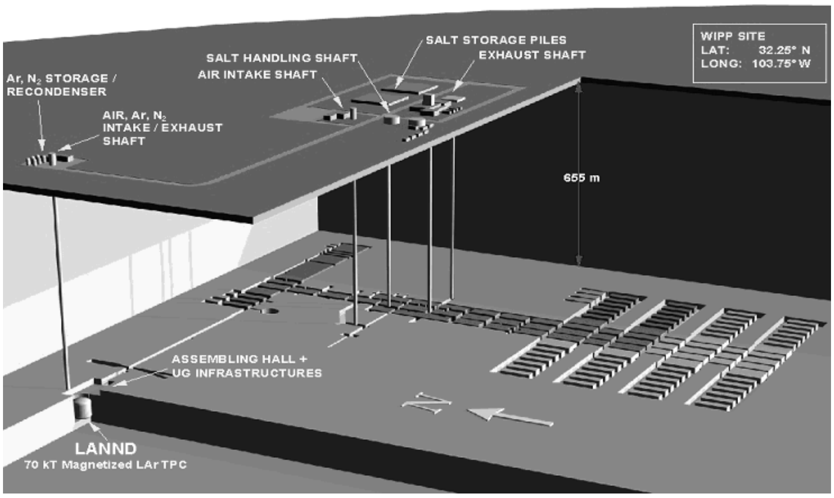

Figure 2. The WIPP underground site near Carlsbad, New Mexico.

In this proposal we analyse the limit on $\sin^2(2\theta_{13})$ that could be reached after 8 years of operation with the CNGS beam. Table 1 lists the event rate for different channels as well as

Table 1. ICARUS T3000 in CNGS beam (≈730 km). Rates from $\nu_\mu \to \nu_e$ oscillations in three family mixing (for $\Delta m^2_{23} = 3.5 \times 10^{-3}$ and eV^2 and $\theta_{23} = 45°$). Rates are normalized to 20 kty. (8 years running on 'shared beam').

θ_{13} degrees	$\sin^2(2\theta_{13})$	$\nu_e CC$	$\nu_\mu \to \nu_\tau$ $\tau \to e$	$\nu_\mu \to \nu_e$	Total	$S/\sqrt{B}$
9	0.095	79	74	84	237	6.8σ
8	0.076	79	75	67	221	5.4σ
7	0.058	79	76	51	206	4.1σ
5	0.030	79	77	26	182	2.1σ
3	0.011	79	77	10	166	0.8σ
1.5	0.003	79	77	2.5	158	0.2σ

Table 2. Optimal $\sin^2(2\theta_{13})$ determination in ν_e background.

'ν_e flux issue'	$\frac{R(\nu_\mu \to \nu_e)}{R(\nu_e)} = \frac{A}{B} \sin^2 2\theta_{13}$
	A = function of [θ_{23}, osc. prob. (4_e)]
	B = Ratio $\frac{(\nu_e)}{(\nu_\mu)}$ in beam
	$\frac{R(\nu_\mu \to \nu_e)}{R(\nu_e)} \cong 1 \to$ signal $\cong$ background
	Difficult to go far below this level; must know background very well
	$A \sim 1/2$ optimal oscillation distance
	$B \sim 1/210^{-2} \to (0.4 - 0.8) \times 10^{-2}$
	NuMi = 0.4, CNGS (??) = 0.8

Table 3. Mini-LANNDD in NuMi medium energy beam (≈730 km). Rates from $\nu_\mu \to \nu_e$ oscillations in three family mixing (for $\Delta m^2_{23} = 3.5 \times 10^{-3}\,\mathrm{eV}^2$ and $\theta_{23} = 45°$). Rates are normalized to 20 kty. (Four years running on beam of 3.8×10^{20} pot).

θ_{13} (degrees)	$\sin^2(2\theta_{13})$	$\nu_e CC$	$\nu_\mu \to \nu_\tau$ $\tau \to e$	$\nu_\mu \to \nu_e$	Total	$S/\sqrt{B}$
9	0.095	60	–	382	442	49σ
8	0.076	60	–	304	364	32σ
7	0.058	60	–	234	294	30σ
5	0.030	60	–	121	181	23σ
3	0.011	60	–	44	104	5.7σ
1.5	0.003	60	–	11	71	1.4σ

Table 4. Mini-LANNDD in NuMi medium energy beam (≈730 km). Rates from $\nu_\mu \to \nu_e$ oscillations in three family mixing (for $\Delta m^2_{23} = 3.5 \times 10^{-3}\,\mathrm{eV}^2$ and $\theta_{23} = 45°$). Rates are normalized to 20 kty. (Four years running on beam of 3.8×10^{20} pot) [6].

Detector position	ν_e (no osc.)	ν_e (osc. = 100%)	$\nu_\mu \to \nu_e$ $\sin^2(2\theta_{13}) = 0.005$	ν_e background	
On-axis	13 460	4000	20	60	≈3σ
Off-axis 5 km	5420	3000	15	24	≈3σ
Off-axis 10 km	1380	1300	8	4.4	≈4σ

the expected ν_e background. A detailed analysis by Andre Rubbia [5] and his group indicates that a value of 0.02 could be reached to 90% CL. A schematic of the limit that one can reach

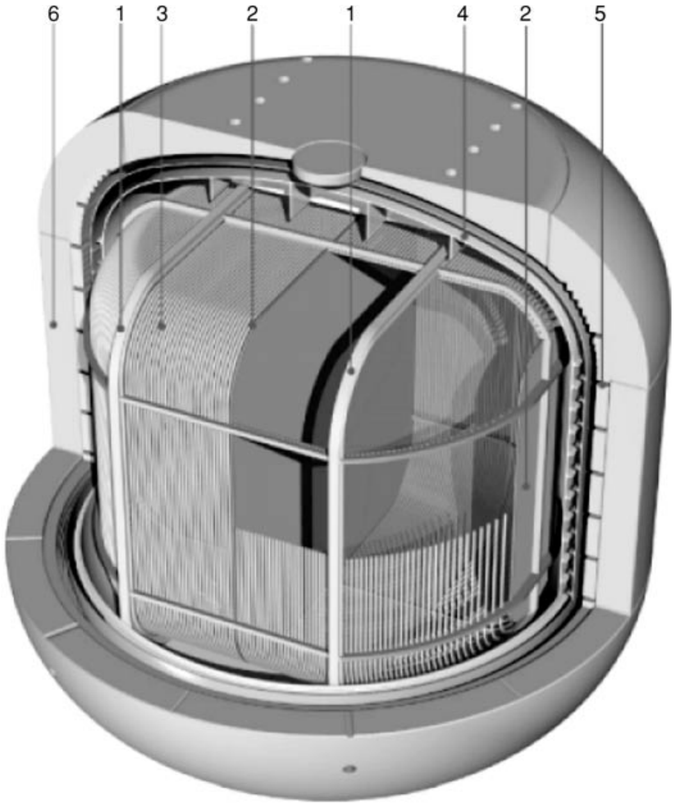

Figure 3. Mini LANNDD: 5000 Tons magnetized liquid argon time projection chamber. Preliminary sketch: (1) wire chambers; (2) cathode planes; (3) drift field electrodes; (4) cryostat; (5) solenoid coil; (6) iron yoke.

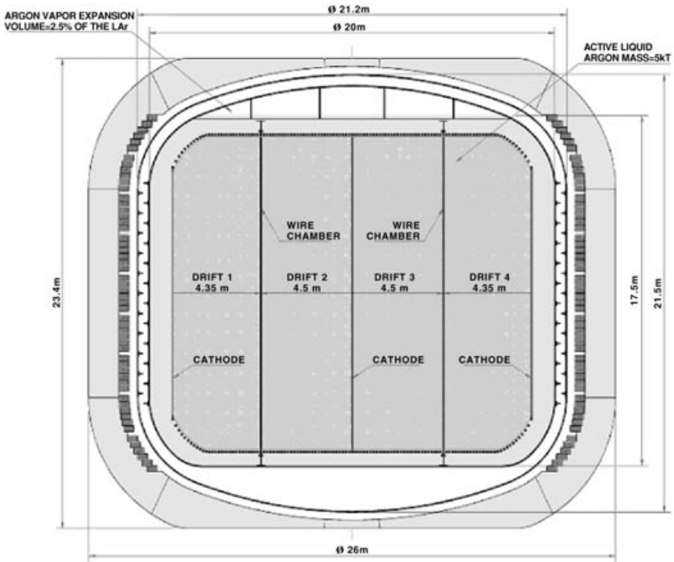

Figure 4. Mini LANNDD: transverse cross section.

Table 5. Mini-LANNDD—Parameters.

Active liquid argon volume	3587.6 m^2
Maximum W × H × D	17.7 m × 15.6 m × 11.2 m
Active liquid argon mass	4986.8 Ton
Total liquid argon volume	5216.8 m^3
Total vapour argon volume	130.6 m^3
Vapour-to-liquid ratio	2.5%
Number of drift regions	4
Drift lengths	2 × 4.35 m + 2 × 4.5 m
Maximum required high voltage	225 kV
Number of cathode planes	3
Number of HV feedthrough	1
Number of wire chambers	2
Number of read-out wire planes	8
Number of read-out wires	85 160
Maximum wire length	16
Maximum wire capacitance	320 pF
Number of signal feedthrough chimneys	32
Maximum signal cable length	5 m
Maximum signal cable capacitance	215 pF
Number of analog–digital processing crate pairs	148
Heat input (radiation)	1.64 kW
Heat input (conduction through cables and supports)	1.3 kW
Heat input (total)	2 kW
LN_2 consumption	1.03 m^3/d
Magnetic field	0.5 T
Total coil copper	5030 Ton
Power dissipation	6.2 MW
Iron yoke mass	26 440 Ton

compared to the background is given in table 2. We see that a value of 0.01 is optimal and with a great deal of effort (or a very good detector such as Mini-LANNDD) (tables 3 and 4), 0.005 might be reached.

3. Mini-LANNDD

We have made a very preliminary design of a 5 kt LANNDD-like detector to use in a NuMi-like beam (or off-axis CNGS beam). Figure 3 shows one design including the cryostat whereas figure 4 shows a cross section of the detector. We assume 5 m drift length. In table 5 we give some preliminary parameters of the detector.

4. The reach of Mini-LANNDD

Using some value given to us by Adam Para [6, 7] we show the signal and background for Mini-LANNDD with 20 kty exposure in tables 3 and 4. Neutral current will be unimportant. Mini-LANNDD can reach ultimate limit possible in the NuMi beam (or off-axis CNGS) of 0.005.

Acknowledgments

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