The N^OE detector for a long baseline neutrino oscillation experiment

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The project of a large underground experiment, N^OE (Neutrino Oscillation Experiment), composed by modules of scintillating fiber calorimeter interleaved with TRD modules, total weight 6.7 ktons,is presented. This apparatus has been optimized for long baseline neutrino oscillation studies, in particular to be sensitive in the region of $\sin^2 2\vartheta$ and $\Delta \mathrm{m}^2$ suggested by the atmospheric neutrino anomaly (fig. 3).

1. INTRODUCTION

One of the open problems in elementary particle physics is whether neutrinos are massless or not. If neutrinos have non zero mass and the mass eigenstates are mixed, the most promising way to measure their mass is through oscillation experiments. In the simplified hypothesis of a mixing between two neutrino families, the probability of observing $\nu_i \to \nu_j$ oscillations at a distance L is given by

$$P(\nu_i \to \nu_j) = \sin^2 2\vartheta \sin^2 \left[1.27 \frac{\Delta m^2 (eV^2) L(km)}{E_\nu (GeV)} \right]$$

where $\Delta \mathrm{m}^2 = |\mathrm{m}_\mathrm{i}^2 - \mathrm{m}_\mathrm{j}^2|$ is the eigenstate mass squared difference, L is the distance from the ν source to the detector, E_ν is the neutrino energy and ϑ the mixing angle.

Recent results from SuperKamiokande [1] confirm the observation of a small atmospheric ν_μ/ν_e contained event ratio. Due to its special features (high flux, known energy spectrum, known initial neutrino direction and flavour and ν_e contamination), a long baseline neutrino beam offers many advantages respect to atmospheric neutrinos to explore a wide region in the $\sin^2 2\vartheta$, $\Delta \mathrm{m}^2$ plane and verify the hints of oscillations.

2. THE N^OE DETECTOR

N^OE (fig. 1) is a massive, fine grain 4.3 kton calorimeter based on scintillating fiber technology (CAL) interleaved with modules of massive transition radiation detector (TRD), 2.4 kton of total weight, proposed for the CERN-GRAN SASSO program [2,3]. TRD and CAL modules joined together form the Basic Module of the N^OE detector (fig. 2), twelve of such BM give rise to the whole 6.7 kton N^OE - LBL detector.

The calorimetric module is implemented embedding scintillating fibers into a low cost and radioactivity free absorber. This radiator is obtained extruding iron ore (magnetite) and recycled plastic together. Extruded slabs, about 6.5 mm thick, become fiber support too. Planes of fibers and radiator, 8×8 m^2 (due to the attenuation length λ=5 m), are crossed alternatively in horizontal and vertical direction in such a way to ensure symmetry and homogeneity to the apparatus. Thin iron sheets ($\sim$ 2 mm) provide the mechanical support for two of such planes, with the X and Y view. The depth of the calorimetric module is 130 cm, which is equivalent to 25 X_o and to 4 λ_I, with an average density of 3.8 g/cm^3. The mass of a calorimetric module is 360 tons, divided in 90 layers (X + Fe + Y).

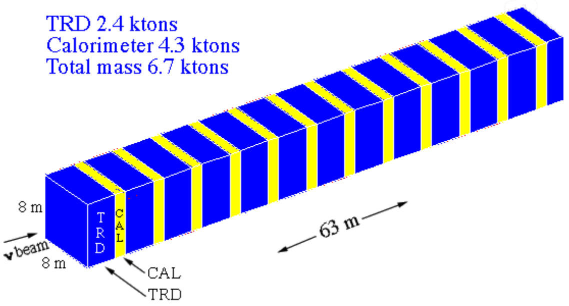

Figure 1. The general view of the N^OE detector

The proposed calorimeter has a very high intrinsic granularity: the average distance of the fibers inside the absorber is $\sim$ 6 mm. To exploit this feature the fiber read-out should have a fine configuration in which fibers are collected in small groups and coupled to the grid of a multianode device (41 fibers grouped correspond to 6.5 $\times$ 6.5 cm^2 of detector area sampled, 18 to 4 $\times$ 4 cm^2).

The energy resolutions for electrons and hadrons in the calorimeter have been evaluated by means of a GEANT Montecarlo simulation. They are, respectively, $\sigma(E)/E = 0.01 + 0.17/\sqrt{E}$ and $\sigma(E)/E = 0.08 + 0.42/\sqrt{E}$.

The shower axis is obtained by using the center of gravity of the energy deposited in each calorimetric grid element (Xe,Ye). The present calculations are performed in the hypothesis of 6.5 $\times$ 6.5 cm^2 channel area, corresponding to a sampling of $\sim$ 1 radiation length. The tracking of both the muon and the hadronic shower axis have been determined and their resolution are given by: $\sigma_\mu(\theta) = 1.27/\sqrt{E_\mu} + 2.27/E_\mu$ and

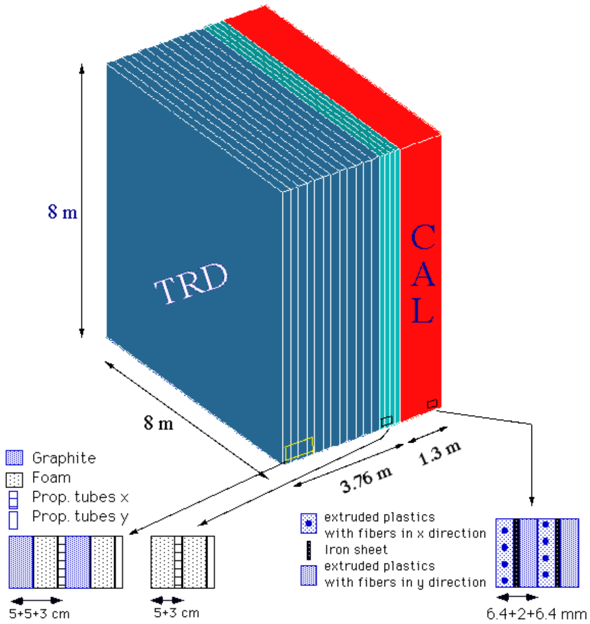

Figure 2. A TRD+CAL Basic Module (BM)

$\sigma_h(\theta) = 10/\sqrt{E_h} + 20/E_h$.

The transition radiation detector (TRD) consists of 32 vertical layers of 8 $\times$ 8 m^2 surface area, each made by polyethylene foam radiator (ρ=35-145 mg/cm^3) and 256 proportional tubes (3 $\times$ 3 cm^2 cross section), filled with a Ar (60%) - Xe (30%) - CO2 (10%) mixture, we already tested in the MACRO TRD [4]. Consecutive layers have tubes rotated of 90 degrees.

A graphite wall of 5 cm thickness is set in front of each of the first 24 layers of the TRD module acting as a 182 ton target for ν_e, ν_τ interactions, to be identified in the following layers. Each target corresponds to 0.25 X_0 while the entire module to about 7 X_0 and 3.5 λ_I. The total length is about 3.76 m.

The transition radiation is read by many layers of proportional tubes (16X + 16Y), so the muon energy can be determined by multiple measurement of energy loss dE/dx once that in the calorimeter a muon track is recognized. Combining informations coming from both subdetector (TRD and CAL) the discrimination between e,μ,π is largely enforced allowing the study of several neutrino oscillation channels.

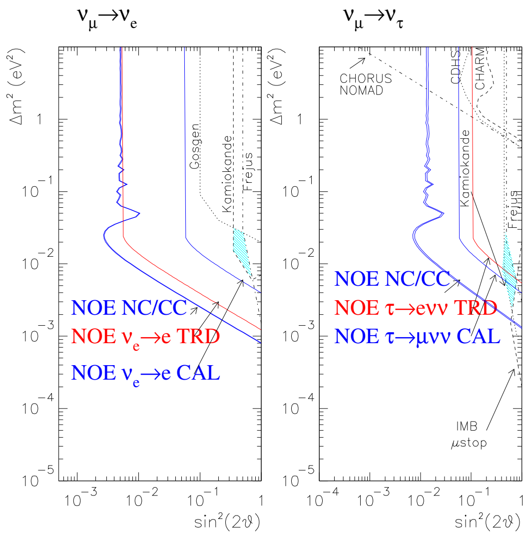

Figure 3. The $N^{O}E$ sensitivity to long baseline ν oscillations

3. OSCILLATING EVENT RATES

The rate of ν_μCC unoscillated events expected to be observed at Gran Sasso by the $N^{O}E$ detector are $\sim$40000 in 3-4 years of operation (table 1), given an exposure of $\sim 10^{20}$ pot (works are in progress to improve Cern ν beam features [5]) and under the hypothesis of a "Ball" neutrino spectrum [6]. In case of oscillation, the $N^{O}E$ apparatus will be able to detect:

1. ν_μ disappearance, by the measure of the ratio NC/CC, which requires a large mass, but not a detailed event reconstruction.

2. Evidence of ν_eCC event excess and ν_τCC interactions respectively for $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\tau$ oscillations.

The hypothesis of maximal transition rates in ν_e and ν_τ are both considered in the present calculations. Results are reported in table 2 for $\Delta m^2 = 0.72 \cdot 10^{-3}$ eV^2, suggested by theoretical models [7], and in table 3 for $\Delta m^2 = 0.5 \cdot 10^{-3}$ eV^2.

No Oscillation

Processes	DIS	QE	RES
ν_μ CC	40000	2239	2798
ν_e CC beam contamination	400	24	26

Table 1
Expected number of events at the Gran Sasso location without oscillation.(DIS = Deep Inelastic Scattering, QE = Quasi Elastic scattering, RES = Barion Resonance production).

Oscillations

($\Delta m^2 = 0.72 \cdot 10^{-3}$ eV^2)

Processes	DIS	QE	RES
ν_μ CC (residual)	28211	1622	2027
$\nu_\mu \rightarrow \nu_e$ CC	10698	604	755
$\nu_\mu \rightarrow \nu_\tau$	3744	265	294
(B.R. $\tau \rightarrow \mu$)	674	48	53
(B.R. $\tau \rightarrow$ e)	674	48	53
(B.R. $\tau \rightarrow \pi$)	517	37	40

Table 2
Expected number of events at the Gran Sasso location with oscillation. Used parameters are $\Delta m^2 = 0.72 \cdot 10^{-3}$ eV^2 , $\sin^2 2\theta = 1$ (max mixing).

Oscillations

($\Delta m^2 = 0.5 \cdot 10^{-3}$ eV^2)

Processes	DIS	QE	RES
ν_μ CC (residual)	32687	1881	2351
$\nu_\mu \rightarrow \nu_e$ CC	5994	338	423
$\nu_\mu \rightarrow \nu_\tau$	1910	135	150
(B.R. $\tau \rightarrow \mu$)	343	24	27
(B.R. $\tau \rightarrow$ e)	343	24	27
(B.R. $\tau \rightarrow \pi$)	229	16	18

Table 3
Expected number of events at the Gran Sasso location with oscillation. Used parameters are $\Delta m^2 = 0.5 \cdot 10^{-3}$ eV^2, $\sin^2 2\theta = 1$ (max mixing).

3.1. ν_τ appearance test

The kinematical identification of the τ decay which follows the ν_τCC interaction requires excellent detector performances: good calorimetric features together with tracking and event topology reconstruction capabilities. N^OE 's choice to have a high granularity but a relatively moderate mass (6.7 Kton), compensates the loss of statistics with the ability to perform measurements in the τ decay channels. In order to separate ν_τ events from the background two basic criteria, adopted mainly by short baseline experiments, can be used:

1. an unbalanced total transverse momentum due to neutrinos produced by the τ decay;

2. the angular correlation between lepton, hadron and missing momentum in the transverse plane.

$\underline{\tau \to \mu}$: Simulations of ν_μCC and ν_τCC events have been performed in order to reconstruct both the unbalanced total transverse momentum and the angular correlation plots $\phi_{l\to h}$ versus $\phi_{pt\to h}$. Our preliminary results, based on a sample of events subject to DIS processes, show that is possible to define cuts allowing to reduce the ν_μCC background of a factor 10^{-2}. Such a modest rejection factor permits an high τ detection efficiency. Taking into account also cuts in fiducial volume, to ensure containment, and in muon energy, to have clear ν_μCC identification, we obtain 108 μ's survived from 674 $\tau \to \mu$ decay and 29 residual μ's from 40000 ν_μCC interactions.

$\underline{\tau \to \pi}$: The search for an high energy isolated pion, at large angle respect to the hadronic shower, still exploit the capability of the apparatus to have a clear kinematical identification of interactions produced in TRD target.

$\underline{\tau \to e}$: The capability of TRD component to distinguish with high accuracy electrons by pions coming from ν_μNC interactions (the rejection is $\sim$ 1% with five layers crossed [4]) combined with the good energy resolution provided by the scintillating fiber calorimeter allows a satisfactory approach to the study of the electronic channel. In addition, electrons generated in the calorimeter can be detected by studying the topology of the electromagnetic shower (maximum charge, depth, shower profile). The electronic channel has a low background due to the beam contamination $\sim$ 1%, i.e. $\sim 400\nu_e$CC, so the required rejection is smaller than that needed for the muon channel. "Fake" electrons could be produced by the decay of π^0's generated in the hadronic core. Cuts in event topology in the TRD, with the constraint to have no conversion in the first layers crossed and energy E $\geq$ 1.5 GeV, can reduce this background to about 2% of the total number of ν_μCC with π^0's.

3.2. ν_e appearance test

Considerations made in the case of the ν_τ appearance, for the channel $\tau \to e$, about the good electron identification capability and the low background of the electronic final state hold, of course, for the ν_e appearance study too.

4. CONCLUSIONS

The N^OE apparatus new layout, combining a dense and granular calorimeter with a "lighter" detector, the TRD, enriched of layers of massive target, is still a full target detector, but with better performances. There is enough mass for NC/CC measurement, even more particle identification is improved and new analysis channels are open or become cleaner.

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