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PROCEEDINGS SUPPLEMENTS

NOE: Atmospheric and long baseline Neutrino Oscillation Experiment

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A design for a large underground experiment using scintillating fiber calorimeter and tracking system is presented. Its calorimeter has been conceived for atmospheric and LBL neutrino oscillation studies.

1. INTRODUCTION

The search for neutrino oscillation (1),(2) in large volume underground experiments represents an exciting issue in the present scenario of the elementary particle physics.

In the simplified case in which oscillations are assumed to occour between only two neutrino species, the probability of an initial ν_i of energy E_ν being equal to ν_j at a distance L is:

$$P(\nu_i \to \nu_j) = sin^2 2\theta \cdot sin^2[1.27\Delta m^2 L/E_\nu]$$

where Δm^2 in eV^2, L in meters and E in MeV.

Atmospheric neutrino experiments performed in underground laboratories show an anomaly in the contained charged current neutrino interactions, interpreted as a possible signal for neutrino oscillations. In particular in water Cerenkov detectors (Kamiokande(3),Imb(4)) the ratio of ν_μ, ν_e charged current interactions (CC) is smaller than measured in calorimetric experiment (Nusex(5),Frejus(6)). Recently Soudan 2 (7), an iron calorimeter detector, finds a small muon electron ratio, in agreement with the water Cerenkov experiments. The present experimental situation, including results from solar and reactor detector, is far from clear.

This leads to consider the possibility to realize new generation underground experiments exploiting new detector technologies and larger sensitive mass.

In addition the possilbility to produce high flux long baseline neutrino beams, allows to increase the range of investigation in the parameters space beyond the regions indicated by the atmospheric neutrino data.

At present Cern to GranSasso neutrino beam is under study as well as other projects at Fermilab, Brookhaven, Serpukov and KeK.

2. DETECTOR

An optimal detector to measure atmospheric and long baseline neutrinos needs the largest possible target mass, has to be deep underground, located at sufficient distance from the neutrino source, to have a good sensitivity in Δm^2, and requires fine grained read out, so even detail of events can be studied. Moreover particle identification and good energy measurement capabilities are needed.

NOE', a fine grained calorimeter (8), scintillating fibers based, and its muon detector, satisfies, as much as possible, this requirements, providing particle identification, good energy measurement and scattering angles as well. Besides the use of fast detector allows short time coincidence to implement soft trigger to get conseguently low energy threshold as well as a clear signatures of π, K and μ decays.

The detector we propose is modular and easily extendible. Fig.1 shows the NOE' general view. The total length is 41 m. with a total mass of 6 Ktons.

2.1. Calorimeter

The calorimeter is located in the inner part of the detector. Each calorimetric block is 1 Kton (fig.2) (7.9x7.3x8) m^3 composed by Basic Modules (B.M.) (0.13x0.52x8) m^3, 2 tons each, logically divided in four Basic Calorimetric Elements (B.C.E.) (0.13x0.13x8) m^3. The B.C.E. can be realized as follow: the element is made by an 8 meters long bar of iron ore radiator with 330 scintillating fibers as active component randomly positioned inside the bar, and parallel to its axis. Iron ore has two advantages:

•the first is the radiopurity. The very low level of background leads to a few BCE single counting rate.

•the second is that iron ore is pratically cost free.

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The cross section of the element is a square 13 cm side. The weight is about 0.5 ton and the thickness 2 radiation lengths.

In table 1 are reported the main features of the iron ore absorber.

A BCE Prototype has already been constructed and succesfully tested with cosmic rays. The energy resolutions have been evaluated by means of a GEANT Monte Carlo simulation. They are, respectively: $\sigma(E)/E = 0.01 + 0.17/\sqrt{E}$ and $\sigma(E)/E = 0.08 + 0.42/\sqrt{E}$

A possible option exists for BCE element: teflon tubes filled with liquid scintillator could be used as active part. Taking into account the different refractive index and the good light trasmission of the scintillator, this device can work as a liquid fibers.

2.2. Tracking system

The tracking detector, interleaved between vertical calorimetric modules, consists of planes of Limited Streamer Tubes or better Resistive Plate Counters. Strip read out provide X and Y coordinates for each plane. RPC's would permit a better timing helping the implementation of a low energy threshold trigger. Besides many BCE and RPC fast timing measurements along the tracks allow discrimination between μ resulting from π and K decays and direct ν_μ CC production.

2.3. Muon detector

Modules made of tracking detector and iron ore are placed at the end, on top and bottom the apparatus (fig.1,2). The purpose of these 2 Ktons modules is to recover muons produced in ν_μ C.C. interaction in the final part or at the border of the calorimetric blocks.

3. PARTICLE IDENTIFICATION

In general particles identification is obtained by the measurement of any two physics variables which are related via the mass. In our case the capability of the experiment to measure ionization loss (ΔE) and the path (ΔL) in each BCE many times along the track, allows μ separation from e and π, using the $\Delta E/\Delta L$ versus range method. To discriminate between electron and hadron shower further variables can be exploited, as an example the 'over-2mip energy'/E_{tot}. Yet, shape and sampling of the shower development improve the separation down to 10^{-3}.

4. ATMOSPHERIC AND LONG BASELINE NEUTRINO RATES

Atmospheric neutrino interactions in NOE detector allow to extend our sensitivity down to 10^{-4} eV^2 (Fig.3). We expect 250 contained ν_μ, ν_e CC events per year. The expected rates of long baseline neutrino interactions, based on the beam simulation (7), is of about 4700 CC events per year.

6. OSCILLATION SIGNATURES

The presence of $\nu_\mu \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_e$ oscillations could be investigate in different ways:

- Anomaly of the ratio: (no μ events)/(μ events) or apparent "NC"/"CC". The tau decay into hadrons or one electron, will look like a neutral current events giving a muon deficit in the apparatus.
- ν_τ appearance analysing tau decay in lepton channel(e, μ). Two neutrinos are produced, hence some kinematical constraints to cut the background could be applied: acoplanarity, missing energy, missing p_t distribution, lepton energy and timing of the events. For $\tau \rightarrow e$ and $\tau \rightarrow \mu$ decays the background and the relative cuts are shown in table 2.
- $\nu_\mu \rightarrow \nu_e$ appearance as an electron excess.

Gathering 15000 ν_μ CC in 3-4 years, and taking into account cross section, branching ratios and τ signal efficiency, the total rejection power around to 10^{-3}, for both τ decays, leads to a sensitivity in $\sin^2 2\theta$ close to 10^{-2} (Fig.3)

7. CONCLUSIONS

Scintillating fibers seems to be a promising technology to implement massive calorimeter when a fast, granular and quasi isotropic detector is required. The iron ore, used as radiator, is totally inexpensive. NOE' is an all active target and measures oscillation signal in two indipendent ways: the first looking a muon deficit in NC/CC and the second analysing tau decays in lepton channel. A very simple small NOE' could be a 300 tons near detector as a beam monitor. Finally the extreme modularity of the experimental design allows to reduce the apparatus time building.

REFERENCES

1. Z. Maki et al. Prog. Theor. Phys. 28 (1962) 1870.
2. B. Pontecorvo Zh. Eksp. Theor. Fiz. 53 (1967) 1717.
3. K.S. Hirata et al. Phys. lett. B 280 (1992) 146.
4. R.Becker-Szendy et al. Phys. Rev. Lett. 69 (1992) 1010.
5. M.Aglietta et al. Europhys. Lett. 8 (1990) 611.
6. Ch. Berger et al. Phys. lett. B 245 (1990) 305.
7. Proc. of Neutrino 94, Eilat 1994.
8. M.Ambrosio et al. NIM A 363 (1995) 604-610.
9. A.E.Ball et al. CERN/ECP 95-13 (1995)

Table 1
Features of the basic calorimetric element.

% FE (Weight)	BCE W (tons)	X_0 (cm)	λ (cm)	$\langle\rho\rangle$ (gr/cm^3)	$\langle Z\rangle$	E_c (Mev)
70	0.5	5.6	44.5	3.0	15.2	49

Table 2
Background, cuts and rejection power for ν_τ and τ appearance in in leptonic channels.

$\nu_\tau \to \tau \to e\nu\nu$			$\nu_\tau \to \tau \to \mu\nu\nu$		
background	cuts	rejec.pow.	background	cuts	rejec.pow.
beam ν_eCC(1.4%)	miss.p_t, miss.E_{tot}	$0.5.10^{-2}$	beam ν_μCC	miss.p_t, miss.E_{tot}	10^{-3}
π^0 in NC(2%)	Energy, topol.	10^{-2}	π, K decays(μ)	Energy, timing	10^{-3}
D ch . in ν_μCC(10^{-3})	Energy, no μ	10^{-1}	D ch . in ν_μCC(10^{-3})	Energy, one μ	10^{-1}

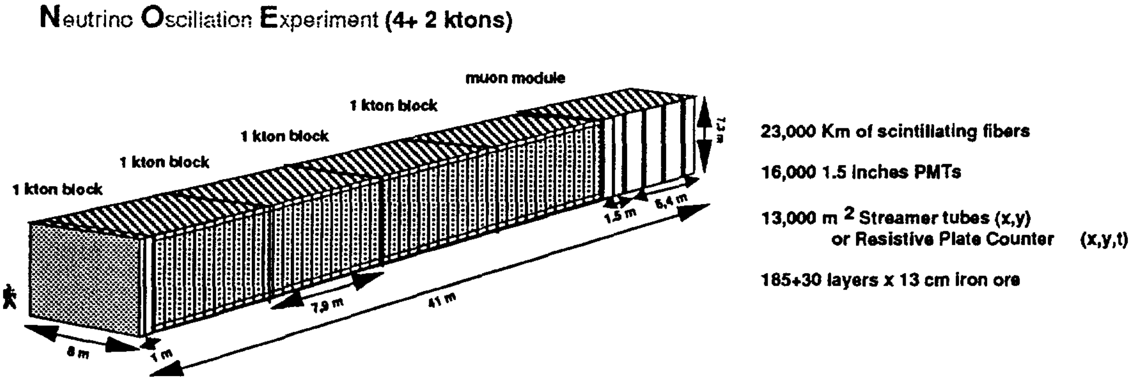

Fig. 1 : General view of NOE detector.

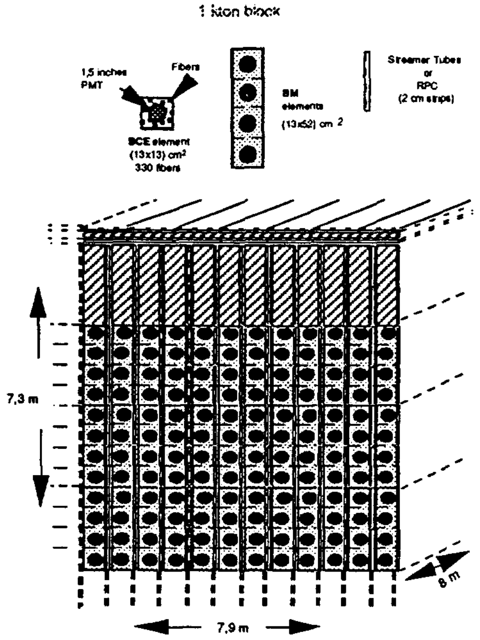

Fig. 2: Calorimeter side view of NOE detector

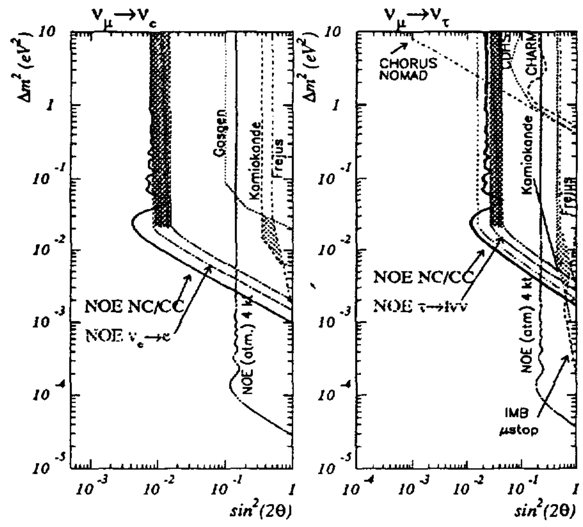

Fig. 3: NOE sensitivity for atmospheric and long baseline neutrinos