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1. INTRODUCTION

On the one hand the problem of neutrino masses and mixing is one of the most fundamental ones in the field of particle and astroparticle physics. On the other hand, indications of possible neutrino masses from non laboratory experiments, in particular the deficit of solar neutrinos and the possibility of a hot component of dark matter suggest a $m(\nu_\tau) \sim 10 \text{ eV}$. The atmospheric neutrino scenario, in which however many uncertainties persist, is also in favour of neutrino oscillations and predicts that neutrinos have mass.

Moreover, a possible evidence for neutrinoless double beta decay[1] is interpreted as a massive Majorana neutrino with $\langle m_\nu \rangle \sim 0.7 \text{ eV}$, and although a straightforward interpretation of the $\beta\beta 0\nu$ signal is that the e-neutrino consists mainly of ν_1 mass eigenstates with $m(\nu_1) \sim 1 \text{ eV}$, it has been shown that solutions which enhance the ν_3 component, such as for example $\langle m_\nu \rangle \simeq |U_{e3}|^2 m_3$, are possible, leading to $m(\nu_\tau) \sim 10 \text{ eV}$ [2].

Perhaps once more we are in the presence of an embarrassment of riches. However it appears extremely interesting that the same value for $m(\nu_\tau)$ is obtained through particle physics and cosmological considerations.

An unprecedented experimental effort is now being developed to search for $m(\nu_\tau)$ and $m(\nu_\mu)$, in the regions indicated, by means of neutrino oscillations: a method which appears to be the most sensitive for detecting small neutrino masses. In analogy to the quarks, the weak interaction eigenstates $\nu_\ell, \ell = e, \mu, \tau$, are described as a linear combination of the mass eigenstates $\nu_i, i = 1, 2, 3$,

through a unitary matrix $\nu_\ell = \sum_{i=1}^3 U_{\ell i} \nu_i$. The probability of neutrinos changing flavour is given by the well known expression (two flavour mixing is considered)

$$P(\nu_e \rightarrow \nu_m) = \sin^2 2\theta \sin^2 \left(1.27 \Delta m^2 \frac{L}{E} \right) \quad (1)$$

with E in GeV , L in km and Δm^2 in eV^2 . The amplitude of the oscillation depends on the mixing angle relating the mass eigenstates to the flavour eigenstates, while their frequency depends on Δm^2 , the difference of the squares of the masses of the neutrino mass eigenstates.

No oscillation evidence has been reported yet from accelerator experiments. These results are usually displayed as exclusion plots in the plane $\sin^2 2\theta - \Delta m^2$, the excluded area being limited mostly by statistical uncertainties and background.

The advantage of searching for neutrino oscillations at accelerators consists mainly in the possibility of tuning the neutrino beam parameters, such as energy and source detector distance, in the region of the neutrino mass being looked for. Moreover accelerators produce collimated and intense $\nu_\mu(\bar{\nu}_\mu)$ beams, with a well understood relative abundance of ν_μ and ν_e .

Assuming that the neutrino masses are related through the see-saw hierarchy and $m(\nu_\tau) \sim 10 \text{ eV}$, the oscillation length $\nu_\mu \rightarrow \nu_\tau$ for a 20 GeV neutrino results from eq. (1) $L_{\mu\tau} \sim 0.5 \text{ km}$, making accelerator experiments rather easy. On the contrary, searching for Δm^2 in the region of 10^{-3} eV^2 , the oscillation length for $\sim 20 \text{ GeV}$ neutrinos becomes $\sim 5 \cdot 10^4 \text{ km}$: nevertheless a number of exiting possibilities for experiments for exploring this region of parameter space have been

proposed.

2. NEW EXPERIMENTS

Two experiments searching for ν_μ appearance in a ν_τ beam are in preparation at CERN-SPS: WA95 known as CHORUS[3] (Cern Hybrid Oscillation Research apparatus) and WA96 known as NOMAD[4] (Neutrino Oscillation Magnetic Detector). Both experiments search for ν_τ with mass in the region of cosmological relevance.

The principle of both the experiments is to search for ν_τ charged current interactions producing a τ lepton to be observed in the detector, followed by τ^- decay. The experiments are planning data taking beginning in April 1994.

The CHORUS experiment to identify the τ decay topology has adopted the high resolution of emulsion technique, the same technique which initiated the particle era.

The detector consists of an emulsion target (800 kg) followed by a tracker. A system of 10^6 scintillating fibres is used to point the tracks of the selected events into the emulsion for computer assisted search for the ν_τ interactions (fig.1).

Figure 1. Expected configuration of a typical $\nu_\tau \rightarrow \tau^- X$ event in the emulsion and scintillating fibre tracker. The average τ^- decay length is of the order of one millimetre.

The signal for a τ decay is a kink in a track extrapolated from the fiber information. The possible background is strongly reduced by the requirement that the τ candidate track before the decay kink balance the P_T of the other tracks in the plane orthogonal to the incident neutrino direction.

NOMAD uses a complementary technique. A very fine-grained target (3 ton), made of 44 drift chambers each consisting of three planes for stereo reconstruction of charged particle tracks is followed by a fine-grained led glass calorimeter for measuring energy and direction of neutral particles. The detector is contained inside the UA-1 magnet and works in a way similar to that of bubble chambers, another glorious technique in the field of particle discoveries; its high resolution permits the identification of the τ signal using only kinematical criteria. Specific requirements on the direction of the missing transverse momentum relative to the hadron jet are very effective in background rejection (see fig.2).

Fig. 3 shows the region of the $\sin^2 2\theta - \Delta m^2$ plane which is explored at 90% confidence level by the combined results of CHORUS and NOMAD for 2.4×10^{19} protons on the target. This suggests that $m(\nu_\tau \geq 50 \text{ eV})$, the region of cosmological interest, can be detected together with a mixing angle $\sin^2 2\theta < 2.3 \cdot 10^{-4}$, a value which includes the expectations based on the analogy quark-lepton $\sin^2 2\theta_{\mu\tau} \simeq \sin^2 2\theta_{cb}$, as well as $\theta_{\mu\tau} \sim \theta_{e\mu}^2$ obtained on rather general ground.

An interesting possibility may exist for going down to $\sin^2(2\theta) \sim 10^{-5}$ by using the ICARUS detector technique of a liquid CH_4 time projection chamber in a 2-tesla magnetic field[5]. The idea here is to use the quasi-free methane protons in a 100 ton detector to determine completely the kinematics of ν_τ -proton collisions, and then reconstruct invariant masses. The τ lepton would appear as a mass peak over a very low background reduced by cuts à la NOMAD.

3. FUTURE PROSPECTS

Another region of interest is the one with $\Delta m^2 \sim 10^{-3} \div 10^{-4} \text{ eV}^2$ and very interesting proposals have been studied to send ν_μ

Figure 2. Distribution in the (ϕ_{mh}, ϕ_{eh}) plane for a) ν_τ CC interactions followed by $\tau^- \rightarrow \nu_\tau e^- \bar{\nu}_e$ decay; b) ν_e CC interactions. The curve defines the selected region for τ^- events.

beams from existing accelerators to the major underground detectors. From CERN to Icarus (three 5K ton liquid argon time projection detectors) in preparation in the Gran Sasso Laboratory[5]. From KEK to Superkamiokande (50 ton water Čerenkov detector) in construction in the Kamioka mine[6]. This experiment, which will look for ν_μ disappearance, will cover the region in the $\Delta m^2 - \sin^2 2\theta$ plane where the atmospheric neutrino effect was found in Kamiokande. From FNAL to Soudan II [7](a modular fine-grain tracking detector with a mass of 1 Kton, possibly upgraded to 5 Kton) located in the Soudan iron mine in Northern Minnesota, some 700 km from Fermilab[7]. The possibility of sending a neutrino

Figure 3. Region of the $(\sin^2 2\theta, \Delta m^2)$ plane excluded by combined results of CHORUS and NOMAD, together with the results of previous searches for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations.

beam from CERN to Superkamiokande, 9000 km away, was also discussed in connection with the possibility of studying matter enhanced neutrino oscillations[5].

Furthermore, there is a proposal for a long baseline experiment from the BNL-AGS to three massive imaging Čerenkov counters at different distances from the ν source[8].

The characteristics of the projects are summarized in Table 1. New long baseline experiments have also been proposed at reactors able to explore the region of very small Δm^2 [9].

Table 1
Long baseline neutrino oscillation projects

Detector	Source	E_p in GeV	Distance in Km	Mass in Ktons	$\Delta m_{\mu e}^2$ *) in eV^2	$\sin^2 \theta_{\mu e}$	$\Delta m_{\mu \tau}^2$ *) in eV^2	$\sin^2 \theta_{\mu \tau}$
ICARUS	CERN	80	730	15	$2 \cdot 10^{-4}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$5 \cdot 10^{-2}$
SUPKAM	CERN	450	8750	50	$5 \cdot 10^{-5}$	$1 \cdot 10^{-4}$		
SUPKAM	KEK	12	250	50	$3 \cdot 10^{-3}$	$5 \cdot 10^{-2}$		
SUDAN2	FNAL	120	710	5	$1 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-2}$
BNL 889	AGS	25	1,3;20	6	$5 \cdot 10^{-3}$	$1 \cdot 10^{-1}$	$5 \cdot 10^{-3}$	$1 \cdot 10^{-1}$

*) Limit for $\sin^2 2\theta = 1$

4. CONCLUSIONS

The oscillation method is one of the most powerful tools for deeply exploring the structure of particles and interactions, as is testified by the spectacular results in the quark sector. The intellectual and technical efforts spent in the new neutrino oscillation experiments should yield positive results; at the very least the deployment of these powerful tools will define new boundaries of paramount importance in particle physics.

REFERENCES

1. A. Piepke, talk given at the "International Europhysics Conference on High Energy Physics", Marseille, July 22 - 28, 1993. In press.
E. Garcia, talk given at this Conference.
2. S.T. Petcov and A. Yu. Smirnov, Preprint IC/93/360 and SISSA 113/93/EP.
3. CHORUS collaboration: N. Armenise et al., CERN-SPSC/90-42 (1990) and CERN-PPE/93-131.
4. NOMAD collaboration: P. Astier et al., CERN-SPSLC/91-48, 53 (1991) and CERN-SPSLC/92-51 (1992).
5. C. Rubbia, CERN-PPE/93-08.
J.P. Revol, Proc. of the "Rencontre de Physique de la Vallée d'Aoste 1993", March 1993.
6. K. Nishikawa, INS-Rep-924-1992.
7. Fermilab P822 Proposal, March 1991.
8. BNL Proposal 889-1993.
9. F. Boehm, Proc. of the "5th International Workshop on Neutrino Telescopes", Venice, March 2-4, 1993, edited by M. Baldo Ceolin, p. 197.