RECENT RESULTS FROM NEUTRINO OSCILLATION EXPERIMENTS AT CERN

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The present results on the $\nu_\mu \to \nu_\tau$ oscillation search by the CHORUS and NOMAD experiments at CERN are summarised. Both experiments have analysed a fraction of the collected samples and no evidence for oscillations is found, leading to a limit in the oscillation probability of $P(\nu_\mu \to \nu_\tau) < 6.0 \cdot 10^{-4}$ at 90% C.L.

1 Introduction

CHORUS and NOMAD are experiments searching for $\nu_\mu \to \nu_\tau$ oscillations in the CERN SPS Wide Band Neutrino Beam. Given the distance from the neutrino source, and the average neutrino energy, both experiments are sensitive to the cosmologically relevant mass range [1] ($\Delta m^2 > 1$ eV^2) and to small mixing angles. The experiments look for the appearance of a ν_τ in a pure ν_μ beam, by detecting the τ^- produced in the CC interactions.

NOMAD uses a purely kinematical technique to select τ candidates decaying to a single electron, a single charged hadron or three charged pions. The results reported at this conference are based on the updated analysis of data from 1995 to 1997 and show significant progress with respect to their previously published ones.[2]

The peculiarity of the CHORUS experiment is the capability of providing the direct observation of the short lived τ track in nuclear emulsion. Recent publications [3,4] report the analysis of a subsample of neutrino interactions, taken in 1994-95, with or without a muon in the final state. In this talk, the updated statistics of the sample characterized by a μ^- in the final state is included.

2 The neutrino beam

The West Area Neutrino Facility (WANF) of the CERN SPS provides a beam of ν_μ with energies mostly above threshold for ν_τ CC interactions.[5] 450 GeV protons are extracted from the SPS accelerator in two 6 ms long spills onto a beryllium target, producing mainly pions and kaons. These secondary particles are magnetically focused and allowed to decay in a 290 m vacuum decay tunnel, followed by an earth and iron shield. Neutrinos originate from these decays in flight and travel an average distance to the detectors of the order of 600 m.

Monte Carlo simulations [6,7] show that the WBB is made of predominantly ν_μ, with a $\bar{\nu}_\mu$ contamination of 5%, and a $\nu_e, \bar{\nu}_e$ contamination at the level of 1%. The estimated ν_τ background [8] is of the order of $3 - 5 \cdot 10^{-6}$ ν_τ charged current interactions per ν_μ charged current interaction, hence negligible. The main ν_μ component has an average energy of the order of 25 GeV.

3 CHORUS

3.1 Apparatus and Experimental Technique

The "hybrid" CHORUS apparatus [6] combines a 770 kg emulsion target with several electronic detectors: a scintillating fiber tracker system, trigger hodoscopes, a magnetic spectrometer, a lead-scintillating fibers calorimeter and a muon spectrometer. Because of its unsurpassed spatial resolution, nuclear emulsion has been chosen as active target and is used both as a τ decay vertex detector and as a high precision tracker. The electronic detectors predict the track location and slope into a set of interface emulsion sheets (ES), which connect the reconstructed event to the tracks measured in the target emulsion. The scanning of both kind of emulsion plates is performed by fully automatised microscopes.[3,4]

All tracks with a reconstructed negative charge and a momentum in the range $0 \leq p_h \leq 20$ GeV/c and $0 \leq p_\mu \leq 30$ GeV/c – for hadrons and muons respectively – are searched for in the ES and then followed upstream in the target emulsion. The last plate at the exit of which the track is observed is defined as the vertex plate. At this plate, different scanning procedures are applied to select the events potentially containing a decay topology (kink). A computer assisted eye-scan is then performed on the selected events to assess the presence of a secondary vertex and measure accurately its topology. A full kinematical reconstruction is possible for interesting events, by means of dedicated measurements in emulsion, complemented by those provided by the electronic detectors, leading to τ candidates or identified background.

3.2 Results

The scanning results [9] are summarised in table 1. No τ^- decay candidate has been found satisfying the selection criteria.

The mean efficiency of the scan-back procedure is found to be $\sim 32\%$ for 0μ and $\sim 42\%$ for 1μ events, the difference reflecting the poorer quality of the hadron track predictions at the interface ES. The kink finding efficiency,

Table 1: Current status of CHORUS analysis.

	1994	1995	1996	1997	All
Pot/10^{19}	0.81	1.20	1.38	1.67	5.06
Main triggers	388k	547k	617k	719k	2271k
1μ events	66911	110916	129669	151105	460k
0μ events	17731	27841	32548	37929	120k
1μ scanned so far	63%	45%	56%	0%	36%
0μ scanned so far	50%	45%	0%	0%	19%
1μ located so far	18286	20642	30128	0	68156
0μ located so far	3401	3805	0	0	7206

$\epsilon_{\rm kink}$, has been evaluated by Monte Carlo and experimentally. The experimental check included the detection of secondary hadron interactions in neutrino events and the analysis of part of the dimuon sample collected in 1995 and 1996. Both analyses yield results in agreement with Monte Carlo expectations.[9]

In absence of τ candidates, the limit on the $\nu_\mu \to \nu_\tau$ oscillation probability can be calculated from the knowledge of the expected background and the signal efficiencies. Main sources of background are the production of charmed hadrons in antineutrino CC interactions, where the primary lepton is not identified, and the much more dangerous hadronic "white kinks", defined as 1-prong nuclear interactions with no heavily ionizing tracks and no evidence for nuclear break up. Both contributions have been evaluated by means of Monte Carlo techniques and experimental data and amount to 0.5 expected events (from the second source, the first being negligible).

In the usual approximation of a two-flavour mixing scheme, and taking into account the total systematic error of 17%, the 90% C.L. upper limit on the oscillation probability is $P(\nu_\mu \to \nu_\tau) < 6.0 \cdot 10^{-4}$.

4 NOMAD

4.1 Detector and Analysis Strategy

The NOMAD detector[7] consists of an active target of 44 drift chambers, with a total fiducial mass of 2.7 tons, within a 0.4 T dipole magnetic field. The chambers serve the double role of providing the target mass and the measurement of the momenta of the charged particles produced in neutrino interactions. Electron identification is achieved with a transition radiation detector, followed by a preshower and a lead-glass electromagnetic calorimeter. External to the magnet there are a hadronic calorimeter and two muon detection stations.

The resolution of the drift chambers is not sufficient to observe the τ candidate directly, as in the case of CHORUS. The ν_τ CC interactions are searched for by looking for a statistical excess of events with τ-like kinematical properties.[2] The so called "kinematical method" relies on two main criteria of signal to background separation: the isolation of the candidates from the hadronic jet, which provides a powerful tool to discriminate between hadrons coming from the τ decay and those produced in a ν_μ NC interaction; and the different kinematical configuration, in the plane perpendicular to the incoming neutrino direction, expected from the background ν_e and ν_μ CC interactions as compared to the τ leptonic decays.

NOMAD uses the likelihood technique to combine all the relevant kinematical variables. The logarithm of the ratio of likelihood functions for signal and background describes the degree of separation between them. It is clear that a level of background rejection of the order of 10^5 can only be achieved by the use of techniques that can simulate the data over five orders of magnitude. On the other hand, neither the neutrino interaction generator nor the modelling of the detector can be trusted to predict the behaviour of the data to such an accuracy. For this reason, an extensive use is made of various *data simulators*, obtained from the data themselves, to correct Monte Carlo predictions. In practice, one starts from two samples of ν_μ CC, a real (DS) and a simulated one (MCS). In both cases the muon is removed and substituted by either a τ decay, an electron or nothing; thus one obtains samples of fake signal, ν_e CC and NC. The Monte Carlo prediction of the efficiency for each sample can now be corrected using the ratio of DS to MCS, which takes into account all the hadronic effects that may have not been correctly described by the Monte Carlo.

4.2 Results

The updated NOMAD analysis [10] presented here is characterized by the application of a "blind box" approach. A blind box is defined around the region where the signal is expected to appear and it is not opened until the analysis can predict the backgrounds outside, as well as in the τ^+ search (not expected from oscillations). In table 2 the τ^- candidates after box opening are reported, together with the expected background and with the number of τ's that would be observed in case of full oscillation. The data shown correspond to about 940,000 ν_μ CC interactions and refer to the above described analyses for all cases in which a ν_τ undergoes a deep inelastic interaction (DIS). Low multiplicity analyses (LM) have not been updated since the published result.[2]

Table 2: Current status of NOMAD analysis.

Channel	Data	Est. Bakg.	$N_{\rm obs}$	N_τ
$\tau \to e^- \nu_\tau \bar{\nu}_e$ DIS	95-97	6.6 ± 0.8	5	2904
$\tau \to e^- \nu_\tau \bar{\nu}_e$ LM	95	$0.5^{+0.6}_{-0.2}$	0	218
$\tau \to h^-(\mathrm{n}\pi^0)\nu_\tau$ DIS	95-97	4.5 ± 1.2	5	2031
$\tau \to h^-(\mathrm{n}\pi^0)\nu_\tau$ LM	95	$0.1^{+0.3}_{-0.1}$	1	198
$\tau \to \rho^- \nu_\tau$ DIS	95-97	$5^{+1.2}_{-0.9}$	5	1900
$\tau \to \pi^-\pi^-\pi^+\nu_\tau$ DIS	95-96	7.0 ± 2.7	5	1011
$\tau \to \pi^-\pi^-\pi^+(\mathrm{n}\pi^0)\nu_\tau$ LM	95	$0.4^{+0.6}_{-0.4}$	0	108
Total		24.1 ± 3.3	21	8370

The results show no evidence for an oscillation signal so a limit on the oscillation probability can be set, based on the unified procedure which is now proposed by the Particle Data Group:[11] $P(\nu_\mu \to \nu_\tau) < 6 \cdot 10^{-4}$ at 90% C.L.

5 Concusions and Outlook

CHORUS and NOMAD have set comparable limits for $\nu_\mu \to \nu_\tau$ oscillations based on the partial statistics so far analysed. A 90% confidence limit exclusion plot in the $\Delta m^2 - \sin^2 2\theta$ plane can be derived for each result and is shown in figure 1. At large Δm^2 the present (identical) limits on the mixing angle are $\sin^2 2\theta_{\mu\tau} < 1.2 \cdot 10^{-3}$.

Analysis is in progress for both experiments. CHORUS data taking on the neutrino beam has finished in 1997. NOMAD has also taken data during 1998 which, with the addition of the channels that have not been updated for the 1996 and 1997 data, will provide further improvement in their sensitivity. The scanning of CHORUS full statistics will lead to a factor 3 improvement in the limit. Furthermore, a second phase of the analysis, with better efficiencies, larger statistics and faster emulsion scanning, has started with the aim of reaching the design sensitivity ($P_{\mu\tau} < 1 \cdot 10^{-4}$).

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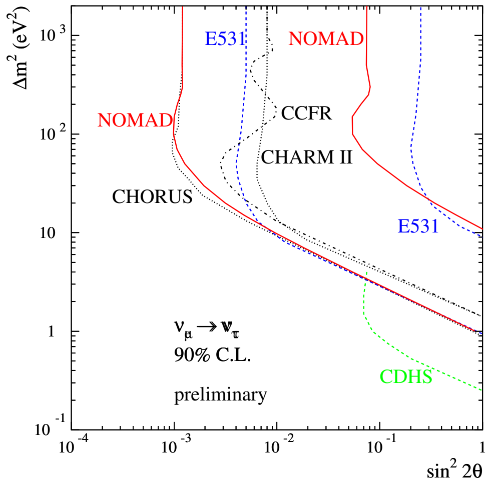

Figure 1: CHORUS and NOMAD 90% C.L. exclusion plot for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations.

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