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Final results of the search for ν_μ to ν_τ oscillations by CHORUS

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Abstract. The final CHORUS results of the search for tau-lepton decays and the analysis of the final statistics in terms of ν_μ - ν_τ oscillation will be presented.

1. Introduction

The CHORUS experiment was designed to search for $\nu_\mu \rightarrow \nu_\tau$ oscillations through the direct observation of charged-current(CC) interactions $\nu_\tau N \rightarrow \tau^- X$, followed by the decay of the τ lepton in nuclear emulsions. The search is sensitive to very small mixings if the mass difference is of the order of a few eV ($\Delta m_{\mu\tau}^2 \geq 1eV^2$). Massive neutrinos in this range have been proposed as candidates for the hot component of the dark matter in the universe. This consideration constitutes the main motivation of the experiment.

The experiment was performed in CERN wide Band neutrino beam, which contains mainly ν_μ with a contamination of ν_τ well below the level of sensitivity that can be reached by this experiment. The ν_μ component of the beam has an average energy of 27 GeV. The CHORUS detector, described in detail in reference [1], is a hybrid set-up that combines a nuclear emulsion target with various electronic detectors such as trigger hodoscopes, a scintillating fiber tracker system, a hadron spectrometer, electromagnetic and hadronic calorimeters, and a muon spectrometer. Neutrino interactions occur in a target of nuclear emulsion, whose exceptional spatial resolution and hit density allow a three dimensional 'visual' reconstruction of the trajectories of the τ lepton and its decay products.

The collaboration has already reported limit on $\nu_\mu \rightarrow \nu_\tau$ oscillation obtained from first phase analysis of neutrino interactions. The analysis of the final statistics in terms of ν_μ - ν_τ oscillation will be presented.

2. Oscillation analysis

During 4-years of operation the emulsion target has been exposed to the neutrino beam for an integrated intensity which corresponds to 5.06×10^{19} protons on target.

The search for ν_τ interactions has been performed for the following decay modes of the τ lepton: $\tau^- \rightarrow \mu^- \nu_\tau \bar{\nu}_\mu$ (C1) , $\tau^- \rightarrow h^- (n\pi^0) \nu_\tau$ (C1) and $\tau^- \rightarrow h^- h^+ h^- (n\pi^0) \nu_\tau$ (C3).

The information of the electronic detectors has been used to define two data sets, the 1μ and 0μ samples distinguished by the presence or absence of one reconstructed muon of negative charge. For each sample a few kinematical selections are applied to reduce the scanning load,

while keeping a high sensitivity to the decay modes of the τ lepton. The resulting $1\mu(0\mu)$ sample consists of 477,600(335,398) events with a reconstructed vertex in emulsion.

For the selected events, the track trajectories reconstructed in the fiber trackers are used to guide the scan in the pair of changeable sheets immediately following the stack containing the interaction vertex using track segments reconstructed in the most upstream $100\mu\text{m}$ of each plate, until it disappears. The corresponding plate is defined as the vertex plate. In total $\sim 150,000$ 1μ and $\sim 37,000$ 0μ events were located in nuclear emulsions. Once the vertex plate is identified, a very fast scanning system is used to perform a detailed analysis of the emulsion volume around the vertex position, recording for each event all track segments within a given angular acceptance we refer this type of scanning as 'NetScan' data taking. The procedure is described in detail in reference [2]. This technique has been applied to 0μ sample for the decay of a τ lepton into hadrons. This method has a much higher efficiency for the hadronic decays of τ lepton than previous methods used. The detail of analysis of 1μ sample for the decay of a τ lepton into muon can be found in reference [3].

Track segments collected in the NetScan volume are analysed off-line to reconstruct the complete event topology. To select interesting decay topologies and reduce the amount of fake secondary vertices a set of selection criteria were applied. The selection criteria select ~ 2500 events as having a decay topology for visual inspection. A secondary vertex found in the emulsion is tagged as a decay vertex if no activity is observed at the decay point and if the number of outgoing particle is consistent with charge conservation.

The efficiency of these procedures, the evaluation of the background, and the choice of the final selections were evaluated from large samples of events generated according to the relevant processes, passed through a GEANT3 [4] based simulation of the detector response. The output was then processed through the same reconstruction chain used for the data. The efficiency for the detection of ν_τ interactions has been split into two terms; the first one, the acceptance is given by efficiency of the reconstruction of the neutrino interaction by the electronic detectors and of the location in the emulsions. The second term, NetScan efficiency, is the efficiency of decay finding in the emulsions. In order to evaluate the NetScan efficiency, realistic conditions of the track densities in the emulsion have to be reproduced. These are obtained by merging the emulsion data of the simulated events with real NetScan data which do not have a reconstructed vertex but contain tracks which stop or pass through the NetScan volume. The combined data are passed through the same NetScan reconstruction and selection programs as used for real data.

The basic requirements adopted to isolate τ decay candidates are a selection, p_T larger than 250 MeV, on the transverse momentum of the decay particle with respect to the parent direction and maximum length for the decay path. An unavoidable background to $\nu_\mu \rightarrow \nu_\tau$ oscillation is caused by the presence of prompt ν_τ 's in the neutrino beam. It is less than 0.1 events and has been neglected. Apart from this, one source of background common to all the decay channels of the τ is due to the production of positive (negative) charmed particles from $\nu_\mu(\bar{\nu}_\mu)$ CC interactions. These events constitute a background if the primary lepton is not identified.

For the decay into single hadron the largest background rate is due to so-called hadronic white kink (WK), defined as 1-prong nuclear interactions with no heavily ionizing tracks or other evidence for nuclear break up. This background can be reduced by exploiting the difference of its kinematical properties with respect to those the τ signal. A useful quantity to reject background events is the angle $\Phi_{\tau-h}$ in the plane transverse to the beam axis, between the direction of the parent candidate measured in emulsion, and the hadronic showers axis. The optimization of the selection has been done maximizing the sensitivity to the oscillation, by computing the average limit that would be obtained with the given set of selections. In Table 1 a summary of the results of the background computation is reported. Table 1 gives the calculated number of background events and number of observed events with various kinematical selections. In all cases, the

Table 1. Summary table of the expected background events. The observed number of events is also shown, together with the maximum number ν_τ observable events.

Sample	background	Data	N_{max}
Phase II: $0\mu C1$	51.5 ± 9.7	59	9447
Phase II: $0\mu C3$	51.0 ± 12.0	48	4974
Phase I: $1\mu C1$	0.100 ± 0.025	0	5014
Phase I: $0\mu C1$	0.300 ± 0.075	0	526

number of observed events is consistent with the expected background. The maximum of the sensitivity is obtained through a compromise between low background and high efficiency for ν_τ detection. To illustrate that efficiency the last column of Table 1 also displays N_{max} , the number of ν_τ events which would be observed in case all incident ν_μ had converted into ν_τ .

In summary, no τ decay is found, neither in the 1μ sample nor in the 0μ sample once the best set of selections is applied. The null observation is used to set limits on oscillation parameters. The limit on the $\nu_\tau \rightarrow \nu_\tau$ oscillation probability obtained $P_{\mu\tau} \leq 1.72 \times 10^{-4}$ at 90% C.L. In a two-family oscillation formalism, the result can be expressed as an exclusion plot in the parameter space $(\sin^2\theta_{\mu\tau}, \Delta m^2)$ as shown in figure 1. The sensitivity [5] of the experiment has been obtained as $S_{\mu\tau} = 2.5 \times 10^{-4}$. In the absence of signal events, the probability to obtain an upper limit of 1.72×10^{-4} or lower is 28%.

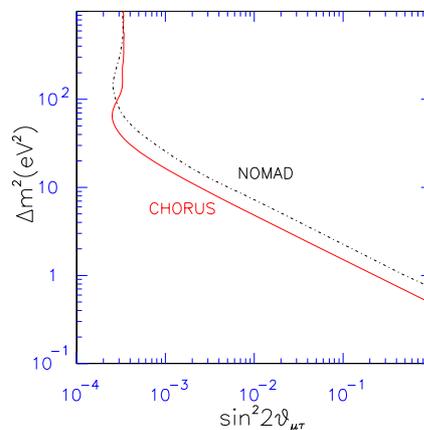


Figure 1. The final CHORUS limit on $\nu_\mu \rightarrow \nu_\tau$ oscillation compared to the NOMAD result.

References

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