CHORUS search for $\nu_\mu \to \nu_\tau$ oscillation

P. Zucchelli for the CHORUS experiment

A first analysis of the complete set of data collected by the CHORUS experiment is presented. No τ candidate has been found, leading to a $\nu_\mu \to \nu_\tau$ mixing excluded down to $sin^2 2\theta_{\mu\tau} = 6.8 \times 10^{-4}$ for large Δm^2 (90% C.L.) and extending the search into the region of Δm$^2 \approx 1\ eV^2$ of cosmological interest. A second *emulsion data-taking* is being performed to improve the oscillation search and to add significant results in the charm physics sector.

1. Introduction

the CHORUS experiment is designed to search for $\nu_\mu \to \nu_\tau$ oscillation through the observation of charged current interactions ν_τ N $\to$ τ^- X, followed by the decay of the τ lepton. It makes use of nuclear emulsion techniques, that allow a three dimensional *visual* reconstruction of the characteristic decay topology of the τ lepton. In a scheme where the mass difference is essentially coinciding with the ν_τ mass, the latter becomes a good candidate for the hot component of the Dark Matter of the Universe. This consideration constitutes the main motivation of the experiment.

2. The experimental setup

The *hybrid* setup of CHORUS, that run on the CERN Wide Band Beam, is described in detail in Ref.[1]. It is composed of an emulsion target, a scintillating fibre tracker system, trigger hodoscopes, a magnetic spectrometer, a lead-scintillator calorimeter and a muon spectrometer.

The nuclear emulsions act as the target and, simultaneously, as detector of the interaction vertex and the decay point of the τ lepton. The scintillating fibre trackers, interleaved between four emulsion stacks, reconstruct the trajectories of the charged particles with a high angular and spatial accuracy and allow the location of the neutrino interactions inside the emulsion target.

3. Data selection

The current search for ν_τ interactions is aiming to detect the decay modes $\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$ and $\tau^- \to$ h$^-(n\pi^0)\nu_\tau$. Both decay channels exhibit in the emulsions a *kink* topology: a track from the neutrino interaction vertex showing a change in direction after a short path (typically of the order of 1 mm). The information of the electronic detectors has been used to define two data sets, the 1μ and 0μ samples.

An event belongs to the 1μ sample if it contains one negative muon with momentum smaller than 30 GeV.

The 0μ sample contains events where no muon is found and at least one track corresponding to a particle of negative charge and momentum in the 1 to 20 GeV interval.

The negative track, hadron or muon, selected as a candidate for τ daughter, is subject to additional cuts in angle and position (fiducial volume); the remaining samples consist of 355,395 and 85,211 events respectively for the 1μ and 0μ data sets.

4. Scanning procedures: Vertex location and Decay search

The automatic emulsion scanning procedure relies on computer controlled microscopes equipped with CCD cameras and fast processors[2]. The location of the emulsion plate containing the interaction vertex is based on the following back of the selected negative tracks, assumed to be the τ daughters, until they disappear. The corresponding emulsion plate is defined as the vertex plate, since it should contain the primary neutrino vertex, or the secondary (decay) vertex, or both. 143,732 1μ and 20,081 0μ events have been located with this technique.

Automatic microscopes can also select the events potentially containing a decay topology

Table 1
Summary table of the expected background events for different selections[3]. The observed number of events is also shown, together with the corresponding maximum number of ν_τ observable events

		charm($\nu + \bar{\nu}$)	White Kink	Total	Observed	N_τ^{max}
1μ	$L_k < 5$ plates	0.1	-	0.1	0	5,014
0μ	$L_k < 3$ plates	0.7	2.6	3.3	4	2,791
	$(L_k(p_h))_{80\%}$	0.5	1.7	2.2	1	2,537
	$(L_k(p_h))_{80\%}$ and $\Phi_{(\tau-H)} > 90^o$	0.3	0.8	1.1	0	2,004

(kink). Different algorithms have been applied as a result of the progress in the scanning procedures and microscopes performances. The most relevant one, called *parent search*, consists in scanning the vertex plate in order to find a track crossing, within a small tolerance, the direction of the daughter candidate. The method provides about 85% of the total kink finding efficiency. A total of 125,000 1μ events and all the 0μ events have been analysed with this method, and 5,006 1μ and 1,823 0μ have been selected for human computer-assisted inspection.

5. Efficiency and backgrounds for the detection of ν_τ interactions

The efficiency for the detection of ν_τ interactions can been split into two terms: the first one is the acceptance, given by the efficiency of the electronic detectors reconstruction and vertex location. The second term is the efficiency of the kink detection in the emulsions. Qualitatively, the error on the absolute value of the acceptance cancels in the **ratio** of *observed* ν_τ to *observed* ν_μ events, used to compute the oscillation probability. More critical is the determination of kink detection efficiency. For that parameter an experimental check of the calculated value is possible by using the data itself, as reported in details in Ref. [3].

The main background, is constituted by the so-called hadronic *white kinks*, defined as 1-prong nuclear interactions with no heavily ionising tracks or other evidence for nuclear break up (blobs or Auger electrons).

This background is measured inside CHORUS by looking for kinks at a distance between primary and secondary vertex outside the τ signal region. Using this data, 2.6±0.8 white kink events are expected with an apparent decay path (L_k) smaller than three plates (typical decay pathlength of a τ). This background can be further reduced by kinematical selection. Several cuts on L_k have been considered and optimised by looking to the sensitivity of the experiment, independently of data in the signal region. In Table 1 a summary of the results is reported, for different kinematical cuts described in details in reference [3]. The table gives the calculated number of background events, the number of observed background events with various cuts and the ν_τ detection efficiency expressed as maximum number of detectable τ in the hypothesis all ν_μ are indeed ν_τ. The final selection, chosen by sensitivity optimisation, also corresponds to zero observed events.

6. Limits on $\nu_\mu \rightarrow \nu_\tau$ oscillation

Within a two flavours mixing scheme, appropriate integrations are performed to take into account the effect of energy dependent cross-sections, acceptances and efficiencies. Fig.1 shows the dependence from the neutrino energy of the global efficiency on ν_τ interactions. It includes the effects of the full analysis chain, and explains the different exclusion curves of the CHORUS and NOMAD[4] experiments.

For the determination of N_τ, i.e. the upper limit on the number of ν_τ candidates, we have used the method proposed by T. Junk [5]. The overall 90% C.L. upper limit on the number of τ decays is 2.4, based on the null observation in the two independent channels, and takes into account the systematic error on efficiencies estima-

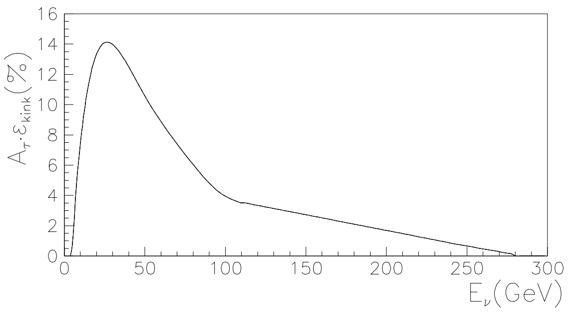

Figure 1. *Total efficiency for ν_τ interactions detection as a function of the neutrino energy.*

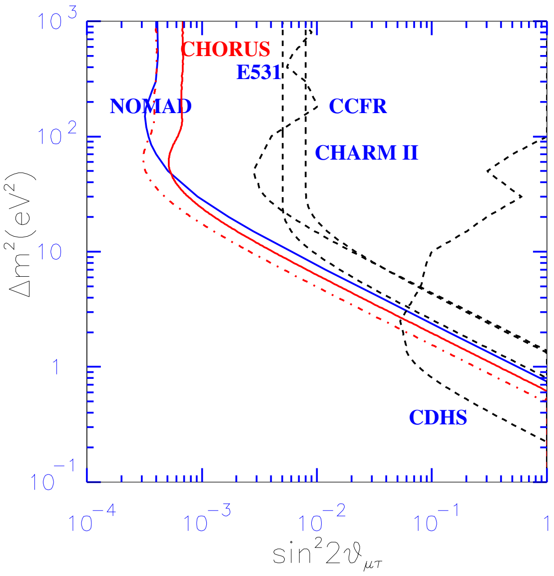

Figure 2. *Present limit on $\nu_\mu \to \nu_\tau$ oscillation compared to the results of other experiments; the meaning of the second CHORUS curve (dash–dotted) is explained in the text.*

tion and normalisation. The 90% C.L. excluded region in the $(sin^2 2\theta_{\mu\tau}, \Delta m^2)$ parameter space is represented in Fig.2. Full mixing between ν_μ and ν_τ is excluded at 90% C.L. for $\Delta m^2 > 0.6\ eV^2$. Large Δm^2 values are excluded at 90% C.L. for $sin^2 2\theta_{\mu\tau} > 6.8 \times 10^{-4}$.

Fig.2 also displays the recent NOMAD result [4]. The two results should not be compared directly, since the statistical treatment of the data is different (Unified Approach,[6]). The same technique, applied to our data, gives an upper limit of 1.4 events, resulting in a much more stringent limit; this behaviour has already been questioned in the literature [7,8]. We believe that an upper limit of 2.4 events, equally well founded statistically, gives information more directly connected to the common use of an exclusion plot. In addition, results close to an upper limit of 2.4 are obtained using techniques other than the one proposed by Junk (see e.g. [7,8]).

For sake of comparison with the NOMAD result, the curve corresponding to the Unified Approach upper limit is also reported in Fig.2.

7. Outlook

In the future the sensitivity of the experiment will be extended to reach its design value ($P_{\mu\tau} = 1 \times 10^{-4}$). Primary factors to achieve this goal are the substantial progress in the automatic scanning speed and various improvements in the reconstruction programs. This will allow to increase the vertex location efficiency and to perform a detailed analysis of the located events, with a consequent increase of the kink detection efficiency as well.

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