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THE CHORUS NEUTRINO OSCILLATION SEARCH EXPERIMENT

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Abstract

The CHORUS experiment has successfully finished run I (320 000 recorded ν_μ CC in 94/95) and performed half of run II (225 000 ν_μ CC in 96). The analysis chain was exercised on a small data sample for the muonic τ decay search using for the first time fully automatic emulsion scanning. This pilot analysis, resulting in a limit $\sin^2(2\theta_{\mu\tau}) \leq 3 \cdot 10^{-2}$, confirms that the CHORUS proposal sensitivity ($\sin^2(2\theta_{\mu\tau}) \leq 3 \cdot 10^{-4}$) is within reach in two years.

Talk given by Christian Weinheimer
at the 28$^{\text{th}}$ *International Conference on High Energy Physics,*
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1 Introduction

Whether or not neutrinos have mass is still one of the most interesting questions of modern-day particle physics, with important implications even for other disciplines, such as cosmology.

An indirect, but sensitive way to search for non-zero neutrino masses, is to look for evidence of neutrino oscillations. The oscillation probability can be expressed in a simplified model with only two weak eigenstates, here ν_μ and ν_τ, which are superpositions of two mass eigenstates with masses m_1 and m_2, as:

$$\mathrm{P}(\nu_\mu \to \nu_\tau) = \sin^2(2\theta_{\mu\tau}) \cdot \sin^2\left(\frac{|\mathrm{m_1}^2 - \mathrm{m_2}^2| \cdot L}{4E}\right) \tag{1}$$

with mixing angle $\theta_{\mu\tau}$, ν energy E, and source detector distance L.

The CHORUS experiment is currently searching for $\nu_\mu \to \nu_\tau$ oscillations by looking for the appearance of ν_τ charged current (CC) interactions using a nearly pure ν_μ beam. The ν_τ CC interactions are characterized by the subsequent decay of the produced τ lepton. The final-state ν will give rise to a "kink" topology between the τ track and those of its daughters. In addition the(se) undetected ν will create an unbalance in the measured transverse momentum. The CHORUS experiment is capable, in addition to determining the event kinematics, of observing directly the kink in the τ decay, resulting in a nearly background-free experiment. CHORUS covers 82% of all τ decays, by looking for the following decay modes:

$$\begin{array}{ll} \tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau & BR = 18\% \\ \tau^- \to h^-(n\pi^0)\nu_\tau & BR = 50\% \\ \tau^- \to \pi^-\pi^+\pi^-(n\pi^0)\nu_\tau & BR = 14\% \end{array} \tag{2}$$

After a brief description of the CHORUS experiment and its current status in section 2, a first pilot analysis on the muonic τ decay is presented in section 3. Sections 4 and 5 give an outlook on future improvements and the conclusion.

2 The CHORUS experiment

2.1 The CERN wide-band ν beam

The CERN wide-band ν beam [1] is mainly composed of ν_μ, with an average energy of 27 GeV. The $\bar{\nu}_\mu$ contamination amounts to a few per cent, the fraction of ν_e and $\bar{\nu}_\mathrm{e}$ is of the order of 1 %. The contribution of prompt ν_τ gives rise to a fraction of ν_τ CC interactions of a few 10^{-6}, relative to ν_μ CC interactions. The mean distance between source and detector is 600 m.

2.2 The experimental setup

To recognize the short flight path of the τ lepton ($c\tau_\tau = 87\mu$m, $\gamma_\tau \approx \mathcal{O}(10)$) and its decay topology the CHORUS experiment is using 800 kg of photographic emulsion as active target, giving a unique 3-dimensional spatial resolution of 1 μm. The emulsion target is divided into 4 stacks of photographic emulsion with an area of 1.4×1.4 m^2, each consisting of 35 plates. A plate is composed of a 100 μm thick plastic base with 350 μm thick emulsion layers on both sides. To find the ν interactions in the emulsion after exposure to the ν beam, 8 scintillating fibre tracking detectors [2] are installed between and downstream of the 4 stacks (see fig. 1). Three interface emulsion sheets (c.s. and. s.s.) are placed between each emulsion stack and the trackers. After having found a track in

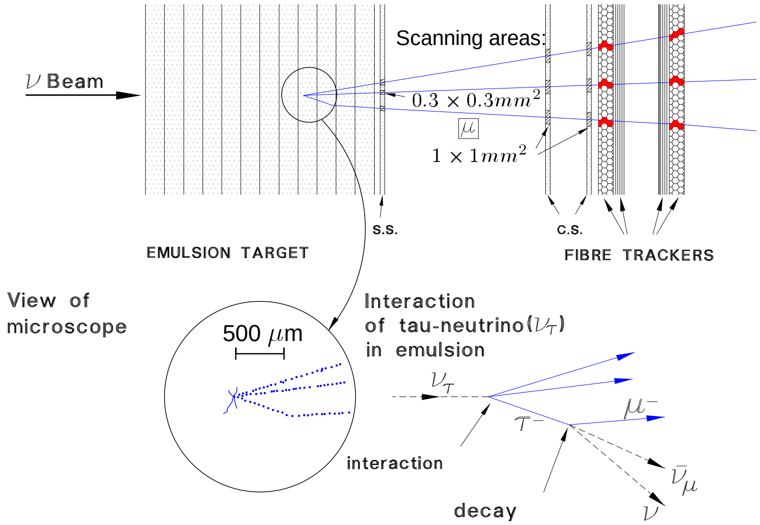

Figure 1: A fraction of the target region consisting of one emulsion stack, the three interface emulsion sheets further downstream (s.s. and c.s.) and one scintillating fibre tracker detector composed of 4 different projections. A τ-kink from a ν_τ CC interaction is illustrated, which would be only visible under the microscope.

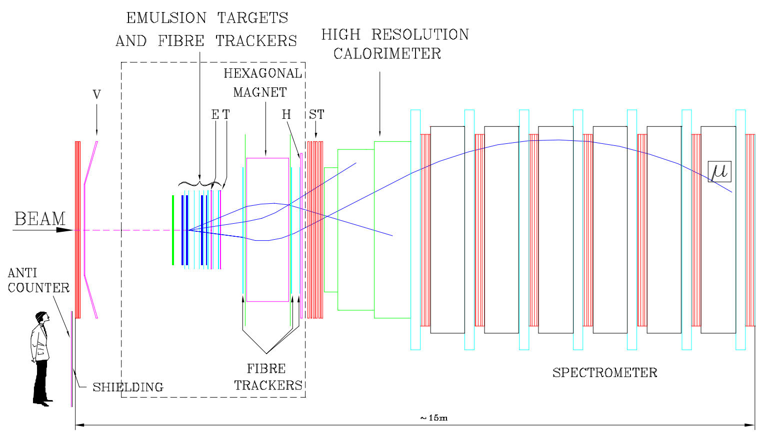

Figure 2: The CHORUS hybrid detector

the most downstream interface sheet (c.s.) by using the tracker prediction (accuracy at c.s.: $\sigma_x \approx 200\ \mu$m, $\sigma_\theta \approx 3$ mrad) the more precise interface emulsion information is used for all the following extrapolation steps.

To enrich the τ-like events by kinematical cuts and to distinguish ν_τ CC interactions from background events also having a short flight path decay (*e.g.*, charmed mesons) the target region is followed downstream by a hadron spectrometer using a toroidal air-core magnet [4] instrumented in front and behind with scintillating fibre tracker planes (Δp/p ≈ 0.3 at 5 GeV), a high resolution lead/scintillating fibres "spaghetti" calorimeter [3] (ΔE/E $= 32\%/\sqrt{(\mathrm{E/GeV})}$ for hadrons), and a muon spectrometer (Δp/p $\approx 10-15\%$). Fig. 2 shows the CHORUS hybrid detector.

2.3 The present status of CHORUS

CHORUS run I consists of data taken from April to October of 1994 and 1995, corresponding to 120 000 and 200 000 ν_μ CC events in the emulsions. CHORUS run II

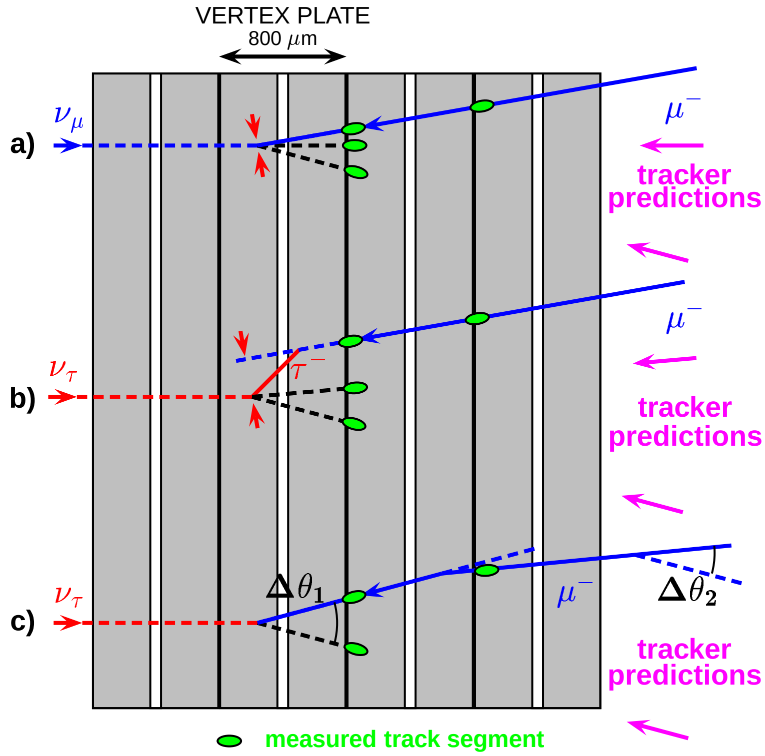

Figure 3: (a) normal ν_μ CC event, (b) ν_τ interactions with τ decay inside the primary vertex plate ("short decay length"), and (c) τ decay further downstream ("long decay length"). The track followed upstream to the vertex is assumed to be the μ^- in all 3 cases.

was started in April 1996 with four new emulsion stacks and some detector improvements. The first of the two years, recently finished, of run II gave 225 000 ν_μ CC events. After the first year of running, emulsion stack 4 was removed (and replaced) in order to start the oscillation search. The analysis of part of these data is the "pilot analysis" described below.

3 The pilot analysis

The idea of the pilot analysis was to exercise the analysis chain on a small but unbiased data sample. This is done for the muonic τ decay only, without applying any kinematical preselection.

The signal of an observed decay $\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$ is characterized by a short flight path kink, of which the kink-daughter is a μ^- and no other lepton originates from the primary vertex [1)].

The background, mainly from muonic charm decays, is estimated to be a few 10^{-6} and can therefore be neglected.

The pilot analysis is done as follows:

1. **Reconstruction of events:** Using the data recorded by the electronic part of the hybrid detector, the neutrino events are reconstructed, the candidates with an identified μ^- are selected, and the track positions at the level of the interface emulsion are predicted.

[1)] To limit the number of events, which have to be rescanned semiautomatically (see below) only muons with $p_\mu < 30\ GeV$ are considered, This cut has an efficiency of about 90% for genuine ν_τ interactions.

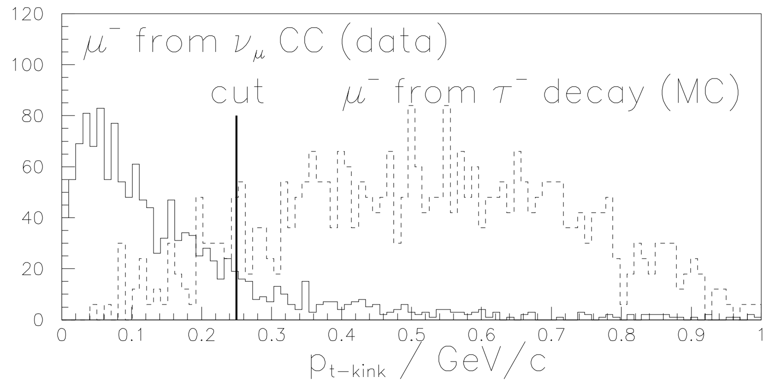

Figure 4: Distribution of p_t-kink values measured by automatic scanning in the "long decay length" analysis and the MC expectation for τ decays. The contribution of 16% of events above the marked cut at 250 MeV is due to uncertainties of the angular measurement, which vanish completely after remeasuring with a more precise method.

2. **Finding of ν vertices:** At least one reconstructed track is searched in the interface emulsion sheets and, if found, is followed upstream in the emulsion target by searching its entry points in the successive plates, until it stops. At the last bulk emulsion plate in which the track is observed, the so-called "vertex plate", the location of the ν vertex is confirmed by looking for all other tracks predicted by the tracking detectors as indicated in fig. 3a [2]. The scanning steps are done fully automatically with computer controlled microscopes looking for track segments inside the emulsion, a technique further developed from an earlier approach [6].
3. **τ-kink analysis:** Two topologies have to be checked.
   "Short decay length" analysis: To check the possibility whether the μ^- is the daughter of a primary particle decaying inside the vertex plate (see fig. 3a and b) the impact parameter of the muon to the vertex is calculated. Events with a measured impact parameter larger than the cut of 2-8 μm [3], as well as the events for which the ν vertex could not be validated, because no second track segment was predicted or found, are checked by an eye-assisted manual scan. A possible kink is then checked against a cut of 250 MeV on "p_t-kink", which is determined by the product of the measured muon momentum p_μ and the difference of two angular measurements at two positions up- and downstream of the tested kink position ($p_t\text{-kink} = p_\mu \cdot \sin(|\theta_1 - \theta_2|)$). No candidate event was left after the eye-assisted manual scan and the application of the p_t-kink cut.
   "Long decay length" analysis: To check by automatic scanning the possibility of a decay further downstream of the vertex plate (see fig. 3c) a p_t-kink value is determined by using the track slope differences of the μ^- and of a reference track, measured at the vertex plate ($\Delta\theta_1$) and secondly by the tracking detectors ($\Delta\theta_2$, see fig. 3c). If this measured value of p_t-kink is larger than the cut of 250 MeV (see fig. 4) or if the vertex could not be validated by a second matching track, the μ^- track is measured more precisely by eye-assisted manual scanning within 5 plates downstream of the vertex plate to give a better estimate on p_t-kink.

[2] If the vertex could not be confirmed, see below.
[3] The value depends on the longitudinal position of the vertex inside the vertex plate

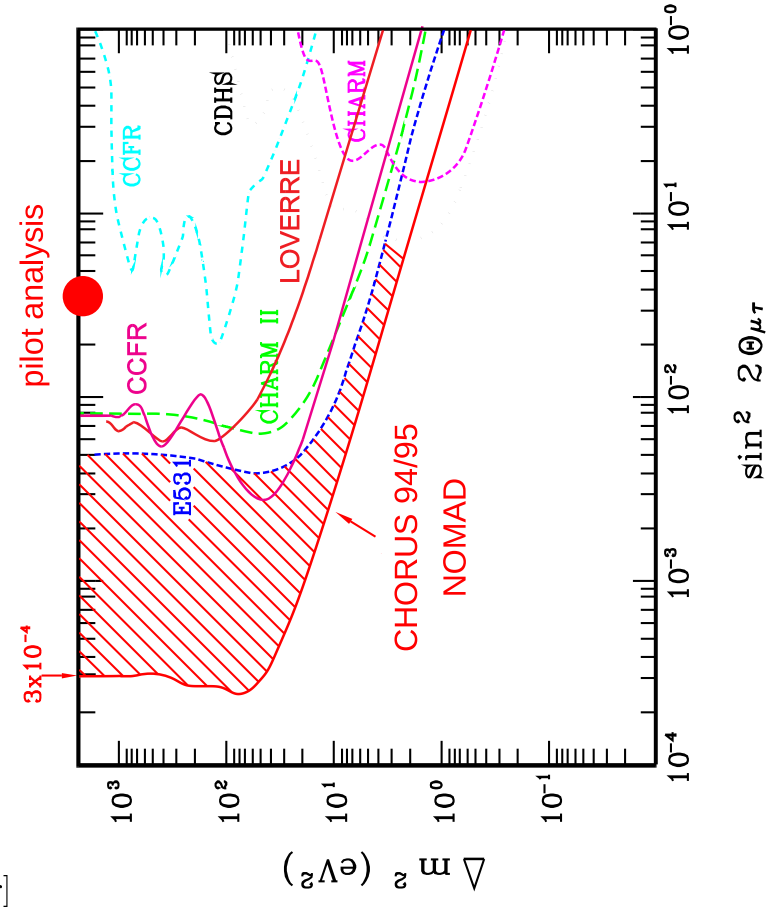

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Figure 5: Exclusion plot in the Δm^2-$\sin^2(2\theta_{\mu\tau})$-plane for $\nu_\mu \to \nu_\tau$ oscillation searches by various experiments, the CHORUS pilot analysis and the proposals of NOMAD and CHORUS (run I only).

3.1 Result

In the case of a large neutrino mass difference ($\Delta m^2 = |m_1{}^2 - m_2{}^2| \gg 4E/L$), eq. 1 simplifies to:

$$P(\nu_\mu \to \nu_\tau) = \sin^2(2\theta_{\mu\tau}) \cdot 1/2 \ . \tag{3}$$

This probability is experimentally determined by the ratio of observed ν_τ CC events $N^{obs}_{\nu_\tau}$ and the observed ν_μ CC events $N^{obs}_{\nu_\mu}$ corrected for the average cross section ratio $\sigma\nu_\mu/\sigma\nu_\tau = 1.89$, the ratio of reconstruction and vertex finding efficiencies and acceptances $A\nu_\mu/A\nu_\tau \approx 0.93$ [4)], the muonic decay branching ratio BR = 0.18 and the kink finding efficiency $\eta_{kink} \approx 0.61$ [4)]:

$$P(\nu_\mu \to \nu_\tau) = \frac{N^{obs}_{\nu_\tau}}{N^{obs}_{\nu_\mu}} \cdot \frac{\sigma\nu_\mu}{\sigma\nu_\tau} \cdot \frac{A\nu_\mu}{A\nu_\tau} \cdot \frac{1}{BR} \cdot \frac{1}{\eta_{kink}} \ . \tag{4}$$

The pilot analysis is based on about 10 000 reconstructed events with a μ^- (the estimated reconstruction efficiency is 0.6), of which about 8000 events pass the 30 GeV cut on p_μ. Out of these 2622 CC events passed the pilot analysis, without finding any τ-candidate.

[4)] The values are obtained from a MC study

By using eq. 3 this leads for the case of large Δm^2 to an upper limit of:

$$\sin^2(2\theta_{\mu\tau}) \leq 3 \cdot 10^{-2} \quad (90\% \; c.l.)^{5)}. \tag{5}$$

This limit is marked in the exclusion plots of previous experiments in fig. 5.

4 Outlook

The pilot analysis was done on a small fraction of the 94/95 data and was only looking for the muonic τ decay. The analysis will take about one or two years of scanning on the present 10 automatic microscopes. The large gain in statistics converts linearly into an improvement of sensitivity, if the background is below 10^{-5}, including the hadronic decay modes as well. Therefore the sensitivity for large Δm^2, estimated in the CHORUS proposal [5], $\sin^2(2\theta_{\mu\tau}) \leq 3 \cdot 10^{-4}$ seems to be in reach within one or two years, if no τ-signal is observed.

5 Conclusion

With this pilot analysis, the CHORUS experiment has tested the analysis chain for the muonic τ decays, using for the first time fully automatic emulsion scanning. It also shows, that the proposed sensitivity of CHORUS is within reach. Improved data quality due to detector improvements may speed up further the analysis.

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5) Since the presentation of this result at the Warsaw ICHEP96 Conference more events have been analysed and the limit is now 10^{-2} (90% c.l.)