CHORUS RESULTS ON OSCILLATION AND CHARM PHYSICS

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The CHORUS detector was exposed to the neutrino beam of the CERN SPS during the years 94-97. About $10^6 \nu_\mu$ CC events were collected in the nuclear emulsion target.
With the present performance of emulsion scanning systems, it has become possible to perform large area volume scanning with fully automatic data-acquisition systems. All tracks belonging to an interaction vertex can be recognized and measured precisely by novel pattern recognition programs. This technique has been used for the recognition of events where short-lived particles are produced. In particular, candidates for the decay of a tau-lepton into hadrons have been searched for in the sample of events where no muon is present in the final state. Besides the oscillation analysis charm production with large statistics can also be studied by this technique. We present results on D^0 production and associated charm production with final statistics.

1 Introduction

A direct but sensitive way to search for non-zero neutrino masses, is to look for evidence for neutrino oscillations.

The CHORUS experiment was designed to search for $\nu_\mu \rightarrow \nu_\tau$ oscillations in the SPS wide-band neutrino beam at CERN through the direct observation of decays of the tau-lepton in the emulsion. The search is sensitive to very small mixing angles down to $sin2\theta_{\mu\tau} \sim 3 \times 10^{-4}$ for the mass difference $\Delta m^2 \sim 1eV^2$. In this scheme neutrino becomes a good candidate for the Dark matter of the Universe. This consideration constitutes the main motivation of the experiment. Since charmed hadrons have a flight length comparable to that of the tau-lepton the experiment is also suitable to study charm production with significantly large statistics.

2 The CHORUS experiment

2.1 The experimental Set-up

The CHORUS detector is a hybrid set-up that combines nuclear emulsion stacks with various electronic detectors. The nuclear emulsion acts both as target for neutrino interactions and as detector, allowing three-dimensional reconstruction of short-lived particles as the τ^- leptons and charmed hadrons. The nuclear emulsion target, which is segmented into four stacks, has an overall mass of 770 kg, each of the stacks consisting of eight modules of 36 plates of size 36×72 cm^2. Each plate has a 90μm plastic support coated on both sides with 350 μm emulsion layers. Each stack is followed by three interface emulsion sheets having a 90 μm emulsion layer on both sides of an 800 μm thick plastic base and by a set of scintillating fiber tracker planes. The interface sheets and the fiber trackers provide accurate particle trajectory predictions into the emulsion stack in order to locate the vertex positions. The accuracy of the fiber tracker prediction is about 150 μm in position and 2 mrad in the track angle. The major drawback is the absence of the time information: any charged particle traversing the emulsion during the exposure will leave a track.

The emulsion scanning is performed by fully automatic microscopes equipped with CCD cameras and a read out system, called *Track Selector*[1]. In order to recognize track segments in an emulsion, a series of tomographic images are taken by focusing at different depths in the emulsion thickness. The digitized images are shifted according to the predicted track angle and then added. The presence of aligned grains forming a track is detected as a local peak of the gray level of the summed image. The track finding efficiency of the track selector is higher than 98% for track slopes less than 400 mrad.

The electronic detectors downstream of the emulsion target include a hadron spectrometer which measures the bending of charged particles in an air-core magnet, a calorimeter where the energy and direction of showers are measured and a muon spectrometer which measures the charge and momentum of muons.

2.2 Data Collection

The West Area Neutrino Facility (WANF) provide a intense beam of neutrinos with average energy of 27 GeV. It consists of mainly of ν_μ with a contamination of 6 %$\bar{\nu_\mu}$ and $\sim$1 % ν_e. The CHORUS detector was exposed to neutrino beam during the years 1994-1997, with an integrated flux of 5.06×10^{19} protons on target; in this four year exposure more than 10^6 neutrino interactions were accumulated in the emulsion target. The analysis of the data from the electronic detectors allows the identification of the set of events possibly originating from the emulsion stacks. For the first phase of the analysis, the events were subdivided into two classes, based on electronic detectors, which are the one-muon and the zero-muon samples, distinguished by the presence or absence of one reconstructed muon of negative charge. For vertex location, track trajectories belonging to reconstructed events in the electronic detectors are used to guide the scanning. The track is first searched in the interface sheets and then followed back into the target emulsion. If it is not found in two consecutive plates, the first of these is defined as *vertex plate*. This plate may contain the primary vertex or the decay vertex, or both. Once the vertex is located,

Table 1. Data flow of the one-mu sample.

	N. of events
vertex predicted	713000
scanned	286965
located	107879
analyzed with netscan	93858

the charm decay search is performed using the *netscan* method [2]. It consists of recording all track segments within an angular acceptance in a volume surrounding the assumed vertex position. The data flow of the one-mu sample is summarized in Table 1.

3 Oscillation analysis

A first analysis of full data set in terms of oscillation search was presented in [3]. The search was performed for both leptonic and hadronic decays of the τ lepton. No τ candidate was found. A $\nu_\mu \rightarrow \nu_\tau$ mixing is excluded down to $sin2\theta_{\mu\tau}$=6.8×10^{-4} for large Δm^2 at 90 %CL.

In order to reach the design sensitivity of the experiment, the complete data set is re-analyzed with Netscan technique. This method has a much higher efficiency for the hadronic decays of the tau then previous methods used. Therefore the sensitivity of the search for $\nu_\mu \rightarrow \nu_\tau$ oscillation could be significantly improved. Also novel methods to reject the background induced by charmed particles have been developed. The analysis of full data set for the oscillation search is in progress.

4 Charm analysis

Charm production in neutrino charged current (CC) interactions has been studied in several experiments [4] with electronic detectors and mostly through the analysis of dimuon events. In these events, the leading

Table 2. Eye -scan results of candidates.

Accepted ev.		Rejected ev.	
V2	820	low mom.	174
V4	225	hadron int	247
C1	453	γ- conv.	93
C3	492	other	225
C5	22		
V6	3		

Table 3. Efficiencies of the *netscan* analysis.

Topology	ϵ_{net}(%)
C1	24.6±0.7
C3	55.7±0.7
C5	60.8±2.6
V2	56.4±0.5
V4	74.3±0.9

muon is interpreted as originating from the neutrino vertex and the other, of opposite charge, as the product of the charmed particle semileptonic decay. Experiments of this type, however, suffer from a significant background of events in which the second muon originates from an undetected decay in flight of a pion or a kaon rather than from a charm decay. Moreover, the type of the charmed particle and its decay topology can not be identified in these experiments. A much lower level of background can be achieved using an emulsion target which provides a sub-micron spatial resolution, and hence, the topological identification of charmed hadron decays. The statistics accumulated in this way is however very limited[5]. The development within CHORUS of automatic scanning devices of much higher speed has made studies of charm production with high statistics possible.

4.1 D^0 production rate measurement

We have analyzed full statistics in terms of D^0 production. In order to select potentially interesting decay topologies we apply the following selection criteria [6]:

- Select tracks originating from the primary vertex and stopping in the *netscan* volume, thus identifying a possible secondary vertex.
- Require for the above tracks, the direction measured in emulsion matches the one reconstructed by the fiber tracker system.

These criteria select 2754 events which are visually inspected to confirm the decay topology. The observable decay topologies are classified as odd- and even-prong decays. These are denoted as V2, V4 or V6 for neutral and C1, C3 or C5 for charged decays according to the multiplicity at decay vertex. The result of the visual inspection is given Table 2.

The rejected events consist mainly of hadronic interactions, gamma conversions and of low momentum tracks which, due to multiple scattering, appear as tracks with a large impact parameter. The remaining rejected events consist either of fake verticies, reconstructed using one or more background tracks, or of verticies with a parent track not connected to the primary vertex.

The efficiency of the charm selection was evaluated with a GEANT3 based simulation of the experiment. Large samples of deep-inelastic neutrino interactions were generated according to the beam spectrum using the JETTA generator derived from LEPTO and JETSET. The simulated response of the CHORUS electronic detectors is processed through the same reconstruction program used for data. To evaluate the *netscan* efficiency, realistic conditions of track densities need to be reproduced. This is achieved by merging the emulsion data of the simulated events with real *netscan* data which do

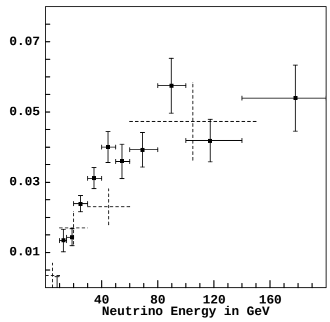

Figure 1. D^0 production rate as a function of neutrino energy. The result of this analysis are shown as solid lines and compared with those of the E531 experiment (dashed lines).

not have a reconstructed vertex but contain tracks which stop or pass through fiducial volume representing the real background[7]. The combined data are passed through the same *netscan* reconstruction and selection programs as used for data. The selection efficiencies are shown in Table 3.

The following results based upon 1045 D^0 decays with an estimated background of 31.7±4.3 K^0 and Λ^0: The topological ratio $Br(D^0 \to V4)/Br(D^0 \to V2)$ is found to be $0.214 \pm 0.016 \pm 0.004$. Combining V4/V2 ratio with $Br(D^0 \to V4) = (13.3 \pm 07) \times 10^{-2}$ and using the PDG tables[8], we can obtain branching ratio of D^0 decaying into neutral particles:

$$\begin{aligned} Br(D^0 \to V0) = 1 - Br(D^0 \to V4) \times \\ (1 + (\frac{Br(D^0 \to V4)}{Br(D^0 \to V2)})^{-1}) \\ = 0.239 \pm 0.048 \pm 0.013 \end{aligned}$$

The average ratio of production rate is

$$\frac{\sigma(D^0)}{\sigma(CC)} = 0.0277 \pm 0.0019 \pm 0.0014.$$

4.2 Associated charm production

Associated charm ($c\bar{c}$) production in neutrino interactions is a very rare process and therefore very difficult to observe. The sub-micron resolution of nuclear emulsion allows the study of this kind of rare processes. We have performed a search in both CC and NC samples. We have analyzed 93858 CC and 30162 NC interactions with *netscan* technique. We applied the selection criteria as discussed in the previous section. Three double charm decays have been observed in NC sample with a estimated background of 0.12 ± 0.02. Five double charm decays have been observed in CC ν_μ with a estimated background of 0.79 ± 0.10. After background subtraction and efficiency correction we estimate the average rate of double charm production at the average neutrino energy of 27 GeV is

$$\frac{\sigma(c\bar{c}\mu^-)}{\sigma_{CC}} = (3.9 \pm 1.9(stat.) \pm 0.6(syst.)) \times 10^{-4}$$

$$\frac{\sigma(c\bar{c}\nu_\mu)}{\sigma_{NC}} = (3.5 \pm 2.1(stat.) \pm 0.6(syst.)) \times 10^{-4}$$

where we have accounted for a systematic uncertainty of 15% coming from efficiency estimation and muon misidentification.

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