PROCEEDINGS

International Europhysics Conference on HEP

Charm production by neutrinos in the CHORUS experiment

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Abstract: We report a measurement of the D^0 production rate in ν_μ charged current interactions. Recent improvements of automatic scanning systems and methods allow the CHORUS experiment at CERN to study charm production with a sub-micron spatial resolution typical for emulsion, leading to very small backgrounds. Based upon 282 D^0 decays with an estimated background of 9.2±1.4 K_s^0 and Λ^0 found in 25693 located ν_μ interactions we obtain a D^0 production rate in ν_μ charged current interactions 1.98±0.13(*stat.*)±0.11(*syst.*)% at 27 GeV average ν_μ energy.

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1. Introduction

In neutrino deep inelastic scattering (DIS), a charmed hadron is produced when a neutrino interacts with a strange (s) sea quark or valance down (d) quark, producing a charm (c) quark. The subsequent fragmentation leads to a charmed hadron, mostly D mesons through the hadronization process. The Feynman diagram for this process is shown in figure 1.

After the first observation [1] of single charm particle production in neutrino interactions, several experiments [2] have studied charmed particle production properties mostly by analyzing opposite sign dimuon events. In these events, the decay of a charmed particle is not seen directly, its presence is inferred from the observation of opposite sign dimuon in the final state. Experiments of this type, however, suffer from a large 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 charmed decay. Nevertheless these experiments have provided measurements of the strange quark content of the nucleon as well as an estimation of the charm quark mass. On the other hand, in order to improve the knowledge of

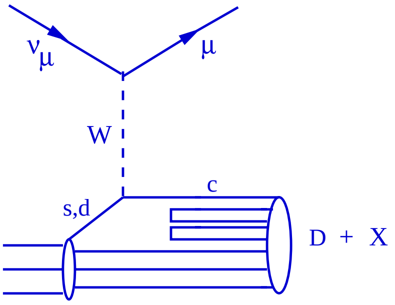

Figure 1: Neutrino charm production in DIS.

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neutrino charm production, one needs an unbiased sample of charm events. Experiments using nuclear emulsion have a sub-micron spatial resolution which allows 3D reconstruction of events. Therefore, it can be used for topological identification of short lived particles like charmed hadrons. Such an experiment was E531 [3], but due to limited statistics, it could provide only qualitative information. The recent development of automatic scanning devices within CHORUS has made studies of charm production with high statistics possible.

2. The CHORUS experiment

The CHORUS detector is a hybrid setup [4] that combines the nuclear emulsion with various electronic detectors: a scintillating fiber tracker, trigger hodoscopes, a hadron spectrometer, a calorimeter and a muon spectrometer.

The nuclear emulsion acts as target and simultaneously, as a detector for neutrino interactions. The emulsion target which is segmented into 4 stacks has an overall mass of 770 kg. Each stack is followed by three interface emulsion sheets 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 emulsion scanning has been performed by fully automatic microscopes equipped with CCD cameras and a read out system, called *Track Selector* [5]. The track finding efficiency of the track selector is higher than 98 % for track slopes less than 400 mrad.

The West Area neutrino Facility (WANF) at CERN provides a neutrino beam of 27 GeV average energy consisting mainly of ν_μ with a 5 % $\bar{\nu}$ contamination. During four years (1994-1997) of operation CHORUS recorded about 10^6 neutrino interactions originating in the emulsion target. Of these, 170,000 have been located and analyzed for $\nu_\mu \rightarrow \nu_\tau$ oscillation [6].

3. Analysis

The CHORUS experiment is mainly dedicated to the $\nu_\mu \rightarrow \nu_\tau$ oscillation search, hence, the data selection [6] for the first phase of the analysis was optimized towards the detection of τ decaying into a single charged particle. In particular, only events with a muon momentum less than 30 GeV/c were selected for emulsion scanning. This cut reduces by 29% the number of events to be scanned. On the other hand, it rejects 15% of the ν_τ interactions if the ν_τ has the same energy spectrum as ν_μ. Therefore, it has a marginal effect on the τ sensitivity but plays a more important role in the present analysis of charm production. In order to correct for this cut about 3K ν_μCC events with a muon momentum greater than 30 GeV/c were located in addition and analyzed.

In order to detect the decay topologies in the emulsion target, a new method called "netscan" [7] has been applied. A fiducial volume of $1.5 \times 1.5 \times 6.3\ mm^3$ centered on the located vertex is scanned and all the track segments within angular acceptance ($|\theta_{y,z}| <$400 mrad) are recorded. The scanning of an event takes 11 min with the latest version of the *Track Selector*, UTS. Typically, about 5K track segments are recorded per event and their

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parameters (3 position coordinates and 2 angles etc.) are stored in a data base. From this huge number of track segments, tracks are reconstructed offline. Tracking and vertex reconstruction involve a number of steps: first, the global (plate by plate) and the local alignment (event by event) have been done by comparing the pattern of segments in a given plate with corresponding pattern in the next plate. Then, tracking is done by extrapolating the track segments on the downstream and upstream plate and searching for candidates for connections. After connection of all matched segments, a second, more accurate, alignment of the plates has been done using tracks passing through the entire volume. These are mainly due to muons associated with the neutrino beam or nearby test beams. After the fine alignment, the residual of the segment positions with respect to the fitted track is about 0.45 μm. After the final alignment, about 400 tracks remain in the fiducial volume. The vast majority can be recognized as due to low energy (typically less than 100 MeV) particles and discarded. Moreover, a χ^2 cut is applied to select the "good" tracks. The final step is the rejection of tracks passing through the scanning volume. After this filtering, the mean number of tracks originating in the scan volume is about 40. Finally, tracks are associated into vertices using the distance of closest approach.

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3.1 Event selection

Tracks originating from the interaction and stopping in the scanning volume are candidates for decays. In order to select interesting decay topologies, various cuts are applied. They are optimized in order to keep the eye-scan load reasonable, while keeping high efficiency for decay finding. The following requirements were used

Accepted events		Rejected events	
V2	225	low momentum	174
V4	57	hadron int.	68
C1	121	e-pair	42
C3	124	δ-ray	2
C5	7	other	30
V2+C1	1		
Total	535		316

Table 1: Eye-scan results of candidates.

- the primary muon and at least one of the stopping tracks in the scanning volume were reconstructed with more than one track segment and matching at the 99 % confidence level the direction of a track reconstructed in the fiber tracker system.
- the impact parameter of at least one of the stopping tracks to the vertex point must be larger than $\sqrt{3^2 + (2\sigma dx)^2}$ μm where $\sigma = \sqrt{0.00305^2 + (0.0194\theta)^2}$ is the parametrization of the angular error and dx is the distance (in the beam direction) of the vertex to the most upstream daughter track segment. This impact parameter must be also smaller than 400 μm. This last cut mainly rejects tracks not related to the neutrino interaction.

The analysis presented here is based on 25,693 netscanned events. The selection criteria retained 851 candidates for the charm decays. In order to confirm the decay topology, these candidates were checked by eye. The result of the eye-scan is given in the Table 1. The purity of the automatic selection is 63 %. The observable decay topologies are classified as odd-prong decays of a charged particle (mainly D^+, D_s^+, Λ_c^+) or even-prong decays of a neutral particle (mainly D^0). These are denoted in Table 2 as V2, V4 or V6 for neutral and C1, C3 or C5 for charged decays according to the prong multiplicity. There is also one event having both V2 and C1 decay topologies denoted as V2+C1. This event is a candidate of associated charm production; further analysis is underway. The rejected sample consists mainly of hadronic interactions, delta rays or gamma conversions ($\sim$ 36 %) and of low momentum tracks which, due to multiple scattering, appear as tracks with a large impact parameter ($\sim$ 54 %). The remaining 10 % consists of fake vertices, reconstructed using one or more background tracks.

The confirmed D^0 sample contains 282 candidates. For 33 of these events (24 V2 and 9 V4), the muon momentum is greater then 30 GeV/c.

3.2 Monte-Carlo simulation

D^0 detection efficiency can be split into two terms: the first term is the location efficiency of ν_μ CC events, given by the efficiency of the reconstruction of the neutrino interaction and of its location in emulsion. The second term is the efficiency of the decay search, the netscan method.

In order to estimate efficiencies and backgrounds, a Monte-Carlo simulation with the complete set-up and event reconstruction has been performed. The location efficiencies are found to be 59.0±0.2% and 51.4±0.4% for all ν_μ CC events and D^0 events respectively. In order to estimate the efficiency of netscan procedure, one needs to reproduce realistic conditions of track density. To achieve this, MC tracks are simulated in the emulsion and then merged with real netscan data. The combined data is then passed through the same reconstruction and selection programs as used for real data.

The systematic uncertainties of netscan efficiency arise mainly from the choice of the event generator and from the variation in the emulsion data quality. The first source of systematic error is estimated to be 3.4% by comparing results obtained with different structure functions and fragmentation functions. The second one is estimated to be 2 % by merging simulated netscan data with different sets of spurious netscan data corresponding to different track densities and different alignment accuracies. The mean netscan efficiency for the D^0 decay search is 58.6±4.0% for V2 and 70.1±4.2% for V4, where errors combine statistical and systematical uncertainties.

By processing ν_μ CC interactions with no D^0 in the final state through the same chain of programs, the background rate is evaluated to be (3.6±1.0) 10^{-4} per located CC event. In the present sample of 25,693 events this corresponds to 9.2±2.6 background events, mainly K_s^0 and Λ^0 decays.

4. D^0 production rate

Taking into account the estimated efficiencies and background, one obtains a D^0 production rate relative to ν_μCC interactions: $\frac{\sigma(D^0)}{\sigma(CC)} = 1.98 \pm 0.13(stat.) \pm 0.11(syst.)\%$ in good agreement with the result of E531 [3] (dashed lines in Figure 2) based on a much lower statistics. The topological ratio V4/V2 is found to be 23.3±4.4% in agreement with the world average value $20.1^{+2.7}_{-1.9}$ %[9]. The dependence of the D^0 production rate in the

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measured neutrino energy is shown in Figure 2. A second phase of analysis of the CHORUS data has been started, with upgraded reconstruction codes and scanning systems. In about one year, it is expected collect an unbiased sample of 3000 charm events will be collected, allowing a detailed and almost background-free study of all the charm production processes.

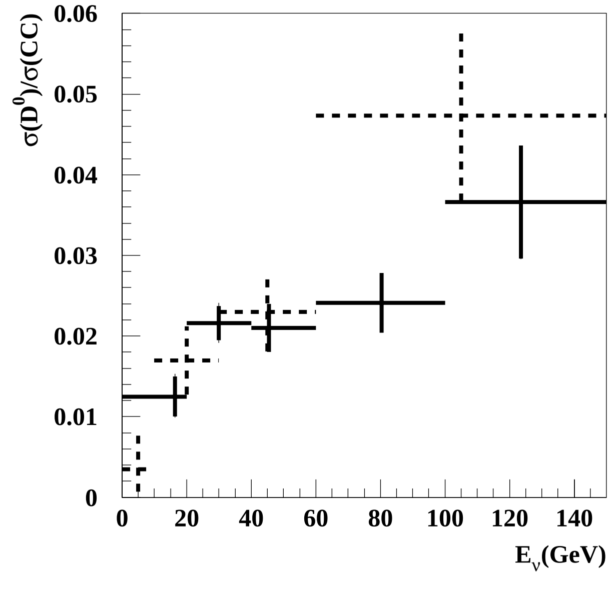

Figure 2: D^0 production rate as a function of neutrino energy. CHORUS result is shown as solid lines. Also E531 result is shown (dashed lines).

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