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CHORUS RESULTS ON CHARM PHYSICS

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During the years 1994-1997, the emulsion target of the CHORUS detector was exposed to the wide band neutrino beam of the CERN-SPS. In total 95,450 charged-current neutrino interactions were located in the nuclear emulsion target and fully reconstructed. Altough the experiment was originally designed to search for $\nu_\mu \rightarrow \nu_\tau$ oscillation by detecting the characteristic decay topology of the τ lepton produced in ν_τ charged-current interactions, it is also possible to study charm particles which have a life-time similar to that of the τ lepton. The nuclear emulsion is used as target for neutrino interactions allowing a three-dimensional reconstruction of short-lived particles to be performed. We report here on the results from the analysis of a sub-sample of the data such as the production rate in ν_μ CC interactions of neutral charmed mesons (D^0) and charmed baryons (Λ_c) together with new measurements based on the final statistics of the CHORUS experiment.

The CHORUS[1] detector is a hybrid setup which combines a nuclear emulsion target with various electronic detectors such as trigger hodoscopes, a scintillating fibre tracker system, an air-core magnet, electromagnetic and hadronic calorimeters and a muon spectrometer. The emulsion target has an overall mass of 770 kg and is segmented into four stacks. Each stack consists of eight modules of 36 plates of size of 36×72 cm^2. Each plate has a 90 μm plastic base coated on both sides with a 350 μm emulsion layer. Each stack was followed by three interface emulsion sheets having a 90 μm emulsion layers on both sides of 800 μm thick plastic base and by a set of scintillating fibre target-tracker planes (TT). The interface emulsion sheets and the fibre tracker system provide particle trajectory predictions with an accuracy of about 150 μm in position and 2 mrad in the track angle. The nuclear emulsion target allows a three-dimensional reconstruction of the decay of short-lived particles such as τ leptons and charmed hadrons.
The emulsion scanning has been performed by fully automatic microscopes equipped with CCD cameras and a read out system, called Track Selector[2]. The track finding-efficiency is higher than 98% for track slopes less than 400 mrad with respect to the direction perpendicular to the emulsion plates. The improvements in the automatic emulsion scanning systems allowed us large-volume data-taking around neutrino interactions located in the emulsion target. Thanks to the sub-micron spatial resolution of the emulsion, production of charmed particles in neutrino interactions followed by their decay can be fully observed. Therefore it is possible to perform a topological identification of charmed hadron decays, which brings very low level background contamination. The CHORUS experiment collected a sample of ∼3,000 neutrino interactions with a charmed particle.

1 Measurement of Λ_c production

The study of Λ_c production has been performed by a statistical approach based on the difference of the lifetimes among charged charm particles by exploiting their different lifetimes and hence flight-length distributions. Since the lifetime of the (Λ_c) is smaller than that of other charged charm hadrons, the sample of charged charm decaying at distances less than 400 μm should be dominated by (Λ_c). On the contrary, long decays are enriched by D^+ and D_s^+ decays. Therefore, two different sets of selection have been adopted for the analysis. The event selection for short flight decays is based on the following criteria: a daughter track must have a minimum distance of 5 μm to 30 μm with respect to a track which is identified as a muon. This selection has been applied to 50,414 ν_μ events and 1614 events were selected for visual inspection. After visual inspection, 62 events were confirmed as 1-prong decay and 66 events were confirmed as 3-prong decay. The criteria applied to long decays were as follows: first both parent and daughter track should be reconstructed. Then we require that the parent track must have a minimum distance smaller than 5 μm with respect to the reconstructed muon and the daughter track must have a minimum distance of 5 μm to 30 μm with respect to the parent track. These criteria were applied to 56,761 ν_μ events and 586 events were selected again for the visual inspection. The confirmed charmed events were classified as 133 1-prong and 77 3-prong.

Combining the short and long decay search and taking into account the detection efficiency and background estimation, the number of Λ_c candidates was found to be $861 \pm 198(stat.) \pm 98(syst.)^{+140}_{-54}(QE)$.

At an average neutrino energy of 27 GeV, the Λ_c production cross section in ν_μ charged current interaction was measured[3] to be:

$$\frac{\sigma(\Lambda_c)}{\sigma(CC)} = (\,1.54 \pm 0.35(stat.) \pm 0.18(syst.)\,) \times 10^{-2}. \tag{1}$$

2 Measurement of quasi-elastic charmed baryon production

A study of quasi-elastic production of charmed baryons in charged-current interactions of neutrinos was performed in the CHORUS emulsion target by looking for their characteristic topologies. In addition to selection criteria similiar to the ones explained above for the short decay search of Λ_c production, some other kinematical cuts were applied to reduce the background.

Since quasi-elastic charmed-baryon production is characterized by low hadronic energy, a significant background rejection was obtained on the basis of the visible energy measured in the calorimeter. For this reason only events with an energy deposition in the calorimeter less than 2 GeV were considered for this study. A further rejection of background from non-quasi elastic processes was obtained by applying a cut on the azimuthal angle between the primary muon and the charmed particle trajectory in the plane transverse to the incident neutrino direction. In this analysis a total of 46,105 ν_μ events was used. After visual inspection and all kinematical cuts 13 candidates with an estimated background of 1.7 events were found. The ratio of the cross-sections for quasi-elastic production of charmed baryons and ν_μCC interactions was measured[4] to be:

$$\sigma(QE)/\sigma(CC) = (0.23^{+0.12}_{-0.06}(stat)^{+0.02}_{-0.03}(syst) \times 10^{-2}$$

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3 Associated charm production

Associated charm production in neutrino interactions is a very rare process. In the past only one event has been observed by the E531 experiment[5] in a neutral-current(NC) interaction. For the NC process, a measurement of the cross-section has been recently produced by NuTeV experiment[6].

Thanks to the excellent spatial resolution of nuclear emulsion, it is possible to perform a direct observation in the CHORUS experiment.

A search for associated charm production in ν_μ charged-current interactions was performed based on the sample of already located single charm events searching for the charmed partner. One event with a double charm decay topology with an estimated background of 0.04 was found[7]. It is considered as evidence of the associated charm production process.

A new search for associated charm production in both charged-current and NC interactions has been started. Several candidates with the characteristics of associated charm production have been found. Figure 1 shows a schematic view of an event which was found in the NC sample. As can be seen from the figure, that the primary vertex is in plate 23. There are one minimum-ionizing(shower) and two heavy-ionizing(black) tracks. A neutral particle decays into two charged particles 62.8 μm downstream of the primary vertex in the same plate. In addition to this neutral particle decay, a second decay has been observed in the plate 22. Detailed analysis on this events shows that this is an associlated charm production in NC. The full analysis will be completed using the final statistics in the near future.

4 Measurement of D^0 production

A first measurement of the production rate of D^0 mesons was performed based on a sample of 25,693 ν_μ charged-current interactions. The following criteria were applied to select D^0 candidates. A muon track at the primary vertex and at least one daughter track were reconstructed in the emulsion and matched with tracks in the detector. The daughter track was required to have a significant impact parameter with respect to the primary vertex, which is $3 \sim 30\ \mu\text{m} < \text{I.P.} < 400\ \mu\text{m}$.

These criteria selected 851 events to be visually inspected to confirm the decay topology and we observed 226 events of 2-prong decay (V2) and 57 events of 4-prong decay (V4). The average efficiency of the D^0 decay search was found to be $(58.6 \pm 0.7)\%$ for V2 and $(70.1 \pm 1.7)\%$ for V4. Based on 282 D^0 decays with an

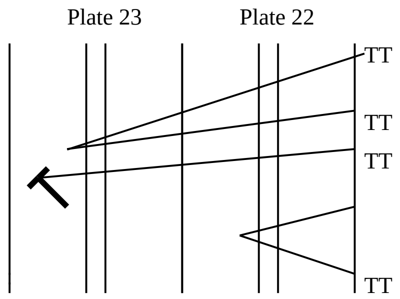

Figure 1. Topology of the candidate event in NC

estimated background of 9.2 K^0 and Λ^0 decays, we obtained[8]

$$\frac{\sigma(D^0 \rightarrow \mathrm{V2,V4})}{\sigma(CC)} = (\, 1.99 \pm 0.13(stat.) \pm 0.17(syst.)\,) \times 10^{-2}. \qquad (2)$$

Now the same analysis as well as the measurement of the branching ratio of D^0 decay modes into all neutrals are in progress based on the full sample (95,450 CC events). The branching ratio of D^0 decay into all neutrals can be simply expressed (neglecting 6-prong decays) as:

$$BR(D^0 \rightarrow \mathrm{V0}) = 1 - \mathrm{V4} \cdot \left(1 + \left(\frac{\mathrm{V4}}{\mathrm{V2}} \right)^{-1} \right). \qquad (3)$$

Because the CHORUS experiment detects charm particles by observing its decay topology, it is possible to perform an inclusive measurement of the ratio of $(D^0 \rightarrow \mathrm{V4})/(D^0 \rightarrow \mathrm{V2})$. The value of $(21.4 \pm 1.6) \times 10^{-2}$ was obtained for this ratio.

Using the $BR(D^0 \rightarrow \mathrm{V4}) = (13.3 \pm 0.6) \times 10^{-2}$ from the PDG[9] tables, which was measured by other experiments for the all V4 decay modes, we obtained a preliminary result of

$$BR(D^0 \rightarrow \mathrm{V0}) = (24.1 \pm 4.5) \times 10^{-2}. \qquad (4)$$

5 Charm production in $\overline{\nu}_\mu$ CC interactions

Knowledge on antineutrino induced charm production is limited. Especially at low energies there is little data and up to now there is no measurement of the charm production fractions.

The study has been performed using $\overline{\nu}_\mu$ contamination of the beam. In this study about 95,000 events with at least one reconstructed muon in the spectrometer were used and for 2,704 events from this sample, the charge of the muon is measured to be positive. Additional selection criteria were applied to obtain a clean sample of $\overline{\nu}_\mu$ CC interactions. For example the following sources could give a positive muon reconstructed in the final state: Neutrino events with the μ^-, but reconstructed as a μ^+ in the spectrometer, neutrino induced charm events for which the leading muon is not reconstructed and μ from π and K decays reconstructed in the spectrometer. To evaluate these contributions as well as the detection efficiency of $\overline{\nu}_\mu CC$ interactions, a detailed simulation of the experiment was performed. The number of $\overline{\nu}_\mu CC$ interactions corrected for background and efficiency was found to be 4,975±187(stat)±53(syst).

The selection criteria for the selection of decay topologies are the same as in the neutrino case. 81 events were selected for visual inspection after applying the selection criteria. After visual inspection, 40 events with a positive muon reconstructed in the spectrometer and showing the topology consistent with a charm decay were found.

A preliminary value for the charm production rate in charged-current interactions induced by $\overline{\nu}_\mu$ is found to be

$$\frac{\sigma(\overline{\nu}_\mu N \to \mu^+ \overline{c} X)}{\sigma(\overline{\nu}_\mu N \to \mu^+ X)} = (\, 5.1^{+1.4}_{-1.0}(stat) \pm 0.1(syst)\,) \times 10^{-2}. \tag{5}$$

6 Charm Momentum Distribution

The main purpose to measure the charm momentum distribution is to have access to fragmentation variables. The measurement of these fragmentation properties of charmed-particle production gives insight in the hadronisation process and allows a better description of charm production to be formulated. With the exception of the E531[10] emulsion experiment, the BEBC [11] bubble-chamber and the NOMAD [12] electronic detector, results have been obtained based on opposite charge two muon (dimuon) data.

The momentum of the D^0 cannot be directly measured in the CHORUS experiment. Instead, one can exploit the correlation between the momentum and the angular distribution of the decay products. Figure 2 shows the correlation of the *geometrical average* of the angle of the decay daughters with respect to the direction of the D^0 (λ) and the momentum of D^0 (p_D). Altough the correlation is clear, no precise measurement of p_D can be obtained on an event-by-event basis. However, the correlation can be exploited to determine the momentum distribution from the λ-distribution on a statistical basis using an unfolding procedure. The unfolding procedure used has been tested on simulated data and it was found that the results are unbiased and the error estimates are correct.

The measurement of the momentum distribution of the D^0 as obtained is shown in Figure 2. The data-points indicate the central value of the result, the vertical error bar is the square-root of the diagonal elements of the covariance matrix, while the horizontal bars show the width of the bins. The dashed line shows the momentum distribution of the charmed hadron. The measured distribution is compatible with the distribution predicted by the Monte-Carlo model.

This study is based on the full data, i.e. the same sample as the one used for the measurement of the D^0 decay into all neutrals as explained above. Now the study

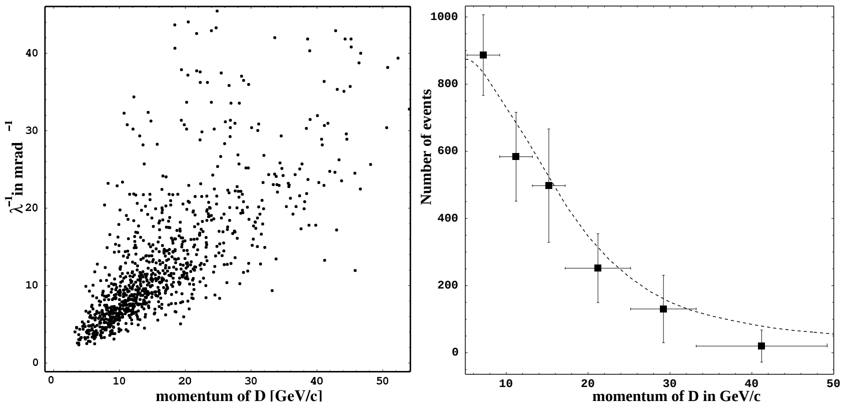

Figure 2. Correlation between D^0 momentum and the inverse of the geometrical average of the angles of daughter tracks with respect to the parent (left) and momentum distribution of D^0s produced inclusively in this experiment (right).

of the measurement of the fragmentation properties of charmed particle production is going on based on this result.

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