EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

A SEARCH FOR THE DECAY $D^0 \rightarrow \mu^+ \mu^-$

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The European Muon Collaboration

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Abstract

$\mu^+ \mu^-$ pairs have been observed in deep inelastic muon-nucleon scattering and their masses measured with high resolution. No significant signal was observed at the D^0 mass. These data allow an upper limit of 3.4×10^{-4} (90% confidence level) to be placed on the branching ratio for the decay mode $D^0 \rightarrow \mu^+ \mu^-$.

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For footnotes see next page.

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In this paper a search for the decay D^0 or $\bar{D}^0 \rightarrow \mu^+ \mu^-$ is reported. The observation of a significant branching ratio for this decay mode would imply the presence of charm changing neutral currents. Such neutral currents are forbidden in the standard model of weak interactions based on the $SU(2) \times U(1)$ gauge theory (1,2,3). However, the standard model is not necessarily the ultimate theory and attempts to go beyond it (e.g. technicolour or composite models) have often required flavour changing neutral currents (4). The contribution of strangeness changing neutral currents must be small or absent to account for the observation of the very small branching ratio for $K_L^0 \rightarrow \mu^+ \mu^-$ (5). Some models allow the existence of charm changing neutral currents whilst leaving strangeness changing neutral currents suppressed (1,2). Thus it is important to look for evidence for the existence of charm changing neutral currents.

Previous experimental searches for charm changing neutral currents have been made by studying $D^0 - \bar{D}^0$ mixing (6,7,8) and by studying wrong sign single muon production in neutrino reactions (9). A search for the decay D^0 or $\bar{D}^0 \rightarrow \mu^+ \mu^-$ gives a different method of searching for such neutral currents.

The data were taken using the M_2 muon beam at CERN with positive muons of energy 280 GeV incident on a 6 meter long target of either hydrogen or deuterium. Deep inelastic scattering events were detected in the EMC forward spectrometer (10), which was triggered by an outgoing μ^+ originating from the target region with an angle to the beam direction of greater than 0.5° . The data were obtained from seven experimental runs, five with hydrogen and two with deuterium in the target. The total number of incident muons recorded was 1.3×10^{12} corresponding to luminosities of 2.0×10^{37} and $3.3 \times 10^{37} \text{ cm}^{-2}$ for hydrogen and deuterium, respectively.

Events with a detected μ^+ and μ^- in the final state were selected for further analysis if they had a well reconstructed vertex in the target and were consistent with having produced the trigger. For the majority of the events a third μ^+ (the scattered muon) remained in the beam region and was not detected. To reduce the number of events originating from the decays of $\pi^\pm$ and $K^\pm$ produced by deep inelastic scattering at low Q^2 the momenta of the detected μ^+ and μ^- were required to be

greater than 15 GeV. Events were also rejected if the μ^+ momentum was greater than 120 GeV in order to reduce the background from higher Q^2 scattering followed by the decay of a π^- or K^- . Fig. 1 shows the measured $\mu^+ \mu^-$ mass distribution for all the experimental runs combined after applying these cuts. A clear J/ψ peak is observed with no other significant structure.

Monte Carlo programmes were written to simulate the production of dimuons from the decay of the D^0 (hereinafter D^0 is taken to mean D^0 or $\bar{D}^0$) and J/ψ mesons. Events were generated and weighted using the photon-gluon fusion model (Fig. 2) which has been shown to give a good representation of the open and bound charm data (11,12,13). The parameters of the model used here are those which gave the best fit to the data (11,12). The decay muons from the D^0 and the J/ψ were tracked through the forward spectrometer and the effects of the measured chamber inefficiencies, hodoscope inefficiencies, multiple coulomb scattering and the known measurement errors were simulated. Each generated event was accepted if it fulfilled the trigger requirements and would have been detected in the forward spectrometer.

A fit of a Gaussian and a smooth background function in the vicinity of the J/ψ peak in Fig. 1 gave the mass and width of the J/ψ to be $3.095 \pm .002$ GeV and $0.036 \pm .002$ GeV, respectively. The measured mass is in reasonable agreement with the known value of the J/ψ mass of $3.0969 \pm .0001$ [14]. The mass resolution at the J/ψ mass was calculated to be 0.033 GeV from the Monte Carlo simulation which is also in reasonable agreement with the measured width. The number of J/ψ decays in the peak was determined to be 366 ± 20 from the fit. The resolution of the dimuon mass from the decay $D^0 \rightarrow \mu^+ \mu^-$ was calculated to be 0.025 GeV from the Monte Carlo simulation. A Gaussian of this width is plotted at the D^0 mass in Fig. 1, to illustrate the expected line shape.

The acceptances for D^0 and J/ψ decay to dimuons were also calculated from the Monte Carlo simulations and these were found to be 5.9% and 16%, respectively. The difference between these values can be understood in terms of the photon-gluon fusion mechanism (Fig. 2). For open charm production the two charmed quarks fragment separately and thus tend to produce lower momentum decay muons than those from the decay of the J/ψ .

To obtain the number of D^0 events allowed by the data, a fit was performed to the mass spectrum in Fig. 1 as follows. A smooth background function plus a Gaussian distribution constrained to have the calculated width of 0.025 GeV and a peak value at the D^0 mass (1.865 GeV), was fitted to the data in the range $1.0 < M < 2.6$ GeV. The best fit ($\chi^2 = 30$ for 22 degrees of freedom) is shown as the smooth curve in Fig. 1 and gave the number of $D^0 \rightarrow \mu^+ \mu^-$ events to be -1 ± 6 .

The branching ratio for $D^0 \rightarrow \mu^+ \mu^-$ was then determined from the data:

$$\frac{\text{Number of } D^0 \rightarrow \mu^+ \mu^- \text{ events}}{\text{Number of } J/\psi \rightarrow \mu^+ \mu^- \text{ events}} = \frac{\sigma_{cc}^- L \epsilon_D f B_{D \rightarrow \mu\mu}}{\sigma_{J/\psi} L \epsilon_{J/\psi} B_{J/\psi \rightarrow \mu\mu}} \quad (1)$$

where σ_{cc}^- , $\sigma_{J/\psi}$ are the total muoproduction cross sections per single nucleon for charm and J/ψ . These have been measured from iron nuclei to be 9.8 ± 3.3 nb and $0.74 \pm .14$ nb, respectively (11,12), at an incident muon energy of 250 GeV. As calculated from the model σ_{cc}^- increases by 20% and $\sigma_{J/\psi}$ by 8% in increasing the beam energy from 250 GeV to 280 GeV, the energy of these data. This increase was allowed for in equation (1). L is the total luminosity, ϵ_D and $\epsilon_{J/\psi}$ are the acceptances for dimuons from D^0 decay and J/ψ decay, respectively. $B_{D \rightarrow \mu\mu}$ is the unknown branching ratio to be determined and $B_{J/\psi \rightarrow \mu\mu}$ is the branching ratio of J/ψ to dimuon pairs, 0.074 ± 0.012 (14). The factor f is the number of D^0 mesons per charm event which was calculated to be 1 from the Lund string model for fragmentation in deep inelastic scattering (15). In this model, which gives a good representation of the fragmentation process for light quarks (16), the charmed quarks fragment to charmed mesons and baryons (D^0 , D^+ , D^{*+} , F , Λ_c , Σ_c). If the charmed quarks fragment only to D^0 and D^+ , with equal probability, f would be expected to be 1. The Lund model shows that the loss of D^0 s due to fragmentation to F , Λ_c and Σ_c is compensated by the greater tendency of D^{*+} mesons to decay to D^0 than to D^+ . From these data an upper limit of 3.4×10^{-4} (90% confidence level) on the branching ratio for $D^0 \rightarrow \mu^+ \mu^-$ was deduced using equation (1). In deducing this upper limit allowance was made for the errors on all the measured quantities and an error of 30% was included for the factor f .

In conclusion a search has been made for the decay $D^0 \rightarrow \mu^+ \mu^-$, which is expected to be suppressed in the standard model of weak interactions based on the $SU(2) \times U(1)$ gauge theory. No evidence was found for this decay mode. The upper limit on the branching ratio for $D^0 \rightarrow \mu^+ \mu^-$, at 90% confidence level, from these data was determined to be 3.4×10^{-4} .

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Figure Captions

Figure 1 The dimuon mass spectrum. The smooth curve is the result of the fit described in the text. The Gaussian shape centred on 1.865 GeV represents the calculated line shape for the decay $D^0 \rightarrow \mu^+ \mu^-$.

Figure 2 The photon gluon fusion model: (a) for open charm production, (b) for J/ψ production.

FIG. 2