AN EXPERIMENTAL LIMIT ON THE INTRINSIC CHARM COMPONENT
OF THE NUCLEON

The European Muon Collaboration

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ABSTRACT

Charm production has been studied through multimMuon events produced in 250 GeV μ^+ -iron interactions. The measured dimuon cross section is in agreement with the photon gluon fusion model at low values of Bjorken x within statistical and systematic errors. At larger values of x_{Bj} the data do not support the magnitude of intrinsic charm used to explain hadroproduction of charm. Upper limits on the intrinsic charm content of the nucleon are derived from the data.

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In previous publications [1] dimuon and trimuon events were studied in 280 GeV μ^+ -iron interactions. These were shown to originate dominantly from the production of charmed particle pairs where one or both produced a secondary muon by semileptonic decay. The data in [1] were shown to be well represented by the photon-gluon fusion model [2].

Several hadron scattering experiments have reported the observation of charm production [3]. The data indicate that the charm production cross section by hadrons is about 1% of the total cross section with a rather flat distribution in Feynman x . These observations have led to the suggestion that the nucleon contains an intrinsic charm component [4] as well as the extrinsic component from the virtual dissociation of gluons to $c\bar{c}$ pairs. Such intrinsic charmed quarks, because of their mass, carry a large fraction of the momentum of the nucleon and these quarks would be expected to contribute to deep inelastic lepton scattering at large values of Bjorken x ($= Q^2/2Mv$) [5].

In this letter new data from a second experimental run with 250 GeV μ^+ and higher luminosity than in [1] are reported. The higher statistical precision allows a search to be made for deviations from the photon-gluon fusion model at large values of Bjorken x due to intrinsic charm.

The apparatus and beam line were identical to [1]. The experiment was performed in the M_2 muon beam at CERN using an iron calorimeter target and the EMC forward spectrometer [6]. The total number of incident muons in this exposure was 3.8×10^{11} corresponding to a luminosity of $3.5 \times 10^{38} \text{ cm}^{-2}$.

The analysis procedure for the multimuon events was similar to that described in [1] and full details will be published elsewhere [7]. Evidence that the inclusive multimuon events originate from charmed hadron production is shown in fig. 1 which gives the missing energy distributions for the final samples of dimuon and trimuon events. The missing energy is defined as the difference between the incident muon energy and the sum of the observed energy in the muon tracks as measured in the spectrometer and the hadron shower energy as measured in the target calorimeter. It can be seen from figs. 1(a), 1(b) and 1(c) that there is a significant positive missing energy of average value $(19 \pm 2) \text{ GeV}$ in the dimuon events and of average value $(31 \pm 4) \text{ GeV}$ in the trimuon. This missing energy is assumed to be carried away by neutrinos.

Figs. 1(a) and (b) also show an absolute calculation of the missing energy distribution from the decays of π and K in the hadron shower [1]. This background process contributes a fraction $(14 \pm 7)\%$ of the dimuon events (with a mean missing energy of 7 GeV) and 1% of the trimuon events.

The large observed mean missing energy indicates prompt, weak decay of heavy quark states rather than the decays of π and K mesons. The fact that the mean missing energy for the trimuons is roughly a factor two higher than that in the dimuons suggests that two heavy quark states are decaying semileptonically in the trimuon events and only one in the dimuon events. Furthermore, allowing for the different acceptance in each process, the ratio of the yields of the trimuon events to the dimuon events is $(7 \pm 3)\%$, consistent with the known semileptonic decay branching ratios of the D mesons [8]. This indicates that the dimuon and trimuon events originate predominantly from the production and semileptonic decay of charmed D mesons.

The ++ and +- dimuon cross sections had little systematic difference and the two samples were combined for the final results. Fig. 2 shows the muon cross section $d\sigma/dx_{Bj}$ plotted against x_{Bj} for dimuon final states, in the range $Q^2 > 1 \text{ (GeV)}^2$, $60 < \nu < 220 \text{ GeV}$ and secondary muon energy $> 16 \text{ GeV}$. This cross section is corrected for the contributions from π and K decay. The error bars shown are the statistical errors only. There is an additional systematic error in normalisation (estimated to be $\pm 11\%$ at small x , rising to $\pm 24\%$ at high x) coming mainly from the uncertainty in calculating the π , K decay contribution.

The smooth curve labelled IC was obtained by calculating the contribution of intrinsic charm to the structure function F_2

$$F_2^{IC} = \frac{4}{9} \xi [c(\xi) + \bar{c}(\xi)], \quad (1)$$

where $c(\xi)$ is the intrinsic charm quark momentum distribution deduced by Brodsky et al. [4]:

$$c(\xi) = \bar{c}(\xi) = 1800 \lambda \xi^2 \left[\frac{1}{3} (1 - \xi) (1 + 10\xi + \xi^2) - 2\xi(1 + \xi) \log \frac{1}{\xi} \right]. \quad (2)$$

Here $\xi = \frac{Q^2 + M_c^2}{2M\nu}$ is the fraction of the nucleon's momentum carried by the intrinsic charmed quark of mass $M_c = 1.35$ GeV [9] and $\int_{\xi_{\min}}^1 c(\xi) d\xi \sim \lambda$, is the probability of finding such a quark and is taken to be 1% to account for the observed hadroproduction cross section for charm [4]. This form of the variable ξ accounts for the mass of the charmed quark in the quark parton model. The value F_2^{IC} from equation (1) was used to calculate the muon cross section taking the value of $R = \frac{\sigma_L}{\sigma_T}$ to be zero. The cross sections in the kinematic range (defined above), where the apparatus had high ($\sim 30\%$) acceptance, was then calculated making the following assumptions. The struck charmed quark was assumed to fragment to a D meson, with the D meson acquiring a fraction z of the charmed quark's momentum in the laboratory frame. The fragmentation function was deduced from the measured decay muon momentum spectrum to be $\exp[(1.6 \pm 1.6)z]$ [7]. The D meson was then assumed to decay semileptonically with a branching ratio of 8.2% [8]. Half the decays were assumed to produce $K^*(890)$ and half to produce K mesons and the weak interaction form factors were taken to be unity. Different models for the fragmentation process were tried and the uncertainty in the intrinsic charm curve due to the fragmentation and the semileptonic branching ratio is $\pm 35\%$ and approximately independent of x_{Bj} .

The smooth curve labelled PGF in fig. 2 is the absolute prediction of the photon-gluon fusion model [2] (i.e. from extrinsic charmed quarks). In this model the charmed quark mass was again taken to be 1.35 GeV [9], the gluon momentum (η) distribution [2] to be

$$\eta G(\eta) = 3 (1 - \eta)^5$$

and the running coupling constant

$$\alpha_s = \frac{12\pi}{25 \log \frac{(Q^2 + \hat{s})}{\Lambda^2}}$$

with $\hat{s}$ being the total energy squared of the $c\bar{c}$ pair in the photon-gluon rest frame. Λ was set to 0.30 GeV. About the same model prediction can be obtained with for example $\Lambda = 0.15$ GeV [10] if the fragmentation or the branching ratio is changed within the measured uncertainty. A fraction $\frac{5}{6}$ of the cross section for $c\bar{c}$ production in the range $4M_c^2 < \hat{s} < 4M_D^2$ (M_D = mass of the D meson) [11] was

included, which contributes about 14% to the total dimuon cross section. In order to calculate the cross section in the defined kinematic range, the charmed quarks were assumed to fragment and decay semileptonically as in the intrinsic charm model. The uncertainty in the absolute height is also $\pm 35\%$.

It can be seen from fig. 2 that the data are well represented in shape by the photon-gluon fusion model with its normalisation being low by $\sim 20\%$ at low x_{Bj} . This discrepancy in normalisation is within the systematic uncertainty of the model. At high values of x_{Bj} , the data tend to be further above the PGF curve but are still much below the contribution expected from intrinsic charm (curve IC). The data were fitted to the sum of the intrinsic charm and photon-gluon fusion predictions each with free normalisation, giving the result $\lambda = (0.12 \pm 0.12)\%$. Allowing for the uncertainties in the prediction due to the fragmentation and decay we find that $\lambda < 0.28\%$ (90% confidence level).

Recently it has been suggested [12] that intrinsic charm could exist at low Q^2 in order to explain the hadroproduction data and that it would evolve away at higher Q^2 in order to be compatible with deep inelastic virtual photo-production of charm. The function $c(\xi)$ was assumed to evolve according to the Altarelli-Parisi equations [13] and maximum evolution was built into the model by neglecting the charmed quark mass and assuming α_s to be fixed at 0.4 [14]. The result of this calculation is shown by the dashed curve in fig. 2. It can be seen that at high x_{Bj} the predicted contribution of intrinsic charm still lies above the data. Performing the fit, described above, to the PGF model and the dashed curve gives a result $\lambda = (0.28 \pm 0.24)\%$ or allows a limit on λ to be set at 0.59% (90% confidence level).

Some threshold behaviour is introduced by using the variable ξ rather than x_{Bj} in equation 2. Other forms of ξ give similar results. For example $\xi = (Q^2 + 4M_c^2)/2Mv$ leads to results which are about 20% lower at large x_{Bj} [11]. For an additional arbitrary threshold behaviour [15] to account for the small contribution of intrinsic charm allowed by the data, a form $(1 - \frac{W_{th}^2}{W^2})^n$ with $n \sim 7$ would be required. Here W_{th} and W are the charm threshold and total virtual photon-proton c.m. energies.

In conclusion, virtual photoproduction of charm has been studied and is found to be rather well represented by the photon-gluon fusion model (i.e. extrinsic charmed quarks) over the measured range of Bjorken x . The contribution of intrinsic charm as proposed in references [4] and [12] is incompatible with the data.

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Figure Captions

Fig. 1 Missing energy distributions of the final data samples,
a) and b) for the like and unlike sign dimuons.
The lower histograms show the calculated contribution of π , K decays.
The smooth curve labelled single arm is the distribution for deep
inelastic scattering events observed in this experiment [16].
c) for trimuons.

Fig. 2 Variation of $\frac{d\sigma}{dx_{Bj}}$ with x_{Bj} for dimuons in the range $Q^2 > 1 \text{ GeV}^2$,
 $60 < \nu < 220 \text{ GeV}$, decay muon energy $> 16 \text{ GeV}$. The horizontal
bars represent the bin widths. The curves are
PGF: photon gluon fusion model,
IC: intrinsic charm model,
ICE: intrinsic charm model with maximum Q^2 evolution.

Fig. 1

Fig. 2