DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 82-038
June 1982

CHARMED QUARK FRAGMENTATION INTO CHARMED HADRONS

by

L.M. Jones and R. Migneron

NOTKESTRASSE 85 · 2 HAMBURG 52

DESY 82-038
June 1982

CHARMED QUARK FRAGMENTATION INTO CHARMED HADRONS

L.M.Jones[1+] and R.Migneron[2++]
Theory Group,DESY
Notkestrasse 85
2000 Hamburg 52
W.Germany

1. Permanent address;Physics Department, 1110 West Green St.,Urbana,Ill. 61801(USA)

2. Permanent address;Dept. of Applied Math. U.of Western Ontario,London,Ontario, N6A5B9,Canada

+Supported in part by the U.S.National Science Foundation

++Supported in part by the NSERC of Canada

ABSTRACT

We show that in a model where fragmentation functions are created from jet calculus followed by recombination, the fragmentation functions of charmed quarks into heavy particles such as the D and Λ_c will fail to peak at low x at presently accessible values of Q^2. Predictions are made for the rate of D production in e^+e^- annihilation, and the ratio of Λ_c to D.

GENERAL METHOD

We use the Konishi-Ukawa-Veneziano(KUV) jet calculus/1/ to compute the distribution of partons in the jet, and a form of the recombination model to make these into mesons/2,3/ or baryons/3-5/. At present energies we allow only three flavors to participate fully in the jet evolution; i.e.gluons are not allowed to split into $c\bar{c}$ pairs at any stage in the evolution or recombination. Hence each charmed quark jet will contain only one charmed hadron, and no other jets will contain charmed particles. As shown in our previous papers(Refs.2-5) this approach has many appealing features, including approximate agreement with experiment for the production of non-charmed mesons and baryons.

In this letter we wish to stress one important feature of this model which strongly influences the energy spectrum of produced heavy particles. Consider the KUV formula for the 2 parton distribution

$$D_{a_1 a_2; i}(x_1, x_2; Q^2) = \sum_{b_1 b_2 j} \int_{Y_0}^{Y} dy \int_0^1 dx\, dz\, dw_1\, dw_2\, D_{a_1 b_1}(w_1, y - Y_0) \cdot \quad (1)$$

$$D_{a_2 b_2}(w_2, y - Y_0)\, \hat{P}^{(z)}_{j \to b_1 b_2}\, D_{ji}(x, Y - y)\, \delta(x_1 - x z w_1)\, \delta(x_2 - x(1-z) w_2)$$

where

$$Y = \frac{1}{2\pi b} \ln\left[1 + \alpha_0 b \ln Q^2/\Lambda^2\right] \; ; \; 12\pi b = 11 N_c - 2 N_f$$

with $$\alpha_s = \frac{1}{b \ln Q^2/\Lambda'^2} \; ; \; \Lambda'^2 = \Lambda^2 e^{-1/(b\alpha_0)}$$

We use $\alpha_0=10$.

The integration variable y represents the position of the splitting vertex P, as shown in Fig.1a. If the partons a_1 and a_2 are to be recombined into a hadron of mass M^2, the mass just before the splitting must always be greater than M^2. Hence the lower limit Y_0 in the KUV formula must obey $Y_0 > y(M^2)$.

Therefore, when the particle produced is quite heavy, the region of integration is much smaller than for the creation of light particles like pions,at present Q^2. Physically speaking, this means much less QCD radiation occurs and the original heavy quark tends to have most of the jet momentum. Hence charmed particles should be concentrated near large x.

In our studies of production of light particles, we showed that in fact in the KUV calculation the original quark usually is a "leading" quark, regardless of Y_0; it is more "leading" when Y_0 is larger. In addition, many pions and other light particles are produced at small x by splitting of the produced gluons into $q\bar{q}$ pairs and the subsequent recombination of these quarks. By forbidding the creation of $c\bar{c}$ pairs, we "turn off" this possibility. This is an approximation to more exact inclusion of the quark masses in the jet calculus, but it seems physically reasonable/6/.

For the production of baryons, we must compute the three parton distribution depicted schematically in Fig 1b. The explicit formula is given by Eq. 2 of Ref.4. Again we allow only three flavors to participate in the jet evolution.

PARAMETERS AND RESULTS

We begin with the available data for non-charmed particles. For the charged pions, for instance, we compute parton sets $q\bar{q}$,qg and gg. All final gluons are then converted into $u\bar{u}$,$d\bar{d}$ and $s\bar{s}$ pairs by a splitting function/7/ which conserves momentum, and all $u\bar{d}$ and $d\bar{u}$ pairs at x_a and x_b are recombined into mesons at x using the recombination function

$$2)\qquad 1.0\ \frac{x_a x_b}{x^2}\ \delta(x_a + x_b - x)$$

Similar calculations are performed for neutral pions, and kaons.

To compute proton yields,we calculate the uud distributions in the same way and recombine them using the recombination function

$$3)\qquad \frac{27}{4}\ \frac{x_a x_b x_c}{x^3}\ \delta(x_a + x_b + x_c - x)$$

(see Refs. 4 and 5 for details about the general features of production of non-charmed baryons as predicted in this model).

In Fig 2 we summarize the results of these calculations at Q^2=1089GeV^2. This figure should be compared with the data shown in Fig 4 of Ref 8. Further discussion of these results and comparison with experiment is contained in Refs.2-5.

We use the same procedure and recombination function to study the D production as were used for the pions and kaons. Only gc and $\bar{q}$c pairs need be computed in the jet calculus. Due to the large mass of the D, we consider the two possibilities Q_0^2=4 GeV^2 and Q_0^2=8GeV^2. In Fig 3a we show the energy dependence of the fragmentation function D_c^D; as shown it rises from a rather flat shape at low Q^2 to a more peaked shape at larger Q^2. For very large Q^2, we would have to include charmed quarks in the QCD evolution; the resulting $g\to c\bar{c}$ vertices would result in further peaking at low x. For comparison we show in Fig 3b the range of parameterizations

preferred by the EMC collaboration/9/ in fitting their charm production. Peaking at large x for D production is also preferred in other reactions/10/.

We can also compute charmed baryon production, by applying the same procedure to the three parton distribution. Using the recombination function of Eq. 3, we obtain the fragmentation functions shown in Fig.3c.

In Fig.4a we show the ratio of fragmentation functions into Λ_c and D, when both have been computed using a value Q_0^2=6 GeV^2. Note that the ratio decreases near x=1; as can be seen by comparison with Fig 4b, the behavior is more like (1-x) than like the $(1-x)^2$ we might expect from counting rule arguments. This behavior is unlike that for non-charmed baryons and mesons(see Ref.3) where the Q_0^2 is much larger for the baryons than the mesons, and one obtains a decrease in the baryon/meson ratio near x=1 only for very large Q^2.

The cross section $s d\sigma/dx$ for "primary" $D^0+\bar{D}^0$ production (equal in our present rough approximation to the production of $D^+ + D^-$ and to the production of each charged state of $D^* + \bar{D}^*$) is shown at a representative Q^2=900 GeV^2 in Fig.5 for the two values Q_0^2=4 and Q_0^2=8 GeV^2 Notice that at large x it is as large as the charged pion cross section (shown here as a dotted line).

Published data on D production distributions is not copious, although preliminary results at Q^2=900 GeV^2 are currently being discussed. SPEAR data at Q^2=50 GeV^2 reported by Rapidis et al/11/ show a rather flat distribution in x from x=.6 to x=.95; however since the minimum value of x allowed at this energy is .54, it is not clear how important kinematical corrections are. After allowing for D^* decay, our model approximately reproduces the ratio of D's to pions reported in Fig 3 of Ref. 11, at the largest x; but it underestimates both cross sections by approximately a factor of 2.

SUMMARY AND CONCLUSIONS

In this model the fragmentation function of the charmed quarks into charmed hadrons is necessarily quite flat at present energies;at the Q^2 values accessible in deep inelastic muon scattering, the functions generally peak near x=1. The results have many features in common with those hypothesized by Suzuki/12/ and Bjorken/13/ using momentum arguments. Similar peaking near large x was produced by Kartvelishvili et al./14/ in a model using Regge arguments for heavy quark trajectories. Their formula,however, lacks Q^2 dependence: so while it agrees with the data of Ref.11 it is not clear that it will be successful at very large Q^2 where the difference between D's and lighter mesons is not so crucial.

Due to the fact that charmed baryons and mesons have similar masses, the ratio of baryons to mesons will tend to decrease near x=1; this is simply because for a given energy it is harder to make 3 partons perturbatively and have them carry all the momentum than it is to make two.

The cross section for the production of primary D^0+$D^{\bar{0}}$ will be comparable in size to that of π^++π^- at large x. Our approximation to the overall size of the recombination term for the charmed quarks can of course be adjusted slightly when more data is known, as can the ratio of D^* to primary D production.

ACKNOWLEDGMENTS

We would like to thank the DESY theory group for their hospitality while this work was being done. In particular, conversations with F. Gutbrod and O. Nachtmann about the charmed quark fragmentation encouraged us to examine it in our framework. We would also like to thank Claus Grossing for discussions about the EMC data. R.M. would like to thank NSERC of Canada for a summer research fellowship.

REFERENCES

1. K.Konishi,A.Ukawa, and G.Veneziano, Phys.Lett.78B,243(1978);Nucl.Phys.B157,45(1979)

2. L.M.Jones,K.E.Lassila,U.Sukhatme and D.E. Willen Phys.Rev.D23,717(1981)

3. L.M.Jones and R.Migneron,"Properties of Gluon Jets", DESY 82-035

4. R.Migneron,L.M.Jones and K.E.Lassila, "Recombination Mechanism for Baryon Production in Jets",SLAC-PUB-2850(to be published in Physics Letters)

5. R.Migneron,L.M.Jones and K.E.Lassila, "Production of Protons and Lambdas in e^+e^- Jets from Jet Calculus and the Recombination Model",SLAC-PUB-2861

6. In practice, in computing the graphs shown in this paper, we have used the same "propagator" $D_{cc}(x,y)$ for the charmed quarks as $D_{uu}(x,y)$. At very small x, $D_{uu}(x,y)$ has an admixture of $u\bar{u}$ pairs which grows with Q^2. Hence our results, as shown here, overestimate the number of charmed quarks (and hence charmed D's) at small x and large Q^2. Since we expect kinematic corrections due to the D mass at small x for all Q^2, and since $c\bar{c}$ pairs certainly are eventually produced for large enough Q^2, we don't regard this as serious. We mention it only to be precise about our actual modus operandi.

7. V.Chang and R.C.Hwa,Phys.Rev.Lett.44,439(1980)

8. TASSO Collaboration,"$\Lambda,\bar{\Lambda}$, Production in e^+e^-Annihilation at 33 GeV Centre of Mass Energy",DESY 81-039

9. C.Gossling,"Production of Open Charm in Muon Nucleon Interactions",talk given at the XVII Rencontre de Moriond,March 1982

10. C.Peterson,talk given at the XIII International Symposium on Multiparticle Dynamics,Volendam,1982.

11. P.A.Rapidis et al,Physics. Letters 84B,p.507(1979)

12. M.Suzuki,Physics Letters 68B,164(1977)

13. J.D.Bjorken,Phys.Rev.D17,171(1978)

14. V.G.Kartvelishvili,A.K.Likhoded and S.R.Slavospitsky, Proceedings of the II International Symposium of Hadron Structure and Multiparticle Production,p.315, Kazimierz(1979);V.G.Kartvelishvili,A.K.Likhoded and V.A.Petrov, Phys. Letters 78B,615(1978)

FIGURE CAPTIONS

Fig 1.

a.Pictorial representation of Eq. 1. The lines with dots represent QCD "propagators" calculated in the leading log approximation. The variable of integration y is determined by the mass of parton j just before the vertex.

b)Pictorial representation of the jet calculus expression for the three parton inclusive cross section

Fig.2.Predictions at Q^2=1089 GeV^2 for the meson and proton plus antiproton production in e^+e^-annihilation using the parameters of Eq.3 for the baryons and Eq.2 for the mesons The option $Q\bar{Q}4$ (four flavors of quarks are making jets,but only 3 flavors are active in the evolution of the jets) is used. These should be compared with the Tasso data shown in Fig 4 of Ref 8.

Fig 3.

a)The fragmentation function D_c^D as a function of Q^2 for Q_0^2=4GeV^2. Note the change in shape from a peak at large x at low values of Q^2 to a peak at small x at large Q^2

b) For comparison with a) we show the range of parameterizations preferred by the EMC collaboration/9/ to fit their data with $1<Q^2<100 GeV^2$ In preparing this graph, these functional forms have been normalized to have roughly the same size at large x as our calculations in a).

c)The fragmentation function of charmed quarks into Λ_c as a function of Q^2 for Q_0^2=6 GeV^2 and Λ=.2GeV.

Fig 4.

a)Ratio of Λ_c production to D production if both are calculated using Q_0^2=6GeV^2

b)Two shapes commonly postulated for the baryon/ meson ratio

Fig 5. Expected size of D meson production in e^+e^- annihilation at Q^2=900GeV^2,compared with pion production. We show the predictions for two values of Q_0^2 which should probably bracket the correct value.

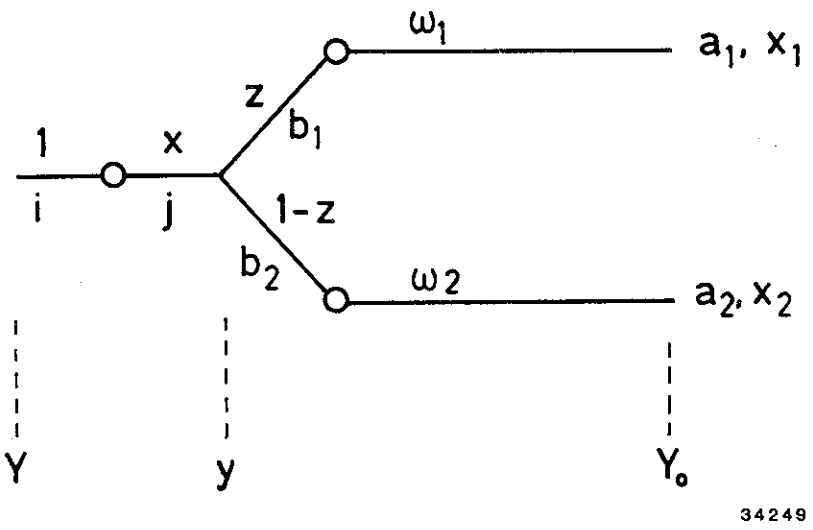

Fig 1a

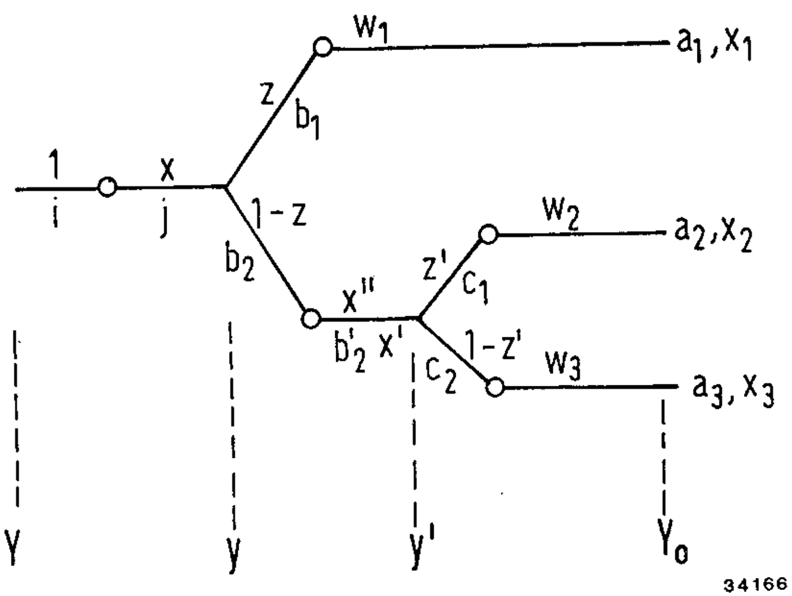

Fig 1b

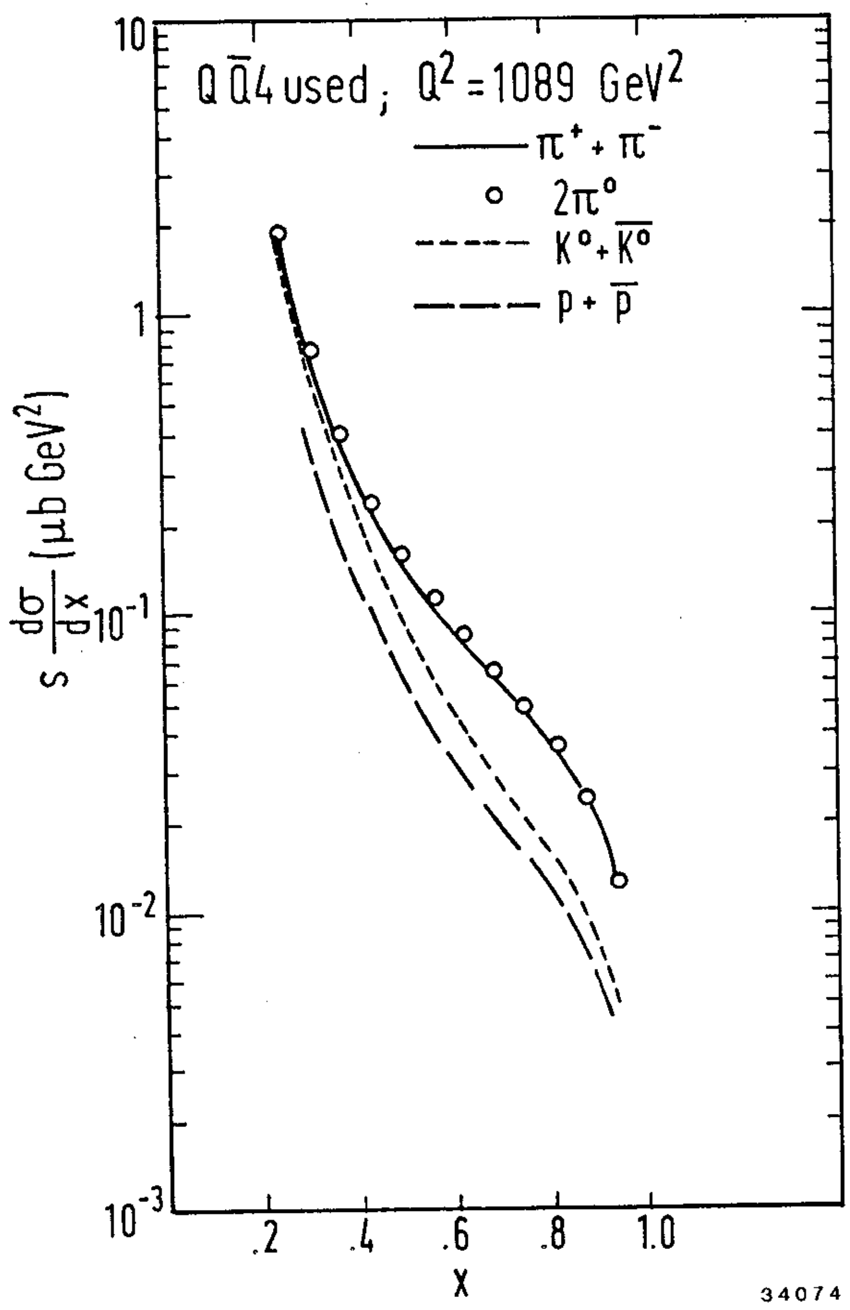

Fig 2

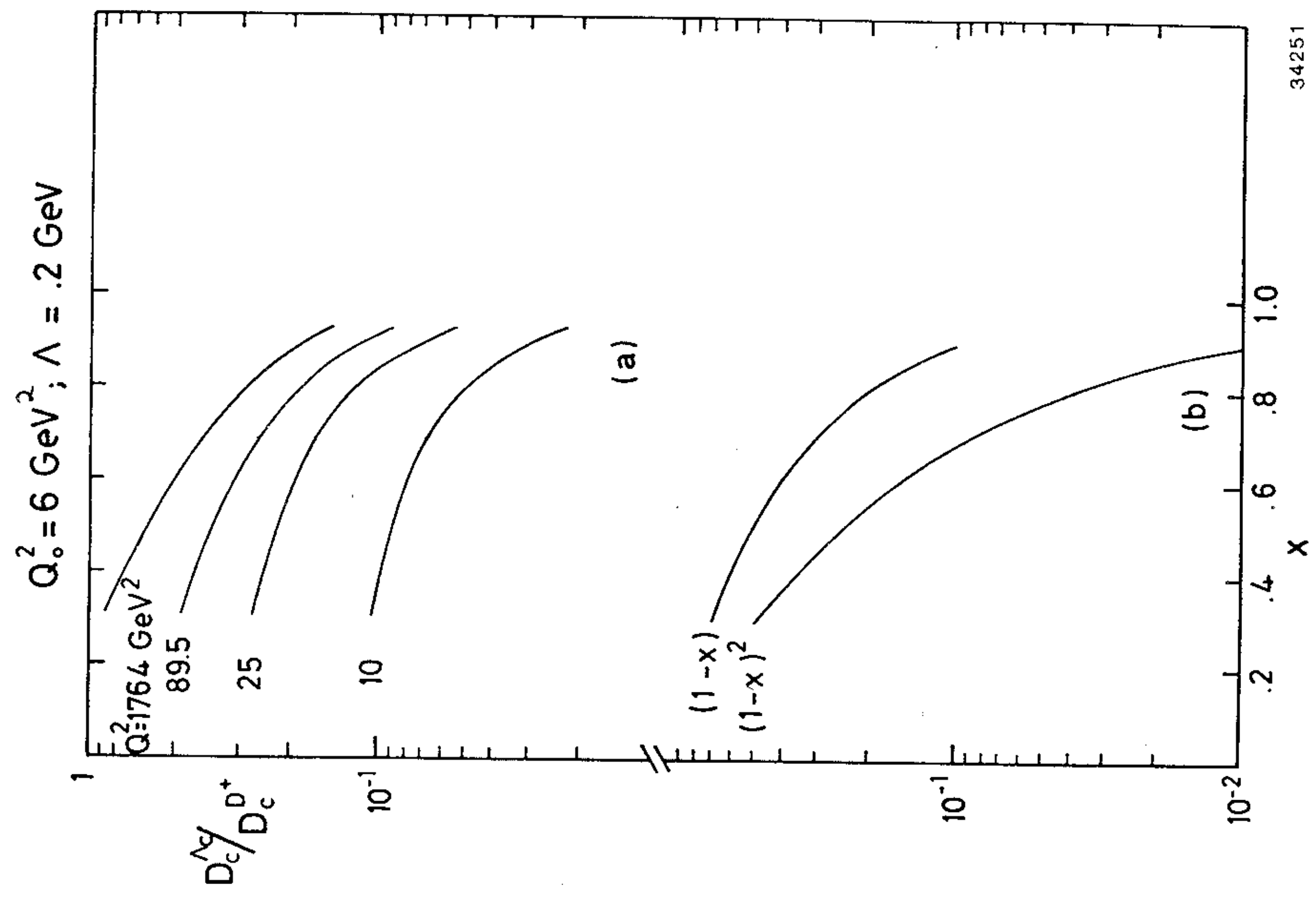
Q²₀ = 6 GeV²; Λ = .2 GeV
Q²=1764 GeV²
89.5
25
10
(a)
(1 - x)
(1 - x)²
(b)
D_c^Λc / D_c^D+
x
34251

Fig 4

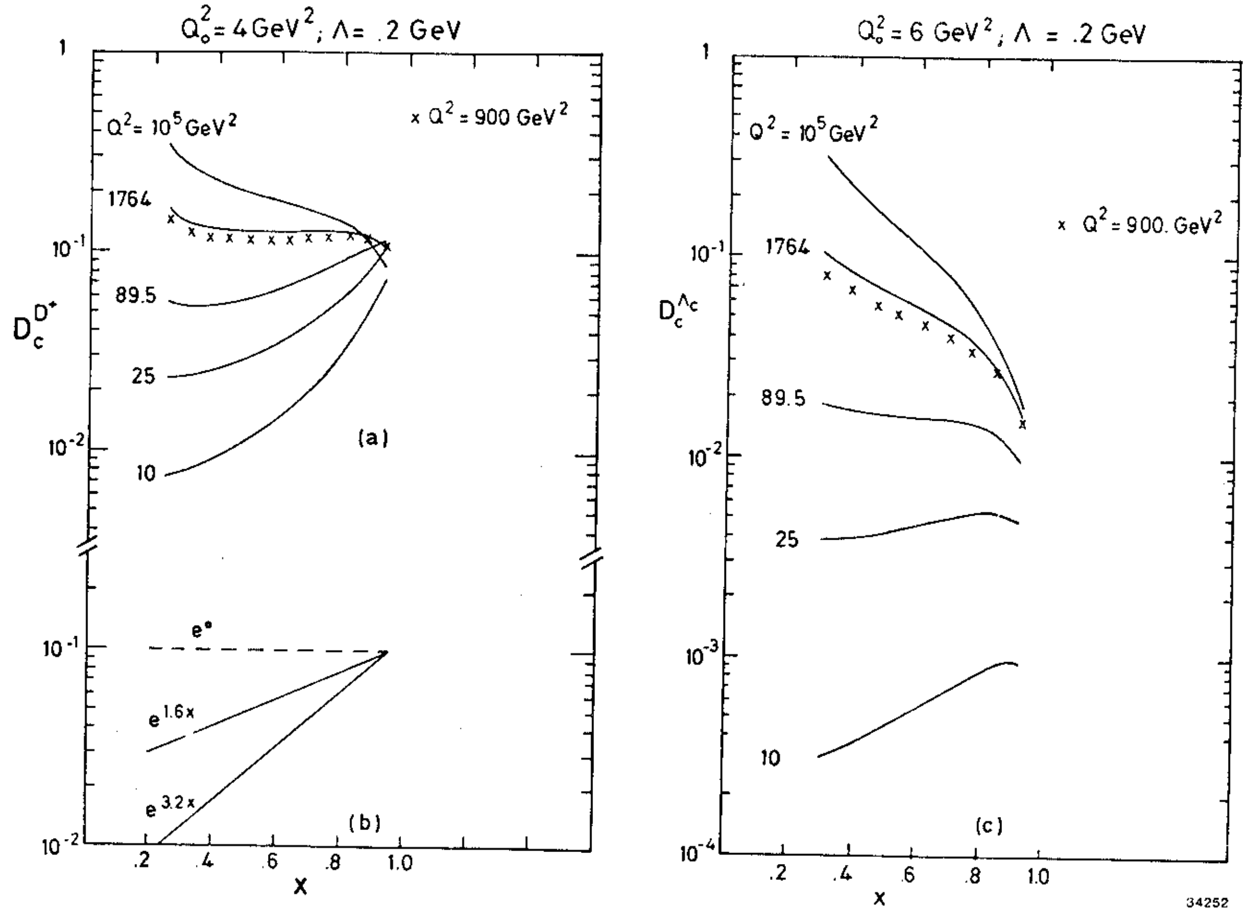
Q²₀ = 4 GeV²; Λ = .2 GeV
Q² = 10⁵ GeV²
× Q² = 900 GeV²
1764
89.5
25
10
(a)
e°
e^1.6x
e^3.2x
(b)
D_c^D+
x
Q²₀ = 6 GeV²; Λ = .2 GeV
Q² = 10⁵ GeV²
× Q² = 900. GeV²
1764
89.5
25
10
(c)
D_c^Λc
x
34252

Fig 3

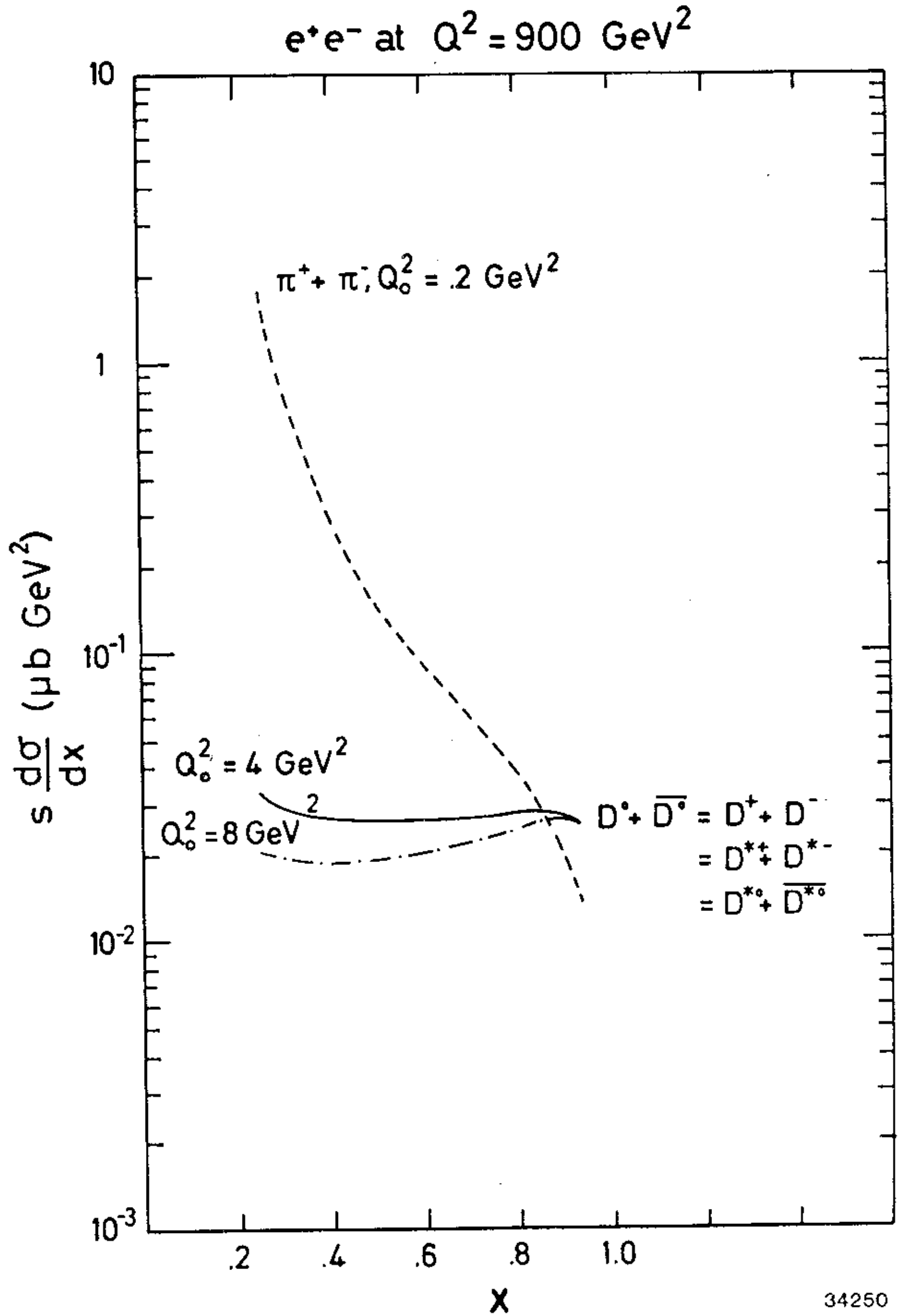
e+e− at Q2 = 900 GeV2
s dσ/dx (μb GeV2)
10
1
10-1
10-2
10-3
π+ + π−, Q02 = .2 GeV2
Q02 = 4 GeV2
Q02 = 8 GeV2
D0 + D̄0 = D+ + D−
= D*+ + D*−
= D*0 + D̄*0
.2
.4
.6
.8
1.0
X
34250

Fig 5