Understanding the Feynman-x distribution of charm D mesons produced in hadronic collisions

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An attempt has been made to demonstrate that the addition of the Drell-Yan-type diagram to the standard fusion contribution to charm production leads to the broadening of the x distribution of the charm D mesons compared to the fusion contribution alone. For the Drell-Yan-type calculation we have made two choices for the charm structure function: namely, soft charm and hard charm; the soft charm function shows a large difference between the leading and the nonleading D mesons, while the hard charm function does not show this difference.

The production of charm particles has been observed by several experiments[1–4] using high-energy π^- beams. The x distribution ($x=2p_{\parallel}^*/\sqrt{s}$) of charm D mesons has been obtained in two different experiments from well-reconstructed D decays: (i) the Lexan Bubble Chamber–European Hybrid Spectrometer (LEBC-EHS) Collaboration[1] from a sample of 57 decays with $x>0$ in 360-GeV/c $\pi^- p$ interactions, and (ii) the Amsterdam-Bristol-CERN-Cracow-Munich-Rutherford (ACCMOR) Collaboration[2] from a sample of 29 decays with $x>0.2$ (their acceptance was small for $x<0.2$) in 200-GeV/c π^--Be interactions. Results from LEBC-EHS Collaboration indicate a leading component in the x distribution from D mesons containing a valence quark of the incident beam particle, whereas the data of ACCMOR do not support a large difference in n between leading and nonleading D mesons [$d\sigma/dx \propto (1-x)^n$]. It may be noted that the shape of the x distribution from a nuclear target cannot be directly compared with that of the proton target because the exponent α, in $\sigma \propto A^{\alpha}$, is a function of x for strange-particle production;[5] the value of α is known to decrease with increasing x and hence the distribution when converted for the hydrogen target becomes flatter. In view of this we shall restrict ourselves to the hydrogen data in this paper.

There have been attempts[1,6] to understand the x distribution in the standard fusion model[7] of flavor creation via gluon-gluon and quark-antiquark fusion leading to $c\bar{c}$ production (c = charm quark) with subsequent fragmentation of the charm quark to D meson. This however is not able to reproduce the leading part of the data[1] with $x>0.5$. There have also been attempts to produce leading-particle effects, e.g., in the intrinsic-charm model[8] and the valon model.[9]

In this paper our purpose is to include the contribution of the Drell-Yan-type diagram of Fig. 1, where a charm quark from one hadron fuses with a light quark from the second hadron to form a D meson, along with the contribution from the standard fusion model. This diagram has been used in the past.[10] However, the usage of this Drell-Yan diagram necessarily needs the knowledge of the charm structure function of the hadron which is not known. For our purpose we shall assume two extreme examples of this function: (i) a soft charm quark like a strange sea in the hadron and (ii) a hard charm quark of the intrinsic-charm model.[8]

The x distribution in a Drell-Yan-type diagram for the production of inclusive D ($x_D=2p_{\parallel}^*/\sqrt{s}$) in reaction $A+B\to D+x$ at center-of-mass energy $\sqrt{s}$ is

$$\frac{d\sigma}{dx_D}=\frac{4\pi^2}{3(M_D{}^2-m_c{}^2)}\frac{g^2}{4\pi}\frac{\sqrt{s}}{2E_D}\sum_{q=u,d}[F_A^c(x_1)F_B^{\bar{q}}(x_2)+F_A^{\bar{q}}(x_1)F_B^c(x_2)+F_A^{\bar{c}}(x_1)F_B^q(x_2)+F_A^q(x_1)F_B^{\bar{c}}(x_2)]\ . \quad (1)$$

The fractional momenta x_1 and x_2 are given by

$$x_1^{\alpha}=(E_D/\sqrt{s}+x_D/2)J^{\alpha}\ , \quad (2a)$$

$$x_2^{\alpha}=(E_D/\sqrt{s}-x_D/2)J^{\alpha}\ . \quad (2b)$$

The additional index α ($=q/\bar{q}$ or $c/\bar{c}$) has been introduced to distinguish the constant J for the massless quark $q/\bar{q}$ and heavy charm quark $c/\bar{c}$: $J^{c/\bar{c}}=1$ and $J^{q/\bar{q}}=(1-m_c{}^2/M_D{}^2)$. Here m_c and M_D are the masses of the charm quark and the charm hadron D, respectively. By setting $m_c=0$ in Eq. (2) one gets back the standard expression for x (Ref. 10). g is the $Dc\bar{q}$ (or $\bar{D}\bar{c}q$) coupling and we take a typical value of $g^2/4\pi$ as 0.5 (Ref. 10).

The charm structure function, $F^c(x)\equiv xc(x)$, of the hadron is not known. We have used the following two forms: (a) a soft charm quark with $F^c_{\pi/p}(x)=0.0025(1-x)^8$, which corresponds to the charm suppression with respect to the strangeness in the sea[11] as $\sim\frac{1}{40}$, and (b) the hard charm quark of Brodsky *et al.*[8] with 0.5% of the intrinsic-charm component in the hadron:

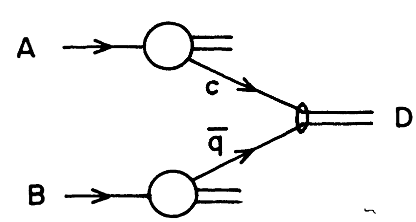

FIG. 1. Drell-Yan-type diagram for the production of a D meson.

$$F_{\pi}^{c}(x)=3x^3[\tfrac{1}{2}(1+4x-5x^2)+x(2+x)\ln x]\ , \quad (3a)$$

$$F_{p}^{c}(x)=9x^3[\tfrac{1}{3}(1-x)(1+10x+x^2) -2x(1+x)\ln(1/x)]\ . \quad (3b)$$

For the light-quark structure functions we have used the parametrizations of Duke and Owens[12] set 1 for the proton and that of Owens[13] set 1 for the pion—both with QCD scale parameter Λ as 0.2 GeV. The mass of the charm quark (m_c) is taken as 1.3 GeV.

The x distribution of the D mesons in the standard fusion model is calculated as per Ref. 6 with the fragmentation function $D(z)$ as $\delta(1-z)$, i.e., the momentum of the D meson to be the same as that of the c quark.[14] Quark structure functions and the values of m_c and Λ are kept the same as in the Drell-Yan calculation.

The results of our calculation for 360-GeV/c π^-p interactions are shown in Figs. 2–4; for pp interaction we have shown the results for 400 GeV/c and 800 GeV/c in Figs. 5 and 6, respectively. In all these figures the solid curve represents the sum of the fusion model and Drell-Yan diagrams with a soft charm quark, the dashed curve as the sum of the fusion model and Drell-Yan diagrams with a hard charm quark and the dot-dashed curve shows the contribution of fusion to the above two curves. It is

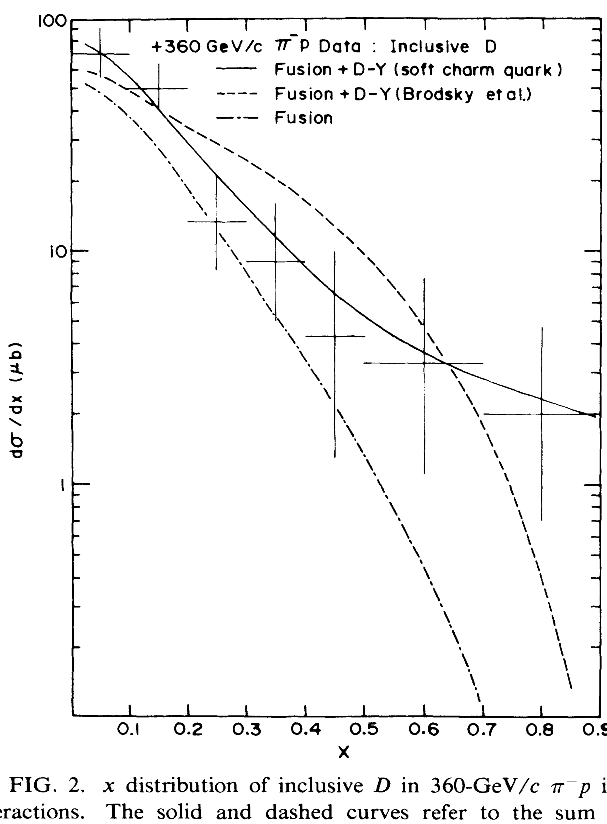

FIG. 2. x distribution of inclusive D in 360-GeV/c π^-p interactions. The solid and dashed curves refer to the sum of fusion model and Drell-Yan-type diagrams with soft charm function and hard charm function, respectively. The dash-dotted curve refers to the fusion contribution alone. Experimental data are taken from Ref. 1.

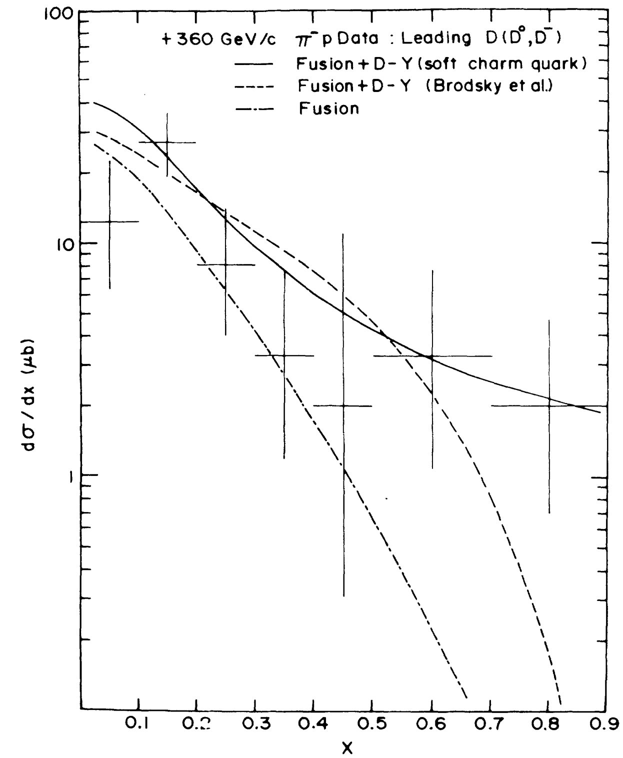

FIG. 3. x distribution of leading D (i.e., D^0+D^-) in 360-GeV/c π^-p interactions. The nomenclatures of the smooth curves are as in Fig. 2.

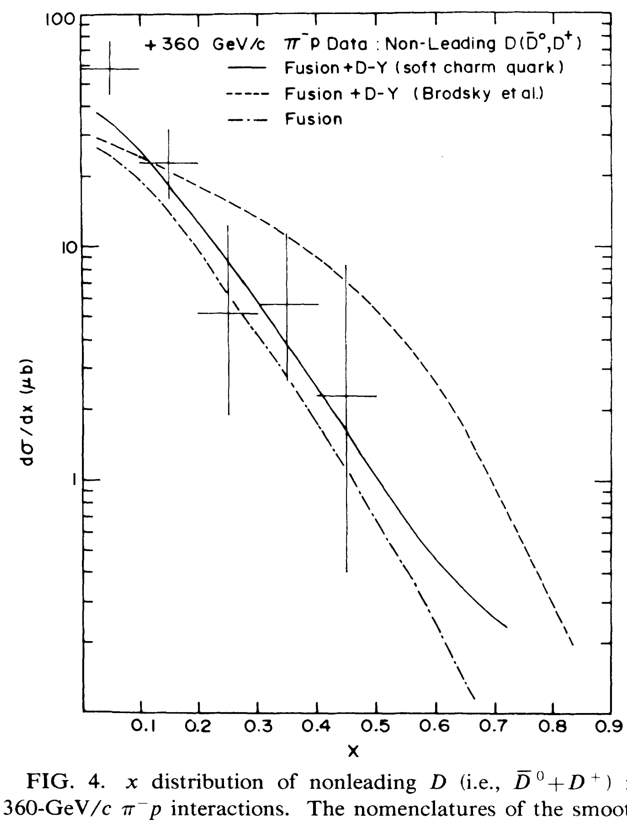

FIG. 4. x distribution of nonleading D (i.e., $\bar{D}^0+D^+$) in 360-GeV/c π^-p interactions. The nomenclatures of the smooth curves are as in Fig. 2.

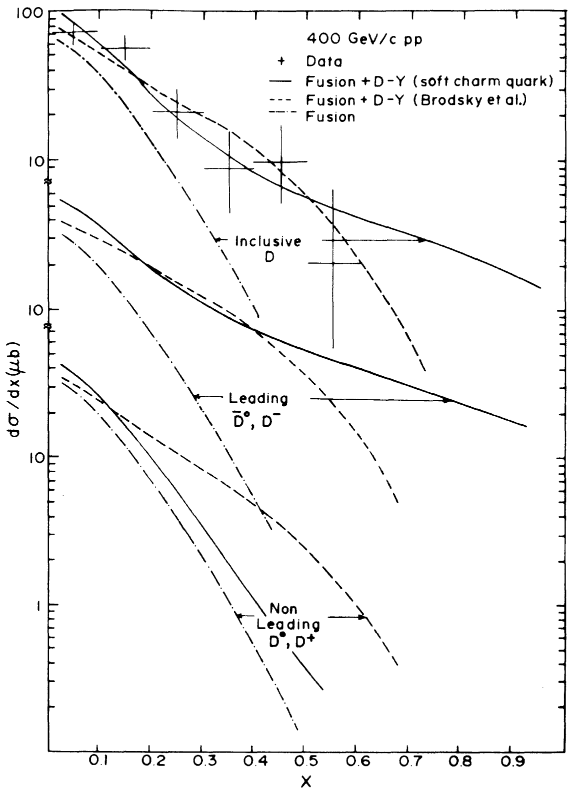

FIG. 5. x distribution of D mesons in 400-GeV/c pp interactions. The top part refers to inclusive D, the middle part to leading D (i.e., $\bar{D}^0+D^-$), and the bottom part to nonleading D (i.e., D^0+D^+). The data for the inclusive D are taken from Ref. 15. The nomenclatures of the smooth curves are as in Fig. 2.

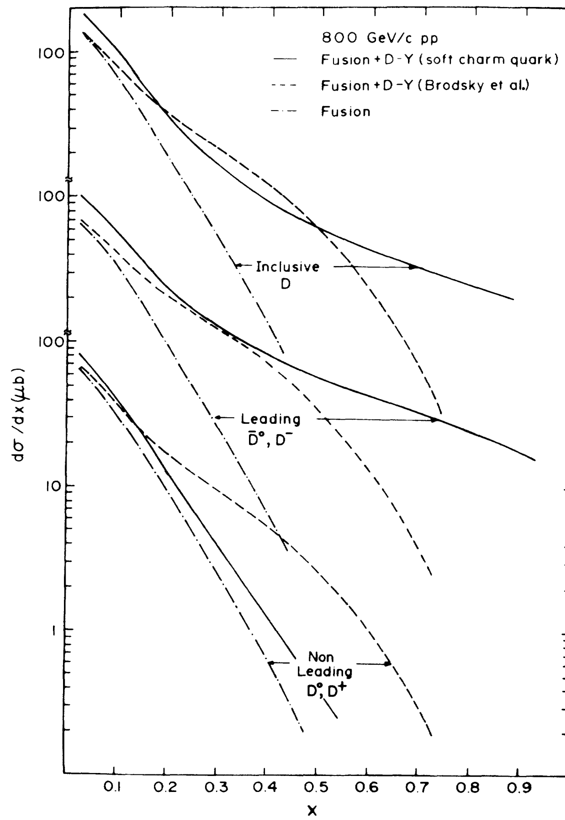

FIG. 6. x distribution of D mesons in 800-GeV/c pp interactions. The top part refers to inclusive D, the middle part to leading D (i.e., $\bar{D}^0+D^-$), and the bottom part to nonleading D (i.e., D^0+D^+). The nomenclatures of the smooth curves are as in Fig. 2.

clear from these figures that the addition of the Drell-Yan diagram broadens the x distribution compared to fusion contribution alone.

Comparisons of our results with the existing data are as follows.

π^-p data. (i) From Fig. 2 we find that the experimental inclusive D distribution[1] is reasonably reproduced by the sum of fusion and Drell-Yan diagrams; the data seem to prefer soft-charm-quark distribution. (ii) The leading D data (i.e., D^0 and D^-) of Fig. 3 and the nonleading (i.e., $\bar{D}^0$ and D^+) of Fig. 4 are also reasonably reproduced by the sum of fusion and Drell-Yan diagrams with a soft charm quark. The choice of a hard charm quark (dotted curves) does not lead to any difference between leading and nonleading distributions. (iii) The inclusive D cross section ($x>0$) as obtained for the sum of fusion and Drell-Yan diagrams with a soft charm quark is 16.5 μb and for the sum of fusion and Drell-Yan diagrams with a hard charm quark it is 17.2 μb to be compared with the experimental data of 15.8$\pm$2.7 μb (Ref. 1).

pp data. (i) The available inclusive D data at 400 GeV/c (Ref. 15) is compared with the calculation in Fig. 5 and it is seen that the data are well reproduced by the sum of fusion and Drell-Yan diagrams. (ii) There are no separate data on leading (i.e., $\bar{D}^0$ and D^-) and nonleading (i.e., D^0 and D^+), but there is an indication that there is no difference in x distribution between the two.[16] The usage of the soft charm quark (solid curves) shows a large difference between the leading and nonleading distributions ($\langle x\rangle_{\text{leading}}-\langle x\rangle_{\text{nonleading}}=0.10$) as in π^-p case, whereas the usage of the hard charm quark does not show any significant difference between the leading and nonleading distributions ($\langle x\rangle_{\text{leading}}-\langle x\rangle_{\text{nonleading}}=0.02$); the pp data therefore seem to prefer the hard-charm-quark distribution. (iii) The calculated inclusive D cross section ($x>0$) at 400 GeV/c is 18.2 μb for the solid curve and 16.5 μb for the dotted curve to be compared with the experimental data of 17.2$\pm$2.1 μb (Ref. 15); the mean value of x is 0.17 for both the solid and the dotted curve, while it is only 0.10 from fusion. (iv) We have shown in Fig. 6 the expected distributions at 800 GeV/c for which the data will soon be available from the E743 experiment at Fermilab. The expected mean value of x for inclusive D is 0.15 for both the solid and the dotted curves, respectively, while it is only 0.09 from fusion. The calculated inclusive D cross section ($x>0$) is 27.4 μb for the solid curve and 23 μb for the dotted curve to be compared with the experimental value of 29^{+11}_{-8} μb (Ref. 15) at 800 GeV/c.

We have thus demonstrated that by adding the contribution of the Drell-Yan-type diagram to the standard fusion model it is possible to get broader x distribution compared to that from the fusion model alone. We have made two choices for the charm structure function and the results are as follows. (i) The soft charm function leads to a large difference in x distribution between leading and nonleading D mesons in $\pi p/pp$ interactions, while the hard charm function does not show any significant difference between the two distributions in $\pi p/pp$ interactions. (ii) $\pi^- p$ data from LEBC-EHS and ACCMOR are not in agreement with each other regarding the difference between leading and nonleading x distributions. (iii) There is an indication from pp data that there is no difference between leading and nonleading distributions and if so it supports hard charm function.

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