FRAGMENTATION OF POLARIZED HEAVY QUARKS

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Relying on the fact that the fragmentation of a $\overline{b}$ antiquark or a c quark into the B_c and B_c^* mesons is hard enough to employ the perturbative quantum chromodynamics, we calculate the fragmentation functions for production of these mesons depending on spin orientation of the initial antiquark (quark). We find that this spin orientation may affect the fragmentation spectrum considerably provided that the spin of the final state $\overline{c}$ (b) jet is determined.

1 Introduction

Quark fragmentation into mesons and baryons has received attention for a long time. While the fragmentation of light quarks such as u, d and s quarks are effectively illustrated by statistical models [1], fragmentation of c and b quarks into mesons like D, D^* and B, B^* are considered as soft quantum chromodynamics phenomena. By this we mean that the fragmentation process could not be described by perturbative quantum chromodynamics. In such situations phenomenological models such as Peterson [2] are employed to describe the phenomena satisfactorily within the frame of existing uncertainities. On the other hand we know that the last quark of the standard model namely the t quark would not materialize into a hadron due to its very large mass [3]. Therefore the unique possiblity which remains is the fragmentation of either a $\overline{b}$ antiquark or a c quark into the B_c and B_c^* mesons. In this case it is believed that the perturbative quantum chromodynamics may be applied to calculate the fragmentation functions [4].

It is revealed from the standard model and also from many experimental collaborations that the quarks produced in certain circumstances are polarized longitudinally [5]. Now it remains to be seen what happens to quark polarization when it fragments into a meson? In view of our discussion of previous paragraph, this question may only be relevant in the case of B_c and B_c^* fragmentation. Of course even in this case there will be depolarization sources like spin-spin forces which depend on the mass difference between the two states.

In the present work we calculate the fragmentation functions for B_c and

B_c^* mesons taking into account the polarization of the initial antiquark (quark) and see to what extent this polarization may affect the fragmentation spectrum in the absence of any depolarization effect.

2 Fragmentation of Polarized Heavy Quarks

In leading order of perturbative quantum chromodynamics the process of a heavy quark fragmenting into a meson is usually described by a dimentionless function $D_{Q\to M}(z,\mu)$ which illustrates the formation of a meson M out of a quark Q which takes the fraction z of the initial quark energy momentum at some appropriate scale μ. The scale is chosen such that the perturbative quantum chromodynamics is applicable. We assume that they are calculated using [6]

$$D_{Q\to H}(z,\mu)=\sum_s\int d^3pd^3k'd^3k|T_M|^2\delta(p+k+k'-p'), \tag{1}$$

where T_M is the probability amplitude,

$$T_M=\frac{4\pi\alpha_s m_1 m_2}{2\sqrt{2p_\circ p'_\circ k_\circ k'_\circ}}\frac{\overline{u}(p',s_{p'})\gamma_\mu u(p,s_p)\overline{u}(k',s_{k'})\gamma^\mu v(k,s_k)}{(k+k')^2(p_\circ+k_\circ+k'_\circ-p'_\circ)}. \tag{2}$$

Here $\alpha_s=g^2/4\pi$ is the strong interaction coupling constant, m_1 and m_2 are quark masses with $m_2>m_1$.

The kinematics and calculational procedures are similar to what appears in references [6,7]. For simplicity we have sumed over all meson final spin states. We have used the general energy and spin projection operators in massless limit. In this limit we have obtained the following results

$$|\Gamma(Q\uparrow,q\uparrow)|^2=|\Gamma(Q\downarrow,q\downarrow)|^2\propto m_1m_2(p'.k') \tag{3}$$

$$|\Gamma(Q\uparrow,q\downarrow)|^2=|\Gamma(Q\downarrow,q\uparrow)|^2\propto\frac{m_1}{m_2}(p.p')(p.k') \tag{4}$$

We have used the REDUCE program for our trace calculations. Similarly we find

$$|\Gamma(\text{Spin Ave.})|\propto\frac{m_1}{m_2}\Big[(p.p')(p.k')+m_2^2(p'.k')\Big]. \tag{5}$$

If we add up (4) and (5), we find $|\Gamma(Q\uparrow)|^2=|\Gamma(Q\downarrow)|^2$ whose avarage value is identical to (6). The corresponding fragmentation functions are obtained by putting (4), (5) and (6) along with (2) into (1) and performing the phase space integrations. We find

$$D_{Q\uparrow,q\uparrow}(z)=D_{Q\downarrow,q\downarrow}(z)=\frac{N}{zF(z)}\left[1-2\frac{\langle k_\perp^2\rangle}{m_{\perp2}^2}\frac{1}{1-z}+\frac{m_{\perp1}^2}{m_{\perp2}^2}\frac{1}{(1-z)^2}\right], \tag{6}$$

and

$$D_{Q\uparrow,q\downarrow}(z) = D_{Q\downarrow,q\uparrow}(z) = \frac{N}{zF(z)}\left[1+\frac{m^2}{m_{\perp 2}^2}\frac{1}{z^2}+\frac{m_{\perp 1}^2}{m_{\perp 2}^2}\left(1-\frac{m_2^2}{m^2}z^2\right)\frac{1}{(1-z)^2}\right], \quad (7)$$

with

$$F(z) = \left[1 - 2\frac{m_1}{m_2} - \frac{1}{z} - \frac{m_{\perp 1}^2}{m^2}\frac{z}{1-z}\right]^4. \quad (8)$$

Here $m_{\perp 1}^2 = m_1^2 + \langle k_\perp^2\rangle$, $m_{\perp 2}^2 = m_2^2 + \langle k_\perp^2\rangle$ and $m = m_1 + m_2$. The input parameters for the above functions are quark masses $m_u = m_d$=0.3 GeV, m_c =1.5 GeV and m_b = 4.9 GeV bearing in mind that we have assumed $m_2 > m_1$. The optimum value of $\langle k_T^2\rangle$ is 1 GeV^2 in agreement with [6].

It is also possible to calculate such functions with definite polarization of the produced meson. Such calculations agree with (7) and (8).

3 Results and Discussion

We have obtained quark fragmentation functions which depend on its spin orientation. They are presented in fragmentation scale and are all normalized to unity. We have examined our fragmentation functions for various mesomic states. First of all we should stress that the determination of final state jet polarization is crucial. In other words if we do not fix this polarization it would be meaningless to talk about intial quark polarization as far as fragmentation is concerned. Our examination shows that the functions get more peaked in the cases of $\uparrow\uparrow$ or $\downarrow\downarrow$ and soften in the cases of $\uparrow\downarrow$ or $\downarrow\uparrow$ leaving the spin avarage case in between. The effect is more striking in the cases of $\bar{c} \to \eta$, ψ and $\bar{b} \to B_c$, B_c^*. We estimate that this would affect the fragmentation probability and the avarage fragmentation parameter, $\langle z\rangle$, up to 20%.

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