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THE ROLE OF QUARK POLARIZATION IN HEAVY QUARK FRAGMENTATION

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Abstract

We calculate the exact fragmentation functions for c and b quark fragmentation taking into account the spin orientation of the initial heavy quark in the form of analytical and rather simple expressions. Our calculations show that spin orientation may have an important effect on the fragmentation spectrum. This effect is more striking in the cases of $c \to D, D^*$; $c \to \psi, \eta$, and $\bar{b} \to B_c, B_c^*$.

1. Introduction

The phenomenon of heavy quark fragmentation has received great attention in the last decade. It has been shown that the fragmentation functions which are needed for the calculation of production cross section of hadrons at the colliders, are calculable in perturbative quantum chromodynamics [1]. Using this technique, the fragmentation functions for mesons containing one or two heavy quarks have been calculated [2]. In all these calculations the average of spin states of the initial heavy quark and sum over spin states of final state particles are carried out. However the standard model prediction and recent experimental confirmation of longitudinal polarization of quarks produced at the colliders such as Z° decay in e^+e^- annihilation [3] incites looking at the procedure more closely by taking this polarization into account.

In the case of baryons, systems such as Λ_s, Λ_c and Λ_b are important. It is sought that u and d quarks in these systems form a spin singlet [4] and therefore the spin of the system is carried by the heavy quark. This phenomenon is interesting two fold. First it permits the study of u and d quark spin contribution to the baryon spin [5]. Second, it concerns determination of Λ's spin and hence tests the standard model [6]. Therefore in the case of mesons it is interesting to look at the fragmentation spectrum watching the spin orientation of initial heavy quark.

In this study we have taken the case of massless quarks into account for simplicity and have obtained the fragmentation spectrum by introducing the quark's polarization with the use of projection operators. We draw our conclusions in the case of D, B, B_c and j/ψ meson state production.

2. Fragmentation of Polarized Heavy Quark

In leading order of perturbative quantum chromodynamics the Feynman diagram for a heavy quark fragmenting into a meson is shown in Figure 1. Usually the procedure is described by a dimensionless function $D_{Q\to H}(z,\mu)$ which illustrates the formation of a hardon H 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 QCD is applicable. We assume that they are calculated using [7]

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

where T_M is the probability amplitude

$$T_M=\frac{4\pi\alpha_s m_1 m_2}{2\sqrt{2p_0 p_0' k_0 k_0'}}\,\frac{\Gamma}{(k+k')^2\,(p_0+k_0+k_0'-p_0')} \qquad (2)$$

Here $\alpha_s=g^2/4\pi$ is the strong interaction coupling constant, m_1 and m_2 are quark masses with $m_2>m_1$ and Γ indicates that part of the amplitude which embeds spinors and gamma matrices involved in the interaction illustrated in Figure 1. It has the following structure

$$\Gamma=\bar{u}(p',s_{p'})\,\gamma_\mu u(p,s_p)\,\bar{u}(k',s_{k'})\gamma^\mu v(k,s_k). \qquad (3)$$

It is assumed that all soft bound state effects are absorbed in T_M. Indeed we have assumed that up to a certain scale the meson constituents fly almost parallel. The kinematics and calculation of the fragmentation function are similar to what appears in references [7,8]. For simplicity we have not taken the spin of the bound state into account and have performed sum 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

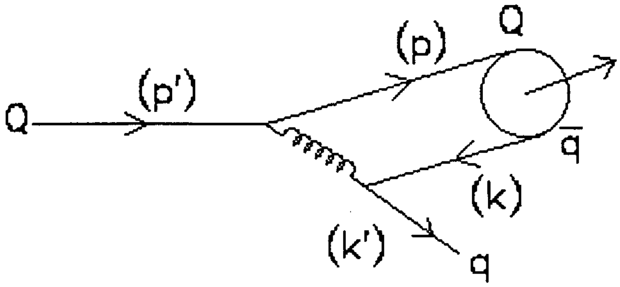

Figure 1. A typical heavy quark emits a gluon which produces a quark-antiquark pair. The heavy quark picks up the antiquark to form a heavy meson. The four momentua are labeled.

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

$$|\Gamma(Q\uparrow,q\downarrow)|^2=|\Gamma(Q\downarrow,q\uparrow)|^2\propto \frac{m_1}{m_2}(p.p')(p.k') \qquad (5)$$

We have used the code REDUCE for our trace calculations. Similar calculations for spin average case give

$$|\Gamma\ (\text{Spin Ave})|^2\propto\frac{m_1}{m_2}\left[(p.p')\,(p.k')+m_2^2\,(p'.k')\right] \qquad (6)$$

If we add (4) and (5), we find $|\Gamma(Q\uparrow)|^2=|\Gamma(Q\downarrow)|^2$ whose average 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 have obtained

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

$$D_{Q\uparrow q\downarrow}(z)=D_{Q\downarrow q\uparrow}(z)=\frac{N}{zF(z)}\left[1+\frac{m^2}{m_{\perp 2}^2}\frac{1}{z^2}+\frac{m_{\perp 1}^2}{m_{\perp 2}^2}\left(1-\frac{m_2^2}{m^2}z^2\right)\frac{1}{(1-z)^2}\right] \qquad (8)$$

where

$$F(z)=\left[1-2\frac{m_1}{m_2}-\frac{1}{z}-\frac{m_{\perp 1}^2}{m^2}\frac{z}{1-z}\right]^4. \qquad (9)$$

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 $\langle k_\perp^2\rangle$ is 1 GeV² in agreement with [7].

3. Results and Discussion

We have obtained quark fragmentation function which depend on their spin orientation. We have considered our fragmentation functions on the fragmentation scale and do not consider their evolution here. They are all normalized to unity. Figures 2-5 show the behaviour of

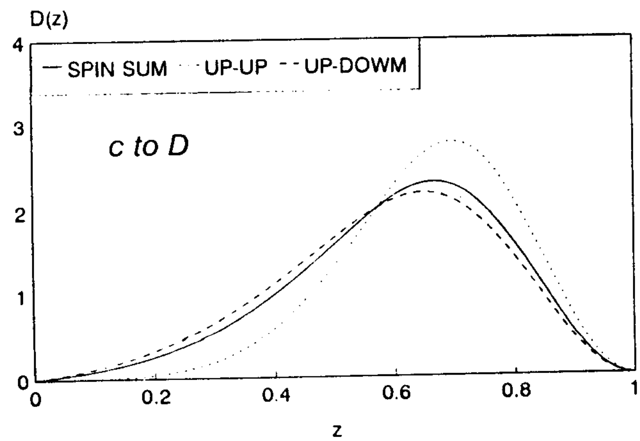

Figure 2. Fragmentation functions for different spin orientation for contributing particles in the case of $c\to D$.

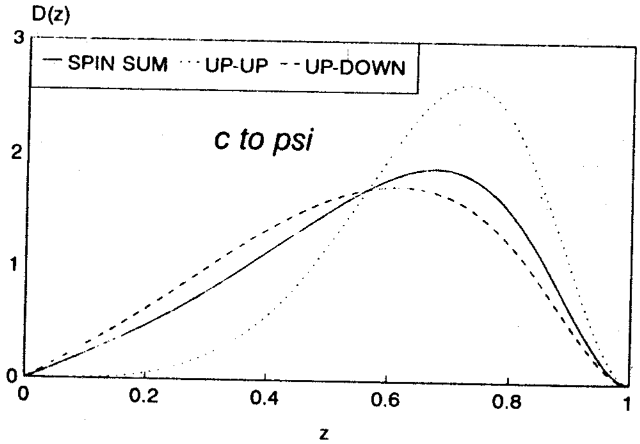

Figure 3. The same as Figure 2 but in the case of $c \rightarrow \psi$.

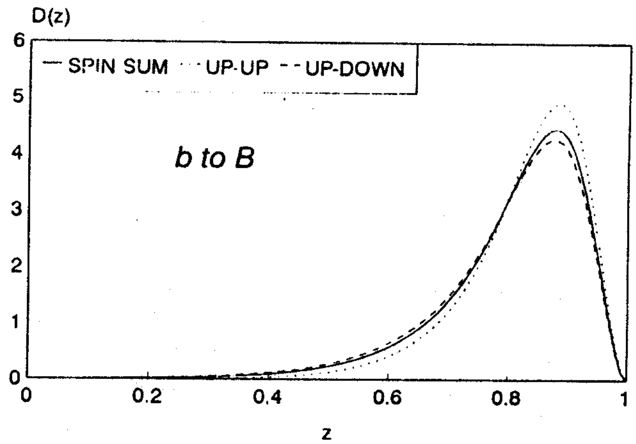

Figure 4. The same as Figure 2 but in the case of $b \rightarrow B$.

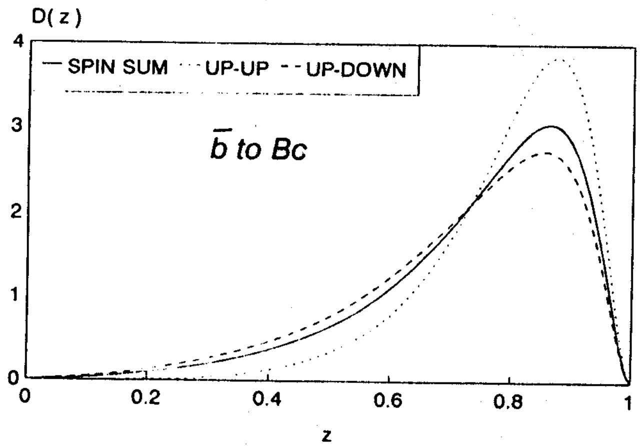

Figure 5. The same as Figure 2 but in the case of $\bar{b} \rightarrow B_c$.

our results in different mesonic states containing c and b quarks. They show that due to spin orientation the average fragmentation parameter, $\langle z \rangle$ is not affected considerably. However the fragmentation probability may vary for different orientations. This effect is more striking in the case of $c \rightarrow$D, ψ and η, and also $\bar{b} \rightarrow B_c$, and B_c^*.

References

1. Braaten, E. *et al, Phys. Rev*, **D 48**, 5049, (1993).
2. Braaten, E. and Yuan, T.C. *Phys. Rev. Lett*, **71**, 1673, (1993); Braaten, E. *et al, Phys. Rev*, **D 48**, 4230, (1993).
3. Buskulie, D. *et al, ALEPH Collab. Phys. Lett*, **B 374**, 319, (1996).
4. See for example Martin, B.R. and Show, G. *'Elementary Particles'*, John Wiley & Sons, (1994).
5. Jaffe, R.L. *Preprint hep-ph*/9605456, 18 Jul 1996.
6. Falk, A.F. *Phys. Rev. Lett*., **77**, 223, (1996).
7. Suzuki, M. *Phys. Rev*. **D 33**, 676, (1986).
8. Gomshi Nobary, M.A. *J. Phys. G: Nucl. Part. Phys*., **20**, 65, (1994).