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SEEING THE B MESONS IN HADRONIC COLLISIONS^{*)}

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ABSTRACT

The weak decays $B \rightarrow \psi(J) + X$ are investigated. It is argued that these decays are dominated by $B \rightarrow \psi(J) K\pi$ (branching ratio of about 1%). Detailed predictions for these decays are made.

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Recently the author has argued ¹⁾ that the best way to discover the B mesons [mesons of quark composition $(\bar{u}b) \sim B^-$ and $(\bar{d}b) \sim B^0$, where b is a heavy quark of charge $(-1/3)$ (constituent of $\gamma(9.5)$] is to look for the decays $B \rightarrow \psi(J) + X$, for several reasons:

a) The $\psi(J)$ particle can easily be produced in the weak decay of the B meson, provided the b-quark decays sequentially ($b \rightarrow c \rightarrow s$), since in this case one can have the weak decay $b \rightarrow c\bar{c}s$, and the $(\bar{c}c)$ pair can form a $\psi(J)$. We have estimated ¹⁾ that the production of a $\psi(J)$ in the B decay occurs relatively often:

$$\frac{\Gamma(B \rightarrow \psi(J) + X)}{\Gamma(B \rightarrow \text{all})} \approx 3 \dots 5 \% \quad (1)$$

b) The $\psi(J)$ meson can easily be identified via its $\mu^+\mu^-$ or e^+e^- decay mode.

c) Since the $\psi(J)$ state is very heavy, the amount of multiparticle phase space is greatly reduced in case of the decay $B \rightarrow \psi X$. Thus the remaining hadronic system X is expected to be relatively simple. Since the weak decay $b \rightarrow c\bar{c}s$ leads to a s-quark, the system X must contain a K meson. Thus we may have $X = K, K\pi, K\pi\pi, \dots$. In ref. (1) it was argued that the simple cases $X = K, K\pi$ should constitute a non-negligible fraction of all decays of the type $B \rightarrow \psi(J) + X$.

Recently a bump at $M = 5.3$ GeV has been observed in the channel $\psi K\pi$ at CERN (WA11 experiment, using a π -beam of 150 ... 175 GeV ²⁾, which we may identify with the B meson. In this case one has

$$\sigma(B) \cdot B(B \rightarrow \psi K\pi) \sim 1 \text{ nb}. \quad (2)$$

If the corresponding branching ratio is of the order of 1%, one finds:

$$\sigma(B) \sim 100 \text{ nb}, \quad (3)$$

which agrees with the cross section for producing B mesons in hadronic reactions estimated in ref. (3).

In this note we should like to study the decays of the type $B \rightarrow \psi(J) + X$ in more details. Such decays can occur in two different ways:

A. The $\bar{c}c$ -system produced in the weak decay $b \rightarrow c \bar{c} s$ forms directly a $\psi(J)$ state.

B. The $\bar{c}c$ -system forms initially another $\bar{c}c$ -state (ψ' , χ -meson), which decays into the $\psi(J)$ by a radiative or hadronic decay.

Certainly the decays of the type A are much easier to observe than the decays of type B. For this reason we shall concentrate on the type B decays. We expect that about 50% of all $B \rightarrow \psi(J) + X$ decays are of type A¹⁾..

Below we shall study a very naive model of the type A decay, which is certainly too simple in order to describe the decays of type A exactly but may well be a good approximation. We assume that the $\psi(J)$ state in the type A decay is formed before the final state interaction between the light u or d quark (the second constituent of the B meson) and the emitted s quark sets in. Since the $\psi(J)$ state is relatively small on the typical hadronic scale of 10^{-13} cm, this may be a good approximation to the real situation. Furthermore, we neglect the motion of the quarks inside the B meson, the binding energy of the quarks and use the constituent quark masses $m_b = 5$ GeV, $m_c = m_d = 0.3$ GeV, $m_s = 0.45$ GeV ($M_B = 5.3$ GeV $= m_b + m_u$). Thus we can describe the decay $B \rightarrow \psi(J) + X$ by the effective b -quark decay $b \rightarrow \psi(J) + s$. In the rest system of the B state we can easily calculate the momentum of the $\psi(J)$ and the s -quark: $p = 1.5$ GeV. Thus the invariant mass of the system consisting of the $\bar{u}(\bar{d})$ and the s quark which is recoiling against the $\psi(J)$ is given by

$$M_{qs}^- = [(M_B - \sqrt{M_{\psi(J)}^2 + p^2})^2 - p^2]^{1/2} \quad (q = u, d)$$

which for $M_B = 5.3$ GeV and $p = 1.5$ GeV is equal to 1.1 GeV.

Thus the hadronic system recoiling against the $\psi(J)$ state is given by a system formed by a s and a $\bar{u}$ or $\bar{d}$ quark of invariant mass 1.1 GeV. We expect that this system consists mainly of $K\pi$, with only a small contribution of $K\pi\pi$ (note that the first resonance decaying into $K\pi\pi$ is $Q[1280]$). We conclude: The type A decay $B \rightarrow \psi(J) + X$ is dominated by the decay $B \rightarrow \psi(J) + K\pi$. The decays $B \rightarrow \psi(J) + K$, $B \rightarrow \psi(J) + K\pi\pi$ are expected to be suppressed. The $(K\pi)$ -system in the decay $B \rightarrow \psi(J) + (K\pi)$ has an invariant mass of about 1.1 GeV, i.e. the decay $B \rightarrow \psi(J) + K^*$ is not expected to occur.

The following decays are possible:

$$\begin{aligned}
 B^-(\bar{u}b) &\rightarrow \psi(J) K^-\pi^0 \\
 &\rightarrow \psi(J) \bar{K}^0\pi^0 \\
 B^0(\bar{d}b) &\rightarrow \psi(J) \bar{K}^0\pi^0 \\
 &\rightarrow \psi(J) K^-\pi^+.
 \end{aligned}$$

All four decays mentioned above occur with equal branching reaction. Using eq.(1) and assuming that 50% of all $B \rightarrow \psi(J) + X$ decays are of type A, one finds:

$$\begin{aligned}
 &B(B^- \rightarrow \psi(J) \bar{K}^0\pi^-) \\
 &= B(B^- \rightarrow \psi(J) K^-\pi^0) \\
 &= B(B^0 \rightarrow \psi(J) K^0\pi^0) = B(B^0 \rightarrow \psi(J) K^-\pi^+) \\
 &\approx 1\%.
 \end{aligned}$$

We expect this estimate to be valid within a factor of two.

We can carry out a similar analysis for the decay of the $B_S^0(\bar{s}s)$ -state, which is expected to have a mass of about 5.45 GeV. Here the system recoiling against the $\psi(J)$ state consists of a $(\bar{s}s)$ -pair, which has the invariant mass of 1.3 GeV. It is difficult to argue that this system should evolve solely into a $K\bar{K}$ -pair, since its mass is close to the $D(1285)$, which decays mainly into $K\bar{K}\pi$ and $\eta\pi\pi$. We expect that the leading decay modes of the B_S^0 state involving a $\psi(J)$ are:

$$\begin{aligned}
 B_S^0 &\rightarrow \psi(J) K\bar{K} \\
 B_S^0 &\rightarrow \psi(J) K\bar{K}\pi \\
 B_S^0 &\rightarrow \psi(J) \eta\pi\pi.
 \end{aligned}$$

We do not expect that the decay modes $B_S^0 \rightarrow \psi(J) \phi$, $B_S^0 \rightarrow \psi(J) \eta$, and $B_S^0 \rightarrow \psi(J) \eta'$ play a significant rôle.

The associated production of the B_S^0 state in hadronic reactions is expected to be suppressed compared to the associated production of B^0 and B^- , since a $\bar{s}s$ pair has to be created during the collision. Nevertheless we feel that the chances are very good that the B_S^0 state can be observed in hadronic reactions by looking for a bump in the invariant mass of the system $\psi(J) K\bar{K}$ and $\psi(J) K\bar{K}\pi$.

Finally we should like to make a remark about the production of B particles in πp and pp collisions. Using the estimates made in ref. (3) for $\sigma(B\bar{B})$ we find in case of pp collisions:

$$\frac{\sigma(\bar{B}B) [400 \text{ GeV}]}{\sigma(\bar{B}B) [150 \text{ GeV}]} \approx 30$$

i.e. the cross section depends strongly on the energy. We have carried out an analogous calculation for π beams. Since pions are expected to have a much stiffer gluon distribution function than nucleons, the cross section for producing B mesons in π -nucleon collisions will be larger than in nucleon-nucleon collisions, especially at relatively low energies ($E \lesssim 150 \text{ GeV}$). However at energies of the order of 400 - 500 GeV we expect that the B production cross section in π -nucleon collisions is only slightly larger than the corresponding cross section in nucleon-nucleon collisions:

$$\frac{\sigma^\pi(\bar{B}B)}{\sigma^N(\bar{B}B)} \approx 1.5 \dots 3.$$

Thus we feel that it is not a great advantage to use a π -beam in order to investigate the B particles. Certainly it would be better to use a proton beam of $\sim 450 \dots 500 \text{ GeV}$ than a pion beam of $\sim 300 \dots 350 \text{ GeV}$.

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References

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