Ref.TH.2775-CERN

A CLEAN TEST OF THE W BOSON EXCHANGE MODEL
FOR THE DECAYS OF CHARM AND BOTTOM MESONS

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ABSTRACT

We propose that a search for specific exclusive channels will test the idea that W boson exchange dominates the decays of charm and bottom mesons. The decay modes we suggest are: $D^0 \rightarrow \phi \bar{K}^0$, $D^0 \rightarrow \eta \bar{K}^0$ vs $D^0 \rightarrow \pi^0 \bar{K}^0$, $B^0 \rightarrow F^+ K^-$, $B^- \rightarrow \bar{K}^0 D^-$, $B^- \rightarrow \phi F^-$ and $B^- \rightarrow \eta F^-$.

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Several attempts have recently been made to account for the observed difference in the lifetimes of charged and neutral D mesons¹⁾. The most naive of these assumes that W boson exchange (or annihilation) diagrams (Fig. 1) dominate the non-leptonic D meson decays²⁾. Since such diagrams exist in D^0 , but not in $D^\pm$ decays, they could lead to shorter lifetimes for the D^0 meson. The purpose of this note is to propose a feasible, clean test of this hypothesis in D decays^{*)}. We also point out the possibility of a similar test in the decays of other heavy flavour states like B mesons.

In D decays the specific mode $D^0 \rightarrow \phi \bar{K}^0$ can arise only through W exchange and not from ordinary charmed quark decay diagrams. Hence a search for this mode would clearly prove or disprove the hypothesis of W exchange dominance.

We can estimate the decay rate relative to the (supposedly) normal decay modes $D^0 \rightarrow \bar{K}^0 \rho^0$ or $(K^*)^- \pi^+$. Let P[V] denote a pseudoscalar [vector] particle; for W exchange the decay rate $\Gamma(D \rightarrow P + V)$ is then proportional to p_V^3/M_D^2 with p_V the momentum of the vector particle in the D rest system (note that in the usual picture which invokes charmed quark decay, we have a factor p^3/M_V^2 instead). We have to include also the suppression factor SF associated with pair production of strange quarks. We estimate $(SF)^2 \sim 1/4 - 1/2$ from various inclusive processes involving $s\bar{s}$ production^{3)**)} and obtain^{***)}

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \phi)}{BR(D^0 \rightarrow \bar{K}^0 \rho^0)} \approx 0.23 - 0.46 \quad (1)$$

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \phi)}{BR(D^0 \rightarrow (K^*)^- \pi^+)} \approx 0.10 - 0.20 \quad (2)$$

) The significance of weak annihilation diagrams for F^+ decays can be studied through a search for the mode $F^+ \rightarrow \pi^+ \pi^+ \pi^-$ as discussed in Ref. 4). One has to keep in mind, however, that the standard model can, at least, in principle, also produce the 3π mode via an 0^+ resonance: $F^+ \rightarrow S^(980) \pi^+ \rightarrow \pi^+ \pi^- \pi^+$ or $F^+ \rightarrow \epsilon(1300) \pi^+ \rightarrow \pi^+ \pi^- \pi^+$.

**) Studies of exclusive channels like $f \rightarrow K\bar{K}/f \rightarrow \pi\pi$ and $A_2 \rightarrow K\bar{K}/f \rightarrow \pi\pi$ might even suggest $(SF)^2 \sim 1$.

**) In the mode $D^0 \rightarrow \bar{K}^0 \rho^0$, which might be observed more easily, one has to include the Clebsch-Gordan coefficient $1/\sqrt{2}$.

Thus we expect a $D^0 \rightarrow \bar{K}^0 \phi$ signal which is comparable to the typical allowed decay mode $D \rightarrow \bar{K}^0 \rho^0$. Assuming $BR(D^0 \rightarrow \bar{K}^0 \rho^0)$ or $BR(D^0 \rightarrow (K^*)^- \pi^+) \approx 1 - 2\%$ we have

$$BR(D^0 \rightarrow \phi \bar{K}^0) \approx 0.2 - 1 \% \quad (3)$$

We believe that observation of this mode, if it exists at all, should not be too difficult in the $K^+ K^- \bar{K}^0$ spectra, since the ϕ has a narrow total width and decays half of the time into charged kaons which carry low momenta.

On the other hand, if W exchange is suppressed, as assumed in the standard model, we anticipate the $D^0 \rightarrow \phi \bar{K}^0$ mode only through OZI rule violation leading to an extremely small value:

$$\frac{BR(D^0 \rightarrow \phi \bar{K}^0)}{BR(D^0 \rightarrow \rho^0 \bar{K}^0)} \approx \left(\frac{p_\phi^3}{m_\phi^2} \right) \left(\frac{m_\rho^2}{p_\rho^3} \right) |\epsilon_{\phi-\omega}|^2 \approx 3 \cdot 10^{-4} \quad (4)$$

where $\epsilon_{\phi-\omega}$ is the ϕ - ω mixing parameter⁵⁾.

The ratio $BR(D^0 \rightarrow \bar{K}^0 \eta)/BR(D^0 \rightarrow \bar{K}^0 \pi^0)$ gives us another useful test of the importance of the W exchange mechanism. For models invoking charmed quark decay we predict

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \eta)}{BR(D^0 \rightarrow \bar{K}^0 \pi^0)} \approx 0.73 \times \frac{1}{2} = 0.37 \quad (5)$$

where we have included simple phase space corrections due to $m_\eta > m_\pi$; for the η we used the empirical ansatz

$$\eta = \frac{1}{2}(\bar{u}u + \bar{d}d) - \frac{1}{\sqrt{2}} \bar{s}s$$

W exchange dominance, on the other hand, reduces the value by an order of magnitude

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \eta)}{BR(D^0 \rightarrow \bar{K}^0 \pi^0)} \approx 0.73 \times 2 \times \left(\frac{1}{2} - \frac{1}{2\sqrt{2}} \right)^2 \approx 0.03 \quad (6)$$

where we have taken $(SF)^2 \sim 1/4$. Even the extreme choice $(SF)^2 \sim 1$ would increase Eq. (6) only by a factor of two. Further SU(3) breaking effects will modify Eqs (5) and (6), probably increasing the values, but it is very unlikely that they can change numbers by an order of magnitude^{*}).

In Cabibbo suppressed decays one can find another mode which is forbidden in the charmed quark decay picture, but is allowed by W exchange through SU(3) breaking, namely $D^0 \rightarrow \bar{K}^0 K^0$, as has been discussed elsewhere⁷⁾. This test, however, cannot be performed easily because of the small expected branching ratio, typically $\sim \Gamma(D^0 \rightarrow K^- \pi^+) \times \tan^2 \theta_c \times (1 - SF)^2$. Moreover, the test could be marred by contributions from "Penguin" diagrams⁸⁾.

If W exchange or weak annihilation is to be important in D decays (but not in K decays), it is tempting to guess that the same is true in the decays of B mesons⁹⁾. Unfortunately, there is a further ambiguity for B decays: the b quark can decay into c and u quarks; it is usually assumed that the transition $b \rightarrow c + W^-$ is stronger than $b \rightarrow u + W^-$, but a substantial contribution from the latter is not yet ruled out¹⁰⁾.

Thus there are two contributions to B^0 decay (Fig. 2a,b) and two to B^- decays (Fig. 3). Keeping colour factors and following the analysis of Ref. 10) on the ratio $b \rightarrow u + W^- / b \rightarrow c + W^-$, one can only conclude at this point that $\Gamma(B^-) \lesssim 3\Gamma(B^0)$, which is not very restrictive or useful.

Again, observation of certain exclusive decay channels can shed some light on the dynamics involved. The transition $b \rightarrow c + W^-$ produces the mode $B^0 \rightarrow F^+ K^-$ through excitation of an $s\bar{s}$ pair from the vacuum. Therefore, it is somewhat suppressed relative to $B^0 \rightarrow D^+ \pi^-$:

*) In a recent preprint⁶⁾ Bander, Silverman and Soni have proposed a mechanism within QCD to explain the dominance of W exchange diagrams for D^0 decays: they argue that emission of a (relatively) hard gluon off the D^0 constituents generates the required enhancement (one sees immediately that this enhancement does not apply to F^+ decays). Assuming the gluon to fragment into SU(2) singlets only one obtains

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \eta(\eta'))}{BR(D^0 \rightarrow \bar{K}^0 \pi^0)} \gg 1$$

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \rho^0)}{BR(D^0 \rightarrow \bar{K}^0 \omega)} \ll \frac{BR(D^0 \rightarrow \phi \bar{K}^0)}{BR(D^0 \rightarrow \omega \bar{K}^0)} \lesssim \frac{1}{4}$$

However, it is hard to see how in such a picture decays like $D^0 \rightarrow K^- \pi^+$, $\bar{K}^0 \pi^0$, $K^- \pi^+ \pi^0$ can be generated with a "normal" branching ratio $\sim 0(2\%)$.

$$\frac{BR(B^0 \rightarrow F^+ K^-)}{BR(B^0 \rightarrow D^+ \pi^-)} \sim \frac{1}{4} - \frac{1}{2} \quad (7)$$

$B^0 \rightarrow D^+ \pi^-$ is, of course, also expected in the standard picture invoking quark decay, but $B^0 \rightarrow F^+ K^-$ is not.

Although the size of the branching ratio $BR(B^0 \rightarrow D^+ \pi^-)$ cannot be estimated in a rigorous fashion, we expect typically - in the same spirit as other authors¹¹⁾ - branching ratios $\sim 0(1/2\%)$ for two-body decays. Of course, one can test Eq. (7) also by comparing $B^0 \rightarrow FK\pi$ with $B^0 \rightarrow D\pi\pi$, where one has to keep in mind the isospin of the final state: $T_f = 1/2$ ²⁾. This remark applies also to the other decay channels we discuss below.

The diagram of Fig. 2b, on the other hand, would lead to $BR(B^0 \rightarrow K^- K^+) \gg \gg BR(B^0 \rightarrow \bar{D}^0 D^0)$ since the latter requires $c\bar{c}$ excitation; yet this ratio should be significantly modified by $SU(4)$ breaking. Therefore, it is unlikely that these channels would provide clean tests for W exchange dominance although they are not generated in the standard picture.

If the transition $b \rightarrow u + W^-$ is sizeable, then weak annihilation would show up most clearly in B^- decays

$$BR(B^- \rightarrow K^- \bar{D}^0) \sim BR(B^- \rightarrow \bar{K}^0 D^-) \sim (2-4) \times BR(B^- \rightarrow \phi F^-) \sim O(\frac{1}{2}\%) \quad (8)$$

In the standard quark decay picture one expects only the mode $B^- \rightarrow K^- \bar{D}^0$, but not $B^- \rightarrow \bar{K}^0 D^-$, ϕF^- , ηF^- .

These considerations can immediately be generalized to the decay of $(b\bar{s})$ or $(b\bar{c})$ states, i.e., bottom mesons containing also strangeness or charm. We mention here only the two modes $(b\bar{c})^- \rightarrow D^- D^0$ and $(b\bar{c})^- \rightarrow F^- \psi$: in the standard model at least one of these decay channels has to have a "normal" branching ratio of the order of, say, 1%. The weak annihilation picture, however, would predict that both are suppressed relative to other exclusive channels like $(b\bar{c})^- \rightarrow \bar{D}^0 K^-$.

Finally, preliminary data provide some evidence for a "narrow" meson state with a mass around 5.3 GeV¹²⁾. It is produced in $\pi^- Be$ collisions and decays into $J/\psi K\pi$. An attractive explanation would be to assume the production of a new flavour decaying as predicted by Fritzsche¹¹⁾. Actually, three decay modes have been seen, namely $B^\pm \rightarrow J/\psi K^0 \pi^\pm$ and $B^0 \rightarrow J/\psi K^- \pi^+$. The important point to note is that while the channel $B \rightarrow J/\psi K\pi$ can be generated by the b quark decay mechanism, it cannot be produced by W exchange. To draw firm conclusions from

this observation is, however, premature; not only are the available data preliminary, but the production cross-section might be different for B^+ , B^- , B^0 and $\bar{B}^0$, in particular in the target and projectile fragmentation region. Therefore, e^+e^- machines can yield more direct information on branching ratios and lifetimes.

ACKNOWLEDGEMENTS

We have benefited very much from discussions with many colleagues, in particular, W. Ochs and C. Schmid. One of us (M.F.) also thanks the Theory Division of CERN for its kind hospitality. Furthermore, we are indebted to J. Ellis for a careful reading of the manuscript.

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Figure Captions

- Fig. 1 : W exchange diagram for D decay.
- Fig. 2 : B^0 decay through the transition (a) $b \rightarrow c + W^-$ and (b) $b \rightarrow u + W^-$.
- Fig. 3 : B^- decay through the transition $b \rightarrow u + W^-$.

FIG. 1

FIG. 2a

FIG. 2b

FIG. 3