Ref.TH.2798-CERN

TESTS OF VARIOUS MODELS FOR THE WEAK DECAYS
OF HEAVY FLAVOUR STATES

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A B S T R A C T

It is discussed how two models which were proposed to explain the lifetime difference between D^0 and D^+ mesons can be subjected to further tests. These two models are the "SU(4) 20-plet dominance" model and the "gluon bremsstrahlung" model for W exchange. The tests can be performed by studying inclusive decays - e.g., F^+ lifetime or semi-leptonic branching ratio - or special exclusive modes in the non-leptonic and semi-leptonic decays. It is suggested that F^+ semi-leptonic decays can lead to glueball production. The decays of bottom mesons are discussed in this context, too.

Ref.TH.2798-CERN
14 December 1979

Several attempts have recently been made to account for the observed difference in the lifetimes of charged and neutral D mesons¹⁾. They either argue for a suppression of D^+ decays by postulating a strong SU(4) 20-plet dominance in the weak interaction²⁾ or they suggest an enhancement of D^0 decays. The most naive idea of this latter kind is to assume that W boson exchange diagrams dominate the non-leptonic decays³⁾. Since such diagrams exist for the Cabibbo allowed decays of D^0 , but not of D^+ mesons, they could lead to shorter lifetimes for the D^0 mesons.

These contributions were previously discarded due to two reasons:

i) a pseudoscalar state cannot decay into two massless fermions via V-A currents; yet s quarks and a fortiori u and d quarks are generally believed to be light compared with charmed quarks or mesons. Therefore helicity factors $(m_s/m_c)^2$ or $(m_d/m_c)^2$ will suppress the transition rates.

ii) The weak coupling is point-like for mesons which are appreciably lighter than the W boson. Therefore the quarks have to overlap to exchange the W boson. This overlap, or the corresponding meson form factor like f_D or f_B for charm or bottom mesons, is not expected to grow linearly with the meson mass. Thus such contributions should be suppressed relative to those from the quark decay mechanism, where the meson mass is the only scale parameter (apart from the Fermi constant G of course).

It had been noted by several people that contributions due to hard gluon emission from the initial quark lines (Fig. 1) do not contain helicity factors. It was then suggested by Bander, Silverman and Soni⁴⁾ that this mechanism also compensates for the suppression described above under point ii): they find a factor $(f_D/m_u)^2$ instead of $(f_D/M_D)^2$ as it was usually assumed. Choosing "not unreasonable" values for f_D and m_u , they could reproduce the observed lifetime difference between D^0 and D^+ , as will be shown below. Qualitatively at least a similar picture emerges if one assumes that the charm mesons are with a sizeable probability in a configuration of three constituents, namely a $c\bar{q}$ quark system plus a gluon⁵⁾. Then helicity factors are not operative anymore and one might furthermore hope that the $c\bar{q}$ overlap is not too small in such a configuration.

To be more definite we will use in the subsequent discussion mainly the gluon bremsstrahlung model since both pictures lead to very similar effects if one keeps all the uncertainties in mind which exist in them.

Another approach, which is more abstract, but also less definite, is the postulate of a "Quark Line Rule"⁶⁾; we will not discuss it in detail here.

As said in the beginning some models argue for an enhancement of D^0 decays, others for a suppression of D^+ decays. The question arises whether one can confidently make predictions on the absolute size of transition rates and confront them with experiment. Unfortunately this is not possible at the moment: to make absolute predictions one has to rely on model assumptions whose soundness cannot be evaluated at the present time. For example, one could argue that in a parton model picture one arrives at a "normal" semi-leptonic branching ratio of $\sim 20\%$ just by counting states, i.e., three coloured quarks and two leptons. Thus the DELCO result

$$BR(D^+ \rightarrow e^+ X) \sim 24 \pm 4 \%$$

$$BR(D^0 \rightarrow e^+ X) < 4.5 \%$$

would indicate that D^+ has a normal decay rate, whereas the D^0 decay rate is enhanced. Yet this conclusion depends obviously on the simple parton model recipe of just counting states. QCD in leading $\log M_W$ on the other hand yields roughly 14% as "normal" semi-leptonic branching ratios. The same uncertainties beset predictions of total lifetimes. Furthermore it has been claimed that a study of exclusive decays $D \rightarrow K\pi$ suggests that $D^+ \rightarrow \bar{K}^0 \pi^+$ has a reduced rate while $D^0 \rightarrow K^- \pi^+$ is normal⁷⁾.

Thus the situation is very unclear as far as absolute predictions are concerned and we will therefore concentrate in the following on relative predictions to distinguish between the different approaches.

The paper will be organized as follows: in Section II we will study the consequences of 20-plet enhancement and of gluon bremsstrahlung for the ratios of inclusive quantities like lifetimes and semi-leptonic branching ratios. In Section III we will discuss exclusive non-leptonic and semi-leptonic channels and in Section IV we give a summary.

II INCLUSIVE RATES

a) 20-plet dominance

Postulating strong 20-plet dominance the authors of Ref. 2) can reproduce $\tau(D^+)/\tau(D^0)$, the semi-leptonic branching ratios of D^0 and D^+ and $BR(D^0 \rightarrow \bar{K}^0 \pi^0)/BR(D^0 \rightarrow K^- \pi^+)$ in a reasonable way. A further analysis of their ansatz shows⁸⁾

$$\tau(F^+) \sim \tau(D^0) \ll \tau(D^+) \quad (1a)$$

$$BR(F^+ \rightarrow e^+ + X) \sim BR(D^0 \rightarrow e^+ + X) \quad (1b)$$

The suppression which is assumed to be operative for the Cabibbo allowed decays of D^+ does not affect the Cabibbo disfavoured decays; therefore one finds for the inclusive rates roughly⁸⁾

$$\begin{aligned} \frac{BR(D^+ \rightarrow \eta + X)}{BR(D^+ \rightarrow \frac{K^-}{\bar{K}^0} + X)} &\sim \frac{BR(D^+ \rightarrow K^+ + X)}{BR(D^+ \rightarrow \frac{K^-}{\bar{K}^0} + X)} \sim \\ &\sim O\left(\frac{\tau(D^+)}{\tau(D^0)} \cdot t_9^2 \theta_c\right) \sim O(0.30) \end{aligned} \quad (2)$$

So far we have neglected phase space corrections due to $m_s \neq 0$ or $2m(K) \gg m(\eta) \neq 0$. It is again not quite clear how to apply them in general. Using a quark decay picture for the inclusive rates one finds

$$\frac{\Gamma(c \rightarrow s \bar{s} u)}{\Gamma(c \rightarrow s \bar{d} u)} \sim \frac{1}{2}$$

for $m_c \sim 3m_s \sim 1.5$ GeV. This phase space correction should probably be applied to $D^+ \rightarrow K^+ + X$ only and not to $D^+ \rightarrow \eta + X$, since $m(\eta) \sim m(K) < 2m(K)$. Then one finds

$$BR(D^+ \rightarrow \frac{K^-}{\bar{K}^0} + X) \sim 76 \% \quad (3a)$$

$$\text{BR}(D^+ \rightarrow \eta + X) \sim 16 \% \quad (3b)$$

$$\text{BR}(D^+ \rightarrow K^+ + X) \sim 8 \% \quad (3c)$$

where we have used

$$\text{BR}(D^+ \rightarrow e^+ + X) + \text{BR}(D^+ \rightarrow \mu^+ + X) \sim 34 \%$$

and

$$\frac{\text{BR}(D^+ \rightarrow e^+ \frac{K^+}{\eta} + X)}{\text{BR}(D^+ \rightarrow e^+ \frac{K^+}{\bar{K}^0} + X)} \sim \tan^2 \theta_c$$

Thus Cabibbo disfavoured modes are enhanced, at least the modes involving η mesons.

Since the D^0 is assumed to have normal decays in this ansatz, one obtains, including phase space corrections as above:

$$\text{BR}(D^0 \rightarrow \frac{K^-}{\bar{K}^0} + X) \sim 92 \% \quad (4a)$$

$$\text{BR}(D^0 \rightarrow \eta + X) \sim 5 \% \quad (4b)$$

$$\text{BR}(D^0 \rightarrow K^+ + X) \sim 3 \% \quad (4c)$$

b) Gluon bremsstrahlung

The authors of Ref. 4) invoke gluon bremsstrahlung and find

$$\frac{\tau(D^+)}{\tau(D^0)} \approx 1 + \left(\frac{m_D}{m_c}\right)^5 \left(\frac{f_D}{f_\pi}\right)^2 \frac{16\pi \alpha_s(m_D^2)}{27} \frac{(f_- + f_+)^2}{4(2 + 2f_+^2 + f_-^2)} \quad (5)$$

where $f_{\pm}$ are the QCD renormalization coefficients of the weak coupling⁹⁾. In the leading log approximation they take the values

$$f_+ \approx 0.68 \quad f_- \approx 2.15$$

Using constituent mass values $m_u \sim 300$ MeV - which is certainly not unreasonable, and a very large value for $f_D - f_{D^0} \sim 800$ MeV - they find:

$$\frac{\tau(D^+)}{\tau(D^0)} \sim 7 \quad (6)$$

Since $f_+ \neq f_-$ due to QCD radiative corrections there are also analogous contributions to F^+ decay and we obtain:

$$\frac{\tau(D^+)}{\tau(F^+)} \sim 1 + \left(\frac{m_F}{m_c}\right)^5 \left(\frac{f_F}{m_s}\right)^2 \frac{16\pi\alpha_s}{27} \frac{(f_- - f_+)^2}{4(2 + 2f_-^2 + f_+^2)} \quad (7)$$

Using $m_s \sim 500$ GeV and $f_F \sim f_D \sim 800$ MeV we get:

$$\frac{\tau(D^+)}{\tau(F^+)} \sim 1.6 \quad (8)$$

i.e., the F^+ is shorter lived than the D^+ , but not by much.

All these numbers have to be taken with quite a grain of salt, of course, because of the large uncertainties involved: neither f_D nor m_u and m_s (or even m_c) are well known or even well defined quantities. Furthermore it is not obvious that m_D is the proper scale at which to define the gluon coupling α_s : soft gluon radiation is cut-off since the emitting hadron is a colour singlet, the cut-off being provided by the space time extension of the hadron. Therefore the form factor f_D should be more appropriate choice for the scale at which to normalize the coupling α_s although the choice of such a relatively small energy scale can cast serious doubts on the applicability of perturbation theory. We will nevertheless proceed using perturbation theory.

As said in the introduction the enhancement mechanism described above does not apply directly to weak annihilation diagrams (Fig. 2a). Yet the situation changes if a second gluon is emitted which can restore colour matching (Fig. 2b). Furthermore the second (and all additional) gluons can be soft, since after the first (hard) gluon emission the $(c\bar{s})$ system is in a colour octet state. One

does not know at present how to calculate reliably soft gluon radiation, where large effective couplings are involved. We can therefore offer only a semi-quantitative argument: a coloured source will emit colour, i.e., gluons, with probability one in a confining theory. On the other hand c and $\bar{s}$ have to have matching colour in order to annihilate into W^+ ; therefore only that part of the soft gluon emission can contribute that restores colour matching which had been offset by the first hard gluon emission. This requirement yields a suppression factor $1/N_c \sim 1/3$ which exactly cancels the colour factor stemming from W fragmentation into the three colours of $u\bar{d}$.

In face of all the uncertainties mentioned above we will set the renormalization coefficients f_- and f_+ equal to one: they are usually calculated as a short distance effect to leading order in $\log M_W$ ⁹⁾; yet the main point made in Ref. 4) is that there is a large contribution from gluon bremsstrahlung which is not a short distance effect.

Applying W exchange to D^0 and weak annihilation to F^+ decays one finds:

$$\frac{\Gamma_{NL}(D^0)}{\Gamma_{NL}(D^+)} \approx 1 + \left(\frac{m_D}{m_c}\right)^5 \left(\frac{f_D}{m_u}\right)^2 \frac{16\pi\alpha_s}{81} \quad (9)$$

$$\frac{\Gamma_{NL}(F^+)}{\Gamma_{NL}(D^+)} \approx 1 + \left(\frac{m_F}{m_c}\right)^5 \left(\frac{f_F}{m_s}\right)^2 \frac{16\pi\alpha_s}{81} \quad (10)$$

We want to stress that the choice of certain values for the parameters involved is somewhat arbitrary and not based on sound theoretical arguments. We pick such values to illustrate the pattern which has to emerge in this picture; the actual numbers, however, should be taken with a grain of salt! We will use in this spirit:

$$\begin{aligned} \alpha_s &\sim 1 \\ f_D &\sim f_F \sim 400 \text{ MeV} \\ m_c &\sim 1.2 \text{ GeV}, m_u \sim 300 \text{ MeV}, m_s \sim 500 \text{ MeV} \end{aligned} \quad (11)$$

Then we obtain

$$\frac{\Gamma_{NL}(D^0)}{\Gamma_{NL}(D^+)} \simeq 11 \quad (12)$$

$$\frac{\Gamma_{NL}(F^+)}{\Gamma_{NL}(D^+)} \simeq 4 \quad (13)$$

The weak annihilation leads also to semi-leptonic decays of F^+ since the emitted gluons can form hadrons:

$$\frac{\Gamma_{SL}(F^+)}{\Gamma_{SL}(D^+)} \simeq 1 + \left(\frac{m_F}{m_c}\right)^5 \left(\frac{f_F}{f_D}\right)^2 \frac{16\pi\alpha_s}{81} \simeq 4 \quad (14)$$

Altogether we then find:

$$\frac{\tau(D^+)}{\tau(D^0)} \sim 7 \quad (15)$$

$$\frac{\tau(D^+)}{\tau(F^+)} \sim 4 \quad (16)$$

We want to emphasize that whereas the semi-leptonic branching ratio for D^0 is suppressed this is not the case for F^+ :

$$\frac{BR(D^0 \rightarrow e^+ X)}{BR(D^+ \rightarrow e^+ X)} \sim \frac{1}{7} \quad (17)$$

$$\frac{BR(F^+ \rightarrow e^+ X)}{BR(D^+ \rightarrow e^+ X)} \sim 1 \quad (18)$$

Since for D^0 and F^+ mesons W exchange and weak annihilation contributes both to Cabibbo allowed and Cabibbo disallowed decays, their strength should be related to each other by $\tan^2 \theta_c$. For D^+ mesons, however, the situation is

different: weak annihilation can contribute only to Cabibbo disfavoured decays. Therefore one expects, ignoring phase space corrections:

$$\frac{BR(D^+ \rightarrow \text{no } K, K^+ + X)}{BR(D^+ \rightarrow \frac{K^-}{K^0} + X)} \sim O\left(\frac{\tau(D^+)}{\tau(D^0)} \cdot \tan^2 \theta_c\right) \sim O(0.30) \quad (19)$$

Since K^+ can be produced only via $s\bar{s}$ excitation, which is suppressed relative to $u\bar{u}$ and $d\bar{d}$ excitation, one expects

$$BR(D^+ \rightarrow \text{no } K) > BR(D^+ \rightarrow K^+ + X) \quad (20)$$

Phase space corrections reduce $BR(D^+ \rightarrow K^-/K^0 + X)$ significantly: calculating it in the quark decay model $c \rightarrow s + \bar{d} + u$, one finds for $m_s \sim 500$ MeV a suppression factor ~ 0.4 . Phase space corrections are not so relevant for the annihilation diagram since there all the quarks, except the charmed quark, are light. Therefore

$$\frac{BR(D^+ \rightarrow \text{no } K)}{BR(D^+ \rightarrow \frac{K^-}{K^0} + X)} \sim 0.60 \quad (21)$$

i.e., the Cabibbo disfavoured D^+ decays containing no kaons should account for a major fraction of D^+ decays.

We have given an (at best) semi-quantitative argument why weak annihilation should contribute to charmed meson decays. If, however, such contributions are suppressed (unlike W exchange) then not only $\tau(F^+) \sim \tau(D^+)$, but also the Cabibbo disfavoured decays of D^+ should be suppressed, their relative strength being $\sim O(\tan^2 \theta_c)$.

There exists some experimental evidence from the Mark II detector that whereas only $\sim 6\%$ of D^0 decays contain no kaons, this is the case for $\sim 31\%$ of D^+ decays, i.e., a large enhancement of such Cabibbo disfavoured modes¹⁰⁾.

This question can also be addressed in another independent, although more indirect way: in hadro- or photoproduction one expects - due to D^* production and spin counting - many more $\bar{D}^0$ than D^- being produced. So far no signal for $\bar{D}^0 \rightarrow \eta + \text{pions}$ has been observed (only for $F^+ \rightarrow \eta + \text{pions}$)¹¹⁾. If one saw then a sizeable η signal in e^+e^- annihilation at ψ'' (3770), one would conclude it to come from $D^\pm$ and not from D^0 decays. There seems to exist some preliminary evidence for such an η signal from the Crystal Ball group at SPEAR¹²⁾.

It is at least very tempting to apply all these concepts to B decays¹³⁾ too, although the uncertainties involved in such an analysis are even larger than for charm decays. For example, there is another parameter not precisely known yet, namely $\xi = (b \rightarrow u + W^-)/(b \rightarrow c + W^-)$. Present knowledge indicates $\xi < 1$ ¹⁴⁾; to make our discussion more quantitative, we will assume $\xi \sim 0$ ($\xi > 0$ affects mainly B^- decays). W exchange diagrams will give us

$$\Gamma(B^-) : \Gamma(B^0) : \Gamma(B_s^-) \simeq \left(2 + \left(\frac{m_B}{m_b} \right)^5 \left(\frac{f_B}{m_d} \right)^2 \frac{16\pi\alpha_s}{135} \right) : \left(2 + \left(\frac{m_{B_s}}{m_b} \right)^5 \left(\frac{f_{B_s}}{m_s} \right)^2 \frac{16\pi\alpha_s}{135} \right) \quad (22)$$

The factors of two appear because W^- can decay into two Cabibbo allowed channels: $\bar{u}d$ and $\bar{c}s$. As first guess we pick

$$m_B \sim 5.3 \text{ GeV}, \quad m_{B_s} \sim 5.5 \text{ GeV}, \quad m_b \sim 4.8 \text{ GeV}$$

$$\alpha_s \sim 1, \quad f_B \sim f_{B_s} \sim 600 \text{ MeV} > f_D$$

and obtain

$$\Gamma(B^-) : \Gamma(B^0) : \Gamma(B_s^-) \simeq 1 : \sim 2.5 : \sim 1.6 \quad (23a)$$

and correspondingly for semi-leptonic branching ratios:

$$BR(B^- \rightarrow e^- + X) : BR(B^0 \rightarrow e^- + X) : BR(B_s^- \rightarrow e^- + X) \simeq 1 : \sim 0.4 : \sim 0.6 \quad (23b)$$

What these numbers should tell us is that lifetime differences between various B states can still be sizeable although they are reduced relative to the case of charmed mesons. Weak annihilation would contribute to $(b\bar{c})$ decays.

However, we expect the decay mode $(b\bar{c}) \rightarrow (b\bar{s}) + X$ to be dominant if this channel is allowed by phase space: for the transition $b \rightarrow cW^-$ is suppressed relative to $\bar{c} \rightarrow \bar{s}W^-$ because of small mixing angles.

As for the $D^\pm$ meson, the Cabibbo disfavoured decays of B^- are enhanced, in this case by a factor of ~ 2.5 . As was stressed by the authors of Ref. 4), for sufficiently high masses there should be a three jet structure in the meson decays, one of these jets being generated by a gluon. Yet we believe that charm and bottom states are not sufficiently heavy for such a phenomenon to become apparent.

III EXCLUSIVE CHANNELS (NON-LEPTONIC AND SEMI-LEPTONIC)

Strong 20-plet dominance affects only non-leptonic decays, since $f_- = f_+ = 1$ for semi-leptonic transitions. For Cabibbo allowed decays the authors of Ref. 2) find $BR(D^0 \rightarrow K^- \pi^+)/BR(D^0 \rightarrow \bar{K}^0 \pi^0) \sim 4$ which is not ruled out by experiment. Also what has been said above on inclusive Cabibbo disfavoured rates, is also true for exclusive channels⁸⁾

$$\frac{BR(D^+ \rightarrow \pi^+ \pi^0)}{BR(D^+ \rightarrow \bar{K}^0 \pi^+)} \ll \frac{BR(D^+ \rightarrow \eta \pi^+, \bar{K}^0 K^+)}{BR(D^+ \rightarrow \bar{K}^0 \pi^+)} \sim O\left(\frac{\tau(D^+)}{\tau(D^0)}, t_g^2 \theta_c\right) \sim O(0.30) \quad (24)$$

where the actual numbers might be modified by phase space corrections and/or symmetry breaking effects. For a discussion of the exclusive channels as generated in the gluon bremsstrahlung picture one can immediately adopt the results of Ref. 15) which was based on a simple W exchange picture with no explicit inclusion of gluons: as said above, we do not believe that the gluon can manifest itself as an independent jet in charm and bottom decays. If it did and fragmented independently into flavour singlet hadrons, one would expect $BR(D^0 \rightarrow K^- \pi^+) \ll \ll BR(D^+ \rightarrow \bar{K}^0 \pi^+)$ ¹⁵⁾, which is not the case. We therefore assume that the gluon "mixes" with the $q\bar{q}$ system to generate the hadrons observed; thus we obtain effectively a simple W exchange picture leading to

$$BR(D^0 \rightarrow \phi \bar{K}^0) \sim 0.2 - 1\% \quad (25a)$$

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \eta)}{BR(D^0 \rightarrow \bar{K}^0 \pi^0)} \sim 0.03 \quad (25b)$$

whereas the quark decay picture gives

$$BR(D^0 \rightarrow \phi \bar{K}^0) \sim 10^{-3} \% \quad (26a)$$

$$\frac{BR(D^0 \rightarrow \bar{K}^0 \eta)}{BR(D^0 \rightarrow \bar{K}^0 \pi^0)} \sim 0.37 \quad (26b)$$

The same mixing of the radiated gluons with the final $q\bar{q}$ system is assumed to occur for weak annihilation contributing to F^+ and Cabibbo disfavoured D^+ decays. There we find

$$\frac{BR(D^+ \rightarrow \pi^0 \pi^+)}{BR(D^+ \rightarrow \bar{K}^0 \pi^+)} \ll \frac{BR(D^+ \rightarrow \bar{K}^0 K^+, \eta \pi^+)}{BR(D^+ \rightarrow \bar{K}^0 \pi^+)} \sim O\left(\frac{\tau(D^+)}{\tau(D^0)} \cdot \tan^2 \theta_c\right) \sim O(0.30) \quad (27)$$

as for 20-plet dominance.

Finally we want to discuss the hadronic final state in $F^+ \rightarrow \ell^+ \nu_\ell + \text{hadrons}$. In the quark decay model one finds¹⁶⁾:

$$\frac{BR(F^+ \rightarrow e^+ \nu_e \omega)}{BR(F^+ \rightarrow e^+ \nu_e \phi)} \ll 1 \quad (28a)$$

$$\frac{BR(F^+ \rightarrow e^+ \nu_e \eta)}{BR(F^+ \rightarrow e^+ \nu_e \eta')} \sim 3 \quad (28b)$$

whereas in the weak annihilation picture where there are only (two or more) gluons in the final hadronic state, one finds, neglecting form factor effects and using $\eta = \frac{1}{2}(u\bar{u} + d\bar{d}) - (1/\sqrt{2}) s\bar{s}$:

$$\frac{BR(F^+ \rightarrow e^+ \nu_e \omega)}{BR(F^+ \rightarrow e^+ \nu_e \phi)} \sim 3 \quad (29a)$$

$$\frac{BR(F^+ \rightarrow e^+ \nu_e \eta)}{BR(F^+ \rightarrow e^+ \nu_e \eta')} \sim \frac{1}{4} \quad (29b)$$

The modes $F^+ \rightarrow e^+ \nu \rho^0$ or $F^+ \rightarrow e^+ \nu \pi^0$ are, of course, possible in either of these schemes.

If F^+ decays actually turn out to be dominated by weak annihilation, then, as was discussed above, the final hadronic state in semi-leptonic decays is mainly generated from gluons. They generate isoscalar states only, as it is reflected in the relations given above. One can then use this final state to look also for a new type of hadronic states, namely "glueballs" of which the lowest lying state should have a relatively narrow width ~ 20 MeV¹⁷⁾. If they exist with masses below M_{F^+} , they should have a good chance to be formed by recombination of the two (or more) gluons emitted. On the other hand it is presently not known how to calculate reliably this recombination probability.

States which have been suspected to contain a large two-gluon component include η, η' and in particular $S^*(980)$ ¹⁷⁾. Therefore $S^*(980)$ could turn out to figure rather prominently in the decays $F^+ \rightarrow e^+ \nu + \text{hadrons}$, where it could be studied more closely. One has to keep in mind, however, that S^* presumably contains an $s\bar{s}$ component; therefore this mode can, at least in principle, also be produced in the standard model. One can look for other relatively narrow isoscalar resonances in $F^+ \rightarrow e^+ \nu_e + \text{hadrons}$, which have not been seen before and thus would be candidates for glueball states.

The same search can be performed in the semi-leptonic decays of B^- if the weak annihilation process yields at least a sizeable contribution to the decays of the bottom mesons and if $\xi = (b \rightarrow u + W^-)/(b \rightarrow c + W^-)$ is not much smaller than unity. Yet there one expects a substantially larger hadronic multiplicity and therefore a search for a hadronic resonance has to deal with a larger combinatorial background.

IV SUMMARY

We have seen that as far as inclusive quantities are concerned, a measurement of $\tau(F^+)$, $BR(F^+ \rightarrow e^+ + X)$ and $BR(D \rightarrow \text{no } K)$ is essential to distinguish between various models on charm decays:

i) 20-plet dominance leads to

$$\tau(F^+) \sim \tau(D^0) \ll \tau(D^+)$$

$$BR(F^+ \rightarrow e^+ + X) \sim BR(D^0 \rightarrow e^+ + X)$$

$$BR(D^+ \rightarrow \text{no } K^- \text{ or } \bar{K}^0) \sim 0.2 - 0.3$$

ii) W exchange dominance, based on gluon bremsstrahlung, yields on the other hand:

$$\tau(F^+) \sim \tau(D^+) \gg \tau(D^0)$$

$$BR(F^+ \rightarrow e^+ + X) \sim BR(D^+ \rightarrow e^+ + X)$$

$$BR(D^+ \rightarrow \text{no } K^- \text{ or } \bar{K}^0) \sim \tan^2 \theta_c \sim 0.05$$

if also weak annihilation gives a major contribution we find

$$\tau(D^0) < \tau(F^+) < \tau(D^+)$$

$$BR(D^0 \rightarrow e^+ + X) \ll BR(F^+ \rightarrow e^+ + X) \sim BR(D^+ \rightarrow e^+ + X)$$

$$BR(D^+ \rightarrow \text{no } K^- \text{ or } \bar{K}^0) \sim 0.35$$

A new major puzzle would be posed if data established $\tau(D^+) \simeq \tau(F^+)$ and at the same time $BR(D^+ \rightarrow \text{no } K^- \text{ or } \bar{K}^0) \sim 0.35$!

Also more theoretical work is needed to put models like the ones discussed above on a sounder and more quantitative basis if they receive further experimental support. This might lead to a new understanding of the $\Delta I = \frac{1}{2}$ rule for kaon and hyperon decays, which is not based on penguin diagrams⁶⁾. This is not an easy task to achieve, yet it is certainly worth the effort: for gluon effects have to be very large to account for the data unlike in deep inelastic scattering where gluon corrections are generally small.

ACKNOWLEDGEMENTS

I have benefited from conversations with many of my colleagues. In particular I am indebted to M.K. Gaillard for instructive discussions and a careful reading of the manuscript.

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FIGURE CAPTIONS

Fig. 1 : Dominant contribution to $D^0 \rightarrow s + \bar{d} + \text{gluon}$.

Fig. 2a : Diagram for $F^+ \rightarrow u + \bar{d} + 1 \text{ gluon}$ with colour mismatch.

Fig. 2b : Diagram for $F^+ \rightarrow u + \bar{d} + 2 \text{ gluons}$ without colour mismatch.

FIG . 1

FIG . 2a

FIG . 2b