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A PROPOSAL TO MEASURE THE D MESON

DECAY CONSTANT F_D^*

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ABSTRACT

Because the branching ratios of the purely leptonic modes of D meson are small compared to the semileptonic decays, we suggest that the decay $D \rightarrow K + \ell + \gamma$ might be used to deduce the value of F_D , the weak decay constant of D meson.

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I. INTRODUCTION

The decay constant F_π , F_K play an important role in the theory of strong interactions, because they are a measure of the breakdown of the chiral symmetry.¹ Furthermore in Quantum Chromodynamics framework, these are also related to the quark wave functions of pseudoscalar mesons at the origin. These wave functions are presumably better known for the heavier quarks where atomic models seem to work, as in the case of the charmonium model for ψ and its excitations. Thus the knowledge of the decay constant F_D for the D meson, and similarly F_F for the F meson would prove of crucial importance as a testing ground for our ideas about hadronic structure.

The direct measurement of the decay rate $D \rightarrow \ell \nu$ seems out of the question for the time because of the small branching ratio compared to semileptonic decays of the D meson. We suggest that the semileptonic decay of the D meson be used, along with PCAC for the K meson to deduce the value of the decay constant. Although this procedure is approximate, the suggested theoretical values of this parameter are so widely scattered that even a rough measurement should be useful.

II. DETERMINATION OF F_D

In the standard Salam-Weinberg model, the weak charged current responsible for the decay of the charmed hadrons into leptons is given by

$$J_\mu = [\bar{c} \gamma_\mu (1 - \gamma_5) s \cos \theta_c - \bar{c} \gamma_\mu (1 - \gamma_5) d \sin \theta_c] \quad (1)$$

The introduction of additional quark doublets in the Salam-Weinberg scheme can introduce further angles in the hadronic current. The present weak interaction phenomenology suggests that this mixing will only introduce

an overall multiplicative factor in Eqn.(1) and our analysis is not affected by it. We defined F_D through:

$$\langle D^+ | \bar{c} \gamma_\mu \gamma_5 d | 0 \rangle = -i p_\mu \frac{F_D}{(2\pi)^{3/2} \sqrt{2} \omega_D} \quad (2)$$

The decay of $D^+ \rightarrow \ell^+ \nu$ is then given by

$$\Gamma(D \rightarrow \ell \nu) = \frac{G_F^2 F_D^2 \sin^2 \theta_c}{8\pi} m_\ell^2 m_D \left(1 - \frac{m_\ell^2}{m_D^2}\right)^2 \quad (3)$$

The decay $D^+ \rightarrow \bar{K}^0 + e^+ + \nu_e$ on the other hand is given by

$$\Gamma(D^+ \rightarrow \bar{K}^0 + e^+ + \nu_e) = \frac{G_F^2 \cos^2 \theta_c |f_+|^2}{768 \pi^3} m_D^5 f(m_K/m_D) \quad (4)$$

where $f(x) = 1 - 8x^2 + 8x^6 - x^8 - 24 \log x$ and is 0.592 for the D meson, while f_+ is the vector form factor whose q^2 dependence we have ignored, and $f_+(0) \approx 1$ from SU(4) symmetry.

Equations (3) and (4) yield (assuming $m_D = 1868.4 \text{ MeV}$, $m_\pi = 137 \text{ MeV}$)

$$\frac{\Gamma(D^+ \rightarrow \mu^+ \nu)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)} \approx 2 \times 10^{-3} (F_D/m_\pi)^2 \quad (5)$$

$$\frac{\Gamma(D^+ \rightarrow \tau^+ \nu)}{\Gamma(D^+ \rightarrow \bar{K}^0 e^+ \nu_e)} \approx 4.7 \times 10^{-3} (F_D/m_\pi)^2 \quad (6)$$

These ratios are too small to allow F_D to be measured directly. Even if F_D were a factor of 4 bigger than $m_\pi \approx F_\pi$, it would still be difficult to measure these ratios. Situation with F^+ decays is somewhat better because of the lack of Cabibbo suppression and more phase space for the $\tau \nu$ mode.

We have

$$P(F^+ \rightarrow \eta e^+ \nu_e) = \frac{G_F^2 \cos^2 \theta_c |f_+|^2}{768 \pi^3} m_F^5 f(m_\eta/m_F) \quad (7)$$

where $|f_+|^2 \approx 2/3$ if η - η' mixing is neglected. We obtain

$$\frac{P(F^+ \rightarrow \mu^+ \nu_\mu)}{P(F^+ \rightarrow \eta e^+ \nu_e)} \approx 3.05 \times 10^{-2} (F_F/m_\pi)^2 \quad (8)$$

$$\frac{P(F^+ \rightarrow \tau \nu_\tau)}{P(F^+ \rightarrow \eta e^+ \nu_e)} \approx 4.85 \times 10^{-1} (F_F/m_\pi)^2 \quad (9)$$

Thus $F^+ \rightarrow \tau \nu_\tau$ is certainly feasible, although $F^\pm$ are not as easily produced as $\bar{D}D$ states.

The best method to determine F_D in the near future is the indirect one of measuring form factors of the semileptonic D decay, and relating the slope of the scalar form factor by PCAC to the ratio F_D/F_K .

Using PCAC for K meson and LSZ reduction technique, we find the analogue of Callan-Treiman relation²

$$\begin{aligned} \lim_{k \rightarrow 0} \langle \bar{K}^0(k) | \bar{c} \gamma_\mu d | D^+(p) \rangle \\ = -\frac{i}{F_K} \langle 0 | [F_5^{\bar{K}^0}, \bar{c} \gamma_\mu d] | D^+(p) \rangle \\ = \frac{F_D}{F_K} p_\mu \end{aligned} \quad (10)$$

The matrix element is as usual expressed in terms of two form factors

From Eq. (13) we therefore have

$$f_s(m_D^2) \cong F_D/F_K \quad (16)$$

Now unlike $f_{\pm}(q^2)$ form factors which have poles in q^2 because of F^* meson, we expect $f_s(q^2)$ to be smooth in q^2

$$f_s(q^2) = f_s(0) \left[1 + \frac{\lambda_s}{m_K^2} q^2 \right] \quad (17)$$

Solving for the slope in terms of F_D we obtain

$$\lambda_s = \frac{m_K^2}{m_D^2} \left[\frac{F_D}{F_K f_s(0)} - 1 \right] \quad (18)$$

The expectation is that $f_s(0) = f_+(0) \approx 1$ from SU(4) symmetry and CVC. Thus if F_D/F_K turns out to be large, there should be a dramatic dependence on q^2 in the scalar form factor.

For completeness we also determine the ratio $f_-(0)/f_+(0)$

This ratio depends on the q^2 dependence of $f_+(q^2)$. It is reasonable to assume that this is dominated by F^* pole

$$f_+(q^2) = f_+(0) \frac{m_{F^*}^2}{m_{F^*}^2 - q^2} \quad (19)$$

$$\langle \bar{K}^0(k) | \bar{c} \gamma_\mu d | D^+(p) \rangle = (p+k)_\mu f_+(q^2) + (p-k)_\mu f_-(q^2) \quad (11)$$

where $q_\mu = (p-k)_\mu$. Off-shell $f_\pm$ are functions of both q^2 and k^2 .

The constraint in Eq.(10) is then expressed as

$$f_+(q^2 = m_D^2, k^2 = 0) + f_-(q^2 = m_D^2, k^2 = 0) = F_D/F_K \quad (12)$$

We assume that the extrapolation in K mesons is as smooth as pions, and obtain

$$f_+(m_D^2) + f_-(m_D^2) = F_D/F_K \quad (13)$$

The best way to use this result is to define the scalar form factor³ which is directly accessible from experiment.

$$f_s^{\mu} \langle \bar{K}^0 | \bar{c} \gamma_\mu d | D^+ \rangle \equiv (m_D^2 - m_K^2) f_s(q^2) \quad (14)$$

$$f_s(q^2) = f_+(q^2) + \frac{q^2}{m_D^2 - m_K^2} f_-(q^2) \quad (15)$$

Combining Eqns. (15), (17), (18) and (19) we obtain

$$\frac{f_-(0)}{f_+(0)} = \frac{m_D^2 - m_K^2}{m_D^2} \left[\frac{F_D}{F_K f_+(0)} - \frac{m_{F^*}^2 + m_D^2}{m_{F^*}^2} \right] \quad (20)$$

The range for $f_-(0)/f_+(0)$ and λ_s as $\frac{F_D}{F_K f_+(0)}$ changes from 2 to .4 is .22 to -1.27, and 0.07 to -0.04, respectively, assuming

$m_{F^*} = 2140 \text{ MeV}$. These may be measured from the branching ratio of $D \rightarrow K + \mu + \bar{\nu}_\mu$ to $D \rightarrow K + e + \bar{\nu}_e$ and their Dalitz plots analyses in the near future. ⁽⁵⁾

III. THEORETICAL EXPECTATION FOR F_D/F_π

Numerous estimates of F_D/F_π and F_F/F_π have been made in the literature based on either chiral $SU(4) \times SU(4)$ symmetry or quark model. Since D and F mesons are far from the Goldstone limit, these estimates are necessarily unreliable. We present them in the following Table I mostly to point out the great theoretical uncertainty.

TABLE 1

Values of F_D/F_π , F_F/F_π and F_K/F_π obtained in various theories.

F_D/F_π	F_F/F_π	F_K/F_π	Reference
.974	1.056	1.28	Das and Deshpande ⁵
0.4	0.4	1.15	Oakes and Sorba ⁶
1.015	1.016	1.00096	Gounaris and Sarantokos ⁷
1.12	1.34	1.11	Takaiwa ⁸
1.517+1.652	1.616+1.892	1.14+1.36	Kandaswamy, et al ⁹
1+11.75	1+15.67	1.22	Dominguez ¹⁰
4.485+5.364	4.765+5.644	1.28	Vaughn ¹¹
- .51+ -3.02	- .37+ -2.52	1.08+1.30	Fukuda ¹²
1.1	-	-	Preparata ¹³
0.3	-	-	Quigg and Rosner ¹⁴

IV. CONCLUSION

We have proposed an indirect measurement of F_D/F_K from the slope of the scalar form factor. This determination is dependent on the validity of the soft K theorem, which is expected to hold because the current algebra estimate of the mass of the S Quark is quite small. The direct measurement of the purely leptonic decay of D meson will not be feasible for some time, though the corresponding F decay might be experimentally accessible.

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REFERENCES

1. S. Glashow and S. Weinberg, Phys. Rev. Lett. 20 (1968) 224; M. Gell-Mann, R. Oakes and B. Renner, Phys. Rev. 175 (1968) 2195; for a comprehensive review see H. Pagels, Phys. Reports C16 (1975) 219.
2. C.G. Callan and S.B. Treiman, Phys. Rev. Lett. 16 (1966) 153.
3. L.M. Chounet, J.M. Gaillard and M.K. Gaillard, Phys. Report 4C(1972) 199; D. Hitlin, Proceedings of the 1973 Slac Summer Institute on Particle Physics, edited by M. Zipf, Slac-167 (1973).
4. D. Hitlin, private communication.
5. K.P. Das and N.G. Deshpande, Oregon preprint, OTIS-92 (1978).
6. R.J. Oakes and P. Sorba, Fermilab preprint, 77/78 - THY.
7. G.J. Gounaris and S.B. Sarantokos, Nuovo Cimento 39A (1977) 554.
8. Y. Takaiwa, Prog. Theor. Phys. 59 (1978) 1625.
9. J. Kandaswamy, J. Schechter and M. Singer, Phys. Rev 17 (1978) 1430.
10. C.A. Dominguez, Mexico preprint.
11. M. Vaughn, Phys. Rev. D13 (1976) 2621.
12. T. Fukuda, Prog. Theor. Phys. 59 (1978) 1613.
13. G. Preparata, CERN preprint, no TH-2271 (1977).
14. C. Quigg and I. Rosner, Phys. Rev.D16 (1977) 1497.