©Proc. Indian natn. Sci. Acad., 47, A, No. 2, 1981, pp. 269-275.

Priented in India.

Particle Physics

SUPPRESSION FACTOR IN THE LEPTONIC AND HADRONIC DECAYS OF THE NEXT QUARKONIUM FAMILY

ABDUL SAMAD *and* MUBARAK AHMAD

Department of Physics, University of Kashmir, Srinagar-190 006

and

G. Q. SOFI

Department of Physics, S. P. College, Srinagar-190 001

(*Received 6 May 1980; after revision 28 August 1980*)

The leptonic and hadronic decay widths of the hypothetical family of top meson $\zeta(t\bar{t})$ are predicted by applying the suppression factor $Q^m(q^2)$.

Keywords: Suppression Factor; *t*-quark; Decay Widths; Top Meson

INTRODUCTION

THE observed symmetry between leptons and quarks suggests besides u, d, s, c, b the existence of a sixth quark t. The charge of the t-quark is predicted to be 2/3 if one groups the quarks in weak isospin doublets, viz.,

$$\begin{pmatrix} u \\ d \end{pmatrix}, \quad \begin{pmatrix} c \\ s \end{pmatrix}, \quad \begin{pmatrix} t \\ b \end{pmatrix}$$

The theoretical predictions for the t mass populate mass values between 10 and 40 GeV (DESY 80/13). But the topological distribution of hadron from the relation $e^+e^- \to$ multihadrons has been studied at PETRA energies between $\sqrt{s} \doteq 22$ and 31.6 GeV. No evidence for the existence of heavy meson with new flavour is seen yet (DESY 79/56). In this note, we anticipate the leptonic decays of this hypothetical family $\zeta\ (t\bar{t})$ with a mass of about 38 GeV/c^2. The suppression factor which we have introduced plays an important role in the decays of the ψ and Υ families. We believe that it will also give good predictions for the decay widths of the ζ family.

SUPPRESSION FACTOR

The idea of introducing the suppression factor into various decay widths is as follows:

Zweig's rule is generallly used as a means of explaining the narrowness of the resonance width of ψ but it does not give a quantitative prescription of how much the decay width of a Zweig forbidden diagram is suppressed. There are at present various schemes of calculating ψ and Υ decays: (*i*) mixing various quark wave functions; (*ii*) group-theoretical method; and (*iii*) dual method, but here we have attempted a fourth possibility (Chew *et al.*, 1978), that the suppression of the ψ decay is due to some dynamic origin by adopting a phenomenological approach, and presented a semi-quantitative prescription that can summarize the present experimental situation in an approximate way. The prescription is written as follows :

Whenever a hadron changes its four momentum, it will be suppressed by a factor of $Q^m(q^2)$, where m is the number of quarks in the hadron that has been bent or twisted. We can check this suppression factor first in elastic hadron scattering. For PP elastic scattering, there are three quarks scattering off three quarks, if the multiple scattering terms are neglected. Then, according to our prescription the differential cross section is

$$\frac{d\sigma}{dt}(PP) \propto [Q^6(q^2)]^2, \text{ where } m = 6.$$

For $\pi P \rightarrow \pi P$ it is

$\frac{d\sigma}{dt}(\pi P) \propto [Q^5(q^2)]^2$, where $m = 5$. The quark diagrams of these cross sections are shown in Fig. 1. The slope parameters b, defined by $\frac{d\sigma}{dt} = A\, e^{bt}$ then approximately satisfy the following equality:

$$b(\pi P) = 5/6\, b(PP).$$

It is satisfied to within 2 per cent accuracy. Similarly in $eP \rightarrow eP$ scattering, three quark lines in the proton suffer a momentum transfer. According to our prescription, the proton form factor is given by

$$F_q(q^2) = Q^3(q^2) \qquad \ldots(1)$$

where $m = 3$. Similarly the pion form factor is

$$F_\pi(q^2) = Q^2(q^2) \text{ here } m = 2 \qquad \ldots(2)$$

The corresponding quark diagrams are shown in Fig. 2. From eqn. (1), the exact suppression factor is obtained as follows:

$$Q(q^2) = F_p^{\frac{1}{3}}(q^2) = \left[\frac{1}{1 + \frac{q^2}{0.71}}\right]^{2/3} \qquad \ldots(3)$$

A relation between the pion form factor and proton form factor contained in eqns. (1) and (2) is

$$F_\pi(q^2) = F_p^{2/3}(q^2) \qquad \ldots(4)$$

This equality has been shown to be consistent with the present experimental data. So far the momentum transfer q^2 is space like for elastic scatterings and form factors. To test whether it makes sense to use eqn. (3) for a time like region, it is necessary

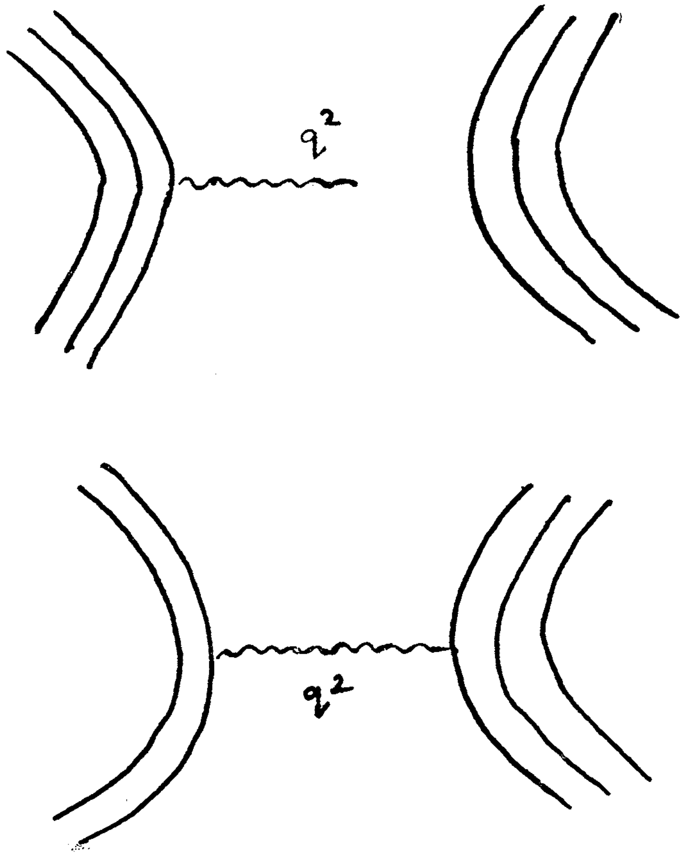

FIG. 1. Elastic pp scattering at Small q² involves the bending of the six quarks with $m=6$ and $\pi\, p$ scattering involves bending of five quarks with $m=5$.

to investigate the inelastic two body scatterings $ab \to cd$. Then the cross section will be suppressed by a factor as follows:

$$\sigma(s)\, \alpha [Q^m(s)]^2 \sim F_p^{2m/3} \sim s^{-4m/3} \qquad \ldots(5)$$

(The proton form factor has not been measured in time like region). We just take the symmetric case for the suppression factor as

$$Q(q) = \left[\frac{1}{1+\frac{s}{0.71}}\right]^{-3/2} \qquad \ldots(6)$$

where s is the energy squared in c.m.s.

Since in a strong interaction, for one-ρ-exchange it should have a ρ-propagator squared and for one-gluon exchange it should have a gluon propagator squared. However, one particle exchange is not a good approximation in strong interaction;

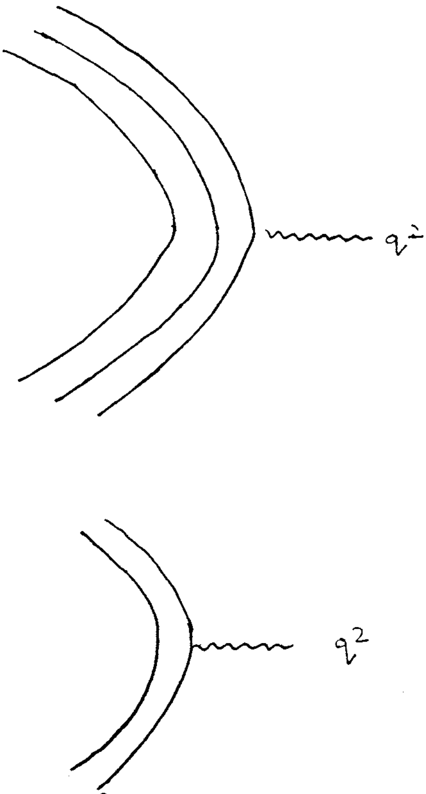

FIG. 2. Quark diagram for the form factor of proton (m=3) and the form factor of the pion (m=2).

(Chew *et al.*, 1979; and Celmaster, 1979) it is not possible to calculate reliably the suppression factor due to four momentum transfer.

LEPTONIC DECAYS

The leptonic decay mode of the ζ family is expected to contain only one quark line which undergoes four momentum change ($m = 1$) see Fig. 3. The momentum transfer squared q^2 is just given by its mass squared m_ζ^2. Hence the suppression factor for the decay rate is

$$Q^2(m_\zeta^2) = F_p^{\frac{2}{3}}(m_\zeta^2) \qquad ...(7)$$

which comes out to be

$$Q^{2m}(s) = \left[\frac{1}{1 + \frac{s}{0.71}}\right]^{4m/3} \qquad ...(8)$$

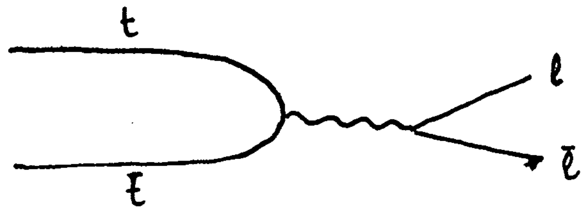

FIG. 3. The quark diagram for the decay of the ζ family into e^+e^-. Here it is $m=1$ process.

If we consider the vector meson V as a bound state of heavy quark Q and antiquark $\bar{Q}$, it decays into a lepton pair through a photon intermediate state in the lowest order Feynman diagram and the decay width in the non-relativistic limit is given by (Jackson, 1976)

$$\Gamma(V \to e^+e^-) = \frac{16\pi\alpha^2 e_Q^2}{M_V^2} |\psi_{(0)}|^2 \qquad \ldots(9)$$

where M_V is the mass of the vector meson, e_Q the charge of quark in units of e and $\psi_{(0)}$ is the quark antiquark wave function at the origin where the annihilation takes place.

By including the suppression factor (8) into the decay formula (9) (with $s = M^2$ and $m = 1$) we write

$$\Gamma(V \to e^+e^-) = \frac{16\pi\alpha^2 e^2_Q}{M_V^2} \left| \psi_{(0)} \right|^2 \cdot Q^2 (M_V^2) \qquad \ldots(10)$$

If we assume the new resonances ζ (37.84), ζ' (38.75), ζ'' (39.48) ζ''' (40.08) and ζ'''' (40.56), respectively, the 1 $^3S_1$, 2 $^3S_1$, 3 $^3S_1$, 4 $^3S_1$ and 5 $^3S_1$ bound states of the quarkonium $t\bar{t}$ and that the annihilation wave function squared times the suppression factor squared has the same dependence as the other vector mesons then the values of $|\psi_{(0)}|^2 Q^2(M_V^2)$ can be calculated and we then predict the leptonic decay widths of ζ, ζ', ζ'', ζ''' and ζ'''' and list them all in Table 1.

Hadronic Decays

According to QCD, the direct hadronic decay (the Zweig forbidden decay) of the vector mesons V may also be considered as the annihilation of Q and $\bar{Q}$ into three gluons, which combine together to become hadrons with the width given by (Jackson, 1977).

$$\Gamma(V \to \text{hadrons}) = \frac{160(\pi^2 - 9)\, \alpha_S^3}{81 \quad M_V^2} |\psi_{(0)}|^2 \qquad \ldots(11)$$

TABLE I
Leptonic decay widths

Mass (GeV)	$\mid \psi_{(0)} \mid^2 Q^2$ (GeV)^3	$\Gamma(V \to e^+e^-)$ (KeV).
ζ 37.84	.5664	46.6492×10^{-8}
ζ' 38.75	.5924	41.7184×10^{-8}
ζ'' 39.48	.6137	38.2808×10^{-8}
ζ''' 40.08	.6315	35.6845×10^{-8}
ζ'''' 40.56	.6458	33.7605×10^{-8}

Hadronic decay widths

Mass (GeV)	α_s	Γ(V → hadrons) KeV)
ζ 37.84	.1242	1.3351×10^{-6}
ζ' 38.75	.1238	1.2993×10^{-6}
ζ'' 39.48	.1235	1.2967×10^{-6}
ζ''' 40.08	.1232	1.2947×10^{-6}
ζ'''' 40.56	.1230	1.2929×10^{-6}

where α_s is the coupling constant in the asymptotically free QCD given by the expression (Chew & Phua, 1979)

$$\alpha_s(s) = \frac{\alpha_s(m_0^2)}{\left(1 + (11 - \frac{2}{3} N\right) \frac{\alpha_s(m_0^2)}{4\pi} \ln/m_0^2} \qquad \ldots(12)$$

where m_0 is the free scale parameter and N is the number of quark flavours. In our paper we choose $m_0 = 37.84$ GeV, the mass top meson ζ, $N = 6$ for the ζ family. With the suppression factor $Q^2(M^2)$ the expression for hadronic decay width is written as

$$\Gamma(V \to \text{hadrons}) = \frac{160(\pi^2 - 9)}{81} \frac{\alpha_s^3}{M_V^2} \mid \psi_{(0)} \mid^2 Q^2(M_r^2). \qquad \ldots(13)$$

The hadronic decay widths calculated are also listed in the Table 1.

CONCLUSIONS

From ordinary hadronic reactions one observes the empirical fact that large-momentum transfer processes are generally suppressed. We followed a prescription that quark which under goes a momentum transfer squared q^2 is suppressed by a factor $Q(q^2)$. We conclude that $Q(q^2)$ is given by the cube root of the proton form factor.

We have thus anticipated the decays of the next quarkonium system ($t\bar{t}$). The suppression factor tends to strongly supress the widths. This correction reduces the predicted leptonic and hadronic decay widths greatly. By including the suppression factor to the charmonium and upsilon families (Chew *et al.*, 1978; and Chew & Phua, 1979), the decays are found to be in agreement with the experimental data. Hence, it is expected that the decay widths we anticipate may be correct and await experimental confirmation.

REFERENCES

Celmaster, W. (1979) Lepton-width suppression of vector meson decays. *Phys. Rev.*, **D 19**, No. 5, 15117–21.

Chew, C. K., Lo, S. Y., and Phua, K. K. (1978) Suppression factor in the decays of the ψ-family *Phys. Rev.*, **D 18**, No. 7, 2495–2502.

Chew, C. K., and Phua, K. K. (1979) Suppression factor in the leptonic and hadronic decays of the Υ-family. *Phys. Rev.*, **D 19**, No. 5, 1512–1516.

Jackson, J. D. (1977) *In Week Interactions at High Energies and the Production of New Particles Proc.* 1976 *SLAC Summer Institute on Particle Physics*, p. 147.

PLUTO Collaboration (1979) Search for a top threshold in hadronic e^+e^- annihilation at energies between 22 and 31.6 GeV. *DESY*, **56**, 1-6.

Wolf, G. (1980) Selected topies on e^+e^- physics. *DESY*, **13**, p. 158.