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SPECULATIONS ON COMPOSITE QUARKS

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Abstract

We propose a simple field theoretic quark model in which the quarks are composite. This quark-hadron bootstrap is the new feature of the model. States like $N^*(1470)$ and $\rho'(1600)$ are interpreted as containing quark excitations. The ratio $\sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ should grow with energy but not necessarily indefinitely. Remarks on proton-proton diffraction dissociation at the ISR energy range are made.

Hadron physics offers a variety of phenomena which do not seem to follow from one simple model. For example, resonances and scaling phenomena can be qualitatively described by the quark model(s) but it turns out that we need two models known as the constituent and current quark models. Recently there have been attempts to combine the two pictures [1]. It is not clear how successful these works should be considered; the reason is, of course, that the quark dynamics is still unknown. In this situation we feel that to make progress one should try to combine phenomenological ideas with reasonable field theoretic models. In the following we shall make such an attempt.

Suppose we have the following basic fields: a charged spin $\frac{1}{2}$ field $\psi(x)$, a neutral pseudoscalar field $\pi(x)$ and a neutral scalar field $\phi(x)$. Following our earlier considerations about quarks and their excitations [2] we assume that the quarks can be constructed from the basic fields as follows. Quarks are $\psi\pi$ $1_j = s_{\frac{1}{2}}$ bound states and the lowest quark excitations q^* are $\psi\phi$ $p_{\frac{1}{2}}$ bound states. The interaction Lagrangian density for the basic fields will be discussed below.

The ground state and 1-excited hadrons are constructed of the quarks in the conventional way [3]. But states like $N^*(1470)$ and $\rho'(1600)$ are more problematic in the quark model. Usually they are considered as radial excitations in the harmonic oscillator model. Calculations with this assumption contradict, however, data in N^* electroproduction [4] and in the ρ' decay [5]. To avoid these difficulties we abandoned in [2] the harmonic oscillator dynamics and suggested that the above hadrons should be interpreted in the quark model as follows

$N^{*}(1470)$	$q^{*}\ q\ q$
$N^{*}(1780)$	$q^{*}\ q^{*}\ q$
$\rho'(1600)$	$q^{*}\ \bar{q}^{*}$

with color or SU(3)' indices suppressed. Otherwise these particles are like the mother states N(940) and $\rho(770)$ in the quark model.

As indicated above we do not assume any explicit dynamics between the quarks. Qualitatively we suppose as a first approximation that the quarks are bound inside hadrons by a scalar potential (gluon) in such a way that any quark cannot escape from the hadron and inside the hadron the quarks are quasifree with an effective mass about 300 MeV. Thus either the quarks are heavy and the binding is strong or there is a more complicated mechanism at work [6,7] .

Let us now consider the interaction Lagrangian density for the basic fields $\psi(x)$, $\pi(x)$ and $\phi(x)$. As emphasized by T.D. Lee [8] the theory should be such as to give only a small amount of scale breaking in deep-inelastic electron-proton scattering. On the other hand one should have strongly bound $\psi\pi$ states and large widths for resonance decays. A solution for these conditions is given in [8]

$$(1) \quad L = f_1\bar{\psi}\psi\phi + if_2\bar{\psi}\gamma_5\psi\,\pi + f_3\pi^4 + f_4\pi^2\phi^2 + h\pi^2\phi + ie\bar{\psi}\gamma_\mu\psi\,A_\mu$$

where A_μ is the electromagnetic field and the couplings should satisfy $h > f_i$ $(i=1,\ldots,4)$ and $f_1^2/4\pi < 0.1$. A detailed theoretical analysis of (1), including estimates for resonance couplings, discussion of form factors and scaling, is given in [8] .

Here we wish to consider some phenomenological consequences of our composite quark model.

First, we note that in order to avoid the quark to be a mixture of $\psi\pi$ and $\psi\phi$ we must require hf_2 to be much smaller than hf_1. Thus the q^* is unstable and decays into $q\pi$ (fig. 1). $N^*(1470)$ and $\rho'(1600)$ decay rates indicate that f_4 should be relatively large.

In [2] it was postulated that $\langle q^*|j_\lambda^{em}|q\rangle$, or $\langle N^*(1470)|j_\lambda^{em}|N\rangle$, is zero in the first approximation. This condition is obtained immediately in the present model. The photon couples only to the $\psi(x)$ and to excite a q^* in $N^*(1470)$ we necessarily need a $\pi(x)$ field like in fig. 1. Experimentally $N^*(1470)$ and $N^*(1780)$ electroproduction is consistent with zero [4] . From the same argument it follows further that in $e^+e^- \to N^*\bar{N}^*$, where the N^* is either $N^*(1470)$ or $N^*(1780)$, one should see the N^*'s only in pairs. This can be tested in future experiments. In $e^+e^- \to 2\pi$ (or 4π) there should not be a ρ' state at $m \sim 1.270$ GeV since this would correspond to a $q\bar{q}^*$ state and $\langle q\bar{q}^*|j_\lambda^{em}|0\rangle$ is zero. The first ρ' should occur at $m \sim 1.600$ GeV corresponding to a $q^*\bar{q}^*$ state. The pion form factor should, in the vector dominance model, be ρ dominated up to $\sqrt{s} \sim m_{\rho'} \sim 1.600$ GeV . These conclusions agree well with data.

Having a relatively large f_4 in (1) , as argued above, we see that the ρ' (1600) decays mainly into $\rho\pi\pi$. The $\pi\pi$ decay mode is due to a graph shown in fig. 2. The ratio $|A(\rho'\to\rho\pi\pi)|/|A(\rho'\to\pi\pi)|$ is proportional to f_1f_4/hf_2 . This is bigger than one since $hf_2 << hf_1$ and f_4 is not too much smaller than h (recall that phase space favors the $\pi\pi$ mode). This is what we called earlier a "radial" selection rule [5] .

A crucial test of the model is the calculation of $R_h = \sigma(e^+e^- \to \text{hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$. Experimentally this ratio is growing still at $\sqrt{s} = 2\,E = 5$ GeV while the quark model gives

$$(2) \qquad \sigma(e^+e^- \to \text{hadrons}) = \frac{4\pi\alpha^2}{3s} \sum_i e_i^2$$

where e_i are the quark charges and thus $R_h = \sum_i e_i^2$. In our model there are more fermions and correspondingly more terms in (2) in which e_i is replaced by $f_i(s)$, the excited quark form factor. Therefore R_h should increase when new channels open. In exclusive $e^+e^- \to$ vector meson we know, as discussed above, that q* production begins at $\sqrt{s} \simeq m_{\rho'}$. Consequently we expect the result with nine colored quarks, $R_h = 2$, to increase when $\sqrt{s} > m_{\rho'} \simeq 1.600$ GeV. This agrees excellently with present data [9].

Another interesting situation where the present composite quark model can obviously be further studied is proton-proton diffraction dissociation into high mass states at the Intersecting Storage Ring energy range. At lower energies diffraction dissociation is known to produce both $N^*(1470)$ and l-excited states. Assuming that the q^* picture is correct the observed heavy nucleon states [10] could be due to production of higher quark excitations, $\psi\pi$ or $\psi\Phi$ with $l > 1$. Obviously also the spin of such N^*'s would be high and the states would be in approximately degenerate spin towers. The above quark excitations decay in the lowest order by Φ or π emission. Thus the multiplicity distribution in the high mass state decays should be enhanced at multiplicity three and six. The quark excitations have steeper form factors than the ground state. Therefore the production of hadrons containing q^* states is expected to be more peripheral than the production of corresponding qqq states. Due to the weak but hard $f_1\bar{\psi}\psi\,\Phi$ and $f_4\,\pi^2\Phi^2$ couplings we also expect large transverse momentum events [8] . Finally, the mechanism of [11] for high-energy proton-proton scattering suggests that the $\log^2 s$ behavior of the total cross section may be related to high mass quark production. This follows if we interpret the corresponding graph of ref. [11] (see our fig. 3.a) as shown in fig. 3.b.

Theoretically our model is interesting in the sense that it gives a quark-hadron bootstrap, introduced in [2] . In fact in [12] it was the nucleon that was considered to be a bound state of the basic fields $\psi(x)$ and $\pi(x)$. When applying the bound state method to quarks instead of the physical hadrons we, of course, had to make additional assumptions. We think, however, that in this way we may obtain a model in which the most important phenomena of hadron physics can be understood. The principal open question is the quark "imprisonment". An interesting possibility might be the combination of the ideas of nonabelian gauge fields with the present model.

In summary, we have proposed a model for hadrons which, if correct, should form a basis for more detailed and quantitative developments (now in preparation). Of particular interest to the model are experimental measurements of high mass resonances in both e^+e^- and pp colliding beams and scale breaking phenomena.

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Figure Captions:

Fig. 1. Graph for the decay $q^{*} \to q+\pi$.

Fig. 2. Graph for $\rho' \to \pi\pi$

Fig. 3.a. Graph of ref. [11] responsible for the logarithmic growth in σ_{pp} .

Fig. 3.b. The graph of fig. 3a as interpreted in the present model.

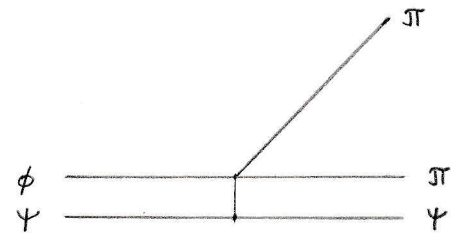

FIG. 1

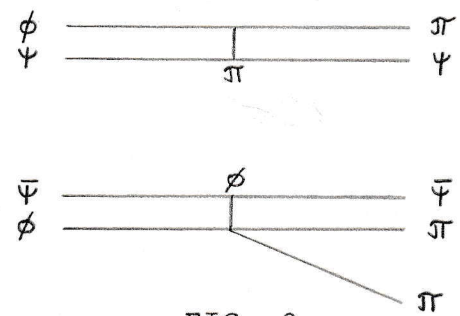

FIG. 2

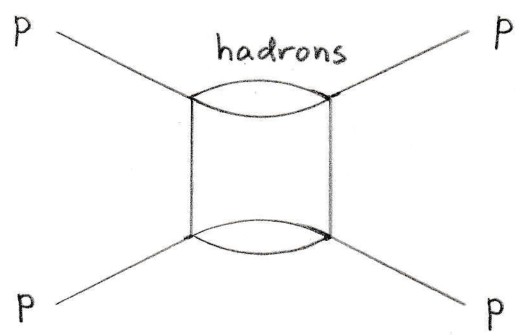

FIG. 3.a.

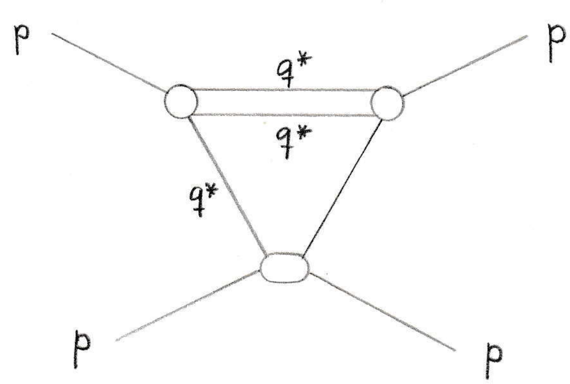

FIG. 3.b.