Search for supersymmetry partners of quarks

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Search for a bound state of quark-antiquark superpartners as a 1^{--} resonance in e^+e^- annihilation may be extremely promising because the electron width of such a resonance may be three orders of magnitude greater than is usually assumed.

There is an acute need for experimental tests of the supersymmetry gauge theories which presently enjoy the limelight in particle physics. It is especially important to search for supersymmetry partners of known particles: gauge bosons, quarks, and leptons. So far, none of these partner particles has been found; all that we have are limitations on their masses (see Ref. 1, for example).

In this letter we propose a new method for searching for supersymmetry partners of quarks (scalar quarks or "squarks") in e^+e^- collisions.[1)] The usual method is based on a search for events caused by the crossing of a threshold for the production of a squark-antisquark pair. The disadvantages of this method stem from the circumstance that the cross section for $e^+e^-\rightarrow\varphi\bar{\varphi}$ reaction reaches its asymptotic behavior slowly (in proportion to β^3, where β is the velocity of the squark), and the asymptotic cross section itself is one-fourth that for spinor quarks with the same electric charge.

The method which we wish to propose is to search not for the threshold for the production of a $\varphi\bar{\varphi}$ pair but for a narrow resonance corresponding to a 1^{--} bound state of a squark and an antisquark. This is of course a standard method for searching for ordinary heavy quarks (e.g., the t quark). In the case of *scalar* quarks, however, it is generally assumed[3] that the corresponding resonance would be so narrow as to be impossible to observe directly. (Estimates[3] based on a nonrelativistic quark model put the electron width of this resonance at a few electron volts at a resonance mass on the order of 20–30 GeV.)

For heavy squarks (we mean the Lagrange or current mass) this is in fact the case, but for light squarks[2)] the situation is fundamentally different.

It has been shown[4] (see Ref. 5 for a review) that the incorporation of the complex structure of the vacuum in models with scalar fields leads to physical properties and a spectrum of hadrons containing scalars which are quite different from the naive expectations. The presence of a vacuum scalar condensate $\langle 0|\varphi^+\varphi|0\rangle$ (introduced in Ref. 4) can lead to (first) a significant increase in the electron width of the vector resonance and (second) a substantial increase in the mass of the bound states containing squarks (up to several tens of GeV). Mass formulas of the type[3)]

$$m(\rho_s) = \sqrt{3}m(\chi_s) = \sqrt{3}m(\pi_s) = 43 < -\alpha_s^{1/6}\,\varphi^+\varphi > \tag{1}$$

can be derived by the sum-rule method for these bound states. Here the particles ρ_s ("vector phionium," 1^{--}), χ_s (the "white quark") and π_s ("scalar phionium," 0^{++}) correspond to the currents $\varphi^+\nabla_\mu\varphi, \varphi^+q$ and $\varphi^+\varphi$, respectively.

From the standpoint of an experimental search, the 1^{--} bound state of a scalar quark and a scalar antiquark, ρ_s, would be of greatest interest.

We see from (1) that the decay of ρ_s into $2\chi_s$ or $2\pi_s$ is forbidden. Vector phionium, if it exists, must therefore be a narrow resonance in e^+e^- annihilation. A rough estimate of the hadron width of ρ_s yields 400–700 keV, while the energy resolution (near $\sqrt{s} = 30$ GeV) would be on the order of 20 MeV.

We know that the controlling factor in a search for narrow resonances in e^+e^- annihilation is the electron width (not the total width) of the resonance.

The sum-rule method gives us the following value for the quantity:

$$\Gamma_{e^+e^-}(\rho_s) = 2.2m \frac{\alpha^2}{27\pi}\left(\frac{3Q_\varphi}{2}\right)^2. \tag{2}$$

For a given resonance mass m, Eq. (2) has no adjustable parameters; here $\alpha = 1/137$, and Q_φ is the electric charge of the squark. We wish to emphasize that the width (2) is 10^3 times the prediction of the nonrelativistic quark model[3] (for a given resonance mass). Numerically, with $m = 30$ GeV and $Q_\varphi = -1/3$, we would have $\Gamma_{e^+e^-} \approx 10$ keV, which would be quite adequate for an experimental observation of ρ_s. Expressions (1) and (2) and the narrowness of the ρ_s resonance are quite general: they are found in any model with a negative[4)] scalar condensate $\langle\varphi^+\varphi\rangle$ and if the squarks themselves are not too unstable (it is sufficient that their width not exceed a few MeV.)

Expressions (1) and (2) are sufficient for deriving limitations on the masses of the particles ρ_s, π_s, and χ_s from experimental data on e^+e^- annihilation in any specific model.[8,1] As an example we cite here the allowed intervals (in GeV) of the masses of the ρ_s resonance according to a model with one triplet of scalar fields (this model is described in detail in Ref. 4), according to data from a search for narrow resonances[8] (see also Ref. 9) and squarks[1] in e^+e^- annihilation: 27.3–28.3, >43.2 in the case $Q_\varphi = 2/3$; and 22.5–29.6, 31.5–32.7, 36.7–39.3, and >43.2 in the case $Q_\varphi = -1/3$.

We thus see that searches for the 1^{--} bound state of a squark and an antisquark as a resonance in e^+e^- annihilation may be an extremely effective method for searching for superpartners of quarks. Curiously, the data available do not rule out the possible existence of such a resonance in the energy interval $\sqrt{s} = 20$–30 GeV, which has already been covered.

Cosmological aspects of the theory of squarks and questions related to searches for new hadrons in terrestrial matter are discussed in Ref. 10.

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[1)]Manifestations of scalar quarks in hadron-hadron collisions are discussed in Refs. 2.

[2)]According to Ref. 6, in the case of a spontaneous breaking of the supersymmetry in a model with the gauge group $SU(3)\times SU(2)\times U(1)$ the mass of the squarks in the tree approximation would unavoidably be small (less than $m_{u,d}$).

[3)] We can assume $\langle -a_s^{1/b}\phi^+\phi\rangle = C\Lambda$ as a plausible estimate of the magnitude of the scalar condensate, where Λ is the reciprocal confinement radius. Perturbation-theory calculations[7] suggest that C may be much greater than 1.

[4)] The positive definiteness of the operator $\varphi^+\varphi$ is generally disrupted by renormalizations.

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