ANOMALOUS $p\bar{p}$ EVENTS AND DECAY OF NEW TYPES OF QUARK MATTER INTO e^+e^-

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We analyze the consequences of the proposal by Glashow that monojet events observed by UA1 are related to a new form of quark matter. We find that this idea requires the production of about 2 e^+e^-, 2 $\mu^+\mu^-$ and 2 γ + hadron events, all at the same large effective mass, for every monojet event explained in this way.

In an attempt to explain the peculiar events seen at the CERN $p\bar{p}$ collider by the UA1 collaboration [1], the exciting idea [2] has been proposed that there exists a new kind of quark matter, endowed with a new strong gauge interaction, "odor", besides the familiar flavor and color. Odor forces are supposed to be similar to QCD, in that $\Lambda_{\text{odor}} \simeq \Lambda_{\text{QCD}}$ and odor quarks are assumed to be unable to form an odor singlet state in conjunction with any number of light, normal, quarks and/or gauge fields. If this is the case, an odor quark pair, $Q\bar{Q}$ ($m_Q \simeq 65$ GeV) produced abundantly by gluon fusion, would be unable to dissociate for a wide range of invariant masses:

$$2m_Q \leqslant m_{Q\bar{Q}} \leqslant 4m_Q \,, \tag{1}$$

and would fall into the lightest, $J = 0$, and 1 odoronium states, by emitting gluons and light odorballs, if necessary. Even though odorballs would escape detection [2], it is unlikely that a large amount of missing $p_\perp$ is produced in this cascade decay.

The peculiar UA1 monojet events, namely:

$$p\bar{p} \to \text{jets} + \text{missing } p_\perp \,,$$

are supposed to arise from odoronium decays

$$(Q\bar{Q})_{J=1} \to H + Z \,, \tag{2}$$

where H is a standard, light Higgs boson, followed by Z decay into $\nu\bar{\nu}$ pairs, and H into hadrons.

Unlike the case of a toponium with a similar mass value, the wide energy range in (1) easily leads to an odoronium production cross section of the order of 1nb. This, together with the relatively large branching ratios involved in process (2) and in the subsequent decays, was the basis for the proposal of ref. [2].

We consider this idea to be very attractive and intriguing. However, looking more closely at the decay modes of odoronium, we have found that it leads to a striking prediction, namely that for each monojet event one should observe definitely more than one, and most likely about two events with an e^+e^- pair with invariant mass

$$m_{e^+e^-} = M_{J=1} \simeq 2m_Q \,,$$

and as many $\mu^+\mu^-$ events at the same mass. Corresponding to the 5 observed monojet events, one would expect at least 5 e^+e^- and 5 $\mu^+\mu^-$ events. Another easily detectable consequence of the scheme is that one should see more than 0.8 and most likely about 2 events with one hard γ plus hadrons, for each monojet event.

We are not sure whether such events should already have been observed in UA1 or UA2. We urge our ex-

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perimental colleagues to make an explicit test of these predictions, to obtain a confirmation or rejection of such a clever idea.

To be definite, we consider one weak isodoublet of mass-degenerate quarks U, D, and assume the electric charge pattern

$$Q_U = q\,, \quad Q_D = q - 1\,. \tag{3}$$

Adapting to this case the well-known charmonium formalism, we find that the decay rate for process (2) is given by

$$\Gamma_{J=1}(Z+H) = \tfrac{4}{3}(\alpha G/\sqrt{2})N|\psi(0)|^2 V^2 \times [1-(M_Z^2+M_H^2)/M^2]^{-2}\Phi\,, \tag{4}$$

with N the overall color and odor multiplicity of $Q(N = N_{col} \times N_{od})$ V the $Q\bar{Q}$ vector coupling to Z, in units of the proton electric charge:

$$V = (\sin\theta_w \cos\theta_w)^{-1}(\tfrac{1}{4}\tau_3 - Q\sin^2\theta_w)\,, \tag{5}$$

and, finally, Φ, the phase space factor:

$$\Phi = (2|\boldsymbol{q}|/M)\{[1+(M_Z^2-M_H^2)/M^2]^2 + 2M_Z^2/M^2\}\,,$$

$$M = M_{J=1} \simeq 2m_Q\,.$$

With the same assumptions which lead to eq. (4), one may compute the decay rate for the process

$$(Q\bar{Q})_{J=1} \to \gamma \text{ or } Z \to e^+e^-\,, \tag{6}$$

which leads to production of e^+e^- (or $\mu^+\mu^-$) pairs with invariant mass M. One finds:

$$\Gamma_{J=1}(e^+e^-) = \tfrac{8}{3}\pi\alpha^2 N|\psi(0)|^2 \times \{|Q - [M^2/(M^2-M_Z^2)]g_L^e V|^2 + |Q - [M^2/(M^2-M_Z^2)]g_R^e V|^2\}\,, \tag{7}$$

where the chiral couplings of the electron are

$$g_L^e = (\sin\theta_w\cos\theta_w)^{-1}(-\tfrac{1}{2}+\sin^2\theta_w)\,,$$

$$g_R^e = \tan\theta_w\,, \tag{8}$$

and V is given by eq. (5). With obvious changes, eq. (7) gives the decay rate into any light $f\bar{f}$ pair. Finally, the γ + H decay rate is given by:

$$\Gamma_{J=1}(\gamma+H) = \tfrac{4}{3}(\alpha G/\sqrt{2})N|\psi(0)|^2 Q^2(1-M_H^2/M^2)\,. \tag{9}$$

We can now parametrize the total decay rates of the $J = 1$ states according to

$$\Gamma_U^{J=1} = \Gamma_U(Z+H) + \Gamma_U(\gamma+H) + 3[\Gamma_U(e^+e^-) + \Gamma_U(\nu\bar{\nu}) + \Gamma_U(u\bar{u}) + \Gamma_U(d\bar{d})] + \Gamma_h \equiv \Gamma_{0U} + \Gamma_h\,, \tag{10}$$

and fimilarly for D. Γ_h is the partial width into color and odor gluons, which is the same in the two cases, and three light fermion families are assumed.

$J = 0$ states are easily shown to be irrelevant for our purposes: they do not decay into $f\bar{f}$ via Z or γ annihilation and we have found the decay width into Z + H to vanish, in the limit where we neglect the odoronium binding energy (i.e. $M = 2m_Q$). In addition, the total hadronic width of $J = 0$ states is considerably larger than $J = 1$ states.

It is a simple matter now to compute the ratio of direct e^+e^- versus Z + H events:

$$R = n(e^+e^-)/n(Z+H) = [\Gamma_U(e^+e^-)/\Gamma_U^{J=1} + \Gamma_D(e^+e^-)/\Gamma_D^{J=1}] \times [\Gamma_U(Z+H)/\Gamma_U^{J=1} + \Gamma_D(Z+H)/\Gamma_D^{J=1}]^{-1} = \frac{\Gamma_U(e^+e^-)}{\Gamma_U(Z+H)}\,\frac{1 + r\Gamma_D(e^+e^-)/\Gamma_U(e^+e^-)}{1 + r\Gamma_D(Z+H)/\Gamma_U(Z+H)}\,. \tag{11}$$

The ratio

$$r = (\Gamma_{0U} + \Gamma_h)/(\Gamma_{0D} + \Gamma_h)\,, \tag{12}$$

varies between 1 and Γ_{0U}/Γ_{0D} and, correspondingly, R varies between

$$R_1 = \frac{\Gamma_U(e^+e^-) + \Gamma_D(e^+e^-)}{\Gamma_U(Z+H) + \Gamma_D(Z+H)}\,, \tag{13}$$

and

$$R_2 = \frac{\Gamma_U(e^+e^-)/\Gamma_{0U} + \Gamma_D(e^+e^-)/\Gamma_{0D}}{\Gamma_U(Z+H)/\Gamma_{0U} + \Gamma_D(Z+H)/\Gamma_{0D}}\,, \tag{14}$$

both R_1 and R_2 are independent from unknown factors such as the overall quark multiplicity, N, or $\psi(0)$.

For the values $M = 130$ GeV, $M_H = 10$ GeV, $\sin^2\theta_w = 0.22$, $q = \frac{2}{3}$ we find

$$\Gamma_{0U}/\Gamma_{0D} = 0.72\,, \tag{15}$$

and

$$0.418 = R_2 \leqslant R \leqslant R_1 = 0.426\,. \tag{16}$$

Taking into account a branching ratio for $Z \to \nu\bar{\nu}$ of

0.18, we conclude that, irrespectively from the value of Γ_h:

$$n(e^+e^-)/n(\text{monojets}) \simeq 2.3 . \qquad (17)$$

The ratio (17) is very insensitive to the values of the unknown parameters. By letting q in eq. (3) vary from $+1$ to $-\frac{4}{3}$, the ratio in eq. (17) varies of about 10%, and the lower bound to R never becomes much smaller than the value given in (16) if we make M to run from 110 GeV to 185 GeV.

There could be a correction to eq. (17) because of the decay

$$(Q\bar{Q})_{J=1} \to \gamma \text{ or } Z \to \tau^+\tau^- , \qquad (18)$$

one τ being missed and the other decaying into ν_τ + hadrons. In this case, process (18) would contribute to monojet events and one should replace eq. (17) by

$$\frac{n(e^+e^-)}{n(\text{monojets})} = \frac{R}{0.18 + 0.65(2f)R} , \qquad (19)$$

where we have assumed a semihadronic branching ratio of 0.65 for τ and f is the probability for completely missing one τ. f can be determined explicitly for a given experimental setup. We think it unlikely that a τ can be missed completely in UA1 or UA2, if it decays into three charged tracks. The one charged prong branching ratio for τ is

$$B(\tau \to 1 \text{ charged part}) = B_{\tau 1} \simeq 0.44 . \qquad (20)$$

A reasonable estimate could be

$$f = 0.1 B_{\tau 1} , \qquad (21)$$

which gives

$$n(e^+e^-)/n(\text{monojets}) = 2.1 . \qquad (22)$$

For the extreme case where

$$f = B_{\tau 1} , \qquad (23)$$

we obtain

$$n(e^+e^-)/n(\text{monojets}) \simeq 1 . \qquad (24)$$

By a similar reasoning, one obtains that the ratio

$$R^\gamma = n(\gamma + H)/n(Z + H) , \qquad (25)$$

is bounded according to

$$0.34 \leqslant R^\gamma \leqslant 0.40 , \qquad (26)$$

and that

$$\frac{n(\gamma + \text{hadrons})}{n(\text{monojets})} = \frac{R^\gamma}{0.18 + 0.65(2f)R} , \qquad (27)$$

with R defined in eq. (11). We find

$$\frac{n(\gamma + \text{hadrons})}{n(\text{monojets})} \simeq 1.7 \quad (f = 0.1\, B_{\tau 1}) ,$$

$$\simeq 0.8 \quad (f = B_{\tau 1}) . \qquad (28)$$

One could also envisage the case where odor matter is made of scalar instead of spin $\frac{1}{2}$ particles. However in this case not only the e^+e^- and hard γ signals disappear, but also the Z + H decay is forbidden, for the ground state $J^{PC} = 0^{++}$.

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