tiplied by a factor 2–3 to obtain the true dimuon rate. A similar conclusion is reached in Ref. 9.

It is interesting to estimate the expected μe event rate in the Fermilab[1] and CERN[2] bubble-chamber experiments due to Y-meson production with $m_Y = 2$ GeV. By comparing our dN/dE_e predictions with the dimuon data and using the appropriate ν spectra we estimate

$$(\sigma_{\mu^- e^+}/\sigma_{\mu^-})(\mathrm{FNAL}) \simeq 2\times 10^{-2}, \quad (8)$$

$$(\sigma_{\mu^- e^+}/\sigma_{\mu^-})(\mathrm{CERN}) \simeq 1\times 10^{-4}, \quad (9)$$

for angular acceptances similar to the dimuon experiment. The slow- and fast-rescaling models happen to lead to essentially the same net rate predictions in Eqs. (8) and (9).

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Are SLAC μe Events Decay Products of Unconfined Integer-Charge Quarks?*

Jogesh C. Pati*
Department of Physics, University of Maryland, College Park, Maryland 20742

and

Abdus Salam
International Centre for Theoretical Physics, Trieste, Italy, and Imperial College, London, England

and

S. Sakakibara*
Department of Physics, City Collge of City University of New York, New York, New York 10031

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It is remarked that the μe events as well as the jet structure observed at SPEAR may both have their origin in the pair production and decays of integer-charge quarks.

Some years back, two of us suggested[1] that conservation of baryon and lepton numbers may not be absolute within the hypothesis of a unified gauge theory for all interactions with integer-charge quarks and leptons as member of one fermion multiplet. We estimated[1,2] that even though quarks could decay into leptons relatively rapidly ($\tau_q \approx 10^{-11}$ to 10^{-12} sec even for light quarks, $m_q = 2$–3 GeV), the proton—a three quark composite—would remain comfortably stable within its present lifetime estimates. The hypothesis of quark decay into leptons provides a simple resolution of the missing-quark mystery without having to assume quark confinement.

We have no compelling theoretical reason to believe that quarks are as light as 1.7–2 GeV; however, if we accept this, and if we make one further assumption that colored vector mesons (gluons) lighter than quarks exist,[3] then it appears that the quark-lepton decays could provide an interesting explanation of the μe events[4] as well as of the jet structure[5] recently observed at the Stanford Linear Accelerator Center (SLAC). In this note we sketch the chain of possible decays and the characteristic signatures which would distinguish between the alternatives of quark versus heavy-lepton parents for these events.

To illustrate our remarks, we follow here closely the restrictions of the basic model,[1] based on the minimal local symmetry $\mathcal{G} = \mathrm{SU}(2)_L \otimes \mathrm{SU}(2)_R \otimes \mathrm{SU}(4)_{L+R}'$, and of the assumption that quark charges are integral. We expect quarks and charged members of the octet of color gluons ($V_\rho^\pm$, $V_{K^*}^\pm$, $V_{K^*}^0$, $\overline{V}_{K^*}^0$, $\tilde{U}$, and $\tilde{V}$) to be produced by e^-e^+ annihilation:

$$e^- + e^+ \to (q+\bar{q}),\ (V_\rho^+ + V_\rho^-),\ (V_{K^*}^+ + V_{K^*}^-). \qquad (1)$$

It has been shown[6] that within the gauge-theory framework, the color-octet part of quark charges do not asymptotically contribute to $\boldsymbol{R}$. Taking this into account, the contributions to the R parameter from the twelve integer-charge quarks possessing four flavors[7] (u, d, s, and c) and three colors (red, yellow, and blue are r, y, and b, respectively) on the one hand and the charged color gluons on the other (treated as *partons*) are given by

$$R(u\bar{u})_{\mathrm{r,y,b}} = R(c\bar{c})_{\mathrm{r,y,b}} = \tfrac{4}{9},$$
$$R(d\bar{d})_{\mathrm{r,y,b}} = R(s\bar{s})_{\mathrm{r,y,b}} = \tfrac{1}{9},$$
$$R(V_\rho^+ V_\rho^-) = R(V_{K^*}^+ V_{K^*}^-) = \tfrac{1}{16} \qquad (2)$$

With nonconfinement, we expect in general some of the parton pairs to "recombine" to form known hadrons. However, a certain fraction of these partons will survive in the final state—as quarks and gluons. The signatures of quarks and charged gluons depend upon their allowed decay modes which we list below.

Charged color gluon decays.—If we assume that the gluons are the lightest color-octet states, then the charged members ($V_\rho^\pm$ and $V_{K^*}^\pm$) decay solely as a result of their *mixing* with the weak $W_L^\pm$ gauge mesons. Some of their allowed and forbidden[8] decay modes are

$$(V_\rho^\pm, V_{K^*}^\pm) \to e\nu,\ \mu\nu$$
$$\to \pi\pi,\ 3\pi,\ 5\pi,\ K\bar{K}$$
$$\to \pi\pi e\nu,\ K\bar{K}e\nu,\ \eta\eta e\nu$$
$$\not\to \pi e\nu,\ Ke\nu. \qquad (3)$$

We estimate that (i) $\Gamma(V_\rho^+ \to e\nu) = \Gamma(V_\rho^+ \to \mu\nu)$, (ii) $\Gamma(V_\rho^+ \to \pi\pi e\nu)/\Gamma(V_\rho^+ \to e\nu) \approx \frac{1}{40} - \frac{1}{10}$, and (iii) $[\sum \Gamma(V_\rho^+ \to \text{hadrons})]/\Gamma(V_\rho^+ \to e\nu) \approx 1-3$; by use of light-cone analysis the last ratio should approach the larger value 3 for relatively large gluon masses ($m_V \gtrsim 3$ GeV). So we expect the $e\nu$ and $\mu\nu$ modes each to have a branching ratio $\approx (35-25)\%$ if the gluon mass $m_V \approx 1-1.5$ GeV and $\approx (15-20)\%$ if the gluon mass $m_V \gtrsim 3$ GeV. For $m_V \approx 1-3$ GeV, we estimate[1,2] that $\tau(V_\rho^+) \approx \tau(V_K{}^{*+}) \approx 10^{-13}$ to 10^{-15} sec.

Quark decays.—First we make a few general remarks: (i) In the basic model there are three gauge bosons (X^0, X^+, and X'^+), which respectively couple red, yellow, and blue quarks of a given flavor to the lepton of the same flavor. Baryon- and lepton-number-nonconserving quark decays occur only because of the spontaneously induced mixing of the X bosons with the weak gauge bosons, W_L's. It is a property of the gauge structure of the basic model[1] that only $X^\pm$ and $X'^\pm$ can mix with $W_L^\pm$, but X^0 cannot mix with $(W_3)_{L,R}$. *Thus the mechanism for yellow and blue quark decays within the basic model is characteristically different from that for the red quarks.* (ii) The dominant decay mechanism for yellow and blue quarks (involving baryon-number nonconservation) is given by the *convergent* loop diagram [Fig. 1(a)], which is of order (Δ^2/m_x^2), Δ^2 being the square of the W-X mixing mass. Note that *Fig. 1(a) may induce semileptonic decays* ($q_{\mathrm{y,b}} \to \nu + mesons$) *involving emission of only neutral leptons (neutrinos)*; it cannot lead to charged-lepton emission. Charged leptons may be emitted either via loop diagrams as in Fig. 1(b), where a $q\bar{q}$ composite (e.g., pion) is emitted from *inside* the loop, or alternatively via tree diagrams as in Fig. 1(c). It is possible to see[1,2] that the rates of processes induced via Figs. 1(b) and 1(c) are strongly suppressed[9] by a factor $\sim (m/m_{W_L})^4$ compared to those induced via Fig. 1(a), where $m \approx m_q$ or m_V. With these considerations, the dominant decay modes of the yellow and blue quarks

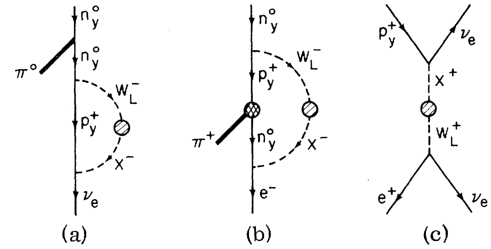

FIG. 1. Mechanisms for yellow and blue quark decays.

are

$$(u^+, d^0, s^0)_{y,b} \to \nu + \text{mesons}(\pi, K, \eta),$$
$$c_{y,b}{}^+ \to s_{y,b}{}^0 + \pi^+,\ \nu_e + D^+,\ \nu_\mu + F^+ . \qquad (4)$$

We obtain τ(y, b quarks) ~ 10^{-11} to 10^{-12} sec for $m_q \approx 2$ GeV. If the charmed mesons (D^+, F^+) are heavy compared to the charmed quarks, the ordinary quark number-conserving weak decays of charmed quarks (e.g., $c_{y,b}{}^+ \to s_{y,b} + \pi^+$) should represent their dominant decay modes.

Consider now decays of red quarks. There are two cases: In the first case $m_q > m_V$ and the dominant decay modes of the red quarks are

$$u_r{}^0 \to (d_y{}^0 + \gamma),\ (V_\rho{}^- + \pi^+ + \nu_e);$$
$$(d^-, s^-)_r \to V_\rho{}^- + \nu_{e,\mu}; \qquad (5)$$
$$c_r{}^0 \to s_y{}^0 + \gamma, u_r{}^0 + \pi^0, s_r{}^- + \pi^+ .$$

We obtain τ(r quarks) $\approx 10^{-11}$ to 10^{-12} sec just like τ(y, b quarks) with $m_q \approx 2$ GeV. The radiative decay modes of the neutral red quarks $u_r{}^0$ and $c_r{}^0$ (arising through $V_\rho{}^+$-$W_L{}^+$ mixing) are found to be the dominant modes if their Q values are $\gtrsim 10$ MeV.

In the second case $m_q < m_V$, although the neutral red quarks $u_r{}^0$ and $c_r{}^0$ still may decay radiatively as in the first case, the charged red quarks would decay (e.g., $d_r{}^- \to e^- + \pi^0$, $s_r{}^- \to \mu^- + \eta$) only by utilizing *both* $V_\rho{}^+$-$W_L{}^+$ and $W_L{}^+$-X^+ mixing; correspondingly their decay rates are found to be suppressed by a factor $\sim (m_V/m_{W_L})^4$ compared to those of the yellow and blue quarks.

Turning now to the origin of the SPEAR μe events, pair production of the yellow and blue quarks (even though present) cannot be responsible for these events, since these quarks decay predominantly semileptonically into $\nu_{e,\mu}$ + mesons. On the other hand, if quarks are heavier than the color gluons (first case), pair production of charged red quarks ($d_r{}^- d_r{}^+$ and $s_r{}^- s_r{}^+$), followed by their sequential decays as shown below, can give rise to anomalous μe pairs as seen at SPEAR:

$$e^- e^+ \to d_r{}^- d_r{}^+ \to (V_\rho{}^- \nu_e) + (V_\rho{}^+ \bar{\nu}_e). \qquad (6)$$
$$\quad V_\rho{}^- \to e^- + \bar{\nu}_e, \quad V_\rho{}^+ \to \mu^+ + \nu_\mu$$

The μe pairs thus arising would appear within the present statistics like three-body leptonic decay of the parent quarks.

Now define $\rho(s) \equiv |f_{qq\gamma}(s)|^2$, where $f_{qq\gamma}(s)$ is the on-mass-shell quark electromagnetic form factor. It follows that $\sigma(e^- e^+ \to q_i\bar{q}_i)/\sigma(e^- e^+ \to \mu^- \mu^+) = R(q_i\bar{q}_i)\rho(s)$, where $R(q_i\bar{q}_i)$ for any given quark pair is given by Eq. (2). [Note that strictly within the parton-model hypothesis we may interpret $\rho(s)$ as the fraction of all $q_i\bar{q}_i$ parton pairs created which "survive" as real particles in the final state.] Noting that asymptotically $R(d_r{}^- d_r{}^+) + R(s_r{}^- s_r{}^+) = \frac{2}{9}$ [see Eq. (2)] and that the branching ratio of the $\mu\nu$ as well as $e\nu$ decay modes of $V_\rho{}^\pm$ is $\approx$ (25–35)%, we find that the net contribution to R of the $\mu^\pm e^\mp$ signals arising from real quark production and decays is given by

$$R_{q\bar{q}}(\mu^+ e^-) = R_{q\bar{q}}(\mu^- e^+) = \tfrac{2}{9}(\tfrac{1}{5} - \tfrac{1}{3})^2 \rho(s) = \rho(s) \times (1.6 - 2.5)\%.$$

Direct production of charged-color-gluon pairs followed by their two-body leptonic decays will also contribute to the signature μe events. Noting that $R(V_\rho{}^+ V_\rho{}^-) + R(V_{K^*}{}^+ V_{K^*}{}^-) = \frac{1}{8}$, the net contribution to $R(\mu^\pm e^\mp)$ from color-gluon pair production is given by $R_{V\bar{V}}(\mu^+ e^-) = R_{V\bar{V}}(\mu^- e^+) = \frac{1}{8}(\frac{1}{5} - \frac{1}{3})^2 \rho'(s) = \rho'(s) \times (0.8 - 1.4)\%$, where $\rho'(s)$ is the square of the color-gluon electromagnetic form factor.

The observed[4] SPEAR μe signal corresponds to a true signal of $R(\mu^+ e^-) = R(\mu^- e^+) = (1-3)\%$. By comparison with the estimate given above, this can be attributed to quark decays only provided that $\rho(s) \equiv |f_{qq\gamma}(s)|^2 \approx \frac{1}{2} - 1$. Not knowing theoretically the precise nature of the quark electromagnetic from factor, we will proceed in this Letter with the assumption[10] that it is hard [i.e., $f_{qq\gamma}(s) \sim (1/\sqrt{2}) - 1$ and is slowly varying at SPEAR energies]. There then exist a host of strong experimental predictions, which we list below.

(i) *Jetlike distribution of hadrons:* Within our hypothesis a large fraction $\rho(s)$ ($\approx \frac{1}{2} - 1$) of the total hadronic annihilation events must involve real $q\bar{q}$ production. Since quarks decay predominantly into neutrino plus known mesons [see Eqs. (4) and (5)], these $q\bar{q}$ pairs would give rise to the final-state hadrons (mesons) emerging in the form of two jets opposite to each other with a distribution characteristic of spin-$\frac{1}{2}$ parentage. Such jet structure is indeed observed[5,11] experimentally at SPEAR. Since quarks carry charges 0 and ±1, the ratio[12] of charged to neutral jets should reach a value $\frac{18}{9}/\frac{12}{9} = \frac{3}{2}$ [see Eq. (2)] above the charmed-quark threshold but below threshold for new flavors[7] (if there exist any).

(ii) *Energy crisis:* Furthermore, these events must be associated with missing neutral energy and momentum carried away by the neutrinos, which may explain the so-called "energy crisis" and the depletion of charged energy[13] observed in $e^- e^+$ annihilation.

(iii) *Nonappearance of charmed particles:* If the charmed particles D and F are relatively heavy compared to the charmed quarks, the charmed quarks rather than decaying into $\nu+D$ or $\nu+F$ would decay preferentially or entirely into uncharmed quarks plus pions [see Eqs. (4) and (5)]. In this case, production of real charmed-quark pairs above threshold will lead to an increase in $R=\frac{4}{3}\rho(s)$, but *this* increase will be reflected in the production of pions and kaons rather than charmed mesons,[14] consistent with the nonappearance of charmed particles in the continuing SPEAR search.

(iv) *$V+A$ couplings:* Given that the W_L gauge mesons couple to $V-A$ currents, it is easy to see that the amplitude for the transition $d_r^- \to V_\rho^- + (d_y^0)_{\text{virtual}} \to V_\rho^- + \nu_e$ must be of the form $\bar{\nu}_e(1+\gamma_5)[F_1\gamma_\mu + F_2\sigma_{\mu\nu}q_\nu]d_r^- V_{\rho\mu}^+$ which is of the $V+A$ form for $F_2=0$.

(v) *Semileptonic signals:* There must exist semileptonic signals such as $e^-e^+ \to \mu^\pm e^\mp + \pi^+\pi^-$ + missing momentum, which arise from semileptonic decay modes of either the color gluons [produced in Reaction (6)] or directly from the charged red quarks. We estimate the strength of such semileptonic signals to be $\approx(2-5)\%$ of the pure leptonic μe signals. Note, by contrast, that semileptonic signals as above cannot arise via pair production and decays of heavy leptons.

(vi) *Neutral quark pair production:* Note the intriguing feature that the neutral quark pairs $u_r^0\bar{u}_r^0$ and $c_r^0\bar{c}_r^0$ would each be produced asymptotically[6] with a cross section given by $R=\frac{4}{9}\rho(s)$ [see Eq. (2)] which is *4 times* that of the charged pair $d_r^-d_r^+$; neutral heavy leptons on the other hand cannot be produced by e^-e^+ annihilation. Production of these neutral quark pairs may be searched for by looking for *monoenergetic low-energy γ rays* ($\approx 10-100$ MeV) near threshold for μe production[4] and charmed-quark production [see decay modes, Reactions (5)].

(vii) *Anomalous leptons in hadronic collisions:* Finally, we expect charged red quarks and charged color gluons to be produced in pairs by $p+p$ collisions with cross sections $\gtrsim 10^{-31}$ cm^2 at Fermilab and CERN intersecting storage ring; their decays should give rise to anomalous dileptons (e^-e^+, $\mu^-\mu^+$, and $\mu^\pm e^\mp$) as well as to single leptons. These may in fact be responsible for the "excess" direct leptons observed in such collisions. Note that there is a sharp distinction between the "strong" production of quarks (and gluons) on the one hand and the weak and electromagnetic production of heavy leptons on the other by such collisions.

We emphasize once again that the SPEAR μe events may arise from quark decays only provided there exist[3] color gluons (or similar colored vector mesons) below 2 GeV. We therefore urge a search[16] for narrow neutral and charged color gluons in the mass region *below* 2 GeV. Finally, to distinguish between quark versus heavy-lepton hypotheses for the μe events, we especially urge searches for (i) anomalous semileptonic μe signals in e^-e^+ annihilation, (ii) monoenergetic low-energy γ rays near threshold for the production of μe events, and (iii) anomalous leptons in hadronic collisions.

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[3]If no such colored vector mesons exist, the μe events would not be relevant for quark decays; one would then need to institute a different type of search for quark decays (see Ref. 2).

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[7]Introduction of new quark flavors (which may be needed to account for the observed value of R) and heavy leptons through the mirror set [for the unifying symmetry $G=\mathrm{SU}(4)^4$] does not alter our discussion here [see, e.g., J. C. Pati and Abdus Salam, Phys. Lett. 58B, 333 (1975)].

[8]$[\Gamma(V_\rho^+ \to \pi e\nu)$ or $\Gamma(V_\rho^+ \to Ke\nu)] \lesssim O(\alpha^2)\,[\Gamma(V_\rho^+ \to e\nu)$ or $\Gamma(V_\rho^+ \to \pi\pi e\nu)]$ by isospin and strangeness selection rules.

[9]Figure 1(b) is strongly suppressed compared to Fig. 1(a), *if* emission of composite mesons (e.g., pions) from quarks is associated with a form factor [e.g., $f_{qq\pi}(k^2) \sim m^2/(k^2-m^2)$]. In this note we make the crucial assumption that quarks, leptons, and gauge mesons are elementary.

[10]This question is under study.

[11]We stress that the familiar parton model considerations do not provide a convincing explanation of the jet structure unless real quark pairs are produced as sug-

gested here.

[12]We thank G. A. Snow for urging this test.

[13]See F. Gilman and R. Schwitters, in *Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, Stanford, California, 1975*, edited by W. T. Kirk (Stanford Linear Accelerator Center, Stanford, Calif., 1975).

[14]This does not, of course, preclude single (and pair) production of charmed particles by neutrino (and hadronic) interactions.

[15]See J. C. Pati, J. Sucher, and C. H. Woo (to be published), and also Ref. 1 for details.

Measurement of $J/\psi(3100)$ Photoproduction in Deuterium at a Mean Energy of 55 GeV*

T. Nash
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

A. Belousov and B. Govorkov
Lebedev Physical Institute, Moscow 117 924, U. S. S. R.

and

D. O. Caldwell, J. P. Cumalat, A. M. Eisner, R. J. Morrison, F. V. Murphy,† and S. J. Yellin
University of California, Santa Barbara, California 93106

and

P. J. Davis, R. M. Egloff, G. Luste, and J. D. Prentice
University of Toronto, Toronto 181, Ontario, Canada
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We report the result of a brief experiment to measure the cross section for photoproduction of $J/\psi(3100)$. At a mean energy of 55 GeV we find this cross section per nucleon to be 37.5 ± 8.2 (statistical) ± 4 (systematic) nb. The result establishes the previously indicated rise in J/ψ photoproduction on protons above 20 GeV and suggests that the rise has occurred by 55 GeV.

The photoproduction cross section of $J/\psi(3100)$ has been measured by several groups[1-3] using different nuclei at energies from 11 GeV to over 100 GeV. The lowest-energy measurement made near threshold at Cornell University and the highest-energy measurement made with the Fermilab broadband photon beam used beryllium as a target. Measurements at Stanford Linear Accelerator Center (SLAC) well above threshold were made with D_2 and H_2 targets. Despite the difficulty of comparing measurements on different nuclei the results at Fermilab indicated a rise in the cross section per nucleon between SLAC energies around 20 GeV and Fermilab energies over 50 GeV.

We report here a first, low-statistics, measurement at high energy of the cross section for the production of the $J/\psi(3100)$ on deuterium in the channel $J/\psi \rightarrow e^+e^-$. By a simple procedure we have also determined the single-nucleon cross section. This result can be compared directly with the SLAC measurements and establishes a significant rise in the photoproduction cross section of J/ψ between SLAC energies[2] below 20 GeV and the energy range for the data of this experiment (31–80 GeV with a mean of 55 GeV). This measurement is based on data taken during a short period of testing of the new tagged photon beam at the Fermi National Accelerator Laboratory. Both the incoming photon and the electron pair energies were measured. The results indicate that the J/ψ were produced elastically or with a very small missing energy.

A beam of (90 ± 2)-GeV electrons radiated photons in a $0.18X_0$ Cu target. Photon energies between 31 and 80 GeV were tagged (subject to a thick-radiator correction to be discussed below) by bending outgoing electrons into a bank of lead-glass shower counters. Almost all electrons in the tagging range were detected so that the photon spectrum was essentially that expected from thick-target bremsstrahlung. The photon energy resolution was about 2 GeV dominated by the electron-beam momentum spread. Veto counters were used to reduce below 2% the probability that a valid tagging signal was not associated with a