# Mirror fermions and the problem of dileptons of identical sign

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An explanation is proposed for the problem of dileptons of identical sign in an $SU(2)_L \times SU(2)_R \times U(1)$ model with mirror quarks. The explanation involves the possible attainment of a significant $(D^0 \rightleftarrows \bar{D}^0)$ mixing in this model.

**1.** Let us examine the expansion of the minimal $SU(2)_L \times SU(2)_R \times U(1)$-symmetry model,[1] which contains a doubled fermion spectrum[2] $(q - Q, l - L)$. The initial Lagrangian of the interaction of the gauge fields with quarks (leptons) is

$$\mathcal{L}^a = ig[\bar{\psi}_L \gamma_\mu \Big(\frac{\vec{\tau}}{2} \otimes e^1 \otimes E_3\Big) A_{\mu L} \psi_L + \bar{\psi}_R \gamma_\mu \Big(\frac{\vec{\tau}}{2} \otimes e^a \otimes E_3\Big) A_{\mu R} \psi_R ] + ig' \bar{\psi} \gamma_\mu \frac{V}{2} \psi B_\mu ,$$

where

$$\psi = (q_i^u, Q_i^u, q_i^d, Q_i^d)_{i=1,2,3} = (u, c, t, U, C, T, d, s, b, D, S, B), \quad \psi_{L,R} = \frac{1 \pm \gamma_5}{2} \psi ,$$

and $\vec{\tau}$ are the Pauli matrices; $e^1 = \mathrm{diag}(1,0)$, $e^2 = \mathrm{diag}(0,1)$, $E_3 = \mathrm{diag}(1,1,1)$; the indices $a = 1,2$ correspond to the two versions of the model that we are considering. The value $a = 1$ is the version which includes doubling massive fermions $(Q_i^{u(d)}, L_i^{u(d)})$ with an isospin $T = 0$, while $a = 2$ corresponds to version 2, with the following quark content:

$$(u_i, d_i)_L \in (2,1,1/3), (U_i, D_i)_R \in (1,2,1/3),$$

$$(U_i)_L \in (1,1,4/3), (D_i)_L \in (1,1,-2/3),$$

$$(u_i)_R \in (1,1,4/3), (d_i)_R \in (1,1,-2/3).$$

In contrast with the minimal left-right-symmetry model and other models that are being discussed in the literature, this approach permits a significant mixing of $D^0$ and $\bar{D}^0$ mesons:

$$\rho_D = [(\Delta m_D)^2 + (\Delta\Gamma_D/2)^2]/[2\Gamma_D^2 + (\Delta m_D)^2 - (\Delta\Gamma_D/2)^2]$$
$$\sim (4\text{–}20) \times 10^{-2}, [\Delta\Gamma = \Gamma_L - \Gamma_S, \Gamma_D = (\Gamma_L + \Gamma_S)/2, \Gamma_{L(S)}$$

are the total decay widths of the $D_L^0$ and $D_S^0$ mesons], predicting a difference between the masses of the long-lived and short-lived states $D_L$ and $D_S$, $\Delta m_D = m(D_L) - m(D_S)$ near the experimental upper boundary,[3] $10^{-12}$–$4 \times 10^{-13}$ GeV. It thus becomes possible to link the appearance of $\mu^\pm e^\pm \mu^\pm \mu^\pm$ pairs in $\nu N$ and $\bar{\nu} N$ experiments $[R_{\nu(\bar{\nu})} = \sigma(\nu(\bar{\nu})N \to l_i^{\pm} l_j^{\pm} X)/\sigma(\nu(\bar{\nu})N \to l_i^{\pm} l_j^{\mp} X) \gtrsim 10^{-1}$ at $E_{\nu(\bar{\nu})} > 40$ GeV$(l_{ij} = e^{\pm}, \mu^{\pm})]$ with leptons of the decay of mixed $D^0 \rightleftarrows \bar{D}^0$ states;

$$\Gamma(D^0(\bar{D}^0)) \to l^{-(+)}\bar{\nu}_l(\nu_l)X^{+(-)})/\Gamma(D^0(\bar{D}^0) \to l^{+(-)}X^{-(+)}\nu_l(\bar{\nu}_l)$$

$$= \rho_D |(1(\mp)\epsilon_D)/(1(\pm)\epsilon_D)|^2 \sim (4\text{–}20) \times 10^{-2},$$

($\epsilon_D$ is the CP-breaking parameter in the $D^0$, $\bar{D}^0$ system). From the mechanism of the associative production of charm, which might generate the major background for processes resulting from $D^0 \rightleftarrows \bar{D}^0$ oscillations in the standard model, we find a predicted value of $R_{\nu(\bar{\nu})}$ one or two orders of magnitude lower than the experimental values of Ref. 4. Furthermore, this mechanism poorly reproduces the observed independence of the parameter $R_{\nu(\bar{\nu})}$ from the energy of the neutrinos (or antineutrinos), which probably corresponds to processes with oscillations of $D^0$ and $\bar{D}^0$ mesons (Fig. 1).

2. The transition to the physical states of fermions in Lagrangian (1) due to the diagonalization of their mass matrix occurs by two mechanisms[2]: (a) "horizontal" (Cabibbo) mixing of generations and (b) a mixing of ordinary $q^u(q^d)$ and "mirror" $Q^u(Q^d)$ quarks within each generation:

$$(d_i)_{L(R)} \to (d_i c_i^d + D_i s_i^d)_{L(R)},$$

$$(D_i)_{L(R)} \to (-d_i s_i^d + D_i c_i^d)_{L(R)},$$

$$(u_i)_{L(R)} \to (u_i c_i^u + U_i s_i^u)_{L(R)},$$

$$(U_i)_{L(R)} \to (-u_i s_i^u + U_i c_i^u)_{L(R)},$$

where $i$ specifies the generation, $c_i = \cos\theta_i$, $s_i = \sin\theta_i$, and $i = 1,2,\ldots$ . The difference

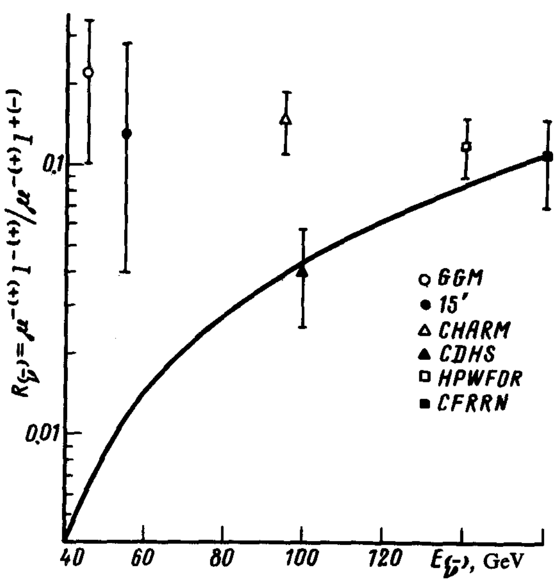


FIG. 1. Ratio of the yield of dileptons of identical sign to that of leptons of different signs, $R_{\nu(\bar{\nu})}$, versus the energy of the (anti-) neutrinos.[8] The solid line is the ratio of the yield of associated charm[9] to isolated charm,[10] normalized to the point of the CFRRN group.

between the matrix of left-hand weak charged currents ($V^L_{ij}$) and the corresponding matrix found in the standard $[SU(2)_L \times U(1)]$ model and the corresponding modification of the parameters of the interaction of weak neutral currents lies within the experimental errors if the following relations hold:

$$|s_1^{u(d)}|_{L(R)} \lesssim 0.3, \quad (s_1^{u(d)})_L = (s_1^{u(d)})^l_L, \tag{2}$$

where $(s_i^{u(d)})^l$ are the corresponding lepton-mixing parameters.

The doubling of the fermion spectrum makes it possible to construct a cancellation mechanism of the Glashow-Iliopoulos-Maiani type not only for the $LL$ and $RR$ diagrams but also for diagrams with the emission of $W_L$ and $W_R$ bosons ($LR$ diagrams).[2,5] As a result, we find useful relations between the quark masses ($q_i$, $Q_i$) and the mixing parameters ($s_i$). For the case of two generations of fermions, for example, we find

$$\left[s_{2L} = \left(s_{1L} + \frac{m_2}{M_2} s_{1R}\right)\right]^{u(d)}, \left[s_{2R} = \left(s_{1R} + \frac{m_2}{M_2} s_{1L}\right)\right]^{u(d)},$$

$$\left[M_2 = \left(M_1 - \frac{m_2}{s_{1L} s_{1R}}\right)\right]^{u(d)}, \tag{3}$$

$$\left[s_{2L} = \frac{M_1}{M_2}\left(s_{1L} + \frac{m_2}{M_2} s_{1R}\right)\right]^{u(d)}, \left[s_{2R} = \frac{M_1}{M_2}\left(s_{1R} + \frac{m_2}{M_2} s_{1L}\right)\right]^{u(d)}$$

$$\left[M_2 = \sqrt{M_1^2 + \frac{m_2 M_2}{s_{1L} s_{1R}}}\right]^{u(d)}, \tag{4}$$

where $m_{1,2}^{u(d)}$ are the masses of the $u(d)$ and $c(s)$ quarks. $M_{1,2}^{u(d)}$ are the masses of the doubling $U(C)$ and $D(S)$ quarks, and $m_1^{u(d)} \ll m_2^{u(d)}$. Expressions (3) and (4) refer to versions (1) and (2), respectively.

**3.** Carrying out the standard calculations of square ($LL$), ($LR$), and ($RR$) diagrams with exchanges of ordinary and mirror quarks in a unitary gauge, we find the principal contributions to the parameter $\Delta m_D$:

$$(\Delta m_D)_{LL} = G_D^{LL} \sum_{i,j=d,s,D,S} (V^L_{ui} V^L_{cj} V^L_{uj} V^L_{ci}) \left[-\frac{3}{4(1-y_i)(1-y_j)} + \frac{f(y_i) - f(y_j)}{y_i - y_j}\right], \tag{5}$$

where

$$f(y_i) = y_i(1 - 2y_i + y_i^2/4)/(1 - y_i)^2;$$

$$(M^2_{W_L} y_i) = m_d^2, (m_s^2), (M_D^2, (M_S^2)), i = d, (s), (D, (S));$$

$$G_D^{LL} = G_F^2/6\pi^2) f_D^2 m_D M^2_{WL}, f_D = 0.3 \text{ GeV},$$

$m_D$ is the mass of the $D$ meson, $(\Delta m_D)_{LL,(LR);(RR)}$ are the contributions of $LL$, $(LR)$, and $(RR)$ diagrams; $V_{ij}^{L(R)}$ are the elements of the matrix of the left-hand (right-hand) weak charged currents. The transition to $(\Delta m_D)^{RR}$ is easily made through the replacements $V_{ij}^L \to V_{ij}^R$, $M_{W_L} \to M_{W_R}$:

$$(\Delta m_D)_{LR} = G_D^{LR} \sum_{i,j=d,\,s,\,D,\,S} (V^L_{ui} V^R_{cj} V^R_{uj} V^R_{ci} \; M_i M_j) \left[ \frac{3b^2 l_n b}{4(1-b)(q_i - b)(q_j - b)} - (f(b, y_i) - f(b, y_j))/(y_i - y_j) \right], \tag{6}$$

where

$$G_D^{LR} = -(G_F^2/4\pi^2) f_D^2 b m_D h_D; \; b = (M_{W_L}/M_{W_R})^2;$$

$$h_D = (m_D/(m_c + m_u) + 1/6, f(b, y_i)$$
$$= y_i [b - (1+b) y_i/4 + y_i^2/4]/(1 - y_i)(b - y_i).$$

Using analogous expressions, we can also easily find the parameter $\Delta m_K$ for the system of $K^0$ and $\bar{K}^0$ mesons.

4. It follows from expression (2)–(6) that an upper limit $(\Delta m_D) \sim (4 \times 10^{-13}$–$10^{-12})$ GeV is easily reached in the case of unequal mixing angles of the left-hand and right-hand quarks

$$[|s_{1,2}|_L \gg |s_{1,2}|_R, |s_{1L}| = (1/5\text{–}1/3)].$$

The masses of the $D$ and $S$ quarks can be assigned to the range 40–250 GeV, which is amenable to study at existing experimental installations. Figures 2 and 3 illustrate the results with plots of the parameter $\Delta m_D$ versus the mass of one of the "lower" doubling quarks, $M_2$, for the case in which the mass $M_1$ of the second lower quark is fixed, for the cases $M_{W_R} \gg M_{W_L}$ and $M_{W_R} = 160$ GeV, respectively. When the mixing angles

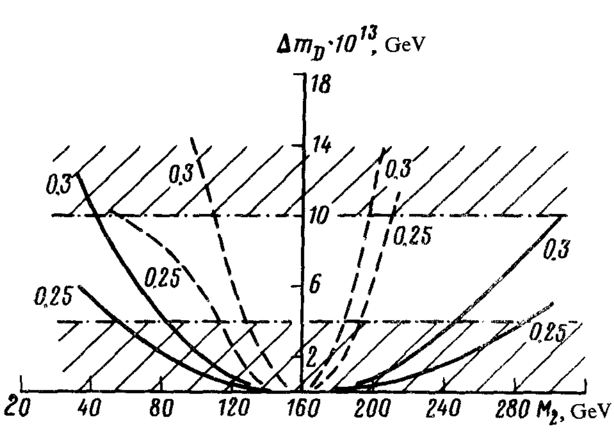


FIG. 2. The parameter $\Delta m_D$ versus the mass of the $S(D)$ quark $(M_2)$ at a fixed mass of the $D(S)$ quark ($M_1 = 160$ GeV) for two given values of the parameter $|s_{1L}^{d,u}|$:0.25 and 0.3. Solid line—Version (1); dashed line—version (2), for the case $M_{W_R} \gg M_{W_L}$. The hatching shows the regions of values $\Delta m_D = 10^{-12}$–$4 \times 10^{-13}$ GeV.

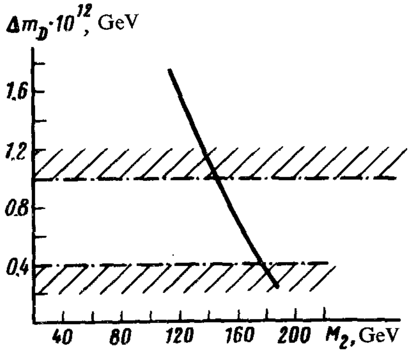


FIG. 3. The parameter $\Delta m_D$ [version (2)] versus the mass of the $S(D)$ quark ($M_2$) at a fixed mass of the $D(S)$ quark ($M_1 = 200$ GeV), for $M_{W_R} = 160$ GeV and $|s_{1L}^{d,u}| = 0.25$. The hatching shows the regions of values $\Delta m_D = 10^{-12}$–$4\times 10^{-13}$ GeV.

angles are equal ($|s_{1L}^{u(d)}| = |s_{1R}^{u(d)}|$), a saturation of the upper boundary ($\Delta m_D$) is possible, provided that the masses of the $D$ and $S$ quarks satisfy $M_{D,S} \gtrsim 10$ TeV. This conclusion remains in force for the $SU(2)\times U(1)$ model with true mirror quarks. For both $|s_{1,2}^L| \gg |s_{1,2}^R|$, and $|s_{1,2}^L| = |s_{1,2}^R|$, the necessary condition $\Delta m_K < 3.5\times 10^{-15}$ GeV is satisfied if $|s_{1L}^u| < 0.3$ and $M_{U,C} \lesssim 200$ GeV. In this approach there is the interesting possibility of relating rare events with large momentum losses, as observed at the CERN $p\bar{p}$ collider,[6] with the production and decay of new hadronic states,[7] including mirror quarks with masses $M_Q \sim 150$–$180$ GeV. In this case it is important to search for new quarks with masses above 40 GeB.

Version (2) of this model is remarkable in that it also allows the existence of relatively light $W_R$ bosons: $M_{W_L} \lesssim M_{W_R} \lesssim 500$ GeV. The decays of "light" $W_R$ bosons might also be one of the sources of rare events with large momentum losses[4,7] ($M_{W_R} \sim 150$–$180$ GeV).

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