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R^4 and R^e in a Extended Standard Model

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The Standard model (SM) is successful in almost all known aspects. Recently, the experimental values of \( R_b = \frac{1}{\Gamma (Z^0 \rightarrow b\bar{b})/\Gamma (Z^0 \rightarrow \text{hadrons})} \) and \( R_c = \frac{1}{\Gamma (Z^0 \rightarrow c\bar{c})/\Gamma (Z^0 \rightarrow \text{hadrons})} \) reported at the Beijing and Brussels [1] do not agree with the SM predictions at the levels of 3.7 and 2.3 standard deviations, respectively. It has greatly interested people. It is expected to search for new physics, namely the models beyond the SM, or the extended SM.

In this letter we will explain the experimental values of \( R_b \) and \( R_c \) in a extended SM. We introduce a new quark \( m \) which has electric charge \( +2/3 \) and is isosinglet under \( SU(2) \). The new quark \( m \) mixes with the SM quark \( c \). It results in the physical quark \( c' \),

\[
C = C' \cos \theta + m' \sin \theta
\]

\[
m' = C' \sin \theta + m' \cos \theta
\]

(1)

where \( \theta \) is the mixing angle.

The decay of a \( Z^0 \) boson into a quark pair \( C \bar{C} \) can be expressed as

\[
\mathcal{L} = \frac{g}{2 \cos \theta_w \sin \theta_w} \left( Z_{\mu \nu} \frac{1}{2} \left[ (C \bar{C}') \right] + \ldots \right)
\]

(2)

where \( \mathcal{E} \) is the electric charge, \( \theta_w \) is the Weinberg angle, \( Z_{\mu \nu} \) are the \( Z^0 \) boson fields and \( C', \bar{C}' \) are the quark fields.

The difference between the tree-level partial decay width \( \Gamma_C \) of a \( Z^0 \) boson into a physical quark pair \( C' \bar{C}' \) and one \( \Gamma_{C'} \) of a \( Z^0 \) boson into a SM quark pair \( \bar{C}C \) can be obtained from eq.(2)

\[
\Delta \Gamma_C = \frac{1}{\Gamma_C} - \Gamma_{C'} = \frac{\frac{1}{2} \sin^2 \theta_w \left[ (1+\frac{2}{3} \sin^2 \theta_w) + (1-\frac{2}{3} \sin^2 \theta_w) \right]}{2 \sin \theta_w} \left( (1+\frac{2}{3} \sin^2 \theta_w) - (1-\frac{2}{3} \sin^2 \theta_w) \right)
\]

(3)

with

\[
y = \frac{m_c}{m_2}
\]

(4)

where \( m_2 \) is the \( Z^0 \) boson mass and we identify approximately the mass of the physical quark \( c' \) with the mass \( m_c \) of the SM quark \( c \).

On the basis of the definition of \( R_c' \), the ratio of the partial decay width for a \( Z^0 \) boson to decay into a quark pair \( \bar{C}C \) to it into all quarks, we have

\[
\frac{\Delta \Gamma_C}{\Gamma_C} = \left( \frac{R_c'^2}{R_c^2} - 1 \right) \left( \frac{1}{\Gamma_C^{SM}} - \frac{1}{\Gamma_C^{LM}} \right)^{-1}
\]

(5)

where \( R_c'^2 \) is the experimental value of \( R_c' \), and \( R_c^2, \Gamma_C^{SM} \) and \( \Gamma_C^{LM} \) are the SM values of \( R_c \), \( \Gamma_C \) and \( \Gamma_{C'} \) in the one-loop electroweak radiative corrections, respectively.

Now we use the experimental value \( R_c'^2 = 0.1843 \pm 0.0074 \) [1] to fit the mixing angle \( \theta \) between quarks \( c \) and \( m \) from eqs.(3)-(5). After the QCD correction for the \( \Delta \Gamma_C \) in eq.(3) is considered and the following values of the quantities are taken\[1\]

\[
R_c^2 = 0.1720, \quad \Gamma_C^{SM} = 0.2993 \quad \text{GeV}
\]

\[
\Gamma_C^{LM} = 1.7403 \quad \text{GeV}, \quad m_2 = 91.187 \quad \text{GeV}
\]

\[
\sin^2 \theta_w = 0.2319
\]

(6)
We obtain the theoretical value of the mixing angle $\theta$ between quarks $c$ and $m$

$$\sin \theta = 0.2328$$  \hspace{1cm} (7)

It means that the physical quark $c'$ is the mixing between the SM quark $c$ and the new quark $m$ with the mixing angle $\theta$ and the theoretical value of the $R_{c'}$, the ratio of the partial decay width for a $Z'$ boson to decay into a physical quark pair $c'c'$ to the hadronic width, in the extended SM is in agreement with the experimental value $R_{c'}^E$.

According to the theoretical value of $R_{c'}$, the $\frac{\Gamma_{c'}}{\Gamma_{c'}}$ is reduced while the $\frac{\Gamma_{b}}{\Gamma_{b}}$ is not changed, then we obtain the theoretical value of $R_{b}$ in the extended SM

$$R_{b} = 0.2203$$  \hspace{1cm} (8)

It is fairly accordant with the experimental value of $R_{b}$ (0.2219±0.0017).

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References