Top forward-backward asymmetry in chiral $U(1)'$ models

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Summary. — We construct flavor-dependent chiral $U(1)'$ models with a $Z'$ boson which couples to the right-handed up-type quarks in the standard model (SM). To make the models have realistic renormalizable Yukawa couplings, we introduce new Higgs doublets with nonzero $U(1)'$ charges. Anomaly-free condition can be satisfied by adding extra chiral fermions. We show that these models could analyze the discrepancy between the SM prediction and empirical data in the top forward-backward asymmetry at the Tevatron.

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of the Higgs sector and its effects must be taken into account together with the $Z'$ boson, in particular, at the LHC. This is true not only in the $Z'$ model, but also in the other models [2] designed to account for quarks ($D$ of $U^2$) and bosons and Higgs doublets including the SM Higgs depends on the charge assignment. One can choose ($g_R^u$)$_{ij} = (R^a)_{ij} u_k (R^a)^{kj}$ with the biunitary matrix ($R^a$)$_{ij}$ diagonalizing the up-type quark mass matrix [7]. In general ($g_R^u$)$_{ij}$ could have nonzero off-diagonal elements.

As we have discussed, we have to introduce new Higgs doublets $H_i$ with $U(1)'$ charges $-u_i$ in order to get realistic renormalizable Yukawa couplings. The number of Higgs doublets including the SM Higgs depends on the charge assignment. One can choose the two-Higgs doublet case with $u_i = (0, 0, 1)$, the three-Higgs doublet case with $u_i = (-1, 0, 1)$, or etc. In the mass basis, the Yukawa interactions of lightest neutral scalar $Y_{ij}$ and pseudoscalar Higgs $a$ can be given by

$$\mathcal{L} = -Y_{ij} u_L^i U_R^j h + i Y^a_{ij} u_L^i U_R^j a + h.c.,$$

where the Yukawa couplings $Y_{ij}$ and $Y^a_{ij}$ are functions of $g_R$, $m_w$ and the mixing angles and vacuum expectation values of the neutral Higgs fields and can have off-diagonal elements [7]. Finally the gauge anomaly can be canceled by introducing an extra generation and two pairs of $SU(2)$ doublets of $SU(3)$ triplets as in Ref. [7].

In our model, it could be expected to have large off-diagonal Yukawa couplings $Y^{(a)}_{ta}$ because they are proportional to the top quark mass. The mixing matrix $(g_R^t)_{ij}$ could generally have nonzero off-diagonal elements. We assume that $(g_R^t)_{13} = (g_R^t)_{14}$ is large, but the other components are well suppressed. Then both the $Z'$ boson and Higgs bosons $h$ and $a$ can contribute to the $t\bar{t}$ production through the $uu \rightarrow t\bar{t}$ process. The $t\bar{t}$ production rate at the Tevatron and LHC is in good agreement with the SM. We impose the bound $\sigma(pp \rightarrow t\bar{t}) < 17$ pb from the CMS experiment [5], but the single top production data give no constraints to our model because of difference between final states in experiments [9] and our model. Lastly we consider $A_{FB} = (0.158 \pm 0.075)$ in the lepton+jets channel at CDF [2]. As an illustration of our model we take $m_{Z'} = 145$ GeV, $m_{h} = 180$ GeV, $m_{a} = 300$ GeV, and $Y^a_{ta} = 1.1$.

In fig. 1, we show the allowed region for $\alpha_x \equiv (g' g_{Ra})^2/(4\pi)$ and $Y_{ta}$. The gray, cyan, green, and yellow regions correspond to the regions allowed by constraints from the top quark decay, the $t\bar{t}$ production cross section at the Tevatron, $A_{FB}$ at CDF, and the same sign top pair production at CMS, respectively. The red region is favored from the empirical data at the Tevatron and LHC. It is remarkable that the strong constraint from the same sign top pair production can be relieved in our model due to the destructive
interference between the $Z'$ boson and Higgs bosons.

Now we examine our model by varying the model parameters. In this analysis we fix $m_{Z'} = 145$ GeV, but we choose the following parameter regions: $180$ GeV $< m_h, m_a < 1$ TeV, $0.005 < \alpha_x < 0.025$, and $0.5 < Y_{tu}, Y_{ta} < 1.5$ with the constraint $|Y_{tu}| < |Y_{ta}|$. In fig. 2, we show the scattered plot for $A_{FB}$ at the Tevatron and the cross section $\sigma^{tt}$ for the same sign top pair production at the LHC. All the red points in fig. 2 satisfy the $t\bar{t}$ cross section rate at the Tevatron. In fig. 2, the points in the right-lower side are allowed by the empirical data. The points in the allowed region have the following bounds: $180$ GeV $< m_h < 250$ GeV, $0.005 < \alpha_x < 0.014$, $0.75 < Y_{tu} < 1.3$, and $0.9 < Y_{ta} < 1.5$. $m_a$ is not constrained by the data. We note that about 7% $A_{FB}$ from the SM NLO contribution is ignored in this work and it could further enhance $A_{FB}$ at the Tevatron.

In conclusions, we presented $U(1)'$ flavor models with flavor dependent $Z'$ couplings only to the RH up-type quarks. Additional Higgs doublets with $U(1)'$ charges were introduced in order to to construct realistic models to have renormalizable Yukawa couplings for the up-type quarks. For cancellation of the gauge anomaly we included the extra fermions charged under $U(1)'$. We showed that our model can explain the forward-backward asymmetry measured at the Tevatron and evade the stringent constraint from the same sign top pair production at the LHC through the destructive interference between the $Z'$ boson and Higgs bosons. We anticipate that our model will be probed in the future experiments.

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Fig. 2. – The scattered plot for $A_{FB}$ at the Tevatron and $\sigma_{tt}$ at the LHC in unit of pb.

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