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Top A_{FB} and charge asymmetry in chiral U(1)′ models with flavored Higgs doublets

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We examine chiral U(1)′ models with flavored Higgs doublets which were introduced to account for the top forward-backward asymmetry at the Tevatron. We find that the models could be consistent with not only the top forward-backward asymmetry at Tevatron, but also the top charge asymmetry at LHC, without too large same-sign top-quark pair production rates in some parameter spaces. We also present possible scenarios which could be consistent with the recent observation of the Higgs boson with about 125 GeV mass at ATLAS and CMS.

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1. Introduction

The top forward-backward asymmetry (A^t_{FB}) measured at the Tevatron is very interesting because it is the only quantity in top physics which deviated from the Standard Model (SM). The SM prediction is $0.072^{+0.011}_{-0.007}$ at the next-to-leading order (NLO) + next-to-next-to-leading logarithm and 0.087 ± 0.010 if NLO corrections to electroweak interactions are included [1]. While the CDF results are (0.158 ± 0.074) in the lepton+jets channel and (0.420 ± 0.158) in the dilepton channel with data of a luminosity of 5.4 fb^{-1} [2]. These results are consistent with the D0 result, $A^t_{FB} = 0.196 \pm 0.060^{+0.018}_{-0.026}$ in the letpon+jets channel [3] as well as the updated result $A^t_{FB} = 0.162 \pm 0.047$ with data of a luminosity of 8.7 fb^{-1} at CDF [4]. The integrated A^t_{FB} has about 2σ deviation between the SM and experiments and it might imply that there is still room for new physics in top physics.

A lot of brilliant models have been proposed to explain the discrepancy in A^t_{FB}, but many of them are rather phenomenological. Usually it is assumed that only the couplings to the top quark are large in order to accommodate the models with the stringent bounds from the Drell-Yan, dijet production, flavor-changing-neutral-current (FCNC) experiments, and so on. In general, it it nontrivial to construct a model with such a large hierarchy between couplings and flavor-dependent couplings. It would be challenging to construct a realistic model.

In this work, we focus on chiral U(1)′ models with flavored Higgs doublets [5]. The model is an extension of a simple Z' model with large flavor-off-diagonal couplings. The Z' boson should be associated with an additional gauge symmetry. In this work, we consider a chiral U(1)′, where only the right-handed up-type quarks in the SM are charged under the U(1)′ [5]. Then, the Higgs sector in the SM must be extended because all the SM fermions charged under U(1)′ would be massless without a Higgs doublet charged under U(1)′. The breaking of the U(1)′ symmetry could generate the mass of the Z' boson and extra chiral fermions, which are necessary for cancellation of the gauge anomaly generated by the chiral U(1)′ symmetry. Finally, both the Z' boson and Higgs bosons, which are a linear combination of the SM-like Higgs doublet and extra Higgs doublets, can affect the top-quark pair production at hadron colliders.

The Large Hadron Collider (LHC) produces a huge number of top-quark pair and new physics models for A^t_{FB} are strongly constrained by top physics at the LHC. Among various measurements we consider two observables, the same-sign top-quark pair production rate and the top charge asymmetry, which may provide stringent tests for the new models.

In this proceeding, we consider two scenarios. One is a light Z' case with a lightest scalar Higgs boson (h), a heavier scalar Higgs boson (H), and a pseudoscalar Higgs boson (a), where the Z' mass $m_{Z'} = 145$ GeV. The other is a light Higgs boson (h) case with a heavier Z' boson, a heavier second Higgs boson (H) and a pseudoscalar Higgs boson (a), where the light Higgs boson mass $m_h = 125$ GeV motivated by the recent observation of a SM-like Higgs boson at the LHC. Finally, we conclude our work.

2. Chiral U(1)′ models with flavored Higgs doublets and constraints

We consider an extra U(1)′ symmetry in addition to the SM gauge symmetry, where only the right-handed up-type quarks are charged under U(1)′. If one assigns U(1)′ charges to the other

SM chiral fermions, the model is strongly constrained by the FCNC experiments at B factories, Drell-Yan experiments, and LEP experiments. Then, only the right-handed up-type quarks with the U(1)′ charges u_i ($i = u, c, t$) interact with the Z' boson, which is the U(1)′ gauge boson. After symmetry breaking of SU(2) and U(1)′, the interaction lagrangian for the Z' boson and the right-handed up-type quarks (U_R^i) in the mass eigenstates can be written as $\mathscr{L} = g' Z'^{\mu} \{(g_R^u)_{ij} \overline{U_R^i} \gamma_\mu U_R^j\}$, where g' is a gauge coupling of U(1)′ and $(g_R^u)_{ij}$ is the 3×3 mixing matrix responsible for the flavor-changing-neutral couplings.

As we have already discussed, additional Higgs doublets H_i with U(1)′ charges $-u_i$ are required in order to construct realistic renormalizable Yukawa couplings for the SM chiral fermions charged under U(1)′. The number of extra Higgs doublets are determined by the U(1)′ charge assignment. For example, we need an extra Higgs doublet for $u_i = (0, 0, 1)$, two extra Higgs doublets for $u_i = (-1, 0, 1)$, etc. as explicitly shown in Ref. [5]. Furthermore, a singlet scalar field Φ is required in order to break the U(1)′ symmetry. In the mass eigenstate, the relevant Yukawa interactions for the top-quark pair production are given by $\mathscr{L} = -Y_{tu}^h \overline{u_L} t_R h - Y_{tu}^H \overline{u_L} t_R H + i Y_{tu}^a \overline{u_L} t_R a + h.c.$, where $Y_{tu}^{h,H,a}$ are corresponding Yukawa couplings and the other couplings are suppressed. Finally, we must add extra fermions to cancel gauge anomaly and possible models were discussed in Ref. [5].

In the chiral U(1)′ models with flavored Higgs doublets, the Z' boson and Higgs bosons h, H, and a can contribute to the top-quark pair production at the hadron colliders according to their couplings. This model must be consistent with the top quark experiments at the Tevatron and LHC. First, we require that the cross section for the top-quark pair production at the Tevatron is in agreement with the measurement at CDF, $\sigma(t\bar{t}) = (7.5 \pm 0.48)$ pb. Secondly, we restrict that the branching ratio of the top quark to the non-SM state is less than 5%. Thirdly, we require that A_{FB}^t in our model is consistent with the recent measurement $A_{FB}^t = 0.162 \pm 0.047$ in lepton+jets channel at CDF [4]. Fourthly, our models are stringently constrained by the same-sign top-quark pair production because of large FCNCs. We require that the cross section for the same-sign top-quark pair production at the LHC is less than the upper bounds, $\sigma(tt) < 17$ pb at CMS [6] and $\sigma(tt) < 4$ pb at ATLAS [7]. Finally, we consider the top charge asymmetry A_C^y at the LHC, which is defined by the difference of numbers of events with the positive and negative $\Delta|y|$ divided by their sum. Here, $\Delta|y| = |y_t| - |y_{\bar{t}}|$ for the rapidities y_t and $y_{\bar{t}}$ of the top and antitop quarks. Its empirical values are $-0.018 \pm 0.028 \pm 0.023$ at ATLAS and $0.004 \pm 0.010 \pm 0.012$ at CMS [8].

3. Light Z' case

In our model, both the Z' boson and Higgs bosons h, H, and a can contribute to the top-quark pair production through their t-channel exchanges. In this section, we discuss the light Z' case with $m_{Z'} = 145$ GeV. Because of the condition for the branching ratio of the top quark, we take the masses of the Higgs bosons to be heavier than the top quark mass. However, this mass region for the Higgs bosons might be inconsistent with the recent search for the Higgs boson at the LHC, which excludes a large region between 130 GeV and 600 GeV [9]. In addition, this mass region is not accommodated with the recent observation of a SM-like scalar boson. We assume that the lightest scalar boson h in our model is decoupled from the top-quark pair production by assuming the coupling of the u-t-h vertex to be sufficiently suppressed. Then, Z', H, and a

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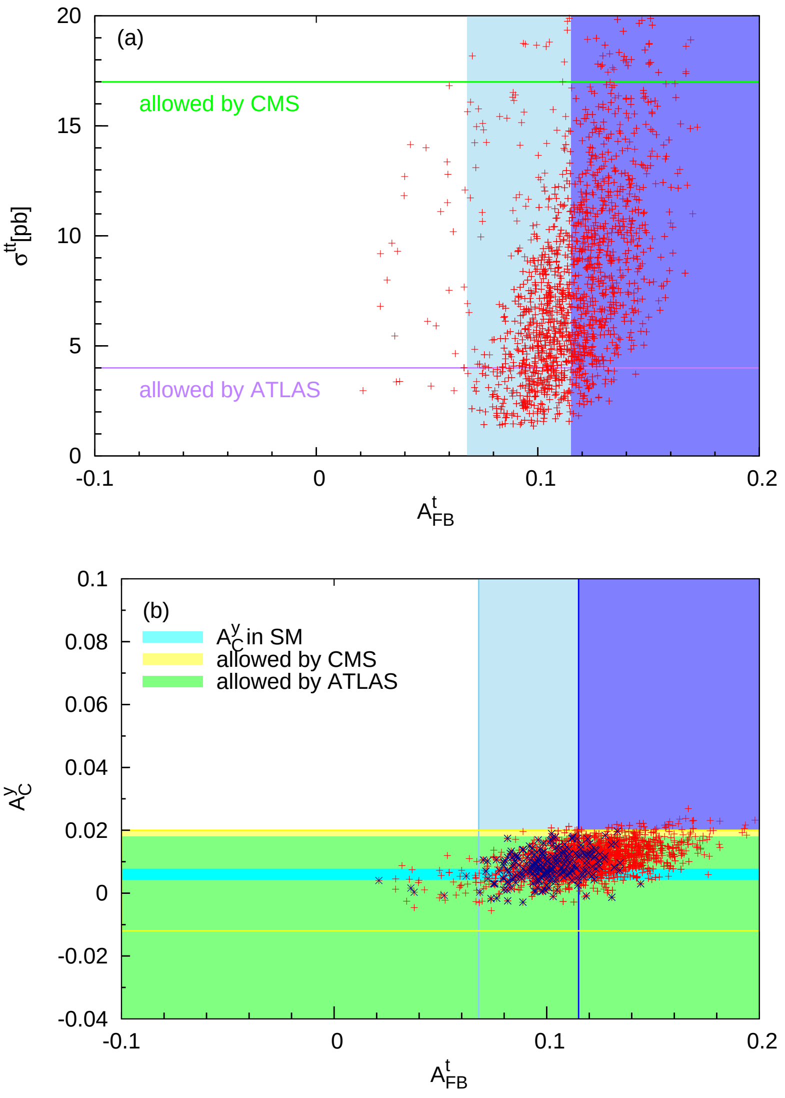

Figure 1: The scattered plots for (a) A^t_{FB} at the Tevatron and σ^{tt} at the LHC in unit of pb, and (b) A^t_{FB} at the Tevatron and A^y_C at the LHC for $m_{Z'} = 145$ GeV.

contribute to the top-quark pair production at the LHC. We scan the following parameter regions: 180 GeV $\leq m_H, m_a \leq 1$ TeV, $0.005 \leq \alpha_x \equiv (g'(g^u_R)_{ut})^2/(4\pi) \leq 0.012$, and $0.5 \leq Y^H_{tu}, Y^a_{tu} \leq 1.5$. We assume $(g^u_R)_{uu}(g^u_R)_{tt} = (g^u_R)^2_{ut}$, but even though we ignore the s-channel contribution by assuming $(g^u_R)_{uu}(g^u_R)_{tt} = 0$, the numerical results do not change so much.

In Fig. 1(a), we present the scattered plot for A^t_{FB} at the Tevatron and $\sigma(tt)$ at the LHC for $m_{Z'} = 145$ GeV. All the red points satisfy the cross section for the top-quark pair production at the Tevatron within 1σ. The blue and skyblue regions are consistent with A^t_{FB} in lepton+jets channel at CDF within 1σ and 2σ, respectively. The horizontal lines are upper bounds on the same-sign top-quark pair production rate at the CMS and ATLAS. We find that there are favored parameter regions which improve A^t_{FB} at the Tevatron and are consistent with the strong bound on $\sigma(tt)$ at the LHC. In Fig. 1(b), we present the scattered plot for A^t_{FB} at the Tevatron and A^y_C at the LHC for $m_{Z'} = 145$ GeV. The vertical bands are the same as the bands in Fig. 1(a). The yellow and green bands correspond to the experimental bounds on A^y_C at CMS and ATLAS, respectively. The cyan line is the prediction for A^y_C in the SM. The red points satisfy the experimental result for the top-quark pair production at the Tevatron within 1σ while the blue points are consistent with both the cross sections for the top-quark pair production at the Tevatron within 1σ and the upper bound for the same-sign top-quark pair production at the LHC. The simple Z' boson model is excluded by the same-sign top-quark pair production at the LHC, but in the chiral U(1)′ models, the destructive interference between the Z' boson and Higgs bosons relieves the constraints from $\sigma(tt)$.

4. Light Higgs boson case with the mass of 125 GeV

In this section, we discuss the light Higgs boson case with the mass of 125 GeV. Then, the Z', h, H, and a bosons contribute to the top-quark pair production at the hadron colliders. The mass of the lightest Higgs boson h is consistent with the recent observation for a SM-like scalar boson at the LHC, but its Yukawa coupling Y^h_{tu} to the top and up quarks must be smaller than 0.5 and the masses of Z', H, and a must be larger than the top-quark mass or almost same as the top-quark mass in order to suppress the branching ratio of the top quark to the non-SM case. We scan the following parameter regions: 160 GeV $\leq m_{Z'} \leq$ 300 GeV, 180 GeV $\leq m_H, m_a \leq$ 1 TeV, $0 \leq \alpha_x \leq 0.025$, $0 \leq Y^h_{tu} \leq 0.5$, and $0 \leq Y^H_{tu}, Y^a_{tu} \leq 1.5$. The region for $m_{Z'}$ is chosen to avoid the strong constraint from the $t\bar{t}$ invariant mass distribution.

In Fig. 2(a), we show the scattered plot for A^t_{FB} at the Tevatron and $\sigma(tt)$ at the LHC for $m_h = 125$ GeV. The red points satisfy the cross section for the top-quark pair production at the Tevatron within 1σ. All the bands and lines in the figure are the same as those in Fig. 1(a). We find that there are some parameter regions which are consistent with all the empirical data considered in this work. We note that there are a lot of points with $\sigma(tt) < 1$ pb. In Fig. 2(b), we show the scattered plot for A^t_{FB} at the Tevatron and A^y_C at the LHC for $m_h = 125$ GeV. Each region on the figure denotes the same experimental constraint as in Fig. 1(b). The red points satisfy the experimental result of the cross section for the top-quark pair production at the Tevatron within 1σ while the blue points are consistent with both the cross section for the top-quark pair production at the Tevatron within 1σ and the upper bound for the same-sign top-quark pair production at the LHC. In this scenario, we find that there are a lot of points which are consistent with all empirical data considered in this work.

5. Conclusion

The top forward-backward asymmetry at the Tevatron is the only signal which might imply the existence of new physics in the top sector. A lot of models have been proposed to be accommodated with A^t_{FB} at the Tevatron, but many of them are rather phenomenological models or disfavored by the same-sign top-quark pair production and charge asymmetry at the LHC. In this work, we examined the chiral U(1)′ models with flavored Higgs doublets. We proposed two scenarios with the light Z' boson or the light Higgs boson. We found that both scenarios can be accommodated

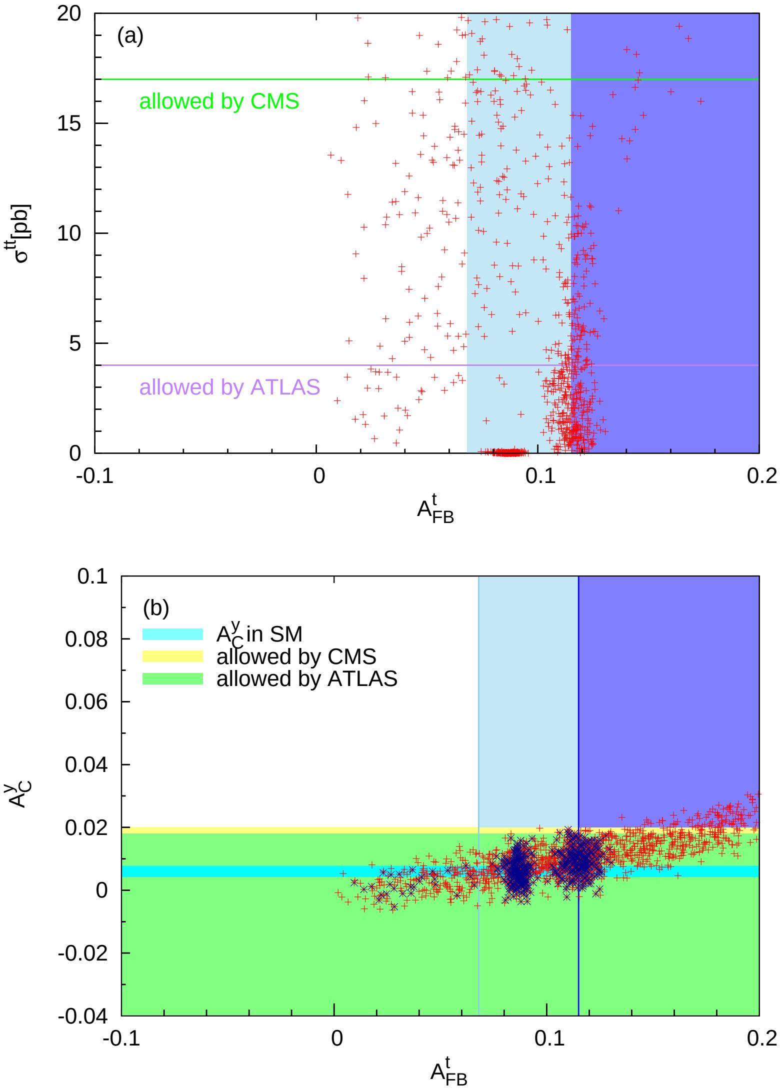

Figure 2: The scattered plots for (a) A^t_{FB} at the Tevatron and σ^{tt} at the LHC in unit of pb, and (b) A^t_{FB} at the Tevatron and A^y_C at the LHC for $m_h = 125$ GeV.

with the constraints from the same-sign top-quark pair production and charge asymmetry at the LHC and at the same time can improve the top forward-backward asymmetry at the Tevatron.

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