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Top Quark Forward-Backward Asymmetry at the Tevatron: A Comparative Study in Different New Physics Models

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Abstract

The top quark forward-backward asymmetry A_t^{FB} measured at the Tevatron is above the Standard Model prediction by more than 2σ deviation, which might be a harbinger for new physics.

In this work we examine the contribution to A_t^{FB} in two different new physics models: one is the minimal supersymmetric model without R-parity (RPV-MSSM) which contributes to A_t^{FB} via sparticle-mediated t -channel process $d\bar{d} \rightarrow t\bar{t}$; the other is the third-generation enhanced left-right model (LR model) which contributes to A_t^{FB} via Z' -mediated t -channel or s -channel processes.

We find that in the parameter space allowed by the $t\bar{t}$ production rate and the $t\bar{t}$ invariant mass distribution at the Tevatron, the LR model can enhance A_t^{FB} to within the 2σ region of the Tevatron data for the major part of the parameter space, and in the optimal case A_t^{FB} can reach 12% which is slightly below the 1σ lower bound. For the RPV-MSSM, only in a narrow part of the parameter space can the λ'' couplings enhance A_t^{FB} to within the 2σ region while the λ' couplings just produce negative contributions to worsen the fit.

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Introduction

As the heaviest fermion with a mass at the weak scale, the top quark is speculated to be a sensitive probe of new physics beyond the Standard Model (SM) [1]. The precision measurement of its properties, now being performed at the Tevatron and to be continued at the CERN Large Hadron Collider (LHC), will either unravel or further constrain new physics related to the top quark.

So far, the production rates of top pair and single top measured at the Tevatron are in good agreement with the SM predictions, but a more than 2σ deviation is reported in the forward-backward asymmetry A_t^{FB} in top pair production, which is defined by

$$A_t^{FB} = \frac{N_t(\cos\theta > 0) - N_t(\cos\theta < 0)}{N_t(\cos\theta > 0) + N_t(\cos\theta < 0)}$$

with θ being the angle between the reconstructed top quark momentum and the proton beam direction in the $t\bar{t}$ rest frame. In the SM, this asymmetry gets its dominant contribution from next-to-leading-order QCD corrections and is found to be several percent: $A_t^{FB}(\text{SM}) = 5.0 \pm 1.5\%$ [2]. Compared with its experimental value $A_t^{FB}(\text{exp}) = 19.3 \pm 6.9\%$ measured by the CDF and D0 collaborations [3], this SM prediction is below the measured value by more than 2σ deviation.

Such a discrepancy might be a new physics footprint in the top quark sector and has been studied in several new physics models, where Kaluza-Klein excitations in extra dimensions [4], the presence of new gauge bosons (Z' , W' , axigluon) [5, 6] or new scalars [7] are utilized to try to explain the discrepancy. Noting that the mechanisms proposed in these literatures can also be realized in some popular new physics models, we in this work study the asymmetry A_t^{FB} in supersymmetric models and left-right models [8].

For the minimal supersymmetric standard model (MSSM) [9], the SUSY influence on $t\bar{t}$ production comes from loop effects, in which the SUSY-QCD effects are dominant over the SUSY-EW effects [10]. But among the SUSY-QCD one-loop diagrams only the box diagrams contribute to the asymmetry A_t^{FB} and, consequently, the contribution is negligibly small (see the discussion in [4]). Therefore, in our analysis we consider the R-parity violating MSSM

(RPV-MSSM) [11] which allows for tree-level contribution from t -channel process $d\bar{d} \rightarrow t\bar{t}$ by exchanging a color-singlet slepton or a color-triplet squark. For general left-right models, since the predicted new gauge bosons are usually at the TeV scale and unlikely to affect A_t^{FB} significantly, we here consider a special left-right model called the third-generation enhanced left-right model [12]. This model predicts a new gauge boson Z' which contributes to A_t^{FB} via t -channel or s -channel processes.

This paper is organized as follows. In Sec. II we describe the calculation of the asymmetry A_t^{FB} in the RPV-MSSM and present some numerical results and discussions. In Sec. III we perform similar analysis in the third-generation enhanced left-right model. Finally, some discussions and the conclusion are presented in Sec. IV.

II. A_t^{FB} in R-Parity Violating MSSM

In the popular MSSM, the invariance of R-parity, defined by $R = (-1)^{2S+3B+L}$ for a field with spin S , baryon number B and lepton number L , is often imposed on the Lagrangian in order to maintain the separate conservation of B and L . Although R-parity plays a beautiful role in the phenomenology of the MSSM (e.g., forbidding proton decay and ensuring a perfect candidate for cosmic dark matter), it is, however, not dictated by any fundamental principle such as gauge invariance and there is no compelling theoretical motivation for it.

The most general superpotential of the MSSM consistent with the SM gauge symmetry and supersymmetry contains R-violating interactions which are given by [11]

$$W_{RPV} = \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \lambda''_{ijk} \epsilon_{\alpha\beta\gamma} U_i^{c\alpha} D_j^{c\beta} D_k^{c\gamma} + \mu_i L_i H_2$$

where i, j, k are generation indices, c denotes charge conjugation, α, β and γ are color indices with $\epsilon_{\alpha\beta\gamma}$ being the totally antisymmetric tensor, H_2 is the Higgs-doublet chiral superfield, and $L_i(Q_i)$ and $E_i(U_i, D_i)$ are the left-handed lepton (quark) doublet and right-handed lepton (quark) singlet chiral superfields. The dimensionless coefficients λ_{ijk} (antisymmetric in i and j) in the superpotential are L-violating couplings, while λ''_{ijk} (antisymmetric in i and j) and λ'_{ijk} (antisymmetric in j and k) are B-violating couplings.

The expression of W_{RPV} implies that both λ'_{ijk} and λ''_{ijk} can induce new top quark interactions. In terms of the four-component Dirac notation, the interactions involved in top pair production are

$$\mathcal{L} = \lambda'_{ijk} [\tilde{d}_{kR}^* \bar{u}_{iL} + \tilde{d}_{jR}^* \bar{u}_{iL}] + \text{h.c.}$$

and these interactions can contribute to the forward-backward asymmetry by the diagrams shown in Fig. 1.

The corresponding amplitudes are then given by

$$\mathcal{M}_{d\bar{d}\rightarrow t\bar{t}}^{\lambda'} = -i\delta_{\alpha\rho}\delta_{\beta\sigma}|\lambda'_{i31}|^2 \frac{\bar{u}(t)P_R u(d)\bar{v}(d)P_L v(t)}{(p_1 - p_3)^2 - m_{\tilde{d}_k}^2}$$

$$\mathcal{M}_{d\bar{d}\rightarrow t\bar{t}}^{\lambda''} = -i\epsilon_{\beta\rho\lambda}\epsilon_{\sigma\alpha\lambda}|\lambda''_{31k}|^2 \frac{\bar{u}(t)\gamma^\mu P_R v(t)\bar{v}(d)\gamma_\mu P_R u(d)}{2[(p_1 - p_4)^2 - m_{\tilde{d}_k}^2]}$$

with $\alpha, \beta, \rho, \sigma$ and λ being color indices of the quarks and squarks. These amplitudes affect A_t^{FB} by interfering with the QCD amplitude $d\bar{d} \rightarrow g^* \rightarrow t\bar{t}$ and also by their own square. In our results presented below, we have included the SM contribution to A_t^{FB} and consider only one coupling non-zero at a time.

The SUSY parameters involved in the calculation are the couplings λ'_{i31} and λ''_{31k} as well as sparticle masses. So far both theorists and experimentalists have intensively studied the phenomenology of these couplings in various processes [13] and obtained some bounds [14].

[TABLE:I]: The upper bounds on the couplings λ'_{i31} ($i = 1, 2, 3$) and λ''_{31k} ($k = 2, 3$) [14].

Couplings	Bounds	Sources
λ'_{i31}	$0.03 m_{\tilde{d}_i} / (100 \text{ GeV})$	QW (Cs)
λ''_{312}	$0.18 m_{\tilde{d}_k} / (100 \text{ GeV})$	$K \rightarrow \pi\nu\bar{\nu}$
λ''_{313}	$0.26 m_{\tilde{d}_k} / (100 \text{ GeV})$	perturbativity
λ''_{323}	$0.97 m_{\tilde{d}_k} / (100 \text{ GeV})$	perturbativity

As can be seen, in case of heavy squarks, these bounds are quite weak. Note that for λ''_{31k} we do not use the stringent bound from $n - \bar{n}$ oscillation [14] because they depend on additional SUSY parameters which are not involved in our processes.

In Fig. 2 we show the dependence of A_t^{FB} on the relevant sparticle masses. Here we assume all squarks and sleptons are degenerate and sum over the contributions from different generations. The couplings λ'_{i31} and λ''_{31k} are fixed at their maximally allowed values which, as shown in Table I, vary with squark mass. The SM parameters are taken as [15]: $m_t = 172.5 \text{ GeV}$, $m_Z = 91.19 \text{ GeV}$, $\sin\theta_W = 0.2228$, $\alpha_s(m_t) = 0.1095$, $\alpha = 1/128$.

[Figure 2: see original paper]: A_t^{FB} versus the sparticle mass in the R-parity violating MSSM. The left (right) panel is induced by λ'_{i31} (λ''_{31k}) which are fixed at their maximally allowed values. The SM contribution to A_t^{FB} is also included.

Fig. 2 indicates that both λ'_{i31} and λ''_{31k} can give a negative contribution to A_t^{FB} and in the worst cases, they decrease A_t^{FB} by 2% and 5% respectively, which

are comparable in size with $A_t^{FB}(\text{SM})$. In a narrow part of the squark mass region ($250 \sim 400$ GeV), the coupling λ''_{31k} can also give a positive contribution to enhance A_t^{FB} to within the 2σ region of the Tevatron data.

We note that the scalar-mediated contributions have been analyzed in a model-independent way in [7] and the results were presented for color-singlet, -triplet, -sextet and -octet scalars respectively. We checked that our analytic results are in agreement with [7] for the color-singlet and -triplet cases except that our study is restricted to a specified model, the RPV-MSSM.

Before ending this section, we give a comment on A_t^{FB} in the top-color assisted technicolor model (TC2) [16]. This model predicts some composite bosons, π_t^0 and π_t^\pm , with mass at the weak scale and having large Yukawa couplings to the top quark. As a result, A_t^{FB} gets additional contribution from t -channel processes $u\bar{u}(c\bar{c}) \rightarrow t\bar{t}$ by exchanging a color-singlet scalar π_t^0 which is similar to Fig. 1(a) in RPV-MSSM. Noting the up quark content in the proton is larger than the down quark content, one may expect a larger effect on A_t^{FB} in the TC2 model than in RPV-MSSM. This is not true because for $u\bar{u} \rightarrow t\bar{t}$ in the TC2 model, its contribution is proportional to $u_R - t_R$ mixing which is determined by the triangular texture of the up-type quark mass matrix and turns out to be very small [17]. As to $c\bar{c} \rightarrow t\bar{t}$, although $c_R - t_R$ mixing may be sizable [17], it actually gives no contribution to A_t^{FB} because the distributions of c and \bar{c} in the proton are approximately the same and so the initial state of this process is symmetric under the exchange of c and \bar{c} .

In fact, we numerically calculated all TC2 contributions to $t\bar{t}$ production at the Tevatron, which include the s -channel processes $gg, b\bar{b} \rightarrow \pi_t^{0*} \rightarrow t\bar{t}$, $t\bar{t} \rightarrow \pi_t^0$, and t -channel processes $b\bar{b} \rightarrow t\bar{t}$ by exchanging π_t^- , and $u\bar{u}, c\bar{c} \rightarrow t\bar{t}$ by exchanging π_t^0 . We found that the TC2 model can change $\sigma_{t\bar{t}}$ by at most 200 fb and A_t^{FB} by order of 10^{-4} .

III. A_t^{FB} in the Third-Generation Enhanced Left-Right Model

In the third-generation enhanced left-right model [12], the gauge group is $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ with gauge couplings g_3, g_L, g_R and g respectively. This model differs from other left-right models by having right-handed gauge bosons couple predominantly to the third generation fermions. Noting that the right-handed gauge boson Z_R will mix with the standard Z_0 to form mass eigenstates Z and Z' , one can write down the neutral gauge interactions of quarks as

$$\begin{aligned} \mathcal{L}_Z = & -\frac{g}{2 \cos \theta_W} \bar{q} \gamma^\mu (g_V - g_A \gamma_5) q (\cos \xi_Z Z_\mu - \sin \xi_Z Z'_\mu) \\ & - \tan \theta_R (\bar{q}_L \gamma^\mu q_L + \bar{u}_{Ri} \gamma^\mu u_{Ri} - \bar{d}_{Ri} \gamma^\mu d_{Ri}) (\sin \xi_Z Z_\mu + \cos \xi_Z Z'_\mu) \\ & - (\tan \theta_R + \cot \theta_R) (\bar{u}_{Ri} \gamma^\mu V_{Rti}^{u*} V_{Rtj}^u u_{Rj} - \bar{d}_{Ri} \gamma^\mu V_{Rbi}^{d*} V_{Rbj}^d d_{Rj}) (\sin \xi_Z Z_\mu + \cos \xi_Z Z'_\mu) \quad (7) \end{aligned}$$

where $\tan \theta_R = g/g_R$, $g_Y = g \cos \theta_R = g_R \sin \theta_R$, ξ_Z is the mixing angle between Z_R and Z_0 , and $V_{Rij}^{u,d}$ are unitary matrices which rotate the right-handed quarks u_{Ri} and d_{Ri} from interaction basis to mass eigenstates. This model also predicts new charged gauge interactions of quarks, but since their effect on A_t^{FB} is small, we do not consider them here. Note that in Eq. (7), q and q_L are summed over all quarks, and the repeated generation indices i and j are also summed.

Eq. (7) indicates that the $Z' \bar{u}_i u_j$ interaction is large when $g_R \gg g_Y$ or $\cot \theta_R \gg 1$. This feature can be utilized to enhance A_t^{FB} by the t -channel process $u\bar{u} \rightarrow t\bar{t}$ if $(V_R^u)_{ut}$ is moderately large. In [12], V_R^d and V_R^u are assumed to be nearly diagonal to satisfy the severe flavor-changing neutral-current (FCNC) constraints. However, as pointed out in [6], a sizable $u_R - t_R$ mixing does not conflict with these constraints given that the other flavor mixings are suppressed. Here we further point out that this pattern of flavor mixings does not necessarily require the up-top element in the up-type quark mass matrix M_u to be much larger than other off-diagonal elements. For example, assuming $(V_R^u)_{ut} = 0.2$, $(V_R^u)_{ct} = 0$ and $(V_R^u)_{uc} = 0$, we numerically solve the equation $V_R^{u\dagger} M_u V_R^u = M_u^{\text{diag}}$ with $M_u^{\text{diag}} = \text{diag}\{m_u^2, m_c^2, m_t^2\}$, and we find it possible that $(M_u)_{ct}$ is several times larger than $(M_u)_{ut}$.

In the third-generation enhanced left-right model, besides the dominant QCD contribution $q\bar{q} \rightarrow g^* \rightarrow t\bar{t}$, diagrams shown in Fig. 3 also contribute to $t\bar{t}$ production at the Tevatron.

The amplitudes of these new contributions are

$$\begin{aligned}
 \mathcal{M}_a &= i\delta_{\alpha\beta}\delta_{\rho\sigma} \frac{g^2}{4c_W^2 s_W^2} \bar{u}(t)\gamma^\mu [g_{tZ}^L P_L + g_{tZ}^R P_R] v(t) \bar{v}(u)\gamma_\mu [g_{uZ}^L P_L + g_{uZ}^R P_R] u(u) \frac{1}{(p_1 + p_2)^2 - m_Z^2} \\
 \mathcal{M}_b &= i\delta_{\alpha\beta}\delta_{\rho\sigma} \frac{g^2}{4c_W^2 s_W^2} \bar{u}(t)\gamma^\mu [g_{tZ'}^L P_L + g_{tZ'}^R P_R] v(t) \bar{v}(u)\gamma_\mu [g_{uZ'}^L P_L + g_{uZ'}^R P_R] u(u) \frac{1}{(p_1 + p_2)^2 - m_{Z'}^2 + i\Gamma_{Z'} m_{Z'}} \\
 \mathcal{M}_c &= i\delta_{\alpha\rho}\delta_{\beta\sigma} \frac{g^2}{4c_W^2 s_W^2} [\xi_Z s_W (\cot \theta_R + \tan \theta_R)]^2 |V_{Rtu}^u|^2 \frac{\bar{u}(t)\gamma^\mu P_R u(u) \bar{v}(u)\gamma_\mu P_R v(t)}{(p_1 - p_3)^2 - m_{Z'}^2} \\
 \mathcal{M}_d &= i\delta_{\alpha\rho}\delta_{\beta\sigma} \frac{g^2}{4c_W^2 s_W^2} [s_W (\cot \theta_R + \tan \theta_R)]^2 |V_{Rtu}^u|^2 \frac{\bar{u}(t)\gamma^\mu P_R u(u) \bar{v}(u)\gamma_\mu P_R v(t)}{(p_1 - p_3)^2 - m_{Z'}^2} \quad (10)
 \end{aligned}$$

where $\Gamma_{Z'}$ is the Z' width obtained by adding all decay channels of Z' , $s_W = \sin \theta_W$, $c_W = \cos \theta_W$, and the coupling coefficients $g_{tZ}^{L,R}$, $g_{uZ}^{L,R}$, $g_{tZ'}^{L,R}$, $g_{uZ'}^{L,R}$ are defined as

$$\begin{aligned}
g_{tZ}^L &= -\frac{1}{2} + \frac{2}{3}s_W^2, & g_{tZ}^R &= \frac{2}{3}s_W^2 \\
g_{uZ}^L &= \frac{1}{2} - \frac{4}{3}s_W^2, & g_{uZ}^R &= -\frac{4}{3}s_W^2 \\
g_{tZ'}^L &= -\frac{1}{2}\xi_Z + s_W^2 \tan\theta_R \xi_Z, & g_{tZ'}^R &= s_W^2 \tan\theta_R \xi_Z + s_W^2 \cot\theta_R \xi_Z \\
g_{uZ'}^L &= \left(\frac{1}{2} - \frac{2}{3}s_W^2\right)\xi_Z + s_W^2 \tan\theta_R, & g_{uZ'}^R &= -\frac{2}{3}s_W^2 \xi_Z + s_W^2 \tan\theta_R
\end{aligned}$$

Note that among the four amplitudes, only \mathcal{M}_c and \mathcal{M}_d interfere with the QCD amplitude.

In this model the new parameters ξ_Z , $\cot\theta_R$, $M_{Z'}$ and $(V_R^u)_{ut}$ are involved in our calculation. Constraints on these parameters were discussed in [12], and it was found that $0 \leq \xi_Z \leq 0.02$ and $\cot\theta_R \leq 20$. As for $M_{Z'}$, we should note that the constraints from CDF search for Z' [18] and from the global fitting of the electroweak precision data [19] are invalid here since these constraints arise mostly from processes involving the first- or second-generation fermions. So far the pertinent bound comes from $e^+e^- \rightarrow b\bar{b}$ at LEP-II, which requires $M_{Z'} \gtrsim 460$ GeV for $\cot\theta_R \geq 10$ [12]. In the following analysis, without stating explicitly, we include the QCD contribution to A_t^{FB} and scan the new free parameters in the ranges

$$500 \text{ GeV} \leq M_{Z'} \leq 2000 \text{ GeV}, \quad 0 \leq \xi_Z \leq 0.02, \quad 10 \leq \cot\theta_R \leq 20, \quad 0.1 \leq (V_R^u)_{ut} \leq 0.2$$

In our discussion we consider two cases, i.e., with and without $u_R - t_R$ mixing. For the no-mixing case, new contributions to A_t^{FB} only come from diagrams (a) and (b) of Fig. 3 and the dependence of A_t^{FB} on $\cot\theta_R$ and $M_{Z'}$ are shown in Fig. 4. This figure shows that a light Z' with relatively small $\cot\theta_R$ can enhance A_t^{FB} to the 2σ region of its experimental value. This is because small $\cot\theta_R$ can enhance $Z'\bar{u}u$ interactions, and a light Z' can make the resonance effect of diagram Fig. 3(b) on $t\bar{t}$ production more significant. Fig. 4 also shows that in the no-mixing case, the Z' contribution to A_t^{FB} can only reach 1%. This is due to the smallness of $Z'\bar{u}u$ couplings (see Eq. (14) and Eq. (15)) and the absence of the interference of diagrams (a) and (b) in Fig. 3 with the dominant QCD amplitude.

[Figure 5: see original paper]: Scatter plots of A_t^{FB} versus $\cot\theta_R$ in the mixing case of the LR model. The left (right) panel is without (with) considering the constraints from $\sigma_{t\bar{t}}$ and $M_{t\bar{t}}$.

In Figs. 5 and 6, we show A_t^{FB} versus $\cot\theta_R$ and $M_{Z'}$, respectively in the mixing case. The left panels of these figures show that the effect of Fig. 3 (mainly diagram (d)) is potentially very large, pushing the value of A_t^{FB} up

to 50%. In this case, the effects on the total $t\bar{t}$ production rate and the $t\bar{t}$ invariant mass distribution are also large and so it is necessary to consider constraints from these observables measured at the Tevatron. Now based on the CDF 4.6 fb^{-1} luminosity data, the measured total cross section is $\sigma_{t\bar{t}}^{\text{exp}} = 7.50 \pm 0.31_{\text{stat}} \pm 0.34_{\text{syst}} \pm 0.15_{\text{th}}$ pb for $m_t = 172.5 \text{ GeV}$ [20]. Combining errors in quadrature, one can get $\sigma_{t\bar{t}} = 7.50 \pm 0.48$ pb, which is in good agreement with the SM prediction $\sigma_{t\bar{t}} = 7.5_{-0.6}^{+0.5}$ pb [21]. The invariant mass distribution was also measured by CDF, and the results are presented in nine bins of $M_{t\bar{t}}$ [22]. When we calculate these observables, we multiply an overall K-factor 1.329 for the dominant tree-level QCD contribution [21]. The right panels of Figs. 5 and 6 are then obtained by requiring the total cross section and the differential cross section in each bin to be within the 2σ regions of their experimental values. These results show that even with the constraints, the third-generation enhanced left-right model can still enhance A_t^{FB} to 12% (well above the 2σ lower bound), but it cannot enhance A_t^{FB} to within the 1σ region of its experimental value. Note that unlike the no-mixing case, large contribution to A_t^{FB} comes from the region where $\cot\theta_R$ is large. The reason is that in the mixing case, the dominant contribution arises from diagram (d) of Fig. 3, and this contribution is proportional to $(\cot\theta_R + \tan\theta_R)^2$.

IV. Discussion and Conclusion

From our study and the previous works [2, 4–7, 23], we can learn that to make sizable contribution to A_t^{FB} , the following two conditions must be satisfied. One is that the initial state must be $u\bar{u}$ and/or $d\bar{d}$, and in case that only $d\bar{d}$ -initiated contribution is responsible for explaining A_t^{FB} , the involved interaction must be strong enough to compensate the suppression of the parton distribution of down quark in the proton. The other is that the amplitude of the $t\bar{t}$ production must contain terms proportional to $\cos\theta$ with θ being the angle between the reconstructed top quark momentum and the proton beam direction in the $t\bar{t}$ rest frame, or in other words, contain terms like $(p_u \cdot p_t)(p_{\bar{u}} \cdot p_{\bar{t}}) - (p_{\bar{u}} \cdot p_t)(p_u \cdot p_{\bar{t}})$. This requirement implies that new physics affects $t\bar{t}$ production through the following ways:

- (1) Through s -channel process $q\bar{q} \rightarrow t\bar{t}$ by exchanging a gauge boson [4, 5]. If this process interferes with the s -channel QCD process $q\bar{q} \rightarrow g^* \rightarrow t\bar{t}$, the interaction of the gauge boson with q and t must have an axial-vector component. Examples in this direction are the presence of Kaluza-Klein excitation of gluon in extra dimensions [4] or the axigluon [5]. If this process does not interfere with the s -channel process, to affect A_t^{FB} by itself, the interaction must have both vector and axial-vector components, like what we studied in diagram (b) of Fig. 3. From yet known studies we can infer that it seems difficult for the latter case to enhance A_t^{FB} significantly without spoiling the constraints from $\sigma_{t\bar{t}}$ and $M_{t\bar{t}}$.
- (2) Through t -channel process $q\bar{q} \rightarrow t\bar{t}$ by exchanging a vector boson or a scalar [6, 7], which interferes with the QCD process $q\bar{q} \rightarrow g^* \rightarrow t\bar{t}$. In

this way, scalar is less efficient than vector boson in explaining A_t^{FB} given that they have the same coupling strength and mass. This is because for the scalar case, there is a competition between spin correlation and the Rutherford singularity [7]. Moreover, as shown in [7], the scalar-mediated contributions can be categorized by the transformation property of the scalar under $SU(3)_c$. If the scalar is color-triplet or -sextet, there exists a large parameter region to explain A_t^{FB} within 1σ and at the same time to keep $\sigma_{t\bar{t}}$ within the experimental errors, while for color-singlet or -octet scalar, it is very difficult to produce a large positive contribution to A_t^{FB} without spoiling the constraint from $\sigma_{t\bar{t}}$ [7]. In our work, we checked this conclusion for color-singlet and -triplet cases.

From our study, we can also learn that, although the top quark pair productions at the Tevatron and the LHC may be sensitive to new physics, the effects of new physics (like the popular MSSM or TC2 models) are usually not so large to be well above the experimental and theoretical uncertainties [10]. A complementary or even more sensitive probe for new physics effects in the top quark sector is top quark FCNC processes, which are extremely suppressed and inaccessible in the SM but can be greatly enhanced by several orders to reach the observable level in some new physics models like the MSSM [24] or the TC2 model [25].

In summary, we in this work calculated the new physics contribution to the top quark forward-backward asymmetry A_t^{FB} at the Tevatron in two different models: the minimal supersymmetric model without R-parity (RPV-MSSM) and the third-generation enhanced left-right model (LR model). We found that in the parameter space allowed by the $t\bar{t}$ production rate and the $t\bar{t}$ invariant mass distribution at the Tevatron, the LR model can enhance A_t^{FB} to within the 2σ region of the Tevatron data for the major part of the parameter space, and in the optimal case A_t^{FB} can reach 12% which is slightly below the 1σ lower bound. For the RPV-MSSM, only in a narrow part of the parameter space can the λ'' couplings enhance A_t^{FB} to within the 2σ region while the λ' couplings just produce negative contributions to worsen the fit. Noting that the R-parity conserving interactions in the MSSM are unlikely to give large enough contribution to A_t^{FB} , we conclude that the MSSM with (without) R-parity will be disfavored (favored in case of λ'' couplings) if the discrepancy of A_t^{FB} persists with more forthcoming data accumulated by the Tevatron. We also checked the top-color assisted technicolor model and found that it gives negligibly small contributions to A_t^{FB} and thus is unlikely to explain the Tevatron data.

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