

Chiral color symmetry and G' -boson mass limit from Tevatron data on $t\bar{t}$ -production

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Abstract

A gauge model with chiral color symmetry of quarks is considered and possible effects of the color G' -boson octet predicted by this symmetry are investigated. The contributions of the G' -boson to the cross section $\sigma_{t\bar{t}}$ and to the forward-backward asymmetry $A_{\text{FB}}^{p\bar{p}}$ of $t\bar{t}$ production at the Tevatron are calculated and analysed in dependence on two free parameters of the model, the mixing angle θ_G and G' mass $m_{G'}$. The G' -boson contributions to $\sigma_{t\bar{t}}$ and $A_{\text{FB}}^{p\bar{p}}$ are shown to be consistent with the Tevatron data on $\sigma_{t\bar{t}}$ and $A_{\text{FB}}^{p\bar{p}}$, the allowed region in the $m_{G'} - \theta_G$ plane is discussed and around $m_{G'} = 1.2 \text{ TeV}$, $\theta_G = 14^\circ$ the region of 1σ consistency is found.

Keywords: Beyond the SM; chiral color symmetry; axigluon; massive color octet; G' -boson; top quark physics.

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The search for a new physics beyond the Standard Model (SM) is now one of the aims of the high energy physics. The simplest extensions of the SM (such as two Higgs models, models based on supersymmetry, left-right symmetry, four color quark-lepton symmetry or models implying the four fermion generation, etc.) predicting the new physics effects at one or a few TeV energies are most interesting now in anticipation of the new results from the LHC which will allow the investigations of new physics effects at the TeV energy scale with very large statistics [1].

One of the simplest extensions of the SM can be based on the idea of the originally chiral character of $SU_c(3)$ color symmetry of quarks. i.e on the gauge group of the chiral color symmetry

$$G_c = SU_L(3) \times SU_R(3) \rightarrow SU_c(3), \quad (1)$$

$$g_L, \quad g_R \rightarrow g_{st},$$

which is assumed to be valid at high energies and is broken to usual QCD $SU_c(3)$ at low energy scale. The immediate consequence of the chiral color symmetry of quarks is the prediction of new color-octet gauge particle: the axigluon G_μ^A in the case of $g_L = g_R$ [2–5] or the G' -boson in general case of $g_L \neq g_R$ [6–8].

$$G_c \Rightarrow \begin{cases} \text{axigluon } G^A & \text{for } g_L = g_R, \quad [2-5], \\ G' - \text{boson} & \text{for } g_L \neq g_R, \quad [6-8], \end{cases}$$

The G' -boson is the octet-colored gauge particle with vector and axial vector coupling constants to quarks of order g_{st} which are defined by gauge coupling constants g_L, g_R . Some

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features of the axigluon (including its phenomenology at the Tevatron) were investigated in ref. [9–12] and the massive color octet with arbitrary vector and axial vector coupling constants to quarks has been considered phenomenologically in ref. [13].

Since it is the colored gauge particle with vector and axial vector coupling to quarks, the G' -boson should give rise the increase of the cross section as well as the appearance of a forward-backward asymmetry in $Q\bar{Q}$ production.

The current CDF data on cross section $\sigma_{t\bar{t}}$ [14] and forward-backward asymmetry $A_{\text{FB}}^{p\bar{p}}$ [15] of the $t\bar{t}$ production at the Tevatron are

$$\sigma_{t\bar{t}} = 7.5 \pm 0.31(\text{stat}) \pm 0.34(\text{syst}) \pm 0.15(\text{lumi})\text{pb} (= 7.5 \pm 0.48\text{pb}), \quad (2)$$

$$A_{\text{FB}}^{p\bar{p}} = 0.193 \pm 0.065(\text{stat}) \pm 0.024(\text{sys}) (= 0.193 \pm 0.069). \quad (3)$$

The SM predictions for $\sigma_{t\bar{t}}$ and $A_{\text{FB}}^{p\bar{p}}$ have been discussed in refs. [16–18] and [12, 19–21] respectively and we quote here the next SM predictions for $\sigma_{t\bar{t}}$ [16] and $A_{\text{FB}}^{p\bar{p}}$ [12]

$$\sigma_{t\bar{t}}^{SM} = 7.35_{-0.80}^{+0.38}(\text{scale})_{-0.34}^{+0.49}(\text{PDFs})[\text{CTEQ6.5}]\text{pb} \div \quad (4)$$

$$7.93_{-0.56}^{+0.34}(\text{scale})_{-0.20}^{+0.24}(\text{PDFs})[\text{MRST2006nnlo}]\text{pb},$$

$$A_{\text{FB}}^{SM}(p\bar{p} \rightarrow t\bar{t}) = 0.051(6). \quad (5)$$

The first and second values in (4) were obtained in NLO+NLL approximation with $m_t = 171$ GeV and correspond to the different choices of the parton distribution functions (CTEQ6.5 and MRST2006nnlo respectively). As seen the experimental and theoretical values of $\sigma_{t\bar{t}}$ (2), (4) are compatible within the experimental and theoretical errors whereas the experimental value of $A_{\text{FB}}^{p\bar{p}}$ (3) exceeds the corresponding theoretical prediction (5) by more than 2σ . This deviation is not so large nevertheless this circumstance is under active discussion now [22–34].

The main goal of my talk is to clean up if the gauge chiral color symmetry (1) is consistent with the CDF data (2), (3) and what bounds on the mass of G' -boson are imposed by these data.

In the case of the gauge chiral color symmetry (1) the 3×3 matrices of the usual gluon fields G_μ and of the G' -boson fields G'_μ are constructed from the basic gauge fields G_μ^L and G_μ^R as

$$G_\mu = s_G G_\mu^L + c_G G_\mu^R,$$

$$G'_\mu = c_G G_\mu^L - s_G G_\mu^R,$$

where

$$s_G = \sin \theta_G = \frac{g_R}{\sqrt{(g_L)^2 + (g_R)^2}}, \quad c_G = \cos \theta_G = \frac{g_L}{\sqrt{(g_L)^2 + (g_R)^2}},$$

θ_G is $G^L - G^R$ mixing angle, $G_\mu = G_\mu^i t_i$, $G'_\mu = G_\mu^i t_i$, t_i , $i = 1, 2, \dots, 8$, are the generators of $SU_c(3)$ group.

To reproduce the usual quark-gluon interaction of QCD the gauge coupling constants g_L , g_R of the gauge group G_c must satisfy the relation

$$\frac{g_L g_R}{\sqrt{(g_L)^2 + (g_R)^2}} = g_{st}(M_{chc}).$$

where M_{chc} is the mass scale of the chiral color symmetry breaking and $g_{st}(M_{chc})$ is the strong coupling constant taken at this mass scale.

The interaction of the G' -boson with quarks in this case takes the form

$$\mathcal{L}_{G'qq} = g_{st}(M_{chc}) \bar{q} \gamma^\mu (v + a\gamma_5) G'_\mu q, \quad (6)$$

where v and a are the vector and axial-vector coupling constants for the which the gauge chiral color symmetry group G_c gives the expressions

$$v = \frac{c_G^2 - s_G^2}{2s_G c_G} = \cot(2\theta_G), \quad a = \frac{1}{2s_G c_G} = 1/\sin(2\theta_G).$$

As a result of the chiral color symmetry breaking the G' -boson picks up the mass

$$m_{G'} = \frac{g_{st}(M_{chc})}{s_G c_G} \frac{\eta}{\sqrt{6}},$$

where η is the VEV of the $(3_L, \bar{3}_R)$ scalar field $\Phi_{\alpha\beta}$ of the group G_c , which breaks the chiral color symmetry, $\langle \Phi_{\alpha\beta} \rangle = \delta_{\alpha\beta} \eta / (2\sqrt{3})$, $\alpha, \beta = 1, 2, 3$ are the $SU_L(3)$ and $SU_R(3)$ indices.

So, the gauge chiral color symmetry model has two free parameters, the G' -boson mass $m_{G'}$ and the $G^L - G^R$ mixing angle θ_G , $tg \theta_G = g_R/g_L$, which gives the possibility to study the phenomenology of the G' -boson in more detail in dependence on these two parameters.

The differential cross section of the process $q\bar{q} \xrightarrow{g, G'} Q\bar{Q}$ in tree approximation with account of the G' -boson interaction (6) and of the gluon contributions has the form [8]

$$\begin{aligned} \frac{d\sigma(q\bar{q} \xrightarrow{g, G'} Q\bar{Q})}{d \cos \hat{\theta}} &= \frac{\pi\beta}{9\hat{s}} \left\{ \alpha_s^2(\mu) f^{(+)} + \frac{\alpha_s(\mu) \alpha_s(M_{chc}) 2\hat{s}(\hat{s} - m_{G'}^2)}{(\hat{s} - m_{G'}^2)^2 + m_{G'}^2 \Gamma_{G'}^2} \left[v^2 f^{(+)} + 2a^2 \beta c \right] + \right. \\ &+ \left. \frac{\alpha_s^2(M_{chc}) \hat{s}^2}{(\hat{s} - m_{G'}^2)^2 + m_{G'}^2 \Gamma_{G'}^2} \left[(v^2 + a^2) (v^2 f^{(+)} + a^2 f^{(-)}) + 8a^2 v^2 \beta c \right] \right\}, \end{aligned} \quad (7)$$

where $f^{(\pm)} = (1 + \beta^2 c^2 \pm 4m_Q^2/\hat{s})$, $c = \cos \hat{\theta}$, $\hat{\theta}$ is the scattering angle of Q -quark in the parton center of mass frame, \hat{s} is the squared invariant mass of $Q\bar{Q}$ system, $\beta = \sqrt{1 - 4m_Q^2/\hat{s}}$, M_{chc} is the mass scale of the chiral color symmetry breaking and μ is a typical scale of the process.

The corresponding to (7) total cross section takes the form [8]

$$\begin{aligned} \sigma(q\bar{q} \xrightarrow{g, G'} Q\bar{Q}) &= \frac{4\pi\beta}{27\hat{s}} \left\{ \alpha_s^2(\mu) (3 - \beta^2) - \frac{\alpha_s(\mu) \alpha_s(M_{chc}) 2\hat{s}m_{G'}^2 v^2 (3 - \beta^2)}{(\hat{s} - m_{G'}^2)^2 + \Gamma_{G'}^2 m_{G'}^2} + \right. \\ &+ \left. \frac{\alpha_s^2(M_{chc}) \hat{s}^2 [(v^4 + 2v^2)(3 - \beta^2) + v^2 a^2 (3 + \beta^2) + 2a^4 \beta^2]}{(\hat{s} - m_{G'}^2)^2 + \Gamma_{G'}^2 m_{G'}^2} \right\}. \end{aligned} \quad (8)$$

The entering into (7), (8) hadronic width of the G' -boson is known [7,13] and can be written as

$$\Gamma_{G'} = \sum_Q \Gamma(G' \rightarrow Q\bar{Q})$$

where

$$\Gamma(G' \rightarrow Q\bar{Q}) = \frac{\alpha_s(M_{chc}) m_{G'}}{6} \left[v^2 \left(1 + \frac{2m_Q^2}{m_{G'}^2} \right) + a^2 \left(1 - \frac{4m_Q^2}{m_{G'}^2} \right) \right] \sqrt{1 - \frac{4m_Q^2}{m_{G'}^2}}$$

is the width of G' -boson decay into $Q\bar{Q}$ -pair.

At $M_{chc} = 1.2 TeV$, for example, we obtain the next estimations for the relative width of G' -boson

$$\Gamma_{G'}/m_{G'} = 0.08, 0.14, 0.33, 0.60, 1.37$$

for $\theta_G = 45^\circ, 30^\circ, 20^\circ, 15^\circ, 10^\circ$ respectively.

As concerns the process of $Q\bar{Q}$ production in gluon fusion $gg \rightarrow Q\bar{Q}$ the G' -boson does not contribute, in tree approximation, to this process.

The differential and total partonic cross sections of the process of $Q\bar{Q}$ production in gluon fusion $gg \rightarrow Q\bar{Q}$ in tree approximation of the SM are well known and have the form

$$\frac{d\sigma_0^{SM}(gg \rightarrow Q\bar{Q})}{d\cos\hat{\theta}} = \alpha_s^2(\mu) \frac{\pi\beta}{6\hat{s}} \left(\frac{1}{1-\beta^2c^2} - \frac{9}{16} \right) \left(1 + \beta^2c^2 + 2(1-\beta^2) - \frac{2(1-\beta^2)^2}{1-\beta^2c^2} \right), \quad (9)$$

$$\sigma_0^{SM}(gg \rightarrow Q\bar{Q}) = \frac{\pi\alpha_s^2(\mu)}{48\hat{s}} \left[(\beta^4 - 18\beta^2 + 33) \log\left(\frac{1+\beta}{1-\beta}\right) + \beta(31\beta^2 - 59) \right]. \quad (10)$$

The G' -boson can generate, at tree-level, a forward-backward asymmetry in $Q\bar{Q}$ -pair production due to the forward-backward difference in the $q\bar{q} \rightarrow Q\bar{Q}$ partonic cross section [8]

$$\begin{aligned} \Delta_{FB}(q\bar{q} \rightarrow Q\bar{Q}) &= \sigma(q\bar{q} \rightarrow Q\bar{Q}, \cos\theta > 0) - \sigma(q\bar{q} \rightarrow Q\bar{Q}, \cos\theta < 0) = \\ &= \frac{4\pi\beta^2a^2}{9} \left(\frac{\alpha_s(\mu)\alpha_s(M_{chc})(\hat{s} - m_{G'}^2) + 2\alpha_s^2(M_{chc})v^2\hat{s}}{(\hat{s} - m_{G'}^2)^2 + m_{G'}^2\Gamma_{G'}^2} \right), \end{aligned} \quad (11)$$

which can give rise to the corresponding forward-backward asymmetry $A_{FB}^{p\bar{p}}$ of $t\bar{t}$ -pair production in $p\bar{p}$ collisions at the Tevatron.

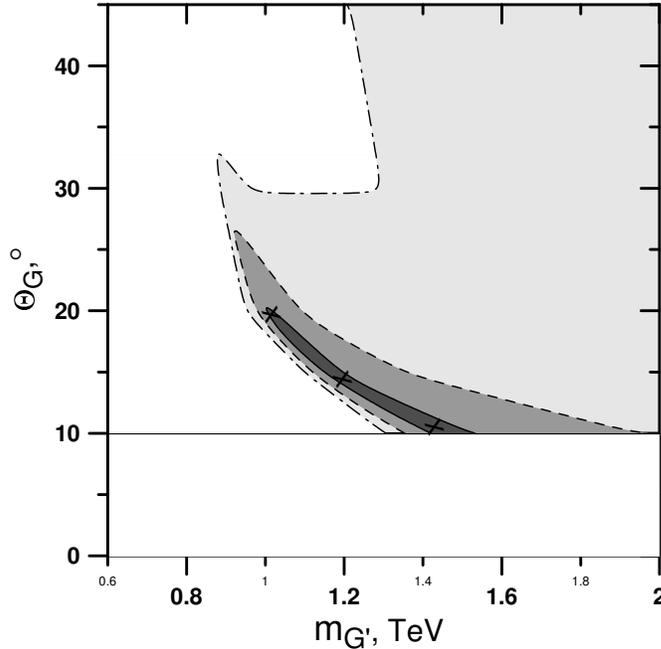


Figure 1: The $m_{G'} - \theta_{G'}$ regions consistent with CDF data on cross section $\sigma_{t\bar{t}}$ and forward-backward asymmetry $A_{FB}^{p\bar{p}}$ in $t\bar{t}$ production within 1σ (dark region), 2σ (grey region) and 3σ (light-grey region).

We have calculated the cross section $\sigma(p\bar{p} \rightarrow t\bar{t})$ of $t\bar{t}$ -pair production in $p\bar{p}$ -collisions at the Tevatron energy using the total parton cross section of quark-antiquark annihilation (8), the total SM parton cross section (10) of the gluon fusion $gg \rightarrow Q\bar{Q}$ and the parton densities AL'03 [35] (NLO, fixed-flavor-number, $Q^2 = m_t^2$) with the appropriate K-factor $K = 1.24$ [36]. Here and below we believe $\mu^2 = Q^2$, $M_{chc} = m_{G'}$.

With the same parton densities we have calculated the forward-backward asymmetry $A_{FB}^{p\bar{p}}$ in $t\bar{t}$ -pair production at the Tevatron in the form

$$A_{FB}^{p\bar{p}} = A_{FB}^{G'} + A_{FB}^{SM}, \quad (12)$$

where $A_{\text{FB}}^{G'}$ is the corresponding G' boson contribution which has been calculated using the differential parton cross section (7) (one can use also the expression (11)) and A_{FB}^{SM} is the SM prediction for $A_{\text{FB}}^{p\bar{p}}$ for which we have used the value (5) of ref. [12].

We have analysed the cross section $\sigma(p\bar{p} \rightarrow t\bar{t})$ and the forward-backward asymmetry $A_{\text{FB}}^{p\bar{p}}$ in dependence on two free parameters of the model, the mixing angle θ_G and G' mass $m_{G'}$, in comparison with the Tevatron data (2), (3) on $\sigma_{t\bar{t}}$ and $A_{\text{FB}}^{p\bar{p}}$. The result of this analysis is shown in $m_{G'} - \theta_G$ plane in Fig.1.

The Fig.1 shows the regions in the $m_{G'} - \theta_G$ plane which are simultaneously consistent with the data (2) and (3) within 1σ (dark region), 2σ (grey region) and 3σ (light-grey region). As seen from the Fig.1 for

$$m_{G'} \gtrsim 1.0 \text{ TeV}$$

in the $m_{G'} - \theta_G$ plane there is the region which is consistent with the CDF data (2), (3) on $\sigma(p\bar{p} \rightarrow t\bar{t})$ and $A_{\text{FB}}^{p\bar{p}}$.

For example, for the masses

$$a) m_{G'} = 1.02 \text{ TeV}, \quad b) m_{G'} = 1.2 \text{ TeV}, \quad c) m_{G'} = 1.4 \text{ TeV} \quad (13)$$

with the appropriate values of θ_G ($\theta_G = 19^\circ$, $\theta_G = 14^\circ$, $\theta_G = 11^\circ$ respectively, these points are marked in Fig.1 by crosses) we obtain for $\sigma_{t\bar{t}}$, $A_{\text{FB}}^{p\bar{p}}$ the values

$$a) \sigma_{t\bar{t}} = 7.98 \text{ pb}, \quad A_{\text{FB}}^{p\bar{p}} = 0.158 (0.107), \quad (14)$$

$$b) \sigma_{t\bar{t}} = 7.61 \text{ pb}, \quad A_{\text{FB}}^{p\bar{p}} = 0.154 (0.103), \quad (15)$$

$$c) \sigma_{t\bar{t}} = 7.57 \text{ pb}, \quad A_{\text{FB}}^{p\bar{p}} = 0.141 (0.090), \quad (16)$$

which are consistent with the CDF data (2), (3) on $\sigma(p\bar{p} \rightarrow t\bar{t})$ and $A_{\text{FB}}^{p\bar{p}}$ within 1σ .

In parentheses in (14)-(16) we show for comparison the G' -boson contributions in $A_{\text{FB}}^{p\bar{p}}$ defined by (11), without the SM contribution (5). As seen, the G' -boson can give in the forward-backward asymmetry $A_{\text{FB}}^{p\bar{p}}$ the contribution of about 10 % .

So, the G' -boson induced by the chiral color symmetry (1) in general case of $g_L \neq g_R$ is consistent with the data (2), (3) and can reduce the difference between the experimental and SM values (3), (5) of the forward-backward asymmetry $A_{\text{FB}}^{p\bar{p}}$ in the $t\bar{t}$ production at the Tevatron.

Summary

- The contributions of G' -boson predicted by the chiral color symmetry of quarks to the cross section $\sigma_{t\bar{t}}$ and to the forward-backward asymmetry $A_{\text{FB}}^{p\bar{p}}$ of $t\bar{t}$ production at the Tevatron are calculated and analysed in dependence on two free parameters of the model, the G' mass $m_{G'}$ and mixing angle θ_G .
- The G' -boson contributions to $\sigma_{t\bar{t}}$ and $A_{\text{FB}}^{p\bar{p}}$ are shown to be consistent with the Tevatron data on $\sigma_{t\bar{t}}$ and $A_{\text{FB}}^{p\bar{p}}$ and the allowed region in the $m_{G'} - \theta_G$ plane is discussed, in particular, it is shown that for

$$m_{G'} > 1.02 \text{ TeV}$$

in the $m_{G'} - \theta_G$ plane there is the region with 1σ consistency.

- So, the G' -boson induced by the chiral color symmetry of quarks in general case of $g_L \neq g_R$ is consistent with the Tevatron data on $\sigma_{t\bar{t}}$ and $A_{\text{FB}}^{p\bar{p}}$ and can reduce the difference between the experimental and predicted by SM values of the forward-backward asymmetry $A_{\text{FB}}^{p\bar{p}}$ in the $t\bar{t}$ production at the Tevatron.

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