Chiral color symmetry
and possible $G'$-boson effects
at the Tevatron and LHC

M.V. Martynov, A.D. Smirnov
Division of Theoretical Physics, Department of Physics,
Yaroslavl State University, Sovietskaya 14,
150000 Yaroslavl, Russia.

Abstract

A gauge model with chiral color symmetry is considered and possible effects of the color $G'$-boson octet predicted by this symmetry are investigated in dependence on two free parameters, the mixing angle $\theta_G$ and $G'$ mass $m_{G'}$. The allowed region in the $m_{G'} - \theta_G$ plane is found from the Tevatron data on the cross section $\sigma_{t\bar{t}}$ and forward-backward asymmetry $A_{FB}^{t\bar{t}}$ of the $t\bar{t}$ production. The mass limits for the $G'$-boson are shown to be stronger than those for the axigluon. A possible effect of the $G'$-boson on the $t\bar{t}$ production at the LHC is discussed and the mass limits providing for the $G'$-boson evidence at the LHC are estimated in dependence on $\theta_G$.

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The search for new physics beyond the Standard Model (SM) induced by higher symmetries (such as supersymmetry, left-right symmetry, etc.) is one of the modern research directions in elementary particle physics. The Large Hadron Collider (LHC) will allow the exploration of the existence of new physics at the TeV energy scale with very large statistics [1]. Top physics is a very promising place to look for new physics effects [2] and a top factory such as the LHC is expected to be a goldmine for studying the SM as well as beyond the SM physics [3].

There are models extending the standard color gauge group $SU_c(3)$ to the group of the chiral color symmetry

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

which is assumed to be valid at high energies and is broken to usual QCD $SU_c(3)$ at low energy scale. Such chiral color theories [4–7] in addition to the usual massless gluon $G_\mu$ predict in the simplest case of $g_L = g_R$ the existence of a new color-octet gauge boson, the axigluon $G_A^\mu$ with mass $m_{G_A}$. The axigluon couples to quarks with an axial vector structure and with the same strong interaction coupling strength as QCD. It has a width

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*E-mail: martmix@mail.ru
†E-mail: asmirnov@univ.uniyar.ac.ru
\[ \Gamma_{G_A} \approx 0.1m_{G_A} \] [8]. Since it is the colored gauge particle with axial vector coupling to quarks, the axigluon should immediately result in the increase of the hadronic cross section and in the appearance of a forward-backward asymmetry of order \( \alpha_s^2 \) [9]. The CDF data on the cross section of the dijet production at the Tevatron [11] exclude at 95% C.L. the axigluon mass region \( 260 \text{ GeV} < m_{G_A} < 1.250 \text{ TeV} \) and the Tevatron data on asymmetry sets the lower mass limit for the axigluon at \( m_{G_A} > 1.2, 1.4 \text{ TeV} \) [9, 12].

The massive color octet with arbitrary vector- and axial-vector-quark coupling constants has been considered phenomenologically in ref. [13]. But it is also interesting to consider the color octet as the gauge boson induced by the chiral color symmetry of a general type.

In the present paper we consider the color-octet boson induced by the gauge chiral color symmetry (1) in general case of \( g_L \neq g_R \). We calculate the possible contributions of this boson to the cross section and to the forward-backward asymmetry of the \( Q\bar{Q} \) production in \( pp \) and \( pp \) collisions in dependence on the free parameters of the model. We compare the results with the Tevatron data on the \( t\bar{t} \) production and discuss a possible effect of this boson in the \( t\bar{t} \) production at the LHC.

To reproduce the usual quark-gluon interaction of QCD the gauge coupling constants \( g_L, g_R \) of the gauge group (1) must satisfy the relation

\[ \frac{g_Lg_R}{\sqrt{(g_L)^2 + (g_R)^2}} = g_{st} \] (2)

where \( g_{st} \) is the strong interaction coupling constant.

The basic gauge fields \( G^L_\mu \) and \( G^R_\mu \) are mixed and form the usual gluon field \( G_\mu \) and the field \( G'_\mu \) of an additional \( G' \)-boson as

\[ G_\mu = \frac{g_RG^L_\mu + g_LG^R_\mu}{\sqrt{(g_L)^2 + (g_R)^2}} \equiv s_G G^L_\mu + c_G G^R_\mu, \] (3)

\[ G'_\mu = \frac{g_LG^L_\mu - g_RG^R_\mu}{\sqrt{(g_L)^2 + (g_R)^2}} \equiv c_G G^L_\mu - s_G G^R_\mu, \] (4)

where \( G^L,R_\mu = G^L,R_{(3)}_{\mu ij}t_i, G_\mu = G^L_\mu t_i, G'_\mu = G'^R_\mu t_i, i = 1, 2, ..., 8, t_i \) are the generators of \( SU_c(3) \) group, \( s_G = \sin \theta_G, c_G = \cos \theta_G, \theta_G \) is \( G^L - G^R \) mixing angle, \( tG = g_R/g_L \).

The symmetry (1) can be softly broken by the scalar field \( \Phi_{\alpha\beta} \), which transforms according to the \( (3_L, 3_R) \) representation of the group (1) and has the VEV \( \langle \Phi_{\alpha\beta} \rangle = \delta_{\alpha\beta} \eta / (2\sqrt{3}) \), \( \alpha, \beta = 1, 2, 3 \) are the \( SU_L(3) \) and \( SU_R(3) \) indices. After such symmetry breaking the gluons are still massless and the \( G' \)-boson acquires the mass

\[ m_{G'} = \frac{g_{st}}{s_Gc_G} \frac{\eta}{\sqrt{6}}. \] (5)

The interaction of the \( G' \)-boson with quarks can be written in the model independent form as

\[ \mathcal{L}_{G'qq} = g_{st} \bar{q}\gamma^\mu(v + a\gamma_5)G'_\mu q \] (6)

where \( v \) and \( a \) are the phenomenological vector and axial-vector coupling constants. The gauge symmetry (1) gives for \( v, a \) the expressions

\[ v = \frac{c_G^2 - s_G^2}{2s_Gc_G} = \cot(\theta_G), \quad a = \frac{1}{2s_Gc_G} = 1/\sin(2\theta_G). \] (7)
So, in the general case of the gauge chiral color symmetry (11) the mass of the $G'$-boson is defined by expression (1) and the vector and axial-vector coupling constants of $G'$-boson with quarks (in contrast to phenomenological approach of ref. [13]) depend on one parameter $\theta_G$ which is defined by the gauge coupling constants $g_L$, $g_R$ satisfying relation (2). This circumstance reduces the possible region of the parameters $v$, $a$, and allows the possibility of studying the phenomenonology of the $G'$-boson in more detail in dependence on two free parameters of the model $m_{G'}$ and $\theta_G$. In the particular case of $g_L = g_R$, $\theta_G = 45°$, $v = 0$, $a = 1$, the $G'$-boson coincides with the axigluon. In the general case of decreasing $\theta_G$, the coupling constants increase according to (7) so that, for example, for $\theta_G = 15°$, $10°$ the perturbation theory parameters take the values $\alpha_s v^2 / \pi \approx \alpha_s a^2 / \pi \approx 0.14$, $0.3$ respectively. In further considerations we restrict ourselves to the mixing angle region $10° \lesssim \theta_G \leq 45°$.

The hadronic width of the $G'$-boson can be written as

$$
\Gamma_{G'} = \sum Q \Gamma(G' \to Q\bar{Q})
$$

(8)

where

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

(9)

is the width of $G'$-boson decay into $Q\bar{Q}$-pair. In the case of neglecting the masses of light quarks (except t-quark) the result (8), (9) agrees with that of ref. [13].

Using the coupling constants (7) from (8), (9) we obtain the next estimations for the relative width of $G'$-boson

$$
\Gamma_{G'}/m_{G'} = 0.11, 0.18, 0.41, 0.75, 1.71
$$

(10)

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

Since it is a strongly interacting particle, the $G'$-boson can give significant contributions to the production of quark–antiquark pairs in $pp$ and $p\bar{p}$ collisions. The differential partonic cross section of the process $q\bar{q} \to Q\bar{Q}$ considering the $G'$-boson and gluon contributions within the tree approximation has been calculated (in agreement with ref. [13]) and can be written as

$$
d\sigma(q\bar{q} \to G' Q\bar{Q})/d \cos \theta = \frac{\alpha_s^2 \pi \beta}{9 \hat{s}} \left\{ f^{(+)} \left( 1 + \frac{2\hat{s}(\hat{s} - m_{G'}^2)}{(\hat{s} - m_{G'}^2)^2 + m_{G'}^2 \Gamma_{G'}^2} \right) \left[ v^2 f^{(+)} + 2a^2 \beta c \right] + \right. \\
\left. \frac{\hat{s}^2}{(\hat{s} - m_{G'}^2)^2 + m_{G'}^2 \Gamma_{G'}^2} \left[ (v^2 + a^2) (v^2 f^{(+)} + a^2 f^{(-)}) + 8a^2 v^2 \beta c \right] \right\},
$$

(11)

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 invariant mass of $Q\bar{Q}$ system, $\beta = \sqrt{1 - 4m_{Q}^2 / \hat{s}}$.

Integration of (11) over the angle gives the corresponding total cross section in the form

$$
\sigma(q\bar{q} \to G' Q\bar{Q}) = \frac{4\pi \alpha_s^2 \beta}{27 \hat{s}} \left\{ 3 - \beta^2 - \frac{2\hat{s} m_{G'}^2 v^2 (3 - \beta^2)}{(\hat{s} - m_{G'}^2)^2 + \Gamma_{G'}^2 m_{G'}^2} + \right. \\
\left. \frac{\hat{s}^2}{(\hat{s} - m_{G'}^2)^2 + \Gamma_{G'}^2 m_{G'}^2} \left[ (v^4 + 2v^2) (3 - \beta^2) + v^2 a^2 (3 + \beta^2) + 2a^4 \beta^2 \right] \right\}.
$$

(12)
In tree approximation, the $G'$-boson does not contribute to the $gg \rightarrow Q\bar{Q}$ process of $Q\bar{Q}$ production in gluon fusion. The differential and total SM partonic cross sections of this process are well known and have the form
\[
\frac{d\sigma(gg \rightarrow Q\bar{Q})}{d\cos \theta} = \alpha_s^2 \frac{\pi \beta}{6s} \left( \frac{1}{1 - \beta^2 s^2} - \frac{9}{16} \right) \left( 1 + \beta^2 c^2 + 2(1 - \beta^2) - \frac{2(1 - \beta^2)^2}{1 - \beta^2 c^2} \right), \tag{13}
\]
\[
\sigma(gg \rightarrow Q\bar{Q}) = \frac{\pi \alpha_s^2}{48s} \left( (3s^2 - 18s^2 + 33) \log \left( \frac{1 + \beta}{1 - \beta} \right) + \beta (31\beta^2 - 59) \right). \tag{14}
\]

Taking into account the parton densities and the values of the $\beta$ parameter in (12) one can see from (12) that the contribution of the $G'$-boson to $Q\bar{Q}$ production is most significant for $t\bar{t}$ production. The $t\bar{t}$ production is well studied at the Tevatron and the recent CDF result for the $t\bar{t}$ production cross section is (14)
\[
\sigma_{t\bar{t}} = 7.0 \pm 0.3(stat) \pm 0.4(syst) \pm 0.4(lumi)pb. \tag{15}
\]

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 parton cross sections (12), (14) and the parton densities AL'03 [15] (NLO, fixed-flavor-number, $Q^2 = m_t^2$) with the appropriate K-factor $K = 1.24$ [16]. The allowed region in $m_{G'} - \theta_{G}$ plane (the unshaded region) which is compatible with data (15) within $2\sigma$ is shown in Fig.1, the $1\sigma$ region is marked by the dashed line. From Fig.1 and by comparing the calculated cross section $\sigma(p\bar{p} \rightarrow t\bar{t})$ with CDF result (15) we find that the $G'$-boson with masses
\[
m_{G'}[TeV] > 0.91(0.9), 1.03(1.05), 1.20(1.23), 1.39(1.44), 1.73(1.82) \tag{16}
\]
is compatible with data (15) within $2\sigma(1\sigma)$ for $\theta_{G} = 45^\circ, 30^\circ, 20^\circ, 15^\circ, 10^\circ$ respectively. The first value in (16) coincides with the known mass limit for the axigluon [18] whereas the next ones are the mass limits for the $G'$-boson in dependence on the mixing angle $\theta_{G}$.

The $G'$ boson can generate, at tree-level, a forward-backward asymmetry through the interference of $q\bar{q} \rightarrow t\bar{t}$ and $q\bar{g} \rightarrow t\bar{t}$ amplitudes [12,17,18]. From (11) we find that the $G'$ boson induces a forward-backward difference in the $q\bar{q} \rightarrow Q\bar{Q}$ cross section of the form
\[
\Delta_{FB}(q\bar{q} \rightarrow Q\bar{Q}) = \sigma(q\bar{q} \rightarrow Q\bar{Q}, \cos \theta > 0) - \sigma(q\bar{q} \rightarrow Q\bar{Q}, \cos \theta < 0) =
\frac{4\alpha_s^2 \pi \beta a^2}{9} \left( \frac{\hat{s} - m_{G'}^2 + 2v^2\hat{s}}{\left( \hat{s} - m_{G'}^2 \right)^2 + m_{G'}^2 \Gamma_{G'}^2} \right). \tag{17}
\]

As seen from (17) in dependence on the values $\hat{s}$, $m_{G'}^2$ and $v$, the $G'$ boson can give a contribution to the forward-backward asymmetry $A_{FB}^{pp}$ in $p\bar{p}$ collisions, which can take positive values as well as negative ones. Concerning the gluon-gluon fusion, one can see from (13) that this process does not contribute to forward-backward asymmetry of the tree level.

The forward-backward asymmetry of top quarks has been measured at the Tevatron. The latest CDF analysis [19] based on $1.9 fb^{-1}$ integrated luminosity gives
\[
A_{FB}^{pp} = \frac{N_t(\cos \theta > 0) - N_t(\cos \theta < 0)}{N_t(\cos \theta > 0) + N_t(\cos \theta < 0)} = 0.17 \pm 0.07\ (stat) \pm 0.04\ (syst). \tag{18}
\]

Using (11) (or (17)) and the parton densities one can calculate the forward-backward asymmetry $A_{FB}^{pp}$ in dependence on $m_{G'}$ and $\theta_{G}$. The allowed region in the $m_{G'} - \theta_{G}$ plane
(the undashed region), which is compatible with data (18) within 2σ is shown in Fig.1. The border of the allowed 1σ region is shown by the dashed line. One can see that the 1σ region allowed by $A_{FB}^p$ data (18) is excluded by the cross section data (15). Nevertheless, there is a region in the $m_{G'} - \theta_G$ plane that is compatible with the data (18) and (15) simultaneously within 2σ (the clean region). Comparing the calculated $A_{FB}^{pp}$ asymmetry with the data (18) and accounting for the mass limits (16) from Fig.1 we find that the $G'$-boson with masses

$$m_{G'} > 1.44\, TeV,\ 1.56\, TeV,\ 1.76\, TeV$$

for $\theta_G = 45^\circ, 30^\circ, 20^\circ$ as well as with masses

$$m_{G'} = 1.20 - 1.32\, TeV,\ > 1.39\, TeV,\ > 1.73\, TeV$$

for $\theta_G = 20^\circ, 15^\circ, 10^\circ$ is compatible with data (18) and (15) simultaneously within 2σ. The first value in (19) is close to the known mass limit for the axigluon [12] resulting from the $A_{FB}^{pp}$ data whereas the other values in (19) and (20) are the new mass limits for the $G'$-boson resulting from the data (18) and (15) simultaneously in dependence on the mixing angle $\theta_G$.

In $pp$ collisions at the LHC the $q\bar{q}$ fluxes are essentially smaller than the $gg$ fluxes, and $t\bar{t}$ production is dominated by the contribution from the $gg$ initial state. However, by increasing the $t\bar{t}$ invariant masses this dominance becomes to be less significant and it is reasonable to search for the $G'$-boson through its effect on the $t\bar{t}$ invariant mass distribution. The large number of top pairs expected to be produced at the LHC (8 million pairs for 10 $fb^{-1}$ integrated luminosity) makes a study of such a differential distribution meaningful.

Using the parton cross sections (12), (14) and integrating them with the parton densities [15] over the final $t$ quark rapidity $y$, we have obtained the $t\bar{t}$ invariant mass distribution $d\sigma_s(pp \to t\bar{t})/dM_{t\bar{t}}$, which can be expected at the LHC when taking into account the $G'$-boson contribution. The background distribution $d\sigma_b(pp \to t\bar{t})/dM_{t\bar{t}}$ is obtained analogously but by neglecting the $G'$-boson contribution in (12). The former distribution exceeds the latter one and has the peak from the $G'$-boson defined by the mass $m_{G'}$ and width (10) of the $G'$-boson.

To distinguish the signal and background events we use the significance estimator [20]

$$S = \sqrt{2\left[(N_s + N_b)\ln(1 + N_s/N_b) - N_s\right]},$$

where $N_s$ and $N_b$ are number of signal and background events in the $t\bar{t}$ invariant mass region $m_{G'} \pm \Delta M$. These numbers can be calculated as

$$N_{s,b} = L\sigma_{s,b}(m_{G'}, \Delta M),\quad \sigma_{s,b}(m_{G'}, \Delta M) = \int_{m_{G'}-\Delta M}^{m_{G'}+\Delta M} \frac{d\sigma_{s,b}(pp \to t\bar{t})}{dM_{t\bar{t}}} dM_{t\bar{t}},$$

where $L$ is integrated luminosity and the integration mass region $\pm \Delta M$ is chosen to maximize the significance estimator $S$. Below we take $\Delta M = 1.28 \Gamma_{G'}$, which corresponds to the $3\sigma$ width in the case of a Gaussian distribution.

We have calculated and analysed the integrated luminosity which is necessary for the evidence of $G'$-boson at the LHC. The integrated luminosity at $3\sigma$ significance ($S = 3$) in dependence on $G'$ mass for different $\theta_G$ is shown in Fig.2. From this figure we find that for $\theta_G = 45^\circ, 30^\circ, 20^\circ, 15^\circ$ the $G'$-boson with masses

$$m_{G'} < 6.5\, TeV,\ 7.0\, TeV,\ 7.9\, TeV,\ 9.8\, TeV$$

for $\theta_G = 45^\circ, 30^\circ, 20^\circ, 15^\circ$.
can be evident in $t \bar{t}$ events at the LHC at integrated luminosity $L = 10 \, fb^{-1}$ with $3\sigma$ significance and expected numbers of signal (background) events $N_s(N_b) = 3.2(0.4)$, $3.1(0.3)$, $3.9(0.7)$, $7.0(3.6)$ respectively. The first value in (23) corresponds to the case of the axigluon.

It should be noted that the chiral extension (1) of the usual $SU_c(3)$ color symmetry and its unification with the electroweak symmetry by the group $G_c \times SU_L(2) \times U(1)$ naturally extends the Higgs sector. For giving the masses to the up and down quarks and to the leptons one needs two scalar doublets ($\Phi^{(1,2)}_{a \beta}$ with the SM hypercharges $Y^{SM} = \mp 1$ and VEVs $\langle \Phi^{(b)}_{a \beta} \rangle = \delta_{a \beta} \rho_0/(2\sqrt{3})$ and a colorless doublet $\Phi^{(3)}_a$ with VEV $\langle \Phi^{(3)}_a \rangle = \delta_{a2} \eta_3/\sqrt{2}$, here $a = 1, 2$ is the $SU_L(2)$ index and $\sqrt{\eta_1^2 + \eta_2^2} = \eta_{SM} \approx 250 GeV$ is the SM VEV. The doublets ($\Phi^{(1,2)}_{a \beta}$) break the chiral symmetry (1) but their VEVs $\eta_1, \eta_2$ are insufficient to give the necessary masses (19), (20) to the $G'$-boson and by this reason one needs an additional scalar field $\Phi^{(0)}_{a \beta}$ which does not interact with fermions and has the VEV $\langle \Phi^{(0)}_{a \beta} \rangle = \delta_{a \beta} \eta_0/(2\sqrt{3})$. In this case the $G'$ mass can be given by expression (5) with $\eta = \sqrt{\eta_1^2 + \eta_3^2 + \eta_0^2}$ and from (5), (20) we find that the VEV of the chiral color symmetry breaking $\eta_0$ can be relatively small, $\eta_0 \gtrsim 800 GeV$.

Because of the decomposition $(3_L, 3_R) = 1_{SU_c(3)} + 8_{SU_c(3)}$ the multiplets ($\Phi^{(1,2)}_{a \beta}, \Phi^{(0)}_{a \beta}$) after the chiral color symmetry breaking give rise to the $SU_c(3)$ octets ($\Phi^{(1,2,8)}_{a \beta} = \Phi^{(1,2)}_{ia \beta} (t_i)_{a \beta}, \Phi^{(0,8)}_{a \beta} = \Phi^{(0)}_{ia \beta} (t_i)_{a \beta}$) and to the color singlets ($\Phi^{(1,2,0)}_{a \beta} = \Phi^{(1,2)}_{0a \beta} \delta_{a \beta}/\sqrt{6}, \Phi^{(0,0)}_{a \beta} = \Phi^{(0)}_{0a \beta} \delta_{a \beta}/\sqrt{6}$). The colorless doublets $\Phi^{(1,2)}_{0a \beta}, \Phi^{(3)}_{a \beta}$ form the SM Higgs doublet $\Phi^{(SM)}_a$ with the SM VEV $\eta_{SM}$ and two additional doublets $\Phi'^a_a, \Phi'^a \eta_2$ for the new gauge $G'$-boson predicts the new scalar fields: the colorless doublets $\Phi'_a, \Phi'_a$, two doublets of color octets $\Phi^{(1,2)}_i$, the color octet $\Phi^{(0)}_i$ and the colorless $SU_L(2)$ singlet $\Phi^{(0)}_0 = (\eta_0 + \chi^{(0)}_0 + i \omega^{(0)}_0)/\sqrt{2}$ with the VEV $\eta_0$. It should be noted that scalar octets of the different origin are predicted also in a number of models [21–27]. Since they are colored particles, the scalar color octets due to their interactions with gluons can be produced in $pp$ collisions and the phenomenology of such particles at the LHC is under active discussion now [23–31]. As concerns the field $\Phi^{(0)}_0$ its real part $\chi^{(0)}_0$ after the chiral color symmetry breaking acquires the mass of order of $\eta_0$ whereas the imaginary part $\omega^{(0)}_0$ is still massless in the tree approximation and in the unitary gauge is not ruled out by a gauge transformation. The features of these new fields will be discussed in more details elsewhere.

In conclusion, we summarize the results found in this work.

The gauge model with the chiral color symmetry of quarks as a possible extension of the Standard Model is considered, and possible effects of the color $G'$-boson octet predicted by this symmetry at the Tevatron and LHC energies are investigated. The hadronic width of the $G'$-boson and the $G'$-boson contributions to the cross section $\sigma_{t\bar{t}}$ and to the forward-backward asymmetry $A^{FB}_{t\bar{t}}$ of $t\bar{t}$ production at the Tevatron are calculated and analysed in dependence on two free parameters of the model, the mixing angle $\theta_G$ and $G'$ mass $m_{G'}$. The allowed region in the $m_{G'} - \theta_G$ plane is found from the Tevatron data on $\sigma_{t\bar{t}}$ and $A^{FB}_{t\bar{t}}$. The mass limits for the $G'$-boson are shown to be stronger than those for the axigluon due to the specific dependence of the $G'$-boson coupling constants on $\theta_G$. A possible effect of the $G'$-boson on the $t\bar{t}$-pair production at the LHC is discussed and the mass limits providing for the $G'$-boson evidence at the LHC with $3\sigma$ significance at the integrated luminosity $L = 10 \, fb^{-1}$ are estimated in dependence on $\theta_G$. 
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Figure captions

Fig. 1. The $m_{G'} - \theta_G$ regions compatible within 2σ with CDF data on $\sigma_{t\bar{t}}$ (the unshaded region) and on $A_{FB}^{p\bar{p}}$ (the undashed region). The dashed lines denote the corresponding 1σ regions.

Fig. 2. The integrated luminosity $L$ needed for 3σ evidence of $G'$-boson at the LHC in dependence on the $G'$ mass for different $\theta_G$. The horizontal dashed line denotes $L = 10 \, fb^{-1}$. 
Figure 1:
$\sqrt{s} = 14$ TeV

Figure 2:

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Fig. 2