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

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Contents

1.Introduction

The search for a new physics beyond the Standard Model (SM) is now one of the aims of the high energy physics. One of the simplest extentions of the SM can be based on the idea of the originally chiral character of $SU_c(3)$ color symmstry of quarks. i.e on the gauge group of the chiral color symmetry

$$\begin{aligned} G_c \;&=\; SU_L(3)\times SU_R(3) \to SU_c(3), \\ & g_L\,, \qquad\quad g_R \quad \to \quad g_{st}, \end{aligned}$$

which is assumed to be valid at high energies and is broken to usual QCD $SU_c(3)$ at low energy scale.

1.Introduction

New gauge particle:

$$G_c \;\Rightarrow\; \begin{cases} \text{axigluon } G^A \;\text{ for }\; g_L = g_R, & [1-4], \\ G' - \text{boson } \;\text{ for }\; g_L \neq g_R, & [5,6], \end{cases}$$

[1]J. C. Pati, A. Salam, Phys. Lett. **B58**, 333–337 (1975),
[2]L. J. Hall, A. E. Nelson,Phys. Lett. **B153**, 430 (1985),
[3]P. H. Frampton, S. L. Glashow, Phys. Rev. Lett. **58**, 2168 (1987),
[4]P. H. Frampton, S. L. Glashow, Phys. Lett. **B190**, 157 (1987),
[5]F. Cuypers, Z. Phys. **C48**, 639–646 (1990),
[6]M. V. Martynov, A. D. Smirnov, Mod. Phys. Lett. **A24**, 1897–1905 (2009).

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

1.Introduction

The current CDF data on cross section $\sigma_{t\bar{t}}$ [7] and forward-backward asymmetry $A_{\rm FB}^{p\bar{p}}$ [8] of the $t\bar{t}$ production at the Tevatron are

$$\sigma_{t\bar{t}} = 7.5 \pm 0.31(stat) \pm 0.34(syst) \pm 0.15(lumi) pb\, (= 7.5 \pm 0.48\, pb),$$
$$A_{\rm FB}^{p\bar{p}} = 0.193 \pm 0.065\ ({\rm stat}) \pm 0.024\ ({\rm sys})\, (= 0.193 \pm 0.069), \quad (?!)$$

[7]CDF Collaboration, Public Note 9913 (2009),
[8]CDF Collaboration, CDF/ANAL/TOP/PUBLIC/9724 (2009).

The SM predictions for $\sigma_{t\bar{t}}$ [9] and $A_{\rm FB}^{p\bar{p}}$ [10] are

$$\sigma_{t\bar{t}}^{SM} = 7.35\ {}^{+0.38}_{-0.80}\ ({\rm scale})\ {}^{+0.49}_{-0.34}\ ({\rm PDFs})[{\rm CTEQ6.5}]\,{\rm pb} \div$$
$$7.93\ {}^{+0.34}_{-0.56}\ ({\rm scale})\ {}^{+0.24}_{-0.20}\ ({\rm PDFs})[{\rm MRST2006nnlo}]\,{\rm pb},$$
$$A_{\rm FB}^{SM}(p\bar{p} \to t\bar{t}) = 0.051(6), \quad (?!)$$

[9]M. Cacciari, S. Frixione, M. L. Mangano, P. Nason, G. Ridolfi, JHEP **09**, 127 (2008),
[10]O. Antunano, J. H. Kuhn, G. Rodrigo, Phys. Rev. **D77**, 014003 (2008).

CDF data $\to$ $m_{G'} \sim\ ?$

2. The chiral color symmetry model and G'-boson

$$G_c \ = \ SU_L(3)\times SU_R(3) \to SU_c(3),$$
$$g_L\,, \qquad g_R \quad \to \quad g_{st},$$

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.

2. The chiral color symmetry model and G'-boson

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^L_μ and G^R_μ as

$$G_\mu = s_G\, G^L_\mu + c_G\, G^R_\mu,$$
$$G'_\mu = c_G\, G^L_\mu - s_G\, G^R_\mu,$$

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, $G_\mu = G^i_\mu t_i$, $G'_\mu = G'^i_\mu t_i$, t_i, $i = 1, 2, ..., 8$, are the generators of $SU_c(3)$ group.

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

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.

2. The chiral color symmetry model and G'-boson

The interaction of the G'-boson with quarks can be written as

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

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

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

So, the gauge chiral color symmetry model has two free parameters, G'-boson mass $m_{G'}$ and the $G^L - G^R$ mixing angle θ_G, $tg\,\theta_G = g_R/g_L$.

3. Cross sections and the forward-backward asymmetry of the partonic processes $q\bar{q}, gg \to Q\bar{Q}$

$$q\bar{q} \overset{g,G'}{\to} Q\bar{Q}$$

The differential cross section of the process $q\bar{q} \to Q\bar{Q}$ with account of the G'-boson and gluon contributions in tree approximation has the form

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

where $f^{(\pm)} = (1+\beta^2c^2 \pm 4m_Q^2/\hat{s})$, $c = \cos\hat{\theta}$, $\hat{\theta}$ 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, $\beta = \sqrt{1-4m_Q^2/\hat{s}}$, M_{chc} is the mass scale of the chiral color symmetry breaking and μ is a typical scale of the process.

3. Cross sections and FB asymmetry of the partonic processes ...

The total cross section has the form

$$\sigma(q\bar{q} \stackrel{g,G'}{\to} Q\bar{Q}) \; = \; \frac{4\pi\beta}{27\hat{s}}\Big\{\alpha_s^2(\mu)\,(3-\beta^2) -$$
$$-\frac{\alpha_s(\mu)\,\alpha_s(M_{chc})\,2\hat{s}m_{G'}^2 v^2(3-\beta^2)}{(\hat{s}-m_{G'}^2)^2+\Gamma_{G'}^2 m_{G'}^2} +$$
$$+\frac{\alpha_s^2(M_{chc})\,\hat{s}^2\big[\,(v^4+2v^2)(3-\beta^2)+v^2a^2(3+\beta^2)+2a^4\beta^2\,\big]}{(\hat{s}-m_{G'}^2)^2+\Gamma_{G'}^2 m_{G'}^2}\Big\}.$$

3. Cross sections and FB asymmetry of the partonic processes ...

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

$$\Gamma_{G'} = \sum_{Q} \Gamma(G' \to Q\overline{Q})$$

where

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

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

3. Cross sections and FB asymmetry of the partonic processes ...

$$gg \to Q\bar{Q}$$

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

The differential and total partonic cross sections of this process in tree approximation of the SM are well known and have the form

$$\frac{d\sigma_0^{SM}(gg \to Q\bar{Q})}{d\cos\hat{\theta}} =$$

$$= \alpha_s^2(\mu)\,\frac{\pi\beta}{6\hat{s}}\left(\frac{1}{1-\beta^2c^2} - \frac{9}{16}\right)\left(1+\beta^2c^2+2(1-\beta^2) - \frac{2(1-\beta^2)^2}{1-\beta^2c^2}\right),$$

$$\sigma_0^{SM}(gg \to Q\bar{Q}) =$$

$$= \frac{\pi\alpha_s^2(\mu)}{48\hat{s}}\left[\left(\beta^4 - 18\beta^2 + 33\right)\log\left(\frac{1+\beta}{1-\beta}\right) + \beta\left(31\beta^2 - 59\right)\right].$$

3. Cross sections and FB asymmetry of the partonic processes ...

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 $q\bar{q} \to Q\bar{Q}$ partonic cross section

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

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

4. Cross section and the forward-backward asymmetry of the $t\bar{t}$-pair production at the Tevatron

We have calculated the cross section

$$\sigma(p\bar{p} \to t\bar{t})$$

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 with account of the G'-boson contribution, the total SM parton cross section of the gluon fusion $gg \to Q\bar{Q}$ and the parton densities AL'03 [11] (NLO, fixed-flavor-number, $Q^2 = m_t^2$) with the appropriate K-factor $K = 1.24$ [12].

Here and below we beleive $\mu^2 = Q^2$, $M_{chc} = m_{G'}$.

[11]S. Alekhin, Phys.Rev. **D67**, 014002 (2003),
[12]J. M. Campbell, J. W. Huston, W. J. Stirling, Rept. Prog. Phys. **70**, 89 (2007).

4. Cross section and FB asymmetry of $t\bar{t}$-production at the Tevatron

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

$$A_{\rm FB}^{p\bar{p}} = A_{\rm FB}^{G'} + A_{\rm FB}^{SM},$$

where $A_{\rm FB}^{G'}$ is the corresponding G' boson contribution which has been calculated using the partonic forward-backward difference $\Delta_{FB}(q\bar{q} \to Q\bar{Q})$ and $A_{\rm FB}^{SM}$ is the SM prediction for $A_{\rm FB}^{p\bar{p}}$ for which we have used the value $A_{\rm FB}^{SM} = 0.051$ of ref. [10].

[10] O. Antunano, J. H. Kuhn, G. Rodrigo, Phys. Rev. **D77**, 014003 (2008),

We have analysed the cross section $\sigma(p\bar{p} \to t\bar{t})$ and the forward-backward asymmetry $A_{\rm FB}^{p\bar{p}}$ in dependence on two free parameters of the model, the mixing angle θ_G and G' mass $m_{G'}$, in comparision with the Tevatron data on $\sigma_{t\bar{t}}$ and $A_{\rm FB}^{p\bar{p}}$.

4. Cross section and FB asymmetry of $t\bar{t}$-production at the Tevatron

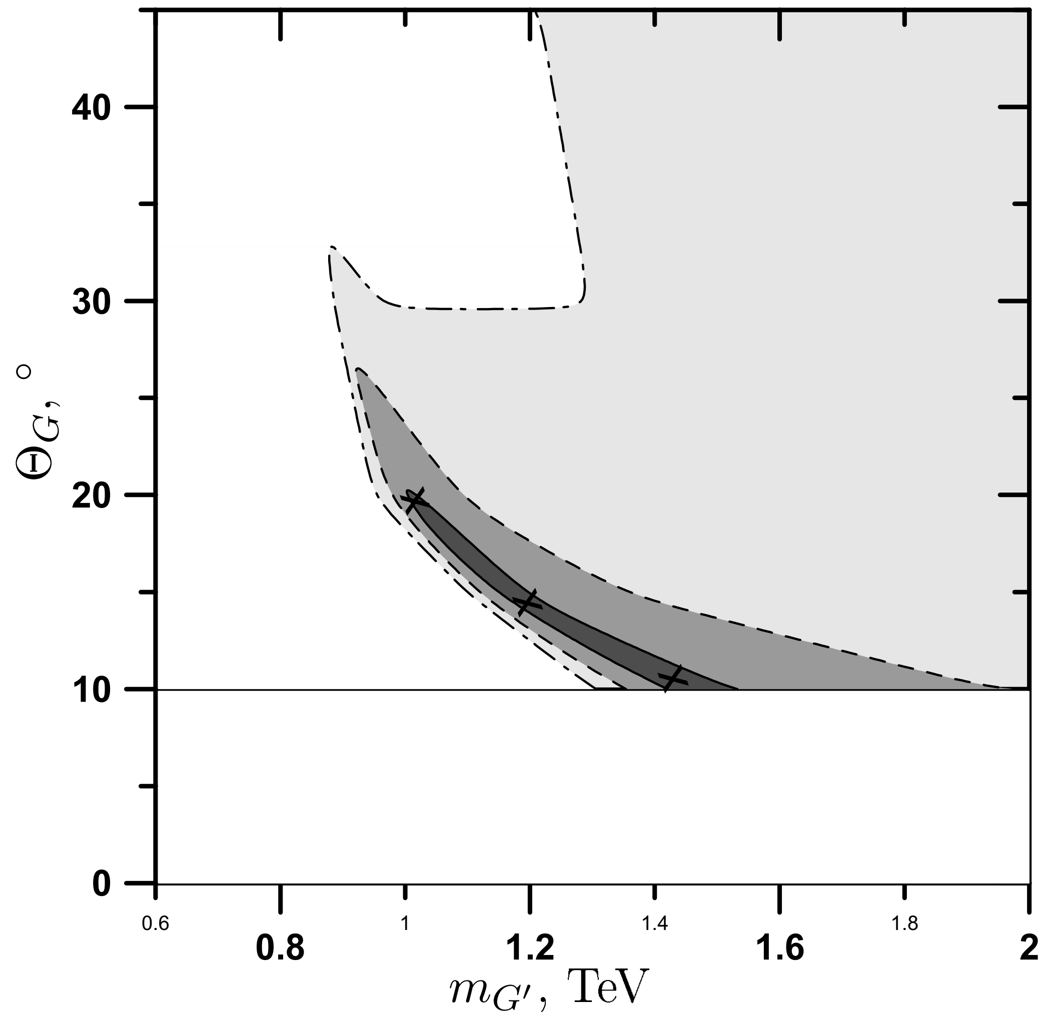

Figure 1: The $m_{G'} - \theta_G$ regions consistent with CDF data on cross section $\sigma_{t\bar{t}}$ and forward-backward asymmetry $A_{\rm FB}^{p\bar{p}}$ in $t\bar{t}$ production within 1σ (dark region), 2σ (grey region) and 3σ (light-grey region).

4. Cross section and FB asymmetry of $t\bar{t}$-production at the Tevatron

As seen from the Fig.1 for

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

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

For example, for the masses

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

with the appropriate values of θ_G we obtain for $\sigma_{t\bar{t}}$, $A_{\rm FB}^{p\bar{p}}$ the values

$$\begin{aligned} a)\; \sigma_{t\bar{t}} &= 7.98\, pb, \qquad A_{\rm FB}^{p\bar{p}} = 0.158, \\ b)\; \sigma_{t\bar{t}} &= 7.61\, pb, \qquad A_{\rm FB}^{p\bar{p}} = 0.154, \\ c)\; \sigma_{t\bar{t}} &= 7.57\, pb, \qquad A_{\rm FB}^{p\bar{p}} = 0.141, \end{aligned}$$

which are consistent with the CDF data on $\sigma(p\bar{p} \to t\bar{t})$ and $A_{\rm FB}^{p\bar{p}}$

$$\begin{aligned} \sigma_{t\bar{t}} &= \; = 7.5 \pm 0.48\, pb, \\ A_{\rm FB}^{p\bar{p}} &= \; = 0.193 \pm 0.069 \end{aligned}$$

within 1σ.

5. 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 $A_{\rm FB}^{p\bar{p}}$ 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 $A_{\rm FB}^{p\bar{p}}$ are shown to be consistent with the Tevatron data on $\sigma_{t\bar{t}}$ and $A_{\rm FB}^{p\bar{p}}$ and the allowed region in the $m_{G'} - \theta_G$ plane is discussed, in particular, it is shown that for

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

there is the region in the $m_{G'} - \theta_G$ plane 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 $A_{\rm FB}^{p\bar{p}}$ and can reduce the difference between the experimental and SM values of the FB asymmetry $A_{\rm FB}^{p\bar{p}}$ in the $t\bar{t}$ production at the Tevatron.

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4. Cross section and FB asymmetry of $t\bar{t}$-production at the Tevatron

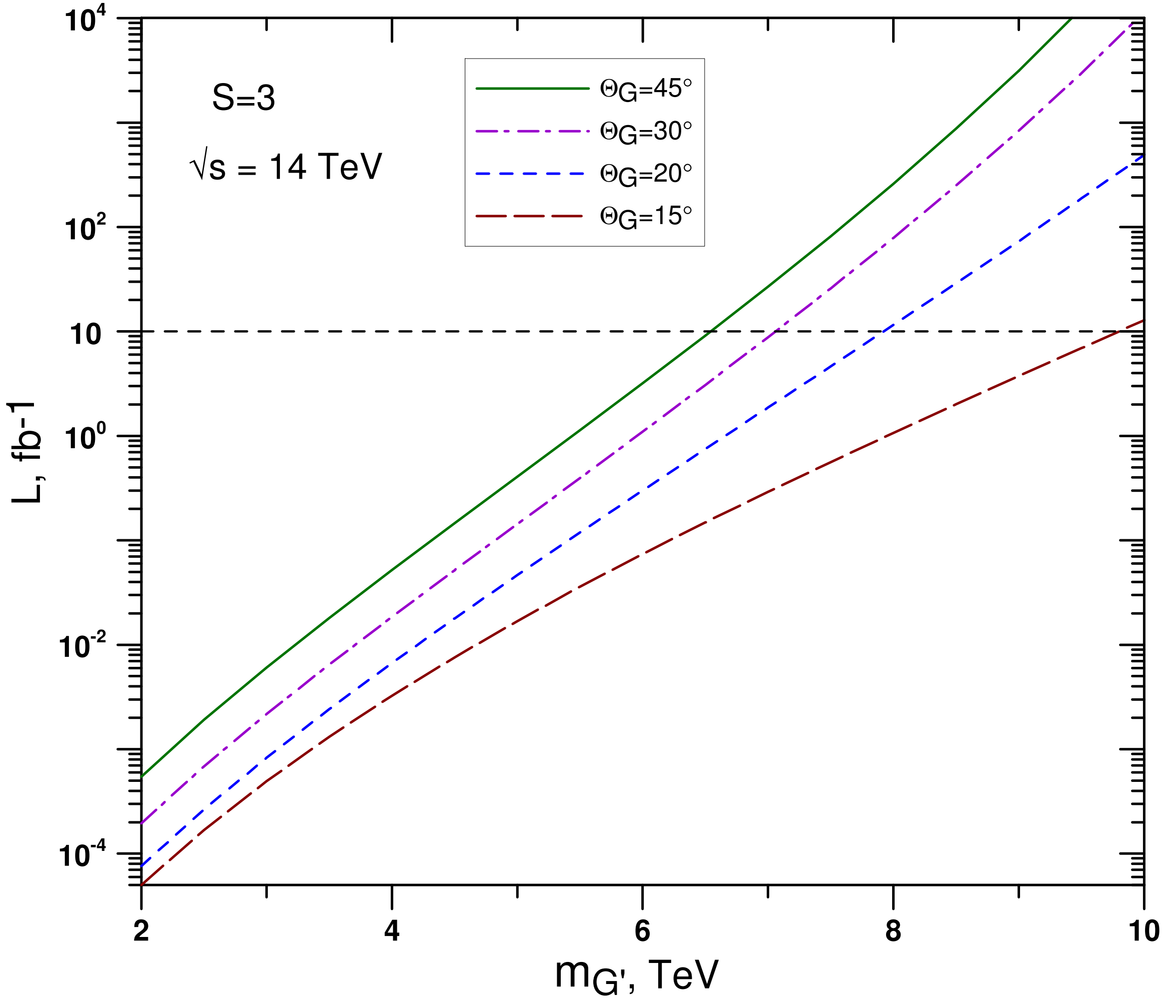

Figure 2: The integrated luminosity L needed for 3σ evidence of G'-boson at the LHC in dependence on the G' mass for different θ_G. The horizontal dashed line denotes $L = 10\ fb^{-1}$.