EPJ Web of Conferences **158**, 02009 (2017) DOI: 10.1051/epjconf/201715802009
QFTHEP 2017

On mass limits for scalar color octet from the LHC data on $t\bar{t}$ invariant mass spectra

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Abstract. The scalar color octet contribution to the resonance $t\bar{t}$-pair production at the LHC is calculated and analyzed with account of the one loop effective two gluon vertex. From current LHC data on total cross section and invariant mass spectrum of $t\bar{t}$ production we found the $(m_{F_2} - \sin\beta)$-plane exclusion regions.

1 Introduction

The search for new physics effects beyond the Standard Model (SM) is now one of the goals of the experiments at the LHC. There are many models predicting new physics effects. The most interesting of them look the models predicting new effects due to enlarging the symmetry of the SM because the search for such effects could help us to find the next symmetry in yet unknown hierarchy of the symmetries which possibly unify the known in the SM electroweak and strong interactions of quarks and leptons.

Extended color symmetries are attractive variants of the new physics. One of such variant of physics beyond the SM can be induced by the possible four color symmetry between quarks and leptons of Pati-Salam type [1]. The four color quark-lepton symmetry can be unified with the electroweak $SU_L(2)\times U(1)$ symmetry of the SM in the minimal way by the group

$$G_{MQLS} = SU_V(4) \times SU_L(2) \times U_R(1), \tag{1}$$

where the first factor is the vector-like group of the four color quark-lepton symmetry the second one is the usual SM electroweak symmetry group for the left-handed fermions and the third one is the corresponding hypercharge factor for the right-handed fermions (the minimal quark-lepton symmetry model – MQLS-model [2, 3]).

As a result of the Higgs mechanism of splitting the masses of quarks and leptons the four color symmetry in its minimal realization on the gauge group (1) predicts in addition to the SM Higgs doublet $\Phi^{(SM)}$ the existence of the new scalar $SU_L(2)$-doublets

$$\begin{pmatrix} \Phi_1' \\ \Phi_2' \end{pmatrix};\begin{pmatrix} S_{1\alpha}^{(+)} \\ S_{2\alpha}^{(+)} \end{pmatrix};\begin{pmatrix} S_{1\alpha}^{(-)} \\ S_{2\alpha}^{(-)} \end{pmatrix};\begin{pmatrix} F_{1c} \\ F_{2c} \end{pmatrix} \tag{2}$$

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with electric charges

$$Q_{\Phi}^{em}: \quad \begin{pmatrix} 1 \\ 0 \end{pmatrix}; \begin{pmatrix} 5/3 \\ 2/3 \end{pmatrix}; \begin{pmatrix} 1/3 \\ -2/3 \end{pmatrix}; \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

respectively.

The fields (2) belong to the (1.2.1)+(15.2.1) representation of the group (1), here the fields Φ_1', Φ_2' form an additional colorless scalar doublet, $S_{1\alpha}^{(\pm)}$, $S_{2\alpha}^{(\pm)}, \alpha = 1, 2, 3$ are the color triplets forming two scalar leptoquark doublets and the fields F_{1c}, $F_{2c}, c = 1, 2...8$ form the scalar doublet of the color octets (the scalar gluon doublet).

Because of their Higgs origin the coupling constants of the doublets (2) with the fermions occur to be proportional to the ratios m_f/η of the fermion masses m_f to the SM VEV η and are small for u-, d-, s-quarks are more significant for c-, b-quarks and are especially significant for t-quark ($m_t/\eta \sim 0.7$). As a result the scalar doublets (2) can manifest themselves more probably in the processes with t-quarks. In particular the scalar octet F_2 could manifest itself as a resonance in $t\bar{t}$-pair production at the LHC. It should be noted that the coupling constants of the doublets (2) with t-quark are known (up to the mixing parameters), which gives the possibility to estimate quantitatively the possible effects from these particles in dependence on their masses. The pair production of the scalar octets in pp-collisions at the LHC has been discussed in Refs [4–16].

In the present paper we calculate the contribution of the scalar octet to the cross section of the resonance $t\bar{t}$-pair production in pp-collisions and analyse the possibility of manifestation of the scalar gluon F_2 of the MQLS-model as the corresponding resonance peak in $t\bar{t}$-pair production at the LHC.

2 MQLS-model scalar color octets — scalar gluons

The details of interactions of the scalar doublets (2) with quarks and leptons can be found in [17, 18]. In particular the interaction of the scalar gluon F_2 with up- and down-quarks in the MQLS-model has the chiral form and can be written as

$$L_{F_2 u_i u_j} = \bar{u}_{i\alpha}\Big[(h_{1F_2}^L)_{ij} P_L\Big](t_c)_{\alpha\beta} u_{j\beta} F_{2c} + \text{h.c.}, \quad (3)$$

$$L_{F_2 d_i d_j} = \bar{d}_{i\alpha}\Big[(h_{2F_2}^R)_{ij} P_R\Big](t_c)_{\alpha\beta} d_{j\beta} F_{2c} + \text{h.c.}, \quad (4)$$

where $t_c, c = 1, 2 \dots 8$ are the generators of the $SU_c(3)$ group, $P_{L,R} = (1 \pm \gamma_5)/2$ are the left and right projection operators and $(h_{1F_2}^L)_{ij}, (h_{2F_2}^R)_{ij}$ are the Yukawa coupling constants, $i, j = 1, 2, 3$ are the generation indices. As a result of the Higgs mechanism of generating the quark and lepton masses the Yukawa coupling constants $(h_{1F_2}^L)_{ij}, (h_{2F_2}^R)_{ij}$ are defined by the expressions

$$(h_{1F_2}^L)_{ij} = -\sqrt{3}\frac{1}{\eta \sin\beta}\Big[m_{u_i}(\delta)_{ij} - (K_1^R)_{ik} m_{\nu_k} (\overset{+}{K}{}_1^L)_{kj}\Big], \quad (5)$$

$$(h_{2F_2}^R)_{ij} = -\sqrt{3}\frac{1}{\eta \sin\beta}\Big[m_{d_i}(\delta)_{ij} - (K_2^L)_{ik} m_{l_k} (\overset{+}{K}{}_2^R)_{kj}\Big], \quad (6)$$

where m_{u_i}, m_{d_i} and m_{ν_k}, m_{l_k} are the masses of up- and down-quarks and of neutrinos and charged leptons, $K_1^{L,R}, K_2^{L,R}$ are the mixing matrices in leptoquark currents which are specific for the model with the four color quark-lepton symmetry and β is a mixing angle of two colorless scalar doublets of MQLS model. Among the coupling constants (5), (6) the largest is the constant $(h^L_{1F_2})_{33}$ which with neglect of the neutrinos masses takes the form

$$(h^L_{1F_2})_{33} = -\sqrt{3}\frac{m_t}{\eta \sin\beta}. \quad (7)$$

The interaction of the scalar gluon F_2 with t-quark can be written as

$$L_{F_2tt} = \bar{t}_\alpha(h^S_{F_2t\bar{t}} + h^P_{F_2t\bar{t}}\gamma_5)(t_c)_{\alpha\beta}t_\beta F_{2c} + \text{h.c.}, \quad (8)$$

where the correspondent scalar and pseudoscalar coupling constants with account of (7) take the form

$$h^S_{F_2t\bar{t}} = h^P_{F_2t\bar{t}} = -\frac{\sqrt{3}}{2}\frac{m_t}{\eta\sin\beta} \approx -0.61/\sin\beta. \quad (9)$$

The coupling constants (9) increase with decreasing $\sin\beta$ so that for $\sin\beta = 1,\ 0.7,\ 0.4$ the perturbation theory parameters take the values $(h^{S,P}_{F_2t\bar{t}})^2/4\pi \approx 0.03,\ 0.06,\ 0.18$ respectively. Below we restrict ourselves by the mixing angle region $0.4 \le \sin\beta \le 1$.

The interactions (3), (4) lead to the decays $F_2 \to u_i\bar{u}_i$, $F_2 \to d_i\bar{d}_i$ and in the case of $m_{F_2} > 2m_t$ the decay $F_2 \to t\bar{t}$ is dominant with the width [17, 18]

$$\Gamma(F_2 \to t\bar{t}) = m_{F_2}\frac{3}{32\pi}\left(\frac{m_t}{\eta}\right)^2\left(1 - 2\frac{m_t^2}{m_{F_2}^2}\right)\sqrt{1 - 4\frac{m_t^2}{m_{F_2}^2}}\frac{1}{\sin^2\beta}. \quad (10)$$

For the masses $m_{F_2} = 400 - 2000$ GeV the width (10) is of about $(2 - 30)/\sin^2\beta$ GeV and $\Gamma_{F_2}/m_{F_2} = (0.5 - 1.5)\%/\sin^2\beta$.

As seen from the expressions (5), (6) the coupling constants of the interaction of the scalar gluon F_2 with u- and d- quarks are of order of $m_u/\eta \sim m_d/\eta \sim 10^{-5}$ and the interactions of these quarks as the initial partons with the scalar gluon F_2 are negligibly small. On the other hand the Lagrangian (8), (9) can induce through the loop contribution of t-quark the more significant effective interaction of two initial gluons with the scalar gluon F_2, which should be taken into account. The analogous effective two gluon interaction is induced also with the colorless scalar Φ'_2.

3 Resonance contribution of scalar color octet to $t\bar{t}$ production

The calculation of the effective two gluon vertex of interaction with the scalar octet is like to that with the colorless scalar and we perform below these calculations simultaneously. For this purpose we write the flavour diagonal interactions of scalar octet and of the scalar color singlet with quarks in the model independent form as

$$L_{\Phi q\bar{q}} = \bar{q}_\alpha(h^S_{\Phi q\bar{q}} + h^P_{\Phi q\bar{q}}\gamma_5)\Phi_{\alpha\beta}q_\beta + \text{h.c.}, \quad (11)$$

where $\Phi_{\alpha\beta} = \Phi_0\delta_{\alpha\beta}$ for the colorless scalar particle Φ_0 and $\Phi_{\alpha\beta} = \Phi_{8c}(t_c)_{\alpha\beta}$ for the scalar octet Φ_8, t_c are the generators of the $SU_c(3)$ group $(c = 1, 2...8)$, $h^S_{\Phi q\bar{q}}$ and $h^P_{\Phi q\bar{q}}$ are the corresponding scalar and pseudoscalar coupling constants. For the MQLS-model the scalars Φ_8 and Φ_0 correspond to F_2 and Φ'_2 respectively.

The effective vertex $\Gamma^{(q)\mu\nu}_{ab\Phi}(p, k_1, k_2)$ of interaction of two gluons with scalar field $\Phi = \Phi_0, \Phi_{8c}$ induced by the Lagrangian (11) with account of one loop contribution of quark q is described by the diagrams in the Fig. 1

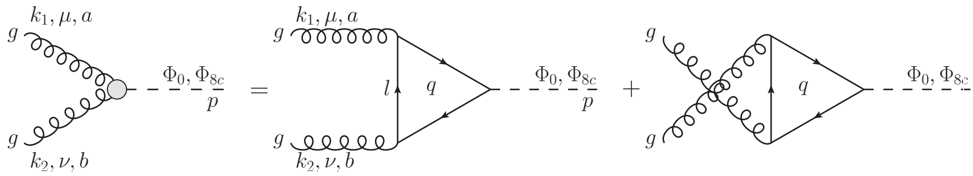

Figure 1. The effective vertex $\Gamma^{(q)\mu\nu}_{ab\Phi}(p, k_1, k_2)$ induced by one loop contribution of quark q for $\Phi = \Phi_0, \Phi_{8c}$.

With account of the contributions of all the quarks the resulted effective vertex $\Gamma^{\mu\nu}_{ab\Phi}(p, k_1, k_2)$ in the case of real gluons ($k_1^2 = 0$, $k_2^2 = 0$, $\hat{s} = p^2 = 2(k_1 k_2)$) can be parametrized as [19]:

$$\Gamma^{\mu\nu}_{ab\Phi}(p, k_1, k_2) = \sum_q \Gamma^{(q)\mu\nu}_{ab\Phi}(p, k_1, k_2) =$$
$$= -C_{ab\Phi} \frac{\alpha_s \sqrt{\hat{s}}}{\pi} \left[\left(g^{\mu\nu} - \frac{2k_1^\nu k_2^\mu}{\hat{s}} \right) F^S_\Phi(\hat{s}) - 2i\varepsilon^{\mu\nu\rho\sigma} \frac{k_{1\rho} k_{2\sigma}}{\hat{s}} F^P_\Phi(\hat{s}) + \frac{2k_1^\mu k_2^\nu}{\hat{s}} G^S_\Phi(\hat{s}) \right] \tag{12}$$

by the form factors

$$F^{S,P}_\Phi(\hat{s}) = \sum_q h^{S,P}_{\Phi q\bar{q}} \tilde{F}^{S,P}(\hat{s}, m_q^2), \qquad G^S_\Phi(\hat{s}) = \sum_q h^S_{\Phi q\bar{q}} \tilde{G}^S(\hat{s}, m_q^2), \tag{13}$$

where $C_{ab\Phi}$ is the color factor with

$$C_{ab\Phi_0} = \delta_{ab}/2 \equiv C_{ab}, \quad C_{ab\Phi_{8c}} = d_{abc}/4 \equiv C_{abc} \tag{14}$$

for the color singlet Φ_0 and for the color octet Φ_8.

For the form factors $\tilde{F}^{S,P}(\hat{s}, m_q^2)$, $\tilde{G}^S(\hat{s}, m_q^2)$ we have found the expressions

$$\tilde{F}^S(\hat{s}, m_q^2) = \frac{m_q}{\sqrt{\hat{s}}} \left[(\hat{s} - 4m_q^2)\, C_0(0, 0, \hat{s}, m_q^2, m_q^2, m_q^2) - 2 \right] \equiv \tilde{F}^S(\rho_q), \tag{15}$$

$$\tilde{F}^P(\hat{s}, m_q^2) = m_q \sqrt{\hat{s}}\; C_0(0, 0, \hat{s}, m_q^2, m_q^2, m_q^2) \equiv \tilde{F}^P(\rho_q), \tag{16}$$

$$\tilde{G}^S(\hat{s}, m_q^2) =$$
$$= \frac{m_q}{\sqrt{\hat{s}}} \left[(\hat{s} + 4m_q^2)\, C_0(0, 0, \hat{s}, m_q^2, m_q^2, m_q^2) + 4B_0(\hat{s}, m_q^2, m_q^2) - \frac{4A_0(m_q^2)}{m_q^2} \right] \equiv \tilde{G}^S(\rho_q), \tag{17}$$

where A_0, B_0, C_0 are the Passarino–Veltman (PV) scalar integrals [20, 21], with account of the explicit form of these integrals the form factors (15)–(17) depend only on the variable $\rho_q = \sqrt{\hat{s}}/m_q$. The form factors (15)–(17) account the one loop contribution of quark q in the model independent way, the specific features of the model are presented by the coupling constants $h^{S,P}_{\Phi q\bar{q}}$ in the form factors (13). Due to the gauge invariance the longitudinal component of the vertex (12) parametrized by the form factor $G^S_\Phi(\hat{s})$ do not enter to the observed variables.

We have calculated the cross section of the process $gg \to Q\bar{Q}$ of $Q\bar{Q}$ pair production in gluon fusion in QCD LO with account also of the effective vertex (12) in Ref. [19]. The diagrams of this process are shown in the Fig. 2.

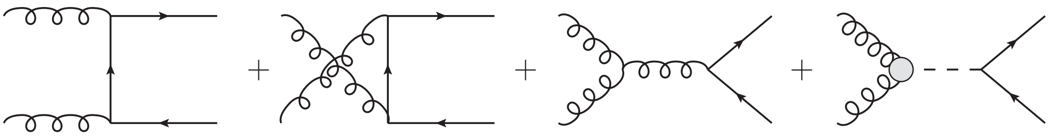

Figure 2. Diagrams of the process $gg \to Q\bar{Q}$ in the SM LO and with account of the effective vertex $\Gamma^{\mu\nu}_{ab\Phi}(p, k_1, k_2)$.

The total cross section of the process $gg \to Q\bar{Q}$ can be written as the sum

$$\sigma_0(gg{\to}Q\bar{Q}, \mu) = \sigma_0^{\rm SM}(gg{\to}Q\bar{Q}, \mu) + \Delta\sigma^{\Phi}(gg{\to}Q\bar{Q}, \mu) \tag{18}$$

of the well known QCD LO cross section

$$\sigma_0^{\rm SM}(gg{\to}Q\bar{Q}, \mu) \;=\; \frac{\alpha_s^2(\mu)\,\pi}{48\hat{s}}\left[\left(v^4 - 18v^2 + 33\right)\log\frac{1+v}{1-v} + v(31v^2 - 59)\right], \tag{19}$$

where $v = \sqrt{1 - 4m_Q^2/\hat{s}}$ is the velocity of quark Q in the center of mass frame, $\hat{s}$ is the squared energy in the center of momentum frame of the gluons, μ is a typical mass scale of the process, and the contribution $\Delta\sigma^{\Phi}(gg{\to}Q\bar{Q}, \mu)$ to this process from the scalar Φ.

For the contribution $\Delta\sigma^{\Phi}(gg{\to}Q\bar{Q}, \mu)$ we have found the expression

$$\Delta\sigma^{\Phi}(gg{\to}Q\bar{Q}, \mu) = \tag{20}$$

$$= \frac{\tilde{C}^{(1)}_{\Phi}}{64}\,\frac{\alpha_s^2(\mu) m_Q}{\pi\sqrt{\hat{s}}}\,\frac{{\rm Re}\left[\left(\hat{s} - m_\Phi^2 - i m_\Phi\Gamma_\Phi\right)\left(-h^{S^*}_{\Phi Q\bar{Q}} v^2 F^S_\Phi(\hat{s}) - h^{P^*}_{\Phi Q\bar{Q}} F^P_\Phi(\hat{s})\right)\right]}{(\hat{s} - m_\Phi^2)^2 + m_\Phi^2\Gamma_\Phi^2}\log\frac{1{+}v}{1{-}v} +$$

$$+ \frac{\tilde{C}^{(2)}_{\Phi}}{1024}\,\frac{\alpha_s^2(\mu) v\hat{s}}{\pi^3}\,\frac{\left|h^S_{\Phi Q\bar{Q}}\right|^2 v^2 + \left|h^P_{\Phi Q\bar{Q}}\right|^2}{(\hat{s} - m_\Phi^2)^2 + m_\Phi^2\Gamma_\Phi^2}\left(|F^S_\Phi(\hat{s})|^2 + |F^P_\Phi(\hat{s})|^2\right) \tag{21}$$

where the form factors $F^{S,P}_\Phi(\hat{s})$ are given by the expressions (13),(15),(16) and $\tilde{C}^{(1)}_\Phi$, $\tilde{C}^{(2)}_\Phi$ are the color factors with

$$\tilde{C}^{(1)}_{\Phi_0} = C_{ab}C_{ab} = 2, \qquad \tilde{C}^{(2)}_{\Phi_0} = C_{ab}C_{ab}\, n_c = 6, \tag{22}$$

$$\tilde{C}^{(1)}_{\Phi_8} = C_{abc}C_{abc} = 5/6, \qquad \tilde{C}^{(2)}_{\Phi_8} = C_{abc}C_{abc}/2 = 5/12 \tag{23}$$

for the color singlet Φ_0 and for the color octet Φ_8 respectively, n_c is the number of colors of the $SU_c(n_c)$ group, the numerical values in (22), (23) correspond to the $SU_c(3)$ group.

The total cross section $\sigma_{tot}(pp \to t\bar{t})$ of the $t\bar{t}$ production in *pp*-collisions with account of the contribution of scalar octet F_2 can be written as the sum

$$\sigma_{tot}(pp \to t\bar{t}) = \sigma^{\rm SM}(pp{\to}t\bar{t}) + \Delta\sigma^{F_2}(pp{\to}t\bar{t}) \tag{24}$$

of the SM cross section $\sigma^{\rm SM}(pp{\to}t\bar{t})$ and the contribution $\Delta\sigma^{F_2}(pp{\to}t\bar{t})$ induced by scalar gluon F_2 via effective vertex (12)–(16).

 DOI: 10.1051/epjconf/201715802009

Table 1. Summary of the most precise ATLAS and CMS measurements of the total $t\bar{t}$ cross sections at 7, 8 and 13 TeV.

Exp.	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]	$\sigma^{\rm tot}(t\bar{t})$ [pb]	Ref.
ATLAS	7	4.6	182.9 ± 3.1 (stat) ± 4.2 (sys) ± 3.6 (lumi) ± 3.3 (bm)	[23]
	8	20.3	242.4 ± 1.7 (stat) ± 5.5 (sys) ± 7.5 (lumi) ± 4.2 (bm)	[23]
	13	3.2	818 ± 8 (stat) ± 27 (sys) ± 19 (lumi) ± 12 (bm)	[24]
CMS	7	5.0	173.6 ± 2.1 (stat)$^{+4.5}_{-4.0}$ (sys) ± 3.8 (lumi)	[25]
	8	19.7	244.9 ± 1.4 (stat)$^{+6.3}_{-5.5}$ (sys) ± 6.4 (lumi)	[25]
	13	2.3	835 ± 3 (stat) ± 23 (sys) ± 23 (lumi)	[26]

We obtain the total cross section from partonic cross sections (19), (21) by integrating the expression

$$\frac{d\sigma_{tot}(pp\to t\bar{t})}{dx_1 dx_2} = \sum_k F_k^{p\bar{p}}(x_1,x_2,\mu_f)K(s)\sigma_0^{SM}(\bar{q}_k q_k\to t\bar{t},\mu) + \\ +F_g^{pp}(x_1,x_2,\mu_f)K(s)\sigma_0^{SM}(gg\to t\bar{t},\mu) + F_g^{pp}(x_1,x_2,\mu_f)\Delta\sigma^{F_2}(gg\to t\bar{t},\mu) \quad (25)$$

over the variables $0 \le x_1, x_2 \le 1$, where x_1, x_2 are partonic parts of the momenta of protons, $\hat{s} = x_1 x_2 s,\ s = (P_1+P_2)^2,\ P_1, P_2$ are the momenta of the colliding protons, $\sigma_0^{SM}(\bar{q}_k q_k\to t\bar{t},\mu)$ is the well known SM LO cross section, $K(s)$ is the K-factor, which we use for the better agreement of the SM LO predictions of the cross section of $t\bar{t}$-pair production with the corresponding aNNNLO SM predictions [22]. The partonic functions in (25) are given as

$$F_k^{pp}(x_1,x_2,\mu_f) = f^p_{q_k}(x_1,\mu_f)f^p_{\bar{q}_k}(x_2,\mu_f) + f^p_{\bar{q}_k}(x_1,\mu_f)f^p_{q_k}(x_2,\mu_f), \quad (26)$$

$$F_g^{pp}(x_1,x_2,\mu_f) = f^p_g(x_1,\mu_f)f^p_g(x_2,\mu_f), \quad (27)$$

where $f^p_{q_k}(x,\mu_f),\ f^p_{\bar{q}_k}(x,\mu_f),\ f^p_g(x,\mu_f)$ are the parton distribution functions of quark q_k of flavor k, antiquark $\bar{q}_k$ and gluons in the proton, μ_f is the factorization scale.

For numerical calculations we use the analytical expressions for scalar Passarino-Veltman integrals $A_0,\ B_0,\ C_0$ from the Ref. [21] and we also perform the cross check with using numerical package LoopTools/FF [27, 28].

For calculations we use the parton distribution functions MMHT 2014 [29] (NNLO, $\mu = \mu_f = m_t$, $m_t = 173.21$ GeV), with the values of K-factors $K(s) = 1.6687,\ 1.6752,\ 1.6833$ for energies $\sqrt{s} = 7, 8, 13$ TeV respectively, in this case the cross section $\sigma^{\rm SM}(pp\to t\bar{t})$ reproduces well the aNNNLO SM predictions for the cross section of $t\bar{t}$ production [22] Also we perform cross check our partons integrations with use PDFs CT14 and METAv10 in the ManeParse (package for the Wolfram Mathematica for parsing various PDF functions) [30], the difference between these results was about 1%.

We have calculated the contributions $\Delta\sigma^{F_2}(pp\to t\bar{t})$ to the total cross section of the $t\bar{t}$ production from the scalar gluon F_2 defined by the last term in the expression (25) for $\sqrt{s} = 7, 8, 13$ TeV, $m_{F_2} = 400 \div 1000$ GeV and $\sin\beta = 0.4 \div 1$, $\Delta\sigma^{F_2}(pp\to t\bar{t})$ varies from 0.3 to 54.9 pb (depending on $\sqrt{s}, m_{F_2}, \sin\beta$) [19].

From current most precise ATLAS and CMS measurements of the total $t\bar{t}$ cross sections at 7, 8 and 13 TeV (Table 1) we found exclusion area at the $(m_{F_2} - \sin\beta)$-plane, the area is shown in the Fig. 3.

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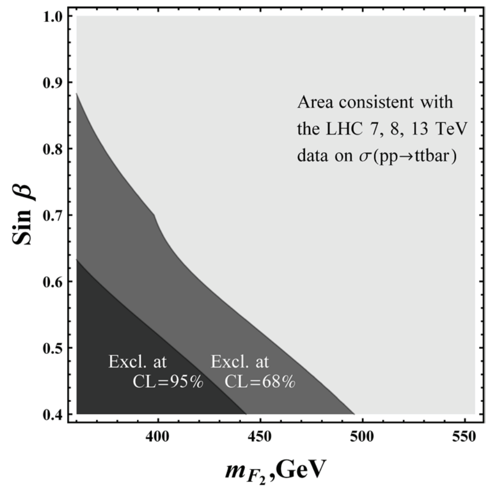

Figure 3. The $(m_{F_2} - \sin\beta)$-plane exclusion regions (at 95% and 68% probability level) resulting from the LHC data on total $t\bar{t}$ cross sections at 7, 8 and 13 TeV [23–26].

Using the known relations between the variables x_1, x_2 and the invariant mass $m_{t\bar{t}}$ of $t\bar{t}$-pair and the rapidity y of the final t-quark

$$m_{t\bar{t}}^2 = x_1 x_2 s, \quad y = \ln\frac{x_1}{x_2}, \qquad x_{1,2} = \frac{m_{t\bar{t}}}{\sqrt{s}}\, e^{\pm y/2} \tag{28}$$

and integrating the expression (25) over the rapidity y with account of the scalar gluon contribution $\Delta\sigma^{F_2}(gg \to t\bar{t}, \mu_f)$ we obtain the invariant mass spectrum $d\sigma(pp \to t\bar{t})/dm_{t\bar{t}}$ in the form

$$\frac{d\sigma_{tot}(pp \to t\bar{t})}{dm_{t\bar{t}}} = \frac{m_{t\bar{t}}}{s} \int_{-\ln(s/m_{t\bar{t}}^2)}^{+\ln(s/m_{t\bar{t}}^2)} \frac{d\sigma_{tot}(pp \to t\bar{t})}{dx_1 dx_2}\, dy. \tag{29}$$

In the same way but with neglect of the scalar gluon contribution $\Delta\sigma^{F_2}(gg \to t\bar{t}, \mu_f)$ we obtain the background invariant mass spectrum $d\sigma_b(pp \to t\bar{t})/dm_{t\bar{t}}$ which is in agreement with the theoretical predictions [31] and with the experimental results [32–34].

With using experimental data on the $t\bar{t}$ invariant mass spectrum (LHC ATLAS 8 TeV, $\mathrm{L} = 20.3\,\mathrm{fb}^{-1}$ [35]) we found exclusion area at the $(m_{F_2} - \sin\beta)$-plane, that is shown in the Fig. 4.

In conclusion, we summarize the results of this paper.

The effective vertex of interaction of the scalar color octet with two gluons is calculated with account of the one loop quark contribution. With account of this interaction the contribution of the scalar color octet to the partonic cross section of resonance $Q\bar{Q}$-pair production in the gluon fusion is calculated.

The total and differential cross sections of the $t\bar{t}$ production in pp-collisions at the LHC are calculated with account of the resonance contribution of scalar color octet F_2 predicted by the minimal model with the four color quark-lepton symmetry and analyzed in dependence on two parameters of the model, the F_2 mass m_{F_2} and mixing angle β.

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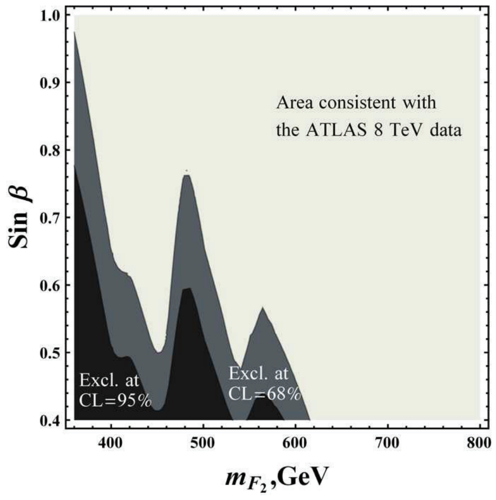

Figure 4. The $(m_{F_2} - \sin\beta)$-plane exclusion regions (at 95% and 68% probability level) resulting from the LHC ATLAS data on $t\bar{t}$ invariant mass spectrum at 8 TeV [35].

From the comparison with the LHC data on total (at $\sqrt{s} = 7, 8, 13$ TeV) and the differential cross sections (at $\sqrt{s} = 8$ TeV) of $t\bar{t}$ production it is shown that there is region of $(m_{F_2} - \sin\beta)$-plane of exclusion by these data. But for $\sin\beta = 1$ and for all the masses m_{F_2} the scalar color octet F_2 gives the contribution to this process of about a few percents and can not be visible in these data.

The work is done within "YSU Initiative Scientific Researches" (Project No. AAAA-A16-116070610023-3)

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