FCNC production of same sign top quark pairs at the LHC

F Larios and F Peñuñuri
Depto. de Fisica Aplicada. CINVESTAV-Mérida. km. 6 Carr. Antigua a Progreso. 97310 Mérida, Yucatán, México.
E-mail: larios@mda.cinvestav.mx, penunuri@mda.cinvestav.mx

Abstract. As a result of FCNC tqV couplings the possibility of same sign top quark pair production at the LHC is analyzed. Besides the SM neutral Z boson, two other neutral bosons are considered, a top-Higgs type scalar and a Z’ boson that appears in Topcolor assisted Technicolor models. We find that the FCNC couplings may produce an interesting signal of same sign top quark pairs that could be observed at the LHC.

Production of same sign top quark pairs appears in a process in which two incoming up type quarks exchange a neutral boson and then change to a pair of (same sign) top quarks[1]. Apart from the standard backgrounds associated with a top quark pair there is no other SM process that can hide this signal. The SM process \( pp \rightarrow bbW^+W^- \) is negligible: of order \( 10^{-5} \)fb, so this is essentially a background free process. Unfortunately, the only way to separate the \( tt \) from the \( tt \) signal is by identification of same charges in the dilepton mode -a mode with very low efficiency. However, the size of the FCNC couplings could be large and the LHC could find many pairs of tops even during the first few years of running[2].

Below, we will discuss separately this process via three intermediary bosons for the FCNC: the SM Z boson, a Z’ boson and a scalar boson that couples strongly with the top quark.

To be consistent with the usual experimental limitations, in this work we have imposed for the rapidity and transverse momentum of each top to be between -2 and 2 and above 40 GeV respectively. The invariant mass of the top pair must be higher than 380 GeV. These cuts reduce the total rate in about 40%.

We have taken the factorization scale equal to the invariant mass of the \( tt \) pair \( \mu = M_{tt} \).

The top quark mass we have used is \( m_t = 175 \)GeV. The Parton Distribution Function (PDF) used was the recent CTEQ6M[3]. Our calculations are at tree level, obtained with the aid of the CompHEP program[4]. It should be noted that NLO and NNLO contributions to this process can increase the production cross section in about 15%[5].

1. FCNC with the Z boson.

The only direct constraint of a \( Ztq \) (\( q = u, c \)) coupling comes from the Tevatron[6]:

\[ \sqrt{|X_{tq}^F|^2 + |X_{tq}^L|^2} \leq 0.8 \]

The weakness of this bound is also evident from the associated upper bound on the branching ratio \( Br(t \rightarrow cZ) \leq 33\%[6] \). However, Run II of the Tevatron is expected to reach a level of 1.5%, which would be translated in a much stronger bound on
$X_{tg}^R \leq 0.04[^7]$. Actually, it has been shown that this coupling can be tested down to values of order $10^{-2}$ at the LHC via the associated production of a top and a $Z$ or $\gamma$ [^8].

With an expected 100 fb$^{-1}$ of luminosity there could be a few hundreds pairs of same sign tops coming from this coupling[^2]. Because of the larger parton luminosity from the $u$ quark the process $uu \rightarrow tt$ is more sensitive to the size of the FCNC couplings. In Ref. [^1] the authors have used $a_{tu}^R$ of the order 0.4 and have obtained a huge rate of a couple tens of pb for the LHC.

### 2. The Topcolor $Z'$

Now we want to consider a heavy $Z'$ boson, such as the one that appears in Topcolor assisted technicolor (TC2) models[^9]. In these models the heavy $Z'$ couples strongly with the third family of quarks and may induce FCNC. The coupling strength is given by $g_2 = e/c_W s_W c_\phi$ where $c_W$ is the cosine of the SM $SU(2)_L \times U(1)_Y$ mixing angle and $\phi$ is the mixing angle for the $Z_1$ and $Z_2$ neutral bosons of the TC2 model. As shown in Ref. [^9] electroweak data requires the mass of $Z'$ to be higher than 1-4 TeV for values of $\sin^2 \phi$ between 0.05 and 0.5 (this range of values implies the diagonal coupling strength $g_2$ to be of order between 0.7 and 1.2). The production cross section of $pp \rightarrow tt$ for different values of $M_{Z'}$ is shown in Ref.[^2]. Given the assumption that the cross section must be at least of order 10 fb to become detectable we can see that $B_{tt}^R$ must be higher than 0.5 to yield this production rate. Again, other processes where the anomalous coupling appears only once in the Feynman diagram are more sensitive. For instance, from Ref. [^10] a loop level induced rare top decay $t \rightarrow cV$ ($V = \gamma, Z$ or gluon) would require a smaller coupling size $B_{tc} = g_1 K_{tc} \sim 0.2$ to become of order $10^{-5}$ (for gluon) or $10^{-6}$ (for $\gamma$) for its branching ratio, which is already at expected detectable levels at the LHC.

Finding a $Z'$, or any heavy resonance, that couples preferentially to the third family is possible via $\tau$ lepton pair production[^11], but it may not be possible at all at any future hadron collider (including the LHC) searching in the $t\bar{t}$ mode[^12].

### 3. Scalar FCNC

Next we want to consider a FCNC scalar coupling of the type $Htq$[^13]. This coupling was also studied in Ref. [^14, 15]. It is not expected that the $y_{tu}^L$ coupling could be very large, maybe of order $\lambda^2 m_t/f_\pi$ with $\lambda = 0.22$ in relation to the CKM mixing parameter (the Cabibbo angle). Also, $y_{uL}^L$ would be less than $\lambda^2 m_t/f_\pi$ [^16, 17]. However, there is no reason to believe the right handed $y_{tg}^R$ coupling couldn’t be much larger. In fact, the dynamical Top-color (TopC) model generally predicts $0.2 \leq y_{tg}^R \leq 0.7$[^16, 17]. For this size of the FCNC coupling the production of top pairs can be significant.

If the scalar Higgs mass is not very high, between 100 and 200 GeV, a coupling somewhat higher than $y_{tg}^R = 0.3$ could give enough rate to be observed at the LHC[^2].

### 4. Identification of $tt$ pairs at LHC

The $tt$ signal is overwhelmed by $t\bar{t}$ production. Separating this signal can only happen via the dilepton mode, in which the two same sign tops produce two same sign leptons. Considering a 50% b-tagging efficiency, this mode will let us observe only a small 2% (or less) fraction of all the top quark pairs produced[^6, 18]. Assuming an overall efficiency of order 1% we can expect to observe from a few to up to several tens of same sign top events every year.
Acknowledgments

We want to thank C.-P. Yuan for numerous suggestions for this work. We also thank Conacyt for support.

References

[1] Y.P. Gouz and S.R. Slabospitsky, Phys. Lett. B457, 177 (1999).
[2] F. Larios and F. Peñunuri, J. Phys. G: Nucl. Part. Phys. 30 (2004) 895.
[3] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P. Nadolsky and W.K. Tung. JHEP 0207 (2002) 012. Also see, hep-ph/0307022.
[4] A. Pukhov, E. Boos, M. Dubinin, V. Edneral, V. Ilyin, D. Kovalenko, A. Kryukov, V. Savrin, S. Shichanin, A. Semenov, CompHEP -a package for evaluation of Feynman diagrams and integration over multiparticle phase space, hep-ph/9908288.
[5] N. Kidonakis and A. Belyaev, JHEP 12, (2003) 004.
[6] F. Abe, et. al. Phys. Rev. Lett. 80, 2525 (1998); See also S. Cabrera, hep-ex/0305066 for a recent report of the D0 and CDF collaborations.
[7] W. Wagner, by the CDF collaboration, Top Quark Physics with CDF, Presented at 14th Topical Conference on Hadron Collider Physics (HCP2002) Karlsruhe, Germany, Sep/29 - Oct/4, 2002. FERMILAB-Conf-02/317-E.
[8] F. del Aguila and J. Aguilar-Saaavedra, Nucl. Phys. B576, 56 (2000).
[9] R.S. Chivukula and E.H. Simmons, Phys. Rev. D66, 015006 (2002).
[10] C.-X. Yue, H. Zong and G.-L. Liu, Mod. Phys. Lett. A 18 (2003) 2187.
[11] K. Lynch, S. Mrenna, M. Narain and E.H. Simmons, Phys. Rev. D63, 035006 (2001).
[12] T. Han, D. Rainwater and G. Valencia, Phys. Rev. D68, 015003 (2003).
[13] C.T. Hill, Phys. Lett. B345, 483 (1995).
[14] J. A. Aguilar-Saaavedra and G. C. Branco, Phys. Lett. B495, 347 (2000).
[15] J. Cao, Z. Xiong and J.M. Yang, Phys. Rev. D67, 071701 (2003).
[16] H.-J. He, S. Kanemura and C.-P. Yuan, Phys. Rev. Lett. 89, 101803 (2002); H.-J. He, and C.-P. Yuan, Phys. Rev. Lett. 83, 28 (1999).
[17] G. Burdman, Phys. Rev. Lett. 83, 2888 (1999);
[18] The D0 Collaboration, Phys. Rev. D67, 012004 (2003).