CDF/PHYS/EXO/PUBLIC/10466

Search for like-sign top quark pair production at CDF with 6.1 fb^{-1}

The CDF Collaboration

URL http://www-cdf.fnal.gov

(Dated: April 9, 2011)

We search for production of same-sign top quark at CDF in data with 6.1 fb^{-1} of luminosity. The observed data agree with the standard model predictions. We present limits on same-sign top quark pair production at CDF using effective operators.

I. INTRODUCTION

Flavour-changing neutral processes involving top quarks offer a clean window to new physics because they are extremely suppressed within the Standard Model (SM). Searches for top (neutral) flavour violation involving SM gauge bosons have already been performed, either in top decays [1, 2] or in single top production at Tevatron [3, 4], LEP [5–9] and HERA [10, 11]. In this note we present the first search for like-sign top pair production, which involves a double top flavour violation. This study is complementary to previous searches because, rather than probing top flavour violation involving SM gauge bosons, tt production is sensitive to other types of new physics involving new heavy resonances. In particular, it can probe the presence of flavour-violating Z' bosons, which have been proposed [12–16] as a possible explanation of the discrepancy between the measured forward-backward asymmetry in $t\bar{t}$ production [17–19] and the SM prediction [20–22].

Like-sign top pairs can be produced in hadron collisions from initial charge 2/3 quarks, being $uu \to tt$ the most important process which can be mediated by: (a) the exchange of a heavy s-channel vector boson, as depicted in Fig. 1 (left), or a t-channel one, as shown on the right-hand side. In the former case the new particle can be a colour-triplet or sextet (respectively labelled as $\mathcal{Q}^5_\mu$, $\mathcal{Y}^5_\mu$ [23]) with charge 4/3, while in the latter it can be a colour singlet Z' or octet g', both with zero charge. Scalars exchanged in s or t channels can mediate tt production as well. For heavy boson masses M much larger than the electroweak symmetry breaking scale v, all these possibilities can be economically described by a gauge-invariant effective four-fermion interaction [24], as shown in Fig. 1 (middle). This model-independent approach is adopted in this note, in order to obtain limits which can eventually be interpreted in the context of various SM extensions.

This note is a companion to an inclusive analysis of the like-sign dilepton signature [25].

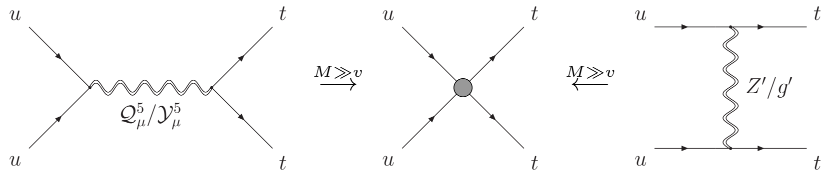

FIG. 1: Production of like-sign top pairs via the exchange of an s-channel (left) or t-channel (right) vector boson. For large resonance masses, both cases can be described by a four-fermion interaction (middle).

TABLE I: Predicted and observed event yields of same-sign dilepton events with at least two jets in data with 6.1 fb^{-1} fb of luminosity.

CDF RunII Preliminary $\int \mathcal{L}dt = 6.1$ fb^{-1}				
Process	Total $\ell\ell$	$\mu\mu$	ee	$e\mu$
$t\bar{t}$	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0
$Z \to \ell\ell$	5.9 ± 1.7	0.0 ± 0.0	4.8 ± 1.6	1.1 ± 0.8
WW, WZ, ZZ	7.2 ± 0.5	1.5 ± 0.2	2.0 ± 0.2	3.7 ± 0.4
$W(\to \ell\nu)\gamma$	0.9 ± 0.7	0.0 ± 0.0	0.5 ± 0.5	0.4 ± 0.4
Fakes	13.8 ± 7.2	3.2 ± 2.4	4.6 ± 2.2	6.0 ± 3.1
Total	28.0 ± 7.5	4.7 ± 2.4	11.9 ± 2.8	11.3 ± 3.3
Data	27	2	16	9

II. DATASET, SELECTION AND BACKGROUNDS

A description of the dataset, selection and background model is provided in the companion note [25]. This study uses the subset of the inclusive sample with at least two jets.

A. Event Yield

Table I shows the observed and predicted event yields, which are in good agreement. The dominant background comes from misidentified leptons, followed by diboson production. See Ref. [25] for details on the background model.

B. Event Kinematics

In each event, we calculate the H_T, the scalar sum of the lepton p_T, the jet E_T andthe missing transverse energy. Figure 2 and Figure 3 show the observed missing energy and H_T distributions in events with two same-sign leptons and at least two jets.

III. EFFECTIVE MODEL

We use a complete set of effective four-fermion operators [24] to parameterise new heavy boson contributions to like-sign top production (see Figure 1). They yield the effective Lagrangian relevant for this process,

$$\begin{aligned}\mathcal{L}_{4F} \;=\; & \tfrac{1}{2}\frac{C_{LL}}{\Lambda^2}(\bar{u}_L\gamma^\mu t_L)(\bar{u}_L\gamma_\mu t_L) + \tfrac{1}{2}\frac{C_{RR}}{\Lambda^2}(\bar{u}_R\gamma^\mu t_R)(\bar{u}_R\gamma_\mu t_R) \\ & -\tfrac{1}{2}\frac{C_{LR}}{\Lambda^2}(\bar{u}_L\gamma^\mu t_L)(\bar{u}_R\gamma_\mu t_R) - \tfrac{1}{2}\frac{C'_{LR}}{\Lambda^2}(\bar{u}_{La}\gamma^\mu t_{Lb})(\bar{u}_{Rb}\gamma_\mu t_{Ra}) + \text{h.c.}\,,\end{aligned} \tag{1}$$

where C_{LL}, C_{RR}, C_{LR} and C'_{LR} are dimensionless constants and Λ is the scale of the new physics. (In the last term the subindices a, b indicate the colour contractions.) The cross-section for tt production at the Tevatron can be

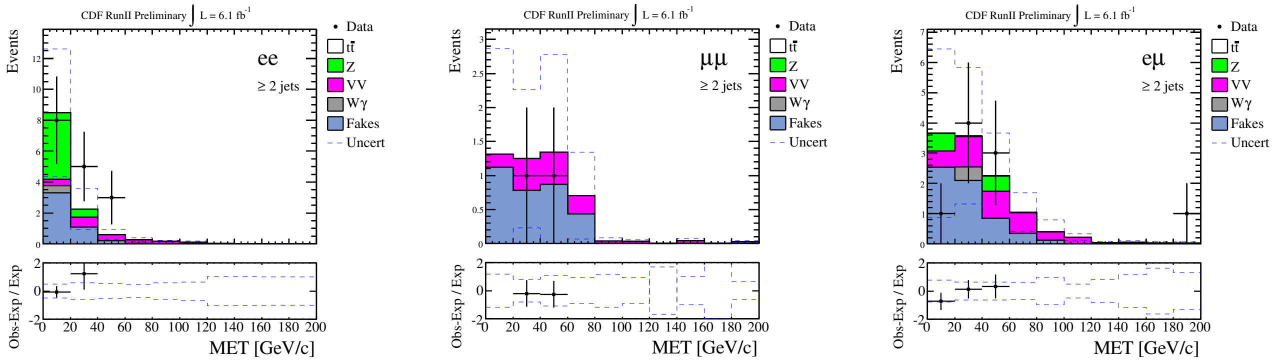

FIG. 2: Distribution of missing transverse energy for observed events with two like-sign lepton and at least two jets (points). Stacked histograms indicate the expected background contributions, see Table I.

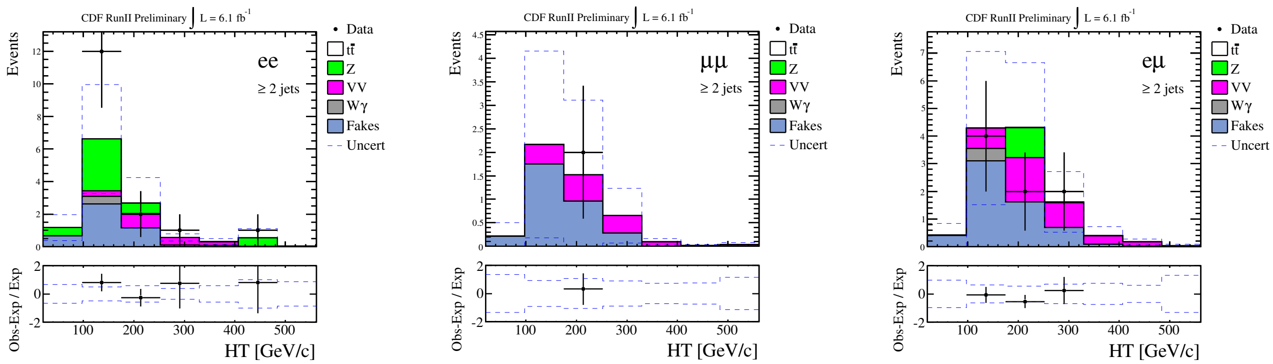

FIG. 3: Distribution of H_T for observed events with two like-sign lepton and at least two jets (points). Stacked histograms indicate the expected background contributions, see Table I.

written in term of these coefficients as [24, 28]

$$\sigma_{tt+\bar{t}\bar{t}} = 2 \times \left[\frac{14.48}{\Lambda^4} \left(|C_{LL}|^2 + |C_{RR}|^2 \right) + \frac{1.811}{\Lambda^4} \left(|C_{LR}|^2 + |C'_{LR}|^2 \right) - \frac{0.52}{\Lambda^4} Re \left(C_{LR} C'^{*}_{LR} \right) \right] \ \mathrm{fb} \cdot \mathrm{TeV}^4 \,. \tag{2}$$

Signal events were generated with PROTOS, showered with PYTHIA and the detector response was simulated using CDFSIM. In order to test possible efficiency variations, three event samples were used correspoding to both quarks left-handed ($C_{LL} = 1$), both right-handed ($C_{RR} = 1$) or mixed ($C_{LR} = 1$).

IV. RESULTS

We present results for same-sign top quark production. Figure 4 shows the observed data and background prediction for the analysis variable, H_T in same-sign dilepton events with at least two jets, with the signal overlaid. Limits on the production cross-section times dilepton branching ratio for the LL, LR and RR modes, as well as on individual coefficients, are shown in Figure 5 and Table II. In Figure 6, we translate these to limits on two out of the four coefficients (assuming the rest are zero).

The limits obtained can be compared to the A_{fb} prediction [26] for various models of flavour-violating Z' bosons [12–15], as a function of $|C_{RR}|/\Lambda^2$, see Figure 7.

Finally, assuming no significant efficiency or shape difference between the different modes, we can set a limit on vector or axial-vector Z' bosons for which

$$C_{LL} = C_{RR} = \mp \tfrac{1}{2} C_{LR} \equiv \mathcal{C} \tag{3}$$

TABLE II: Upper limits (95% CL) on production cross-section times branching ratio $\mathrm{BR}(W \to \ell\nu)^2$ for individual chirality modes left-left (LL), right-right (RR), or left-right (LR) assuming only one non-zero mode. Also shown are limits (95% CL) on the coefficients of the four-fermion effective Lagrangian (see Eq. 1), assuming one non-zero mode. Limits are shown graphically in Figure 5. Limits with two non-zero coefficients are shown in Figure 6.

	LL	LR	RR
$\sigma_{tt+\bar{t}\bar{t}} \times \mathrm{BR}(W \to \ell\nu)^2$ [fb]	54	51	44
$\lvert C\rvert/\Lambda^2$ [TeV^{-2}]	4.1	11.3	3.7

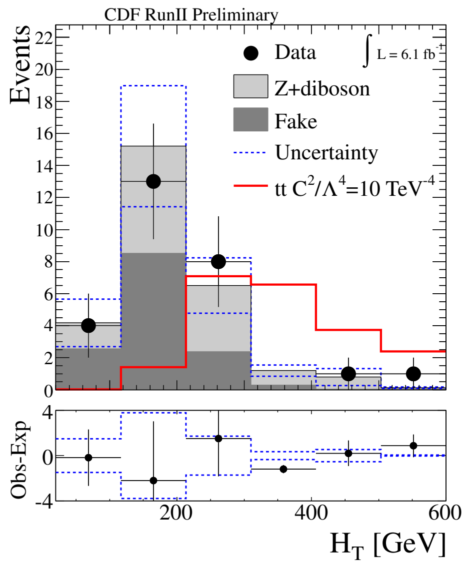

FIG. 4: Distribution of expected and observed data in H_T, with expected same-sign topquark pair signal overlaid.

using the result from the LL mode, which is the weakest. In this case, the cross section in Eq. 2 translates into

$$\sigma_{tt+\bar{t}\bar{t}} = 2 \times (14.48 \times 2 + 1.811 \times 4)\, \frac{|\mathcal{C}|^2}{\Lambda^4}\ \mathrm{fb} \cdot \mathrm{TeV}^4\,,$$

which gives a 95% CL limit of

$$|\mathcal{C}|/\Lambda^2 < 2.6\ \mathrm{TeV}^{-2}$$

V. CONCLUSIONS

We have performed the first dedicated search for same-sign top quark pair production in hadron collisions. We see no evidence for production and set limits on the cross-section using a Lagrangian of effective operators, which can be applied to a broad set of models.

Future studies at the LHC will probe smaller values of the couplings.

Acknowledgments

We acknowledge Tim Tait for useful conversations. We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the

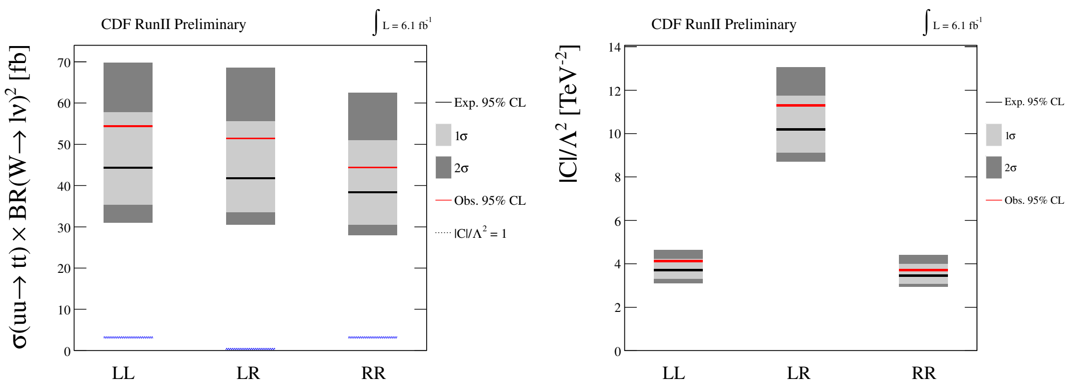

FIG. 5: Limits on same-sign top quark pair production in left-left, left-right, and right-right chirality modes. Left, in terms of cross-sections, compared to theory predictions for $C = 1$. Right, expressed as limits on the C coefficients. See Table II for numerical values.

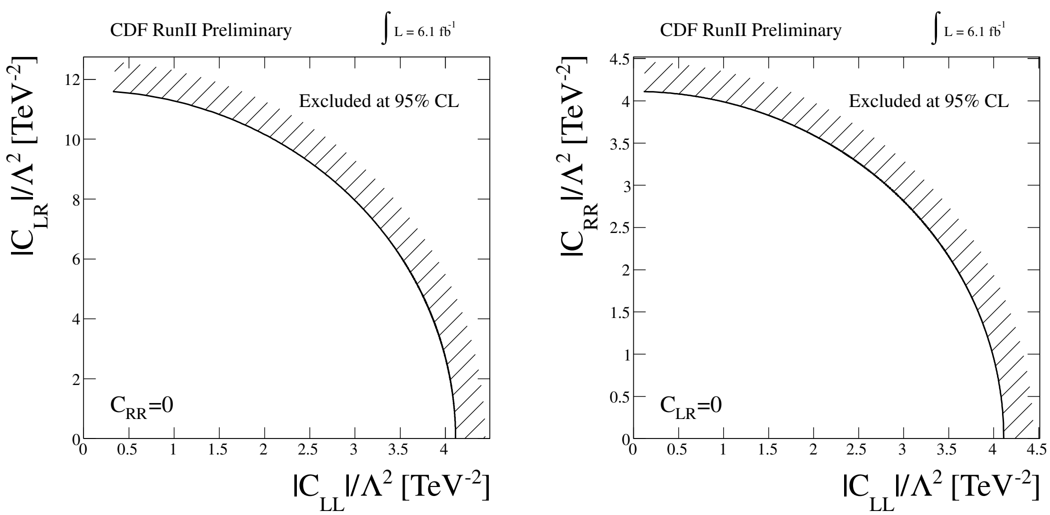

FIG. 6: Limits on two of four operator coefficients assuming the rest is zero. These make the conservative assumption that the kinematics of a combination of two modes (LL,LR,RR) can be described by the mode with the smallest efficiency, LL.

National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comisión Interministerial de Ciencia y Tecnología, Spain; in part by the European Community's Human Potential Programme under contract HPRN-CT-2002-00292; and the Academy of Finland.

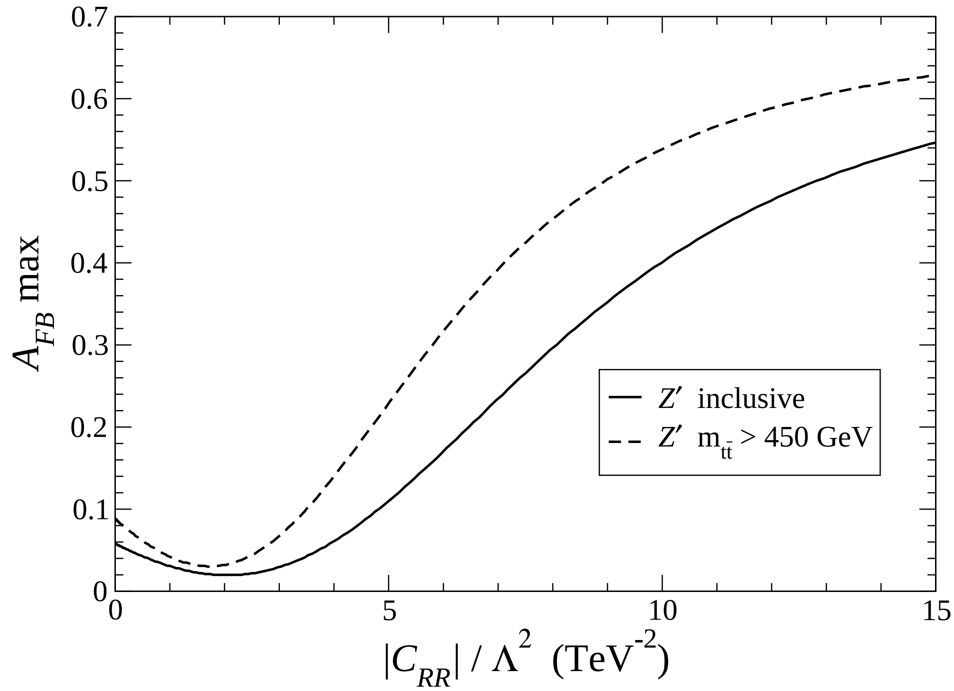

FIG. 7: Relation between A_{fb} and the coefficient $|C_{RR}|/\Lambda^2$ for flavour-violating Z' models [26].

[1] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **101**, 192002 (2008) [arXiv:0805.2109 [hep-ex]].
[2] V. M. Abazov *et al.* [D0 Collaboration], arXiv:1103.4574 [hep-ex].
[3] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **102**, 151801 (2009) [arXiv:0812.3400 [hep-ex]].
[4] V. M. Abazov *et al.* [D0 Collaboration], Phys. Lett. B **693**, 81 (2010) [arXiv:1006.3575 [hep-ex]].
[5] G. Abbiendi *et al.* [OPAL Collaboration], Phys. Lett. B **521**, 181 (2001) [arXiv:hep-ex/0110009].
[6] A. Heister *et al.* [ALEPH Collaboration], Phys. Lett. B **543**, 173 (2002) [arXiv:hep-ex/0206070].
[7] P. Achard *et al.* [L3 Collaboration], Phys. Lett. B **549**, 290 (2002) [arXiv:hep-ex/0210041].
[8] J. Abdallah *et al.* [DELPHI Collaboration], Phys. Lett. B **590**, 21 (2004) [arXiv:hep-ex/0404014].
[9] and J. Abdallah [DELPHI Collaboration], Eur. Phys. J. C **71**, 1555 (2011) [arXiv:1102.4455 [hep-ex]].
[10] S. Chekanov *et al.* [ZEUS Collaboration], Phys. Lett. B **559**, 153 (2003) [arXiv:hep-ex/0302010].
[11] A. Aktas *et al.* [H1 Collaboration], Eur. Phys. J. C **33**, 9 (2004) [arXiv:hep-ex/0310032].
[12] S. Jung, H. Murayama, A. Pierce and J. D. Wells, Phys. Rev. D **81** (2010) 015004 `[0907.4112 [hep-ph]]`.
[13] D. Choudhury, R. M. Godbole, S. D. Rindani and P. Saha, `1012.4750 [hep-ph]`.
[14] J. Cao, L. Wang, L. Wu and J. M. Yang, `1101.4456 [hep-ph]`.
[15] E. L. Berger, Q. H. Cao, C. R. Chen, C. S. Li and H. Zhang, `1101.5625 [hep-ph]`.
[16] S. Jung, A. Pierce and J. D. Wells, `1103.4835 [hep-ph]`.
[17] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. Lett. **100** (2008) 142002 `[0712.0851 [hep-ex]]`.
[18] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **101** (2008) 202001 `[0806.2472 [hep-ex]]`.
[19] T. Aaltonen *et al.* [CDF Collaboration], `1101.0034 [hep-ex]`.
[20] L. G. Almeida, G. F. Sterman and W. Vogelsang, Phys. Rev. D **78**, 014008 (2008) [arXiv:0805.1885 [hep-ph]].
[21] O. Antunano, J. H. Kuhn and G. Rodrigo, Phys. Rev. D **77**, 014003 (2008) [arXiv:0709.1652 [hep-ph]].
[22] M. T. Bowen, S. D. Ellis and D. Rainwater, Phys. Rev. D **73**, 014008 (2006) [arXiv:hep-ph/0509267].
[23] F. del Aguila, J. de Blas and M. Perez-Victoria, JHEP **1009**, 033 (2010) [arXiv:1005.3998 [hep-ph]].
[24] J. A. Aguilar-Saavedra, Nucl. Phys. B **843** (2011) 638 [arXiv:1008.3562 [hep-ph]].
[25] CDF10454
[26] J. A. Aguilar-Saavedra and M. Perez-Victoria, arXiv:1103.2765 [hep-ph].
[27] M. I. Gresham, I. W. Kim and K. M. Zurek, `1103.3501 [hep-ph]`.
[28] J.-A. Aguilar-Saavedra, private communication