Searches for New Physics in the Top Sector at the Tevatron

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The top quark, discovered in 1995 by the CDF and D0 collaborations at the Tevatron collider at Fermilab, is the heaviest known elementary particle today. Due to its high mass and short lifetime, the top quark plays a special role in searching for physics beyond the Standard Model. In this article, recent results of searches for new physics in the top sector, performed by CDF and D0, are presented. In particular, we discuss the search for $t\bar{t}$ resonances, for tj resonances, the search for heavy fourth generation quarks, for dark matter produced in association with single tops, the study of anomalous couplings, the search for boosted top quarks as well as the analysis of Lorentz Invariance violation in the top quark sector.

1 Introduction

Discovered in 1995 by the CDF and D0 collaborations, the top quark [1, 2] is the heaviest known elementary particle today, with a mass of $m_t = 173.18 \pm 0.94$ GeV [3]. The top quark decays before hadronization, therefore being the only particle to study bare quarks. Furthermore, the Yukawa coupling of the top quark and the Higgs boson is expected to be large due to its high mass. The special properties of the top quark make it an interesting particle to study and as windwo to new physics.

In the following, recent searches for physics beyond the Standard Model (SM) in the top quark sector, performed by the CDF and D0 collaborations using Tevatron Run II data, are presented.

2 Searches for New Physics in Top Quark Production

At the Fermilab Tevatron, a proton-antiproton collider with a center of mass energy of $\sqrt{=}1.96$ TeV, top quark production occurs dominantly in pairs ($t\bar{t}$) through the strong interaction, with about 85% via $q\bar{q}$ annihilation and about 15% via gluon-gluon fusion. At about half the production cross section of $t\bar{t}$, single top quark production via the electroweak interaction takes place.

For measurements of the $t\bar{t}$ production cross section and top quark properties, the $t\bar{t}$ final states are classified according to the decays of the two W bosons from the top and anti-top decay. We separate the final states into dileptonic, semileptonic and allhadronic channels according to the number of leptons in the final state. If the lepton is a hadronic decaying tau, the events are treated as separate channels (τ+lepton and τ+jets).

In the SM, no $t\bar{t}$ resonances exist, while many models beyond the SM predict production via a resonance, as for example Topcolor assisted technicolor models. Using events in the semileptonic final state, both bthe CDF and D0 collaboration searched for a narrow resonance X, with $\Gamma_X = 1.2\% M_X$, by searching for a bump in the spectrum of the invariant $t\bar{t}$ mass, $m_{t\bar{t}}$. Using events with at least four jets and 4.8 fb^{-1} of data at CDF and at least three jets and 5.4 fb^{-1} at D0, limits on $\sigma(p\bar{p} \to X) \times B(X \to t\bar{t})$ versus M_X have been extracted. In the benchmark model of topcolor assisted technicolor, a $Z^{'}$ for masses below 835 GeV is excluded by D0 [4] and below 900 GeV by CDF [5] at the 95% confidence level (CL).

Recently, CDF performed a search for a top plus jet (tj) resonance M using the full Run II data set of 8.7 fb^{-1} by looking for a tj resonance in the $t\bar{t}j$ system. A kinematic fitter is applied on events with at least five jets, of which at least one has to be identified as a b-jet, in the semileptonic final state, and a bump search in the tj invariant mass is performed. Limits are set on $\sigma(p\bar{p} \to Mt\bar{t})$, resulting in upper limits between 0.61 pb and 0.02 pb at the 95% CL. These can be translated into limits on the mass of M assuming M to be part of a new color singlet or color triplet model [6].

Another search recently performed by CDF using 7.7 fb^{-1} investigates the possibility of a dark matter candidate D produced in association with a top quark. Single top events, where the top quark decays fully hadronically and the dark matter candidate leaves high missing transverse energy in the detector, are used for this search. A template fit of the missing transverse energy spectrum is performed in events with at least three jets and no leptons, inspecting dark matter candidates with masses of up to 150 GeV. Upper limts on $\sigma(p\bar{p} \to Mt\bar{t})$ can be set as function of m_D [7], which are about 0.5 pb over the investigated mass range.

3 Searches for New Physics in Top Quark Decay

In the SM, the top quark decays with a probability of almost 100% into a W-boson and a b-quark. The coupling of the W boson to fermions has the $V - A$ form of a left-handed vector interaction. Possible new physics could occur if the coupling of the W boson to the top and bottom quark (tWb coupling) is of the form of right-handed vector couplings, or left- or right-handed tensor couplings. In an effective Lagrangian approach, the different couplings can be introduced as form factors f_V^L, f_V^R, f_T^L, f_T^R, describing the left (L) and right (R) handed vector (V) and tensor (T) couplings, respectively. In the SM, $f_V^L = 1$ and all others are zero.

Recently, the D0 collaboration performed a search for anomalous couplings using information from single top quark production and the measurement of the W helicity in top quark decays. Using single top quark events, mutlivariate discriminants are trained on a single top sample with either f_V^R, f_T^L, or f_T^R set to one as the signal sample, while SM single top ($f_V^L = 1$) is considered as part of the background. For each trained multivariate discriminant, the pair of one of the anomalous couplings form factors and the coupling form factor f_V^L are then considered simultaneously, and limits can be extracted in the plane of (f_V^R, f_V^L) , (f_T^L, f_V^L), or (f_T^R, f_V^L) [8]. Furthermore, the W helicity in top quark decays can be measured using the distribution of the angle between the direction opposite to the top quark and the direction of the down-type fermion (charged lepton or down-type quark) from the decay of the W boson, both in the W boson rest frame [9]. The extracted W helicity fractions can be interpreted as limits on f_V^R, f_T^L, or f_T^R. By combining the analysis of anomalous couplings in single top events with information from the W helicity analysis, posterior probability density distributions for the anomalous coupling form factors are obtained. This provides 95% CL limits on anomalous tWb

couplings of $|f_V^R|^2 < 0.30$, $|f_T^L|^2 < 0.05$, and $|f_T^R|^2 < 0.12$ [10].

4 Top-related Searches for New Physics

Until today, three generations of quarks and leptons are known in the SM. A simple extension would be the inclusion of a fourth generation of fermions. Both collaborations, D0 and CDF, searched for pair production of massive fourth generation quarks, t', assuming the decay into a W boson and a down-type quark. CDF allows this down-type quark to be d, s or b, while D0 assumes a b-quark. The search is performed in the semileptonic final state with at least four jets, of which at least one has to be an identified b-jet at D0. The $t'\bar{t'}$ sample is expected to have a higher fitted top mass and a larger scalar sum of the lepton and jet p_Ts, thus the search is performed as a template fit of these two observables. Upper limts on $\sigma(p\bar{p} \to t'\bar{t'})$ are extracted as function of the t' mass $m_{t'}$, resulting in lower limits on $m_{t'}$ at the 95% CL of $m_{t'} > 285$ GeV at D0 [11] using 5.3 fb^{-1} and $m_{t'} > 358$ GeV by CDF [12] using 5.6 fb^{-1}.

Another top related search recently performed by the CDF collaboration is a search for massive, collimated jets, which serves as a test of quantum chromodynamics and can give insights into parton showering models. The search aims to select events where the decay products of the top quark are collimated into one single, massive jet. Using 6.0 fb^{-1}, CDF requires events with at least one jet cluster with $p_T > 400$ GeV, and high jet masses [13]. The search is performed in the lepton+jets final state, where high missing transverse energy is required, and the allhadronic final state, where for each event two jets are required to have high jet mass and the event has no missing transverse energy. Upper limits can be set on the $t\bar{t}$ production cross section for two cases. The resulting upper limit is $\sigma_{t\bar{t}} < 38$ fb at the 95% CL for events where at least one top is produced with $p_T > 400$ GeV, and $\sigma_{t\bar{t}} < 20$ fb for the pair production of massive objects produced with $p_T > 400$ GeV.

At D0, the possibility of Lorentz invariance violation in the top quark sector has been considered, by searching for a time dependent $t\bar{t}$ production cross section in the lepton plus jets final state, using 5.3 fb^{-1} of data. Lorentz-violating terms can be introduced to the SM Lagrangian via an effective field theory in the standard-model extension (SME) framework [14]. The SME predicts $\sigma_{t\bar{t}}$ to depend on the sidereal time, due to the change of the orientation of the D0 detector with the rotation of the Earth relative to fixed stars. No indication for a time dependent $\sigma_{t\bar{t}}$ can be observed, and first constraints on Lorentz invariance violation in the top quark sector are set [15].

5 Conclusion and Outlook

In this report, a collection of recent searches for physics beyond the SM in the top quark sector by the CDF and D0 collaborations has been discussed. New models have been tested using up to the full Tevatron data set. No evidence for physics beyond the SM has been seen yet.

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References

[1] F. Abe *et al.* [CDF Collaboration], Phys. Rev. Lett. **74**, 2626 (1995) [arXiv:hep-ex/9503002].

[2] S. Abachi *et al.* [D0 Collaboration], Phys. Rev. Lett. **74**, 2632 (1995) [arXiv:hep-ex/9503003].

[3] [Tevatron Electroweak Working Group and CDF Collaboration and D0 Collab], arXiv:1107.5255 [hep-ex].

[4] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **85**, 051101 (2012).

[5] T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. D **84**, 072004 (2011).

[6] T. Aaltonen *et al.* [CDF Collaboration], CDF Conf. Note 10776 (2012).

[7] T. Aaltonen *et al.* [CDF Collaboration], arXiv:1202.5653v1 (2012).

[8] V. M. Abazov *et al.* [D0 Collaboration], Phys. Lett. B **703**, 21 (2012).

[9] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **83**, 032009 (2011).

[10] V. M. Abazov *et al.* [D0 Collaboration], arXiv:1204.2332 [hep-ex] (2012).

[11] V. M. Abazov *et al.* [D0 Collaboration], Phys. Rev. D **85**, 051101 (2012).

[12] T. Aaltonen *et al.* [CDF Collaboration], arxiv:1107.3875 (2011).

[13] T. Aaltonen *et al.* [CDF Collaboration], Conf. Note 10234 (2011).

[14] D. Colladay and V.A. Kostelecky, Phys. Rev. D **58**, 116002 (1998); V.A. Kostelecky, Phys. Rev. D **69**, 105009 (2004).

[15] V. M. Abazov *et al.* [D0 Collaboration], arXiv:1203.6106 (2012).