

Searches for rare and beyond the Standard Model top quark decays at the Tevatron

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Summary. — The Tevatron experiments CDF and D0 investigated the top quark decay in search of deviations from the Standard Model. Rare processes expected in the Standard Model as well as decays including hypothetical particles of models beyond the Standard Model were investigated. This contribution gives an overview of the studies that were performed with datasets of up to 7.5 fb^{-1} of integrated luminosity.

PACS 14.65.Ha – Top quarks.

PACS 14.70.Pw – Other gauge bosons.

PACS 14.80.-j – Other particles (including hypothetical).

1. – Introduction

Since the discovery of the top quark by CDF and D0 at the Tevatron in 1995 [1,2] the number of top events available for experimental studies has been increased by more than two orders of magnitude. The Tevatron recently completed its operation with a delivered integrated luminosity of more than 10 fb^{-1} . Up to 75% of these data have already been analyzed to investigate, amongst other studies, whether the decay of top quark actually behaves as expected by the Standard Model (SM). Modifications of the top quark decay may arise from modifications affecting how the top quark acts under the electromagnetic, weak or strong interaction. Also hypothetical particles of models beyond the Standard Model can change the top quark decay.

To start we shall remind the reader of the results on the decay width of the top quark. Section 3 discusses the investigation of rare processes due to electromagnetic and weak interaction. Analyses assuming particles beyond the SM are described in sect. 4. This section finishes with a study on colour flow which can also be interpreted as a test of the strong interaction in top quark decays within the SM.

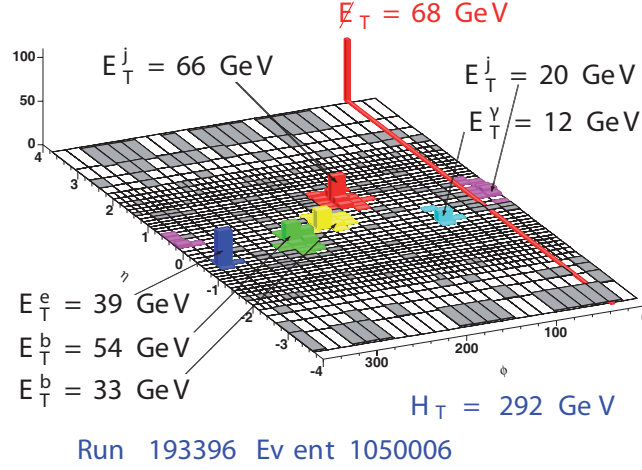


Fig. 1. – Top pair event with hard photon in the final state observed by CDF [9].

2. – Width

The overall top quark width has been determined at the Tevatron in different ways. CDF has investigated the distribution of reconstructed top quark masses to obtain an upper limit on the width. Using 4.3 fb^{-1} of data they obtain $\Gamma_t < 7.5 \text{ GeV}$ [3, 4]. D0 has combined the results from the branching fraction measurement in top quark pair production with the measurement of the single top quark t -channel production cross-section. The t -channel production cross-section, measured from 2.3 fb^{-1} , is proportional to the partial width $\Gamma_t(t \rightarrow Wb)$. The branching fraction $R = \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)}$ obtained from 1 fb^{-1} is then used to determine the total width of the top quark to be $\Gamma_t = 1.99^{+0.69}_{-0.55} \text{ GeV}$ [5].

These results are in good agreement with the SM expectation, but leave enough room for modifications of rare processes and for BSM processes in the top quark decay.

3. – Rare Processes

3'1. $tt\gamma$. – From charge conservation in its decay to SM particles, the top quark charge could be constrained to the expected $2/3$, excluding the exotic $4/3$ option [6-8]. Nevertheless the top quark could have an anomalous coupling to the photon.

CDF investigated the production of top quark pair events that include an isolated energetic photon. Special emphasis is given to the modeling of background due to misidentified photons, which is derived from data. In 6.0 fb^{-1} of data CDF finds 30 candidate events, cf. fig. 1. CDF concludes to see evidence for top pair plus photon production with $\sigma_{t\bar{t}\gamma} = 0.18 \pm 0.08 \text{ pb}$ [9]. The result is in good agreement with the SM NLO prediction of 0.17 pb .

3'2. Associated Higgs production. – In the SM the production of a Higgs boson in association with top quark pair events is a very rare process. In models with multiple Higgs doublets or in the presence of anomalous contributions to the top quark Yukawa couplings this process may be enhanced.

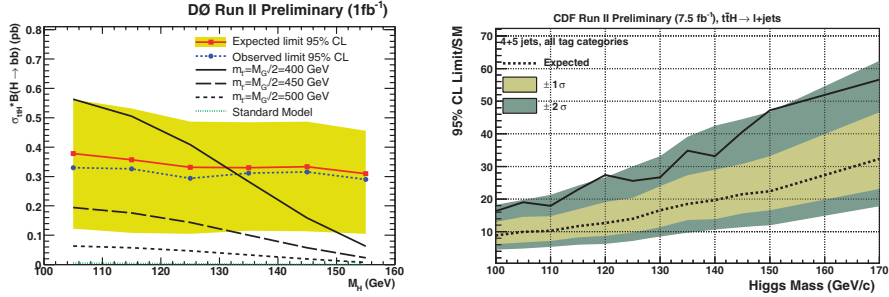


Fig. 2. – Limits on cross-section for ttH production obtained by D0 [10] (left). Limits on the ratio of the observed cross-section for ttH over the SM expectation for selection with explicit lepton selection determined by CDF [11] (right).

CDF and D0 have searched for this channel in semileptonic top quark decay with various requirements on the number of jets, the number of identified b -jets and with or without explicit reconstruction of the charged lepton. The D0 result obtained with 2.1 fb^{-1} is shown in fig. 2 (left). It is compared to predictions of a model with a heavy axigluon [10]. CDF results are obtained using 7.5 fb^{-1} and 5.7 fb^{-1} with and without identified leptons, respectively [11, 12]. The obtained limits are presented in terms of the cross-section for ttH relative to the SM expectation, fig. 2 (right). Neither of the experiments sees an evidence for the anomalous ttH production.

3.3. Flavour changing neutral currents. – Both Tevatron experiments also investigated their data samples for signs of top quark decays through flavour changing neutral currents (FCNC). CDF investigated dilepton events assuming one FCNC and one hadronic top quark decay using 1.9 fb^{-1} [13]. D0 checked for trilepton events in assuming one FCNC and one leptonic top quark decay in 4.1 fb^{-1} [14]. The results of both experiments are given in terms of anomalous tqZ and $tq\gamma$ couplings. These are compared to other such results in fig. 3.

4. – Beyond the Standard Model Particles

4.1. Decay to charged Higgs bosons. – Many BSM models predict the existence of charged Higgs bosons. Depending on their mass these could contribute to the top quark decay and thereby alter the branching fractions expected from the SM, as well as the decay kinematics.

Both Tevatron experiments have searched for charged Higgs bosons in top quark decays. D0 provides results based on comparing the event rates obtained for semileptonic and dileptonic top quark pair decays including a subchannel with one hadronic τ decay. From these the branching fraction can be constrained to be below 15 to 25% depending on the H^\pm boson mass and its decay mode [16]. CDF reconstructs the decay kinematic and investigates the distribution of reconstructed H^\pm boson mass. This allows to achieve stricter limits, if the H^\pm boson mass is far from the W boson mass [17].

In addition CDF has searched for a CP-odd Higgs boson in the decay chain of $t \rightarrow H^\pm b \rightarrow W^\pm a_1^0 b$. The dominating decay channel for $m_{a_1^0} < 2m_b$ is $a_1^0 \rightarrow \tau^+ \tau^-$ and yield additional soft tracks from τ decays. Using 2.7 fb^{-1} of data CDF sets limit on the

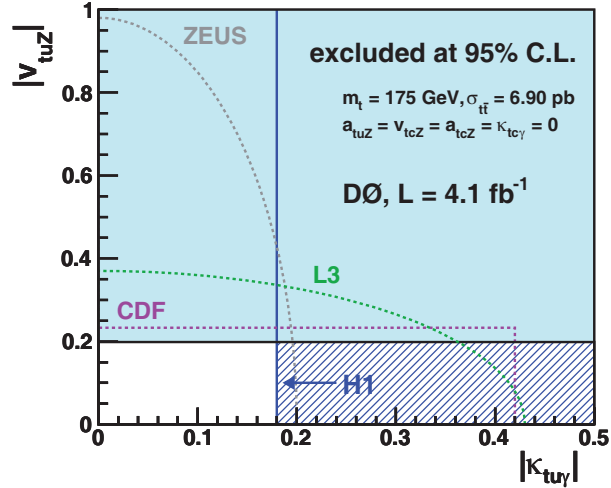


Fig. 3. – Summary of limits on FCNC anomalous top quark couplings [14].

branching fraction of top to this decay mode for various assumed mass values of H^\pm and a_1^0 as shown in fig. 4 [15].

4.2. *Colour flow in top pair decays.* – In the SM the top quark decay happens through the colourless W boson. Conceptually, also a coloured object (octet) could mediate the process. Exploiting observables that are sensitive to the amount of hadrons produced between two jets gives some handle to distinguish singlet from octet processes. In semileptonic top decay from 5.3 fb^{-1} D0 obtains that the fraction for production through colourless (singlet) decay to be $f_{\text{Singlet}} = 0.56 \pm 0.36_{\text{stat}} \pm 0.22_{\text{syst}}$ consistent with the SM expectation of 1 [18].

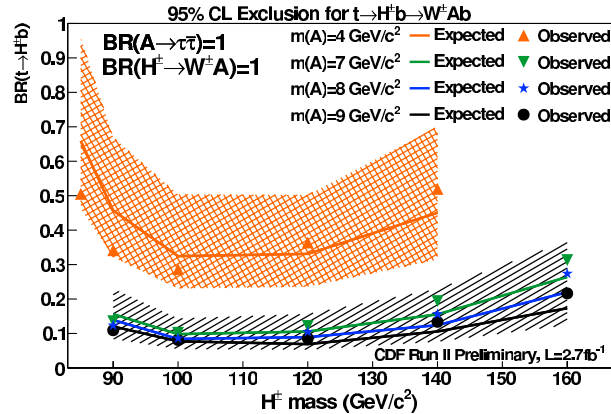


Fig. 4. – Limits on the contribution of a CP-odd Higgs boson to top quark decays [15].

5. – Summary

The Tevatron experiments CDF and D0 have investigated top quark decays for various rare and BSM channel. The analyses presented use up to 7.5 fb^{-1} of $p\bar{p}$ collisions with $\sqrt{s} = 1.96 \text{ TeV}$. The results obtained probe the top quark decay down to the several percent level. So far no significant deviation from the SM model was seen.

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