Recent top physics results from the D0 experiment

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Abstract

We review recent measurements of the properties of the top quark by the D0 experiment: the decay width of the top quark, the CKM matrix element V_{tb}, the helicity of the W boson, anomalous couplings at the Wtb vertex, violation of invariance under Lorentz transformations, and the asymmetry of $t\bar{t}$ production due to the strong colour charge. The measurements are performed using data samples of up to 5.4 fb^{-1} acquired by the D0 experiment in Run II of the Fermilab Tevatron $p\bar{p}$ collider at a centre-of-mass energy of $\sqrt{s} = 1.96$ TeV.

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The pair-production of the top quark was discovered in 1995 by the CDF and D0 experiments [1] at the Fermilab Tevatron proton-antiproton collider. Observation of the electroweak (EW) production of single top quarks was presented only 3 years ago [2]. The large top quark mass of 173.2 ± 0.9 GeV [3] and the resulting Yukawa coupling of about 0.996 ± 0.006 suggest that the top quark could play a crucial role in EW symmetry breaking. Precise measurements of the properties of the top quark provide a crucial test of the consistency of the standard model (SM) and could hint at physics beyond the SM. The full listing of top quark measurements by the D0 experiment can be found in Ref. [4].

At the Tevatron, top quarks are mostly produced in pairs via the strong interaction. In the framework of the SM, the top quark decays to a W boson and a b quark nearly 100% of the time, resulting in a $W^+W^-b\bar{b}$ final state from top quark pair production. Thus, $t\bar{t}$ events are classified according to the W boson decay channels as "dileptonic", "all–jets", or "lepton+jets". The EW production of single top quarks is classified via s and t channel, as well as associated Wt production.

We extract the total decay width of the top quark [5] from the partial decay width $\Gamma_{t\to Wb}$, measured using the t-channel cross section for single top quark production [6], and from the branching fraction $\mathcal{B}_{t\to Wb}$, measured in $t\bar{t}$ events [7], from up to 5.4 fb^{-1} of data. This extraction is made under the assumption that the EW coupling in top quark production is identical to that in the decay, and using the next-to-leading order (NLO) calculation of the *ratio* $\Gamma^{\text{SM}}_{t\to Wb}/\sigma^{\text{SM}}_{t-\text{channel}}$, i.e. $\Gamma_t = \frac{\sigma_{t-\text{channel}}}{\mathcal{B}_{t\to Wb}} \times \frac{\Gamma^{\text{SM}}_{t\to Wb}}{\sigma^{\text{SM}}_{t-\text{channel}}}$.

Properly taking into account all systematic uncertainties and their correlations among the measurements of $\Gamma_{t \to Wb}$ and $\sigma_{t-\text{channel}}$, we find $\Gamma_t = 2.00^{+0.47}_{-0.43}$ GeV, which translates into a top-quark lifetime of $\tau_t = (3.3^{+0.9}_{-0.6}) \times 10^{-25}$ s, in agreement with the SM expectation. This constitutes the world's most precise indirect determination of Γ_t to date. Furthermore, we use the t-channel discriminant of the above measurement to extract a limit of $|V_{tb}| > 0.81$ at 95% C.L., without the commonly made assumptions that $t \to Wb$ exclusively, or on the relative s and t channel rates.

In the SM, the top quark decays into a W boson and a b quark with a probability of $> 99.8\%$, where the on-shell W boson can be in a left-handed, longitudinal, and right-handed helicity state. A NLO calculation in the SM predicts $f_- = 0.301$, $f_0 = 0.698$, and $f_+ = 4.1 \times 10^{-4}$, respectively. A deviation from the SM expectation could indicate a contribution from new physics. We simultaneously measured the f_0 and f_+ helicity fractions in the dilepton and $\ell + \text{jets}$ final states using 5.4 fb^{-1} of data [8]. A model-independent fit to the distribution in $\cos \theta^*$, where θ^* is the angle between the three-momentum of the top quark and the down-type fermion in the W boson rest frame, yields $f_0 = 0.67 \pm 0.10$ and $f_+ = 0.02 \pm 0.05$, in agreement with the SM expectation. The combination with measurements by CDF in the dilepton and $\ell+\text{jets}$ final states using up to 4.8 fb^{-1} yields $f_0 = 0.72 \pm 0.08$ and $f_+ = -0.03 \pm 0.46$ [9].

The SM provides a purely left-handed vector coupling at the Wtb vertex, while the most general and lowest-dimension effective Lagrangian allows a right-handed vector coupling f_V^R as well as tensor couplings f_T^L and f_T^R. We extracted limits on those anomalous couplings from single top production in 5.4 fb^{-1} using both shapes of kinematic distributions as well as the overall and s versus t channel event rates [10]. This was done under the assumption of real, i.e. CP-conserving couplings and a spin 1/2 top quark predominantly decaying to Wb. The results are shown in Table 1. Furthermore, we exploit that anomalous couplings at the Wtb vertex will alter the rates of the three helicity states of W bosons in $t\bar{t}$ decays, and combine the above analysis with the one in Ref. [8] to obtain improved limits [11], shown in Table 1.

Scenario	W helicity only	single top only	combination
$|f_V^R|^2$	0.62	0.89	0.30
$|f_T^L|^2$	0.14	0.07	0.05
$|f_T^R|^2$	0.18	0.18	0.12

Table 1: Observed upper limits on anomalous Wtb couplings at 95% C.L. from W boson helicity assuming $f_V^L = 1$, from the analysis of single top events, and their combination, for which no assumption on f_V^L is made, using 5.4 fb^{-1}.

Invariance under Lorentz transformations is a fundamental property of the SM. We performed a search for Lorentz invariance violation (LIV) by examining the $t\bar{t}$

production cross section in $\ell+$jets final states using 5.3 fb^{-1} [12]. We quantified LIV in the top sector using in the SM Extension (SME) formalism [13], which parametrises the amount of LIV in terms of bilinear coefficients and results in a $t\bar{t}$ production rate which is modulated in full or half-units of a siderial day due to the rotation of the Earth. Thus, we investigate the $t\bar{t}$ production rate in 12 bins of the siderial phase, normalised by the recorded luminosity per bin. Our results are consistent with the SM hypothesis, and we proceed to set limits on LIV [12].

In the SM, the pair production of top quarks in $p\bar{p}$ collisions, a CP eigenstate, is symmetric at LO under charge conjugation. NLO calculations predict a small forward-backward asymmetry A_{fb} of the order of 5% in the $t\bar{t}$ rest frame. It is due to a negative contribution from the interference of diagrams for initial and final state radiation, and a (larger) positive contribution from the interference of box and tree-level diagrams. This experimental situation is unique to the Tevatron. A convenient observable for the Tevatron is $A_{\text{fb}} \equiv \frac{N^{\Delta y>0}-N^{\Delta y<0}}{N^{\Delta y>0}+N^{\Delta y<0}}$, where $\Delta y \equiv y_t - y_{\bar{t}}$, y_t ($y_{\bar{t}}$) is the rapidity of the t ($\bar{t}$) quark. Another common observable does not depend on a full reconstruction of the $t\bar{t}$ system: $A_{\text{fb}}^{\ell} \equiv \frac{N^{q_\ell y_\ell>0}-N^{q_\ell y_\ell<0}}{N^{q_\ell y_\ell>0}+N^{q_\ell y_\ell<0}}$, where q_ℓ is the lepton charge.
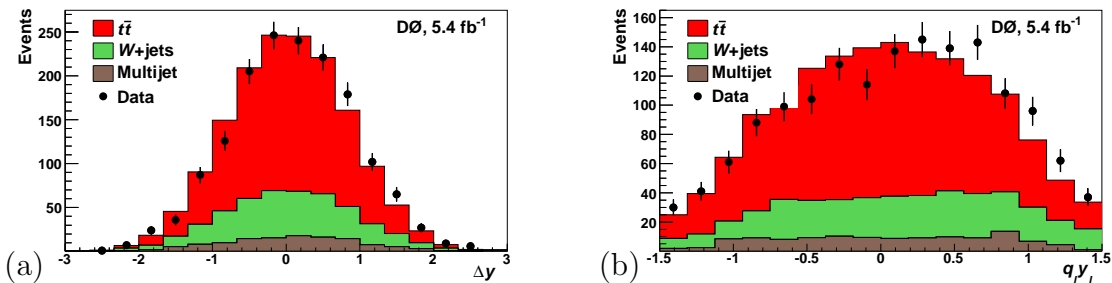

Figure 1: **(a)** The reconstructed distribution in Δy in $\ell+$ jets final states using 5.4 fb^{-1}. **(b)** The reconstructed distribution in charge-signed lepton rapidity $q_\ell y_\ell$.

We measured A_{fb} in the $t\bar{t}$ rest frame in $\ell+$ jets final states on a dataset corresponding to 5.4 fb^{-1} using $t\bar{t}$ event candidates fully reconstructed with a kinematic fitter, and found $A_{\text{fb}} = 9.2\% \pm 3.7\%$ at the reconstruction level [14]. Our result, shown in Fig. 1 (a), is about 1.9 standard deviations (SD) away from the MC@NLO [15] prediction of $2.4 \pm 0.7\%$. After correcting for detector acceptance and resolution we find $A_{\text{fb}} = 19.6 \pm 6.5\%$, 2.4 SD away from the MC@NLO prediction of $5.0 \pm 0.1\%$. In addtion, we measured A_{fb} in various subsamples defined by $m_{t\bar{t}} \lessgtr 450$ GeV and by $|\Delta y| \lessgtr 1.0$. We do not find any statistically significant dependencies. Furthermore, we have measured the lepton-based asymmetry and find $A_{\text{fb}}^{\ell} = 14.2 \pm 3.8\%$ and $15.2 \pm 4.0\%$ at reconstruction and parton level, respectively, while MC@NLO predicts $A_{\text{fb}}^{\ell} = 0.8 \pm 0.6\%$ and $2.1 \pm 0.1\%$. Our results display some tension with the NLO SM

prediction. This may indicate a contribution from new physics, but may as well be due to contributions at higher orders in α_s within the SM.

I presented recent measurements of key properties of the top quark by the D0 experiment, most in good agreement with SM expectations. The forward-backward asymmetry A_{fb} of $t\bar{t}$ production displays tension between the measurement and the SM NLO calculations. We look forward to updates with the full dataset of 9.7 fb^{-1} in the near future. I would like to thank my fellow D0 collaborators and also the staffs at Fermilab and collaborating institutions, as well as the D0 funding agencies.

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