Top quark physics at CDF

Costas Vellidis[1]

[1]FNAL, Batavia, IL 60510, USA

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We present recent measurements from CDF of spin correlations, of the top decay relative branching ratio BR(t→Wb)/Σ_qBR(t→Wq) and the derived indirect constraint on the $|V_{tb}|$ CKM matrix element, of the single top production cross section and the derived direct constraint on $|V_{tb}|$, and of the forward-backward asymmetry in top pair production.

1 Measurements

In the standard model (SM) top quark pairs are produced in a definite spin state depending on the production mechanism: in a spin 1 state via quark pair annihilation (∼85% at the Tevatron) or in a spin 0 state via gluon fusion (∼15% at the Tevatron). Since the top quark decays before hadronization, the spin information is passed to the decay products and thus the spin correlation of the top quark pair can be measured from decay product angular distributions. The (frame dependent) correlation strength, in a frame with spin quantization axis in the direction of the colliding beams, is predicted by the SM to be $\kappa^{SM}_{beam} = 0.78^{+0.03}_{-0.04}$ [1] and is measured at CDF to be $\kappa^{ll}_{beam} = 0.04 \pm 0.56$ [2] in the dilepton channel and $\kappa^{lj}_{beam} = 0.72 \pm 0.69$ [3] in the lepton+jets channel. The measurements are done by fitting Monte Carlo (MC) angular distribution templates to data corresponding to 5.1 fb^{-1} and 5.3 fb^{-1} of integrated luminosity, respectively.

In the SM the top quark decays into a W boson and a b quark almost 100% of the time. Therefore, two b quarks are expected in each top pair event. The finite b-tagging efficiency determines the size of top pair event samples with 0, 1, or 2 tagged jets. The ratio R = BR(t→Wb)/Σ_qBR(t→Wq), where q = d, s, or b, is measured at CDF from the size of each subsample via a 2D likelihood fit to data corresponding to the full integrated luminosity of 8.7 fb^{-1}, simultaneosuly with the top pair production cross section $\sigma(p\bar{p} \to t\bar{t})$. The results are R = 0.94±0.09 and $\sigma(p\bar{p} \to t\bar{t})$ = 7.5±1.0 pb [4]. Then R is used to constrain the CKM matrix element $|V_{tb}|$ to be 0.97±0.05 or $|V_{tb}|$>0.89 at 95% confidence level (CL), assuming a unitary 3×3 CKM matrix [4].

Single top quarks are produced via electroweak (EW) interaction mechanisms, by the exchange of a W boson in the s or t channel. Single top production in association with a W boson is very suppressed at the Tevatron but is included for consistency in the signal model. The measurement of the single top production cross section is an important test of the SM as it is sensitive to new physics, such as flavor-changing neutral currents, heavy weak bosons W′ and CP violation, and also provides a direct measurement of $|V_{tb}|$. It is experimentally challenging because it requires the extraction of a small signal out of a large background with large uncertainty. The measurement is based on the use of neural network to discriminate

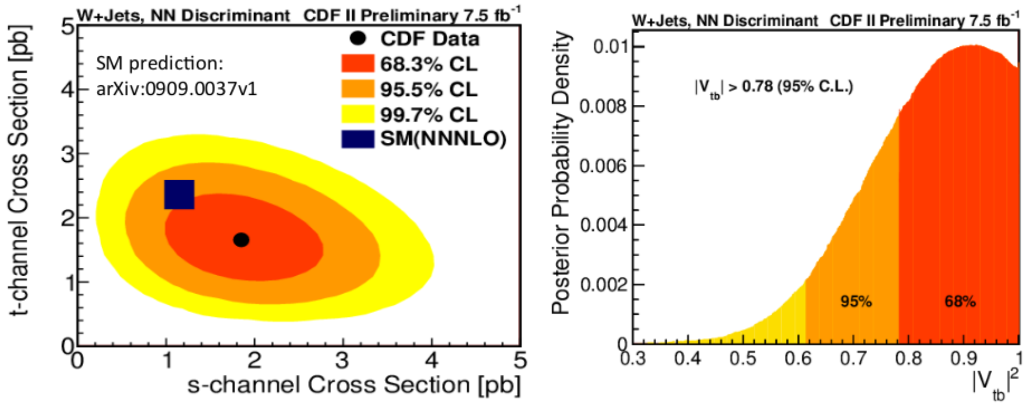

Figure 1: **Left:** 1-, 2- and 3-σ contour plots of the 2D single top cross section fit to the data, compared with the SM prediction. **Right:** 1- and 2-σ exclusion of $|\mathrm{V_{tb}}|^2$ values.

the signal from the background assuming a top quark mass of 172.5 GeV/c^2 and using data corresponding to 7.5 fb^{-1} of integrated luminosity. Figure 1 shows the 2D fit result of the s- and t-channel production cross section, compared with the SM prediction [5], and the 68% and 95% CL limits on $|\mathrm{V_{tb}}|$ derived from the 1D fit of the combined s+t-channel cross section [6]. The results are $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb, $\sigma_t = 1.49^{+0.47}_{-0.42}$ pb, $\sigma_{s+t} = 3.04^{+0.57}_{-0.53}$ pb and $|\mathrm{V_{tb}}| = 0.92^{+0.10}_{-0.08}$(stat.+syst.)$\pm$0.05(theory).

In the SM top pairs are produced isotropically in leading order (LO). Next-to-leading order (NLO) quantum chromodynamics (QCD) predicts a small forward-backward asymmetry $\mathrm{A_{FB}}$ in the rapidity difference $\Delta y = y_t - y_{\bar{t}}$ distribution. A calculation using the NLO QCD program POWHEG [7], corrected for EW terms at NLO [8], gives an inclusive asymmetry of 6.6%. The forward-backward asymmetry has been measured at the Tevatron using about half the data set, with the results summarized in Table 1. The results show an unexpectedly large asymmetry.

Measurement	Parton Level $\mathrm{A_{FB}}$ (%)
CDF Lepton+Jets[9]	15.8±7.4
CDF Dilepton[10]	42±16
CDF Dilepton[11]	20.1±6.7
D0 Lepton+Jets[12]	19.6±6.5

Table 1: Tevatron $\mathrm{A_{FB}}$ measurements using data corresponding to ~5 fb^{-1} of integrated luminosity.

To investigate further this property of top pair production, particularly the dependencies on sensitive kinematic variables, CDF measured the asymmetry using the full data set corresponding to 8.7 fb^{-1} of integrated luminosity [13].The inclusive result is shown in Figure 2. The kinematic dependencies of the asymmetry are shown in Figure 3. Parton level shape corrections use a regularized unfolding algorithm to avoid instabilities arising from the statistical fluctuations. The dependencies are well approximated by a linear model. Both the magnitude of

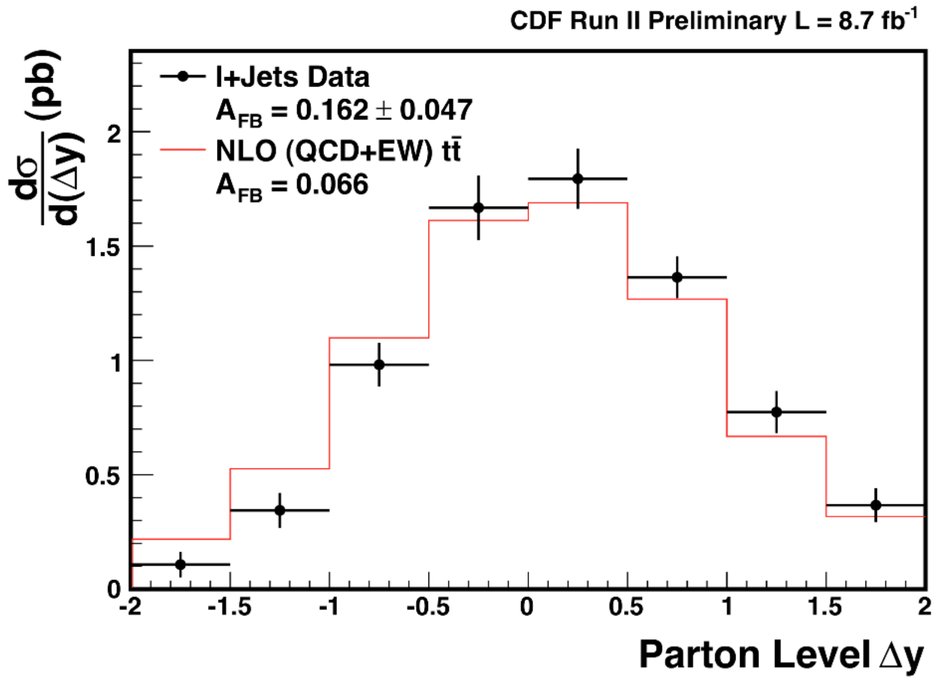

Figure 2: The $t\bar{t}$ production cross sectionin the lepton+jets channel, differential in the $t - \bar{t}$ rapidity difference, measured with the full CDF data set and compared with a NLO QCD+EW calculation.

inclusive result and the slopes of the differential asymmetries are stronger than the predictions of the NLO QCD+EW calculations at the level of 2.0σ - 2.5σ.

Several possibilities are examined to explain the discrepancy between the predicted and observed asymmetry. One possibility is a mismodeling within the SM such as mismodeled top pair transverse momentum spectrum or missing higher order corrections. Another possibility is new physics: many models have been proposed to interpret the measured asymmetry such as axigluon or heavy boson (Z', W') exhange models. Measurements of other top quark properties, such as differential cross sections and spin observables, can help differentiate between the various possibilities and are currently pursued at CDF.

2 Summary

We reported high precision measurements of spin correlations, branching ratio, single top production cross section and forward-backward asymmetry in top pair production from CDF.

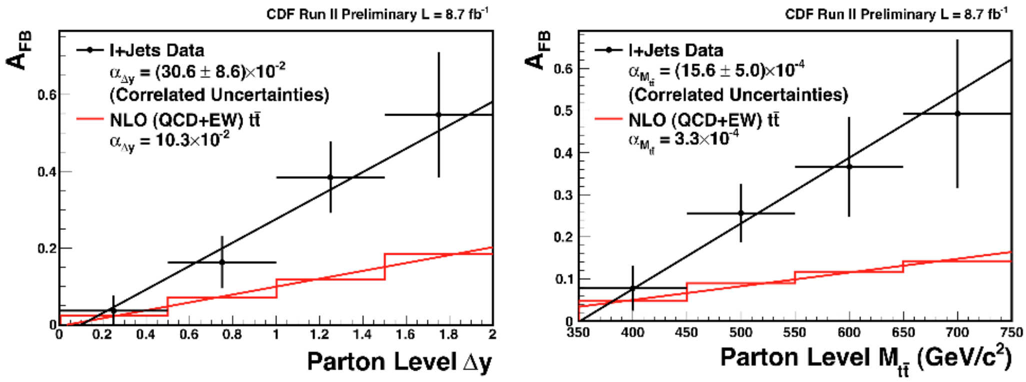

Figure 3: The forward-backward asymmetry, differential in the $t - \bar{t}$ rapidity difference (left) and in the $t\bar{t}$ invariant mass (right), measured with the full CDF data set and compared with NLO QCD+EW calculations.

Constraints on the $|V_{tb}|$ CKM matrix element are also imposed by the single top and branching ratio measurements. In general, good agreement with the standard model is observed. Exception is the asymmetry which appears stronger in magnitude and with stronger kinematic dependencies than the NLO QCD+EW predictions at the level of 2σ.

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