DØ TOP PHYSICS

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The Tevatron proton–antiproton collider at Fermilab operates at a centre of mass energy of 1.96 TeV and is currently the only source for the production of top quarks. Recent DØ results on the top quark's production cross section and its properties such as mass, helicity of the W in its decay and branching fraction $B(t \to Wb)$ are presented, and probe the validity of the Standard Model (SM).

1. Introduction

The top quark, which completes the quark sector of the SM, was discovered in 1995 at the Tevatron by the CDF and DØ Collaborations [1]. Being the heaviest of all quarks with a mass of 178.0 ± 4.3 GeV/c^2 [2], it couples most strongly to the Higgs boson, and its lifetime of $\approx 4 \cdot 10^{-25}$ s means that it is the only quark that decays before it can hadronise, preserving spin information, and providing a way to study the decay of an essentially free quark. Measuring the production cross section of the top quark and its different properties such as mass, W helicity in its decay, branching fraction $B(t \to Wb)$, *etc.*, and comparing with predictions of the SM is a very powerful tool for searching for physics beyond the SM.

2. Top quark production at the Tevatron

In $p\overline{p}$ collisions at a centre of mass energy $\sqrt{s} = 1.96$ TeV, top quarks are produced predominantly in pairs: $p\overline{p} \to t\bar{t}$ + X via the strong interaction (85% $q\overline{q}$ annihilation and 15% gluon-gluon fusion). At next-to-next-to-leading order, the corresponding SM cross section is 6.77 ± 0.42 pb [3]. According to the SM, the top quark decays predominantly into W bosons and b quarks. Hence, there are three event classes to be observed resulting from $t\bar{t}$ decay, which depend on the decay mode of the W bosons: (i) a dilepton final state where both W bosons decay leptonically, resulting in two isolated high-p_T leptons, missing transverse energy $\not\!\!E_T$ corresponding to the two neutrinos and two jets, (*ii*) a lepton+jets final state where one W boson decays leptonically, the other one hadronically, resulting in one isolated high-p_T lepton, $\not\!\!E_T$ and four jets, and (*iii*) an all-jets final state where both W bosons decay to $\overline{q}q'$ pairs producing six jets. In all final states, two of the jets are b-jets, and additional jets can arise from ISR/FSR. The all-jets final state represents the biggest branching fraction of $t\bar{t}$ events (≈46%), but it is also difficult to separate from a big multijet background. The dilepton final state without τ leptons constitutes ≈5% of the $t\bar{t}$ events and gives the cleanest signal, but also suffers from low statistics. The lepton+jets events in the e+jets or μ+jets channels yield ≈29% of the branching fraction and provide the best compromise between sample purity and statistics.

In addition to $t\bar{t}$ pair production, top quarks can also be produced singly via the electroweak interaction through a Wtb vertex. A measurement of single top quark production consequently provides direct access to the CKM matrix element V_{tb}. Depending on the virtuality (squared four-momentum) of the participating W boson (Q^2_W), there are two contributions: the s-channel $q'\bar{q} \rightarrow t\bar{b}$ ($Q^2_W > 0$), with a predicted cross section of 0.88 ± 0.05 pb [4], and the t-channel $q'g \rightarrow tq\bar{b}$ ($Q^2_W < 0$), with a predicted cross section of 1.98 $^{+0.28}_{-0.22}$ pb [5]. The contribution from single top production in both s and t channels of $bg \rightarrow tW$ can be neglected at Tevatron energies [6].

We present only results from leptonic channels containing a muon or an electron, and $W \rightarrow \tau$ decays are therefore included in a partial way, depending on the τ decay mode.

3. Measurement of the t$\bar{\text{t}}$ production cross section

The $t\bar{t}$ pair production cross section has been measured by DØ in several decay modes, using either purely topological and kinematic event properties to separate the $t\bar{t}$ signal from background, or by adding identification of b-jets based mainly on the long lifetime of B hadrons. Several algorithms are deployed for b-jet identification, *e.g.*, searching for muons in jets resulting from semileptonic B decays (soft-μ tag) or using reconstructed secondary vertices (SVT), or the significance of impact parameters of tracks within jets relative to primary vertices (CSIP). The probability to tag at least one jet in a $t\bar{t}$ lepton+jets event by its lifetime is ≈60%, whereas the main background from W+jets production is tagged in only ≈4% of the cases, resulting in an improved signal to background ratio in tagged analyses. An advantage of topological analyses is that they do not depend on the assumption of 100% branching of $B(t \rightarrow Wb)$, and are therefore less model-dependent than tagging analyses. Analysing different decay channels helps to improve statistics of top events, and studies of properties, as well as probing of physics beyond the SM that could result in enhancement/depletion in some particular channel. Figure 1 shows an overview of all cross section measurements performed thus far at DØ. We find that all measurements are in good agreement with the SM and with each other.

4. Measurement of the top quark mass

The top quark mass is a fundamental parameter that is not predicted by the SM, but can be used together with the W mass to constrain the mass of the Higgs boson via radiative corrections. DØ has measured the top quark mass in the lepton+jets and dilepton channels using different techniques: In the lepton+jets channel, a kinematically-constrained fit is used to extract the top quark mass from preselected events, using either template mass spectra for signal and background (template method) or an analytical likelihood for calculating the probability for any event to be signal or background (ideogram method). In the dilepton channel, of the 6-particle final state, only four objects are detected together with $\not{E}_T$, which provides an underconstrained problem. As proposed by Dalitz, Goldstein [7] and Kondo [8], a hypothesised value of the top quark mass can be used to solve for the $t\bar{t}$ momenta. The solutions yield a weight distribution for each preselected event as a function of the top quark mass. Using its peak as an estimator of the mass for each event, and comparing the resulting distribution from all preselected events to signal and background templates, provides an estimate of the top quark mass. All the measurements are shown in Fig. 1, and all are in agreement with the current world average [2]. The final goal is to measure the top quark mass with 1% precision in Run II.

5. Measurement of the W helicity in $t\bar{t}$ decays

Top quark decay in the V−A charged current weak interaction proceeds only via a left-handed (f^{-}= 30%) and a longitudinal (f^{0}=70%) fraction of W helicities, which is reflected in the angular distribution of the charged lepton relative to the line of flight of the top quark in the W rest frame in lepton+jets final states. Using data corresponding to integrated luminosities of 169 pb^{-1} (e+jets) and 158 pb^{-1} (μ+jets), and comparing the above mentioned angular distribution in data to templates, where we set f^0 to its SM value, and vary the right-handed fraction f^+, and correspondingly

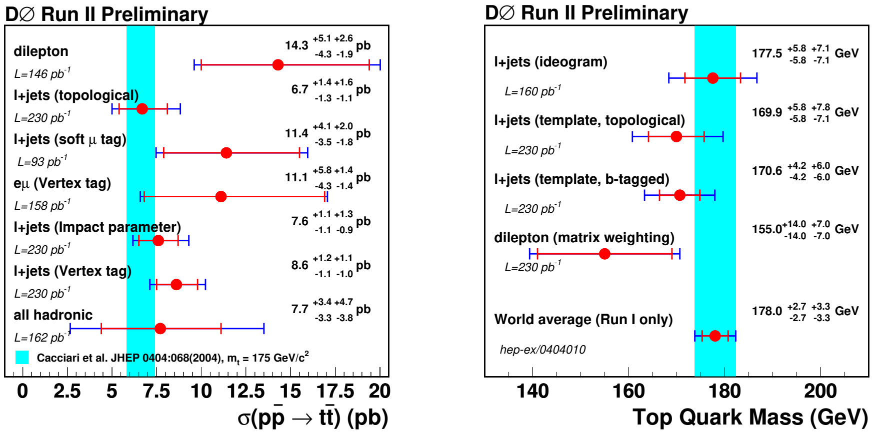

Figure 1. Left: $t\bar{t}$ pair production cross section as measured by DØ in Run II, and the SM prediction. Right: Top quark mass measurements from DØ in Run II compared to the world average based on Run I measurements.

f^-, between 30% and 0%, we obtain an upper limit on f^+ from a binned likelihood fit of:

$$f^+ < 0.24 \text{ (90\% CL)},$$

in agreement with expectation from the SM.

6. Measurement of B($t \to Wb$) / B($t \to Wq$)

The ratio of branching fractions R = B($t \to Wb$) / $\Sigma_{q=d,s,b}$ B($t \to Wq$) is constrained within the SM to $0.9980 < R < 0.9984$ at 90% CL [9], assuming three fermion generations, unitarity of the CKM matrix and neglect of non-W decays of the top quark. DØ has measured R in the lepton+jets channel using data corresponding to integrated luminosities of 169 pb^{-1} (e+jets) and 158 pb^{-1} (μ+jets), by comparing the number of single to double b-tagged events, using one b-jet to identify the $t\bar{t}$ event and the second one for the measurement of the relative fraction of $t \to Wb$. For example, applying the SVT algorithm for b-tagging, we obtain the following result for R from a simultaneous fit of R and the $t\bar{t}$ cross section:

$$R = 0.70^{+0.27}_{-0.24}\,\text{(stat)}\;^{+0.11}_{-0.10}\,\text{(syst)}.$$

This agrees with the SM expectation.

7. Search for single top quark production

Thus far, the search for single top quark production has been performed only for the cases where the W boson decays into an electron or muon and neutrino, resulting in final states with one isolated high-p_T lepton, $\not\!\!E_T$ and two or three jets. Using data for an integrated luminosity of 230 pb^{-1}, with selections optimised for leptonic W decays, maximal acceptance of signal and good modelling of the remaining backgrounds, a set of common discriminating variables is used to separate signal from the background. One analysis is based on classical cutoff criteria, optimised via a random grid search, and another on a multivariate (neural nets/decision trees) analysis. The neural network analysis gives the best limits:

$$\sigma_s < 6.4\,\text{pb}\,(95\%\ \text{CL}), \qquad \sigma_t < 5.0\,\text{pb}\,(95\%\ \text{CL}).$$

These limits represent a factor of two improvement relative to all other measurements, and are in agreement with expectations from the SM.

8. Summary

A wealth of top analyses is being pursued at DØ, continuing to probe the validity of the SM. So far, all measurements are in agreement with the SM. More detailed descriptions of the analyses can be found online [10]. Continuously improving the analysis methods, and using the increasing integrated luminosity from a smoothly running Tevatron, expected to deliver more than 4 fb^{-1} by the end of Run II, we are moving towards precision measurements and hopefully discoveries within and outside the SM.

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