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Top Quark Physics at CDF

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Abstract

The existence of the top quark, discovered by CDF and DØ in 1995, has been re-established in the burgeoning dataset being collected in Run 2 of the Tevatron at Fermilab. Results from CDF on the top quark production cross section and top quark mass are consistent with the Standard Model expectations. The well-characterized top data samples will make it possible in the future to probe further for new physics in the top quark sector.

Introduction

Since its 1995 discovery at CDF and DØ[1], the top quark has been identified as a possible window into electroweak symmetry breaking and even into physics beyond the Standard Model. Run 2 at the Fermilab Tevatron, with proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV, offers a unique chance to expand the world's top quark data sample and to enhance our knowledge of the physics of the top quark. Top physics at CDF also provides a testbench for tools and techniques which will be useful for physics analysis at future hadron colliders, especially the LHC.

1 Properties of the Top Quark in the Standard Model

Top quark pair production at the Tevatron proceeds predominantly through quark-antiquark annihilation, although gluon fusion contributes about 15% of the total cross section; single top production is suppressed by a factor of two relative to $t\bar{t}$ production.

The large mass of the top quark (roughly $175 \text{ GeV}/c^2$) impacts its phenomenology significantly. Unitarity constraints in the CKM matrix require large

values for V_{tb} , so a heavy top quark decays to a W boson and b quark. In fact, the decay occurs before hadronization can take place. The experimental signature for $t\bar{t}$ production is 2 b jets along with decay products from two W bosons, be they leptons or hadronic jets.

2 Top Quark Pair Production Cross Section

The measurement of the top quark production cross section is important for two reasons. First, it may give us the first signs of new physics related to top quarks. Second, even if there are no surprises, the measurement establishes and validates the data samples in which we study top quarks.

Analyses in the dilepton channel select events in which both W bosons decay leptonically. The signature of lepton + missing transverse energy + 2 jets is clean but suffers from limited statistics. Two dilepton event selections, one requiring two identified leptons (currently limited to electrons and muons), and one requiring an identified lepton plus an isolated track, result in tight and loose dilepton samples which yield cross sections consistent with each other and with Standard Model predictions. Figure 1 shows the missing transverse energy distribution for events passing the lepton + track selection; the characterization of the sample is quite complete.

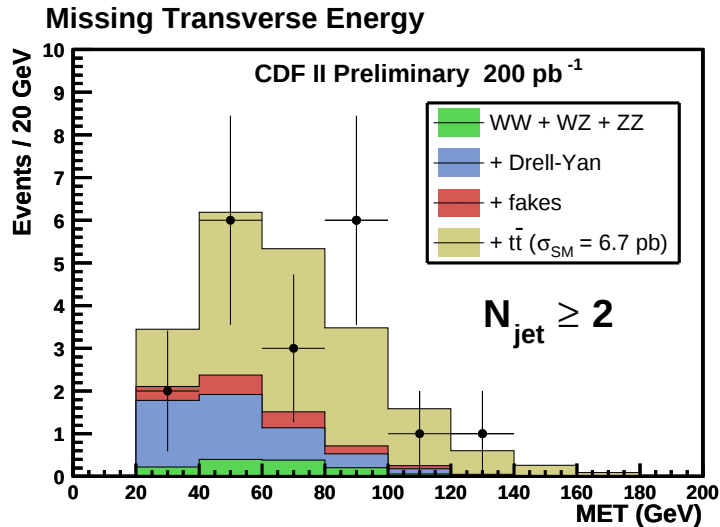


Figure 1: Missing transverse energy in events passing the lepton + track top dilepton selection.

Analyses in the lepton + jets channel select events in which only one W decays leptonically. The sample size is larger than the dilepton sample, but there is significant background contamination in this selection. Judicious use of b-jet

tagging can improve the purity of the sample. We have developed a secondary vertex tagger, which is sensitive to the long lifetime of b quarks, as well as a soft muon tag, which is sensitive to b quark semileptonic decay. Figure 2 shows the results from a vertex-tagged selection as a function of number of hadronic jets; the excess in the 3- and 4-jet bins above predicted background is interpreted as $t\bar{t}$ production. It's also possible to estimate the top signal fraction by fitting kinematic distributions to a sum of signal and background templates. This allows us to measure a cross section even without any b-tagging.

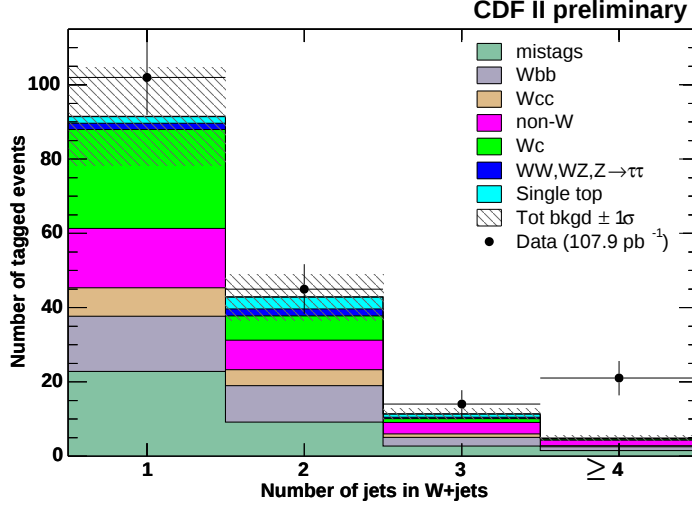


Figure 2: Number of jets with $|\eta| < 2$ and $E_T > 15$ GeV for vertex-tagged events in the lepton + jets top sample .

Results from the various top quark pair production cross sections are summarized in Figure 3. The results from the two different topologies are consistent, as are results from b-tagged samples and untagged samples. The experimental results from CDF are entirely consistent with the Standard Model prediction[2] of $6.7^{+0.7}_{-0.9}$ pb at $m_t = 175$ GeV/ c^2 .

3 Top Quark Mass Measurements

Measuring the top quark mass to high precision is one of the main physics objectives of the Tevatron Run 2 program. The top quark mass measurement itself presents several challenges. Chief among them is the calibration of jet energies, relating the detector-level observables to parton-level energies. Another difficulty is the assignment of jets to the correct partons in top decay.

Two preliminary results represent our first measurements of the top mass in Run 2. The first method, in the vertex-tagged lepton + jets sample, fits

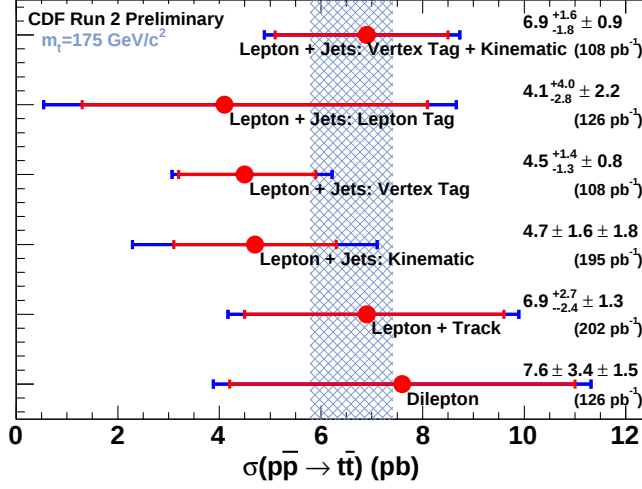


Figure 3: Summary of CDF top pair production cross section measurements.

the reconstructed mass spectrum to Monte Carlo-based templates to obtain $m_t = 177.5^{+12.7}_{-9.4}(\text{stat.}) \pm 7.1(\text{syst.}) \text{ GeV}/c^2$ (Fig. 4). The second method, in the dilepton sample, uses a similar template approach to derive $m_t = 175 \pm 17(\text{stat.}) \pm 8(\text{syst.}) \text{ GeV}/c^2$.

4 Future Measurements of Top Quark Characteristics

As the amount of collected Run 2 data increases over the next few years, CDF's top quark sample will grow, and systematic uncertainties which are determined from the data will decrease significantly. We can therefore expect from CDF ever more precise measurements of the top quark's properties. A larger data sample will also make possible new measurements of the top quark, including branching ratio constraints, $t\bar{t}$ kinematics and possible $t\bar{t}$ resonances, helicity of W bosons from top decay, and the search for single top production. In addition to other as-yet-unknown possibilities, this ensures that top quark physics will continue to be rich with opportunity in Run 2 at CDF.

Acknowledgments

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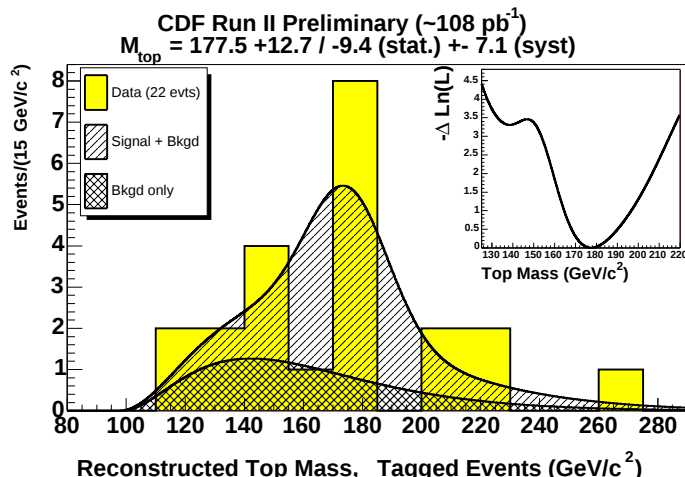


Figure 4: Final mass template fit for vertex-tagged lepton + jets top sample.

for the stimulating scientific program and to thank them for their gracious hospitality.

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