TOP QUARK PROPERTIES AT THE TEVATRON

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The Tevatron experiments CDF and DØ have analyzed up to 750 pb^{-1} of Run II data, leading to high precision measurements of the top quark mass. Their combination yields a new preliminary world average of $m_t = 172.5 \pm 2.3$ GeV, corresponding to a precision of 1.3%. An overview of the top quark measurements is presented, as well as a selection of the latest results regarding other top quark properties accessible at the Tevatron.

1. Top Quarks at the Tevatron

In $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, top quarks are predominantly produced in pairs via the strong interaction. According to the Standard Model, the top quarks subsequently decay into a b quark and a W boson. Several analysis channels are classified based on the decay modes of the two W bosons. With $300 - 750$ pb^{-1} of data, the most precise measurements are currently obtained int the *lepton+jets* channel. Here, one W boson decays leptonically in either an electron or muon and the corresponding neutrino, and the other W boson decays hadronically. Consequently, this final state is characterized by the presence of one high energetic isolated electron or muon, significant missing transverse energy $\not{E}_T$ due to the undetected neutrino, and four or more calorimeter jets. The *dilepton* channel allows for the extraction of a much cleaner signal. Measurements in this channel are currently still limited by the statistical uncertainty. With several fb^{-1} of Tevatron data, their importance in the world average will increase relative to the lepton+jets measurements. In a $t\bar{t}$ event, two of the calorimeter jets in these final states originate from a b quark, and both CDF and DØ utilize lifetime tagging algorithms to identify them, based on the charged particle tracks associated with each jet. Final states involving τ leptons or no lepton at all are not considered here, but current efforts forecast significant contributions from these channels in the near future.

2. Top Quark Mass Measurements

The best single measurement of the top quark mass is currently extracted with the *template method* [1] from lepton+jets events at CDF. For each event, the top quark mass is reconstructed using a kinematic fit to the $t\bar{t}$ hypothesis. The distribution of reconstructed top quark masses in the data sample is then compared to template distributions from Monte Carlo simulated events with various top quark masses, using an unbinned likelihood fit. The sample is subdivided according to the number of b-tagged jets to optimize the statistical power of the method, as illustrated in Figure 1 (Left). The top quark mass is measured to be $m_{\mathrm{t}} = 173.4 \pm 2.5$ (stat. + JES) ± 1.3 (syst.) GeV.

The statistically most powerful method, employed by both the CDF and DØ collaboration, is the *matrix element method* [2]. For each event, the probabilities to originate from the signal and background processes are computed, based on the respective matrix elements and parametrized detector resolutions. The top quark mass is extracted by minimizing the joint likelihood of all event probabilities. This method is applied by both CDF and DØ to lepton+jets events, and CDF uses it in the dilepton channel as well. Even though the CDF lepton+jets measurement is limited to a subsample of the template measurement described above, it yields about the same precision: $m_{\mathrm{t}} = 174.1 \pm 2.5$ (stat. + JES) ± 1.3 (syst.) GeV.

To minimize the total uncertainty on top quark mass measurements in the lepton+jets channel, both experiments use a constraint of the mass of the hadronically decaying W boson to reduce the dominant systematic uncertainty due to the jet energy scale calibration. In Figure 1 (Right) the result of the DØ lepton+jets matrix element measurement is shown in the top mass vs jet energy scale plane.

The combination of all relevant Run I and Run II measurements from CDF and DØ yields the current world average of $m_{\mathrm{t}} = 172.5 \pm 2.3$ GeV [3], see Figure 2.

3. Measurements of other Top Quark Properties

The Standard Model (SM) precisely determines other top quark properties. Top quark decays therefore offer many opportunities to test these predictions and to search for physics beyond the standard model.

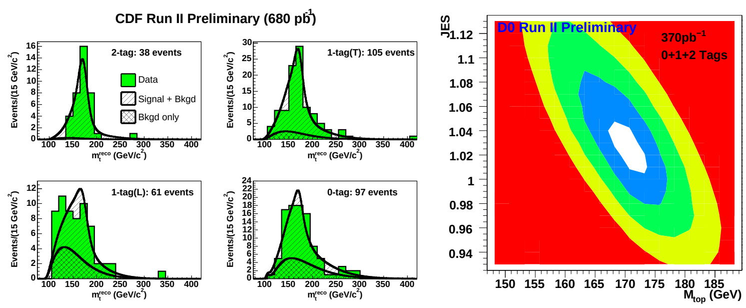

Figure 1. *Left*: Top mass fits to CDF lepton+jets events with the template method. This measurement represents the single most precise determination of $m_{\rm t}$ to date. *Right*: DØ matrix element method: $n-\sigma$ contours in the top mass vs jet energy scale plane.

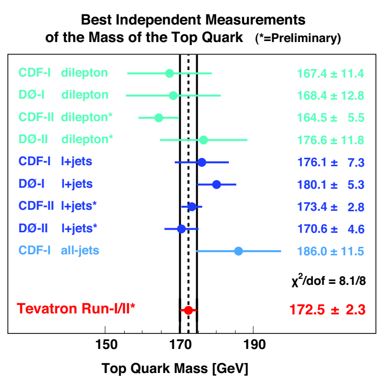

Figure 2. Combination of Run I and Run II results from both CDF and DØ yield the current preliminary world average of $m_{\rm t} = 172.5 \pm 1.3$ (stat.) $\pm$ 1.9 (syst.) GeV.

Because of the V-A structure of the weak interaction, top quark decays to a right-handed polarized W boson are suppressed. CDF and DØ reconstruct top pair decays in lepton+jets and dilepton events and study the lepton $p_{\rm T}$ and $cos\theta^*$ distributions, both sensitive to the W boson polarization. Both find no significant deviation from the SM prediction, and upper 95% $C.L.$ limits on the fraction f^+ of right-handed polarized W bosons are derived: $f^+ < 0.27$ (CDF), and $f^+ < 0.24$ (DØ).

Exotic models predict the existence of a $4^{\rm th}$ quark generation, containing another top-like heavy quark with charge $Q = -4/3e$ [4]. DØ achieves discrimination between the decays $t \rightarrow W^+ b/\bar{t} \rightarrow W^- \bar{b}$ ($Q_t = 2/3e$) and

$t \to W^- b / \bar{t} \to W^+ \bar{b}$ ($Q_t = -4/3e$) by measuring the b-jet charge using associated charged tracks. The exotic scenario of $Q_t = -4/3e$ is ruled out at 94% $C.L.$.

CDF and DØ search the $t\bar{t}$ invariant mass spectrum in lepton+jets events for resonances and find no significant excess w.r.t. the SM expectation. Various topcolor models (e.g. "topcolor assisted technicolor" [5]) predict the existence of a heavy leptophobic neutral gauge boson X. Limits on the mass of such a particle are derived at 95% $C.L.$: $m_X > 725$ GeV (CDF, 682 pb^{-1}), and $m_X > 680$ GeV (DØ, 370 pb^{-1}).

4. Conclusions

With up to 750 pb^{-1} of integrated luminosity per experiment analyzed, the Tevatron has entered an era of high precision determination of the top quark mass. The latest measurements by both CDF and DØ are combined with previous Tevatron results to yield a new preliminary world average [3] of $m_{\rm t} = 172.5 \pm 2.3$ GeV. The dataset is expected to correspond to an integrated luminosity of $4-8$ fb^{-1} by the end of Run II, forecasting a total top quark mass error as low as $\delta m_{\rm t} \sim 1.5$ GeV. These results will remain significant for years to come, even beyond the startup of the LHC.

Top quark pair decays offer numerous possibilities to search for physics beyond the Standard Model. Some of the latest studies are presented and show good agreement with Standard Model predictions. These measurements are statistically limited and will greatly benefit from the increased datasets soon to be available.

References

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