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Direct measurement of the top quark mass in $p\bar{p}$ collisions at D0

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The mass of the top quark is a fundamental parameter of the Standard Model and has to be determined experimentally. In these proceedings, I review recent direct measurements of the top quark mass in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV recorded by the D0 experiment at the Tevatron. The measurements are performed in final states containing one and two charged leptons. I will present the legacy combination of all top quark mass measurements from the D0 experiment and their combination with results from the CDF experiment. A relative precision of down to 0.3% is attained.

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1. Introduction

Since its discovery [1, 2], the determination of the top quark mass m_t, a fundamental parameter of the Standard Model (SM), has been one of the main goals of the CERN Large Hadron Collider (LHC) and of the Fermilab Tevatron Collider. Indeed, m_t and masses of W and Higgs bosons are related through radiative corrections that provide a consistency check of the SM [3]. Furthermore, m_t dominantly affects the stability of the SM Higgs potential [4]. With $m_t = 173.34 \pm 0.76$ GeV, a world-average combined precision of 0.44% has been achieved [5].

In the SM, the top quark decays to a W boson and a b quark nearly 100% of the time. Thus, $t\bar{t}$ events are classified according to W boson decays as "dileptonic" ($\ell\ell$), "lepton+jets" (ℓ+jets), or "all–jets". In the following, I will present recent measurements in the former two channels; a full listing of m_t results from the D0 can be accessed through Ref. [6].

2. Dilepton channel

The most precise single measurement of m_t in the $\ell\ell$ channel at the Tevatron is performed by the D0 Collaboration using 9.7 fb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV [7]. The selection requires two isolated leptons (e or μ) of opposite charge, missing transverse momentum $E_{\mathrm{T}}^{\mathrm{miss}}$ due to neutrinos, ≥ 2 jets, where at least one of which is identified as originating from a b quark (b-tagged), and other topological selection. Leaving m_t as a free parameter, $\ell\ell$ final states are kinematically underconstrained by two degrees of freedom. In this analysis, distributions in rapidities of the neutrino and the antineutrino are postulated, and a weight is calculated, which depends on the consistency of the reconstructed $\vec{p}_{\mathrm{T}}{}^{\nu\bar{\nu}} \equiv \vec{p}_{\mathrm{T}}{}^{\nu} + \vec{p}_{\mathrm{T}}{}^{\bar{\nu}}$ with the measured missing transverse momentum $E_{\mathrm{T}}^{\mathrm{miss}}$ vector, as a function of m_t. D0 uses the first and second moment of this weight distribution to define templates and extract m_t, as shown in Fig. 1 (a) for the first moment μ_w. To reduce the systematic uncertainty, the *in situ* jet energy scale (JES) calibration in the ℓ+jets channel derived in Ref. [10] is applied, accounting for differences in jet multiplicity, luminosity, and detector ageing. The final result reads $m_t = 173.32 \pm 1.36(\mathrm{stat}) \pm 0.85(\mathrm{syst})$ GeV. The dominant systematic uncertainties come from the knowledge of the absolute JES (0.47 GeV) and its flavour-dependence (0.36 GeV), and higher order effects on the signal modelling (0.33 GeV).

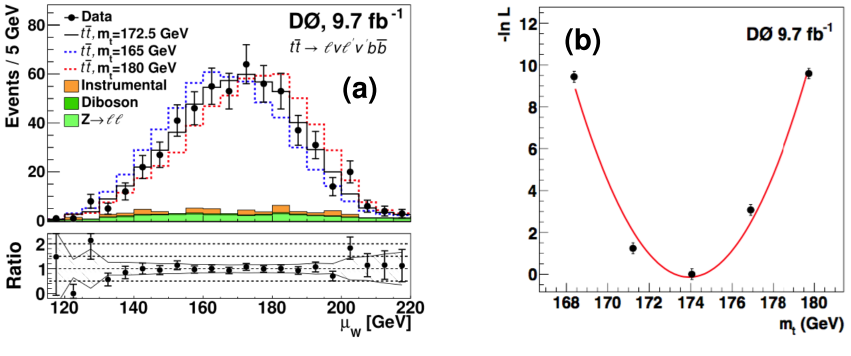

Figure 1: **(a)** The distribution in the mass estimator μ_w compared to MC simulations for different m_t hypotheses in the $\ell\ell$ channel using the neutrino weighting analysis [7]. **(b)** The likelihood in m_t in the $\ell\ell$ channel using the ME analysis [8].

The top quark mass is also extracted using the matrix element (ME) technique using the same data and a similar selection in the $\ell\ell$ channel [8]. This technique determines the probability of observing a given event under both the $t\bar{t}$ signal and background hypotheses, as a function of m_t [9]. This probability is calculated *ab initio* using the respective MEs of the $t\bar{t}$ signal and dominant Z+jets background, taking into account effects from parton showering (PS), hadronisation, and finite detector resolution. In this analysis, a SM prior is assumed for the transverse momentum distribution of the $t\bar{t}$ system, and the neutrino momenta are integrated over to overcome the challenge of the kinematically underconstrained system. After constraining the JES using ℓ+jets channel results [10], $m_t = 173.93 \pm 1.61(\text{stat}) \pm 0.88(\text{syst})$ GeV is obtained, as shown in Fig. 1 (b). The systematic uncertainty is dominated by the knowledge of the absolute JES (0.46 GeV) and its flavour-dependence (0.30 GeV), b quark jet identification (b-tagging, 0.28 GeV), and hadronisation modelling (0.32 GeV).

3. Lepton+jets channel

The most precise single measurement of m_t from the Tevatron is performed by the D0 Collaboration using 9.7 fb^{-1} of data in the ℓ+jets channel [10] with a ME technique. The analysis was performed blinded in m_t. This selection requires the presence of one isolated lepton, E_T^{miss}, and exactly four jets with at least one b-tag. A new JES calibration from exclusive γ+jet, Z+jet, and dijet events is applied to account for differences in detector response to jets originating from a gluon, a b quark, and u, d, s, or c quarks. The overall JES k_{JES} is calibrated *in situ* by constraining the reconstructed invariant mass of the hadronically decaying W boson to $M_W = 80.4$ GeV. The likelihood over all candidate events is maximised in (m_t, k_{JES}) as shown in Fig. 2 (a), and $m_t = 174.98 \pm 0.58(\text{stat+JES}) \pm 0.49(\text{syst})$ GeV is obtained.

The estimation of systematic uncertainties is refined through an updated detector calibration, in particular improvements to the b-quark JES corrections [11], and using recent improvements in modeling the $t\bar{t}$ signal. Furthermore, the statistical component from limited number of MC events is eliminated by reducing the computation time of the ME technique by a factor of 90 [12],

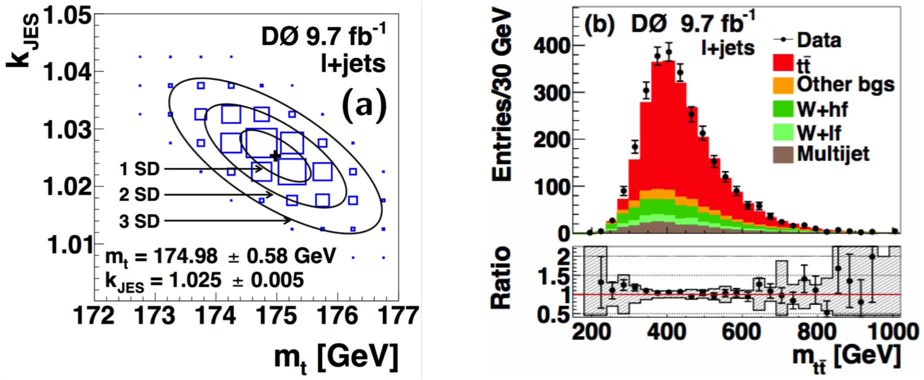

Figure 2: **(a)** The likelihood in (m_t, k_{JES}) in the ℓ+jets channel using the ME technique [10]. Fitted contours of equal probability are overlaid as solid lines. The maximum is marked with a cross. **(b)** Invariant mass of the $t\bar{t}$ system for best-fit values of m_t and k_{JES}. In the ratio of data to SM prediction, the total systematic uncertainty is shown as a shaded band.

which results in a more precise estimation of systematic uncertainties. The dominant systematic uncertainties come the modeling of higher-order corrections (0.15 GeV), hadronisation (0.26 GeV), and the knowledge of the JES dependence on its flavour (0.16 GeV) as well as kinematic properties of the jet not captured by k_{JES} (0.21 GeV).

4. Combined results

Measurements of m_t from D0 in a given channel in Runs I and II of the Tevatron are statistically combined, accounting for correlations between sources of systematic uncertainty. The final result reads $m_t = 174.95 \pm 0.40(\text{stat}) \pm 0.63(\text{syst})$ GeV [13] with a p-value of 47%. A similar combination including m_t results from the CDF Collaboration in Runs I and II, as shown in Fig. 3, results in $m_t = 174.30 \pm 0.35(\text{stat}) \pm 0.54(\text{syst})$ GeV [14], corresponding to a relative precision of 0.37% and a p-value of 46%.

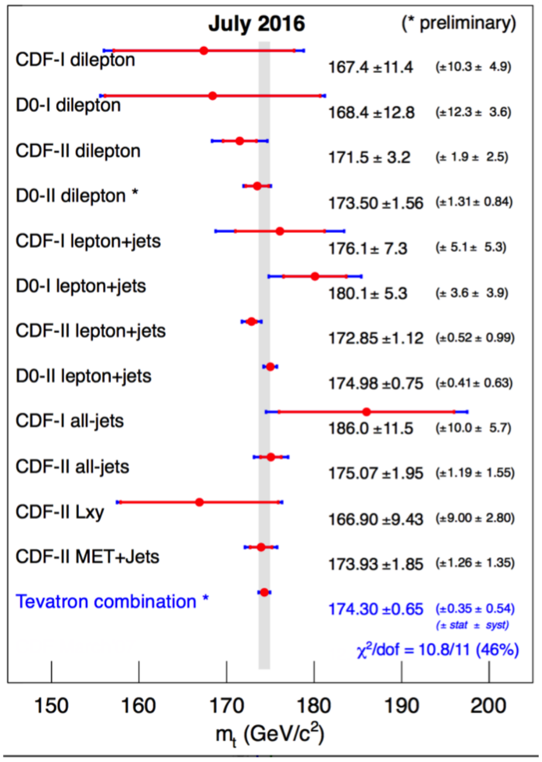

Figure 3: Overview of recent m_t measurements at the Tevatron [14].

5. Conclusions

I presented recent measurements of m_t, a fundamental parameter of the SM. The most precise single measurement at the Tevatron of $m_t = 174.98 \pm 0.58(\text{stat+JES}) \pm 0.49(\text{syst})$ GeV is performed by the D0 Collaboration in the ℓ+jets channel, corresponding to a relative precision of 0.43%. The combination with all other measurements from the D0 experiment results in $m_t = 174.95 \pm 0.40(\text{stat}) \pm 0.63(\text{syst})$ GeV. The Tevatron combination yields $m_t = 174.30 \pm 0.35(\text{stat}) \pm 0.54(\text{syst})$ GeV, which corresponds to a relative precision of 0.37%.

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