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Combination of CDF and DØ results on the mass of the top quark using up to 8.7 fb^{-1} at the Tevatron

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Abstract

We summarize the current top-quark mass measurements from the CDF and DØ experiments at Fermilab. We combine published Run I (1992–1996) measurements with the most precise published and preliminary Run II (2001–2011) measurements based on data sets corresponding to up to 8.7 fb^{-1} of $p\bar{p}$ collisions. Taking correlations of uncertainties into account, and combining the statistical and systematic uncertainties, the resulting preliminary Tevatron average mass of the top quark is $M_{\mathrm{t}} = 173.20 \pm 0.87$ GeV/c^2, corresponding to a relative precision of 0.50%.

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1 Introduction

This note reports the Tevatron average top-quark mass obtained by combining the most precise published and preliminary measurements of the top-quark mass. It is an update of the combination presented in Ref. [1], where further details can be found. The ATLAS and CMS collaborations have also performed a combination of their most recent top quark mass measurements [2].

The CDF and DØ collaborations have performed several direct experimental measurements of the top-quark mass (M_{t}) using data collected at the Tevatron proton-antiproton collider located at the Fermi National Accelerator Laboratory. These pioneering measurements were first based on approximately 0.1 fb^{-1} of Run I data [3]-[14] collected from 1992 to 1996, and included results from the decay channels $t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow qq'bqq'\bar{b}$ (alljets), $t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow \ell\nu bqq'\bar{b}$ (ℓ+jets), and $t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow \ell^+\nu b\ell^-\bar{\nu}\bar{b}$ ($\ell\ell$), where $\ell = e$ or μ. Decays with $\tau \rightarrow e, \mu$ are included in the direct $W \rightarrow e$ and $W \rightarrow \mu$ channels. In Run II (2001–2011), many top mass measurements have been performed, and those considered here are the most recent results in these channels, using up to 8.7 fb^{-1} of data for CDF (corresponding to the full CDF Run II dataset) [15, 16, 17, 18], and up to 5.4 fb^{-1} of data for DØ [19, 20, 21]. The CDF analysis based upon charged particle tracking for exploiting the transverse decay length of b-tagged jets (L_{XY}) and the transverse momentum of electrons and muons from W boson decays (p_T^{lep}) uses a data set corresponding to a luminosity of 1.9 fb^{-1} [22], and there are no plans to update this analysis. The DØ Run II measurements presented in this note include the most recent Run II measurement in the $\ell\ell$ [21] channel using 5.4 fb^{-1} of data and in the ℓ+jets channel [20] with 3.6 fb^{-1} of data. Both results are now published. Since the combination performed in 2011 [23], a new final state signature was introduced by CDF that requires events to possess missing transverse energy ($\not\!\!E_T$) and jets, but no identified lepton ("MEt") [15, 24]. This sample is statistically independent from the previous three CDF channels.

With respect to the July 2011 combination [23] and the published version of the combination [1], the Run II CDF measurement in the ℓ+jets channel has been updated using 8.7 fb^{-1} of data, an improved analysis technique, and improved jet energy resolution [16]. The CDF measurement in the MEt channel was updated to use the full Run II data set for CDF of 8.7 fb^{-1} of data as well [15]. The now published Run II CDF measurements in the $\ell\ell$ channel [17] and alljets channel [18] are unchanged. The measurement based on charged particle tracking [22] was incorporated as described in the past combinations [23]. From the corresponding analysis only the measurement of the top quark mass using the mean decay length L_{XY} of B hadrons in b-tagged lepton+jets events has been used. It is independent of energy information in the calorimeter, and its main source of systematic uncertainty is uncorrelated with the dominant ones from the jet energy scale calibration in other measurements. This measurement of m_t is essentially uncorrelated with the higher precision CDF result from the lepton+jets channel. The overlap between the data samples used for the decay-length method and the lepton+jets sample has therefore no effect.

The Tevatron average top-quark mass is obtained by combining five published Run I measurements [4, 5, 7, 9, 12, 13] with four published Run II CDF results [16, 17, 18, 22], one preliminary Run II CDF result [15], and two published Run II DØ results [20, 21]. This combination supersedes previous combinations [23, 25, 26, 27, 28, 29, 30, 31, 32, 33].

The definition and evaluation of the systematic uncertainties and the understanding of the correlations among channels, experiments, and Tevatron runs is the outcome of many years of joint work between the CDF and DØ collaborations and is described in detail elsewhere [1].

The input measurements and uncertainty categories used in the combination are detailed in Sections 2 and 3, respectively. The correlations assumed in the combination are discussed in Section 4 and the resulting Tevatron average top-quark mass is given in Section 5. A summary is presented in Section 6.

2 Input Measurements

Twelve measurements of M_{t} used in this combination are shown in Table 1. The Run I measurements all have relatively large statistical uncertainties and their systematic uncertainties are dominated by the total jet energy scale (JES) uncertainty. In Run II both CDF and DØ take advantage of the larger $t\bar{t}$ samples available and employ new analysis techniques to reduce both of these uncertainties. In particular, the Run II DØ analysis in the ℓ+jets channel and the Run II CDF analyses in the ℓ+jets, alljets, and MEt channels constrain the response of light-quark jets using the kinematic information from $W \to qq'$ decays (so-called *in situ* calibration) [9, 34]. Residual JES uncertainties associated with p_T and η dependencies as well as uncertainties specific to the response of b jets are treated separately. The Run II DØ $\ell\ell$ measurement uses the JES determined in the ℓ+jets channel by *in situ* calibration [21].

The DØ Run II ℓ+jets analysis uses the JES determined from the external calibration derived from γ+jets events as an additional Gaussian constraint to the *in situ* calibration. Therefore, the total resulting JES uncertainty is split into one part obtained from the *in situ* calibration and another part determined from the external calibration. To do this, the measurement without external JES constraint has been combined iteratively with a pseudo-measurement using the method of Refs. [35, 36] that uses only the external calibration in a way that the combination gives the total JES uncertainty. The splitting obtained in this way is used to assess both the statistical part of the JES uncertainty and the part of the JES uncertainty due to the external calibration constraint [37].

The L_{XY} technique developed by CDF uses the decay length of B mesons from b-tagged jets. While the statistical sensitivity of this analysis is not as good as that of the more traditional methods, this technique has the advantage that it is almost entirely independent of JES

Table 1: Summary of the measurements used to determine the Tevatron average M_{t}. Integrated luminosity ($\int \mathcal{L}\ dt$) has units of fb^{-1}, and all other numbers are in GeV/c^2. The uncertainty categories and their correlations are described in Section 3. The total systematic uncertainty and the total uncertainty are obtained by adding the relevant contributions in quadrature. "n/a" stands for "not applicable", "n/e" for "not evaluated".

	Run I published					Run II published						Run II prel.
	CDF			DØ		CDF				DØ		CDF
	ℓ+jets	$\ell\ell$	alljets	ℓ+jets	$\ell\ell$	ℓ+jets	$\ell\ell$	alljets	Lxy	ℓ+jets	$\ell\ell$	MEt
$\int \mathcal{L}\ dt$	0.1	0.1	0.1	0.1	0.1	8.7	5.6	5.8	1.9	3.6	5.3	8.7
Result	176.1	167.4	86.0	180.1	168.4	172.85	170.28	172.47	166.90	174.94	174.00	173.95
In situ light-jet calibration (iJES)	n/a	n/a	n/a	n/a	n/a	0.49	n/a	0.95	n/a	0.53	0.55	1.05
Response to $b/q/g$ jets (aJES)	n/a	n/a	n/a	0.0	0.0	0.09	0.14	0.03	n/a	0.0	0.40	0.10
Model for b jets (bJES)	0.6	0.8	0.6	0.7	0.7	0.16	0.33	0.15	n/a	0.07	0.20	0.17
Out-of-cone correction (cJES)	2.7	2.6	3.0	2.0	2.0	0.21	2.13	0.24	0.36	n/a	n/a	0.18
Light-jet response (2) (dJES)	0.7	0.6	0.3	2.5	1.1	0.07	0.58	0.04	0.06	0.63	0.56	0.04
Light-jet response (1) (rJES)	3.4	2.7	4.0	n/a	n/a	0.48	2.01	0.38	0.24	n/a	n/a	0.40
Lepton modeling (LepPt)	n/e	n/e	n/e	n/e	n/e	0.03	0.27	n/a	n/a	0.17	0.35	n/a
Signal modeling (Signal)	2.6	2.9	2.0	1.1	1.8	0.61	0.73	0.62	0.90	0.77	0.86	0.64
Jet modeling (DetMod)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.36	0.50	0.0
Offset (UN/MI)	n/a	n/a	n/a	1.3	1.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Background from theory (BGMC)	1.3	0.3	1.7	1.0	1.1	0.12	0.24	0.0	0.80	0.18	0.0	0.0
Background based on data (BGData)	0.0	0.0	0.0	0.0	0.0	0.16	0.14	0.56	0.20	0.23	0.20	0.12
Calibration method (Method)	0.0	0.7	0.6	0.6	1.1	0.00	0.12	0.38	2.50	0.16	0.51	0.31
Multiple interactions model (MHI)	n/e	n/e	n/e	n/e	n/e	0.07	0.23	0.08	0.0	0.05	0.0	0.18
Systematic uncertainty (Syst)	5.3	4.9	5.7	3.9	3.6	0.98	3.09	1.49	2.90	1.24	1.44	1.35
Statistical uncertainty (Stat)	5.1	10.3	10.0	3.6	12.3	0.52	1.95	1.43	9.00	0.83	2.36	1.26
Total uncertainty	7.3	11.4	11.5	5.3	12.8	1.11	3.79	2.06	9.46	1.50	2.76	1.85

uncertainties since it uses primarily tracking information.

The DØ Run II ℓ+jets result is a combination of the published Run IIa (2002–2005) measurement [19] with 1 fb^{-1} of data and the result obtained with 2.6 fb^{-1} of data from Run IIb (2006–2007) [20]. This analysis includes an additional particle response correction on top of the standard *in situ* calibration. The DØ Run II $\ell\ell$ result is based on a neutrino weighting technique using 5.4 fb^{-1} of Run II data [21].

Table 1 lists the individual uncertainties of each result, subdivided into the categories described in the next Section. The correlations between the inputs are described in Section 4.

3 Uncertainty Categories

We employ uncertainty categories similar to what was used for the previous Tevatron average [1, 23], with small modifications to better account for their correlations. They are divided such that sources of systematic uncertainty that share the same or similar origin are combined as explained in Ref. [1]. For example, the *Signal modeling* (*Signal*) category discussed below includes the uncertainties from different systematic sources that are correlated due to their origin in the modeling of the simulated signal samples.

Some systematic uncertainties have been separated into multiple categories to accommodate specific types of correlations. For example, the jet energy scale (JES) uncertainty is subdivided into six components to more accurately accommodate our best understanding of the relevant correlations between input measurements.

For this note we use the new systematic naming scheme described in Ref. [1]. In parentheses, the old names of the systematic uncertainties are provided. There is a one-to-one matching between the new and old systematic definitions of categories.

Statistical uncertainty (Statistics): The statistical uncertainty associated with the M_{t} determination.

***In situ* light-jet calibration (iJES):** That part of the JES uncertainty that originates from *in situ* calibration procedures and is uncorrelated among the measurements. In the combination reported here, it corresponds to the statistical uncertainty associated with the JES determination using the $W \to qq'$ invariant mass in the CDF Run II ℓ+jets, alljets, and MEt measurements and the DØ Run II $\ell\ell$ and ℓ+jets measurements. For the DØ Run II ℓ+jets measurement, it also includes the uncertainty coming from the MC/data difference in jet response that is uncorrelated with the other DØ Run II measurements. Residual JES uncertainties arising from effects not considered in the *in situ* calibration are included in other categories.

Response to $b/q/g$ jets (aJES): That part of the JES uncertainty that originates from average differences in detector electromagnetic over hadronic (e/h) response for hadrons produced in the fragmentation of b-jets and light-quark jets.

Model for b jets (bJES): That part of the JES uncertainty that originates from uncertainties specific to the modeling of b jets and that is correlated across all measurements. For both CDF and DØ this includes uncertainties arising from variations in the semileptonic branching fractions, b-fragmentation modeling, and differences in the color flow between b-quark jets and light-quark jets. These were determined from Run II studies but back-propagated to the Run I measurements, whose *Light-jet response (1)* uncertainties (*rJES*, see below) were then corrected to keep the total JES uncertainty constant.

Out-of-cone correction (cJES): That part of the JES uncertainty that originates from modeling uncertainties correlated across all measurements. It specifically includes the modeling uncertainties associated with light-quark fragmentation and out-of-cone corrections. For DØ Run II measurements, it is included in the *Light-jet response (2) (dJES)* category.

Light-jet response (1) (rJES): The remaining part of the JES uncertainty that covers the absolute calibration for CDF's Run I and Run II measurements. It also includes small contributions from the uncertainties associated with modeling multiple interactions within a single bunch crossing and corrections for the underlying event.

Light-jet response (2) (dJES): That part of the JES uncertainty that includes DØ's Run I and Run II calibrations of absolute response (energy dependent), the relative response (η-dependent), and the out-of-cone showering correction that is a detector effect. This uncertainty term for CDF includes only the small relative response calibration (η-dependent) for Run I and Run II.

Lepton modeling (LepPt): The systematic uncertainty arising from uncertainties in the scale of lepton transverse momentum measurements. It was not considered as a source of systematic uncertainty in the Run I measurements.

Signal modeling (Signal): The systematic uncertainty arising from uncertainties in $t\bar{t}$ modeling that is correlated across all measurements. This includes uncertainties from variations of the amount of initial and final state radiation and from the choice of parton density function used to generate the $t\bar{t}$ Monte Carlo samples that calibrate each method. For DØ, it also includes the uncertainty from higher-order corrections evaluated from a comparison of $t\bar{t}$ samples generated by MC@NLO [38] and ALPGEN [39], both interfaced to HERWIG [40, 41] for the simulation of parton showers and hadronization. In this combination, the systematic uncertainty arising from a variation of the phenomenological description of color reconnection (CR) between final state particles [42, 43] is included in the *Signal modeling* category. The CR uncertainty is obtained by taking the difference between the PYTHIA 6.4 tune "Apro" and the PYTHIA 6.4 tune "ACRpro" that differ only in the CR model. This uncertainty was not evaluated in Run I since the Monte Carlo generators available at that time did not allow for variations of the CR model. These measurements therefore do not include this source of systematic uncertainty. Finally, the systematic uncertainty associated with variations of the MC generator used to calibrate the mass extraction method is added. It includes variations observed when substituting PYTHIA [44, 45, 46] (Run I and Run II) or ISAJET [47] (Run I) for HERWIG [40, 41] when modeling the $t\bar{t}$ signal.

Jet modeling (DetMod): The systematic uncertainty arising from uncertainties in the modeling of jet interactions in the detector in the MC simulation. For DØ this includes uncertainties from jet resolution and identification. Applying jet algorithms to MC events, CDF finds that the resulting efficiencies and resolutions closely match those in data. The small differences propagated to M_{t} lead to a negligible uncertainty of 0.005 GeV, which is then ignored.

Background based on data (BGData): This includes uncertainties associated with the modeling using data of the QCD multijet background in the alljets, MEt, and ℓ+jets channels and the Drell-Yan background in the $\ell\ell$ channel. This part is uncorrelated between experiments.

Background from theory (BGMC): This systematic uncertainty on the background originating from theory (MC) takes into account the uncertainty in modeling the background sources. It is correlated between all measurements in the same channel, and includes uncertainties on the background composition, normalization, and shape of different components, e.g., the uncertainties from the modeling of the W+jets background in the ℓ+jets channel associated with variations of the factorization scale used to simulate W+jets events.

Calibration method (Method): The systematic uncertainty arising from any source specific to a particular fit method, including the finite Monte Carlo statistics available to calibrate each method.

Offset (UN/MI): This uncertainty is specific to DØ and includes the uncertainty arising from uranium noise in the DØ calorimeter and from the multiple interaction corrections to the JES. For DØ Run I these uncertainties were sizable, while for Run II, owing to the shorter calorimeter electronics integration time and *in situ* JES calibration, these uncertainties are negligible.

Multiple interactions model (MHI): The systematic uncertainty arising from a mismodeling of the distribution of the number of collisions per Tevatron bunch crossing owing to the steady increase in the collider instantaneous luminosity during data-taking. This uncertainty has been separated from other sources to account for the fact that it is uncorrelated between experiments.

These categories represent the current preliminary understanding of the various sources of uncertainty and their correlations. We expect these to evolve as we continue to probe each method's sensitivity to the various systematic sources with improving precision.

4 Correlations

The following correlations are used for the combination:

- The uncertainties in the *Statistical uncertainty (Stat)* and *Calibration method (Method)* categories are taken to be uncorrelated among the measurements.

Table 2: The matrix of correlation coefficients used to determine the Tevatron average top-quark mass.

	Run I published					Run II published						Run II preliminary
	CDF			DØ		CDF				DØ		CDF
	ℓ+jets	$\ell\ell$	alljets	ℓ+jets	$\ell\ell$	ℓ+jets	$\ell\ell$	alljets	L_{XY}	ℓ+jets	$\ell\ell$	MEt
CDF-I ℓ+jets	1.00	0.29	0.32	0.26	0.11	0.49	0.54	0.25	0.07	0.21	0.12	0.27
CDF-I $\ell\ell$	0.29	1.00	0.19	0.15	0.08	0.29	0.32	0.15	0.04	0.13	0.08	0.17
CDF-I alljets	0.32	0.19	1.00	0.14	0.07	0.30	0.38	0.15	0.04	0.09	0.06	0.16
DØ-I ℓ+jets	0.26	0.15	0.14	1.00	0.16	0.22	0.27	0.12	0.05	0.14	0.07	0.12
DØ-I $\ell\ell$	0.11	0.08	0.07	0.16	1.00	0.11	0.13	0.07	0.02	0.07	0.05	0.07
CDF-II ℓ+jets	0.49	0.29	0.30	0.22	0.11	1.00	0.48	0.29	0.08	0.30	0.18	0.33
CDF-II $\ell\ell$	0.54	0.32	0.38	0.27	0.13	0.48	1.00	0.25	0.06	0.11	0.07	0.26
CDF-II alljets	0.25	0.15	0.15	0.12	0.07	0.29	0.25	1.00	0.04	0.16	0.10	0.17
CDF-II L_{XY}	0.07	0.04	0.04	0.05	0.02	0.08	0.06	0.04	1.00	0.06	0.03	0.04
DØ-II ℓ+jets	0.21	0.13	0.09	0.14	0.07	0.30	0.11	0.16	0.06	1.00	0.39	0.18
DØ-II $\ell\ell$	0.12	0.08	0.06	0.07	0.05	0.18	0.07	0.10	0.03	0.39	1.00	0.11
CDF-II MEt	0.27	0.17	0.16	0.12	0.07	0.33	0.26	0.17	0.04	0.18	0.11	1.00

- The uncertainties in the *In situ light-jet calibration (iJES)* category are taken to be uncorrelated among the measurements except for D0's $\ell\ell$ and ℓ+jets measurements, where this uncertainty is taken to be 100% correlated since the $\ell\ell$ measurement uses the JES calibration determined in ℓ+jets channel.
- The uncertainties in the *Response to b/q/g jets (aJES)*, *Light-jet response (2) (dJES)*, *Lepton modeling (LepPt)*, and *Multiple interactions model (MHI)* categories are taken to be 100% correlated among all Run I and all Run II measurements within the same experiment, but uncorrelated between Run I and Run II and uncorrelated between the experiments.
- The uncertainties in the *Light-jet response (1) (rJES)*, *Jet modeling (DetMod)*, and *Offset (UN/MI)* categories are taken to be 100% correlated among all measurements within the same experiment but uncorrelated between the experiments.
- The uncertainties in the *Backgrounds estimated from theory (BGMC)* category are taken to be 100% correlated among all measurements in the same channel.
- The uncertainties in the *Backgrounds estimated from data (BGData)* category are taken to be 100% correlated among all measurements in the same channel and same run period, but uncorrelated between the experiments.
- The uncertainties in the *Model for b jets (bJES)*, *Out-of-cone correction (cJES)*, and *Signal modeling (Signal)* categories are taken to be 100% correlated among all measurements.

Using the inputs from Table 1 and the correlations specified here, the resulting matrix of total correlation coefficients is given in Table 2.

The measurements are combined using a program implementing two independent methods: a numerical χ^2 minimization and the analytic best linear unbiased estimator (BLUE) method [35, 36]. The two methods are mathematically equivalent. It has been checked that they give identical results for the combination. The BLUE method yields the decomposition of the uncertainty on the Tevatron $M_{\rm t}$ average in terms of the uncertainty categories specified for the input measurements [36].

5 Results

The resultant combined value for the top-quark mass is

$$M_{\rm t} = 173.20 \pm 0.51\,({\rm stat}) \pm 0.71\,({\rm syst})\ {\rm GeV}/c^2.$$

Adding the statistical and systematic uncertainties in quadrature yields a total uncertainty of 0.87 GeV/c^2, corresponding to a relative precision of 0.50% on the top-quark mass. It has a χ^2 of 8.5 for 11 degrees of freedom, corresponding to a probability of 67%, indicating good agreement among all input measurements. The breakdown of the uncertainties is shown in Table 3. The total statistical and systematic uncertainties are reduced relative to the Summer 2011 combination [23] and the published combination [1] due to the increase of the CDF data samples in the ℓ+jets and MEt analyses and better treatment of JES corrections in the ℓ+jets analysis.

The pull and weight for each of the inputs, as obtained from the combination with the BLUE method, are listed in Table 4. The input measurements and the resulting Tevatron average mass of the top quark are summarized in Fig. 1.

The weights of some of the measurements are negative, which occurs if the correlation between two measurements is larger than the ratio of their total uncertainties. In these instances the less precise measurement will acquire a negative weight. While a weight of zero means that a particular input is effectively ignored in the combination, channels with a negative weight affect the resulting $M_{\rm t}$ central value and help reduce the total uncertainty [35]. To visualize the weight each measurement carries in the combination, Fig. 2 shows the absolute values of the weight of each measurement divided by the sum of the absolute values of the weights of all input measurements. Negative weights are represented by bins with a different (grey) color. We note, that due to correlations between the uncertainties the relative weights of the different input channels may be significantly different from what one could expect from the total accuracy of each measurement as represented by error bars in Fig. 1.

No input has an anomalously large pull. It is, however, still interesting to determine the top-quark mass separately in the alljets, ℓ+jets, $\ell\ell$, and MEt channels (leaving out the L_{XY} measurement). We use the same methodology, inputs, uncertainty categories, and correlations as described above, but fit the four physical observables, $M_{\rm t}^{\rm alljets}$, $M_{\rm t}^{\ell+\rm jets}$, $M_{\rm t}^{\ell\ell}$, and $M_{\rm t}^{\rm MEt}$ separately. The results of these combinations are shown in Figure 3 and Table 5.

Table 3: Summary of the Tevatron combined average M_{t}. The uncertainty categories are described in the text. The total systematic uncertainty and the total uncertainty are obtained by adding the relevant contributions in quadrature.

	Tevatron combined values (GeV/c^2)
M_{t}	173.20
In situ light-jet calibration (iJES)	0.36
Response to $b/q/g$ jets (aJES)	0.09
Model for b jets (bJES)	0.11
Out-of-cone correction (cJES)	0.01
Light-jet response (2) (dJES)	0.15
Light-jet response (1) (rJES)	0.16
Lepton modeling (LepPt)	0.05
Signal modeling (Signal)	0.52
Jet modeling (DetMod)	0.08
Offset (UN/MI)	0.00
Background from theory (BGMC)	0.06
Background based on data (BGData)	0.13
Calibration method (Method)	0.06
Multiple interactions model (MHI)	0.07
Systematic uncertainty (syst)	0.71
Statistical uncertainty (stat)	0.51
Total uncertainty	0.87

Table 4: The pull and weight for each of the inputs, as obtained from the combination with the BLUE method to determine the average top quark mass.

	Run I published					Run II published						Run II preliminary
	CDF			DØ		CDF				DØ		CDF
	ℓ+jets	$\ell\ell$	alljets	ℓ+jets	$\ell\ell$	ℓ+jets	$\ell\ell$	alljets	Lxy	ℓ+jets	$\ell\ell$	MEt
Pull	+0.40	−0.51	+1.11	+1.32	−0.38	−0.51	−0.82	−0.41	−0.67	1.42	+0.30	+0.45
Weight [%]	−4.7	−1.1	−0.9	+0.4	−0.2	+62.0	−0.3	+10.5	+0.22	+20.6	+1.4	+11.9

Using the results of Table 5 we calculate the following chi-squared values including correlations: $\chi^2(\ell+\text{jets}-\ell\ell) = 1.30/1$, $\chi^2(\ell+\text{jets}-\text{alljets}) = 0.07/1$, $\chi^2(\ell+\text{jets}-\text{MEt}) = 0.11/1$, $\chi^2(\ell\ell-\text{alljets}) = 0.42/1$, $\chi^2(\ell\ell-\text{MEt}) = 1.22/1$, and $\chi^2(\text{alljets}-\text{MEt}) = 0.19/1$. These correspond to chi-squared probabilities of 25%, 79%, 74%, 52%, 27%, and 66% respectively, indicating that the top-quark mass determined in each decay channel is consistent in all cases.

To test the influence of the choices in modeling the correlations, we performed a cross-check by changing all non-diagonal correlation coefficients of the correlation matrix defined in

Table 5: Summary of the combination of the 12 measurements by CDF and DØ in terms of four physical quantities, the mass of the top quark in the alljets, ℓ+jets, $\ell\ell$, and MEt decay channels.

Parameter	Value (GeV/c^2)	Correlations			
		$M_{\mathrm{t}}^{\mathrm{alljets}}$	$M_{\mathrm{t}}^{\ell+\mathrm{jets}}$	$M_{\mathrm{t}}^{\ell\ell}$	$M_{\mathrm{t}}^{\mathrm{MEt}}$
$M_{\mathrm{t}}^{\mathrm{alljets}}$	172.7 ± 1.9	1.00			
$M_{\mathrm{t}}^{\ell+\mathrm{jets}}$	173.2 ± 0.9	0.25	1.00		
$M_{\mathrm{t}}^{\ell\ell}$	170.0 ± 2.1	0.19	0.41	1.00	
$M_{\mathrm{t}}^{\mathrm{MEt}}$	173.8 ± 1.8	0.13	0.26	0.18	1.00

Section 4 from 100% to 50% and re-evaluated the combination. The result of this large variation of degree of correlation is a $+0.19$ GeV/c^2 shift of the top-quark mass and reduces the total uncertainty negligibly. The chosen approach is therefore conservative.

We also performed separate combinations of all the CDF and DØ measurements. The results of these combinations are 172.72 ± 0.93 GeV/c^2 for CDF and 174.89 ± 1.42 GeV/c^2 for DØ. Taking all correlations into account, we calculate the chi-square value $\chi^2(CDF - D\text{Ø}) = 2.25/1$ corresponding to a probability of 13%.

6 Summary

An update of the combination of measurements of the mass of the top quark from the Tevatron experiments CDF and DØ has been presented. This preliminary combination includes five published Run I measurements, six published Run II measurements, and one preliminary Run II measurement, but the majority of these measurements are not yet performed on the full datasets available. Taking into account the statistical and systematic uncertainties and their correlations, the preliminary result for the Tevatron average is $M_{\mathrm{t}} = 173.20 \pm 0.51\,(\mathrm{stat}) \pm 0.71\,(\mathrm{syst})$ GeV/c^2, where the total uncertainty is obtained assuming Gaussian systematic uncertainties. The central value is $0.02\,\mathrm{GeV}/c^2$ higher than our July 2012 average [1] of $M_{\mathrm{t}} = 173.18 \pm 0.94\,\mathrm{GeV}/c^2$. Adding in quadrature the statistical and systematic uncertainties yields a total uncertainty of 0.87 GeV/c^2 which represents an improvement of 8%.

The mass of the top quark is now known with a relative precision of 0.50%, limited by the systematic uncertainties, which are dominated by the jet energy scale uncertainty. This result will be further improved when all analysis channels from CDF and DØ using the full Run II data set are finalized.

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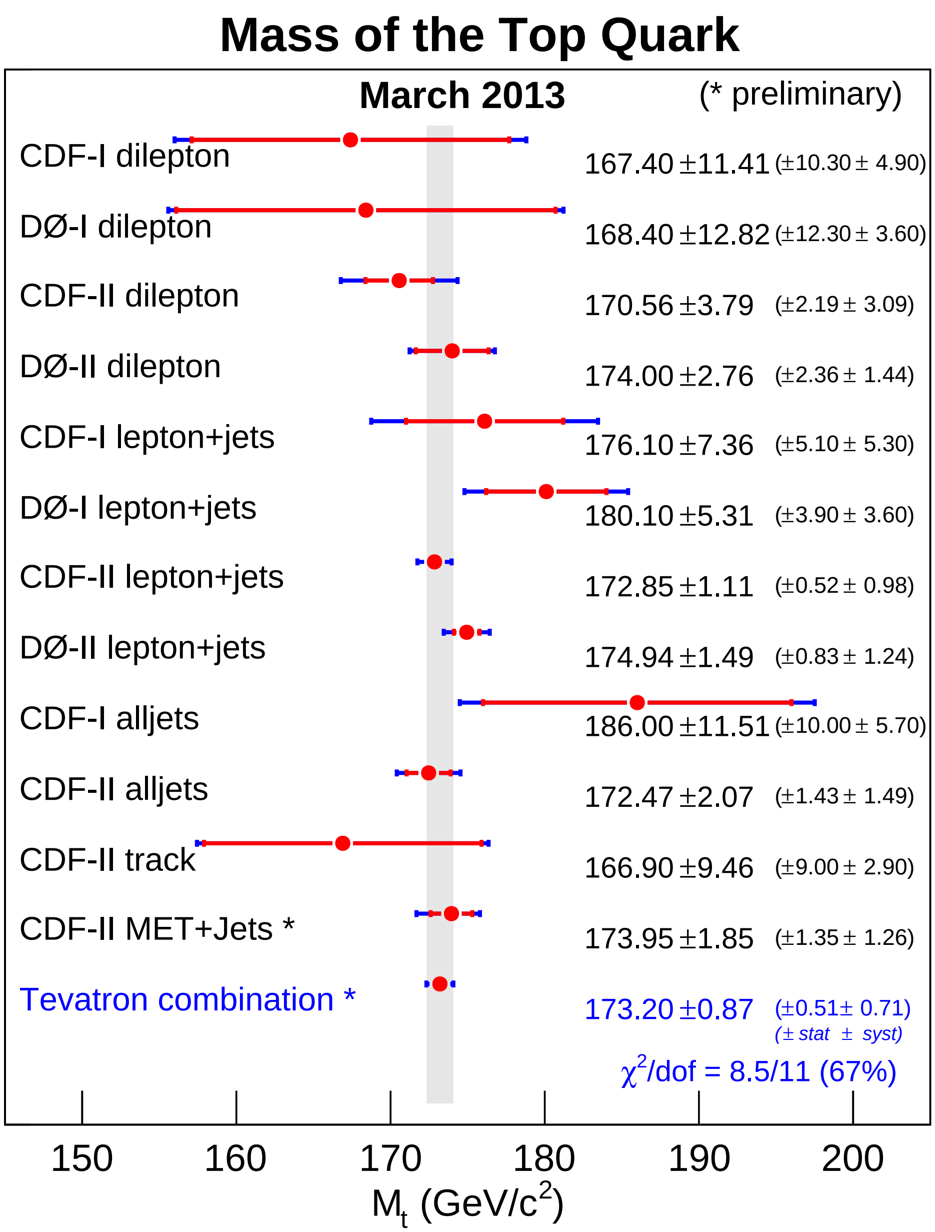

Figure 1: Summary of the input measurements and resulting Tevatron average mass of the top quark.

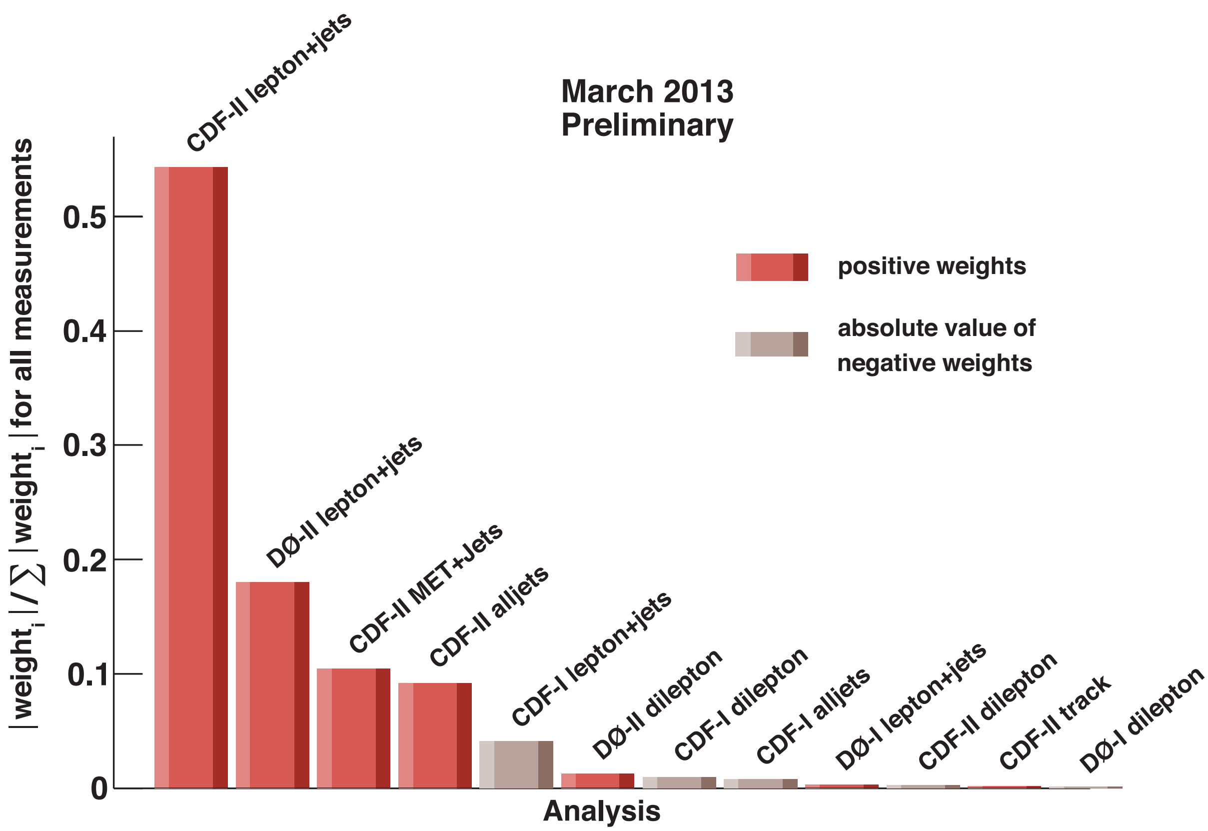

Figure 2: Relative weights of the input measurements in the combination. The relative weights have been obtained by dividing the absolute value of each measurement weight by the sum over all measurements of the absolute values of the weights. Negative weights are represented by their absolute value, but using a grey color.

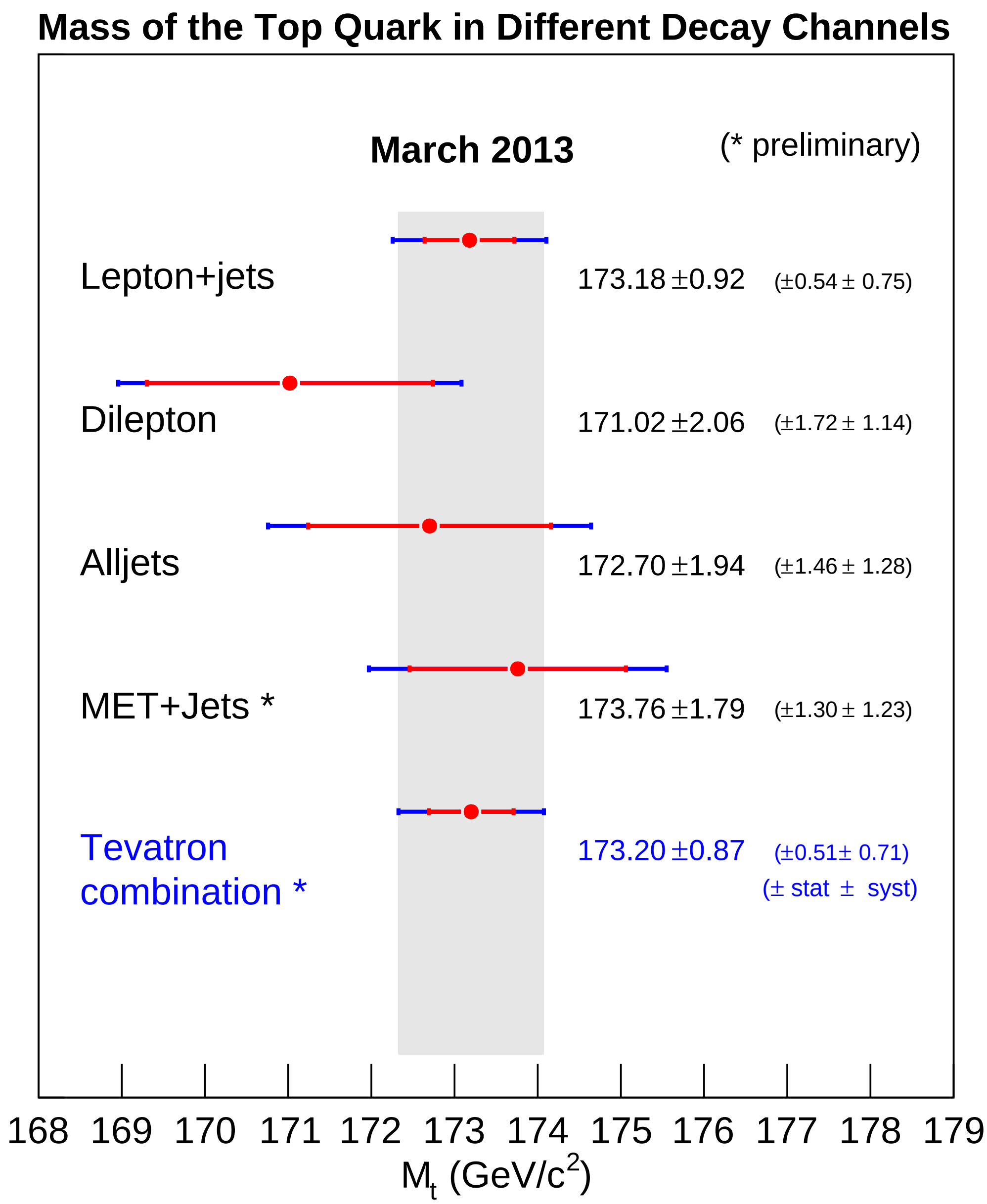

Figure 3: Summary of the combination of the 12 top-quark measurements by CDF and DØ for different final states.

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