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Combination of CDF and DØ results on the mass of the top quark using up to 5.8 fb^{-1} of data

The Tevatron Electroweak Working Group[1]
for the CDF and DØ Collaborations

Abstract

We summarize the 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-present) measurements using up to 5.8 fb^{-1} of data, adding new analyses (the $\not\!\!E_T$+Jets analysis) and updating old ones. Taking uncertainty correlations into account, and adding in quadrature the statistical and systematic uncertainties, the resulting preliminary Tevatron average mass of the top quark is $M_{\mathrm{t}} = 173.2 \pm 0.9$ GeV/c^2.

[1]The Tevatron Electroweak Working Group can be contacted at tev-ewwg@fnal.gov.
More information can be found at `http://tevewwg.fnal.gov`.

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, $M_{\rm t}$.

The experiments CDF and DØ, taking data at the Tevatron proton-antiproton collider located at the Fermi National Accelerator Laboratory, have made several direct experimental measurements of the top-quark mass, $M_{\rm t}$. The pioneering measurements were based on about 0.1 $\rm fb^{-1}$ of Run I data [1 - 12] collected from 1992 to 1996, and included results from the $t\bar{t} \to W^+bW^-\bar{b} \to qq'bqq'\bar{b}$ (allh), $t\bar{t} \to W^+bW^-\bar{b} \to \ell\nu bqq'\bar{b}$ (l+jt)[2], and $t\bar{t} \to W^+bW^-\bar{b} \to \ell^+\nu b\ell^-\overline{\nu}\bar{b}$ (di-l) decay channels.

Several additional measurements have been performed in Run II (2001 - present) in all decay modes. The Run II measurements considered here are the most recent results in the l+jt, di-l, and allh channels using $5.6-5.8$ $\rm fb^{-1}$ of data [13, 14, 15, 16, 17, 18] except for the CDF analysis using charged particle tracking that has not been updated and uses luminosity of 1.9 $\rm fb^{-1}$ [19]. Moreover, a new analysis requiring missing transverse energy ($\not\!\!E_T$) plus jets was added by CDF [20]. This sample is statistically independent from the other channels and is accounted as a forth channel (called $\not\!\!E_T$+Jets or MEt).

With respect to the July 2010 combination [21], the Run II CDF measurement in the all-hadronic channel has been updated using 5.8 $\rm fb^{-1}$ of data and improved analysis technique [15]. The $\not\!\!E_T$+Jets channel was added by CDF with 5.7 $\rm fb^{-1}$ of data. The now published Run II CDF measurements in the di-l channel [13] and l+jt channel [14] are unchanged. The measurement based on charged particle tracking [19] has been split into the decay length significance L_{XY} and lepton transverse momentum p_T^{lep} parts and the latter was removed from the combination because of a statistical correlation with other samples.

The DØ Run II measurements presented in this note include the most recent Run II measurement in the di-l [18] channel using 5.4 $\rm fb^{-1}$ of data and the updated one in the l+jt channel [17] with 3.6 $\rm fb^{-1}$ of data. Both results are accepted for publication.

The Tevatron average top-quark mass is thus obtained by combining five published Run I measurements [2, 3, 5, 7, 10, 11] with three published Run II CDF results [13, 14, 19], two preliminary Run II CDF results [15, 20] and two published Run II DØ results [17, 18]. The combination takes into account the statistical and systematic uncertainties and their correlations using the method of Refs. [22, 23] and supersedes previous combinations [21, 24, 25, 26, 27, 28, 29, 30, 31].

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.

[2] Here $\ell = e$ or μ. Decay channels with explicit tau lepton identification are presently under study and are not yet used for measurements of the top-quark mass. Decays with $\tau \to e, \mu$ are included in the direct $W \to e$ and $W \to \mu$ channels.

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

2 Input Measurements

For this combination twelve measurements of M_{t} are used: five published Run I results, five published Run II results, and two preliminary Run II results, all reported in Table 1. In general, 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 these uncertainties. In particular, the Run II DØ analysis in the l+jt channel and the Run II CDF analyses in the l+jt, allh and MEt channels constrain the response of light-quark jets using the kinematic information from $W \to qq'$ decays (*in situ* calibration). 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 CDF and DØ di-l measurements and the CDF measurement based on charged particle tracking [19] use a JES determined from external calibration samples. Some parts of the associated uncertainty are correlated with the Run I JES uncertainty as noted below.

The DØ Run II l+jt 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 emerging from the *in situ* calibration and another part emerging from the external calibration. To do that, the measurement without external JES constraint has been combined iteratively with a pseudo-measurement using the method of Refs. [22, 23] which uses only the external calibration in a way that the combination give the actual total JES uncertainty. The splitting obtained in this way is used to assess the statistical part of the JES uncertainty, and the part of the JES uncertainty coming from the external calibration constraint [32].

The analysis technique developed by CDF and referred as "Lxy" uses the decay-length from b-tagged jets. While the statistical sensitivity is not as good as the more traditional methods, this technique has the advantage that since it uses primarily tracking information, it is almost entirely independent of JES uncertainties. As the statistics of this sample will continue to grow, this method is expected to offer a cross-check of the top-quark mass largely independent of the dominant JES systematic uncertainty.

The DØ Run II l+jt result is a combination of the published Run IIa (2002–2005) measurement [16] with 1 fb^{-1} of data and the result obtained with 2.6 fb^{-1} Run IIb (2006–2007) [17].

Table 1: Summary of the measurements used to determine the Tevatron average M_t. Integrated luminosity ($\int \mathcal{L}\ dt$) has units in fb^{-1}, and all other numbers are in GeV/c^2. The uncertainty categories and their correlations are described in the Sec. 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 preliminary	
	CDF			DØ		CDF			DØ		CDF	
	allh	l+jt	di-l	l+jt	di-l	di-l	Lxy	l+jt	di-l	l+jt	allh	MEt
$\int \mathcal{L}\ dt$	0.1	0.1	0.1	0.1	0.1	5.6	1.9	5.6	5.2	3.6	5.8	5.7
Result	186.0	176.1	167.4	180.1	168.4	170.28	166.90	173.00	173.97	174.94	172.47	172.32
iJES	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.58	n/a	0.53	0.95	1.54
aJES	n/a	n/a	n/a	0.0	0.0	0.14	n/a	0.13	1.57	0.0	0.03	0.12
bJES	0.6	0.6	0.8	0.7	0.7	0.33	n/a	0.23	0.40	0.07	0.15	0.26
cJES	3.0	2.7	2.6	2.0	2.0	2.13	0.36	0.27	n/a	n/a	0.24	0.20
dJES	0.3	0.7	0.6	2.5	1.1	0.58	0.06	0.01	1.50	0.63	0.04	0.05
rJES	4.0	3.4	2.7	n/a	n/a	2.01	0.24	0.41	n/a	n/a	0.38	0.45
LepPt	n/e	n/e	n/e	n/e	n/e	0.27	n/a	0.14	0.49	0.17	-	-
Signal	2.0	2.6	2.9	1.1	1.8	0.73	0.90	0.56	0.74	0.77	0.62	0.74
DetMod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.33	0.36	0.0	0.0
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
BGMC	1.7	1.3	0.3	1.0	1.1	0.24	0.80	0.273	0.0	0.18	0.0	0.0
BGData	0.0	0.0	0.0	0.0	0.0	0.14	0.20	0.06	0.47	0.23	0.56	0.12
Method	0.6	0.0	0.7	0.6	1.1	0.12	2.50	0.10	0.10	0.16	0.38	0.14
MHI	n/e	n/e	n/e	n/e	n/e	0.23	0.0	0.10	0.0	0.05	0.08	0.16
Syst	5.7	5.3	4.9	3.9	3.6	3.09	2.90	1.06	2.45	1.24	1.49	1.82
Stat	10.0	5.1	10.3	3.6	12.3	1.95	9.00	0.65	1.83	0.83	1.43	1.80
Total	11.5	7.3	11.4	5.3	12.8	3.79	9.46	1.24	3.06	1.50	2.06	2.56

This analysis includes an additional particle response correction on top of the standard in-situ calibration. The DØ Run II di-l result is based on a matrix element technique using 5.4 fb^{-1} of Run 2 data [18].

Table 1 also lists the uncertainties of the results, 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 [21] with small modifications to optimize them according to the correlations. They are divided such that sources of systematic uncertainty that share the same or similar origin are combined and the differences with the previous Tevatron Average are explained in the definitions. For example, the "Signal" category discussed below includes the uncertainties from initial state radiation (ISR), final state radiation (FSR), and parton density functions (PDF)—all of which affect the modeling of the $t\bar{t}$ signal. For this combination, we added the generator and color reconnection systematic to the signal category.

Some systematic uncertainties have been broken down into multiple categories in order to accommodate specific types of correlations. For example, the jet energy scale (JES) uncertainty is subdivided into six components in order to more accurately accommodate our best estimate of the relevant correlations.

Statistics: The statistical uncertainty associated with the M_t determination.

iJES: That part of the JES uncertainty which 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+jt, allh, and $\not\!\!E_T$+Jets measurements and the DØ Run II l+jt measurement. It also includes for DØ Run II l+jt measurement 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.

aJES: That part of the JES uncertainty which originates from differences in detector electromagnetic over hadronic (e/h) response between b-jets and light-quark jets.

bJES: That part of the JES uncertainty which originates from uncertainties specific to the modeling of b-jets and which 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-jets and light-quark jets. These were determined from Run II studies but back-propagated to the Run I measurements, whose rJES uncertainties (see below) were then corrected in order to keep the total JES uncertainty constant.

cJES: That part of the JES uncertainty which originates from modeling uncertainties correlated across all measurements. Specifically it includes the modeling uncertainties associated with light-quark fragmentation and out-of-cone corrections. For DØ Run II measurements, it is included in the dJES category.

dJES: That part of the JES uncertainty which originates from limitations in the data samples used for calibrations and which is correlated between measurements within the same data-taking period, such as Run I or Run II, but not between experiments. For CDF this corresponds to uncertainties associated with the η-dependent JES corrections which are estimated using di-jet data events. For DØ this includes uncertainties in the calorimeter response for light jets, uncertainties from p_T- and η-dependent JES corrections and from the sample dependence of using γ+jets data samples to derive the JES.

rJES: The remaining part of the JES uncertainty which is correlated between all measurements of the same experiment independently from the data-taking period, but which is uncorrelated between experiments. It is specific to CDF and is dominated by uncertainties in the calorimeter response to light-quark jets, and also includes small uncertainties associated with the multiple interaction and underlying event corrections.

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: The systematic uncertainty arising from uncertainties in the $t\bar{t}$ modeling which is correlated across all measurements. This includes uncertainties from variations in the ISR, FSR, and PDF descriptions 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 [33] and ALPGEN [34], both interfaced to HERWIG [35, 36] 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 between final state particles [37, 38] is included in the Signal. The CR uncertainty is obtained taking the difference between PYTHIA 6.4 tune "Apro" and PYTHIA 6.4 tune "ACRpro" that only differ only in the color reconnection model. Monte Carlo generators which explicitly include different CR models for hadron collisions have recently become available. This was not possible in Run I; these measurements therefore do not include this source of systematic uncertainty. Moreover, the systematic uncertainty associated with variations of the physics model used to calibrate the fit methods is added also. It includes variations observed when substituting PYTHIA [37–39] (Run I and Run II) or ISAJET [42] (Run I) for HERWIG [35, 36] when modeling the $t\bar{t}$ signal.

Detector Modeling (DetMod): The systematic uncertainty arising from uncertainties in the modeling of the detector in the MC simulation. For DØ this includes uncertainties from jet resolution and identification. CDF found these effects to have a negligible contributions to the measured mass.

Background from MC (BGMC): In this version of the combination the background systematic is separated in two parts: the MC part and the data part. Background from MC takes into account the uncertainty in modeling the background sources. They are correlated between all measurements in the same channel, and include uncertainties on the background composition and on normalization and shape of different components, e.g., the uncertainties from the modeling of the W+jets background in the l+jt channel associated with variations of the factorization scale used to simulate W+jets events.

Background from Data (BGData): This includes uncertainties associated with the modeling of the QCD multijet background using data in the allh, MEt and l+jt channels and uncertainties associated with the modeling of the Drell-Yan background in the di-l channel evaluated from data. This part is uncorrelated between experiment.

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.

Uranium Noise and Multiple Interactions (UN/MI): This 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 Hadron Interactions (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 with DØ measurements.

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 ever improving precision.

4 Correlations

The following correlations are used for the combination:

- The uncertainties in the Statistical, Method, and iJES categories are taken to be uncorrelated among the measurements.
- The uncertainties in the aJES, dJES, LepPt and 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 rJES, Detector Modeling and 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 Background from MC category are taken to be 100% correlated among all measurements in the same channel.
- The uncertainties in the Background from Data 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 bJES, cJES and 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.

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+jt	di-l	allh	l+jt	di-l	l+jt	di-l	Lxy	l+jt	di-l	allh	MEt
CDF-I l+jt	1.00	0.29	0.32	0.25	0.11	0.45	0.53	0.07	0.20	0.09	0.23	0.22
CDF-I di-l	0.29	1.00	0.18	0.14	0.07	0.25	0.31	0.03	0.13	0.07	0.14	0.13
CDF-I allh	0.32	0.18	1.00	0.14	0.06	0.26	0.37	0.03	0.09	0.04	0.14	0.13
DØ-I l+jt	0.25	0.14	0.14	1.00	0.16	0.24	0.27	0.05	0.13	0.06	0.11	0.10
DØ-I di-l	0.11	0.07	0.06	0.16	1.00	0.10	0.12	0.01	0.07	0.04	0.06	0.05
CDF-II l+jt	0.45	0.25	0.26	0.24	0.10	1.00	0.43	0.08	0.27	0.13	0.24	0.23
CDF-II di-l	0.53	0.31	0.37	0.27	0.12	0.43	1.00	0.05	0.10	0.05	0.23	0.21
CDF-II Lxy	0.07	0.03	0.03	0.05	0.01	0.08	0.05	1.00	0.05	0.02	0.03	0.03
DØ-II l+jt	0.20	0.13	0.09	0.13	0.07	0.27	0.10	0.05	1.00	0.38	0.15	0.15
DØ-II di-l	0.09	0.07	0.04	0.06	0.04	0.13	0.05	0.02	0.38	1.00	0.08	0.08
CDF-II allh	0.23	0.14	0.14	0.11	0.06	0.24	0.23	0.03	0.15	0.08	1.00	0.13
CDF-II MEt	0.22	0.13	0.13	0.10	0.05	0.23	0.21	0.03	0.15	0.08	0.13	1.00

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 [22, 23]. 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_{t} average in terms of the uncertainty categories specified for the input measurements [23].

5 Results

The combined value for the top-quark mass is: $M_{\mathrm{t}} = 173.18 \pm 0.56\ (\mathrm{stat}) \pm 0.76\ (\mathrm{syst})\ \mathrm{GeV}/c^2$. Adding the statistical and systematic uncertainties in quadrature yields a total uncertainty of $0.94\ \mathrm{GeV}/c^2$, corresponding to a relative precision of 0.54% on the top-quark mass. Rounding off to two significant digits in the uncertainty, the combination provides $M_{\mathrm{t}} = 173.2 \pm 0.9\ \mathrm{GeV}/c^2$. It has a χ^2 of 8.3 for 11 degrees of freedom, which corresponds to a probability of 68.5%, indicating good agreement among all the input measurements. The breakdown of the uncertainties is shown in Table 3. In general, the total statistical error did not decrease comparing to Summer 2010 combination. This effect is due to the new systematic categories, especially the Background from Data, which practically has the same correlations as the statistical uncertainty. With this category we transfer some part from the systematic uncertainty to the statistical one and we expect these systematic uncertainties to decrease with increasing the statistics of the data samples.

Independently that the total statistical error did not decrease the total JES uncertainty is $\pm 0.49\,\mathrm{GeV}/c^2$ with $\pm 0.39\,\mathrm{GeV}/c^2$ coming from its statistical component and $\pm 0.30\,\mathrm{GeV}/c^2$ from the non statistical component. The total statistical uncertainty is $\pm 0.56\,\mathrm{GeV}/c^2$.

The pull and weight for each of the inputs are listed in Table 4. The input measurements and the resulting Tevatron average mass of the top quark are summarized in Fig. 1.

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	173.18
iJES	0.39
aJES	0.09
bJES	0.15
cJES	0.05
dJES	0.21
rJES	0.12
Lepton p_T	0.10
Signal	0.51
Detector Modeling	0.10
UN/MI	0.00
Background from MC	0.23
Background from Data	0.12
Method	0.09
MHI	0.08
Systematics	0.76
Statistics	0.56
Total	0.94

The weights of some of the measurements are negative. In general, this situation can occur if the correlation between two measurements is larger than the ratio of their total uncertainties. This is indeed the case here. In these instances the less precise measurement will usually acquire a negative weight. While a weight of zero means that a particular input is effectively ignored in the combination, a negative weight means that it affects the resulting M_t central value and helps reduce the total uncertainty. 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.

Although no input has an anomalously large pull and the χ^2 from the combination of all measurements indicates that there is good agreement among them, it is still interesting to also fit for the top-quark mass in the allh, l+jt, di-l, MEt channels separately. We use the same methodology, inputs, uncertainty categories, and correlations as described above, but fit the four physical observables, M_t^{allh}, $M_t^{\mathrm{l+j}}$, $M_t^{\mathrm{di\text{-}l}}$and M_t^{Met}separately. The results of these

Table 4: The pull and weight for each of the inputs used to determine the Tevatron average mass of the top quark. See Reference [22] for a discussion of negative weights.

	Run I published					Run II published					Run II preliminary	
	CDF			DØ		CDF			DØ		CDF	
	l+jt	di-l	allh	l+jt	di-l	l+jt	di-l	Lxy	l+jt	di-l	allh	Met
Pull	+0.40	−0.51	+1.12	+1.32	−0.37	−0.24	−0.81	−0.67	1.5	0.27	+0.39	−0.36
Weight [%]	−4.7	−1.0	−0.8	−0.0	−0.2	+56.1	+1.5	+0.3	+27.5	+1.5	+13.2	+6.8

Table 5: Summary of the combination of the 12 measurements by CDF and DØ in terms of three physical quantities, the mass of the top quark in the allh $M_{\rm t}^{\rm allh}$, l+jt $M_{\rm t}^{\rm l+j}$, di-l $M_{\rm t}^{\rm di\text{-}l}$ and MEt $M_{\rm t}^{\rm Met}$ decay channels.

Parameter	Value (GeV/c^2)	Correlations			
		$M_{\rm t}^{\rm allh}$	$M_{\rm t}^{\rm l+j}$	$M_{\rm t}^{\rm di\text{-}l}$	$M_{\rm t}^{\rm Met}$
$M_{\rm t}^{\rm allh}$	172.7 ± 2.0	1.00			
$M_{\rm t}^{\rm l+j}$	173.4 ± 1.0	0.20	1.00		
$M_{\rm t}^{\rm di\text{-}l}$	170.8 ± 2.1	0.18	0.38	1.00	
$M_{\rm t}^{\rm Met}$	172.1 ± 2.5	0.10	0.28	0.14	1.00

combinations are shown in Table 5.

Using the expression in reference [43] and the results of Table 5 we calculate the following chi-squares $\chi^2(LJT - DIL) = 1.77/1$, $\chi^2(LJT - HAD) = 0.12/1$, $\chi^2(LJT - \not{E}_T + Jets) = 0.28/1$, $\chi^2(DIL - HAD) = 0.52/1$, $\chi^2(DIL - \not{E}_T + Jets) = 0.18/1$ and $\chi^2(HAD - \not{E}_T + Jets) = 0.04/1$. These correspond to chi-squared probabilities of 18%, 73%, 60%, 47%, 67%, 89% respectively, and indicate that all channels are consistent with each other.

We performed a cross-check changing all non-diagonal correlation coefficients from 100% to 50% and re-started the combination procedure. The result from this extreme check is 0.17 GeV/c^2 shift of the top mass with negligible decreasing of the total error.

We computed the combination of the Run I measurements only which gives: 178.1±4.6 GeV/c^2 with $\chi^2 = 2.6/4$ and the combination of only the Run II measurements: 173.6 ± 1.0 GeV/c^2 with $\chi^2 = 2.8/6$.

We also performed the separated combinations of all the CDF measurements and all the DØ ones yielding to: 172.67 ± 1.04 GeV/c^2 for CDF and 175.08 ± 1.47 GeV/c^2 for DØ. Taking all correlations into account, we calculate the chi-square $\chi^2(CDF - D\O) = 2.59/1$ corresponding to a probability of 11%.

6 Summary

A preliminary combination of measurements of the mass of the top quark from the Tevatron experiments CDF and DØ is presented. The combination includes five published Run I measurements, five published Run II measurements, and two preliminary Run II measurements. Taking into account the statistical and systematic uncertainties and their correlations, the preliminary result for the Tevatron average is: $M_{\rm t} = 173.18 \pm 0.56$ (stat) ± 0.76 (syst) GeV/c^2, where the total uncertainty is obtained assuming Gaussian systematic uncertainties. Adding in quadrature the statistical and systematic uncertainties yields a total uncertainty of 0.94 GeV/c^2, corresponding to a relative precision of 0.54% on the top-quark mass. Rounding off the uncertainty to two significant digits, the combination provides $M_{\rm t} = 173.2 \pm 0.9$ GeV/c^2. The central value is 0.12 GeV/c^2 lover than our July 2010 average of $M_{\rm t} = 173.32 \pm 1.06$ GeV/c^2, while the relative precision has improved by 13% with respect to the previous Tevatron average.

The mass of the top quark is now known with a relative precision of 0.54%, limited by the systematic uncertainties, which are dominated by the jet energy scale uncertainty. This source of systematic uncertainty is expected to improve as larger datasets are collected since analysis techniques constrain the jet energy scale using kinematical information from $W \to qq'$ decays. With the full Run II dataset the top-quark mass will be known to an accuracy better than the one presented in this paper. To reach this level of precision further work will focus on a better understanding of b-jet modeling, and in the uncertainties in the signal and background simulations. For first time the total uncertainty of the combination is below 1 GeV. With the current level of precision, the exact renormalization scheme definition corresponding to the current top mass measurements should be studied theoretically in more details.

7 Acknowledgments

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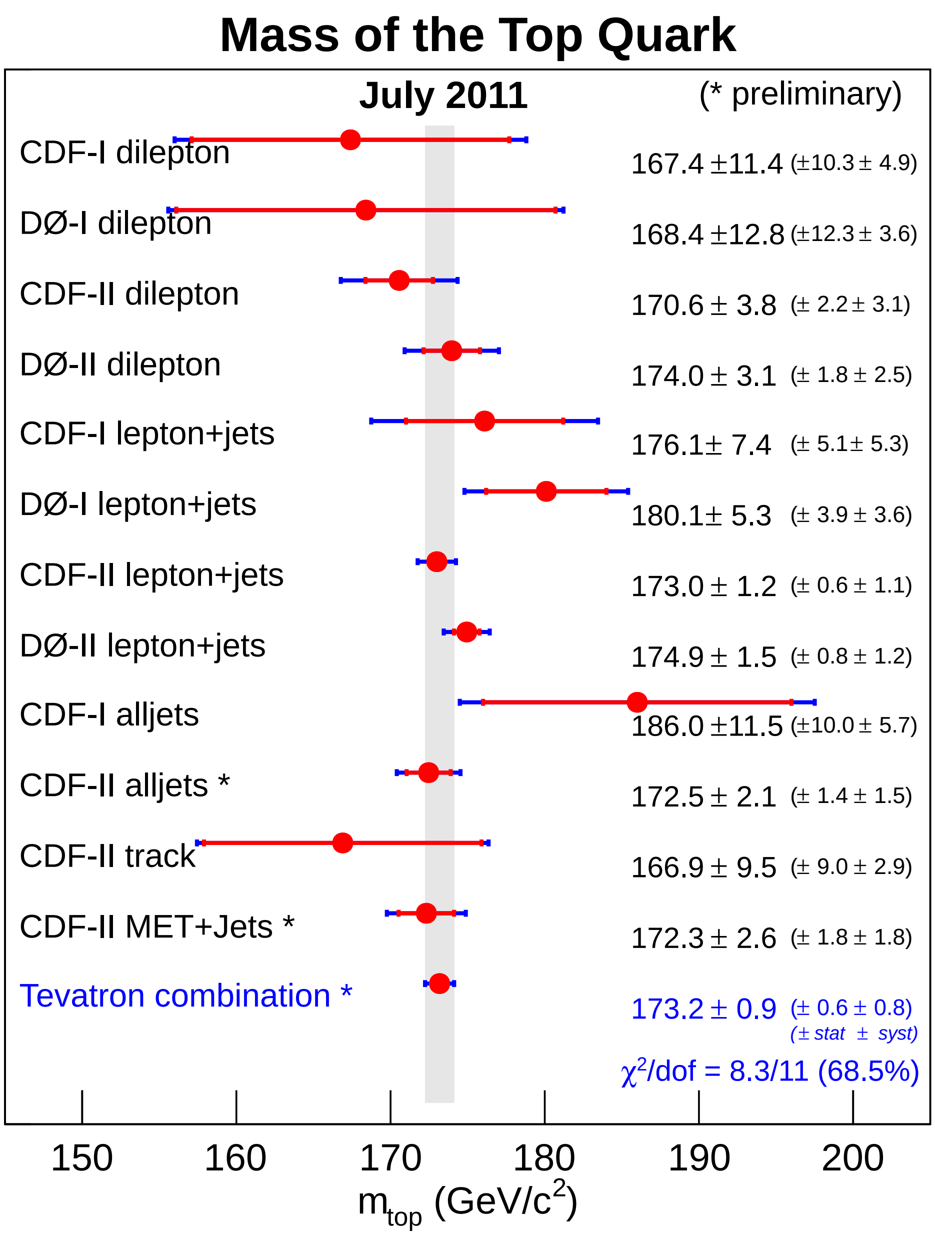

Figure 1: Summary of the input measurements and resulting Tevatron average mass of the top-quark.

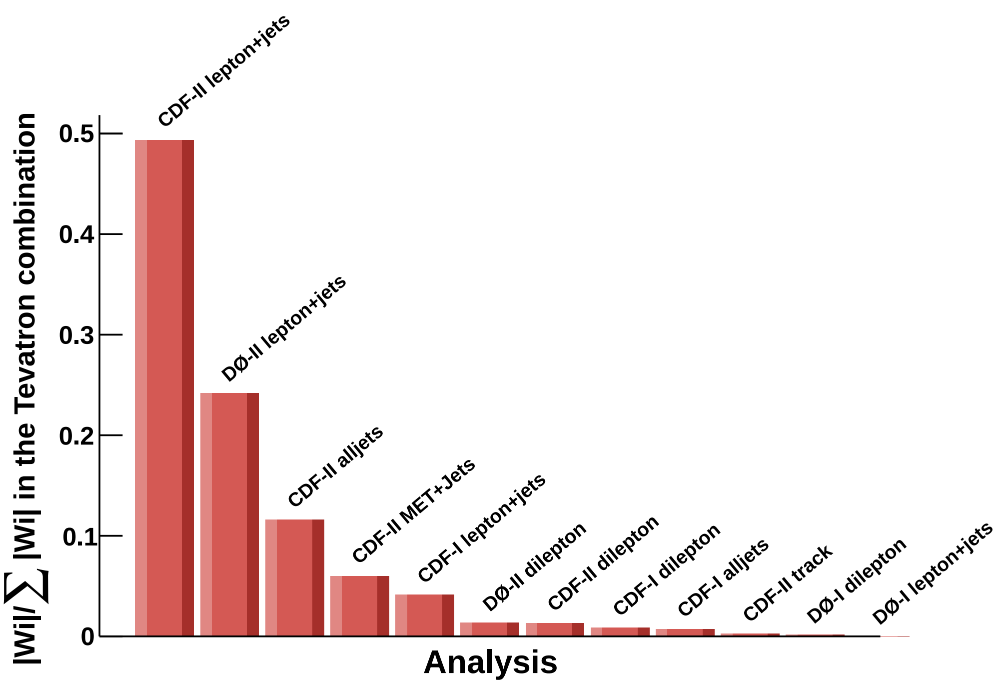

Figure 2: Relative weights of the input measurements in the combination. The relative weights have been obtained dividing the absolute value of each measurement weight by the sum over all measurements of the absolute values of their weights.

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