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

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### 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  $5.8 \text{ fb}^{-1}$  of data, adding some new analyses and updating old ones. Taking uncertainty correlations properly into account, and adding in quadrature the statistical and systematic uncertainties, the resulting preliminary Tevatron average mass of the top quark is  $M_t = 173.2 \pm 0.9 \text{ GeV}/c^2$ .

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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,  $M_t$ .

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,  $M_t$ . The pioneering measurements were based on about  $100 \text{ pb}^{-1}$  of Run I data [1 - 12] collected from 1992 to 1996, and include results from the  $t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow qq'bqq'\bar{b}$  (allh),  $t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow \ell\nu bqq'\bar{b}$  (l+jt)<sup>2</sup>, and  $t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow \ell^+\nu b\ell^-\bar{\nu}\bar{b}$  (di-l) decay channels.

Several more 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  $4.8 - 5.8 \text{ fb}^{-1}$  of data (the CDF analysis using charged particle tracking is not updated and it has luminosity  $1.9 \text{ fb}^{-1}$ ) and improved analysis techniques [13, 14, 15, 16, 17, 18, 19, 20, 21]

With respect to the July 2010 combination [22], the Run II CDF measurement in the all-hadronic channel has been updated using  $5.8 \text{ fb}^{-1}$  of data, and improved analysis technique [16]. A new analysis in  $\cancel{E}_T$  plus jets channel was added by CDF. This sample is statistically independent from the other channels and is accounted like a forth channel (called  $\cancel{E}_T$ +Jets, MEt) [17]. The now published Run II CDF measurements in the di-l channel [13], l+jt channel [14] are unchanged. The measurement based on charged particle tracking [15] has been divided by  $L_{XY}$  and  $p_T^{lep}$  parts and the  $p_T^{lep}$  part was removed from the combination because of a possible large statistical correlation with other samples.

The DØ Run II measurements presented in this note include the most recent Run II measurements in the dilepton [21] channel using  $5.2 \text{ fb}^{-1}$  and the updated lepton plus jets channel [19, 20] with  $3.6 \text{ fb}^{-1}$  of data.

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, 15], two preliminary Run II CDF results [16, 17] and two preliminary Run II DØ results [20, 21]. The combination takes into account the statistical and systematic uncertainties and their correlations using the method of Refs. [23, 24] and supersedes previous combinations [25, 26, 27, 28, 29, 30, 31, 32, 22].

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.

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<sup>2</sup>Here  $\ell = e$  or  $\mu$ . 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  $\tau \rightarrow e, \mu$  are included in the direct  $W \rightarrow e$  and  $W \rightarrow \mu$  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 eleven measurements of  $M_t$  are used: five published Run I results, three published Run II results, and four 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 and allh channels constrain the response of light-quark jets using the kinematic information from  $W \rightarrow qq'$  decays (*in situ* calibration). Residual JES uncertainties associated with  $p_T$  and  $\eta$  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 of Ref. [15] 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  $\gamma$ +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. [23, 24] 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 [33].

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 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 [18] with  $1 \text{ fb}^{-1}$  of data and the preliminary result obtained with  $2.6 \text{ fb}^{-1}$  Run IIb

Table 1: Summary of the measurements used to determine the Tevatron average  $M_t$ . Integrated luminosity ( $\int \mathcal{L} dt$ ) has units in  $\text{fb}^{-1}$ , and all other numbers are in  $\text{GeV}/c^2$ . 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. The new measurements utilized here are the two CDF preliminary results in the last column.

	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	-	-	-	-	-	-	-	0.58	-	0.53	0.95	1.54
aJES	-	-	-	-	-	0.14	-	0.13	1.57	0.0	0.03	0.12
bJES	0.6	0.6	0.8	0.7	0.7	0.33	0.0	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	0.0	0.0	0.24	0.20
dJES	0.3	0.7	0.6	0.0	0.0	0.58	0.06	0.01	1.50	0.63	0.04	0.05
rJES	4.0	3.4	2.7	2.5	1.1	2.01	0.24	0.41	0.0	0.0	0.38	0.45
LepPt	0.0	0.0	0.0	0.0	0.0	0.27	0.0	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	-	-	-	1.3	1.3	-	-	-	-	-	-	-
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	-	-	-	-	-	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

(2006–2007) dataset. The recent update of this analysis includes a new calibration of the particle reponses in MC with data.

The DØ Run II di-l result is a new result with  $5.2 \text{ fb}^{-1}$  datasets [21].

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 [22] 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  $W \rightarrow qq'$  invariant mass in the CDF Run II l+jt and allh measurements and DØ Run II l+jt measurement. 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. This category also includes uncertainties associated with the jet identification and resolution, trigger and  $b$ -jets tagging. It is uncorrelated with the DØ Run I and CDF measurements.

**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  $D\bar{O}$  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  $\eta$ -dependent JES corrections which are estimated using di-jet data events. For  $D\bar{O}$  this includes uncertainties in the calorimeter response for light jets, uncertainties from  $p_T$ - and  $\eta$ -dependent JES corrections and from the sample dependence of using  $\gamma$ +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. For CDF, this 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. For  $D\bar{O}$  Run II measurements, it is included in the dJES category.

**LepPt:** The systematic uncertainty arising from uncertainties in the scale of lepton transverse momentum measurements. This is an important uncertainty for CDF’s track-based measurement. 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  $D\bar{O}$  it also includes the uncertainty from higher order corrections evaluated from a comparison of  $t\bar{t}$  samples generated by MC@NLO [34] and ALPGEN [35], both interfaced to HERWIG [36, 37] 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 [38, 39] 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 [43] (Run I) for HERWIG [36, 37] when modeling the  $t\bar{t}$  signal.

**Detector Modeling:** The systematic uncertainty arising from uncertainties in the modeling of the detector in the MC simulation. For  $D\bar{O}$  this includes uncertainties from jet resolution

and identification. CDF found these effects to have a negligible contributions to the measured mass.

**Background from MC:** In this version of the combination the background systematic is separated in two parts: MC part and 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 shape, e.g. the uncertainties from the modeling of the  $W$ +jets background in the Lepton plus jets channel (uncertainties associated with variations of the factorization scale used to model  $W$ +jets background).

**Background from Data:** This includes particular uncertainties associated with the modeling of the QCD multijet background using data in the allh, MET and l+jt channels, uncertainties associated with the modeling of the Drell-Yan background in the di-l channel.

**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. For  $D\bar{O}$  this uncertainty also includes the uncertainties from modeling of the QCD multijet background determined from data and dominated by limited statistics.

**Uranium Noise and Multiple Interactions (UN/MI):** This is specific to  $D\bar{O}$  and includes the uncertainty arising from uranium noise in the  $D\bar{O}$  calorimeter and from the multiple interaction corrections to the JES. For  $D\bar{O}$  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  $D\bar{O}$  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. Variations in the assignment of uncertainties to the uncertainty categories, in the back-propagation of the bJES uncertainties to Run I measurements, in the approximations made to symmetrize the uncertainties used in the combination, and in the assumed magnitude of the correlations, have all a small impact ( $< 0.150 \text{ GeV}/c^2$ ) in the combined  $M_t$  and total uncertainty.

## 4 Correlations

The following correlations are used for the combination:

- The uncertainties in the Statistical, Mrthod, 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 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.
- The uncertainties in the bJES, cJES, Signal, CR, and MC 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  $\chi^2$  minimization and the analytic best linear unbiased estimator (BLUE) method [23, 24]. 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 [24].

## 5 Results

The combined value for the top-quark mass is:  $M_t = 173.18 \pm 0.56$  (stat)  $\pm 0.76$  (syst) GeV/ $c^2$ . Adding the statistical and systematic uncertainties in quadrature 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 to two significant digits in the uncertainty, the combination provides  $M_t = 173.2 \pm 0.9$  GeV/ $c^2$ . It has a  $\chi^2$  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 like the statistical uncertainty it is treated like it. With this category we transfer some part from the systematic uncertainty

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

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  $\pm 0.49 \text{ GeV}/c^2$  with  $\pm 0.39 \text{ GeV}/c^2$  coming from its statistical component and  $\pm 0.30 \text{ GeV}/c^2$  from the nonstatistical component. The total statistical uncertainty is  $\pm 0.56 \text{ GeV}/c^2$ .

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.

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.

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 ( $\text{GeV}/c^2$ )	
$M_t$	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

Table 4: The pull and weight for each of the inputs used to determine the Tevatron average mass of the top quark. See Reference [23] for a discussion of negative weights.

	Run I published					Run II published			Run II preliminary			
	CDF		DØ			CDF			CDF		DØ	
	l+jt	di-l	allh	l+jt	di-l	l+jt	di-l	Lxy	allh	Met	l+jt	di-l
Pull	+0.40	-0.51	+1.12	+1.32	-0.37	-0.24	-0.81	-0.67	+0.39	-0.36	1.5	0.27
Weight [%]	-4.7	-1.0	-0.8	-0.0	-0.2	+56.1	+1.5	+0.3	+13.2	+6.8	+27.5	+1.54

Although no input has an anomalously large pull and the  $\chi^2$  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

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  $M_t^{\text{allh}}$ , 1+jt  $M_t^{1+j}$ , di-1  $M_t^{\text{di-1}}$  and MEt  $M_t^{\text{Met}}$  decay channels.

Parameter	Value (GeV/ $c^2$ )	Correlations			
		$M_t^{\text{allh}}$	$M_t^{1+j}$	$M_t^{\text{di-1}}$	$M_t^{\text{Met}}$
$M_t^{\text{allh}}$	$172.7 \pm 2.0$	1.00			
$M_t^{1+j}$	$173.4 \pm 1.0$	0.20	1.00		
$M_t^{\text{di-1}}$	$170.8 \pm 2.1$	0.18	0.38	1.00	
$M_t^{\text{Met}}$	$172.1 \pm 2.5$	0.10	0.28	0.14	1.00

fit the four physical observables,  $M_t^{\text{allh}}$ ,  $M_t^{1+j}$ ,  $M_t^{\text{di-1}}$  and  $M_t^{\text{Met}}$  separately. The results of these combinations are shown in Table 5.

Using the expression in reference [44] and the results of Table 5 we calculate the following chi-squares  $\chi^2(LJT - DIL) = 1.77/1$ ,  $\chi^2(LJT - HAD) = 0.12/1$ ,  $\chi^2(LJT - \cancel{E}_T + Jets) = 0.28/1$ ,  $\chi^2(DIL - HAD) = 0.52/1$ ,  $\chi^2(DIL - \cancel{E}_T + Jets) = 0.18/1$  and  $\chi^2(HAD - \cancel{E}_T + Jets) = 0.04/1$ . These correspond to chi-squared probabilities of 18%, 73%, 60%, 47%, 67%, 89% respectively, and indicate that all channels are reasonably 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.

## 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, three published Run II measurements, and four preliminary Run II measurements. Taking into account the statistical and systematic uncertainties and their correlations, the preliminary result for the Tevatron average is:  $M_t = 173.18 \pm 0.56$  (stat)  $\pm 0.76$  (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  $M_t = 173.2 \pm 0.9$  GeV/ $c^2$ .

The central value is 0.12 GeV/ $c^2$  lower than our July 2010 average of  $M_t = 173.32 \pm$

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  $W \rightarrow qq'$  decays. It can be expected that with the full RunII 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 be focuses on a better understanding of  $b$ -jet modeling, and in the uncertainties in the signal and background simulations. For first time the total uncertainty is below 1 GeV.

## 7 Acknowledgments

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## Mass of the Top Quark

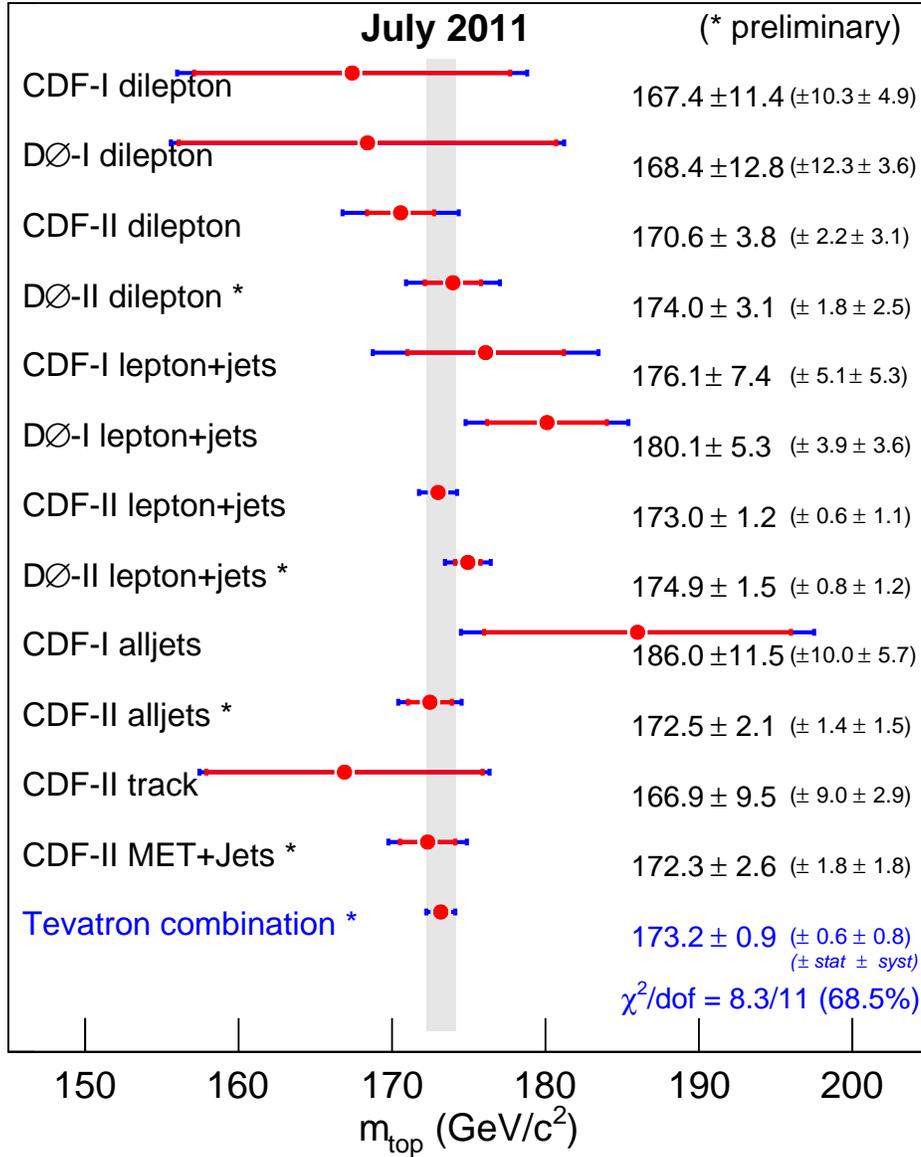


Figure 1: Summary of the input measurements and resulting Tevatron average mass of the top-quark.

Chart 3

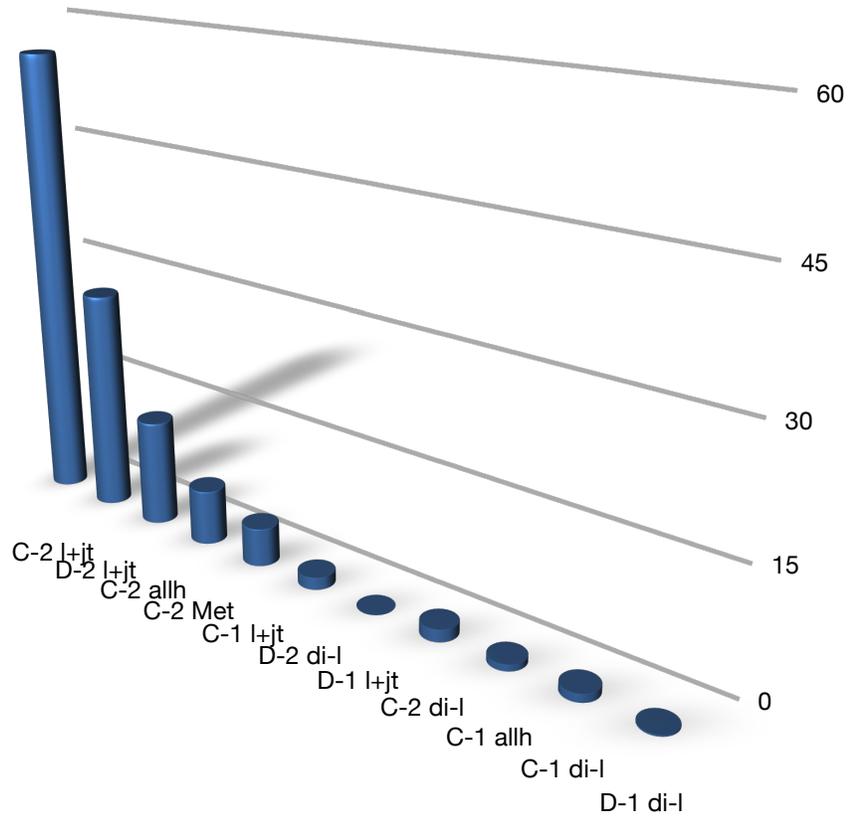


Figure 2: Relative weights of the input measurements in the combination. The relative weights have been obtained dividing the absolute value of each measurement weight by the sum over all measurements of the absolute values of their weights.

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