CDF note 8743

Combination of CDF Top Mass Results Using the $1\,\mathrm{fb}^{-1}$ Data Set

The CDF Collaboration
URL http://www-cdf.fnal.gov
(Dated: March 20, 2007)

We summarize the CDF measurements of the top-quark mass, M_t, based on the $1\,\mathrm{fb}^{-1}$ data set. We combine the most recent Run-II results with the published Run-I results, assuming Gaussian systematic uncertainties, to obtain, $M_t = 170.5 \pm 1.3\,(\mathrm{stat}) \pm 1.8\,(\mathrm{syst})\,\mathrm{GeV}/c^2$, which corresponds to a total uncertainty of $2.3\,\mathrm{GeV}/c^2$ and a relative uncertainty of 1.3%.

Preliminary Results for Winter 2007 Conferences

I. INTRODUCTION

We combine the CDF published top-quark mass results from Run-I [1-3] with four Run-II results using $0.7 - 1\,\mathrm{fb}^{-1}$ of data [4-7]. Results from the $t\bar{t} \to qq'bqq'\bar{b}$ (HAD), $t\bar{t} \to \ell\nu qq'b\bar{b}$ (LJT), and $t\bar{t} \to \ell^+\nu b\ell^-\overline{\nu}\bar{b}$ (DIL) final states are included. These measurements are combined accounting for statistical and systematic correlations using the method of reference [8]. The Run-II measurement in the LJT channel yields the single most precise result. Relative to the previous CDF combination reported in [9], this combination includes updates of the Run-II analyses in the HAD channel, which now uses an in-situ JES calibration to reduce it's total uncertainty by 20% relative to a similar analysis on the same data-set.

The error categories used in the combination are detailed in Section II while the input measurements themselves are summarized in Section III. The correlations used in the combination are discussed in Section IV and the resulting top-quark mass is given in Section V.

II. ERROR CATEGORIES

We employ the same error categories as used for the Tevatron world average [10]. They have evolved to include a detailed breakdown of the various sources of uncertainty and aim to lump together sources of systematic uncertainty that share the same or similar origin. For example, the "Signal" category discussed below includes the uncertainties from ISR, FSR, and PDF - all of which affect the modeling of the $t\bar{t}$ signal. Additional categories have been added in order to accommodate specific types of correlations. For example, the jet energy scale (JES) uncertainty is sub-divided into several components in order to more accurately accommodate our best estimate of the relevant correlations. Each error category is discussed below.

Statistical: The statistical uncertainty associated with the M_t determination.

iJES: The statistical uncertainty on the JES arising from the in-situ $W \to qq'$ calibration alone. Residual JES uncertainties, which arise from effects not considered in the in-situ calibration, are included in the Method category below.

aJES: This is specific to DØ Run II and is only included here in order to be consistent with reference [10].

bJES: The systematic uncertainty specific to the modeling of b-jets. This includes uncertainties arising from variations in the semi-leptonic branching fraction, b-fragmentation modeling, and differences in the color flow between b-quark jets and light-quark. This is usually labeled "B Jet" for CDF Run-II analyses.

cJES: The systematic uncertainty on the JES arising from the modeling of fragmentation and out-of-cone corrections. This is the quadrature sum of the L7 and L8 JES uncertainties for CDF Run-II analyses.

dJES: The systematic uncertainty on the JES arising from the relative corrections. This is the L1 JES uncertainties for CDF Run-II analyses.

rJES: The systematic uncertainty on the JES arising from the modeling of the calorimeter response and underlying event and multiple interaction corrections. This is the quadrature sum of the L4, L5, and L6 JES uncertainties for CDF Run-II analyses.

Signal: The systematic uncertainty arising from uncertainties in the modeling of the $t\bar{t}$ signal including variations in the ISR, FSR, and PDF descriptions used to generate the $t\bar{t}$ Monte Carlo samples that calibrate each method.

Generator: The systematic uncertainty associated with variations observed when substituting Pythia (Run I and Run II) or ISAJET (Run I) for HERWIG when modeling the $t\bar{t}$ signal.

UN/MI: This is specific to DØ Run I and is only included here in order to be consistent with reference [10].

Background: The systematic uncertainty arising from uncertainties in modeling the dominant background sources, including q^2 variations. This is the quadrature sum of the "Background Shape" and "Background normalization" uncertainties for most CDF Run-II analyses.

Method: The systematic uncertainty arising from any source specific to a particular fit method, including the variations in B-tagging efficiency and the finite Monte Carlo statistics available to calibrate each method. This is the quadrature sum of the "Method", "B-tag", and "MC Statistics" categories for most CDF Run-II analyses.

These categories represent the current preliminary understanding of the various error categories 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 error categories and in the correlations assumed affect the combined top mass and related uncertainty by $< 50\,\mathrm{MeV}/c^2$ - a factor of 50 smaller than the total uncertainty on the combination reported here.

III. INPUT MEASUREMENTS

For this combination we use seven measurements. Three published Run-I [1-3] results and four Run-II results [4-7]. They are summarized in Table I. The correlations between the various inputs are described in the next section. Based on studies described in reference [11] the statistical correlation between the L_{xy} and LJT inputs is set to 0 in the combination. Variations of this statistical correlation within a reasonable range negligably affect the combination.

There are other measurements in the LJT, DIL, and HAD channels. Once their correlations with the present measurements are understood, we can include them here. We chose to use the method from each channel with the *a priori* best sensitivity.

	Run II Preliminary				Run I Published		
Input	LJT	DIL	HAD	L_{xy}	LJT	DIL	HAD
M_t	170.9	164.5	171.1	183.9	176.1	167.4	186.0
iJES	1.4	0.0	2.4	0.0	0.0	0.0	0.0
aJES	0.0	0.0	0.0	0.0	0.0	0.0	0.0
bJES	0.6	0.6	0.4	0.0	0.6	0.5	0.6
cJES	0.0	2.8	0.0	0.0	2.7	2.6	3.0
dJES	0.2	1.6	0.0	0.0	0.7	0.6	0.3
rJES	0.0	1.3	0.0	0.3	3.4	2.8	4.0
Signal	1.1	0.9	1.3	1.4	2.6	2.8	1.8
Genratr	0.2	0.9	1.0	0.7	0.1	0.6	0.8
UN/MI	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Backgnd	0.2	0.7	1.0	2.3	1.3	0.3	1.7
Method	0.4	0.9	0.7	4.8	0.0	0.7	0.6
Sys-Total	1.9	3.9	3.2	5.6	5.3	4.9	5.7
Stat	1.6	3.9	2.8	14.8	5.1	10.3	10.0
Total	2.5	5.6	4.3	15.8	7.3	11.4	11.5

TABLE I: The measurements used to determine the CDF combined top-quark mass. All numbers are in units of GeV/c^2. The error categories and their correlations are defined in the text.

For the L_{xy} measurement, we include the systematic uncertainty associated with the potential mis-modeling of the background decay length distribution in the "Method" category, since it's a source of uncertainty unique to this method. For the Run-I measurements, we back propagate the systematic uncertainty specific to B-jets (bJES) as determined in Run II and then correct the Run-I absolute corrections (rJES) to keep the total JES uncertainty constant. Variations of these assumptions were previously explored and found to negligibly affect the combination. We haven't explicitely revisited these studies here since the weight the Run-I measurements carry in the combination diminishes as the precision of the Run-II measurements improves so that the effect of these variations can only get smaller.

IV. CORRELATIONS

The following correlations are used when making the combination:

- The uncertainties in the Statistical, Method, and iJES categories are taken to be uncorrelated among the measurements.
- The uncertainties in the aJES and dJES and categories are taken to be 100% correlated among all Run I and all Run II measurements, but uncorrelated between Run I and Run II.

- The uncertainties in the Background category are taken to be 100% correlated among all measurements in the same channel.
- The uncertainties in the bJES, cJES, rJES, Signal, and Generator categories are taken to be 100% correlated among all measurements.

Using the inputs from Table I and the correlations specified here, the resulting matrix of total correlation co-efficients is given in Table II. Varying the correlations by 10% (1.0 $\rightarrow$ 0.9 and 0.0 $\rightarrow$ 0.1) negligibly affected the combined top-quark mass and related uncertainty. It is interesting to note that, as expected, the L_{xy} measurement is only weakly correlated with the other inputs. Thus, with enough data, it will provide an important consistency check, largely independent of jet energy scale.

	Run II Preliminary				Run I Published		
	HAD	L_{xy}	LJT	DIL	LJT	DIL	HAD
HAD	1						
L_{xy}	0.04	1					
LJT	0.17	0.05	1				
DIL	0.10	0.03	0.13	1			
LJT	0.12	0.07	0.19	0.36	1		
DIL	0.09	0.03	0.12	0.23	0.29	1	
HAD	0.10	0.02	0.08	0.26	0.32	0.19	1

TABLE II: The resulting matrix of total correlation coefficients used to determine the CDF combined top-quark mass.

V. RESULTS

Using the measurements of Table I, the correlations of Section IV, and assuming Gaussian systematic uncertainties, the CDF combined top mass is

$$M_t = 170.5 \pm 1.3\,(\mathrm{stat}) \pm 1.8\,(\mathrm{syst})\ \mathrm{GeV}/c^2 \quad (1)$$
$$= 170.5 \pm 2.3\ \mathrm{GeV}/c^2 \quad (2)$$

with $\chi^2/dof = 5.5/6$, which corresponds to a chi-squared probability of about 51%, indicating good agreement among all the input measurements. The method of reference [8] decomposes the total uncertainty into the contributions from the various error categories as: iJES ($\pm$1.1), quadrature sum of other JES categories ($\pm$0.7), Signal ($\pm$1.1), Generator ($\pm$0.4), Background ($\pm$0.3), and Method ($\pm$0.3), where all numbers are in units of GeV/c^2. The corresponding pull and weight for each of the inputs is listed in Table III. The input measurements and the resulting CDF combined M_t are summarized in Figure 1.

	Run II Preliminary				Run I Published		
	LJT	DIL	HAD	L_{xy}	LJT	DIL	HAD
Pull	+0.32	-1.17	+0.17	+0.86	+0.80	-0.30	+1.37
Weight	+69%	+10%	+19%	+1.1%	+0.4%	+0.1%	+0.4%

TABLE III: The pull and weight for each of the inputs used to determine the CDF combined top quark mass.

Although the chi-squared from the combination of all measurements indicates that there is good agreement among them, and no input has an anomalously large pull, it is still interesting to also fit for the top mass in the LJT, DIL, and HAD channels separately. We use the same methodology and include the systematic correlations among the measurements as described in Section IV. The results are shown in Table IV. Using the expression in reference [13] we calculate the following chi-squares $\chi^2(LJT-DIL) = 2.8/1$, $\chi^2(LJT-HAD) = 0.1/1$, and $\chi^2(DIL-HAD) = 2.6/1$. These correspond to chi-squared probabilities of 10%, 81%, and 11%, respectively, and indicate that all channels are reasonably consistent with each other.

	fit value (GeV/c^2)	correlations M(LJT)	M(DIL)	M(HAD)
M(LJT)	171.1 ± 2.5	1		
M(DIL)	162.7 ± 5.0	0.22	1	
M(HAD)	172.2 ± 4.1	0.21	0.15	1

TABLE IV: The results of a fit to determine the top-quark mass in the three final states separately.

VI. CONCLUSION

We have combined CDF Run-I and Run-II top-quark mass measurements from all three final states, HAD, LJT, and DIL to get a CDF combined top-quark mass of $170.5 \pm 2.3\,\mathrm{GeV}/c^2$, which corresponds to a relative precision of 1.3%. These CDF measurements are combined with Run-I and Run-II DØ measurements to form a new world average top-quark mass as described in reference [10].

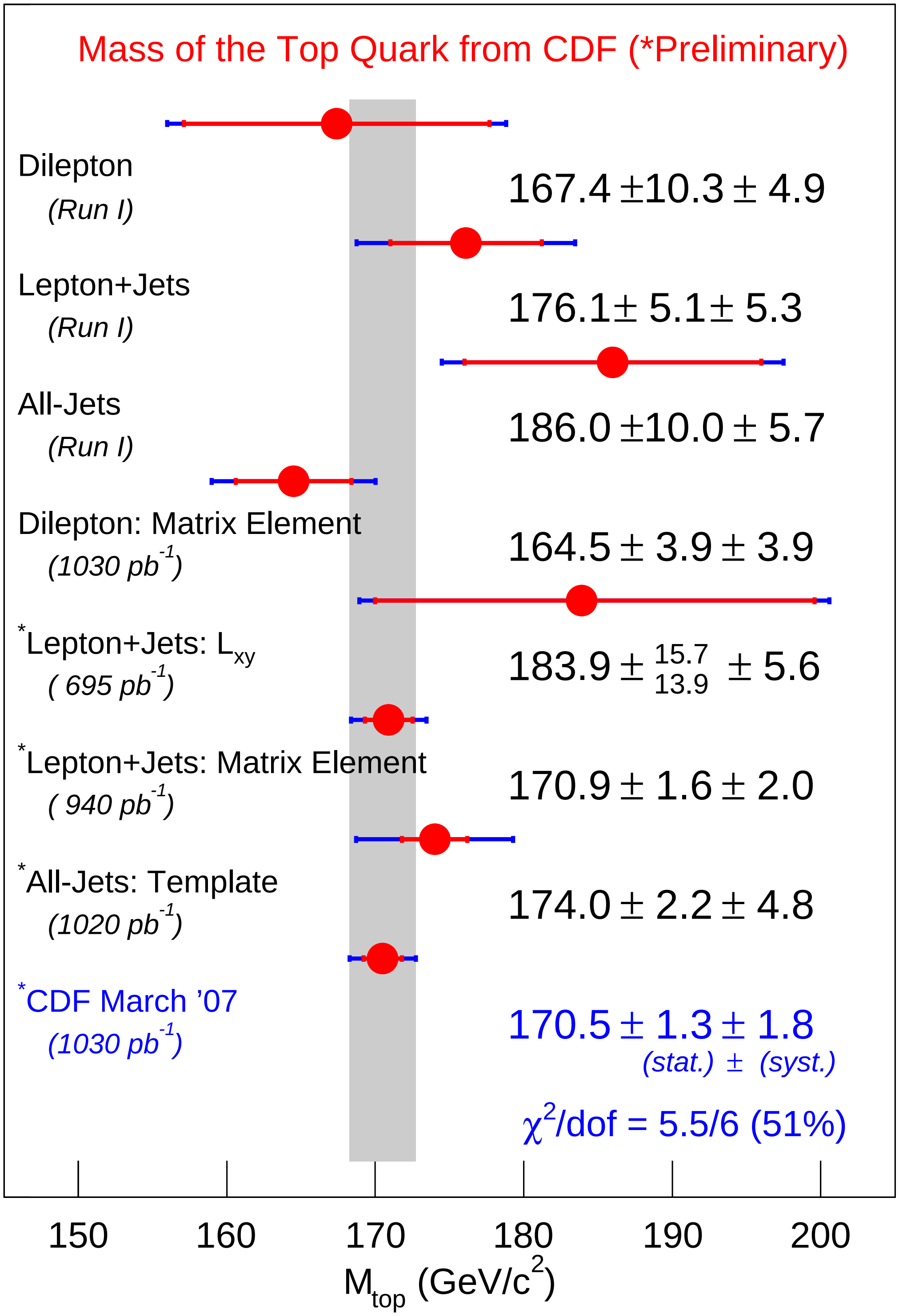

FIG. 1: A summary of the input measurements and resulting CDF combined top-quark mass.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium fuer Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-2002-00292, and the Academy of Finland.

---

[1] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **79**, (1997) 1992.
[2] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **80**, (1998) 2779.
[3] CDF Collaboration, F. Abe *et al.*, Phys. Rev. **D63**, (2001) 032003.
[4] CDF Collaboration, *Measurement of the Top-Quark Mass Measurement Using the Matrix Element Analysis Technique in the Lepton+Jets Channel with In-Situ $W \to jj$ Calibration*, CDF Conference Note 8375.
[5] CDF Collaboration, A. Abulencia *et al.*, Phys. Rev. D **75**, (2007) 031105(R).
[6] CDF Collaboration, *Measurement of the Top Quark Mass in the All-hadronic Channel using an in-situ Calibration of the Dijet Invariant Mass with 0.9* fb^{-1}, CDF Conference Note 8709.
[7] CDF Collaboration, *Updated Measurement of the Top Quark Mass in the Lepton+Jets Channel using the Decay Length Technique*, CDF Conference Note 8133.
[8] L. Lyons, D. Gibaut, and P. Clifford, Nucl. Instrum. Meth. **A270** (1988) 110;
A. Valassi, Nucl. Instrum. Meth. **A500** (2003) 391.
[9] CDF Collaboration, *Combination of CDF Top Mass Results Using up to 1 fb^{-1} of Data*, CDF Conference Note 8459.
[10] Tevatron Electroweak Working Group, *Combination of CDF and D0 Results on the Top-Quark Mass*, Fermilab-TM-2380-E, (hep-ex/0703034).
[11] CDF Collaboration, *Updated Combination of CDF Top Mass Results Using up to 750 pb^{-1} of Data*, CDF Conference Note 8222.
[12] the CDF Jet Energy Scale and Resolution Working Group,
http://www-cdf.fnal.gov/physics/new/top/public/jets/cdfpublic.html
[13] For two measurements, x and y, we calculate their consistency using $\chi^2 = (x-y)^2/\sigma^2_{x-y}$, where $\sigma^2_{x-y} = \sigma^2_x + \sigma^2_y - 2\rho_{xy}\sigma_x\sigma_y$, where ρ_{xy} is the x, y correlation coefficient.