DØ Note 6189

Combination of the DØ top quark mass measurements

The DØ Collaboration
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We present a combination of the top quark mass measurements performed by the DØ experiment in lepton plus jets (ℓ+jets) and dilepton ($\ell\ell$) channels. The combined result yields:

$$m_{\rm top} = 175.08 \pm 0.77\,({\rm stat}) \pm 1.25\,({\rm syst})\ {\rm GeV},$$
$$m_{\rm top} = 175.08 \pm 1.47\,({\rm stat + syst})\ {\rm GeV}.$$

Result for winter 2011 conferences

I. INTRODUCTION

The combination of top quark mass ($m_{\rm top}$) measurements presented in this note includes the best DØ measurements from Run I of the Tevatron in the dilepton [1] and $\ell+$jets [2] channels, and the most recent Run II measurements in the dilepton [3] channel using 5.4 fb^{-1} and the $\ell+$jets [4, 5] channel with 3.6 fb^{-1} of data. This combination supersedes the previous result [6].

II. METHOD AND INPUTS

We use the BLUE [7] method to combine of the $m_{\rm top}$ measurements following the same procedure, using essentially the same classes of uncertainties and the same program as used to compute the Tevatron average of $m_{\rm top}$ [8].

Table I summarizes the measurements and the corresponding statistical and systematic uncertainties that enter the combination. The categories of uncertainties represent the current understanding of the sources of uncertainty and their correlations. We expect these to evolve as we continue to probe the sensitivity of each method to each source of uncertainties with greater precision. We give below a short explaination for what these categories contain (see [8] for further details).

iJES: That part of the jet energy scale (JES) uncertainty which originates from in situ calibration procedures and is of statistical origin. To properly take into account the correlation between the $\ell+$jets and dilepton channels, it also contains the flavor dependent jet response systematic uncertainty for the $\ell+$jets channel.

aJES: That part of the JES uncertainty which originates from differences in detector response between b-jets and light-quark jets for the dilepton channel.

bJES: That part of the JES uncertainty which originates from uncertainties specific to the Monte Carlo (MC) modeling of b-jets like variations of the semileptonic branching fractions or b-fragmentation modeling.

cJES: That part of the JES uncertainty which originates from MC modeling uncertainties associated with light-quark fragmentation and out-of-cone corrections. For 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. It includes uncertainties in the calorimeter response for light jets, and uncertainties from p_T- and η-dependent JES corrections.

rJES: The remaining part of the JES uncertainty. For Run II measurements, it is included in the dJES category.

Detector Modeling: The systematic uncertainty arising from uncertainties in the modeling of the detector in the MC simulation. This includes uncertainties from jet resolution and identification.

Lepton pt: The systematic uncertainty arising from uncertainties in the scale of lepton transverse momentum and lepton momentum resolution measurements.

Signal Modeling: The systematic uncertainty arising from uncertainties in the $t\bar{t}$ modeling. This includes uncertainties from variations of the ISR, FSR, the choice of PDF and from higher order corrections.

Background from MC: The uncertainty in modeling the background sources measured using MC simulation. This includes uncertainties from the modeling of the $W+$jets background in the $\ell+$jets channel.

Background from Data: The uncertainty in modeling the background sources evaluated from data. This includes uncertainties on the signal fraction, trigger and b-jet identification.

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

Color Reconnection (CR): The systematic uncertainty arising from a variation of the phenomenological description of color reconnection between final state particles.

Multiple Hadron Interactions (MHI): The systematic uncertainty arising from a mismodeling of the distribution of the number of collisions per Tevatron bunch crossing.

Uranium Noise and Multiple Interactions (UN/MI): This is specific to DØ Run I measurements and includes the uncertainty arising from uranium noise in the calorimeter and from the multiple interaction corrections to the JES.

For the current combination, we introduced some modifications to the categories specified in [8]. The category "MC" has been merged with the "Signal Modeling" as they have the same correlation (fully correlated between among measurements) and similar physical origin. The category "Fit" of Ref. [8] has been given a more appropriate name "Method". A new category, "Detector Modeling", has been introduced for systematic uncertainties related to detector resolution and reconstruction effects that are correlated among all measurements in the same experiment. In Ref. [8], to ensure proper correlation for these modeling uncertainties, they were included to "aJES", despite that they were not related to the jet energy scale. The category "Background" has been split into "Background from MC" and "Background from Data". This has no impact on the present combination, but will be used to properly take into account the correlations with CDF meaurements. In particular, "Background from MC" is expected to be fully correlated between the same CDF and DØ channels, while "Background from Data" will be correlated only for measurements in the same channel within the same experiment for the same data taking period. These changes are expected to take effect for the next computation of the Tevatron average m_{top}. A summary of the correlations between the different systematic categories is shown in Table II.

As discussed in Ref. [5], uncertainties for the Run IIa measurement in the $\ell+$jets channel [4] have been updated. In particular, uncertainties associated with the model for hadronization, higher-order corrections, modeling of color reconnection, and the momentum scale for leptons have been re-examined for the $\ell+$jets result of Ref. [4]. Also, the central value of this measurement was shifted by 1.28 GeV, following the estimation of the flavor dependence of jet energy corrections in MC events [5].

The $\ell+$jets measurement uses the matrix element method with an in-situ jet energy calibration. In addition, it takes advantage of an externally determined jet energy scale calibration to achieve the highest precision. To take into account correlations among different sources of systematic uncertainty, the uncertainty on JES is separated into two parts, one arising from the in-situ calibration, and the other from the standard JES. This separation is unchanged since the previous combination, and is documented in Ref. [6].

The combined Run IIa and Run IIb measurement in the $\ell+$jets channel yields [5]:

$$m_{\mathrm{top}}{}^{\ell+\mathrm{jets}} \;=\; 174.94 \pm 0.83\,(\mathrm{stat}) \pm 1.24\,(\mathrm{syst})\ \mathrm{GeV}.$$

The dilepton mass measurement entering this combination also uses the matrix element technique [3] for the ee, $e\mu$ and $\mu\mu$ channels both for Run IIa and Run IIb, leading to:

$$m_{\mathrm{top}}{}^{\ell\ell} \;=\; 173.97 \pm 1.83\,(\mathrm{stat}) \pm 2.45\,(\mathrm{syst})\ \mathrm{GeV}.$$

The assignment of uncertainties to different categories is influenced by two factors: the nature of the source and the treatment of correlations defined for combining the mass measurements from the Tevatron [8]. A summary of the assignment of the systematic uncertainties of the input measurements from Run II into the categories defined above is shown in Table III.

III. RESULTS

Combining the $\ell+$jets and $\ell\ell$ measurements from Run I and Run II, we obtain:

$$m_{\mathrm{top}} = 175.08 \pm 0.77\,(\mathrm{stat}) \pm 1.25\,(\mathrm{syst})\ \mathrm{GeV}\ \mathrm{or}\ m_{\mathrm{top}} = 175.08 \pm 1.47\,(\mathrm{stat}+\mathrm{syst})\ \mathrm{GeV}.$$

Table IV summarizes the weights of individual measurements. The χ^2 for the combination is 1.5 for 3 degrees of freedom, which corresponds to a probability of 68% of getting a larger value of χ^2. A breakdown of uncertainties on the combined result is given in Table V.

Figure 1 displays a summary of the input m_{top} measurements and the combined DØ result, as well as the Tevatron average and the top quark mass extracted by DØ from the measurement of the $t\bar{t}$ cross section [11].

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	Run I		Run II	
	$\ell+$jets	$\ell\ell$	$\ell+$jets	$\ell\ell$
Luminosity	130 pb^{-1}	130 pb^{-1}	3.6 fb^{-1}	5.4 fb^{-1}
$m_{\rm top}$	180.1 GeV	168.4 GeV	174.94 GeV	173.97 GeV
iJES	0.0	0.0	0.53	0.00
aJES	0.0	0.0	0.00	1.57
bJES	0.7	0.7	0.07	0.40
cJES	2.0	2.0	0.00	0.00
dJES	0.0	0.0	0.63	1.50
rJES	2.5	1.1	0.00	0.00
Det. Modeling	0.0	0.0	0.36	0.33
Lepton pt	0.0	0.0	0.18	0.49
Signal Modeling	1.1	1.8	0.72	0.74
Bkg from MC	1.0	1.1	0.18	0.00
Bkg from Data	0.0	0.0	0.23	0.47
Method	0.6	1.1	0.16	0.10
CR	0.0	0.0	0.28	0.10
MHI	0.0	0.0	0.05	0.00
UN/MI	1.3	1.3	0.00	0.00
syst. uncertainty	3.9	3.6	1.24	2.45
stat. uncertainty	3.6	12.3	0.83	1.83
total	5.3	12.8	1.50	3.06

TABLE I: Inputs to the combination of $m_{\rm top}$ measurements at DØ , with uncertainties specified in GeV.

	Run I		Run II	
	$\ell+$jets	$\ell\ell$	$\ell+$jets	$\ell\ell$
iJES				
aJES			×	×
bJES	×	×	×	×
cJES	×	×	×	×
dJES			×	×
rJES	×	×	×	×
Det. Modeling	×	×	×	×
Lepton pt			×	×
Signal Modeling	×	×	×	×
Bkg from MC	×	o	×	o
Bkg from Data				
Method				
CR			×	×
MHI			×	×
UN/MI	×	×	×	×
statistical				

TABLE II: Summary of correlations among sources of uncertainties. An × or *o* within any category indicates the uncertainties that are 100% correlated, and no symbol indicates absence of correlation.

Kingdom); MSMT and GACR (Czech Republic); CRC Program and NSERC (Canada); BMBF and DFG (Germany); SFI (Ireland); The Swedish Research Council (Sweden); and CAS and CNSF (China).

[1] DØ Collaboration, B. Abbott *et al.*, Phys. Rev. Lett. **80**, 2063 (1998), DØ Collaboration, B. Abbott *et al.*, Phys. Rev. D **60**, 052001 (1999).
[2] DØ Collaboration, V. Abazov *et al.*, Nature **429**, 638 (2004).
[3] DØ Collaboration, V. Abazov *et al.*, "Precise Measurement of the Top Quark Mass in the Dilepton Channel at D0", to be submitted to PRL.
[4] DØ Collaboration, V. Abazov *et al.*, "Precise measurement of the top quark mass from lepton+jets events at DØ ", Phys. Rev. Lett. **101**, 182001 (2008).

	Run II $\ell+$jets	Run II $\ell\ell$
iJES	part of in-situ JES $\oplus$ Data-MC jet response	0
aJES	0	b/light response
bJES	b-modeling	b-quark modeling
cJES	0	0
dJES	part of in-situ JES $\oplus$ Residual JES	JES
rJES	0	0
Det. Modeling	Jet ID $\oplus$ Jet resolution	Jet resolution
Lepton pt	Lepton momentum scale	Lepton pt scale $\oplus$ muon resolution
Signal Modeling	Hadronization $\oplus$ Higher order effects $\oplus$ ISR/FSR $\oplus$ PDF	Hadronization/Higher Order $\oplus$ ISR/FSR $\oplus$ PDF
Bkg from MC	W+jets heavy flavor scale factor $\oplus$ Background modeling	0
Bkg from Data	Multijet contamination $\oplus$ Signal fraction $\oplus$ b-tagging $\oplus$ trigger	Signal fraction
Method	MC calibration	MC calibration
CR	Color reconnection	Color reconnection
MHI	Multiple hadron interactions	0
UN/MI	0	0

TABLE III: Summary of the assignments of the systematic uncertainties in Ref. [5] and [3] in term of the Tevatron categories defined in Ref. [8]. In each category, the quadratic sum of the assigned uncertainties is performed.

	Run I		Run II	
	$\ell+$jets	$\ell\ell$	$\ell+$jets	$\ell\ell$
weight	4.08%	0.25 %	89.74 %	5.93 %

TABLE IV: Summary of contributing weights for the individual measurements.

[5] DØ Collaboration, V. Abazov *et al.*, "Precise measurement of the top quark mass from lepton+jets events at D0", to be submitted to PRD.

[6] "Combination of the DØ top quark mass measurements", DØ note 5900-CONF

[7] L. Lyons, D. Gibaut and P. Clifford, Nucl. Instrum. and Methods A **270**, 110 (1988) and A. Valassi, Nucl. Instrum. and Methods A **500**, 391 (2003).

[8] CDF and DØ Collaborations,"Combination of CDF and DØ results on the mass of the top quark using up to 5.6 fb^1 of data", D0 note 6090-CONF, arXiv:1007.3178

[9] CDF Note 6804, http://hep.uchicago.edu/ hslee/ISR/cdf6804_ISR_DY.ps

[10] L. Lyons, D. Gibaut, and P. Clifford, "How to combine correlated estimates of a single physical quantity", Nucl. Instrum. Meth. **A270** 110 (1988)

[11] DØ Collaboration, V. Abazov *et al.*, "Combination and interpretation of $t\bar{t}$ cross section measurements with the D0 detector", D0 note 5907-CONF

	all channels
iJES	0.48
aJES	0.09
bJES	0.12
cJES	0.09
dJES	0.65
rJES	0.11
Det. Modeling	0.35
Lepton pt	0.19
Signal Modeling	0.74
Bkg from MC	0.20
Bkg from Data	0.21
Method	0.14
CR	0.26
MHI	0.05
UN/MI	0.06
systematic	1.25
statistical	0.77
total	1.47

TABLE V: Breakdown of systematic uncertainties on the combined DØ m_{top} measurement, with uncertainties given in GeV.

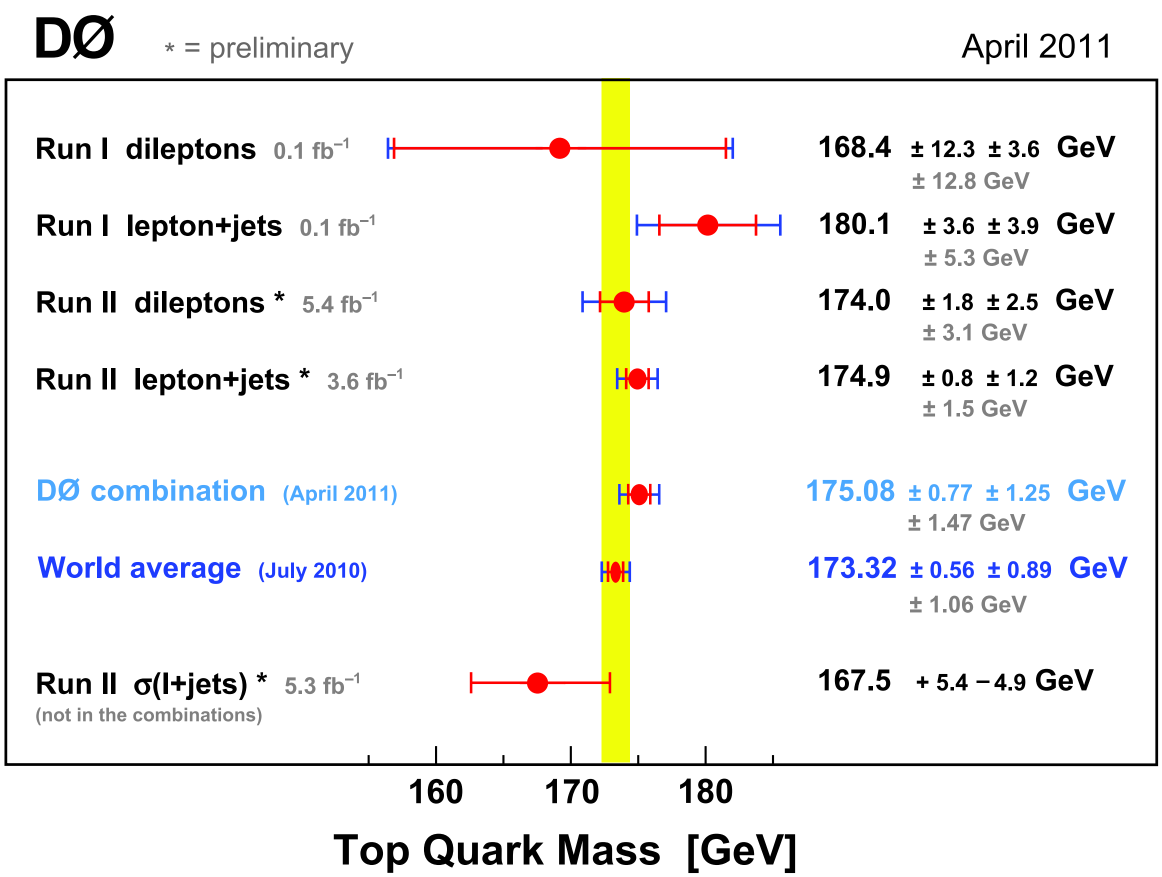

FIG. 1: A summary of the m_{top} measurements used for the DØ combination along with the DØ combination result, the Tevatron average of m_{top} and the top quark mass extracted from the cross section measurement. This extracted m_{top} value is not used in the combinations.