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2012 Update of the Combination of CDF and D0 Results for the Mass of the W Boson

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Abstract

We summarize and combine the results on the direct measurements of the mass of the W boson in data collected by the Tevatron experiments CDF and D0 at Fermilab. Earlier results from CDF Run-0 (1988–1989), D0 and CDF Run-I (1992–1995) and D0 results from 1 fb^{-1} (2002–2006) of Run-II data are now combined with two new, high statistics Run-II measurements: a CDF measurement in both electron and muon channels using 2.2 fb^{-1} of integrated luminosity collected between 2002 and 2007, and a D0 measurement in the electron channel using 4.3 fb^{-1} collected between 2006 and 2009. As in previous combinations, the results are corrected for inconsistencies in parton distribution functions and assumptions about electroweak parameters used in the different analyses. The resulting Tevatron average for the mass of the W boson is $M_{\text{W}} = 80,387 \pm 16$ MeV and a new world average including data from LEP II is $M_{\text{W}} = 80,385 \pm 15$ MeV.

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1 Introduction

The CDF and D0 experiments at the Tevatron proton-antiproton collider located at the Fermi National Accelerator Laboratory have made several direct measurements of the width, Γ_{W}, and mass, M_{W}, of the W boson. These measurements use both the $e\nu_e$ and $\mu\nu_\mu$ decay modes of the W boson.

Measurements of M_{W} have been published by CDF from the data of Run-0 [1], Run-I [2, 3] Run-II [4] and by D0 from Run-I [5, 6, 7, 8] and Run-II [9]. This document adds new Run-II measurements from CDF [10] and D0 [11]. The new CDF result supersedes and replaces the 200 pb^{-1} Run-II measurement [4] used in previous combinations. There are no new measurements of the width of the W since the previous average [12] in March 2010.

This note reports the combination of the mass measurements. The combination takes into account the statistical and systematic uncertainties as well as correlations among systematic uncertainties. It supersedes the previous combinations [13, 14, 15]. As with previous combinations, the measurements are combined using the analytic BLUE method [16].

2 New measurements

2.1 CDF

The CDF collaboration has extended its measurement [10] of the W boson mass to use 2.2 fb^{-1} of Run-II data taken between 2002 and 2007. Both the muon ($\mu\nu_\mu$) and electron ($e\nu_e$) channels are included and the central tracker has been used to set the absolute energy scale, using J/ψ and Υ decays in addition to the Z boson. The CDF result comes from the combination of 6 observables, $M_T^{(\mu)}$, $p_T^{(\mu)}$, $\not\!\!E_T^{(\mu)}$, $M_T^{(e)}$, $p_T^{(e)}$ and $\not\!\!E_T^{(e)}$. The combined result is $M_{\mathrm{W}} = 80,387 \pm 12$ (stat.) ± 15 (syst.) MeV. Table 1 summarizes the sources of uncertainty in the CDF measurement.

2.2 D0

The D0 collaboration has measured the W boson mass [11] using 4.3 fb^{-1} of Run-II data taken between 2006 and 2009. The measurement is performed in the electron channel and uses the $Z \to e^+e^-$ process as the calibration for the energy scale, effectively measuring the ratio M_W/M_Z. This calibration method eliminates many common systematic uncertainties but is limited by the available Z boson statistics. This measurement is complementary to the previous Run-II measurement [9] which used data from 2002–2006.

The new D0 result uses the two most sensitive observables: the transverse mass $M_T^{(e)}$ and the electron transverse momentum $p_T^{(e)}$. The missing transverse momentum $\not{E}_T^{(e)}$ has larger uncertainties and was not used in the combination. These observables yield a combined W boson mass, $M_{\text{W}} = 80,367 \pm 13$ (stat.) ± 22 (syst.) MeV. The individual contributions to the uncertainty are summarized in Table 2.

Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Hadronic recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
Experimental subtotal	10
Parton distributions	10
QED radiation	4
$p_T(W)$ model	5
Production subtotal	12
Total systematic uncertainty	15
W-boson statistics	12
Total uncertainty	19

Table 1: Uncertainties for the combined result on M_W from CDF [10].

3 Combination with older Tevatron measurements

As documented in the 2008 and 2009 combinations [14, 15], the oldest measurements from Run-0 and Run-Ia were made using older PDF sets and have been corrected [14] to modern PDF sets. These older results have also been adjusted to use the same combination technique ("BLUE") as in later combinations. All masses have also been corrected for a small dependence on the input W boson width in order to achieve consistency across all results. The value of $\Gamma_{\rm W}$ quoted here corresponds to a Standard Model definition based on a Breit-Wigner propagator in the "running-width scheme", $1/(M^2 - M_{\rm W}^2 + iM^2\Gamma_{\rm W}/M_{\rm W})$, with a width parameter, $\Gamma_{\rm W} = 2092.2 \pm 1.5$ MeV predicted by the Standard Model [17] using a revised 2012 world average W boson mass of $80,385 \pm 15$ MeV. All measured masses are corrected to this value using $\Delta M_W = -(0.15 \pm 0.05)\Delta\Gamma_{\rm W}$ as in Ref. [14]. The W boson mass uncertainty arising from an uncertainty in the W boson width is now consistently treated across all measurements.

Table 3 summarizes all of the inputs to the combination and the corrections made to

Source	Uncertainty (MeV)
Electron energy calibration	16
Electron resolution model	2
Electron shower modeling	4
Electron energy loss model	4
Hadronic recoil energy scale and resolution	5
Electron efficiencies	2
Backgrounds	2
Experimental subtotal	18
Parton distributions	11
QED radiation	7
$p_T(W)$ model	2
Production subtotal	13
Total systematic uncertainty	22
W-boson statistics	13
Total uncertainty	26

Table 2: Uncertainties for the new D0 M_W measurement [11].

ensure consistency across measurements.

	CDF-0	CDF-Ia	CDF-Ib	D0-I	CDF-II (2.2 fb^{-1})	D0-II (1.0 fb^{-1})	D0-II (4.3 fb^{-1})
M_W published	79910	80410	80470	80483	80387	80400.7	80367.4
Uncertainty (publ.)	390	180	89	84	19	43	26
Γ_W (publ.)	2100	2064	2096	2062	2094	2099.6	2100.4
Corrections							
$\Delta\Gamma$	1.2	-4.2	0.6	-4.5	0.3	1.1	1.2
PDF	20	-25	0	0	0	0	0
BLUE	-3.5	-3.5	-0.1	0	0	0	0
Total	17.7	-32.7	0.5	-4.5	0.3	1.1	1.2
M_W(corr)	79927.7	80377.3	80470.5	80478.5	80387.3	80401.8	80368.6
Uncertainties							
Total	390.9	181.0	89.3	83.4	19.0	43.2	25.8
PDF	60	50	15	8.1	10	10.4	11
Rad. Corr.	10	20	5	12	4	7.5	7
Γ_W	0.5	1.4	0.3	1.5	0.2	0.4	0.5

Table 3: The inputs used in the M_{W} combination. All entries are in MeV.

4 Correlation of the new Run II results with other Tevatron measurements

The greatly improved statistical power of these recent measurements has made systematic uncertainties in the W boson production and decay model more significant. As a result, a more careful treatment of model uncertainties has been undertaken. We have adopted a standard in which, for shared model uncertainties, the minimum uncertainty across experiments is assumed to be a fully correlated uncertainty while excesses above that level are generally assumed to be due to uncorrelated differences between experiments. One exception is the two D0 Run-II measurements which use very similar models and are treated as fully correlated.

The experimental systematic uncertainties for D0 are dominated by the energy scale for electrons and are almost purely statistical, as they are derived from the limited sample of Z decays. CDF uses independent data from the central tracker to set the muon and electron energy scales. For these reasons all of the experimental uncertainties are assumed to be completely uncorrelated with each other and with all previous measurements.

Three sources of systematic uncertainties due to modeling of the production and decay of W and Z bosons are assumed to be at least partially correlated between all Tevatron measurements, namely (1) the parton distribution functions (PDFs), (2) the assumed width of the W boson (Γ_W) and (3) the electroweak radiative corrections.

1. <u>PDFs</u>

   Both experiments use the CTEQ6.6 [18] parton distribution as the central PDF set in their W boson production model. D0 uses the older CTEQ6.1 [19] error set to estimate the PDF uncertainties while CDF uses MSTW2008 [20] and cross-checks with the CTEQ6.6 error set. Because these PDF sets are similar, and rely on common inputs, the uncertainties introduced by PDFs in the recent measurements are assumed to be largely correlated and treated using the prescription for partial correlations described above. [†]

2. <u>Width of the W boson</u>

   We assume that the very small uncertainty due to the uncertainty in the W boson width is 100% correlated across all measurements.

3. <u>Radiative Corrections</u>

   Current estimates of the uncertainties due to radiative corrections include a significant statistical component. The PHOTOS [21] radiative correction model has been used in the recent measurements with cross-checks from W(Z)GRAD [22] and HORACE [23]. These studies yield model differences consistent within statistical uncertainties. We assume that there is a correlated uncertainty of 3.46 MeV[10] due to the common use of PHOTOS with the remaining uncertainties being uncorrelated.

[†] The D0 Run-I measurement used both central and forward electrons. Because of the larger rapidity coverage, the PDF uncertainty was both smaller and different from all other measurements considered here. Simulation studies indicate a correlation of approximately 70% between the PDF component of this measurement and the others.

	Relative Weights in %
CDF-0	0.1
CDF-Ia	0.5
CDF-Ib	1.9
D0-I	2.8
CDF-II (2.2 fb^{-1})	60.3
D0-II (1.0 fb^{-1})	7.9
D0-II (4.3 fb^{-1})	26.5

Table 4: Relative weights of the contributions in %.

5 Combination of Tevatron M_{W} measurements

The seven measurements of M_{W} to be combined are given in Table 3 and include both new results discussed above but exclude the superseded 0.2 fb^{-1} CDF Run-II result [4]. The combined Tevatron W boson mass, from all measurements, calculated using the BLUE method [16] is:

$$M_W = 80,387 \pm 16 \text{ MeV}\,. \tag{1}$$

The χ^2 for the combination is of 4.2 for 6 degrees of freedom, with a probability of 64%. Table 4 shows the relative weights of each measurement in the combination.

The global correlation matrix for the seven measurements is shown in Table 5.

6 World Average

We also combine all of the Tevatron measurements with the W boson mass determined from WW production at LEP II [24]. The combination of all of the Tevatron results with the LEP II preliminary result of $80,376 \pm 33$ MeV [24], assuming no correlations, yields a new world average for the W boson mass:

$$M_W = 80,385 \pm 15 \text{ MeV}\,. \tag{2}$$

The χ^2 is 4.3 for 7 degrees of freedom with a probability of 74%. Figure 1 illustrates the new combined W boson mass estimates.

	CDF-0	CDF-Ia	CDF-Ib	D0-I	CDF-II ($2.2\ fb^{-1}$)	D0-II ($1.0\ fb^{-1}$)	D0-II ($4.3\ fb^{-1}$)
CDF-0	1.	0.002	0.003	0.002	0.015	0.007	0.011
CDF-Ia	0.002	1.	0.007	0.005	0.033	0.014	0.024
CDF-Ib	0.003	0.007	1.	0.009	0.066	0.029	0.049
D0-I	0.002	0.005	0.009	1.	0.044	0.019	0.032
CDF-II ($2.2\ fb^{-1}$)	0.015	0.033	0.066	0.044	1.	0.137	0.23
D0-II ($1.0\ fb^{-1}$)	0.007	0.014	0.029	0.019	0.137	1.	0.137
D0-II ($4.3\ fb^{-1}$)	0.011	0.024	0.049	0.032	0.23	0.137	1.

Table 5: Correlation coefficients between the different experiments.

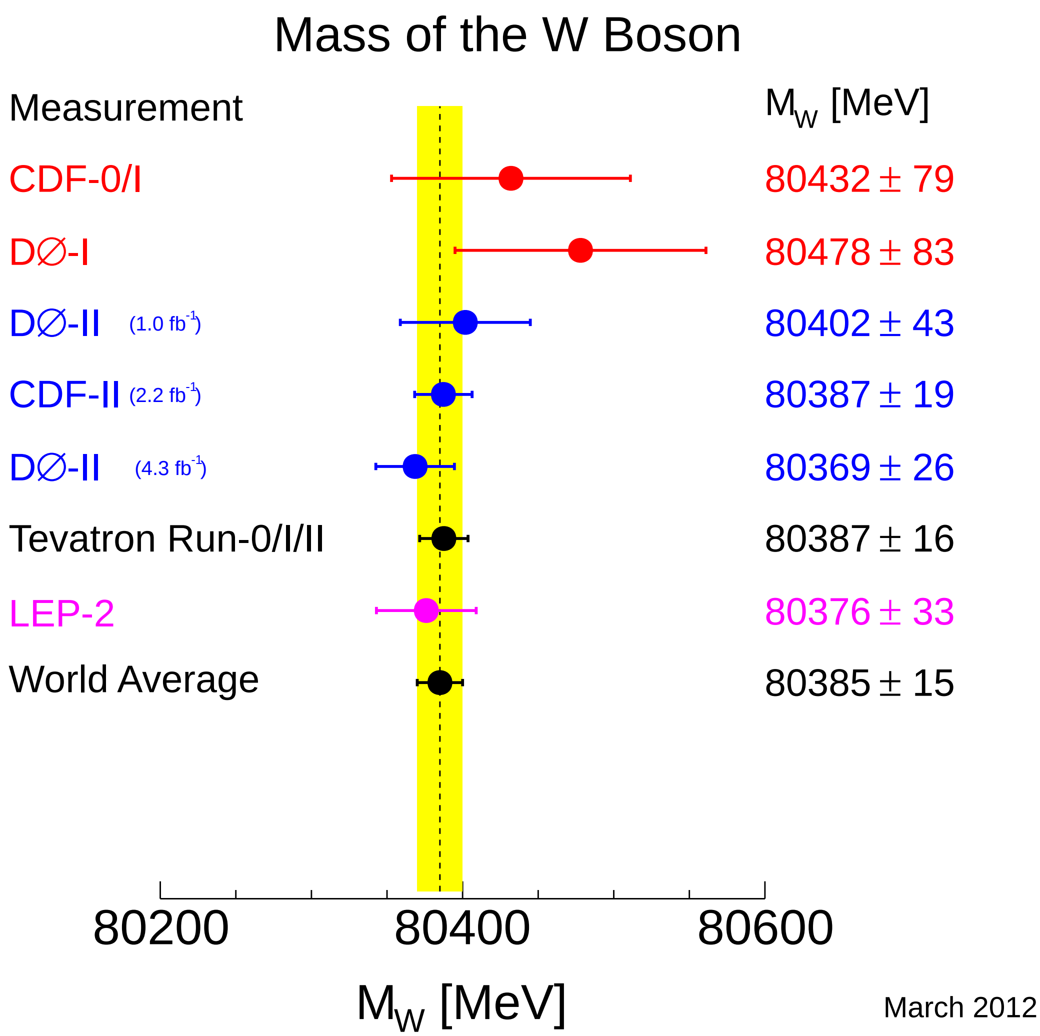

Figure 1: Summary of the measurements of the W boson mass and their average as of March 2012. The result from the Tevatron corresponds to the values in this note (see Table 3) which include corrections to the same W boson width (2092.2 MeV) and PDFs. The LEP II result is from Ref. [24]. An estimate of the world average of the Tevatron and LEP results assuming no correlations between the Tevatron and LEP is included.

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