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Updated 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. Results from CDF Run-0 (1988-1889) and Run-I (1992-1995) have been combined with D0 results from Run-I, the CDF 200 pb^{-1} published results from the first period of Run-II (2001-2004) and the recent 1 fb^{-1} result in the electron channel from D0 (2002-2006). The results are corrected for any 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 $M_{\text{W}} = 80,420 \pm 31$ 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 $e\nu$ and $\mu\nu$ decay modes of the W.

Measurements of M_{W} have been reported by CDF from the data of Run-0 [1], Run-I [2, 3] and recently Run-II [4] and by D0 from Run-I [5, 6, 7]. This document adds a new D0 measurement from Run-II [8]. There are no new measurements of the width of the W since the previous average in July 2008[10] and it will not be discussed further.

This note reports the combination of the mass measurements, and takes into account statistical and systematic uncertainties as well as correlations among systematic uncertainties. It supercedes the previous summaries [9, 10]. The measurements are combined using the analytic BLUE method [11, 12] which is mathematically equivalent to the methods used in previous combinations [9, 10], but, in addition, yields the decomposition of the uncertainty on the average in terms of categories specified in the input measurements [12]. These changes are described in more detail in Ref. [10].

As in the July 2008 analysis [10], there are three significant changes relative to the pre-2008 averages:

- The individual M_{W} measurement channels for CDF Run-0, Run-Ia and Run-Ib are now combined for each run period using the BLUE method to achieve a consistent statistical treatment across all results. The Run-I D0 and Run-II CDF measurements were already combined using the BLUE method.
- The central values of the mass measurements made with very old PDF sets are corrected to use the same parton distribution functions (PDFs) from CTEQ6M [13] with uncertainty estimates from the CTEQ6M, CTEQ6.1M [14] and MRST2003 [15] PDF sets[†].

  The new D0 Run-II measurement uses CTEQ6.1M while the CDF Run II measurement used CTEQ6M. The difference in the mass extracted using these PDF sets was found to be less than 1 ± 4 MeV, where 4 MeV is the statistical uncertainty on the estimated difference. No correction is applied for this difference.

[†]The CDF Run-0 and Run-Ia results were obtained from very old PDF sets (MRS-B [16] and MRS-D′ [17] respectively) that did not utilize the W charge asymmetry results and so provide somewhat offset predictions from the more modern PDF sets used in the later analyses. The predictions based on the more modern MRS [15] and CTEQ [13] sets used in Run-Ib and Run-II analyses have a variance smaller than the common PDF errors assumed in these analyses i.e. ≈ 10 MeV. We therefore only apply PDF corrections to the CDF Run-0 and Run-Ia results since the shifts for these data are larger than 10 MeV. We retain the PDF uncertainties of 60 MeV and 50 MeV quoted in the original publications. We note that these corrections were also applied in the Run-I CDF combination presented in [3].

- The mass values are also corrected to the same assumed W boson width value in order to achieve consistency across all results. The value of $\Gamma_{\rm W}$ quoted here corresponds to a 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, $\Gamma_{\rm W} = 2093.2 \pm 2.2$ MeV predicted by the standard model [18] using the 2008 world average W boson mass of $80,398 \pm 25 MeV$. All measured masses are corrected to this value using $\Delta M_W = -(0.15 \pm 0.05)\Delta\Gamma_{\rm W}$ as in Ref. [10]. The W boson mass uncertainty arising from an uncertainty in the W boson width is now consistently treated across all measurements.

The shifts due to these corrections are shown in Table 1 below, which summarizes all of the inputs to the combination. [‡]

	CDF 0	CDF Ia	CDF Ib	D0 I	CDF II	D0 II
M_W published	79,910	80,410	80,470	80,483	80,413	80,400.7
Total uncertainty published	390	180	89	84	47.9	43
Γ_W used in publication	2,100	2,064	2,096	2,062	2,094	2,099.6
Corrections						
$\Delta\Gamma_W$ correction applied	1.1	-4.4	0.5	-4.7	0.2	1.0
PDF correction applied	20	-25	0	0	0	0
BLUE correction applied	-3.5	-3.5	-0.1	0	0	0
Total correction	17.6	-32.9	0.4	-4.7	0.2	1.0
M_W **corrected**	79,927.6	80,377.1	80,470.4	80,478.3	80,413.2	80,401.7
Uncertainties						
Total BLUE uncertainty	390.9	181.0	89.3	83.4	47.9	43.3
Uncorrelated uncertainty	386.1	172.8	87.9	82.1	44.7	41.3
PDFs	60	50	15	8.1	12.6	10.4
Radiative corrections	10	20	5	12	11.6	7.5
Γ_W (published)	0	20	0	10	0	0.5
Γ_W (this analysis)	0.5	1.5	0.5	1.5	0.5	0.5

Table 1: Table 1 of the 2008 summary [10], updated with the D0 result from Run-II. All entries are in MeV.

[‡]As described in [10], the use of the BLUE method in internal combinations caused the early Run-0, Run-Ia and Run-Ib CDF $M_{\rm W}$ values to change by -3.5 MeV, -3.5 MeV and $+0.1$ MeV respectively. These corrections are also listed in Table 1. When these new values are combined using the BLUE method, the Run-0/I CDF combination is changed from $80,433 \pm$ 79 MeV quoted in [3] and used in previous combinations [9], to $80,436 \pm$ 81 MeV.

2 New data from D0 on M_{W}

The W boson mass determined by D0 in Run-II [8], using W decays into electrons and neutrinos from 1 fb^{-1} of data at $\sqrt{s} = 1960$ GeV, derives from 3 observables: the transverse mass M_T, the electron transverse momentum p_T^e and the transverse missing momentum, which yield a combined W boson mass of $80,401 \pm 21(stat.) \pm 38(syst.)$ MeV. The individual contributions to the uncertainty are summarized in Table 2.

Source	Uncertainty in MeV	Correlation coefficient with other experiments
Experimental uncertainties		
W Statistics	21.0	0
Electron energy calibration	33.4	0
Electron resolution model	2.2	0
Electron energy offset	5.2	0
Electron energy loss model	4.0	0
Recoil model	7.8	0
Electron efficiencies	5.2	0
Backgrounds	3.2	0
Production uncertainties		
PDFs	10.4	1.0
EWK radiative corrections	7.5	1.0
Boson p_T	2.7	0
Γ_W	0.5	1.0

Table 2: Contributions (in MeV) to the uncertainty for the D0 Run-II W boson mass result.

3 Correlation of the D0 Run II result with other measurements

The experimental systematic uncertainties on the new D0 measurement are dominated by the energy scale for electron candidates and are almost purely statistical, as they are mainly derived from the limited sample of Z^0 decays. All of the experimental uncertainties are assumed to be uncorrelated with previous measurements.

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

The D0 measurement also includes an uncertainty in the boson p_T distribution parameterization which is derived from a global fit to deep-inelastic scattering and hadron collider data [19]. In previous analyses, this source of uncertainty is treated differently, and it is therefore regarded as uncorrelated with the earlier measurements.

Current estimates of the uncertainties due to radiative corrections include a significant statistical component. The WGRAD/ZGRAD [20] and PHOTOS [21] models are used in the different measurements and yield results consistent within statistical uncertainties. We assume that the effects of radiative corrections are 100% correlated between measurements because the models used are quite similar, but we anticipate that both the uncertainties and the correlations have the potential to be reduced in the future using better models and higher statistics in simulations.

4 Combination of Tevatron M_{W} measurements

The six measurements of M_{W} to be combined are given in Table 1. The CDF Run-0, Run-Ia and Run-Ib values correspond to averages of two measurements in different channels where internal correlated systematic uncertainties e.g. momentum scale, are accounted for in the averaging. The Run-I D0 measurement combines 10 measurements using the BLUE method. The Run-II CDF measurement combines a total of six individual measurements in the muon and electron decay channels.

Tables 1 and 2 of our previous summary [10] are now extended with the combined D0 Run-II result. The combined Tevatron result is calculated using BLUE with input from Table 1 which includes the new D0 Run-II result.

The combined Tevatron result for the mass of the W is:

$$M_W = 80,420 \pm 31 \text{ MeV}\,. \tag{1}$$

The χ^2 for the combined result of 2.69 for 5 degrees of freedom, corresponds to a probability of 74.8%. Table 3 shows the weight of each measurement entering the combination.

The total uncertainty of 31 MeV on the Tevatron average is split up into an uncorrelated uncertainty of 26.9 MeV, and systematic uncertainties due to assumptions about the production of W and Z bosons of 11.6 (PDF), 9.3 MeV (radiative corrections), and 0.8 MeV (Γ_W). The global correlation matrix for the 6 measurements is shown in Table 4.

5 Conclusion

The new direct measurement of the mass of the W by the D0 experiment has been combined with the previous CDF and D0 measurements. The new Tevatron result for the W boson mass is:

$$M_W = 80,420 \pm 31 \text{ MeV}. \tag{2}$$

For the first time the total uncertainty of 31 MeV from the Tevatron is smaller than that of 33 MeV from LEP II [23].

The combination of the new Tevatron result with the LEP II preliminary result, assuming no correlations, yields the world average:

$$M_W = 80,399 \pm 23 \text{ MeV}. \tag{3}$$

Figure 1 shows an update of the Figure 1 of the TEVEWWG note [10] displaying the new results.

	Relative Weights in %
CDF 0	0.10
CDF Ia	0.60
CDF Ib	9.39
D0 I	10.98
CDF II	34.64
D0 II	44.28

Table 3: Relative weights of the contributions in %.

	CDF 0	CDF Ia	CDF Ib	D0 I	CDF II	D0 II
CDF 0	1.0	0.045	0.027	0.019	0.047	0.041
CDF Ia		1.0	0.053	0.043	0.100	0.086
CDF Ib			1.0	0.024	0.058	0.050
D0 I				1.0	0.061	0.049
CDF II					1.0	0.106
D0 II						1.0

Table 4: Correlation coefficients between the different experiments using the method of Ref. [10].

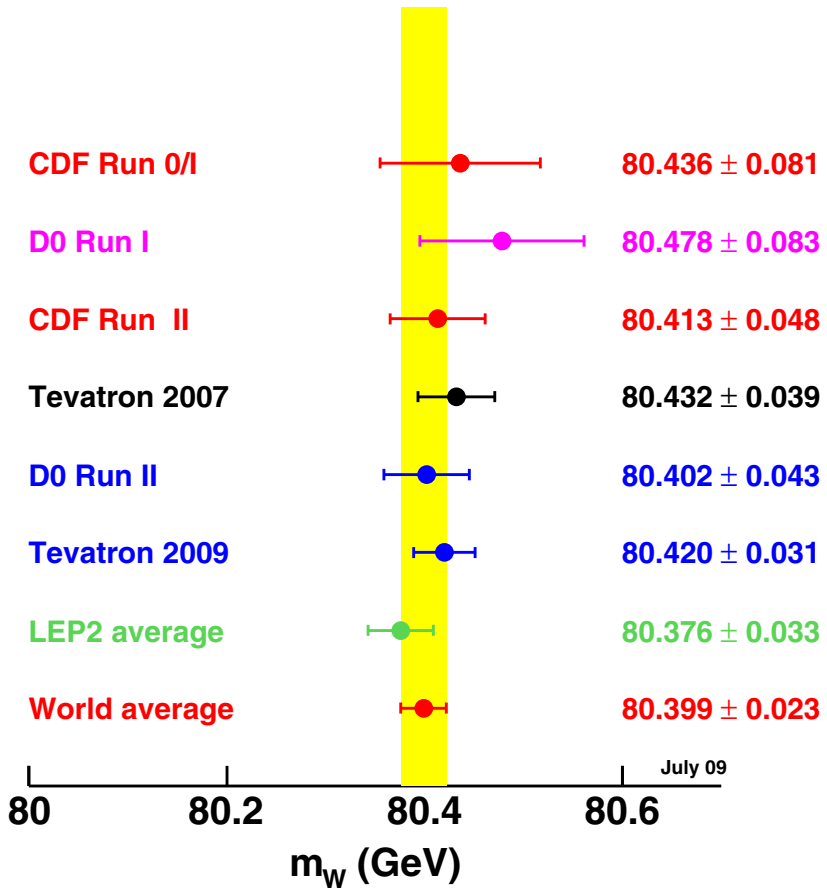

Figure 1: Summary of the measurements of the W boson mass and their average as of July 2009. The result from the Tevatron corresponds to the values in this note (see Table 1) which include corrections to the same W boson width and PDFs. The LEP II result is from Ref. [23]. An estimate of the world average of the Tevatron and LEP results assuming no correlations between the Tevatron and LEP is included.

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