Fermi National Accelerator Laboratory

FERMILAB-Conf-99/155-E
CDF and D0

New Tevatron Measurements of the W Boson Mass

T. Dorigo
For the CDF and D0 Collaborations
Harvard University

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

June 1999

Published Proceedings of the *34th Rencontres de Moriond: QCD and Hadronic Interactions*,
Les Arcs, France, March 20-27, 1999

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

NEW TEVATRON MEASUREMENTS OF THE W BOSON MASS

T. DORIGO, *Harvard University*
on behalf of the CDF and D0 Collaborations
Fermi National Accelerator Laboratory,
M.S. 223, 60510 Batavia (IL)

The CDF and D0 Collaborations obtain new measurements of the W boson mass using data taken between 1994 and 1996. CDF updates the previous result obtained from $W \to \mu\nu$ decays, reducing many systematic uncertainties, and performs a new measurement using a high statistics sample of $W \to e\nu$ events; combining these measurements with the previous ones yields $M_W^{CDF} = 80.433 \pm 0.079\ GeV/c^2$. D0 also extends the previous result, based on central electron events, by including events with electrons landed in the forward calorimeters; the combined D0 result is $M_W^{D0} = 80.474 \pm 0.093\ GeV/c^2$. The numbers obtained by the two experiments can be combined, together with the older UA2 one ($M_W^{UA2} = 80.36 \pm 0.37\ GeV/c^2$), by assuming a 25 MeV/c^2 common error, to yield a hadron collider average of $M_W = 80.448 \pm 0.062\ GeV/c^2$.

1 Introduction

The Tevatron is the highest energy collider in the world. Bunches of protons and antiprotons are accelerated to an energy of 900 GeV each and collided at a rate of 300 kHz in the core of CDF and D0. These are two multi-purpose detectors, both composed of a central tracking system, a finely grained calorimeter system, and outer muon chambers. CDF has its strong point in a high precision magnetic tracking, fortified by a very high performance silicon vertex detector; D0 is non-magnetic, but boasts a very precise and hermetic uranium-liquid argon calorimeter.

A total of more than $100,000$ leptonic W decays have been detected at the Tevatron during the 1992-93 (run 1a, 20 pb^{-1}) and 1994-96 (run 1b, 90 pb^{-1}) data taking periods. Precision measurements of M_W based on subsets of that data have already been reported by the CDF and D0 Collaborations[1,2,3]. These results have recently been perfected by the two experiments: in Sec. 2 we summarize the improvements of the measurement performed by CDF in the muon and electron channel, and in Sec. 3 we describe the improvements of the electron channel analysis by D0. We conclude in Sec. 4.

2 New CDF Results

After the M_W measurements in the electron and muon channels based on run 1a data [1], CDF presented in 1997 a preliminary result obtained from the run 1b muon data [4]. Since then, detailed calibration studies and a better determination of the relevant parton distribution functions (PDF) have allowed an improved measurement and a sizable reduction of the systematic uncertainties. After a painstaking work to understand the calibration of the e.m. calorimeter, the high statistics run 1b electron data was also used to obtain another precise measurement of the W mass.

In hadron collisions a W mass cannot be computed directly from observable quantities in the leptonic decay, due to the undetermined longitudinal component of the neutrino momentum: one is then forced to derive M_W from quantities tightly correlated to it. The most effective estimator is the transverse mass of the lepton-neutrino pair, $M_T = 2\sqrt{P_T{}^l P_T{}^\nu sin(\Delta\phi/2)}$, where P_T^l and P_T^ν are the transverse momenta of charged lepton (electron or muon) and neutrino, and $\Delta\phi$ is their azimuthal opening angle. Despite the poor resolution on P_T^ν, which is computed using the transverse energy imbalance in the calorimeter, the transverse mass is a better estimator than the well-measured lepton P_T alone, being much less affected than the latter by the transverse motion of the produced W boson, which is governed by non-perturbative QCD processes and cannot be modeled with sufficient accuracy.

To produce precise Monte Carlo templates of the transverse mass, and hence measure M_W by fitting them to the observed spectrum, it is necessary to model the W production mechanism in detail, and to understand the detector response and resolution to charged leptons and hadronic recoil. A precise knowledge of the u- and d-quark distribution functions is also mandatory: the parton luminosities influence the critical trailing edge of the transverse mass distribution, and they further determine the longitudinal motion of W production, thereby effecting our acceptance and thus the measured shape of M_T.

To calibrate the muon momentum measured in the tracker the Z mass is measured in a sample of $\mu^+\mu^-$ decays, making use of the well-known value of M_Z. This adds a 85 MeV/c^2 systematic uncertainty to M_W due to the statistics of the Z peak. Nonlinearities in the momentum scale are studied by measuring the mass of the other known dimuon resonances (J/ψ, ψ, and Υ particles) as a function of the average curvature of the muon tracks, and are found negligible (Fig. 2, left). The momentum resolution is also obtained from fits to the Z peak: the resulting uncertainty amounts to 20 MeV/c^2.

A detailed parameterization is used to model the W recoil response and resolution: the response of the calorimeter to minimum bias data yields an estimate of the resolution of the calorimeter to the hadronic recoil; the model is then tuned by studying the recoil in leptonic Z decays, where the boson transverse momentum is well measured. Finally, the W boson P_T spectrum is obtained from a measurement of $d\sigma/dP_T$ in Z events and a theoretical prediction for the ratio of W and Z P_T distributions. The combined systematic uncertainty due to the recoil modeling and the P_T^W theoretical assumptions amounts to 40 MeV/c^2.

To understand the impact of different choices of PDF sets on the measured W mass value the *MRST*, *MRS-R1*, and *MRS-R2* sets are studied. These are chosen among the ones in best agreement with the recently improved measurement of the lepton charge asymmetry in W decays [6]. They are varied from their default values (Fig. 2, right) in order to span both the measured values of lepton asymmetry in the rapidity range relevant to the W mass measurement ($|\eta_l| < 1$), and the precise measurements of the d/u ratio by the NMC, E866, and NA51 Collaborations. The resulting variations in the measured W mass are smaller than 15 MeV/c^2, which is the value taken as a systematic uncertainty.

For the electron channel analysis the same method is used to choose the PDF set and determine the associated systematics, while independent but similar methods to those discussed above are used for the modeling of the boson P_T and the hadronic recoil. The electron energy resolution is determined from fits to the peak of M_Z in a sample of $Z \to e^+e^-$ decays: its uncertainty effects M_W with a 25 MeV/c^2 systematic error.

To determine the electron energy scale CDF relies on the LEP measurement of M_Z, as is done in the muon analysis. In principle, in the electron channel one could alternatively provide a mass value

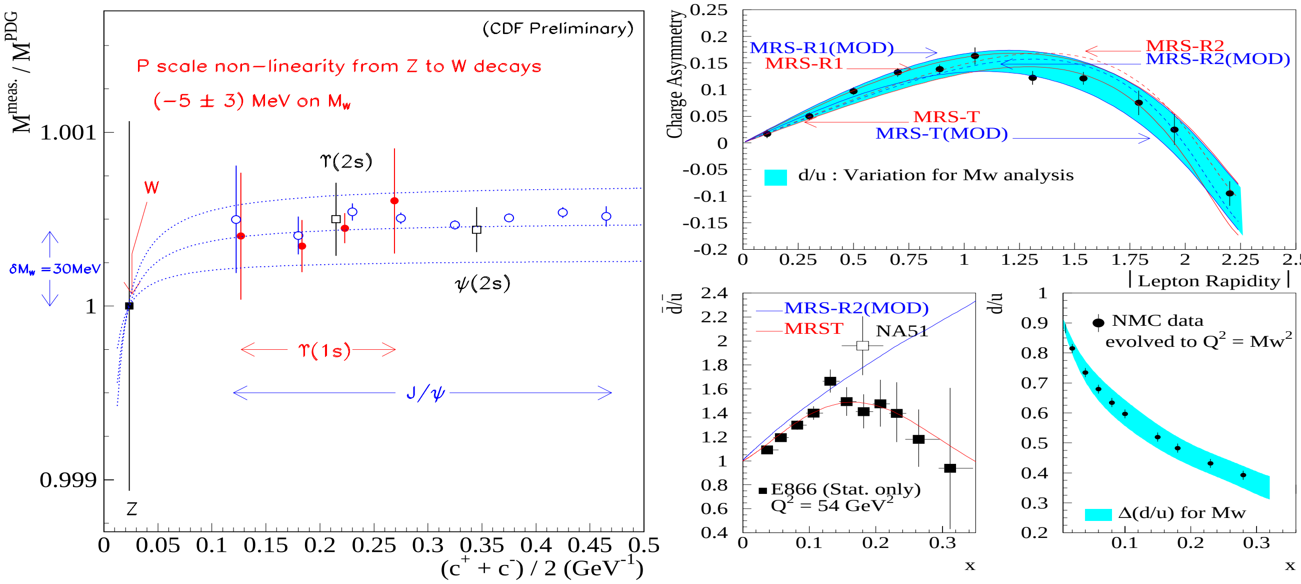

Figure 1: Left: Determination of the momentum scale. The ratio between measured and PDG [5] mass for various $\mu^+\mu^-$ resonances is studied as a function of the average curvature of the muon tracks. Right: To estimate the effect of the PDF choice on M_W, different sets are varied to span the range allowed by CDF's W asymmetry measurement and other precise determinations of the d/u ratio (bottom).

independent of M_Z by trusting the so-called E/p method: it consists in using the Monte Carlo to fit the shape of the ratio between measured calorimeter energy and track momentum of the electrons, which shows a characteristic asymmetric shape due to the radiation of internal and external photons. That method, however, yields an energy scale which, when used to compute the Z mass from the dielectron decays, gives a result over four standard deviations too low. We have carefully investigated this problem, checking every plausible hypothesis, but, despite our efforts, we still do not understand why the E/p method does not work. We are thus forced to obtain the electron energy scale from fits to M_Z: this technique has a statistically dominated error, it is homogeneous with the muon analysis, and it is more conservative than the E/p method, since it does not rely on Monte Carlo modeling of electron bremsstrahlung. The uncertainty due to the determination of the electron energy scale is then dominated by the Z statistics used in the fit and amounts to 75 MeV/c^2.

The final CDF result in the muon channel is $M_W = 80.465 \pm 0.143\ GeV/c^2$; the electron channel yields instead $M_W = 80.473 \pm 0.113\ GeV/c^2$. The common error among these measurements is only 16 MeV/c^2, and the combined run 1b W mass is thus $M_W = 80.470 \pm 0.089\ GeV/c^2$. Combining this number with previously published CDF results yields $M_W^{CDF} = 80.433 \pm 0.079\ GeV/c^2$.

3 New $D0$ Results

A precise measurement of the W mass from 28,323 events containing central electrons has been reported last year by the $D0$ collaboration [3]; that analysis has been extended recently to include 11,090 W events with a forward electron. We describe the peculiarities of the high rapidity analysis in what follows.

The forward $W \to e\nu$ sample is collected by selecting good electron candidates with $E_T > 30\ GeV$ in the "endcap" calorimeters ($1.5 < |\eta_e| < 2.5$), $\not{E}_T > 30\ GeV$, and a measured hadronic recoil $P_T^W < 15\ GeV/c$. After this selection the background contamination is of the order of a few percent; it includes $Z \to e^+e^-$ decays where one electron escaped the detector, and QCD events with a jet faking an electron and abnormally large $\not{E}_T$. The $W \to \tau\nu \to e\nu\nu$ process is not considered a background, and is included in the Monte Carlo datasets to model the signal.

The electron energy scale in the central and forward calorimeters is determined from fits to the Z mass in a set of 3,778 $Z \to e^+e^-$ decays of different topologies (central-central, central-endcap, endcap-endcap). The constant term in the electron resolution is also determined from Z events by matching the

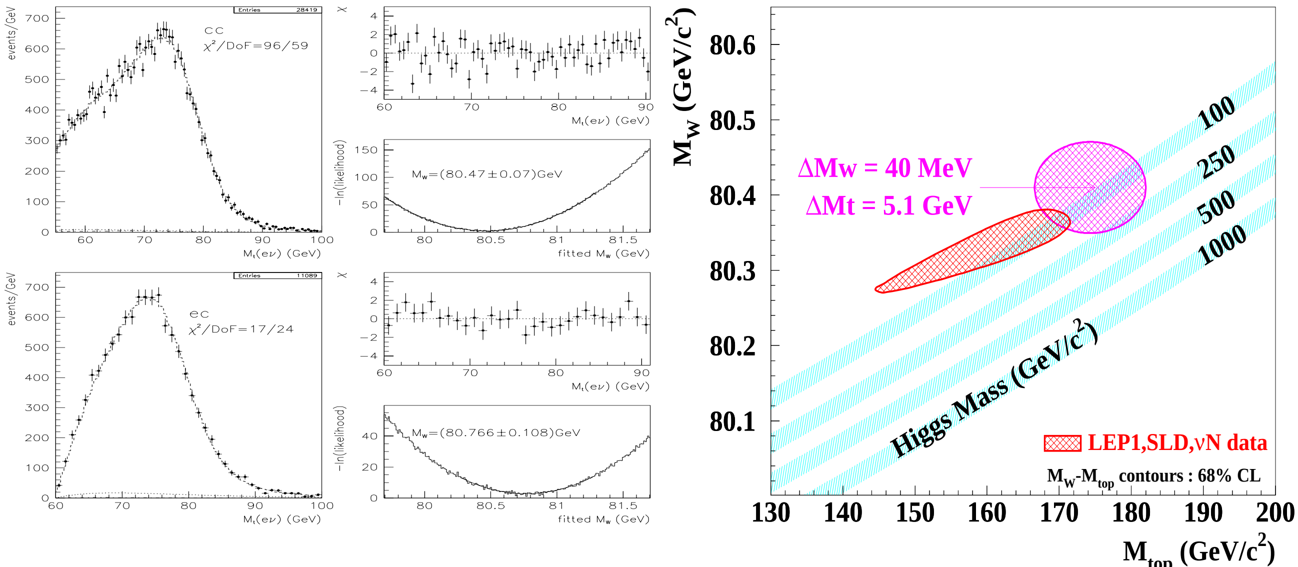

Figure 2: Left: Transverse mass fits of the central (top) and forward (bottom) electron datasets by $D0$. Right: Experimental bounds on the Higgs boson mass from the world average measurements of M_W and M_{top}.

width of the Z mass peak between data and Monte Carlo simulations in the three dielectron topologies.

The recoil response and resolution are found to be insensitive to the rapidity of the W electron. They are studied using the relationship among the P_T of the dielectron pair and the measured calorimeter response in $Z \to e^+e^-$ data.

In order to measure M_W, likelihood fits are performed to the distributions of three variables: the transverse mass M_T (see Fig. 2, left), the electron P_T, and the missing E_T. The transverse mass fit to the forward electron dataset alone yields $M_W = 80.766 \pm 0.234\ GeV/c^2$, which can be combined with the published central electron result [3)] to yield $M_W = 80.497 \pm 0.098\ GeV/c^2$. A further reduction in the total error can be obtained by accounting for the correlations among the three different fits to the central and forward datasets, thereby exploiting their full potential: the final run 1b result is then $M_W = 80.487 \pm 0.096\ GeV/c^2$. This can in turn be combined with the run 1a result [2)] to yield $M_W^{D0} = 80.474 \pm 0.093\ GeV/c^2$.

4 New Hadron Collider Average and Concluding Remarks

The numbers obtained by the two experiments can be combined, together with the older UA2 one ($M_W = 80.36 \pm 0.37\ GeV/c^2$), by assuming a 25 MeV/c^2 common error, to yield a hadron collider average of $M_W = 80.448 \pm 0.062\ GeV/c^2$.

In conclusion, the CDF and D0 experiments have measured the W mass to better than 0.1% accuracy using their datasets collected during 1992-1996 at the Tevatron collider. These determinations are competitive with those obtained by the LEP II experiments and, together with the measured top quark mass, help tightening the constraints on the Standard Model Higgs boson mass (see Fig. 2, right).

References

1. F. Abe *et al.*, *Phys. Rev. Lett.* **75**, 11 (1995); F. Abe *et al.*, *Phys. Rev.* D **52**, 4784 (1995).
2. S. Abachi *et al.*, *Phys. Rev. Lett.* **77**, 3309 (1996).
3. B. Abbott *et al.*, *Phys. Rev. Lett.* **80**, 3000 (1998).
4. A. Gordon, Proc. of the XXXII Rencontres de Moriond - Electroweak Interactions and Unified Theories, Ed. Frontieres 1997.
5. C. Caso *et al.*, Eur. Journ. Phys. **C3**, 1 (1998).
6. F. Abe *et al.*, *Phys. Rev. Lett.* **81**, 5754 (1998).