Fermi National Accelerator Laboratory

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W Mass Measurements from DØ and CDF Experiments at TeVatron

Chang Kee Jung
for the DØ and the CDF Collaborations
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

State University of New York at Stony Brook

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Abstract

We present preliminary measurements of the W boson mass made by the DØ and CDF experiments using data collected at the Fermilab TeVatron $\bar{p}p$ collider operating at $\sqrt{s} = 1.8$ TeV. The result from the CDF $W \rightarrow e\nu$ data analysis is $M_W = 80.47 \pm 0.15(\text{stat}) \pm 0.25(\text{sys})$ GeV/c^2 and the result from the CDF $W \rightarrow \mu\nu$ data analysis is $M_W = 80.29 \pm 0.20(\text{stat}) \pm 0.24(\text{sys})$ GeV/c^2. The result from the DØ $W \rightarrow e\nu$ data analysis is $M_W = 79.86 \pm 0.16(\text{stat}) \pm 0.31(\text{sys})$ GeV/c^2. When combined with the previous measurements, these results yield a world average value of M_W, 80.23 ± 0.18 GeV/c^2.

1. Introduction

The W boson mass M_W is one of the fundamental parameters of the Standard Model. With already precisely measured the Z boson mass (better than 0.01%), α and G_μ, a precision measurement of M_W provides a stringent test of the SM. The W mass is also sensitive to the top quark mass (quadratically) and the Higgs boson mass (logarithmically) through radiative loop correction. Thus, a precision measurement of M_W can provide constraint to the top quark mass and eventually to the Higgs mass. Furthermore M_W provides a constraint on S and T parameters[1] which are introduced to study heavy physics effects on the gauge boson self-energies.[2]

To date, the direct measurements of M_W have been made only at the hadronic colliders and it will remain so until the LEP II collider starts its operation. In this paper, we present the most recent measurements of the W boson mass made by the DØ and CDF experiments using data collected at the Fermilab TeVatron $\bar{p}p$ collider operating at $\sqrt{s} = 1.8$ TeV. The analyses are based on about 20 pb^{-1} (CDF) and about 13 pb^{-1} (DØ) of data collected during the 1992-93 collider run. The CDF[3] and DØ[4] detectors are described in detail elsewhere.

2. Overview of the M_W measurement Techniques

Measuring M_W using the leptonic decays of the W boson requires a measurement of neutrino momentum. The neutrino momentum, however, cannot be measured directly and inferred by the visible energy in the event. Since energy along the beam line is not well known, we define the transverse mass of the W as following:

$$M_T^W = \sqrt{2p_T^l p_T^\nu (1 - \cos\phi_{l,\nu})},$$

where $\phi_{l,\nu}$ is the azimuthal angle between the lepton and the neutrino direction. The basic techniques of measuring M_W, then, involve fitting the transverse mass spectra of the Ws to spectra generated with fast Monte Carlo (MC) simulations. The fast MC simulation is necessary since it is extremely hard to generate sufficient number of full detector simulated events for a desired statistical accuracy.

The p_T spectrum of the W boson in the fast MC is generated with the next to leading order calculation[5] in DØ and with the data p_T spectrum of the Z boson in CDF. DØ uses the HMRSb structure function and CDF uses the MRS D_' structure function. The MC's are further tuned using the information from data as much as possible including effects of acceptance, resolution, underlying events, multiple interactions, missing p_T resolution, etc. The same set of event selection cuts are applied to the data and the simulated MC event samples. The MC events are corrected for final state radiations and relevant background contributions are included. M_T^W spectra for various M_W values are generated and compared to the M_T^W spectra of the data. The best fit M_W values are obtained using the maximum likelihood method.

3. Event Selection

For M_W measurements, DØ uses only $W \to e\nu$ channel events while CDF uses both $W \to e\nu$ and $W \to \mu\nu$ channels. The event selection criteria for both experiments are quite similar to each other. The minimum lepton p_T and the missing p_T for the W candidates are required to be 25 GeV. The minimum and maximum of M_T^W are required to be 60 GeV and 90 GeV for DØ , 60 GeV and 100 GeV for CDF. DØ requires the p_T of W to be less than 30 GeV. CDF requires there are no other jets with E_T greater than 20 GeV and no other tracks with p_T greater than 10 GeV. Both experiments require the leptons to be in the central rapidity region and apply various lepton quality cuts. After these requirements DØ has 4817 events, and CDF has 6421 $W \to e\nu$ and 4090 $W \to \mu\nu$ events for W mass fitting.

4. Energy Scale and Underlying Event Corrections

In order to make a precision measurement of M_W, calibration of a detector for its momentum-energy scale is an absolute necessity. DØ determines the calorimeter energy scale and its uncertainties by comparing mass fits of $Z \to ee$ events to the LEP Z mass. The linearity of the calibration between the W and Z masses is also determined from the $Z \to ee$ events, making use of the fact that the electrons from these decays cover a wide range of energies in the lab frame, depending on the momentum of the Z and the decay angle. The Z mass is fit as a function of the factor $f = 2(E_1 + E_2)\sin^2(\gamma/2)/M$, where E_1 and E_2 are the energies of the two electrons in the lab frame, γ is the opening angle in that frame, and M is the invariant mass. This is shown in Fig. 1. A linear fit to this plot determines an offset which is consistent with zero and a slope. The energy scale contribution to the uncertainty in the W mass measurement is estimated to be ± 260 MeV. CDF calibrates their detector for its momentum scale by using $\psi \to \mu\mu$ events in their central tracking chambers. From a comparison of their reconstructed ψ mass with the Particle Data Group value, they obtain a correction

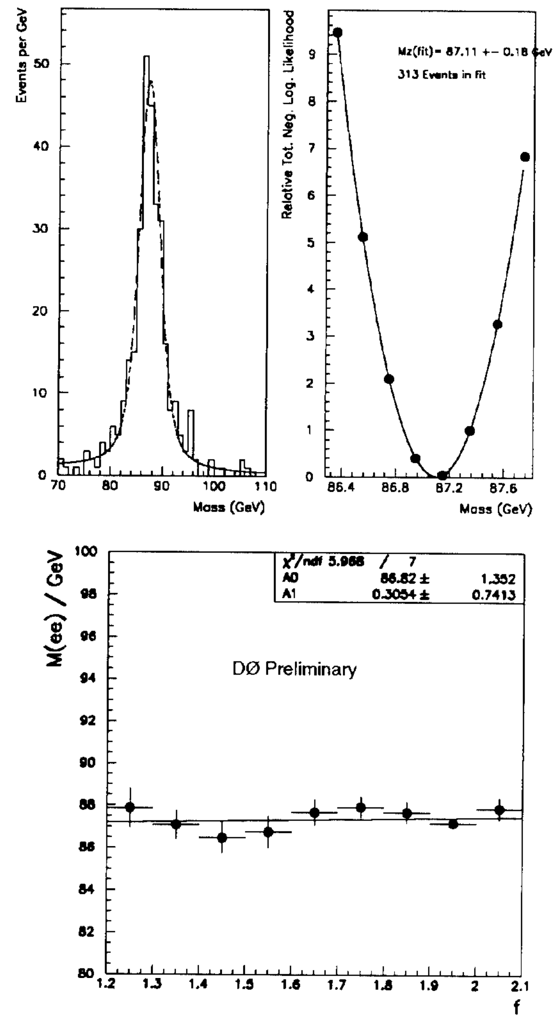

Figure 1. DØ calorimeter calibration data: the $M(ee)$ spectrum and $\langle M(ee)\rangle$ vs. f (see text) for the $Z \to ee$ sample.

factor to the momentum scale of 1.00076 ± 0.00071. The result is checked with the Υ and Z resonances, as shown in Fig. 2. CDF then transfers the momentum scale correction to the calorimeter energy scale determination by using a sample of W electrons. The energy scale is determined by fitting the ratio of the measured electron energy in the calorimeter to the measured momentum in the tracking chamber to a simulated lineshape which includes the effects of radiative W decays and external bremsstrahlung in the detector material.

The response of the detector to the low energy hadrons from recoiling soft jets against the W or from underlying events is poorly known. Both DØ and CDF utilize the information from Z data samples to correct for the uncertainty in the response. Detailed descriptions of the correction methods can be found elsewhere.[6]

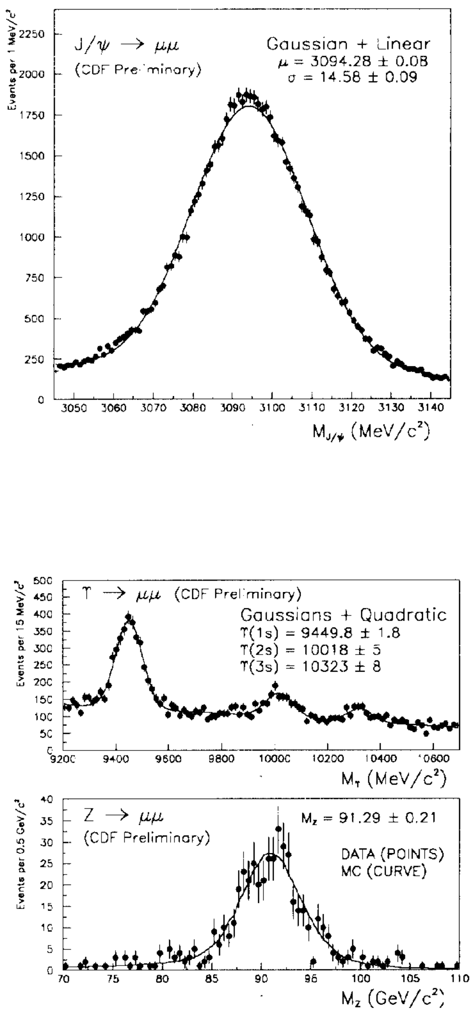

Figure 2. CDF spectrometer calibration data: $\psi \to \mu\mu$, $\Upsilon \to \mu\mu$ and $Z \to \mu\mu$. The ψ sample sets the calibration scale, and the other resonances serve as checks.

5. Backgrounds and Radiative Corrections

The major backgrounds to the $W \to e\nu$ events are $W \to \tau\nu$ and QCD events. These backgrounds are included in the MC's. CDF finds a shift of +80 MeV in the W mass when the backgrounds are included in the fit. The major backgrounds to the $W \to \mu\nu$ events are $W \to \tau\nu$, $Z \to \mu\mu$, $Z \to \tau\tau$, cosmic ray and QCD events. CDF finds a shift of +232 MeV in the W mass when these backgrounds are included.

CDF also corrects their results for radiative decays of Ws, while DØ does not yet correct for the radiation. CDF finds a shift of +80 MeV in the W mass for the $W \to e\nu$ analysis and a shift of +154 MeV for the $W \to \mu\nu$ analysis when the correction is applied. Neither experiment has yet included an uncertainty on this correction to the systematic errors in the W mass measurements.

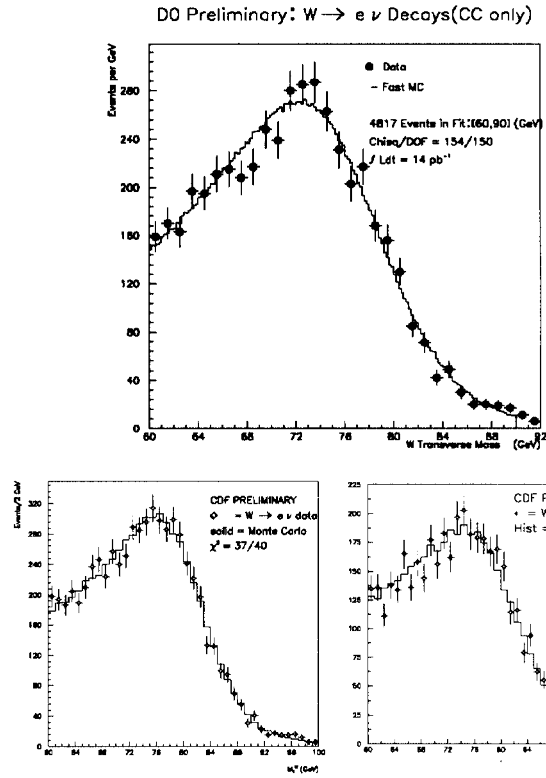

Figure 3. Fits to the W transverse mass spectra for DØ electrons, CDF electrons and CDF muons. Note that the scale on the DØ spectrum is 60-92 GeV, while the CDF spectra go from 60-100 GeV.

6. Results

The final transverse mass spectra, after calibration corrections, are shown in Fig. 3 along with the best MC fits. In each case the agreement between the data and the MC fit is excellent. The results of the mass fits are (in GeV/c^2):

$$M(W) = \begin{cases} 80.47 \pm 0.15(\text{stat}) \pm 0.25(\text{sys}) & \text{CDF}(e) \\ 80.29 \pm 0.20(\text{stat}) \pm 0.24(\text{sys}) & \text{CDF}(\mu) \\ 79.86 \pm 0.16(\text{stat}) \pm 0.31(\text{sys}) & \text{DØ}(e). \end{cases}$$

The sources of systematic uncertainties are summarized in Table 1. The results from both experiments are still preliminary, and several of the systematic uncertainties are expected to improve in the final result, including the DØ energy scale contribution and the CDF resolution uncertainty. The CDF and DØ groups have together produced a world average which combines these three new results with the earlier CDF[7] and UA2[8] measurements of $M(W)$. The new average accounts for errors (100 MeV in PDF) that are assumed to be common to the measurements. The result is

$$M(W) = 80.23 \pm 0.18 \text{ GeV (1994 World Average)}$$

The individual measurements and the average are compared in Fig. 4 to the Standard Model predictions

Table 1. Uncertainties in the W mass measurements, in MeV.

	CDF (e)	CDF (μ)	DØ(e)
Energy Scale	130	60	260
Resolution	140	120	70
Background	50	50	30
Fitting	20	20	30
PDF	100	100	70
p_T^W and und. evt.	120	145	120
Width	-	-	20
Total Sys.	250	240	307
Statistical	150	200	160
Total (Stat + Sys)	290	300	346

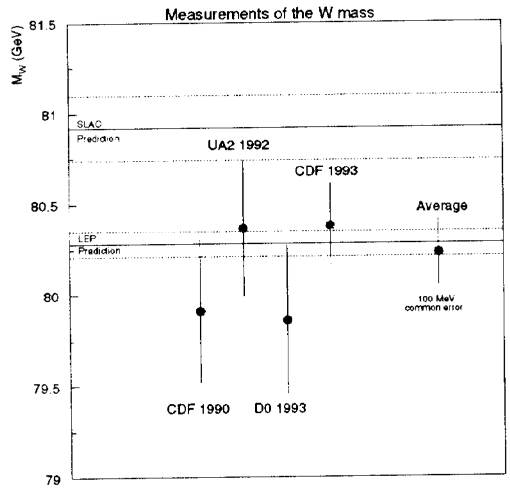

Figure 4. Comparison of hadron collider $M(W)$ measurements and indirect $M(W)$ predictions.

extrapolated from LEP measurements[9] and from SLAC left-right asymmetry measurements[10]. The direct $M(W)$ measurements are in good agreement with one another and with the LEP prediction, but are about 2σ from the SLAC prediction. In Fig. 5, the relationship among the top quark, the W and the Higgs masses in the minimal Standard Model[11] is shown along with the current measurements. Although the present uncertainties in the measured W and top masses are now large, it is feasible to obtain a significant constraint on the Higgs mass in the future, if the uncertainty in the top quark mass becomes about 5 GeV and the uncertainty in the W mass becomes about 50 MeV. Studies indicate these precisions should be attainable with the expected increase in statistics of about 1 fb^{-1}.[12]

7. Conclusion

The DØ and the CDF experiments at the Fermilab TeVatron have measured the W mass with the 1993-1994 collider data. The new measurements result in a new world average value of the W mass $M(W) =$

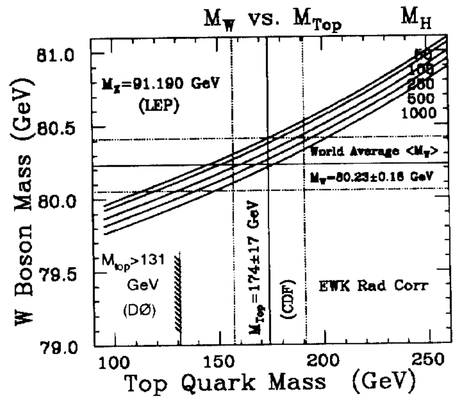

Figure 5. Minimal Standard Model predictions for mass relations. The curves show $M(W)$ as a function of $M(\text{top})$ for various values of $M(\text{Higgs})$. The horizontal band is the world average of $M(W)$ from hadron colliders, and the vertical band is the $M(\text{top})$ range suggested by recent evidence from CDF[13], while the region at the left is excluded by the DØ top search[14].

80.23 ± 0.18 GeV/c^2 when combined with the previous statistically independent measurements. No significant deviation from the SM predictions have been observed.

The W mass measurements have already reached the systematic limit of precision. However, the systematic uncertainties are expected to decrease as more data are accumulated. Both CDF and DØ are also continuously improving their analysis methods to better estimate the systematic uncertainties. Currently the Tevatron is running at a luminosity greater than 10^{31} $\text{cm}^{-2}\text{s}^{-1}$ and is expected to run untill the end of 1995 yielding more than 100 pb^{-1} of accumulated data for both experiments. This work is supported in part by the U.S. Department of Energy under contract No. DE-FG02-92ER40697.

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