Fermi National Accelerator Laboratory

FERMILAB-Conf-94/282-E

A Measurement of the Mass of the W Vector Boson at CDF

Randy M. Keup
The CDF Collaboration

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

Department of Physics, University of Illinois
Urbana, Illinois 61801

September 1994

Published Proceedings *Eighth Meeting of the Division of Particles and Fields of the American Physical Society (DPF'94),* University of New Mexico, Albuquerque, New Mexico, August 2-6, 1994

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

Disclaimer

CDF/PUB/ELECTROWEAK/PUBLIC/2743
FERMILAB-CONF-94/282-E

A MEASUREMENT OF THE MASS OF THE W VECTOR BOSON AT CDF

RANDY M. KEUP
Department of Physics, University of Illinois
Urbana, IL 61801, USA
The CDF Collaboration

ABSTRACT

We present a preliminary measurement of the mass of the W vector boson using the decays $W \to e\nu$ and $W \to \mu\nu$. The mass of the W is an important parameter of the standard model. Through its relation to both the top quark and the higgs sector, it provides a sensitive probe of the electroweak theory. During the last run of Fermilab's Tevatron, CDF recorded $\bar{p}p$ collisions at $\sqrt{s}$ = 1.8 TeV corresponding to an integrated luminosity of 19.3 pb^{-1}. An analysis of both decay channels yields a combined mass measurement of $M_W = 80.38 \pm 0.23$ GeV/c^2.

1. Introduction

With the precision measurement of the Z° mass from LEP[1] and the recent evidence for the top quark,[2] a precise measurement of the W mass is a crucial step in testing the Standard Model. We present a preliminary measurement of the W mass from data collected by the CDF detector during the 1992 - 1993 run.

2. Mass Measurement

We determine the mass by fitting the transverse mass distribution given by $m_T = \sqrt{2p_T^l p_T^\nu(1 - \cos\Delta\phi)}$, where transverse is with respect to the beamline. We therefore need to measure the transverse momentum of the lepton, $\vec{p}_T^{\,l}$, and the neutrino, $\vec{p}_T^{\,\nu}$.

2.1. Lepton Measurement

We measure the energy of the electron using the central electromagnetic calorimeter (CEM) while the muon is measured in the 14 kG magnetic field with the central tracking chamber (CTC).

First the CTC is aligned by requiring electrons and positrons to give the same ratio of energy as measured in the CEM to momentum as measured in the CTC. This works because of the fact that the CEM measurement is independent of the charge of the electron, i.e. whether it is an electron or positron, whereas the alignment of the CTC affects them differently. The absolute momentum scale of the CTC is determined by comparing the mass of the J/ψ as measured by the CTC using muon decays with

Published Proceedings Eighth Meeting of the Division of Particles and Fields of the American Physical Society (DPF'94), University of New Mexico, Albuquerque, NM, August 2-6, 1994

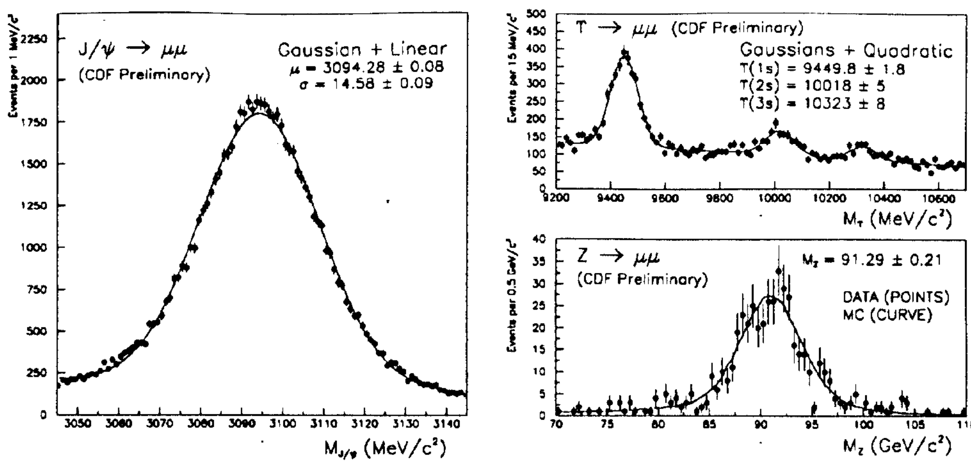

Fig. 1. Left: Invariant mass distribution near J/ψ peak. Points are data, curve is a gaussian plus linear background fit. Upper right: Invariant mass distribution near the Υ peak. The curve is three gaussians plus a quadratic background fit. The fit values have not had the momentum scale shift applied. Lower right: Invariant mass distribution near the Z° pole. The Monte Carlo is a LO generator with radiative corrections.

the world average of 3096.93 $\pm$ 0.09 MeV/c^2. Figure 1 contains a plot of the dimuon mass spectrum near the J/ψ with a fit to a gaussian plus linear background overlaid. The fit value after radiative corrections is 3094.58$\pm$2.2 MeV resulting in a momentum scale of 1.00076 $\pm$ 0.00071. As further confirmation of the absolute momentum scale, we also check the masses of the three lowest Υ states and the mass of the Z° (Fig. 1).

Next the CEM is calibrated by requiring that the mean E/p be the same everywhere to get relative corrections and by comparing E/p for the entire sample to a radiative Monte Carlo prediction to get the overall scale. Figure 2 is a plot of E/p with the Monte Carlo overlaid. The right-hand tail of the E/p distribution is caused by the emission of both internal and external collinear bremsstrahlung. To verify the scale of the CEM, the Z° mass from electron decays is also measured (Fig. 2).

2.2. *Neutrino Momentum Measurement*

We determine the neutrino transverse momentum, $\vec{p}_T^{\,\nu}$, by measuring the transverse momentum of the hadrons recoiling from the W, $\vec{P}_T^{\,hadrons}$. We define $\vec{P}_T^{\,hadrons}$ as $\Sigma(E_{tower} \cdot \vec{n}_{tower})_T$, where the T as usual means the transverse components, E is the energy in the ith calorimeter tower, and $\vec{n}$ is a unit vector pointing from the vertex to the ith calorimeter tower. Before constructing this vector, we remove from the calorimeter energy the contributions from the leptons and replace them with an average underlying event energy of 30 MeV. Given this vector, we then have from momentum conservation, $\vec{p}_T^{\,\nu} = -\vec{p}_T^{\,l} - \vec{P}_T^{\,hadrons}$.

2.3. *Data Selection*

We use leptons with $\eta < 1$ and require both $\vec{p}_T^{\,l}$ and $\vec{p}_T^{\,\nu}$ to be greater than 25 GeV and $\vec{P}_T^{\,hadrons}$ less than 20 GeV. We also require no other track greater than 10 GeV

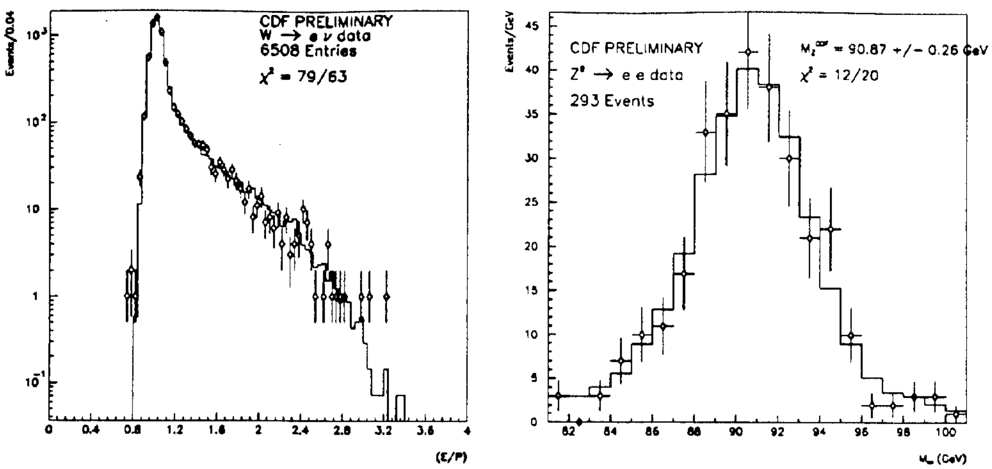

Fig. 2. Left: Ratio of CEM energy to CTC momentum for electrons from the W sample. The points are data and the histogram is a radiative Monte Carlo. Right: Dielectron mass distribution near the Z peak. The points are the data and the histogram is a LO Monte Carlo with radiative corrections.

and no jet greater than 20 GeV. The resultant data samples total 6421 electrons and 4090 muons.

3. Monte Carlo and Fitting

We determine the W mass by fitting the m_T distribution from the data with a set of Monte Carlo m_T distributions generated over a range of mass and width values, which we refer to as templates.

The Monte Carlo we use is a leading order generator using MRSD-′ structure functions fed into a parametric detector simulation. The transverse momentum, p_T^W , of the W is added in by hand and constrained by the data. We start with the p_T distribution taken from Z events, which is well measured relative to the p_T^W distribution since we detect both decay leptons, and scale it to account for any differences between the true p_T^W and the measured Z p_T distributions. After p_T^W has been inserted, we simulate the detector response to a vector boson of that p_T by selecting a Z event with the same boson p_T and using the detector response from that event in our Monte Carlo. This means there are no intricate models that need to be constructed to deal with the nonlinear response of the detector at low energies. All resolutions are already contained within the Z data.

The one adjustable parameter in this is the scale factor on the Z p_T distribution. It is constrained by comparing the $u_{||}$ and $u_\perp$ distributions between Monte Carlo and data. These u distributions are the projections of the recoil vector, $\vec{P}_T^{hadrons}$, parallel to ($u_{||}$) and perpendicular to ($u_\perp$) the lepton direction. We constrain to the widths of these distributions as they are less sensitive to backgrounds than the means.

Once we have accumulated the Monte Carlo templates, we calculate an unbinned negative log likelihood for each m_T template and find the minimum. Figure 3 shows the m_T distributions with the best fit histogram overlaid. The likelihood is calculated from 60 GeV to 100 GeV

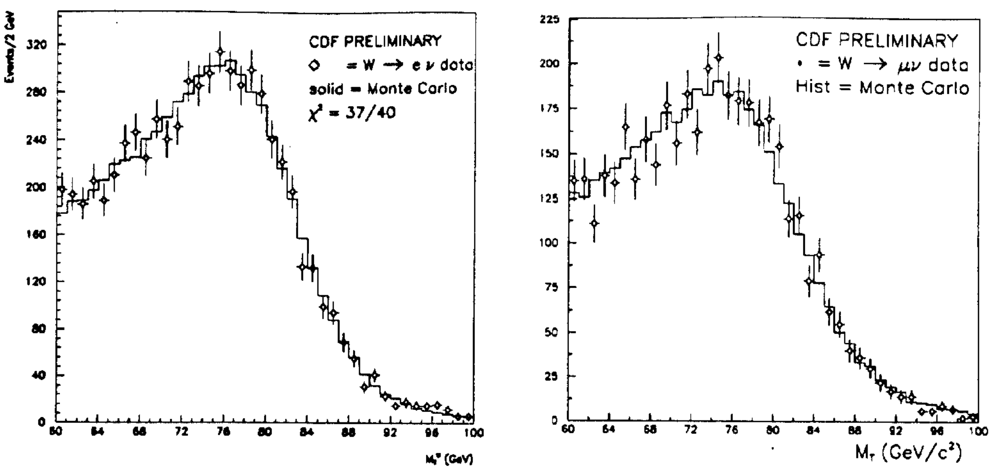

Fig. 3. Transverse mass distributions with best fit histogram overlaid. Left: $W \rightarrow e\nu$. Right: $W \rightarrow \mu\nu$.

4. Systematic Uncertainties

Lepton Momentum Scale: The momentum scale as determined from the J/ψs contributes 60 MeV common uncertainty. There is an additional 120 MeV uncertainty from the CEM scale for electrons as determined from the E/p fit.
Lepton Momentum Resolution: Both the electron energy resolution and the muon momentum resolution are determined from fitting the Z width. These fits result in resolutions of $(\delta E/E)^2 = (13.5\%/\sqrt{E_T})^2 + (2.1 \pm 1.0)\%^2$ and $\delta P_T/P_T = (0.09 \pm 0.02)\% \cdot P_T$, leading to mass uncertainties of 140 and 120 MeV.
Neutrino Scale: The extent to which we can distinguish a bias in the neutrino measurement is governed by the statistical uncertainty of the mean of the underlying event distribution, $u_{\|}$. This contributes 70 and 90 MeV for e and μ respectively.
p_T^W *Scale:* The scale factor is constrained by the widths of $u_{\|}$ and $u_{\perp}$ and results in uncertainties of 40 and 70 MeV for electrons and muons. Because it was constrained independently to e and μ, we take it as an uncorrelated uncertainty.
Detector Model: The detector response was modelled with Z events of which we have only limited statistics and which have an intrinsic smearing from the lepton resolutions. The effect of the limited number of events was studied and found to contribute less than 20 MeV while the smearing of the Z p_T caused a systematic shift of 80 MeV. Both of these are common to e and μ.
Backgrounds: The dominant backgrounds in the muon sample come from Z decays, where one muon is too far forward to have made a track in the CTC (4.35%), $W \rightarrow \tau\nu \rightarrow \mu\nu\nu$ (1.2%), and cosmic rays where one track was not found (0.8%). Electrons suffer mainly from $W \rightarrow \tau\nu \rightarrow e\nu\nu$ (also 1.2%). The resulting shifts in mass from backgrounds are 80 ± 50 and 232 ± 50 MeV for e and μ.
Radiative Corrections: Since the Monte Carlo is a leading order generator, we must also apply corrections for the radiative decays of the W. These are simulated with a slower $\mathcal{O}(\alpha)$ generator and result in shifts of 80 and 154 MeV for e and μ.
Structure Functions: To estimate the uncertainty due to not exactly knowing the

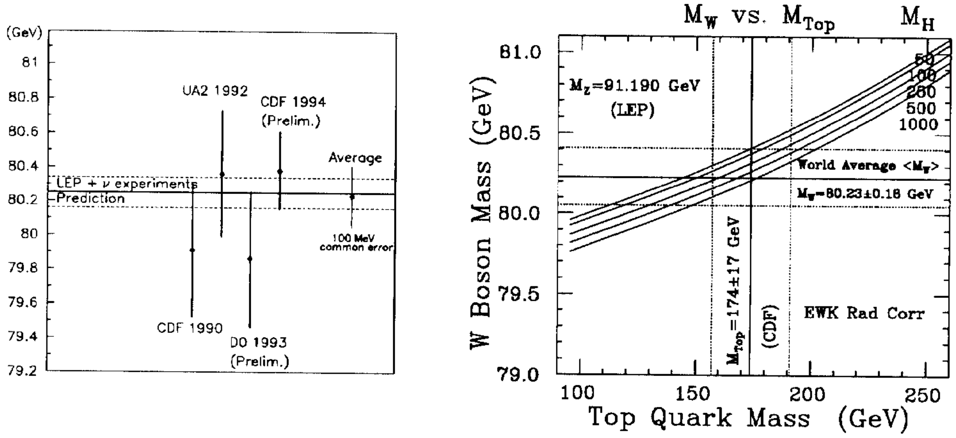

Fig. 4. Left: Comparison of this measurement to others. Right: Standard Model relationship between M_W, M_{TOP}, and M_{HIGGS}.

proton structure, we use a variety of structure functions and take the extreme shifts of 100 MeV as a common uncertainty.

5. Results

For the $W \rightarrow e\nu$ channel, we have measured the W mass to be $M_W = 80.47 \pm 0.15(STAT) \pm 0.21(SYST) \pm 0.13(SCALE)$ GeV/c^2 while for $W \rightarrow \mu\nu$ we have found it to be $M_W = 80.29 \pm 0.20(STAT) \pm 0.22(SYST) \pm 0.06(SCALE)$ GeV/c^2. Combining the two, taking the structure function and momentum scale uncertainties as common, yields

$$M_W \;=\; 80.38 \;\pm\; 0.23\; GeV/c^2.$$

We can also combine this with previous measurements by CDF,[3] UA2,[4] and the current DØ measurement[5] to get $M_W = 80.23 \pm 0.18$ GeV/c^2. In Fig. 4, we compare this measurement of the W mass with other measurements and the current world average as well as the LEP prediction.[6] We also present in Fig. 4 the current state of the Standard Model in the form of the relationship between M_W, M_{TOP}, and M_{HIGGS}.

References

1. L. Arnaudon *et al.* (Working Group on LEP Energy), *Phys. Lett.* **B307** (1993) 187.
2. F. Abe *et al.* (CDF Collaboration), *Phys. Rev. Lett.* **73** (1994) 225, and submitted to Phys. Rev. D.
3. F. Abe *et al.* (CDF Collaboration), *Phys. Rev. Lett.* **65** (1990) 2243.
4. J. Alitti *et al.* (UA2 Collaboration), *Phys. Lett.* **B276** (1992) 354.
5. Q. Zhu (DØ Collaboration), *The Ninth Topical Workshop on Proton-Antiproton Collider Physics,* October 18-22, 1993.
6. M. Swartz. *XVI International Symposium on Lepton-Photon Interactions,* August 10-15, 1993.