W Boson Mass Measurement from CDF

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1 Introduction

The W boson mass receives self-energy corrections due to vacuum fluctuations involving virtual particles. Thus the W boson mass probes the particle spectrum in nature, including particles that have yet to be observed directly. The W boson mass can be calculated at tree level using the precise measurements of the Z boson mass, the Fermi coupling G_F and the electromagnetic coupling α_{em}. In order to extract information on new particles, we need to account for the radiative corrections to M_W. With the discovery of a 'Higgs like' particle at the LHC [1], the measured M_W can be used as a consistency check when compared with the predicted W boson mass in the Standard Model (including radiative corrections due to the Higgs boson loop). At the Tevatron, W bosons are mainly produced by valance quark-antiquark annihilation, with initial state gluon radiation generating a typical transverse boost. The transverse momentum (p_T^l) distribution of the decay lepton has a characteristic Jacobian edge whose location is sensitive to the W boson mass. The neutrino transverse momentum (p_T^ν) can be inferred by imposing p_T balance in the event. The transverse mass, defined as $m_T = \sqrt{2p_T^l p_T^\nu(1 - cos[\phi^l - \phi^\nu])}$, includes both measurable quantities in the W decay. We use the m_T, p_T^l and p_T^ν distributions to extract M_W. These distributions do not lend themselves to analytic parameterizations, which leads us to use a Monte Carlo simulation to predict their shape as a function of M_W.

2 Momentum and Energy Scale Calibration

The key aspect of the measurement is the calibration of the lepton momentum, which is measured in a cylindrical drift chamber called the Central Outer Tracker (COT). The electron energy is measured using the central electromagnetic (EM) calorimeter and its angle measurement is provided by the COT trajectory. The momentum scale is set by measuring the J/Ψ and $\Upsilon(1S)$ masses using the dimuon mass peaks. The J/Ψ sample spans a range of muon p_T, which allows us to tune our ionization energy loss model such that the measured mass is independent of muon p_T. We obtain

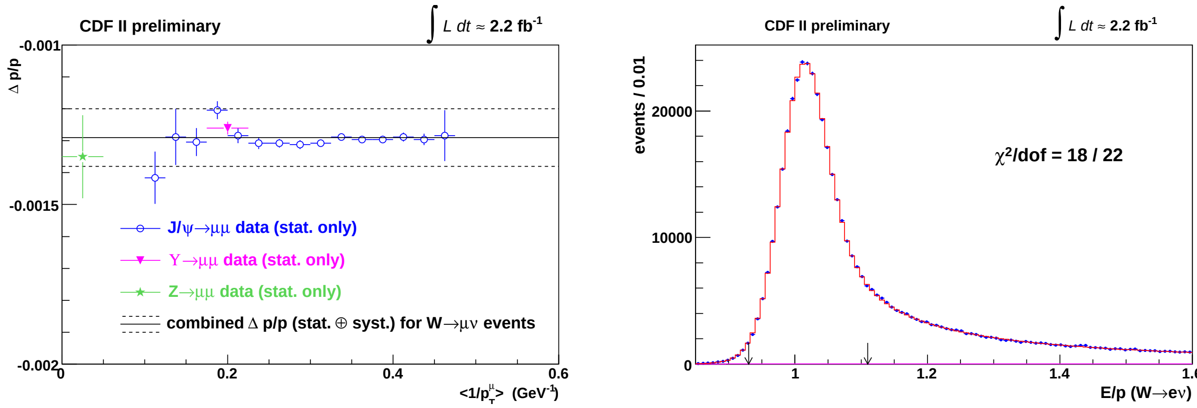

Figure 1: Left: Momentum scale summary: $\Delta p/p$ vs $1/p_T$ for J/Ψ, $\Upsilon(1S)$ and Z boson samples. The dotted line represents the independent uncertainty between J/Ψ and $\Upsilon(1S)$. Right: Energy scale calibration using E/p from $W \to e\nu$ events.

consistent calibrations from the J/Ψ, $\Upsilon(1S)$ mass fits shown in Fig. 1 (left). The momentum scale extracted from the $Z \to \mu\mu$ mass fit, shown in the same figure, is consistent, albeit with a larger, statistics-dominated uncertainty. Given the tracker momentum calibration, we fit the peak of the E/p distribution of the signal electrons in the $W \to e\nu$ sample (Fig. 1 right) in order to calibrate the energy measurement of the electromagnetic (EM) calorimeter. The energy scale is adjusted such that the fit to the peak returns unity. The model for radiative energy loss is constrained, by comparing the number of events in the radiative tail of the E/p distribution. The calorimeter energy calibration is performed in bins of electron E_T to constrain the calorimeter non-linearity. The calibration yields a $Z \to ee$ mass measurement of $M_Z = 91230 \pm 30_{stat}$ MeV/c^2, in good agreement with the world average (91187.6±2.1 MeV/c^2 [2]); we obtain the most precise calorimeter calibration by combining the results from the E/p method and the $Z \to ee$ mass measurement.

3 Hadronic Recoil Calibration

The recoil against the W or Z boson is computed as the vector sum of transverse energy over all calorimeter towers, where the towers associated with the leptons are explicitly removed from the calculation. The response of the calorimeter to the recoil is described by a response function which scales the true recoil magnitude to simulate the measured magnitude. The hadronic resolution receives contributions from ISR jets and the underlying event. The latter is independent of the boson p_T and modeled using minimum bias data. The recoil parameterizations are tuned on the mean and rms of the p_T-imbalance in $Z \to ll$ events as a function of boson p_T.

4 Event Generation and Backgrounds

We generate W and Z events with RESBOS [3], which captures the QCD physics and models the W p_T spectrum. The RESBOS parametrization of the non-pertubative form factor is tuned on the dilepton p_T distribution in the Z boson sample. Photons radiated off the final-state leptons (FSR) are generated according to PHOTOS [4] and checked with HORACE [5]. We use the CTEQ6.6 [6] set of parton distribution functions (PDFs) at NLO and evaluate their uncertainties on the W boson mass and verify that the MSTW2008 [7] PDFs give consistent results.

Backgrounds passing the event selection have different kinematic distributions from the W signal and are included in the template fit according to their normalizations.

5 Results and Conclusions

The fits to the three kinematic distributions m_T, p_T^l and p_T^ν in the electron and muon channels give the W boson mass results shown in Table 1. The transverse mass

Distribution	Fitted M_W [e-channel] (MeV/c^2)	Fitted M_W [μ-channel] (MeV/c^2)
m_T	$80408 \pm 19_{stat} \pm 18_{syst}$	$80379 \pm 16_{stat} \pm 16_{syst}$
p_T^l	$80393 \pm 21_{stat} \pm 19_{syst}$	$80348 \pm 18_{stat} \pm 18_{syst}$
p_T^ν	$80431 \pm 25_{stat} \pm 22_{syst}$	$80406 \pm 22_{stat} \pm 20_{syst}$

Table 1: Fit results from the distributions used to extract M_W with uncertainties.

distribution for the $W \to \mu\nu$ channel is shown in Fig. 2 (left). We combine the six W boson mass fits including all correlations to obtain M_W=80387±12(stat)±15(syst) MeV/c^2. The uncertainties for the combined result on M_W are summarized in Table 2. With a total uncertainty of 19 MeV/c^2, this measurement is the most precise measurement to date. The new world average becomes M_W=80385±15 MeV/c^2 [8], which is in good agreement with the Standard Model prediction of M_W=80359±11 MeV/c^2 [9]. This is illustrated in Fig. 2 (right), which shows the $\Delta\chi^2$ vs M_W from the Standard Model fit as the blue (grey) band, including (excluding) the 'Higgs like' discovery at the LHC [1] at a mass near ∼126 GeV/c^2. The world average measured M_W is represented by the red point. The updated world average W boson mass impacts the global precision electroweak fits for the Higgs boson mass $M_H=94^{+29}_{-24}$ GeV/c^2 [2] which is also in good agreement with the discovery at the LHC [1]. Sensitivity to beyond the Standard Model physics contributions to M_W requires an improved direct

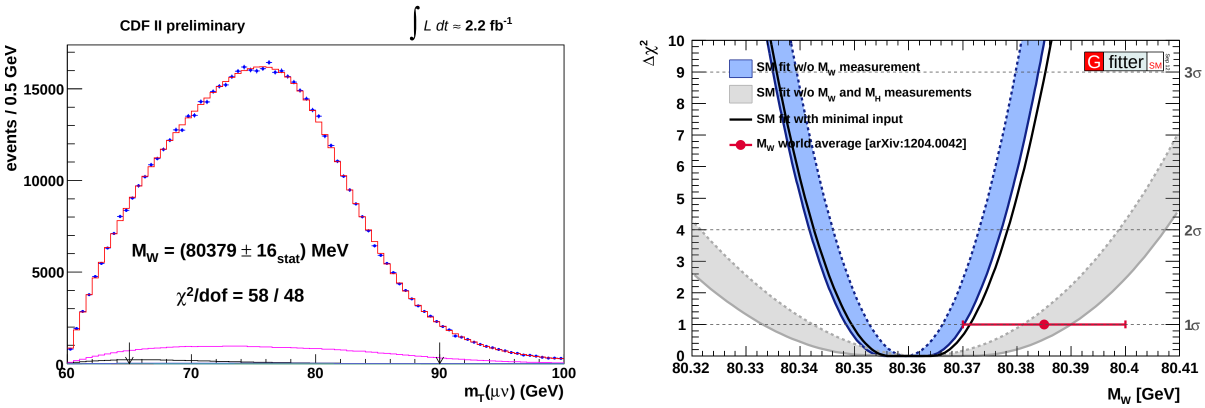

Figure 2: Left: Transverse mass fit in the muon decay channel. Right: $\Delta\chi^2$ vs M_W from the Standard Model fit is shown in the blue band [9], the world average measured M_W is represented by the red point.

Table 2: Uncertainties for the combined result on M_W.

Source	Uncertainty (MeV/c^2)
Lepton Energy Scale and Resolution	7
Recoil Energy Scale and Resolution	6
Backgrounds	3
$p_T(W)$ Model	5
Parton Distributions	10
QED radiation	4
W-boson statistics	12
Total Uncertainty	19

measurement of M_W, as well as improvements in the theoretical prediction of the W boson mass. An improved W boson mass measurement can be achieved by using the full Tevatron datasets and on the longer term, making precise measurements using LHC data. The theoretical predictions are currently limited by uncertainties on α_{em}, the top quark mass and higher order calculations.

I would like to thank my colleagues from the CDF collaboration in particular the W boson mass group for their hard work on this important analysis.

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