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FIRST RUN II MEASUREMENT OF THE W BOSON MASS WITH THE COLLIDER DETECTOR AT FERMILAB

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The CDF collaboration has analyzed $\sim$200 pb^{-1} of Tevatron Run II data taken with the CDF II detector between February 2002 and September 2003 to measure the W boson mass. With a sample of 63964 $W \rightarrow e\nu$ decays and 51128 $W \rightarrow \mu\nu$ decays, we measure M_W = 80413$\pm$34(stat)$\pm$34(syst) MeV/c^2. The total measurement uncertainty of 48 MeV/c^2 makes this result the most precise single measurement of the W boson mass to date.

1. Introduction

The W boson mass is an important Standard Model (SM) parameter. It 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 hypothetical particle of most immediate interest is the Higgs boson. The W boson mass can be calculated at tree level using the three 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 due to the dominant top-bottom quark loop diagrams. For fixed values of other inputs, the current uncertainty on the top quark mass measurement 170.9$\pm$1.8 GeV/c^2 [1] corresponds to an uncertainty in its W boson mass correction of 11 MeV/c^2. Measurements of the W boson mass from Run I of the Tevatron and LEP with uncertainties of 59 MeV/c^2 [2] and 33 MeV/c^2 [3] respectively, yield a world average of 80392$\pm$29 MeV/c^2 [3]. It is clearly profitable to reduce the W boson mass uncertainty further as a means of constraining the Higgs boson mass.

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*on behalf of the CDF collaboration

2. Measurement Strategy

At the Tevatron, W bosons are mainly produced by valance quark-antiquark annihilation, with initial state gluon radiation (ISR) generating a transverse boost. The transverse momentum (p_T^l) distribution of the decay lepton has a characteristic Jacobian edge whose location, while sensitive to the W boson mass, is smeared by the transverse boost of the W boson. The neutrino p_T (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 and provides the most precise quantity to measure M_W. We use the m_T, p_T^l and p_T^ν distributions to extract the W boson mass. 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. These lineshape predictions depend on a number of physical and detector effects, which we constrain from control samples or calculation. By fitting these predictions to the data with a binned maximum-likelihood fit, we extract the W boson mass.

3. Energy Scale Calibration

The key aspect of the measurement is the calibration of the lepton energy. The trajectory of the charged lepton is measured in a cylindrical drift chamber. 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 (2-10 GeV/c), which allows us to tune our ionization energy loss model. We obtain consistent calibrations from the J/Ψ, $\Upsilon(1S)$ and Z boson mass fits shown in Fig. 1 (left). The tracker resolution is tuned on the observed width of the $\Upsilon(1S)$ and Z boson mass peaks. 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, shown in Fig. 1 (right), in order to calibrate the energy measurement in the electromagnetic (EM) calorimeter. The model for radiative energy loss is tuned, using the radiative tail of the E/p distribution. The calorimeter energy calibration is performed in bins of electron p_T to constrain the calorimeter non-linearity. The calibration yields a $Z \to ee$ mass measurement of $M_Z = 91190 \pm 67_{stat}$ MeV/c^2, in very good agreement with the world average (91187.6 ± 2.1 MeV/c^2 [3]); we obtain the most precise calorimeter calibration by combining the results from the E/p method and the $Z \to ee$ mass measurement. The EM calorimeter resolution model is tuned on the widths of the E/p and $Z \to ee$ mass peaks.

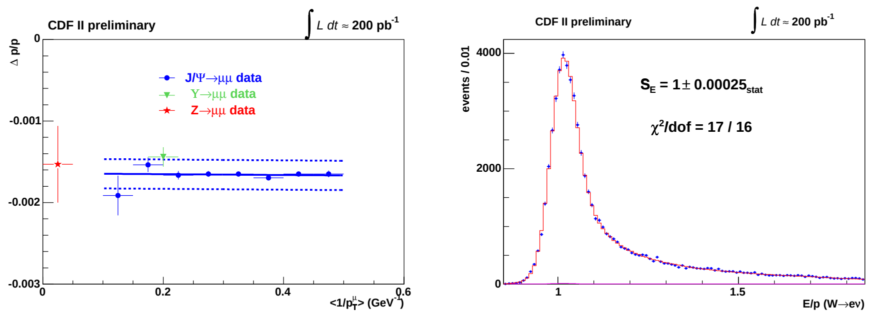

Figure 1. Left: Momentum scale summary: $\Delta p/p$ vs $1/p_T$ for J/Ψ, $\Upsilon(1S)$ and Z boson dimuon data. The dotted line represents the independent uncertainty between J/Ψ and $\Upsilon(1S)$. Right: Energy scale calibration using E/p distribution from $W \to e\nu$ events.

4. Hadronic Recoil Calibration

The recoil is 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 transverse momentum and modeled using minimum bias data. The recoil response and resolution 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. Cross-checks of the recoil model using W and Z boson data show good agreement and validate the model.

5. Event Generation and Backgrounds

We generate W and Z events with RESBOS[4], 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 WGRAD[5]. The FSR photon energies are increased by 10% to account for 2-photon radiation[6]. We use the CTEQ6M[7] set of parton distribution functions and apply their uncertainties.

Backgrounds arise in the W boson samples from jets fragmenting into high-p_T tracks and EM clusters, $Z \to ll$ where one of the leptons is not reconstructed, $W \to \tau\nu$, kaon and pion decays in flight (DIF), and cosmic ray muons. The latter two are backgrounds in the muon channel only.

6. 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 fit in the $W \to \mu\nu$ channel is shown in Fig. 2 (left). The uncertainties for the m_T fits in both channels are summarized in Table 2. We combine the six W boson mass fits including all correlations to obtain M_W=80413±34(stat)±34(syst) MeV/c^2. Inclusion of this result increases the world average W boson mass to M_W=80398±25 MeV/c^2 [3], reducing its uncertainty by 15%. The updated world average impacts the global precision electroweak fits, reducing the preferred Higgs boson mass fit by 6 GeV/c^2 to $M_H=76^{+33}_{-24}$ GeV/c^2. The 95% CL upper limit on the Higgs mass is 144 GeV/c^2 (182 GeV/c^2) with the LEP II direct limit included (excluded)[3 8]. The direction of this change has interesting theoretical implications: as Fig 2 (right) shows, the M_W vs M_{top} ellipse moves a little deeper into the light-Higgs region excluded by LEP II, and into the region favored by the minimal supersymmetry model (MSSM). While this is a one-sigma effect, it arouses further interest in higher precision measurements of

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

Distribution	$W \to e\nu$ (MeV/c^2)	χ^2/dof	$W \to \mu\nu$ (MeV/c^2)	χ^2/dof
m_T	$80493 \pm 48_{stat} \pm 39_{syst}$	86/48	$80349 \pm 54_{stat} \pm 27_{syst}$	59/48
p_T^l	$80451 \pm 58_{stat} \pm 45_{syst}$	63/62	$80321 \pm 66_{stat} \pm 40_{syst}$	72/62
p_T^ν	$80473 \pm 57_{stat} \pm 54_{syst}$	63/62	$80396 \pm 66_{stat} \pm 46_{syst}$	44/62

Table 2. Systematic and total uncertainties for the m_T fits. The last column shows the correlated uncertainties.

Systematic (MeV/c^2)	$W \to e\nu$	$W \to \mu\nu$	Common
Lepton Energy Scale and Resolution	31	17	17
Recoil Energy Scale and Resolution	11	11	11
Lepton Removal	9	5	5
Backgrounds	8	9	0
$p_T(W)$ Model	3	3	3
Parton Distributions	11	11	11
QED radiation	11	12	11
Total Systematics	39	27	26
Total Uncertainty	62	60	26

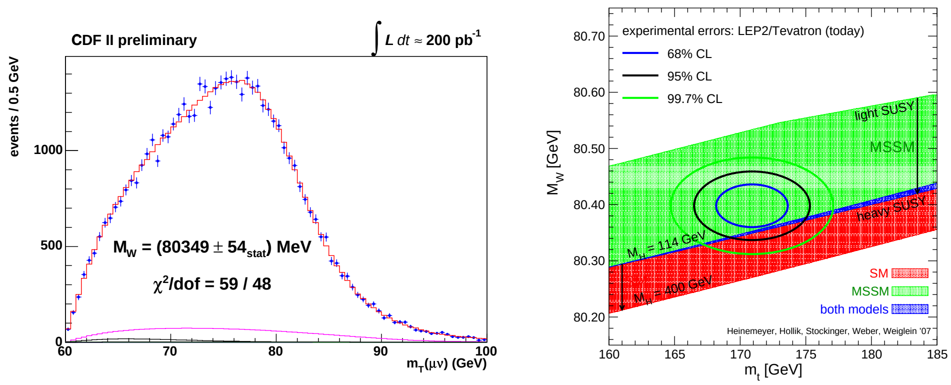

Figure 2. Left: Transverse mass fit in the muon decay channel. Right: Constraint on M_H from direct M_W and M_{top} measurements along with SM and MSSM calculations.

M_W (and M_{top}). Most of the systematic uncertainties in this measurement (Table 2) are limited by the statistics of the control samples used. CDF has now accumulated an integrated luminosity of about 2 fb^{-1} and we look forward to a W boson mass measurement with precision better than the current world average of 25 MeV/c^2, with the dataset in hand.

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