W mass and width measurements at the Tevatron

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A measurement of the W boson mass(M_W) and width (Γ_W) using 200 and 350pb^{-1} of CDF Run II data respectively is presented. The measurements were performed in both the electron and muon channels. The W mass is obtained by fitting to the peak of the W transverse mass distribution whereas the width is extracted by fitting to the tail of the distribution. We measure $M_W = 80413 \pm 48$ MeV and $\Gamma_W = 2032 \pm 71$ MeV both of which represent the single most precise measurements of these quantities to date.

1 Introduction

The mass of the W boson receives radiative corrections from loops of virtual particles. The most dominant contributions are from the Higgs boson loop and the top-bottom loop where the Higgs boson contribution is proportional to the logarithm of its mass(M_H). A precision measurement of the W mass therefore allows us to place an indirect constraint on M_H. The width of the W boson is predicted with high precision within the Standard Model(SM), W width measurement provides a valuable test of the SM prediction.

W bosons are produced in proton-antiproton collisions at the Tevatron, predominantly via valence quark anti-quark annihilation. Events are selected where the W boson decays leptonically to $e\nu$ or $\mu\nu$ as these decay modes provide relatively clean signatures for detection. The invariant mass of the W is difficult to reconstruct since a large fraction of longitudinal information is lost as fragments of the $q\bar{q}$ collision escape down the beam pipe. Transverse quantities are therefore used for the measurements, in particular the transverse mass, M_T, which is defined as:

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

where p_T^l is the transverse momentum of the charged lepton, p_T^ν is the transverse momentum of the neutrino and $\phi_{l\nu}$ is the azimuthal angle between the charged lepton and the neutrino. The W mass is extracted by fitting to the peak of the M_T distribution, the region 65-90 GeV. The width is obtained by fitting to the tail of the distribution(90-200 GeV) and exploiting the slower fall-off of the Breit-Wigner lineshape compared to the detector resolution.

A dedicated, fast Monte Carlo simulation is used to generate the M_T distribution used in the fits. Parton Distribution Functions (PDFs) are provided by the CTEQ6M [5] set. The W is produced with a non-zero transverse momentum and the shape of the p_T spectrum is taken from RESBOS [2]. All final state QED radiation is simulated with the Berends and Kleiss [3] program for the width and WGRAD [4] for the mass.

2 Lepton Momentum Scale and Resolution

One of the key aspects of the measurement is an accurate determination of the lepton momentum. The momentum of the lepton is measured in the Central Outer Tracker(COT), a cylindrical drift chamber placed in a magnetic field of 1.4T. Charged particles ionise atoms of the gas in the chamber producing a track where the momentum of the lepton can be inferred from the curvature of the track. The momentum scale and resolution of the COT is calibrated using the control samples, $J/\psi \rightarrow \mu\mu$, $\Upsilon(1S) \rightarrow \mu\mu$ and $Z \rightarrow \mu\mu$. The invariant mass of the dimuon pair is measured and compared to the world average mass of the reconstructed particle, in order to calibrate the detector.

3 Lepton Energy Scale and Resolution

The energy of the lepton is measured in the Central Electromagnetic Calorimeter (CEM). The CEM is calibrated by using E/p, the ratio of the energy measured in the calorimeter to the momentum measured in the COT. By using this quantity, the already well calibrated momentum measurement can be used to calibrate the calorimeter. The energy scale obtained from this method is then cross-checked by using the resonance peak of the $Z \rightarrow ee$ sample. The invariant mass of the dielectron pair as measured in the calorimeter is compared to the world average mass of the Z boson.

4 Hadronic Recoil Calibration

The neutrino is not detected in the CDF detector, its transverse momentum can be inferred from the missing transverse energy ($\not\!\!E_T$) in the detector. This is obtained by summing over the energy in all the calorimeter towers excluding those containing or neighbouring the electron. This is what is referred to as the recoil and it is denoted by $\vec{U}$. The $\not\!\!E_T$ can then be defined in terms of the recoil as $-(\vec{U} + \vec{p_T^l})$.

The recoil receives contributions from three main sources. When the W boson is produced it recoils against initial state gluon radiation from the incoming quarks giving it a net non-zero transverse momentum. Gluon radiation forms hadronic jets that end up in the calorimeter. Other processes coinciding with the W boson production(underlying event) also contribute to the recoil as well as final state photon radiation from the charged lepton which is not emitted collinear with the lepton.

The recoil can be resolved into two components, U_1 which is parallel to the direction of the Z p_T and U_2 which is perpendicular to it. U_1 is largely boson p_T dependent and U_2 is mostly underlying event dependent. This enables a parametrisation of the recoil in terms of these components. Parameters of the model are determined by fitting to $Z \rightarrow ll$ data and minimum-bias data.

5 Backgrounds

The W event sample is contaminated by backgrounds arising from several sources. W bosons decaying to hadrons can fake $W \rightarrow l\nu$ if one of the jets fakes a lepton and the other is mis-measured giving a false $\not\!\!E_T$. $Z \rightarrow ll$ events can fake a W event if one of the leptons is not reconstructed. In the muon channel, backgrounds arise from kaons and pions decaying in the COT, cosmic rays and $W \rightarrow \tau\nu$ events. The amount and shape of background contamination in the signal sample is estimated using data for non-electroweak background and Pythia [1] Monte Carlo for electroweak background. Backgrounds are added to the Monte Carlo templates.

ΔM_W [MeV]	e	μ	C
Lepton Scale	30	17	17
Lepton Resolution	9	3	0
Recoil Scale	9	9	9
Recoil Resolution	7	7	7
Lepton ID	3	1	0
Lepton Removal	8	5	5
Backgrounds	8	9	0
$p_T(W)$	3	3	3
PDF	11	11	11
QED	11	12	11
Total Systematic	39	27	26
Statistical	48	54	0
Total	62	60	26

$\Delta\Gamma_W$ [MeV]	e	μ	C
Lepton Scale	21	17	12
Lepton Resolution	31	26	0
Simulation	13	0	0
Recoil	54	49	0
Lepton ID	10	7	0
Backgrounds	32	33	0
$p_T(W)$	7	7	7
PDF	16	17	16
QED	8	1	1
M_W	9	9	9
Total Systematic	78	70	23
Statistical	60	67	0
Total	98	97	23

Table 1: Systematic and statistical uncertainties for the W mass(left) and width(right). The last column denotes the uncertainties that are common between the electron and the muon channels.

6 Result

The systematic and statistical uncertainties for M_W and Γ_W are summarised in Table 1. M_W was obtained by fitting to the three kinematic distributions m_T, p_T^l and p_T^ν. The combined fitted value obtained is $M_W = 80413 \pm 48$ MeV which is the world's most precise single measurement of this quantity. The result increases the world average central value by 6 MeV and reduces the uncertainty by 15%. Figure 1 shows the M_T fits for M_W in the electron and muon channels. Figure 2 shows the M_T fits for Γ_W in the electron and muon decay channels. The combined fitted value obtained is $\Gamma_W = 2032 \pm 71$ MeV, also the world's most precise single direct measurement of this quantity. This result reduces the world average central value by 44 MeV and uncertainty by 22% and is in good agreement with the Standard Model prediction.

References

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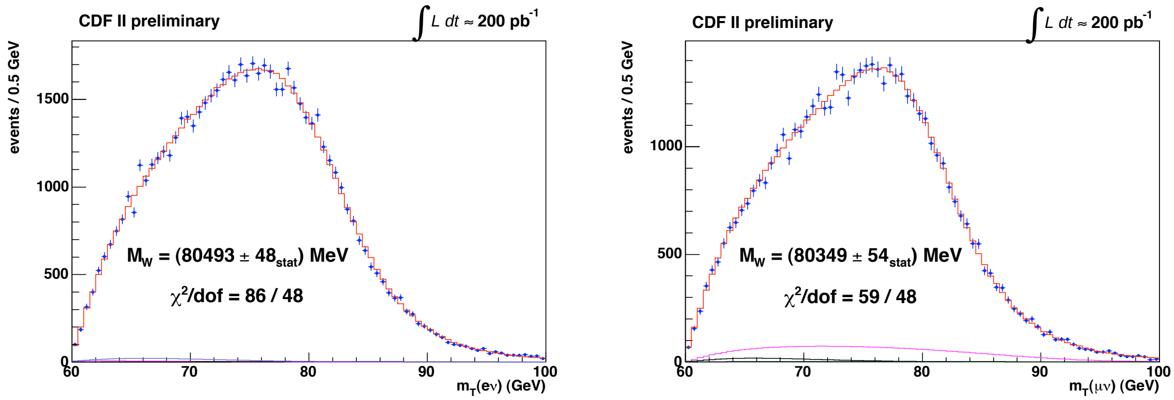

Figure 1: Transverse mass fits for M_W in $W \to e\nu$(left) and $W \to \mu\nu$(right)

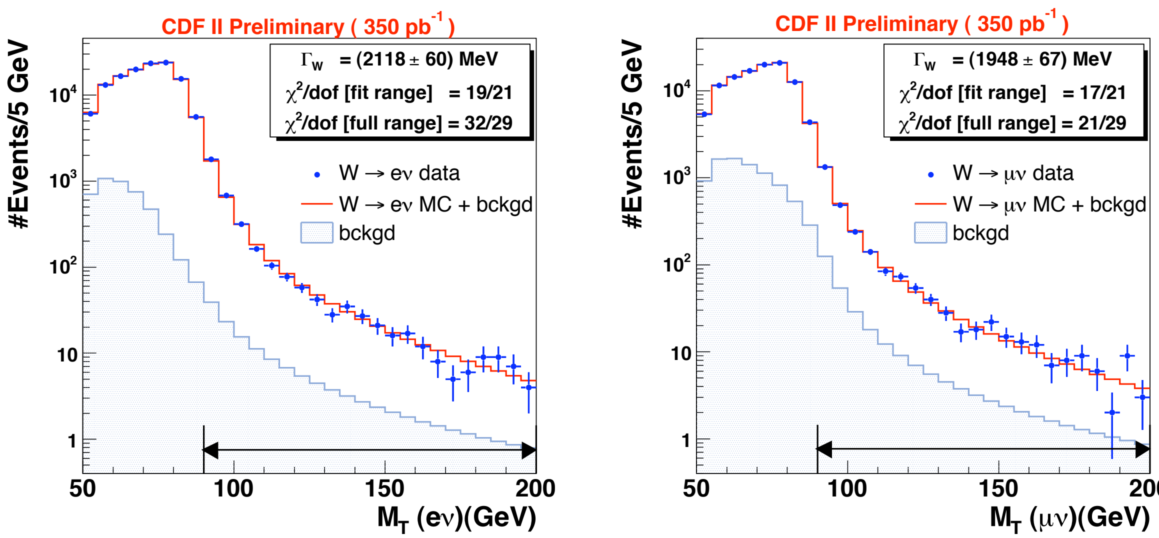

Figure 2: Transverse mass fits for Γ_W in $W \to e\nu$(left) and $W \to \mu\nu$(right)