

W production and properties at CDF

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Abstract. I present measurements of the W boson charge asymmetry and the W boson width (Γ_W) using 350 pb⁻¹ of CDF Run II data. The charge asymmetry is the first direct measurement, which uses a new technique to reconstruct the W rapidity by constraining its mass; the result will further constrain Parton Distribution Functions in future fits. The width measurement relies on a fit to the W transverse mass distribution. We measure $\Gamma_W = 2032 \pm 71$ MeV which is in good agreement with the Standard Model prediction.

1. Introduction

W bosons are produced at the Tevatron proton-antiproton collider via quark-antiquark annihilation. They quickly decay into two fermions which, due to the large mass of the W , typically have a high momentum in the direction transverse to the beam, p_T . The leptonic decay channels have a clean experimental signature and can therefore be utilised to make precision measurements of W properties, such as its width (Γ_W) and mass (M_W), and to probe the quantum-chromodynamic (QCD) aspects of the production mechanism. This document describes a measurement of the W charge asymmetry made in the $e\nu$ decay channel and Γ_W , made in the $e\nu$ and $\mu\nu$ decay channels, using 350 pb⁻¹ of CDF Run II data.

2. W charge asymmetry

Parton Distribution Functions (PDFs) are parameterised functional forms that describe the momentum distribution of partons in hadrons. The parameters are constrained by many data sets from different experiments. The $u(\bar{u})$ quark carries on average a higher fraction of the (anti)proton's momentum than the $d(\bar{d})$ quark, meaning that a $W^+(W^-)$ produced via $u\bar{d}(d\bar{u})$ annihilation will tend to be boosted in the direction of the (anti)proton beam. This results in a W charge asymmetry, defined as:

$$A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W}, \quad (1)$$

where y_W is the rapidity of the W and $\sigma(W^\pm)$ is the cross-section of W production. This distribution is sensitive to the difference between the u and d PDFs at the scale $Q^2 \approx M_W^2$ and is an important input to the global PDF fits. In particular the measurement will help to reduce the PDF uncertainty on future M_W and Γ_W measurements.

Since the neutrino momentum in the direction of the beam, p_z^ν , is not known, traditionally a measurement of the electron charge asymmetry is made. This distribution is a convolution of $A(y_W)$ and the $W \rightarrow e\nu$ angular decay structure and places a less strong constraint on PDFs than

$A(y_W)$. This analysis extracts $A(y_W)$ by constraining $M_W = 80.4 \text{ GeV}/c^2$, giving two possible solutions for p_z^ν . Each solution receives a probability weight according to the decay structure and $\sigma(W^\pm)$. The W charge asymmetry is then extracted after correcting for detector effects. The process is iterated to eliminate any dependence of the weighting factor on the asymmetry itself. The measured W charge asymmetry is compared to the prediction from PDFs using CTEQ5L and the corresponding error from the CTEQ6.1 [1] error sets in Figure 1. The experimental uncertainties are lower than the uncertainties from the PDFs indicating that they will help to constrain the PDFs in future fits.

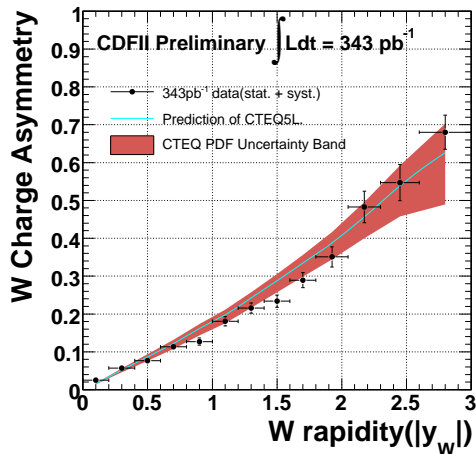


Figure 1. The W charge asymmetry distribution compared to the CTEQ5L PDF prediction with the CTEQ6.1 error sets shown as the uncertainty band.

3. W width measurement

Since neutrinos are not detected in CDF, the invariant mass of the W decay products cannot be reconstructed. Instead we reconstruct the transverse mass, which is defined as $M_T = \sqrt{2p_T^\ell p_T^\nu (1 - \cos \phi_{\ell\nu})}$, where p_T^ℓ and p_T^ν are the p_T of the charged lepton and the neutrino respectively and $\phi_{\ell\nu}$ is the azimuthal angle between them. p_T^ν is inferred from the transverse momentum imbalance in the event.

A fast, parameterised Monte Carlo simulation is used to predict the M_T distribution as a function of Γ_W . After adding background distributions to the Monte Carlo, a binned maximum-likelihood fit to the data is performed in the region 90–200 GeV/c^2 to extract Γ_W . The fit is performed in the high M_T tail region, which is sensitive to the Breit-Wigner line-shape but less sensitive to the Gaussian detector resolutions than the peak region. These line-shape predictions depend on a number of production and detector effects, described below.

The W p_T spectrum, which is non-zero due to initial state gluon radiation from the incoming quarks, is modelled with RESBOS [2]. QED corrections for up to one photon emission are simulated with Berends and Kleiss [3]. Systematic uncertainties arise from non-perturbative QCD parameters affecting the W p_T spectrum, and also from neglecting to model the effect of a second photon from the final state charged lepton. PDFs affect the acceptance and kinematics of decay products. The Monte Carlo is interfaced with the CTEQ6.1 [1] PDFs, and their error sets are used to estimate the PDF uncertainty.

The simulation has a fast detector response model which is tuned to $Z \rightarrow \ell\ell$ and $W \rightarrow \ell\nu$ data, systematic uncertainties come predominantly from the limited statistics in the data. The scale and resolution of the drift chamber muon momentum measurement are calibrated using a fit to the $Z \rightarrow \mu\mu$ resonance peak. The electron energy is measured in the calorimeter and the

momentum is measured in the drift chamber ¹. The well calibrated momentum measurement can therefore be used to calibrate both the calorimeter scale and resolution, using the ratio between the electron energy measured in the calorimeter and the track momentum (E/p) in $W \rightarrow e\nu$ events. The scale and resolution are also obtained from the $Z \rightarrow ee$ resonance peak and the results are combined.

The neutrino p_T is determined from the missing transverse energy, \cancel{E}_T , in the detector. A recoil vector, \vec{U} , is defined as the vector sum of the transverse energy in all calorimeter towers, excluding those surrounding the lepton. The \cancel{E}_T is then defined as $-(\vec{U} + p_T^{\cancel{e}})$. The recoil is represented by a parameterised model, which is tuned to $Z \rightarrow \ell\ell$ events.

The dominant systematic uncertainties on Γ_W come from modelling the lepton resolutions and the recoil as well as modelling the background M_T distributions and normalisations.

Figure 2 shows the M_T fits for Γ_W in the muon and electron decay channels. The results are combined to give the final result $\Gamma_W = 2032 \pm 71$ MeV, the world's most precise single measurement, which is in good agreement with the Standard Model prediction of 2093 ± 3 MeV [4]. This result reduces the world average central value by 44 MeV and uncertainty by 22%. CDF has also made an indirect measurement of Γ_W , obtained from a measurement of the ratio of the cross-section times branching ratio for leptonically decaying W 's and Z 's [5]. This measurement yields $\Gamma_W = 2092 \pm 42$ MeV, which is consistent with the direct measurement.

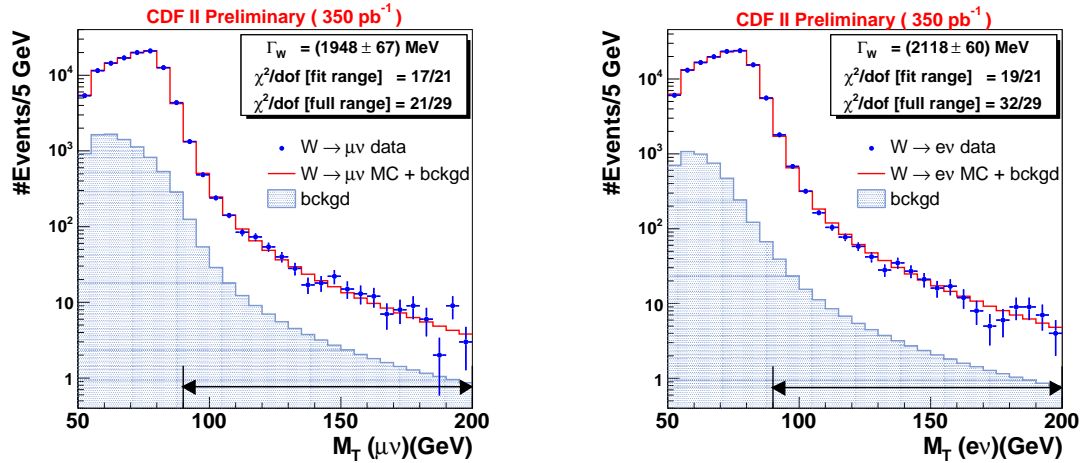


Figure 2. Transverse mass fits for Γ_W in $W \rightarrow \mu\nu$ (left) and $W \rightarrow e\nu$ (right) events. The fits are performed in the region 90–200 GeV.

References

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¹ Since the mass of the electron is negligible, the true momentum and energy values are the same. However collinear photon radiation from the electron, which is clustered back into the calorimeter energy measurement, can decrease the track momentum measurement. These effects are well modelled in the simulation.