PROCEEDINGS OF SCIENCE

W and Z properties (including M_W) from Tevatron

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Most recent results of electroweak physcis analyses performed by CDF and DØ are reported. These include W boson mass and width, W boson, electron, and muon charge asymmetries, Z boson rapidity, Z boson forward-backward asymmetry, limit on the branching fraction of $W \to \pi\gamma$ rare decay. The data used in these analyses was collected at the center-of-mass energy of 1.96 TeV. Integrated luminosity ranges from 0.75 fb^{-1} to 4.9 fb^{-1} depending on the analysis.

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1. Introduction

Electroweak physics is an important part of the overall physics research program at the Tevatron. Large production rates of the W and Z bosons as well as clean experimental signatures associated with their leptonic decays[1] allow us to perform measurements that cover a very broad range of physics implications.

We describe recent electroweak physics results from CDF and D0 collaborations. Measurement of the W boson mass (M_W) [3] provides us with a uniquely powerful key to uncovering the origin of the electroweak symmetry breaking and learing about new physics. On the other hand, the width of the W boson (Γ_W) is expected to be insensitive to new physics. Therefore its precise measurement [4] is very important for improving the experimental knowledge of the Standard Model. Measurements of W (or lepton) charge asymmetry [5, 6] as well as Z boson rapidity [7] allow us to constrain parton distribuion functions (PDFs). Finally, we also look for new physics in electroweak processes by measuring forward-backward asymmetry (A_{FB}) in the Z boson decays and searching for $W \to \pi\gamma$ rare decay.

Electrons are identified as an electromagnetic (EM) cluster reconstructed with a simple cone algorithm. To reduce the background of jets faking electrons, electron candidates are required to have a large fraction of their energy deposited in the EM section of the calorimeter and pass energy isolation and shower shape requirements. Electron candidates are classified as *tight* if a track is matched spatially to EM cluster and if the track transverse momentum is close to the transverse energy of the EM cluster. In CDF [1], electrons are reconstructed both in the central calorimeter and plug calorimeter ($|\eta| < 2.8$) while electrons in D0 [2] are reconstructed in the central and endcap calorimeters ($|\eta| < 1.05$ and $1.5 < |\eta| < 3.2$). Here $\eta = -\ln\tan(\theta/2$, and θ is the polar angle with respect to the proton direction. Both CDF and D0 require *tight* electrons in the central calorimeter ($|\eta| < 1.05$) for $Z \to e^+e^-$ candidates.

Muons are identified by a track in the muon system matched to a track in the central tracking system. For CDF the measurement in the muon channel includes the muons reconstructed in the central muon extension sub-detector which extends the coverage from $|\eta| < 0.6$ to $|\eta| < 1$. For D0 the muon reconstruction is extended to the forward muon detector with a coverage up to $|\eta| = 2.0$.

2. W Mass and Width

A precision measurement of M_W is one of the highest priorities for the Tevatron experiments. M_W measurement combined with precise measurement of the top quark mass (M_{top}), constrains the mass of the Higgs boson. We report on the most recent measurement of M_W by the D0 collaboration [3] in the $W \to e\nu$ decay mode with an integrated luminosity of 1 fb^{-1}. M_W is measured using three transverse kinematic variables: the transverse mass $m_T = \sqrt{2p_T^e p_T^\nu(1-\cos\Delta\phi)}$, the lepton (p_T^e) and neutrino (p_T^ν) transverse momentum distributions, where $\Delta\phi$ is the opening angle between the electron and neutrino momenta in the plane transverse to the beam. A sophisticated parametrized Monte Carlo simulation is used for modeling these variables as a function of M_W. M_W

[1] high transverse energy lepton p_T^l and large transverse missing energy $\not\!\!E_T$ for W or two high transverse energy leptons for Z. By “lepton" in this paper we mean electron or muon.

is extracted from a binned maximum-likelihood fit between the data and simulation. Γ_W is measured with m_T variable using the same analysis framework as M_W. Fig. 1 shows a comparison of the m_T distributions for data and FASTMC. It also shows final M_W result from D0 along with other M_W measurements and combinations D0 result agrees with the world average and the individual measurements and is more precise than any other M_W measurement from a single measurement.
Although M_W and Γ_W measurements are performed with the same method and both rely on m_T distribution, they are mostly sensitive to different features of the latter. M_W is mostly sensitive to the position of the Jacobian peak. Γ_W is mostly sensitive to the tail of the tail. To first order Γ_W is proportional to the fraction of events in the tail. Fit for Γ_W is performed in the high m_T tail region (90-200 GeV). m_T distribution is shown in Fig. 2 shows the This region is sensitive to the Breit-Wigner line-shape and less sensitive to the detector resolution. Measured value is $\Gamma_W = 2.028 \pm 0.039(\text{stat}) \pm 0.061(\text{syst})$ GeV. Table 1 gives the detailed breakdown of the systematic uncertainties for both M_W and Γ_W measurements.

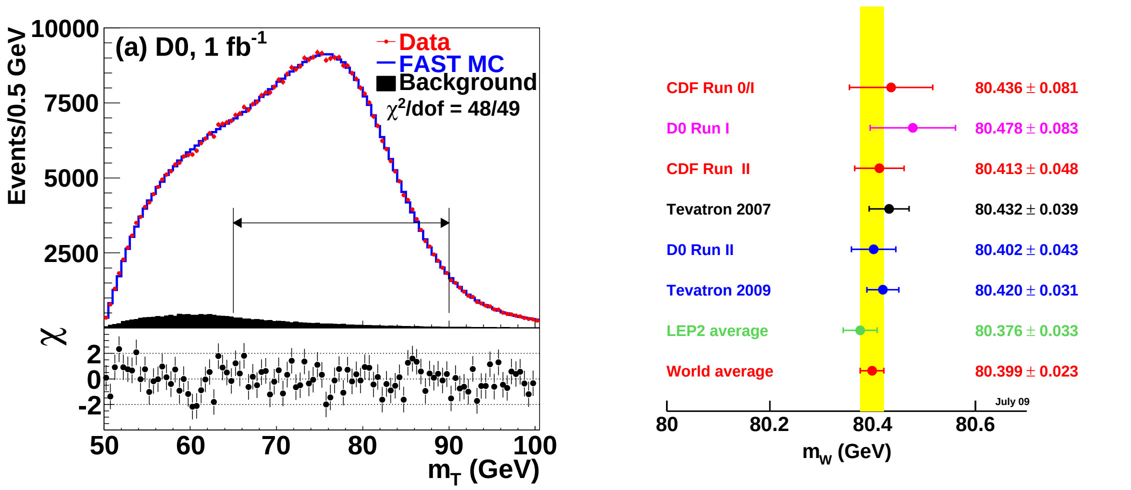

Figure 1: Left: m_T distribution in $W \to e\nu$ data and simulation (FASTMC). Added background is shown as well. Corresponding fit result is $m_W = 80.401 \pm 0.023(\text{stat})$ GeV. Signed χ distribution is shown in the bottom of part of the plot. Signed χ is defined as $\chi_i = [N_i - (\text{FASTMC}_i)]/\sigma_i$ for each point in the distribution, N_i is the data yield in bin i and σ_i is the statistical uncertainty in bin i.
Right: summary of the measurements of the W boson mass and their average. The result from the Tevatron corresponds to the values which includes corrections to the same W boson width and PDFs. The LEP II results are from [8]. An estimate of the world average of the Tevatron and LEP results is made assuming no correlations between the Tevatron and LEP uncertainties.

3. *W* charge asymmetries and *Z* rapidity

As the u quark tends to carry a higher fraction of the proton's momentum than the d quark, the $W^+(W^-)$ is boosted, on average, in the proton(anti-proton) direction. Such asymmetry in the W boson rapidity distribution has traditionally been studied in terms of charged lepton asymmetry, as W boson rapidity cannot be determined on the event-by-event basis, since neutrino escapes the

Source	σ MeV m_T	p_T^e	$\not{E}_T$
Electron energy calibration	34	34	34
Electron resolution model	2	2	3
Electron energy offset	4	6	7
Electron energy loss model	4	4	4
Recoil model	6	12	20
Electron efficiencies	5	6	5
Backgrounds	2	5	4
Experimental Subtotal	35	37	41
PDF	10	11	11
QED	7	7	9
Boson p_T	2	5	2
Production Subtotal	12	14	14
Total	37	40	43

Source	$\Delta\Gamma_W$ (MeV)
Electron energy scale	33
Electron resolution model	10
Recoil model	41
Electron efficiencies	19
Backgrounds	6
PDF	20
Electroweak radiative corrections	7
Boson p_T	1
M_W	5
Total Systematic	61

Table 1: Systematic uncertainties. Left: M_W measurement. Right: Γ_W measurement

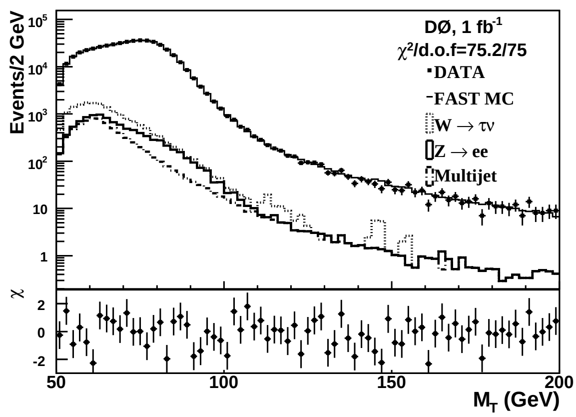

Figure 2: The M_T distributions for data and fast MC simulation with background added (top) and signed χ values for each bin (bottom). Signed χ is defined in the caption of Fig. 1. Fitted Γ_W value is used for the fast MC prediction. The distribution of the fast MC simulation with background added is normalized to the number of data events in the region $50 < M_T < 100$ GeV.

detection. Charged lepton asymmetry, is the convolution of $W^{\pm}$ production and V-A (vector-axial vector) decay asymmetries. D0 muon charge asymmetry distribution is shown on the left of Fig. 3. CDF used a sophisticated method which allows to measure W asymmetry [5] rather than lepton asymmetry. In this method neutrino momentum is determined using W mass constraint, W decay structure, and W production cross-section as a function of rapidity. Measured W charge asymmetry and comparisons with theory are shown on the right of Fig. 3
PDFs can also be constrainted with Z boson rapidity distribution. CDF measured Z boson cross-section as a function of Z boson rapidity [7] with electrons. Fig. 4 shows measured cross-section

and comparisons with theory.

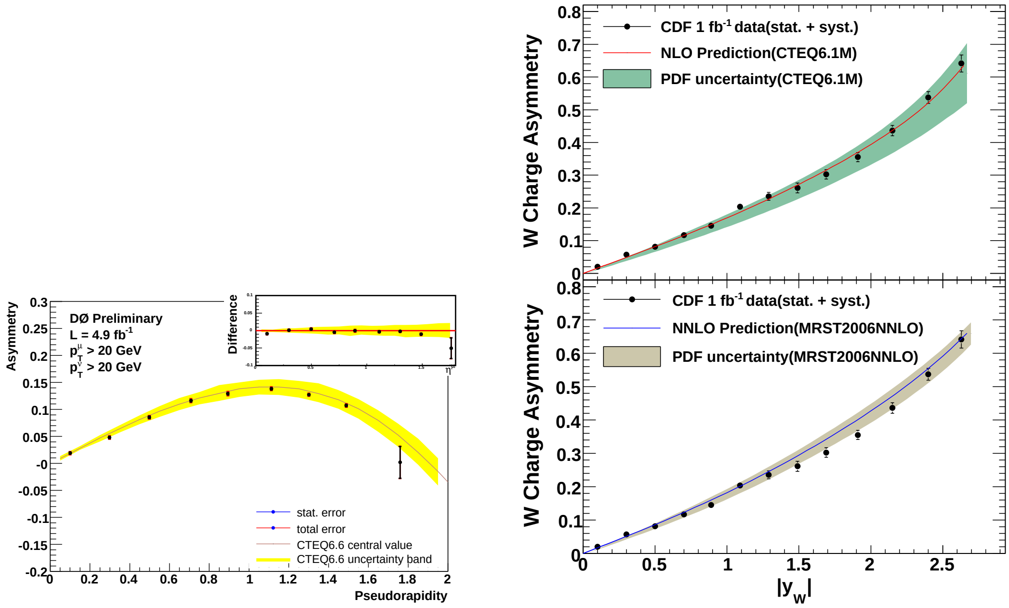

Figure 3: Left: DØ folded muon charge asymmetry distribution. The shaded band is the envelope determined using forty CTEQ6.1M PDF uncertainty sets, the solid (red) line is the CTEQ6.1M central value, and the dotted (blue) line is the charge asymmetry determined using MRST04 NLO PDFs. Right:CDF directly measured asymmetry, A$|y_W|$ with prediction from NLO CTEQ6.1 (top) and NNLO MRST2006 (bottom) with their associated PDF uncertainties

4. Forward-Backward Asymmetry and $W \to \pi\gamma$ rare decay.

Forward-Backward asymmetry in $Z \to ll$ events arises from the presence of both vector and vector-axial couplings between intermeidate bosons and leptons. Therefore A_{FB} can serve as a measure of relative strength between the two types of coupling as well as a very fine probe of new particles that decay into oppositely charged leptons. Events are classified as forward or backward based on the angle between the negatively charged lepton and proton direction, measured in the rest frame of the di-lepton system. CDF measured A_{FB} using electrons. Unfolded distribution and comparison with PYTHIA v6.216 is shown in Fig. 5. Standard Model predicts a number of rare decays of the W boson which remain unobserved. $W \to \pi\gamma$ rare decay produces a clean final state. Theory predicts the ratio of branching fractions of $W \to \pi\gamma$ and $W \to e\nu$ in the range of $10^{-6} - 10^{-8}$. CDF extracted the limit on this ratio from $\pi\gamma$ invariant mass distribution with background estimated using the side band fit. The limit is set at 6.4×10^{-6} at 95% CL. Reconstructed $\pi\gamma$ invariant mass distribution is shown in Fig.5.

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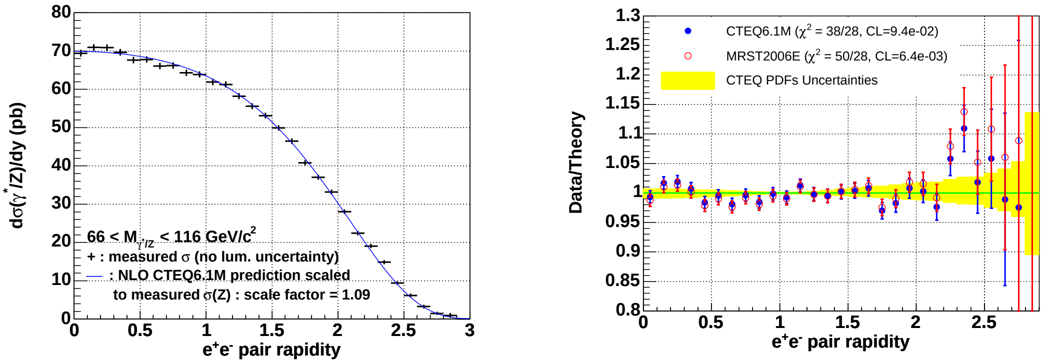

Figure 4: Left: measured $d\sigma/dy$ over the entire rapidity range. The points are the measured cross sections versus dy and the solid line is the theory prediction (scaled to the measured total cross section) for CTEQ6.1M NLO PDFs.The 6% uncertainty in the integrated luminosity is not included in the error bars. Right: the ratio of experimental distribution of $d\sigma/dy$ to the theoretical predictions for CTEQ6.1M(NLO), and MRST2006(NNLO) PDF models. The shaded band corresponds to the PDF's uncertainty obtained from CTEQ6.1M PDFs.

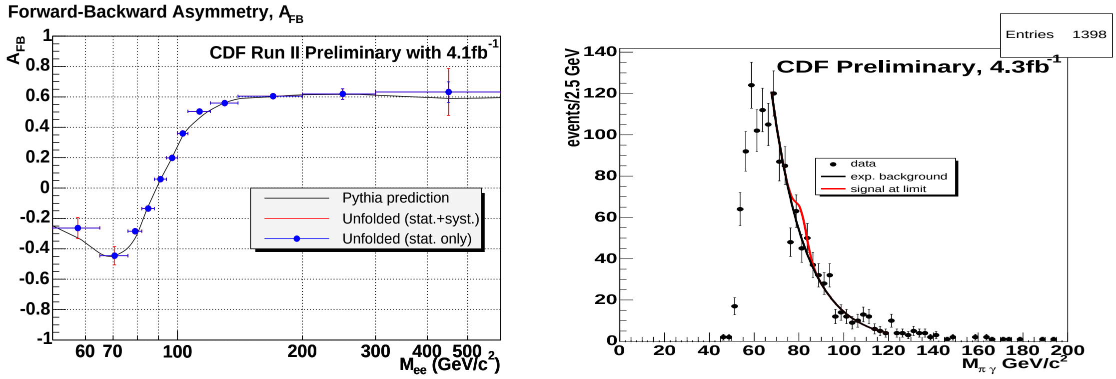

Figure 5: Left: Forward-Backward Asymmetry in $Z \to ee$ events. Unfolded distribution (red and blue) compared with PYTHIA prediction (black). Right: Reconstructed $\pi\gamma$ invariant mass distribution, from which BR($W \to \pi\gamma$)/BR($W \to e\nu$) limit is extracted.

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