PROCEEDINGS OF SCIENCE

W and Z boson production (CDF)

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Precise studies of rapidity distributions and asymmetries in W and Z boson production offer important constraints on the parton distribution functions describing the structure of protons. Improving the knowledge of the parton content of protons can help avoid systematic limitations in measuring the mass of the W boson. Measurements of Z rapidity and of charge asymmetry as a function of W rapidity in CDF Run-II datasets corresponding to the integrated luminosities of 2.1 fb^{-1} and 1fb^{-1}, respectively, are presented.

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1.Introduction

Measurements of W charge asymmetry, Z forward-backward asymmetry and rapidity distributions measured at Tevatron constrain the proton parton distribution functions (PDF) at large-x, an essential input to all calculations of parton-parton processes at present and future hadron colliders (LHC). At present, uncertainties in PDF are limiting from above the systematic errors in W mass measurement, currently to ~11 MeV/c^2 CDF and ~ 20 MeV/c^2 at LHC. The Tevatron measurements complement those from HERA and fixed target neutrino experiments, which provide information on PDF at smaller Q^2 scale range.

1.1. Data

The W asymmetry measurement presented in this paper is based on Run-II data recorded with CDF detector and corresponding to the integrated luminosity of 1 fb^{-1}, while the Z asymmetry result is based on a 2.1 fb^{-1} data sample. The Tevatron, after some initial difficulties in the first few years at the beginning of Run-II (2001-?), is operating now very reliably, and has delivered 6.6 fb^{-1} to CDF and D0 experiments and more than 5 fb^{-1} have been recorded. The already approved running through 2010 will result in an increase of the delivered luminosity to 9 fb^{-1}. If the run is extended through 2012, the delivered luminosity will reach 12 fb^{-1} (10 fb^{-1} recorded), doubling the presently available samples. The CDF detector has been upgraded for Run-II; for both W and Z analyses presented in this paper the most important are the new “plug” calorimeter improving the energy resolution and acceptance to pseudorapidities 1.1<|η|<3.6; and a new, longer, silicon vertex detector allowing a charge measurement up to |η|~3.

1.2. W asymmetry in the rapidity distribution

At Tevatron ($p\underline{p}$) at $\sqrt{s}$=1.96 TeV, the electroweak bosons W^+(W^-) are produced predominantly by the weak interaction of u(d) quarks and $\underline{d}$($\underline{u}$) antiquarks. Since u quarks carry (on average) larger fraction of proton’s momentum than d quarks, W^+ is boosted along the proton direction (W^- is boosted in the antiproton direction). The difference in the respective rapidity distributions gives rise to a charge asymmetry[1]:

$$A_{W^+}(\sqrt{s},y) = A_{W^-}(\sqrt{s},-y) \equiv \frac{\sigma_{W^+}(\sqrt{s},y) - \sigma_{W^+}(\sqrt{s},-y)}{\sigma_{W^+}(\sqrt{s},y) + \sigma_{W^+}(\sqrt{s},-y)}; \qquad y = \frac{1}{2}\ln(\frac{E+p_{\|}}{E-p_{\|}}).$$

$$A_{W^+}(\sqrt{s},y) = A_{W^-}(\sqrt{s},-y) \propto \frac{u(x_1)d(x_2) - u(x_2)d(x_1)}{u(x_1)d(x_2) + u(x_2)d(x_1)}$$

where $x_1 = M_W e^{y} / \sqrt{s}, x_2 = M_W e^{-y} / \sqrt{s}$.

Measuring charge asymmetry constrains the proton parton distribution functions (PDF), in the W boson case it is the ratio *u(x)/d(x)*. In the past, Tevatron experiments measured the charge

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asymmetry of *leptons* resulting from W decays as a function of *pseudorapidity* (η). Such asymmetry is a convolution of the *production* W charge asymmetry and V-A asymmetry from W decays into leptons. The two tend to cancel at large $|\eta|\sim 2$, and the convolution complicates and weakens the constraint on proton PDF, as it is making the *lepton* asymmetry much smaller in magnitude than the *production* W charge asymmetry $A_{W^+}(\sqrt{s},y)$. A new CDF analysis presented in this paper measures *directly* $A_{W^+}(\sqrt{s},y)$. Experimentally, one cannot measure $p^W{}_{\parallel} = p^{lepton}{}_{\parallel} + p^{\nu}{}_{\parallel}$ needed to calculate the W rapidity, as the neutrino from W decay escapes undetected, and its momentum is unknown. However, the measured missing transverse energy provides information about the neutrino transverse momentum, and one can use the (W) mass constraint to find $p^{\nu}{}_{\parallel}$. The quadratic equation $M_W{}^2 = (E^{lepton} + E^{\nu})^2 - (\vec{p}^{\,lepton} + \vec{p}^{\,\nu})^2$ yields two solutions $p^{\nu}{}_{\parallel,1}, p^{\nu}{}_{\parallel,2}$. The ambiguity can be resolved on *a statistical basis,* using a weighting factor

$$w^{\pm}_{1,2} = \frac{P_{\pm}(\cos\Theta^*_{1,2}, y_{1,2}, p_T^W)\sigma(y_{1,2})}{P_{\pm}(\cos\Theta^*_1, y_1, p_T^W)\sigma(y_1) + P_{\pm}(\cos\Theta^*_2, y_2, p_T^W)\sigma(y_2)}$$

where $\pm$ is W charge, and indices 1,2 indicate the two W rapidity solutions; the factors $P_{\pm}(\cos\Theta^*_{1,2}, y_{1,2}, p_T^W)\sigma(y_{1,2}) = (1 \mp \cos\Theta^*)^2 + Q(y_W, p_T^W)(1 \pm \cos\Theta^*)^2$ are evaluated using the differential cross sections from a NNLO QCD calculation[2]; and the ratio of the two terms, Q, was determined from MC@NLO. All those factors have a very weak dependence on the assumed asymmetry, we obtain the final result by iteration, reaching convergence after just a few steps[3].

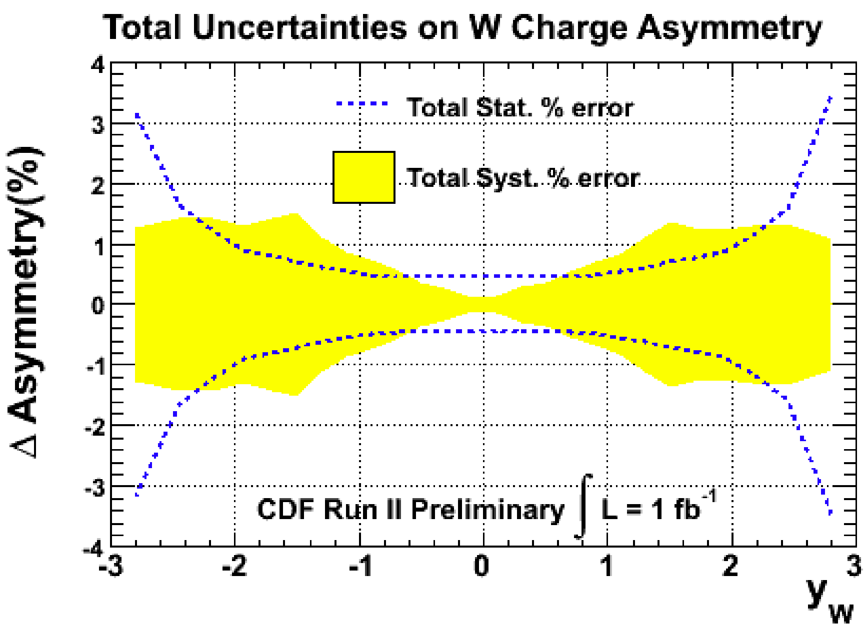

Figure 1. Total total systematic (yellow) compared to total statistical (blue) uncertainties (in %).

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Following the standard CDF W selection cuts, 538k events in central calorimeter and 177k events in forward (plug) calorimeter were selected. The main backgrounds are QCD (1.2±0.2% in central and 0.7±0.2% in plug) and $Z \rightarrow e^+e^-$ (0.59±0.02% in central and 0.54±0.03% in plug). $W \rightarrow \tau\nu \rightarrow e\nu$ events are not considered background, and are included in the signal acceptance for the W charge asymmetry analysis. The total uncertainties in the W asymmetry measurement are presented in Figure 1. The results for the *directly* measured W charge asymmetry are shown below in Figure 2. The plots for W^+ and W^- agree very well, and they were folded onto a single plot and compared with NLO and NNLO calculations, the latter being in a better agreement with the data.

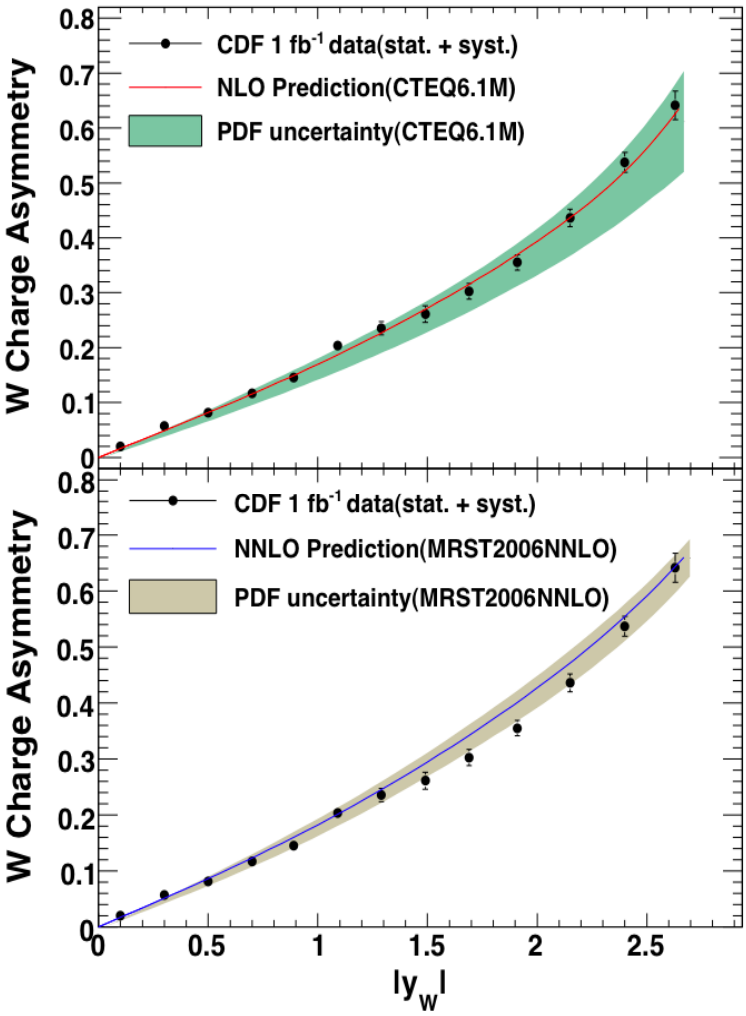

Figure 2. The measured W production charge asymmetry (points with errror bars) and predictions from (a) NLO CTEQ6.1 with the associated PDFs uncertainty and (b) NNLO MRTST2006 and its associated PDFs uncertainty.

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1.3. Z rapidity distribution

Drell-Yan production of e^+e^- pairs provides another set of constraints on the proton PDF. In events in which a dilepton pair is produced at large rapidity, y, one parton carries a large and the other a small proton momentum fraction, x. In LO, the momentum fractions, x_1, x_2, are related to rapidity through $x_1, x_2 = (M/\sqrt{s})e^{\pm y}$. A new CDF measurement is based on 2.1 fb^{-1} dataset and extends the measured rapidity range to |y|<2.9, very close to the kinematical limit of |y|=3. Events were divided into three topologies, CC-with both leptons in the central calorimeter (|y|<1.1); CP-one lepton in central and the other in plug (|y|<3.6); and PP-both leptons in plug. There were 51k, 86k and 31k events in CC, CP and PP categories, with background fractions of 0.24±0.03%,1.55±0.44% and 3.40±0.75%, respectively. Events in the Z mass window defined as 66 GeV/c^2 $< M(e^+e^-) <$ 116 GeV/c^2 were accepted. Backgrounds are small, primarily from the electroweak WW, WZ, W and Z, and QCD inclusive top production, and are estimated from simulations to be at the level of 0.41±0.02%. After the acceptance corrections and background subtraction, the total cross section for |y|<2.9 is measured to be 256.0±0.7(stat)±2.0(syst) pb (6% luminosity error is not included). The final plots showing Z rapidity, together with the background estimates, and the folded rapidity distribution with NLO and NNLO calculations are shown below in Figures 3 and 4, respectively. Neither calculation gives a very good fit, indicating the need for more tuning. However, the new CDF result (and D0) results have already allowed a better (more robust and flexible) parametrization of the proton valence d-quark PDF, MSTW 2008[4].

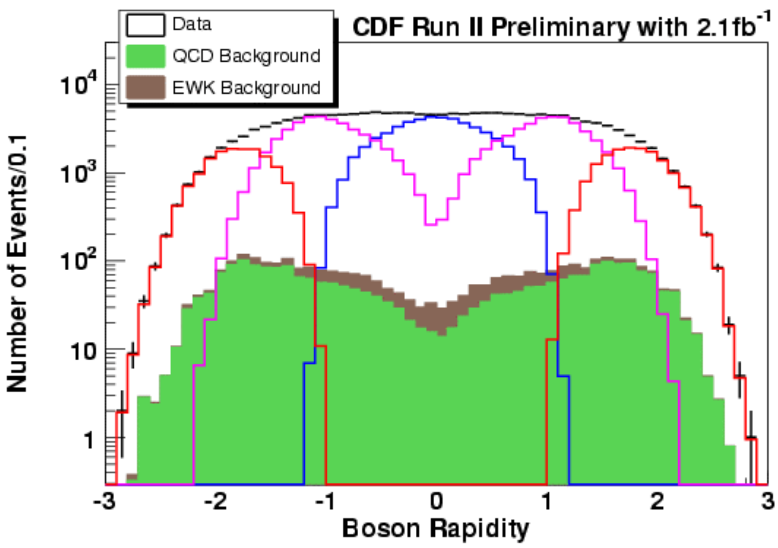

Figure 3. The dielectron rapidity distribution of the data and the backgrounds. Green histogram is the QCD background and the brown histogram is from the electroweak processes. Black line shows the distribution from all data events combined.

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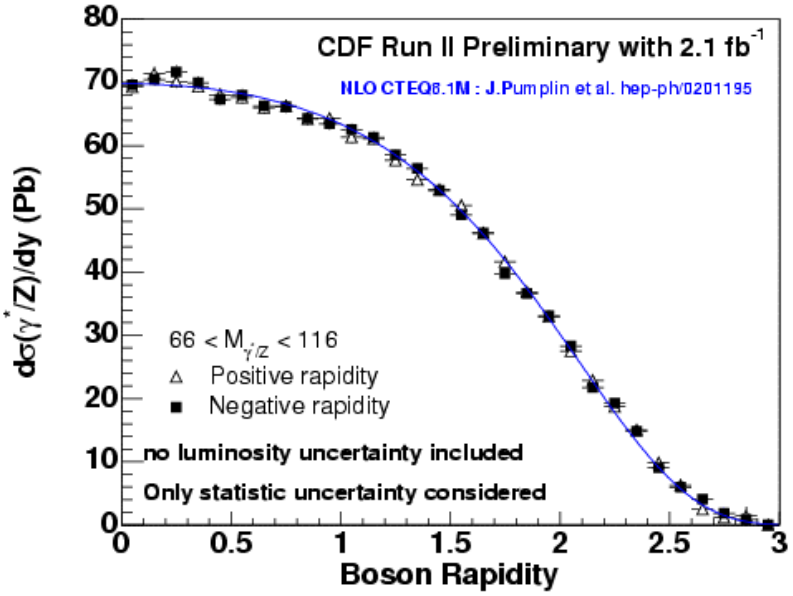

Figure 4. The measured $d\sigma / dy$ for $p\bar{p} \to Z^0 / \gamma^* \to e^+e^-$ in the negative and positive rapidity. Negative rapidity directions are folded onto positive rapidity directions. Only statistical uncertainties are considered and shown in this plot.

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