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Measurement of the $\sigma(p\bar{p} \to W) \times BF(W \to e\nu)$ in the forward region

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Abstract

In this note we update the $\sigma(p\bar{p} \to W) \times BF(W \to e\nu)$ measurement described in [1], [2] and [3]. In particular, we use here the same acceptance definition (using NNLO calculation) as in the central analysis (described in [4]). Using combined calorimetric and tracking information, we measure a cross section of 2.796 $\pm$0.013(stat)$^{+0.095}_{-0.090}$(syst) $\pm$ 0.168 (lum.) nb. The result is in agreement with previous CDF measurements in the central region and with theoretical estimates. We also measure the ratio of the central–to–forward cross section in the electron channel to be: R_{exp} = 0.925 $\pm$ 0.033.

Contents

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1 Introduction

We present an update of the measurement of the W($\rightarrow e\nu$) cross section in the plug region, using combined calorimetric and tracking information.

In this note we describe the cross section measurement performed using the plug electron dataset collected between March 2002 and February 2004, equivalent to about 223 pb^{-1} and reconstructed with version 5.3.3 of the offline (“`gen5`”).

With respect to the result blessed on feb. 9, 2006 and documented in [1], [2] and [3] here we describe the following changes:

1) We make the selection without “prefiltering” the data sample. In this way it is straitforward to quantify the fraction of events passing each step of the analysis (see table 1). Changes in the final selection are minimal (0.1 pb^{-1}, 0.04%).

2) The procedure to obtain the electroweak background coming from $Z \rightarrow ee$ events has been corrected to account for the difference between γ^*/Z and pure Z processes.

3) The acceptance calculation is now based on the NNLO calculation (instead of the NLO as at the time of blessing).

4) We add an additional contribution to systematics to take into account higher order corrections.

5) We add the measurement of the central to forward ratio of cross sections.

2 Signal Selection

2.1 Data Sample

The data set we use corresponds to runs between 149264 and 179056 taken from March 2002 until February 2004. Only good runs (according to V7 of good-run list electron + silicon 1101) are selected. The data set corresponds to about 223 pb^{-1}, after applying the correcting factor 1.019. We apply a number of selection criteria to strip events out of production dataset "`bpel0d`" (*PLUG_ELECTRON* stream reconstructed with Offline version 5.3.3_*nt*). For the measurement itself we use events collected by trigger path *MET_PEM*.

2.2 Data Reduction

Details of the selection criteria can be found in [3]. We select our candidate events by applying the following requirements:

- *MET_PEM* trigger fired;
- at least one EM cluster belongs to PLUG with 1.2< $|\eta|$ <2.8;
- at least one calorimetric EM cluster with $E_T > 20$ GeV;
- EM cluster must have Had/Em < 0.05;
- EM cluster must be isolated: IsoRel< 0.1;
- Missing Transverse Energy $MET > 25$ GeV;
- at least one 3D track pointing to the EM cluster within a cone radius of ΔR <0.4, with ΔX, ΔY (PES measured coordinate – extrapolated track) < 3 cm in the X and Y coordinates;
- z_0 coordinate of the track matched to the EM cluster to be: $|Trkz_0| < 60$ cm;
- $E/p < 2$.

48165 candidate events pass these cuts. 24601 events are found in the EAST plug, 23564 in the WEST.

Table 1 summarizes the number of events passing each cut. In the EAST and WEST columns events are counted if they have at least one electromagnetic cluster passing the cut (for this reason the sum of EAST and WEST can be higher than the first column number).

requirement	N.of events	East	West
Trigger MET_PEM	5397878	N/A	N/A
At least one Em object	5396073		
plug region and 1.2$<|\eta|<2.8$	4696573	2448522	2646046
$E_T > 20$ GeV	4382731	2116848	2323101
Had/Em< 0.05	2722848	1300569	1431380
Isorel< 0.1,	1155431	554894	601077
$MET > 25$ GeV	245644	123659	122036
Matching track	74121	37841	36282
$|Trkz_0| < 60$ cm	71890	36811	35081
$E/p < 2$	48165	24601	23564

Table 1: *Events of the data sample passing the various cuts. Some events can appear on both the East and West columns.*

3 Summary of efficiencies

3.1 Electron candidate selection efficiencies

Efficiencies for the Had/Em and relative isolation Isorel (ID efficiency), track matching ($\varepsilon_{track}(Z_{data})$) and E/p requirements are evaluated using the plug leg of $Z \to ee$ CP events [3] ("`zewk0d`" data set). Tracking efficiency is corrected to take into account the difference in W and Z kinematics [3]. Table 2 summarizes these efficiencies. The systematic uncertainty is dominated by the background subtraction procedure from the $Z \to ee$ sample.

3.2 Trigger Efficiency

The efficiency of the MET_PEM trigger path was studied using backup triggers. The combined $L1\_MET15$ and $L3\_MET15$ trigger efficiency was evaluated using the $PLUG\_ELECTRON20$ trigger path. The $L2\_PEM20$ and $L3\_PEM20$ efficiencies are measured

	Selection efficiencies
ε_{ID}	0.955 ± 0.002 (stat) ± 0.019 (syst)
$\varepsilon_{track}(W_{data})$	0.462 ± 0.005 (stat) ± 0.0014 (syst)
$\varepsilon_{E/p}$	0.713 ± 0.007 (stat) ± 0.0004 (syst)

Table 2: *Selection efficiencies.*

using the $Z \to ee$ CP candidates (collected by selecting the central electron, thus a completely independent trigger). Trigger efficiencies have been corrected to take into account the differences in W and Z E_T spectra [3]. Trigger efficiencies at the various levels are:

$$\varepsilon_{L1L3\_MET15} = 0.9990 \pm 0.00046$$

$$\varepsilon_{L2\_PEM20} = 0.9642 \pm 0.0003(stat.) \pm 0.0031(syst.)$$

$$\varepsilon_{L3\_PEM20} = 0.9977 \pm 0.00008(stat.)^{+0.0014}_{-0.0028}(syst.)$$

The overall trigger efficiency is the product of:

$$\varepsilon_{Tot} = \varepsilon_{L1\_MET15\&L3\_MET15} \times \varepsilon_{L2\_PEM20} \times \varepsilon_{L3\_PEM20|L2\_PEM20}$$

and it is $\varepsilon_{Tot} = 0.9610 \pm 0.0006(stat)^{+0.0034}_{-0.0041}(syst)$.

4 Background Summary

Background is made of two different contributions: the QCD (non W) background, and the background due to EWK processes.

QCD background is computed studying the MET vs IsoRel plot. A 50% systematic uncertainty is assigned to this prediction.

Background contributions from the $W \to \tau\nu$ and $Z \to ee$ events are estimated using Montecarlo "`wewk9t`" sample for $W \to \tau\nu$ and "`zewk6d`" sample for $Z \to ee$ [3].

The MC used to determine the acceptance for $Z \to ee$ events is a γ^*/Z MC. The theoretical value for R used to evaluate the relative production rates of W and Z events is defined for pure Z exchange ($R = 10.67 \pm 0.15$).

Therefore, we re-defined the denominator of the acceptance calculation taking events in the MC sample with 66 GeV/c^2 $< M_{ll} <$ 116 GeV/c^2, and we applied a theoretical correction of 1.004 [4].

Table 3 summarizes the number of events identified in the various regions of the Met vs Isorel plane:

- region A: MET <10 GeV, IsoRel < 0.1;
- region B: MET <10 GeV, IsoRel > 0.2;
- region C: MET >25 GeV, IsoRel > 0.2;
- region D: MET >25 GeV, IsoRel < 0.1 (signa region).

Sample	A	B	C	D	Generated events
Data	103721	69091	881	48165	N.A.
$W \to e\nu$	1780	0	1549	287793	3824210
$Z \to ee$	140220	550	38	7822	983343
$W \to \tau\nu$	620	10	248	9830	5593800

Table 3: *Samples used to calculate the QCD background using the MET-Iso method.*

Table 4 summarizes the background contributions to the signal region. The errors in table are statistical only.

Source of background	Expected Background events
raw QCD (non–W) background	1323 ± 62
corrected QCD (non–W) background	846 ± 57
$W \to \tau\nu$	1070 ± 12
$Z \to ee$	417 ± 5

Table 4: *Summary of expected background contamination.*

As a cross–check, the QCD background contribution has been evaluated also using the fake rate method [3]. The result is: 1200 ± 360 events (the error is given by the 30% uncertainty on the fake rate) and is consistent with the MET vs Isorel result.

5 Kinematical and Geometrical Acceptances

To estimate the kinematical and geometrical acceptance we used a sample of $W \to e\nu$ events generated with Pythia version 6.216 and reconstructed using 5.3.3 (sample "`wewkfe`").

In figure 1 we show the acceptance $A(y)$ distribution obtained from Pythia after full detector simulation, where y is the W rapidity from Montecarlo parton–level information. The central geometrical acceptance value is obtained embedding the $A(y)$ distribution into either the NLO or the NNLO calculation of $d\sigma/dy$.

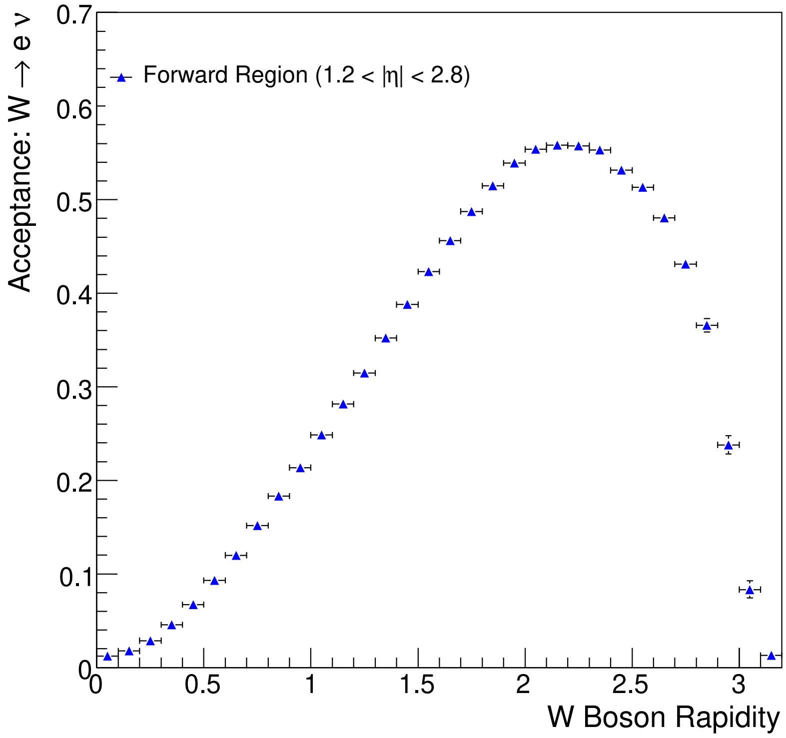

Figure 1: *Acceptance obtained from Pythia + full detector simulation as a function of "hepg" W boson rapidity.*

For the blessed cross section result we evaluated the acceptance from the NLO calculation of $d\sigma/dy$ using J. Stirling code and MRST01E PDF. The result was [2].:

$$A = \frac{\int \frac{\mathrm{d}\sigma}{\mathrm{dy}} A(y)\mathrm{dy}}{\int \frac{\mathrm{d}\sigma}{\mathrm{dy}}\mathrm{dy}} = 0.2555 \pm 0.0002(stat.).$$

Using L. Dixon et al. code and computing the NLO $d\sigma/dy$ we obtain:

$$A = 0.2558 \pm 0.0002(stat.).$$

Using instead a NNLO calculation of $d\sigma/dy$ based on MRST 2001 NNLL PDF set we obtain:

$$A = 0.2567 \pm 0.0002(stat.).$$

Changing the renormalization scales used in NNLO calculation of $d\sigma/dy$ by a factor of two in both directions we observe a very small effect on the central acceptance value (less than 0.1%):

$$NNLO(\mu R/Q = \mu F/Q = 0.5) \rightarrow A = 0.25655 \pm 0.00021$$

$$NNLO(\mu R/Q = \mu F/Q = 2.0) \rightarrow A = 0.25670 \pm 0.00021$$

The differences in the central acceptance values obtained from NNLO and NLO calculation with MRST NLL PDF set were also very small (less than 0.1 %).

We checked differences in the central acceptance values obtained from a NLO calculation using both the default MRST01E and CTEQ6.1 PDF sets. We obtain:

$$CTEQ6.1(NLO) \rightarrow A = 0.2580 \pm 0.0002$$

$$MRST01E(NLO) \rightarrow A = 0.2555 \pm 0.0002.$$

The difference between the central value in NLO and NNLO calculation is taken as an estimate of the effect of higher order corrections. Therefore we add a contribution of $\Delta A/A = 0.47\%$ as an additional systematics.

6 Systematic uncertainty on acceptance

To estimate the systematic uncertainty on the kinematical and geometrical acceptances we used Montecarlo samples.

The performance of data modeling was studied and followed by an additional post simulation tuning, with aim to improve agreement between data and MC. Scaling and smearing factors, applied to Montecarlo energy, were obtained comparing $Z \rightarrow ee$ CP data (“`zewk0d`” data set) and MC (“`zewk6d`”) [3]. Recoil energy, obtained as total transverse energy measured in calorimeter after removing energy deposited by charged lepton from W decay was tuned as well. The recoil energy affects measured MET.

We calculated the systematic uncertainty on acceptance due to the following effects:

- Energy Scale and Resolution;
- P_T of W;
- Extra Material;
- Recoil Energy Modeling;

- PDF Uncertainty;
- NLO-NNLO difference (higher order corrections);
- PVZ difference in data and MC.

6.1 Energy Scale and Resolution

The scaling applied to Montecarlo energy to get the best agreement with data is: –1.9 ± 0.2 % (East plug) and –1.6 ± 0.2 % (West plug). The smearing factors are: +2.4 ± 0.4 % for both east and west [3].

Therefore the uncertainty due to the electron E_T cut was evaluated by varying the plug EM energy scale and energy resolution by $\pm\ 1\sigma$ ($\pm\ 3\sigma$) for the scaling and smearing effects separately. Effects on the acceptance are shown in Table 5.

Systematics	$(\lvert\Delta A\rvert)/A\ 3\sigma(\%)$	$(\lvert\Delta A\rvert)/A\ 1\sigma(\%)$
Scale +	0.656	0.219
Scale –	0.637	0.232
Smear +	0.085	0.018
Smear –	0.106	0.043

Table 5: *Effect on the acceptance of $\pm 3\sigma$ and $\pm 1\sigma$ change in Monte Carlo energy scale and smear. Last row indicates the $(\Delta A)/A$ when smearing is set to 0.*

The largest difference between the $\pm 1\sigma$ acceptances and the mean value was taken as systematic uncertainty. Its value is ΔA/A (%) = 0.232 for scale and ΔA/A (%) = 0.043 for resolution.

6.2 P_T of W

In order to study how our understanding of the shape of the W boson p_T affects our acceptance calculation we use four parameters (PARP(62),(64),(91) and (93)) of Pythia MC.

The largest variation in acceptance for each of $\pm 3\sigma$ is taken as systematic contribution from each one of the three parameters (PARP(93) gives negligible effect). Total uncertainty for P_T modeling is obtained by adding in quadrature all variations, see table 6.

Parameter	(Δ A)/A (%)
PARP(62)	0.0067
PARP(64)	0.0275
PARP(91)	0.0124
PARP(93)	-
Total	0.03090

Table 6: *The uncertainty in $W \to e\nu$ acceptance for tuned Pythia p_T W parameters. The largest variation from $\pm 3\sigma$ is considered as contribution for given parameter.*

6.3 Extra Material

The systematic uncertainty on the acceptance due to our knowledge of the detector material description was calculated by using 2 special MC samples obtained putting $\pm$ 1/3 X_0 of material (copper) in front of the plug calorimeters [2].

We evaluated scaling and smearing parameters for each of the $\pm 1/3X_0$ samples using the same procedure that was used for the default MC sample.

After applying the appropriate scaling and smearing for each given sample, we calculate new values of acceptance. The largest difference in acceptance is taken as the corresponding contribution to acceptance systematics. The results of extra material studies are summarized in table 7.

Description	(Δ A)/A (%)
+ 1/3% of X_0 Cu	+0.032
- 1/3% of X_0 Cu	–0.713
Contribution to acceptance	0.713

Table 7: *Change in acceptance for extra material.*

6.4 Recoil Energy Modeling

In order to check the Montecarlo model for calorimeter energy deposition (which plays an important role in determining MET) we study the energy recoiling against the W ($\vec{U} = -\vec{MET} - \vec{E}_T^e$) [2]. $\vec{U}$ is studied using the two components: parallel $U_{||}$ and perpendicular $U_{\perp}$ to the charged lepton direction in the transverse plane of the detector.

The corrections to apply to the Montecarlo recoil energy model are an overall scale correction ("scale correction") and an additional constant term ("shift correction"), applied separately for both the parallel and perpendicular directions [2].

$$U_{\parallel} = scale_{\parallel} \times (U_{\parallel} + shift_{\parallel})$$

$$U_{\perp} = scale_{\perp} \times (U_{\perp} + shift_{\perp})$$

In order to determine the best values for the scale and shift correction factors a χ^2 fit is performed between the data recoil energy and the Montecarlo distributions, for a range of scaling and shifting constants. An iterative process is used, until the χ^2 fits for both the scale and shift constants stabilize [2].

The effect of a possible mis–modeling of $\vec{U}$ on the acceptance calculation was estimated by taking the $\pm 3\sigma$ (or $\pm 1\sigma$) variation, where σ was computed from the χ^2 fits. The summary of the $\vec{U}$ variables and acceptance changes are in table 8.

We took the quadratic sum of the largest changes in acceptance as systematic uncertainty.

Parameter	Scale $U_{\parallel}$	Shift $U_{\parallel}$	Scale $U_{\perp}$	Shift $U_{\perp}$
$\lvert\Delta A\rvert/A_{-3\sigma}(\%)$	0.210	0.248	0.098	0.0000
$\lvert\Delta A\rvert/A_{+3\sigma}(\%)$	0.227	0.238	0.096	0.0027
Total $\pm 3\sigma$	0.350			
$\lvert\Delta A\rvert/A_{-1\sigma}(\%)$	0.073	0.084	0.033	0.0012
$\lvert\Delta A\rvert/A_{+1\sigma}(\%)$	0.073	0.084	0.031	0.0019
Total $\pm 1\sigma$	0.116			

Table 8: *Results of χ^2 fits in study of recoil energy effect on the acceptance.*

6.5 PDF Uncertainty

Momentum distributions of quarks and gluons inside the proton are inputs of the MC samples used to evaluate the acceptance. The uncertainties in these distributions contribute to the overall uncertainty on the acceptance value. The effect of the choice of Parton Distribution Functions (PDF's) in the MC was studied by using CTEQ6 PDF, which is described by 20 parameters. The default values for these parameters are determined by minimizing the χ^2 of a global fit to experimental data.

The acceptance was calculated changing by $\pm 90\% CL$ (equivalent to $\pm 1.6\sigma$) each parameter:

$$A_i = \frac{\int \frac{\mathrm{d}\sigma_i}{\mathrm{d}y} A(y) \mathrm{d}y}{\int \frac{\mathrm{d}\sigma}{\mathrm{d}y} \mathrm{d}y}$$

where $\mathrm{d}\sigma_i/\mathrm{d}y$ was calculated at NLO with the CTEQ6 PDF error set.

In the following we call A_i^{up} (A_i^{down}) the acceptance obtained for a shift of the i-th eigenvector value equivalent to +1.6 (–1.6) σ. Then we define:

$$\Delta A_i^{up} = A_i^{up} - A_0$$

$$\Delta A_i^{down} = A_i^{down} - A_0.$$

where A_0 is the acceptance obtained with the default eigenvalues.

Using the same prescription to combine the 40 error set results as in the W/Z “PRD” [4], we get: $\Delta A_{max}^{up} = 1.70\%$ and $\Delta A_{max}^{down} = -1.29\%$.

If we use the ”CTEQ” prescription as by the Joint Physics meeting of 5-5-2006 (talk by Joey Huston), we obtain $\Delta A_{max}^{up} = 1.78\%$ and $\Delta A_{max}^{down} = -1.34\%$.

6.6 PVZ study

Events with no PVZ pass our selection criteria both in data and MC. The fraction of events with no PVZ is 1.54% in data and 0.71% in MC events. Since the relative number is different in data and MC, this could potentially bias our acceptance calculation. In order to take into account this effect, we take randomly the same fraction as in data of MC events without PVZ, and for those events we use raw variables (i.e. reconstructed with respect to the detector center). The effect on the acceptance is: $\Delta A/A$ = 0.049%. This additional uncertainty is added to the acceptance systematic effects.

6.7 Summary of uncertainties on the acceptance

The overall uncertainty on the acceptance is summarized in table 9. As a contribution to acceptance uncertainty we take 1σ for for energy scale and resolution and 3σ for the recoil uncertainty. The total relative contribution is: $+1.95, -1.60\%$.

Source	Syst. uncertainty (%)
plug E_T^e scale	0.232
E_T^e resolution	0.043
P_T^W	0.031
$\vec{U}$	0.350
Material	0.713
PDF's	+1.70 -1.29
NLO-NNLO diff	0.47
PVZ study	0.049
Total	+1.95 -1.60

Table 9: *Systematic uncertainty on the acceptance. For E_T^e scale and resolution we are taking $\pm 1\sigma$ uncertainty. For $\vec{U}$ we are taking $\pm 3\sigma$ uncertainty. The PDF contribution has been evaluated using the NLO calculation of $d\sigma/dy$ and CTEQ "error" set.*

7 Results

7.1 Cross Section Calculation

Various efficiencies relevant to this measurement are summarized in table 10, while table 11 is a summary of what is used for the cross section measurement. In order to correct the luminosity for the finite (±60 cm) length of the interaction region, we use the correction factor ($\varepsilon_{Lum} = 0.948 \pm 0.001(\text{stat}) \pm 0.005(\text{syst})$ obtained from [6]).

	Value		Syst.error
ε_{Kin}	0.2567 ± 0.0002		${}^{+0.0050}_{-0.0041}$
ε_{ID}	0.955 ± 0.002		0.019
ε_{trig}	0.9610 ± 0.00055		${}^{+0.0034}_{-0.0041}$
$\varepsilon_{E/p}$	0.713 ± 0.007		0.0004
$\varepsilon_{tracking}$	0.462 ± 0.005		0.0014
ε_{Lum}	0.948 ± 0.001		0.005
Overall ε	0.0735 ± 0.0011		${}^{+0.0021}_{-0.0019}$

Table 10: *Summary of Efficiencies.*

N.candidate events	48165	
N.background QCD events	846 ± 57 (stat)	± 423 (sys)
N.background Z events	417 ± 5 (stat)	
N.background $W \to \tau\nu$ events	1070 ± 12 (stat)	
Lumin.(pb^{-1})	223	± 13 (sys)
ε	0.0735 ± 0.0011 (stat)	${}^{+0.0021}_{-0.0019}$ (sys)

Table 11: *Quantities used for cross section measurement.*

The value of the cross section is: $\sigma \times BR(W \to e\nu) = 2796 \pm 13(stat)^{+95}_{-90}(sys) \pm 168(lum)$ pb, consistent with previous CDF results and with theoretical prediction.

7.2 Central to forward ratio

We evaluate the central to forward ratio of cross sections. We define: $\sigma(\text{visible}) = \sigma \times A$ where A is the kinematical and geometrical acceptance (i.e. in the forward region this is equivalent to say that we measure the cross section for E_T(ele) > 20 GeV, E_T(neutrino) > 25 GeV, $1.2 < |\eta| < 2.8$). We follow the strategy to assign all systematic uncertainties (but PDF and NLO/NNLO effect) to σ(visible). In this way most of the luminosity uncertainty cancels out in the ratio (we conservatively estimate a residual 1% systematic due to the measurement of luminosity) and the measurement accuracy can be used to constrain PDF's. All other uncertainties are uncorrelated.

The central cross section value in the electron channel, based on 72 pb^{-1} of data [4, 5] is: σ(central) = 2771 $\pm$ 49 pb. The corresponding σ(visible, central) = (2771 $\pm$ 49) $\times$ (0.2397) pb = 664.2 $\pm$ 11.7 (i.e. σ for a reconstructed E_T(electron) > 25 GeV, E_T(neutrino) > 25 GeV $|\eta| < 1$) and σ(visible, forward) = 718 $\pm$ 21 pb. In table 12 we summarize the NLO and NNLO acceptances for the central and forward analysis. The uncertainties quoted here only take into account PDF and NLO/NNLO contributions.

	central	forward
NNLO	$0.2397^{+0.0035}_{-0.0042}$	$0.2567^{+0.0050}_{-0.0041}$
NLO MRST01E	$0.2405^{+0.0011}_{-0.0014}$	$0.2555^{+0.0017}_{-0.0014}$
NLO CTEQ	$0.2385^{+0.0028}_{-0.0036}$	$0.2580^{+0.0044}_{-0.0033}$

Table 12: NNO and NNLO acceptances for central and forward regions

The experimental ratio is: $R_{exp} = \sigma_{(visible,central)} \,/\, \sigma_{(visible,forward)} = 0.925 \pm 0.033$. This number can be compared to the NLO ratio of acceptances $A_{(central)} \,/\, A_{(forward)}$ (CTEQ) = $0.9243^{+0.023}_{-0.030}$(PDF) $\pm$ 0.0043 (NLO-NNLO) and $A_{(central)} \,/\, A_{(forward)}$ (MRST01E) = $0.9414^{+0.010}_{-0.012}$(PDF) $\pm$ 0.0044 (NLO-NNLO). Those ratios were computed by varying one by one the ratio of acceptances for each PDF eigenvalue (40+1 for CTEQ and 30+1 for MRST). For consistency with previous measurements we used the W/Z PRD prescription [4] to compute the contribution due to the PDF. In fig. 2 we show the variation of the ratio with respect to the central value for the two PDF sets and with the result of this measurement.

8 Conclusion

We present a measurement of the cross section times branching fraction for $W \to e\nu$ in CDF, where the electron is identified in the plug region by combining calorimetric and tracking information. Tracking and calorimeter information were treated separately as in the central region. A cross section of $2796 \pm 13(stat)^{+95}_{-90}(sys) \pm 168(lum)$ pb is measured using 223 pb^{-1}, consistent with other Run II CDF results. Combining this measurement with the previous result obtained in the central region, we measure the ratio of central to forward cross sections: R_{exp} =

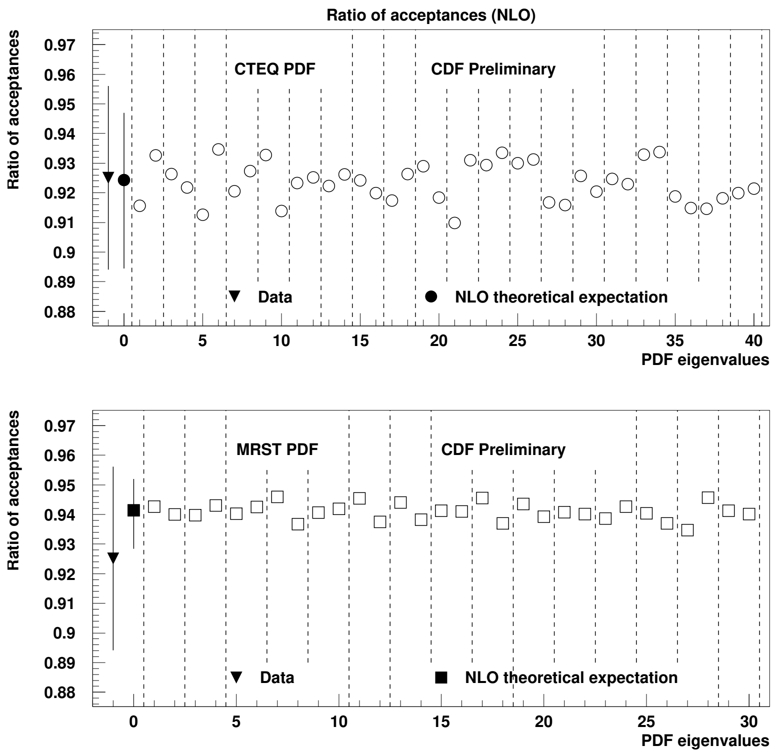

Figure 2: *Variation of the ratio as a function of the eigenvalue of the PDF set.*

$\sigma_{(visible,central)}$ / $\sigma_{(visible,forward)}$ = 0.925 ± 0.033.

Acknowledgements

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