# W and Z production : Asymmetry, Z(Pt), W+charm from Tevatron

XLIIIrd Rencontres de Moriond
Electroweak Session - La Thuile, March 01-08, 2008

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# ElectroWeak Physics at Tevatron

*Liang Han: next talk*

## *Diboson Production*

*WW/WZ/ZZ/Wγ/Zγ...*

***Prove gauge boson self-interaction***
***Sensitive to new physics***
***Background to Higgs, top, SUSY***

## *W Mass and Width*

*W Mass :*
***Constraint on Higgs mass***

*W Width :*
***Useful test of SM***

*Jiyeon Han: this talk*

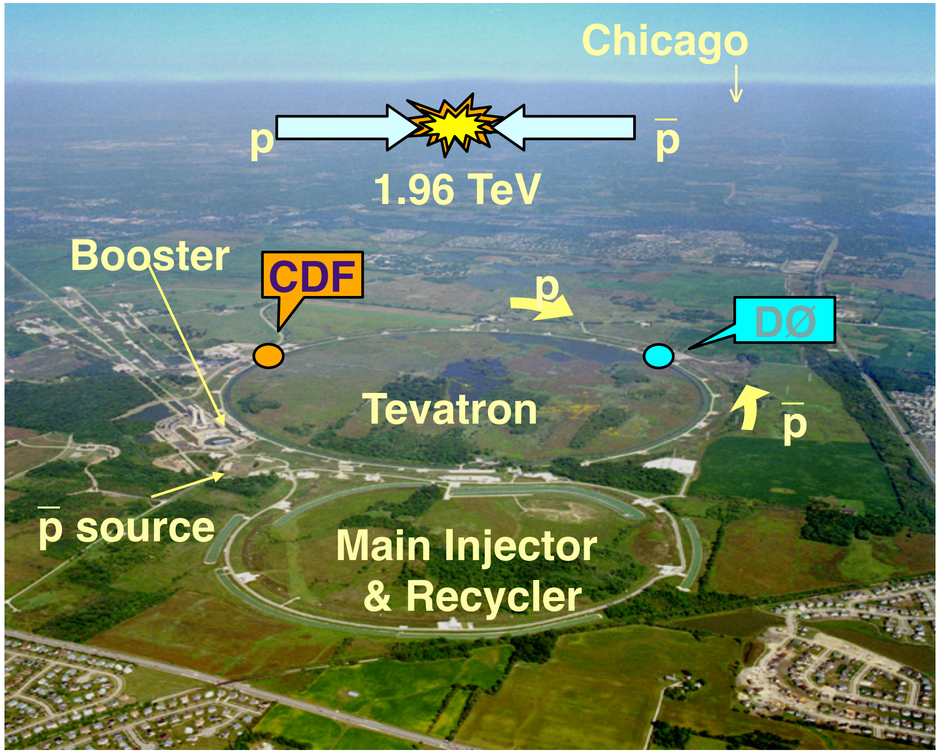
***W/Z differential cross section*** *:*
$d\sigma/dy$, $d\sigma/dp_T$ (Z)
***W/Z boson asymmetry***

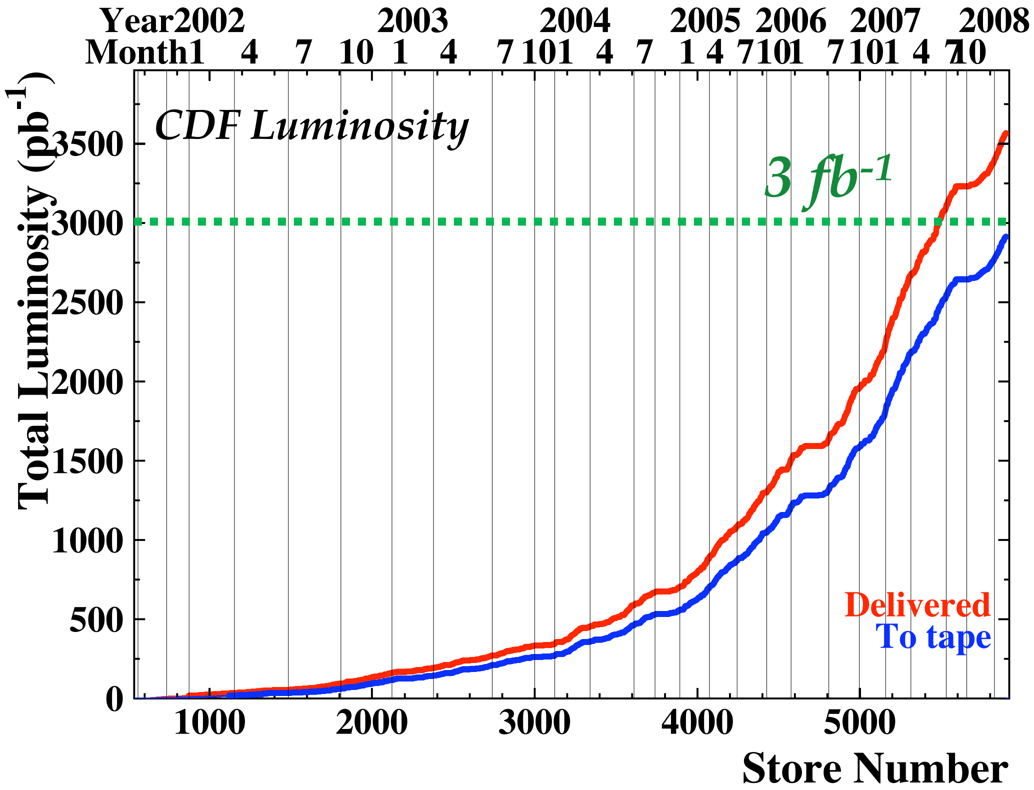
***Test of SM predictions***
***Constraint of parton distribution functions***

*W+c-jet measurement : sensitive to s-quark PDFs*

# Tevatron Experiments at Fermilab

- Tevatron Experiments at Fermilab, CDF and D0



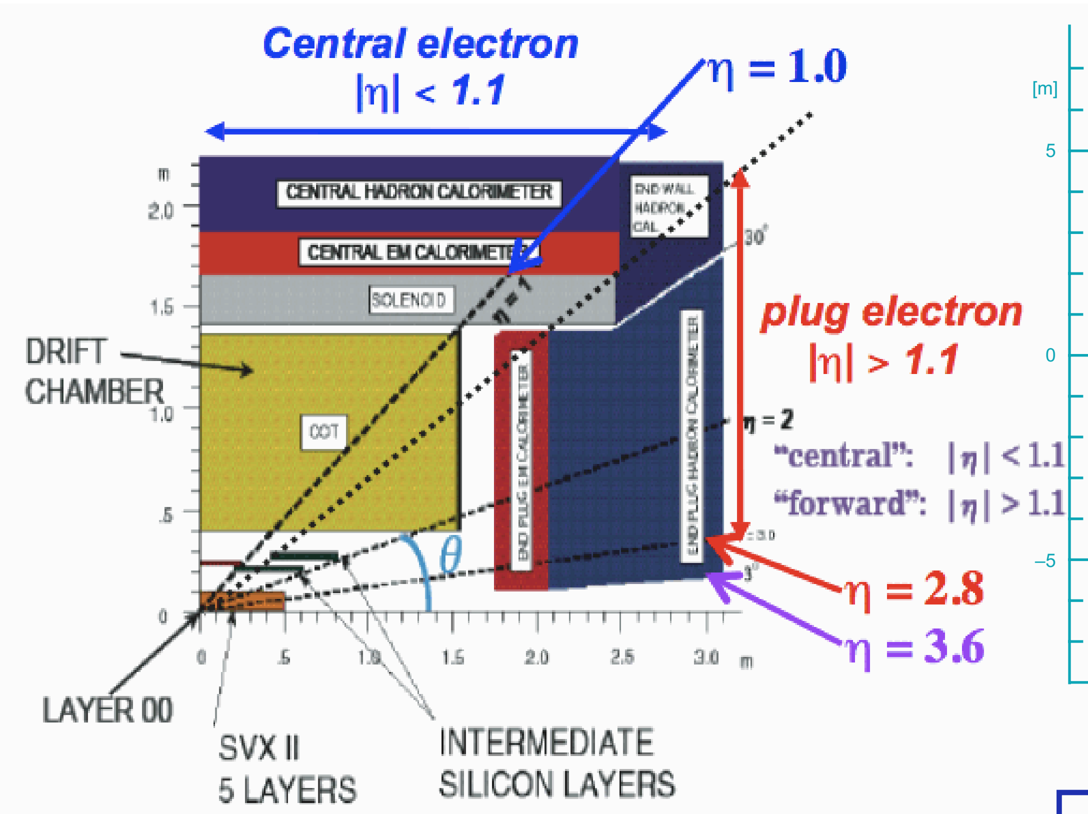



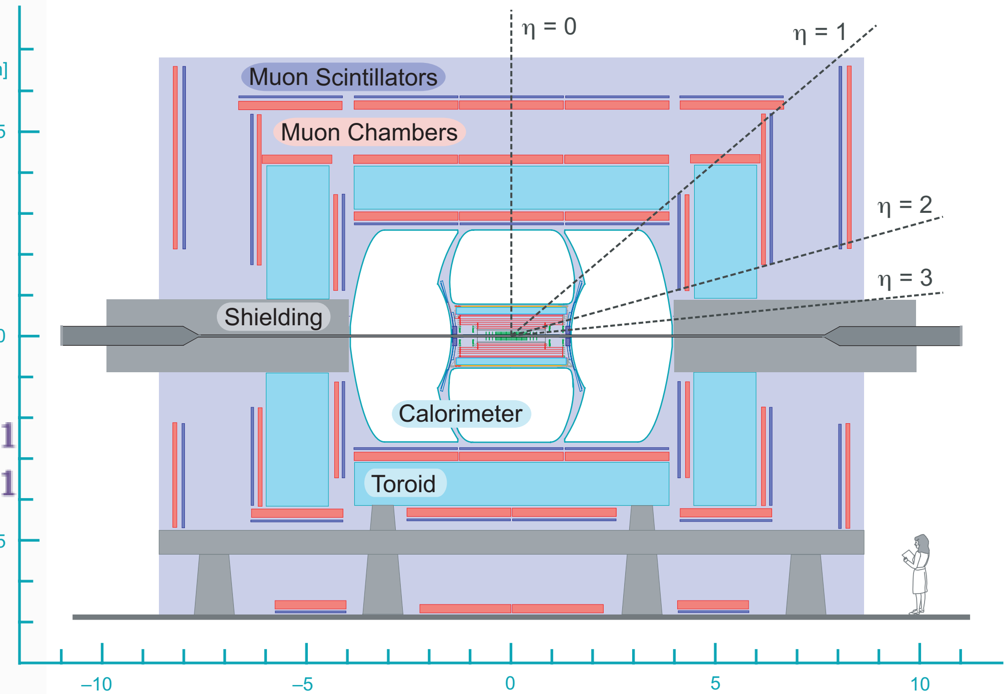

- Improving data yield at the $\textbf{Tevatron Collider}: p\bar{p} \textbf{ at } \sqrt{s} = 1.96 \textbf{ TeV}$
- 3 $fb^{-1}$ recorded to tape

# CDF and D0 Detectors

## CDF Detector

## D0 Detector




$$\eta = -ln(tan(\theta/2))$$

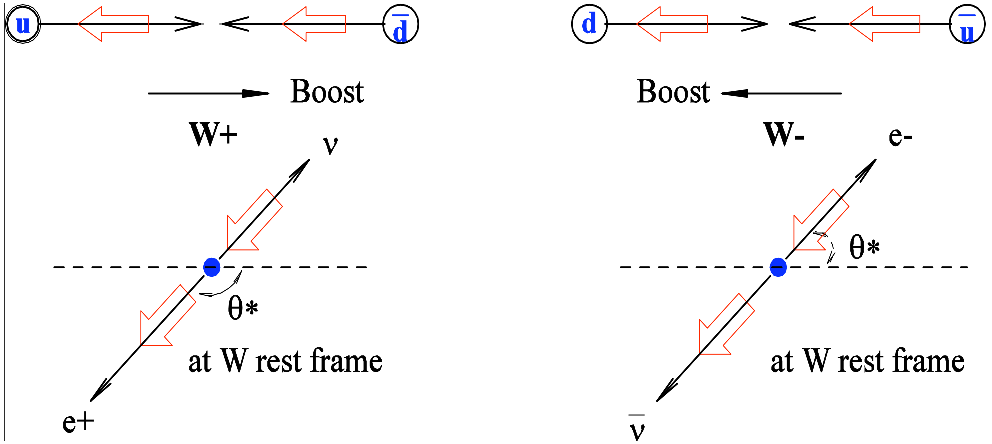
*Better momentum resolution of tracks*

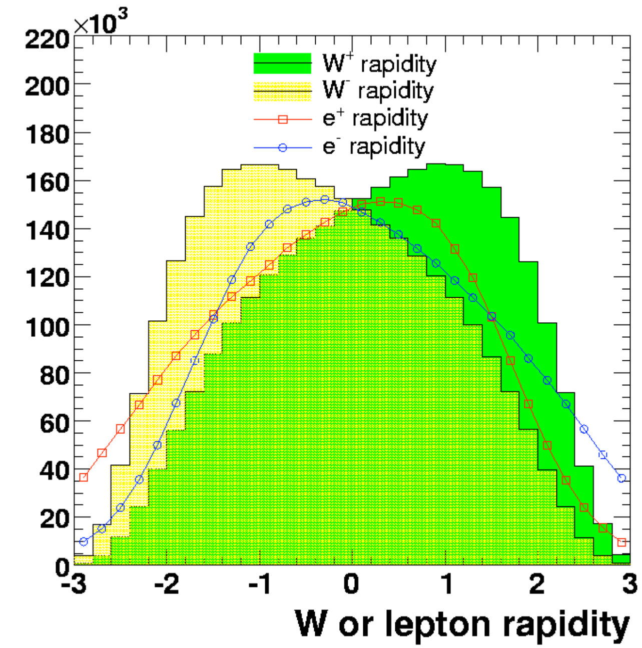
*Muon: 3 layers with iron toroid magnet*

*Good coverage of forward track :*
*more events in high rapidity region*

# W Charge Asymmetry

- $W^+$ and $W^-$ decay from $p\bar{p}$




- W Charge Asymmetry, $A(y_W)$

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

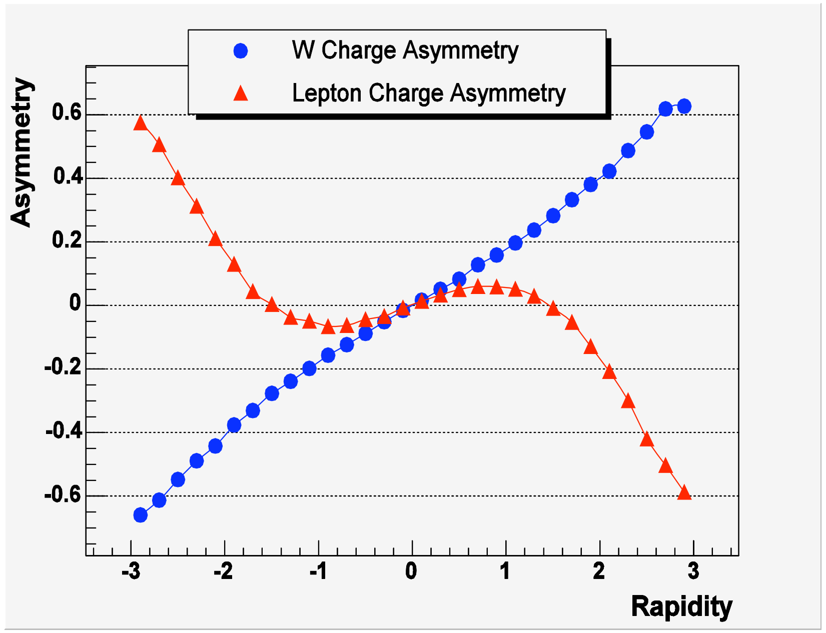
$$\approx \frac{[d(x_2)/u(x_2) - d(x_1)/u(x_1)]}{[d(x_2)/u(x_2) + d(x_1)/u(x_1)]} \text{ where } x_{1,2} = \frac{M_W}{\sqrt{s}} e^{\pm y_W}$$

***$A(y_W)$ is sensitive to $d(x)/u(x)$ slope***

- Lepton Charge Asymmetry

W includes υ : hard to measure $A(y_W)$

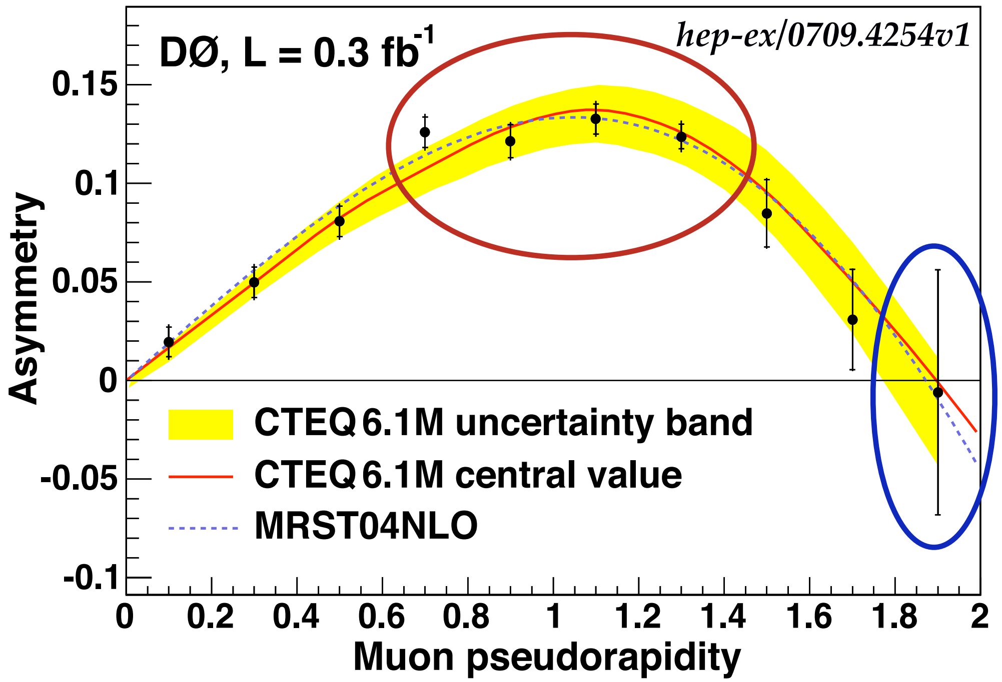
$$A(\eta_\ell) = \frac{d\sigma(\ell^+)/d\eta_\ell - d\sigma(\ell^-)/d\eta_\ell}{d\sigma(\ell^+)/d\eta_\ell + d\sigma(\ell^-)/d\eta_\ell}$$




: Convolution of W Asymmetry, but V-A interaction reduces the observable asymmetry

# Lepton Charge Asymmetry at D0

- Muon Charge Asymmetry ($W \rightarrow \mu \upsilon$)
  - $0.3\ fb^{-1}$ data at D0
  - Measurement up to $\eta_{\mu} \approx 2.0$
  - Central region, $0.7 \lesssim |\eta_{\mu}| \lesssim 1.3$ has smaller experimental uncertainty than PDF uncertainty from CTEQ
  - High pseudorapidity : Statistics limited




*Central region has been used in PDF fit already ($|\eta_{\mu}|<1.3$)*

*High rapidity region is important to prove high x region ($|\eta_{\mu}|>1.3$)*

*CTEQ 6.1M central : J.Pumpkin et al. , J. hep 07, 012 (2002)*
*CTEQ 6.1M uncertainty: D.Stump et al. , J. hep 10, 046 (2003)*
*MRST04NLO:A.D. Martin et al. PLB 604, 61 (2004)*

# W Charge Asymmetry at CDF

- W-Charge Asymmetry ($W \rightarrow e\nu$) : 1 $fb^{-1}$
  - Reconstruct $y_W$ by using W mass constraint

$$y_W = \frac{1}{2} ln(\frac{E - P_z}{E + P_z}) \rightarrow P_z^W = P_z^\ell + P_z^\nu$$

***Can't measure*** $P_z^\nu$

***Two solution for*** $P_z^\nu$ ***from :***

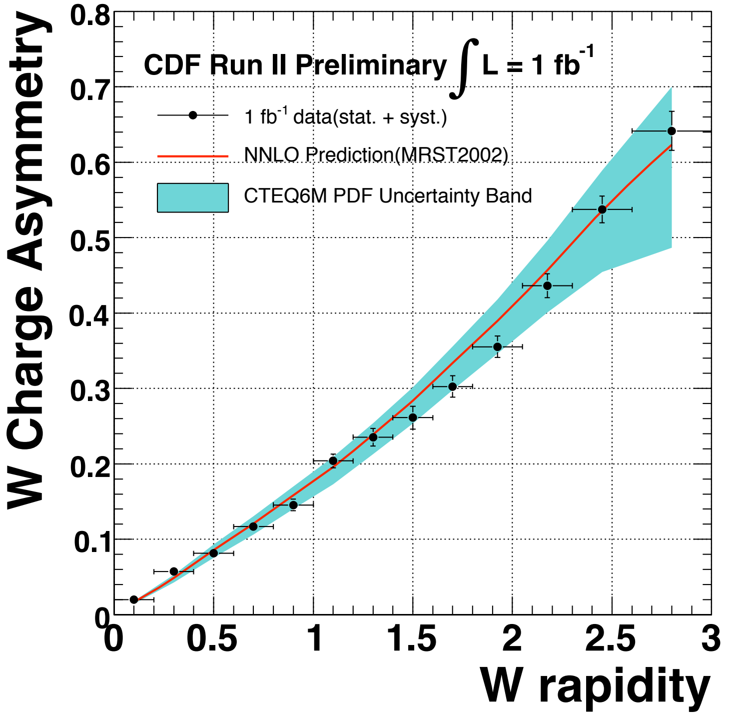
$$M_W^2 = (E_\ell + E_\nu)^2 - (P_\ell + P_\nu)^2$$

- Each $\boldsymbol{P_z^\nu}$ solution is weighted by
  1) V - A decay distribution for the center-of-mass decay angle $\theta^*$
  2) $W^\pm$ production cross-sections in $y_W$
  3) $W^\pm$ transverse momentum : $\boldsymbol{P_T^W}$
- Iterate method to remove input bias

***Experimental uncertainty is smaller than uncertainty from theory prediction***

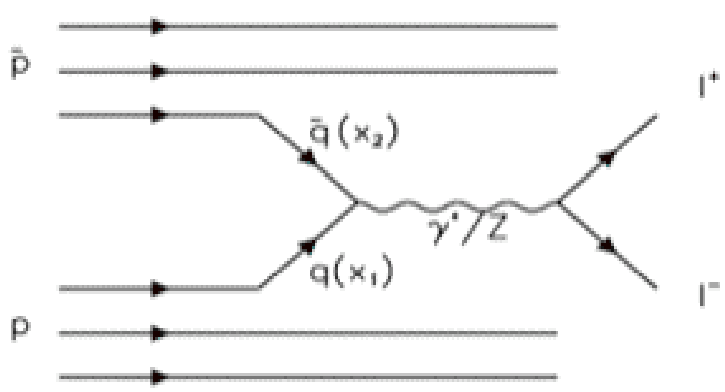
***Good agreement with NNLO prediction using MRST2002 PDFs***

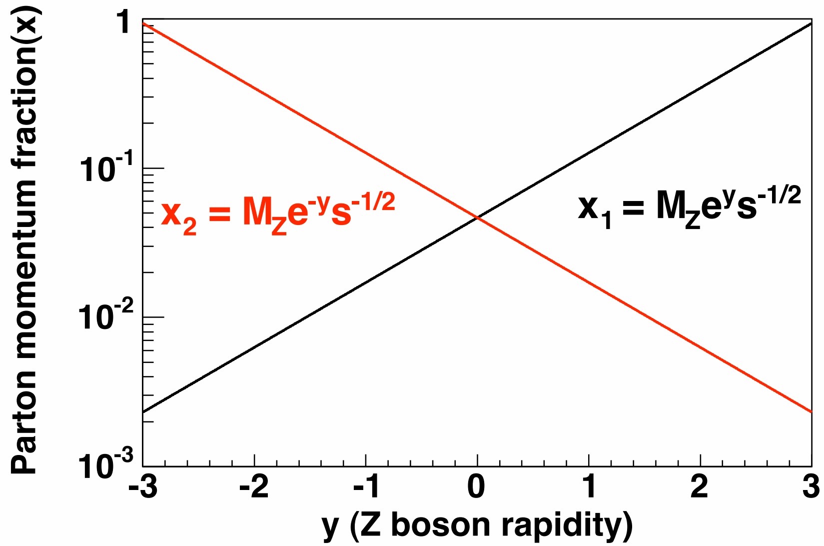
*NNLO : C.Anastasiou et al. PRD D69,094008*
*MRST2002 PDFs: A.D.Martin et al. EPJ C28,455*



# Z/γ* Boson Rapidity

- Rapidity of Drell-Yan process

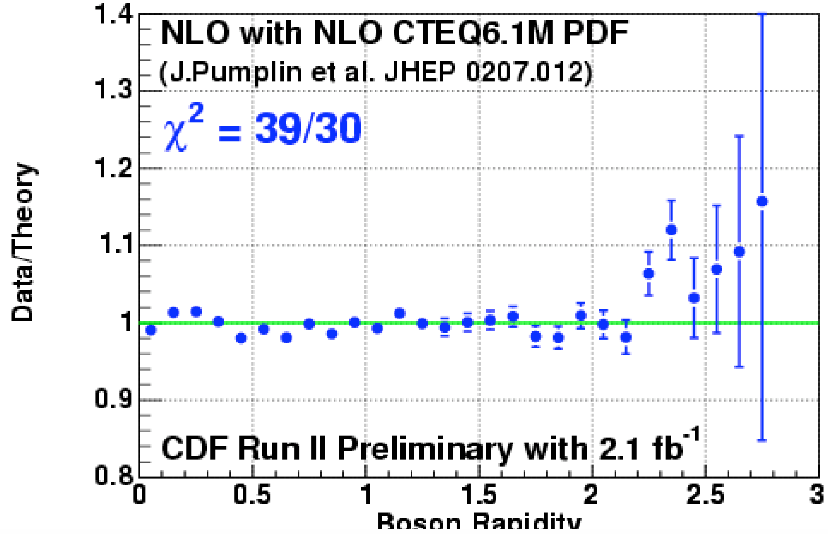


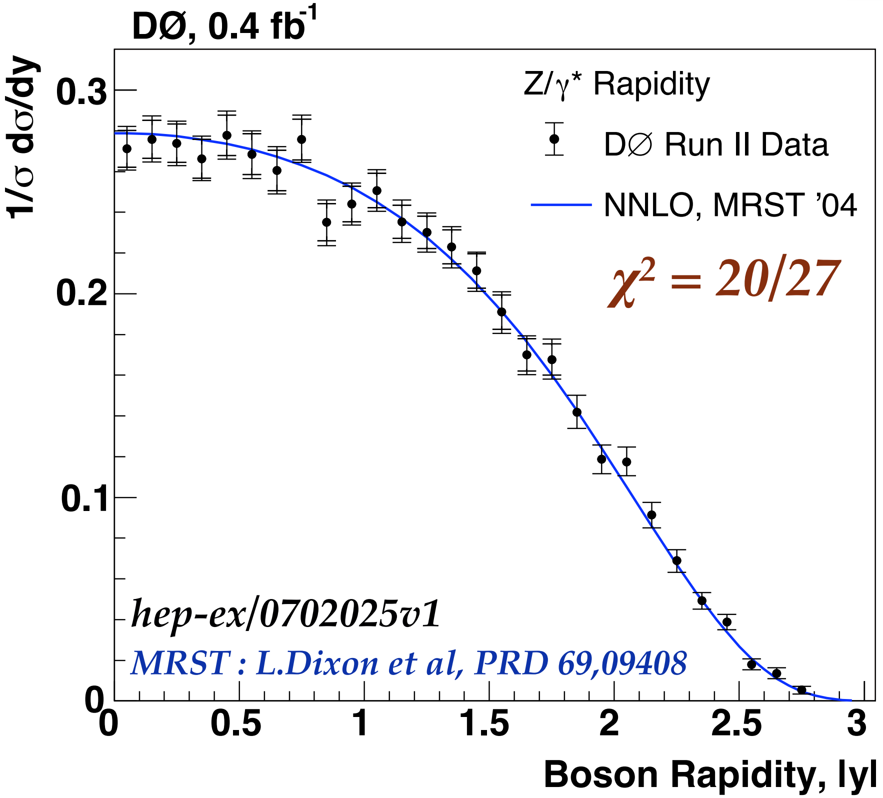



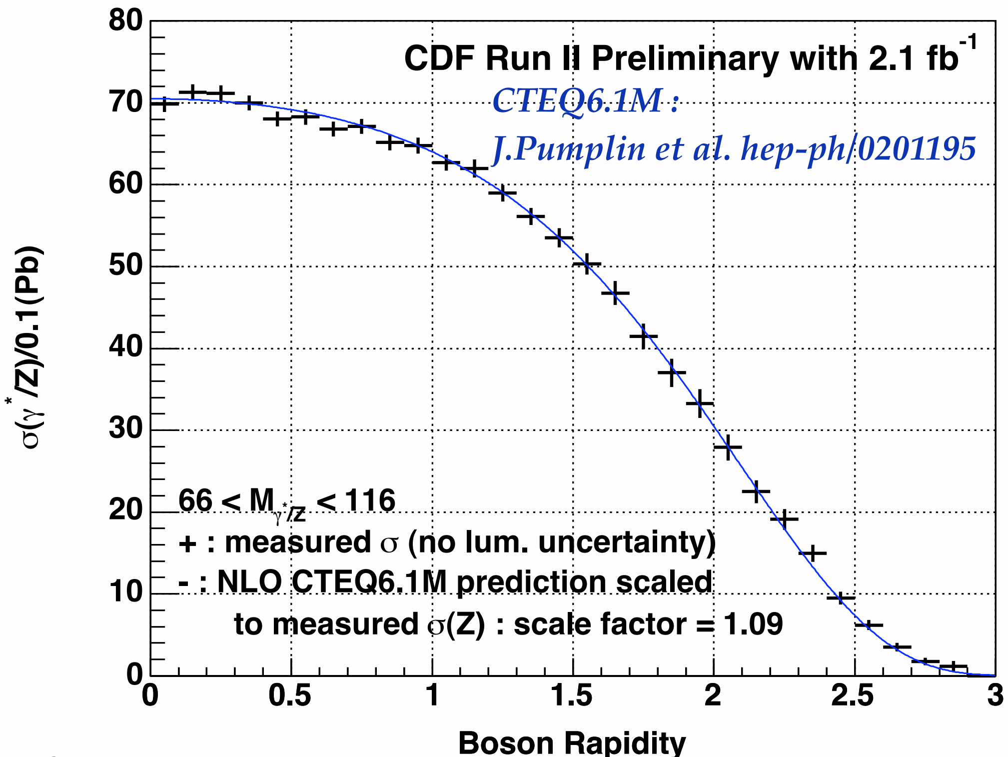

- Parton momentum fractions($x_{1,2}$) determines rapidity of Z boson ($y_Z$)
- The measurement of high $y_Z$ region probes high x region
- dσ/dy distribution tests the theory predictions
    - In LO, the rapidity distribution is sensitive to PDFs
    - In higher order(NLO or NNLO), gluons in the initial state start contributing to the rapidity distribution
    - Comparison of data and predictions gives better understanding of PDF structure

# $d\sigma/dy_Z$ measurement from Tevatron

- $d\sigma/dy$ with dielectron in the final state
- Rapidity ($y_Z$) reaches up to $y_Z \sim 2.9$
- D0 measurement shows good agreement with *NNLO MRST*
- New CDF measurement prefers *NLO CTEQ6.1M* PDFs



# Z/γ* Boson Transverse Momentum

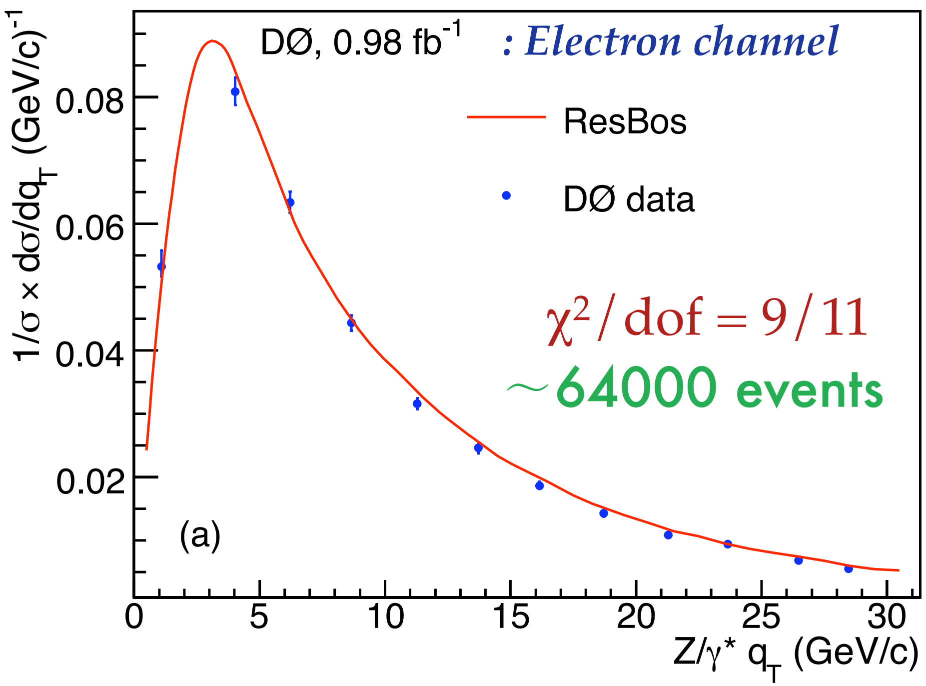
- Z boson $p_T$ can be measured over a wide range of values
  ⇒ Ideal test for predictions of QCD

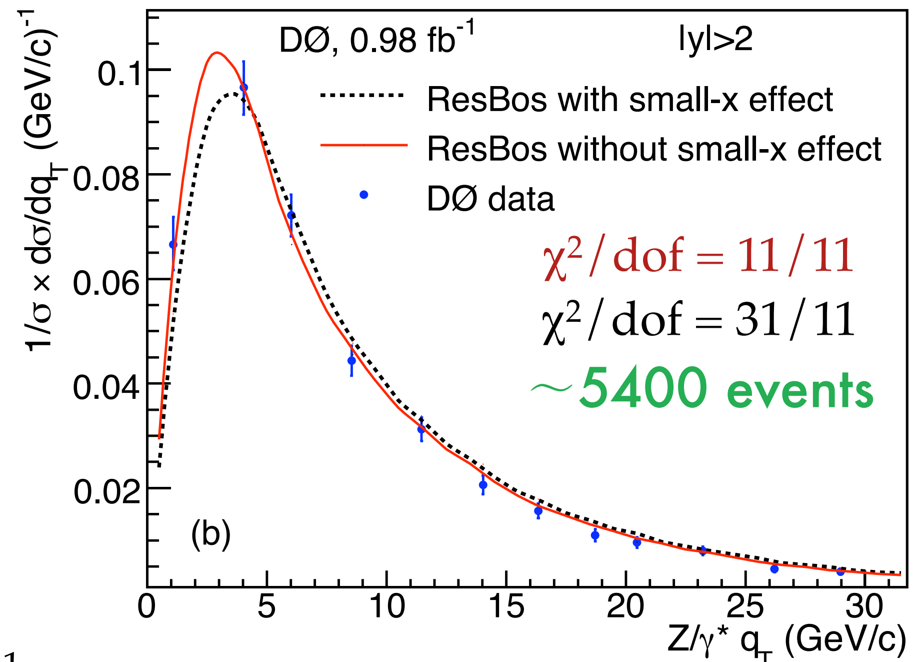
| Large $p_T$ region ($p_T$>30 GeV/c) | Low $p_T$ region ($p_T$<30 GeV/c) |
|---|---|
| Radiation of single parton with high $p_T$ is dominant<br>pQCD calculation(NNLO) gives reliable predictions<br>K. Melnikov and F. Petriello, PRD 74, 114017 | Multiple soft gluon emission effect is dominant<br>Soft gluon resummation technique is developed<br>J.Collins, D.Soper, and G.Sterman Nucl. Phys. B250,119 |

- “Small-x broadening” effect
  - A wider $p_T$ distribution in large rapidity region is predicted
  - Resummation form factor for processes involving small-x parton need to be modified
  - Z bosons in $2<|y|<3$ probe Bjorken x region, $0.002<|x|<0.006$
    ⇒ Measurement tests the modified form factor in small x

# $Z(p_T)$ Measurement at D0 (I)

- ResBos used for the event generator :
  BLNY parameterization for low $p_T$, NLO pQCD for high $p_T$
  ( BLNY : non-perturbative function, ResBos: C. Balazs and C.P Yuan, PRD 56, 5558(1997) )
- PHOTOS used for simulating the final state photon radiation effects
  ( E. Barberio and Z. Was, Comput. Phys. Commun. 79, 291)
- ResBos including gluon resummation agrees well with data in all y regions
- First test of "small-x broadening effect" using high y region at Tevatron
- Data with |y|>2 disfavors additional small-x form factor

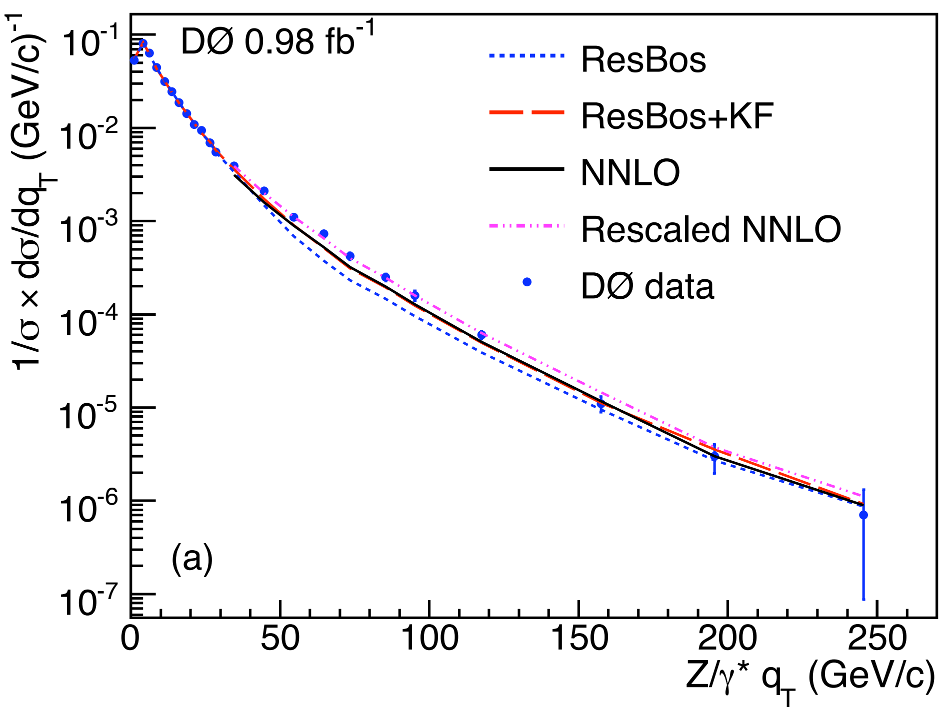


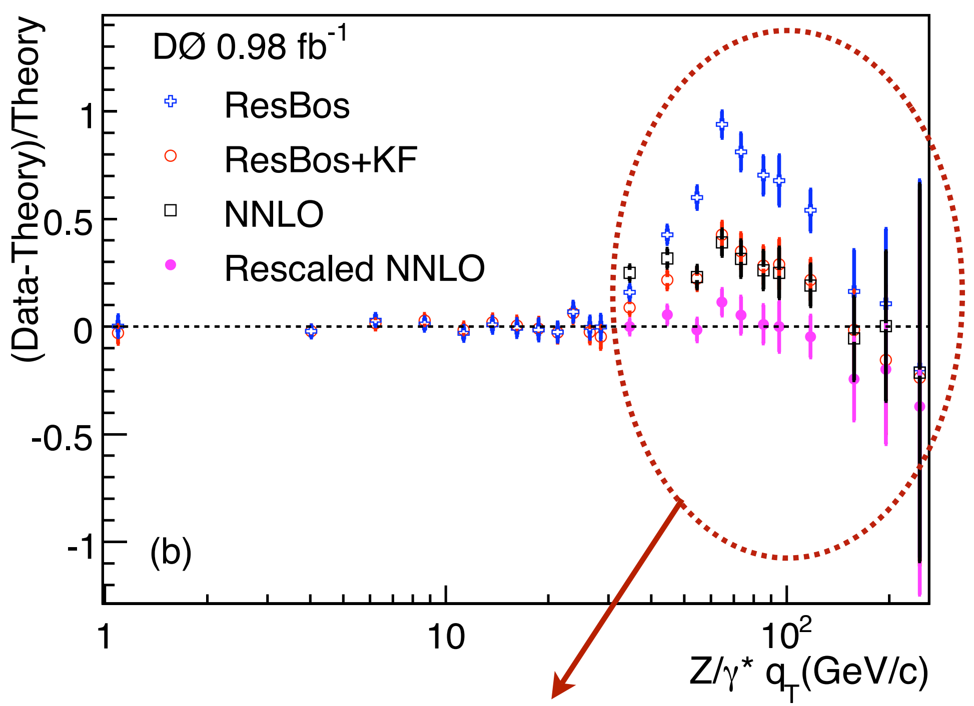



# Z($p_T$) Measurement at D0 (II)

- Normalized differential cross section ( $\frac{1}{\sigma}\frac{d\sigma}{dp_T}$ ) in $p_T$<260 GeV/c
- Data is compared with different theory predictions
- For $p_T$<30 GeV/c, resummation model describes data well
- For $p_T$>30 GeV/c, NNLO calculation agrees with data only in shape

*NNLO : K. Melnikov et al. PRD 74,114017*
*MRST 2001 NNLO PDFs : A.D. Martin et al. PLB 531,216*

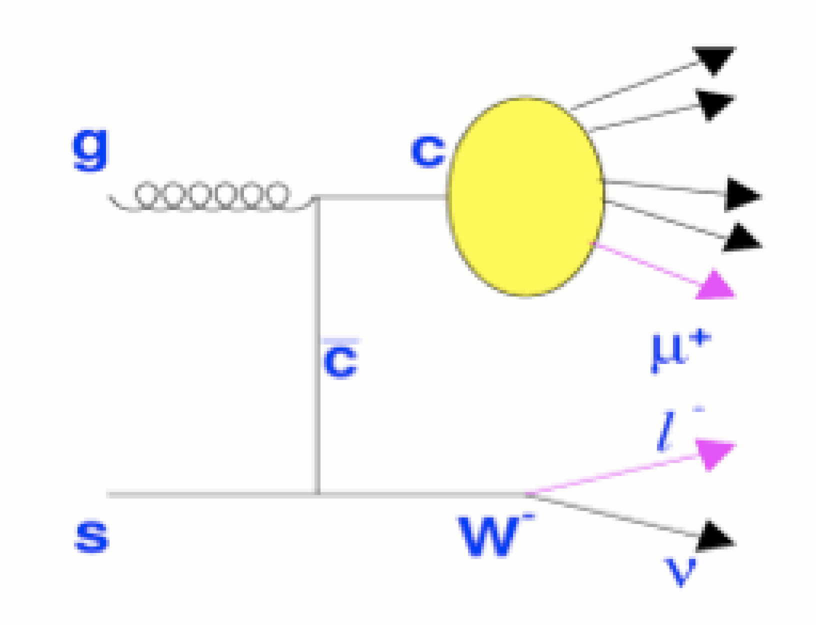



*Normalization factor doesn't match*

# W+charm

- Possible background to top, stop quark and SM Higgs production
- $|V_{cd}|^2$ suppresses d-quark-gluon fusion production
  $\Rightarrow$ Wc production provides direct sensitivity to s-quark PDFs
- s-quark PDF is important for these processes at Tevatron/LHC
  $SM: \ p\bar{p}/pp \rightarrow sg \rightarrow W^- + c, \ \ Higgs: \ p\bar{p}/pp \rightarrow s\bar{c} \rightarrow H^-$
- A probe of s-quark PDF at hadron colliders tests QCD evolution




"μ-tagged jet" method :
Consider the electric charge correlation of μ from c-quark and lepton from W
Require events with opposite charge
$N_{OS} \gg N_{SS}$

# W+c-jet fraction at D0

- D0 measures $\frac{\sigma(\mathbf{p\bar{p} \to W + c - jet})}{\sigma(\mathbf{p\bar{p} \to W + jets})}$ with ~1 $fb^{-1}$ data
- W+c-jet selection
  - All lepton channels considered for W boson decay
  - $Z \to \mu\mu$ rejected by requiring $M_{\mu\mu}$<70 GeV/$c^2$ for μ-channel
- σ(W+c-jet) fraction compared with theory prediction in jet $p_T$

  : ALPGEN calculates the matrix element
  PYTHIA does showering and hadronization
- Measurement is consistent with theory prediction

**For $p_T$>20GeV/c**

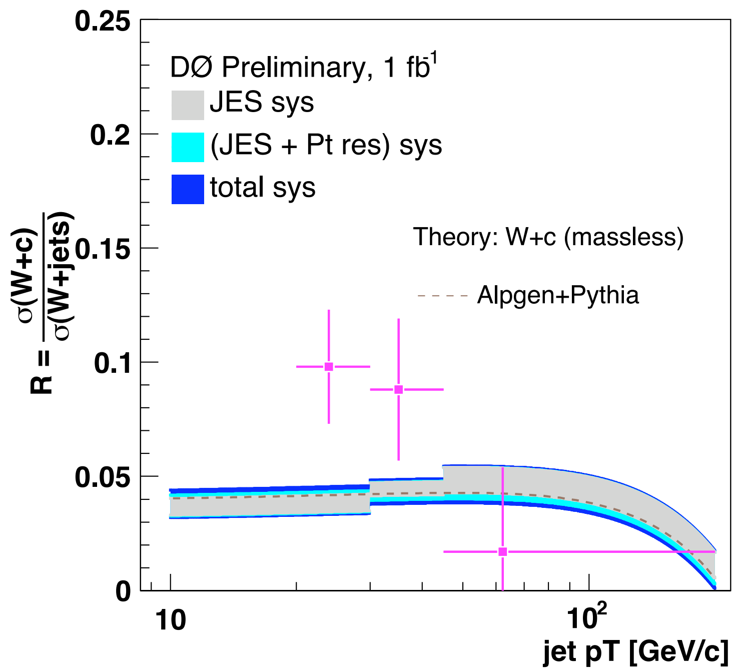
$$\frac{\sigma(W + c - jet)}{\sigma(W + jets)} = 0.071 \pm 0.017$$

**e-channel:**

$0.060 \pm 0.021(stat.) \pm^{0.005}_{0.007} (sys.)$

**μ-channel:**

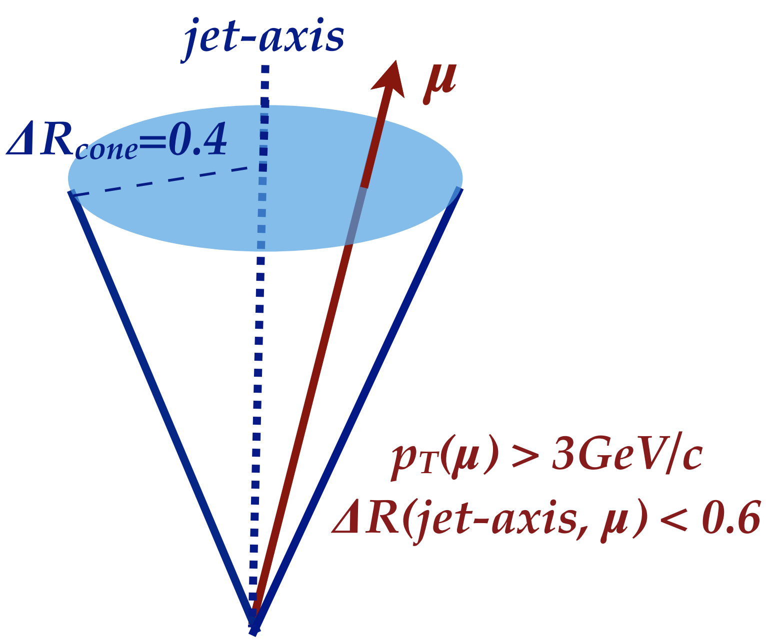
$0.093 \pm 0.029(stat.) \pm 0.005(sys.)$

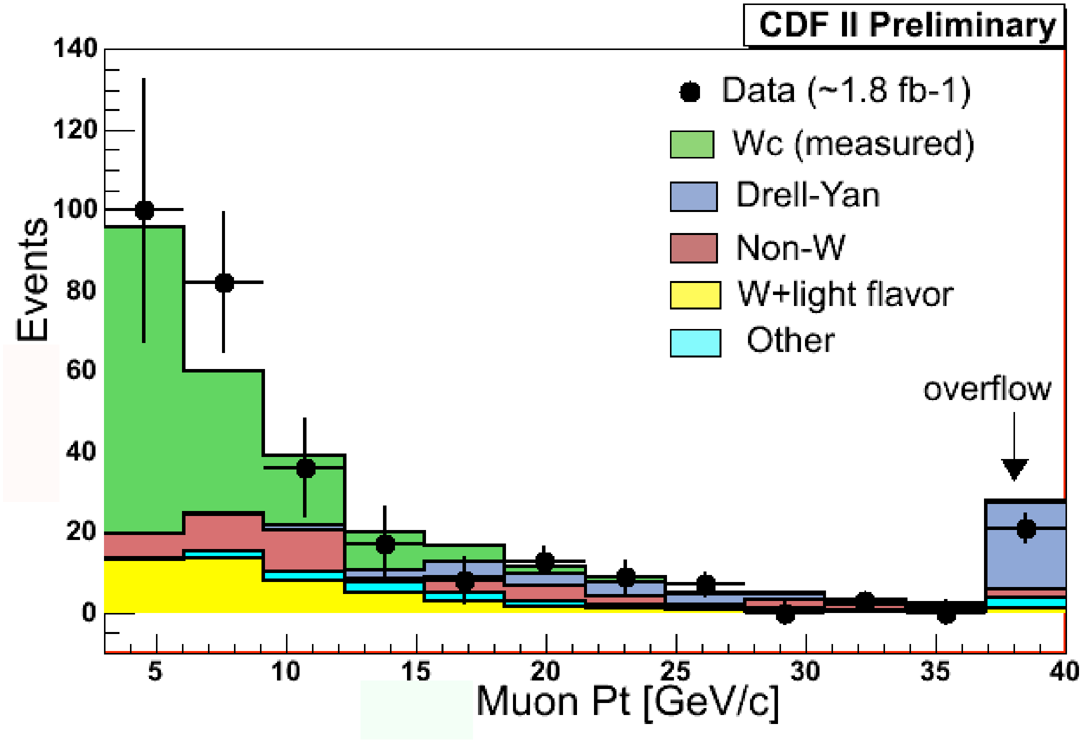


# W+c-jet cross section at CDF

- CDF measures total cross section of W+c-jet with ~1.8 $fb^{-1}$ data
- electron and muon channels considered for W boson decay
- c-jet with $p_T(c) > 20$ GeV/c and $|\eta(c)| < 1.5$

  : c-jet identified from semileptonic decay by looking for a muon within jet
- $\sigma_{\mathbf{Wc}} \times \mathbf{BR}(\mathbf{W} \to \ell\nu) = \mathbf{9.8 \pm 2.8(stat.)^{+1.4}_{-1.6}(sys.) \pm 0.6(lum)\ pb}$
- Measurement agrees with NLO calculation : $11.0^{+1.4}_{-3.0}\ pb$



# Conclusion

- Various approaches to understand PDFs are on going at Tevatron
- CDF and D0 are measuring W/Z boson properties and W+c-jet process with more statistical power
- Most of results improve the experimental uncertainty
  $\Rightarrow$ give better power to discriminate theory predictions
- W charge asymmetry and $d\sigma/dy$ measurement extend the rapidity region up to y~2.9 and give more information for high x region

**Measurements provide more constraint to PDFs**
**Need more feedback from theorist**
**More data will provide better precise measurement**

# Back Up Slides

# W Charge Asymmetry at CDF (I)

- W-Charge Asymmetry ($W \rightarrow e\upsilon$) : 1 $fb^{-1}$
  - Reconstruct $y_W$ by using W mass constraint

$$y_W = \frac{1}{2} ln\left(\frac{E - P_z}{E + P_z}\right) \rightarrow P_z^W = P_z^\ell + P_z^\nu$$

*Can't measure $P_z^\nu$*
*Two solution for $P_z^\nu$ from :*
$$M_W^2 = (E_\ell + E_\nu)^2 - (P_\ell + P_\nu)^2$$

  - Develop the weight factor for two solution : ***$P_{z1}^\nu$ and $P_{z2}^\nu$***

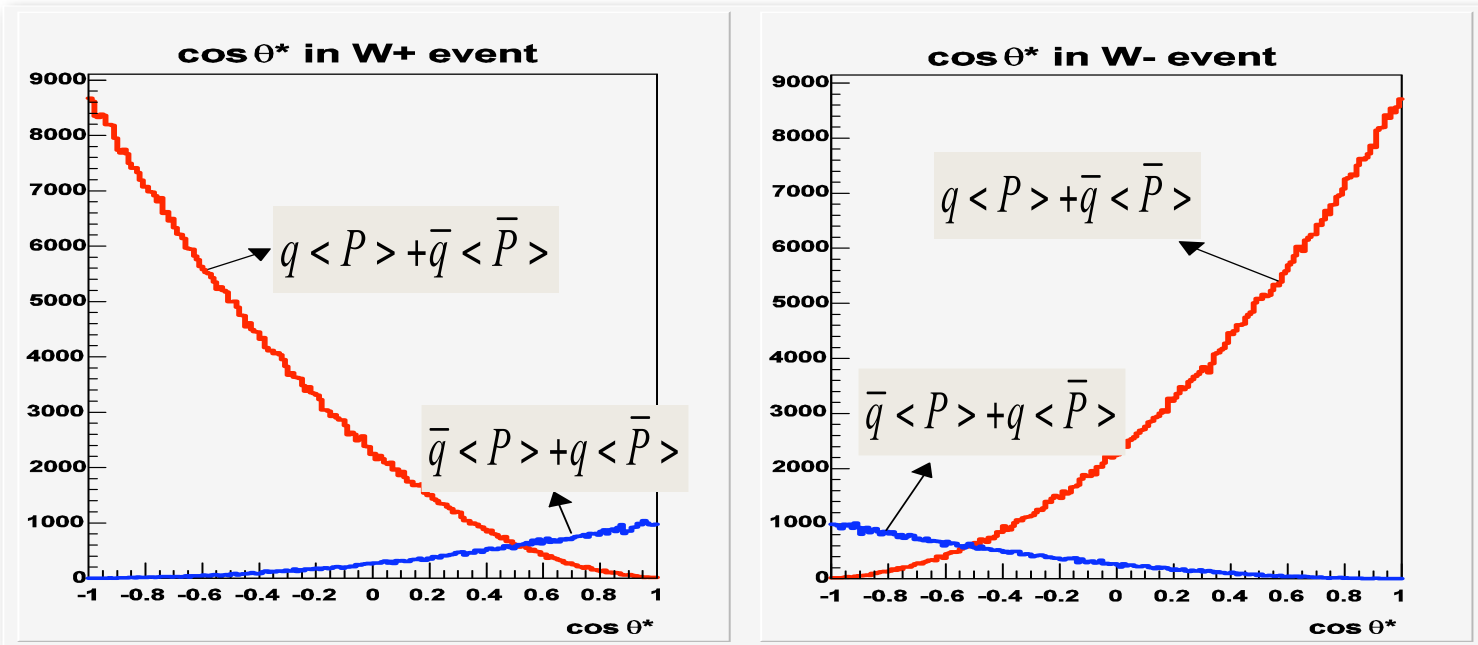
$$\mathbf{F}^{\pm}_{\mathbf{1,2}} = \frac{\mathbf{P}_\pm(\cos\theta^*_{\mathbf{1,2}}, \mathbf{y_{1,2}}, \mathbf{p_T^W})\sigma_\pm(\mathbf{y_{1,2}})}{\mathbf{P}_\pm(\cos\theta^*_{\mathbf{1}}, \mathbf{y_1}, \mathbf{p_T^W})\sigma_\pm(\mathbf{y_1}) + \mathbf{P}_\pm(\cos\theta^*_{\mathbf{2}}, \mathbf{y_2}, \mathbf{p_T^W})\sigma_\pm(\mathbf{y_2})}$$

$$P_\pm(cos\theta^*, y_W, P_T^W) = A * \{(1 \mp cos\theta^*)^2 + Q(y_W, P_T^W)(1 \pm cos\theta^*)^2\}$$

*Weighting factor :*
*1) cos$\theta^*$*
*: Q is the ratio of quark(proton) to anti-quark(proton) induced to W production and is parameterized by LO calculation*
*2) differential cross section, $\sigma(y)$*
*3) W transverse momentum, $p_T{}^W$*

# W Charge Asymmetry at CDF(II)

- W production probability from angular distribution




$$P_{\pm}(\cos\theta^*, y_W, p_t^W) = (1 \mp \cos\theta^*)^2 + Q(y_W, p_t^W)(1 \pm \cos\theta^*)^2$$

$q<P>+\bar{q}<\bar{P}>$ $\bar{q}<P>+q<\bar{P}>$

**ratio of two angular distributions at each rapidity**

# W Charge Asymmetry at CDF(III)

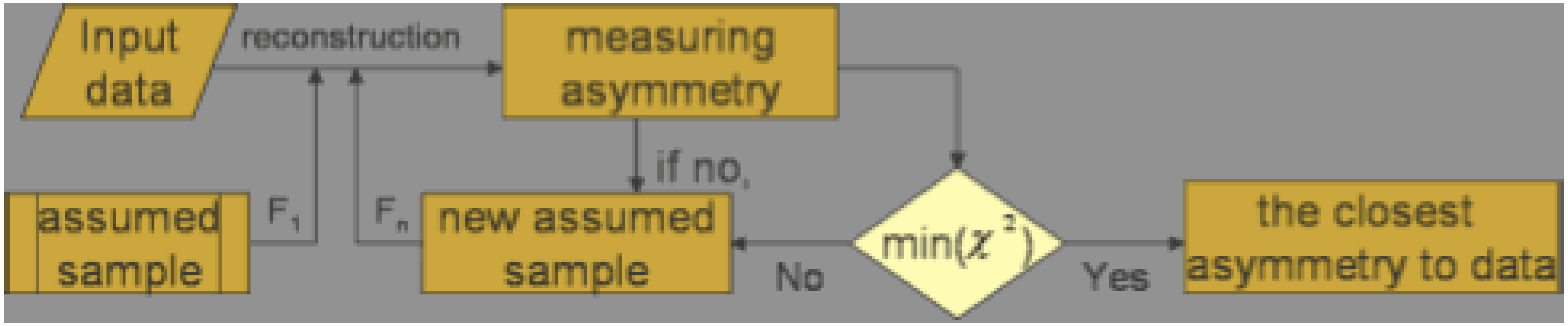
- Iteration process

$$\mathbf{F}^{\pm}_{1,2} = \frac{\mathbf{P}_{\pm}(\cos\theta^{*}_{1,2}, \mathbf{y}_{1,2}, \mathbf{p}_{T}^{W})\sigma_{\pm}(\mathbf{y}_{1,2})}{\mathbf{P}_{\pm}(\cos\theta^{*}_{1}, \mathbf{y}_{1}, \mathbf{p}_{T}^{W})\sigma_{\pm}(\mathbf{y}_{1}) + \mathbf{P}_{\pm}(\cos\theta^{*}_{2}, \mathbf{y}_{2}, \mathbf{p}_{T}^{W})\sigma_{\pm}(\mathbf{y}_{2})}$$

$$P_{\pm}(cos\theta^{*}, y_W, P_T^W) = A * \{(1 \mp cos\theta^{*})^2 + Q(y_W, P_T^W)(1 \pm cos\theta^{*})^2\} \qquad (3)$$

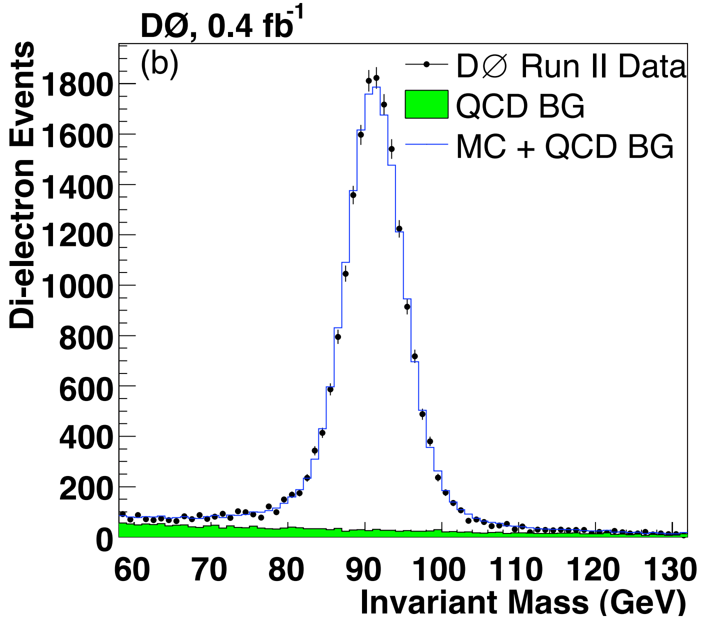
where $Q(y_W, P_T^W)$ is the ratio of quark(proton) to anti-quark(proton) induced to $W$ production and is parameterized by a LO calculation(Pythia).

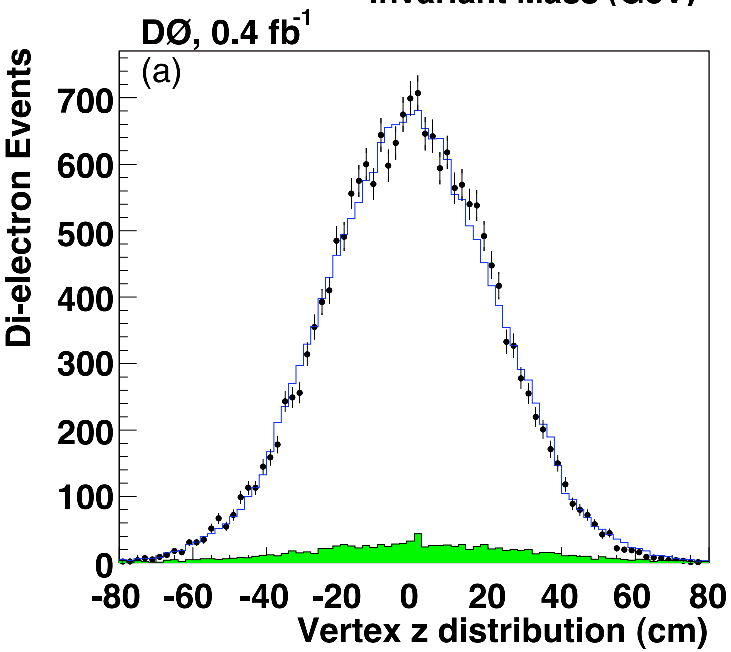
**Iteration**

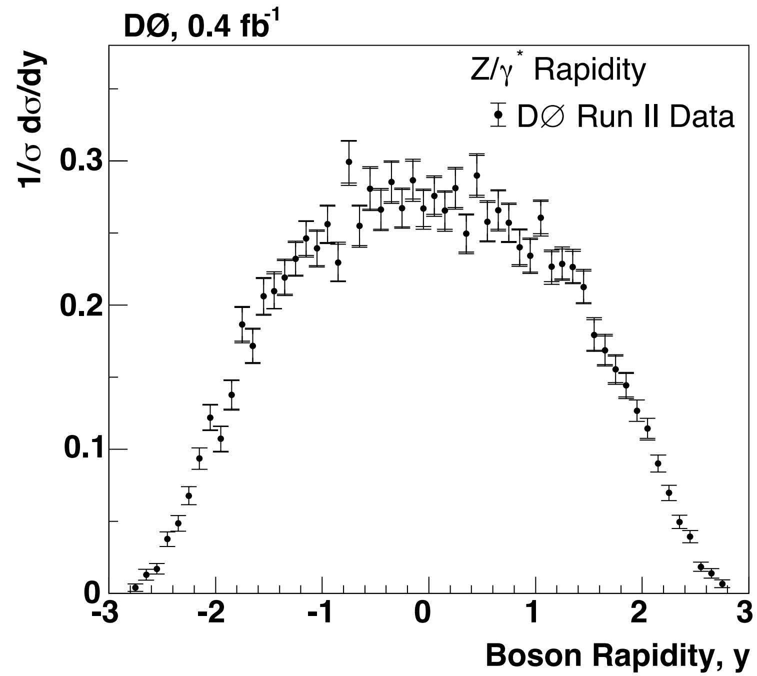


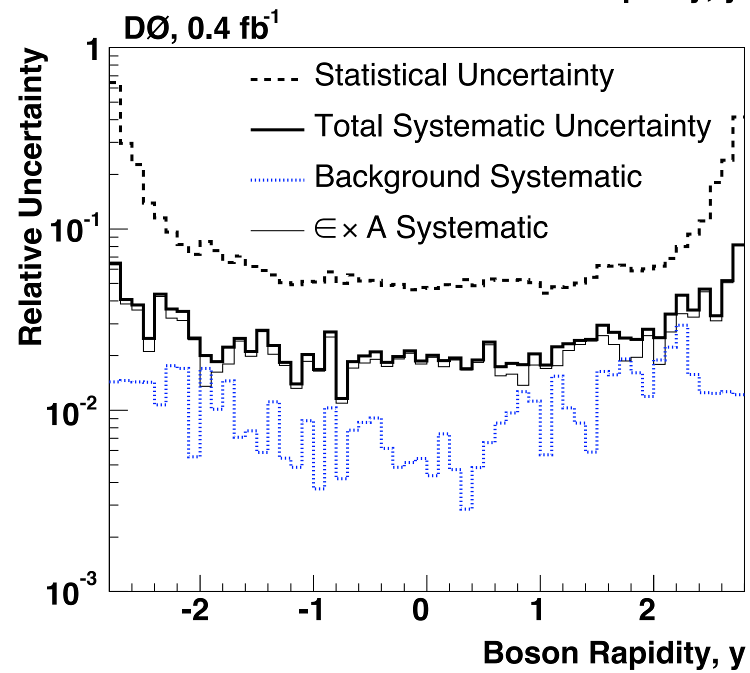
# $d\sigma/dy_Z$ measurement at D0

- Z mass and vertex distribution



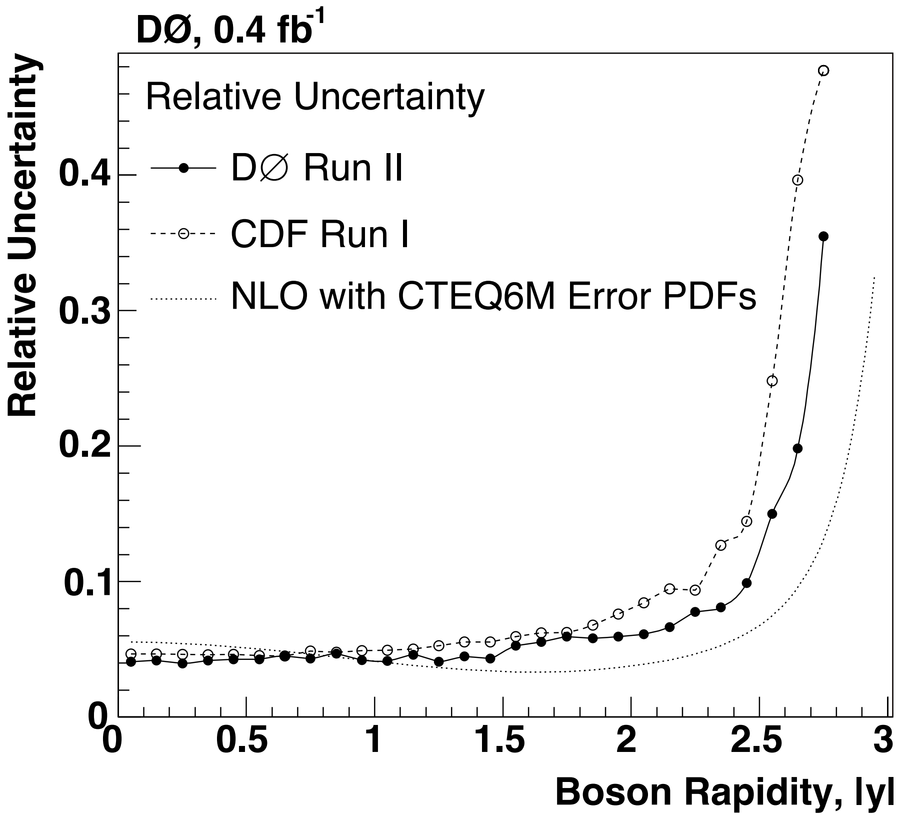



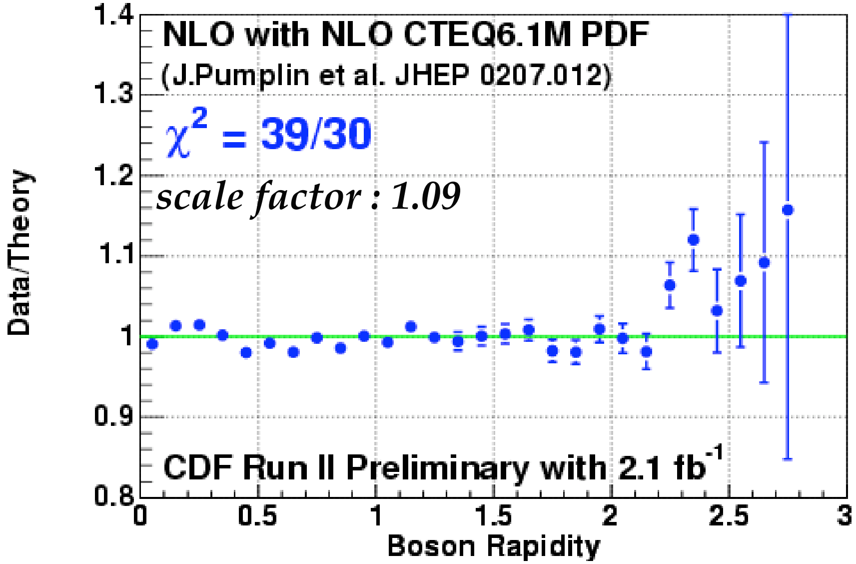
# dσ/dy$_Z$ measurement at D0

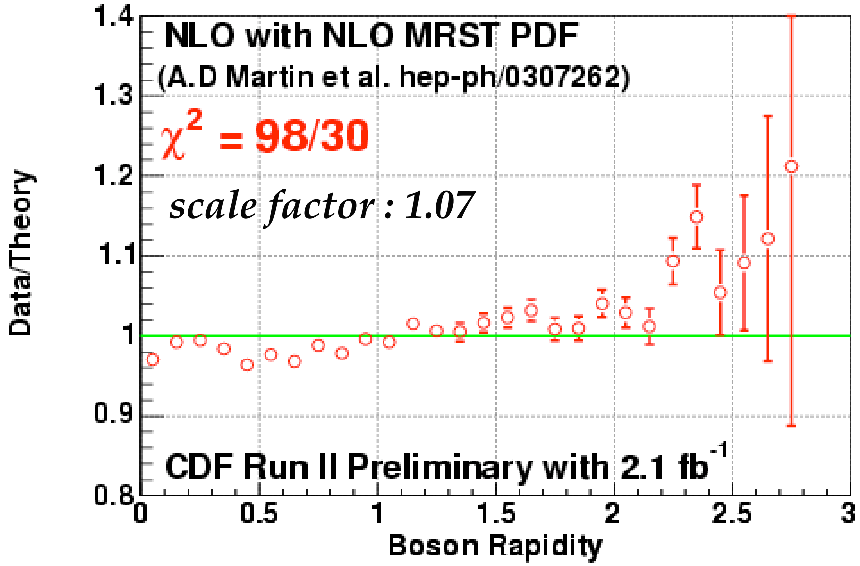
- Relative uncertainty

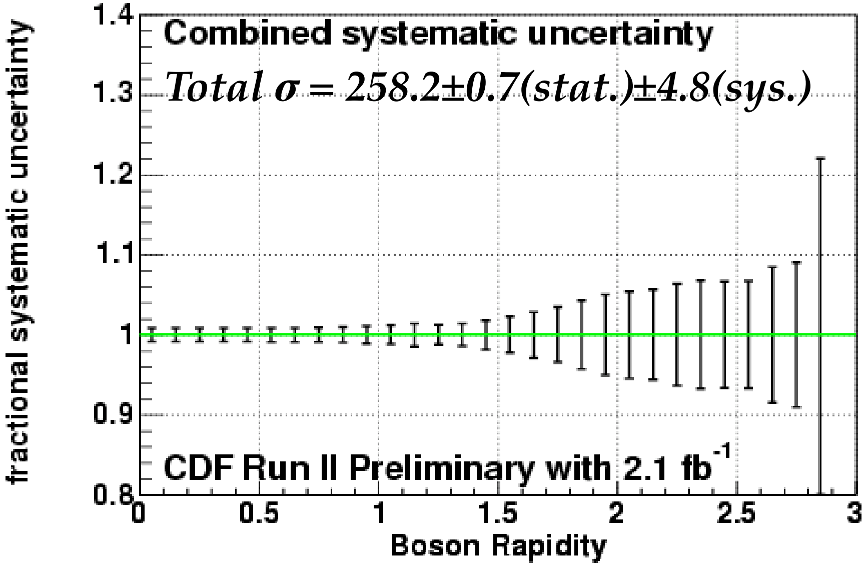


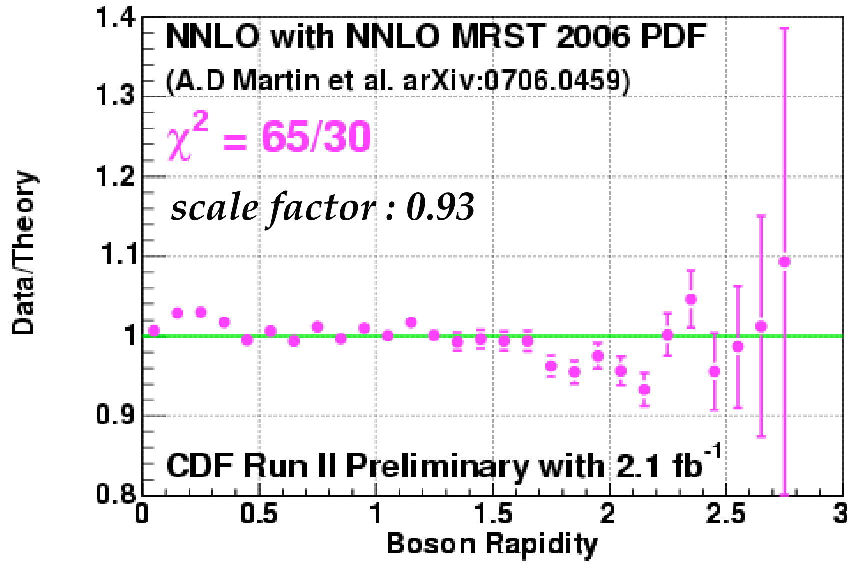
# dσ/dy$_Z$ measurement at CDF

- Data and Theory Comparison (only statistic uncertainty considered)



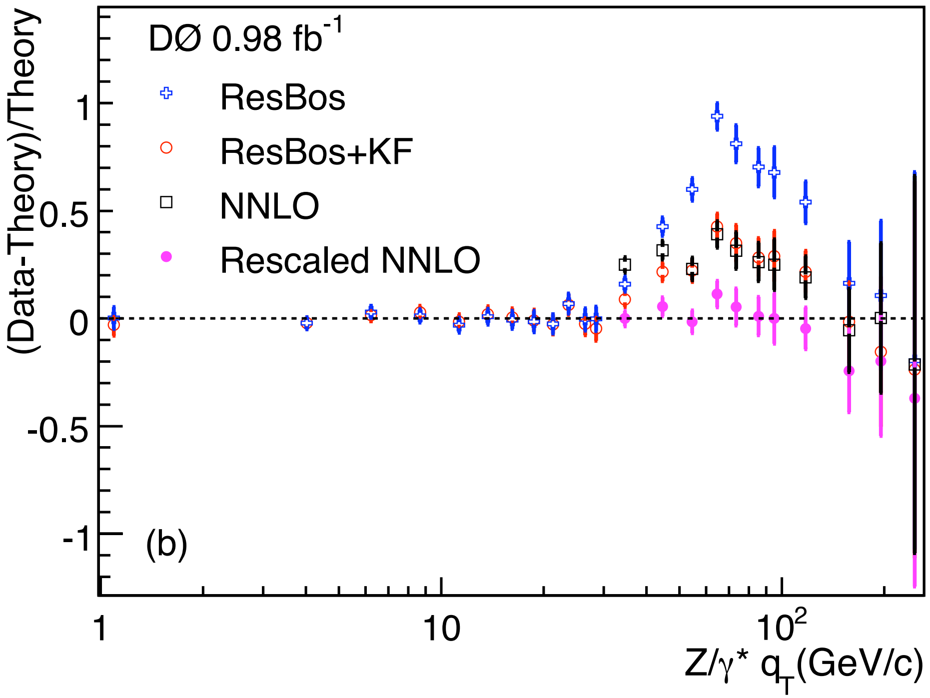



# Z($p_T$) measurement at D0

- Fractional differences between data and MC




***K-factor : NLO to NNLO***

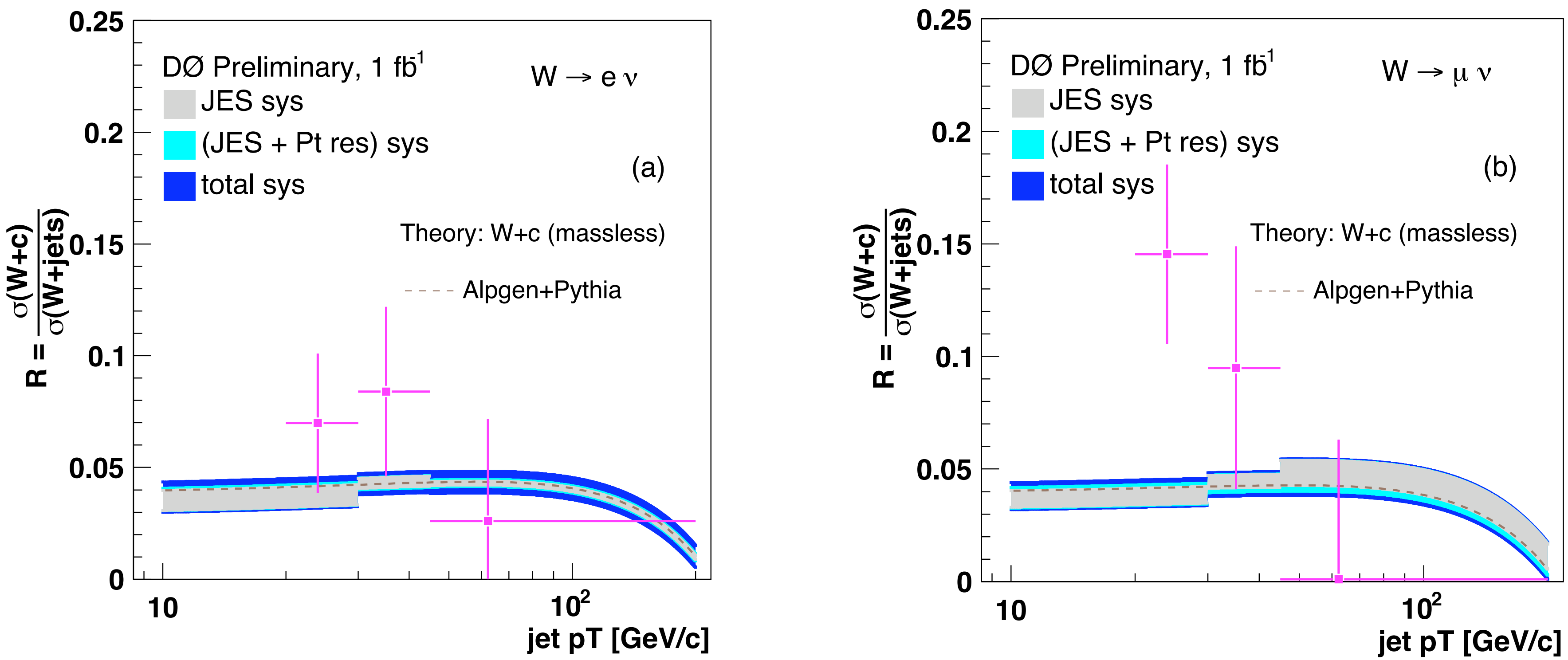
***Rescaled NNLO :***

***NNLO calculation rescaled to data at $p_T$= 30GeV/c***

***Scale factor = 1.25***

# W+c-jet at D0

- $\frac{\sigma(p\bar{p} \rightarrow W + c - jet)}{\sigma(p\bar{p} \rightarrow W + jets)}$ of electron and muon channel in $p_T$




- Result is consistent with LO perturbative QCD prediction