W and Z Production at the Tevatron:

Recent Results and Prospects

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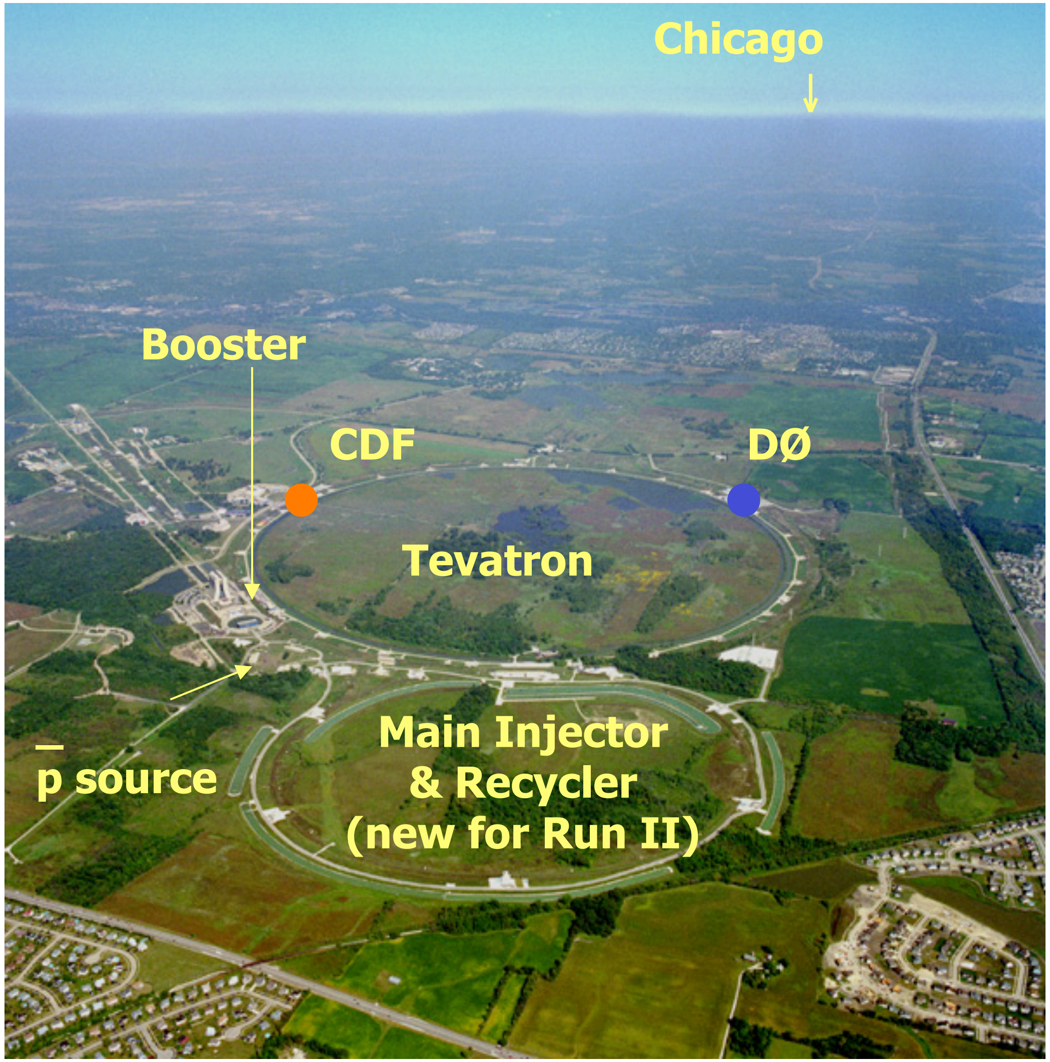
on behalf of the CDF and DØ collaborations

Overview

- Introduction:
  - Tevatron, detectors and integrated luminosity
  - Z and W production and detection
  - Motivation for precise measurements
- Recent results
  - Z transverse momentum ← New for this conference
    - $Z \rightarrow \mu\mu$, 1 fb^{-1}, DØ
  - Z transverse momentum using ϕ^*_η ← New for this conference
    - $Z \rightarrow ee$ & $Z \rightarrow \mu\mu$, 7.3 fb^{-1}, DØ
  - Z cross section and rapidity ← New for winter 2010 conferences
    - $Z \rightarrow ee$, 2.2 fb^{-1}, CDF
  - W charge asymmetry — New for winter 2010 conferences ↓
    - $W \rightarrow e\nu$, 1 fb^{-1}, CDF
      - re-analysis in terms of lepton A_{FB} allowing direct comparison with
    - $W \rightarrow \mu\nu$, 4.9 fb^{-1}, DØ
  - Z forward-backward asymmetry ← New for winter 2010 conferences
    - $Z \rightarrow ee$, 4.1 fb^{-1}, CDF
  - N.B. W mass measurements covered elsewhere
- Prospects

The Fermilab Tevatron Collider



1992-95 Run I:

$\int L dt$ ~ 0.1 fb^{-1}, 1.8 TeV

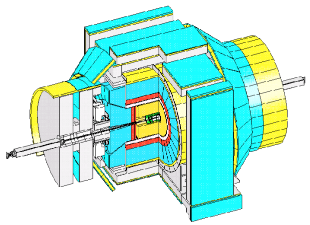
Major accelerator/detector upgrades

2002-11 Run II:

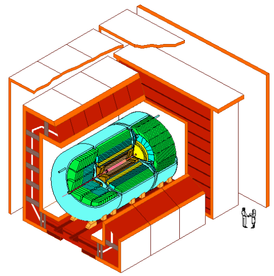
$\int L dt$ ~ 9 fb^{-1} delivered, 1.96 TeV

$\int L dt$ ~ 12 fb^{-1} expected by 2011

Further running 2012-2014?
- being considered

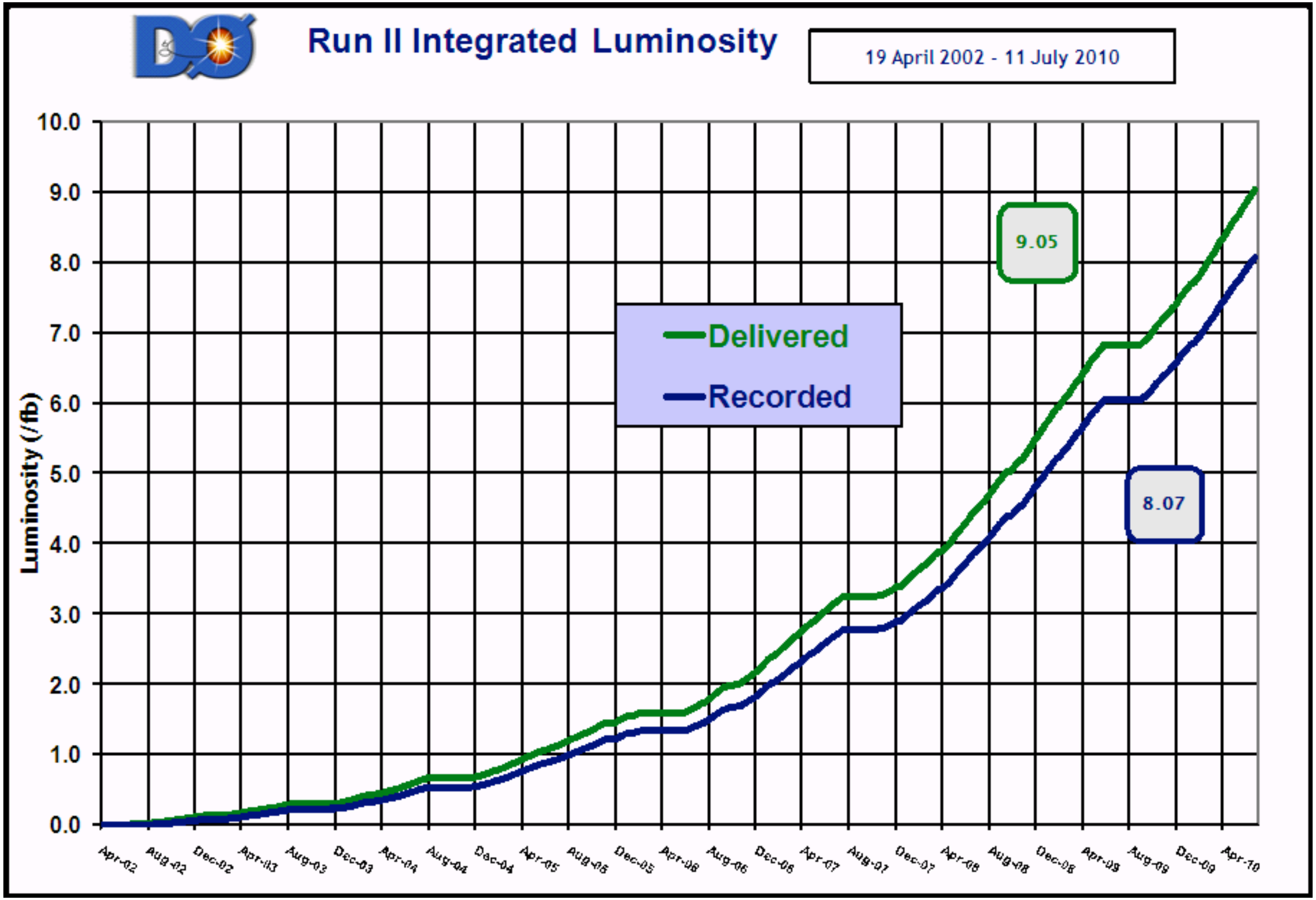


CDF



DØ

Integrated Luminosity History

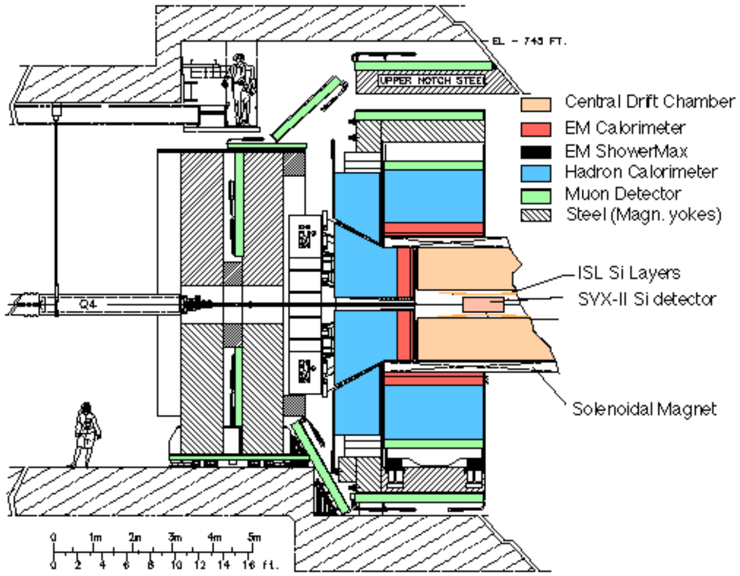


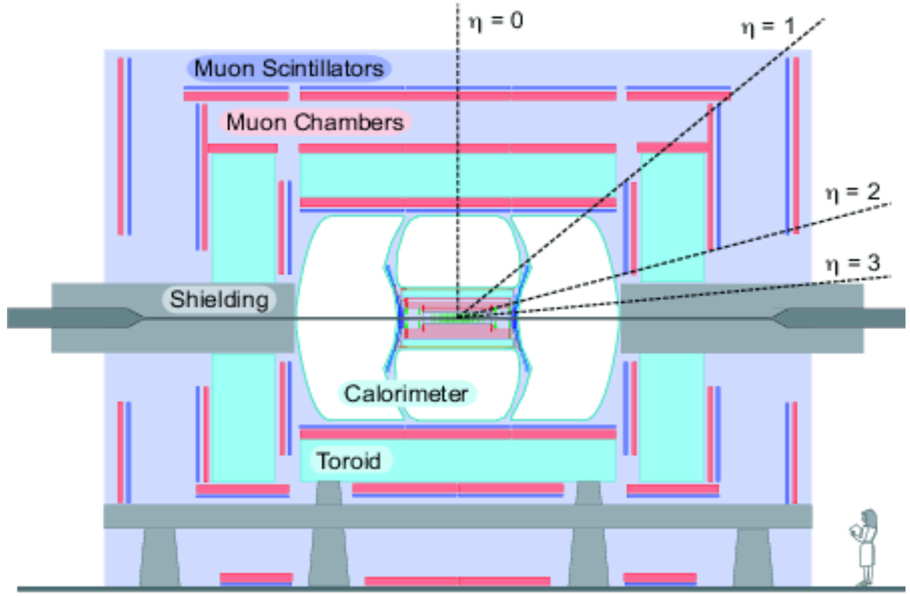
Average data taking efficiency since 2002 is 84% (CDF) and 89% (DØ)

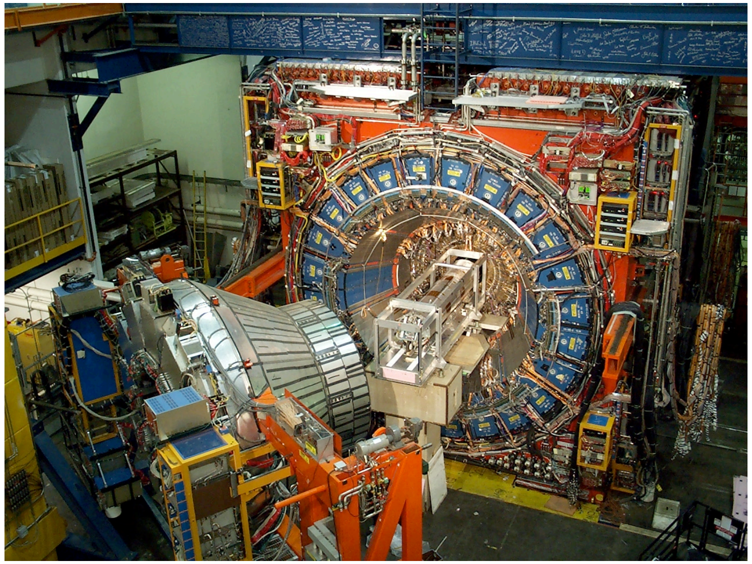
CDF

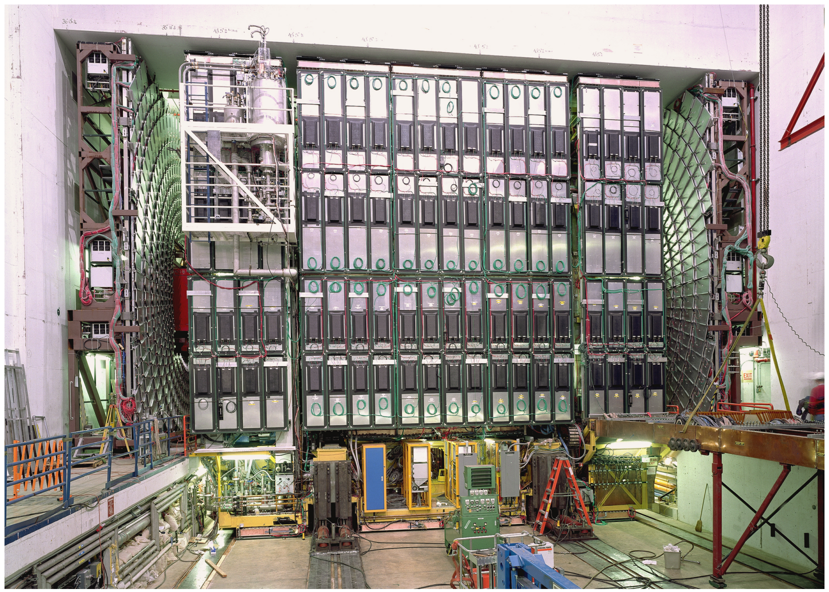
DØ

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

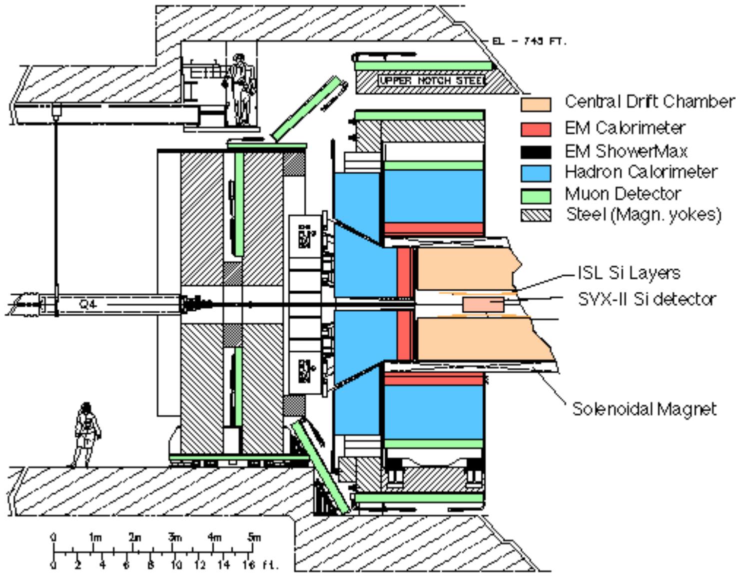




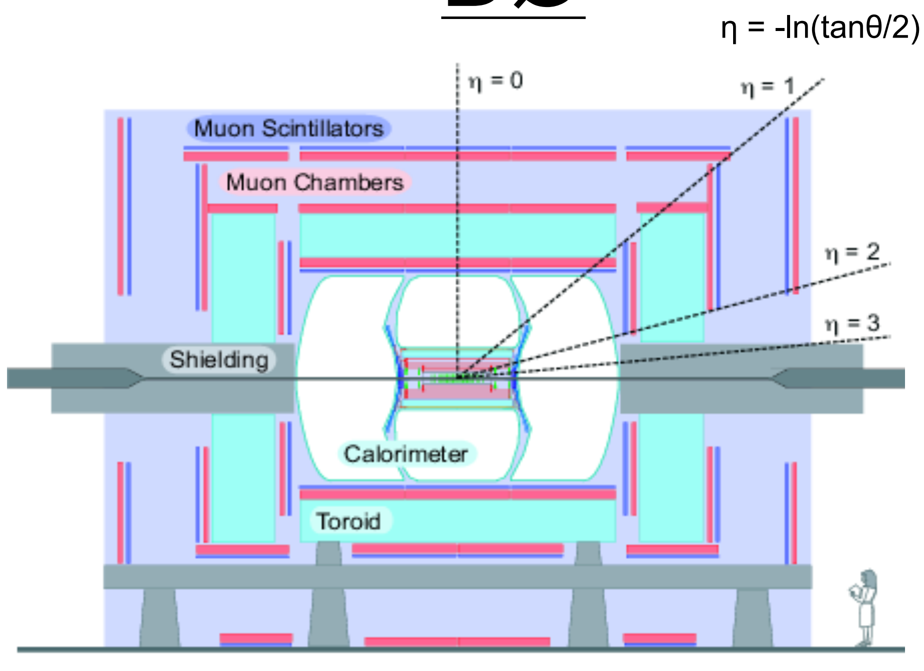




CDF



DØ



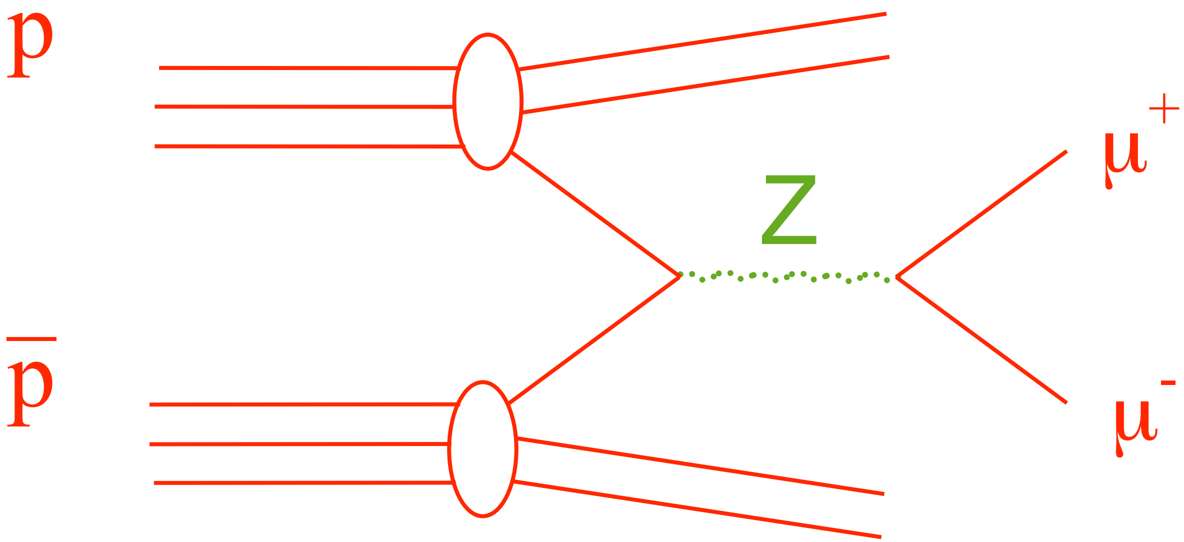
CDF detector highlight

- Large volume, high precision, charged particle tracker
  - 9-layer silicon tracker
  - 96-layer drift chamber
  - 1.4 m outer radius

DØ detector highlight

- High acceptance, low background, muon system
  - 0.5 m outer radius for DØ central tracker!

Producing W and Z in $p\bar{p}$



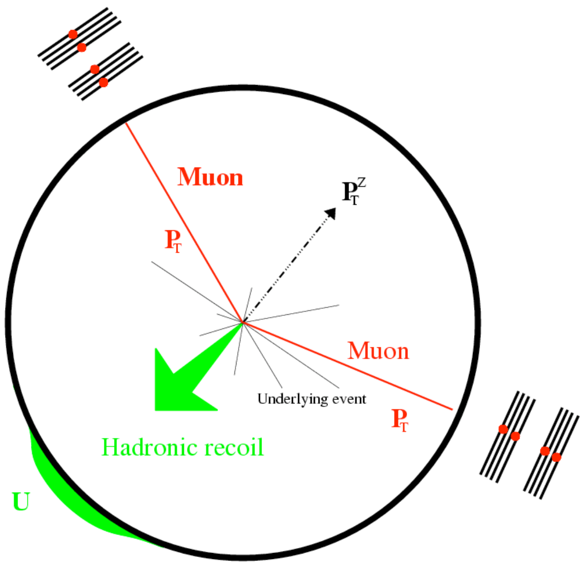
- Proton is a composite object
  - PDFs (Parton Distribution Functions)
  - gluon bremsstrahlung

$m_{\ell\ell}^2 = x_1 x_2 s$

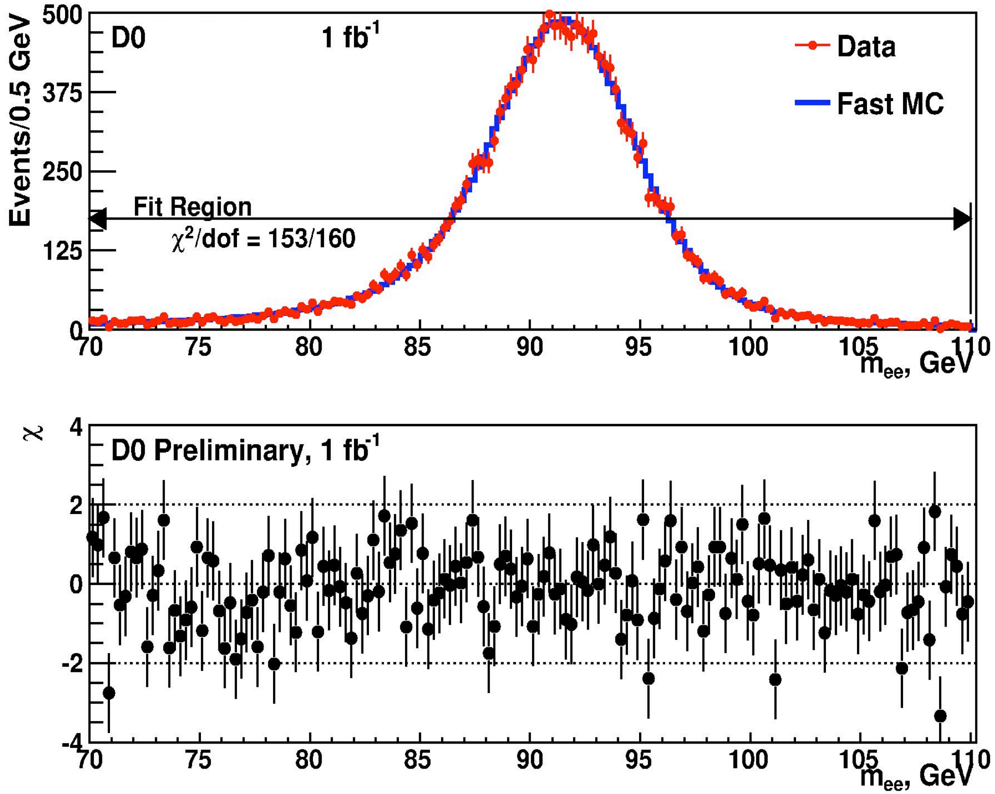
$x_{1,2} = e^{\pm y} m_{\ell\ell} / \sqrt{s}$

Select ~ 10^6 tagged $W \rightarrow \ell\nu$ and ~ 10^5 $Z \rightarrow \ell^+\ell^-$ events per fb^{-1}

Signatures of W and Z Production at the Tevatron



- $Z \rightarrow \ell^+\ell^-$: pair of charged leptons:
  - high p_T
  - isolated
  - opposite-charge
- peak in $\ell^+\ell^-$ invariant mass



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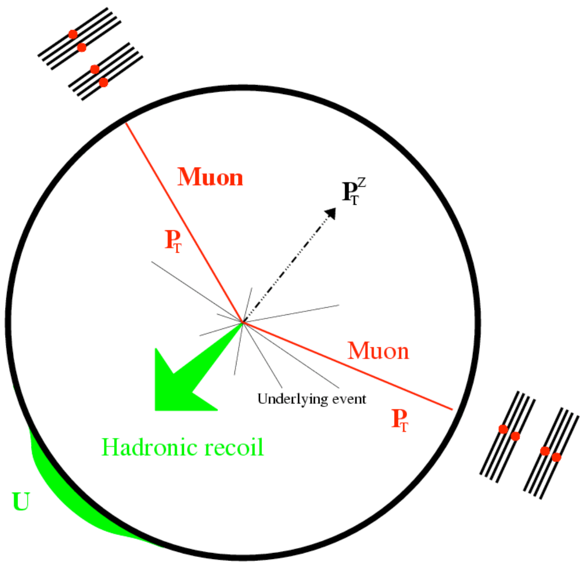

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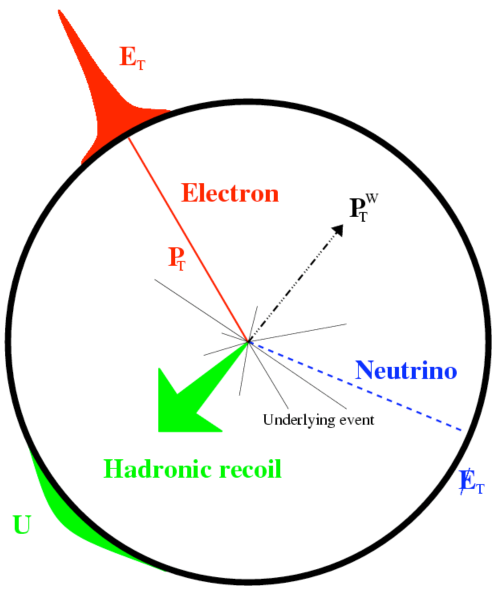
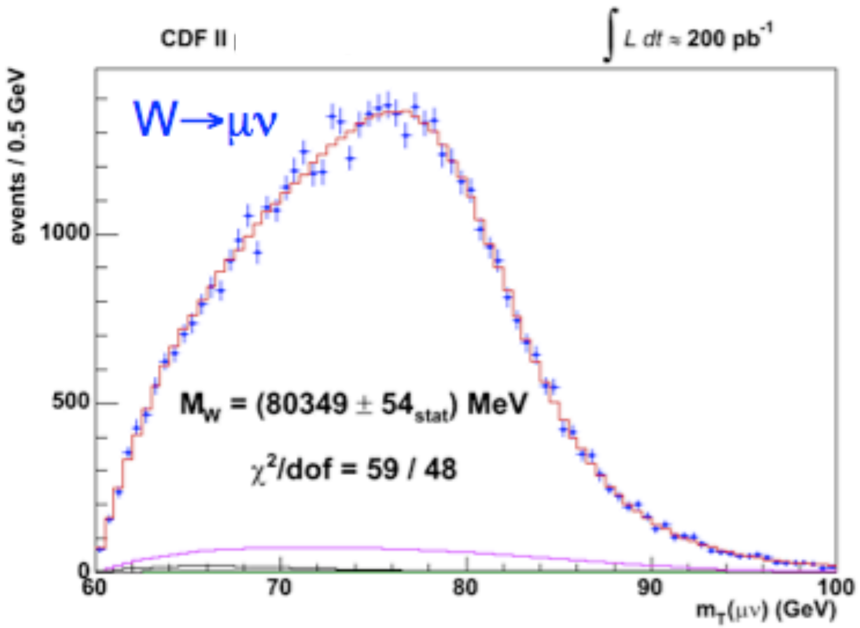
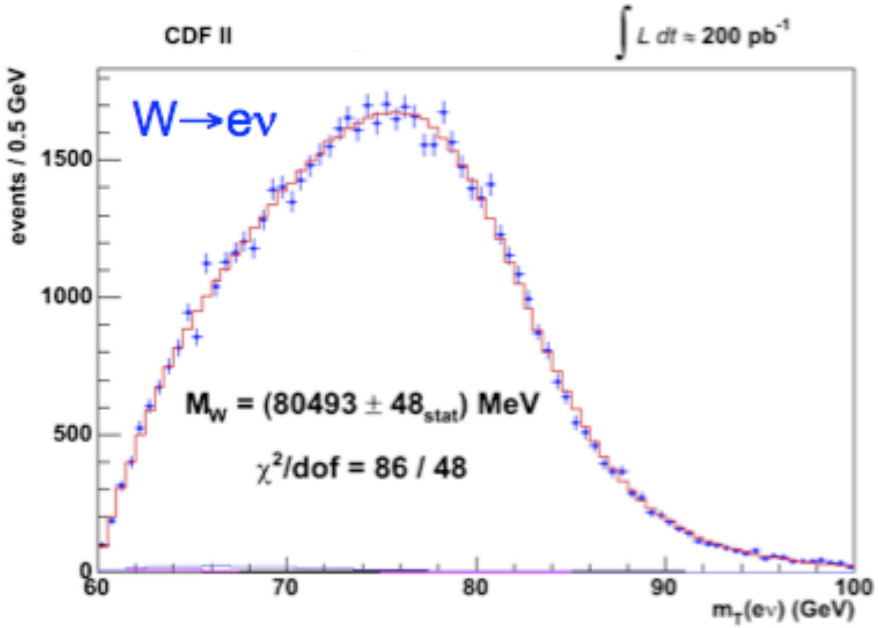


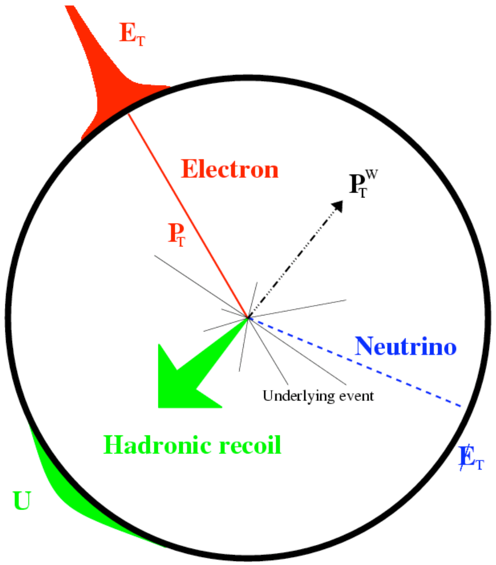
- $W \rightarrow \ell\upsilon$: single charged lepton:
  - high p_T
  - isolated
- E_T^{miss} (from υ)
  - cannot measure longitudinal υ
- peak in "transverse mass"

transverse mass: $m_T = \sqrt{2 p_T^{\,l} p_T^{\,\nu} (1 - \cos\phi_{l\nu})}$

Signatures of W and Z Production at the Tevatron







transverse mass: $m_T = \sqrt{2 p_T^{\,l} p_T^{\,\nu} (1 - \cos\phi_{l\nu})}$

- $W \to \ell\,\upsilon$: single charged lepton:
  - high p_T
  - isolated
- E_T^{miss} (from υ)
  - cannot measure longitudinal υ
- peak in “transverse mass”

Why bother?

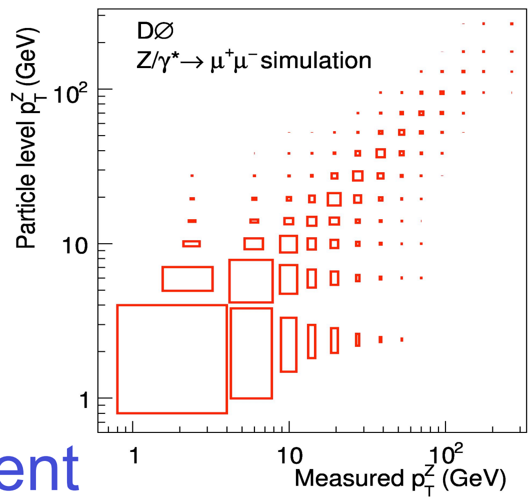
- Electroweak production
- Leptonic final states
- High statistics samples
- Low backgrounds

➢ Precise measurements!

- Clean probe of QCD and EW interactions
- Essential to tie standard processes down before claiming discoveries
  – either at the Tevatron or the LHC

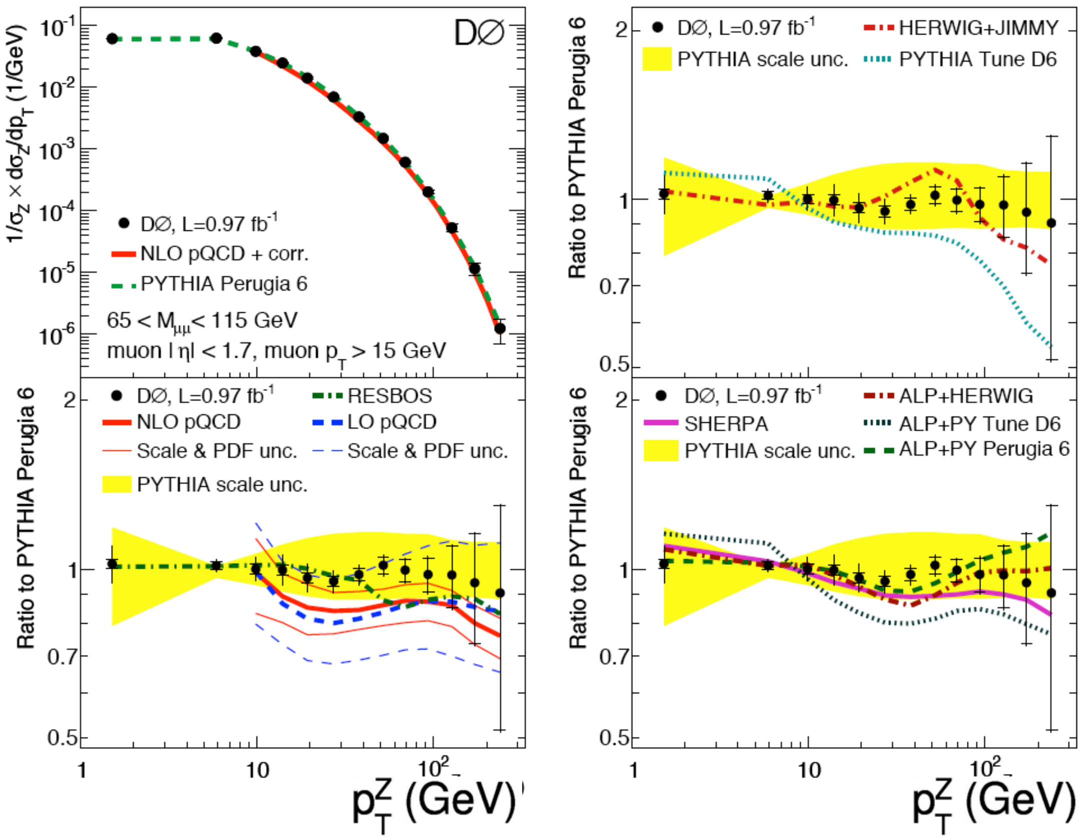
$Z \rightarrow \mu\mu$ transverse momentum

- $Z \rightarrow \mu\mu$, 1 fb^{-1}, DØ
- Unfold p_T^Z resolution

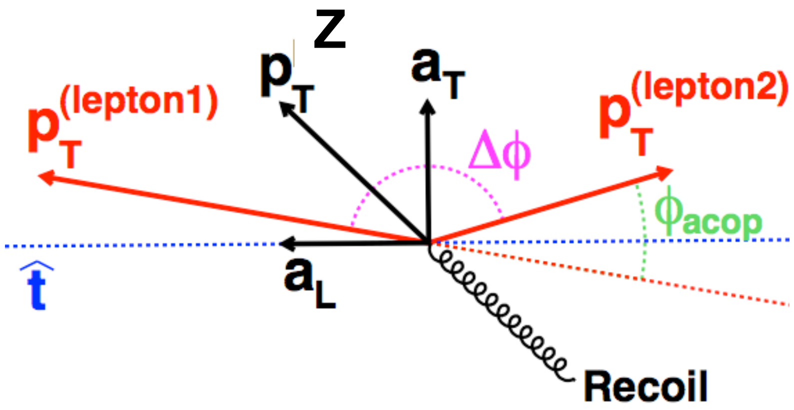


- For $p_T^Z < 30$ GeV
  - $\sigma_{syst} \sim 5\%$
  - dominated by p_T^{μ} resolution systematics
  - cf. $\sigma_{stat} \sim 1\%$
  - Restricts choice of bin widths
- Have such measurements reached the end of the road?

Data-MC agreement

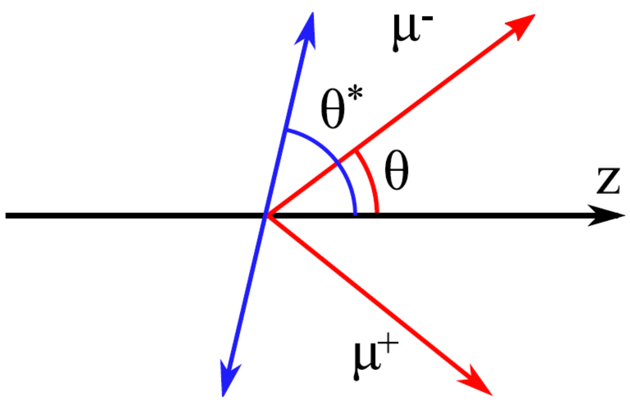


Study of p_T^Z using a novel method



$$\phi^*_\eta = \tan\left(\frac{\phi_{\rm acop}}{2}\right)\sin(\theta^*_\eta)$$

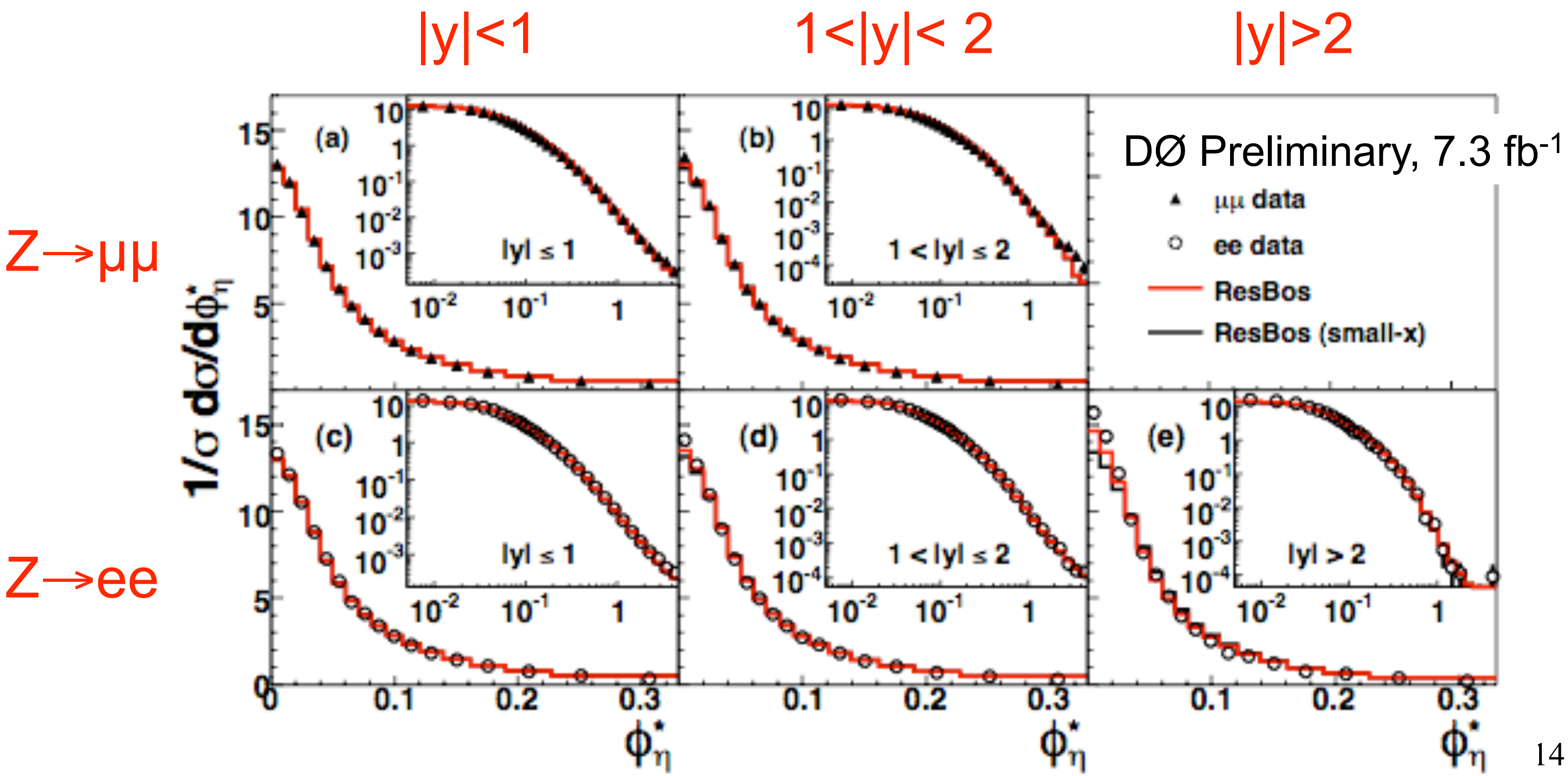
$$\cos(\theta^*_\eta) = \tanh\left(\frac{\eta^- - \eta^+}{2}\right)$$



- a_T less susceptible to detector resolution and efficiency variations than $p^T{}_Z$
- $a_T/m_{\ell\ell}$ even less susceptible to detector resolution
- $\phi^*_\eta \approx a_T/m_{\ell\ell}$
- measured using only the directions of the leptons and thus very well measured

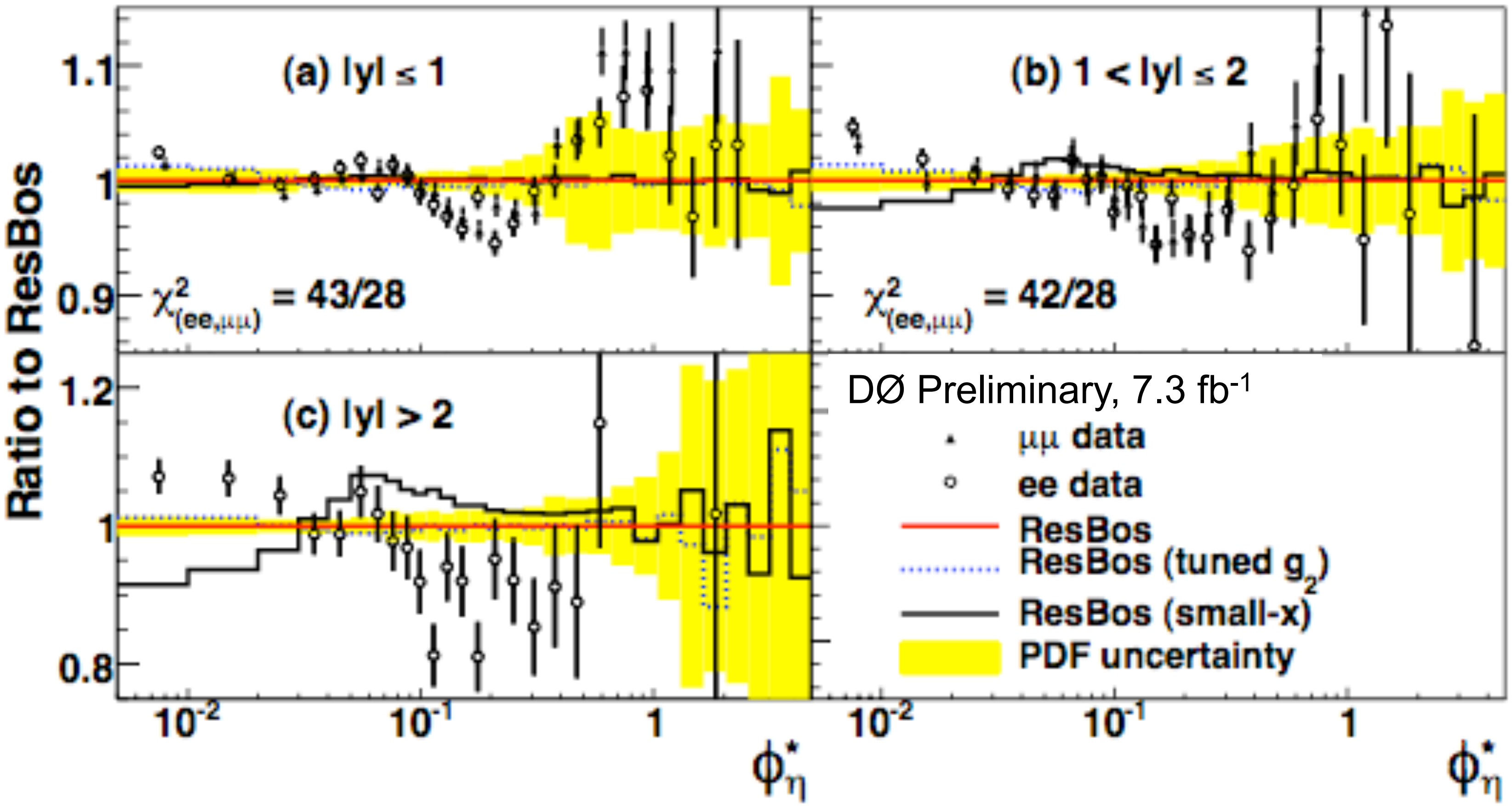
Study of p_T^Z using a novel method

- $Z \to ee$, $Z \to \mu\mu$; 7.3 fb^{-1}, DØ
- 966,000 events with $70 < m_{\ell\ell} < 110$ GeV
  - Compare corrected data to ResBos
    - with and without small-x broadening [Nadolsky, et al, Phys. Rev. D 64,114011 (2001)]



Study of p_T^Z using a novel method

- At low ϕ^*_η : narrow bins, σ_{stat} ~ 5 per mille and σ_{syst} ~ 1 per mille
- Compare Z→ee, Z→μμ corrected data
  - ratio to ResBos



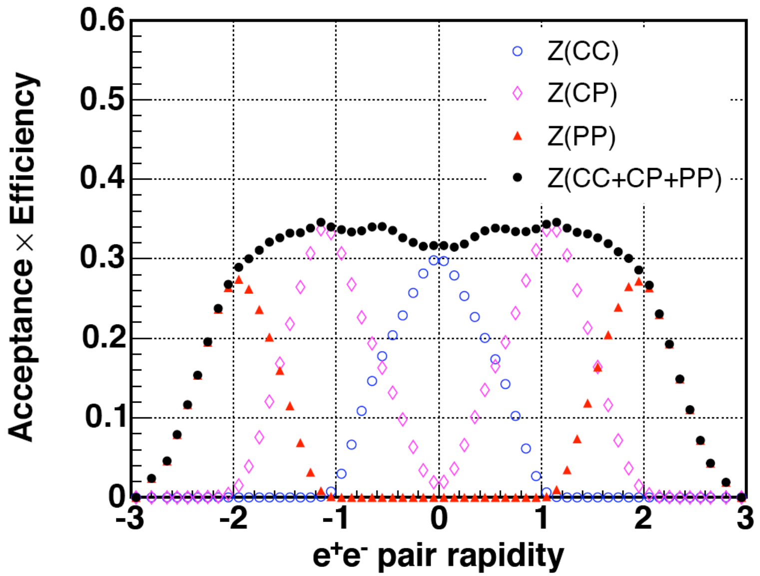
- Small-x broadening option clearly disfavoured

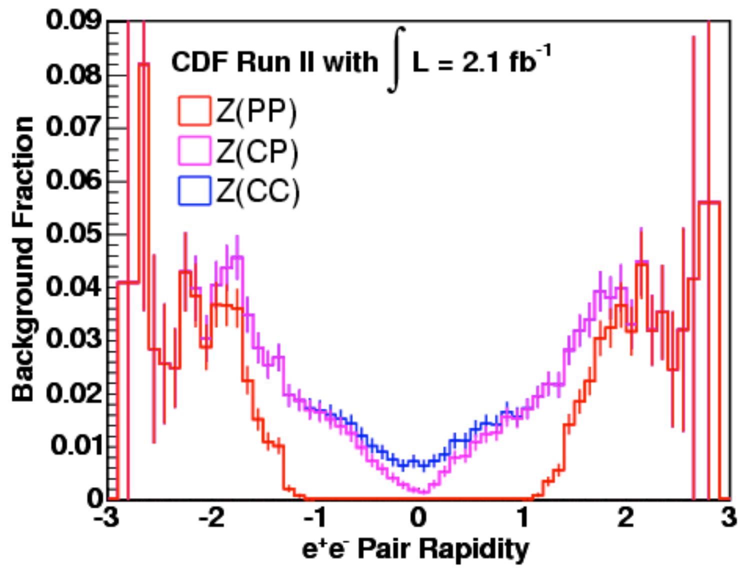
Z→ee total cross section and rapidity

- Z→ee, 2.2 fb^{-1}, CDF
- Electron coverage out to $|\eta|<2.8$
- Select 168000 candidate events in range $|y|<2.9$

Acceptance x Efficiency Background Fraction

– using central (C) and forward (plug, P) electrons





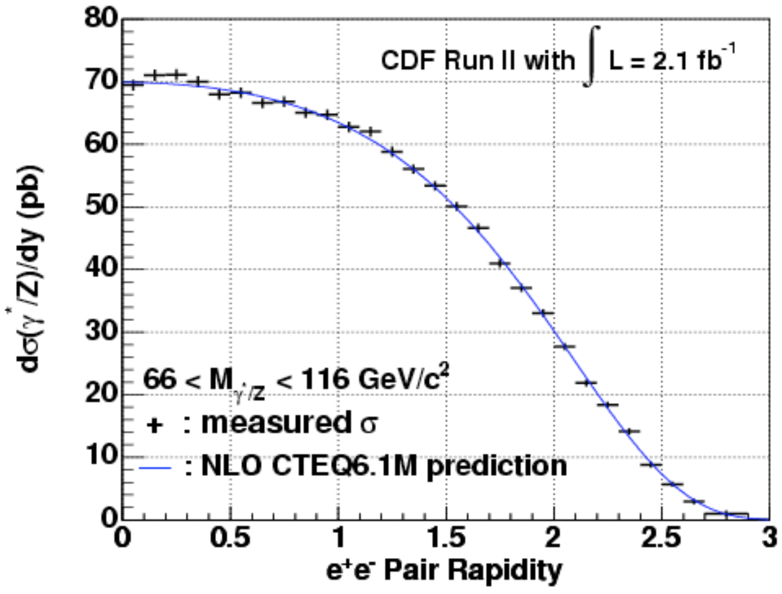
σ = 256.6 ± 0.7 (stat.) ± 2.0 (syst.) ± 15.4 (lumi) pb

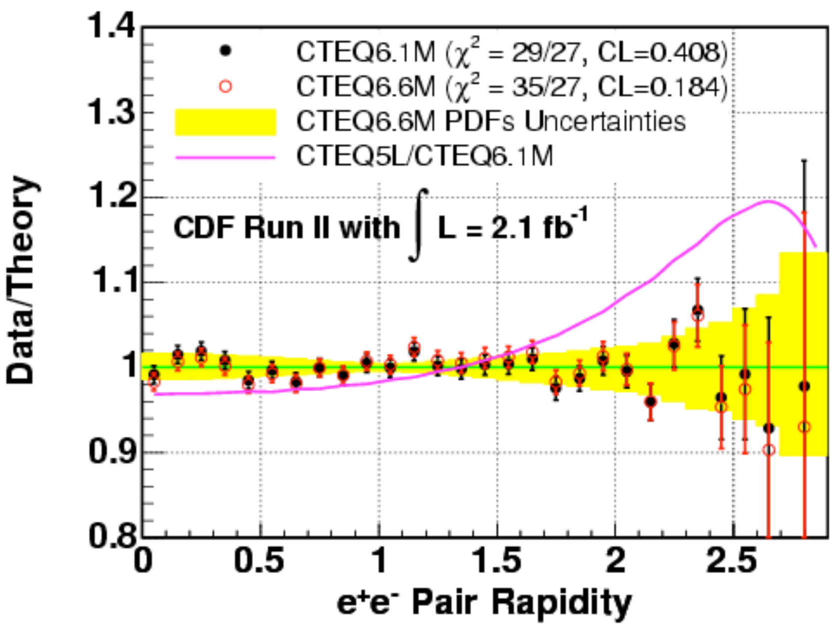
cf. σ = 238.7 +7.1 -7.0 pb (CTEQ6.6M NLO)

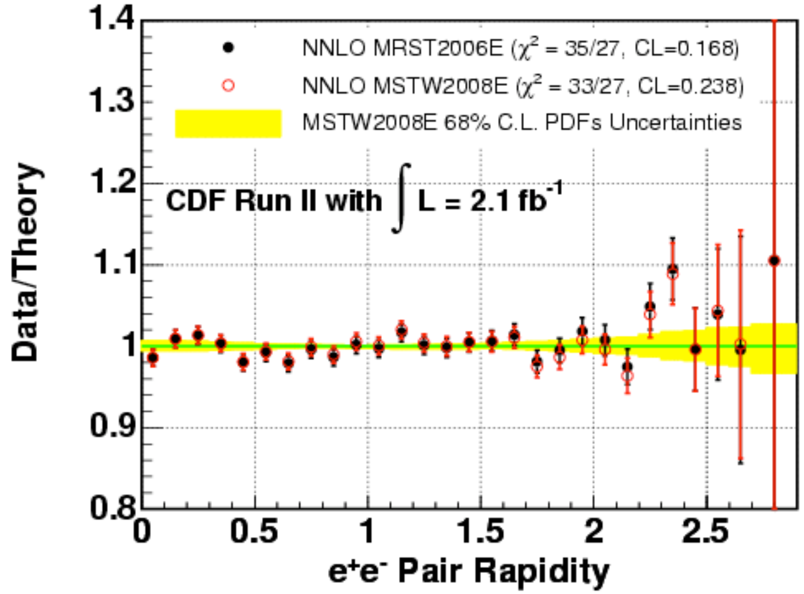
σ = 248.7 +5.1 -4.0 pb (MSTW2008E NNLO)

$d\sigma^Z/dy$

- $d\sigma^Z/dy$ sensitive to PDFs
- Total cross section and $d\sigma^Z/dy$ in good agreement with theory

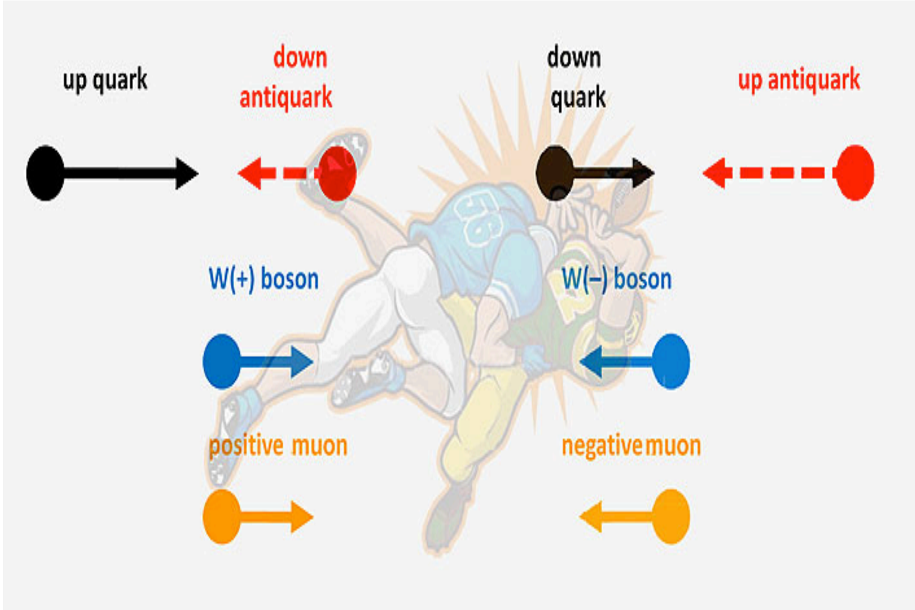


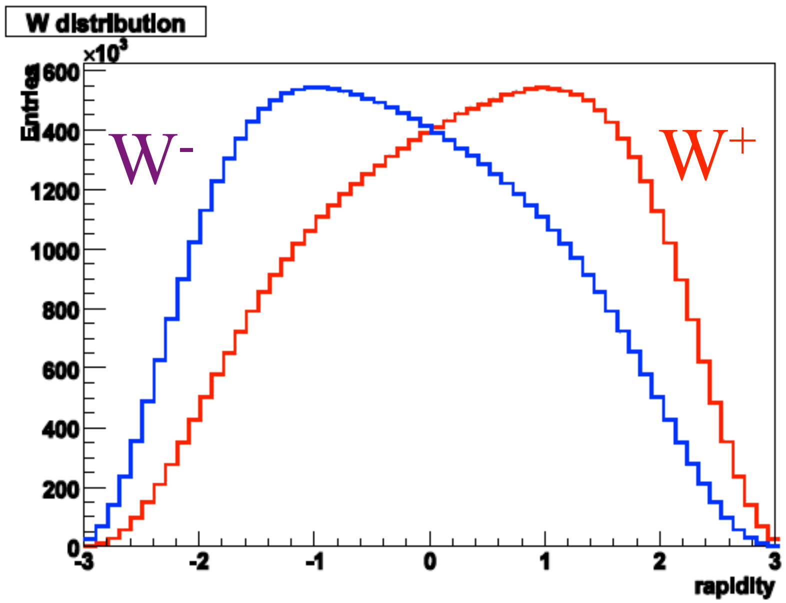


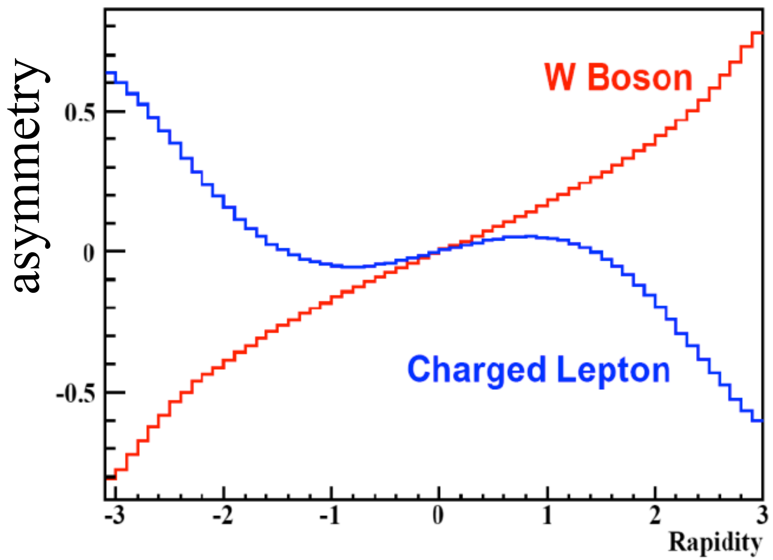


W Charge Asymmetry and PDFs

- u quark PDF is harder than d quark PDF
- W^+ (W^-) tends to be boosted along proton (antiproton) direction
- asymmetry = $(N^+-N^-)/(N^++N^-)$
- We actually observe the charged lepton
- W decay partially washes out asymmetry



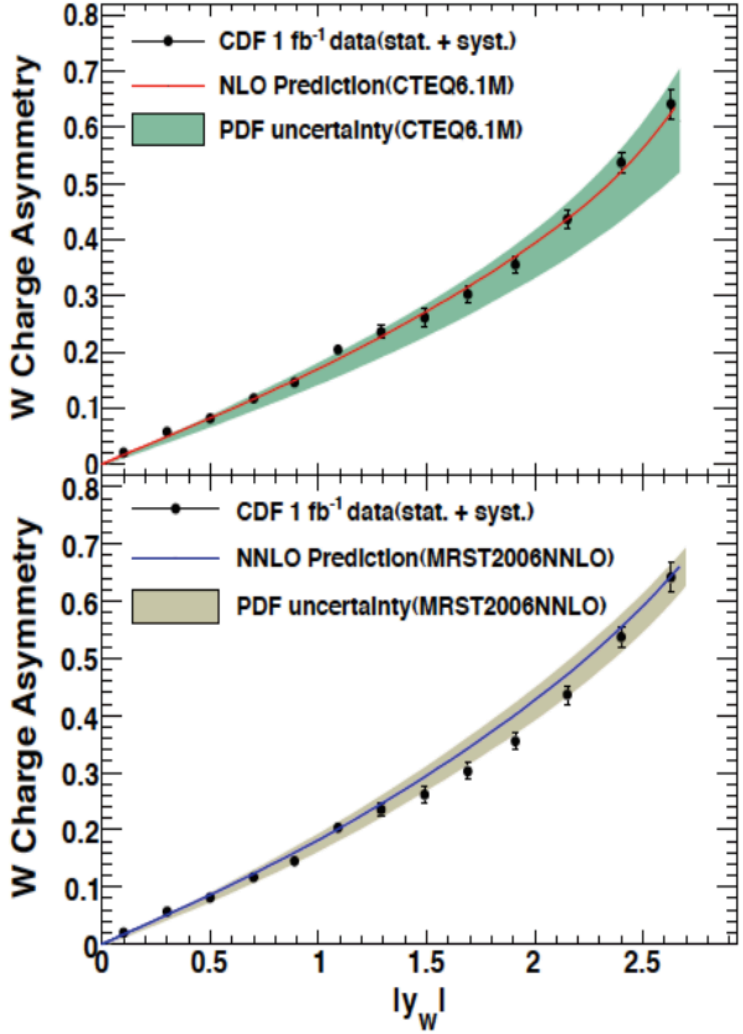




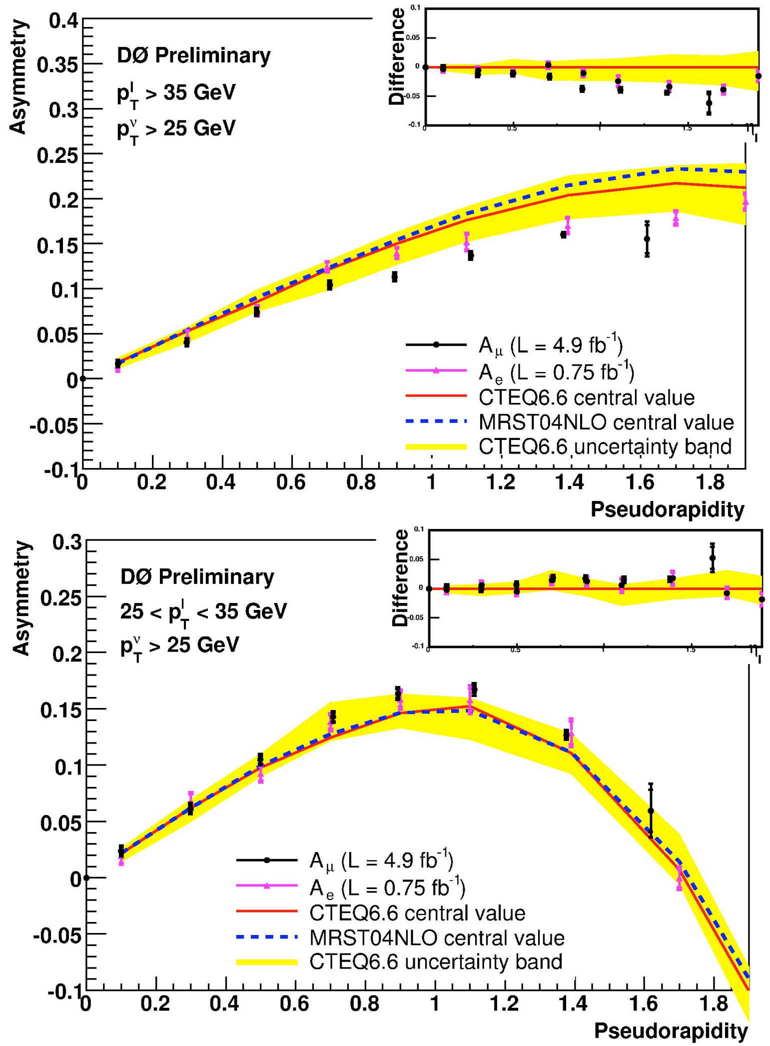
W Charge Asymmetry and PDFs

- Experiments published measurement in different form

Inclusive W boson charge A_{FB} (CDF)



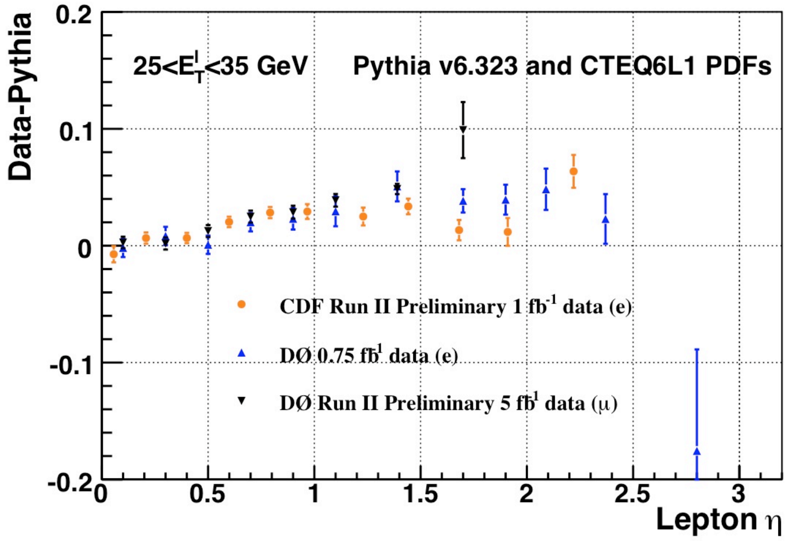
Charged lepton A_{FB} in lepton p_T bins (DØ)



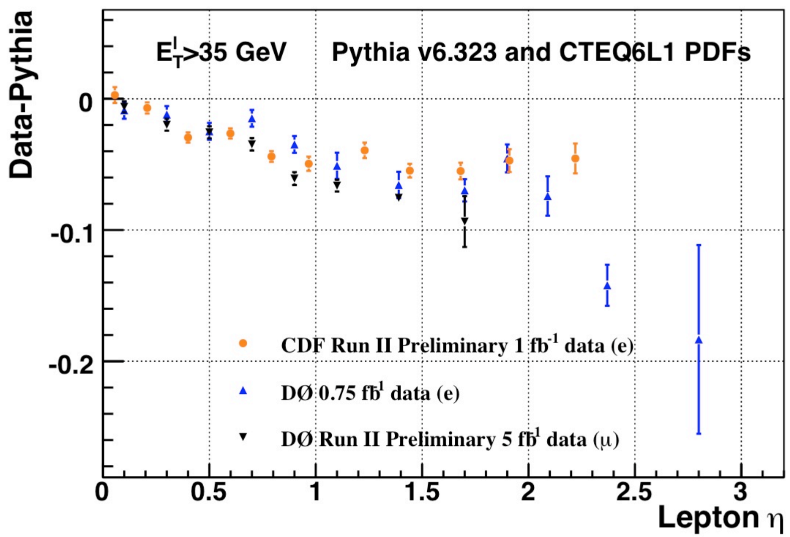
MSTW and CTEQ have problems to incorporate both CDF and DØ data into their global PDF fits

W Charge Asymmetry and PDFs

- CDF have re-analyzed their data (stat. uncertainties only) to allow a direct comparison with DØ



- The experiments agree!
- The problem looks to be in the theory!



Forward-backward asymmetry in Z→ee

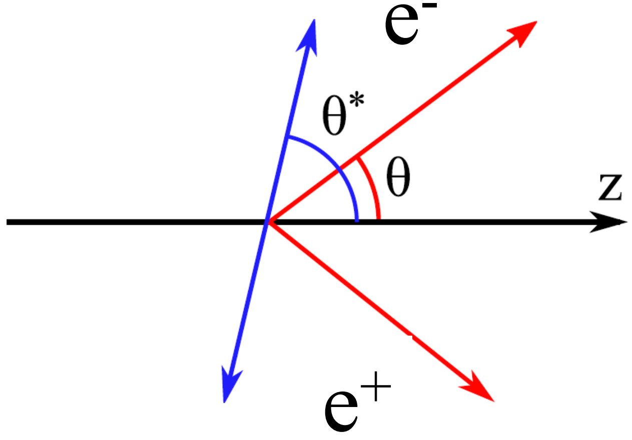
4.1 fb^{-1}, CDF   218000 candidate events

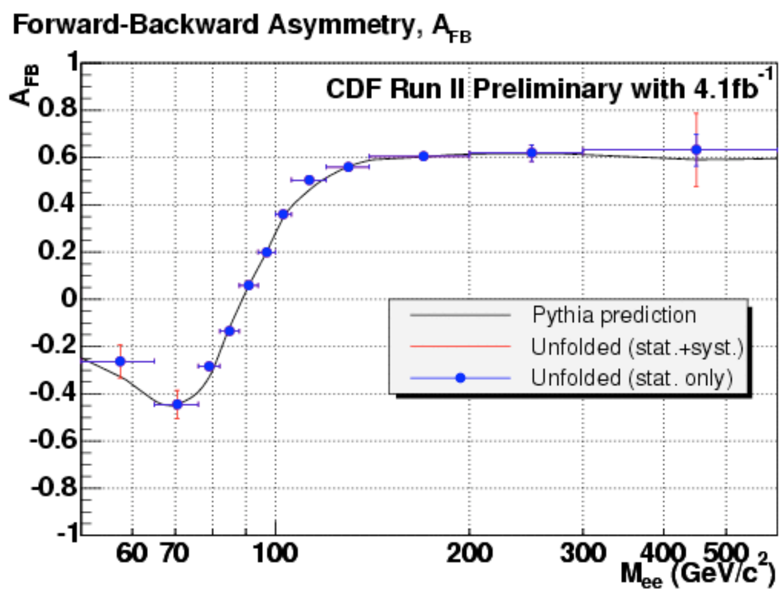
In the rest frame of the dilepton system:

$A_{FB} = (N_F - N_B) \ / \ (N_F + N_B)$

where:

N_F (N_B) is the number of e^- scattered in the same hemisphere as the outgoing proton (antiproton) beam





Prospects with 10-20 fb^{-1}

- It would be good to see measurements of each important quantity
  - transverse momentum, rapidity, asymmetry
  - as function of $m_{\ell\ell}$
- Using full data set
  - from both CDF and DØ
  - in both $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$
- Many of these measurements have the potential to remain statistics limited
  - scope for clever ideas!
- Potential impact on EW couplings, QCD models, PDFs

Example: Forward-backward asymmetry in Z→ℓℓ

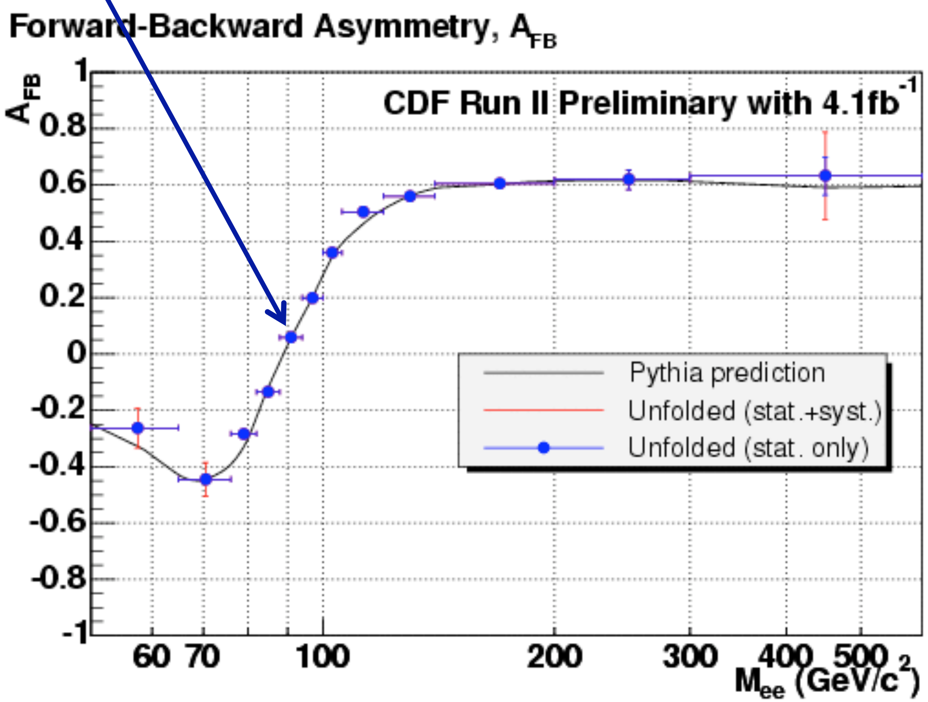
In the rest frame of the dilepton system:

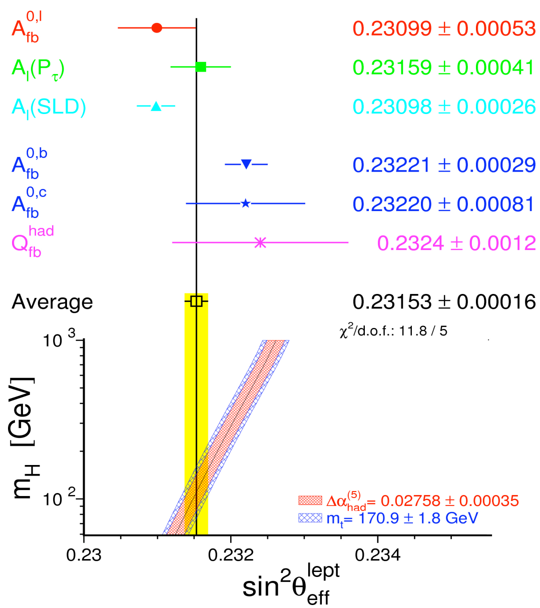
$A_{FB} = (N_F - N_B) \; / \; (N_F + N_B)$

Could achieve a high statistical precision

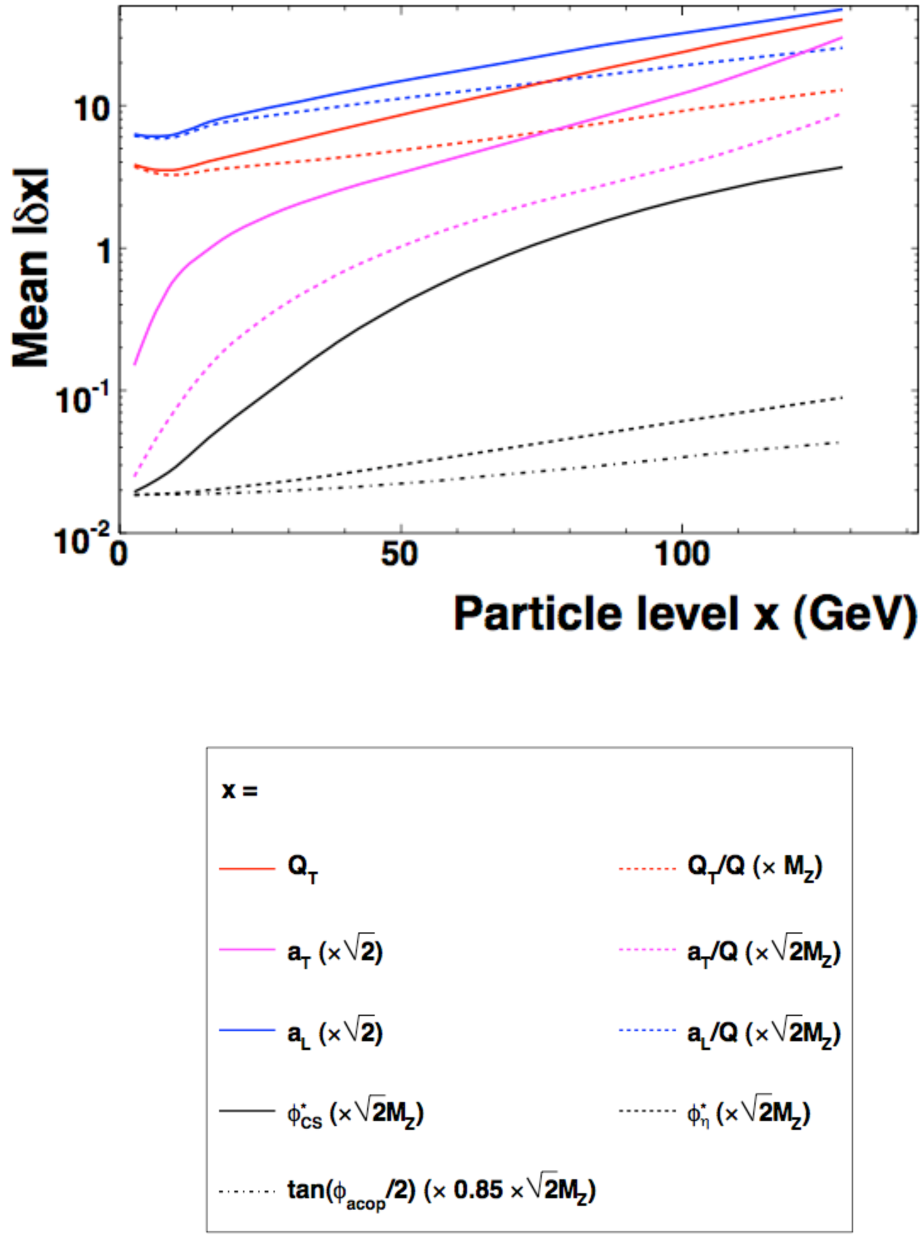
$\Delta\sin^2\theta_W^{eff} \approx \pm 0.0002$ (stat.) ± 0.0005 (PDF) ← Needs work!

In addition, can extract world's best a, v couplings for light quarks

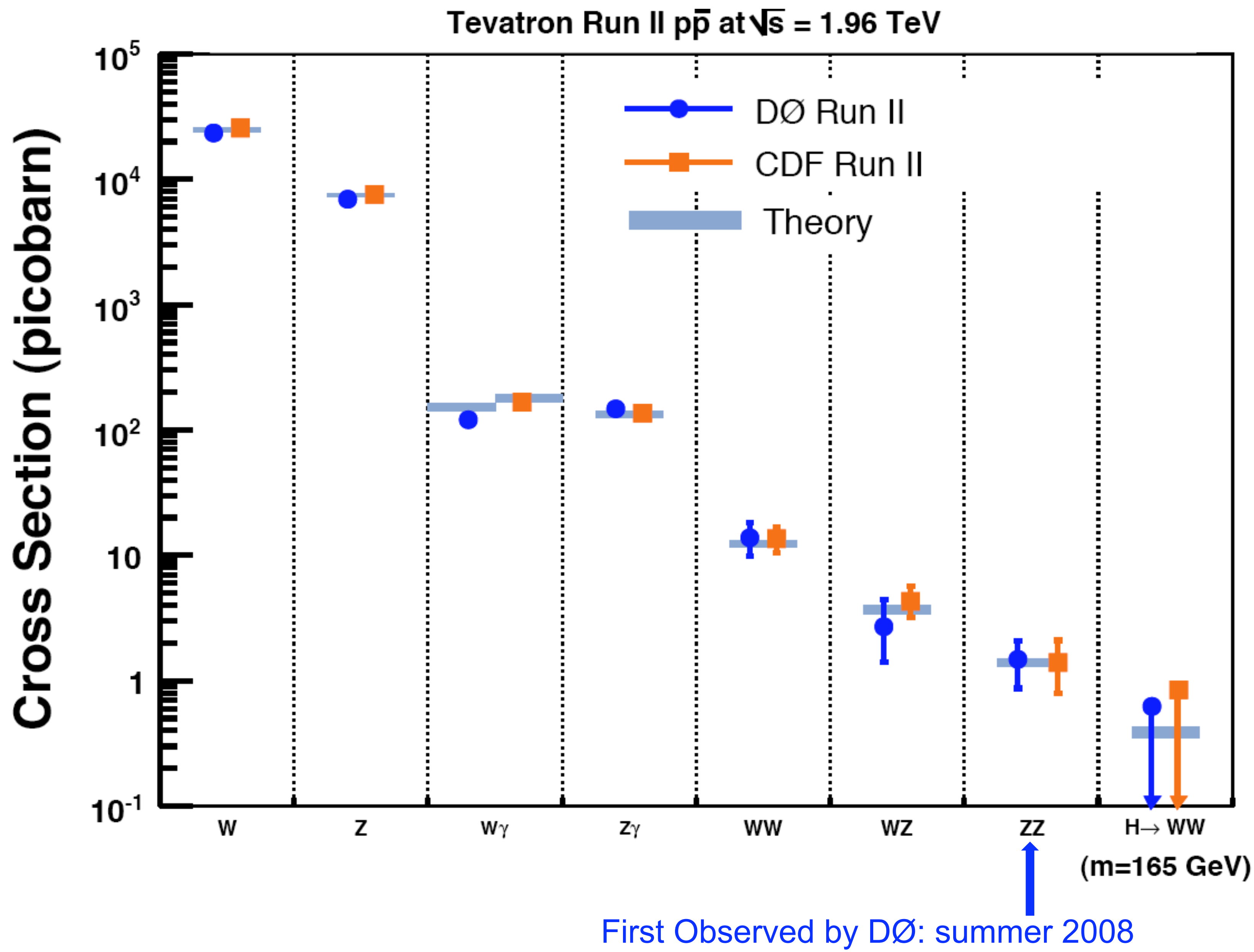




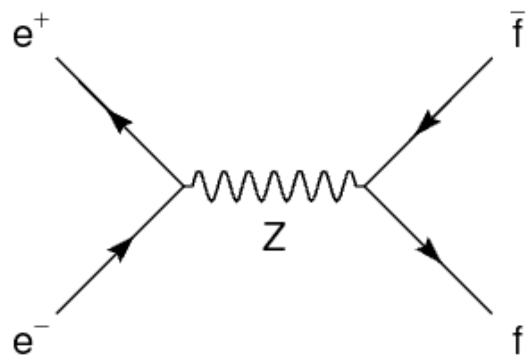
Backup Slides


Mean |δx|
10
1
10^{-1}
10^{-2}
0
50
100
Particle level x (GeV)
x =
Q_T
Q_T/Q ($\times M_Z$)
a_T ($\times\sqrt{2}$)
a_T/Q ($\times\sqrt{2}M_Z$)
a_L ($\times\sqrt{2}$)
a_L/Q ($\times\sqrt{2}M_Z$)
ϕ^*_{CS} ($\times\sqrt{2}M_Z$)
ϕ^*_η ($\times\sqrt{2}M_Z$)
$\tan(\phi_{acop}/2)$ ($\times$ 0.85 $\times\sqrt{2}M_Z$)

EW Cross Sections at the Tevatron



Parameters of The Standard Model

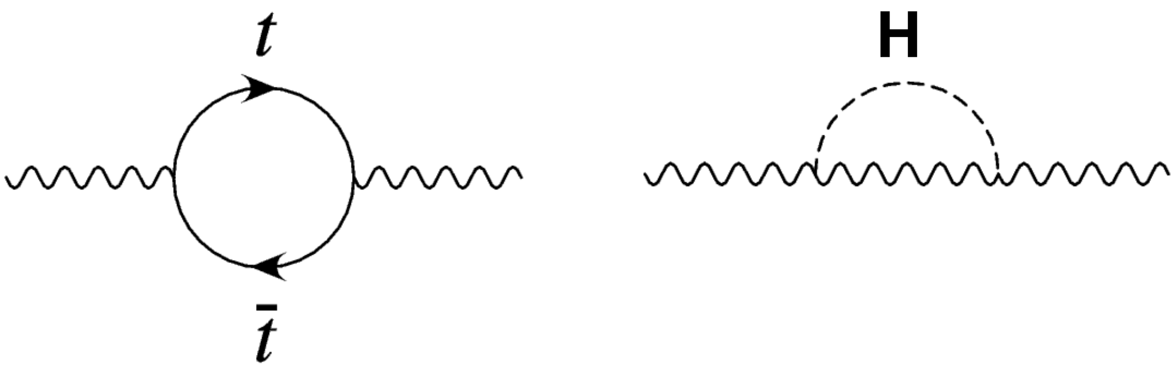


- At the level of simple "tree level" diagrams the EW interactions are determined by three "input" parameters
- Masses of W and Z also given in terms of coupling constants

$$m_W{}^2 = m_Z{}^2 \cos^2\theta_W = \frac{\pi\alpha}{\sqrt{2} G_F \sin^2\theta_W}$$

- For practical purposes we use as inputs the three most precisely known EW experimental observables:
  - The fine structure constant: $\alpha = e^2/2\varepsilon hc$
  - Fermi constant (measured in muon decay $\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$): G_F
  - Z mass: m_Z
- Adding QCD requires an additional constant:
  - The strong coupling constant: α_s

Loops

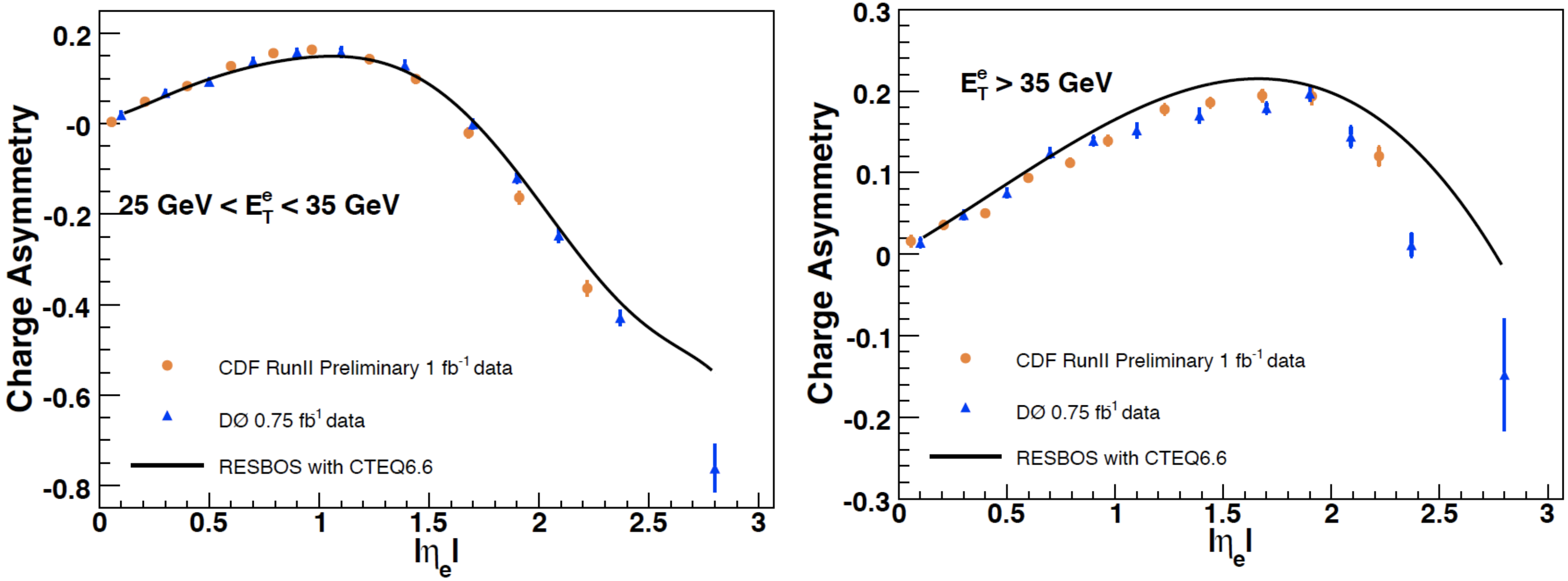


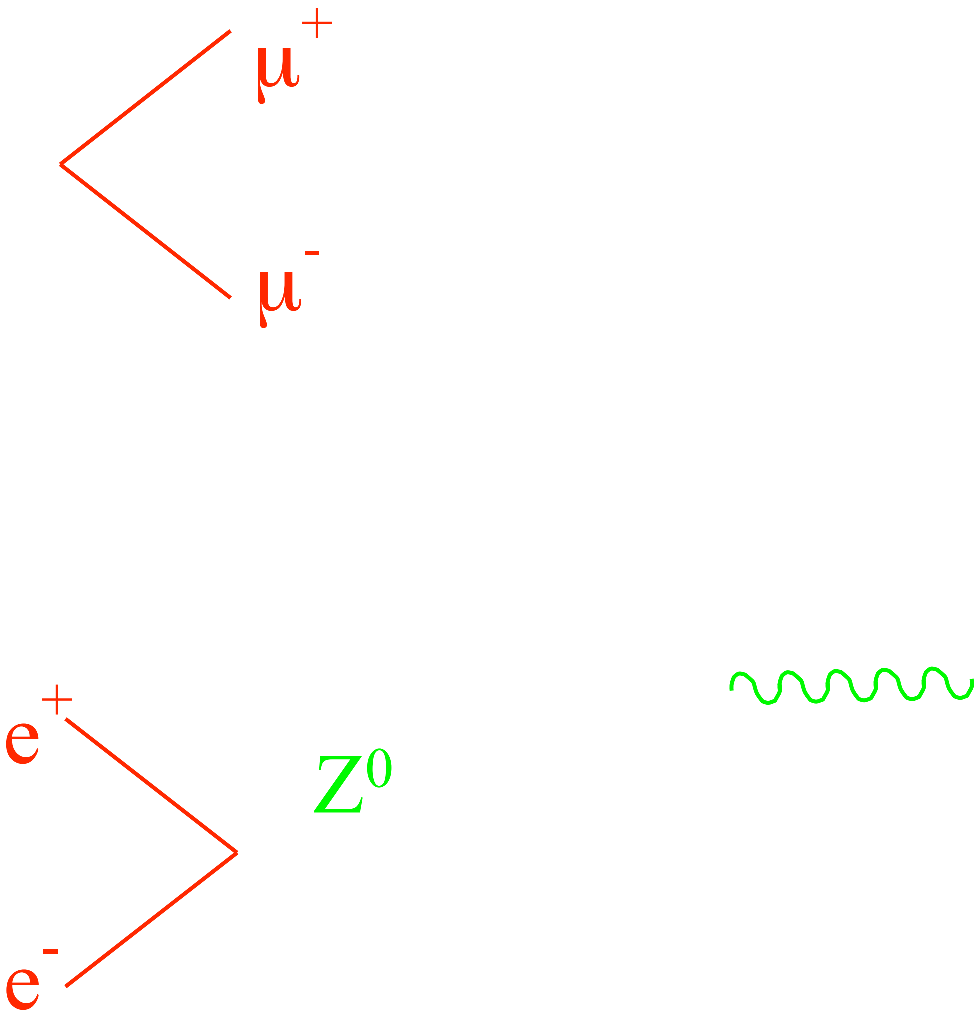
- Loops cause running of coupling constants
  - $\alpha \rightarrow \alpha(Q^2)$
  - $\sin^2\theta_W \rightarrow \sin^2\theta_W^{eff}$
- EW observables then depend on:
  - α, G_F, m_Z, m_t, m_H
- Basic programme:
  - Measure precisely L and R couplings of each fermion to γ, Z, W
  - Measure precisely boson self-interactions
  - Measure precisely α_s, α, G_F, m_Z, m_t
  - Test consistency of measurements with Standard Model predictions
  - Find the Higgs!
    - (or other new particles beyond the Standard Model)

- a

W Charge Asymmetry and PDFs

- CDF have re-analyzed their data (stat. uncertainties only) to allow a direct comparison with DØ




μ+
μ-
e+
e-
Z0