W, Z and Drell-Yan Production II Asymmetries

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For the DØ and CDF Collaborations

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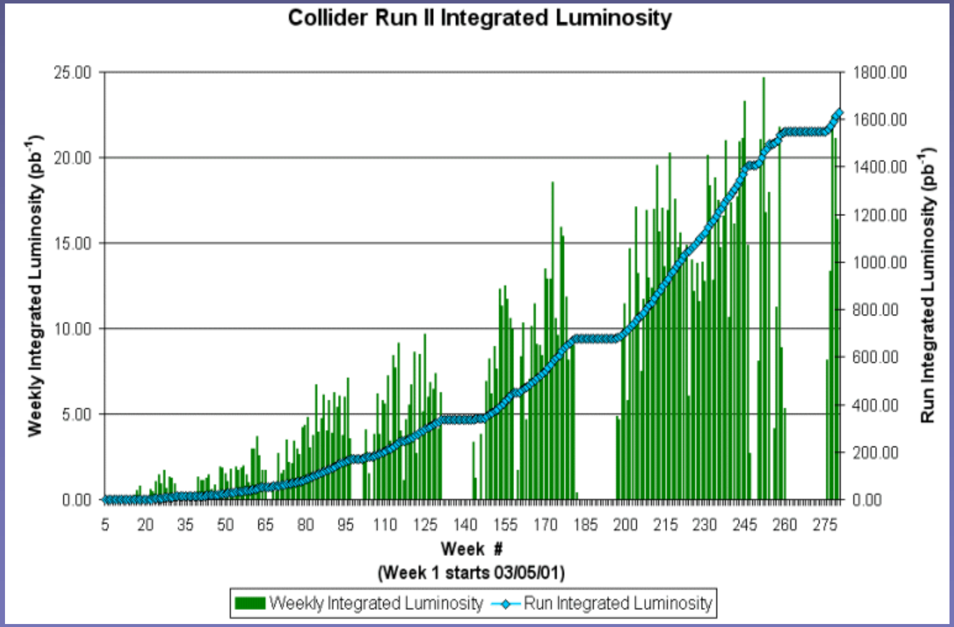
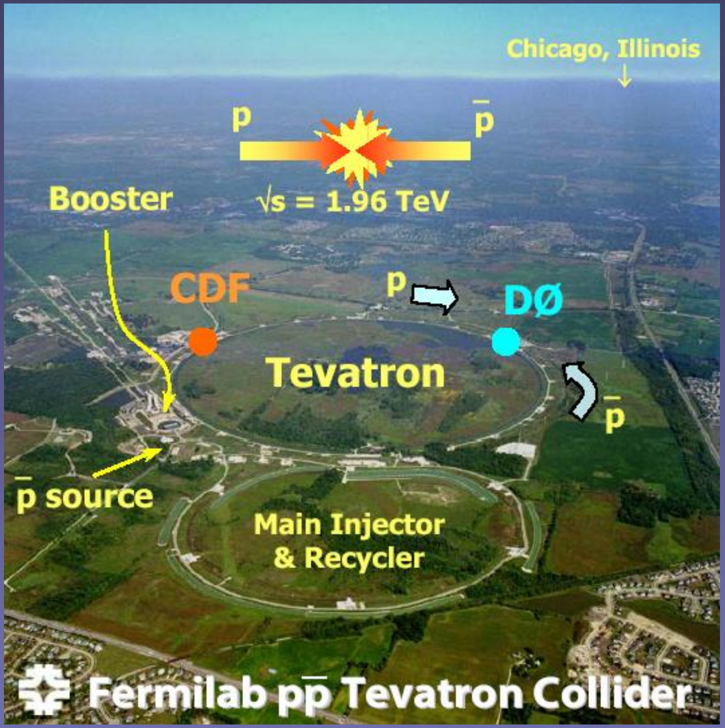
Outline

- W production charge asymmetry
  - $W \rightarrow \mu\nu$ (DØ) and $W \rightarrow e\nu$ (CDF)
  - direct method in $W \rightarrow e\nu$ (CDF)
- $Z \rightarrow ee$ forward/backward asymmetry (CDF)
- Summary



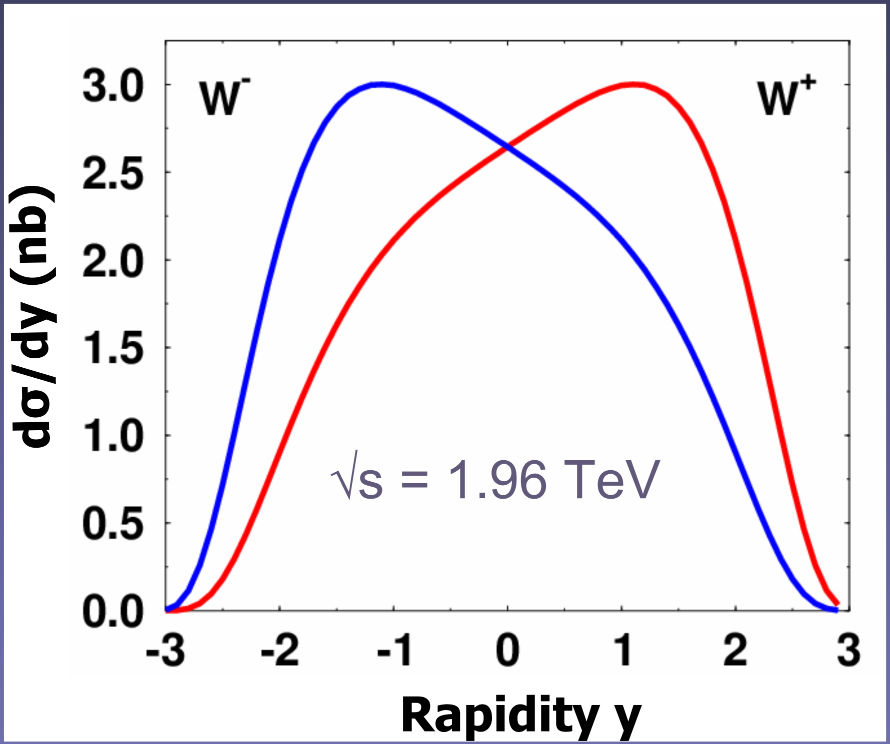


W boson production charge asymmetry

- u quarks typically carry more of a proton's momentum than d quarks
  - W^+ goes in the proton direction
  - W^- in the antiproton direction
- Use this difference to get information about the proton's u and d distributions – PDFs

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

$$\approx \frac{\frac{u}{d}(x_p) - \frac{u}{d}(x_{\bar{p}})}{\frac{u}{d}(x_p) + \frac{u}{d}(x_{\bar{p}})}$$



Q^2, x reach

Traditionally, PDFs are measured in deep inelastic scattering – high energy electron-nucleon interactions.

W asymmetry measurements:

$$Q^2 \approx M_W^2, \quad x = \frac{M_W}{\sqrt{s}} e^{\pm y_W}$$

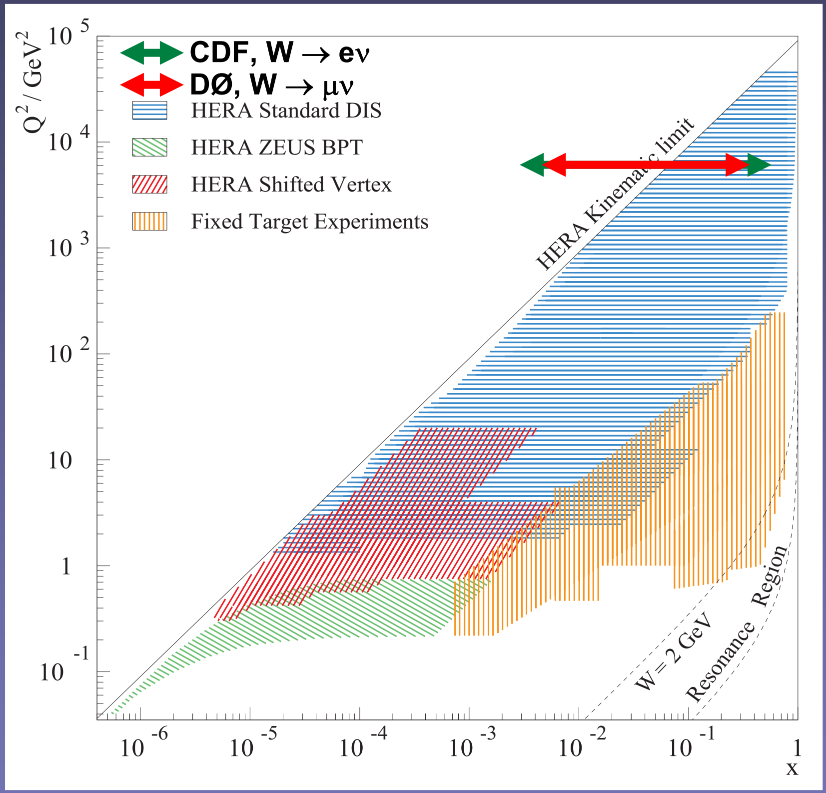
for $|y_W| < 2$ ($W \rightarrow \mu\nu$, DØ)

$0.005 < x < 0.3$

for $|y_W| < 2.5$ ($W \rightarrow e\nu$, CDF)

$0.003 < x < 0.5$

Q^2, x coverage for CDF, DØ, HERA and fixed target experiments



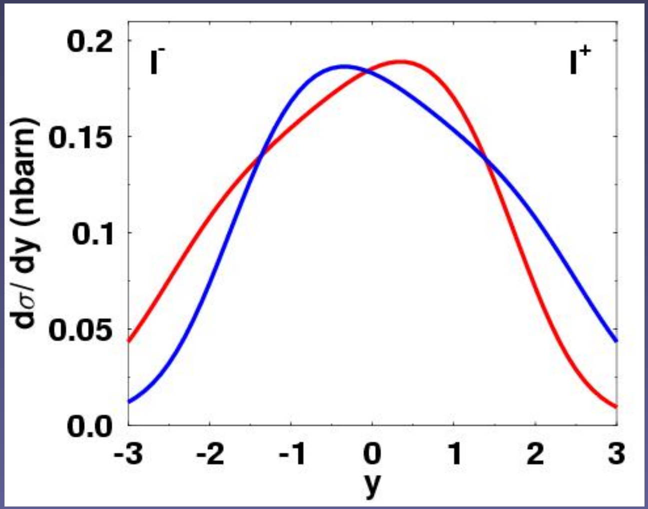
x = momentum fraction of parton

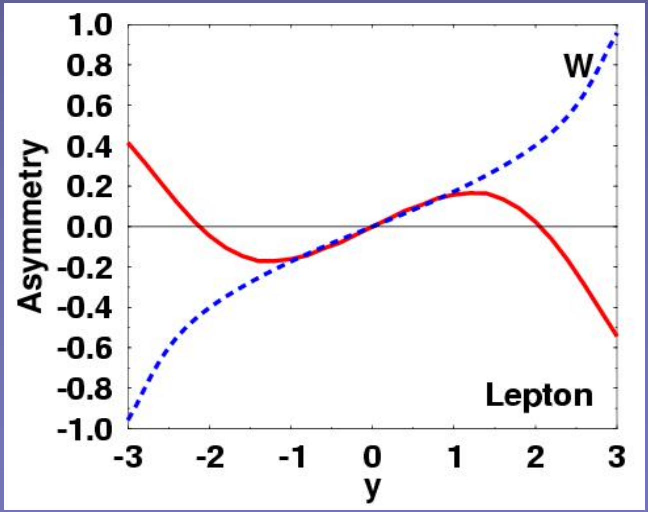
Q^2 = square of momentum transfer

Lepton charge asymmetry

- W asymmetry difficult to measure
  - neutrino longitudinal momentum
- Lepton pseudorapidity is available
- Lepton asymmetry is a combination of the W asymmetry and V–A interaction from decay
  - at higher lepton transverse momentum, V–A contribution is smaller, $A(y_\ell)$ is larger
  - at higher lepton rapidity, V–A contribution is larger, $A(y_\ell)$ is smaller

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





For all muon momenta

W → μν (DØ) and W → eν (CDF)

W → μν

L = 230 pb^{-1}
$p_T^{\mu} > 20$ GeV
$|\eta| < 2.0$
$\not{E}_T > 20$ GeV
$M_T > 40$ GeV

W → eν

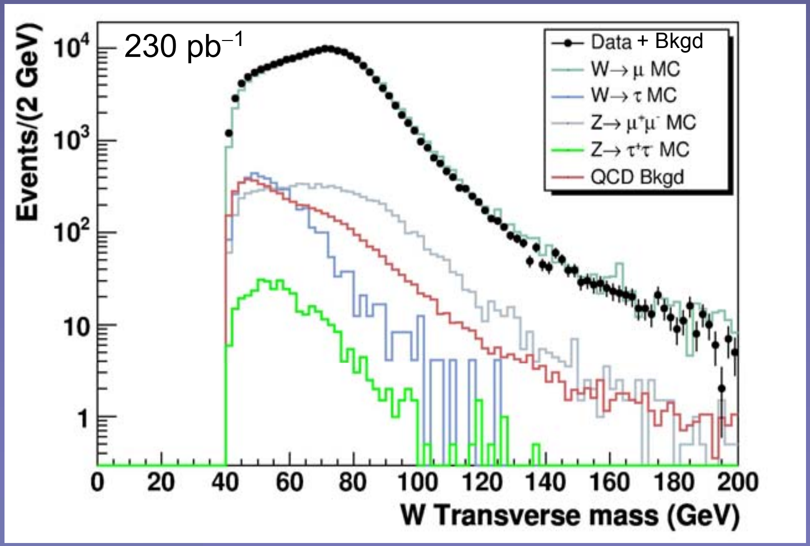
L = 170 pb^{-1}
$E_T^{e} > 25$ GeV
$|\eta| < 2.5$
$\not{E}_T > 25$ GeV
$50 < M_T < 100$ GeV

Tight selections to reduce charge and event misidentification

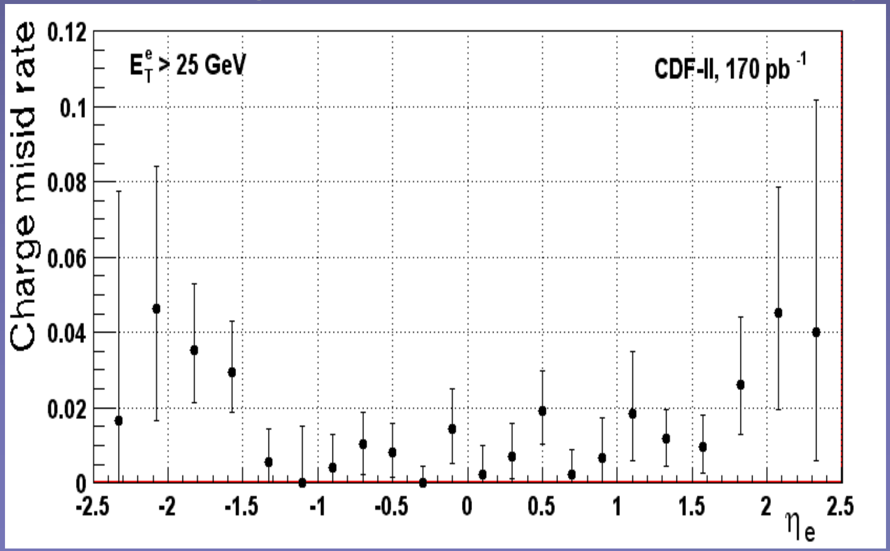
charge misid ≈10^{-4} for W → μν
≈10^{-2} for W → eν

Analyses done bin-by-bin

DØ transverse mass distribution



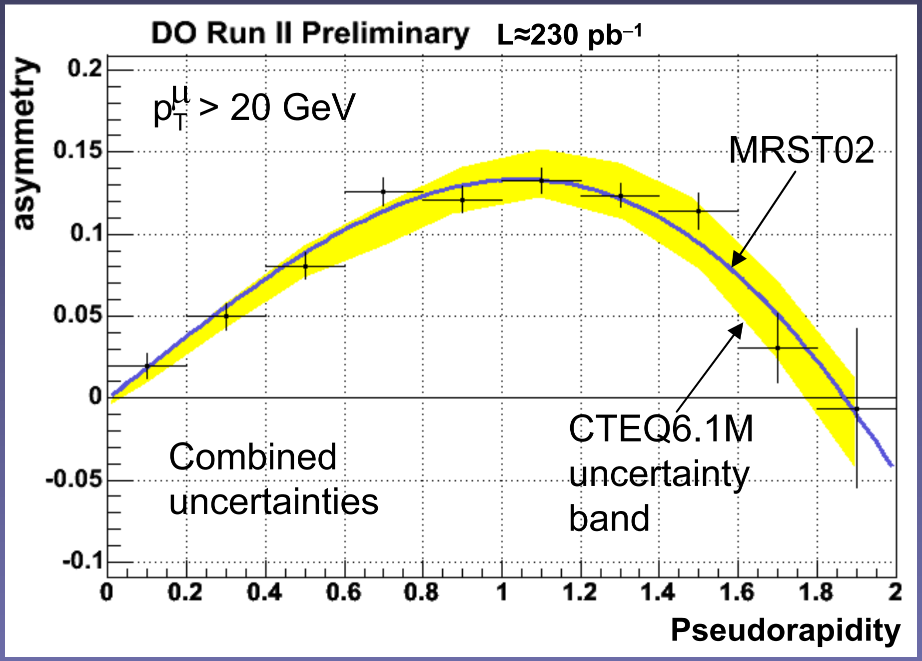
CDF charge misid vs pseudorapidity



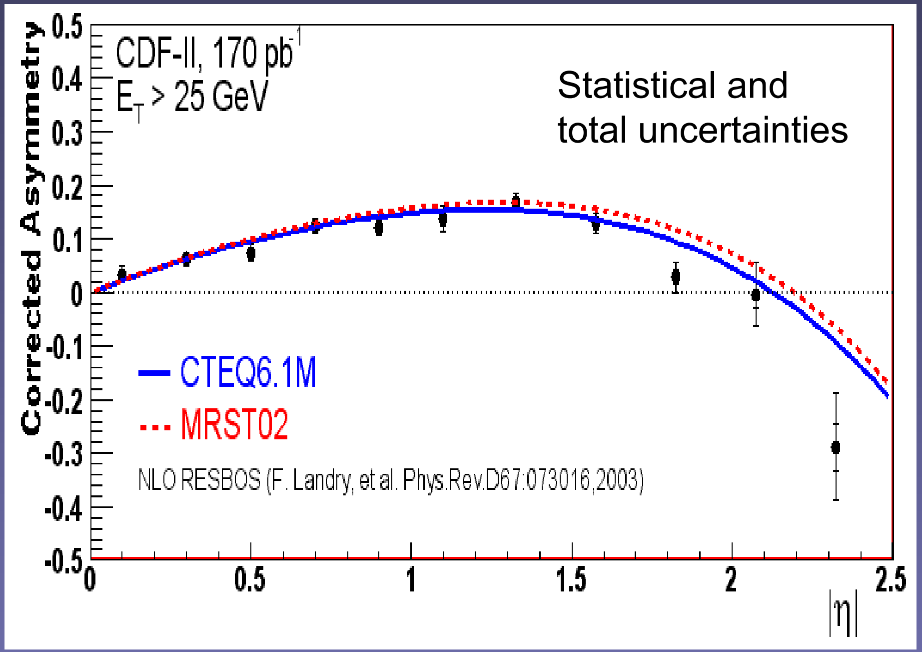
PRD 71, 051104(R) (2005)

Asymmetry vs pseudorapidity

$W \to \mu\nu$



$W \to e\nu$



PRD 71, 051104(R) (2005)

W production and decay are CP invariant; fold the asymmetry to increase statistics.

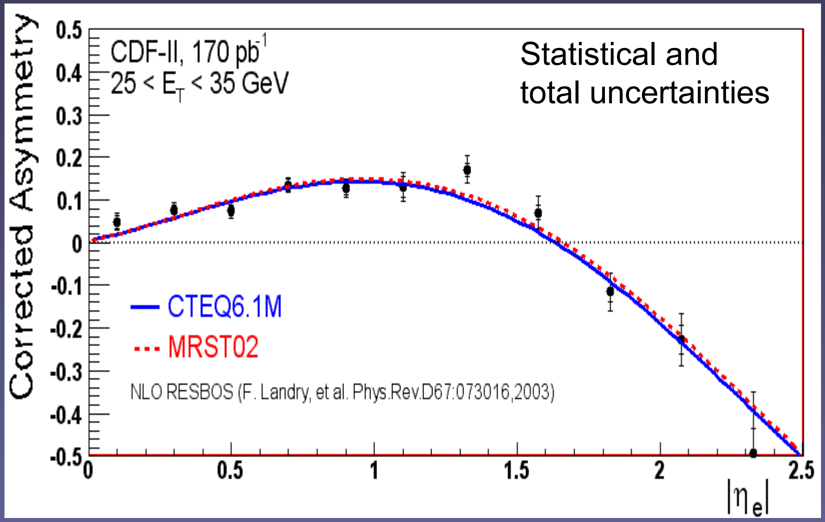
Statistical uncertainties comparable to or much larger than systematic for $|\eta| \gtrsim 0.4$

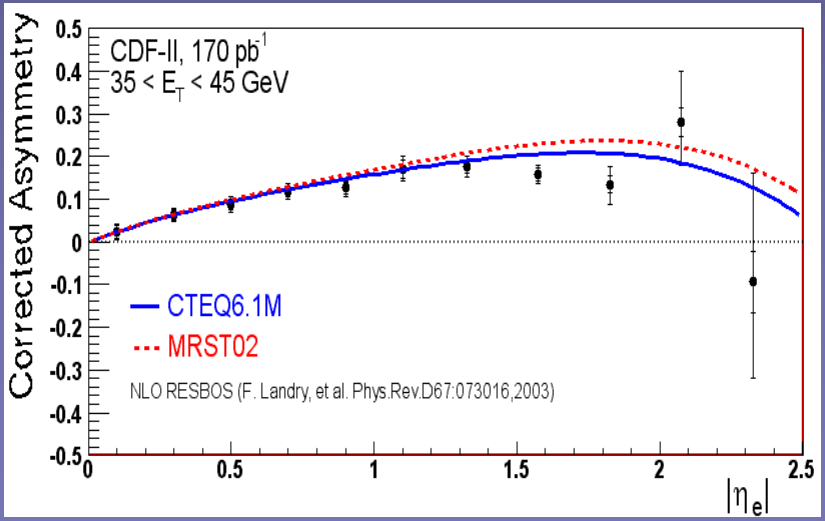
Asymmetry in E_T bins (CDF)

Improve correspondence between η_e and y_W

- For a given η_e, E_T regions probe different ranges of y_W (x); higher E_T bin covers a narrower y_W range
- p_Z ambiguity is a smaller effect for high-E_T electrons

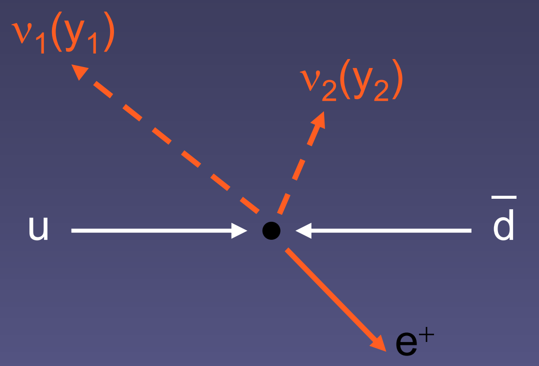
$25 < E_T < 35$ GeV
$35 < E_T < 45$ GeV

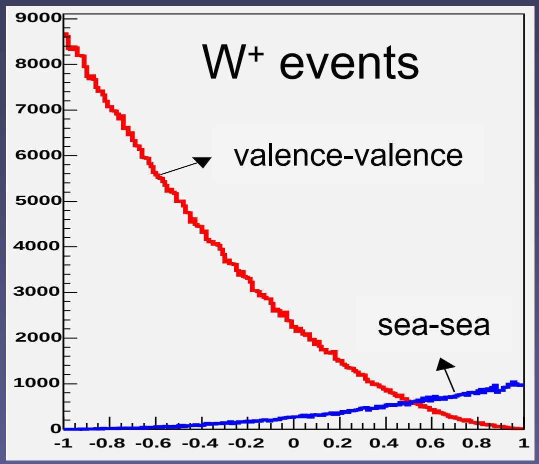




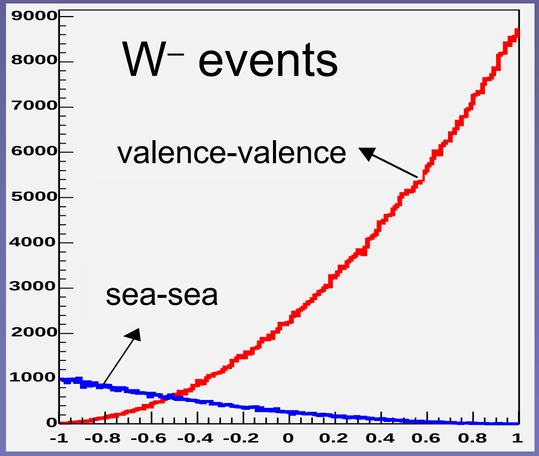
PRD 71, 051104(R) (2005)

Direct W asymmetry method – CDF





$\cos\theta^*$



$\cos\theta^*$

Reconstruct y_W distribution

W mass constraint

Weight the two solutions

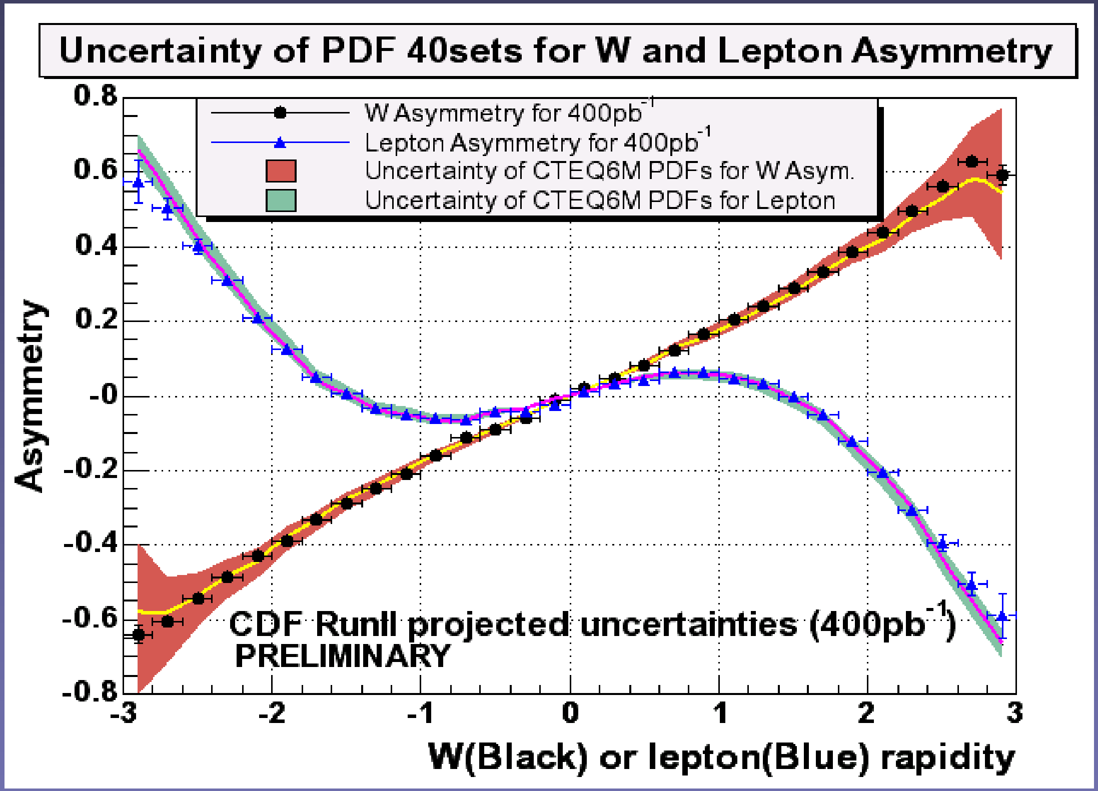
- weight takes production and decay into account
- depends on $\cos\theta^*$, $y_{1,2}$, p_T^W, $\sigma(y_{1,2})$, y_W

Iterate since weight depends on y_W

θ^* = angle of charged lepton in W frame

Projected uncertainties of direct method

Compare expected statistical uncertainties in W asymmetry and lepton asymmetry with CTEQ6M error sets



400 pb^{-1} Pythia events

$E_T^e > 25$ GeV

$\not{E}_T > 25$ GeV

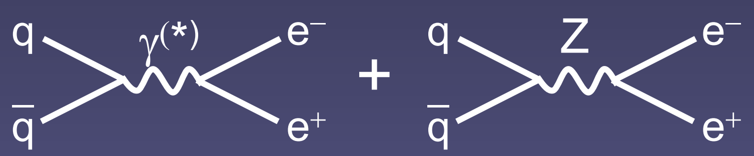
Direct method for W asymmetry measurement shows improved statistical uncertainty

Estimated systematics are small

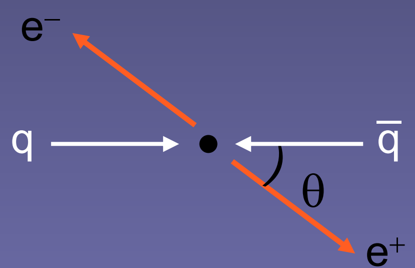
$Z \to$ ee forward-backward asymmetry (CDF)

Interference between $\gamma^{(*)}$ and Z exchanges

Interference depends on M_{ee}



Primarily γ^* exchange below Z
Z exchange at Z
Z/γ exchange above Z



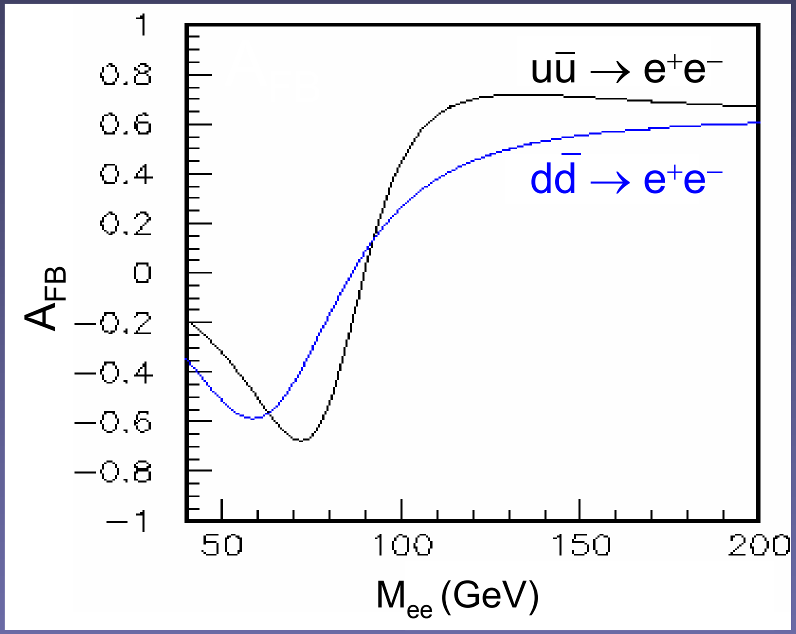
$$\frac{d\sigma}{d\cos\theta} = A(1+\cos^2\theta) + B\cos\theta$$

A and B depend on $g_V^{q,\ell}$, $g_A^{q,\ell}$, Q_q and Q_ℓ and are related through the forward-backward asymmetry, $A_{FB} = \frac{3B}{8A}$

$$A_{FB} = \frac{\sigma(\cos\theta>0) - \sigma(\cos\theta<0)}{\sigma(\cos\theta>0) + \sigma(\cos\theta<0)}$$

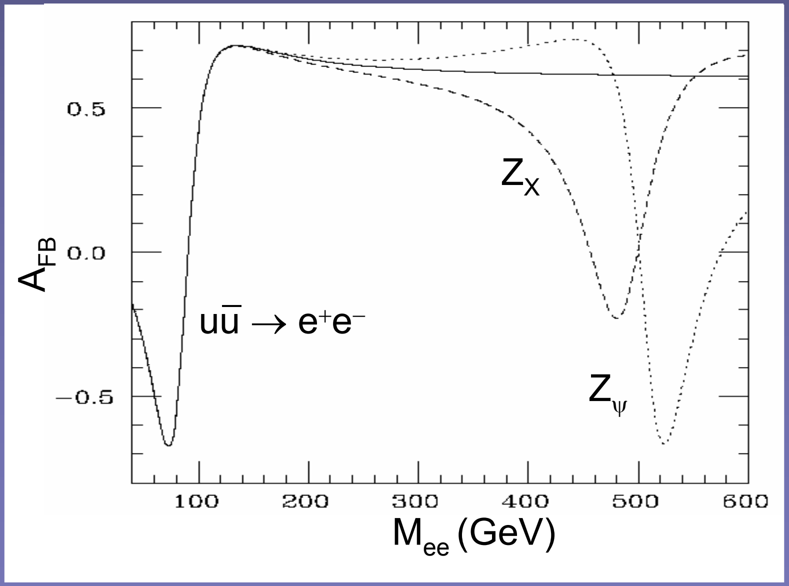
$$= \frac{N_F - N_B}{N_F + N_B}$$

A_{FB} distributions



Probe relative strengths of Z-q couplings; sensitive to u and d quarks separately

500 GeV Z′



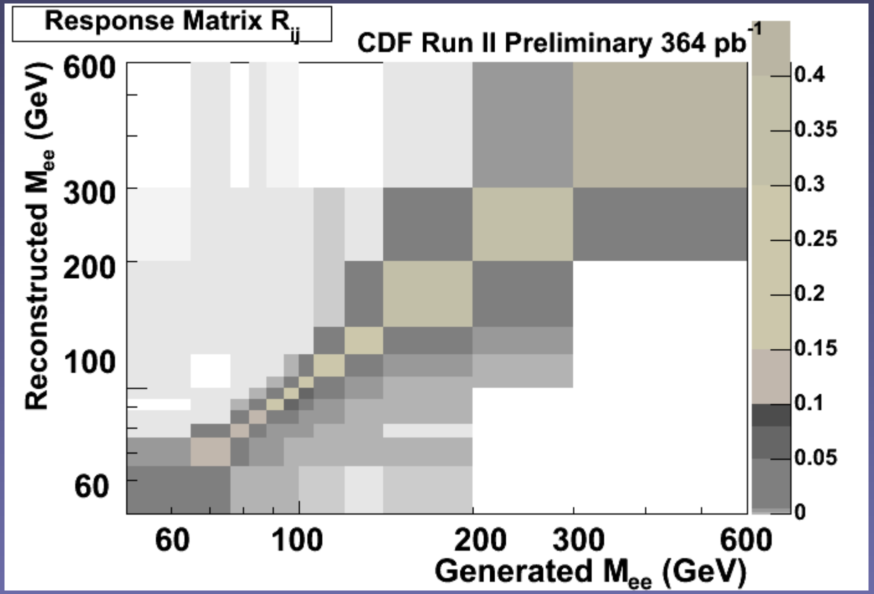
J.L. Rosner, PRD 54, 1078 (1996)

Exchange of new particle(s) would alter A_{FB}

Determining A_{FB}

Since it's a ratio, reduced systematics of luminosity, acceptances/efficiencies

$$A_{FB} = \frac{\dfrac{N_F - N_F^{bkg}}{a_F} - \dfrac{N_B - N_B^{bkg}}{a_B}}{\dfrac{N_F - N_F^{bkg}}{a_F} + \dfrac{N_B - N_B^{bkg}}{a_B}}$$



Correct for background, acceptance/efficiency

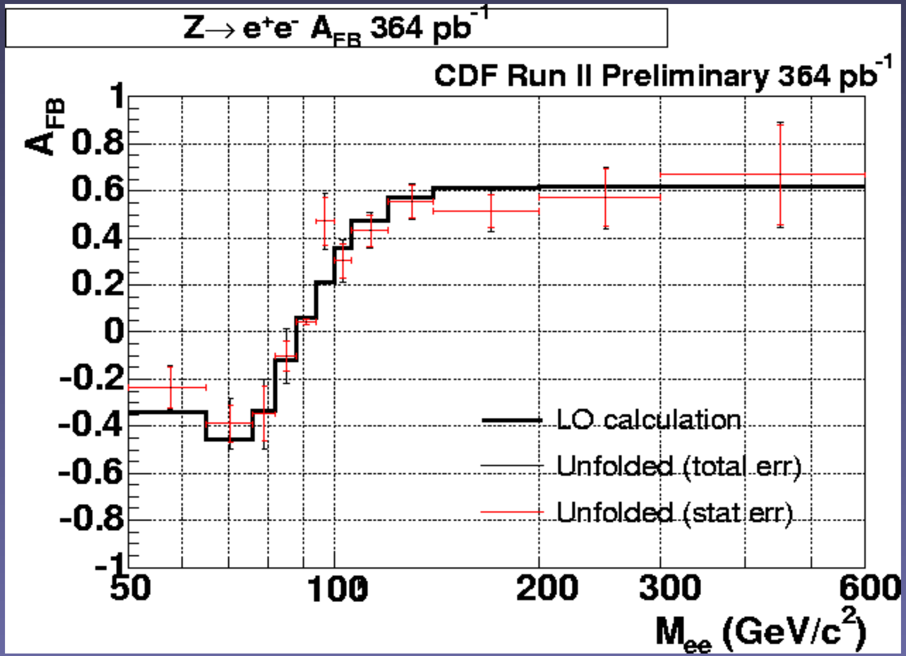
Acceptance is symmetric; distribution is not
    shifts A_{FB} within a mass bin

Event migration between bins
    large correlations between bins near Z pole

ISR and FSR

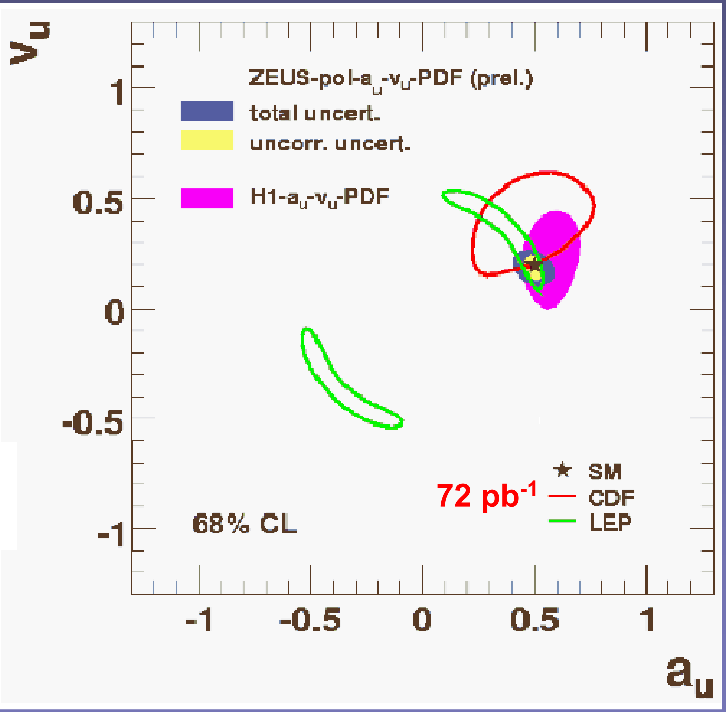
Use a matrix based on MC events to "unfold" raw A_{FB} distribution (correct for acceptance/efficiency and smearing)

Unfolded A_{FB} distribution



Agreement with LO SM calculation is χ^2/dof = 10.9/12

No evidence for additional gauge bosons



Can fit for quark and electron couplings
Example using 72 pb^{-1} result

CDF: PRD 71, 052002 (2005)
Wichmann, HCP 2006

Updating to 1 fb^{-1}

Summary

Both DØ and CDF are measuring W and Z/γ asymmetries

useful for constraining PDF fits

for gaining information on quark and electron EW couplings

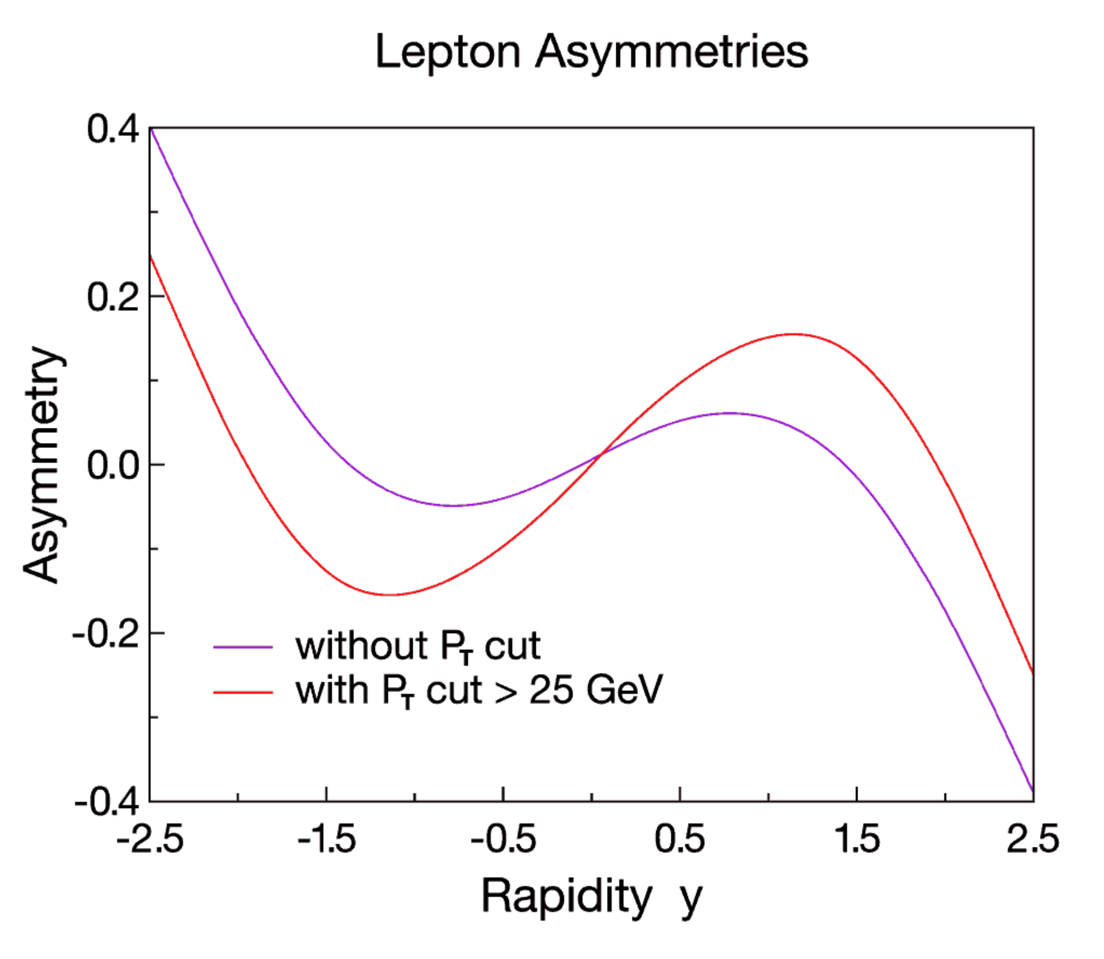
for searching for additional gauge bosons

and, of course, for testing the Standard Model

Both experiments have significantly more data available, over 1fb^{-1}, and are making progress on extending these analyses to include this data.

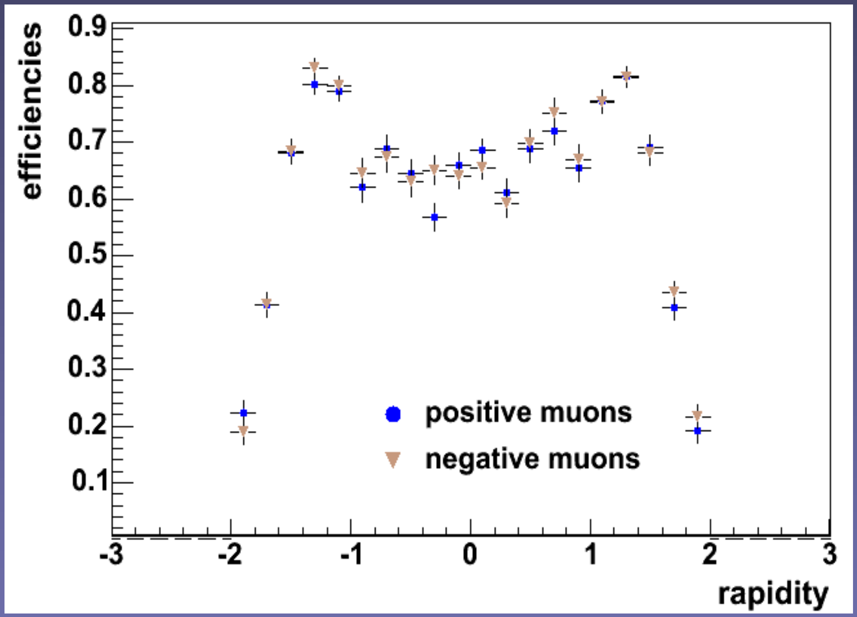
Backup Slides

Lepton asymmetry and p_T cut

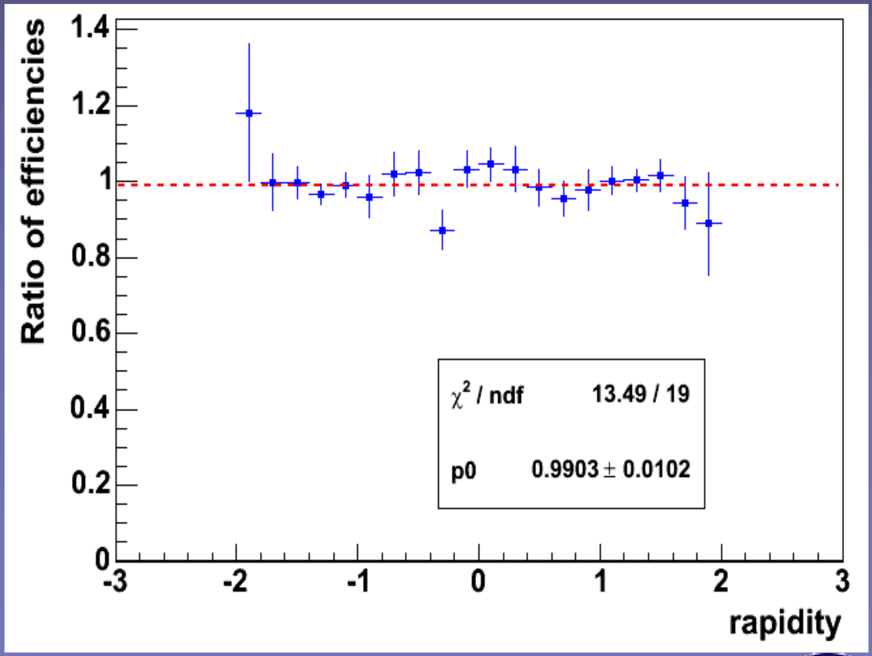


DØ overall efficiency ratio

Overall efficiency ratio = product of individual ratios



L2 muon trigger efficiency
L3 track trigger efficiency
Offline muon reconstruction efficiency
Offline tracking efficiency

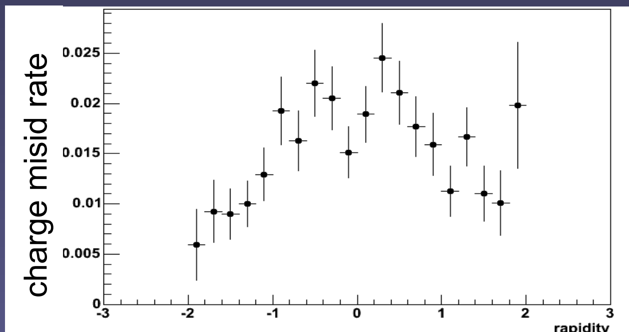


$$\frac{\varepsilon_+}{\varepsilon_-} = 0.99 \pm 0.01$$

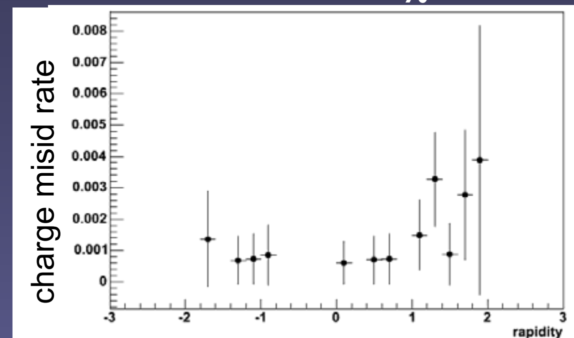
$\chi^2/\text{dof} = 0.71$

DØ charge misidentification

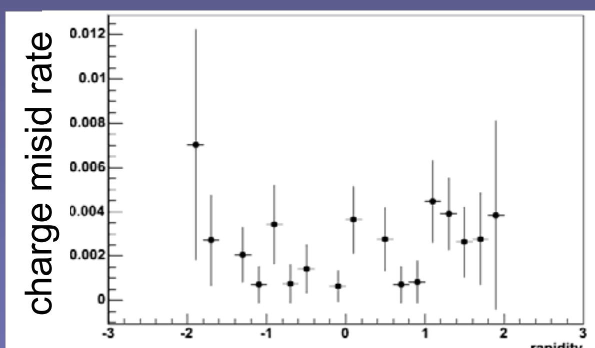
1. Only isolated muons



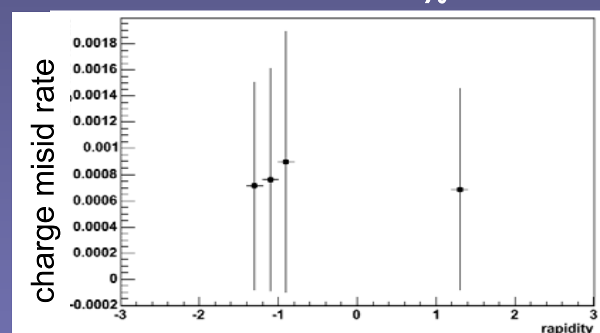
3. Plus additional χ^2/dof



2. Plus hits in the tracker



4. dca but no χ^2



Sample of 10,000 ee events. After all selection cuts, only one same-sign event remains.

- Cross checks
  - no Z invariant mass cut
  - reduced muon pT cut
  - use other triggers
  - study misid in GEANT MC
- No difference

Charge misid rate = $(0.01\pm0.01)\%$ for $|\eta| \leq 1.0$
$(0.01\pm0.05)\%$ for $|\eta| > 1.0$

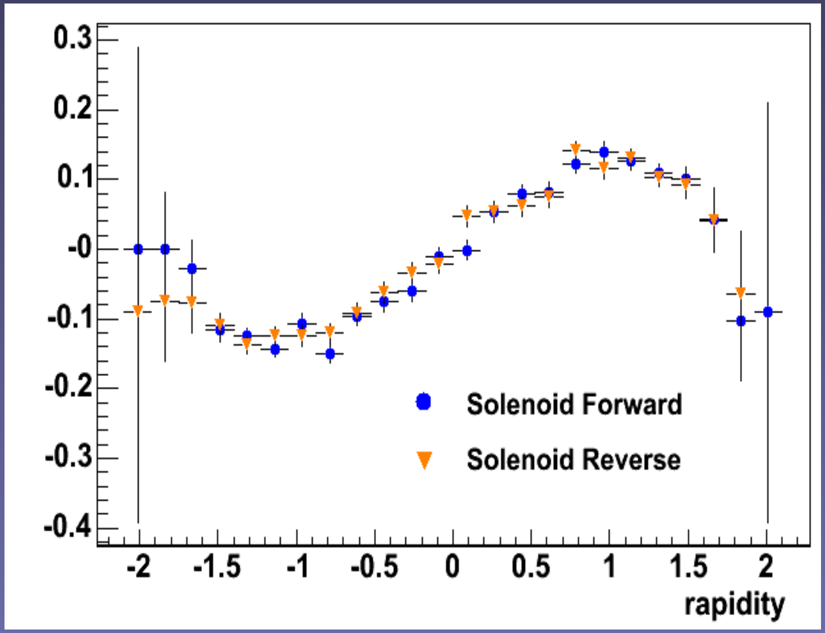
inflate uncertainty at high $|\eta|$ due to low statistics

DØ systematic uncertainties

- Data
  - differences in efficiencies for μ^+ and μ^-
    - take $\frac{\varepsilon_+}{\varepsilon_-} = 1.0$ and use uncertainty as a systematic
  - charge misidentification
- Background
  - PMCS modeling of EW backgrounds
    - muon energy in calorimeter
    - hadronic energy scale ($\not{E}_T$)
    - uncertainty in signal isolation efficiency
  - uncertainty in background isolation efficiency

Vary everything by $\pm1\sigma$,
use change in asymmetry as uncertainty.

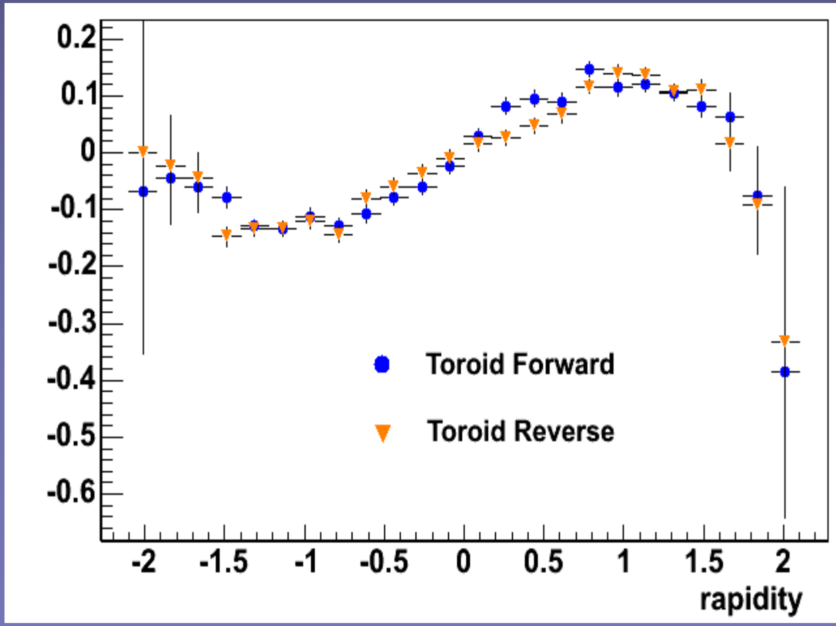
DØ magnet polarities



Solenoid polarities

Toroid polarities

Data is 50.7% : 49.4%



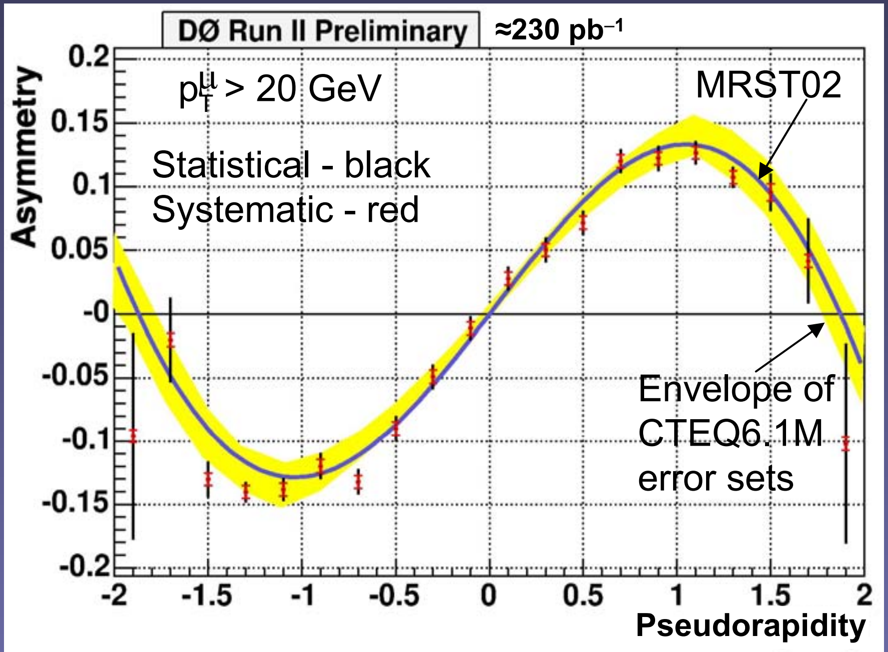
W → μν (DØ) and W → eν (CDF)

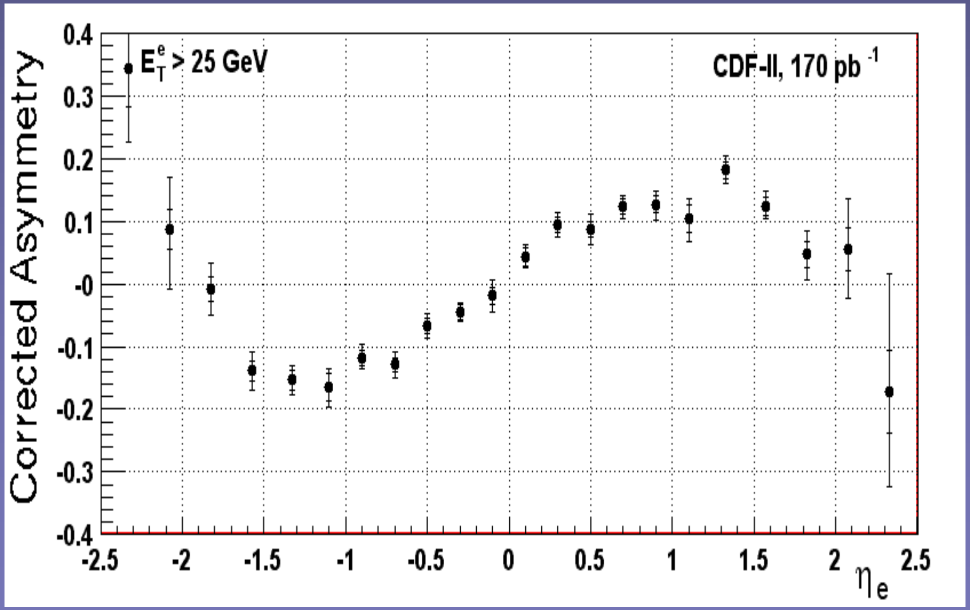
W → μν

Z → μμ
Z → ττ, τ → μνν
W → τν, τ → μνν
QCD multijet

W → eν

Z → ee
W → τν, τ → eνν
QCD multijet

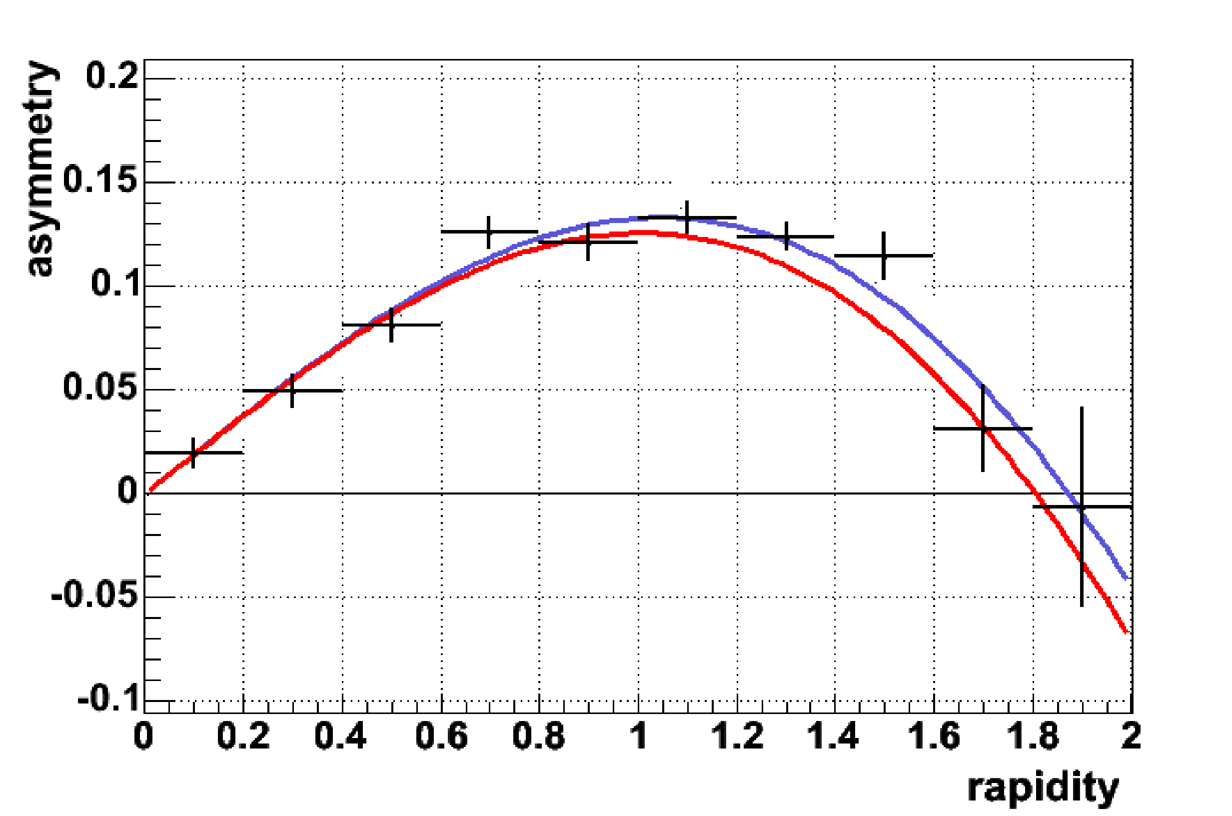




Analyses done bin-by-bin

PRD D 71, 051104(R) (2005)

DØ folded asymmetry plot



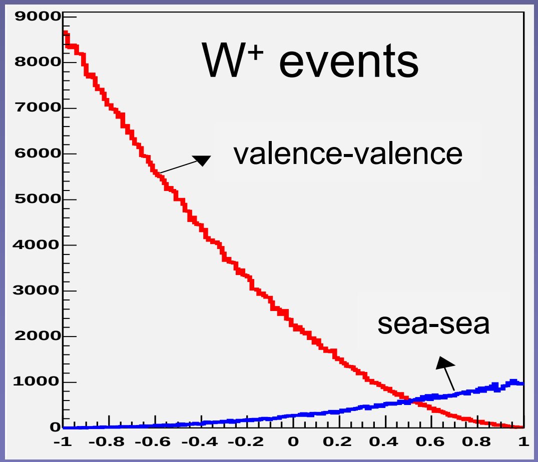
Red curve: CTEQ6.1M central value
Blue curve: MRST02
Combined uncertainties.

CDF W asymmetry weighting

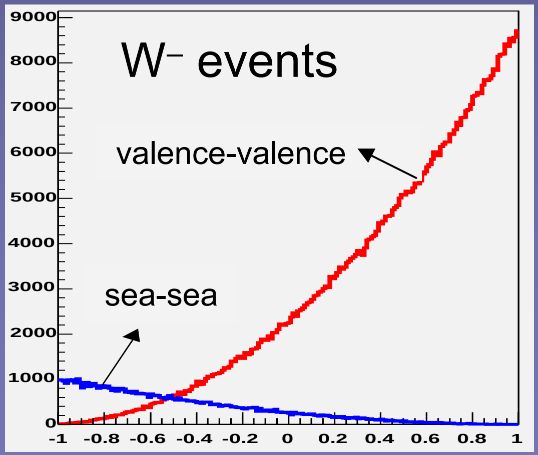
$$P_{\pm}(\cos\theta^*_{1,2}, y_{1,2}, p_T^W) = (1 \mp \cos\theta^*)^2 + Q(y_W, p_T^W)(1 \pm \cos\theta^*)^2$$

valence-valence — ratio of two distributions — sea-sea

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

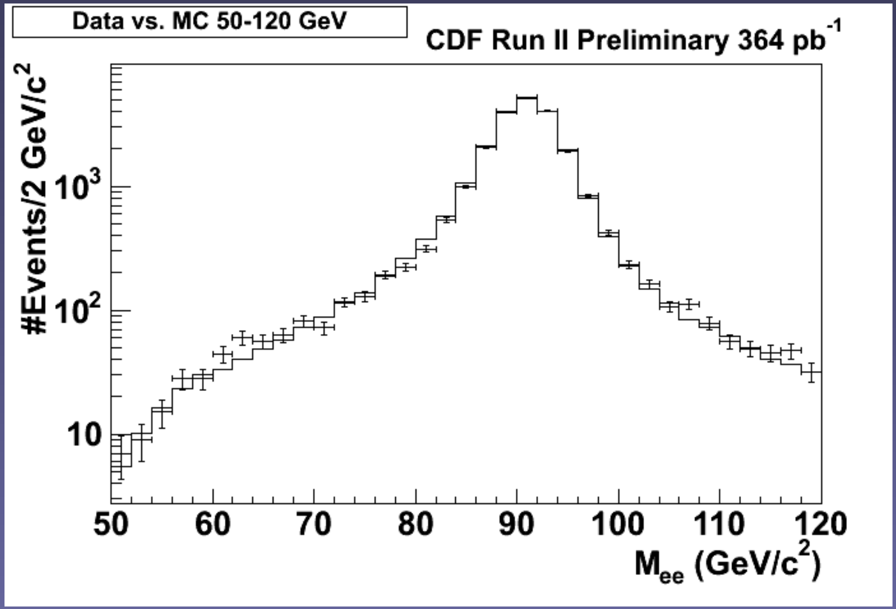


$\cos\theta^*$



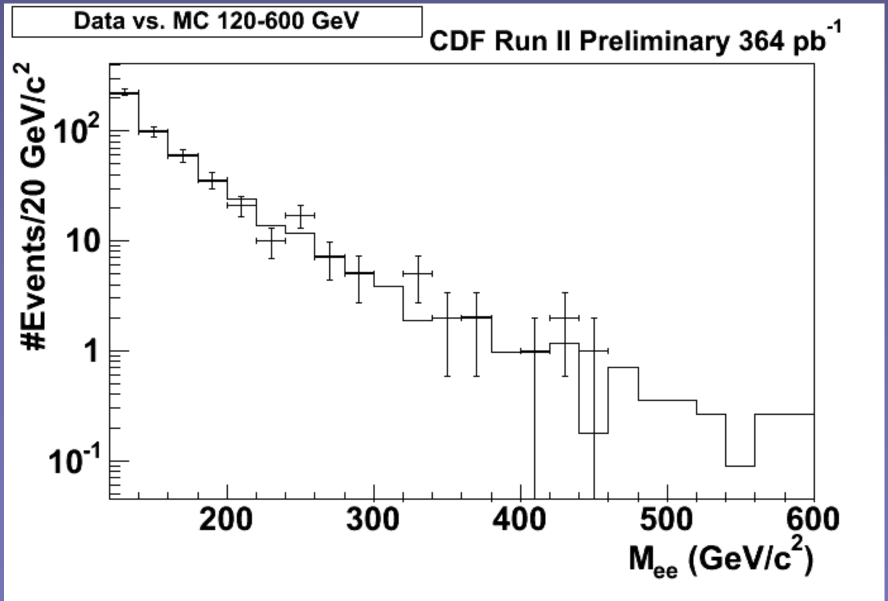
$\cos\theta^*$

CDF Z → ee mass distributions



Low mass region

High mass region



CDF A_{FB} background

	CC	CP	Total	uncertainty
Data	9455	13455	22910	
Jet Fake	10.6	128	138.6	21.6
WW->llνν	5.9	6.5	12.4	0.6
WZ (Z->ee)	5.6	6.4	12.0	0.6
W->eν+γ/jets	3.7	70.5	74.3	6.1
ttbar	3.2	1.9	5.1	0.3