Results of W and Z Boson Asymmetries from the Tevatron.

Sinjini Sengupta
University of Minnesota
RAL Seminar
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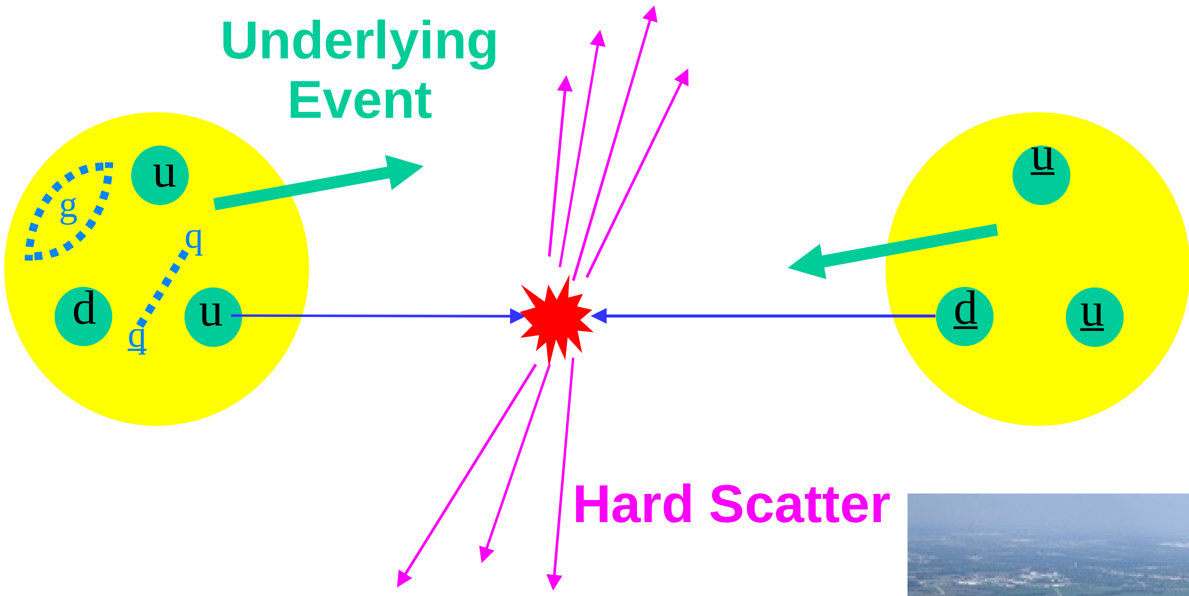
Outline

- W and Z Production at the Tevatron
- What and how of the W Charge and the Z Forward-Backward Asymmetries
- The D∅ and CDF Detectors
- W Charge Asymmetry: analysis and results
- Z Forward-Backward Asymmetry: analysis and results
- W and Z Asymmetry analyses at the LHC.

The Tevatron



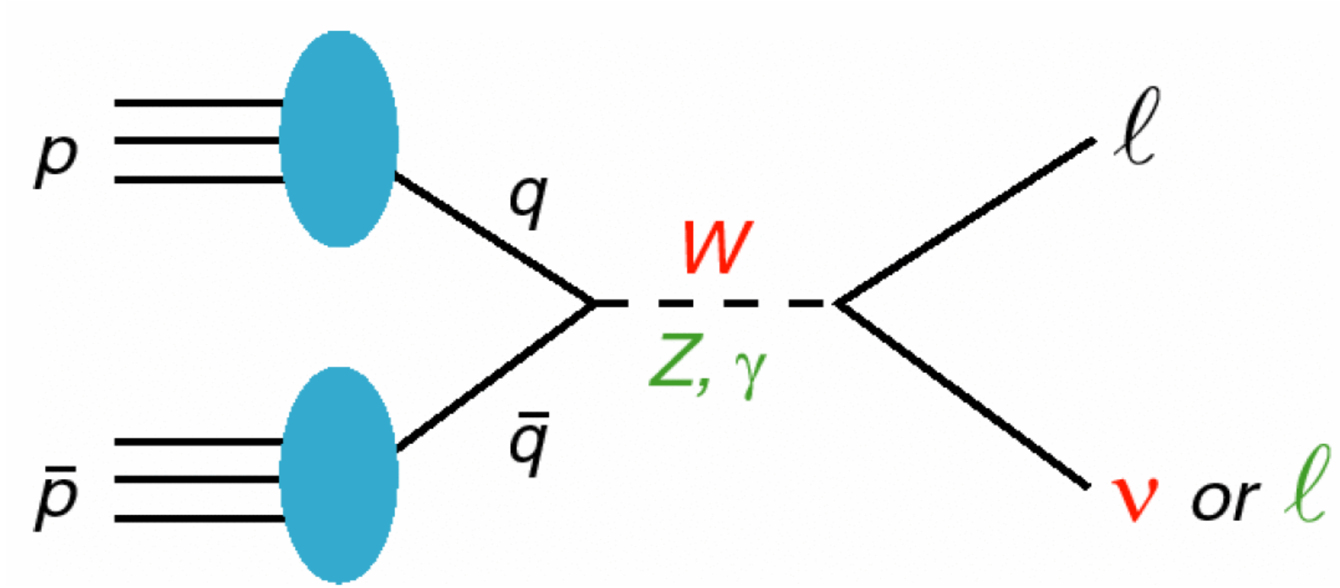
$p\bar{p}$ collisions ⇒
qq(g) interactions

$\sqrt{s} = 1.96\, TeV$

Fermilab Tevatron:

- Circumference ~ 4 mi.
- 7 accelerators
- 1000 superconducting magnets

W and Z Production



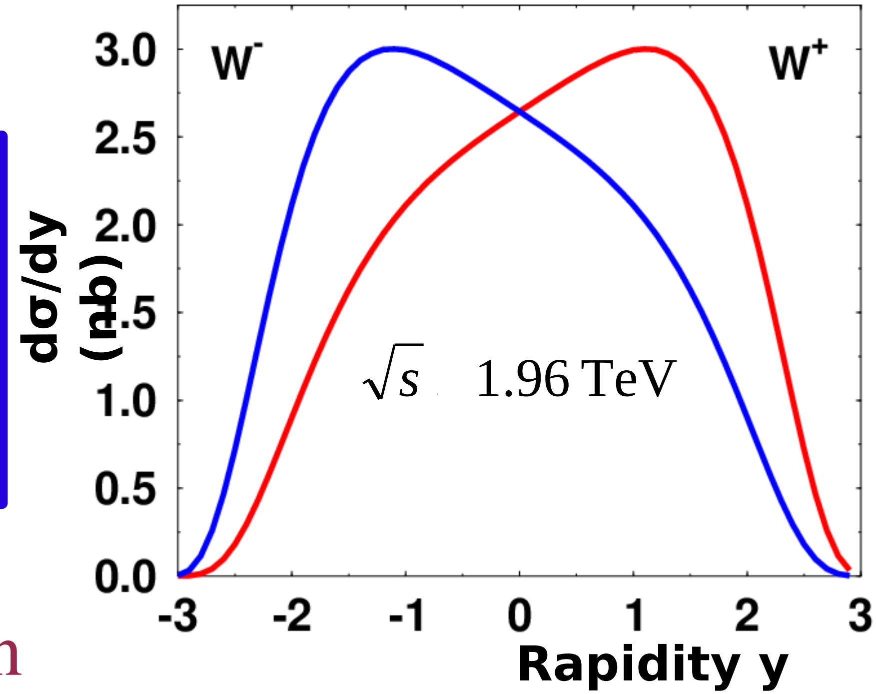
W production: $u + \underline{d} \rightarrow W^{+}$
$\underline{u} + d \rightarrow W^{-}$

Z production: $u + \underline{u} \rightarrow Z$
$d + \underline{d} \rightarrow Z$

W Charge Asymmetry

The u quark typically carries more of the proton's momentum and the W^+ is boosted in the direction of the proton.

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



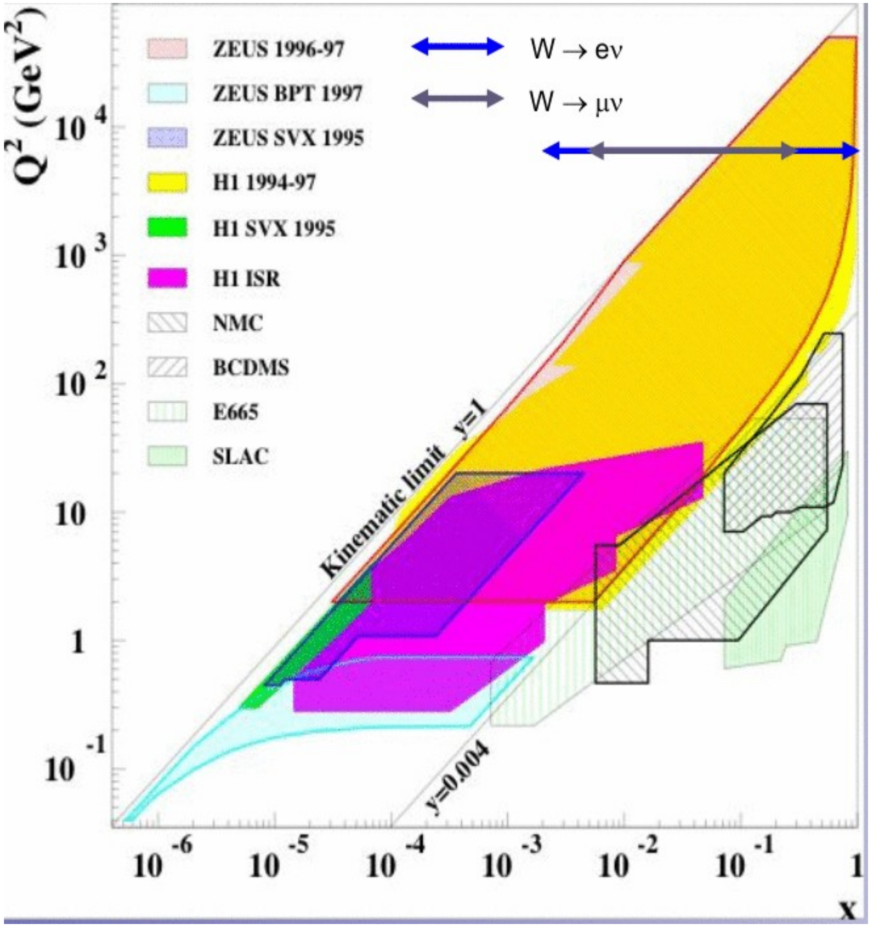
$$\frac{d\sigma(W^\pm)}{dy} = $$ W±(y) cross section

Rapidity y = $\frac{1}{2}[\ln\frac{(E+P_z)}{(E-P_z)}]$

Physics Motivation

The **W charge asymmetry** is used to constrain the PDFs : (d/u) quark ratio at ($Q^2 \sim M_W^{\ 2}$) and ($0.002 < x < 0.8$)

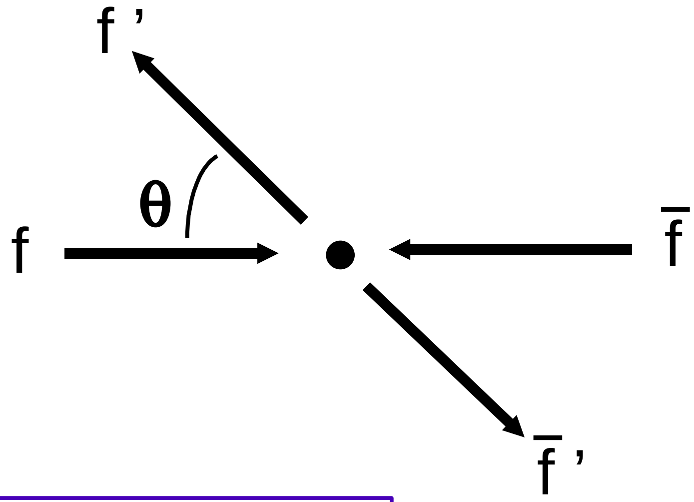
- PDFs are used as inputs to virtually all hadronic cross section calculations.
- Improvements in the knowledge of PDFs help reduce the uncertainty in the W mass measurement, the mass of the top quark and the mass of the Higgs.



Forward Backward Asymmetry

- Presence of both vector and vector-axial couplings of EW bosons to fermions in $q\bar{q} \rightarrow Z/\gamma^* \rightarrow l^+l^-$ gives rise to an asymmetry in the polar angle of the lepton momentum relative to the incoming quark momentum in the rest frame of the lepton pair (A_{FB}).

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



- The cross section depends on θ

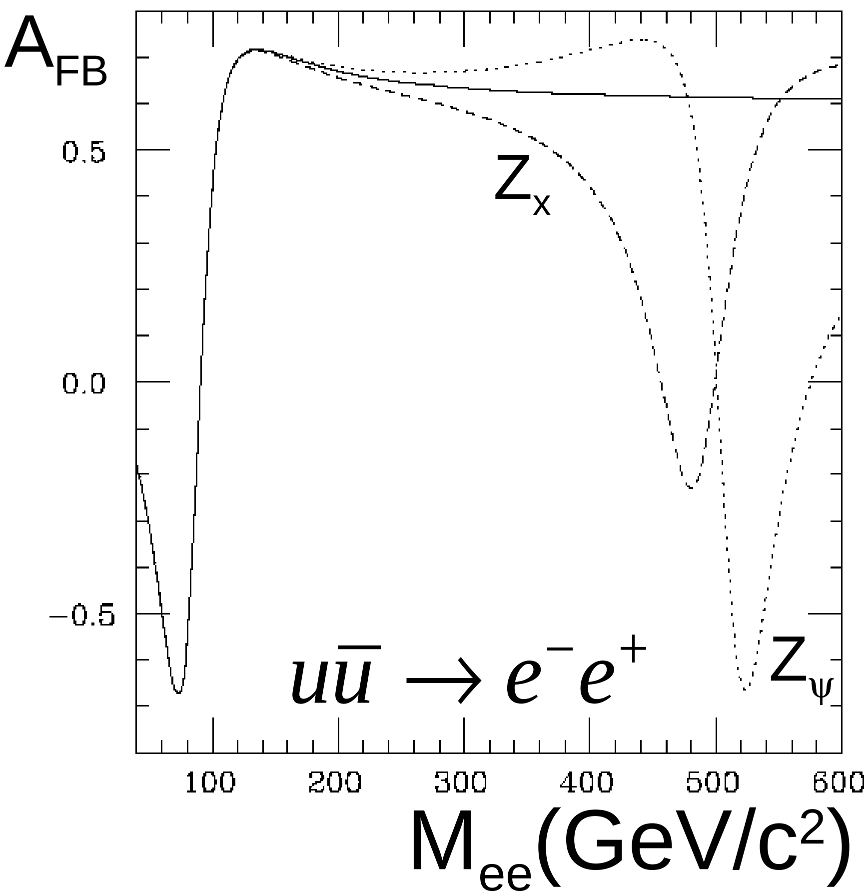
$$d\sigma/d(\cos\theta) = N \left[3/8 \left(1+\cos^2\theta\right) + A_{FB}\cos\theta \right]$$

Physics Motivation

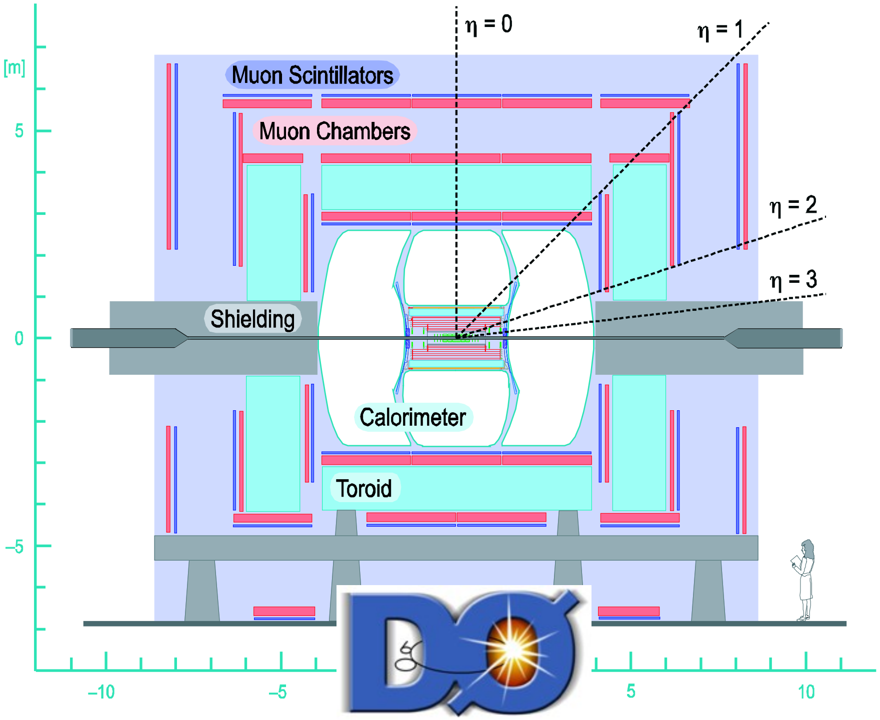
- The **Z forward backward Asymmetry** (A_{FB}) study is a sensitive probe of the couplings between the Z boson and the fermions.
- The A_{FB} probes for new physics as it is sensitive to new heavy gauge bosons (ex: Z') which are predicted in many extensions of the Standard Model.

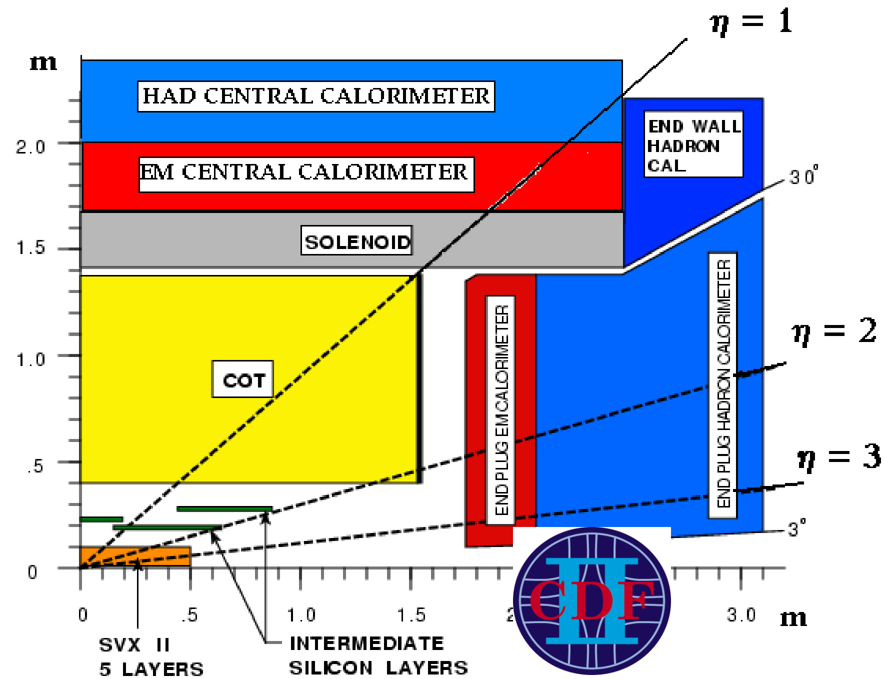
500 GeV/c² Z':

Rosner, J.L.: Phys. Rev. D 54, 1078 (1996)



The DØ and CDF Detectors





End Cap covers high η ~ 4.0
Tracking extends to η ~ 2.0
can probe up to y~3.0

Plug Cal. covers high η ~ 3.9
Silicon Tracker covers η ~ 2.8
can probe up to y~2.9

The W Charge Asymmetry

Lepton charge asymmetry

$W^{\pm}$ rapidity is hard to measure because of the neutrino's longitudinal momentum.

Lepton rapidities are more accessible

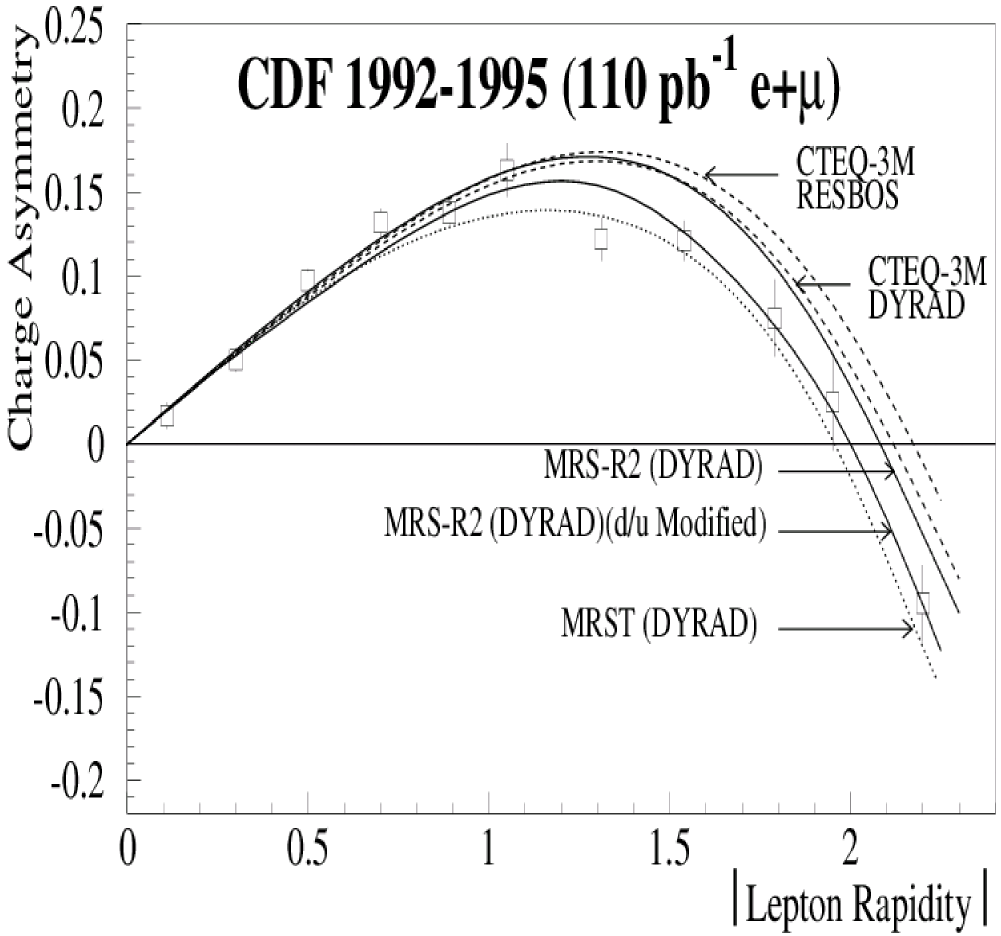
Lepton asymmetry = W asymmetry + V-A interaction (from decay).

The V-A interaction is well understood. (smaller at higher lepton P_T and larger at higher lepton rapidities)

Lepton charge asymmetry can be measured instead.

$$A(\eta_l) = \frac{\frac{d\sigma(l^+)}{d\eta} - \frac{d\sigma(l^-)}{d\eta}}{\frac{d\sigma(l^+)}{d\eta} + \frac{d\sigma(l^-)}{d\eta}}$$

W Asymmetry results (CDF RunI)



CDF RunI $W \rightarrow e+\mu$

$\mathscr{L}$ = 110 pb-1

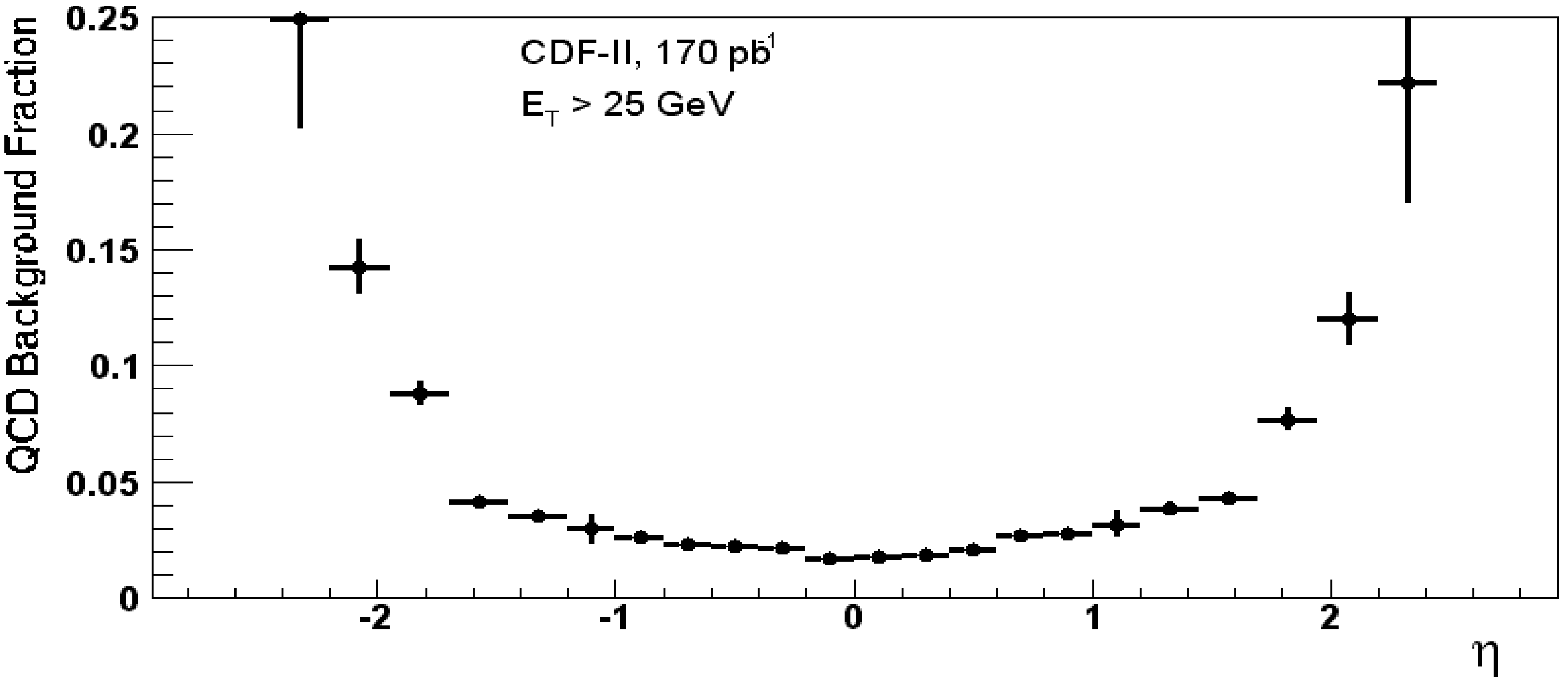
$E_T > 25$ GeV

Missing $E_T > 25$ GeV

constraint on d/u ratio
$0.006 < x < 0.34$

$W \to e^{\pm}\nu$ Asymmetry Measurement

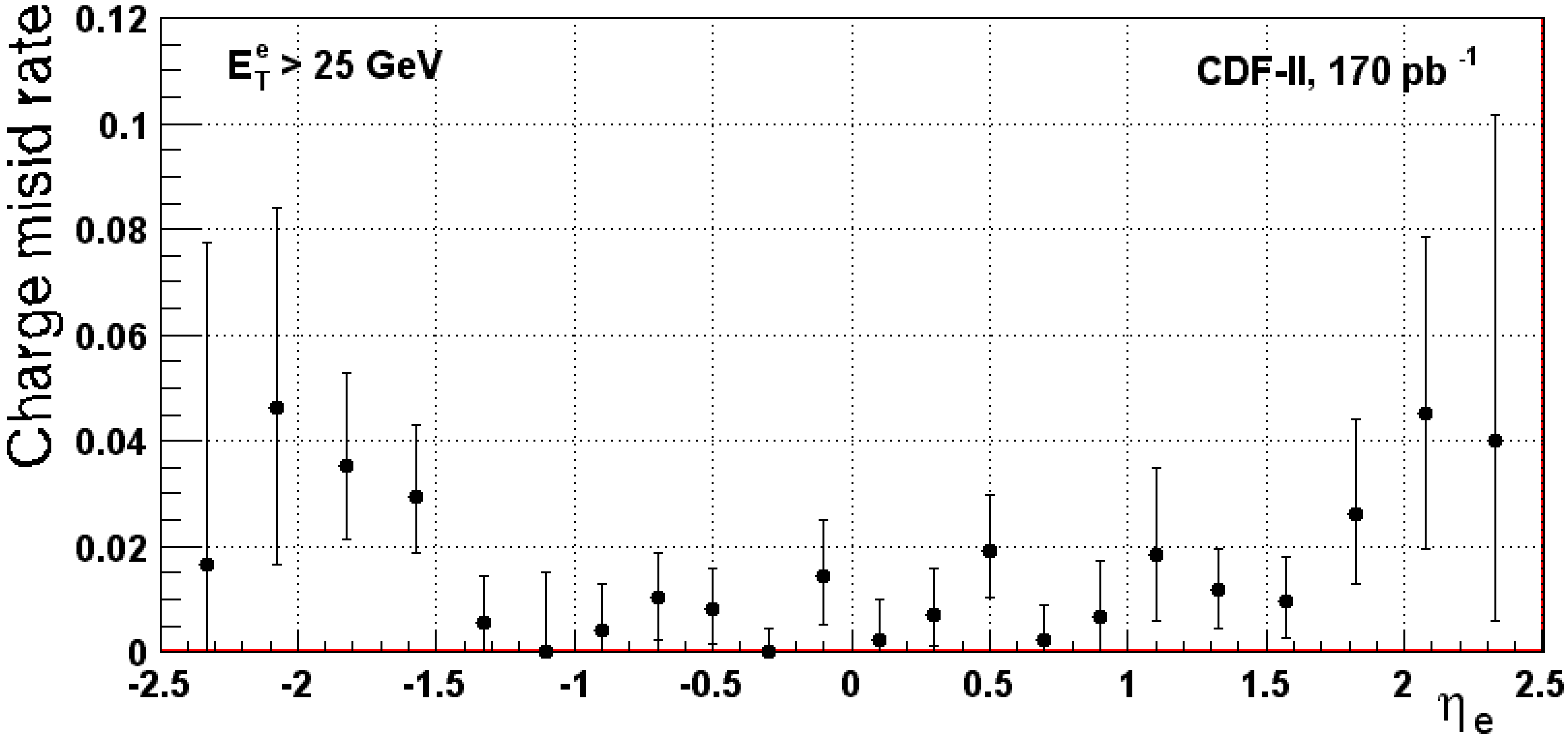
- Event Selection
  - E_T < 25 GeV, MET > 25 GeV
- Asymmetry is corrected for backgrounds from
  - W decay to τ to e, $Z \to e^+e^-$ (asymmetric, from MC)
  - QCD (using Isolation vs MET in data)



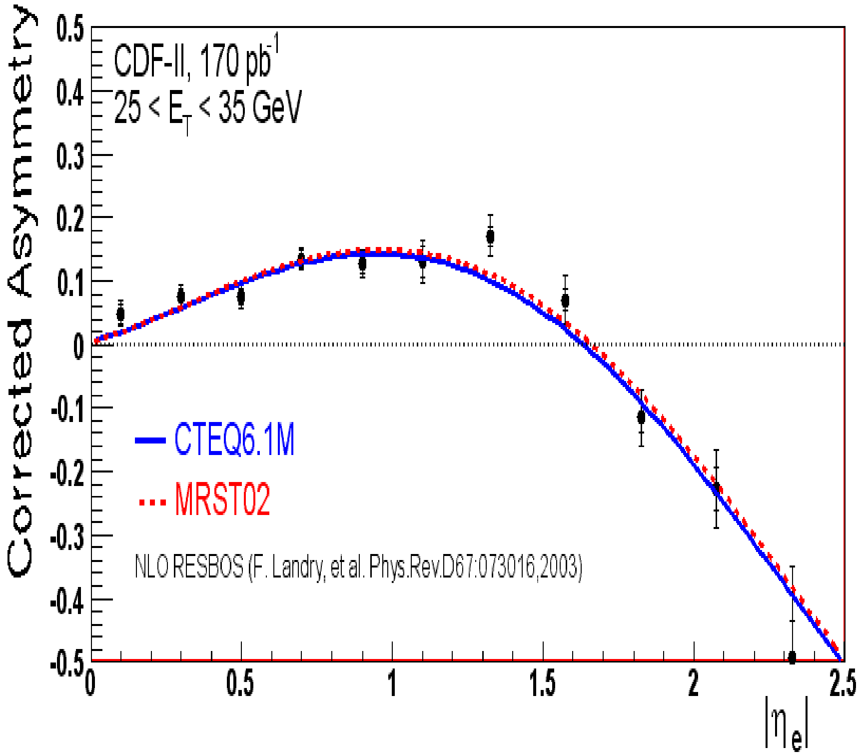
Charge misidentification

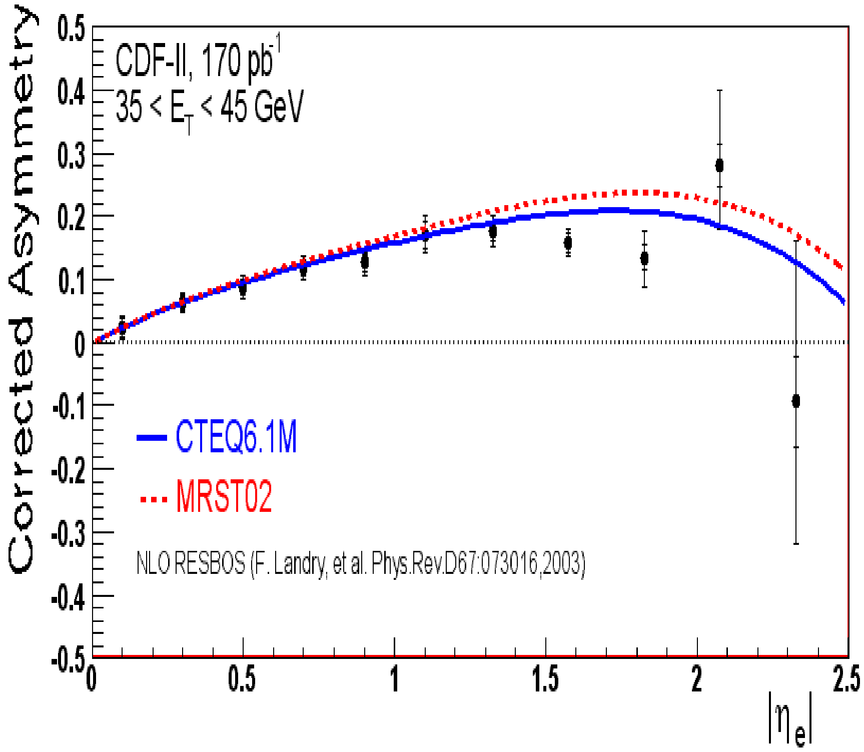
- Important to get the charge correct as mis-measurement of charge dilutes the asymmetry

A(true) = A(measured)/(1-2fq)



Folded Lepton Asymmetry





Gained sensitivity to W production asymmetry with E_T dependence.
Published in Phys.Rev.D Rapid communication, 2005.

Muon Asymmetry Measurement

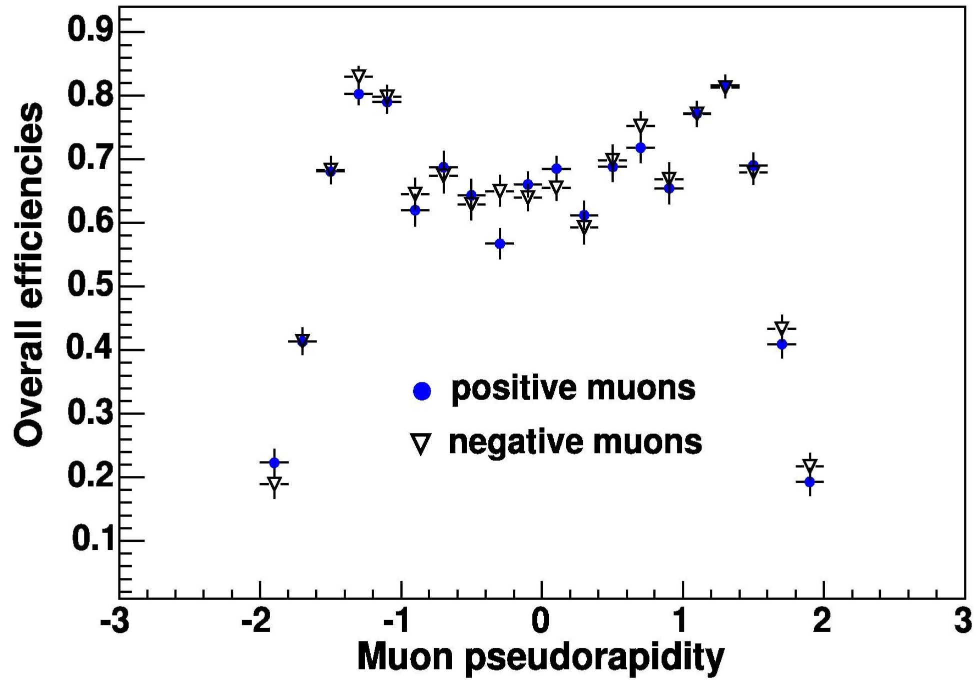
- Event selection for $W^{\pm} \rightarrow \mu^{\pm} \nu$
  - Muon matched to central track with P_T>20 GeV
  - Missing E_T > 20 GeV
  - W Transverse mass > 40 GeV
  - Track Quality cuts
  - Muon isolated in Tracker and Calorimeter
  - Timing and vertex constraints
  - Reject events with 2nd good track or muon.

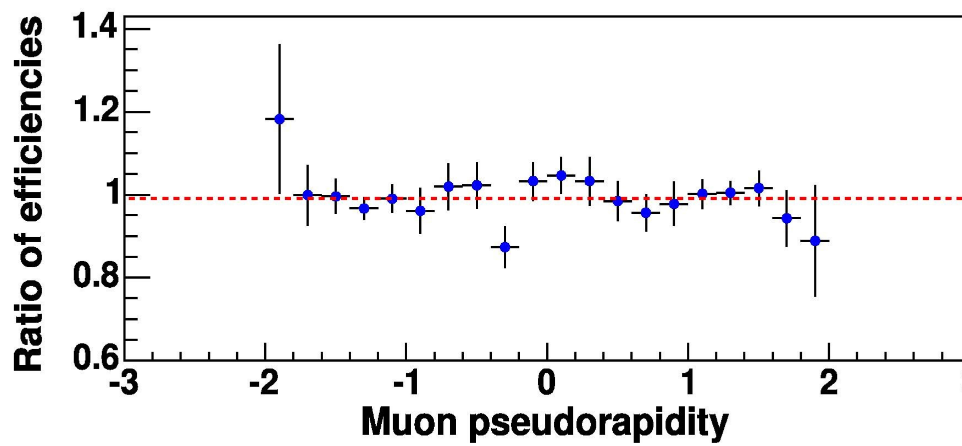
Biases and Efficiencies

Asymmetry depends on P_T and η so check for biases in momentum and charge.

Overall efficiency =
ε(tracking) x
ε(trigger track) x
ε(muon id) x
ε(trigger muon)

$$\frac{\epsilon^{+}}{\epsilon^{-}} = 0.99 \pm 0.01$$

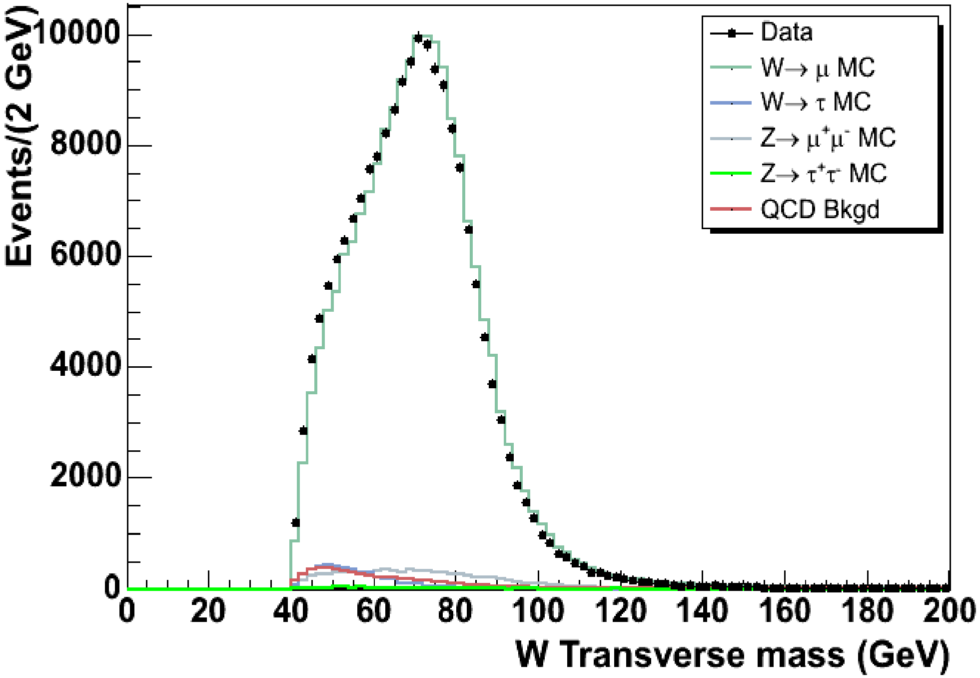




Charge ID/ Backgrounds

- Misidentification of charge at large P_T and η dilutes the asymmetry.

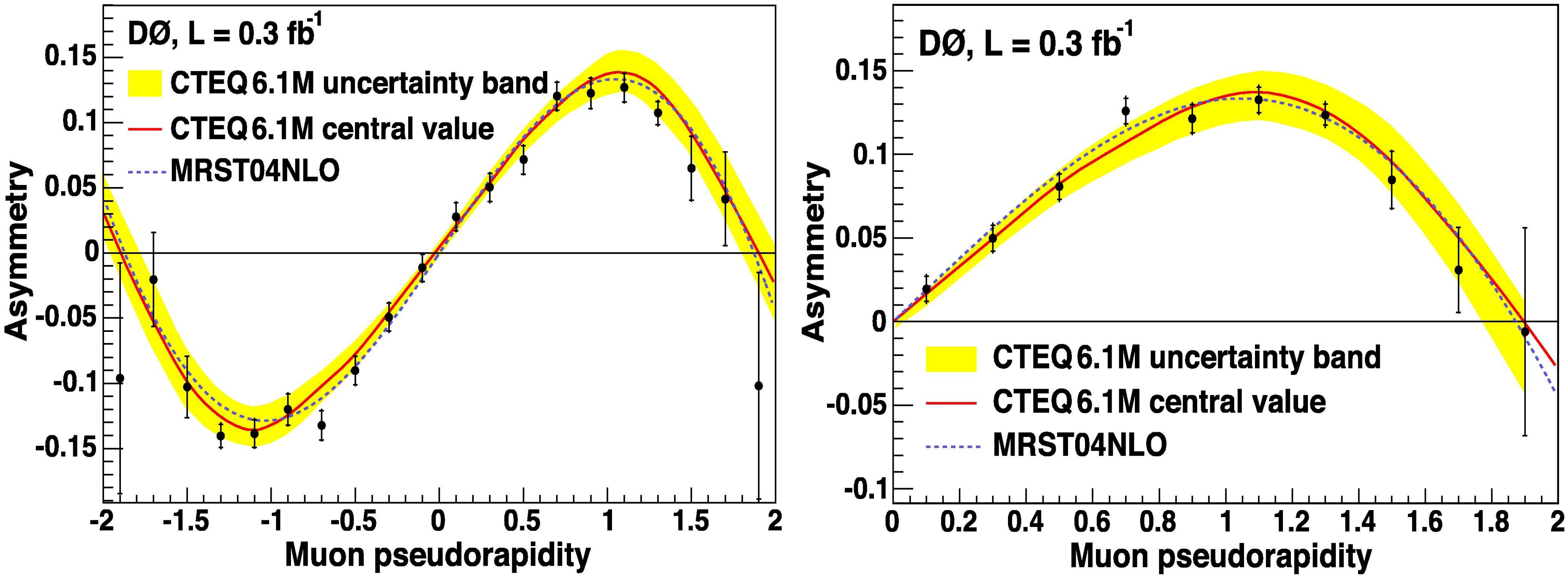
$$misid\ \ rate = \frac{N_{ss}}{N_{ss}+N_{os}}$$



Sources of background:

- $Z \rightarrow \mu\mu$
- $W \rightarrow \tau\nu$
- $Z \rightarrow \tau\tau$
- QCD

DØ Muon Asymmetry

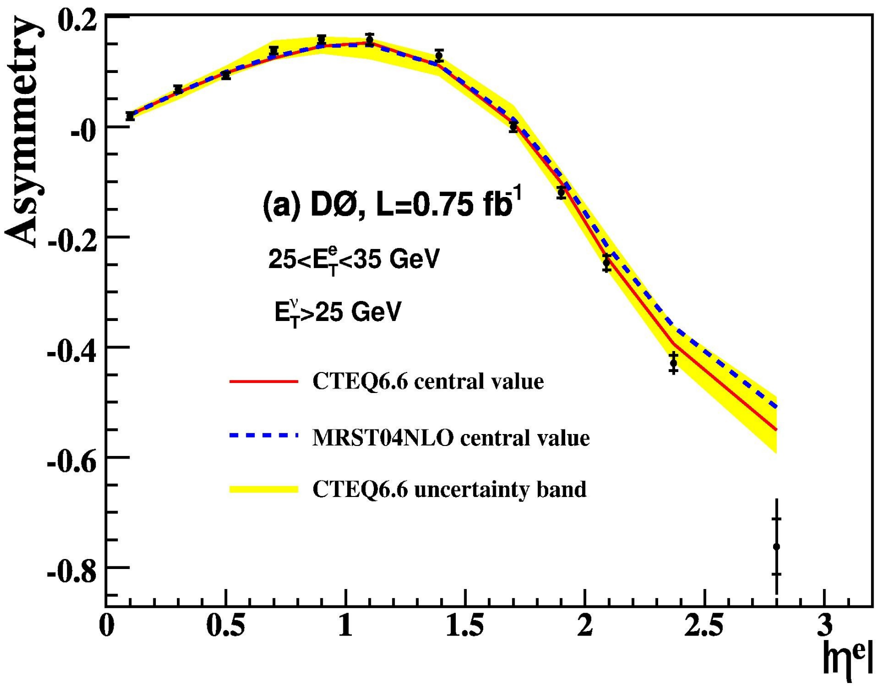


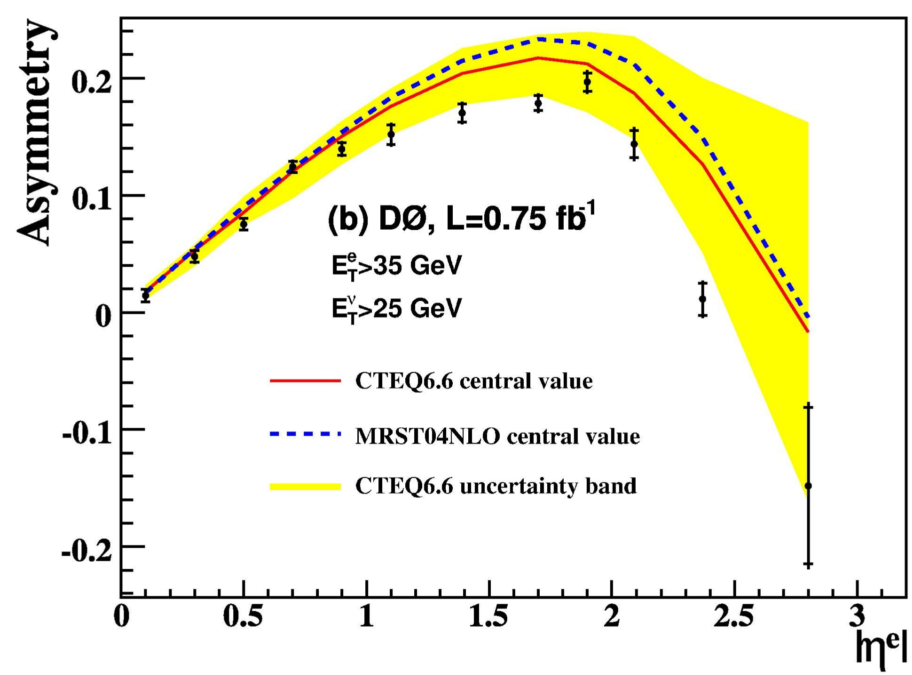
W production and decay are CP invariant so the asymmetry is folded to increase statistics.

First Muon Asymmetry measurement from the Tevatron
Published in Phys.Rev.D Rapid Comm. 2007

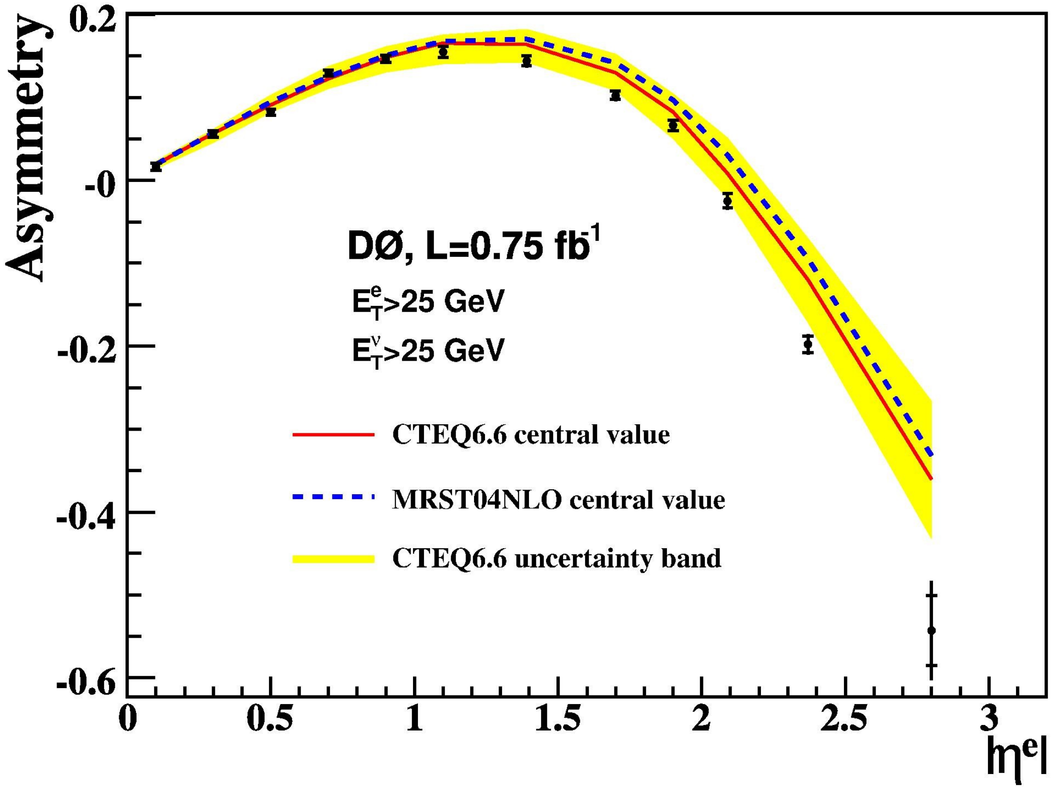
Electron Asymmetry in E_T bins (DØ)

- Analysis has 4 types of electrons (detector location).
- This allows for different misidentifications, efficiencies and multijet backgrounds.





Electron Charge Asymmetry (DØ)



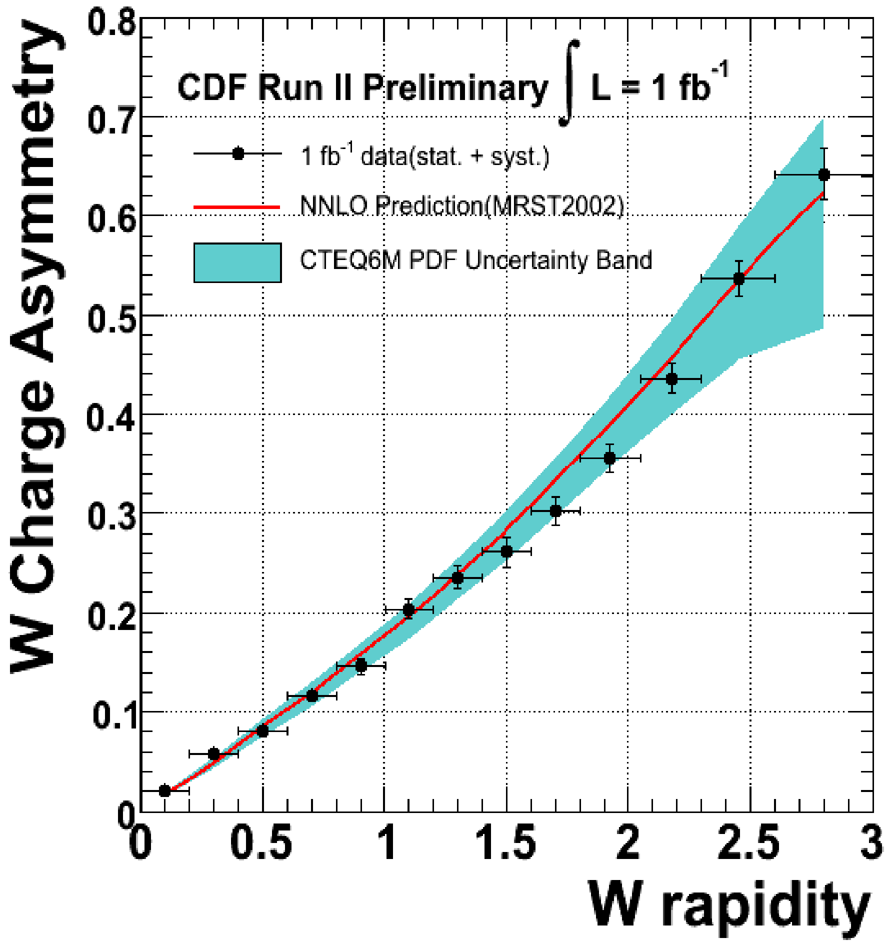
L=0.75 fb^{-1}

Uncertainties are smaller than the CTEQ error bands except for the highest η bins.

Most precise Asymmetry measurement to date.
Results submitted to P.R.L.

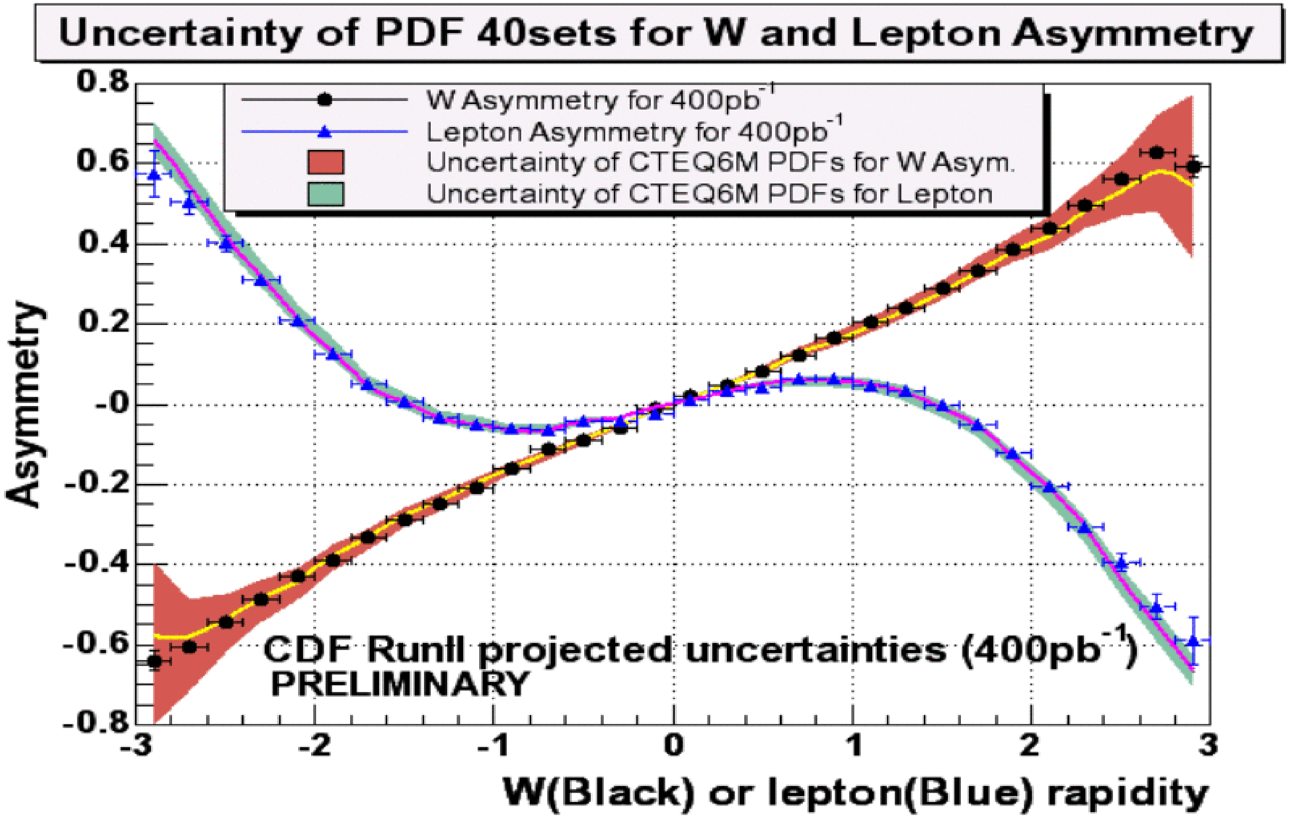
Direct W Asymmetry measurement

- Reconstruct W rapidity with a W mass constraint
- Two possible solutions
- Weight the two solutions
  - production/decay
  - $\cos\theta^*$, P_T^W
  - rapidity distributions
- Iterate to find the correct asymmetry.
- E^T > 25 GeV, MET > 25 GeV, L= 1.0 fb^{-1}



Direct W Asymmetry measurement

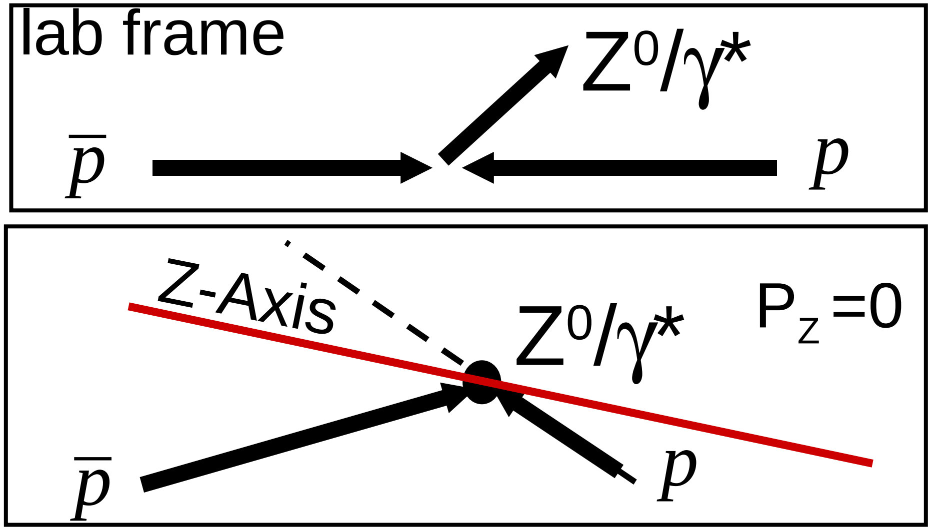
- Compare expected uncertainties with CTEQ6.1 error sets for 400 pb^{-1} Pythia events.
- Direct method for W asymmetry measurement shows improved statistical uncertainty.



The Z Forward Backward Asymmetry

Calculating A_{FB}

- $\cos\theta^*$ in Collin-Soper frame
  - Minimize ambiguity in the incoming quark Pt



$\cos\theta^* > 0 \equiv$ Forward

$\cos\theta^* < 0 \equiv$ Backward

- Calculating A_{FB}:

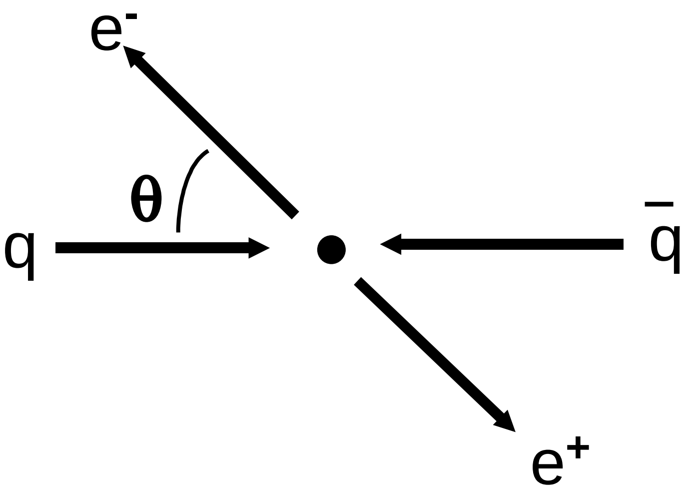
$$A_{FB} = \frac{d\sigma(\cos\theta^* > 0) - d\sigma(\cos\theta^* < 0)}{d\sigma(\cos\theta^* > 0) + d\sigma(\cos\theta^* < 0)}$$

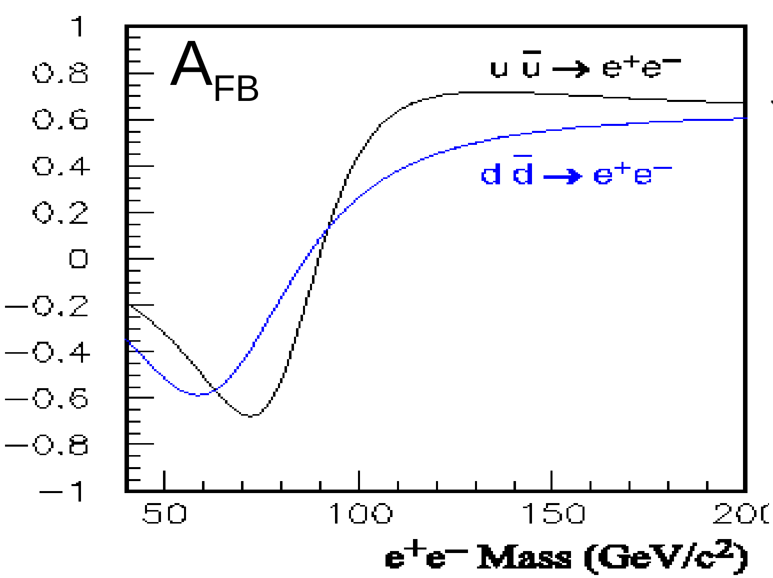
$$A_{FB} = \frac{\dfrac{N^+ - N^+_{Bkgrnd}}{a^+} - \dfrac{N^- - N^-_{Bkgrnd}}{a^-}}{\dfrac{N^+ - N^+_{Bkgrnd}}{a^+} + \dfrac{N^- - N^-_{Bkgrnd}}{a^-}}$$

a : Forward/Backward Acceptance & Efficiency

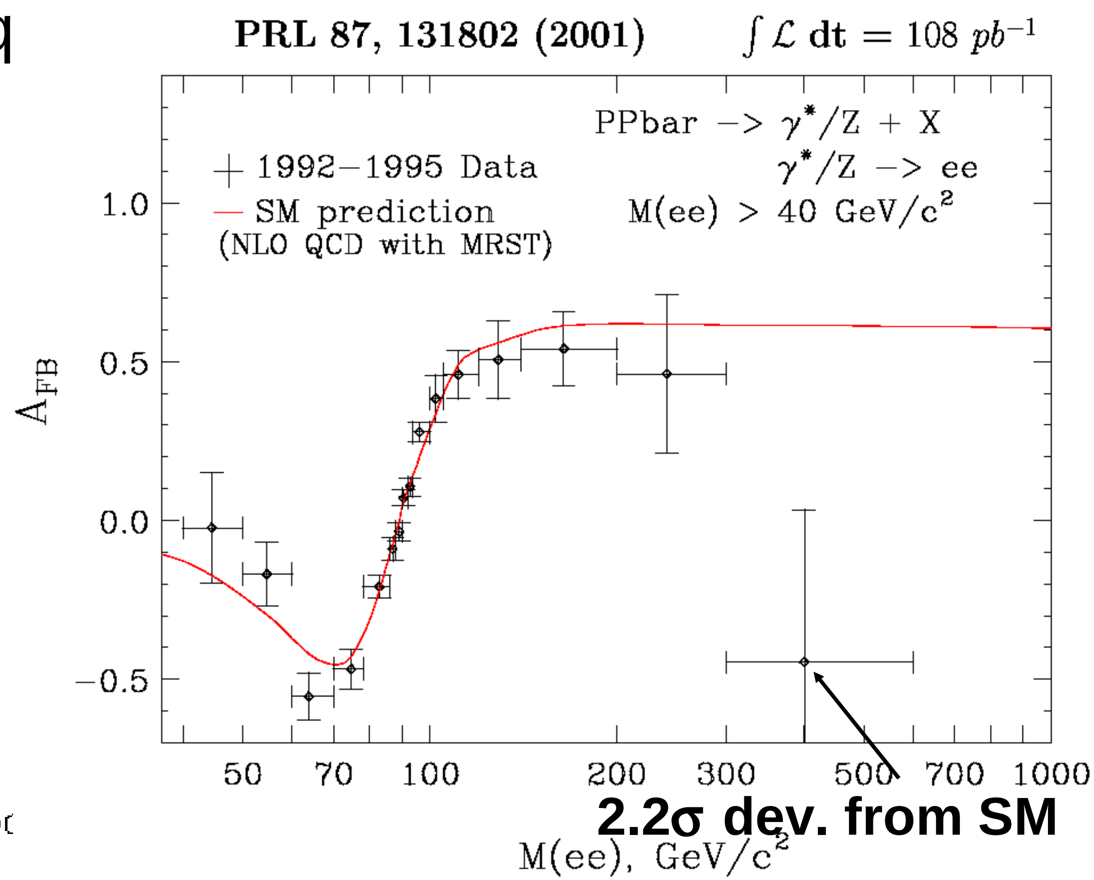
$N^\pm$: Forward/Backward Candidates

A_{FB} results (CDF RunI)





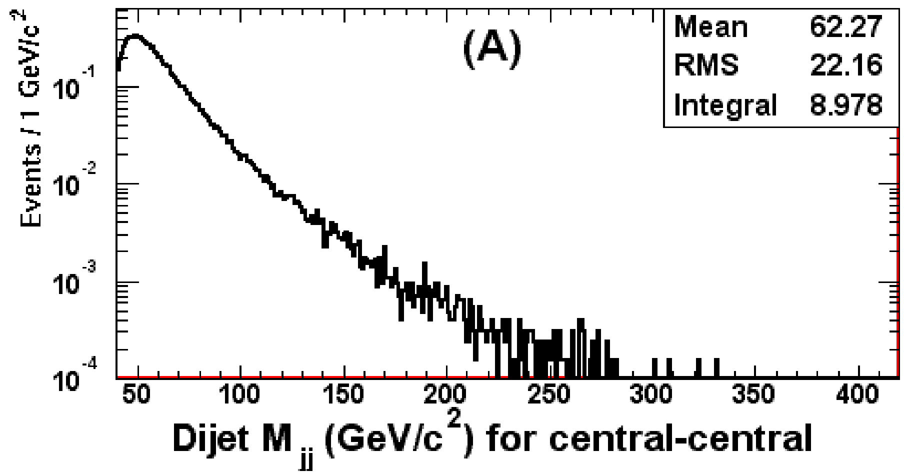
CDF Run I (~110 pb^{-1})

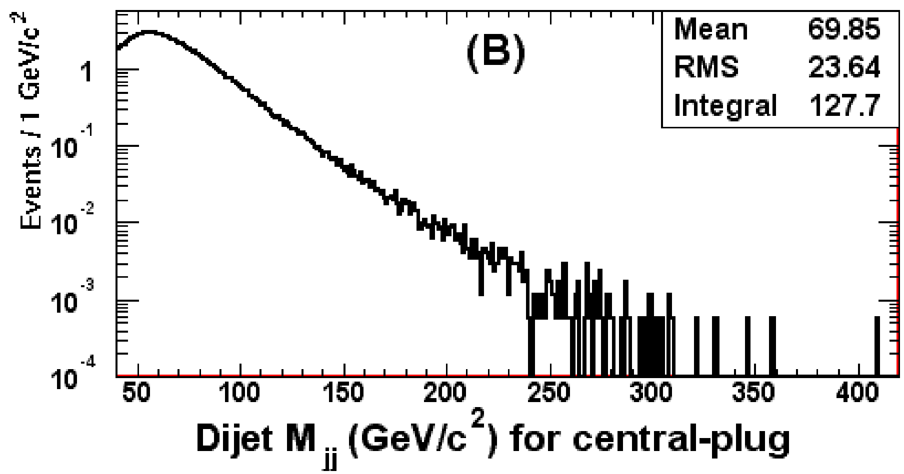


2.2σ dev. from SM

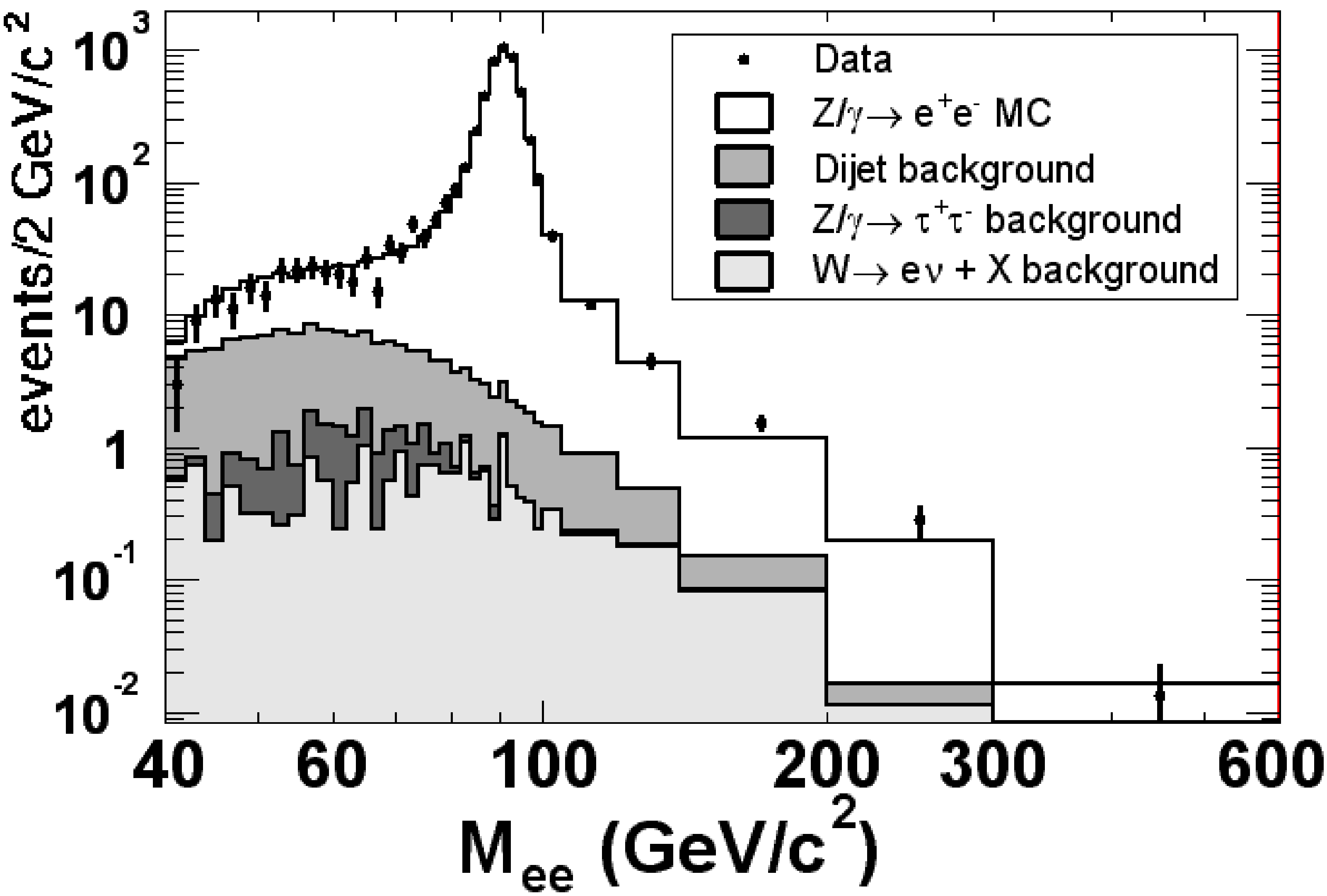
A_{FB} Analysis

- 2 high P_T isolated electrons, E_T > 20 GeV
- Backgrounds:
  - – Dijet (dominant)
  - – $W \rightarrow e\nu + X$
  - – $Z \rightarrow \tau\tau$
  - – WZ and WW
  - – Top

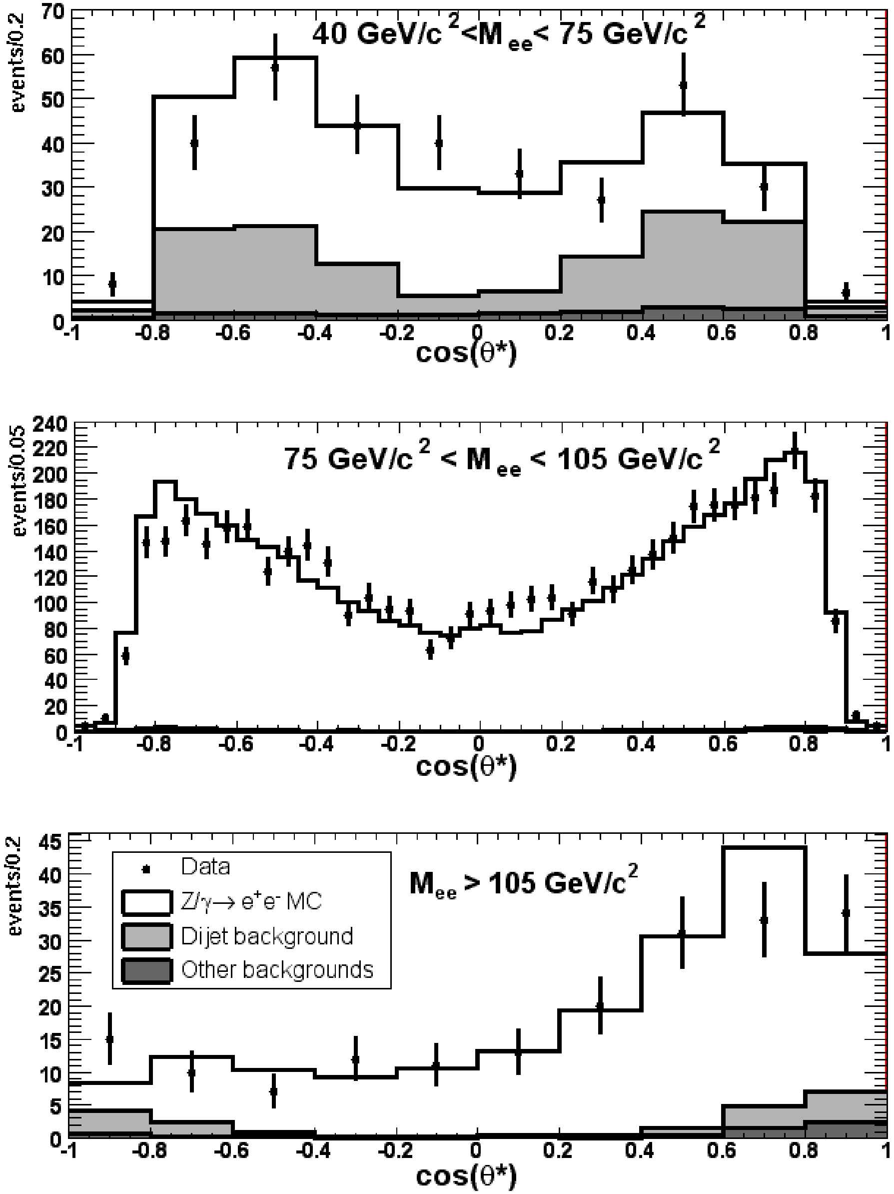




Data-MC comparison

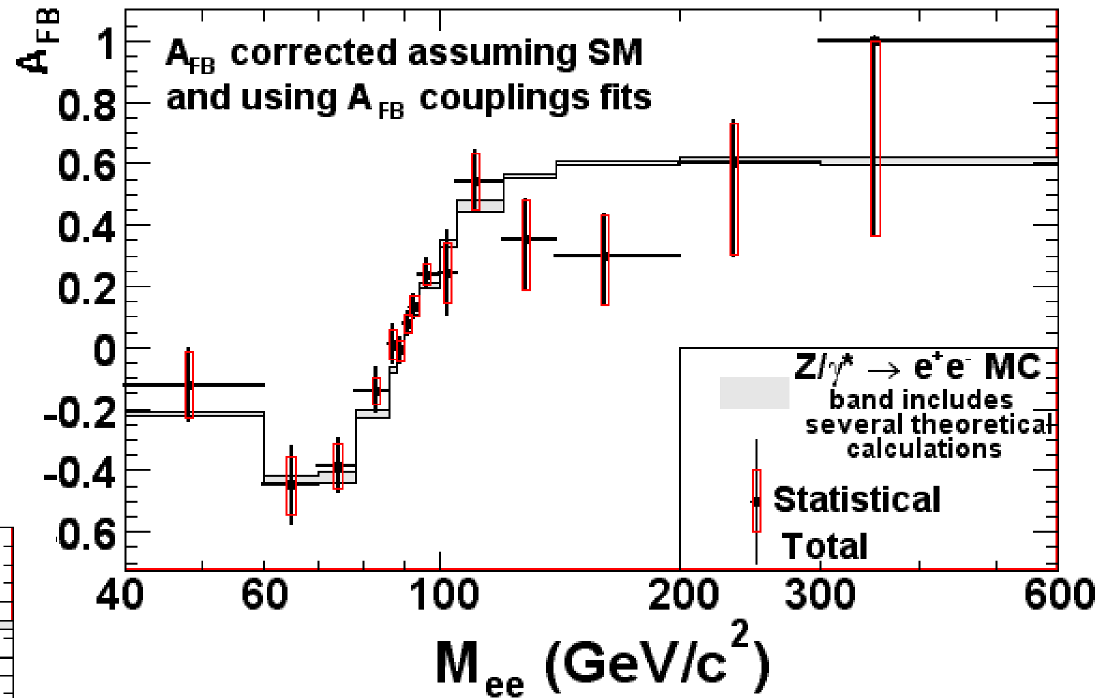


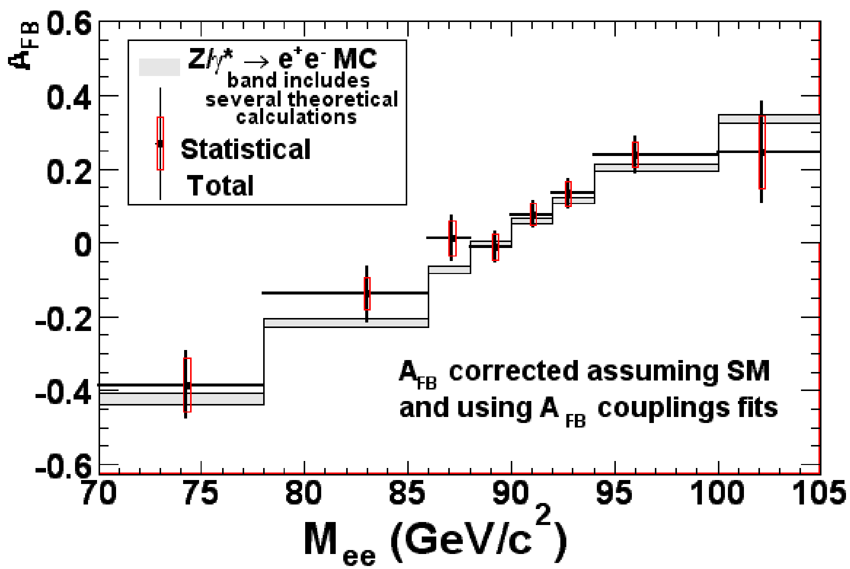
Data-MC (cosθ*)



A_{FB} results at 72 pb^{-1}

- SM results with measured Z couplings.



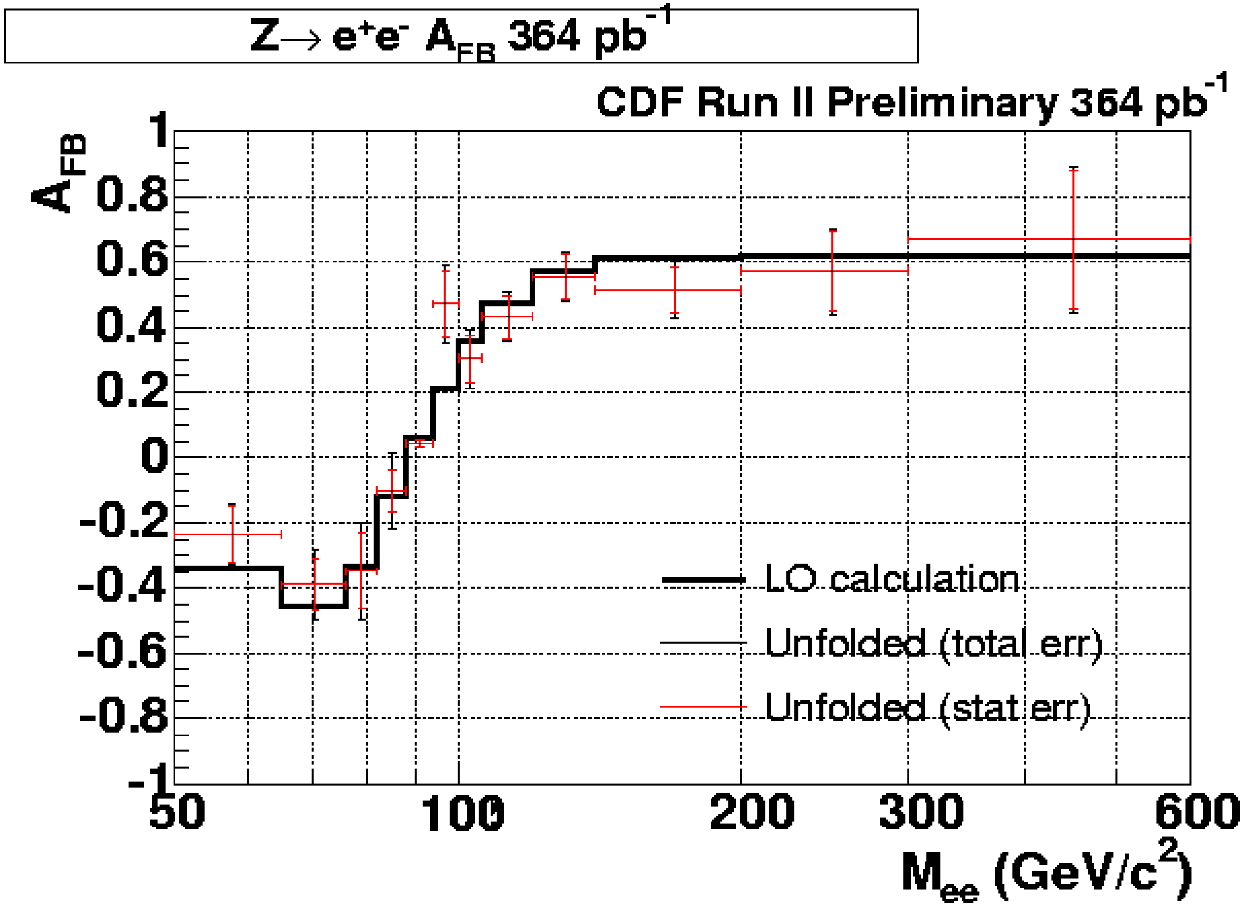


$$\sin^2\theta_W = 0.2238 \pm 0.0046(\text{stat}) \pm 0.0020(\text{syst})$$

χ^2/ndf = 12.71/14.0

Published in PRD 2005

New A_{FB} results at 364 pb^{-1}



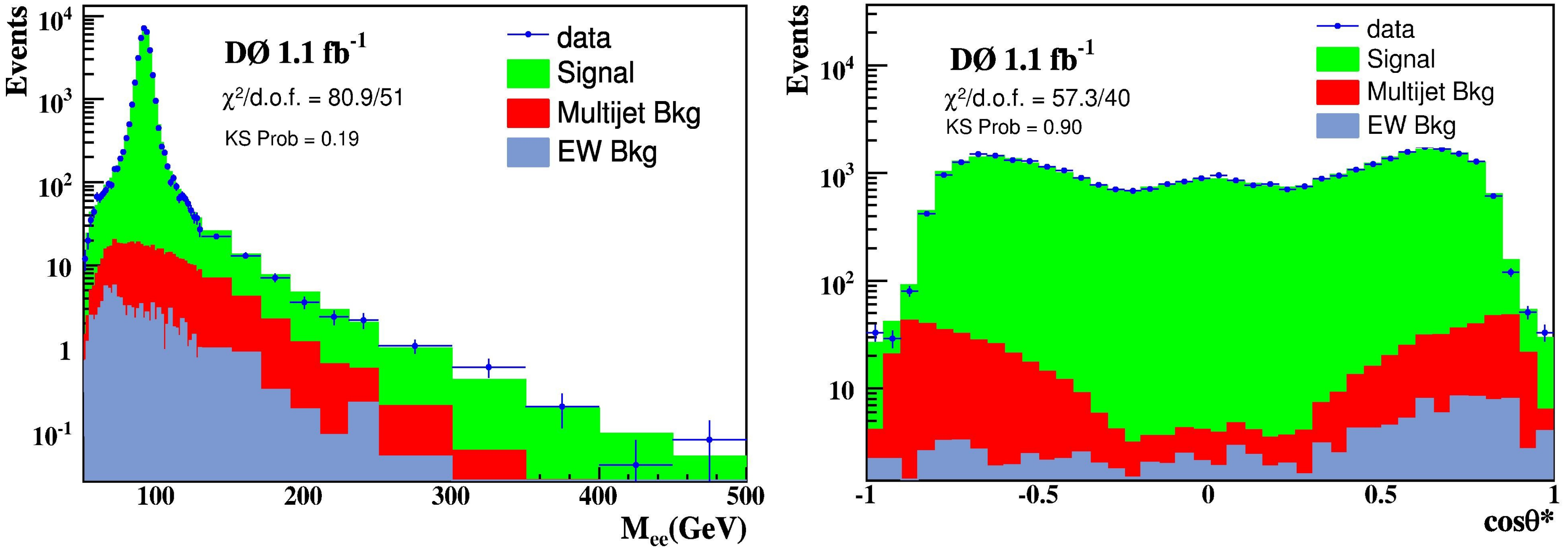
M_T>50 GeV/c^2

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

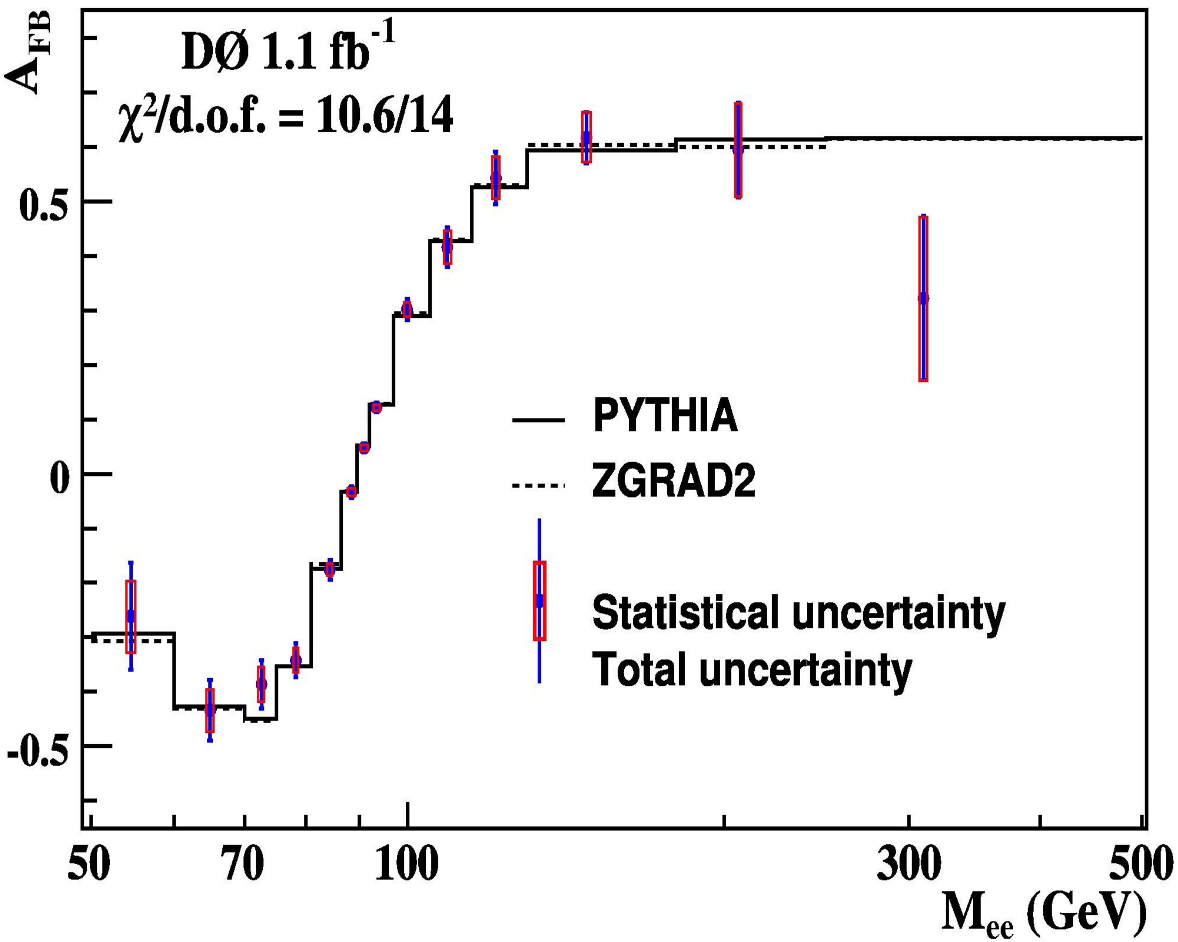
Matrix inversion method is used to correct for the distortion in the measurement due to detector resolution and FSR.

A_{FB} measurement

- Event selection:
  - 2 central electrons, $|\eta| < 2.5$, $E_T > 25$ GeV
  - $50 < M_{ee} < 500$ GeV
- Corrections for background, charge misidentification, acceptance and efficiencies.



A_{FB} at 1.1 fb^{-1}



Unfolding is via response matrices using MC.

Good chi-sq agreement (=10.6/14).
No evidence for extra gauge boson.

Submitted to PRL.

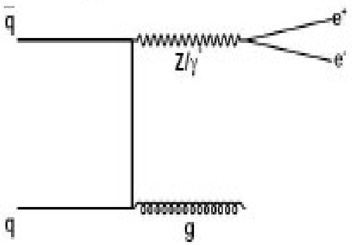
$\sin^2\theta_W$

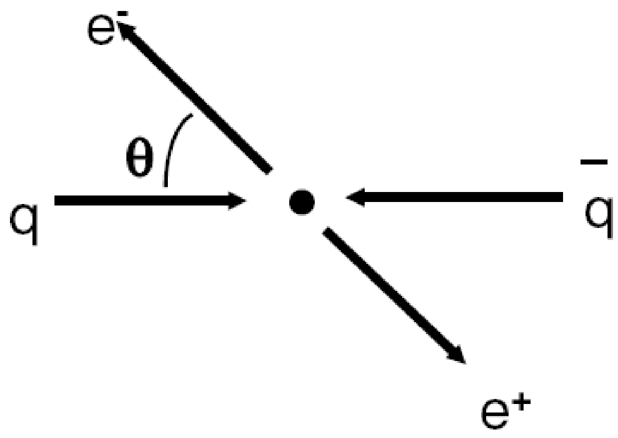
- Compare the raw A_{FB} distribution from data to 40 MC A_{FB} distributions and correct for higher order QCD, QCD and EW effects.
  - $\sin^2\theta_W = 0.2327 \pm 0.0018$ (stat) $\pm$ 0.006 (syst)
  - At $50 < M_{Z/\gamma*} < 500$ GeV/c^2
- With 8 fb^{-1} and both electron and muon channels, the Tevatron will approach the world average uncertainty.

Asymmetries at the LHC

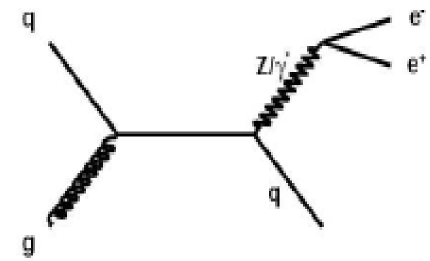
- Z forward-backward Asymmetry : which direction is forward?

$q\bar{q} \rightarrow Z + jets$





$qg \rightarrow Z + jets$



- W Charge Asymmetry : No valence antiquarks, must come from sea or gluons leading to a dilute asymmetry distribution.

Conclusions

- Lots of asymmetry results from the Tevatron
  - More expected as more data is analyzed. Both experiments have upto 4.0 fb^{-1} of data
- Good agreement with SM predictions
- Better constraints on PDFs achieved.
- No conclusive results for new physics yet!

Eagerly waiting for the LHC data!!!

Backup Slides

Coupling results (72 pb^{-1})

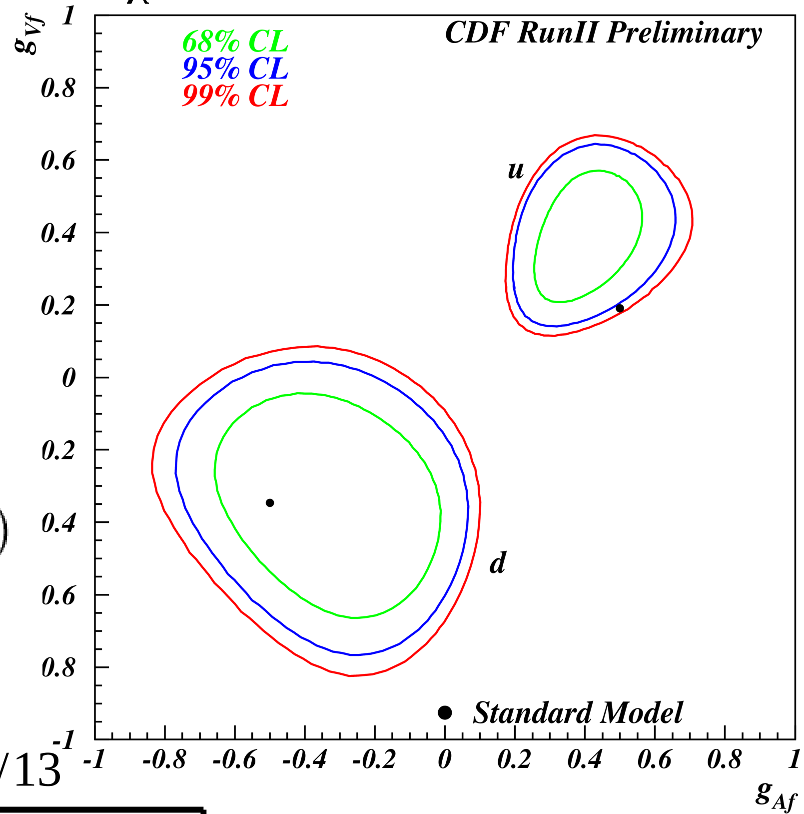
Quark Couplings

	This Study	2 fb^{-1} Uncert.	Experimental values (PDG)	SM Prediction
u_L	**0.41±0.14**	±0.028	0.330±0.016	0.3459±0.0002
u_r	**0.01±0.12**	±0.024	-0.176±0.008	-0.1550±0.0001
d_L	**-0.32±0.26**	±0.057	-0.439±0.011	-0.4291±0.0002
d_r	**-0.02±0.34**	±0.088	-0.023±0.058	0.0776±0.0001

$$\sin^2\theta_W = 0.2238 \pm 0.0046(\text{stat}) \pm 0.0020(\text{syst})$$

χ^2/ndf = 12.71/14.0

$\chi^2/\text{ndf} = 10.66/11$



Electron Couplings: $\chi^2/\text{ndf} = 12.5/13$

	This study	SLD+LEP	SM prediction
e_V	**-0.056±0.018**	**-0.03816±0.00047**	**-0.03816 ± 0.00047**
e_A	**-0.536±0.190**	**-0.50111±0.00035**	**-0.5064 ± 0.0001**