W/Z boson asymmetry measurements at DØ

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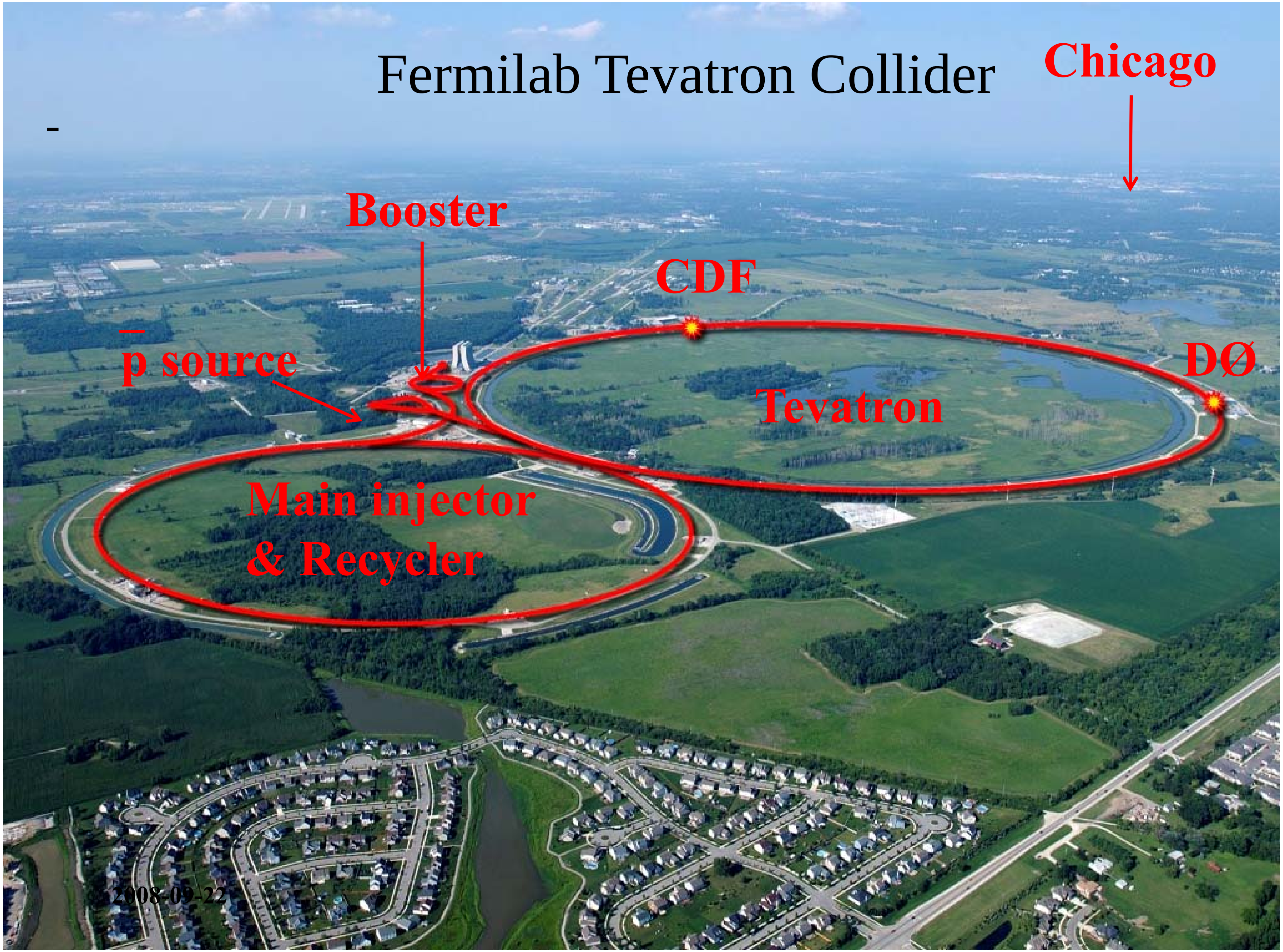
Outline

- Introduction
- Electron charge asymmetry ($W \to e\nu$)
- Forward-backward charge asymmetry (A_{FB}) and extraction of weak mixing angle ($\sin^2\theta_W$) ($Z/\gamma^* \to ee$)
- Conclusions


Fermilab Tevatron Collider
Chicago
Booster
CDF
p̄ source
DØ
Tevatron
Main injector
& Recycler
2008-09-22

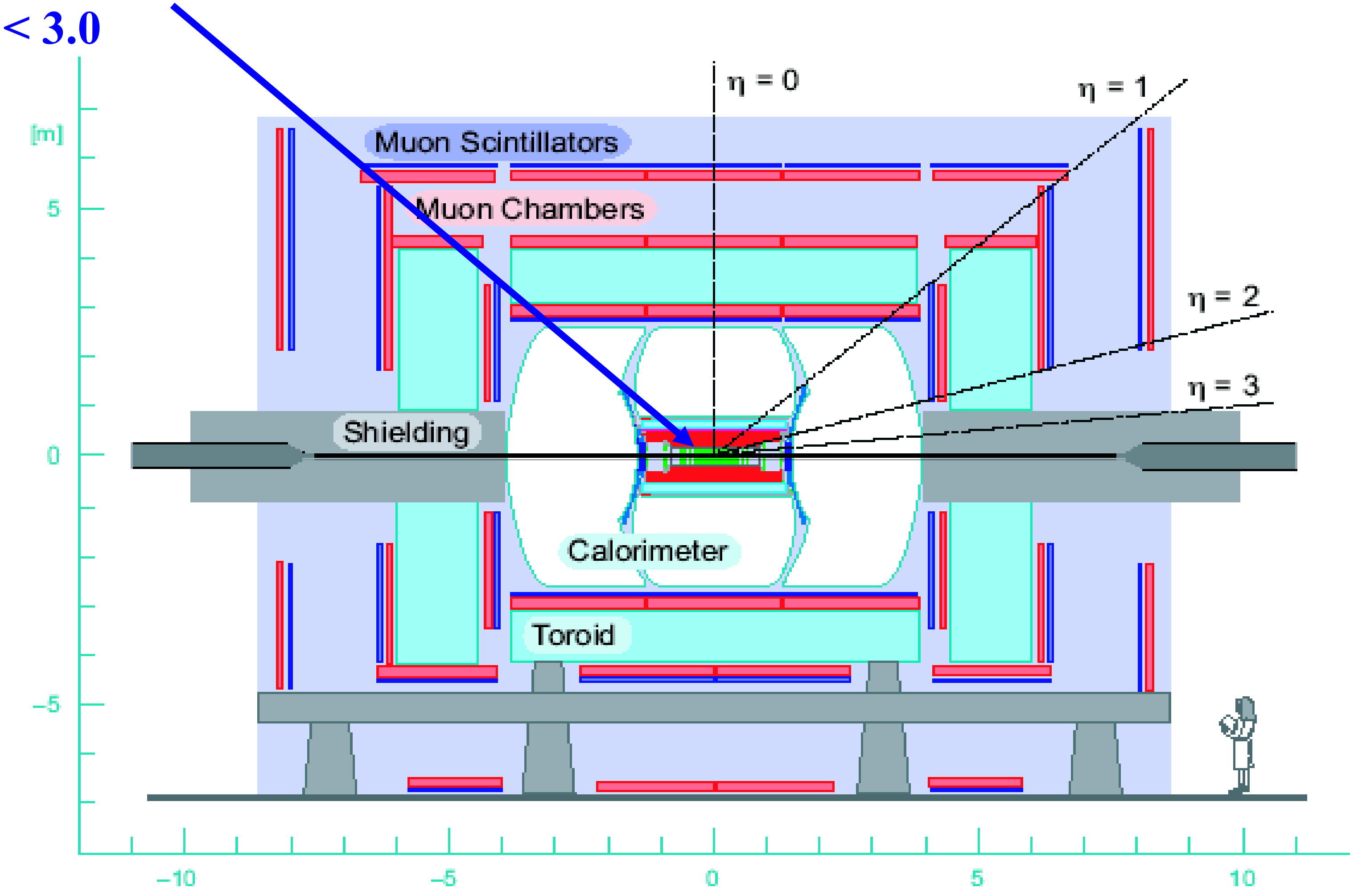
DØ Detector

Silicon Microstrip Tracker (SMT)

Central Fiber Tracker (CFT)

2 T magnetic field

Coverage: $|\eta| < 3.0$

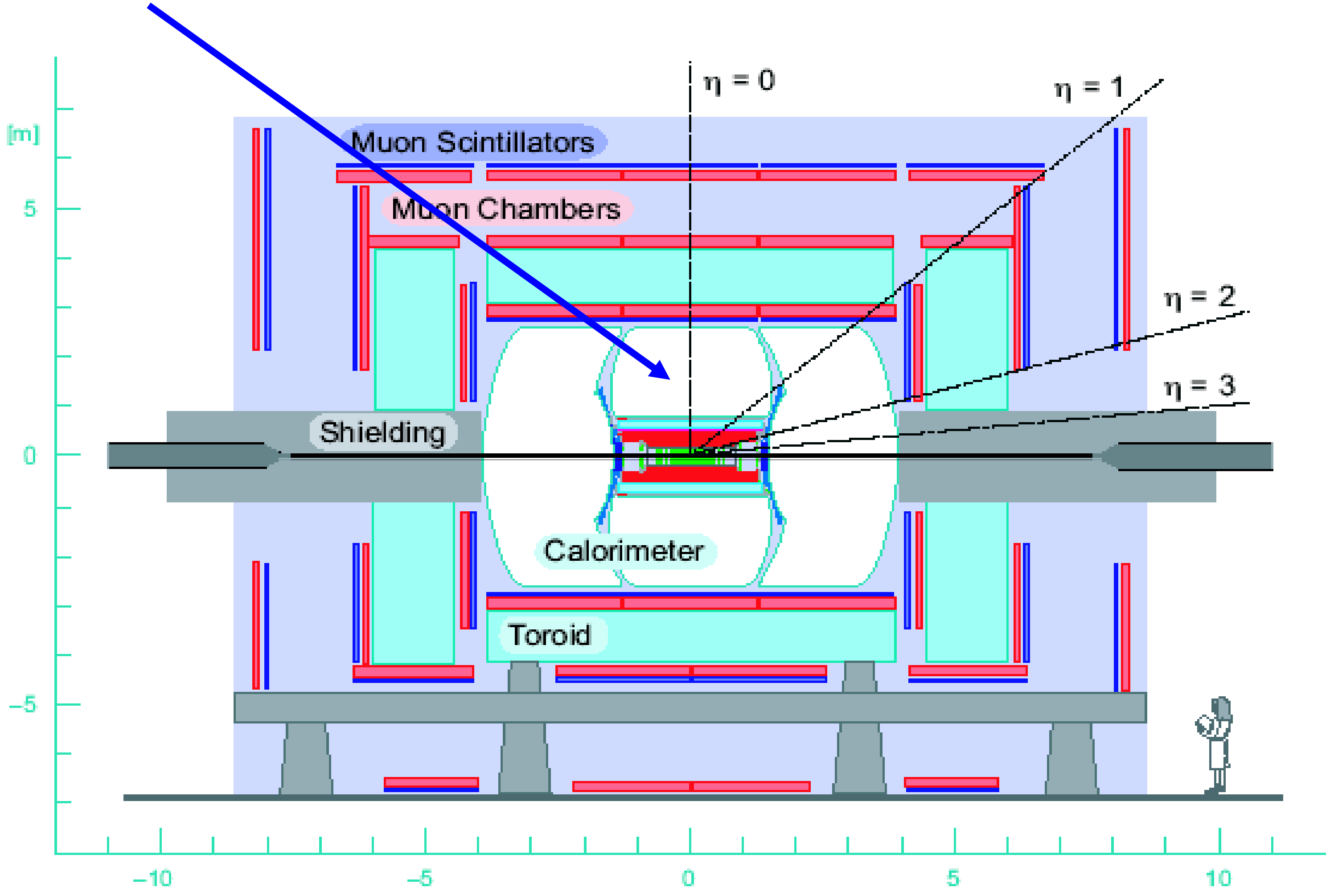


DØ Detector

Uranium Liquid Argon calorimeters

Central (CC) and Endcap (EC)

Coverage: |η| < 4.2

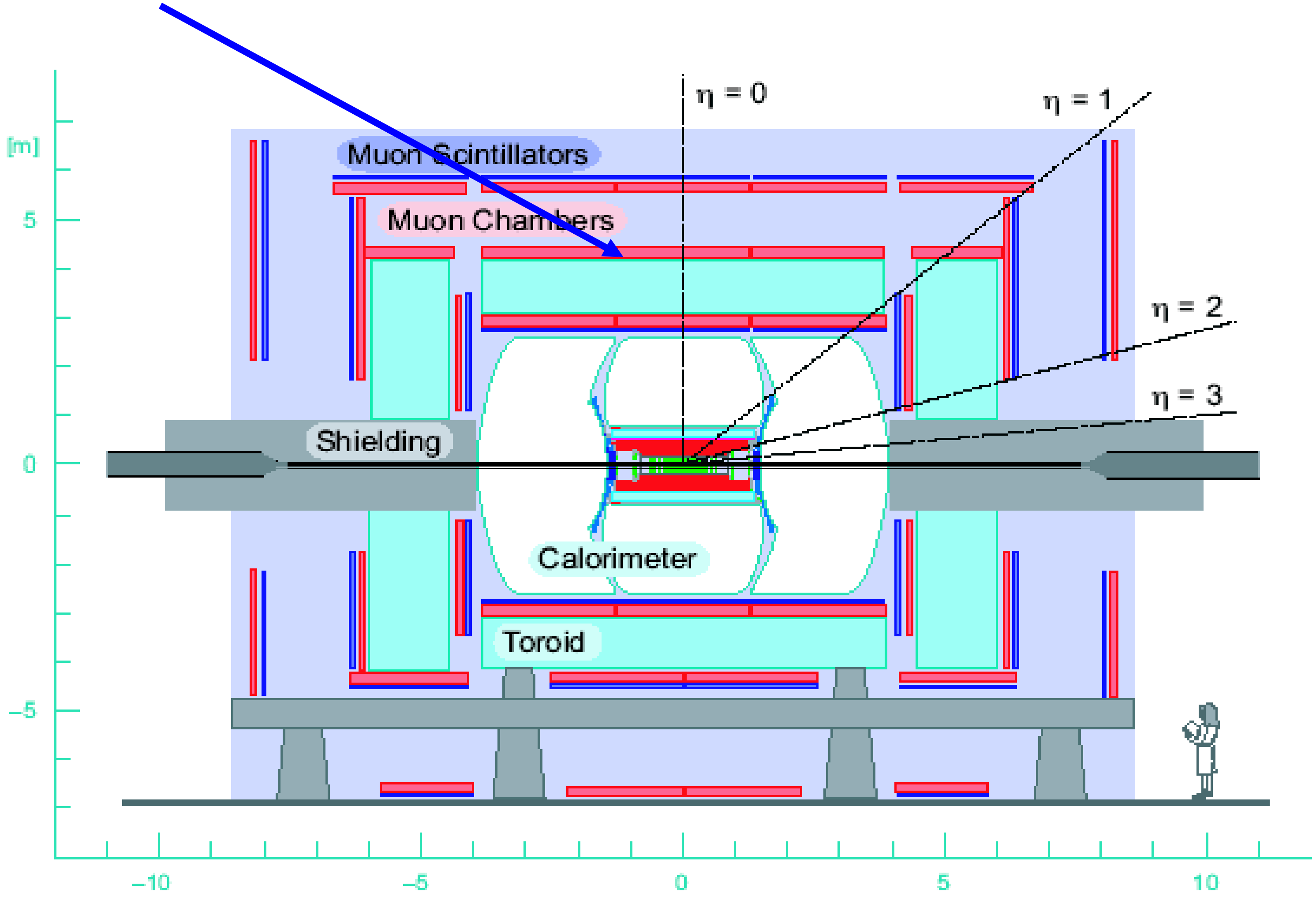


DØ Detector

Drift chambers and scintillator counters

1.8 T toroids

Coverage: |η| < 2.0



The DØ Collaboration

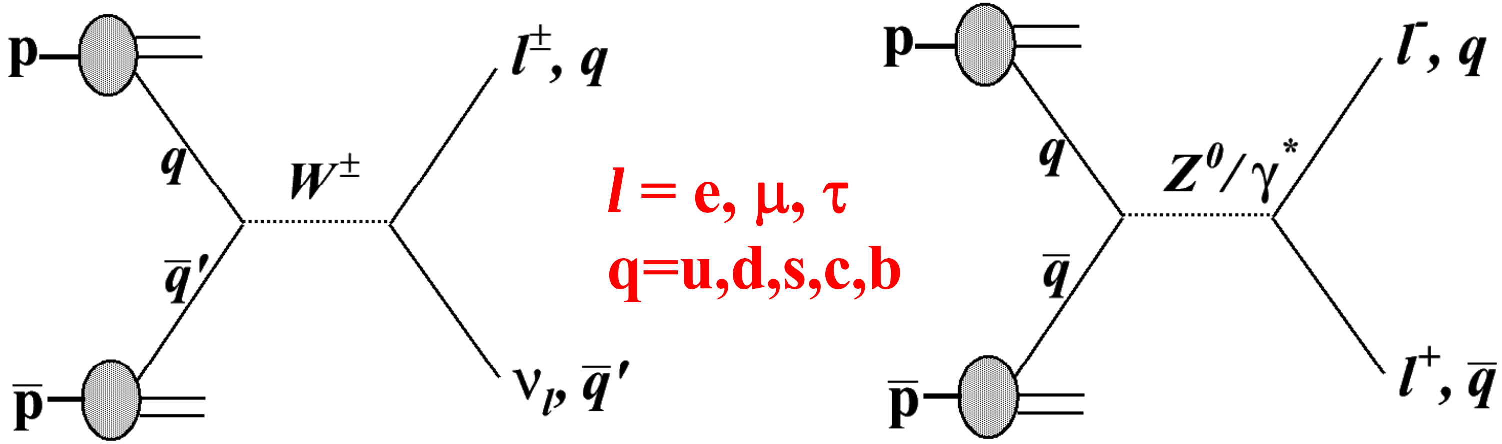
Institutions: 82 total, 38 US, 44 non-US

Collaborators:
554 physicists from 18 countries
Physics:
B, EW, QCD, Top, Higgs, New Phenomena

September 2007

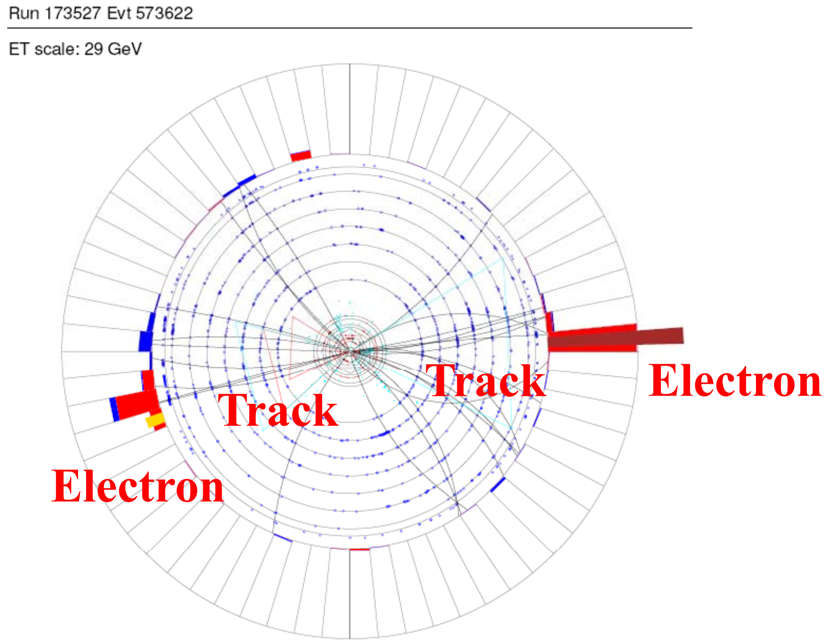
Introduction

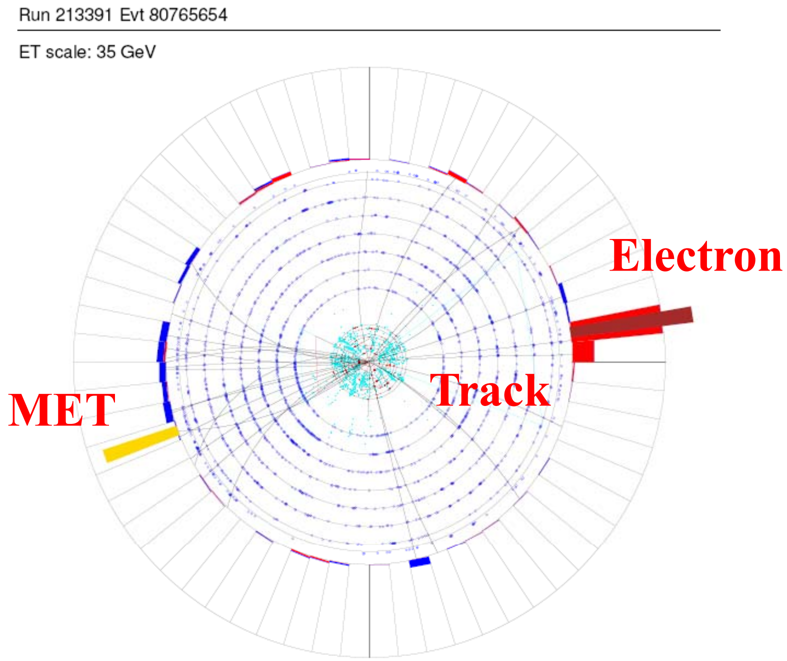
- Electroweak group $\rightarrow$ WZ group
- W and Z boson production at Tevatron



- Z (→ee, μμ) events are often used for detector calibration
- W/Z are backgrounds for many measurements and searches
- Make precision measurements of electroweak parameters
- Test high-order QED and QCD corrections
- Constrain parton distribution functions (PDFs)
- Search for physics beyond the SM

Z and W events

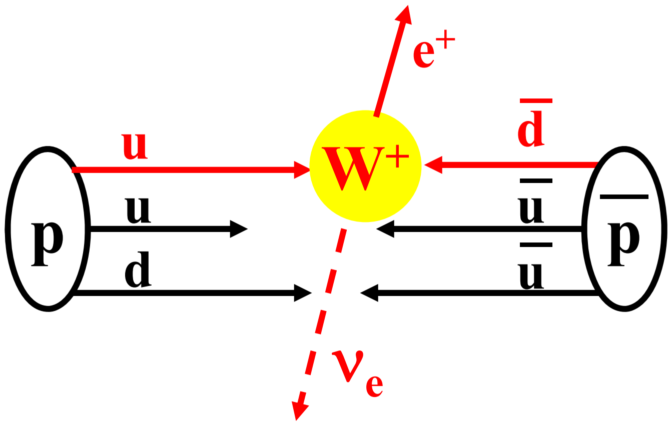


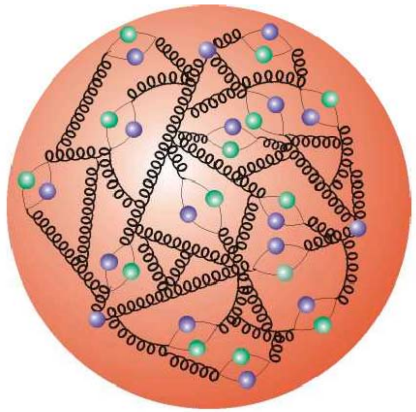


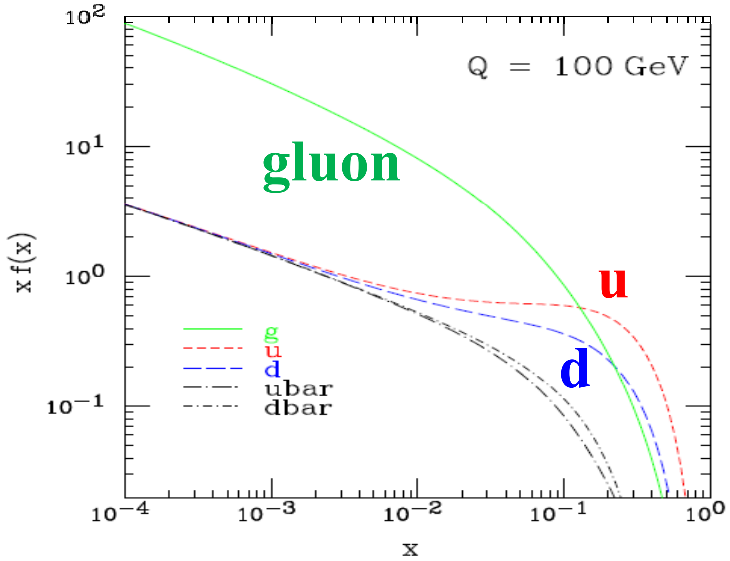
- Z boson: Two high p_T electrons
  - Both electrons are detected and their energies measured
- W boson: One high p_T electron, one high p_T neutrino
  - Electron is detected and energy measured
  - Neutrino cannot be detected
  - $p_T(\nu)$ is inferred by the "missing E_T (MET)" in the detector

Electron Charge Asymmetry
($W \to e\nu$)

Parton Distribution Functions







- PDFs describe the momentum distribution of parton in the proton
  - x: momentum fraction of parton, Q^2: square of momentum transfer
  - Cannot be calculated from first principles, extracted from experiments
  - Parameterized at a fixed scale Q_0 with smooth functions with many parameters
  - Apply assumptions and constraints from theory and experimental results
  - Extrapolate from Q_0 to different Q^2
- At least two major collaborations: CTEQ and MSTW (originally MRST)
- Well constrained PDFs are essential for all studies at hadron colliders
  - Expect Tevatron Run II ΔM_W <15 MeV, currently 15 MeV due to PDFs

W Charge Asymmetry

- u quarks carry on average more momentum than d quarks in the proton

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

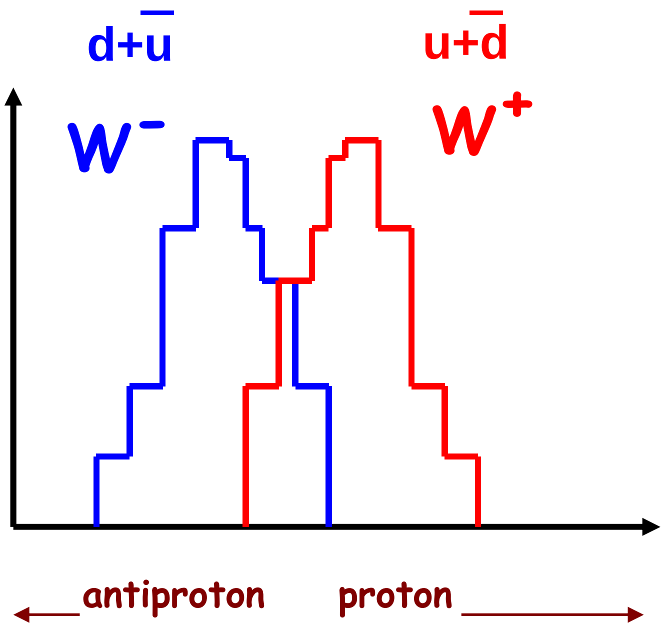
- A(y) sensitive to u(x)/d(x) in the proton

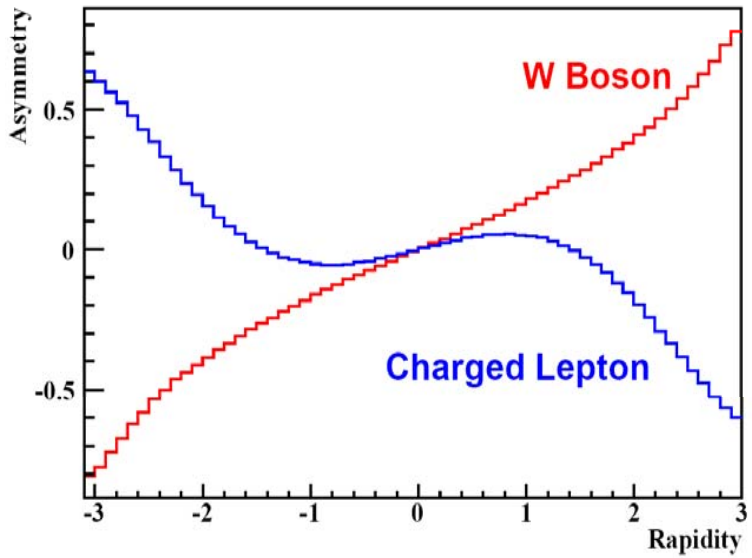
$W \rightarrow e\nu \;\; \Rightarrow$ A(y) difficult to measure

- W asymmetry → Lepton asymmetry

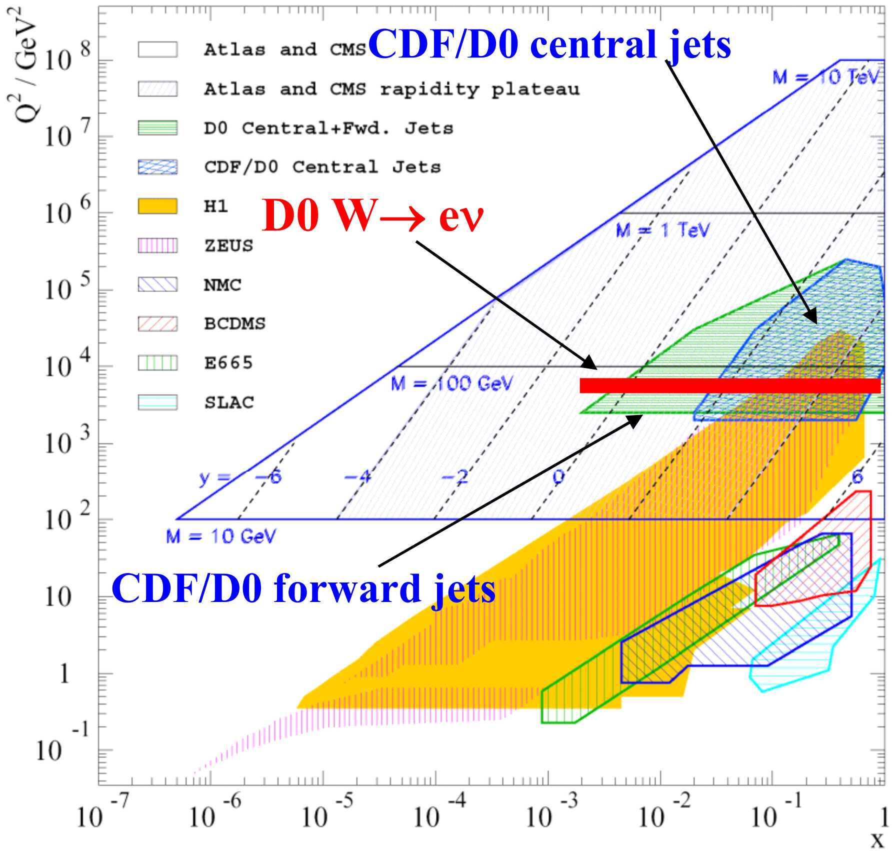
$$A(\eta_l) = \frac{d\sigma(l^+)/d\eta - d\sigma(l^-)/d\eta}{d\sigma(l^+)/d\eta + d\sigma(l^-)/d\eta}$$

- $y \approx \eta$ for leptons
- Lepton asymmetry: A(y) ⊗ (V-A)
- The V-A structure of the $W^{+(-)}$ decay favors a backward (forward) lepton
- Most systematics reduced due to the ratio





x-Q^2 reach



x = momentum fraction of parton
Q^2 = square of momentum transfer

- W asymmetry measurement:

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

- This measurement:

$$|y_W| < 3.2 \Rightarrow 0.002 < x < 1.0$$

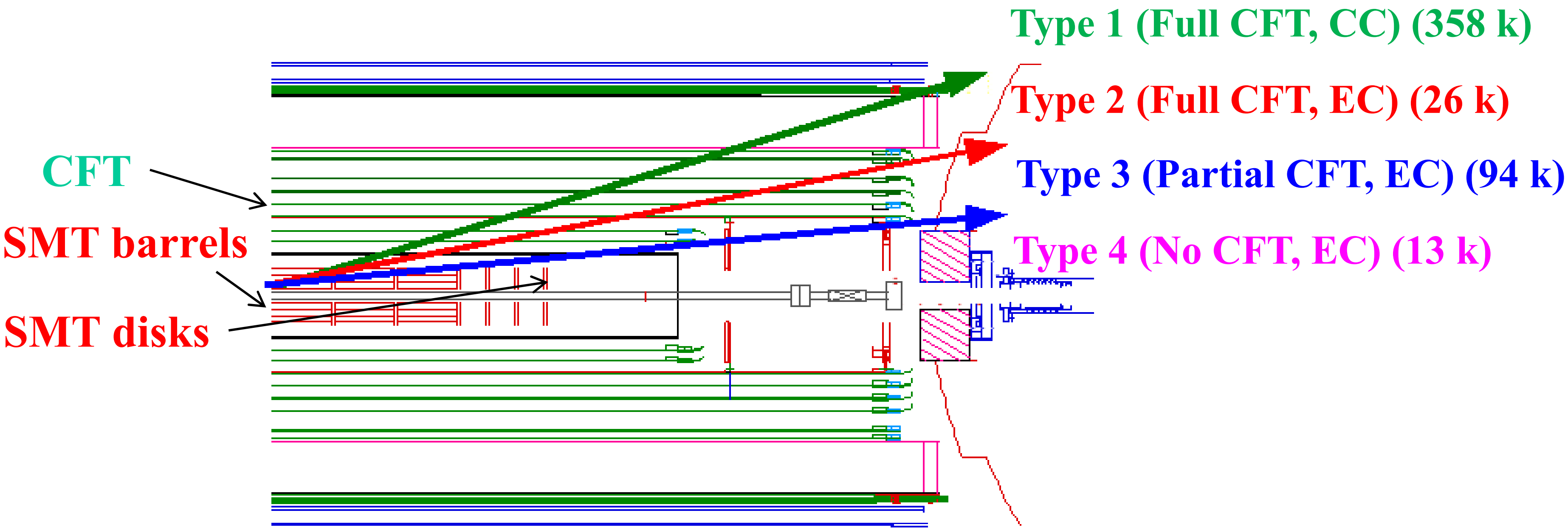
- Previous measurements:

$$|y_W| < 2.5 \Rightarrow 0.003 < x < 0.5$$

- Complementary to central and forward jet measurements at D0 and CDF
- LHC will explore very different x-Q^2 region (low x and high Q^2)

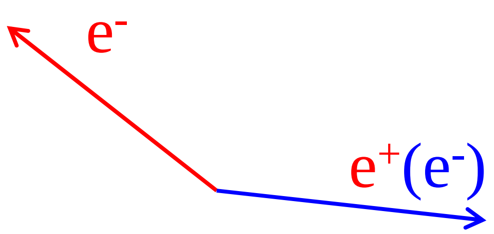
Electron Types

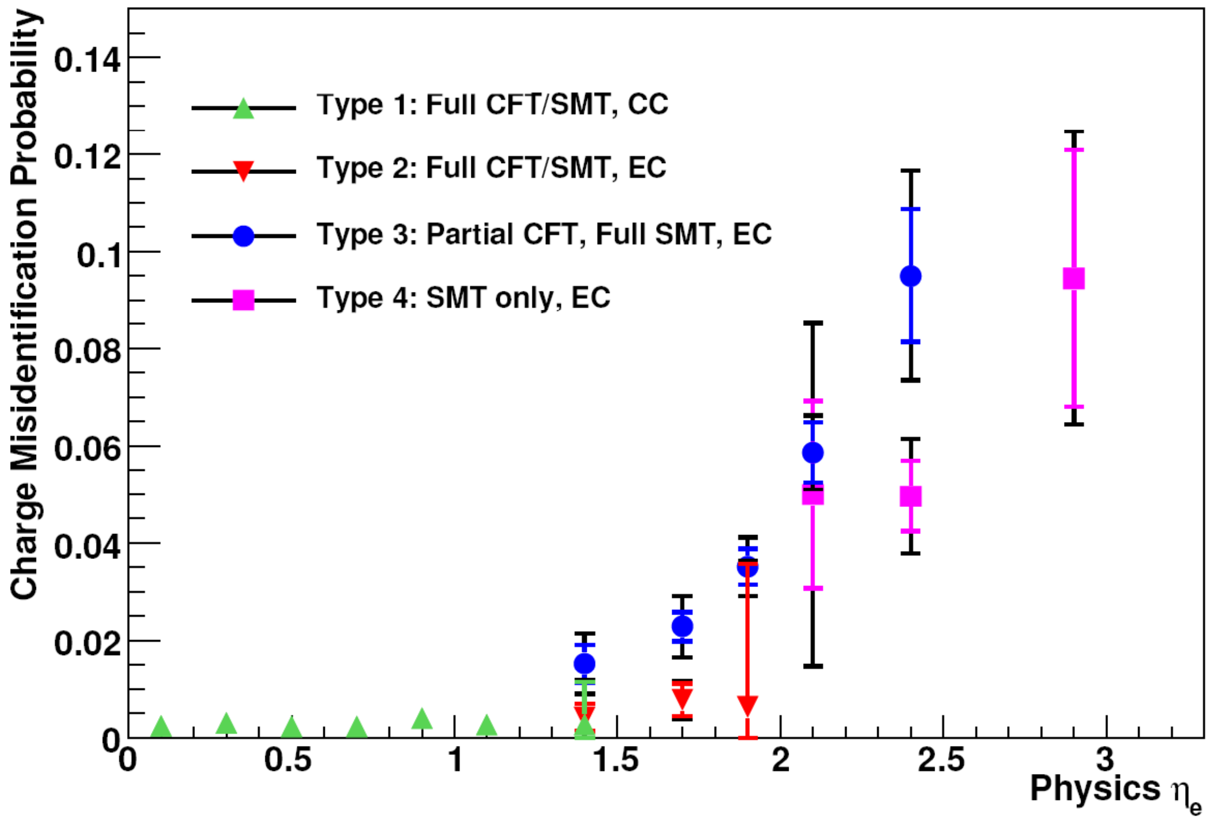
- Important to determine electron charge correctly
- High rapidity bins suffer from low statistics and higher charge mis-identification rate
- Splitting data into 4 electron types depending on the position of EM cluster, incident angle and the primary vertex
- Different track quality cuts applied for different electron types



Charge Mis-identification

- Charge mis-identification dilutes the asymmetry
- Rate measured using $Z \to ee$ events: tight selection requirements on one electron, and check the charge of the other electron
- ~ 0.3% for $|\eta|<1$, ~ 9% for $2.8<|\eta|<3.2$ (CDF: 18% for $2< |\eta| <2.5$)





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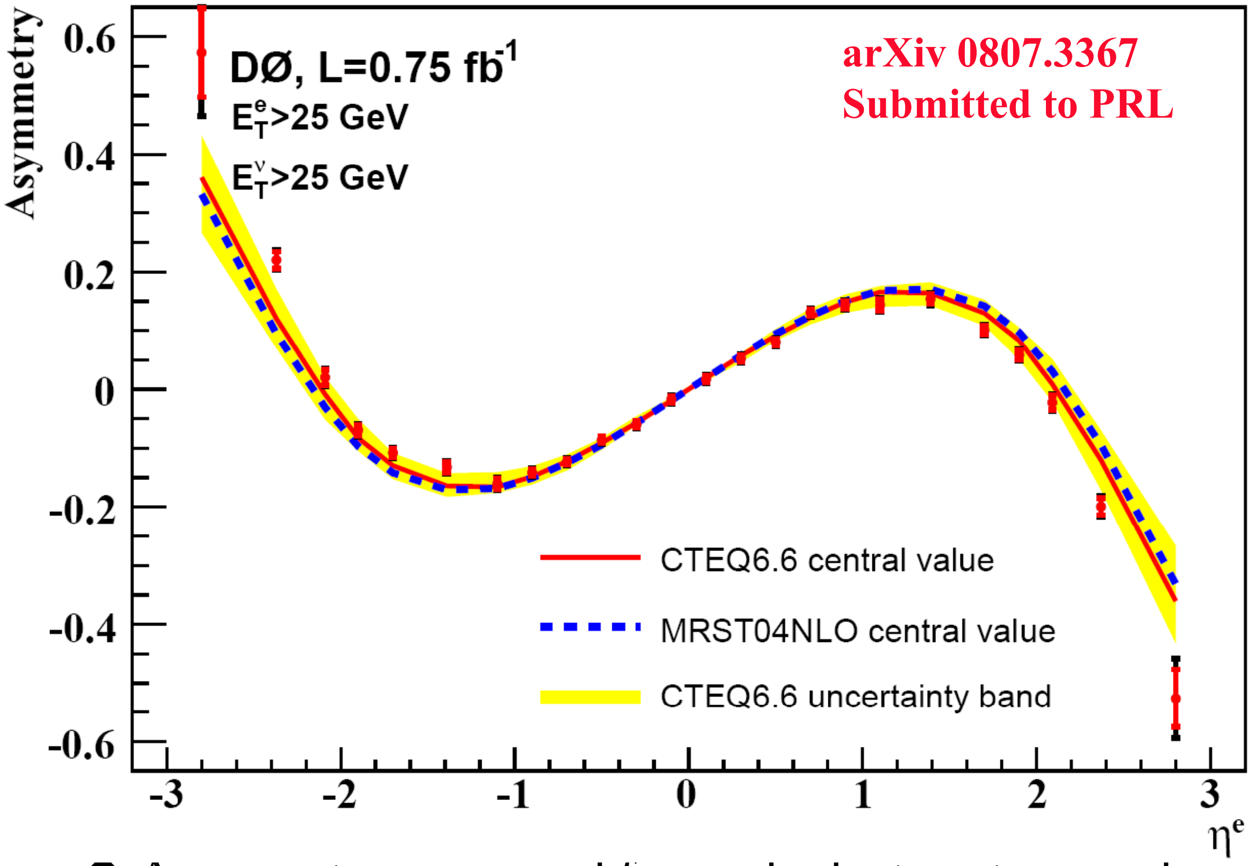
Electron charge asymmetry for E_T>25 GeV

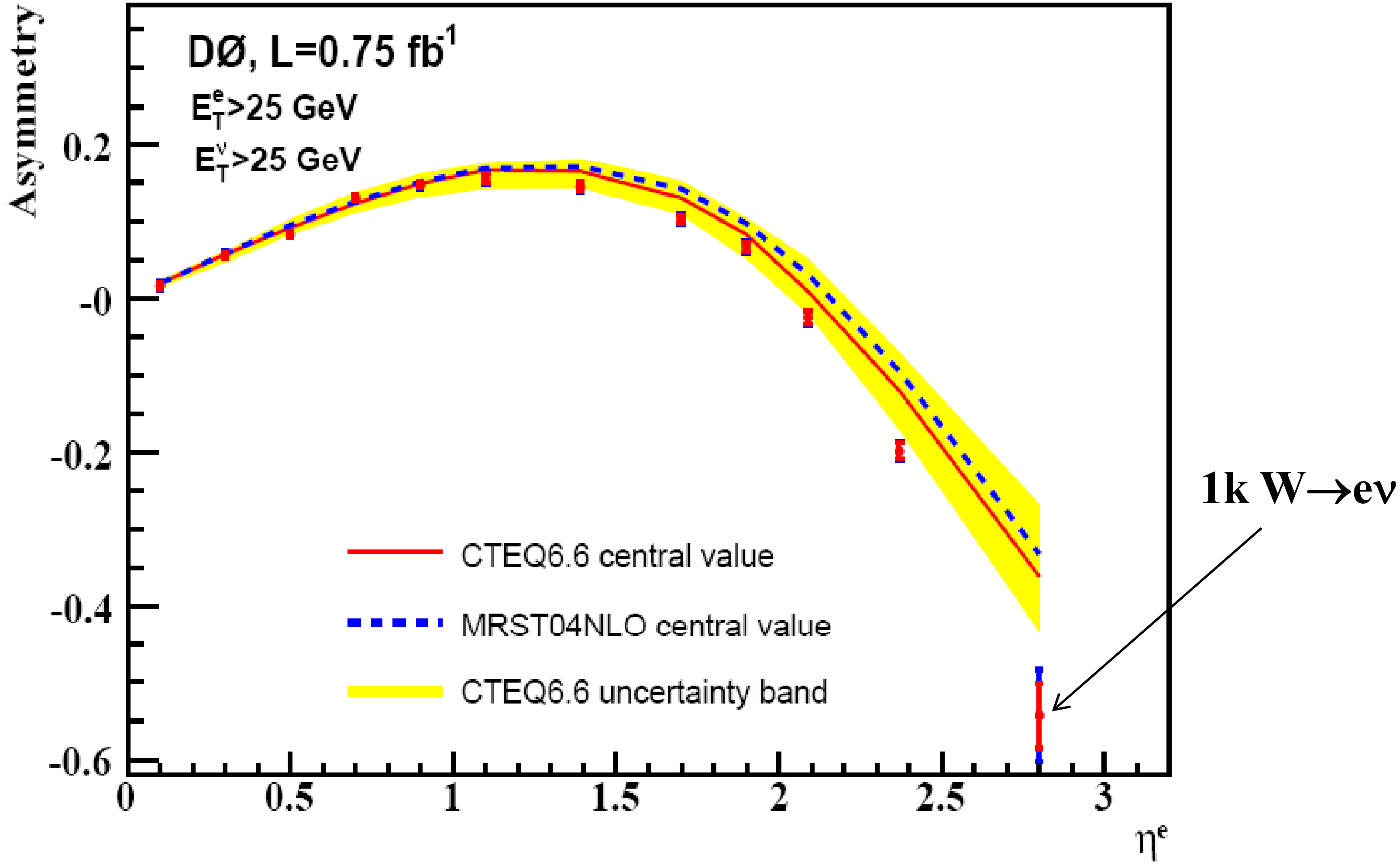


- Asymmetry measured for each electron type and then combined together
- CP invariance: A(-η) = -A(η)
- Fold data to increase the available statistics

- ResBos + PHOTOS (Balazs and Yuan, PRD 56, 5558 (1997), Barberio and Was, Comput. Phys. Commun 79, 291 (1994))
- Latest CTEQ6.6 NLO PDFs with 44 uncertainty PDF sets (P. Nadolsky *et al.*, PRD 78, 013004 (2008))
- MRST04NLO: (A.D. Martin *et al.*, PLB 604, 61 (2004))
- PDF uncertainties: (D. Stump *et al.*, JHEP 0310, 046 (2003))

$$\Delta A^{\pm} = \sqrt{\sum_{i=1}^{n} [A(a_i^{\pm}) - A_0]^2}$$

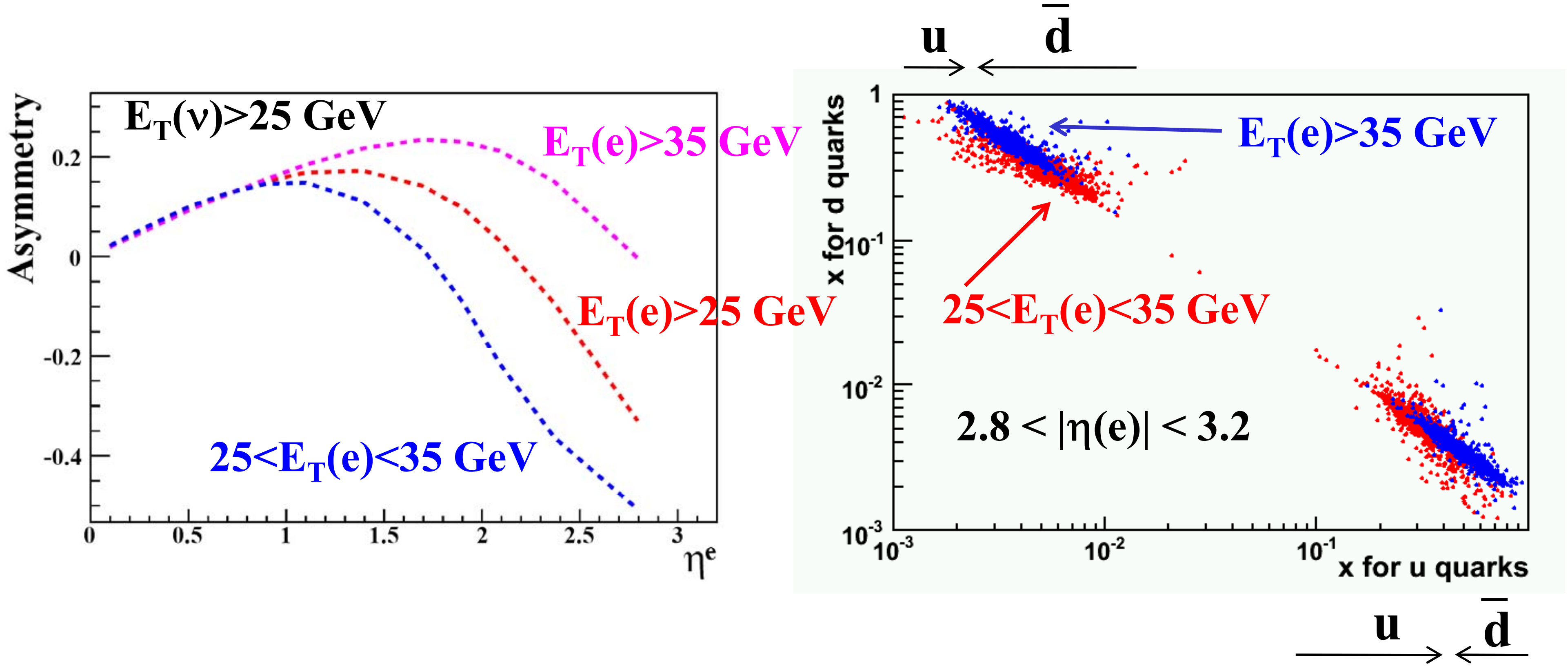
Folded charge asymmetry for E_T>25 GeV



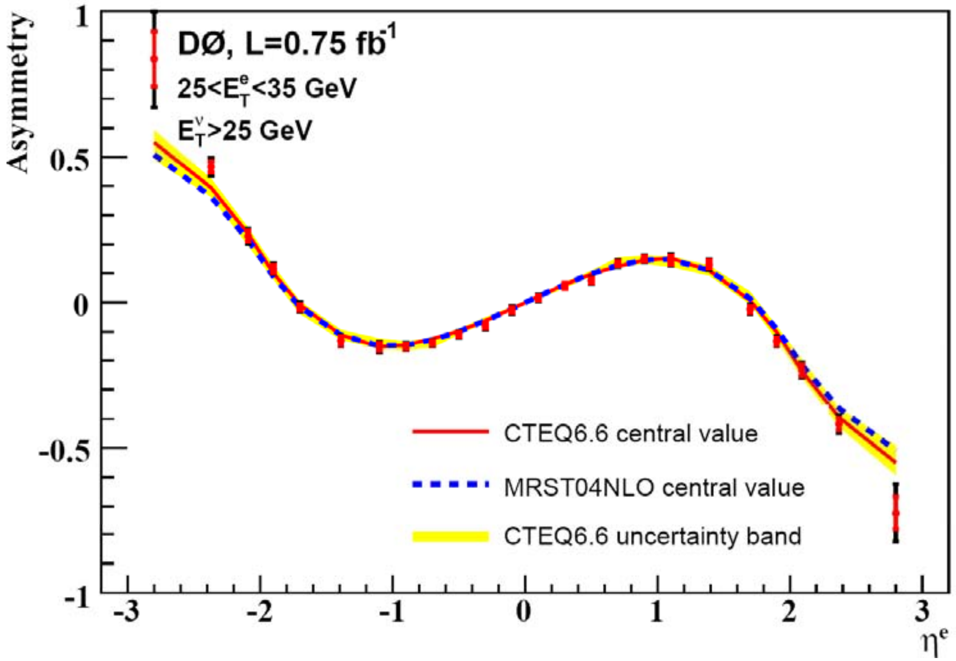
◆ Experimental uncertainties smaller than theoretical uncertainties for all bins except the largest rapidity bin

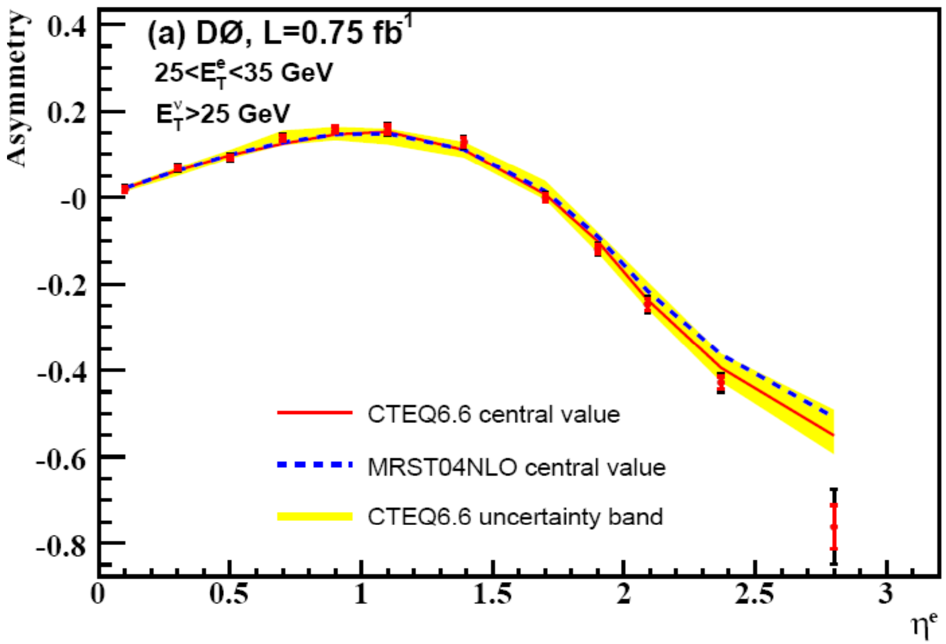
Electron E_T Bins

- For a given $\eta(e)$, different electron E_T bins probe different ranges of y_W
  - Higher E_T bin covers a narrower y_W range
  - At higher electron E_T, V-A distribution smaller, $A(\eta)$ is larger
- Allows a finer probe of the u and d quarks with different x

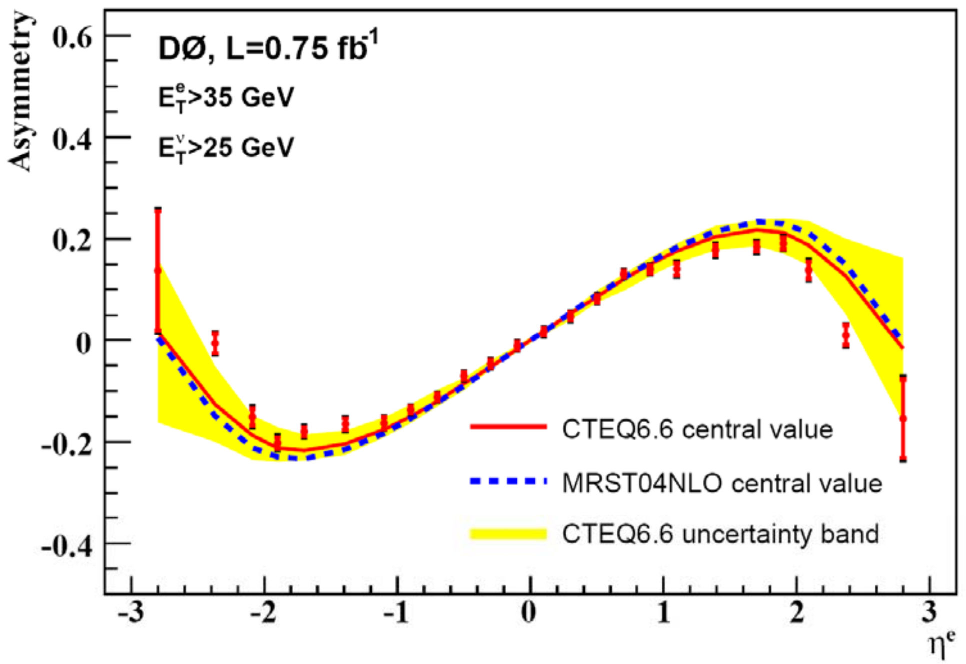


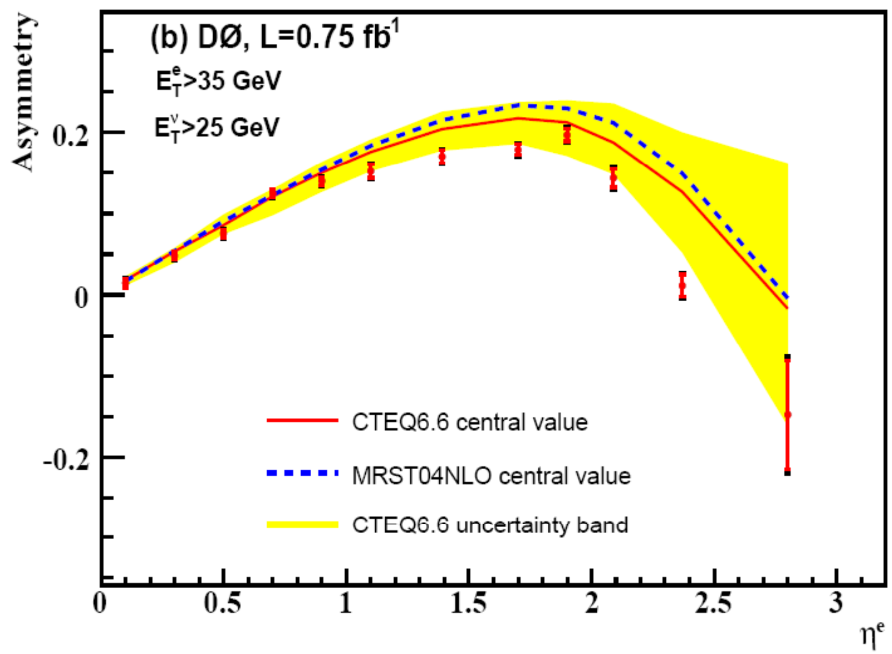
Electron charge asymmetry for 25<E_T<35 GeV



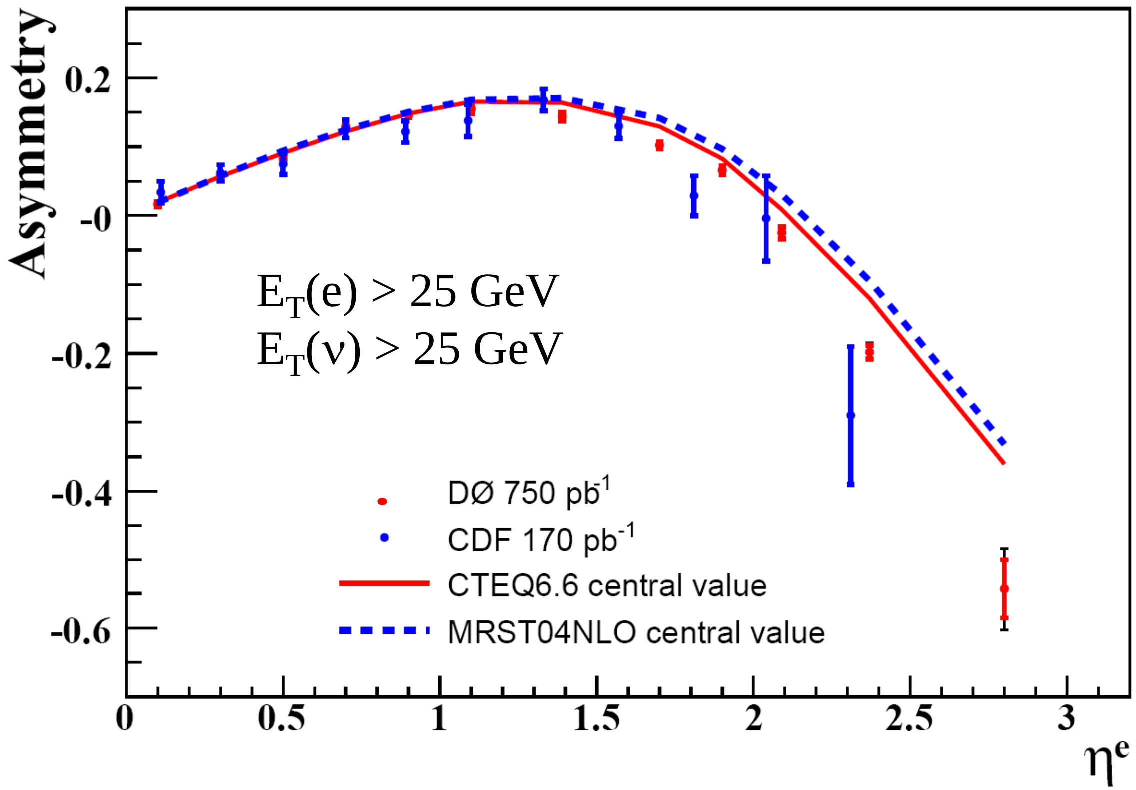


Electron charge asymmetry for E_T>35 GeV





Comparison between DØ and CDF results

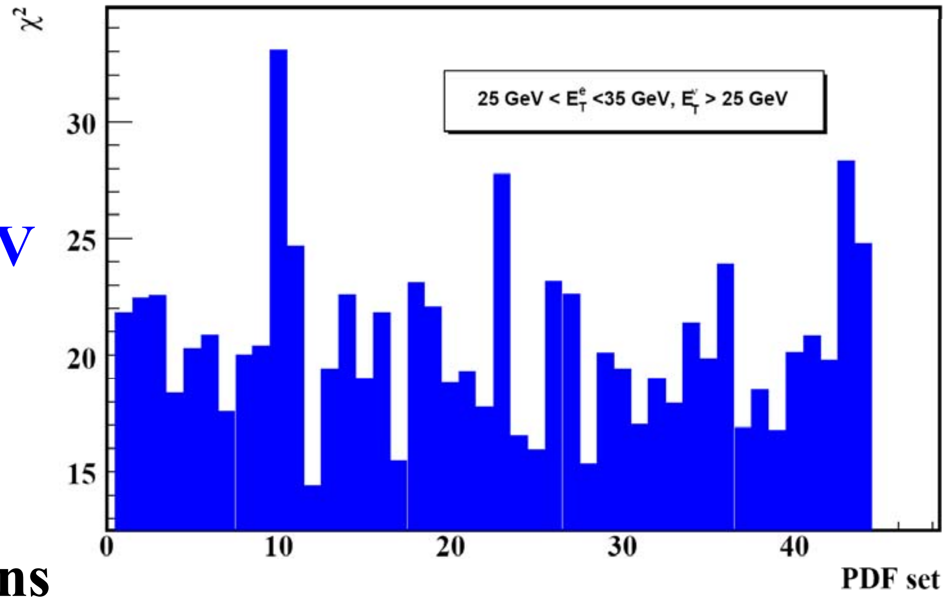


- DØ (750 pb^{-1}) vs CDF (170 pb^{-1}) (PRD 71, 051104R (2005))
- Both results agree with each other within uncertainties
- Both results indicate smaller asymmetry at high rapidity than predicted
- Larger η coverage
- significantly smaller overall uncertainties

- Experimental uncertainties smaller than PDF uncertainties for most η bins (33 out of 36)
- Can improve the precision and accuracy of next generation PDF sets
- Request from MSTW group to use our data for MSTW2008 PDF fits

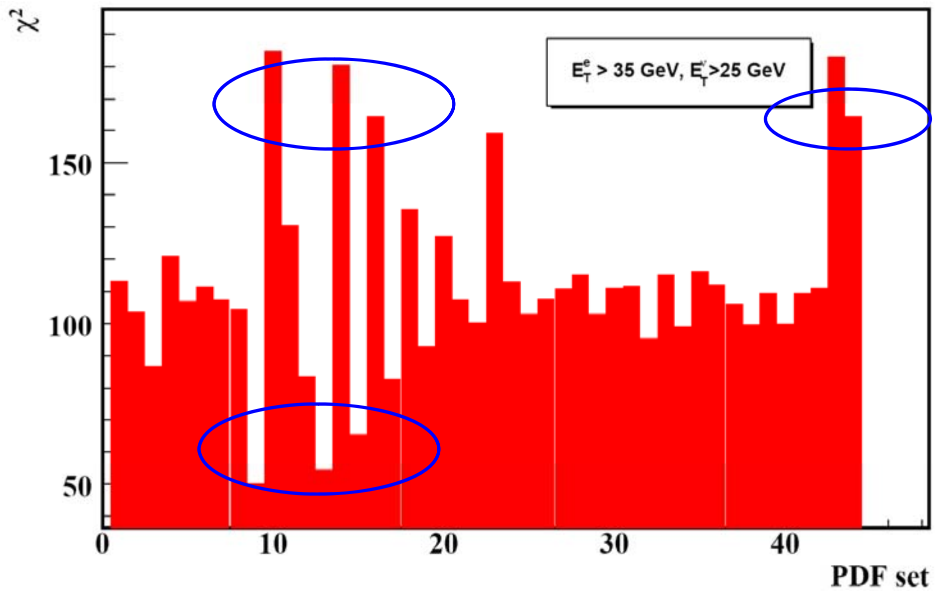
χ^2 between data and predictions

$25<E_T(e)<35$ GeV



12 electron η bins

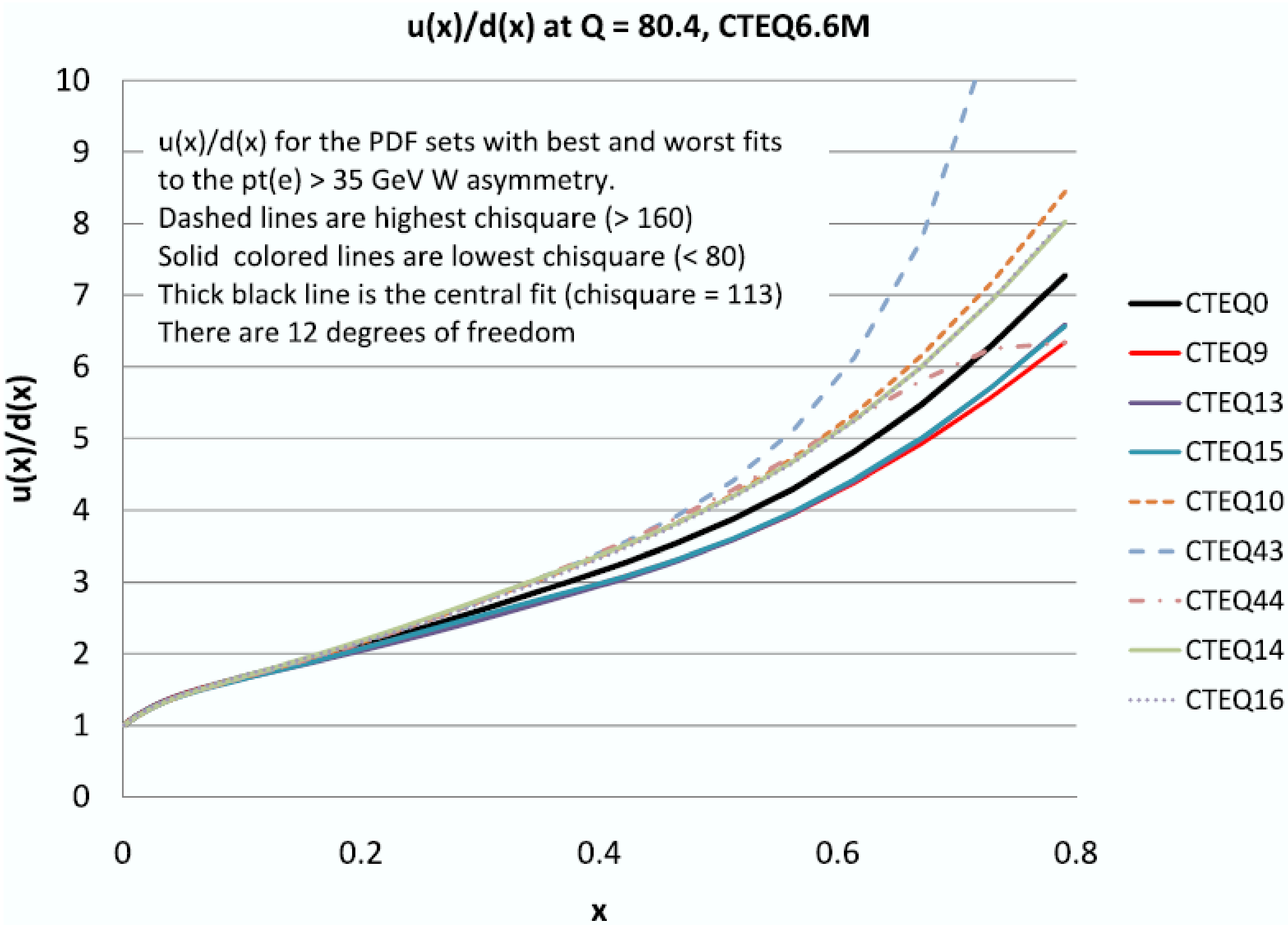
$E_T(e)>35$ GeV



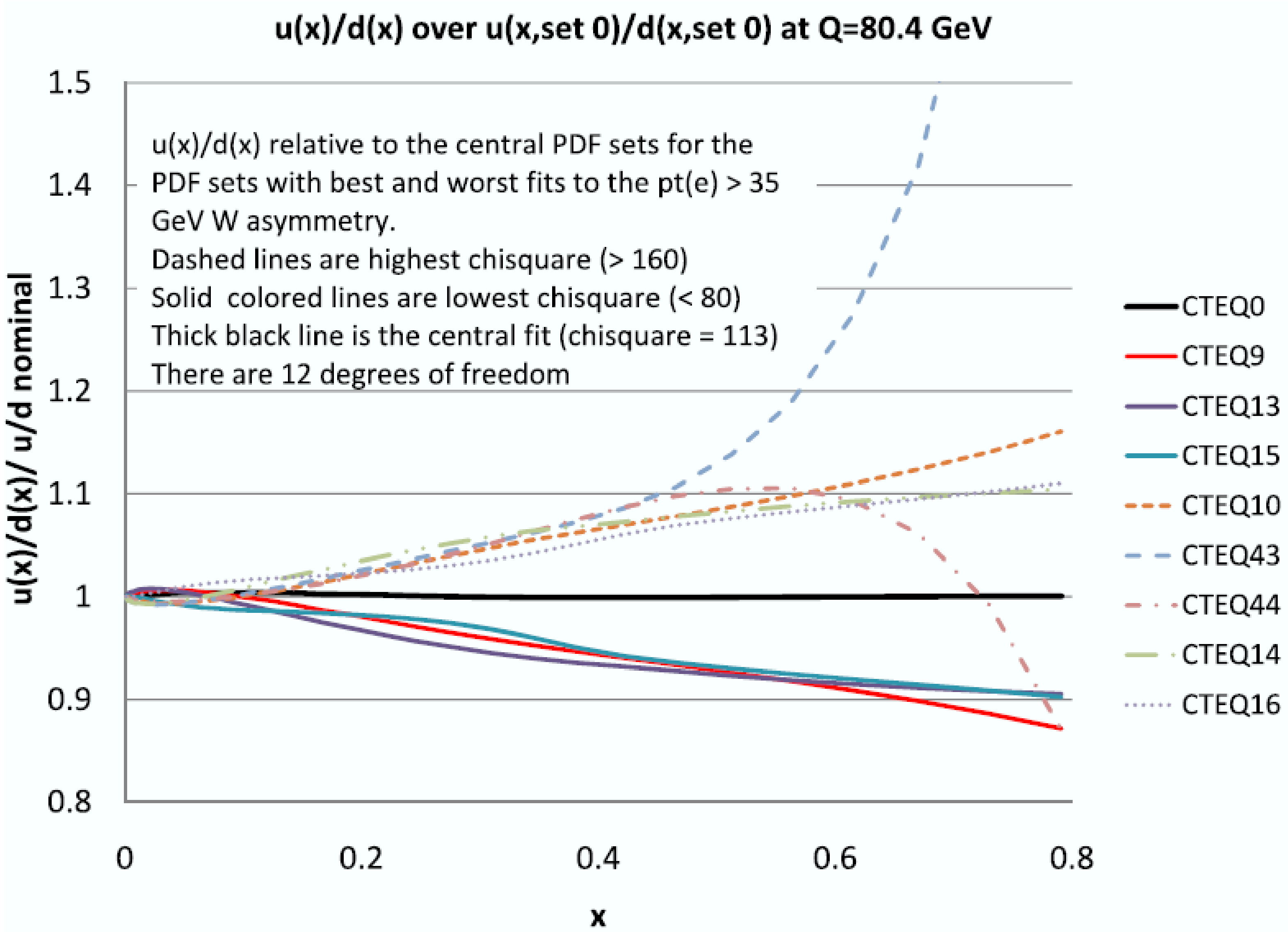
Prefer set 9, 13 and 15

Disfavor set 10, 14, 16, 43 and 44

Implication of our results on PDFs



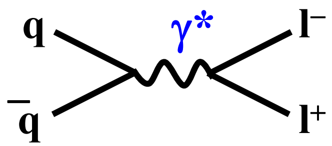
Implication of our results on PDFs



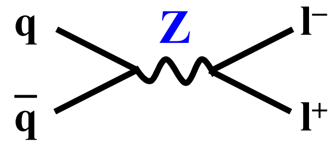
A_{FB} measurement and extraction of $\sin^2\theta_W^{eff}$ $(Z/\gamma^* \rightarrow ee)$

Z/γ* Forward-backward asymmetry

◆ $q\bar{q} \rightarrow l^+l^-$: mediated by γ*, Z and Z/γ*

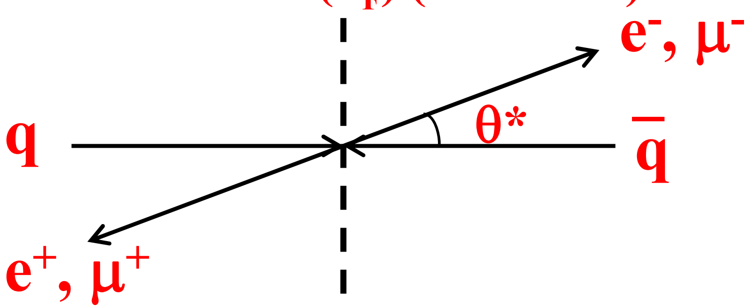


Vector coupling

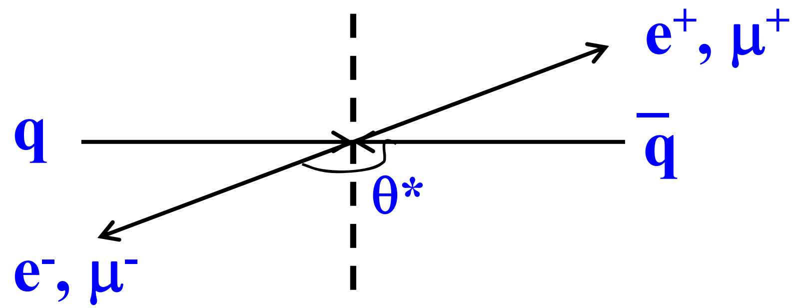


Vector & axial-vector coupling

FORWARD (σ_F) ($\cos\theta^* > 0$)



BACKWARD (σ_B) ($\cos\theta^* < 0$)



θ^* defined in the Collins-Soper frame (Z/γ* rest frame)

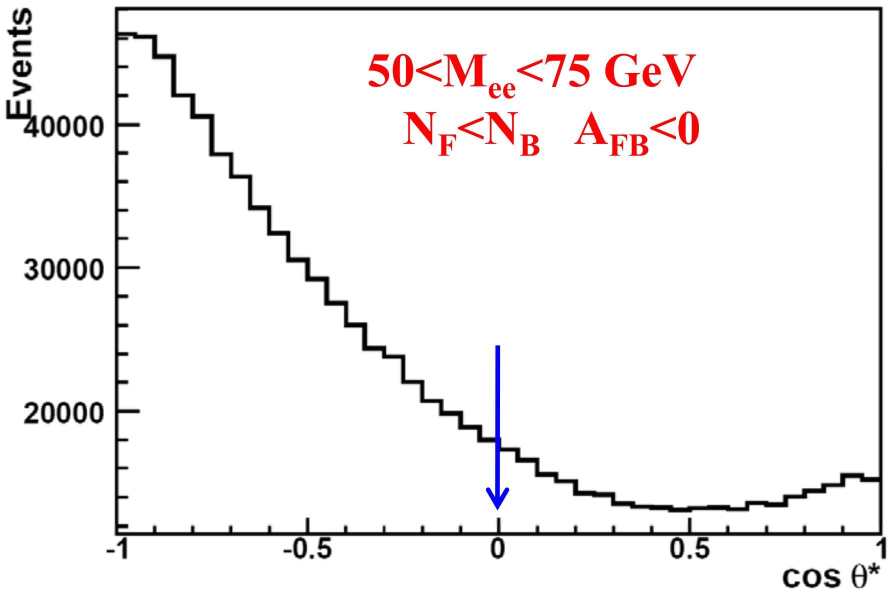
◆ θ*-dependent differential cross section:

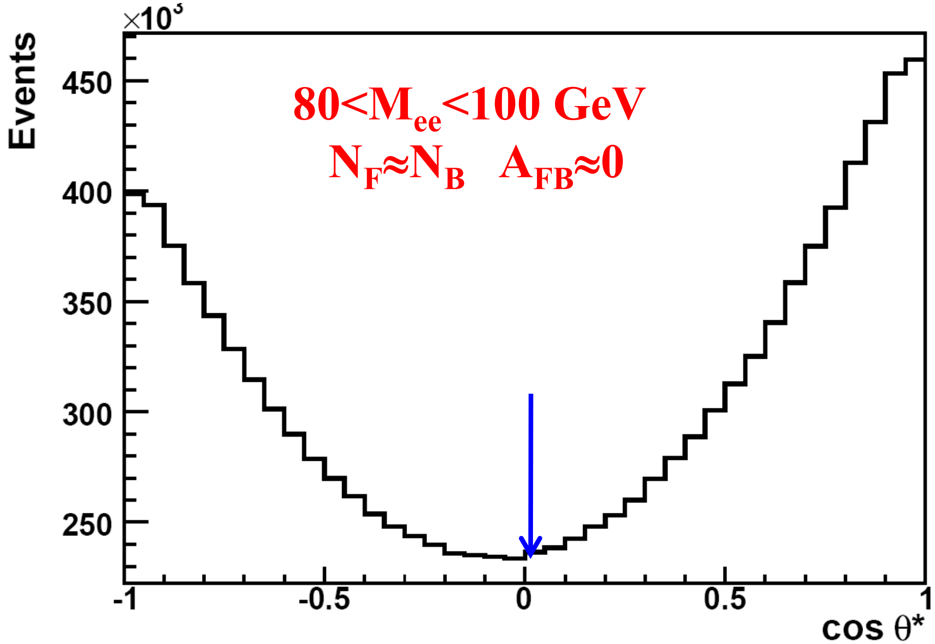
$1 + \cos^2\theta^*$ (pure γ*) $1 + \cos^2\theta^*$ and $\cos\theta^*$ (both pure Z and Z/γ* interference)

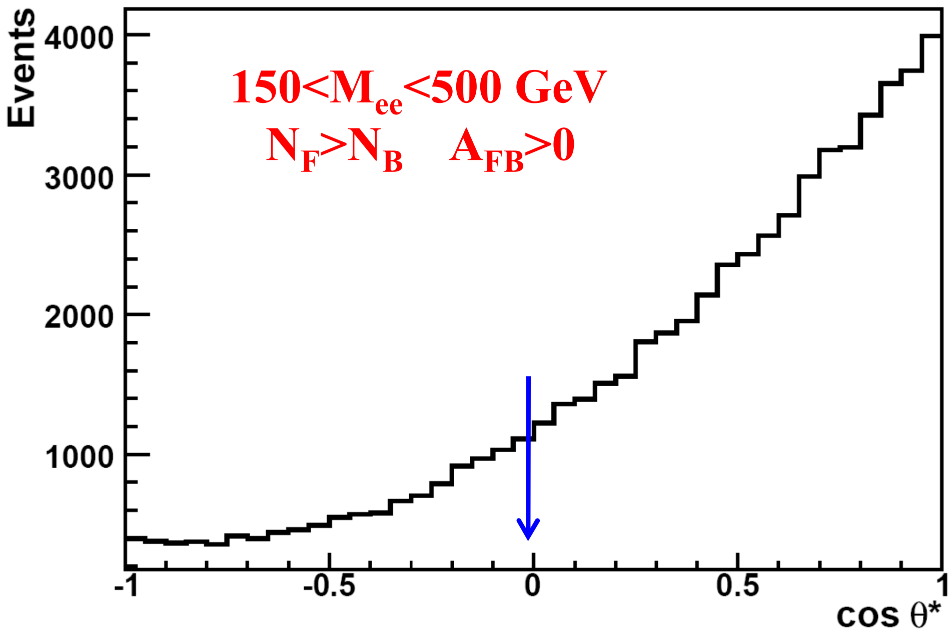
$$d\sigma/\cos\theta^* = A \times (1 + \cos^2\theta^*) + B \times \cos\theta^*$$

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

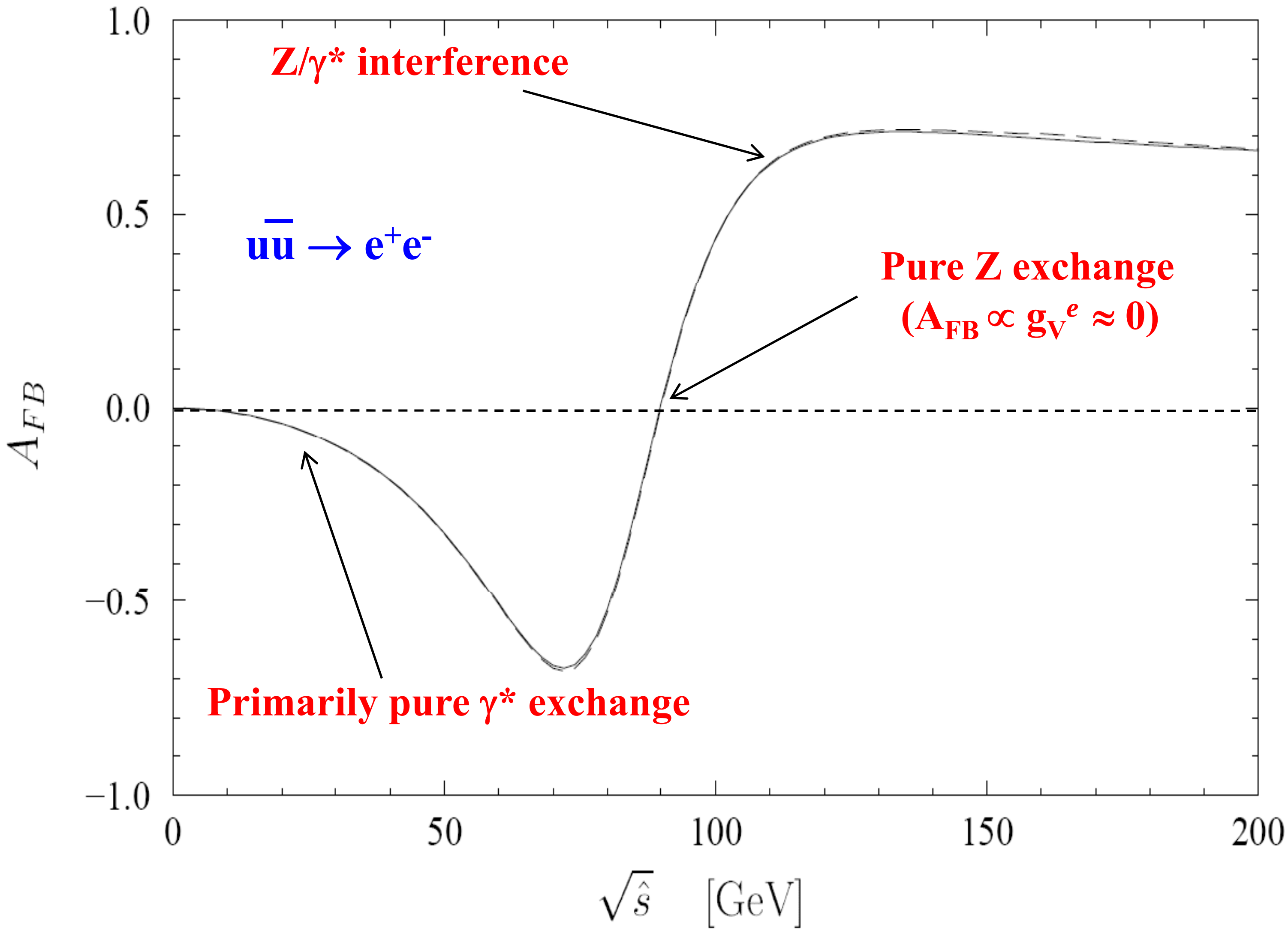
cosθ* distribution using Pythia







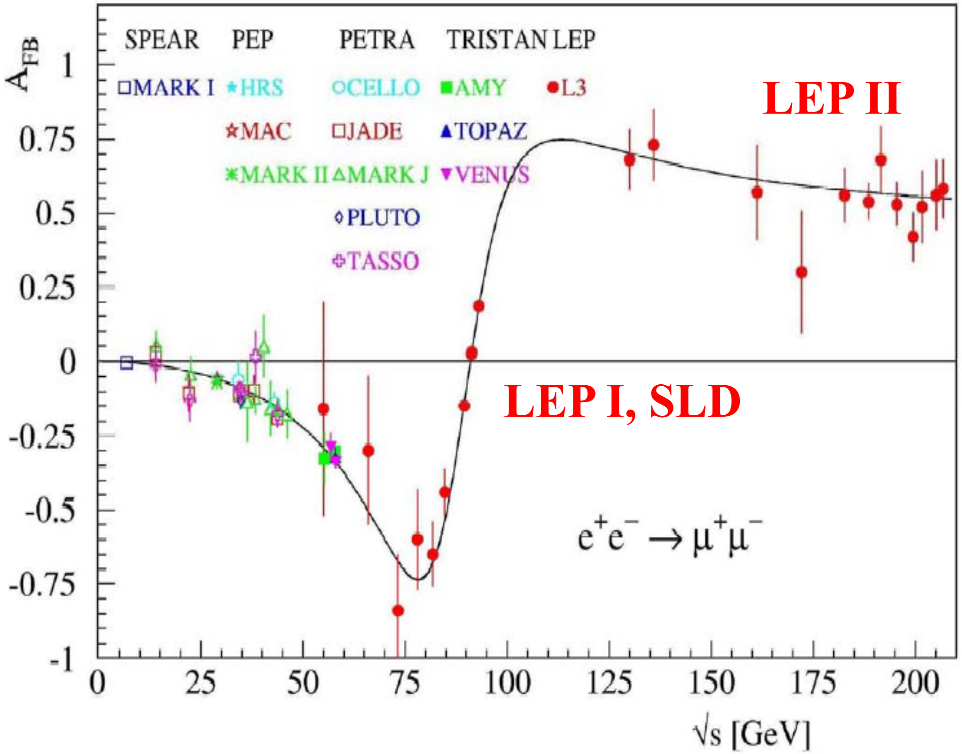
A_{FB} distribution

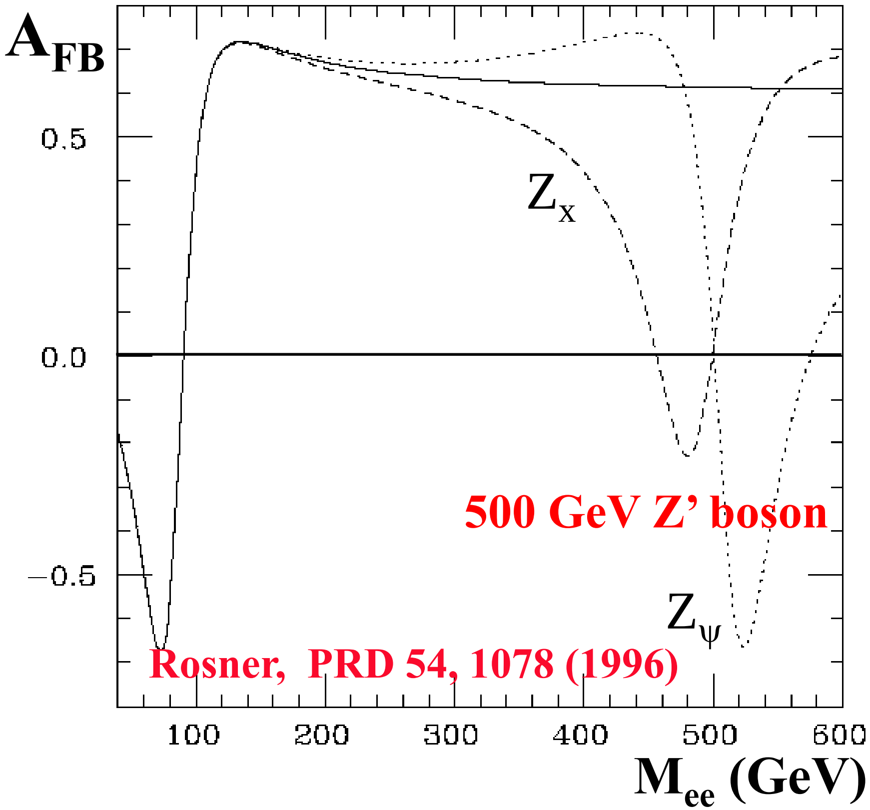


A_{FB} at e^+e^- collider and hadron collider

- Precise measurement around Z pole
- Difficult to reach very high energies (> 200 GeV)

- New resonance (Z', LED etc) can interfere with Z and γ^*
- A_{FB} measurement complementary to bump search





A_{FB} in $Z/\gamma^* \to ee$ at Tevatron

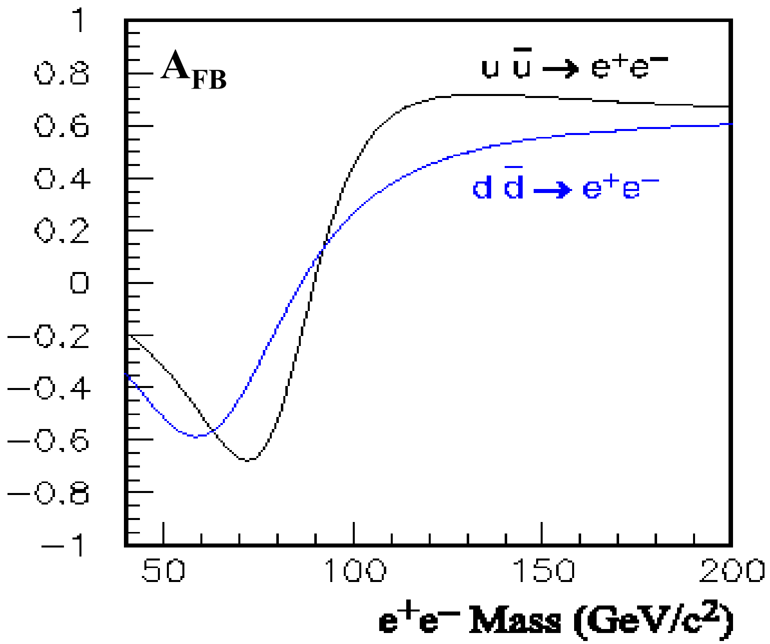
- $u\bar{u}$ $(d\bar{d}) \to Z/\gamma^* \to e^+e^-$
- SM couplings of fermions to Z boson:
  - Axial-vector coupling:

    $$g_A = I_f^3$$

  - Vector coupling:

    $$g_V = I_f^3 - 2Q_f \sin^2\theta_W$$

  - With $\sin^2\theta_W = 0.232$:
    - $g_A = -0.5$, $g_V = -0.036$ for electron
    - $g_A = 0.5$, $g_V = 0.191$ for u quark
    - $g_A = -0.5$, $g_V = -0.345$ for d quark

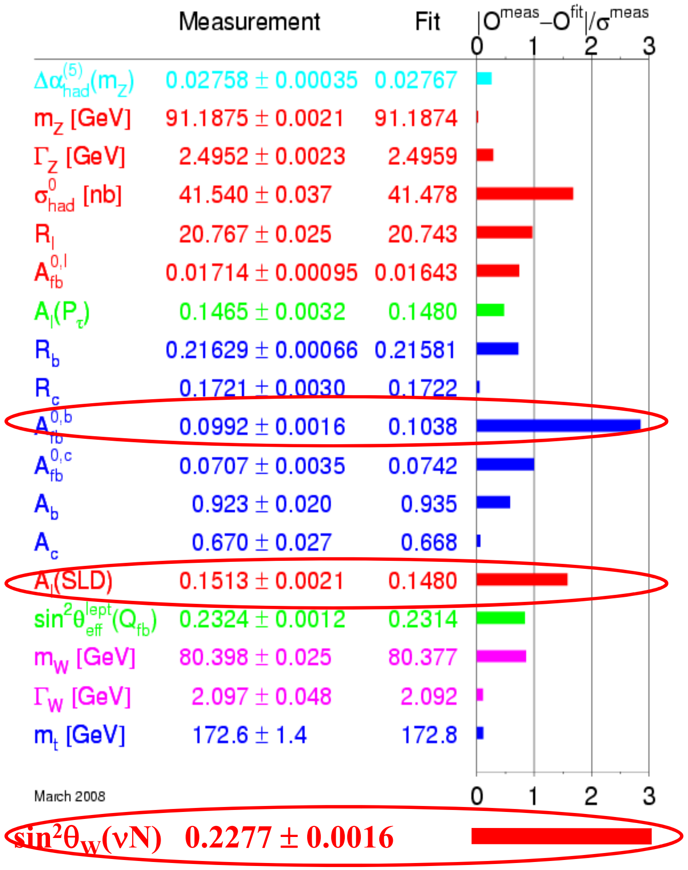


- Probe the relative strengths of Z-light quark couplings
- Can be used to make constraints on PDFs

Weak mixing angle $\sin^2\theta_W$

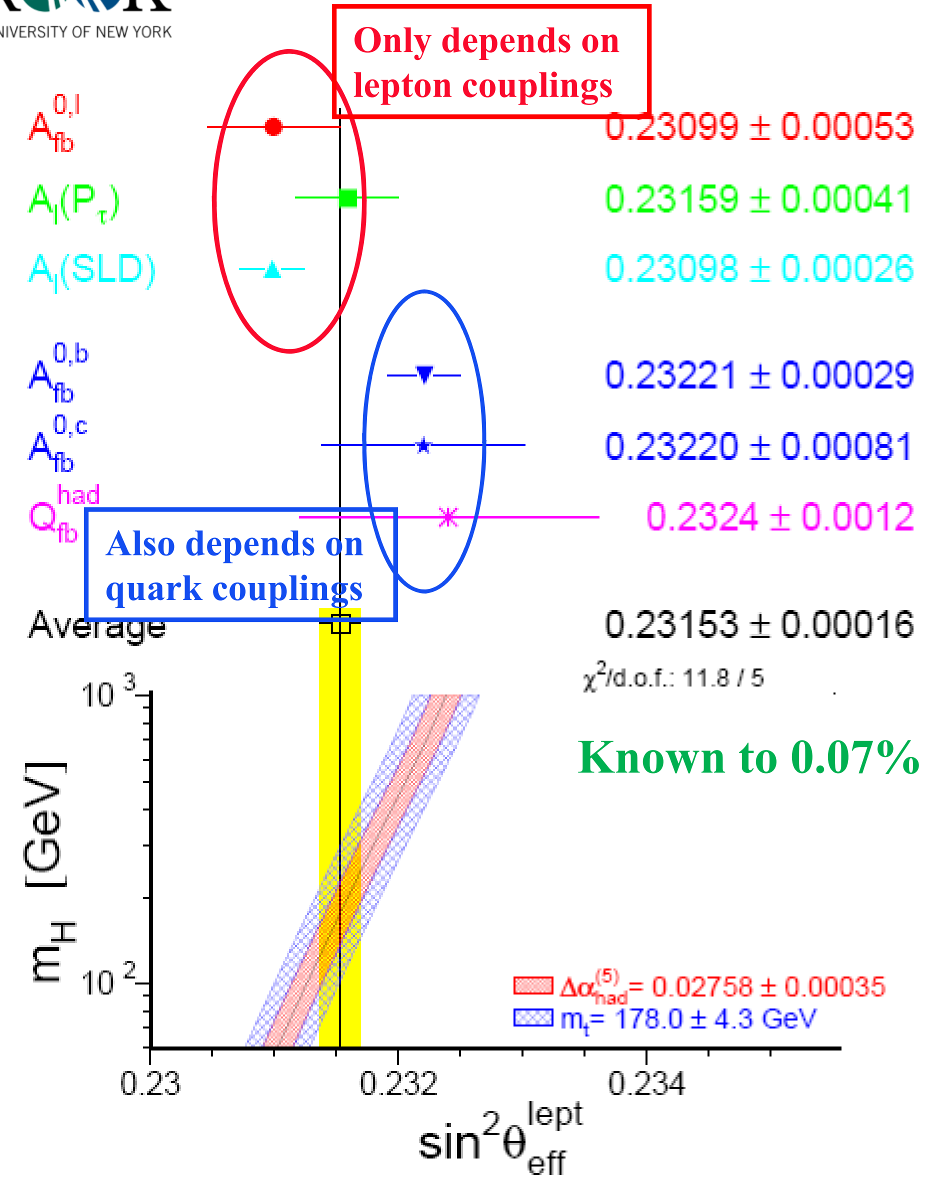
- A_{FB} is sensitive to $\sin^2\theta_W$ ($\sin^2\theta_W^{eff}$ includes higher order corrections)
- LEP A_{FB}^b and SLD A_{LR}: off by 3σ in opposite direction
- NuTeV $\sin^2\theta_W$ result: 3σ away from the global EW fit

LEP EWWG, Phys. Rep. 427, 257 (2006)

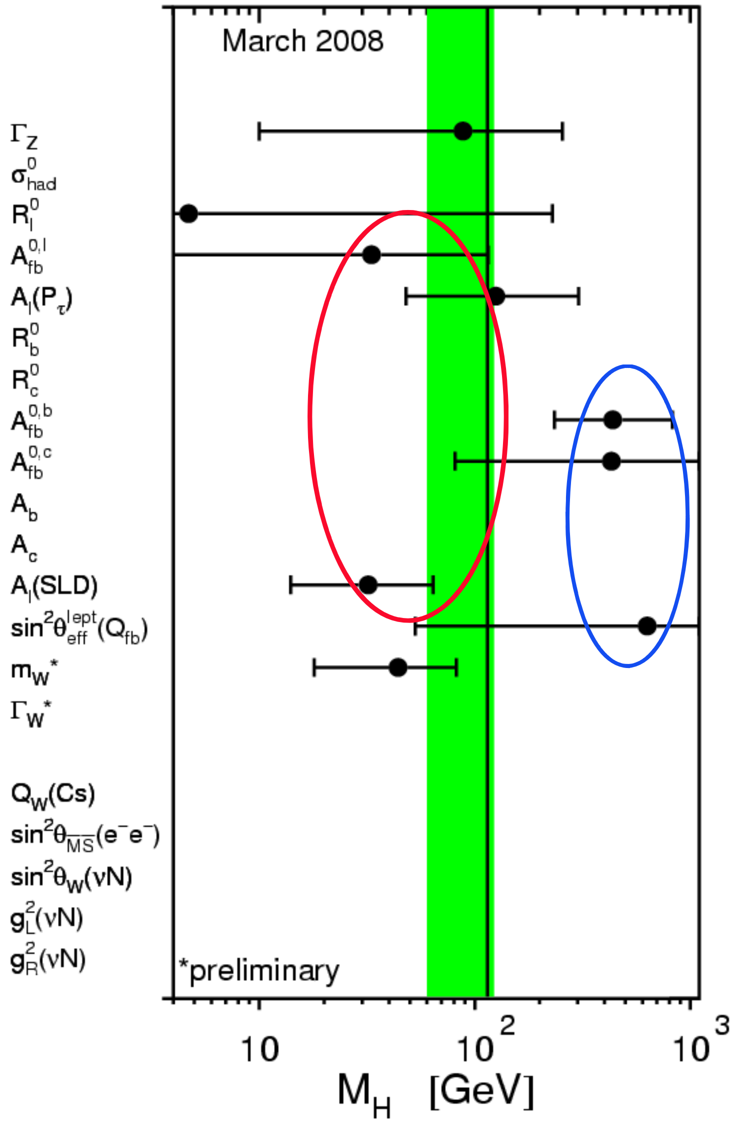


G.P. Zeller *et al.*, PRL 88, 091802 (2002)

Weak mixing angle $\sin^2\theta_W$ (cont.)



Known to 0.07%

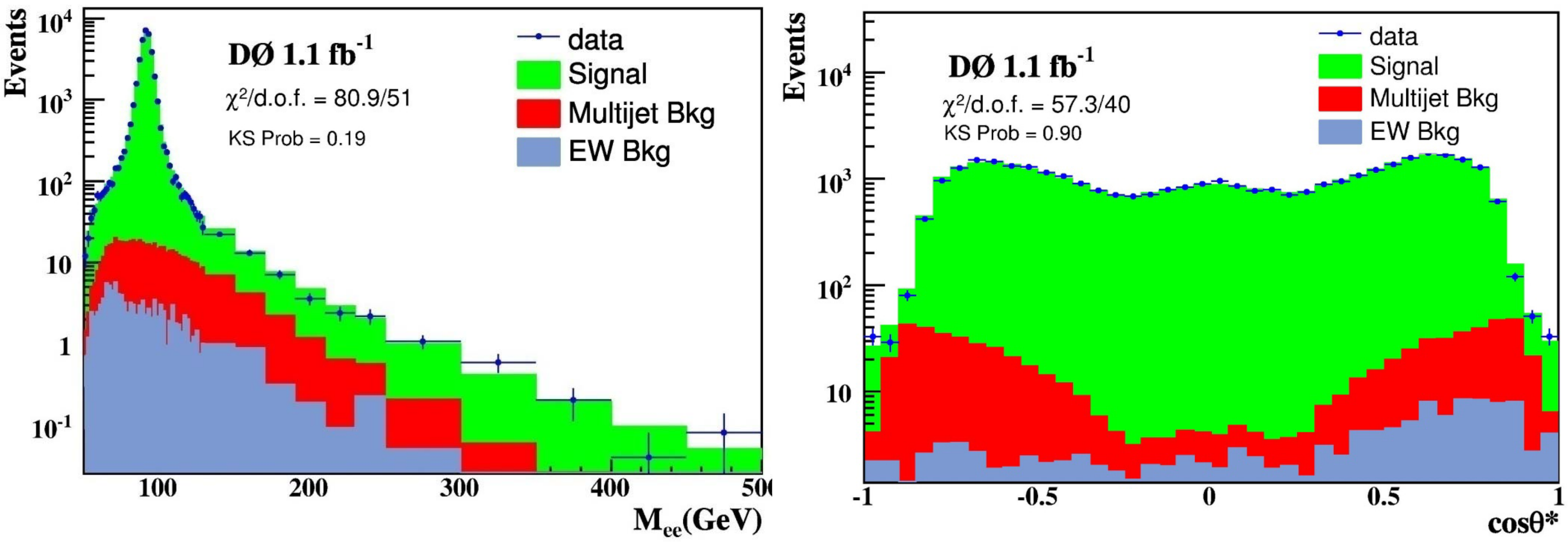


Event selection

- Integrated luminosity: 1065 ± 65 pb^{-1}
- Two electrons satisfy:
  - $p_T > 25$ GeV
  - Isolated with large EM fraction
  - Shower shape consistent with that of an electron
- $50 < M_{ee} < 500$ GeV
- A_{FB} measured in 14 mass bins
- Bin size chosen by detector resolution and available statistics

Mass range (GeV)	CC Forward	CC Backward	CE Forward	CE Backward
50 – 60	69	78	15	16
60 – 70	104	158	51	91
70 – 75	96	117	64	93
75 – 81	191	235	172	293
81 – 86.5	749	763	843	970
86.5 – 89.5	1388	1357	1860	1694
89.5 – 92	2013	1918	2543	2214
92 – 97	2914	2764	3132	2582
97 – 105	686	549	867	470
105 – 115	153	97	243	88
115 – 130	101	39	167	61
130 – 180	91	33	202	69
180 – 250	31	13	53	16
250 – 500	14	15	17	4

M_{ee} and cosθ* distributions

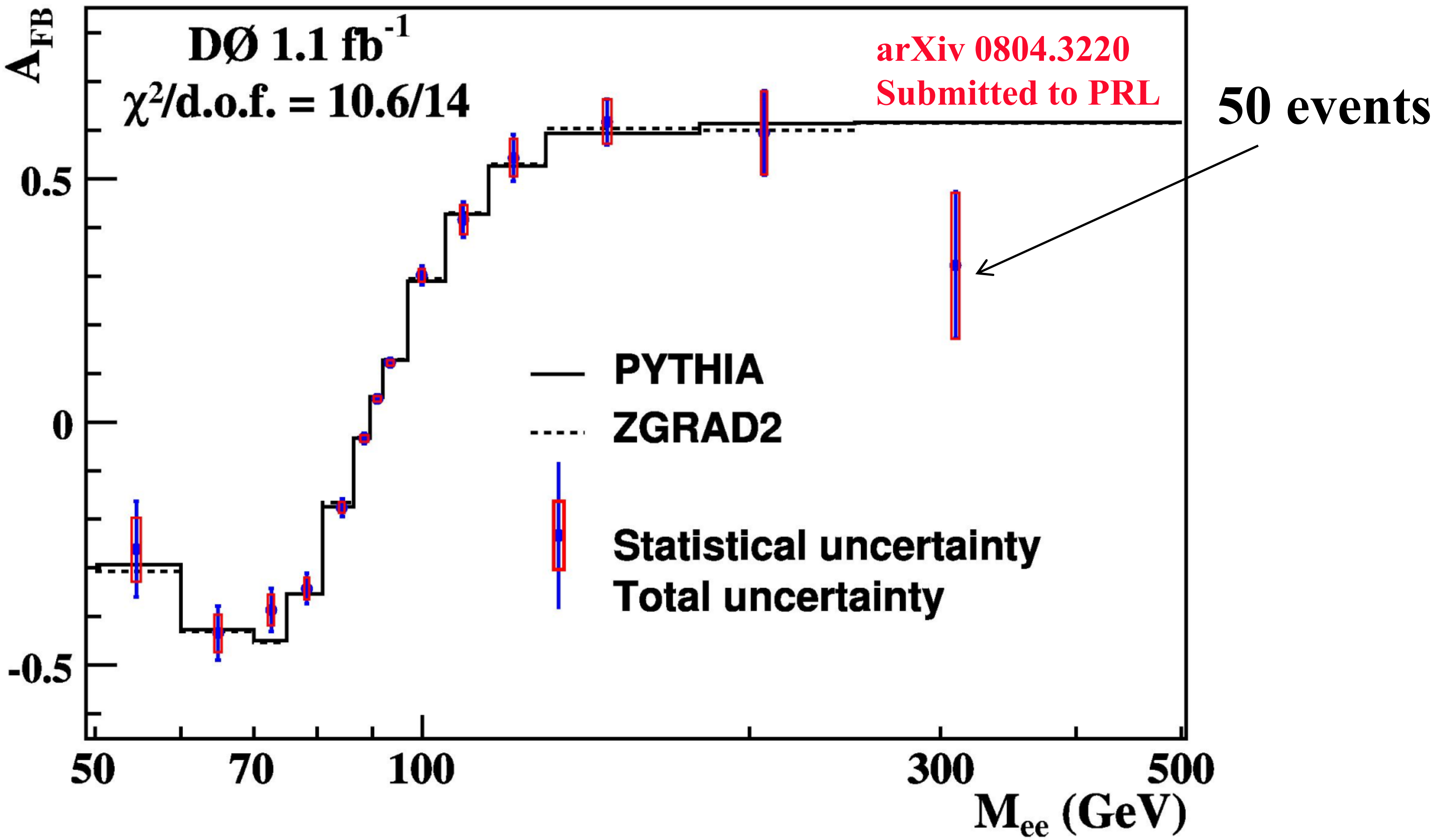


- QCD multijet background estimated using collider data (0.9%)
- Electroweak backgrounds estimated using Geant MC simulation:
  - $Z/\gamma^* \to \tau\tau$, W+X, WW, WZ, ttbar

A_{FB} Unfolding

- Raw A_{FB} → Unfolded A_{FB}
  - Detector resolution:
    - Events migrate from one mass bin to the other
    - Especially important for mass bins near Z pole
  - Acceptance and efficiencies
- Iterative matrix inversion method
  - Migration matrix measured using Geant MC simulation
  - Procedure tested by comparing the truth and unfolded spectrum generated using pseudo-experiments
- Systematic uncertainties on the unfolded A_{FB}
  - Unfolding bias
  - Electron energy scale and resolution
  - Backgrounds

Unfolded A_{FB}



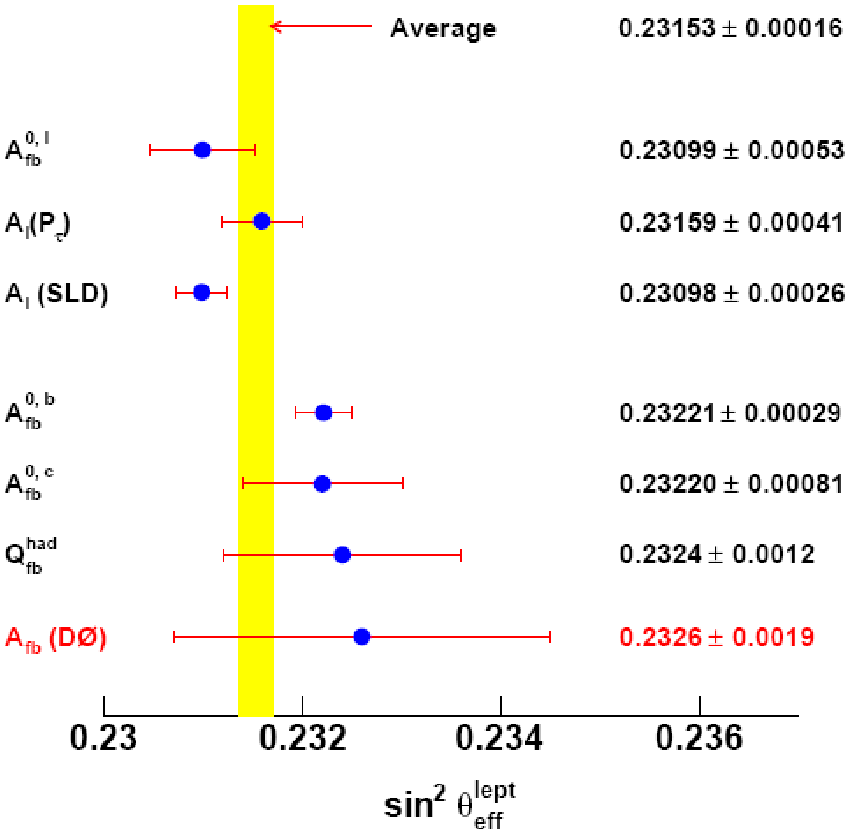
- 10 times more data than previous published results
- Unfolded A_{FB} distribution agrees with SM predictions

$\sin^2\theta_W^{eff}$ Result

- Extraction of $\sin^2\theta_W^{eff}$ using PYTHIA:
  - Obtained from backgrounds-subtracted A_{FB} distribution
  - Compared with A_{FB} templates according to different values of $\sin^2\theta_W^{eff}$ generated with PYTHIA and GEANT-based MC simulation
- Fitted results (for $70<M_{ee}<110$ GeV):

$$\sin^2\theta_W^{eff} = 0.2326 \pm 0.0018\ (\text{stat.}) \pm 0.0006\ (\text{syst.})$$

  - Mainly dominated by statistical uncertainty
  - Systematic uncertainties:
    - PDFs (0.0005)
    - EM energy scale/resolution (0.0003)



- Our $\sin^2\theta_W^{eff}$ result agrees with the global EW fit
- Uncertainty comparable with the uncertainties from
  - Combined Q^{had}_{FB} from four LEP experiments (0.0012) (better than OPAL/DELPHI results, close to L3 result, worse than ALEPH result)
  - NuTeV measurement (0.0016)
- Approach world average uncertainty (0.0003 for 8 fb^{-1}, e + μ, with CDF)

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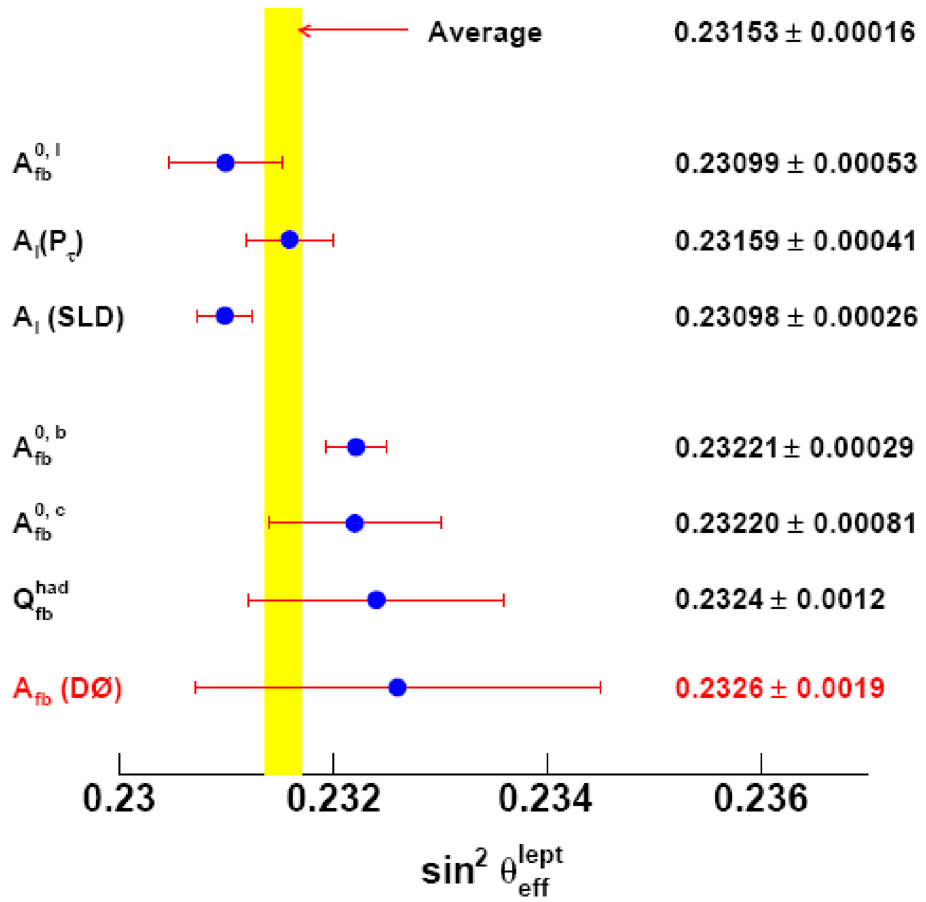
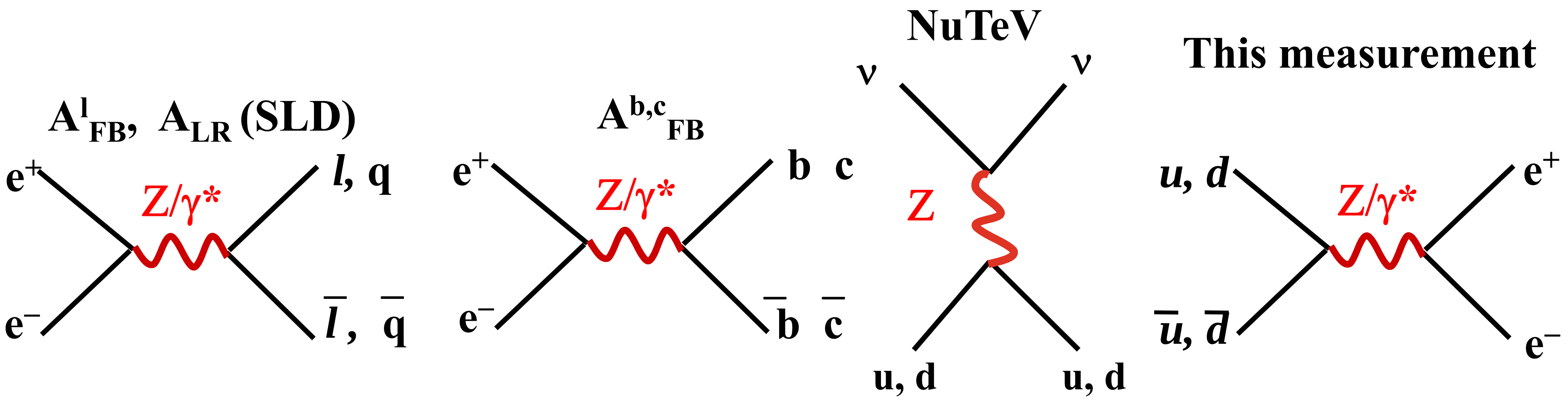
Difficult to tag light quarks in final state

Relies on MC to determine relative fraction of different quark species (with b, c contributions removed)





Conclusions

- **Electron charge asymmetry ($W \to e\nu$)**
  - Measured in three different electron E_T bins
  - Experimental uncertainties smaller than PDF uncertainties for most $\eta(e)$ bins
  - Useful for future global PDF fits
  - Best lepton charge asymmetry measurement to date
- **A_{FB} measurement and extraction of $\sin^2\theta^{eff}_W$ ($Z \to ee$)**
  - Unfolded A_{FB} distribution agrees with SM predictions
  - $\sin^2\theta_W^{eff} = 0.2326 \pm 0.0018$ (stat.) ± 0.0006 (syst.)
  - Sensitive to Z-u and Z-d couplings
  - Most precise A_{FB} and $\sin^2\theta_W^{eff}$ measurements at the Tevatron
- More data (> 4 fb^{-1} so far) collected, better understanding of the detector, more high precision electroweak measurements expected!