Tevatron Measurements of Electroweak Boson Production

Ryan J. Hooper

On Behalf of the CDF and D0 Collaborations

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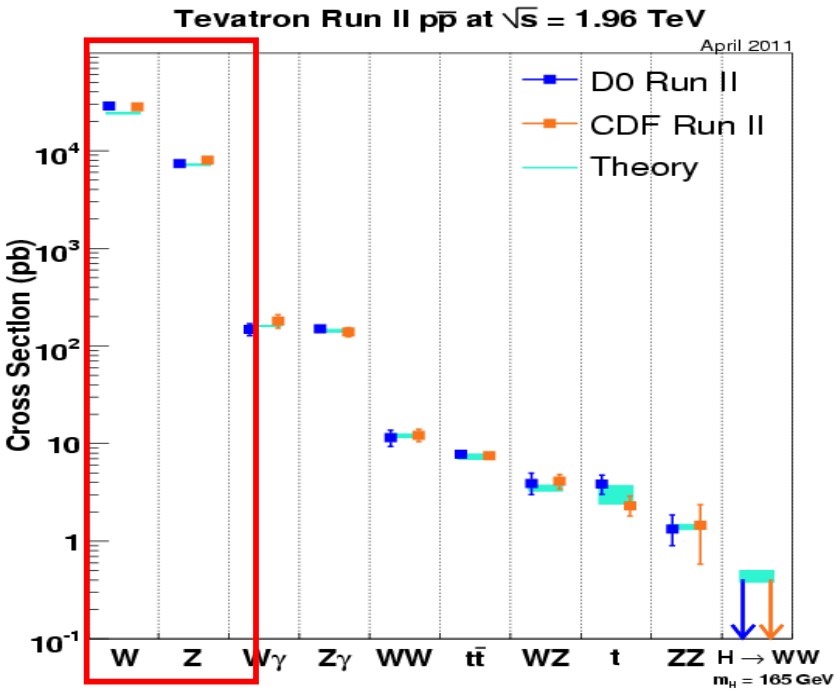
Outline

- The What
- The Why
- The Where
- The How
- The Results
- The End!

The What & Why: The Electroweak Bosons (Ws & Zs)

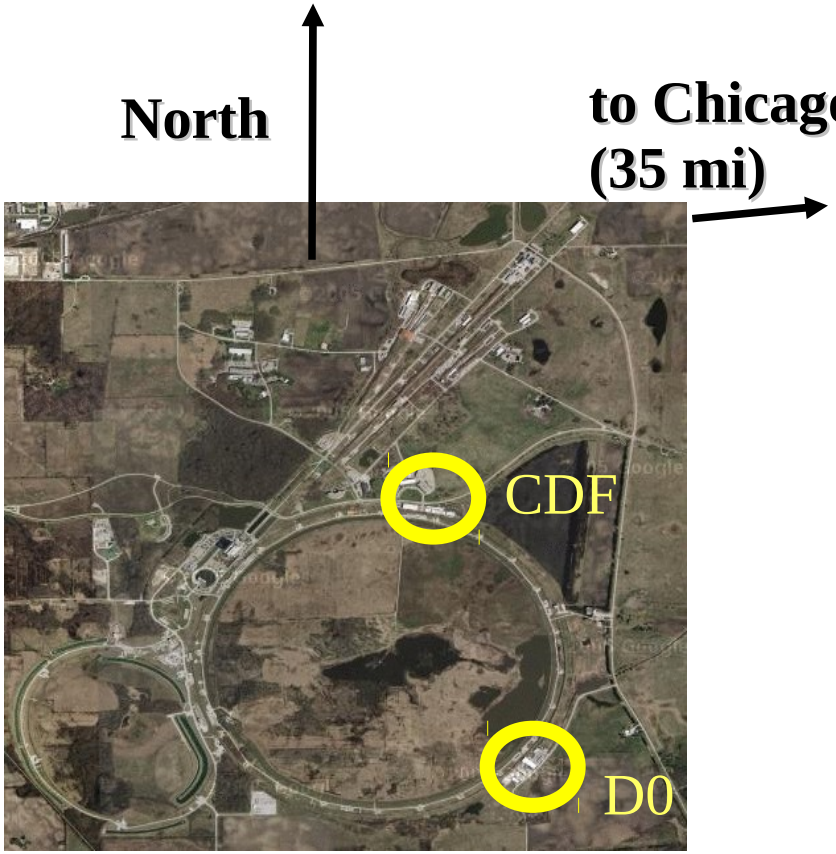
- Typically used as "standard candles" for searches
- Production cross sections well measured (circa 2000's)

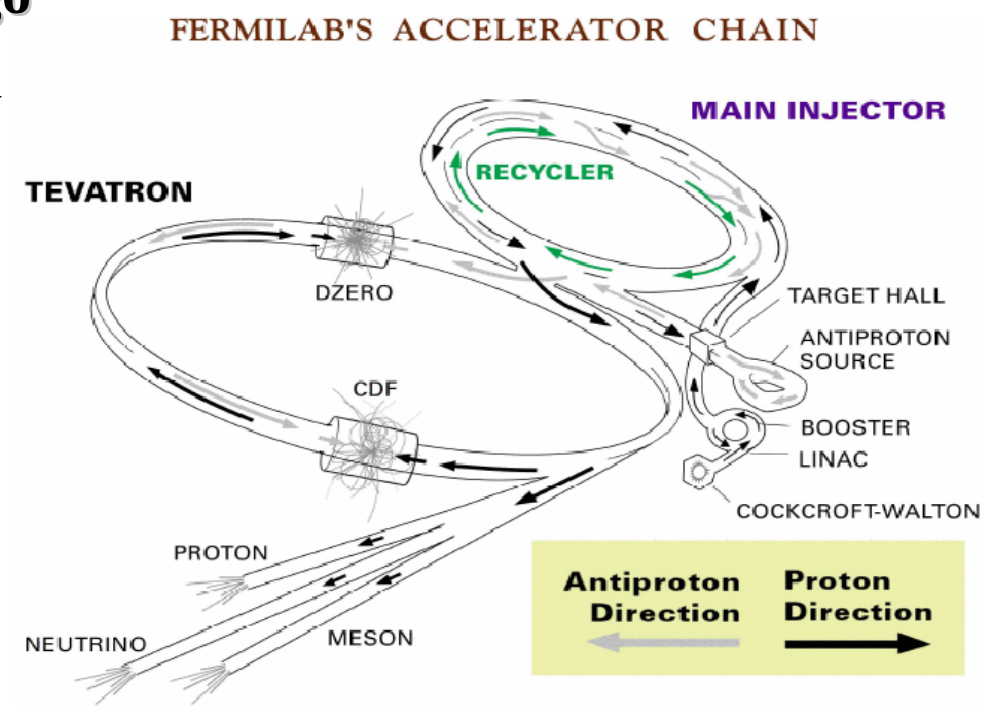


- Tevatron has produced millions of *W*s & hundreds of thousands of *Z*s!
- Large statistics allows detailed studies of properties
  - Boson's transverse momentum, decay product's angular dependencies, charge asymmetries ...
    - Sensitive to underlying physics

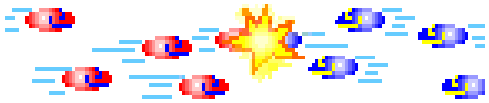
The Where: The Tevatron Accelerator

- **The Tevatron Accelerator at Fermilab**



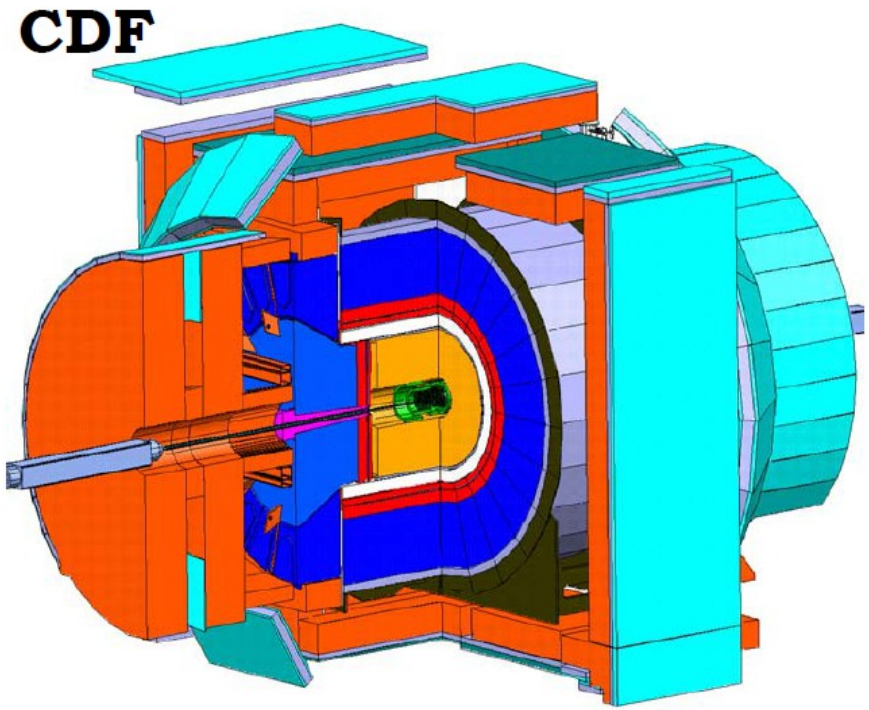


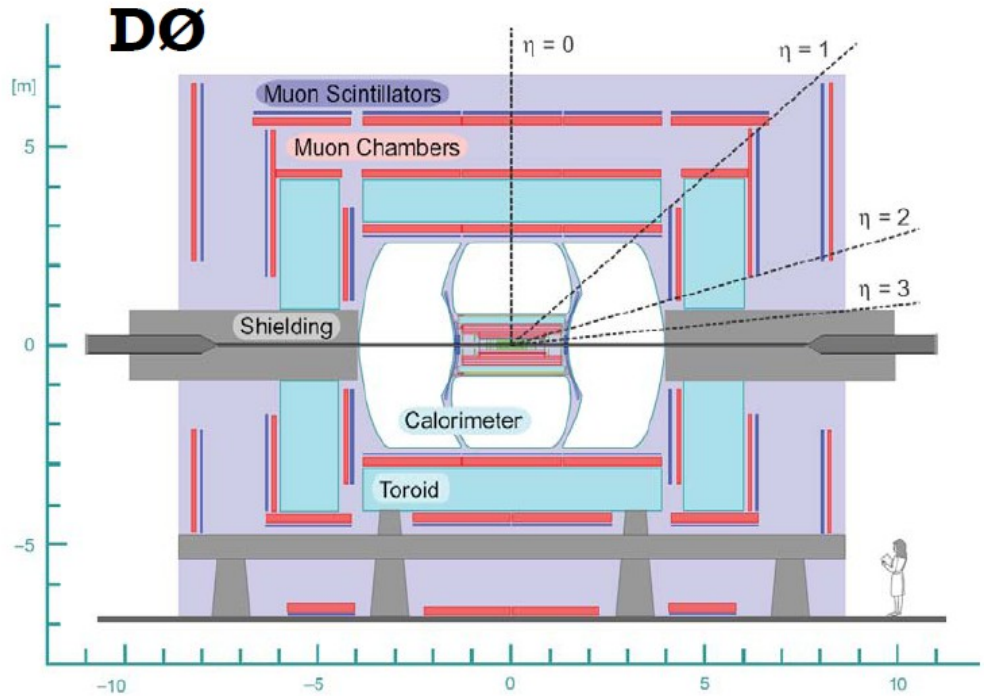
- **Tevatron collides protons and anti-protons at** $\sqrt{s} = 1.96\,TeV$
  - **Very efficient running for many years**



The Where: The Detectors

- **Both are typical collider detectors**





- **Silicon & drift chamber tracker in 1.4T solenoid**
- **Pb/Fe scintillating calorimeter**
- **Scintillating and drift chamber muon systems**

- **Silicon & scintillating fiber tracker in 2T solenoid**
- **U & liquid Ar calorimeter**
- **Scintillating and drift chamber muon systems**

The How: Data Selections

- **Focus on newest (2011) *Z* results & (2009 & prelim.) *W* results**
- **Both experiments use similar data selections**
  - **For *Z*'s:**
    - **At least one high E_T triggered lepton (CDF)**
    - **Fire one of a list of dilepton triggers (DØ)**
    - **One high E_T (> 20 GeV) electron (e^-)**
    - **One high E_T (> 20 GeV) positron (e^+)**
  - **For *W*'s:**

DØ

- **$\mu\nu$ final state**
- **One of many single μ triggers**
- **μ has matched central track**
- **μ p_T > 20 GeV**
- **Isolated**
- **Cosmic timing veto**
- **$\not{E}_T$ > 20 GeV**
- **High transverse mass ($M_T^{\mu\nu} > 40 GeV$)**

CDF

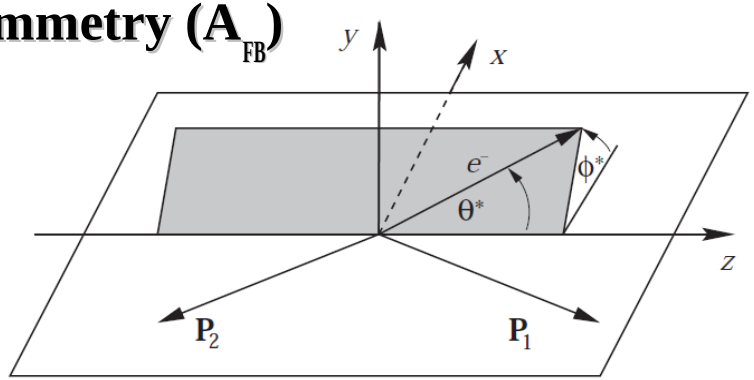
- **$e\nu$ final state**
- **Combination of high E_T/p_T and high $\not{E}_T$ trigger**
- **e E_T > 25 GeV (central)**
- **e E_T > 20 GeV (end plug)**
- **Isolated**
- **$\not{E}_T$ > 25 GeV**

The Results: DØ's New $Z/\gamma^* \rightarrow e^+e^-$ Analysis

- **Vector (V) & Axial (A) couplings to the *Z***
- **Give rise to a forward-backward charge asymmetry (A_{FB})**

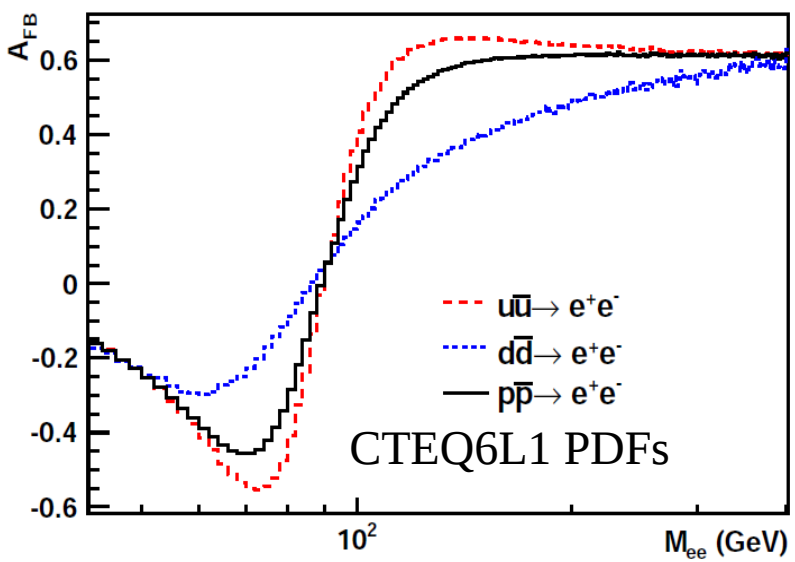
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

F=Forward: cos(θ *) > 0
B=Backward: cos(θ *) < 0



Z/γ^* center-of-mass frame

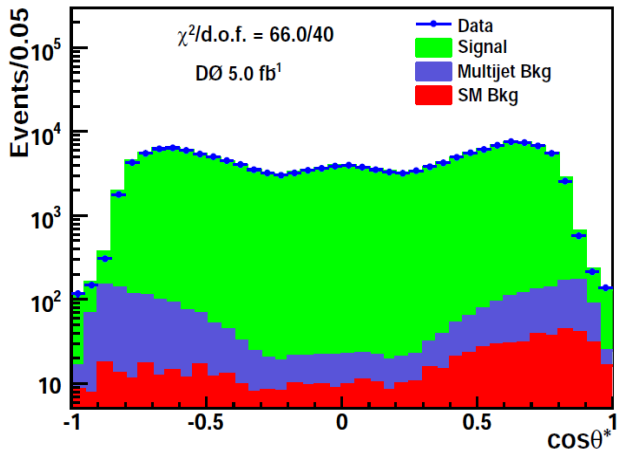
- **Pythia leading order (LO) A_{FB}**

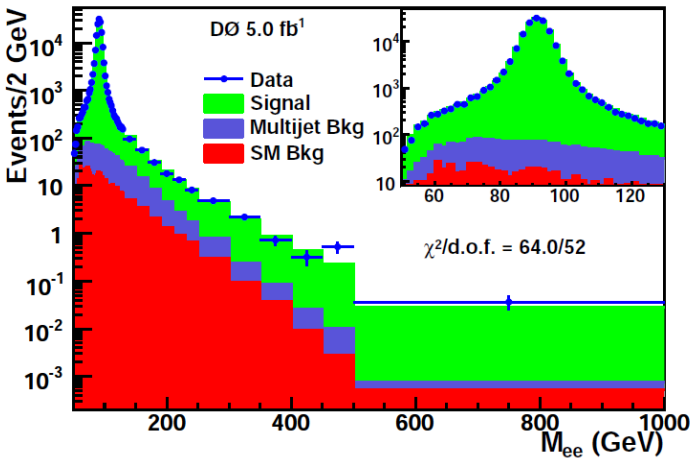


- **Due to** $g_V^f = I_3^f - 2q_f \cdot \sin^2\theta_W$, $g_A^f = I_3^f$, **A_{FB} is sensitive to the weak mixing angle**

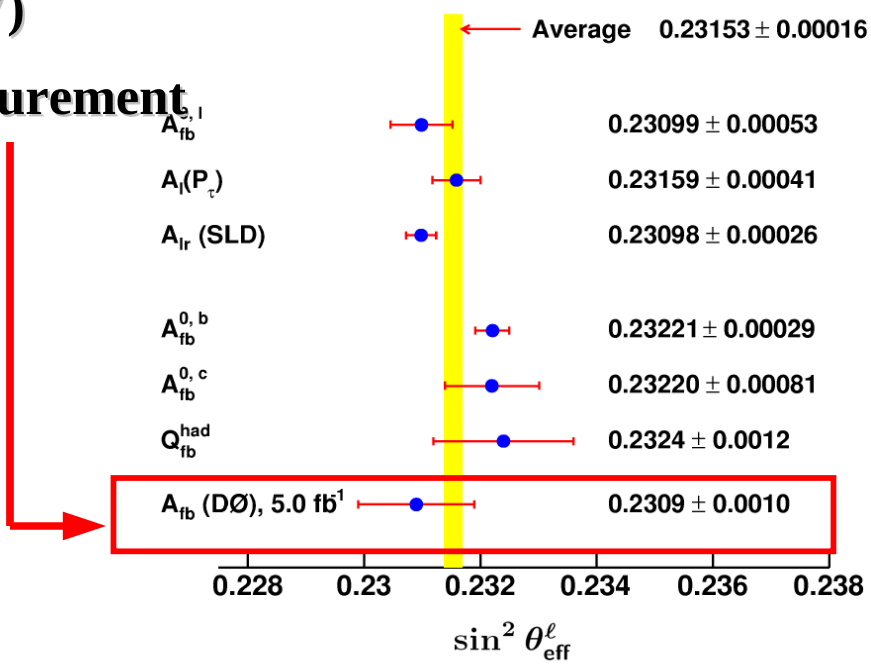
The Results: DØ's New $Z/\gamma^* \rightarrow e^+e^-$ Analysis

- Construct A_{FB} vs. M_{ee} from background subtracted data





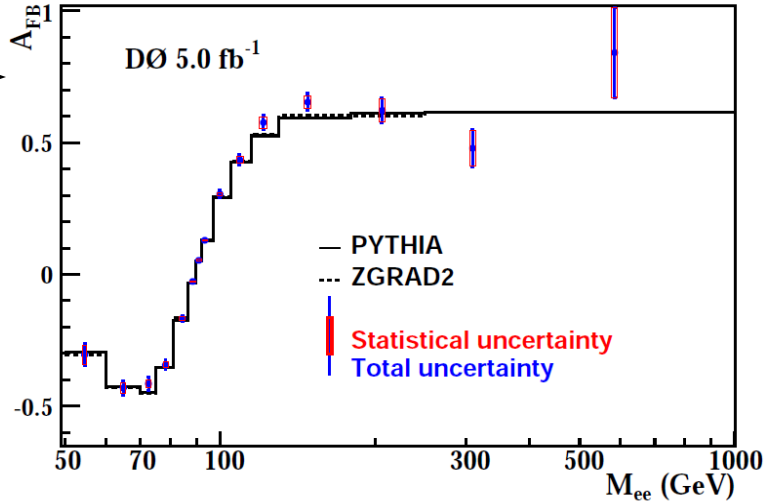
- Analyze Z pole region ($70 < M_{ee} < 130$ GeV)
- Fit $A_{FB}(\sin^2(\theta_W))$ templates to extract measurement



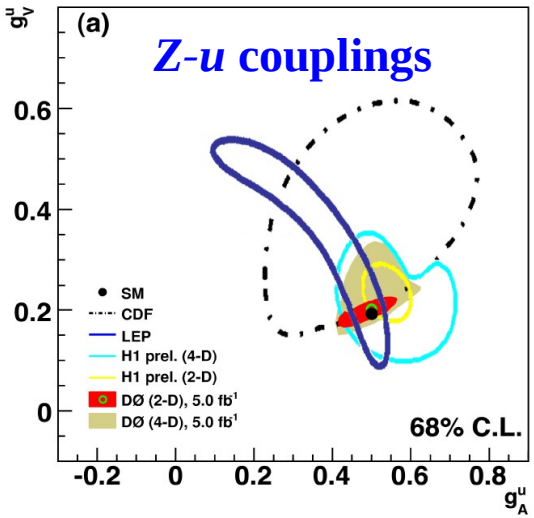
- Comparable to the LEP c-quark result
- More precise than the LEP hadronic charge (Q) result!

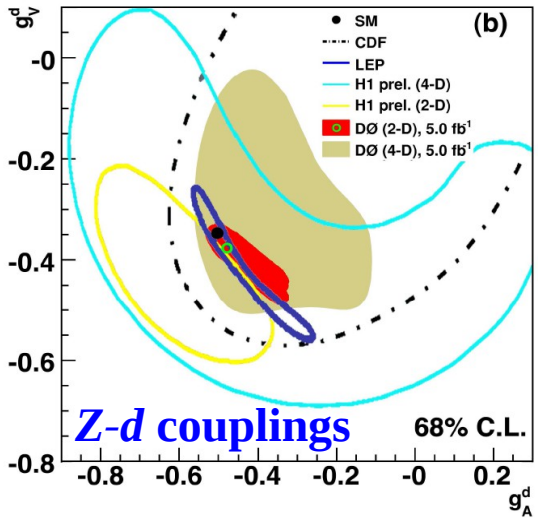
DØ's New $Z/\gamma^* \rightarrow e^+e^-$ Analysis

- Construct an unfolded A_{FB}
- Fit templates of the Z-light quark (u,d) couplings



ArXiv:1104.4590, Accepted by: Phys. Rev. D





	g^u_A	g^u_V	g^d_A	g^d_V
D0 (5.0 fb^{-1})	0.502 ± 0.040	0.208 ± 0.014	-0.495 ± 0.037	-0.379 ± 0.027
SM	0.501	0.192	-0.502	-0.347

- **Most precise measurement to date!**

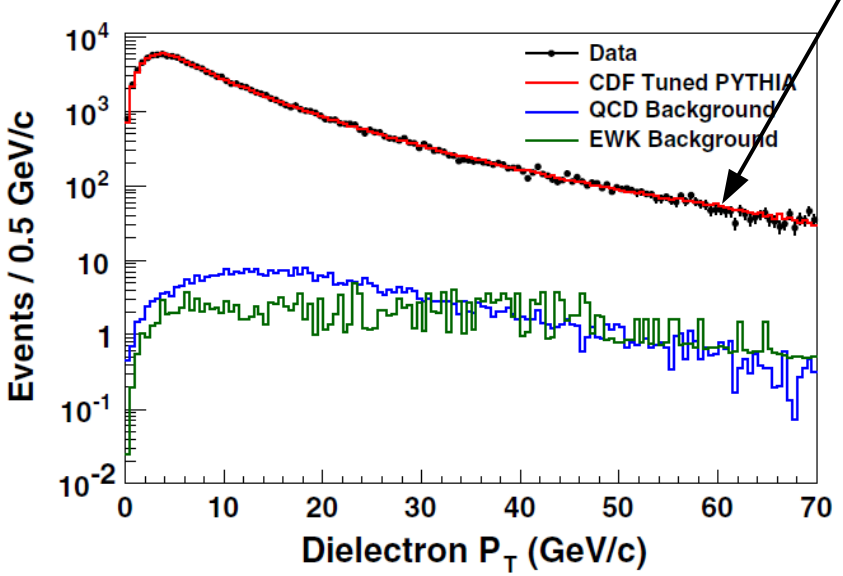
CDF's $Z/\gamma^* + X$ Angular Coefficients Analysis

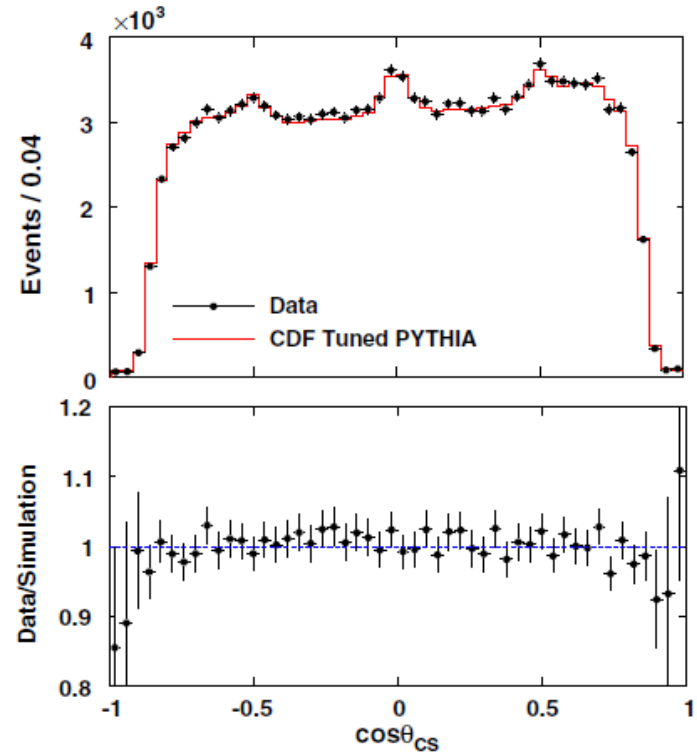
- Analyze dielectron data around the Z peak (66 GeV < M_{ee} < 116 GeV)
- Compare to the expected Drell-Yan +X differential cross sections

$$\frac{d\sigma}{d\cos\theta} \propto (1+\cos^2\theta) + \frac{1}{2}A_0(1-3\cos^2\theta) + A_4\cos\theta \qquad \frac{d\sigma}{d\phi} \propto 1 + \frac{3\pi A_3}{16}\cos\phi + \frac{A_2}{4}\cos 2\phi$$

- Includes $q\bar{q} \to Z/\gamma^* + gluon\,(annihilation)$ and $qg \to Z/\gamma^* + q\,(Compton)$ contributions
- Analyze e^+e^- P_T, $\cos(\theta^*)$, and ϕ data

Higher P_T Z/γ^*'s

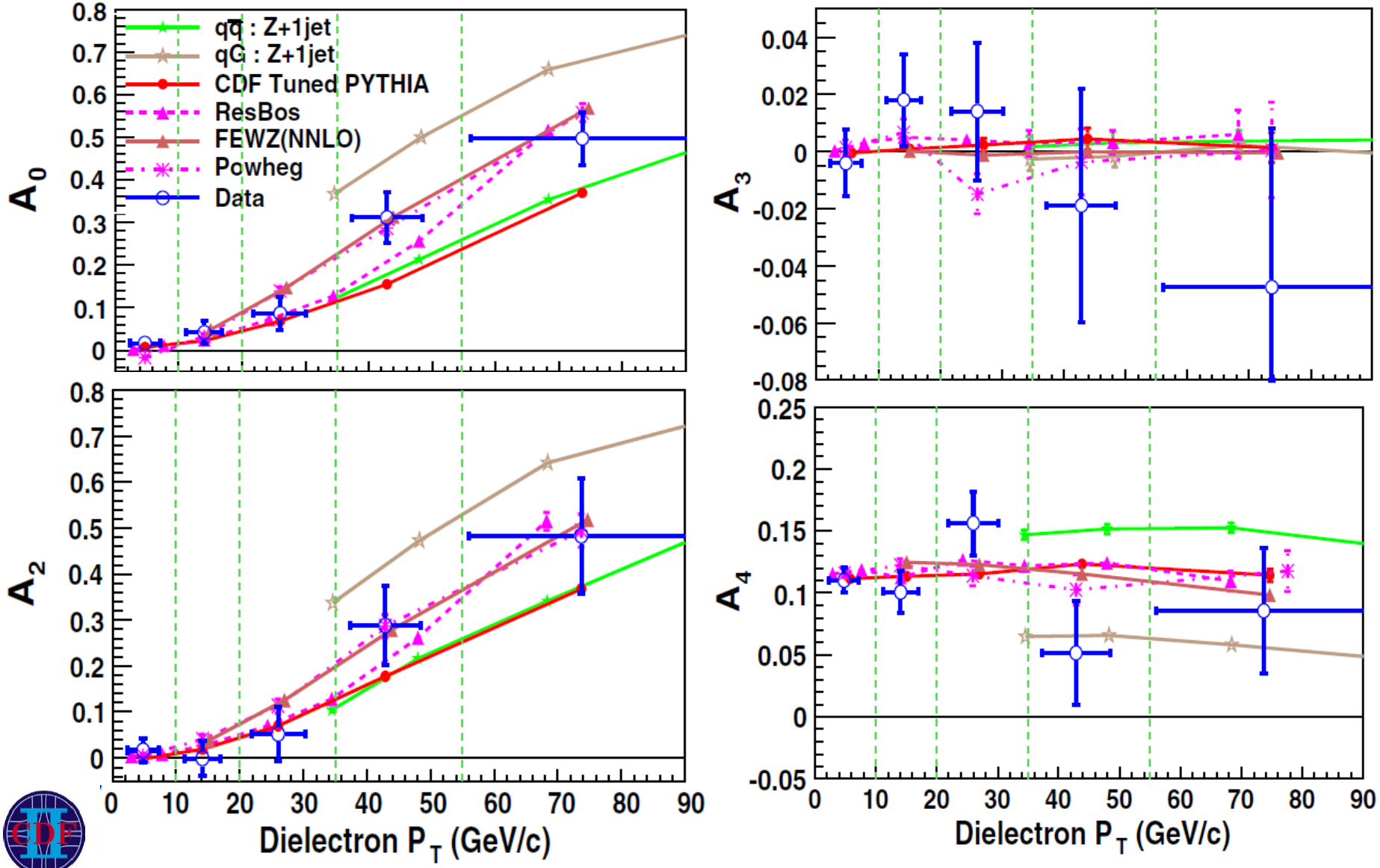




2.1 fb^{-1} of data

CDF's $Z/\gamma^* + X$ Angular Coefficients Analysis

- Fit coefficients templates versus dielectron P_T



CDF's $Z/\gamma^* + X$ Angular Coefficients Analysis

- **Lan-Tung relation predict $A_0 = A_2$ ($A_0 - A_2 = 0$) for spin 1 gluons**
- **Violations could indicate something new**

e^+e^- P_T bin (GeV)	$A_0 - A_2$
0 - 10	$(0.005 \pm 0.314) \times 10^{-1}$
10 - 20	$(0.434 \pm 0.458) \times 10^{-1}$
20 - 35	$(0.341 \pm 0.706) \times 10^{-1}$
35 - 55	0.023 ± 0.105
> 55	0.014 ± 0.139

Uncertainties are stat. + syst.

Published: PRL **106**, 241801 (2011)

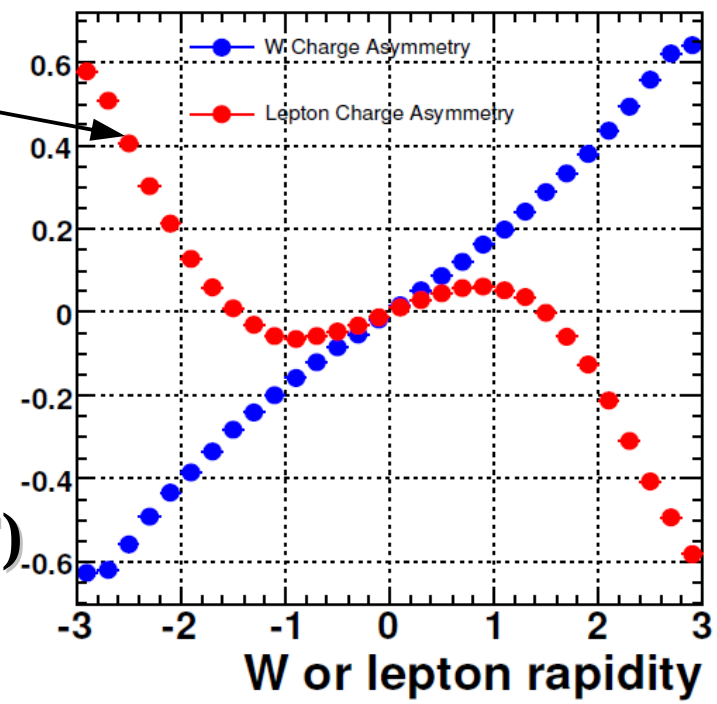
- **Clearly the data favors spin 1 gluons!**

W Charge Asymmetry

- *u*-quarks carry more of the proton's momentum than *d*'s
- W^+'s tend to get boosted along p^+ direction
- Leads to a charge asymmetry with direct connections to PDFs

$$A(y_W) = \frac{d\sigma(W^+)/dy_W - d\sigma(W^-)/dy_W}{d\sigma(W^+)/dy_W + d\sigma(W^-)/dy_W} \approx \frac{u(x_1)d(x_2) - d(x_1)u(x_2)}{u(x_1)d(x_2) + d(x_1)u(x_2)}$$

- However, its the lepton we see!

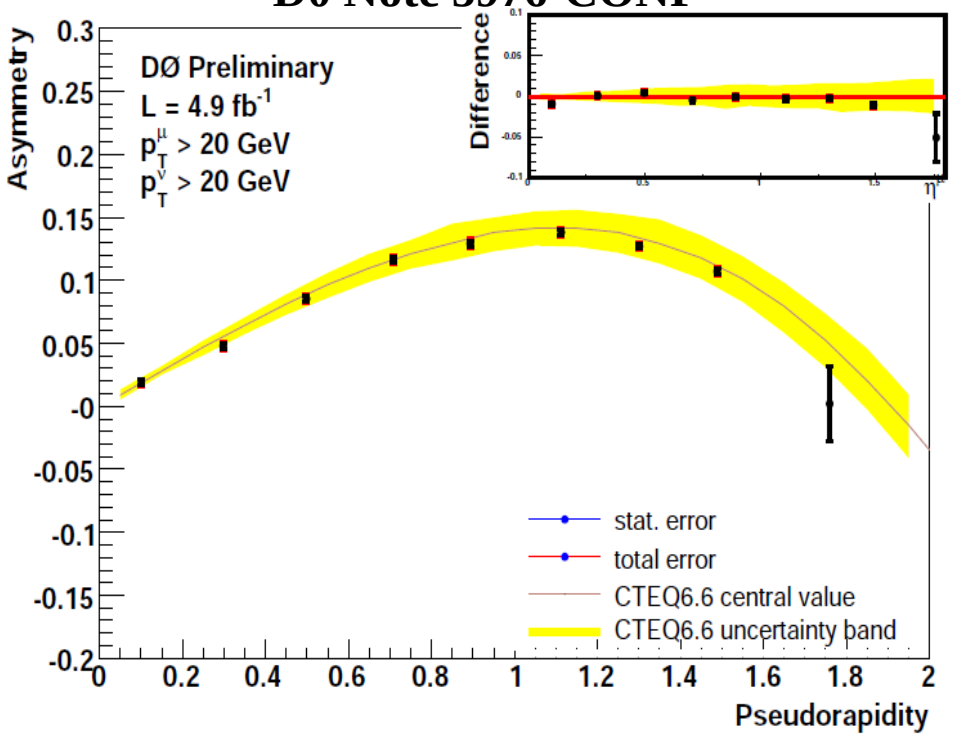


- Assuming SM (V-A) couplings and using $e\nu$ *W*-mass constraint can recover *W* asymmetry (CDF)

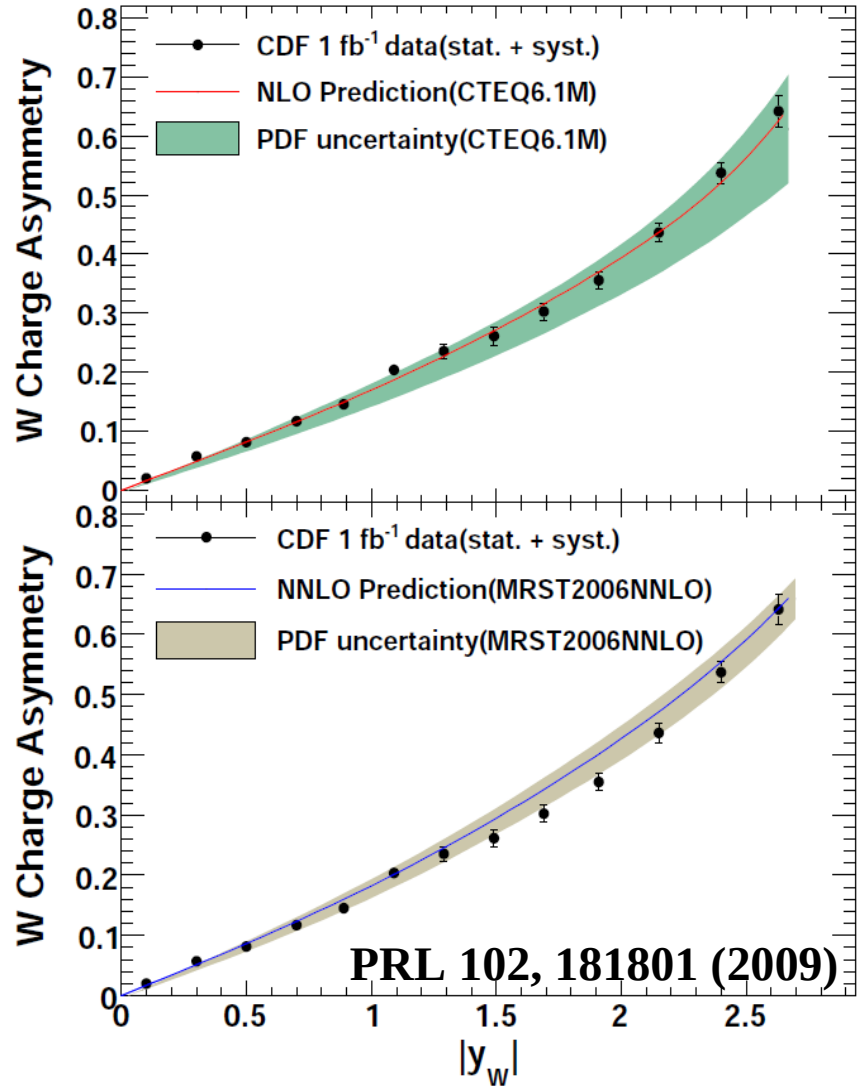
W Charge Asymmetry Results

D0's W → $\mu\nu$ preliminary μ asymmetry result

D0 Note 5976-CONF



CDF's W → $e\nu$ result



PRL 102, 181801 (2009)

- **Note experimental uncertainties smaller than PDF uncertainties**

Constrain/give feedback on PDFs!

The End: Summary

- Accelerator and detector running very smoothly for ~10 years
- Millions/Hundreds of thousands of *W*'s and *Z*'s to study
- *Z*'s to extract/confirm several SM parameters
  - Weak mixing angle (θ_W), really $\sin^2(\theta_W)$
  - Z-light (u,d) quark couplings
  - Angular coefficients (A_0, A_2, A_3, A_4) and more gluon spin-1 evidence
- *W*'s charge asymmetry used to constrain/improve PDF's
- Even though Tevatron turns off September 30th we are not done yet … still have ~5fb^{-1} of data yet to analyze

Stay tuned for even more high(er) precision results!