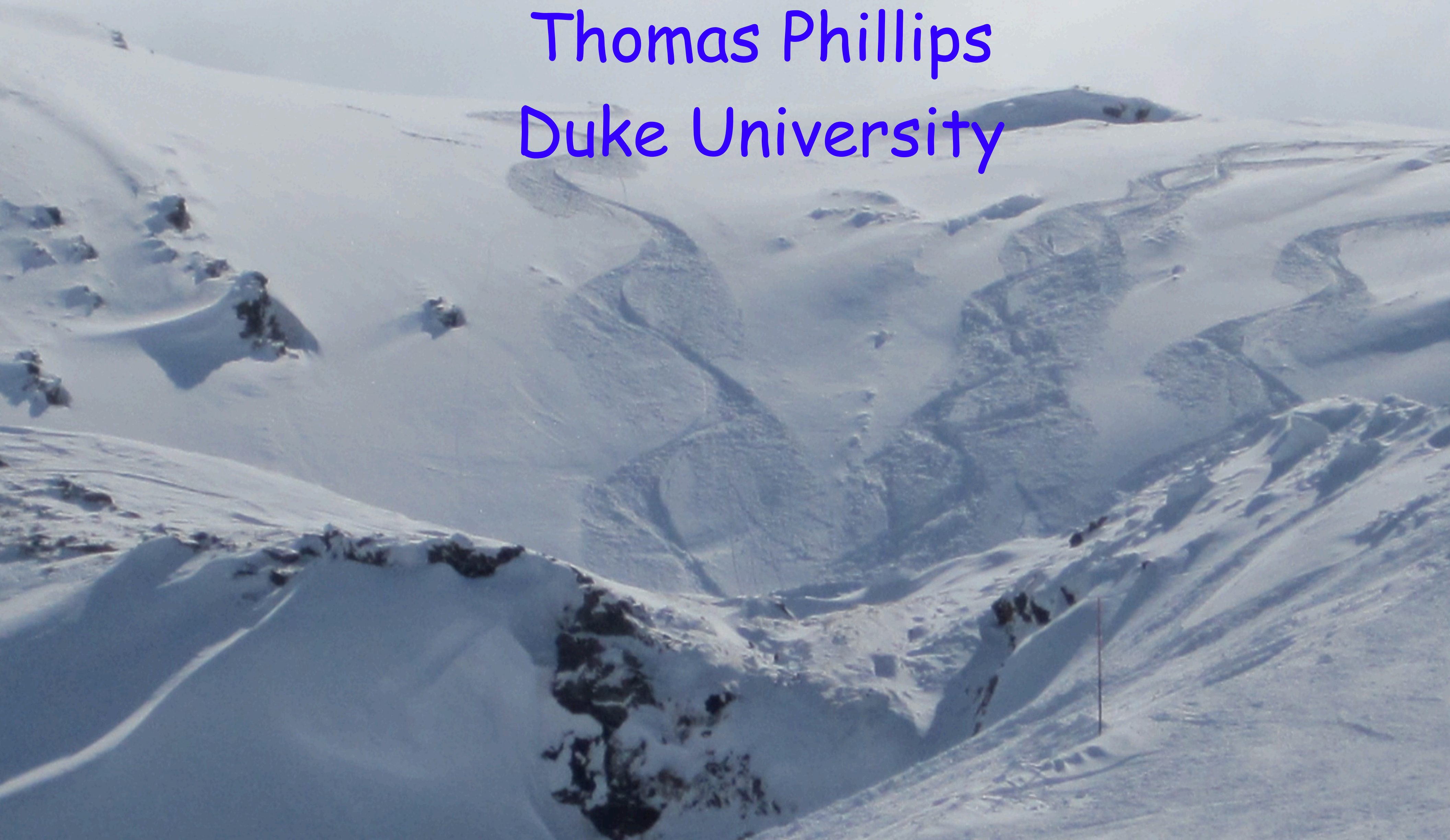
Single W & Z Production at the Tevatron

Moriond Electroweak, March 2012

Thomas Phillips

Duke University



Single ~~W &~~ Z Production
(separate W-mass talk)
at the Tevatron

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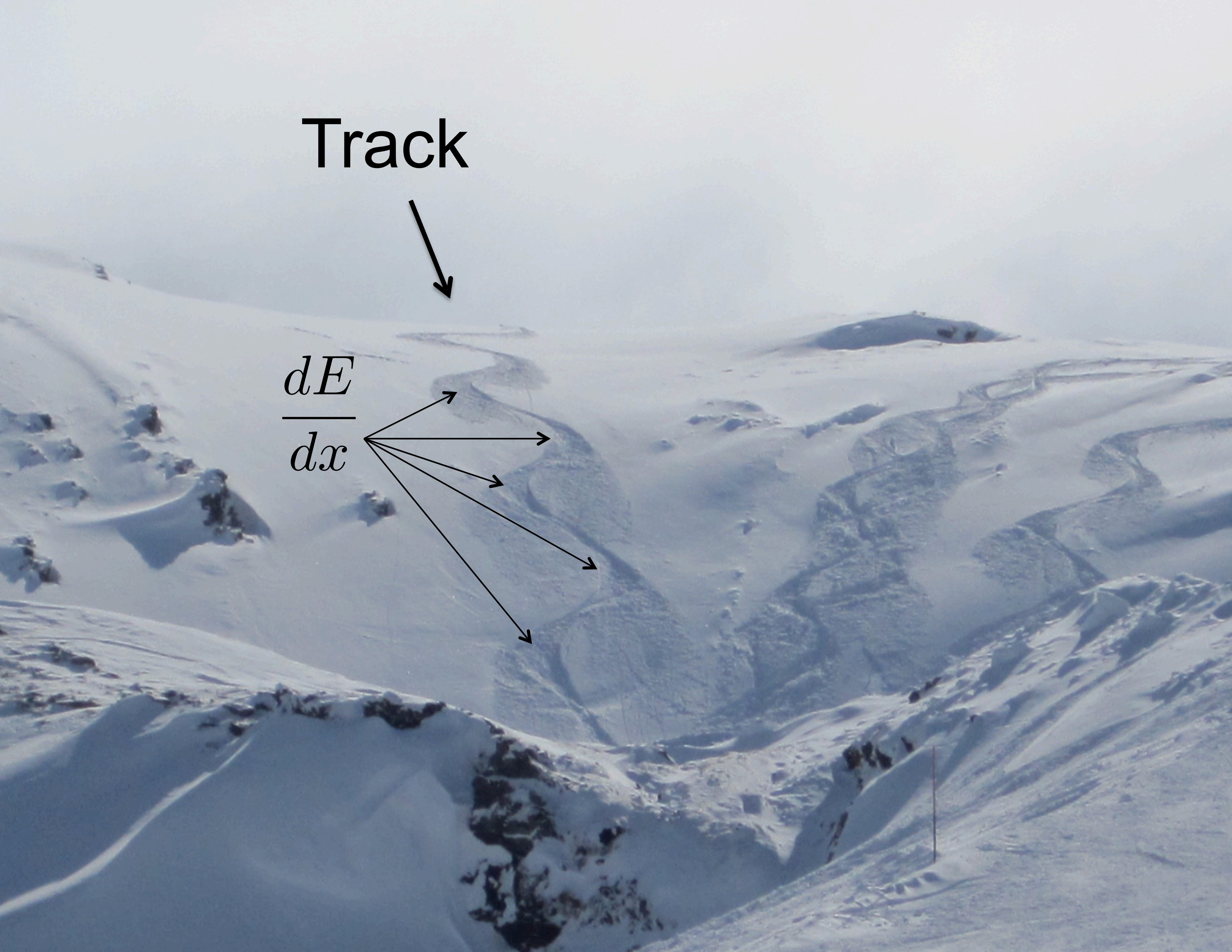
Track


Track
$\frac{dE}{dx}$

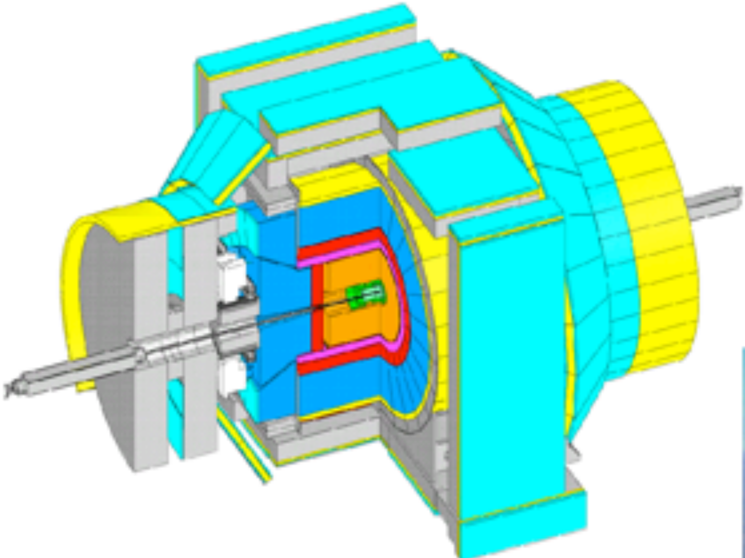
Track
$p_T = ?$
p_T
p_T
p_T
p_T
p_T

Motivation

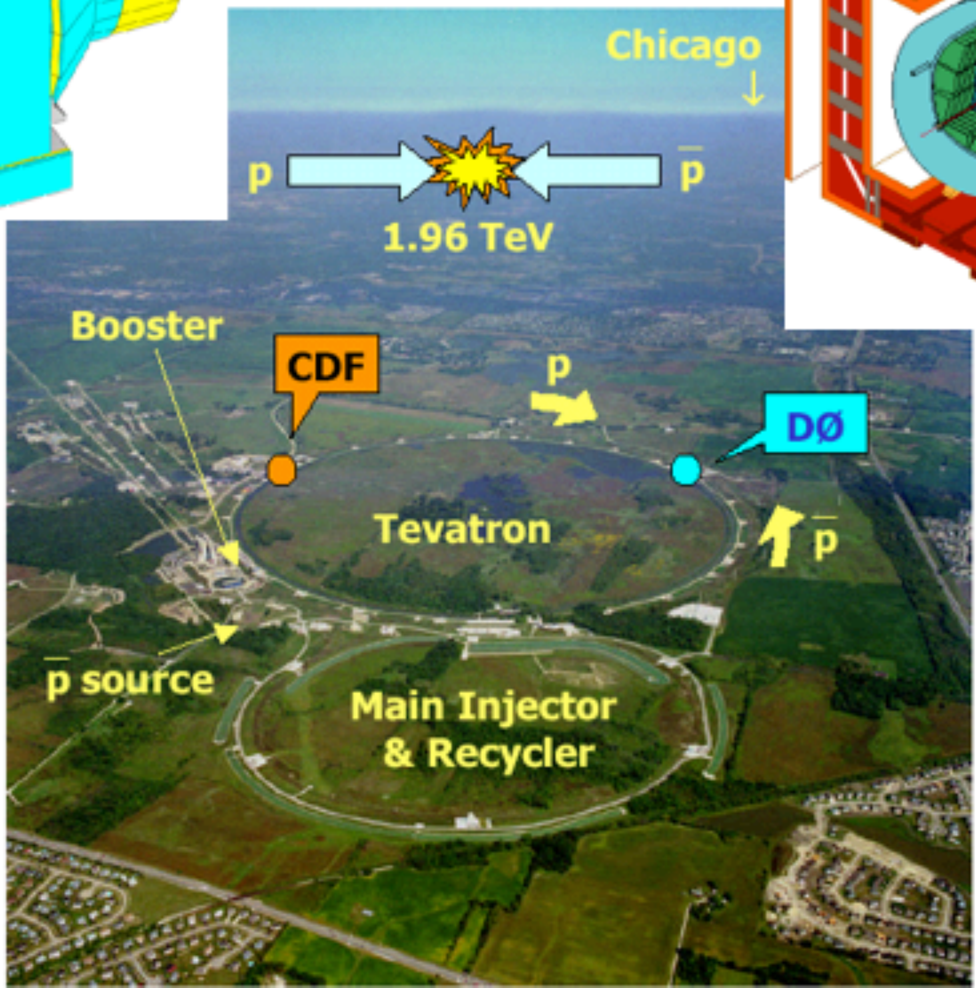
What can we now learn from single Z' s?

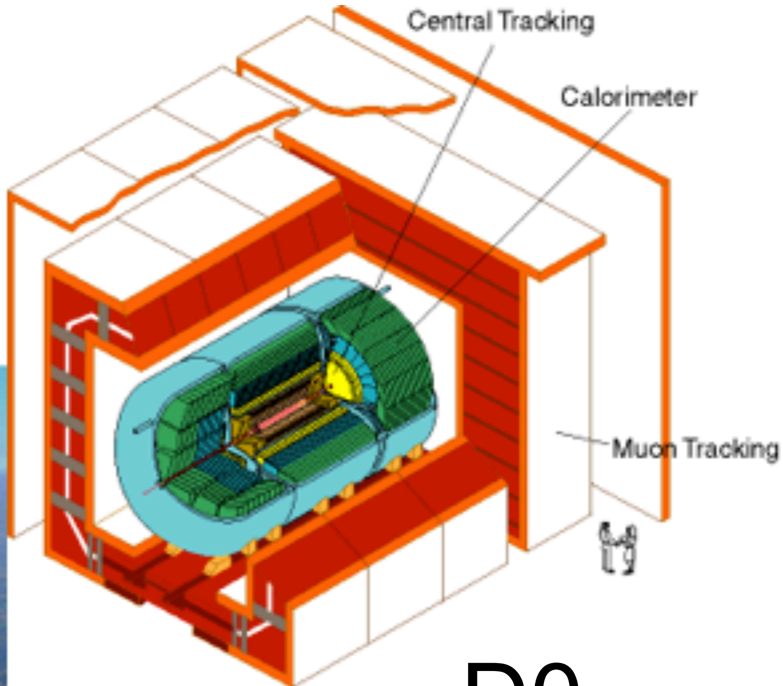
- ➔Interference between γ and Z (i.e. new physics)
- ➔weak mixing angle
- ➔vector & axial-vector q_{light}-Z couplings
- ➔Spin of the gluon
- ➔Test/improve state-of-the-art QCD modeling
  - resummation technology
  - $\mathcal{O}(\alpha_s^2)$: Fully exclusive and differential for
    - lepton pair
    - final state partons
  - Finite boson widths; γ-Z interference
  - boson-lepton spin correlations
  - inputs to help improve PDF' s

Tevatron Experiments



CDF

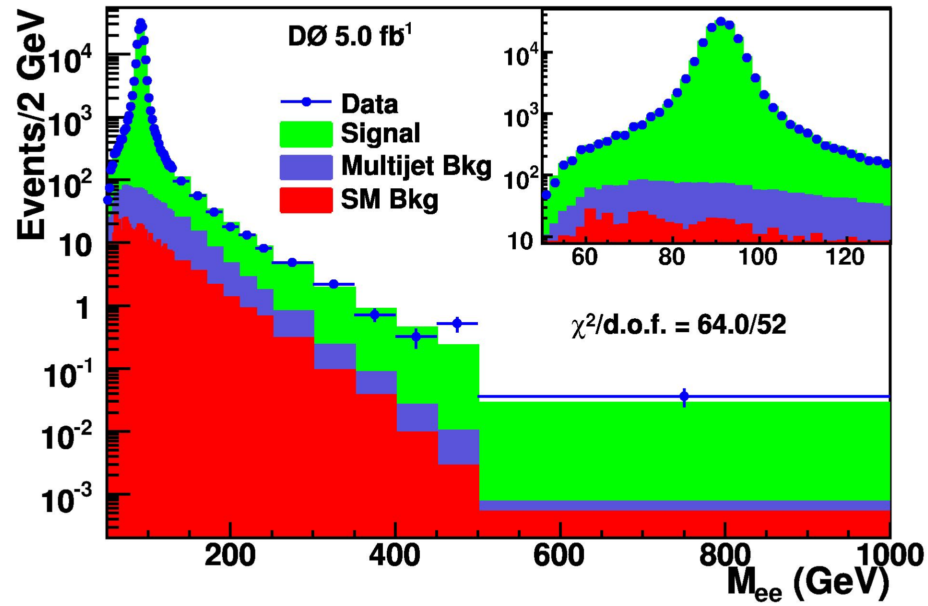


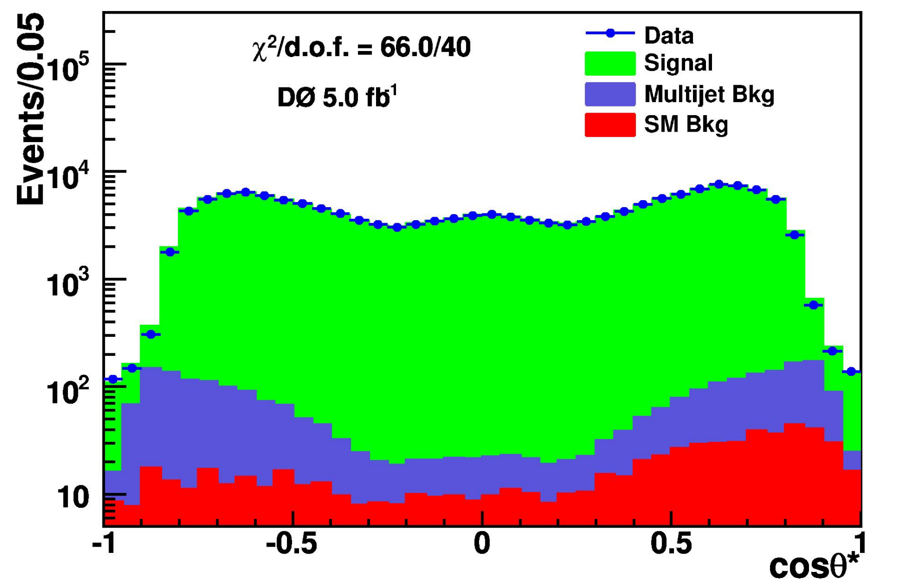


D0

Z/γ F/B Asymmetry

- Select $p\bar{p} \rightarrow Z/\gamma^* \rightarrow e^+e^-$
  - ➔ two electron candidates with $E_T > 25$ GeV
    - isolated
    - at least one with $|\eta| < 1.0$ and matched to a track
    - opposite charge if both central (CC)
  - ➔ 157,553 in 5.0/fb
    - 73755 CC
    - 83798 CE

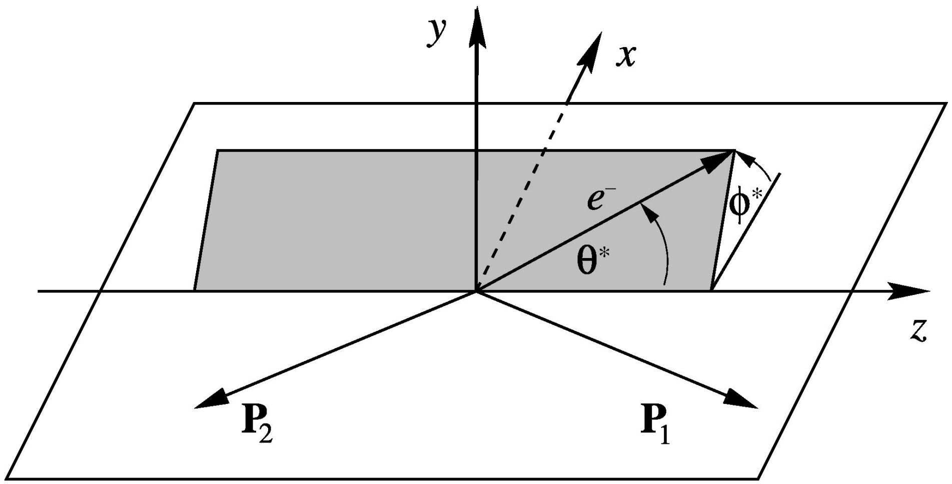


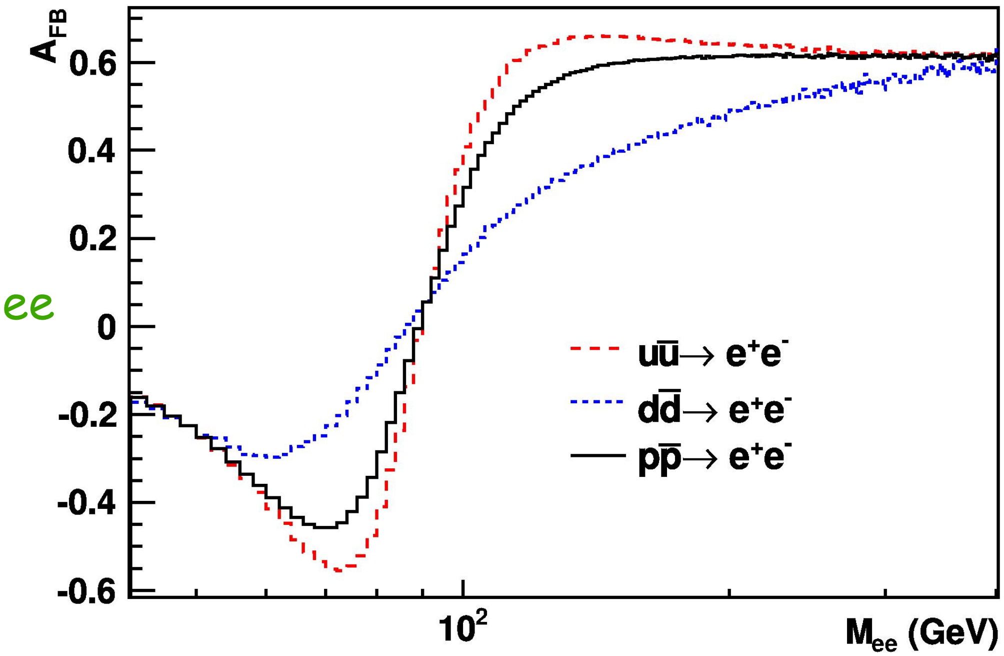


Z/γ F/B Asymmetry

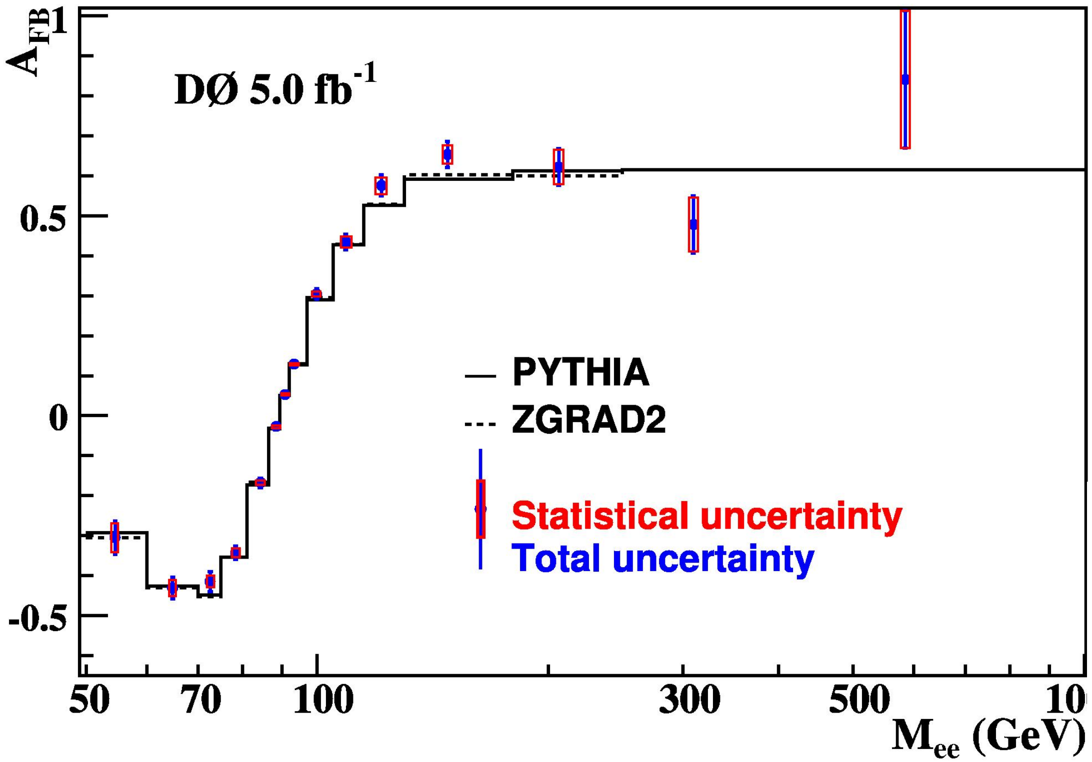
- Measured
  - ➔ Forward ($\cos\theta^* > 0$)
  - ➔ Backward ($\cos\theta^* < 0$)
  - ➔ Collins-Soper frame
- Forward-Backward asymmetry sensitive to:
  - ➔ $\sin^2\theta_{eff}$ near Z pole

    $$g_v^f/g_A^f = 1 - 4|q_f|\sin^2\theta_{eff}^f$$
  - ➔ new physics at large M_{ee}
    - Z/γ^* interference
    - ~constant at 0.6



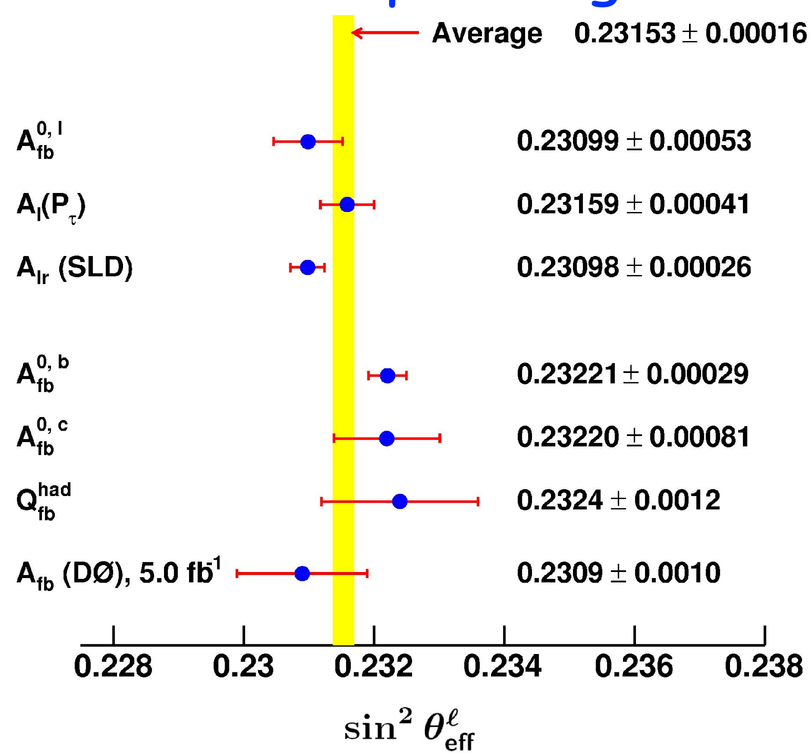


Weak Mixing Angle



Measure by fitting to simulated MC A_{FB} templates with different $\sin^2\theta_{eff}$

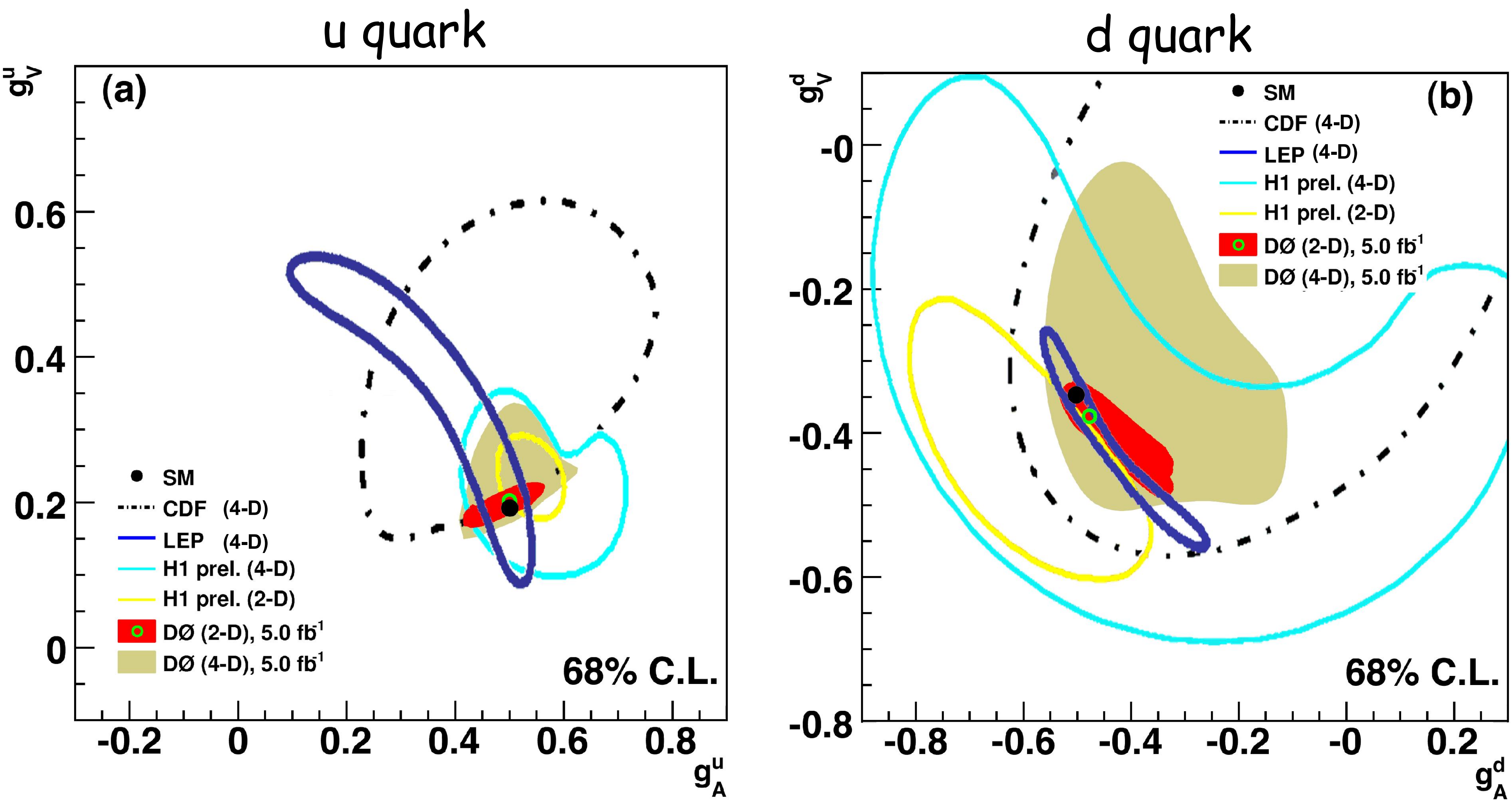
➔ dominated by events in the Z pole region



Measured value:

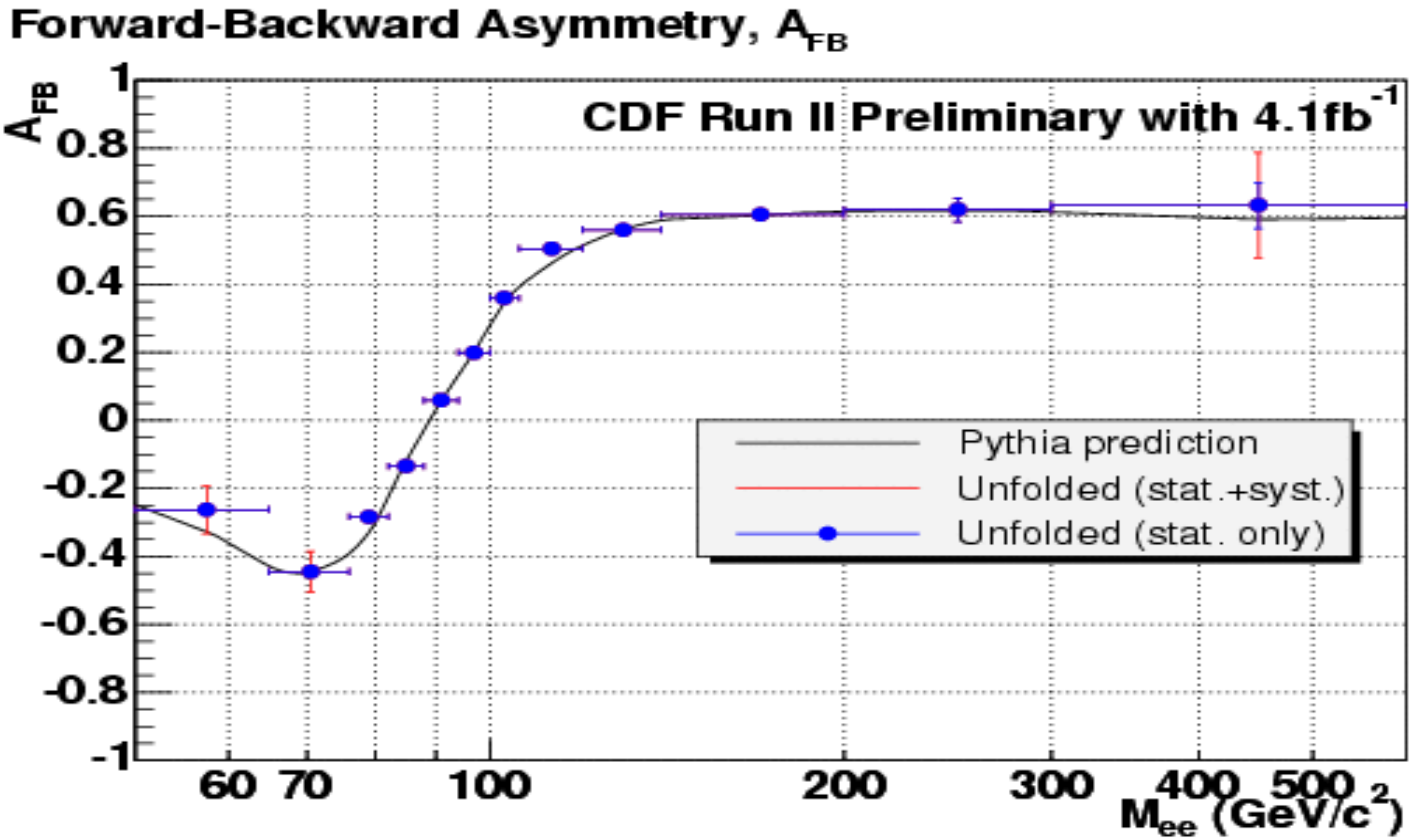
$$\sin^2\theta^l_{eff} = 0.2309 \pm 0.0008 \pm 0.0006$$

Light-quark Couplings to Z



- Vector (g_V) and axial-vector (g_A) couplings
  - → 4-D (tan): fit all four couplings
  - → 2-D (red): fix other quark couplings at SM values

CDF F/B Asymmetry



CDF also measured Z/γ F/B Asymmetry but chose to measure $\sin^2\theta_W$ using angular coefficients instead

Single Z's at CDF

$Z/\gamma \rightarrow e^+e^-$ in 2.1 fb^{-1}:

- Central-central (CC)

  E_T > 25/15 GeV

  $|\eta_{det}|<1.1$ 51951

- Central-plug (CP)

  E_T > 20 GeV

  C: $|\eta_{det}|<1.1$ 63752

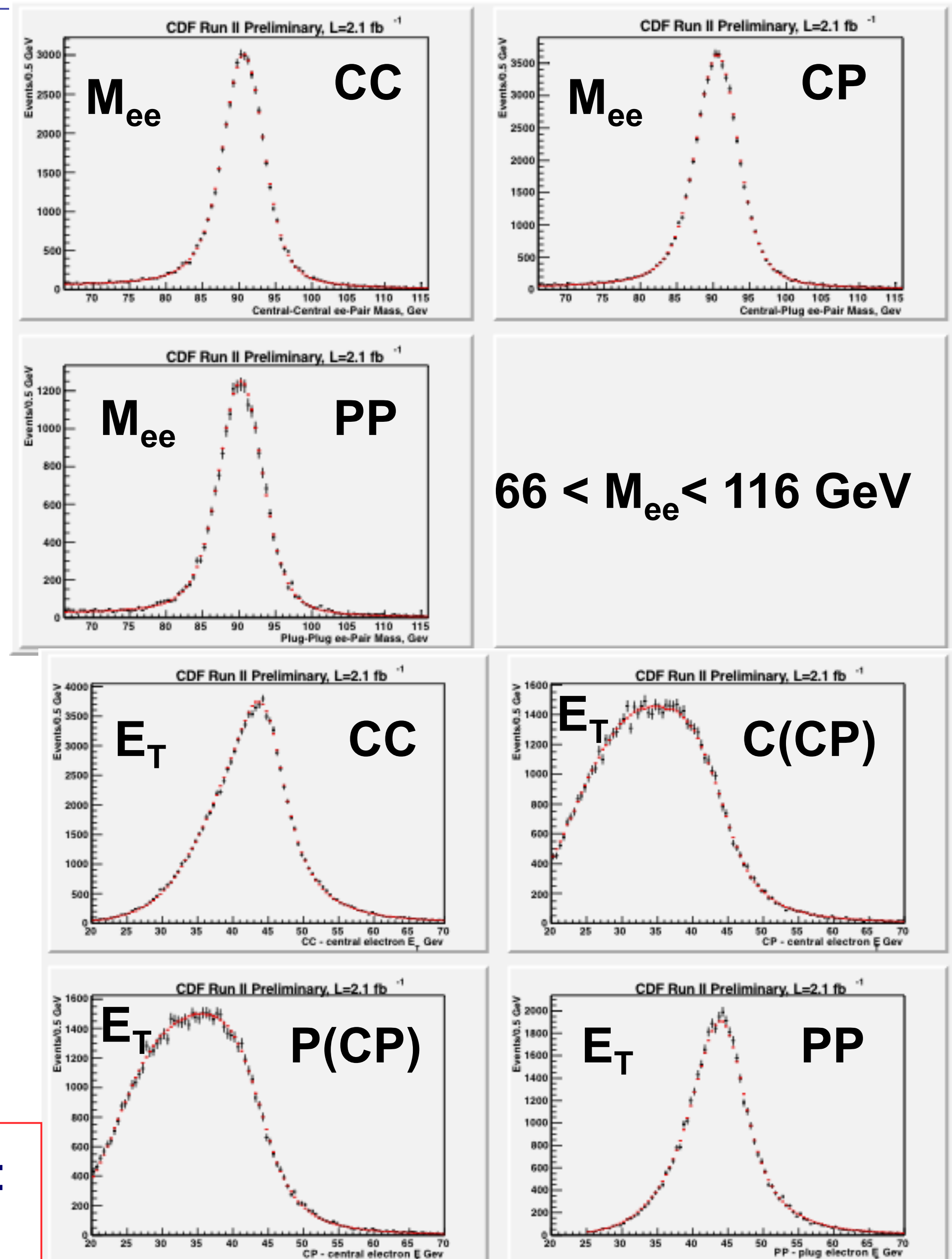
  P: $1.2<|\eta_{det}|<2.8$

- Plug-plug (PP)

  E_T > 25 GeV 22469

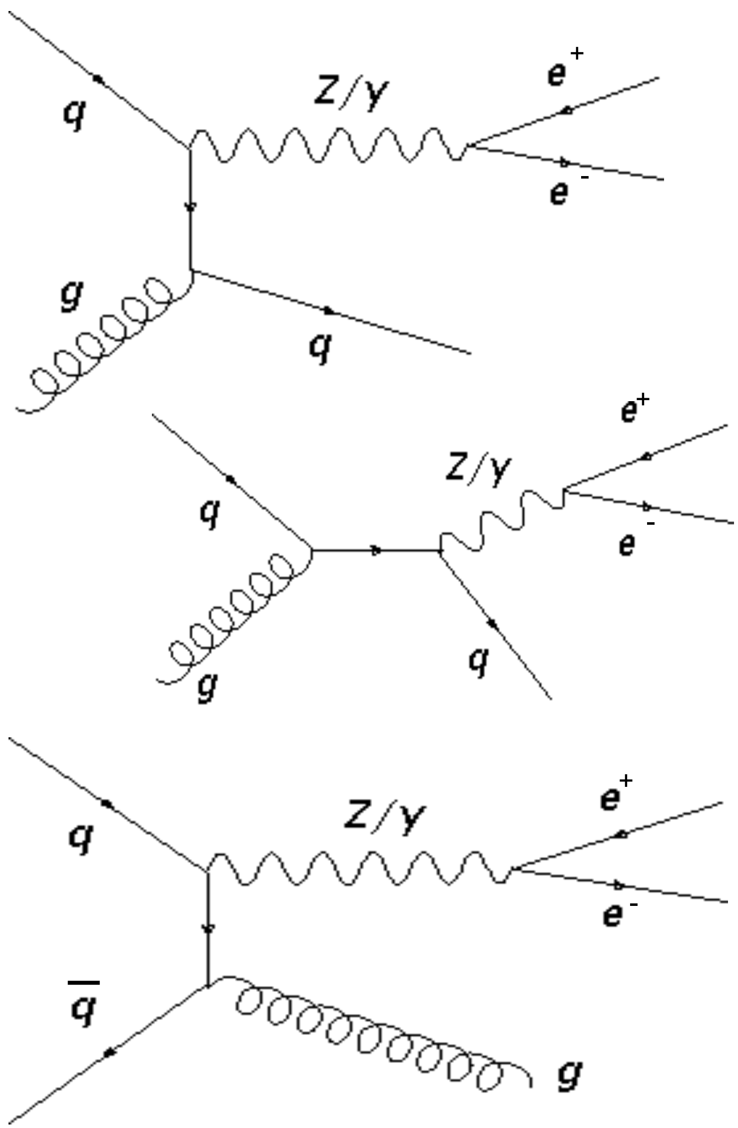
  $1.2<|\eta_{det}|<2.8$

Low backgrounds because tracks required:
QCD (data) 0.3%; EWK (MC) 0.2%



Drell-Yan Production & Decay

$\mathcal{O}(\alpha_s)$:



- NNLO calculation
  - ➔ FEWZ2
  - ➔ fixed order $\mathcal{O}(\alpha_s^2)$
  - ➔ MSTW2008 NNLO PDF's
  - ➔ fully & exclusively differential in
    - final state leptons
    - final state partons
- Resummation calculation
  - ➔ ResBos
    - Collins, Soper & Sterman formalism
    - fixed order perturbative QCD
    - all-order summation of large terms from gluon emission

Angular Distributions

General expression for angular dist. of final state electron

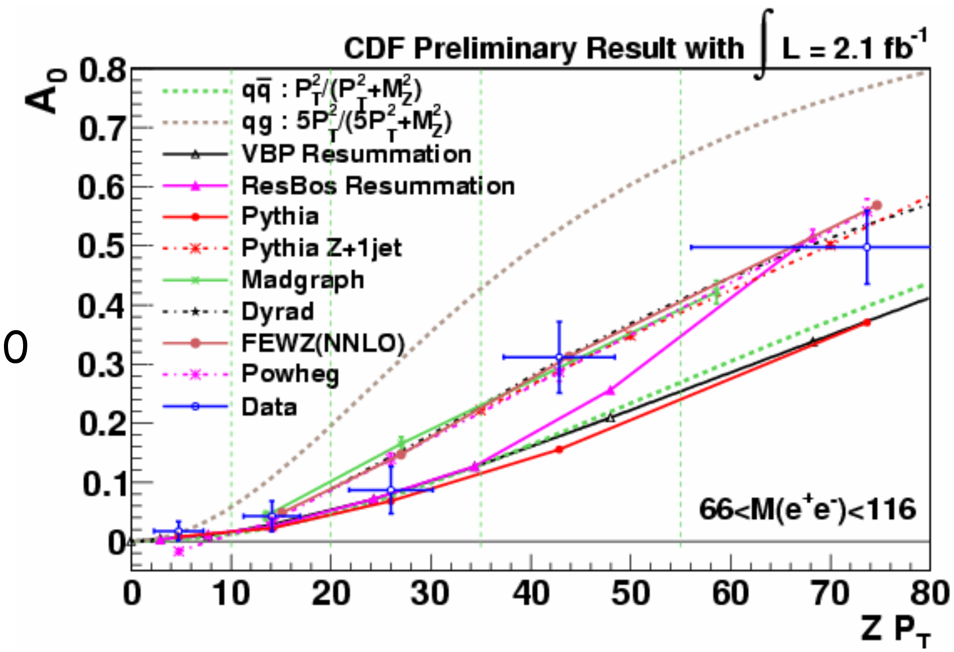
- ➔Collins-Soper frame
- ➔ A_0 to A_7 fcns of
  - M_{ee}, P_T, rapidity y
- ➔In pQCD,
  - A_5 A_6 A_7 near 0
  - A_1 A_3 small (integrate ±y)
  - A_4 sensitive to $\sin^2\theta_W$
  - A_0=A_2
    - = $P_T^2/(M^2+P_T^2)$ for qq
    - = $5P_T^2/(M^2+5P_T^2)$ for $q\bar{g}$

$$
\begin{aligned}
\frac{d\sigma}{d\cos\theta d\phi} &\propto (1+\cos^2\theta) \\
&+ \frac{1}{2}A_0(1-3\cos^2\theta) + A_1\sin 2\theta\cos\phi \\
&+ \frac{1}{2}A_2\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi \\
&+ A_4\cos\theta + A_5\sin^2\theta\sin 2\phi \\
&+ A_6\sin 2\theta\sin\phi + A_7\sin\theta\sin\phi
\end{aligned}
$$

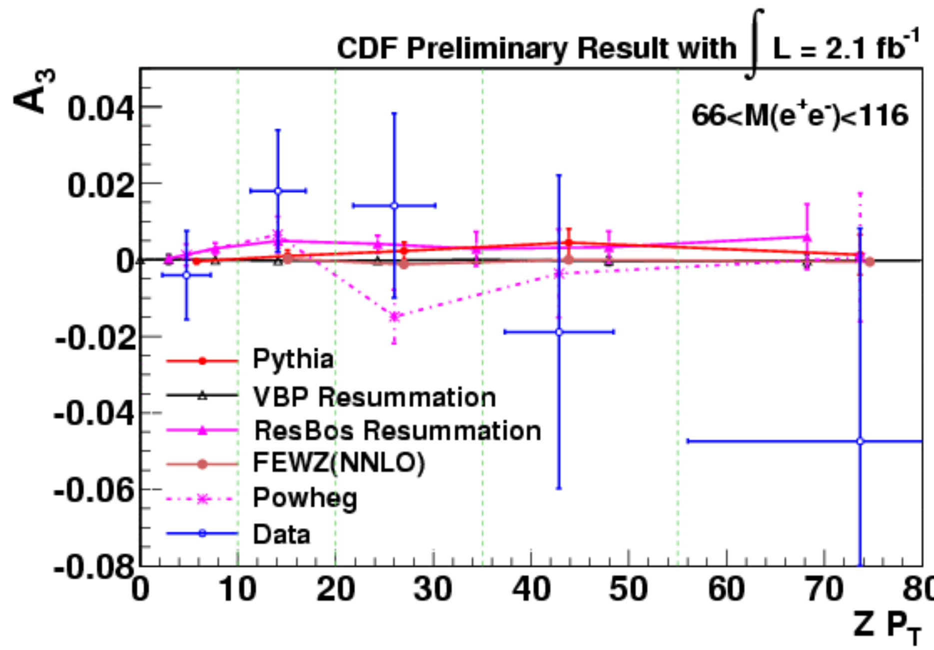
Can use A_4 to measure $\sin^2\theta_W$

Last expression is Lam-Tung equation
Only valid for vector (spin-1) gluons;
badly broken for scalar (spin-0) gluons

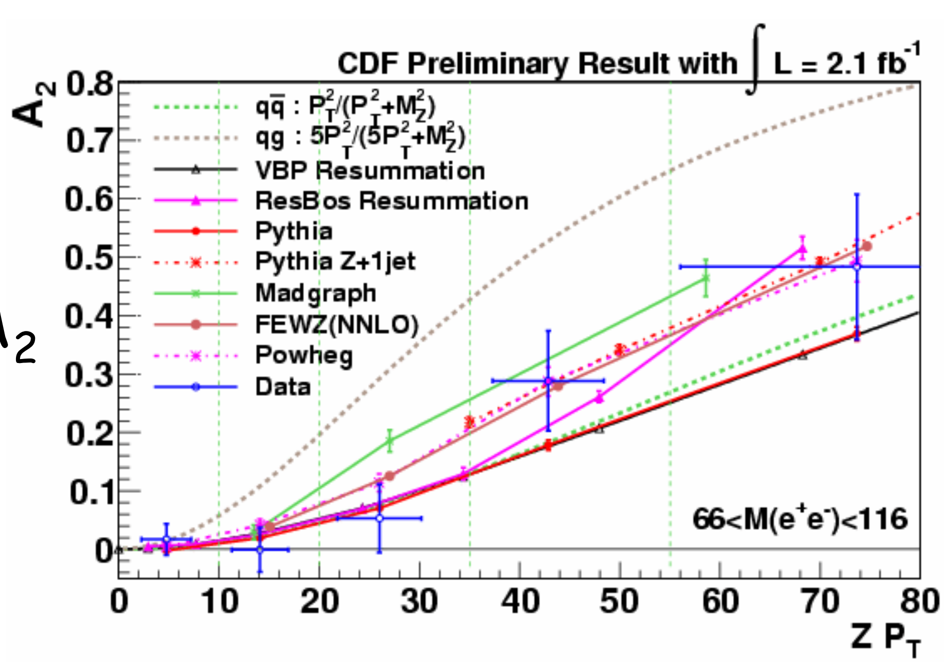
Angular Coefficients



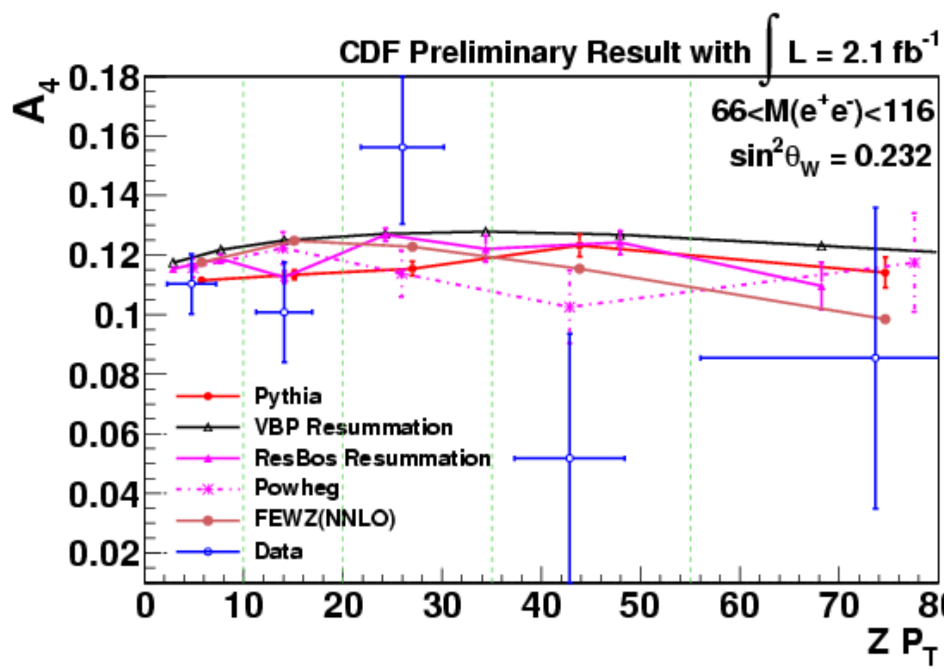
A_0



A_3

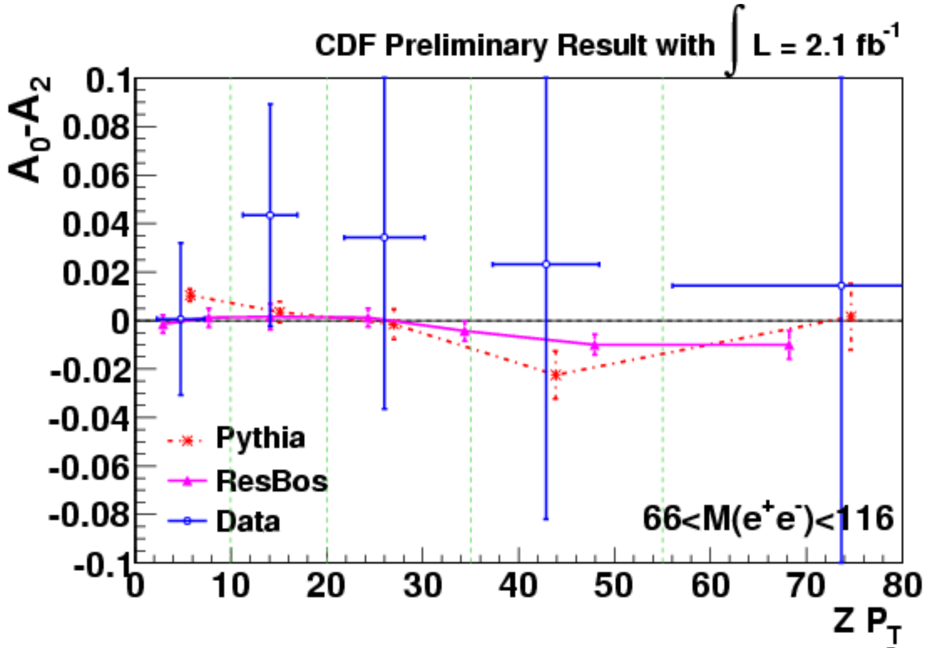


A_2



A_4

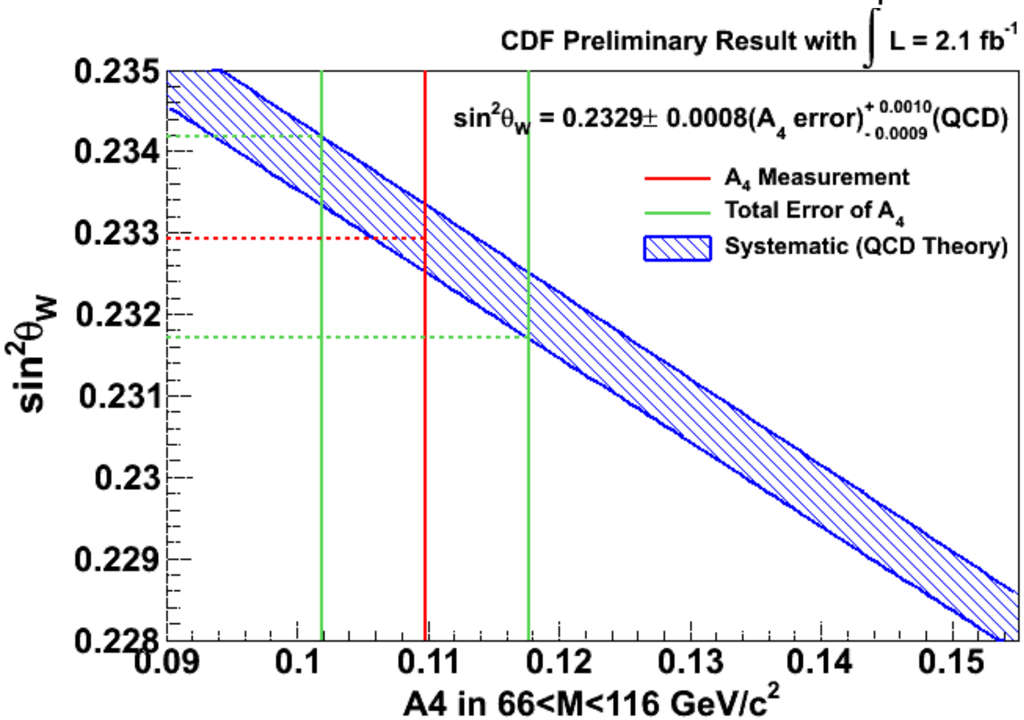
Angular Results

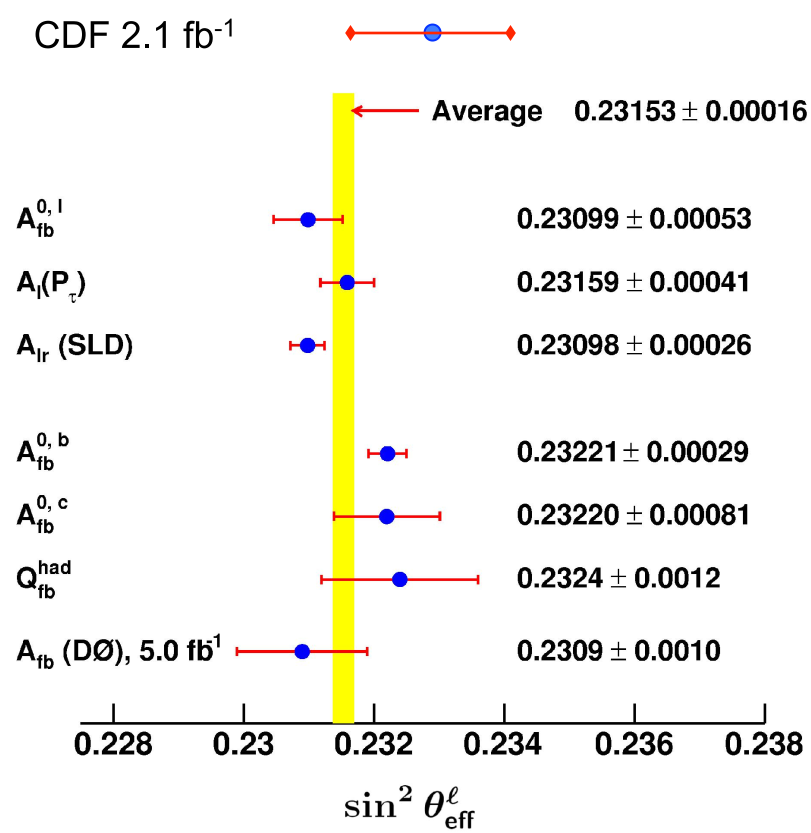


A_0-A_2 consistent with 0, as expected for vector gluon

Extract using A_4:

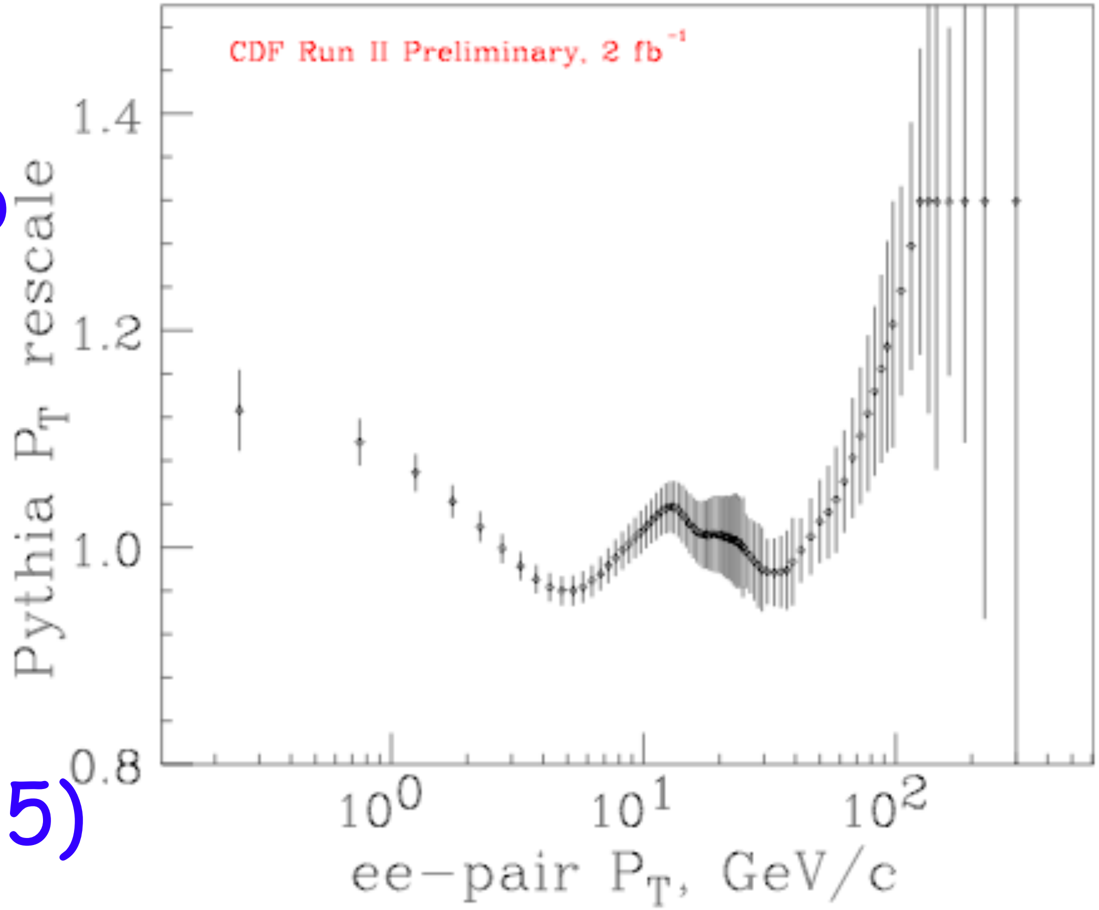
$\sin^2\theta_W = 0.2329 \pm 0.0008^{+0.0010}_{-0.0009}$ (QCD)



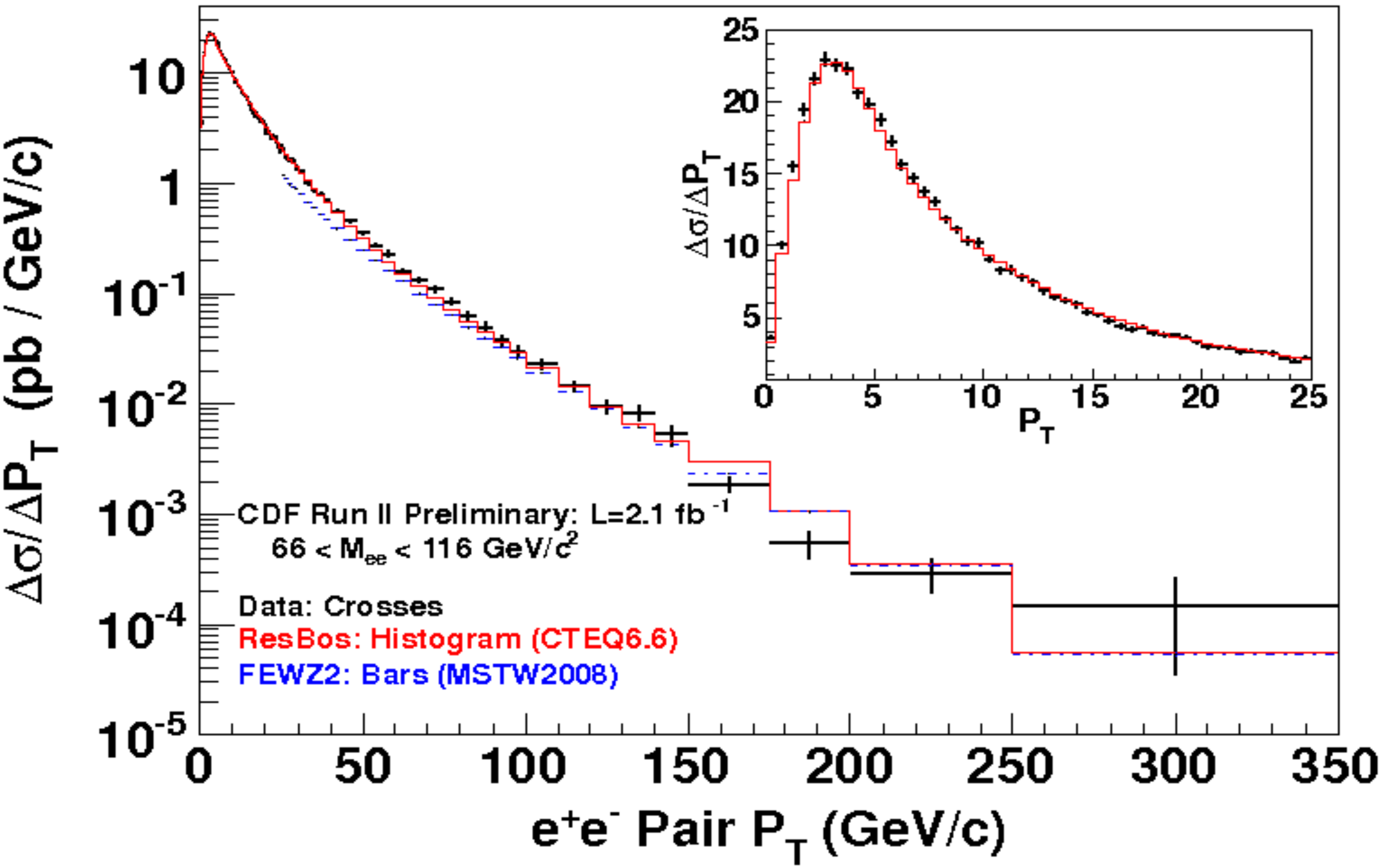


Z Transverse Momentum

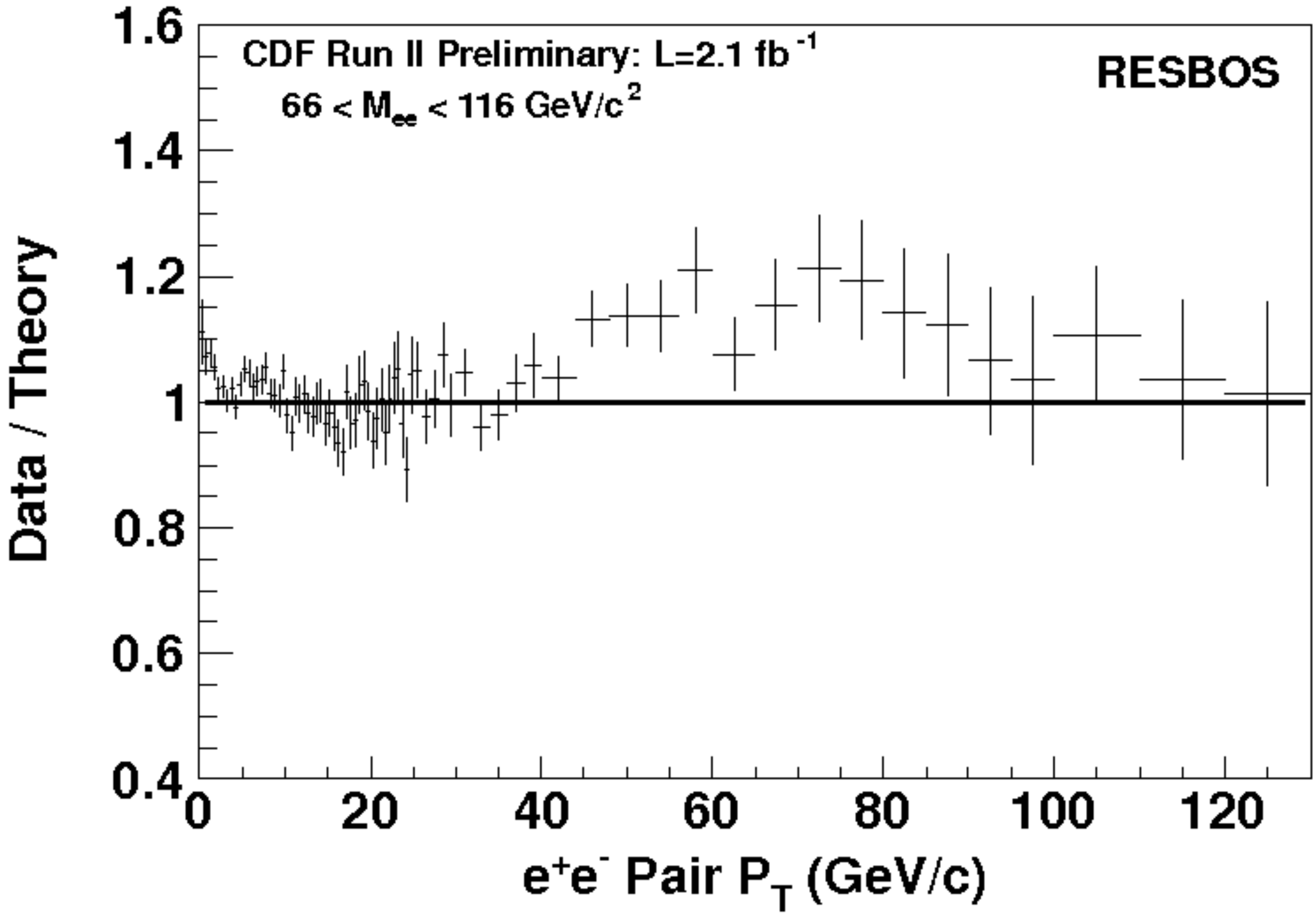
- Same dataset is used to measure transverse momentum as angular coefficients
- At low P_T, smearing is large (2.2 GeV/c) compared to bin size (0.5)
  - ➔Correct Pythia P_T to get flat data/sim
  - ➔use simulated events to get bin-by-bin unfolding



Z Transverse Momentum



Z Transverse Momentum



ResBos total cross section normalized to data

Precise enough to help refine DY P_T phenomenology

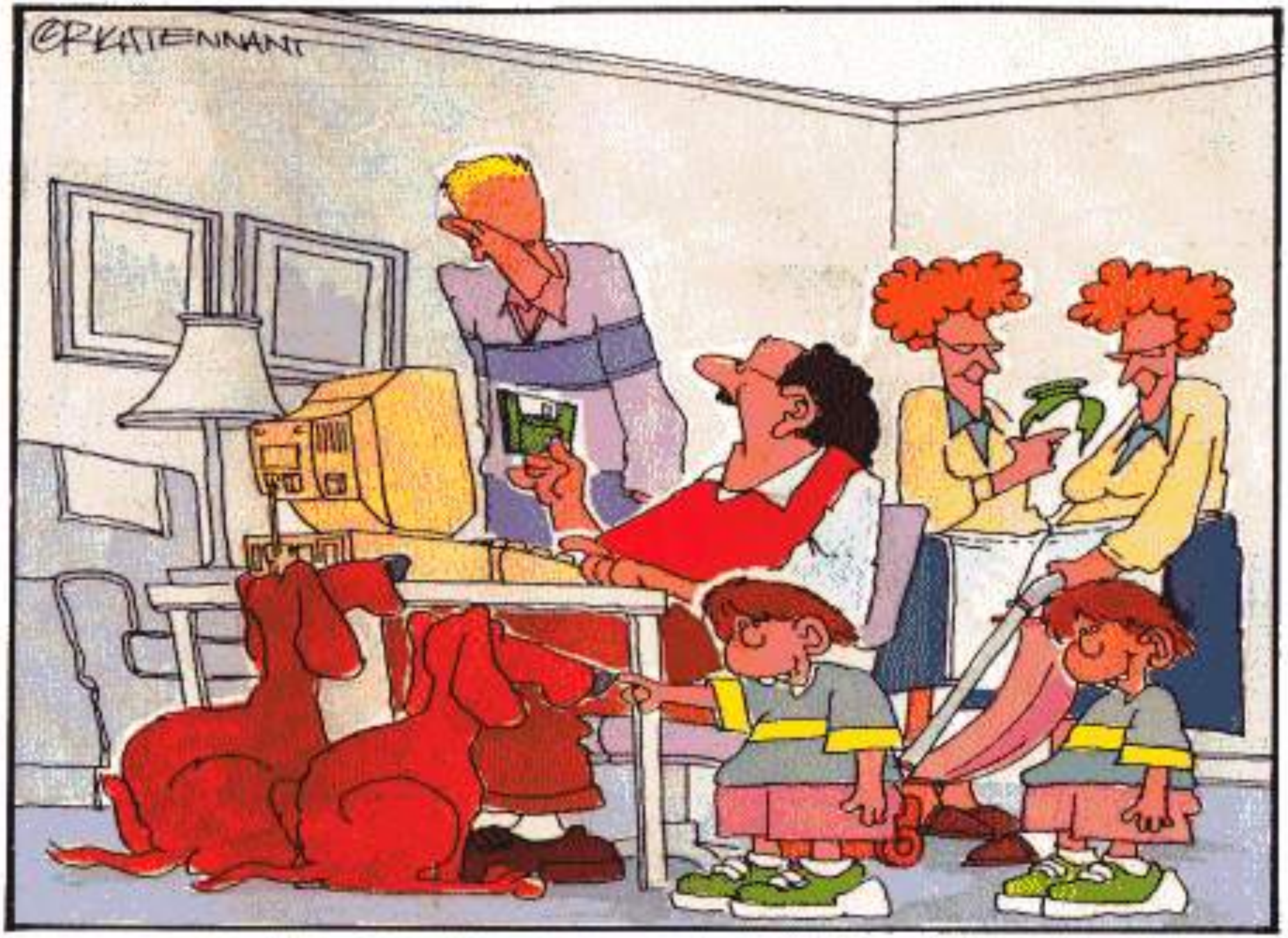
Summary

Z Boson production is well described by the Standard Model!

Precision measurements of

- ➔ A_{FB}
  - $\sin^2\theta_{eff} = 0.2309 \pm 0.0008 \pm 0.0006$
  - vector and axial-vector coupling of Z to u & d quarks
- ➔ Angular Coefficients
  - Consistent with vector gluon
  - $\sin^2\theta_W = 0.2329 \pm 0.0008^{+0.0010}_{-0.0009}$ (QCD)
- ➔ P_T
  - precise enough to help refine Drell-Yan phenomenology

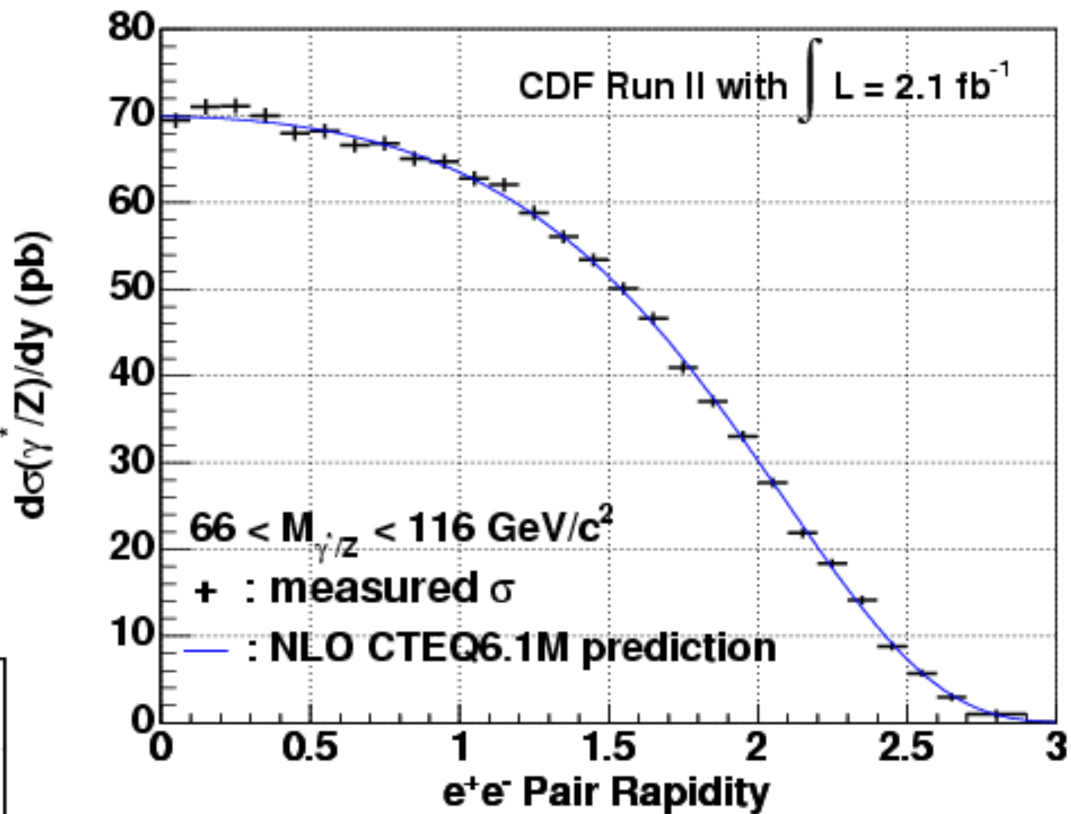
Backup

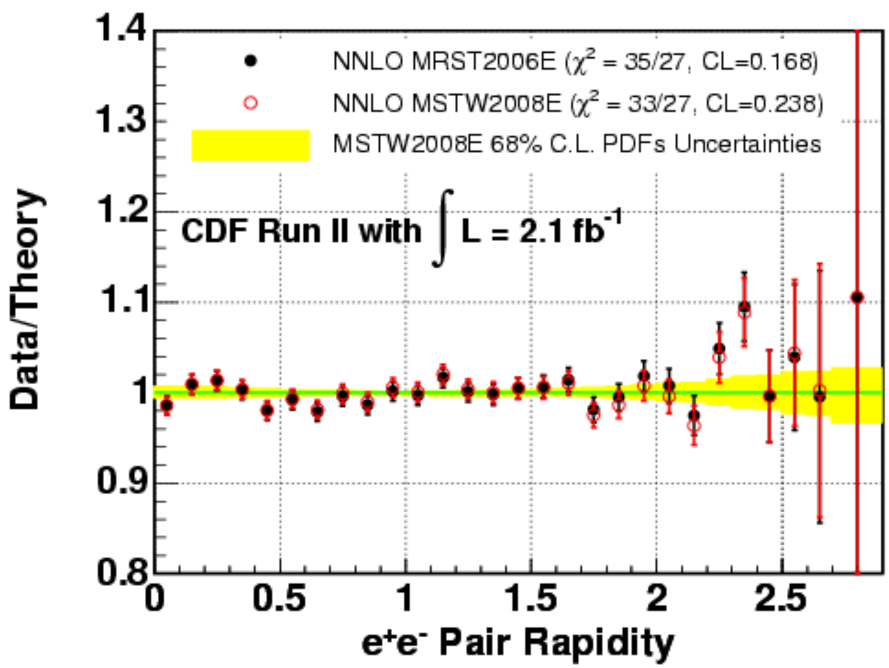


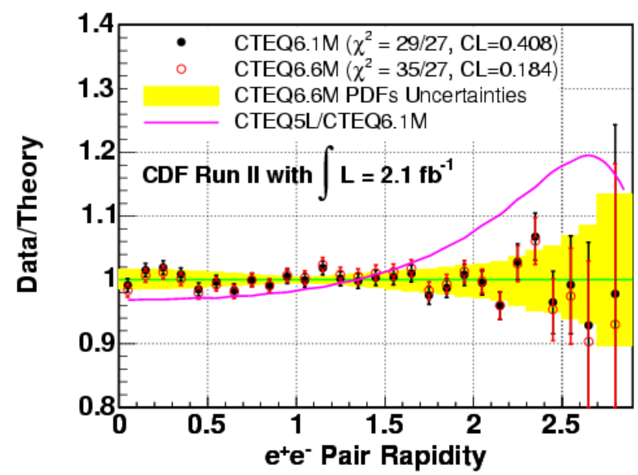
" I ALWAYS BACK UP EVERYTHING."

$Z/\gamma \rightarrow e^+e^-$ $d\sigma/dy$

- Same dataset as P_T and angular measurements
  - → σ = 256.6 ± 0.7 ± 0.6 pb
  - → input for PDF fits
  - → NLO CTEQ6.1 best







$$\sin^2\theta^l_{eff} = 0.2309 \pm 0.0008 \pm 0.0006$$

Electroweak radiative corrections result in different values for up and down quarks compared to electrons:

$$\sin^2\theta^u_{eff} = \sin^2\theta^l_{eff} - 0.0001$$
$$\sin^2\theta^d_{eff} = \sin^2\theta^l_{eff} - 0.0002$$