MANCHESTER 1824

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Single W and Z production and asymmetries at the Tevatron

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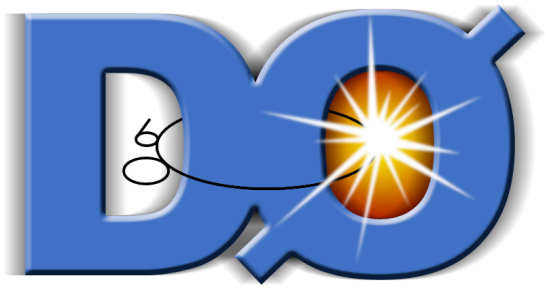
On behalf of the CDF and DØ Collaborations

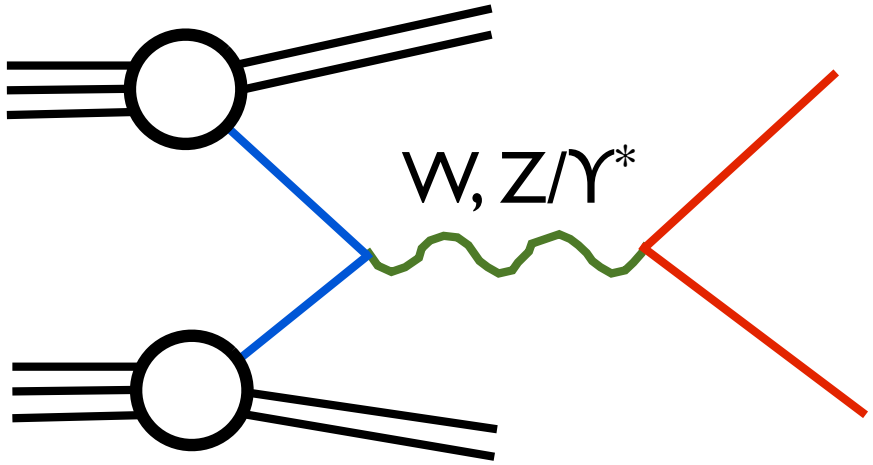
Rencontres de Moriond EW 2011

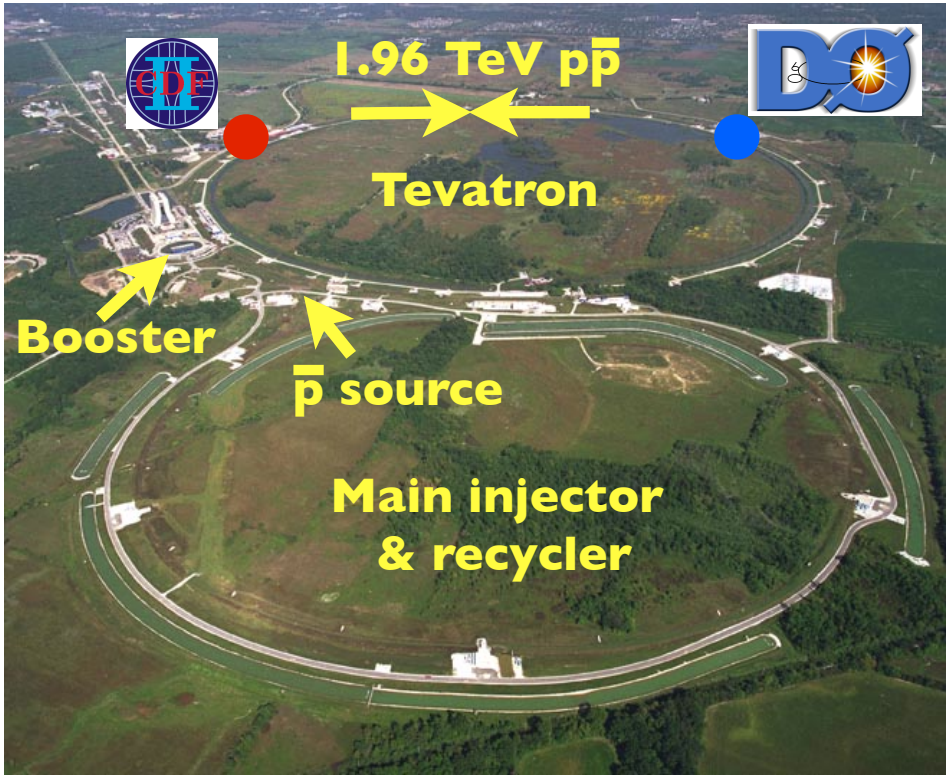
14th March 2011



W and Z production at the Tevatron

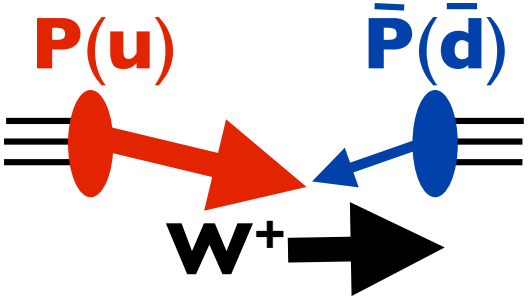
- Ideal for testing understanding of QCD
  - Parton distribution functions, initial state radiation, non-perturbative form factors.
  - W and Z production is a background to many Higgs and new physics searches.
- Tevatron = W and Z boson factory
  - Will present result with 7.3 fb^{-1} and 966k Z/Υ^* candidates!
- Complementary to LHC
  - W and Z mainly produced by valence quark annihilation
  - CP symmetric collider is ideal for asymmetry measurements



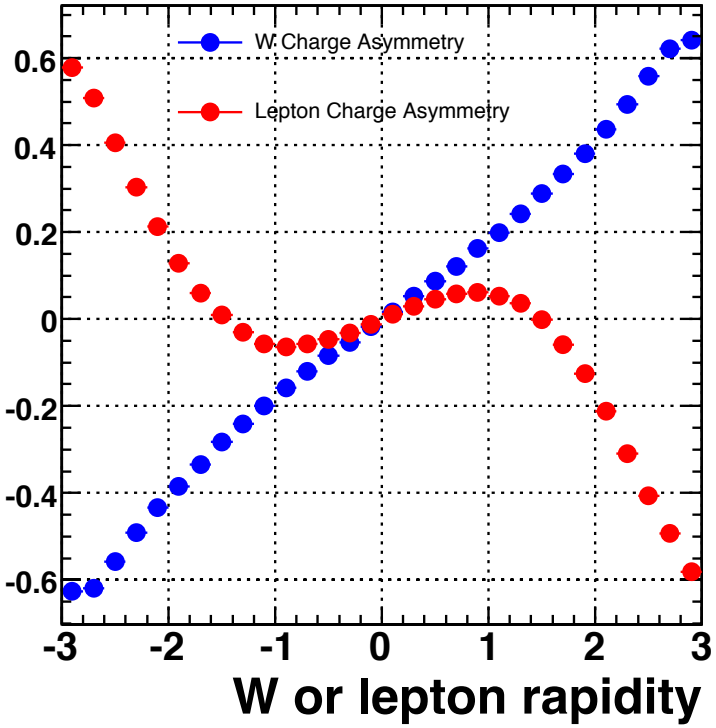


W charge asymmetry

- At the Tevatron, W and Z bosons mostly produced by valence quark annihiliation.
  - e.g. W^+ mostly via u(proton) and $\bar{d}$(antiproton).
- Valence u($\bar{u}$) quarks have harder PDFs than d($\bar{d}$) quarks.
  - W^+ Boosted along proton direction.



$$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$$



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

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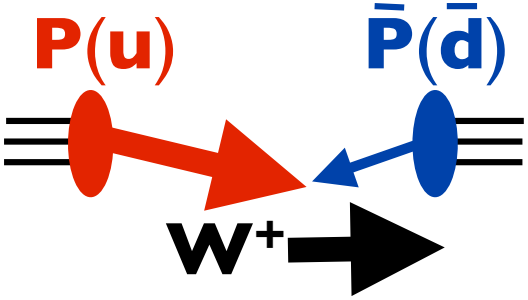

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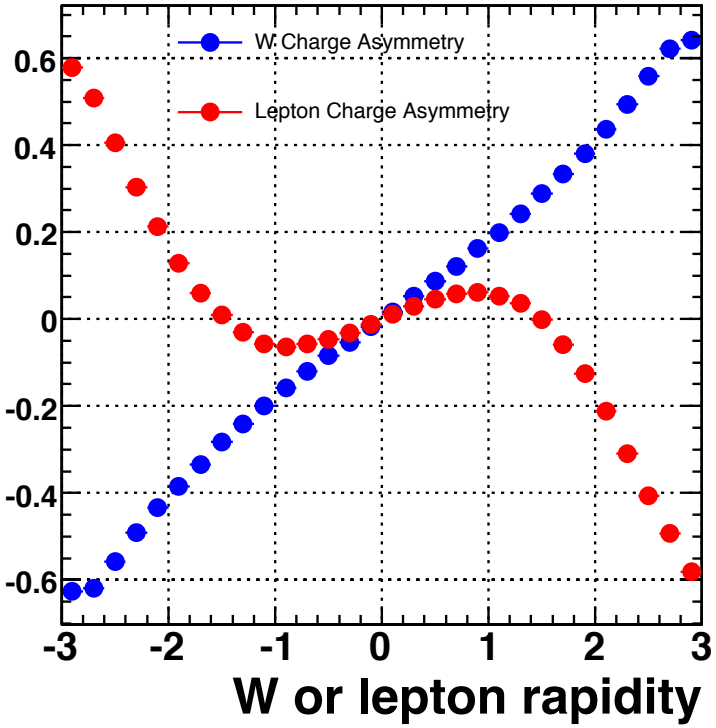
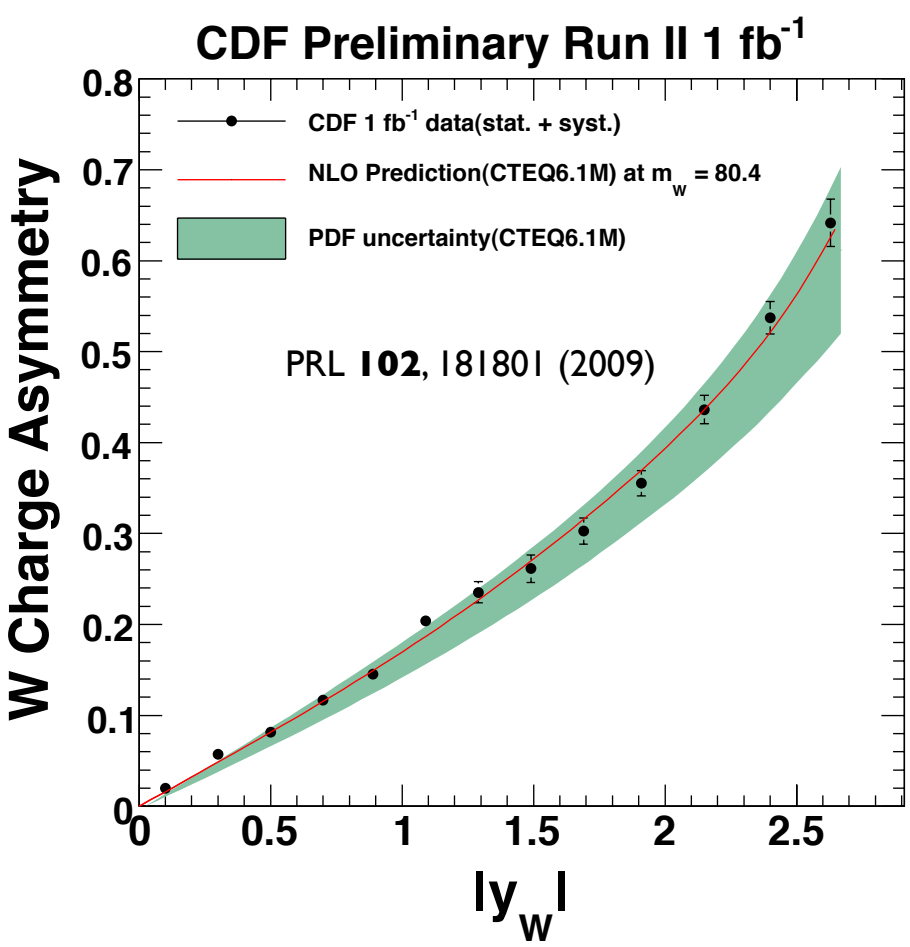
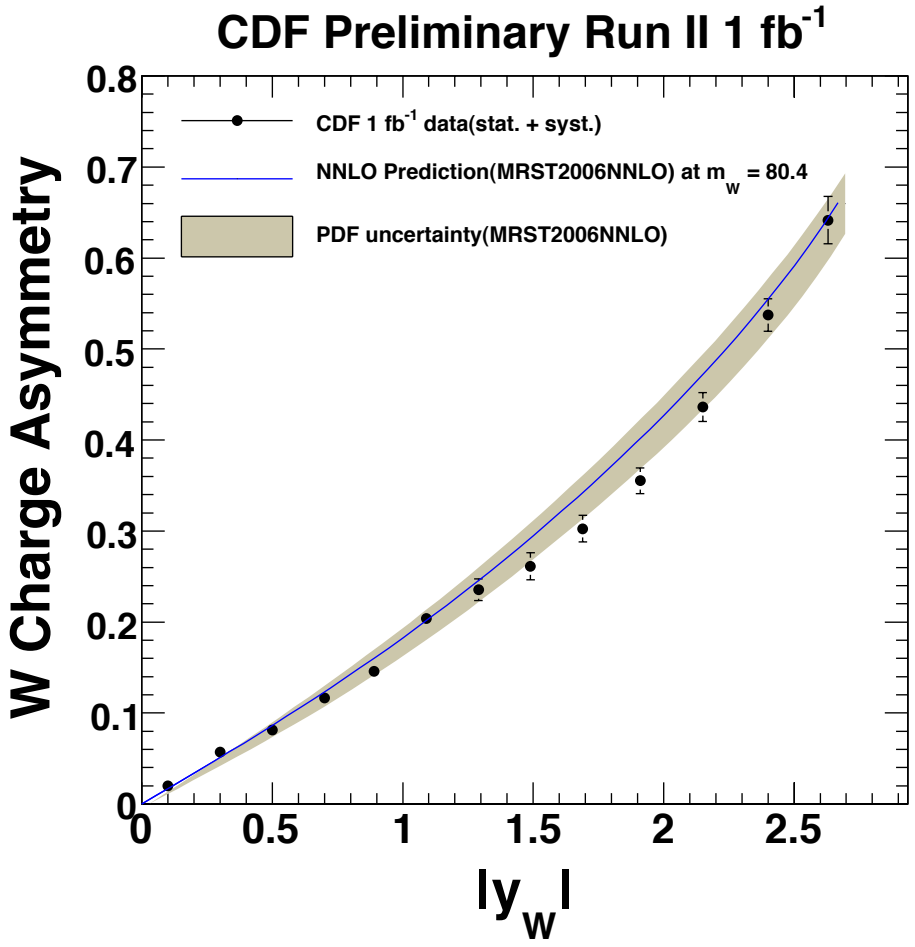


- $$A(\eta) = \frac{\frac{d\sigma(W^+)}{d\eta} - \frac{d\sigma(W^-)}{d\eta}}{\frac{d\sigma(W^+)}{d\eta} + \frac{d\sigma(W^-)}{d\eta}} \approx A(y) \otimes (V - A)$$
  - lepton charge asymmetry folds in the V-A decay asymmetry.

W charge asymmetry (CDF)

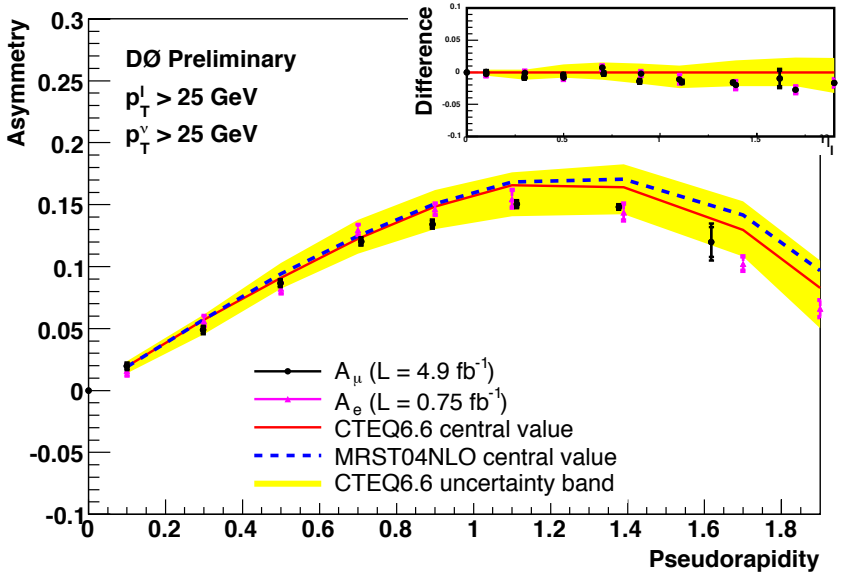
- W rapidity estimated statistically using kinematic constraints and assumptions on the angular distribution in the $W \rightarrow e\nu$ decay.
- Data are well described by pQCD predictions.

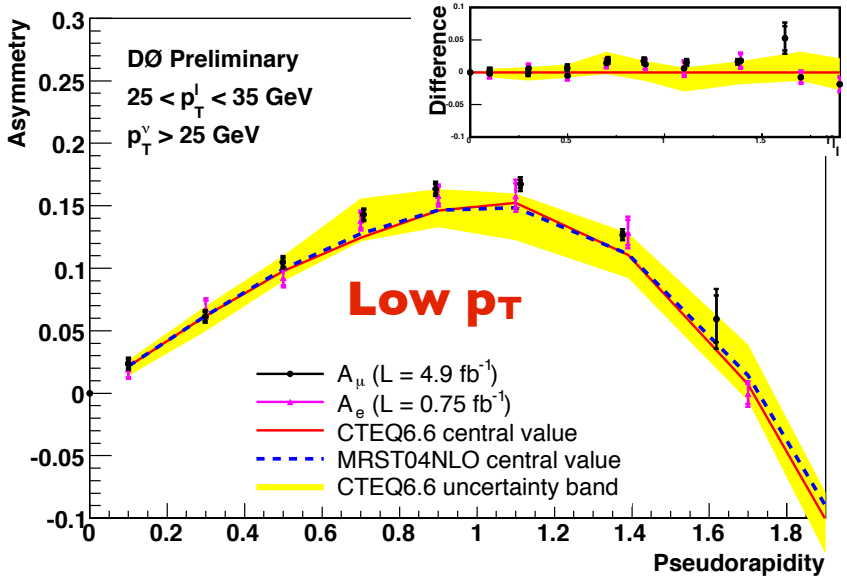


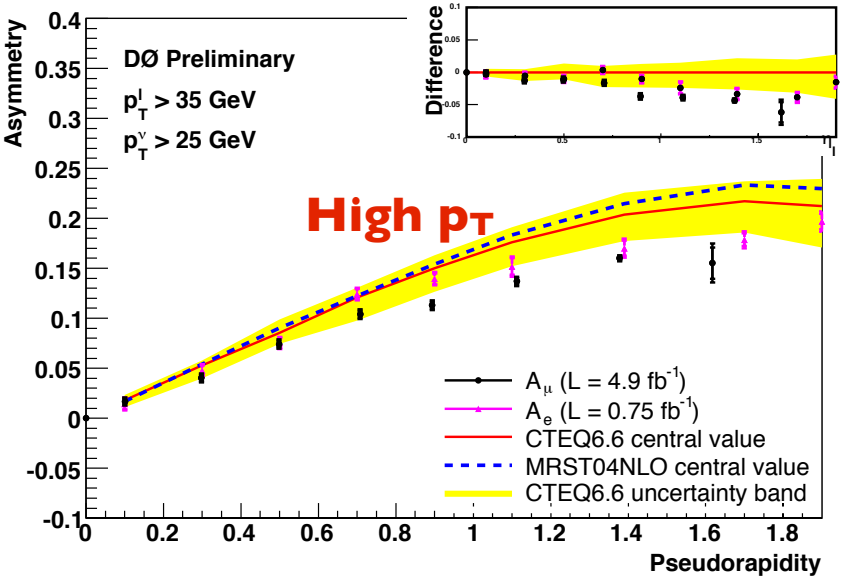


lepton charge asymmetry (DØ)

- Directly observable but less sensitive to production asymmetry.
  - Improved by binning in lepton p_T
- Disagreement with QCD predictions at large lepton p_T.



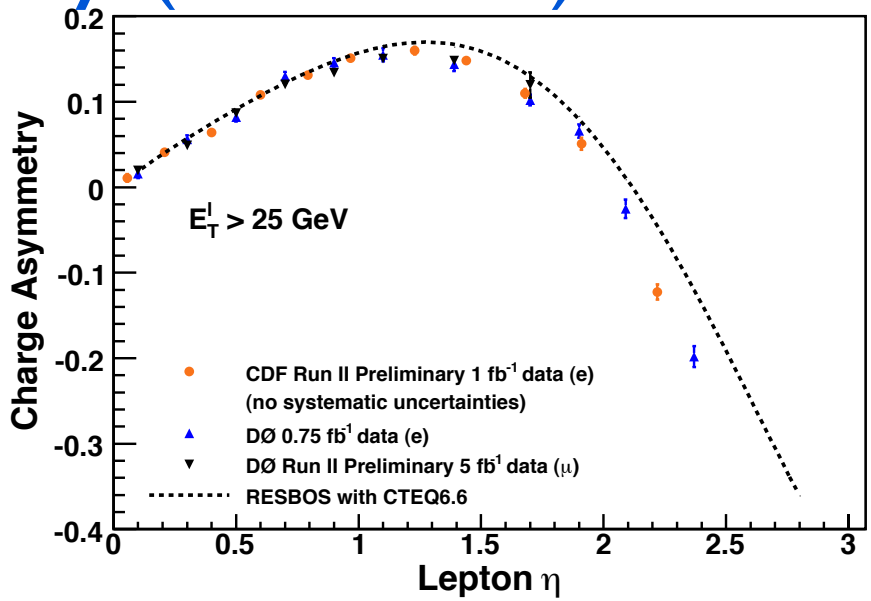


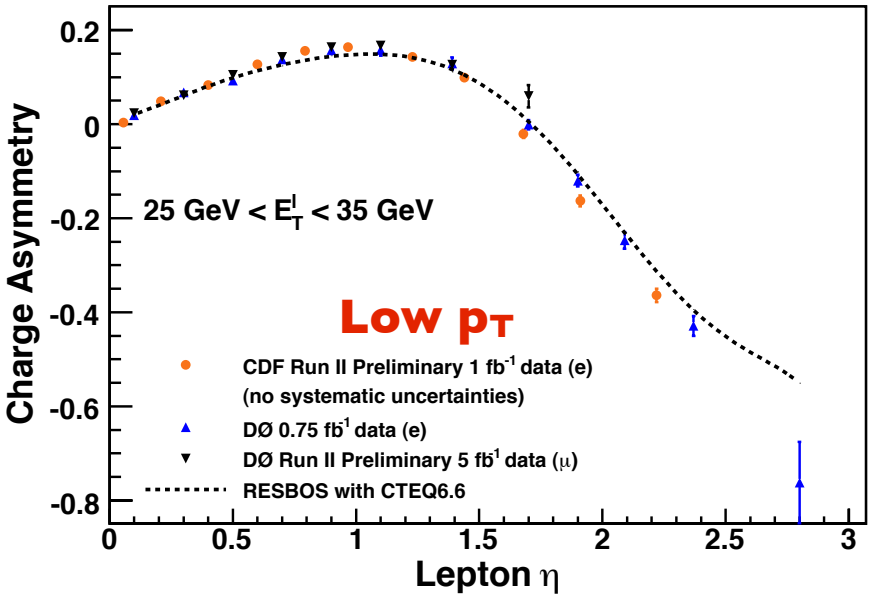


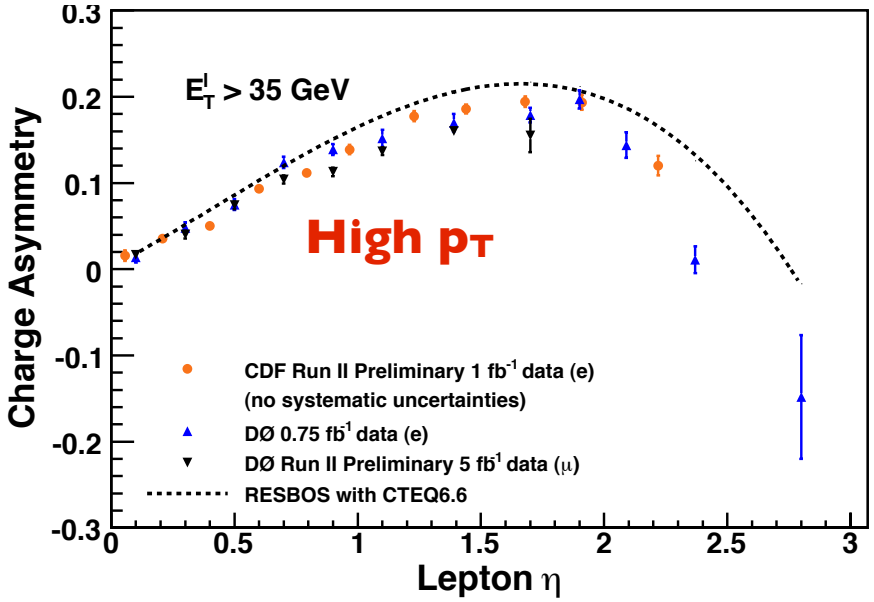
PRL **101**, 211801 (2008), 5976-CONF (2009).

lepton charge asymmetry (DØ/CDF)

- Directly observable but less sensitive to production asymmetry.
  - Improved by binning in lepton p_T
- Disagreement with QCD predictions at large lepton p_T.
  - Confirmed by CDF







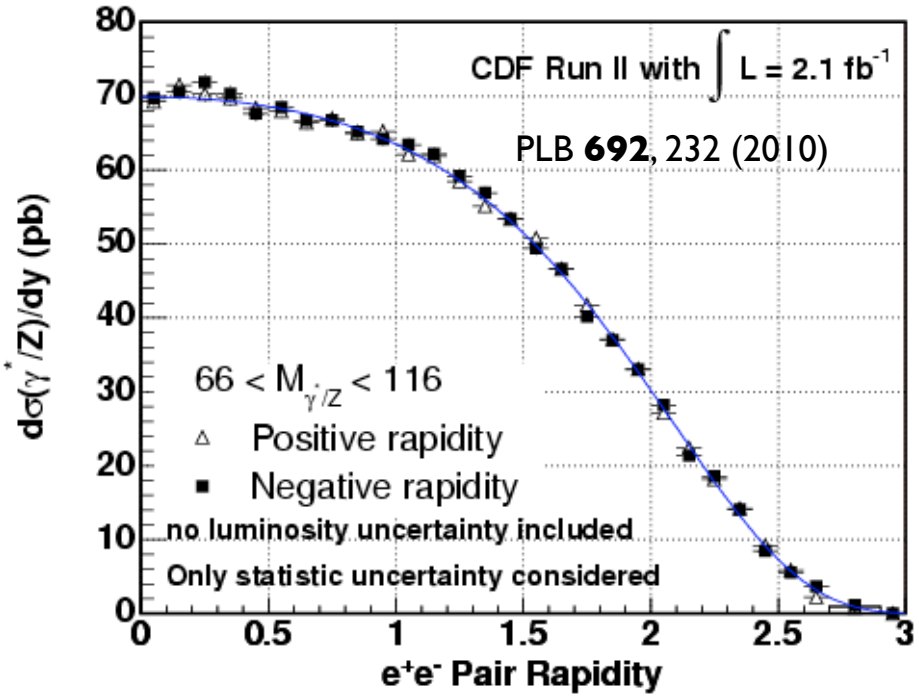
PRL **101**, 211801 (2008), 5976-CONF (2009).

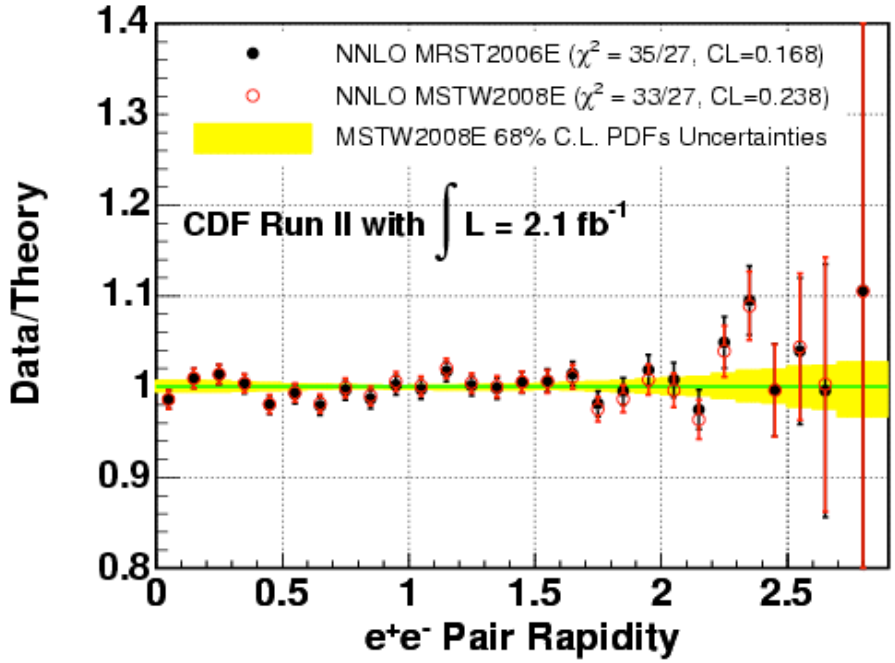
$Z/\Upsilon^* \rightarrow ee$ $d\sigma/dy$ (CDF)

- Helps to constrain valence quark PDFs
- Good agreement between $d\sigma/dy$ data and pQCD over wide range of rapidities.
- Most precise measurement of inclusive cross section

$$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y} \qquad y = \frac{1}{2} \ln \frac{x_p}{x_{\bar{p}}}$$

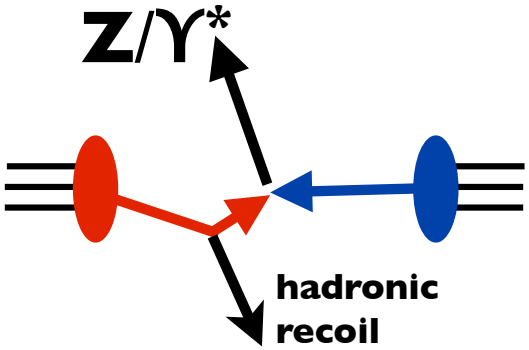
σ = 256.6 ± 0.7 (stat) ±2.0 (syst) ± 15.4 (lumi)

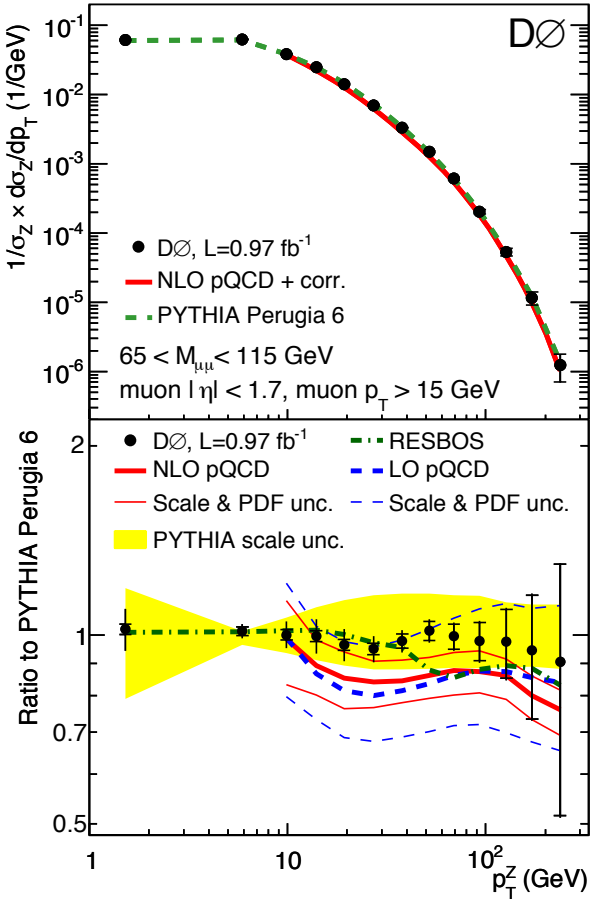


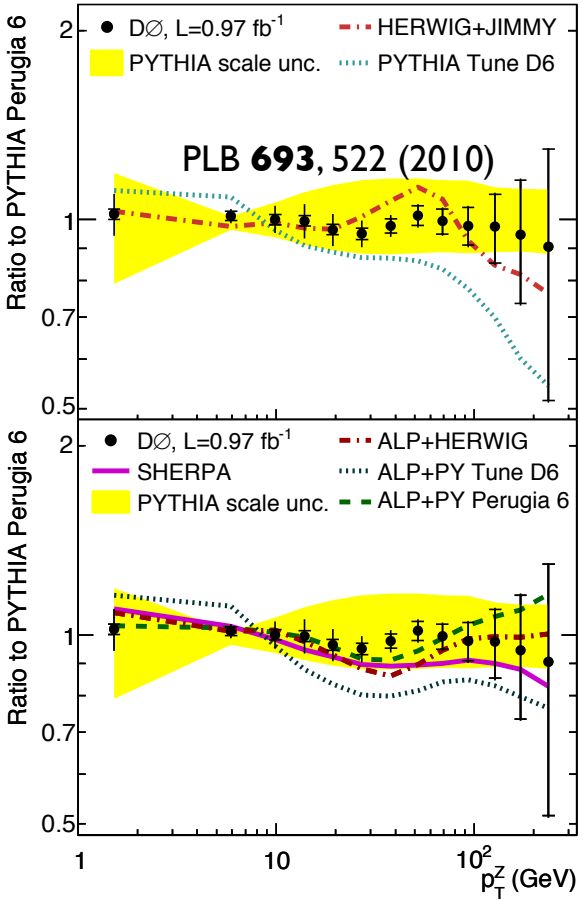


$Z/\Upsilon^* \rightarrow \mu\mu$ p_T (DØ)

- Comparison with various pQCD calculations and MC event generator predictions.
  - Verification is important for Higgs and new physics searches.

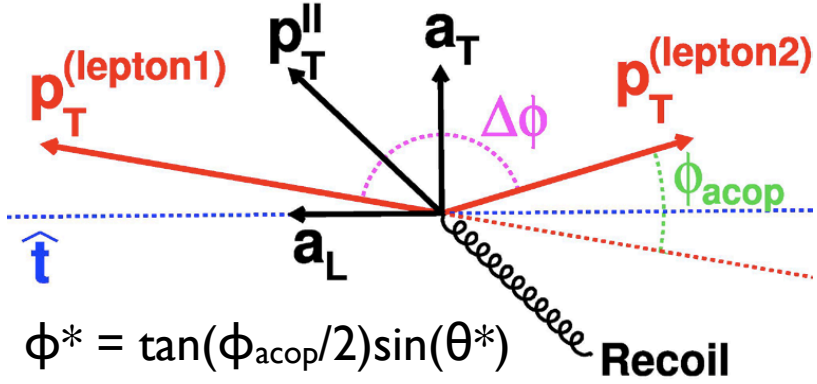






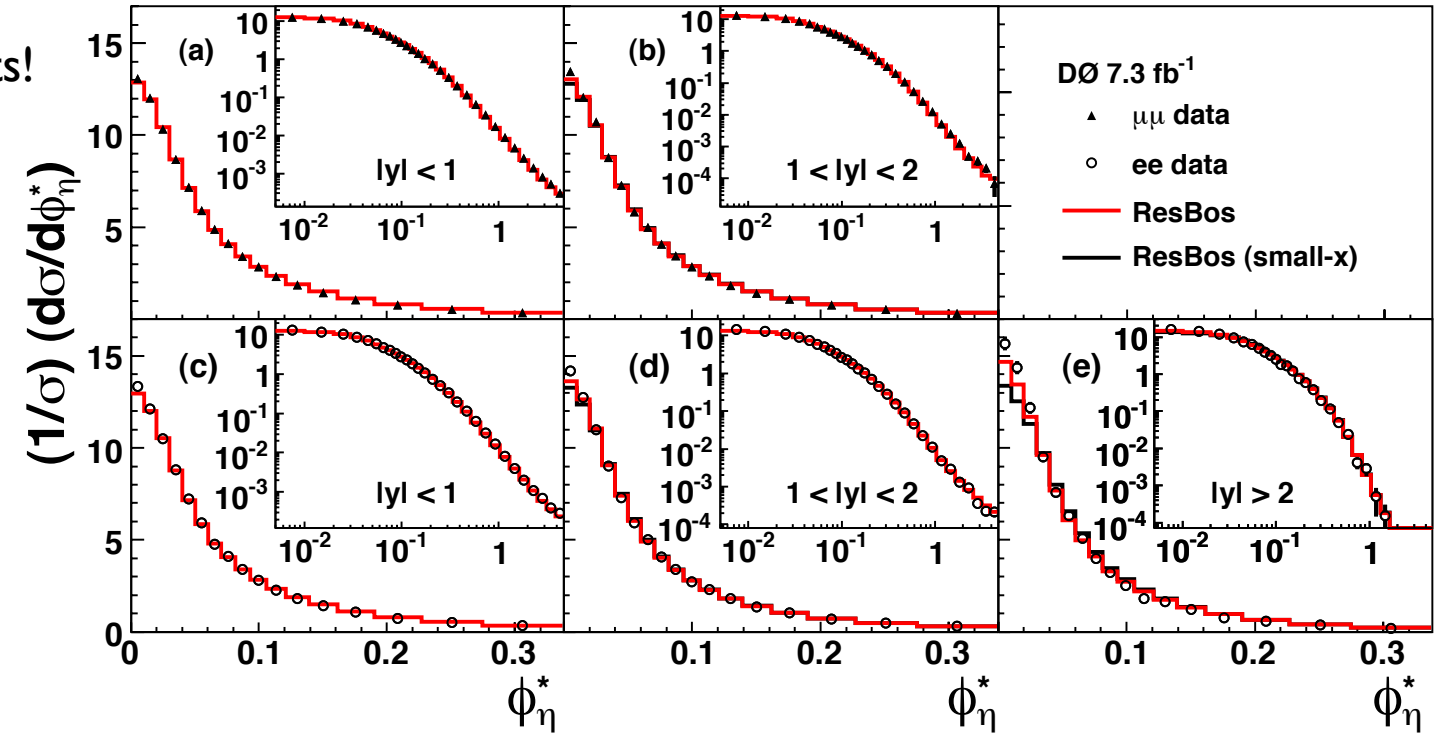
$Z/\Upsilon^* \rightarrow ee/\mu\mu$ $d\sigma/d\phi^*$ (DØ)

- Alternative variable to study the Z/Υ^* p_T
  - Less sensitive to detector resolution and selection efficiency.
- Binning in rapidity probes x-dependence of non-perturbative form factors



$\phi^* = \tan(\phi_{acop}/2)\sin(\theta^*)$

966k events!



arXiv:1009.1580 [hep-ex], arXiv:1010.0262, accepted by PRL (2011).

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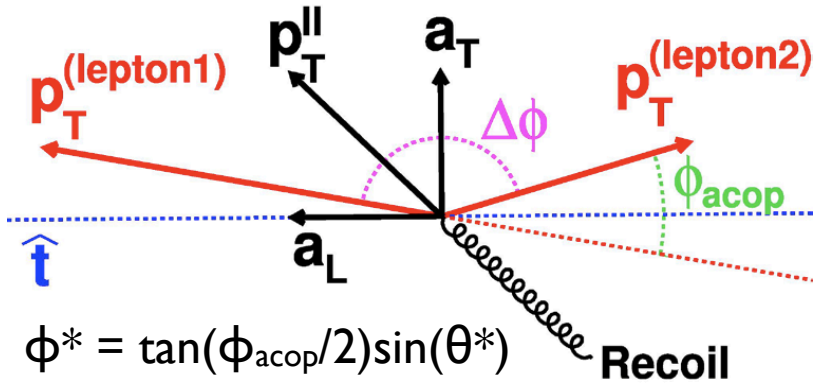

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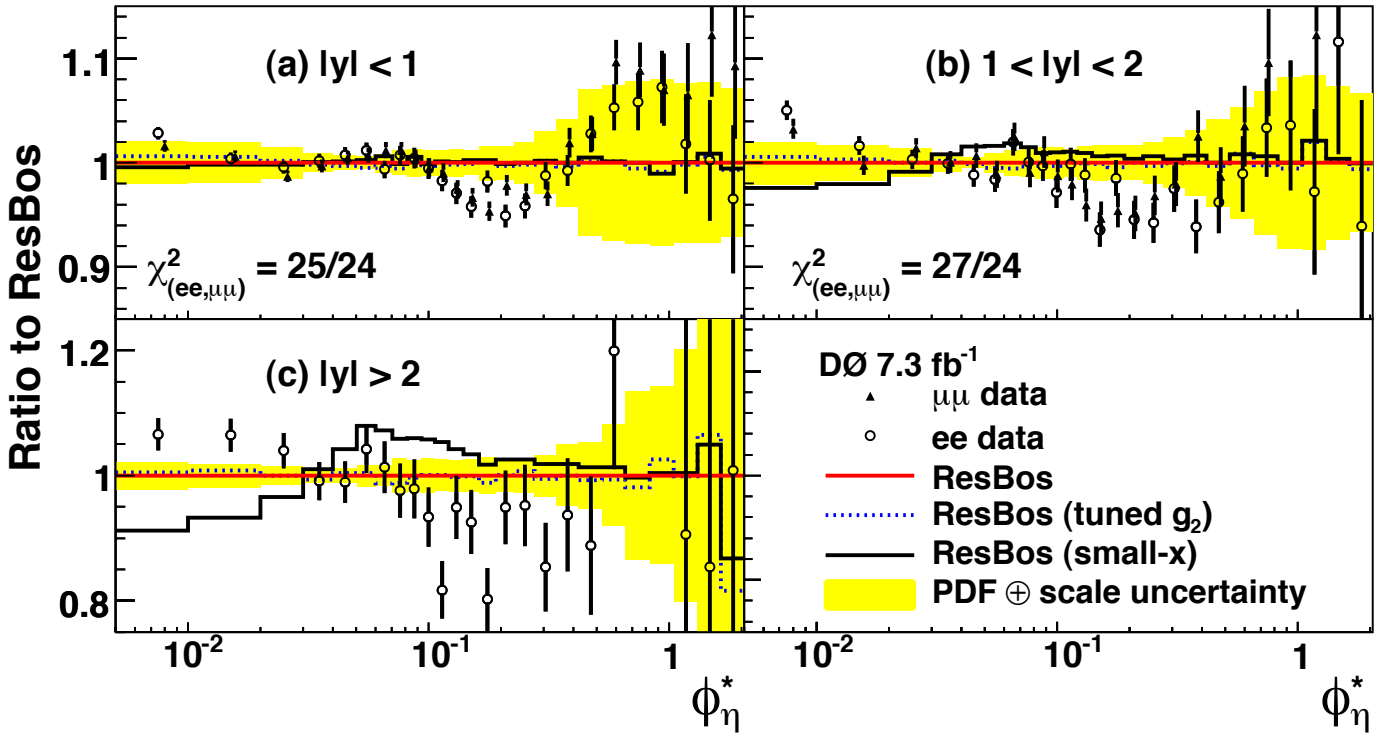

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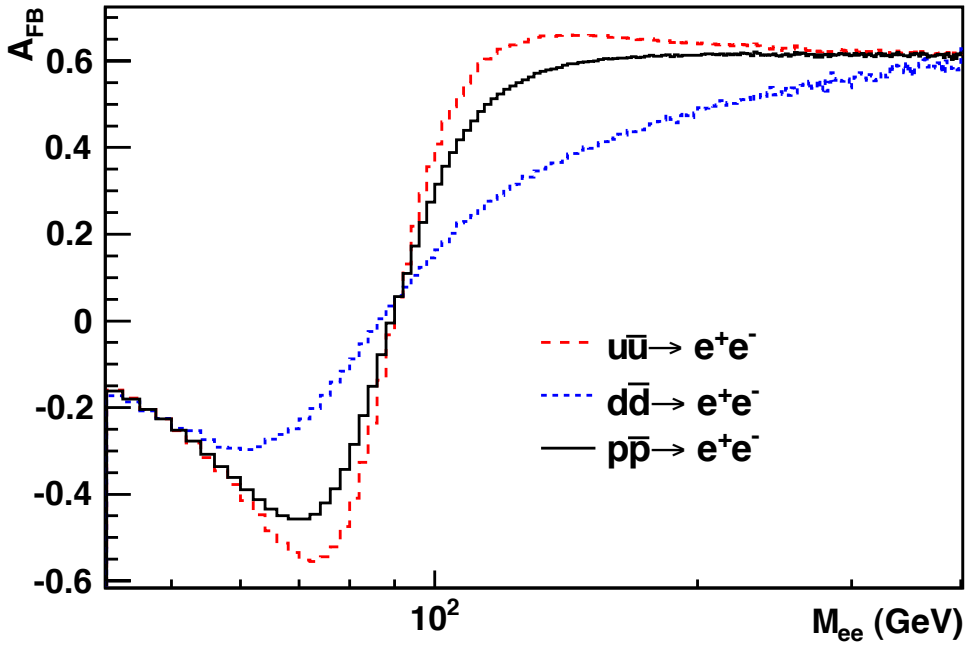
Z/Υ* A_{FB}

- Coupling of Z/Υ* to fermions contains both vector and axial-vector components.
- Leads to asymmetry in the polar angle θ^* of the negatively charged lepton in the dilepton rest frame (or Collins Soper frame).
  - A_{FB} dominated by Z/Υ* interference above and below the Z pole.
  - Sensitive to additional heavy gauge bosons.

$$g_v^f = I_3^f - 2Q_f \sin^2\theta_w$$
$$g_a^f = I_3^f$$

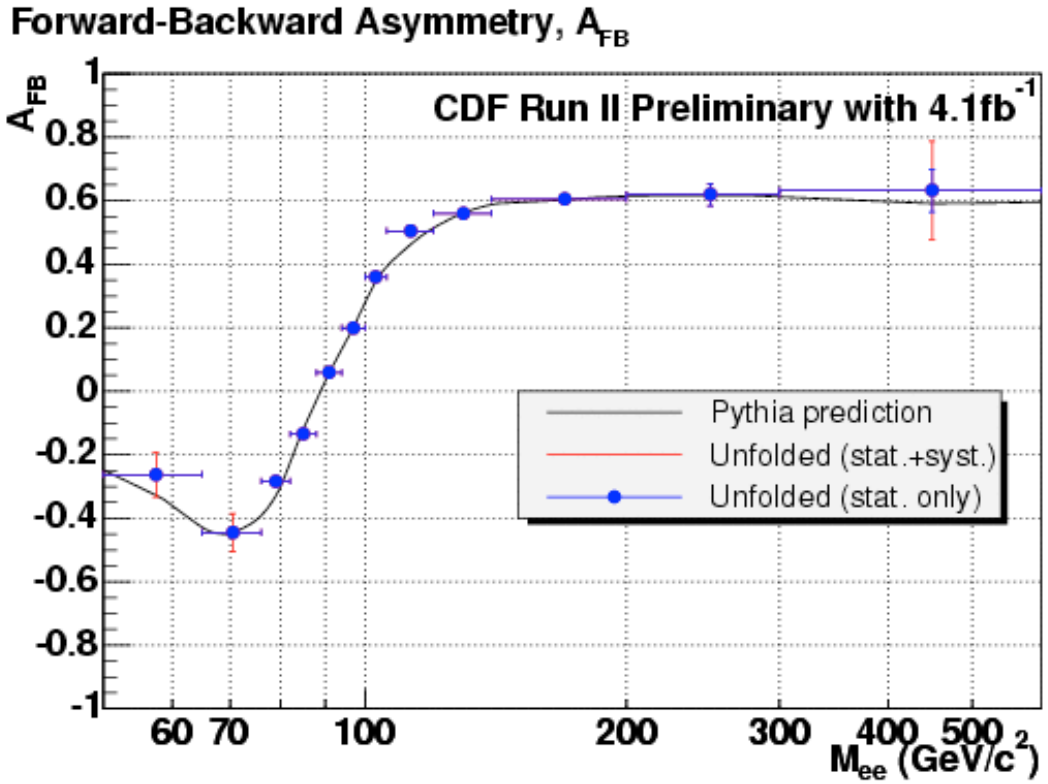
$$\frac{d\sigma}{d\cos\theta^*} = A(1+\cos^2\theta^*) + B\cos\theta^*$$

$$A_{\mathrm{FB}} = \frac{\sigma_{\mathrm{F}} - \sigma_{\mathrm{B}}}{\sigma_{\mathrm{F}} + \sigma_{\mathrm{B}}} \quad \begin{matrix} \mathrm{F}: & \cos(\theta^*) > 0 \\ \mathrm{B}: & \cos(\theta^*) < 0 \end{matrix}$$



$Z/\gamma^* \rightarrow ee$ A_{FB} (CDF)

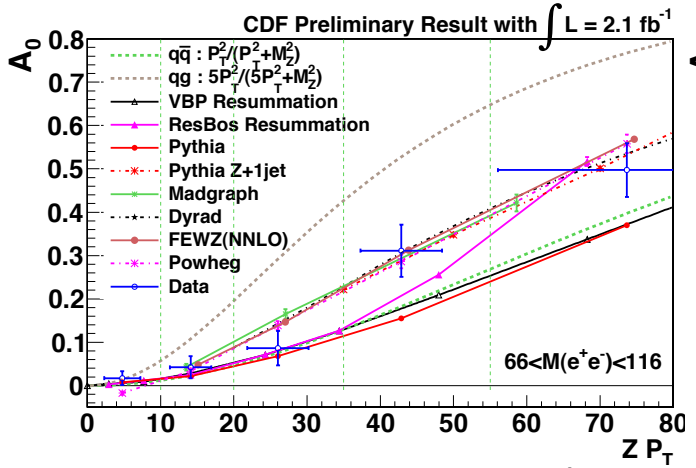
- Unfolded A_{FB} agrees well with PYTHIA prediction
  - No evidence for new physics at high mass

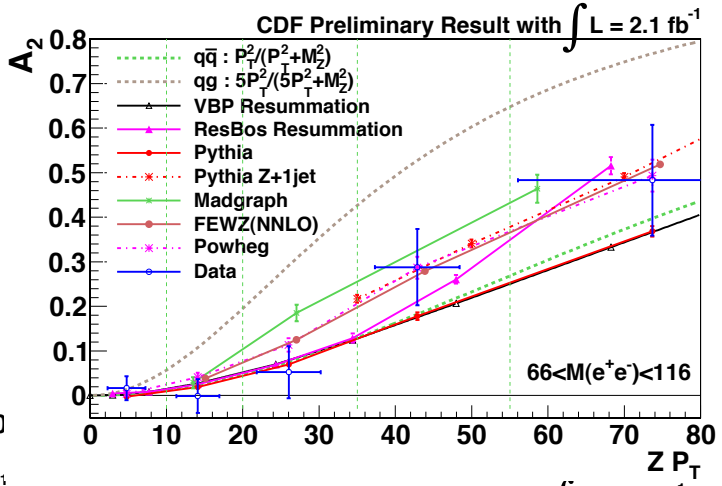


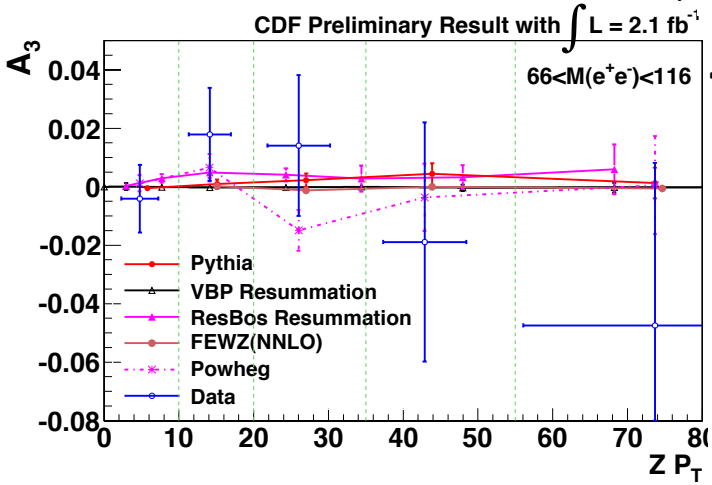
$Z/\Upsilon^* \rightarrow ee$ angles (CDF)

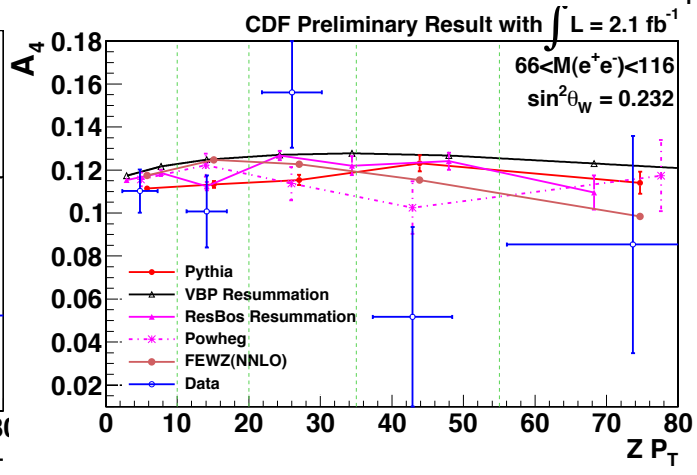
- Extension of A_{FB} to look differentially in ϕ
- Angular distributions depend on A_n parameters.
  - Depend on dilepton kinematics

$$d\sigma/d\cos\theta d\phi = (1+\cos^2\theta) + \tfrac{1}{2}A_0(1-3\cos^2\theta) + A_1\sin 2\theta\cos\phi + \tfrac{1}{2}A_2\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi + A_4\cos\theta + A_5\sin^2\theta\sin 2\phi + A_6\sin 2\theta\sin\phi + A_7\sin\theta\sin\phi.$$





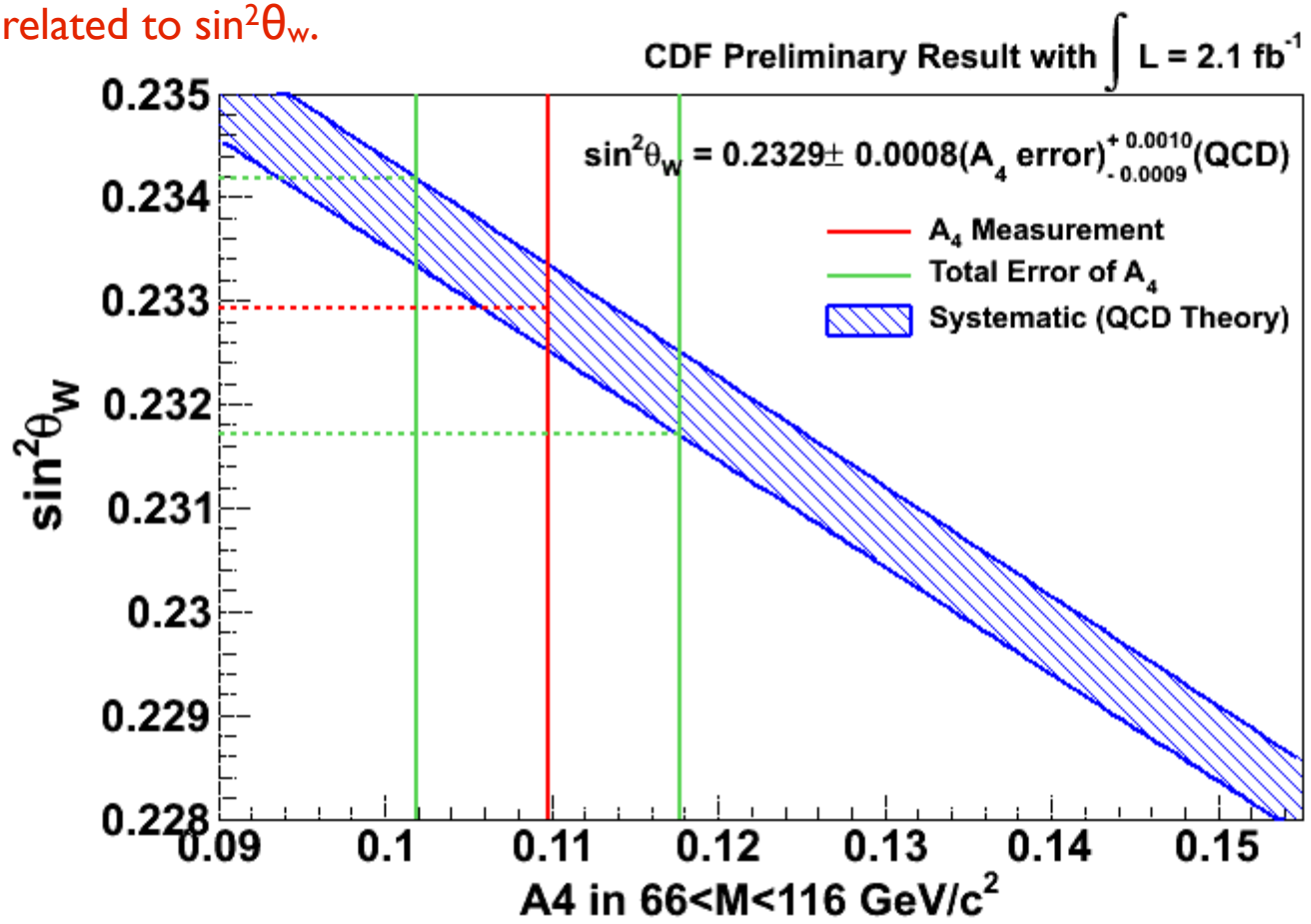




$Z/\Upsilon^* \rightarrow ee$ angles (CDF)

- Extension of A_{FB} to look differentially in ϕ
- Angular distributions depend on A_n parameters.
  - Depend on dilepton kinematics
  - A_4 related to $\sin^2\theta_w$.

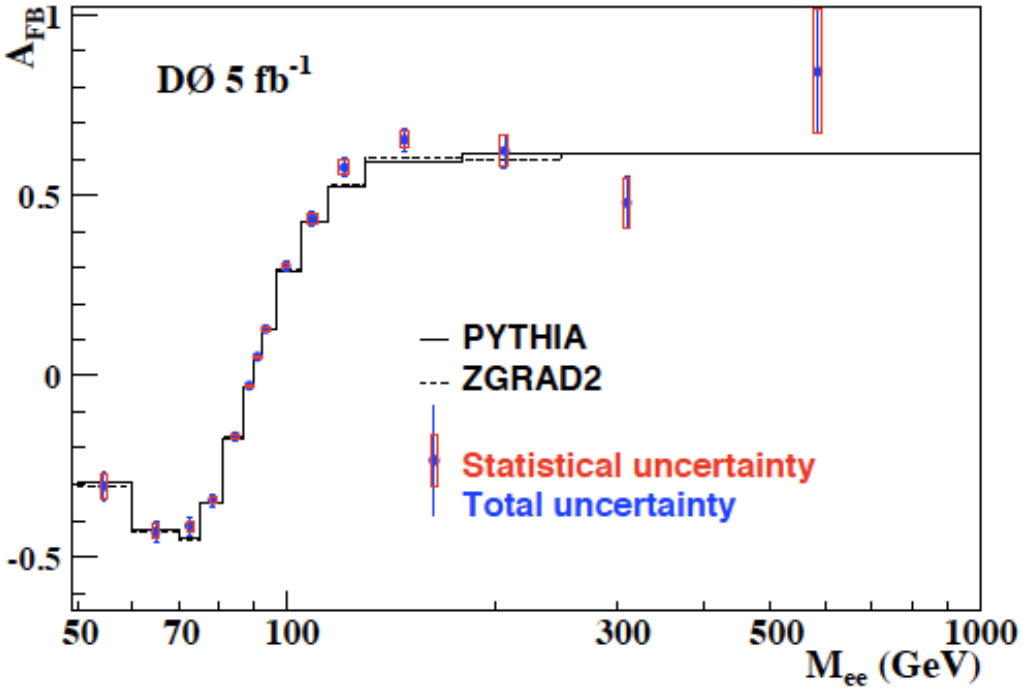
$$d\sigma/d\cos\theta d\phi = (1+\cos^2\theta) + \tfrac{1}{2}A_0(1-3\cos^2\theta) + A_1\sin 2\theta\cos\phi + \tfrac{1}{2}A_2\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi + A_4\cos\theta + A_5\sin^2\theta\sin 2\phi + A_6\sin 2\theta\sin\phi + A_7\sin\theta\sin\phi.$$

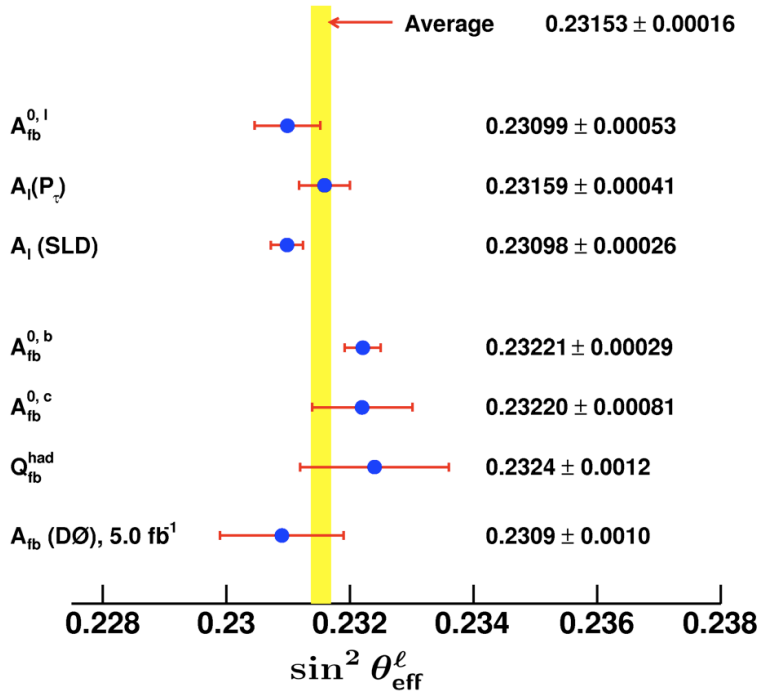


$Z/\gamma^* \rightarrow ee$ A_{FB} (DØ)

- Unfolded A_{FB} agrees well with PYTHIA/ZGRAD2.
  - No evidence for new physics at high mass
- $\sin^2\theta_w$ measurement at hadron collider which doesn't look out of place on world average plot!
  - Final Tevatron precision approaching single LEP experiment!

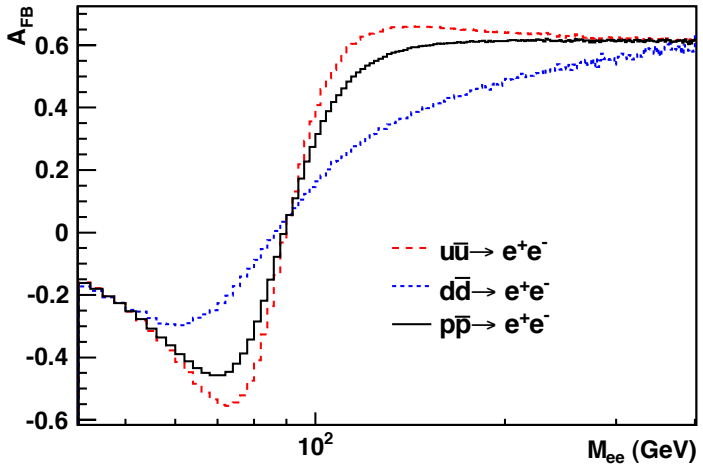
Source	$\Delta\sin^2\theta_w$
Statistical	0.00080
Systematics	0.00061
PDF	0.00048
EM scale/resolution	0.00029
MC statistics	0.00020
EM efficiency	0.00008
Charge mis-id	0.00004
Higher orders	0.00008
Total	0.00102

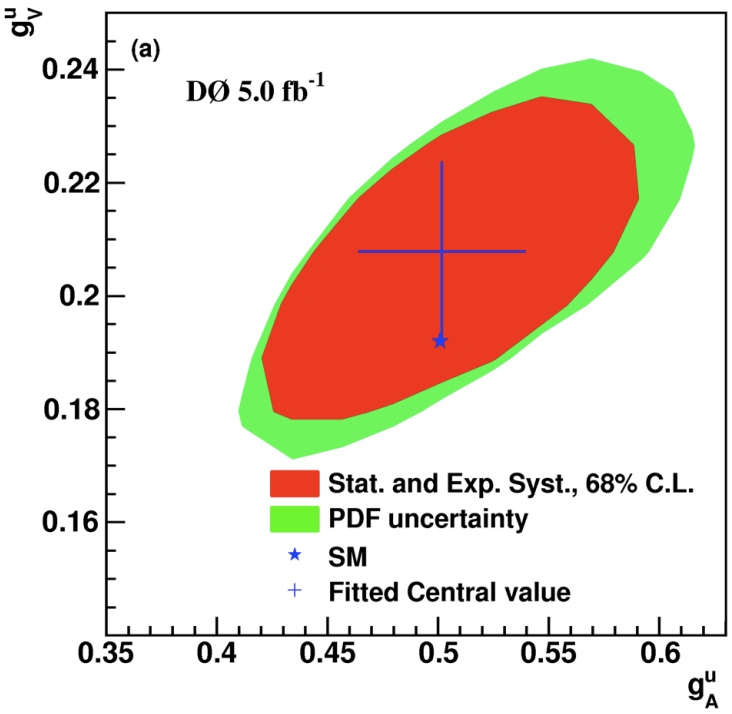


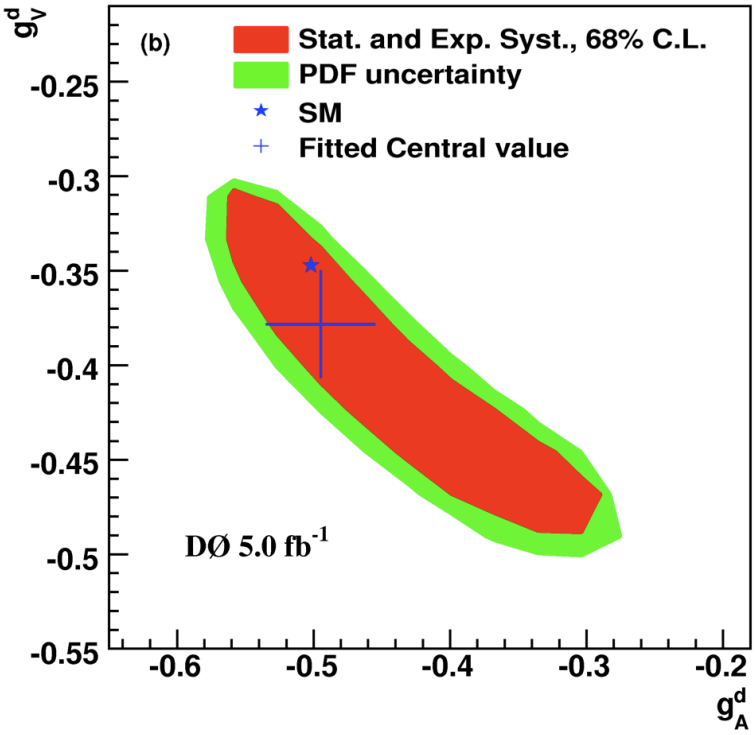


$Z/\Upsilon^* \rightarrow ee$ A_{FB} (DØ)

- Z/Υ^* mostly from $u\bar{u}$ and $d\bar{d}$ annihilation
  - Measure the Z-u and Z-d couplings.
- Good agreement with SM.
  - Most precise measurement of these parameters.







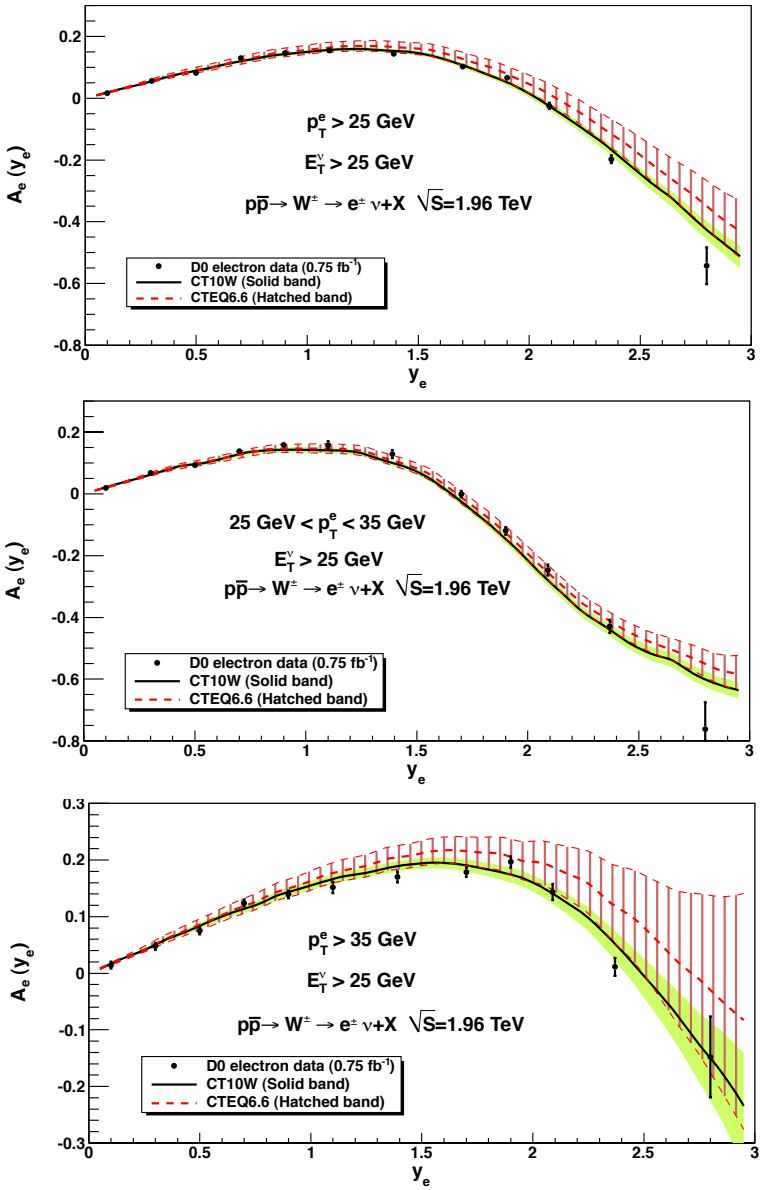
Conclusions

- Rich programme of W and Z measurements from Tevatron.
- Complementarity with LHC.
- Huge event samples.
- Many of these analyses will be updated with the final Tevatron dataset, and improvements in techniques.

Backup slides

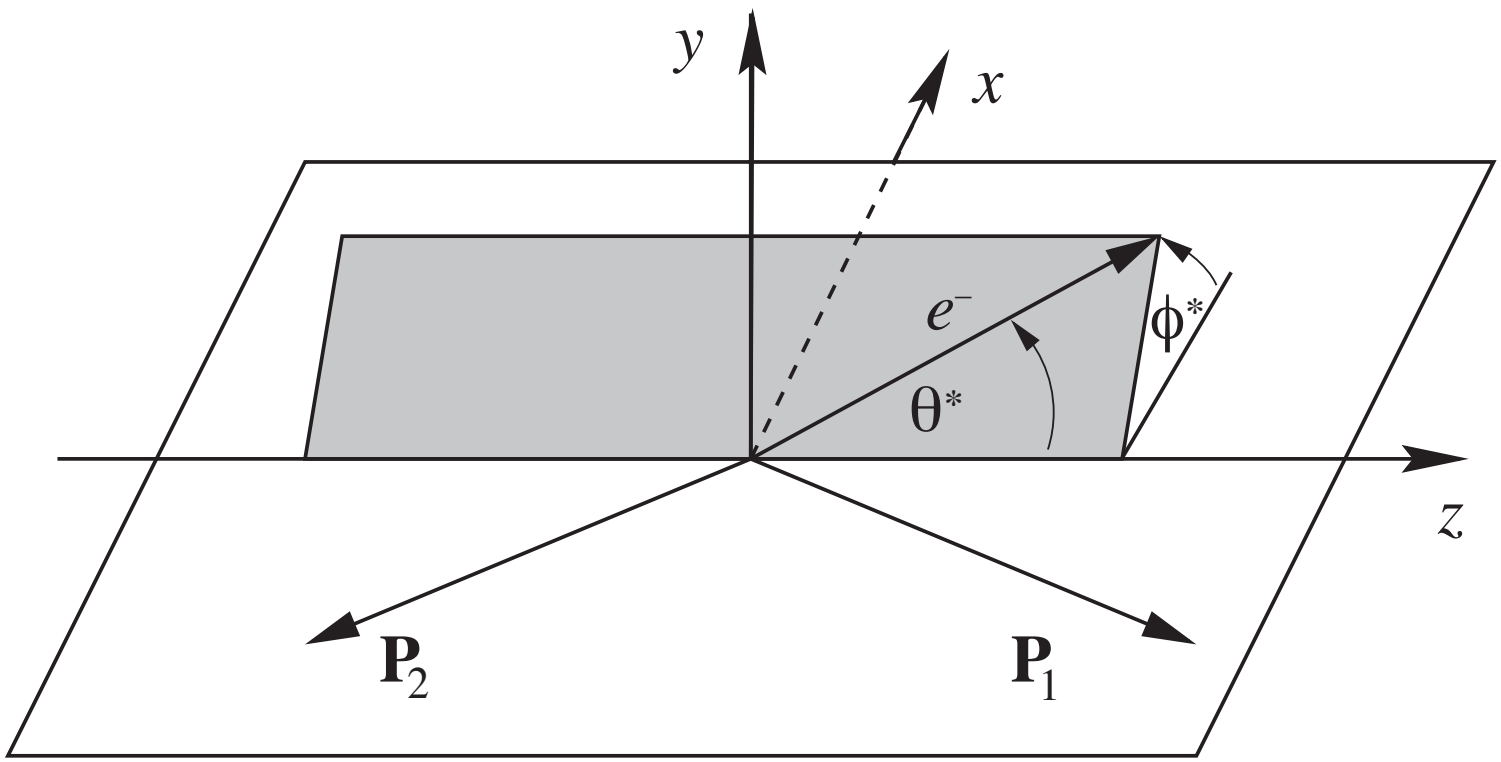
W charge asymmetry puzzle

- CDF W charge asymmetry agrees with pQCD
- DØ lepton charge asymmetry disagrees with pQCD
- CDF lepton charge asymmetry agrees with DØ
- Recent study by CTEQ collaboration
  - Soft gluon resummation and higher order (NLO → NNLO) effects are important.
  - PDFs can be made to fit the W and lepton charge asymmetries, but tension with NMC and BCDMS NC DIS data on proton/D targets.



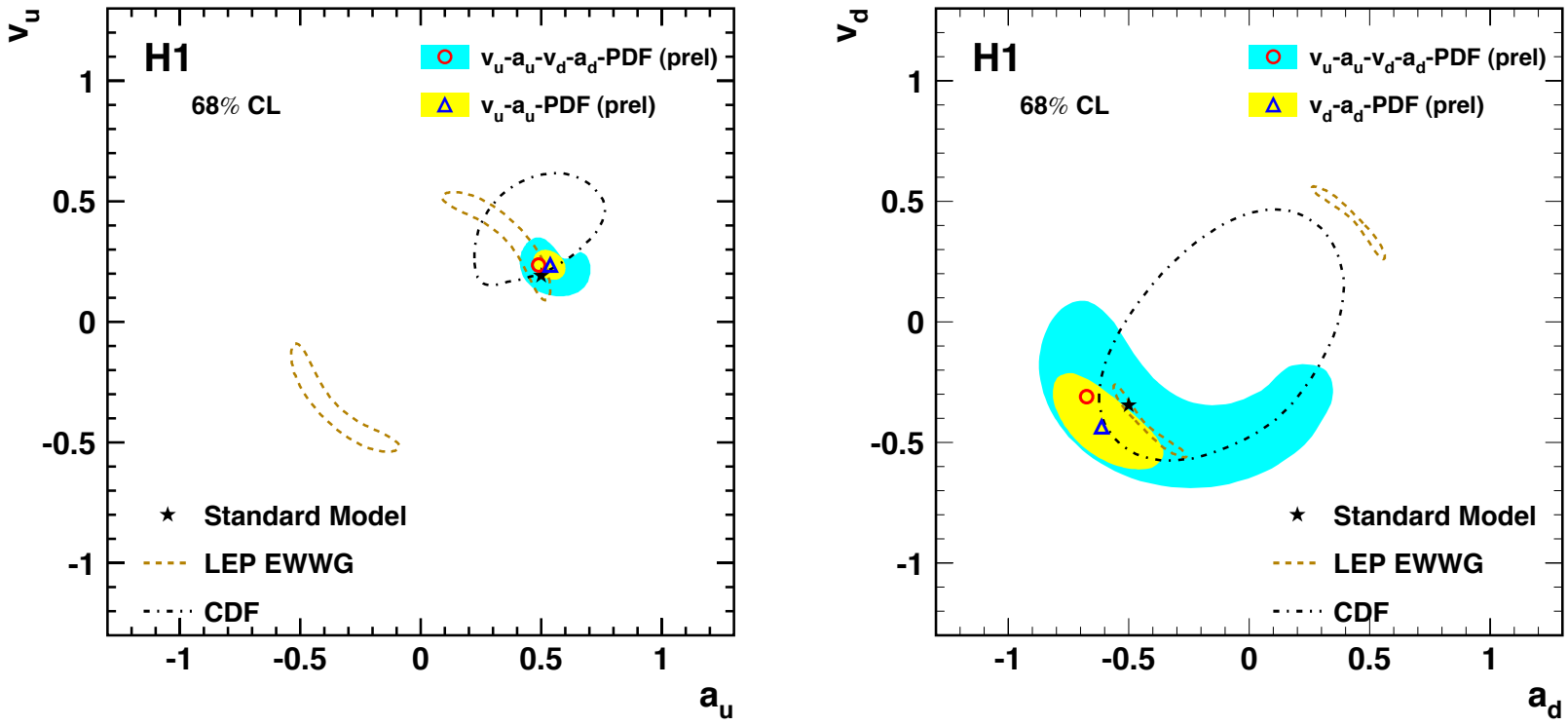
M. Guzzi et al., CT10 parton distribution functions and other developments in the global QCD analysis, arXiv: 1101.0561v1[hep-ph] (2010).

Collins Soper frame



J. C. Collins and D. E. Soper, Phys. Rev. **D 16**, 2219 (1977).

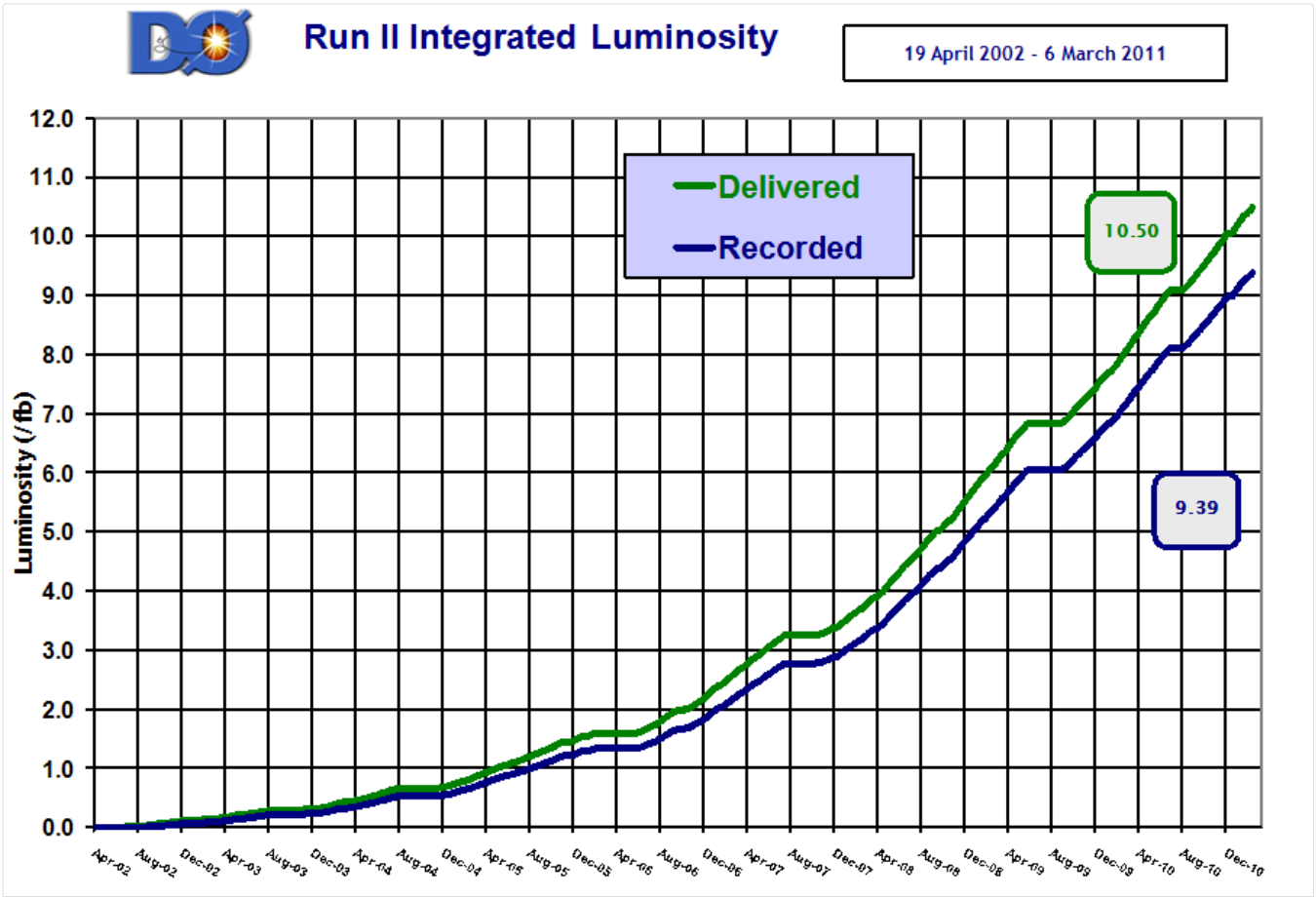
Z- light quark couplings



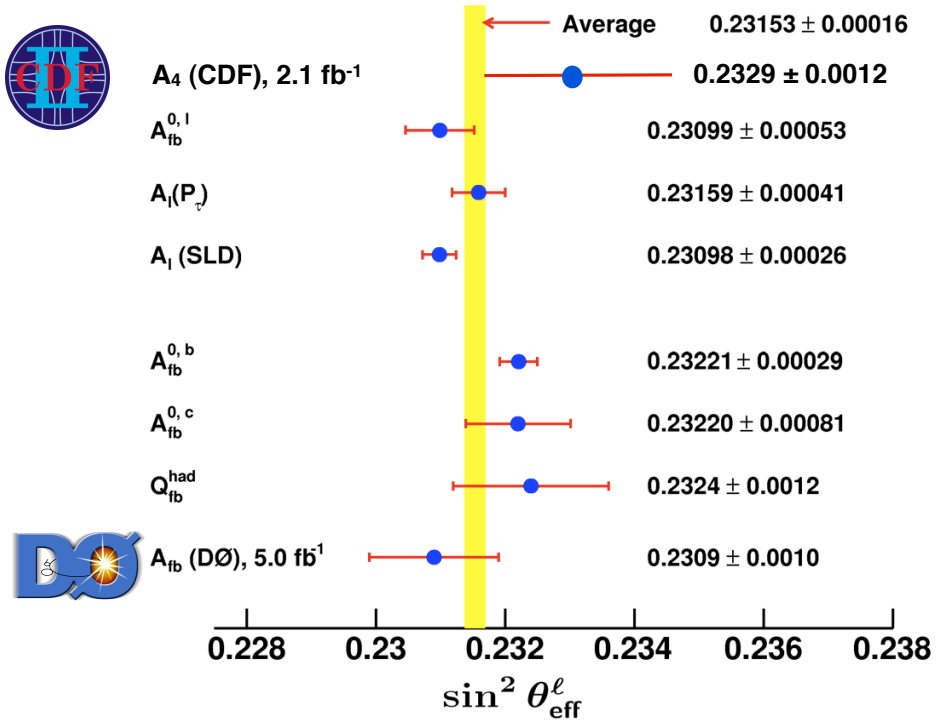
H1 Collaboration, Combined Electroweak and QCD Fit of Inclusive Neutral and Charged Current Data with Polarized Lepton Beams at HERA, **H1prelim-10-042** (2010).

Tevatron luminosity

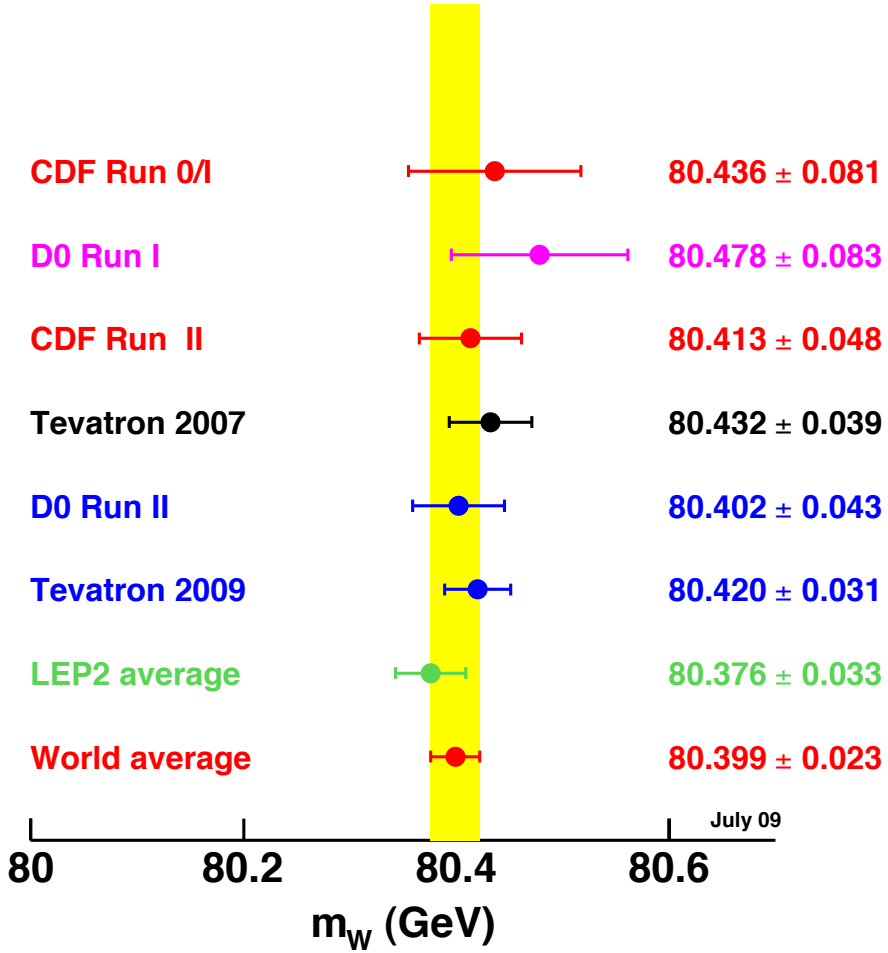
- More than 9 fb^{-1}.
- 12 fb^{-1} expected by September 2011



$\sin^2\theta_w$ comparison

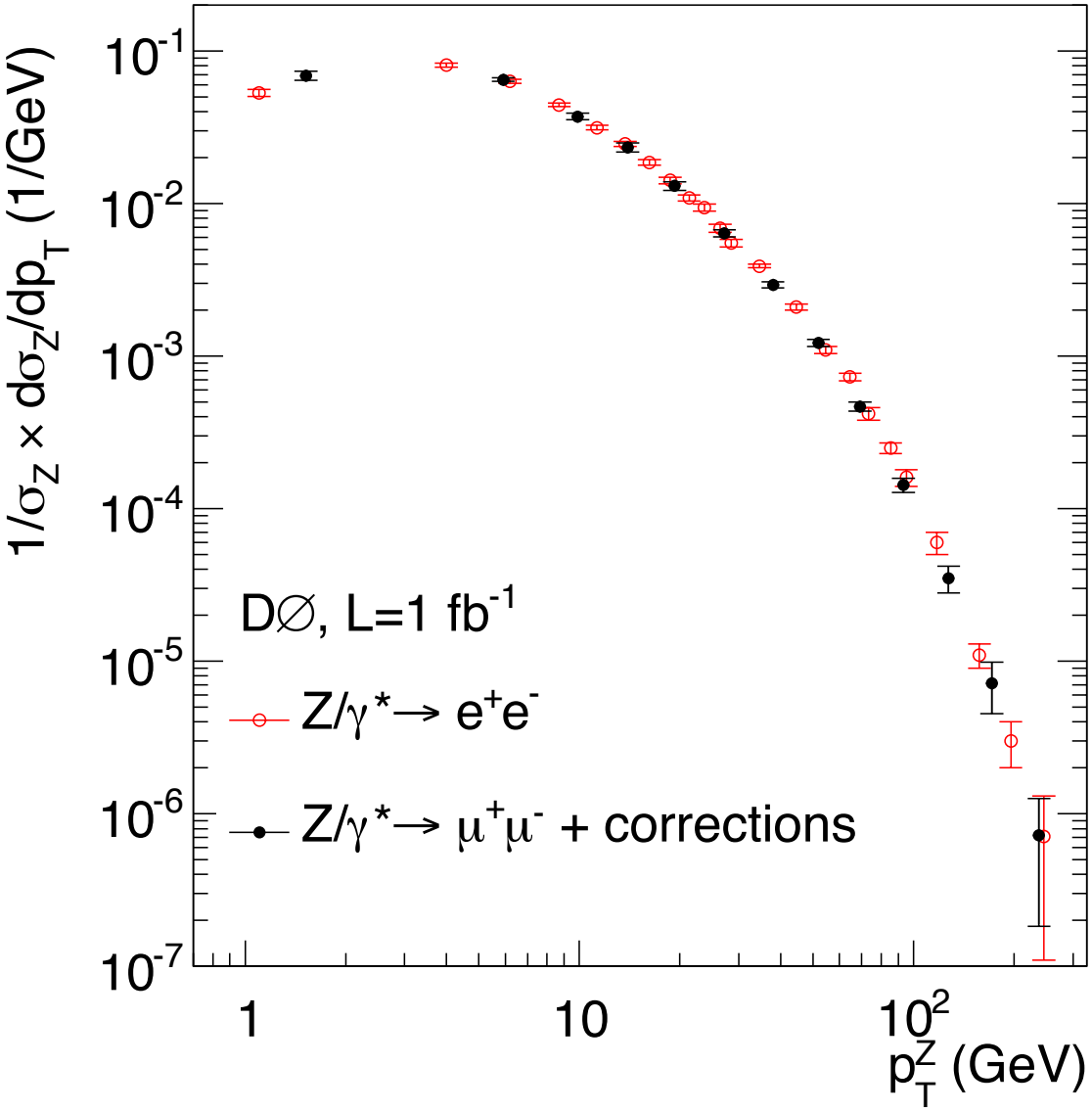


W mass



- Already better precision than LEP
- Expect ~25 MeV uncertainty per Tevatron experiment in next round.

DØ Z p_T (ee vs μμ)



CDF σ(Z/Υ*)

Model	*Total cross section*
CTEQ5L(LO)	183.3
MRST2001E(NLO)	$241.0^{+2.8}_{-3.4}$
MRST2004(NLO)	241.2
MSTW2008E(NLO)	$242.6^{+4.6}_{-5.5}$
CTEQ6.1M(NLO)	$236.1^{+9.3}_{-9.2}$
CTEQ6.6M(NLO)	$238.7^{+7.1}_{-7.0}$
MRST2006E(NNLO)	$251.6^{+2.8}_{-3.1}$
MSTW2008E(NNLO)	$248.7^{+5.1}_{-4.0}$
Data	$256.6 \pm 0.7 \pm 2.0 \pm 15.4$