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A measurement of the muon charge asymmetry from W boson decays

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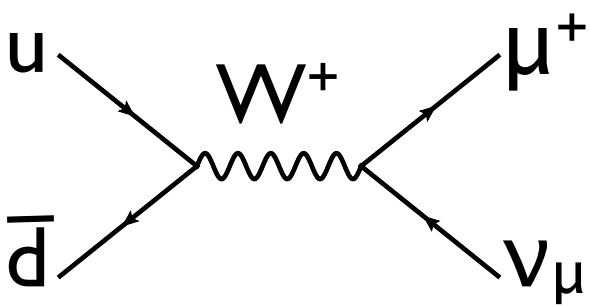
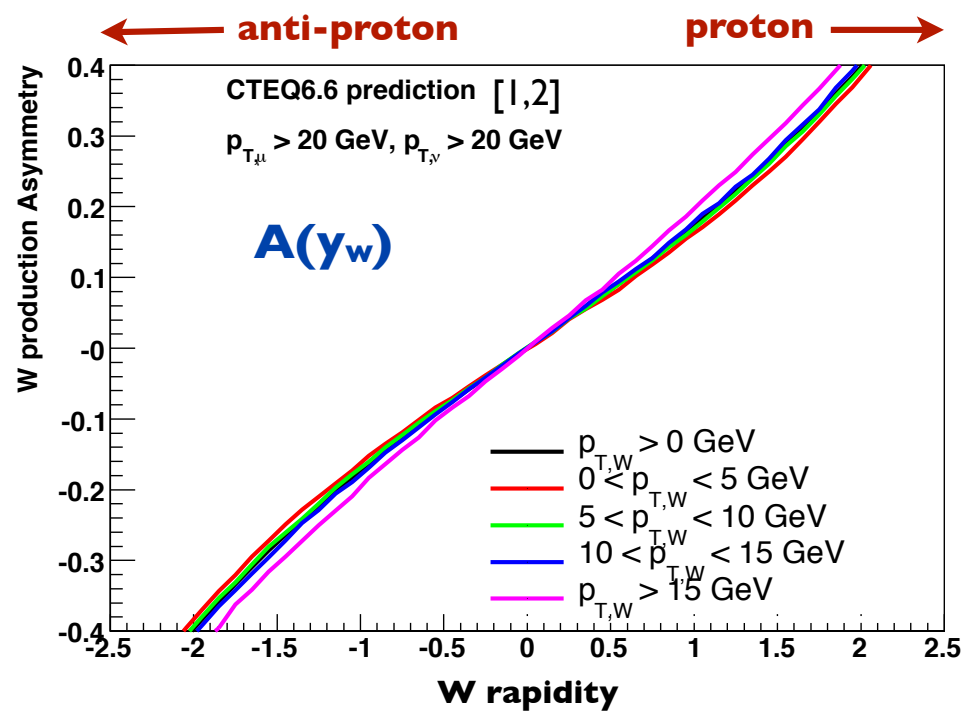
W production at the Tevatron

- In proton-antiproton collisions, W production is mostly valence u and d quark annihilation.
  - On average, u quarks carry more of the proton(anti-proton) momentum, than d quarks.
- Results in a production asymmetry, $A(y_w)$.
  - $W^+(W^-)$ are boosted along the proton(anti-proton) direction.
- The W rapidity (y_w) cannot be measured directly, due to the unknown p_z of the ν.



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



[1] C. Balazs, C. P. Yuan, Phys. Rev. D 56, 5558-5583 (1997).
[2] P. M. Nadolsky et al., Phys. Rev. D 78. 013004 (2008)

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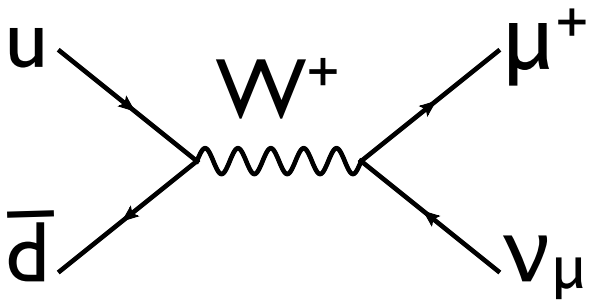
- Results in a production asymmetry, $A(y_W)$.
  - $W^+(W^-)$ are boosted along the proton(anti-proton) direction.
- The W rapidity (y_W) cannot be measured directly, due to the unknown p_z of the ν.
  - Measure instead the muon charge asymmetry, $A(\eta)$, which folds in the V-A decay asymmetry.



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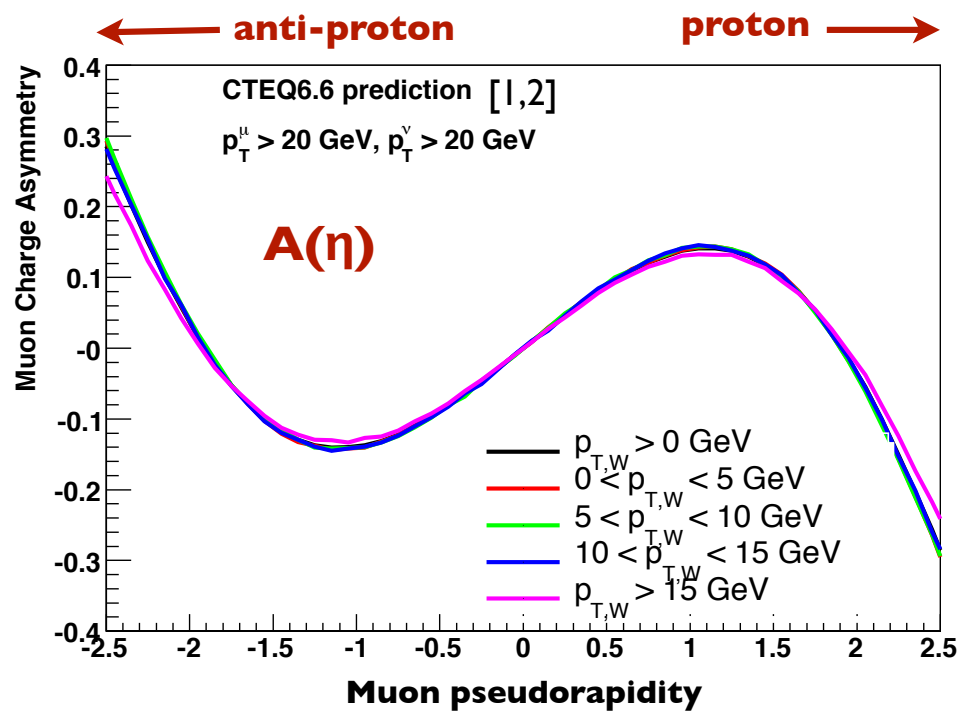

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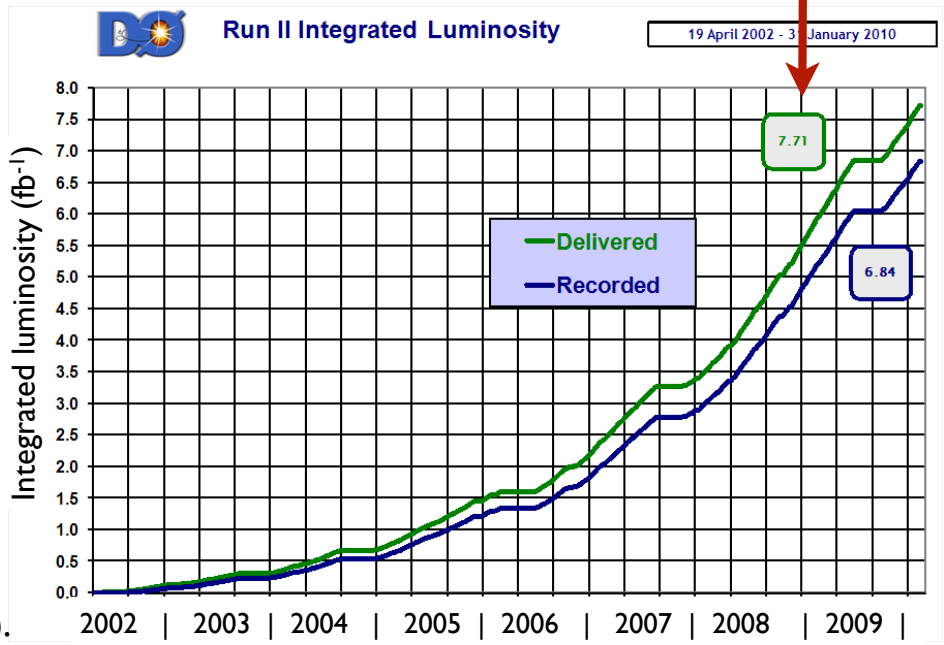
Motivations and earlier measurements

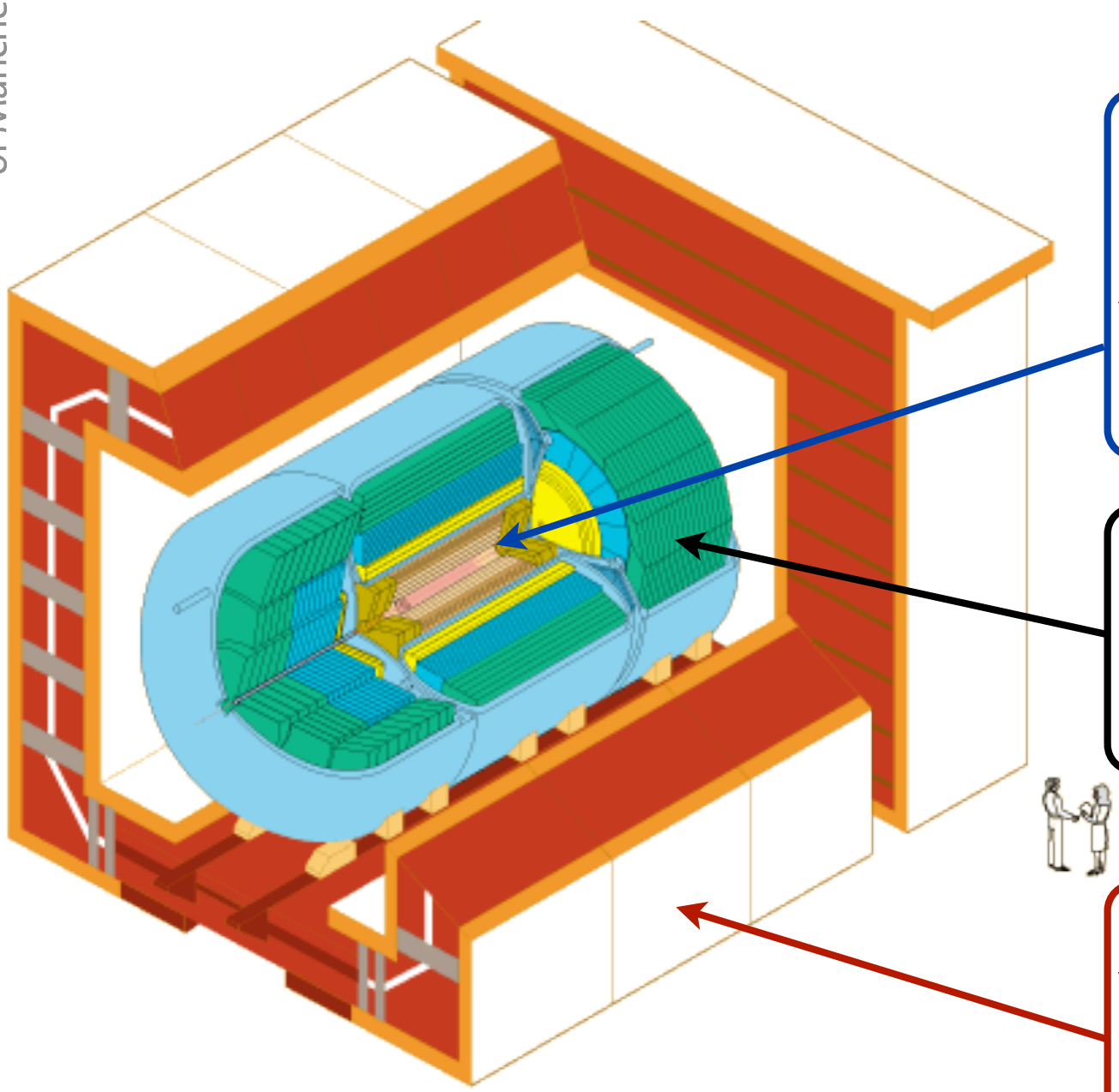
- This measurement constrains the u and d quark PDFs,
- Leading to increased precision on cross section predictions.
  - E.g. predictions for Higgs and NP production, and many of their backgrounds.
  - W mass measurement (current σ_{PDF} ~ 13 MeV[1]).
- Previous lepton asymmetry measurements.
  - Muon channel from DØ with 300 pb^{-1} [2].
  - Electron channel from DØ with 750 pb^{-1} [3].
- Alternative W asymmetry measurement.
  - CDF $W \rightarrow e\nu$ asymmetry using 1.0 fb^{-1} [4].

This analysis (4.9 fb^{-1})



[1] DØ Collaboration, V. M. Abazov et al., Phys. Rev. Lett. 103 141801 (2009).
[2] DØ Collaboration, V. M. Abazov et al., Phys. Rev. Lett 101 211801 (2008).
[3] DØ Collaboration, V. M. Abazov et al., Phys. Rev. D 77 011106 (2008).
[4] CDF Collaboration, T. Aaltonen et al., Phys. Rev. Lett. 102, 181801 (2009).

The DØ detector



Central tracker

Inner silicon tracker covers the region $|\eta|<3$, and scintillating wire tracker covers $|\eta| < 2$. Both are inside a 2T solenoidal field, whose polarity is regularly flipped.

Calorimeter

Liquid Argon and uranium, with excellent energy resolution, and angular coverage.

Muon system

Wire chambers and trigger scintillators cover up to $|\eta_{det}| < 2$. 1.8 T toroidal magnet for momentum measurement.

[1] The DØ Collaboration, V. M. Abazov et al., Nucl. Instr. Meth. A 565 463-537 (2006).

Event selection

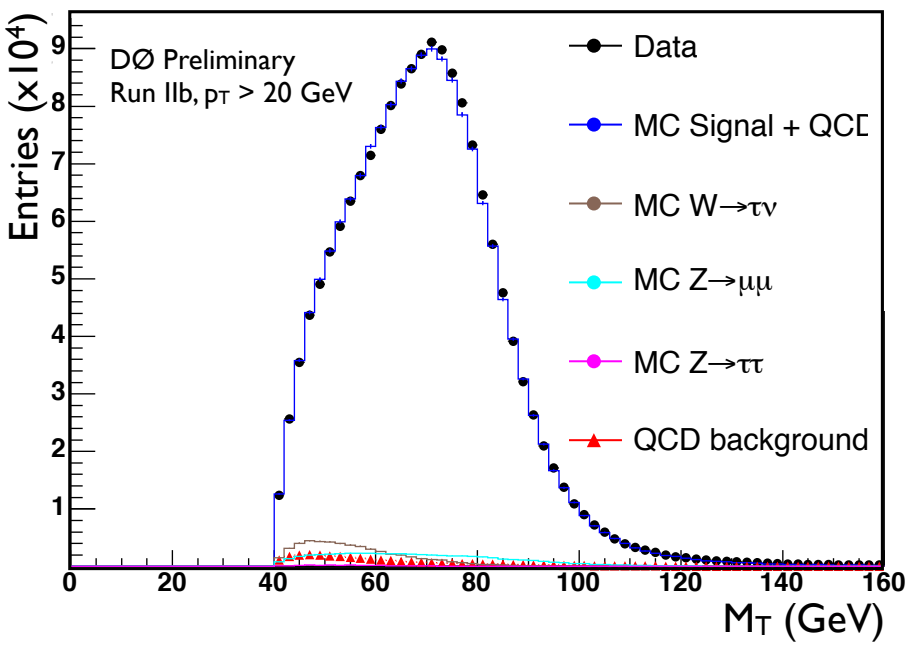
- Select a high statistics background free sample of $W \rightarrow \mu\nu$ events.
- Events are required to have fired a single muon trigger and
  - contain one isolated muon* with $p_T > 20$ GeV,
  - event missing transverse energy, $\not{E}_T > 20$ GeV,
  - transverse mass, $M_T > 40$ GeV.
- 1.7 M events after selection.

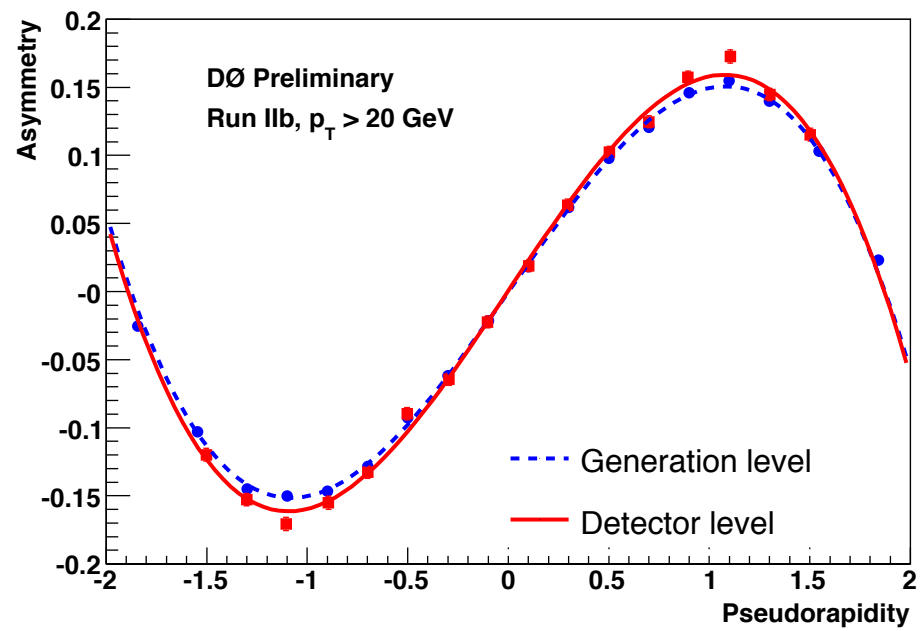
*Events with a second back-to-back muon are vetoed, in order to control backgrounds from $Z/\gamma^* \rightarrow \mu\mu$ events.
Muons are isolated in the calorimeter and tracker to reject muons from heavy flavour jet decays, and are required to be in coincidence with the bunch crossing to reduce contamination from cosmic ray muons.

$$M_T = \sqrt{2p_T^{\mu}p_T^{\nu}(1-\cos(\Delta\phi))}$$

Signal + background simulation

- The measured muon charge asymmetry must be corrected for
  - backgrounds, and detector resolution and acceptance.
- Signal and electroweak backgrounds are simulated by Monte Carlo event generators.
  - Events are generated using PYTHIA, and passed through a GEANT based detector simulation, and scaled to higher order predictions.
  - The simulation is corrected for trigger efficiency and differences compared to data in various offline efficiencies, and central tracker momentum resolution.
- Multijet backgrounds are estimated from data.



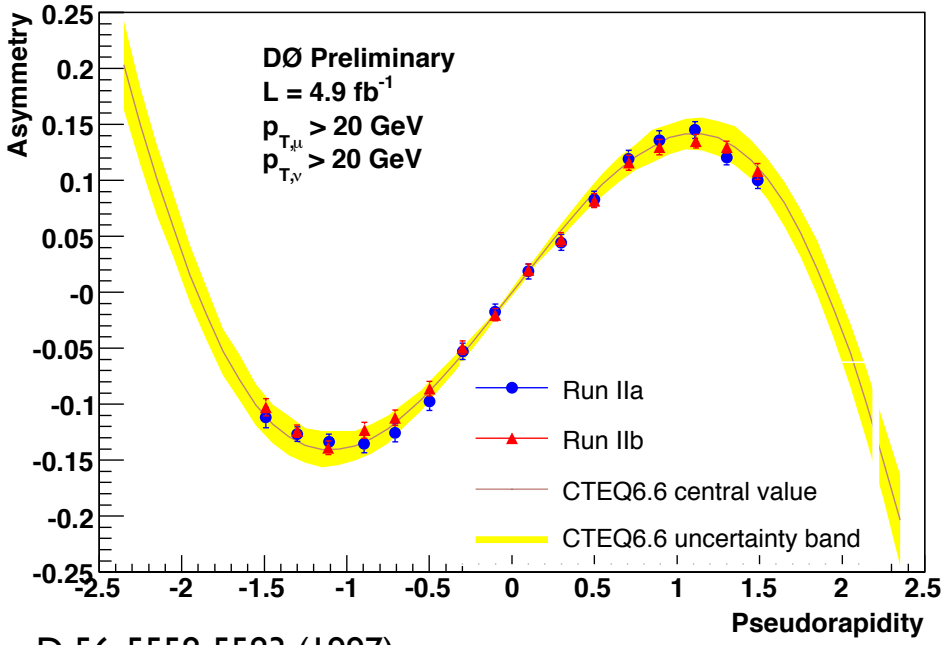


Systematic uncertainties

- In such a charge asymmetry measurement, we benefit from the cancelation of many systematic uncertainties.
  - E.g. luminosity and absolute efficiencies, since this is a ratio measurement.
- Nevertheless, the dominant sources of systematic uncertainty are
  - the modelling of electroweak, and multijet backgrounds,
  - and parameterisation of the detector corrections.
- Apart from the highest η_μ bins, $\sigma_{stat} \approx \sigma_{syst}$.

Results

- The data are compared to an NLO prediction from ResBos[1], with QED radiative corrections from PHOTOS[2], and CTEQ 6.6 PDFs[3].
- Assuming A(η) = -A(-η), we can "CP fold" the asymmetry to increase statistics.



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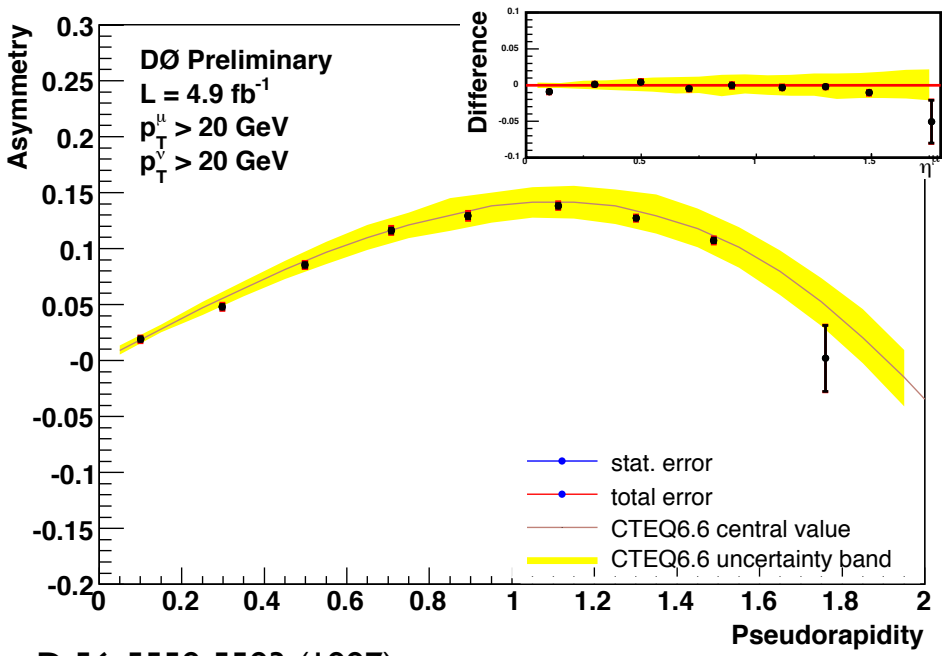
- Apart from the highest η_μ bin, the data are more precise than the prediction.
  - The data are well described by the prediction.



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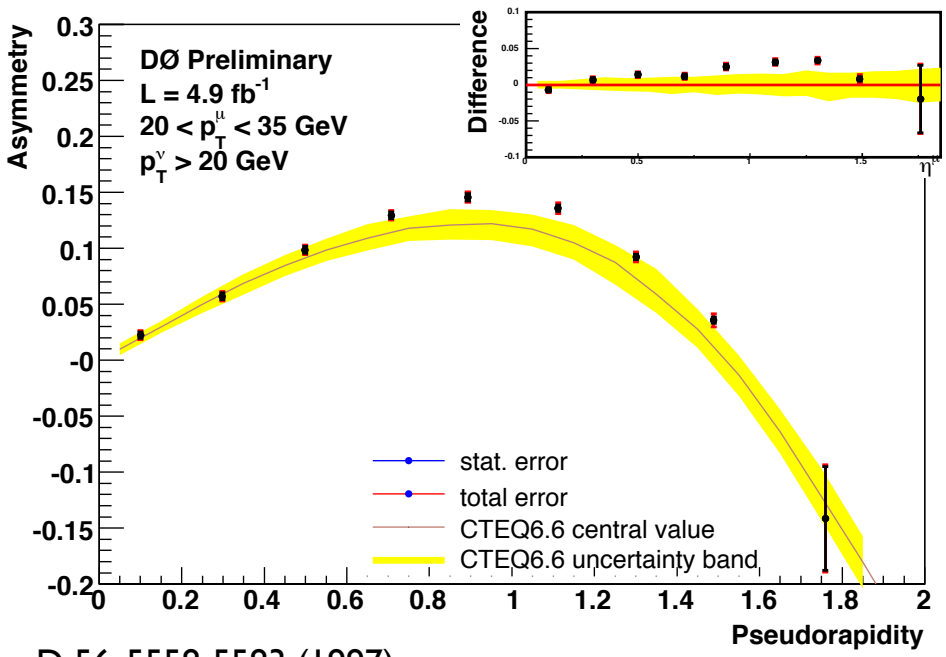
  - The data are poorly described by the prediction for $20 < p_T(\mu) < 35$ GeV.



V-A decay asymmetry dominates at low $p_T(\mu)$

[1] C. Balazs, C. P. Yuan, Phys. Rev. D 56, 5558-5583 (1997).
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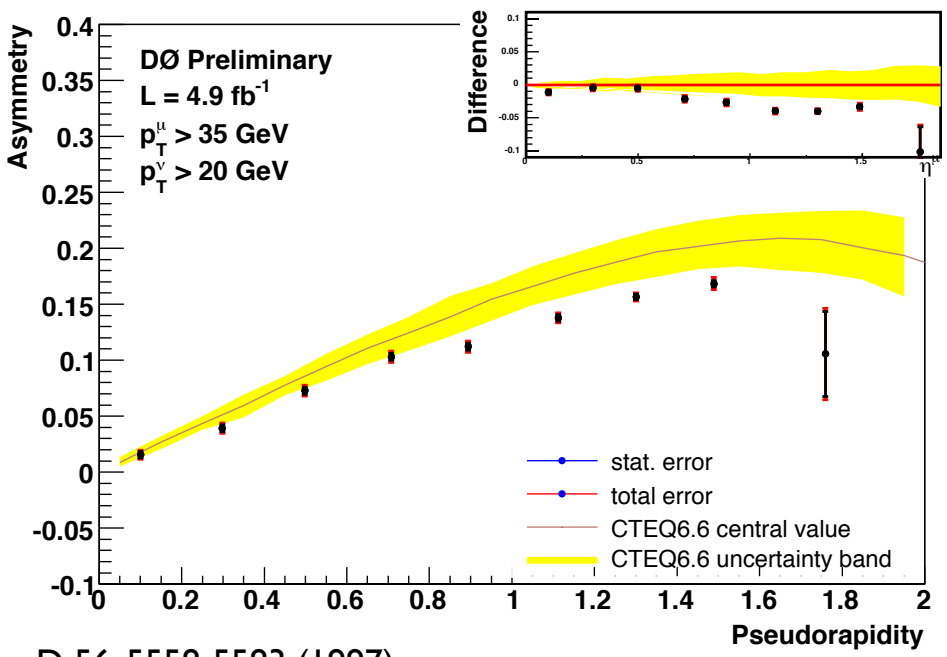
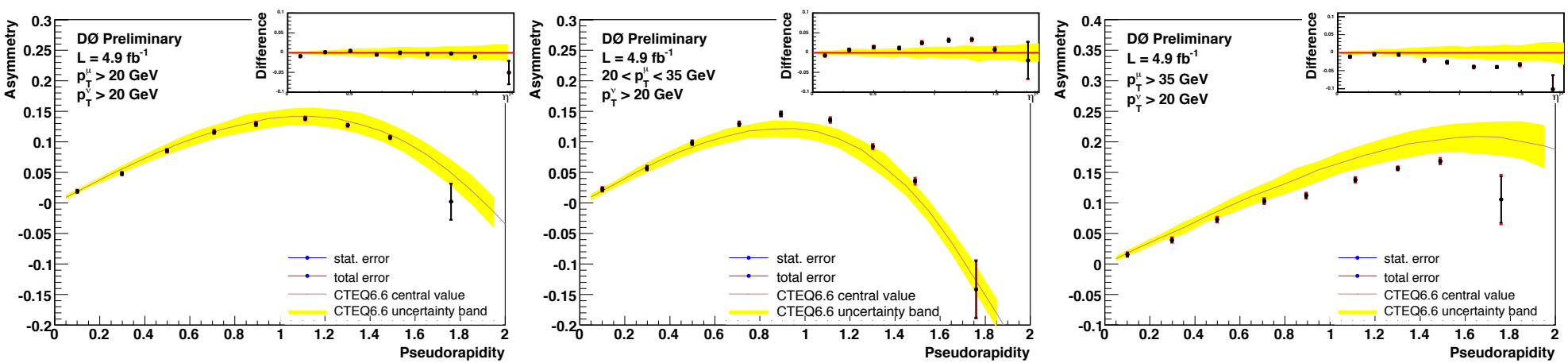


Production asymmetry dominates at high $p_T(\mu)$

[1] C. Balazs, C. P. Yuan, Phys. Rev. D 56, 5558-5583 (1997).
[2] E. Barberio, Z. Was, Comp. Phys. Comm. 79, 291 (1994).
[3] P. M. Nadolsky et al., Phys. Rev. D 78. 013004 (2008)

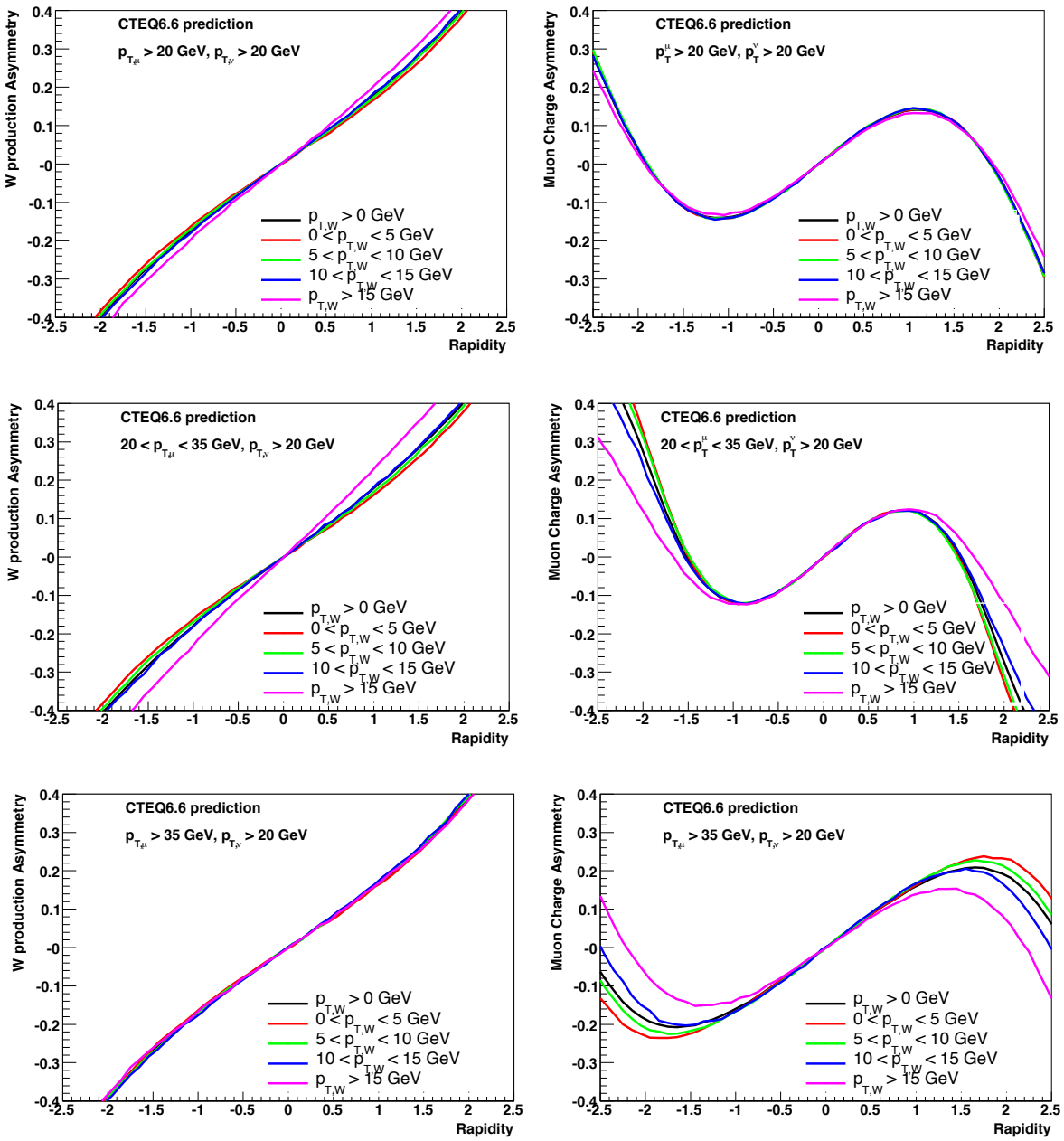
Conclusions

- DØ has measured the muon charge asymmetry with 4.9 fb^{-1} of data.
  - Most precise measurement of this quantity, using the largest data set.
- The data are compared to NLO predictions with CTEQ 6.6 PDFs.
  - Data are well described by the prediction for inclusive $p_T(\mu)$,
  - but poorly described when split into two bins of $p_T(\mu)$.
- Apart from the highest η_μ bin, the data are more precise than the prediction.
  - Will provide tight constraints on the u and d quark PDFs,
  - which will benefit the entire hadron collider physics spectrum!



Backup slides

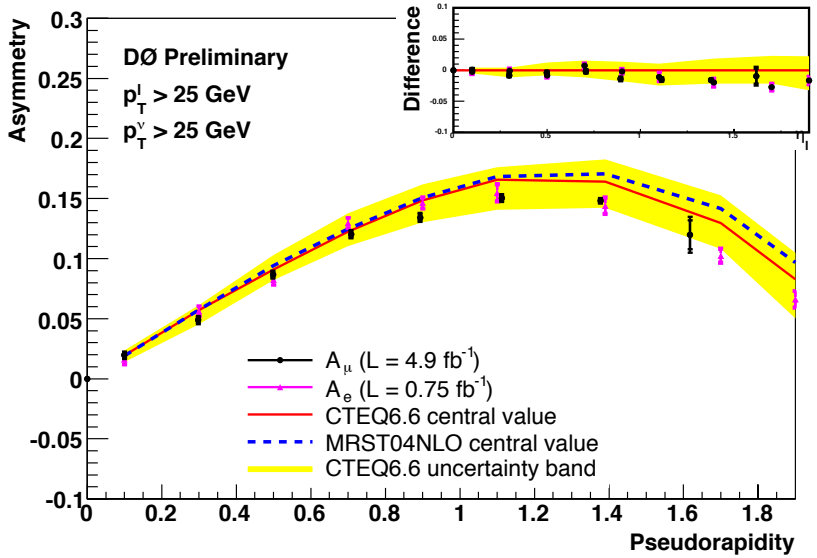
Binning in muon p_T

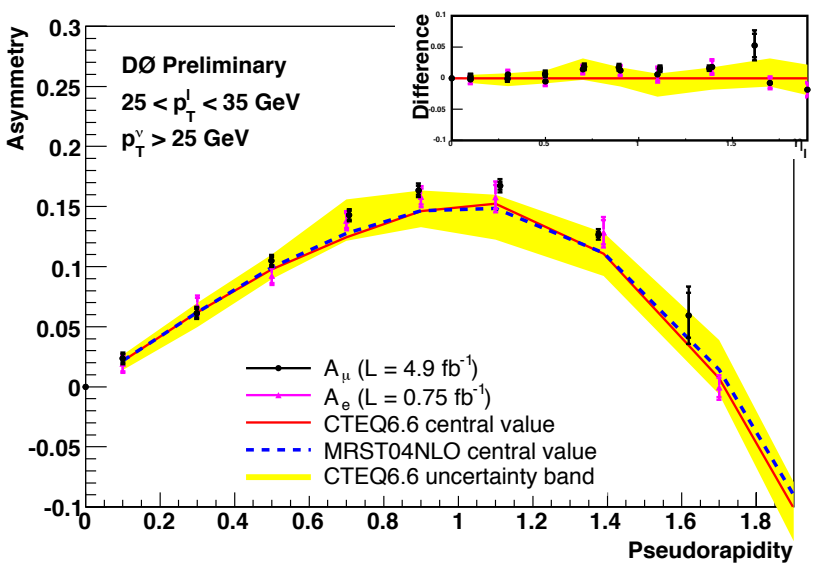


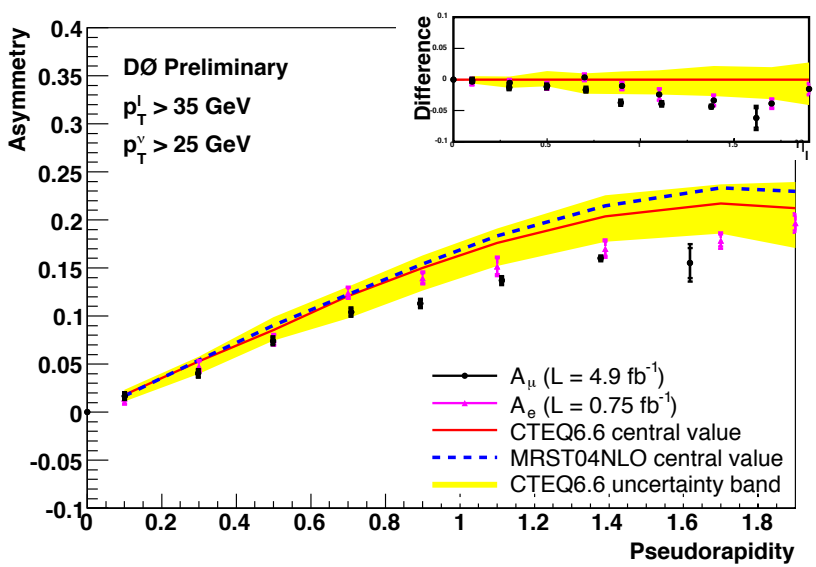
- Low p_T and high η_μ
  - V-A asymmetry dominates
- High p_T and low η_μ
  - W asymmetry dominates
- Further dependence on $p_T(W)$

Compare with $A(\eta_e)$ and MRST PDFs

- Compare with published DØ electron charge asymmetry[1]
- Comparison is complicated by different binning in η_μ, but the two measurements are in reasonable agreement.
- CTEQ6.6 and MRST04NLO predictions agree very well.



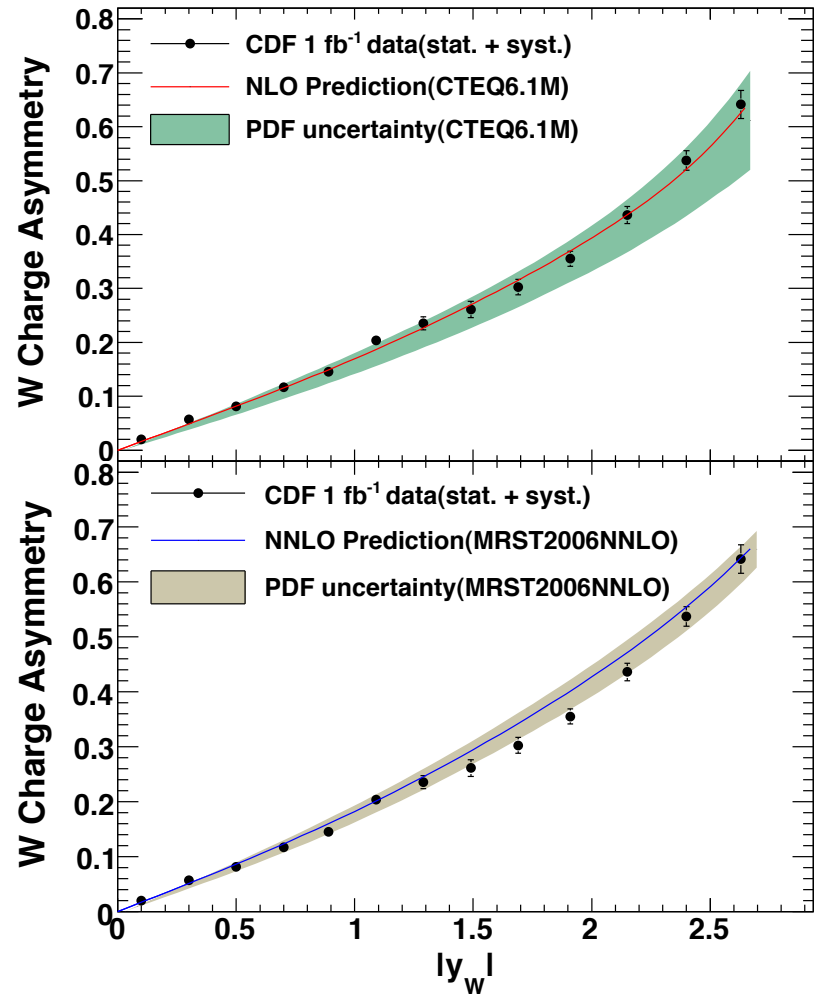




[1] DØ Collaboration, V. M. Abazov et al., Phys. Rev. Lett. 103 141801 (2008).

CDF measurement

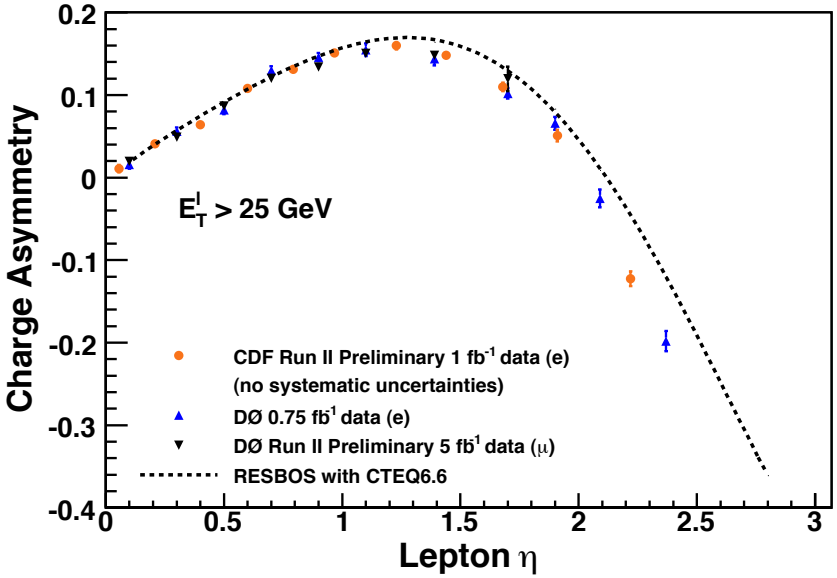
- By constraining the invariant mass of the electron and neutrino to the PDG W mass, the neutrino longitudinal momentum can be determined with a two fold ambiguity.
- This can be resolved statistically, by making assumptions about the V-A coupling of the decay.
- The data agree reasonably well with NLO predictions with CTEQ 6.1m and MRST2006NLO PDFs.

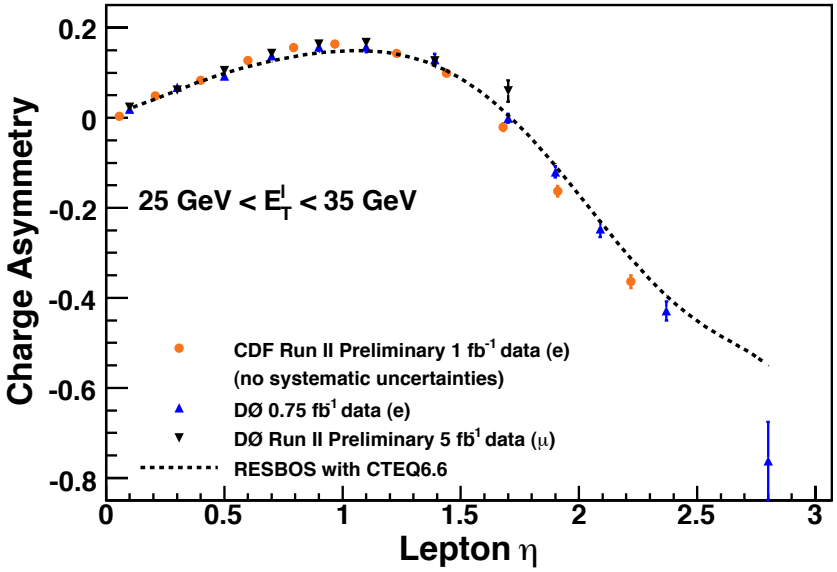


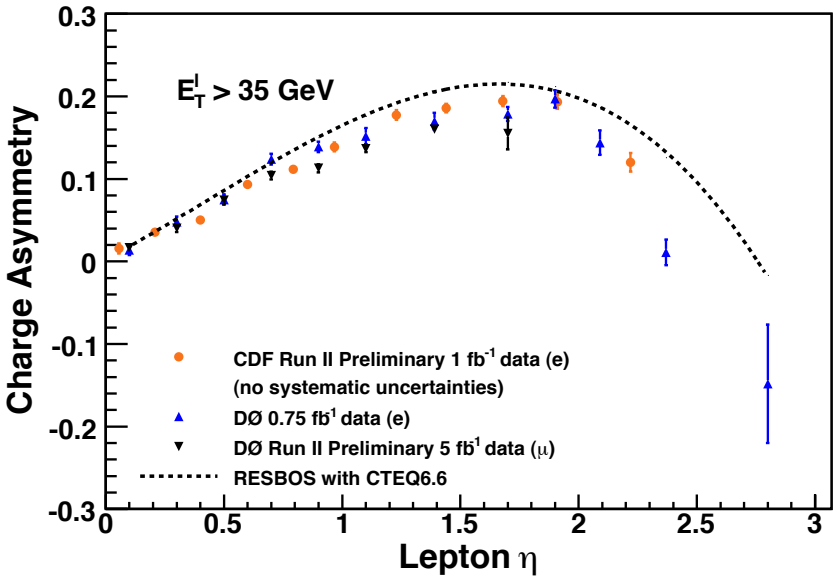
[1] CDF Collaboration, T. Aaltonen et al., Phys. Rev. Lett. 102, 181801 (2009).

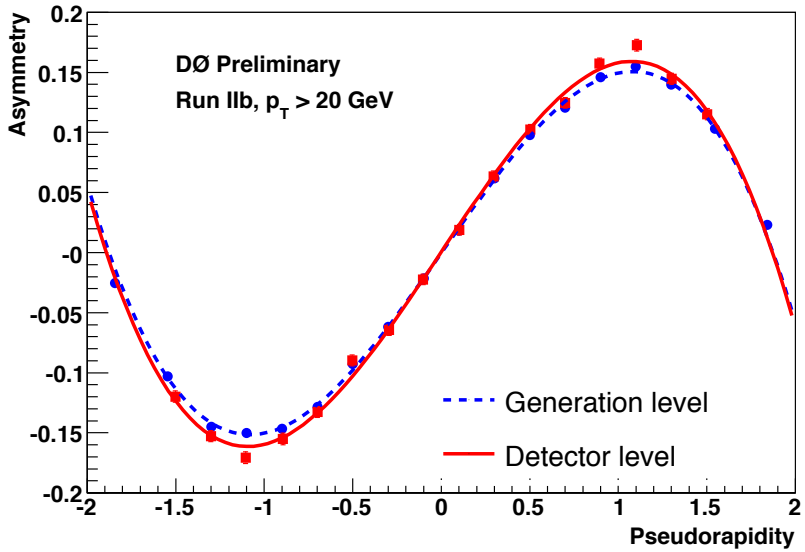
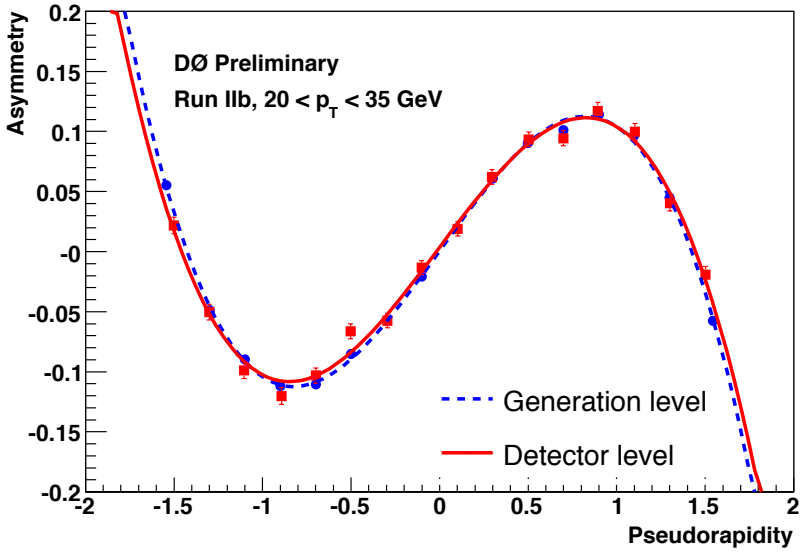
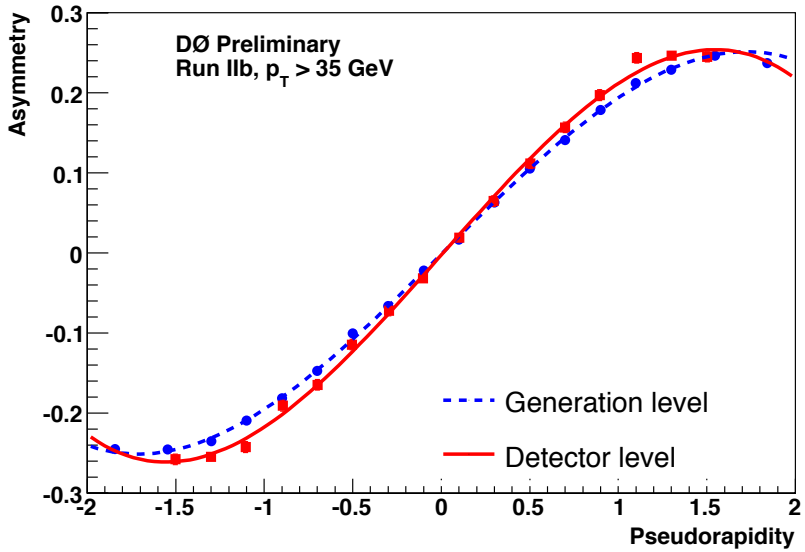
CDF/DØ comparison

- CDF also measured the electron charge asymmetry (without systematics), and find good agreement with the published DØ data.
- Neither agree with NLO prediction, when binned in $p_T(\mu)$.







Detector corrections

- Generator level and detector level asymmetries are parameterised, and the data is corrected by the ratio.