Measurements of W Charge Asymmetry

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On behalf of DØ
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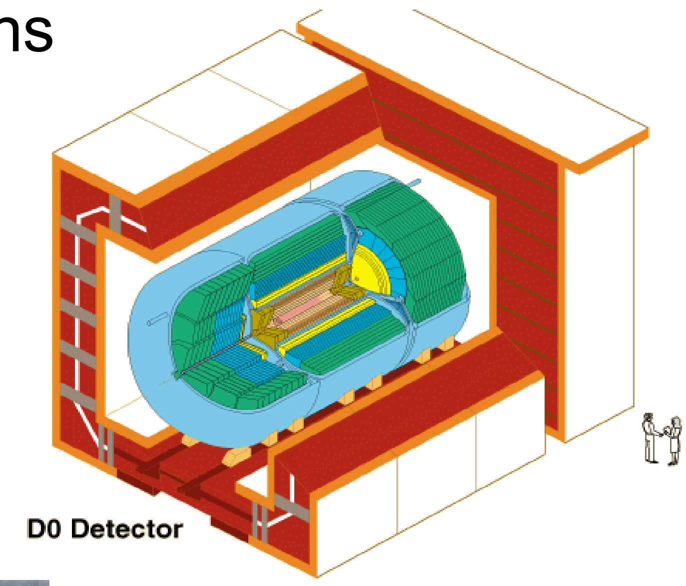
Overview

- DØ detector review
- Why W charge asymmetry?
- Two versions: W rapidity and electron rapidity
- Common analysis selection
- Procedures
- Results

- For comparison only, will show CDF W asymmetry using W's to electrons (W rapidity) and DØ $W \rightarrow \mu\nu$ result (lepton rapidity)

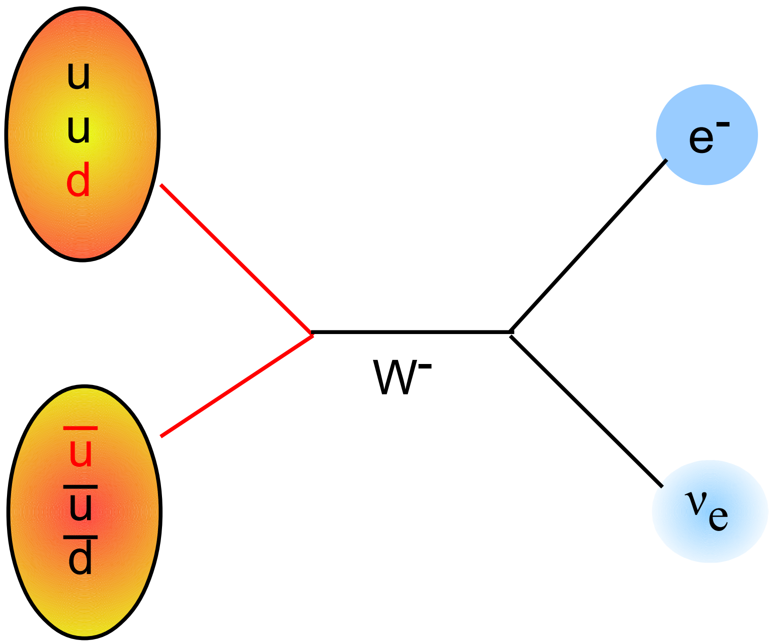
Tevatron and DØ

- Tevatron is 2π km with 1.96 TeV p-$\bar{p}$ collisions
  - Operation ended September 2011
- Analysis uses full data set, 9.7 fb^{-1}
- Detector has inner tracker, magnet, calorimeter and muon system
  - DØ also regularly reverses magnet polarity



Looking into the Proton

- Measurement looks at how many W's (via leptons) there are with positive or negative charge
- Using Tevatron data, gain information about the proton (for PDF's)
  - W^+ is more likely to be in the p direction and W^- is more likely to be in the $\overline{\text{p}}$ direction
- Can also be done at the LHC, but information is different (W mostly from gluons or sea quarks, not valence quarks)

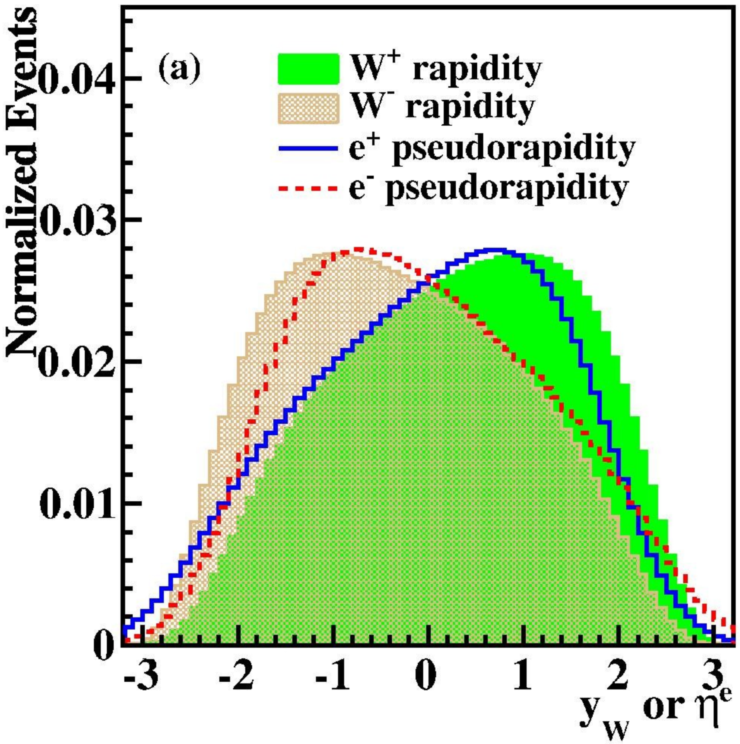


$$A(y_W) = \frac{d\sigma_{W^+}/dy_W - d\sigma_{W^-}/dy_W}{d\sigma_{W^+}/dy_W + d\sigma_{W^-}/dy_W}$$

$$u + \bar{d} \to W^+ \text{ and } \bar{u} + d \to W^-$$

A Tale of Two Methods

- Traditional method, lepton rapidity:
  - Use ratio of difference in the number of charged leptons to total leptons to derive asymmetry
  - V-A structure of W boson decay modifies the asymmetry (increasing uncertainties)
- Newer W rapidity method:
  - Use the difference in number of charged W's directly
  - Missing neutrino p_z requires some creativity to get full W information, assumes W mass value
  - Better +/- separation, lower uncertainties

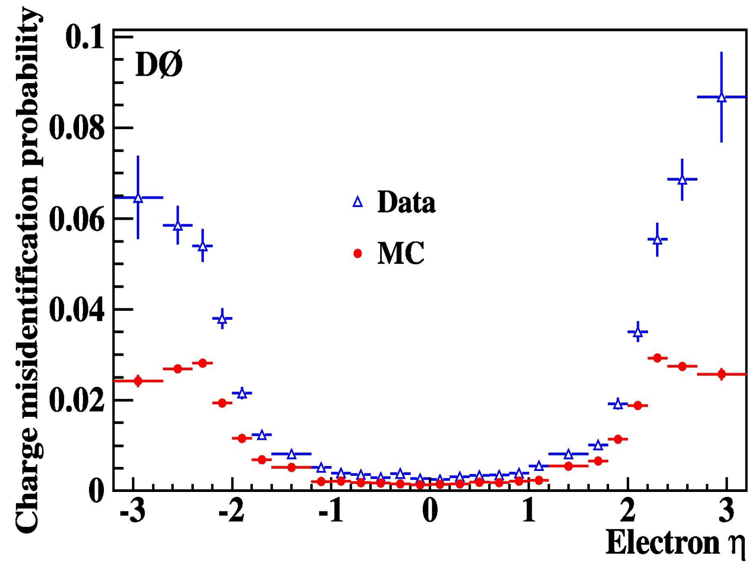


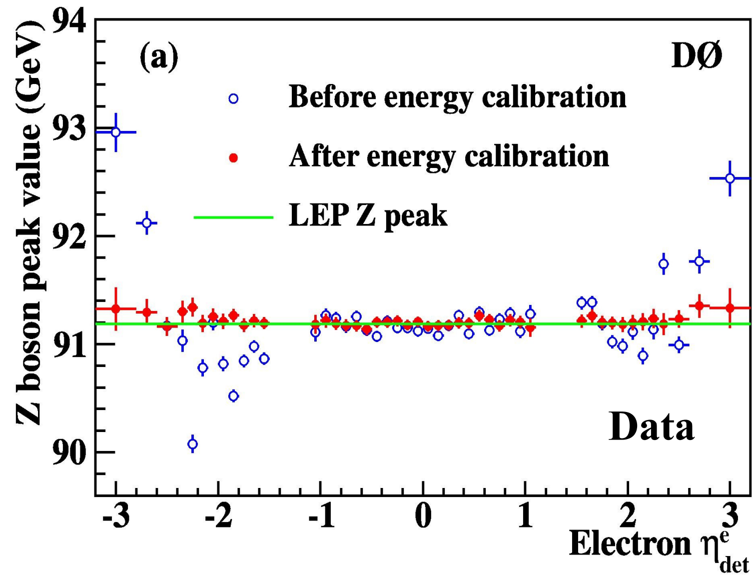
Analysis Selection

- Require exactly one electron
  - Electron is triggered, isolated, most energy in the EM calorimeter, and cluster has track matched to it
  - Electron range (detector limits) is $\eta < |1.1|$ and $|1.5| < \eta < |3.2|$
- Electron $p_T > 25$ but < 100 GeV, missing energy > 25 GeV
- Additional selections include restrictions on the z vertex range, W boson transverse mass, recoil and total calorimeter activity
- Backgrounds include $W \rightarrow \tau\nu$, $Z \rightarrow ee$, $Z \rightarrow \tau\tau$, QCD
  - Biggest background is QCD (4%) but it has no charge asymmetry
- Analysis has several applied efficiencies and corrections including charge mis-ID, electron energy scale, trigger, hadronic response, electron ID efficiency, etc. I'll discuss the first two.

Analysis Corrections

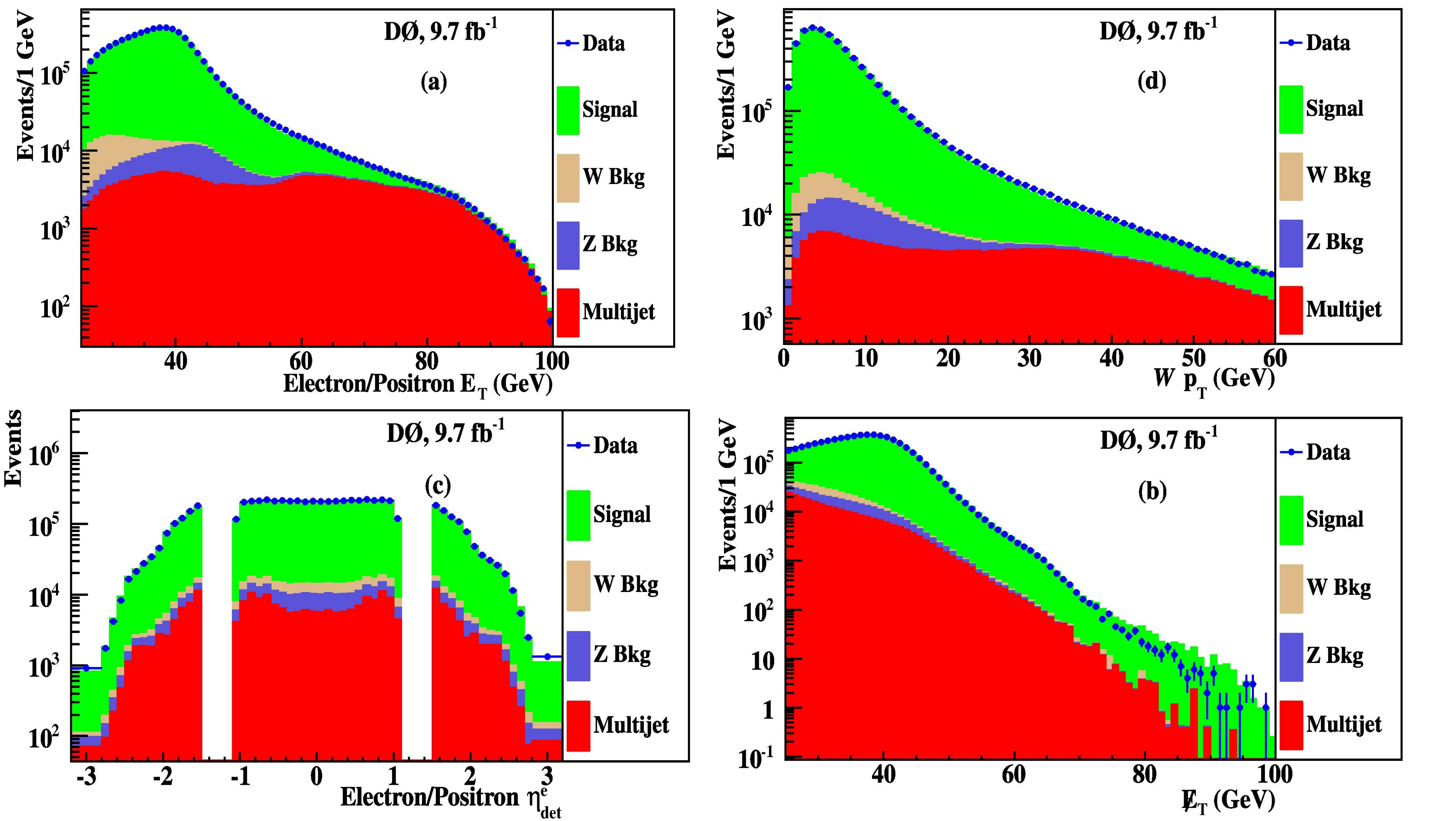
- Charge mis-ID:
  - Tag and probe method with $Z \rightarrow ee$
  - Function of η and electron p_T
  - Similar efficiency in data and MC for central region. In forward region, adjust MC to match data mis-ID using random charge flips
- Electron energy:
  - Background subtracted Z events are fit to determine the mass peak
  - Compare to LEP value and fit for correction parameters iteratively
  - Lepton η, luminosity and calorimeter scalar E_T dependencies





Example Distributions

- Agreement is good after initial selections and corrections



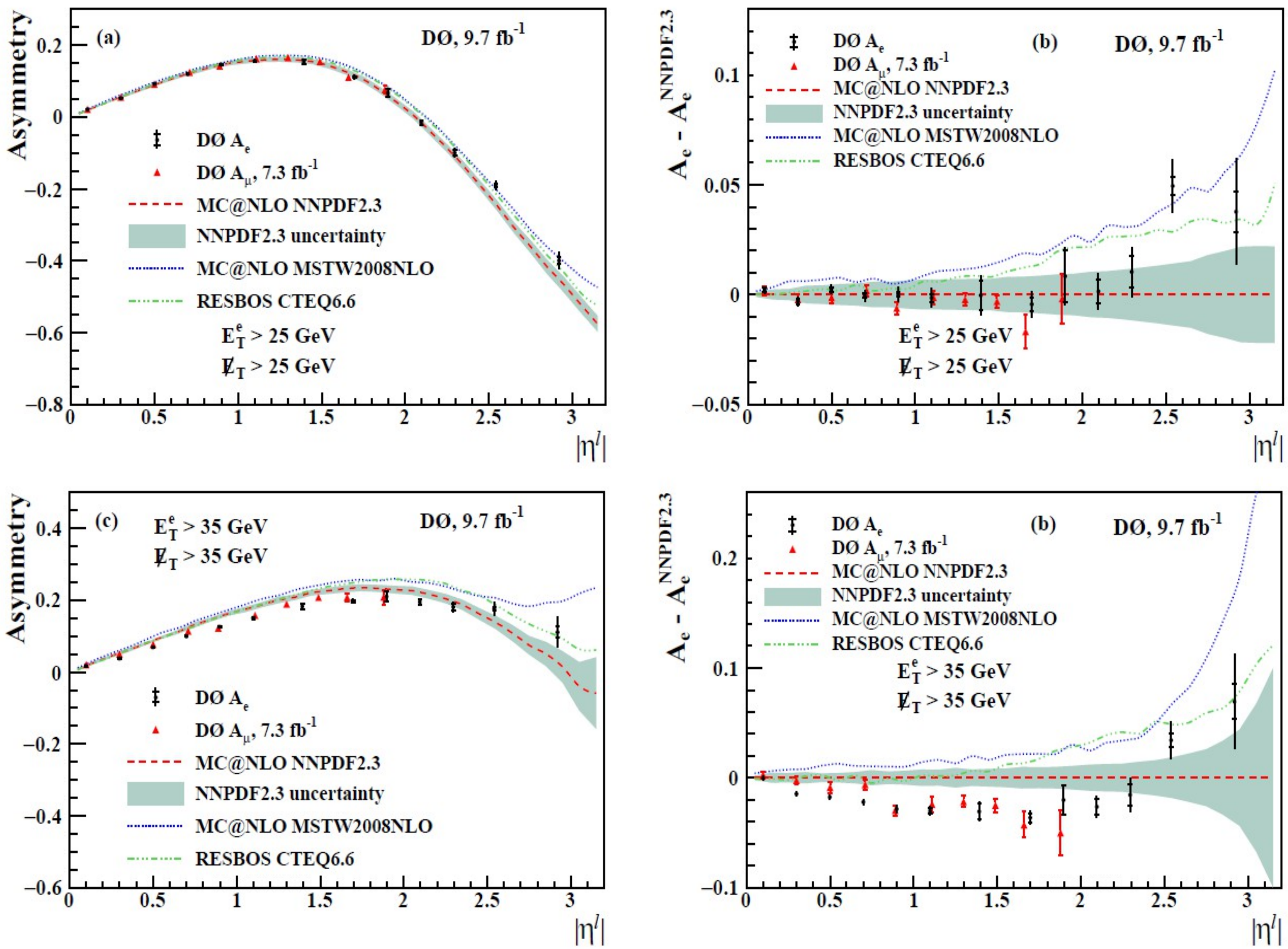
Lepton Asym Details

- Generally speaking, if the W^+ and W^- efficiencies and acceptances are very similar, we can approximate

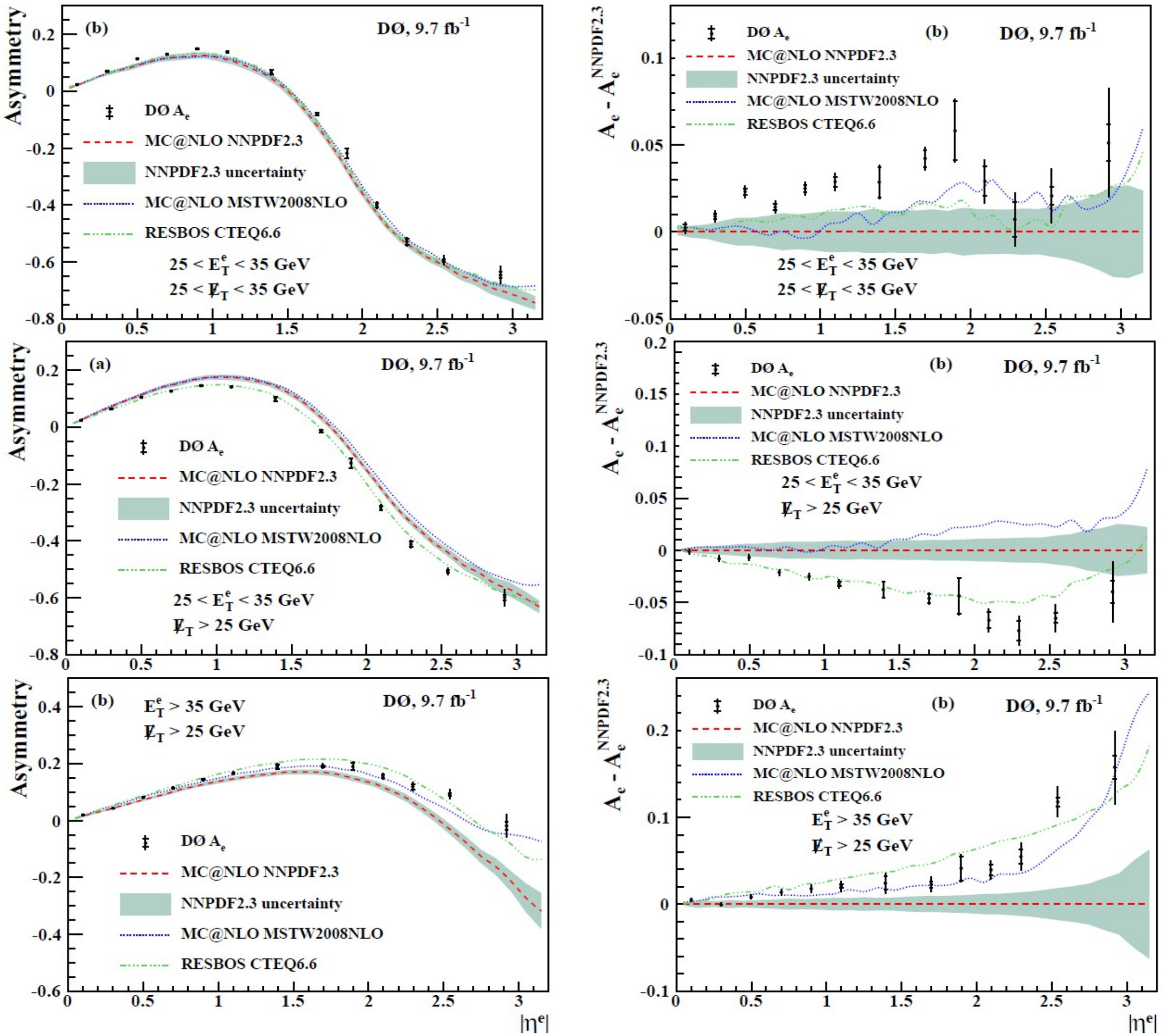
$$A(\eta^e) = \frac{N^{e^+}(\eta^e) - N^{e^-}(\eta^e)}{N^{e^+}(\eta^e) + N^{e^-}(\eta^e)}$$

  - Then asymmetry is essentially the difference in the number of charged leptons
- We account for electron selection efficiencies, luminosity, and event acceptance on the number of electrons, and then unfold, removing detector effects to compare with the generator level
- 5 bins, for electron p_T and/or missing E_T thresholds of 25 and 35 GeV (symmetric and asymmetric bins- listed on result plots)
- Result improves upon and replaces the previous measurement

Lepton Asym Results



Lepton Asym Results



W Asym Details

- Asymmetry is difference in W differential cross-sections (in rapidity) over total. Complication from neutrino z momentum:

$$y_W = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}$$

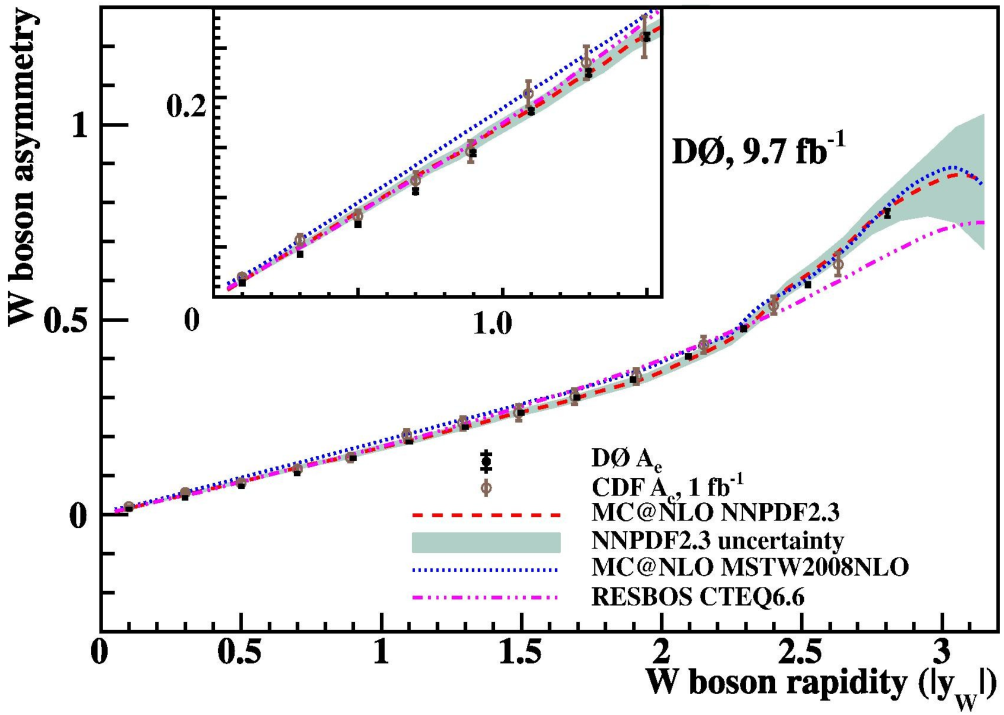
- But, we know W mass well, so we can determine z momentum (assuming the W boson mass) to within a two-fold ambiguity:

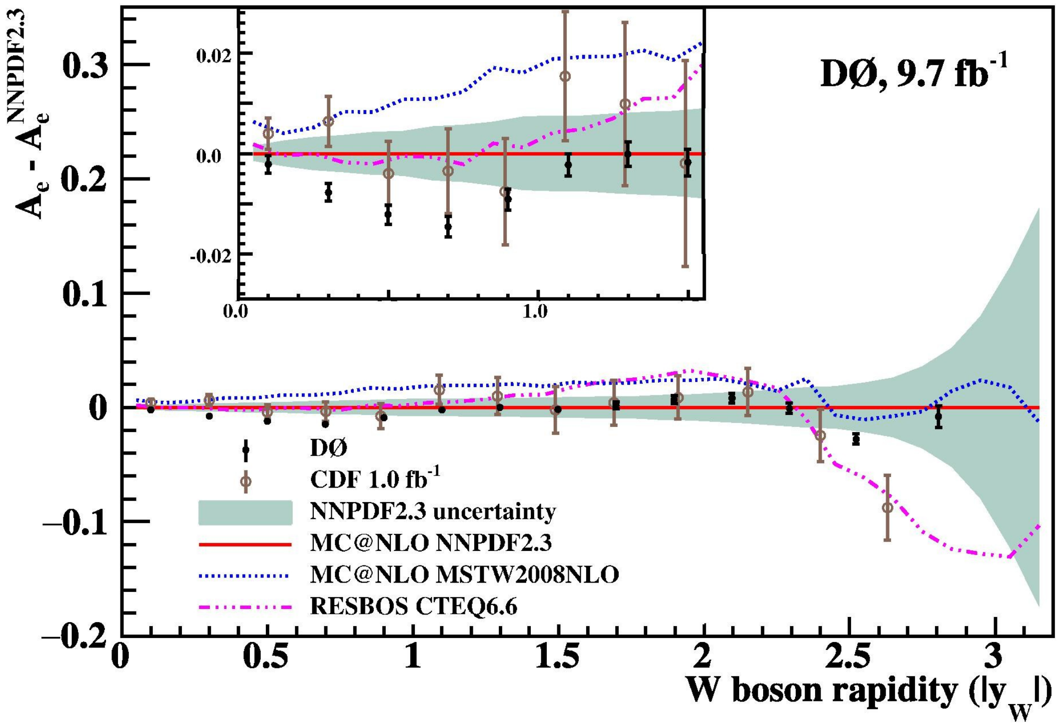
$$M_W^2 = (E_e + E_\nu)^2 - (\vec{P}_e + \vec{P}_\nu)^2$$

  (In the case of a complex result, missing E_T is assumed to be mis-reconstructed and adjusted until the result is real)

- Ambiguity resolved by assigning weights to the event, for each solution, related to cosθ*, W rapidity and W p_T
  - Predicted differential cross-section in rapidity and cosθ* ratio (part of the p_z weight) from event generators. Weight updated iteratively (removes potential bias) until weights converge

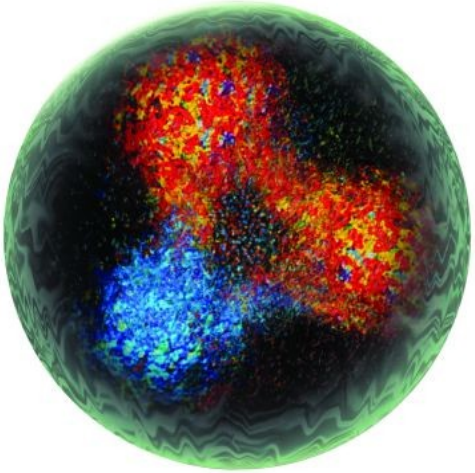
W Asym Results





Summary

- New W charge asymmetry measurements from DØ using W's which decay to electrons and neutrinos
- Two methods shown, one related to the difference in number of charged electrons, the other reconstructing the W using the W boson mass to extrapolate missing neutrino pz information
  - The lepton measurement replaces the previous result
- Measurements generally agree with previous DØ muon and CDF results
- These measurements are the most precise to date and should be useful for future PDF sets



Other Info

- Some papers used in or related to this talk:
  - Phys. Rev. Lett 112, 151803 (2014); Erratum: Phys. Rev. Lett. 114, 049901 (2015) (DØ, W asym, electron)
  - Phys. Rev. D 91, 032007 (2015); Erratum: Phys. Rev. D 91, 079901 (2015) (DØ, lepton asym, electron)
  - Phys. Rev. D 88, 091102(R) (2013) (DØ, lepton asym, muon)
  - PRL 102, 181801 (2009) (CDF, W asym, electron)
  - Phys. Rev. D 77, 111301(R) (2008) (W asym, method proposal)

Weights in Detail

- Probability for W boson production, where Q is the quark, anti-quark production:

$$P_{\pm}\left(\cos\theta^*, y_W, p_T^W\right) = \left(1 \mp \cos\theta^*\right)^2 + Q\left(y_W, p_T^W\right)\left(1 \pm \cos\theta^*\right)^2$$

- Weighting factor

$$w_i^{\pm} = \frac{P_{\pm}\left(\cos\theta_i^*, y_i, p_T^W\right) d\sigma^{\pm}\left(y_i\right)/dy_W}{\sum_i P_{\pm}\left(\cos\theta_i^*, y_i, p_T^W\right) d\sigma^{\pm}\left(y_i\right)/dy_W}$$

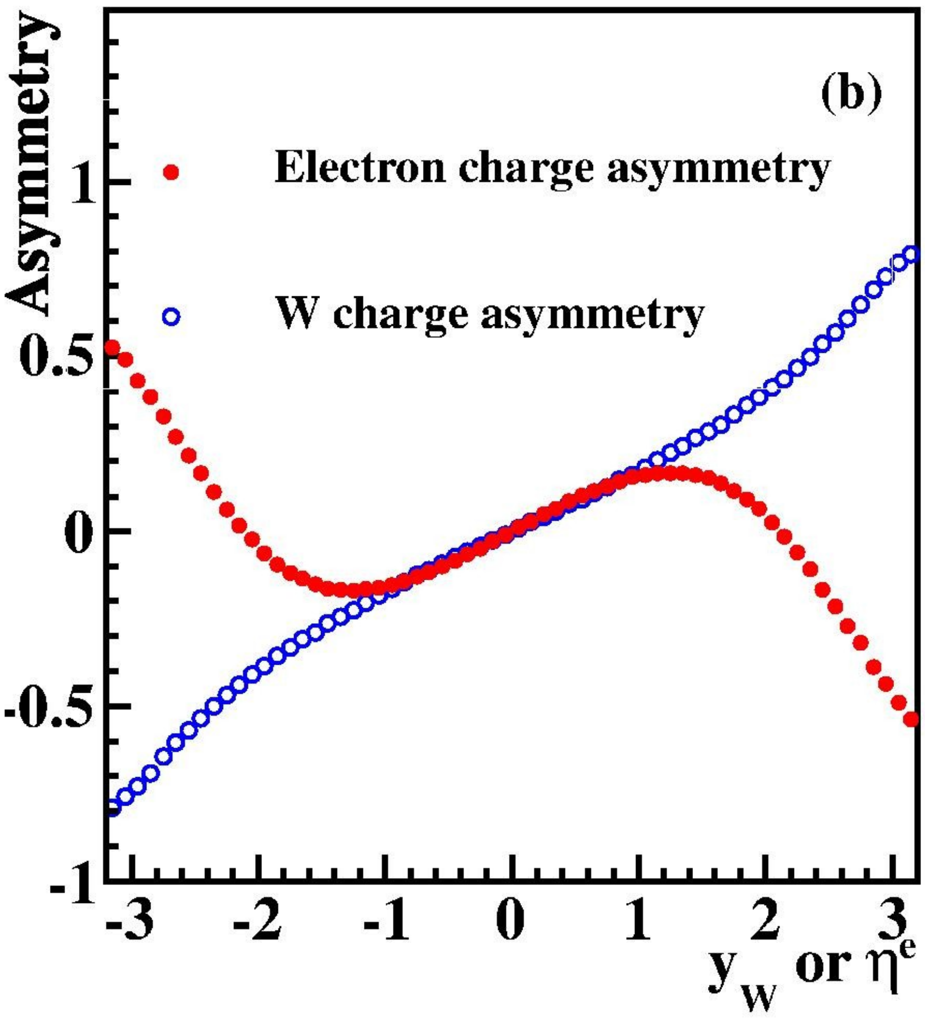
- Q and differential cross-section terms obtained from event generators

PDFs

- x = momentum fraction of parton
- Q^2 = squared momentum scale for parton interactions
- Info for $0.002 < x < 0.99$ with $|\eta| < 3.2$, $Q^2 \sim M_W^2$

Asymmetry

- Asymmetry differences largest at large angles
- Differences due to V-A structure of W decay



Systematic Uncertainties (lepton Asym)

- Example systematic uncertainties table

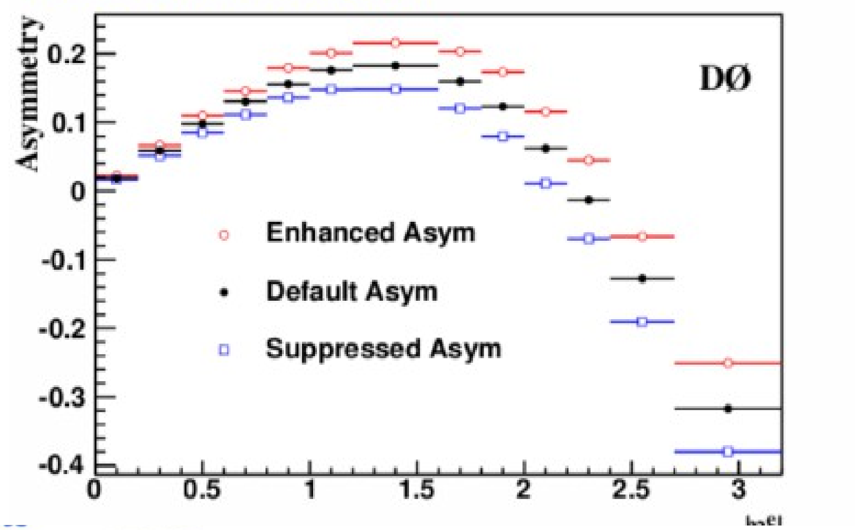
TABLE II: Summary of absolute systematic uncertainties for the CP-folded electron charge asymmetry for kinematic bin $E_T^e > 25$ GeV, $\not{E}_T > 25$ GeV. The calorimeter has a gap in the range of $1.1 < \eta_{\rm det}^e < 1.5$, so some systematic uncertainties in the η^e bin $1.2 - 1.6$ are large compared to those of the neighboring η^e bins. The uncertainties are multiplied by 1000.

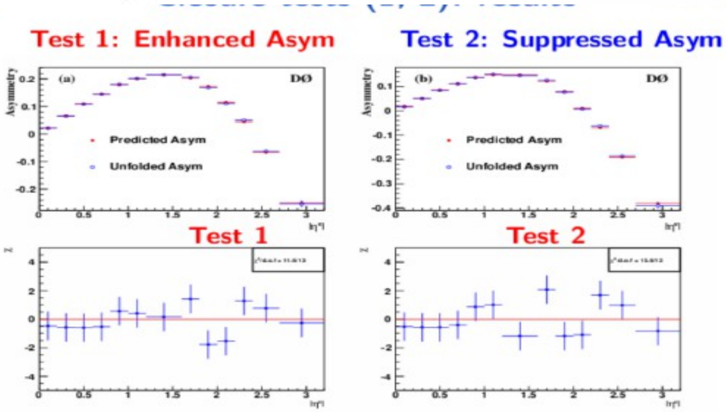
η^e	Gen	EMID	$K_{\rm eff}^{q,p}$	Energy	Recoil	Model	Bkgs	$Q_{\rm mis}$	Unfolding	Total
0.0 – 0.2	0.06	0.02	0.20	0.03	0.04	0.28	0.26	0.54	0.82	1.08
0.2 – 0.4	0.06	0.18	0.10	0.18	0.26	0.75	0.54	0.56	0.81	1.40
0.4 – 0.6	0.12	0.24	0.27	0.25	0.35	1.05	0.87	0.59	0.80	1.79
0.6 – 0.8	0.07	0.34	0.04	0.34	0.49	1.32	1.81	0.60	0.80	2.55
0.8 – 1.0	0.12	0.36	0.12	0.36	0.53	1.72	2.37	0.76	0.85	3.23
1.0 – 1.2	0.09	0.37	0.47	0.37	0.55	2.42	2.71	1.20	1.17	4.10
1.2 – 1.6	0.03	0.42	0.64	0.39	0.58	4.10	3.94	1.67	1.04	6.11
1.6 – 1.8	0.11	0.28	0.18	0.22	0.34	4.26	1.37	1.53	0.95	4.85
1.8 – 2.0	0.34	0.36	1.07	0.05	0.10	4.21	1.43	2.46	1.13	5.34
2.0 – 2.2	0.37	0.36	1.38	0.04	0.07	3.33	1.75	4.37	1.47	6.14
2.2 – 2.4	0.19	0.30	2.78	0.02	0.05	3.40	1.54	7.15	1.93	8.76
2.4 – 2.7	0.21	0.43	5.54	0.29	0.48	4.24	2.16	8.65	2.36	11.6
2.7 – 3.2	0.05	0.87	9.00	0.81	1.30	3.48	3.99	18.9	5.48	22.3

Unfolding

- Migration matrix: used to remove detector resolution effects
  - Electron and positron are expected to have same detector response
  - Study migration matrices for all events (elec+posi): no input bias
- $K_{\text{eff}}^{\pm}$: relative efficiency for positrons and electrons
  - Use $Z \to ee$ events to study $K_{\text{eff}}^{\pm}$: track bias from alignment + solenoid polarity
  - Only study $K_{\text{eff}}^{\pm}$ for track cuts, do not expect calorimetry cu to have such effects
- Acc × Eff: to remove kinematic and geometric cut effects

Test 1: Enhanced Asym
Test 2: Suppressed Asym





W Asym, more material

- Asymmetry and x : lepton asymmetries are from a larger range of parton x values compared with W asymmetry
- The W asymmetry is expected to be more sensitive to the u/d ratio