W Charge Asymmetry at CDF

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on behalf of CDF collaboration

Ph.D. thesis of Bo-Young Han

Outline

- Introduction and Analysis Technique
- Signal, Backgrounds and Corrections
- Uncertainties
- Preliminary results
**W Charge Asymmetry and PDFs**

- At Tevatron, $W^\pm$ are produced primarily by $u_{\text{proton}}$ ($\bar{d}_{\text{anti-proton}}$) and $\bar{u}_{\text{anti-proton}}$ ($d_{\text{proton}}$).

\[
A(y_W) = \frac{d\sigma_+ / dy_W - d\sigma_- / dy_W}{d\sigma_+ / dy_W + d\sigma_- / dy_W} \\
\approx \frac{u(x_+)d(x_-) - d(x_+)u(x_-)}{u(x_+)d(x_-) + d(x_+)u(x_-)}
\]

where $x_\pm = \frac{M_W}{\sqrt{s}} e^{\pm y_W}$

- $u$ quarks carry more momentum than $d$ quarks

\[
y_w = \frac{1}{2} \ln \left( \frac{E + P_z}{E - P_z} \right)
\]
Lepton Charge Asymmetry

- Previous work from TeVatron has measured the charge asymmetry vs. lepton pseudorapidity ($\eta$) in $W \rightarrow \ell \nu$

- This observable is a convolution of the $W$ charge asymmetry and V-A $W$ decay angular distribution
Lepton and W Rapidity

Lepton prefers to decay against boost

\[ \frac{d\Gamma(W \rightarrow e^\pm \nu)}{d\theta^*} \propto \left(1 \mp \cos \theta^*\right)^2 \]
Analysis Technique

- Measure $W^\pm$ rapidity $y_W = \frac{1}{2} \ln \left( \frac{E + P_z}{E - P_z} \right)$

- Use $W$ mass constraint
  solve eqn. $M_W^2 = (E_l + E_v)^2 - (P_l + P_v)^2$
  answer: $P_{z1}^v, P_{z2}^v$

- Weight the two solutions $F_{1,2}^\pm = \frac{P_+ (\cos \theta_{1,2}^*, y_{1,2}, p_{T}^W) \sigma_+ (y_{1,2})}{P_+ (\cos \theta_{1}^*, y_{1}, p_{T}^W) \sigma_+ (y_{1}) + P_+ (\cos \theta_{2}^*, y_{2}, p_{T}^W) \sigma_+ (y_{2})}$

- This method must be iterated to remove input bias

\[ \text{shown it does not depend on assumed charge asymmetry} \]
Complications: Detector Effects

- Response matrix showing the acceptance, smearing and final state effects
  - QED, $W \rightarrow \tau \nu \rightarrow e \nu \nu \nu$

- $Y_1$ weighting factor
- $Y_2$
- $wt_1$
- $wt_2$
- $Y_W$
- $Y_W$ true rapidity
- FSR

- depends on physics input → should be iterated
- doesn't depend on physics input → need not be iterated
Complications:

W Production from the sea

- Sign of V-A angular bias flips when $W^\pm$ is produced from anti-quarks
  - take this fraction as an input

\[ P_\pm (\cos \theta^*, y_W, p_t^W) = (1 \mp \cos \theta^*)^2 \]

\[ + Q(y_W, p_t^W) (1 \pm \cos \theta^*)^2 \]

ratio of two angular distributions at each rapidity
What is input, and what is measured?

- Inputs from theory:
  \[ \frac{\bar{u} + \bar{d}}{u + d} \text{ and } \frac{d\sigma(p\bar{p} \to W^+ X)}{dy_w} + \frac{d\sigma(p\bar{p} \to W^- X)}{dy_w} \]

- Output from iteration:
  \[ A(y_W) = \frac{\frac{d\sigma(p\bar{p} \to W^+ X)}{dy_w} - \frac{d\sigma(p\bar{p} \to W^- X)}{dy_w}}{\frac{d\sigma(p\bar{p} \to W^+ X)}{dy_w} + \frac{d\sigma(p\bar{p} \to W^- X)}{dy_w}} \]

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Summary of Data Issues

- Require one high $E_T$ electron and missing $E_T$ to tag the neutrino
  - $E_T^e > 25(20)$ GeV in central (plug) detector
  - missing $E_T > 25$ GeV

- Detector response, including missing $E_T$, tuned on $Z \rightarrow e^+e^-$ sample

- Highlight backgrounds (primarily jets faking electrons) and charge mis-measurement
  - also, trigger and detector acceptance and smearing
Data and Simulation Kinematic Distributions, W→ev Sample

- Scale and resolution tuned on Z→e⁺e⁻
Backgrounds

- Measure jet backgrounds directly in data
  - use extra energy “isolation” around electron to separate, and fit shape to background fraction
- Illustrative fit (one of many) shown at right
  - use jet sample to predict measured $y_W$ and charge from this sample
  - uncertainty is $\sim 0.15\%$ of total sample
- A number of minor backgrounds (real $W$s) from simulation
Electron Charge Identification

- Charge identification is crucial for this measurement.
- Forward tracking has fewer points at shorter lever arm.
- Determine directly from (background subtracted)

\[
f_{mis} = \frac{N_{\text{same sign}}}{N_{\text{opposite sign}} + N_{\text{same sign}}}
\]
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Systematic Effects

- Detector response
  - energy scale and smearing for electron and recoil
  - efficiency to find electron and pass missing $E_T$ cut

- Inputs
  - PDF uncertainties (CTEQ6 PDF error sets) for total $W$ production and quark/anti-quark fractions
Evaluation

- Derive result with shifted parameters
- Systematics dominate only if $y_W < 0.2$ or $> 2.6$

**Systmatics from the cluster Energy scale**

- largest detector effect: energy scale

**Systmatics from Q factor**

- largest PDF effect: qbar/q

**Systmatics from Electron ID Eff.**

- largest selection effect: elec. cuts

**Systmatics from Charge Fake Rate**

- charge fake rate uncertainty

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K. McFarland, W Charge Asymmetry
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Input PDFs

- We are in the process of documenting how result depends on input PDFs
  - PDF fitters can explicitly put this in (or ignore if small)

- effect of increasing valence u+d by +5%
- effect of increasing sea u+d by +5%
Systematics correlated bin-to-bin.. show as a band

- Positive and negative $y_W$ agree, so fold
- Compared to NNLO (MRST) w/ NLO error PDF band (CTEQ)
CDF Preliminary Result (1fb⁻¹)

- Compare CTEQ6M and MRST2006 with PDFs and their uncertainties

![Graphs showing comparison between CTEQ6M, MRST2006, and data](image)
Conclusions

- First direct measurement of $W$ charge asymmetry
  - despite additional complication of multiple solutions, it works!
  - appears that it will have impact on $d/u$ of proton
- Looking forward to working with PDF fitting groups to incorporate
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- Backup
Results

| $|y_{W}|$ | $A(y_{W})$ | $\sigma_{sys}$ | $\sigma_{sys+stat}$ |
|-------|-----------|---------------|---------------------|
| 0.0 - 0.2 | 0.0199 | ±0.0013 | ±0.0034 |
| 0.2 - 0.4 | 0.0571 | ±0.0027 | ±0.0042 |
| 0.4 - 0.6 | 0.0813 | ±0.0037 | ±0.0049 |
| 0.6 - 0.8 | 0.1168 | ±0.0055 | ±0.0063 |
| 0.8 - 1.0 | 0.1456 | ±0.0072 | ±0.0079 |
| 1.0 - 1.2 | 0.2040 | ±0.0084 | ±0.0092 |
| 1.2 - 1.4 | 0.2354 | ±0.0109 | ±0.0118 |
| 1.4 - 1.6 | 0.2613 | ±0.0143 | ±0.0151 |
| 1.6 - 1.8 | 0.3027 | ±0.0135 | ±0.0144 |
| 1.8 - 2.05 | 0.3553 | ±0.0126 | ±0.0141 |
| 2.05 - 2.3 | 0.4363 | ±0.0134 | ±0.0158 |
| 2.3 - 2.6 | 0.5374 | ±0.0136 | ±0.0178 |
| 2.6 - 3.0 | 0.6415 | ±0.0116 | ±0.0260 |

CDF Run II Preliminary $\int L = 1 fb^{-1}$

- 1 fb$^{-1}$ data (stat + syst.)
- NLO Prediction (CTEQ6M)
- PDF uncertainty (CTEQ6M)
Systematics

Table 1: Systematic uncertainties for the $W$ production charge asymmetry. The values shows the correlated uncertainties for both positive and negative rapidities.

| $|y_W|$ | CFR | BKG | EM | Recoil | Trig | ID | PDF | Stat. (1fb$^{-1}$) |
|-------|-----|-----|----|--------|------|----|-----|------------------|
| 0.0 - 0.2 | 0.02 | 0.04 | 0.01 | 0.11 | 0.03 | 0.02 | 0.03 | 0.31 |
| 0.2 - 0.4 | 0.01 | 0.09 | 0.04 | 0.22 | 0.08 | 0.07 | 0.08 | 0.32 |
| 0.4 - 0.6 | 0.02 | 0.11 | 0.06 | 0.22 | 0.13 | 0.17 | 0.15 | 0.33 |
| 0.6 - 0.8 | 0.03 | 0.15 | 0.07 | 0.34 | 0.14 | 0.30 | 0.22 | 0.32 |
| 0.8 - 1.0 | 0.03 | 0.20 | 0.07 | 0.42 | 0.11 | 0.47 | 0.24 | 0.34 |
| 1.0 - 1.2 | 0.04 | 0.18 | 0.08 | 0.33 | 0.09 | 0.69 | 0.27 | 0.38 |
| 1.2 - 1.4 | 0.05 | 0.18 | 0.15 | 0.67 | 0.06 | 0.78 | 0.28 | 0.43 |
| 1.4 - 1.6 | 0.04 | 0.14 | 0.14 | 1.10 | 0.04 | 0.85 | 0.28 | 0.50 |
| 1.6 - 1.8 | 0.08 | 0.12 | 0.26 | 0.92 | 0.03 | 0.89 | 0.29 | 0.55 |
| 1.8 - 2.05 | 0.22 | 0.13 | 0.31 | 0.82 | 0.06 | 0.80 | 0.34 | 0.62 |
| 2.05 - 2.3 | 0.44 | 0.21 | 0.53 | 0.59 | 0.17 | 0.85 | 0.42 | 0.83 |
| 2.3 - 2.6 | 0.45 | 0.19 | 0.62 | 0.40 | 0.27 | 0.86 | 0.50 | 1.10 |
| 2.6 - 3.0 | 0.14 | 0.10 | 0.60 | 0.43 | 0.28 | 0.65 | 0.53 | 2.30 |
NNLO K-factor:
\[(d\sigma^{\text{NNLO}}/dy_W)/(d\sigma^{\text{LO}}/dy_W)\]

- NNLO \(d\sigma^{\pm}/dy_W\) (mrst2002 PDFs) from theoretical prediction.