Measurement of W/Z properties at the Tevatron

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Results shown today: 3-5 fb\(^{-1}\)

Delivered \(\sim 8.8\) fb\(^{-1}\)

CDF on tape \(\sim 6.6\) fb\(^{-1}\)

D0 has similar numbers

Data taking eff. \(\sim 90\%\)
Large dataset

Prolific datasets: 600k Zs, 6M Ws for either e or μ
End of 2011: CDF W & Z samples twice that of LHC (1fb⁻¹ @ 7 TeV)
And then there is also the D0 sample which is of similar size (>600K Z→μμ in 6 fb⁻¹)
**W & Z at the Tevatron**

**Electron:** EM Calorimeters High Pt (Track) Isolated

**Muons:** Muon Detectors High $P_T$ Isolated

**Neutrinos:** Large Missing Energy Only Transverse ($E_T$ or Met)

**W Signature:** Isolated Lepton and $E_T$

**Z Signature:** Two Isolated Leptons (diff charge)
Test of QCD

Can be used to check calculations

⇒ NLO since long time
⇒ NNLO
⇒ (recently with full spin correlations)

\[
\sigma = \sum_{ab} \int dQ \delta(Q - 2E_p \sqrt{x_p x_p}) \int dx_p f_a(x_p, Q) \int dx_p f_b(x_p, Q) \sigma(Q)
\]

- Sum over quarks, gluons
- Kinematic constraint
- Parton distribution functions
- Calcuable hard scattering cross section
Precision of data now allows to measure asymmetries differential in lepton $E_T$
Exposed some inconsistencies with latest PDF fits

Tevatron results also discussed by H. Schellmann this morning in Session 6
Number of issues have come to light:

- Compatibility of the CDF and D0 data
- Differences between resummation vs NLO+PS vs NNLO

CDF/D0 broadly consistent

CDF has taken published W asymmetry data & produced lepton asymmetry for the PDF fitters to aid CDF/D0 comparisons
- MC@NLO describes data better than RESBOS

- NNLO effects small but not negligible

W Charge Asymmetry

MC@NLO to NNLO

Courtesy R. Thorne

![Graph](image)

$E_T < 35$ GeV

RESBOS to MC@NLO
Use $Z \rightarrow ee$ to constrain PDFs

HERA $F_2$ / jet & Tevatron jet & W/Z data necessary for accurate PDFs for robust LHC predictions

\[ Y_Z = 0.5 \ln \left( \frac{x_p}{x_{\overline{p}}} \right) \]

OLD PDF NLO $\chi^2/df = 70/28$
NEW PDF NLO $\chi^2/df = 51/28$
Constraining PDFs

u-valence already well constrained from $F_2$ data ($e_Q^2$)

CDF Z rapidity allows more robust determination of d-valence at high-x albeit with a larger error than before!

![Graph showing the ratio of MSTW 2008 NNLO and MRST 2006 NNLO to MSTW 2008 NNLO at $Q^2 = 10^4$ GeV$^2$. The graph displays a range of values for the ratio as a function of $x$. The MSTW 2008 NNLO curve is represented by a black line with shaded regions indicating uncertainty, while the MRST 2006 NNLO curve is represented by a red line. The x-axis represents $x$ values ranging from $10^{-3}$ to 1, and the y-axis represents the ratio ranging from 0.85 to 1.15.]
Z Forward Backward Asymmetry

Sensitive to:
- Quark and lepton Z couplings ($\sin^2 \theta_W$)
- Possible new Z'

Pseudo Experiment Results

\[
\frac{d\sigma}{d\cos\theta} = A(1 + \cos^2 \theta) + B \cos \theta
\]
A_{fb} for Z\rightarrow ee

Expect to extract sin^2\theta_W with precision of 0.0007.

CDF Run II Preliminary with 4.1 fb^{-1}

DO results with 1 fb^{-1} in PRL 101, 191801
sin^2\theta_W=0.2326\pm0.0018(stat)\pm0.0006(syst)

With about 8 fb^{-1} per experiment to be collected in Run II we expect to reach (Tevatron only) the WA accuracy
**W rare decays**

Clean final state: enhanced by BSM physics.
SM branching fraction: $10^{-6} - 10^{-8}$

Will become very interesting at the LHC...
W rare decays

206 candidate events in signal (75 < $M_{\pi\gamma} < 85$ GeV) region

$\text{BR}(W \rightarrow \pi\gamma)/\text{BR}(W \rightarrow ev) < 6.4 \times 10^{-5}$ at 95% confidence

Firenze, April 21 2010
Firenze, April 21 2010

**W Mass Measurement**

Recoil & Underlying Event Energies

Production and Decay Model

Momentum/Energy Scale & Resolution

Requires a detailed understanding (~10 MeV) of all aspects of W boson production and detection

Fit a bidimensional distribution in $M_T, \Gamma_W$

CDF blinded Mass fit

CDF Run II Preliminary

$\chi^2/dof = 69/58$
Together with $M_{\text{top}}$ constrains the EWSB sector

- Logarithmic corrections
- For equal contribution $\Delta M_W \approx 0.006 \Delta M_{\text{top}}$
- Current $\Delta M_{\text{top}} = 1.3$ GeV/c$^2$

- Imply $\Delta M_W = 8$ MeV (current: 23)

Experimental Challenge

That’s what we like!
How to deal with...

$M_W$ cannot be directly reconstructed due to missing neutrino $P_z$

- Use estimators
  - $M_T = \sqrt{2P_T l_1 \cdot P_T \nu(1-\cos l, \nu))}$
  - $P_T(l, \nu)$ where $l$ is a charged lepton (e or mu)

- CDF: uses both leptons
- D0: only electrons

- Underlying event enters through subtle effects

- For the electron channel, understanding the energy scale is the key
Z→ee provides calibration to tune effects in MC

- With increased Z statistics better understanding of energy scale
- Material
  - Longitudinal shower development
  - dE/dx, etc
  - MC material model tuning

Linear response model:

\[ E_{\text{True}} = E_{\text{meas}} \times \alpha + \beta \]
Three different estimators (100% correlated):

$M_T, p_T, p_{T\nu}$
**MW results**

CDF and D0 had several measurements in Run Ia, b. In Run II

- **CDF (200 pb⁻¹)**
  - $80.413 \pm 0.034$ (stat) $\pm 0.034$ (syst)

- **D0 (1 fb⁻¹)**
  - $80.401 \pm 0.021$ (stat) $\pm 0.038$ (syst)

- Can we beat LEP?

  **YES, WE CAN**
Combine all Tevatron results using the B.L.U.E. method

- Take into account all correlations among results
- Rescale RunI results to take into account
  - New pdfs
  - New $\Gamma_W$

Tevatron Avg: $80.420 \pm 0.031$
WA: $80.399 \pm 0.023$
**Mw Perspectives**

We can do better:

- **Statistics:**
  - More than 6 fb\(^{-1}\) to tape per experiment

- **Systematics**

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<th>Parameter</th>
<th>L = 200 pb(^{-1})</th>
<th>L = 200 pb(^{-1})</th>
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<tr>
<td><strong>Total</strong></td>
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</table>

**\(M_T\)**

**\(P_T(l,\nu)\)**

**MET**

Largest experimental: lepton scale

Largest theoretical: pdfs
Beyond a few fb$^{-1}$ overall uncertainty does not improve significantly without better understanding of systematics, but energy scale systematics is statistically limited.
Expected to agree with SM

Deviations could be very interesting..

Measurement exploits tail of $M_T$ distribution (Lorentz shape)

Mass Width

$\text{MC}$

$$\chi^2/d.o.f=75.2/75$$

$D_6, 1 \text{ fb}^{-1}$

Events/2 GeV

$\Gamma_W=2.6 \text{ GeV}$

$\Gamma_W=2.1 \text{ GeV}$

$\Gamma_W=1.6 \text{ GeV}$

$M_\tau (\text{GeV})$

$M_T (\text{GeV})$
Combined result

Tevatron has (Feb. 2010) a new combination:

$$\text{D0} = 2.028 \pm 0.038 \text{(stat)} \pm 0.061 \text{(syst.)} \ (1 \text{ fb}^{-1})$$

$$\text{CDF} = 2.032 \pm 0.045 \text{(stat)} \pm 0.053 \text{(syst)} \ (350 \text{pb}^{-1})$$

Tevatron: $2.046 \pm 0.049 \text{ GeV/c}^2$

WA: $2.085 \pm 0.042 \text{ GeV/c}^2$
CONCLUSION

CDF and D0 have a very large sample of Ws, Zs

- Detectors well understood
- Backgrounds under control
  - EWK precision tests ($\sin^2\theta_W$) are possible
- Constraining PDFs is one of the (many) things that TeV can do for LHC
- $M_W$ will be one of the lasting heritages
  - It will also constrain the Higgs sector before actual Higgs observation

Many thanks to: Mark Lancaster, Larry Nodulman, Junjie Zhu, Jan Stark + many others from CDF and D0!