QCD and Electroweak Physics at the Tevatron

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Outline

- Jet Physics
  - inclusive cross sections
  - kt algorithm
- Inclusive Boson production
  - $\gamma$
  - $W/Z$ cross sections
  - $Z$ rapidity
  - $W$ asymmetry
- $W/Z +$ jets
- $W$ properties
- Prospects with $> 1$ fb-1
Gluon distributions at high x from pp scattering

\[ s(\text{ep}! \ eX) / x \left[ \frac{4}{9}(u + \bar{u}) + \frac{1}{9}(d + \bar{d}) \right] \]

\[ s(\text{pp}! \ j j) / x_1 x_2 \left[ q_1 + q_1 + \frac{9}{4} G_1 \right] \left[ q_2 + q_2 + \frac{9}{4} G_2 \right] \]
Inclusive jets – different algorithms

- Cone jets
  - easy to understand
  - hard to define
  - hard to calculate
  - easy to subtract multiple interactions

- kt jets
  - hard to understand
  - easy to calculate
  - but what about additional interactions at high $L$?

\[ d_{ij} = \min(E_{T,i}^2, E_{T,j}^2) \frac{\Delta R_{ij}^2}{D^2} \]
\[ d_{ii} = E_{T,i}^2 \]
Typical event from CDF

Raw Jet $P_T$ [GeV/c]
$\rightarrow$ JetClu $R=0.7$
$\rightarrow$ MidPoint $R=0.7$
$\rightarrow$ $K_T$ $D=1.0$
$\rightarrow$ $K_T$ $D=0.7$

Event 1860695   Run 185777

Only towers with $E_T > 0.5$ GeV are shown
Central jet $d\sigma/dp_T$

Note, an underlying event and hadronization correction of up to 20% is applied at low PT.

CDF Run II Preliminary

Parton to Hadron Level Corrections

- Underlying event
- Hadronization
- Uncertainty

CDF Run II Preliminary

NLO pQCD EKS CTEQ 6.1M, $(\mu = p_T^{1/2})$
Midpoint $R_{hors}=0.7$, $R_{had}=0.75$, $R_{sep}=1.3$
$0.1 < |y| < 0.7$

$\int L = 385 \text{ pb}^{-1}$

$\frac{d^2\sigma}{dp_T^2} \text{ [nb/(GeV/c)]}$

- Total systematic uncertainty
- Data corrected to parton level
- NLO pQCD

$0 \quad 100 \quad 200 \quad 300 \quad 400 \quad 500 \quad 600 \quad 700$

$0 \quad 10^{-1} \quad 10^{-2} \quad 10^{-3} \quad 10^{-4} \quad 10^{-5} \quad 10^{-6} \quad 10^{-7} \quad 10^{-8}$
$k_T$ jets and cone jets

can match $k_T$ spectra at low and high luminosity by adding $\sim 1.6$ GeV/interaction

$k_T$ algorithm

CDF Run II Preliminary

midpoint cone algorithm
kT algorithm results in 4 rapidity bins
D0 2004
new energy scale
will halve the errors
Photon production

- Important for the future $H \rightarrow \gamma\gamma$
- Less energy smearing than jets
- Better understanding of energy scale
- Purity is lower

![Graph showing photon purity vs. $p_T$ (GeV)]
Direct photons

\[ \frac{d^2\sigma}{dp_T^2 dh} \text{(pb/GeV)} \]

\[ L = 326 \text{ pb}^{-1} \]

\[ \text{NLO QCD} \]

\[ (\mu_R = \mu_F = \mu_t = p_T) \]

CTEQ6.1M

\[ \text{Data/Theory} \]

\[ \text{ratio of data to theory (JETPHOX)} \]

\[ \text{CTEQ6.1M PDF uncertainty} \]

\[ \text{scale dependence} \]

\[ (\mu_R = \mu_F = \mu_t = 0.5p_T \text{ and } 2p_T) \]

CDF Diffractive diphotons

3 events so far

V. Khoze, A. Martin, M. Ryskin & J. Stirling

H at LHC?

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W/Z physics - Tag and Probe method

- Find a really good lepton, use as a ‘TAG’.
  - Passed trigger
  - Tight shower cuts
  - Good track match
- Use some component (track or shower) to make another PROBE lepton and from that a $Z^0$
- Was the PROBE efficient for trigger/tracking/shower?
- Use MC to correct for residual biases ~2%.
W/Z physics to high rapidity

- Tevatron beamspot is long compared to the detector size. Vertices far from the center along the beam axis can reach low values of polar angle not possible from the center of the detector.
Tracking efficiency for different $z_{vtx}$

$z_{vtx} \sim 0$, $\eta_{det} = 2$, $\eta_{phys} = 2$
Reach rapidity not accessible at $z_{vtx} = 0$

$z_{vtx} \sim -40 \, cm$, $\eta_{det} = 2$, $\eta_{phys} > 2$
Z rapidity distribution

C. Anastasiou, L. Dixon, K. Melnikov and F. Petriello
W asymmetry

\[
W^- 

d \leftrightarrow u 
\quad u \rightarrow d 
W^+ 
\]

\[
A(y_W) = \frac{\frac{ds(W^+) = dy_W \bar{y}}{ds(W^+)} + \frac{ds(W^-) = dy_W}{ds(W^-)}} ;
\]

\[
A(x_1; x_2) = \frac{u(x_1) \bar{d}(x_2) \bar{y}}{u(x_1) \bar{d}(x_2) + d(x_1) u(x_2)} 
\]

\[
A(r_e) = \frac{\frac{ds(e^+) = dr_e \bar{y}}{ds(e^+)} + \frac{ds(e^-) = dr_e}{ds(e^-)}} ;
\]

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\[ A(\eta_e) = \frac{d\sigma(e^+)/d\eta_e - d\sigma(e^-)/d\eta_e}{d\sigma(e^+)/d\eta_e + d\sigma(e^-)/d\eta_e} \]

CDF-II, 170 pb$^1$

- \(35 < E_t < 45 \text{ GeV}\)


CDF-II, 170 pb$^1$

- \(25 < E_t < 35 \text{ GeV}\)

Z pt contribution

Boson Pt tuned at low rapidity – does it work at high rapidity?

- hep-ph/0410375
- Phys.Rev.D72:033015,2005 (Berge, Nadolsky, Olness and Yuan)
W/Z + jets

W/Z production with jets, especially b jets is important in understanding many interesting Higgs, Top and more exotic channels
W/Z+jets

CDF Run II Preliminary

W → eν + ≥ n jets, 127 pb⁻¹

CDF Data

JetClu R=0.4 (E_T > 15 GeV, |η| < 2.4) w/ syst. ± Jet Energy Uncertainty

LO QCD \( \mu_R = M_W \) Alpgen

LO QCD \( \mu_F = \langle p_T \rangle \) Alpgen

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**Z^0 + b jet. CDF RUN II Preliminary**

Fit of Mass at Secondary Vertex

- $\sqrt{s} = 1.96$ TeV, $L \sim 335$ pb$^{-1}$
- $E_T > 20$ GeV
- $|\eta| < 1.5$

- $N_{\text{data}} = 101$
- $N_{\text{MC}} = 99$
- $N_{\text{light}} = 30 \pm 12$
- $N_c = 23 \pm 19$
- $N_b = 46 \pm 15$

**Z^0 + b jet. CDF RUN II Preliminary**

Tagged Jets

- $\sqrt{s} = 1.96$ TeV, $L \sim 335$ pb$^{-1}$
- $E_T > 20$ GeV
- $|\eta| < 1.5$

**DØ Preliminary**

- $L = 382$ pb$^{-1}$
- $W \geq 1$ b-tagged jets

**DØ Preliminary**

- $L = 382$ pb$^{-1}$
- $W + 2$ b-tagged jets
\( Z^0 + b \) jet. CDF RUN II Preliminary

Tagged Jets
\( \sqrt{s} = 1.96 \text{ TeV}, L = 335 \text{ pb}^{-1} \)
\( E_T^T > 20 \text{ GeV} \)
\( |\eta|^T < 1.5 \)

\( Z + b' s \)
W mass

Direct measurements

From Z couplings
W mass variables

\[ m_T = \sqrt{2p_T^1 p_T^\nu (1 - \cos(\Delta \phi))}. \]
CDF $M_T$ analysis

Present combined error is 76 MeV

<table>
<thead>
<tr>
<th>Systematic [MeV]</th>
<th>Electrons (Run 1b)</th>
<th>Muons (Run 1b)</th>
<th>Common (Run 1b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepton Energy Scale and Resolution</td>
<td>70 (80)</td>
<td>30 (87)</td>
<td>25</td>
</tr>
<tr>
<td>Recoil Scale and Resolution</td>
<td>50 (37)</td>
<td>50 (35)</td>
<td>50</td>
</tr>
<tr>
<td>Backgrounds</td>
<td>20 (5)</td>
<td>20 (25)</td>
<td></td>
</tr>
<tr>
<td>Production and Decay Model</td>
<td>30 (30)</td>
<td>30 (30)</td>
<td>25 (16)</td>
</tr>
<tr>
<td>Statistics</td>
<td>45 (65)</td>
<td>50 (100)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>105 (110)</td>
<td>85 (140)</td>
<td>60 (16)</td>
</tr>
</tbody>
</table>
PDF uncertainties in W mass 90% CL

MT method
Bottom line ~ 22 MeV @ 90%

PT method
Bottom line ~ 35 MeV @ 90%

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PDF sensitivity to Asymmetry

PDF sets 3 and 4

CTEQ PDF sets $\pm 1\sigma$ compared to D0 Asymmetry sensitivity with $\sim 400$ pb$^{-1}$

Projected errors from D0 data
Prospects

- 1 fb\(^{-1}\) samples now available

- Calibration of charged lepton and recoil to 0.1% is very difficult at a hadron collider.
  - Use the Z but not all problems cancel in the W/Z scale ratio

- \(P_T\) becomes more powerful with more statistics. Especially if new data on \(\sigma(y, p_T)\) and W asymmetry constrain the physics models.
Prospects II

- I showed nothing with more than about $\frac{1}{2}$ of the data now recorded by CDF/D0.
- Higher statistics measurements will be coming out over the next year (month!).
Conclusions

- No big surprises, just improvements
More conclusions

- Inclusive jets
  - production measurements with higher energy/statistics -> better $G(x)$
  - kt algorithm works at high luminosity at hadron colliders
- W/Z production
  - Now measured over full rapidity range
  - NNLO predictions being tested
  - enough statistics for asymmetry, polarization, low pt behavior to refine PDF’s and nonperturbative corrections.
- Bosons + jets
  - ALPGEN/pythia models describe the observed rates for multijets and for b jets.
- W mass
  - statistics on the way
  - theoretical errors can be reduced using existing Run II data
  - calibration is hard!