Talk #2

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Drell-Yan Production

Proton

Anti-Proton

Underlying Event

Initial-State Radiation

Anti-Lepton

Lepton

CDF Run 2

Multiple Parton Interactions

Proton

Anti-Proton

Underlying Event

PT(hard)

Outgoing Parton

Outgoing Parton

Outgoing Parton
Recent CDF Run 2 “Underlying Event” Results

- Two Classes of Events: “Leading Jet” and “Back-to-Back”.
- Two “Transverse” regions: “transMAX”, “transMIN”, “transDIF”.
- Data Corrected to the Particle Level: unlike our previous CDF Run 2 “underlying event” analysis which used JetClu to define “jets” and compared uncorrected data with the QCD Monte-Carlo models after detector simulation, this analysis uses the MidPoint jet algorithm and corrects the observables to the particle level. The corrected observables are then compared with the QCD Monte-Carlo models at the particle level.
- For the 1st time we study the energy density in the “transverse” region.

New CDF Run 2 results ($\mathcal{L} = 385$ pb$^{-1}$):
Look at charged particle and calorimeter tower correlations in the azimuthal angle $\Delta \phi$ relative to the leading calorimeter jet (MidPoint, $R = 0.7$, $f_{\text{merge}} = 0.75$, $|\eta| < 2$).

Define $|\Delta \phi| < 60^\circ$ as “Toward”, $60^\circ < -\Delta \phi < 120^\circ$ and $60^\circ < \Delta \phi < 120^\circ$ as “Transverse 1” and “Transverse 2”, and $|\Delta \phi| > 120^\circ$ as “Away”. Each of the two “transverse” regions have area $\Delta \eta \Delta \phi = 2 \times 60^\circ = 4\pi/6$. The overall “transverse” region is the sum of the two transverse regions ($\Delta \eta \Delta \phi = 2 \times 120^\circ = 4\pi/3$).
Look at the \textit{“transverse”} region as defined by the leading jet ($|\eta| < 2$) or by the leading two jets ($|\eta| < 2$). \textit{“Back-to-Back”} events are selected to have at least two jets with Jet#1 and Jet#2 nearly \textit{“back-to-back”} ($\Delta\phi_{12} > 150^\circ$) with almost equal transverse momenta ($P_T(jet#2)/P_T(jet#1) > 0.8$) and $P_T(jet#3) < 15 \text{ GeV/c}$.

- Shows the $\Delta\phi$ dependence of the charged particle density, $dN_{\text{chg}}/d\eta d\phi$, for charged particles in the range $p_T > 0.5 \text{ GeV/c}$ and $|\eta| < 1$ relative to jet#1 (rotated to $270^\circ$) for $30 < E_T(jet#1) < 70 \text{ GeV}$ for \textit{“Leading Jet”} and \textit{“Back-to-Back”} events.
### “Transverse” Observables

#### Particle and Detector Level

<table>
<thead>
<tr>
<th>Observable</th>
<th>Particle Level</th>
<th>Detector Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>( dN_{chg}/d\eta d\phi )</td>
<td>Number of charged particles per unit ( \eta-\phi ) ( (p_T &gt; 0.5 \text{ GeV/c},</td>
<td>\eta</td>
</tr>
<tr>
<td>( d\text{PTsum}/d\eta d\phi )</td>
<td>Scalar ( p_T ) sum of charged particles per unit ( \eta-\phi ) ( (p_T &gt; 0.5 \text{ GeV/c},</td>
<td>\eta</td>
</tr>
<tr>
<td>( \langle p_T \rangle )</td>
<td>Average ( p_T ) of charged particles ( (p_T &gt; 0.5 \text{ GeV/c},</td>
<td>\eta</td>
</tr>
<tr>
<td>PT( \text{max} )</td>
<td>Maximum ( p_T ) charged particle ( (p_T &gt; 0.5 \text{ GeV/c},</td>
<td>\eta</td>
</tr>
<tr>
<td>( d\text{ETsum}/d\eta d\phi )</td>
<td>Scalar ( E_T ) sum of all particles per unit ( \eta-\phi ) ( (\text{all } p_T,</td>
<td>\eta</td>
</tr>
<tr>
<td>PT( \text{sum}/ET\text{sum} )</td>
<td>Scalar ( p_T ) sum of charged particles ( (p_T &gt; 0.5 \text{ GeV/c},</td>
<td>\eta</td>
</tr>
</tbody>
</table>
“TransDIF” is very sensitive to the “hard scattering” component of the “underlying event”!

- Use the leading jet to define the MAX and MIN “transverse” regions on an event-by-event basis with MAX (MIN) having the largest (smallest) charged PTsum density.

- Shows the “transDIF” = MAX-MIN charge PTsum density, \(dPT_{\text{sum}}/d\eta d\phi\), for \(p_T > 0.5\) GeV/c, \(|\eta| < 1\) versus \(P_T(jet#1)\) for “Leading Jet” and “Back-to-Back” events.
Shows the charged particle density, \( dN_{\text{chg}}/d\eta d\phi \), in the “transMAX” and “transMIN” region (\( p_T > 0.5 \text{ GeV/c} \), \( |\eta| < 1 \)) versus \( P_T(\text{jet#1}) \) for “Leading Jet” and “Back-to-Back” events.

Compared the (corrected) data with PYTHIA Tune A (with MPI) and HERWIG (without MPI) at the particle level.
``TransMAX/MIN” PTsum Density
PYTHIA Tune A vs HERWIG

Shows the charged PTsum density, \(dP_{T\text{sum}}/d\eta d\phi\), in the “transMAX” and “transMIN” region (\(p_T > 0.5\) GeV/c, \(|\eta| < 1\)) versus \(P_T(jet#1)\) for “Leading Jet” and “Back-to-Back” events.

Compares the (corrected) data with PYTHIA Tune A (with MPI) and HERWIG (without MPI) at the particle level.
“Transverse” $<P_T>$ and $<P_{T\text{max}}>$

PYTHIA Tune A vs HERWIG

- Shows the average transverse momentum, $<P_T>$, and $<P_{T\text{max}}>$ for charged particles in the “transverse” region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $P_T(\text{jet#1})$ for “Leading Jet” and “Back-to-Back” events.

- Compares the (corrected) data with PYTHIA Tune A (with MPI) and HERWIG (without MPI) at the particle level.
"TransMAX/MIN" ETsum Density
PYTHIA Tune A vs HERWIG

"Leading Jet"
Jet #1 Direction

"Back-to-Back"
Jet #1 Direction

Jet #2 Direction

- Shows the ETsum density, \( \frac{dET_{\text{sum}}}{d\eta d\phi} \), in the "transMAX" and "transMIN" region (all particles \(|\eta| < 1\)) versus \( P_T(\text{jet#1}) \) for "Leading Jet" and "Back-to-Back" events.

- Compares the (corrected) data with PYTHIA Tune A (with MPI) and HERWIG (without MPI) at the particle level.
"Transverse" Charged Fraction
PYTHIA Tune A vs HERWIG

- Shows the PTsum/ETsum in the "transverse" region versus P_T(jet#1) for "Leading Jet" and "Back-to-Back" events, where PTsum is the scalar P_T sum of charged particles (p_T > 0.5 GeV/c, |η| < 1) and ETsum is the scalar E_T sum of all particles (|η| < 1).
- Compares the (corrected) data with PYTHIA Tune A (with MPI) and HERWIG (without MPI) at the particle level.
“TransDIF” is very sensitive to the “hard scattering” component of the “underlying event”!

- Use the leading jet to define the MAX and MIN “transverse” regions on an event-by-event basis with MAX (MIN) having the largest (smallest) charged PTsum density.
- Shows the “transDIF” = MAX-MIN ETsum density, dET_sum/dηdφ, for all particles (|η| < 1) versus Pt(jet#1) for “Leading Jet” and “Back-to-Back” events.

CDF Run 2 Preliminary data corrected to particle level

1.96 TeV

MidPoint R = 0.7 |η(jet#1) < 2

Particles (|η|<1.0, all Pt)
Shows the ETsum density, $dE_T/d\eta d\phi$, in the “transMAX” and “transMIN” region (all particles $|\eta| < 1$) versus $P_T(jet#1)$ for “Leading Jet” and “Back-to-Back” events.

Compares the (corrected) data with PYTHIA Tune A (with MPI) and a tuned version of JIMMY (with MPI, $PT_{JIM} = 3.25$ GeV/c, default = 2.5 GeV/c) at the particle level.

JIMMY was tuned to fit the energy density in the “transverse” region for “leading jet” events!

JIMMY: MPI
J. M. Butterworth
J. R. Forshaw
M. H. Seymour

CDF Run 2 Preliminary
data corrected to particle level

MidPoint $R = 0.7$ $|\eta(jet#1)| < 2$

Particles ($|\eta|<1.0$, all PT)
The Energy in the “Underlying Event” in High $P_T$ Jet Production

"Transverse" $<\text{Densities}>$ vs $P_T(jet#1)$

**JIMMY at CDF**

**JIMMY**
- MPI
- J. M. Butterworth
- J. R. Forshaw
- M. H. Seymour

**JIMMY** was tuned to fit the energy density in the “transverse” region for “leading jet” events!

**JIMMY: MPI**
- J. M. Butterworth
- J. R. Forshaw
- M. H. Seymour

**JIMMY** Runs with HERWIG and adds multiple parton interactions!

**"Hard" Scattering**

- Proton
- AntiProton
- Underlying Event
- Outgoing Parton
- Final-State Radiation

**"Transverse" $<\text{Densities}>$ vs $P_T(jet#1)$**

**TeV4LHC - Fermilab**

**Rick Field - Florida/CDF**

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Shows the charged PTsum density, $dE_{T,\text{sum}}/d\eta d\phi$, in the “transMAX” and “transMIN” region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $P_T$ (jet#1) for “Leading Jet” and “Back-to-Back” events.

Compares the (corrected) data with PYTHIA Tune A (with MPI) and a tuned version of JIMMY (with MPI, $PT_{\text{JIM}} = 3.25$ GeV/c) at the particle level.
Shows the charged particle density, $dN_{\text{chg}}/d\eta d\phi$, in the “transMAX” and “transMIN” region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $p_T$ (jet#1) for “Leading Jet” and “Back-to-Back” events.

Compares the (corrected) data with PYTHIA Tune A (with MPI) and a tuned version of JIMMY (with MPI, $PT_{\text{JIM}} = 3.25$ GeV/c) at the particle level.
“Transverse” $<p_T>$
PYTHIA Tune A vs JIMMY

- Shows the charged particle $<p_T>$ in the “transverse” region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $p_T$ (jet#1) for “Leading Jet” and “Back-to-Back” events.

- Compares the (corrected) data with PYTHIA Tune A (with MPI) and HERWIG and a tuned version of JIMMY (with MPI, PTJIM = 3.25 GeV/c) at the particle level.
“Transverse” PTsum Density
PYTHIA Tune A vs JIMMY

Shows the charged PTsum density in the “transverse” region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $P_T$ for “Leading Jet” and “Back-to-Back” events.

Compares the (corrected) data with PYTHIA Tune A (with MPI) and HERWIG and a tuned version of JIMMY (with MPI, $P_{TJIM} = 3.25$ GeV/c) at the particle level.
**Summary**

- **Particle Level Data:** CDF has new data on the “underlying event” that is corrected to the particle level so that it can be used to tune the QCD Monte-Carlo models without requiring CDF detector simulation!

- **Interesting Physics:** We see interesting dependence of the “underlying event” on the transverse momentum of the leading jet (*i.e.* the $Q^2$ of the hard scattering). For the “leading jet” case the “transMAX” densities rise with increasing $P_T$(jet#1), while for the “back-to-back” case they fall. The rise in the “leading jet” case is due to hard initial and final-state radiation, which has been suppressed in the “back-to-back” events. The “back-to-back” data show a decrease in the “transMIN” densities with increasing $P_T$(jet#1) which is very interesting.

- **PYTHIA Tune A** does not produce enough energy in the “underlying event”! **JIMMY 325** ($PTJIM = 3.25$ GeV/$c$) fits the energy in the “underlying event” but does so by producing too many particles (*i.e.* it is too soft).

- We are making good progress in understanding and modeling the “underlying event”. However, we do not yet have a perfect fit to all the features of the “underlying event”!
The Future

Much more QCD physics to come from the Tevatron!

Some CDF-QCD Group Analyses!

- Jet Cross Sections and Correlations: MidPoint and KT algorithms with $L = 1 \text{ fb}^{-1}$!
- DiJet Mass Distributions: $\Delta\phi$ distribution, compositness.
- Heavy Flavor Jets: $b$-jet and $b$-bar jet cross sections and correlations.
- Z and W Bosons plus Jets: including $b$-jets.
- Jets Fragmentation: jet shapes, momentum distributions, two-particle correlations.
- Underlying Event Studies: distributions as well as averages for charged particles and energy for jet, jet+jet, $\gamma$+jet, $Z$+jet, and Drell-Yan.
- Pile-Up Studies: modeling of pile-up.
- Monte-Carlo Tuning: New Run 2 PYTHIA tune?, tuned JIMMY, PYTHIA 6.3, Sherpa, etc..

Analyses using 1fb$^{-1}$ of data by Winter 2006!