“Underlying Events” Analysis Corrected to the Particle Level

Outline of the Talk

- The goal of this note is to produce 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 (i.e. CDFSIM). Unlike the previous Run 2 “underlying event” analysis which used JetClu to define “jets” and compared uncorrected data with PYTHIA Tune A and HERWIG after detector simulation (CDFSIM), this analyses uses the MidPoint algorithm and corrects the observables to the particle level.

- Look at charged particles \( p_T > 0.5 \text{ GeV/c}, |\eta| < 1 \) and energy (calorimeter towers \( E_T > 0.1 \text{ GeV}, |\eta| < 1 \) in the “transverse” region for both “leading jet” and “back-to-back” events.

- For completeness I will show both the uncorrected data compared with compared with PYTHIA Tune A + CDFSIM with HERWIG + CDFSIM and the corrected observables are compared with PYTHIA Tune A, HERWIG, and tuned JIMMY at the particle level (i.e. generator level).
The “Transverse” Region

Charged Particles
\( p_T > 0.5 \text{ GeV}/c, \ |\eta| < 1 \)

Calorimeter Towers
\( E_T > 0.1 \text{ GeV}, \ |\eta| < 1 \)

- Look at the “transverse” region as defined by the leading calorimeter jet (MidPoint, \( R = 0.7, f_{\text{merge}} = 0.75, |\eta| < 2 \)).
- Study the charged particles \( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1) \) and form the charged particle density, \( dN_{\text{chg}}/d\eta d\phi \), and the charged scalar \( p_T \) sum density, \( dP_{\text{sum}}/d\eta d\phi \).
- Study the calorimeter towers \( (E_T > 0.1 \text{ GeV}, |\eta| < 1) \) and form the scalar \( E_T \) sum density, \( dE_T/d\eta d\phi \).

- Look at the “transverse” regions as defined by the leading jet (MidPoint R = 0.7, |\(\eta| < 2\)) or by the leading two jets (MidPoint R = 0.7, |\(\eta| < 2\)).
- “Back-to-Back” events are selected to have at least two jets with Jet#1 and Jet#2 nearly “back-to-back” (\(\Delta\phi_{12} > 150^\circ\)) with almost equal transverse energies (\(P_T(jet#2)/P_T(jet#1) > 0.8\)) and \(P_T(jet#3) < 15\text{ GeV/c}\).
“Transverse” Observables: Particle and Detector Level

<table>
<thead>
<tr>
<th>Observable</th>
<th>Particle Level</th>
<th>Detector Level</th>
</tr>
</thead>
</table>
| \(dN_{\text{chg}}/d\eta d\phi\) | Number of charged particles per unit \(\eta-\phi\)  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\) | Number of “good” charged tracks per unit \(\eta-\phi\)  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\) |
| \(d\text{PTsum}/d\eta d\phi\) | Scalar \(p_T\) sum of charged particles per unit \(\eta-\phi\)  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\) | Scalar \(p_T\) sum of “good” charged tracks per unit \(\eta-\phi\)  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\) |
| \(<p_T>\) | Average \(p_T\) of charged particles  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\) | Average \(p_T\) of “good” charged tracks  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\) |
| PTmax | Maximum \(p_T\) charged particle  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\)  
P\(\text{PTmax} = 0\) for no charged particle | Maximum \(p_T\) “good” charged tracks  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\)  
P\(\text{PTmax} = 0\) for no “good” charged track |
| \(d\text{ET}/d\eta d\phi\) | Scalar \(E_T\) sum of all particles per unit \(\eta-\phi\)  
\( (\text{all } p_T, |\eta| < 1)\) | Scalar \(E_T\) sum of all calorimeter towers per unit \(\eta-\phi\)  
\( (E_T > 0.1 \text{ GeV}, |\eta| < 1)\) |
| PTsum/ETsum | Scalar \(p_T\) sum of charged particles  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\)  
divided by the scalar \(E_T\) sum of all particles  
\( (\text{all } p_T, |\eta| < 1)\) | Scalar \(p_T\) sum of “good” charged tracks  
\( (p_T > 0.5 \text{ GeV}/c, |\eta| < 1)\)  
divided by the scalar \(E_T\) sum of calorimeter towers  
\( (E_T > 0.1 \text{ GeV}, |\eta| < 1)\) |

- Observables examined in the “transverse” region as they are defined at the particle level and the detector level. The mean charged particle \(<p_T>\) and the charged fraction \(\text{PTsum/ETsum}\) are constructed on and event-by-event basis and then averaged over the events. There is one \(\text{PTmax}\) per event with \(\text{PTmax} = 0\) if there are no charged particles.
“transMAX” and “transMIN” Densities

- Define the MAX and MIN “transverse” regions on an event-by-event basis with MAX (MIN) having the largest (smallest) density. Each of the two “transverse” regions have an area in η-φ space of 4π/6.
- The “transMIN” region is very sensitive to the “beam-beam remnant” and multiple parton interaction components of the “underlying event”.
- The difference, “transDIF” (“transMAX” minus “transMIN”), is very sensitive to the “hard scattering” component of the “underlying event” (i.e. hard initial and final-state radiation).
Monte-Carlo Generation

<table>
<thead>
<tr>
<th>PT(hard) minimum</th>
<th>Events</th>
<th>PT(hard) minimum</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 GeV/c</td>
<td>3,093,106</td>
<td>3 GeV/c</td>
<td>1,014,070</td>
</tr>
<tr>
<td>10 GeV/c</td>
<td>1,039,093</td>
<td>10 GeV/c</td>
<td>1,018,974</td>
</tr>
<tr>
<td>18 GeV/c</td>
<td>4,285,687</td>
<td>18 GeV/c</td>
<td>5,001,261</td>
</tr>
<tr>
<td>40 GeV/c</td>
<td>4,228,873</td>
<td>40 GeV/c</td>
<td>5,071,205</td>
</tr>
<tr>
<td>60 GeV/c</td>
<td>992,087</td>
<td>60 GeV/c</td>
<td>1,044,202</td>
</tr>
<tr>
<td>90 GeV/c</td>
<td>1,497,108</td>
<td>90 GeV/c</td>
<td>2,057,661</td>
</tr>
<tr>
<td>120 GeV/c</td>
<td>2,068,377</td>
<td>120 GeV/c</td>
<td>2,035,473</td>
</tr>
<tr>
<td>150 GeV/c</td>
<td>1,488,786</td>
<td>150 GeV/c</td>
<td>1,922,568</td>
</tr>
<tr>
<td>200 GeV/c</td>
<td>1,042,280</td>
<td>200 GeV/c</td>
<td>968,906</td>
</tr>
<tr>
<td>300 GeV/c</td>
<td>1,045,314</td>
<td>300 GeV/c</td>
<td>885,867</td>
</tr>
<tr>
<td>400 GeV/c</td>
<td>1,043,634</td>
<td>400 GeV/c</td>
<td>858,936</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>21,824,345</strong></td>
<td><strong>Total</strong></td>
<td><strong>21,879,123</strong></td>
</tr>
</tbody>
</table>

- PYTHIA Tune A (5.3.3nt) and HERWIG (5.3.3nt) was generated with the minimum PT(hard) values shown. Stntuples (5.3.3nt dev242) were created for the QCD group by Anwar Bhatti, Ken Hatakeyama, and Craig Group.
Data Selection: “Leading Jet” and “Back-to-Back”

<table>
<thead>
<tr>
<th>Event Selection</th>
<th>Min-Bias</th>
<th>JET20</th>
<th>JET50</th>
<th>JET70</th>
<th>JET100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Events</td>
<td>20,586,733</td>
<td>30,470,383</td>
<td>9,908,366</td>
<td>4,641,247</td>
<td>5,366,515</td>
</tr>
<tr>
<td>“Good” Events (version 7)</td>
<td>18,180,015</td>
<td>19,835,681</td>
<td>6,868,114</td>
<td>3,432,992</td>
<td>4,031,324</td>
</tr>
<tr>
<td>MetSig &lt; 5 GeV$^{1/2}$, sumET &lt; 1.5 TeV</td>
<td>18,179,280</td>
<td>19,818,879</td>
<td>6,785,357</td>
<td>3,316,514</td>
<td>3,602,989</td>
</tr>
<tr>
<td>1 Q12 ZVtx, $</td>
<td>z</td>
<td>&lt; 60$ cm</td>
<td>15,416,180</td>
<td>10,851,963</td>
<td>3,745,616</td>
</tr>
<tr>
<td>“Leading Jet” $</td>
<td>\eta(jet#1) &lt; 2</td>
<td>$</td>
<td>3,712,407</td>
<td>7,679,594</td>
<td>3,200,065</td>
</tr>
<tr>
<td>“Back-to-Back” $P_T(jet#3) &lt; 15$ GeV/c</td>
<td>2,474</td>
<td>1,462,547</td>
<td>878,014</td>
<td>491,930</td>
<td>602,256</td>
</tr>
<tr>
<td>“Back-to-Back”/“Leading Jet”</td>
<td>0.07%</td>
<td>19.04%</td>
<td>27.44%</td>
<td>29.84%</td>
<td>31.96%</td>
</tr>
</tbody>
</table>

• The data used in this analysis arise from the set of Stntuples created for the QCD group by Anwar Bhatti, Ken Hatakeyama, and Craig Group ($L \sim 380$ pb$^{-1}$). Events are required to be on the “goodrun” list (version 7). They are also required to have a missing $E_T$ significance less than 5 GeV$^{1/2}$ and to have a sum$E_T < 1.5$ TeV. Except for the Min-Bias data we require events to have one and only one quality 12 vertex with $|z| < 60$ cm. For the Min-Bias data we allow zero or one quality 12 vertices. This only affects the observables for leading jet $P_T$ below 10 GeV/c. Above $P_T(jet#1) = 10$ GeV/c the fraction of events with no quality 12 vertex is negligible.
**Method 1: Correcting to the Particle Level**

**Method 1 (one step method):**

<table>
<thead>
<tr>
<th>Particle Level Observable</th>
<th>Detector Level Observable</th>
<th>“Response” Factor</th>
<th>“Correction” Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEN = Particle Jet#1 P_T Bin</td>
<td>CDFSIM = Calorimeter Jet#1 P_T Bin (uncorrected)</td>
<td>CDFSIM/GEN</td>
<td>GEN/CDFSIM</td>
</tr>
</tbody>
</table>

- PYTHIA Tune A (or HERWIG) are used to calculate the observables at the particle level in bins of particle jet#1 P_T (GEN) and at the detector level in bins of calorimeter jet#1 P_T (uncorrected). The detector level data in bins of calorimeter jet#1 PT (uncorrected) are corrected by multiplying by QCD Monte-Carlo factor, GEN/CDFSIM.
- Smooth curves have been drawn through the QCD Monte-Carlo predictions to aid in comparing the theory with the data.

Fits to the QCD Monte-Carlo results the density of charged particles in the “transMAX” and “transMIN” regions for “leading jet” events as a function of the leading particle jet P_T for PYTHIA Tune A (left) and HERWIG (right).
Method 2: Correcting to the Particle Level

Method 2 (two step method):

<table>
<thead>
<tr>
<th>Particle Level Observable</th>
<th>Detector Level Observable</th>
<th>“Response” Factor</th>
<th>“Correction” Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEN = Particle Jet#1 (P_T) Bin</td>
<td>CDFSIM = Calorimeter Jet#1 (P_T) Bin (corrected)</td>
<td>CDFSIM/GEN</td>
<td>GEN/CDFSIM</td>
</tr>
</tbody>
</table>

- Correct the leading calorimeter jet \(P_T\) by comparing the matching leading particle jet with the leading calorimeter jet.
- PYTHIA Tune A is used to calculate the observables at the particle level in bins of particle jet#1 \(P_T\) (GEN) and at the detector level in bins of calorimeter jet#1 \(P_T\) (corrected). The detector level data in bins of calorimeter jet#1 \(P_T\) (corrected) are corrected by multiplying by QCD Monte-Carlo factor, GEN/CDFSIM.

Differences between method 1 and 2 used to estimate systematic uncertainties!

Shows the correction to the leading calorimeter jet \(P_T\) from PYTHIA Tune A and HERWIG (left) and the “response” factor from PYTHIA Tune A for method 1 and method 2 (right).
Method 1 “Response” Factors: “Leading Jet” Events

PYTHIA Tune A

HERWIG

“TransMAX” Charged Particle Density: dN/d\eta d\phi

Method 1 “response” factors for the density of charged particles, dN_{chg}/d\eta d\phi, with p_T > 0.5 GeV/c and |\eta| < 1 in the “transMAX” region for “leading jet” events as a function of the leading jet P_T. Shows the particle level prediction (GEN) versus the leading particle jet P_T and the detector level result (CDFSIM) versus the leading calorimeter jet P_T (uncorrected) with |\eta| < 2 for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet P_T (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

**PYTHIA Tune A**

Method 1 “response” factors for the density of charged particles, dNchg/d\(\eta\)d\(\phi\), with p_T > 0.5 GeV/c and |\(\eta\)| < 1 in the “transMIN” region for “leading jet” events as a function of the leading jet P_T. Shows the particle level prediction (GEN) versus the leading particle jet P_T and the detector level result (CDFSIM) versus the leading calorimeter jet P_T (uncorrected) with |\(\eta\)(jet#1)| < 2 for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet P_T (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

**PYTHIA Tune A**

- Charged PTsum Density: $dP_{T}/d\eta d\phi$
- MidPoint R = 0.7 $|\eta(jet)| < 2$
- CDF Run 2 Preliminary
- Charged Particles ($|\eta| < 1.0, P_{T} > 0.5$ GeV/c)

**HERWIG**

- Charged PTsum Density: $dP_{T}/d\eta d\phi$
- MidPoint R = 0.7 $|\eta(jet)| < 2$
- CDF Run 2 Preliminary
- Charged Particles ($|\eta| < 1.0, P_{T} > 0.5$ GeV/c)

Method 1 “response” factors for the PTsum density of charged particles, $dP_{T}/d\eta d\phi$, with $P_{T} > 0.5$ GeV/c and $|\eta| < 1$ in the “transMAX” region for “leading jet” events as a function of the leading jet $P_{T}$. Shows the particle level prediction (GEN) versus the leading particle jet $P_{T}$ and the detector level result (CDFSIM) versus the leading calorimeter jet $P_{T}$ (uncorrected) with $|\eta(jet#1)| < 2$ for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet $P_{T}$ (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

**PYTHIA Tune A**

![Graph showing the "TransMIN" Charged PTsum Density: dPT/d\(\eta\)d\(\phi\) for PYTHIA Tune A.]

**HERWIG**

![Graph showing the "TransMIN" Charged PTsum Density: dPT/d\(\eta\)d\(\phi\) for HERWIG.]

Method 1 “response” factors for the PTsum density of charged particles, dPTsum/d\(\eta\)d\(\phi\), with \(p_T > 0.5\) GeV/c and |\(\eta\)| < 1 in the “transMIN” region for “leading jet” events as a function of the leading jet \(p_T\). Shows the particle level prediction (GEN) versus the leading particle jet \(p_T\) and the detector level result (CDFSIM) versus the leading calorimeter jet \(p_T\) (uncorrected) with |\(\eta\)(jet#1)| < 2 for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet \(p_T\) (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

PYTHIA Tune A

HERWIG

Method 1 “response” factors for the mean charged particle, \( <p_T> \), for \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 1 \) in the “transMIN” region for “leading jet” events as a function of the leading jet \( P_T \). Shows the particle level prediction (GEN) versus the leading particle jet \( P_T \) and the detector level result (CDFSIM) versus the leading calorimeter jet \( P_T \) (uncorrected) with \( |\eta(jet#1)| < 2 \) for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet \( P_T \) (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” factors for the maximum $p_T$ charged particles, $P_T^{\text{max}}$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ in the “transverse” region for “leading jet” events as a function of the leading jet $p_T$. Shows the particle level prediction (GEN) versus the leading particle jet $p_T$ and the detector level result (CDFSIM) versus the leading calorimeter jet $p_T$ (uncorrected) with $|\eta(\text{jet}#1)| < 2$ for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet $p_T$ (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

**PYTHIA Tune A**

**HERWIG**

Method 1 “response” factors for the ETsum density of all particles, $d\mathcal{E}/d\eta d\phi$, with $|\eta| < 1$ in the “transMAX” region for “leading jet” events as a function of the leading jet $P_T$. Shows the particle level prediction (GEN) versus the leading particle jet $P_T$ and the detector level result (CDFSIM) versus the leading calorimeter jet $P_T$ (uncorrected) with $|\eta(\text{jet#1})| < 2$ for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet $P_T$ (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

PYTHIA Tune A

HERWIG

Method 1 “response” factors for the ETsum density of all particles, dET/d\eta d\phi, with |\eta| < 1 in the “transMIN” region for “leading jet” events as a function of the leading jet P_T. Shows the particle level prediction (GEN) versus the leading particle jet P_T and the detector level result (CDFSIM) versus the leading calorimeter jet P_T (uncorrected) with |\eta(jet#1)| < 2 for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet P_T (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

**PYTHIA Tune A**

Method 1 “response” factors for the charged fraction, PTsum/ETsum, in the “transverse” region for “leading jet” events as a function of the leading jet P_T, where PTsum includes charged particles with p_T > 0.5 GeV/c and |\eta| < 1 and the ETsum includes all particles with |\eta| < 1. Shows the particle level prediction (GEN) versus the leading particle jet P_T and the detector level result (CDFSIM) versus the leading calorimeter jet P_T (uncorrected) with |\eta(#jet)| < 2 for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet P_T (i.e. response factor).

**HERWIG**

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Leading Jet” Events

Method 1 “response” factors for the “transMAX”, “transMIN” and the “transverse” region (average of “transMAX” and “transMIN”) for “leading jet” events as a function of the leading jet $P_T$ for PYTHIA Tune A. Shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet $P_T$ (i.e. response factor) for the charged particle density, the charged PTsum density and the energy density.
Method 1 “Response” Factors: “Back-to-Back” Events

**PYTHIA Tune A**

"TransMAX" Charged Particle Density: \(\frac{dN}{d\eta d\phi}\)

<table>
<thead>
<tr>
<th>Transverse Charged Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
</tr>
<tr>
<td>0.25</td>
</tr>
<tr>
<td>0.50</td>
</tr>
<tr>
<td>0.75</td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.25</td>
</tr>
<tr>
<td>1.50</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>PT(jet#1 uncorrected) or PT(particle jet#1) (GeV/c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
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<td>400</td>
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<tr>
<td>450</td>
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<tr>
<td>500</td>
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</table>

**HERWIG**

"TransMAX" Charged Particle Density: \(\frac{dN}{d\eta d\phi}\)

<table>
<thead>
<tr>
<th>Transverse Charged Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
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<tr>
<td>0.25</td>
</tr>
<tr>
<td>0.50</td>
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<tr>
<td>0.75</td>
</tr>
<tr>
<td>1.00</td>
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<tr>
<td>1.25</td>
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<tr>
<td>1.50</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>PT(jet#1 uncorrected) or PT(particle jet#1) (GeV/c)</th>
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</thead>
<tbody>
<tr>
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<td>400</td>
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<tr>
<td>450</td>
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<tr>
<td>500</td>
</tr>
</tbody>
</table>

Method 1 “response” factors for the density of charged particles, \(dN_{chg}/d\eta d\phi\), with \(p_T > 0.5 \text{ GeV/c}\) and \(|\eta| < 1\) in the “transMAX” region for “back-to-back” events as a function of the leading jet \(P_T\). Shows the particle level prediction (GEN) versus the leading particle jet \(P_T\) and the detector level result (CDFSIM) versus the leading calorimeter jet \(P_T\) (uncorrected) with \(|\eta| < 2\) for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet \(P_T\) (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Back-to-Back” Events

**PYTHIA Tune A**

**HERWIG**

Method 1 “response” factors for the density of charged particles, $dN_{ch}/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ in the “transMIN” region for “back-to-back” events as a function of the leading jet $p_T$. Shows the particle level prediction (GEN) versus the leading particle jet $p_T$ and the detector level result (CDFSIM) versus the leading calorimeter jet $p_T$ (uncorrected) with $|\eta(jet#1)| < 2$ for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet $p_T$ (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Back-to-Back” Events

PYTHIA Tune A

HERWIG

CDF Run 2 Preliminary

```
"TransMAX" Charged PTsum Density: dPT/dηdφ

"Back-to-Back"

CFSIM/GEN

CFSIM

GEN

MidPoint R = 0.7 |η(jet)| < 2

1.96 TeV

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

```

```
"TransMAX" Charged PTsum Density: dPT/dηdφ

"Back-to-Back"

CFSIM/GEN

CFSIM

GEN

MidPoint R = 0.7 |η(jet)| < 2

1.96 TeV

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

```

```
"TransMAX" Charged PTsum Density: CDFSIM/GEN

"Back-to-Back"

CFSIM/GEN

CFSIM

HW

PY Tune A

MidPoint R = 0.7 |η(jet)| < 2

1.96 TeV

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

```

Method 1 “response” factors for the PTsum density of charged particles, dPTsum/dηdφ, with pT > 0.5 GeV/c and |η| < 1 in the “transMAX” region for “back-to-back” events as a function of the leading jet PT. Shows the particle level prediction (GEN) versus the leading particle jet PT and the detector level result (CDFSIM) versus the leading calorimeter jet PT (uncorrected) with |η(jet#1)| < 2 for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet PT (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Back-to-Back” Events

**PYTHIA Tune A**

**HERWIG**

Method 1 “response” factors for the PTsum density of charged particles, dPTsum/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 in the “transMIN” region for “back-to-back” events as a function of the leading jet P_T. Shows the particle level prediction (GEN) versus the leading particle jet P_T and the detector level result (CDFSIM) versus the leading calorimeter jet P_T (uncorrected) with |η(jet#1)| < 2 for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet P_T (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Back-to-Back” Events

PYTHIA Tune A

Herwig

Method 1 “response” factors for the mean charged particle, \( <p_T> \), for \( p_T > 0.5 \) GeV/c and \( |\eta| < 1 \) in the “transverse” region for “back-to-back” events as a function of the leading jet \( P_T \). Shows the particle level prediction (GEN) versus the leading particle jet \( P_T \) and the detector level result (CDFSIM) versus the leading calorimeter jet \( P_T \) (uncorrected) with \( |\eta(jet#1)| < 2 \) for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet \( P_T \) (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Back-to-Back” Events

PYTHIA Tune A

HERWIG

Method 1 “response” factors for the maximum $p_T$ charged particle, $PT_{max}$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ in the “transverse” region for “back-to-back” events as a function of the leading jet $p_T$. Shows the particle level prediction (GEN) versus the leading particle jet $p_T$ and the detector level result (CDFSIM) versus the leading calorimeter jet $p_T$ (uncorrected) with $|\eta(jet#1)| < 2$ for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet $p_T$ (i.e. response factor).
Method 1 “Response” Factors: “Back-to-Back” Events

Method 1 “response” factors for the ETsum density of all particles, $dE/d\eta d\phi$, with $|\eta| < 1$ in the “transMAX” region for “back-to-back” events as a function of the leading jet $P_T$. Shows the particle level prediction (GEN) versus the leading particle jet $P_T$ and the detector level result (CDFSIM) versus the leading calorimeter jet $P_T$ (uncorrected) with $|\eta(jet#1)| < 2$ for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN versus the leading jet $P_T$ (i.e. response factor).

“Response” factor for PYTHIA Tune A and HERWIG!
Method 1 “Response” Factors: “Back-to-Back” Events

**PYTHIA Tune A**

**HERWIG**

Method 1 “response” factors for the ETsum density of all particles, $d\mathrm{ET}/d\eta d\phi$, with $|\eta| < 1$ in the “transMIN” region for “back-to-back” events as a function of the leading jet $P_T$. Shows the particle level prediction (GEN) versus the leading particle jet $P_T$ and the detector level result (CDFSIM) versus the leading calorimeter jet $P_T$ (uncorrected) with $|\eta(\text{jet#1})| < 2$ for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN versus the leading jet $P_T$ (*i.e.* response factor).
Method 1 “Response” Factors: “Back-to-Back” Events

**PYTHIA Tune A**

| Method 1 “response” factors for the charged fraction, PTsum/ETsum, in the “transverse” region for “back-to-back” events as a function of the leading jet PT, where PTsum includes charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 1 \) and the ETsum includes all particles with \( |\eta| < 1 \). Shows the particle level prediction (GEN) versus the leading particle jet PT and the detector level result (CDFSIM) versus the leading calorimeter jet PT (uncorrected) with \( |\eta(#1)| < 2 \) for PYTHIA Tune A and HERWIG. Also shows the ratio of the detector level to the particle level, CDFSIM/GEN, versus the leading jet PT (i.e. response factor).
Systematic Uncertainties

- The systematic uncertainty in correcting to the particle level is estimated by combining the two factors shown below. The first factor, $\sigma_1$, comes from correcting the observables to the particle level using method 1 and examining the bin-by-bin difference between PYTHIA Tune A and HERWIG for each observable. The second factor, $\sigma_2$, is set large enough to include the differences between method 1 and method 2 and pile-up (only affects the transverse energy).
- The systematic uncertainty is added in quadrature with the statistical error.

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_1$</td>
<td>Bin by bin difference between the data corrected by PYTHIA Tune A and HERWIG using method 1.</td>
</tr>
<tr>
<td>$\sigma_2$</td>
<td>Difference between method 1 and method 2 and pile-up and miscellaneous (3% for charged particle, 5% for energy)</td>
</tr>
</tbody>
</table>

Data at 1.96 TeV corrected to the particle level using method 1 and method 2 using PYTHIA Tune A. The open red squares are the data corrected to the particle level using method 1 with errors that include both the statistical error and the systematic uncertainty. The black dots are the data corrected to the particle level using method 2 (with no errors).
Charged Particle Density: Detector Level vs Particle Level

“Leading Jet”

“Back-to-Back”

(top) Uncorrected data compared with theory + CDFSIM (bottom) Corrected data compared with theory at the particle level.
Charged Particle Density: Detector Level vs Particle Level

"Leading Jet"

"Transverse" Charged Particle Density: dN/dηdφ

CDF Run 2 Preliminary

"Leading Jet"

data uncorrected

|η|<2

PY Tune A

MidPoint R = 0.7 |η(jet#1)< 2

1.96 TeV

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

PT(jet#1 uncorrected) (GeV/c)

0.0 0.2 0.4 0.6 0.8 1.0

0 50 100 150 200 250 300 350 400 450

"Transverse" Charged Density

"Transverse" Charged Particle Density: dN/dηdφ

CDF Run 2 Preliminary

"Back-to-Back"

"Transverse" Charged Particle Density: dN/dηdφ

CDF Run 2 Preliminary

"Back-to-Back"

data uncorrected

theory + CDFSIM

PY Tune A

MidPoint R = 0.7 |η(jet#1)< 2

1.96 TeV

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

PT(jet#1) uncorrected) (GeV/c)

0.0 0.2 0.4 0.6 0.8 1.0

0 50 100 150 200 250 300 350 400 450

"Transverse" Charged Density

"Transverse" Charged Particle Density: dN/dηdφ

CDF Run 2 Preliminary

"Back-to-Back"

data corrected to particle level

|η|<2

PY Tune A

MidPoint R = 0.7 |η(jet#1)< 2

1.96 TeV

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

PT(jet#1) (GeV/c)

0.0 0.2 0.4 0.6 0.8 1.0

0 50 100 150 200 250 300 350 400 450

"Transverse" Charged Density

"Transverse" Charged Particle Density: dN/dηdφ

CDF Run 2 Preliminary

"Back-to-Back"

data corrected to particle level

|η|<2

PY Tune A

MidPoint R = 0.7 |η(jet#1)< 2

1.96 TeV

Charged Particles (|η|<1.0, PT>0.5 GeV/c)

PT(jet#1) (GeV/c)

0.0 0.2 0.4 0.6 0.8 1.0

0 50 100 150 200 250 300 350 400 450

"Transverse" Charged Density

For Blessing

For Blessing

(top) Uncorrected data compared with theory + CDFSIM (bottom) Corrected data compared with theory at the particle level.
Charged PTsum Density: Detector Level vs Particle Level

"Leading Jet"  
"Back-to-Back"

CDF Run 2 Preliminary

- Uncorrected data compared with theory + CDFSIM
- Corrected data compared with theory at the particle level.

For Blessing

(top) Uncorrected data compared with theory + CDFSIM  
(bottom) Corrected data compared with theory at the particle level.
Charged PTsum Density: Detector Level vs Particle Level

“Leading Jet”

“Back-to-Back”

CDF Run 2 Preliminary

data uncorrected
theory + CDFSIM

PY Tune A
HW

1.96 TeV

MidPoint R = 0.7 |η(jet#1)| < 2
Charged Particles (|η|<1.0, PT>0.5 GeV/c)

CDF Run 2 Preliminary

data uncorrected
to particle level
theory + CDFSIM

PY Tune A

1.96 TeV

MidPoint R = 0.7 |η(jet#1)| < 2
Charged Particles (|η|<1.0, PT>0.5 GeV/c)

For Blessing

(top) Uncorrected data compared with theory + CDFSIM (bottom) Corrected data compared with theory at the particle level.
Charged Average $<\text{PT}>$: Detector Level vs Particle Level

"Leading Jet"

"Transverse" Charged Particle Mean PT

CDF Run 2 Preliminary

data uncorrected
theory + CDFSIM

PY Tune A

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

Charged Particles ($|\eta| < 1.0$, $\text{PT} > 0.5$ GeV/c)

1.96 TeV

For Blessing

(top) Uncorrected data compared with theory + CDFSIM

(bottom) Corrected data compared with theory at the particle level.

"Back-to-Back"

"Transverse" Charged Particle Mean PT

CDF Run 2 Preliminary

data uncorrected
theory + CDFSIM

PY Tune A

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

Charged Particles ($|\eta| < 1.0$, $\text{PT} > 0.5$ GeV/c)

1.96 TeV

For Blessing
Charged PTmax: Detector Level vs Particle Level

"Leading Jet"

"Transverse" Charged PTmax

CDF Run 2 Preliminary data uncorrected theory + CDFSIM

MidPoint R = 0.7 |\eta|<1.0, PT>0.5 GeV/c

Charged Particles (|\eta|<1.0, PT>0.5 GeV/c)

1.96 TeV

PT(jet#1 uncorrected) (GeV/c)

0 50 100 150 200 250 300 350 400 450

"Leading Jet"

PY Tune A

HW

CDF Run 2 Preliminary data corrected to particle level

MidPoint R = 0.7 |\eta|<1.0, PT>0.5 GeV/c

Charged Particles (|\eta|<1.0, PT>0.5 GeV/c)

1.96 TeV

PT(jet#1) (GeV/c)

0 50 100 150 200 250 300 350 400 450

"Back-to-Back"

"Transverse" Charged PTmax

CDF Run 2 Preliminary data uncorrected theory + CDFSIM

MidPoint R = 0.7 |\eta|<1.0, PT>0.5 GeV/c

Charged Particles (|\eta|<1.0, PT>0.5 GeV/c)

1.96 TeV

PT(jet#1 uncorrected) (GeV/c)

0 50 100 150 200 250 300 350 400 450

"Back-to-Back"

"Transverse" Charged PTmax

CDF Run 2 Preliminary data corrected to particle level

MidPoint R = 0.7 |\eta|<1.0, PT>0.5 GeV/c

Charged Particles (|\eta|<1.0, PT>0.5 GeV/c)

1.96 TeV

PT(jet#1) (GeV/c)

0 50 100 150 200 250 300 350 400 450

"Back-to-Back"

For Blessing

For Blessing

(top) Uncorrected data compared with theory + CDFSIM (bottom) Corrected data compared with theory at the particle level.
ETsum Density: Detector Level vs Particle Level

“Leading Jet”

“Back-to-Back”

(top) Uncorrected data compared with theory + CDFSIM (bottom) Corrected data compared with theory at the particle level.
ETsum Density: Detector Level vs Particle Level

**“Leading Jet”**

- CDF Run 2 Preliminary data uncorrected theory + CDFSIM
- MidPoint R = 0.7 \(|\eta(\text{jet})| < 2\)
- Towers (\(|\eta| < 1.0, \text{ET} > 0.1 \text{ GeV}\))
- PY Tune A

**“Back-to-Back”**

- CDF Run 2 Preliminary data uncorrected theory + CDFSIM
- MidPoint R = 0.7 \(|\eta(\text{jet1})| < 2\)
- Towers (\(|\eta| < 1.0, \text{ET} > 0.1 \text{ GeV}\))
- HW

(top) Uncorrected data compared with theory + CDFSIM
(bottom) Corrected data compared with theory at the particle level.
Charged Fraction PTsum/ETsum: Detector Level vs Particle Level

"Leading Jet"

"Back-to-Back"

(top) Uncorrected data compared with theory + CDFSIM (bottom) Corrected data compared with theory at the particle level.

Data at 1.96 TeV on the charged particle density, $dN_{chg}/d\eta d\phi$ with $p_T > 0.5$ GeV/c and $|\eta| < 1$ in the “transMAX” region, “transMIN” region, and “transverse” region (average of “transMAX” and “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet $p_T$ compared with PYTHIA Tune A and HERWIG. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).

Data at 1.96 TeV on the charged PTsum density, \( d\text{PT}_{\text{sum}}/d\eta d\phi \) with \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 1 \) in the “transMAX” region, “transMIN” region, and “transverse” region (average of “transMAX” and “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet PT compared with PYTHIA Tune A and HERWIG. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).
Data at 1.96 TeV on the average $<p_T>$ and the maximum $p_T$, $PT_{max}$, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1$ in the “transverse” region for “leading jet” and “back-to-back” events as a function of the leading jet $P_T$ compared with PYTHIA Tune A and HERWIG. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).

Data at 1.96 TeV on the ETsum density, $dE_T/d\eta d\phi$ for particles with $|\eta| < 1$ in the “transMAX” region, “transMIN” region, and “transverse” region (average of “transMAX” and “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet $P_T$ compared with PYTHIA Tune A and HERWIG. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).
Data at 1.96 TeV on the difference of the “transMAX” and “transMIN” region (“transDIF” = “transMAX” minus “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet $P_T$ compared with PYTHIA Tune A and HERWIG. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).

PYTHIA Tun A and HERWIG agree with the “transDIF” energy density”!
“Leading Jet” Energy Density: HERWIG vs JIMMY

Data at 1.96 TeV on the ETsum density, dE_T/d|η|dφ for particles with |η| < 1 in the “transMAX” region and the “transMIN” region for “leading jet” events as a function of the leading jet P_T compared with PYTHIA Tune A and HERWIG (left) and compared with PYTHIA Tune A and tuned JIMMY (right). JIMMY was tuned to fit the “transverse” energy density (PTJIM = 3.25 GeV/c). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).
“Leading Jet” PTsum Density: HERWIG vs JIMMY

Data at 1.96 TeV on the charged PTsum density, $dP_{T\text{sum}}/d\eta d\phi$ with $P_T > 0.5$ GeV/c and $|\eta| < 1$ in the “transMAX” region and the “transMIN” region for “leading jet” events as a function of the leading jet $P_T$ compared with PYTHIA Tune A and HERWIG (left) and compared with PYTHIA Tune A and tuned JIMMY (right). JIMMY was tuned to fit the “transverse” energy density ($P_T\text{JIM} = 3.25$ GeV/c). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).
“Leading Jet” Nchg Density: HERWIG vs JIMMY

Data at 1.96 TeV on the charged particle density, dN_{ch}/d\eta d\phi with p_T > 0.5 GeV/c and |\eta| < 1 in the “transMAX” region and the “transMIN” region for “leading jet” events as a function of the leading jet P_T compared with PYTHIA Tune A and HERWIG (left) and compared with PYTHIA Tune A and tuned JIMMY (right). JIMMY was tuned to fit the “transverse” energy density (PT\_JIM = 3.25 GeV/c). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).
Data at 1.96 TeV on the ETsum density, $dE_T/d\eta d\phi$ for particles with $|\eta| < 1$ in the “transMAX” region, “transMIN” region, and “transverse” region (average of “transMAX” and “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet $P_T$ compared with PYTHIA Tune A and tuned JIMMY ($PT_{JIM} = 3.25$ GeV/c). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).
Charged PT\text{sum} Density: “Leading Jet” vs “Back-to-Back”

Data at 1.96 TeV on the charged PT\text{sum} density, \( \frac{d\text{PT}_{\text{sum}}}{d\eta d\phi} \) with \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 1 \) in the “transMAX” region, “transMIN” region, and “transverse” region (average of “transMAX” and “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet P\text{T} compared with PYTHIA Tune A and tuned JIMMY (\( \text{PTJIM} = 3.25 \text{ GeV/c} \)). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).
Data at 1.96 TeV on the average $\langle p_T \rangle$ and the maximum $p_T$, $pT_{\text{max}}$, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1$ in the “transverse” region for “leading jet” and “back-to-back” events as a function of the leading jet $p_T$ compared with PYTHIA Tune A and tuned JIMMY ($pT_{\text{JIM}} = 3.25$ GeV/c). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).

Data at 1.96 TeV on the difference of the “transMAX” and “transMIN” region (“transDIF” = “transMAX” minus “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet $P_T$ compared with PYTHIA Tune A and tuned JIMMY ($PT_{JIM} = 3.25$ GeV/c). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).

Data at 1.96 TeV on the charged particle density, \(dN_{\text{chg}}/d\eta d\phi\) with \(p_T > 0.5\) GeV/c and \(|\eta| < 1\) in the “transMAX” region, “transMIN” region, and “transverse” region (average of “transMAX” and “transMIN”) for “leading jet” and “back-to-back” events as a function of the leading jet \(P_T\) compared with PYTHIA Tune A and tuned JIMMY (\(PT_{\text{JIM}} = 3.25\) GeV/c). The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and compared with the theory at the particle level (i.e. generator level).