Outline of Talk

- Review what we learned in Run 1 about “min-bias”, the “underlying event”, and “initial-state radiation”.

- Compare the Run 1 analysis which used the leading “charged particle jet” to define the “underlying event” with Run 2 data.

- Study the “underlying event” in Run 2 as defined by the leading “calorimeter jet” and compare with the “charged particle jet” analysis.

- Study the properties of “charged particle jets” and “calorimeter jets” in Run 2.
Outline of Talk

» Review what we learned in Run 1 about “min-bias”, the “underlying event”, and “initial-state radiation”.

» Compare the Run 1 analysis which used the leading “charged particle jet” to define the “underlying event” with Run 2 data.

» Study the properties of “charged particle jets” and “calorimeter jets” in Run 2.

Also, I have included some thoughts from Michelangelo at the end of my talk.
The “Underlying Event” in Hard Scattering Processes

- What happens when a high energy proton and an antiproton collide?

- Most of the time the proton and antiproton ooze through each other and fall apart (i.e. no hard scattering). The outgoing particles continue in roughly the same direction as initial proton and antiproton. A “Min-Bias” collision.

- Occasionally there will be a “hard” parton-parton collision resulting in large transverse momentum outgoing partons. Also a “Min-Bias” collision.

- The “underlying event” is everything except the two outgoing hard scattered “jets”. It is an unavoidable background to many collider observables.
The “Underlying Event” in Hard Scattering Processes

What happens when a high energy proton and an antiproton collide?

Most of the time the proton and antiproton ooze through each other and fall apart (i.e. no hard scattering). The outgoing particles continue in roughly the same direction as initial proton and antiproton. A “Min-Bias” collision.

Occasionally there will be a “hard” parton-parton collision resulting in large transverse momentum outgoing partons. Also a “Min-Bias” collision.

The “underlying event” is everything except the two outgoing hard scattered “jets”. It is an unavoidable background to many collider observables.

“Min-Bias”

Are these the same?

No!

“underlying event” has initial-state radiation!
The underlying event in a hard scattering process has a “hard” component (particles that arise from initial & final-state radiation and from the outgoing hard scattered partons) and a “soft?” component (“beam-beam remnants”).

Clearly? the “underlying event” in a hard scattering process should not look like a “Min-Bias” event because of the “hard” component (i.e. initial & final-state radiation).

However, perhaps “Min-Bias” collisions are a good model for the “beam-beam remnant” component of the “underlying event”.

The “beam-beam remnant” component is, however, color connected to the “hard” component so this comparison is (at best) an approximation.
PYTHIA models the “soft” component of the underlying event with color string fragmentation, but in addition includes a contribution arising from multiple parton interactions (MPI) in which one interaction is hard and the other is “semi-hard”.

The probability that a hard scattering events also contains a semi-hard multiple parton interaction can be varied but adjusting the cut-off for the MPI.

One can also adjust whether the probability of a MPI depends on the $P_T$ of the hard scattering, $P_T$(hard) (constant cross section or varying with impact parameter).

One can adjust the color connections and flavor of the MPI (singlet or nearest neighbor, q-qbar or glue-glue).

Also, one can adjust how the probability of a MPI depends on $P_T$(hard) (single or double Gaussian matter distribution).
CDF Run 1 “Min-Bias” Data
Charged Particle Density

CDF “Min-Bias” data on the number of charged particles per unit pseudo-rapidity at 630 and 1,800 GeV. There are about 4.2 charged particles per unit $\eta$ in “Min-Bias” collisions at 1.8 TeV ($|\eta| < 1$, all $P_T$).

→ Convert to charged particle density, $dN_{\text{chg}}/d\eta d\phi$, by dividing by $2\pi$. There are about 0.67 charged particles per unit $\eta$-$\phi$ in “Min-Bias” collisions at 1.8 TeV ($|\eta| < 1$, all $P_T$).
CDF Run 1 “Min-Bias” Data
Charged Particle Density

**Charged Particle Pseudo-Rapidity Distribution: \( \frac{dN}{d\eta} \)**

- **CDF Published**
- **CDF Min-Bias 1.8 TeV**
- **CDF Min-Bias 630 GeV**
- **all PT**

- **\( <\frac{dN_{\text{chg}}}{d\eta}> = 4.2 \)**

- **“Min-Bias” data on the number of charged particles per unit pseudo-rapidity at 630 and 1,800 GeV. There are about 4.2 charged particles per unit \( \eta \) in “Min-Bias” collisions at 1.8 TeV (|\( \eta \)| < 1, all PT).

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

- **CDF Published**
- **CDF Min-Bias 630 GeV**
- **CDF Min-Bias 1.8 TeV**
- **all PT**

- **\( <\frac{dN_{\text{chg}}}{d\eta d\phi}> = 0.67 \)**

- **Convert to charged particle density, \( \frac{dN_{\text{chg}}}{d\eta d\phi} \), by dividing by \( 2\pi \). There are about 0.67 charged particles per unit \( \eta-\phi \) in “Min-Bias” collisions at 1.8 TeV (|\( \eta \)| < 1, all \( P_T \)).

- **There are about 0.25 charged particles per unit \( \eta-\phi \) in “Min-Bias” collisions at 1.8 TeV (|\( \eta \)| < 1, \( P_T > 0.5 \) GeV/c).**
CDF Run 1 “Min-Bias” Data

---

**PT Dependence**

- Shows the energy dependence of the charged particle density, dN_{chg}/d\eta d\phi, for “Min-Bias” collisions compared with HERWIG “Soft” Min-Bias.
- Shows the P_T dependence of the charged particle density, dN_{chg}/d\eta d\phi dP_T, for “Min-Bias” collisions at 1.8 TeV collisions compared with HERWIG “Soft” Min-Bias.
- HERWIG “Soft” Min-Bias does not describe the “Min-Bias” data! The “Min-Bias” data contains a lot of “hard” parton-parton collisions which results in many more particles at large P_T than are produces by any “soft” model.

---

CDF Preliminary

CDF Min-Bias data at 1.8 TeV

HW “Soft” Min-Bias at 630 GeV, 1.8 TeV, and 14 TeV

Lots of “hard” scattering in “Min-Bias”!
HERWIG “hard” QCD with $P_T(\text{hard}) > 3$ GeV/c describes well the high $P_T$ tail but produces too many charged particles overall. Not all of the “Min-Bias” collisions have a hard scattering with $P_T(\text{hard}) > 3$ GeV/c!

HERWIG “soft” Min-Bias does not fit the “Min-Bias” data!
Min-Bias: Combining "Hard" and "Soft" Collisions

- HERWIG "hard" QCD with $P_T(hard) > 3$ GeV/c describes well the high $P_T$ tail but produces too many charged particles overall. Not all of the "Min-Bias" collisions have a hard scattering with $P_T(hard) > 3$ GeV/c!

- One cannot run the HERWIG "hard" QCD Monte-Carlo with $P_T(hard) < 3$ GeV/c because the perturbative 2-to-2 cross-sections diverge like $1/P_T(hard)^4$?

CDF Preliminary
PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off parameters, which allows one to run with \( P_T(hard) > 0 \). One can simulate both “hard” and “soft” collisions in one program.

The relative amount of “hard” versus “soft” depends on the cut-off and can be tuned.

This PYTHIA fit predicts that 12% of all “Min-Bias” events are a result of a hard 2-to-2 parton-parton scattering with \( P_T(hard) > 5 \text{ GeV/c} \) (1% with \( P_T(hard) > 10 \text{ GeV/c} \)).

Lots of “hard” scattering in “Min-Bias”!

Tuned to fit the “underlying event”!

12% of “Min-Bias” events have \( P_T(hard) > 5 \text{ GeV/c} \!\!\!\!\!\!\!\!\!\!

1% of “Min-Bias” events have \( P_T(hard) > 10 \text{ GeV/c} \!\!\!\!\!\!\!\!\!\!

PYTHIA Tune A
CDF Run 2 Default

PYTHIA Tune A
CDF Run 2 Default

CDF Published

Pythia 6.206 Set A
CDF Min-Bias 1.8 TeV

1.8 TeV \( |\eta|<1 \)

\( 1.8 \text{ TeV all PT} \)

\( \frac{dN}{d\eta d\phi} \)

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\( \frac{d}{d\phi d\eta} \)
“Underlying Event”
as defined by “Charged particle Jets”

- Charged Jet #1 Direction

<table>
<thead>
<tr>
<th>Charged Jet #1 Direction</th>
<th>Charged Particle Δφ Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Toward”</td>
<td>P_T &gt; 0.5 GeV/c</td>
</tr>
<tr>
<td>“Toward-Side” Jet</td>
<td>“Toward” region is very sensitive to the “underlying event”!</td>
</tr>
<tr>
<td>“Away-Side” Jet</td>
<td>“Away” region</td>
</tr>
</tbody>
</table>

- Look at charged particle density in the “transverse” region!

- Perpendicular to the plane of the 2-to-2 hard scattering

- Charged particle correlations in the azimuthal angle Δφ relative to the leading charged particle jet.

- Define |Δφ| < 60° as “Toward”, 60° < |Δφ| < 120° as “Transverse”, and |Δφ| > 120° as “Away”.

- All three regions have the same size in η-φ space, ΔηxΔφ = 2x120° = 4π/3.
"Transverse" P_T Distribution

Compares the average “transverse” charge particle density with the average “Min-Bias” charge particle density (|\eta|<1, P_T>0.5 GeV). Shows how the “transverse” charge particle density and the Min-Bias charge particle density is distributed in P_T.
Compared the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus $P_T$(charged jet#1) and the $P_T$ distribution of the “transverse” density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD hard scattering predictions of ISAJET 7.32 (default parameters with $P_T$(hard)$>3$ GeV/c).

The predictions of ISAJET are divided into three categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants), charged particles that arise initial-state radiation, and charged particles that arise from the outgoing jets plus final-state radiation.
Plot shows average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus $P_T$ (charged jet #1) compared to the QCD hard scattering predictions of ISAJET 7.32 (default parameters with $P_T$(hard)>3 GeV/c).

The predictions of ISAJET are divided into two categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants); and charged particles that arise from the outgoing jet plus initial and final-state radiation (hard scattering component).
Plot shows average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus $P_T$ (charged jet#1) compared to the QCD hard scattering predictions of HERWIG 5.9 (default parameters with $P_T$(hard)>3 GeV/c).

The predictions of HERWIG are divided into two categories: charged particles that arise from the break-up of the beam and target (beam-beam remnants); and charged particles that arise from the outgoing jet plus initial and final-state radiation (hard scattering component).
HERWIG 6.4
"Transverse” P_T Distribution

HERWIG has the too steep of a P_T dependence of the “beam-beam remnant” component of the “underlying event”!

CDF Data
data uncorrected
theory corrected

1.8 TeV | |<0.5 GeV

Herwig P_T(chgjet#1) > 5 GeV/c
“Transverse” <dNchg/dηdφ> = 0.40

Herwig P_T(chgjet#1) > 30 GeV/c
“Transverse” <dNchg/dηdφ> = 0.51

Compares the average “transverse” charge particle density (|η|<1, P_T>0.5 GeV) versus P_T(charged jet#1) and the P_T distribution of the “transverse” density, dN_{chg}/dηdφdP_T with the QCD hard scattering predictions of HERWIG 6.4 (default parameters with P_T(hard)>3 GeV/c. Shows how the “transverse” charge particle density is distributed in P_T.
Pythia uses multiple parton interactions to enhance the underlying event.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSTP(81)</td>
<td>0</td>
<td>Multiple-Parton Scattering off</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Multiple-Parton Scattering on</td>
</tr>
<tr>
<td>MSTP(82)</td>
<td>1</td>
<td>Multiple interactions assuming the same probability, with an abrupt cut-off $P_T_{\text{min}}=\text{PARP}(81)$</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a single Gaussian matter distribution, with a smooth turn-off $P_{T0} = \text{PARP}(82)$</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a double Gaussian matter distribution (governed by $\text{PARP}(83)$ and $\text{PARP}(84)$), with a smooth turn-off $P_{T0} = \text{PARP}(82)$</td>
</tr>
</tbody>
</table>

Hard Core

Multiple parton interaction more likely in a hard (central) collision!

and now HERWIG!

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

PyTHIA: Multiple Parton Interaction Parameters
## Tuning PYTHIA: Multiple Parton Interaction Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARP(83)</td>
<td>0.5</td>
<td>Double-Gaussian: Fraction of total hadronic matter within PARP(84)</td>
</tr>
<tr>
<td>PARP(84)</td>
<td>0.2</td>
<td>Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.</td>
</tr>
<tr>
<td>PARP(85)</td>
<td>0.33</td>
<td>Probability that the MPI produces two gluons with color connections to the “nearest neighbors.”</td>
</tr>
<tr>
<td>PARP(86)</td>
<td>0.66</td>
<td>Probability that the MPI produces two gluons either as described by PARP(85) or as a closed gluon loop. The remaining fraction consists of quark-antiquark pairs.</td>
</tr>
<tr>
<td>PARP(89)</td>
<td>1 TeV</td>
<td>Determines the reference energy $E_0$.</td>
</tr>
<tr>
<td>PARP(90)</td>
<td>0.16</td>
<td>Determines the energy dependence of the cut-off $P_{T0}$ as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)\varepsilon$ with $\varepsilon = PARP(90)$</td>
</tr>
<tr>
<td>PARP(67)</td>
<td>1.0</td>
<td>A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.</td>
</tr>
</tbody>
</table>

- **Hard Core**: Affects the amount of initial-state radiation!
- **Multiple Parton Interaction**: Determine by comparing with 630 GeV data!
- **Take $E_0 = 1.8$ TeV**: Reference point at 1.8 TeV
"Transverse" Charged Particle Density: $dN/d\eta d\phi$

Plot shows the “Transverse” charged particle density versus $P_T(chgjet#1)$ compared to the QCD hard scattering predictions of **PYTHIA 6.206** ($P_T(hard) > 0$) using the default parameters for multiple parton interactions and CTEQ3L, CTEQ4L, and CTEQ5L.

Default parameters give very poor description of the “underlying event”!

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<td>MSTP(81)</td>
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<tr>
<td>MSTP(82)</td>
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<td>PARP(81)</td>
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<td>2.1</td>
<td>2.1</td>
<td>1.9</td>
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<tr>
<td>PARP(89)</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>PARP(90)</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td></td>
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<tr>
<td>PARP(67)</td>
<td>4.0</td>
<td>4.0</td>
<td>1.0</td>
<td>1.0</td>
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</table>

Note Change
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)
Plot shows the “Transverse” charged particle density versus $P_T(\text{chgjet#1})$ compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Tune A (PARP(67)=4)).
Predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for the azimuthal angle, $\Delta \phi$, between a $b$-quark with $P_T^1 > 15$ GeV/c, $|y_1| < 1$ and $b\bar{b}$-quark with $P_T^2 > 10$ GeV/c, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta \phi$ ($\mu b/^{\circ}$) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.
Predictions of HERWIG 6.4 (CTEQ5L) for the azimuthal angle, $\Delta \phi$, between a b-quark with $PT_1 > 15$ GeV/c, $|y_1| < 1$ and bbar-quark with $PT_2 > 10$ GeV/c, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta \phi$ ($\mu b/^{\circ}$) for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.
Predictions of PYTHIA 6.158 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for diphoton system PT and the azimuthal angle, $\Delta\phi$, between a photon with $PT_1 > 12$ GeV/c, $|y_1| < 0.9$ and photon with $PT_2 > 12$ GeV/c, $|y_2| < 0.9$ in proton-antiproton collisions at 1.8 TeV compared with CDF data.
Compares the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus $P_T$(charged jet#1) and the $P_T$ distribution of the “transverse” density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD Monte-Carlo predictions of two tuned versions of PYTHIA 6.206 ($P_T$(hard) > 0, CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).
Plots show CDF data on the charge particle density and the charged PT\textsubscript{sum} density in the “transverse” region.

The data are compared with the QCD Monte-Carlo predictions of HERWIG 6.4 (CTEQ5L, P\textsubscript{T}(hard) > 3 GeV/c) and two tuned versions of PYTHIA 6.206 (P\textsubscript{T}(hard) > 0).
"Min-Bias" collision events are used in this comparison.

Compared the average "transverse" charge particle density ($\eta < 1$, $P_T > 0.5$ GeV) versus $P_T$ (charged jet#1) and the $P_T$ distribution of the "transverse" and "Min-Bias" densities with the QCD Monte-Carlo predictions of a tuned version of PYTHIA 6.206 ($P_T$(hard) > 0, CTEQ5L, Set A). Describes "Min-Bias" collisions!
Compared the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus $P_T$(charged jet#1) and the $P_T$ distribution of the “transverse” and “Min-Bias” densities with the QCD Monte-Carlo predictions of a tuned version of PYTHIA 6.206 ($P_T$(hard) > 0, CTEQ5L, Set A). Describes “Min-Bias” collisions! Describes the “underlying event”!
Shows the average “transverse” charge particle density (|\eta|<1, P_T>0.5 GeV, corrected) and the true (|\eta|<1, P_T>0) “transverse” charged particle density, dN_{chg}/d\eta d\phi predicted by HERWIG 6.4 (P_T(hard) > 3 GeV/c, CTEQ5L) and two tuned versions of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A & Set C).

There are roughly 1.4 charged particles per unit \eta-\phi (P_T > 0) in the “transverse” region compared to 0.67 for a typical CDF “Min-Bias” collision (9 charged particles per unit \eta compared to 4).
Shows the average “transverse” charge $P_T^{\text{sum}}$ density ($|\eta|<1, P_T>0.5$ GeV, corrected) and the true ($|\eta|<1, P_T>0$) “transverse” charged $P_T^{\text{sum}}$ density, $dP_T^{\text{sum}}/d\eta d\phi$ predicted by HERWIG 6.4 ($P_T^{(\text{hard})} > 3$ GeV/c, CTEQ5L) and two tuned versions of PYTHIA 6.206 ($P_T^{(\text{hard})} > 0$, CTEQ5L, Set A & Set C).

There is roughly 1 GeV/c per unit $\eta-\phi$ ($P_T > 0$) from charged particles in the “transverse” region for $P_T^{(\text{ch}g\text{jet#1})} = 35$ GeV/c. Note, however, that the “transverse” charged $P_T^{\text{sum}}$ density increases rapidly as $P_T^{(\text{ch}g\text{jet#1})}$ increases.
“Transverse” Charged Particle Density

“Transverse” region as defined by the leading “charged particle jet”

-Charged Particle Jet #1

Direction

Δφ

“Toward”

“Transverse”

“Away”

Excellent agreement between Run 1 and 2!

Shows the “transverse” charge particle density (|η|<1, \(P_T>0.5\) GeV) as a function of the transverse momentum of the leading charged particle jet from Run 1.

Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1. The errors on the (uncorrected) Run 2 data include both statistical and correlated systematic uncertainties.
“Transverse” Charged Particle Density

Show the data on the average “transverse” charge particle density $dN/d\eta d\phi$ as a function of the transverse momentum of the leading charged particle jet from Run 1.

Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1. The errors on the (uncorrected) Run 2 data include both statistical and systematic uncertainties.

Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (i.e. after CDFSIM).

PYTHIA Tune A was tuned to fit the “underlying event” in Run I!
“Transverse” Charged PTsum Density

- Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (i.e. after CDFSIM).
- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1. The errors on the (uncorrected) Run 2 data include both statistical and correlated systematic uncertainties.
- Shows the agreement between Run 1 and 2!
“Transverse” Charged PTsum Density

Shows the data on the average “transverse” charged PTsum density ($|\eta|<1$, $P_T>0.5$ GeV) as a function of the transverse momentum of the leading charged particle jet from Run 1.

Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1. The errors on the (uncorrected) Run 2 data include both statistical and correlated systematic uncertainties.

Shows the prediction of PYTHIA Tune A at 1.96 TeV after detector simulation (i.e. after CDFSIM).

PYTHIA Tune A was tuned to fit the “underlying event” in Run 1!
shows the “matched” JetClu jet $E_T$ versus the transverse momentum of the leading “charged particle jet” (closest jet within $R = 0.7$ of the leading jet).

The leading chgjet comes from a JetClu jet that is, on the average, about 90% charged!

shows the ratio of $P_T$(chgjet#1) to the “matched” JetClu jet $E_T$ versus $P_T$(chgjet#1).
Relationship Between “Calorimeter” and “Charged Particle” Jets

- Shows the “matched” JetClu jet $E_T$ versus the transverse momentum of the leading “charged particle jet” (closest jet within $R = 0.7$ of the leading chgjet).

- Shows the EM fraction of the “matched” JetClu jet and the EM fraction of a typical JetClu jet.
Look at charged particle correlations in the azimuthal angle $\Delta \phi$ relative to the leading JetClu jet.

- Define $|\Delta \phi| < 60^\circ$ as “Toward”, $60^\circ < |\Delta \phi| < 120^\circ$ as “Transverse”, and $|\Delta \phi| > 120^\circ$ as “Away”.
- All three regions have the same size in $\eta$-$\phi$ space, $\Delta \eta \times \Delta \phi = 2 \times 120^\circ = 4\pi/3$. 

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"Transverse" Charged Particle Density

![Diagram showing the "Transverse" region as defined by the leading calorimeter jet.]

Shows the data on the average "transverse" charge particle density ($|\eta|<1$, PT>$0.5$ GeV) as a function of the transverse energy of the leading JetClu jet ($R = 0.7$, $|\eta(jet)| < 2$) from Run 2, compared with PYTHIA Tune A after CDFSIM.
"Transverse" Charged Particle Density

- Shows the data on the average "transverse" charge particle density (|\(\eta\)|<1, PT>0.5 GeV) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |\(\eta\)(jet)| < 2) from Run 2, compared with PYTHIA Tune A after CDFSIM.

- Compares the "transverse" region of the leading "charged particle jet", chgjet#1, with the "transverse" region of the leading "calorimeter jet" (JetClu R = 0.7), jet#1.
Shows the data on the average "transverse" charged PTsum density ($|\eta|<1$, PT>0.5 GeV) as a function of the transverse energy of the leading JetClu jet (R = 0.7, $|\eta(jet)| < 2$) from Run 2, compared with PYTHIA Tune A after CDFSIM.
Shows the data on the average “transverse” charged PTsum density ($|\eta|<1$, PT$>0.5$ GeV) as a function of the transverse energy of the leading JetClu jet ($R = 0.7$, $|\eta(jet)| < 2$) from Run 2, compared with PYTHIA Tune A after CDFSIM.

Compares the “transverse” region of the leading “charged particle jet”, chgjet#1, with the “transverse” region of the leading “calorimeter jet” (JetClu $R = 0.7$), jet#1.
"Transverse" Charged Particle Density

Shows the data on the average “transverse” charge particle density (|η|<1, PT>0.5 GeV) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |η(jet)| < 2) from Run 2, compared with PYTHIA Tune A after CDFSIM.
“Transverse” Charged Particle Density

Shows the data on the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) as a function of the transverse energy of the leading JetClu jet ($R = 0.7$, $|\eta(jet)| < 2$) from Run 2, compared with PYTHIA Tune A after CDFSIM.

 Shows the generated prediction of PYTHIA Tune A before CDFSIM.

 Shows the ratio CDFSIM/Generated for PYTHIA Tune A.
The Leading “Charged Particle” Jet

- Shows the data on the average number of charged particles within the leading “charged particle jet” (|\(\eta|\leq 1\), \(P_T > 0.5\) GeV, \(R = 0.7\)) as a function of the transverse momentum of the leading “charged particle jet” from Run 1.

Excellent agreement between Run 1 and 2!

- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1. The errors on the (uncorrected) Run 2 data include both statistical and correlated systematic uncertainties.
The Leading “Charged Particle” Jet

- Shows the data on the average number of charged particles within the leading “charged particle jet” (|η|<1, \(P_T>0.5 \text{ GeV}, R = 0.7\)) as a function of the transverse momentum of the leading “charged particle jet” from Run 1.

- Compares the Run 2 data (Min-Bias, JET20, JET50, JET70, JET100) with Run 1. The errors on the (uncorrected) Run 2 data include both statistical and correlated systematic uncertainties.

Excellent agreement between Run 1 and 2!

PYTHIA produces too many charged particles in the leading “charged particle jet”!
The Leading “Calorimeter” Jet

- Shows the Run 2 data on the average number of charged particles (|\(\eta\)|<1, \(P_T\)>0.5 GeV, \(R = 0.7\)) within the leading “calorimeter jet” (JetClu \(R = 0.7, |\eta(jet)| < 0.7\)) as a function of the transverse energy of the leading “calorimeter jet”.

- Compares the number of charged particles within the leading “calorimeter jet” (JetClu \(R = 0.7, |\eta(jet)| < 0.7\)) with the number of charged particles within the leading “charged particle jet” (JetClu \(R = 0.7\)), jet#1.

PYTHIA produces too many charged particles in the leading “calorimeter jet”!
**The Leading “Jet”**

- Shows charged particle multiplicity distribution ($|\eta|<1, P_T>0.5 \text{ GeV/c}$) within the leading “charged particle jet” and in the “transverse” region as defined by the leading “charged particle jet” for the range $30 < P_T(\text{chgjet#1}) < 70 \text{ GeV/c}$ compared with PYTHIA Tune A.

- Shows charged particle multiplicity distribution ($|\eta|<1, P_T>0.5 \text{ GeV/c}$) within the leading “calorimeter jet” (JetClu, $R = 0.7$, $|\eta(\text{jet})| < 0.7$) and in the “transverse” regions as defined by the leading “calorimeter jet” (JetClu, $R = 0.7$, $|\eta(\text{jet})| < 2$) for the range $30 < E_T(\text{jet#1}) < 70 \text{ GeV}$ compared with PYTHIA Tune A.
The Leading “Jet”

- Shows charged particle multiplicity distribution ($|\eta|<1$, $P_T>0.5$ GeV/c) within the leading “charged particle jet” and in the “transverse” regions as defined by the leading “charged particle jet” for the range $30 < P_T(\text{chgjet#1}) < 70$ GeV/c compared with PYTHIA Tune A.

PYTHIA Tune A describes the “underlying event”!

But PYTHIA produces too many charged particles within the leading “jet”!
The Leading “Calorimeter” Jet

Charged Particle Multiplicity

→ Shows the Run 2 data on the average number of charged particles (|η|<1, P_T>0.5 GeV, R = 0.7) within the leading “calorimeter jet” (JetClu R = 0.7, |η(jet)|< 0.7) as a function of E_T(jet#1) compared with PYTHIA Tune A after CDFSIM.

→ Shows the generated prediction of PYTHIA Tune A before CDFSIM.

→ Shows the ratio CDFSIM/Generated for PYTHIA Tune A.

→ Shows “corrected” Run 2 data compared with PYTHIA Tune A (uncorrected).
The Leading “Calorimeter” Jet Charged Particle Multiplicity

- Shows the Run 2 data on the average number of charged particles (|\eta|<1, P_T>0.5 GeV, \( R = 0.7 \)) within the leading “calorimeter jet” (JetClu \( R = 0.7 \), |\eta(jet)|< 0.7) as a function of \( E_T(jet#1) \) compared with PYTHIA Tune A after CDFSIM.

- Shows the ratio CDFSIM/Generated for PYTHIA Tune A before CDFSIM.

- Correction becomes large for \( E_T(jet#1) > 100 \) GeV and depends on \( E_T(jet#1) \)!

- Shows the generated prediction of PYTHIA Tune A.

CDF Preliminary data uncorrected

Average Nchg Charged Particles (|\eta|<1.0, P_T>0.5 GeV/c)

JetClu R = 0.7 |\eta(jet)| < 0.7

PY Tune A Generated
PY Tune A + CDFSIM
CDF Run 2 Uncorrected
The Leading “Calorimeter” Jet
Charged Particle Multiplicity

- Shows the Run 2 data on the average number of charged particles \(|\eta|<1, P_T>0.5\text{ GeV, } R=0.7\) within the leading “calorimeter jet” (JetClu R = 0.7, \(|\eta|<0.7\)) as a function of ET(jet#1) compared with PYTHIA Tune A after CDFSIM.

- Shows the generated prediction of PYTHIA Tune A before CDFSIM.

- Shows the ratio CDFSIM/Generated for PYTHIA Tune A.

- Shows “corrected” Run 2 data compared with PYTHIA Tune A (uncorrected).

- Multiply data by the “unfolding function” determined from PYTHIA Tune A to get “corrected” data.
The Leading “Calorimeter” Jet
Charged Particle Multiplicity

![Diagram showing charged particle multiplicity distribution.]

- Shows charged particle multiplicity distribution (|\eta| < 1, \text{PT} > 0.5 \text{GeV/c}) within the leading “calorimeter jet” (JetClu, R = 0.7, |\eta(jet)| < 0.7) for the range 30 < E_T(jet#1) < 70 GeV compared with PYTHIA Tune A before and after CDFSIM.

**Small correction for 30 < E_T(jet#1) < 70 GeV!**

**PYTHIA produces too many charged particles within the leading “jet”!**
The Leading “Jet”

- Shows the transverse momentum distribution of charged particles (|η|<1) within the leading “charged particle jet” compared with PYTHIA Tune A. The plot shows dN_{chg}/dz with \( z = P_T / P_T(\text{chgjet#1}) \) for the range 30 < \( P_T(\text{chgjet#1}) < 70 \) GeV/c.

- Shows the transverse momentum distribution of charged particles (|η|<1) within the leading “calorimeter jet” (JetClu, \( R = 0.7 \), |η(jet)| < 0.7) compared with PYTHIA Tune A. The plot shows dN_{chg}/dz with \( z = P_T / E_T(\text{jet#1}) \) for the range 30 < \( E_T(\text{jet#1}) < 70 \) GeV.
SHOWS THE TRANSVERSE MOMENTUM DISTRIBUTION OF CHARGED PARTICLES (|η|<1) WITHIN THE LEADING "CHARGED PARTICLE JET" COMPARED WITH PYTHIA TUNE A. THE PLOT SHOWS dN/dz WITH z = PT/PT(chgjet#1) FOR THE RANGE 30 < PT(chgjet#1) < 70 GeV/c.

PYTHIA PRODUCES TOO MANY "SOFT" CHARGED PARTICLES WITHIN THE LEADING "JET"!
The Leading “Calorimeter Jet”

Shows average charged PTsum fraction, \( \text{PTsum}/E_T(\text{jet#1}) \), and the average charged PTmax fraction, \( \text{PTmax}/E_T(\text{jet#1}) \), within the leading “calorimeter jet” (JetClu, \( R = 0.7 \), \( |\eta(\text{jet})| < 0.7 \)) compared with PYTHIA Tune A.

Shows distribution of the charged PTsum fraction, \( z = \text{PTsum}/E_T(\text{jet#1}) \), and the distribution of charged PTmax fraction, \( z = \text{PTmax}/E_T(\text{jet#1}) \), within the leading “calorimeter jet” (JetClu, \( R = 0.7 \), \( |\eta(\text{jet})| < 0.7 \)) for the range \( 95 < E_T(\text{jet#1}) < 130 \text{ GeV} \) compared with PYTHIA Tune A.
The Leading "Calorimeter Jet"

Shows average charged PTsum fraction, PTsum/ET(jet#1), and the average charged PTmax fraction, PTmax/ET(jet#1) within the leading "calorimeter jet" (JetClu, R = 0.7, |\(\eta(\text{jet})| < 0.7\)) compared with CDF Preliminary data uncorrected, theory corrected, and PYTHIA Tune A 1.96 TeV Charged Particles (|\(\eta| < 1.0, \text{PT} > 0.5 \text{GeV/c}\)).

PYTHIA does okay on the charged PTmax fraction! But PYTHIA does not do well on the charged PTsum fraction!
The Leading “Calorimeter” Jet
Charged $P_T$ sum Fraction

⇒ Shows average charged $P_T$sum fraction, $P_T$sum/$E_T$(jet#1), within the leading “calorimeter jet” (JetClu, $R = 0.7$, $|\eta(jet)| < 0.7$) compared with PYTHIA Tune A after CDFSIM.
The Leading “Calorimeter” Jet
Charged PT\text{sum} Fraction

- Shows average charged PT\text{sum} fraction, PT\text{sum}/E_T(jet\#1), within the leading “calorimeter jet” (JetClu, R = 0.7, |\eta(jet)| < 0.7) compared with PYTHIA Tune A after CDFSIM.
- Shows the generated prediction of PYTHIA Tune A before CDFSIM.
- Shows the ratio CDFSIM/Generated for PYTHIA Tune A.
- Shows “corrected” Run 2 data compared with PYTHIA Tune A (uncorrected).
The Leading “Calorimeter” Jet
Charged PTsum Fraction

- Shows average charged PTsum fraction, PTsum/ET(jet#1), within the leading “calorimeter jet” (JetClu, R = 0.7, |η(jet)| < 0.7) compared with PYTHIA Tune A after CDFSIM.
- Shows the generated prediction of PYTHIA Tune A before CDFSIM.
- Shows the ratio CDFSIM/Generated for PYTHIA Tune A.
- Shows “corrected” Run 2 data compared with PYTHIA Tune A (uncorrected).

Multiply data by the “unfolding function” determined from PYTHIA Tune A to get “corrected” data.

Very large correction that depends on ET(jet#1)!
Shows distribution of the charged PTsum fraction, $z = \text{PTsum}/\text{ET}(\text{jet#1})$, within the leading “calorimeter jet” (JetClu, $R = 0.7$, $|\eta(\text{jet})| < 0.7$) for the range $95 < \text{ET}(\text{jet#1}) < 130$ GeV compared with PYTHIA Tune A before and after CDFSIM.

I could multiply data by the “unfolding function” determined from PYTHIA Tune A?... BUT could I trust the result? ???
Systematic errors due to initial-state radiation can be estimated by comparing PYTHIA Tune A (more radiation) and PYTHIA Tune B (less radiation).

But it is also important it always compare PYTHIA and HERWIG!

The best is to compare all three: PYTHIA (Tune A & B) and HERWIG.
There is excellent agreement between the Run 1 and the Run 2. The "underlying event" is the same in Run 2 as in Run 1 but now we can study the evolution out to much higher energies!

PYTHIA Tune A does a good job of describing the "underlying event" in the Run 2 data as defined by "charged particle jets" and as defined by "calorimeter jets". HERWIG Run 2 comparisons will be coming soon!

Lots more CDF Run 2 data to come including MAX/MIN "transverse" and MAX/MIN "cones".

Also see Mario’s Run 2 “energy flow” analysis!
The determination of the top mass will unfortunately have to rely on some MC input. This is true even in absence of backgrounds. It is therefore useful to start right away separating the background-related issues with the signal-related ones. Let us start from the signal.

Let us assume there is no background contamination and we isolated a pure sample of t-tbar events. The key experimental systematics will then be related to:

- light jet energy scale
- b jet energy scale
- initial/final-state radiation effects
- acceptance/event selection biases

Information on the corrections which have to be applied to the data is obtained through control samples (e.g. gamma+jet or Z+jets for the e-scale of light jets). However more work is required to transport these energy corrections to the physically different environment of light jets in a t-tbar final state. The "porting" procedure, which is driven by MC modeling, needs to be validated, and its systematics established.
Reasons why the porting of e-scale corrections is non-trivial (namely requires model-dependent corrections) include:

- light jets in top events arise from W decays. Their properties (energy, multiplicity, fragmentation function) are fixed in the W rest frame. When the W is boosted, the jet's ET will change, but properties like multiplicity and fragmentation function won't (up to detector effects). Therefore a 20 GeV or an 80 GeV light jet in top decays behave as a 40 GeV jet, boosted to 20 or 80 GeV, rather than as a 20 or 80 GeV jet produced as a recoil to a gamma or a Z.

- a similar comment applies to b jets, for the same reason.

- light jets in top decays are dominated by quarks, while in any other control sample there will typically be gluons as well; so the features of the jets are different.

Studies which should be performed to validate the procedures should include:

- a study of the fragmentation function (or even more inclusive observables, such as jet shapes, jet energy profiles) for light jets and b-tagged jets in top-rich samples.

- a study of frag-function (or more inclusive observables, as above) in the e-scale-fixing control samples (gamma+jet, Z+jet).
The exercise can start even before the data have statistics large enough. For example, it would be good to compare the properties of the jets in the two MC samples (in other words, to compare the MC predictions for the structure of a 40 GeV jet recoiling against a gamma, and a 40 gev jet form top decay), as well as simulating how large the MC predicts the corrections will have to be. If the differences/corrections are small, we can gain confidence that this won't be a problem (the same exercise will have to be repeated using PYTHIA and HERWIG, at least). If the differences/corrections are large, we will need a careful planning of MC-validation measurements.

Information about the description of the ISR and FSR has to be brought into the game. All studies done on the structure of the UE in Z/W events (see work done by Rick) have to be brought into a t-mass measurement perspective. Assuming that most extra jet form ISR in top events will come at large rapidity, a possible first observable could be the rapidity distribution of soft jets in t-tbar events. In order to test the ISR performance of the MC’s on control samples which share some of the physics of t-tbar events, I would propose the following:

- large-mass DY events (take events with DY masses as close as possible to 2 mtop; the statistics is lousy, if non 0. one should then go to masses as large as possible, and monitor the jet activity as a function of DY mass).
A Few Thoughts

- large mass dijets: take events with two high-pt, central jets (within eta<1), and study the extra-jet activity as a function of the dijet mass. Extra jets well separated from the leading 2 jets will most likely arise from ISR (the MC can help deciding how to define the extra jets to optimize this requirement; maybe a cut in deltaR is enough, maybe a request eta>2 is better). Tests done in the region of dijet mass close to 400 gev will provide strong constraints on the mc description of isr in t-tbar events.

- Other issues:
  - Calibrating the light jets "on site" using the W mass constraint on an event-by-event basis is useful, but is not an unambiguous procedure. Since we have two jets, there is an infinite number of ways in which the energy of the two jets can be independently rescaled, all leading to the W mass, but each leading to a different value for the W momentum (which is the ingredient entering in the top mass fit). Whatever the recipe to calibrate light jets, the impact of this ambiguity should be established (the MC, however inaccurate, should be enough to assess this systematics).
  - In W decays we'll typically have a 3rd jet. Whether or not this appears as an independent jet after the W boost requires some study. Any algorithm aimed at establishing rules for the acceptance or rejection of extra jets (or for the dynamical rescaling of the jet cones, to try absorb the extra jet) ultimately requires validation, and to first approximation requires an evaluation of the systematics based on the MC.
In general, I would expect the MC to describe well these decays, since the physics was constrained by the 3 jet decays at LEP. It is important to verify whether the MC has matrix element corrections. PYTHIA, as well as the most recent versions of HERWIG, have them in,

Background issues: Here the problem is mostly to understand how the background affects the MC validation procedures which use the top-enhanced sample.

The issue can be tackled by ensuring that the MC's for the background correctly reproduce the jet properties in background-dominated samples. So the above analyses should be repeated using, for example, non-b tagged W+3/4 jets final states (or, even better, Z+3/4 jets). The statistics is larger, so I would look at fragmentation functions, jet shapes, inter-jet radiation patterns.

The whole process will take a long time, and will need coordination with the QCD group. The question "what do we do if the MC's don't describe the data or "ok, the MC seems fine, what's next" can only be addressed once we have made a first pass.