A Closer Look at the “Underlying Event” in Run 2:  
PYTHIA Tune A vs HERWIG

Outline of the Talk

• Look at charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and study the charged particle and $P_T\text{sum}$ densities in the **MAX and MIN “transverse” regions** as defined by the leading calorimeter jet (JetClu, $R = 0.7$, $|\eta| < 2$) for both “leading jet” and “back-to-back” events. Compare with **PYTHIA Tune A + CDFSIM with HERWIG + CDFSIM**.

• Use the highest $p_T$ particle in the “transverse” region to define “associated” densities and look at “jets structure” in the “underlying event” (*i.e.* the “transverse” region). **Do the particles in the “underlying event” come from “jets”?**

• Compare the “birth” of jet#3 in the “transverse” region with the “birth” of jet#1 in “min-bias” collisions.

“Wish list” from the CERN MC Workshop!
The “Transverse” Region

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

- Look at the “transverse” region as defined by the leading calorimeter jet (JetClu R = 0.7, $|\eta| < 2$).
- Study the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) and form the charged particle density, $dN_{ch}/d\eta d\phi$, and the charged scalar $p_T$ sum density, $dP_{T\text{sum}}/d\eta d\phi$. Each region “toward”, “away”, and “transverse” region has an area in $\eta$-$\phi$ space of $4\pi/3$. 

Use the leading jet to define the “transverse” region.

Look at the density of charged particles in the “transverse” region.

- Look at the “transverse” regions as defined by the leading jet (JetClu $R = 0.7$, $|\eta| < 2$) or by the leading two jets (JetClu $R = 0.7$, $|\eta| < 2$).
- “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 ($E_T(jet#2)/E_T(jet#1) > 0.8$).

- Shows the $\Delta \phi$ dependence of the charged particle density, $dN/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for $30 < E_T(jet#1) < 70$ GeV for “leading jet” and “back-to-back” events.
- Also shows charged particle density, $dN/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “min-bias” collisions.

- Shows the $\Delta \phi$ dependence of the charged particle density, $dN/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to $270^\circ$) for $30 < E_T(\text{jet#1}) < 70$ GeV for “leading jet” and “back-to-back” events.
- Also shows charged particle density, $dN/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “min-bias” collisions.

- Shows the $\Delta \phi$ dependence of the charged PTsum density, $d\text{PT}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for $30 < E_T(\text{jet#1}) < 70$ GeV for “leading jet” and “back-to-back” events.
- Also shows charged PTsum density, $d\text{PT}/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “min-bias” collisions.

- Shows the $\Delta\phi$ dependence of the charged PTsum density, $dPT/d\eta d\phi$, for charged particles in the range $p_T > 0.5$ GeV/c and $|\eta| < 1$ relative to jet#1 (rotated to 270°) for $30 < E_T(jet#1) < 70$ GeV for “leading jet” and “back-to-back” events.
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“Leading Jet” Charge Density: PY Tune A vs HERWIG

Charged Particle Density: $dN/d\eta d\phi$

**CDF Preliminary**
- Leading Jet
- PY Tune A

**Data - Theory: Charged Particle Density $dN/d\eta d\phi$**

**CDF Preliminary**
- PYTHIA Tune A
- HERWIG

30 < ET(jet#1) < 70 GeV

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

"Transverse" Region

Jet#1

0 30 60 90 120 150 180 210 240 270 300 330 360

$\Delta \phi$ (degrees)

0.1 1.0 10.0

Charged Particle Density

0 30 60 90 120 150 180 210 240 270 300 330 360

$\Delta \phi$ (degrees)
“Leading Jet” PTsum Density: PY Tune A vs HERWIG

Data - Theory: Charged PTsum Density $dP_T/d\eta d\phi$

CDF Preliminary data uncorrected theory + CDFSIM

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

30 < $ET(jet\#1)$ < 70 GeV

Jet#1 "Transverse" Region

Charged PTsum Density (GeV/c)
“Back-to-Back” Charge Density: PY Tune A vs HERWIG

![Graphs showing charge particle density vs. #phi](image-url)
“Leading Jet” PTsum Density: PY Tune A vs HERWIG

Charged PTsum Density: \( \frac{dP_T}{d\eta d\phi} \)

- **Back-to-Back**
- **PY Tune A**

Charged Particles
\( |\eta| < 1.0, P_T > 0.5 \text{ GeV/c} \) for 30 < \( E_T(\text{jet#1}) < 70 \text{ GeV} \)

CDF Preliminary data uncorrected theory + CDFSIM

**Jet#1** "Transverse" Region

Data - Theory: Charged PTsum Density \( \frac{dP_T}{d\eta d\phi} \)

- **Back-to-Back**
- **PYTHIA Tune A**

Charged Particles
\( |\eta| < 1.0, P_T > 0.5 \text{ GeV/c} \) for 30 < \( E_T(\text{jet#1}) < 70 \text{ GeV} \)

CDF Preliminary data uncorrected theory + CDFSIM

**Jet#1** "Transverse" Region

Data - Theory: Charged PTsum Density \( \frac{dP_T}{d\eta d\phi} \)

- **Back-to-Back**
- **HERWIG**

Charged Particles
\( |\eta| < 1.0, P_T > 0.5 \text{ GeV/c} \) for 30 < \( E_T(\text{jet#1}) < 70 \text{ GeV} \)

CDF Preliminary data uncorrected theory + CDFSIM

**Jet#1** "Transverse" Region
• 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 $\eta$-$\phi$ space of $4\pi/6$.

• The “transMIN” region is very sensitive to the “beam-beam remnant” and multiple parton interaction components of the “underlying event”.

• The difference, “transMAX” minus “transMIN”, is very sensitive to the “hard scattering” component of the “underlying event” (i.e. hard initial and final-state radiation).

"AVE Transverse" Charge Density: $dN/d\eta d\phi$

"MAX-MIN Transverse" Charge Density: $dN/d\eta d\phi$

"AVE Transverse" PTsum Density: $dPT/d\eta d\phi$

"MAX-MIN Transverse" PTsum Density: $dPT/d\eta d\phi$

CDF Preliminary data uncorrected theory + CDFSIM

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

Min-Bias Leading Jet
Back-to-Back

CDF Preliminary

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

Min-Bias Leading Jet
Back-to-Back

CDF Preliminary

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

Min-Bias Leading Jet
Back-to-Back

CDF Preliminary

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

Min-Bias Leading Jet
Back-to-Back

CDF Preliminary

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

Min-Bias Leading Jet
Back-to-Back

- Define PTmaxT on and event-by-event bases to be the highest pT charged particle (pT > 0.5 GeV/c, |η| < 1) in the “transverse” region.
- Shows the average PTmaxT versus ET(jet#1) for “back-to-back” and “leading jet” events.
- Also shows the average maximum pT charged particle, PTmax, for “min-bias” collisions (pT > 0.5 GeV/c, |η| < 1).
"Transverse" PTmax: PY Tune A versus HERWIG

- Define PTmaxT on and event-by-event bases to be the highest pT charged particle (pT > 0.5 GeV/c, |η| < 1) in the "transverse" region.
- Shows the average PTmaxT versus ET(jet#1) for "back-to-back" and "leading jet" events compared with PYTHIA Tune A and HERWIG after CDFSIM.
“Leading Jet”: “Associated” Transverse Densities

- Use the **leading jet** to define the “transverse” region and look at the maximum $P_T$ charged particle in the “transverse” region, $P_T\text{max}$. Define “transMAX” to be the “transverse” region that contains $P_T\text{max}$ and “transMIN” to be the other “transverse” region.
- Shows the “transMAX” and “transMIN” associated charged particle density, $dN/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $P_T\text{max}$) as a function of $E_T(jet\#1)$ compared with the average “transverse” charged particle density.
“Leading Jet”: “Associated” Transverse Densities

- Use the leading jet to define the “transverse” region and look at the maximum $p_T$ charged particle in the “transverse” region, $PT_{maxT}$. Define “transMAX” as the “transverse” region that contains $PT_{maxT}$ and “transMIN” as the other “transverse” region.
- Shows the “transMAX” and “transMIN” associated charged particle density, $dN/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) as a function of $E_T(jet#1)$ compared with the average “transverse” charged particle density.

It is more probable to find a particle accompanying $PT_{maxT}$ than it is to find a particle in the “transverse” region!
“Leading Jet”: “Associated” Transverse PTsum Density

- Use the leading jet to define the “transverse” region and look at the maximum $P_T$ charged particle in the “transverse” region, $PT_{maxT}$. Define “transMAX” to be the “transverse” region that contains $PT_{maxT}$ and “transMIN” to be the other “transverse” region.
- Shows the “transMAX” and “transMIN” associated charged PTsum density, $dPT/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) as a function of $E_T(jet#1)$ compared with the average “transverse” charged particle density.
“Associated” Transverse Densities: PY Tune A vs HERWIG
“Associated” Transverse Densities: PY Tune A vs HERWIG
• Use the leading jet in “back-to-back” events to define the “transverse” region and look at the maximum $p_T$ charged particle in the “transverse” region, $PT_{maxT}$.

• Look at the $\Delta \phi$ dependence of the “associated” charged particle and $PT_{sum}$ densities, $dN/d\eta d\phi$ and $dPT/d\eta d\phi$ for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including $PT_{maxT}$*) relative to $PT_{maxT}$.

• Rotate so that $PT_{maxT}$ is at the center of the plot (*i.e.* 180°).
Back-to-Back: “Associated” Charge Density $\Delta \phi$ Dependence

- Shows the $\Delta \phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) relative to $PT_{maxT}$ (rotated to 180$^\circ$) for $PT_{maxT} > 0.5$ GeV/c, $PT_{maxT} > 1.0$ GeV/c and $PT_{maxT} > 2.0$ GeV/c, for “back-to-back” events with $30 < E_T(jet#1) < 70$ GeV.
- Shows “jet structure” in the “transverse” region (i.e. the “birth” of the third jet).

“Associated” densities do not include $PT_{maxT}!$
Back-to-Back: “Associated” Charge Density $\Delta \phi$ Dependence

- Shows the $\Delta \phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) relative to $PT_{maxT}$ (rotated to $180^\circ$) for $PT_{maxT} > 0.5$ GeV/c, $PT_{maxT} > 1.0$ GeV/c and $PT_{maxT} > 2.0$ GeV/c, for “back-to-back” events with $30 < E_T(jet#1) < 70$ GeV.

“Associated” densities do not include $PT_{maxT}!
Back-to-Back: “Associated” Charge Density $\Delta \phi$ Dependence

- Shows the $\Delta \phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, *not including $PT_{maxT}$*) relative to $PT_{maxT}$ (rotated to 180$^\circ$) for “back-to-back” events with $30 < E_T(jet#1) < 70$ GeV.

- Shows $\Delta \phi$ dependence of the charged particle density, $dN/d\eta d\phi$ ($p_T > 0.5$ GeV/c, $|\eta| < 1$) relative to jet#1 (rotated to 270$^\circ$) for “back-to-back events” with $30 < E_T(jet#1) < 70$ GeV.
Back-to-Back: “Associated” Charge Density $\Delta\phi$ Dependence

- Shows the $\Delta\phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, (p_T > 0.5 GeV/c, |$\eta$| < 1) relative to jet#1 (rotated to 270°) for “back-to-back events” with 30 < $E_T$(jet#1) < 70 GeV.

- Shows $\Delta\phi$ dependence of the charged particle density, $dN/d\eta d\phi$ (p_T > 0.5 GeV/c, |$\eta$| < 1) relative to PTmaxT for “back-to-back” events with 30 < $E_T$(jet#1) < 70 GeV.

It is more probable to find a particle accompanying PTmaxT than it is to find a particle in the “transverse” region!
Back-to-Back: “Associated” Charge Density $\Delta\phi$ Dependence

- Shows the $\Delta\phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) relative to $PT_{maxT}$ (rotated to 180$^\circ$) for “back-to-back” events with $30 < E_T(jet#1) < 70$ GeV.

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Back-to-Back: “Associated” Charge Density $\Delta\phi$ Dependence

- Shows the $\Delta\phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5 \text{ GeV/c}, |\eta| < 1$, not including $PT_{\text{max}}$) relative to $PT_{\text{max}}$ (rotated to $180^0$) and the charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5 \text{ GeV/c}, |\eta| < 1$) relative to jet#1 (rotated to $270^0$) for “back-to-back” events with $30 < E_T(\text{jet#1}) < 70$ GeV.
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- Shows the $\Delta\phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) relative to $PT_{maxT}$ (rotated to 180°) and the charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$) relative to jet#1 (rotated to 270°) for “back-to-back” events with $30 < E_T(jet#1) < 70$ GeV.
Back-to-Back: “Associated” Charge Density $\Delta\phi$ Dependence

- Shows the $\Delta\phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($P_T > 0.5$ GeV/c, $|\eta| < 1$, $PT_{maxT} > 2$ GeV/c, not including $PT_{maxT}$) relative to $PT_{maxT}$ (rotated to 180°) and the charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$) relative to jet#1 (rotated to 270°) for $30 < E_T(jet\#1) < 70$ GeV.
Back-to-Back: “Associated” Charge Density $\Delta \phi$ Dependence

- Shows the $\Delta \phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5 \text{ GeV/c}, |\eta| < 1$, $PT_{\text{maxT}} > 2 \text{ GeV/c}$, not including $PT_{\text{maxT}}$) relative to $PT_{\text{maxT}}$ (rotated to 180°) and the charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5 \text{ GeV/c}, |\eta| < 1$) relative to jet#1 (rotated to 270°) for $30 < E_T(\text{jet#1}) < 70 \text{ GeV}$.
Back-to-Back: “Associated” Charge Densities $\Delta \phi$ Dependence

**Associated Particle Density: $dN/d\eta d\phi$**

- **CDF Preliminary data uncorrected**
- Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)

**Associated PTsum Density: $dPT/d\eta d\phi$**

- **CDF Preliminary**
- Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)

**Charged Particle Density: $dN/d\eta d\phi$**

- **CDF Preliminary data uncorrected**
- Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)

**Charged PTsum Density: $dPT/d\eta d\phi$**

- **CDF Preliminary data uncorrected**
- Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)
“Min-Bias” Associated Charged Particle Density

- Use the maximum $p_T$ charged particle in the event, PTmax, to define a direction and look at the “associated” density, $dN/d\eta d\phi$.
- Shows the data on the $\Delta \phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including PTmax) relative to PTmax (rotated to 180°) for “min-bias” events. Also shown is the average charged particle density, $dN/d\eta d\phi$, for “min-bias” events.
“Min-Bias” Associated Charged Particle Densities

**Associated Particle Density: \( dN/d\eta d\phi \)**

- **CDF Preliminary data uncorrected**
- Charged Particles \((|\eta|<1.0, PT>0.5 \text{ GeV/c})\)
- \(P_T^{\text{max}} > 2.0 \text{ GeV/c}\)
- \(P_T^{\text{max}} > 1.0 \text{ GeV/c}\)
- \(P_T^{\text{max}} > 0.5 \text{ GeV/c}\)

**Associated PTsum Density: \( dP_T/d\eta d\phi \)**

- **CDF Preliminary data uncorrected**
- Charged Particles \((|\eta|<1.0, PT>0.5 \text{ GeV/c})\)
- \(P_T^{\text{max}} > 2.0 \text{ GeV/c}\)
- \(P_T^{\text{max}} > 1.0 \text{ GeV/c}\)
- \(P_T^{\text{max}} > 0.5 \text{ GeV/c}\)

**Charged Particle Density: \( dN/d\eta d\phi \)**

- **CDF Preliminary data uncorrected**
- **Associated Density** \(P_T^{\text{max}} \text{ not included}\)
- **Charge Density**

**Charged PTsum Density: \( dP_T/d\eta d\phi \)**

- **CDF Preliminary data uncorrected**
- **Associated Density** \(P_T^{\text{max}} \text{ not included}\)
- **PTsum Density**
“Min-Bias” Associated Charge Densities vs PY Tune A

- Shows the data on the $\Delta \phi$ dependence of the “associated” charged particle and PTsum density, $dN/d\eta d\phi$ and $dPT/d\eta d\phi$, for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{\text{max}}$) relative to $PT_{\text{max}}$ (rotated to 180°) for “min-bias” events with $PT_{\text{max}} > 0.5$ GeV/c and $PT_{\text{max}} > 2.0$ GeV/c compared with PYTHIA Tune A (“min-bias”).

- PYTHIA Tune A (“min-bias”) predicts slightly too much “hard scattering” in “min-bias” collisions (i.e. it does not have exactly the right “hard” versus “soft” mixture).
“Associated” Charge Density: “Back-to-Back” vs “Min-Bias”

- Shows the $\Delta\phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PTmaxT$) relative to $PTmaxT$ (rotated to 180°) for “back-to-back” events with $30 < E_T(jet#1) < 70$ GeV and $PTmaxT > 2.0$ GeV/c and for “min-bias” collisions relative to $PTmax$ (rotated to 180°) with $PTmax > 2.0$ GeV/c.
“Associated” Charge Density: “Back-to-Back” vs “Min-Bias”

- Shows the $\Delta \phi$ dependence of the “associated” charged particle density $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) relative to $PT_{maxT}$ (rotated to 180°) for “back-to-back” events with $30 < E_T(jet#1) < 70$ GeV and $PT_{maxT} > 2.0$ GeV/c and for “min-bias” collisions relative to $PT_{max}$ (rotated to 180°) with $PT_{max} > 2.0$ GeV/c.
“Associated” Charge Density: “Back-to-Back” vs “Min-Bias”

- Shows the $\Delta \phi$ dependence of the “associated” charged particle density, $dN/d\eta d\phi$, ($p_T > 0.5$ GeV/c, $|\eta| < 1$, not including $PT_{maxT}$) relative to $PT_{maxT}$ (rotated to $180^0$) for “back-to-back” events with $30 < ET(jet#1) < 70$ GeV and $PT_{maxT} > 2.0$ GeV/c and for “min-bias” collisions (times 1.65) relative to $PT_{max}$ (rotated to $180^0$) with $PT_{max} > 2.0$ GeV/c.
Associated Densities: “Back-to-Back” versus “Min-Bias”
“Back-to-Back” Associated Densities: PY Tune A vs HERWIG

CDF Preliminary
data uncorrected
theory + CDFSIM
Back-to-Back

Associated Particle Density: \( dN/d\eta d\phi \)

30 < \( ET(\text{jet#1}) < 70 \) GeV

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

PTmaxT not included

Data - Theory: Associated Particle Density \( dN/\eta d\phi \)

CDF Preliminary
data uncorrected
theory + CDFSIM
Back-to-Back

30 < \( ET(\text{jet#1}) < 70 \) GeV

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

PTmaxT not included

CDF Preliminary
data uncorrected
theory + CDFSIM
PTmaxT not included

HERWIG

PTmaxT > 0.5 GeV/c

“Jet#1” Region

30 < \( ET(\text{jet#1}) < 70 \) GeV

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

PTmaxT not included

“Jet#1” Region

PTmaxT > 0.5 GeV/c

PTmaxT > 0.5 GeV/c

PTmaxT > 0.5 GeV/c
“Back-to-Back” Associated Densities: PY Tune A vs HERWIG

![Graph 1: Associated PTsum Density dPT/dφ]

- Charged Particles (|η|<1.0, PT>0.5 GeV/c)
- PTmaxT not included
- PY Tune A
- 30 < ET(jet#1) < 70 GeV

CDF Preliminary
- data uncorrected
- theory + CDFSIM

![Graph 2: Associated PTsum Density dPT/dφ]

- Charged Particles (|η|<1.0, PT>0.5 GeV/c)
- PTmaxT not included
- HERWIG
- 30 < ET(jet#1) < 70 GeV

CDF Preliminary
- data uncorrected
- theory + CDFSIM

![Graph 3: Data - Theory: Associated PTsum Density dPT/dφ]

- Charged Particles (|η|<1.0, PT>0.5 GeV/c)
- Back-to-Back
- PTmaxT not included
- PYTHIA Tune A

CDF Preliminary
- data uncorrected
- theory + CDFSIM

![Graph 4: Data - Theory: Associated PTsum Density dPT/dφ]

- Charged Particles (|η|<1.0, PT>0.5 GeV/c)
- Back-to-Back
- PTmaxT not included
- HERWIG
“Back-to-Back” Associated Densities: PY Tune A vs HERWIG

**Associated Particle Density: \( dN/d\eta d\phi \)**

### CDF Preliminary
- Data uncorrected
- Theory + CDFSIM
- \( \phi > 2.0 \text{ GeV/c} \)
- \( 30 < \text{ET(jet#1)} < 70 \text{ GeV} \)
- Back-to-Back

### Charged Particles
- \( |\eta| < 1.0, \text{PT} > 0.5 \text{ GeV/c} \)
- \( \text{PTmaxT not included} \)

### Data - Theory: Associated Particle Density \( dN/d\eta d\phi \)

### CDF Preliminary
- Data uncorrected
- Theory + CDFSIM
- \( \phi > 2.0 \text{ GeV/c} \)
- \( 30 < \text{ET(jet#1)} < 70 \text{ GeV} \)
- Back-to-Back

### Charged Particles
- \( |\eta| < 1.0, \text{PT} > 0.5 \text{ GeV/c} \)
- \( \text{PTmaxT not included} \)
“Back-to-Back” Associated Densities: PY Tune A vs HERWIG

Associated PTsum Density: \( \frac{dP_T}{d\eta d\phi} \)

- Charged Particles
- \((\eta < 1.0, P_T > 0.5 \text{ GeV/c})\)
- \(P_T^{\text{maxT}}\) not included

CDF Preliminary
- data uncorrected
- theory + CDFSIM

Associated PTsum Density (GeV/c)

- \(P_T^{\text{maxT}} > 2.0 \text{ GeV/c}\)
- PY Tune A

30 \(<\ ET(\text{jet#1}) < 70 \text{ GeV}\)

Back-to-Back Charged Particles
- \(|\eta| < 1.0, P_T > 0.5 \text{ GeV/c}\)

CDF Preliminary
- data uncorrected
- theory + CDFSIM

PTmaxT

"Jet#1"

Region

Data - Theory: Associated Particle Density \( \frac{dN}{d\eta d\phi} \)

- Charged Particles
- \((\eta < 1.0, P_T > 0.5 \text{ GeV/c})\)
- \(P_T^{\text{maxT}} > 2.0 \text{ GeV/c}\) (not included)

CDF Preliminary
- data uncorrected
- theory + CDFSIM

30 \(<\ ET(\text{jet#1}) < 70 \text{ GeV}\)

Back-to-Back Charged Particles
- \(|\eta| < 1.0, P_T > 0.5 \text{ GeV/c}\)

CDF Preliminary
- data uncorrected
- theory + CDFSIM

PTmaxT

"Jet#1"

Region

Data - Theory

CDF Preliminary
- data uncorrected
- theory + CDFSIM

30 \(<\ ET(\text{jet#1}) < 70 \text{ GeV}\)

Back-to-Back Charged Particles
- \(|\eta| < 1.0, P_T > 0.5 \text{ GeV/c}\)

CDF Preliminary
- data uncorrected
- theory + CDFSIM

PTmaxT

"Jet#1"

Region

Data - Theory
Summary & Conclusions

• By selecting events with at least two jets that are nearly back-to-back we are able to look closer at the “beam-beam remnant” and multiple parton interaction components of the “underlying event”. PYTHIA Tune A (with multiple parton interactions) does a good job in describing the “underlying event” (i.e. “transverse” regions) for both “leading jet” and “back-to-back” events. HERWIG (without multiple parton interactions) does not have enough activity in the “underlying event” for $E_T(jet#1)$ less than about 150 GeV, which was also observed in our published Run 1 analysis.

• To examine the “jet” structure in the “underlying event” we define “associated” charged particle densities that measure the number of charged particles and scalar $p_T$ sum of charged particles accompanying the maximum $p_T$ charged particle in the “transverse” region, $P_TmaxT$. The data show strong correlations. For $E_T(jet#1)$ greater than about 50 GeV there is a higher density of charged particles “associated” with $P_TmaxT$ (not including $P_TmaxT$) in the “transMAX” region than there is in the average “transverse” region. These correlations indicate “jet” structure in the “underlying event” (i.e. “transverse” region) at $P_TmaxT$ values as low as 1.0 GeV/c!