Outline of Talk

✦ Study the **calorimeter towers & charged particles** in the “underlying event” (i.e. “transverse” region) as defined by the leading “calorimeter jet”.

✦ Also study the **calorimeter towers & charged particles** in the “toward” and “away” regions (i.e. the overall event topology).

✦ Look at the **HAD and EM** component of the towers separately (as well as the sum). Define and study the **GAM** component of the towers in the “transverse” region.
Jet Event Structure: Calorimeter & Tracks

Outline of Talk:

- Study the calorimeter towers & charged particles in the "underlying event" (i.e. the "transverse" region) as defined by the leading "calorimeter jet".

- Also study the calorimeter towers & charged particles in the "toward" and "away" regions (i.e. the overall event topology).

- Look at the HAD and EM components of the towers separately (as well as the sum). Define and study the GAM component of the towers in the "transverse" region.

Compare the data with PYTHIA Tune A which was tuned to fit the charged particle component of the "underlying event" in Run 1.
"Toward", "Transverse", and "Away" Regions

**Charged Particle**

Δφ Correlations

(P_T > 0.5 GeV/c |η| < 1)

**Calorimeter Tower**

Δφ Correlations

(E_T > 0.1 GeV |η| < 1)

- Look at charged particle and calorimeter tower correlations in the azimuthal angle Δφ relative to the leading calorimeter jet (JetClu R = 0.7, |η| < 2).

- 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 = 4.2.

The "transverse" region is very sensitive to the "underlying" event!

Each of the three regions have an area of ΔηΔφ = 4π/3 = 4.2

The "toward" region includes the leading jet

Look at the density of charged particles and calorimeter towers in η-φ space in the three regions.

Collaboration Meeting

September 19, 2003

Rick Field

Page 3
"Transverse" Region
Number Density

- Shows the data on the average "transverse" charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) and the average "transverse" calorimeter tower density ($|\eta|<1$, $E_T>0.1$ GeV) as a function of the transverse energy of the leading JetClu jet ($R=0.7$, $|\eta(jet)|<2$).

- PYTHIA Tune A + CDFSIM predicts about 0.75 less towers ($E_T > 100$ MeV) per unit $\eta$-$\phi$ less than seen in the data. Note that $\Delta\eta \times \Delta\phi = 0.1 \times 15^\circ$ corresponds to about 38 towers per unit $\eta$-$\phi$. 
Shows the data on the average "transverse" charge particle density (|\(\eta|<1, \ P_{T}>0.5 \text{ GeV}\)) and the average "transverse" calorimeter tower density (|\(\eta|<1, \ E_{T}>0.1 \text{ GeV}\)) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |\(\eta(\text{jet})| < 2\)).

PYTHIA Tune A + CDFSIM predicts about 0.75 less towers (E_{T} > 100 \text{ MeV}) per unit \(\eta-\phi\) less than seen in the data. Note that \(\Delta \eta \times \Delta \phi = 0.1 \times 15^\circ\) corresponds to about 38 towers per unit \(\eta-\phi\).
Shows the data on the average “transverse” charged PTsum density ($|\eta|<1, P_T>0.5$ GeV) and the average “transverse” calorimeter tower ETsum density ($|\eta|<1, E_T>0.1$ GeV) as a function of the transverse energy of the leading JetClu jet ($R = 0.7, |\eta(jet)| < 2$).

PYTHIA Tune A + CDFSIM predicts about 250 MeV less tower ETsum ($E_T > 100$ MeV) per unit $\eta$-$\phi$ less than seen in the data. The corresponds to about 1 GeV in the “transverse” region.
Shows the data on the average “transverse” charged PTsum density (|\eta|<1, P_T>0.5 GeV) and the average “transverse” calorimeter tower ETsum density (|\eta|<1, ET>0.1 GeV) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |\eta(jet)| < 2).

PYTHIA Tune A + CDFSIM predicts about 250 MeV less tower ETsum (E_T > 100 MeV) per unit \eta-\phi less than seen in the data. The corresponds to about 1 GeV in the “transverse” region.
Shows the data on the average 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) for the “toward”, “transverse” and “away” regions compared with PYTHIA Tune A (after CDFSIM).

PYTHIA Tune A describes well the average density of charged particles in the “toward” and “transverse” regions, but predicts too many charged particles in the “away” region.
Shows the data on the average tower density ($|\eta|<1, E_t>0.1$ GeV) as a function of the transverse energy of the leading JetClu jet ($R=0.7, |\eta(jet)|<2$) for the “toward”, “transverse” and “away” regions compared with PYTHIA Tune A (after CDFSIM).

There are more towers in the data in all three regions than predicted by PYTHIA Tune A (after CDFSIM)!
Shows the data on the average tower density \(|\eta|<1, E_T>0.1 \text{ GeV}\) as a function of the transverse energy of the leading JetClu jet \((R = 0.7, |\eta(jet)| < 2)\) for the “toward”, “transverse” and “away” regions compared with PYTHIA Tune A (after CDFSIM).

Shows the data on the average tower density \(dN/d\eta d\phi\) \(|\eta|<1, E_T>0.1 \text{ GeV}\) as a function of \(\Delta\phi\) relative to the leading JetClu jet \((R = 0.7, |\eta(jet)| < 2)\) for the region \(30 < E_T(jet#1) < 70 \text{ GeV}\) compared with PYTHIA Tune A (after CDFSIM).
Calorimeter Tower Density
“Toward” “Transverse” “Away”

Show the data on the average tower density (|η|<1, ET>0.1 GeV) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |η(jet)| < 2) for the “toward”, “transverse” and “away” regions compared with PYTHIA Tune A (after CDFSIM).

Shows the data on the average tower number density dN/dΔφ (|η|<1, ET>0.1 GeV) as a function of Δφ relative to the leading JetClu jet (R = 0.7, |η(jet)| < 2) for the region 30 < E_T(jet#1) < 70 GeV compared with PYTHIA Tune A (at 1.96 TeV).

Look at the region 30 < E_T(jet#1) < 70 GeV

Collaboration Meeting
September 19, 2003
Shows the data on the average charged PTsum density ($|\eta|<1$, $P_T>0.5$ GeV) as a function of the transverse energy of the leading JetClu jet ($R = 0.7$, $|\eta(jet)| < 2$) for the “toward”, “transverse” and “away” regions compared with PYTHIA Tune A (after CDFSIM).

PYTHIA Tune A describes well the average PTsum density of charged particles in the “transverse” region, but does not precisely describe the “toward” and “away” regions.
There is more tower ETsum in all regions than predicted by PYTHIA Tune A + CDFSIM!

- Shows the data on the average tower ETsum density ($|\eta|<1, E_T>0.1$ GeV) as a function of the transverse energy of the leading JetClu jet ($R = 0.7, |\eta(jet)| < 2$) for the "toward", "transverse" and "away" regions compared with PYTHIA Tune A (after CDFSIM).

- There is more tower ETsum in all three regions than predicted by PYTHIA Tune A (after CDFSIM)!
The figure shows the data–theory comparison for the charged PTsum density $(|\eta|<1, P_T>0.5 \text{ GeV})$ and the tower ETsum density $(|\eta|<1, E_T>0.1 \text{ GeV})$ as a function of the transverse energy of the leading JetClu jet $(R = 0.7, |\eta(\text{jet})| < 2)$ for the “toward”, “transverse” and “away” regions, where theory is PYTHIA Tune A (after CDFSIM).

Corresponds to about 20 GeV in the “toward” region!
Data-Theory: ETsum Density
“Toward” “Transverse” “Away”

Shows the data – theory for the charged PTsum density ($|\eta|<1$, $P_T>0.5$ GeV) and the tower ETsum density ($|\eta|<1$, $E_T>0.1$ GeV) as a function of the transverse energy of the leading JetClu jet ($R=0.7$, $|\eta(jet)|<2$) for the “toward”, “transverse” and “away” regions, where theory is PYTHIA Tune A (after CDFSIM).

Shows the data - theory for the charged PTsum density ($|\eta|<1$, $P_T>0.5$ GeV) and the tower ETsum density ($|\eta|<1$, $E_T>0.1$ GeV) as a function of $\Delta \phi$ relative to the leading JetClu jet ($R=0.7$, $|\eta(jet)|<2$) for the region $30 < E_T(jet#1) < 70$ GeV.
Data - Theory: ETsum Density
“Toward” “Transverse” “Away”

Look at the region 30 < ET(jet#1) < 70 GeV

→ Shows the data – theory for the charged tower ETsum density (|η|<1, E_T>0.1 GeV) in the leading JetClu jet (R = 0.7, |η(jet)| < 2) for the “toward”, “transverse” and “away” regions, where theory is PYTHIA Tune A 1.96 TeV.

→ Shows the data - theory for the charged PTsum density (|η|<1, P_T>0.5 GeV) and the tower ETsum density (|η|<1, E_T>0.1 GeV) as a function of ∆φ relative to the leading JetClu jet (R = 0.7, |η(jet)| < 2) for the region 30 < ET(jet#1) < 70 GeV.
“Transverse” Region
ETsum & PTsum Density

The excess ETsum seen in the data comes primarily from the EM component!

Shows the data on the average “transverse” charge PTsum density ($|\eta|<1$, $P_T>0.5$ GeV) and the average “transverse” calorimeter HAD & EM tower ETsum density ($|\eta|<1$, $E_T(HAD+EM)>0.1$ GeV) as a function of the transverse energy of the leading JetClu jet ($R=0.7$, $|\eta(jet)| < 2$).

PYTHIA Tune A + CDFSIM predicts about 200 MeV less EM tower ETsum per unit $\eta$-$\phi$ and about 50 MeV less HAD tower ETsum per unit $\eta$-$\phi$ less than seen in the data in the “transverse” region.
“Transverse” Region “GAM” Towers

- Shows the data on the average “transverse” charge PTsum density ($|\eta|<1, PT>0.5 \text{ GeV}$) and the average “transverse” calorimeter HAD & EM tower ETsum density ($|\eta|<1, \text{ET}(\text{HAD+EM})>0.1 \text{ GeV}$) as a function of the transverse energy of the leading jet (Clu jet ($R=0.7, |\eta(\text{jet})| < 2$)).

- Shows the EM fraction for “transverse” calorimeter towers ($\text{ET}(\text{HAD+EM}) > 100 \text{ MeV}, |\eta| < 1$) for $30 < \text{ET}(\text{jet#1}) < 70 \text{ GeV}$ compared with PYTHIA Tune A (after CDFSIM).

Define “GAM” towers to be those towers with $\text{ET}(\text{had})/\text{ET}(\text{em}) < 0.125$ (or EM fraction $> 0.89$).

Log Scale!

CDF Preliminary data uncorrected theory + CDFSIM

Look at the region $30 < \text{ET}(\text{jet#1}) < 70 \text{ GeV}$
Shows the data on the average “transverse” GAM tower ETsum density (|\(\eta|<1, E_T(\text{HAD+EM})>0.1 \text{ GeV}) as a function of the transverse energy of the leading JetClu jet (R = 0.7, |\(\eta|(<2)). Also shows the tower ETsum (HAD+EM) minus the GAM tower ETsum (i.e. “CHG” tower ETsum).

**PYTHIA Tune A + CDFSIM** predicts about 250 MeV less “GAM” tower ETsum per unit \(\eta-\phi) and than seen in the data in the “transverse” region and agrees with the “CHG” tower ETsum.
PYTHIA Tune A + CDFSIM does a good job of describing the charged particle component of the of the “underlying event” (i.e. the “transverse” region), but does not perfectly describe the charged particle component in the “toward” and “away” regions.

There are more calorimeter towers and more tower ETsum ($E_T > 100$ MeV, $|\eta| < 1$) in all three regions in the data than predicted by PYTHIA Tune A + CDFSIM.

The excess tower number and tower ETsum density for the data over PYTHIA Tune A + CDFSIM in the “transverse” region can be almost entirely attributed to GAM towers.
**Summary & Conclusions**

Jet Event Structure

- **PYTHIA Tune A + CDFSIM** does a good job of describing the charged particle component of the "underlying event" (i.e. the "transverse" region), but does not perfectly describe the charged particle component in the "toward" and "away" regions.

- There are more calorimeter towers and tower ETsum (E_T>100 MeV, |η|<1) in all three regions than predicted by PYTHIA Tune A + CDFSIM.

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*Collaboration Meeting*  
*September 19, 2003*  
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HERWIG comparisons coming soon!