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THE UNDERLYING EVENT AT CDF

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We study the behavior of the "underlying event" in $p\bar{p}$ collisions at E_{cms} = 1.96 TeV by analyzing charged particle correlations in the transverse region of hard scattering events and comparing to minimum-bias events.

1 Measuring the Underlying Event

In hadron-hadron collisions the final state of hard parton-parton scattering is characterized by high E_T jets but also contains a number of low p_T particles that are collectively referred to as the "underlying event". Phenomenologically the underlying event can be thought as being made of everything except the hard scattered jets [1] and receives contributions from the particles originating from the breakup of the proton and antiproton ("beam-beam remnants") as well as from initial and final state radiation. A third contribution may be given by multiple parton scattering [2].

Experimentally it is possible to take advantage of the clear topological structure of hard scattering events (the two high p_T jets that are roughly back-to-back in azimuthal angle) to isolate the $\eta - \phi$ regions in the final state that are sensitive to the underlying event and analyze its properties [3].

We use CDF data collected during RunII at E_{cms}=1.96 TeV with minimum-bias (MB) trigger (2596553 events) and with jet triggers of increasing E_T threshold: 20, 50, 70 and 100 GeV (respectively 3127001, 802003, 352820 and 393118 events). A comprehensive description of the CDF detector can be found in [4].

In this analysis "jets" are defined by the JetClu algorithm with radius R=$\sqrt{(\Delta\eta^2 + \Delta\phi^2)}$=0.7 in the region $|\eta|$ <2.0. The "leading" jet is the highest E_T jet in the event and is required to have a minimum E_T=15 GeV. The direction of the leading jet is used to define the relative azimuthal angle $\Delta\phi$ between the jet and the charged particles. We restrict ourselves to charged particles measured with the central tracking chamber (COT) in the range p_T >0.5 GeV/c and $|\eta|$ <1 where the tracking efficiency is close to unity and uniform. The "transverse" region is defined by $60^\circ < |\Delta\phi| < 120^\circ$ and is perpendicular to the plane of the hard parton-parton scattering. Its area in $\eta - \phi$ space is $\Delta\eta\Delta\phi = 4\pi/3$.

Primary particles are selected by requiring tracks to pass within 2 cm of the event vertex along the beam axis and within 1 cm in the transverse plane. The systematic error on such selection is added in quadrature to the statistical uncertainty to form the overall error in all the plots presented.

2 Transverse Region and Back-to-back Jet Events

The transverse region is very sensitive to the underlying event [5]. In this region we analyze the density of charged particles $dN_{ch}/d\eta d\phi$ and the density of the scalar p_T sum ($PTsum$) of these particles $d(PTsum)/d\eta d\phi$. It is observed that the transverse region densities increase with the leading jet E_T. This is because the amount of initial and final state radiation also increases with the jet E_T. On an event-by-event basis we define a "TransMAX" and a "TransMIN" region to be the transverse region containing the largest (smallest) number of charged particles or $PTsum$, depending on which density is analyzed. One expects that TransMax will pick up the hardest initial and final state radiation, while both TransMAX and TransMIN should receive "beam-beam remnants" contributions so that the TransMIN should be more sensitive to the "beam-beam remnants' component and to multiple parton interactions. The particle and $PTsum$ densities increase with the leading jet E_T in the TransMAX region and decrease in the TransMIN region (Fig.1).

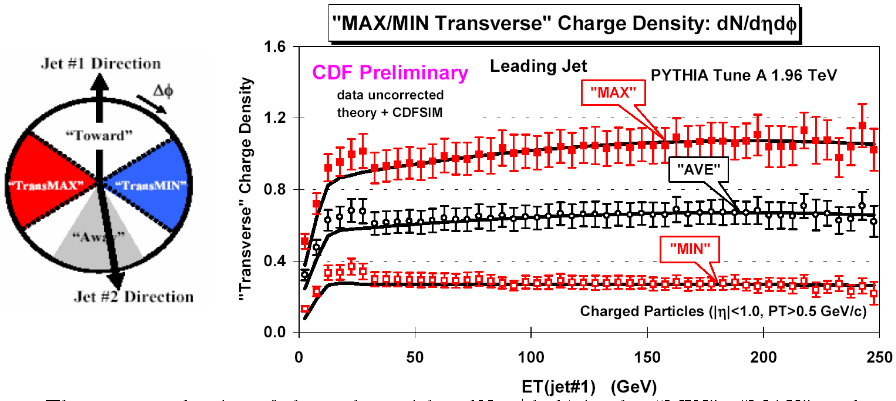

Figure 1. The average density of charged particles $dN_{ch}/d\eta d\phi$ in the "MIN", "MAX" and average transverse region of leading jet events. The same behavior could be observed for the $dPTsum/d\eta d\phi$ density.

It is possible to select a subsample of events where initial and final state radiation is strongly suppressed by requiring a second jet in $\Delta\phi > 150°$ from the leading one and $E_T(jet1)/E_T(jet2) > 0.8$. We also require no third jet with E_T >15 GeV. In this subsample we observe no increased activity with the leading jet E_T in the transverse region (Fig.2). The densities are similar to the TransMIN densities and both are quite close to the Minimim-Bias average ($dN_{ch}/d\eta d\phi \simeq$0.25 and $d(PTsum)/d\eta d\phi \simeq$0.24).

3 Jet Structure in Underlying Event and Minimum Bias

We now study the correlation in azimuthal angle $\Delta\phi$ among charged particles in the transverse regions. We define $PTmaxT$ to be the highest p_T particle in the (two) transverse regions and examine the $\Delta\phi$ dependence of the charged particles and $PTsum$ densities relative to the $PTmaxT$ direction ("associated" densities). In our plots the direction of $PTmaxT$ is always rotated to $\Delta\phi$ = 180° and the associated densities do *not* include $PTmaxT$ itself.

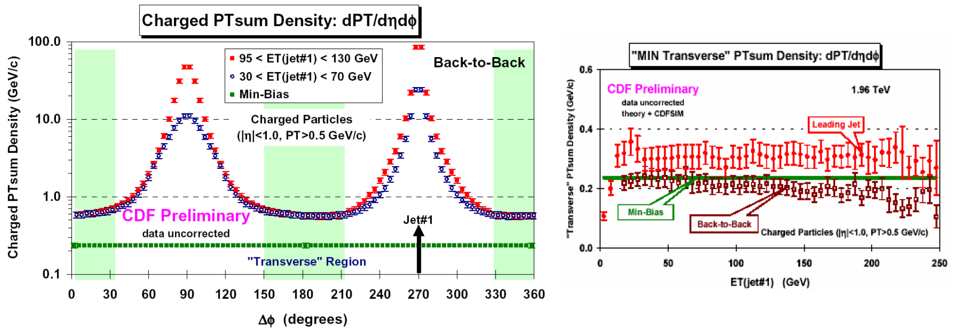

Figure 2. Left: $\Delta\phi$ dependence of the scalar $PTsum$ density relative to the direction of the leading jet for samples of different leading jet E_T. Right: average $PTsum$ density in the "MIN" transverse region for leading jet and back-to-back jet events. The average value in MB events is also shown. In both plots the same behavior could be observed for particle density.

Even in the "back-to-back" jet events where initial and final state radiation is strongly suppressed, the associate densities distribution clearly shows a jet structure in the transverse region (Fig.3) at p_T ~1 GeV/c. The density associated with $PTmaxT$ is larger than the average density in the transverse region (Fig.4).

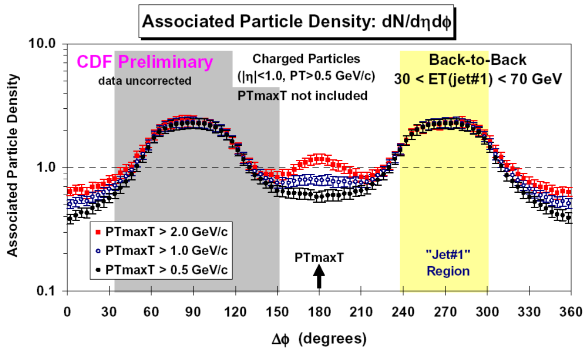

Figure 3. $\Delta\phi$ dependence of the "associated" charged particle density relative to the direction of the highest p_T particle of the transverse region ($PTmaxT$, not included in the computation of the density) in back-to-back jet events.

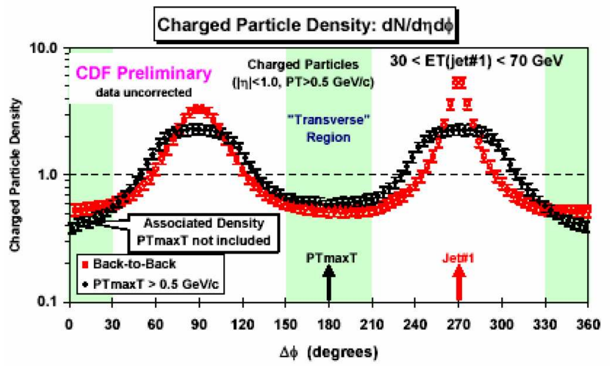

Figure 4. "Associate" charged particle density relative to the direction of $PTmaxT$ (the highest p_T particle) compared to the $\Delta\phi$ dependence of the density relative to the leading jet direction in "back-to-back" jet events.

Finally, we study correlations among charged particles in MB collisions and compare to the transverse region of hard scattering processes. We use the maximum p_T charged particle in MB events ($PTmax$) to define a direction and plot the $\Delta\phi$ dependence of the "associated" cherged particles and $PTsum$ densities relative to $PTmax$. Fig.5 clearly shows jet structure also in MB collisions.

The shape of the "associate" density in the transverse region of "back-to-back" jet events are very similar to the associate density in MB interactions, the only observable difference being a constant "offset" value of $\simeq$1.65 (Fig.5 right): the distribution of charged particles within MB number one jet is similar to the distributions of jet number three in the transverse region of "back-to-back" collisions.

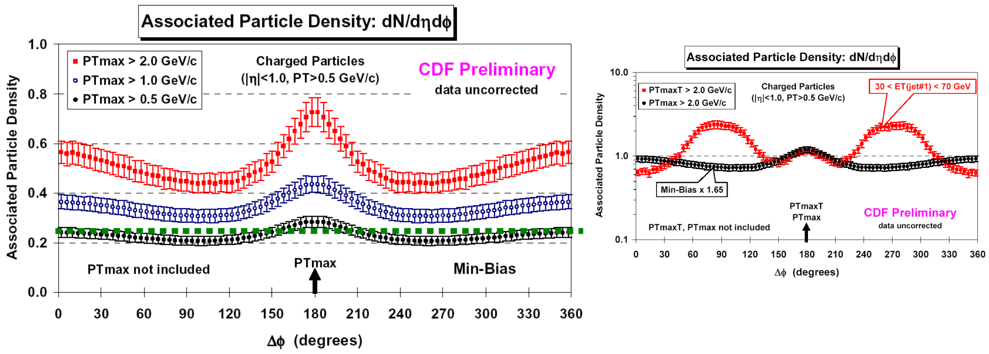

Figure 5. Left: $\Delta\phi$ dependence of the charged particle density relative to the direction of $PTmax$ (the highest p_T particle, not included in the computation of the density and rotated to 180°) in MB collisions. For comparison is shown also the global average density value.
Right: $\Delta\phi$ dependence of the "associated" charged particle density relative to the direction of $PTmaxT$ in "back-to-back" jet compared to the density in MB events (multiplied by 1.65).
The behavior of the $PTsum$ density is similar to particle density in both plots.

4 Conclusions

The "beam-beam remnant" and mutiple parton interaction component of the underlying event ("TransMIN" region) is similar to minimum-bias and independent of the leading jet E_T.

Data show a strong correlation in the transverse region of hard scattering collisions, indicating a jet structure in the underlying event also when initial and final state radiation is strongly suppressed. Minimum-bias events also show a jet structure very similar in shape to that observed in the transverse region of "back-to-back" jet events and differs only by a constant offset.

References

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