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Modelling Calorimeter Energy Flow from the Underlying Event in $t\bar{t}$ Events

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Abstract

We present a study of the modelling of calorimeter energy flow from the "underlying event" in $t\bar{t}$ events. We compare Monte Carlo samples created using different Parton Density Functions, as well as a PYTHIA Tune A sample and W plus three or more jet data, chosen due to its similarity to $t\bar{t}$ events. We find that while PYTHIA Tune A exhibits a more energetic "underlying event" than our other Monte Carlo samples, all of the Monte Carlo samples substantially underestimate the energy of the "underlying event" in the data.

1 Introduction

In the study of high p_T $p\bar{p}$ interactions, we rely heavily on Monte Carlo calculations to model real data and form methods to study it. It is thus pertinent that this modelling is reasonable and that we understand it's accuracy. It is also important that we understand the dependence of the models on parameters of the Monte Carlo generators, such as the Parton Density Function used by the generator.

The "underlying event" in $t\bar{t}$ events consists of all particles produced in the event except the outgoing high p_T leptons and jets produced by the top and anti-top quarks' decay products. In general, understanding the "underlying event" in hard $p\bar{p}$ interactions should allow for improved jet energy calibration. An improved understanding of out-of-cone jet energy and final state radiation, "splash out", as well as "underlying event" energy contributions to jets, are all essential to a better understanding of the jet energy uncertainty. In particular, in $t\bar{t}$ events, better measurements of these effects may lead to improved top mass measurements.

Already in Run II, the "underlying event" in hard scattering interactions has been studied and the modelling of PYTHIA Tune A compared to Min Bias and jet trigger data by isolating regions that are perpendicular to the plane of the hard scattering [2]. Additionally, the energy deposition in jet-sized cones in Min Bias events has been examined [1]. The latter study found an E_T of 0.32 GeV in cones of R=$\sqrt{\Delta\eta^2 + \Delta\phi^2}$= 0.4 in events with one vertex. Here, we restrict our study to $t\bar{t}$ events.

By examining the sensitivity of the "underlying event" to the use of different Parton Density Functions (PDFs), we can enhance our understanding of the uncertainty that should be attached to the "underlying event" energy in Monto Carlo in top quark pair production. Our primary intention in this note is to study calorimeter energy flow in regions that are dominated by the "underlying event" and to provide a preliminary evaluation of the modelling of this energy flow. We look at $t\bar{t}eventscreatedusingdifferentPDFsandatW+ threeormorejetsamples, whichshouldbecomparabletot\bar{t}events.$In Section II, we describe the Monte Carlo samples used and briefly outline our approach to study and measure the energy flow. We present our results in Section III and provide conclusions in Section IV.

2 Method

According to the standard model, top quarks essentially always decay into a b quark and a W boson. The W in turn decays either leptonically, into a lepton and a neutrino, or hadronically, into a quark and an antiquark. In a $t\bar{t}$ event, then, we will have two W bosons and thus two decay mechanisms. Here we focus on events where one W decays leptonically and the other hadronically.

Using the PYTHIA Monte Carlo generator, we generated, simulated and reconstructed 50 000 $t\bar{t}$, lepton + jet events for each of the PDFs CTEQ5L, MRS G, and BM Set A and for Rick Field's PYTHIA Tune A. We use the 4.8.4 REMAKE version of the official top group data sample for summer 2003 [3] . Jets were defined using the JetCluModule with R=0.4 and an E_T cut of 5 GeV. We keep events that have one tight lepton [4] , at least three tight jets (jets within $|\eta|$<2 with $E_T > 15$ GeV and missing $E_T > 20$ GeV). To minimize multiple interaction effects, we also require that the data has either zero or one vertex with at least 10 tracks.

One approach to studying the "underlying event" is to isolate $\eta - \phi$ regions that are not significantly influenced by jet activity. We searched for cones of R=0.4 in $\eta - \phi$ space whose centroids are seperated from the centroids of all jets in the event by an $\eta - \phi$ distance of at least 1.4. For each event in which such a cone can be found, we define the best cone as the one which is farthest from the nearest jet. We first find the best cone whose centroid is within $|\eta|$<2.8. Additionally, we divide $\eta - \phi$ space into "strips", each with a $\mid \Delta\eta|$ of 0.5, and identify the best cones in these regions. The transverse energy deposition in these cones is our first measure of the underlying energy in an event.

We also measured the energy density in $|\eta|$ strips that are 2 towers wide as another measure of the $|\eta|$ dependence of the underlying energy. To avoid the flow of energy from jets, we require all towers in this measurement to be at least R=1.0 from all jets. Essentially, this method measure the same property as the preceeding one; however the first method is biased towards those regions that are farthest from the jets, so we expect more energy flow in the second measurement.

It is also desirable to have a more complete measure of the "underlying event" energy, and so we also examine the total tranverse energy density (E_T per unit $\eta - \phi$) outside of all jets. To minimize the effects of out-of cone energy, we require such energy deposition to be at least R=0.6 from the centroid of every jet in the event. We also obtained a measure of the out of cone energy by looking at the E_T density in regions that are between a distance of R= 0.4 and 1.0 from a jet's centroid, as well as between 0.6 and 0.8 and between 0.8 and 1.0, on an event by event basis.

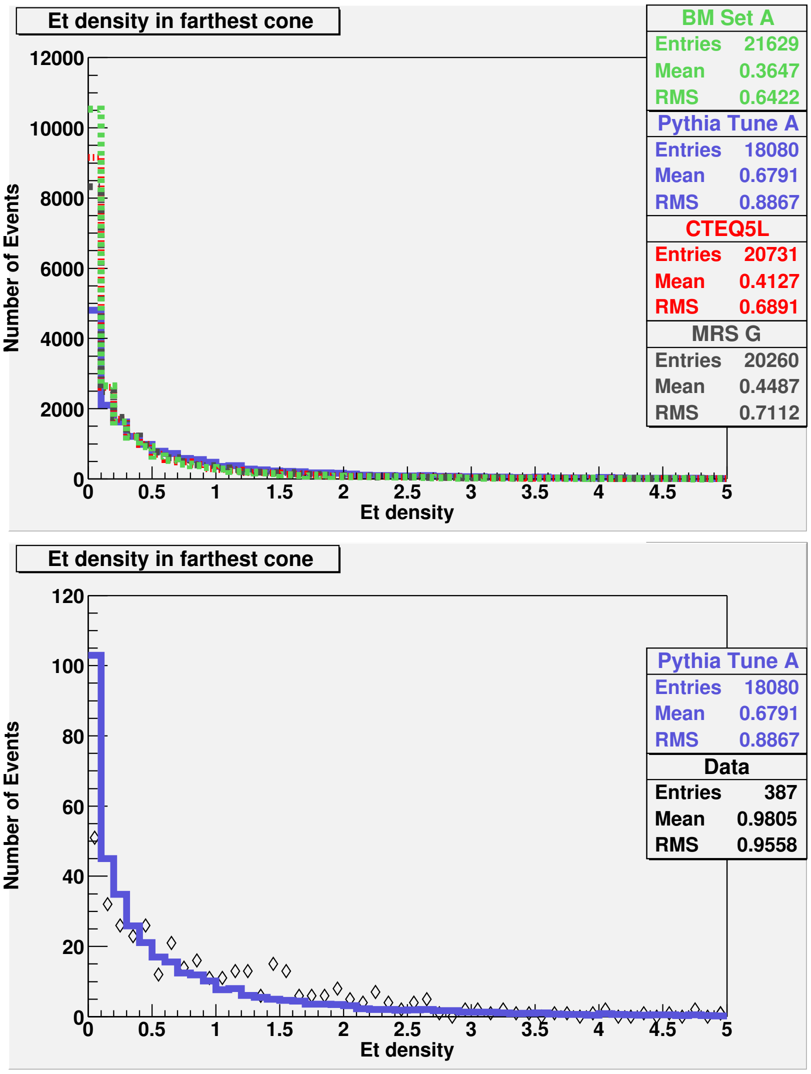

Figure 1: E_T density [GeV/(unit $\eta - \phi$)] in most isolated cone in event. Monte Carlo samples are compared on the top and data is compared with PYTHIA Tune A on the bottom. The PYTHIA Tune A entries on the latter curve are scaled by a factor of 0.0214 to facilitate comparison with the data. On the Monte Carlo plot, the red (dotted) curve corresponds to CTEQ5L, the green (dashed) to BM Set A, the grey (dot-dash) to MRS G and the purple (solid) to PYTHIA Tune A.

3 Results

The transverse energy density in cone's of R=0.4 in the $|\eta|$ regions described in the last section is compared in Figs. 2. The decrease in energy due to increasing $|\eta|$ may be attributed to the higher jet concetration in the central region (note as well that there is a dip in 0.5< $|\eta|$ <1.5, which may be attributed to the cracks in that region). Fig. 4 and Fig. 5 demonstrate the $|\eta|$ dependence of the $\eta - \phi$ distance from the cone to the nearest jet and the depedence of the E_T in that cone on this distance, respectively. For all entries, the Monte Carlo samples demonstrate an underlying event that is less energetic than that seen in the data.

Fig. 3 shows the η dependence of the E_T density, measured in bins of two η towers. As this measurement is taken in an entire strip of $\eta - \phi$ space, rather than only the area that is farthest from the jets, we expect it to be more repesentative of energy flow than the measurements made in the cones. In both cases, the largest difference among the Monte Carlo samples is seen between PYTHIA Tune A and the other samples. Among the different

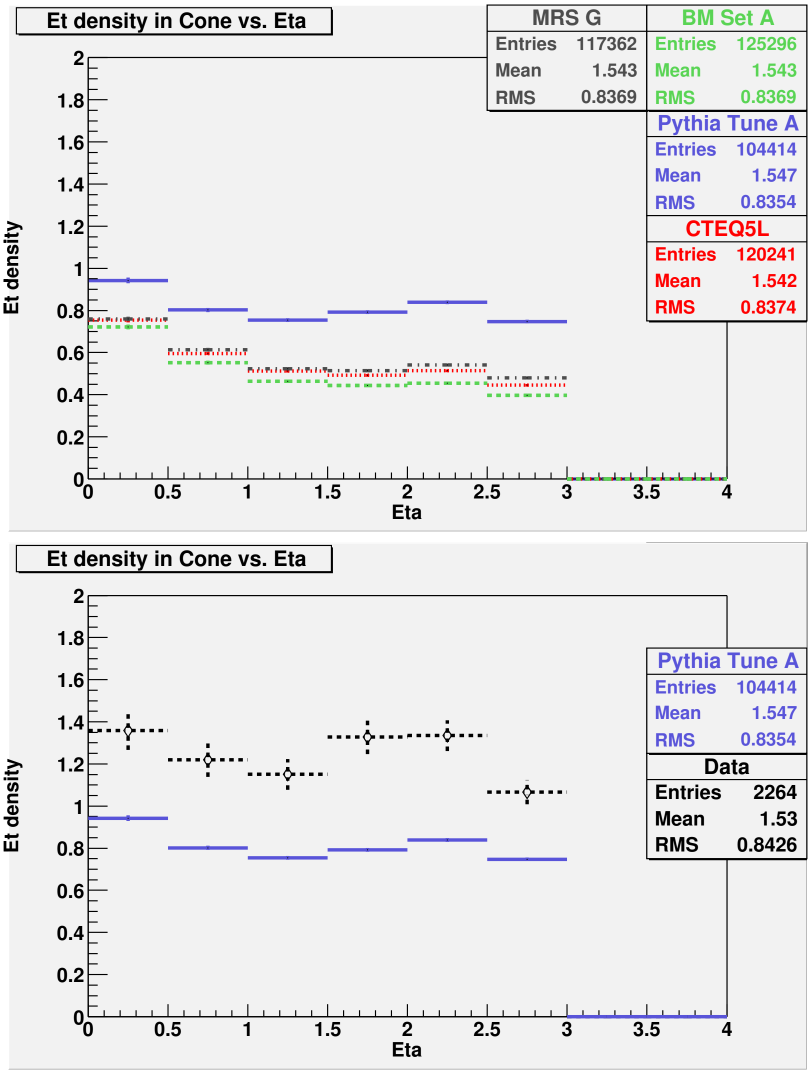

Figure 2: E_T density [GeV/(unit $\eta - \phi$)]in cones of R=0.4 vs η . Monte Carlo samples are shown on the top and data on the bottom. PYTHIA Tune A is also included on the data plot to facilitate comparison. On the Monte Carlo plot, the red (dotted) curve corresponds to CTEQ5L, the green (dashed) to BM Set A, the grey (dot-dash) to MRS G and the purple (solid) to PYTHIA Tune A.

PDFs, the discrepensies are on average about 15 percent, which is somewhat significant, though small compared to the difference between these samples and the Tune A sample. Again, the data gives results that are far higher than the Monte Carlo.

Fig. 6 shows the E_T density of the region that is at least R=1.0 from all the jets. As this measurement includes regions that are closer to the jets than previous calculations, it is more sensitive to out of cone energy. We thus expect it to be higher than the others. Note the broader distribution of PYTHIA Tune A compared to the other Monte Carlo samples.

Fig. 7 shows the E_T density within various annulli from a jet's centroid. Note the steeper drop in the data in comparison to the Monte Carlo. The larger difference between the 0.4-0.6 and 0.6-0.8 bins in Monte Carlo may be an indication that the Monte Carlo over estimates jet fragmentation, or that the jets are too narrow. Also note that at a displacement of close to R=1.0 from the centroid the E_T density is comparable to that found with the other measurements. We can say, then, that out of cone corrections do not significanty influence our measurements at a distance of R=1.0.

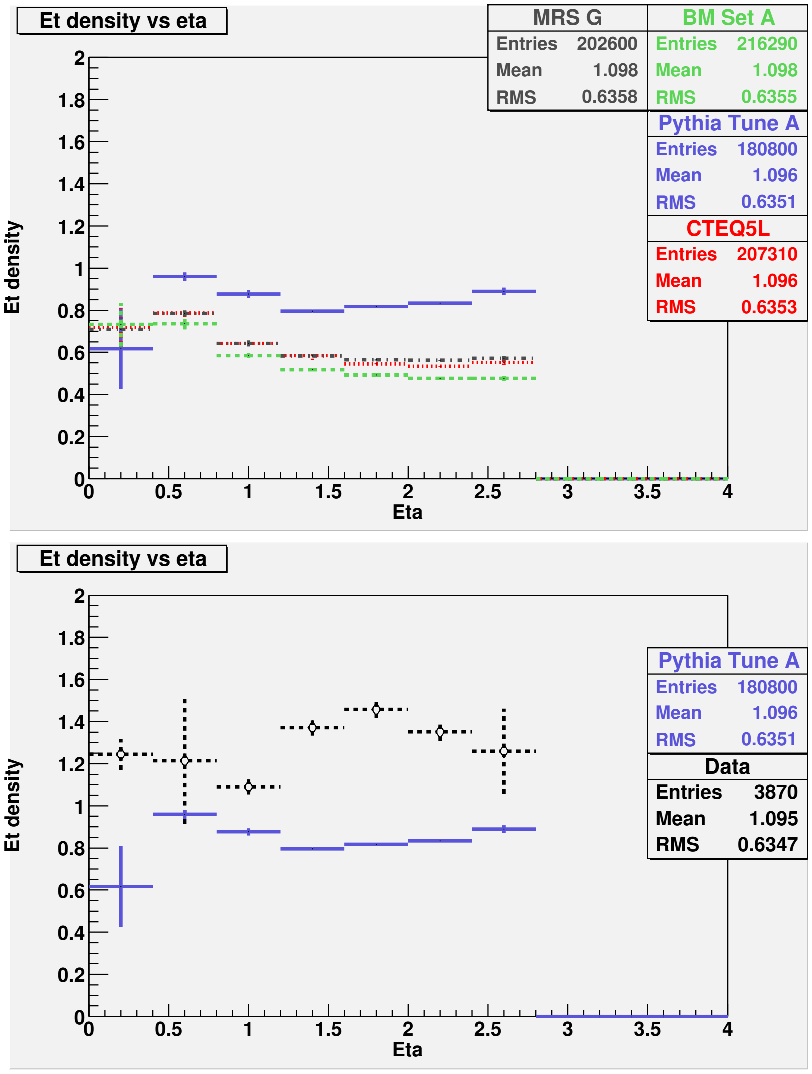

Figure 3: E_T density [GeV/(unit $\eta - \phi$)] vs η . Measurements are made in slices with width of two η towers and the density is measured outside R=1.0 from all jets. Monte Carlo samples are shown on the top and data on the bottom. PYTHIA Tune A is also included on the data plot to facilitate comparison. On the Monte Carlo plot, the red (dotted) curve corresponds to CTEQ5L, the green (dashed) to BM Set A, the grey (dot-dash) to MRS G and the purple (solid) to PYTHIA Tune A.

4 Conclusion

Understanding the "underlying event", and ensuring that the Monte Carlo models it well, is an important factor in undertanding jet energy corrections. Here we have started looking at the "underlying event" in $t\bar{t}$ events, with the ultimate intention being to help improve the top mass measurement. We compared calorimeter energy flow in regions that are sensitive to the "underlying event" in Monte Carlo samples created with different PDFs, as well as one with PYTHIA Tune A, and a data sample.

By all measures, PYTHIA Tune A exhibits a more energetic "underlying event" than the other samples. All of the Monte Carlo samples considerably underestimate the "underlying event" energy that we see in the data. The "underlying event" E_T density seen in PYTHIA Tune A is between 0.8 and 1.0 GeV/C, while the other Monte Carlo samples show a density of between 0.5 and 0.7 GeV/C and discrepencies of up to about 15 percent between themselves. The data shows an "underlying event" E_T density of between 1.0 and 1.4 GeV/C.

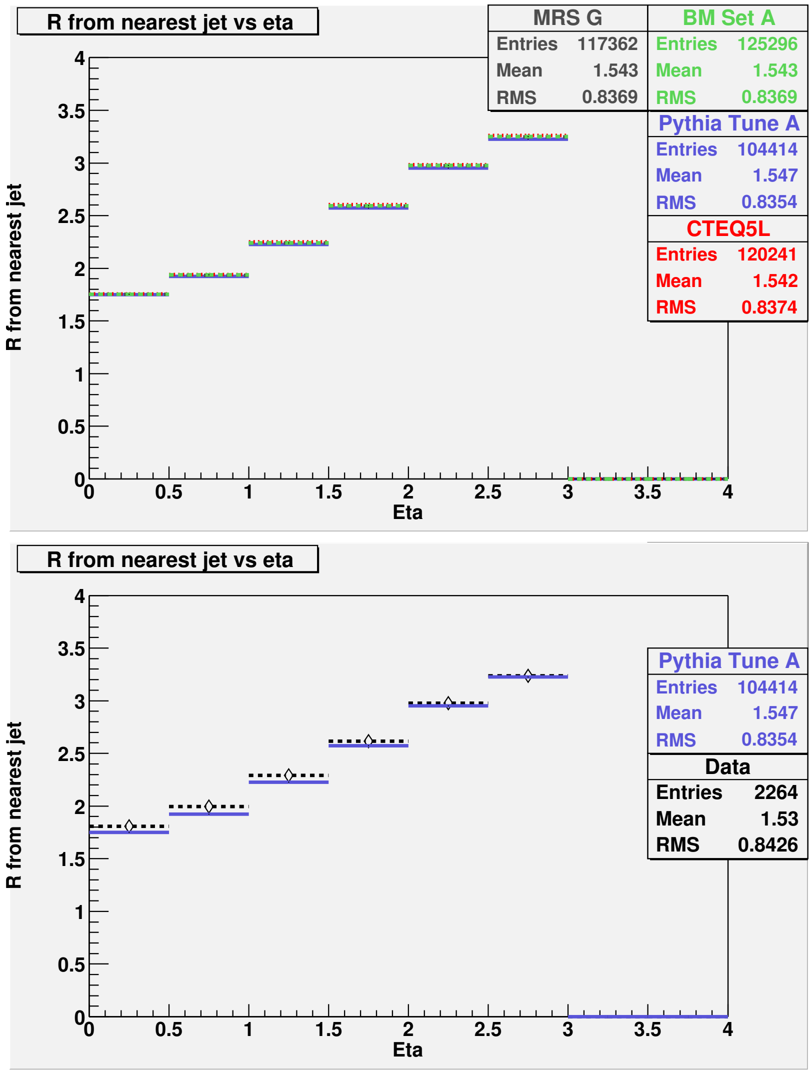

Figure 4: Eta dependence of the distance from the cone to the nearest jet in the Monte Carlo (top) and data (bottom). On the Monte Carlo plot, the red (dotted) curve corresponds to CTEQ5L, the green (dashed) to BM Set A, the grey (dot-dash) to MRS G and the purple (solid) to PYTHIA Tune A.

Additionally, there is possibly an indication that jet fragmentation is higher in the Monte Carlo samples than in the data.

References

[1] J.-F. Arguin, B Heinemann, CDFNote 6239 (February, 2003).

[2] Rick Field, CDFNote 6548 (April, 2003).

[3] Evelyn J. Thomsom CDFNote 6403 (July, 2003).

[4] We made the following cuts on the leptons: Electrons:Require electromagetic E_T greater than 20 GeV, track p_T greater than 10 GeV/C, isolation fraction less than 0.1 and $|\eta|$ less than 2. Muons: Require electromagnetic energy less than 2 GeV, hadronic energy less than 6 GeV, isolation fraction less than 0.1, track p_T greater than 20 GeV and |eta| less than 2.

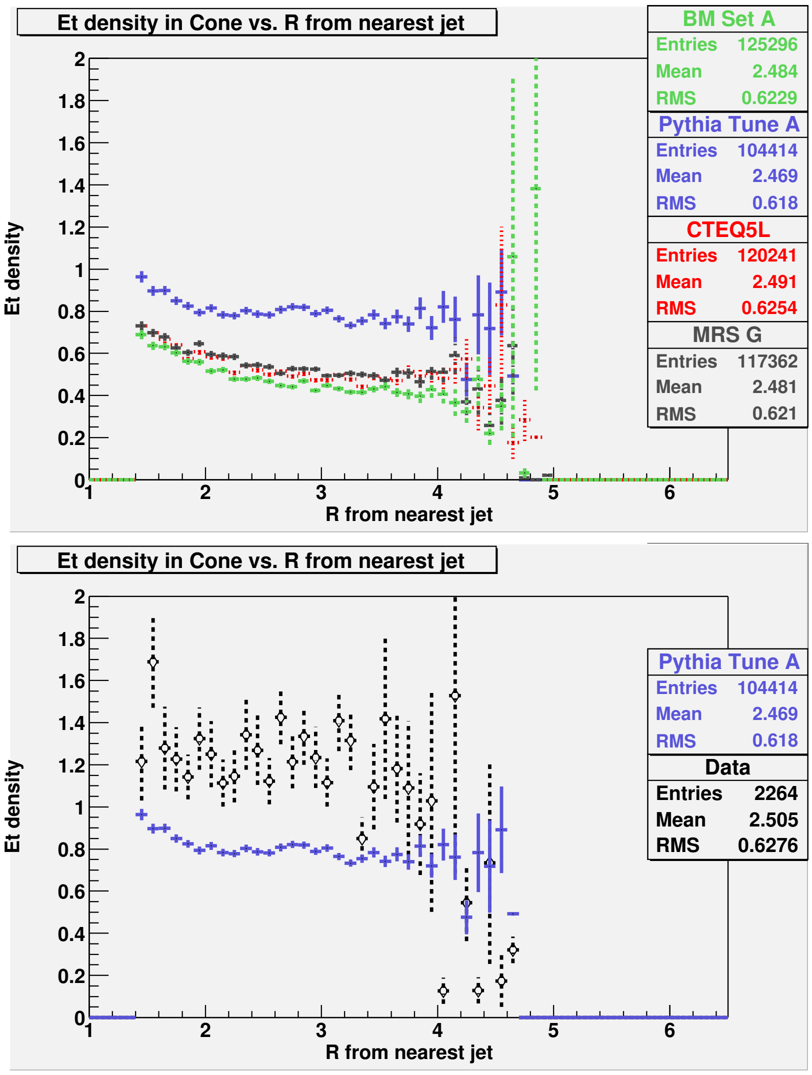

Figure 5: Dependence of the E_T density [GeV/(unit $\eta-\phi$)]in a cone of R=0.4 on the displacement from the nearest jet in the Monte Carlo (top) and data (bottom). PYTHIA Tune A is also included on the data plot to facilitate comparison. On the Monte Carlo plot, the red (dotted) curve corresponds to CTEQ5L, the green (dashed) to BM Set A, the grey (dot-dash) to MRS G and the purple (solid) to PYTHIA Tune A.

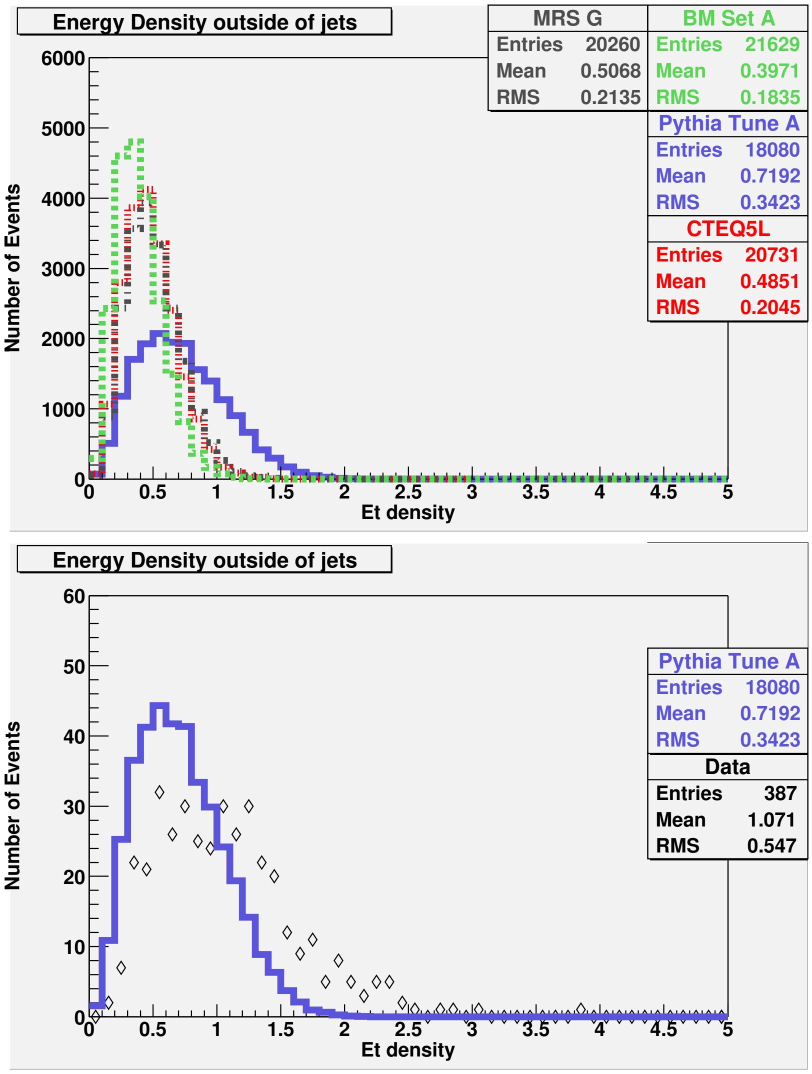

Figure 6: E_T density [GeV/(unit $\eta - \phi$)] in entire $\eta - \phi$ space excluding the region that is within R=1.0 from any jet's centroid in the Monte Carlo samples (top) and data (bottom). PYTHIA Tune A is also included on the data plot to facilitate comparison. The PYTHIA Tune A entries on the latter curve are scaled by a factor of 0.0214 to facilitate comparison with the data. On the Monte Carlo plot, the red (dotted) curve corresponds to CTEQ5L, the green (dashed) to BM Set A, the grey (dot-dash) to MRS G and the purple (solid) to PYTHIA Tune A.

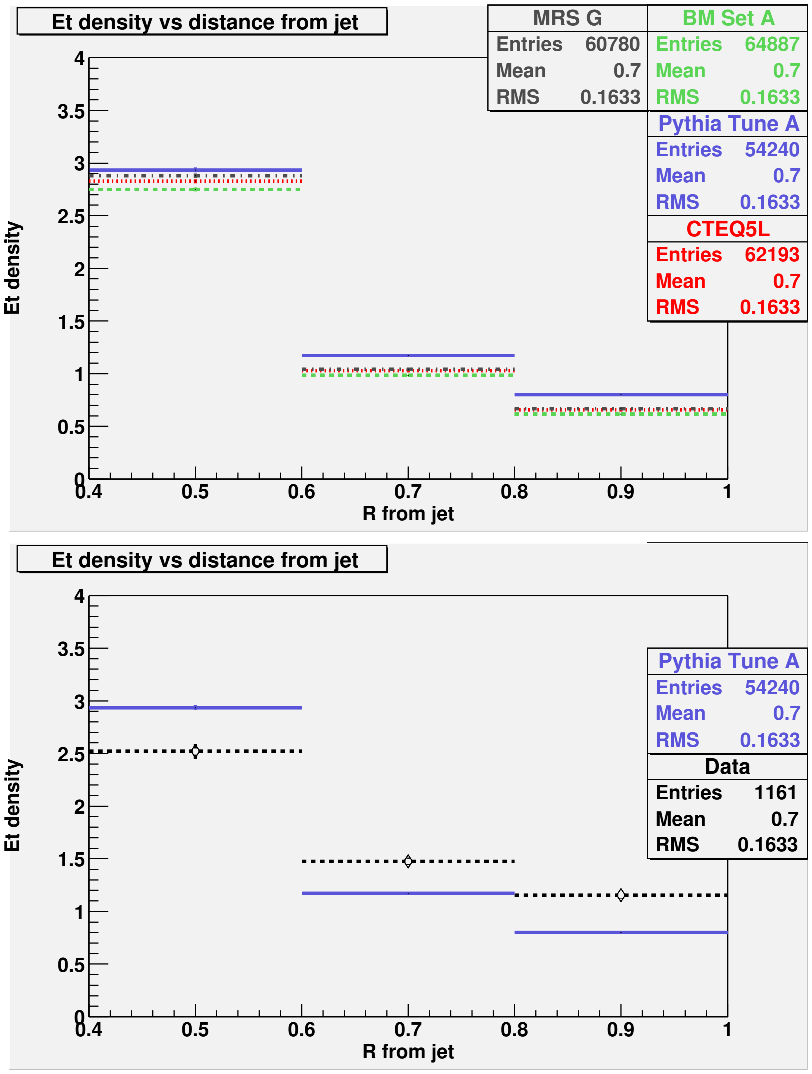

Figure 7: E_T density [GeV/(unit $\eta - \phi$)] as a function of displacement from the jets in the Monte Carlo samples (top) and data (bottom). PYTHIA Tune A is also included on the data plot to facilitate comparison. On the Monte Carlo plot, the red (dotted) curve corresponds to CTEQ5L, the green (dashed) to BM Set A, the grey (dot-dash) to MRS G and the purple (solid) to PYTHIA Tune A.