Reducing Cosmic Ray Background

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1.Introduction

1.1 LHC and ATLAS

The Large Hadron Collider (LHC) is a 14 TeV proton-proton synchrotron located on the French Swiss Border near Geneva. The four experiments, ATLAS, LHCb, ALICE and CMS are located around the LHC ring. The ATLAS detector is a general purpose detector which consists of the inner detector, the calorimeters, the muon spectrometers and magnets. Figure 1 shows where these components are located within ATLAS. The ATLAS colorimeter subsystems consist of electromagnetic calorimeters and hadronic calorimeters. The hadronic calorimeters include the Tile Calorimeter (TileCal), Liquid Argon (LAr) end-cap calorimeters (HEC), and Liquid Argon forward calorimeter (FCAL).

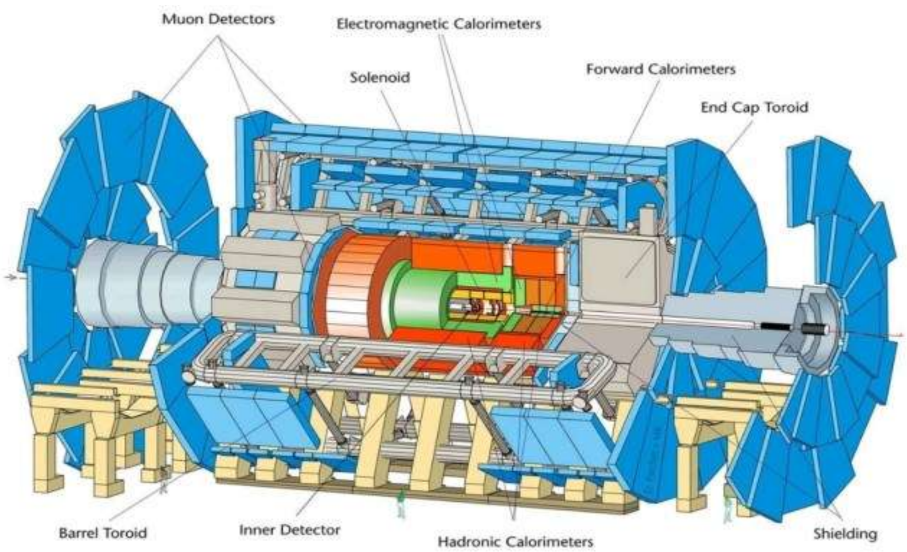

Figure 1 : The ATLAS detector

The coordinate system used to define the ATLAS detector is eta and phi. Phi is the azimuthal angle which is measured around the beam axis, the z axis. The x-y plane is perpendicular to the direction the beam is traveling. Eta is pseudorapidity and is defined by $\eta = -\ln(\tan(\theta/2))$, where theta is the angle which is measured up from the beam axis.

1.1.1 Tile Calorimeter

This analysis focuses on the reduction of comic ray background in the Tile Calorimeter (TileCal). The TileCal is made up of the barrel, which covers an eta range of -1< eta <1, and two extended barrels which cover the regions defined by -1.7<eta<-0.8 and 0.8<eta<1.7. In the TileCal hadronic showers are absorbed by steel, and detected by scintillating tiles. The information registered by these tiles is read by 10 000 photomultipliers (PMTs).

2.MET and Fake MET

Particles traveling toward each other in the z axis have momentum only in the z direction. From conservation of momentum laws, one can conclude that the total momentum in the x and y direction of the particles is zero before and after particles collide. After a collision occurs and new particles scatter off into the x and y directions, the Tile Calorimeter should be able to detect the energy deposits from all known particles. If the sum of the x and y momentum of all the known particles is not zero; some particles created in the collisions were not detected. Missing transverse energy (MET) is calculated by summing up the energy deposits (p^x_i, p^y_i) in each Tile calorimeter cell:

$$\not{E}_T = \sqrt{(\sum_i p_i^x)^2 + (\sum_i p_i^y)^2}$$

Searching for undetected particles by examining missing transverse energy is what might unveil new particles and lead to new physics theories.

2.1 Cosmic Background as source of Fake MET

An imbalance of momentum in the x and y direction is often caused by cosmic rays passing through the detector. There is a variety of cosmic sources responsible for generating high fake missing transverse energy. The most common sources of high cosmic energy deposits are air showers and muons undergoing hard bremsstrahlung. This analysis of two M7 runs (run 69373 and run 70237) revealed that missing transverse energy is generated at a much higher rate than expected. Due to the large amount of high energy events that generated missing transverse energy, the events were subdivided into three energy groups and analyzed. Group One consisted of events that were in the energy range of 100 GeV to 500 GeV. Group Two contained events which were in the energy range of 500GeV to 1TeV. Group Three consisted of 14 over 1 TeV events, three of which claimed to contain over 4 TeV of energy. The graphs below show the rate at which these high energy events occurred, and the rate at which they generated missing transverse energy.

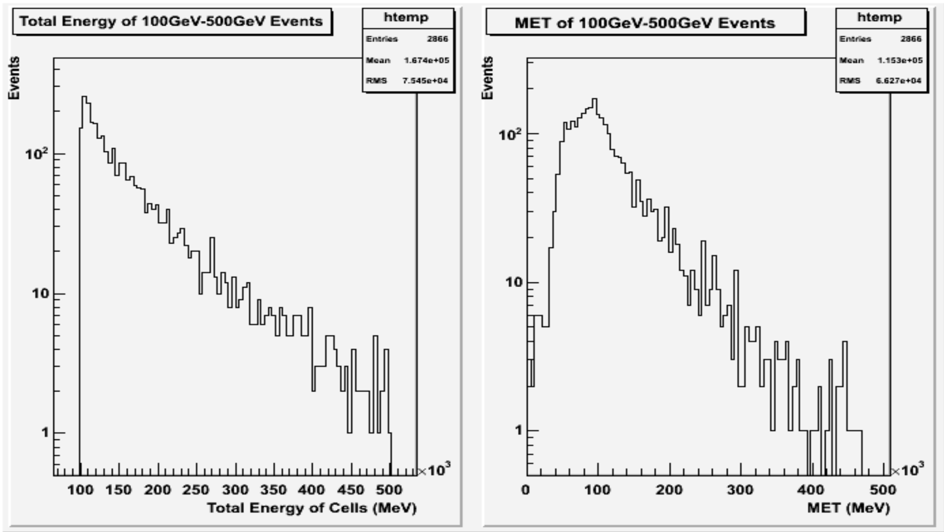

Figure 2 : Rate of 100 GeV - 500 GeV Events

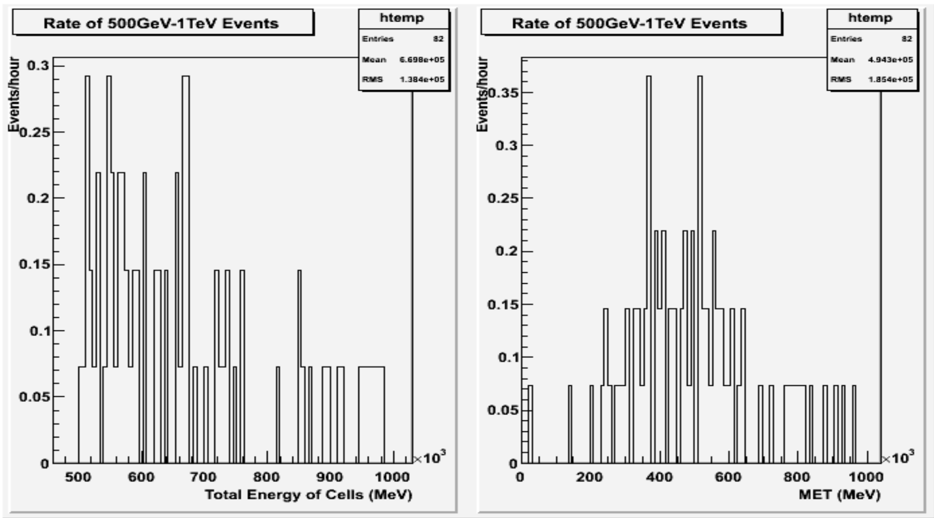

Figure 3 : Rate of 500 GeV – 1 TeV Events

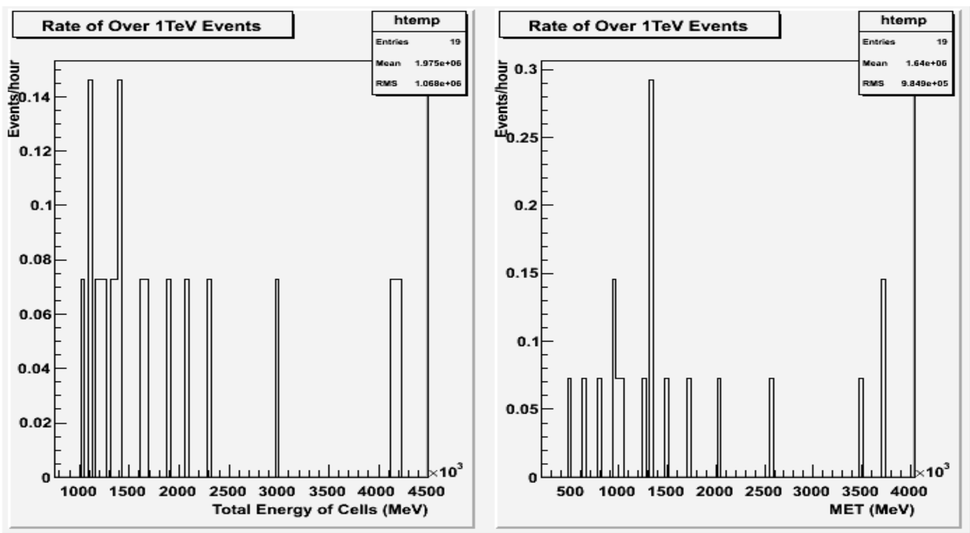

Figure 4 : Rate of Over 1 TeV events

From the plots above one can see that every hour there are 4-5 events with an energy of 400 GeV to 500 GeV, and one event with an energy of 800GeV to 1TeV. The last plot indicates that an over 1 TeV event occurs every 4.5 hours.

Each group of events was analyzed by making event displays in ATLANTIS. The events that were analyzed in Groups One and Two were cosmic events. The matching pulse shapes in the event displays in Figure 5 indicate that the energy deposits were due to cosmic rays and not noise.

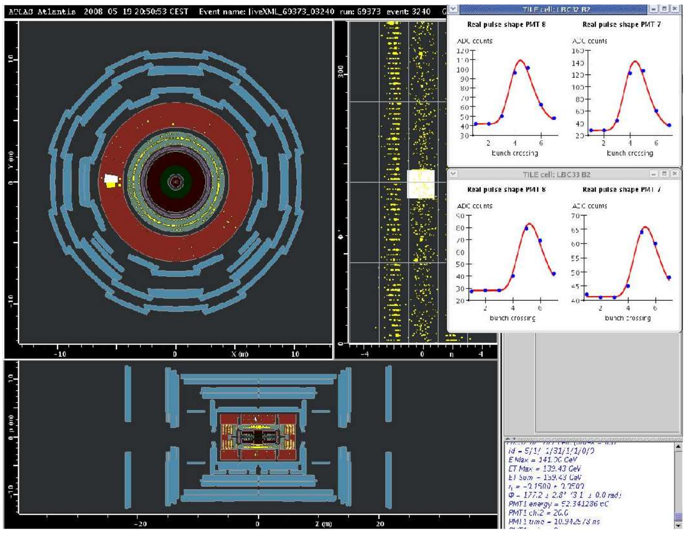

Figure 5: Event display of Event in Group 1

Out of the 14 events in Group Three, 12 of them were due to cosmic rays. In event 37239, 4 TeV of energy was detected. The event display for this rare event shows that the ADC counts were saturated at 1200 counts. Events such as this is due to muons undergoing hard bremsstrahlung.

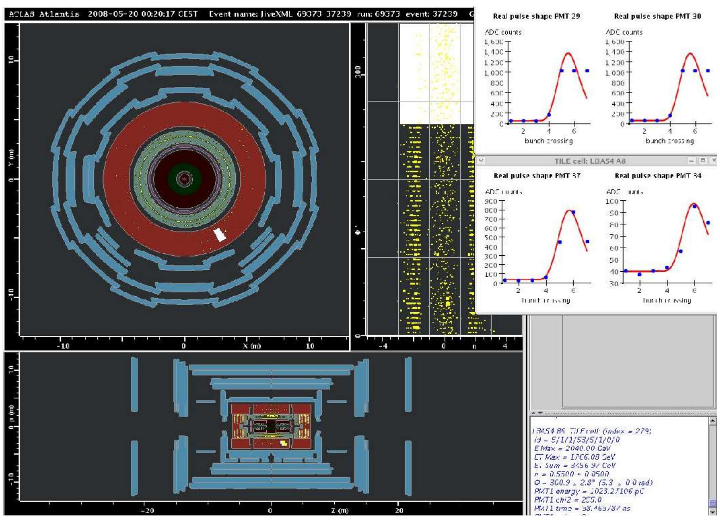

Figure 6: Event display of event with saturated channels

In run 69373, two of the events in Group Three were due to calibration pulses set off in the detector for reasons which are not yet understood. An event display for one of these events is shown in the figure below. In these calibration pulse events modules LBA 54 and LBA 59 light up, and all of the energy deposits in these modules are at 180 ADC counts. Although the pulse shapes for these events appear good, the fact that one entire module is lit up indicates that the event is not due to cosmic muons. These seemingly random calibration events are still under investigation.

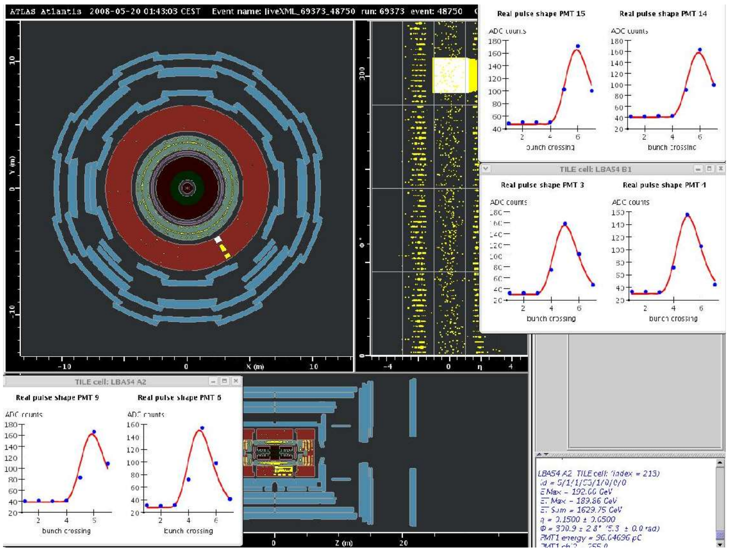

Figure 7: Event display of event with calibration pulse

3. Reducing Cosmic Background

Energy deposits from cosmic rays need to be eliminated in order to obtain a better understanding of energy distributions that originate from collisions. It is important to eliminate high energy cosmic rays because they can be mistaken for SUSY and other physics signals. The data cleaning tools used to eliminate cosmic rays are designed in such a way that the TileCAl recognizes and rejects muons and other comics independently of the muon spectrometer. The first method used to eliminate cosmic background is an electromagnetic fraction cut. Timing cuts are another useful tool that further reduces the number of events that contain only cosmic rays.

3.1 Electromagnetic Fraction (F_{EM}) Cuts

Electromagnetic fraction cuts are the first cuts applied to data in order to reduce cosmic background. Electromagnetic fraction is defined as

$$F_{EM} = E(LAr)/[E(LAr) + E(TileCal)]$$

For SUSY signals and QCD jets the electromagnetic fractions is expected to peak at around 0.7 or 0.8. The electromagnetic fraction of cosmic ray muons is expected to peak at around 0.05 because cosmic muons loose approximately 300 MeV in the LAr and 2-3 GeV in the TileCal. This makes it possible to separate and reject cosmic ray events. The first attempt to make F_{EM} cuts was made by calculating the F_{EM} for all the cells in the LAr and TileCal. In order to reduce noise 200 MeV and 400 MeV cell level cuts were made in the LAr and TileCal respectively. Calculating F_{EM} in such a way was not very useful due to the large quantity of LAr cells and large amounts of noise. Figure 8 shows that when F_{EM} is calculated in such a way, the cosmic ray F_{EM}, shown in red, is almost indistinguishable from the F_{EM} of QCD jets.

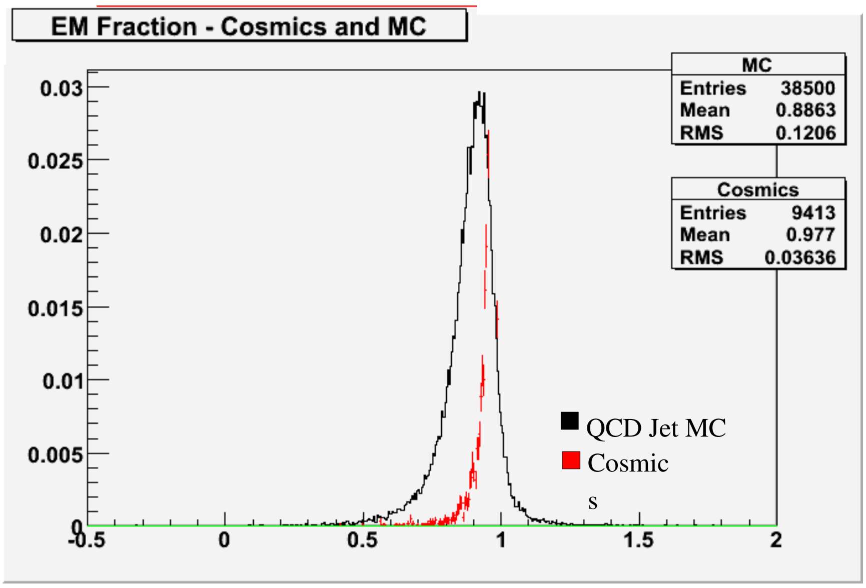

Figure 8: F_{EM} calculated from cells VS F_{EM} from jet MC

Because calculating F_{EM} by including all the cells in the event did not prove to be useful, another technique for making F_{EM} cuts was explored. The F_{EM} of 0.7 cone tower jets was graphed by using the variable jetEmfCone7H1TowerJets. This variable is calculated using various jet algorithms and automatically generated in the reconstructed data. Figure 9 shows that calculating F_{EM} by using tower jets leads to a more clear distinction between the cosmic data and simulated jet data. The red plot shows the F_{EM} of cone 0.7 tower jets, while the black plot shows the simulated F_{EM} for QCD jets. The plot shows that making an F_{EM} cut at 0.2 would eliminate many cosmic ray events without disrupting the events which contain real jets.

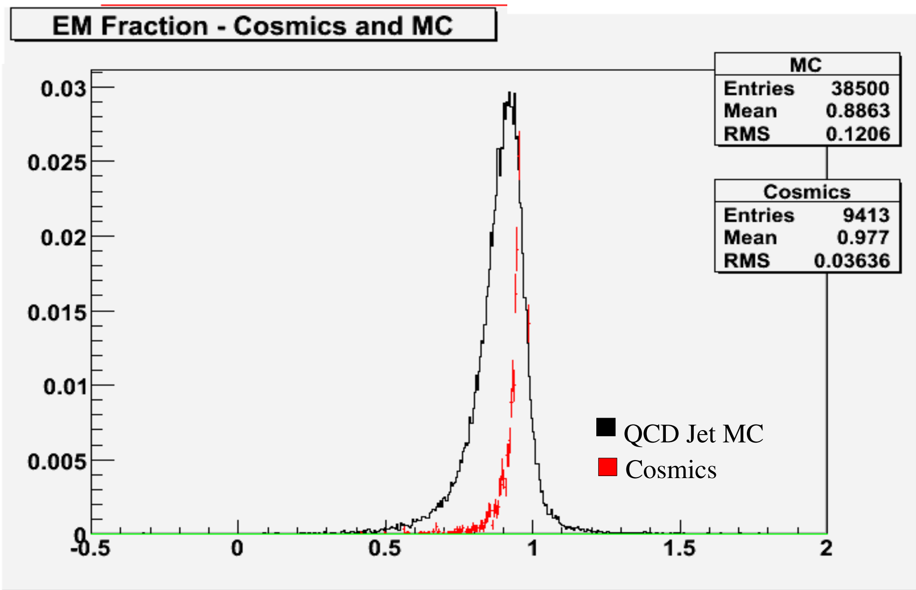

Figure 9: F_{EM} calculated from Jets VS F_{EM} from Jet MC

3.2 Time Cuts

Calorimeter timing is another tool that can be used to reject cosmic rays, beam-gas events and beam-halo events. The time is defined to be 0 at the center of the detector. Particles traveling up from the interaction point have a negative travel time, while particles traveling down from the interaction point have a positive time. In order to perform the up and down time calculation the calorimeter is divided into an upper segment, phi>0, and a lower segment, phi <0. The time in each segment is weighted by the energy of each cell, and calculated using the formula :

$$t_{up(down)} = \frac{\sum_i (E_i^{up(down)} \times t_i)}{\sum_i E_i^{up(down)}}$$

Subtracting the particles up time from its down time represents the particles time of flight. For particles coming from the interaction the up minus down time should be centered at around 0. The value has a small deviation from zero due to electronics noise. Cosmic muons enter the detector from the top and travel 6-7m before reaching the bottom of the detector. Traveling near the speed of light, their time of flight is approximately 18-20 ns. Thus the up minus down time for cosmic muons should peak near -18 ns. The width of the time of flight distribution for cosmic rays is approximately 3 ns. Figure 10 shows the up minus down time for cosmic rays. As shown in this plot, a cut can be made at -9ns (2 sigma from 0), in order to reject cosmic events.

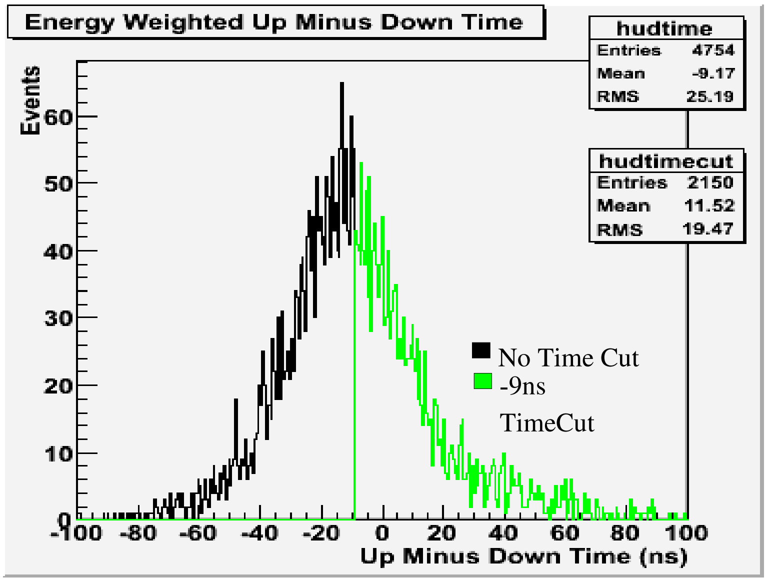

Figure 10: Up minus down time for cosmic rays

3.3 Reducing Fake MET

As discussed above, missing transverse energy can be reduced by making jet electromagnetic cuts and timing cuts. The energy and MET calculation was performed on only the cells which are in the jets. There are two alternative methods which could have been used to calculate MET. The first method is to perform energy and MET calculations on all the cells in the events. However including all the cells also includes all the unwanted energy deposits from noise. Narrowing in on the cells that are only in the jets reduces a lot of noise. The second method to perform the MET calculation was to use jet level variables from the ntuple such as p_x_jet and p_y_jet. These variables are calculated using jet algorithms which exclude a lot of cells. As a result, the MET appears much larger than it actually is. In Figure 11 the MET calculated from the jet variables is shown in blue, while the MET calculated by selecting all the cells in the jets is shown in red. The MET calculated at a jet level appears larger because many cells that could balance the momentum in the x and y directions were rejected by the jet algorithm.

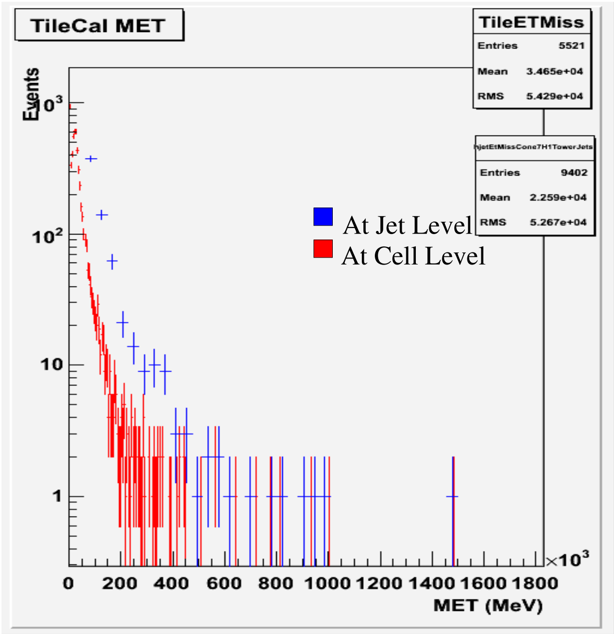

Figure 11: MET calculated at jet level VS MET calculated at cell level

Thus, the energy and MET was calculated by selecting cells in jets and making an additional 50 MeV noise cut on all the cells. This calculation is shown in red in Figure 12. An F_{EM} cut of 0.2 was made on the highest energy jet in each event. This reduced the number of events by 4298, and eliminated all of the high energy events. The blue graph shows the effect of the F_{EM} cut on the energy and missing transverse energy. An additional timing cut at -9ns was performed, which reduced the number of events by 520. The effect of the timing cut is shown in green in figure

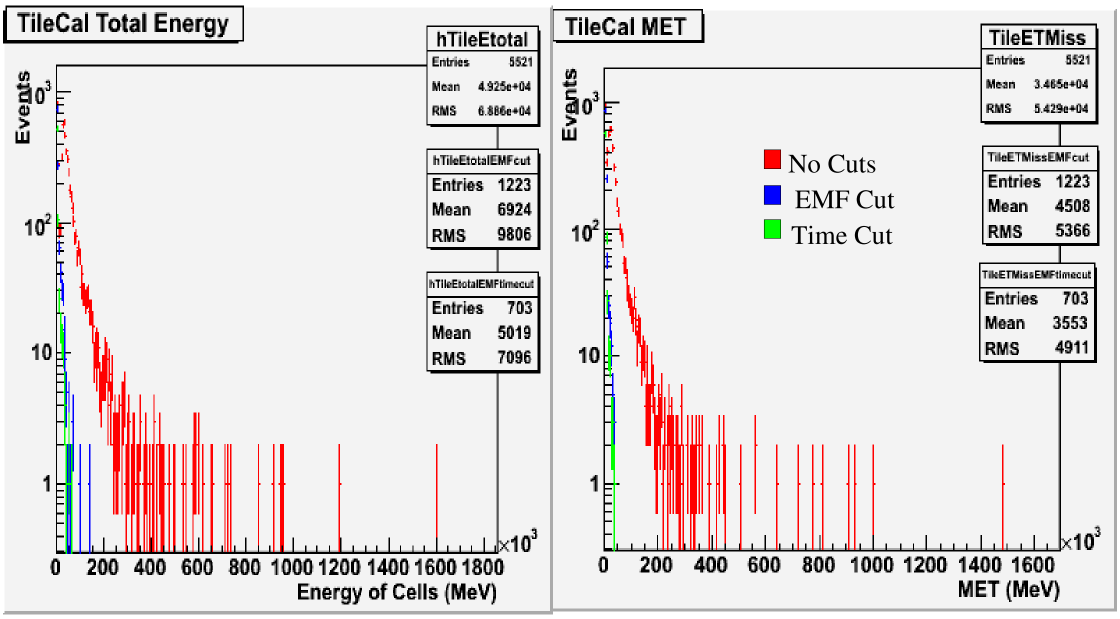

Figure 12: F_{EM} and Time cuts on Energy and MET

From the plots above, it is clear that making an F_{EM} cut of 0.2 on the highest energy jet in each event, and a timing cut at -9ns significantly reduces cosmic background.

4 Conclusion

It is necessary to attempt to eliminate cosmic background in order to make an accurate analysis of future collision data. In this analysis, two types of data cleaning techniques were studied. It was found that the electromagnetic fraction, calculated at a jet level, is a useful tool for reducing the amount of cosmic events. An F_{EM} cut of 0.2 was made on the highest energy jet in each event, which eliminated all the high energy events. Calorimeter timing was another useful technique for eliminating cosmic background. Applying a time cut at -9ns eliminated many cosmic events which survived the F_{EM} cut.