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20 November 2002

Updated Level 2 Missing Transverse Energy Trigger Studies at Low Luminosity

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Abstract

We present results on the missing transverse energy trigger at Level 2 for low luminosity running ($2 \cdot 10^6 mb^{-1}$ Hz) . The trigger threshold for 1Hz is found to be 115GeV. With a veto against back to back jets in the transverse plane to reduce the QCD background the threshold is lowered to 90GeV. The Level 1 missing E_t trigger requires much higher rate than Level 2 to achieve same high signal efficiency.

Contents

1 Introduction

We present results on low luminosity ($2 \cdot 10^7 mb^{-1} Hz = 2 \cdot 10^{33} cm^{-2} s{-1}$) trigger rates of the CMS experiment comparing generated and measured quantities. We also calculate 95% efficient cuts and background rates at that cut of a Higgs channel. It is an update of [2] with higher statistics. The previous high luminosity study was summarized in [1].

The rates for a level 1 missing transverse energy trigger have previously been presented in [3] and [4] for low and high luminosity. Since then the low luminosity estimate has been changed from 10^{33} to $2 \times 10^{33} cm^{-2} s{-1}$. The updated results are presented in [5] .

2 Event sample and software

This analysis uses event samples from the HLT 2002 summer and fall data production. A summary of the production can be found at [7].

All events were generated using Pythia6([6]). QCD event sample were generated in 12 $\hat{p}_t$ bins as shown in Table 1). A color code in the table is used in figures in the following sections to indicate contribution of each QCD bin to trigger rates.

The generated events were processed through CMSIM125 for detector simulation. ooHit formation and digitization were done using `ORCA_6_2_3` . A pile-up simulation was done during the digitization process. In average 3.46 minimum bias events were added to each bunch from bunch crossing -5 to $+3$.

Jets and missing E_t were reconstructed using `ORCA_6_2_3` and `JetMetAnalysis` version 2.07 [9]. This analysis uses jets reconstructed by iterative cone algorithm with a cone size of 0.5. The Level 1 missing E_t algorithm is described in [5].

Table 1: QCD two-jet event samples

$\hat{p}_t$ (GeV/c)	σ_i (mbarn)	N_i	color	style
0-15	52.368	94802	black	dotted
15-20	1.854	247998	red	dash dotted
20-30	$7.819 \cdot 10^{-1}$	243218	black	line
30-50	$1.849 \cdot 10^{-1}$	426417	blue	dashed
50-80	$2.433 \cdot 10^{-2}$	146141	black	dotted
80-120	$3.359 \cdot 10^{-3}$	133497	red	dash dotted
120-170	$5.654 \cdot 10^{-4}$	147495	black	line
170-230	$1.163 \cdot 10^{-4}$	139071	blue	dashed
230-300	$2.812 \cdot 10^{-5}$	100170	black	dotted
300-380	$7.848 \cdot 10^{-6}$	86679	red	dash dotted
380-470	$2.396 \cdot 10^{-6}$	60963	black	line
470-600	$9.249 \cdot 10^{-7}$	59670	blue	dashed

Off-line missing E_t was calculated using the EcalPlusHcalTower objects with a threshold of 500 MeV per tower in the full rapidity coverage of the CMS calorimeter.

The reconstructed jets and missing E_t were written to ntuple files using the ntuple maker (`JetMetAnalysis` version 2.07 [9]) of the JetMET physics group ([8]). The ntuple files contained generated particles, generator level jets and missing E_t in addition to L1 and off-line jets and missing E_t.

3 Method of calculating trigger rates

The bunch crossing rate is $40.08MHz$, the ratio of filled bunches in the LHC ring is $2808/3564$ [10], so the average total bunch crossing rate is $B_0 = 31.578MHz$.

Various cases of calculating trigger rates are discussed in [11]. Single objects, multiple objects, and objects having contribution from multiple events in the presence of pile-up require different methods. The method chosen also depends on the information available for the particular events as well as on the available CPU power.

Event weights for the case when an object (like missing E_t or jets) has contribution from multiple events (pile-up) are discussed in [12] . Formulas for individual event weights and average event weights are provided there. Individual weights has to be calculated on fly during the actual personal analysis, because among others it requires as input the statistics (number of bunch crossings) of every $\hat{p_t}$ bin . The weight of a bunch crossing (ntuple event) is

$$W(\hat{n}) = \frac{B_0 \mu}{\sum_j N_j \frac{n_j}{f_j}}$$

where $N_j = 1, ..., N_{bin}$ is the statistics of the $\hat{p_T}$ bin, i.e. the bin that has its first event from that bin, n_j is the number of $\hat{p_T}$ events in the bunch crossing, $f_j = \frac{\sigma_i}{\sigma_{total}}$ is the relative cross section of the ith bin, B_0 is the bunch crossing rate and μ is the average pile-up (3.46) .

A better method [11] would select pile-up by their $\hat{p_T}$ - also taking into account of the $\hat{p_T}$ of the primary interaction - it may be useful to consider this option in the future, because weighting needs considerable time, and during analysis one has to do it every time, while the production of data only happens once.

4 Generated missing E_t

We calculated the generated missing E_t using generated particles excluding neutrinos and muons. The left plot of Figure 1 shows the event rate of generated missing E_t calculated using particles in whole η region, while the right using only particles within the calorimeter scope ($|\eta| < 5.0$). No pile-up event was included. A clear smearing of the missing E_T is seen in missing $E_t < 70$GeV due to particles escaping into a hole for the beam pipe in the forward calorimeter (HF).

Studies [14] showed that for higher $\hat{p}_t$ QCD events the $gg \to c\bar{c}$ and $gg \to gc\bar{c}$ with subsequent semi-leptonic decays do important contribution to the real missing E_t. See also [2].

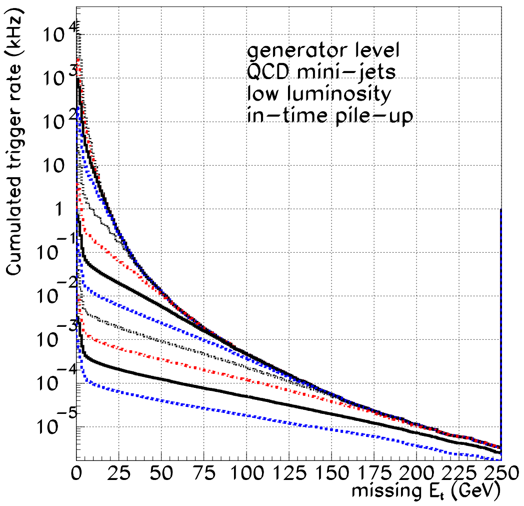

Figure 1: The cumulative bunch crossing rates of QCD background events as a function of the generated missing E_t threshold. The contribution of a particular $\hat{p}_t$ bin is displayed by the distance between two colored curve. The color coding is shown in Table 1. The left figure is calculated from all the particles excluding neutrinos and muons. The right figure also excludes particles pointing to beyond the coverage of the calorimeter ($\eta = 5$).

4.1 Effect of the beam hole

As seen in figure 1 particles escaping to the beam hole smear the generated missing E_t below 70 GeV. In order to see the smearing effect clearly, we divided the event sample to two sets (Figure 2). The first set contains events with zero or small missing E_t ($< 10GeV$). The second set contains events with larger missing E_t ($> 10GeV$) due to semi-leptonic decays of c and b quarks. The figure (right) shows that events with practically no real generated missing E_t can not acquire more than about $70GeV$ contribution from the effect of vanishing energy in the beam hole. For the events that have a big real missing E_t no noticeable smearing is seen above $E_t > 50GeV$.

The kinematical limit of the E_t that a parton and its jet can carry at $\eta = 5.0, 5.5, 5.7$ are $E_t = 94, 57, 47GeV$ respectively for $7TeV$ beam energy. In the $\eta = 5.0$ case (i.e. at the boundary of the calorimeter) we expect only about half of the energy is missing after jet fragmentation, while in the other two cases ($\eta = 5.5, 5.7$) most all of it does. It means that the missing E_t in the 3 cases is $47, 57 or 47GeV$ respectively, i.e. the missing E_t caused by the beam hole does not exceed about $60GeV$ in case of no pile-up. The low luminosity pile-up increases this limit to $70GeV$. This simple view of the beam hole effect is consistent with what seen in Figure 2. These limits are slightly bigger than those of [2], we attribute it to the bigger statistics we have now.

5 Reconstructed Missing E_t

5.1 Missing E_t Resolution and Fake Missing E_t

Figures 3 and 4 show the average value and the RMS of the reconstructed missing E_t of the QCD background as a function of the $\hat{p}_t$ of the primary interaction. The missing E_t resolution (the average value) shows clear dependence on the $\hat{p}_t$ and is significantly worse at higher $\hat{p}_t$.

We have to be careful when interpreting these plots, because the cross section of the last $\hat{p}_t$ is eight orders of magnitude smaller then that of the first bin (see Table 1). The average value of the missing E_t distribution does not say anything about the upper end tail, which determines the contribution to the trigger rate. Because of the big difference of cross sections, a much smaller (even eight orders of magnitude smaller) tail can significantly contribute to the trigger rate.

It was shown in [2] that more than $3/4$ of events with the reconstructed missing $E_t > 100$GeV had originally zero

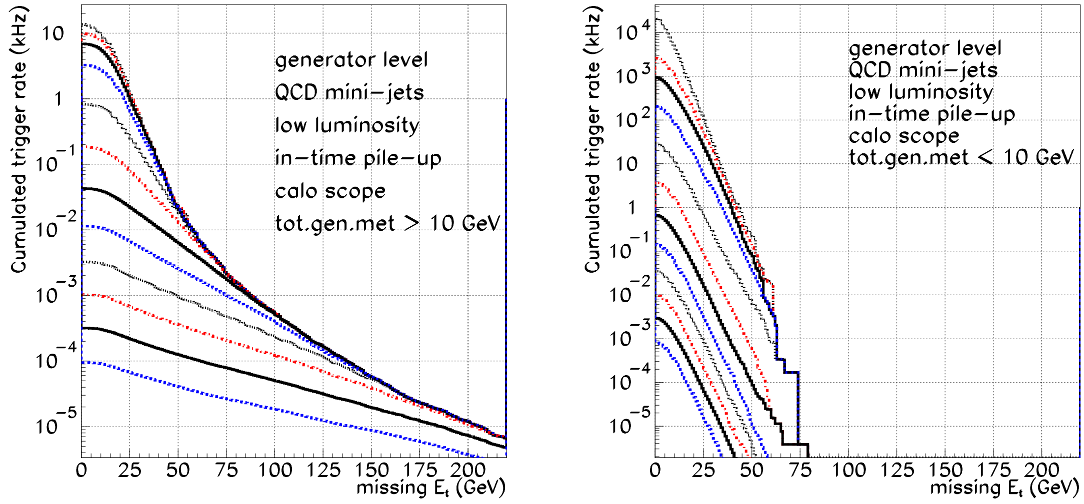

Figure 2: The cumulative generated event rate (not the bunch crossing rate) of QCD background events is shown as a function of the calorimeter scope generated missing E_t cutoff on a logarithmic scale for two cases. The left plot shows the rate for events that have total generated missing $E_t > 10GeV$ while the right plot shows the rest of the events (missing $E_t < 10GeV$) .

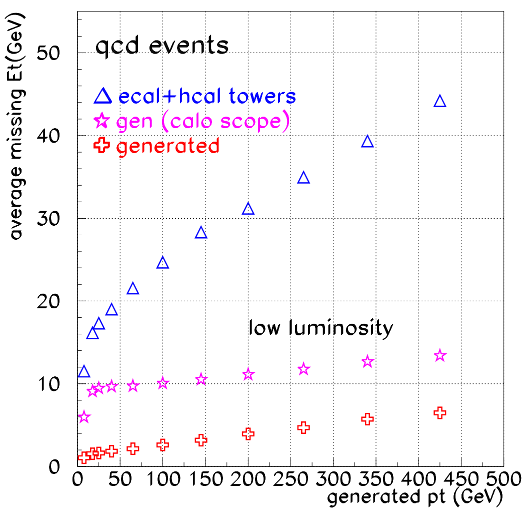

Figure 3: The average value of missing E_t of QCD background events is shown as a function of the $\hat{p}_t$ of the "signal" interaction.

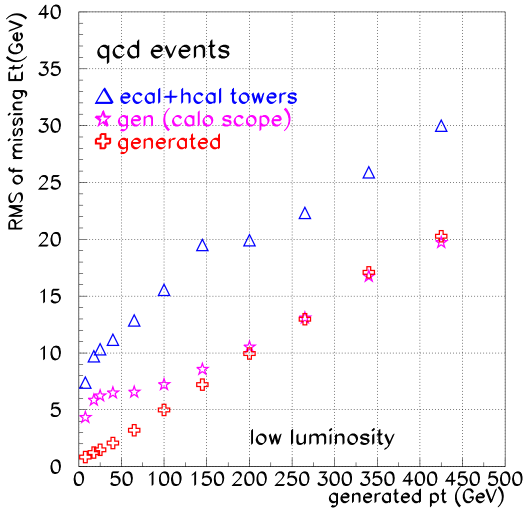

Figure 4: The standard deviation of the missing E_t distribution of QCD background events is shown as a function of the $\hat{p}_t$ of the "signal" interaction.

missing E_t in the sample. This fake missing E_t, especially in lower $\hat{p}_t$ bins, contributes significantly to the missing E_t trigger rate. The fake missing E_t comes from bad reconstruction of lower energy jets. The QCD background of high missing E_t has dominantly two energetic back to back jets on the transverse plane of balanced generated missing E_t . When this system is boosted in the z direction, one jet tends to be a forward high energy jet, while the other is becoming a low energy central jet. For the latter one both the response (non-linearity) ? and then resolution are worse . The forward jets have bigger energy particles, for which the response is closer to one, also the resolution of the energy measurement is better.

6 Missing E_t Trigger Rates

6.1 Fixing a Software Bug

Calculating missing E_t rates is the best tool to manifest rare software bugs. We found events with un-physically large energy deposit in the very forward calorimeter. The problem was traced to a shower library overflow in CMSIM125. The overflow happened for particles of energy bigger than 1 TeV. We removed these bad events with a simple filter, removing events that have a 1 TeV particle or bigger. This way we dropped approximately 2% of the events.

Figure 5 compares the effect of the bug (left plot) to the case when the bug is fixed. At first sight, looking only at the upper edge of the distribution, neglecting the contribution of the particular $\hat{p}_t$ bins, the buggy left plot looks even better, because the bug free right plot has a drop around 100 GeV. But the bin details in the left plot show the anomaly, also we know from our past studies, that 200 GeV threshold for a trigger rate of 1 Hz would not be true.

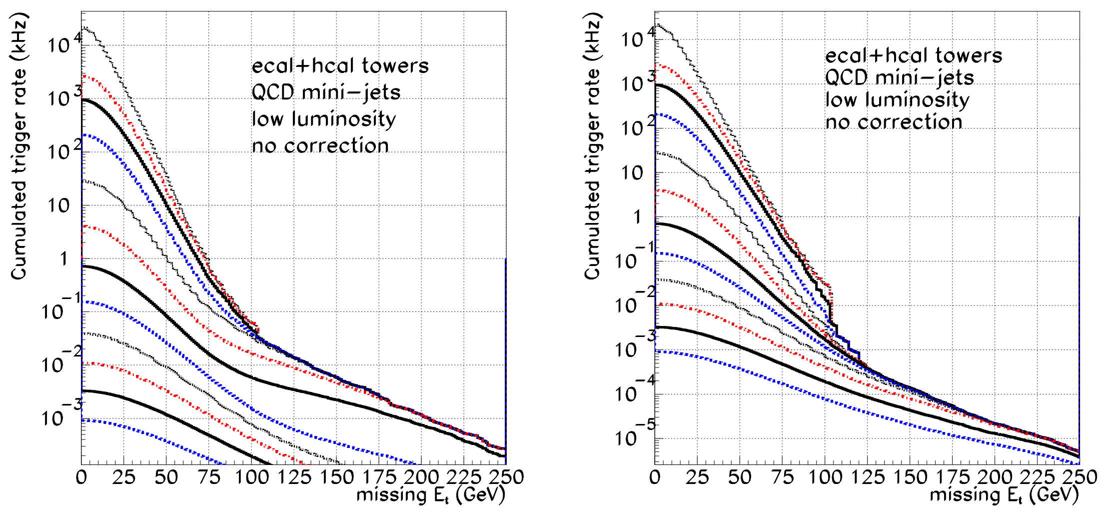

Figure 5: The cumulative reconstructed missing E_t trigger rate of QCD background events is shown as a function of the E_t cutoff on a logarithmic scale. The missing E_t is calculated from uncorrected ECAL+HCAL towers. The left figure is made of all the events, while the right one shows the rate after removing the software bug.

6.2 Rates for the High Level Trigger

As a L2.0 algorithm, we have calculated missing E_t from uncorrected energy of off-line towers, see Figure 5 for the rates before (left) and after (right) removing the software bugs.

There is a drop of the rate around 100 GeV, and the contributions of the particular $\hat{p}_t$ bins clearly show the reason. Even lower $\hat{p}_t$ bins contribute to high reconstructed missing E_t. Though the relative number of higher missing E_t events is less for lower $\hat{p}_t$ with respect to the total number of events of the same $\hat{p}_t$ bin, the significantly bigger cross section of lower $\hat{p}_t$ events leads comparable contribution to higher missing E_t for every $\hat{p}_t$ bin.

We have exploited the current capacity of the CMS production system, and still we would need more statistics with the current $\hat{p}_t$ binning. We might consider to reunite some of the lower $\hat{p}_t$ bins thus allow longer tail from the same combined number of events. It seems, that we need 10 times higher statistics, which we can reach doubling the statistics of bins 2 to 6, and reuniting them. The first bin seems to have enough statistics, and a normal end of the missing E_t distribution.

We can extrapolate the rate of Figure 5 and we estimate the following. We have to set the second level missing E_t threshold at 125 GeV, that is a bit too high for Higgs around $120 GeV/c^2$ mass.

Thus we also looked at the rate with topology cuts of [2] (see Figure 6). The left plot has the rate after the 2 jet topology cut of [2] ($|\Delta\Phi - \pi| > 0.5$ for the axes of the first two jets). The right plot in addition excludes 1 jet events.

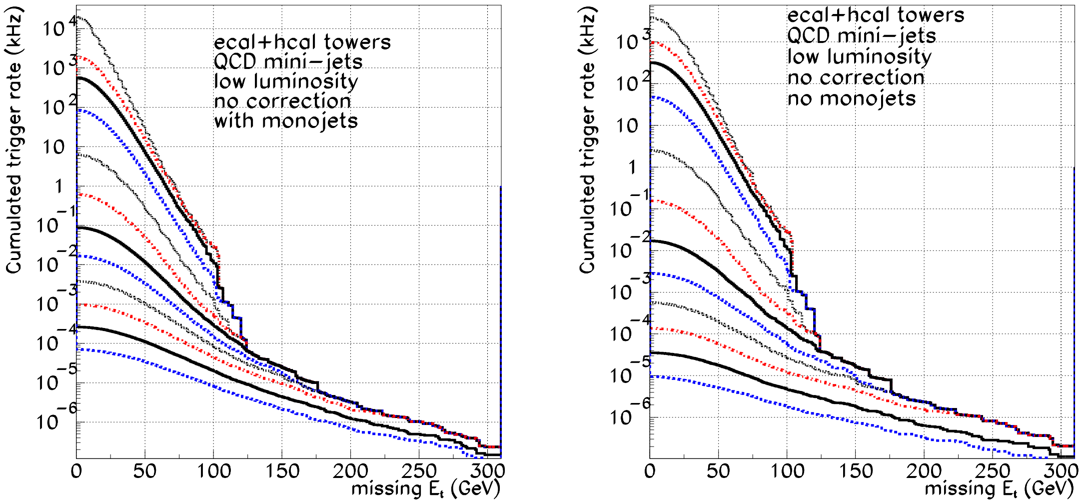

Figure 6: The cumulative reconstructed missing E_t trigger rate of QCD background events excluding two kind of topologies is shown as a function of the E_t cutoff on a logarithmic scale. The missing E_t is calculated from uncorrected ECAL+HCAL towers also software bugs are removed . The left figure excludes 2 jet (back to back in Φ) topologies, where the axes of the two biggest E_t jets are closer than 0.5 in Φ, while the right plot in addition excludes 1 jet events.

It is hard to estimate the missing E_t threshold, because the relevant $\hat{p}_t$ run out of statistics, but the thresholds are definitely higher than we estimated them in [2]. Then we had lower statistics available and did not expect the lower $\hat{p}_t$ bins contribute to so high missing E_t. Essentially the topology cut does not seem to work.

In order to see the effect of fake missing E_t, we split the right plot of Figure 5 by a cut to events that have less or more than $10 GeV$ of generated missing E_t (see Figure 7) .

One can observe that the right plot (purely fake missing E_t) has always bigger rate than the left plot which carries not only fake, but also real missing E_t . The difference is the smallest in the 80-100 GeV region, but here we are obviously missing some statistics from the right (fake missing E_t) plot. It is important to understand the reason of this long tail and to find a way to reduce it in future studies.

To improve the performance of the missing E_t trigger [15] proposed a method to calculate a corrected missing E_t ("Type 2 correction"). It corrects the average missing E_t to the proper (generated) missing E_t, using corrected jet E_t and corrected out-of-cone off-line trigger towers. The tower correction factors are those of 30 GeV jets. Figure 8 (left plot) shows the corrected missing E_t trigger rate.

The corrected missing E_t trigger rate is bigger, than the uncorrected one. It is accordance with our experience, that energy is usually underreconstructed by the CMS calorimeter system. It is corrected by the Type 2 correction, i.e. the energy values are shifted to bigger values. Nevertheles the main source of fake missing E_t is not the underreconstruction of the energy (nonlinearity of the calorimeter), but the resolution of the energy measurement, thus correcting up the energy leads to longer upper tail of the E_t distribution hence to bigger missing E_t trigger rate.

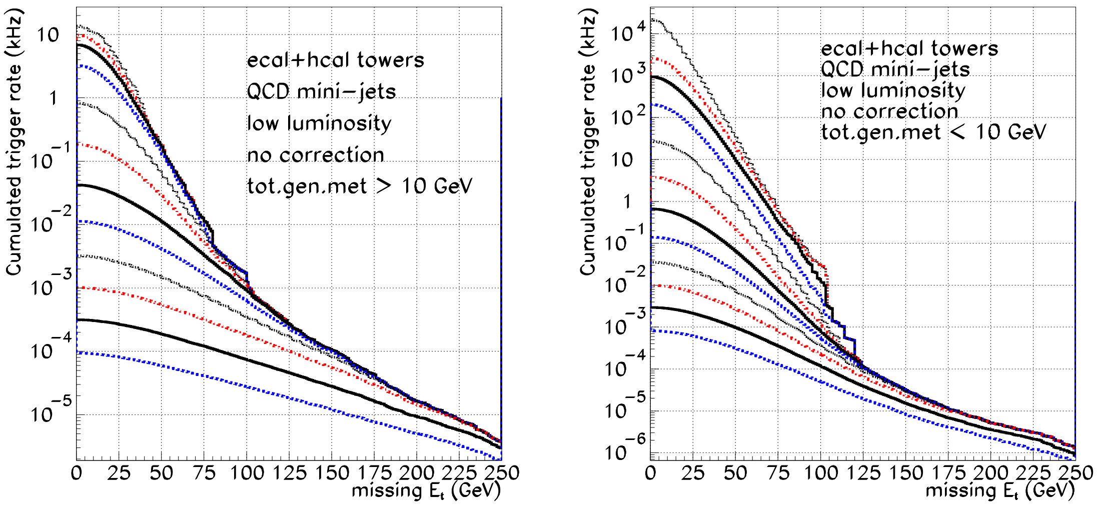

Figure 7: The cumulative reconstructed missing E_t trigger rate of QCD background events is shown as a function of the E_t cutoff on a logarithmic scale. The missing E_t is calculated from uncorrected ECAL+HCAL towers. The left figure is made of events that have generated missing E_t bigger than 10 GeV, while the right one has less than 10 GeV .

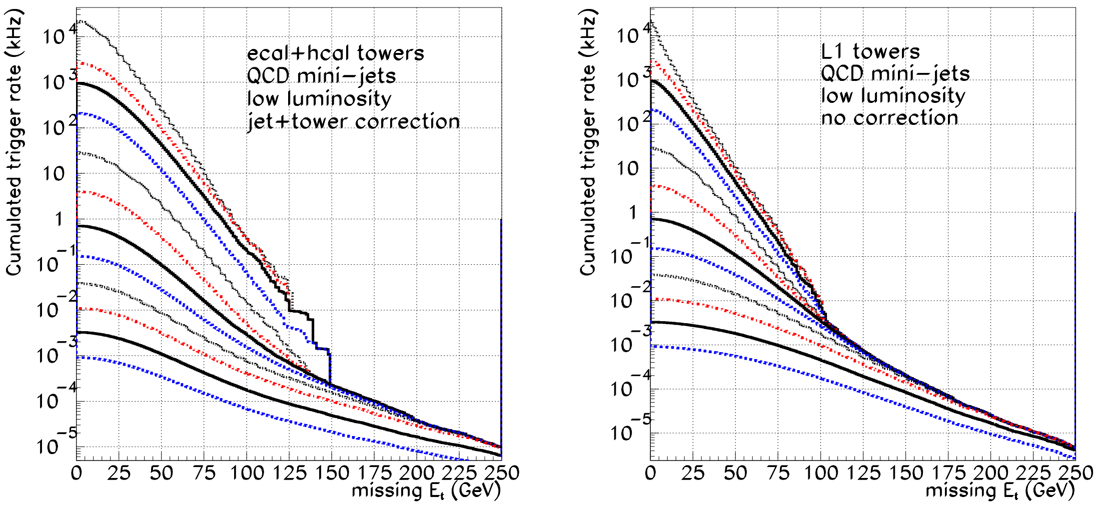

Figure 8: The cumulative reconstructed missing E_t trigger rate of QCD background events is shown as a function of the E_t cutoff on a logarithmic scale. The left figure has missing E_t calculated from corrected jets and out-of-jet ECAL+HCAL towers. The right figure has the first level missing E_t. The contribution of a particular $\hat{p}_t$ bin is displayed by the distance between two colored curves.

6.3 Rates for the First Level Trigger

Figure 8 (right plot) shows the cumulative trigger rate for the missing E_t trigger calculated from trigger tower primitives, after removing the bugs of Section 6.1

We can reach the aimed 1 kHz first level exclusive missing E_t rate by a cut of missing $E_t > 65GeV$. We can see, that every $\hat{p}_t$ bin above 15 GeV/c contribute to the first level missing E_t background at the 1 kHz rate, and the lower is the $\hat{p}_t$ the higher the contribution is.

7 Jets + Missing E_t Trigger Rate

We have investigated the possibility of using a jet E_t cut as an aid for the missing E_t only trigger. At this point we did not want to go to very high jet E_t threshold, or to a multi-jet case, because we are focusing on channels like the invisible Higgs, which has low visible energy, because the decay products of the Higgs escape detection, thus the final state has typically two low E_t jets with a big gap in the η distribution.

Figure 9 shows the generated (left) and the Level 2.0 reconstructed (right) 1 jet + missing E_t trigger rate. On these plots no jet topology (Φ) cuts were applied.

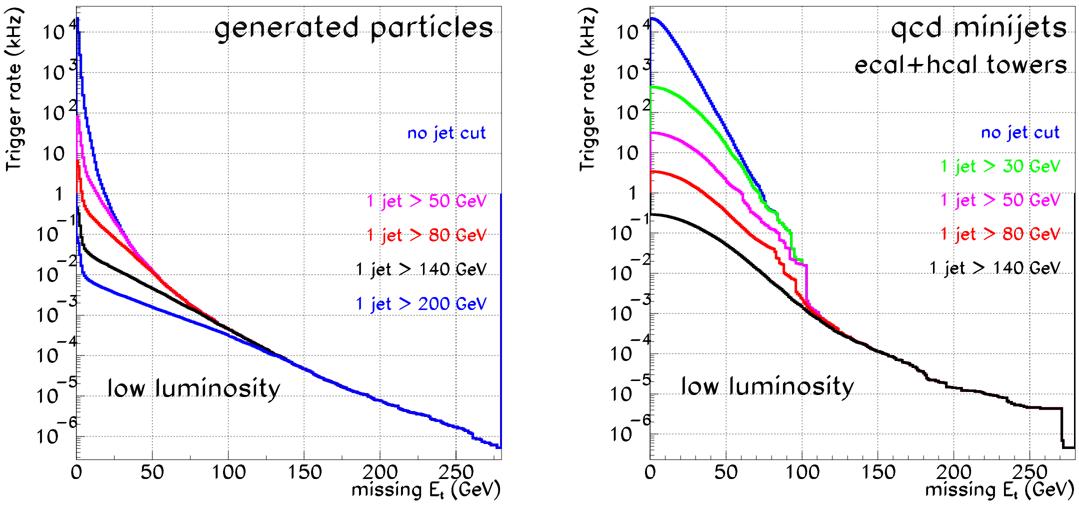

Figure 9: The cumulative generated (left) and reconstructed (right) jet + missing E_t trigger rate of QCD background events is shown as a function of the E_t cutoff on a logarithmic scale.

One can observe, that the rate curves of different jet threshold merge about the missing E_t threshold of 120-130 GeV. We still miss some statistics here. It seems that we can not further improve the missing E_t trigger using only one jet of relatively low E_t threshold.

The missing E_t plus jets trigger may become important at higher luminosity. It will be a subject of future investigation.

8 Efficiency for $SUSY$ and $Higgs$ samples

We have applied the missing E_t trigger on a Higgs-boson (m = 180 GeV/c^2, decaying into two leptons) sample. The missing E_t distribution for this signal samples is shown by Figure 10. The trigger efficiency is shown by Figure 11, it shows strong dependence on the threshold.

In order to compare the performance of Level 1 and Level 2 missing E_t trigger, we plot the missing E_t trigger rates of the QCD back ground with 95% efficiency for signal sample.

We defined the efficiency as the following two cases.

- Keep 95% of events above the missing E_t.

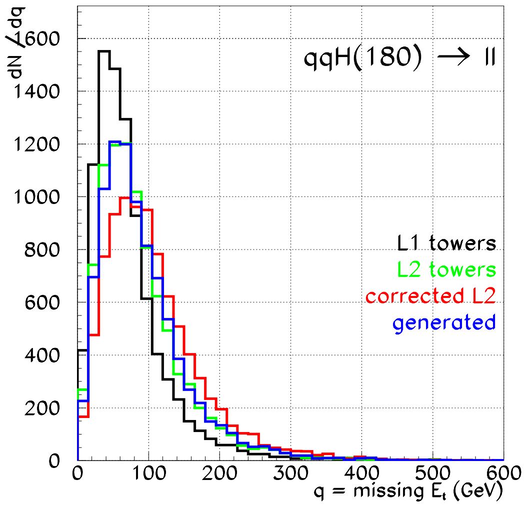

Figure 10: Missing E_t distribution of the low mass SUSY channel.

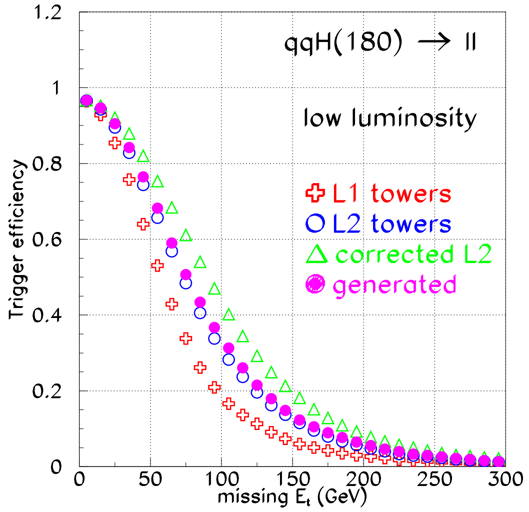

Figure 11: Absolute trigger efficiency of the low mass SUSY channel.

- Keep 95% of events at the missing E_t.

Figure 12 shows the trigger cuts (y-axis) to keep 95% of events above the missing E_t (x-axis). Figure 13 shows the corresponding trigger rate at Level 1 and Level 2 due to the QCD background. Level 1 requires about a factor of 10 100 larger rates than Level 2 in order to achieve the same 95% efficiency around the generated missing E_t where the L2 rate is 1Hz.

Figure 14 shows the trigger cuts (y-axis) to keep 95% of events at the missing E_t (x-axis) . Figure 15 shows the corresponding trigger rates at Level 1 and Level 2 due to the QCD background events. Level 1 also requires 10 to 100 larger rate as same as previous cases.

Although Level 1 can take 100 higher rate than Level 2, source of the difference has to be investigated and understood.

9 Conclusions

We have investigated the missing E_t trigger at $10^{33}cm^{-2}s{-}1$. For 1Hz trigger rate, Level 2 missing E_t threshold is 125GeV. An additional jet to the missing E_t did not improve the Level 2 rate.

Level 1 requires 10-100 times larger rates than Level 2 in order to have the same 95% efficiency. The source of the difference between those two triggers needs to be investigated. Type 2 correction did not improve the performance of the Level 2 trigger.

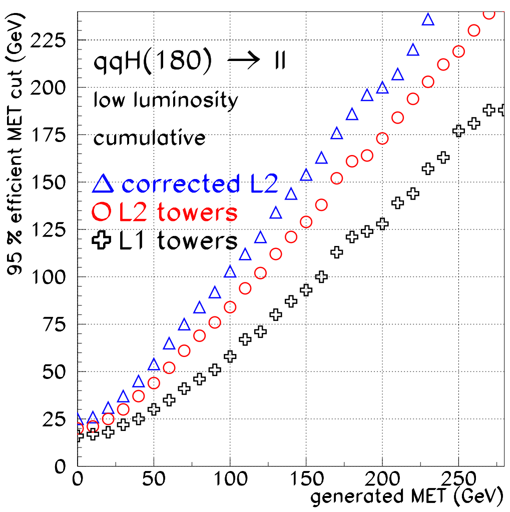

Figure 12: The 95% effective missing energy cut calculated from several quantities as a function of the generated missing E_t . The figure is cumulative, i.e. the cut refers to the sum of events above the generated missing E_t .

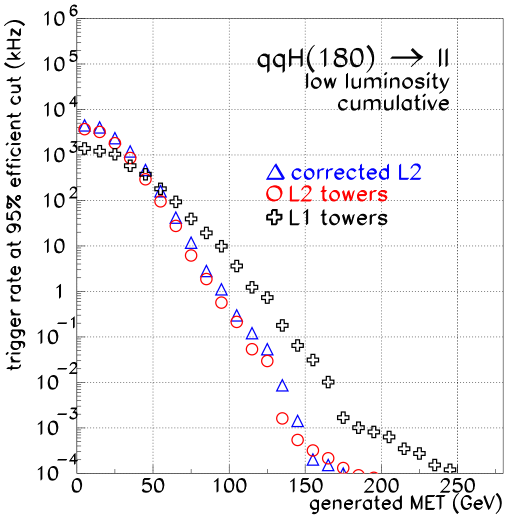

Figure 13: The background trigger rate at the 95% efficient missing transverse energy cut that belongs to the generated missing E_t . The figure is cumulative, i.e. the cut refers to the sum of events above the generated missing E_t .

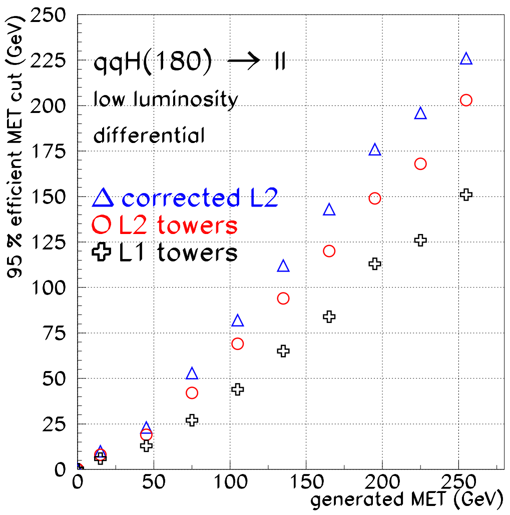

Figure 14: The 95% effective missing energy cut calculated from several quantities as a function of the generated missing E_t . The figure is differential, i.e. the cut refers to the sum of events sliced around the generated missing E_t .

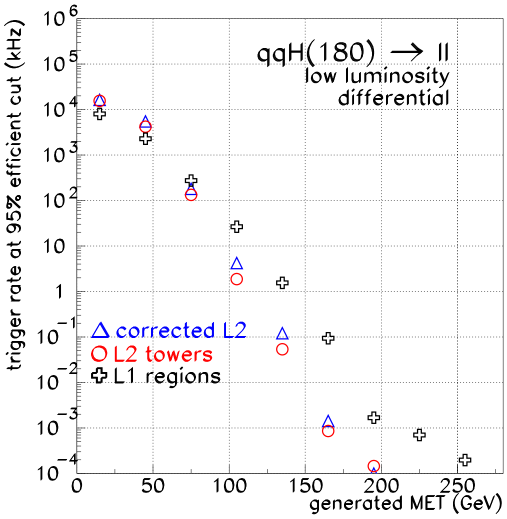

Figure 15: The background trigger rate at the 95% efficient missing transverse energy cut that belongs to the generated missing E_t. The figure is differential, i.e. the cut refers to the sum of events sliced around the generated missing E_t .

Acknowledgements

One of us (P.H.) would like to thank the Hungarian National Scientific Research Fund (OTKA) for its financial support (contract no. T029264)

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