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Results of visual scan of high $\not\!\!E_{\mathrm{T}}$ events in 7 TeV pp collision data

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Abstract

We present the results of a visual scan of high $\not\!\!E_{\mathrm{T}}$ events (tc$\not\!\!E_{\mathrm{T}} > 60$ GeV OR pf$\not\!\!E_{\mathrm{T}} > 60$ GeV) in an inclusive sample of XX nb^{-1} of 7 TeV pp collision data, after applying the official noise clean-up available in CMSSW_3_7_0_patch2. The scan is performed separately for events with tc$\not\!\!E_{\mathrm{T}} > 60$ GeV and pf$\not\!\!E_{\mathrm{T}} > 60$ GeV since the noise clean-up is implemented differently in the two $\not\!\!E_{\mathrm{T}}$ algorithms. The CMS software *Fireworks* has been used to produce the event displays. The high $\not\!\!E_{\mathrm{T}}$ events have been visually inspected and classified in different cathegories. The results of this scan can provide hints to further improve the noise cleaning and to identify possible problems and inconsistencies in the algorithms employed in CMS for the $\not\!\!E_{\mathrm{T}}$ reconstruction.

Contents

1 Introduction

Commissioning studies performed with test beams, cosmic runs and early 0.9 TeV, 2.36 TeV and 7 TeV pp collision data have identified several sources of anomalous noise (i.e. noise not produce solely from expected fluctuations in the electronics) in the calorimeters of the CMS experiment:

- *ECAL barrel spikes* - Energy deposits in individual channels affected by the noise are cleaned using both topological and timing information of the reconstructed hits. This type of noise is not correlated with collisions. More details are available at XXX.
- *HF PMT hits* - Energy deposits in individual channels affected by the noise are cleaned using both topological and timing information of the reconstructed hits. PMT hit noise is correlated with collisions. More details are available at XXX.
- *HPD/RBX noise in HCAL barrel and endcaps* - Events with identified HPD/RBX noise are removed from the analysis using a filter based on both topological and timing information of the reconstructed energy deposits. IonFeedback noise has also been observed but typically affect a few channels and produces low energy signals. A cleaning for IonFeedback noise is not yet available. HPD/RBX noise is not correlated with collisions. More details are available at XXX.

In addition, machine-induced background, in the form of beam halo [XXX] and beam scraping events [XXX], have been observed.

The overlap of either anomalous noise or machine-induced background with a pp collision event produces an unbalance in the reconstructed missing transverse energy in the event, which can produce large tails in the $\not\!\!E_{\mathrm{T}}$ distribution.

We present the results of a visual scan of high $\not\!\!E_{\mathrm{T}}$ events (tc$\not\!\!E_{\mathrm{T}} > 60$ GeV OR pf$\not\!\!E_{\mathrm{T}} > 60$ GeV) in an inclusive sample of XX nb^{-1} of 7 TeV pp collision data, after applying the official noise clean-up available in CMSSW_3_7_0_patch2. The full selection criteria are described in Section 2). The scan is performed separately for events with tc$\not\!\!E_{\mathrm{T}} > 60$ GeV and pf$\not\!\!E_{\mathrm{T}} > 60$ GeV since the noise clean-up is implemented differently in the two $\not\!\!E_{\mathrm{T}}$ algorithms. The CMS software *Fireworks* [XXX] has been used to produce the event displays. The high $\not\!\!E_{\mathrm{T}}$ events have been visually inspected and classified in different cathegories. The results of this scan can provide hints to further improve the noise cleaning and to identify possible problems and inconsistencies in the algorithms employed in CMS for the $\not\!\!E_{\mathrm{T}}$ reconstruction.

2 Datasample, Event Selection, and Noise Cleaning

Dataset and CMSSW release:

- dataset: /MinimumBias/Commissioning10-GOODCOLL-Jun9thSkim_v1/RECO
- CMSSW release: CMSSW_3_7_0_patch2

Event selection:

- Physics declared bit
- BPTX bit 0
- Removal of beam scraping events
- Good primary vertex

See details at [XXX].

Noise cleaning

Noise cleaning/event filter for calotower-based $\not\!\!E_{\mathrm{T}}$ algorithms (Calo$\not\!\!E_{\mathrm{T}}$ and tc$\not\!\!E_{\mathrm{T}}$):

- ECAL barrel spikes (reject RecHits): topology (kWeird flag = swiss cross variable) + timing (kOutOfTime flag) [XXX];

- HF PMT hits (reject Rechits): topology (HFLongShort flag = PET+S9/S1) + pulse shape (HFDigiTime flag) [XXX];
- HPD/RBX noise in HBHE (reject events): combination of pulse shape and topological variables [XXX].

Noise cleaning (reject RecHits) for pf$etmiss$ is described at [XXX]. Timing and topology are used to reject RecHits affected by ECAL and HF noise. Topology only is used to reject rechits affected by HBHE noise. No events are rejected.

NOTE: The HPD/RBX noise filter is applied for both the tc$\not\!\!E_{\mathrm{T}}$ and pf$\not\!\!E_{\mathrm{T}}$ analysis presented in this note, in order to have the same number of events passing the selection.

3 Scan of high $\not\!\!E_{\mathrm{T}}$ events

Two high $\not\!\!E_{\mathrm{T}}$ skims have been produced and stored in the directory
SKIMDIR = XXXXX :

- tc$\not\!\!E_{\mathrm{T}}$ skim: tc$\not\!\!E_{\mathrm{T}} > 60$ GeV
  Root file in RECO format at:
  SKIMDIR/YYYY
- pf$\not\!\!E_{\mathrm{T}}$ skim: pf$\not\!\!E_{\mathrm{T}} > 60$ GeV
  Root file in RECO format at:
  SKIMDIR/YYYY

A visual scan of these events have been performed using the CMS event display software “Fireworks”. We decided to compare tc$\not\!\!E_{\mathrm{T}}$ and pf$\not\!\!E_{\mathrm{T}}$ tails, since they both uses tracker information to correct the $\not\!\!E_{\mathrm{T}}$ measurement, while we excluded raw Calo$\not\!\!E_{\mathrm{T}}$ algorithm from the analysis, which only relies on calorimeter information (and therefore provides a lower $\not\!\!E_{\mathrm{T}}$ resolution).

It should pointed out that the results of a visual scan are always subject to a personal judgment. Nevertheless, they should provide, with good approximation, a realistic picture of the events populating the $\not\!\!E_{\mathrm{T}}$ tails after applying the current noise clean-up.

The result of the scan for tc$\not\!\!E_{\mathrm{T}}$ skim and pf$\not\!\!E_{\mathrm{T}}$ skim are summarized in the Tables 1 and 2, respectively.

Category		Number of events	Comments
ECAL		**25**	
EB	spike at EB-EE boundary	23	all removed by Particle-Flow cleaning
EB	spike	1	removed by Particle-Flow cleaning
EE	spike	1	removed by Particle-Flow cleaning
HCAL		**45**	
HF	multi-PMT-hits or phi-strip events	12	5 cleaned by Particle-Flow cleaning
HF	double-PMT-hits	23	18 cleaned by Particle-Flow cleaning
HF	PMT hit embedded in a jet	3	not cleaned by Particle-Flow cleaning
HB	IonFeedback/HPD/RBX noise	6	low-multipl. noise, not cleaned by PF
HE	IonFeedback/HPD/RBX noise	1	low-multipl. noise, not cleaned by PF
PHYSICS		**36**	
Physics	1 jet	1	large pf$\not\!\!E_{\mathrm{T}}$ as well
Physics	2 jets	10	6 of them have pf$\not\!\!E_{\mathrm{T}}$ $<$ OR $<<$ than tc$\not\!\!E_{\mathrm{T}}$
Physics	3 jets	12	5 of them have pf$\not\!\!E_{\mathrm{T}}$ $<$ OR $<<$ than tc$\not\!\!E_{\mathrm{T}}$
Physics	4 jets	9	4 of them have pf$\not\!\!E_{\mathrm{T}}$ $<$ OR $<<$ than tc$\not\!\!E_{\mathrm{T}}$
Physics	5 jets	2	1 of them has pf$\not\!\!E_{\mathrm{T}}$ $\approx$1/2$\times$ tc$\not\!\!E_{\mathrm{T}}$
Physics	6 jets	2	both have pf$\not\!\!E_{\mathrm{T}}$ $\approx$1/2$\times$ tc$\not\!\!E_{\mathrm{T}}$
OTHERS		**1**	
Others	HB activity + muon	1	large pf$\not\!\!E_{\mathrm{T}}$ as well
TOTAL		**107**	

Table 1: Results of visual scan of events with tc$\not\!\!E_{\mathrm{T}} > 60$ GeV.

Category		Number of events	Comments
ECAL		**0**	
HCAL		**19**	
HF	multi-PMT-hits or phi-strip events	4	large tc$\not\!\!E_{\mathrm{T}}$ as well
HF	double-PMT-hits	4	large tc$\not\!\!E_{\mathrm{T}}$ as well
HF	PMT hit embedded in a jet	3	large tc$\not\!\!E_{\mathrm{T}}$ as well
HB	IonFeedback/HPD/RBX noise	7	low-multipl. noise, large tc$\not\!\!E_{\mathrm{T}}$ as well
HE	IonFeedback/HPD/RBX noise	1	low-multipl. noise, large tc$\not\!\!E_{\mathrm{T}}$ as well
PHYSICS		**18**	
Physics	1 jet	1	large tc$\not\!\!E_{\mathrm{T}}$ as well
Physics	2 jets	5	large tc$\not\!\!E_{\mathrm{T}}$ as well
Physics	3 jets	6	large tc$\not\!\!E_{\mathrm{T}}$ as well
Physics	4 jets	3	large tc$\not\!\!E_{\mathrm{T}}$ as well
Physics	5 jets	1	large tc$\not\!\!E_{\mathrm{T}}$ as well
Physics	6 jets	1	pf$\not\!\!E_{\mathrm{T}}$ $\approx$2$\times$ tc$\not\!\!E_{\mathrm{T}}$
Physics	jet + muon	1	large tc$\not\!\!E_{\mathrm{T}}$ as well
OTHERS		**6**	
Others	large muon-induced pfMET	5	very small calo$\not\!\!E_{\mathrm{T}}$/tc$\not\!\!E_{\mathrm{T}}$
Others	HB activity + muon	1	large tc$\not\!\!E_{\mathrm{T}}$ as well
TOTAL		**43**	

Table 2: Results of visual scan of events with pf$\not\!\!E_{\mathrm{T}} > 60$ GeV.

4 Description and event displays of high $\not{E}_T$ events

4.1 EB, spike at EB-EE boundary

We see EB spikes occurring at the boundary between ECAL barrel and endcaps.

The ECAL spikes topological cuts employed in the calotower cleaning for Calo$\not{E}_T$ and tc$\not{E}_T$ are not currently applied to identify "spikes" candidates occuring at the boundary between ECAL barrel and endcaps. Most of such events should be removed by the timing cuts. Nevertheless, some of them still survives after the noise clean-up, as the event shown in Figure 1.

Such EB spikes are instead all cleaned by PF cleaning, which applies relaxed topological cuts also at the EB-EE boundary.

4.2 EB, EE spikes

We see one event with an isolated spike in ECAL barrel (EB) far from the EB-EE boundaries (Figure 2, left plot) and one event with an isolated spike in ECAL endcap (EE) (Figure 2, right plot).

Calotower-based cleaning for spikes is not applied in EE (it is understood that spikes are due to particles hitting an APD, which are mounted only in the ECAL barrel). The case of EB spike, far from the EB-EE boundary and not cleaned, should be investigated.

Both events are cleaned by PF; note that PF cleaning for spikes is applied by default also in EE.

4.3 HF, multi-PMT-hits or phi-strip events

These events are characterized by several anomalous hits in adjecent cells; sometimes they show up as a strip of hits at the same $i\phi$ location, as the ones reported in Figure 3. This type of noise cannot be cleaned by the existing topological algorithms but could be cleaned by the timing or pulse shape based cleaning if hits are out-of-time or have a malformed pulse shape. A topological cleaning based on the multiplicity of hits above certain energy threshold at the same $i\phi$ location might be effective at identifying such noise. The source of such events is not yet fully understood.

Some of these events are identified by PF cleaning but not by calotower based cleaning. Studies are ongoing to understand the differences.

4.4 HF, double-PMT-hits

These events are characterized by significant energy in both long and short fibers in a single isolated tower, as shown in Figure 4. For high $\not{E}_T$ events, this noise often shows up in the towers located at the smallest η value in HF (η=3). This can be explained by the fact that, for a given energy, a noise occurring at smaller η produces a larger transverse energy, and therefore is more visible at high $\not{E}_T$. Anyway it's not excluded that double-hits occurrs also at larger η; but in this case such events might fall in the bulk of $\not{E}_T$ distribution.

This type of noise cannot be cleaned by current calotower-based topological algorithms (PET or S9/S1) but can be cleaned by the timing or pulse shape based cleaning if hits are out-of-time or have a malformed pulse shape. However, cases of in-time double-hits with good pulse shape have been observed. In such cases, a cleaning based on S8/S1 isolation variable could be effective, where S8/S1 is defined in a similar way to S9/S1 with the companion RecHit energy from the same HF tower left out from the sum. On the other hand, this type of cleaning is not expected to be fully safe for isolated particles, in particular for physically bigger towers at lower η values. Preliminary studies on the use of S8/S1 isolation variable have been performed but not yet finalized.

PF cleaning can flag most of these noisy events. Studies are ongoing to understand the differences.

4.5 HF, PMT hit embedded in a jet

These events are characterized by one or more anomalous hits embedded inside a jet, as shown in Figure 5. This type of noise could arise from muons coming from in-flight decays of hadronic particles or from a jet punch-through. In both cases such jets could be identified using the JetID variables since it is expected that a large fraction of the total jet energy would come from only one or two HF towers. Due to an overlap between real and anomalous signal there are two cleaning strategies possible: an entire event could be rejected or a more sophisticated anomalous energy subtraction algorithm would have to be developed.

Neither calotower-based cleaning nor PF cleaning are able to identify these noise events.

4.6 HBHE, IonFeedback/HPD/RBX noise

These events are characterized by low multiplicity noise and single noisy channels in HCAL barrel or endcap. Two examples are shown in Figure 6. Improved timing cuts could be employed to identify these residual noise events.

Neither calotower-based cleaning nor PF cleaning are able to identify these residual HBHE noise events.

4.7 Physics

It is observed that approximately 30% of the high $\not\!\!E_{\mathrm{T}}$ events consists in physics events, typically multi-jet events where the large fake $\not\!\!E_{\mathrm{T}}$ is produced by jet energy mis-measurements. In Figure 7, you see some examples of physics events with large $\not\!\!E_{\mathrm{T}}$.

In about 50% of high tc$\not\!\!E_{\mathrm{T}}$ events with multi-jet topology, pf$\not\!\!E_{\mathrm{T}}$ values are smaller than tc$\not\!\!E_{\mathrm{T}}$ values. More details can be found in the Tables 1 and 2, and in the list of events posted at the end of the note.

4.8 Others, large muon-induced pf$\not\!\!E_{\mathrm{T}}$

We observed 5 events with large pf$\not\!\!E_{\mathrm{T}}$ (sometimes a few hundreds GeV) but very small Calo$\not\!\!E_{\mathrm{T}}$ and tc$\not\!\!E_{\mathrm{T}}$. In all the events, a muon with high p_T is reconstructed, but it seems that no correspondent inner track is found. The muon is reconstructed as “global muon” and “standalone muon”, but not as “tracker muon”. An example is shown in Figure 8.

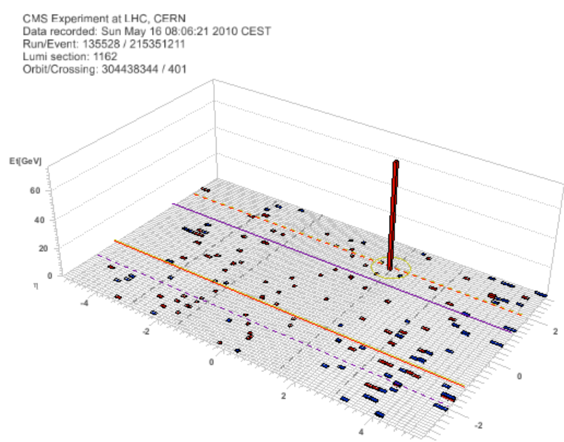

Figure 1: Example of an “EB spike at EB-EE boundary” event

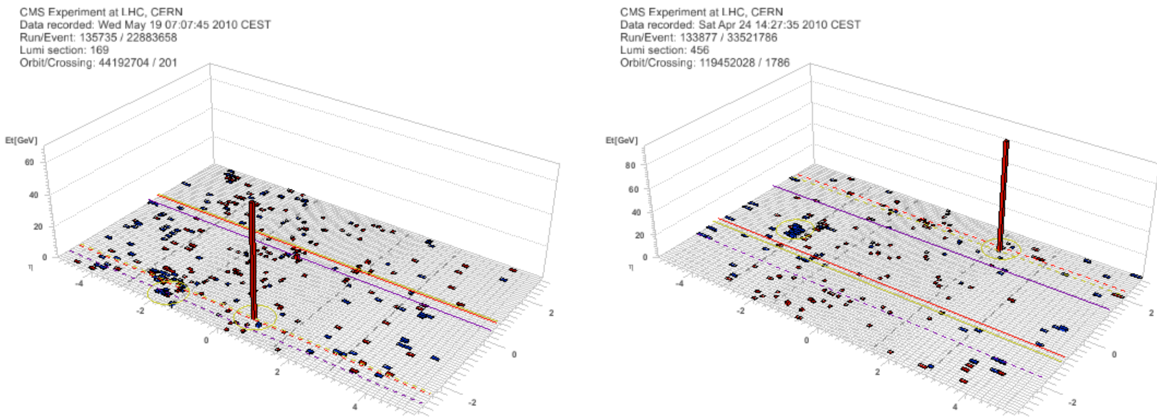

Figure 2: Example of an “EB spike” (left) and an “EE spike” (right) event

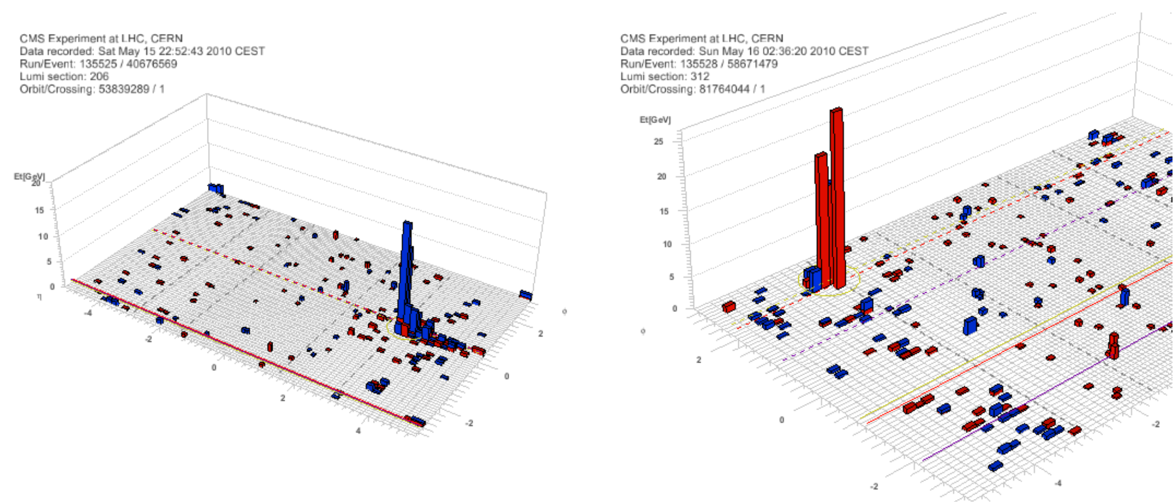

Figure 3: Example of two “HF multi-PMT-hits or phi-strip” events

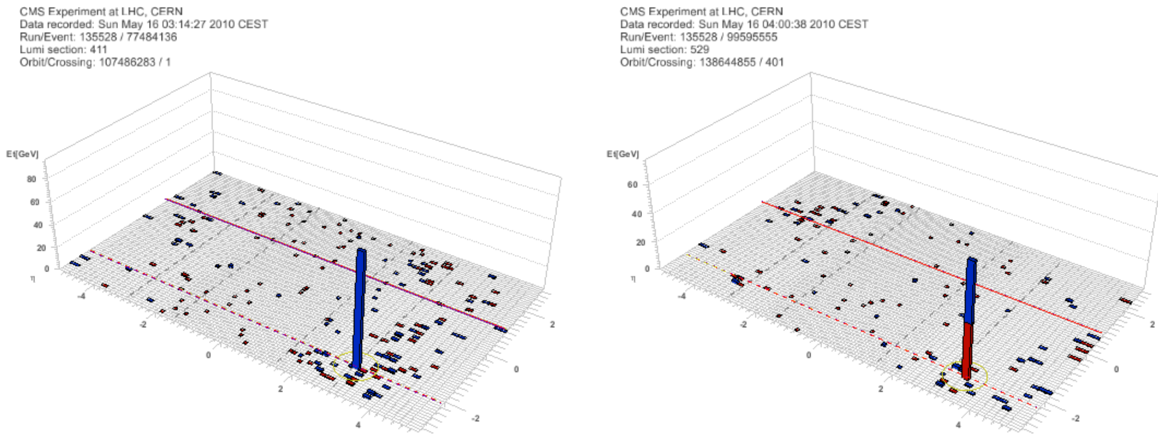

Figure 4: Example of two "HF double-PMT-hits" events. Event in left plot is cleaned by PF and not by calotower-based cleaning; the event on the right is not cleaned by any of the two. NOTE: The event display for the left plot is mis-leading since the hit is not single, as it seems, but double. In fact, in HF, blue=2*E_S=hadEnergy, while red=$E_L - E_S$=emEnergy. In this event the emEnergy ("red") is negative, but both energies in long and short fibers, E_L and E_S, are large (several undreds of GeV). The event display only shows positive quantities (only the hadEnergy = "blue"), so the "negative" red spike is not visible and it gives the illusion of a single hit. It is observed that most of events cleaned by PF have negative emEnergy.

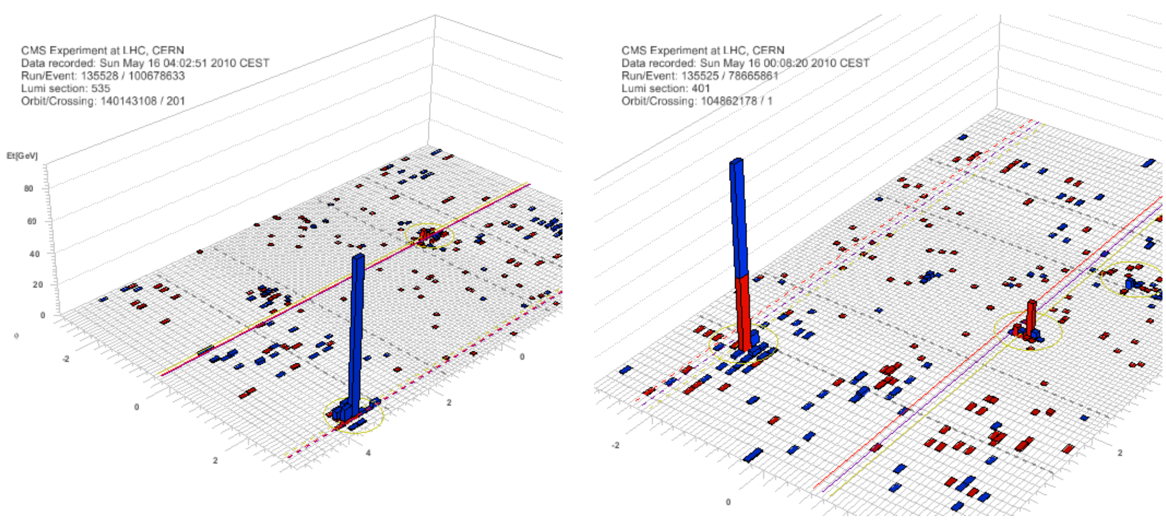

Figure 5: Example of two "HF PMT hit embedded in a jet" events

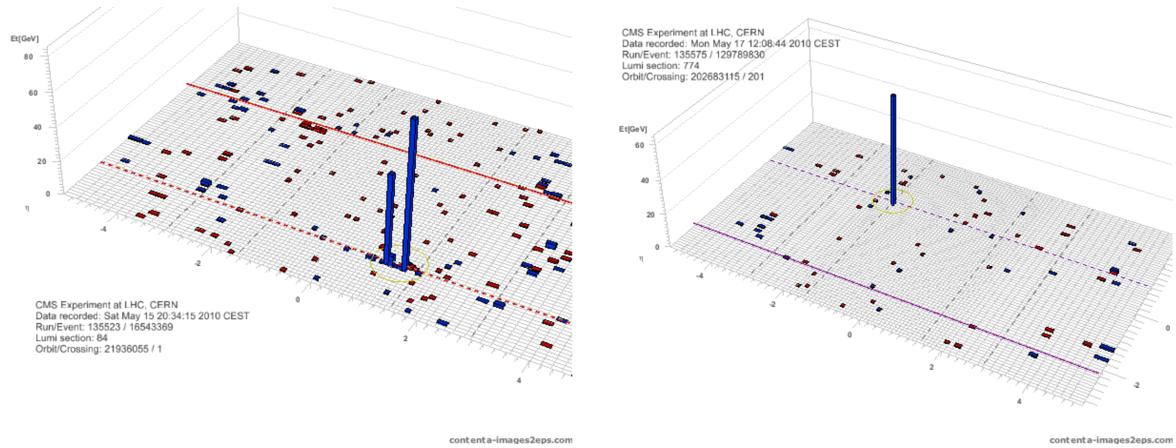

Figure 6: Example of two "HBHE IonFeedback/HPD/RBX" noise events. The left plot shows an HPD/RBX noise event with low hit multiplicity. The right plot show instead an isolated spike, probably IonFeedback noise affecting an individual channel.

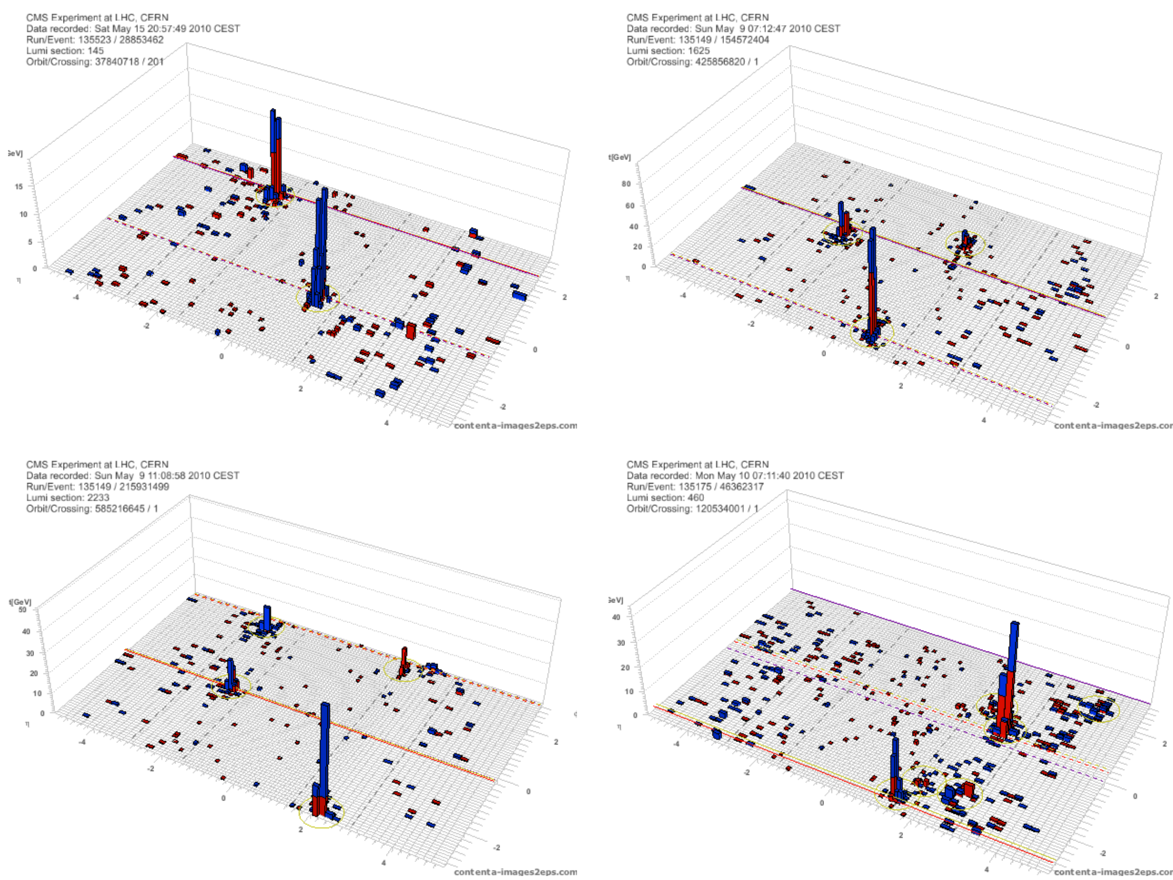

Figure 7: Example of "Physics" events with multi-jet topology

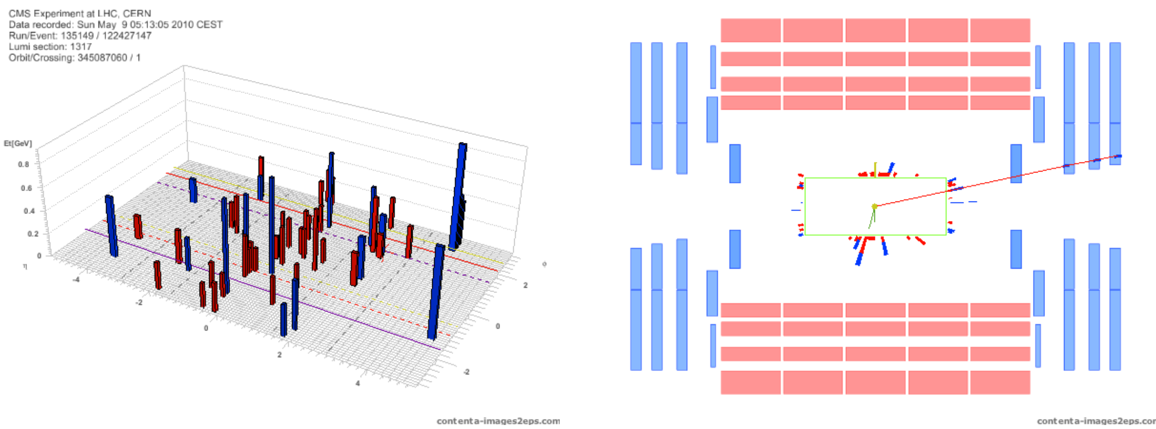

Figure 8: Example of a "large muon-induced pf$\not\!\!E_{\mathrm{T}}$" event shown in the eta/phi view (left) and in the transverse plane view (right). There is an high p_T muon reconstructed as "global muon" and "standalone muon" , but not as "tracker muon".