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Part II: CMS

The Rockefeller University group is actively involved in Super-symmetry (SUSY) search and search for new particles which decay into jets. As described above, we just completed a dijet resonance study at the CDF. Experience gained at the CDF in dijet resonance analysis will be a great asset at the CMS. Our work on different aspects of jets including clustering algorithms, jet energy scale determination is crucial for any study involving jets. For SUSY we have worked on the new trigger design, determination of various standard model backgrounds. These studies are described in section 1. One of us (Anwar Bhatti) is co-leader of CMS All-hadronic, a SUSY subgroup, and co-leader of USCMS LPC Jet+MET group doing similar studies and is mentoring students and post doctorate fellow from Fermilab, Cukurova University, Tata Institue and Iowa University on various aspects of SUSY analysis. The SUSY and dijet studies are described in sections 1 and 2. We also worked in jetshape studies (section 3) which was thesis topic of Pelin Kurt, a graduate student from Cukurova University. We have taken a new responsibility, namely, understanding the hadron calorimeter noise and cosmic ray background in recently taken data. These studies are described in section 4. Previously we wrote the code to correct the missing transverse energy for muons [5, 6]. Muon deposit very small energy in the calorimeter and thus calorimeter based $\not{E}_T$ must be corrected for momentum carried by muons. Currently we are working on data quality monitoring DQM from missing transverse energy point of view. Kenichi Hatakeyama is leading the CMS effort of monitoring jet and $\not{E}_T$ objects. This work is described in section 5.

Since we joined the CMS collaboration in March 2006, we have worked on hadron calorimeter, jet energy scale corrections missing transverse energy corrections and jet reconstruction algorithms. One of us was member of jet energy scale task force which finalized the CMS procedure to determine the jet energy scale. The task report after an extensive collaboration review was made public in June, 2008 [12]. Our contribution to jet energy scale work during last year and future plans are described in section 6.

In February 2008, CMS management constituted a Calorimeter Task Force to access and possibly improve the status of calorimeter simulation. One of us (Anwar Bhatti) is member of this task force. The task force studies the calorimeter response measured in the test beam and compared it with both Geant-based simulation, and parametrized simulation and reported its conclusions in reference 7.

One of us participated in the Les Houches 2007 workshop on "Physics at TeV Colliders", studying the jet algorithms. The report including the recommendations for LHC experiments from this workshop were published in Dec, 2007 [2]. At CMS, we lead the successful effort to adopt the Seedless-Infra-Safe cone (SISCONE) clustering algorithm [10]. CMS Collaboration has decided to support three jet algorithms, SISCONE, k_T and iterative cone algorithms. Iterative cone algorithms is being used in high level trigger. Our SISCONE studies were described in detail in our last years report.

1 Search for Super-Symmetry

A substantial increase of the center of mass energy relative to the Tevatron will provide us with a great opportunity for finding physics beyond the Standard Model (SM) at the LHC. The most popular beyond the standard model theory, Super-symmetry (SUSY), is a space-time symmetry and relates bosonic fields with fermionic fields. It leads to the symmetry between the matter particles (fermions) and the force carriers (bosons). SUSY predicts existence of a new stable particle which interact very weakly with matter and thus is possible dark matter candidate. This fact coupled with the beauty of unification makes SUSY an attractive theory.

A generic signature of the production of squarks $\tilde{q}$ and gluinos $\tilde{g}$ (super-partners of the SM quarks and gluons) is a missing transverse energy in events containing multi-jets. For the low mass SUSY point LM1 ($m_{\tilde{q}} \sim 600$ GeV, $m_{tildeg} \sim 520$ GeV, $\tan\beta = 10$), the $\not\!\!E_T$ distribution is shown in Fig. 1. This large $\not\!\!E_T$ which arises from lowest mass super-symmetric paarticle which are stable and leave the detector without any interactions is signature of SUSY.

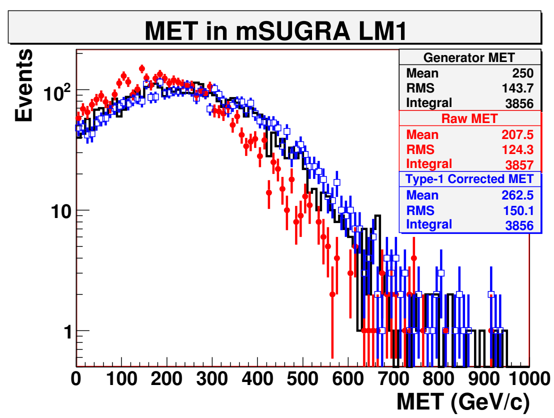

Figure 1: The $\not\!\!E_T$ in SUSYmulti

At LM1, for $\sqrt{s} = 14$ TeV, the SUSY production cross section is ∼50 pb which can be compared to $\sim 10^3$ pb of top quark pair production, $\sim 10^4$ pb of Z boson production and $\sim 10^7$ pb of QCD jet productions with at least two jets with p_{T} above 50 GeV. All these processes have large missing $\not\!\!E_T$ in the event and must be suppressed by well designed cuts.

We are searching for SUSY using the classic signature *i.e.* multijet events with a large missing transverse energy arising from weakly interacting particles. This is a natural application of our expertise from the work at the Collider Detector at Fermilab (CDF).

$\not\!\!E_T$ is a global quantity which is quite hard to understand, specially, at the start of the run. Any detector problem, calorimeter noise, comsic rays interacting the calorimeter and particles coming along the beam can give rise to fake $\not\!\!E_T$. The largest physics background to SUSY events is QCD multi-jet events where $\not\!\!E_T$ arised from either semi leptonic decays where out going neutrinos carry large energy or large fluctuations in

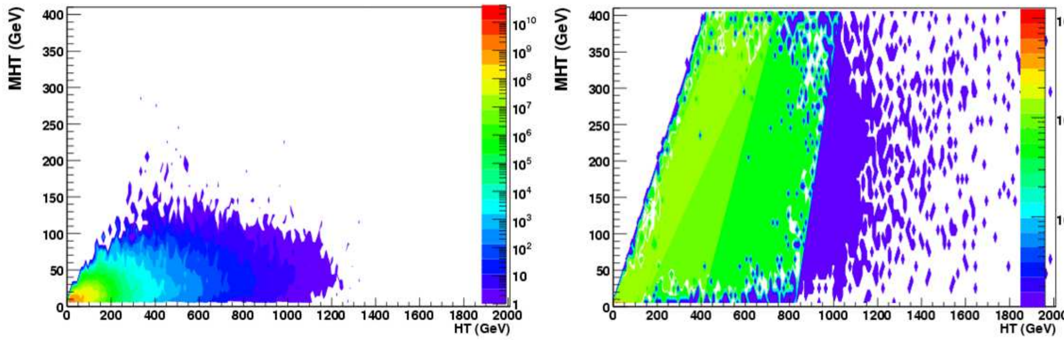

Figure 2: H_{T} and MH_{T} distributions for QCD (left) and SUSYLM1 events. The QCD events are concentrated at lower MH_{T}.

calorimeter response to jets. Recently a new variable, $\alpha_T = p_T^{(2)}/m_{jj}$ has been proposed [24] to distinguish QCD from SUSY events where $p_T^{(2)}$ is p_{T} of second highest p_{T} jet and m_{jj} is the mass of dijet sample. An analysis using this variable for two jet final state has already been approved by CMS collaboration. In collaboration with Imperial College, Texas A& M and University of Iowa groups, we are extending this analysis to three and four jet events. A three jet system can be reduced to a two jet system by combining two of the jets. Monte Carlo studies show that, even in three jet sample, the QCD background can be reduced to practically zero.

1.1 Trigger Studies

As discussed above that the standard model (SM) processes have huge production rate even compared to a very low mass SUSY production rate. Although SM rate cabe suppressed by judicious cuts during analysis, triggering for SUSY events is a different problem. The SM rate can be suppressed by requiring a large $\not\!\!E_T$ >200 GeV in the event as was implemented in previous CMS SUSY trigger. However, this trigger is only $\sim$ 50% efficient for LM1 point. In addition, based on our experience at CDF and from analysis of hadron calorimeter data, we know that $\not\!\!E_T$ has large contribution from the calorimeter readout noise, the cosmic rays and beam halo. Thus a $\not\!\!E_T$ based trigger is not very stable specially at start of the run where the detector will not be well understood. We proposed a new trigger which is based H_T and MH_T as defined below.

$$H_T = \sum_{P_T^{\mathrm{jet}} > P_T^{min}} P_T^{i,\mathrm{jet}} \qquad\qquad MH_T = |\sum_{P_T^{\mathrm{jet}} > P_T^{min}} \vec{P}_T^{i,\mathrm{jet}}|$$

At trigger level, the event rate is dominated by the QCD events. We studies the trigger rate using a large QCD dijet sample with 15 < jet p_{T} < 3500 GeV. The H_{T} vs MH_{T} for QCD and SUSY events is shown in Fig. 2. The QCD events are concentrated at very low H_{T} and MH_{T} values but have a huge rate. We studies the L1 trigger rates and decided not to require any $\not\!\!E_T$ or MH_{T} at L1. We proposed a L1 H_{T} trigger with

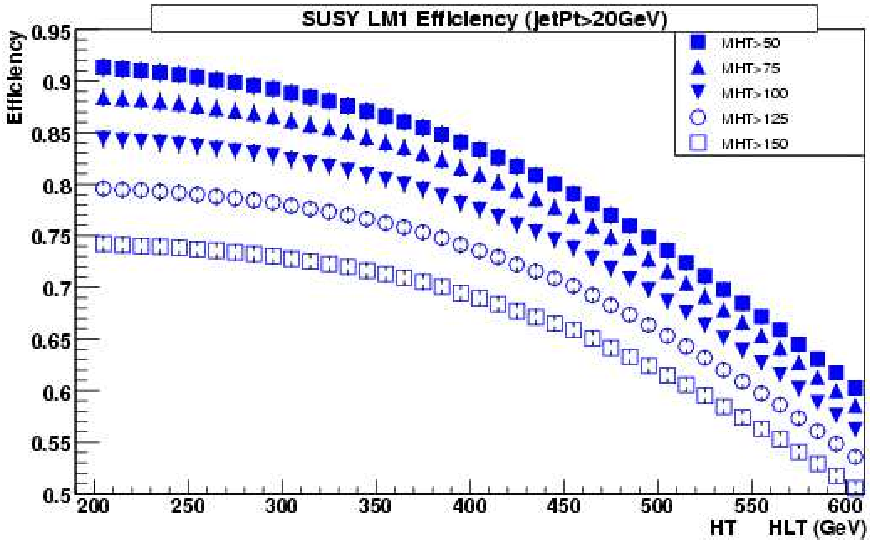

Figure 3: Efficiency for SUSY LM1 point vs H_{T} for various values of MH_{T} cuts. For H_{T} =250 and MHT=100 GeV, the trigger rate is ~ 4 hertz for instantaneous luminosity of 2×10^{32}.

a threshold of 200 GeV. Here the H_{T} is calculated using jet with p_{T} >10 GeV. At this threshold the L1 trigger rate is 2 kHz compared to total capacity of 50 kHz i.e. this trigger will consume only 4% of total bandwidth.

For High Level Trigger (HLT), we concluded that jet p_{T} cut of 20 GeV is high enough to reject detector noise while low enough to include any new physics. The trigger efficiency for LM1 SUSY events vs H_{T} cut for various values of MH_{T} is shown in Fig. 3. The proposed operating point is H_{T} =250 GeV and MH_{T} =100 GeV. At this point trigger rate is $\sim$ 4 Hz and SUSY LM1 efficiency is $\sim$ 85%. In addition to main trigger, we proposed a back-up trigger with H_{T} =200 GeV, MHT=50 GeV and p_{T} >15 GeV. Even after pre-scale factor of 500, this trigger has rate of 0.7 Hz, enough to study the efficiency of main trigger.

We presented this proposal to CMS Trigger Studies group [15] in April 2008 and it was accepted. The trigger software has been implemented and will be used to collect data at startup. We plan to optimize the minimum jet p_{T} threshold using the noise, cosmic and beam halo data recently collected during global runs.

1.2 Generic SUSY Search using Multijet+$\not\!\!E_T$ Events

At LHC, all three $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, $\tilde{q}\tilde{\bar{q}}$ processes contribute. The super-particles decays and final state has standard model particles and two Lightest SUSY Particles (LSP). In R-parity conserving models, LSP is stable and leaves the detector without any interaction, resulting in large $\not\!\!E_T$. For SUSY parameters where gluino is more massive compared to squark, gluino decays into $\tilde{q}$ and $\bar{q}$. Fig. 4 shows a typical decay chain of the $\tilde{g}\tilde{q}$ in the

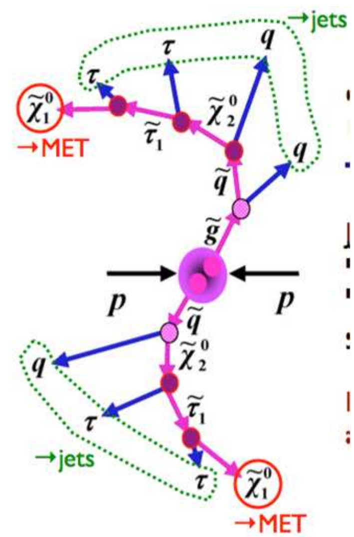

Figure 4: SUSY decay chain

final state. After decays the event contains three jets, 4τs and two $\tilde{\chi}_1^0$, the LSPs. Such an event can be identifies by multi-jet events with large $\not\!\!E_T$ signature. This analysis has been performed by the CDF and D0 collaborations. At the CMS, the initial study was performed by M. Spiropulu *et al.* [17] and that study showed that LM1 SUSY is observavle at $\sqrt{s} = 14$ TeV with only $10\,\mathrm{pb}^{-1}$ of integrated luminosity.

Major backgrounds to this signal include a) beam/cosmic ray/noise induced background, b) QCD multi-jet events, c) $t\bar{t}$ event, and d) Z+multi-jet production. We are studyig (a), (b) and (d) backgrounds.

- The beam halo and cosmic ray background can be removed by selecting on event properties, particularly cutting on charged particle energy and electromagnetic energy fractions of the event. As described in section 4, we are working to indentify $\not\!\!E_T$ arising from these sources and remove it.

- The QCD multi-jet production rate is huge. These events $\not\!\!E_T$ arises either from the fluatuations in calorimeter response to hadrons or from semi-leptonic dacays of heavy quarks where neutrinos carry a large fraction of energy. In these events, the $\not\!\!E_T$ is aligned with the jet direction and thus QCD background can be largely reduced by utilizing the correlation between the $\not\!\!E_T$ and jet directions in azimuthal angle. The quantity $R_{1(2)} = \sqrt{(\delta\phi_{1(2)})^2 + (\pi - \delta\phi_{2(1)})^2}$ where $\delta\phi_i = |\phi_{j(i)} - \phi_{\not E_T}|$. The correlation plot between R_1 and R_2 for QCD and SUSY events is shown in Fig. 5. The more than 80% of the QCD events are removed by R_1, R_2 cuts while keeping 90% of the SUSY signal. However, due to large cross section, even after these cuts QCD is the largest background. We are working on estimating the remaing background from the data.

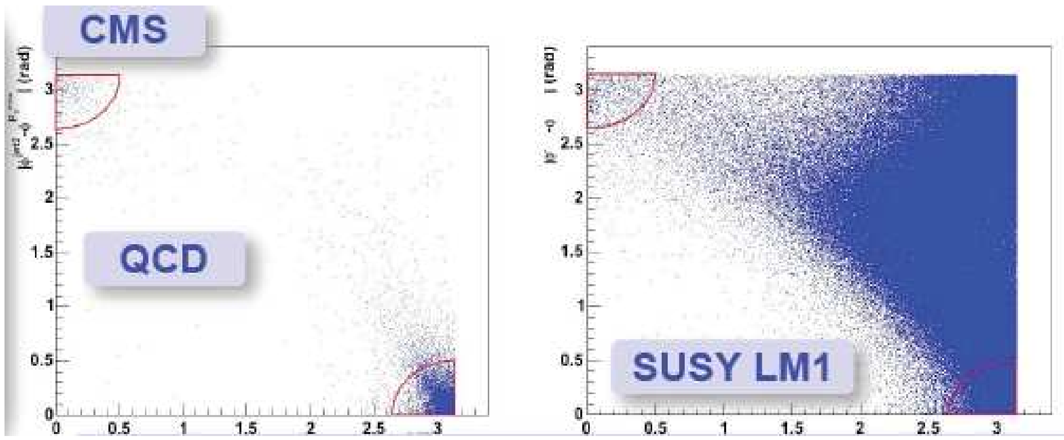

Figure 5: Correlation between R_1 and R_2 variable for QCD and SUSY LM1 events. For QCD, the $\vec{\not{E}}_T$ is aligned with either first or second jet. A cut of R_1 and R_2 removed 80% of the QCD events while keeping 90% of the LM1 SUSY signal events.

- Z+multi-jet production where the Z boson decays into $\nu\bar{\nu}$, and W+multi-jet production where $W \to \tau\nu$ and the τ lepton decays into hadrons, constitute irreducible SM backgrounds. These irreducible backgrounds must be estimated from the data by measuring rates in similar channels and normalizing them to the signal region. In particular, the $Z \to \mu\mu$+multi-jet or $Z \to ee$+multi-jet rates can be used to predict the $Z \to \nu\nu$+multi-jet background. The $Z \to \nu\nu$+multi-jet rate was estimated from $Z \to \mu\mu$+multi-jet events in [17]. However, this procedure relied on Monte Carlo simulation. We are working on developing data driven technique.

  During past year, we studied the muon identification and quality chriteria to measure the $Z \to \mu\mu$+multi-jet events and showed that this technique gives a reasonably accurate determination of $Z \to \nu\nu$+multi-jet background for integrated luminoisty $\mathcal{L}$ of $600\,\mathrm{pb}^{-1}$. For lower $\mathcal{L}$, total number of $Z \to \mu\mu$+multi-jet events passing the SUSY cuts is too small. We are studying the procedure to determine the $Z \to \mu\mu$ rate by relaxing the SUSY cuts and then extrpolating the measured rate to the signal region. Fig. 6 shows the $\not{E}_T$ distribution of $Z \to \mu\mu$+multi-jet events for $\mathcal{L} = 1\ \mathrm{fb}^{-1}$. For low $\mathcal{L}$, we expect a few event in the signal ($\not{E}_T > 200$) region. We plan to measure the $Z \to \mu\mu$ rate in the region $100 < \not{E}_T < 200$ and extrapolate the measured rate to signal region. The validity of the procedure will be checked using $Z \to \mu\mu$+2-jet data.

1.3 Other SUSY Related Activities

In addition to above SUSY related activities, we are working closely with Elif Albayak, graduate student from University of Iowa on a data driven technique to determine the QCD background for multi-jet+$\not{E}_T$ analysis. We plan to estimate the high $\not{E}_T$ tail by smearing the low $\not{E}_T$ events using a response function determined from dijet events. This

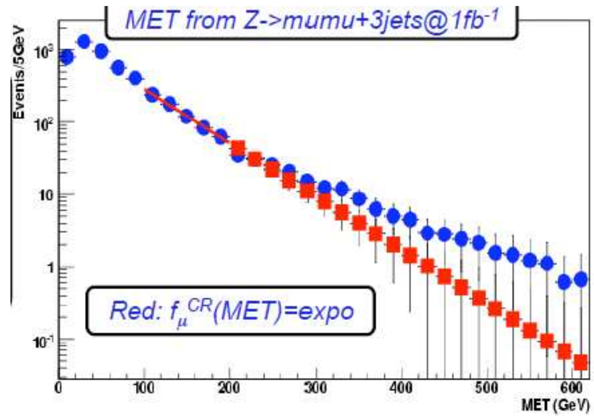

Figure 6: $\not{E}_T$ distribution in $Z \to \mu\mu$+3 jet events.

study is in preliminary stage but looks promising. Taylan Yetkin (Iowa) and Teruki Kamon (TAMU) are also working on this analysis.

We collaborated with Seema Sharma, a graduate student from Tata Institute, India on extracting SUSY signal at LM2 point. At this point, $\tan\beta = 35$ and thus final state is rich in τ leptons. In fact 54% of events have at least one identifiable hadronic τ. We used particle flow algorithm to reconstruct τ leptons. This algorithm has higher energy resolution τ than calorimeter τs. Seema graduated in Sept, 2008 and has joined Fermilab as a post doctoral fellow. We plan to continue this collaboration and analyze real data. Unfortunately, greater than $1\,\mathrm{fb}^{-1}$ is needed to observe this signal.

2 Search for New Physics using Dijet Events

Dijet production is the dominant process at hadron colliders and has the highest p_T reach for new physics. In addition, confirmation of the Standard Model in the inclusive jet cross section measurement is a must to validate detector performance. We are collaborating with D. Mason, R. Harris (Fermilab), and others on this measurement and on a search for new physics in dijet events. This analysis is one of the early flagship analyses. The collaboration approved the proposed analysis in early 2008 and the paper is published [1].

The analysis has been performed for various values of the integrated luminosity. The expected number of jets versus jet transverse momentum is shown in Fig. 7(left) for 10 pb^{-1} of pp collisions at $\sqrt{s}$ = 14 TeV. We see that CMS will be able to observe TeV jets with only 10 pb^{-1}. Contact interactions increase the rate of high p_T jet production. Fig. 7(right) shows the fractional difference between the QCD event rate and the event rate in the presence of contact interactions. We expect that at the start of data taking the jet energy scale uncertainty will be $\sim 10\%$. Even with only 10 pb^{-1} of accumulated data, jet energy scale uncertainties dominate the analysis. Using this small set of data, we will be able to rule out a compositeness scale $\Lambda = 3.0$ TeV. The current Tevatron limit is 2.7 TeV. As more data is accumulated and our understanding of the detector

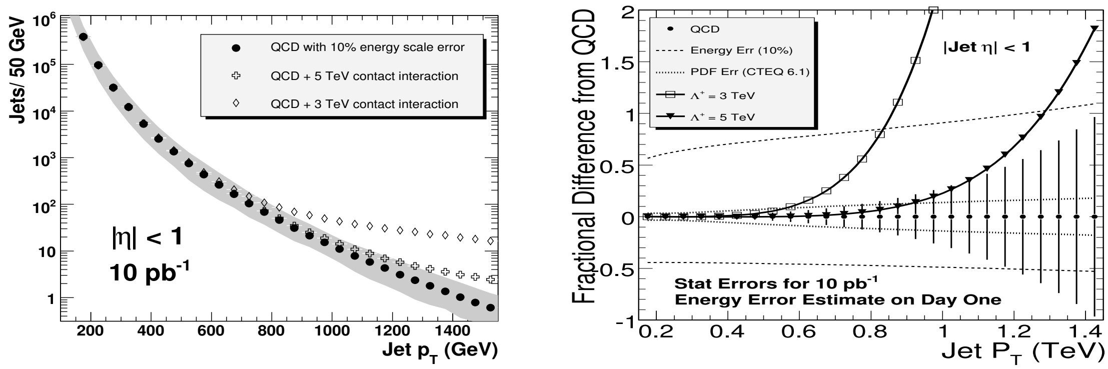

Figure 7: The CMS analysis reach for the contact interaction parameter Λ, for an integrated luminosity of 10 pb^{-1}.

improves, we will be able to rule out or even observe $\Lambda = 15$ TeV.

The CMS dijet mass group is also working on a search for new particles decaying into dijets, e.g. Z', excited quarks, axigluons, and Randall-Sundrum gravitons, by looking for resonance structures in the dijet mass distribution and in the ratio of dijet production rate in $|y| < 0.5$ to the production rate in the $0.5 < |y| < 1.3$ region. This ratio is sensitive to new physics, as new physics is expected to be more central than the large QCD background which is dominated by the $1/(1 - cos\theta)^2$ distribution. As described above, we just completed the dijet resonance search analysis at CDF and in collaborating with Manoj Jha from DIP DI FISCA, INFN, Bologna Itlay, we started search for new physics using the dijet ratio analysis. The experience gained at CDF will help the analysis at the CMS.

Over last few months, the focus has shifted from feasibility studies to trigger design and understanding of detector related noise and jet energy scale corrections, unsmearing procedure and estimation of systematic uncertainties. We are working on the jet energy scale corrections and understanding the detector related noise and the procedures to suppress the noise. In addition, we are working on validating the jet triggers used to collect noise and cosmic ray data.

3 Transverse Momentum Distribution in a Jet

The transverse momentum profile of a jet, jet shape [18, 19] is sensitive to multi parton emissions from the primary outgoing parton and provides a good test of parton showering description of Quantum Chromodynamics (QCD), the theory of strong interactions. Historically jet shape has been used to test perturbative QCD (pQCD) α_s^3 calculations [3, 20]. This leading order calculation, with only one additional gluon in a jet, showed a reasonable agreement with the observed jet shapes. While confirming the validity of these pQCD calculations, these studies also indicated that jet clustering, underlying

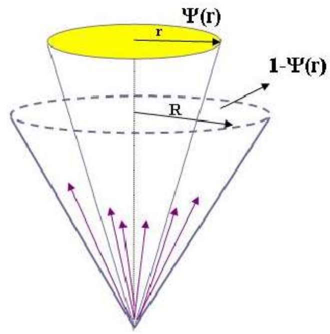

Figure 8: Definition of the integrated jet shape, $\psi(r)$.

event contribution and hadronization effects must be considered. These effects can be accurately modeled using event generators. Current Monte Carlo (MC) event generator use pQCD inspired parton shower models, in conjunction with the hadronization and the underlying event models, to generate the final state particles. These MC generators are extensively used to model the signal and background events in most analyses at hadron colliders. Jet shapes can be used to tune these MC generators. QCD predicts gluon jets to be broader than quark jets because of the gluon-gluon coupling strength being larger than that of the quark-gluon coupling. The structure of quark and gluon jets can be investigated by comparing measurements of the jet shapes in different processes in which the final-state jets are enriched with either quark or gluon initiated jets. Previously, jet shapes have been measured extensively in $p\bar{p}$ collisions at Tevatron and ep collisions at [4, 21, 22]. In this paper, we present a study the QCD jets jet shapes at particle and calorimeter level in the central region of the CMS detector and compare the results obtained with various MC generators. The sensitivity of jet shapes to modeling of the underlying event (UE) and to the flavour of initiating parton are also explored.

The jet shape is defined as the average fraction of the jet transverse momentum within a cone of a given size r around the jet axis,$r = \sqrt{(y_i - y_j)^2 + (\phi_i - \phi_j)^2}$, where i refers to the particle, calorimeter tower or track, and j to the jet. Jet shapes can be studied by using an integrated or a differential distribution. Here we present results for the integrated jet shapes. Only events are considered for which the two highest P_T (leading) jets are within $|y| < 1$. All particles and calorimeter towers within distance R=0.7 from the jet axis are used. This large cone size ensures that most of the parent parton energy is included.

The integrated jet shapes (see Fig. 8) , ψ^{CAL} and $\psi^{PARTICLE}$ corresponding to calorimeter tower and particle energies, respectively, are defined as:

$$\psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{P_T(0, r)}{P_T(0, R)} \tag{1}$$

where $P_T(0, r)$ is the scalar sum of transverse momenta of all particles within the distance r from the jet axis with $\psi(R = r) = 1$.

The jet axis is determined using SISCone jet clustering algorithm with cone size R=0.7 to determine the jet axis. In this algorithm, two jets are merged if they share $> 75\%$ of p_{T} the smaller jet; otherwise the shared energy is appropriately divided.

Due to various detector effects, the measured (calorimeter) jet shape is different than the true (particle) jet shape. The magnetic field of CMS bend charged particles and those are with $P_T < 0.9$ GeV do not reach to the calorimeter. In addition showers from a particle as it interacts with the detector material will spread its energy over many calorimeter towers. The measured jet shapes must be corrected for these detector effects. The correction factors were determined from MC events pass the CMS detector simulation as a function of distance from the jet axis. For this approach to be valid, the MC simulation must describe the calorimeter response accurately. We plan to used a data-driven technique to estimate the accuracy of the simulation. We tested the correction derived from PYTHIA on an independent sample generated using ALPGEN [23]. The correction factors determined from PYTHIA events work reasonably well for ALPGEN. We estimated the effect of different sources of systematic uncertainties e.g.jet energy scale, non-linearity of calorimeter response, dependence of jet shape correction on fragmentation models. These contribution add up to 10% uncertainty for 60 GeV jets, decreasing to 5% for highest p_{T} jets. The change jetshapes with different underlying event tunes and different MC event generators (Pythia and Herwig) was also studied.

Jet shapes are sensitive to quark and gluon jet contributions, and the comparison of gluon and quark jets provides a test of QCD. Figure 9 presents the P_T fraction of a jet cone $R = 0.7$, that lies outside the cone size r=0.2 as function of the jet P_T. MC data are compared with parton shower MC predictions for quark and gluon jets. The figure shows that both quark and gluon jets become narrower when transverse energy increases. In addition, the relative fraction of quark jets increases with the increasing p_{T}. This study was thesis of Pelin Kurt, an LHC physics center visiting Ph.D student from Cukorova University who is expected graduate in Fall 2008. She presented these results at APS meetinng (April 2008), Fermilab New Perspective Conference (poster May 2008), 4th Conference On Physics at LHC-2008, 29 Sep-4 Oct 2008, Split (Croatia) and will present at Internationa Conference on Particle Physics, Istanbul, Turkey (Oct, 2008).

4 Hadron Calorimeter Noise Studies

Missing transverse energy $\not\!\!E_T$ is an global observable may be crucial for discovery of new physics, specially SUSY at LHC. $\not\!\!E_T$ is calculated using calorimeter energies. Various sources beam halo, cosmic rays, noisy and dead cells in calorimeter can produce fake $\not\!\!E_T$. In addition, large $\not\!\!E_T$ where none is expected may indicate to software/reconstruction problems. Thus $\not\!\!E_T$ can be used to monitor both detector and software performance.

There are many reasons to get fake missing E_T: beam halo, noisy or dead cells, and fake sources due to missing E_T algorithm. Missing E_T can be used as a global calorimeter quantity to monitor both hardware performance and software problems.

One of us (Ming Yang) is coordinator of hadron calorimeter (HCal) group activities

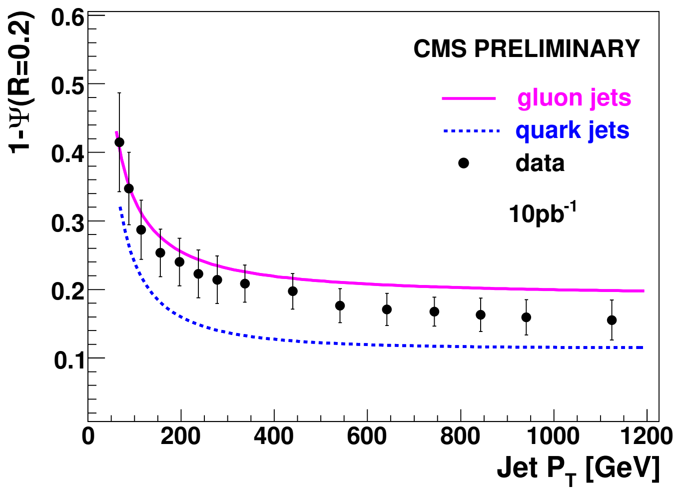

Figure 9: The fractional transverse momentum of a jet outside r=0.2, 1- $\psi(0.2)$, as a function of the jet P_T for jets in the central region of rapidity $|y| < 1$. The predictions from PYTHIA Tune DWT (black points) and the separate predictions for quark (dashed) and gluon (solid) initiated jets. Systematic and statistical errors are included. Systematics will be diccused in th next section. The total error includes the quadrature of systematics and statistical uncertainty. Systematic uncertainity is a quadrature combination of each source while statistical uncertainty on each point is calculated as $rms/\sqrt{N}$ where rms is the rms of the histogram and N is the number of expected jet in the bin for luminosity of 10 pb^{-1}. Being an integrated shape, the uncertainties at different r points are partially correlated.

at CMS Remote Operation Center (ROC) at Fermilab. The HCal ROC actives include real time monitoring of data being taken at CERN and giving feed back to the HCal team at CERN, local data processing and prompt analysis. We are concentrating on understanding the large noise observed in these data. We are collaboration with Shuichi Kunori (Maryland), Latife Vergili (Çukurova University). Alfredo Gurrola (Texas A&M University) to study the global cosmic run data at LPC, Fermilab.

CMS calorimeter is consists of electromagnetic calorimeter (ECal), central hadron calorimeter (HCal), and forward calorimeter. HCal covers pseudo rapidity upto $|\eta| = 3$. Region of $3 < |\eta| < 5.2$ is covered by forward hadron calorimeter. HCal is brass-scintillator based sampling calorimeter which readout by Hybrid photo-diodes (HPD). One HPD reads has 19 channels and readouts one ϕ slice. Four HPD are housed in one readout box (RBX) and reads out two ϕ slices. We are studying the noise produced by HPDs.

CMS collected data using a partial and full detector during 2008. Initially Hcal noise and muon triggers were used. Currently CMS is commissioning calorimeter based jet triggers.

These data is divided in four periods of data taking without magnetic field (Cruzet1 to Cruzet4) and one period of data at 3.8T of magnetic field (Craft). We studied the missing E_T distributions in Cruzet3 runs. We found a large number of events with missing E_T greater than 100 GeV/c. Some events even with missing E_T greater than 5 TeV/c. For example, cosmic Run 51490 has 183 events with missing E_T greater than 5 TeV/c (FIG 10). We are working to understand the mechanism which produced these events, identify the characteristics of the noise and how to filter out them.

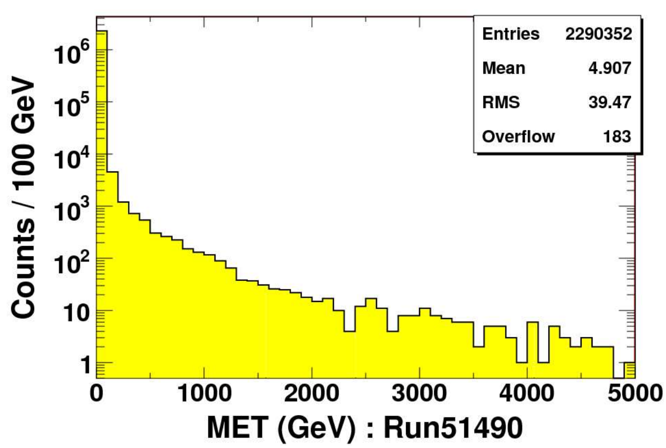

Figure 10: The missing E_T distribution of Run 51490.

4.1 Global runs and high missing E_T events

Since CMS reconstructed data does not contain digitization information, we developed protocol and software to select high missing E_T events from cosmic run data, pick raw data and rebuild raw and digitization information to the reconstructed data for group usage. Since the rate of events with large missing E_T is normally below 10Hz after 50 GeV/c cut, the streaming process can be quickly done within few hours after we get data at remote operation center at Fermilab during the cosmic run. We also developed software that can quickly read out digitization information so shifters can do prompt analysis during the data taking and monitor high missing E_T related information.

We studied Run 51490 which was taken using both muon and hcal triggers, and Run 51047 where only muon trigger is used. extensively. The HCal triggers are especially designed to trigger HCal noise events. In Craft, Run 60274 with jet triggers and 3T magnetic field are studied.

4.2 Noise Events Classification

Based on digitization and reconstructed hits (RecHits) information, we found HCal noise events can be classified into following four categories described below. In addition to the categories, we also observed pedestal and ion feedback noises in cosmic runs. These types of noise have very low energy and thus its effect can be minimized by relative mild threshold and is not discussed here.

- **RBX noise events:** Readout box (RBX) noise event refers to event with all four readout modules in one readout box fired at the same time. The exact reason why RBX noise event will happen is not clear. We also found HCal RecHits of RBX noise event have a more flat energy profile than other noise events. RBX noise events are observed in cosmic run data with either Muon triggers and/or with HCal triggers. Based on whether a Muon is co-existed in the RBX noise events, we further classify RBX noise events into two types: Type1, without Muon triggered, and type 2, with Muon triggered.

- **HPD noise events:** HPD noise events are one of the majority noise events we observed in cosmic run data. We found the typical HPD noise rate is about 3 Hz at $MET > 50$GeV/c. When a HPD noise event appears, we found all HCal channels in one specific iPhi fired at the same time. The typical discharge for those noise events is larger than 60 fc. Based on the width of energy profile, we separate HPD noise events into type one (wider) and type two (narrow) events.

  Type 1 HPD noise events involve multi-tower discharge. Those events will either be re-constructed to a single jet or multi-jet, depends on the width of the peak. FIG 11 (left) shows the type 1 HPD noise in events display software.

  Type 2 HPD noise events have much narrow energy profile and usually we can only see one discharged channel. This type of noise events even exist when 8KV high voltage is turned off and 3T magnetic field is on. This indicates the coating on HPD might contain radiative material which generates electrons and causes giant peak even without 8KV high voltage.

  For type 2 HPD noise events, we found the signal of HPD noise is well contained in the two time slices. However, this signature is not observed in type 1 HPD nose.

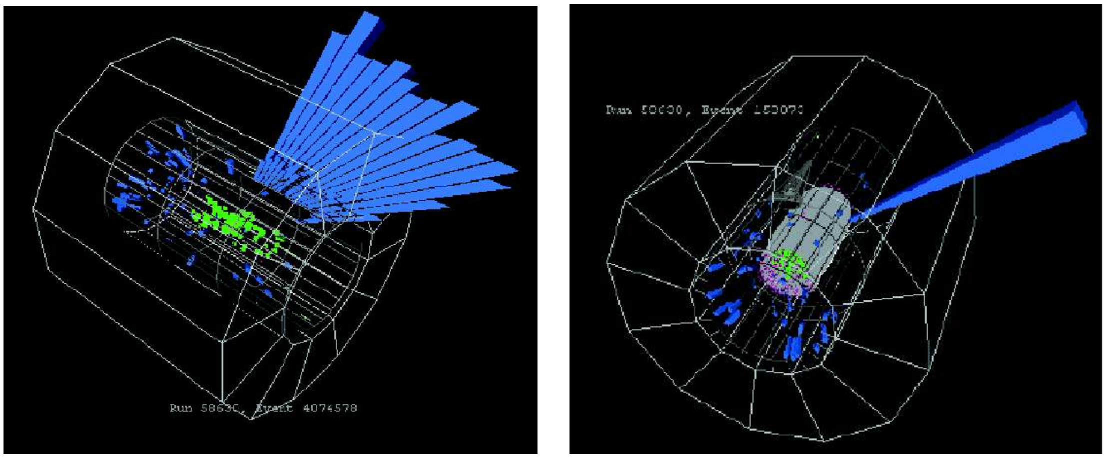

Figure 11: HPD noise events type 1 (left) and type 2 (right) from events display

- **Muon/Air shower signal:** We found low energy jets form incident single Muon or Muon shower can also introduce high missing E_T. FIG 12 shows multi muon shower events in Run 51047. This event also has MET=132.4 GeV/c. The possible reasons for this type of noise are either from Muon Bremsstrahlung or hitting sensitive readout electronic device.

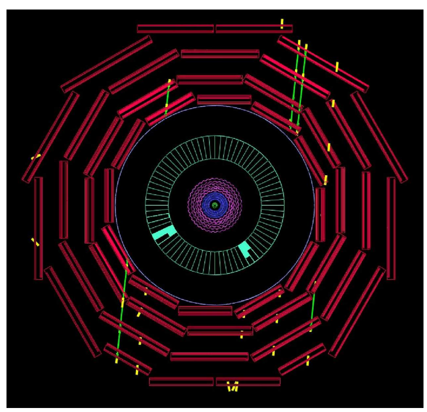

Figure 12: Multi Muon shower events in HB.

- **EB abnormal events:** EB abnormal events are the noise from ECal which created large missing E_T. We first observed this type of events in Cruzet3 runs. Since EB abnormal events only involve ECal, it can be removed by applying a cut on ECal and HCal energy ratio. ECal group is working on this issue.

4.3 Rate and Effect of HCal noise on physics analysis

The number of high missing E_T events are small number comparing to the total number of events in the run. We studied two runs to understand the rate of noise events. Run 51490 is the Cruzet3 run with Muon and HCal trigger, total 2.7 M events. HPD high voltage is 8KV. The number of noise events in this run is about 0.1% of total number of events. Run 51047 is the run taken only with Muon triggers. We observed much lower noise rate comparing with runs taken with HCal triggers. The noise events in this run is less than 0.002% out of total 5.8 M events.

For RBX noise events, we manually checked 100 events in Run 51490, and scaled them to the total number of events triggered in the run. We found the rate of RBX events when MET> 50 GeV/c is about 0.5 Hz. Using the similar scaling method, the HPD noise in Run 51490 is about 3 Hz when MET> 50 GeV/c. Events with Muon shower is about 0.05 Hz when MET> 50 GeV/c. When we increases the missing E_T threshold, the rate is even smaller. This indicates even though the number of noise events is big, it is still a smaller fraction and can be avoided by using carefully designed triggers.

4.4 Noise Filters

There are two ways to remove RBX and HPD noise events. One is to apply cuts on calorimeter properties after jet and missing E_T are reconstructed. Another way is to apply filter on raw and digitization information before reconstruction of jet and missing E_T. For the first method, since both RBX and HPD noise events are HCal only events. We can remove those events by comparing the amount of the hadronic and EM energy of each jet. We define hadronic and EM energy ratio:

$$Hadronic\, ratio = E_{HCal}/E_{tot} \quad (2)$$
$$Em\, ratio = E_{ECal}/E_{tot} \quad (3)$$

FIG 13 compares the hadronic and EM ratio of IteractiveCone5 jets in events with P_T larger than 100 GeV/c from Run 51490 to those from SUSY_LM2 Monte Carlo sample. If we cut hadronic ratio and EM ratio at 98%, majority of the noise events can be removed.

FIG 14 shows the result with hadronic energy ratio cut only and with both EM and hadronic energy ratio cuts. For noise events with missing E_T greater than 200 GeV/c, noise rate drops from 0.98Hz to 0.03Hz with hadronic energy ratio cut only and to 0.0006 Hz with combined EM and hadronic energy ratio cuts.

5 Jet and $\not\!\!E_T$ Data Quality Monitoring

We are working on the data quality monitor (DQM) for the JetMET physics object group (POG) with F. Chlebana from Fermilab. A good control of the jets and missing

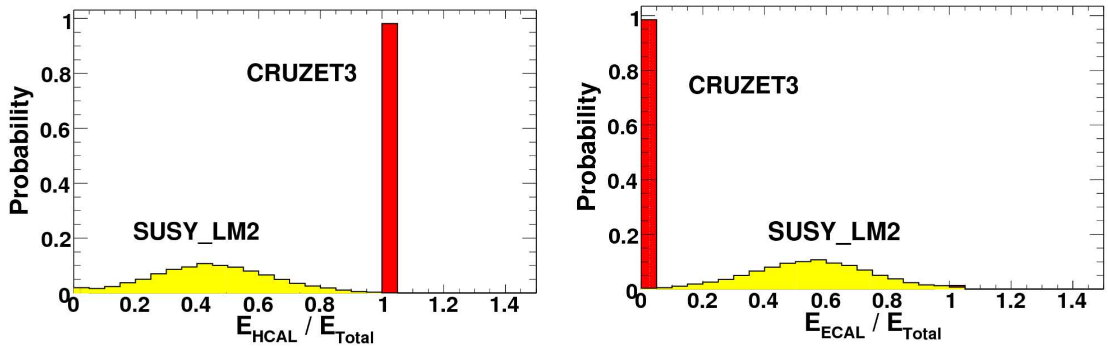

Figure 13: Hadronic energy and EM energy ratio for data (left) and Monte Carlo (right).

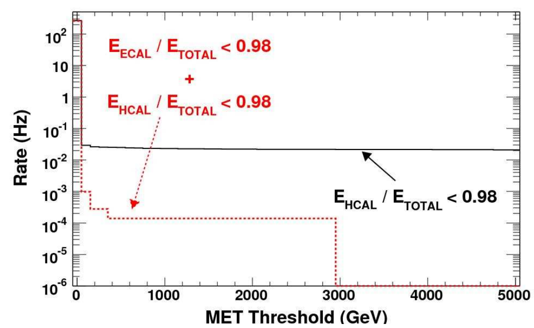

Figure 14: Noise rate after hadronic energy and EM energy ratio cut.

E_T quantities are central to the SUSY search we plan to perform at CMS, and it lead us to work on this project, but this project will be the important ingredient for the success of a large fraction of the other physics analyses at CMS as well.

The DQM at CMS can be divided into (1) online DQM and (2) offline DQM. The online DQM runs right after the data taking on the limited statistics, and monitors the detector-level quantities. The offline DQM runs on the full statistics as a part of standard reconstruction at Tier-0 ("prompt reconstruction") and Tier-1 ("re-reconstruction"). It confirms the findings in the online DQM, and in addition it monitors the reconstructed physics objects such as the photons, electrons, muons, jets and missing E_T. In offline DQM, we check cross-detector effects, *e.g.*, electrons E_T from the electromagnetic calorimeter and its p_T from the tracking system, which will not be done in the online DQM. The work flow of the JetMET DQM is shown in Fig. 15.

The goals of the JetMET DQM is to identify good runs and luminosity sections [1] which can be used for physics analysis based on the jet and missing E_T related observables. This will provide the quality information for the Barrel, Endcap and Forward calorimeters, and will complement the detector-level quality monitoring for these

[1] One luminosity section is about 90 seconds.

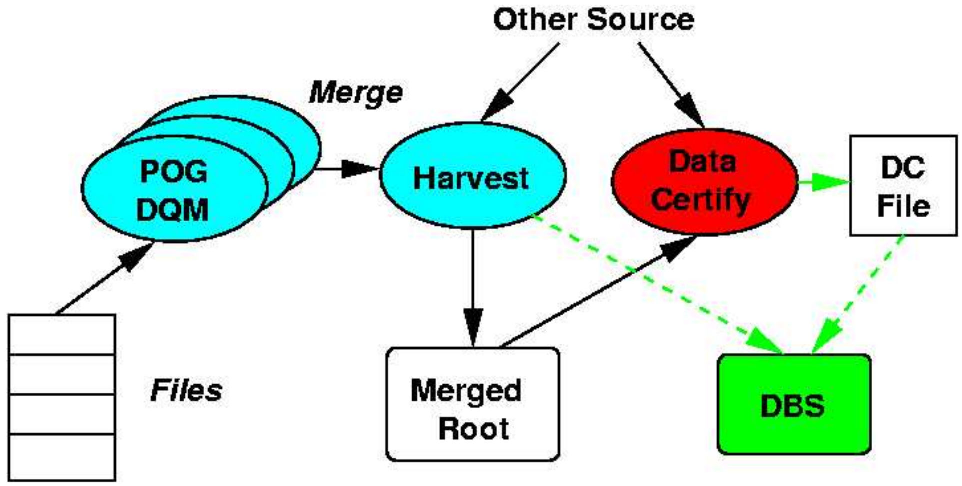

Figure 15: The work flow of the JetMET DQM.

calorimeters.

We are quite advanced among the physics object groups. We have implemented the first version of the monitoring code and data certification algorithm which determines the goodness of a run and luminosity section, and we tested them on the cosmic ray trigger data. We are currently working toward making our monitoring more comprehensive and stable, and integrating our machinery into the centralized CMS offline DQM system. The JetMET DQM code may become an example for the other physics object groups' monitoring. Fig. 16 shows the project of $\not\!\!E_T$ along x and y axis. This was produced DQM process which is automatically run after data reconstruction. Based on the agreement between luminosity section distribution with the standard distributions, he data from each luminosity section will be marked good or bad.

We are working toward making the fully functional monitoring code by the next Spring when we expect to have the first proton-proton collision data.

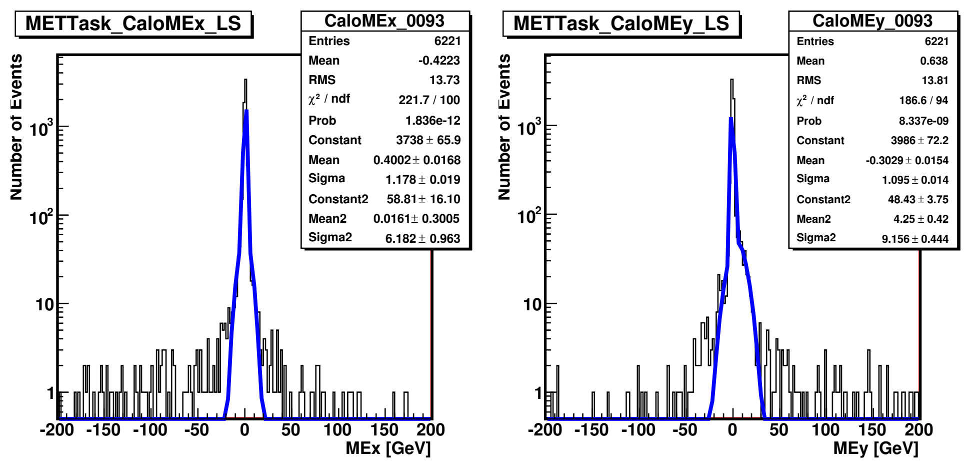

Figure 16: Missing Transverse energy ($\not\!\!E_T$) components along x and y where $\not\!\!E_T$ is calculated all calorimeter towers in CMS data.

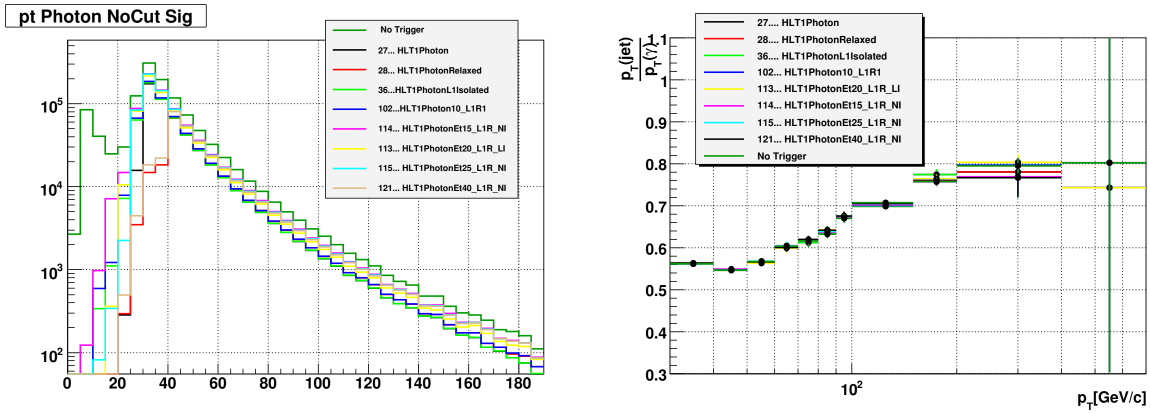

Figure 17: P_T distribution and jet response in photon-jet events for different trigger selections. The jet response is almost independent of trigger requirements.

6 Jet Energy Scale Determination

The rockefeller group has been very active in planning the determiniation of jet energy scale (JES) at CMS. In 2006, we wrote the initial plan to determine JES in CMS Phys. Technical Design Report [16]. We wrote the initial software to make the detector response uniform verse psuedo-rapidity using dijet balancing and did the initial studies. We also wrote the software to determine absolute correction using Monte Carlo informations. Last year we worked on the data driven technique to determine absolute corrections. We did various studies using photon-jet balancing to evaluate the differences between the true aboslute corrections and those determined using photon-jet balancing. These studies have been described in our previous reports. The final note on CMS jet energy scale plans was approved by collaboration in June 2008 [12].

Over last year, many people have joined the CMS jet energy scale group. Kostas Kousouris (Fermilab) is working on dijet balancing and absolute corrections using simulated events. Daniele Del Re (Universita di Roma) and Mikko Voutilainen (Helsinki) joined the photon-jet balancing effort. Over last year, focus of photon-jet studies has shifted to understanding dijet background where one of the jet mimics a photon. These fake photons can be rejected by requiring the photon candidates to isolated from any track and any energy deposition in electromagnetic and hadron calorimeters. In addition, the real data taking conditions *e.g.* trigger must be taken into account. CMS did a full excercise of early calibration in 2008, CSA08. In this exercise, Monte Carlo data generated using start-up conditions was analyzed as "real" data and jet energy corrections were derived. We contributed to measuring the photon trigger efficiency. Fig. 17 shows the efficeincy of photon triggers used in CSA08 exercise and the jet energy response for various photon triggers. These trigger have different photon isolation requirements. Due to technical reasons, CSA08 exercise was done on pure photon+jet samples. The study should be repeated by mixing in the dijet background.

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