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Jet energy measurements in CMS

O. Kodolova

SINP MSU, Moscow, Russia

Abstract

The expected performance of CMS for jet energy measurements is discussed. The use of the different calibration methods allows to restore the linearity of the CMS calorimeter relative to jets and improve the jet energy resolution.

Figure 1: Complexities in the jet definition arise from several processes include final state radiation, underlying event fragments and the detector-level collection of particle energies.

1 Introduction

Event signatures for SUSY, Higgs boson production, and other new physics processes require the reconstruction and measurement of jets coming from high-momentum quarks and gluons. The jet energy resolution and linearity are key factors in separating signal events from background and in measuring the properties of the signal.

An example of jet reconstruction in a hard interaction forming QCD dijets, with its characteristic features, is shown in Fig. 1. The parameters of the initial parton corresponding to the particle jet depends on a number of factors including final state radiation, which can lead to the splitting of the jet in the detector. Taking a large cone of $R = 1.5$ in η, ϕ , the jet reconstruction collects a large fraction of the energy of the initial parton. Such a cone is also susceptible to collecting the energy of non-isolated additional partons in the hard interaction in addition to energy from the underlying event, pile-up interactions and electronic noise.

2 CMS detector

A characteristic feature of the CMS detector is its large superconducting solenoid delivering an axial magnetic field of 4 T [2]. The hadron and electromagnetic calorimeters are located inside the coil (except the forward calorimeter) and cover the pseudorapidity range $|\eta| < 5$. The calorimeters are designed to allow jet reconstruction in the full pseudorapidity region. The calorimeter extends to $\eta = 5$, but jets can be measured if their axes lie in the range $|\eta| < 4.5$. At $\eta = 5$, half the jet will be lost. In addition, the CMS detector has a silicon tracker ($|\eta| < 2.4$) which allows track momenta to be determined with a resolution better than 1% for low- p_T tracks (p_T between 0.5 GeV and a few tens of GeV and $|\eta| < 1$).

3 Jet reconstruction

The first step in the reconstruction, before invoking the jet algorithm, is to apply noise and pile-up suppression.

The second step is to apply one of the jet finding algorithm (iterative cone algorithm, middle point algorithm or Kt algorithm [1]-[4]) and get the jet energy and position.

The factors influencing the reconstructed jet energy can be divided into two groups. In addition to the factors, shown in Figure 1 and connected with the jet as a physical object, jets are affected by the detector performance, e.g electronic noise, magnetic field which deflects low energy charged particles out of the jet reconstruction cone,

Figure 2: The ratio of the reconstructed jet transverse energy E_T^{Rec} to the generated transverse energy E_T^{MC} as a function of E_T^{MC} for jets with $|\eta_{jet}| < 1$ reconstructed by the iterative cone $R = 0.5$ algorithm before (circles) and after (squares) MC jet calibration.

the responses of the calorimeters to electromagnetic and hadronic showers (e/h ratio), and some other sources of the energy loss. While many of the corrections for effects in the first group are channel dependent, the bulk of the detector effects are more channel independent and common correction coefficients can be provided.

At the third step the calibration methods are applied to restore a correspondence in the measured jet properties between matched reconstructed and particle-level jets.

4 Jet calibration

Algorithms for jet energy corrections may be classified according to the different objects that are used for the corrections.

Jet-based corrections are implemented by weighting the energies from the longitudinal calorimeter compartments.

Cluster-based coefficients are applied separately to electromagnetic and hadronic clusters, separated according to the cluster origin (electron, γ , hadron).

As for track based corrections, the tracks that are deflected from the jet region due to magnetic field can be added to the jet energy reconstructed in calorimeter. The response of charged particles within the jet area can be changed to the momentum (energy) of the tracks giving impact on the ECAL surface inside the jet region.

4.1 Monte Carlo calibration of Jet Response (jet based)

The jets are reconstructed with one of the jet finding algorithms. Particle-level jets are found by applying the same jet algorithm to stable particles (excluding neutrinos and muons). A matching criterion, based on the distance $\Delta R = \sqrt{d\eta^2 + d\phi^2} < 0.2$, is used to associate particle-level and reconstructed jets. The ratio of reconstructed jet transverse energy to the particle-level jet transverse energy as a function of the particle-level jet transverse energy is approximated by the set of functions for the different η regions.

The jet energy linearity and resolution after applying Monte-Carlo corrections are shown in Figs. 2,3 for the iterative cone algorithm.

4.2 The calibration of Jet Response with γ +jet channel (jet based)

The channels of γ/Z +jet and $W^- \rightarrow jj$ (from $t\bar{t}$ production) will give the first estimation of the absolute energy scale. The jet energy scale is set using the kinematics relationship of transverse momentum balancing between the direct photon and the jet. The measured observable $k_{jet} \equiv \frac{p_T^{jet}}{p_T^{meas}}$ provides an approximate value for the true parton-level calibration of the jet given by $k_{jet}^{true} \equiv \frac{p_T^{jet}}{p_T^{parton}}$. The systematic shifts introduced by the difference

Figure 3: The jet energy resolution as a function of generated jet energy for the different pseudorapidity intervals.

Figure 4: Relative systematic errors $((k_{jet} - k_{jet}^{true})/k_{jet}^{true})$ on the calibration of the jets initiated by the light quarks (solid lines) and the jets from the QCD sample (including gluons, dashed lines) for the iterative cone algorithm with cone radii of $R = 0.5$ (circles) and $R = 0.7$ (triangles) and for the K_T -cluster algorithm using the E_T -scheme (crosses) for the $E_T^{tower} > 0.5$ GeV.

between gluon and quark jets are presented in Figure 4.

The correction with γ +jet channel can be applied to particle jet with the additional MC correction taking into account the difference between parton and particle jet: $E_{Tptcl}^{jet} = E_{Tjet}^{parton} \times k_{jet}^{ptcl}$.

4.3 The calibration of Jet Response with use of tracks

A response subtraction procedure was proposed in Ref. [5]. For each track reaching the calorimeter surface within the reconstruction jet area, the expected response is subtracted from the calorimeter jet energy and the track momentum is used instead. This subtraction procedure does not require cluster separation and is therefore well suited to the case of high occupancy or coarse granularity. The momenta of the tracks that reach the calorimeter surface out of the reconstruction cone are simply added to the calorimeter jet energy.

The resolution is improved by a factor 1.7 for 20 GeV jets and by 15% for 100 GeV jets (Fig. 5). The correction almost completely restores the mass scale and the resolution is improved by 10% (Fig. 6).

Figure 5: The jet transverse energy resolution as a function of the original jet transverse energy in a single jet sample; reconstruction with calorimeter only (close circles), out-of-cone tracks (open circles), subtraction procedure of expected responses using library of responses (close squares).

References

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Figure 6: Ratio of the reconstructed to the generated X mass with calorimeters only (empty histogram) and with calorimeter + tracks corrections (hatched histogram).