

Missing transverse energy performance with the CMS detector

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The results of comprehensive studies of missing transverse energy as measured by the CMS detector in pp collisions at a centre-of-mass energy of 7 TeV are presented. Three missing transverse energy reconstruction algorithms are deployed for various physics analyses. The scale and resolution for missing transverse energy are validated using vector boson and dijet events, and severe mismeasurements due to the detector are studied. We also parametrize the effects of multiple pp interactions within the same bunch crossings on the scale and resolution. A tool, called missing transverse energy significance, based on particle resolutions in each event is also presented.

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1. Introduction

Neutral weakly interacting particles, such as neutrinos, escape from typical collider detectors without producing any direct response in the detector elements. The presence of such particles must be inferred from the imbalance of total momentum. The vector momentum imbalance in the plane perpendicular to the beam direction is particularly useful in pp and p \bar{p} colliders, and is known as missing transverse momentum, here denoted \vec{E}_T . Its magnitude is called missing transverse energy, and is denoted E_T .

Missing transverse energy is one of the most important observables for discriminating leptonic decays of W bosons and top quarks from background events which do not contain neutrinos, such as multijet and Drell–Yan events. It is also an important variable in searches for new weakly interacting, long-lived particles. Many beyond-the-standard-model scenarios, including supersymmetry, predict events with large E_T . A good understanding of large E_T events is very important for searches and a high-performance E_T resolution is vital for precision measurements like top or W mass measurements.

2. Reconstruction of E_T

In general, \vec{E}_T is the negative of the vector sum of the transverse momenta of all final-state particles reconstructed in the detector. CMS has developed three distinct algorithms to reconstruct \vec{E}_T : (a) PF E_T , which is calculated using a complete particle-flow technique [1]; (b) Calo E_T , which is based on calorimeter energies and the calorimeter tower geometry [2]; and (c) TC E_T , which corrects Calo E_T by including tracks reconstructed in the inner tracker after correcting for the tracks' expected energy depositions in the calorimeter [3].

In the following, distributions involving Calo E_T include both jet energy scale (type-I) and unclustered energy scale (type-II) corrections [4, 5], those involving PF E_T include type-I corrections, and those involving TC E_T are uncorrected, as these were the corrections that were available at the time the analyses presented here were performed and are the versions used most typically in 2010 and 2011 physics analyses.

3. Large E_T due to misreconstruction

Various instrumental causes can lead to anomalous \vec{E}_T measurements. For example, the CMS calorimeters occasionally record anomalous signals that correspond to particles hitting the transducers or produced by rare random discharges of the readout detectors. Detailed studies of the various effects are documented in detail in [5, 6]. For some types of anomalous energies, the number of affected channels is small and the event can still be used in physics analysis after the removal of the anomaly. We refer to the removal process as “cleaning” the event. If a large number of channels are affected, “filters” instead tag the event as not suitable for use in physics analysis.

The basic strategy for the cleaning is based on information such as unphysical charge sharing between neighbouring channels in η - ϕ and/or depth, and timing and pulse shape information. The Calo E_T and PF E_T distributions from minimum-bias and jet data samples are shown before and after removal of the anomalous signals in Fig. 1, demonstrating the effect of the cleaning and filters.

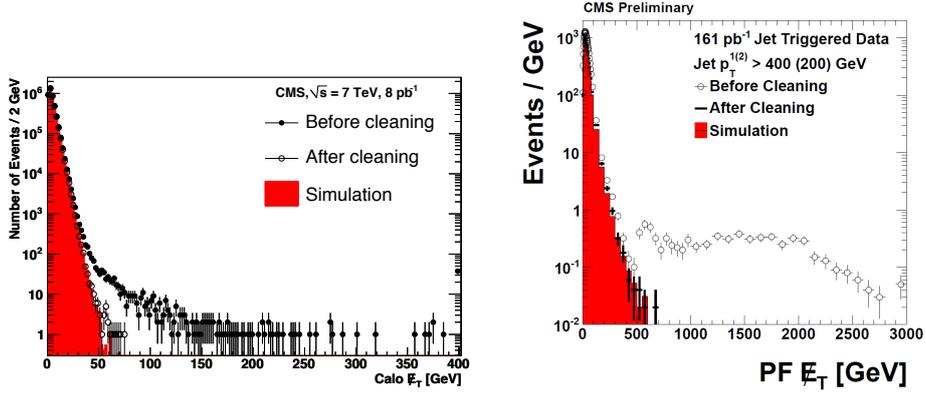


Figure 1: (left) Calo E_T distributions in a minimum-bias data sample without (black dots) and with (open circles) cleaning and filters, compared to simulation [5]. (right) PF E_T distributions in a jet data sample without (open circles) and with (black dots) cleaning and filters, compared to simulation [7].

4. Missing transverse energy scale and resolution

The performance of \vec{E}_T has been studied using dijet events and events where an identified Z boson or isolated γ is present, comparing the momenta of the well-measured vector boson to the hadronic recoil [5, 7]. The agreement in response and resolution between the different samples is good. The measured E_T scale agrees with the expectations of the detector simulation, but the resolution is degraded by 10% in data. As expected, the missing transverse energy reconstructed with the particle-flow algorithm gives the best performance.

The effects of multiple pp interactions within the same bunch crossings on the scale and resolution have been studied [5]. We find that pile-up interactions contribute to the degradation of the E_T resolution but have little effect on the scale of the components of E_T . We also find that we can model its effects with a simple parametrization. The degradation of the resolution with increasing pile-up is shown in Fig. 2.

5. E_T significance

A spurious nonzero \vec{E}_T in an event can have contributions from many sources, including measurement resolution, reconstruction inefficiencies, instrumental defects, and improper pattern recognition. Events in which the reconstructed \vec{E}_T is consistent with contributions solely from particle-measurement resolutions and efficiencies can be identified by evaluating the \vec{E}_T significance. The significance offers an event-by-event assessment of the likelihood that the observed E_T is consistent with zero given the reconstructed content of the event and known measurement resolutions.

The computation of the \vec{E}_T significance used in CMS is described in [5]. The performance of this variable has been studied in dijet events and in the context of a W+jets analysis. In dijet events, an exponential significance distribution and a flat probability distribution are obtained as expected for events with no genuine E_T . This significance variable has been introduced into the selection criteria of a W+jets analysis and a superior signal to background ratio is obtained compared to the

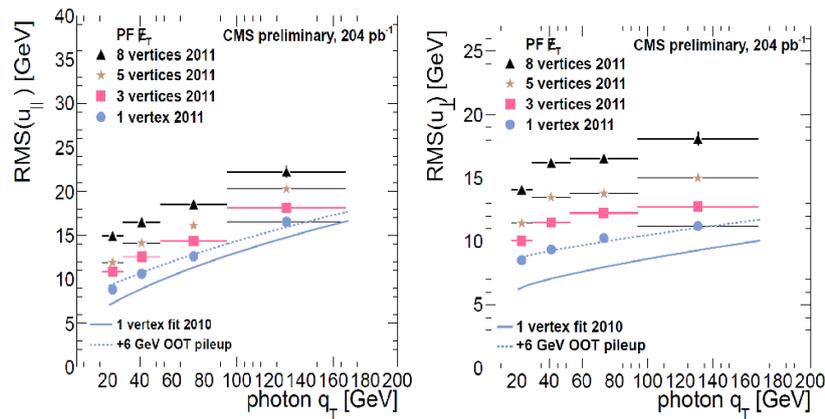


Figure 2: Resolution curves for components of hadronic recoil calculated using $PF\cancel{E}_T$ in γ +jets events, measured in events with various numbers of primary vertices, (left) parallel to the boson direction, and (right) perpendicular to the boson direction [7].

results with the traditional variables \cancel{E}_T or \cancel{E}_T divided by the square root of the $\sum E_T$, regardless of the amount of pileup in the event [8].

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