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Hadronic Event Shapes at CMS

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Abstract

In this note, a study of hadronic event shapes in QCD events at the Large Hadron Collider (LHC) is shown. The study is based on a GEANT detector simulation of the Compact Muon Solenoid (CMS) detector. Calorimetric jet momenta, determined by the k_T jet clustering algorithm, are used as input for calculating various event-shape variables, which probe the structure of the hadronic final state. It is shown that the normalized event-shape distributions are robust under variations of the jet energy scale and resolution effects, which makes them particularly suitable for early data analysis and tuning of Monte Carlo models.

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Hadronic Event Shapes at CMS

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1 Event-Shape Variables

Event shapes belong to the most widely used variables to study QCD dynamics, especially at e^+e^- and ep colliders. Event-shape observables are defined in terms of the four-momenta of jets in the final state. Recently a large set of new hadronic event-shape variables has been proposed in Ref. [2]. An important aspect of these variables is their normalization to the total transverse momentum or energy in the event. Therefore, it is anticipated that energy scale uncertainties should cancel out to a large extent. Thus we believe that they represent a useful tool for very early measurements of the properties of QCD events at LHC and the tuning of Monte Carlo models.

Analogously to event-shapes in e^+e^- annihilations hadronic event-shape variables have been defined in the transverse plane, such as the transverse thrust

$$T_{\perp} \equiv \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_{T,i} \cdot \vec{n}_T|}{\sum_i p_{T,i}} \quad (1)$$

where $p_{T,i}$ are the transverse particle momenta with respect to the beam axis. The axis for which the maximum is obtained is called the thrust axis. The variable which is typically used for perturbative calculations is $\tau_{\perp} \equiv 1 - T_{\perp}$. Calorimetric jet momenta are used as input for the transverse thrust calculation. In the following, we concentrate only on the central region of the detector, which we consider especially suitable for early data analysis. Below the results of a first simulation study [3] of measurements of these event-shape variables with the Compact Muon Solenoid (CMS) detector [4] are summarized.

2 Monte Carlo Samples and Primary Selection

PYTHIA 6.409 [5] is used to simulate proton-proton collisions with a centre of mass energy $\sqrt{s} = 14$ TeV. The events have been passed through a full GEANT based simulation of the CMS detector. Events are preselected by requiring two or more calorimeter jets, corrected for their relative and absolute response, with a transverse energy $E_T \geq 60$ GeV. The two hardest jets of the event are required to be central, within a region of $|\eta| < \eta_C = 1.3$ and

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thus in the barrel region of the CMS calorimeter. Only central jets with $E_T \geq 60$ GeV are used for the event-shape calculation. The threshold on the transverse energy of the leading jet is set at $E_{T,1} > 80$ GeV.

3 Systematic Uncertainties

Often, the leading source of systematic errors in QCD data analysis is the limited knowledge of the jet energy scale (JES) and, to a lesser extent, the jet energy resolution. By definition (see Eq. (1)), event-shapes are expected to be rather robust against both sources of systematic errors. At startup a global uncertainty of 10% on the knowledge of the jet energy scale is assumed for CMS [6]. By varying the jet energy scale in this range the resulting normalized event-shape distributions deviate by 5-10% from the reference distribution over the whole energy range as can be seen in Fig. 1.

The effect of the jet energy resolution is studied by applying the jet energy resolution smear function in Eq. (2) on generator level jets:

$$\frac{\sigma(p_T)}{p_T} = \sqrt{\left(\frac{5.2}{p_T}\right)^2 + \left(\frac{1.2}{\sqrt{p_T}}\right)^2 + (0.043)^2} \quad (2)$$

The smeared event-shape distributions deviate by less than 5% from the unsmeared distribution over most of the energy range (Fig. 1).

Figure 1: Left: The effect of a variation by 10% in the jet energy scale on the transverse thrust distribution using corrected calorimeter jets determined by the k_T algorithm with a D-parameter of $D=0.6$. The two lower histograms show the deviations of the scaled distributions to the reference distribution. Right: The effect of the jet energy resolution on the central transverse thrust distribution. The lower histogram shows the deviation from the unsmeared distribution.

4 Results

In order to demonstrate the sensitivity of hadronic event-shape distributions to different models of multi-jet production, we compare the central transverse thrust distribution to the generator level predictions as obtained from two generators that contain different models of QCD multi-jet production, PYTHIA 6.409 and ALPGEN 2.12 [7]. The ALPGEN samples used in our study contain QCD processes from 2 up to 6 jets.

In Figure 2 the distribution of the central transverse thrust can be seen. These events are selected from a jet trigger, based on the calibrated transverse energy of the hardest jet $E_{T,1} > 60$ GeV with a prescale of 100. The error bars on the data points include the statistical uncertainties corresponding to an integrated luminosity of $\int \mathcal{L} = 10 \text{ pb}^{-1}$ and the systematic errors due to jet energy scale and jet energy resolution as discussed in the previous section. The corrected calorimeter jets correspond to the PYTHIA samples, and they are found to be compatible with the generator level jets from PYTHIA. It can be seen that there is a significant difference with respect to the ALPGEN distribution, reflecting the different underlying matrix element calculations in the generators and the different parameter choices. The result shows that early measurements of event-shape variables allow to study differences in the modeling of QCD multi-jet production.

Figure 2: The central transverse thrust distribution for a leading jet with $E_{T,1}^{\text{cor}} > 80$ GeV with the statistical and dominant systematic errors expected after an integrated luminosity of $\int \mathcal{L} = 10 \text{ pb}^{-1}$. The prescale of the trigger is assumed to be 100. The distributions are compared to the generator level distributions of PYTHIA and ALPGEN.

5 Conclusions

We demonstrate the use of hadronic event shapes measured with the CMS experiment. The event-shape variables are evaluated using calorimetric jet momenta as input. We present an estimate of the dominant systematic uncertainties at startup, resulting from jet energy resolution effects and from the limited knowledge of the jet energy scale. Using the example of the central transverse thrust we show that hadronic event shapes can be powerful handles in comparing and tuning different models of multi-jet production.

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