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Jet Reconstruction in CMS using Charged Tracks only

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Abstract

We present results on the performance of jet reconstruction in CMS, using charged tracks only. Jet reconstruction with tracks is completely independent from jet finding with calorimeter towers and is an extremely clean and efficient way to find jets, and determine their directions with good precision. A commissioning analysis using approximately $100 \mu\text{b}^{-1}$ of minimum bias pp collision data at $\sqrt{s} = 7 \text{ TeV}$ shows that for jets with $p_T > 10 \text{ GeV}/c$ the agreement between the data and PYTHIA predictions for properties of minimum bias events appears to be good, and there is consistency of track jets and calorimeter-based jets.

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We present results on the performance of jet reconstruction in CMS, using charged tracks only. Jet reconstruction with tracks is completely independent from jet finding with calorimeter towers and is an extremely clean and efficient way to find jets, and determine their directions with good precision. A commissioning analysis using approximately $100 \mu\text{b}^{-1}$ of minimum bias pp collision data at $\sqrt{s} = 7$ TeV shows that for jets with $p_T > 10$ GeV/c the agreement between the data and PYTHIA predictions for properties of minimum bias events appears to be good, and there is consistency of track jets and calorimeter-based jets.

1. Introduction

Four different types of jets are reconstructed at CMS, making use of different sub-detectors and differing in how the individual contributions are combined to form the inputs to the jet clustering algorithm: calorimeter jets, Jet-Plus-Track (JPT) jets, Particle-Flow (PF) jets, and track jets [1, 2]. While calorimeter jets and track jets are reconstructed from completely independent sub-detectors, which allows for cross-validation, JPT jets and PF jets make use of all detector components of CMS to obtain the best possible performance. This variety of reconstruction methods allows for continuous cross-validation of algorithms as well as detector components. This summary will focus on the jet reconstruction from tracks only. The performance and commissioning of calorimeter jets, JPT jets and PF jets can be found in Ref. [1, 3]. In the following we will show that track jets provide an extremely efficient way to find jets with very small fake rates, excellent angular resolutions and unambiguous association to a single primary vertex in the interaction region, making them transparent to pile-up effects.

2. Track jet Reconstruction CMS

Track jets are reconstructed from tracks of charged particles, measured using the CMS tracker [4] which covers the pseudo-rapidity region of $|\eta| < 2.5$. The tracker

consists of a silicon pixel detector with 3 barrel layers and 2 forward disks, surrounded by a silicon strip detector with 10-12 barrel and forward layers with 40% stereo views and is located in the 3.8 T field of a superconducting solenoid.

For the commissioning of track jets on a broad scale with the first LHC data, tracks with a minimal set of quality requirements are selected as input for the track jet reconstruction, ensuring a low fake rate and at the same time sufficient efficiency to reconstruct track jets down to transverse momenta of a few GeV/c. Tracks with $p_T > 300$ MeV/c are kept, ensuring an optimal reconstruction of low p_T track jets. The track quality selection is based on the high purity flag of the standard CMS reconstruction [5], the distance to the primary vertex, the transverse momentum error, and the χ^2 of the track fit.

Track jets are built by clustering the selected tracks using the anti- k_T algorithm [6] with jet cone size of $R = 0.5$ through the FASTJET interface [7]. They are clustered separately for each primary vertex in the event, by association of tracks to the primary vertices (PV) by their distance projected along the beam direction.

3. Performance of track jets

In this section, the performance of track jets evaluated using Monte Carlo events generated with PYTHIA [8] and passed through a full GEANT 4-based [9] simulation of the CMS detector will be summarized.

One of the most important characteristics of jet reconstruction is the correspondence between the reconstructed jets and the “true” jets, the jets clustered from simulated stable particles after the PYTHIA hadronization step (“GenJets” in the following). The efficiency of matching GenJets with $|\eta| < 2$ to reconstructed track jets within $\Delta R < 0.5$, i.e. the reconstruction efficiency, is larger than 99% for GenJets with $p_T > 15$ GeV/c [2]. The fraction of reconstructed track jets that are not matched (within $\Delta R < 0.3$) to GenJets, i.e. the “fake-rate”, is lower than 1% for track jets with uncalibrated $p_T > 10$ GeV/c.

Several instrumental effects, including tracker noise, beam backgrounds, tracker misalignment, material budget, can influence tracking efficiency and fake rates, thereby affecting the performance of track jet reconstruction. It was found that all effects induce an effect on the track jet matching efficiency and mis-match rates below 1%, demonstrating the robustness of track jet reconstruction [2].

The angular resolutions of track jets in both η and ϕ are smaller than 0.05 units for a corresponding GenJet $p_T > 10$ GeV/c in $|\eta| < 2$ and improve with increasing p_T [1]. Angular resolutions are degraded at the edge of the tracker ($|\eta| > 2$), where track jets of cone-size 0.5 reach beyond the limits of the detector.

The energy response of track jets is the average fraction of energy reconstructed in a track jet with respect to its “true” GenJet energy. It is constant at about 60% up to a GenJet p_T of several 100 GeV/c, which corresponds to the average fraction of charged particles in a quark/gluon jet as neutral particles are not measured by the tracker [10]. At even higher p_T the energy reconstruction using tracks is

degraded due to mis-reconstruction of very dense and straight tracks.

An important effect influencing jet reconstruction at the LHC is pile-up, i.e. the presence of multiple collisions in the same bunch-crossing. The impact of pile-up interactions on track jet measurements was studied using collision data by looking at the distribution of H_T , the sum of the p_T of the jets in an event, where the sum runs over the track jets associated to each primary vertex separately, with each vertex contributing in the distribution [2]. The fact that the measured H_T is the same for events with one or two vertices shows that track jets are robust in the presence of two pile-up interactions.

Simulations [10] have shown that also in the presence of more pile-up interactions, given the primary vertex z resolution [5, 11] and average expected vertex separation, track jets are expected to be transparent to pile-up effects even in higher LHC luminosity scenarios, when LHC bunch intensities are increased and the beam is further reduced in transverse size.

In summary, track jets in CMS have a very good performance in jet finding and position measurement and are transparent to pile-up interactions. Energy measurement is restricted to the charged component of jets and therefore limited w.r.t. jet reconstruction methods making use of calorimeter information. Track jets are therefore best suited for analyses focusing on jet counting or very low p_T jets.

4. Commissioning with first data

In May 2010, the LHC delivered the first pp collisions at $\sqrt{s} = 7$ TeV. Early data were used to fully commission the tracking algorithms and track jets. A detailed overview on the tracking commissioning can be found in Ref. [5, 11]. In this section, the commissioning of track jets [2] will be described.

The data used for commissioning was collected using a Level-1 minimum bias trigger, selecting correct LHC bunch crossings and requiring activity in the beam scintillation detectors on each side of the CMS detector. A veto on Level-1 triggers which indicate the occurrence of beam halo effects and a filter on beam scraping events were applied. Finally, the reconstruction of one good primary vertex (PV) reconstructed from at least 4 tracks in the central region of the CMS detector was required. The data used in this analysis corresponds to an integrated luminosity of approximately $100 \mu\text{b}^{-1}$ with an estimated relative uncertainty on the luminosity of the data sample of 10% [12].

To provide an overall validation of track jets in CMS, inclusive track jet kinematics and jet constituent properties were studied. The data was compared to a reference minimum-bias Monte Carlo sample produced with PYTHIA 8.1 [8] and processed with a GEANT 4-based [9] simulation of the CMS detector, tuned to the LHC parameters and detector conditions during the first collisions at $\sqrt{s} = 7$ TeV. In order to select a sample, in which well modeling by the event generator is expected, a minimum of uncalibrated $p_T > 10$ GeV/c was required for the track jets.

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Fig. 1. (a) Track jet multiplicity per event and (b) p_T for inclusive track jets. The Monte Carlo distributions are normalized to the data luminosity estimate, and the green area reflects a 10% luminosity uncertainty. Inclusive track jets (c) η and (d) ϕ distributions, (e) number of jet constituents and (f) p_T fraction of the leading track. The distributions are normalized to the number of track jets in each plot.

Figure 1 shows the track jet multiplicity per event, the p_T , η and ϕ distributions for inclusive track jets, the number of jet constituents and the p_T fraction of the leading track. All distributions show at least reasonable agreement of data and simulation. A detailed discussion is given in Ref. [2], including an analogous study of the properties of di-jet events.

Due to their very low mis-match rates and high jet finding efficiency, track jets were also used to cross-check calorimeter jets and PF jets. The correspondence of track jets, calorimeter jets and PF jets was studied by measuring the matching efficiency defined as the fraction of jets that can be matched to a jet of other type within $\Delta R < 0.5$ as a function of calibrated jet p_T . The matching efficiency is a convolution of the jet reconstruction efficiency and the effect of jet position resolutions [13]. It was found that the matching efficiency is consistent between data and simulation [2].

5. Conclusions

Track jets are a highly efficient tool for jet finding in CMS down to very low p_T . A detailed commissioning study of track jets using the first CMS pp collision data

taken in 2010 at a center-of-mass energy of 7 TeV has shown good agreement with simulations. Benefiting from their excellent performance, track jets have been used in the very first CMS analyses. In the underlying event activity analysis [15,16] the number and momentum of charged particles were measured in the region transverse to the leading track jet. The cross section analysis of the open beauty production with muons [17] used the transverse momentum of the muon with respect to the closest track jet to discriminate b-quark events from background.

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