# Jet Reconstruction with charged tracks only in CMS

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## Overview

The performance of jet finding using only charged tracks in CMS is investigated. Different jet algorithms are applied to QCD di-jet events in a wide range of transverse momenta (15GeV/c<$p_T$<2.2TeV/c), on hadronic top pair multi-jet events and on Z+jets events. Results using jets made with tracks or calorimeter towers are compared for energy response, angular resolution and jet matching to the leading partons. The jet reconstruction performance in the presence of pile-up interactions is presented for the Z+jets sample.

## Jet Reconstruction

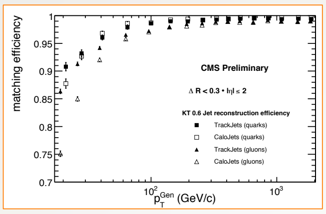
In CMS jets are normally reconstructed using energy deposits in calorimeter towers ("CaloTowers") as inputs [2]. CaloTowers collect both the charged and the neutral component of the parton hadronization, however, due to the 3.8 Tesla inner CMS magnetic field, CaloTowers fail to collect the energy of low momentum charged particles which don't reach the calorimeter, and in general carry a displaced azimuthal direction for all charged particles with $\Delta\phi$~1.1/ $p_T$ ( GeV/c) for transverse momentum $p_T$ > 1 GeV/c.

Jet finding with charged tracks only is completely **independent** from jet finding with CaloTowers and is an alternative way to find and count jets, and determine their directions. Jets made with tracks and also have independent detector-related systematic uncertainties that can be evaluated separately. The results presented are obtained assuming ideal conditions for the alignment and calibration of the CMS detectors.

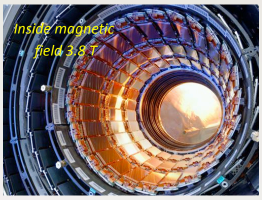
Jets are built using the Iterative Cone or the $k_T$ algorithms with different clustering size parameters. We compare jets reconstructed using the following inputs:

1. visible Monte Carlo truth particles (**GenJets**),
2. calorimeter towers (**CaloJets**),
3. reconstructed charged tracks (**TrackJets**).

The efficiency to reconstruct correctly a GenJet with CaloJets or TrackJets is studied using QCD di-jet events, where the GenJet is associated to the leading parton in the event with |η|<2, well within the Tracker acceptance. Results show that requiring ΔR<0.3 for the (η,ϕ) distance of the reconstructed jet to the GenJet, **TrackJets show an improvement over CaloJets for the matching of jets with $p_T$(Gen)<80GeV/c.**




## CMS Tracker and Track Reconstruction

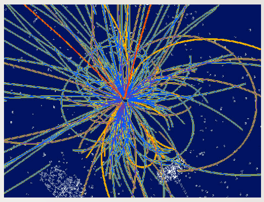



CMS relies on a very large Silicon pixel and micro-strip Tracker to reconstruct the tracks and vertices of charged particles. For particles crossing the central region of CMS the Tracker provides measurements in 13 different layers at radii from *r=4.4cm* to *r=1.1m* around the beam axis.

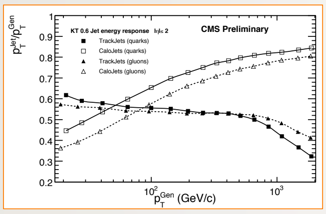
The standard track reconstruction [3] is performed in three stages:

1) seeding in the inner layers
2) pattern recognition with a Combinatorial Kalman Filter
3) least-squares fit for the final estimation of the track parameters

In CMS charged particles represent the jet component that is measured best both in terms of energy resolution and of angular direction. The tracking momentum measurements are more accurate than the calorimeter measurements for charged hadrons with energies up to several hundreds of GeV. Moreover the direction of charged particles at the interaction point is extremely well determined by the track reconstruction with resolutions Δϕ ~ Δ cot θ ~ $10^{-3}$



## Jet Energy Response

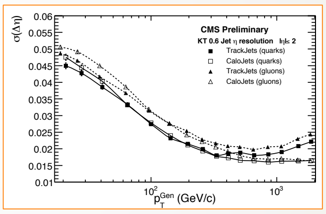


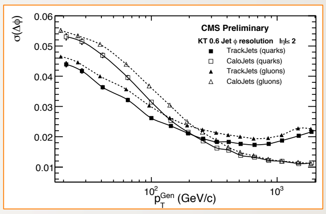

The energy response of reconstructed TrackJets and CaloJets is defined as the average $p_T$(reco)/$p_T$(Gen) ratio and measured in QCD di-jet events. . Results show that the CaloJet response increases as a function of $p_T$(Gen) while the **TrackJet response is rather stable around 55%**, decreasing slowly and dropping for $p_T$(Gen)≥ 1 TeV/c. The drop is due to *difficulties in track reconstruction near the core of high-$p_T$ collimated jet*, where high $p_T$ tracks share hits in the Tracker inner layers.

The response to gluon jets is lower than for quark jets, in particular for the CaloJet response, due to the magnetic field bending away the low $p_T$ charged fragmentation particles from the outer regions of the jet.

## Jet Angular Resolution

The angular resolution of TrackJets and CaloJets is evaluated with respect to the direction of the GenJet and defined as the RMS of the Δη and Δϕ distributions measured in QCD di-jet events.



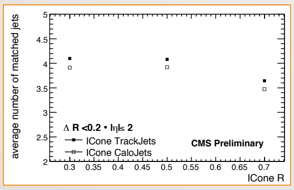



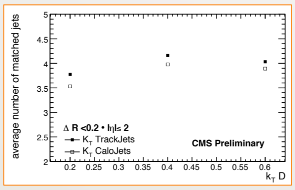

Results show that **TrackJets yield better ϕ resolutions for for $p_T$(Gen)<200GeV/c while the η resolutions are very similar**, as the η direction of CaloJets is corrected to the position of the primary interaction vertex determined with reconstructed tracks.

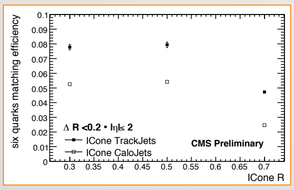
## Reconstruction of hadronic top pairs

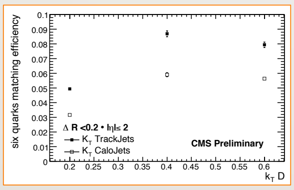
To evaluate the performance of TrackJets in a multi-jet environment, samples of hadronic top pairs are analyzed where all quarks are well within the Tracker acceptance (|η|<2). The six quarks are matched to the reconstructed jets requiring ΔR<0.2, and quarks that match to the same jet (merging) are excluded.

Different transverse energy thresholds are applied to reconstructed jets ($E_T$>12 GeV for TrackJets and $E_T$>13 GeV for CaloJets) in order to obtain the same jet multiplicities for all jet collections.



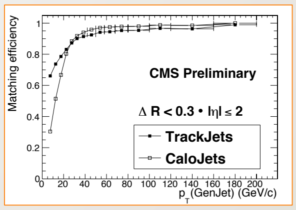

The average number of matched jets and the efficiency to match all six jets, as a function of the Iterative Cone radius (R) and of the $k_T$ distance (D) show that the optimal clustering values are in the R=0.3-0.5 and D=0.4-0.6 range.
**The best efficiencies are 7-8% for TrackJets and 5-6% for CaloJets.**

## Performance with Z+jets events

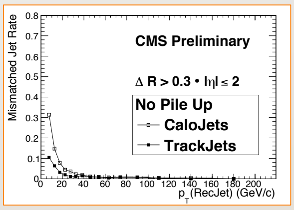
Multi-jet events associated with W/Z bosons are relevant for Standard Model measurements as well as for new physics searches. In such measurements TrackJets can provide a robust method for jet counting.

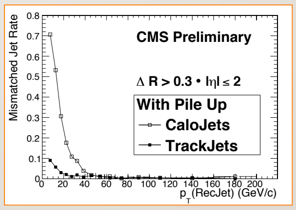
In the analysis of Z+jets events two muons with $p_T$>20 GeV/c are required and only other tracks that are consistent to originate from the same vertex of the leading muon are used to cluster TrackJets.

In Z+jets events the efficiency to match GenJets with reconstructed jets within ΔR<0.3 is better using TrackJets when trying to match GenJets with $p_T$<30 GeV




The jet mismatched rate is defined as the fraction of reconstructed jets which are not matched to any of the GenJets within ΔR<0.3. **The natural mismatched rate for TrackJets is about three times lower that for CaloJets for reconstructed jets with $p_T$<40 GeV/c.**




Pile up effects are studied mixing an average of 5 Minimum Bias events to the signal Z+jets events. The tracks vertex origin information is used so that **TrackJets are insensitive to pile-up backgrounds**, while for CaloJets more jets and jet constituents are added to the event, escalating the CaloJet mismatched rate level for $p_T$<40 GeV/c.

## References

[1] CMS Collaboration, *Performance of Jet Reconstruction with Charged Tracks only*, Physics Analysis Summary PAS JME-08-001 (2008).

[2] CMS Collaboration, *Performance of Jet Algorithms in CMS*, Physics Analysis Summary PAS JME-07-003 (2007)

[3] CMS Collaboration, *CMS physics Technical Design Report*, CERN-LHCC-2006-001