CMS Jet Reconstruction

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Overview

CMS in the past has used an iterative pile-up (PU) algorithm for heavy ion underlying event (UE) subtraction [1], which suffers from several deficiencies:

- No flow (υ_2, υ_3, ...) subtraction
- Auto-subtraction in e.g. quark jets and radiation in the same pseudorapidity
- Loss of particle flow (combined tracking and calorimetry) information (energies have to be binned into calorimeter towers)

The new algorithm, denoted "HF/Voronoi" [2–4], uses the forward hadronic calorimeter (HF) energy and flow information to predict the midrapidity UE energy distribution. It perform a whole event subtraction in arbitrary geometry, such that a jet algorithm operating on the resulting "hard event", when a jet reconstruction algorithm is applied to, reconstructs into the fully subtracted jets. The "jet-less" approach has the additional benefit that this hard event is not only useful for jet measurements, but also:

- Event shape measurement
- Missing E_T measurement
- Photon isolation

The HF/Voronoi algorithm is the first "jet-less" algorithm for PU and UE mitigation, and has triggered the development of comparable pp algorithms such as the CMS PUPPI (Pile-Up Per Particle Identification) algorithm for the future high luminosity CERN LHC pp runs [5].

Structure of the Algorithm

1. HF to midrapidity prediction

A nonlinear regression model describes the energy (bulk and flow) in all detector pseudorapidity ranges as function of the HF energy distribution. The parameters in this model is determined by a self-adapting algorithm, i.e. by machine learning, on minimum bias (MB) data and Monte Carlo (MC) event generator, and automatically captures:

- Nonlinearities in the calorimeter
- Low p_T charged particles from the UE, that loops in the B field and hits the endcap at oblique angles
- The residual difference between data vs. event generator and detector MC

2. Subtraction by Voronoi diagram

A Voronoi diagram in the (η, φ)-plane is used to associate a unique area to each particle, such that the UE density can be fully removed particle-by-particle.

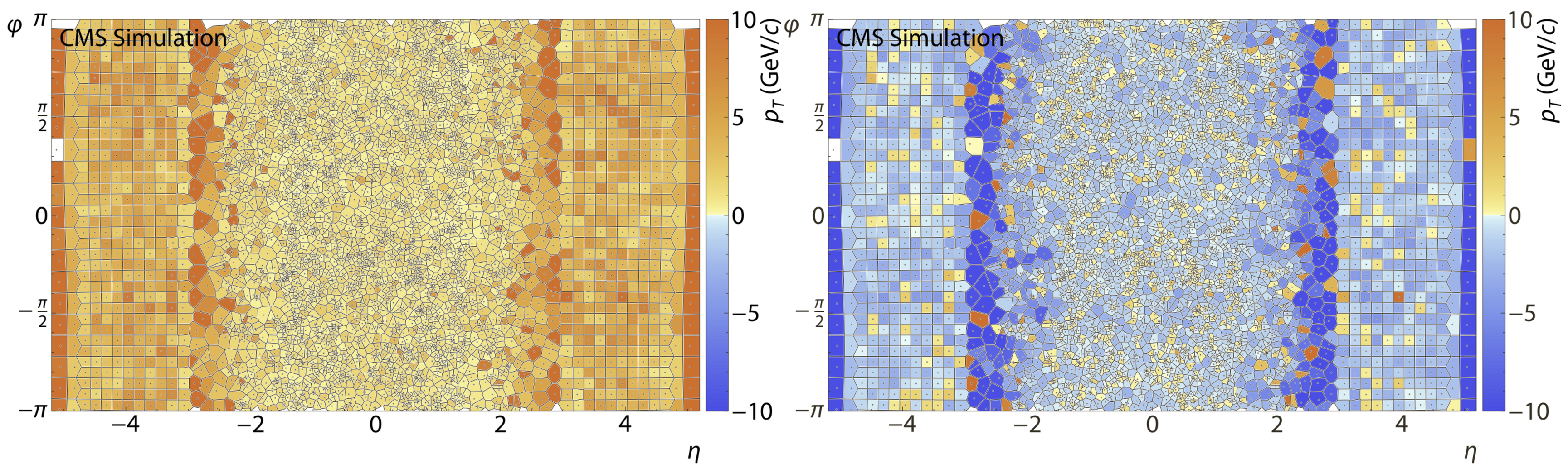

Fig. 1 Voronoi tessellated HYDJET/GEANT particle-flow event (combined tracks and calorimeter towers) before (left) and after (right) subtraction.

3. Equalization into a positive event

This step is needed for iterative clustering algorithms (such as anti-k_t). The event that remains after UE subtraction contains positive and negative p_T fluctuations. When truncating the negative fluctuation to zero, this results in a positive bias.

The negative fluctuations are however not "real", as the UE energy is not localized, therefore its association with a particular particle vs. its neighbors is only coincidental. Redistribution with neighboring particles can be described as linear optimization problem, which we solve for a positive event that maximally mimicks the full, subtracted (positive/negative) event.

A standard iterative algorithm is applied on the hard+positive event and is expected to reconstruct in to the correct jet energy.

Monte Carlo Performance Studies

The performance of the algorithm is studied using $\sqrt{s}$ = 2.76 TeV pp PYTHIA tune Z2 events, embedded into $\sqrt{s_{NN}}$ = 2.76 TeV PbPb HYDJET events, and then simulated with the CMS GEANT detector simulation. The performance is also compared to FastJet median-ρA subtraction, as being applied in CMS pp for pile-up subtraction. A set CMS standard jet energy calibration has been derived and applied on the MC to obtain the jet energy performance.

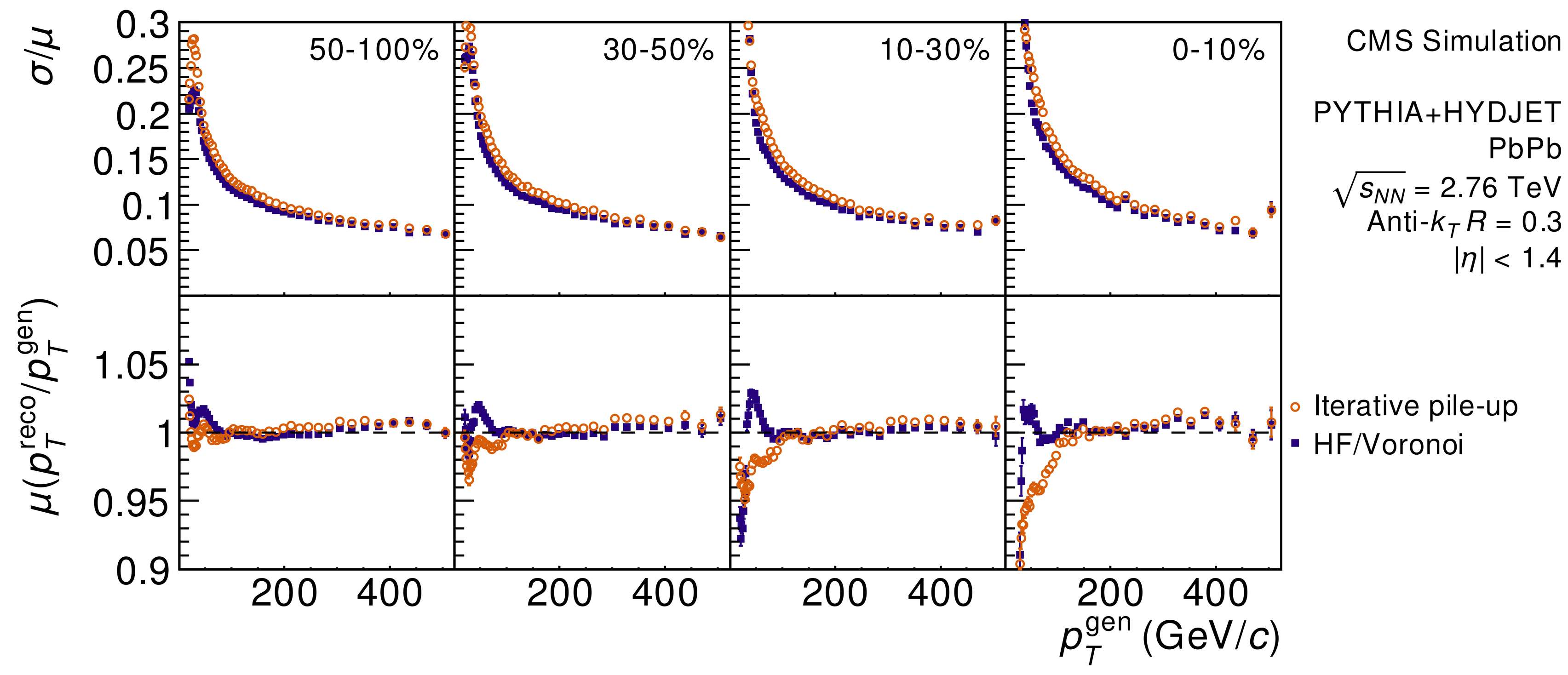

Fig. 2 Jet energy scale and resolution as function of the generator truth energy.

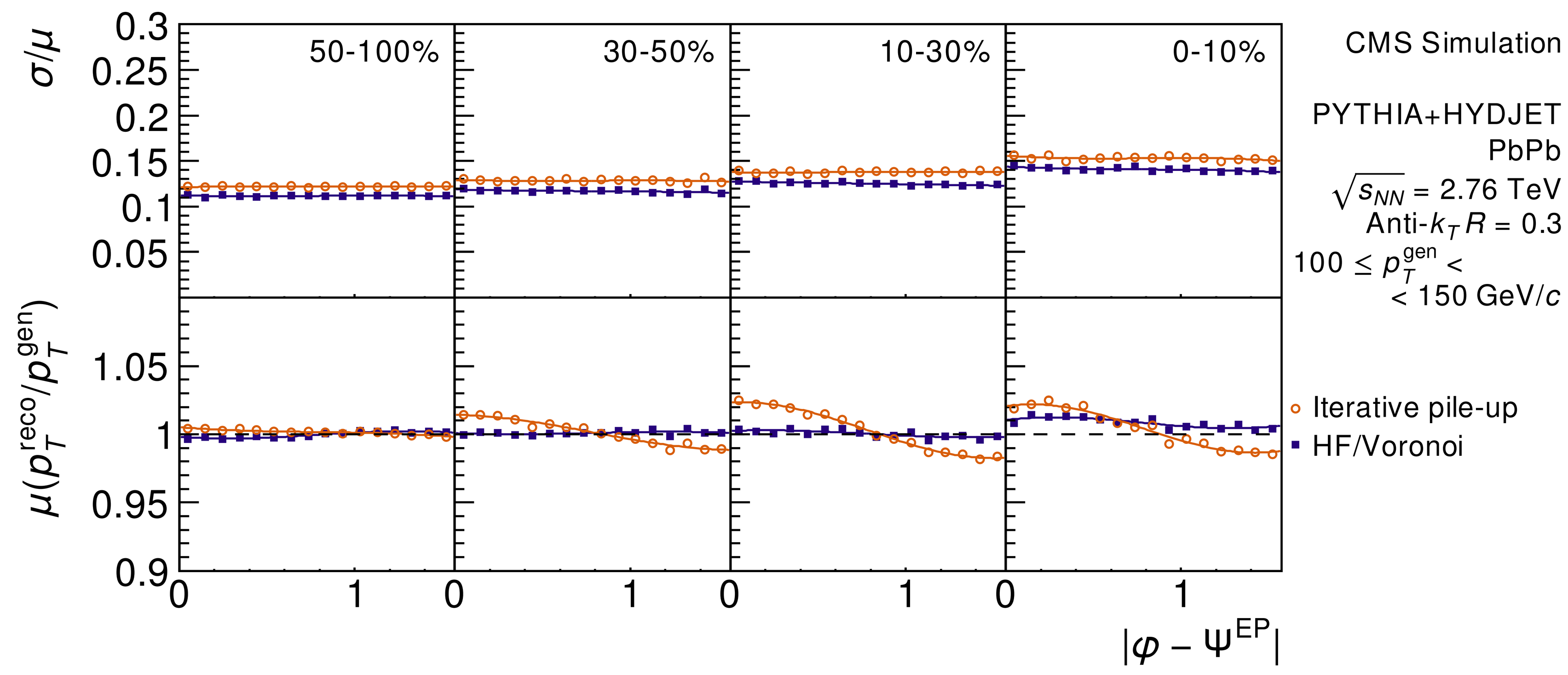

Fig. 3 Jet energy scale and resolution as function of the relative angle with respect to the event plane.

These studies shows that the HF/Voronoi algorithm outperforms the current CMS UE/PU algorithms.

Commissioning for 2014 CMS PbPb Re-Reconstruction

For the 2014 CMS PbPb jet–charged particle correlation analyses, a re-reconstruction of the PbPb data set is performed, with inproved tracking and the availability of the HF/Voronoi algorithm for particle-flow and calorimetric jets (and further combined with improvements to the jet energy calibration procedure). The result exhibits a correct calorimetric jet energy at 1–2%-level down to 40 GeV/c. Any potential performance difference in data vs. HYDJET is further constrained by measuring the random cone energy in both data and MC, where difference is at 0.5 GeV/c level, or 1% for 40 GeV/c jets.

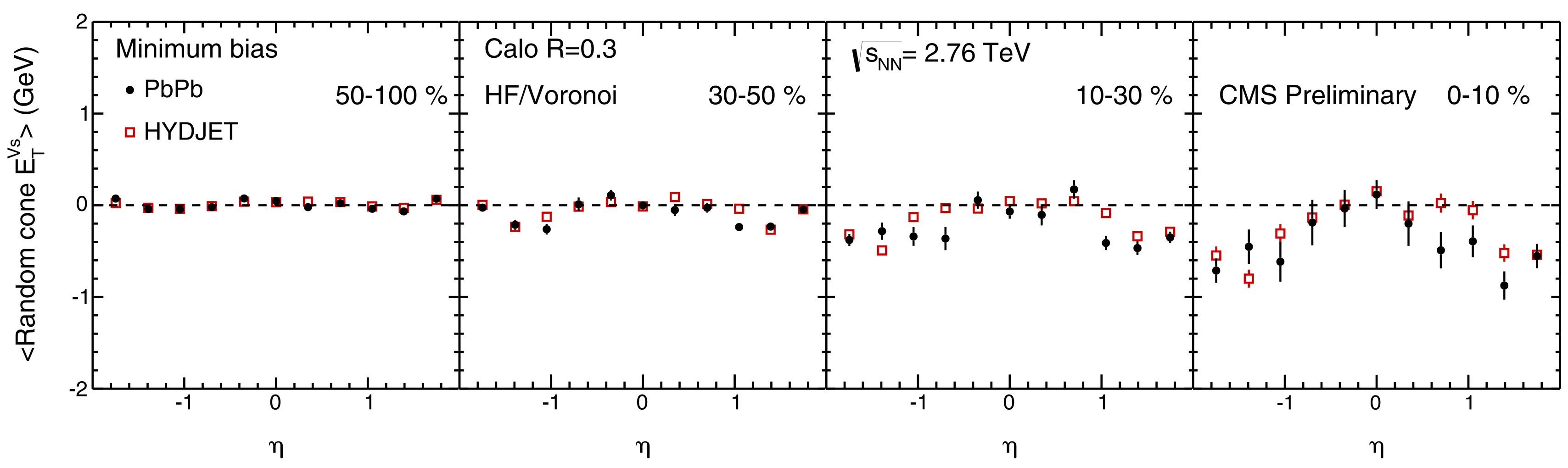

Fig. 4 Random cone energy comparison between data and HYDJET of the calorimetric HF/Voronoi for the 2014 CMS PbPb jet–charged particle correlation analyses.

Reference

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[2] Y.-s. Lai (for the CMS Collaboration), "Underlying-Event Subtraction in Heavy Ion Collisions", UPMC Jet Workshop, 1–4 July 2013, Paris.

[3] Y.-s. Lai (for the CMS Collaboration), "Heavy Ion PU Removal Methods", Mitigation of Pileup Effects at the LHC, 16–18 May 2014, Geneva.

[4] CMS Collaboration, "Underlying-Event Subtraction for Particle Flow", CMS-DP-2013/018.

[5] N. V. Tran (for the CMS Collaboration), "PUPPI", Mitigation of Pileup Effects at the LHC, 16–18 May 2014, Geneva.