1 Particle Identification and Event Reconstruction

1.1 Particle Flow

The Particle Flow (PF) algorithm [1] identifies and reconstructs all the stable-visible particles produced in the hard interaction combining the information collected by the CMS sub-detectors in order to optimaze the determination of their direction, energy and type. The PF technique performs the global event recostruction clasifying all the visible particles into five mutually exclusive groups: photons, neutral hadrons, charged hadrons, electrons and muons. This list of individual particles (called "PF Candidates") are used as an input in further algorithms to reconstruct higher level objects such as jets, missing transverse energy and tau-leptons.

The capabilities of the CMS detector are ideal for using the PF technique as a global event reconstruction. The high granularity of the inner tracker and the ECAL, the hermiticity of the HCAL, the high performance of the muon system along with the strong and magnetic field provided by the superconducting solenoid allow PF technique to reach a high performance reconstruction in all physics objects, in particular jets and MET [2].

The PF technique is performed in three steps: First, the algorithm builts the so-called "PF elements" which consist of tracks reconstructed in the Inner Tracker, energy clusters recostructed in the calorimeters and tracks observed in the muon system; the second stage addresses the topological association of the basic PF elements each other using the "link-algorithm"; finally, individual particles are identified and reconstructed from the content of the linked elements.

1.1.1 Track Reconstruction

The track reconstruction in the inner tracker is one of the most important keys of the global event reconstruction. The inner tracker, due to its high granularity, provides a precise recontruction of the charged-particle tracks and consecuently give rise to a accurate reconstruction of the primary vertex, identifying it from the pileup interactions.

The track reconstruction is performed in several steps by a process called *iterative tracking*. In the initial iterations, the iterative tracking applies a tight criteria in order to search for tracks easy to identify (tracks with relative high p_T produced near the interaction region). In the next iterations, the hits unambiguously assigned to a track are removed. This reduces the combinatorial complexity in the subsectuent iterations and allows to loosen the selection criteria to identify the tracks associated with low p_T. In the first three iterations, the iterative tracking reaches an efficiency up to 99.5% for isolated muons and larger than 90% for charged hadrons in jets [1]. Last iterations relaxes the constrains on the origin of the vertex to find tracks originated outside the beam spot (secondary charged particles from photon conversions in the tracker material) and to reconstrcut the remaining tracks. Each iteration could be summarized in 4 steps:

- Tracks are seeded using 2 o 3 hits, giving rise to the initial track candidates and their initial trajectory parameters.
- The track is extrapolated outwards of the inner tracker with the purpose to find additional hits associated to the track. The track finder algorithm is based on the Kalman filter.
- A fit on the track is performed to estimate the all the possible information of the trajectory.
- Tracks are selected on basis of the quality flags, whether they are compatible with some criterias such as χ^2 and if they are originated from the primary vertex.

The efficiency estimation of the track reconstruction is performed comparing the reconstructed tracks with MC samples which contains just single muons or pions. Muons are ideal for this purpose since muons, unlike electrons, have a negligible energy loss through bremsstrahlung radiation due to the interaction with the tracker material. Unlike muons, charged pions (a tau decay product) do not only undergo Coulomb scattering but it (as all hadrons) also lose energy though strong interactions with the tracker material. These nuclear interactions are not taken into account int the track Finder algorithm reducing the track reconstruction effciency. The tracking efficiency is higher than 99% for isolated muons with a $\mathrm{p_T} > 1\mathrm{GeV}$ while for charged pions is close to 95% for $\mathrm{p_T} > 1\mathrm{GeV}$ [3] (See figure 1.1)

1.1.2 Clustering

Other of the main parts for the PF technique, in addition to the tracks, is the reconstruction of the calorimetric clusters. The calorimeter clusters are used to: identify the energy deposits which come from photons and neutral hadrons, and discriminate them from the energy deposits due charged hadrons; besides it reconstructs the electrons along with their associated Bremsstrahlung radiation; and helps to determinate the track parameters of the charged hadrons which were not measured accurate from the track reconstruction (for example, charged hadrons that are outside of the tracker acceptance, or charged hadrons with high p_T). The clustering is performed for each part of the CMS calorimeter system: ECAL, HCAL, HF and PS.

The clustering algorithm proceeds from the "cluster seeds" identified at local level. Cluster seeds are selected from individual calorimeter cells which have a maxima energy deposits above a given energy. Once the cluster seed is selected, the algorithm searches for energy deposits in the boundarying cells with a common side. The algorithm aggregates to the cluster at least one additional cell with a maxima energy higher than two standard desviations from the electronic noise: for the ECAL, 80 MeV in barrel and up to 300 MeV in the end-caps for the ECAL, while 800 MeV for the HCAL [1]. The combination of these cells are know as "topological clusters". The topological clusters are taken as "particle flow clusters" seeds in order to solve any overlapping among clusters.

1.1.3 Link algorithm

As mentioned earlier, a particle is expected to produce signatures in diferent subdetectors, giving rise to one or more so-called PF elements: tracks, clusters and tracks in the muon system; for example, a charged hadron, as the pion, would produce a track in the inner tracker along

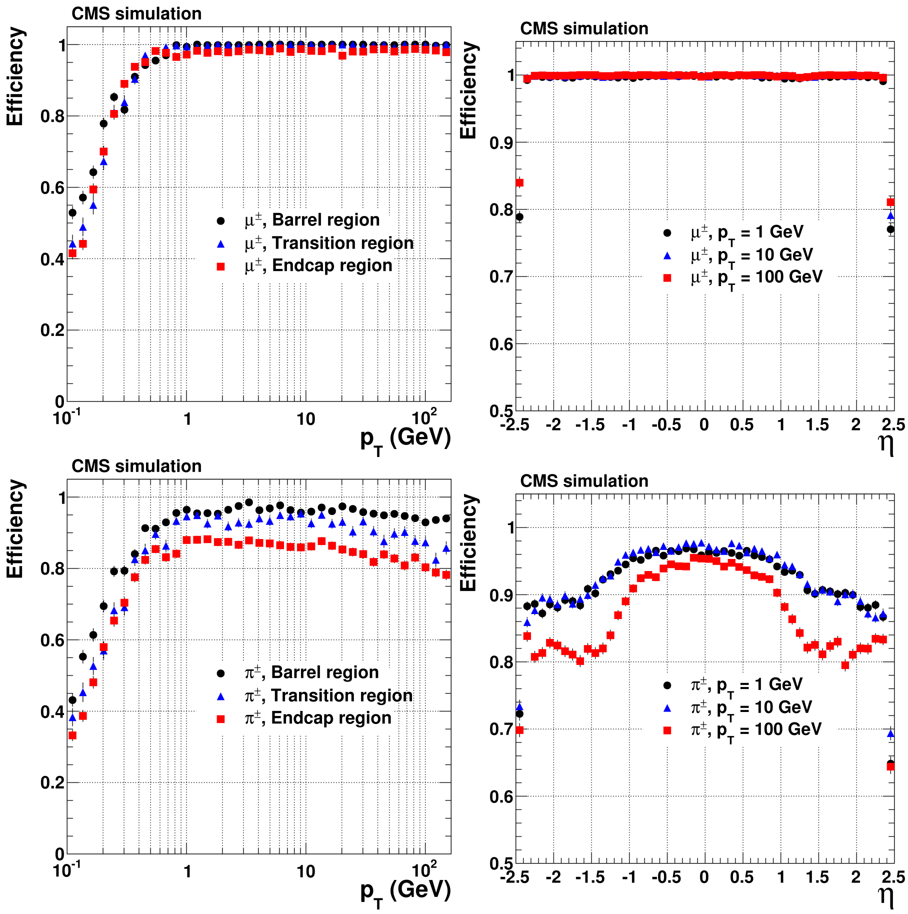

Figure 1.1: Efficiency of reconstructed track as function of p_{T} and η for muons (top) and charged pions (bottom). Figure taken from [3]

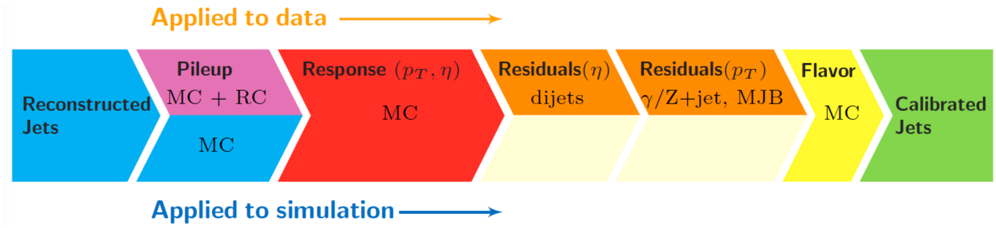

Figure 1.2: Levels of corrections for PF jet four-momentum. Figure taken from [5]

with energy deposits in both calorimeters. PF uses the *link algorithm* to perform a topological combination of the PF elements recontructed in the different subdetectors with the aim of reconstructing fully each particle in the event.

1.2 Jets Reconstruction

The PF technique [1] takes the information collected by the CMS subdetectors in order to identify and reconstruct all the vissible final-state particles (electrons, muons, photons, charged hadrons and neutral hadrons) produced in the hard interaction. The PF technique reconstructs the jet constituents individually from the combination of tracks and calorimeter clusters. Then, the jet reconstruction is performed with the anti$-\mathrm{k}_T$ algorithm [4] iterating over all the PF objects, using a distance parameter of $\Delta R = 0.4$ in the $\eta - \phi$ plane, where $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$.

The four-momentum of the reconstructed jet is the addition of the four-momenta of all the PF objects associated to the jet. However due to detector responses and experimental effects, the PF jet four-momentum does not correspond to the four-momentum at parton or hadron level; therefore, jet energy corrections (JEC) are required. Figure 1.2 shows the different levels of corrections which are applied in a fixed sequence. Each correction corresponds to a multiplicative factor C on the PF jet four-momentum (p_μ^{raw}):

$$p_\mu^{corrected} = C \times p_\mu^{raw} \tag{1.1}$$

The first step in the chain is the “L1 corrections” (also refered as “pileup offset”). It attends the additional tracks and the excess of energy deposits in the calorimeters due pile-up events . The amount of the pile-up contribution to the jet energy can be estimated from the global per-event $p_{T,offset}$ density ρ and the jet area [6]. This amount is obtained from simulated dijet events with and without PU.

The second level of JEC is related with the detector response to hadrons (L2L3 MC-truth corrections), correcting the non-uniformity in η and the non-linearity in p_T. The simulated jet response is determinated with QCD-multijet events generated with Pythia and with a simulation of the CMS detector based on Geant4.

After these steps, the L2L3 Residual corrections are applied in order to address the remaining difference between the jet response on data and MC (of the order of 1%). This corrections are achieved with data-driven methods, using dijet samples for η-dependent corrections and γ/Z+jets samples for the corrections to p_T. The last stage of the JEC (L5) is optional and it accounts the jet-flavor corrections.

1.3 MET

1.4 Photon Reconstruction

1.5 Muon Reconstruction

1.6 Electron Reconstruction

1.7 B-Jet Reconstruction

1.8 Tau Lepton

1.8.1 Tau Reconstruction

1.8.2 Working Points

Efficiency of Working Points

1.8.3 Fake Rates

1.8.4 Perspectives Run III

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