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Identification of τ hadronic decays in the CMS experiment

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Summary. — New reconstruction and identification strategies for hadronic decays of τ leptons are described in detail. The improvements achieved using Particle Flow based techniques are also presented.

PACS `07.05.Hd` – Data acquisition: hardware and software.
PACS `07.05.Kf` – Data analysis: algorithms and implementation; data management.
PACS `07.05.Rm` – Data presentation and visualization: algorithms and implementation.
PACS `29.85.Fj` – Data analysis.

1. – Introduction

In the LHC era τ leptons are expected in final states of many interesting physics channels such as Higgs-bosons (h, H, A $\rightarrow \tau\tau$, $H^{\pm} \rightarrow \tau\nu$), SUSY and other exotic-particles. For this reason an efficient and accurate τ reconstruction and identification is an important part of the CMS physics programme. Early results about the feasibility of these studies can be found in refs. [1] and [2]. In this summary, the strategy used by CMS to identify and reconstruct τ hadronic decays with particle-flow techniques is described.

2. – Tau identification methods

2·1. *The Particle Flow technique.* – Within the Particle Flow (PF) framework all tracks and calorimeter clusters are first independently reconstructed in each subdetector (ref. [3]). Then all PF stable candidates (μ, e, $\pi^{\pm}$, π^0 and γ) are reconstructed by linking among them one or more of these signals in a through combination. This list is then used to derive composite physics objects such as jets which are clustered using standard jets algorithms (ref. [4]). In this report, a cone algorithm is used with cone size of 0.5 in (η-ϕ) space (ref. [5]). The tau identification benefits from the depth of information available describing each particle in the jet resulting in an improvement in both the energy and angular resolution with respect to the calorimeter-based identification where the resolutions are largely dominated by hadron calorimeter granularity (fig. 1).

(*) On behalf of the CMS Collaboration.

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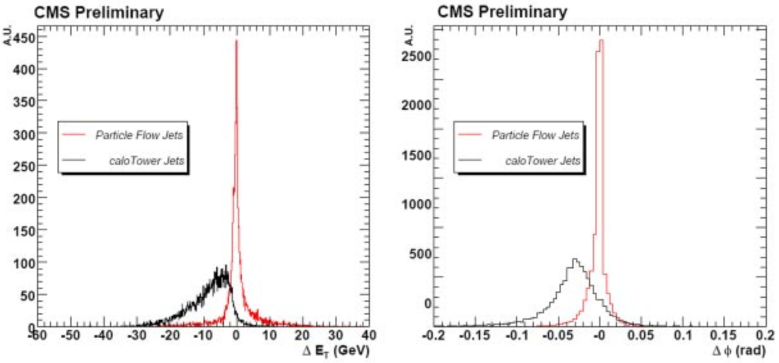

Fig. 1. – (Colour online) Comparison between PF-based (red) and calorimeter-based (black) reconstruction of single τ's with $p_T = 50\,\text{GeV}/c$. Difference between the measured E_T (left) and ϕ (right).

2˙2. *Tau reconstruction: preselection.* – It relies mainly on simple and robust methods to reduce the amount of huge QCD background still keeping a large efficiency for all decay modes and preserving the selection from any possible bias. A cut of $15\,\text{GeV}/c$ is first applied to the p_T of a reconstructed PF jet. Then at least one charged hadron with $p_T > 5\,\text{GeV}/c$ located at a distance less than 0.1 in the (η-ϕ) space from the jet direction is required. The highest-momentum charged hadron that satisfies this condition is called the leading track of the jet. Around the leading track a signal cone, which is expected to contain all τ decay products, and an isolation annulus, in which little activity is expected due to the isolation characteristics of τ-jets (in particular no charged hadron or photon above the p_T threshold of, respectively, 1 and $1.5\,\text{GeV}/c$) are defined (isolation algorithm). The leading track finding marginal efficiency (determined with respect to the τ candidates satisfying the previous cuts) shows the probability for a PF jet to contain a charged particle with $p_T > 5\,\text{GeV}/c$ (fig. 2). The efficiency is good for τ candidates, which have a low charged-particle multiplicity. On the other hand, low-p_T QCD jets which dominate the background typically have a high charged-particle multiplicity. For this reason this discriminator is very powerful for QCD rejection.

An alternative approach to the definition of signal cone with fixed size is the use of a shrinking cone definition, in which the size scales as $5/E_T$ with minimum and maximum values set, respectively, to 0.07 and 0.15. It relies on the fact that τ-jets

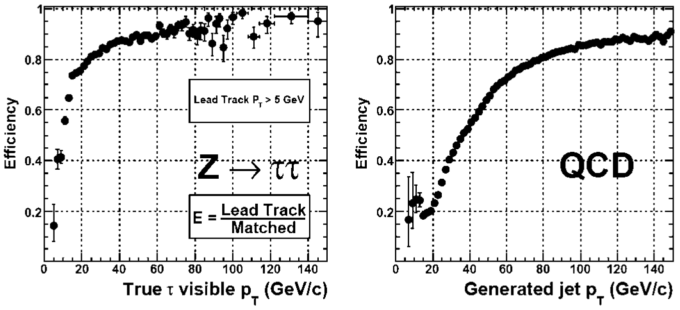

Fig. 2. – Leading track finding marginal efficiency as a function of the true p_T for τ's coming from a typical signal process as Z → $\tau\tau$ (left) and for jets from the QCD background (right).

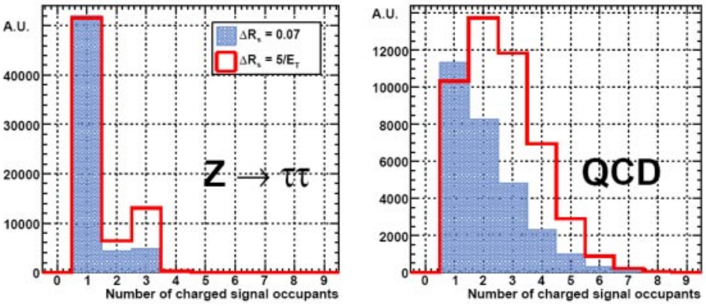

Fig. 3. – Charged-hadron multiplicity distributions in the signal cone for taus (left) and QCD jets (right) with the fixed ($\Delta R_{\mathrm{sig}} = 0.07$) and shrinking ($\Delta R_{\mathrm{sig}} < 5/E_T$) signal cone definitions.

become more collimated at higher energies. Its main advantage is the better acceptance of the three-prong τ decays because of the larger signal cone in which all tracks can fit. In fig. 3 the number of charged signal occupants is reported for both the fixed ($\Delta R_{\mathrm{sig}} = 0.07$) and shrinking ($\Delta R_{\mathrm{sig}} < 5/E_T$) signal cone definitions; the recovery of the three-prong decays is clearly observable.

A comparison between the global efficiencies of the preselection cuts as a function of the true p_T for the shrinking signal cone definition for signals and QCD background is displayed in fig. 4. Efficiences are respect to candidates with $p_T > 5\,\mathrm{GeV}/c$ and $|\eta| < 2.5$.

2˙3. *Tau high-level identification.* – It allows one to tune the efficiency *vs.* purity levels and is mainly aimed at suppressing electrons and muons which fake a τ-candidate.

2˙3.1. e and μ rejection. The μ rejection is based on the standard reconstruction criteria which allow a τ selection efficiency and a muon rejection efficiency $> 99\%$.

The standard e rejection leads to an efficiency of 90% for electrons and 5% for pions. These values can be further improved to 92.5% for taus and 1.5% for electrons with an ad-hoc optimized electron veto which takes into account the ratios E/P and $H_{3\times3}/P$. In fig. 5 the efficiencies for typical electron rejection criteria are compared to the optimized electron veto. The electron pre-identification cut is labeled E_{id}.

2˙3.2. Tau neural classifier (TaNC). A neural classifier is developed for a better discrimination of taus from the QCD multijet processes. The algorithm starts with the

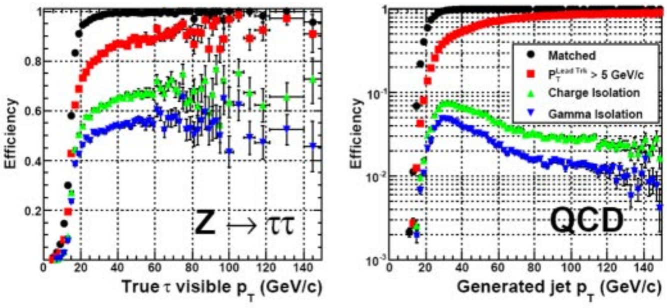

Fig. 4. – Global efficiencies of the successive pre-selection cuts as a function of the true p_T for signal (left) and QCD jets (right) events using the $5/E_T$ shrinking signal cone definition.

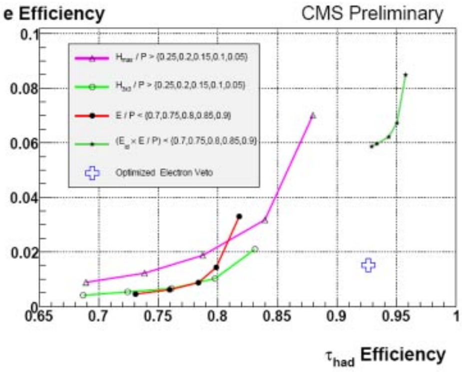

Fig. 5. – (Colour online) Efficiencies for selecting taus and electrons for several electron rejection variables including the Optimized Electron Veto (displayed as a blue cross).

reconstruction of each τ decay mode, then for each one, a neural net is applied, previously trained on a sample of the same decay mode. Preliminary results show that the TaNC algorithm is able to achieve an efficiency of 53% with a fake rate of 0.5%, which is significantly better than the classical fixed-cone performance and the shrinking-cone performance.

3. – Conclusions

The performance of new methods based on a Particle Flow algorithm for τ hadronic decay identification and reconstruction are reported. These new techniques demonstrate good efficiency of selection with high background rejection power. In particular the leading track requirement provides a significant suppression of QCD events. Moreover the shrinking-cone approach allows a better selection of three-prongs decays at low energy, otherwise not recovered by the fixed-cone approach because of the smaller size of signal cone. It has been also described how these selections can be tuned to achieve customizable levels of efficiency *vs.* purity. Several improvements are still expected and are actively being pursued like a better tuning of photon isolation, taking into account the reconstruction of photon conversion also for PF electrons.

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