Performance of the DeepTau algorithm for the discrimination of taus against jets, electron, and muons

CMS Collaboration

Abstract

The performance of the newly developed DeepTau algorithm for the discrimination of taus against jets, electrons, and muons is summarized. The algorithm exploits recent deep neural network multi-classification methods. It outperforms previous discrimination methods significantly in the sense of miss-identification probability of jets, electrons, or muons as taus for given tau identification probability. The agreement of the simulation with the data is good and residual differences are well understood.
Performance of the DNN-based tau identification algorithm (DeepTau) for Run 2

The CMS Collaboration
Detector Performance Summary Note

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Introduction

• Jets originating from quarks or gluons, electrons, and muons can be misidentified as hadronic tau decays

• To efficiently discriminate hadronic taus against these main background sources, the information from multiple sub-detectors within CMS must be exploited

• DeepTau is a new multiclass tau identification algorithm based on a convolutional deep neural network (DNN)

• In order to achieve an optimal tau identification performance, DeepTau combines information from the high-level reconstructed tau features together with the low level information from the inner tracker, calorimeters and muon sub-detectors using particle flow candidates, electrons and muons reconstructed within the tau isolation cone

• DeepTau also takes advantage of more inclusive tau reconstruction decay mode definitions that were recently developed in CMS: three charged prongs + 0 or 1 \( \pi^0 \) with relaxed matching conditions added to previously reconstructed 1 charged prong + 0, 1, 2 \( \pi^0 \) and three charged prongs + 0 \( \pi^0 \) with tight matching conditions
  • In the following plots, the decay modes defined with this more inclusive criteria are referred to as “updated decay modes”
DeepTau algorithm

• Input variables
  • 1 global event variable: the average energy deposition density ($\rho$)
  • 42 high-level variables that are used during tau reconstruction or proven to provide discriminating power by previous tau POG studies
  • For each candidate reconstructed within the tau signal or isolation cones, information about 4-momentum, track quality, relation with the primary vertex, calorimeter clusters, and muon stations is used, if available:
    • From 7 to 27 variables (depending on the candidate type) for each particle flow candidate
    • 37 variables for each fully reconstructed electron candidate
    • 37 variables for each fully reconstructed muon candidate
  • Candidates belonging to the inner and outer cones are separated and split into two grids with $\eta \times \varphi$ cell size of 0.02×0.02 (0.05×0.05) for the inner (outer) cone
  • Network architecture:
    • High level variables and each input cell are pre-processed by a few fully connected dense layers
    • For the inner (outer) grid, the pre-processed cell data are fed into 5 (10) 2D convolutional layers with 3×3 window size, which result in 64 features that are passed to the next step
    • All features from previous steps are combined and passed through 5 dense layers
    • Probabilities of the reconstructed tau candidate being electron, muon, quark or gluon jet, or hadronic tau are estimated by the 4 NN outputs
DeepTau discrimination against jets from $t\bar{t}$

- The performance is evaluated using Monte Carlo (MC) simulation, applying the following preselection on the reconstructed tau candidates: $p_T \in (20, 1000)$ GeV, $|\eta| < 2.3$, $|dz| < 0.2$ cm, where $dz$ is the longitudinal impact parameter of the tau with respect to the primary vertex.

- Tau ID efficiency is estimated from $H \rightarrow \tau\tau$ MC using reconstructed tau candidates that match hadronically decaying taus at the generator level.

- Jet misidentification probability is estimated from $t\bar{t}$ MC using reconstructed tau candidates that don’t match prompt electrons, muons or products of hadronic tau decays at the generator level.

- Plots below show DeepTau performance on 2017 MC.

- Working points of the discriminators are indicated by the dots.
DeepTau discrimination against jets from W+jets

- The performance is evaluated using Monte Carlo (MC) simulation, applying the following preselection on the reconstructed tau candidates: $p_T \in (20, 1000)$ GeV, $|\eta| < 2.3$, $|dz| < 0.2$ cm

- Tau ID efficiency is estimated from $H \to \tau\tau$ MC using reconstructed tau candidates that match hadronically decaying taus at the generator level

- Jet misidentification probability is estimated from W+jets MC using reconstructed tau candidates that don’t match prompt electrons, muons or products of hadronic tau decays at the generator level

- Plots below show DeepTau performance on 2017 MC

- Working points of the discriminators are indicated by the dots
DeepTau discrimination against electrons

- The performance is evaluated using Monte Carlo (MC) simulation, applying the following preselection on the reconstructed tau candidates: $p_T \in (20, 1000)$ GeV, $|\eta| < 2.3$, $dz < 0.2$ cm.
- Tau ID efficiency is estimated from $H \rightarrow \tau\tau$ MC using reconstructed tau candidates that match hadronically decaying taus at the generator level.
- Electron misidentification probability is estimated from Drell-Yan MC using reconstructed tau candidates that match electrons at the generator level.
- Plots below show DeepTau performance on 2017 MC.
- Working points of the discriminators are indicated by the dots.
DeepTau discrimination against muons

- The performance is evaluated using Monte Carlo (MC) simulation, applying the following preselection on the reconstructed tau candidates: $p_T \in (20, 1000) \text{ GeV}$, $|\eta| < 2.3$, $|dz| < 0.2 \text{ cm}$

- Tau ID efficiency is estimated from $H \to \tau\tau$ MC using reconstructed tau candidates that match hadronically decaying taus at the generator level

- Muon misidentification probability is estimated from Drell-Yan MC using reconstructed tau candidates that match muons at the generator level

- Plots below show DeepTau performance on 2017 MC

- Working points of the discriminators are indicated by the dots
In both plots modelled contributions are fit to the data

Event selection:
- well identified and isolated muon with $p_T > 25$ GeV, $|\eta| < 2.4$, $|dz| < 0.2$ cm
- tau candidates with $p_T > 20$ GeV, $|\eta| < 2.3$, $|dz| < 0.2$ cm
- $\mu\tau$ pair with an opposite charge and $\Delta R(\mu, \tau) > 0.5$

Selection using discriminators from JINST 13 (2018) P10005:
- Tight WP against jets
- VVLoose WP against electrons
- Tight WP against muons

Selection using DeepTau IDs:
- Tight WP against jets
- VVLoose WP against electrons
- VLoose against muons

With DeepTau selection, the yield from genuine $\tau_h$ increases by $\approx 20\%$, while yield from fakes decreases by $\approx 23\%$.