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Nuclear and Particle Physics Proceedings 287–288 (2017) 111–114

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Tau Lepton Reconstruction in ATLAS

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Abstract

Tau leptons play a key role in many measurements and searches within and beyond the Standard Model of particle physics performed at the LHC. We present here the performance of the reconstruction, identification and energy measurement algorithms for hadronic tau lepton decays currently used by the ATLAS collaboration. We also introduce a new reconstruction method which uses the individual charged and neutral hadrons in tau decays to improve the 4-momentum resolution, while also providing increased sensitivity to tau polarization and Higgs CP state measurements.

Keywords: tau leptons, ATLAS

1. Reconstruction and identification of hadronic tau decays in Run 2 of the LHC at ATLAS

Tau leptons will play a very important role in the Run 2 physics program at the LHC. They offer the best channel to observe the Higgs boson directly decaying to fermions and also the best channel in searches for the neutral Higgs boson predicted by the Mimimal Supersymmetric Standard Model. Furthermore, a number of extensions of the SM predict that processes involving these particles have significantly increased rates compared to those of other channels. Due to the relative complexity of data analyses involving tau leptons, a large phase space of these models remains unexplored to date.

The ATLAS detector [1] is one of the two general purpose detectors used to record the outcome of the proton-proton collisions at a center-of-mass energy $\sqrt{s}$ = 13 TeV delivered by the LHC. It measures 25x25x46 meters and has a cylindrical shape, being symmetrical around the collision point situated at its center. Several layers of subdetectors surround the beam pipe that traverses the detector along its central longitudinal axis of symmetry. Protons circulating through the beam pipe at almost the speed of light come from opposite directions and collide in the center of the detector at rates up to 1 billion Hz.

A tracking detector which records with a very high accuracy the tracks of most charged particles produced in the collisions, called the Inner Detector (ID), is placed at the very center immediately surrounding the beam pipe. It is surrounded by a calorimeter with a double function of measuring the energies of particles that interact with its material, including the neutral ones that leave no tracks in the Inner Detector, and of stopping most particles. The detector is completed by a muon spectrometer situated outside of the calorimeter. Only one in a million collisions is flagged by a multi-step trigger system as potentially interesting and recorded for further study.

With a mass of 1.78 GeV, taus are the heaviest of all leptons and the only ones heavy enough to decay hadronically. Their lifetime $c\tau$ is 87 μm, which means that they decay inside the beam pipe, before reaching any detector. The large variety of final states into which they decay makes them very challenging to reconstruct and identify at hadron colliders. Since the leptonic decay products of the tau lepton can not be distinguished from prompt electrons or muons, we will only discuss here the hadronic decays.

The typical signature of a hadronic decay of the tau in ATLAS is a narrow jet or spray of particles in the calorimeter, associated to one or three tracks in the ID.

http://dx.doi.org/10.1016/j.nuclphysbps.2017.03.056

The tau reconstruction [2] starts with a jet obtained using the anti-k_t algorithm with a distance parameter of 0.4. These jets are required to have a momentum transverse to the beam direction $p_T > 10$ GeV and to be within the acceptance of the tracking detectors by imposing $|\eta| < 2.5$, where $\eta = -\ln\tan(\frac{\theta}{2})$ and θ is the polar angle. A special Tau Vertex Association algorithm sums the p_T of the tracks in a cone with $\Delta R < 0.2$ around the jet direction to identify the vertex associated with the tau. The number of tracks reconstructed for true 1-prong and 3-prong taus is shown in Fig. 1. The tau reconstruction efficiency is about 70% up to 200 GeV, slowly decreasing towards 50% for 3-prongs of 500 GeV. The inclusion of a special prescription for merged hits increases the 3-prong reconstruction efficiency by 10% at high p_T [3]. The systematic uncertainty on reconstructing the true number of tracks is 2-5%.

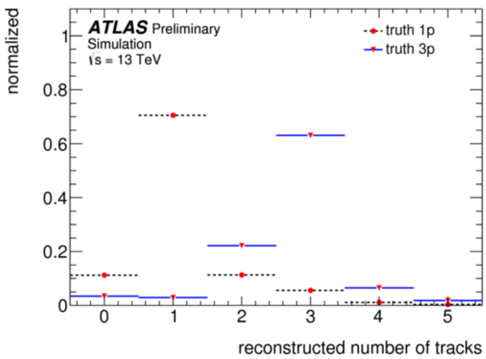

Figure 1: The reconstructed number of tracks for true 1-prong and 3-prong taus [2].

Since many jets formed by quarks or gluons can fake the signature of tau leptons, a multivariate analysis algorithm based on Boosted Decision Trees (BDT) is used to distinguish between taus and jets due to other particles. It is trained separately for 1-prong and 3-prongs using taus from $Z \to \tau^+\tau^-$ Monte Carlo (MC) simulations as signal and jets from MC multijet events as background. The input variables are chosen mostly among shower shape variables that use the narrowness of the tau jet to distinguish it from other jets. The output of the BDT is shown in Fig. 2 for both 1-prong and 3-prong taus.

Three working points called Loose, Medium and Tight are chosen such that they deliver an efficiency approximately constant as a function of p_T for reconstruction and identification of true tau leptons of 60 (50), 55 (40) and 45 (30)% for 1-prong (3-prong) tau candidates, while the acceptance for background jets is about 5%, 1% and 0.3% respectively.

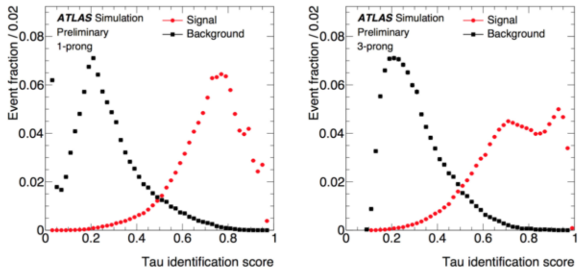

Figure 2: The BDT output distribution for 1-prong (left) and 3-prong (right) tau leptons, as well as for background jets [2].

The uncertainty on the tau identification efficiency is evaluated using dedicated $Z \to \tau^+\tau^-$ MC samples generated with different configurations for inner detector material, calorimeter performance and calibration, underlying event tunes, shower model and pileup model. It has values of 5-15% for 1-prong taus, and 6-19% for 3-prong taus.

The energy of the tau candidate is measured in a $R < 0.2$ cone and calibrated to true visible energy using a η and p_T dependent scale factor called the Tau Energy Scale (TES). The energy resolution of 1-prong and 3-prong taus is shown in Fig. 3. The uncertainty on the tau energy measurement is 4% for 1-prong taus and 4-6% for 3-prong taus.

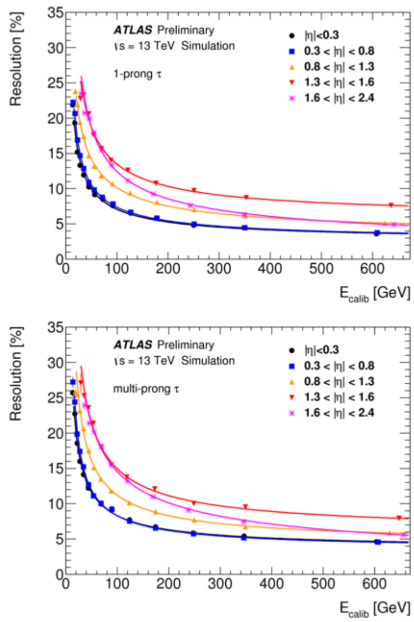

Figure 3: The energy resolution for 1-prong (top) and 3-prong (right) tau leptons [2].