Tau Reconstruction And Identification Performance in ATLAS

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1. Introduction

Tau leptons play an important role in the physics program of the ATLAS experiment at the LHC, as they are relevant both for Standard Model measurements as well as for searches for new physics. A tau lepton decays to leptons 35.2% of the time and to hadrons the remaining 64.8%. As the leptonic decays are extremely hard to distinguish from prompt leptons, the focus here will be on the reconstruction and identification of the hadronic decays. These are dominated by the production of charged pions along with a neutrino and possibly one or more neutral pions. There are also decay modes involving kaons, but they are substantially rarer. Experimentally, the hadronic decays can be separated by the number of "prongs" (charged decay products), with 1 prong decays being the most common (49.5%), followed by 3 prong decays (15.2%). Besides the number of prongs, the experimental signature consists of collimated energy deposits in the calorimeter, since the hadronic tau decay produces a relatively narrow tau-jet, often with a rela-
tively large electromagnetic component due to the neutral pions decaying to photons. Additionally, the hadronic tau decay can be characterized by a large leading track momentum fraction and, possibly, a secondary vertex.

Two components of the ATLAS detector are crucial to tau reconstruction: the tracker and the calorimeter. The tracker is immersed in a 2 T magnetic field generated by the central solenoid, and consists of three subsystems: the Pixel detector, the Semi-Conductor Tracker (SCT), and the Transition Radiation Tracker (TRT). The first two subsystems cover a region of $|\eta| < 2.5$ in pseudorapidity, while the TRT reaches up to $|\eta| = 2.0$. The electromagnetic (EM) and hadronic calorimeters cover the range $|\eta| < 4.9$, with the $\eta$ region matched to the inner detector having a finer granularity in the EM section. The EM calorimeter uses liquid argon (LAr) as the active material and lead as absorber, the hadronic calorimeter uses steel and scintillating tiles in the barrel region, while the end-caps use LAr as the active material and copper as the absorber.

2. Reconstruction and Identification

The reconstruction of hadronic tau decays in ATLAS is seeded by calorimeter jets. These jets are reconstructed using the anti-$k_t$ algorithm, with a distance parameter $R = 0.4$, using three-dimensional topological calorimeter energy clusters as inputs. Only jets with $E_T > 10$ GeV and within $|\eta| < 2.5$ are retained. Reconstructed tracks are then associated to the seeds, to form tau candidates. In order to be considered a track has to be within the core cone, defined as the region within $\Delta R < 0.2$ around the axis of the seed jet, have $p_T > 1$ GeV, and pass the following quality criteria:

- Number of pixel hits $\geq 2$,
- Number of pixel hits + number of SCT hits $\geq 7$,
- $|d_0| < 1.0$ mm and $|z_0 \sin \theta| < 1.5$ mm.

Since hadronic tau decays consist of a specific mix of charged and neutral pions, the energy scale of hadronic tau candidates is calibrated inde-

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*a*ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the $z$-axis along the beam pipe. The $x$-axis points from the IP to the center of the LHC ring, and the $y$-axis points upward. Cylindrical coordinates ($r, \phi$) are used in the transverse plane, $\phi$ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle $\theta$ as $\eta = -\ln \tan(\theta/2)$. The distance $\Delta R$ in the $\eta - \phi$ space is defined as $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$.

$b$ $d_0$ is the distance of closest approach of the track to the reconstructed primary vertex in the transverse plane. $z_0$ is the longitudinal distance of closest approach.
pendently of the jet energy scale. As a first step, the clusters associated with
the seed jet are calibrated using the local hadron calibration (LC). The
cells of the clusters are weighted to correct the measured energies for the
non-compensation of the calorimeters and for energy deposits outside re-
constructed clusters and in un-instrumented (dead) material, based on the
local properties of the clusters. As a second step, an additional correction
specific for hadronic tau decays is applied. This correction is derived from
simulation of various physics processes involving tau leptons, is binned in
\( p_T, \eta \) and track multiplicity of the tau candidate, and is applied on top of
the LC calibration. The uncertainties on the tau energy scale are evaluated
by comparing the responses in different Monte Carlo (MC) samples (varying
a number of conditions, such as the detector geometry, the hadronic shower
model etc.) and an indicative example of the uncertainties as a function of
the true tau lepton’s \( p_T \) can be seen in Fig. 1(a).

The reconstruction process described above has a high efficiency, but
also suffers from a very low purity, the main background coming from QCD
jets, with a secondary background from electrons. A second step is therefore
necessary to reduce these backgrounds, referred to as the \textit{Tau Identifica-
tion}. Using information both from the calorimeter and the tracker, several
discriminating variables are constructed and then used by three different
algorithms, developed to discriminate between signal and backgrounds: a
cut-based selection, a projective likelihood discriminant, and a boosted de-
cision tree. Figure 1 shows two examples of such variables – the full listing
and definitions of all variables can be found in. The performance of the
three methods is compared in Fig. 2(a), for 3 prong tau candidates. The
performance of one of the methods is also demonstrated on a \( Z \rightarrow \tau \tau \)
selection, shown before and after tau identification has been applied.
3. Efficiency and Mis-identification Measurements

The efficiency of the tau identification is measured in $W \to \tau\nu$ events\(^9\) using two different methods. In the tag & probe method, the $E_{\text{T}}^{\text{miss}}$ significance, $S_{E_{\text{T}}^{\text{miss}}}^c$, is used to tag events. The track multiplicity spectrum of jets and tau candidates is fitted, to extract the $W \to \tau\nu$ spectrum, with the template for the QCD multijet background extracted from a low $S_{E_{\text{T}}^{\text{miss}}}^c$ control region.

This method is cross-checked with a second method, where the measured $W \to \tau\nu$ yield is compared to the expectation from the $W$ cross-section measured in the $e$ and $\mu$ channels. In both measurements, the result is in agreement with the efficiency expected from MC (Fig. 3(a)).

The mis-identification probability has also been measured in data, using a number of different processes.\(^10\) Depending on whether a jet is quark- or gluon-initiated the probability of it faking a hadronic tau decay is expected to be different. Measurements have therefore been done using both gluon-dominated (QCD dijet and trijet events) and quark-dominated ($\gamma$+jet, $Z$+jet) processes, and the results are indeed different (Fig. 3). The electron mis-identification probability has also been measured, using a tag & probe method on $Z \to ee$ events – data and MC expectations were found to be in agreement, except in the calorimeter transition region, for which correction factors for the MC were calculated based on this measurement.

4. Summary and Outlook

The tau reconstruction and identification in ATLAS is well-performing and reliable. Efficiency and mis-identification probabilities have been measured in data, using a number of different methods and processes. A lot of in-

\(^{c}S_{E_{\text{T}}^{\text{miss}}} = E_{\text{T}}^{\text{miss}}/(0.5 \text{ GeV}^{1/2} \sqrt{\Sigma E_T})$, where $E_{\text{T}}^{\text{miss}}$ is the transverse component of the vector sum of all energy deposits in the calorimeter, calibrated to their respective energy scale, and $\Sigma E_T$ the scalar sum of the $E_T$ of all topological clusters.
Fig. 3. Left: Ratio of the $\tau$ efficiency measured in data over that in MC. Centre and right: mis-identification probabilities as a function of $p_T$ measured in a QCD dijet and in a $\gamma$+jet sample. In all three plots, the values are for a selection yielding tau signal efficiencies of $55 - 60\%$.

Interesting physics results involving taus have already been released by ATLAS: Standard Model measurements\textsuperscript{11–13} that complement measurements in other channels and at the same time demonstrate the good performance of the tau reconstruction, as well as searches for new physics\textsuperscript{14–16} that are already excluding substantial parts of the relevant parameter space. Further studies of the ID efficiency, energy scale and other tau properties, such as resolving the tau-jet substructure, are underway with the large amount of data being collected during 2011, and many more interesting physics results with taus are to be expected.

References

8. https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauPublicCollisionResults