

Observation of $Z \rightarrow \tau_h \tau_\ell$ Decays with the ATLAS detector

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A study of $Z \rightarrow \tau\tau$ decays has been performed with the ATLAS experiment at the Large Hadron Collider. The channel with one τ lepton decaying into an electron or muon and the second one into hadrons has been considered. The analysis is based on a data sample corresponding to an integrated luminosity of 8.3 pb^{-1} for the electron channel and 8.5 pb^{-1} for the muon channel, taken at a proton-proton centre-of-mass energy of 7 TeV. In the muon channel a total of 51 data events is selected, with a total estimated background of 9.9 ± 2.1 events. In the electron channel a total of 29 data events is selected, with an estimated background of 11.8 ± 1.7 events. The obtained number of events in data is compatible with the Standard Model expectation.

1 Introduction

Many new physics searches being undertaken by the ATLAS experiment¹, such as that for the Higgs boson, in particular in the $H \rightarrow \tau\tau$ channel, supersymmetric or exotic signatures include τ leptons in the final state. The $Z \rightarrow \tau\tau$ process is an important background and should be observed² and well measured. In this analysis final states were considered where one τ lepton decays leptonically and the other hadronically. It is possible to trigger on the single light leptons and obtain an unbiased sample of hadronically decaying τ leptons, which can be used for studies of reconstruction and identification of hadronically decaying τ leptons and τ triggers.

2 Object Selection

Following the requirement of a single light lepton trigger with a low p_T threshold, either a reconstructed electron or muon is selected together with a hadronically decaying τ lepton candidate. Electron identification uses calorimeter information, tracking information or a combination of both to define variables to accurately discriminate between real and fake electrons in particular from jets. Electrons are selected with $p_T > 15 \text{ GeV}$ and must pass “tight” level identification³. Muon identification uses Inner Detector tracks and Muon-Spectrometer tracks, combined using a chi-square (χ^2) matching procedure⁴. Selected muons must have $p_T > 15 \text{ GeV}$.

Reconstruction of hadronically decaying τ leptons is seeded by jets reconstructed with the anti- k_T algorithm⁵. Tracks with $p_T > 1 \text{ GeV}$ which pass quality requirements are then associated to the τ candidates and various identification variables are calculated per candidate from the combined calorimeter and tracking information⁶. Selected τ candidates must pass “tight” cut-based identification⁶.

Leptons from $Z \rightarrow \tau\tau$ decays are typically isolated, unlike those in the multijet background. Two isolation variables are defined, the first, $Iso_{PT}^{0.4}$, is a sum of transverse momenta of tracks in a cone of $\Delta R = 0.4$ ^a around the lepton, divided by its transverse momentum. For electrons and

^aThe distance ΔR in the $\eta - \phi$ space is defined as $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$.

muons the cut $Iso_{PT}^{0.4} < 0.06$ is applied. The second variable, $Iso_{ET}^{\Delta R}$, is a sum of the transverse energy of neutral and charged particles in the calorimeter, divided by the transverse momentum of the lepton. For electrons the cut $Iso_{ET}^{0.3} < 0.1$ is used, for muons $Iso_{ET}^{0.4} < 0.06$ is applied. For both variables the contribution to the sum of the track momenta or of the energies in the isolation cone from the light lepton itself is corrected for, using an inner cone of $\Delta R = 0.05$. Figure 1 shows the $Iso_{ET}^{0.4}$ and $Iso_{ET}^{0.3}$ variables for muons and electrons respectively.

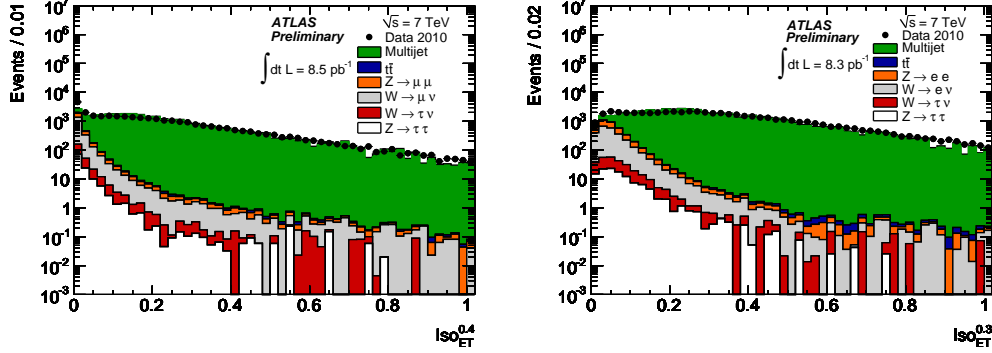


Figure 1: Isolation variables $Iso_{ET}^{0.4}$ and $Iso_{ET}^{0.3}$ for muons (left) and electrons (right) respectively, after selecting one τ candidate and one lepton. All backgrounds were obtained from Monte Carlo, weighted by cross-section and their sum normalized to data; they are represented by the shaded areas and the dots are the data.

3 Event selection

3.1 $W + jets$ suppression cuts

$W + jets$ is an important background, where the light lepton comes from the decay of the W , and one of the additional jets in the event is identified as the τ candidate. These events can be suppressed by requiring that the E_T^{miss} vector be reconstructed inside of the region defined by the light lepton and the τ candidate. The following variable is defined:

$$\sum \cos \Delta\phi = \cos(\phi(\ell) - \phi(E_T^{\text{miss}})) + \cos(\phi(\tau_h) - \phi(E_T^{\text{miss}})); \quad (1)$$

$\sum \cos \Delta\phi$ is zero when the two τ leptons are back to back, as is often the case in signal events. It is negative when the E_T^{miss} lies outside of the azimuthal angle spanned by the decay products, as seen in Fig. 2. Cutting at $\sum \cos \Delta\phi > -0.15$ significantly reduces the $W + jets$ contribution.

The transverse mass, calculated using the 4-vector of the light lepton and the E_T^{miss} vector, defined as:

$$m_T(\ell, E_T^{\text{miss}}) = \sqrt{2 p_T(\ell) \cdot E_T^{\text{miss}} \cdot (1 - \cos \Delta\phi(\ell, E_T^{\text{miss}}))} \quad (2)$$

also provides good separation. In Fig. 2 it is shown with all other cuts applied, further illustrating the strength of the $\sum \cos \Delta\phi$ cut.

3.2 Further cuts

To suppress contributions to the background from $Z \rightarrow \ell\ell + jets$ processes, a veto is placed on any event containing more than one light lepton and the visible mass, the invariant mass of the visible decay products, the light lepton and the τ candidate, is required to be in the window 35–75 GeV. Additional requirements on the τ candidate ensure further multijet rejection. The τ candidate must have exactly one or three tracks, which is strongly characteristic of hadronic τ decays, and unit electric charge of opposite sign to the selected light lepton.

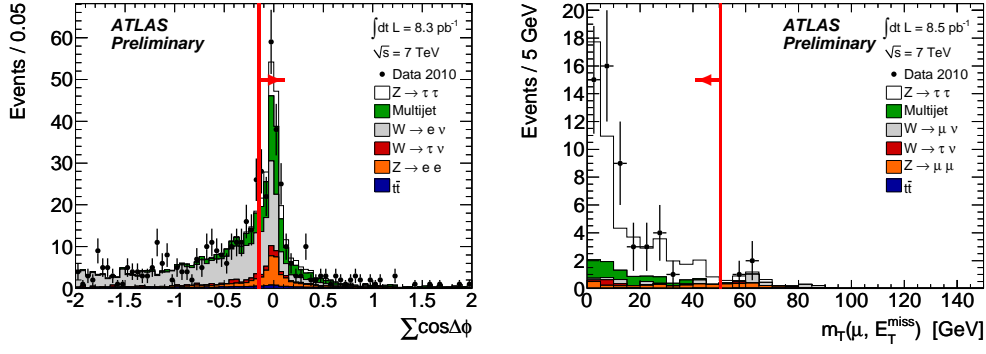


Figure 2: The distribution of $\sum \cos \Delta\phi$ (left) following the full object selections and dilepton veto, in the electron channel. The m_T distribution (right), with all other cuts applied, in the muon channel. The dots are the data and the contributions from background are indicated by the shaded areas.

4 Background estimation

The backgrounds from processes $Z \rightarrow \ell\ell$ and $t\bar{t}$ are estimated from Monte Carlo, normalized using a scale factor while $W \rightarrow \ell\nu$ and $W \rightarrow \tau\nu$ use Monte Carlo normalized to agree with data.

4.1 Data-driven multijet background estimation

The multijet background is estimated with a data-driven ABCD matrix method. The control samples are created by inverting the uncorrelated τ identification and lepton isolation requirements. The signal region A is defined as: isolated lepton and tight τ candidate, and the control regions are B: non-isolated lepton and tight τ candidate, C: isolated lepton and loose and not tight τ candidate and D: non-isolated lepton and loose and not tight τ candidate.

The multijet contribution to the signal region A can be calculated from Equation (3):

$$N^A = N^B \left(\frac{N^C}{N^D} \right), \quad (3)$$

where N^i is the number of multijet background events in region i . Since regions B, C, and D are not completely multijet-pure, corrections are applied for the expected contaminations from electroweak backgrounds from Monte Carlo in each region. Using these equations, the expected number of multijet events in the signal region A is:

$$N_{\text{QCD}}^A = \begin{cases} 5.2 \pm 0.7 \text{ (stat.)} \pm 0.7 \text{ (syst.)} & \text{muon channel} \\ 6.8 \pm 0.6 \text{ (stat.)} \pm 0.7 \text{ (syst.)} & \text{electron channel.} \end{cases} \quad (4)$$

5 Observation of $Z \rightarrow \tau_h \tau_\ell$ candidates

After the visible mass cut there are 51 data events in the muon channel and 29 events in the electron channel. From the background estimates described for multijets, W, Z and $t\bar{t}$ decays, combined accounting for correlations between their uncertainties, there is a total estimated background of 9.9 ± 2.1 events in the muon channel and 11.8 ± 1.7 events in the electron channel. This is compatible with the Standard Model signal expectation of $39.9 \pm 1.8(\text{stat.}) \pm 6.8(\text{syst.})$ and $24.5 \pm 1.4(\text{stat.}) \pm 5.9(\text{syst.})$ events in the muon and electron channels respectively. The main contributions to the systematic uncertainties come from the τ fake rates from jets and electrons and the energy scale. The results for both channels are summarized in Table 1.

Figure 3 shows distributions of the visible mass of selected events, with the visible mass window marked by vertical red lines.

Table 1: Summary of observed numbers of events and a summary of the background estimations.

| | Muon channel | Electron channel |
|---------------------------------------|----------------------------------------------------|----------------------------------------------------|
| Data (after all selections) | 51 | 29 |
| Total estimated background | 9.9 ± 2.1 | 11.8 ± 1.7 |
| Estimated multijet background | $5.2 \pm 0.7(\text{stat.}) \pm 0.7(\text{syst.})$ | $6.8 \pm 0.6(\text{stat.}) \pm 0.7(\text{syst.})$ |
| Estimated $W, Z, t\bar{t}$ background | $4.7 \pm 0.5(\text{stat.}) \pm 1.5(\text{syst.})$ | $5.0 \pm 0.6(\text{stat.}) \pm 1.4(\text{syst.})$ |
| Data (after background subtraction) | 41.1 ± 2.1 | 17.2 ± 1.7 |
| SM signal expectation | $39.9 \pm 1.8(\text{stat.}) \pm 6.7(\text{syst.})$ | $24.5 \pm 1.4(\text{stat.}) \pm 5.9(\text{syst.})$ |

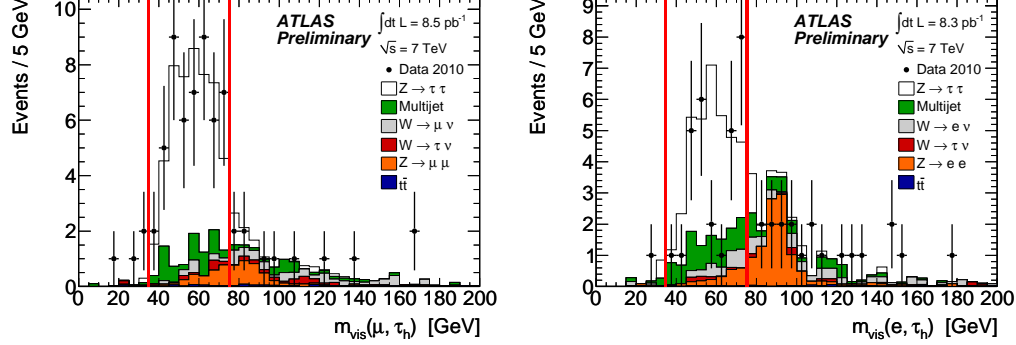


Figure 3: The distributions of the visible mass of the combination of the chosen τ candidate and the light lepton, for the muon (left) and electron (right) channels. The distributions are shown after the full event selection, except for the visible mass window. The dots are the data and the background contributions are the shaded areas.

6 Summary

An observation of $Z \rightarrow \tau_\ell \tau_h$ decays has been performed with the ATLAS experiment at the Large Hadron Collider at a proton-proton centre-of-mass energy of 7 TeV. The obtained number of events agrees with the Standard Model prediction.

References

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