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Measurement of the $Z \rightarrow \tau\tau$ and $W \rightarrow \tau\nu$ cross sections with the ATLAS detector

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The cross-sections the for $W \rightarrow \tau\nu$ and $Z \rightarrow \tau\tau$ processes are measured with 36 pb^{-1} of LHC data collected by the ATLAS detector. The cross section for Z bosons decaying to two taus are measured in four channels based on the decay modes of the τ leptons: electron-hadron, muon-hadron, electron-muon, and muon-muon. The cross-section for W bosons decaying to a tau and a neutrino are measured when the tau decays hadronically. A total cross-section of 11.6 $\pm$ 0.3(stat) $\pm$ 1.7(sys) $\pm$ 0.4(lumi) nb is measured for the $W \rightarrow \tau\nu$ process, while a total cross-section of 0.97 $\pm$ 0.07(stat) $\pm$ 0.06(sys) $\pm$ 0.03(lumi) nb is measured for the $Z \rightarrow \tau\tau$ process.

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1. Introduction

The measurement of the W and Z boson production cross-sections with τ leptons in the final state [1, 2] is important in demonstrating the capabilities of the ATLAS detector in searching for hitherto unseen physics processes. The study of W and Z bosons with taus in the final state allows for the measurement of the hadronic tau trigger, reconstruction, and identification efficiencies in data. Reconstruction and identification of tau leptons is important, for example, for searches for the Standard Model (SM) Higgs boson as well as Supersymmetric neutral and charged Higgs bosons.

Tau leptons decay hadronically (τ_h) with a branching ratio of 65% and leptonically (e/μ) with a branching ratio of 35%. The W boson production cross-section is measured when the tau decays hadronically $(W \to \tau_h \nu_\tau)$, while the Z boson production cross-section is measured in four final states where the visible decay products are: an electron and a hadronic tau $(\tau_h \tau_e)$, a muon and a hadronic tau$(\tau_h \tau_\mu)$, an electron and a muon $(\tau_e \tau_\mu)$, and to two muons $(\tau_\mu \tau_\mu)$. The total cross-section, in all scenarios, is measured using:

$$\sigma_{W/Z} = \frac{N_{\text{obs}} - N_{\text{background}}}{BA_{W/Z} C_{W/Z} \mathscr{L}} \tag{1.1}$$

where B is the branching ratio for the specific final state, $A_{W/Z}$ is the theoretical acceptance, $C_{W/Z}$ is the detector acceptance, and $\mathscr{L}$ is the integrated luminosity.

2. Event Selection

2.1 $W \to \tau_h \nu_\tau$

The event signature for $W \to \tau_h \nu_\tau$ decays is one narrow jet containing either one or three tracks (τ_h) and large missing energy transverse to the beam direction $(E_{\text{T}}^{\text{miss}})$. Events were triggered with a hadronic tau combined with large $E_{\text{T}}^{\text{miss}}$. Events were further selected with offline cuts of $20 < p_{\text{T}}(\tau_h) < 60$ GeV, and $E_{\text{T}}^{\text{miss}} > 30$ GeV. $Z \to \ell\ell$ and $W \to \ell\nu(\ell = e\mu)$ events were rejected by vetoing on the presence of an identified electron or muon, while the multijet background was removed with a cut on the $E_{\text{T}}^{\text{miss}}$ significance $(S_{E_{\text{T}}^{\text{miss}}} > 6.0)$ defined as:

$$S_{E_{\text{T}}^{\text{miss}}} = \frac{E_{\text{T}}^{\text{miss}}[\text{ GeV}]}{0.5 * \sqrt{\text{ GeV}} \sqrt{E_{\text{T}}[\text{ GeV}]}} \tag{2.1}$$

where E_{T} represents the scalar sum of all transverse energy in the event.

2.2 $Z \to \tau\tau$

In all four final states single lepton triggers were used to trigger the events (an e trigger was used for the $\tau_e \tau_\mu$ final state). For the $\tau_h \tau_e$ and $\tau_h \tau_\mu$ final states one offline identified and isolated $e(\mu)$ with $p_{\text{T}} > 16(15)$ GeV together with a tightly identified τ_h are required. For the $\tau_e \tau_\mu$ final state an identified and isolated electron with $p_{\text{T}} > 16$ GeV and an identified and isolated muon with $p_{\text{T}} > 10$ GeV are required. The $\tau_\mu \tau_\mu$ final state required two identified and isolated muons respectively with $p_{\text{T}} > 15$ and $p_{\text{T}} > 10$ GeV. The $W \to \ell(e\mu)\nu$ backgrounds were suppressed by cutting on the transverse mass of the lepton and $E_{\text{T}}^{\text{miss}}(\tau_h \tau_e,\ \tau_h \tau_\mu)$ or by requiring the $E_{\text{T}}^{\text{miss}}$to be

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between the two leptons ($\tau_h\tau_e$, $\tau_h\tau_\mu$, and $\tau_e\tau_\mu$). The $Z \to \ell\ell$ backgrounds in the $\tau_h\tau_e$ and $\tau_h\tau_\mu$ final states were removed by requiring only one identified lepton, while this background was removed with a boosted decision tree in the $\tau_\mu\tau_\mu$ final state. The $t\bar{t}$ background was removed in the $\tau_e\tau_\mu$ final state by cutting on the total ΣE_{T} of the two leptons, all selected jets, and the $E_{\mathrm{T}}^{\mathrm{miss}}$($\Sigma E_{\mathrm{T}} < 150$ GeV). In all four final states the $\ell\tau_h/\ell\ell$ pairs were required to have opposite signs (OS).

3. Background Estimation

The multijet background for all W/Z decay modes was estimated from data using an ABCD method (eq. 3.1). In an ABCD method, events are split into four regions: the signal region(A), and 3 background regions(B, C, and D). The regions are classified based on two uncorrelated variables: "tight" vs. "loose" τ_h candidates and high vs. low $S_{E_{\mathrm{T}}^{\mathrm{miss}}}$ for the $W \to \tau_h\nu_\tau$ events, OS vs Same Signed (SS) events and high vs low lepton isolation for the $\tau_h\tau_e$, $\tau_h\tau_\mu$, and $\tau_e\tau_\mu$ final states, and high vs. low isolation for the lead muon and high vs. low isolation for the sub-leading muon in the $\tau_\mu\tau_\mu$ final state. In order for this method to succeed, the amount of signal must be low in regions B, C, and D. Finally, any electroweak contamination is removed in regions B, C, and D based on estimates from MC.

$$N_A^{Multijet} = \frac{(N_B^{\mathrm{DATA}} - N_B^{EWK})(N_C^{\mathrm{DATA}} - N_C^{EWK})}{(N_D^{\mathrm{DATA}} - N_D^{EWK})} \tag{3.1}$$

Any correlations between the two variables were either measured to be negligible or accounted for in all final states.

4. Systematic Uncertainties

The systematic uncertainties considered for each each final state include: trigger efficiency, energy scale, (ℓ/τ_h) identification efficiency, lepton (e/μ) isolation, Monte Carlo pileup re-weighting, underlying event model, theoretical cross sections of MC backgrounds, charge misidentification, and the multijet background estimation method. The final cross sections were computed separately for each uncertainty considered, both scaled up and down, where the final systematic uncertainty was the individual components added in quadrature. When combing the results for the four final states of the $Z \to \tau\tau$ decay, each systematic uncertainty was treated as either correlated or uncorrelated where appropriate.

5. Results

The measured $W \to \tau_h\nu_\tau$ cross section is $11.1 \pm 0.3(\mathrm{stat}) \pm 1.7(\mathrm{sys}) \pm 0.4(\mathrm{lumi})$nb, while the measured combined $Z \to \tau\tau$ cross section is $0.97 \pm 0.07(\mathrm{stat}) \pm 0.06(\mathrm{sys}) \pm 0.03(\mathrm{lumi})$nb. Both measurements are in agreement with the Standard Model predictions of 10.46 nb and 0.99 nb for the W and Z respectively.

References

[1] The ATLAS Collaboration 2011 arXiv:1108.4101v1 [hep-ex]

[2] The ATLAS Collaboration 2011 arXiv:1108.2016v1 [hep-ex]

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