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Physics with Tau Lepton Final States in ATLAS

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Abstract. The ATLAS detector records collisions from two high-energetic proton beams circulating in the LHC. An integral part of the ATLAS physics program are analyses with tau leptons in the final state. Here an overview is given over the studies done in ATLAS with hadronically-decaying final state tau leptons: Standard Model cross-section measurements of $Z \to \tau\tau$, $W \to \tau\nu$ and $t\bar{t} \to b\bar{b}\ \ e/\mu\nu\ \ \tau_{\rm had}\nu$; τ polarization measurements in $W \to \tau\nu$ decays; Higgs searches and various searches for physics beyond the Standard Model.

1 Introduction

The ATLAS [1] physics program covers a wide range of analyses with tau leptons in the final state, which are important both to test the Standard Model (SM) and in searches for new physics. In 2010 and 2011, the LHC [2] was operated at a center-of-mass energy of $\sqrt{s} = 7$ TeV, and at $\sqrt{s} = 8$ TeV in 2012. Physics searches presented here are based on the full 2011 dataset of 4.7 fb^{-1} if not otherwise stated.

With a mass of 1.77 GeV and a proper decay length of 87 μm, tau leptons decay inside the LHC beam pipe and can only be identified by their decay products. Tau leptons decay either leptonically or hadronically. The leptonic decay into an electron or muon and neutrinos can not be distinguished from prompt light lepton production, and can not be used for tau identification. The hadronic mode ($\tau_{\rm had}$) occurs in 65% of all cases. The tau decays then mostly into charged and neutral pions and a neutrino. The neutrino can not be detected directly, which leads to missing transverse energy $E_{\rm T}^{\rm miss}$ in the event. Requirements on the direction and amount of $E_{\rm T}^{\rm miss}$ is widely used in physics analyses with tau leptons in the final state to reject background. The hadrons are reconstructed as a jet of particles, which can easily be faked by quark- or gluon-initiated jets. These jets and $\tau_{\rm had}$ are separated using different shower shape variables and track multiplicities [3]. However, multi-jet events remain one of the main backgrounds in analyses containing $\tau_{\rm had}$. Since the misidentification probability depends on the quark-gluon composition of the multi-jet background, it is estimated individually for each analysis using data driven techniques, like ABCD-methods, control regions or template fits. The performance of $\tau_{\rm had}$ reconstruction and identification has been tested in data using tag-and-probe methods on $Z \to \tau\tau$ and $W \to \tau\nu$ events.

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2 Standard Model cross-section measurements

The SM processes $W \to \tau\nu$ and $Z \to \tau\tau$ are backgrounds in many studies with final state tau leptons, in particular in searches for the Higgs boson. It is therefore important to study and measure the cross-sections precisely. Furthermore, deviations from predicted SM cross-sections are an indicator for new physics processes. Three measurements with tau leptons in the final state have been performed: $W \to \tau\nu$ [4], $Z \to \tau\tau$ [5] and $t\bar{t} \to b\bar{b}\ e/\mu\nu\ \tau_{\rm had}\nu$ [6]; 34 pb^{-1}, 36 pb^{-1} of 2010 data and 2.05 fb^{-1} of 2011 data have been used, respectively. The measured cross-sections[1] are in good agreement with previous measurements and theoretical predictions:

$$\sigma_{t\bar{t}} = 186 \pm 13(stat) \pm 20(syst) \pm 7(lumi)\ \text{pb},$$
$$\sigma_{W\to\tau\nu} = 11.1 \pm 0.3(stat) \pm 1.7(syst) \pm 0.4(lumi)\ \text{nb},$$
$$\sigma_{Z\to\tau\tau} = 0.97 \pm 0.07(stat) \pm 0.06(syst) \pm 0.03(lumi)\ \text{nb}.$$

3 Measurement of the τ polarization in $W \to \tau\nu$ decays

The polarization of tau leptons can be measured by analyzing the kinematics of their decay products. The average polarization of the final state tau lepton in $W \to \tau\nu$ decays has been measured using 24 pb^{-1} of 2010 data. The polarization was extracted in $\tau \to \rho\nu \to \pi\pi^0\nu$ decays by analyzing the sharing of energy between the charged and neutral pions. The result, $P_\tau = -1.06 \pm 0.04(stat)\,^{+0.05}_{-0.07}(syst)$, is in good agreement with the expected V–A coupling of the charged weak current.

[1] Total production cross section for $t\bar{t}$ measurement; Total production cross section times branching ratio for W and Z measurement; $\sigma_{Z\to\tau\tau}$ is measured for a visible mass of 66 – 116 GeV.

4 Searches for physics beyond the Standard Model

In searches for physics beyond the SM it is especially important to consider all possible lepton final states, as the coupling to third generation leptons is enhanced in several theories. In ATLAS, different searches for new physics with $\tau_{\rm had}$ in the final state are done.

In GMSB-like supersymmetric (SUSY) models, the supersymmetric partner of the tau lepton, the $\tilde{\tau}$, can be the next-to-lightest SUSY particle. Heavier, short lived particles then decay in a cascade to the $\tilde{\tau}$ and finally to the lightest SUSY particle. This leads to a signature with one or two τ in the final state, additional jets or leptons and $E_{\rm T}^{\rm miss}$. Four channels with $\tau_{\rm had}$ have been considered in the current search: exactly 1 $\tau_{\rm had}$, ≤ 2 $\tau_{\rm had}$, 1 $\tau_{\rm had}$ + 1 μ, 1 $\tau_{\rm had}$ + 1 e. Using the full 2011 dataset, no excess above Standard Model expectation was observed and limits on parameters of a minimal GMSB model were set [8].

Many new physics models allow lepton flavor violation in interactions with charged leptons. R-parity violating SUSY models are one example, where a heavy narrow resonance, e.g. a $\tilde{\nu}_\tau$, can decay into a pair of opposite-sign leptons with different flavor. Searches for the three possible final states $e\mu$, $e\tau_{\rm had}$ and $\mu\tau_{\rm had}$ have been performed using the full 2011 dataset. No excess over the SM expectation was observed. Lower limits on a $\tilde{\nu}_\tau$ mass of 1610 GeV ($e\mu$), 1110 GeV ($e\tau_{\rm had}$) and 1100 GeV ($\mu\tau_{\rm had}$) were set for a specific R-parity violating SUSY model [9].

Searches for high mass resonances were also performed using SM-like conditions. Four final states were being searched for: $\tau_\mu\tau_{\rm had}$, $\tau_e\tau_{\rm had}$, $\tau_e\tau_{mu}$ and $\tau_{\rm had}\tau_{\rm had}$. No excess above SM expectation was observed in the full 2011 dataset. The result was interpeted within the context of the Sequential Standard Model and a Z' with a mass <1.4 TeV could be excluded at 95% CL [10].

Another type of potential new bosons are leptoquarks which couple to both leptons and quarks and have fractional charge. Assuming that leptoquarks couple only to one generation, the third generation leptoquark decays like $LQ_3 \to b\tau$. The current search considers pair produced LQ_3 with two final states: 1 high $p_{\rm T}$ electron or muon + high $p_{\rm T}$ $\tau_{\rm had}$ + $E_{\rm T}^{\rm miss}$+ 2 high $p_{\rm T}$ jets. No excess above Standard Model expectation was observed using the full 2011 dataset. For this specific leptoquark model, a lower limit on the LQ_3 mass of 538 GeV was set at 95% CL [11].

5 Standard Model Higgs searches

A search for the SM Higgs boson decaying into a pair of tau leptons has been performed combining results from 4.6 fb^{-1} and 13 fb^{-1} of ATLAS data, at 7 TeV and 8 TeV center-of-mass energy, respectively [12]. For a SM Higgs with a mass m_H between 100 GeV and 150 GeV, the tau lepton decay channel provides the best possibility to measure the Higgs coupling to fermions. Three decay channels are considered: $\tau_{\rm lep}\tau_{\rm lep}$, $\tau_{\rm lep}\tau_{\rm had}$, $\tau_{\rm had}$ $\tau_{\rm had}$. In each channel, the search is optimized in several subcategories, focussing on the different Higgs production mechanisms. No significant excess over SM background expectation is observed and limits on the cross section times branching ratio are set as a function of the Higgs boson mass m_H with a 95% CL. For m_H = 125 GeV, expected and observed limits are 1.9 and 1.2 times the SM prediction, respectively.

6 Beyond the Standard Model Higgs searches

The Minimal Supersymmetric Standard Model (MSSM) contains five Higgs particles, where two of them are charged and three are neutral. Over large regions of the MSSM parameter space, the Higgs decay to tau leptons is enhanced and $H^\pm \to \tau\nu$ and $A/H/h \to \tau\tau$ can be among the dominant decay modes. Searches for both a potential neutral or charged Higgs boson have been performed with the full 7 TeV dataset [13, 14]. In the neutral Higgs search four channels are considered: $\tau_e\tau_\mu$, $\tau_e\tau_{\rm had}$, $\tau_\mu\tau_{\rm had}$ and $\tau_{\rm had}\tau_{\rm had}$. The search for the charged Higgs is performed in $t\bar{t}$ events, where one top quark decays into bW and the other one into $bH^\pm$. No excess over the SM expectation was observed. For both Higgs types, specific regions of the MSSM parameter space could be excluded.

7 Conclusion

ATLAS covers a large variety of measurements with $\tau_{\rm had}$ in the final state, ranging from SM measurements over Higgs searches to physics beyond the Standard Model. The SM measurements have proven the good performance of $\tau_{\rm had}$ reconstruction and identification algorithms, which is important for searches of new physics processes and particles. Using $\tau_{\rm had}$ final states, the ATLAS collaboration could set exclusion limits on a variety of new physics models.

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