Searches for new phenomena in final states with taus using the ATLAS detector

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The 17th International Workshop on Tau Lepton Physics (TAU2023)
Louisville, USA, 4-8 December 2023
doi:10.21468/SciPostPhysProc.17

Abstract

Many theories beyond the Standard Model predict new phenomena, such as leptoquarks, vector like leptons, Z' and W' bosons, supersymmetry, new scalars or heavy leptons, in final states with isolated, high-p_{T} taus. Searches for new physics with such signatures, produced either resonantly or non-resonantly, are performed using the ATLAS experiment at the LHC. The most recent results at $\sqrt{s} = 13$ TeV in proton-proton collision, are presented in this contribution.

Received 2024-05-03
Accepted 2024-12-09
Published 2025-07-23
doi:10.21468/SciPostPhysProc.17.014

1 Introduction

The Standard Model (SM) of particle physics has been verified to high precision by several experiments during the 20th and 21st centuries. Despite its success, several observations have been made which have exposed the theory's shortcomings in various aspects and fostered new theoretical ideas.

Many theories Beyond the SM (BSM) predict new phenomena in final states with isolated, high-p_{T} τ-leptons. Searches with these signatures, produced either resonantly or non-resonantly, are performed by the ATLAS Collaboration [1].

The most recent results, using the full Run-2 dataset at 13 TeV with 139 fb^{-1} and 140 fb^{-1} of integrated luminosity, are described in this contribution, considering τ-leptons from both SM and BSM particles. An identification algorithm based on a recurrent neural network [2] has been exploited by all the analyses [3, 11], to discriminate the visible decay products of the hadronic decay of τ-lepton candidates from jets initiated by quarks or gluons.

2 $H \to \tau\tau + E_T^{miss}$

A search for dark matter produced in association with a Higgs boson in final states with two hadronically decaying τ-leptons and missing transverse momentum has been performed [3]. The analysis considered a model-independent topology, providing a reinterpretation of its result in terms of a two Higgs doublet (2HDM)+a model featuring two scalar Higgs doublets and a pseudoscalar singlet field.

The analysis uses two different signal regions which in turn are divided into four and two $m_{\mathrm{T}}^{\tau_1} + m_{\mathrm{T}}^{\tau_2}$ bins,[1] respectively, to target different parts of the parameter space. No deviations from the SM prediction are found, then model-independent upper limits are set at 95% confidence level (CL) on the visible cross-section varying between 0.04 and 0.08 fb, depending on which of the signal region bins is considered.

3 $HH \to bb\tau\tau$

ATLAS searched for a non-resonant production of Higgs boson pairs in the $HH \to b\bar{b}\tau^-\tau^+$ channel [4]. To improve the sensitivity of the analysis, dedicated regions are defined to account for gluon-gluon Fusion (ggF) and Vector Boson Fusion (VBF) production modes, exploiting a multivariate technique (MVA).

A Boost Decision Tree is applied at two levels: the first step is used to separate ggF from VBF production events; the second BDT discriminates the remaining signal events from background candidates. For the ggF channel, two signal regions for different values of the di-Higgs mass ($m_{HH} < 350$ GeV and $m_{HH} \geq 350$ GeV) are defined.

No significant excess above the expected background from SM processes is observed. An observed upper limit $\mu_{HH} < 5.9$ is set at 95% CL on the Higgs boson pair production cross-section normalised to its SM prediction.

4 $X \to SH \to VV\tau\tau$

ATLAS presented a search for a new heavy scalar particle X decaying into a SM Higgs boson and a BSM singlet scalar particles S [5]. The results are also interpreted in terms of 2HDM, 2HDM+S and the minimal supersymmetric models. The analysis focused on the most sensitive final states, with two hadronically decaying τ-lepton candidates from an Higgs boson and one or two light leptons from the decay of S in a pair of W or Z boson, which decay hadronically or to neutrinos.

A MVA discriminant based on event kinematics is used to separate the signal from the background. No excess over the SM expectations is found, then upper limits between 72 fb and 542 fb are set on the cross-section $\sigma(pp \to X \to SH)$ assuming the same SM-Higgs boson-like decay branching ratios for the S particle decaying in a pair of W or Z bosons.

5 Vector-like leptons in a doublet model

A search for vector-like leptons (VLL) in final states with at least two light-leptons and zero or more hadronic τ-lepton decays has been provided by the ATLAS Collaboration [6]. VLL in a doublet model introduces two fermions $L' = \left(\nu'_\tau, \tau'\right)$, which are assumed to be degenerate

[1] The variable m_{T}^{τ} indicates the transverse mass of a τ-lepton.

in mass. Seven BDTs (one for each signal region) are trained looking for different leptons multiplicities and leptons charges, and they are used to maximize the discrimination of signal and backgrounds (including fake leptons) events.

No excess of events is observed beyond the SM expectation, thus excluding at 95% CL VLLs coupling to third-generation SM leptons in the mass range from 130 GeV to 900 GeV.

6 LeptoQuarks: $LQ \to b\tau$ and $LQLQ \to b\tau b\tau$

Leptoquarks (LQ) produced in association with a b-quark and decaying into a b-quark and a τ-lepton have been searched by the ATLAS Collaboration [7], including also LQ pairs and non-resonant production, due to similar final states. Two different channels are considered by the analysis, depending on the τ-lepton decay modes. Results are also interpreted in terms of vector and scalar LQ, and with a model-independent approach.
In the Yang-Mills (minimal coupling) scenario, vector LQs with a mass less than 1.58 (1.35) TeV are excluded at 95% CL for a gauge coupling of 1.0 and less than 2.05 (1.99) TeV for a gauge coupling of 2.5. Considering scalar LQs, masses below 1.28 (1.53) TeV are excluded at 95% CL for a Yukawa coupling of 1.0 (2.5).

The ATLAS Collaboration searched also for a pair-produced scalar or vector LQs decaying into a b-quark and a τ-lepton [8], in the same channels as the single LQ search. A parametrised neural network is used to enhance the signal sensitivity into two signal regions.

No significant excess over the SM expectation is observed. Assuming a branching ratio $\mathcal{B}(LQ \to b\tau) = 100\%$, scalar leptoquarks with masses below 1460 GeV are excluded at 95% CL, while for vector leptoquarks the corresponding limit is set to 1650 GeV (1910 GeV) in the minimal-coupling (Yang-Mills) scenario.

7 Excited τ-leptons

ATLAS presented a search for excited τ-leptons and LQs in events with two hadronically decaying τ-leptons and at least two jets. [9]. According to some models, SM quarks and leptons, could be composed by particles called *preons*. They predict the existence of excited states towering over the known SM leptonic and quark ground states.

A four-fermion contact interaction (CI) is assumed to produce an excited τ-lepton, with its consequent decay into a SM τ-lepton and a quark-antiquark pair. LQs are produced in pairs via the strong interaction, singly coupling to a charm or lighter quark and a τ-lepton.

Since no excess of data over the background prediction is observed, upper limits on the masses of these particles have been set. Excited τ-leptons with masses below 2.8 (4.6) TeV are excluded at 95% CL for CI scale set to 10 TeV (equal to the excited τ-lepton mass), while for LQs this limit is set to 1.3 TeV for a branching ratio $\mathcal{B}(LQ \to c\tau) = 100\%$.

8 Lepton flavour violation $Z' \to \ell\ell'$

Lepton Flavour Violation (LFV) in particle decay is allowed in the SM due to neutrino oscillations. However, the expected branching ratio is so tiny, that any evidence of LFV observed at LHC would be a signal of physics BSM.

The ATLAS Collaboration has searched for heavy particles decaying into different-flavours, in final states with two opposite-sign leptons, including hadronically decaying τ-leptons [10].

The analysis results are also interpreted in terms of: Z' boson LFV, Quantum Black Hole (QBH) and R-Parity Violating (RPV) SUSY.

No significant excess over the Standard Model predictions is observed. Different lower limits on the mass are set by the analysis at 95% CL depending on the considered scenario. In the $e\tau$ channel they are 4 TeV for LFV Z', 2.8 TeV for RPV SUSY and 5.2 TeV for QBH in the context of the ADD n=6.

9 Electroweak SUSY

Evidence for direct production of staus or charginos ($\tilde{\chi}^{\pm}_{1,2}$) and neutralinos ($\tilde{\chi}^{0}_{j}, j = 1,2,3,4$) in final states with at least two hadronically decaying τ-leptons has been searched by ATLAS in three analyses [11]. Intermediate decay via W and Higgs bosons or staus are also considered for chargino and neutralino production. Different signal regions are defined via a BDT to target the specific SUSY scenario.

No deviations from the SM prediction are found, and exclusion limits at 95% CL are set on the different models. In the scenario of direct stau production, mass-degenerate $\tilde{\tau}_{L,R}$ are excluded up to 500 GeV. For the direct production of a chargino pairs, $\tilde{\chi}^{\pm}_{1}$ masses are excluded up to 970 GeV, while $\tilde{\chi}^{\pm}_{1}$ and $\tilde{\chi}^{0}_{2}$ masses up to 1160 GeV (330 GeV) are excluded for $\tilde{\chi}^{\pm}_{1}\tilde{\chi}^{0}_{2}/\tilde{\chi}^{+}_{1}\tilde{\chi}^{-}_{1}$ production with subsequent decays via staus (W and Higgs bosons).

10 Conclusion

This proceeding provides an overview of the most recent results from the ATLAS Collaboration, searching for new phenomena in final states with isolated, high-p_{T} τ-leptons. All the presented analyses have been performed using data from LHC proton-proton collisions at $\sqrt{s} = 13$ TeV with 139 fb^{-1} and 140 fb^{-1} of integrated luminosity. Several kinds of signatures and models haven been explored to find for possible evidence of new physics events. No significant excesses with respect to the SM expectations have yet been observed and exclusion limits for several scenarios of Beyond the Standard Model physics are set.

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