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Search for the production of vector-like lepton pairs in final states containing tau-leptons with the ATLAS detector

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The '4321' renormalizable model proposes a mechanism that accommodates the experimental anomalies found in B-meson decays while remaining consistent with all other indirect flavor and electroweak precision measurements. Among the fundamental particles provided by the '4321' model are up to three families of Vector-Like Leptons (VLLs). Using the full dataset corresponding to 140 fb^{-1} of integrated luminosity collected by the ATLAS detector in pp collisions with $\sqrt{s} = 13$ TeV at the LHC, a search is presented for VLL pairs as predicted by the '4321' model. Signal-like events are selected with at least one hadronically decaying tau-lepton candidate, no light-leptons, and at least three b-tagged jets. No significant excess above the Standard Model background expectation is found, and 95% confidence level upper limits on the VLL production cross-section are derived as a function of the VLL mass. The observed (expected) lower limits on the VLL mass are 910 GeV (970 GeV).

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1. Introduction

The '4321' model [1] is an ultra-violet complete model that contains a gauge structure that is invariant under the local group $\mathcal{G}_{4321} \equiv SU(4) \times SU(3)' \times SU(2)_L \times U(1)'$. This model extends the Standard Model (SM) by introducing beyond the SM particles, which includes a colour octet (G'), a weak isospin-singlet vector leptoquark (U_1, electric charge 2/3e), a colour singlet Z' boson, and three generations of vector-like fermions: vector-like quarks (VLQ) $U/D, C/S, T/B$ and vector-like leptons (VLL) $N_1/E_1, N_2/E_2, N_3/E_3$. This model sets the VLLs to be SU(2) doublets with a charged and a neutral component.

This search [2], presented at the conference, targets the electroweak production of VLL pairs in pp collisions at $\sqrt{s}$ = 13 TeV using the Run-2 dataset collected by the ATLAS experiment [3]. The VLL pairs (E^+N, E^+E^- or $N\overline{N}$) are produced via decays of off-shell $W^\pm$ or Z/γ^* bosons in the '4321' model. Each VLL undergoes a 3-body decay via an off-shell U_1, decaying first into $E^+ \rightarrow U_1\bar{b}$ or $N \rightarrow \overline{U}_1 t$ followed by $U_1 \rightarrow t\bar{\nu}_\tau$ or $U_1 \rightarrow b\tau^+$, as shown in Figure 1. Such decays provide final states characterized by many jets, of which four contain a b-hadron (b-jets), and multiple hadronically decaying τ-leptons (τ_{had}).

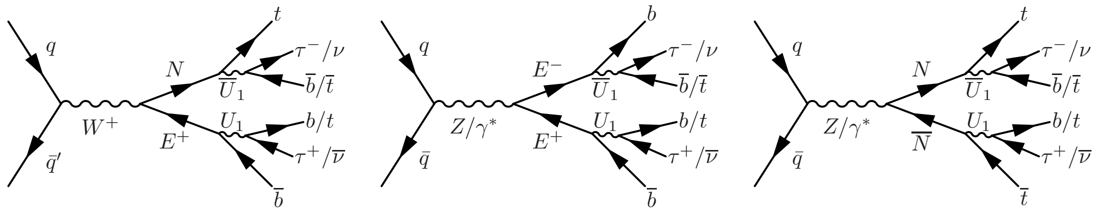

Figure 1: Illustrative Feynman diagrams for vector-like lepton pair production and decays in the '4321' model for $pp \rightarrow E^+N$, $pp \rightarrow E^+E^-$, and $pp \rightarrow N\overline{N}$ [2].

A previous search for VLLs in the '4321' model was performed by the CMS Collaboration [4], where a local 2.8σ excess was observed using the Run-2 data for the 600 GeV VLL mass (m_{VLL}). Somewhat milder excesses were present for other m_{VLL} values in the 500 - 1100 GeV range.

2. Search strategy and background estimation

Five orthogonal signal regions (SR) are defined in order to constrain the background and maximize the signal sensitivity. These SRs contain events selected by a combination of single-τ_{had}, di-τ_{had}, missing transverse energy ($E_{\text{T}}^{\text{miss}}$), and b-jet triggers containing at least one τ_{had} candidate, at the least three b-jets, and no light-leptons. Events containing one τ_{had} are split according to the trigger that selected the event, where events triggered by $E_{\text{T}}^{\text{miss}}$ and single-τ_{had} are separated from events selected by the b-jet triggers. These two categories of events are further split into two regions: one containing exactly three b-tagged jets, and the other containing at least four b-tagged jets. No splitting is applied for events containing at least two τ_{had}, where a single SR contains events with at least three b-tagged jets selected by a combination of single-τ_{had}, di-τ_{had}, and $E_{\text{T}}^{\text{miss}}$ triggers.

Multivariate analysis techniques are used to search for VLLs in all SRs. Neural Network (NN) score distributions, parametrised in terms of the VLL mass, are taken as the final discriminant variables to extract the signal.

The simultaneous likelihood fit is preceded by kinematic-dependent corrections, applied to $t\bar{t}$, $Z+$jets, and fake-τ_{had} backgrounds. These corrections are derived using dedicated selections and applied to the respective background events in all relevant analysis regions. For the $Z+$jets background, a correction dependent on the number of jets is applied. For the fake-τ_{had} background, corrections are applied depending on each fake-τ_{had} transverse momentum and the number of associated tracks. As for the $t\bar{t}$ background, corrections are applied according to the number of jets in the event, the truth flavour of the additional QCD jets produced, and the truth kinematics of the top-quark pair present in the event.

Multijet background originating from QCD processes is estimated using two data-driven methods: the matrix method for channels with a single τ_{had}, while for di-τ_{had} channels, the event yield of opposite-charged di-τ_{had} are estimated from same-charge di-τ_{had} events, where charge symmetry in the multijet background is assumed.

Besides the pre-fit corrections, seven dedicated control regions (CRs) are used to normalise the leading backgrounds and constrain their systematic uncertainties in the likelihood fit to data: $Z+$jets (categorised into light- and heavy-flavour additional jets), $t\bar{t}$ (split according to the additional b-jets or c-jets from the QCD emissions), and multijet (separated according to the estimation method).

3. Results

A maximum-likelihood fit is performed for each signal hypothesis on all bins of the signal and control regions. Figure 2 displays a comparison of the distributions of observed and expected events in the five SRs and seven CRs after the combined likelihood fit under the background-only hypothesis, considering the mass of 1 TeV in the evaluation of NN score distribution. No significant pulls or constraints are found in the nuisance parameters. There are no strong correlation factors among the fitted values of the normalisation parameters of $t\bar{t}+$jets, $Z+$jets and multijet background.

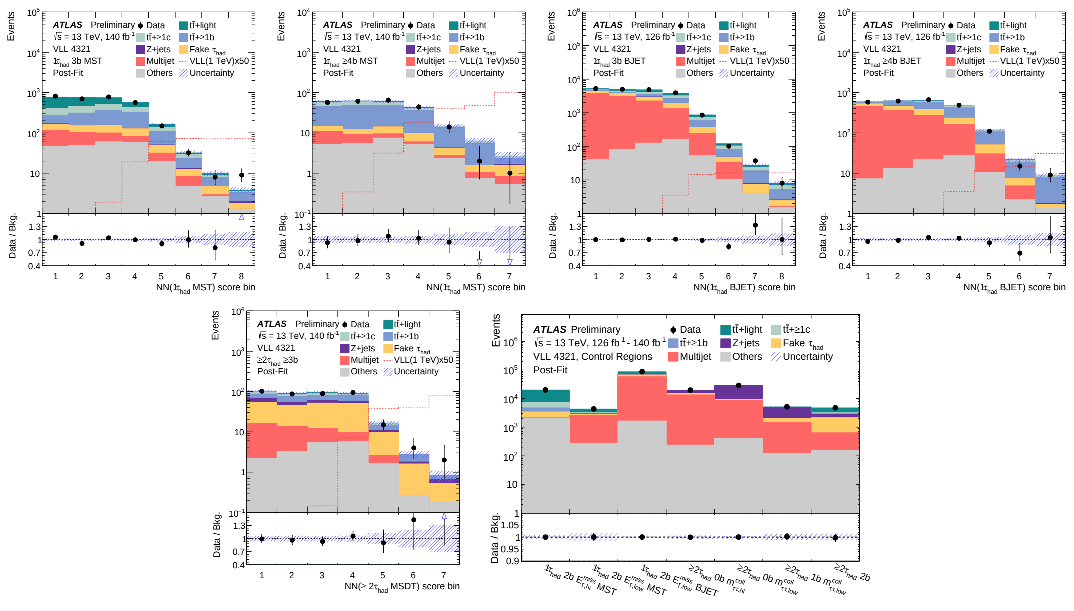

Figure 2: Comparison between data and background predictions for the event yields in the SRs and CRs [2].

The main uncertainty sources in this analysis come from the limited size of the simulated Monte Carlo and real data samples, followed by the background normalisations and $t\bar{t}$ modelling.

In general, good agreement between the data and predicted background yields is found across all event categories. The observed p-value, representing the probability of the data being compatible with the background-only hypothesis, is checked for each explored signal scenario, and the smallest value is found to be 0.13, corresponding to a local significance of 1.1σ, for the 400 GeV signal point.

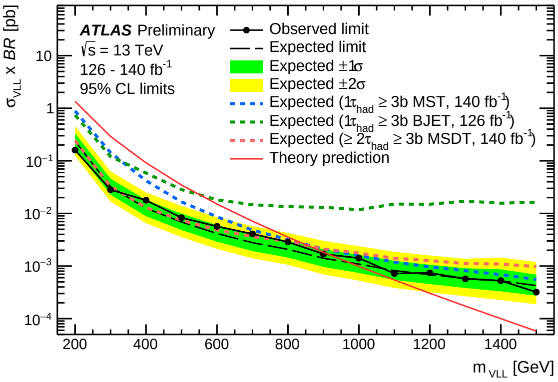

Figure 3: Observed (solid line with markers) and expected (dashed line) 95% CL upper limits on the VLL pair production cross-section (σ_{VLL}) times branching ratio (BR) to third generation quarks and leptons as a function of m_{VLL} [2].

In the absence of any significant excess above the SM background prediction, 95% confidence level (CL) upper limits are set on the cross-section for the VLL pair production as a function of the assumed m_{VLL}. Figure 3 shows the 95% CL upper limits on the VLL pair production cross-section as a function of m_{VLL}. The observed and expected 95% CL lower limits on m_{VLL} are 910 GeV and 970 GeV, respectively.

This first ATLAS result on the search for VLLs undergoing a 3-body decay into third-generation SM fermions disfavours the 2.8σ excess at the 600 GeV VLL mass reported by the CMS Collaboration [4]. The ATLAS observed p_0 for the same representative signal mass point is 0.18, corresponding to a local significance of 0.9σ. The 95% CL observed (expected) upper limit on the signal cross-section for the VLL mass of 600 GeV is 5.8 fb (4.1 fb).

References

[1] L. Di Luzio, J. Fuentes-Martin, A. Greljo, M. Nardecchia and S. Renner, Maximal Flavour Violation: a Cabibbo mechanism for leptoquarks, JHEP 11 (2018) 081, arXiv: 1808.00942 [hep-ph].

[2] ATLAS Collaboration, Search for electroweak production of vector-like leptons in multiple tau and b-jets final states in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, ATLAS-CONF-2024-008, https://cds.cern.ch/record/2904563.

[3] ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003.

[4] CMS Collaboration, Search for pair-produced vector-like leptons in final states with third-generation leptons and at least three b quark jets in proton-proton collisions at $\sqrt{s}$ = 13 TeV, Phys. Lett. B 846 (2023) 137713, arXiv: 2208.09700 [hep-ex].