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 model

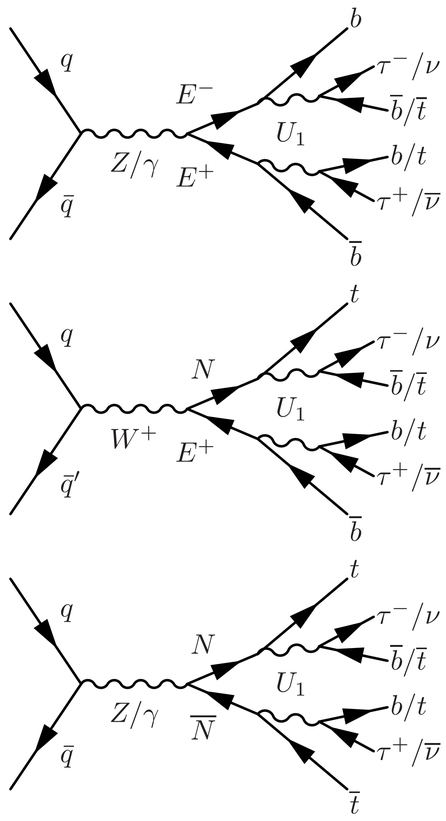
The 4321 model [1] is a UV-complete model that extends the SM with a new symmetry group:

$$SU(4) \times SU(3)' \times SU(2)_L \times U(1)'$$

- It introduces:
  - Color octet (g'), Vector LQ (U_μ), Color singlet (Z').
  - VLQ doublets: U/D, C/S, T/B.
  - VLL doublets: N_1/E_1, N_2/E_2, N_3/E_3.
- Accommodates B-meson anomalies.
- VLLs have a mass around 1 TeV.
- VLLs decays via off-shell vector LQ U_1 into third generation quarks and leptons.
- The electroweak production of VLL pairs offers a phenomenology with multiple taus, b-jets, jets, leptons, and E_T^{miss}.

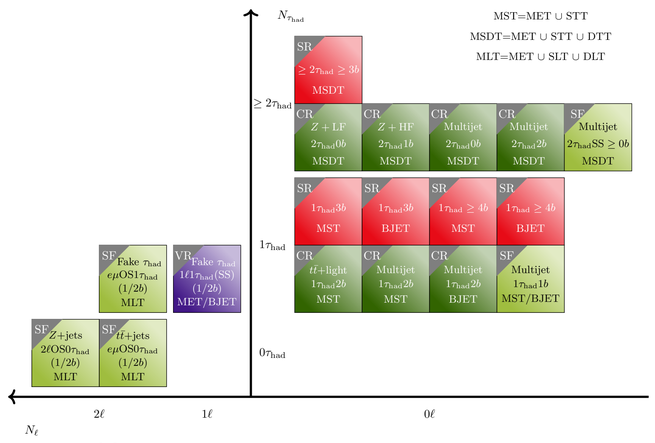
$$1\tau \begin{bmatrix} EN \to b(b\tau)t(t\nu) \\ EE \to b(b\tau)b(t\nu) \\ NN \to t(b\tau)t(t\nu) \end{bmatrix} \quad 2\tau \begin{bmatrix} EN \to b(b\tau)t(b\tau) \\ EE \to b(b\tau)b(b\tau) \\ NN \to t(b\tau)t(b\tau) \end{bmatrix}$$

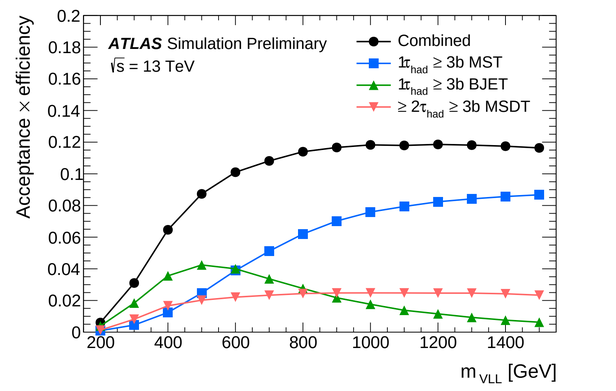
- 2.8σ excess seen by the CMS experiment [2].



Search strategy

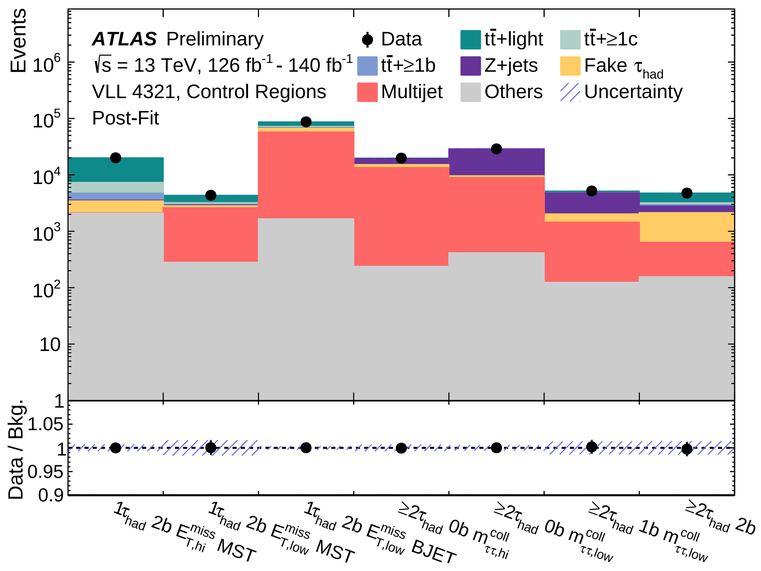
- Orthogonal signal regions analyzing different τ multiplicities with ≥ 3 b-jets and no light-leptons.
- Improved use of ATLAS triggered data by categorizing events in orthogonal "trigger buckets".
- E_T^{miss}, single-tau, di-tau, and b-jet triggers composing the MET, STT, DTT, and BJET buckets, respectively.
- Mass-parameterized neural network score as discriminating variable in the joint likelihood fit to data.
- 3 neural network trainings: 1τ MST, 1τ BT, $\geq 2\tau$ MSDT.
- **Signal regions:** $1\tau/\geq 2\tau, \geq 3b, 0\ell$
- **Control regions:** $1\tau, 2b$; $2\tau OS \times (0b, 1b, 2b)$
- **Background corrections:** $\geq 1\ell$ channels used for V+jets, $t\bar{t}$, and fake τ_{had} corrections. $1\tau, 1b$ and 2τSS for multijet background estimations.

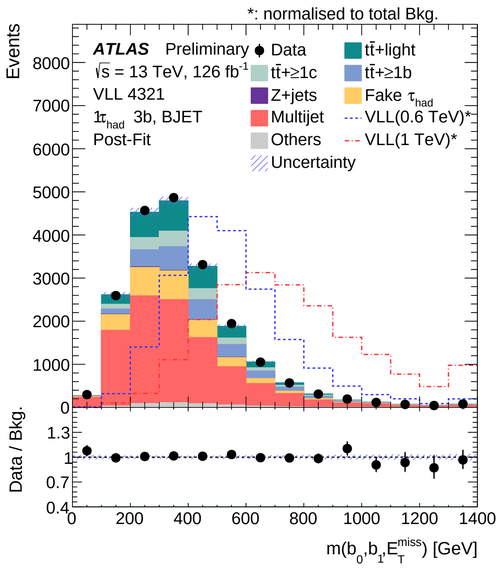


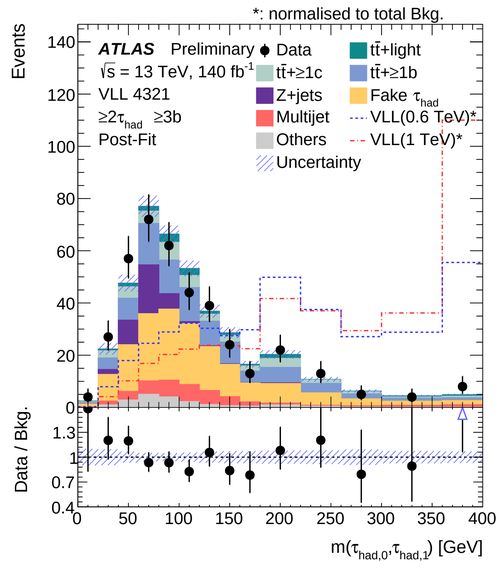


Background estimation

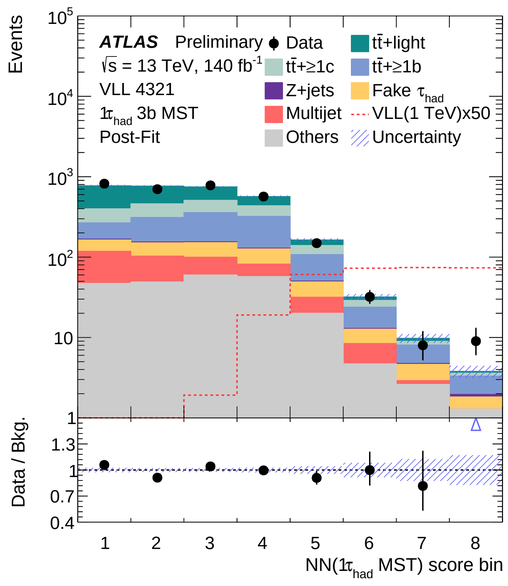
- N_{jets}-dependent correction for Z+jets events.
- Reweighting to theory, heavy-flavour scaling, and N_{jets}-dependent correction for $t\bar{t}$ events.
- Fake τ_{had} background corrected using a semi-data-driven approach.
- Multijet background estimated with the matrix method in the 1τ regions.
- 2τOS multijet background estimated assuming charge symmetry: $N_{\text{QCD}}^{2\tau\text{OS}} = N_{\text{QCD}}^{2\tau\text{SS}}$.
- Control Regions designed to measure Z+jets, $t\bar{t}$, and multijet background normalisations, which free-float in the fit to data.
- **Uncertainties:** The main uncertainty sources in this analysis come from Monte Carlo and data statistics, followed by the background normalisations and $t\bar{t}$ modelling.

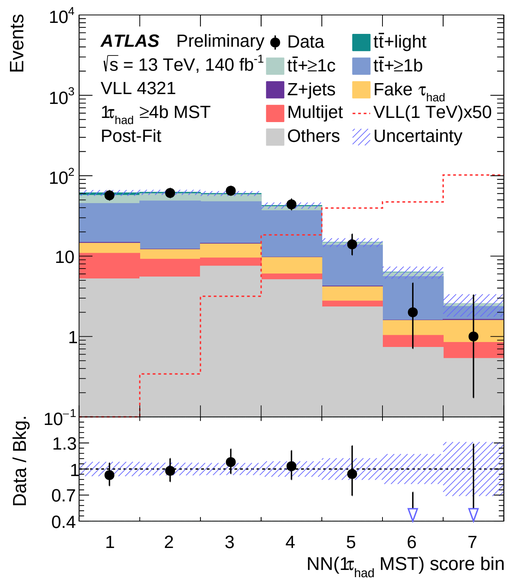


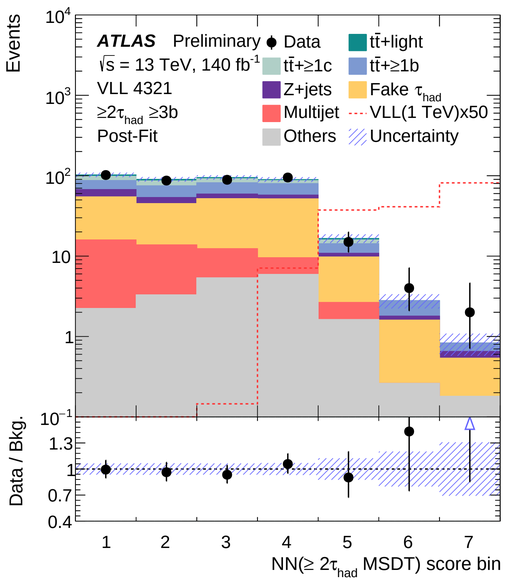


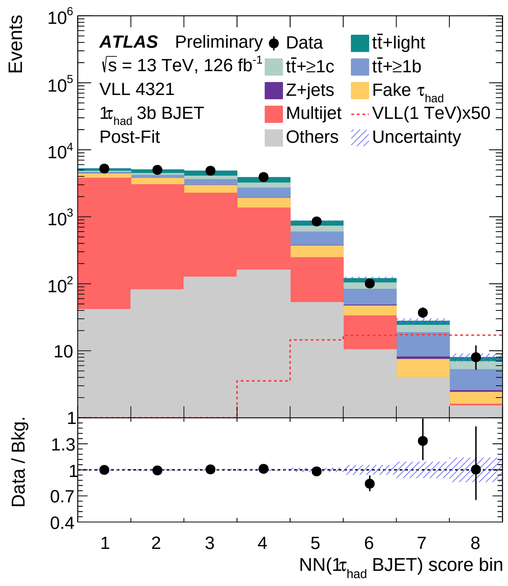


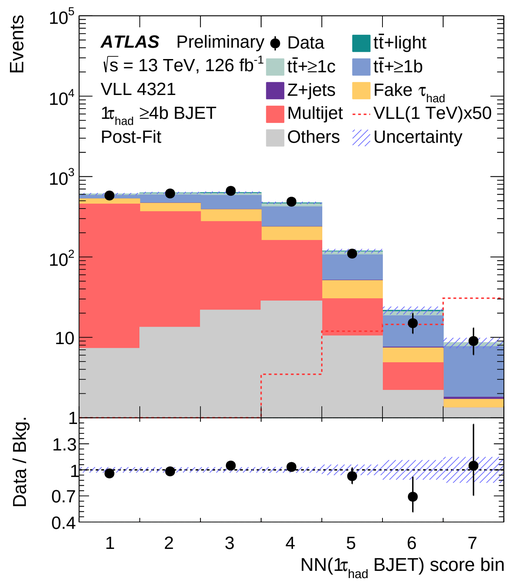
Signal regions





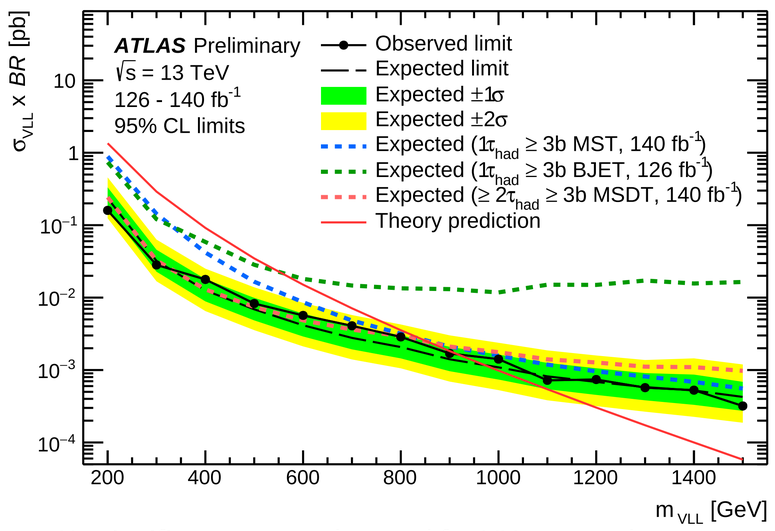






- 1τ MST: E_T^{miss} and single-τ triggers. Dominates sensitivity at high m_{VLL}. Mainly $t\bar{t}$ events.
- 1τ BJET: b-jet triggers. Contributes at low m_{VLL}. Dominated by $t\bar{t}$ and multijet backgrounds.
- $\geq 2\tau$ MSDT: E_T^{miss}, single-τ, and di-τ triggers. Dominates at low m_{VLL}. Mainly $t\bar{t}$ events with real or fake τ_{had}.
- Good agreement between data and the Standard Model background following the background-only fit to data.

Expected and observed limits



- No significant excess observed for VLL masses between 200 and 1500 GeV.
- Highest local significance reaching slightly over 1σ (1.1σ for the 400 GeV mass point).
- The 95% CL upper limits on the production cross-section times branching ratio into third generation SM fermions sets a lower observed (expected) limit on the VLL mass at 910 GeV (970 GeV).
- Signal-like excess observed by CMS is not confirmed.

References

[1] L. Di Luzio *et al*. JHEP 11 (2018) 81.

[2] CMS Collaboration. Phys. Lett. B 846 (2023) 137713.