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Searches for lepton-flavour-violating decays of the Higgs boson into $e\tau$ and $\mu\tau$ in $\sqrt{s} = 13$ TeV TeV pp collisions with the ATLAS detector

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This document presents direct searches for lepton flavour violation in Higgs boson decays, $H \rightarrow e\tau$ and $H \rightarrow \mu\tau$, performed using data collected with the ATLAS detector at the LHC. The searches are based on a data sample of proton–proton collisions at a centre-of-mass energy $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 138 fb^{-1}. Both leptonic ($\tau \rightarrow \ell\nu_\ell\nu_\tau$) and hadronic ($\tau \rightarrow$ hadrons ν_τ) decays of the τ-lepton are considered and two background estimation techniques are employed: the MC-template method, based on data-corrected simulation samples, and the data-driven Symmetry method, based on exploiting the symmetry between electrons and muons in the Standard Model backgrounds. The observed (expected) upper limits set on the branching ratios at 95% confidence level, $\mathcal{B}(H \rightarrow e\tau) < 0.20\%$ (0.12%) and $\mathcal{B}(H \rightarrow \mu\tau) < 0.18\%$ (0.09%), are obtained with the MC-template method from a simultaneous measurement of potential $H \rightarrow e\tau$ and $H \rightarrow \mu\tau$ signals. The best-fit branching ratio difference, $\mathcal{B}(H \rightarrow \mu\tau) - \mathcal{B}(H \rightarrow e\tau)$, measured with the Symmetry method in the channel where the τ-lepton decays to leptons, is $(0.25 \pm 0.10)\%$, compatible with a value of zero within 2.5σ.

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[*] Speaker

1. Introduction

While lepton flavour is an accidental symmetry of the Standard Model (SM), the observation of neutrino oscillations indicates that it is not an exact symmetry of nature. For the charged sector, many SM extensions predict lepton flavour violating (LFV) decays of the Higgs boson. This article presents the direct searches for LFV decays of the Higgs boson into $e\tau$ and $\mu\tau$ using pp collision data from ATLAS [1] at $\sqrt{s} = 13$ TeV collected during the period from 2015 to 2018, corresponding to an integrated luminosity of 138 fb^{-1}.

2. Analysis strategy, background estimation, multivariate and statistical analysis

The analysis searches for two independent signals: $H \to e\tau$ and $H \to \mu\tau$. Two channels: $\ell\tau_{\ell'}$ and $\ell\tau_{\text{had}}$ are considered, corresponding to the leptonic ($\tau \to \ell' \nu_{\ell'} \bar{\nu_\tau}$) and hadronic ($\tau \to$ hadrons ν_τ) decays of the τ-lepton, where ℓ / ℓ' is used to denote electrons and muons, also referred to as ‘light leptons’.

This analysis considered the main production modes of the Higgs boson: gluon fusion, vector boson fusion (VBF) and associated production with a vector boson. Events are first filtered by the *Baseline* selection criteria and then further classified into two statistically independent categories, VBF and non-VBF, based on the kinematic properties of the jets produced in association with the Higgs boson candidate.

Regarding background estimation, two different methods are employed. The ‘Symmetry’ method is applied to the $\ell\tau_{\ell'}$ channel only, while the ‘MC-template’ method is applied to both $\ell\tau_{\ell'}$ and $\ell\tau_{\text{had}}$ channels.

The Symmetry method is a data-driven approach which is based on the assumption that the SM processes are symmetric with respect to the exchange of a prompt electron and a prompt muon. This symmetry would be broken if there is signal of LFV decays with $\mathcal{B}(H \to e\tau) \neq \mathcal{B}(H \to \mu\tau)$. In this method, the data are split into two samples ($e\tau$ and $\mu\tau$) according to the kinematic distributions of the two selected leptons. One sample then can be used as a background estimation of the other, while the different detector efficiencies between electron and muon are corrected. The lepton efficiencies are estimated as a product of the reconstruction, identification and isolation efficiencies, and are applied per event, depending on the kinematic properties of the electron and muon. Other asymmetries due to misidentified objects, mainly arising from τ_{had} misidentified as light leptons and photons as electrons, are corrected by a data-driven method.

For the MC-template method, all backgrounds but the misidentified objects are estimated using Monte Carlo (MC) simulation. In the $\ell\tau_{\ell'}$ channel, the main background contributions arise from top-quark production, $Z \to \tau\tau$, diboson processes and events with misidentified leptons. The top-quark and $Z \to \tau\tau$ background normalisations are obtained from data using additional control regions (CRs). The diboson process modelling is checked in an additional validation region. The events with lepton being misidentified from heavy-flavour decays, photon conversion, a jet or a τ_{had} are estimated through data-driven techniques, based on the control regions with same-sign lepton charge pair or inverted isolation. In the $\ell\tau_{\text{had}}$ channel, the main background contributions arise from the $Z \to \tau\tau$, top-quark and events with jet misidentified as τ_{had}. The $Z \to \tau\tau$ background normalisation is constrained by data in the signal regions, while that of the top-quark background is constrained using the $\ell\tau_{\ell'}$ top-quark CRs in the simultaneous fit of the $\ell\tau_{\text{had}}$ and $\ell\tau_{\ell'}$ channels. Same as the $\ell\tau_{\ell'}$ channel, the diboson process modelling is validated in a dedicated validation region. The misidentified τ_{had} background is estimated using data-driven techniques based on control regions with inverted τ-lepton identification.

To enhance the separation of signal from various background contributions, two MVA techniques are employed. Fully connected deep neural networks (NNs) are applied to the Symmetry method, while boosted decision trees (BDTs) are applied to the MC-template method. The choices of input kinematic variables and hyperparameters are optimized separately for $\ell\tau_{\ell'}$ and $\ell\tau_{\text{had}}$ channels, and for VBF and non-VBF categories. For the MC-template method, a final score is obtained from the combination of individual BDTs trained with signal against various backgrounds. For the Symmetry method, a combination of three NNs is used for the VBF category, while multiclassifier NNs are used for the non-VBF category. These final MVA scores are then used as the final discriminants for the statistical analysis. Figure 1 shows the plots of the post-fit MVA score distributions from three categories.

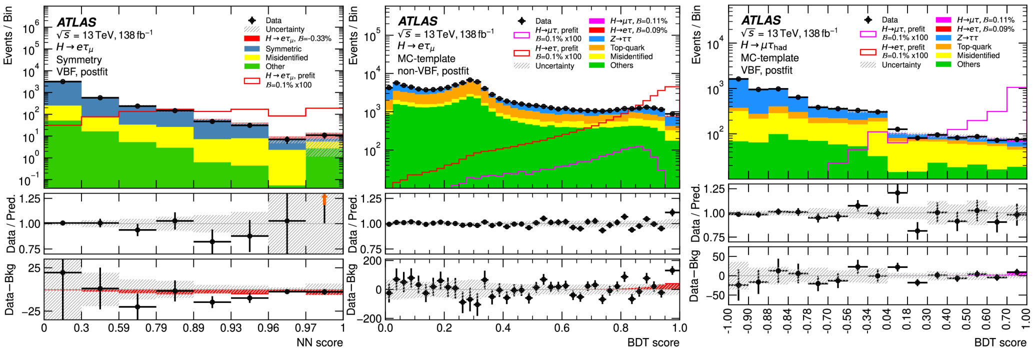

Figure 1: Post-fit MVA score distributions in the Symmetry method $e\tau_\mu$ VBF (left), the MC-template $e\tau_\mu$ non-VBF (centre) and the MC-template $\mu\tau_{\text{had}}$ VBF (right) categories.

3. Results

The statitsical analysis uses a likelihood profile fit and the branching ratios ($\mathcal{B}$) of the LFV processes, $\mathcal{B}(H \to e\tau)$ and $\mathcal{B}(H \to \mu\tau)$, are the parameters of interest (POIs). Three different statistical anlayses are performed, differing in the POI definitions and replying on different inputs from the two background estimation methods:

- 1 POI fit: Independent fit of $\mathcal{B}(H \to e\tau)$ or $\mathcal{B}(H \to \mu\tau)$. One is assumed to be zero when fitting the other. Samples are taken from the combination of the Symmetry and the MC-template method.
- 2 POI fit: Simultaneous fit of $\mathcal{B}(H \to e\tau)$ and $\mathcal{B}(H \to \mu\tau)$. Only the samples from the MC-template method are utilized.
- Branching ratio difference: A fit for $\mathcal{B}(H \to e\tau) - \mathcal{B}(H \to \mu\tau)$, which utilized the Symmetry method in the $\ell\tau_{\ell'}$ channel only.

For the 1 POI fit, the choice of combining the MC-template and the Symmetry methods is based on the overall expected sensitivity of the combination. The Symmetry method is chosen for the $\ell\tau_{\ell'}$ VBF category, with the rest of the samples taken from the MC-template method. The independent fits on each branching ratio give the observed (expected) limits at 95% confidence level (CL) of 0.23% (0.12%) for $H \to e\tau$ and 0.17% (0.09%) for $H \to \mu\tau$, which a 1.9σ and 2.2σ of excess is observed for each channel respectively.

For the 2 POI fit, the observed (expected) upper limits are constrained to be 0.20% (0.12%) for $H \to e\tau$ and 0.18% (0.09%) for $H \to \mu\tau$, which is compatible with SM within 2.1σ.

The best-fit value of the branching ratio difference is found to be $\mathcal{B}(H \to e\tau) - \mathcal{B}(H \to \mu\tau) = 0.25 \pm 10\%$, which is compatible with zero within 2.5σ.

The results of both the 2 POI fit and the branching ratio difference are presented in Figure 2.

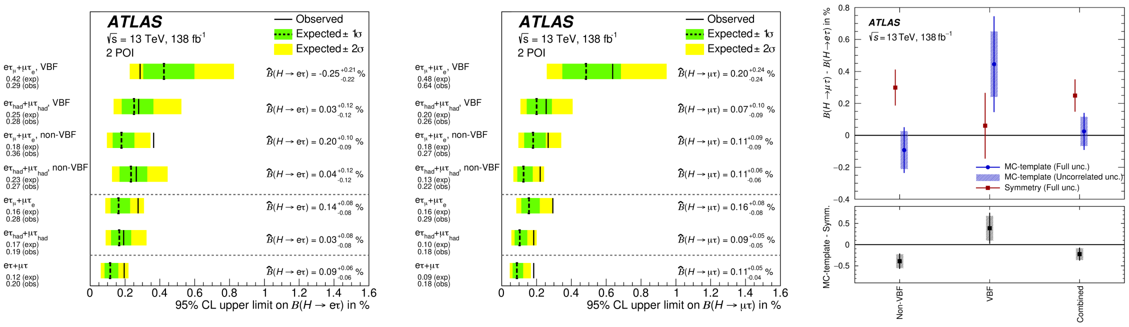

Figure 2: The best-fit results and the 95% CL upper limits on the LFV branching ratios of the Higgs boson, taken from the simultaneous 2 POI on $H \to e\tau$ (left) and $H \to \mu\tau$ (centre), and the best-fit value of the branching ratio difference with the $\ell\tau_{\ell'}$ samples from the Symmetry method (right). [2]

4. Conclusion

These proceedings present direct searches for lepton-flavour-violating decays of the Higgs boson into $e\tau$ and $\mu\tau$ final states, based on the full Run 2 datasets of pp collisions at a centre-of-mass energy $\sqrt{s}$ = 13 TeV, corresponding to an integrated luminosity of 138 fb^{-1}. Two different background estimation methods are employed. The observed (expected) upper limits at 95% confidence level are 0.20% (0.12%) for $H \to e\tau$ and 0.18% (0.09%) for $H \to \mu\tau$. The best-fit value of the branching ratio difference is $\mathcal{B}(H \to e\tau) - \mathcal{B}(H \to \mu\tau) = 0.25 \pm 10\%$.

References

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

[2] A. Colloboration, *Searches for lepton-flavour-violating decays of the Higgs boson into $e\tau$ and $\mu\tau$ in $\sqrt{s}$ = 13 TeV pp collisions with the ATLAS detector*, JHEP **07** (2023) 166, arXiv: `2302.05225 [hep-ex]`.