The 15th International Workshop on Tau Lepton Physics

Search for flavor-changing neutral currents in the top-quark decays $t \to Hq$ with $H \to \tau^+\tau^-$ in proton-proton collisions at $\sqrt{s} = 13$ TeV

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ATLAS EXPERIMENT

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Abstract

A search for flavour-changing neutral current (FCNC) decays of a top quark decaying to an up-type quark (q = u, c) and the Standard Model (SM) Higgs boson in the di-tau final state is presented. The analysis uses a data sample collected in 2015 and 2016, which corresponds to a total integrated luminosity of 36.1 fb^{-1} of $\sqrt{s} = 13$ TeV proton-proton collisions recorded with the ATLAS detector at the Large Hadron Collider. No deviation from the SM expectation is observed. Model-independent upper limits are derived for the FCNC decaying branching ratio. The result is combined with analyses targeting other Higgs decay channels, which allows to set even stronger limits.

Introduction

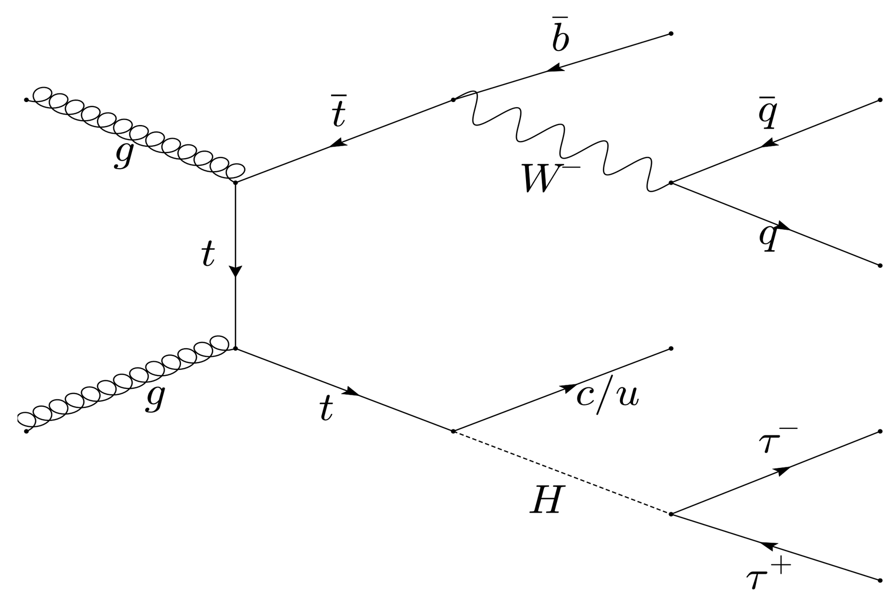
Motivation:

- The observation of tqH interactions would directly point to the new physics with new interactions:

$$\mathcal{L} = \lambda_{tcH}\bar{t}Hc + \lambda_{tuH}\bar{t}Hu + h.c.$$

- Good sensitivity: $H \to \tau^+\tau^-$ decay branching ratio is decent. τ lepton selection can significantly reduce background.

Signal topology:



Topology Reconstruction

- **To find the jet from top FCNC decay:**
Minimize $\Delta R_x, x = 3j, 4j$ among all of the possible combinatorics for 3jet, ≥4jet events respectively.

$$\Delta R_{4j} \equiv \Delta R(j_{\mathrm{FCNC}}, H) + \Delta R(j_1, b) + \Delta R(j_2, b) + \Delta R(j_1, j_2)$$
$$\Delta R_{3j} \equiv \Delta R(j_{\mathrm{FCNC}}, H) + \Delta R(j_W, b)$$

Where j_{FCNC} denotes the FCNC jet candidate, j_i denotes the i-th jet from W decay. b denotes the b-jet.

- **To find the 4-momenta of neutrinos:**
Scan the 4-momanta of the neutrinos to mimimize χ^2. (Assuming they are massless)

$$\chi^2 = -2\ln\mathcal{P}_1 - 2\ln\mathcal{P}_2 + \left(\frac{m_{\tau_1}^{\mathrm{fit}} - 1.78}{\sigma_\tau}\right)^2 + \left(\frac{m_{\tau_2}^{\mathrm{fit}} - 1.78}{\sigma_\tau}\right)^2 + \left(\frac{m_H^{\mathrm{fit}} - 125}{\sigma_{\mathrm{Higgs}}}\right)^2 + \left(\frac{E_{x,\mathrm{miss}}^{\mathrm{fit}} - E_{x,\mathrm{miss}}}{\sigma_{\mathrm{miss}}}\right)^2 + \left(\frac{E_{y,\mathrm{miss}}^{\mathrm{fit}} - E_{y,\mathrm{miss}}}{\sigma_{\mathrm{miss}}}\right)^2$$

Where $\mathcal{P}$ is the probability obtained by MMC method. The footnote "fit" means the value is derived from the reconstructed neutrinos.

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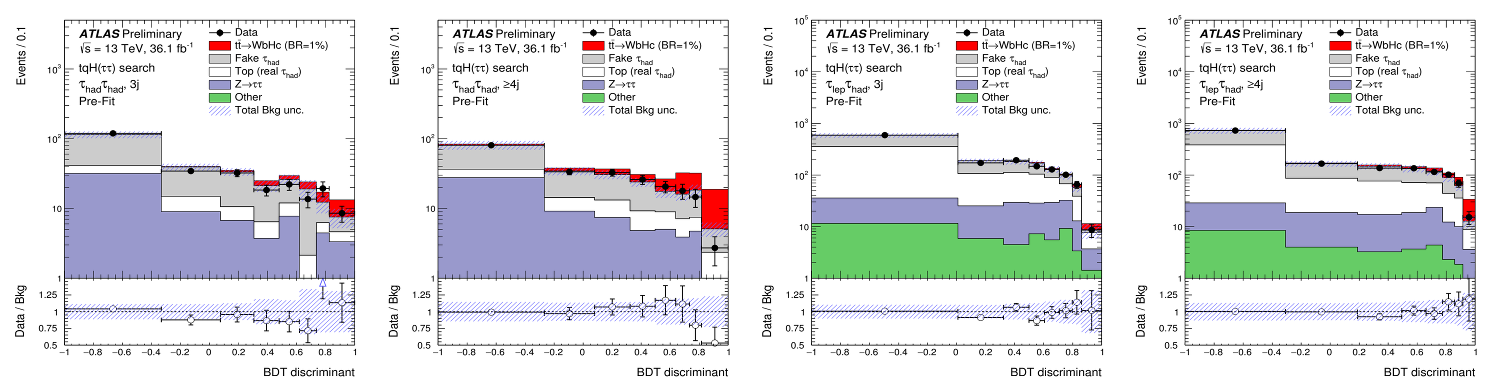
Multi-Variate Analysis

The Multi-Variate Analysis (MVA) takes advantage of the information derived from the topology reconstruction. The input variables include the invariant masses of Higgs, W bosons, top quarks. The missing transverse energy, the energy fraction of visible decay product of τ leptons are also used.



Results

Apply the MVA method to improve the separation of signal and background. A combined fit is conducted based on the MVA discriminant to study the statistics. No deviation from the SM expectation is observed. Upper limits are derived for the FCNC decaying branching ratio.

limits in %	$t \to Hc$	$t \to Hu$
Expected	$0.21^{+0.11}_{-0.06}$	$0.20^{+0.10}_{-0.06}$
Observed	0.19	0.17

Event Selection and Categorisation

Exactly one b-tagged jet.

Categories	**Exactly one e/μ at least one Loose τ**	**Veto e/μ, at least two Loose τ's the leading tau is medium**
At least 4 jets	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$, ≥4jet	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$, ≥4jet
Exactly 3 jets	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$, 3jet	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$, 3jet

Standard Model Background

Irreducible background:

- $t\bar{t}$ process with real τ leptons.
- Di-boson background.
- $Z \to l^+l^-$.

Reducible background:

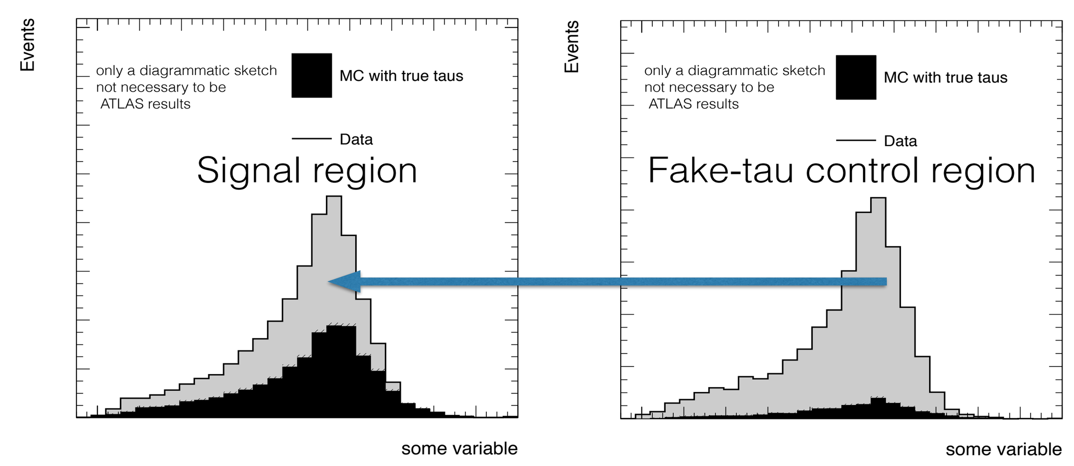
- multi-jet process.
- $t\bar{t}$ process with fake τ leptons.
- W+jets.

Background Estimate

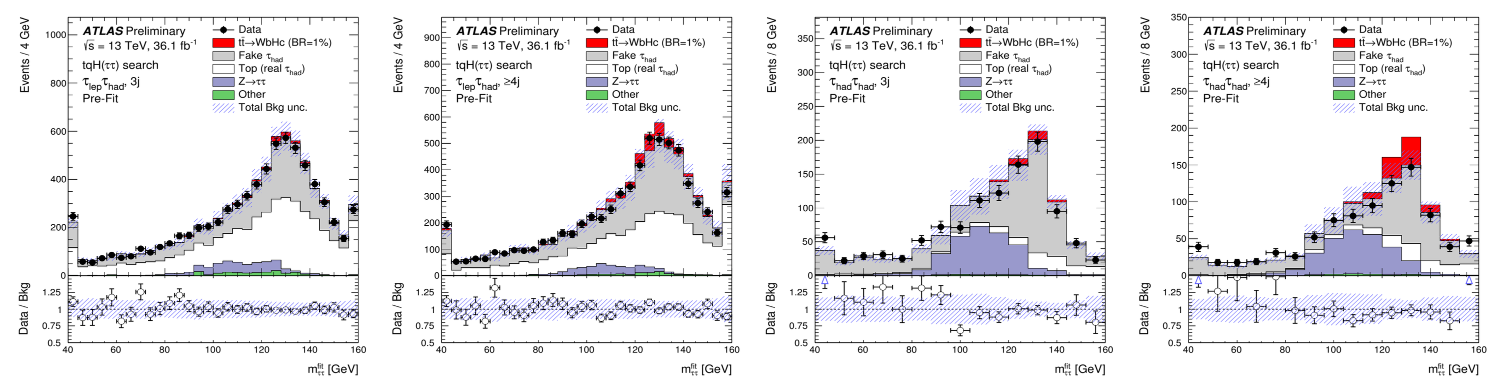
In order to model the reducible background (also called fake background), a data-driven method is adopted. After the pre-selection, the signal region (SR) and fake-tau control region (CR) are defined as follows:

The leading (sub-leading) tauID in $\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ ($\tau_{\mathrm{had}}\tau_{\mathrm{had}}$) categories	**Opposite charged**	**Same charged**
Medium	Signal region	
Anti-Medium	Fake-tau control region	

The reducible background in SR is represented by the fake events in fake-tau CR indicated below with a normalization factor:



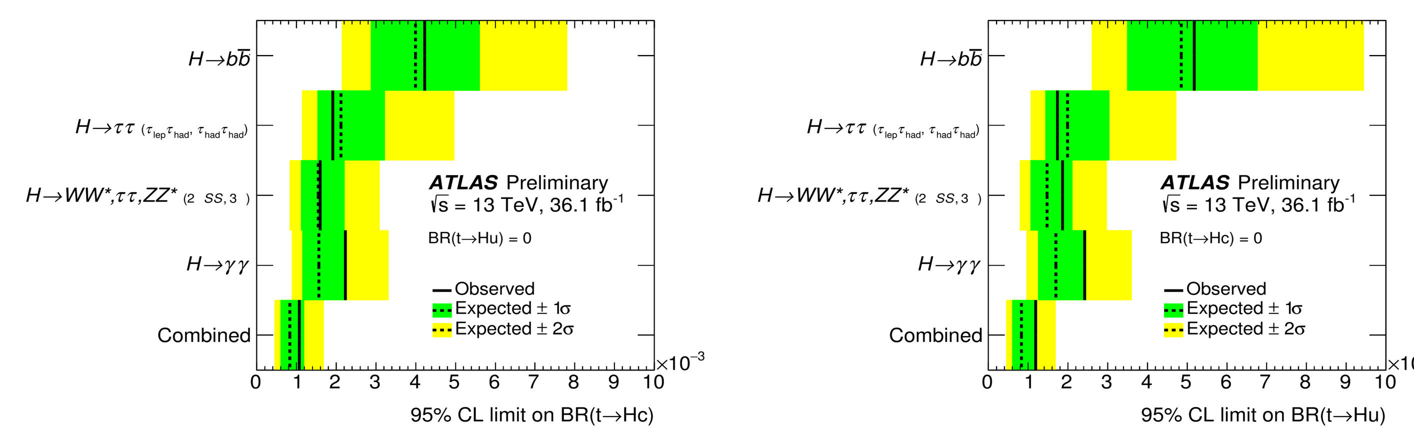
The control plots shows good agreement between data and predictions (pre-fit):



Combination

The results are combined with $H \to bb$, $H \to \gamma\gamma$, multi-lepton searches:

	95% CL upper limits on $\mathcal{B}(t \to Hc)$ Observed (Expected)	95% CL upper limits on $\mathcal{B}(t \to Hu)$ Observed (Expected)
$H \to b\bar{b}$	4.2×10^{-3} (4.0×10^{-3})	5.2×10^{-3} (4.9×10^{-3})
$H \to \tau\tau$ ($\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$, $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$)	1.9×10^{-3} (2.1×10^{-3})	1.7×10^{-3} (2.0×10^{-3})
$H \to WW^*, \tau\tau, ZZ^*$ (2ℓSS, 3ℓ)	1.6×10^{-3} (1.5×10^{-3})	1.9×10^{-3} (1.5×10^{-3})
$H \to \gamma\gamma$	2.2×10^{-3} (1.6×10^{-3})	2.4×10^{-3} (1.7×10^{-3})
Combination	1.1×10^{-3} (8.3×10^{-4})	1.2×10^{-3} (8.3×10^{-4})



$Br(t \to cH) \sim 10^{-3}$ in 2HDM with flavour violating Yukawa couplings is expected.

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