Search for FCNC with top quark and Higgs at ATLAS experiment

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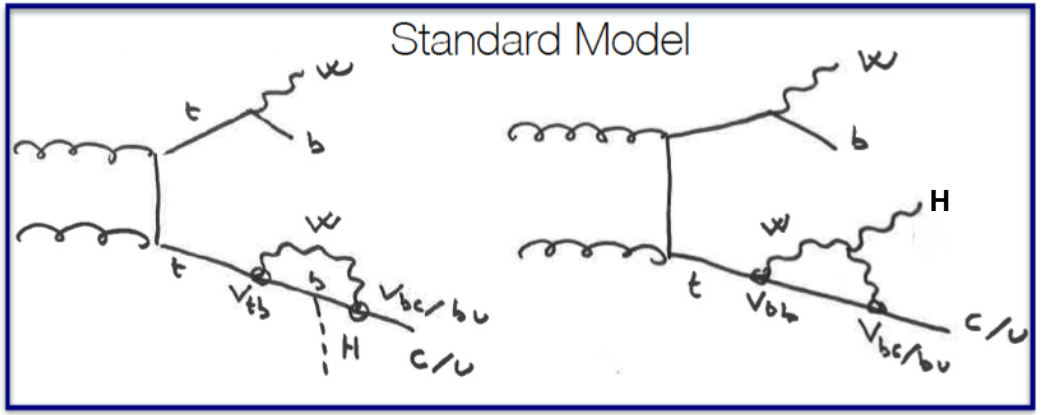
Introduction

- Flavor changing neutral current (FCNC) in the decay of t→Hq (q=u,c) is highly suppressed in the SM
  - ➢ The GIM can render partial cancelation among the loop amplitudes where the Higgs is irradiated by a W



$$V_{tb}V_{cb}^{*} + V_{ts}V_{cs}^{*} + V_{td}V_{cd}^{*}$$

- BR can be enhanced by BSM:

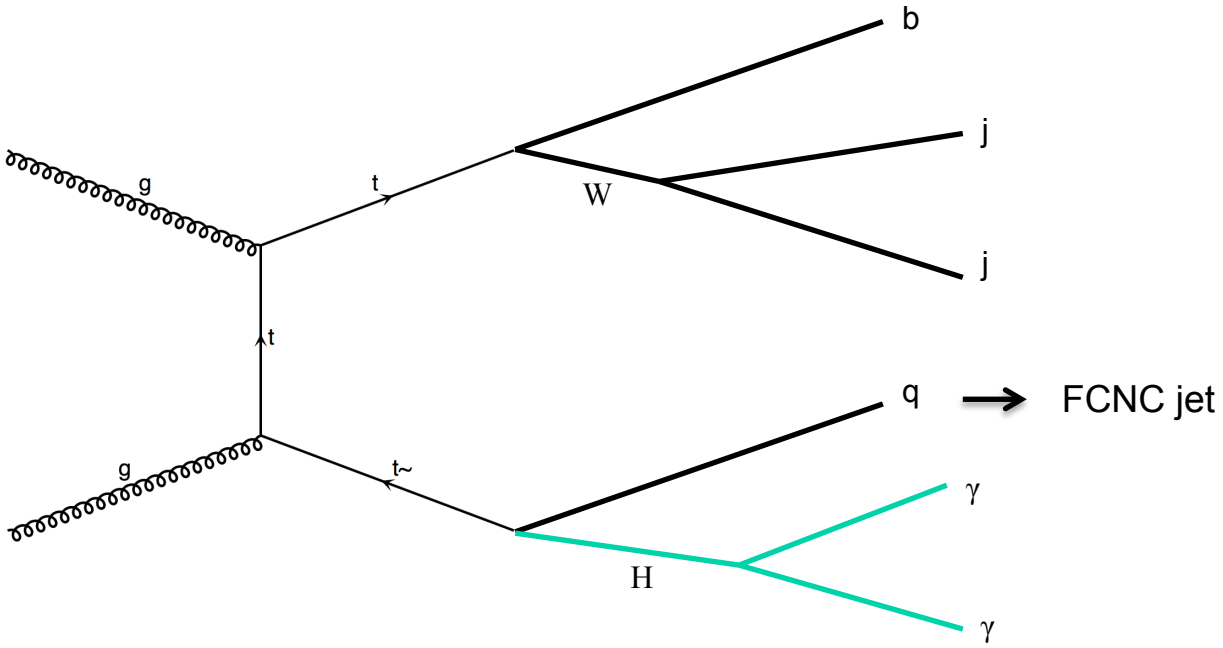
	SM	QS	2HDM	FC 2HDM	MSSM	RPV SUSY
BR(t→Hu)	2×10^{-17}	$\sim10^{-5}$	$\sim10^{-5}$	-	$\sim10^{-5}$	$\sim10^{-6}$
BR(t→Hc)	3×10^{-15}	$\sim10^{-5}$	$\sim10^{-3}$	$\sim10^{-5}$	$\sim10^{-5}$	$\sim10^{-6}$

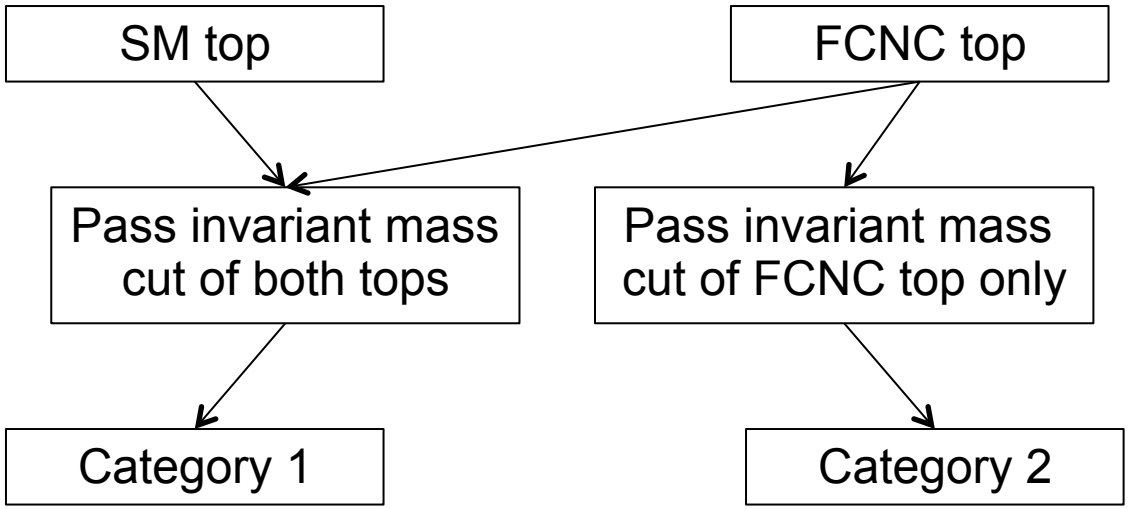
[PRD 67 (2003) 035003, PRD 55 (1997) 3156, PRD 75 (2007) 075021, PRD 58 (1998) 055001, PRD 75 (2007) 015002, et al.]

FCNC t→qH(γγ) search

[JHEP 10 (2017) 129]

Events with 2 photons ,
p_T > 40, 30 GeV,
100 < $m_{\gamma\gamma}$ < 160 GeV



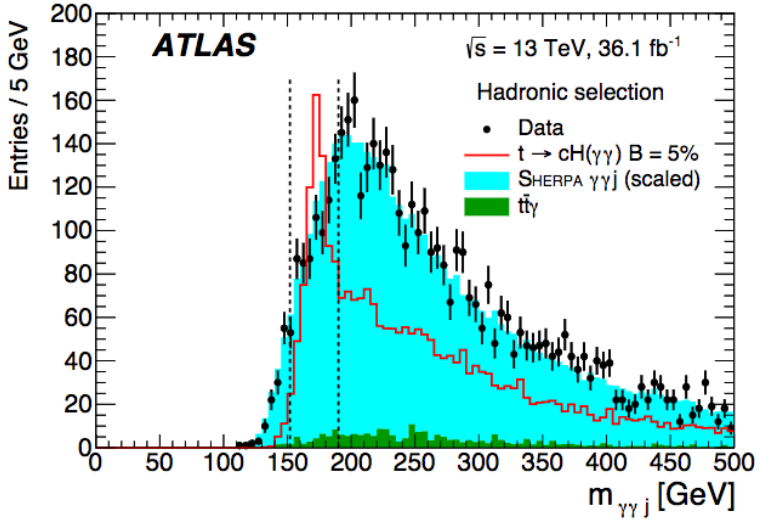


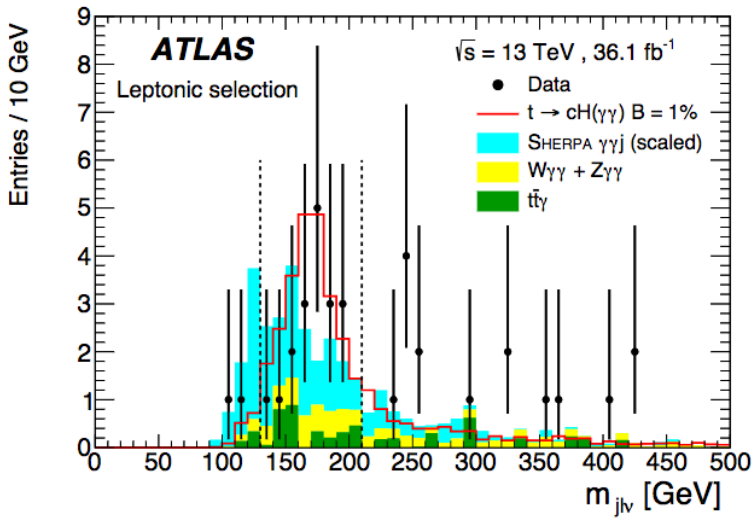
Events are further divided into leptonic and hadronic modes depending on the other top decay

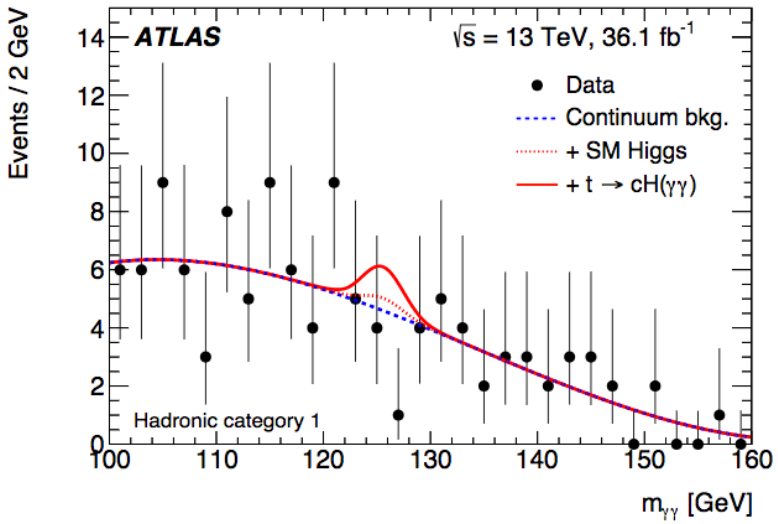
4/2 jets for hadronic/ leptonic channels

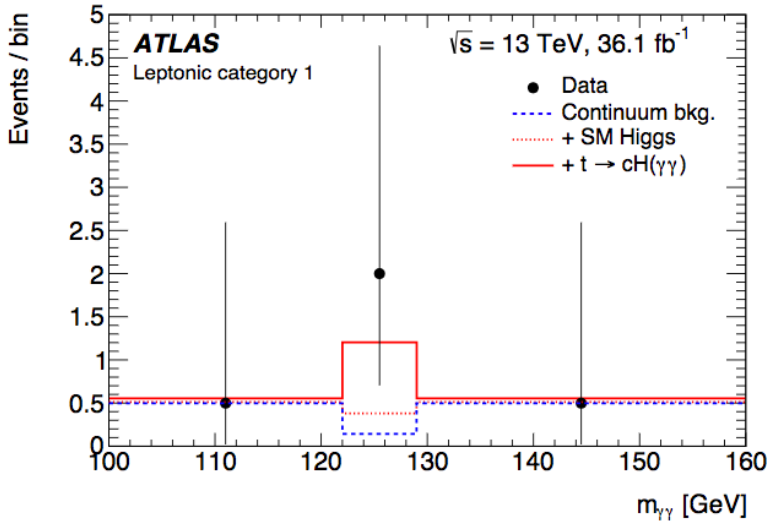
FCNC t→qH(γγ) search

[JHEP 10 (2017) 129]





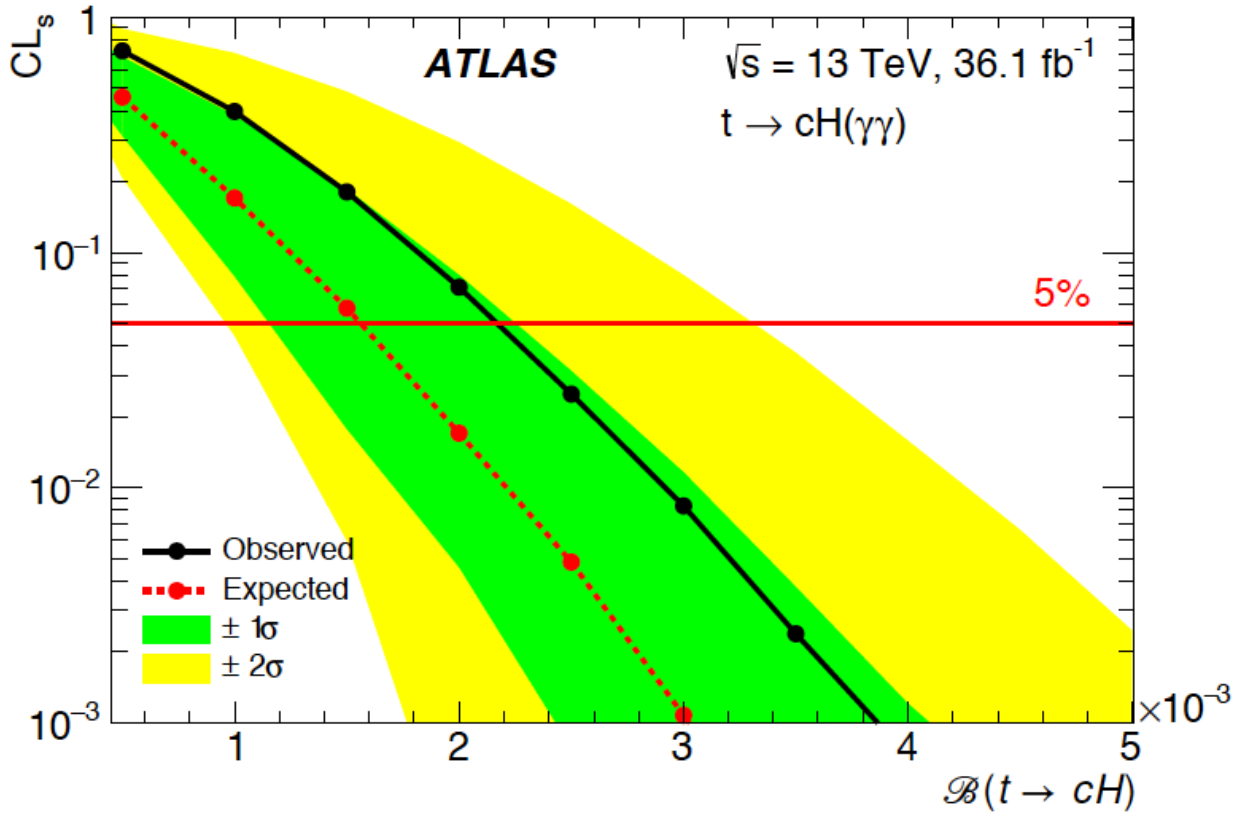




Fit the $m_{\gamma\gamma}$ spectra to extract the sensitivity

FCNC t→qH(γγ) search

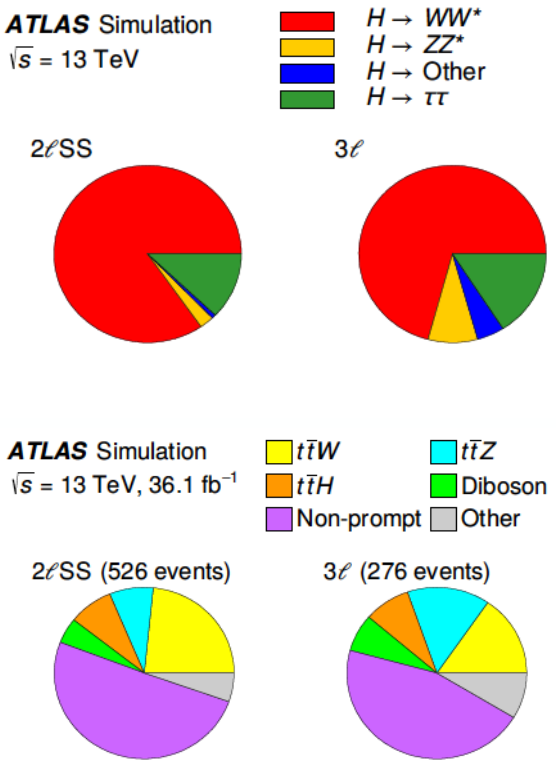
[JHEP 10 (2017) 129]



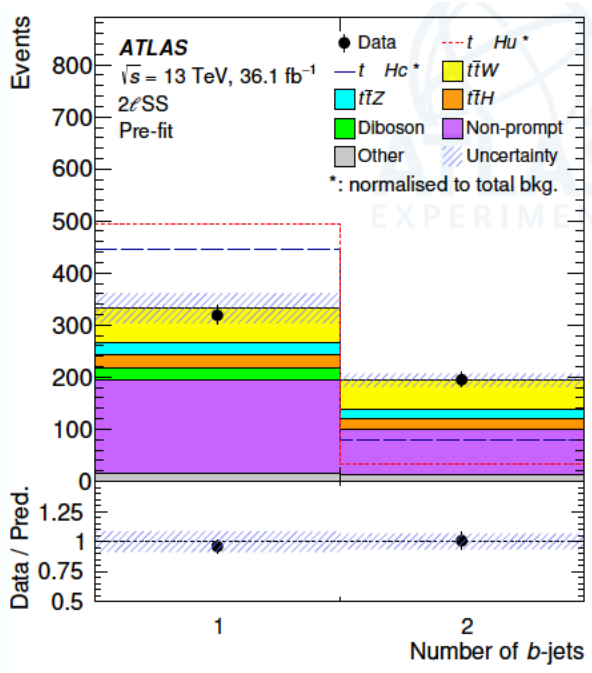
Obs. (exp.) BR(t→uH) (%)	Obs. (exp.) BR(t→cH) (%)
0.24 (0.17)	0.22 (0.16)

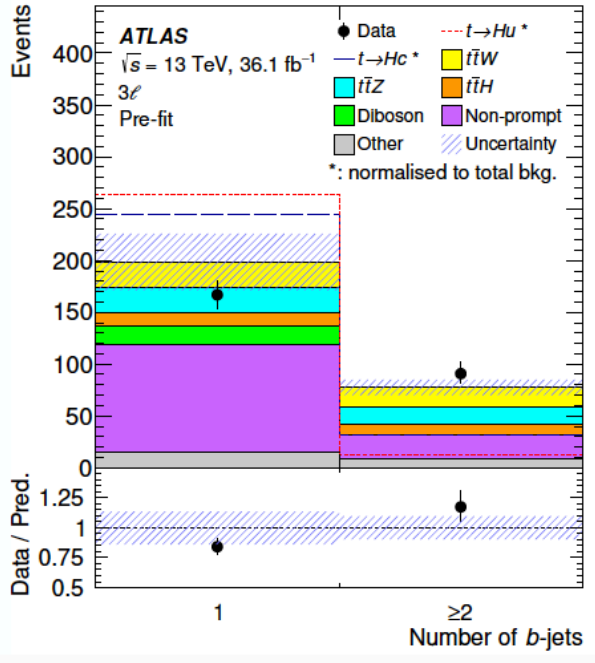
FCNC t→qH with multilepton (ML) search

- Same production, but search for H→ττ,WW*,ZZ* with 2 or 3 leptons (e/μ) in the final state
  - ➢ Same-sign 2 leptons, ≥4 jets, 1 or 2 b-jets
  - ➢ 3 leptons, ≥2 jets, ≥1 b-jet



[PRD 98 (2018) 032002]



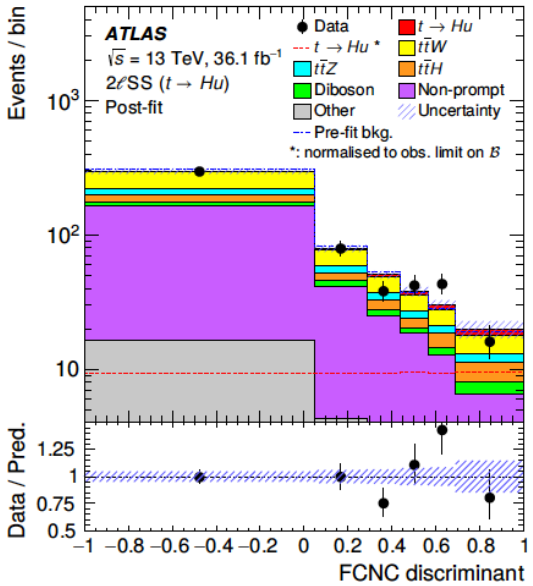


FCNC t→qH with multilepton (ML) search

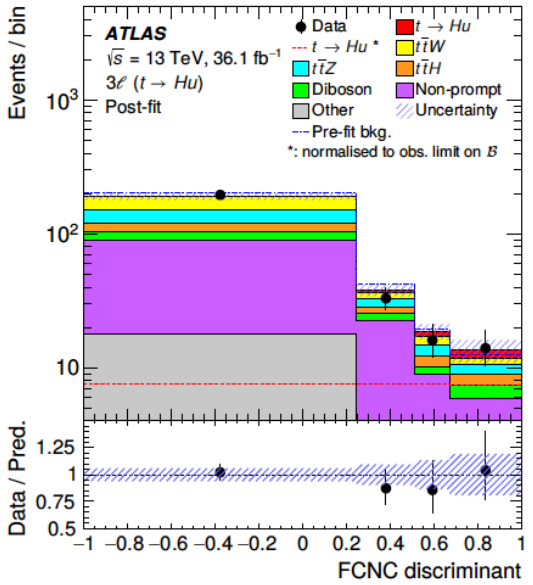
- Re-use ttH analysis, update new background estimation and new BDT training

[PRD 98 (2018) 032002]

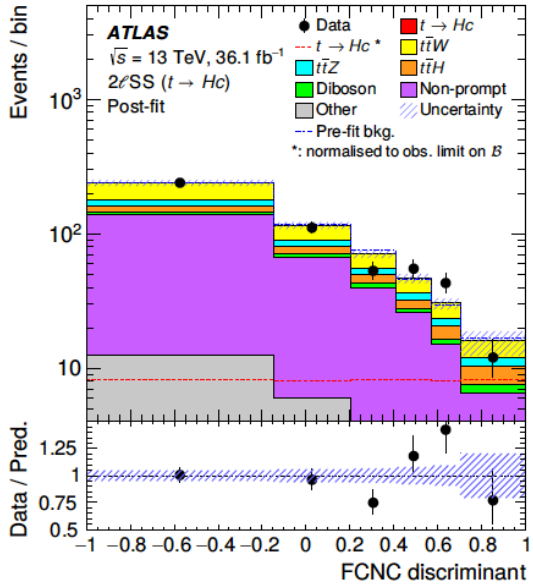
2*l* SS t→uH



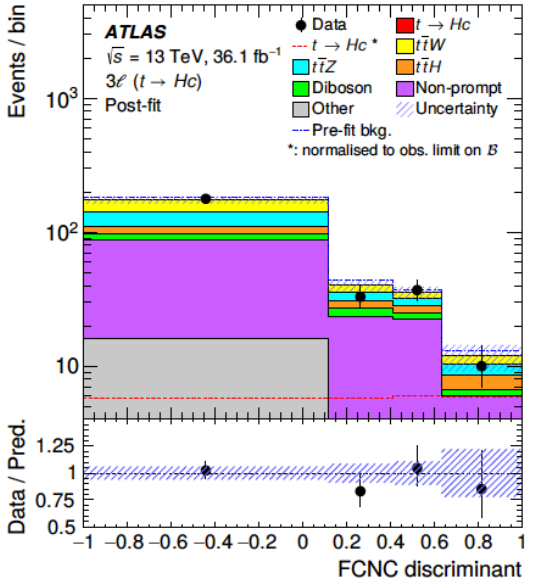
3*l* t→uH



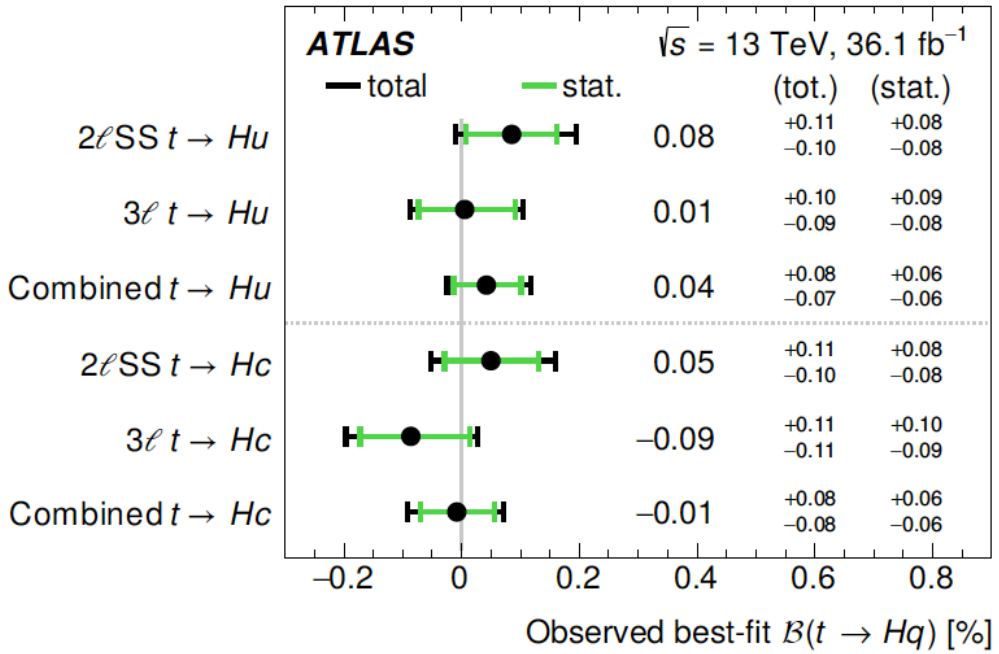
2*l* SS t→cH

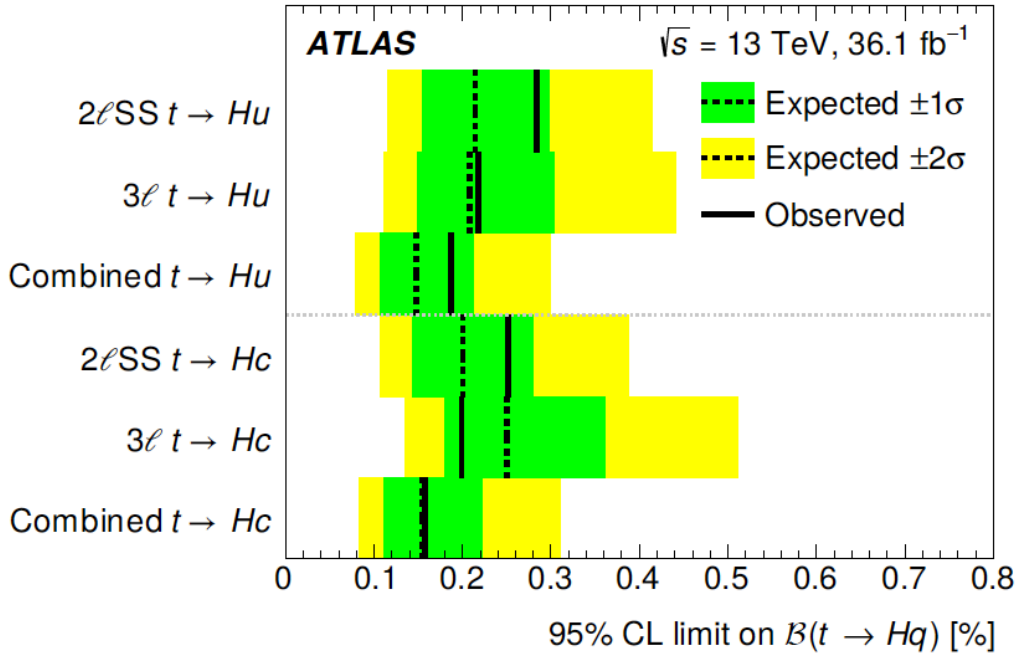


3*l* t→cH



FCNC t→qH with multilepton (ML) search



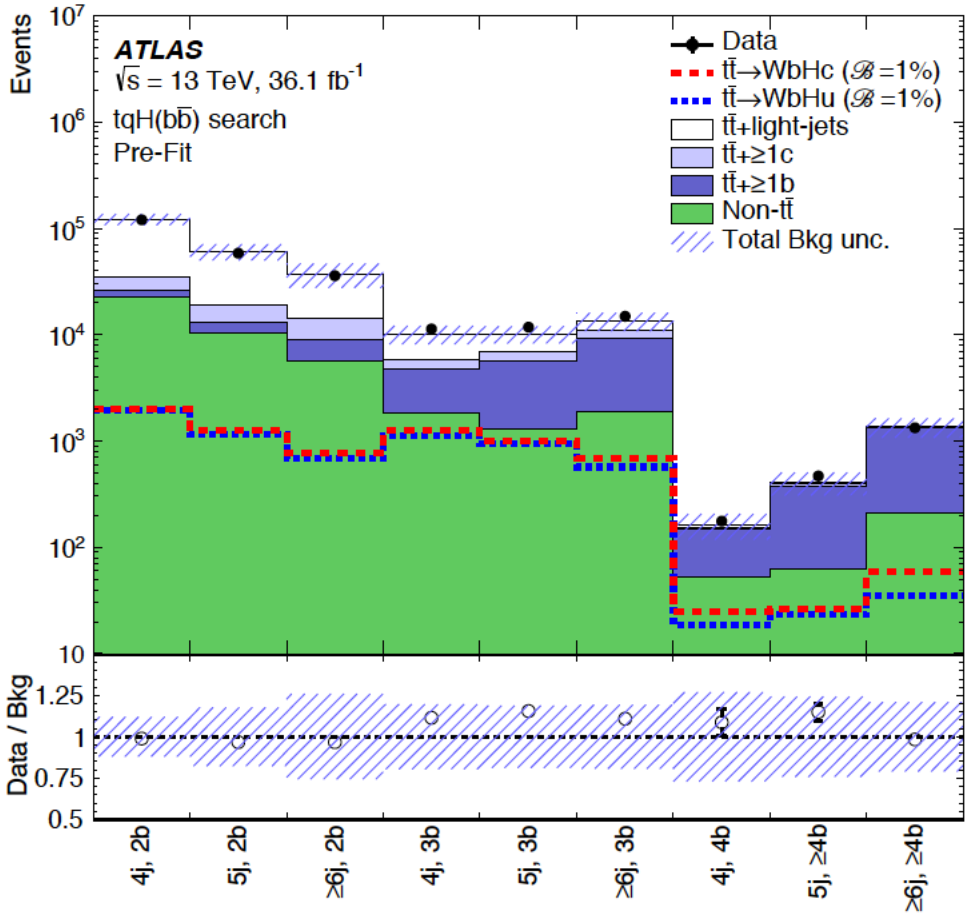


[PRD 98 (2018) 032002]

Obs. (exp.) BR(t→uH) (%)	Obs. (exp.) BR(t→cH) (%)
0.16 (0.15)	0.19 (0.15)

FCNC t→qH(bb) search [arXiv:1812.11568]

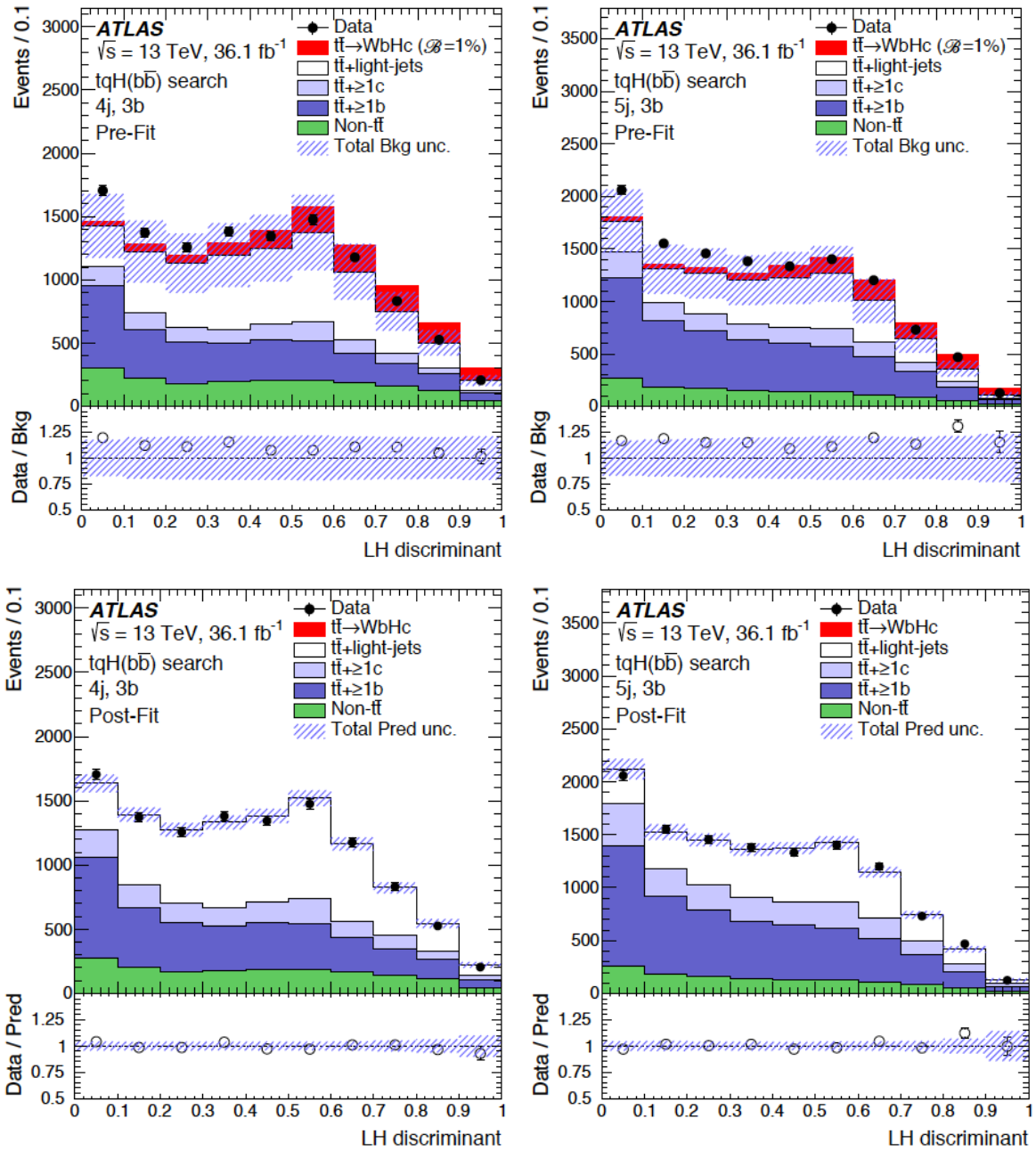
- Require exactly 1 lepton, ≥4 jets, ≥2 b-jet
- 9 analysis regions with different combinations of n jets + m b-jets



- Most sensitive regions are 5j,3b and 4j,3b

FCNC t→qH(bb) search

[arXiv:1812.11568]

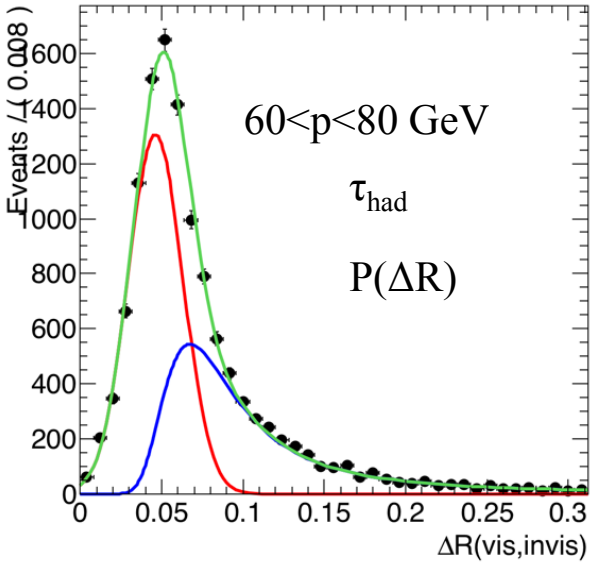


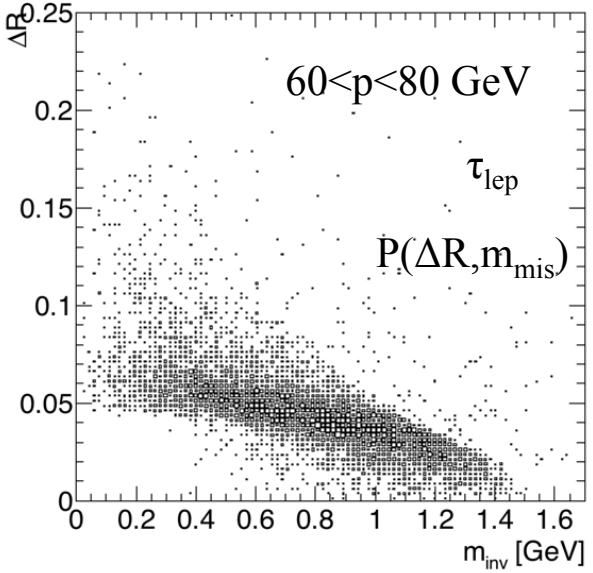
- Use Likelihood (LH) discriminant based on two-body and three-body invariant masses that correspond to the expected resonances under signal ans background hypotheses per event

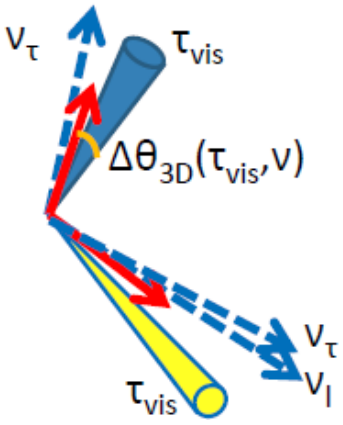
$$L(\mathbf{x}) = \frac{P^{\mathrm{sig}}(\mathbf{x})}{P^{\mathrm{sig}}(\mathbf{x}) + P^{\mathrm{bkg}}(\mathbf{x})}$$

FCNC t→qH(ττ) search

- Due to boosted taus, the neutrinos from tau decay tend to be aligned with the visible tau decay products. Assuming exact collinearity, the di-tau mass can be uniquely reconstructed ("collinear mass")
- However, ATLAS used a mass reconstruction method, which builds a likelihood that incorporates tau decay kinematics – MMC, which improves the di-tau mass reconstruction







Hadronic and leptonic taus are parameterized (based on MC info.) differently, depending on if the total invisible 4-vetor has a mass

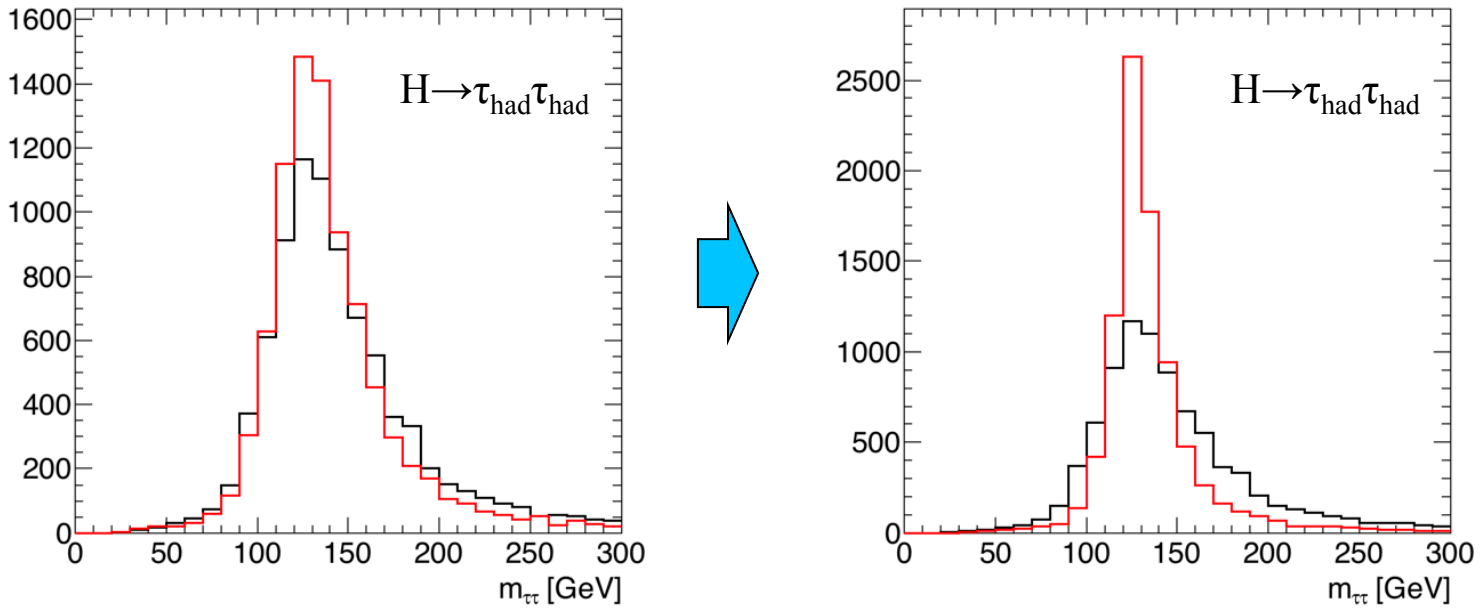
H→ττ Mass [PRD 93 (2016) 113010]

- The invisible 4-vectors from tau decays are obtained per event by minimizing a combined χ^2:

$$\chi^2 = -2\ln P_1 - 2\ln P_2 + \left(\frac{m_{\tau_1}^{fit} - 1.78}{\sigma_\tau}\right)^2 + \left(\frac{m_{\tau_2}^{fit} - 1.78}{\sigma_\tau}\right)^2 + \left(\frac{m_H^{fit} - 125}{\sigma_H}\right)^2 + \left(\frac{E_{x,mis}^{fit} - E_{x,mis}}{\sigma_{mis}}\right)^2 + \left(\frac{E_{y,mis}^{fit} - E_{y,mis}}{\sigma_{mis}}\right)^2$$

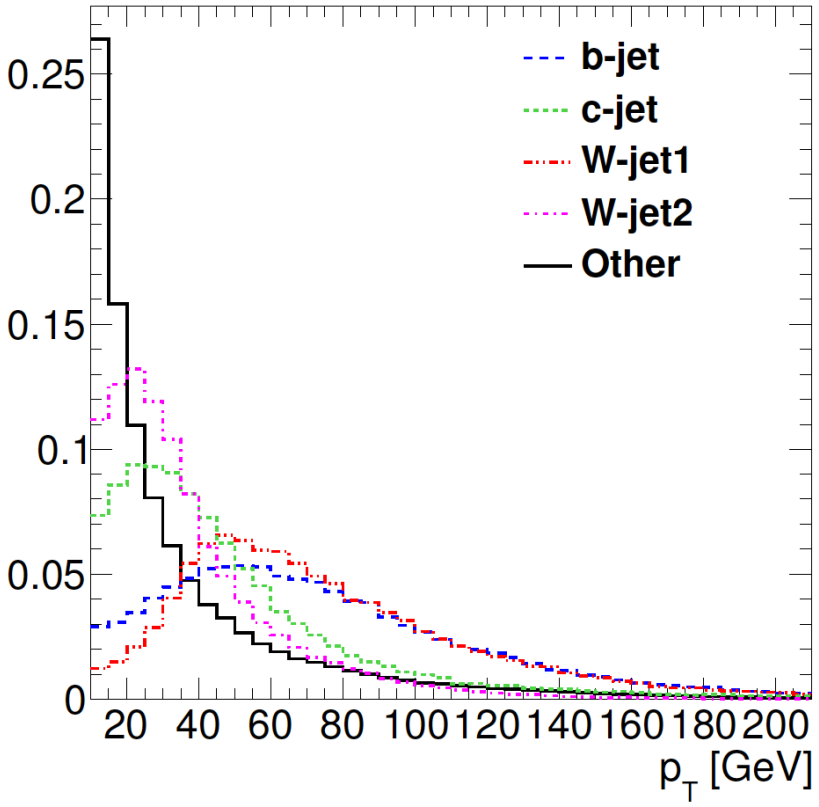
Tau Kinematics Constraint | Higgs Mass | MET Constraint

The H→ττ mass resolution improves with different constraints:



Black: MET constraint only (collinear mass)
Red (left): MET + tau kinematics constraint
Red (right): MET + tau kinematics constraint + Nominal Higgs mass constraint

Signal categorization ($t\to qH$, $H\to\tau\tau$) [PRD 93 (2016) 113010]



Assigning jets to the signal topology ($t\bar{t} \to WbHc \to qqb\tau\tau c$) can not always be done correctly: some jets' p_T is below object acceptance, multiple extra jets from QCD radiation:

- Radiation jets are often softer that the ones from top decay
- The FCNC jet from $t\to Hc$ decay, and the subleading jet from W boson decay, have non-negligible chances of missing the object selection, with the former leading to **unmatched** part of the signal

Consequently, divide the events into 3 jets and ≥4 jets categories, and each is further divided into $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ channels

Jet assignment ($t\to qH$, $H\to\tau\tau$) [PRD 93 (2016) 113010]

In the so-called 3-jet category:

- For the 3-jet events (at least one of which should be b-tagged), if they can form a top, and satisfy

$$\left(\frac{m_{j_1j_2}-80.4}{20}\right)^2+\left(\frac{m_{j_1j_2b}-172.5}{25}\right)^2<5,$$

  Then this event is discarded (no c-jet in the event)

- Otherwise, the c-jet is defined as the configuration that gives the least ΔR sum of (think of the boosted topology):

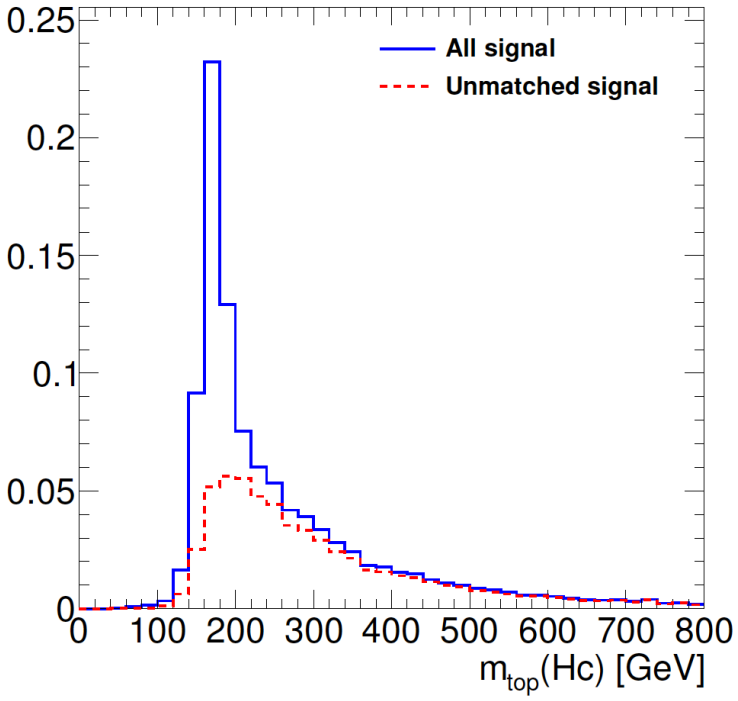
$$\Delta R(j_c,H)+\Delta R(j_{W1},b)$$

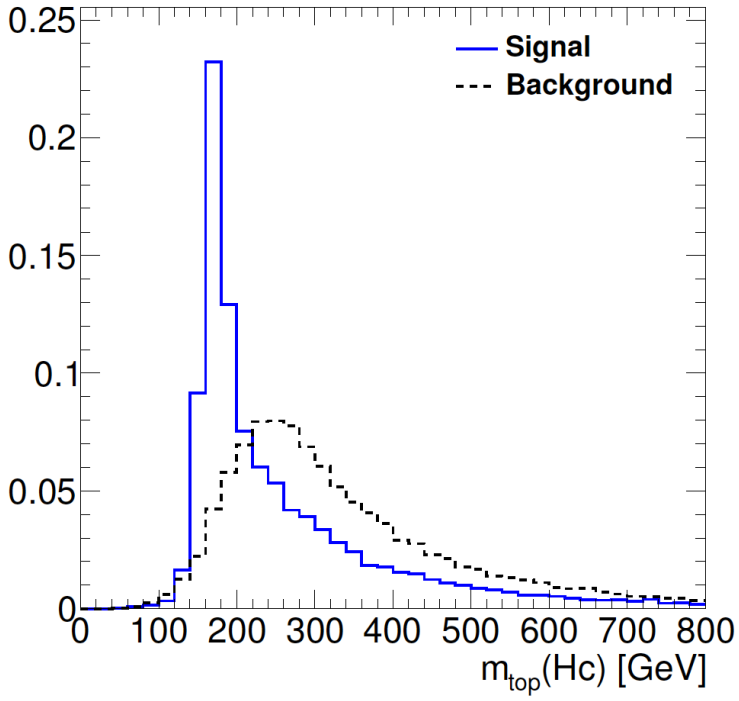
In the 4-jet bin ($\geq$4 jets inclusively), only the leading 4 jets are considered, out of which at least one should be b-tagged. The c-jet is also found by a minimum ΔR sum:

$$\Delta R(j_c,H)+\Delta R(j_{W1},b)+\Delta R(j_{W2},b)+\Delta R(j_{W1},j_{W2})$$

FCNC top mass (t→qH, H→ττ) [PRD 93 (2016) 113010]

After the jet assigment, the top mass from the t→Hc decay can be reconstructed:

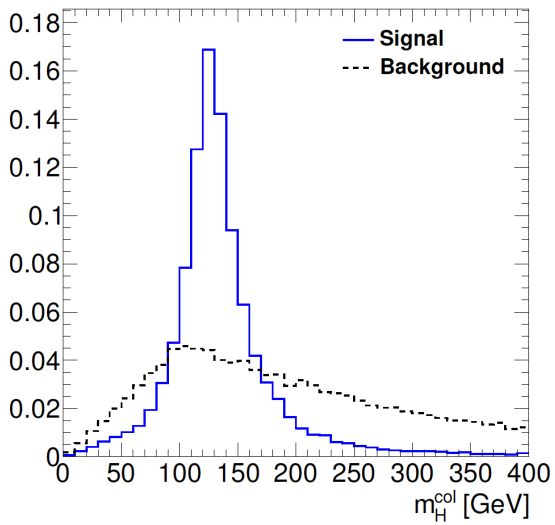


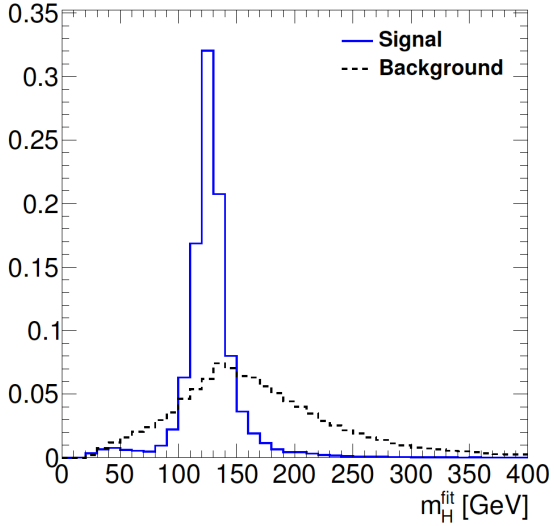


- Analogous to the H→γγ chnnael, a top mass peak appears for events with truth-matched FCNC jet, but we also have a fraction of the signal events with unmatched FCNC jet
- The background is also not peaking in this mass distribution as shown in the right plot

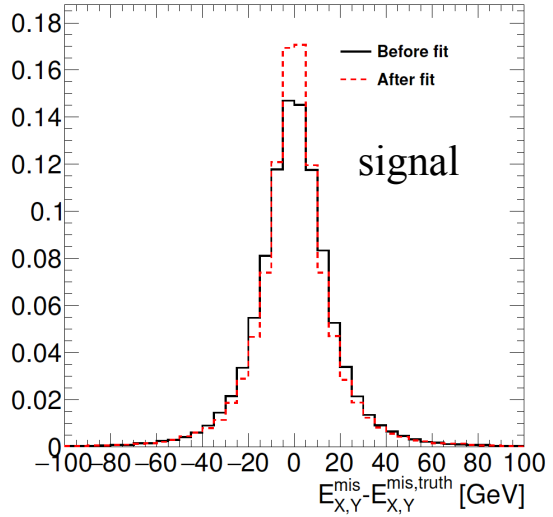
Higgs mass and MET (t→qH, H→ττ) [PRD 93 (2016) 113010]

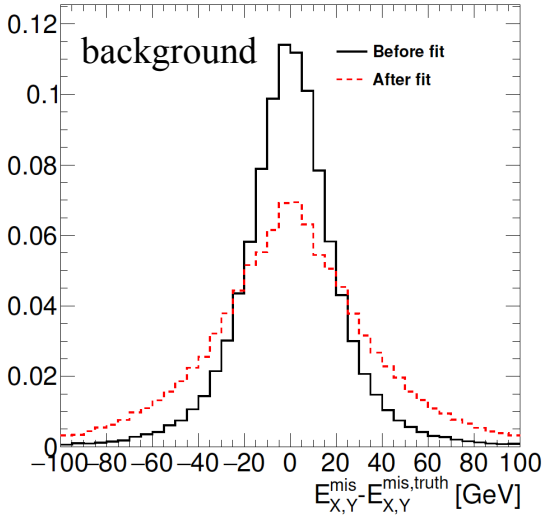
The di-tau mass in background (dominated by ttbar) also changes after the fit:





Meanwhile, the MET gets worse (better) in the background (signal):

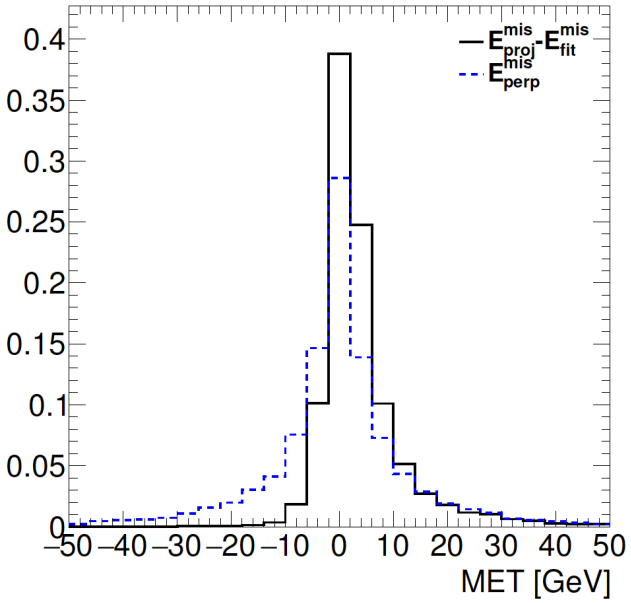


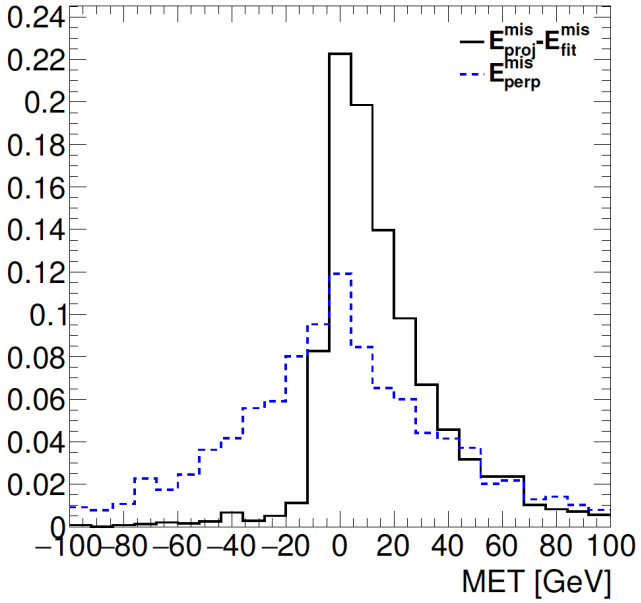


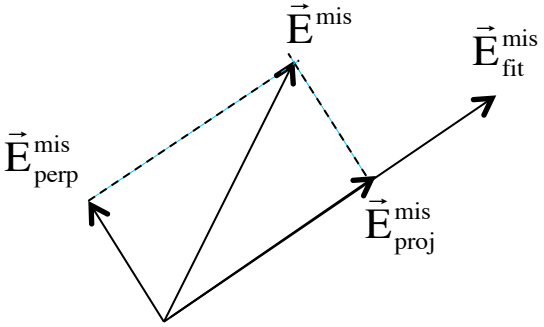
Higgs mass and MET (t→qH, H→ττ) [PRD 93 (2016) 113010]

- At reconstruction level, this means that MET varied within its resolution to get closer to the true MET in signal, while it has to vary a lot (a large fake MET is created) to conform to the mass constraint

- The variation in MET vector can be expressed in terms of MET projections:



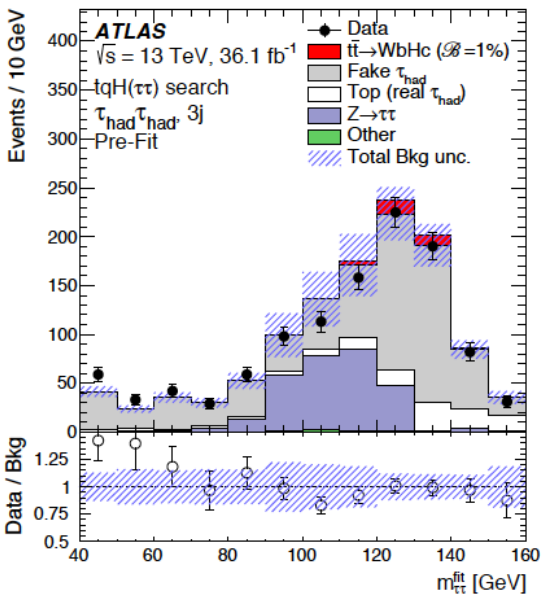


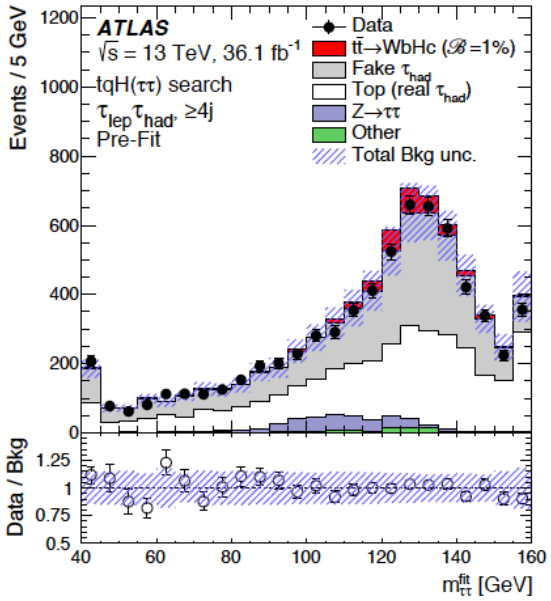


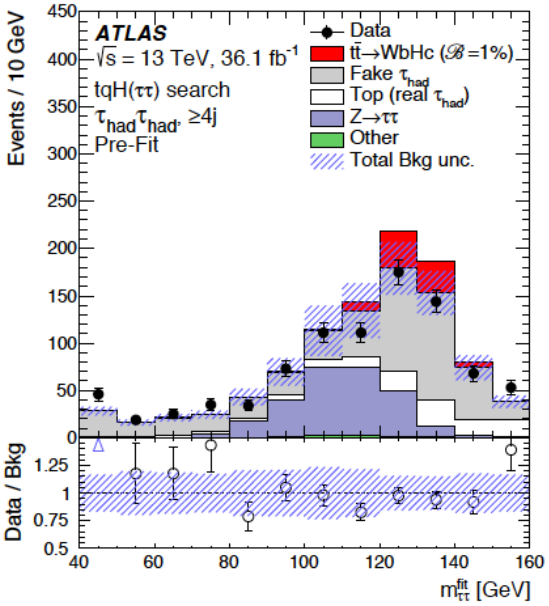
The MET change can be used as a discriminant between signal and background, with the BDT method

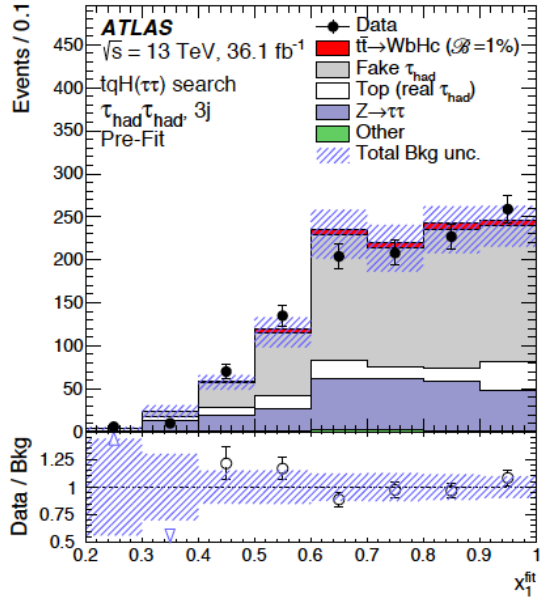
FCNC t→qH(ττ) search

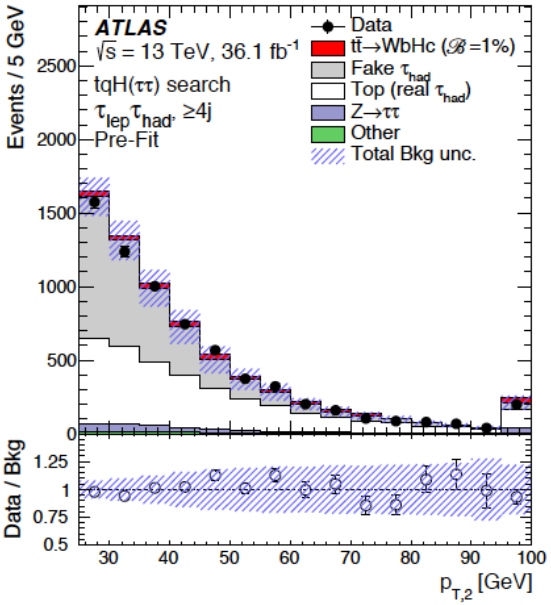
[arXiv:1812.11568]

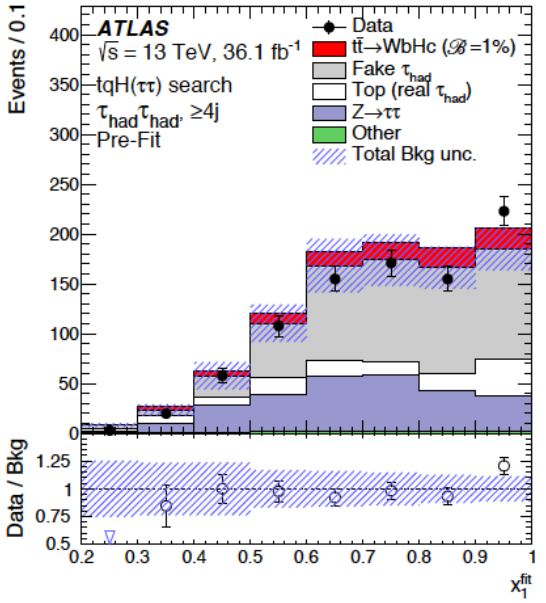






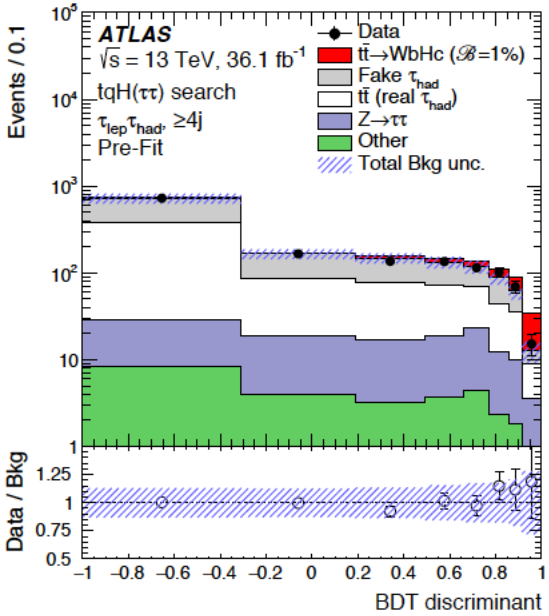


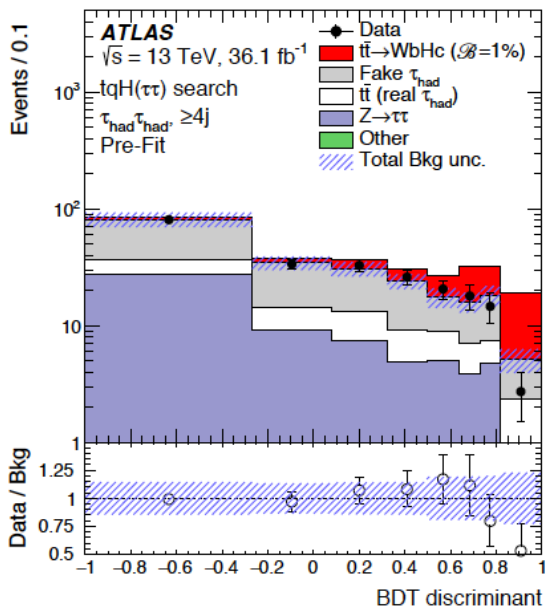


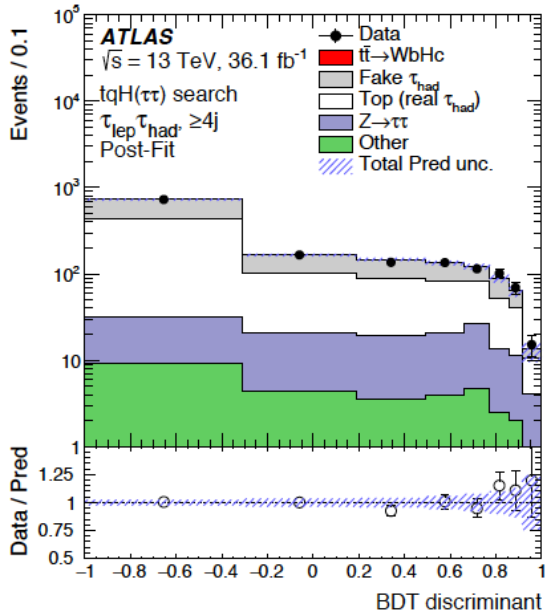


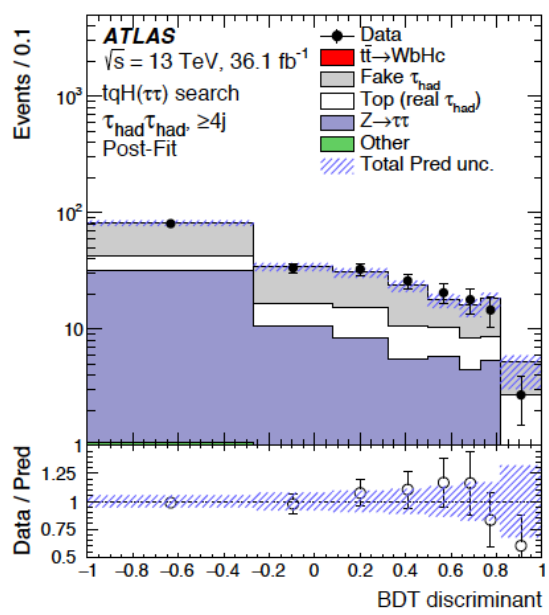
FCNC t→qH(ττ) search

[arXiv:1812.11568]



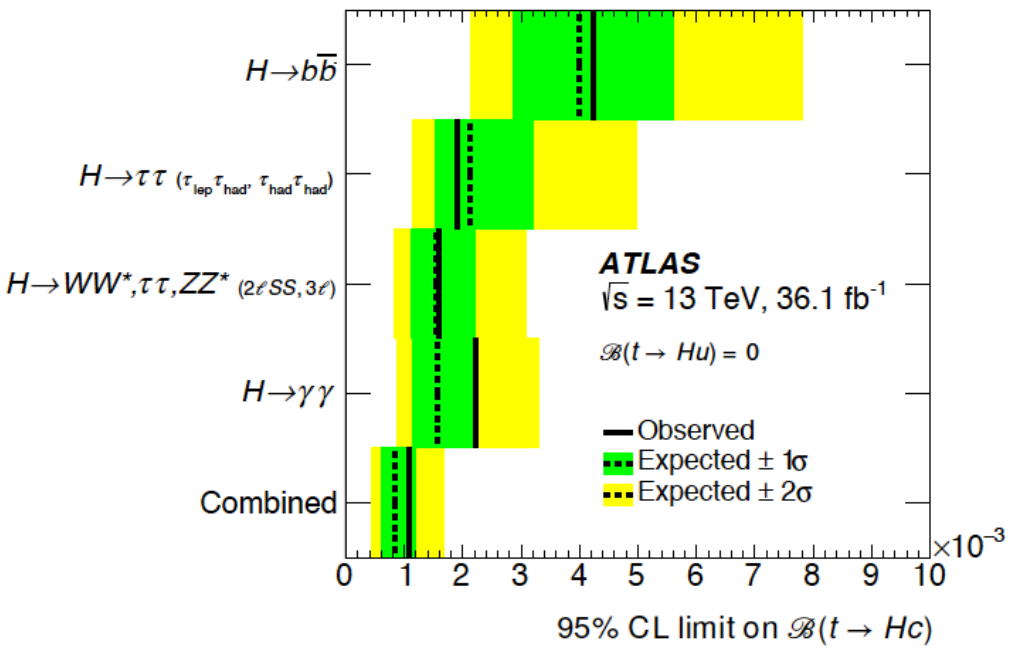


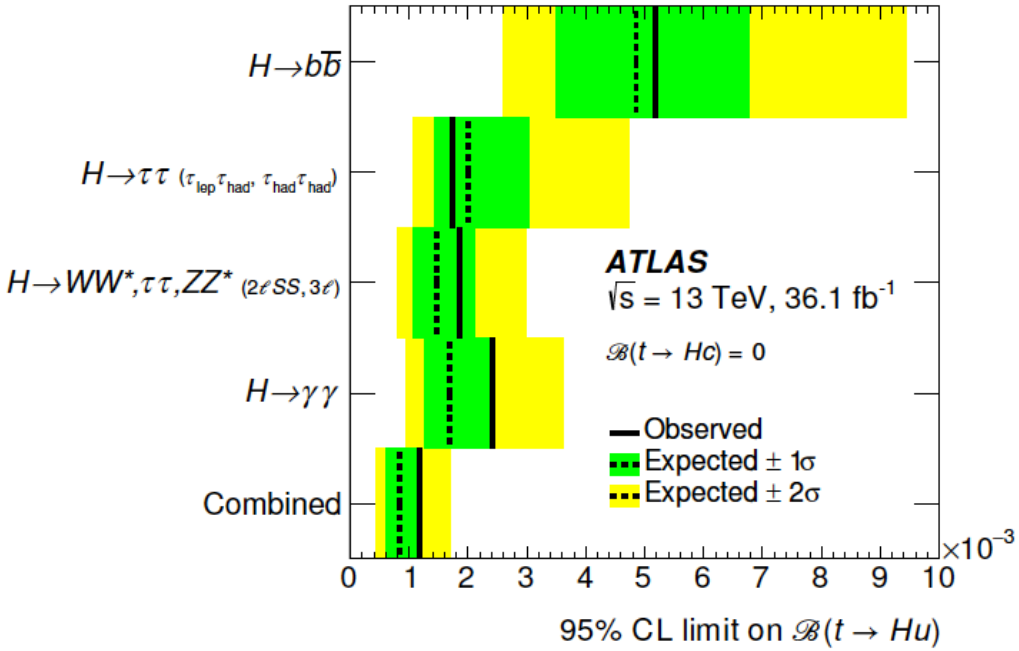




- Require exactly 1 b-jet
- Use data-driven background estimation for jet faking τ_{had}
- Use 9-14 variables for BDT analysis
- Most sensitive regions are 4-jet categories

FCNC t→qH(bb,ττ) search [arXiv:1812.11568]

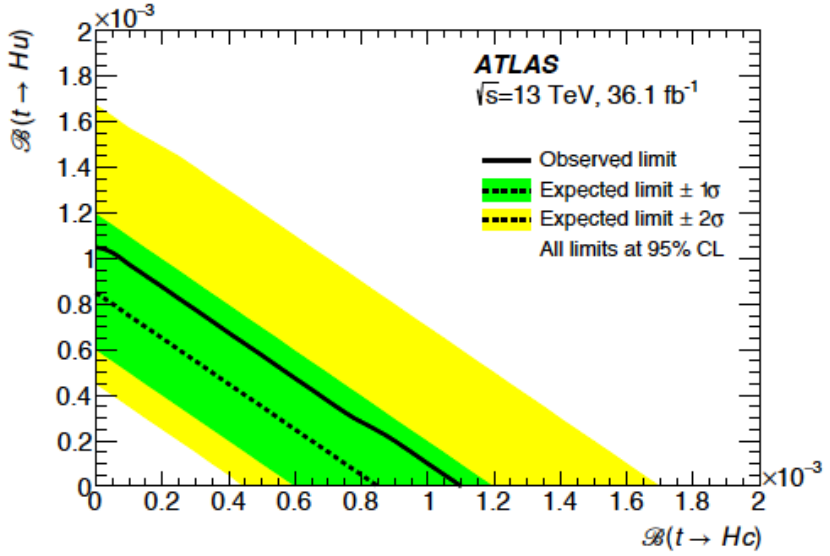


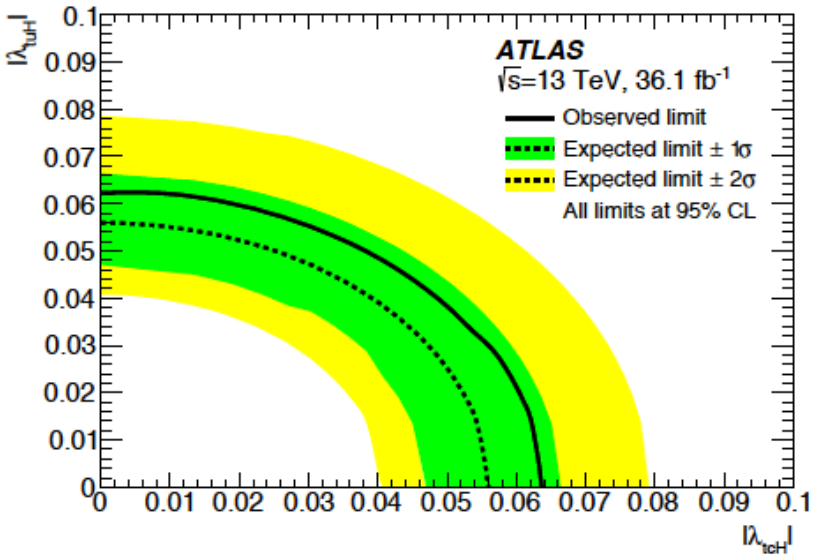


	Obs. (exp.) BR(t→uH) (%)	Obs. (exp.) BR(t→cH) (%)
H→bb	0.52 (0.49)	0.42 (0.40)
H→ττ	0.17 (0.20)	0.19 (0.21)

FCNC t→qH combination [arXiv:1812.11568]

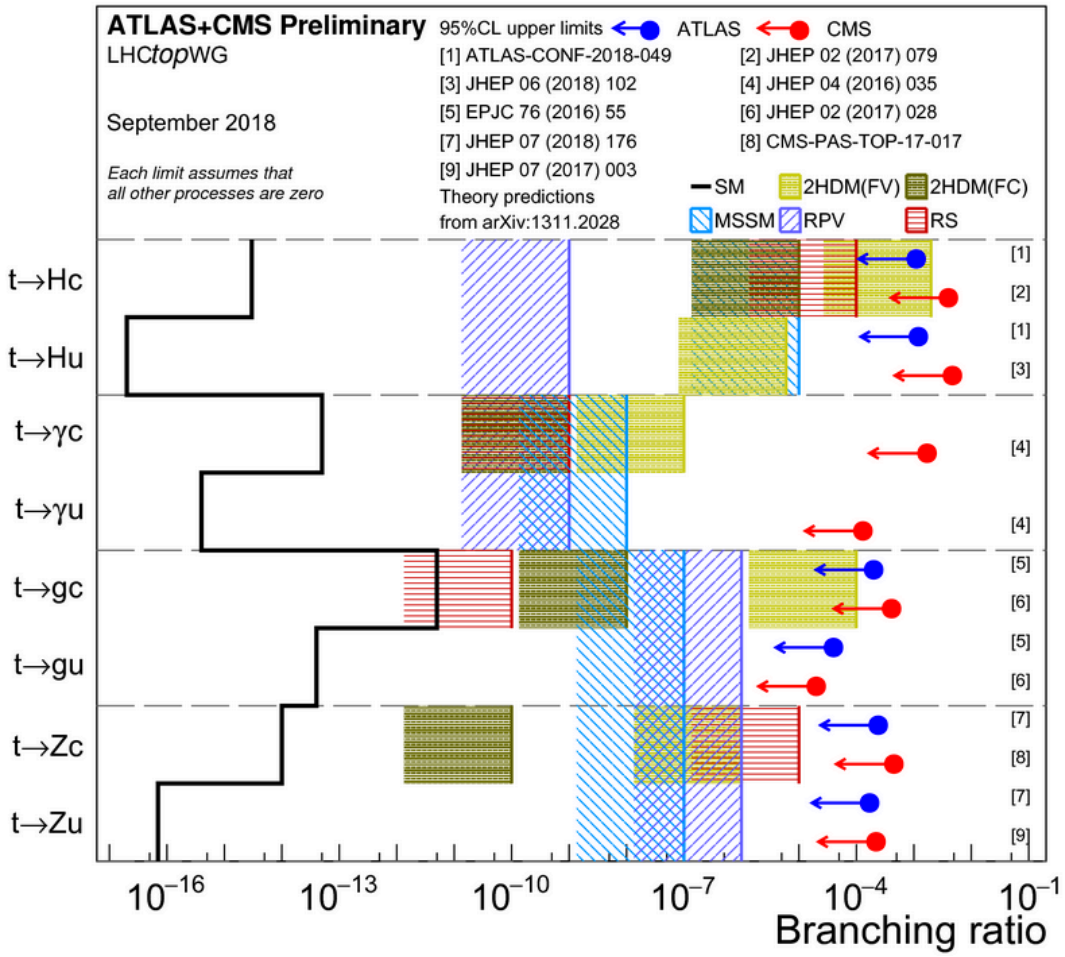
	95% CL upper limits on $\mathcal{B}(t \to Hc)$ Observed (Expected)	95% CL upper limits on $\mathcal{B}(t \to Hu)$ Observed (Expected)
$H \to b\bar{b}$	4.2×10^{-3} (4.0×10^{-3})	5.2×10^{-3} (4.9×10^{-3})
$H \to \tau\tau$ ($\tau_{\text{lep}}\tau_{\text{had}}$, $\tau_{\text{had}}\tau_{\text{had}}$)	1.9×10^{-3} (2.1×10^{-3})	1.7×10^{-3} (2.0×10^{-3})
$H \to WW^*, \tau\tau, ZZ^*$ (2ℓSS, 3ℓ) [22]	1.6×10^{-3} (1.5×10^{-3})	1.9×10^{-3} (1.5×10^{-3})
$H \to \gamma\gamma$ [21]	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})



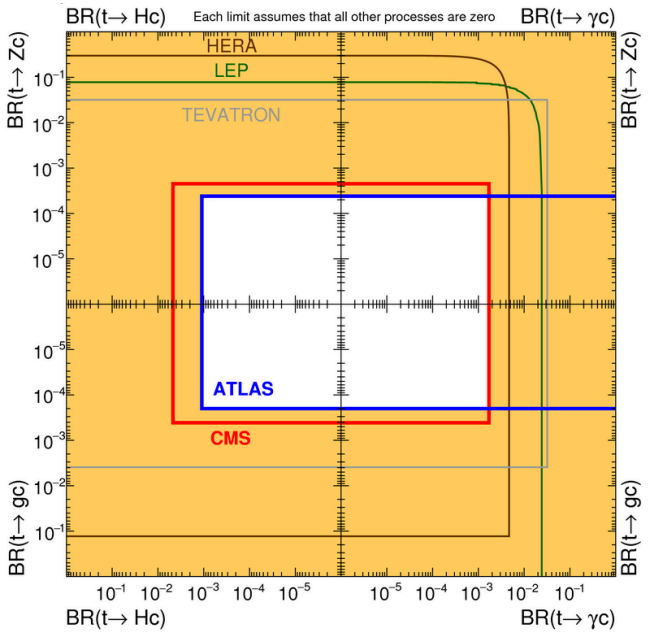


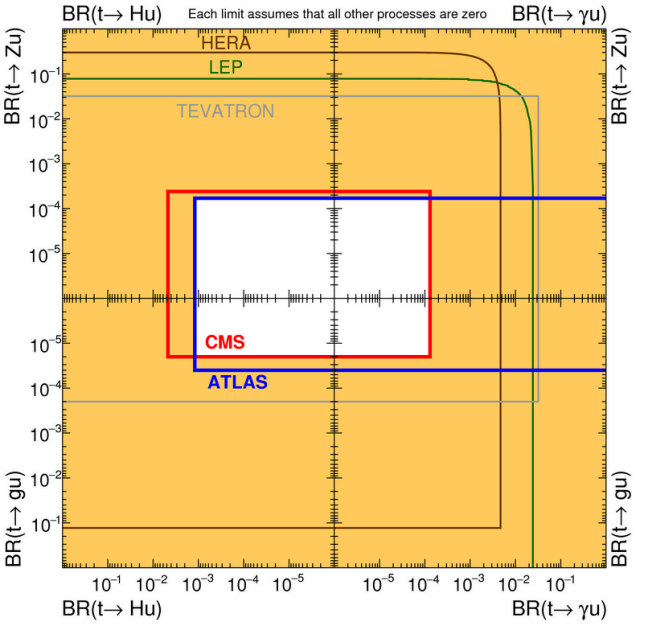
$$\mathcal{L}_{\text{FCNC}} = -\lambda_{tLqR}\bar{t}_L q_R H - \lambda_{qLtR}\bar{q}_L t_R H + h.c. \qquad |\lambda_{tqH}| = (1.92 \pm 0.02)\sqrt{\mathcal{B}(t \to Hq)}$$

LHC top FCNC (summary)



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCTopWGSummaryPlots





Summary

First phase of ATLAS program for FCNC top-quark decay into Higgs searches is carried out for all major Higgs decay modes with 36.1 fb^{-1} of run-2 data. No significant excess in $t \rightarrow qH$ process is observed in the ttbar production

The current results give the best limit on BR($t \rightarrow qH$) so far, which also outperforms run-1 limits. Limits entering a region where the most optimal estimation for BR($t \rightarrow qH$) at ~10^{-3} as predicted by some models

Search for FCNC continues to provide a very promising area to test BSM physics predictions. Stay tuned for the results based on full Run-2 data, and run-3

Backup Slides

References:

ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults