tqH FCNC Searches

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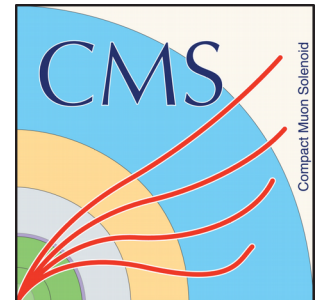
Higgs Toppings, 31 May 2018

TEXAS
The University of Texas at Austin

ATLAS
EXPERIMENT

CMS

Introduction

- Standard Model: the only fundamental process that changes fermion flavor is W emission/absorption (charged currents).
  - Interactions of γ/g/Z/H (neutral currents) are flavor-diagonal.
  - further, CKM unitarity → flavor-changing neutral currents in loops with Ws are highly suppressed (GIM mechanism).
- There is no reason additional degrees of freedom from BSM models need to respect the SM flavor structure
  - suppressed FCNC sets strong constraints on BSM!
- With large sample of top quarks at LHC, able to directly probe FCNC interactions of top: $t \to q\gamma$, $t \to qg$, $t \to qZ$, $t \to qH$

SM $B(t \to cH) \sim 3 \times 10^{-15}$
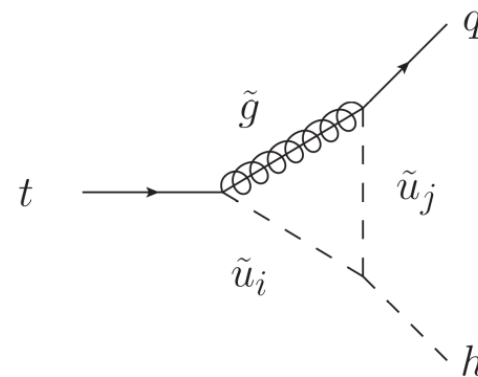
- Tree-level vertices in more complex Higgs sectors

  - misalignment of multiple Yukawa coupling matrices

  - generic unless symmetries imposed

  - "Cheng-Sher ansatz":
    off-diagonal Yukawa coupling $\lambda_{tq} = \dfrac{\sqrt{2m_t m_q}}{v}$
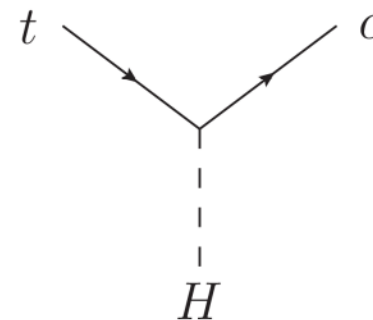
- Loop-induced effective vertices, e.g. MSSM

*Multiple conventions for coupling normalizations;
typically compare t → Hq branching fractions*

Table 1-7. *SM and new physics model predictions for branching ratios of top FCNC decays. The SM predictions are taken from [119], on 2HDM with flavor violating Yukawa couplings [119, 120] (2HDM (FV) column), the 2HDM flavor conserving (FC) case from [121], the MSSM with 1TeV squarks and gluinos from [122], the MSSM for the R-parity violating case from [123, 124], and warped extra dimensions (RS) from [125, 126] .*

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

arxiv:1311.2028

- $m_t > m_H + m_q$: top quark can decay to qH.
  Top pairs produced copiously at LHC → search for t → qH decays.

  - Cheng-Sher ansatz: B(t → cH) ~ 0.15%

    ~ 90k events in 36 fb^{-1}

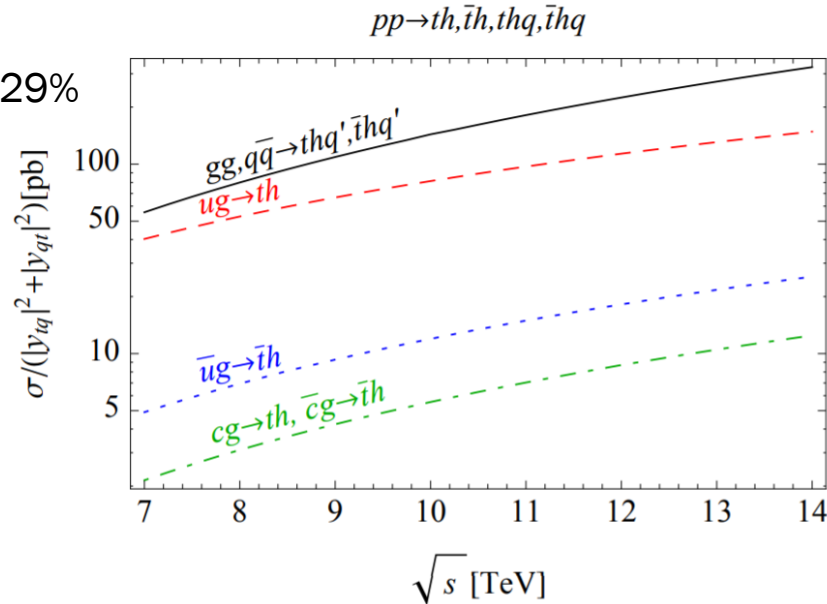- tqH vertex can induce anomalous pp → tH production

  - most relevant for tuH, due to proton having valence u.
  - proton has more u than $\bar{u}$ → charge asymmetry!
  - no associated b (unlike SM tH); valence on glue → high longitudinal momentum
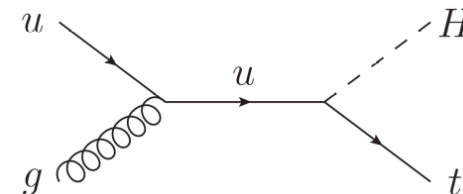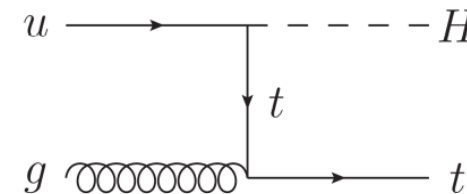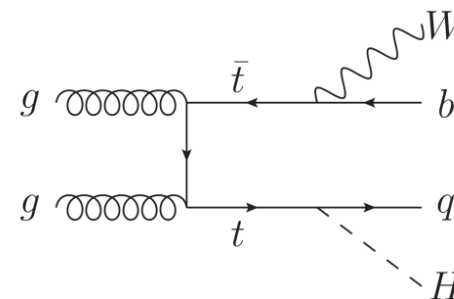
σ norm. to B(t → qH) = 29%

SM tH: 92 fb
SM t̄tH: 507 fb

$pp \to th, \bar{t}h, thq, \bar{t}hq$

pp → t̄t, t/t̄ → Hq

tuH single top

tuH single antitop

tcH single top/antitop

- Single top cross section only appreciable for ug → tH
 - scales with t → uH branching fraction
- tH production can give an additional handle on tuH coupling
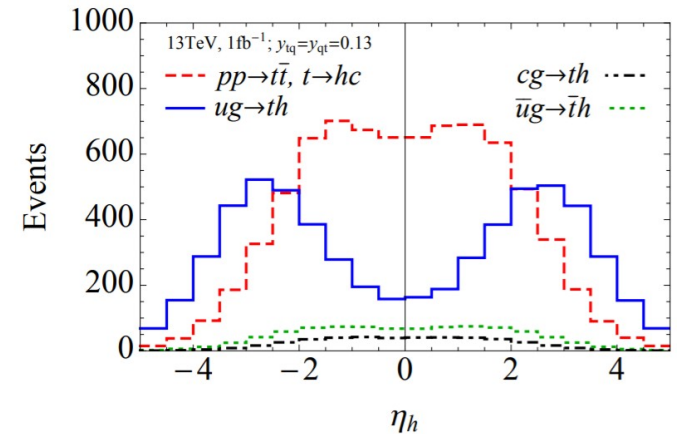
*Greljo, Kamernik, Kopp,
JHEP 07(2014) 046*

- **"Standard" channels for searches set by Higgs decays**

  - γγ:
    - ✓ narrow peak, full top reconstruction
    - ✗ small branching fraction

  - bb:
    - ✓ wide peak, full top reconstruction, high rate
    - ✗ combinatorics, hard backgrounds

  - multilepton (WW, ττ, ZZ):
    - ✓ reasonable rate, small backgrounds
    - ✗ no full reconstruction

- **Reject ttH production:**
  - only one b-jet from top decay!
  - lower overall jet multiplicity
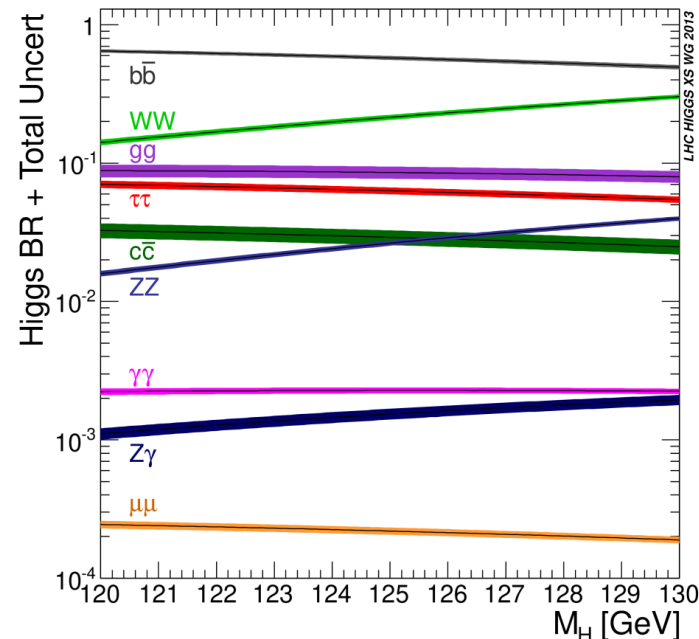
All channels exploited by both ATLAS & CMS @ 8 TeV
Combined results (95% CL):
CMS: B(t → Hu) < 0.55%, B(t → Hc) < 0.40%
ATLAS: B(t → Hu) < 0.45%, B(t → Hc) < 0.46%
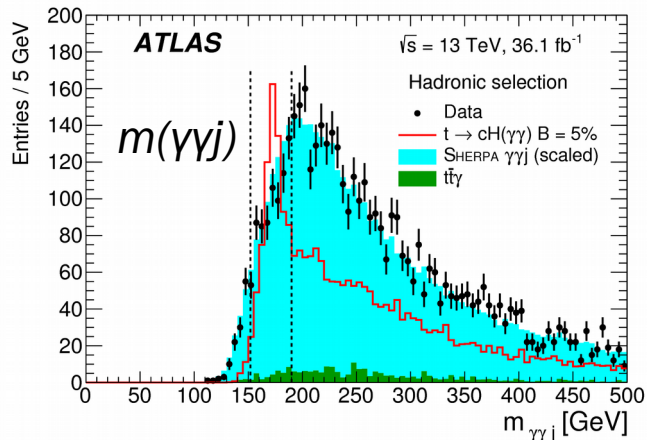*[JHEP 02(2017) 079, JHEP 12(2015) 061]*

- Look for events pp $\rightarrow$ t$\bar{\text{t}}$ $\rightarrow$ ($\gamma\gamma$q)(Wb)

  - Narrow H $\rightarrow$ $\gamma\gamma$ peak : challenge is not Higgs finding, but rather exclusion of SM Higgs production mechanisms

  - Both W $\rightarrow$ qq (hadronic) and W $\rightarrow$ lν (leptonic) final states considered. Full reconstruction of event possible (in leptonic case, using W mass constraint for MET)
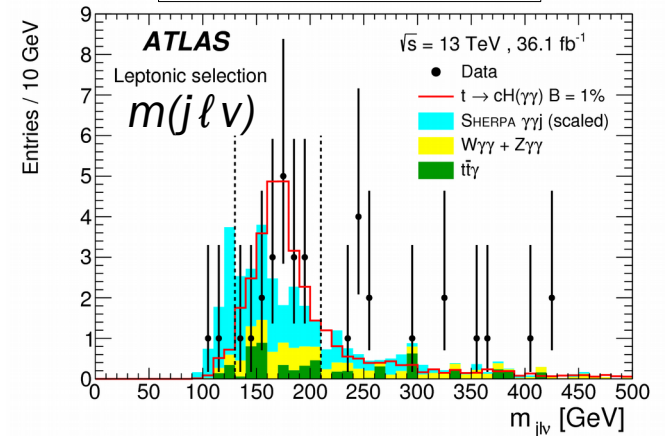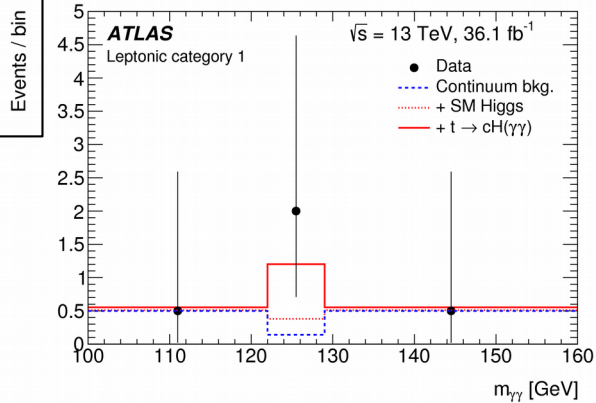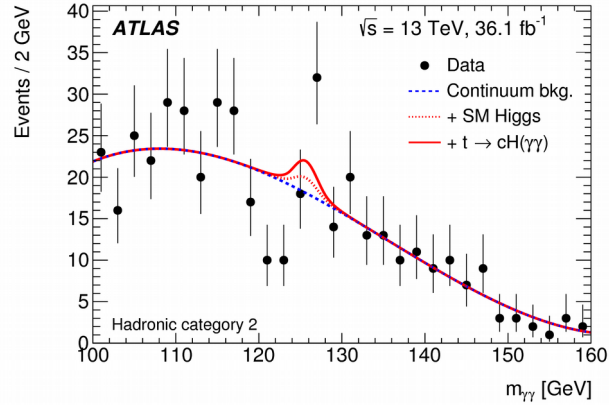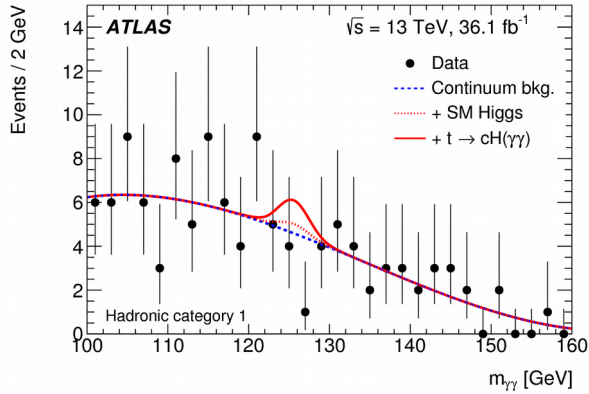
- **13 TeV ATLAS result**

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hadronic category
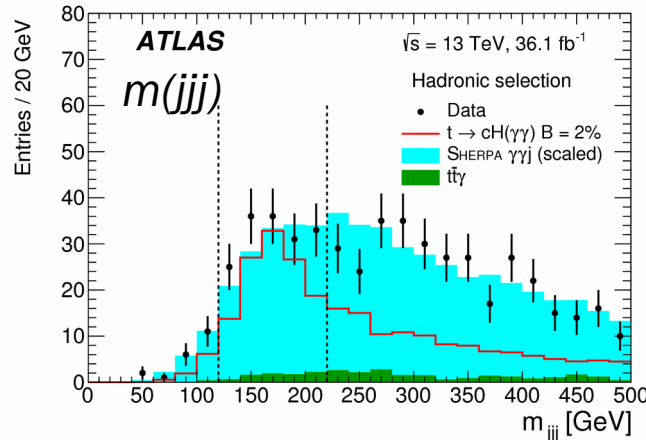
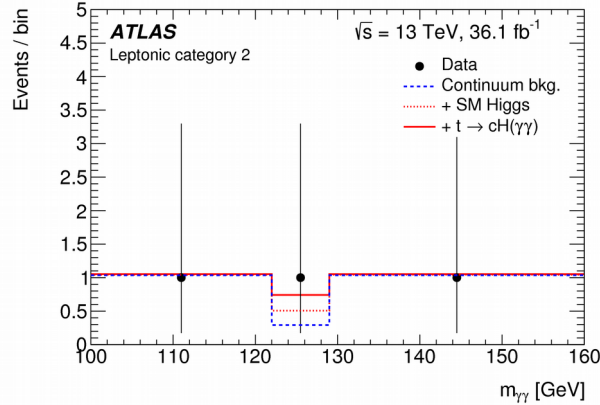leptonic category

Diphoton

good SM top reco

fail SM top reco

B(t → cH) < 0.22% (0.16% exp)
B(t → uH) < 0.24% (0.17% exp)

@ 95% C.L.

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CMS 8 TeV:
B(t → qH) ≲ 0.42 - 0.47%

H → bb

- t → ℓvb events considered

- **13 TeV CMS result**: consider both top decay and single top production

  arxiv:1712.02399

  - ratio between the two is fixed

- signal regions: 3 or ≥4 jets ⊗ 2, 3, 4 b-tags

  - most sensitive regions are those with 3 b-tags

  - 4 b-tag region recovers some sensitivity for t → Hc (charm frequently tagged as b)

- use BDT to choose best assignment of reconstructed objects to Higgs, top decay, then use another BDT to separate FCNC signal from backgrounds
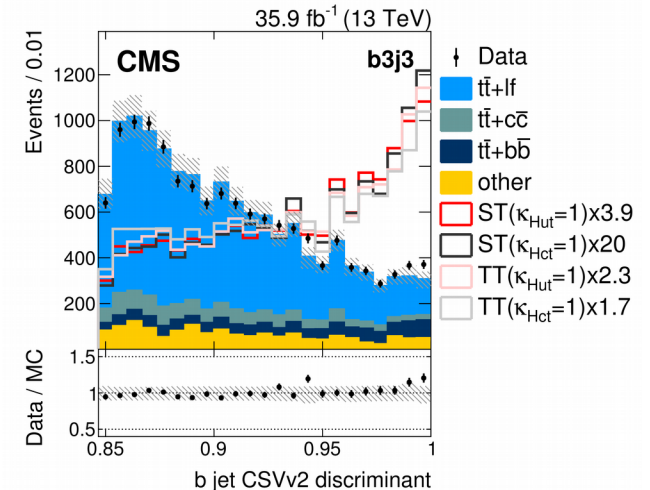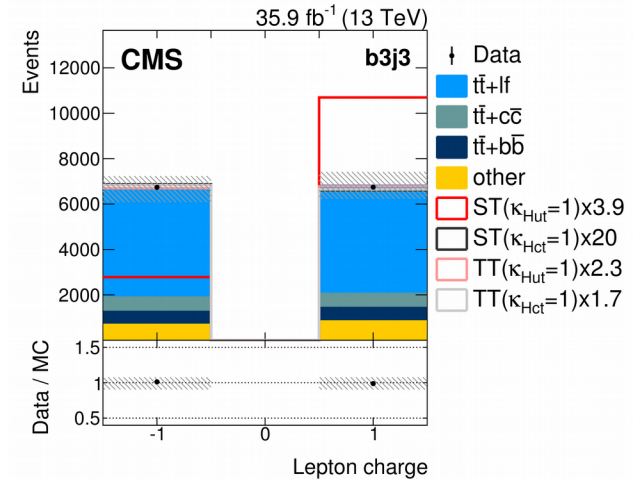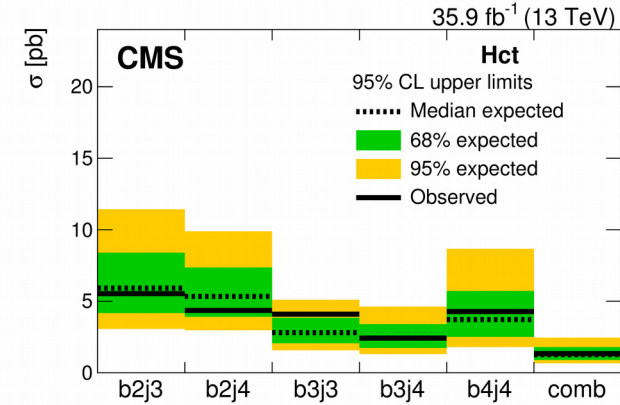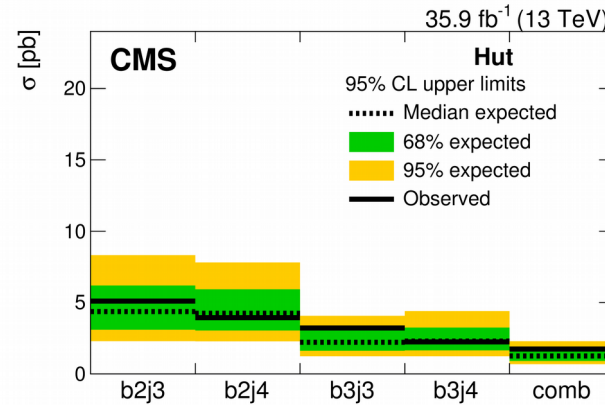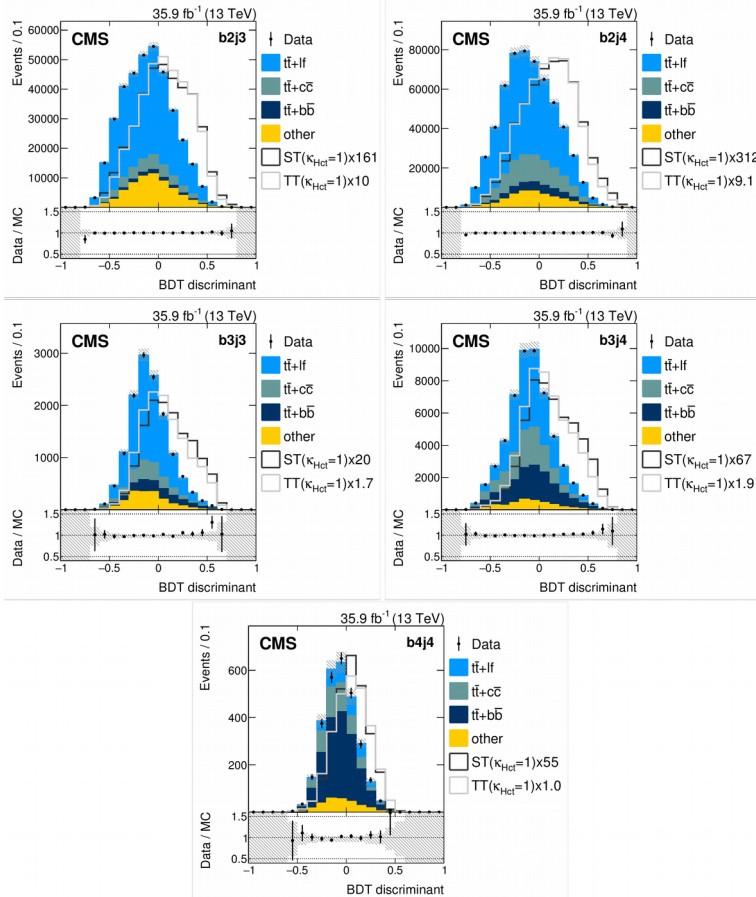
- 20% improvement in tuH limit by considering tH production

arxiv:1712.02399

B(t → uH) < 0.47% (0.34% exp)
B(t → cH) < 0.47% (0.44% exp)

@ 95% C.L.

ATLAS 8 TeV:
B(t → qH) ≲ 0.56 - 0.61%

Multilepton

- Two same sign leptons or three leptons (lepton = e or μ)

  - target t → ℓ vb, H → WW → ℓ vqq or ℓ v ℓ v (also contributions from H → ττ, ZZ)

- 13 TeV ATLAS result: uses the same SRs as ttH search

  - two same sign leptons + ≥ 4 jets

  - three leptons + ≥ 2 jets

  arxiv:1805.03483

- BDTs to separate FCNC signal from main backgrounds:

  - tt production with non-prompt lepton from b hadron decay

  - ttV production

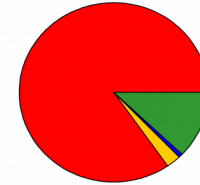*Higgs decay fractions*

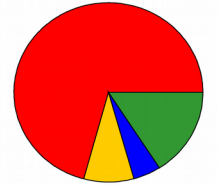**ATLAS** Simulation
$\sqrt{s}$ = 13 TeV

- H → WW*
- H → ZZ*
- H → Other
- H → ττ

2ℓSS   3ℓ

Backgrounds

ATLAS Simulation
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}

- $t\bar{t}W$
- $t\bar{t}H$
- Non-prompt
- $t\bar{t}Z$
- Diboson
- Other

2ℓSS (526 events)   3ℓ (276 events)
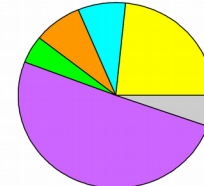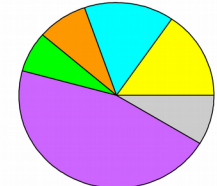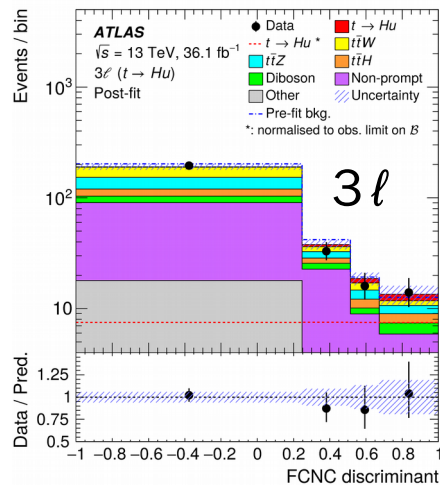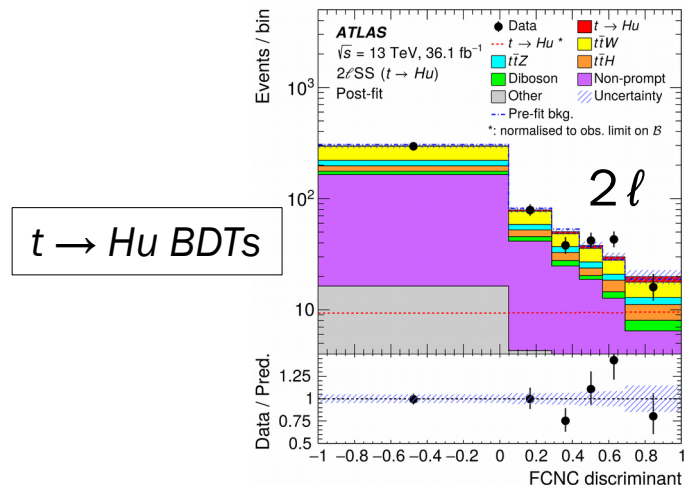
- FCNC signal contaminates regions used for data-driven non-prompt lepton estimates!
  - tell fit how normalization, shape of non-prompt bkg change with nonzero signal

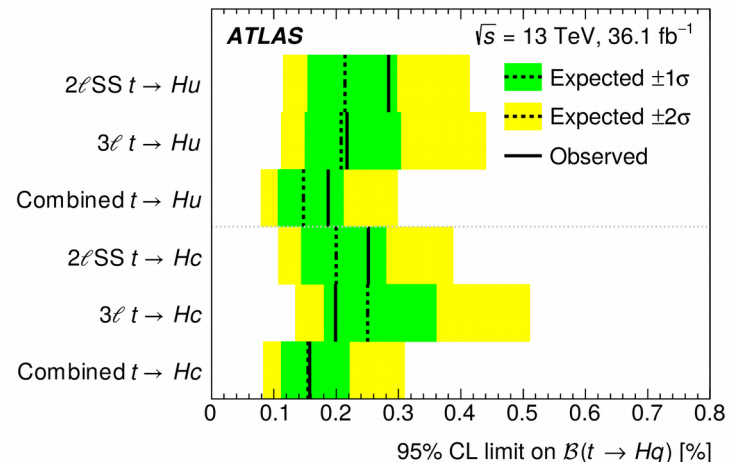- $B(t \to qH) \lesssim 0.16\text{-}0.19\%$ @ 95% CL

arxiv:1805.03483

t → Hu BDTs

CMS 8 TeV:
B(t → qH) ≲ 0.86 - 0.93%

- Search for off-flavor-diagonal top-Higgs couplings now able to exclude couplings in a phenomenologically interesting range

- First results of 13 TeV searches becoming available

  – combinations of channels will give best limits

- Multiple Higgs decay channels used, with wide range of different backgrounds + systematic sensitivities

- Exciting future ahead!

Inks Lake SP
Burnet, TX

Selection	Hadronic		Leptonic	
Category	1	2	1	2
	Signal $t \to cH$			
Acceptance with stat. unc. [%]	2.89 ± 0.10	4.15 ± 0.12	0.96 ± 0.03	0.27 ± 0.02
Expected events for $\mathcal{B} = 0.2\%$	$7.85^{+0.64}_{-0.67}$	$11.30^{+0.91}_{-0.96}$	$2.60^{+0.21}_{-0.23}$	$0.71^{+0.07}_{-0.07}$
	SM Higgs boson resonant background			
Expected events	$1.17^{+0.09}_{-0.11}$	$3.27^{+0.25}_{-0.27}$	$0.26^{+0.02}_{-0.03}$	$0.23^{+0.02}_{-0.02}$
$t\bar{t}H$ fraction	90%	68%	92%	77%