tHq FCNC in ATLAS and CMS

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on behalf of the ATLAS and CMS Collaborations

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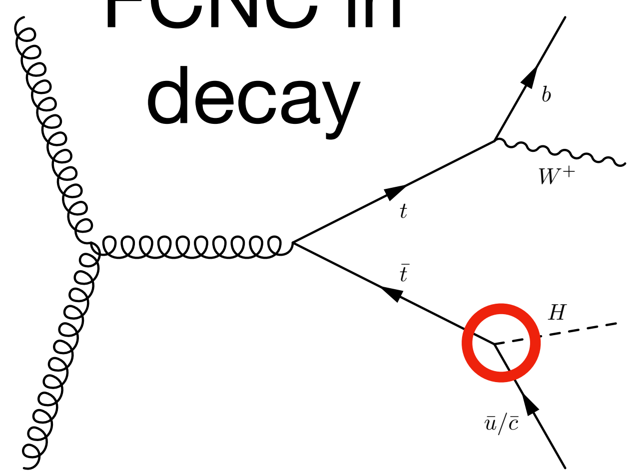
FCNC in top quark sector

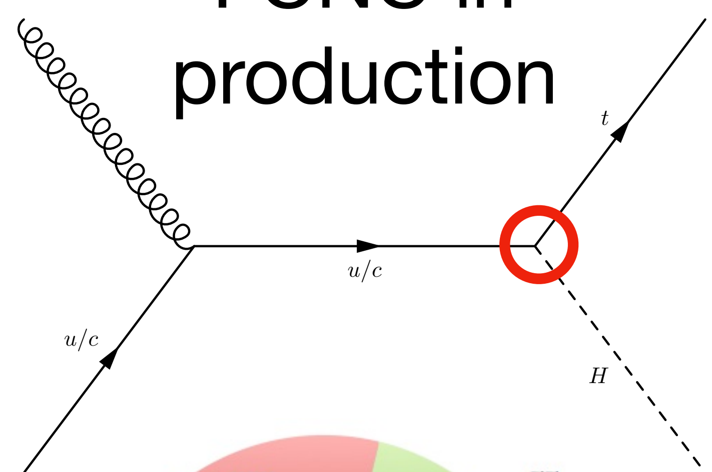
- Flavor changing neutral currents are forbidden in SM at tree level
- Highly suppressed at higher orders by GIM mechanism
- Top quark is the heaviest particle in the SM: FCNC would allow t→Xu or t→Xc decays with X any neutral boson
- BR of top quarks decays into bosons and up or charm quarks in the SM all << 10^{-11}
- Any sign of t→Xu or t→Xc clear sign of new physics
- This talk will **focus on t→Hq**: Many new results and ongoing efforts!

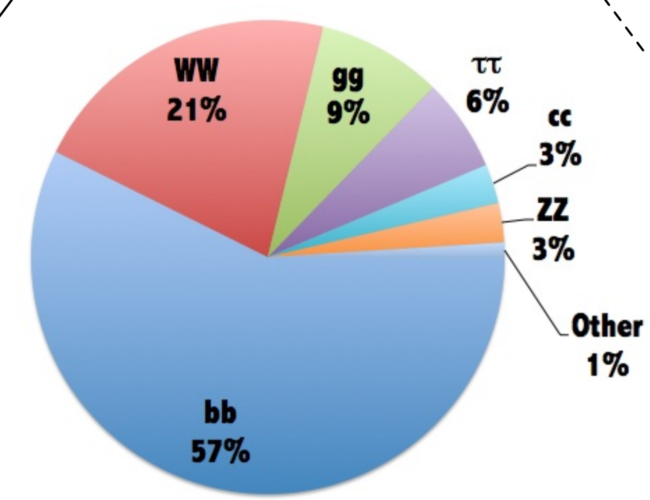
	ATLAS	CMS
H→γγ	2309.12817	PRL129, 032001 (2022)
H→bb	JHEP07 (2023) 199	JHEP02 (2022) 169
H→ττ	JHEP06 (2023) 155	-
leptonic	ongoing	CMS-PAS-TOP-22-002

FCNC in decay



FCNC in production



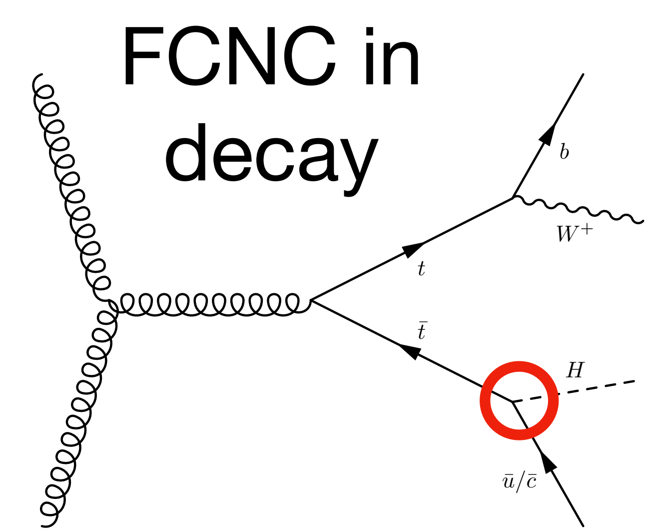


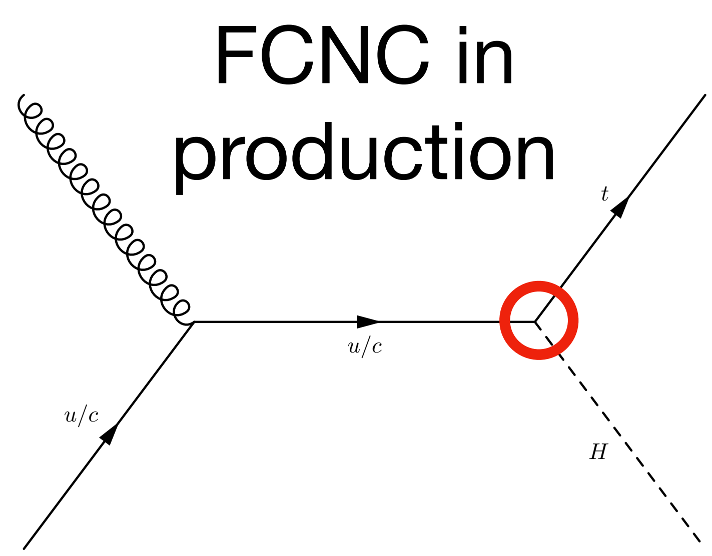
Signal samples and simulation

- CMS uses "kappa framework" with effective Lagrangian, LO samples generated with MG5

$$\mathcal{L} = \sum_{q=u,c} \frac{g}{\sqrt{2}} \bar{t} \kappa_{Hqt} \left(F^{L}_{Hq} P_L + F^{R}_{Hq} P_R \right) qH + h.c.,$$

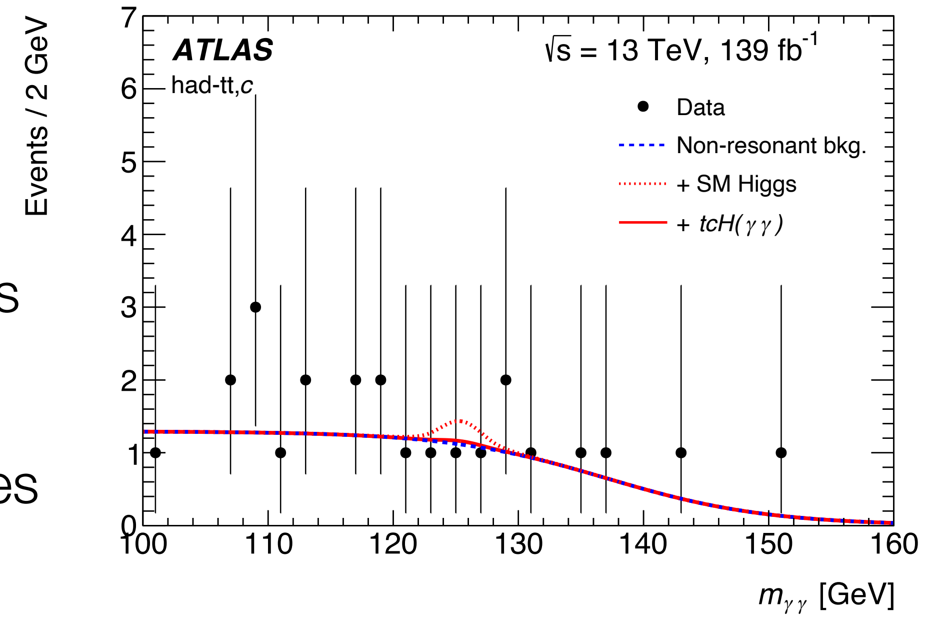
  - ttbar production at LO with up to 2 partons in ME, FCNC decay via Madspin
  - Single top sample and x-sec at LO precision
- ATLAS uses TopFCNC model (Feynrules DB, [1], [2])
  - Powheg for ttbar production, FCNC decay via Madspin and TopFCNC
  - MG5@NLO for tH production
  - No tH channel included in H→bb search
- σ(ttbar)=832pb (NNLO+NNLL) used in both collaborations

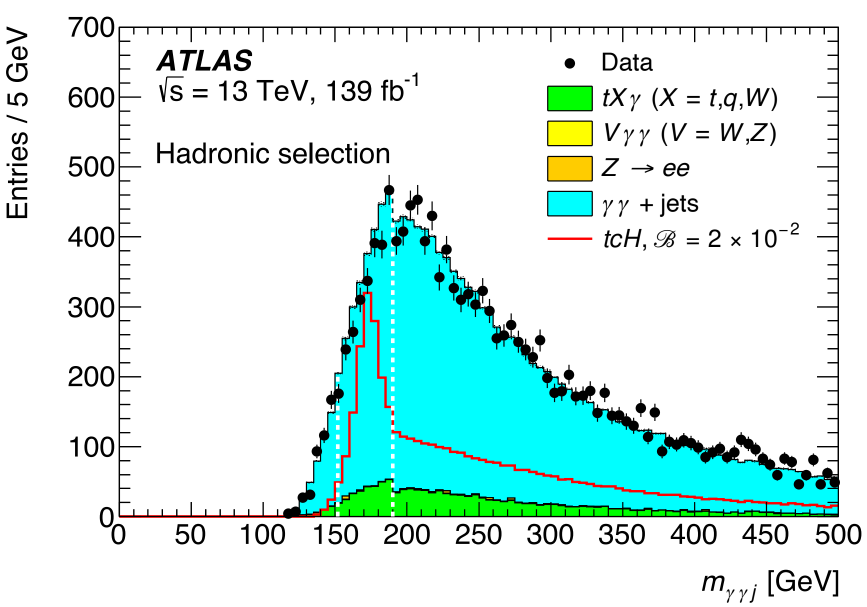


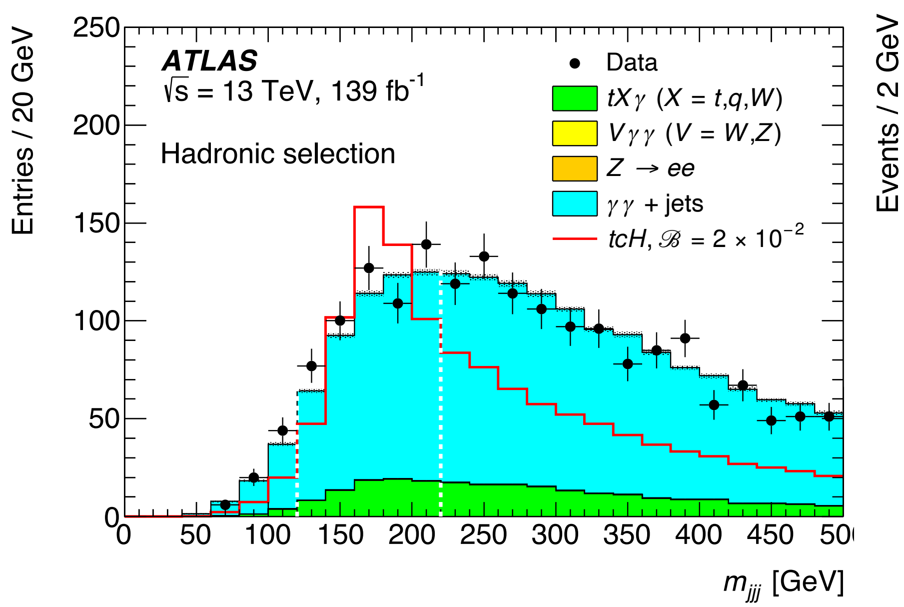


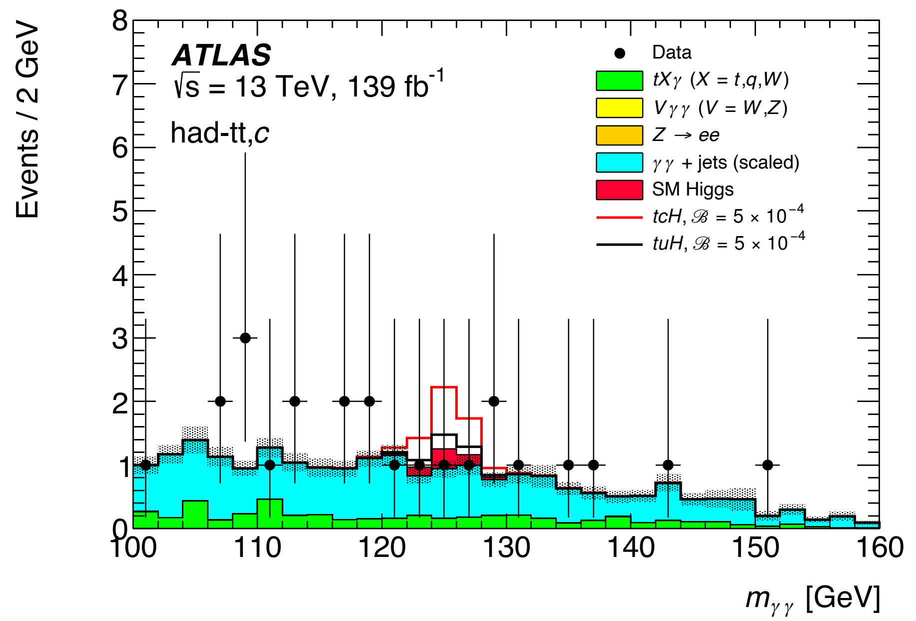
H→γγ in ATLAS

- Select events using diphoton trigger
- Hadronic and leptonic category, events with 2+ leptons rejected
- Utilize DL1r jet flavor tagger for b and charm tagging
- Split into targeted tt and tH categories with subcategories to enhance sensitivity
  - based on jet multiplicity, $m_{\gamma\gamma j}$, m_{jjj} , c-tagged jet, BDT scores
- BDTs used to further improve sensitivity
  - 7 optimized input variables used in both tt and tH categories
  - Minimum BDT score for event selection optimized by maximizing expected significance



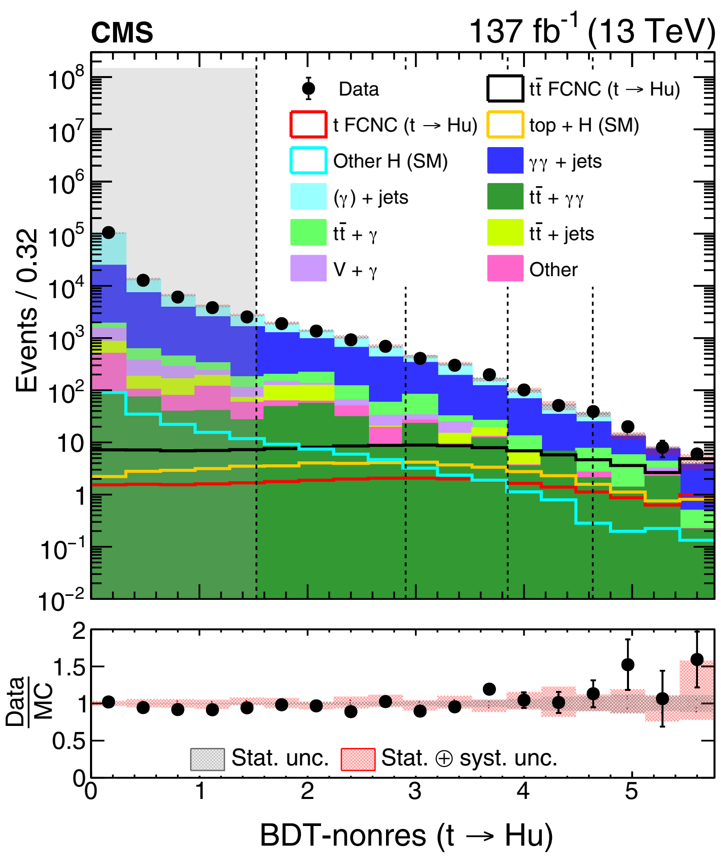


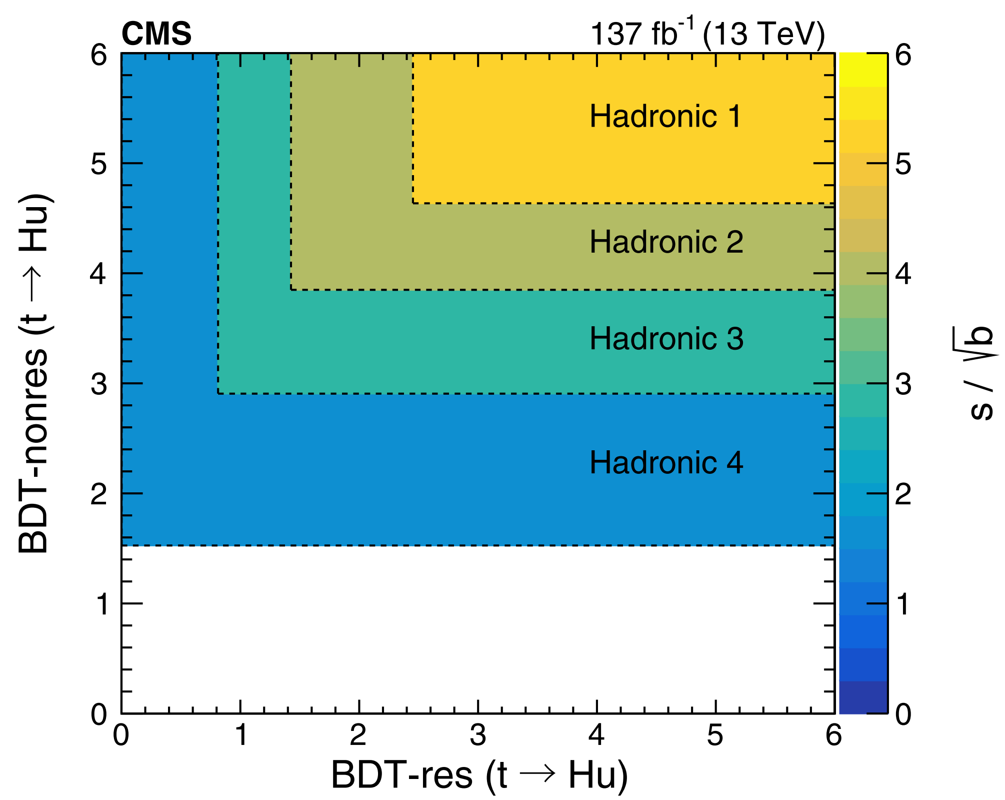


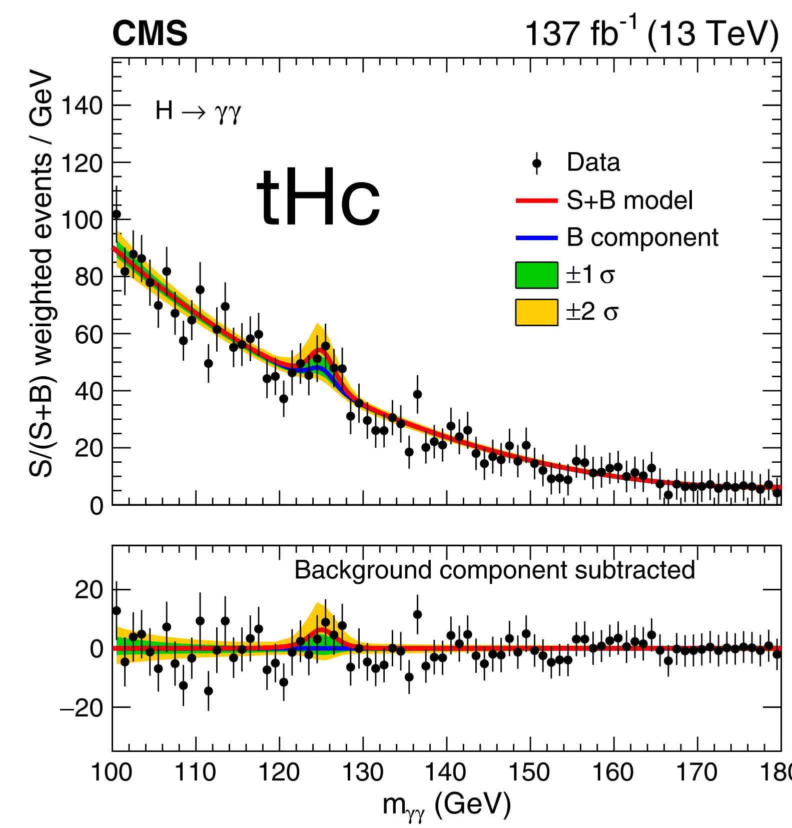


H→γγ in CMS

- Leptonic and hadronic channels, all events selected with diphoton triggers
- Use dedicated BDTs for each coupling, channel and major background (resonant or non-resonant) → 8 total
  - Build categories based on BDT scores
- Simultaneously fit $m_{\gamma\gamma}$ distributions in all hadronic/leptonic categories
  - Signal and resonant background modeled using sum of double-sided Crystal Ball and Gaussian function
  - Non-resonant background modeled from data using discrete profiling method



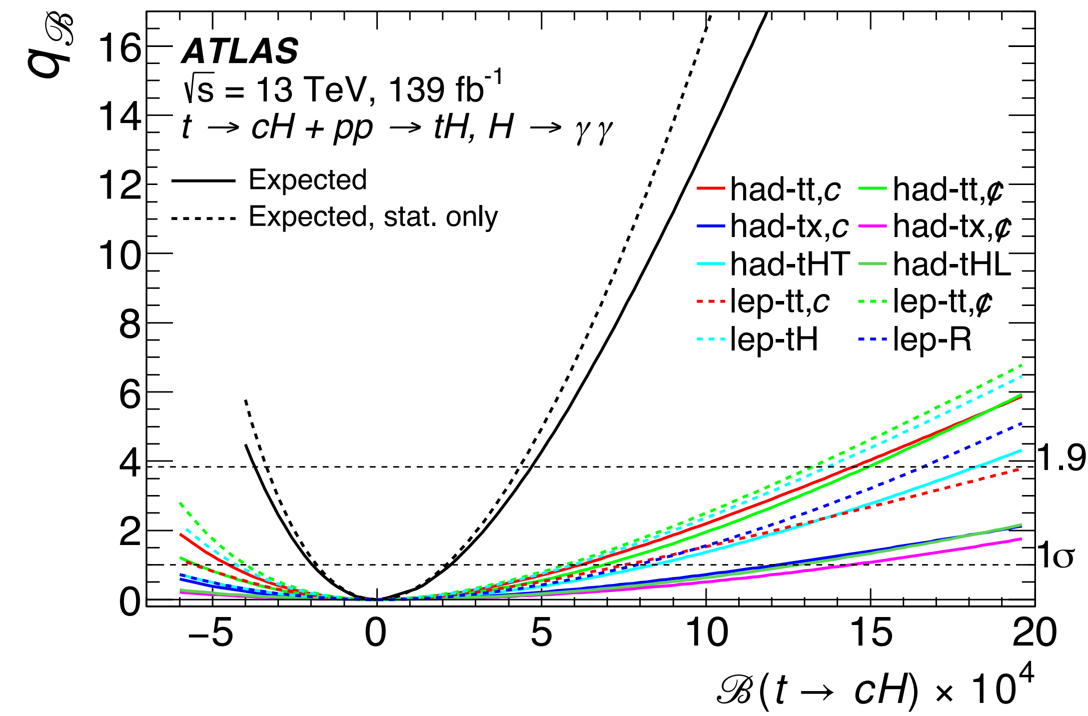


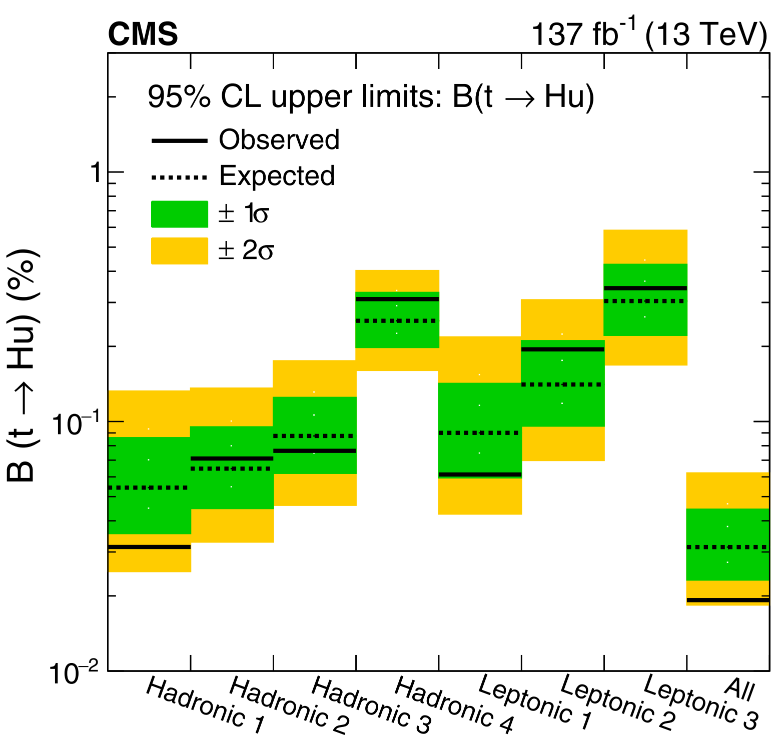


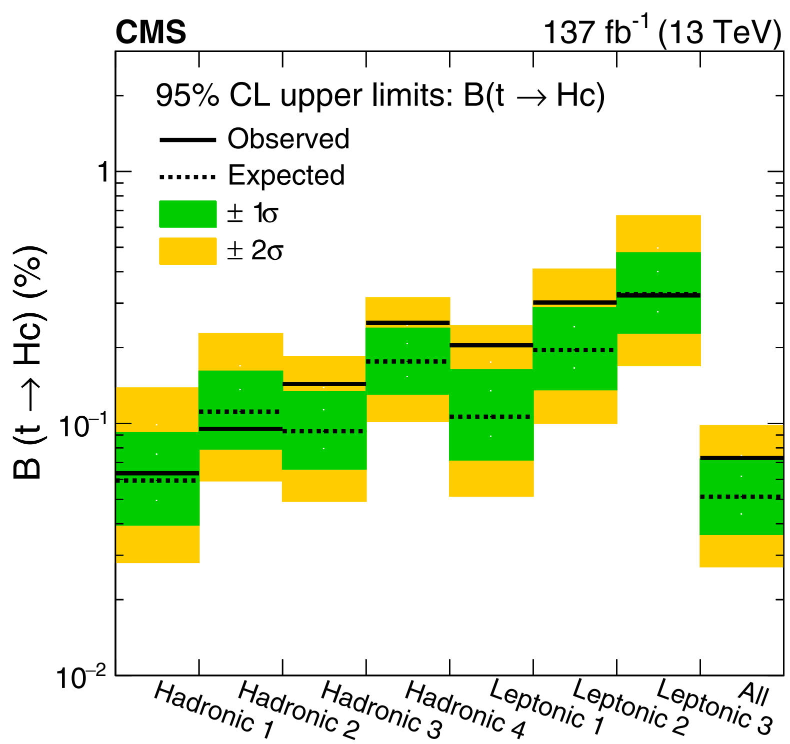
H→γγ results

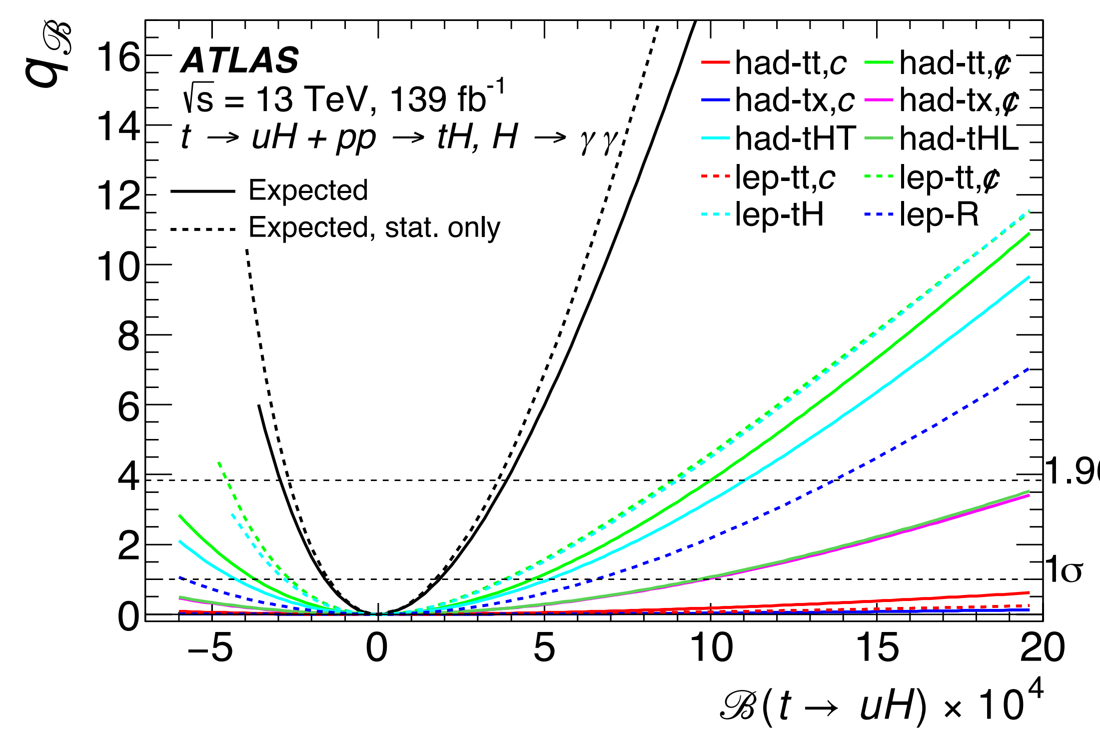
- Expected (Observed) results for ATLAS and CMS as BR × 10^{-4}

	ATLAS	CMS
tHc	4.7 (4.3)	5.1 (7.3)
tHu	3.9 (3.8)	3.1 (1.9)



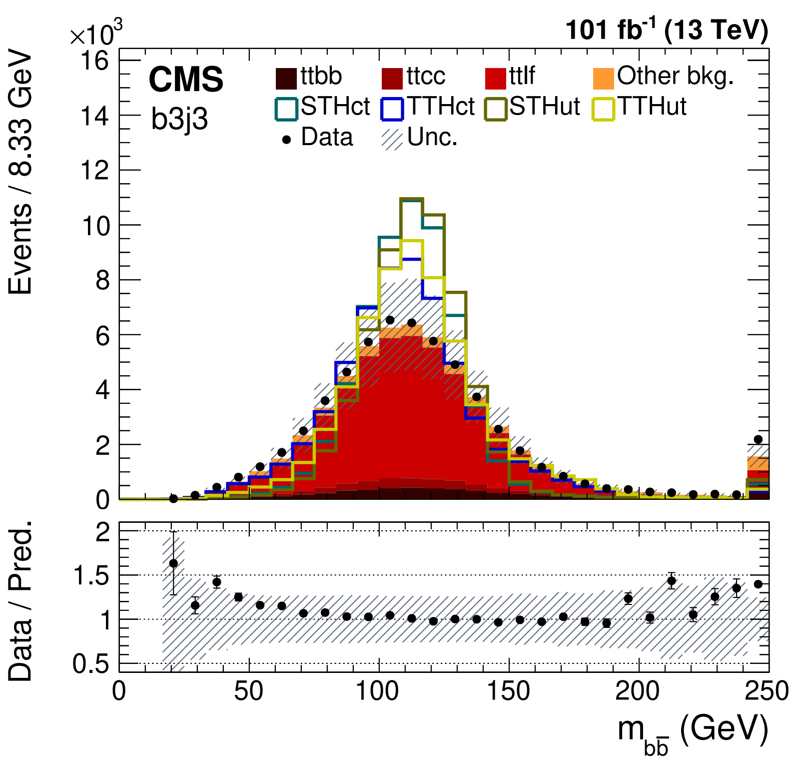


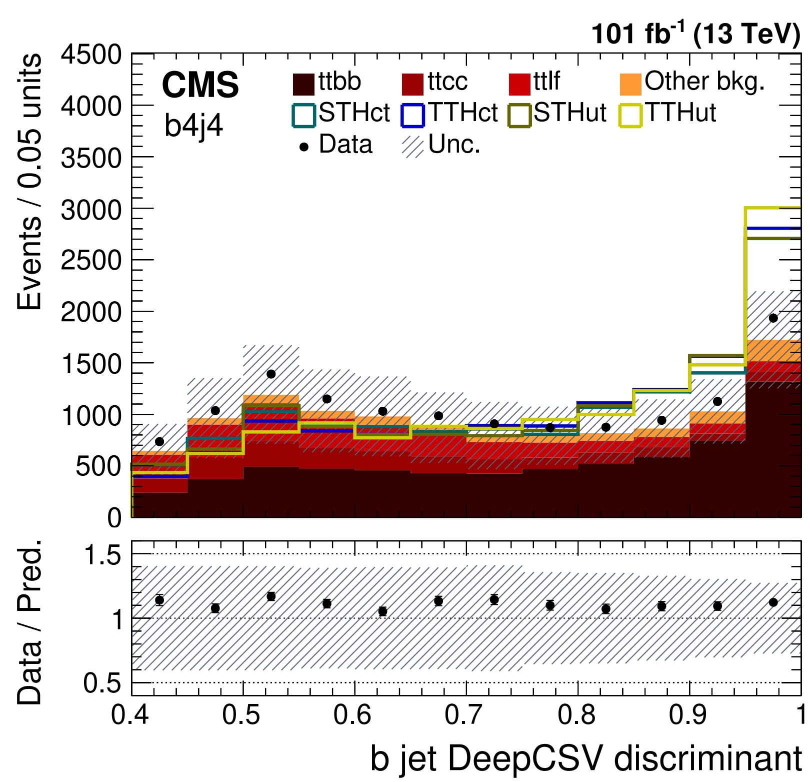


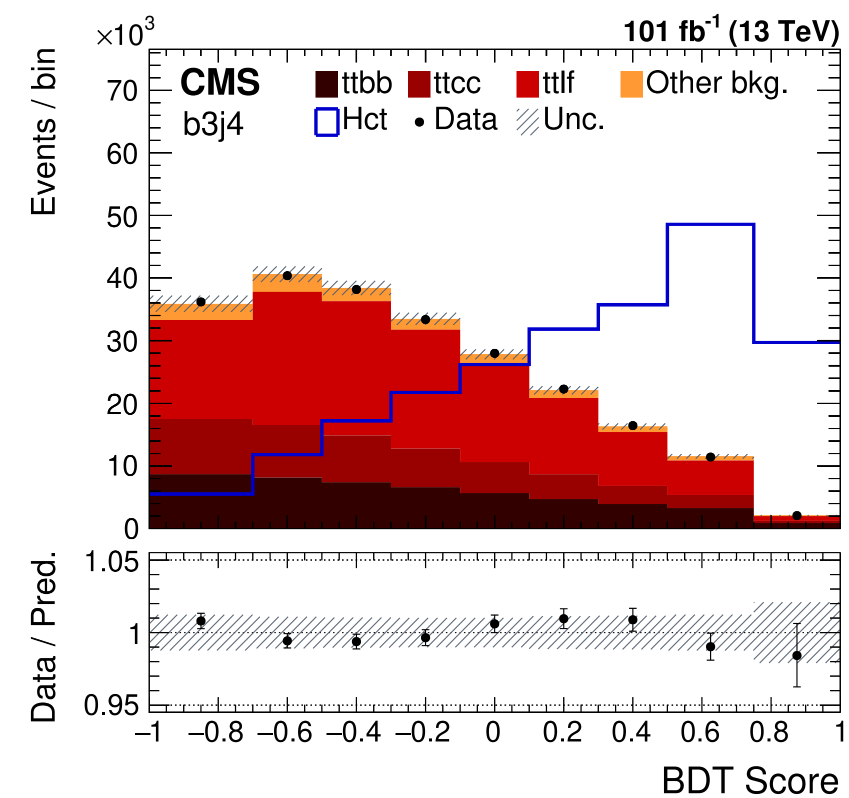


H→bb in CMS

- Leptonic top quark decay for trigger, build categories based on jet and b-tagged jet multiplicity
- Use residual neural network for reconstructing Higgs and top from decay products, higher efficiency (~80% for signals and ttbar background) than kinematic fit
- Individual BDTs trained for different couplings, jet categories
  - 164 input kinematic distributions
  - b-tagging scores among the highest ranked variables
- 2016 result based on previous analysis strategy

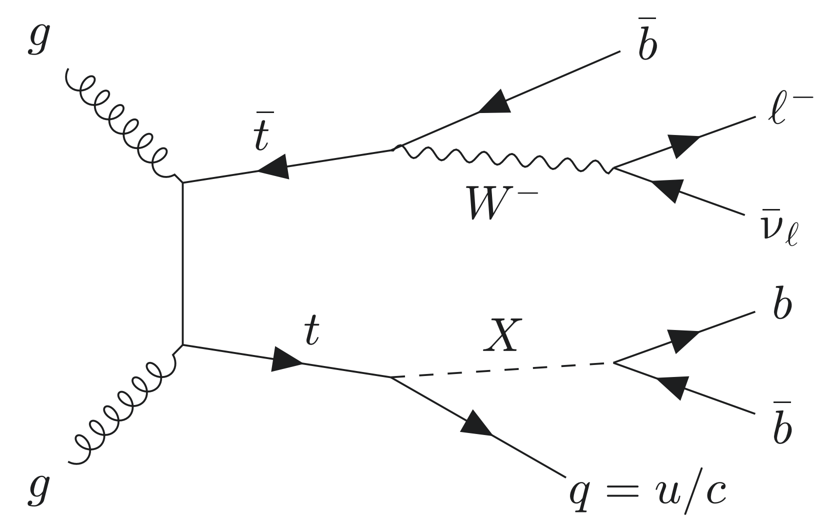


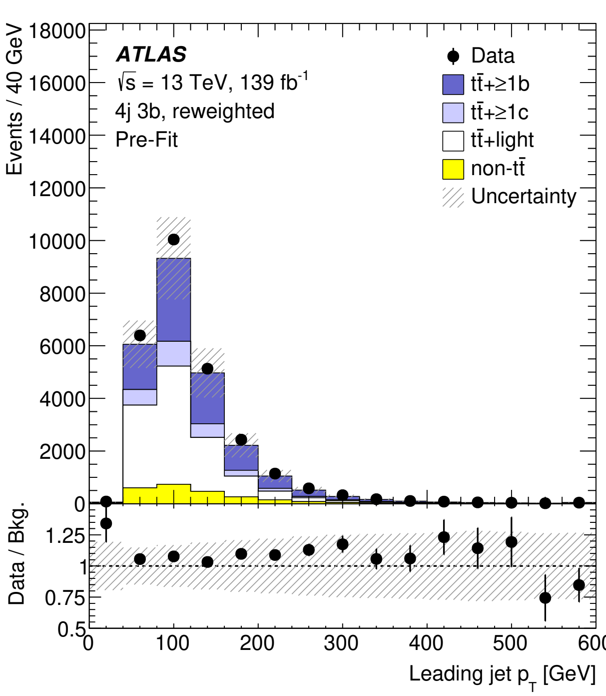


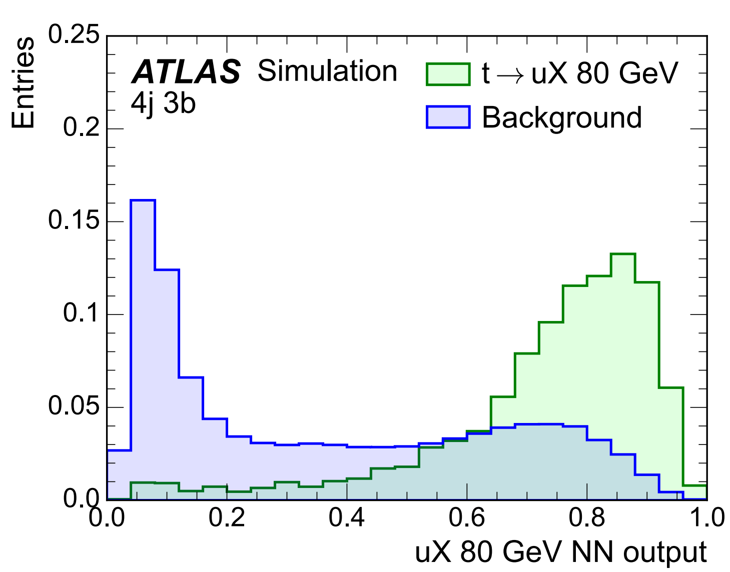


H→bb in ATLAS

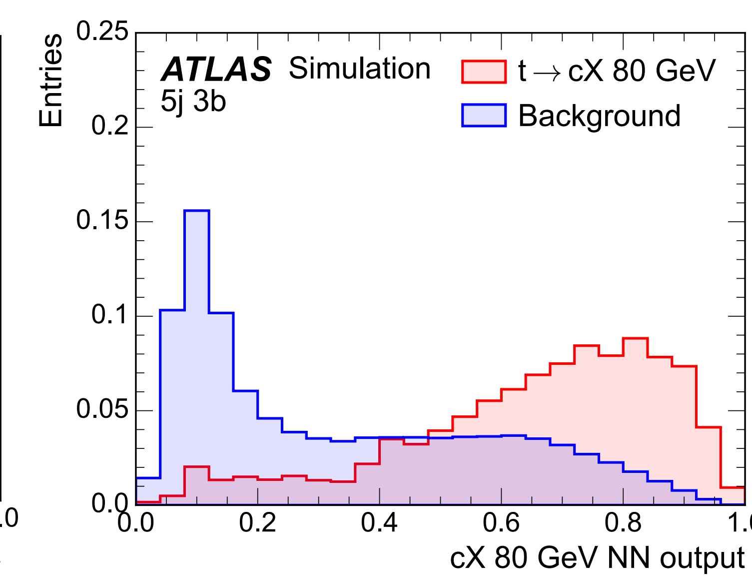
- More inclusive analysis design: one leptonic top, other top with FCNC decay involving any light scalar with X→bb
- Apply data-driven corrections to simulated background samples, correcting for mismodeling of additional radiation in parton shower
- Neural net trained using inputs of object kinematics and event observables, X particle mass → allows differentiation of signals
    - NN evaluated for each mass hypothesis individually



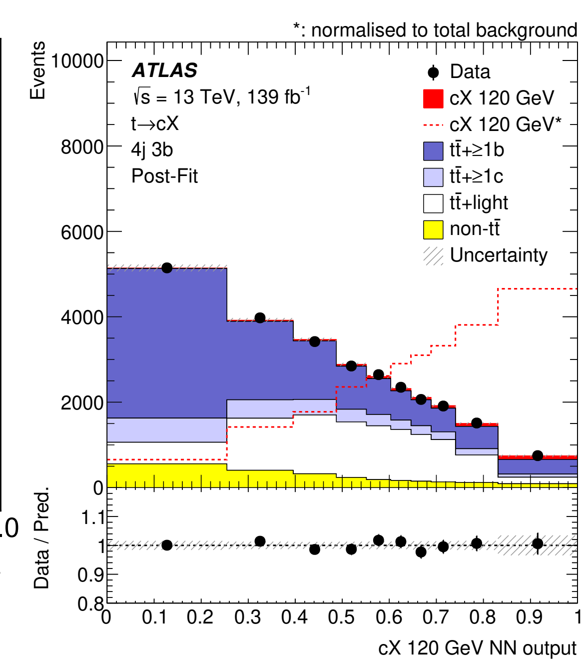




(d) $m_X = 80\,\mathrm{GeV}$, 4j 3b



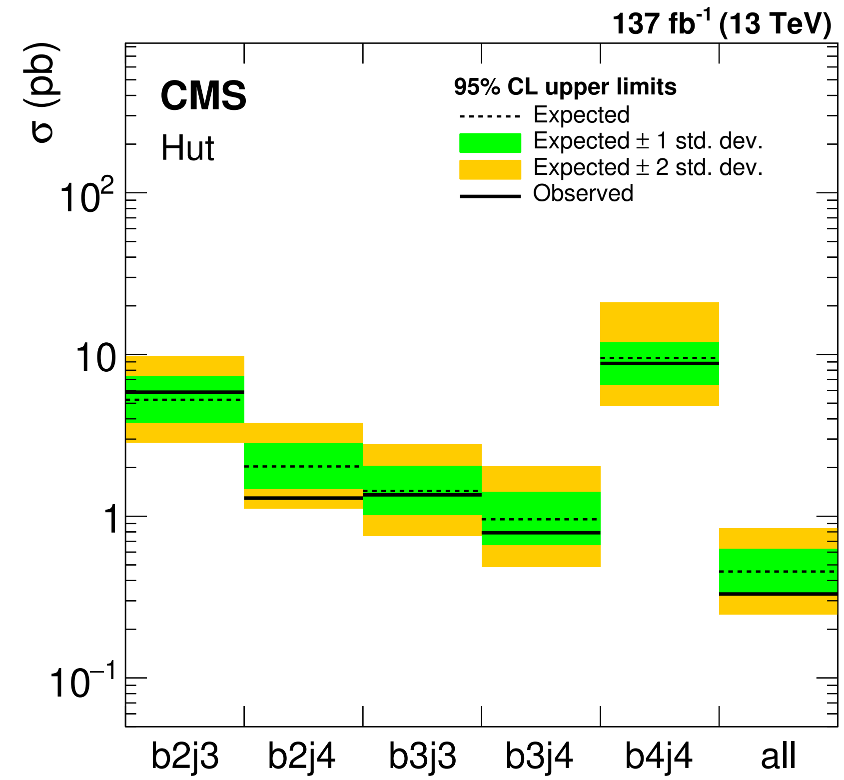
(e) $m_X = 80\,\mathrm{GeV}$, 5j 3b

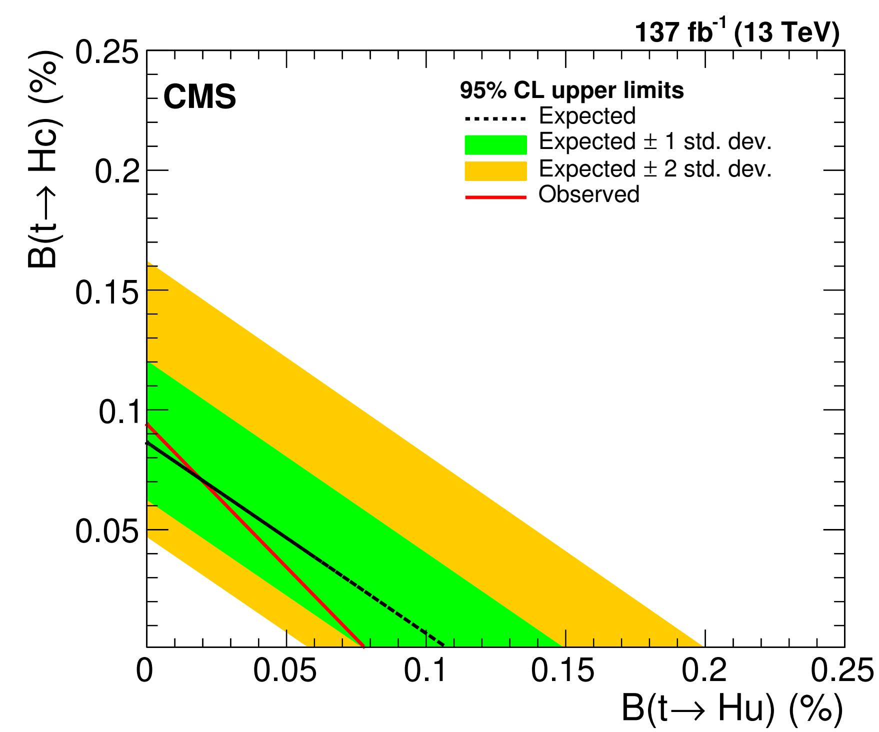


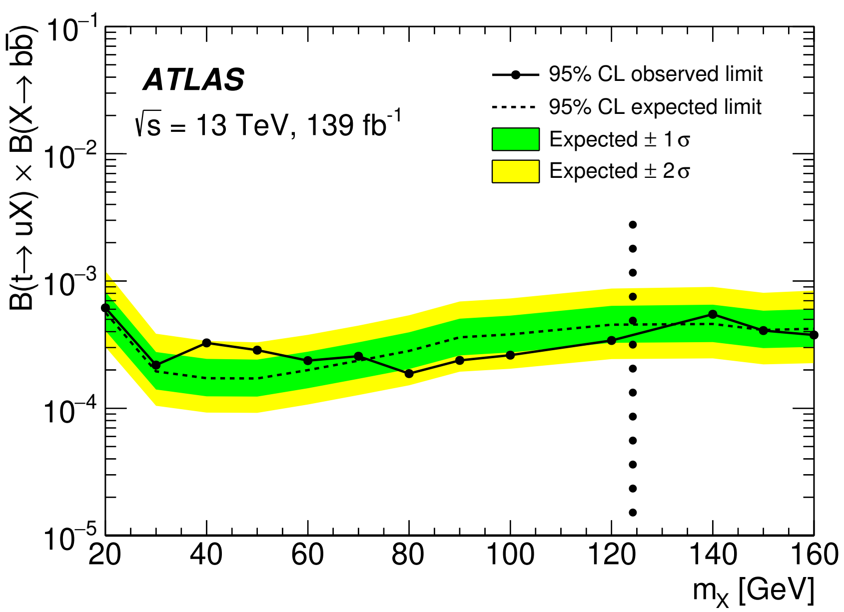
H→bb results

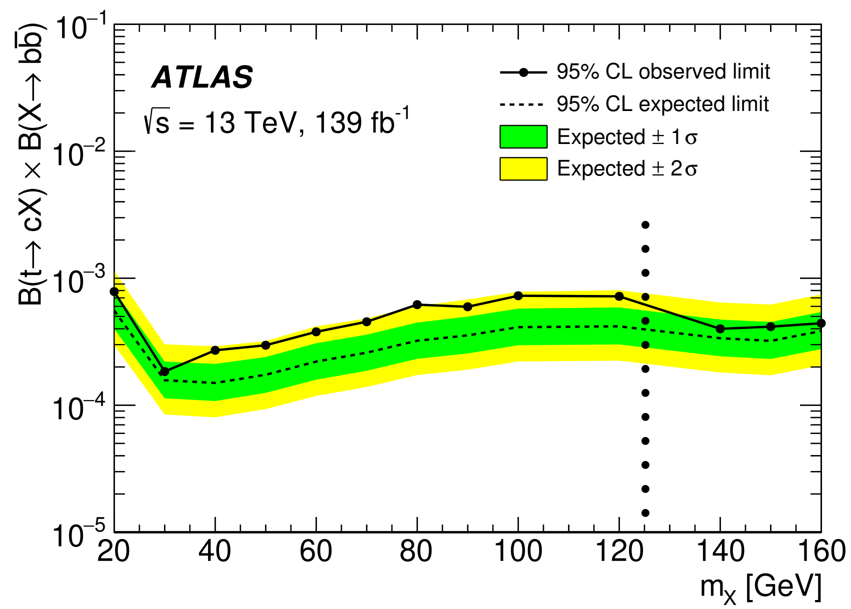
- ATLAS limits as function of scalar mass
- Expected (Observed) results for ATLAS and CMS as BR × 10^{-4}

	ATLAS	CMS
tHc	7.7 (11.9)	8.6 (9.4)
tHu	8.8 (7.7)	11 (7.9)



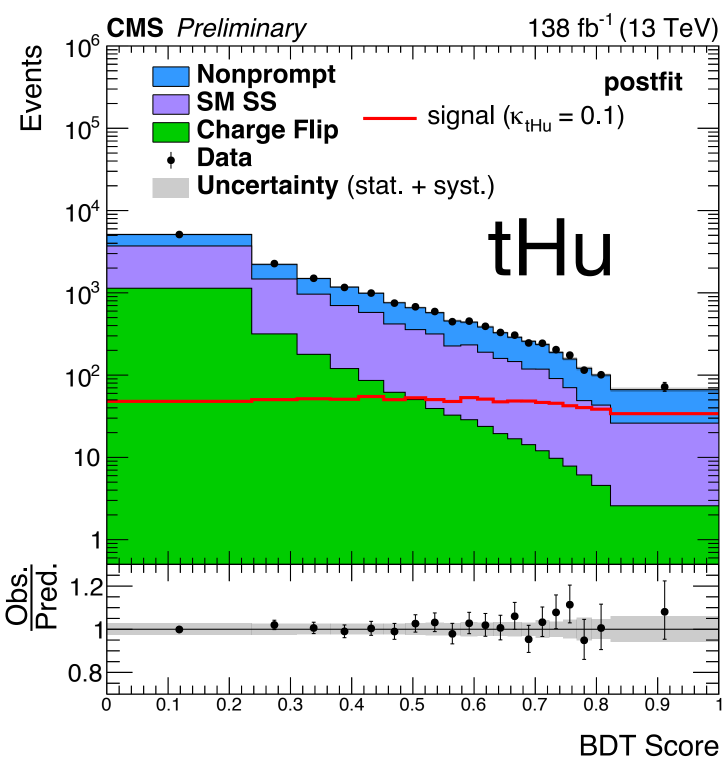


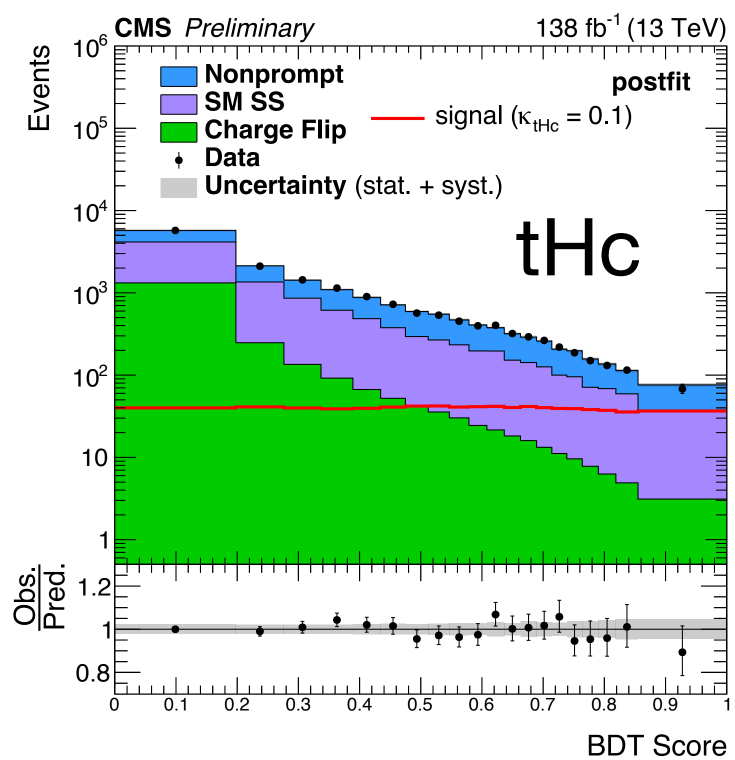


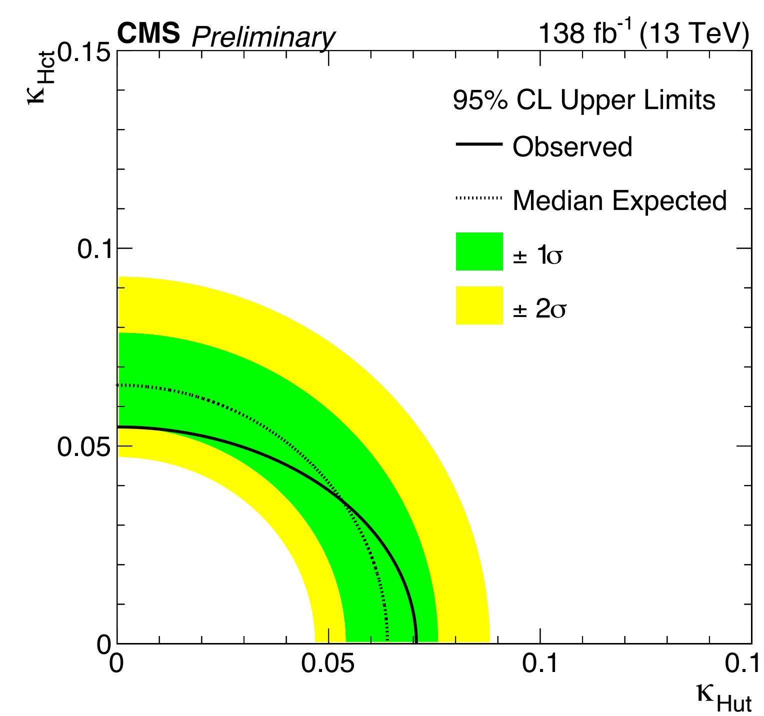


CMS multilepton

- Select events with dilepton triggers, require one pair of light leptons with same charge
- Data driven estimation methods used for nonprompt lepton and charge flip backgrounds, prompt lepton background taken from simulation
- Dedicated BDTs used for tHu and tHc couplings, utilizing charm tagger to enhance sensitivity to tHc
  - b-tagging and charm tagging scores from DeepJet algorithm amongst most important features in BDT

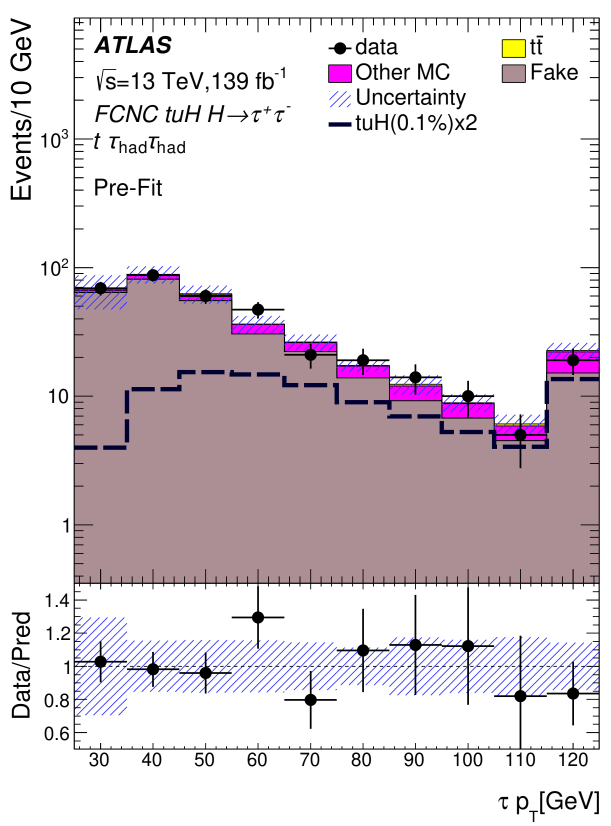


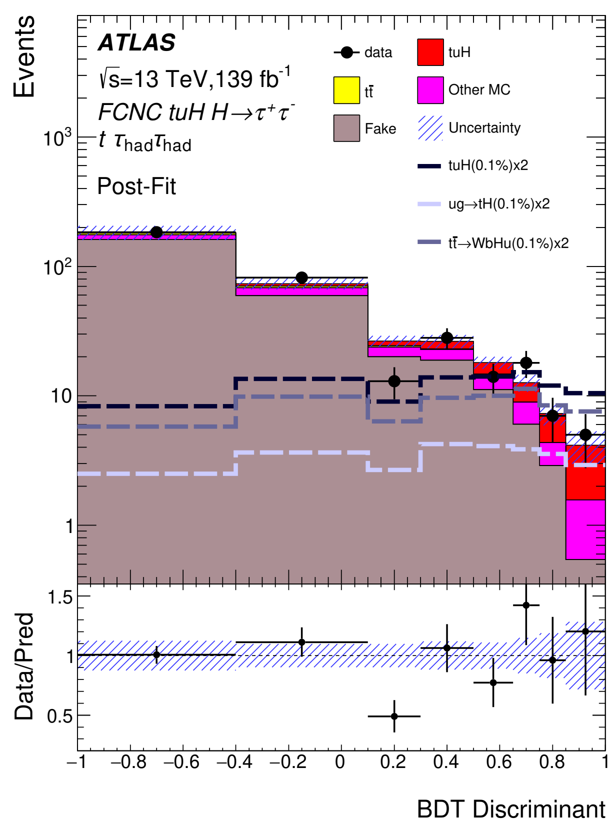


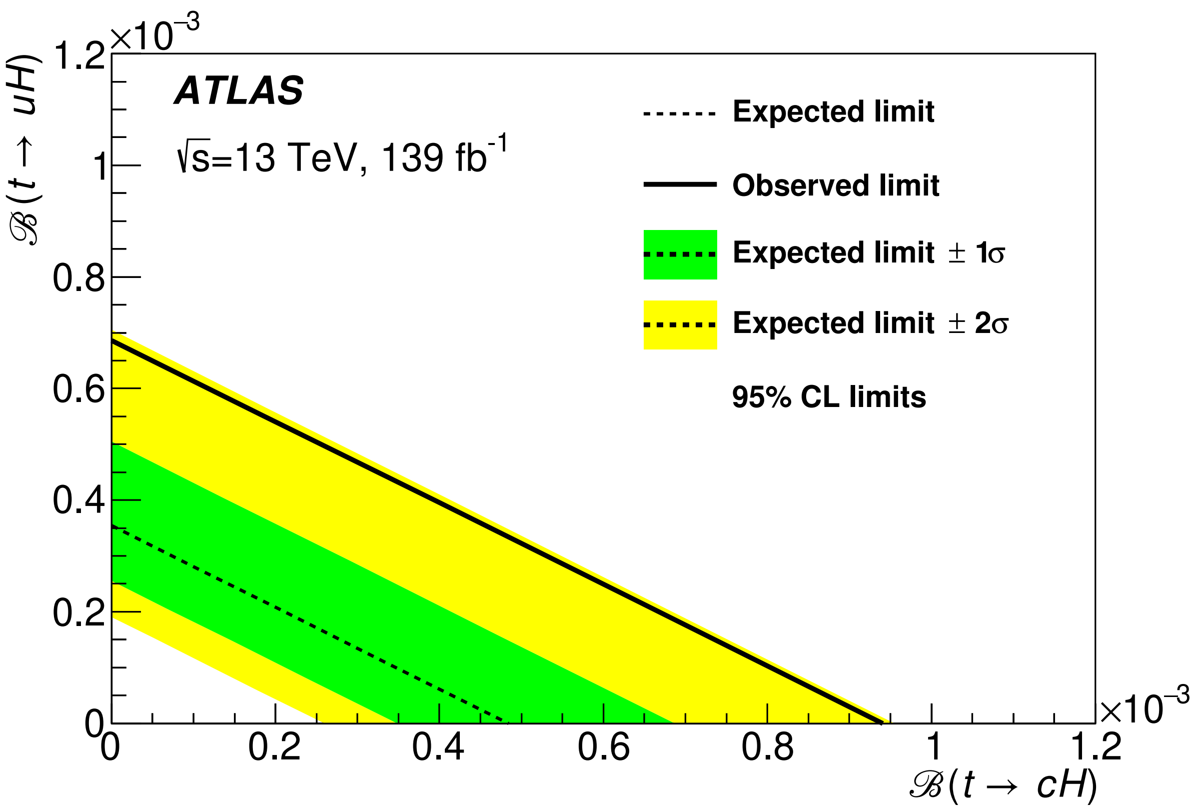


H→$\tau\tau$ in ATLAS

- Events selected using single lepton or di-tau triggers
- Use both hadronic or leptonic top channels
  - 7 signal regions based on number of light leptons, τ_{had} candidates, light flavor jets
  - Only $\tau_{had}\tau_{had}$ channel used for leptonic top decay to avoid overlap with other analyses
- Data driven bkg estimates for nonprompt leptons (corrected simulation, fake-factor method) and fake taus (ABCD method)
- Targeted BDTs with different set of input variables used in each signal region
- Observe 2.3sigma excess, driven by $t_{lep}\tau_{had}\tau_{had}$ channel, sensitivity driven by leptonic channels

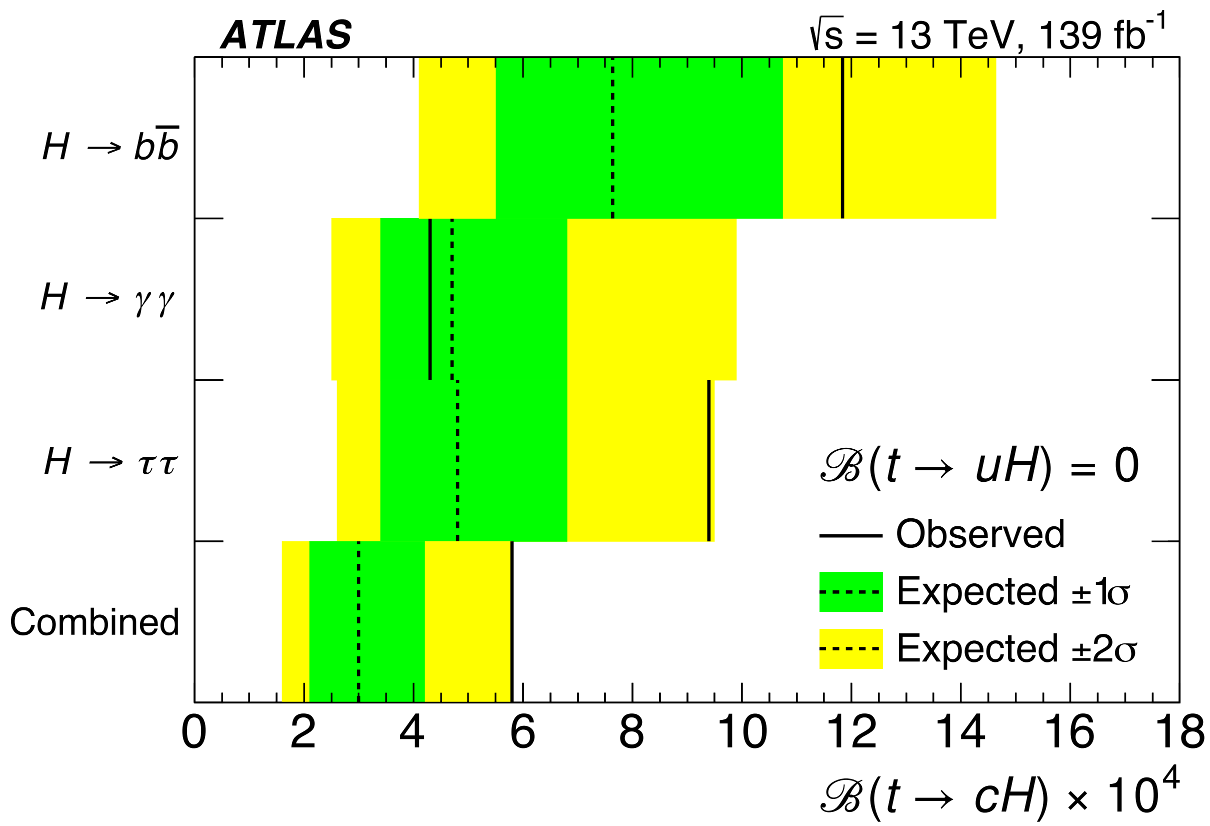


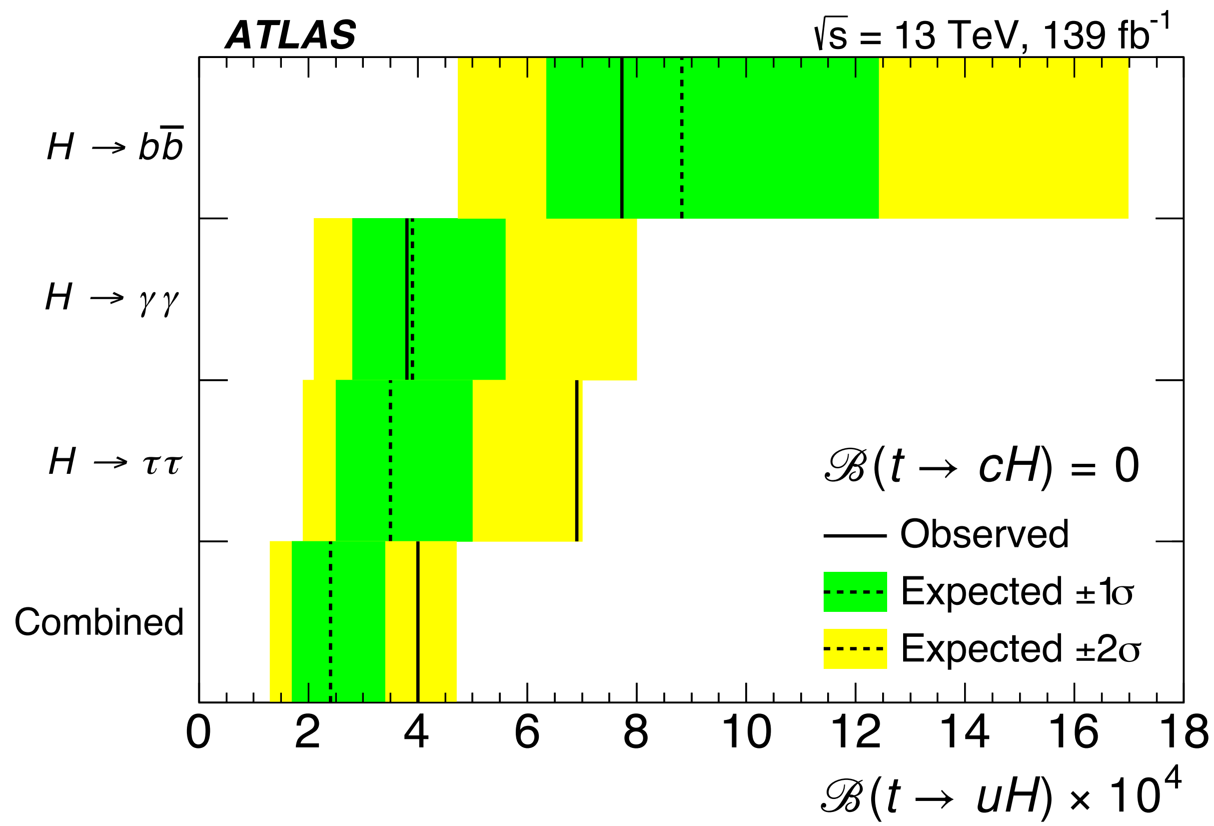




ATLAS Combination

- Run 2 combination of public results: $H\rightarrow\tau\tau$, $H\rightarrow\gamma\gamma$, $H\rightarrow bb$
- Correlation scheme carefully studied
  - Luminosity, PU modeling, JES correlated between all analyses
  - b-tagging correlated between $H\rightarrow\tau\tau$, $H\rightarrow bb$
- Some uncertainties kept uncorrelated for simplicity
  - Dominant systematics are analysis specific
  - $H\rightarrow\tau\tau$, $H\rightarrow\gamma\gamma$ are statistically dominated

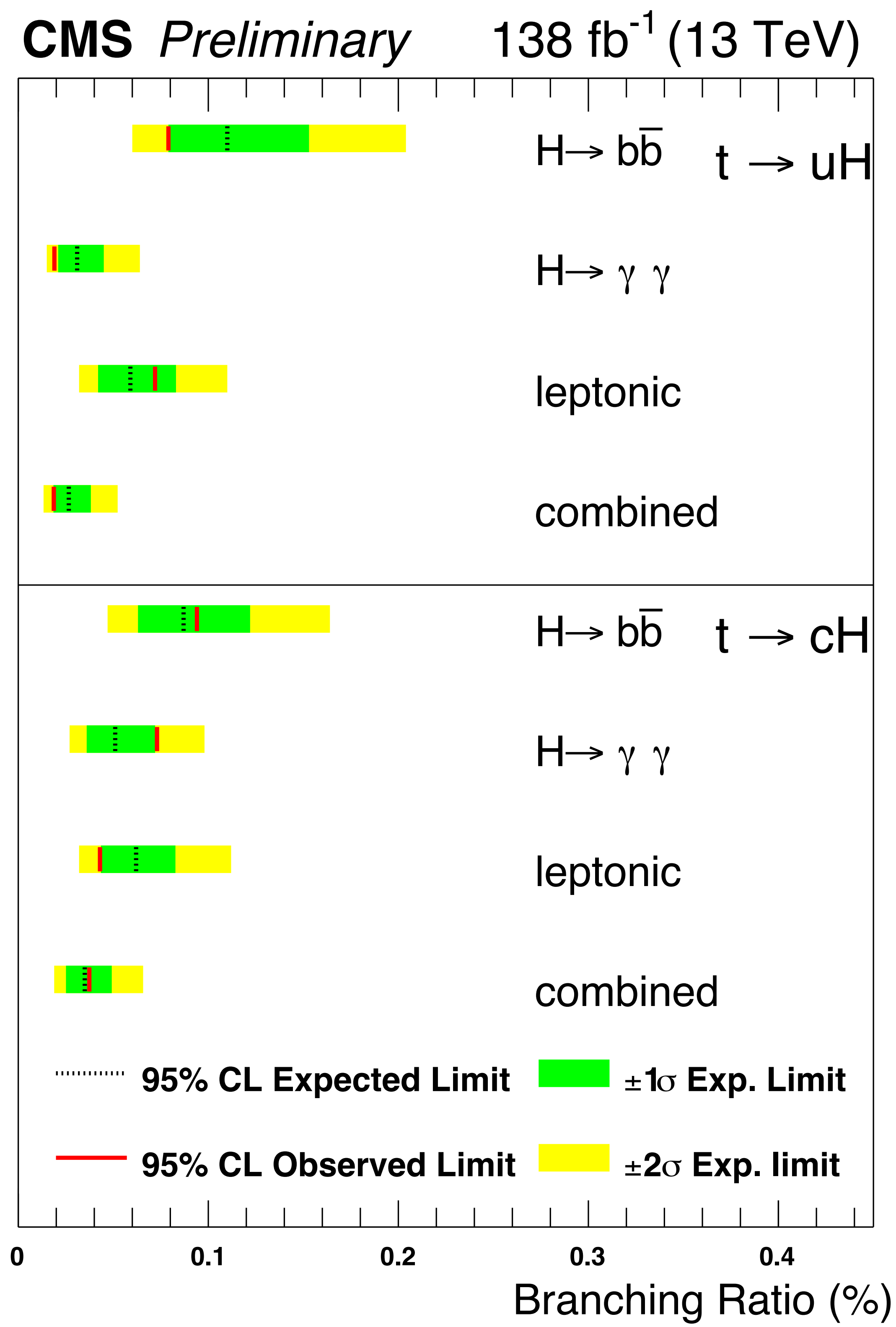




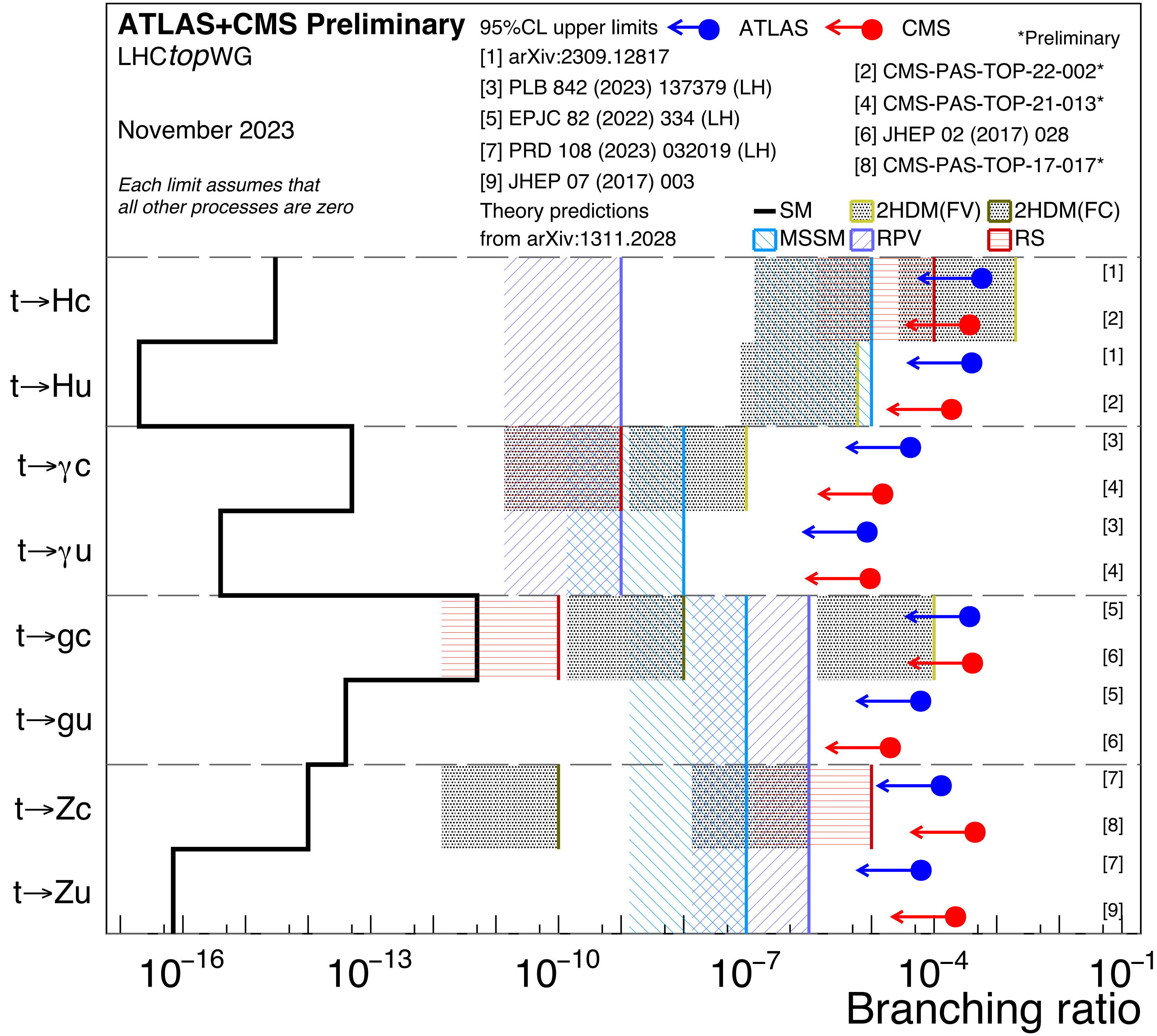
CMS Combination

- No (significant) overlap between signal or control regions
- Experimental systematic uncertainties estimated with similar methods are fully correlated between analyses (e.g. JES, luminosity, lepton identification)
- Theoretical uncertainties (PDF, shape, normalization) are correlated between analyses for appropriate processes
- Choice of correlation scheme has very minimal impact on final result (dominating uncertainties are usually analysis specific)
- Main drivers of combined result: H → γγ and leptonic channels

Analysis	$\mathcal{B}(t \to Hu)$ observed (expected)	$\mathcal{B}(t \to Hc)$ observed (expected)
$H \to b\bar{b}$ [24]	0.079 (0.11)%	0.094 (0.086)%
$H \to \gamma\gamma$ [25]	0.019 (0.031)%	0.073 (0.051)%
Leptonic (this paper)	0.072 (0.059)%	0.043 (0.062)%
Combination	0.019 (0.027)%	0.037 (0.035)%

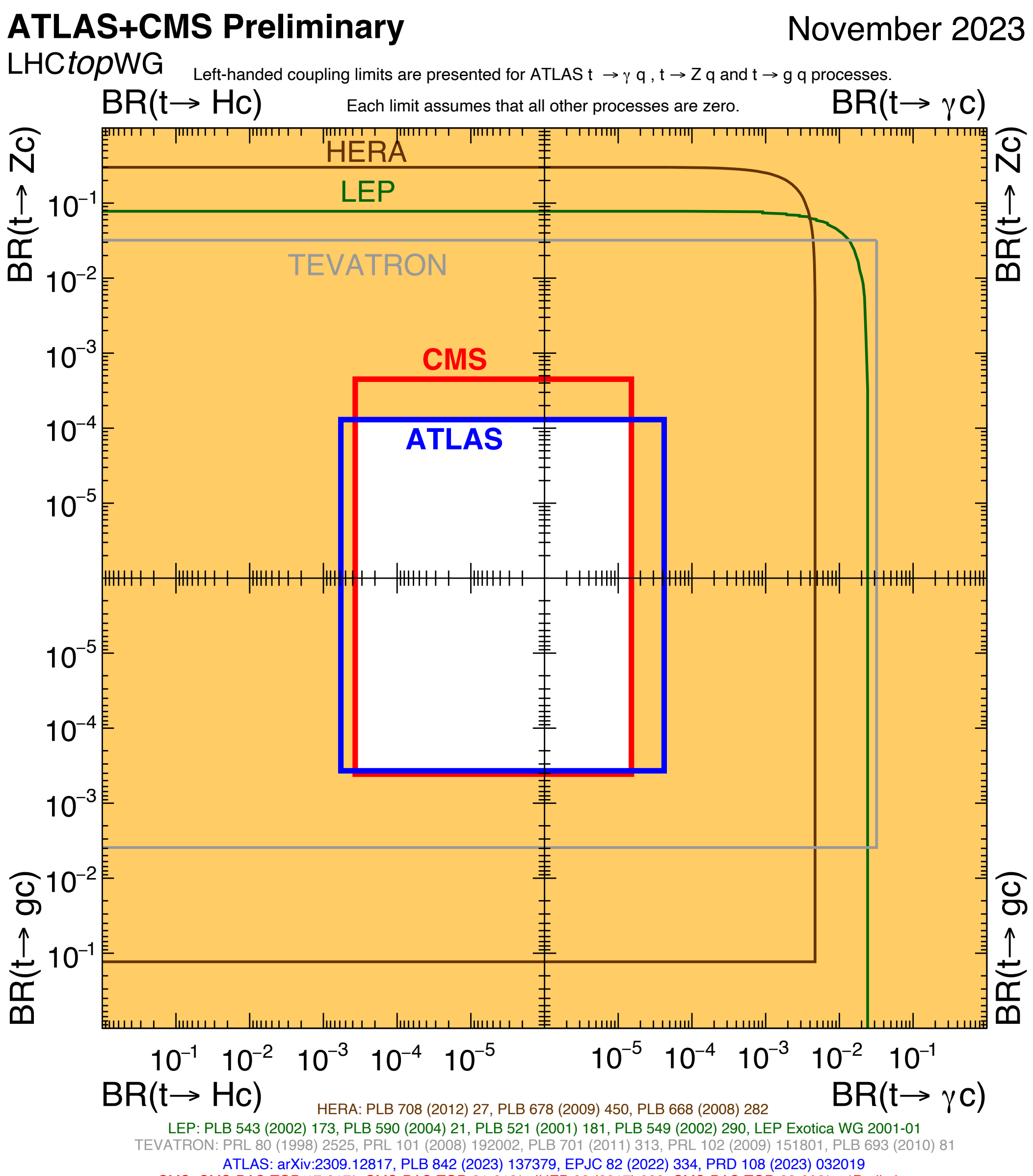


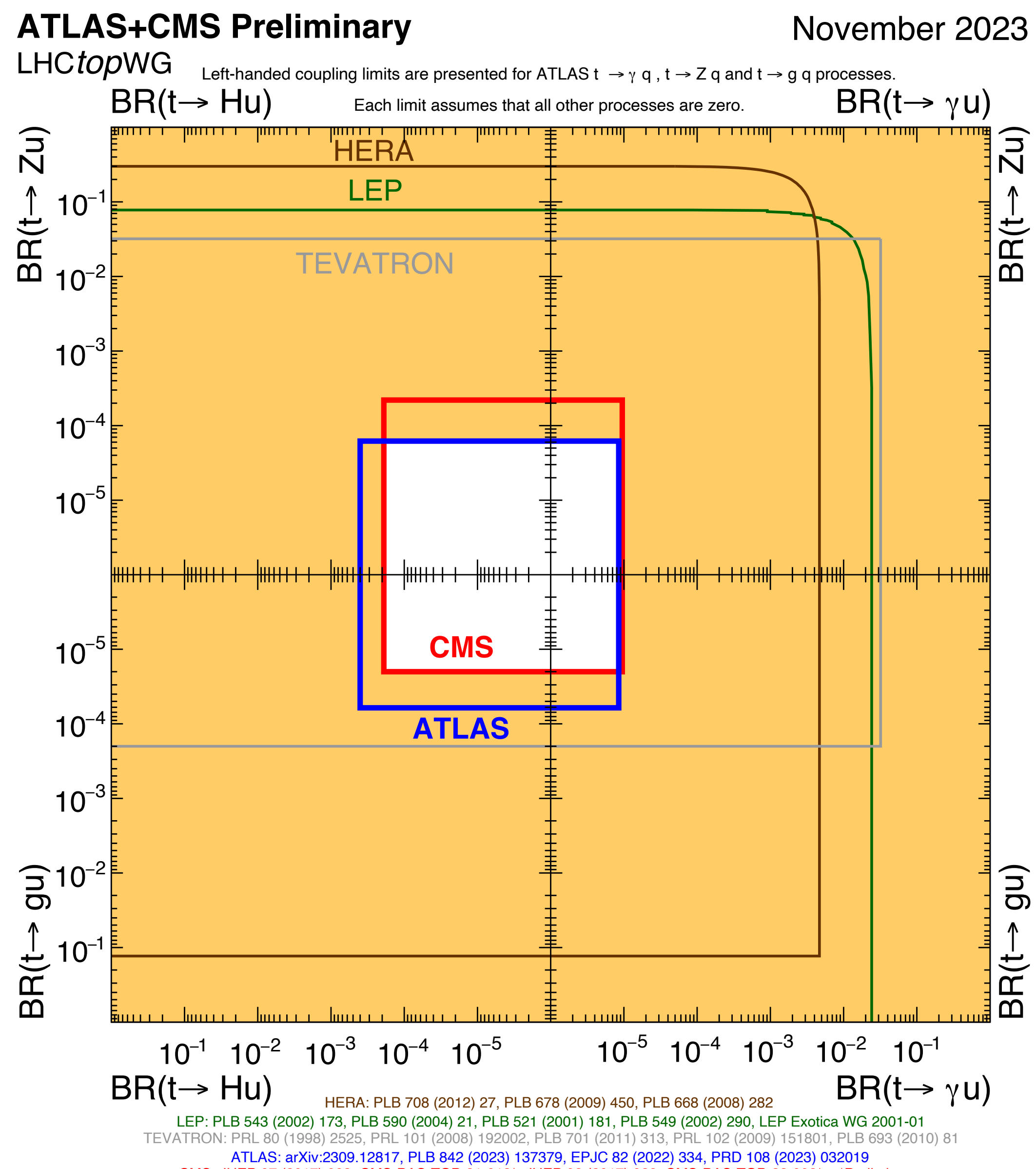
Big Picture


ATLAS+CMS Preliminary
LHCtopWG
November 2023
Each limit assumes that all other processes are zero
95%CL upper limits ATLAS CMS
*Preliminary
[1] arXiv:2309.12817
[2] CMS-PAS-TOP-22-002*
[3] PLB 842 (2023) 137379 (LH)
[4] CMS-PAS-TOP-21-013*
[5] EPJC 82 (2022) 334 (LH)
[6] JHEP 02 (2017) 028
[7] PRD 108 (2023) 032019 (LH)
[8] CMS-PAS-TOP-17-017*
[9] JHEP 07 (2017) 003
Theory predictions from arXiv:1311.2028
SM
2HDM(FV)
2HDM(FC)
MSSM
RPV
RS
t→Hc
t→Hu
t→γc
t→γu
t→gc
t→gu
t→Zc
t→Zu
10^{-16}
10^{-13}
10^{-10}
10^{-7}
10^{-4}
10^{-1}
Branching ratio

Big Picture

- 8-axis overview of limits on FCNC BR of t➞Xc and t➞Xu
- LHC limits surpass previous constraints by order(s) of magnitude by now





Summary & Outlook

- Many interesting results for tHq FCNC have been released fairly recently
- Combinations within CMS and ATLAS have yielded constraints that start constraining some BSM models, e.g. 2HDM(FV)
- Exchange between CMS and ATLAS teams has started concerning a potential combination
    - Hopefully a first simple combination (without proper correlation scheme) can be put together quickly to gauge potential improvement
    - Need to understand differences of (production mode) sample and inclusive cross section, correlations