ttH/tH: Experimental Status

General Meeting of the
LHC Higgs Cross Section Working Group
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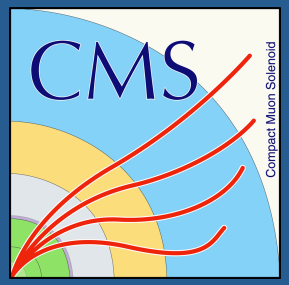
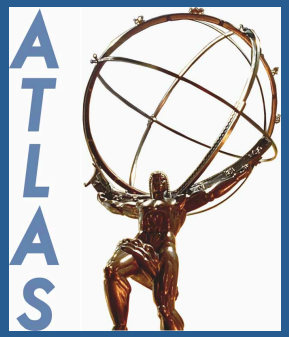
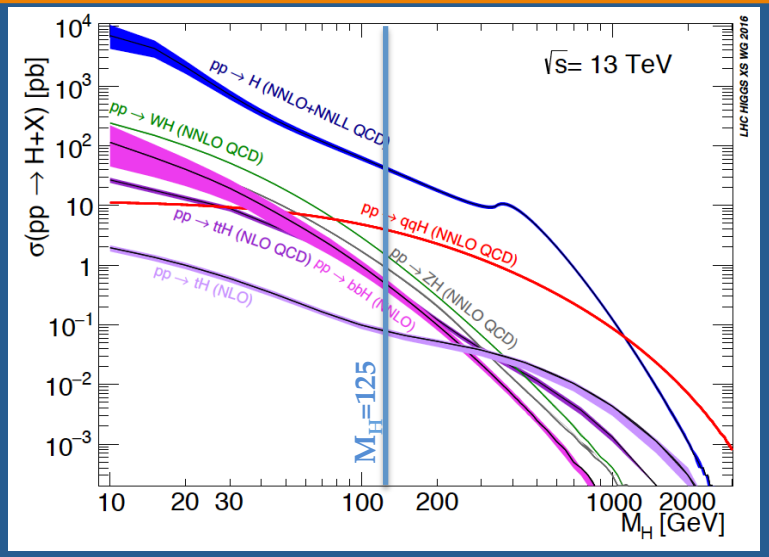
Stefan Guindon,
Chris Neu,
Stefano Pozzorini,
Laura Reina
Benjamin Stieger

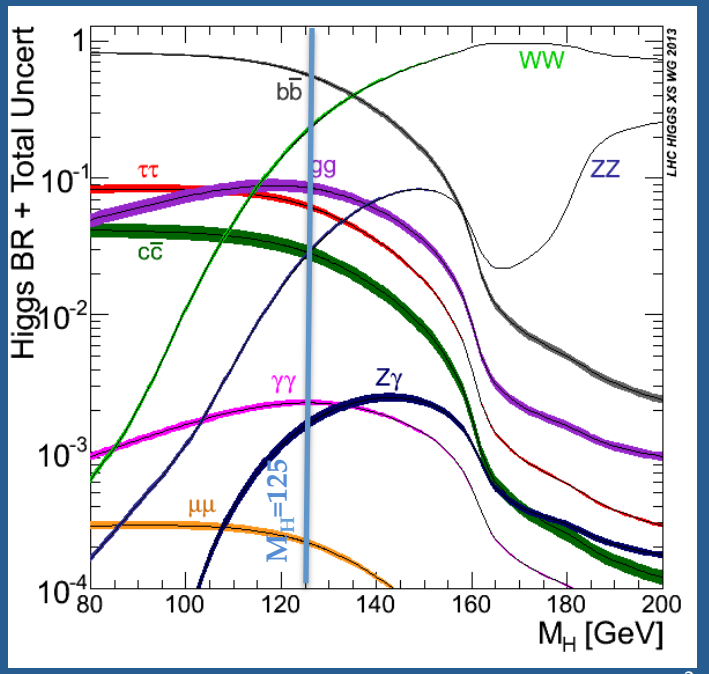




Motivation

- Direct measurement of top-Higgs coupling is essential for full characterization of the Higgs boson:
  - Within the SM, the Higgs coupling to the top quark, Y_t, is predicted to be by far the largest
    - *needs to be verified*
  - For fermions, only Y_b and Y_τ probed so far
    - *complements existing information*
  - Y_t will be the easiest (and perhaps only) up-type fermion coupling to probe
    - *probes something unique*
  - The top quark plays a unique role in many SM-like EWSB extensions/alternatives, affecting the observed Y_t
    - *possible window to new physics*





Motivation

- Best avenue to measure the top-Higgs coupling is through observation of ttH production
  - Need to do everything we can to enable the observation of this process
  - A single-channel observation of ttH will need corroboration in other decay modes
    - ttH,H→bb and ttH,multileptons and ttH,H→ττ all important
    - Very rare yet very pure ttH,H→γγ essential as well – especially for precision studies post-first-measurement

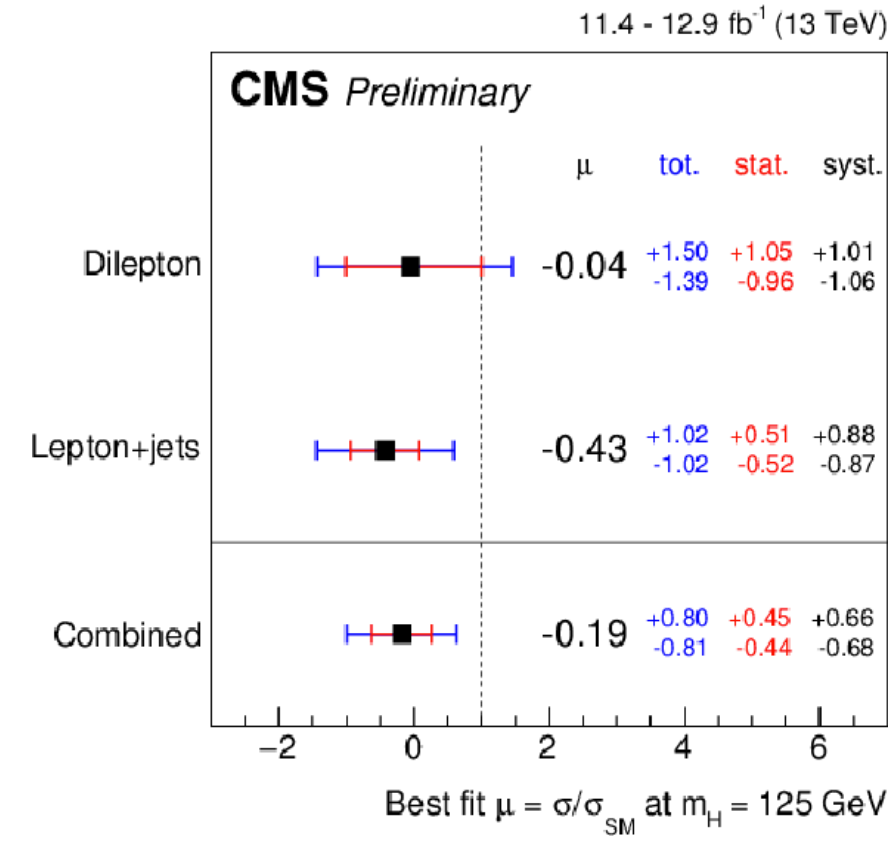
- tH production is crucial as well
  - Access to new physics through sensitivity to the sign of top Yukawa coupling
  - Supplements searches in the ttH campaign

- ttH/tH is a bit unique compared to other WG1 subgroups:
  - ttH production has not yet been observed in a statistically-satisfying way

- Below is a summary of status ttH and tH search campaigns at 13 TeV

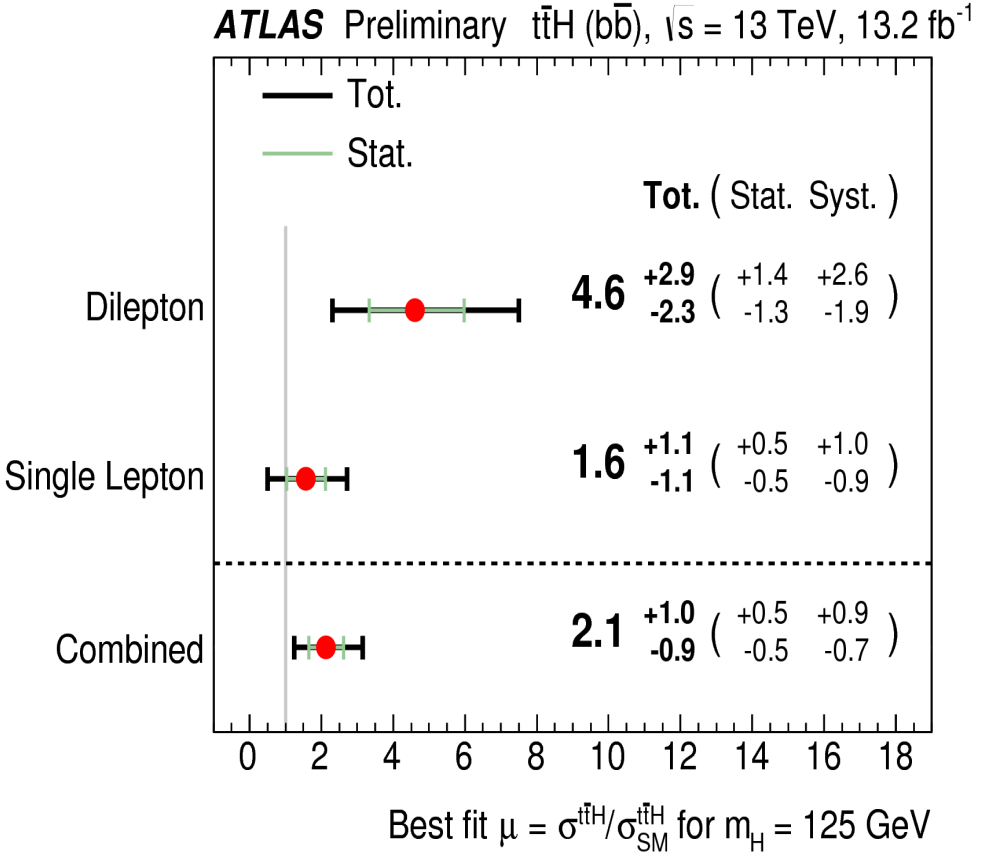
State of the Searches: ttH, H→bb

CMS-HIG-16-038



Upper limit: $\mu < 1.5$ (1.7) obs (exp) at 95% CL

ATLAS-CONF-2016-080

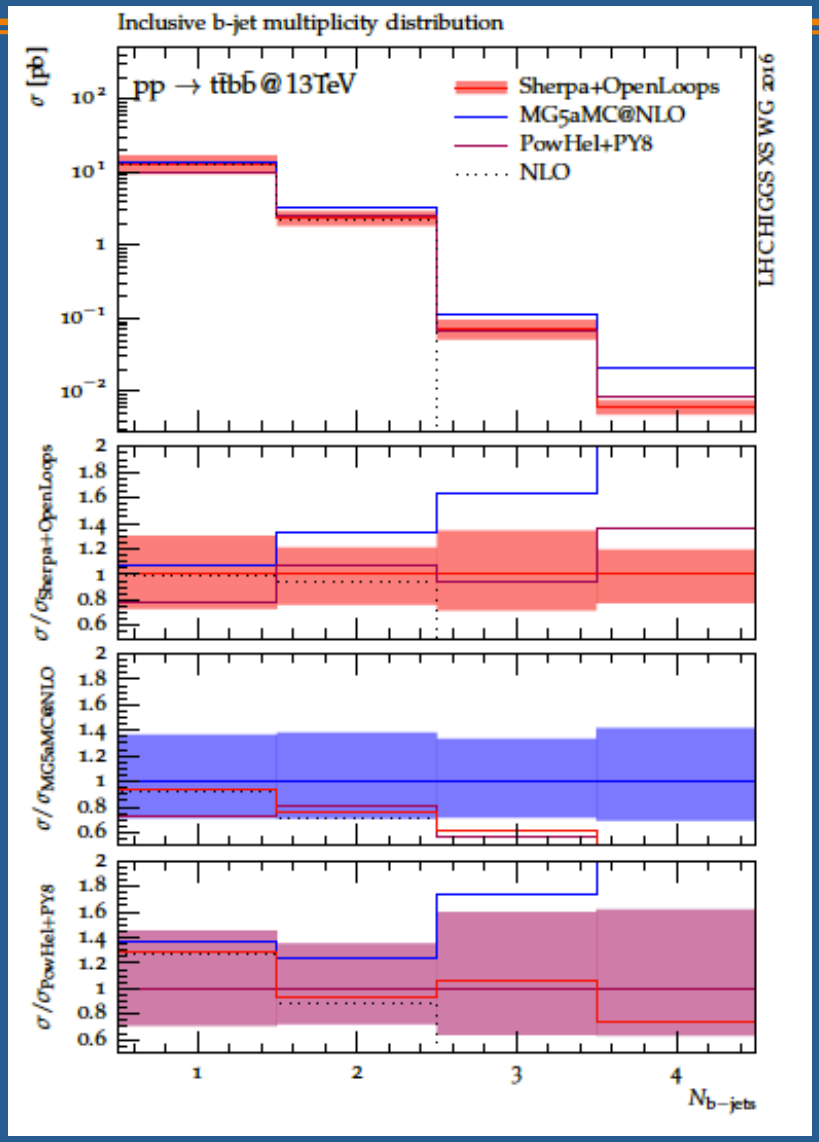


$\mu < 4.0$ (1.9) obs (exp) at 95% CL

- Systematics-limited search:
  - Leading experimental systematics, mostly associated with b tagging, being investigated
  - Theory systematics – it's all about tt+HF…

ttH,H->bb: The Key is Understanding tt+HF

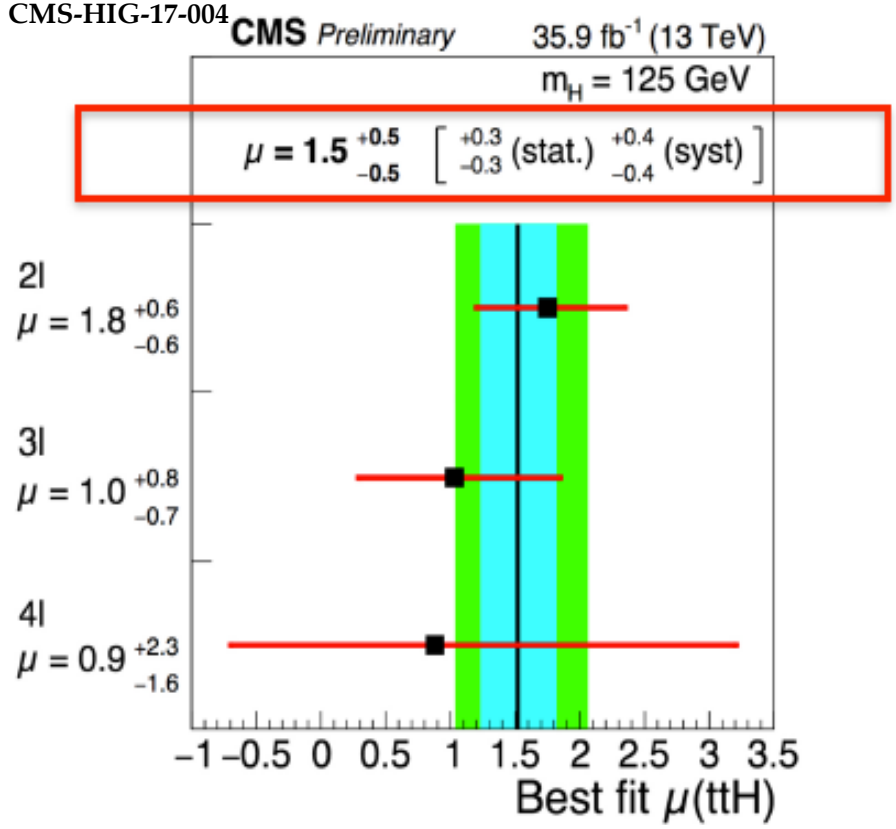
- Canonical ad-hoc 50% rate uncertainty on all tt+HF processes
  - tt+b-jets is an irreducible signature
  - tt+charm even less known than tt+b-jets
  - Huge impact on analyses
- The tt+b-jets process is poorly understood
  - Only recently do we have NLO calculations for the xsec
  - And even more recently NLO ME+PS events for use in analyses
- But NLO ≠ better, necessarily, if the predictions are poor
- Focus currently:
  - Compare various NLO ME+PS events for tt+bb
    - Consistency under well-defined conditions?
    - New scale treatment in MG5_aMC@NLO 2.5.4?
  - How do these state-of-the-art tools compare to CMS data
    - Need control regions independent from ttH signal-extraction campaign



See SP's talk earlier, and updates in ttH/tH WG meetings in coming weeks!

State of the Searches: ttH in multilepton signatures

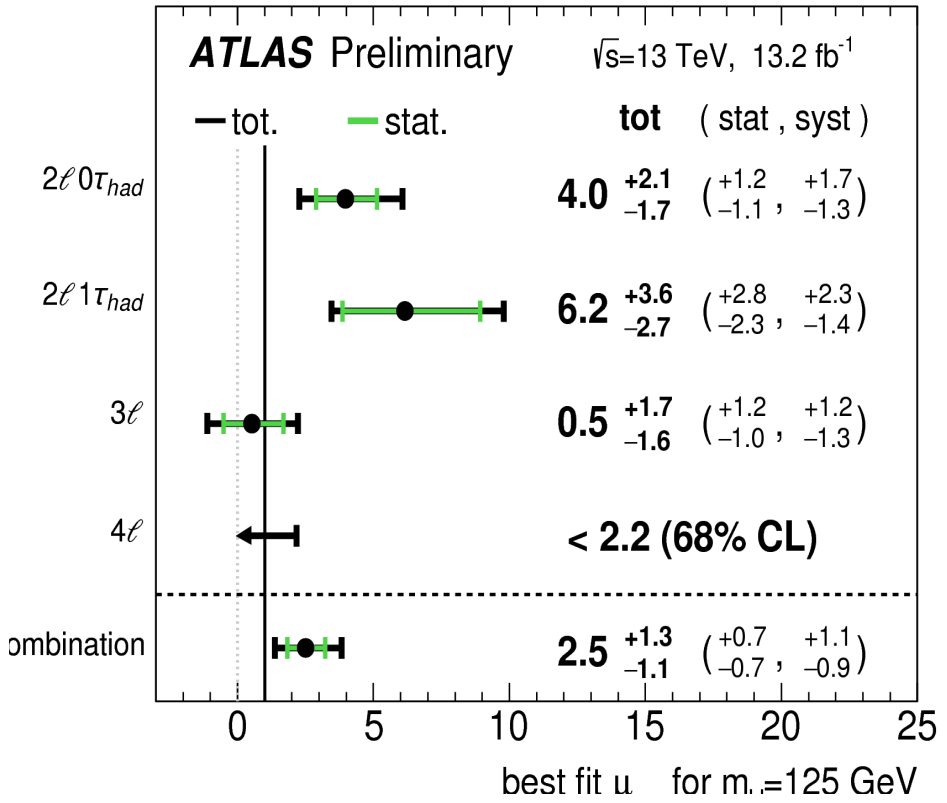
CMS-HIG-17-004



Best fit: $\mu = 1.5\ ^{+0.3}_{-0.3}(\text{stat})\ ^{+0.4}_{-0.4}(\text{syst})$

Significance of observation is 3.3σ, whereas the expectation, assuming SM-level of ttH was 2.4σ

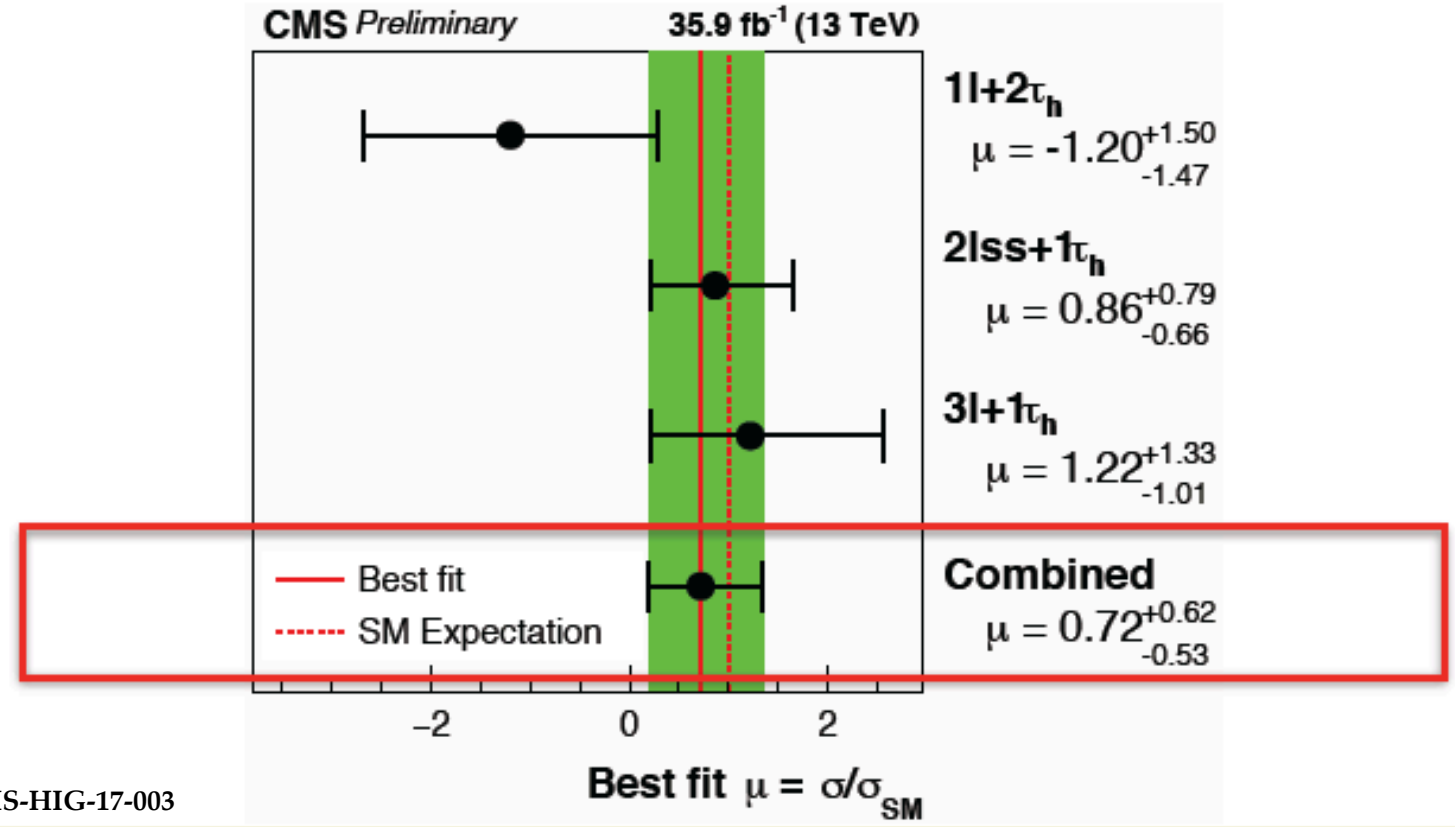
ATLAS-CONF-2016-058



Upper limit: $\mu < 4.9\ (2.3)$ obs (exp) at 95% CL

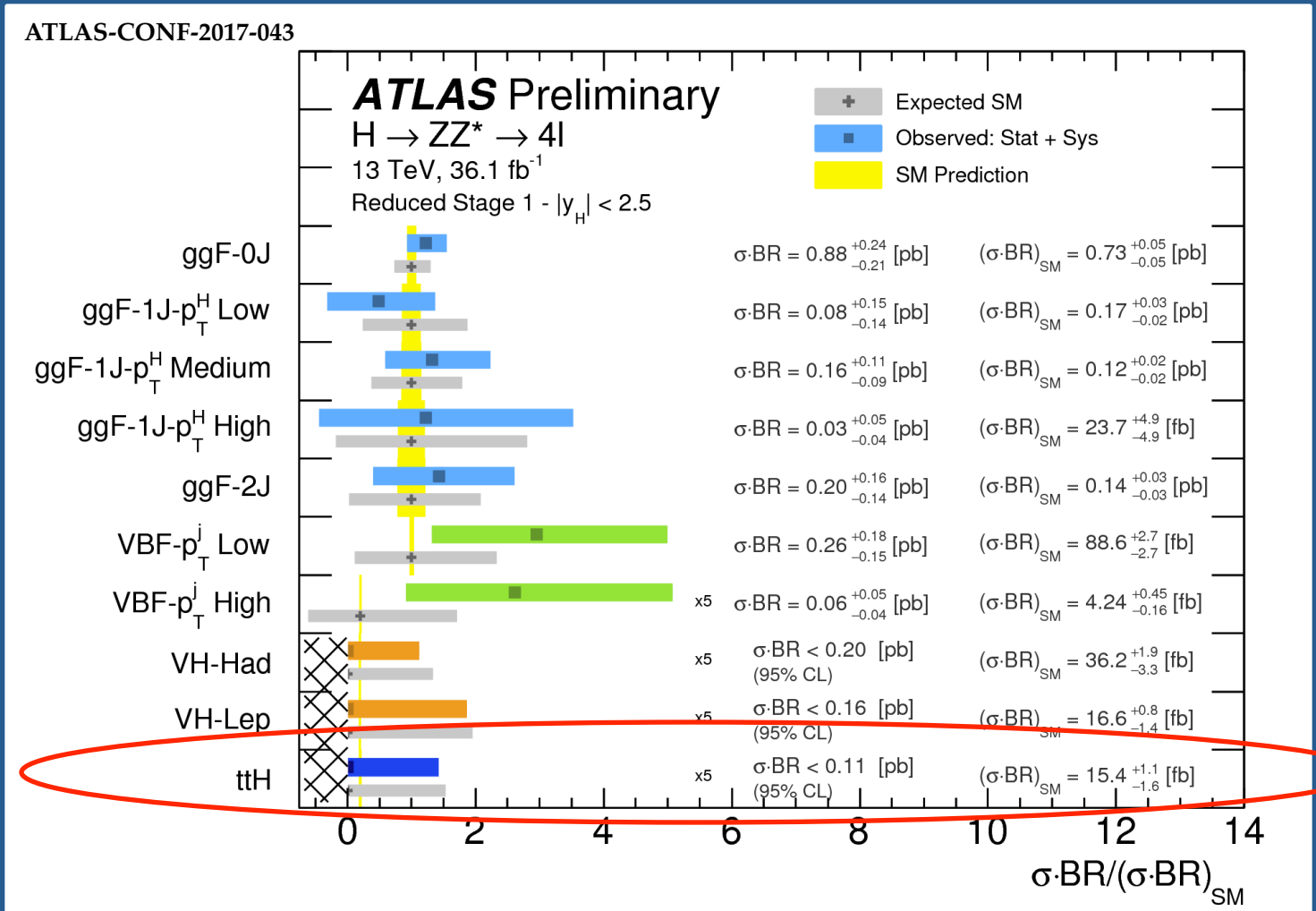
- CMS has achieved sensitivity to SM-level of ttH in this signature, ATLAS soon
- Both experiments are systematics limited…how can we improve?

State of the Searches: ttH, H→ττ at CMS



- Best fit: $\mu = 0.72\ ^{+0.62}_{-0.53}$ (stat ⊘ syst)
- Significance of observation is 1.4σ, whereas the expectation, assuming SM-level of ttH production was 1.8σ
- Upper limit: $\mu < 2.0$ (1.1) obs (exp) at 95% CL

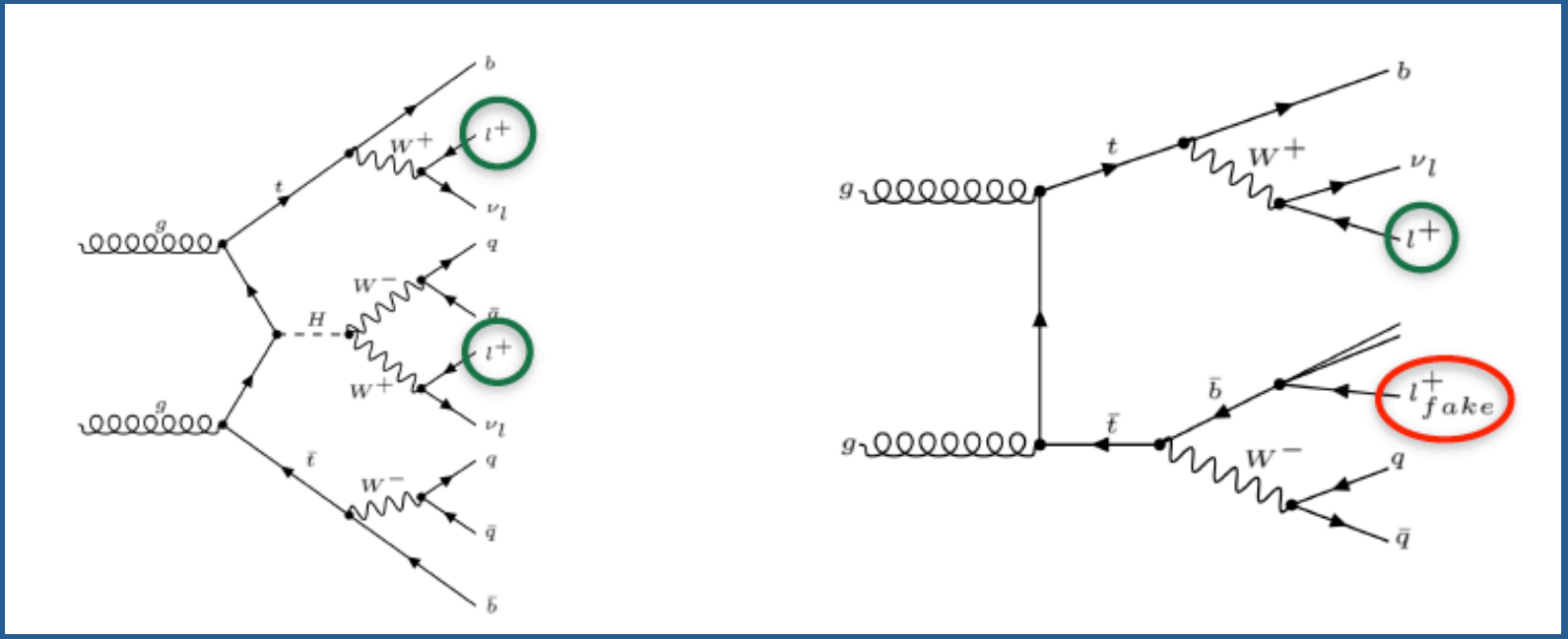
State of the Searches: volunteer ttH, H→ZZ→4lep at ATLAS



Upper limit: $\mu < 7.1$ (7.4) obs (exp) at 95% CL

- Recent result from ATLAS on ttH in 4-lep

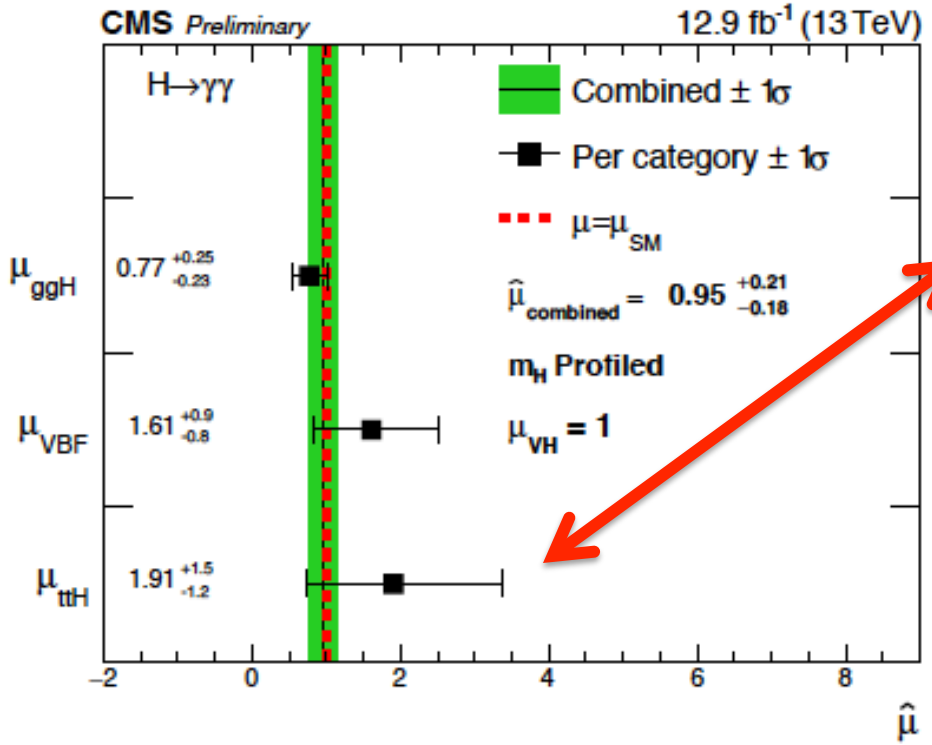
ttH in multileptons: Leading systematic uncertainties



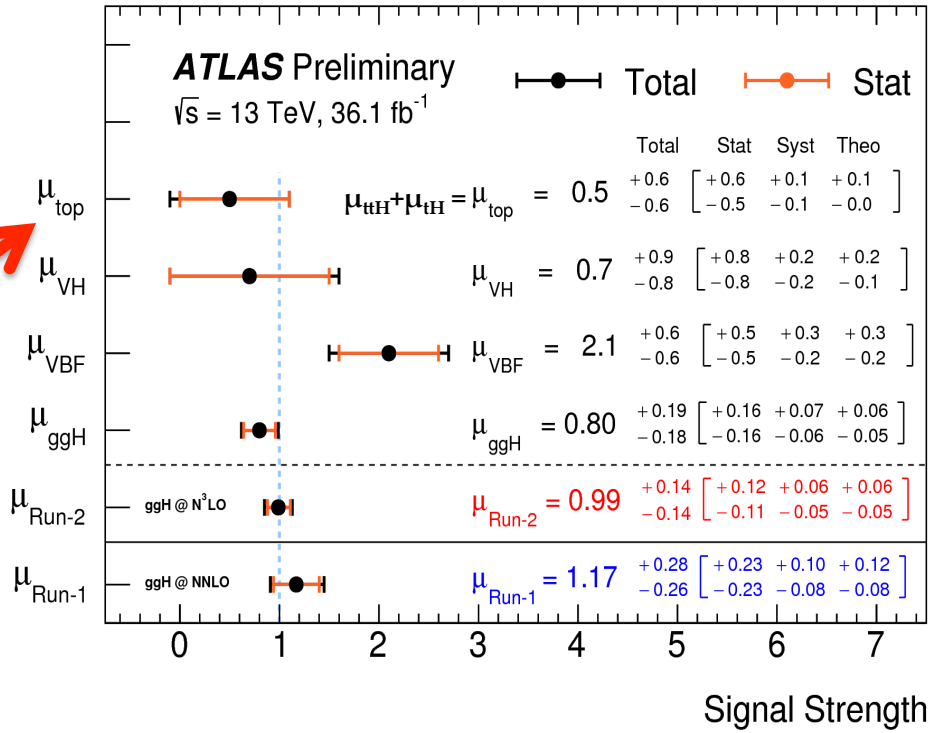
- Opportunities:
  - Improve our understanding of authentic leptons but from non-prompt sources
  - Theoretical cross sections on ttW and ttW:
    - NLO currently good to ~±15%, driven by missing higher order terms
    - NNLO tricky computationally

State of the Searches: ttH, H→γγ

CMS-HIG-16-020



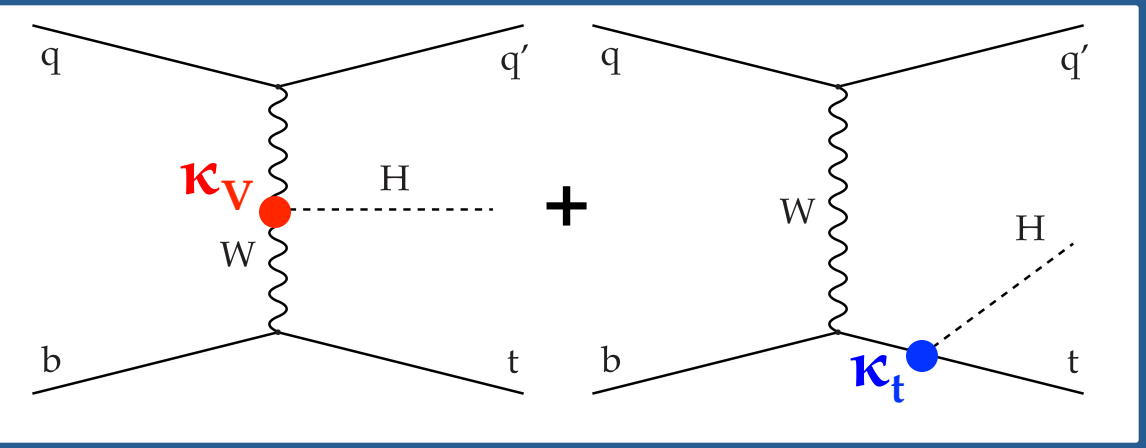
ATLAS-CONF-2017-045



- Uncertainty driven by statistics at both experiments
- Somewhat an afterthought…but will be a workhorse
  - *Good things come to those who wait…and build a solid analysis in the meantime*

Single top + Higgs Searches

tHq Analyses: Different Approach to Y_t

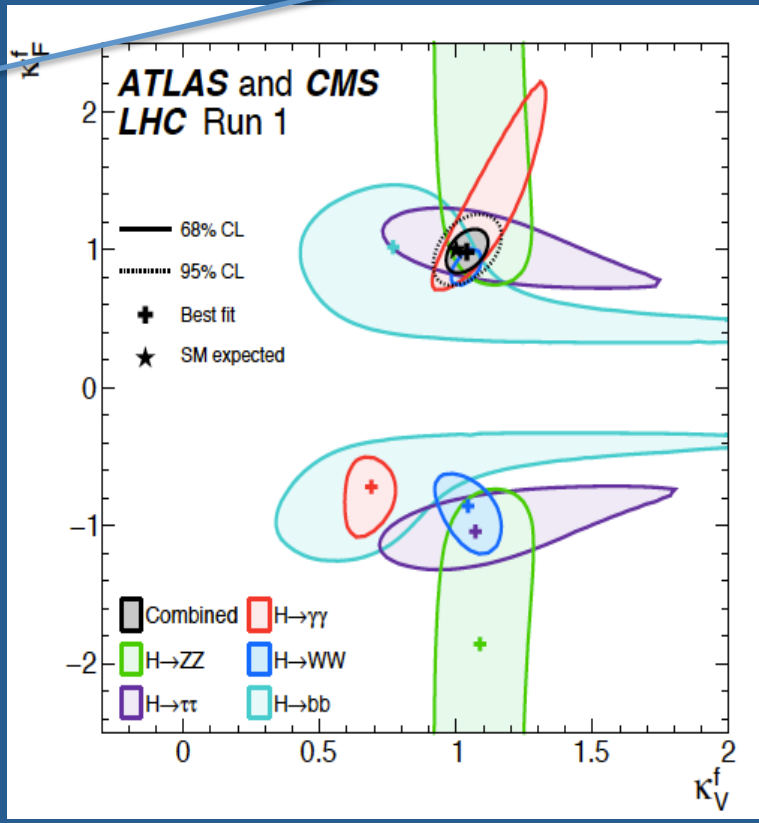


$\kappa_V = g_{HVV} / g_{HVV(SM)}$

$Y_t = \kappa_t Y_{t(SM)}$

$\sigma(tHq) \approx a\,\kappa_t^2 + b\,\kappa_V^2 + c\,\kappa_t\,\kappa_V$

- Hence this process is dependent on the *sign* of the top-Higgs coupling
- Interference effects suppress tHq production in the SM, but if Y_t is negative there is considerable enhancement:
  - For 8 TeV,
    - $\sigma_{SM}(tHq) = 18$ fb
    - $\sigma(tHq, Y_t = -1) = 230$ fb
- ttH is far less sensitive to this negative coupling

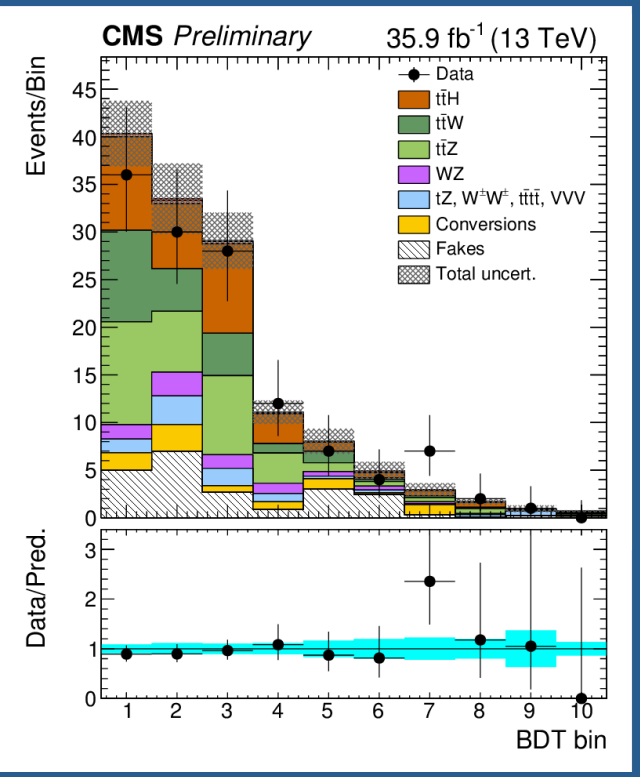


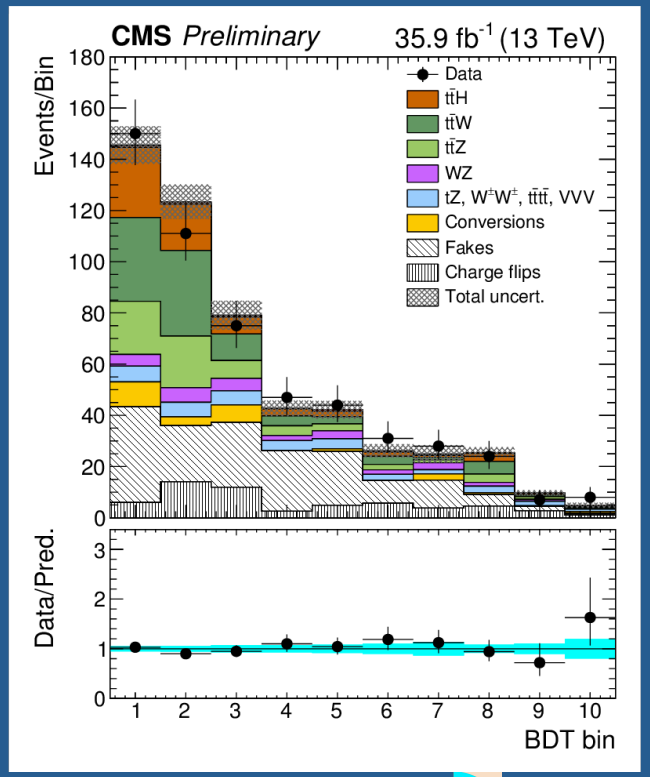
tHq 13TeV Analyses

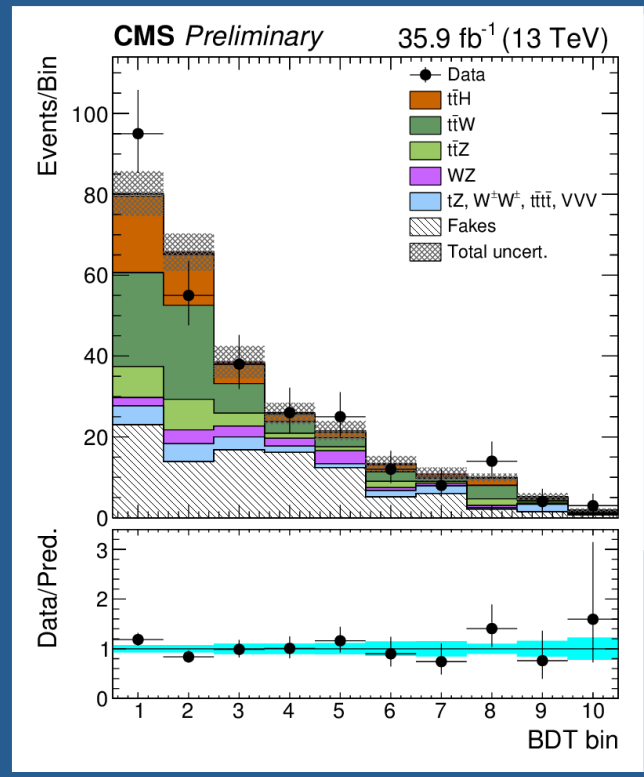
CMS-PAS-HIG-17-005

- Suite of tH analyses performed at 8 TeV:
  - See for instance JHEP 06 (2016) 177, PLB 740 (2015)
- Campaign at 13 TeV underway, first results from CMS:

Scenario	Channel	Obs. Limit (pb)	Exp. Limit (pb) Median	$\pm1\sigma$	$\pm2\sigma$
$\kappa t/\kappa_V = -1$	$\mu\mu$	1.00	0.58	[0.42, 0.83]	[0.31, 1.15]
	eμ	0.84	0.54	[0.39, 0.76]	[0.29, 1.03]
	$\ell\ell\ell$	0.70	0.38	[0.26, 0.56]	[0.19, 0.79]
	Combined	**0.64**	**0.32**	[0.22, 0.46]	[0.16, 0.64]
$\kappa t/\kappa_V = 1$ (SM-like)	$\mu\mu$	0.87	0.41	[0.29, 0.58]	[0.22, 0.82]
	eμ	0.59	0.37	[0.26, 0.53]	[0.20, 0.73]
	$\ell\ell\ell$	0.54	0.31	[0.22, 0.43]	[0.16, 0.62]
	Combined	**0.56**	**0.24**	[0.17, 0.35]	[0.13, 0.49]







Input from the Experiments: Studies We Would Like to See

- Several needs still exist:

Finalize tt+HF background recommendations for ttH,H→bb:

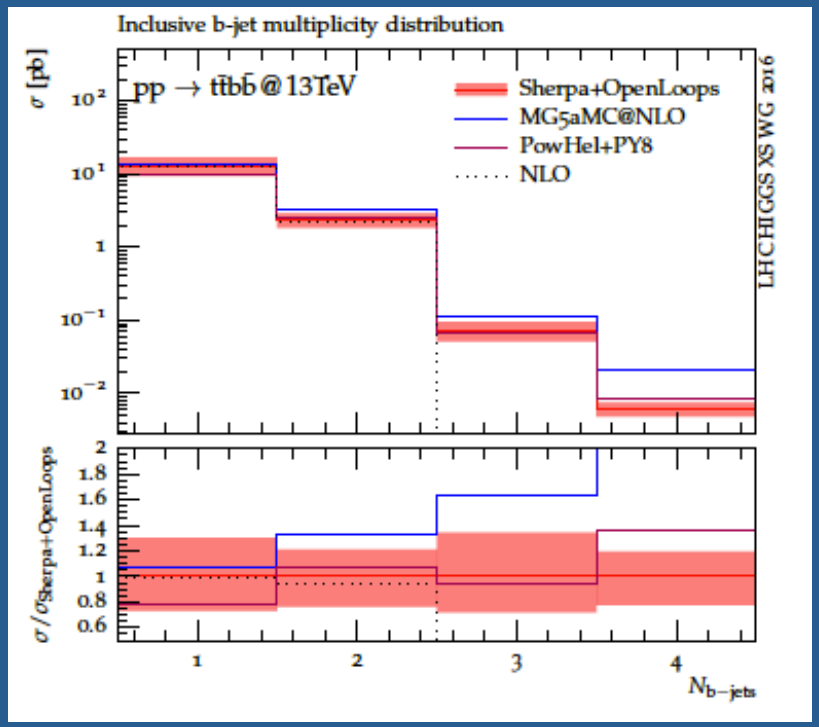
- Systematics and modeling of tt+bb drives sensitivity to ttH(bb)
  - Important to have proper and justified systematics model
  - Profiling of these systematics is used significantly

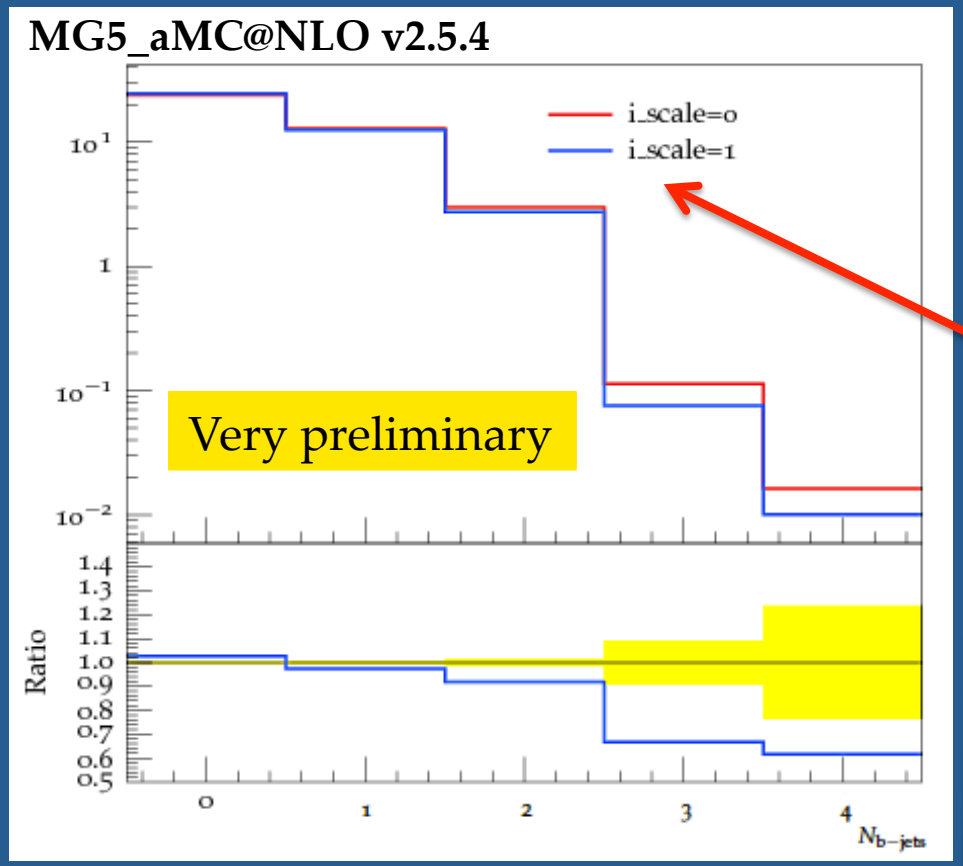
- 4FS vs 4FS differences of aMC@NLO_MG5 vs Sherpa+OpenLoops from YR4
  - Very large uncertainties compared to the Sherpa+OpenLoops systematics
  - Is there any motivation to keep this difference as a systematics uncertainty?
  - Need to understand settings (e.g. scales used) for each tt+bb 4FS prediction

- Kinematic re-weighting of 5FS sample to 4FS sample does not change the kinematics drastically
  - Component re-weighting important since we correlate across all regions (including single and dilepton channels)
  - Replacement is difficult since it could potentially result in discontinuities in certain variables where replacement is performed

YR4 Reprise:
New Shower Starting Scale in MG5_aMC@NLO

Recall...



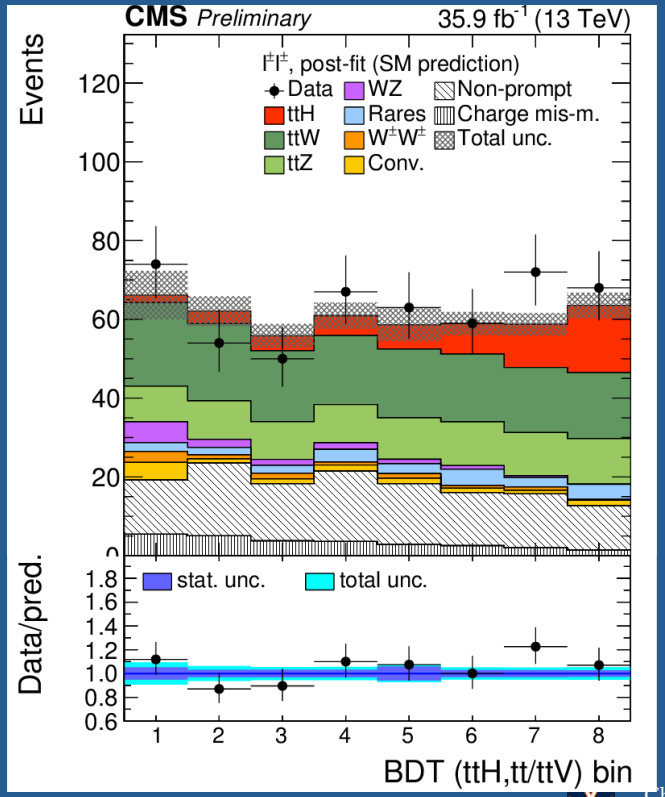


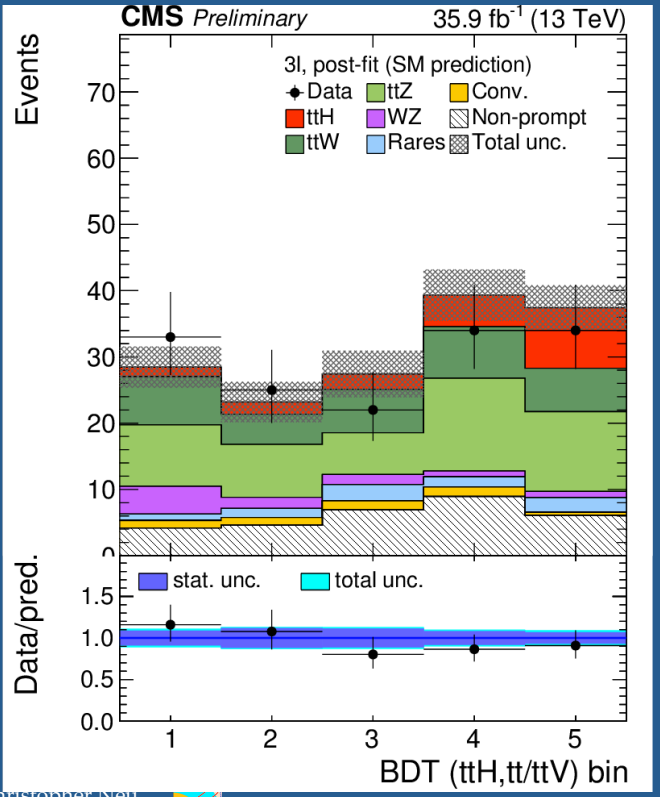
- Hypothesis:
  - Discrepancy due to inequivalent shower starting scale in MG5_aMC@NLO and Sherpa+OpenLoops
- MG5_aMC@NLO authors implemented in v2.5.3 (and subsequent) the ability to adjust this shower starting scale
  - Testing underway now – results from study at an upcoming ttH/tH WG mtg
- Must be followed by data-driven validation – preferably in regions independent of ttH signal extraction

Input from the Experiments: Studies We Would Like to See

ttW/ttZ at NNLO:

- Significant uncertainty on ttW/ttZ backgrounds which makes the observation of ttH in multileptons – no observable with strong correlation to M_H – difficult to achieve high precision
  - It's *there* – but how much?
- Followed by continuation of precision measurements of the ttV processes

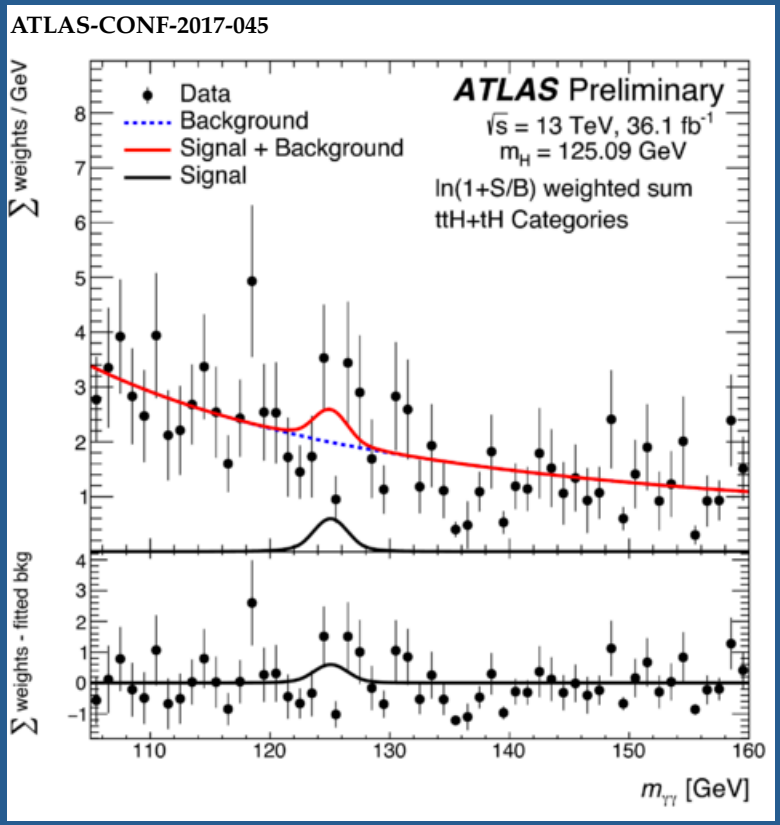




Input from the Experiments: Studies We Would Like to See

$t\bar{t}+\gamma\gamma$ at (N)NLO:

- $t\bar{t}H,H\rightarrow\gamma\gamma$ signal is clear, yet very rare
  - Searches for $t\bar{t}H,H\rightarrow\gamma\gamma$ currently rely on data-driven background models
  - Parametrized into signal region based on a falling exponential model



- But $t\bar{t}H,H\rightarrow\gamma\gamma$ will provide <u>the most-clear and satisfying signature:</u>
  - a diphoton bump at 125
  - in events with a well-identified ttbar system with b-tagged jets, leptons, MET, reconstructed top candidates

- Hence, $t\bar{t}H,H\rightarrow\gamma\gamma$ will be a very important process for precision differential $t\bar{t}H$ production studies
- Ideal to have high-precision simulated samples of $t\bar{t}+\gamma\gamma$ as part of such characterization studies

Summary

- Higgs physics has now moved from the search and discovery phase into a precision measurement era
- Characteristics of this Higgs boson need to be measured with high precision. The measurement campaign has so far revealed no significant deviations from the predictions of the SM
- A few crucial ones remain to be measured – the most foremost being the coupling between the top quark and the Higgs boson
- First direct measurement of the top-Higgs coupling is among the primary goals of the LHC physics program.
- Input from the community via the ttH/tH subgroup of the HXSWG will help achieve this first direct measurement of the top-Higgs coupling
  - Three topics of future work discussed here, but others will arise

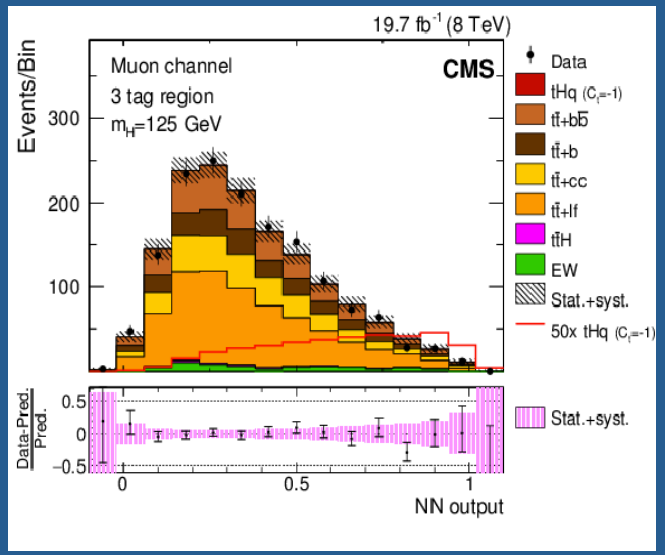
Backup

tHq 8TeV Analyses

JHEP 06 (2016) 177

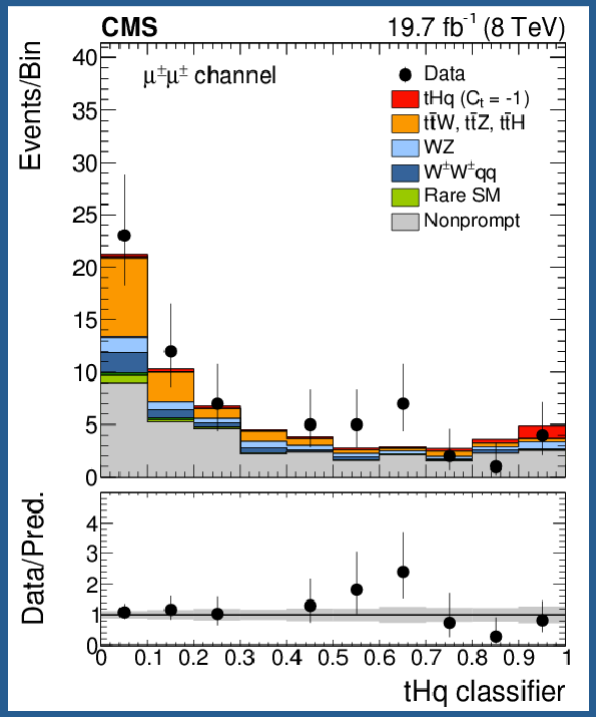
tHq, H → bb

Leptonic W decay
3-,4-tag categories
MVA for tHq v. ttbar



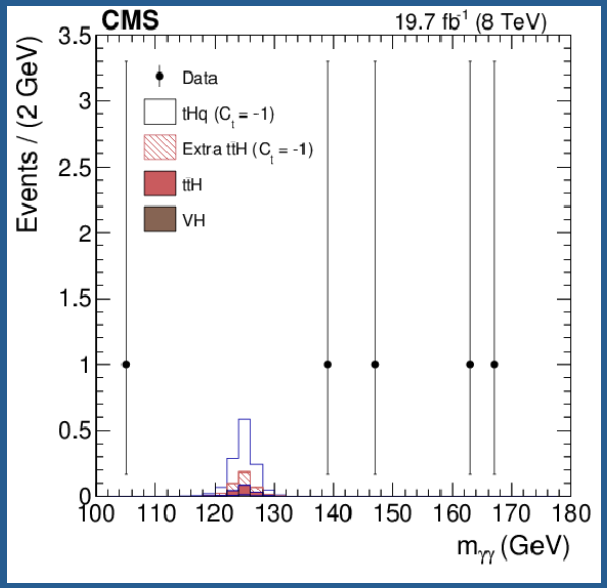
tHq, H → WW, ττ

Same-sign 2lep and 3lep
MVA for tHq v. bkgd



tHq, H → γγ

Enhancement on production and decay side.
No events survive in data.



Expected (observed) upper limits:

$\sigma/\sigma(Y_t = -1) < 5.4\ (7.6)$

$\sigma/\sigma(Y_t = -1) < 5.0\ (6.7)$

$\sigma/\sigma(Y_t = -1) < 4.1\ (4.1)$

Combined upper limit $\sigma/\sigma(Y_t = -1) < 2.0\ (2.8)$

13 TeV results coming soon!