5th International Conference on New Frontiers in Physics ICNFP2016

ttH production at 13 TeV (CMS)

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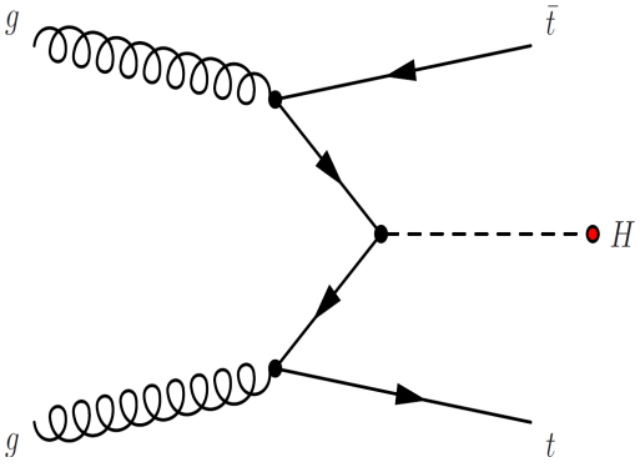
On behalf of the CMS Collaboration

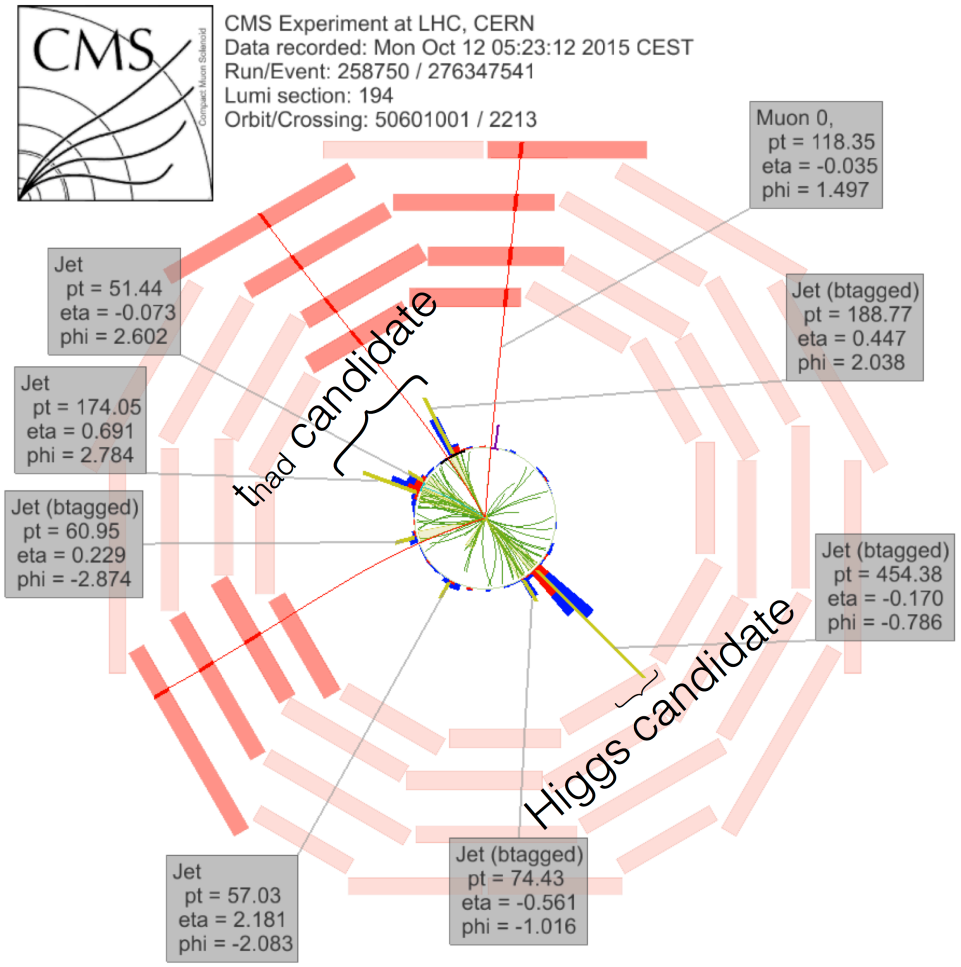
Kolymbari, Crete, Greece, 6 - 14 July 2016

Outline

- First ttH results at the 13 TeV:
  - ttH (multilepton)
  - ttH (bb)
  - ttH (γγ)

also combined

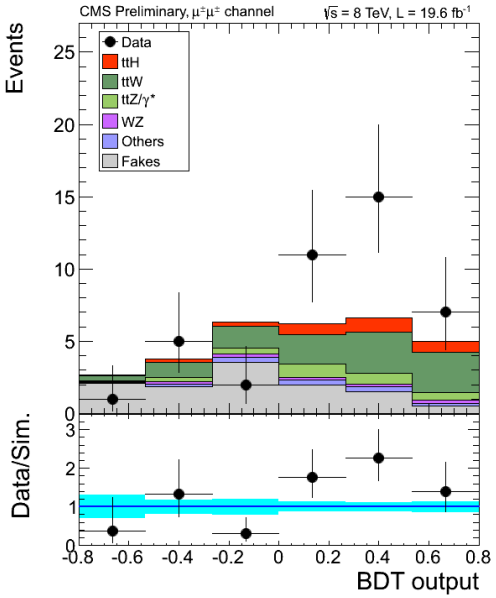




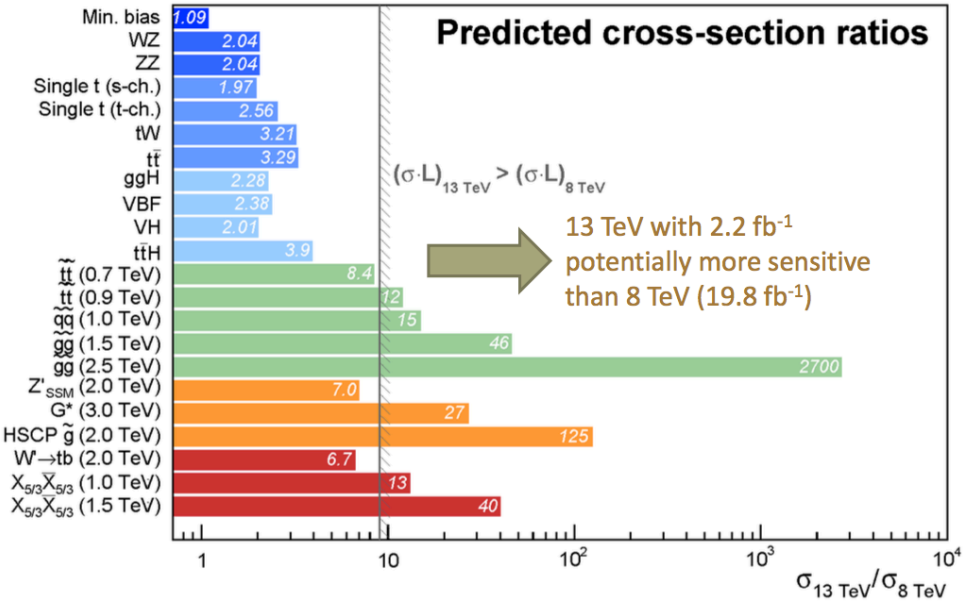
ttH production : theoretical motivation

- Higgs boson discovered, now focus is on measuring its properties
- Largest coupling to the top quark ($Y_t \approx 1$) from all the SM particles
- top-Higgs coupling directly accessible only through the ttH process
- Can be used to constrain BSM physics in the gg->Higgs production

JHEP 09 (2014) 087



J. Olsen (CERN Jamboree 2015)

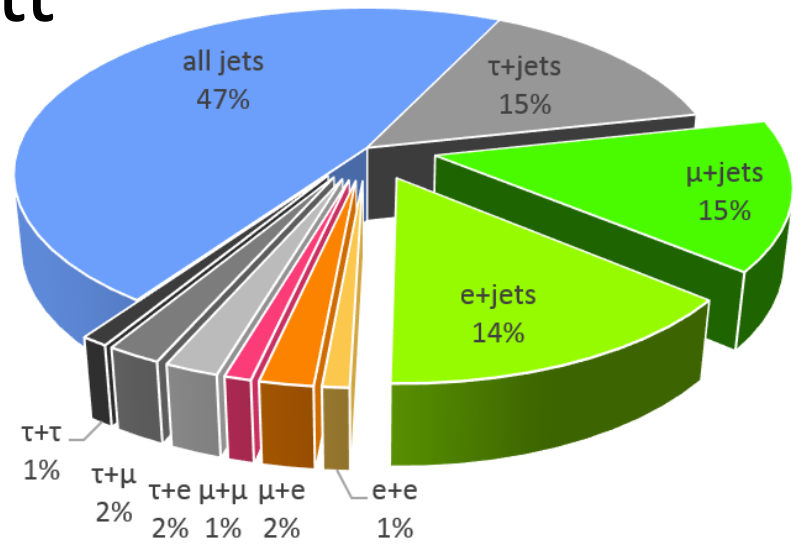


- Small CS, but ≈4 times larger at the 13 TeV
- An excess observed in μμ channel at 8 TeV
- BSM (SUSY, heavy top, little Higgs, RS etc.)

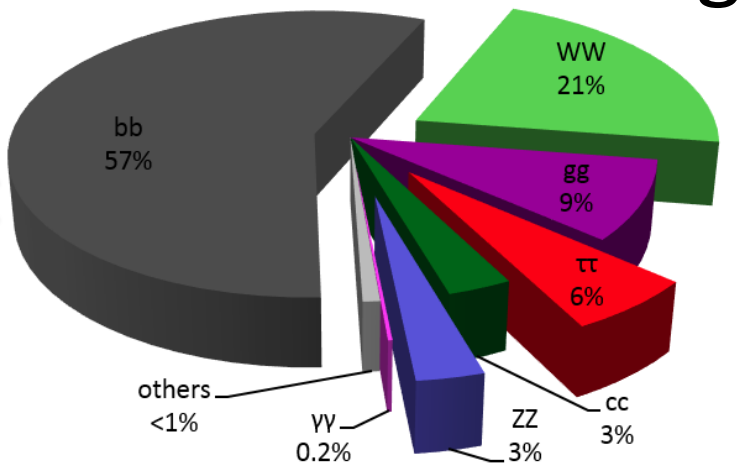
ttH production : experimental signatures

- Final state signatures defined by the decay modes of top quark and Higgs boson

tt



Higgs

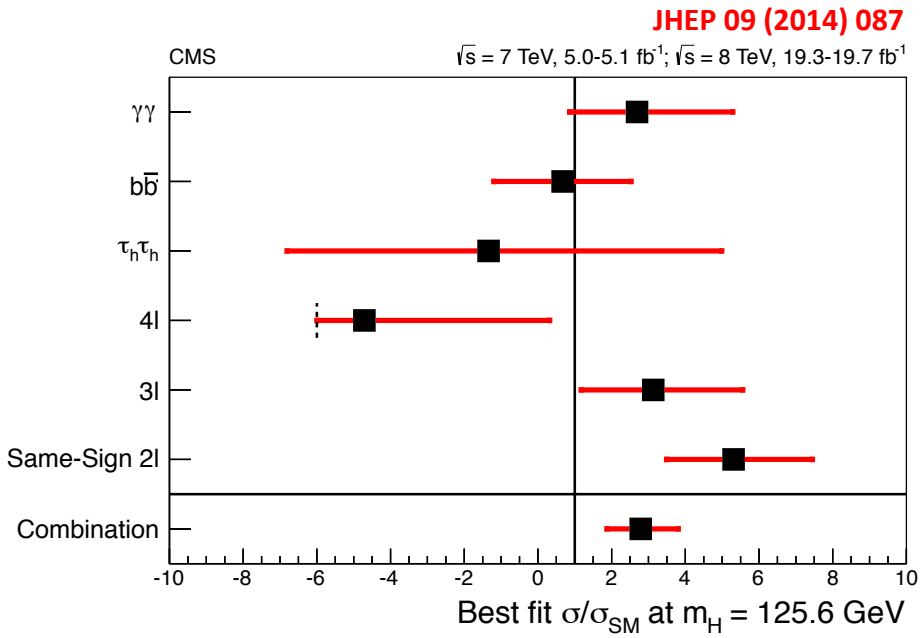


- ttH (multileptons) and ttH (bb) consider semileptonic and fully leptonic tt decays
- ttH (γγ) channel takes into account also the fully hadronic decay of the tt system

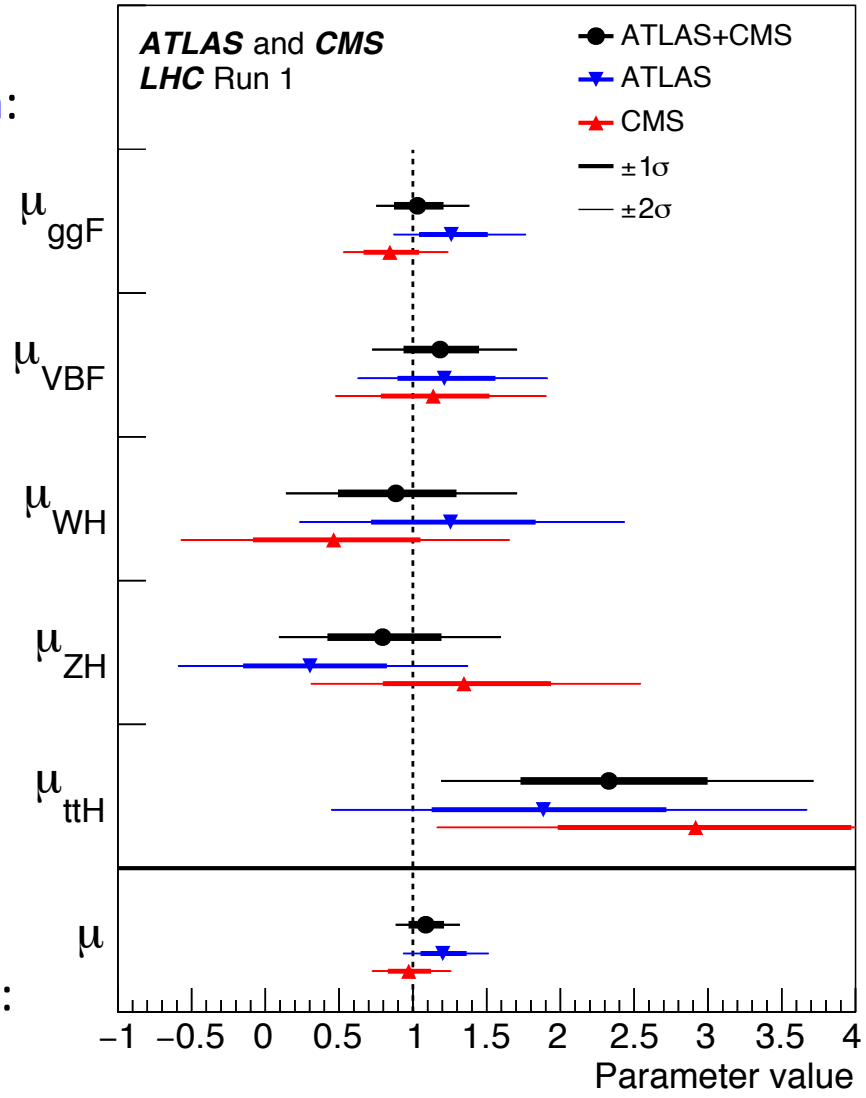
ttH production: LHC Run I results

arXiv:1606.02266

- CMS results: all channels and combination:

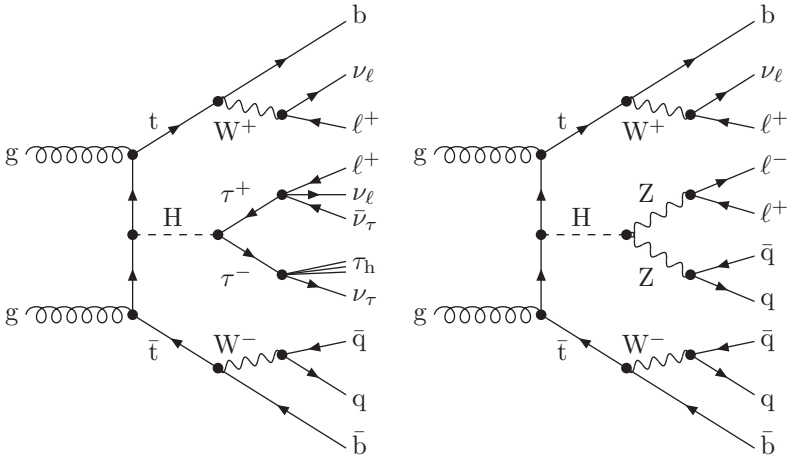


- Also combined with ATLAS measurements:



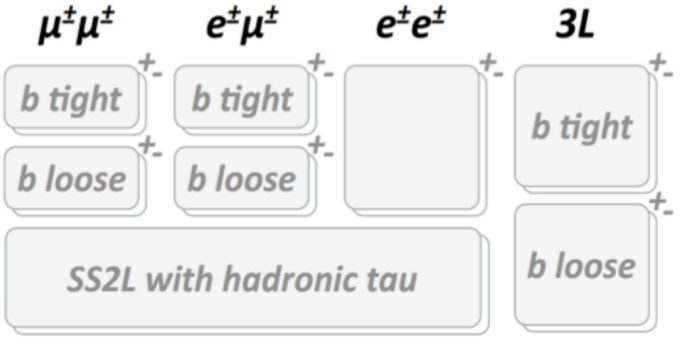
ttH (multileptons) : analysis strategy

- Two main analysis categories:
  - Two SS leptons: $p_T > 20$, 10 (15) GeV for μ (e), $|\eta| < 2.4$ and ≥ 4 jets ($p_T > 25$ GeV, $|\eta| < 2.4$), 0.6 MET + 0.4 HT > 30 GeV
  - At least 3 leptons: $p_T > 20$, 10 and 10 GeV, $|\eta| < 2.4$ and ≥ 2 jets ($p_T > 25$ GeV, $|\eta| < 2.4$), 0.6 MET + 0.4 HT > 30 GeV



- Lepton identification: dedicated BDT to reject non-prompt leptons, jets and charge mis-ID

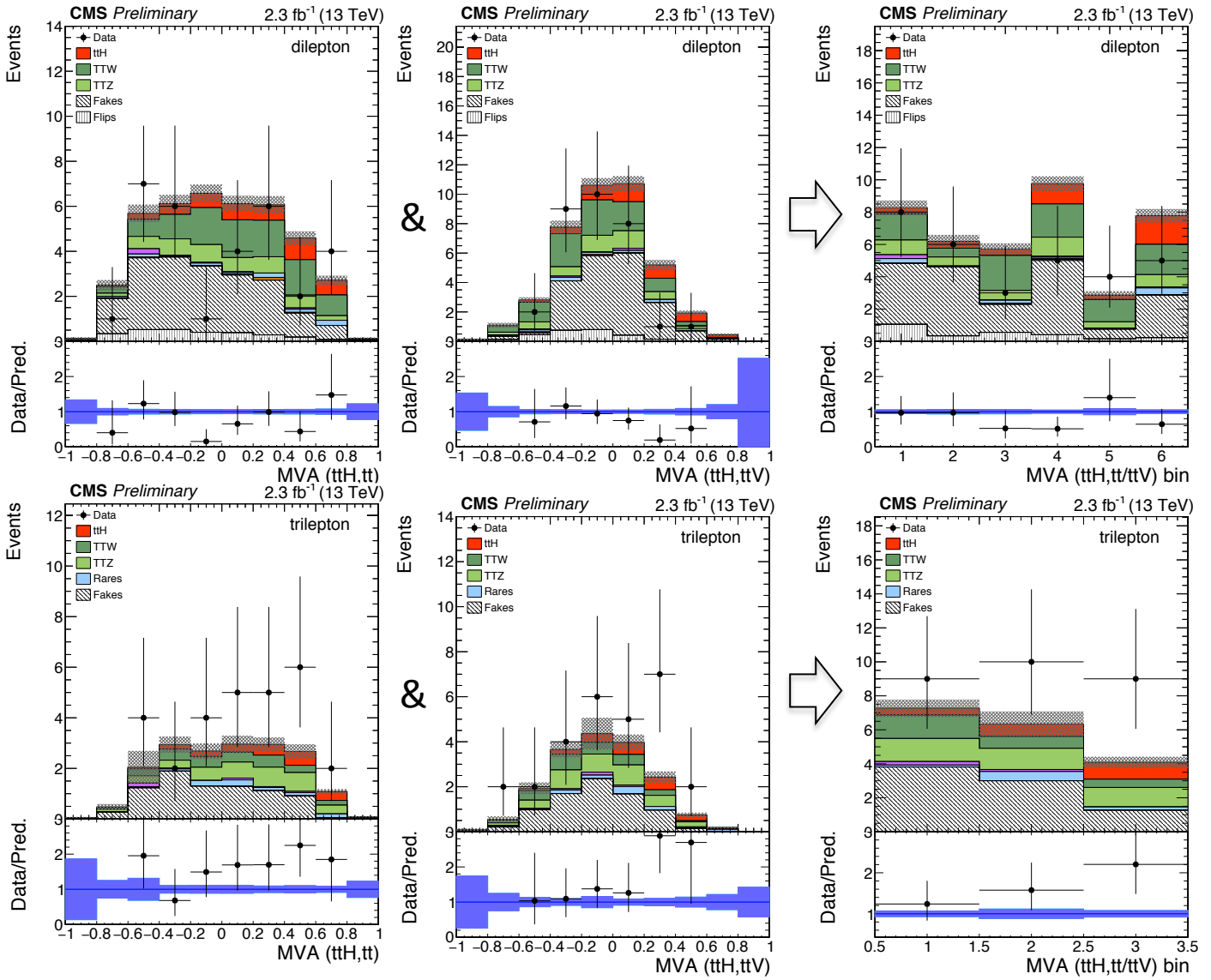
- Additional sub-categories made according to the lepton flavor and charge, multiplicity of b-jets & hadronic taus



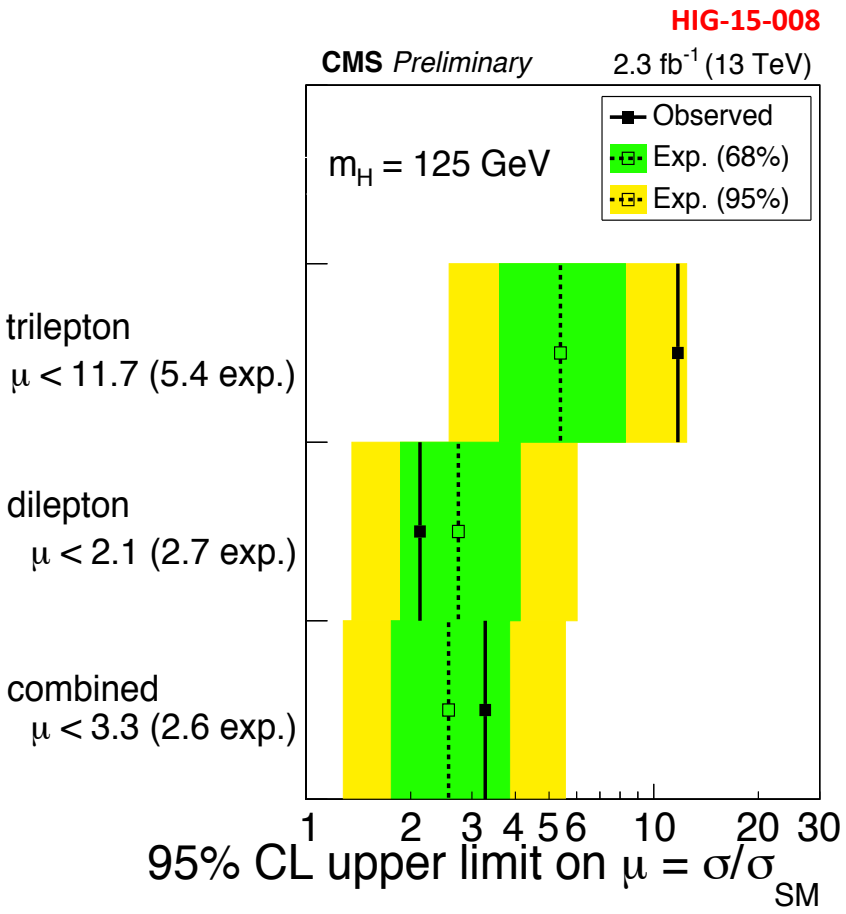
ttH (multileptons) : signal extraction

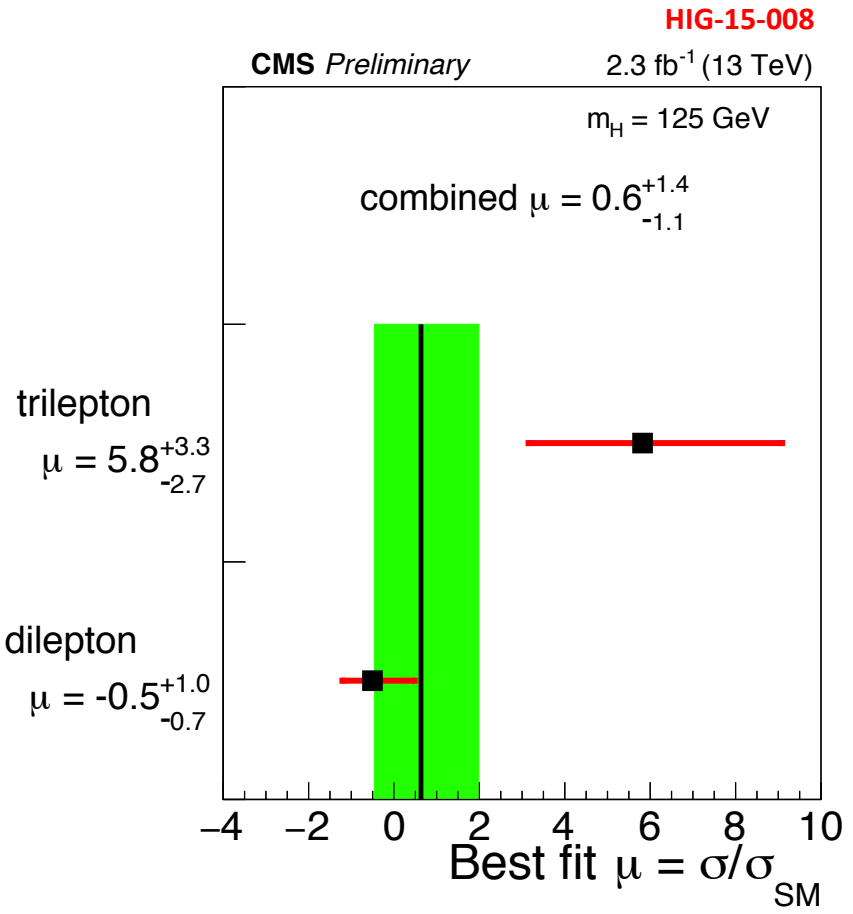
HIG-15-008

- Main background:
  - ttW/Z: irreducible, taken from the MC
  - fakes: reducible, in QCD and Z+jets reversing lepton ID
- Signal extraction:
  - 2DMVA: vs tt/ttV
  - Combined fit to all discriminator bins



ttH (multileptons) : results

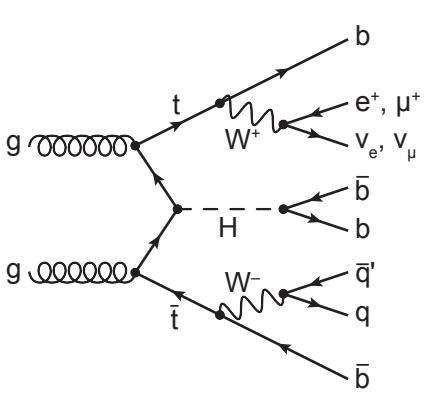




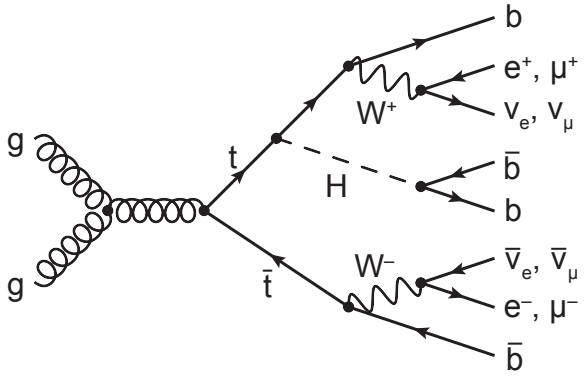
- Small deficit in the dilepton channel, some excess observed in the trilepton case

ttH (bb) : analysis strategy

- Two main analysis categories:
  - 1 lepton: $p_T > 25$ (35) GeV for μ (e), $|\eta| < 2.1$ and ≥ 4 jets ($p_T > 30$ GeV, $|\eta| < 2.4$)
  - 2 leptons: $p_T > 20$, 15 GeV, $|\eta| < 2.4$ and ≥ 3 jets ($p_T > 30$, 30 and 20 GeV, $|\eta| < 2.4$)



lepton + jets



dileptons

- Dominant background: tt+jets
  - separated by the lepton flavor
  - irreducible: the tt+bb process
  - background yields dominate

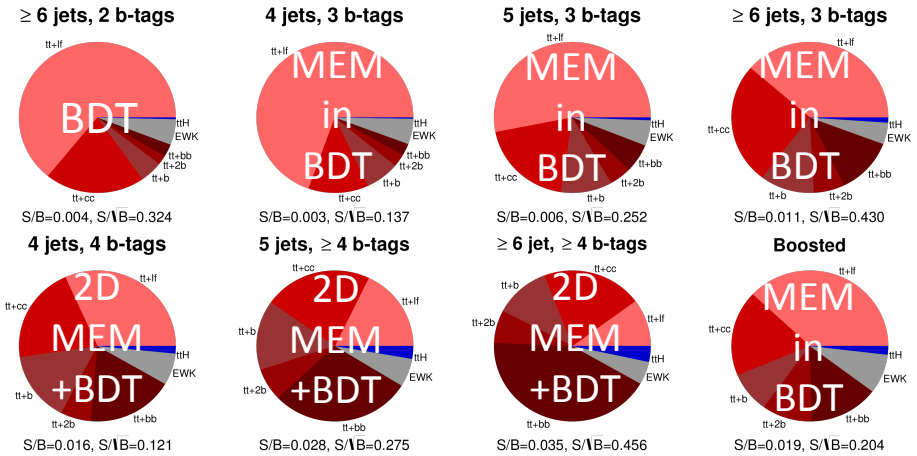
HIG-16-004

	3 jets, 2 b-tags	3 jets, 3 b-tags	≥ 4 jets, 2 b-tags	≥ 4 jets, 3 b-tags	≥ 4 jets, ≥ 4 b-tags
$t\bar{t}$+lf	2558.6 ± 542.7	26.6 ± 10.5	2271.6 ± 505.0	60.3 ± 25.6	0.9 ± 0.8
$t\bar{t}+c\bar{c}$	220.9 ± 103.4	22.7 ± 13.6	478.4 ± 234.4	78.4 ± 45.4	3.4 ± 2.9
$t\bar{t}$+b	65.4 ± 28.5	21.4 ± 10.2	126.2 ± 57.7	52.2 ± 25.1	2.7 ± 1.6
$t\bar{t}$+2b	16.9 ± 7.6	6.6 ± 3.1	42.9 ± 20.2	22.3 ± 10.7	1.2 ± 0.7
$t\bar{t}+b\bar{b}$	8.6 ± 4.2	3.6 ± 1.8	48.9 ± 23.7	39.8 ± 18.8	13.4 ± 7.1
Single Top	93.2 ± 16.7	3.0 ± 1.0	87.6 ± 15.8	7.3 ± 2.5	0.4 ± 0.4
V+jets	14.5 ± 11.0	1.3 ± 0.8	16.0 ± 7.4	0.0 ± 0.0	0.0 ± 0.0
$t\bar{t}$+V	3.6 ± 0.9	0.3 ± 0.2	16.4 ± 3.2	3.2 ± 0.9	0.5 ± 0.2
Diboson	1.7 ± 0.9	0.0 ± 0.0	1.2 ± 1.0	0.1 ± 0.0	0.0 ± 0.0
Total bkg	2983.4 ± 590.4	85.6 ± 25.6	3089.2 ± 650.6	263.6 ± 79.9	22.5 ± 9.8
$t\bar{t}H$	1.4 ± 0.2	0.4 ± 0.1	8.1 ± 1.1	3.6 ± 0.6	1.0 ± 0.3
Data	3123	115	2943	319	27
S/B	0.00047	0.0051	0.0026	0.014	0.046
Data/B	1.0 ± 0.2	1.3 ± 0.4	1.0 ± 0.2	1.2 ± 0.3	1.2 ± 0.5

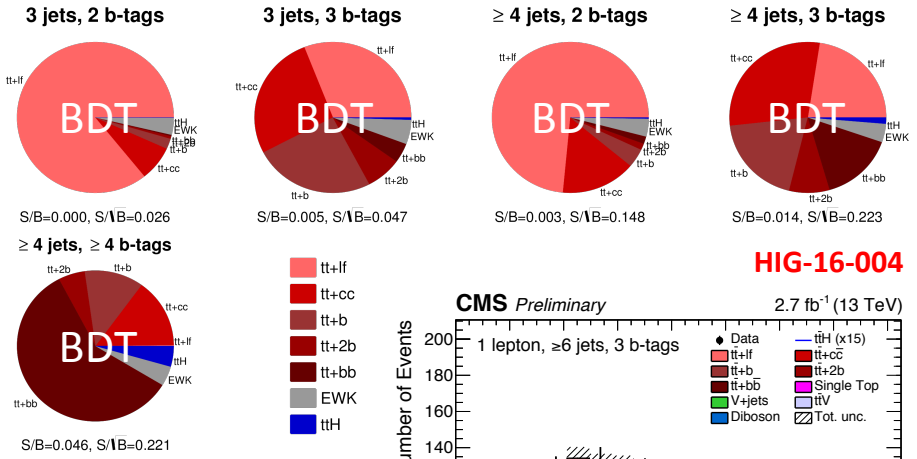
ttH (bb) : signal extraction

- Machine learning (BDT) combined with physics-motivated method (matrix element – MEM)

lepton + jets



dileptons



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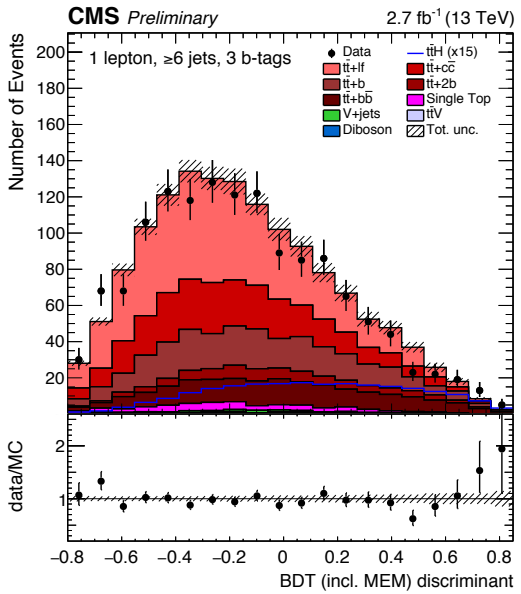

- Both lepton+jets and dileptons channel use BDT discriminator
- Lepton+jets uses also the MEM (input to BDT & 2D MET+BDT)
- Boosted category: had. top and Higgs with fat jet substructure

ttH (bb) : results

- Simult. max. likelihood fit in all categories

  - Best fit: $\hat{\mu}_{\text{obs}} = -2.0^{+1.8}_{-1.8}$, 1.7σ below expect.

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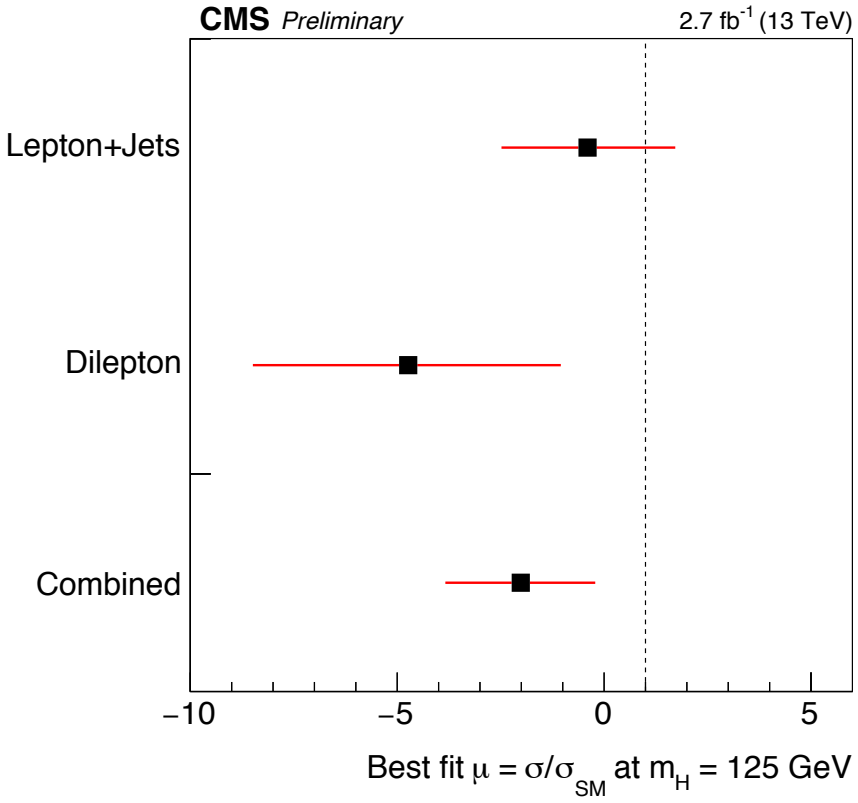

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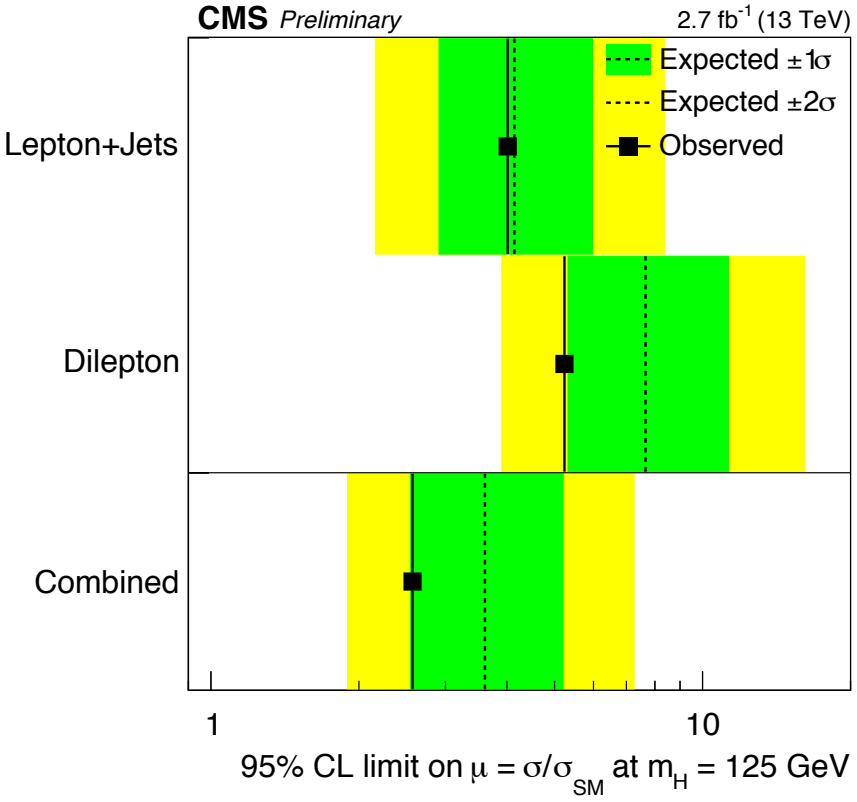
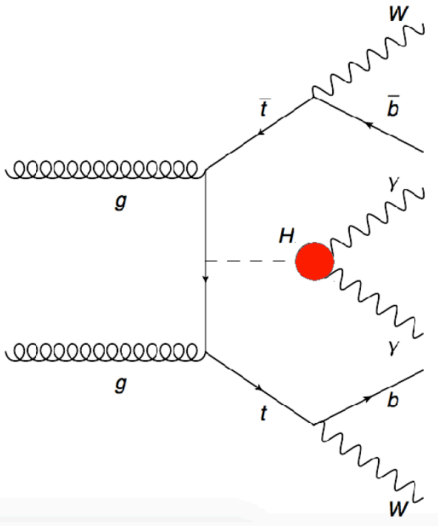


The 95% CL upper limits:

Channel	Best-fit μ	Observed UL	Expected UL
Lepton+jets	$-0.4^{+2.1}_{-2.1}$	4.0	$4.1^{+1.8}_{-1.2}$
Dilepton	$-4.7^{+3.7}_{-3.8}$	5.2	$7.7^{+3.6}_{-2.3}$
Combined	$-2.0^{+1.8}_{-1.8}$	2.6	$3.6^{+1.6}_{-1.1}$

ttH (γγ) : analysis strategy

- Two main analysis categories:
  - Leptonic: 2γ with $p_T > m_{\gamma\gamma}/2$, $m_{\gamma\gamma}/4$, BDT, ≥ 1 leptons with $p_T > 20$ GeV and ≥ 2 jets: $p_T > 25$ GeV, $|\eta| < 2.4$, ≥ 1 b-jets
  - Hadronic: 2γ with $p_T > m_{\gamma\gamma}/2$, $m_{\gamma\gamma}/4$, BDT, zero leptons and ≥ 5 jets: $p_T > 25$ GeV, $|\eta| < 2.4$, ≥ 1 b-jets



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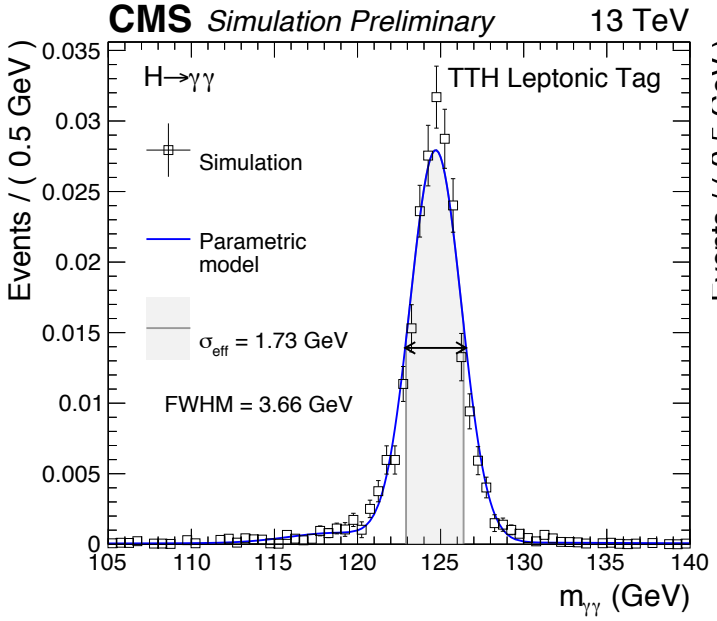

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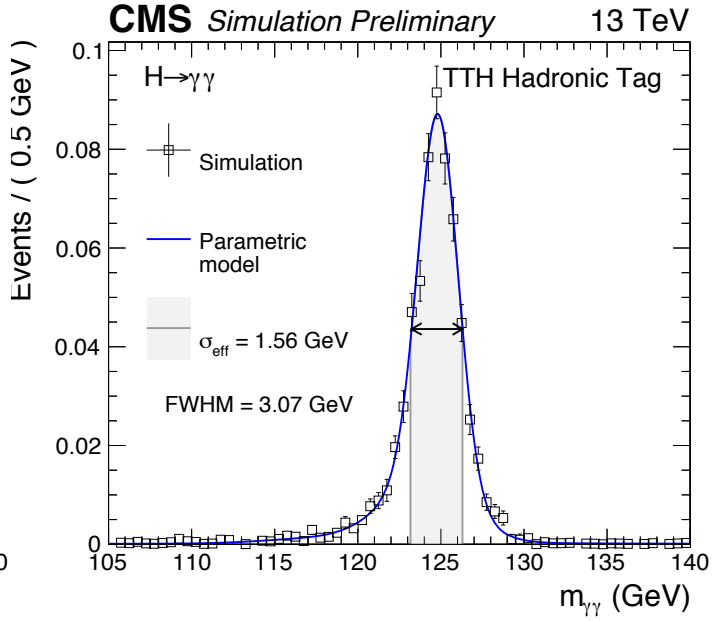

- Clean signature & excellent $m_{\gamma\gamma}$ res.
- Main backgrounds:
  - irreducible: tt + γγ
  - reducible: tt+(γ)+jet
- BDT approach used

ttH (γγ) : signal extraction

- Smooth functions used to fit $m_{\gamma\gamma}$ distribution, several functional forms (discrete profiling)

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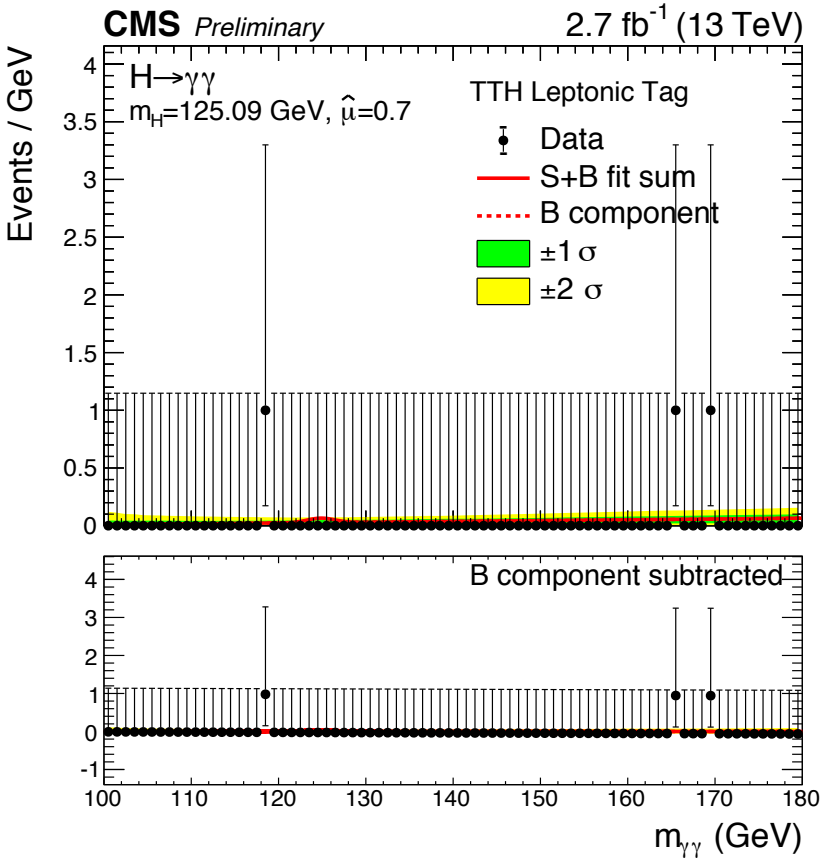

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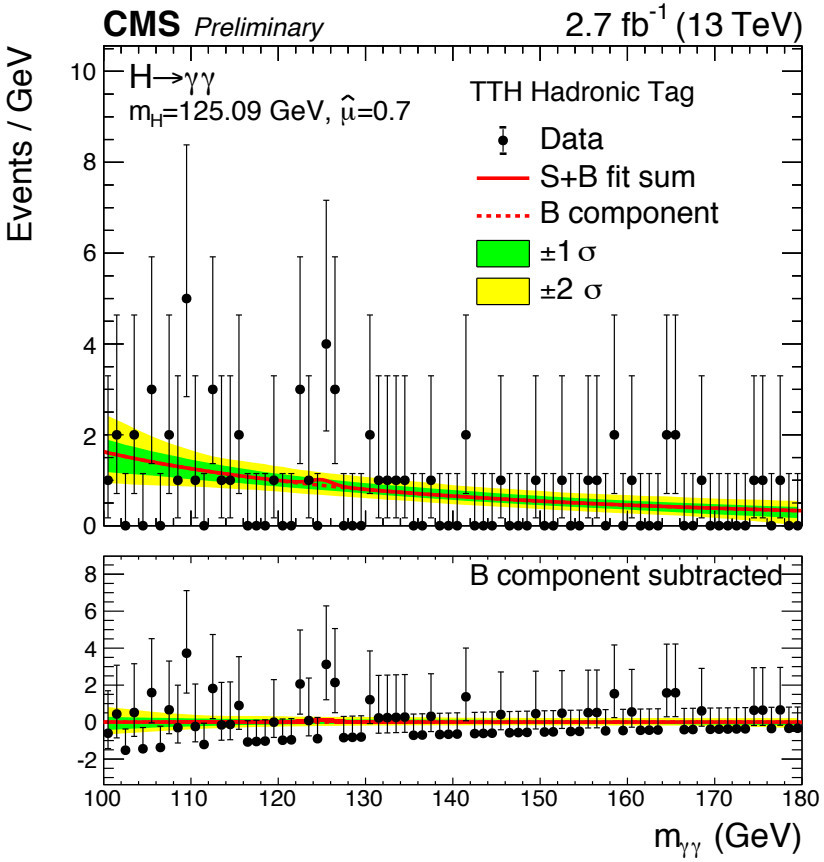
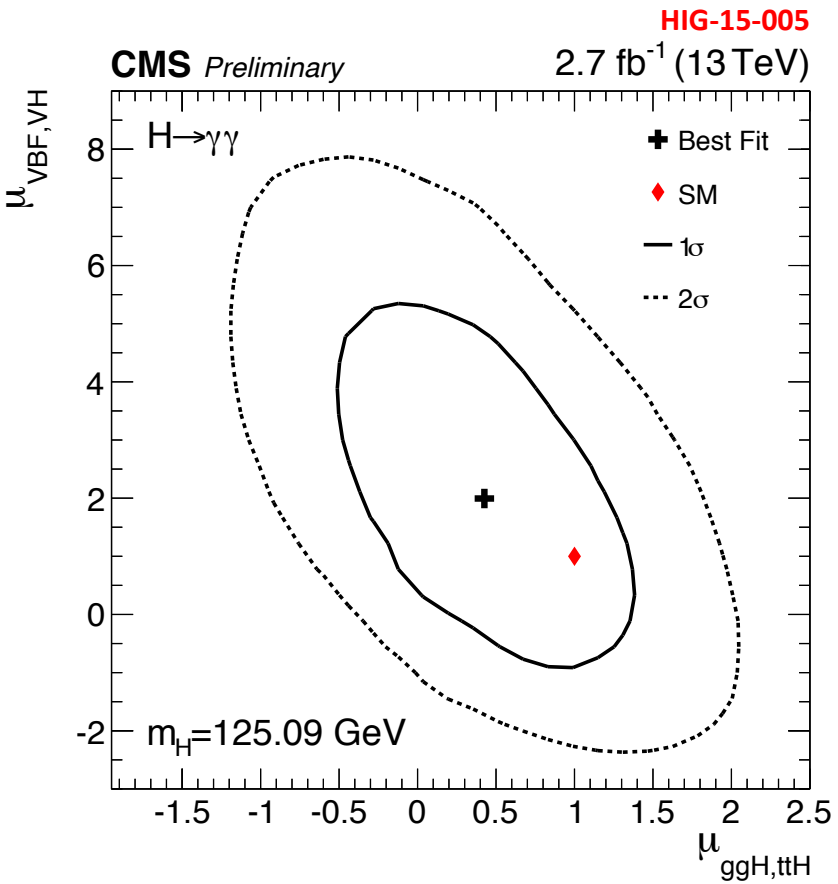
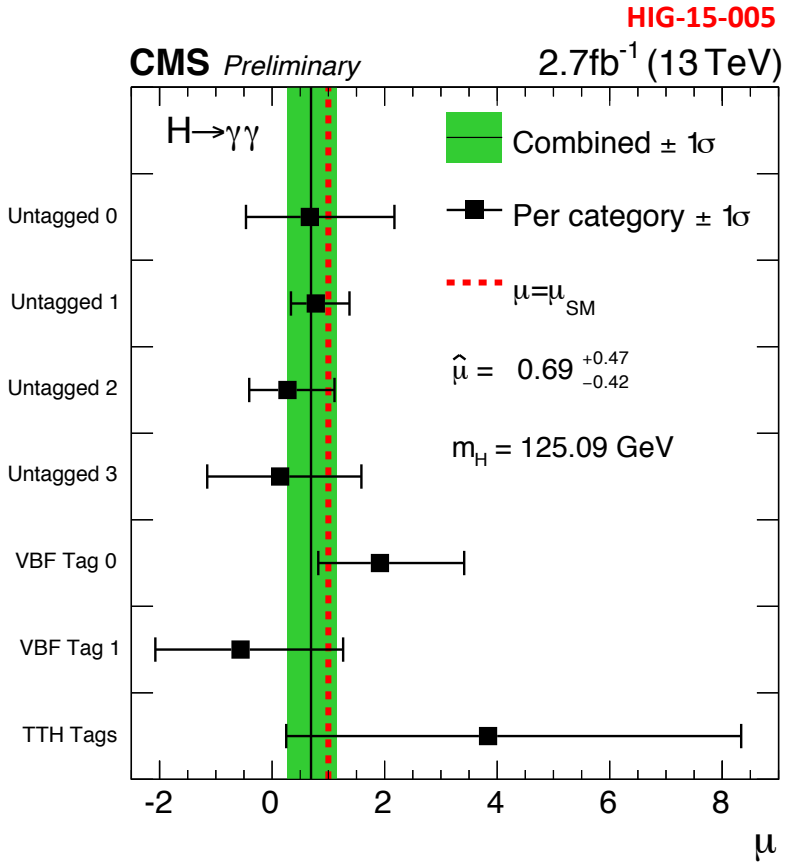


- High purity for both leptonic and hadronic tags (87% and 96%, respectively), low statistics

ttH (γγ) : results

- Results of all H (γγ) channels summarized
- Leptonic and hadronic ttH tags combined

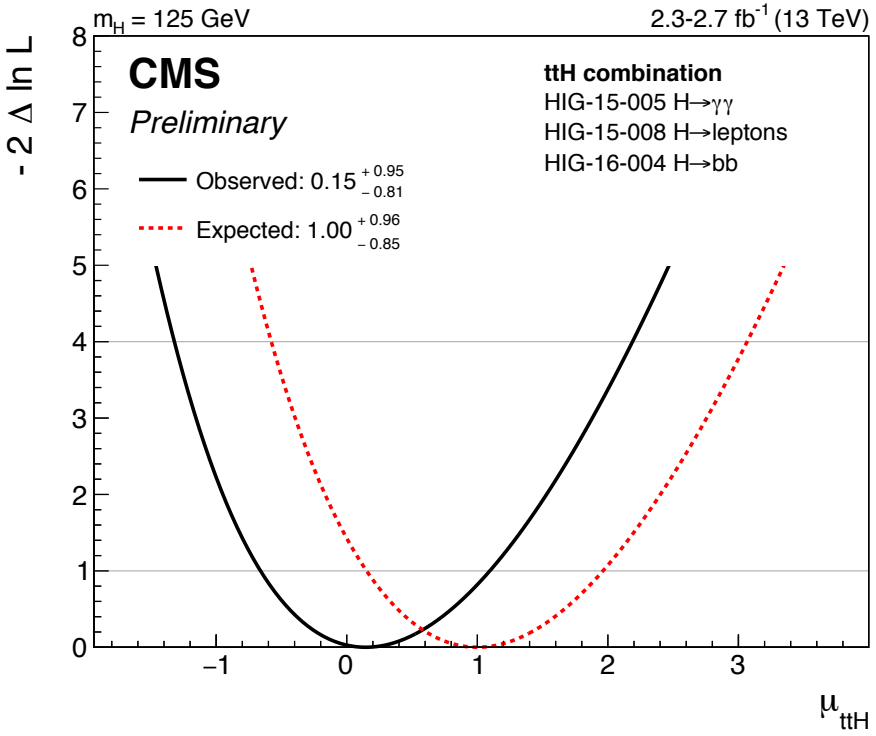


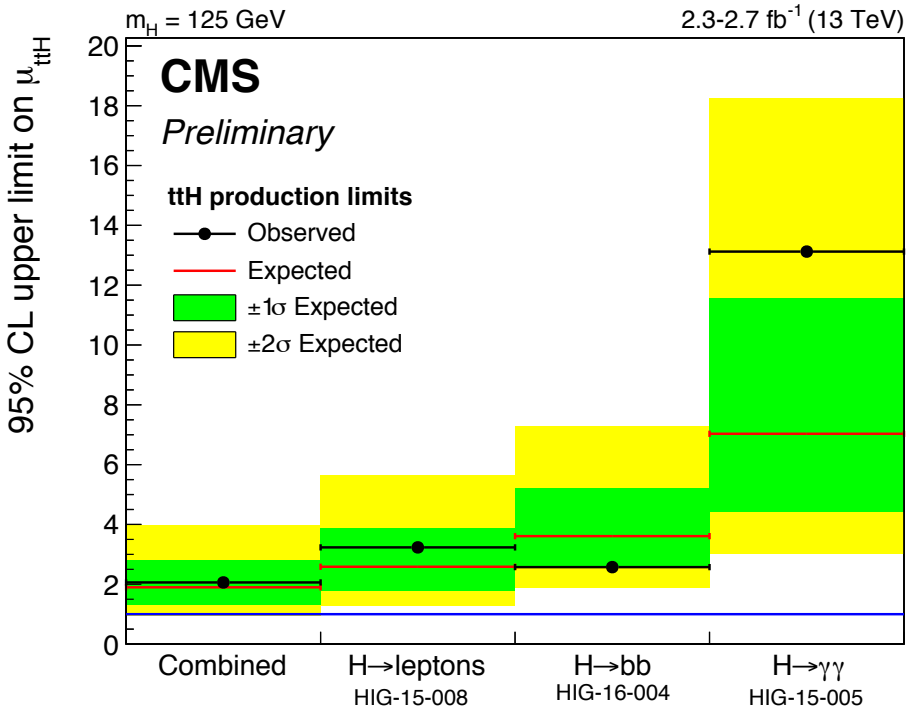


- 2D best fit & expectation of $\mu = \sigma/\sigma_{SM}$ for fermionic and bosonic production

ttH combination results

https://twiki.cern.ch/twiki/bin/view/CMSPublic/TTHCombMoriond2016





Best fit value : $\mu_{ttH} = 0.15^{+0.95}_{-0.81}$

Run 1 : $\mu_{ttH} = 2.8 \pm 1.0$

Observed (expected) limit : μ_{ttH} = 2.1 (1.9)

Run 1: μ_{ttH} = 4.5 (1.7)

Summary

- First measurement of ttH production at 13 TeV using the 2015 CMS data:

  ttH (multileptons) ttH (bb) ttH (γγ)

- An overall agreement with the Standard Model expectation is observed

- Similar sensitivity reached as in the 8 TeV analysis (with much less data)

- The observation of ttH production and a measurement of the top-Higgs Yukawa coupling represent one of the main priorities for the LHC Run 2

- Many more results to come with the expected luminosity in 2016 (30 fb^{-1})