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Pheno - 9 to 11 May 2016, Pittsburgh

$t\bar{t}H$ production studies at 13 TeV with CMS

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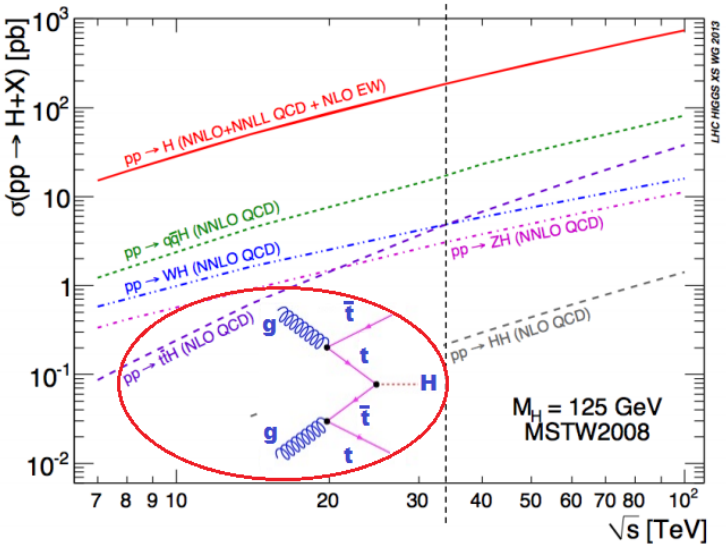
On behalf of the CMS collaboration

Motivations for studying the $t\bar{t}H$ process

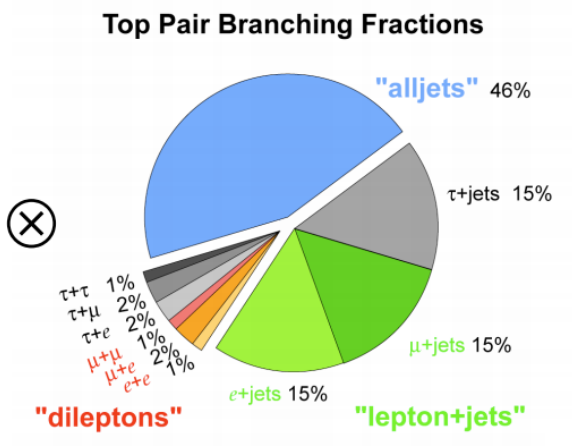
- After the new boson discovery (Higgs-like), focus on measuring its properties $\rightarrow$ couplings to fermions, gauge bosons, and itself
- Top quark is the most strongly-coupled SM particle ($Y_t \approx 1$)
- Indirect constraints on the top-Higgs Yukawa coupling Y_t from loop diagrams where top quark contribute to $gg \rightarrow H$ production and $H \rightarrow \gamma\gamma$ decay but assuming no new particles
- Directly probe top-Higgs coupling through $t\bar{t}H$ production mechanism
- Large deviation from SM Higgs coupling could be explained by some beyond SM models with enhanced $t\bar{t}H$ production without changing the Higgs BR (Vector-like, heavy top partner, Compositeness, RS, little Higgs)

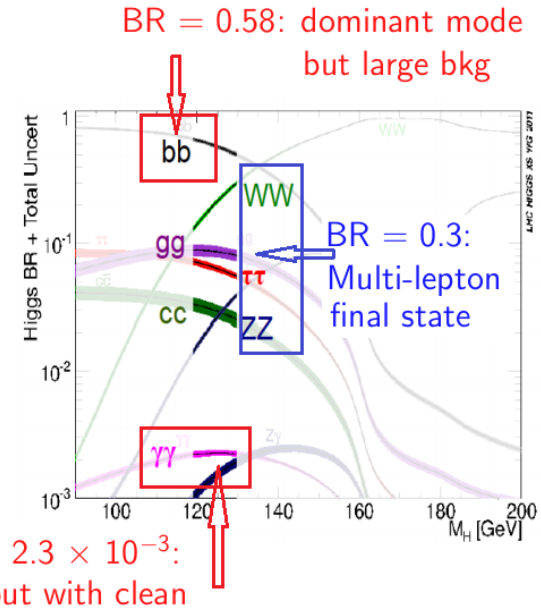
The $t\bar{t}H$ measurement

Production



Decay





Challenges

- Low signal cross-section
- Complicated final states with high-jet/b-tag multiplicity
  A priori, some handles but large combinatorial and physics bkg
  (in large part irreducible and affected by large sys unc)

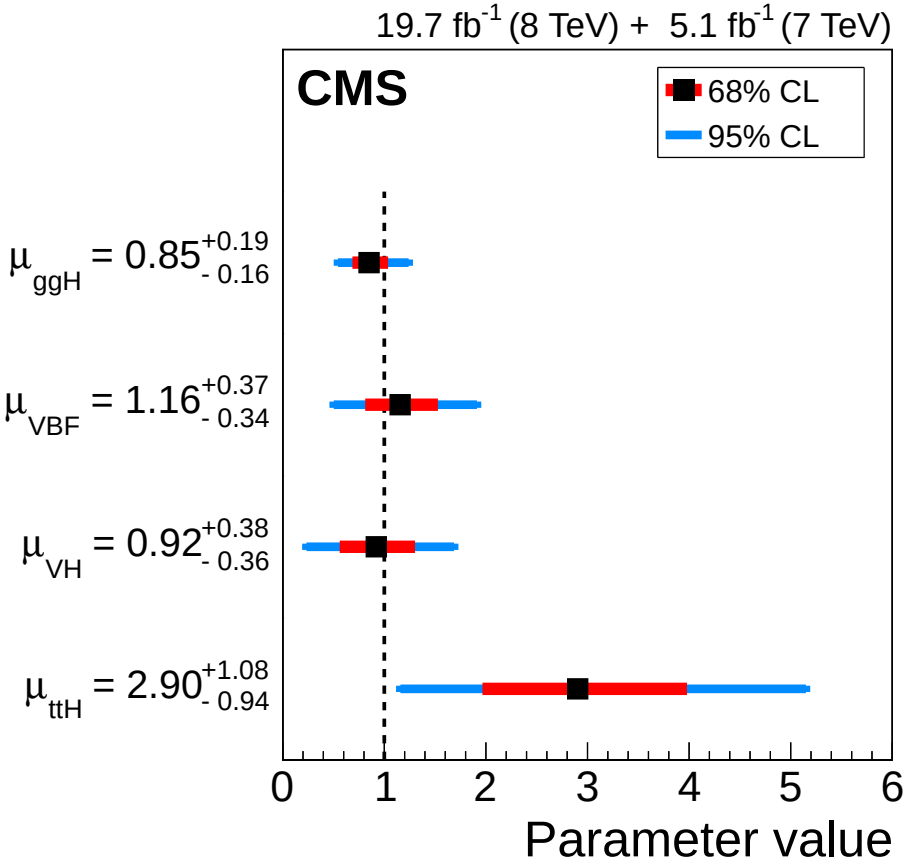
$\sqrt{s}$ (TeV)	7	8	13
$t\bar{t}H(m_H = 125GeV)$ (fb)	86	130	507
$t\bar{t}$ (pb)	177	253	832

$t\bar{t}H$ cross section increased by 3.9
while $t\bar{t}$ cross section by 3.3
at 13 TeV (compared to 8 TeV)

Summary of CMS RunI results

$\mu_{t\bar{t}H}$ dominated by $t\bar{t}H$

- $H \to b\bar{b}$
- $H \to$ MultiLeptons
- $H \to \gamma\gamma$

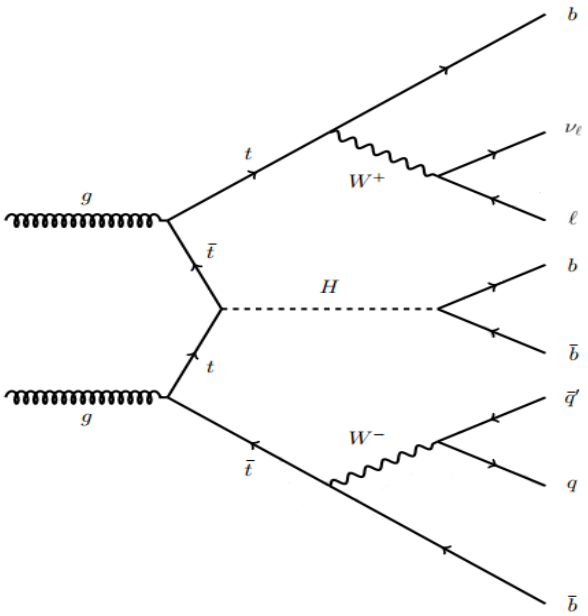


$$\mu_{t\bar{t}H} = 2.90^{+1.08}_{-0.94}$$

Event selection in $t\bar{t}H, H \to b\bar{b}$ [PAS-HIG-16-004]

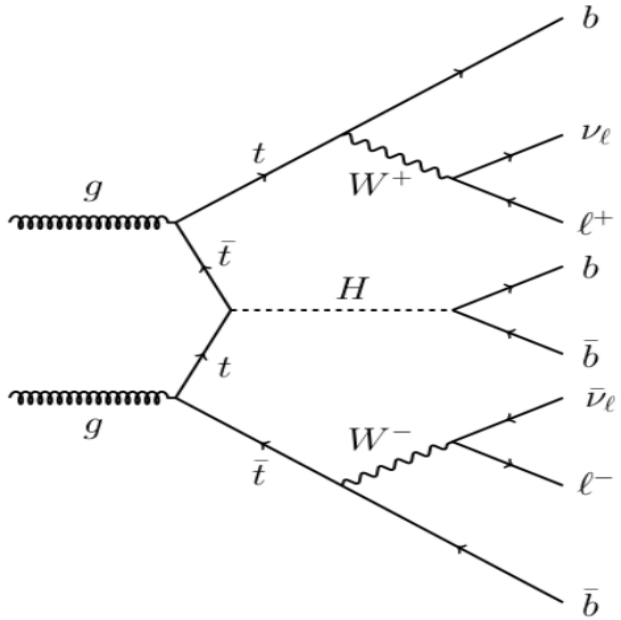
Two main categories according to the decays of top pairs

Single lepton



- 1 ℓ: pT$>$ 25 (30) GeV for μ (e); $|\eta|$ $<$2.1
- $\geq$ 4 jets (pT$>$30 GeV, $|\eta|$ $<$2.4)

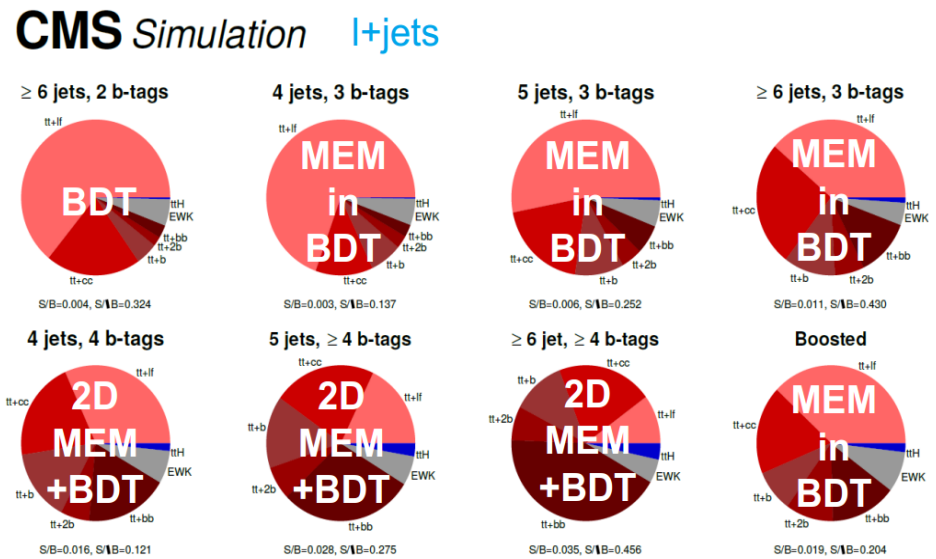
Dilepton

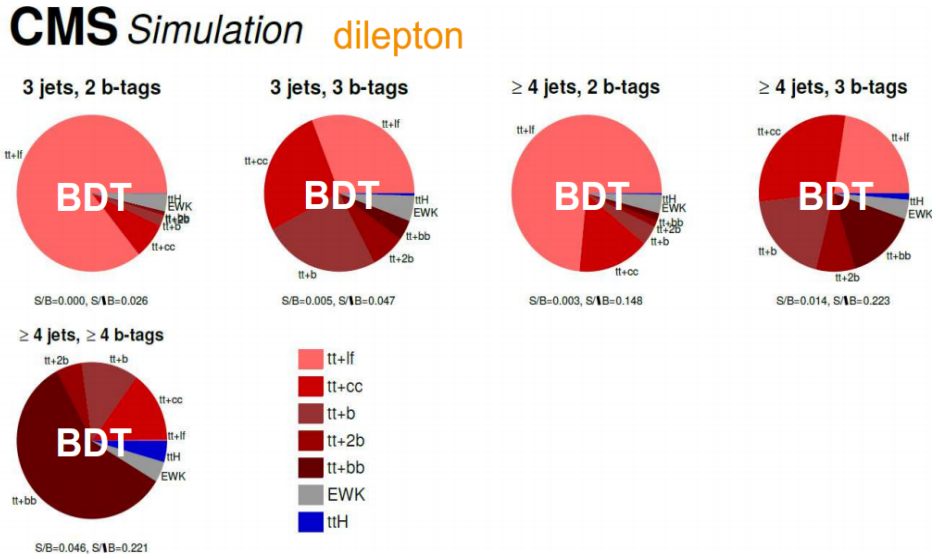


- 2 ℓ: pT$>$ 20,15 GeV; $|\eta|$ $<$2.4
- $\geq$ 3 jets (pT$>$30,30,20 GeV, $|\eta|$ $<$2.4)

- Sub-categorisation: jet and b-jet ($\geq$ 2) multiplicity
  Bkg-like (low # of b-jet): constrain the background
  Sig-like (high # of b-jet): extract the signal

Background characterisation in $t\bar{t}H, H \to b\bar{b}$



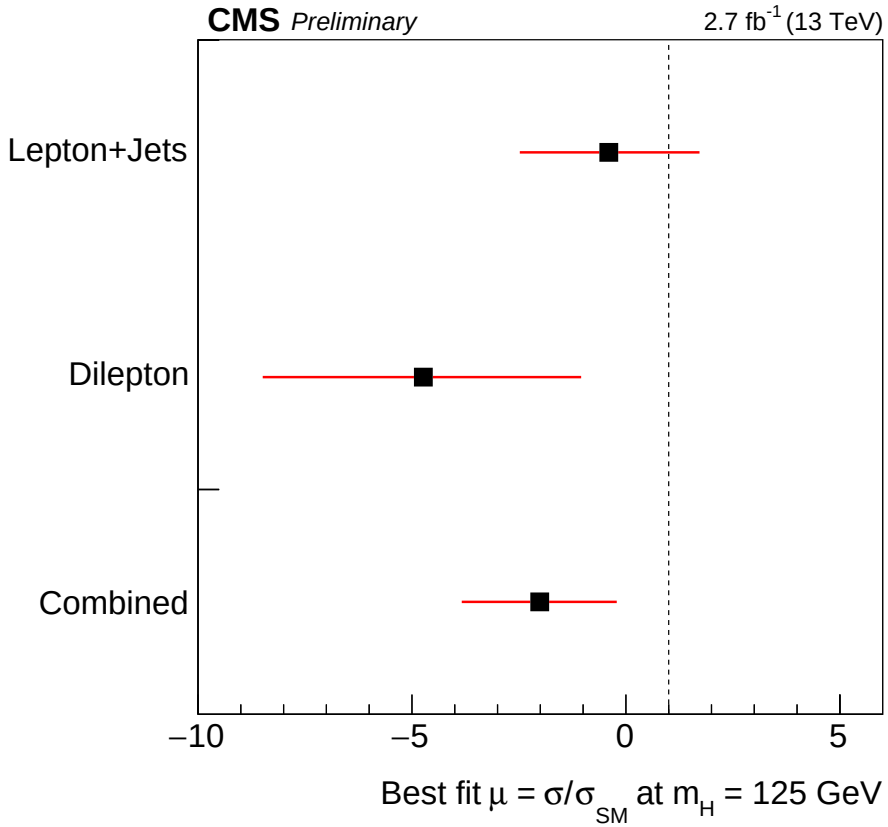


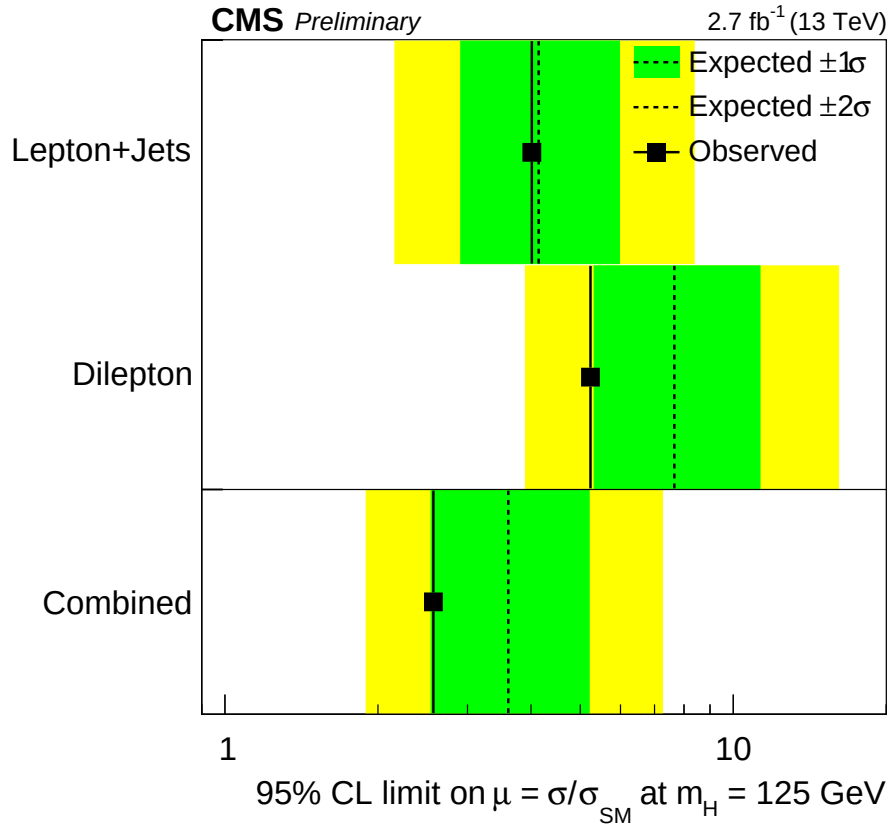
- Use dedicated BDT per category and/or MEM methods
- Introduce boosted category (first time): identify hadronic top and Higgs using substructure information of fat jet

- Use dedicated BDT per category

Results of $t\bar{t}H, H \to b\bar{b}$

Simultaneous binned maximum-likelihood fit to data in all analysis categories

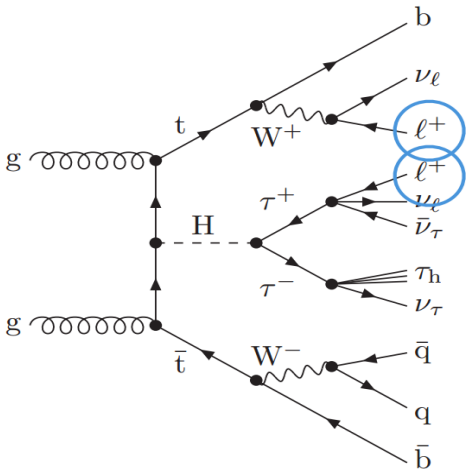




Event selection in $t\bar{t}H, H \rightarrow$MultiLeptons [PAS-HIG-15-008]

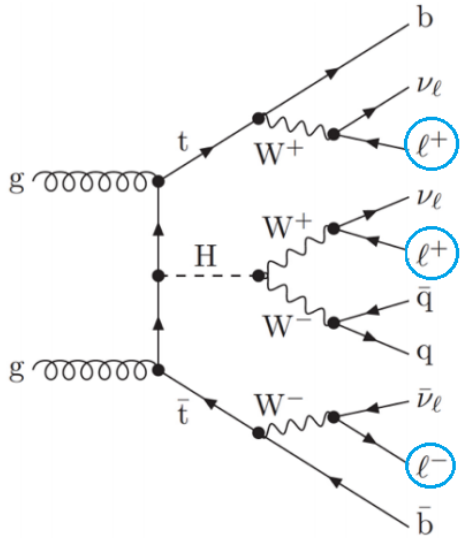
Two main categories according to the lepton multiplicity

Dilepton



- 2 same-sign ℓ: pT> 20, 10 (15) GeV for μ (e); $|\eta|$ <2.4
- $\geq$ 4 jets (pT>25 GeV, $|\eta|$ <2.4)

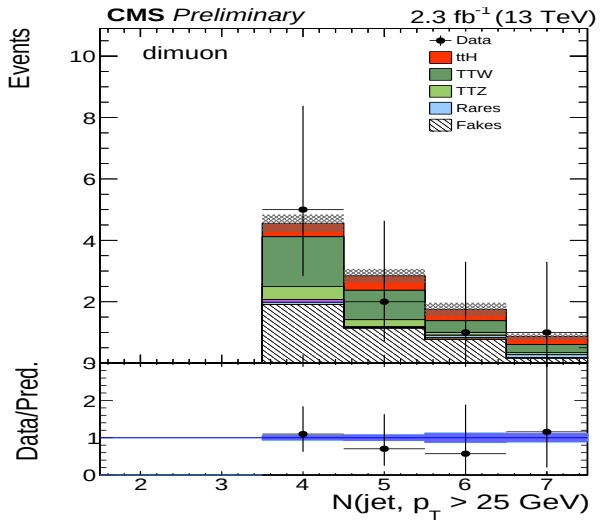
Trilepton

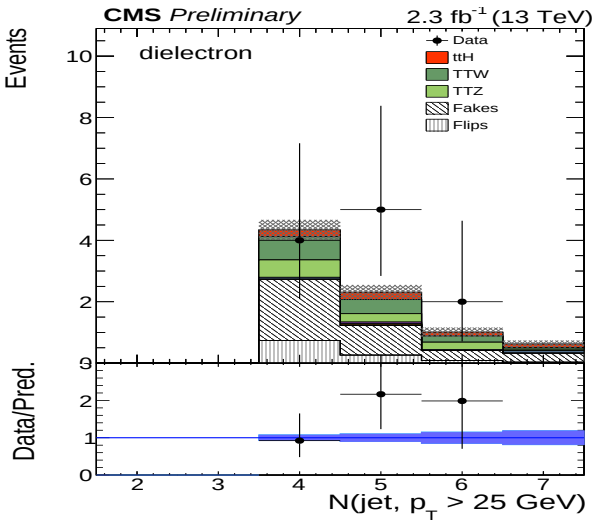


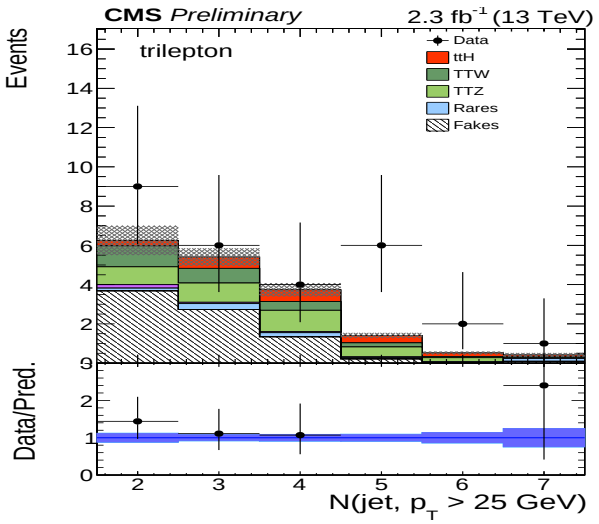
- $\geq$ 3 ℓ: pT> 20, 10, 10 GeV; $|\eta|$ <2.4
- $\geq$ 2 jets (pT>25 GeV, $|\eta|$ <2.4)

- Lepton identification through a dedicated BDT to mitigate misidentification from non-prompt leptons, jets, and charge mismeasurements
- Sub-categorisation: lepton flavour, lepton charge, presence of τ_h, b-jet multiplicity

Background characterisation in $t\bar{t}H$, $H \rightarrow$MultiLeptons



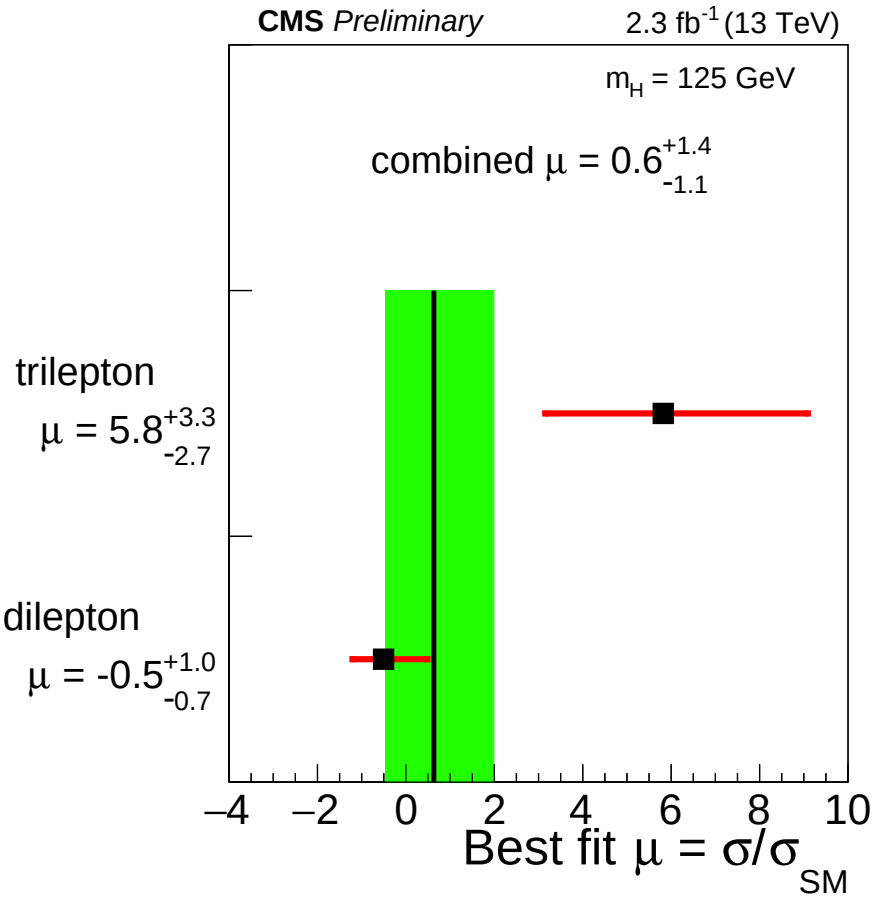


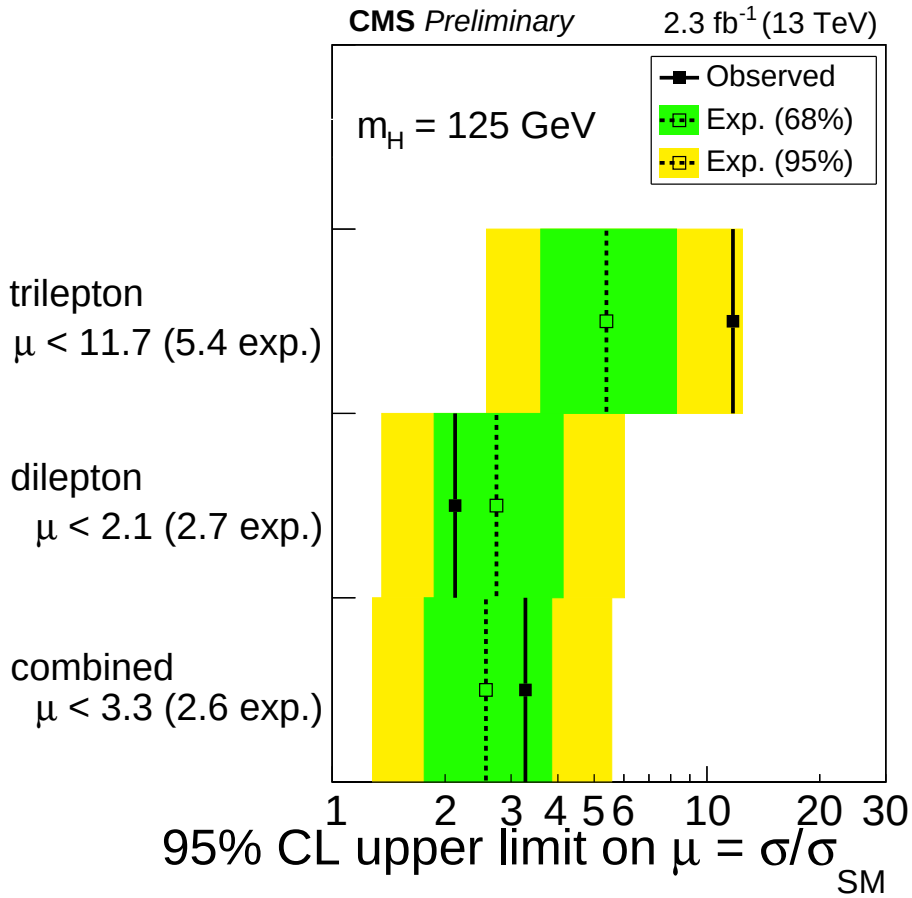


- Fakes
  Weight data events selected with reversed lepton BDT by P(pT,η,flavour) (measured from data in multijet and Z+jets events)
- $t\bar{t}W$, $t\bar{t}Z$
  Irreducible, taken from simulation

Results of $t\bar{t}H, H \rightarrow$MultiLeptons

The signal is extracted from a combined multivariate discriminator obtained by a training against $t\bar{t}$ and $t\bar{t}W, Z$





Event selection in $t\bar{t}H, H \to \gamma\gamma$ [PAS-HIG-15-005]

Two main categories according to the decays of top pairs

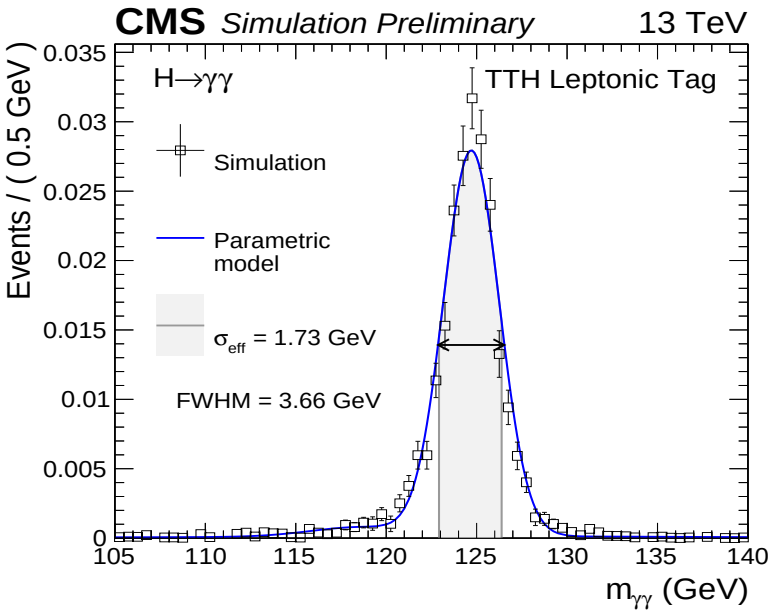
Leptonic tag

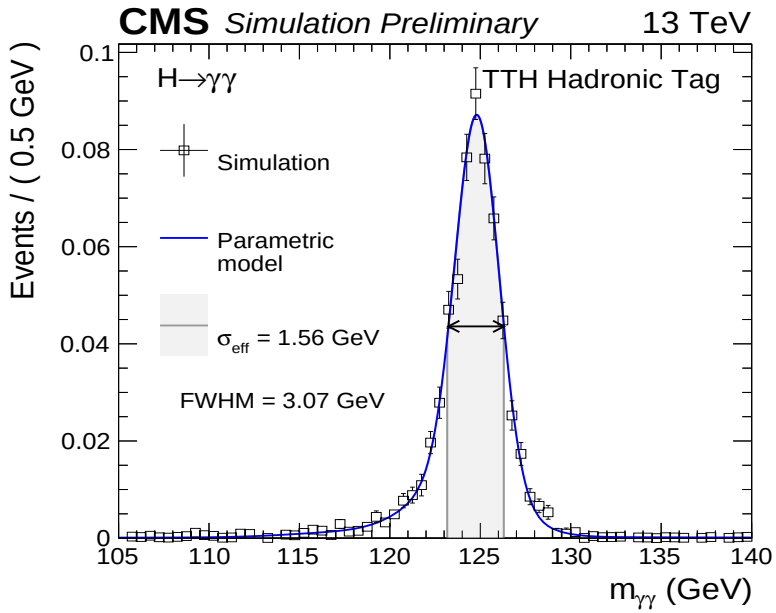
- 2 γ: pT> $m_{\gamma\gamma}/2, m_{\gamma\gamma}/4$
- Diphoton selection through dedicated BDT
- $\geq$ 1 ℓ: pT>20 GeV
- $\geq$ 2 jets: pT>25 GeV, $|\eta|$ <2.4, $\geq$ 1 b-jet

Hadronic tag

- 2 γ: pT> $m_{\gamma\gamma}/2, m_{\gamma\gamma}/4$
- Diphoton selection through dedicated BDT
- No leptons
- $\geq$ 5 jets: pT>25 GeV, $|\eta|$ <2.4, $\geq$ 1 b-jet

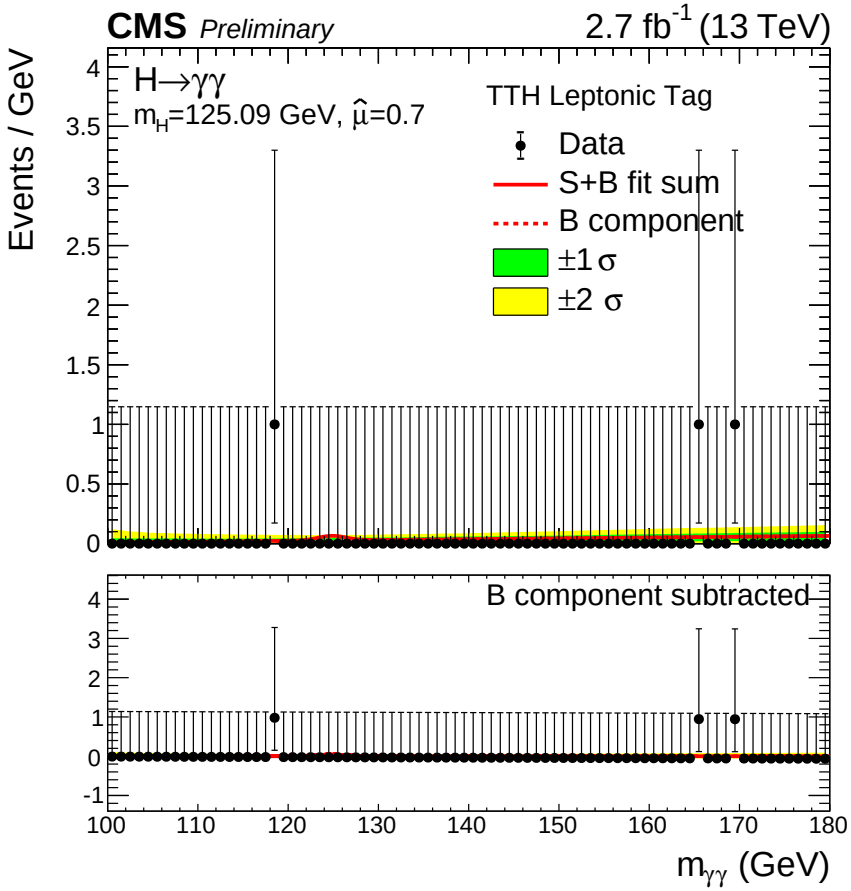
Clean resonant signature (tough tiny BR) $\rightarrow$ search for a resonance in $m_{\gamma\gamma}$

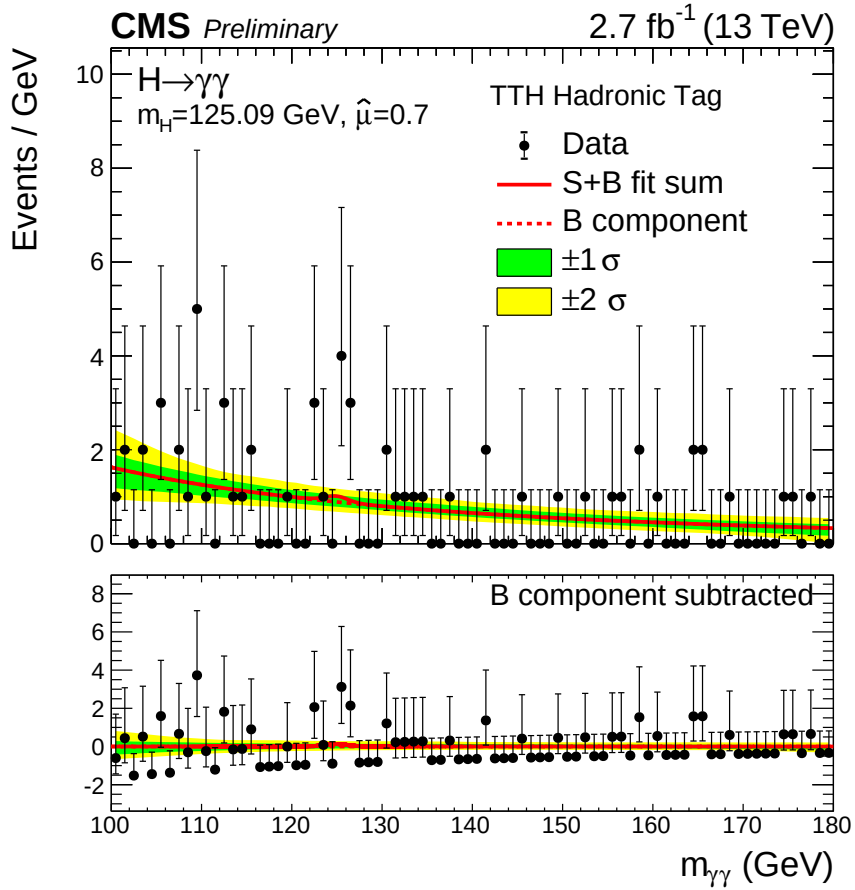




Background characterisation and result of $t\bar{t}H, H \to \gamma\gamma$

Smooth fit functions, several functional forms

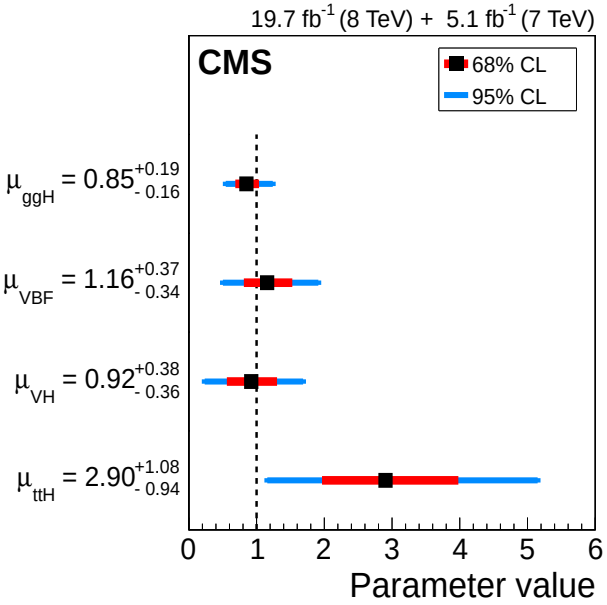




$$\hat{\mu}_{t\bar{t}H-tags} = 3.8^{+4.5}_{-3.6}$$

Combined results

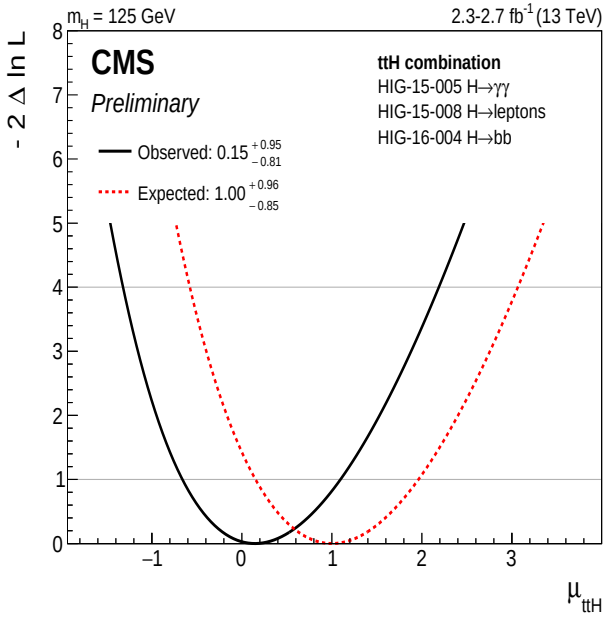
8 TeV + 7 TeV



Best-fit value of

$\mu_{t\bar{t}H} = 2.90^{+1.08}_{-0.94}$

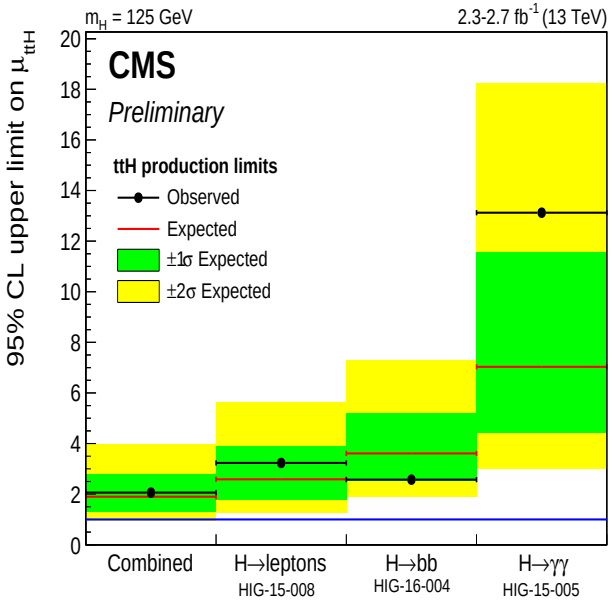
13 TeV



Best-fit value of

$\mu_{t\bar{t}H} = 0.15^{+0.95}_{-0.81}$

13 TeV



Observed limit on

$\mu_{t\bar{t}H} = 2.1$

Conclusions

- $t\bar{t}H$ observation and Yukawa coupling measurement
  amongst priorities for Run 2 at LHC

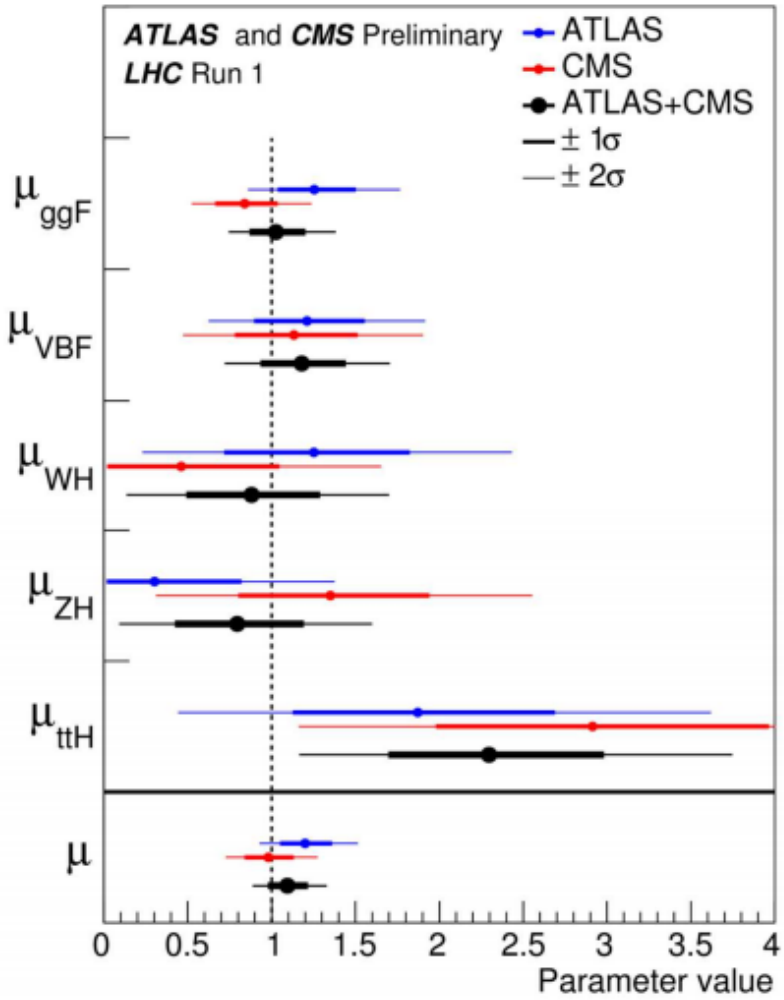
- CMS has performed following measurements with 13 TeV data of 2015:
  $t\bar{t}H, H \to b\bar{b}$
  $t\bar{t}H, H \to$ MultiLeptons
  $t\bar{t}H, H \to \gamma\gamma$

- From the combination of the results:
  Best-fit value of $\mu_{t\bar{t}H} = 0.15^{+0.95}_{-0.81}$ (SM expectation is $1.00^{+0.96}_{-0.85}$)
  Observed limit on $\mu_{t\bar{t}H} = 2.1$ (expected limit $= 1.9$)

- More data to come (expected about 30 fb^{-1} in 2016)

Summary of ATLAS and CMS RunI results

- Combination of all Higgs analysis channels
- μ_{ttH} dominated by: ttH($\gamma\gamma$), ttH(multilepton), ttH(bb)



	μ (ttH)
ATLAS	1.9 +0.8 -0.7
CMS	2.9 +1.0 -0.9
Combined	2.3 +0.7 -0.6

$t\bar{t}H, H \rightarrow$ MultiLeptons sub-categories

Sub-categorisation according to

- lepton flavour
- lepton charge
- presence of τ_h
- b-jet multiplicity