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CLHC - 22 to 24 Dec 2017, Nanjing

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

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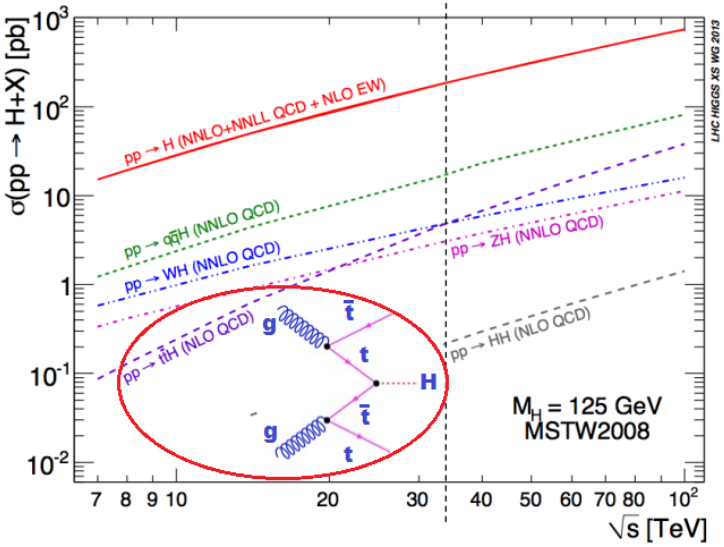
On behalf of the IHEP CMS group

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



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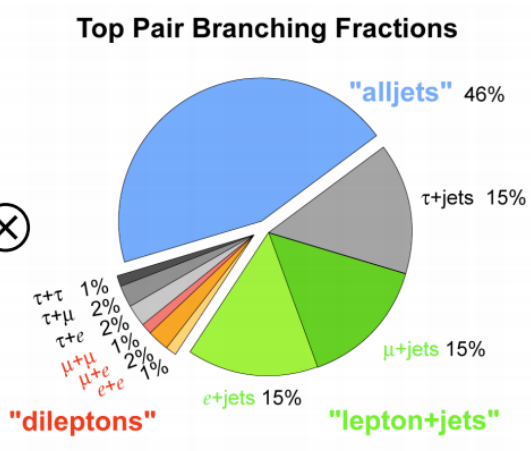
Decay



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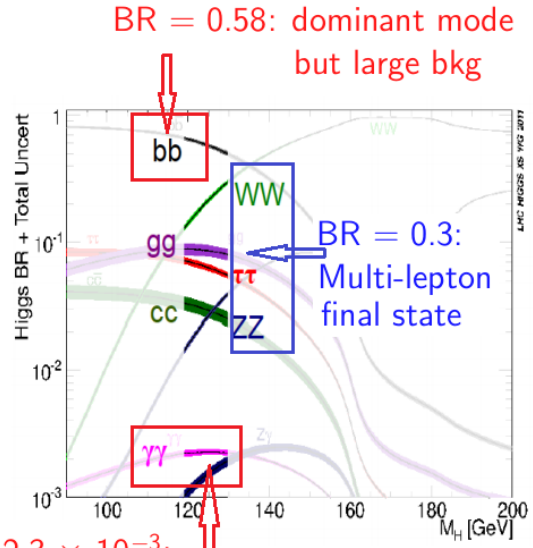


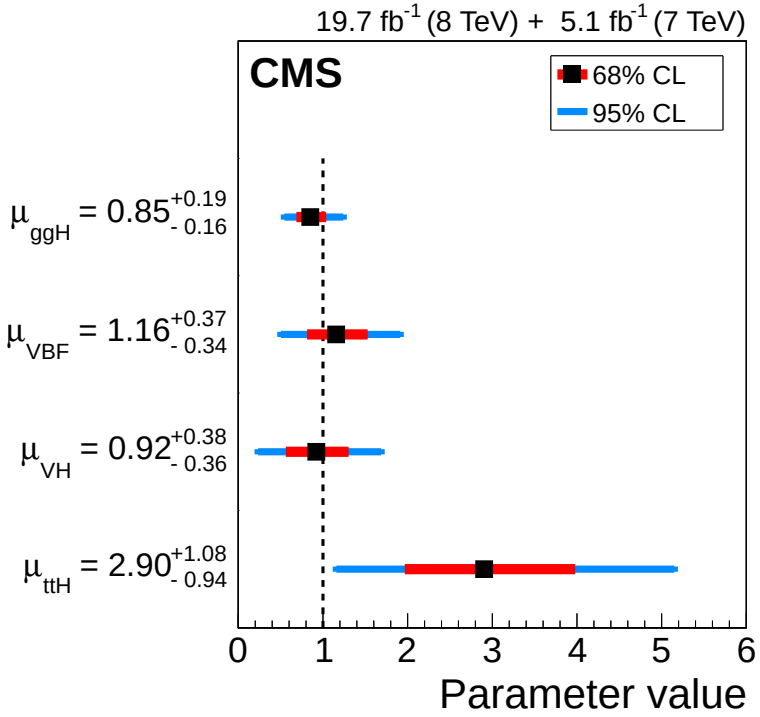
Challenges

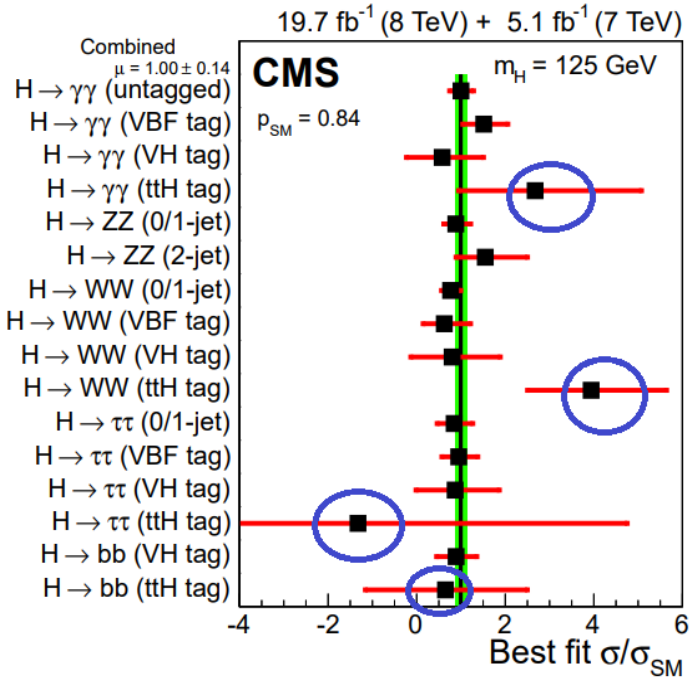
- Low signal cross-section
- Complicated final states with high-jet/b-tag multiplicity
  A priori, some handles but large combinatorial and physics bkg
  (in large part irreducible and affected by large sys unc)

$\sqrt{s}$ (TeV)	7	8	13
$t\bar{t}H(m_H = 125 GeV)$ (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)

CMS RunI results





$\mu_{t\bar{t}H}$, only channel reaches 2 σ, dominated by $t\bar{t}H$

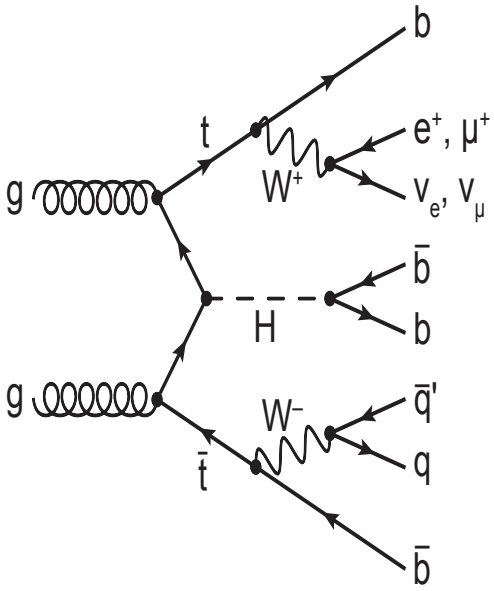
- $H \to b\bar{b}$
- $H \to$ MultiLeptons
- $H \to \gamma\gamma$

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

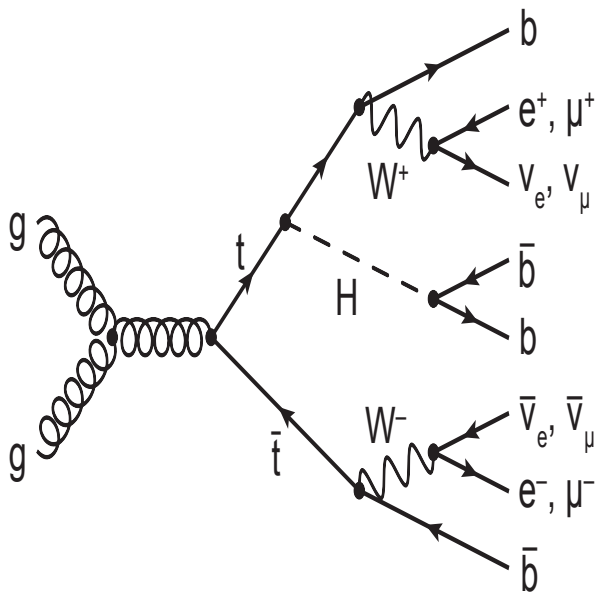
Event selection in $t\bar{t}H, H \to b\bar{b}$ [PAS-HIG-16-038]

Two main categories according to the decays of top pairs

lepton+jets



Dilepton



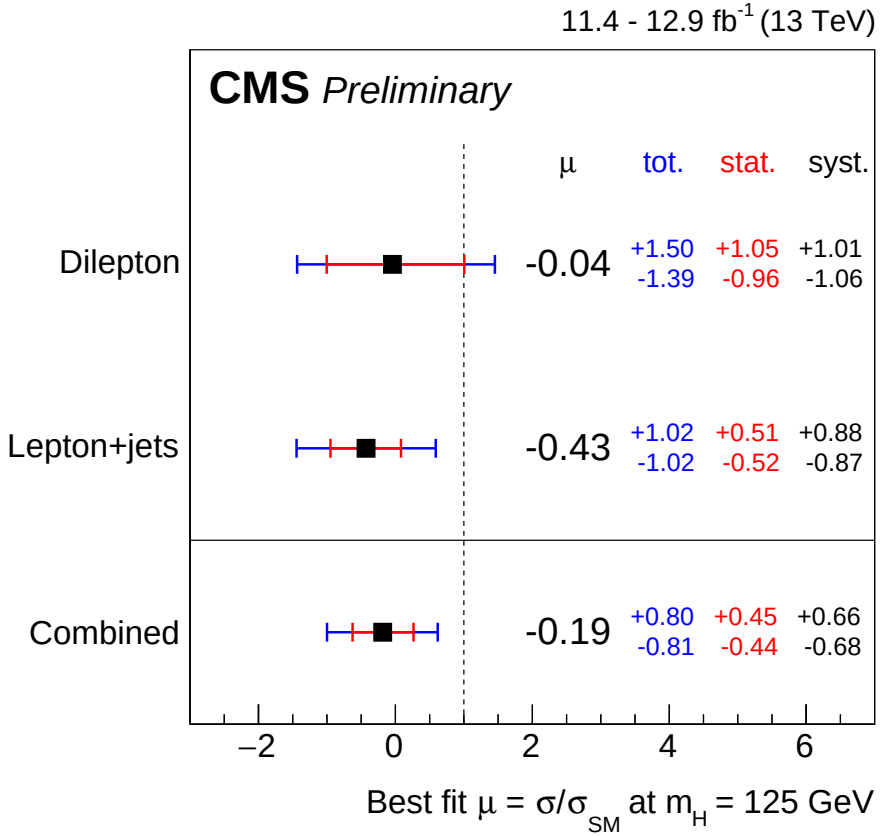
- 1 ℓ: pT> 25 (30) GeV for μ (e); $|\eta|$ <2.1
- $\geq$ 4 jets (pT>30 GeV, $|\eta|$ <2.4)

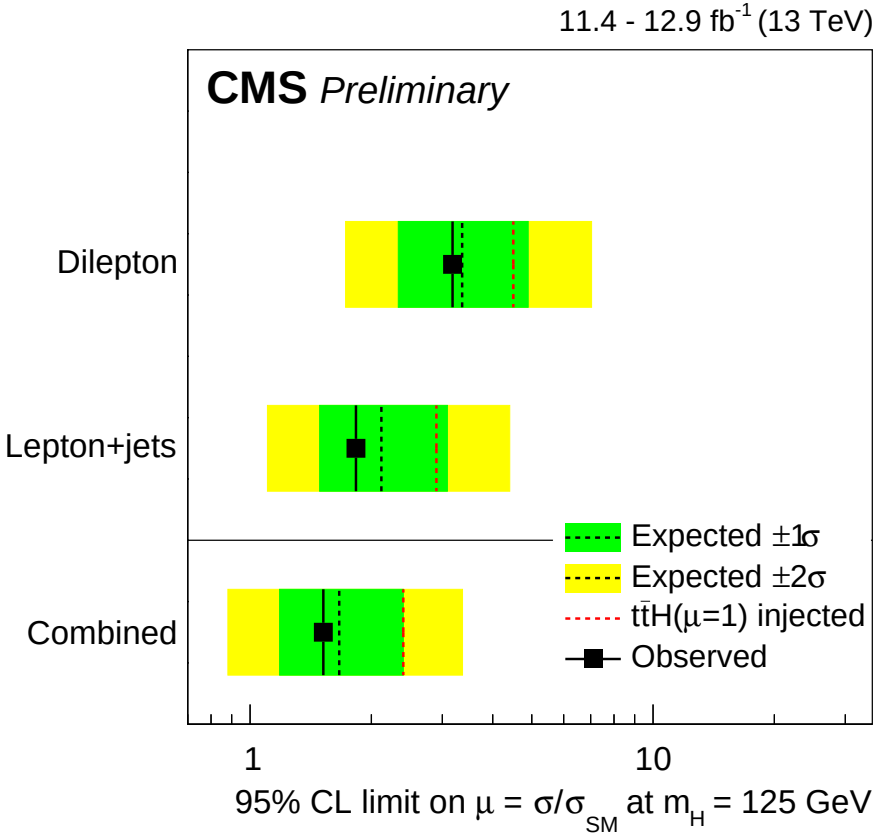
- 2 ℓ: pT> 20,15 GeV; $|\eta|$ <2.4
- $\geq$ 3 jets (pT>30,30,20 GeV, $|\eta|$ <2.4)

- Sub-categorisation: jet and b-jet ($\geq$ 3) multiplicity
- IHEP participants: HB.Liao, F.Romeo, A.Spiezia, J.Thomas, HQ.Zhang

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 $t\bar{t}H, H \to \gamma\gamma$ [PAS-HIG-16-040]

Two main categories according to the decays of top pairs

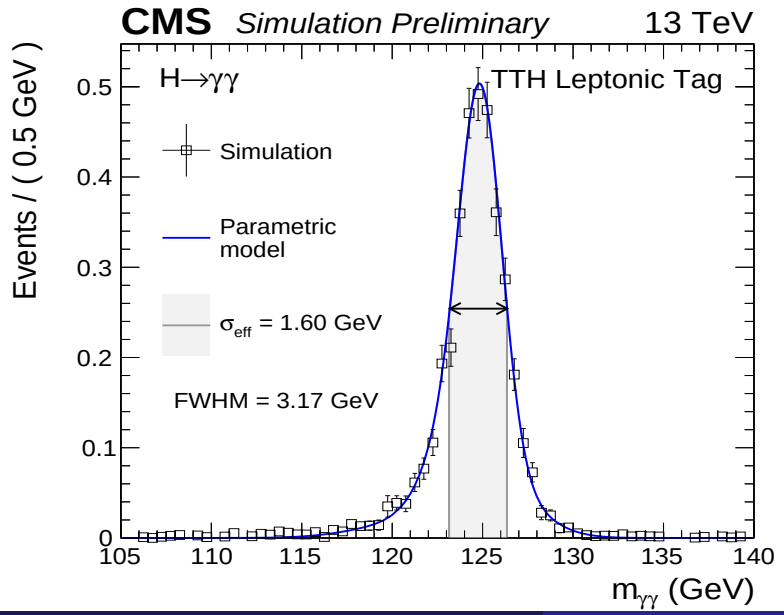
Leptonic tag

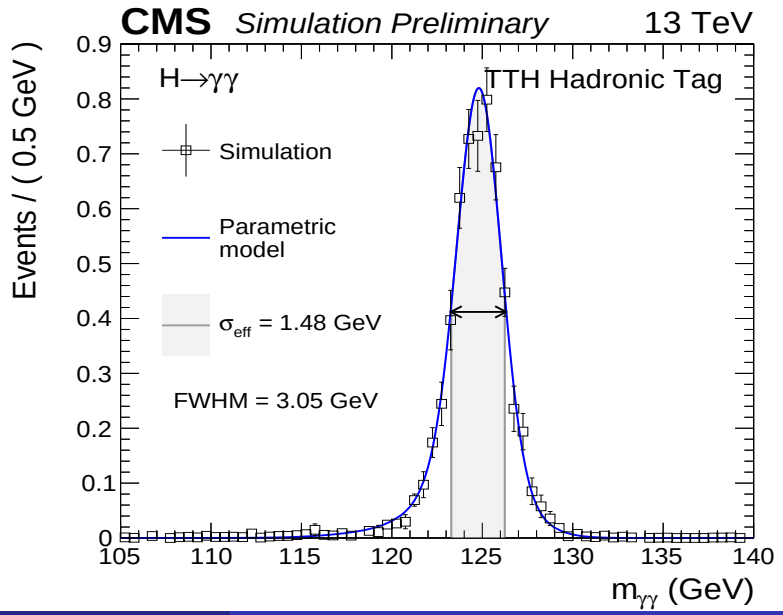
- 2 γ: pT> $m_{\gamma\gamma}/2, m_{\gamma\gamma}/4$
- Diphoton selection through dedicated BDT
- $\geq$ 1 ℓ: pT>20 GeV
- $\geq$ 2 jets: pT>25 GeV, $|\eta|$ <2.4, $\geq$ 1 b-jet

Hadronic tag

- 2 γ: pT> $m_{\gamma\gamma}/3, m_{\gamma\gamma}/4$
- Diphoton selection through dedicated BDT
- No leptons
- $\geq$ 5 jets: pT>25 GeV, $|\eta|$ <2.4, $\geq$ 1 b-jet

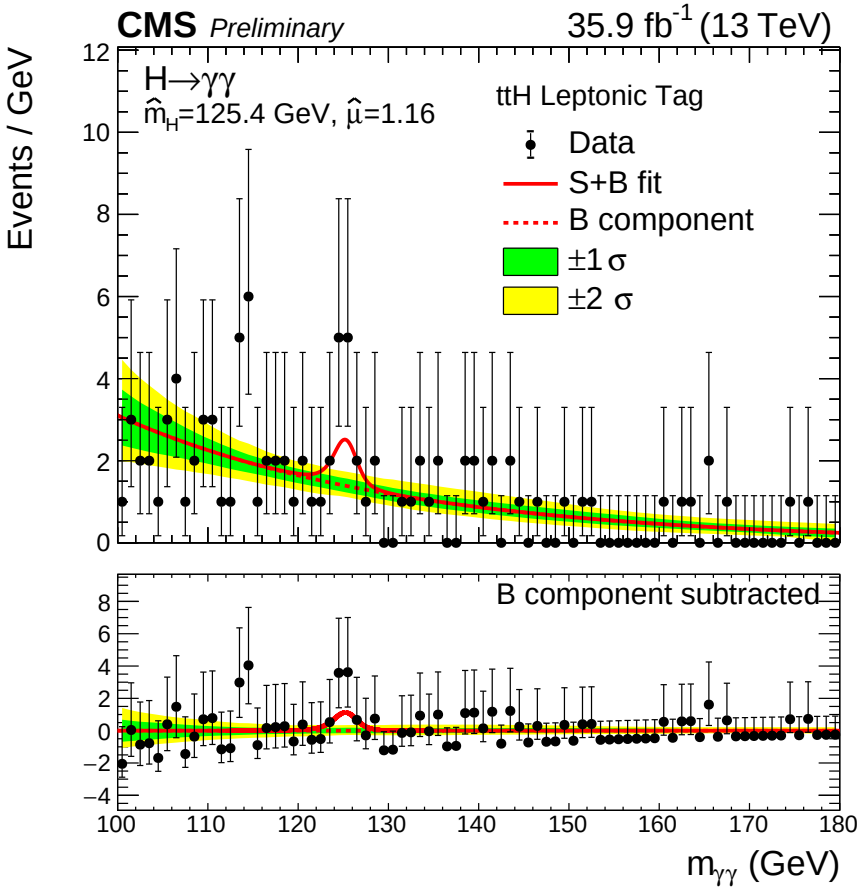
Clean resonant signature (tough tiny BR) $\to$ search for a resonance in $m_{\gamma\gamma}$

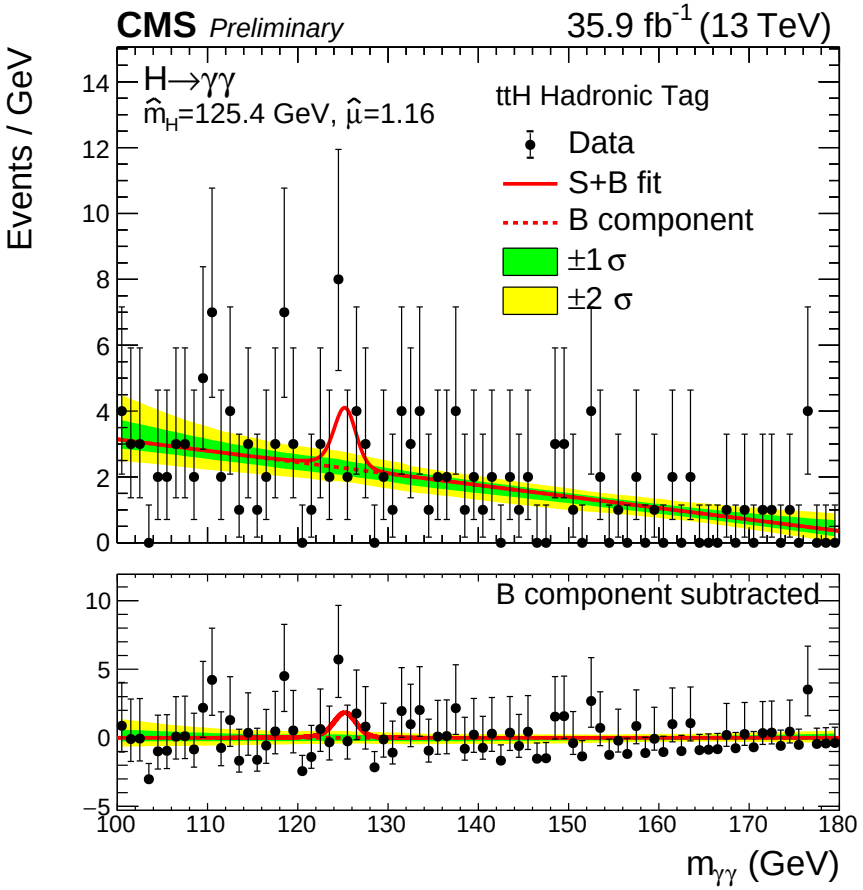




Background characterisation and result of $t\bar{t}H, H \to \gamma\gamma$

Smooth fit functions, several functional forms





$$\hat{\mu}_{t\bar{t}H-tags} = 2.2^{+0.9}_{-0.8}$$

Event selection in $t\bar{t}H$, $H \rightarrow$MultiLeptons with τ_h [PAS-HIG-17-003]

Three main categories according to the lepton and tau_h multiplicity

lepton + 2 tau_h

- 1 ℓ: pT> 20 (25) GeV for μ (e); $|\eta|$ <2.1
- 2 tau_h : opposite charge

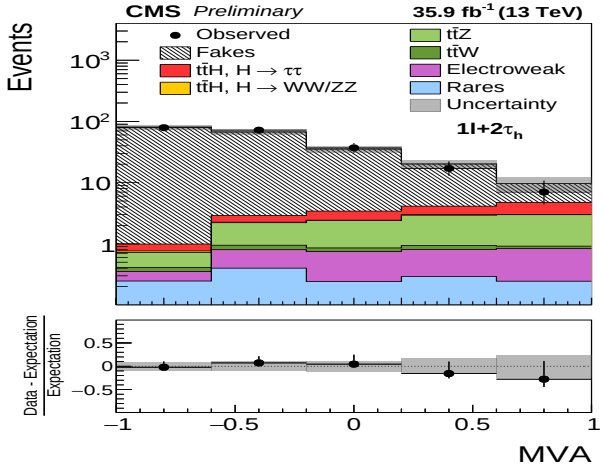
Dilepton + 1 tau_h

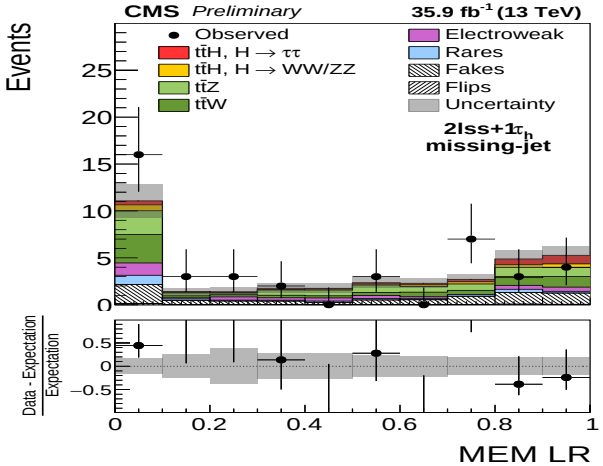
- 2 same-sign ℓ: pT> 25, 10 (15) GeV for μ (e); $|\eta|$ <2.5
- $\geq$ 3 jets (pT>25 GeV, $|\eta|$ <2.4)

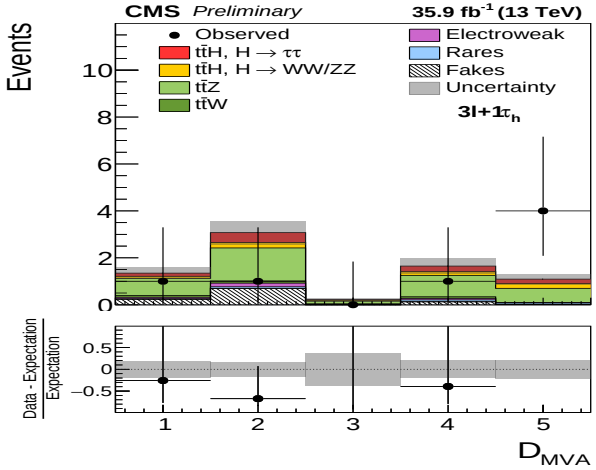
Trilepton + 1 tau_h

- 3 ℓ: pT> 20, 10, 10 GeV; $|\eta|$ <2.5
- $\geq$ 2 jets (pT>25 GeV, $|\eta|$ <2.4)

Signal is extracted using BDT(1 ℓ) ; MEM (2 ℓ) ; combined BDT (3 ℓ) discriminator

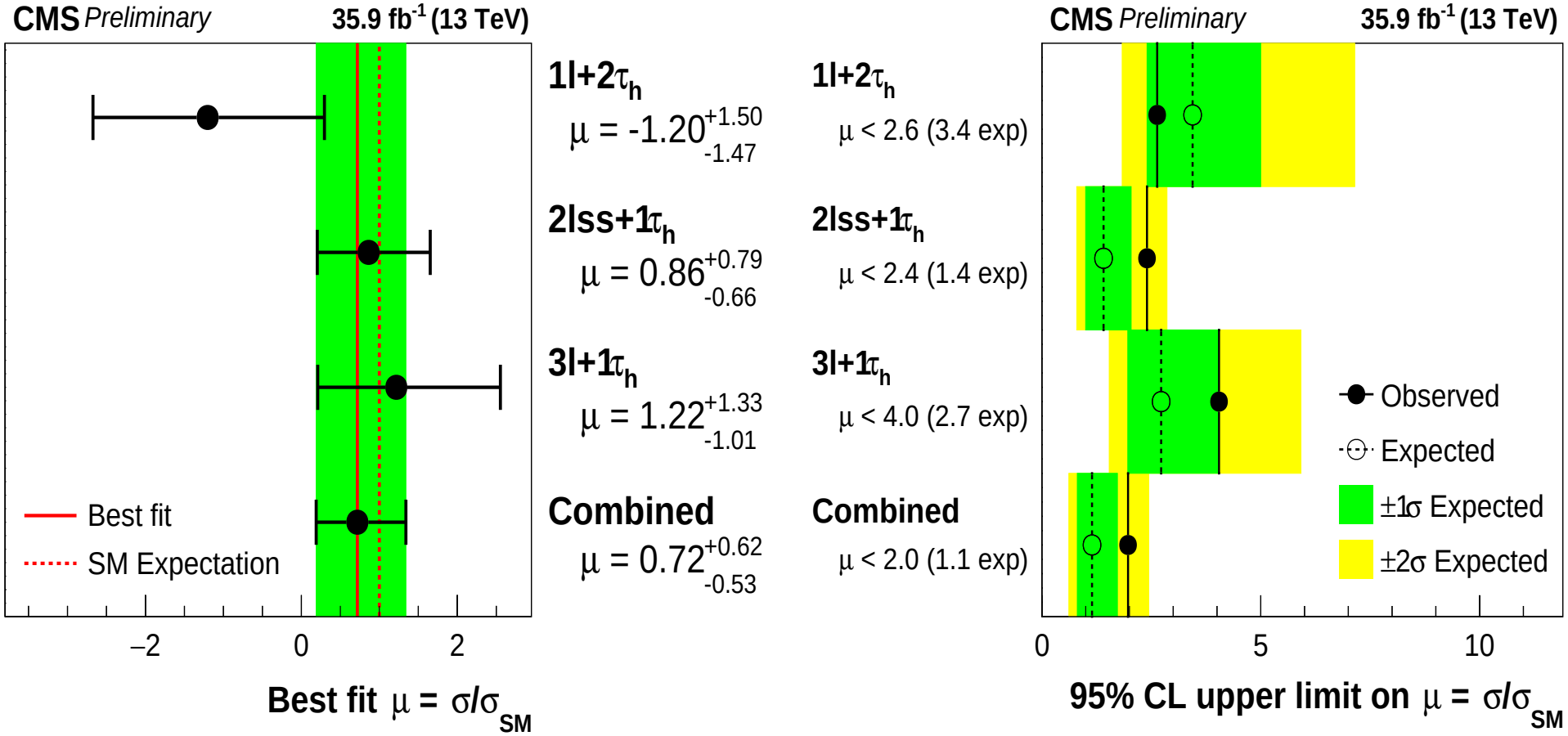






Results in $t\bar{t}H$, $H \rightarrow$MultiLeptons with tau_h

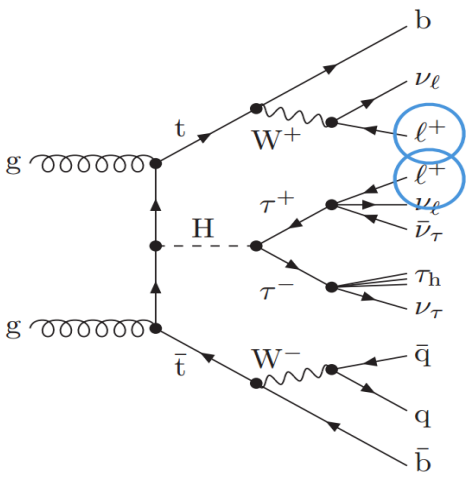
The signal rate μ is computed for each of the categories individually and for thier combination, upper limit on μ is computed at 95% CL



Event selection in $t\bar{t}H$, $H \rightarrow$MultiLeptons w/o τ_h [PAS-HIG-17-004]

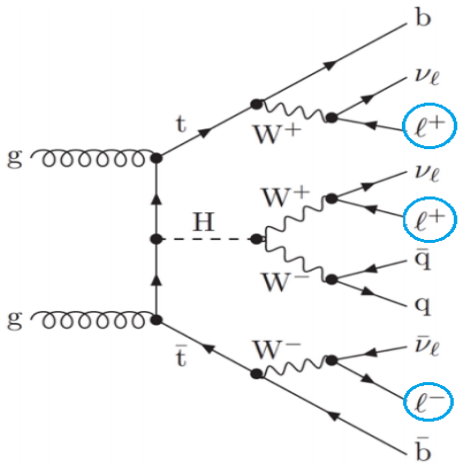
Two main categories according to the lepton multiplicity

Dilepton



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

Trilepton

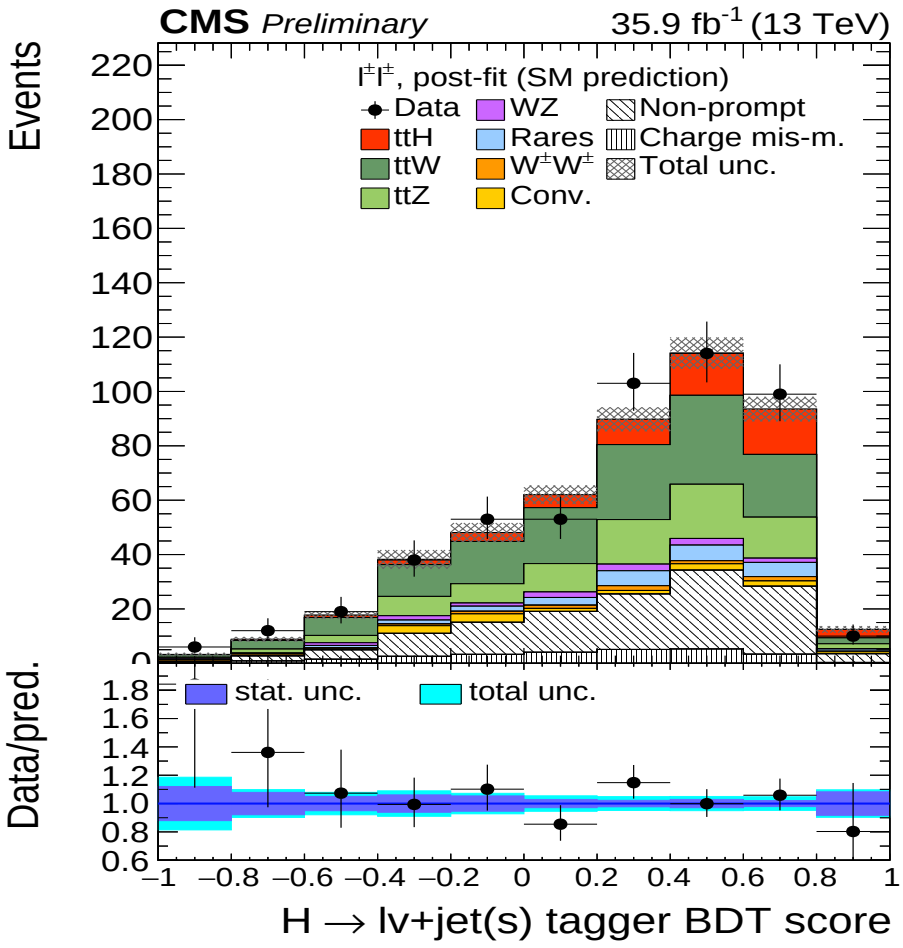


- $\geq$ 3 ℓ: pT> 25, 15, 15 GeV; $|\eta|$ <2.4
- $\geq$ 2 jets (pT>25 GeV, $|\eta|$ <2.4)

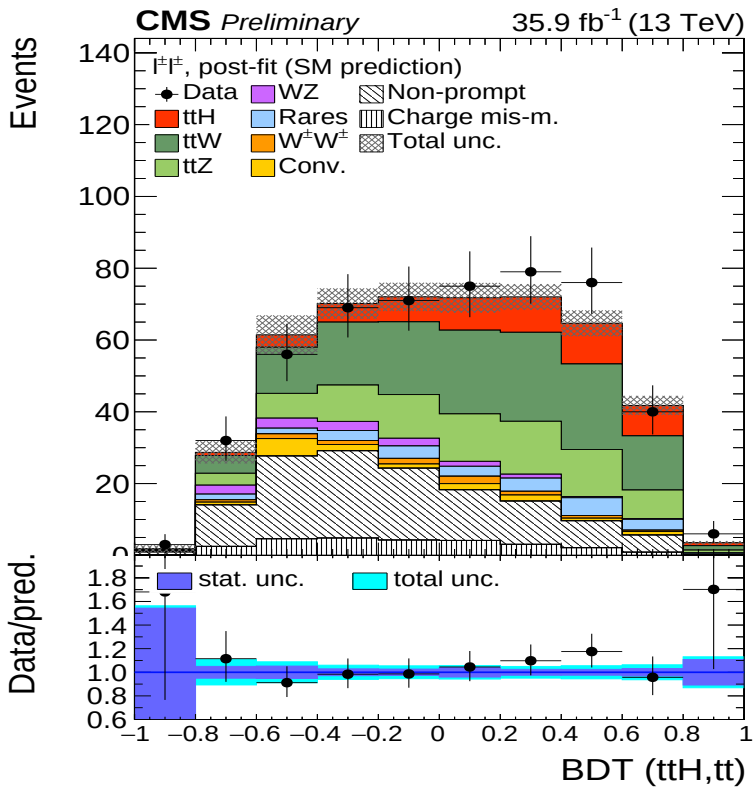
- Lepton identification through a dedicated BDT
- Analyis with hadronic tau is done separately
- IHEP participants: BH.Li , F.Romeo, HQ.Zhang

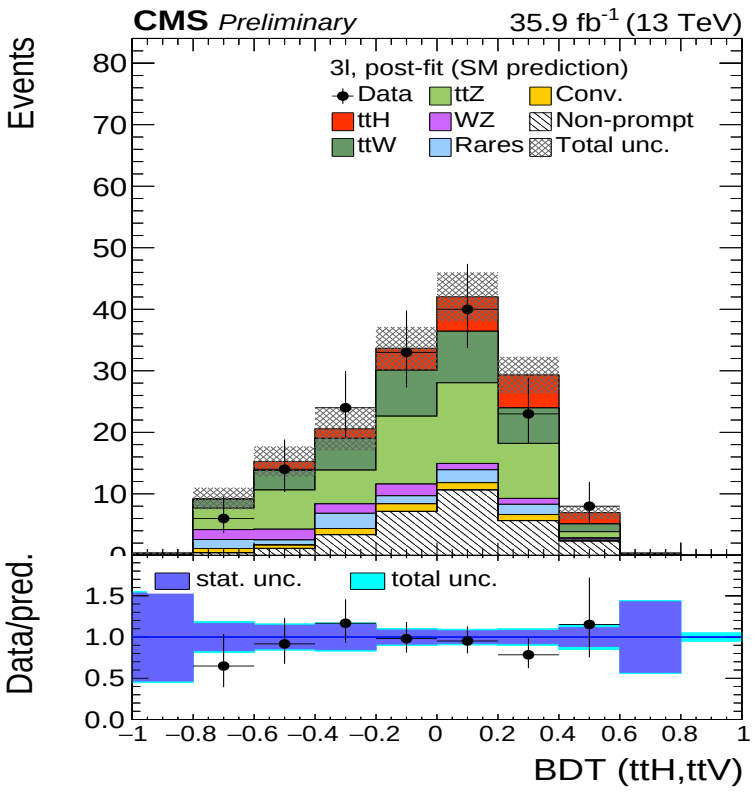
Hjet Tagger in $t\bar{t}H$, $H \rightarrow$MultiLeptons w/o τ_h

- Hj Tagger : BDT
- Objective : Identifiying a Jet decayed from W from Higgs
- Sig: correctly matched Jet in $t\bar{t}H$
  bkg: all jets in $t\bar{t}V$
- Variables :
  jet ID (b-tagging, qg likelihood)
  geometric (dR to l) properties
- take the highest BDT score jet



Background Characterisation of $t\bar{t}H$, $H \rightarrow$ MultiLeptons w/o τ_h



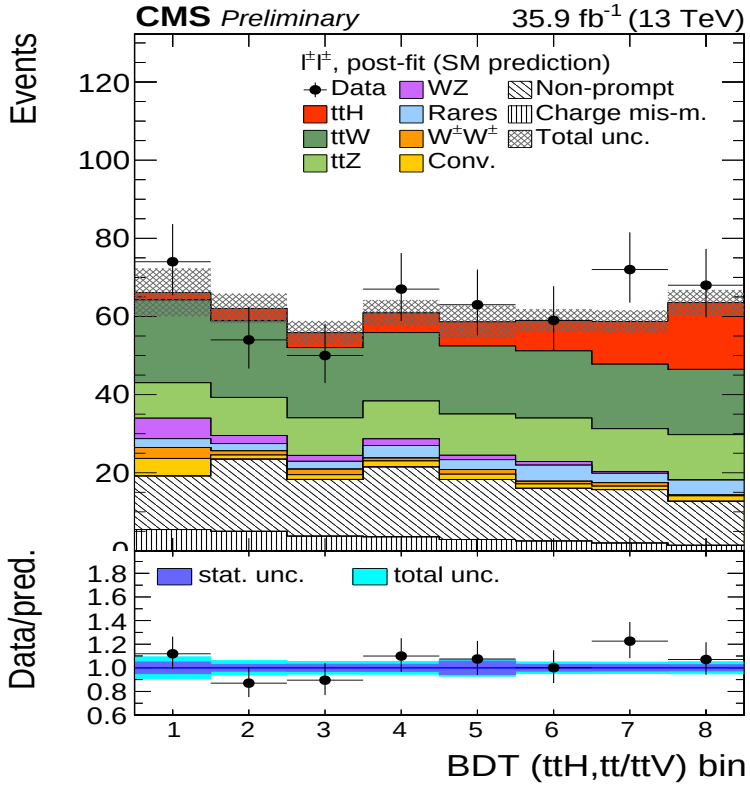


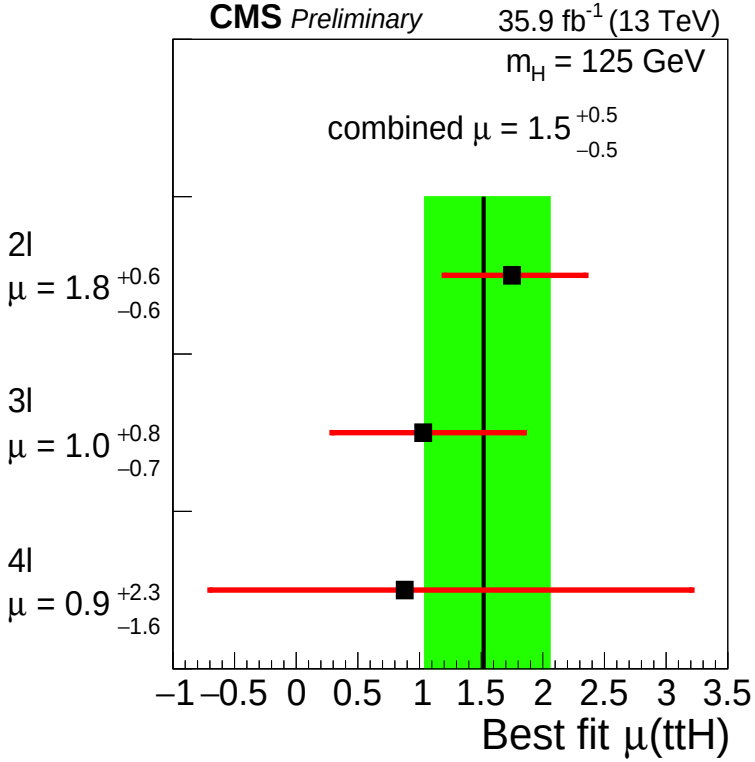
- Mismeasured charge (Flips): Weight data events selected with opposite sign
- Objects misidentified as prompt leptons (Fakes): Weight data events selected with reversed lepton BDT
- $t\bar{t}W$, $t\bar{t}Z$: Irreducible, taken from simulation

Results of $t\bar{t}H$, $H \rightarrow$MultiLeptons w/o τ_h

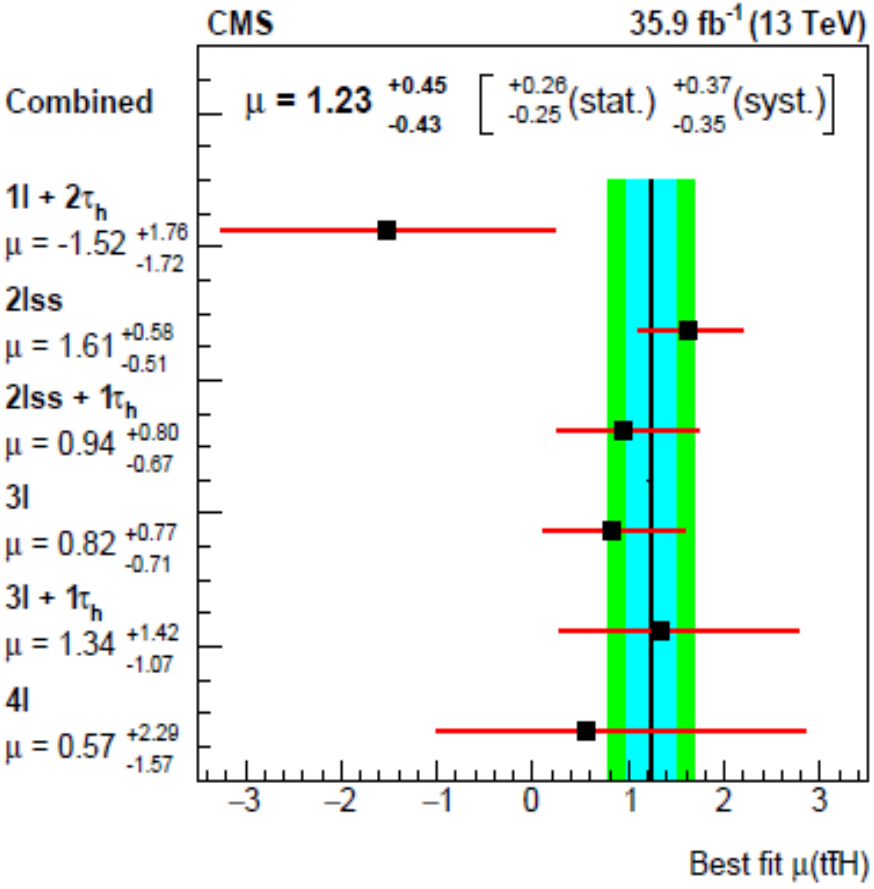
The 2l and 3l signal are extracted from a combined multivariate discriminator obtained by a training against $t\bar{t}$ and $t\bar{t}W, Z$

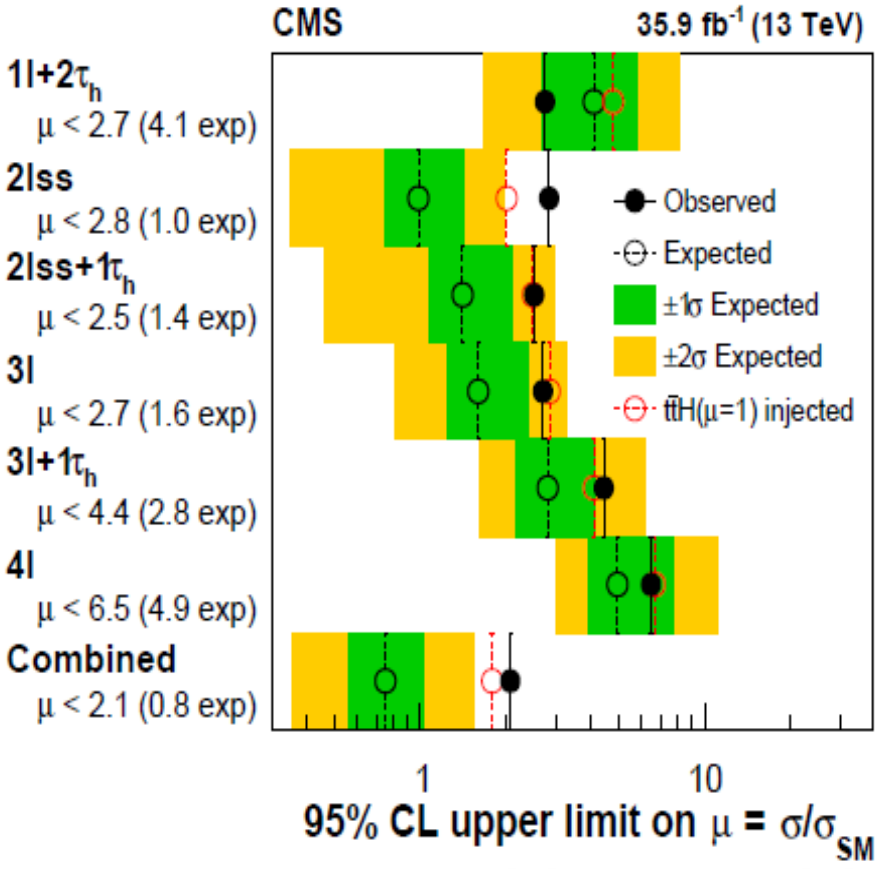
The 4l, due to low statistics, is estimated using less sophisticated method





Combined results of $t\bar{t}H$, $H \rightarrow$MultiLeptons





Conclusions

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

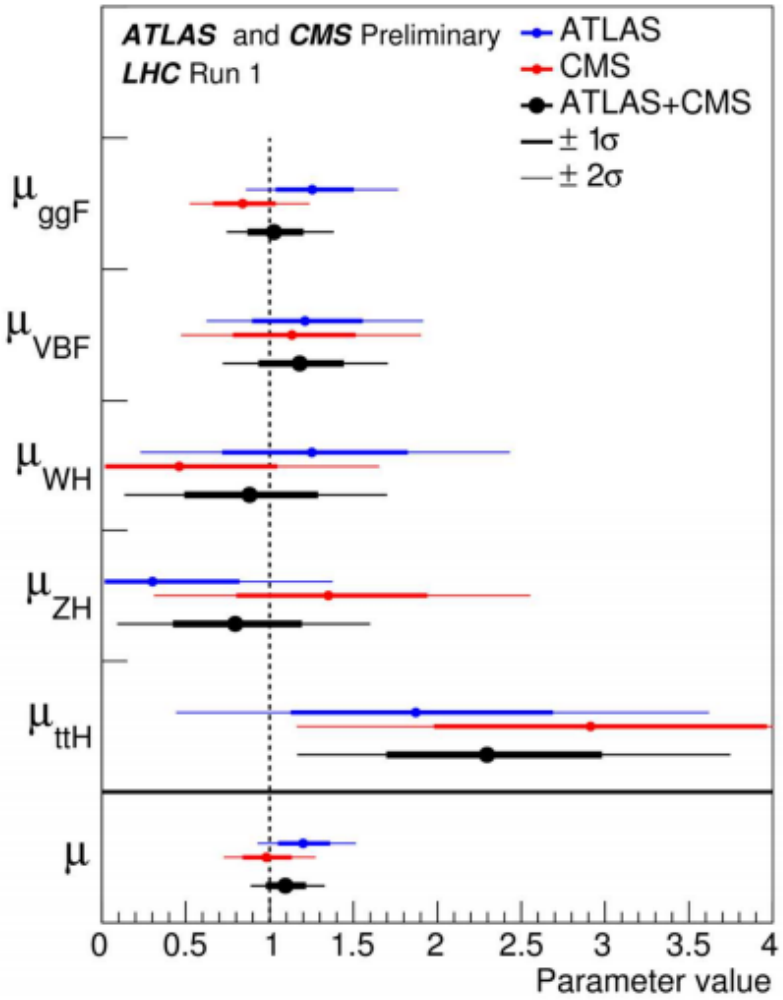
- CMS has performed following measurements with 13 TeV data of 2016:
  $t\bar{t}H, H \to b\bar{b}$
  $t\bar{t}H, H \to \gamma\gamma$
  $t\bar{t}H, H \to$ MultiLeptons

- The results:
  $\mu_{t\bar{t}H,H\to b\bar{b}}$: Best-fit value of $-0.19^{+0.80}_{-0.81}$
  $\mu_{t\bar{t}H,H\to\gamma\gamma}$: Best-fit value of $2.2^{+0.9}_{-0.8}$, with observed (expected) significance of $3.3\sigma(1.5\sigma)$
  $\mu_{t\bar{t}H,H\to MultiLeptons}$: Best-fit value of $1.23^{+0.45}_{-0.43}$, with observed (expected) significance of $3.2\sigma(2.8\sigma)$

- data to come in 2017

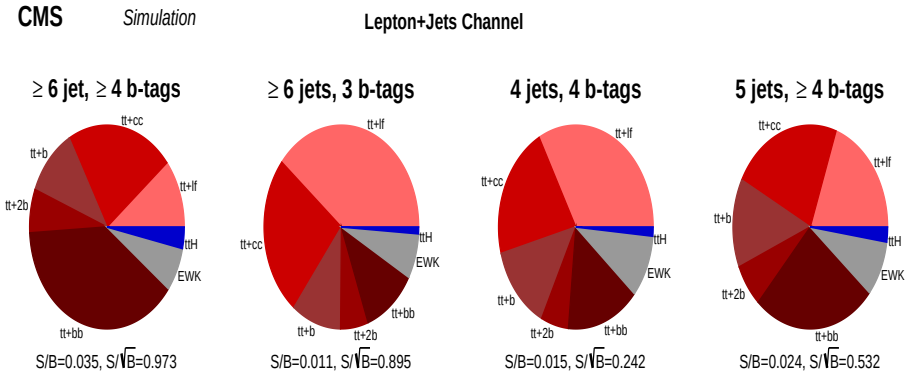
Summary of ATLAS and CMS RunI results

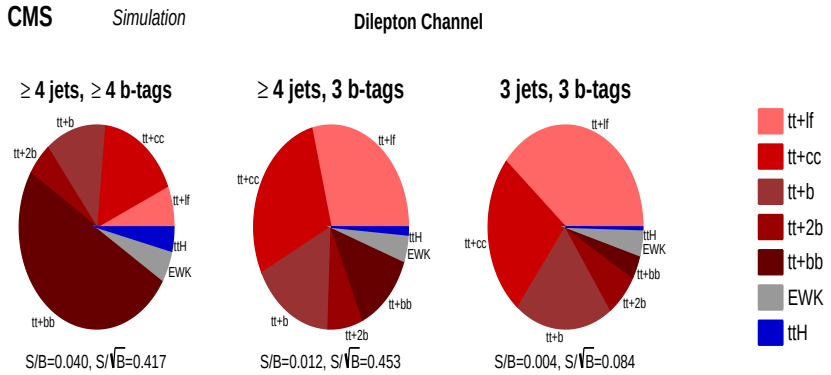
- Combination of all Higgs analysis channels
- μ_{ttH} dominated by: ttH($\gamma\gamma$), ttH(multilepton), ttH(bb)



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

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



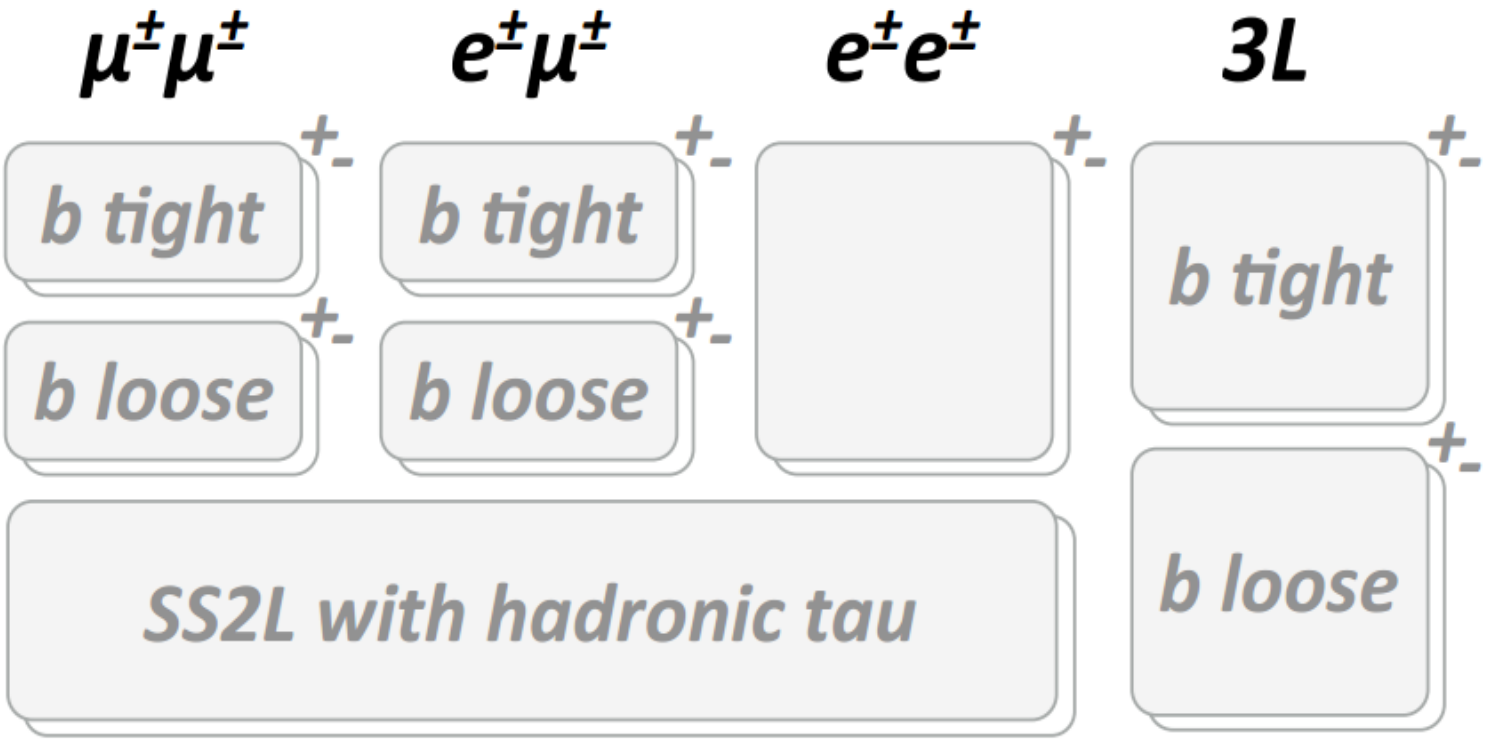


- Use dedicated BDT per category and/or MEM methods
- Use dedicated BDT per category

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

Sub-categorisation according to

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



$t\bar{t}H, H \rightarrow$ MultiLeptons 3l,4l signal extraction