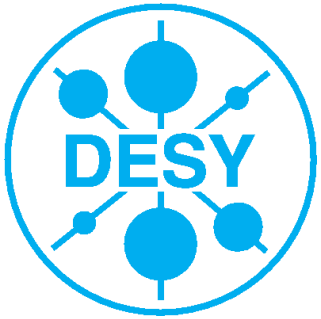
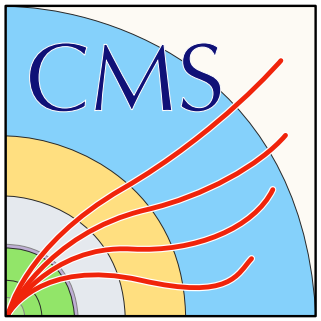



# Measurements of the Yukawa couplings of the Higgs boson at CMS

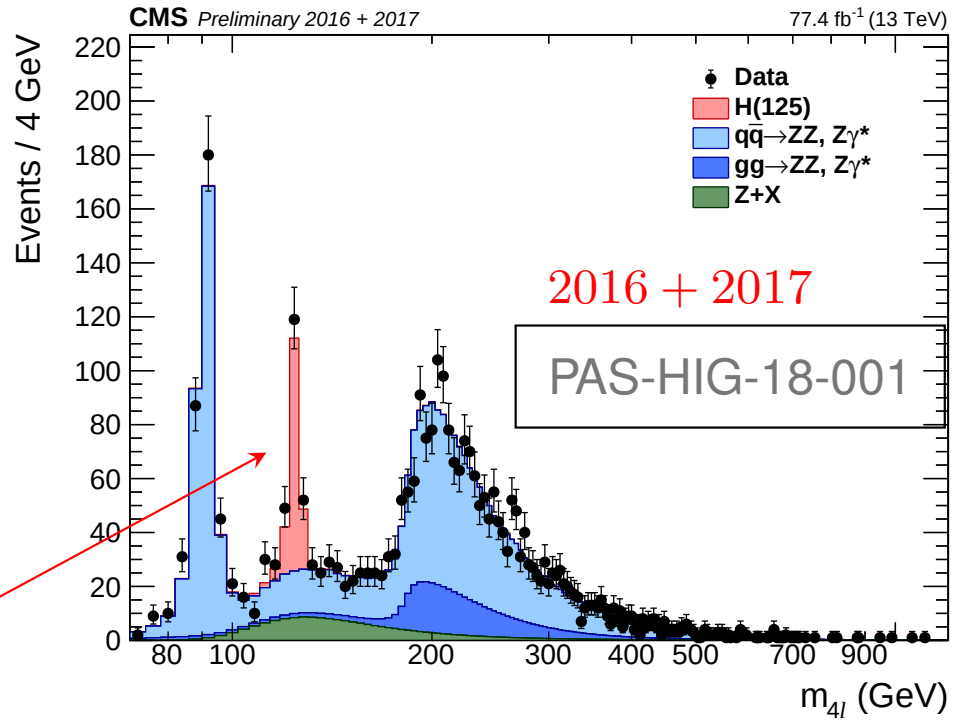
Marino Missiroli (DESY),

on behalf of the CMS Collaboration

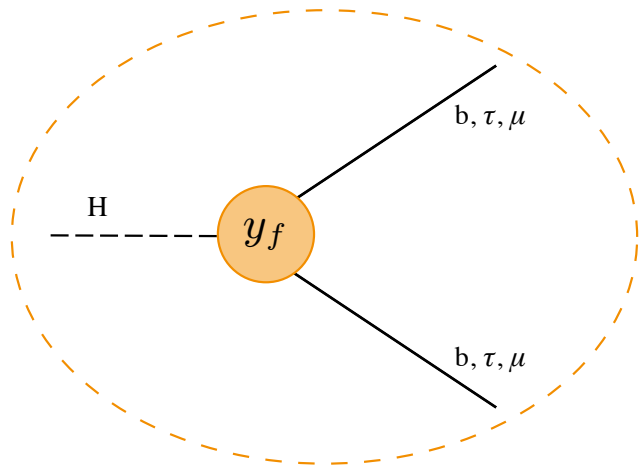
30th Rencontres de Blois, 3-8 June 2018

# The SM Higgs boson

- *The* milestone of LHC Run-1
  - discovery of a new boson with $m \sim 125\ \mathrm{GeV}$ by ATLAS and CMS
- first discovered in bosonic decay modes: $H \to \gamma\gamma$, $H \to ZZ^* \to 4\ell$
- thus far consistent with SM Higgs




- key to the SM Higgs: coupling to fermions
  - $Hf\bar{f}$ Yukawa interaction leads to fermion masses
  - $y_f$ coupling strength proportional to $m_f$



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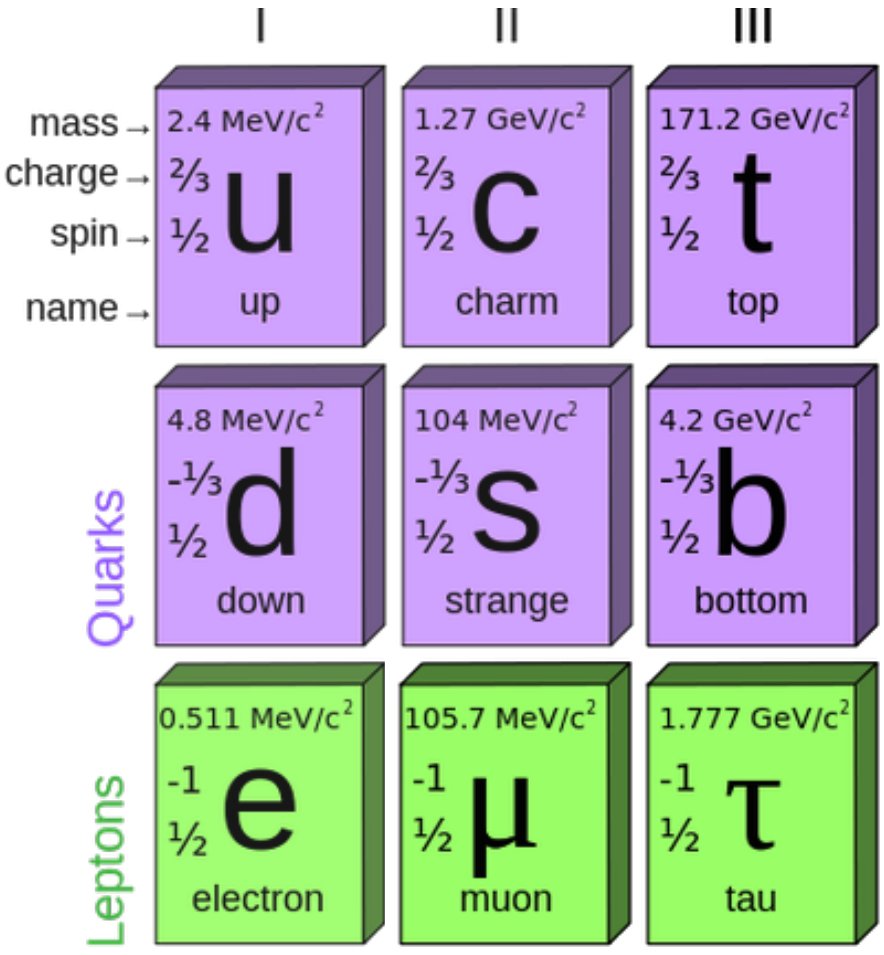

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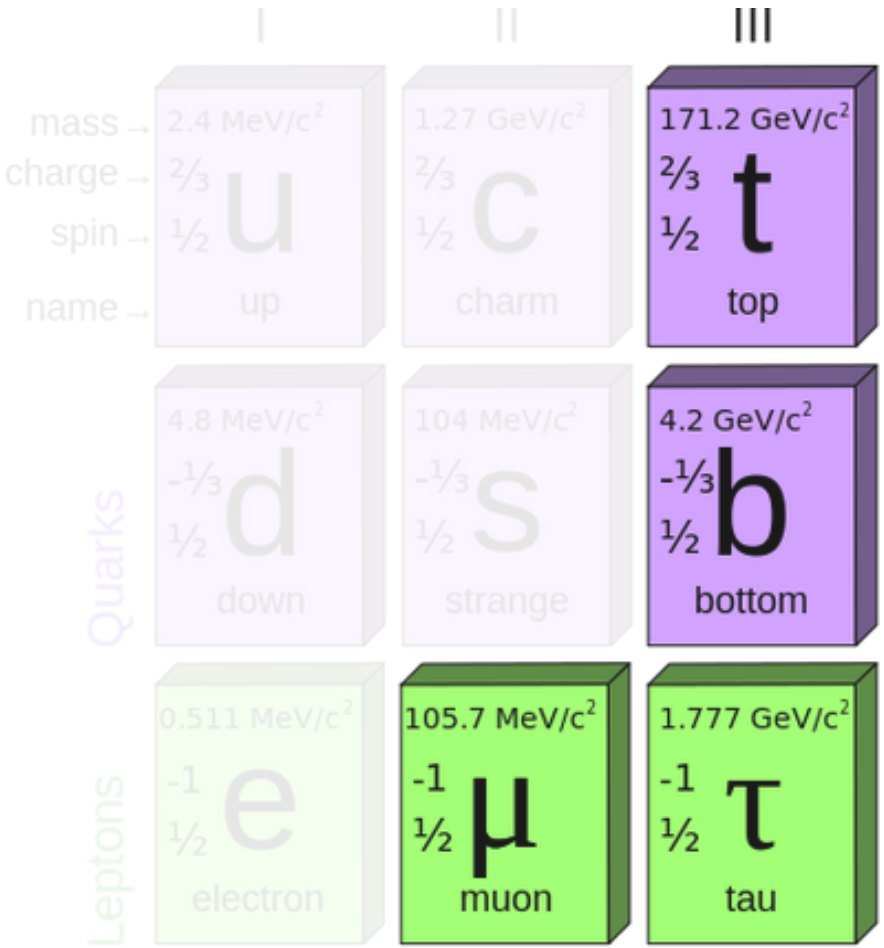
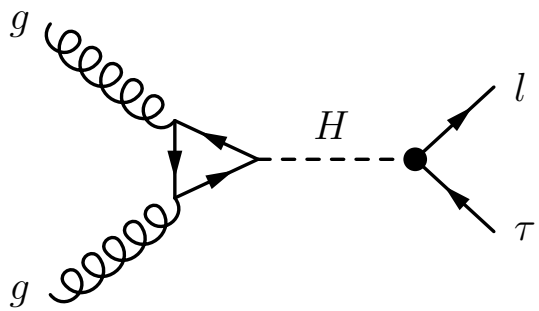


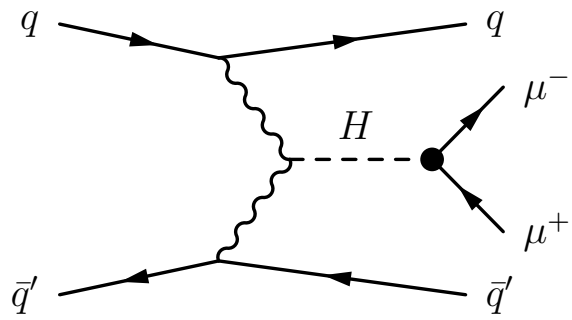

- Focus on couplings within reach at the LHC:
  - Higgs decays to $\mu\mu$, $\tau\tau$, $b\bar{b}$
  - $t\bar{t}H$ and $tH$ production to directly probe Higgs-top coupling

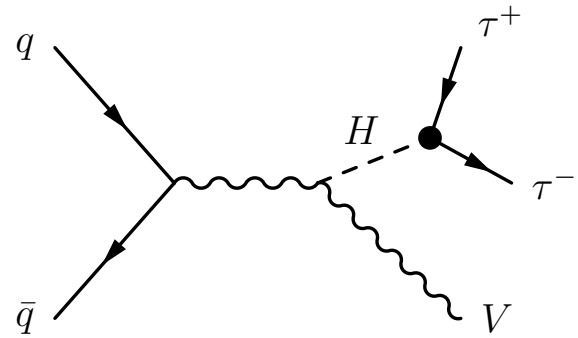
$$\mu = \sigma/\sigma_{\text{SM}}$$

- Reminder: CMS results from Run-1

| | |
|---|---|
| $H \to \mu\mu$ | $\mu_{95\%\ \text{CL}} < 7.4$ obs |
| $H \to \tau\tau$ | evidence ($3.2\sigma$ obs) |
| $H \to b\bar{b}$ | excess of $2.1\sigma$ (obs) |
| $t\bar{t}H$ | $\mu_{\text{fit}} = 2.8 \pm 1.0$ ($3.4\sigma$) |



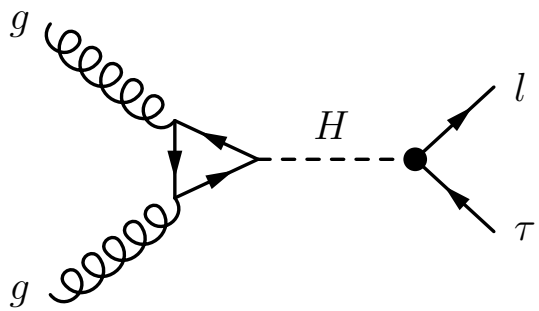

# Higgs couplings to leptons

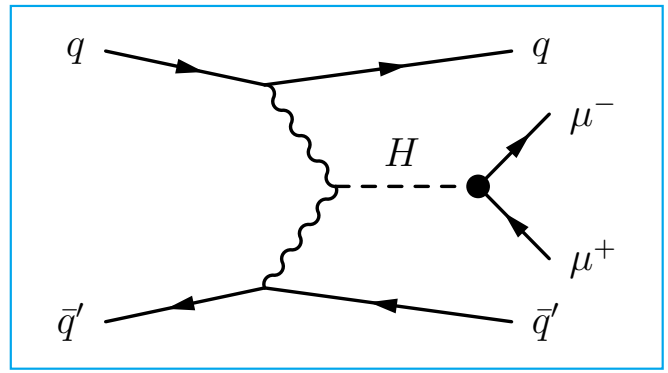
HIG-17-001 search for lepton-flavor violating $H \to \ell\tau$ decays

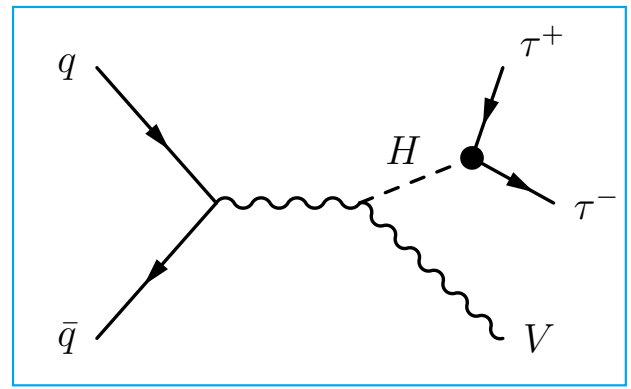
PAS-HIG-17-019 search for $H \to \mu\mu$

HIG-16-043 observation of $H \to \tau\tau$

PAS-HIG-18-007 NEW search for $VH(\to \tau\tau)$ with leptonic $V$ decays

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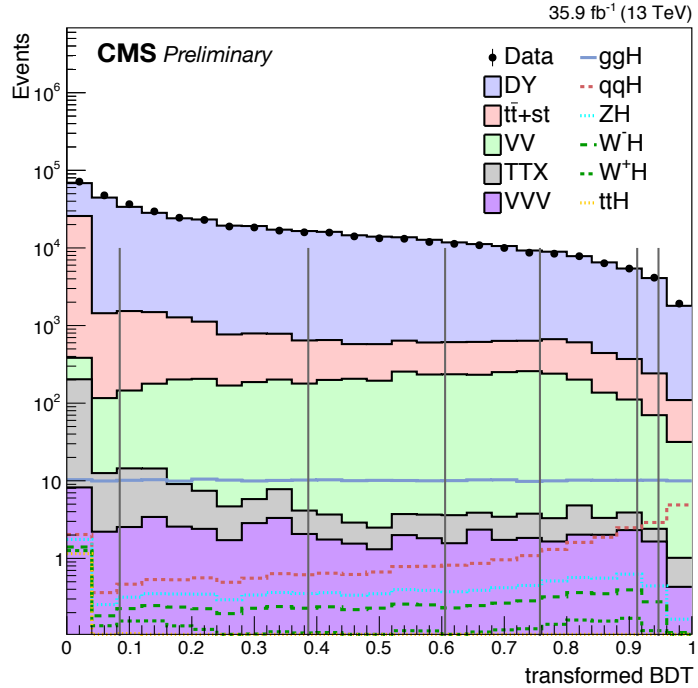
# Search for $H \to \mu\mu$ decays

**PAS-HIG-17-019**

- very rare process $\sigma_{\text{SM}}(H \to \mu\mu) \sim 10$ fb, but clean exp. signature:

  $\mu^{\pm}\mu^{\mp}$ (+ 2 jets, for VBF)

- 15 SR categories defined by BDT discrim.
- signal and bkg modeled with analytical functions and fit to $m_{\mu\mu}$ spectra

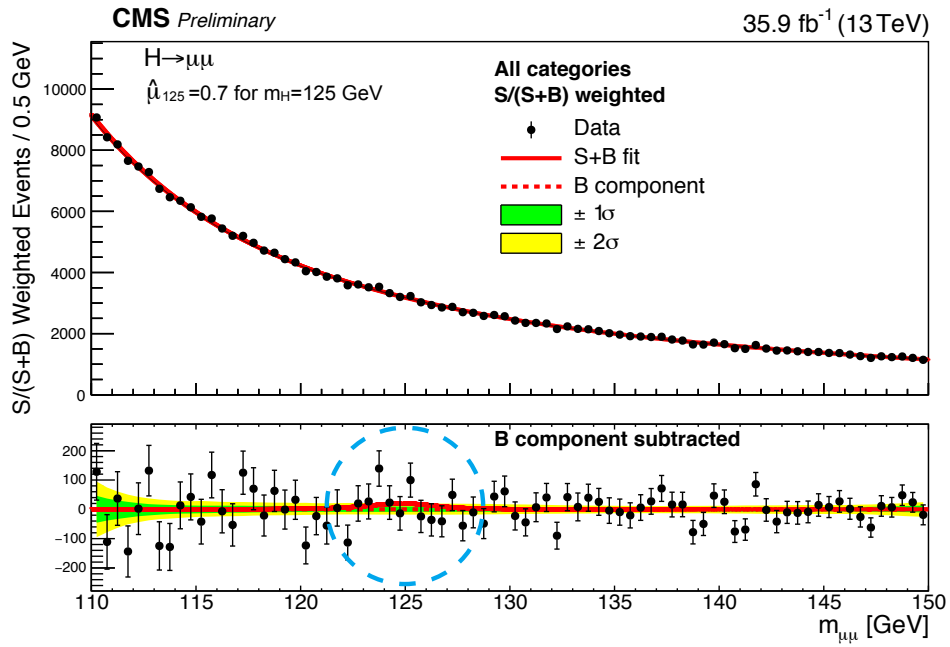



no significant excess observed, but sensitivity approaching SM prediction

Obs. (Exp.) significance: $0.98\sigma$ $(1.09\sigma)$

$95\%$ CL upper limit on $\mu = \sigma/\sigma_{\text{SM}}$:

$\mu < 2.64\,(1.89)$ obs (exp)

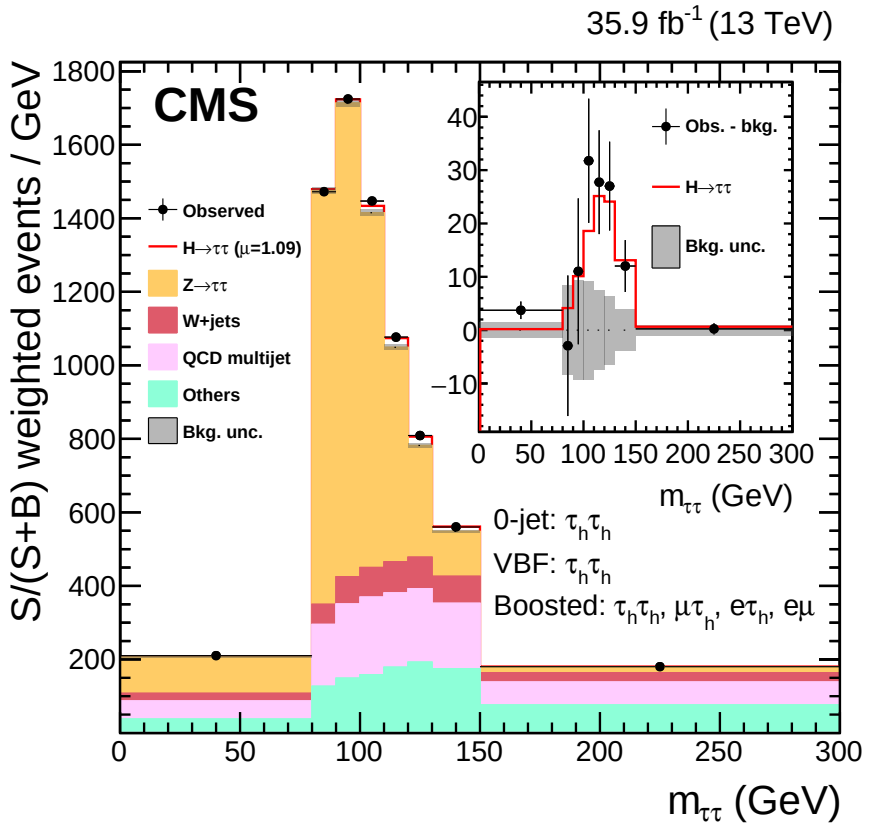


# Observation of $H \to \tau\tau$ decays

**HIG-16-043, Phys. Lett. B 779 (2018) 283**

- $\tau\tau$ channels: $\tau_h\tau_h$, $\mu\tau_h$, $e\tau_h$, $e\mu$
- 3 categories: 0-jet, VBF, boosted
- bkgs data-driven (QCD multi-jet), or from MC+CR-corrections ($Z \to \tau\tau$)
- combined fit to $m_{\tau\tau}$ (or $m_{\text{vis}}$)
  - VBF (boosted): 2D fit in $m_{jj}$ ($p_T^{\tau\tau}$) bins
- excess of events in data around $125$ GeV

best-fit $\mu = 1.09^{+0.27}_{-0.26}$ (Run 2)




Obs (Exp) $H \to \tau\tau$ significance

| | |
|---|---|
| Run-2 | $4.9\sigma$ $(4.7\sigma)$ |

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- 3 categories: 0-jet, VBF, boosted
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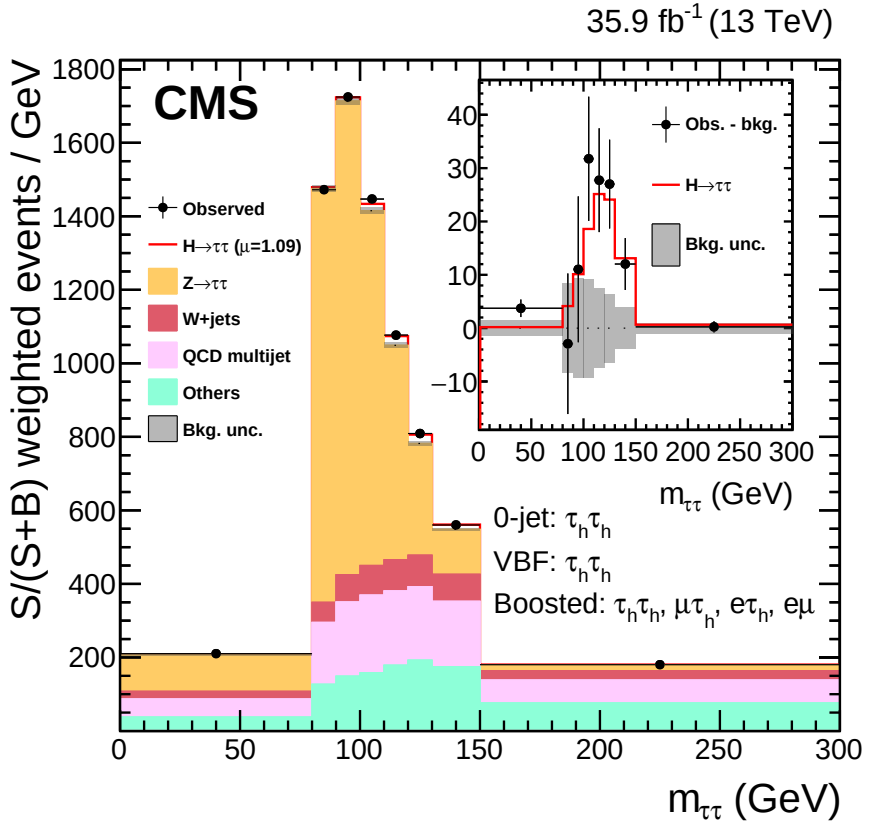
- combined fit to $m_{\tau\tau}$ (or $m_{\text{vis}}$)
  - VBF (boosted): 2D fit in $m_{jj}$ ($p_T^{\tau\tau}$) bins
- excess of events in data around $125$ GeV

best-fit $\mu = 0.98^{+0.18}_{-0.18}$ (Run 1+2)

$\Longrightarrow$ Observation of $H \to \tau\tau$




Obs (Exp) $H \to \tau\tau$ significance

| | |
|---|---|
| Run-2 | $4.9\sigma$ $(4.7\sigma)$ |
| Run-1 + Run-2 | $5.9\sigma$ $(5.9\sigma)$ |

# NEW Search for $VH(\to \tau\tau)$ with $V \to \ell\nu,\ \ell\ell$

**PAS-HIG-18-007**

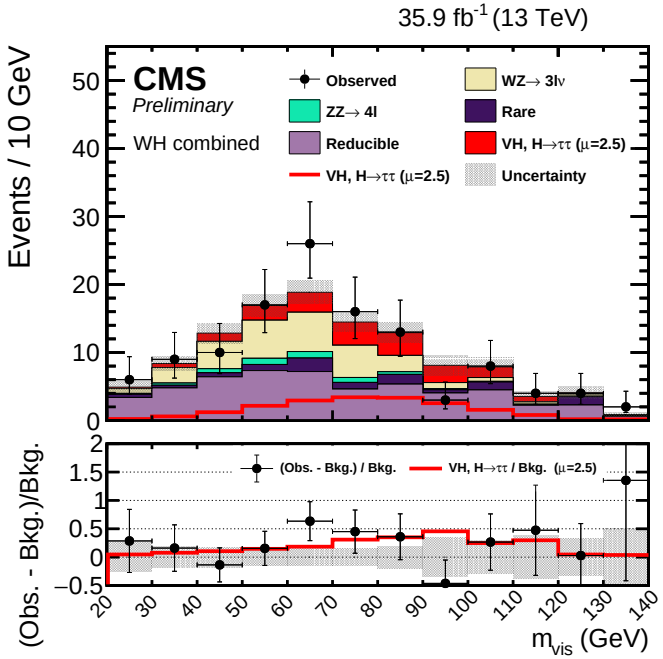
$WH$ channels: $e^{\pm}\mu^{\pm}\tau_{\mathrm{h}},\ \mu^{\pm}\mu^{\pm}\tau_{\mathrm{h}},\ e\tau_{\mathrm{h}}\tau_{\mathrm{h}},\ \mu\tau_{\mathrm{h}}\tau_{\mathrm{h}}$

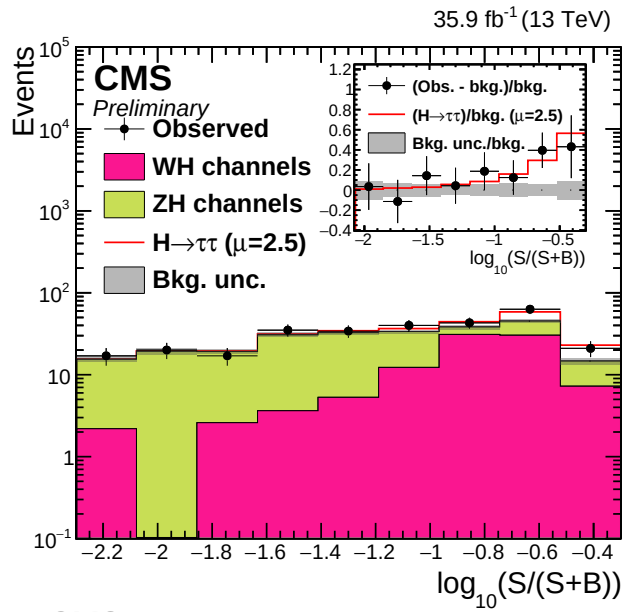
$ZH$ channels: $(ee, \mu\mu) \times (e\mu, e\tau_{\mathrm{h}}, \mu\tau_{\mathrm{h}}, \tau_{\mathrm{h}}\tau_{\mathrm{h}})$

- SM backgrounds:
  - irreducible $WZ, ZZ$ bkgs from simulation
  - jet $\to e, \mu, \tau_{\mathrm{h}}$ fake-rate ($t\bar{t}$, DY) data-driven
- combined fit to $m_{\tau\tau}$ ($ZH$) and $m_{\mathrm{vis}}$ ($WH$)
  - main syst: lepton eff., reducible bkgs

Obs. (Exp.) significance: $2.3\sigma$ $(1.0\sigma)$

Best-fit $\mu = 2.54^{+1.35}_{-1.26}$ (Run-2, VH)



# NEW Search for $VH(\to \tau\tau)$ with $V \to \ell\nu,\ \ell\ell$

**PAS-HIG-18-007**

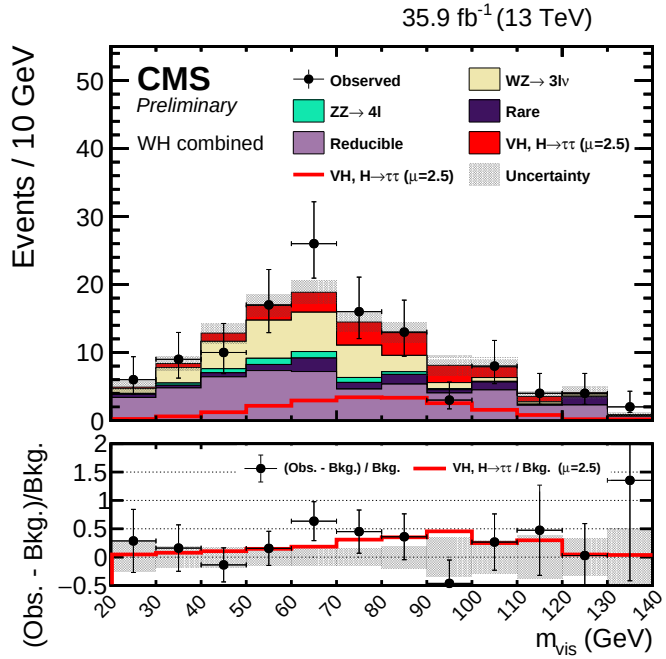
$WH$ channels: $e^{\pm}\mu^{\pm}\tau_h,\ \mu^{\pm}\mu^{\pm}\tau_h,\ e\tau_h\tau_h,\ \mu\tau_h\tau_h$

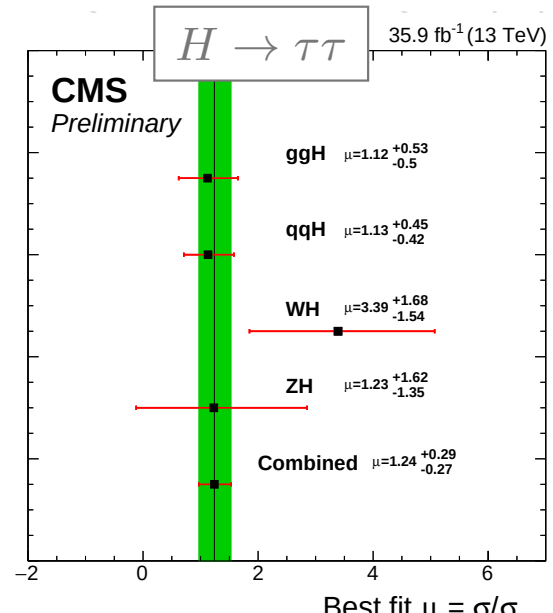
$ZH$ channels: $(ee, \mu\mu) \times (e\mu, e\tau_h, \mu\tau_h, \tau_h\tau_h)$

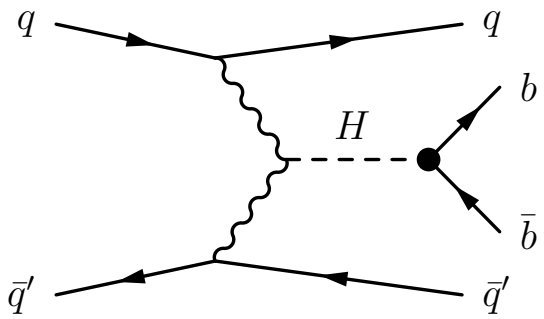
- SM backgrounds:
  - irreducible $WZ, ZZ$ bkgs from simulation
  - jet $\to e, \mu, \tau_h$ fake-rate ($t\bar{t}$, DY) data-driven
- combined fit to $m_{\tau\tau}$ ($ZH$) and $m_{\text{vis}}$ ($WH$)
  - main syst: lepton eff., reducible bkgs

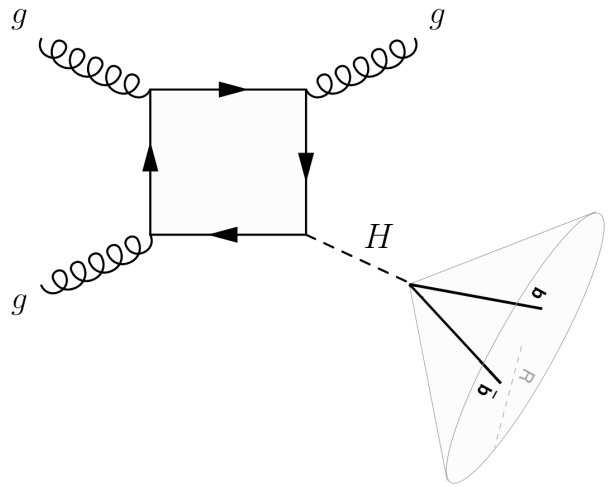
➤ combined with Run-2 $H \to \tau\tau$:

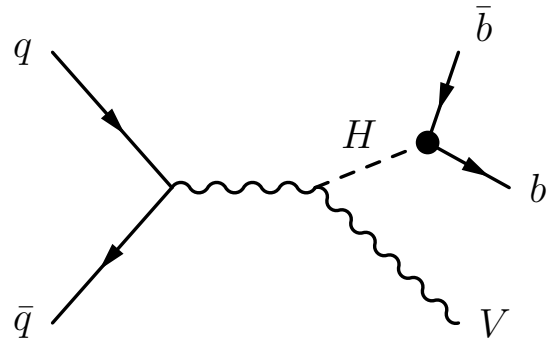
Best-fit $\mu = 1.24^{+0.29}_{-0.27}$ (Run-2, ggF+VBF+VH)





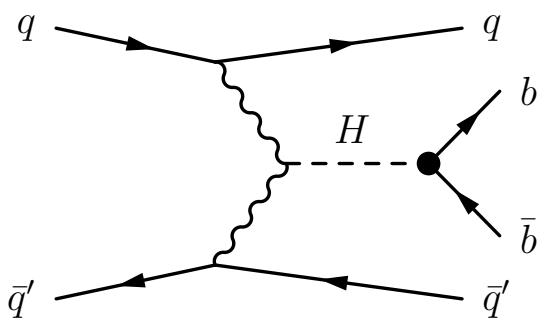



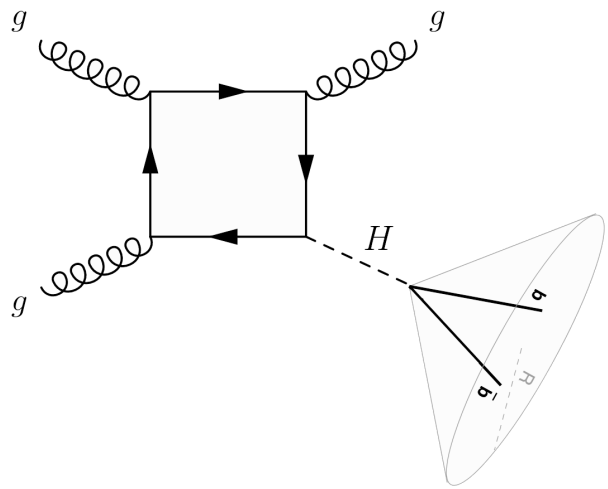

# Higgs coupling to the bottom quark

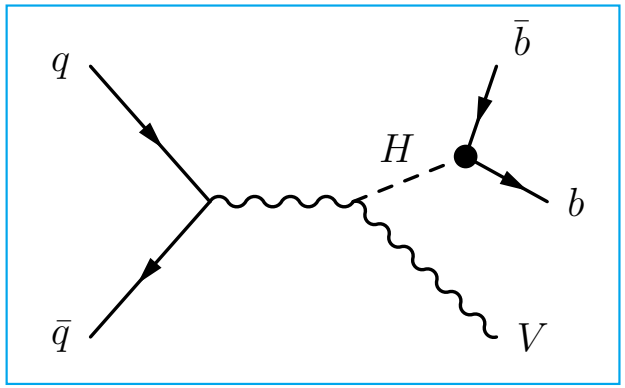
PAS-HIG-16-003 search for $H \to b\bar{b}$ in VBF production

HIG-17-010 search for boosted $gg \to H \to b\bar{b}$

HIG-16-044 evidence of $VH(\to b\bar{b})$

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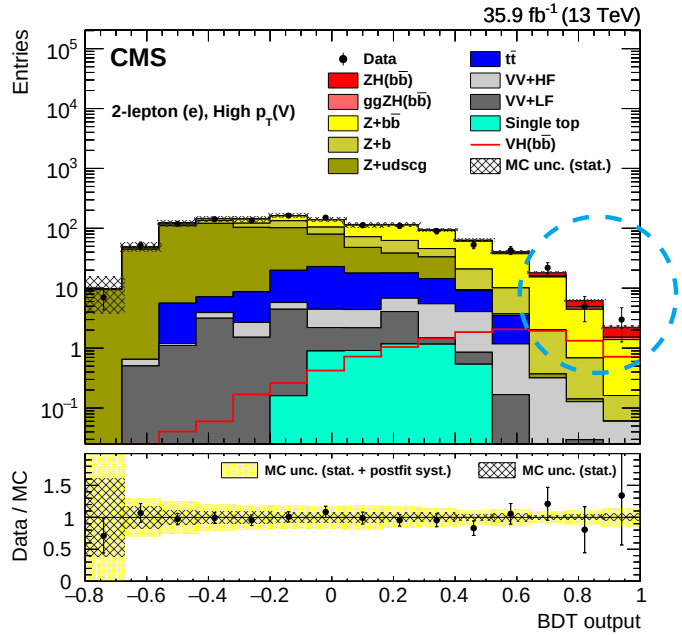
HIG-16-044 evidence of $VH(\to b\bar{b})$

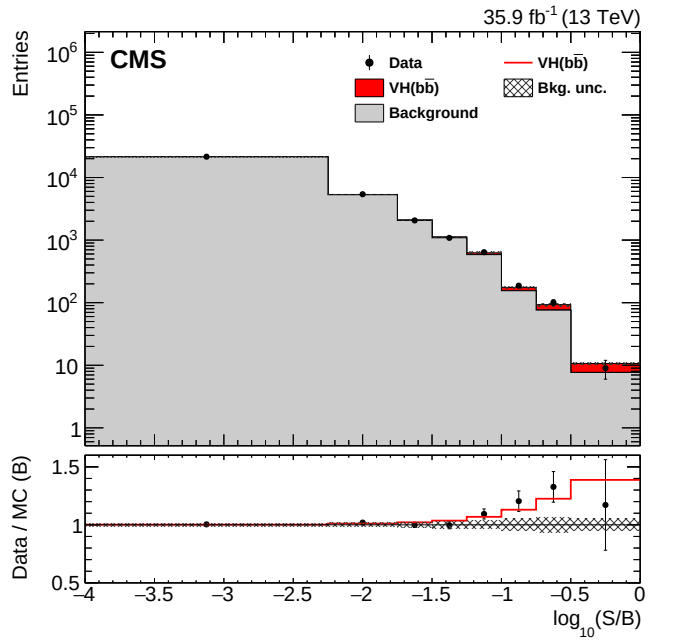
# Evidence of $VH(\to b\bar{b})$ production

**HIG-16-044, Phys. Lett. B 780 (2018) 501**

- $H(b\bar{b})$ in association with $W, Z$ boson
  - leptonic $V$ decays: $0\ell$ ($\nu\nu$), $1\ell$ ($\ell\nu$), $2\ell$ ($\ell\ell$)
  - main bkgs: $V$ + light-f, $V$ + heavy-f, $t\bar{t}$
  - high-$p_T(V)$ cut to suppress bkgs
- combined fit to BDT discriminators in SRs + dedicated CRs for DY and $t\bar{t}$
  - bkgs from MC with free-floating norm.
  - main syst: $V$ + lf/hf norm., MC modeling

| Data used | Significance expected | Significance observed | Signal strength observed |
|---|---|---|---|
| Run 1 | 2.5 | 2.1 | $0.89^{+0.44}_{-0.42}$ |
| Run 2 | 2.8 | 3.3 | $1.19^{+0.40}_{-0.38}$ |
| Combined | 3.8 | 3.8 | $1.06^{+0.31}_{-0.29}$ |



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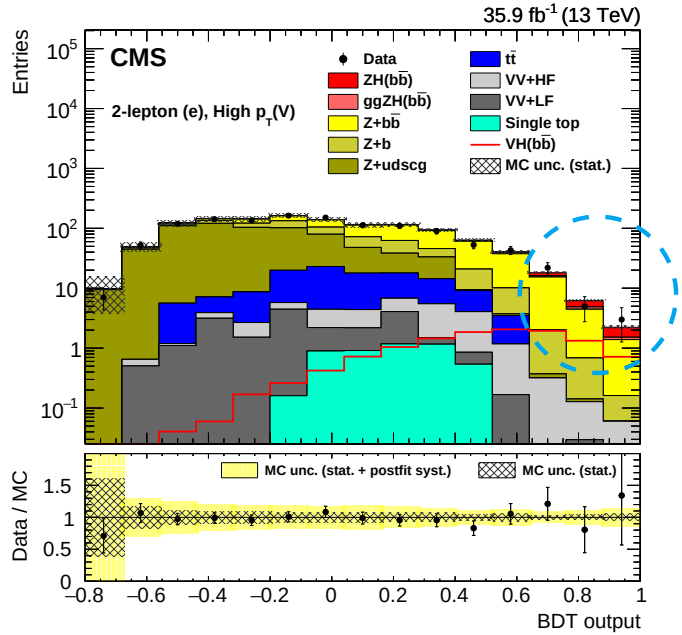


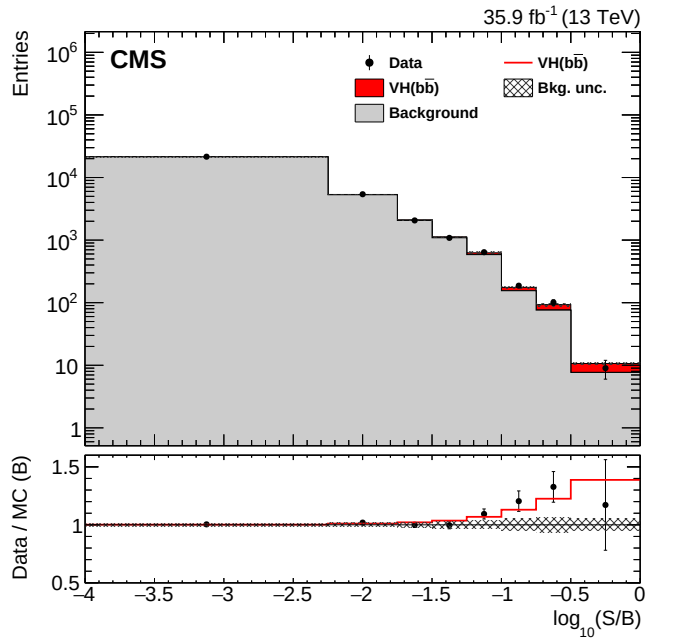

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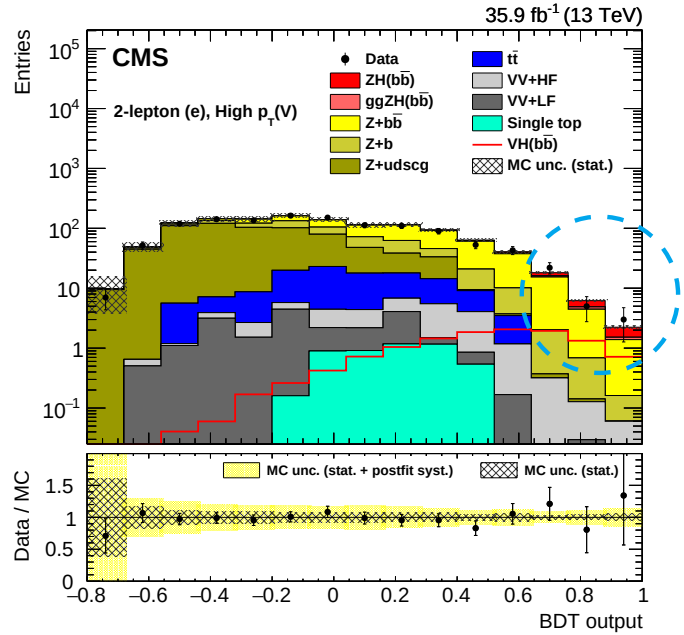
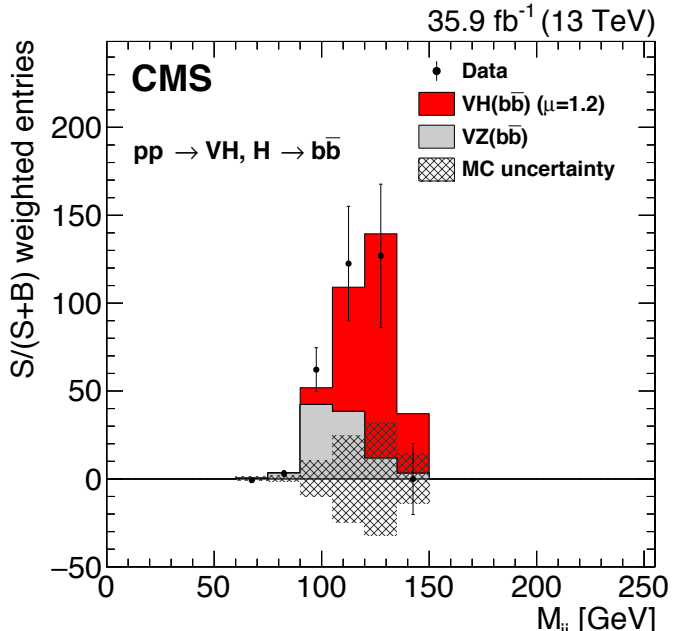
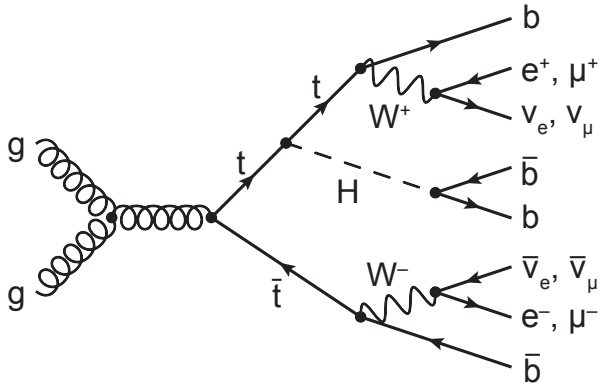
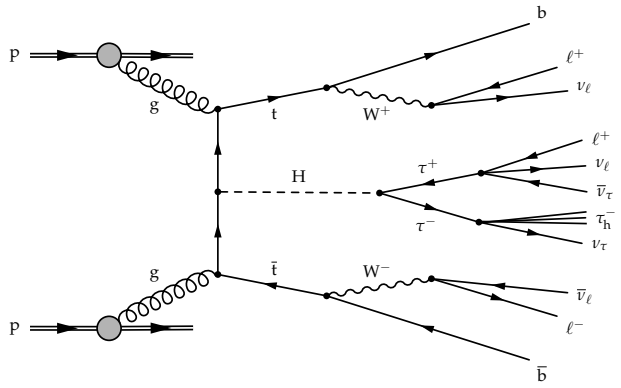
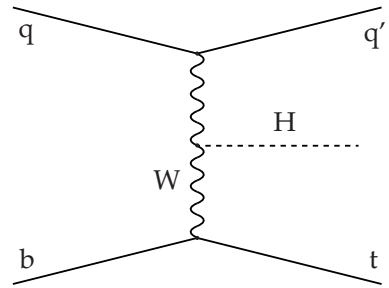





# Higgs coupling to the top quark

PAS-HIG-17-005 search for $tH$ in multilepton final states

PAS-HIG-17-016 NEW search for $tH$ with $H \to b\bar{b}$

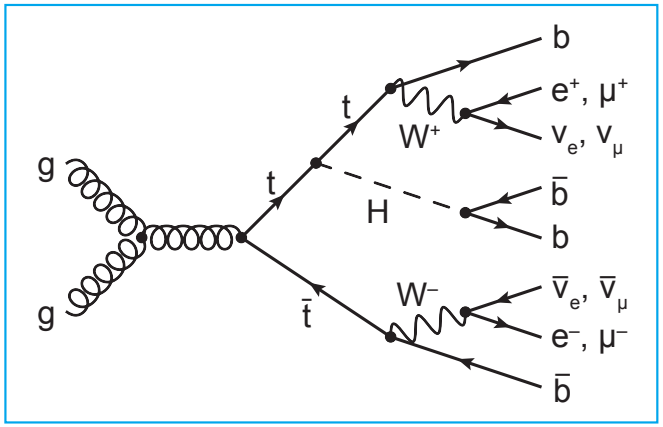
HIG-17-018 evidence of $t\bar{t}H$ in multilepton final states

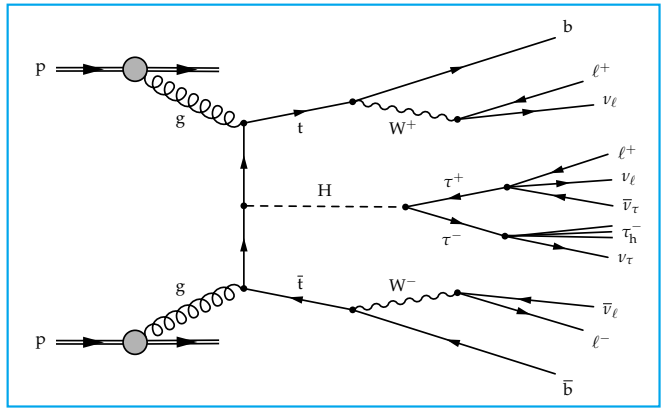
HIG-17-026 search for $t\bar{t}H(\to b\bar{b})$ with leptonic top decays

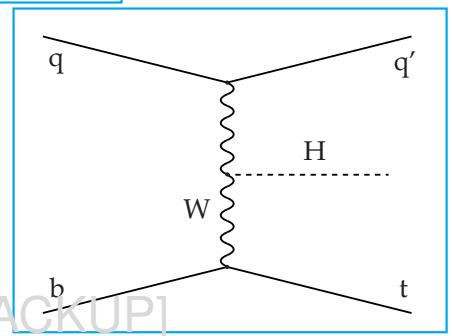
HIG-17-022 search for $t\bar{t}H(\to b\bar{b})$ in all-jet final states

HIG-17-035 combination of $t\bar{t}H$ searches at CMS

see talk by D. Salerno




# Higgs coupling to the top quark

PAS-HIG-17-005 search for $tH$ in multilepton final states [BACKUP]

PAS-HIG-17-016 NEW search for $tH$ with $H \to b\bar{b}$

HIG-17-018 evidence of $t\bar{t}H$ in multilepton final states

HIG-17-026 search for $t\bar{t}H(\to b\bar{b})$ with leptonic top decays

HIG-17-022 search for $t\bar{t}H(\to b\bar{b})$ in all-jet final states [BACKUP]

HIG-17-035 combination of $t\bar{t}H$ searches at CMS

see talk by D. Salerno

# NEW Search for $tHq$ and $tHW$ with $H \to b\bar{b}$

**PAS-HIG-17-016**

- $tH$ sensitive to sign of top-Higgs coupling

  $1\ell$ + MET + $\geqslant 3$ b-jets + 1 forward-jet

- BDT for jet-parton assignment under $tHq$, $tHW$ and $t\bar{t}$ hypotheses

- BDTs as final discriminators:

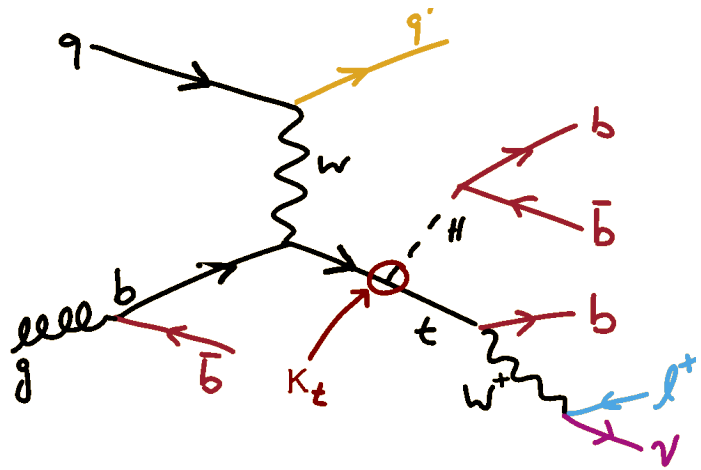
  **3b** and **4b** SRs $tH$ vs. $t\bar{t}$

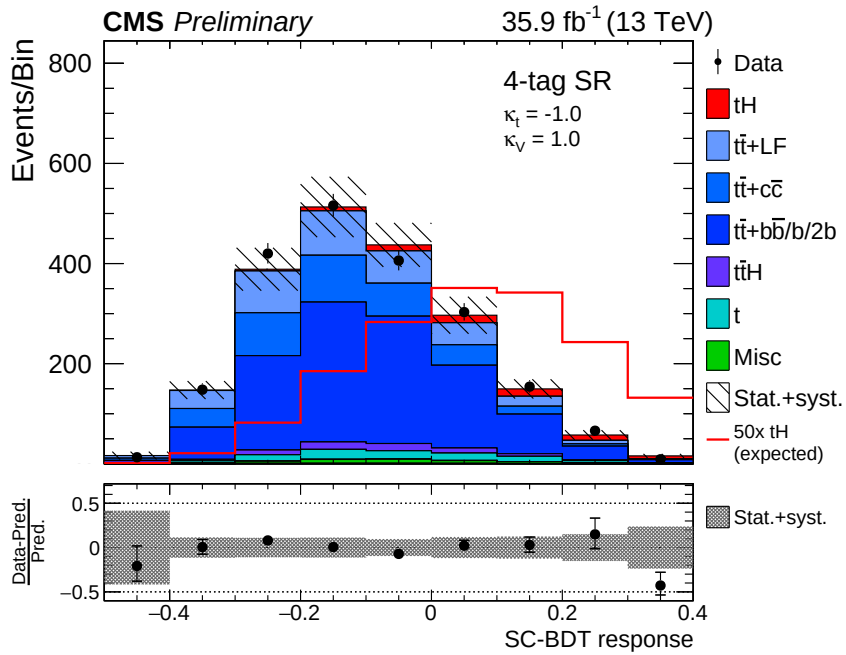
  $2\ell$ category $t\bar{t}+$ light vs. $t\bar{t}+$ hf

- main sys: $t\bar{t}+$ hf modeling, b-tagging eff.

- limits on $\mu_{tH(+t\bar{t}H)}$ as func. of $\kappa_t$ and $\kappa_V$

| | |
|---|---|
| $tH$-only $[\kappa_t = +1]$ | $\mu_{95\%} < 89.5\,(41.4)$ obs. (exp.) |
| $tH$-only $[\kappa_t = -1]$ | $\mu_{95\%} < 5.83\,(2.94)$ obs. (exp.) |



# Search for $t\bar{t}H(\to b\bar{b})$ with leptonic top decays

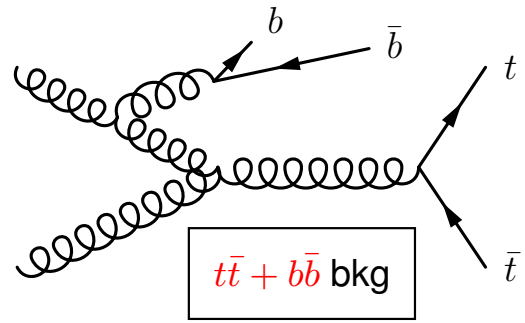
**HIG-17-026, submitted to JHEP**

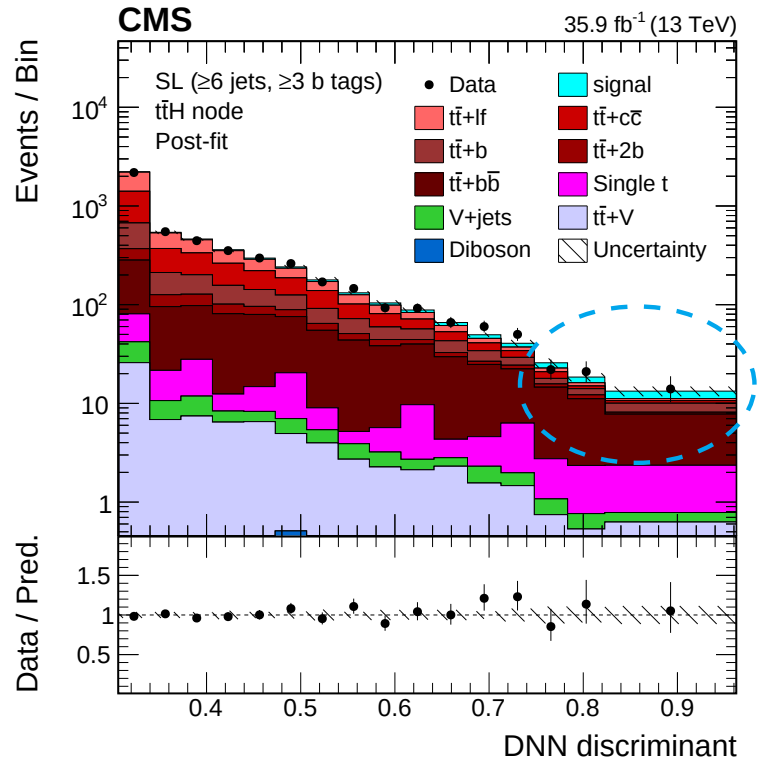
- $(1\ell$ or $\ell^{\pm}\ell^{\mp}) + \geq 4$ jets and $\geq 3$ b-jets
- dominant bkg: $t\bar{t}$ (+ heavy flavor: $c\bar{c}$, $b$, $b\bar{b}$)
  - bkgs from simulation with large prior unc.
- jet combinatorics hinders $H \to b\bar{b}$ reco

  $\Longrightarrow$ MVA methods for final discriminant

  $\ell$ + jets: multi-class Deep Neural Network

  dilepton: (BDT, MEM) 2D dist.
- main sys: $t\bar{t}$ + hf modeling, b-tagging eff.



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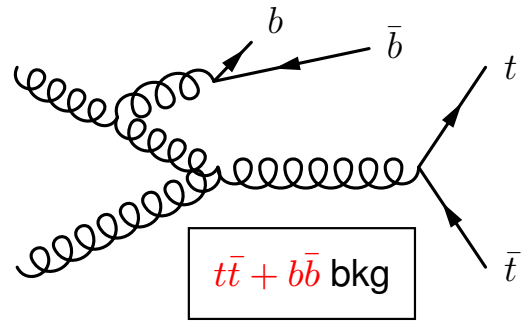


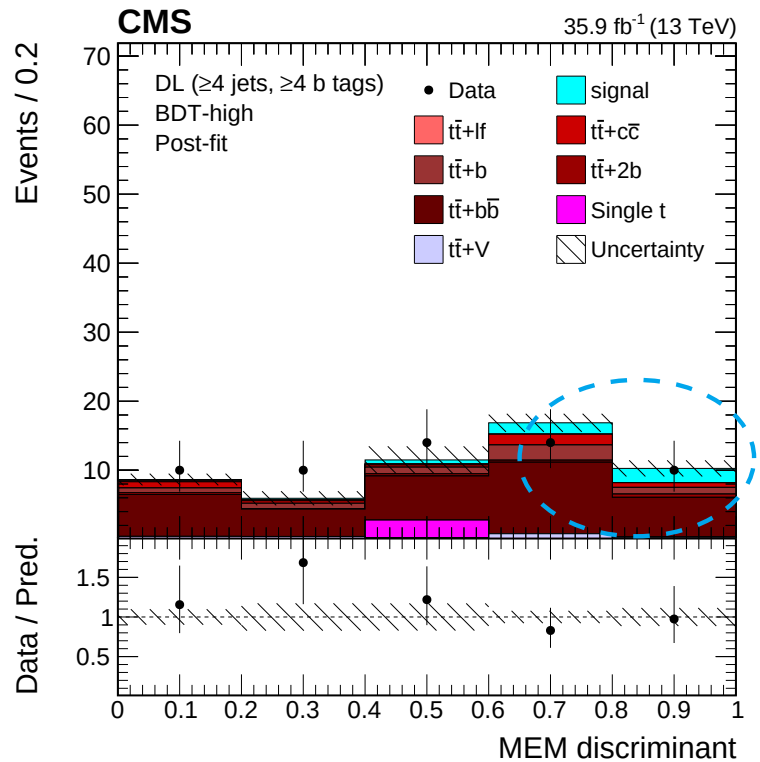

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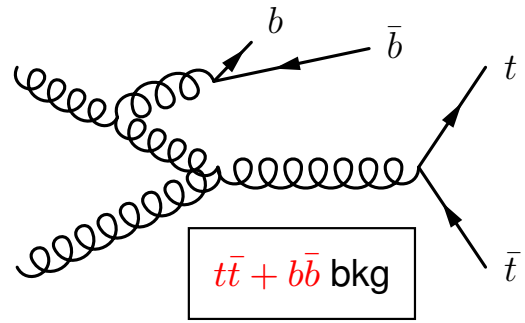
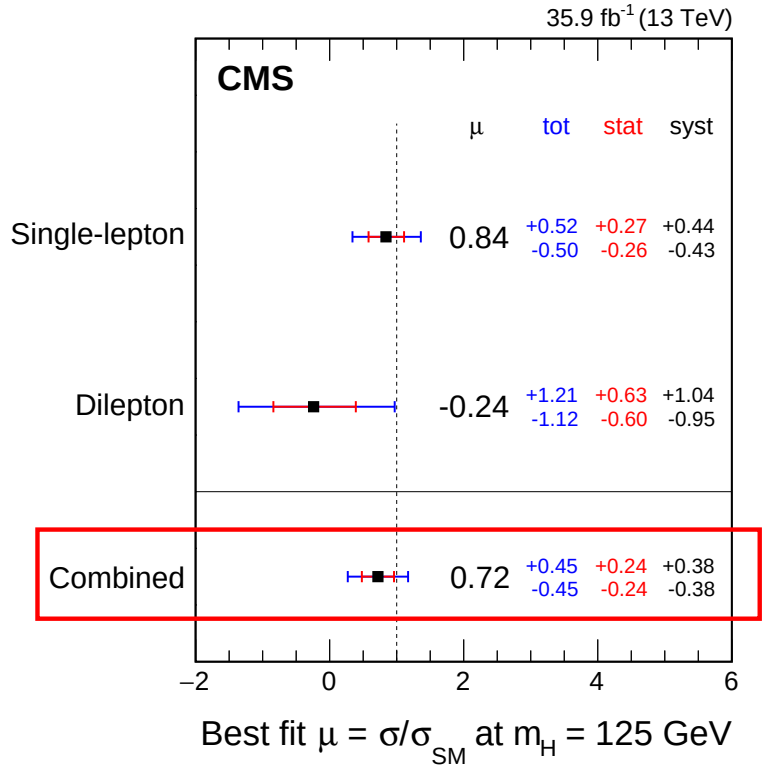
Obs. (Exp.) significance: $1.6\sigma$ $(2.2\sigma)$



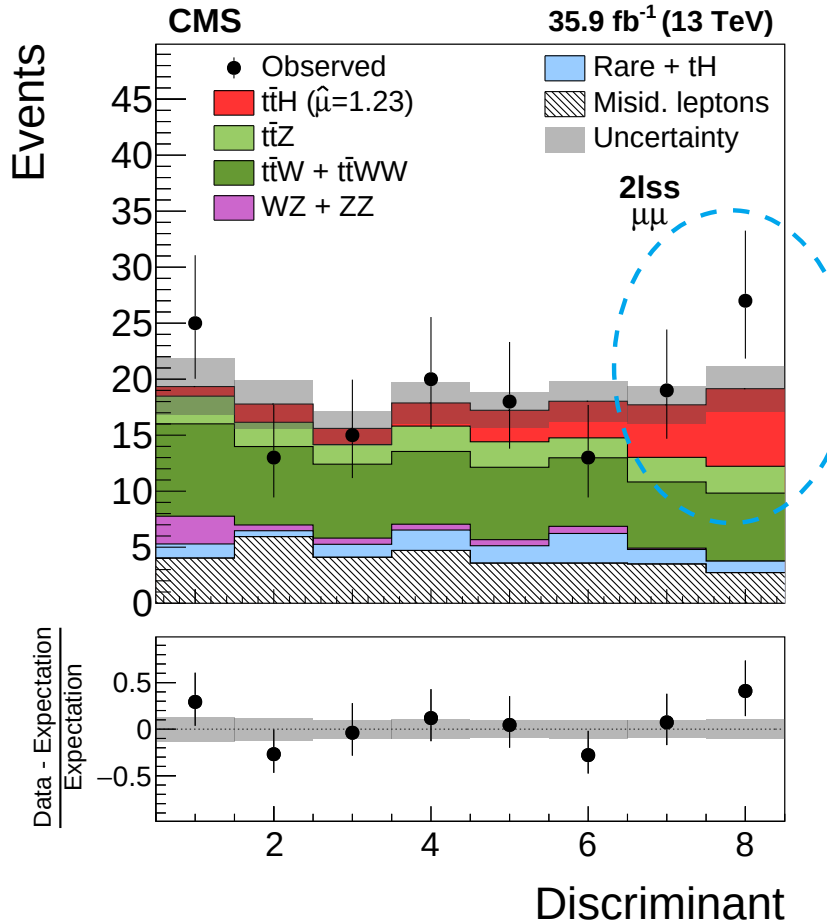
# Evidence of $t\bar{t}H$ in multilepton final states

**HIG-17-018, submitted to JHEP**

- targets $H$ decays to $WW^*$, $ZZ^*$, $\tau\tau$

| $1\ell{+}2\tau_h$ | $2\ell$ SS $(+\tau_h)$ | $3\ell(+\tau_h)$ | $4\ell$ |
|---|---|---|---|

- extensive use of MVA techniques:
  - lepton-ID, final discriminants (BDT, MEM)
- bkgs: $t\bar{t}V$, $VV$ (MC+CR), fake-$\ell$ (data-dr.)
- main systematics: lepton $\varepsilon$, fake-$\ell$ bkg



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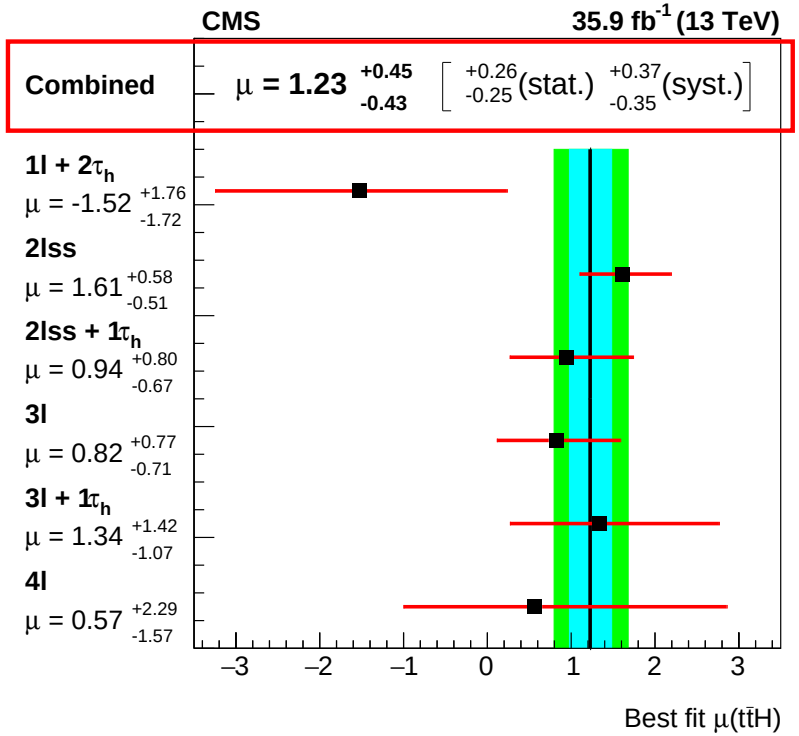
Obs. (Exp.) significance: $3.2\sigma$ $(2.8\sigma)$

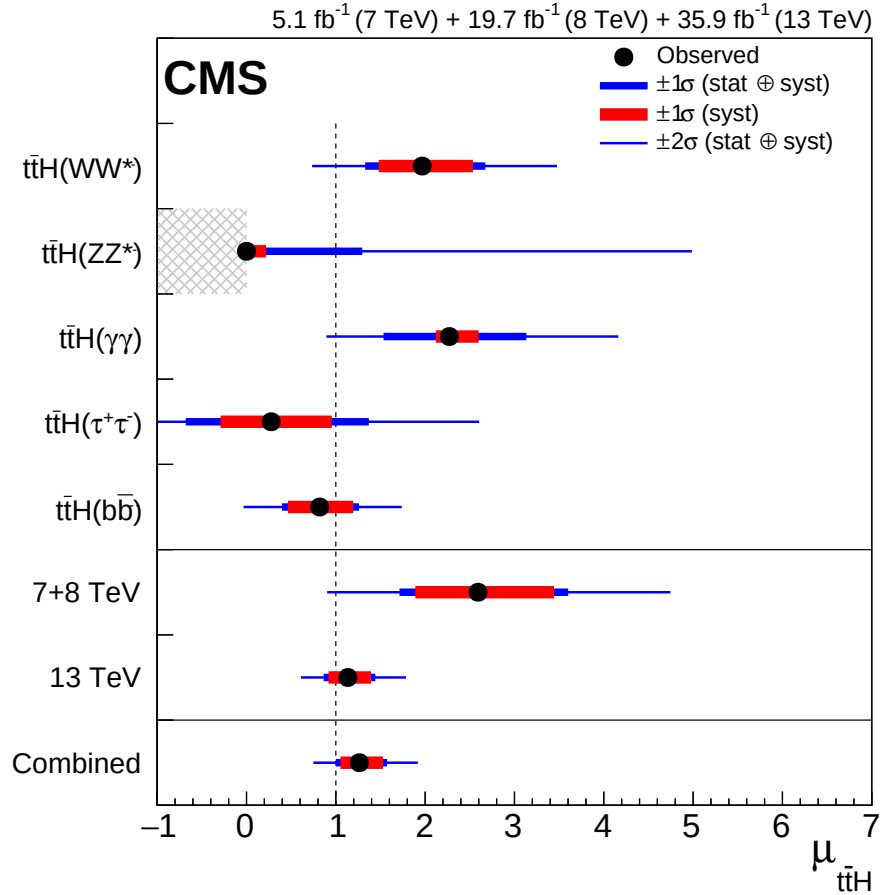
$\Longrightarrow$ Evidence of $t\bar{t}H \rightarrow$ multilepton



# First LHC $t\bar{t}H$ observation

**HIG-17-035, accepted by PRL**

- CMS combination of all $t\bar{t}H$ searches in Run-1 and Run-2
  - multilepton and $b\bar{b}$: $\Delta\mu^{\text{syst}} > \Delta\mu^{\text{stat}}$
  - $\gamma\gamma$ and $ZZ^*$: limited by stats



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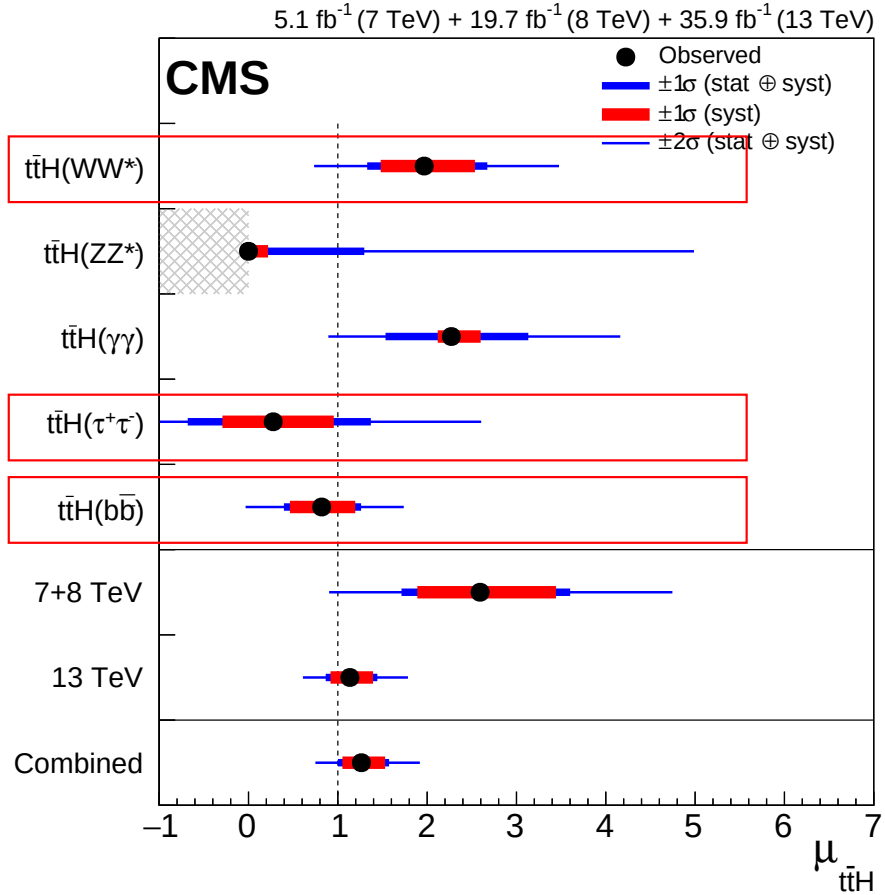

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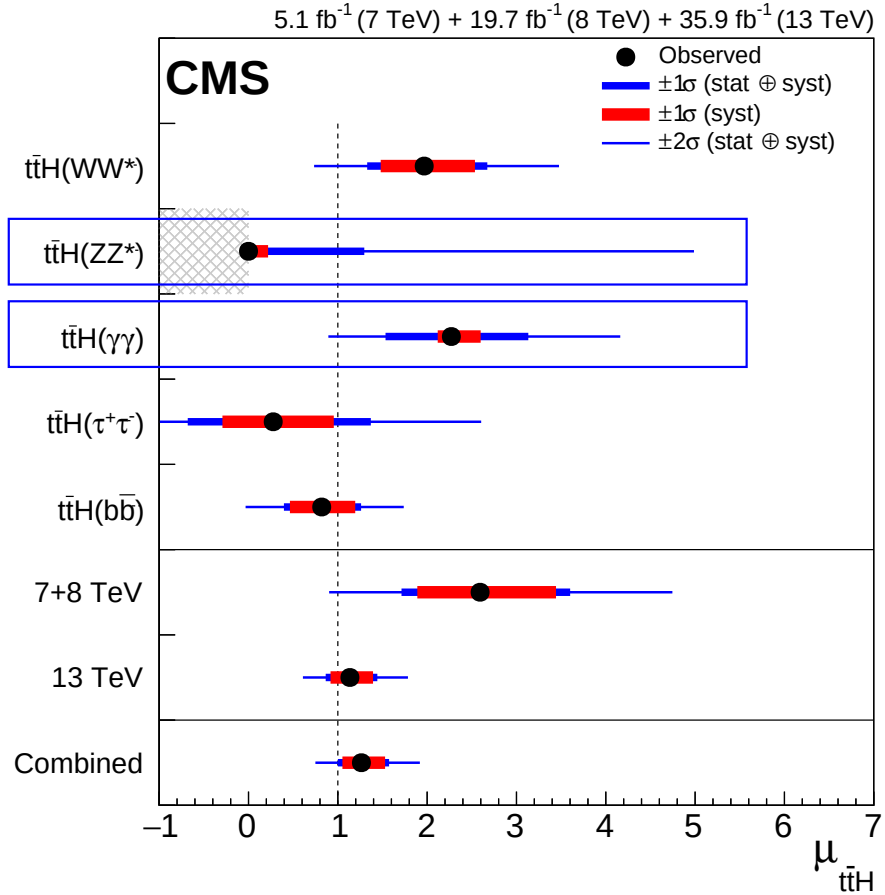

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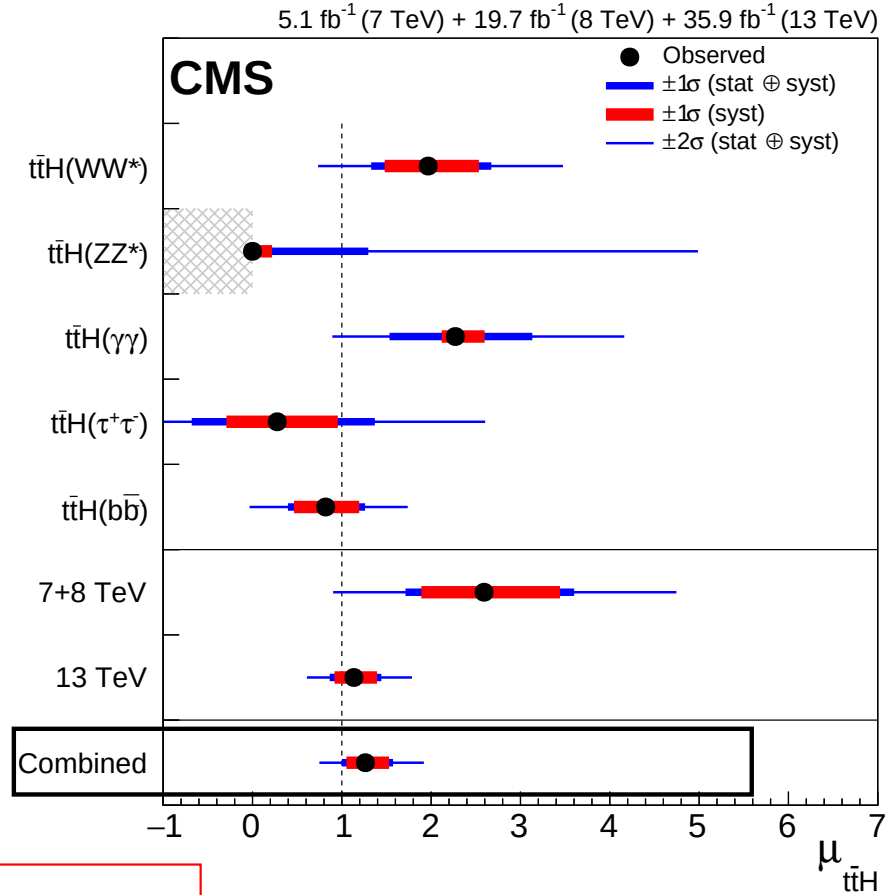
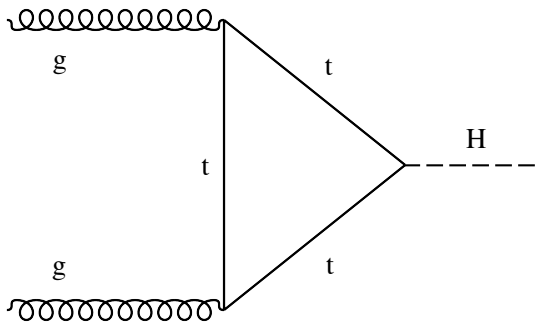
| Parameter | Best fit | Uncertainty Stat | Expt | Thbgd | Thsig |
|---|---|---|---|---|---|
| $\mu_{t\bar{t}H}$ | $1.26^{+0.31}_{-0.26}$ $\left(^{+0.28}_{-0.25}\right)$ | $^{+0.16}_{-0.16}$ $\left(^{+0.15}_{-0.15}\right)$ | $^{+0.17}_{-0.15}$ $\left(^{+0.16}_{-0.15}\right)$ | $^{+0.14}_{-0.13}$ $\left(^{+0.13}_{-0.12}\right)$ | $^{+0.15}_{-0.07}$ $\left(^{+0.11}_{-0.05}\right)$ |

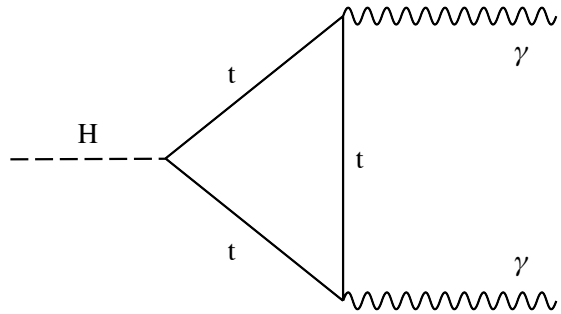
Obs. (Exp.) significance: $5.2\sigma$ $(4.2\sigma)$

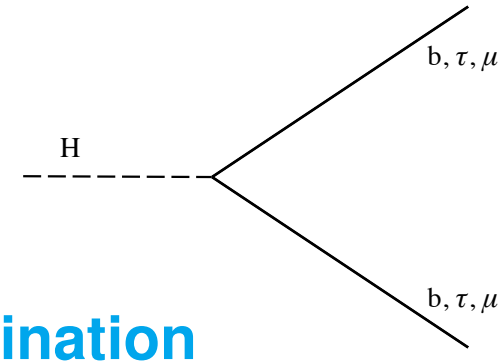



- observation of $t\bar{t}H$ production
- $\mu_{t\bar{t}H}$ in agreement with SM

$\Delta\mu_{t\bar{t}H} \sim 23\%$




# A look at Yukawa couplings in Higgs combination

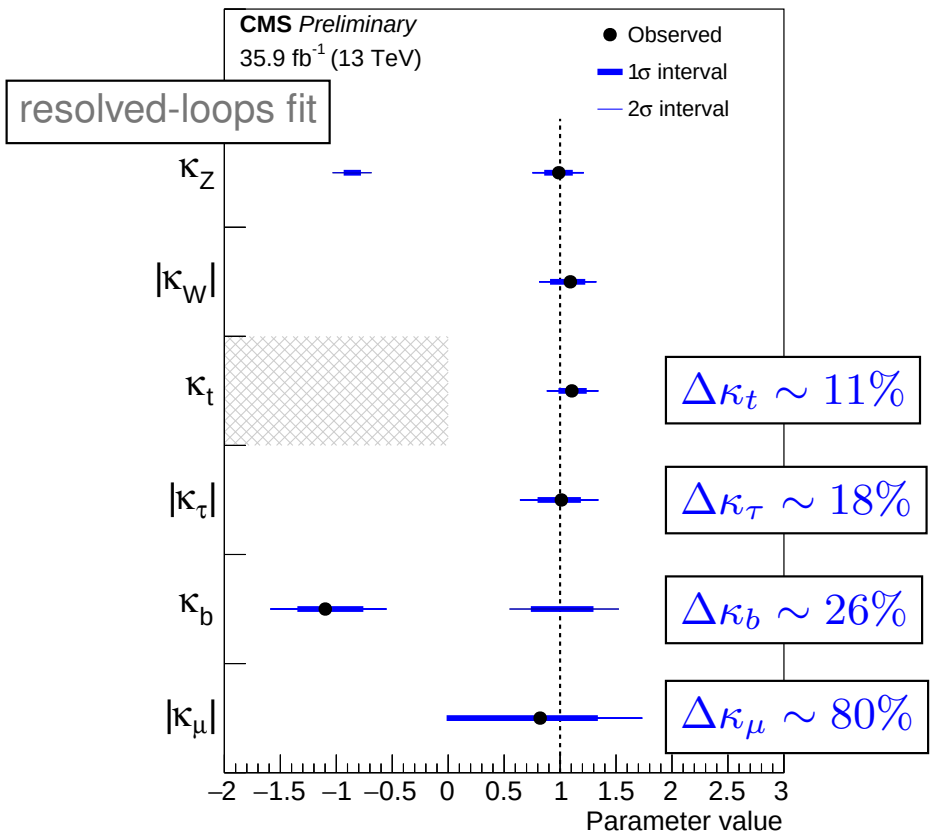
PAS-HIG-17-031 Combined measurements of Higgs boson couplings in $pp$ collisions at $\sqrt{s} = 13$ TeV

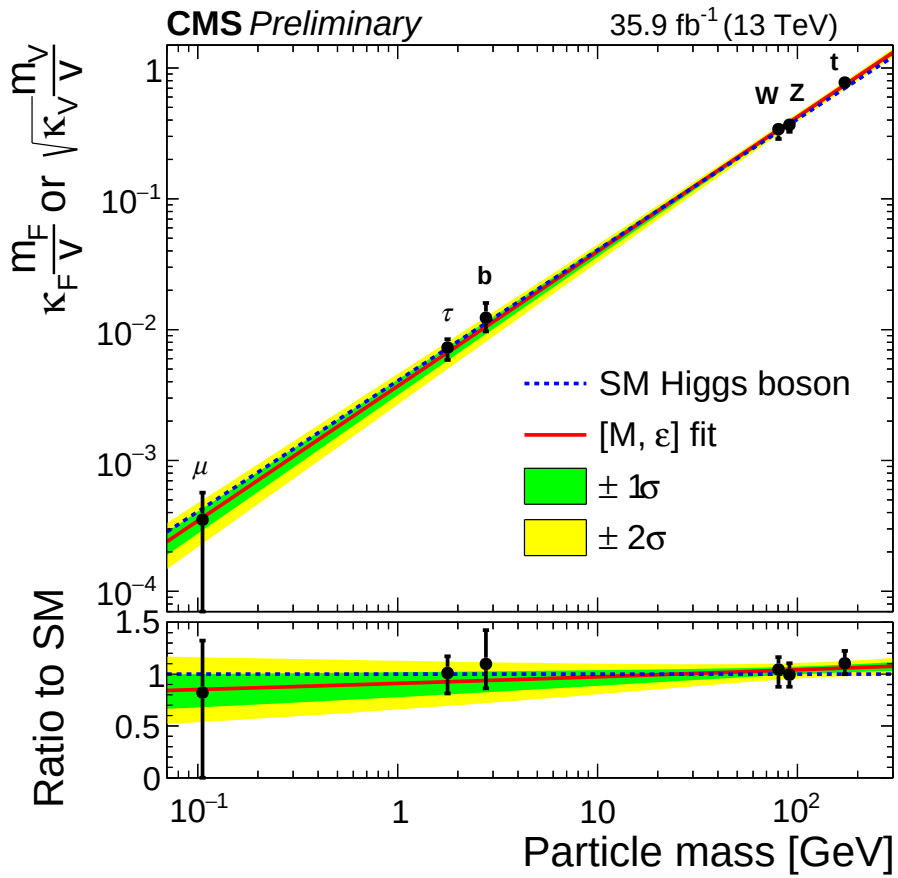
see talk by T. Strebler

# Yukawa couplings in combined Higgs analyses

**PAS-HIG-17-031**

- combined measurements of Higgs boson couplings with Run-2 data
- showing only fit assuming SM expr. for ggF and $H(\gamma\gamma)$ loops
- focus on Higgs-fermion couplings



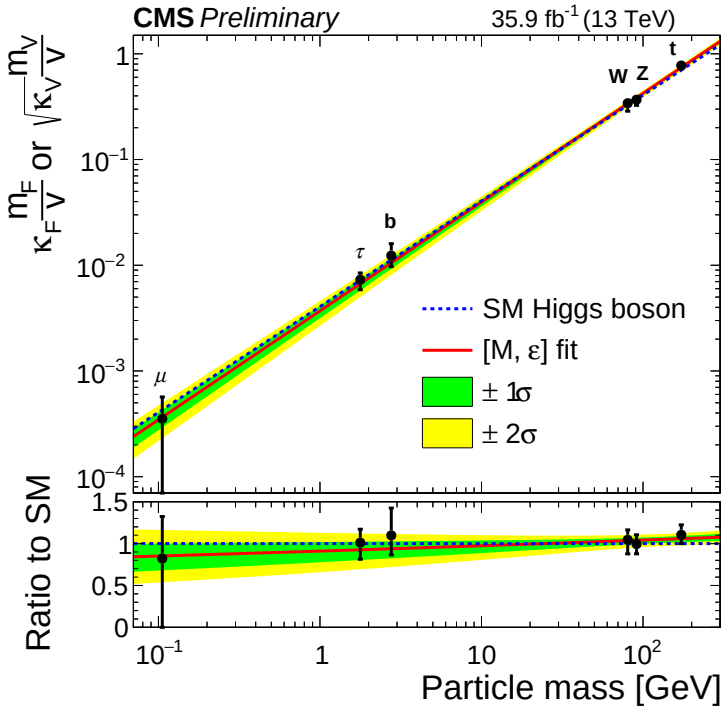



# Summary

- measurements of Higgs Yukawa couplings crucial test of the SM

- wide range of results produced by CMS:
  - best upper limit on $\sigma(H \to \mu\mu)$
  - observation of $H \to \tau\tau$
  - evidence of $VH(\to b\bar{b})$
  - observation of $t\bar{t}H$ production

- no significant deviations from SM

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- already looking at **2017** data (e.g. HIG-18-001) and **2018** data-taking underway
- new and updated results to be expected in the months ahead

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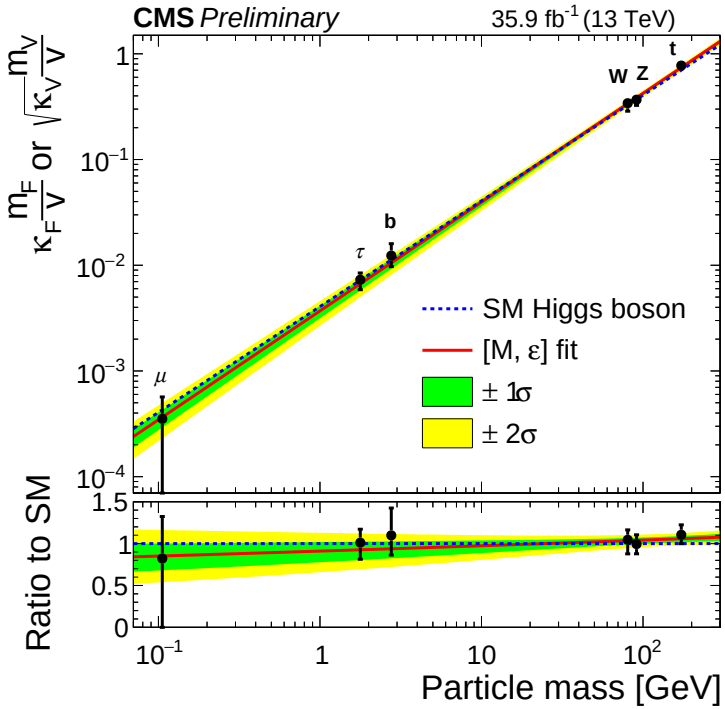


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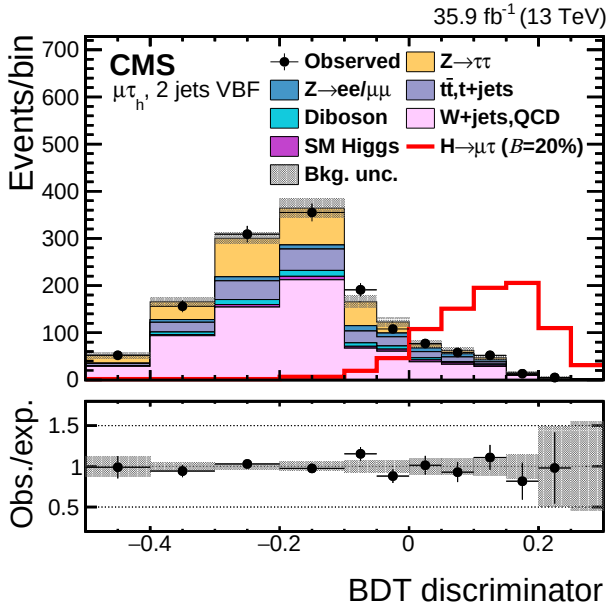
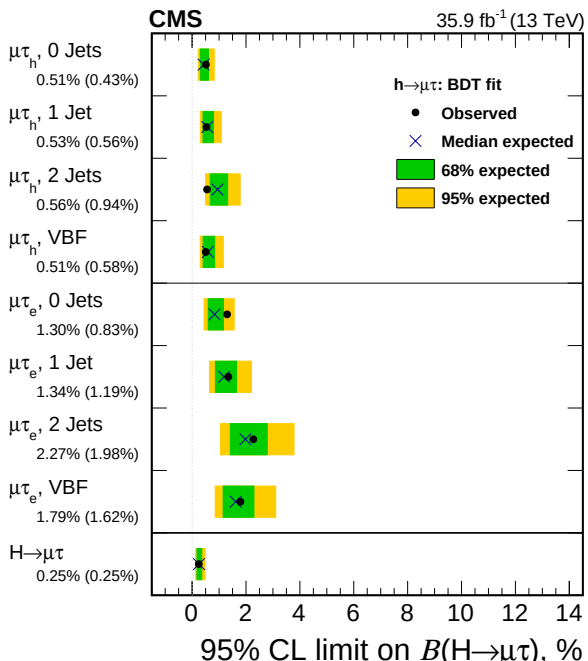
# BACKUP

# Search for lepton-flavor violating $H \to \ell\tau$ decays

**HIG-17-001, accepted by JHEP**

- off-diagonal Yukawa couplings
  expected to be zero in SM
- 4 channels: $e\tau_\mu$, $e\tau_\mathrm{h}$, $\mu\tau_e$, $\mu\tau_\mathrm{h}$
- DY from MC, $W$ and multi-jet data-driven
- BDT discriminant for final fit to data
  - sensitivity limited by systematics
- no significant excess observed
- Obs (Exp) $95\%$ CL limit on $\mathrm{BR}_{\ell\tau}$:
  - $\mathrm{BR}(H \to \mu\tau) < 0.25\%\,(0.25\%)$
  - $\mathrm{BR}(H \to e\tau) < 0.61\%\,(0.37\%)$



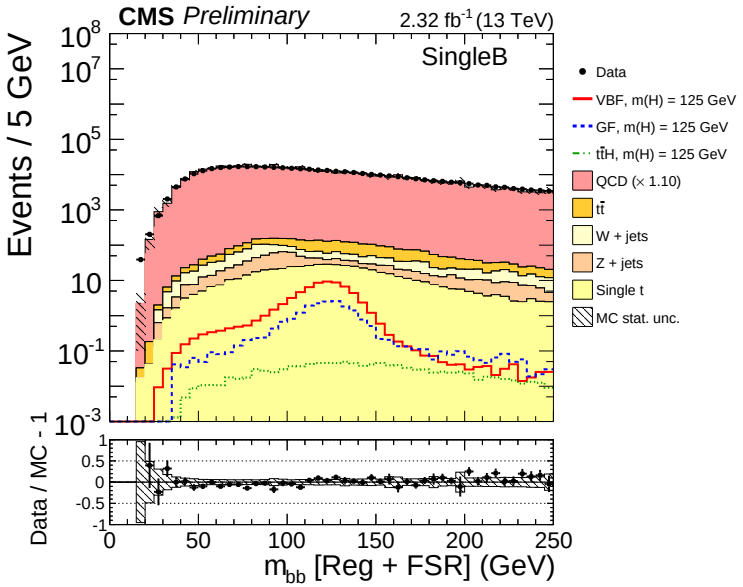



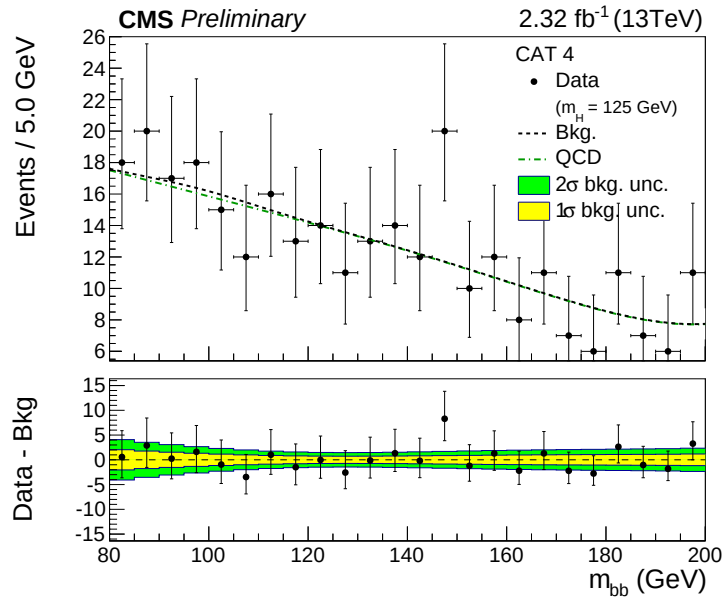
# Search for $H \to b\bar{b}$ in VBF production

**PAS-HIG-16-003**

- events with $\geqslant 4$ jets and $\geqslant 1$ b-jet
- dedicated triggers requiring b-jet(s) and dijet with large $\Delta\eta_{jj}$ and $m_{jj}$
- b-energy regr. to improve $m_{b\bar{b}}$ resolution
- unbinned fit to $m_{b\bar{b}}$ in 7 SR categories
- sensitivity limited by stats (only $2.3\ \mathrm{fb}^{-1}$)
  - main sys. unc. from QCD bkg modeling
- combined with Run-1 search:

Obs. (Exp.) upper limit: $\mu_{95\%} < 3.4\,(2.3)$

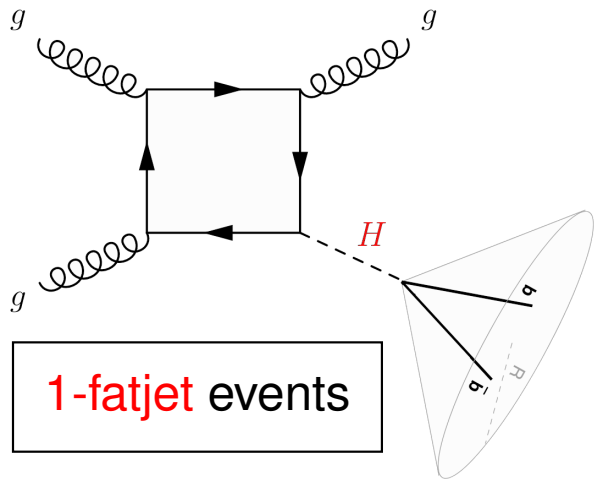


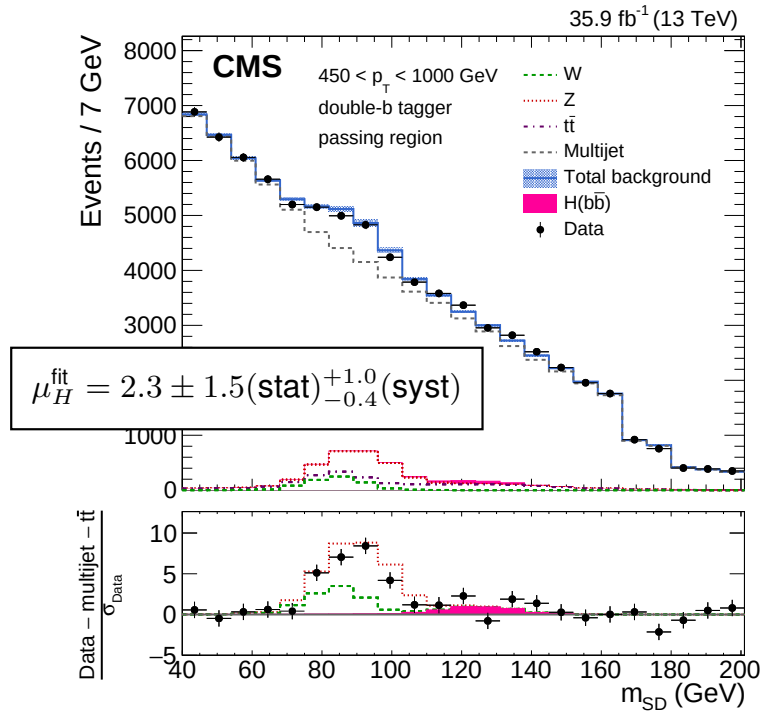
# Search for boosted $gg \to H \to b\bar{b}$ production

**HIG-17-010, Phys. Rev. Lett. 120 (2018) 071802**

- boosted $H(b\bar{b})$ recoiling against ISR jet
- inclusive search for $H \to b\bar{b}$
  made possible at the LHC using
  b-tagging and jet substructure techniques
- search in fatjet mass (6 $p_T$ categories)
  - data-driven method for QCD multi-jet bkg
  - $W/Z \to q\bar{q}$ to constrain jet-related sys




1-fatjet events




Obs. (Exp.) upper limit: $\mu_{95\%} < 5.8\,(3.3)$

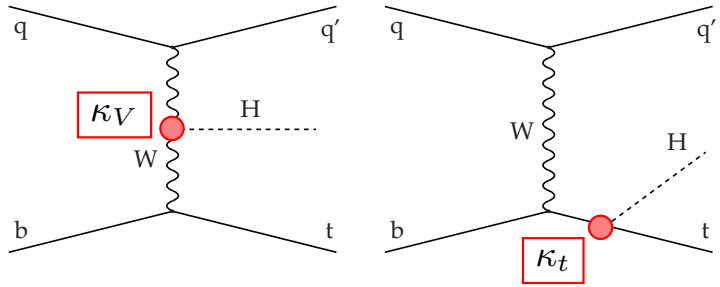
$H(b\bar{b})$ significance: obs. $1.5\sigma$ (exp. $0.7\sigma$)

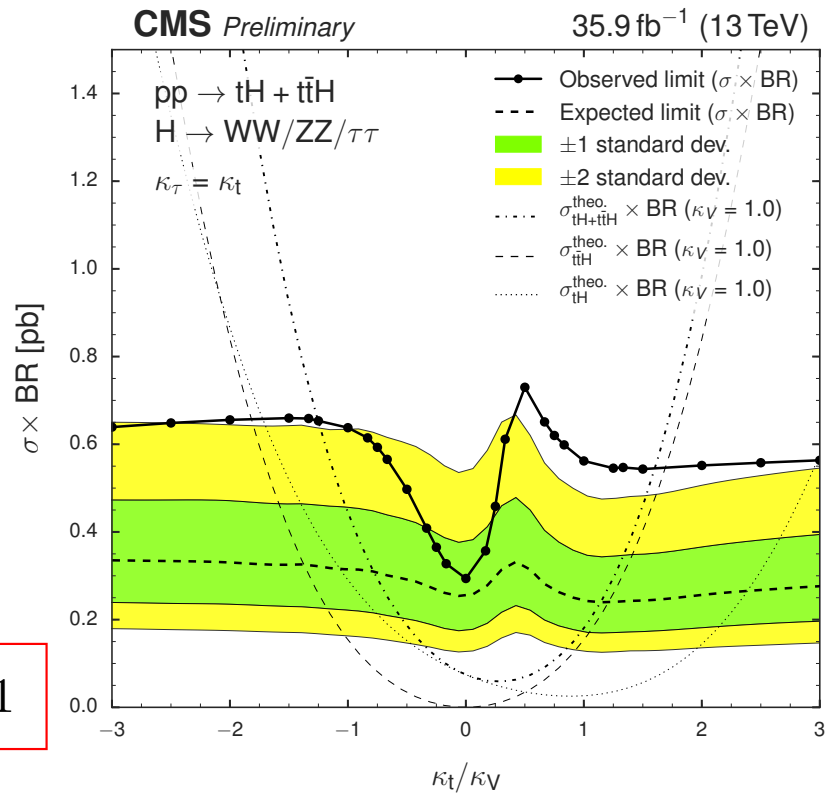
# Search for $tHq$ in multilepton final states

**PAS-HIG-17-005**

- $tH$ sensitive to sign of top-Higgs coupling
- (SS $2\ell$ or $3\ell$) + 1 b-jet + 1 forward-jet
- methods similar to $t\bar{t}H$ multilepton
  - lepton ID, bkg modeling, MVA discrim.
- sensitivity limited by systematics
  - lepton eff., bkg normalizations
- limits on $\mu_{tH+t\bar{t}H}$ as func. of $\kappa_t$ and $\kappa_V$

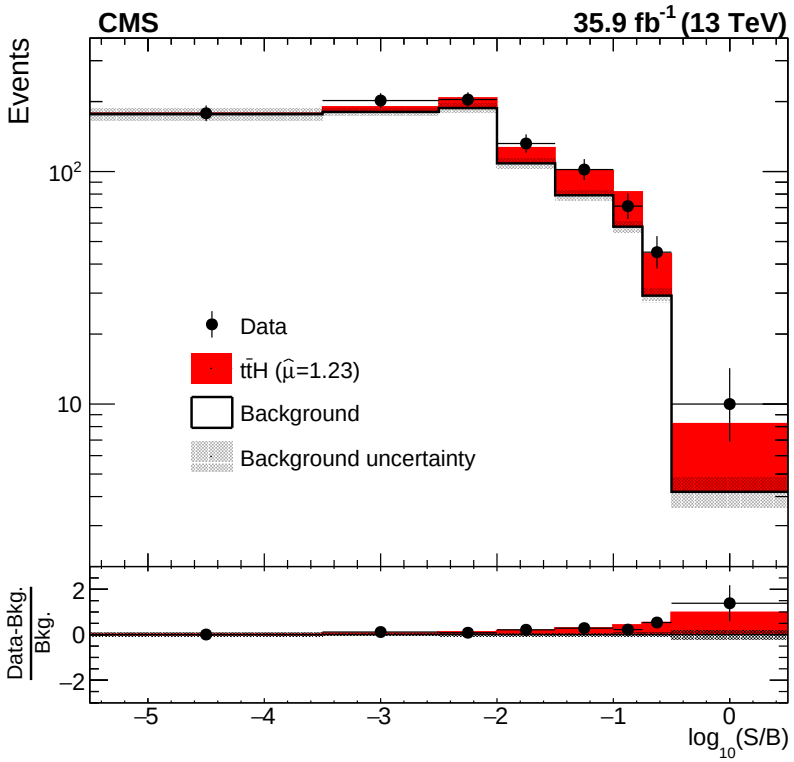
$-1.25 > \kappa_t > 1.6$ excluded at $95\%$ CL for $\kappa_V = 1$

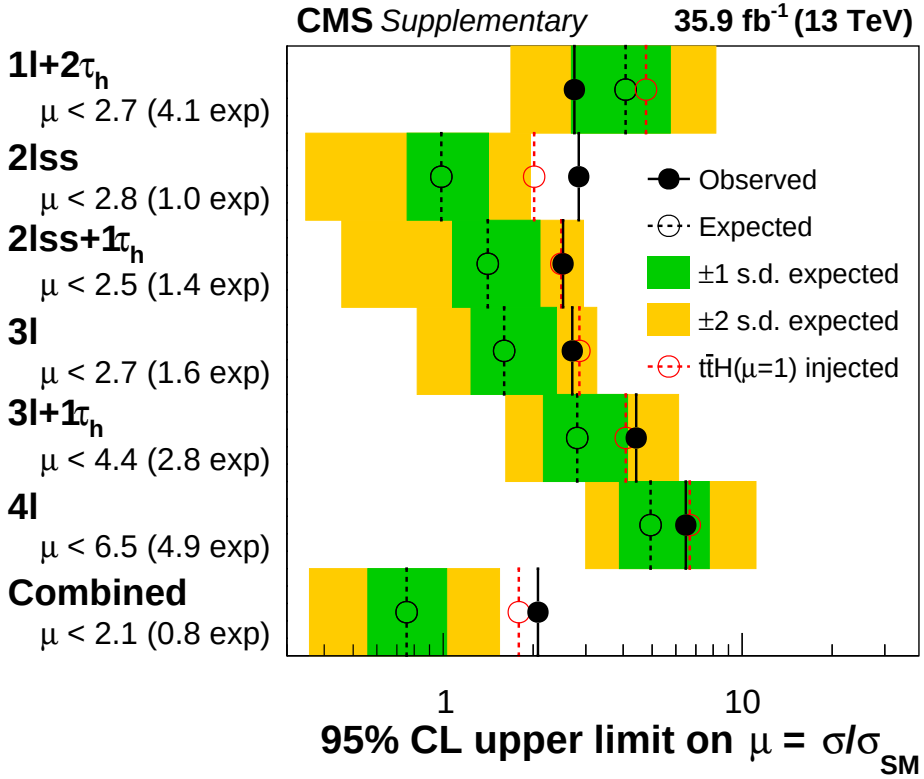


# Evidence of $t\bar{t}H$ in multilepton final states

**HIG-17-018, submitted to JHEP**



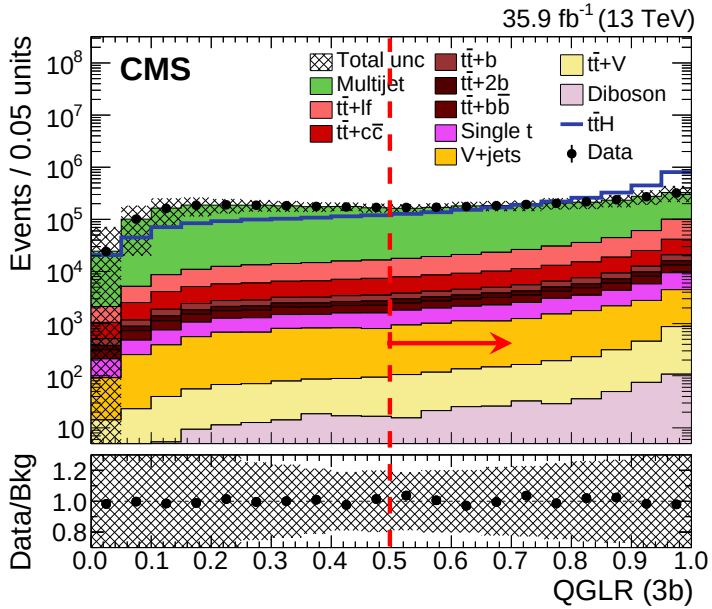



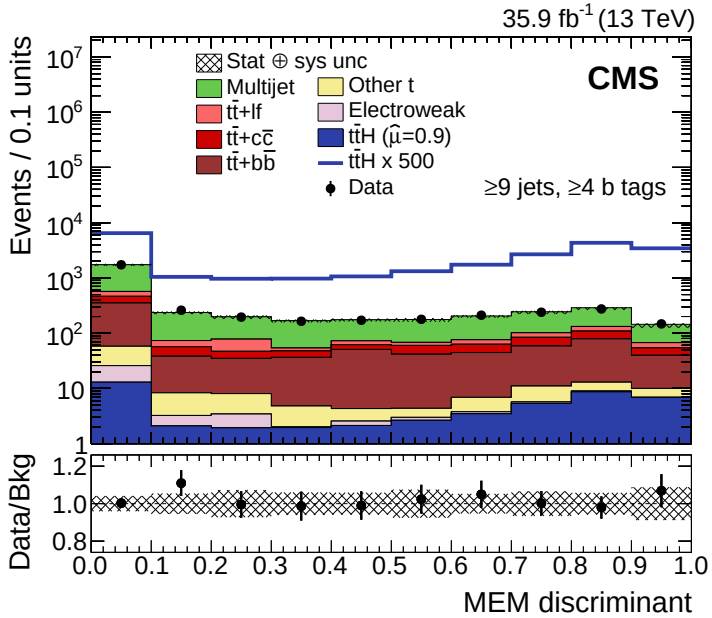
# Search for $t\bar{t}H(\to b\bar{b})$ in fully-hadronic decays

**HIG-17-022, submitted to JHEP**

- events with $\geqslant 7$ jets and $\geqslant 3$ b-jets
  - highest $t\bar{t}H$ BR, but huge QCD multijet bkg
- quark-gluon jet tagger to reduce bkg
- data-driven QCD bkg using $2$b CR
- fit to Matrix Element discriminant designed to separate $t\bar{t}H$ and $t\bar{t}+b\bar{b}$
  - 6 categ based on # of jets and b-jets
- sensitivity limited by systematics
  - QCD shape modeling, b-tagging

Obs. (Exp.) upper limit: $\mu_{95\%} < 3.8\,(3.1)$

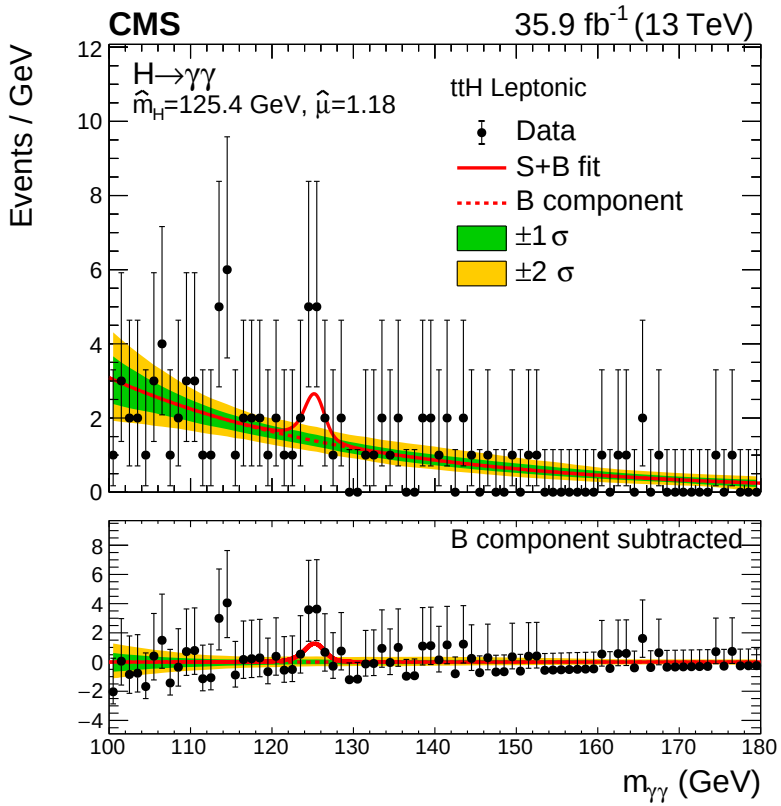


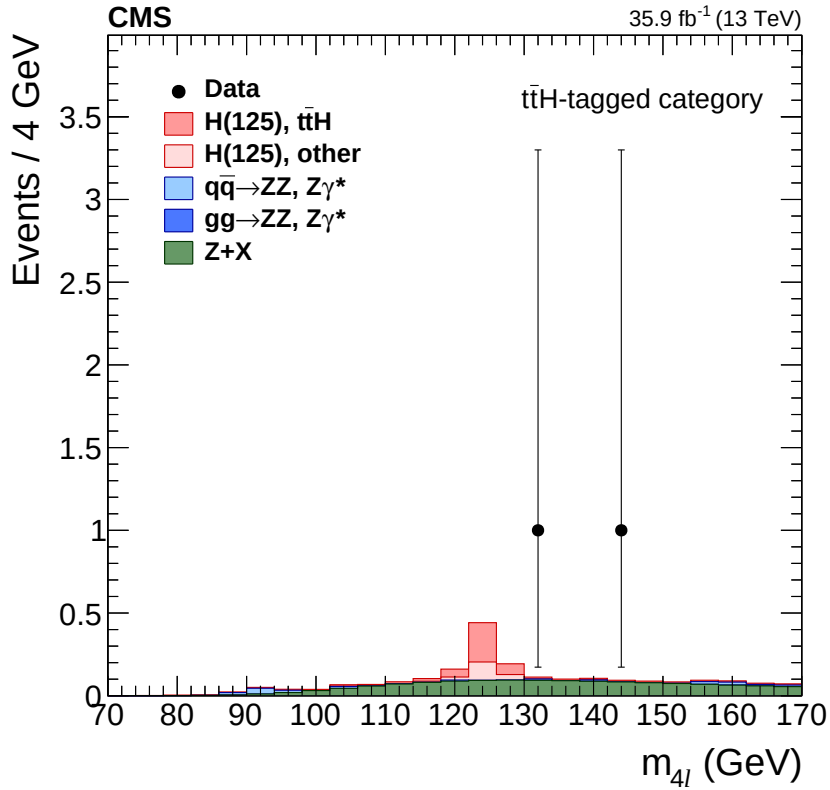



# $t\bar{t}H(\to \gamma\gamma)$ and $t\bar{t}H(\to ZZ^* \to 4\ell)$ channels

**HIG-16-040, HIG-16-041**

- $t\bar{t}H$ categories in inclusive $H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$ analyses
- both channels statistically limited



# Combination of $t\bar{t}H$ searches

## HIG-17-035, accepted by PRL

uncertainties on $\mu_{t\bar{t}H}$

| Uncertainty source | $\Delta\mu$ | |
|---|---|---|
| Signal theory | +0.15 | −0.07 |
| Inclusive ttH normalisation (cross section and BR) | +0.15 | −0.07 |
| ttH acceptance (scale, pdf, PS and UE) | +0.004 | −0.004 |
| Other Higgs boson production modes | +0.002 | −0.003 |
| Background theory | +0.14 | −0.13 |
| tt + bb/cc prediction | +0.13 | −0.11 |
| tt + V(V) prediction | +0.06 | −0.06 |
| Other background uncertainties | +0.03 | −0.03 |
| Experimental | +0.17 | −0.15 |
| Lepton (inc. $\tau_h$) trigger, ID and iso. efficiency | +0.08 | −0.06 |
| Misidentified lepton prediction | +0.06 | −0.06 |
| b-Tagging efficiency | +0.05 | −0.04 |
| Jet and $\tau_h$ energy scale and resolution | +0.04 | −0.04 |
| Luminosity | +0.04 | −0.03 |
| Photon ID, scale and resolution | +0.01 | −0.01 |
| Other experimental uncertainties | +0.01 | −0.01 |
| Finite number of simulated events | +0.08 | −0.07 |
| Statistical | +0.16 | −0.16 |
| Total | +0.31 | −0.26 |

best-fit $\mu_{t\bar{t}H}$

| Parameter | Best fit | Uncertainty: Stat | Expt | Thbgd | Thsig |
|---|---|---|---|---|---|
| $\mu_{t\bar{t}H}^{WW^*}$ | $1.97^{+0.71}_{-0.64}$ $\left(^{+0.57}_{-0.54}\right)$ | $^{+0.42}_{-0.41}$ $\left(^{+0.39}_{-0.38}\right)$ | $^{+0.46}_{-0.42}$ $\left(^{+0.36}_{-0.34}\right)$ | $^{+0.21}_{-0.21}$ $\left(^{+0.17}_{-0.17}\right)$ | $^{+0.25}_{-0.12}$ $\left(^{+0.12}_{-0.03}\right)$ |
| $\mu_{t\bar{t}H}^{ZZ^*}$ | $0.00^{+1.30}_{-0.00}$ $\left(^{+2.89}_{-0.99}\right)$ | $^{+1.28}_{-0.00}$ $\left(^{+2.82}_{-0.99}\right)$ | $^{+0.20}_{-0.00}$ $\left(^{+0.51}_{-0.00}\right)$ | $^{+0.04}_{-0.00}$ $\left(^{+0.15}_{-0.00}\right)$ | $^{+0.09}_{-0.00}$ $\left(^{+0.27}_{-0.00}\right)$ |
| $\mu_{t\bar{t}H}^{\gamma\gamma}$ | $2.27^{+0.86}_{-0.74}$ $\left(^{+0.73}_{-0.64}\right)$ | $^{+0.80}_{-0.72}$ $\left(^{+0.71}_{-0.64}\right)$ | $^{+0.15}_{-0.09}$ $\left(^{+0.09}_{-0.04}\right)$ | $^{+0.02}_{-0.01}$ $\left(^{+0.01}_{-0.00}\right)$ | $^{+0.29}_{-0.13}$ $\left(^{+0.13}_{-0.05}\right)$ |
| $\mu_{t\bar{t}H}^{\tau^+\tau^-}$ | $0.28^{+1.09}_{-0.96}$ $\left(^{+1.00}_{-0.89}\right)$ | $^{+0.86}_{-0.77}$ $\left(^{+0.83}_{-0.76}\right)$ | $^{+0.64}_{-0.53}$ $\left(^{+0.54}_{-0.47}\right)$ | $^{+0.10}_{-0.09}$ $\left(^{+0.09}_{-0.08}\right)$ | $^{+0.20}_{-0.19}$ $\left(^{+0.14}_{-0.01}\right)$ |
| $\mu_{t\bar{t}H}^{b\bar{b}}$ | $0.82^{+0.44}_{-0.42}$ $\left(^{+0.44}_{-0.42}\right)$ | $^{+0.23}_{-0.23}$ $\left(^{+0.23}_{-0.22}\right)$ | $^{+0.24}_{-0.23}$ $\left(^{+0.24}_{-0.23}\right)$ | $^{+0.27}_{-0.27}$ $\left(^{+0.26}_{-0.27}\right)$ | $^{+0.11}_{-0.03}$ $\left(^{+0.11}_{-0.04}\right)$ |
| $\mu_{t\bar{t}H}^{7+8\,\mathrm{TeV}}$ | $2.59^{+1.01}_{-0.88}$ $\left(^{+0.87}_{-0.79}\right)$ | $^{+0.54}_{-0.53}$ $\left(^{+0.51}_{-0.49}\right)$ | $^{+0.53}_{-0.49}$ $\left(^{+0.48}_{-0.44}\right)$ | $^{+0.55}_{-0.49}$ $\left(^{+0.50}_{-0.44}\right)$ | $^{+0.37}_{-0.13}$ $\left(^{+0.14}_{-0.02}\right)$ |
| $\mu_{t\bar{t}H}^{13\,\mathrm{TeV}}$ | $1.14^{+0.31}_{-0.27}$ $\left(^{+0.29}_{-0.26}\right)$ | $^{+0.17}_{-0.16}$ $\left(^{+0.16}_{-0.16}\right)$ | $^{+0.17}_{-0.17}$ $\left(^{+0.17}_{-0.16}\right)$ | $^{+0.13}_{-0.12}$ $\left(^{+0.13}_{-0.12}\right)$ | $^{+0.14}_{-0.06}$ $\left(^{+0.11}_{-0.05}\right)$ |
| $\mu_{t\bar{t}H}$ | $1.26^{+0.31}_{-0.26}$ $\left(^{+0.28}_{-0.25}\right)$ | $^{+0.16}_{-0.16}$ $\left(^{+0.15}_{-0.15}\right)$ | $^{+0.17}_{-0.15}$ $\left(^{+0.16}_{-0.15}\right)$ | $^{+0.14}_{-0.13}$ $\left(^{+0.13}_{-0.12}\right)$ | $^{+0.15}_{-0.07}$ $\left(^{+0.11}_{-0.05}\right)$ |