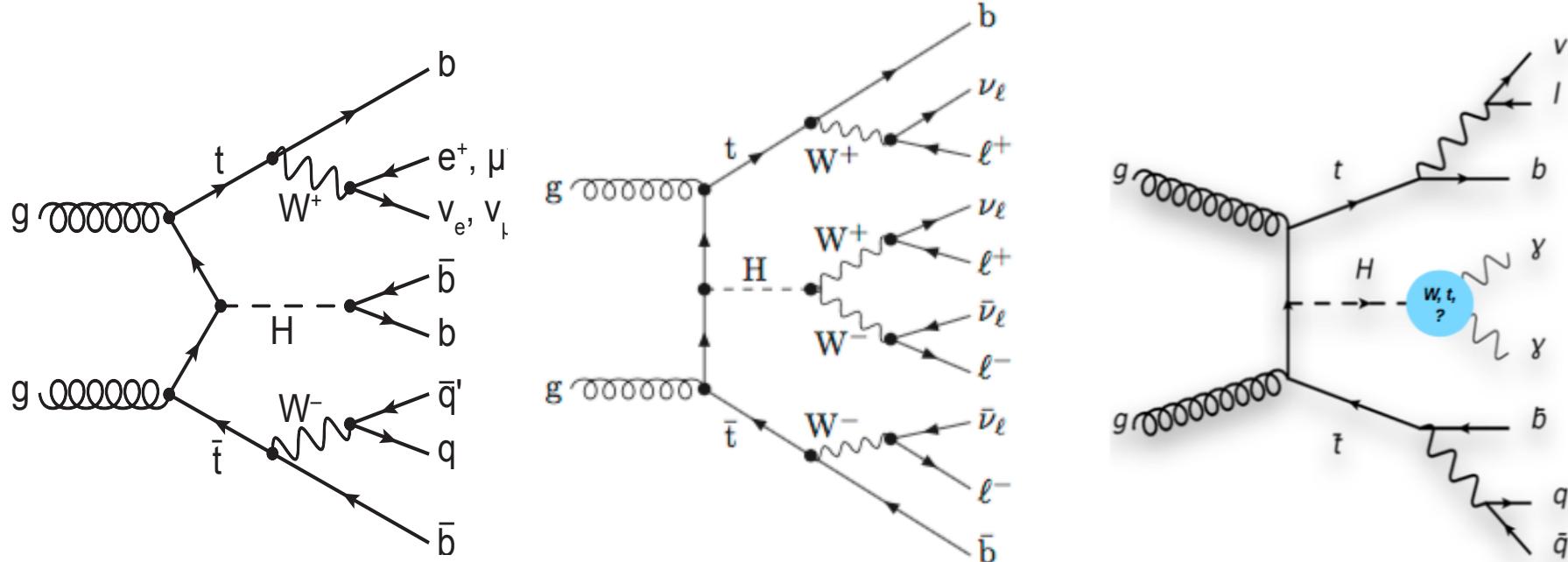


# CMS ttH analysis @ 13 TeV



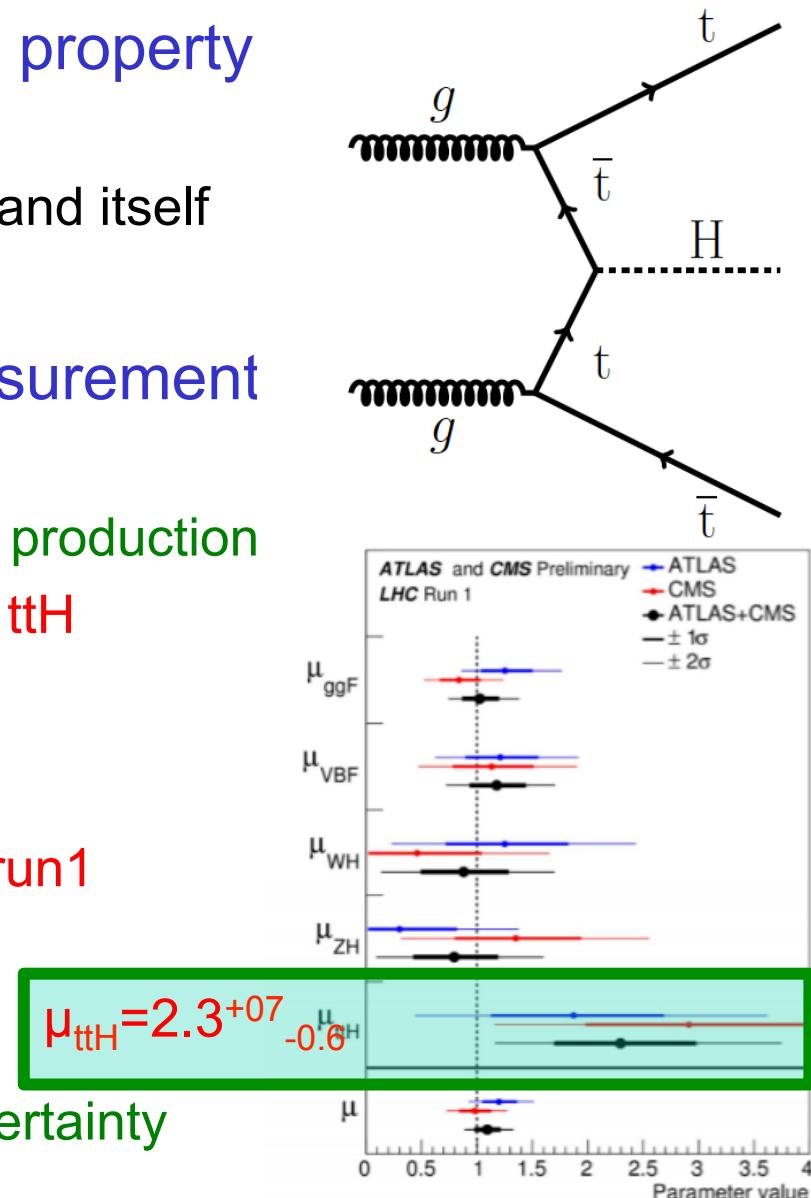
张华桥 (高能物理研究所)

On behalf of CMS collaboration

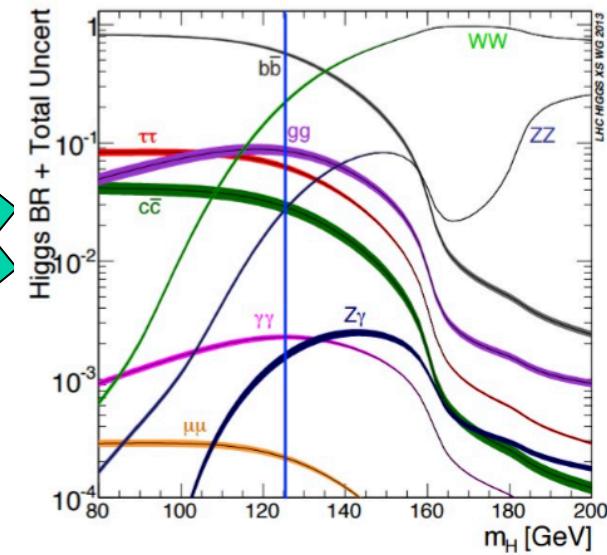
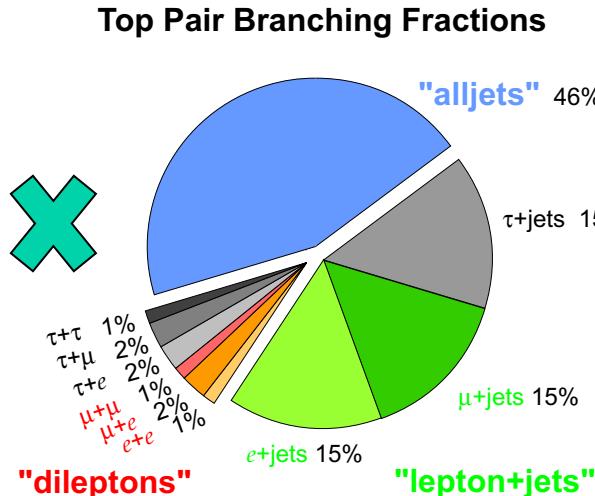
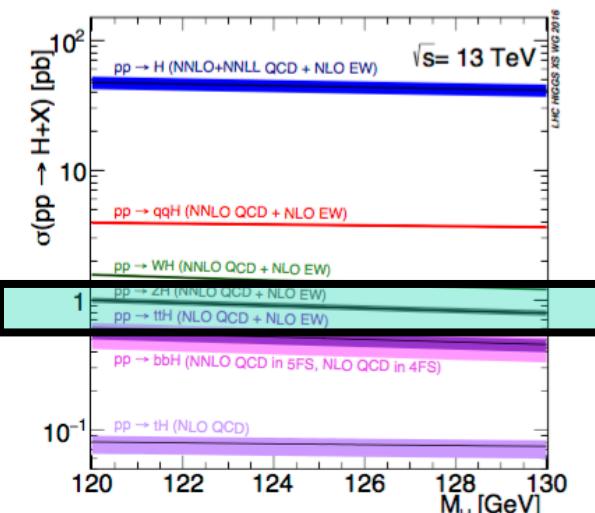
中国物理学会高能物理分会第十二届全国粒子物理学学术会议(8/22-26,2016@合肥)

# Motivation of ttH analysis

- After Higgs discovery, focus now: property
  - Mass, width, Spin, parity etc
  - Couplings to fermion, gauge boson, and itself
- Top-Higgs Yukawa coupling measurement
  - The largest coupling to fermion  $\sim 1$
  - Indirect constrains from gluon fusion production
  - Direct measurement at tree level via ttH
- Not yet observed so far
  - 4.4 sigma combine ATLAS/CMS @ run1
- $2\sigma$  deviation from SM @ run 1
  - Consistent with SM due to large uncertainty



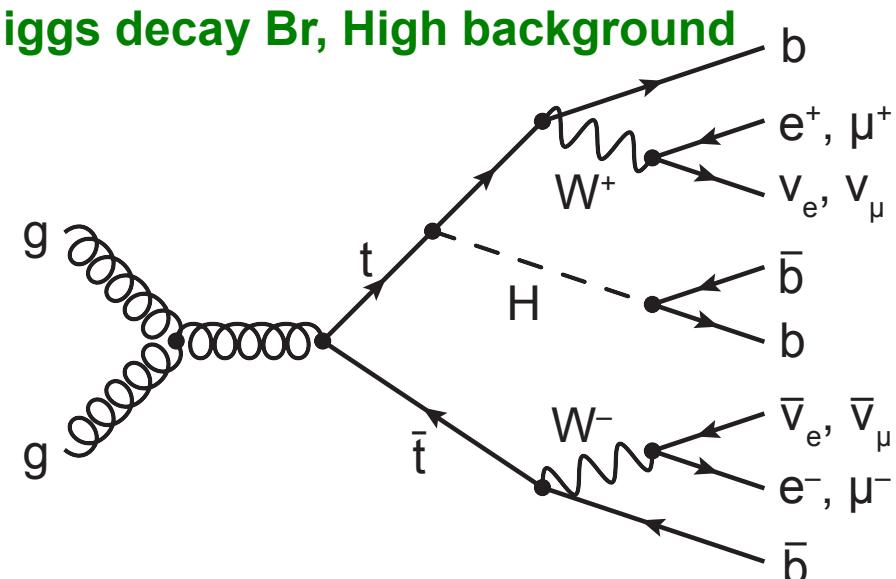
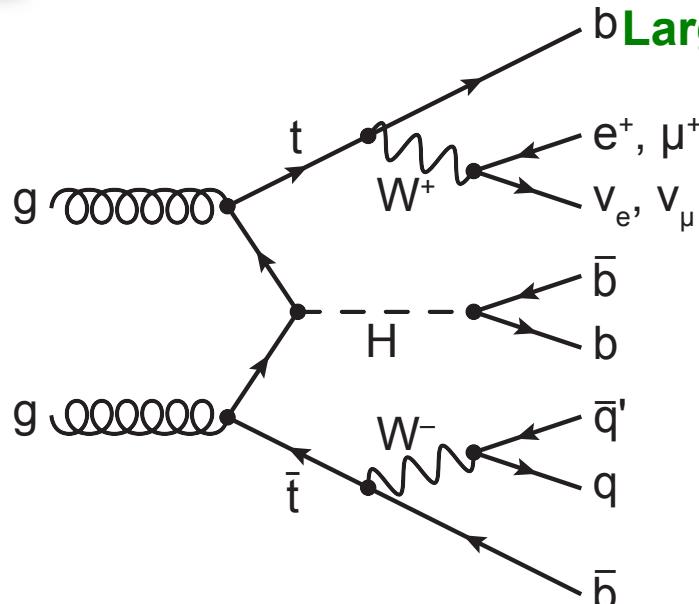
# ttH measurement @ 13 TeV



- Low production cross section
  - 2 orders smaller than gluon fusion
- Complicate final states: tt + Higgs
- Advantage:

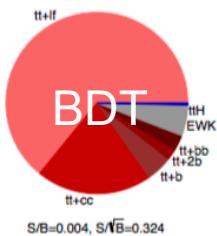
$H \rightarrow bb$ : 58,.1%  
 $H \rightarrow WW/ZZ/TT$ : 30.4%  
 $H \rightarrow \gamma\gamma$ : 0.23%

Cross section (fb) @NLO	$t\bar{t}H$	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}$ (NNLO)
8 TeV	133	232	206	2,53E+05
13 TeV	507	566	760	8,32E+05
13 TeV / 8TeV	3.8	2.4	3.7	3.3

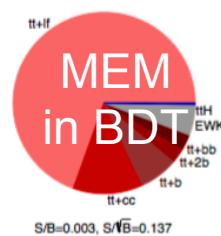


- Divided into 1 lepton and 2 lepton analysis
  - One  $e(\mu)$  of  $P_T > 30$  (25) GeV,  $|\eta| < 2.1$ ,  $>= 4$  jets of  $P_T > 30$  GeV,  $|\eta| < 2.4$
  - Two  $e/\mu$  of  $P_T > 20/15$  GeV,  $|\eta| < 2.4$ ,  $>= 3$  jets of  $P_T > 30, 30, 20$  GeV,  $|\eta| < 2.4$
- Categorize events based on number of jets, b-jets (next slide)
- Combined fit with all categories
  - Background categories: constrain backgrounds
  - Signal enriched categories: extract signal

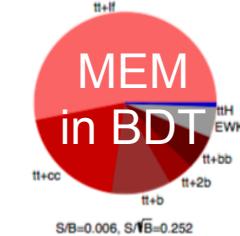
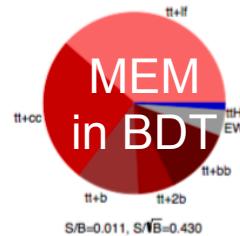
## Lepton+Jets

 $\geq 6$  jets, 2 b-tags

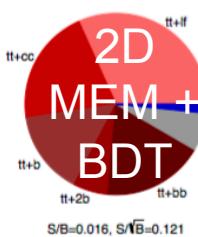
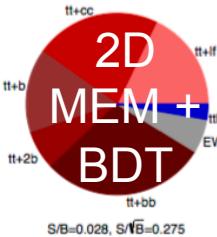
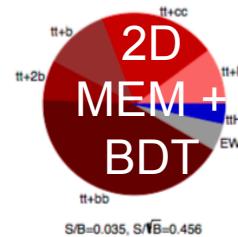
4 jets, 3 b-tags



5 jets, 3 b-tags

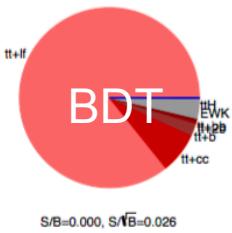
 $\geq 6$  jets, 3 b-tags

4 jets, 4 b-tags

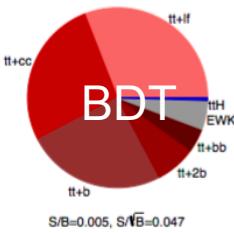
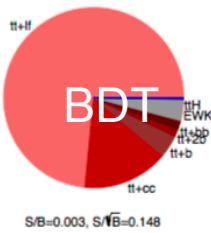
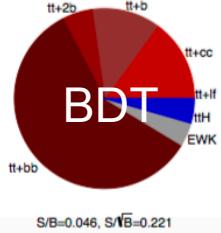
5 jets,  $\geq 4$  b-tags $\geq 6$  jet,  $\geq 4$  b-tags

## Dilepton

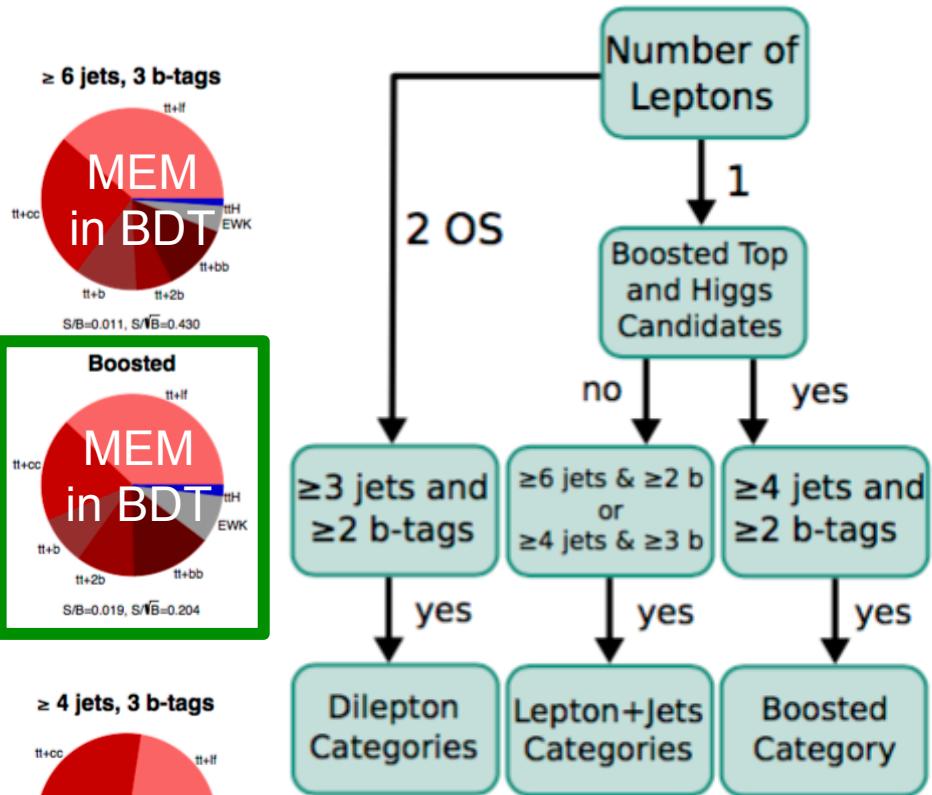
3 jets, 2 b-tags



3 jets, 3 b-tags

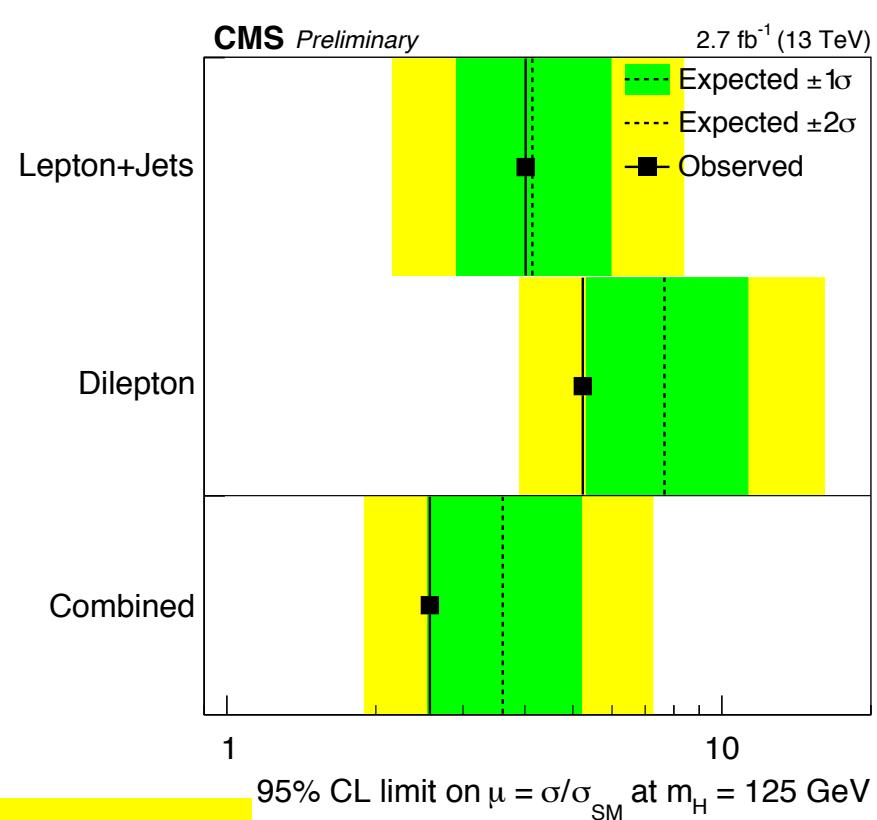
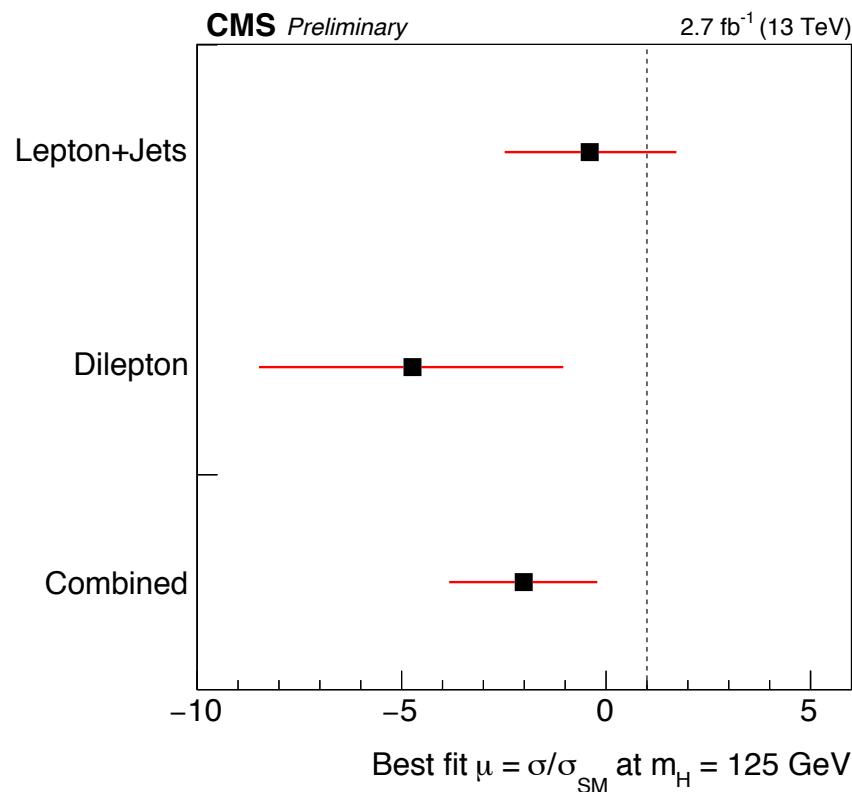
 $\geq 4$  jets, 2 b-tags $\geq 4$  jets,  $\geq 4$  b-tags

tt+lf  
tt+cc  
tt+b  
tt+2b  
tt+bb  
EWK  
ttH



- Event selected in 13 categorizes
  - BDT and/or MEM used per category
  - Tt+jets dominated in all categories

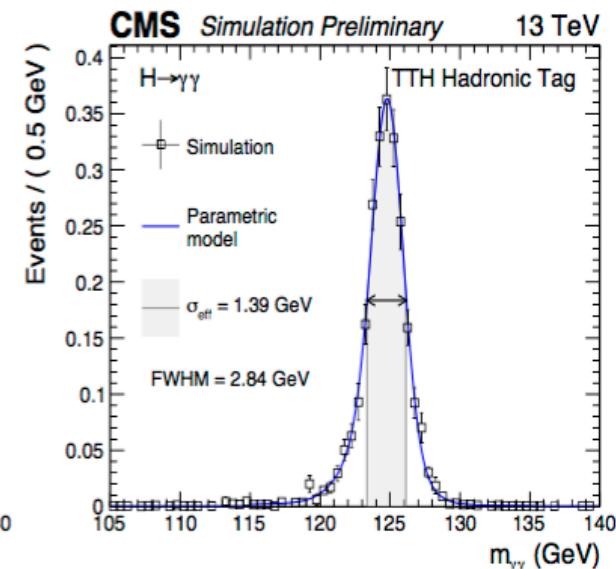
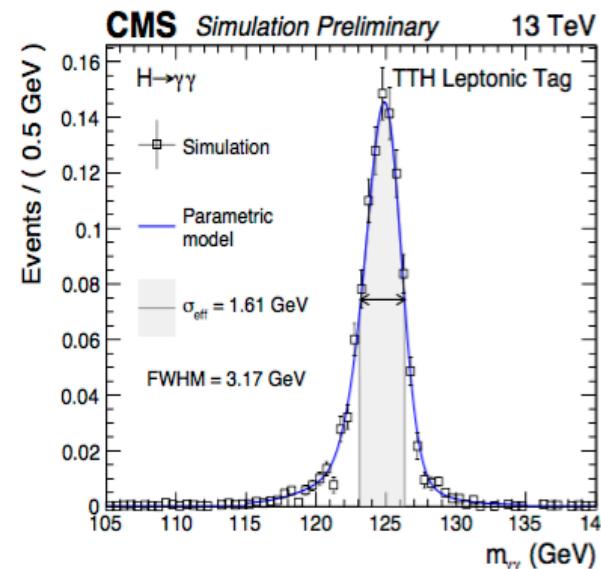
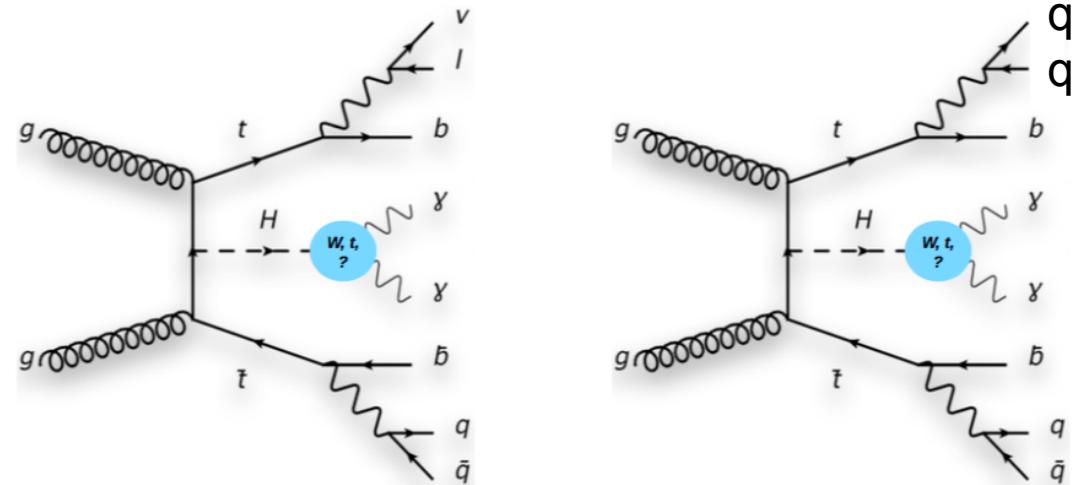
- Simultaneous binned maximum likelihood fit to all categories
- Results with 2015 data only ( $2.7 \text{ fb}^{-1}$ )
  - 2016 data ( $>20 \text{ fb}^{-1}$  now) analysis are ongoing



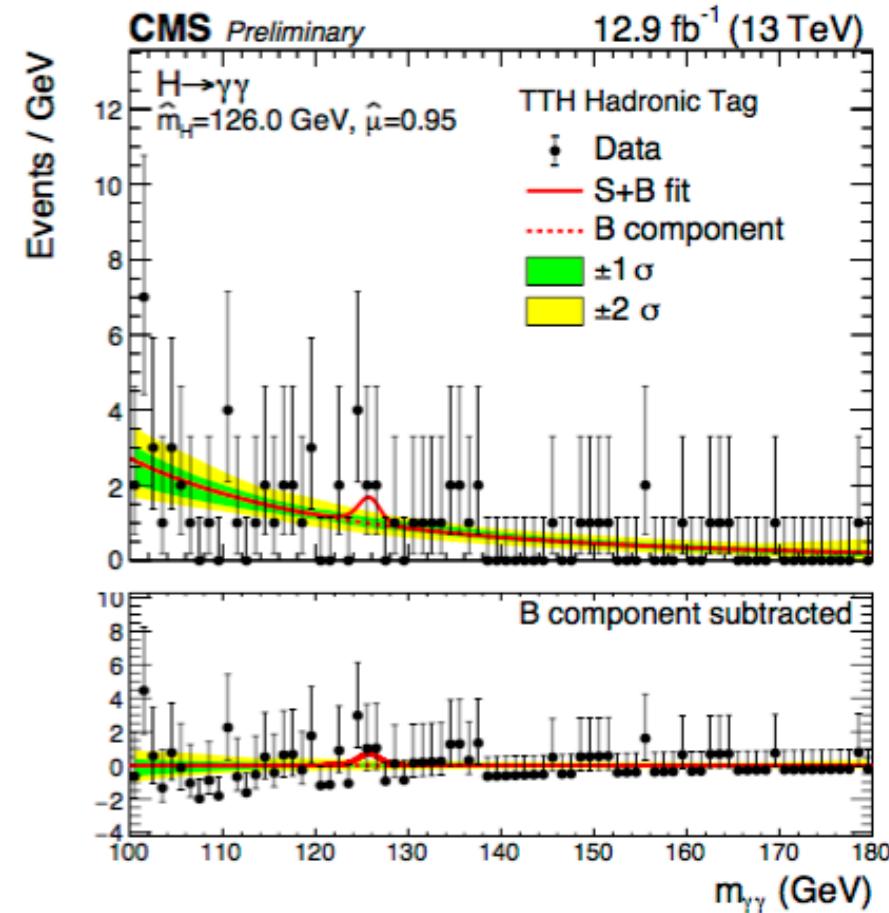
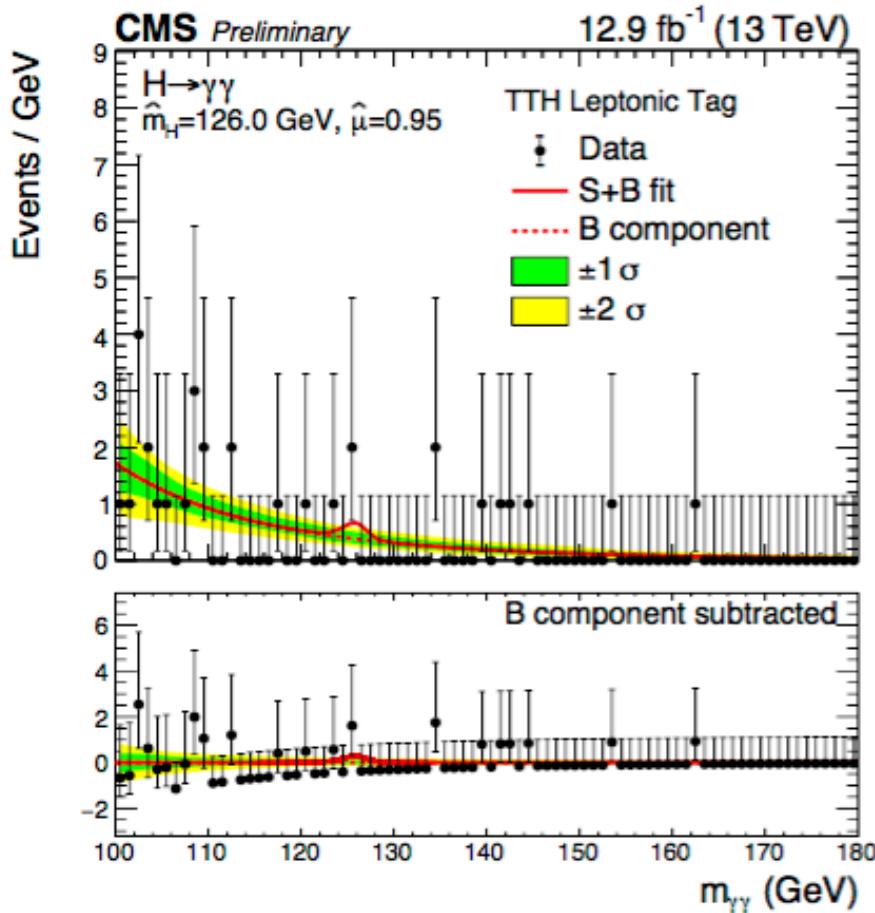
$$\mu_{\text{ttH}} < 2.6(3.6)$$

- Use MVA to separate diphoton pairs
- 2 categories
- Leptonic Tag
  - $2\gamma, \text{Pt} > m_{\gamma\gamma}/2, m_{\gamma\gamma}/4$
  - $\geq 1 \text{ lep}, \text{Pt} > 20 \text{ GeV}$
  - $\geq 2 \text{ jet}, \text{Pt} > 25 \text{ GeV}$ 
    - $\geq 1 \text{ b-tagged}$
- Hadronic Tag
  - $2\gamma, \text{Pt} > m_{\gamma\gamma}/2, m_{\gamma\gamma}/4$
  - No leptons
  - $\geq 5 \text{ jets}, \text{Pt} > 25 \text{ GeV}$ 
    - $\geq 1 \text{ b-tagged}$
- Good mass resol.

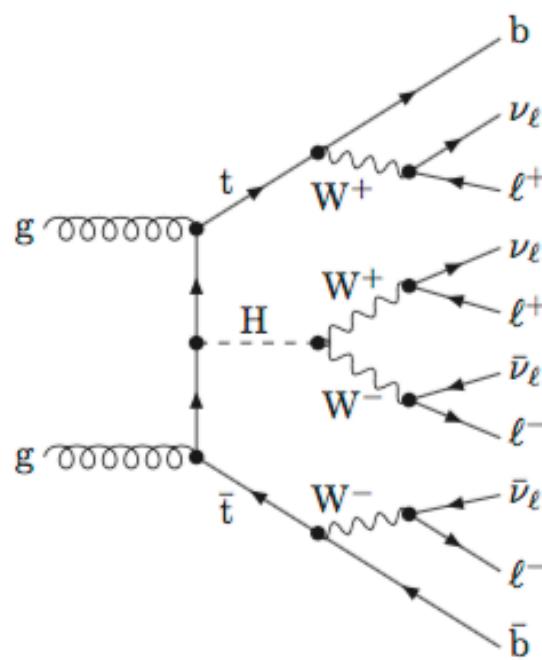
**Very clean, low rate, Best Higgs mass resolution**



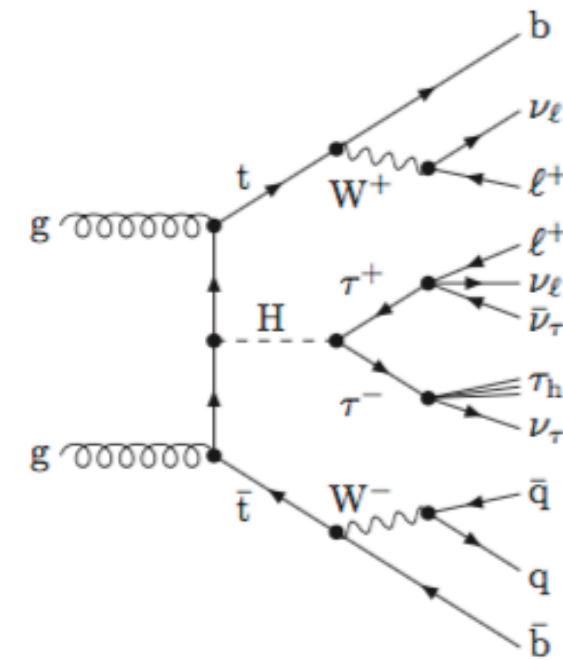
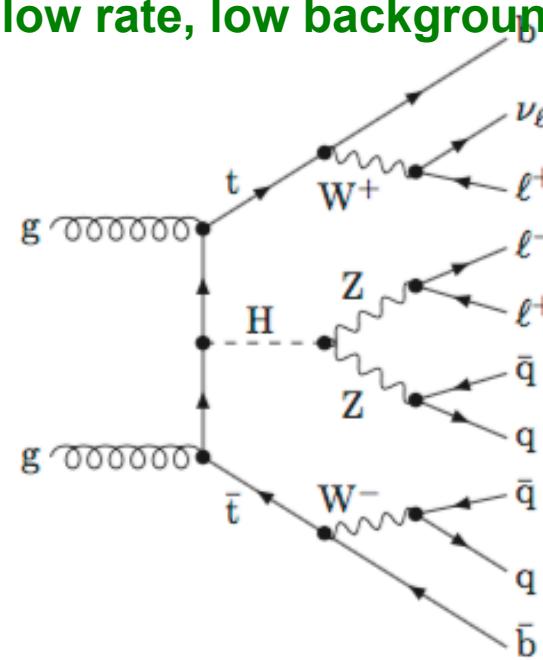
- Signal extracted by fitting  $m_{\gamma\gamma}$  with smooth falling B + signal
  - Limited statistics



$$\mu_{\text{ttH}} = 1.91^{+1.5}_{-1.2}$$



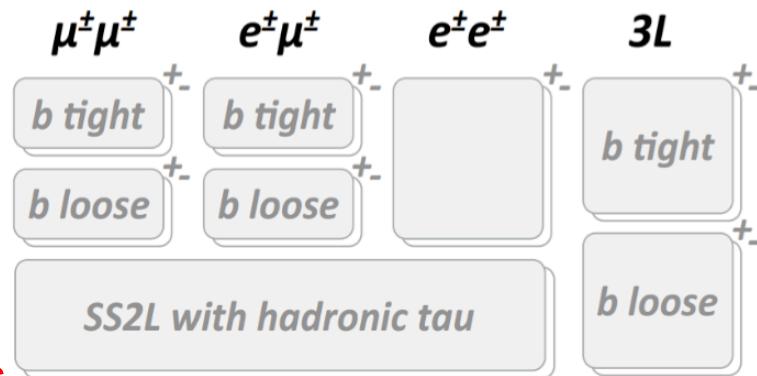
**low rate, low background**



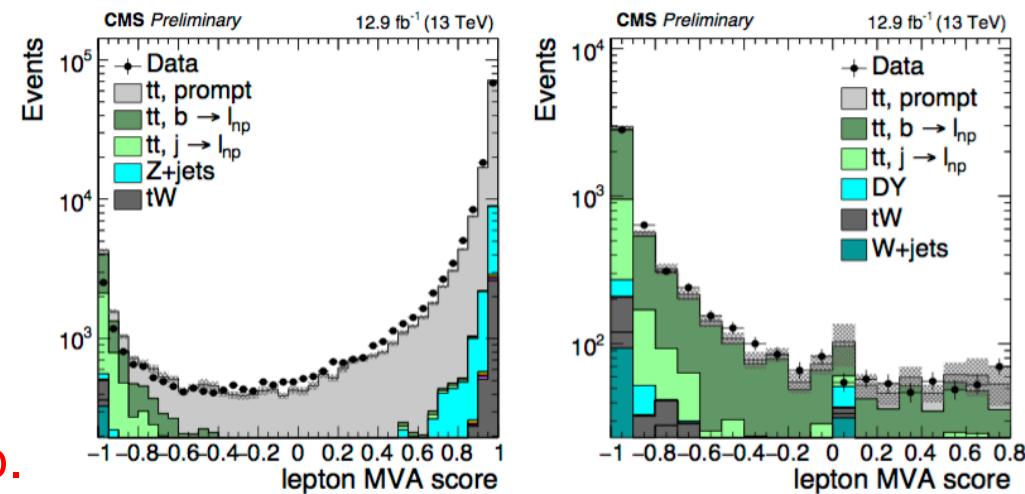
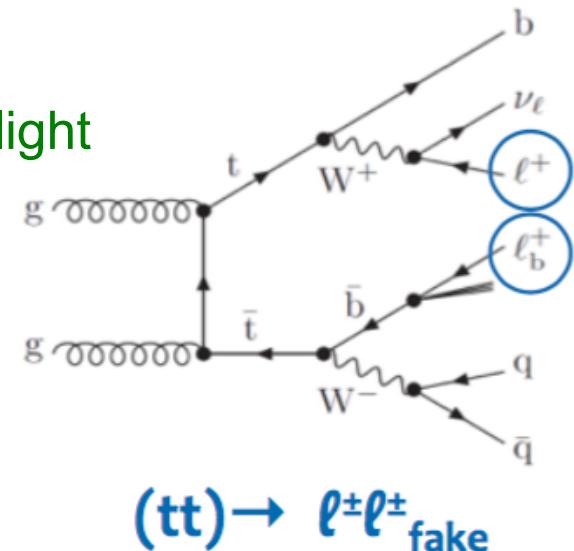
- ttH, H $\rightarrow$ Multilepton from H $\rightarrow$ WW,ZZ, $\tau\tau$
- Select events based on number of leptons
  - 2 same sign leptons( $Pt > 25, 10(15)\text{GeV}$ ) + 4 jets( $Pt > 25\text{GeV}$ ) +  $E_T^{\text{miss}}$  +  $H_T^{\text{miss}}$
  - $\geq 3$  leptons ( $Pt > 10\text{GeV}$ , with Z veto) + 2 jets( $Pt > 25\text{GeV}$ ) +  $E_T^{\text{miss}}$  +  $H_T^{\text{miss}}$
- B-tagged jets required
  - At least 2 loose or 1 medium b-tagged jets

	$\mu\mu$	$ee$	$e\mu$	$3\ell$
t̄W	$18.3 \pm 0.9$	$6.8 \pm 0.6$	$24.5 \pm 1.1$	$12.2 \pm 0.7$
t̄Z/ $\gamma^*$	$5.8 \pm 0.6$	$7.4 \pm 0.6$	$15.3 \pm 1.3$	$22.6 \pm 1.0$
Di-boson	$1.4 \pm 0.2$	$1.1 \pm 0.2$	$2.6 \pm 0.3$	$5.7 \pm 0.4$
ttt̄t	$0.8 \pm 0.2$	$0.4 \pm 0.1$	$1.5 \pm 0.2$	$1.2 \pm 0.1$
tqZ	$0.2 \pm 0.3$	$0.4 \pm 0.4$	$0.6 \pm 0.6$	$2.7 \pm 0.8$
Rare SM bkg.	$1.6 \pm 0.3$	$0.5 \pm 0.1$	$1.8 \pm 0.1$	$0.3 \pm 0.1$
Charge mis-meas.		$6.7 \pm 0.1$	$10.0 \pm 0.1$	
Non-prompt leptons	$33.4 \pm 1.2$	$23.1 \pm 1.1$	$61.9 \pm 1.7$	$51.0 \pm 1.8$
All backgrounds	$61.5 \pm 1.7$	$46.4 \pm 1.5$	$118.0 \pm 2.5$	$95.7 \pm 2.3$
t̄H ( $H \rightarrow WW^*$ )	$6.3 \pm 0.2$	$2.6 \pm 0.1$	$8.5 \pm 0.2$	$8.0 \pm 0.2$
t̄H ( $H \rightarrow \tau\tau$ )	$1.6 \pm 0.1$	$0.7 \pm 0.1$	$2.5 \pm 0.1$	$2.1 \pm 0.1$
t̄H ( $H \rightarrow ZZ^*$ )	$0.2 \pm 0.0$	$0.1 \pm 0.0$	$0.3 \pm 0.0$	$0.5 \pm 0.0$
Data	74	45	154	105

- Dominate background
  - Non-prompt(Fakes) ~50%
  - t̄W ~25%
- Events further categorized by
  - Presence of tau jets, lepton charge, jets

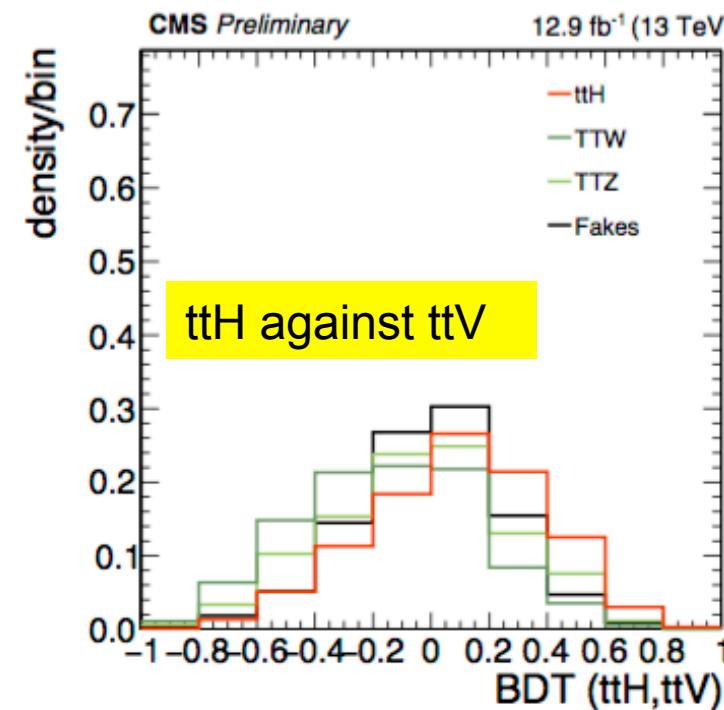
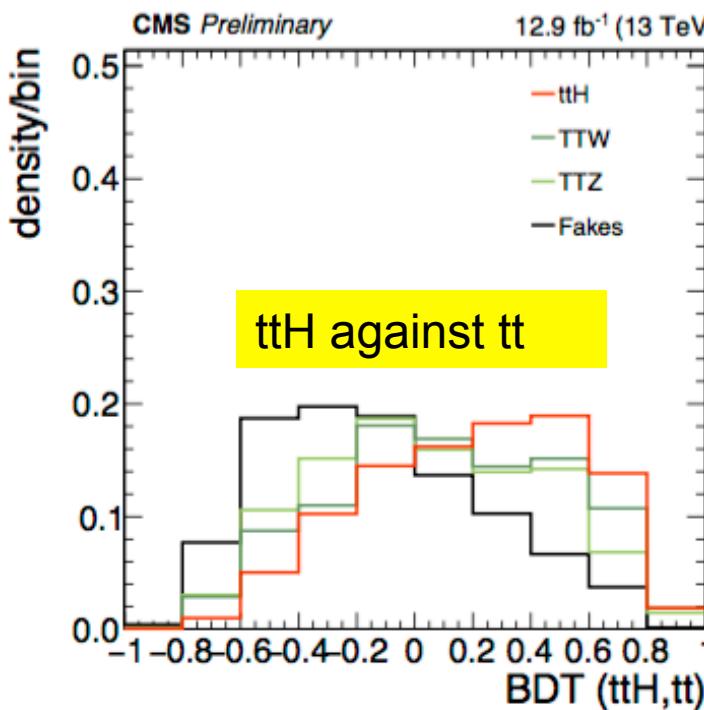


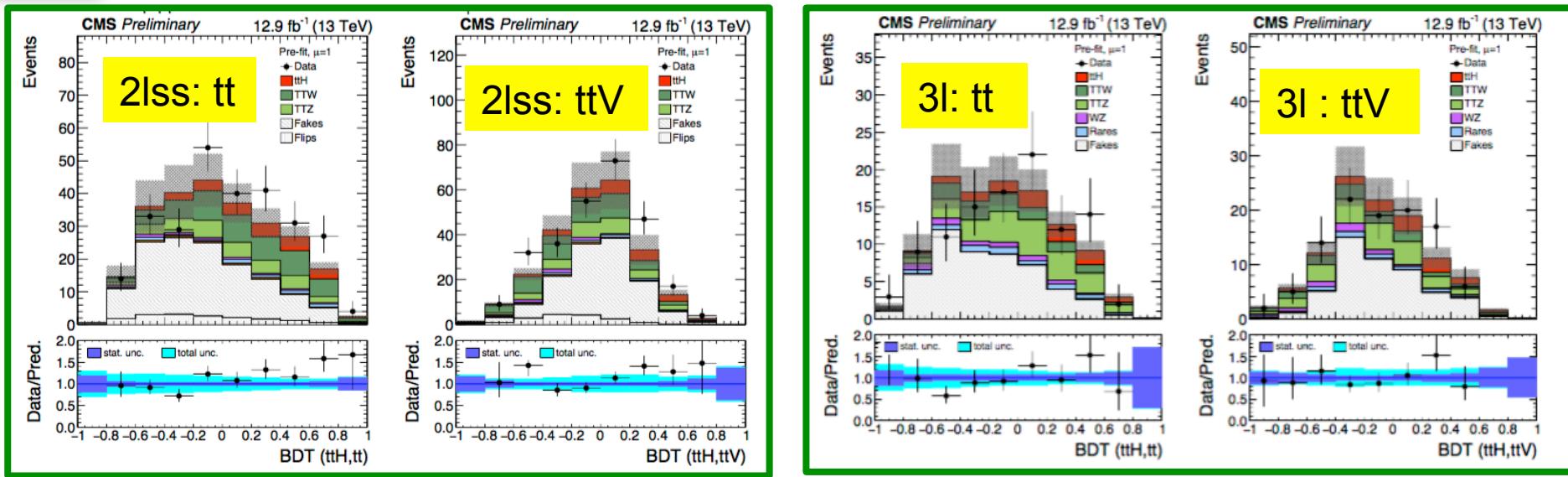
- Non-prompt backgrounds
  - Mainly from b-jets in tt events
  - Few from mis-identified light jets and decay-in-flight
- Multivariable used for separation
  - Isolation
  - Vertex
  - Relation with nearby jets
- Data validated performance
- Data-driven estimation
  - Loose → tight fake prob.
  - Loose → tight charge flip prob.



- Using BDT to separate signal against tt and ttV
  - Jets multiplicity, lepton/jet angular separation, MET, lepton Pt
- New MEM weights for ttH and ttV hypotheses (3 lepton only)

$$w_{i,\alpha}(\Phi') = \frac{1}{\sigma_\alpha} \int d\Phi_\alpha \cdot \delta^4(p_1^\mu + p_2^\mu - \sum_{k \geq 2} p_k^\mu) \cdot \frac{f(x_1, \mu_F) f(x_2, \mu_F)}{x_1 x_2 s} \cdot \left| \mathcal{M}_\alpha(p_k^\mu) \right|^2 \cdot W(\Phi' | \Phi_\alpha).$$

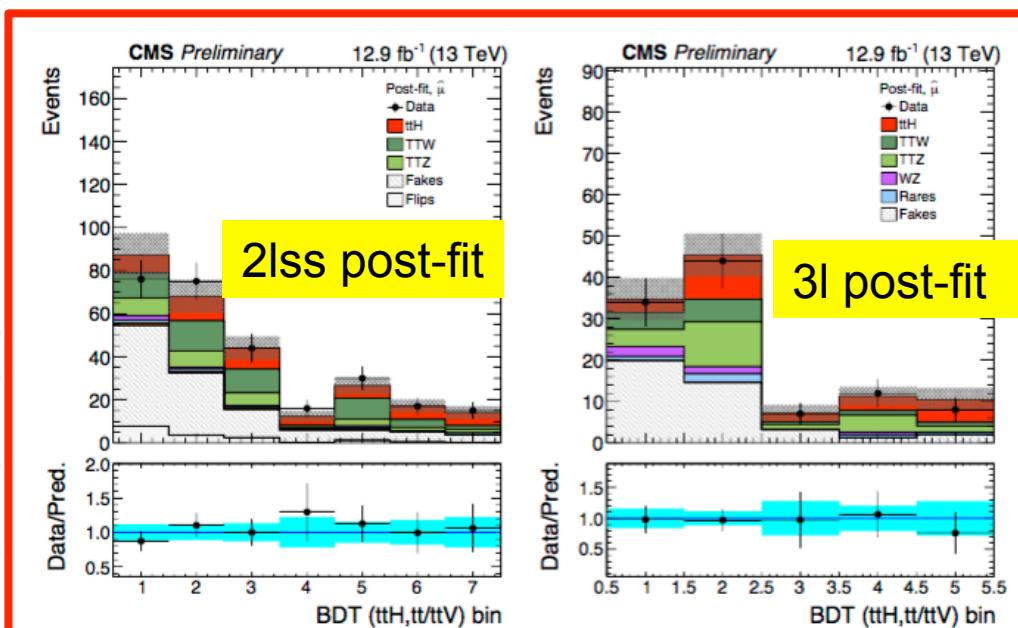




- 2 D fitting to the BDT
  - ttH against tt / ttH against ttV

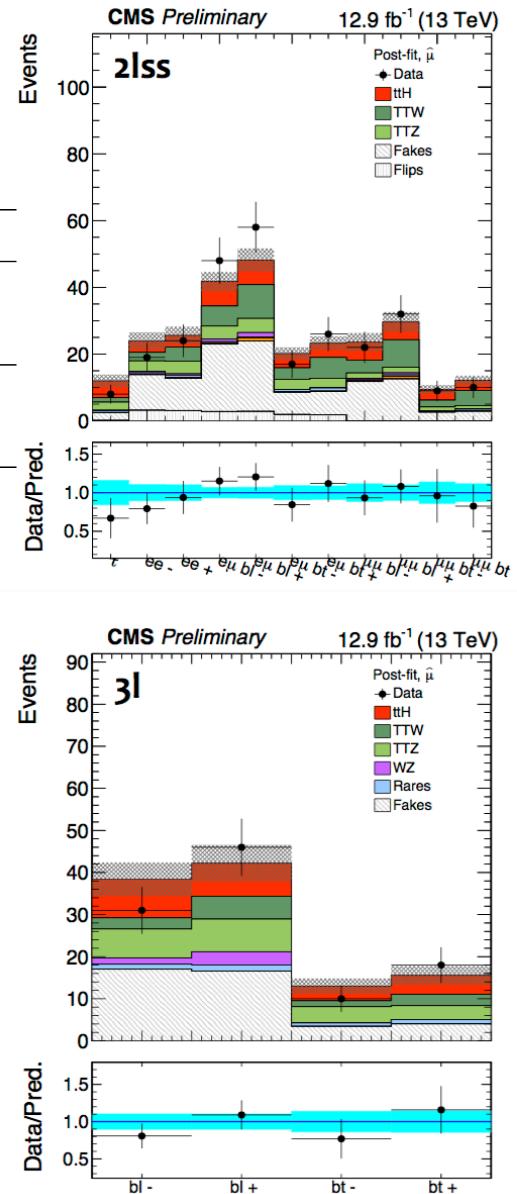
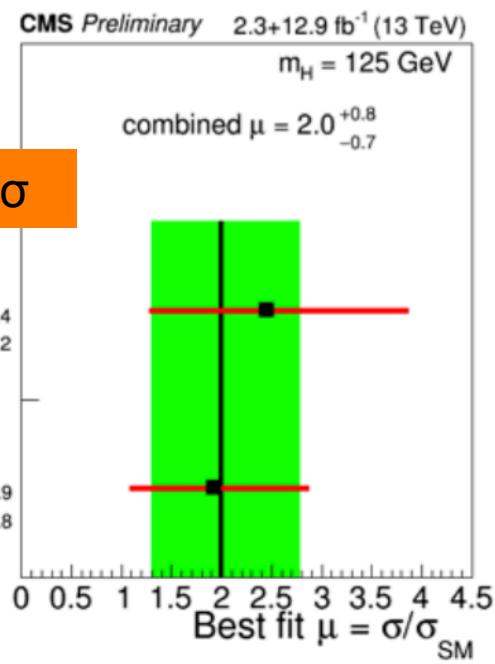
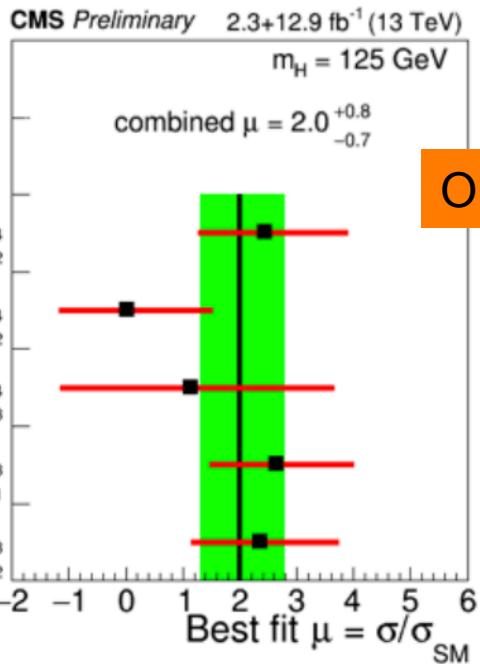
Table 9: Coordinates of the bins that represent the partitioning of the 2D BDT plane.

	bin 1	bin 2	bin 3	bin 4	bin 5	bin 6	bin 7
2lss( $t\bar{t}$ )	(-1.0, -0.2]	(-0.2, 0.1]	(0.1, 0.4]	(0.1, 0.4]	(0.4, 1.0]	(0.4, 1.0]	(0.4, 1.0]
2lss(ttV)	(-1.0, 1.0]	(-1.0, 1.0]	(-1.0, 0.3]	(0.3, 1.0]	(-1.0, 0.1]	(0.1, 0.4]	(0.4, 1.0]
3l( $t\bar{t}$ )	(-1.0, -0.3]	(-0.3, 0.3]	(-0.3, 0.3]	(0.3, 1.0]	(0.3, 1.0]		
3l(ttV)	(-1.0, 1.0]	(-1.0, 0.25]	(0.25, 1.0]	(-1.0, 0.25]	(0.25, 1.0]		



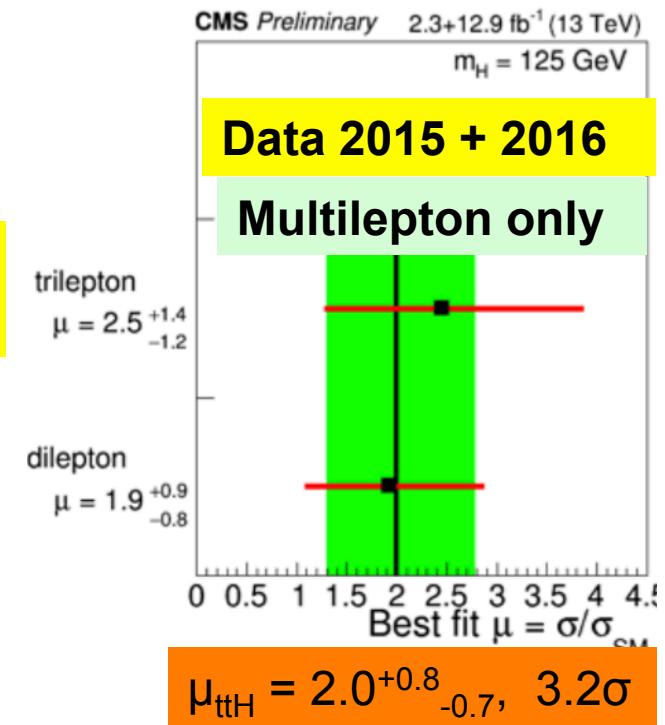
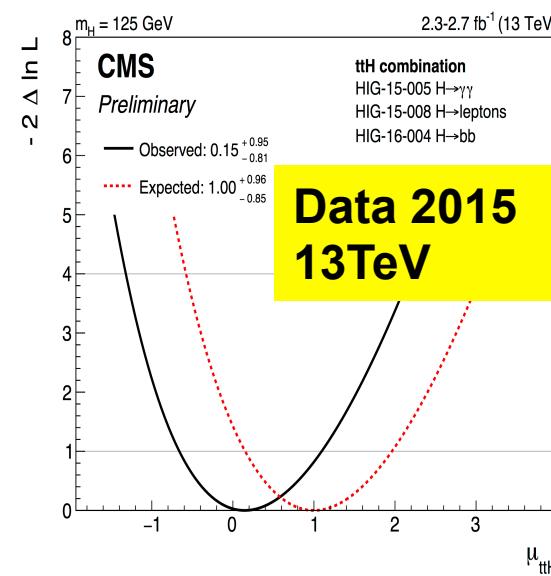
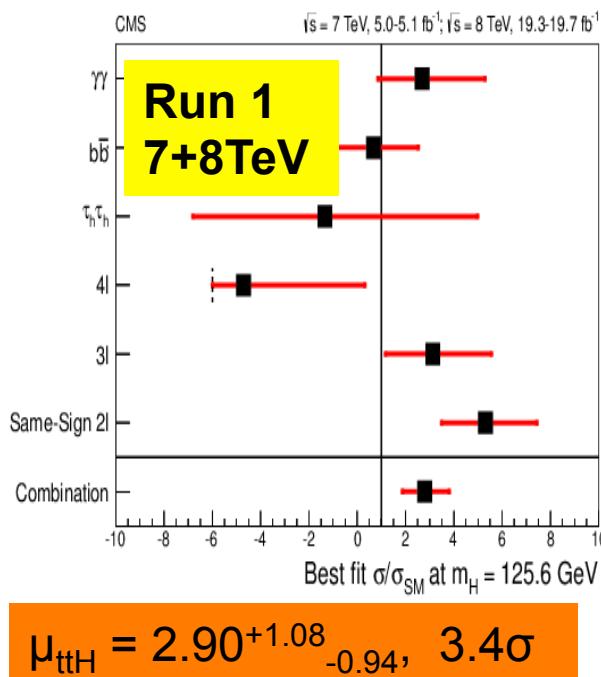
- Results with 13 TeV data
  - 2015 ( $2.3\text{fb}^{-1}$ ) + 2016 ( $12.9\text{fb}^{-1}$ )

Category	Obs. limit	Exp. limit $\pm 1\sigma$	Best fit $\mu \pm 1\sigma$
Same-sign dileptons	4.6	$1.7^{+0.9}_{-0.5}$	$2.7^{+1.1}_{-1.0}$
Trileptons	3.7	$2.3^{+1.2}_{-0.7}$	$1.3^{+1.2}_{-1.0}$
Combined categories	3.9	$1.4^{+0.7}_{-0.4}$	$2.3^{+0.9}_{-0.8}$
Combined with 2015 data	3.4	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$



# Summary and outlook

- The 13 TeV ttH analysis is presented
  - $\text{ttH}, \text{H} \rightarrow \text{bb}$ :  $2.7 \text{ fb}^{-1}$  @ 13 TeV, data 2015:  $\mu_{\text{ttH}} < 2.6$  (3.6) @ 95% CL
  - $\text{ttH}, \text{H} \rightarrow \gamma\gamma$ :  $12.9 \text{ fb}^{-1}$  @ 13 TeV, data 2016:  $\mu_{\text{ttH}} = 1.91^{+1.5}_{-1.2}$
  - $\text{ttH}, \text{H} \rightarrow \text{Multilepton}$ :  $12.9 \text{ fb}^{-1}$  @ 13 TeV, data 2015 + 2016:  $\mu_{\text{ttH}} = 2.0^{+0.8}_{-0.7}$
- Evidence of ttH can be observed in multilepton channel only
  - Expect observation soon

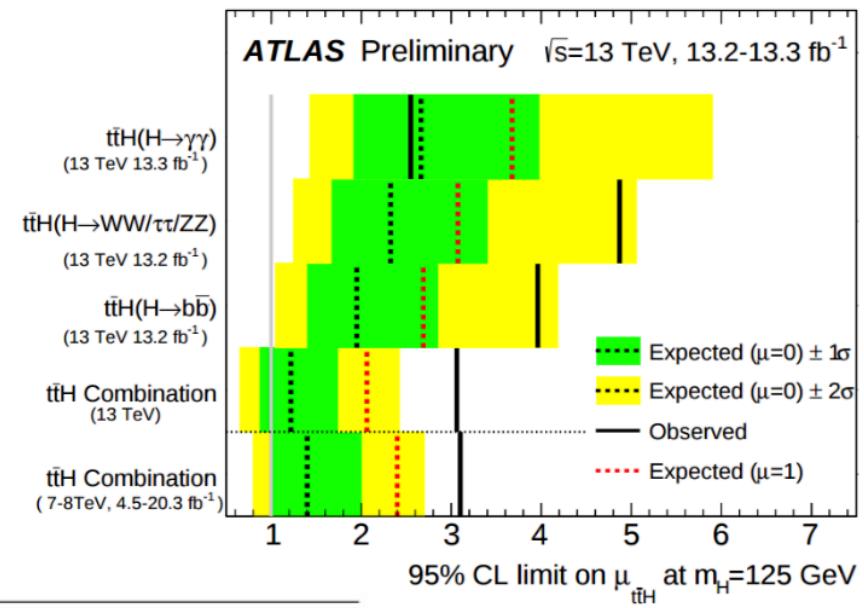
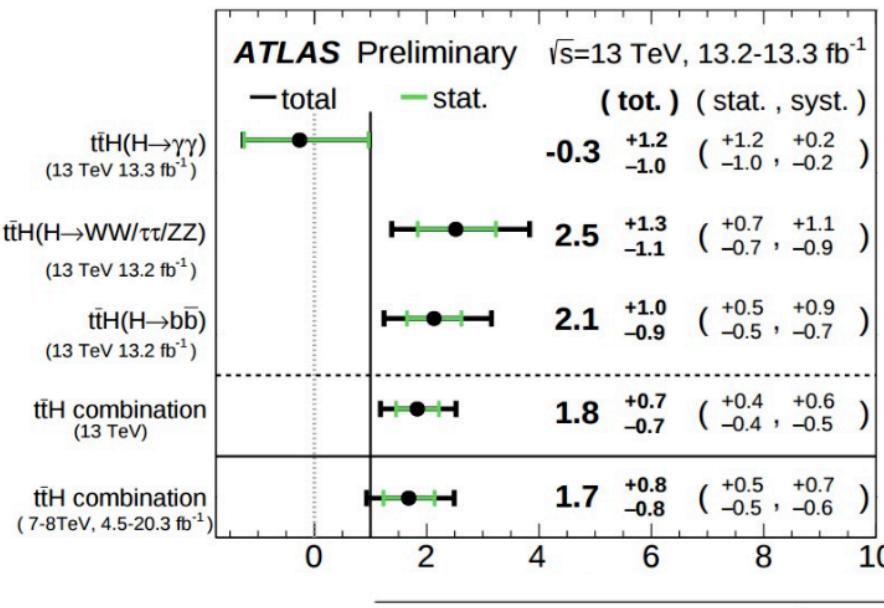




# backup

# ATLAS 13 TeV results

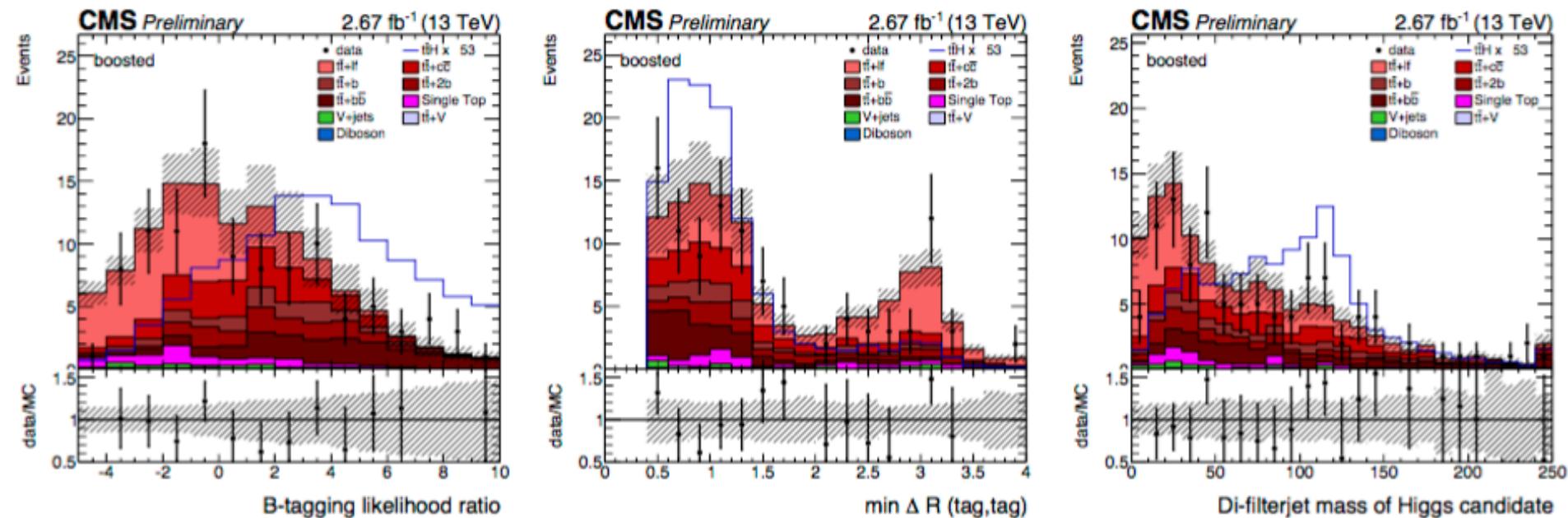
- 13 TeV 13.2-13.3  $\text{fb}^{-1}$
- Combine  $H \rightarrow b\bar{b}$ , multilepton,  $\gamma\gamma$



Channel	Significance	
	Observed [ $\sigma$ ]	Expected [ $\sigma$ ]
$t\bar{t}H, H \rightarrow \gamma\gamma$	-0.2	0.9
$t\bar{t}H, H \rightarrow (WW, \tau\tau, ZZ)$	2.2	1.0
$t\bar{t}H, H \rightarrow b\bar{b}$	2.4	1.2
$t\bar{t}H$ combination	2.8	1.8

# Example analysis of boost objects

## S/B: 1/53



- *B-tagging likelihood ratio*:  $\text{t}\bar{\text{t}}+\text{bb}^{\bar{\text{b}}}$ -likelihood/ $\text{t}\bar{\text{t}}+\text{lf}$ -likelihood, calculated from b-tags of jets, taking  $\eta$  and  $p_T$  dependency of b-tagging into account
- $\min \Delta R(\text{tag},\text{tag})$ : two close tagged jets in  $\text{t}\bar{\text{t}}\text{H}$  events
- *Di-filterjet mass*: peak close to Higgs boson mass

# Data/MC comparison for ttH, H $\rightarrow$ Multilepton

