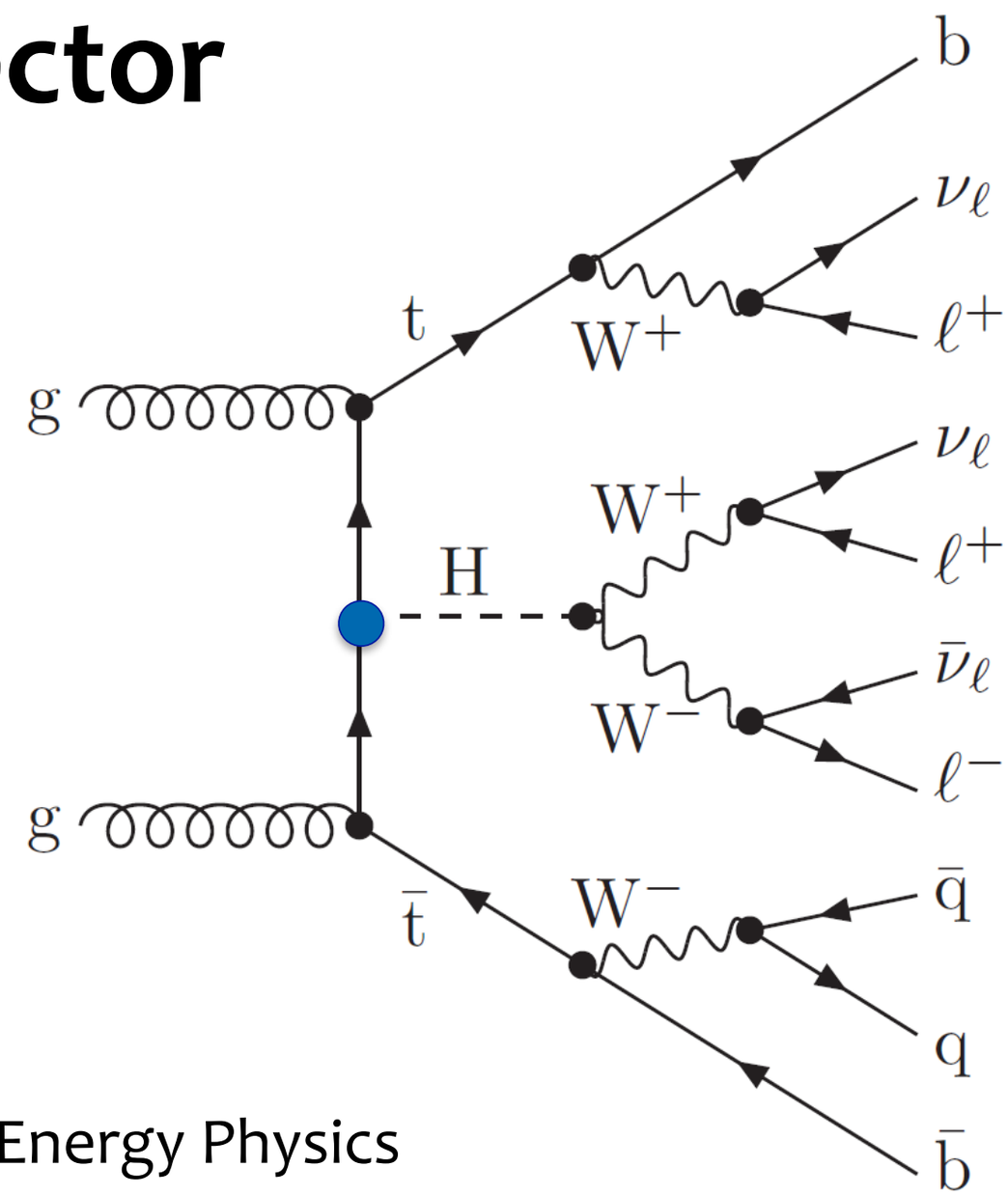
Search for Higgs bosons produced in association with top quarks in the CMS detector



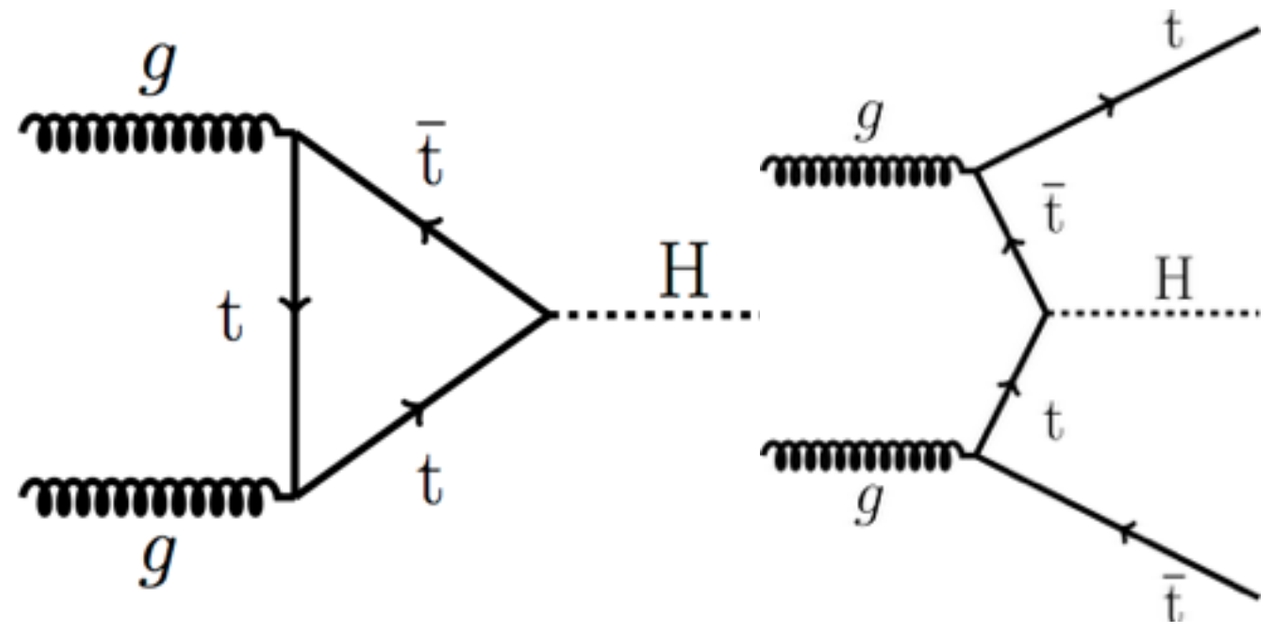
Marco Peruzzi (CERN)
on behalf of the CMS Collaboration

38th International Conference on High Energy Physics
Chicago (U.S.A.), August 4th, 2016

Introduction

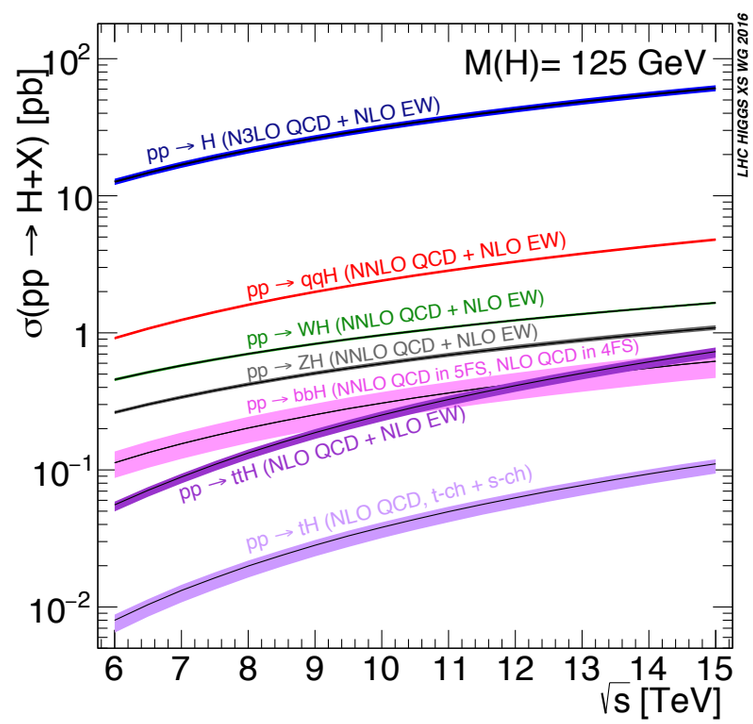
JHEP 09 (2014) 087

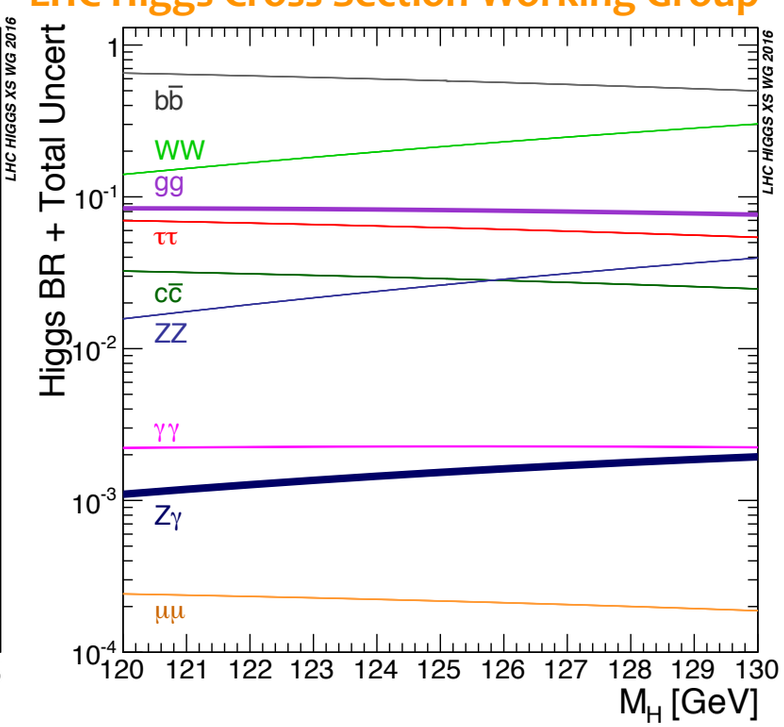
- Probing the **ttH coupling** at LHC:
  - via gluon fusion cross section, assuming no BSM particles running in the loop
  - **directly at tree level, via associated production**



- σ for ttH ~ **510 fb** at 13 TeV
- BR to bb ~ 60%, WW* ~ 20%, smaller for other final states
- **Challenging due to the presence of additional jets and leptons from top decay**

LHC Higgs Cross Section Working Group

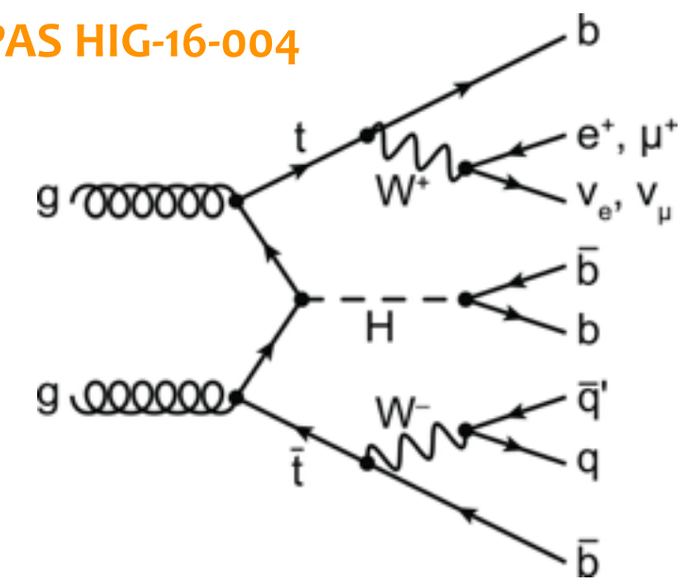


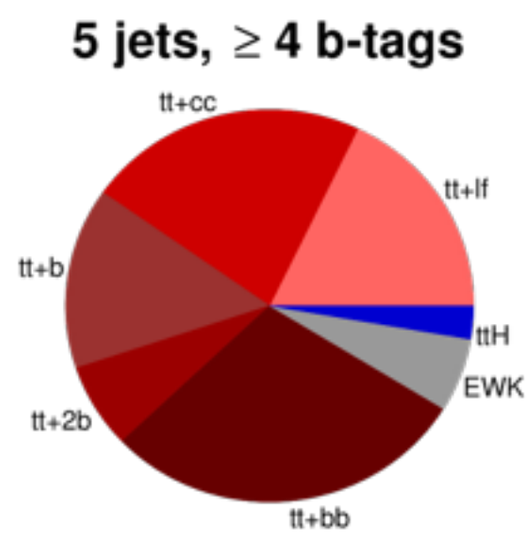


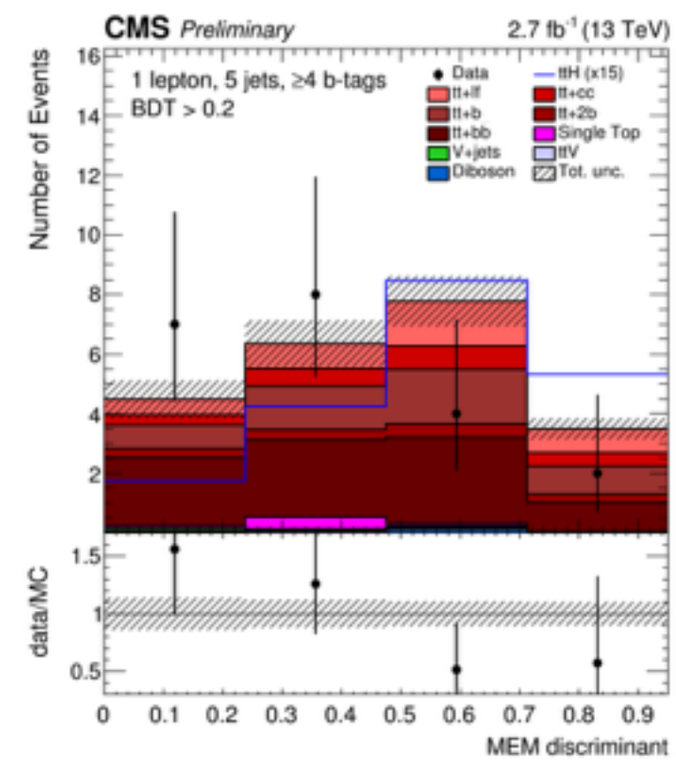
Searches for ttH at CMS

- **tt + b-jets**, targeting Higgs decay to bb
  - **high cross section x BR**, but complex multi-jet final state
  - reduce tt+jets using kinematic variables and MEM (details in C. Palmer's talk)

CMS PAS HIG-16-004





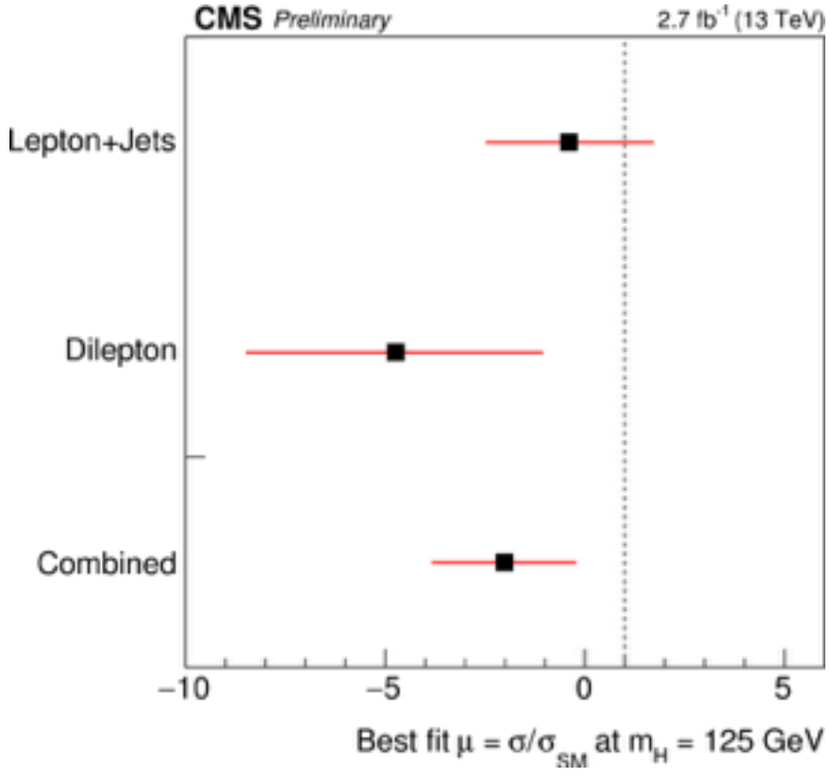


- **tt + leptons**, targeting Higgs decays to WW*, ZZ*, $\tau\tau$
  - lower rate, **low background multi-lepton final state**
- **tt + γγ**, targeting Higgs decay to γγ
  - small branching ratio, but **very clean** final state (small systematic uncertainty)

Results with 2015 data

- Higgs to bb

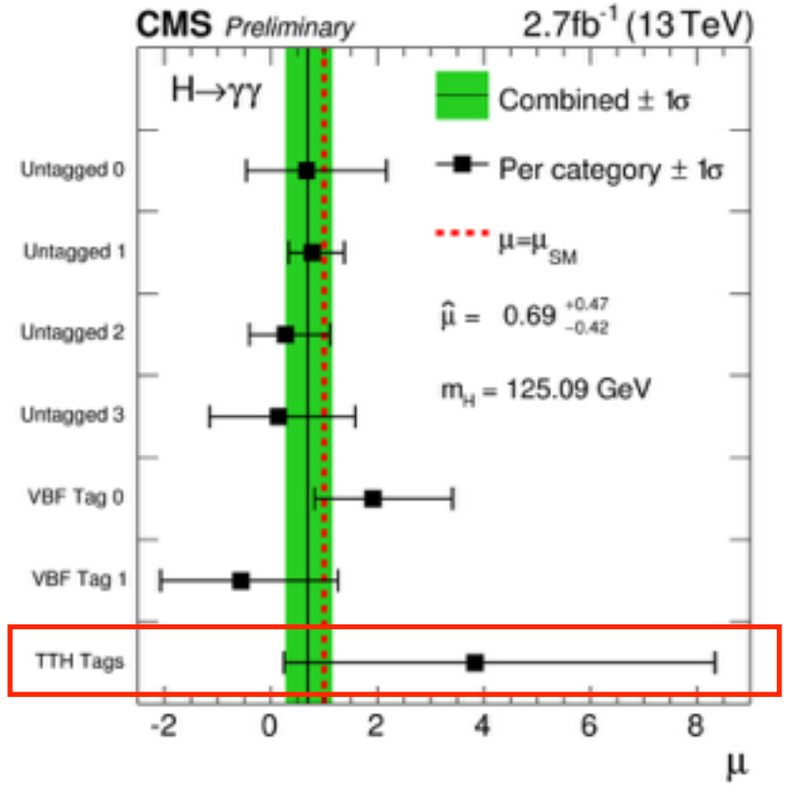
$$\hat{\mu}_{\text{obs}} = -2.0^{+1.8}_{-1.8}$$



CMS PAS HIG-16-004

- Higgs to γγ

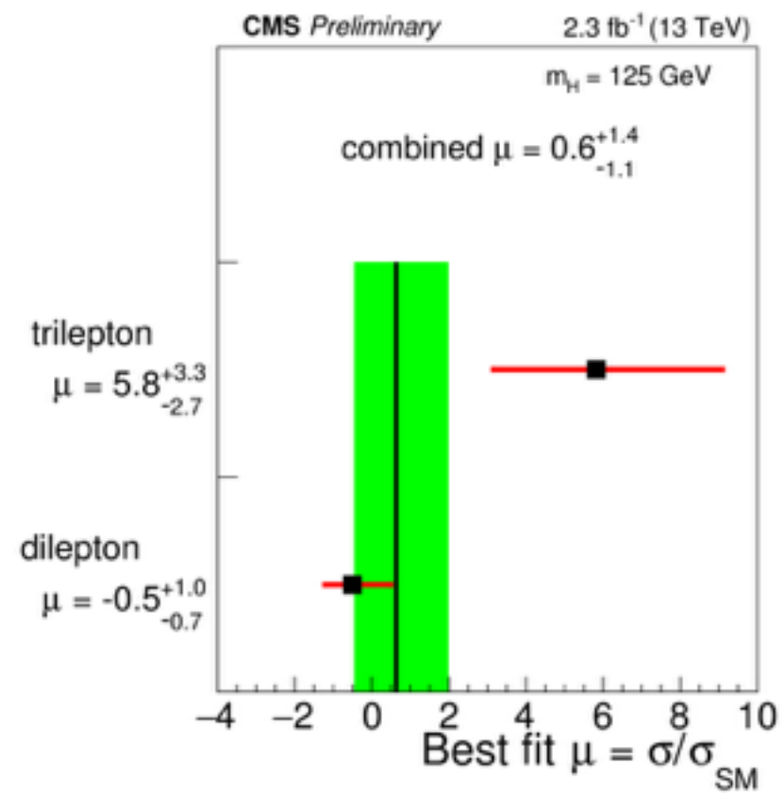
$$\hat{\mu}_{\text{obs}} = 3.8^{+4.5}_{-3.6}$$



CMS PAS HIG-15-005

- Multi-lepton

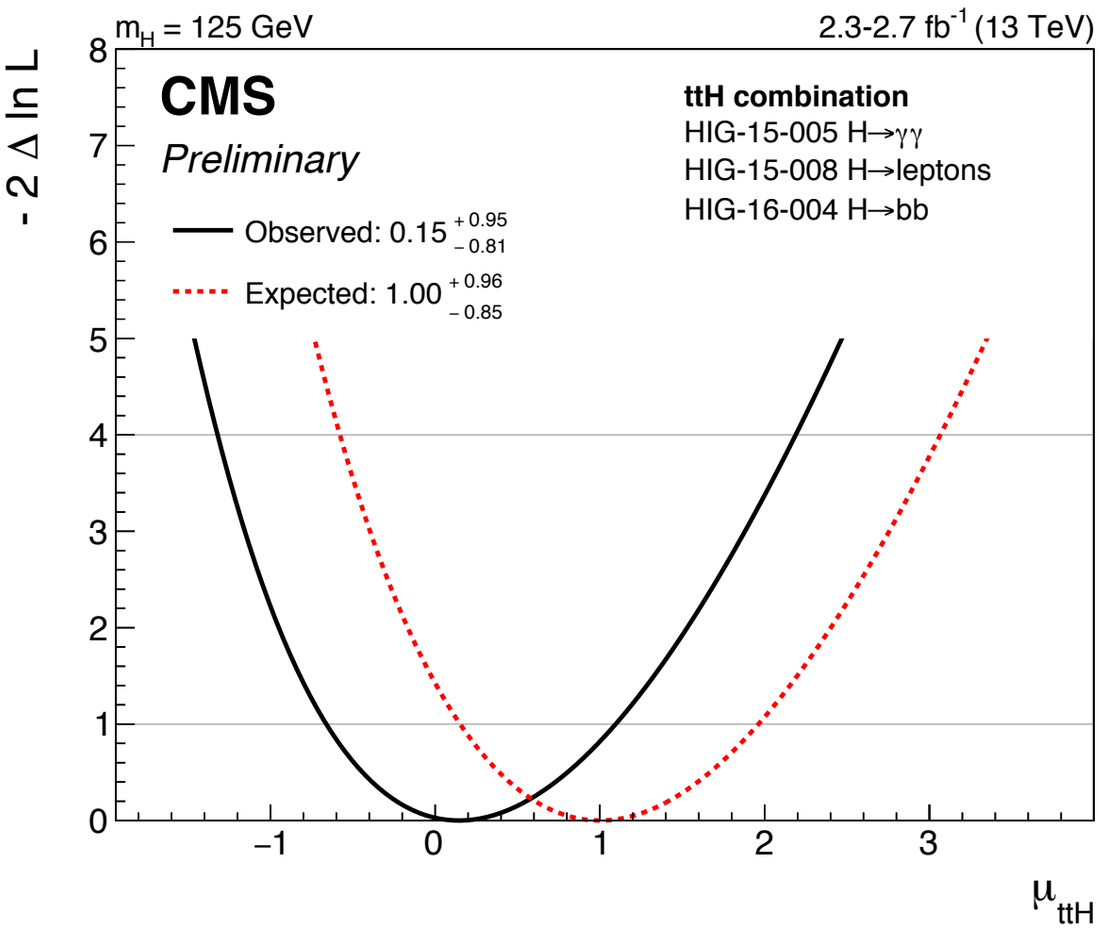
$$\hat{\mu}_{\text{obs}} = 0.6^{+1.4}_{-1.1}$$

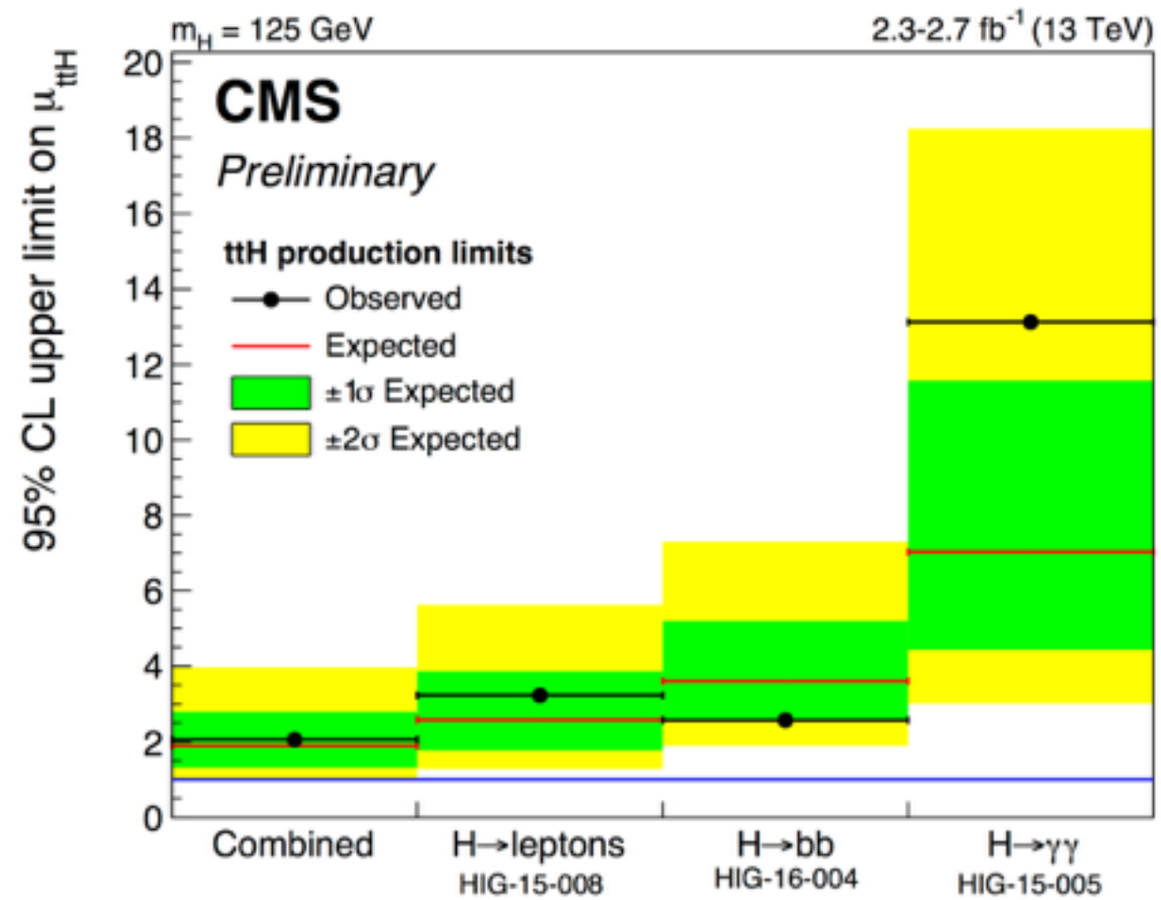


CMS PAS HIG-15-008

Results with 2015 data

Moriond 2016 CMS ttH combination (link)



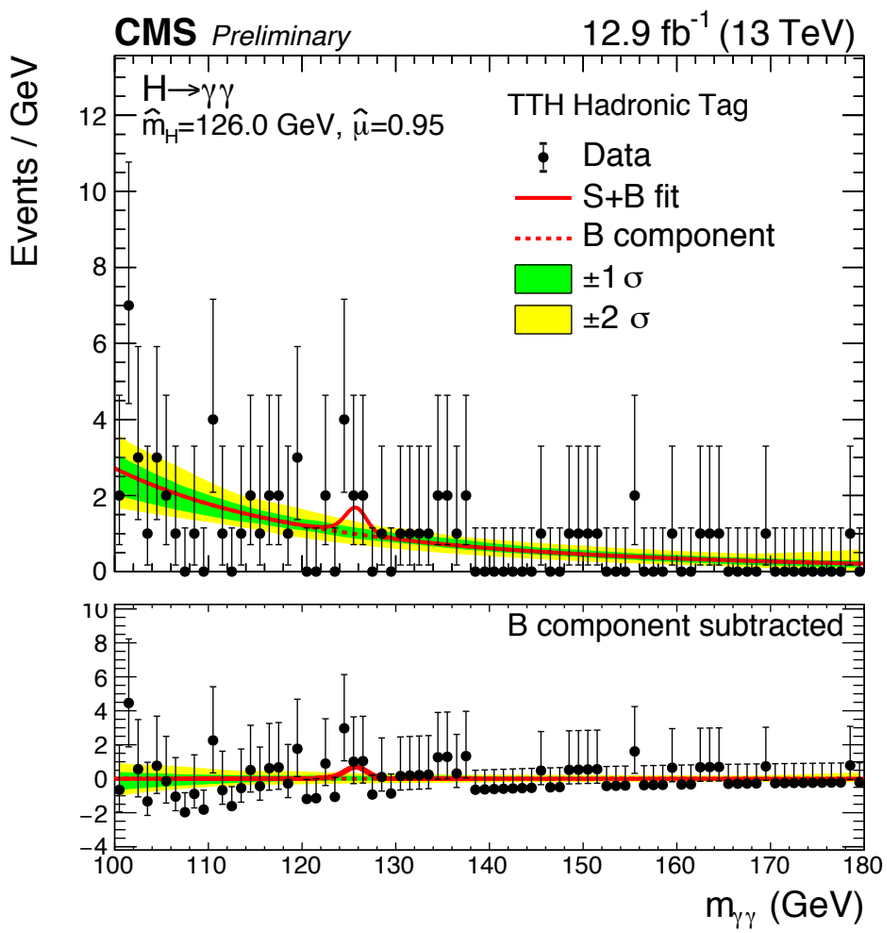


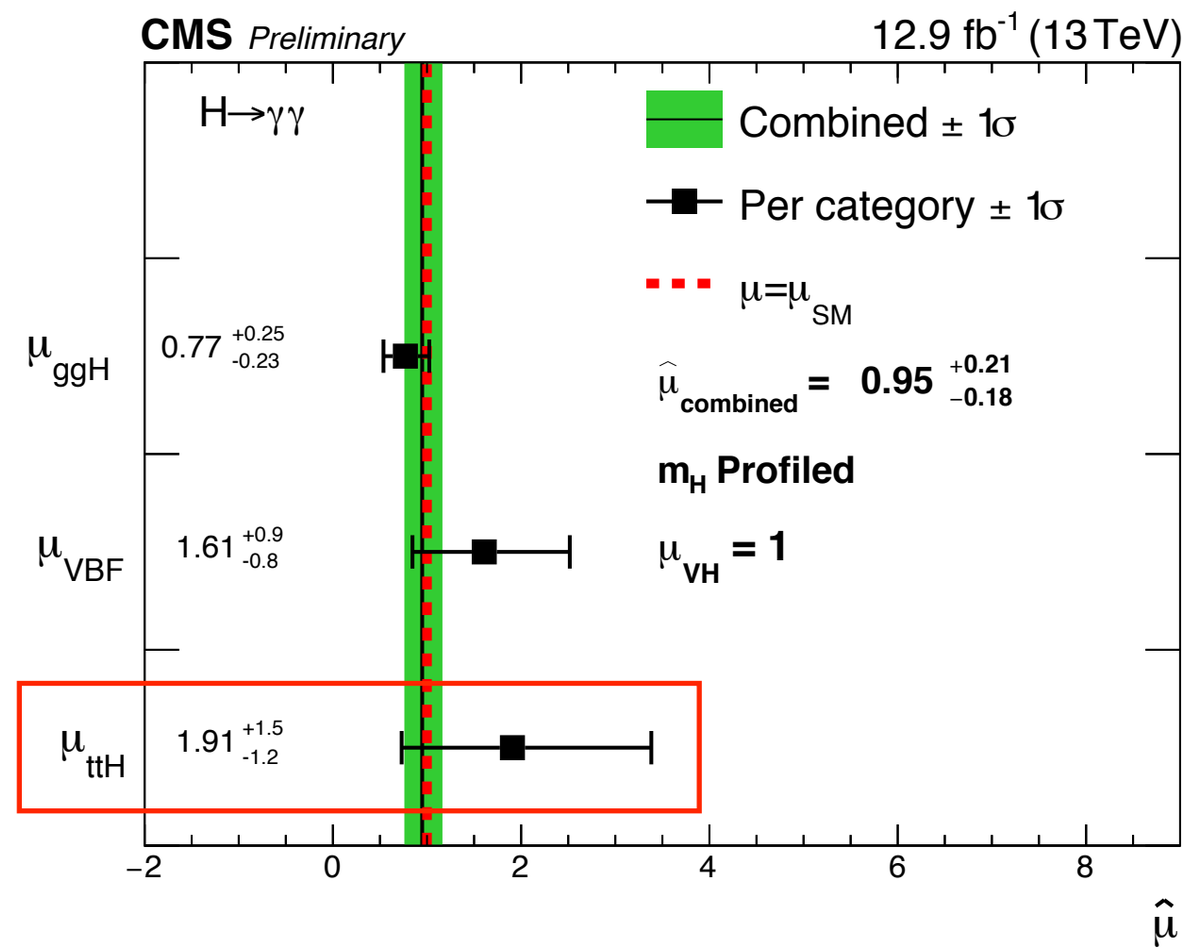
- Result of the combination of ttH searches with 2015 data: **compatible with the SM**
- **Sensitivity is about 1 x SM**

Updates with 2016 data

New results

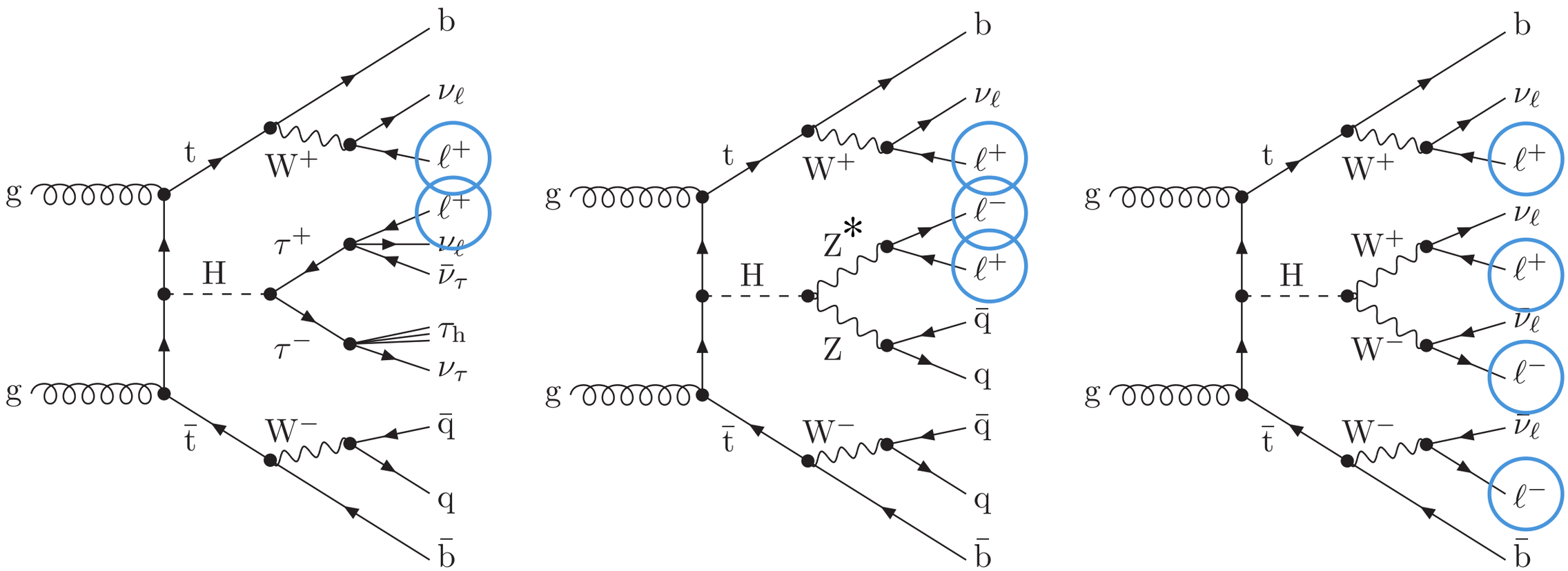
- **ttH, Higgs to γγ** (details in V. Tavolaro's talk): **tagged H→γγ categories selecting hadronic and leptonic top decays** CMS PAS HIG-16-020





- **New ttH multi-lepton result**, presented in the following CMS PAS HIG-16-022

ttH in multi-lepton final states



- Target multi-lepton final states from **Higgs decays to WW*, ZZ*, $\tau\tau$**
- Channels:
  - **two same-sign leptons** + 4 jets
  - **at least three leptons** (with Z veto) + 2 jets
- At least 2 loose or 1 medium **b-tagged jets**

Event yields

CMS PAS HIG-16-022

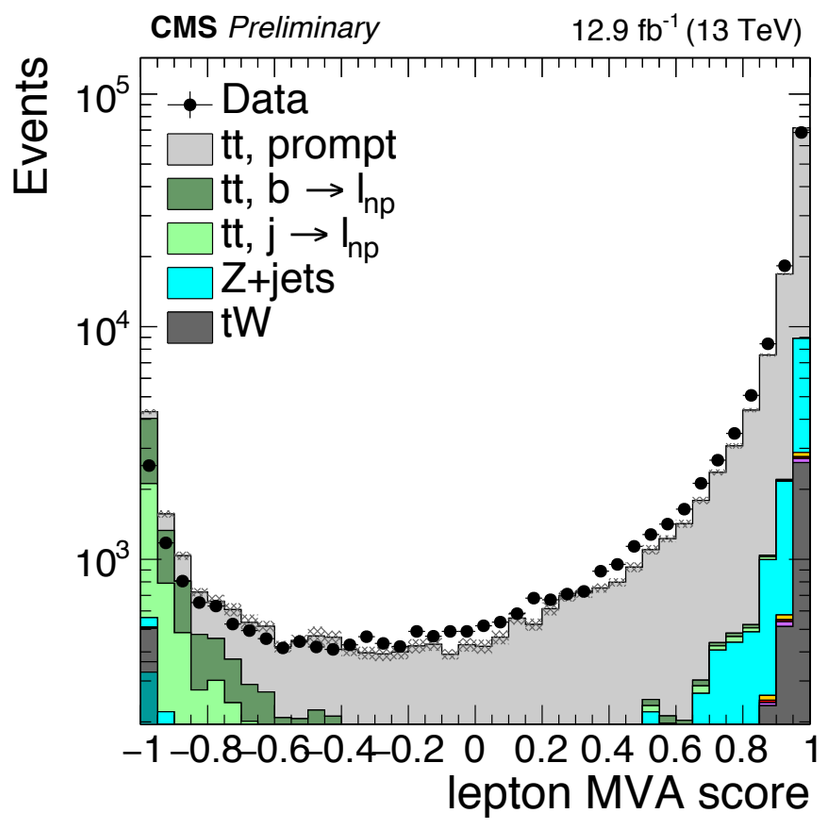
12.9 fb^{-1}, stat. unc. only

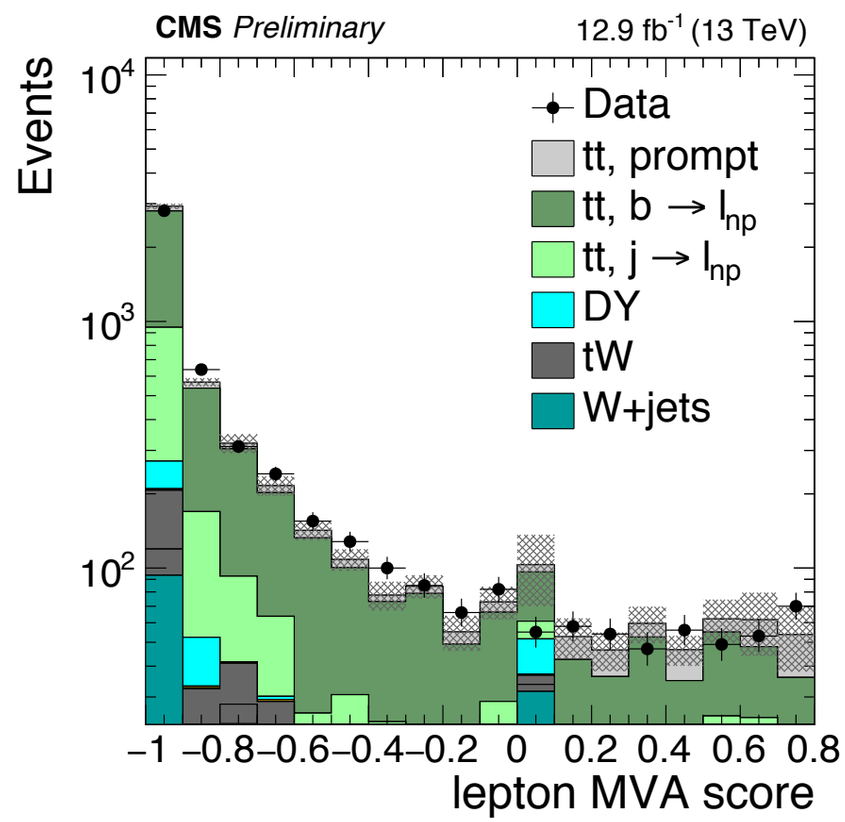
	$\mu\mu$	ee	eμ	3ℓ
$t\bar{t}W$	18.3 ± 0.9	6.8 ± 0.6	24.5 ± 1.1	12.2 ± 0.7
$t\bar{t}Z/\gamma^*$	5.8 ± 0.6	7.4 ± 0.6	15.3 ± 1.3	22.6 ± 1.0
Di-boson	1.4 ± 0.2	1.1 ± 0.2	2.6 ± 0.3	5.7 ± 0.4
tttt	0.8 ± 0.2	0.4 ± 0.1	1.5 ± 0.2	1.2 ± 0.1
tqZ	0.2 ± 0.3	0.4 ± 0.4	0.6 ± 0.6	2.7 ± 0.8
Rare SM bkg.	1.6 ± 0.3	0.5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

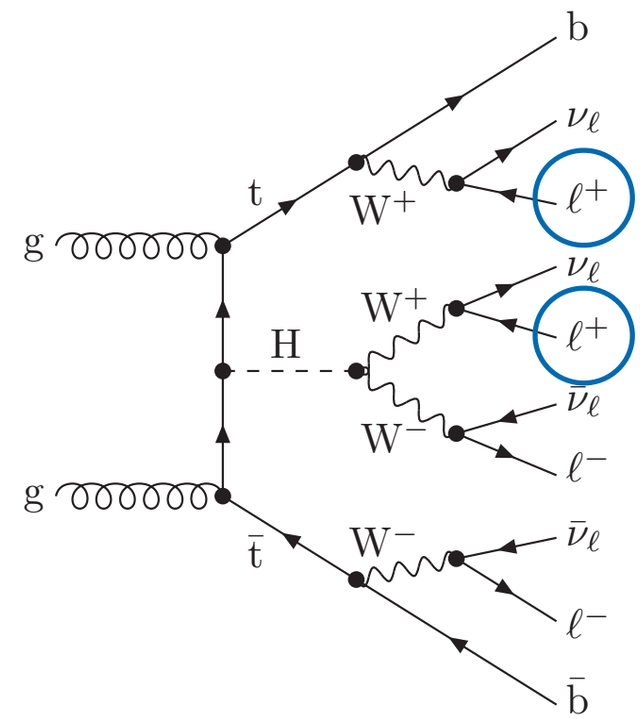
- Main sources of background:
  - **irreducible**: ttV (from MC), di-boson (validated in data)
  - **reducible**: non-prompt leptons in tt events and charge mis-ID, data-driven

Lepton selection

CMS PAS HIG-16-022

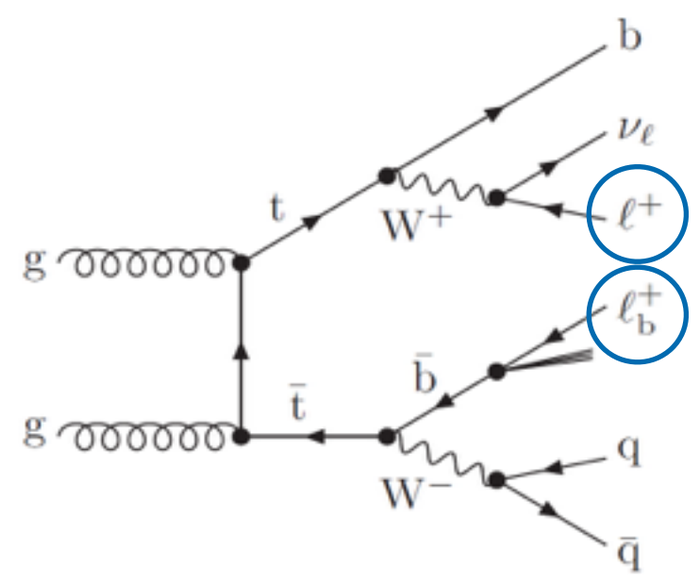






(ttH,H→WW) → $\ell^{\pm}\ell^{\pm}$

- Goal: **reject non-prompt leptons** (mainly from b-jets in tt, but also mis-identified light jets and decay-in-flight)
- **Multivariate discriminant based on isolation, vertex and identification lepton observables**
- Performance validated in data control regions
- **Data-driven** estimate of residual background using a **tight-to-loose method**



(tt)→ $\ell^{\pm}\ell^{\pm}_{fake}$

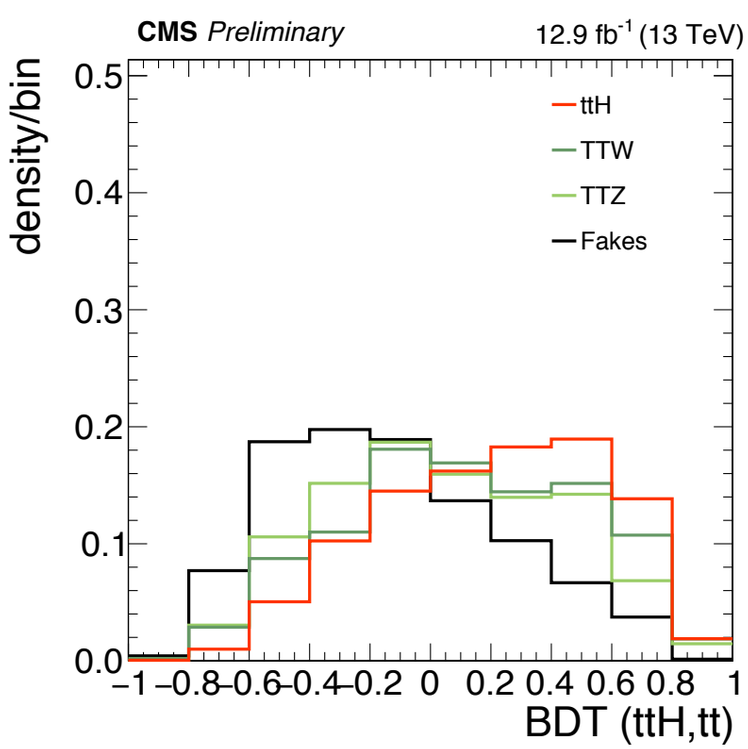
Kinematic discrimination

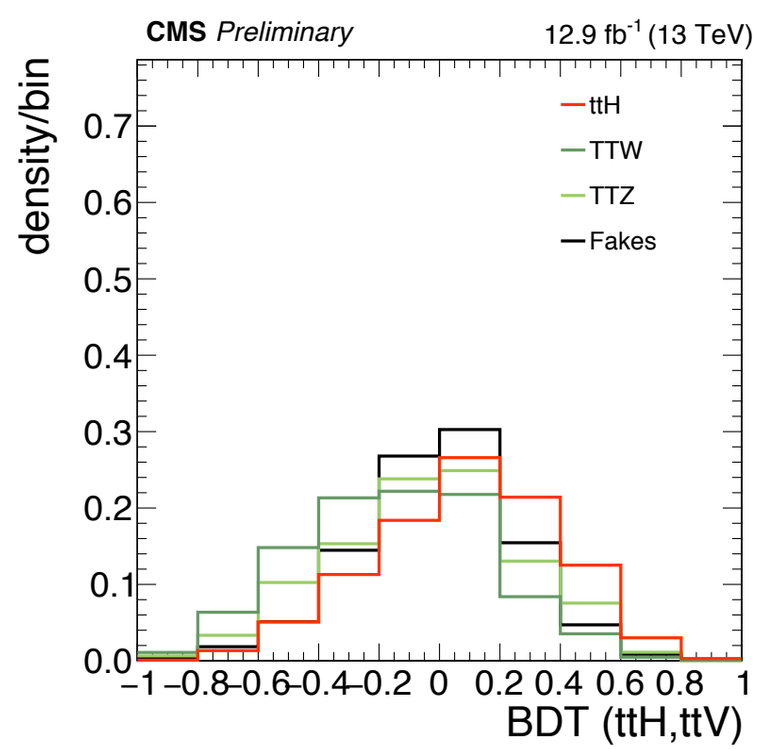
CMS PAS HIG-16-022

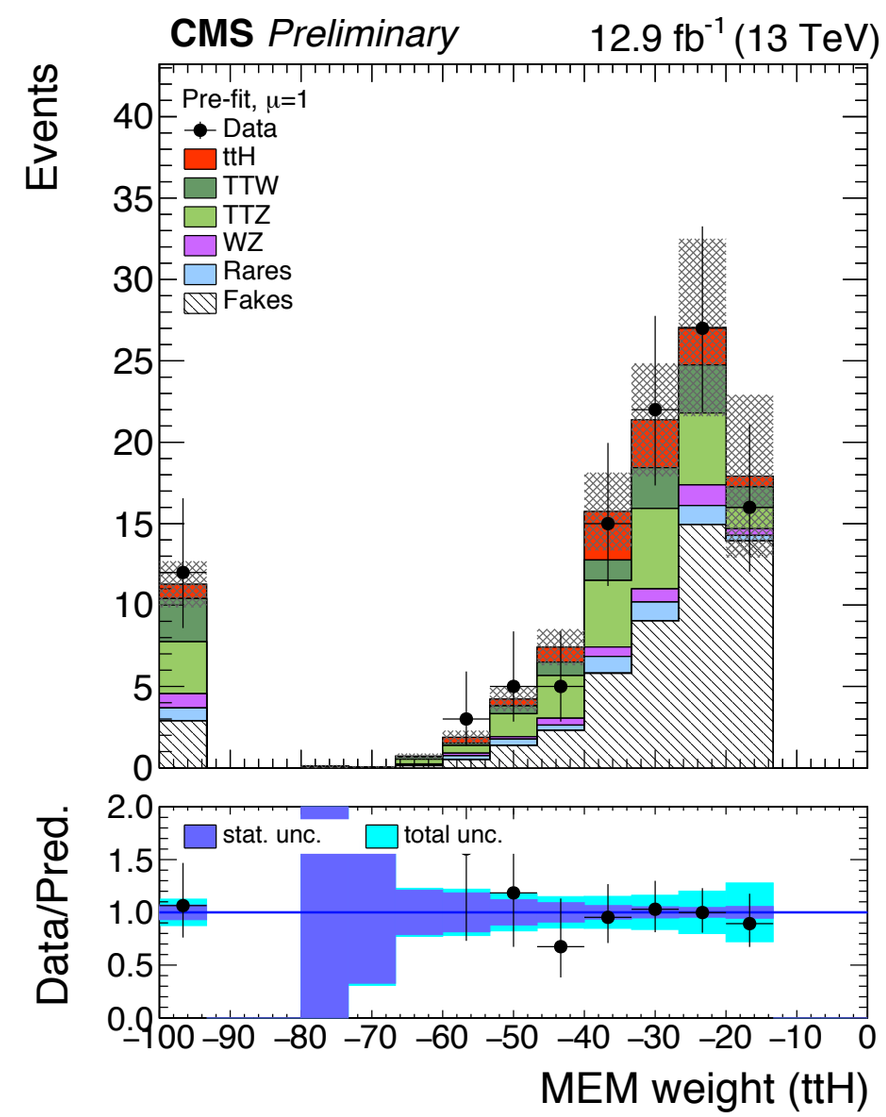
- Using **kinematic observables to improve discrimination against tt and ttV events**: jet multiplicity, lepton/jet angular separation, MET, lepton p_T
- New for 2016 analysis **in 3l: matrix element weights for ttH and ttV hypotheses**

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

- Separate **BDT discriminators** against tt and ttV:







Signal extraction

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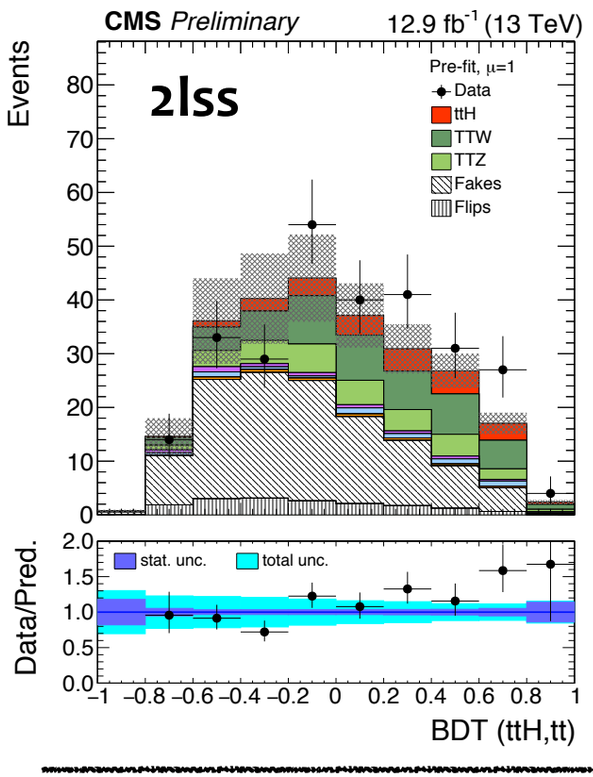
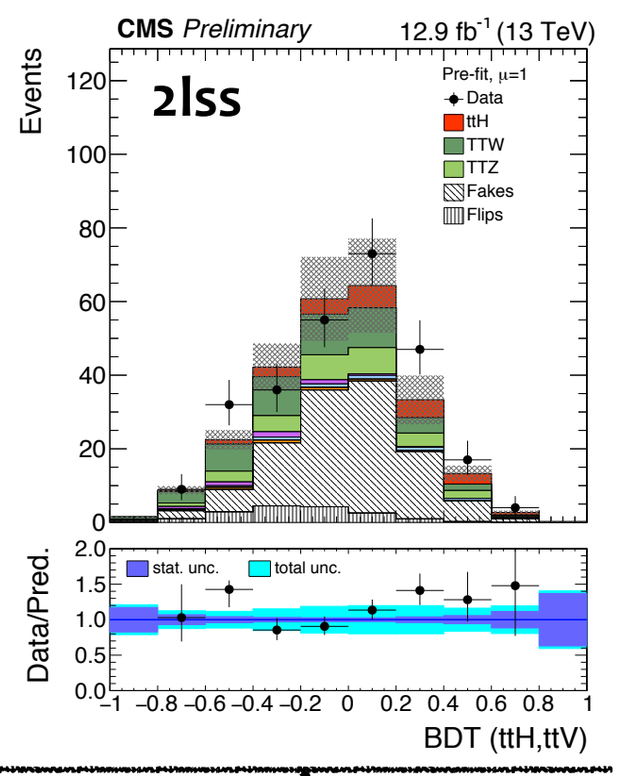
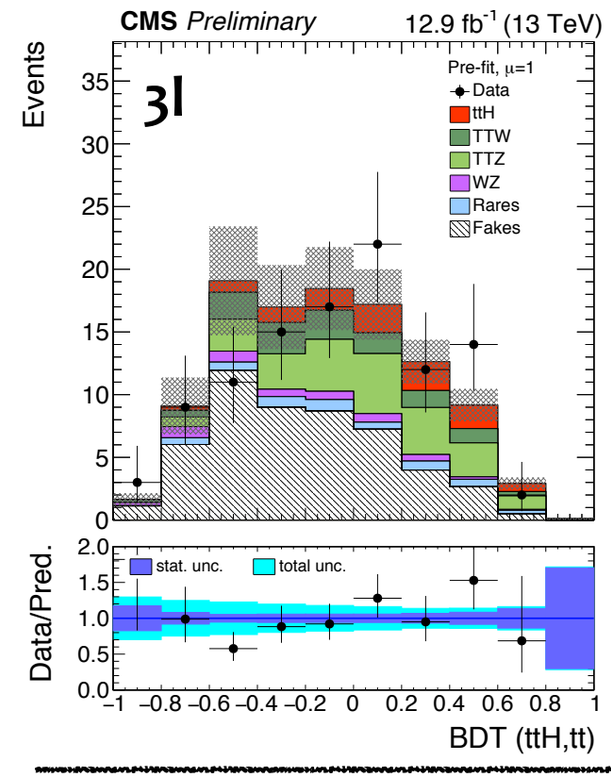
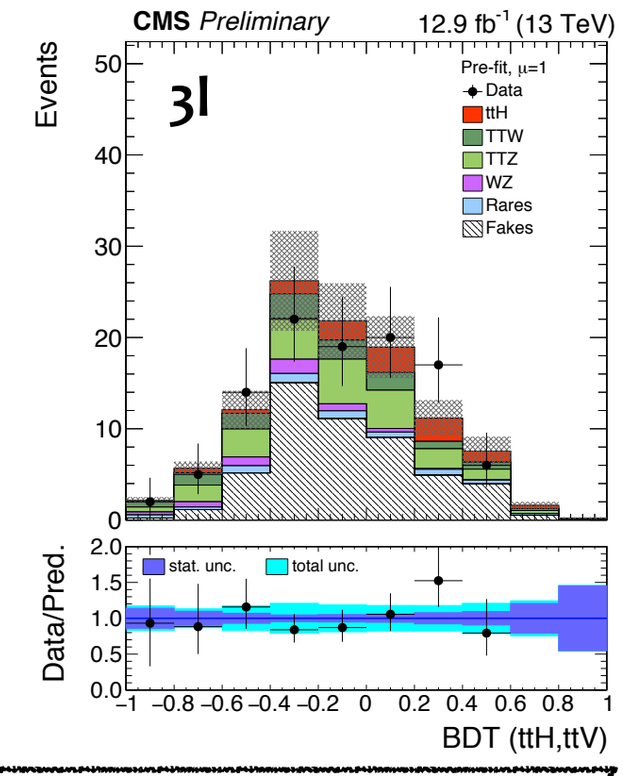
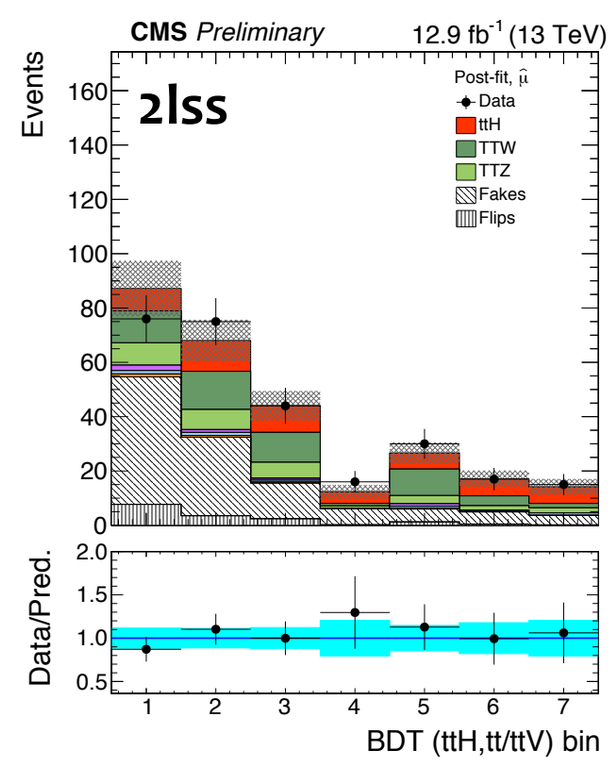


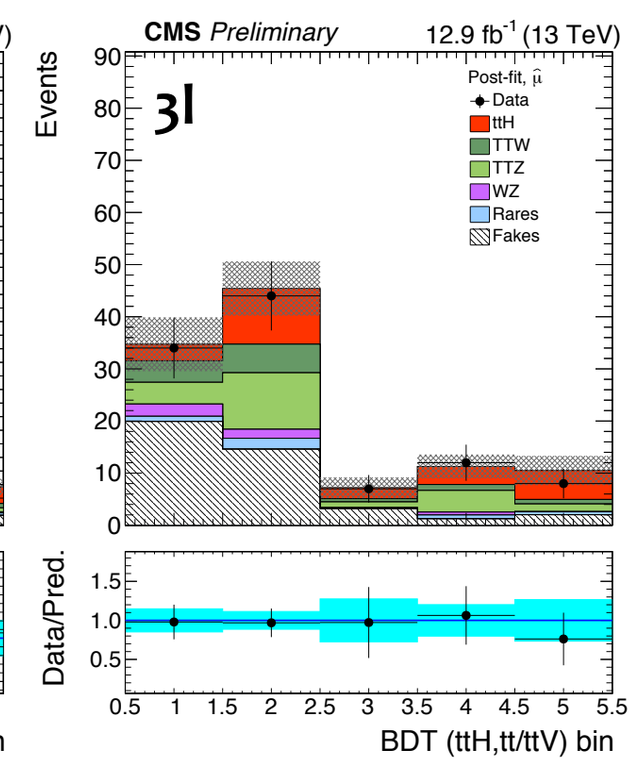




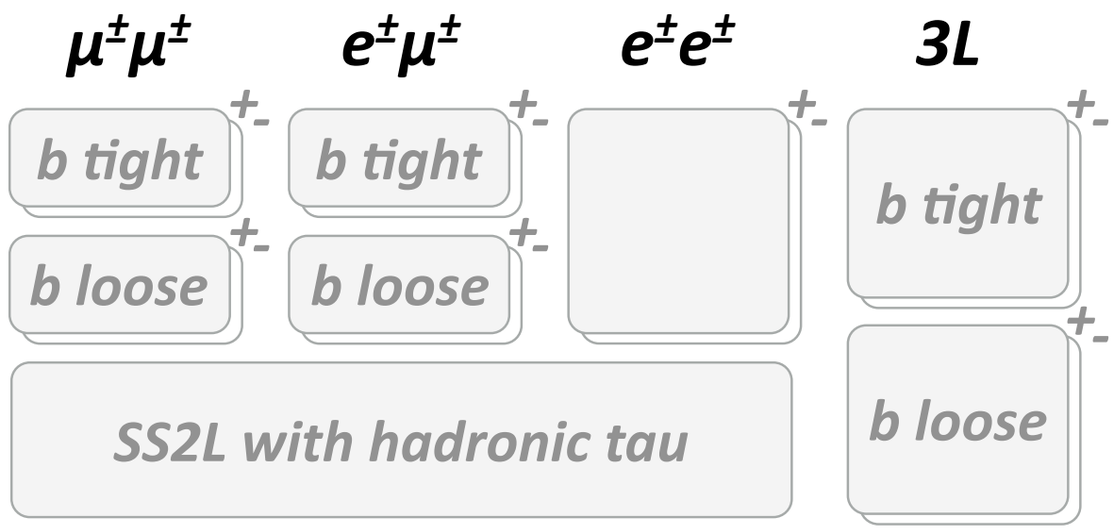


- The signal is extracted via a **2-dimensional fit to the BDT discriminators:**





Event categorization



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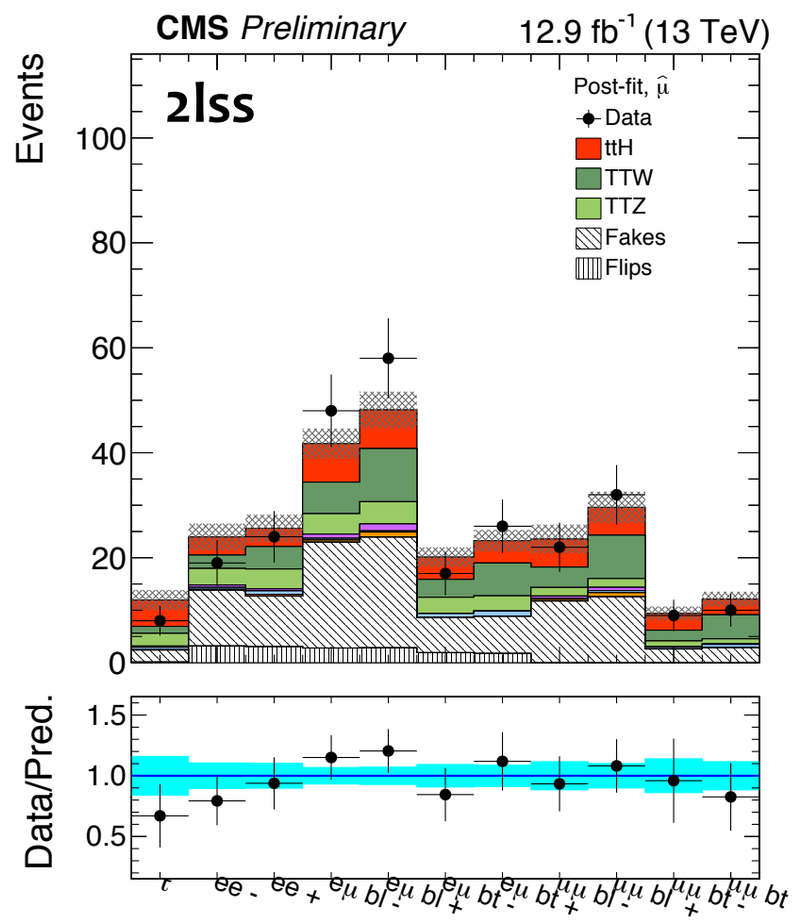
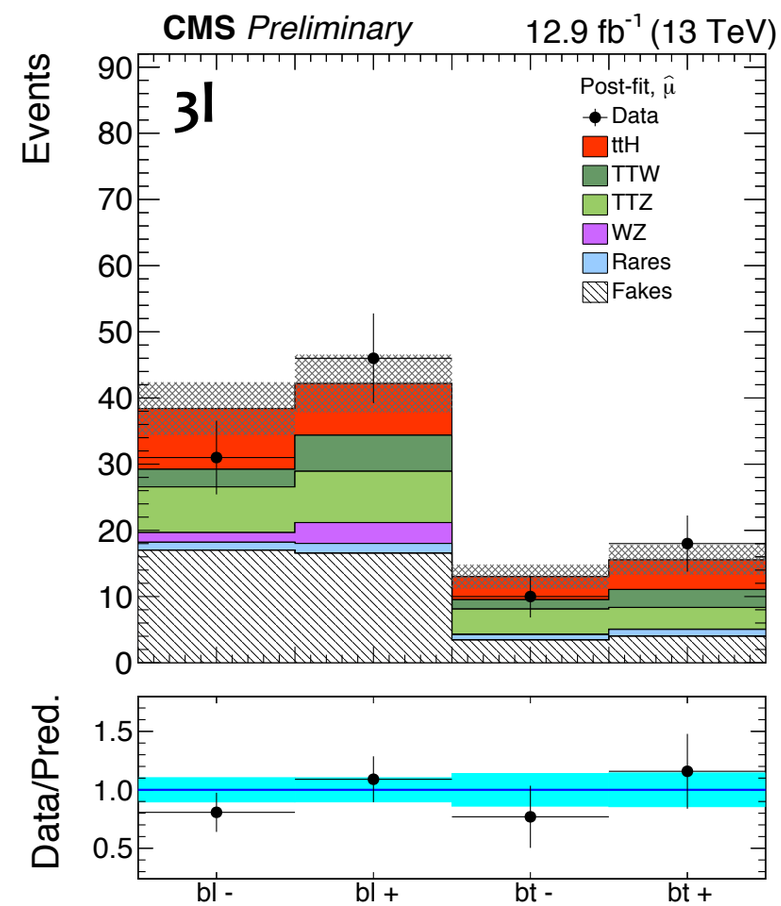
- **Further categorization** based on **lepton flavor, presence of b-jets, hadronically-decaying τ, lepton charge**

- Post-fit yields in each category:
- Main systematic uncertainties:
  - lepton selection efficiency
  - fake rate measurement for background estimate





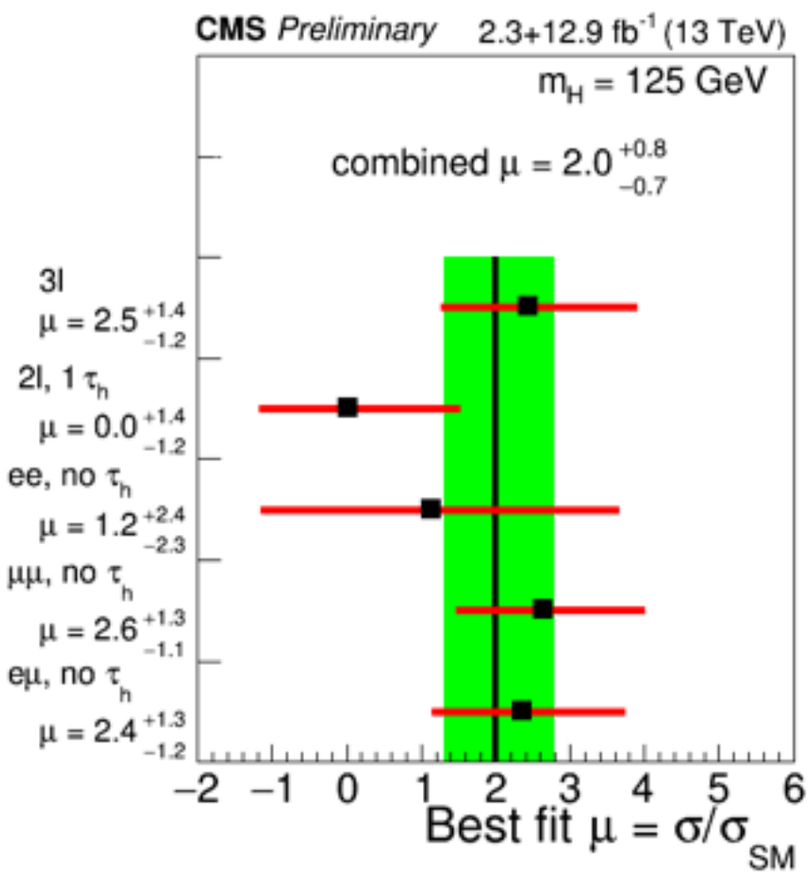
New results

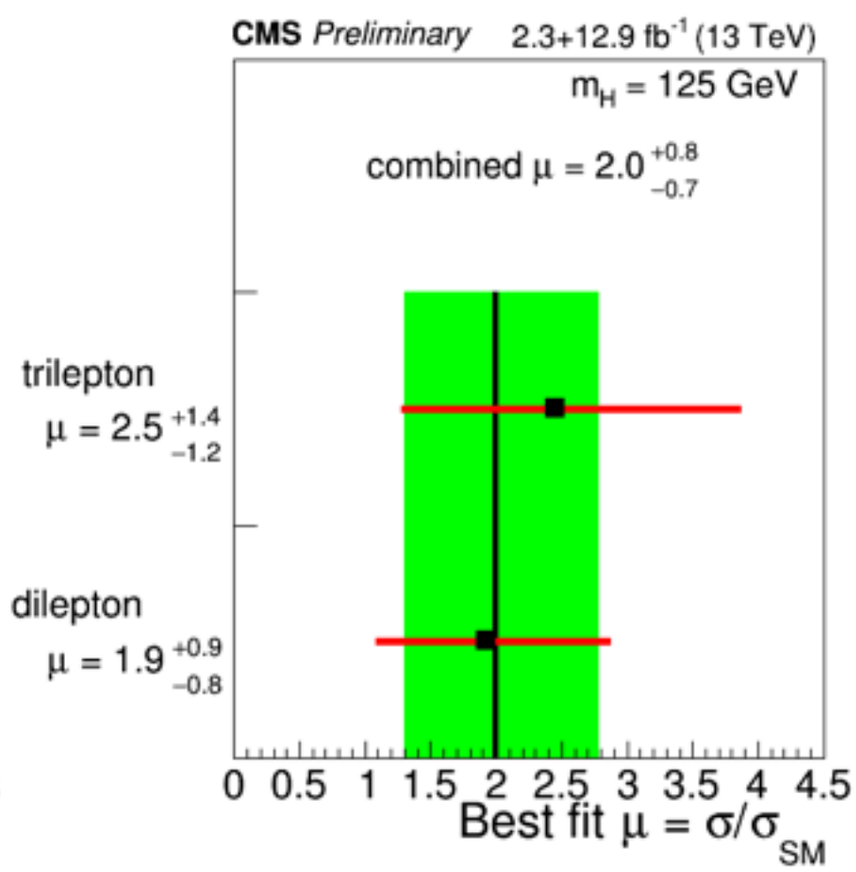
Results

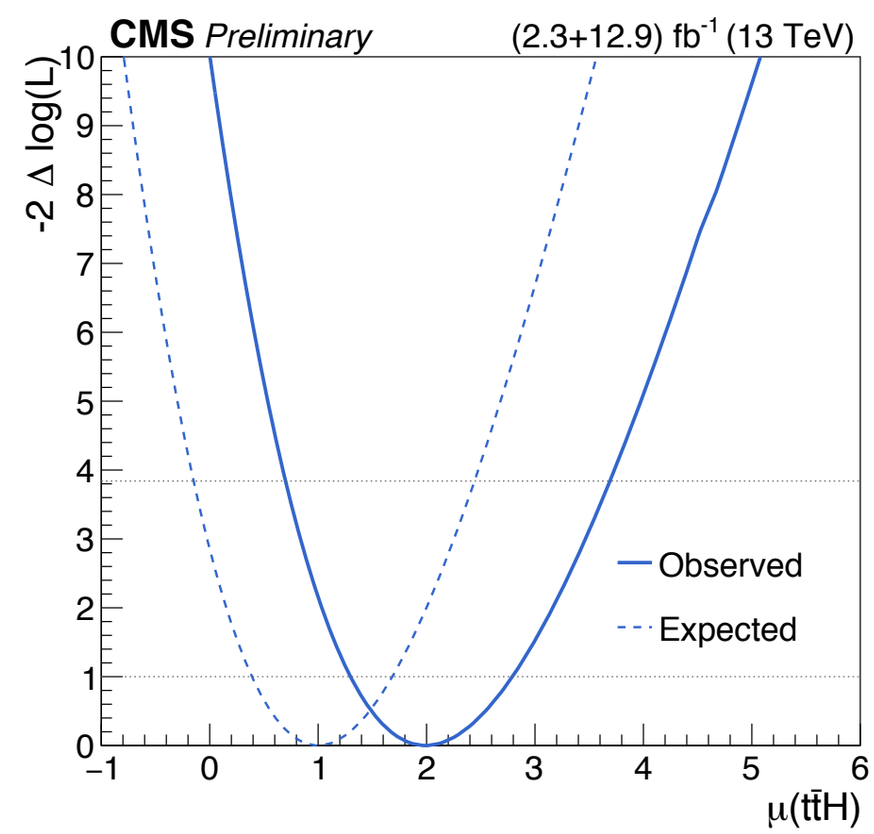
CMS PAS HIG-16-022

- Results with **2016 dataset** and from the **combination with the ttH multi-lepton 2015 result:**

Category	Obs. limit	Exp. limit $\pm 1\sigma$	Best fit μ $\pm 1\sigma$
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	$1.3^{+0.6}_{-0.4}$	$2.0^{+0.8}_{-0.7}$







Outlook

- We have presented studies of associate production of the Higgs boson and top quarks with the CMS experiment

- **Probing the Higgs coupling** with the top quark at tree level
- **Challenging final states** with jets and leptons from top decay
- **Advanced methods** are used to improve the signal purity and discriminate it from tt+jets and ttV background processes

- Combination of 2015 results is in agreement with the SM expectation
- Updated results:
  - **ttH multi-lepton:** $\mu = 2.0^{+0.8}_{-0.7}$ (2015 + 2016 combination)
  - **ttH, H→γγ:** $\mu = 1.9^{+1.5}_{-1.2}$ (2016 dataset)

Further discussion in E. Ntomari's poster later this week.