Measurements of ttH production at CMS

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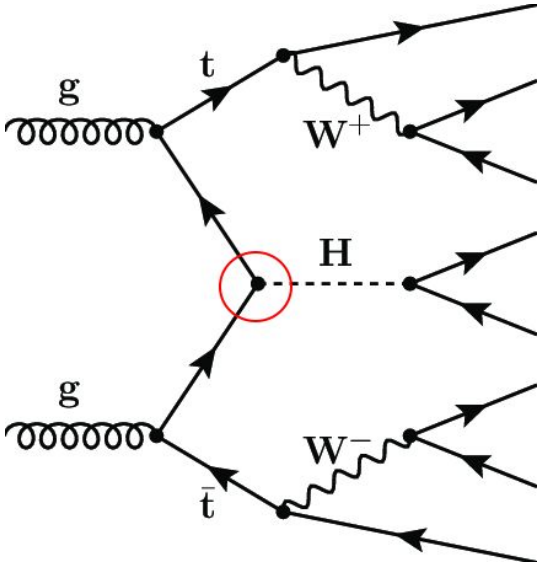
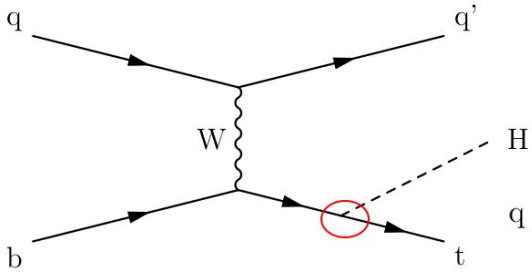
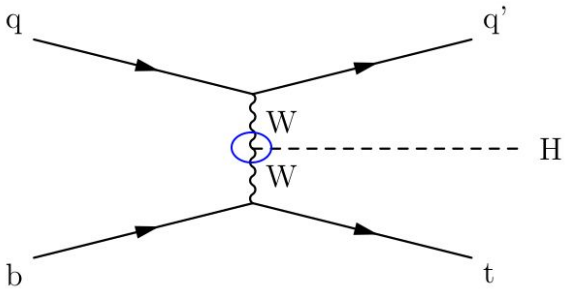
Introduction

- ttH and tH are crucial for understanding the **top-Higgs coupling**
  - Leading processes with this **coupling at tree level**
  - Complementary to gluon fusion measurements
- Tiny cross section compared to other SM processes:
  - ttH → ~500 fb
  - tHW and tHq → ~70 fb, 15 fb







- tH processes give additional information on the relative sign of k_t and k_W
- k_t would give an enhancement of the tH cross section by a factor of ~10

Measurements per final state

- ttH yields to a rich variety of final states

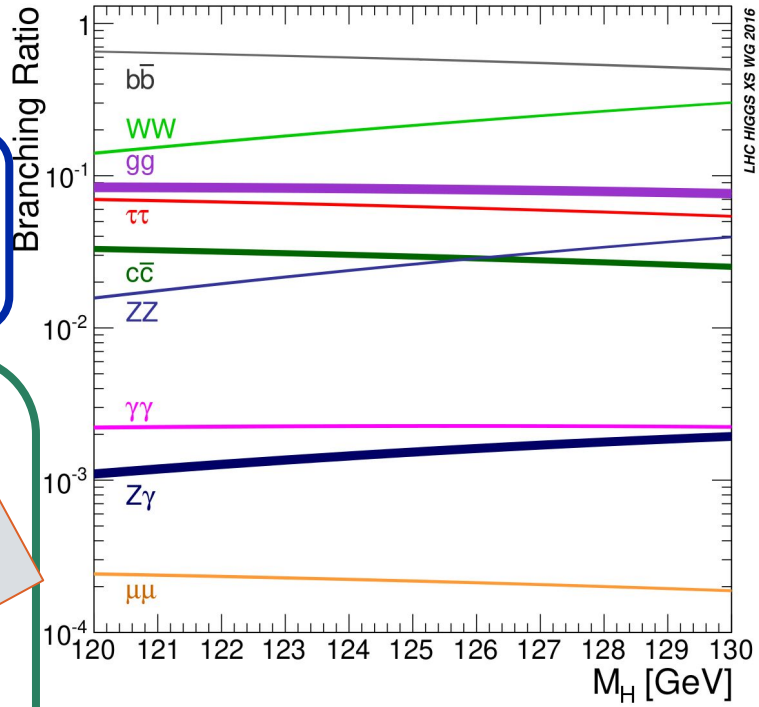
- **H → bb**
  - Large background, maximal branching ratio
  - HIG-18-030

2016+2017, ~70 fb^{-1}

- **H → WW*, ττ (multilepton channel)**
  - Moderate background, intermediate branching ratio, **5σ sensitivity**
  - Eur. Phys. J. C 81 (2021) 378
- **H-> ZZ*, γγ**
  - Very small branching ratio
  - Very small background, clear proxy to the Higgs kinematics, **5σ observation**
  - Phys. Rev. Lett. 125, 061801 (2020)

Covered in this talk

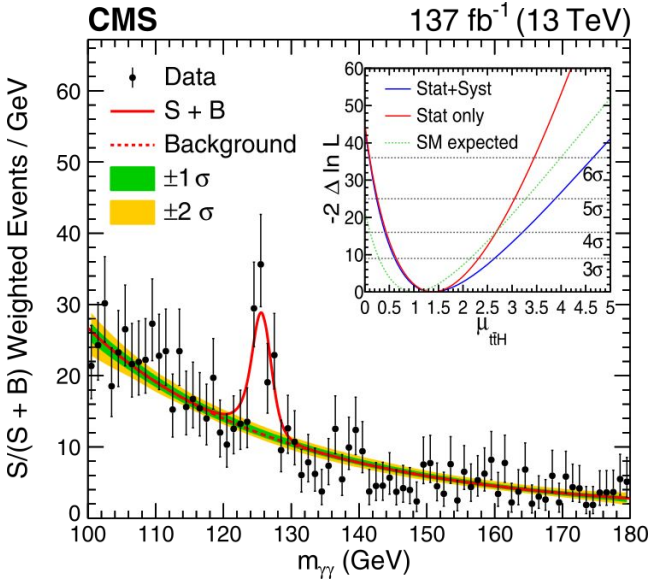
Full run 2, 137 fb^{-1}

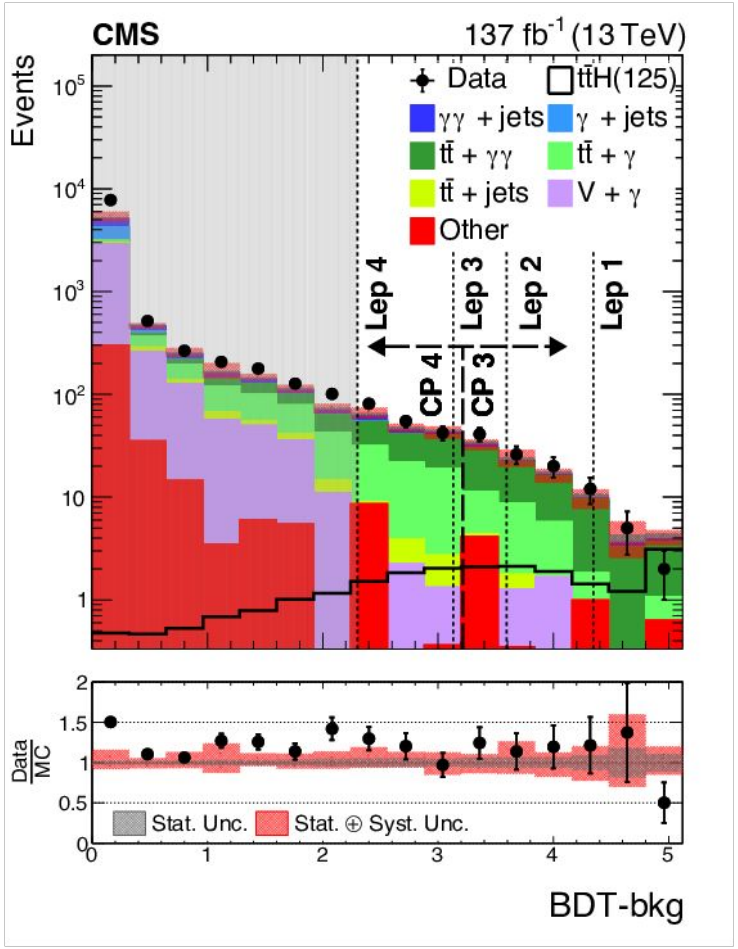


- Combination of channels provided first time observation of the process
  - PRL 120, 231801 (2018)

tt(H→γγ) analysis

- Events categorized in leptonic and hadronic depending on the decay of the top quarks
- Events categorized according
  - BDT background
  - CP odd vs CP even
- Signal obtained by fitting $m_{\gamma\gamma}$ in all the categories

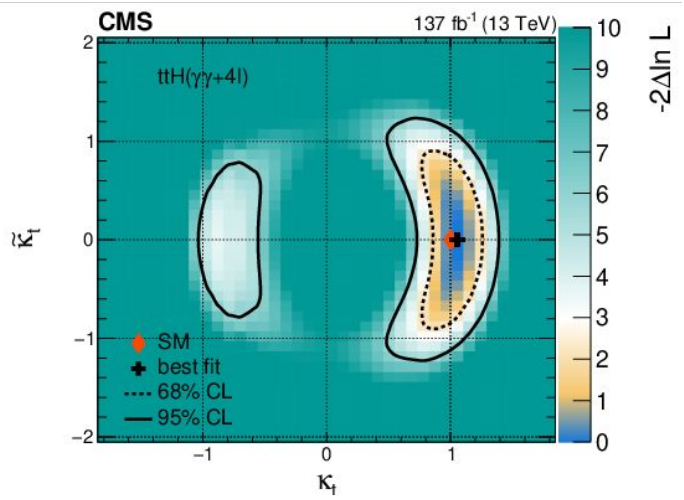




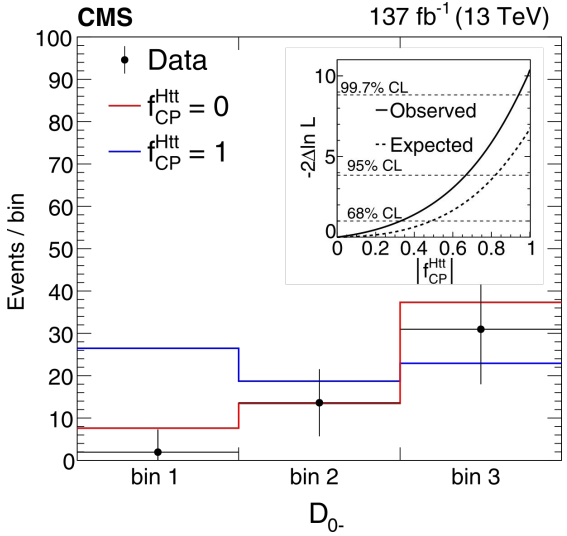
tt(H→γγ) interpretation

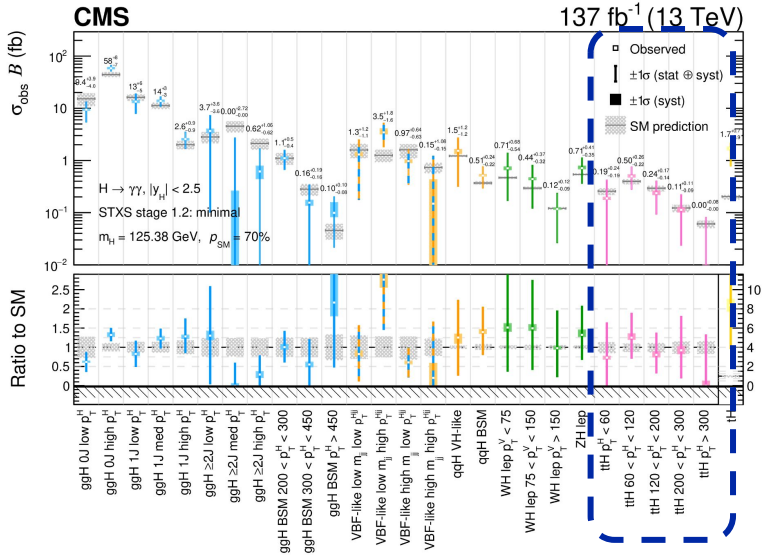
- Observed ttH signal strength $\mu_{ttH}=1.38^{+0.36}_{-0.29}$
- Expected (observed) significance: 6.6 s.d. (4.7s.d.)
- **Observation** of ttH production in this channel
- Limits on the presence of CP-odd top Yukawa interacti
- All results consistent with the SM

$$\mathcal{A}(Htt) = -\frac{m_t}{v}\bar{\psi}_t(\kappa_t + i\tilde{\kappa}_t\gamma_5)\psi$$



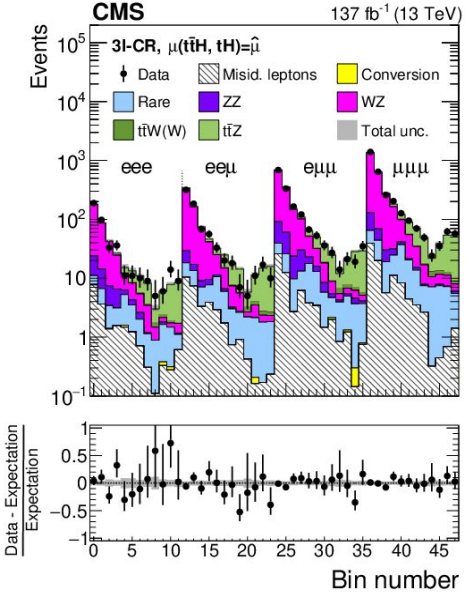
Including combination with HZZ

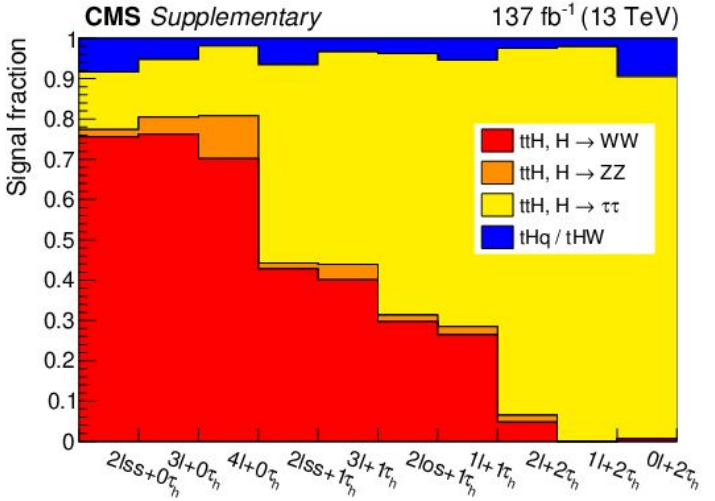


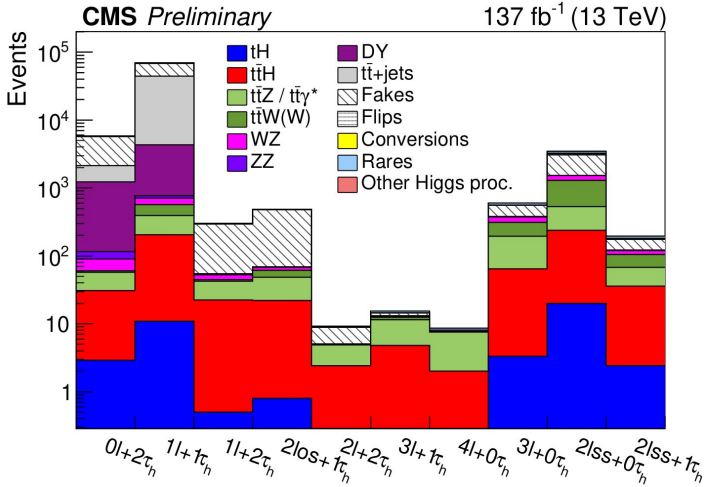


ttH multilepton (ttH→ WW*, ττ)

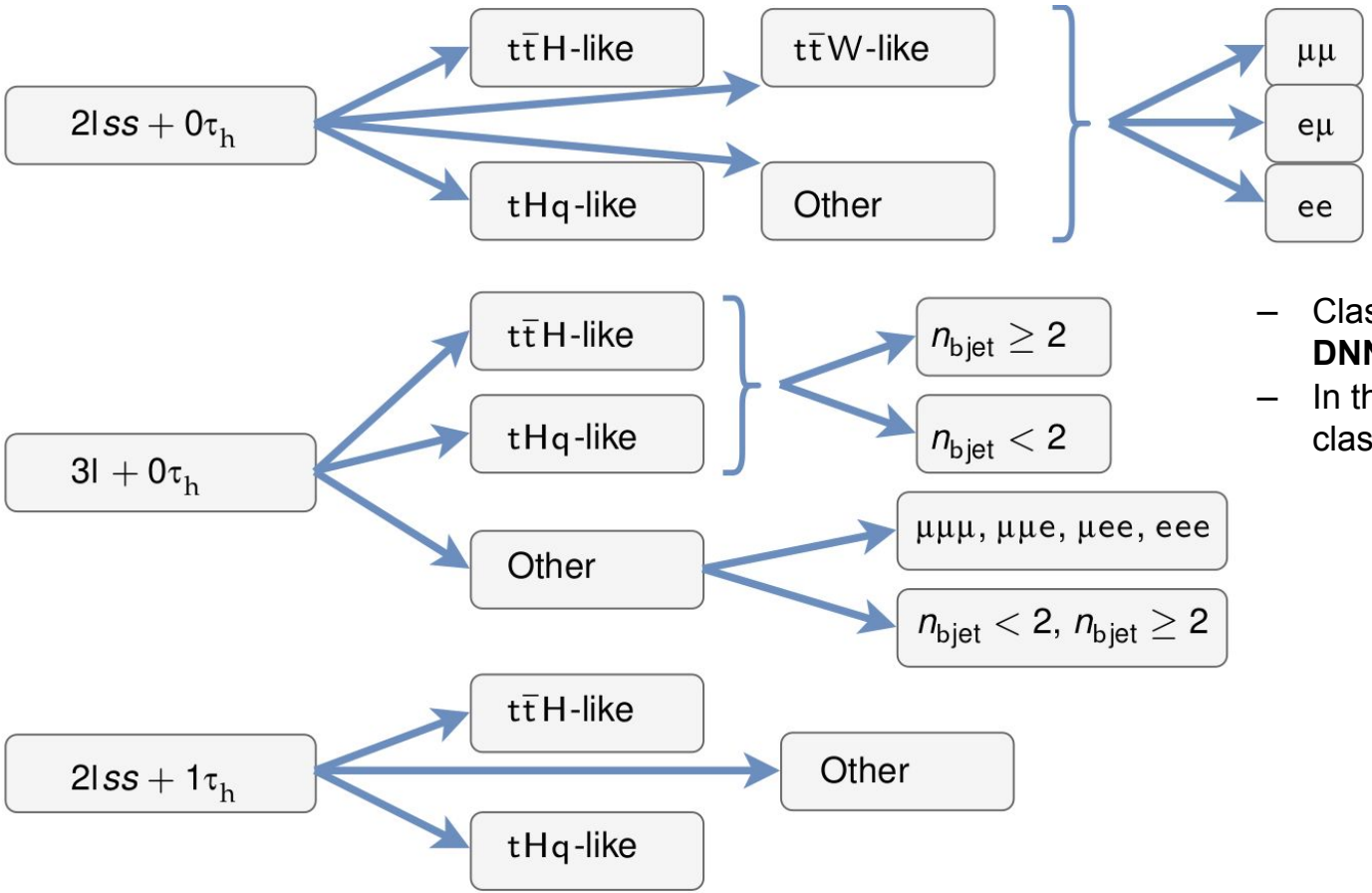
- **Measuring both ttH and tH**
- Varied final states, depending on the decay modes of the Ws and τ
- **10 disjoint regions** based on lepton and τ_h multiplicity
- Selection still **dominated by backgrounds**
- 2lss+0τ_h, 2lss+1τ_h and 3l+0τ_h allow to have **sensitivity to tHq production**
- Use of control regions to constrain irreducible backgrounds







Event classification

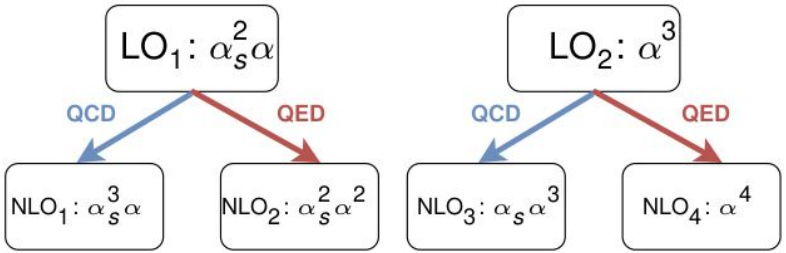


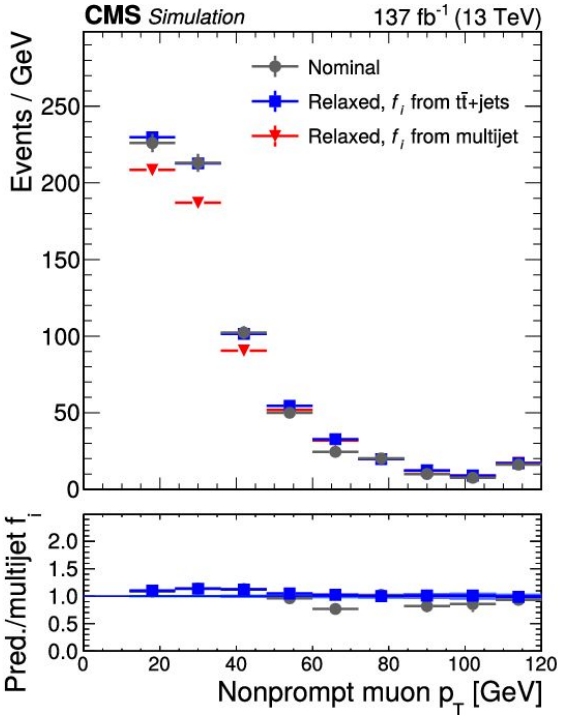
- Classification based on **multiclass DNN** score and **event topology**
- In the rest of the regions, events are classified based on a **BDT score**

Background estimation

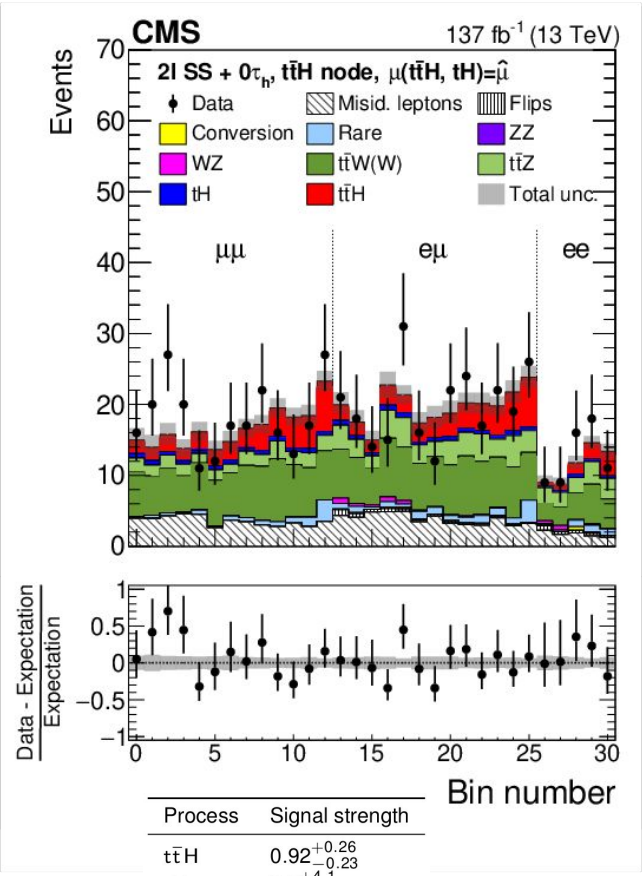
- Combination of data driven and MC-based background estimations
- Irreducible backgrounds are estimated using state-of-the-art MC simulations
- Their normalization is freely floating in the signal extraction fit → no assumption is made on the normalization

- ttW kinematics are simulated with MC simulations that include subleading NLO_3 corrections

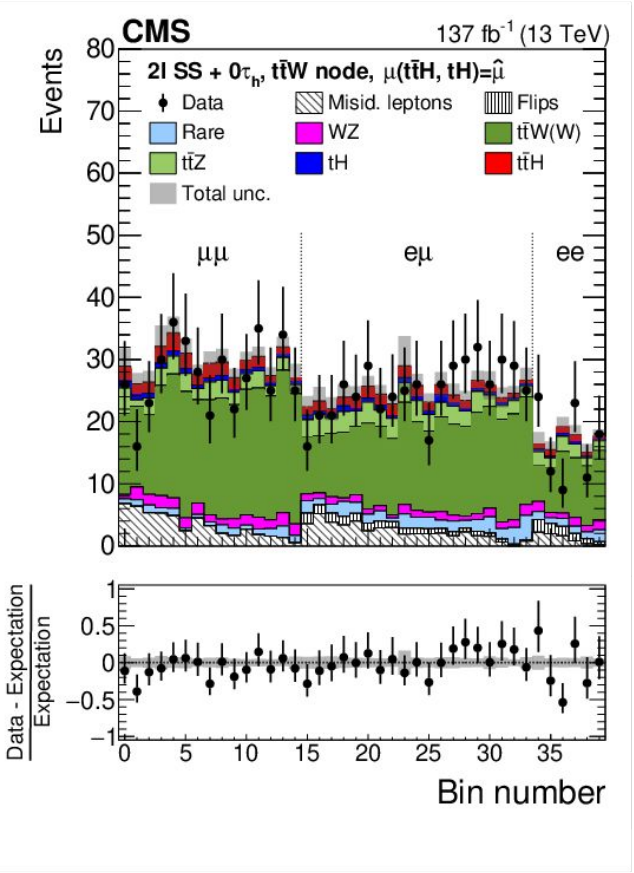




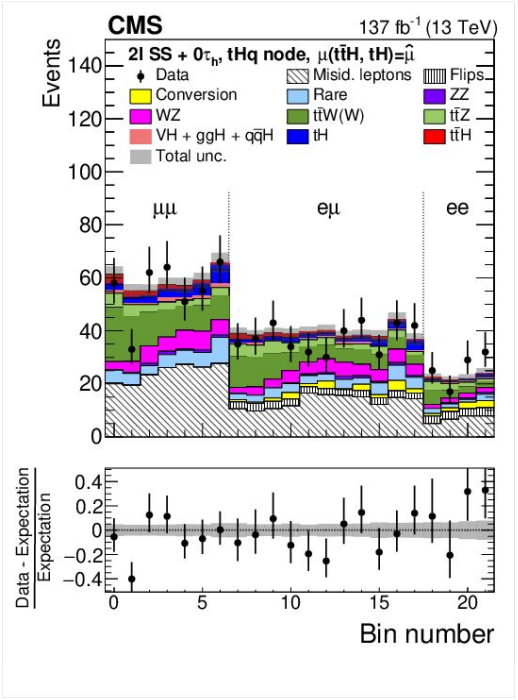
Results



Process	Signal strength
$t\bar{t}H$	$0.92^{+0.26}_{-0.23}$
tH	$5.7^{+4.1}_{-4.0}$
$t\bar{t}Z$	1.03 ± 0.14
$t\bar{t}W$	1.43 ± 0.21

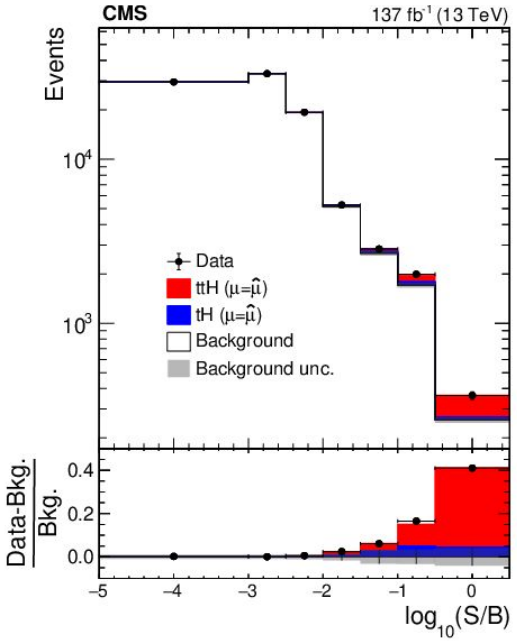


- Significant presence of signal in the dedicated signal region
- Very pure selection of ttW production in its dedicated control region



Results

- Signal extracted by fitting yields in all signal regions
- Significance of ttH production: obs 4.7 (exp 5.2) s.d.
- Significance of tH production: obs 1.4 (exp 0.3) s.d.



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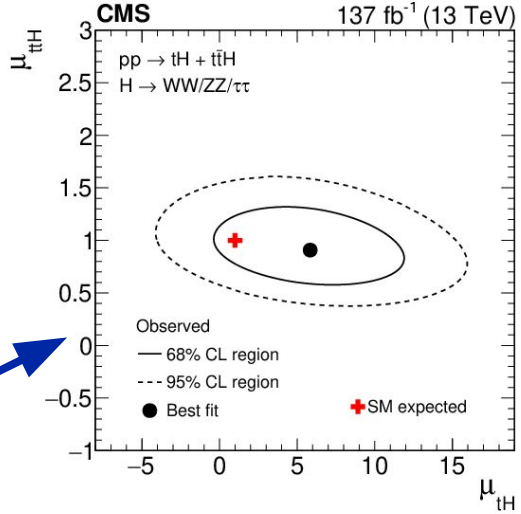

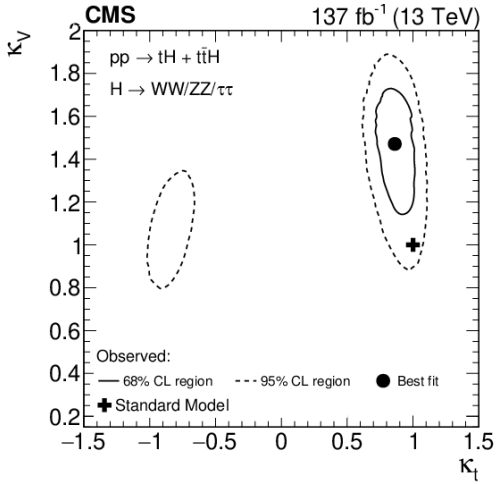

- Limits set on k_V and k_t based on the data yields
- Their effect on cross section, branching ratio and kinematic variables taken into account

Conclusions

- ttH and tH are very important processes to have an understanding of the top-Higgs interactions
- Rich variety of final states, due to the different decay modes of the Higgs
- Diphoton and multilepton final states provide 5σ-level sensitivity
- Allow to probe
  - Higgs couplings with the top and the W boson
  - CP violation terms in the top Yukawa interaction
- All results so far consistent with the SM Higgs!
- Keep posted for more upcoming results:
  - other final states
  - new searches for BSM effects