Observation of ttH at CMS

Huaqiao Zhang (IHEP)

Observation of ttH production

4th June 2018, LHCP/PRL and others…


PHYSICAL REVIEW LETTERS
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Observation of $t\bar{t}H$ Production
A. M. Sirunyan et al. (CMS Collaboration)
Phys. Rev. Lett. 120, 231801
Article References No Citing Articles PDF HTML Export Citation
ABSTRACT
The observation of Higgs boson production in association with a top quark-antiquark pair is reported, based on a combined analysis of proton-proton collision data at center-of-mass energies of $\sqrt{s}$ = 7, 8, and 13 TeV, corresponding to integrated luminosities of up to 5.1, 19.7, and 35.9 fb^{-1}, respectively. The data were collected with the CMS detector at the CERN LHC. The results of statistically independent searches for Higgs bosons produced in conjunction with a top quark-antiquark pair and decaying to pairs of W bosons, Z bosons, photons, τ leptons, or bottom quark jets are combined to maximize sensitivity. An excess of events is observed, with a significance of 5.2 standard deviations, over the expectation from the background-only hypothesis. The corresponding expected significance from the standard model for a Higgs boson mass of 125.09 GeV is 4.2 standard deviations. The combined best fit signal strength normalized to the standard model prediction is 1.26
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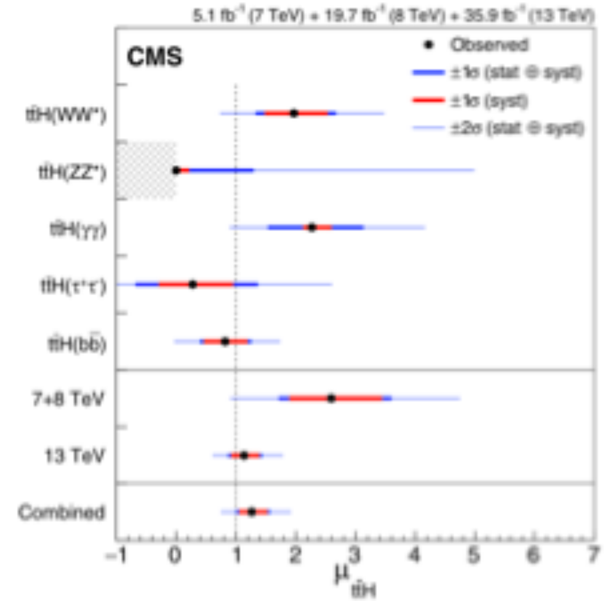
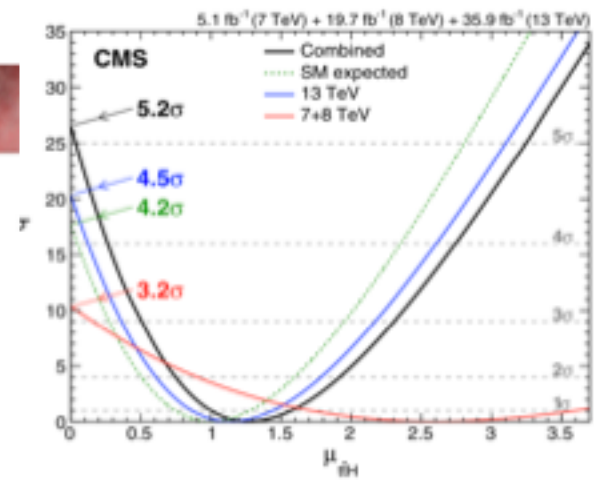
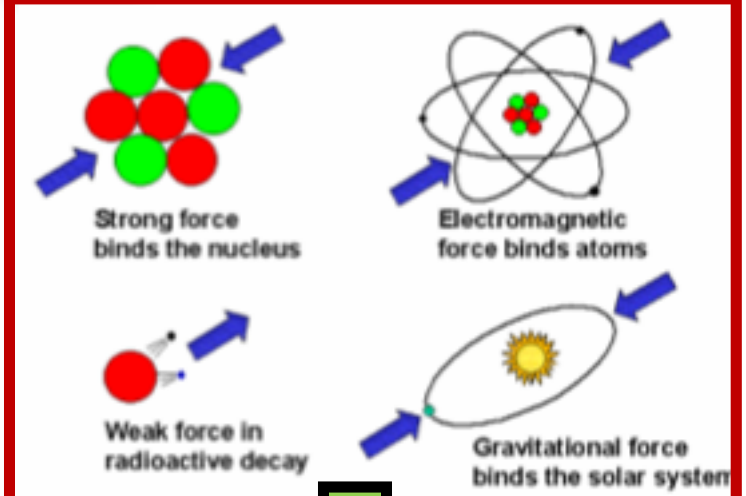
PHYSICAL REVIEW JOURNALS 125

Phys. Rev. Lett. 120, 231801





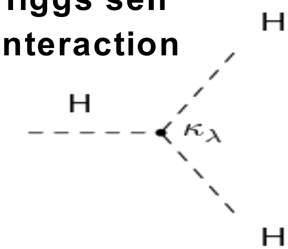
Why ttH is important (1)



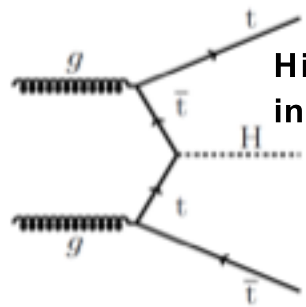
July 2012
Higgs Discovery

2 new forces

Higgs self interaction



small cross section, to be detected



Higgs-fermion interaction

verify its existence now at LHC!!

The past of universe
Phase transition?

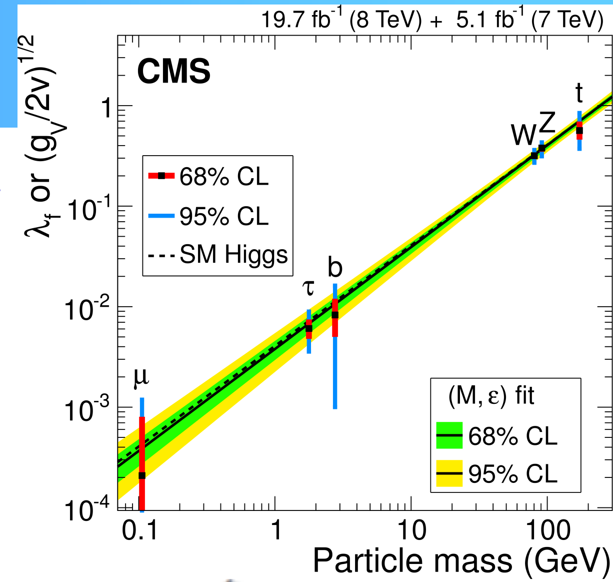
The future of universe
Decay of Vacuum?

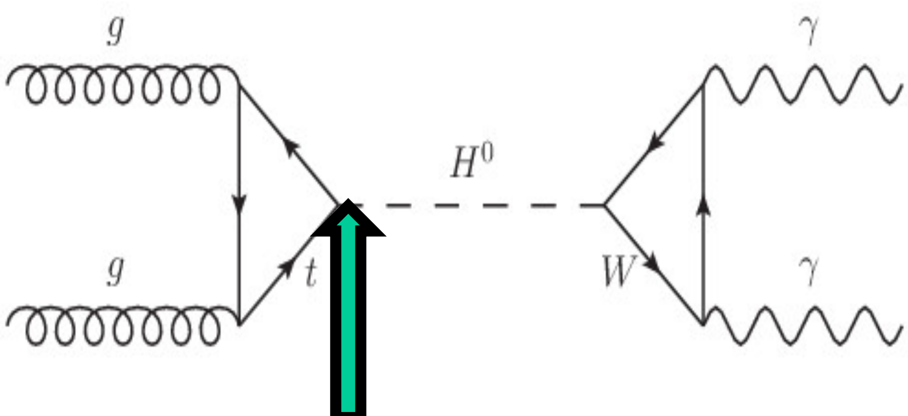
Gavin Salam at LHCP 2018 <Theory Vision> summary

Is this any less important than the discovery of the Higgs boson itself?
My opinion: no, because fundamental interactions are as important as fundamental particles

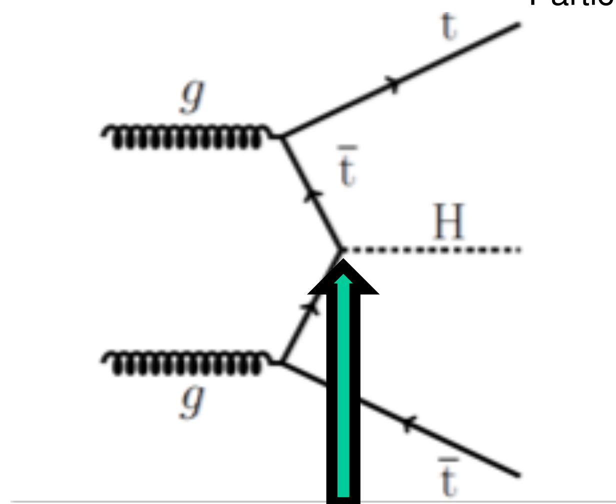
Why ttH is important (2)

- Explore Higgs-Fermion interactions at LHC
  - The strength of Higgs-Fermion interactions
    - Higgs-Top coupling is the largest
  - At LHC: Model dependent vs independent





Indirect detection, model dependent

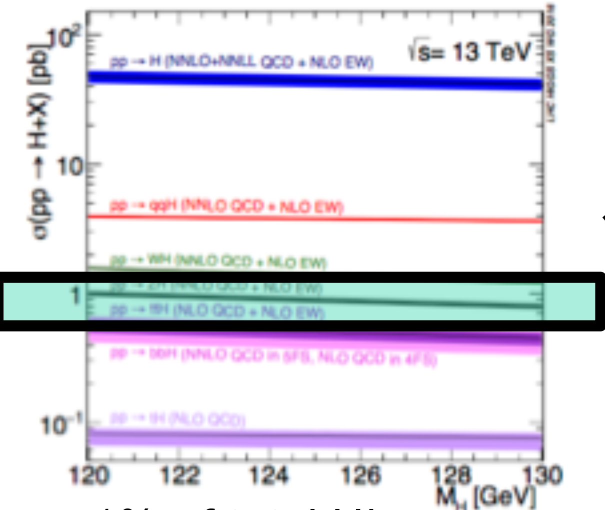


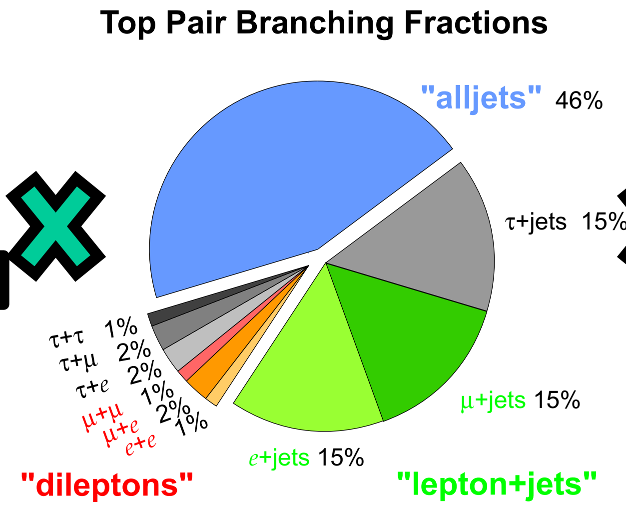
direct detection

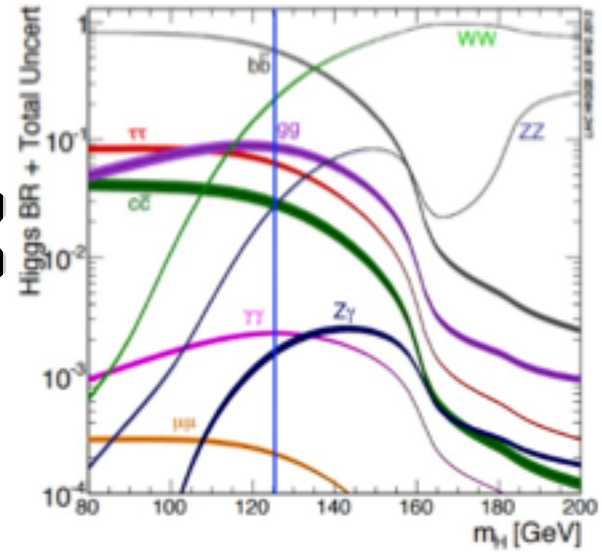
ttH: probably the only channel that can **direct** probe Higgs Yukawa coupling at LHC

How?

- Production
- Decays





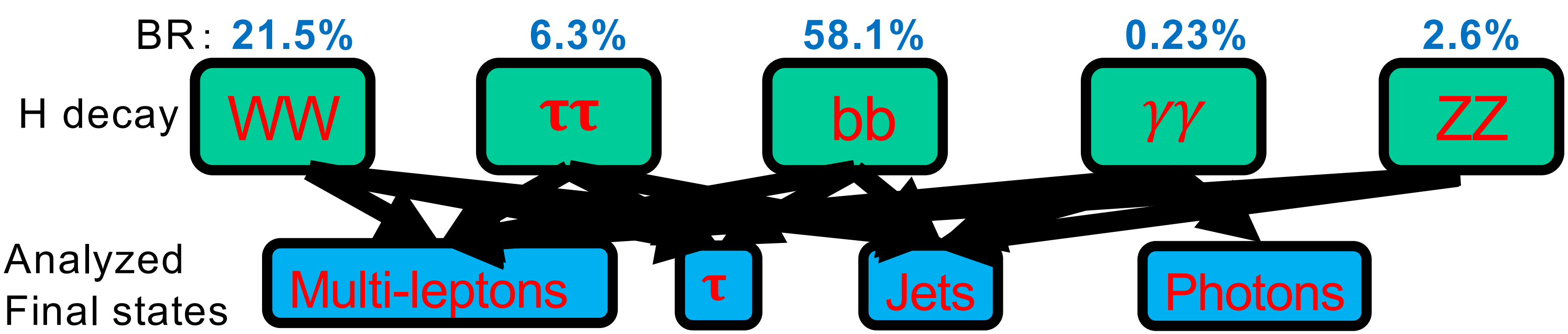


~1% of total Higgs

~0.06% of ttbar

~1/10^{11} of total interaction

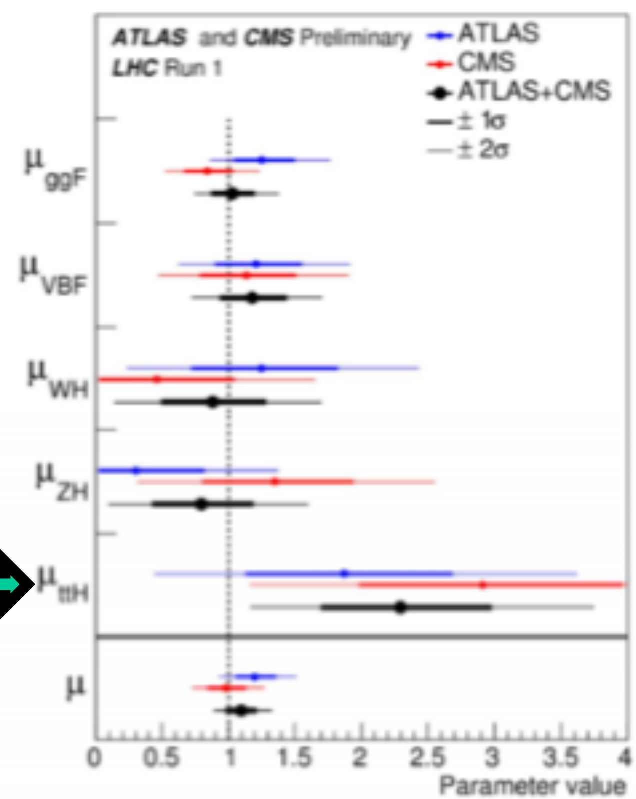
Hundreds of complex final states



History of ttH searches at LHC

- Feasibility study prior to LHC data taking
  - ATLAS CSC book
- Hunting ttH at LHC run 1
  - Run 1 ATLAS + CMS combination: 4.4σ

$\mu_{ttH}=2.3^{+07}_{-0.6.}$, Slightly higher than SM



- High priority analysis at Run2 (13 TeV)

Cross section (fb) @NLO	tt̄H	tt̄W	tt̄Z	tt̄ (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

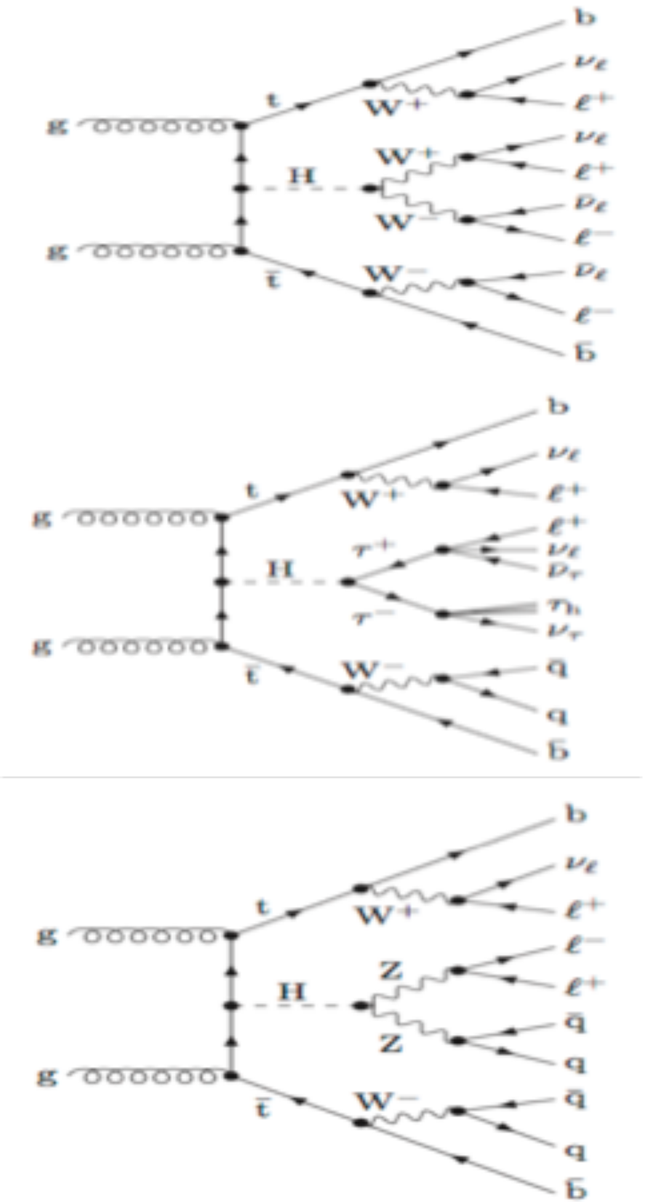
Observation of ttH now !!

Data up to 2016

ttH multilepton (H→WW/ZZ/ττ)

arXiv:1803.05485
Submitted to JHEP

- ttH,H→WW: large BR
  - Dominate signal in multilepton analysis
- ttH,H→ ττ: Small BR
  - Enriched in some categories
- ttH,H→ZZ: Very small BR
  - Very few signal, excluded in the 4l
- 6 final states analyzed
  - 2 lepton same-sign (2lss)
  - 3 leptons (3l)
  - 4 leptons (4l)
  - 1l + 2 hadronic taus
  - 2lss + 1 hadronic tau
  - 3l + 1 hadronic tau



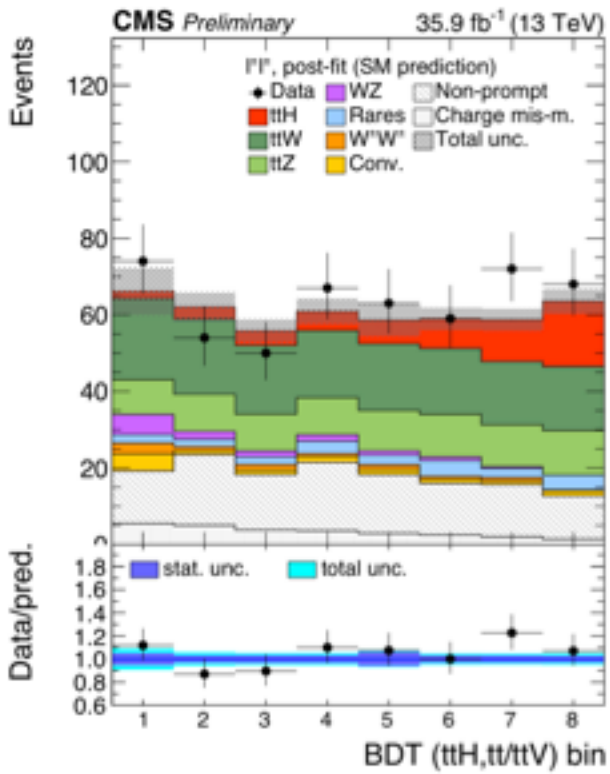
Multi-lepton without tau: strategy

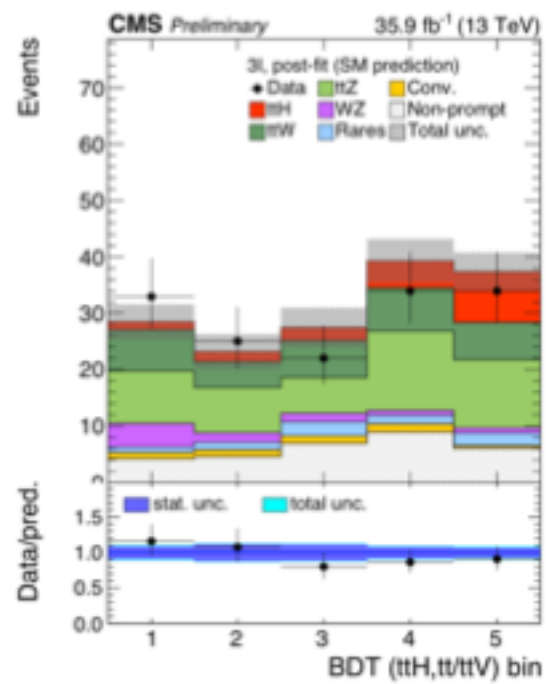
IHEP gave pre-approval talk

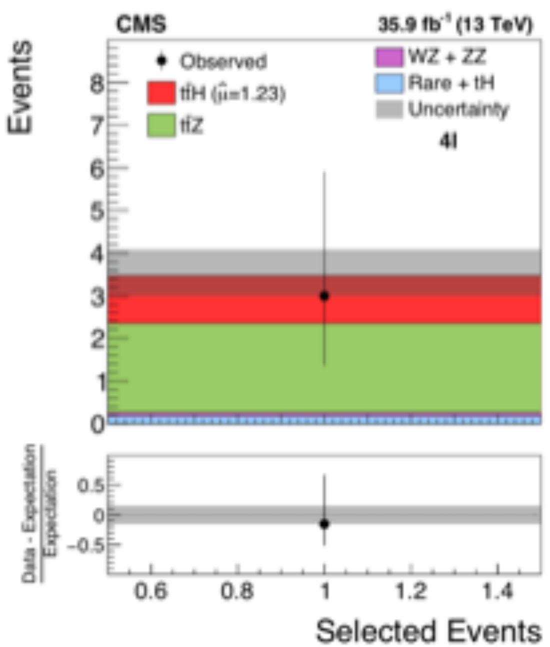
- **2lSS**: 2D BDT analysis
  - Signal: **53.8**
  - BKG: **423**
    - non-prompt lepton: 28%, ttV: 53%

3l: MEM + BDT, 2D analysis
Signal: **18.5**
BKG: **131.4**
non-prompt lepton: 23%, ttV: 60%

4l: number counting
Signal: **0.9**
BKG: **2.4**
ttV: 89%

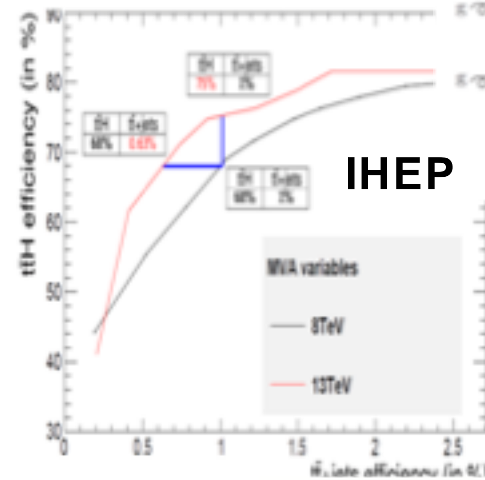


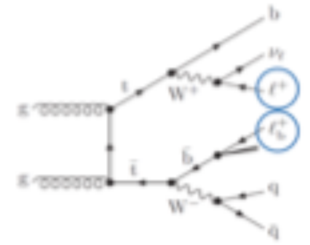




Non-prompt background rejection/estimation

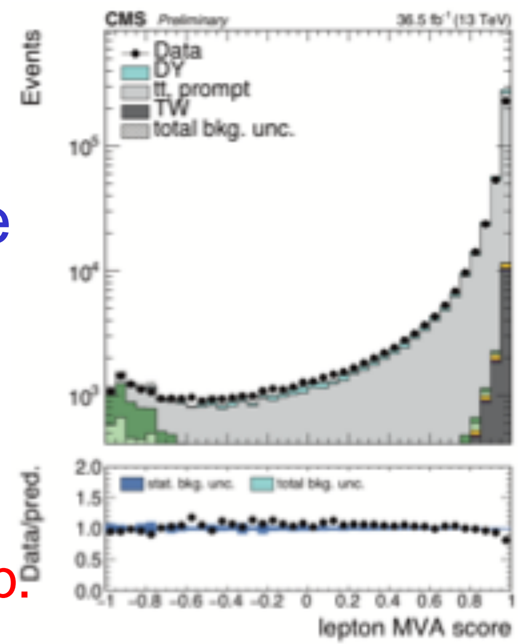
- Non-prompt backgrounds
  - Mainly from b-jets in tt events
  - mis-identified light jets and decay-in-flight
- Multivariable to enhance separation
  - Isolation/kinematics
  - Vertex impact parameter
  - (Relation with) nearby jets
- Data validated performance
- Data-driven estimation
  - Loose → tight fake prob.
  - Loose → tight charge flip prob.

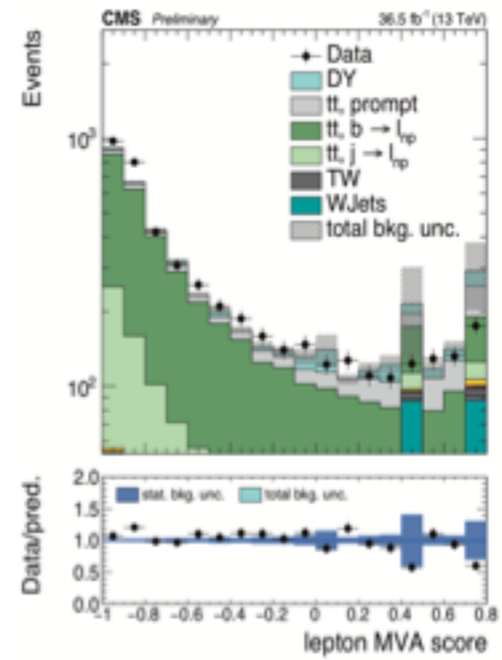




IHEP

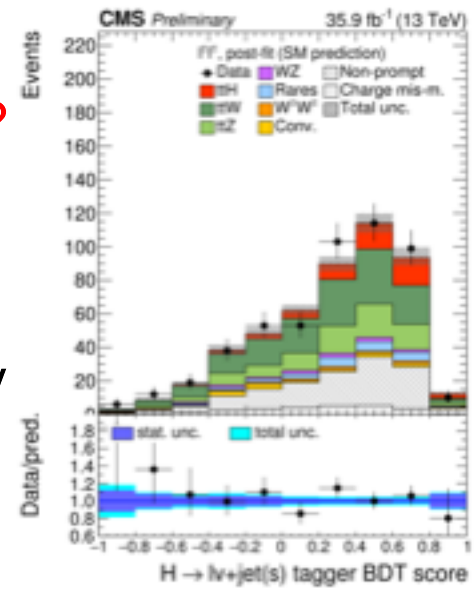
(tt)→ $\ell^\pm\ell^\pm_{fake}$

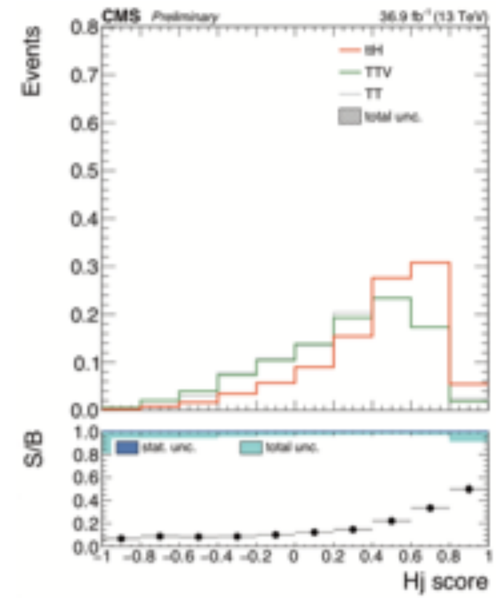


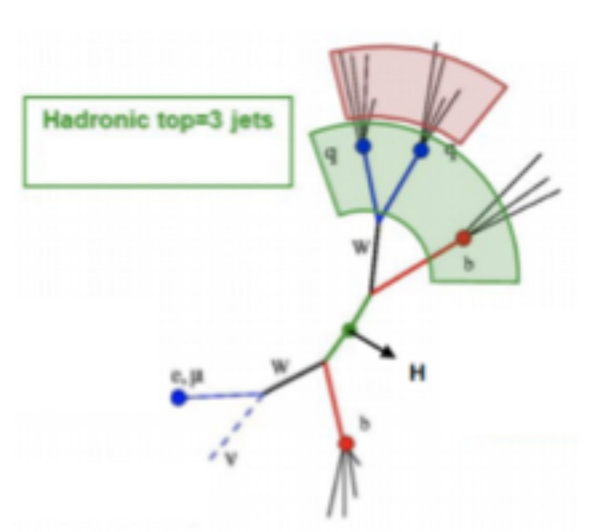


Multi-lepton without tau: Signal vs background

- Problem: no ttH reco
  - How to separate ttH from bkg?
- Hj tagger (2L) **[IHEP]**
  - Tagging jets from Higgs decay
  - Aim to extract ttH from ttV
- Hadronic top tagger (2L)
  - BDT: Reconstruct hadronic top
- MEM (3L) [**PKU** and IPHC]
  - Separate ttH from ttV in 3L





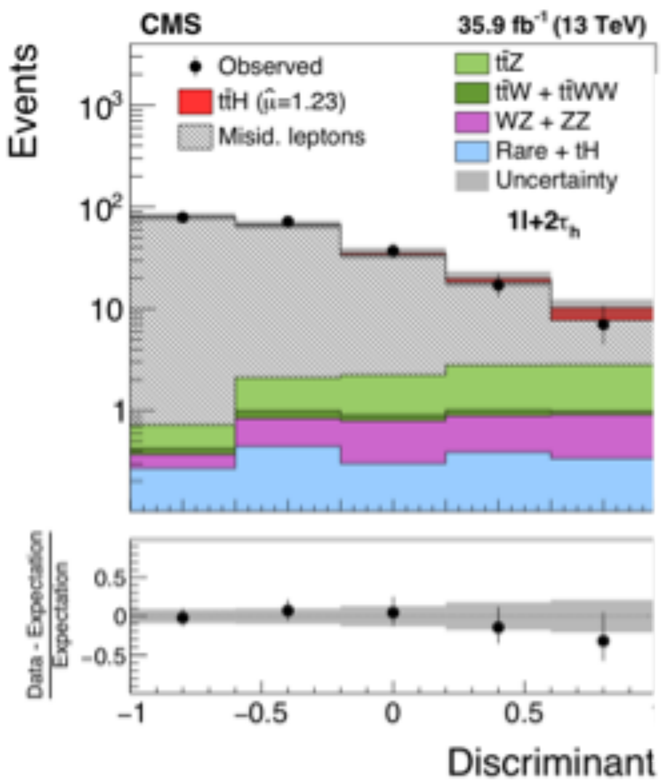


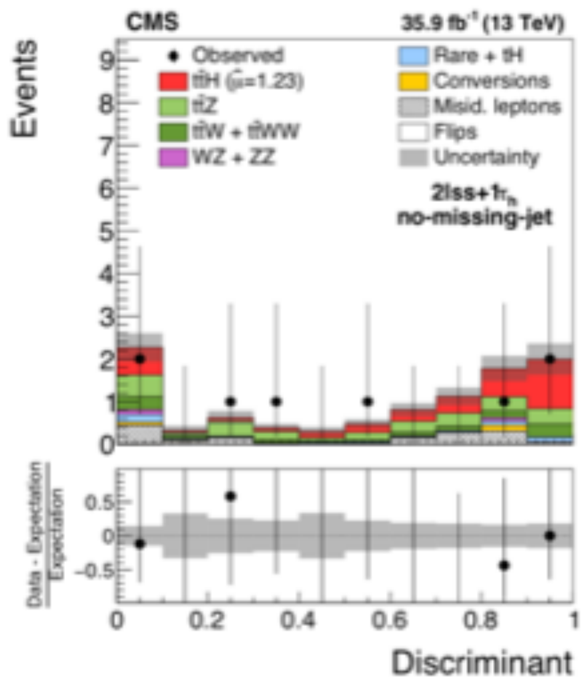
Multi-lepton with tau: strategy

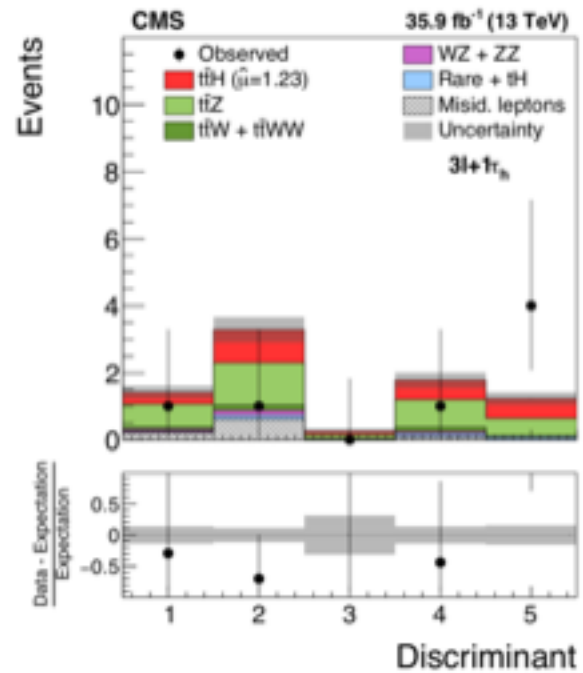
- **1l+2τh**: BDT analysis
  - Signal: **5.8**
  - BKG: **206.3**
    - misID lepton: 95%

2lss+1 τh : MEM analysis
Signal: **9.4**
BKG: **36.1**
misID lepton: 24%, ttV: 51%

3l+1 τh : 2D BDT
Signal: **2.1**
BKG: **5.3**
ttV: 64%



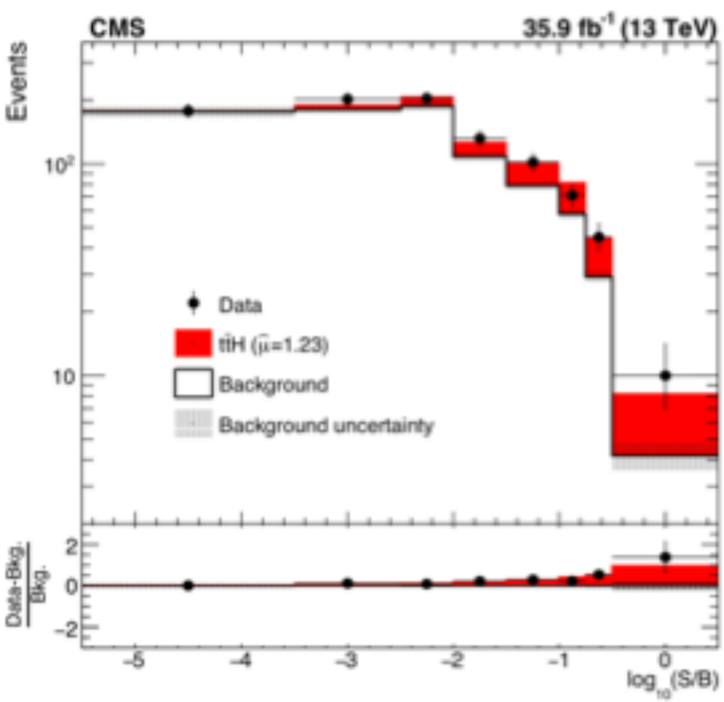


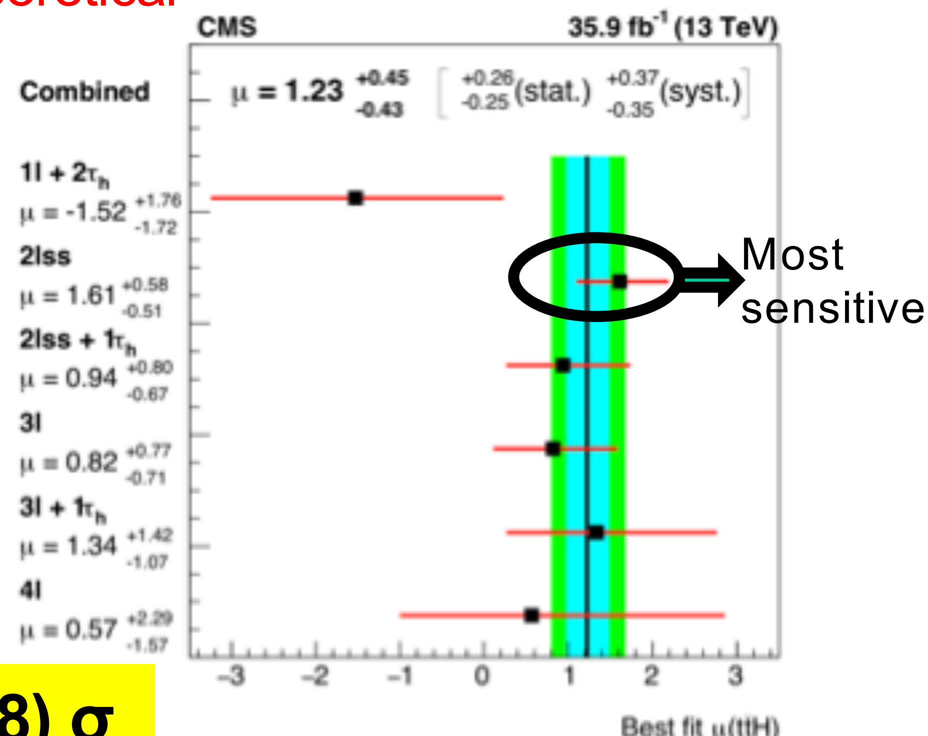


Multilepton analysis results [Evidence]

arXiv:1803.05485
Submitted to JHEP

- Combine multi-lepton channels
  - Simultaneous ML fit to discriminate of 6 categories
  - Potential signal excess is quantified by p-value
- Dominate uncertainties:
  - lepton eff. Reducible bkg est. Theoretical





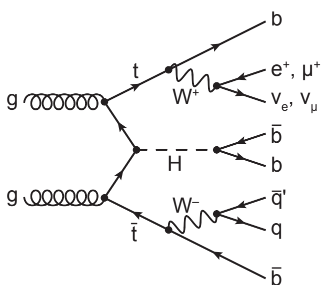
3.2 (2.8) σ

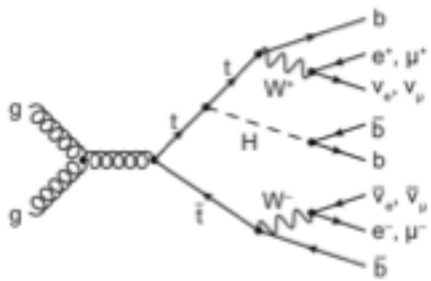
$$\mu = 1.23^{+0.45}_{-0.43}\ (1.00^{+0.42}_{-0.38})$$

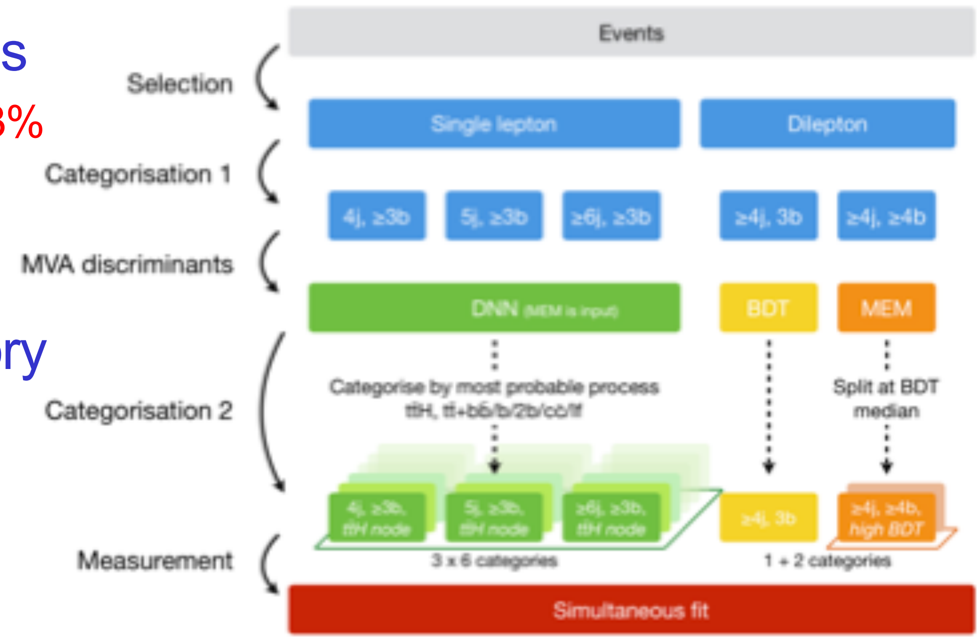
ttH,H→bb: Leptonic channel

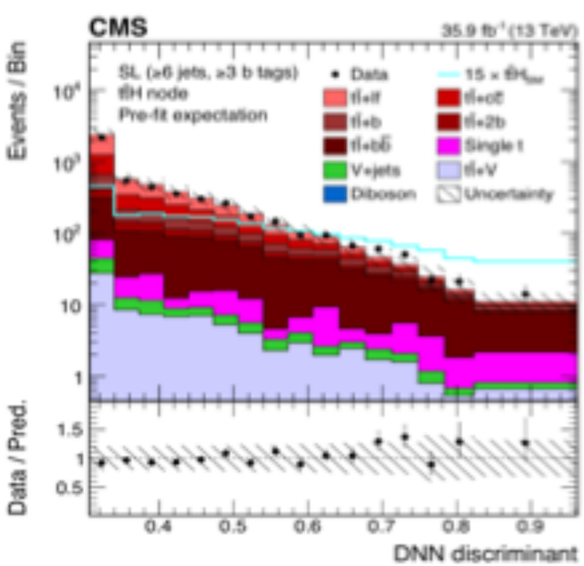
arXiv:1804.03682
Submitted to JHEP

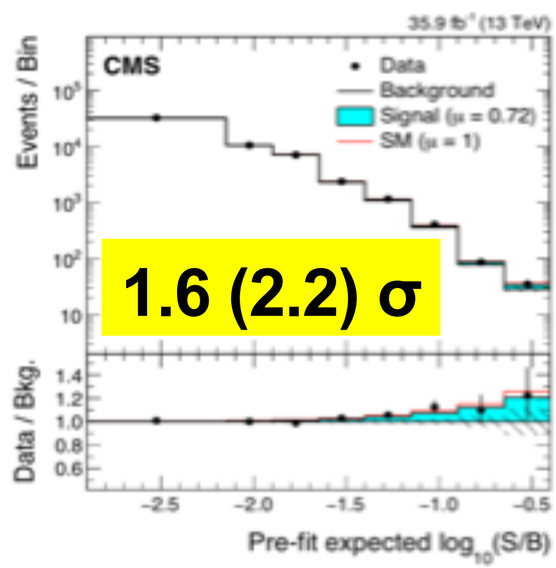
- ttHbb: l+jets and dilepton channels
  - S/B :1.2%, 2.8%, 2.8%,1.4%,3.2%,13%
- Analysis using DNN, BDT, MEM
- Major background from tt+jets
- Main uncertainties from tt+hf theory

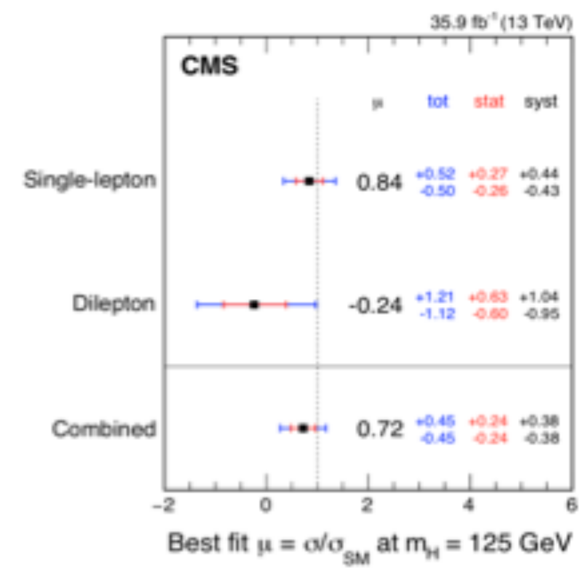








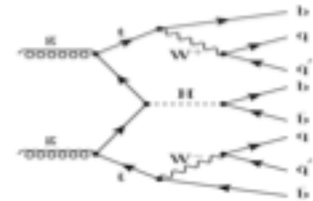


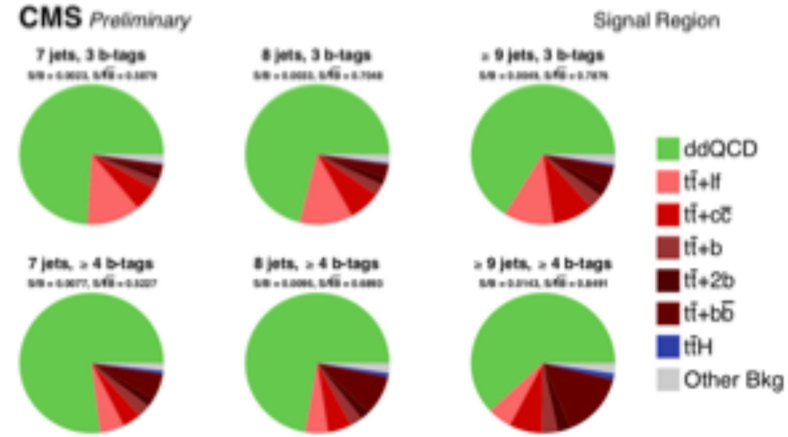


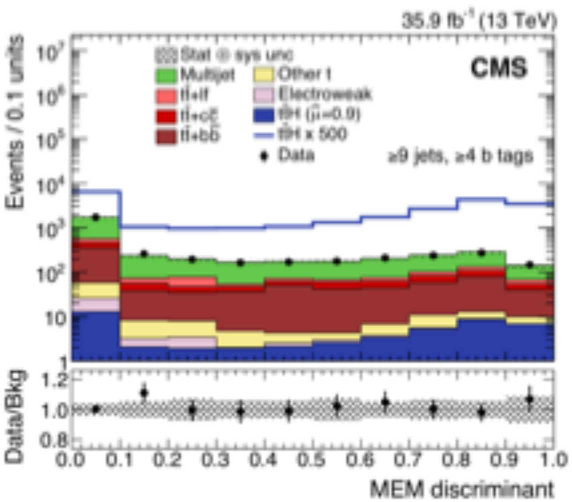
ttH,H→bb: Hadronic channel

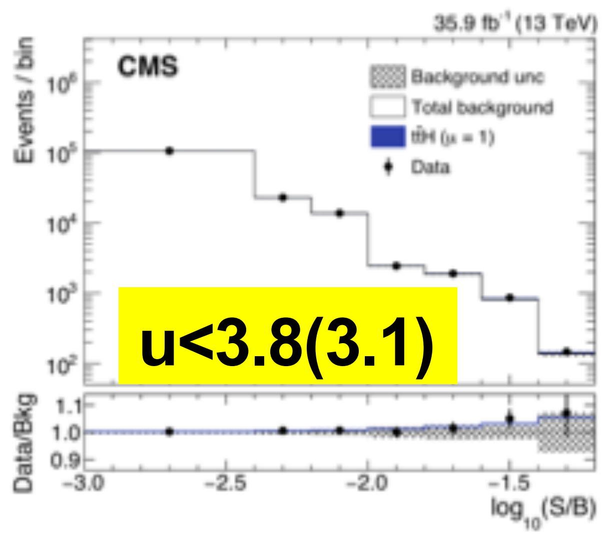
arXiv:1804.03682
Accepted by JHEP

- ttHbb full hadronic channel
  - 6 categories by 3/≥4 b jets and 7/8/≥9 jets
  - S/B:0.5%,0.7%,0.9%,2.3%,2.5%,3.6%
- Analysis using MEM
- Major background:
  - Milti-jets(~60%) and tt+jets(~40%)
- Main uncertainties: QCD estimation









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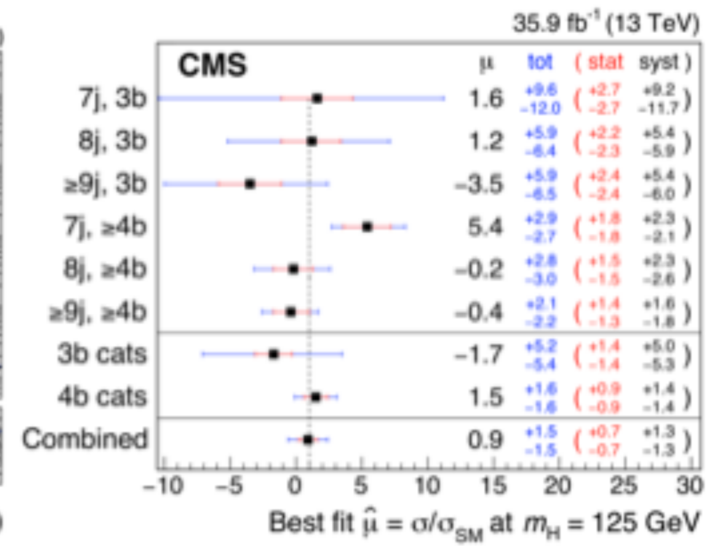
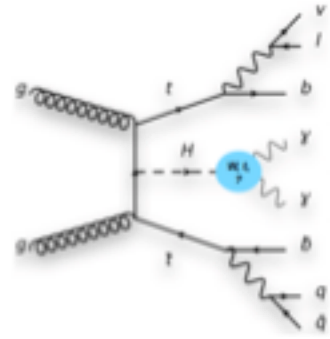
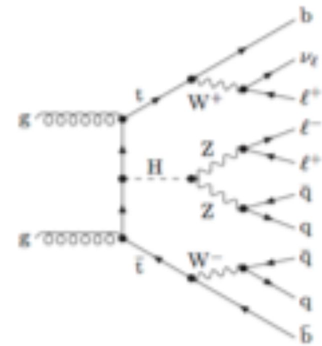


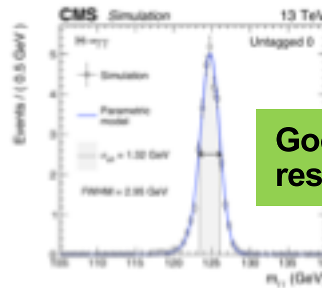
ttH,H→γγ/ZZ

arXiv:1804.02716
JHEP11(2017)047

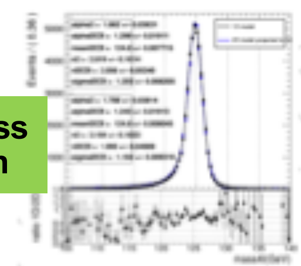
- Additional category in the common H→γγ, H→ZZ analysis IHEP
- H→γγ: semileptonic/hadronic categories, BDT analysis
  - Bump hunting on a smooth falling background
- H →ZZ: ≥5 leptons/4l + ≥4J1T
  - Limited by statistics, expect 0.35 signal

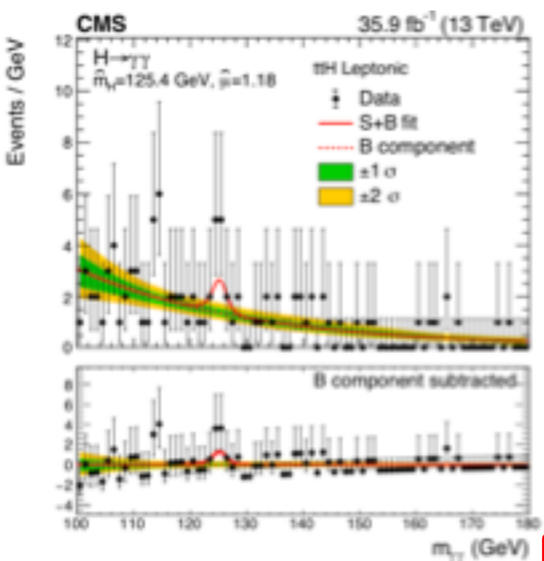


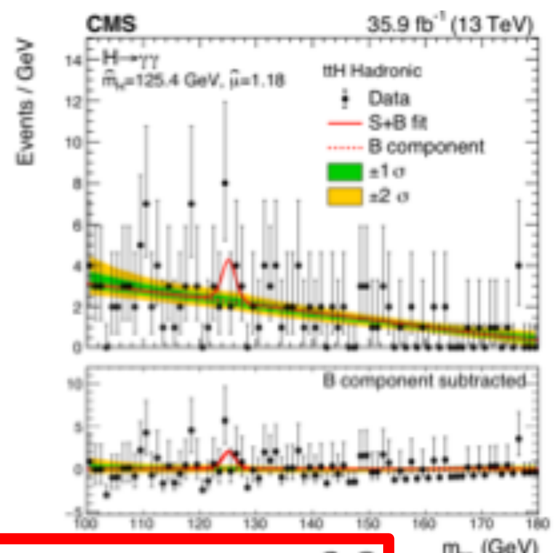


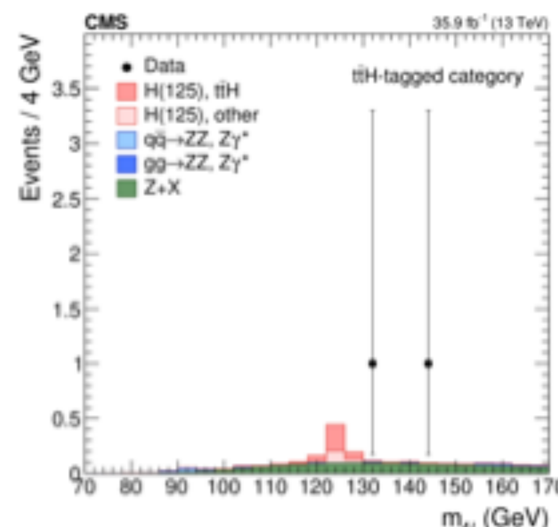


Good mass resolution









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

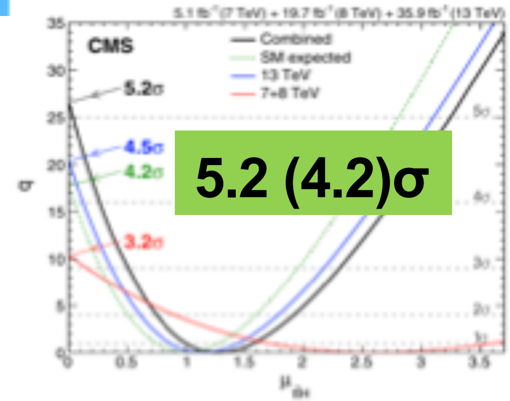
$$\sigma_{t\bar{t}H} / \sigma_{theo} = 0.00^{+1.18}_{-0.00}$$

Combination: Observation of ttH

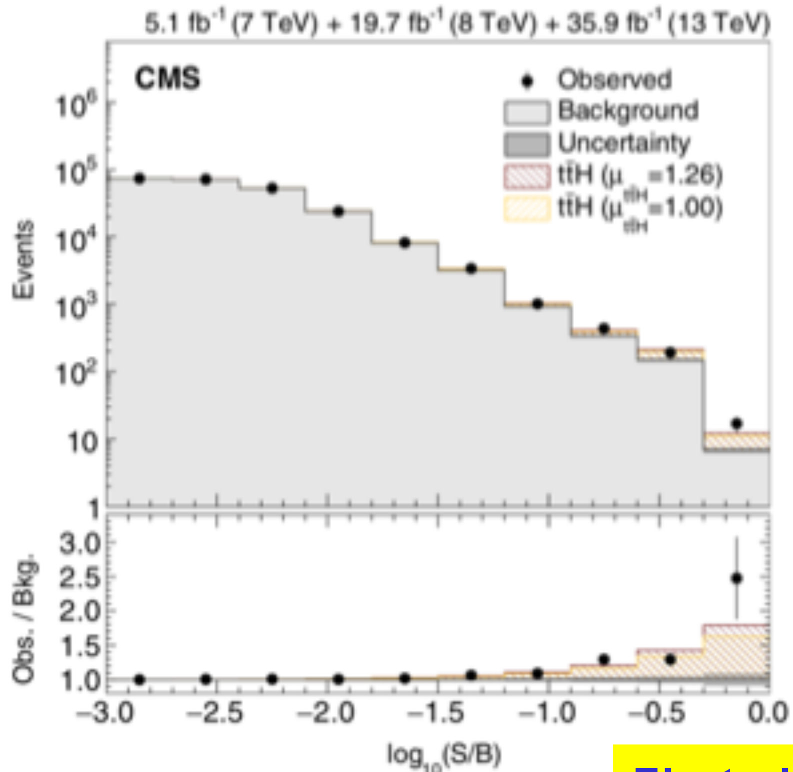
Phys. Rev. Lett. 120, 231801

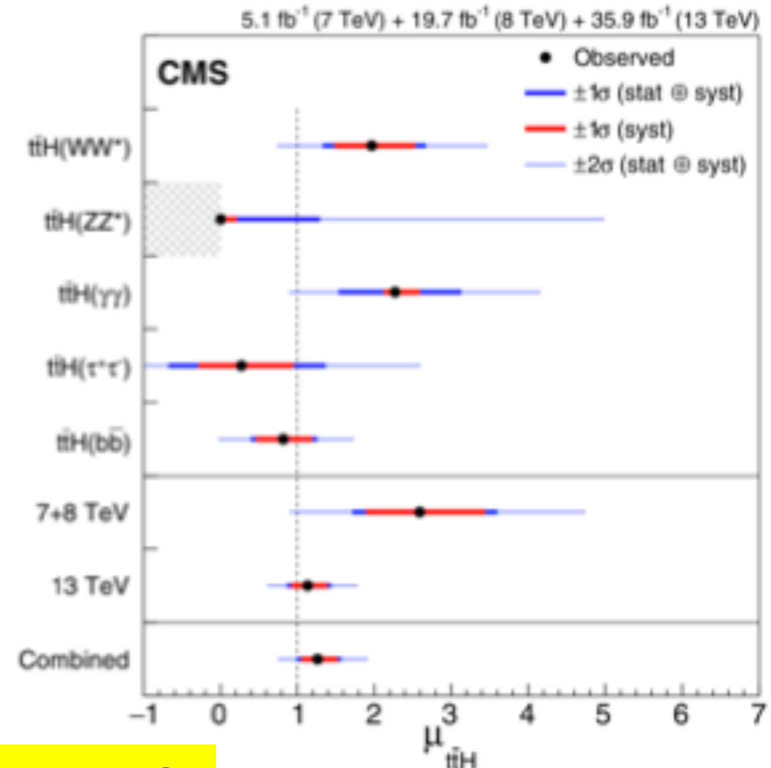
- Combination of ttH,H→WW/ ττ /bb/γγ/ZZ
  - 7TeV + 8TeV + 13 TeV(35.9 fb^{-1}, data taken up to 2016)
- Simultaneous ML fit to all decay modes/Ecm

$$\mu_{t\bar{t}H} = 1.26^{+0.31}_{-0.26}$$



5.2 (4.2)σ





First observation, ATLAS confirmed with more data

Summary

- Observation of ttH at CMS
  - Revel the interactions between Higgs and top quark ==> new force
  - Consistent with SM predictions, room for new physics

- Chinese CMS collogues contributed to the final states of
  - Higgs decay to WW, bb, $\gamma\gamma$, ZZ (except tautau);
  - pre-approval talk of ttH multilepton → most important channel to Obv.

- Measurement of of Higgs-top Yukawa coupling
  - Model dependent, more data needed

- Future of ttH:
  - Oberservation/measurements in individual final states
  - Extract Higgs-Top Yukawa coupling(Yt) @ HL-LHC:
  - Precise measure Yt at Electron- positron collider @ ~500 GeV Ecm