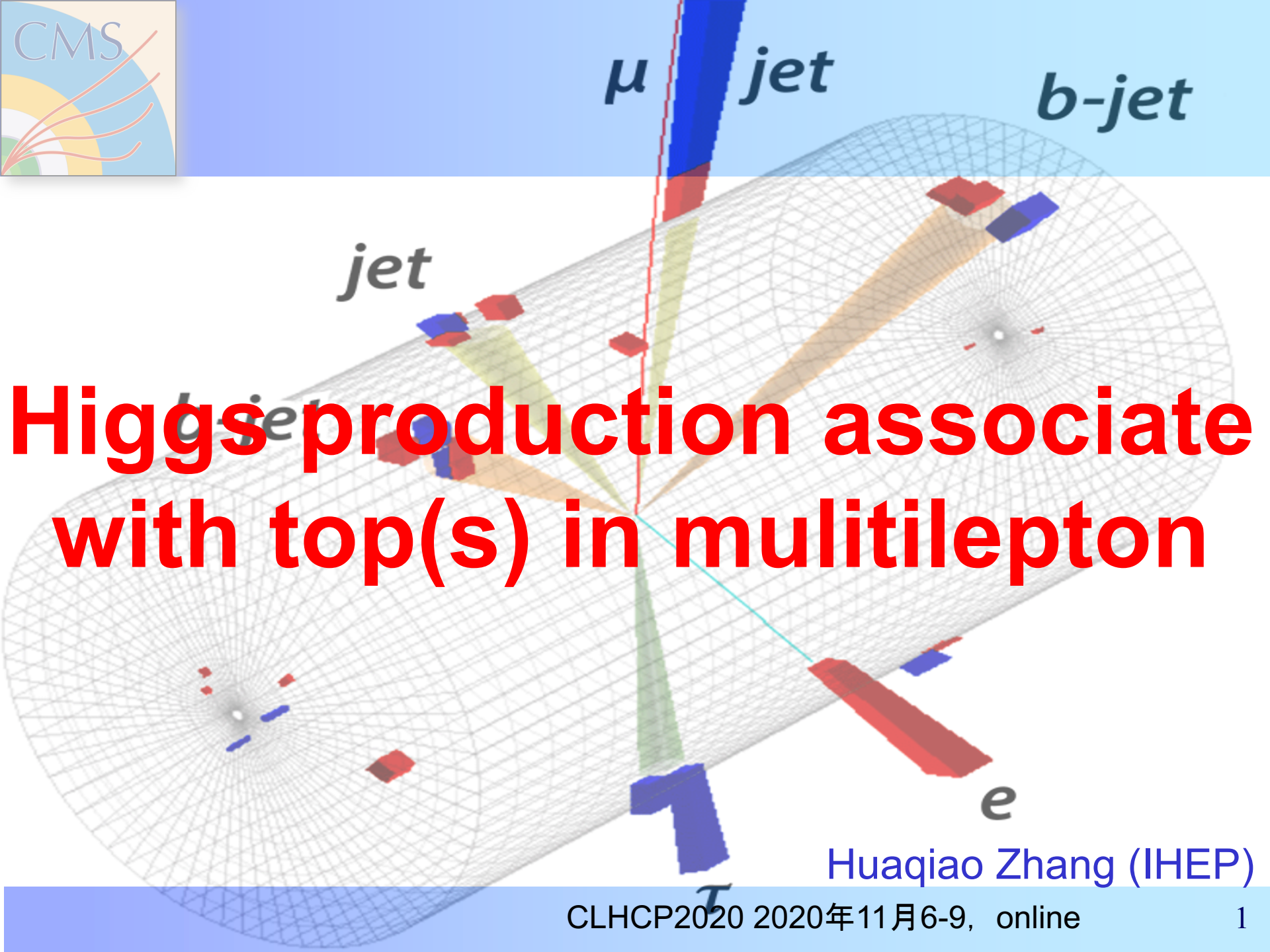
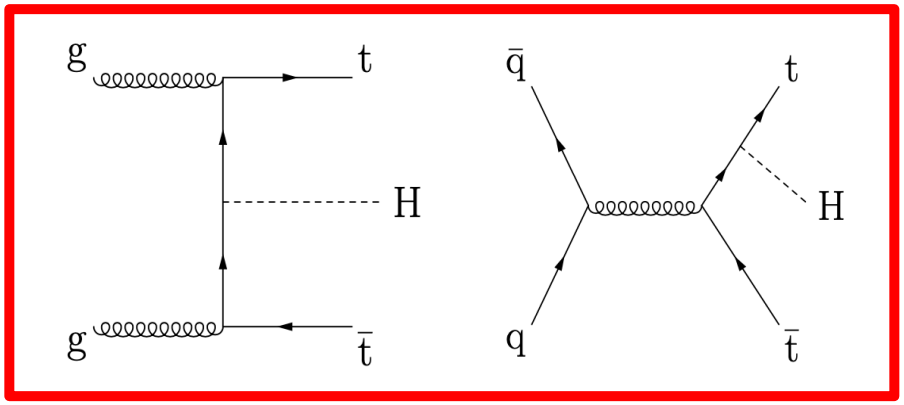


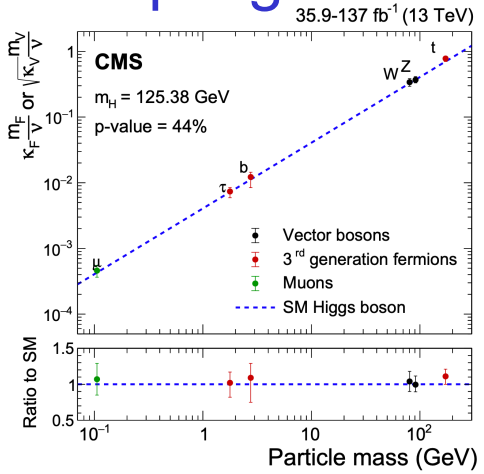
Higgs production associate with top(s) in mulitilepton

Huaqiao Zhang (IHEP)

Motivation of Higgs production associate with top(s)

- ttH: Direct detection of top-Higgs Yukawa coupling

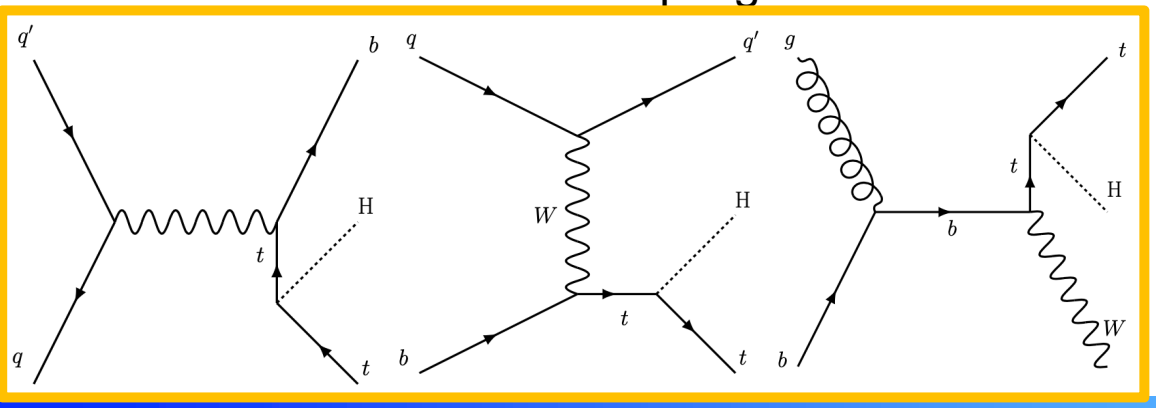




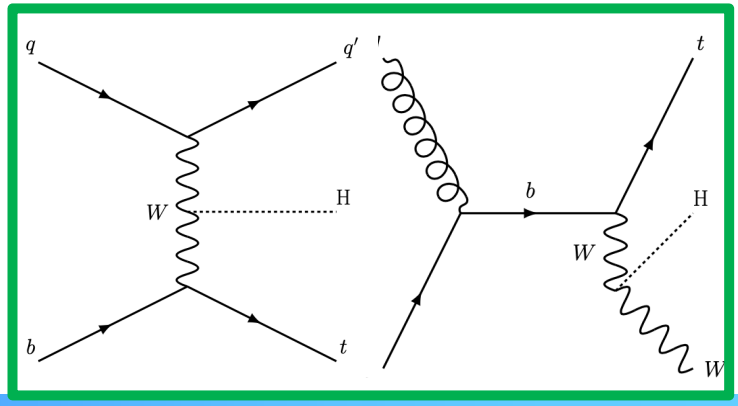
Top-Higgs Yukawa coupling: The largest

- tH: sensitive to top-Higgs and W-H coupling relations

Via H-t coupling

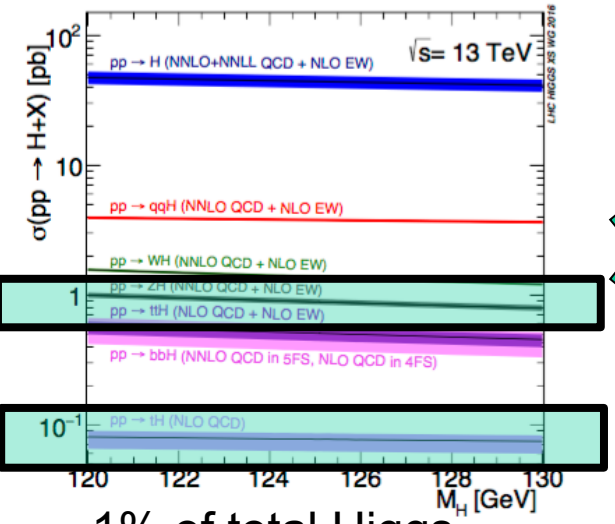


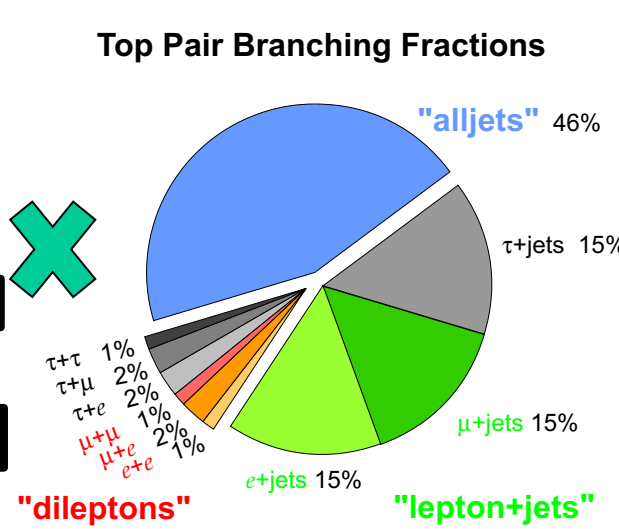
Via H-W coupling

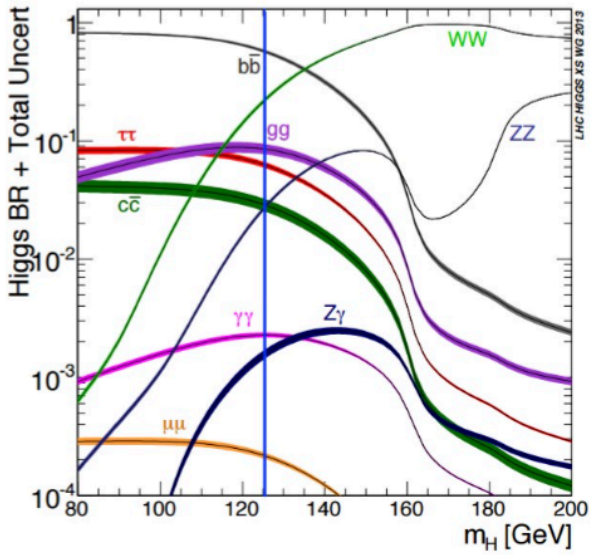


How to search them at LHC?

- Production
- Decays







~1% of total Higgs
~0.06% of ttbar
~$1/10^{11}$ of total interaction

Hundreds of complex final states

BR: 21.5% 6.3% 58.1% 0.23% 2.6%

H decay: WW ττ bb γγ ZZ

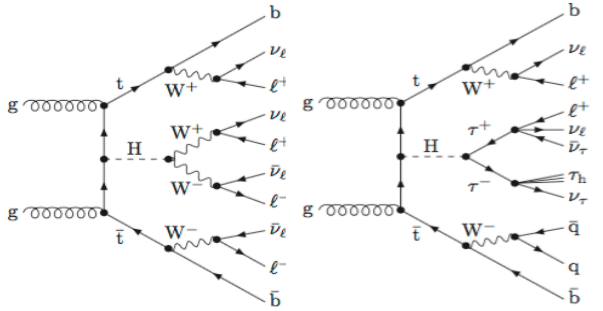
Analyzed Final states: Multi-leptons, τ, Jets, Photons

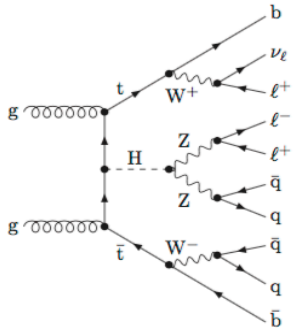
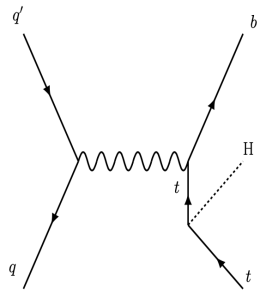
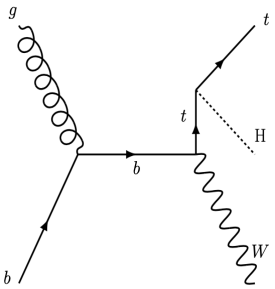
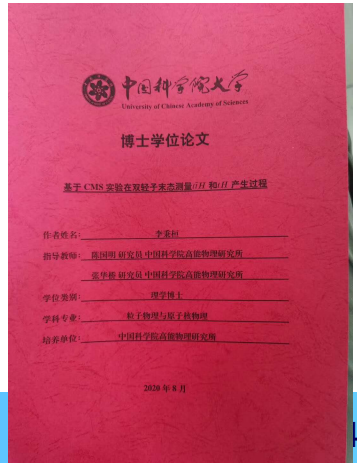
Status of higgs production associate with top studies

- First obverstion of ttH by both CMS/ATLAS in 2018: updates

	ATLAS		CMS	
t/ttH,H→bb	ATLAS-CONF-2020-058	Run2(1.3/3.0)	CMS-PAS-HIG-18-030	2016+2017
t/ttH,H→WW	ATLAS-CONF-2019-045	2016+2017	CMS-PAS-HIG-19-018	run2
t/ttH,H→ττ	ATLAS-CONF-2019-045	2016+2017	CMS-PAS-HIG-19-018	run2
t/ttH,H→ZZ	ATLAS-CONF-2019-045 arXiv:2004.03969 (4l)	2016+2017 run2	CMS-PAS-HIG-19-018	run2
t/ttH,H→γγ	PRL 125 (2020) 061802	Run2(5.2/4.4)	PRL 125 (2020) 061801	Run2(6.6/4.7)
ttH,H→inv	ATLAS-CONF-2020-052	run2	CMS-PAS-HIG-18-008	2016(re-interp)

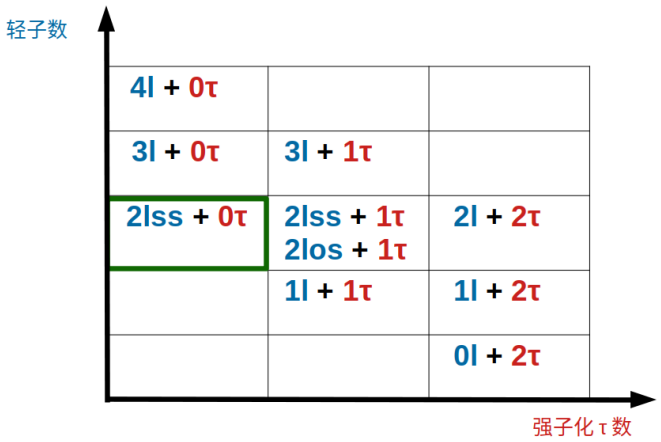
- My focus: CMS run2 multilepton analysis & Binghuan's thesis

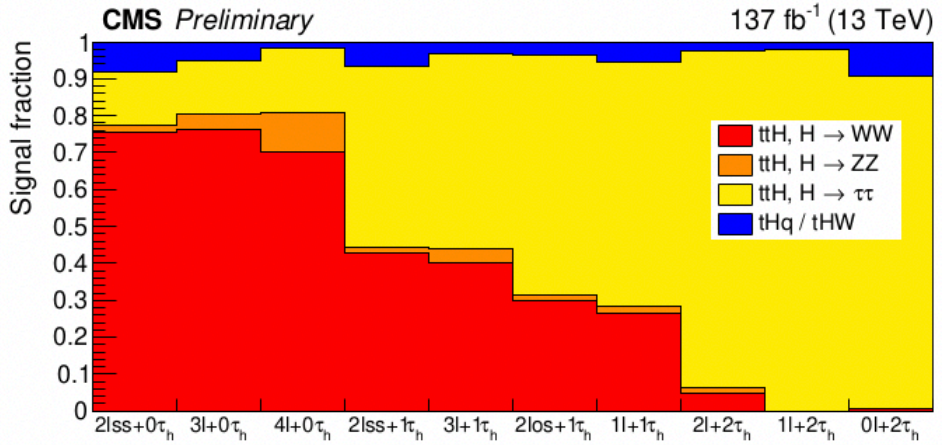


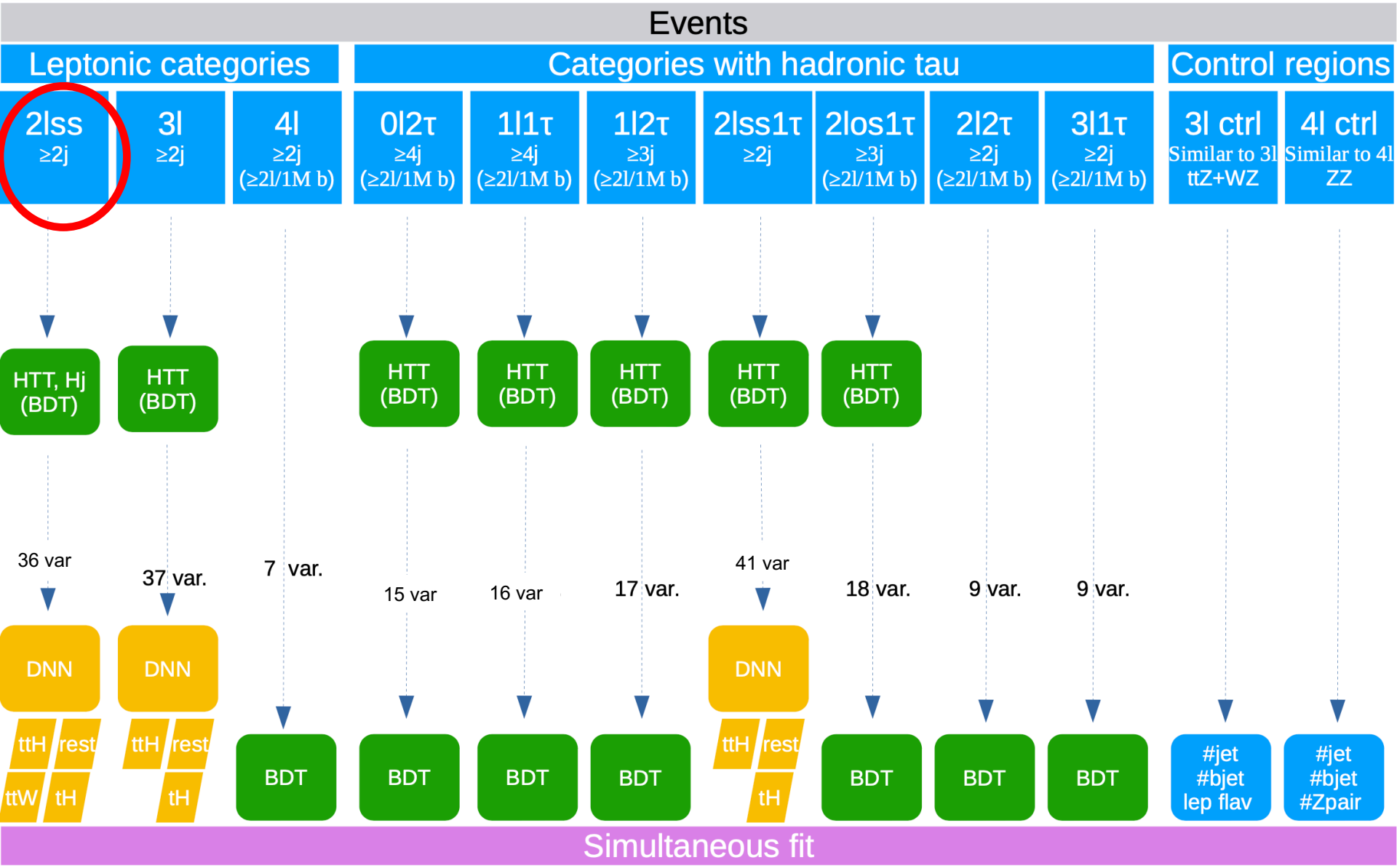
Signal region definition

- Main decay modes in multilepton final states
  - ttH, H→WW : Largest BR and selected signal events
  - ttH, H→ττ : Enriched in hadronic τ region
  - ttH, H→ZZ (no 4l) : Small contribution with excellent mass resolution
  - tHq/tHW : Small but critical for interference studies
- Signal categarized by the presence of leptons
- 10 signal region defined
  - Different composition of ttH, tHq/tHW





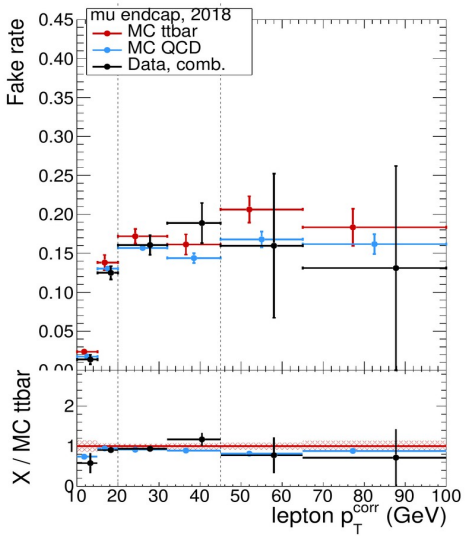
Overview of multilepton analysis strategy

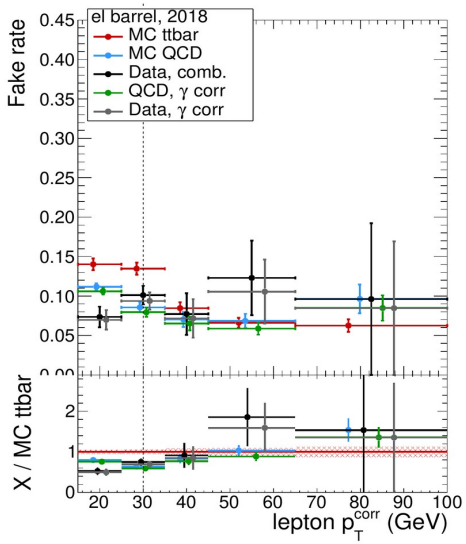


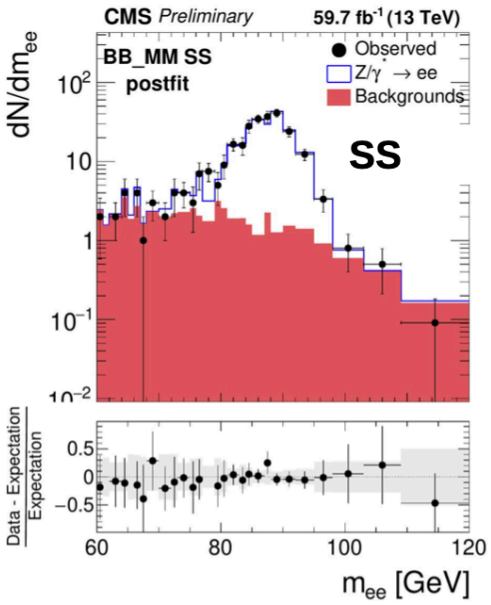
Fakes are the dominate background in many channels

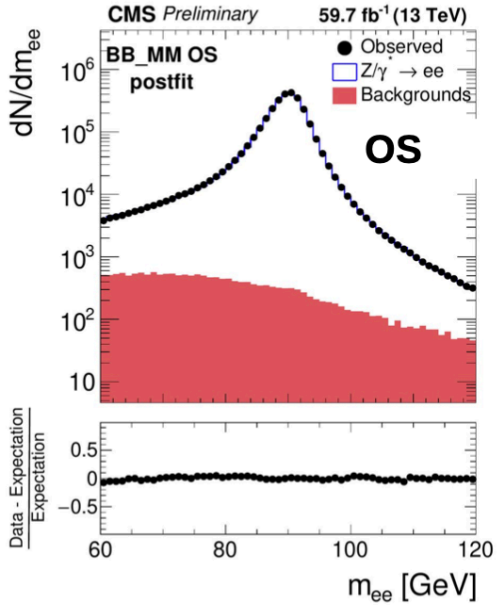
Data driven fake background estimation

- Fake estimation
  - Fake rate estimated using QCD in MR
    - In binning of pt, η
  - Validate in signal region like Application Region
  - Estimation with uncertainties including mismodeling
- Charge flip
  - Electron charge flip rates estimated from Z/→ee events in the 2l OS/SS
  - Negnigible from muon





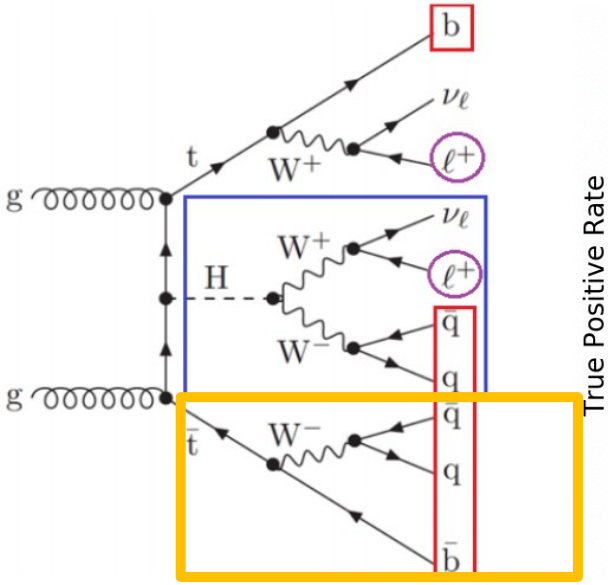


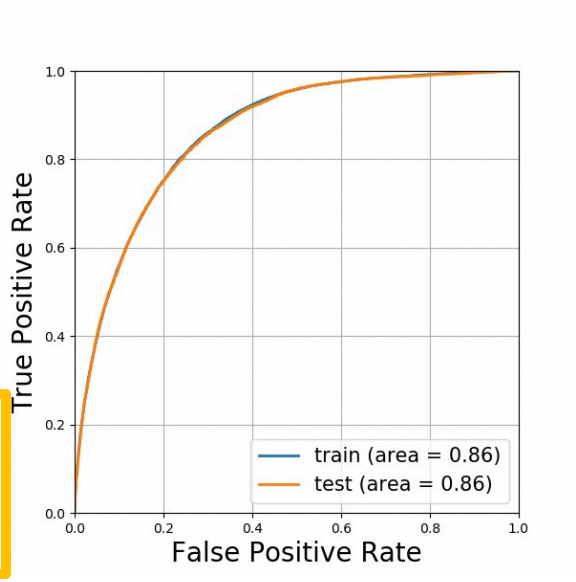


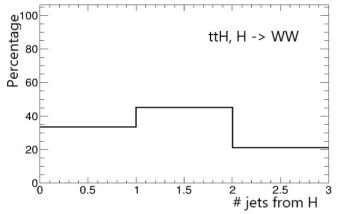
Higgs-jet tagger

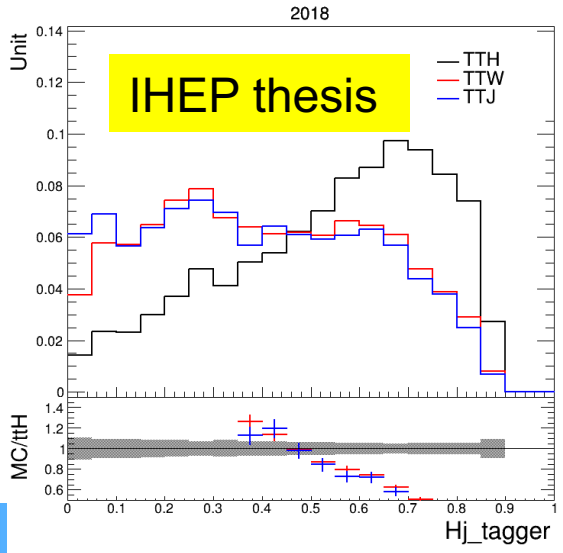
2L SS

- Main differnce of background and signal: The Higgs
- Very challenge to reconstruct Higgs in multilepton FS
  - At least 2 neutrinos, 1 from Higgs system, 1 from top system
  - Missing Jets due to geo/Pt acceptance
  - Combinataries
- Tag jets from Higgs decays based on relations to other obj.
  - Powerful to seperate ttH from Backgrounds





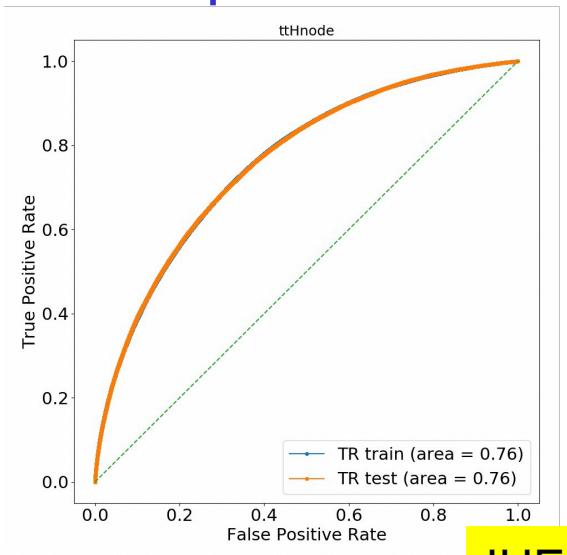


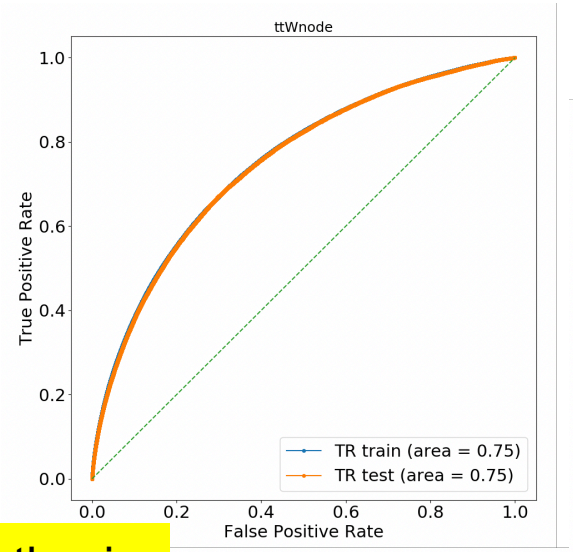


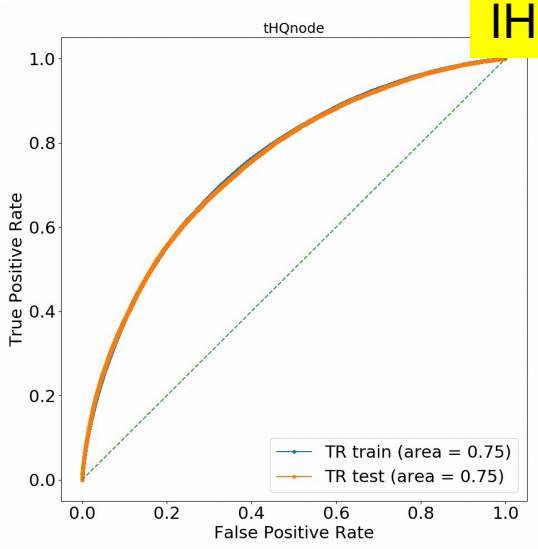
Signal extraction: DNN performance

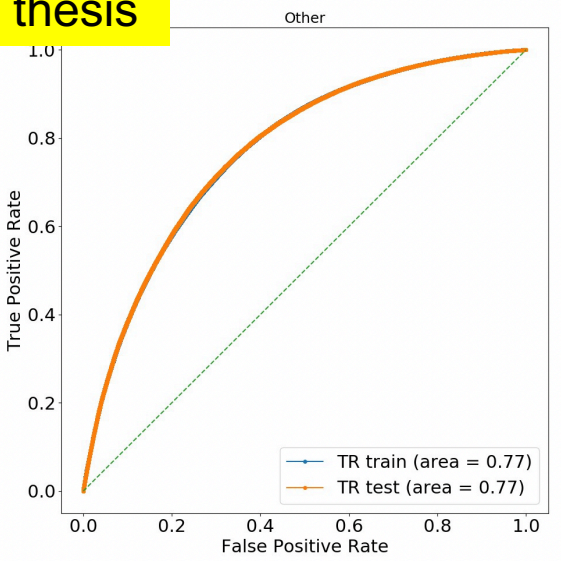
2L SS

- Input features: obj. 4vec., H-j tagger, top tagger + others
- 4 output nodes: ttH, tHQ, ttW, others

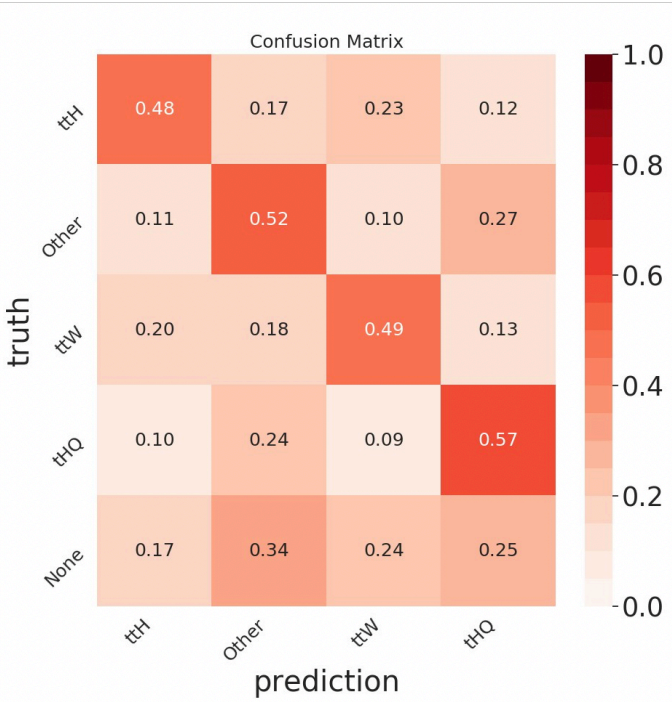








IHEP thesis



~10% improvement than 2D BDT

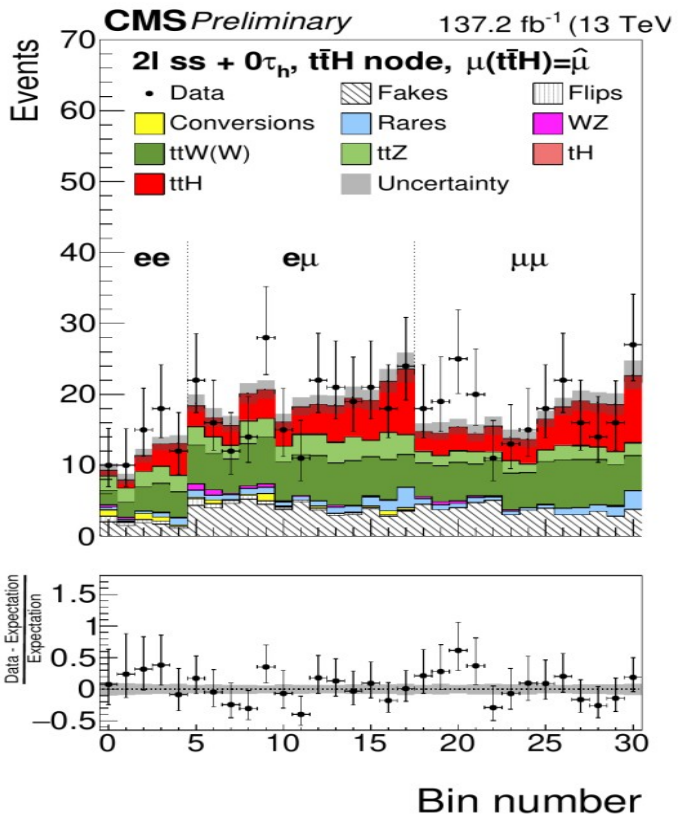
Systematics

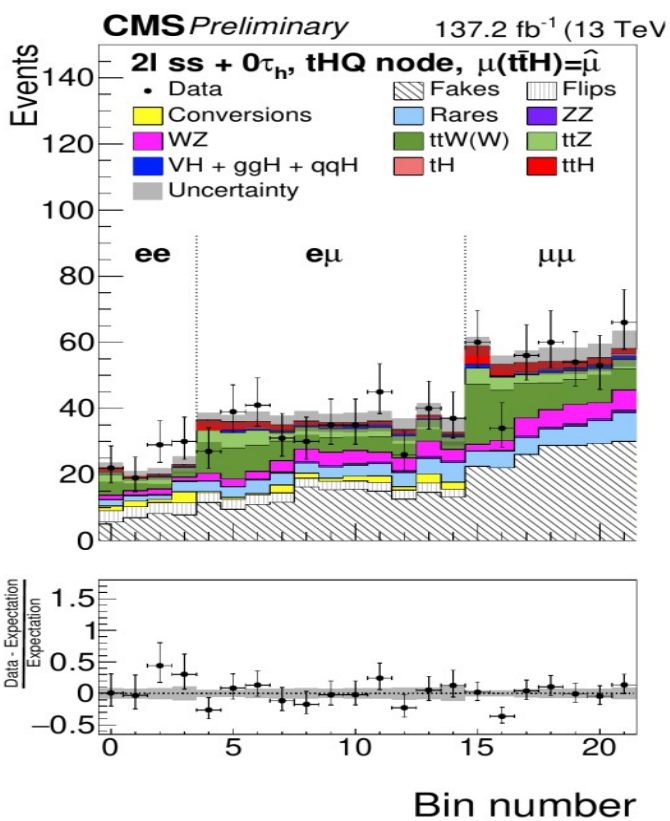
2L SS

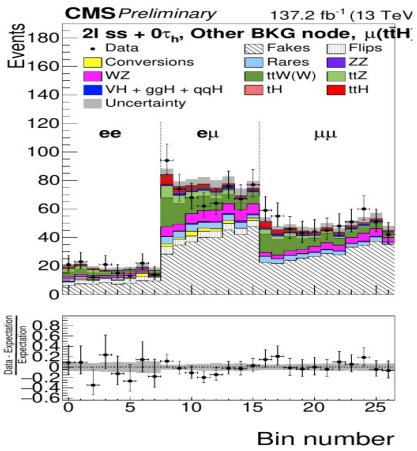
误差项	NP 类型	2016-2018 关联性	对预期事例数的影响
触发效率	Shape	Uncorrelated	1-3%
轻子鉴别效率	Shape	Correlated	2-6%
JES/JER	Shape	Uncorr. (stat.)/ Corr.(exp.)	1-5%
b-tagging 效率	Shape	Uncorr. (stat.) / Corr. (exp.)	2-7%
Unclustered Energy	Shape	Correlated	1-2%
Signal rate	Norm. / Shape	Correlated	4-11%
Fakes rate	Shape	Uncorrelated	20-50%
Flips rate	Norm.	Correlated	30%
MC background rate	Norm.	Correlated	30-50%
亮度	Norm.	Uncorr. / Corr.	2-3%
L1 prefiring	Shape	Uncorrelated	≈ 1%

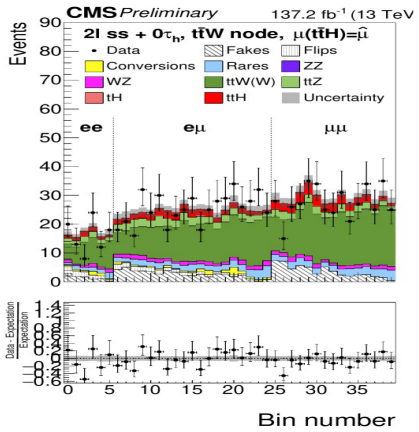
IHEP thesis

Results from 2L SS





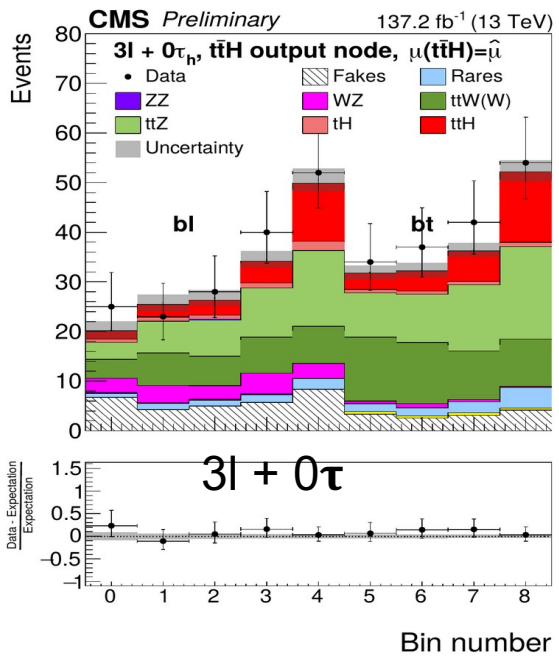


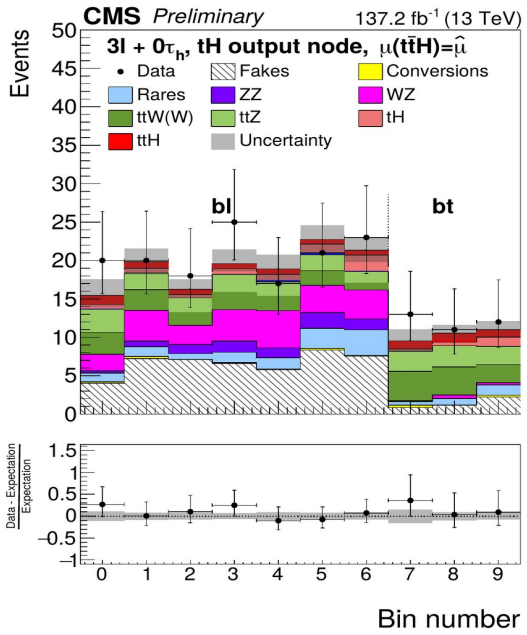


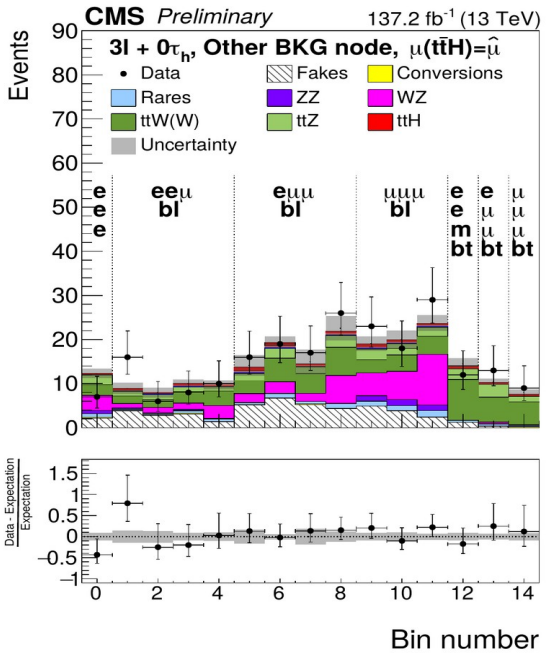
	Expected Signal strength $\pm 1\sigma$							
	2016		2017		2018		Run 2	
Process	BDT	DNN	BDT	DNN	BDT	DNN	BDT	DNN
$\mu_{t\bar{t}H}$	$1.00^{+0.64}_{-0.59}$	$+1.000^{+0.60}_{-0.55}$	$1.00^{+0.61}_{-0.55}$	$1.00^{+0.58}_{-0.53}$	$1.00^{+0.56}_{-0.51}$	$1.00^{+0.51}_{-0.46}$	$1.00^{+0.38}_{-0.34}$	$1.00^{+0.35}_{-0.32}$
μ_{tH}	$1.00^{+19.03}_{-19.24}$	$1.00^{+8.77}_{-8.41}$	$1.00^{+17.97}_{-17.39}$	$1.00^{+10.00}_{-8.75}$	$1.00^{+18.47}_{-18.82}$	$1.00^{+7.81}_{-7.56}$	$1.00^{+11.19}_{-11.00}$	$1.00^{+5.38}_{-5.13}$
$\mu_{t\bar{t}W}$	$1.00^{+0.55}_{-0.49}$	$1.00^{+0.29}_{-0.25}$	$1.00^{+0.42}_{-0.38}$	$1.00^{+0.28}_{-0.24}$	$1.00^{+0.43}_{-0.38}$	$1.00^{+0.24}_{-0.21}$	$1.00^{+0.31}_{-0.28}$	$1.00^{+0.20}_{-0.18}$

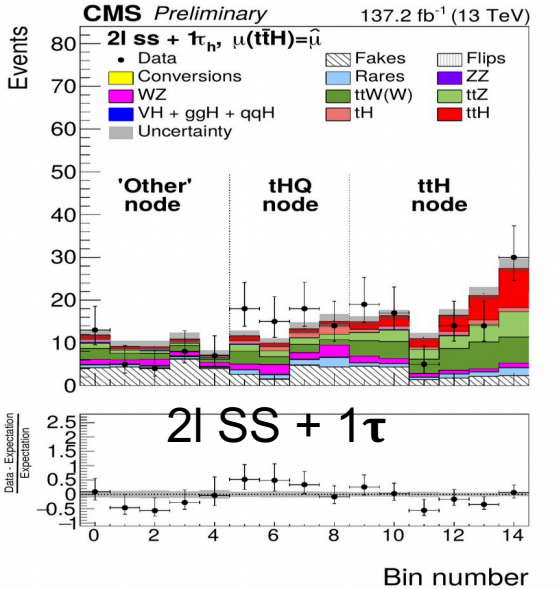
ttH:4.2(3.4)σ
tH: -0.6(0.2)σ

DNN: 3l + 0τ and 2lss + 1τ





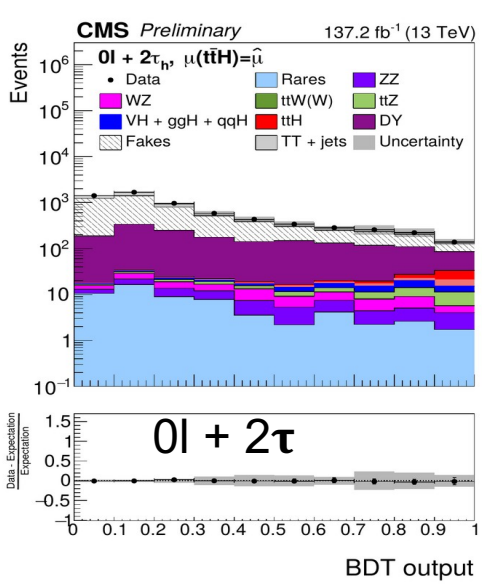


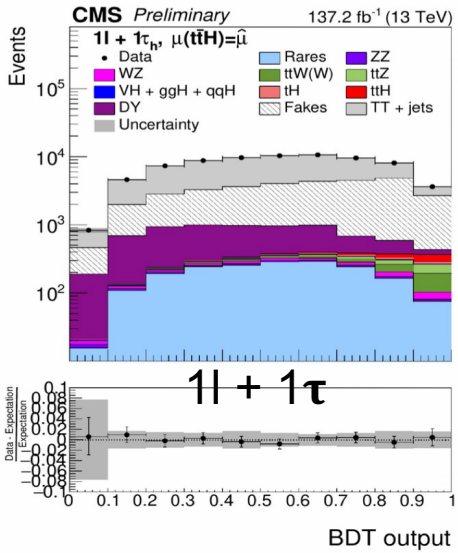


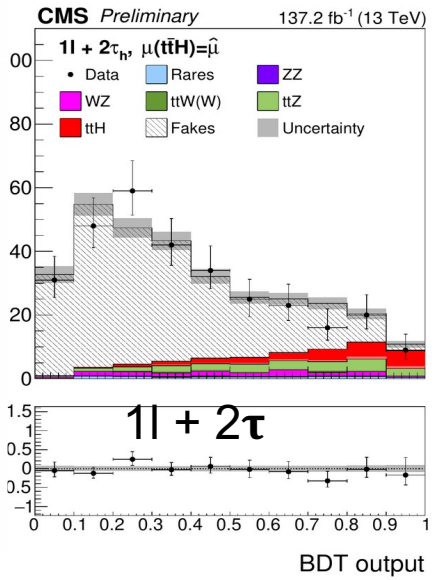
Same DNN as strategy as 2L SS + 0 τ

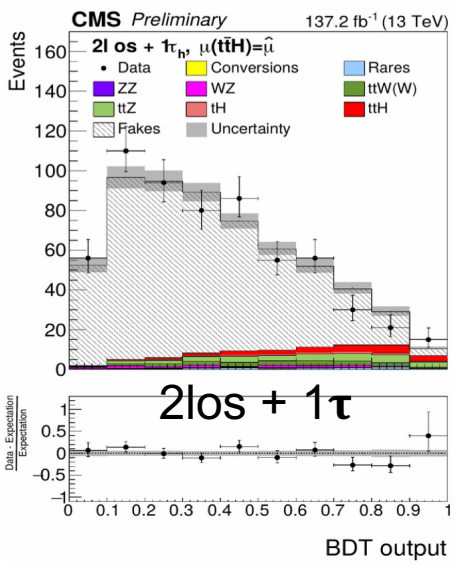
No obvious mis-modeling

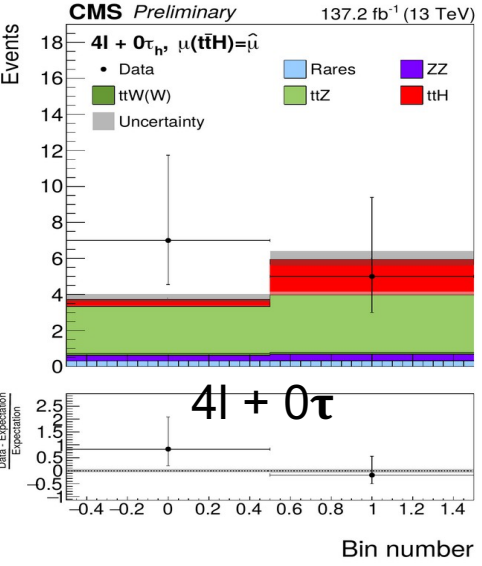
BDT: other signal regions

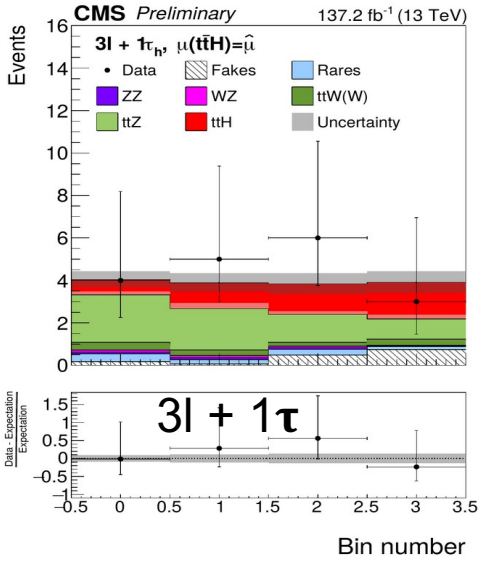


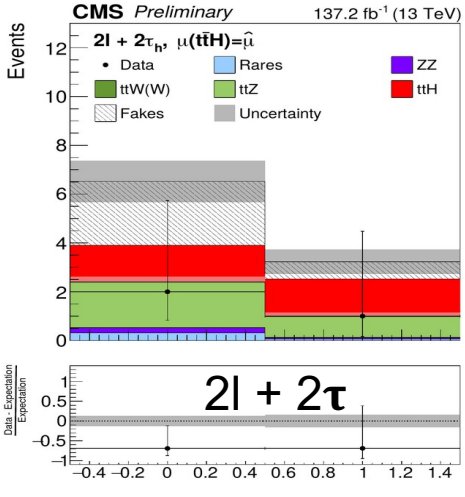












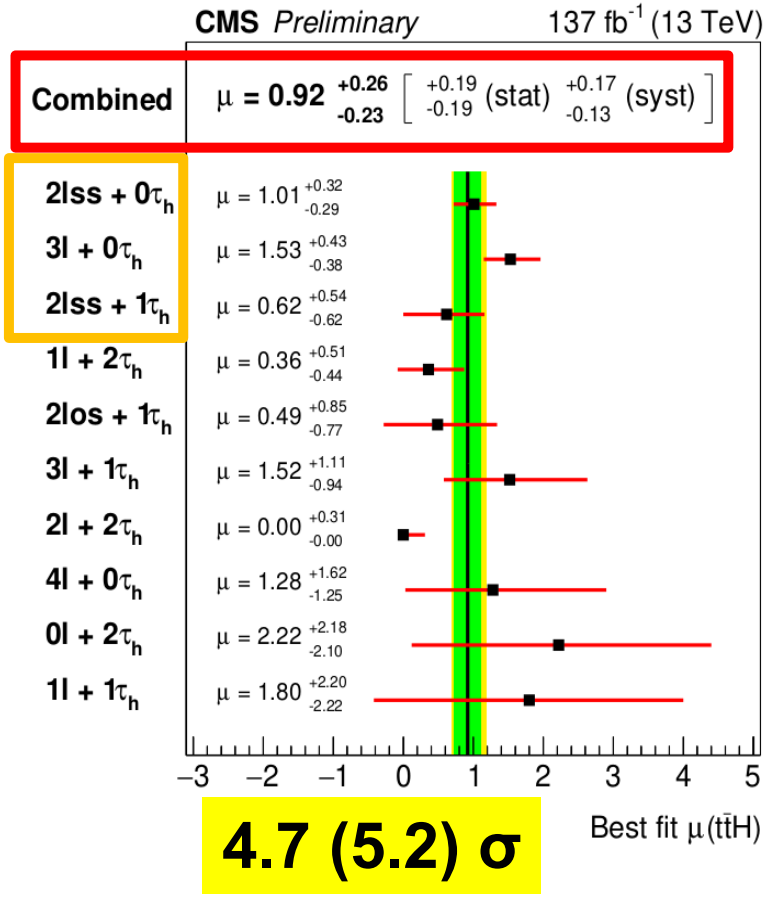
BDT analysis

Dominate bkg are fakes(2-3l)

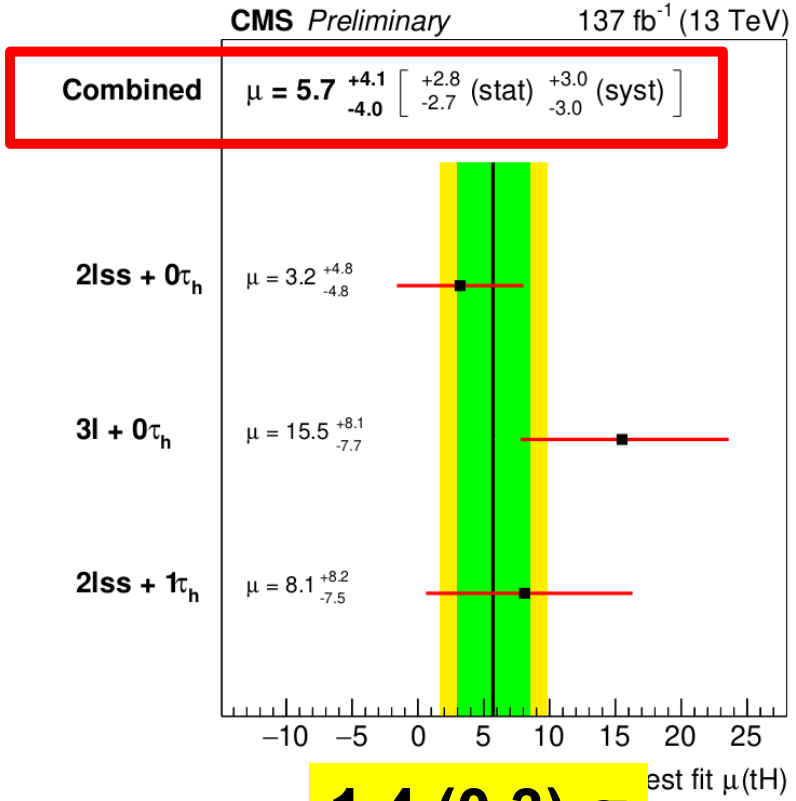
No mis-modeling

ttH and tH measurement in multilepton

- Combined likelyhood fitting including contral regions
  - Normalization of ttW,ttZ are floating
  - Fix one signal to SM while estimate the other

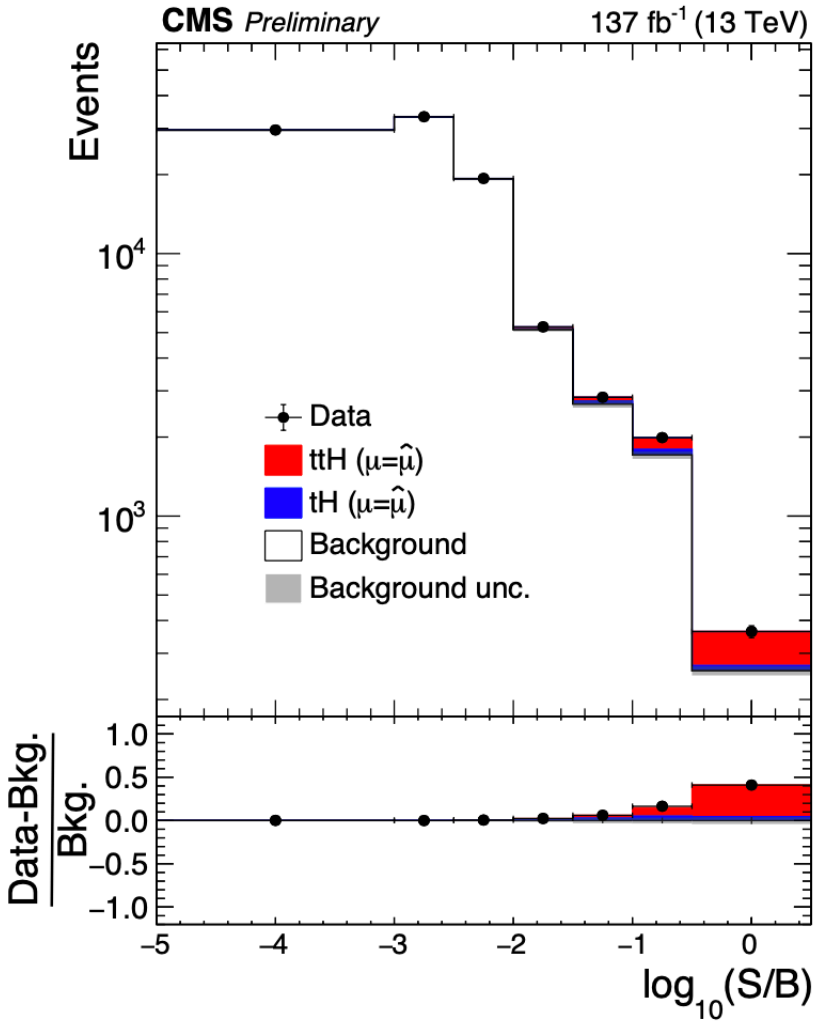


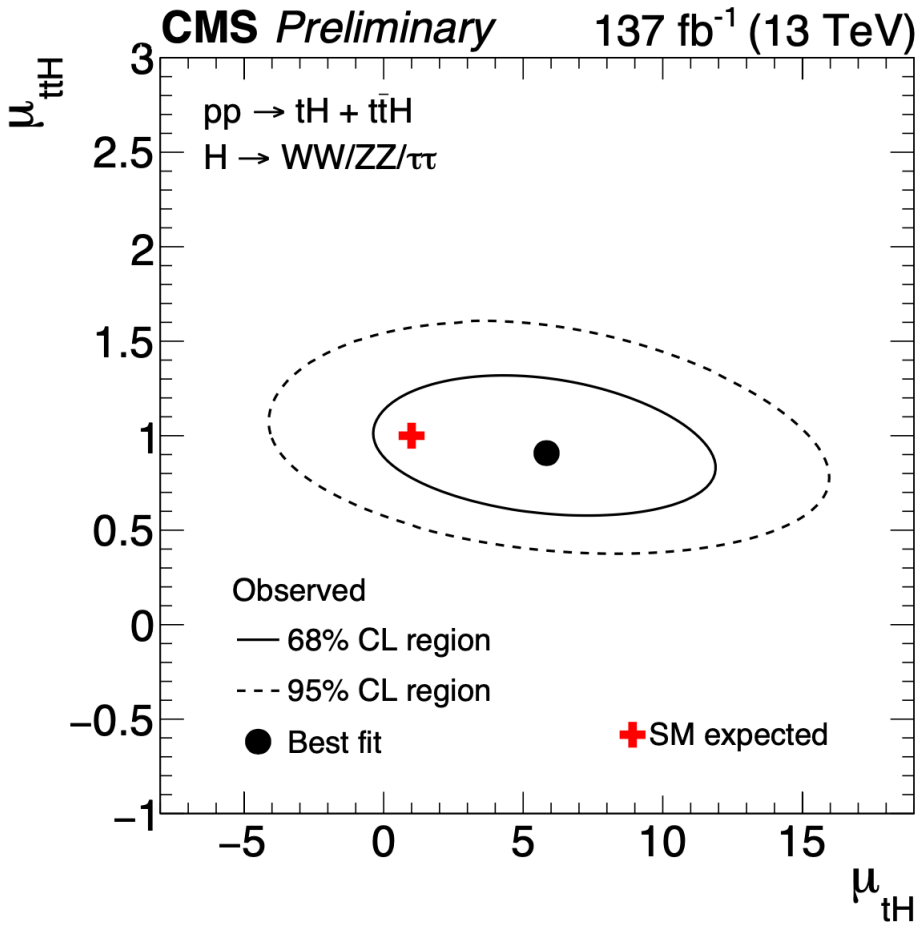
4.7 (5.2) σ



1.4 (0.3) σ

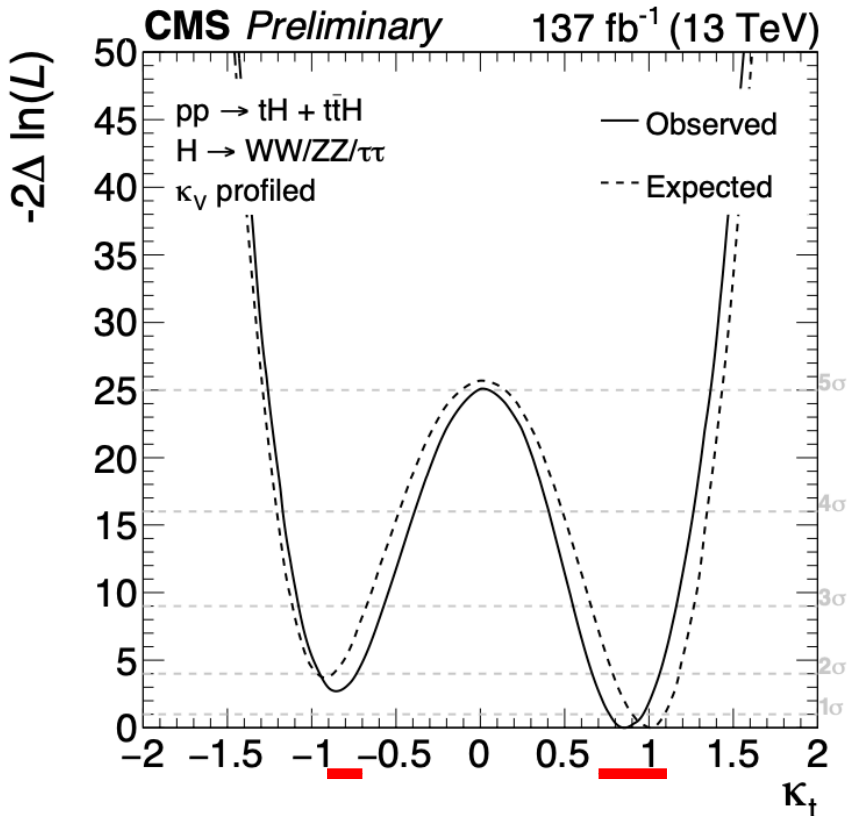
Correlation of ttH and tHq measurements

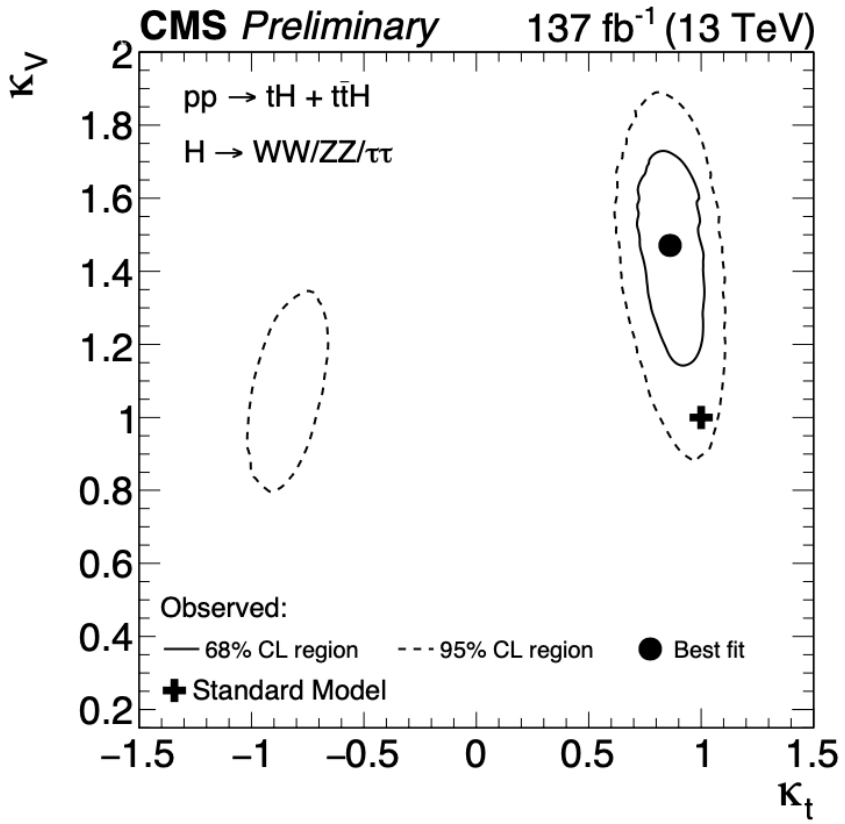




Results of H-t and H-W interference

- Expected excluding: Out side of $0.8 < \kappa_t < 1.2$
- Observed excluding: Out side of $0.7 < \kappa_t < 1.1$ and $-0.9 < \kappa_t < -0.7$





$$\sigma_{tHq} = (2.633\kappa_t^2 + 3.578\kappa_V^2 - 5.211\kappa_t\kappa_V) \times \sigma_{tHq}^{SM}$$

$$\sigma_{tHW} = (2.909\kappa_t^2 + 2.310\kappa_V^2 - 4.220\kappa_t\kappa_V) \times \sigma_{tHW}^{SM}$$

MC weights generated to account for XS and kinamatics differences

Summary

- ttH + tH analysis in the multi-lepton final states
  - Full run 2 data included
  - Most sensitive channel so far at LHC

- Measured ttH and tH crossection:
  - ttH: $466.4 \pm 96.3\,(\text{stat}) \pm 38.2\,(\text{syst})$ fb
  - tH: $423 \pm 201\,(\text{stat}) \pm 221\,(\text{syst})$ fb.

- Next steps:
  - CP/EFT/Differential study of ttH and tH


CMS

Table 5: Input variables to the multivariant discriminants in each of the ten analysis channels. The symbol "—" indicates that the variable is not considered.

	$2\ell\text{ss}+0\tau_h$	$2\ell\text{ss}+1\tau_h$	$3\ell+0\tau_h$	$0\ell+2\tau_h$	$1\ell+1\tau_h$	$1\ell+2\tau_h$	$2\ell\text{os}+1\tau_h$	$2\ell+2\tau_h$	$3\ell+1\tau_h$	$4\ell+0\tau_h$
Electron multiplicity	✓	✓	✓	—	—	—	—	—	—	—
Three-momenta of leptons and/or τ_hs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Transverse mass of leptons and/or τ_hs	✓	✓	—	✓	✓	✓	✓	—	—	—
Invariant mass of leptons and/or τ_hs	✓	—	—	✓	✓	✓	✓	✓	✓	—
SVFit mass of leptons and/or τ_hs	—	—	—	✓	✓	—	—	—	—	—
ΔR between leptons and/or τ_hs	✓	✓	✓	✓	✓	✓	✓	✓	—	—
cos*θ of leptons and τ_hs	—	—	—	✓	✓	✓	—	✓	—	—
Charge of leptons and/or τ_hs	✓	✓	✓	—	✓	—	—	—	—	—
Has SFOS lepton pairs	—	—	✓	—	—	—	—	—	✓	✓
Jet multiplicity	✓	✓	✓	—	—	—	—	—	—	—
Jets three-momenta	✓	✓	✓	—	—	—	—	—	—	—
Average ΔR between jets	✓	✓	✓	✓	✓	✓	✓	✓	—	—
Forward jet multiplicity	✓	✓	✓	—	—	—	—	—	—	—
Leading forward jet three-momenta	✓	✓	✓	—	—	—	—	—	—	—
Minimum $\Delta\eta$ between leading forward jet and jets	—	✓	✓	—	—	—	—	—	—	—
b jet multiplicity	✓	✓	✓	—	—	—	—	—	—	—
Invariant mass of b jets	✓	✓	✓	✓	✓	✓	✓	✓	—	—
Linear discriminant L_D	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hadronic top quark tagger	✓	✓	✓	✓	✓	✓	✓	—	—	—
Hadronic top p_T	—	✓	✓	—	—	✓	✓	—	—	—
Higgs jet tagger	✓	—	—	—	—	—	—	—	—	—
Number of variables	36	41	37	15	16	17	18	9	9	7