ttH into leptons

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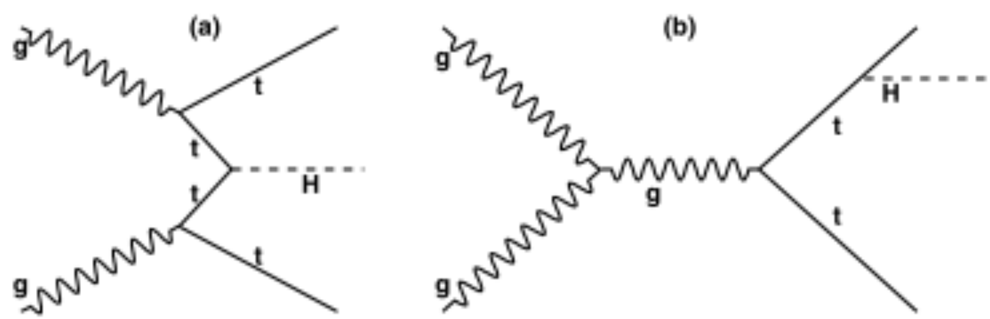
Introduction

- After Higgs boson discovery in 2012, still many properties to measure.
- Due to its large mass, top quark could play a leading role in EWSB.
- Higgs doesn't decay directly in top quarks but direct measurement of top Yukawa coupling possible in ttH production.

- At LHC, 8 TeV pp collisions, ttH cross section is 130pb (NLO)



Multilepton final states

- 3 Higgs decays contributions:
  - H → WW, H→ZZ, H→ττ with at least 1 W, Z or τ decaying leptonically.
- Additional leptons may come from top pair decay.

- 5 Clean experimental signatures:
  - 2 same-sign leptons (e, μ) + b-tagged jets
  - 3 leptons + b-tagged jets (e, μ)
  - 4 leptons + b-tagged jets (e, μ)

The presence of hadronic or leptonic τ are taken into account in the signal contribution:

  - 2 same-sign leptons (e, μ) + 1 τ + b-tagged jets
  - 1 lepton (e, μ) + 2 τs + b-tagged jets

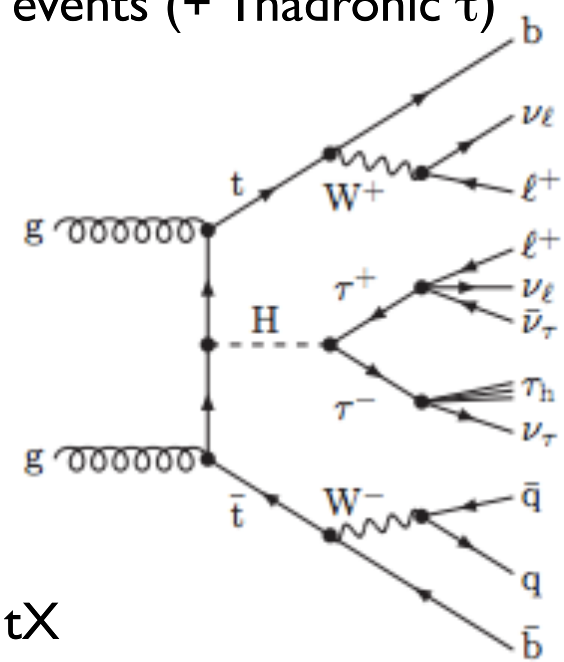
Channel Name	e,μ requirements	τ requirement
Same-sign	=2 $Q(\ell\ell)=\pm2$	=0
1 τ	=2 $Q(\ell\ell)=\pm2$ or 3 $Q(\ell\ell\ell)=\pm1$	≥ 1
3 leptons	=3 $Q(\ell\ell\ell)=\pm1$	=0
2 τs	=1	=2
4 leptons	=4	ignored

Status

- Public results from CMS *(CMS PAS HIG-13-020)*
- ATLAS preparing a paper:
  - Aim is to have a combination between various channels
  - Possibility to combine with CMS
- En France:
  - ATLAS: Clermont (same-sign, coordination multi-leptons)

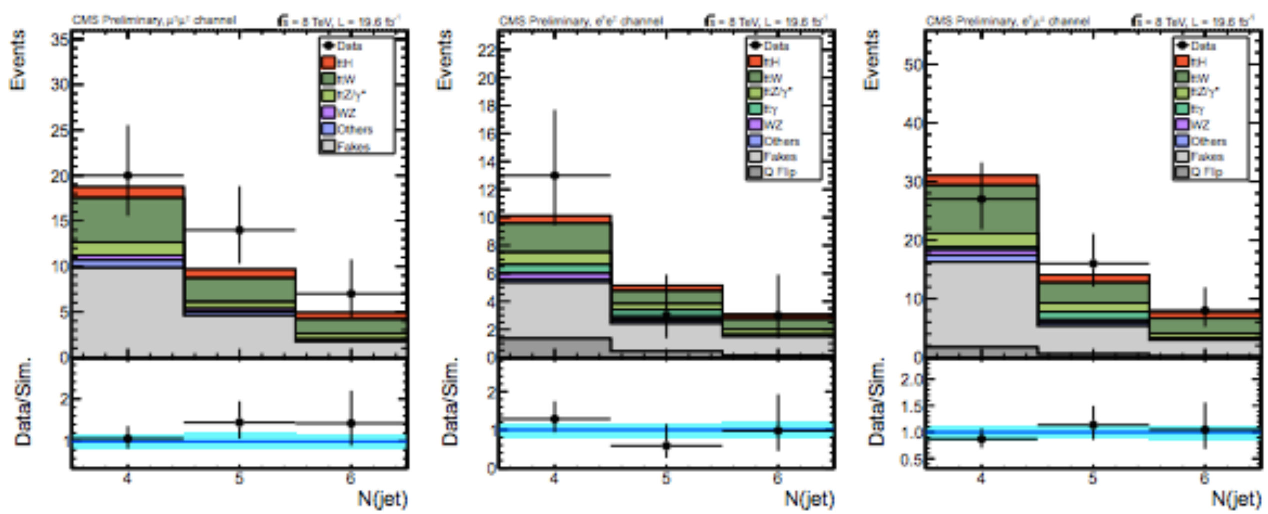
2 same-sign leptons

- Only H→WW can produce 2 prompts same-sign leptons at truth level:
  - Because of the acceptance, H→ZZ can also contribute
  - H→ττ events can produce same-sign events (+ 1hadronic τ)
- Signal properties:
  - 6 quarks in the final state
  - ⇒ Large jet multiplicity
- Main backgrounds:
  - ttV
  - Fake/non-prompt leptons from ttbar, tX
  - Fake same-signs (Charge mis-identification) from ttbar



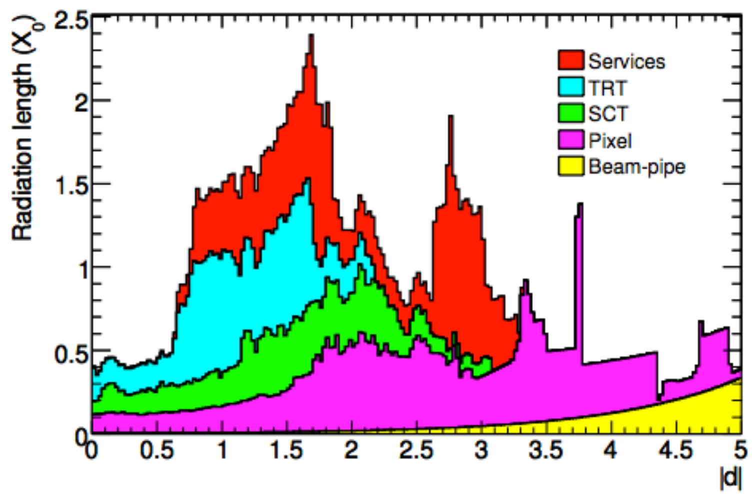
2 same-sign leptons

- Analysis strategy:
  - Most of the sensitivity comes from the same-sign signature
  - Di-bosons reduced with b-tag + multiplicity cuts (typically >=4 jets)
  - tt and ttV reduced with multiplicity cut
  - Gain with event reconstruction small (top backgrounds)
  - Use of a MVA (BDT in CMS) leads to a small gain w.r.t. a categorisation (njets, nbjets) (ATLAS)



Charge mis-identification

- Background specific to same-sign channel:
  - Depends strongly on the material in the detector and its simulation:



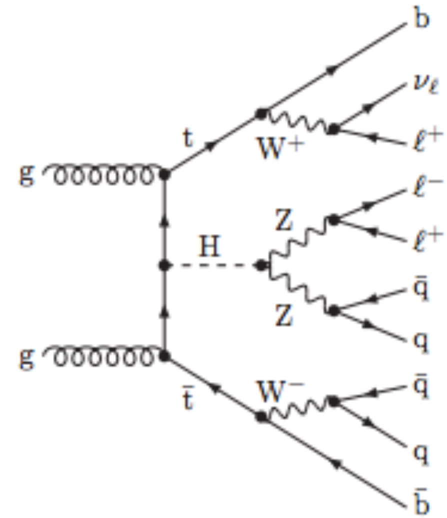
Material distribution at the exit of the inner detector of ATLAS as a function of | η |

  - Charge flip rates derived from data preferred to simulation
  - Use of Z→ee events to measure and parametrise the rates
  - Modelled in pT, eta
  - Main systematic due to the size of the Z→ee sample

- Tools and method from Exotic same-sign analysis (cf. presentation by Loïc Valery)

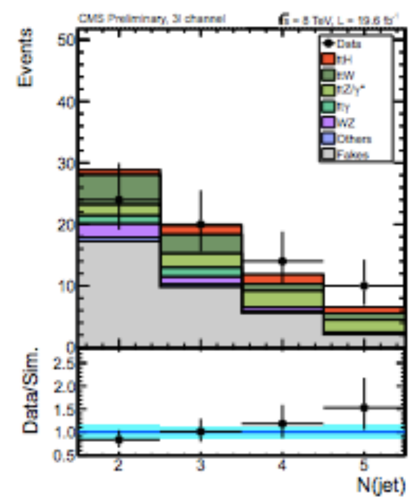
3 leptons

- 3 Higgs decays can produce 3lepton final state, at truth level:
  - 70% from H→WW
  - 20% from H→ττ
  - 10% from H→ZZ



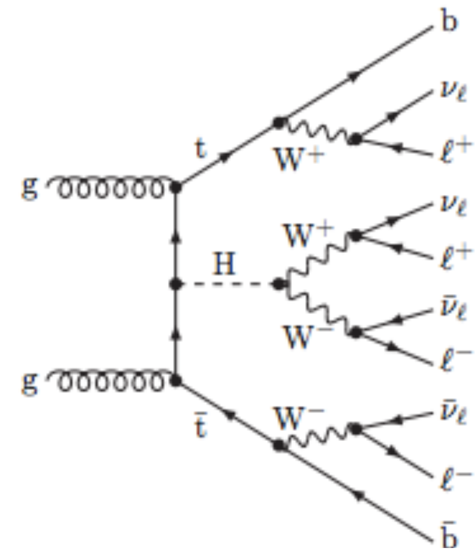
- Signal properties:
  - 4 quarks in the final state
  - Typical jet multiplicity of 4

- Main backgrounds:
  - ttV
  - Fake leptons from ttbar, tX

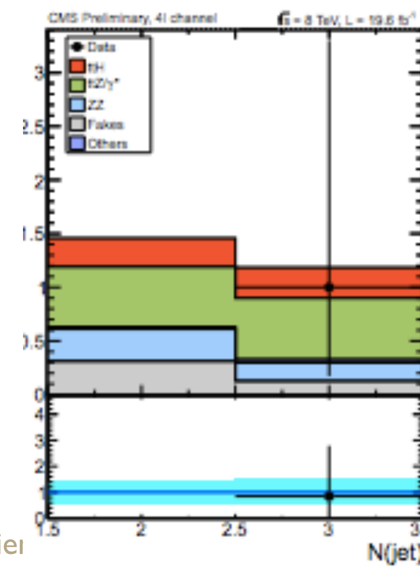


4 leptons

- 3 Higgs decays can produce 3lepton final state, at truth level:
  - 50% from H→WW
  - 30% from H→ττ
  - 20% from H→ZZ



- Signal properties:
  - 0, 2 or 4 quarks in the final states depending on the Higgs decay
  - Clean signal but very small σxBr



- Main backgrounds:
  - ttV
  - diboson

ττ channel

- ττ+1lepton targets H→ττ decays:

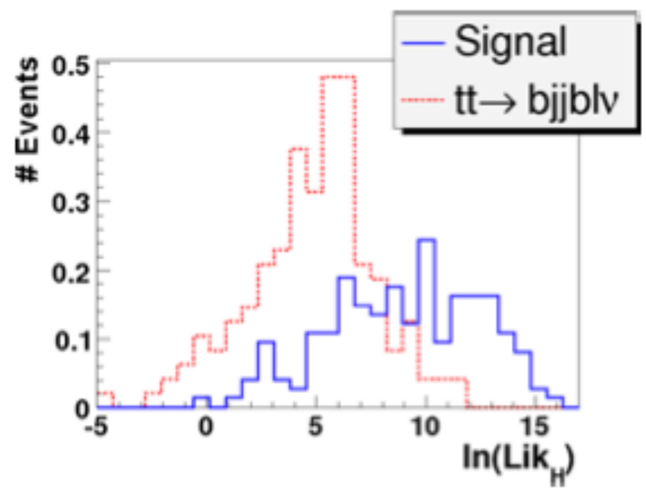
  - 16% from H→WW
  - 80% from H→ττ
  - 2% from H→ZZ

- Signal properties:
  - 4 quarks in the final states
  - Depends on τ reco. performances

- Main backgrounds:
  - ttV
  - ttbar (fake τs)

ττ channel

- CMS: Use of BDT with global observables
- ATLAS: Event reconstruction easier in ττ channel w.r.t other multilepton ttH channels, use of Likelihood method for combinatorix (masses, DRs, …) → Best Likelihood from each event is used as discriminant:



$t\bar{t}H \to t\bar{t}\tau^+\tau^-$—toward the measurement of the top-Yukawa coupling
Eur. Phys. J. C (2009) 59: 731–754

ttV background

- Most important non-reducible background
- Dedicated group (ATLAS) for data constraint
- Unlikely to provide a constraint more precise than theory uncertainty in Run I

→ Estimated on simulated events

→ Keep ttV control regions in the fits for a possible profiling of ttV

→ ttZ is tested directly in a 3 lepton control region enriched in Z bosons and ttW in same-sign low jet region (4 jets)

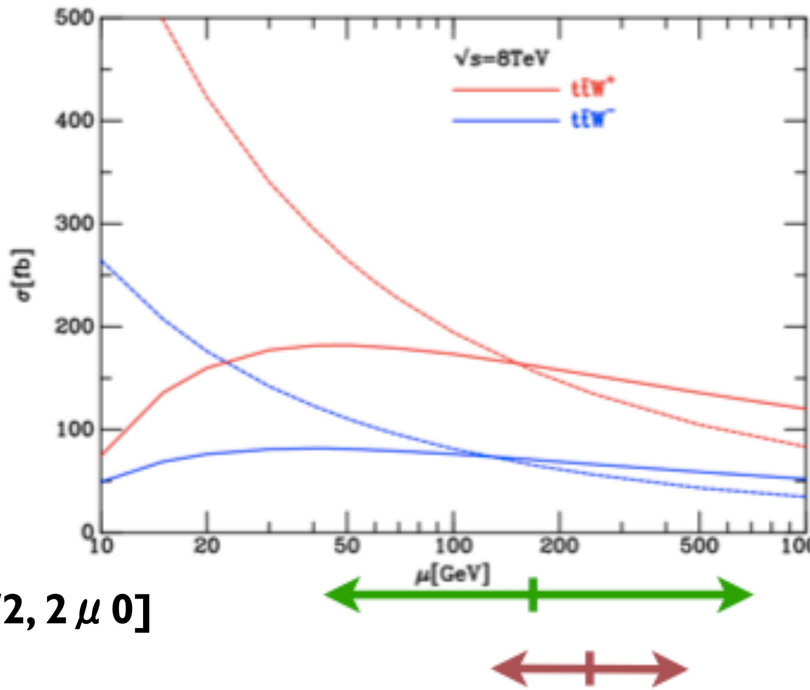
- Inclusive production cross sections are taken from NLO computations

- Uncertainties:
  - Theoretical for higher orders
  - PDFs
  - Lepton, b-tag efficiencies, JES

Process	σ_{NLO} [fb]	k-factor
$t\bar{t}$+W	**232**	1.18
$t\bar{t}$+Z	**205.7**	1.33

ttV background

- Two calculations (most optimistic used by CMS, most pessimistic by ATLAS):
  - arXiv:1204.5678 - Campbell et al.
    - **σ NLO(ttW) = 232 fb**
    - ttW+ +14%/-22% ← scale and **pdf+ α s**
    - ttW- +17%/-22% ← scale and **pdf+ α s**
    - scale **μ 0 = mt** → range=**[mt/4, 4mt]**
  - arXiv:1208.2665 - Garzelli et al.
    - **σ NLO(ttW) = 203.1 fb**
    - **σ NLO(ttZ) = 205.7 fb**
    - ttZ ±10% ← scale only
    - ttW ± 10% ← scale only
    - scale **μ 0 = mt + mV/2** → range=**[μ 0/2, 2 μ 0]**



- Typical ttV systematic used in ATLAS is 30%, in CMS 10%

ttV background

- ttV systematic being refined in ATLAS
- Approach considered:
  - Use scale uncertainties from Campbell et al. or Garzelli et al.
  - Validate MadGraph5 aMC@NLO by reproducing cross sections and uncertainties
  - Calculate the PDF uncertainty with aMC@NLO and use that value.

  (Should lead to an intermediate systematic (15-20%))

- Binned systematic in number of jets needed if a categorized fit is used

Fake/non prompt leptons background

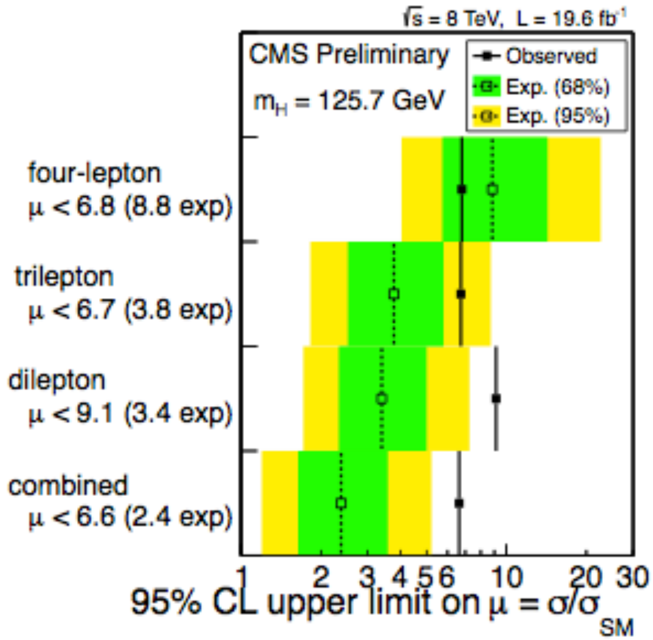
- Reducible background estimated on data
- Matrix Method: (cf. same-sign exotic analysis by Loïc Valery)
  - Used in ttH for di-leptonic channels
  - rates and efficiencies derived from control regions
  - Event with fake leptons derived from loose di-leptonic sample
  - Predicts shapes and yields in signal region
  - Typical uncertainty 30%

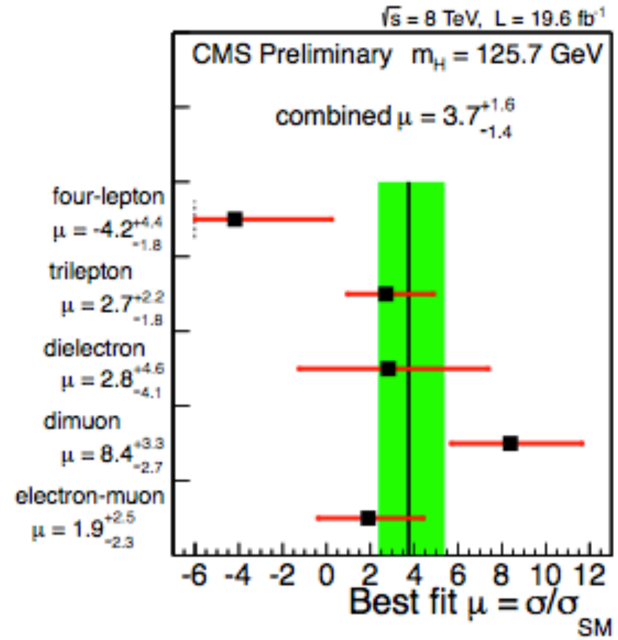
- Event based estimate:
  - Extrapolation from 3 control regions (as in an ABCD method)
  - Use of object properties (isolation, reverse-isolations, ID, anti-IDs,…) and event properties (number of jets, Ht, …) to define the regions
  - Predicts yields but no shapes
  - Typical uncertainty 30%
  - Method considered for all the channels in ATLAS

Main Systematics (CMS)

Syst Name	Rate or Shape	Description
$t\bar{t}H$ higher orders	rate	Theoretical uncertainty on $t\bar{t}H$ cross section.
$t\bar{t}W$ higher orders	rate	Theoretical uncertainty on $t\bar{t}W$ cross section.
$t\bar{t}Z$ higher orders	rate	Theoretical uncertainty on $t\bar{t}Z$ cross section.
PDF	rate	Theoretical uncertainty on cross sections for $t\bar{t}H$, $t\bar{t}W$, $t\bar{t}Z$. Correlated in all channels for all processes sharing a dominant production mechanism.
$t\bar{t}H$ PDF Shape	shape only	Theoretical uncertainty from PDF on shape.
$t\bar{t}W$ PDF Shape	shape only	Theoretical uncertainty from PDF on shape.
$t\bar{t}Z$ PDF Shape	shape only	Theoretical uncertainty from PDF on shape.
$t\bar{t}H$ PYTHIA tune	shape only	Theoretical uncertainty on MC modeling.
$t\bar{t}W$ MADGRAPH tune	shape only	Theoretical uncertainty on MC modeling.
$t\bar{t}Z$ MADGRAPH tune	shape only	Theoretical uncertainty on MC modeling.
Non-prompt Fake Rate	envelope	Applied to reducible non-prompt backgrounds.
Charge-flip	envelope	Applied to charge flip background for 2ℓ channel.
WZ	rate	Uncertainty from fit in control region.
ZZ	rate	Uncertainty from fit in control region.
Jet Energy Scale	template	Applied to WZ,ZZ,$t\bar{t}W$,$t\bar{t}Z$,$t\bar{t}H$.
b-tagging efficiency	rate	Applied to WZ,ZZ,$t\bar{t}W$,$t\bar{t}Z$,$t\bar{t}H$.
b-tagging fake rate	rate	Applied to WZ,ZZ,$t\bar{t}W$,$t\bar{t}Z$,$t\bar{t}H$.
Lepton Trigger Scale factor	rate	Applied to WZ,ZZ,$t\bar{t}W$,$t\bar{t}Z$,$t\bar{t}H$.
Lepton preselection Scale factor	rate	Applied to WZ,ZZ,$t\bar{t}W$,$t\bar{t}Z$,$t\bar{t}H$.
Lepton MVA discriminator scale factor	rate	Applied to W,ZZ,$t\bar{t}W$,$t\bar{t}Z$,$t\bar{t}H$.
Luminosity	rate	Applied to WZ,ZZ,$t\bar{t}W$,$t\bar{t}Z$,$t\bar{t}H$.

Sensitivities (CMS)





- Same-sign and 3 lepton channels are the most sensitive channels
- Fitted signal strengh 3.7+1.6-1.4 (68% CL), excess in same-sign and 3 leptons
- Sensitivity hierarchy ~similar in ATLAS

14 TeV

- Important increase of cross-section at 14TeV:

Process	LO σ (fb)	NLO σ (fb)	K-Factor
$t\bar{t}H + 1p$	533.6	609.9	1.14
$t\bar{t}W + 2p$	548.7	706.2	1.29
$t\bar{t}ll + 2p$	74.5	74.1	0.99
$t\bar{t}WW + 1p$	10.4	n/a	—

- One of the largest XS increase between RunI and RunII
- Many systematic uncertainties expected to be reduced (more control data, larger fake CR, ttV measurements, …)

Source	300 fb^{-1}	3000 fb^{-1}
Top fake rate	17%	2%
$\sigma(t\bar{t}H)_{SM}$	16%	16%
Other cross section systematics	8%	3%
All systematics	27%	17%
Systematics without $\sigma(t\bar{t}H)_{SM}$	18%	4%

- Boost effect in multileptons not clear

Summary and outlooks

- Multilepton channels allows to constrain the top-Higgs coupling
- The various channels covers many Higgs decay channels (WW, $\tau\tau$, ZZ):
  - Use of signature approach (not targeting an exclusive Higgs decay)
- Most sensitive channels are same-sign and 3 lepton channels
- Main backgrounds:
  - ttV → intensive work on related systematics
  - Instrumental backgrounds → fake leptons and charge mis-identification with dedicated studies
- 14TeV is being studied → ttH is promising, good constraint should be quickly obtained in Run II