Search for the associated production of the Higgs boson with a top quark pair in multilepton final states with the ATLAS detector

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on behalf of the ATLAS collaboration

TOP-LHC-France @Clermont-Ferrand

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Introduction

- **Reminder: I am going to show ATLAS run 1 analysis.**
  ATLAS run 2 ttH analysis has not been published yet.

- **Outline of this presentation**
  - analysis motivation
  - object and event selection
  - background compositions
  - ttV background validation
  - fake background estimation
  - pre-fit event yields
  - results
  - for run 2 analysis ...
  - Summary

Discovery of the SM Higgs boson

- **An Higgs-like particle was observed by ATLAS and CMS experiment in 2012** → Peter W. Higgs and François Englert are awarded with Nobel Prize in 2013 !
- **In July 2012**

  observation of an Higgs-like particle

  (in combine $H\to\gamma\gamma$, $H\to WW$ and $H\to ZZ$ channels)
- **In March 2013**

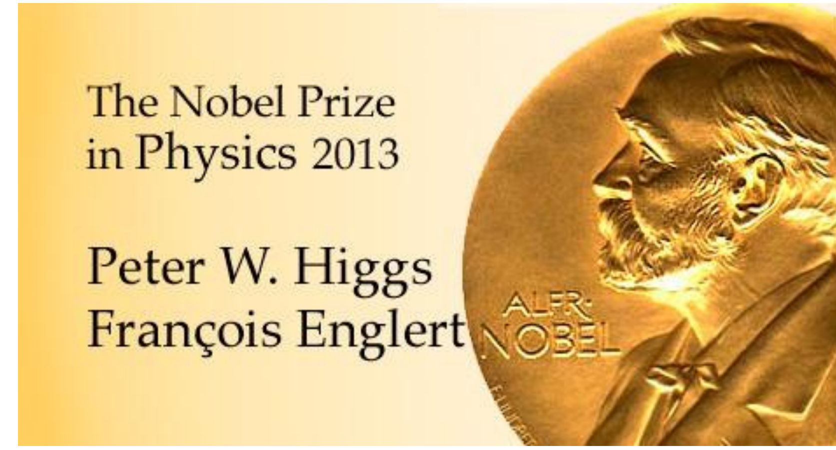
  confirmed by spin/CP & coupling constraints

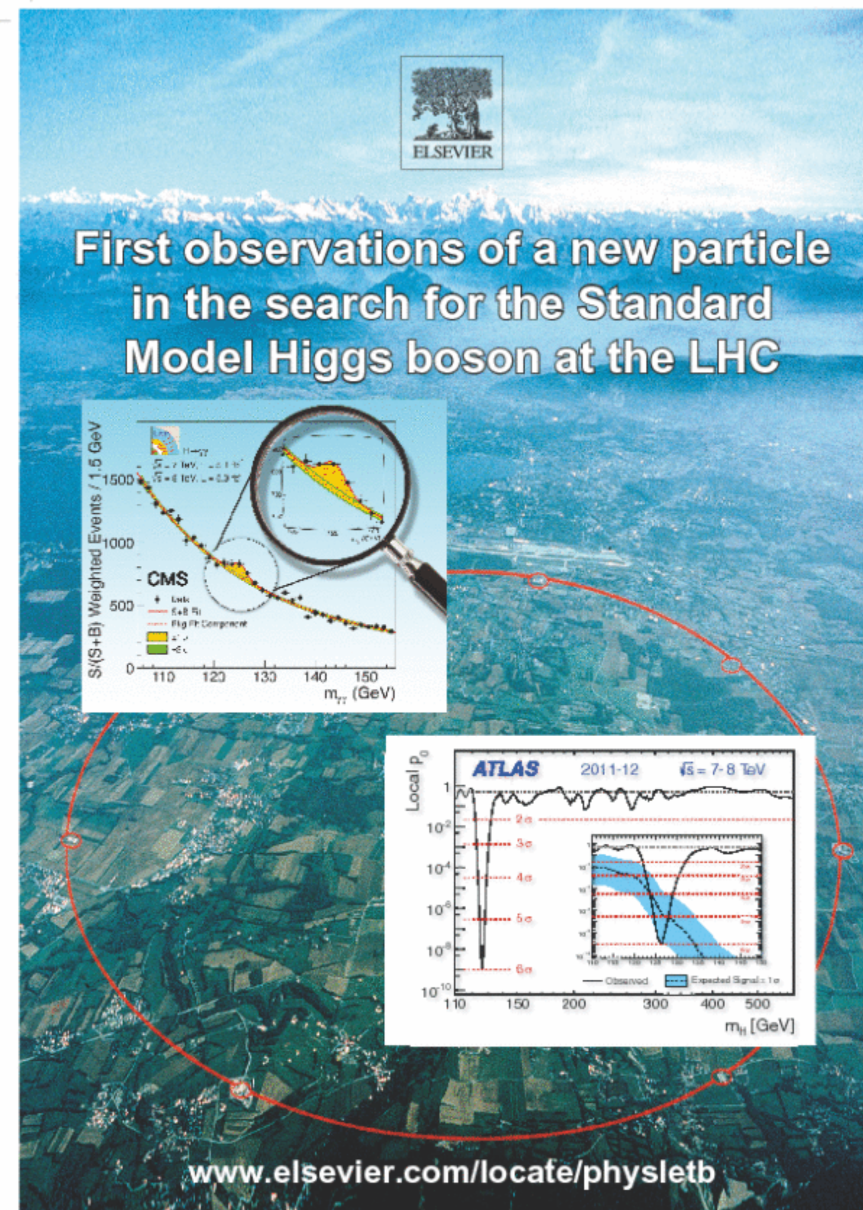
  observation of $H\to\gamma\gamma$, $H\to ZZ$, *evidence of VBF*
- **In Nov. 2013**

  evidence for $H\to\tau\tau$ *decay*
- **In Dec. 2014**

  observation of $H\to WW$ *decay*
- Up to now (**ATLAS+CMS run 1 combination**)

  observation of $H\to\tau\tau$ *and VBF production*





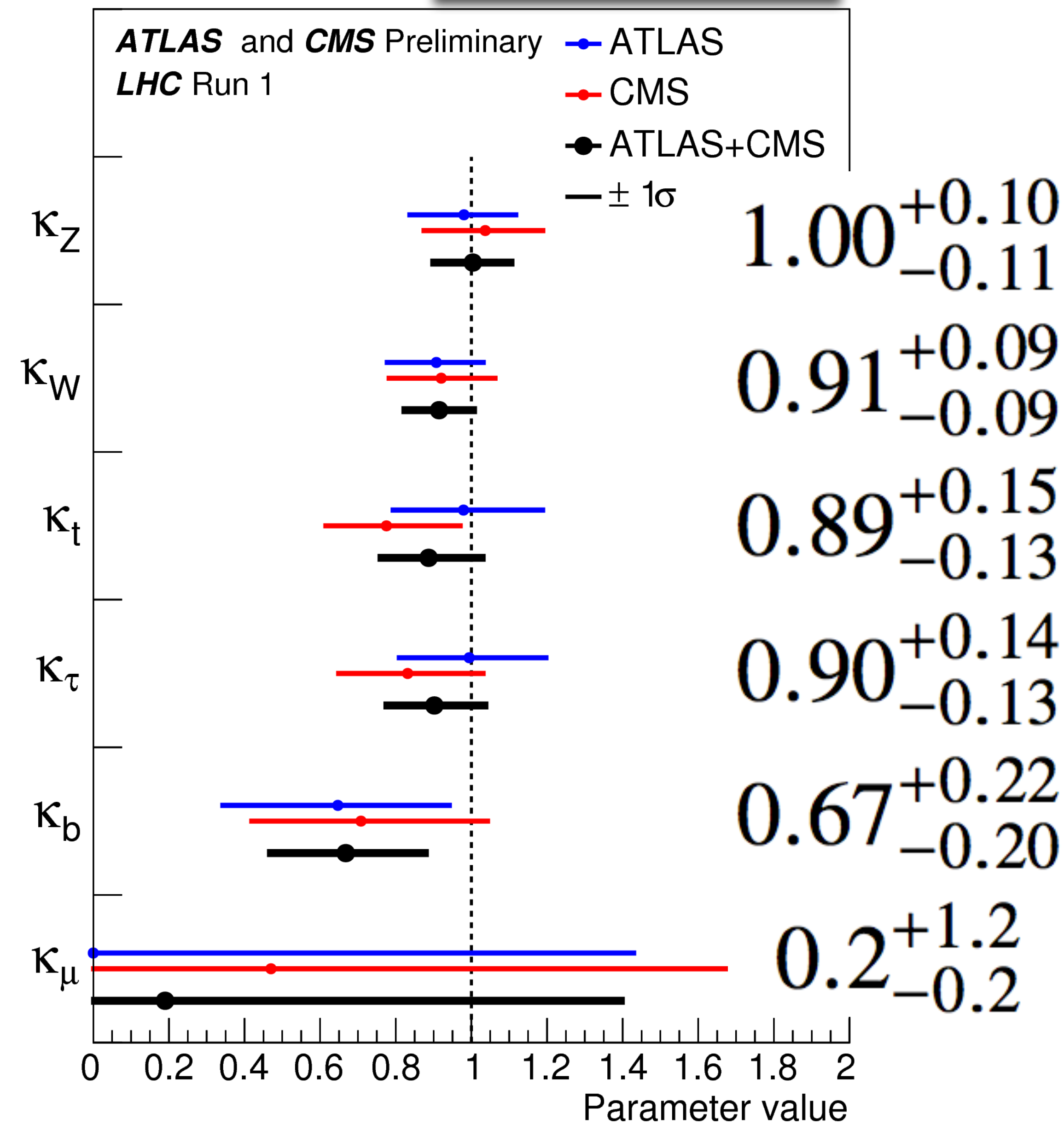
New discovered Higgs boson measured properties

- **ATLAS+CMS combined measurement** of Higgs boson mass:

$$125.09 \pm 0.21\,(\text{stat.}) \pm 0.11\,(\text{syst.})\ \text{GeV}$$

$$\kappa_j^2 = \sigma_j / \sigma_j^{\text{SM}}$$

- **Best-fit values of coupling modifier**
  couplings to vector bosons ~ 10% uncer.
  couplings to fermions > 15% uncer.



- **Any deviation might be hint for new physics, by**
  - searching as much as rare decays
  - precise measurement on properties of the new discovered particle

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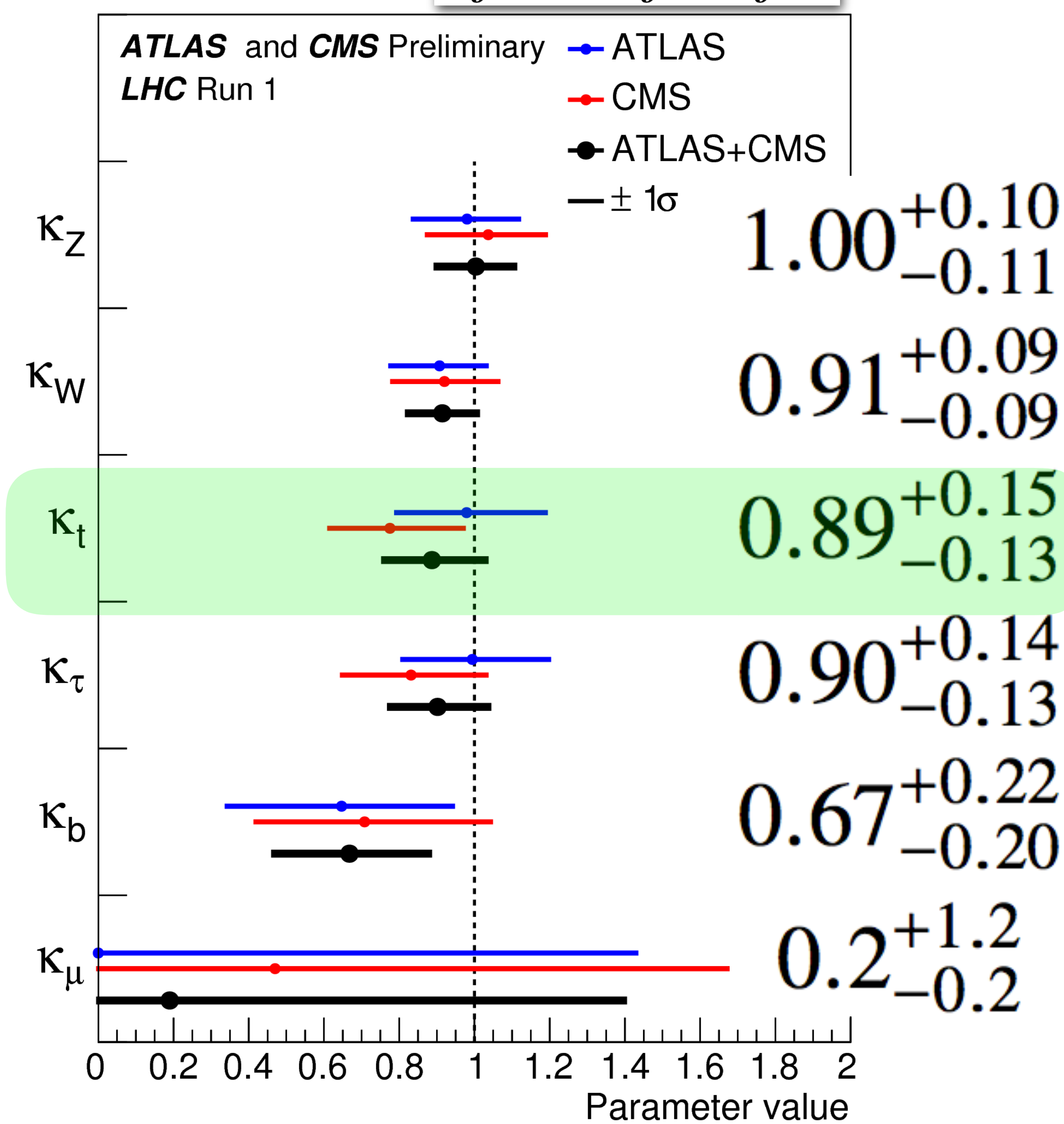
- **Top Yukawa coupling Y_t (close to unity) is one of all biggest forces we should care about !**

$$\kappa_j^2 = \sigma_j / \sigma_j^{SM}$$



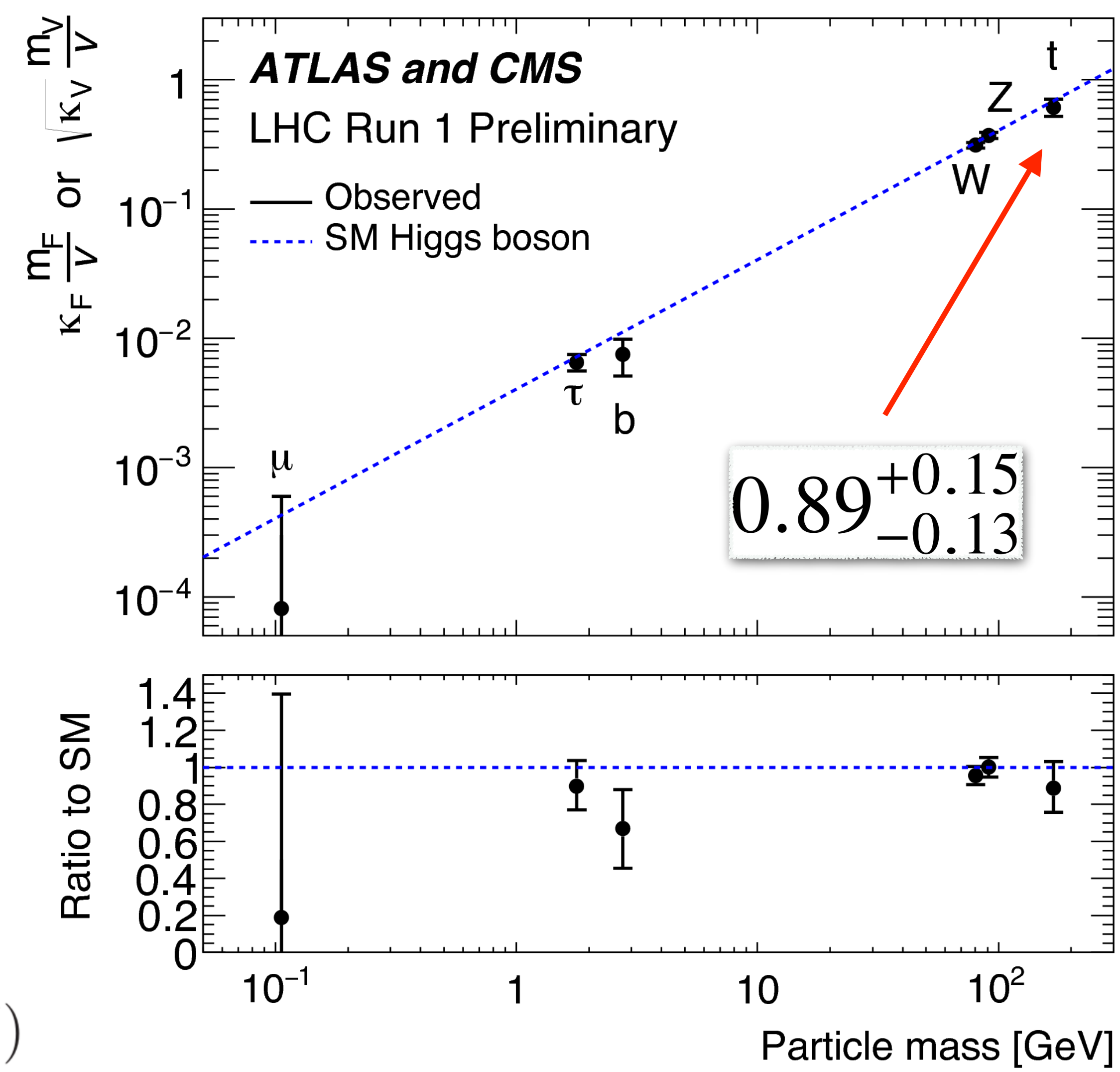
Top Yukawa coupling indirect measurements

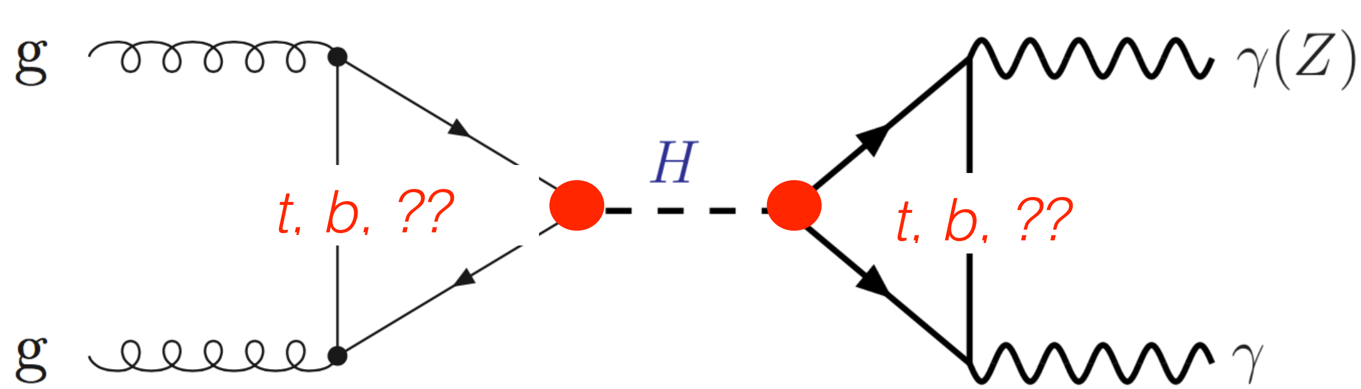
- **Can be derived from top mass, top pair cross section measurements**

  ($y_t=\sqrt{2}m_t/v$. need precise top pole mass!)

- **It has been constraint from Higgs production and decay measurements.**

  mainly from Higgs gluon fusion production and $H\to\gamma\gamma$, where top Yukawa coupling exists in loops, **assuming there is no BSM !**





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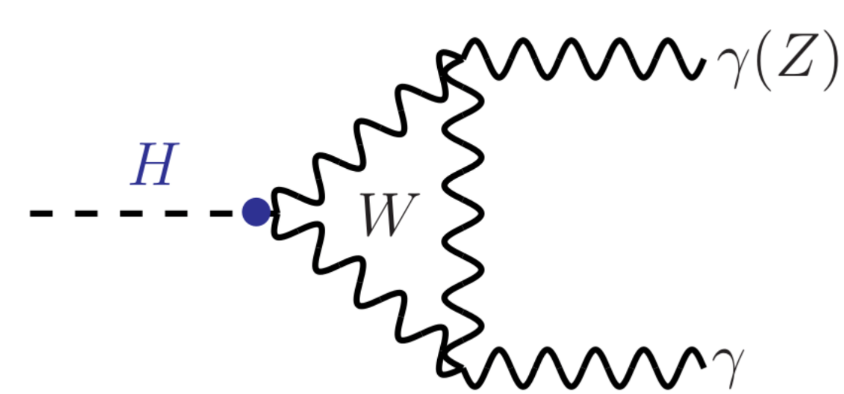
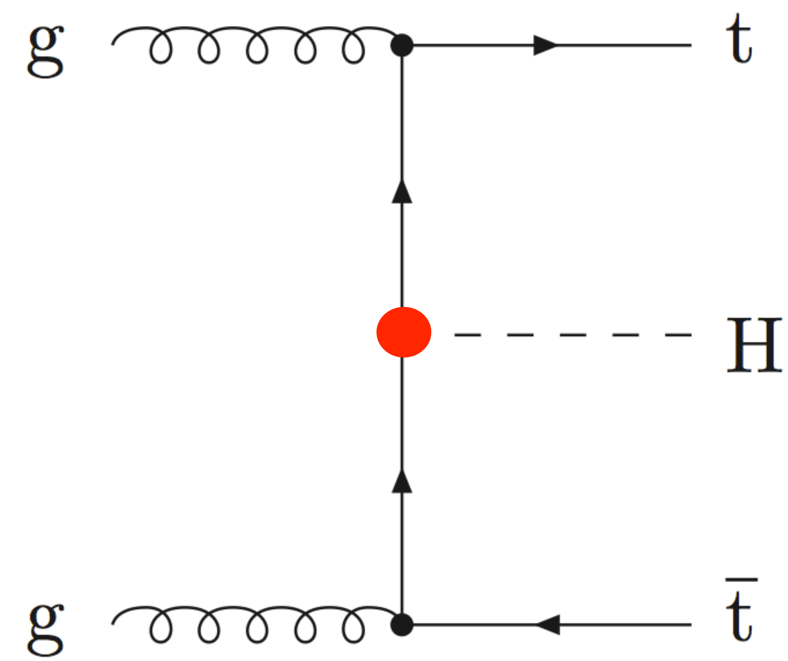
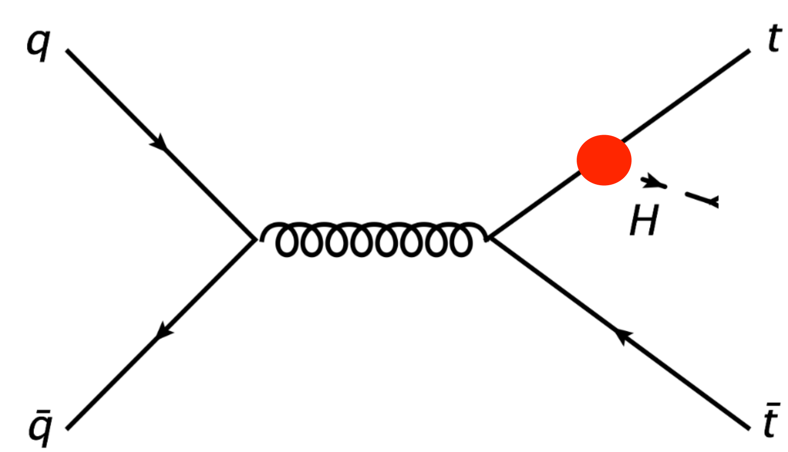


Top Yukawa coupling direct measurement

- Y_t **direct measurement from ttH production mode**
  → any deviation might be hint for new physics





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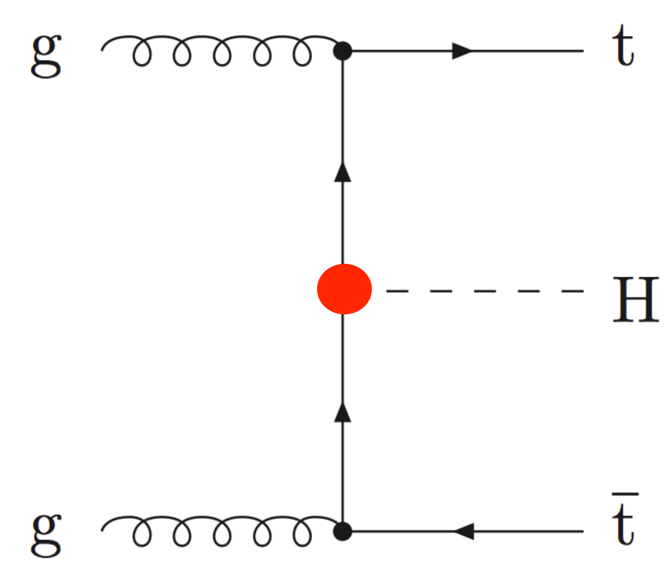
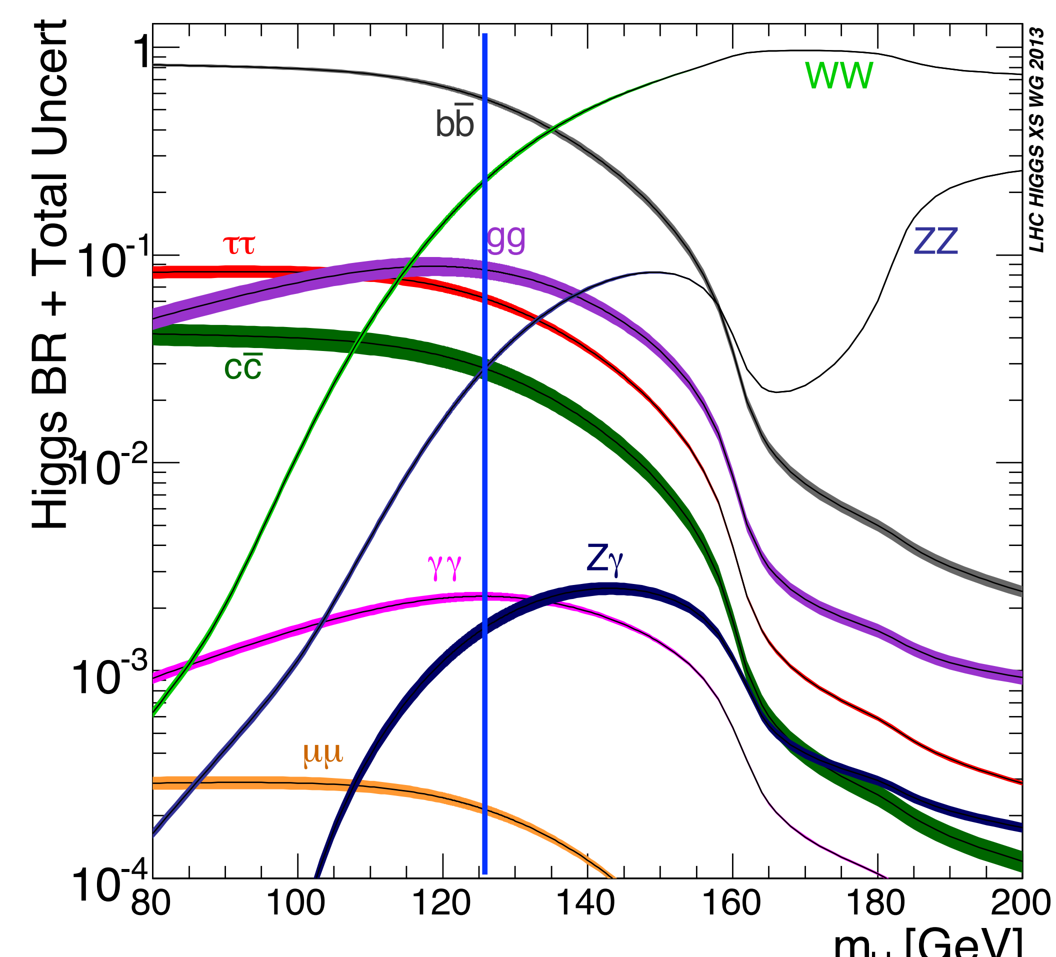


- **ttH cross section @8TeV: 129fb (1/200 of total Higgs production cross section)**

- **Searches for the ttH production** include many decay modes (branch ratio ~88%)
  - $H \to bb$ 57.5±1.9%
  - $H \to WW$ 21.6±0.9%
  - $H \to \tau\tau$ 6.30±0.36%
  - $H \to ZZ$ 2.67±0.11%
  - $H \to \gamma\gamma$ 0.23±0.01%



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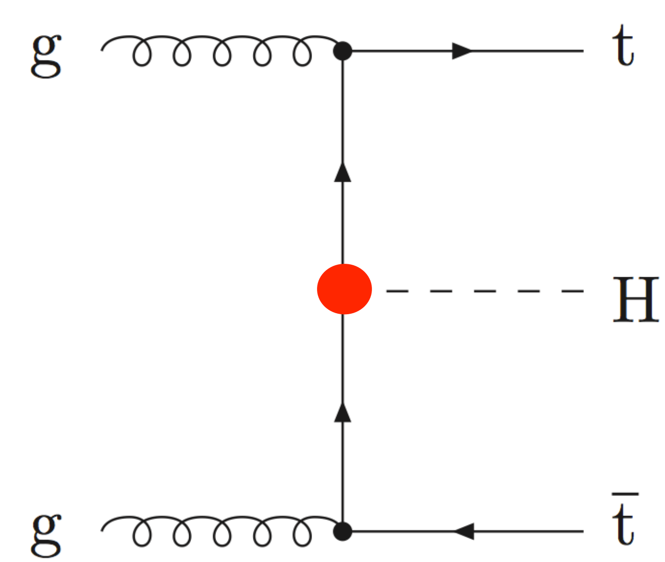

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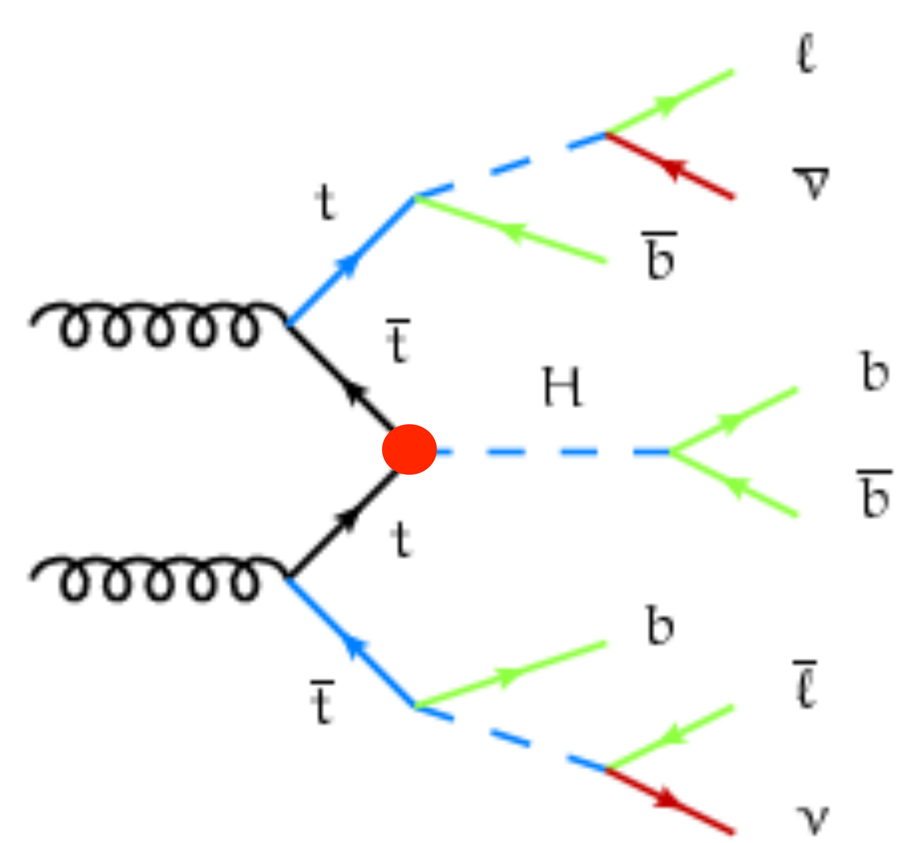
ttH(bb)



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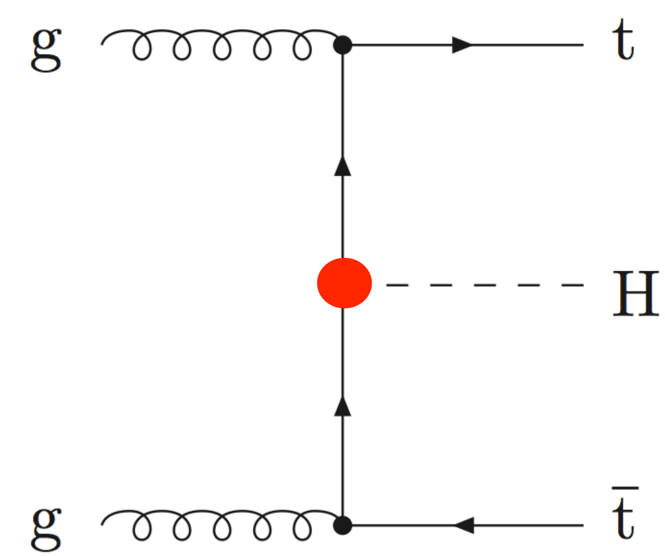

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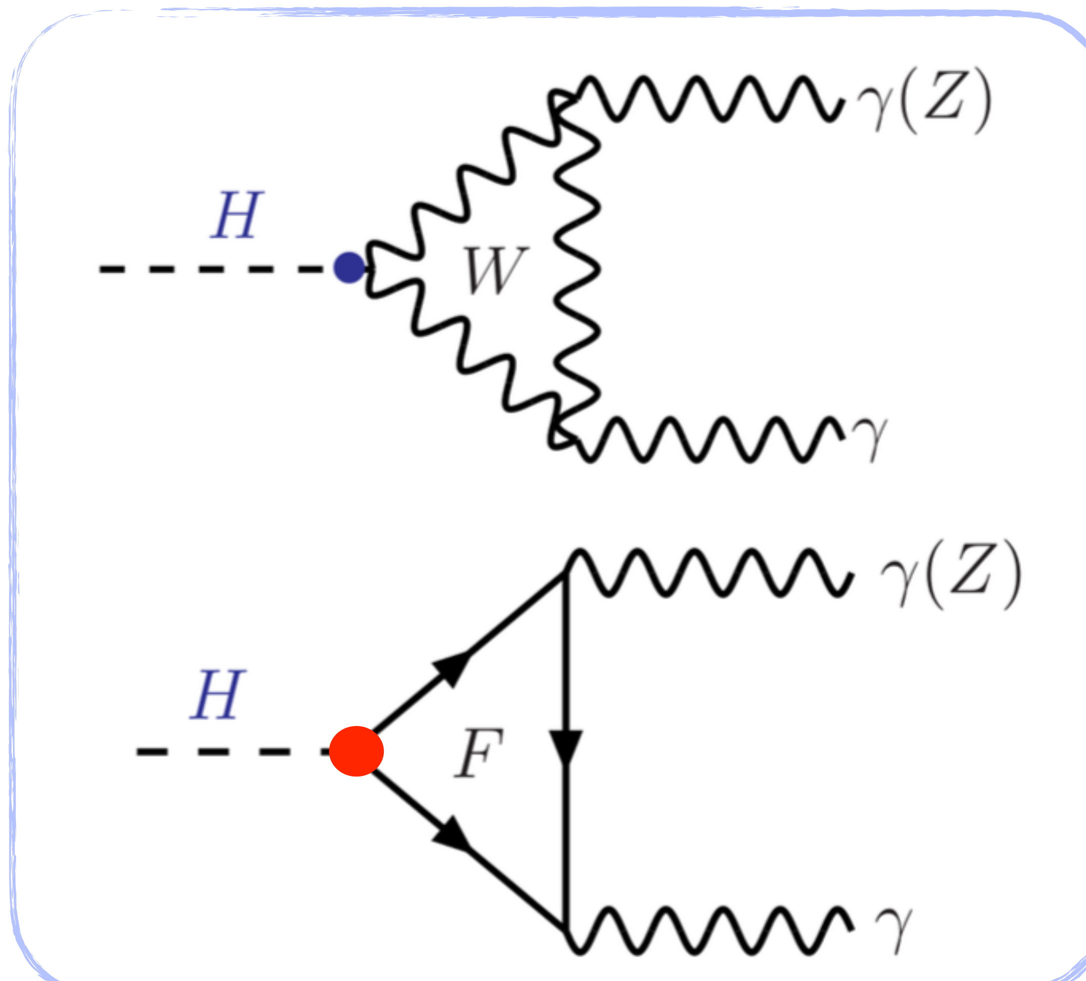

Top Yukawa coupling direct measurement

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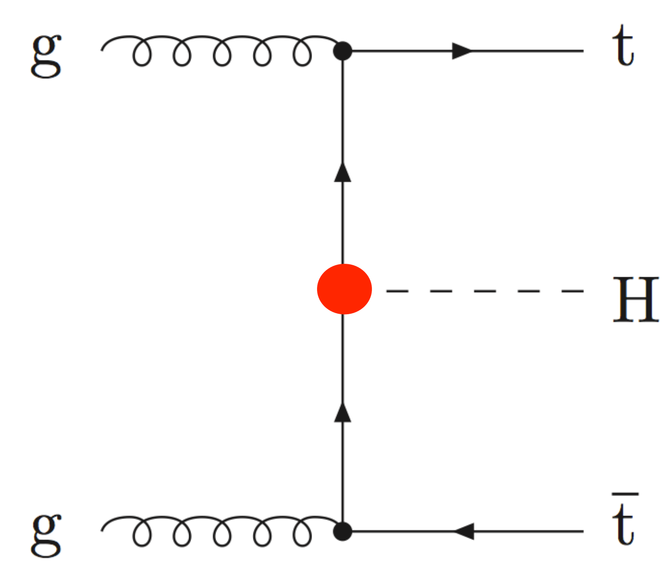

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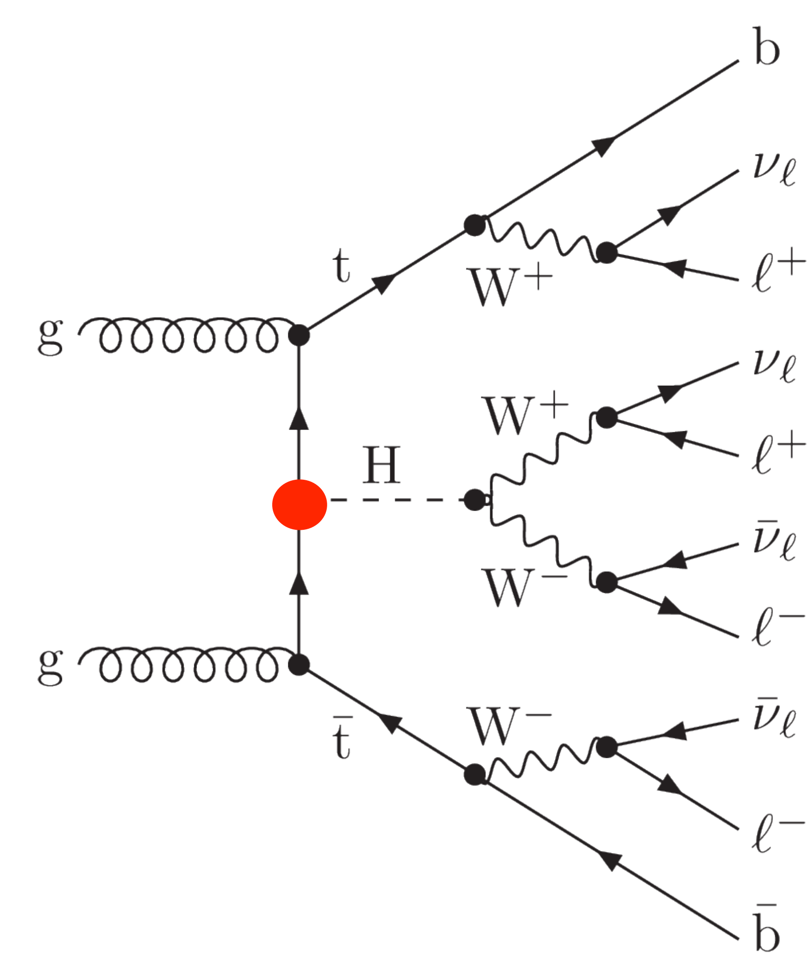
  ttH (multi-leptons)
  - $H \to \gamma\gamma$ 0.23±0.01% ttH($\gamma\gamma$)



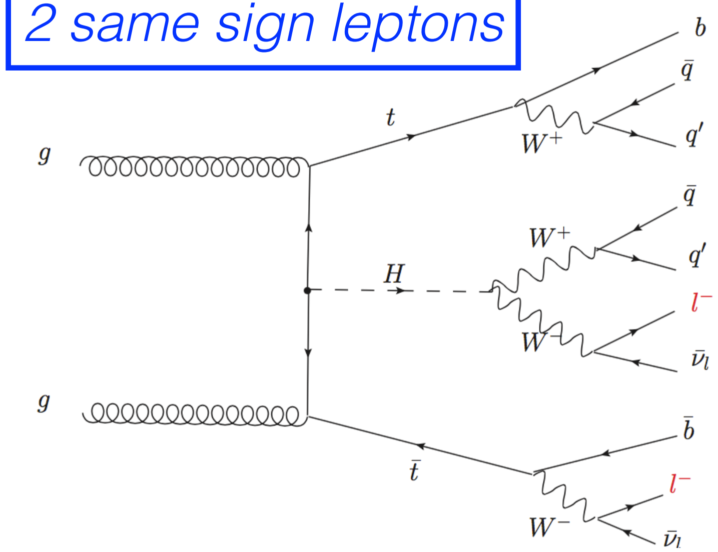
- **ATLAS searches for ttH production in multi-leptons with full 8 TeV data set will be shown in next..**

ttH(multi-leptons) signal topologic

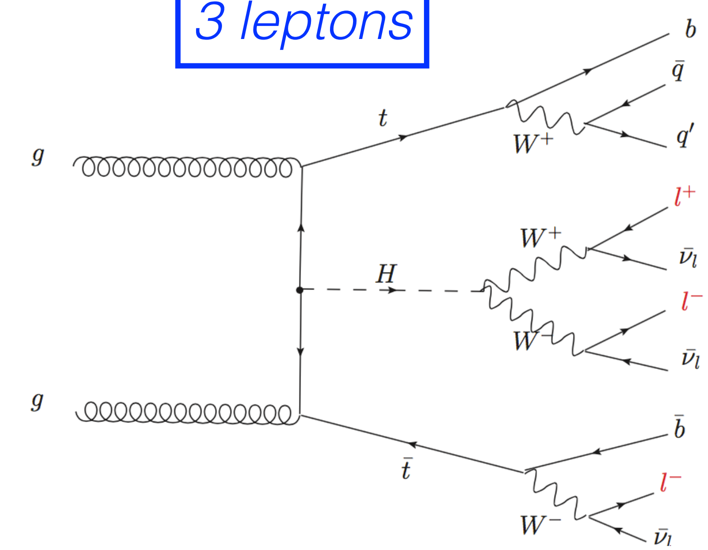
- Multi-leptons analysis targets on **Higgs decays into WW/ZZ/$\tau\tau$**
- **Five categories** are considered

	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{\text{had}}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{\text{had}}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{\text{had}}$	4%	93%	0%	3%

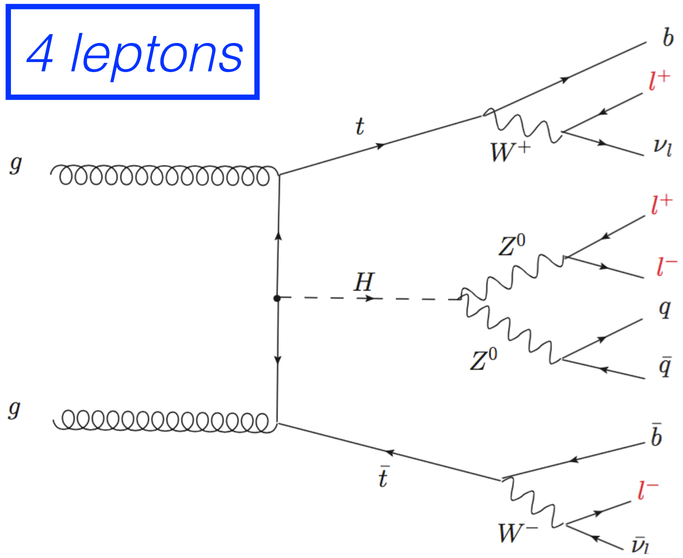
2 same sign leptons



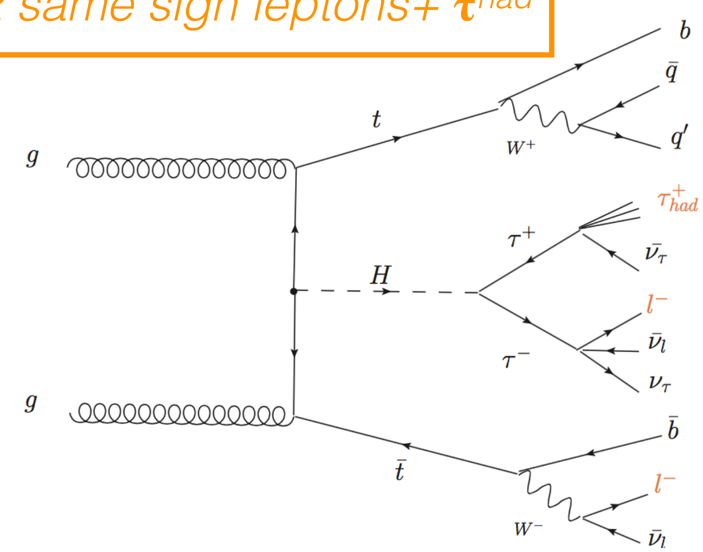
3 leptons



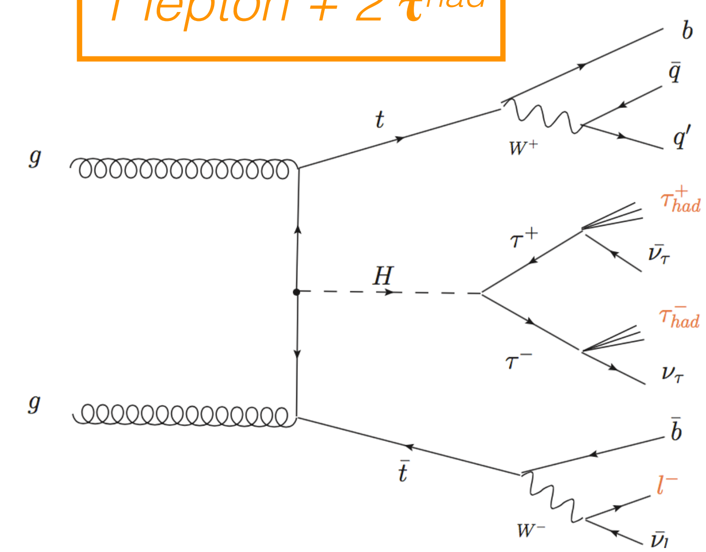
4 leptons



2 same sign leptons+ τ^{had}



1 lepton + 2 τ^{had}



<table>
<tr><th></th><th colspan="3">Leptons</th><th>Jets</th><th>B-Tags</th><th>Hadronic Taus</th></tr>
<tr><td>Common</td><td></td><td colspan="2">$p_T > 10$ GeV
≥ 1 trigger matched lepton</td><td>$N_j \geq 2$</td><td>$N_b \geq 1$</td><td>$p_T^{\tau} > 25$ GeV</td></tr>
<tr><td rowspan="7">2l</td><td rowspan="7">$N_l = 2$</td><td colspan="2">$\Sigma Q_{lep} = \pm 2$
$|\eta_{electron}| < 1.37$
$p_T^{lead} > 25$ GeV
$p_T^{sub} > 20$ GeV</td><td></td><td rowspan="7">$N_b \geq 1$</td><td rowspan="7">$N_\tau = 0$</td></tr>
<tr><td>2lee4j</td><td>2 $e^\pm$</td><td rowspan="3">$N_j = 4$</td></tr>
<tr><td>2lem4j</td><td>1 $e^\pm$, 1 $\mu^\pm$</td></tr>
<tr><td>2lmm4j</td><td>2 $\mu^\pm$</td></tr>
<tr><td>2lee5j</td><td>2 $e^\pm$</td><td rowspan="3">$N_j \geq 5$</td></tr>
<tr><td>2lem5j</td><td>1 $e^\pm$, 1 $\mu^\pm$</td></tr>
<tr><td>2lmm5j</td><td>2 $\mu^\pm$</td></tr>
<tr><td>3l</td><td>$N_l = 3$</td><td colspan="2">$p_T^{same\ sign\ leptons} > 20$ GeV
$\Sigma Q_{lep} = \pm 1$
$|M_{ll}^{OS\ SF} - M_Z| > 10$ GeV</td><td colspan="2">$N_j \geq 4$ & $N_b \geq 1$
or
$N_j = 3$ & $N_b \geq 2$</td><td>-</td></tr>
<tr><td>2ltau</td><td>$N_l = 2$</td><td colspan="2">$\Sigma Q_{lep} = \pm 2$
$p_T^{lead} > 25$ GeV
$p_T^{sub} > 15$ GeV
$|M_{ll} - M_Z| > 10$ GeV</td><td>$N_j \geq 4$</td><td>$N_b \geq 1$</td><td>$N_\tau = 1$

$Q_\tau = -Q_{lep}$</td></tr>
<tr><td>1l2tau</td><td>$N_l = 1$</td><td colspan="2">$p_T^{lepton} > 25$ GeV</td><td>$N_j \geq 3$</td><td>$N_b \geq 1$</td><td>$N_\tau = 2$
$\Sigma Q_\tau = 0$
$60 < M_{\tau\tau}^{vis}$ (GeV) < 120</td></tr>
<tr><td rowspan="3">4l</td><td rowspan="3">$N_l = 4$</td><td colspan="2">$\Sigma Q_{lep} = 0$
$p_T^{lead} > 25$ GeV
$p_T^{sub} > 15$ GeV
$M_{ll}^{OS\ SF} \geq 10$ GeV
100 GeV $< M_{4l} <$ 500 GeV
$|M_{ll}^{OS\ SF} - M_Z| > 10$ GeV</td><td rowspan="3">$N_j \geq 2$</td><td rowspan="3">$N_b \geq 1$</td><td rowspan="3">-</td></tr>
<tr><td>Z-depleted</td><td>0 OS SF
lepton pairs</td></tr>
<tr><td>Z-enriched</td><td>$\geq$1 OS SF
lepton pairs</td></tr>
</table>

Background compositions

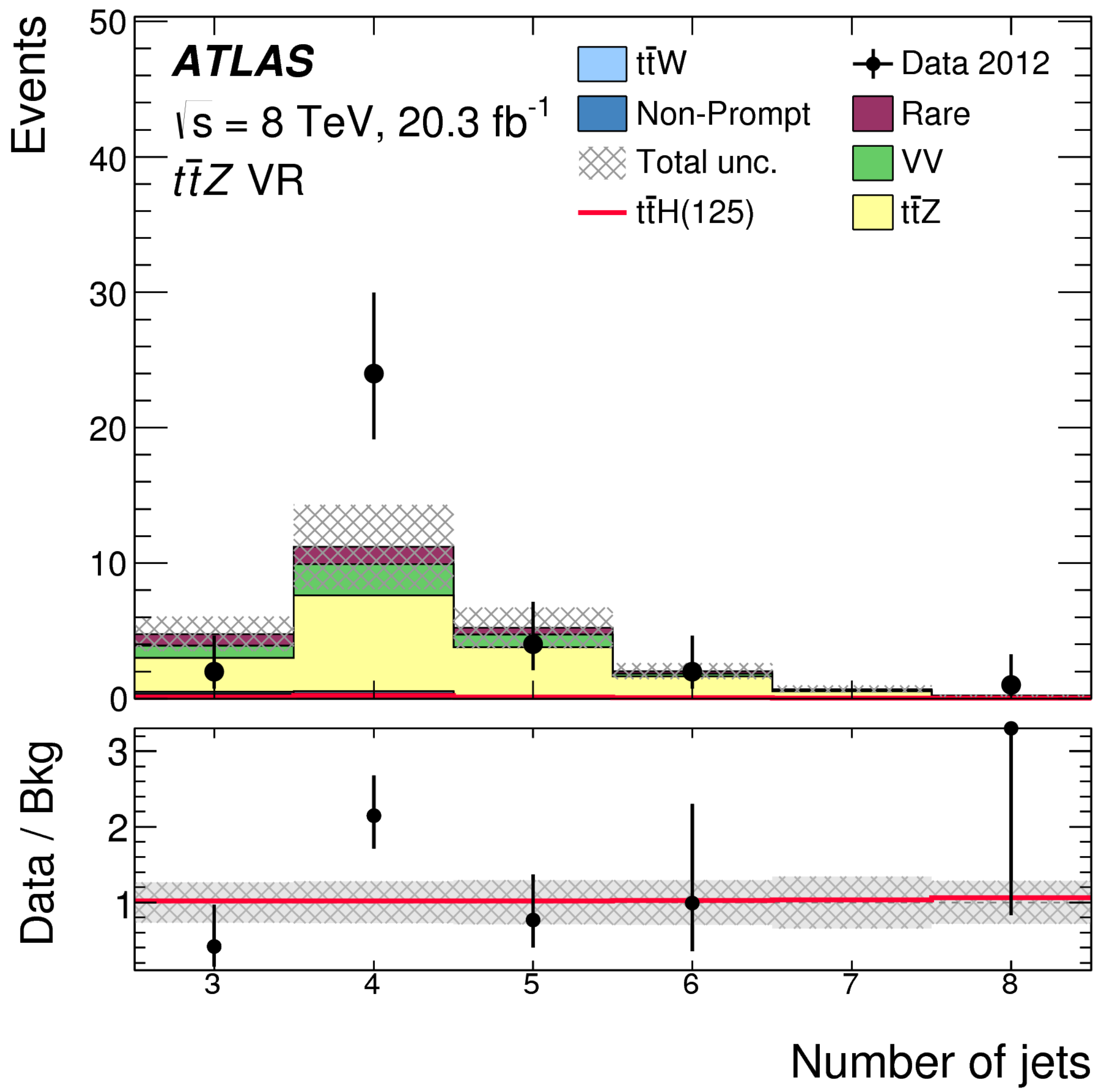
- **Irreducible backgrounds**
  - have prompt lepton final states as signal
    - 3l: ttZ, ttW, VV
    - 2lSS+tau: ttZ, ttW, VV
    - 2lSS: ttW, ttZ, VV
    - 4l: ttZ, VV, ttW
    - 1l+2tau: VV, ttZ, ttW
  - rely on MC estimates and theoretical uncertainties

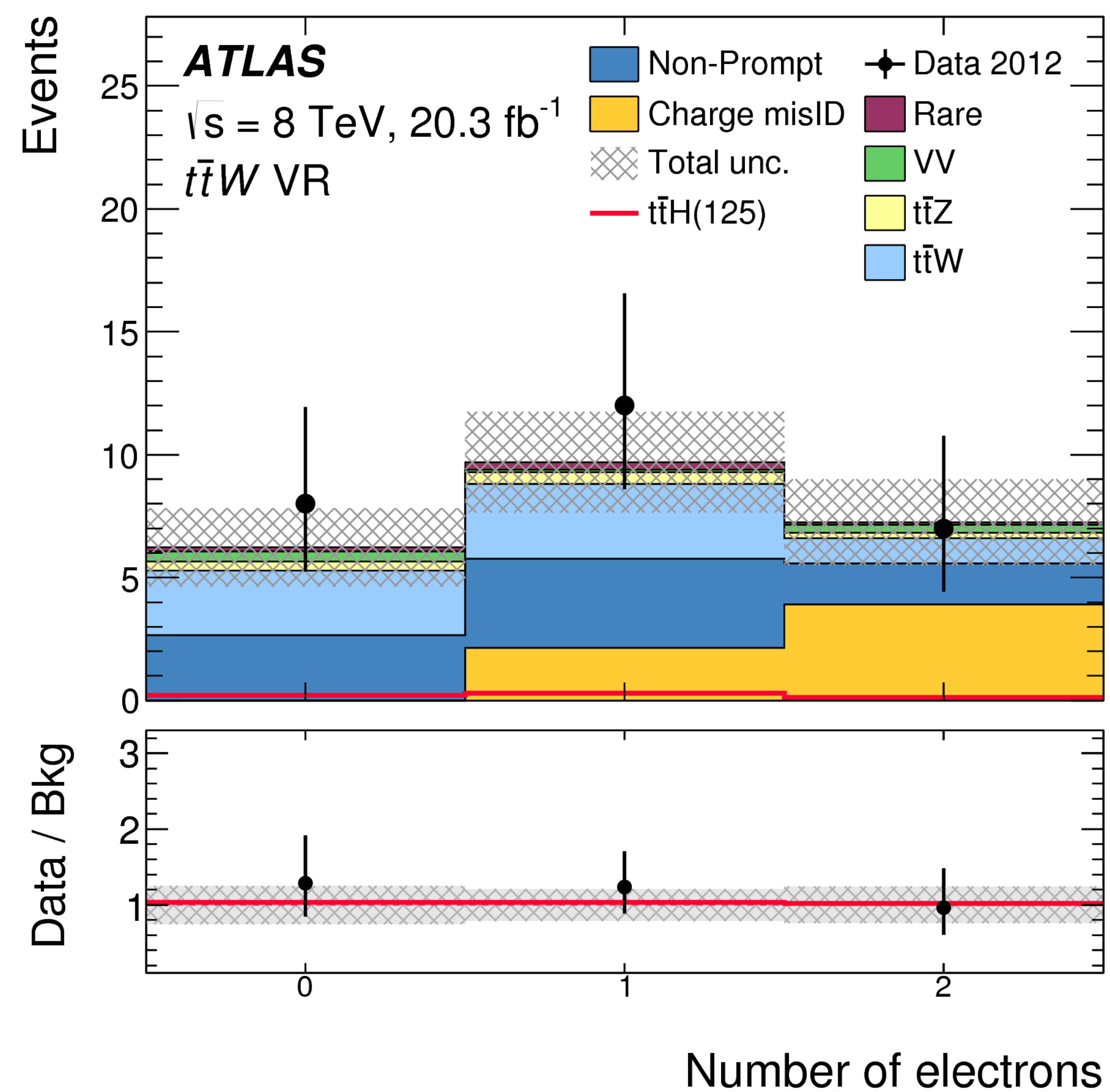
- **Reducible backgrounds**
  - have at least one lepton to be fake or electron charge flip
    - electron charge flip only in 2lSS channel
    - fakes: ttbar, single-top, tW
  - based on data-driven estimates

- **Other rare backgrounds:** ttWW, tH, tZ, 4-tops
  - relay on MC estimates and theoretical uncertainties

Validation of irreducible backgrounds

- **ttV validation regions -> close to signal regions**
  - ttZ: 3l selection but events within Z mass window
  - ttW: 2lSS selection but [2,3] jets and >= 2 b-jets → ~30% purity





- **Data and MC are in good agreement within uncertainties !**

Validation of irreducible backgrounds

- **VV backgrounds (WZ,ZZ, triboson production), total uncertainty ~ 50%**
  - WZ+0jets is well modelled up to 4 jets -> validation region
  - WZ+b-jets -> 100% uncertainty being signed
  - WW+b-jets and ZZ+b-jets -> 100% uncertainty
  - negligible impact on final results

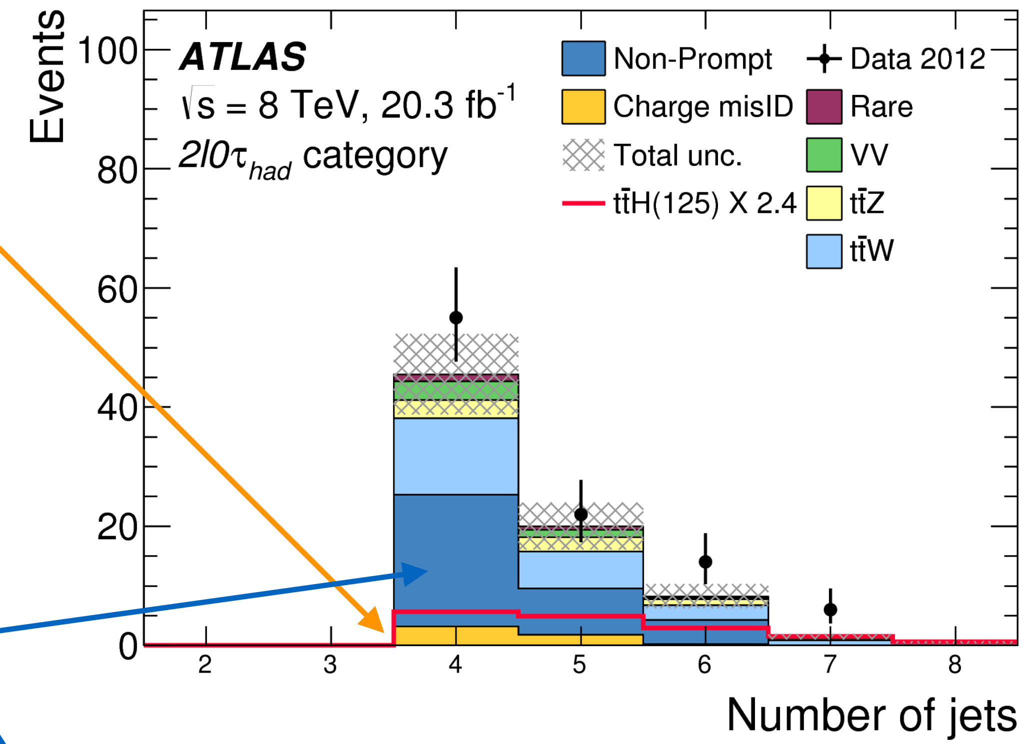
Reducible background measurements

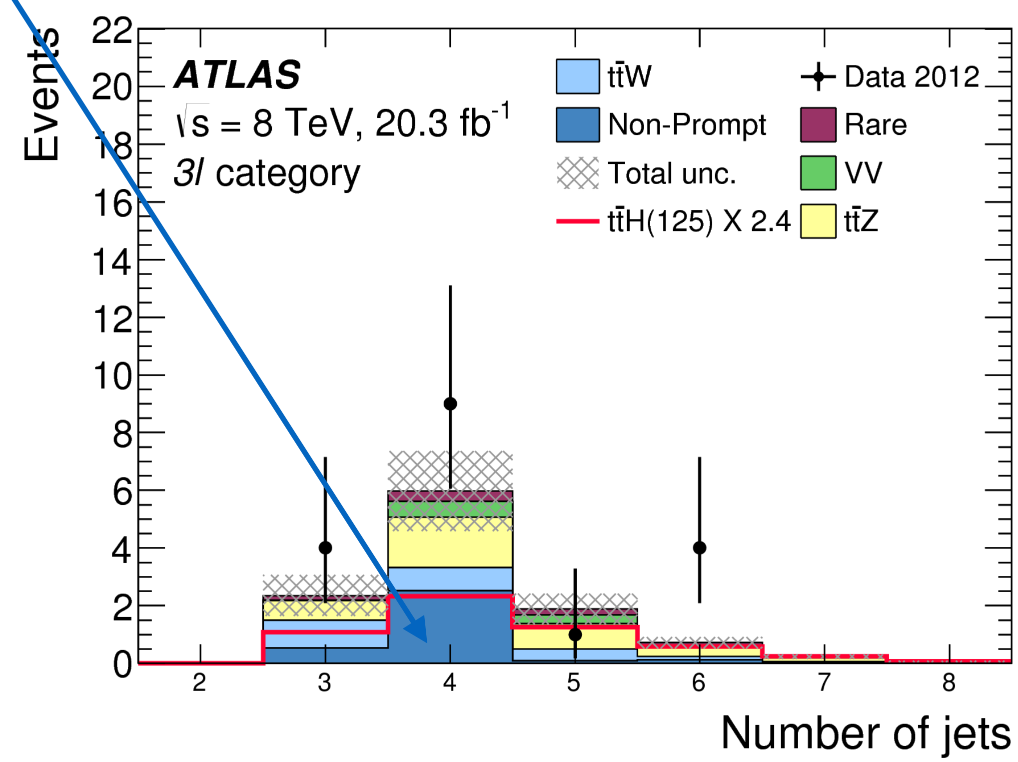
- **Electron charge flip background**

  $$(e^{\pm} \to e^{\pm}\gamma^{*} \to e^{\pm}e^{+}e^{-})$$

  - estimate probability of charge flip using Z→ee events
  - dominant uncertainty from low statistics of Z→ee sample

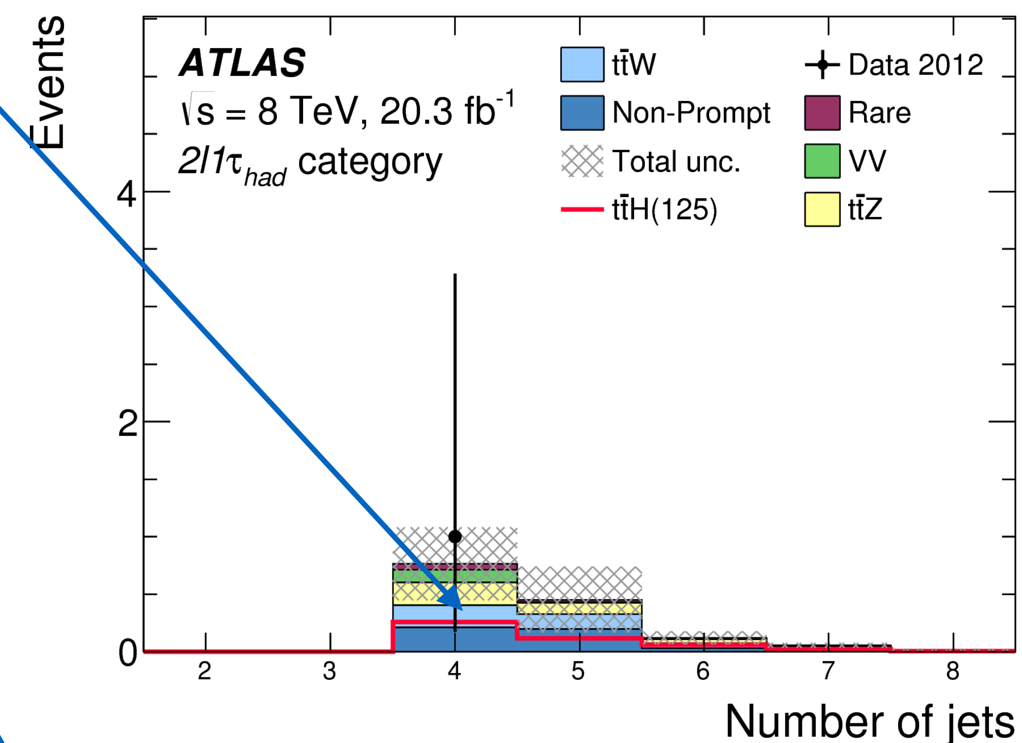
- **Fake lepton backgrounds**
  - 2lSS: estimated in control region multiplied by fake factor derived from low jet multiplicity data -> ~ 32%-52% total uncertainty
  - 3l: from fake factor derived from MC -> ~ 20% uncertainty
  - 4l: estimated from fake factor in 3l -> negligible

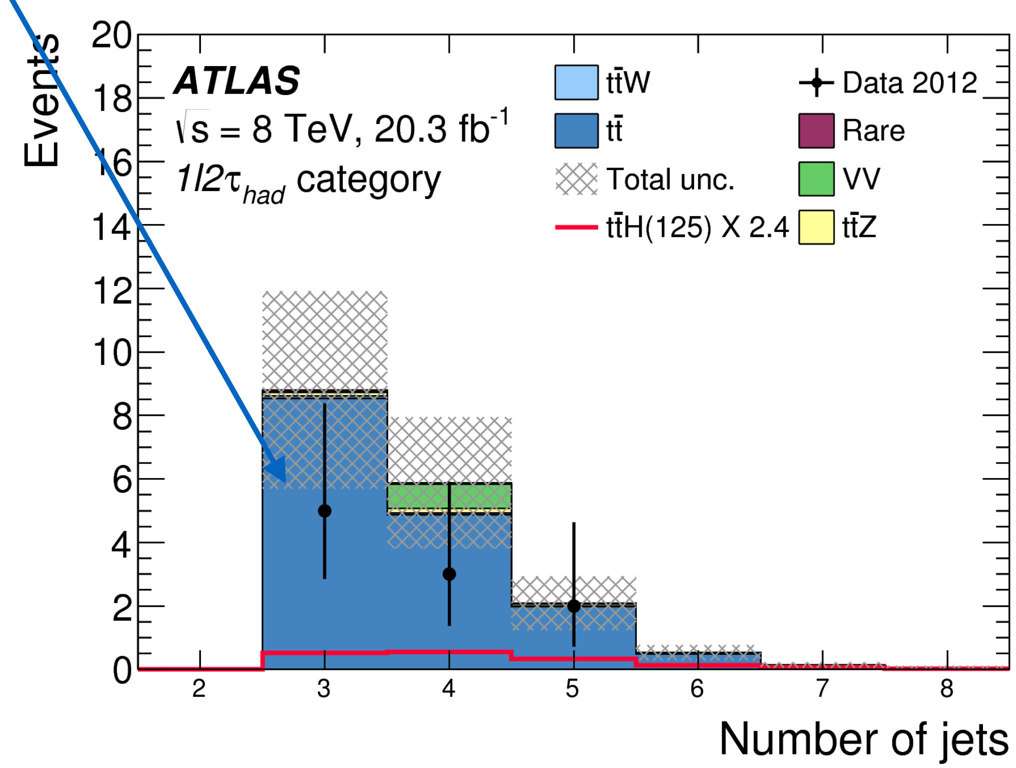




Reducible background measurements

- **Fake lepton background in 2lSS+tau**
  - estimated using sideband method based on jet multiplicity and lepton isolation
- **Hadronic tau mis-identification**
  - biggest background for 1l+2tau
  - estimated from fast simulation MC and being cross checked with data-driven method
  - 36% uncertainty from data vs MC comparison





Expected and observed yields

- This is cut-and-counting analysis

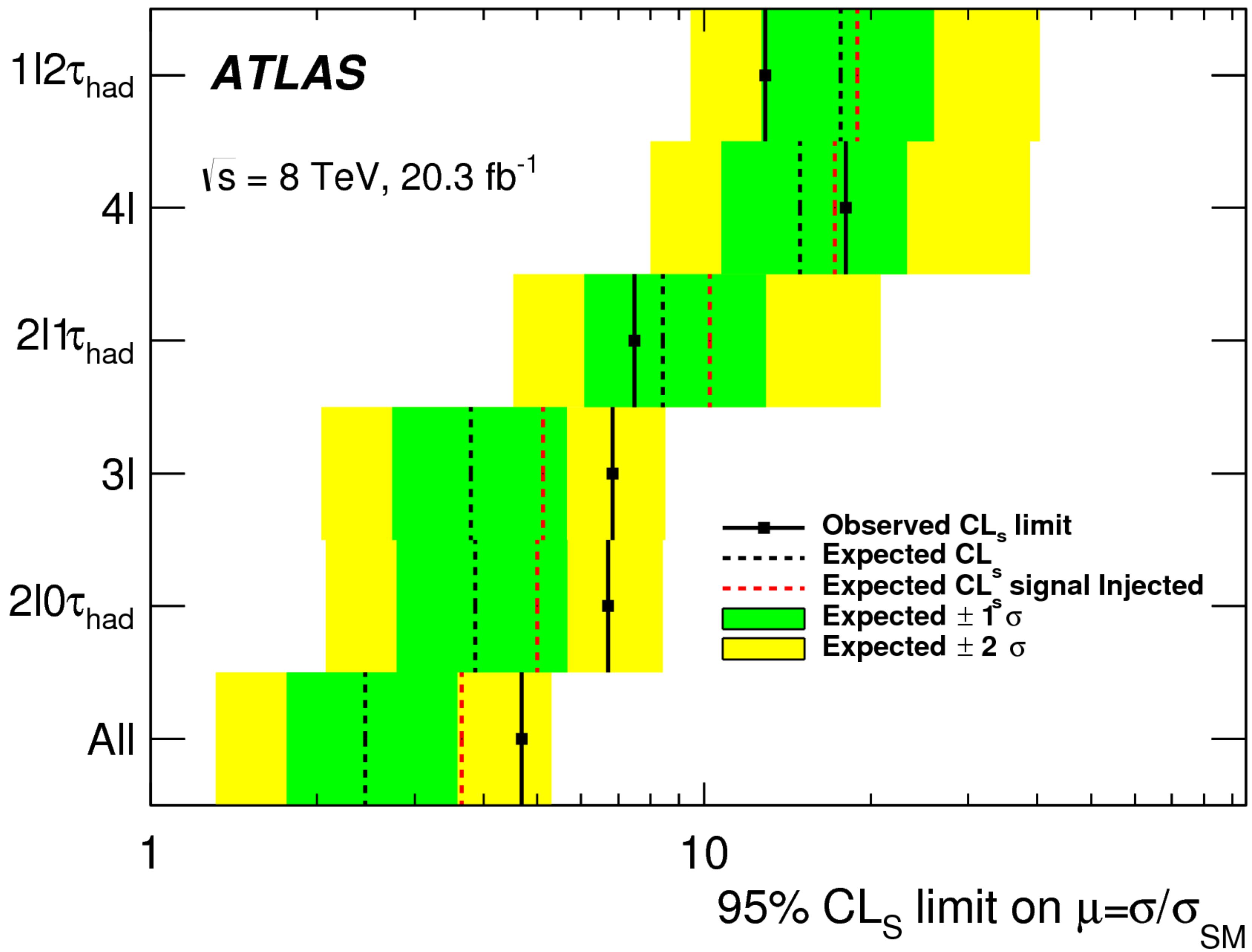
Category	q mis-id	Non-prompt	$t\bar{t}W$	$t\bar{t}Z$	Diboson	Expected bkg.	$t\bar{t}H$ $(\mu = 1)$	Observed
$ee + \geq 5j$	1.1 ± 0.5	2.3 ± 1.2	1.4 ± 0.4	0.98 ± 0.26	0.47 ± 0.29	6.5 ± 1.8	0.73 ± 0.14	10
$e\mu + \geq 5j$	0.85 ± 0.35	6.7 ± 2.4	4.8 ± 1.2	2.1 ± 0.5	0.38 ± 0.30	15 ± 3	2.13 ± 0.41	22
$\mu\mu + \geq 5j$	–	2.9 ± 1.4	3.8 ± 0.9	0.95 ± 0.25	0.69 ± 0.39	8.6 ± 2.2	1.41 ± 0.28	11
$ee + 4j$	1.8 ± 0.7	3.4 ± 1.7	2.0 ± 0.4	0.75 ± 0.20	0.74 ± 0.42	9.1 ± 2.1	0.44 ± 0.06	9
$e\mu + 4j$	1.4 ± 0.6	12 ± 4	6.2 ± 1.0	1.5 ± 0.3	1.9 ± 1.0	24 ± 5	1.16 ± 0.14	26
$\mu\mu + 4j$	–	6.3 ± 2.6	4.7 ± 0.9	0.80 ± 0.22	0.53 ± 0.30	12.7 ± 2.9	0.74 ± 0.10	20
3ℓ	–	3.2 ± 0.7	2.3 ± 0.7	3.9 ± 0.8	0.86 ± 0.55	11.4 ± 2.3	2.34 ± 0.35	18
$2\ell 1\tau_{\mathrm{had}}$	–	$0.4\,^{+0.6}_{-0.4}$	0.38 ± 0.12	0.37 ± 0.08	0.12 ± 0.11	1.4 ± 0.6	0.47 ± 0.08	1
$1\ell 2\tau_{\mathrm{had}}$	–	15 ± 5	0.17 ± 0.06	0.37 ± 0.09	0.41 ± 0.42	16 ± 5	0.68 ± 0.13	10
4ℓ Z-enr.	–	$\lesssim 10^{-3}$	$\lesssim 3 \times 10^{-3}$	0.43 ± 0.12	0.05 ± 0.02	0.55 ± 0.15	0.17 ± 0.02	1
4ℓ Z-dep.	–	$\lesssim 10^{-4}$	$\lesssim 10^{-3}$	0.002 ± 0.002	$\lesssim 2 \times 10^{-5}$	0.007 ± 0.005	0.025 ± 0.003	0

- Reducible backgrounds are from data-driven estimates

- Irreducible backgrounds are estimated from simulation, and validated in each dedicated validation region.

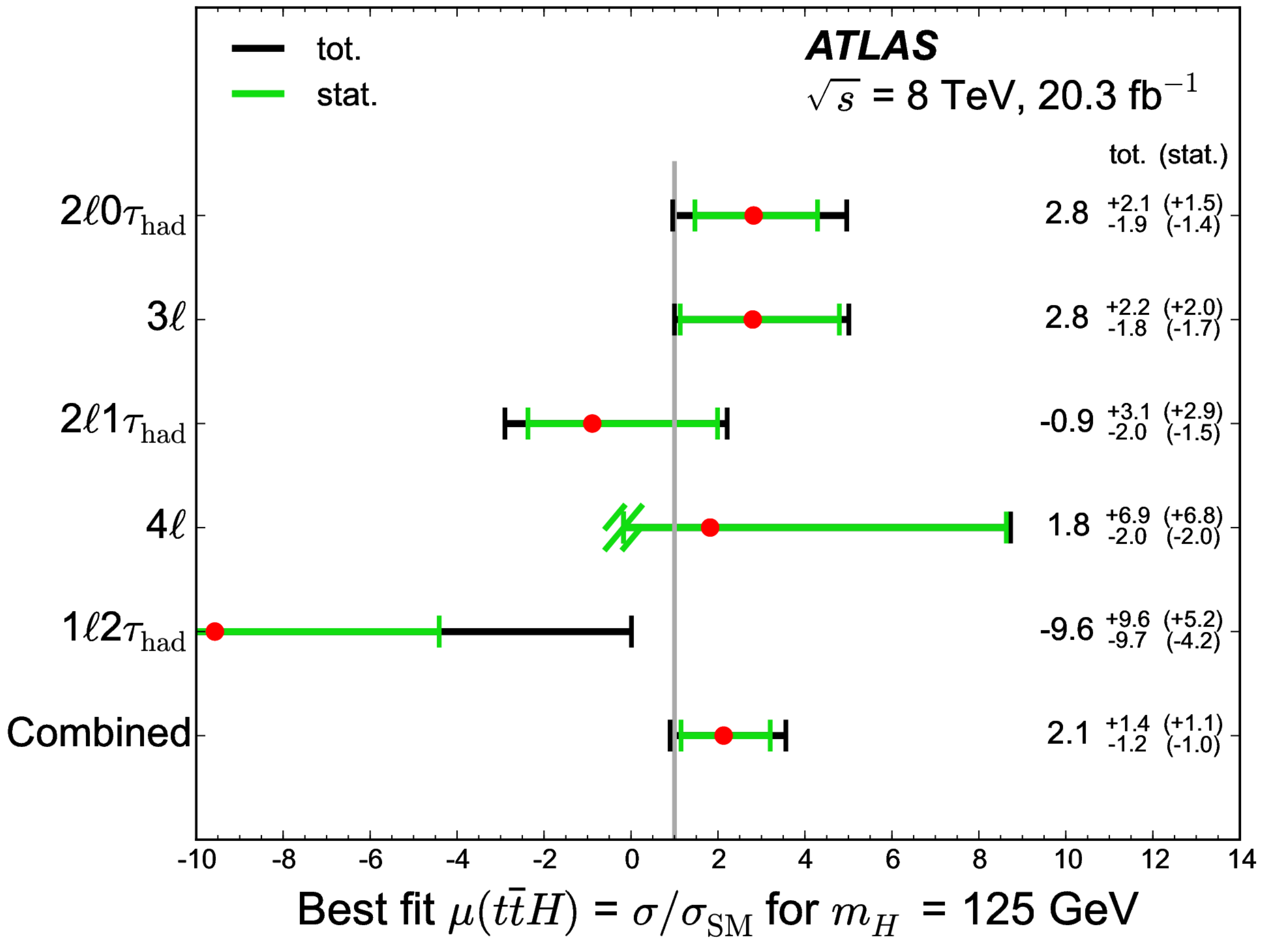
Results

- At 95% C.L., observed (expected) limit on ttH signal strength is 4.7(2.4) @m_H = 125 GeV, corresponding to significance 1.8σ.



Results

- Measured ttH signal strength is $2.1^{+1.4}_{-1.2}$



dominated by statistical uncertainty!

main systematical error from fake background estimates:

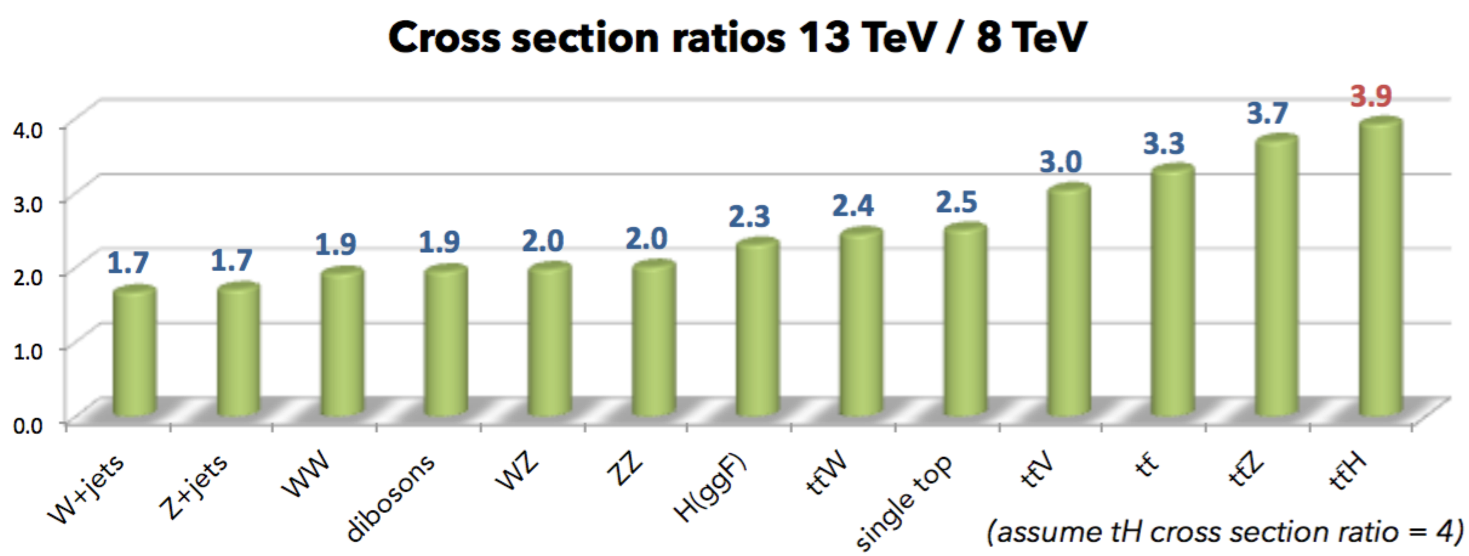
Source	$\Delta\mu$	
$2\ell 0\tau_{\text{had}}$ non-prompt muon transfer factor	$+0.38$	-0.35
$t\bar{t}W$ acceptance	$+0.26$	-0.21
$t\bar{t}H$ inclusive cross section	$+0.28$	-0.15
Jet energy scale	$+0.24$	-0.18
$2\ell 0\tau_{\text{had}}$ non-prompt electron transfer factor	$+0.26$	-0.16
$t\bar{t}H$ acceptance	$+0.22$	-0.15
$t\bar{t}Z$ inclusive cross section	$+0.19$	-0.17
$t\bar{t}W$ inclusive cross section	$+0.18$	-0.15
Muon isolation efficiency	$+0.19$	-0.14
Luminosity	$+0.18$	-0.14

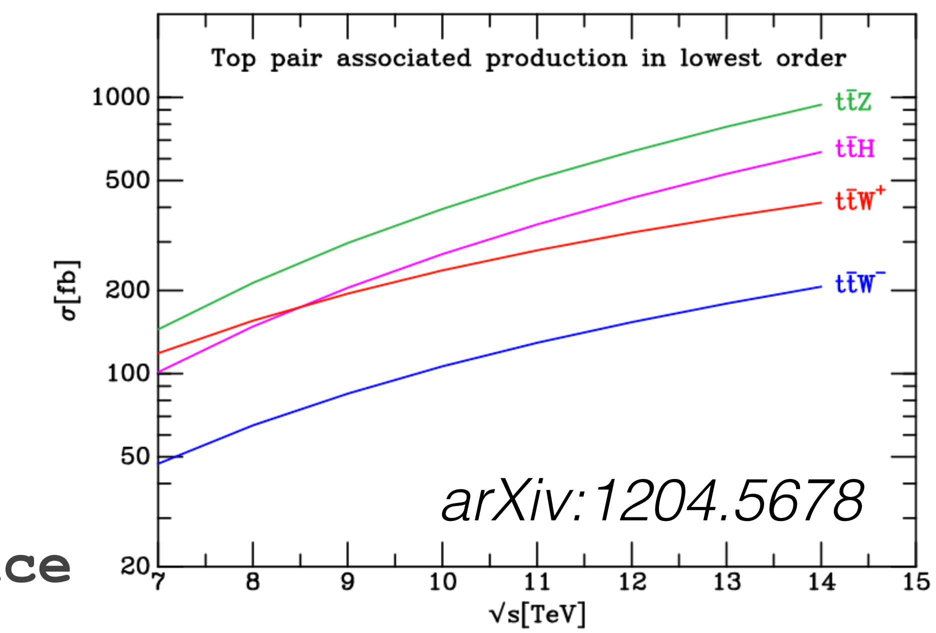
- The result is sensitive to ttV production cross section

$$\mu(t\bar{t}H) = 2.1 - 1.4\left(\frac{\sigma(t\bar{t}W)}{232\text{ fb}} - 1\right) - 1.3\left(\frac{\sigma(t\bar{t}Z)}{206\text{ fb}} - 1\right)$$

Run 2 analysis - promising improvements

- **Increase of center-of-mass energy improves significance.**





- **Increase of luminosity -> better significance**
  - reduce fake estimate uncertainty
  - data can be used to constrain irreducible backgrounds
- **Further event categorisation**
  - 2lSS: sum of lepton charge to be ++ and --
  - 2lSS: in 1b-jet and 2b-jets -> do further optimisation
- **Multi-variate techniques**
  - improve signal reconstruction and separation from background
  - move to shape analysis

Summary

- Search for ttH production in multilepton final states has been performed in ATLAS with 8 TeV data set.
- At 95% C.L., observed (expected) limit on signal strength is 4.7(2.4) @m_H = 125 GeV.
- Measured ttH signal strength is 2.1 (+1.4)(-1.2). Its uncertainty is dominated by statistical one.
- Run 2 analysis of this channel looks promising !

Backup

MC event generator configurations

Process	ME Generator	Parton Shower	PDF	Tune
$t\bar{t}H$	HELAC-Oneloop [41, 42] + POWHEG-BOX [48–50]	PYTHIA 8 [43]	CT10 [44]/CTEQ6L1 [45, 46]	AU2 [47]
$tHqb$	MADGRAPH [33]	PYTHIA 8	CT10	AU2
tHW	MG5_aMC@NLO [29]	HERWIG++ [51]	CT10/MRST LO** [52]	UE-EE-4 [53]
$t\bar{t}W + \leq 2$ partons	MADGRAPH	PYTHIA 6 [54]	CTEQ6L1	AUET2B [55]
$t\bar{t}(Z/\gamma^{*}) + \leq 1$ parton	MADGRAPH	PYTHIA 6	CTEQ6L1	AUET2B
$t(Z/\gamma^{*})$	MADGRAPH	PYTHIA 6	CTEQ6L1	AUET2B
$q\bar{q}, qg \to WW, WZ$	SHERPA [56]	SHERPA	CT10	SHERPA default
$qq \to qqWW, qqWZ, qqZZ$	SHERPA	SHERPA	CT10	SHERPA default
$q\bar{q}, qg \to ZZ$	POWHEG-BOX [57]	PYTHIA 8	CT10	AU2
$gg \to ZZ$	GG2ZZ [58]	HERWIG [59]	CT10	AUET2 [60]
$t\bar{t}$	POWHEG-BOX [61]	PYTHIA 6	CT10/CTEQ6L1	Perugia2011C [62]
s-, t-channel, Wt single top	POWHEG-BOX [63, 64]	PYTHIA 6	CT10/CTEQ6L1	Perugia2011C
$Z \to \ell^{+}\ell^{-} + \leq 5$ partons	ALPGEN [65]	PYTHIA 6	CTEQ6L1	Perugia2011C
$W \to \ell\nu + \leq 5$ partons	ALPGEN	PYTHIA 6	CTEQ6L1	Perugia2011C