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Search for the 125 GeV Higgs Boson produced in association with top quarks

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On behalf of the ATLAS collaboration

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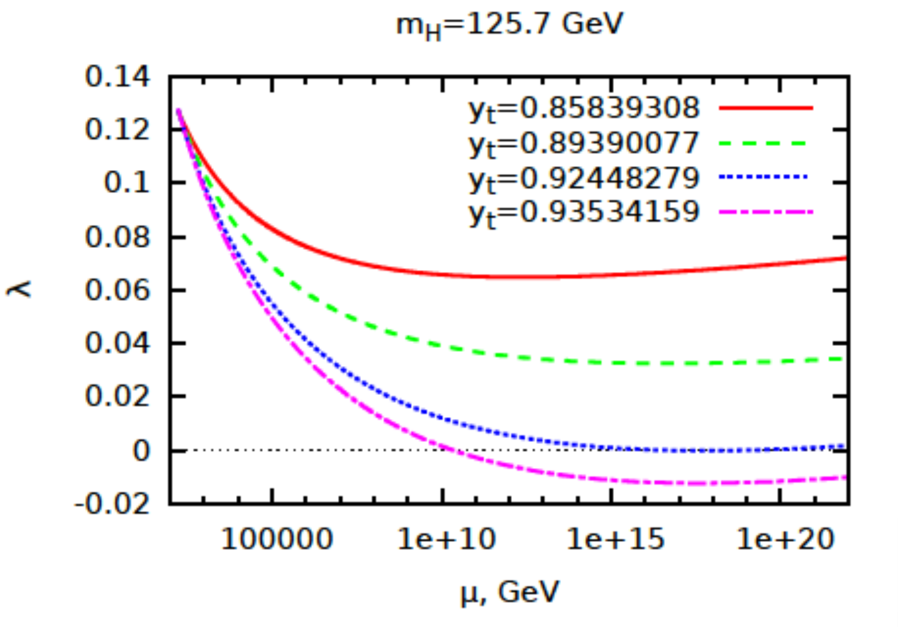
Motivation

- Evidence of the Higgs coupling to fermions is a milestone in Higgs studies

- Top Yukawa coupling is the most important one:
  - Strongest coupling of the Standard Model, ~1
  - Sensitive to New Physics
  - Significant role in EW vacuum stability:
    Running of Higgs self coupling (λ) sensitive to Top Yukawa coupling (y_t)



F. Bezrukov, M. Shaposhnikov

Motivation

- y_t can be determined:
  - From Top mass measurement
  - From Higgs production and $\gamma\gamma$ decay

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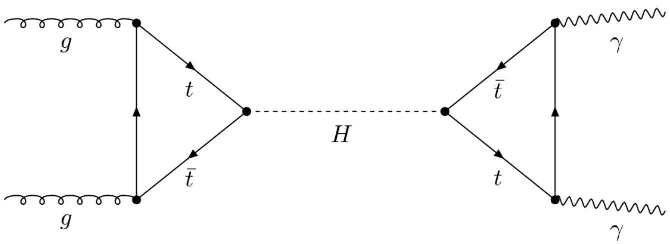

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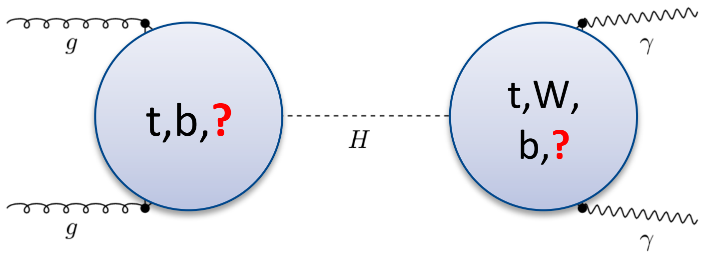

Sensitive to New Physics contributions

Motivation

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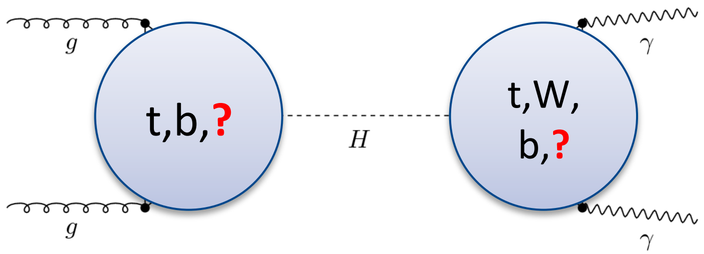
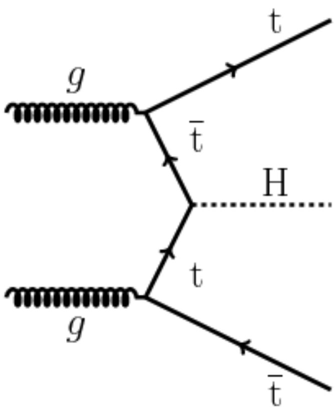
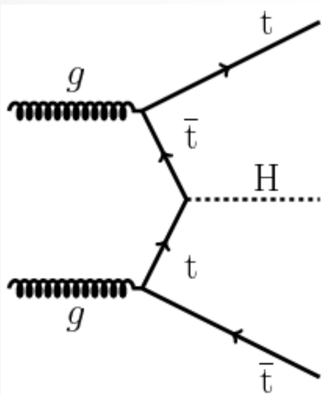


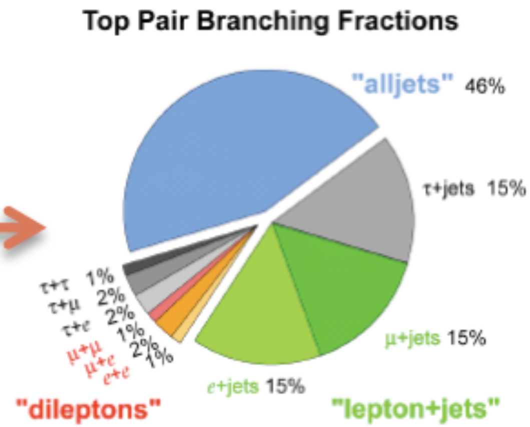
Sensitive to New Physics contributions

- From ttH production
    - provide evidence of the existence of y_t
    - Measurement at tree level



ttH signature





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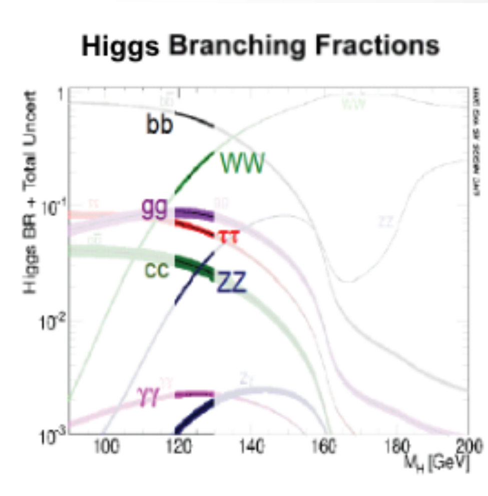
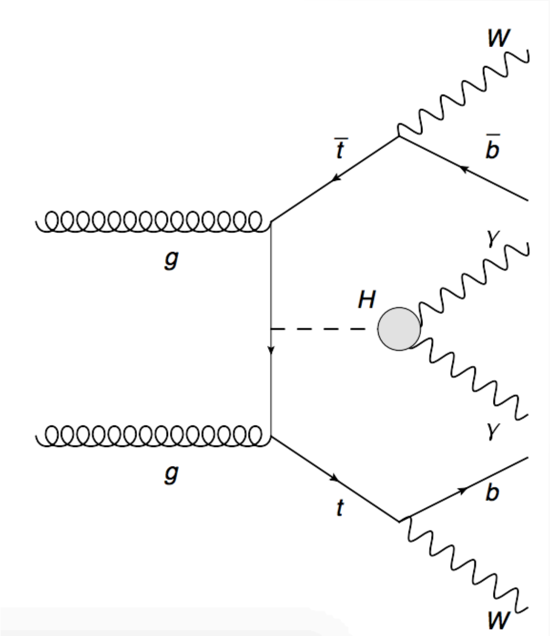


$\sqrt{s}$=8TeV: σ(ttH) = 130 fb^{-1}
~2700 events / experiment

- ttH final state combines top pair decay signature and Higgs decay signature → large number of possible final states
- 3 families of signatures:
  - $2b+2\gamma$ ($H\rightarrow\gamma\gamma$)
  - $4b$+X ($H\rightarrow bb$)
  - $2b$+leptons ($H\rightarrow WW, ZZ, \tau\tau$)

ttH (H to γγ)

- Small BR compensated by small backgrounds and good diphoton mass resolution
- Signature:
  - Driven by ttbar decay mode
  - Hadronic category:
    - High jet and *b*-tag multiplicities
  - Leptonic category:
    - One or more high quality charged lepton
    - Cuts slightly loosened to be sensitive to tH



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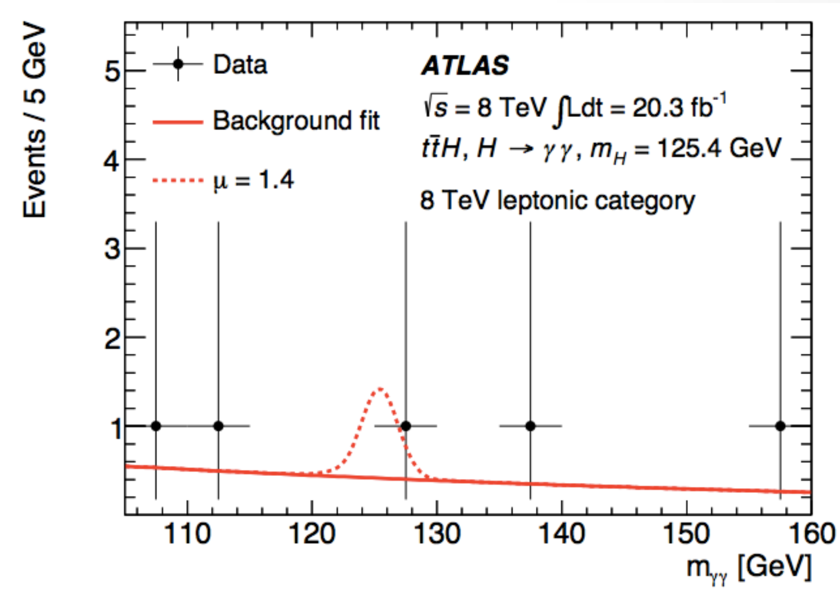
ttH (H to γγ)

Category	N_H	ggF	VBF	WH	ZH	$t\bar{t}H$	$tHqb$	WtH	N_B
7 TeV leptonic selection	0.10	0.6	0.1	14.9	4.0	72.6	5.3	2.5	$0.5^{+0.5}_{-0.3}$
7 TeV hadronic selection	0.07	10.5	1.3	1.3	1.4	80.9	2.6	1.9	$0.5^{+0.5}_{-0.3}$
8 TeV leptonic selection	0.58	1.0	0.2	8.1	2.3	80.3	5.6	2.6	$0.9^{+0.6}_{-0.4}$
8 TeV hadronic selection	0.49	7.3	1.0	0.7	1.3	84.2	3.4	2.1	$2.7^{+0.9}_{-0.7}$

[%]

- Analysis strategy:
  - Discriminant parameter: $m_{\gamma\gamma}$
  - Signal modelling based on MC simulation:
    - Crystal ball + gaussian function
  - Higgs background (MC simulation)
  - Continuum background – data driven
    - Modelled by exponential function
    - Fit for each category to the data sidebands



- Dominant systematic uncertainties:
  - MC modelling:
    - large uncertainty on the underlying event
    - 100% uncertainty on ggF, VBF and WH+HF productions
  - Continuum background modelling
- The analysis is limited by statistical uncertainty.

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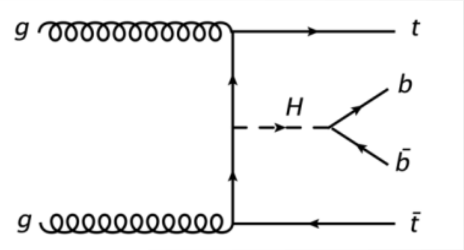
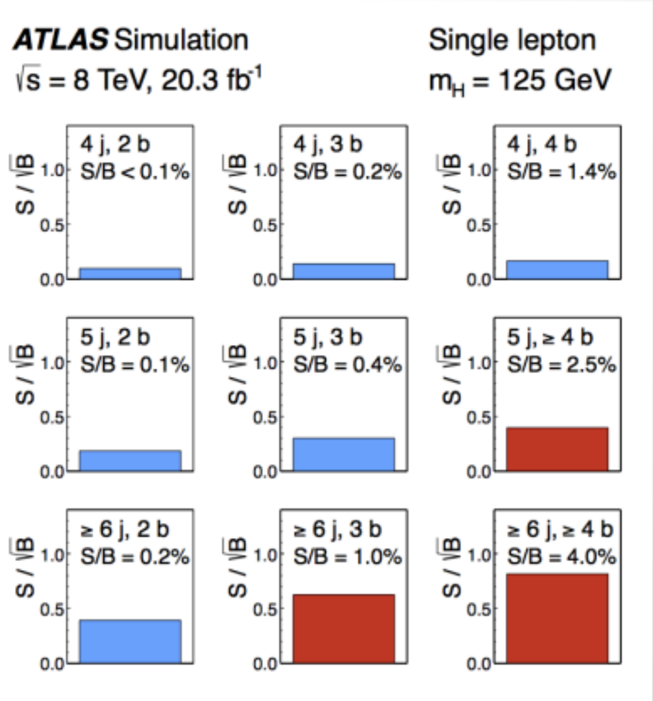
ttH (4*b*+leptons)

- Benefits from the large H → bb branching ratio

- Signature:
  - Categorise events by jet and *b*-tag multiplicities.
  - Single lepton category:
    - Exactly 1 lepton with at least 4 jets and 2 *b*-tagged jets
    - Control regions: (4j, 2*b*), (4j, 3*b*), (4j, 4*b*), (5j, 2*b*), (5j, 3*b*) and (≥6j, 2*b*)
    - Signal regions: (5j, ≥4*b*), (≥6j, 3*b*) and (≥6j, ≥4*b*)
  - Opposite sign dilepton category:
    - Exactly 2 opposite sign leptons with at least 2 *b*-tags
    - Control regions: (2j, 2*b*), (3j, 2*b*) and (≥4j, 2*b*)
    - Signal regions: (3j, 3*b*), (≥4j, 3*b*) and (≥4j, ≥4*b*)





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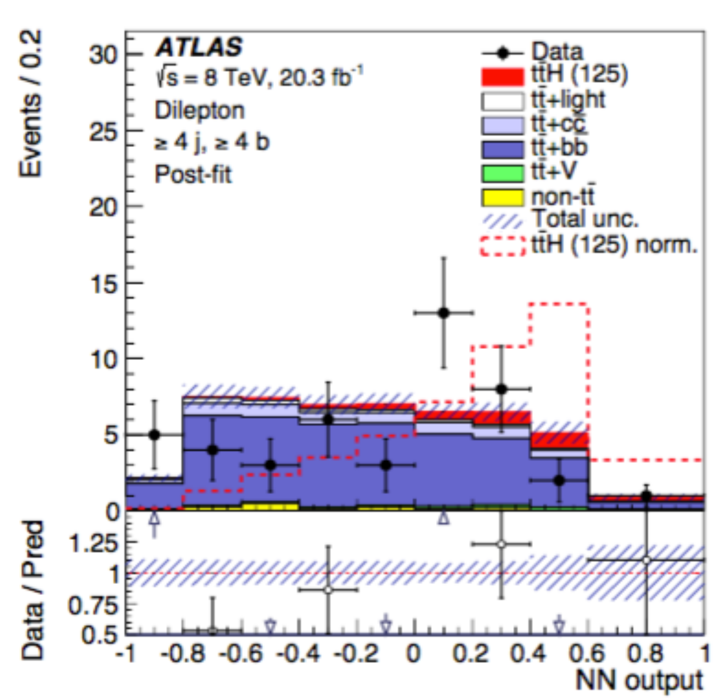
ttH (4*b*+leptons)

- Analysis strategy:
  - Improve sensitivity by keeping low and high significance regions separated.
  - Build Neural Network (NN) discriminant from kinematic variables to separate signal and background in signal-rich regions.
  - Use of Matrix Element Method as input in NN
  - tt+HF modelling: Breakdown of tt+HF events based on flavours
  - Control and signal regions fit simultaneously to constrain the systematic uncertainties
  - MC tag rate function (TRF) instead of cutting on b-tagging multiplicity

single lepton channel

	2 *b*-tags	3 *b*-tags	$\geq$ 4 *b*-tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NN	NN
$\geq$ 6 jets	H_T^{had}	NN	NN



- ttbb: main irreducible background
- Main systematic uncertainties:

  ttbb and ttcc normalisation and shapes (largely constrained by simultaneous fit)

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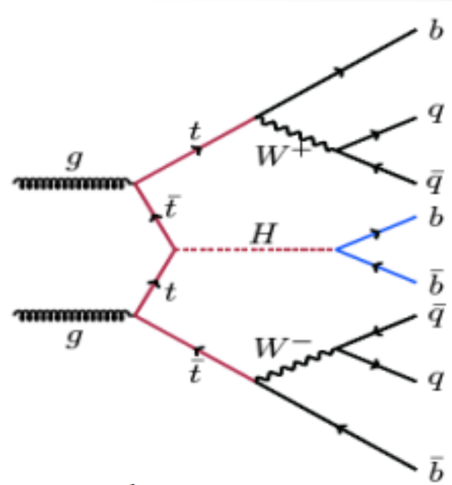
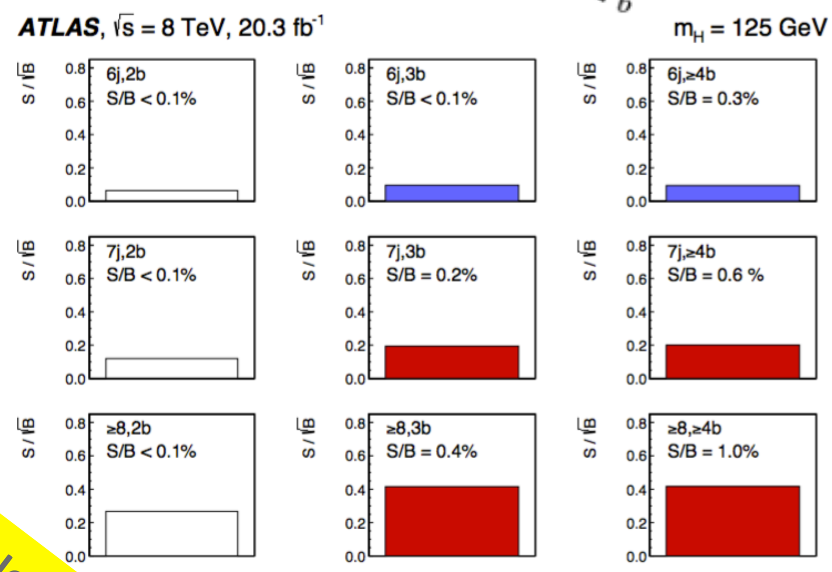
ttH (multijets, H → *bb*)

- Benefits from the large H → bb (58%) and all hadronic ttbar (45%) branching ratios
- Large multijet background



- Signature:
  - Multijet final state, no lepton with at least 6 jets and 2 *b*-tags
  - Categorise events by jet and *b*-tag multiplicities
  - Control regions: (6j, 3*b*) and (6j, ≥4*b*)
  - Signal regions: (7j, 3*b*), (7j, ≥4*b*), (≥8j, 3*b*) and (≥8j, ≥4*b*)



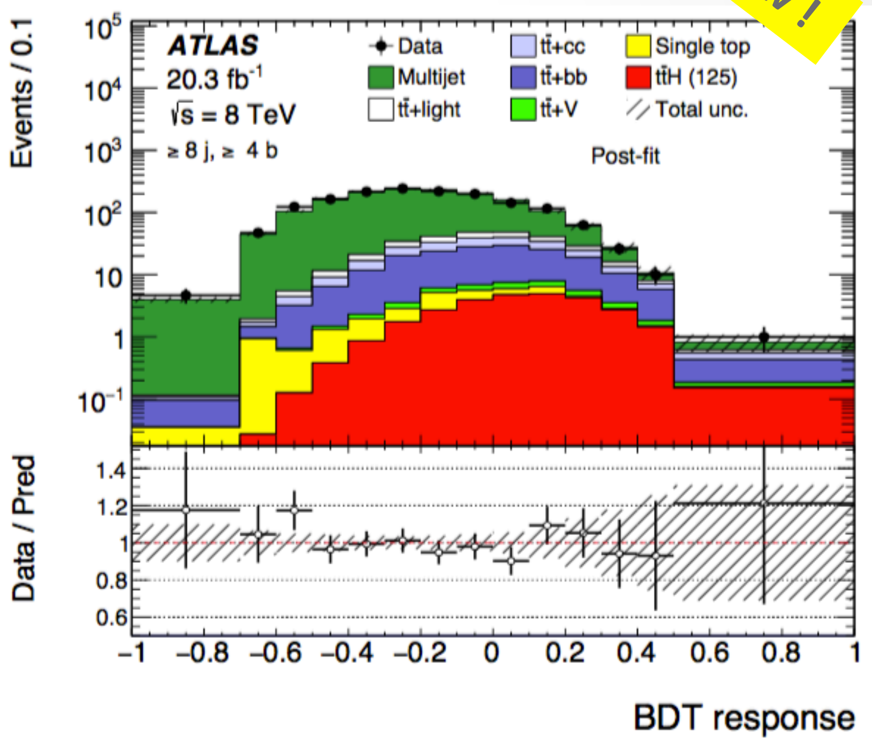
New !

ttH (multijets, H → *bb*)

- Analysis strategy:
  - MC tag rate function (TRF) instead of cutting on *b*-tagging multiplicity
  - Dedicated data-driven multijet estimation:
    - Tag rate function in 2*b*-tag region
    - Validation in data and MC regions
  - tt+HF modelling: Breakdown of tt+HF events based on flavours
  - BDT as discriminant parameter in all regions

- Main systematic uncertainties:
  - Multijet normalisation
  - ttbb normalisation/modelling: Most irreducible background of the analysis

New !



ttH (multileptons)

- Mainly probe H → W^+W^-, H → ZZ and H → $\tau^+\tau^-$
- Signature:
  - Categorise channels by number of leptons:
    - **2leptons**, no τ had: same sign light leptons
    - **3 leptons**: sum of the charge equals ±1, no requirement on had τ
    - **2leptons**, 1τ had: same sign light leptons and opposite sign τ
    - **4 leptons**: sum of the charge equals 0
    - **1lepton**, 2τ had: opposite sign τ pair

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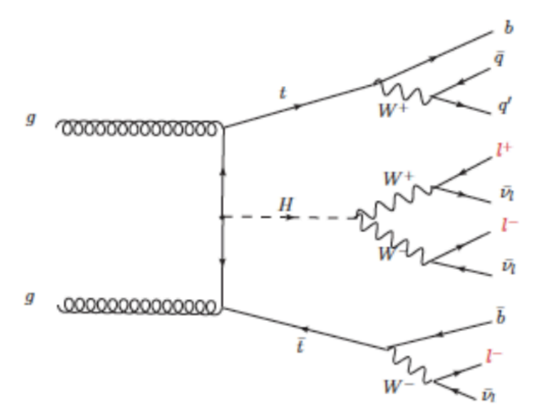
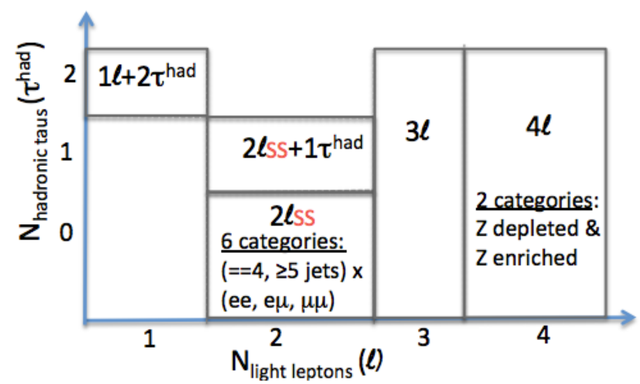
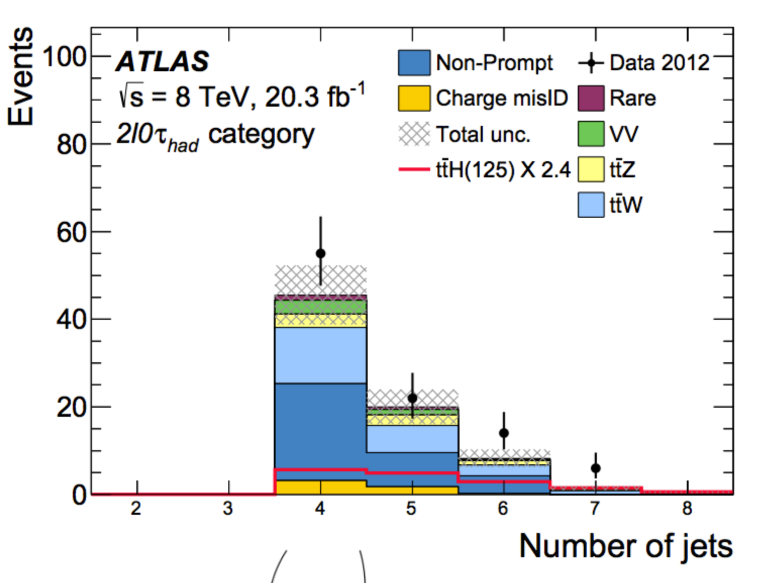




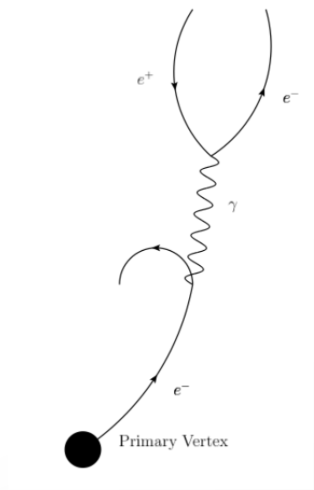
	Higgs boson decay mode			
Category	WW^*	$\tau\tau$	ZZ^*	Other
$2\ell 0\tau_{had}$	80%	15%	3%	2%
3ℓ	74%	15%	7%	4%
$2\ell 1\tau_{had}$	35%	62%	2%	1%
4ℓ	69%	14%	14%	4%
$1\ell 2\tau_{had}$	4%	93%	0%	3%

ttH (multileptons)

- Analysis strategy:
  - Background estimations:
    - Irreducible bkg: tZ, ttW and ttZ estimated on MC
    - Instrumental bkg: Non –prompt leptons and charge mis ID estimated on data
    - In 1lepton 2τ, main bkg coming from τ fakes modelled by MC
  - Counting experiment



- Main systematics:
  - Leading uncertainty due to non-prompt lepton estimate
  - Other systematics are related to the normalisation and acceptance of ttH, ttW and ttZ



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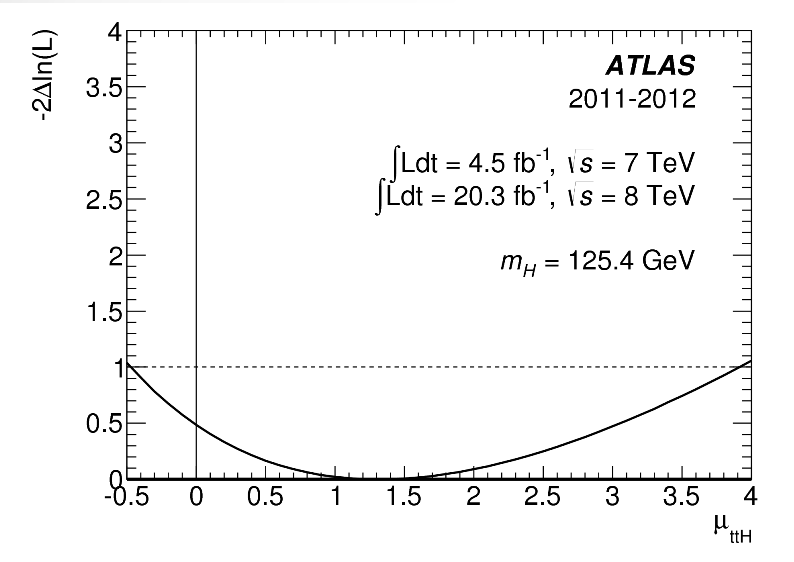
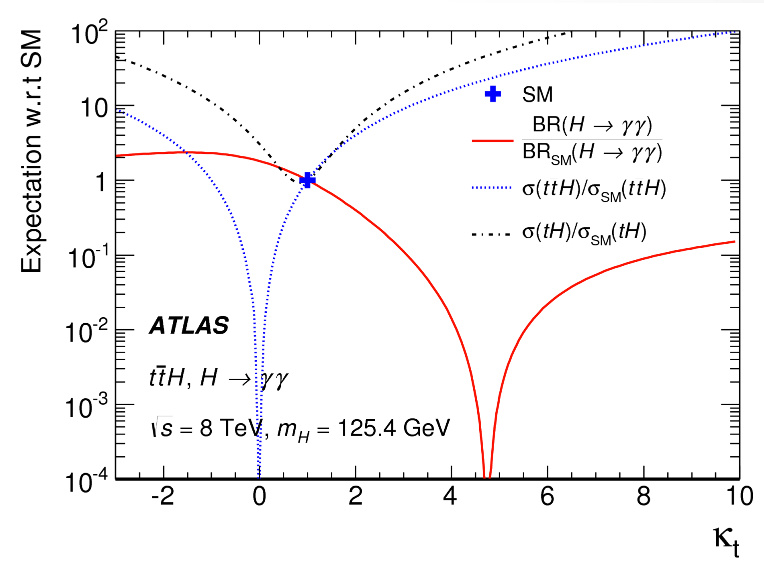
Results

ttH (H to γγ)





- Signal strengh from leptonic and hadronic categories:

$$\mu = 1.2 +2.6/-1.5$$

- ttH into γγ interpreted in terms of coupling κ_t: $-1.5 < \kappa_t < 8$
- Channels sensitive to tH production:

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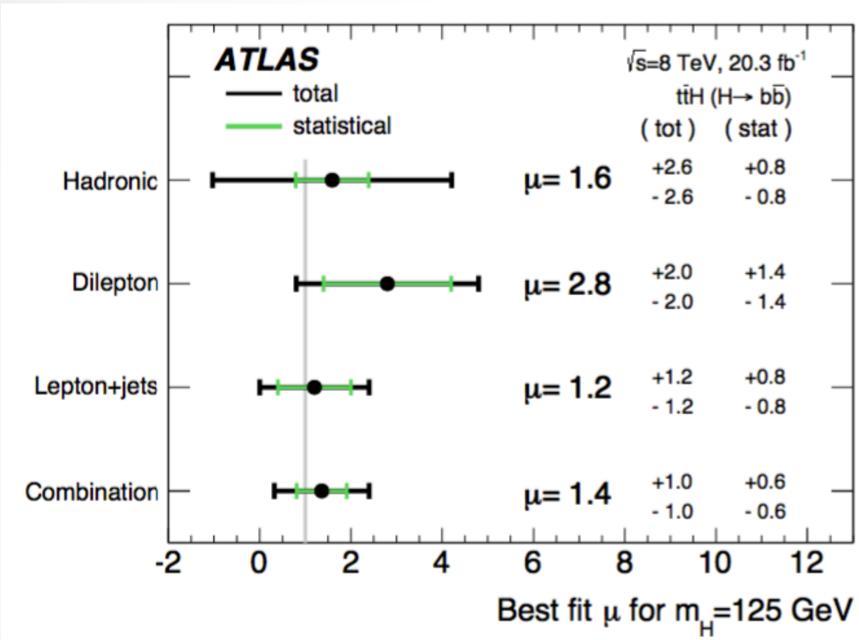
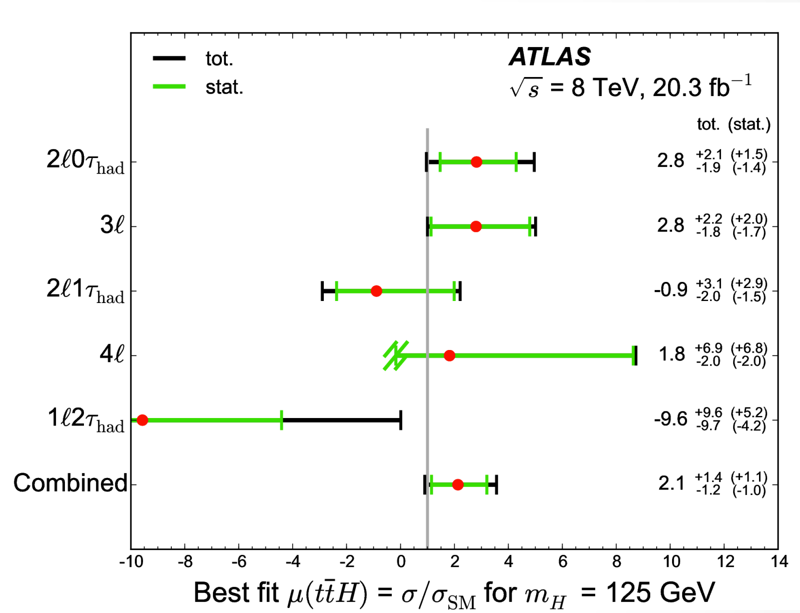
ttH (H → *bb*, multileptons)





- Signal strengh from combined H→bb channels: $\mu = 1.4 \pm 1.0$
- Signal strengh from combined multilepton channels: $\mu = 2.1 \, {+1.4} \, {-1.2}$

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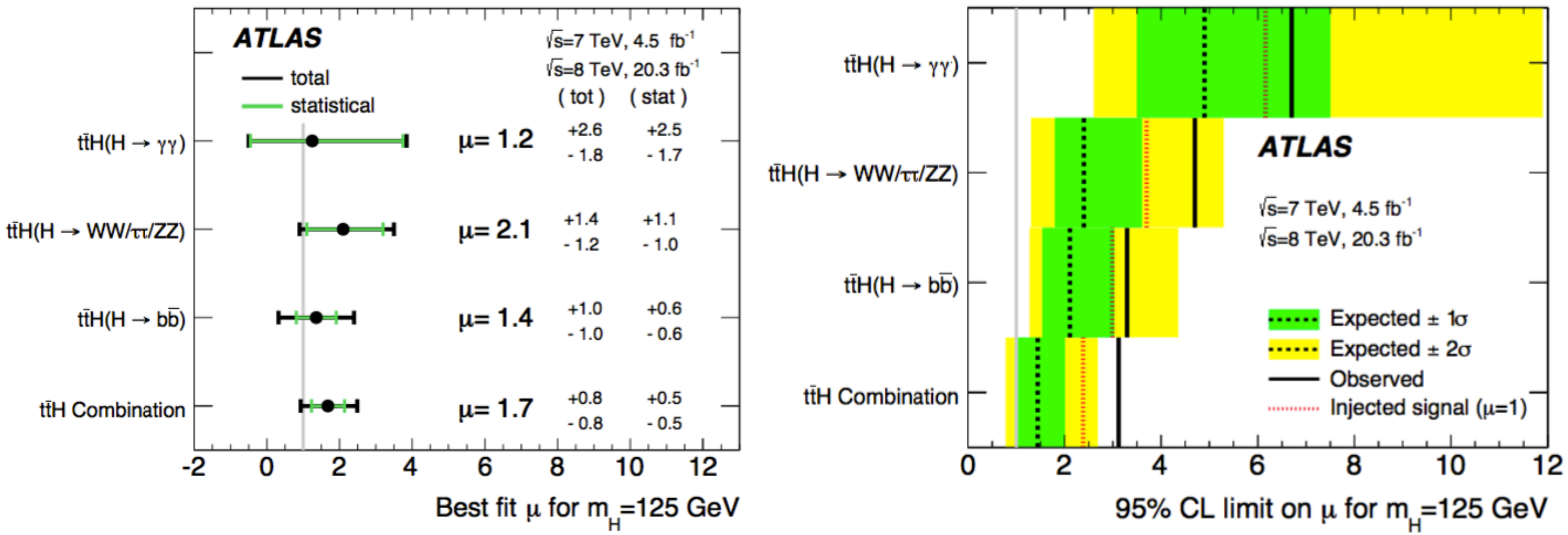
Combination



- Combination of all Run 1 ttH searches:
  - mttH = 1.7 ± 0.5 (stat) ± 0.6 (syst)
  - Limit: 3.1 × SM (obs), 1.4 × SM (exp)
- 2σ from background-only hypothesis
- Compatible with SM signal

Conclusion

- LHC Run 1 data allowed the Higgs boson discovery
- ATLAS has shown the feasibility and potential of ttH searches in different channels (γγ, *bb*, multileptons)
- ttH searches combined into global Higgs coupling measurement:
  Eur. Phys. J. C76 (2016)
- Run 2 will allow to target first ttH evidence:
  - Higher luminosity
  - Improved detector performances with IBL
  - Optimised analysis
  - Increase of signal cross-sections:
    ttH × 3.9, ttW/Z × 3, tt × 3.3