Search for the Higgs boson in the ttH production channel using the ATLAS detector

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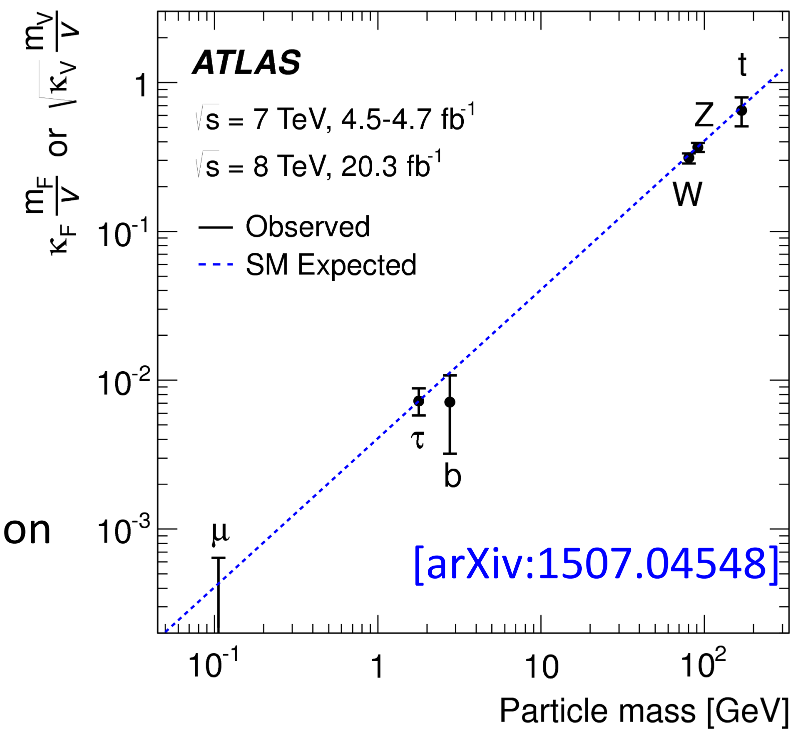
ttH, Motivation

Higgs boson discovered. Must verify properties!

- ○ Relative rates of production and decay modes
- ○ Coupling to other particles
  - • Fermion mass is proportional to this coupling; largest is coupling to top quark

$$Y_X = \sqrt{2}\frac{m_X}{V_H}$$

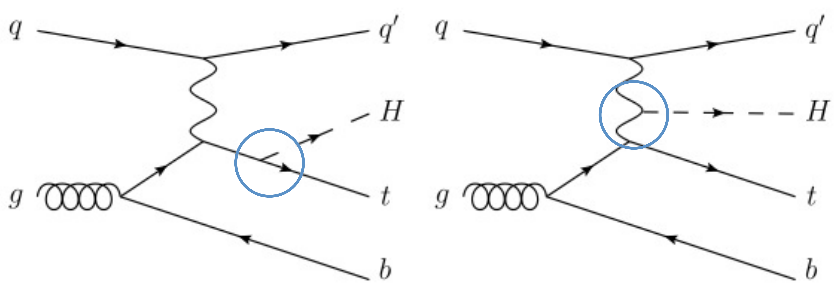
Measurement of ttH allows direct access to the top Higgs Yukawa coupling



ttH analyses also sensitive to tH

- ○ Sensitive to relative the sign of κ_t given the interference between Y_t and g_{HWW}
- ○ Any deviation from SM will affect tH cross section

$\sigma(qb \rightarrow tHq') \sim 3.4\kappa_t^2 + 3.56\kappa_w^2 - 5.96\kappa_t\kappa_w$

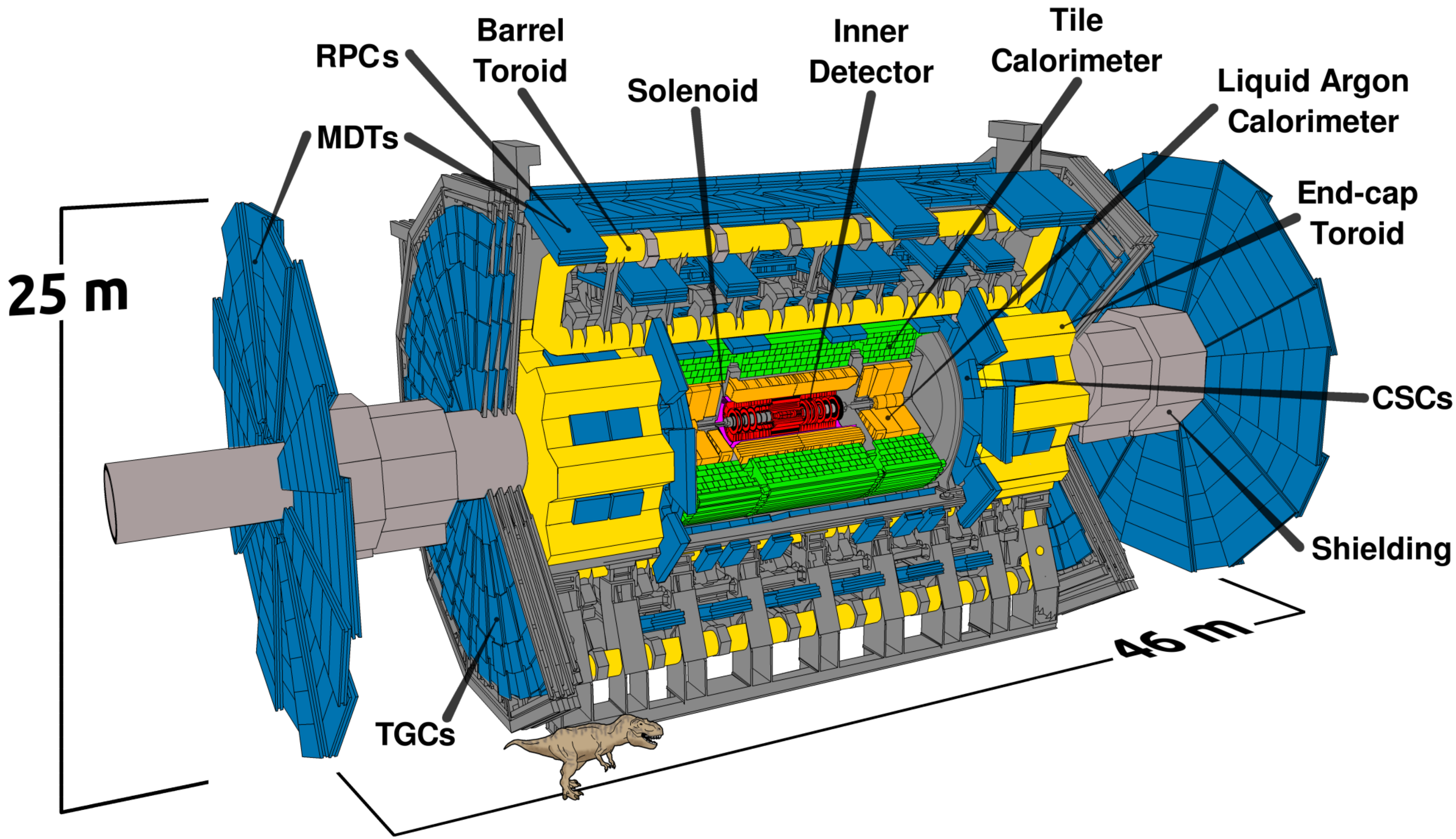


(a) (b)

$$Y_t = Y_t^{SM}\,\kappa_t$$

$$\kappa_X^2 = \frac{\Gamma_{H\rightarrow X}}{\Gamma^{SM}_{H\rightarrow X}}$$

ATLAS:



RPCs
Barrel Toroid
Solenoid
Inner Detector
Tile Calorimeter
Liquid Argon Calorimeter
MDTs
End-cap Toroid
25 m
CSCs
Shielding
TGCs
46 m

ATLAS

Analyses are separated by different Higgs decays, which contain several different final state signatures

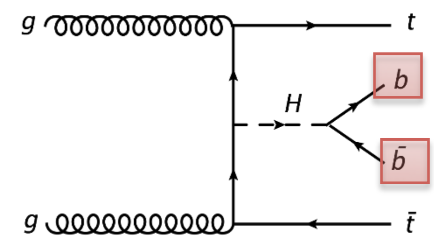
$t\bar{t}H \rightarrow b\bar{b}$

[Eur. Phys. J. C 75 (2015) 349]

$\mathcal{L}$ = 20 fb^{-1} (8 TeV)

Highest branching fraction

But important ttbar +heavy/light flavour background



$t\bar{t}H \rightarrow multileptons$

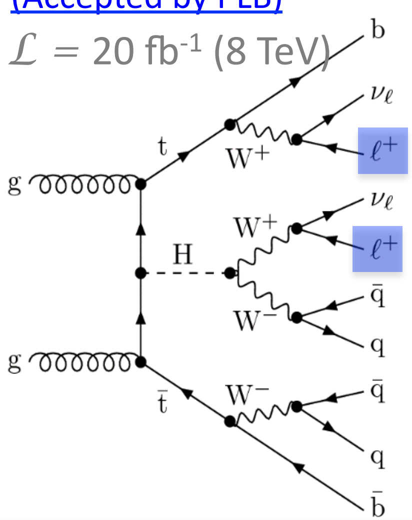
(WW/ττ/ZZ)

[ATLAS-HIGG-2013-26 (Accepted by PLB)]

$\mathcal{L}$ = 20 fb^{-1} (8 TeV)

Good signal purity and good branching ratio

Low statistics



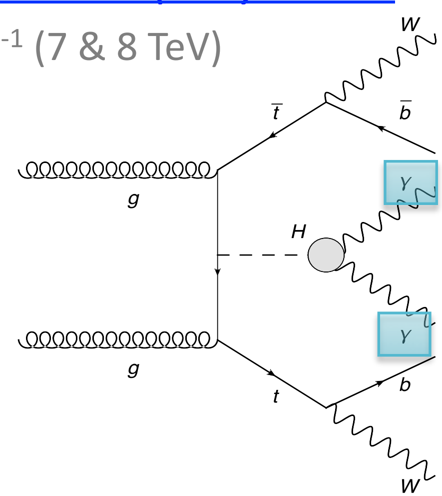
$t\bar{t}H \rightarrow \gamma\gamma$

[Physics Letters B 740 (2015) 222-242]

$\mathcal{L}$ = 25 fb^{-1} (7 & 8 TeV)

Best mass peak resolution

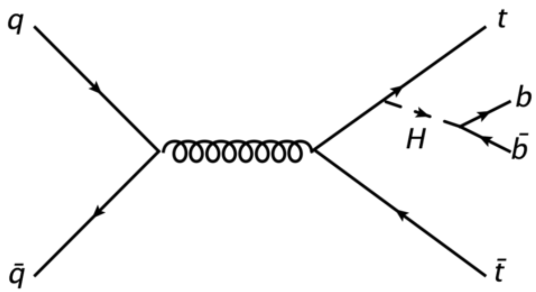
High signal purity
Low statistics
BR(H→γγ)~0.2%

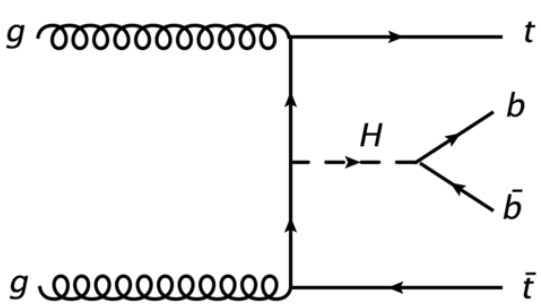


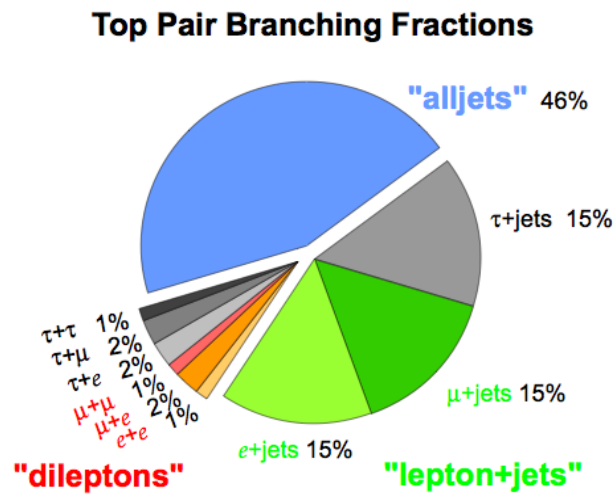
$$t\bar{t}H \to b\bar{b}$$

Analysis ‘channels’ according to decay of top quark pair

- ○ Dilepton
- ○ Single lepton

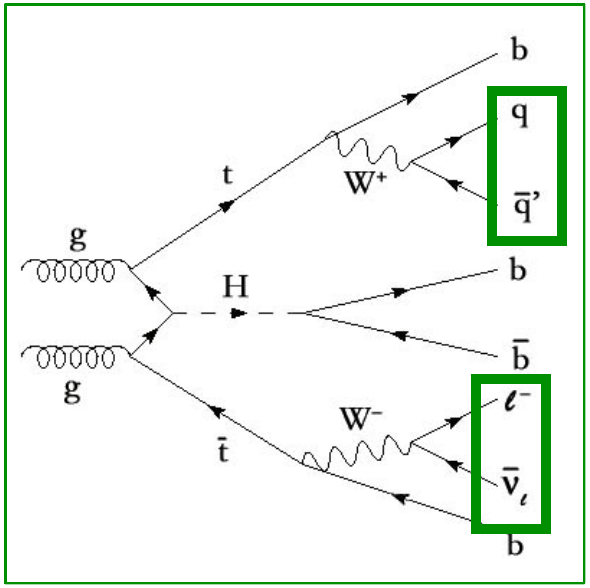






Single lepton:

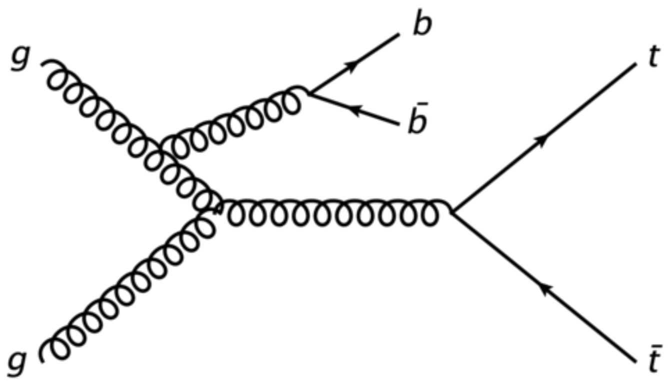
- ○ One top decays leptonically, the other hadronically
- ○ 6 jets (including 4 b jets) + 1 lepton



Di-lepton:

- ○ Both tops decay leptonically
- ○ 4 b jets + 2 lepton

Primary background is top pair + b jets (tt+bb)

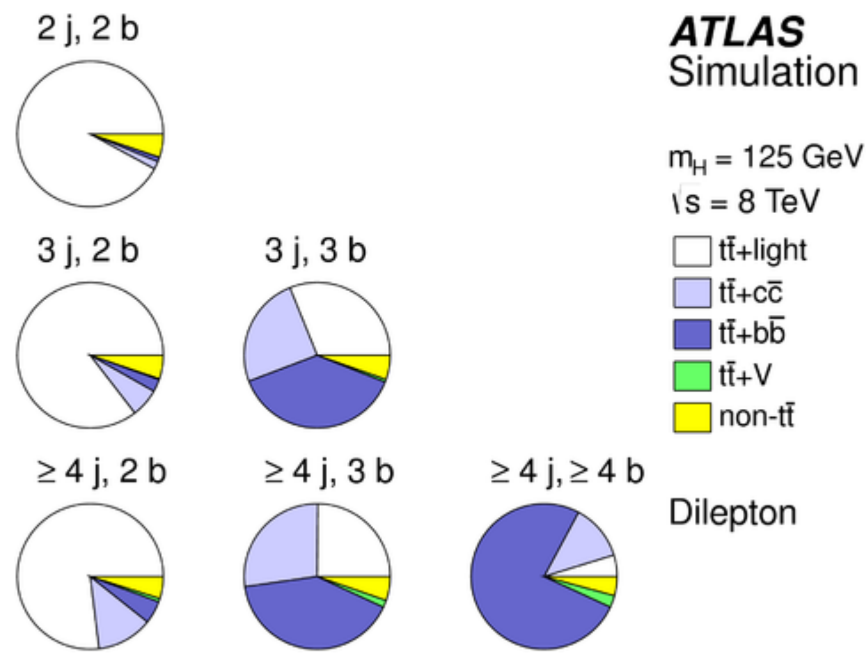


- Identical final state, irreducible background
- Signal vs background discrimination is difficult
- Gluon can also produce light or c quarks
- To enhance sensitivity, categorize events into regions in jet and b-tag multiplicity

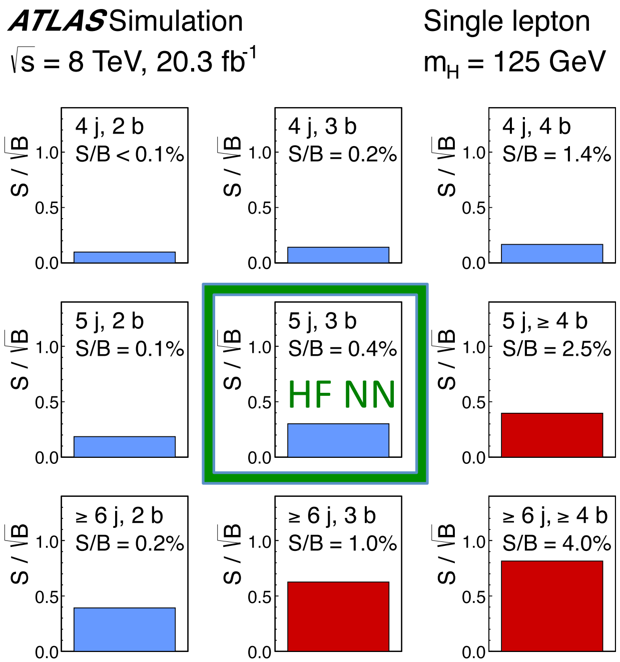
σ(ttH) at 8 TeV ~ 0.13 pb

σ(ttbb) at 8 TeV ~ $\mathcal{O}$(12) pb

- tt+bb background modeled with Powheg +Pythia 6 (NLO + Parton Shower) reweighted to Sherpa OpenLoops (NLO Matrix Element)



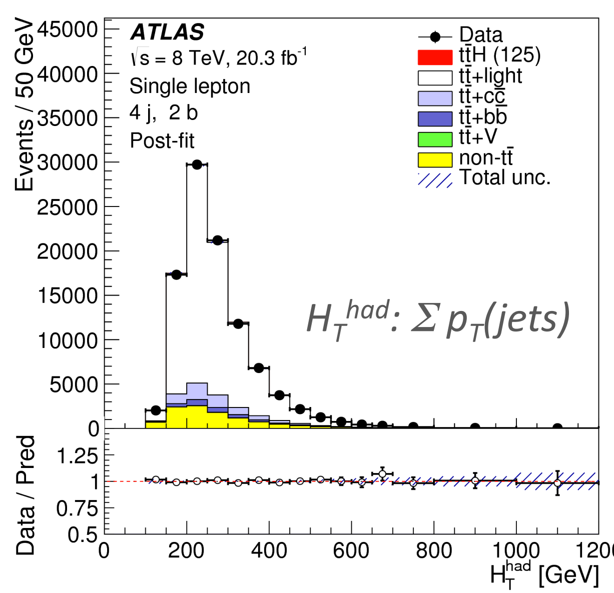
Background composition in Dilepton



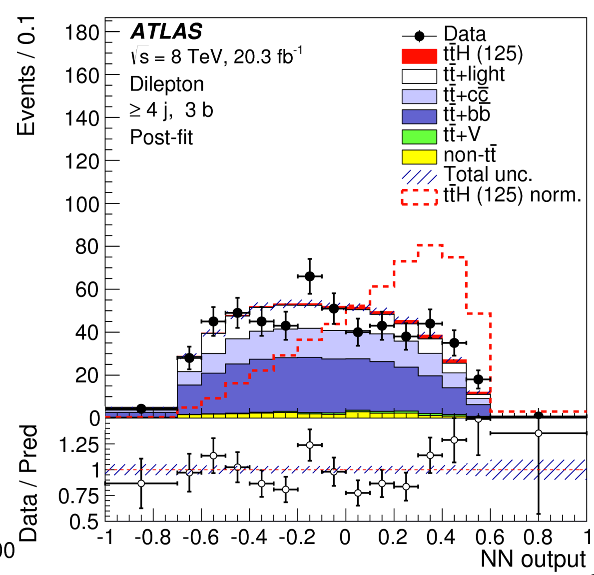
- S/√B shown for single lepton channel. Red for signal regions and blue for control regions
- Fit signal and control regions simultaneously to reduce impact of systematics in signal region
- Both channels use a neural network discriminant in signal region and H_T variable in control regions

5j 3b region in single lepton channel has a unique network trained to distinguish tt+HF (heavy flavor) from tt+light

4j 2b in single lepton



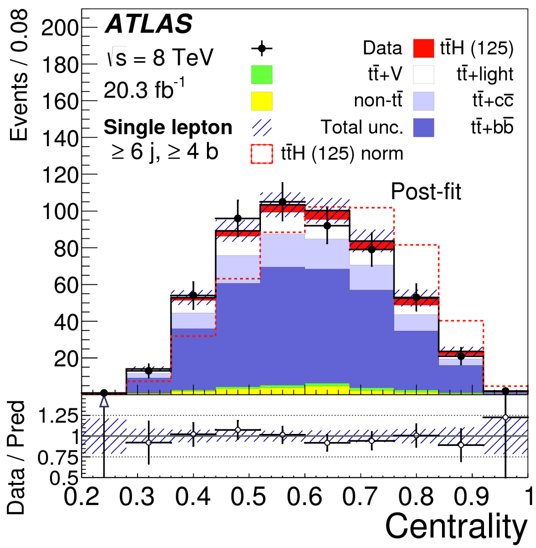
4j 3b in dilepton

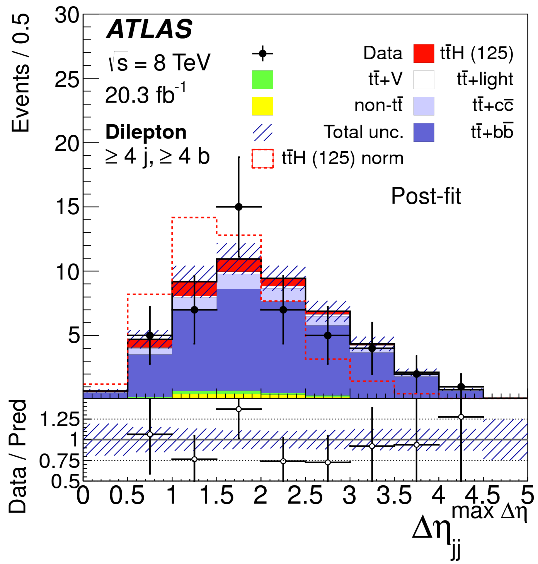


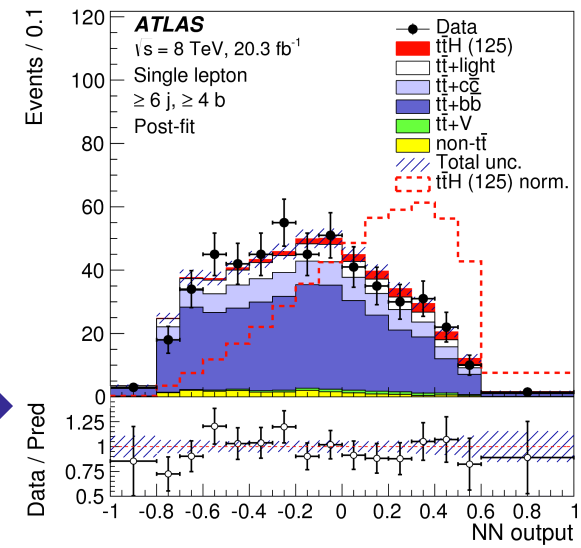
- Use kinematic variables to train network to distinguish signal from background
- Neural networks trained individually in each region
- Variable choice (10 or 12 variables) optimized for each region

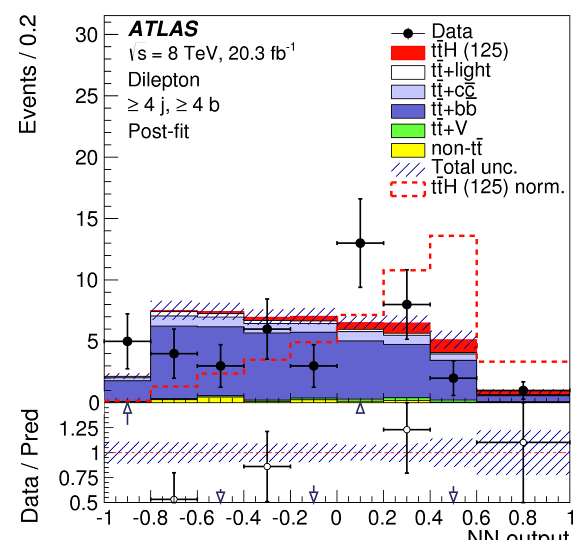
NN Output:

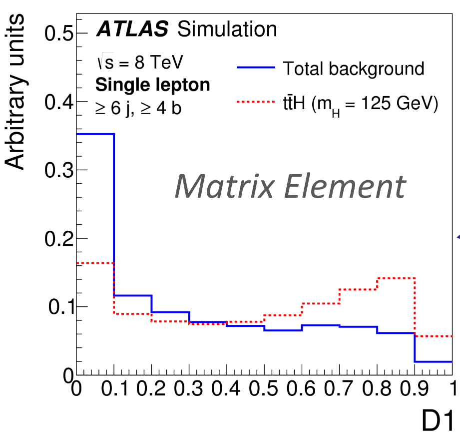
Input Variables:





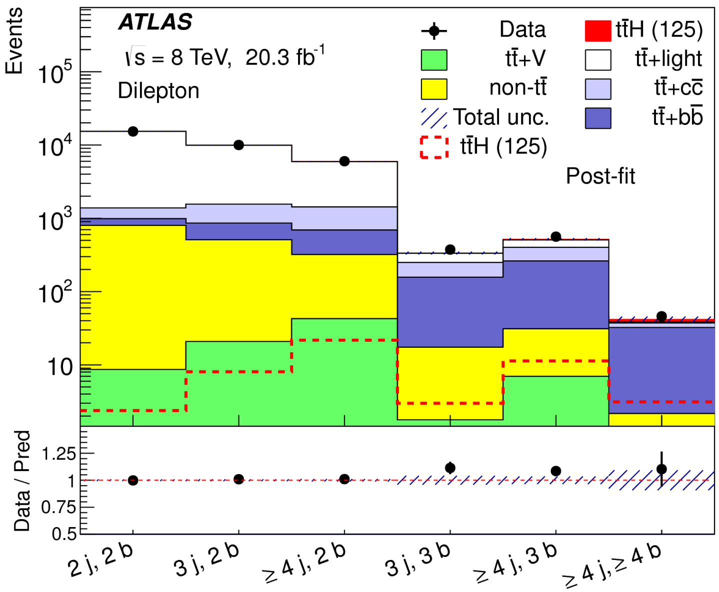






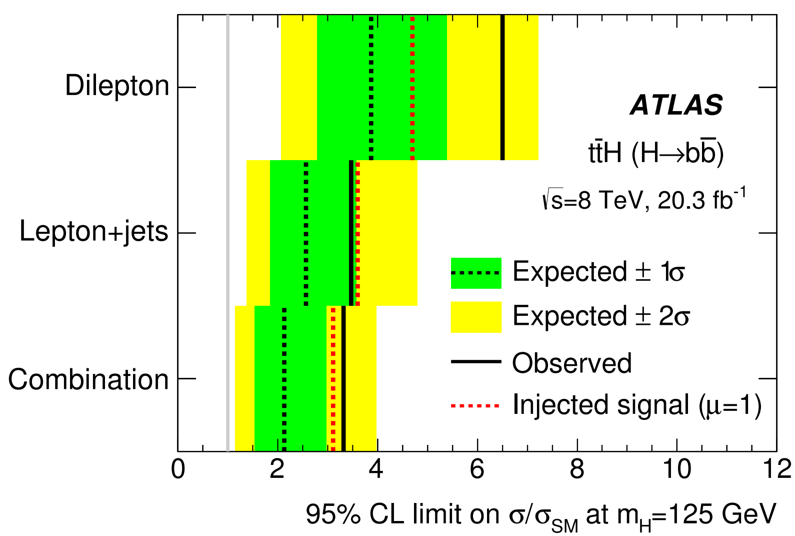
2 variables from matrix element method added in single lepton channel neural networks

H -> bb, Systematics and Results

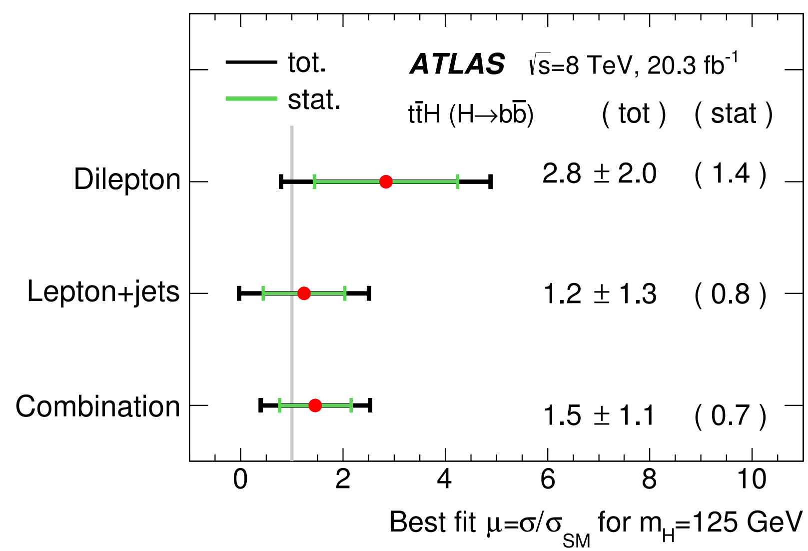


- ○ Systematics treated as nuisance parameters in profile likelihood fit across all regions
- ○ Most significant systematics are
  1. tt+bb normalization
  2. Jet energy scale
  3. tt+cc normalization
  4. tt+bb renormalization and scale

$\mu_{ttH}(\sigma/\sigma_{SM}) < 3.4$ obs (2.2 exp) @ 95% CL

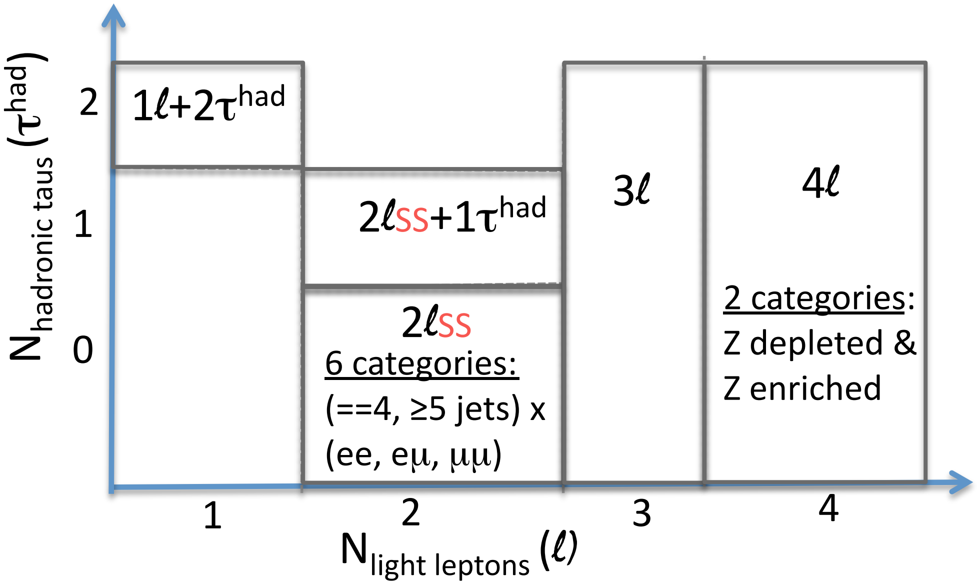


$\mu = 1.5 \pm 1.1$

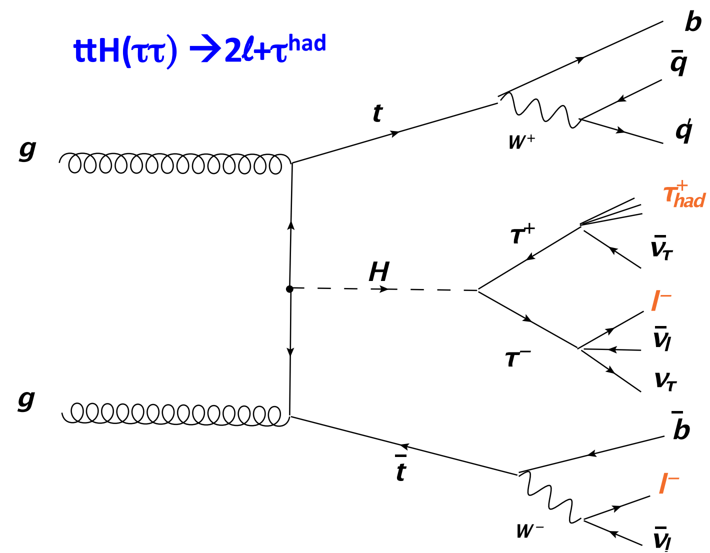


$t\bar{t}H \rightarrow multileptons$

Analysis split into 5 channels in e/μ and tau multiplicity

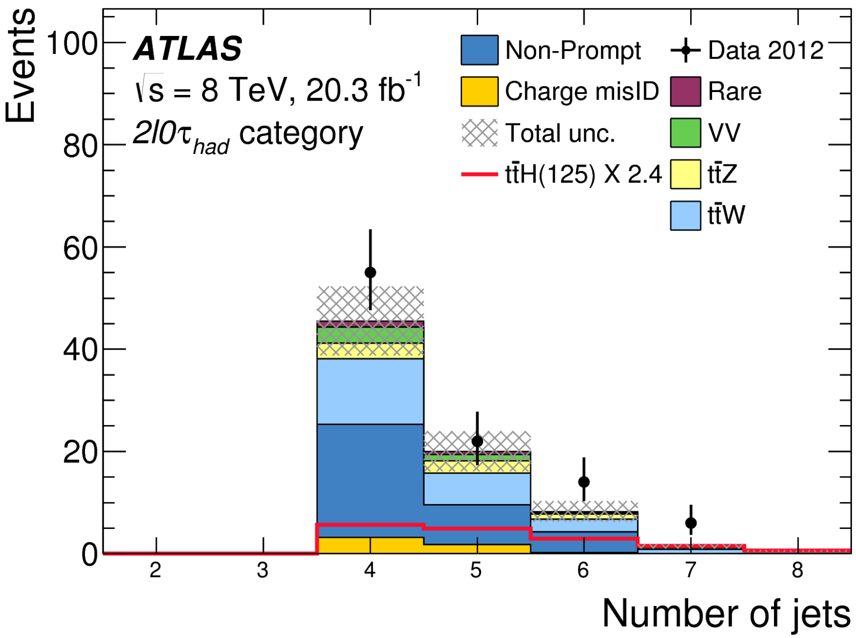


Selection criteria for each channel tuned to maximize sensitivity for various final states, e.g. cuts on # jets, m(OS lepton pairs), # b-tags, etc…



	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%

Contributions from leading Higgs decay modes to each channel



Primary Backgrounds:

Irreducible, Estimated from MC:
- ttW, ttZ
- Diboson

Reducible, data driven:
- Non-prompt leptons
- Charge mis-identification

Leading systematic uncertainties and impact on μ:

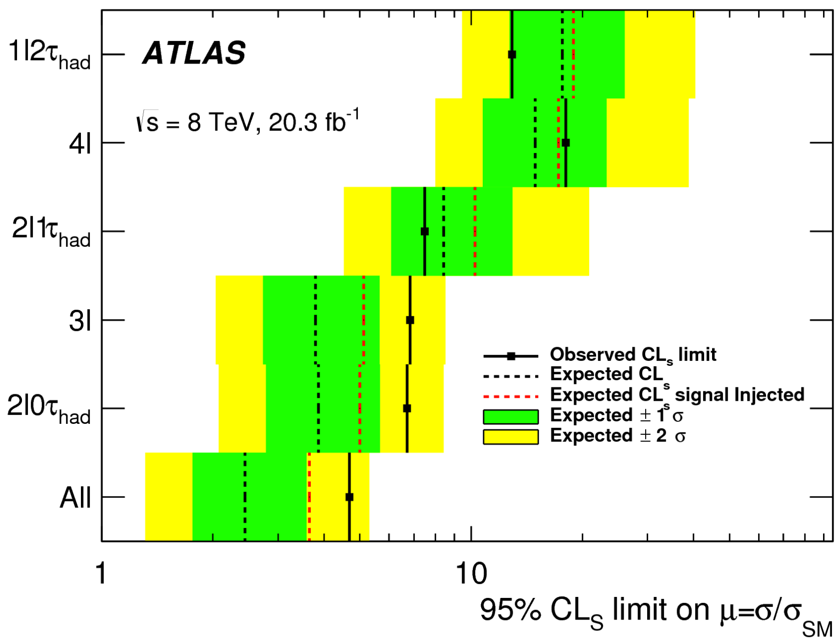
Source	$\Delta\mu$	
$2\ell 0\tau_{\rm had}$ non-prompt muon transfer factor	+0.38	−0.35
$t\bar{t}W$ acceptance	+0.26	−0.21
$t\bar{t}H$ inclusive cross section	+0.28	−0.15
Jet energy scale	+0.24	−0.18
$2\ell 0\tau_{\rm had}$ non-prompt electron transfer factor	+0.26	−0.16
$t\bar{t}H$ acceptance	+0.22	−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

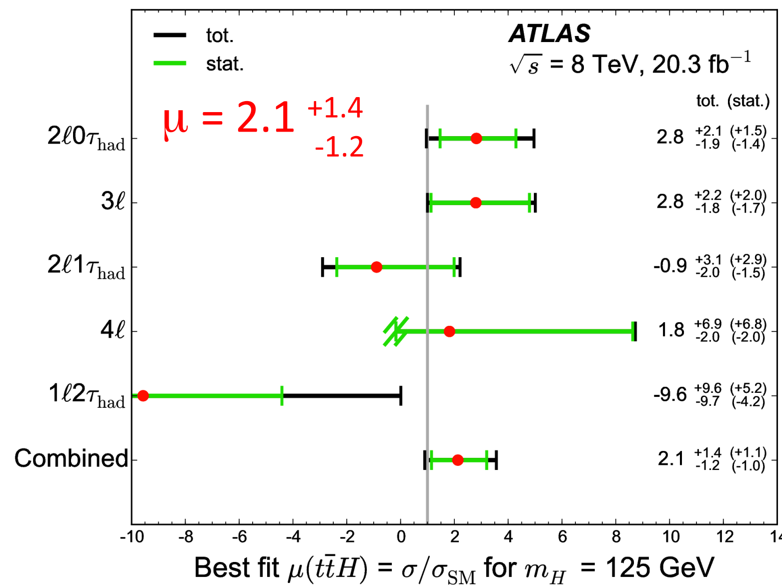
Background enriched control regions are used to verify modeling

ttH -> Multileptons, Results

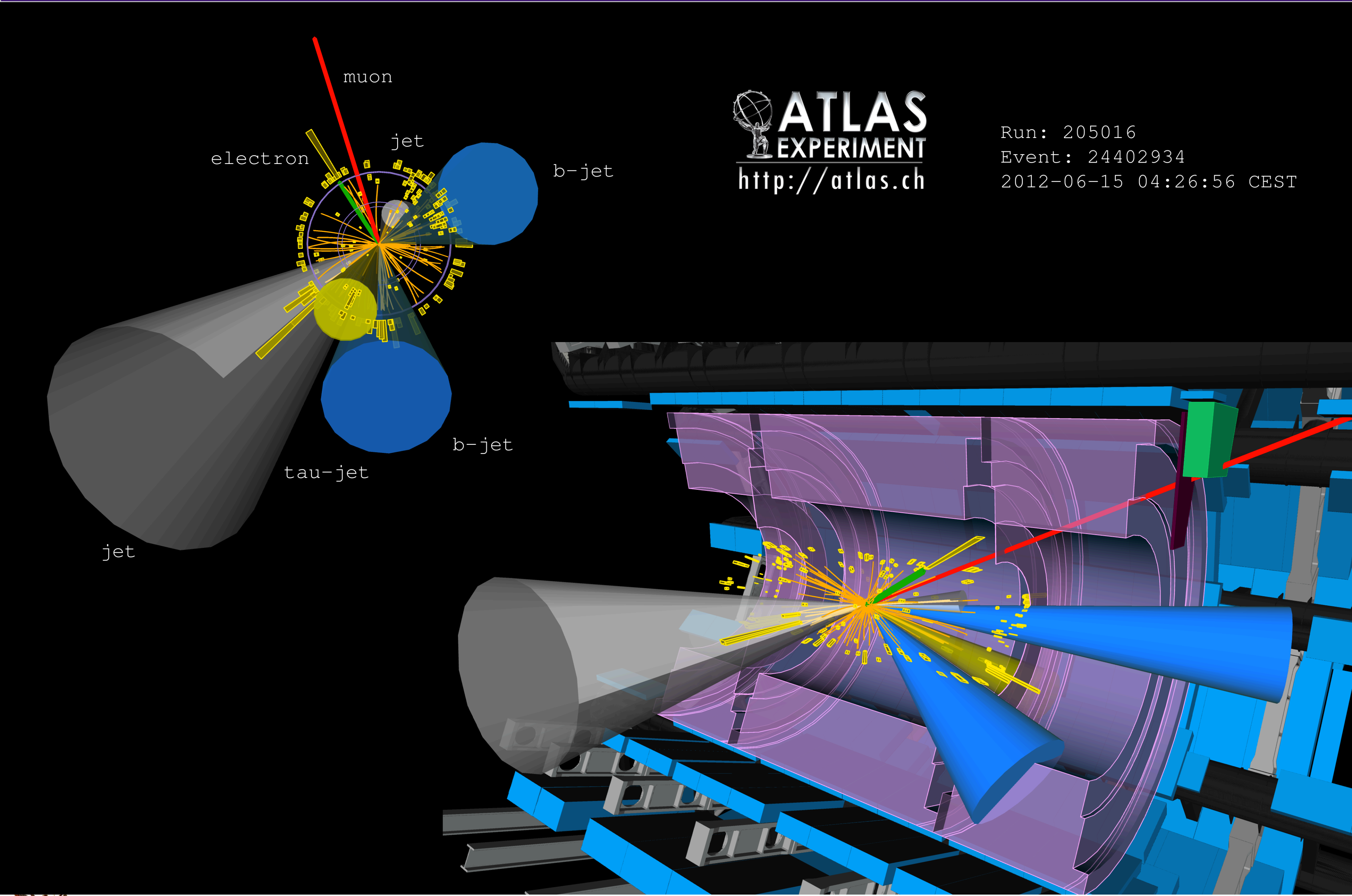
Channel	SM Higgs	Backgrounds	Data
$2\ell SS+0\tau^{had}$	6.6±1.4	77±13	98
3ℓ	2.34±0.32	11.4±3.1	18
$2\ell SS+1\tau^{had}$	0.47±0.02	1.4±0.6	1
4ℓ	0.20±0.01	0.55±0.17	1
$1\ell+2\tau^{had}$	0.68±0.07	16±6	10

$\mu_{ttH}(\sigma/\sigma_{SM}) < 4.7$ obs (2.4 exp) @ 95% CL





ttH -> Multileptons, Event Display



single 2l+tau candidate event

$$t\bar{t}H \rightarrow \gamma\gamma$$

H -> γγ also split into channels according to top pair decay:

- Leptonic (Single lepton and Di-lepton included)
  - Cuts are chosen to retain some sensitivity to tH
- Hadronic (Both tops decay hadronically)

Overall strategy is to fit sideband for background shape of $M_{\gamma\gamma}$, then fit signal on top

Expected number of events for M_H = 125.4 GeV after event selection – **Total = 1.3**

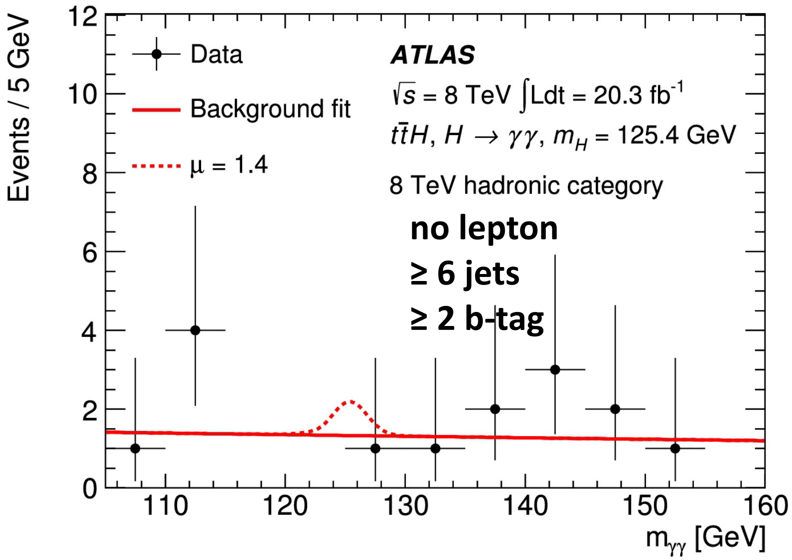
Background integral in signal region (120-130) determined from S+B unbinned fit to the range 105-160 GeV **Total = $4.6^{+1.3}_{-0.9}$**

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	$2.7^{+0.9}_{-0.7}$

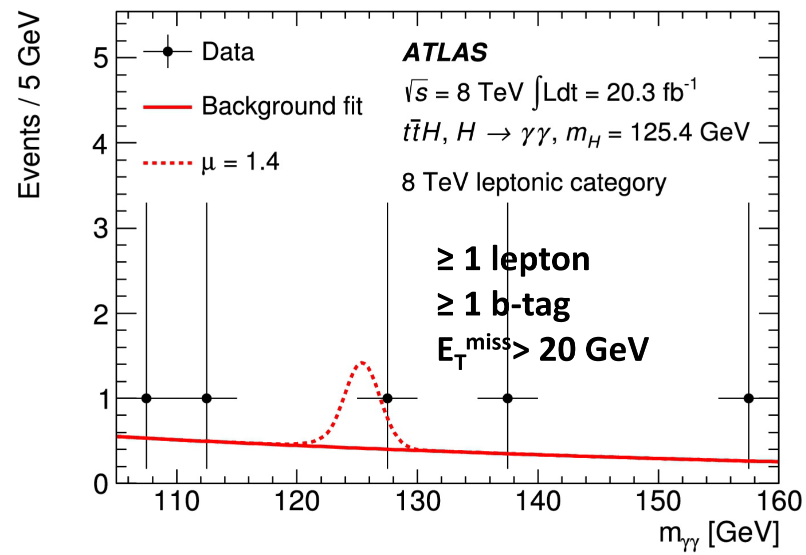
Expected percentages of non-ttH contamination (largest source of systematic uncertainty)

ttH -> γγ, Results

Hadronic



Leptonic



Limit:

$\mu_{ttH} < 6.7$ obs (4.9 exp) @ 95% CL

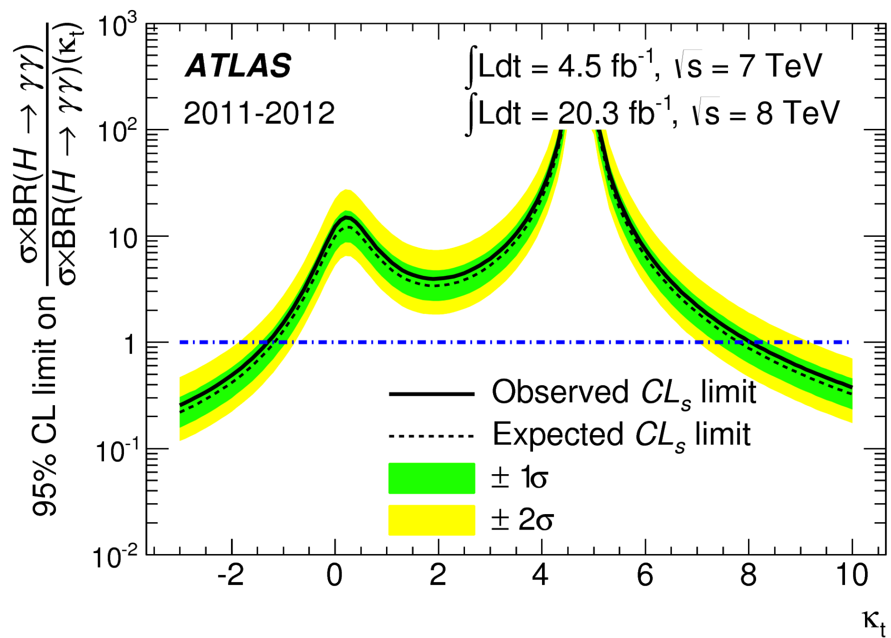
Measured μ:

$\mu = 1.3^{+2.5}_{-1.7}(\text{stat.})^{+0.8}_{-0.4}(\text{syst.})$

Also sets limits on strength of top Yukawa coupling, κ_t :

$-1.3 < \kappa_t < +8.0$ @ 95% CL

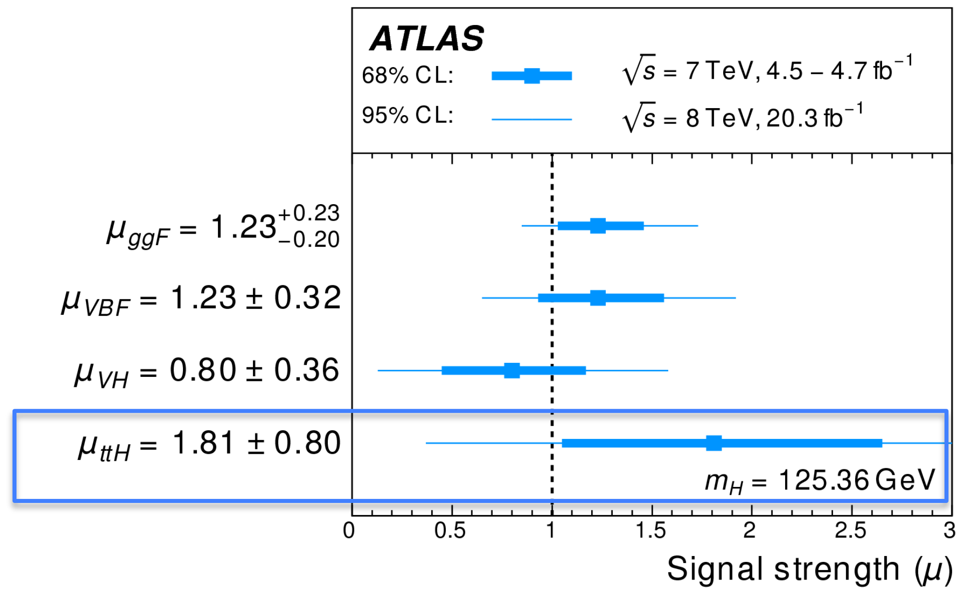
Total H -> γγ cross section as function of κ_t:



Conclusions

With Run I Data, ATLAS has set limits and measurements on the Higgs boson produced in association with a top quark pair through 3 channels:

- ttH→γγ: μ < 6.7 obs (4.9 exp);
- ttH→bb: μ < 3.4 obs (2.2 exp);
- ttH→leptons: μ < 4.7 obs (2.4 exp);

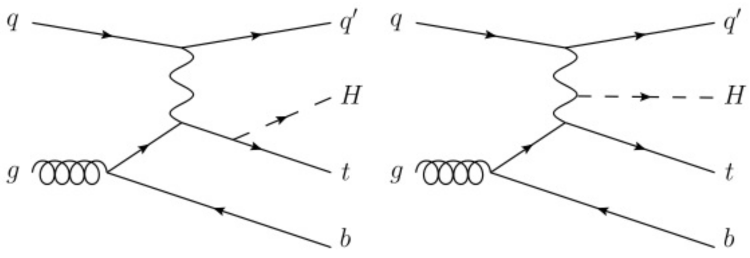


- The analyses are all statistically limited
- ttH benefits from increased luminosity in Run II
- ttH cross section rises faster than background

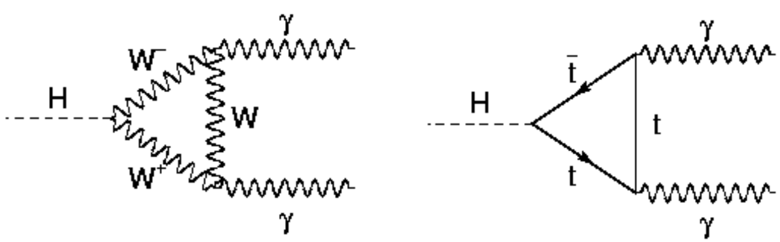
Combined fitted result for ttH production is μ=1.81±0.80

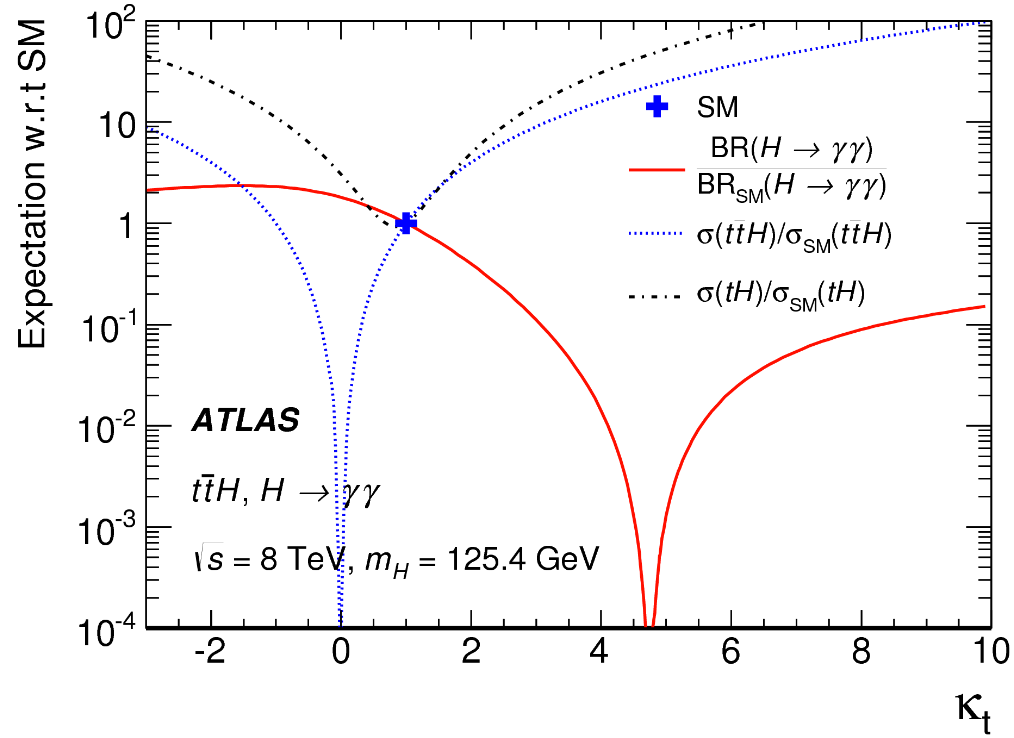
From 8 to 13 TeV:
Increase in σ(ttH) ~ **4**
Increase in σ(tt) ~ 3.3

Thank You



(a) (b)





For kt = 0 process is turned off, and the top quark contribution to *tH* production and to the loop-induced $H \to \gamma\,\gamma$ decay is removed, leaving mainly the contribution from *W* bosons.

Cancellations of the contributions of top quarks and W bosons to the loop-induced $H \to \gamma\gamma$ decay lead to a minimum of the $BR(H \to \gamma\gamma)$ around a value of $\kappa t = +4.7$.

Higgs Production mechanisms

(single top processes discussed later)