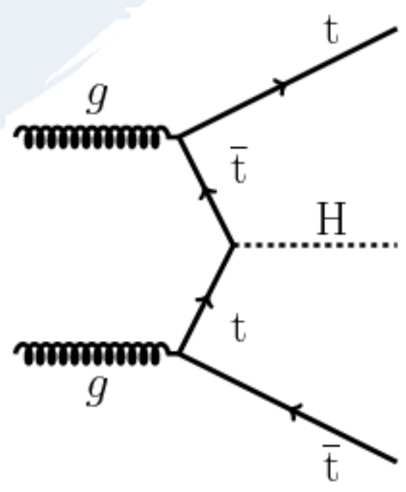
Measurement of the top-Yukawa coupling and the search for ttH production



Introduction

- Due to large mass of top quark, top-Yukawa coupling is nearly unitary and paramount to an understanding of EWSB
  - ttH production offers a unique opportunity for direct measurement of the coupling and could provide hints to new physics
  - Several Higgs decay channels with very different strategies and advantages

Diphoton Channel

This channel capitalizes on the fine resolution of the diphoton mass to enhance sensitivity and is also inclusive of tH production.

Event Selection

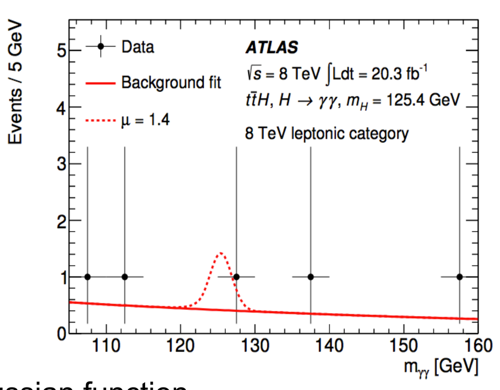
- Hadronic Category
  - High jet and b-tag multiplicity
  - Optimized to supress ggH, VBF & WH + HF content
- Leptonic Category
  - One or more high quality, charged lepton
  - Inclusive of tH production, sensitive to difference in the relative sign of Y_t and g_{HWW} which could differ with new physics

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

Background Modeling

- Modeled by simple exponential
- Fit for each category to the data sidebands using 7+8 TeV data
- Validated in data control region with loosened isolation + ID



Signal Modeling

- Modeled by a Crystal Ball + Gaussian function
- Shape parameters are parameterized as a function of m_H to allow for interpolation between different Higgs masses.
- Shape assumed to be same among different Higgs productions

Systematic Uncertainties

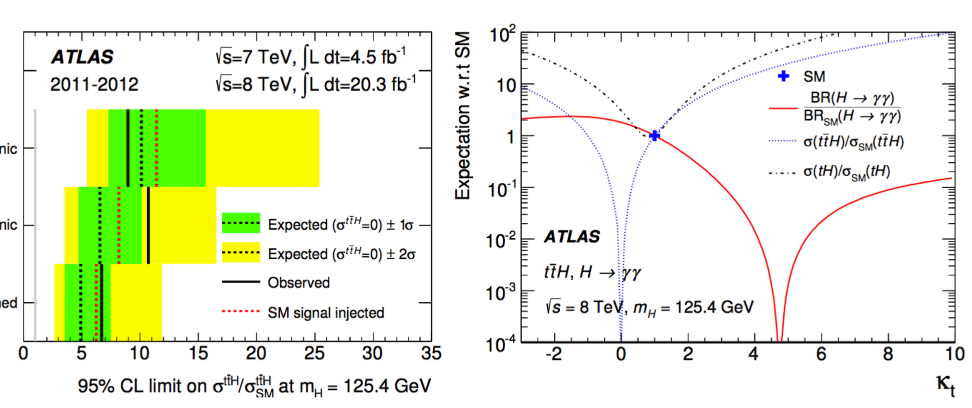
Dominant systematics from…

- **MC Modeling**
  - large uncertainty on the underlying event
  - 100% uncertainty on ggF, VBF, & WH productions in association with HF motivated by past studies on ttbar+HF and WH+HF
- **Background Modeling**
  - Estimated by fitting BG + signal model in background control region and quantifying signal excess as uncertainty

	$t\bar{t}H$ [%]		$tHqb$ [%]		WtH [%]		ggF [%]	WH [%]
	had.	lep.	had.	lep.	had.	lep.	had.	lep.
Luminosity	±2.8							
Photons	±5.6	±5.5	±5.6	±5.5	±5.6	±5.5	±5.6	±5.5
Leptons	< 0.1	±0.7	< 0.1	±0.6	< 0.1	±0.6	< 0.1	±0.7
Jets and E_T^{miss}	±7.4	±0.7	±16	±1.9	±11	±2.1	±29	±10
Bkg. modeling	0.24 evt.	0.16 evt.	applied on the sum of all Higgs boson production processes					
Theory ($\sigma \times$ BR)	+10,−13		+7,−6		+14,−12		+11,−11	+5.5,−5.4
MC modeling	±11	±3.3	±12	±4.4	±12	±4.6	±130	±100

Results

Consistent with the SM, no significant excess is observed
95% CL limits set on σ_{ttH} x BR(H→γγ) and top-Yukawa coupling κ_t



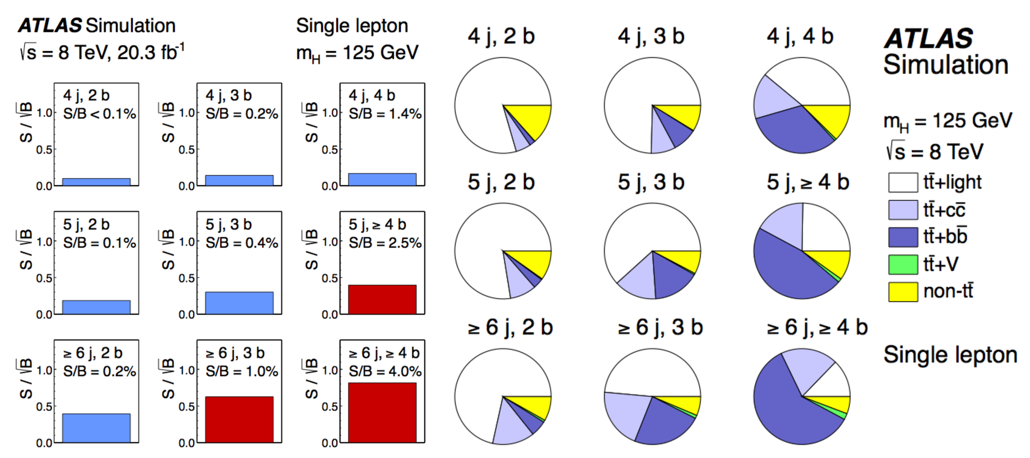
Bottom Channel

This channel allows for a measurement of the Higgs coupling to both 3[rd] generation quarks and benefits from the large H→bb branching ratio.

Event Selection

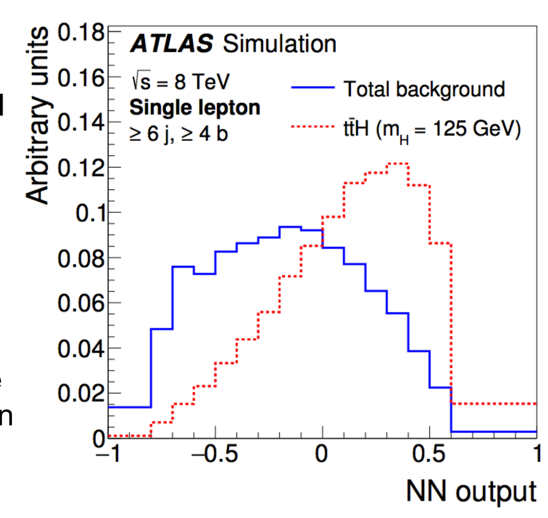
Categorized into regions of m jets of which n jets are b-tagged (mj, nb)
Signal regions are selected such that S/B > 1% and S/√B > 0.3

- Single Lepton Category
  - Exactly one lepton with at least 4 jets and 2 b-tags
  - Control regions of (4j, 2b), (4j, 3b), (4j, 4b), (5j, 2b), (5j, 3b), & (≥ 6j, 2b)
  - Signal regions of (5j, ≥4b), (≥ 6j, 3b), & (≥ 6j, ≥ 4b)
- OS Dilepton Category
  - Exactly two OS leptons with at least 2 b-tags
  - Control regions of (2j, 2b), (3j, 2b), (3j, 3b) & (≥ 4j, 2b)
  - Signal regions of (≥ 4j, 3b) & (≥ 4j, ≥ 4b)



Analysis Strategy

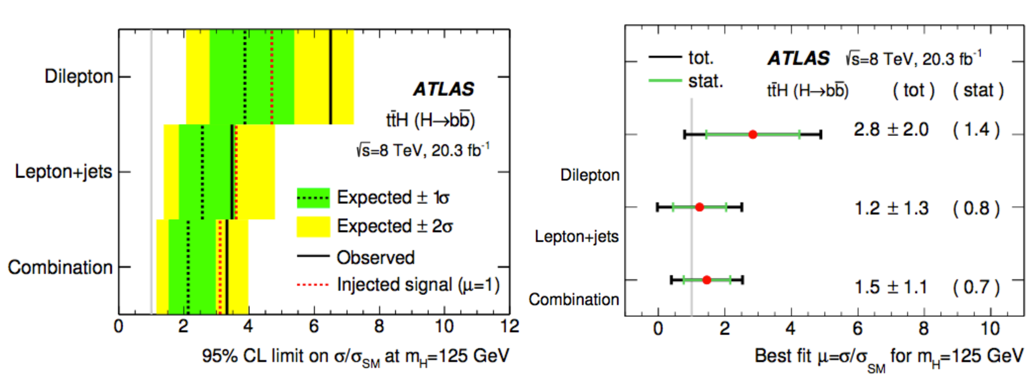
- NeuroBayes NN used on signal regions to improve sensitivity.
- Control regions are fit simultaneously to constrain systematics using H_T^{had} as the discriminant variable
- Input variables from kinematics and matrix element method are chosen on ranking of separation power and correlations



Systematics & Results

Systematic Uncertainties are dominated by tt+bb and tt+cc normalization and modeling but are largely constrained by a simultaneous fit to the many control regions.

No significant excess is observed but 95% CL upper limits are set on σ_{ttH} x BR(H→bb) and the best fit signal strength w.r.t the SM is measured



Multilepton Channel

This channel is sensitive to the Higgs coupling to the 3rd generation charged lepton as well as the off-shell couplings of H→WW* and H→ZZ*.

Event Selection

Events are categorized into regions with explicit requirements on lepton and hadronic tau multiplicity and many jets with at least 1 b-tag

- 2 lep, 0 τ_{had}
  - Same sign light leptons
- 2 lep, 1 τ_{had}
  - Same sign light leptons
- 1 lep, 2 τ_{had}
  - Opposite sign tau pair
- 3 lep
  - Sum of charge equal to ±1
  - No requirements on τ_{had}
- 4 lep
  - Sum of charge equal to 0
  - Z veto to suppress ttZ

The table on the right shows the fraction of ttH decays that enter each category.

The 'Other' category is dominated by H→bb and H→μμ

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%

Analysis Strategy

The multilepton channel uses a simple cut-and-count analysis.

Background Estimation

- Irreducible backgrounds such as tZ, ttW, ttZ and diboson production are estimated from MC simulation.
- Reducible backgrounds from non-prompt lepton production and electron charge misidentification are estimated from data
- In the 1 lepton + 2 τ_{had} category, the primary background comes from fake hadronic taus which are modeled using MC simulation and validated against a data-driven estimate.

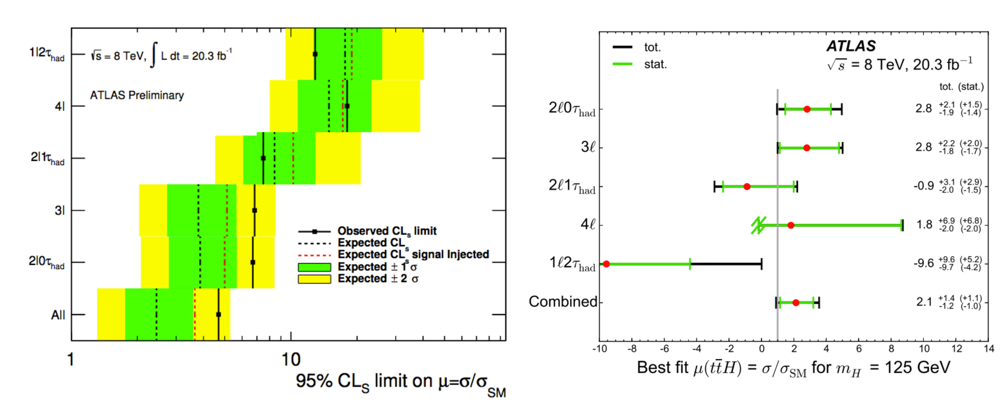
Systematic Uncertainties

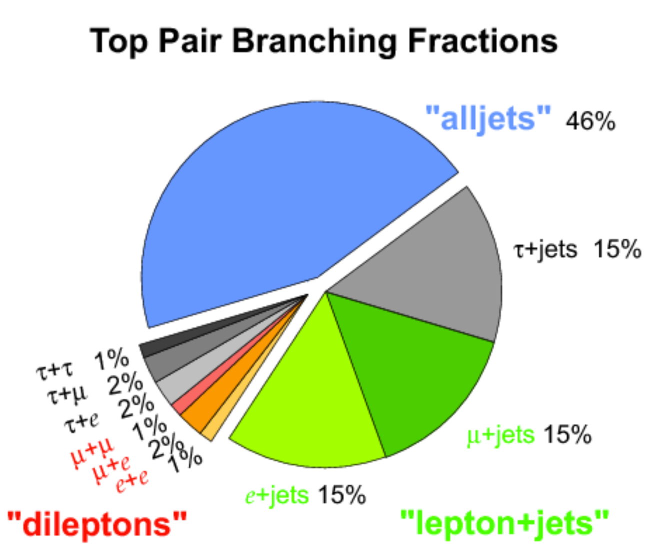
The leading source of systematics comes from the non-prompt lepton transfer factor (used to extrapolate the non-prompt lepton yield) as well as the acceptance and cross section of ttH and ttV

Source	$\Delta\mu$	
$2\ell 0\tau_{had}$ 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
$2\ell 0\tau_{had}$ 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

Results

Consistent with the SM, no significant excess is observed
95% CL limits set on σ_{ttH} x BR(H→multileptons)
and the best fit signal strength w.r.t the SM is measured

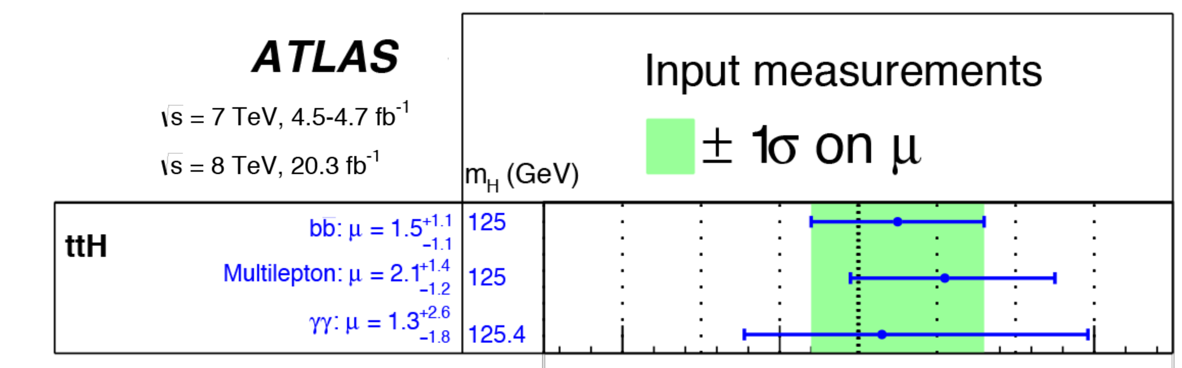




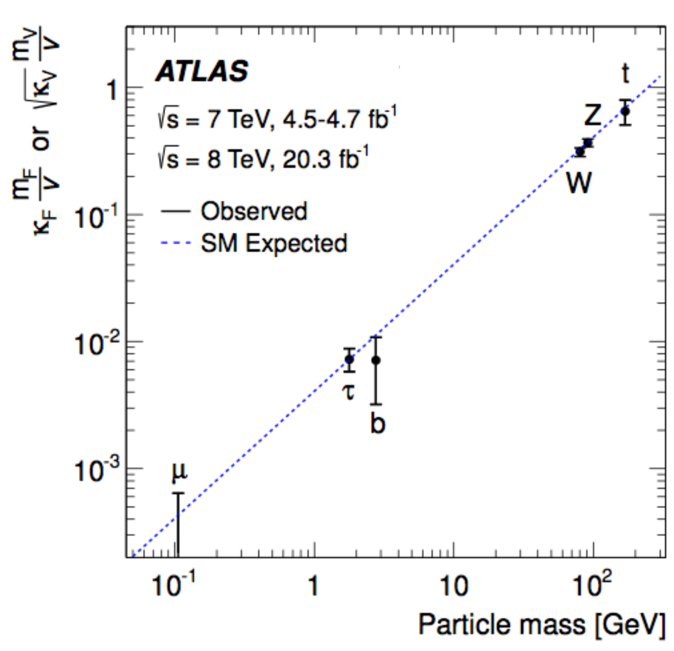
Combination & Future

Using the full Run 1 dataset, no significant excess is observed. A 95% CL limit and measurement of the signal strength is included into the ATLAS Higgs combination. Observation is expected to be possible within Run 2.

Combined signal strength μ at m_H = 125.36 GeV
$\mu_{ttH} = 1.81 \pm 0.80$



ttH production	95% CL limit
$H \to b\bar{b}$	$\mu < 3.4$
$H \to$ multileptons	$\mu < 4.7$
$H \to \gamma\gamma$	$\mu < 6.7$



Physics Letters B 740 (2015) 222-242 [H→γγ]
Eur. Phys. J. C (2015) 75:349 [H→bb]
arXiv:1506.05988 [hep-ex] [multileptons]
arXiv:1507.04548 [hep-ex] [combination]

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ATLAS EXPERIMENT