Backgrounds & Uncertainties in ttH(γγ)

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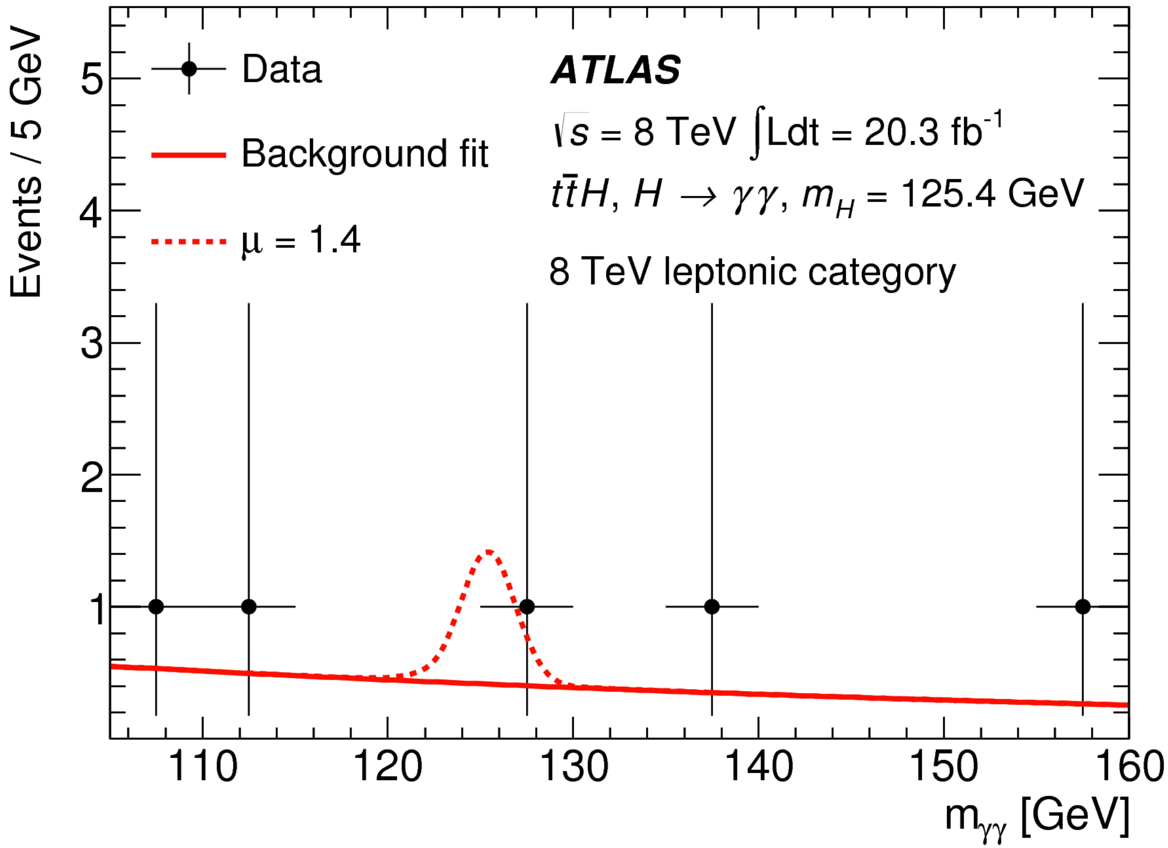
The ATLAS ttH(γγ) Analysis



ttH(γγ) analysis:

- ttH signal
- non-ttH Higgs BGs
- continuum BG fit

arXiv: 1409.3122

Modeling

Sample	Generator	PDF	Generator tune	σ [pb] at 7 TeV	σ [pb] at 8 TeV
$t\bar{t}H$	Powhel + Pythia8	CT10	AU2 CT10	$0.086^{+0.008}_{-0.011}$	$0.129^{+0.012}_{-0.016}$
$tHjb\ \kappa_t = +1$	MG5 + Pythia8	CT10	AU2 CT10	$0.0111^{+0.0009}_{-0.0008}$	$0.0172^{+0.0012}_{-0.0011}$
$tHjb\ \kappa_t = -1$	MG5 + Pythia8	CT10	AU2 CT10	$0.040^{+0.003}_{-0.003}$	$0.059^{+0.004}_{-0.004}$
$tHjb\ \kappa_t = 0$	MG5 + Pythia8	CT10	AU2 CT10	$0.129^{+0.010}_{-0.009}$	$0.197^{+0.014}_{-0.013}$
$WtH\ \kappa_t = +1$	aMC@NLO + Herwig++	CT10	AU2 CT10	$0.0029^{+0.0007}_{-0.0006}$	$0.0047^{+0.0010}_{-0.0009}$
$WtH\ \kappa_t = -1$	aMC@NLO + Herwig++	CT10	AU2 CT10	$0.0043^{+0.0011}_{-0.0008}$	$0.0073^{+0.0017}_{-0.0013}$
$WtH\ \kappa_t = 0$	aMC@NLO + Herwig++	CT10	AU2 CT10	$0.016^{+0.004}_{-0.003}$	$0.027^{+0.006}_{-0.005}$
WH	Pythia8	CTEQ6L1	AU2 CTEQ6L1	15.1 ± 1.6	19.3 ± 2.0
ZH	Pythia8	CTEQ6L1	AU2 CTEQ6L1	1.22 ± 0.03	1.58 ± 0.04
ggF	PowHeg + Pythia8	CT10	AU2 CT10	0.579 ± 0.016	0.705 ± 0.018
VBF	PowHeg + Pythia8	CT10	AU2 CT10	0.335 ± 0.013	0.415 ± 0.017

All cross sections correspond to Higgs mass of 125 GeV

Continuum Background Fit

- Model continuum background with $e^{a\, m_{\gamma\gamma}}$
  - Function validated in data control regions obtained by loosening photon ID and isolation requirements.
  - Fit performed over range of $m_{\gamma\gamma} \in$ 105-160 GeV for each category
  - Use BG+Signal fit to find bias of model choice (spurious signal)

	Observed limit	Expected limit	$+2\sigma$	$+1\sigma$	-1σ	-2σ
Combined (with systematics)	6.7	4.9	11.9	7.5	3.5	2.6
Combined (statistics only)	6.3	4.7	10.5	7.0	3.4	2.5
Leptonic (with systematics)	10.7	6.6	16.5	10.1	4.7	3.5
Leptonic (statistics only)	10.2	6.4	15.1	9.6	4.6	3.4
Hadronic (with systematics)	9.0	10.1	25.4	15.6	7.3	5.4
Hadronic (statistics only)	8.5	9.5	21.4	14.1	6.8	5.1

Current Event Selection

Current event selection optimized for limits

Pre-Selection

2 Photons

- Leading $E_T > 0.35 * m_{\gamma\gamma}$
- Sub-Leading $E_T > 0.25 * m_{\gamma\gamma}$
- $m_{\gamma\gamma} \in$ 105-160 GeV

Leptonic Selection

- $\geq$ 1 e/μ (p_T > 15 /10 GeV), $\geq$ 1 jets (p_T > 25 GeV), $\geq$ 1 b-tag (80% WP*)
- MET $\geq$ 20 GeV for 1 b-tag
- Veto on $m_{e\gamma} \in$ 84 - 94 GeV

To reduce the backgrounds from final states without top quarks

Shown to largely reduce electron fakes with small impact to signal

* WP = Working Point

Current Event Selection

Current event selection optimized for limits

Pre-Selection

2 Photons

- Leading $E_T > 0.35 * m_{\gamma\gamma}$
- Sub-Leading $E_T > 0.25 * m_{\gamma\gamma}$
- $m_{\gamma\gamma} \in$ 105-160 GeV

Each category optimized to suppress ggF production

Hadronic Selection

No charged leptons

- $\geq$ 6 jets ($p_T > 25$ GeV), $\geq$ 2 b-tags (80% WP*)
- $\geq$ 5 jets ($p_T > 30$ GeV), $\geq$ 2 b-tags (70% WP*)
- $\geq$ 6 jets ($p_T > 30$ GeV), $\geq$ 1 b-tag (60% WP*)

Avoid looser jet and b-tag requirements due to larger ggF contributions and poor understanding of ggF+HF

* WP = Working Point

Current event selection optimized for limits

Pre-Selection

2 Photons

- Leading $E_T > 0.35 * m_{\gamma\gamma}$
- Sub-Leading $E_T > 0.25 * m_{\gamma\gamma}$
- $m_{\gamma\gamma} \in$ 105-160 GeV

Leptonic Selection

- ≥ 1 e/μ (p_T > 15 /10 GeV),
  ≥ 1 jets (p_T > 25 GeV),
  ≥ 1 b-tag (80% WP*)
- MET ≥ 20 GeV for 1 b-tag
- Veto on $m_{e\gamma} \in$ 84 - 94 GeV

Hadronic Selection

No charged leptons

- ≥ 6 jets (p_T > 25 GeV),
  ≥ 2 b-tags (80% WP*)
- ≥ 5 jets (p_T > 30 GeV),
  ≥ 2 b-tags (70% WP*)
- ≥ 6 jets (p_T > 30 GeV),
  ≥ 1 b-tag (60% WP*)

* WP = Working Point

Differences in CMS Event Selection

CMS Selection

vs.

Our Differences

Pre-Selection

2 Photons

- Leading $p_T > m_{\gamma\gamma} / 2$ ($E_T > 0.35 * m_{\gamma\gamma}$)
- Sub-Leading $p_T > 25$ GeV ($E_T > 0.25 * m_{\gamma\gamma}$)
- $m_{\gamma\gamma} \in$ 100-180 GeV ($m_{\gamma\gamma} \in$ 105-160 GeV)

Leptonic Selection

- ≥ 1 e/μ ($p_T > 20$ GeV),
  ≥ 2 jets ($p_T > 25$ GeV),
  ≥ 1 b-tag
- ≥ 1 e/μ ($p_T > 15/10$ GeV),
  ≥ 1 jets ($p_T > 25$ GeV),
  MET cut for 1 b-tag
  Veto on $m_{e\gamma} \in$ 84-94 GeV

Hadronic Selection

No charged leptons

- ≥ 4 jets ($p_T > 25$ GeV),
  ≥ 1 b-tags
- Require 5j1b, 6j1b, & 6j2b categories with different jet pt and b-tagging WPs

arXiv: 1408.1682

Higgs backgrounds dominated by ggF and WH

tH productions contribute significantly to each channel

Current Selection Yields

% Higgs Yield

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

*N_B is integrated number of events for background fit in the 120-130 GeV window

Hadronic channel weakened by large continuum background

Current Selection Yields

% Higgs Yield

Category	N_H	ggF	VBF	WH	ZH	$t\bar{t}H$	$tHqb$	WtH	N_B*
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Comparison to CMS Yields

ATLAS Yields

% Higgs Yield

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	$0.5^{+0.5}_{-0.3}$
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*N_B is integrated number of events for background fit in the 120-130 GeV window

CMS Yields

	7 TeV	8 TeV	
	All decays	Hadronic channel	Leptonic channel
$t\bar{t}$H	0.21 (91%)	0.51 (94%)	0.45 (98%)
gg → H	0.01 (4%)	0.02 (4%)	0 (0%)
VBF H	0 (0%)	0 (0%)	0 (0%)
WH/ZH	0.01 (4%)	0.01 (2%)	0.01 (2%)
Total H	0.23	0.54	0.46
Data	9	32	11

Different selections

↓↓↓

Very different background contributions

arXiv: 1408.1682

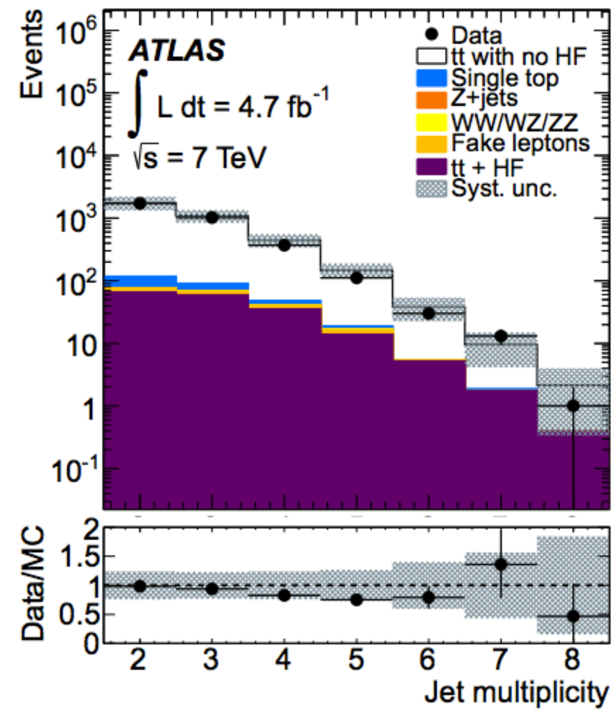
Systematics

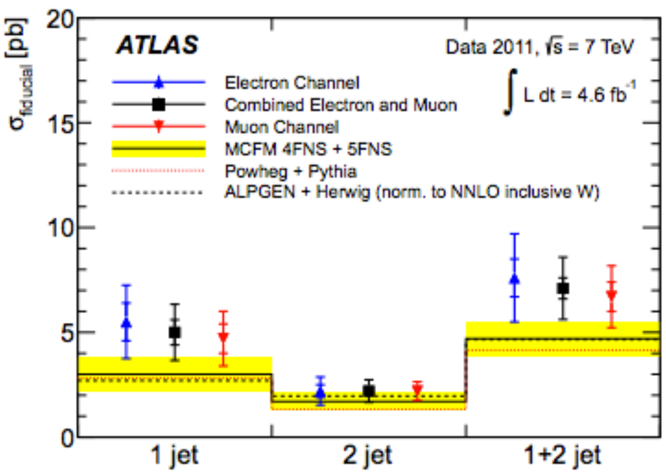
	$t\bar{t}H$ [%]		$tHqb$ [%]		WtH [%]		ggF [%]	WH [%]
	had.	lep.	had.	lep.	had.	lep.	had.	lep.
Luminosity	±2.8							
Photons	±5.6	±5.5	±5.6	±5.5	±5.6	±5.5	±5.6	±5.5
Leptons	< 0.1	±0.7	< 0.1	±0.6	< 0.1	±0.6	< 0.1	±0.7
Jets and E_T^{miss}	±7.4	±0.7	±16	±1.9	±11	±2.1	±29	±10
Bkg. modeling	0.24 evt.	0.16 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

Includes 100% HF Content Uncertainty

Data driven photon ID + Isolation uncertainties obtained using electrons from Z→ee + jets in data and MC and applying photon criteria ggF+HF uncert motivated by tt+HF modeling

- Both processes are gluon initiated
- Use 100% uncertainty to be conservative
- Maybe this isn't conservative enough?
  → To be sure, we avoid possible 5j1b, 4j2b & 4j1b categories with higher ggF content





WH+HF uncert motivated by W+b-jet modeling

- Both processes are initiated by qq

Differences from CMS Systematics

HF content uncertainty

↓↓↓

gg→H contamination uncertainty

Perhaps our uncertainties are too conservative?

Source	Rate uncertainty Signal	Backgrounds
Experimental		
Integrated luminosity	2.2–2.6%	2.2–2.6%
Jet energy scale	0.0–8.4%	0.1–11.5%
CSV b-tagging	0.9–21.7%	3.0–29.0%
Lepton reco. and ID	0.3–14.0%	1.4–14.0%
Lepton misidentification rate (H → leptons)	—	35.1–45.7%
Tau reco. and ID (H → hadrons)	11.3–14.3%	24.1–28.8%
Photon reco. and ID (H → photons)	1.6–3.2%	—
MC statistics	—	0.2–7.0%
Theoretical		
NLO scales and PDF	9.7–14.8%	3.4–14.7%
MC modeling	2.3–5.1%	0.9–16.8%
Top quark p_T	—	1.4–6.9%
Additional hf uncertainty (H → hadrons)	—	50%
H contamination (H → photons)	36.7–41.2%	
WZ (ZZ) uncertainty (H → leptons)	—	22% (19%)

* Table from CMS ttH combination, not all numbers reflective of ttH(γγ)

arXiv: 1408.1682

Current Results

Despite many differences, limits between both analyses are very comparable

ATLAS Published Results

	Observed limit	Expected limit	$+2\sigma$	$+1\sigma$	-1σ	-2σ
Combined (with systematics)	6.7	4.9	11.9	7.5	3.5	2.6
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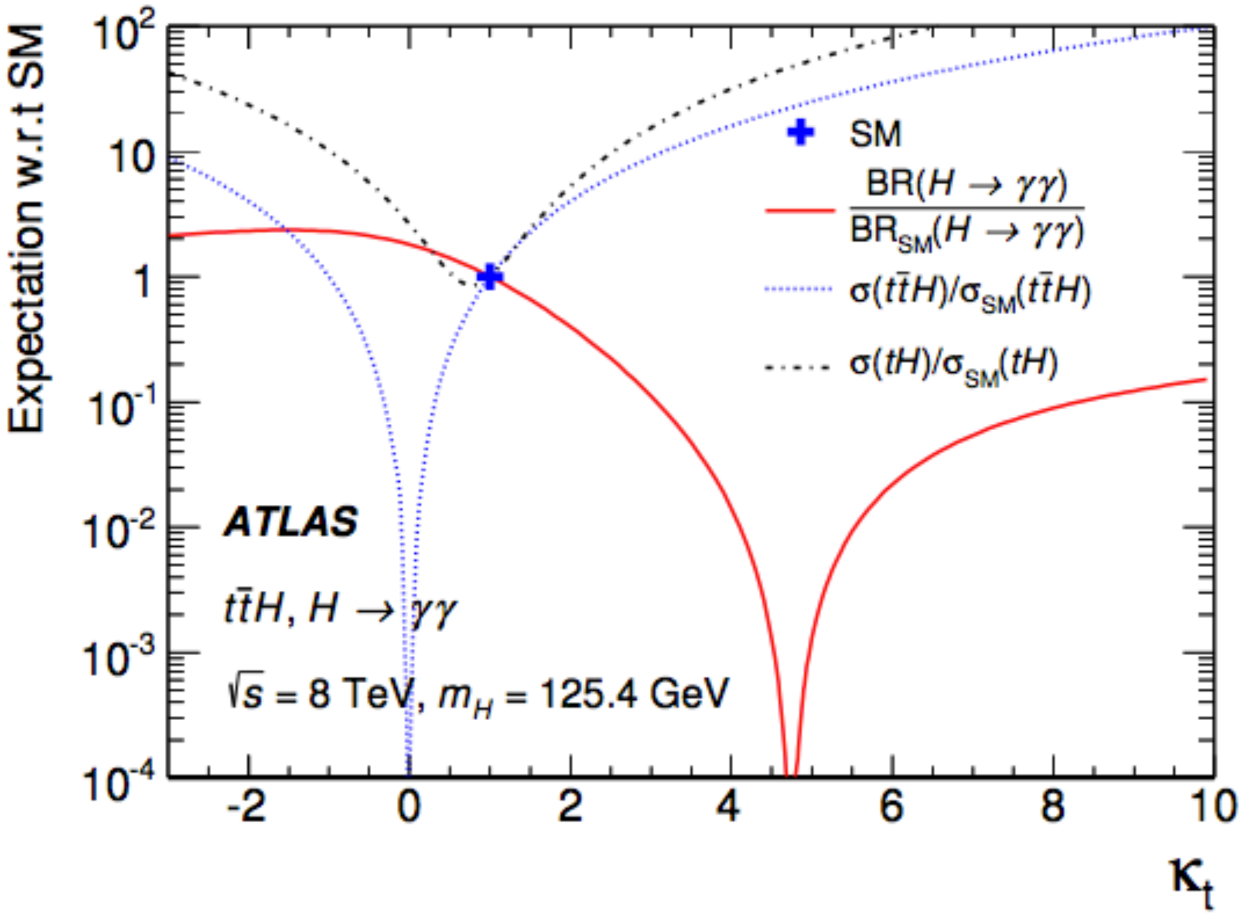
CMS Published Results

ttH channel	Best-fit μ	95% CL upper limits on $\mu = \sigma/\sigma_{SM}$ ($m_H = 125.6\,\mathrm{GeV}$)				
			Expected			
	Observed	Observed	Median signal-injected	Median	68% CL range	95% CL range
$\gamma\gamma$	$+2.7^{+2.6}_{-1.8}$	7.4	5.7	4.7	[3.1, 7.6]	[2.2, 11.7]

Results can also be interpreted as limits on the top-Higgs Yukawa coupling (κ_t)

Variations in κ_t affect σ_{ttH}, σ_{tH} & BR($H \rightarrow \gamma\gamma$)



Conclusions

- No show stoppers for background treatment in Run II ☺

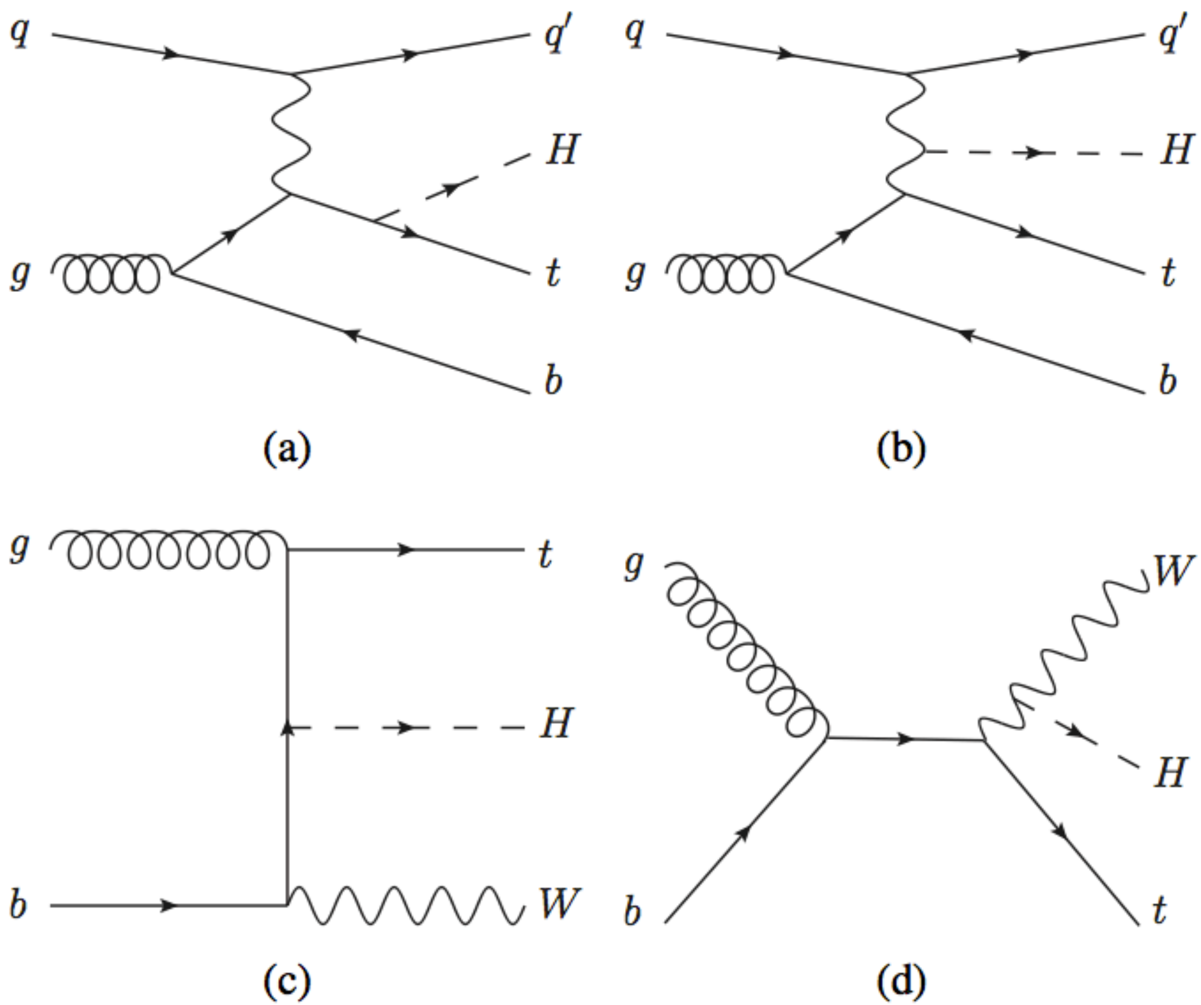
- How can we get better control of ggF+HF & WH+HF?

- How to consistently treat ttH, tHqb, & WtH?

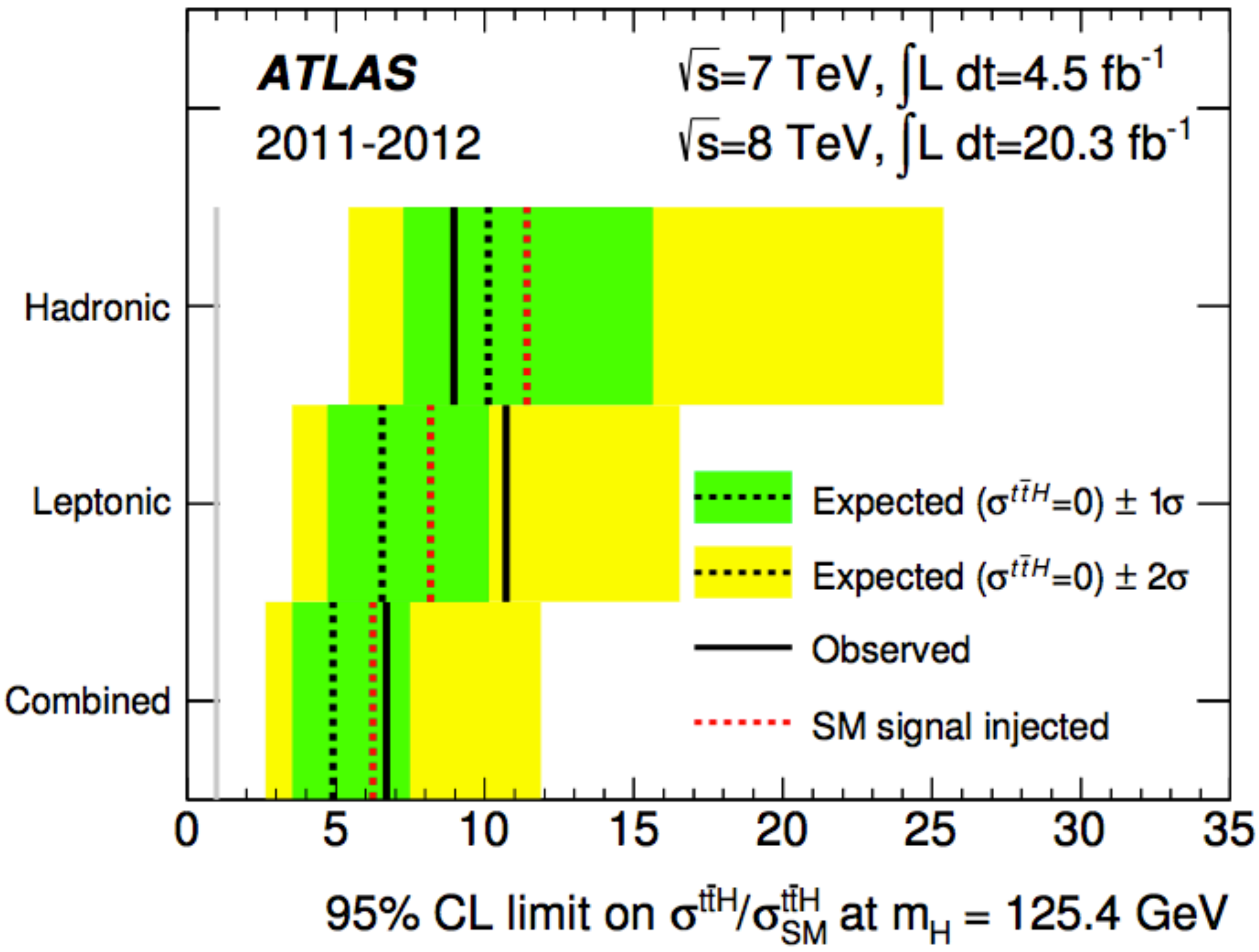
Thanks For Listening!

Backup

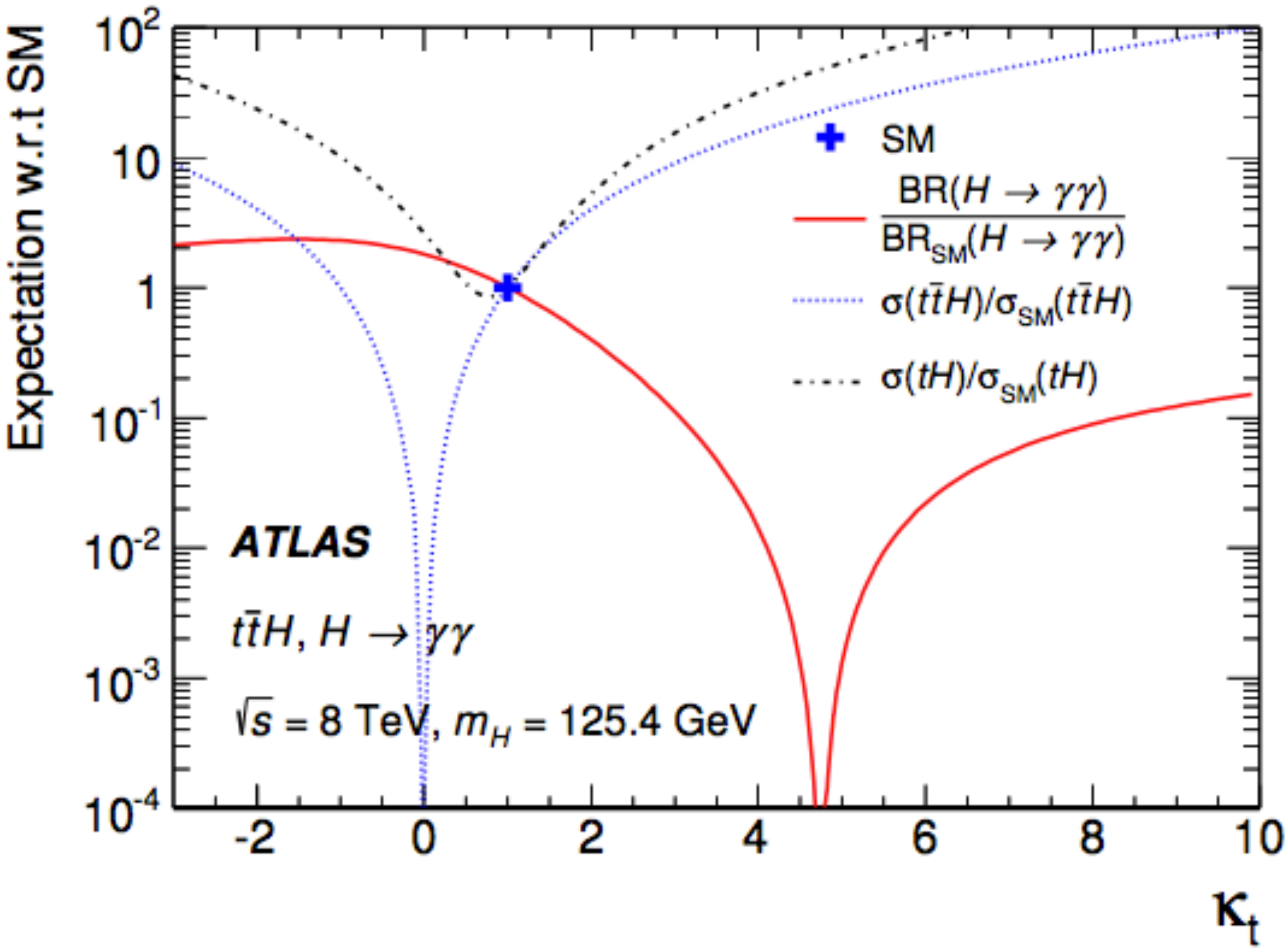
tHqb and WtH Diagrams



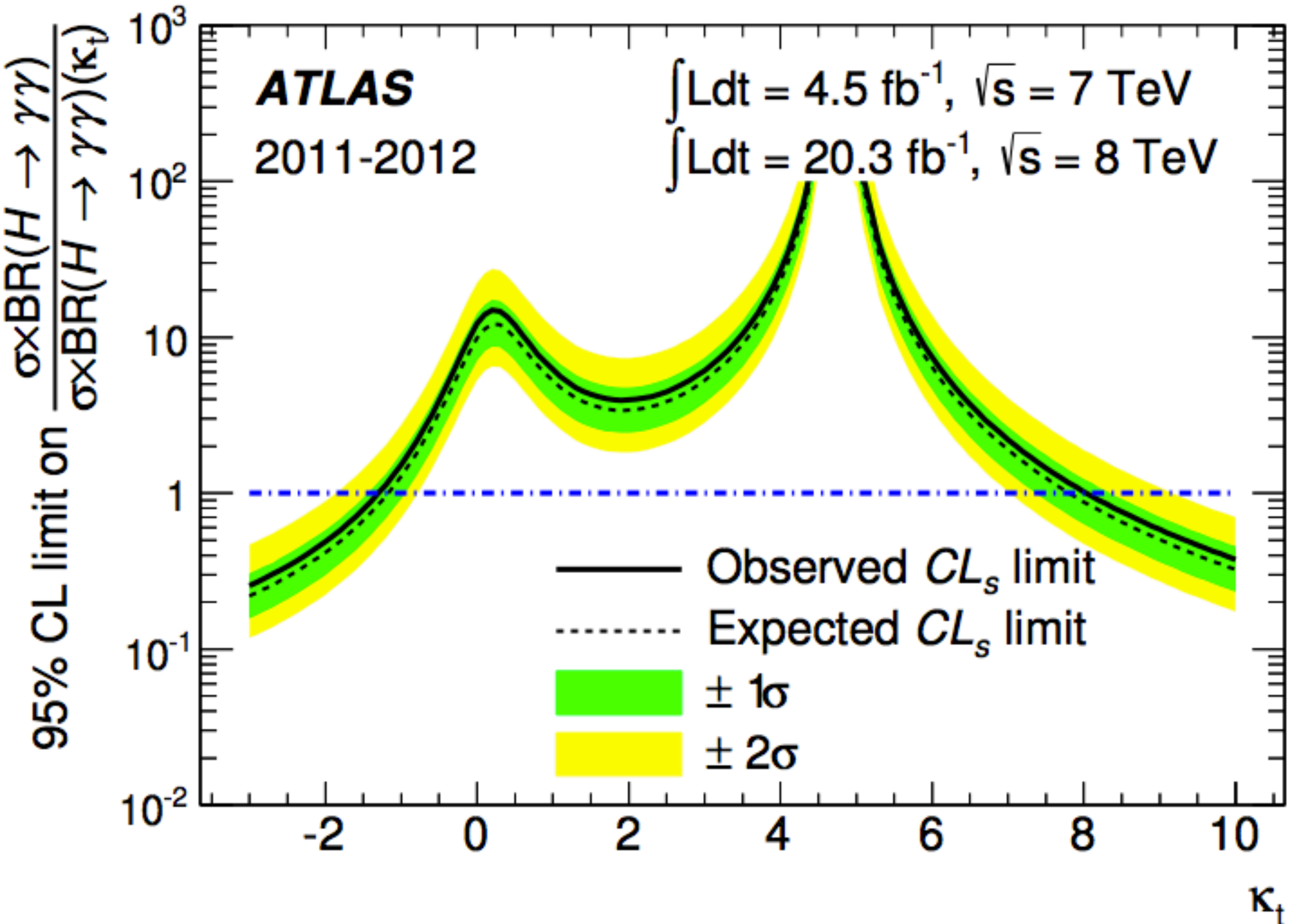
Limits on ttH

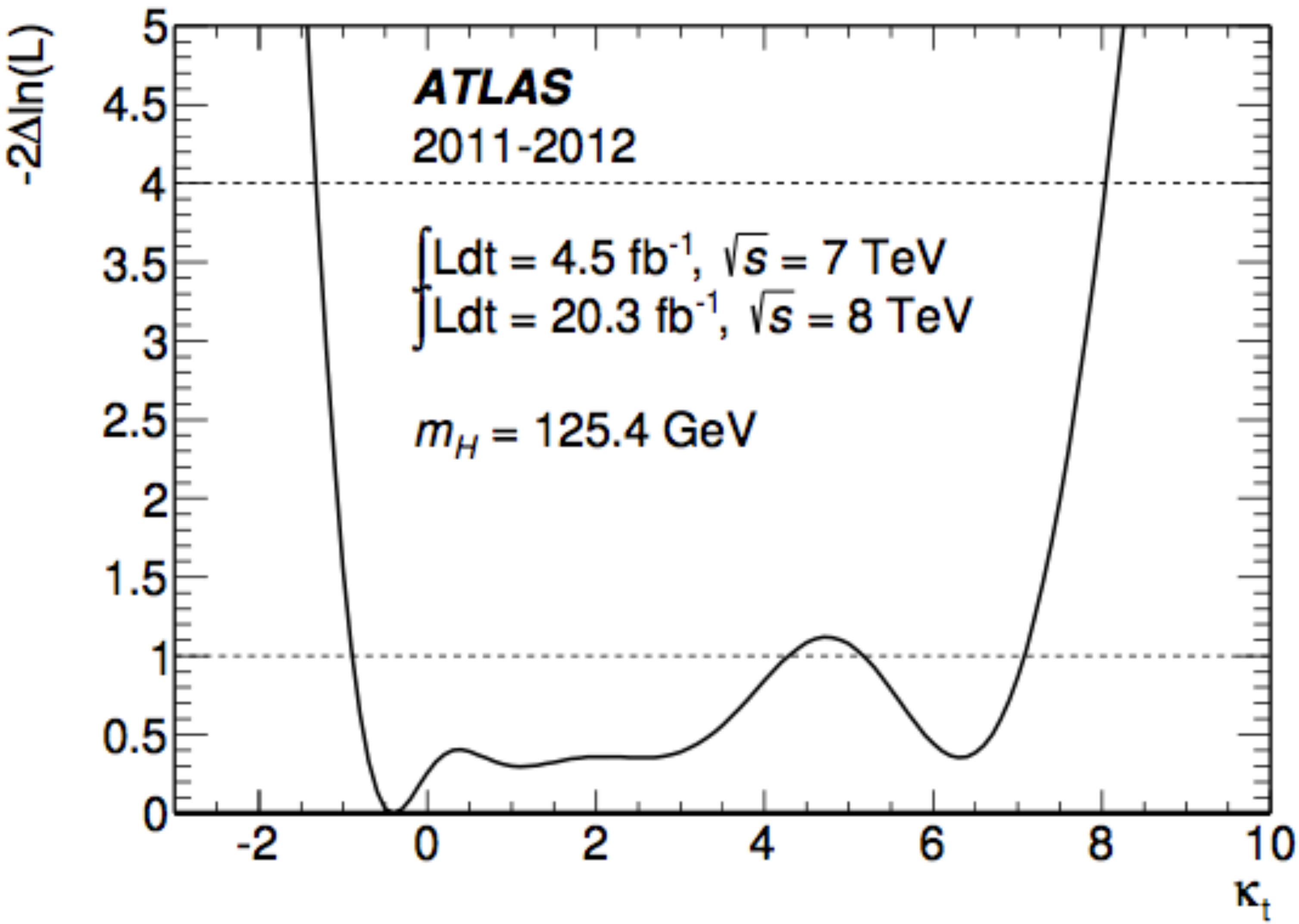


XS+BR as function of κ_t



Limits on Inclusive Higgs





ATLAS
2011-2012
∫Ldt = 4.5 fb⁻¹, √s = 7 TeV
∫Ldt = 20.3 fb⁻¹, √s = 8 TeV
m_H = 125.4 GeV
-2Δln(L)
κ_t
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
-2
0
2
4
6
8
10