13th LHC Mini-Workshop

Search for Top Quark and Higgs Boson Associated Production at ATLAS

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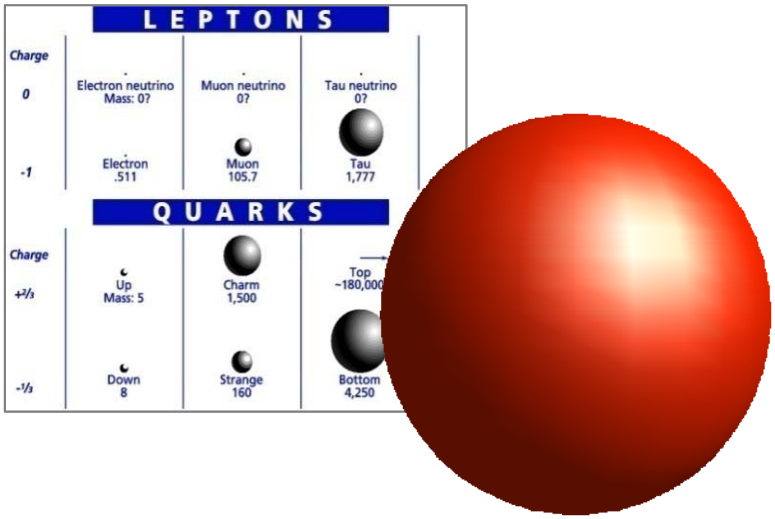
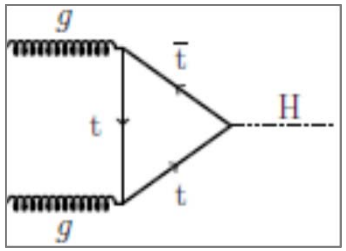
Why search top + higgs?

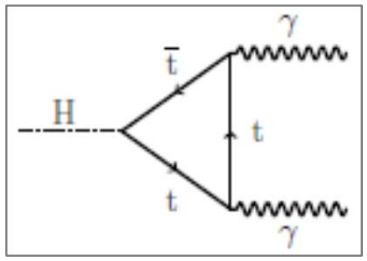


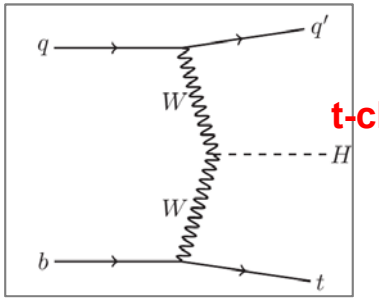
Top quark is heavy

- How to understand it? EWSB?
- Direct measurement or probe of g_{Ht}: value? sign?
- Sensitive to BSM physics

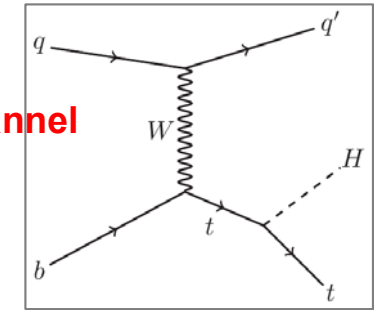
$$g_{Ht} = \sqrt{2}\, m_t / \mathrm{VEV} = \sqrt{2}\ 173.1\ \mathrm{GeV} / 246\ \mathrm{GeV} \approx 1$$

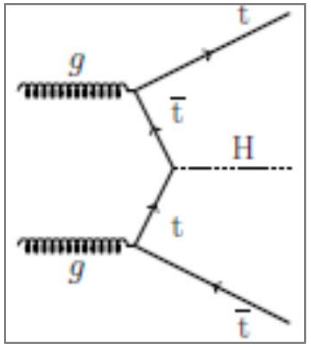






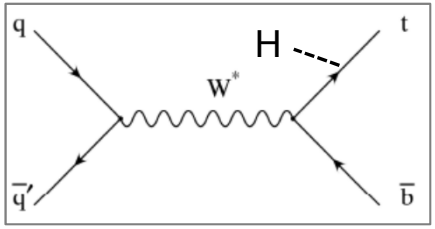
t-channel



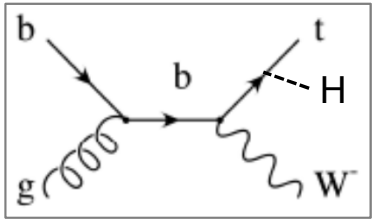


Double top + higgs:
σ ~ 130 pb @ LHC 8 TeV

Single top + higgs: σ ~ 18 pb, t-channe

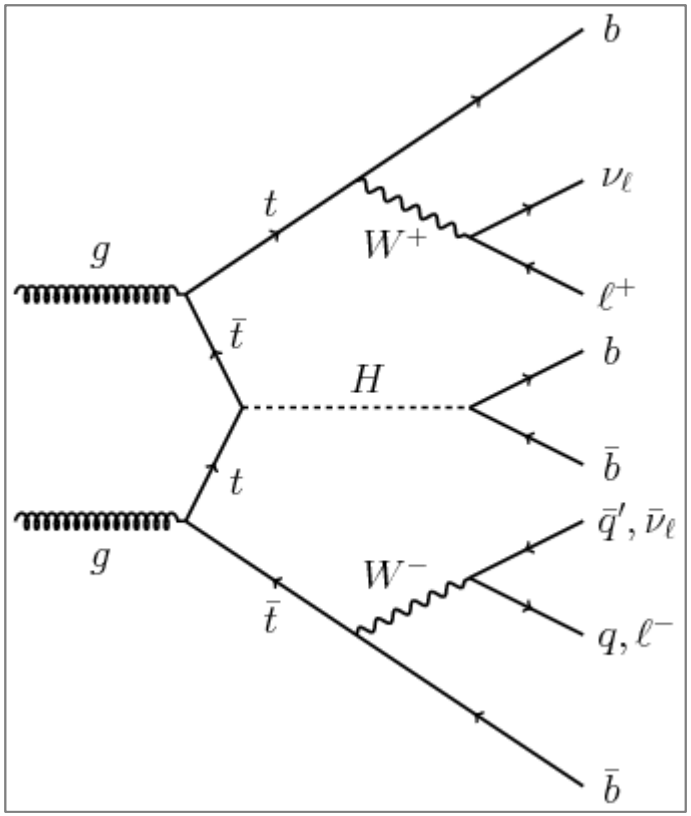


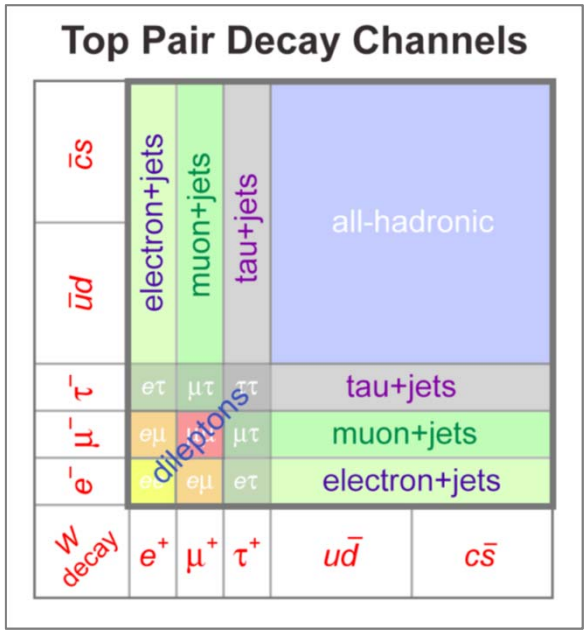
s-channel



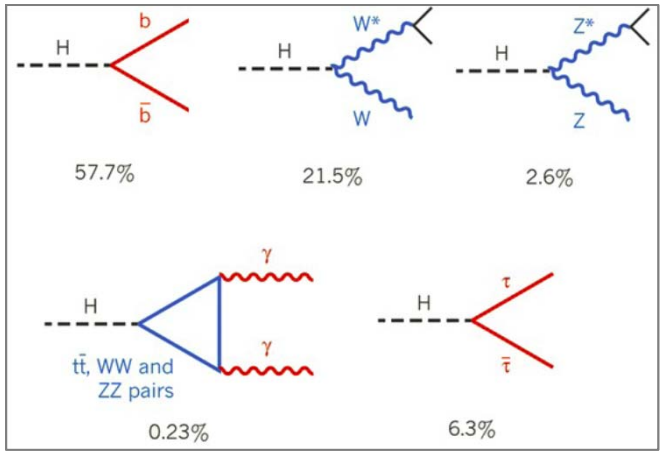
tW-channel

But it is difficult (of course)





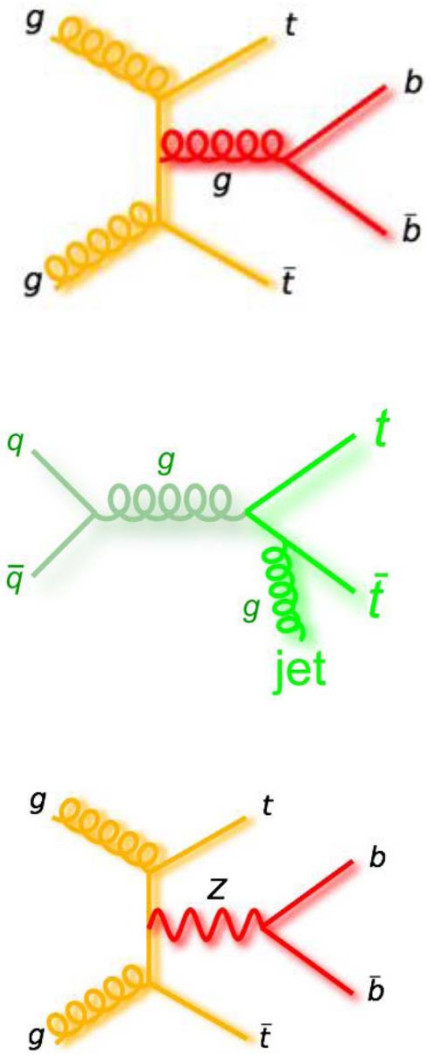
- **Small signal**
- **Background complicated and not fully known**
- **b-Jet identification, assignment critical**

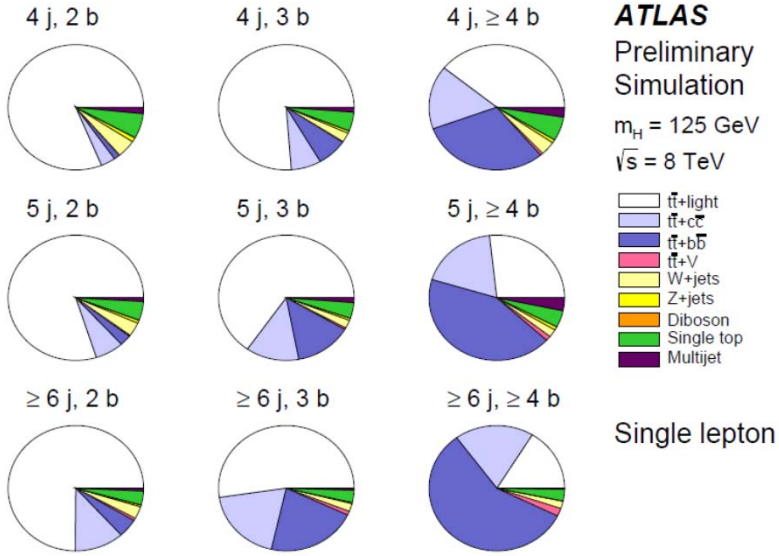


Divide & Conquer!

ttH (H → bb)

- **Irreducible background:**
  tt + heavy flavor
- **Reducible background:**
  tt + light jets
- **Other smaller background:**
  tt + W/Z
  W/Z + jets
  QCD, single top





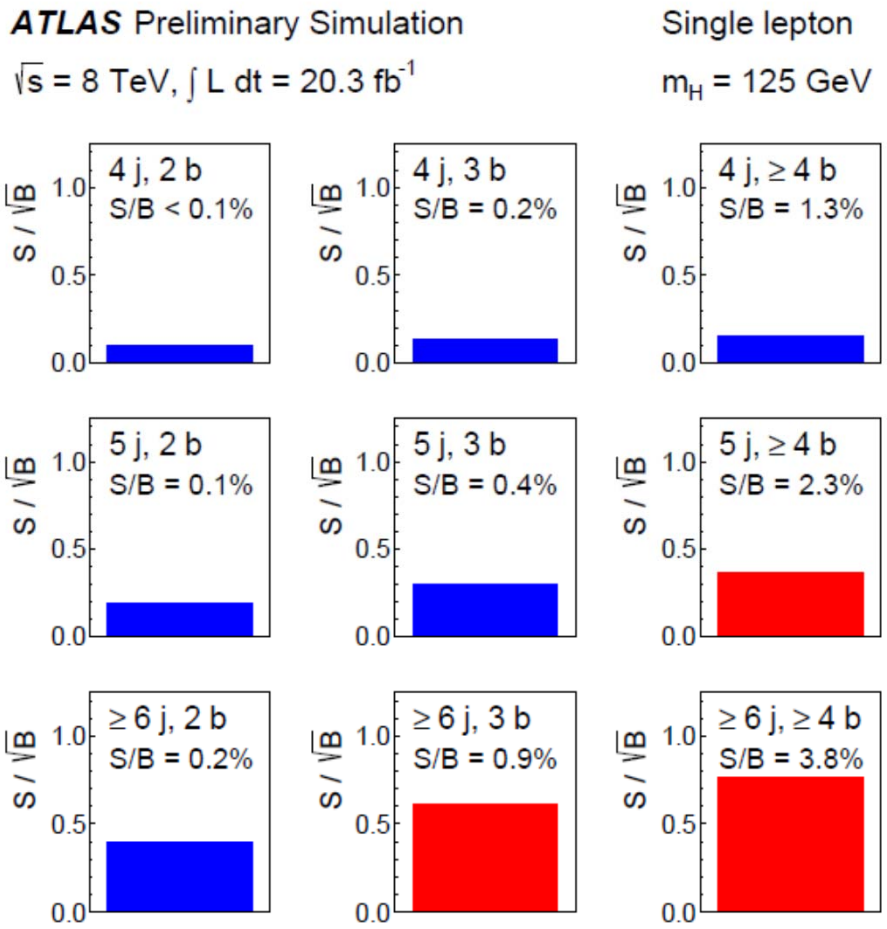
ttH (H → bb)

Different topologies to constrain/reduce background

- **#Jet, #b-tag**
- **Control region**
- **Signal region**

Simultaneous template fit to multiple channels

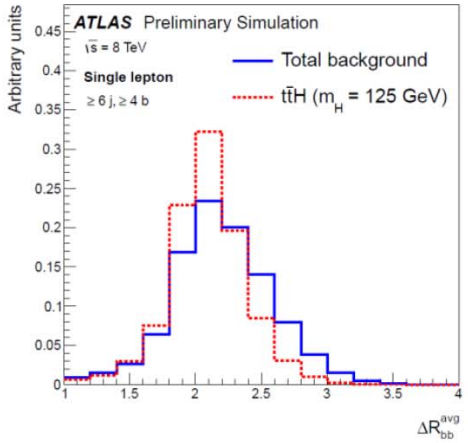
- **Separate 'good' from 'bad'**
- **Control region helps to constrain background (normal.)**

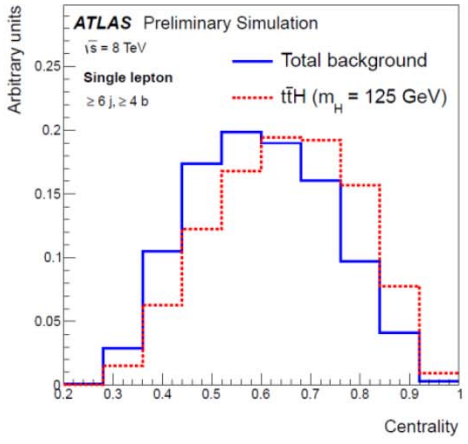


	2 b-tags	3 b-tags	≥ 4 b-tags
4 jets	HT	HT	HT
5 jets	HT	NN HF	NN
≥ 6 jets	HT	NN	NN

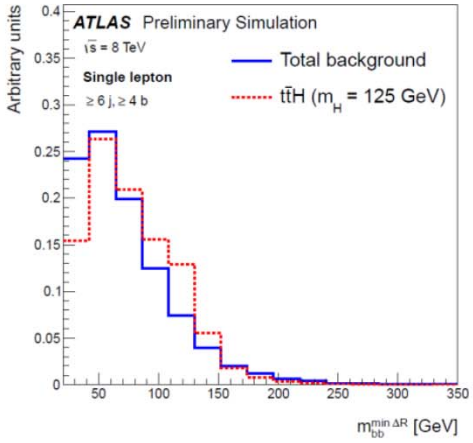
ttH (H → bb)

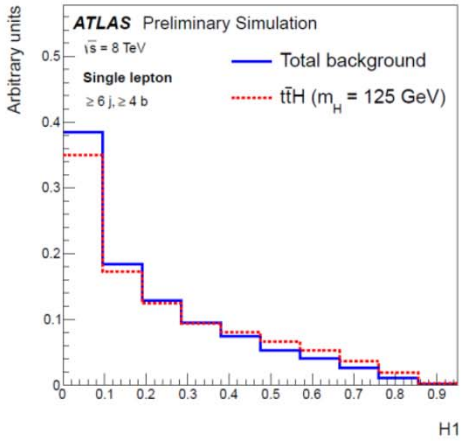
Object variables





Dijet variables





Global variables

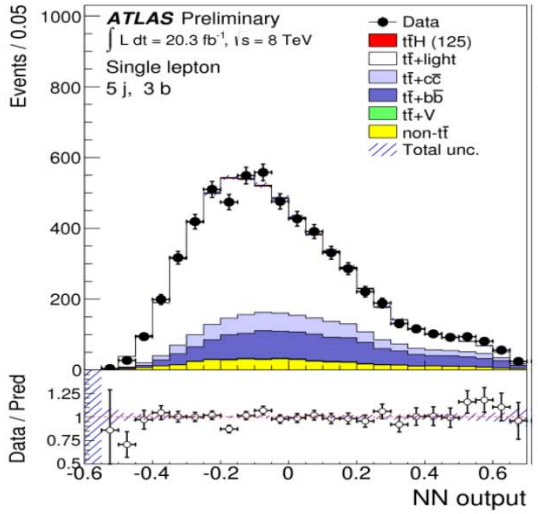
Variable	(≥ 6j, ≥ 4b)	(≥ 6j, 3b)	(5j, ≥ 4b)	(5j, 3b)
ΔR_{bb}^{avg}	1	5	5	-
$m_{bb}^{min\ \Delta R}$	2	9	3	1
Centrality	3	2	1	-
H1	4	3	2	-
p_T^{jet5}	5	8	-	-
$\text{Aplanarity}_{b-jet}$	6	-	7	-
$m_{uu}^{min\ \Delta R}$	7	7	-	2
$\Delta R_{bb}^{max\ p_T}$	8	-	-	-
$\Delta R_{lep-bb}^{min\ \Delta R}$	9	10	10	-
$m_{bj}^{max\ p_T}$	10	6	-	-
N_{40}^{jet}	-	1	4	-
$m_{bj}^{min\ \Delta R}$	-	4	-	-
$m_{jj}^{max\ p_T}$	-	-	6	-
H_T^{had}	-	-	8	-
$m_{jj}^{min\ \Delta R}$	-	-	9	-
$m_{bb}^{max\ m}$	-	-	-	3
$p_{T,uu}^{min\ \Delta R}$	-	-	-	4
m_{jjj}	-	-	-	5
$\Delta R_{uu}^{min\ \Delta R}$	-	-	-	6
$m_{bb}^{max\ p_T}$	-	-	-	7

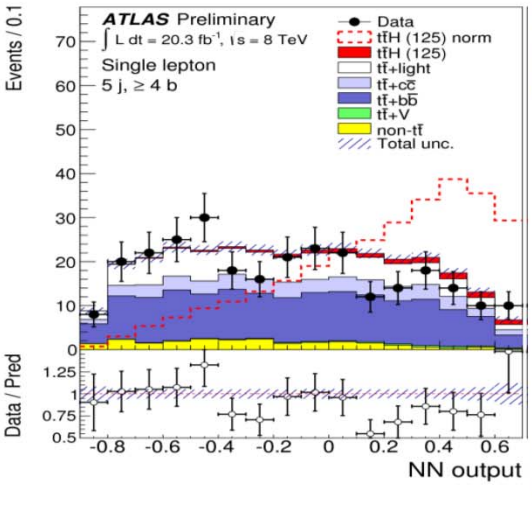
10 more discriminating variables chosen for each channel

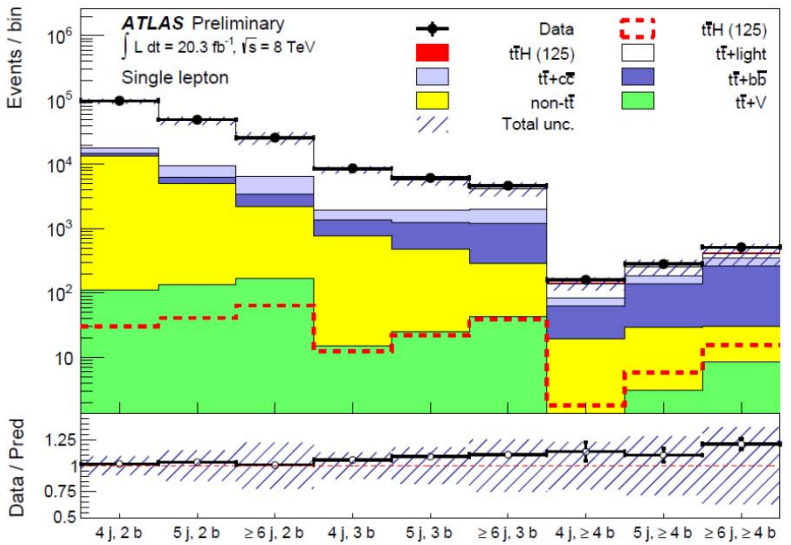
ttH (H → bb)

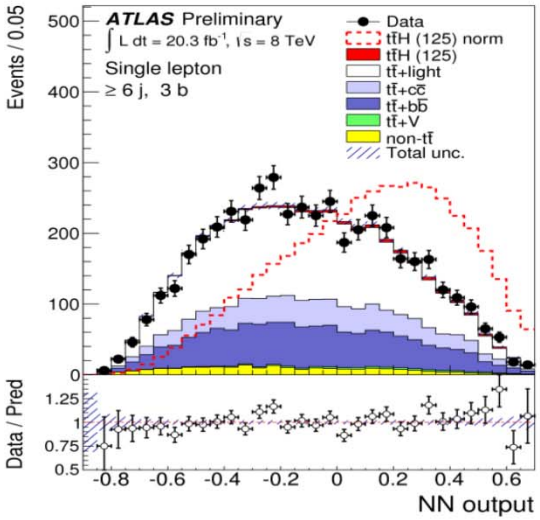
Discriminant output for channels

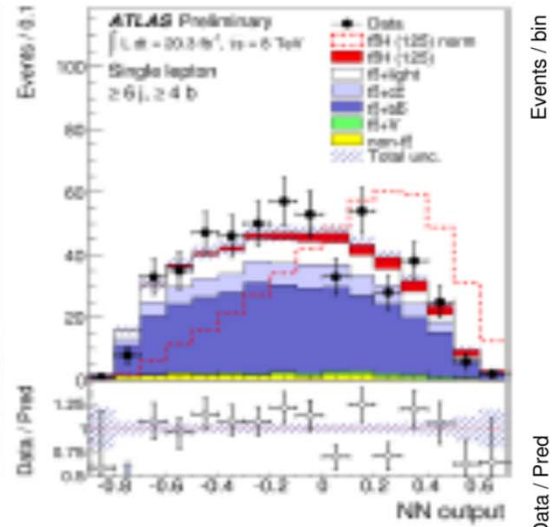
Pre-fit (profile likelihood method)

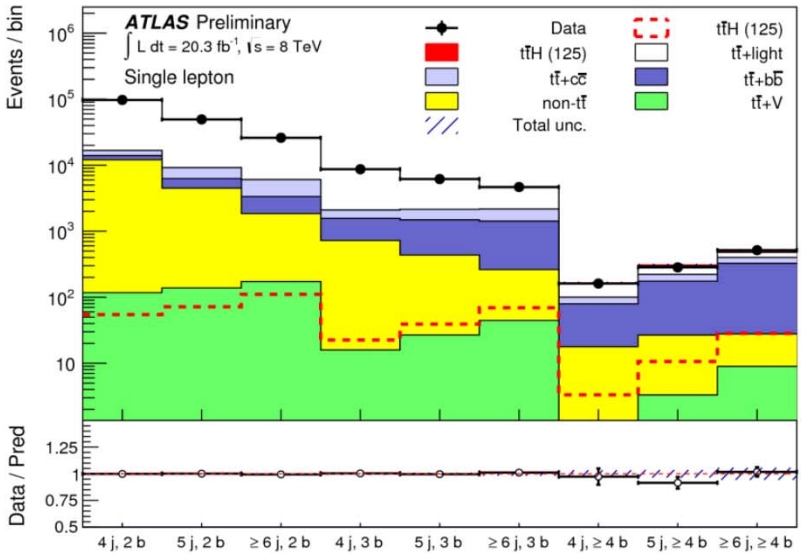






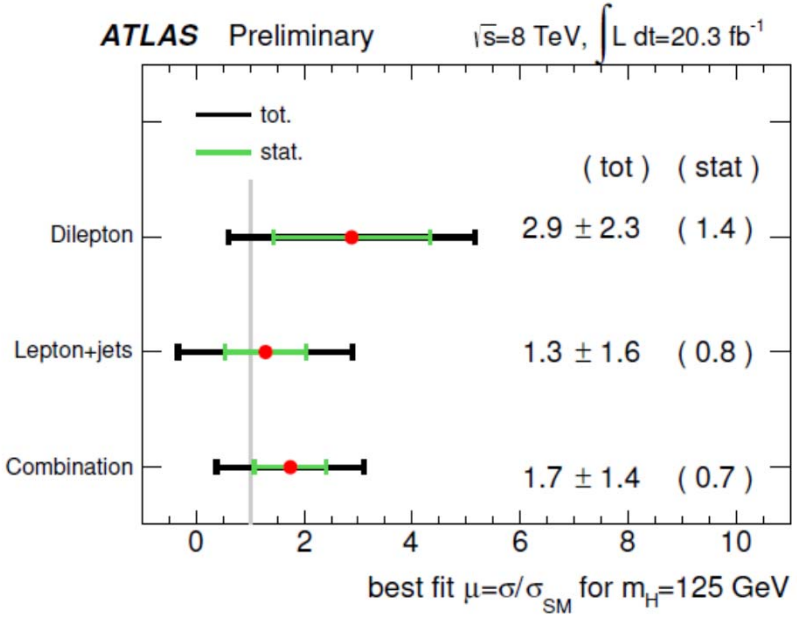






ttH (H → bb)

ATLAS-CONF-2014-011



95% C.L. limit on σ/σ^{SM}	Observed	Median expected
Single Lepton	4.2	3.1
Dilepton	6.7	4.3
Combination	4.1	2.6

Signal strength $\mu = 1.7 \pm 1.4$

Systematics dominated search

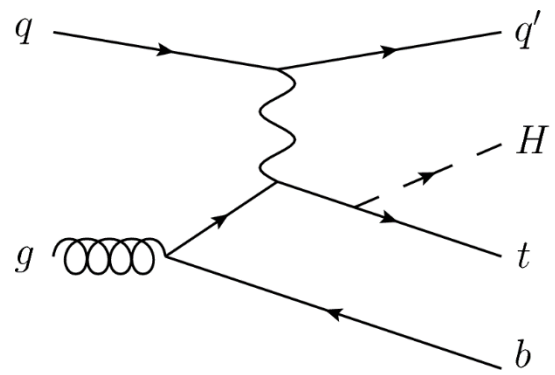
- **Systematics: ± 1.2, statistics: ± 0.7**
- **Need to understand tt + heavy flavor better: ± 50% normal.**
- **Plan to include more statistical methods: matrix element**
- **Combination with other Higgs decay modes also help**

ttH (H → X)

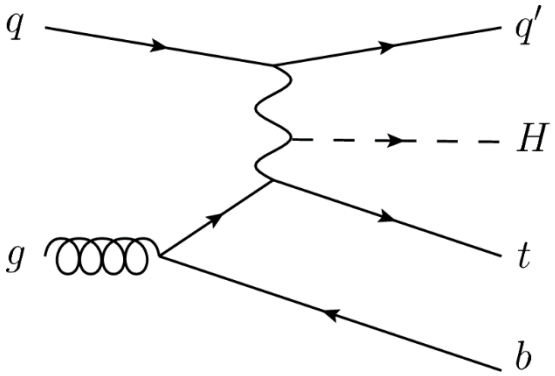
Combination of H->bb, H->WW/ZZ/$\tau\tau$, H->$\gamma\gamma$

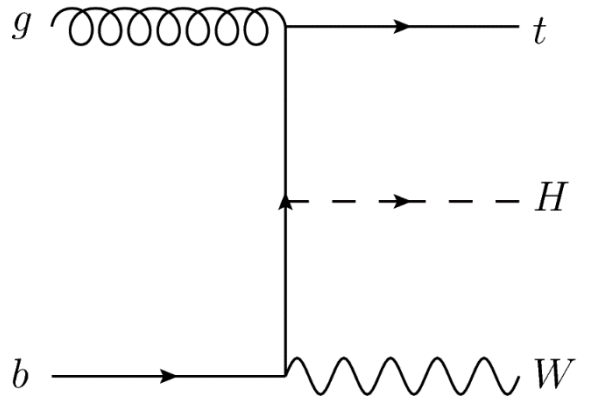
- See Huaqiao's talk tomorrow (CMS)
- Similar sensitivity seen from both experiments
  - H → bb decay channel outperformed anticipation
  - Still systematics dominated
- Predicted to achieve 5σ discovery with 100 fb^{-1} Run II data

tqH (H → γγ)

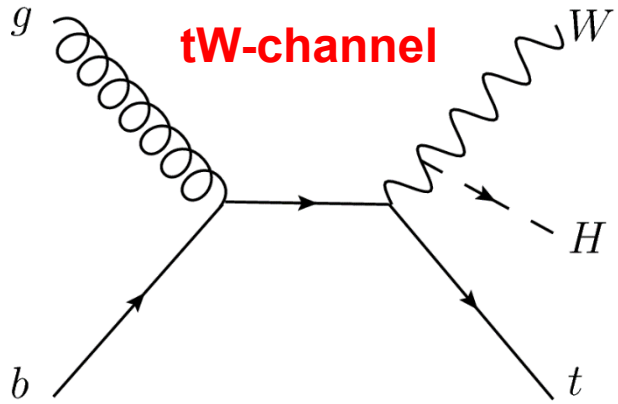


t-channel





tW-channel



Special interest for single top + Higgs production

- **Higgs radiated off t or W: interference depends on g_{Ht} sign**
  - **σ increase by 10 times if g_{Ht} = -1 relative to g_{Hw}**
- **New physics can play a different role in ttH and tH production**

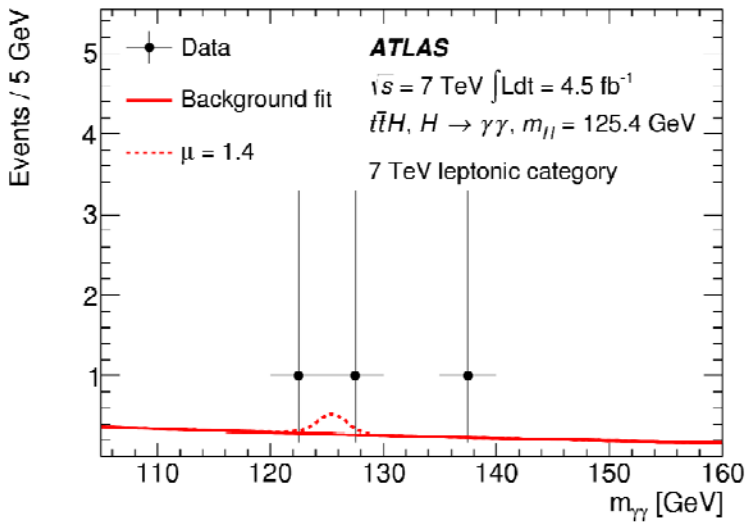
ttH + tqH (H → γγ)

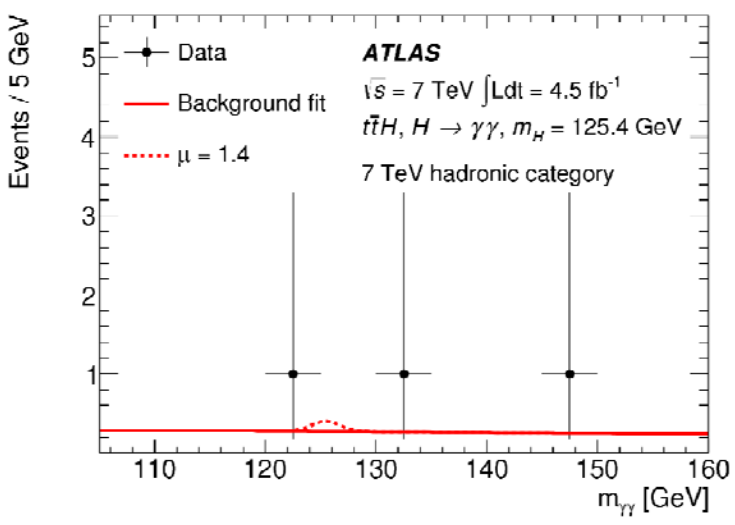
Process	σ [pb] at 7 TeV	σ [pb] at 8 TeV
$t\bar{t}H$	$0.086^{+0.008}_{-0.011}$	$0.129^{+0.012}_{-0.016}$
$tHqb, \kappa_t = +1$	$0.0111^{+0.0009}_{-0.0008}$	$0.0172^{+0.0012}_{-0.0011}$
$tHqb, \kappa_t = 0$	$0.040^{+0.003}_{-0.003}$	$0.059^{+0.004}_{-0.004}$
$tHqb, \kappa_t = -1$	$0.129^{+0.010}_{-0.009}$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

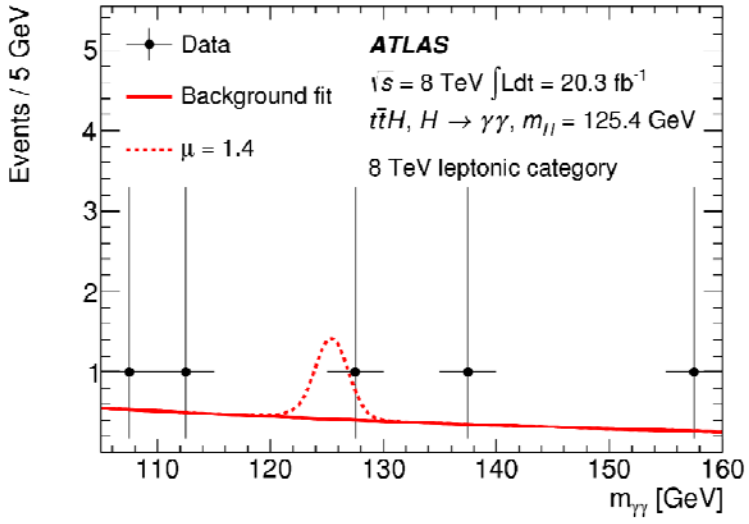
Can select both ttH and tH as signal

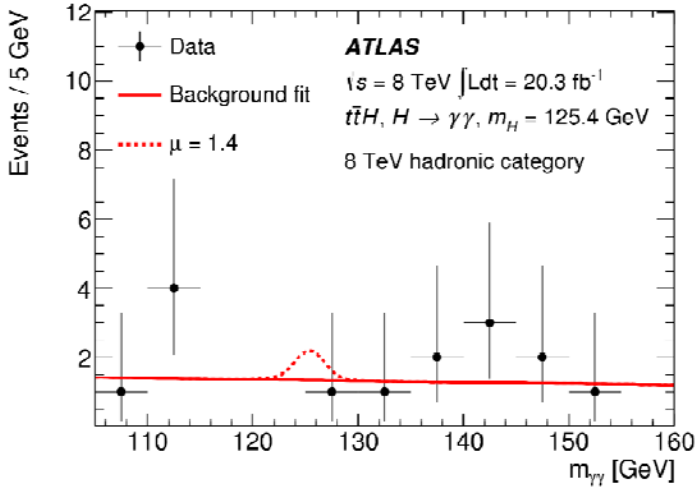
- **H → γγ small BR causes small signal, but with good mass resolution**
- **Top quark decay categories: (semi-)leptonic, hadronic**
- **Optimized on ttH and considering tH acceptance as well**

ttH + tqH (H → γγ)


Data
Background fit
μ = 1.4
ATLAS
√s = 7 TeV ∫Ldt = 4.5 fb⁻¹
tt̄H, H → γγ, m_H = 125.4 GeV
7 TeV leptonic category
Events / 5 GeV
m_γγ [GeV]


Data
Background fit
μ = 1.4
ATLAS
√s = 7 TeV ∫Ldt = 4.5 fb⁻¹
tt̄H, H → γγ, m_H = 125.4 GeV
7 TeV hadronic category
Events / 5 GeV
m_γγ [GeV]


Data
Background fit
μ = 1.4
ATLAS
√s = 8 TeV ∫Ldt = 20.3 fb⁻¹
tt̄H, H → γγ, m_H = 125.4 GeV
8 TeV leptonic category
Events / 5 GeV
m_γγ [GeV]


Data
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ATLAS
√s = 8 TeV ∫Ldt = 20.3 fb⁻¹
tt̄H, H → γγ, m_H = 125.4 GeV
8 TeV hadronic category
Events / 5 GeV
m_γγ [GeV]

ttH + tqH (H → γγ)

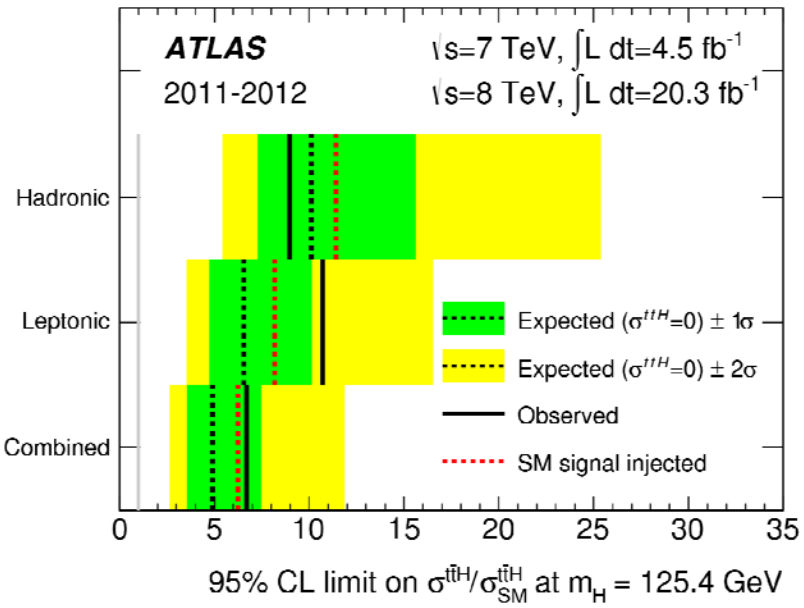
Category	N_H	ggF	VBF	WH	ZH	$t\bar{t}H$	$tHqb$	WtH	N_B
7 TeV leptonic selection	0.10	0.6	0.1	14.9	4.0	72.6	5.3	2.5	$0.5^{+0.5}_{-0.3}$
7 TeV hadronic selection	0.07	10.5	1.3	1.3	1.4	80.9	2.6	1.9	$0.5^{+0.5}_{-0.3}$
8 TeV leptonic selection	0.58	1.0	0.2	8.1	2.3	80.3	5.6	2.6	$0.9^{+0.6}_{-0.4}$
8 TeV hadronic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

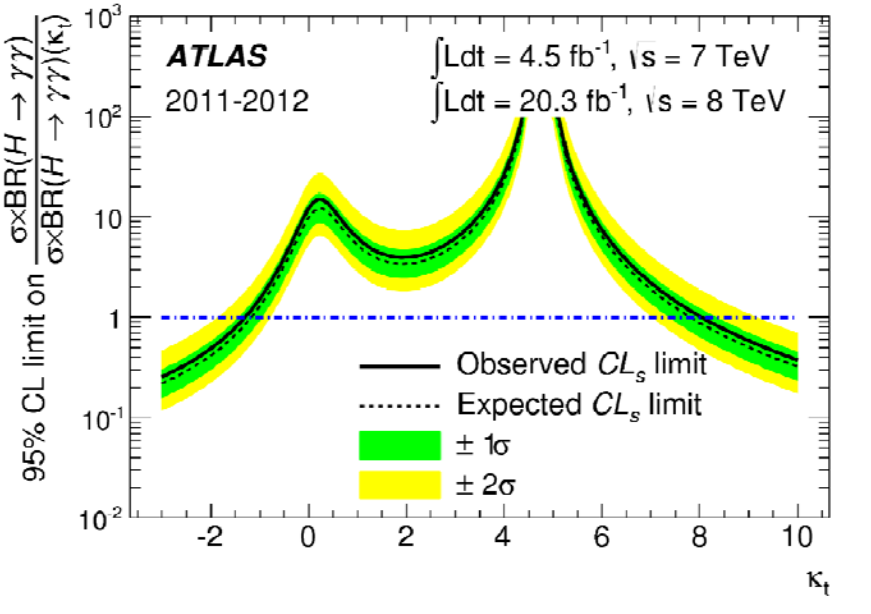
High signal purity

- **ttH + tH combined purity: ~ 85-90%**
- **Continuous background parameterized by analytical function**
  - **Fake photons**
- **Statistics dominated analysis**

ttH + tqH (H → γγ)

arXiv:1409.3122
Submitted to PLB

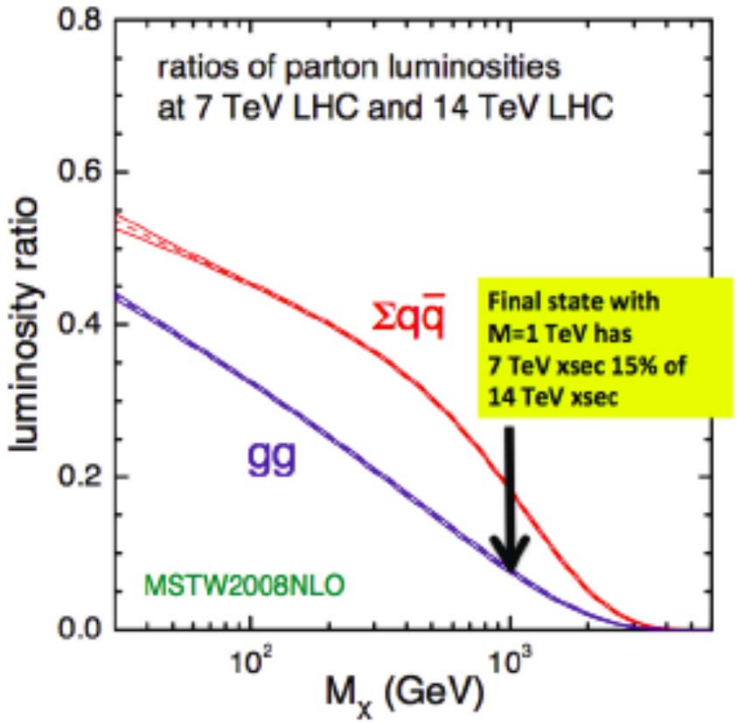


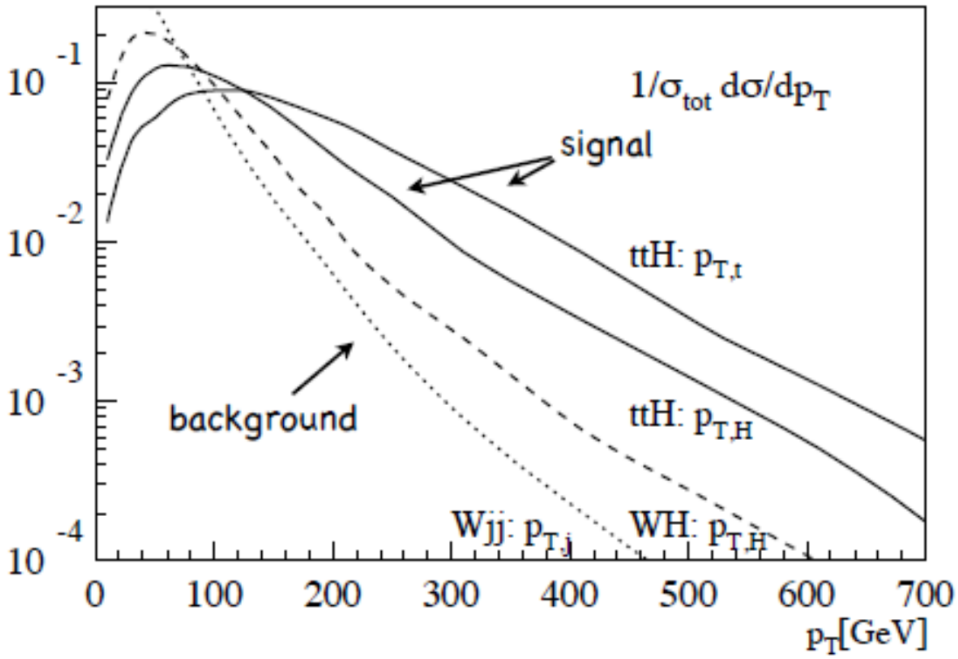


Limit on both ttH production and Higgs-top coupling (κ_t)

- $\sigma_{(ttH,\ H\to\gamma\gamma)} < 6.7$ SM, $\sigma_{(ttH+tH,\ H\to\gamma\gamma)} < 5.7$ SM
- $\mu_{ttH} = 1.3\ ^{+2.5}_{-1.7}$ (Stat.) $^{+0.8}_{-0.4}$ (Syst.)
- κ_t changes ttH, tH production rate, and H → γγ, and others
- $-1.3 < \kappa_t < 8.0$

Boosted ttH?



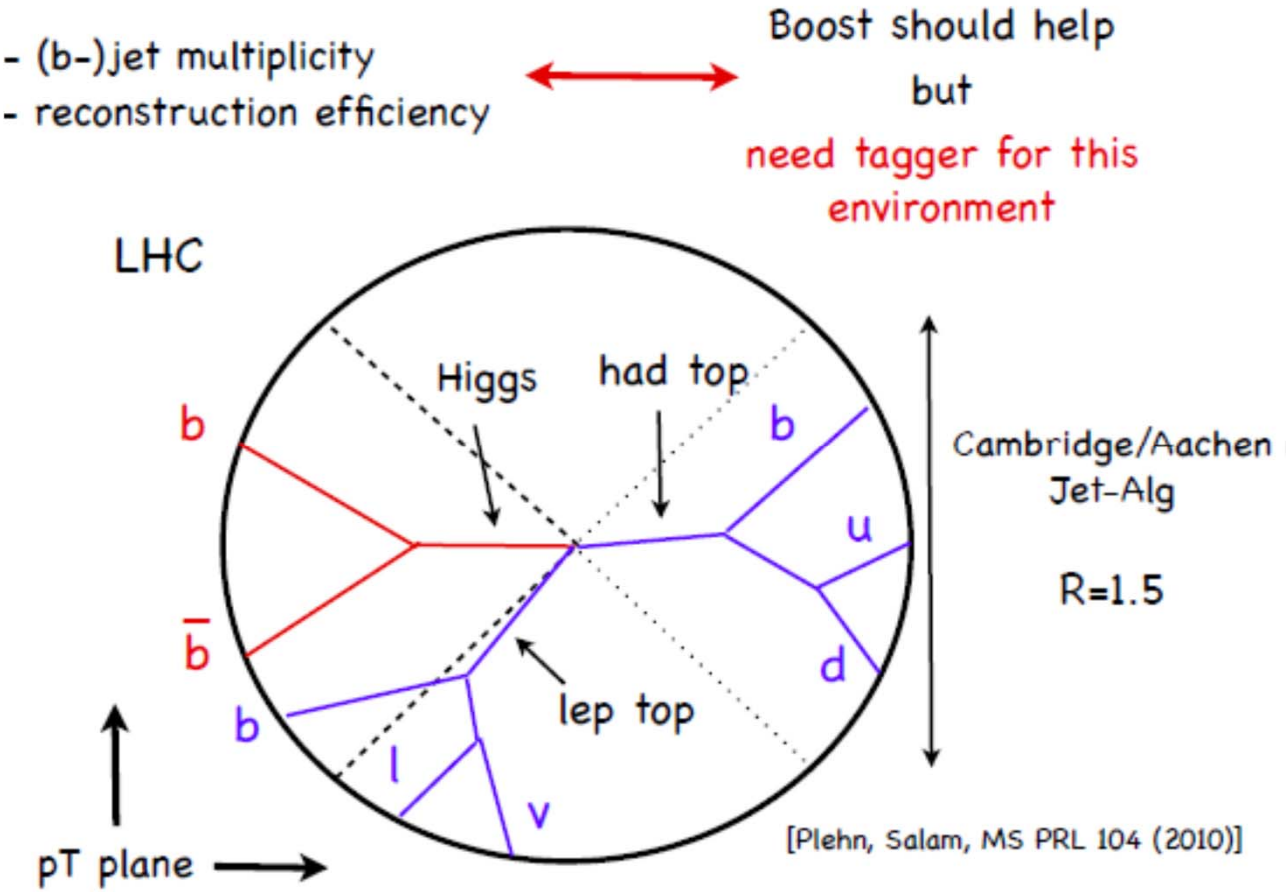


14 TeV run 'boosts' things (particles)

- **ttH is a heavy state**
- **S/B could improve after 'boosted'**
- **Studies ongoing, many ideas and techniques…**

Boosted ttH

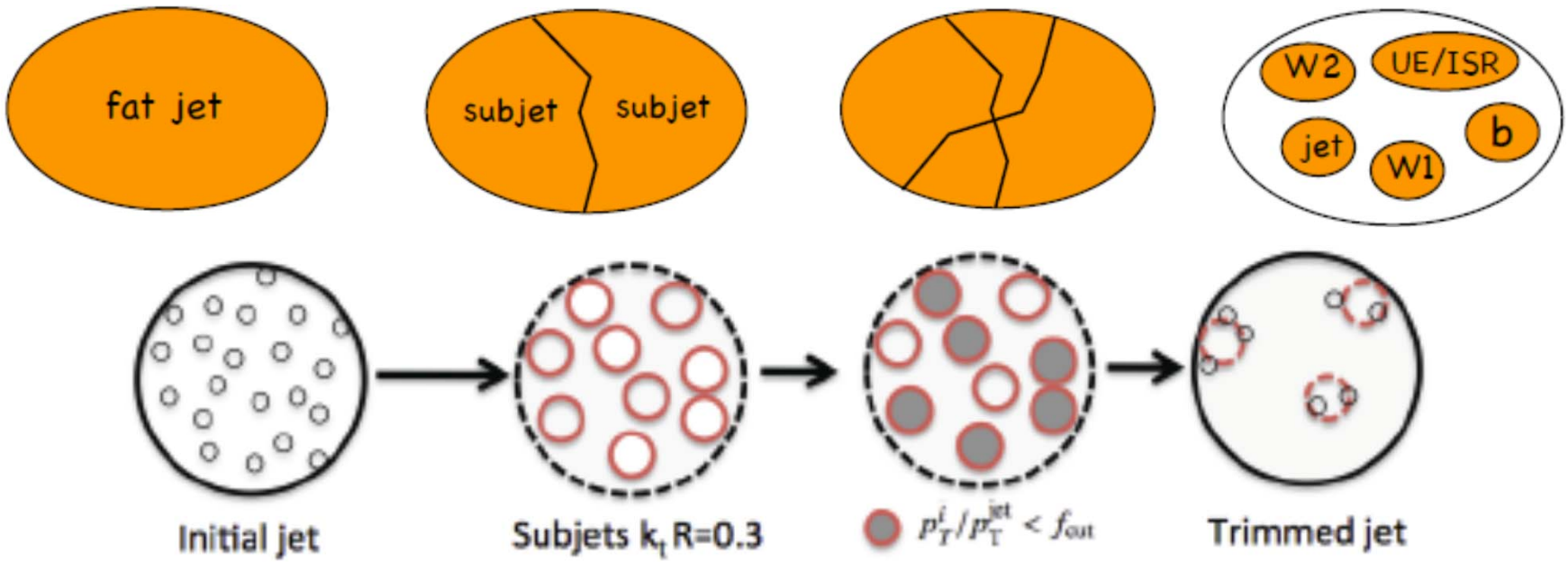
- (b-)jet multiplicity
- reconstruction efficiency



Everything comes by with a price tag

- **Deal with large-R jet: fat jet**
- **Need to look at jet substructure: special tagger**

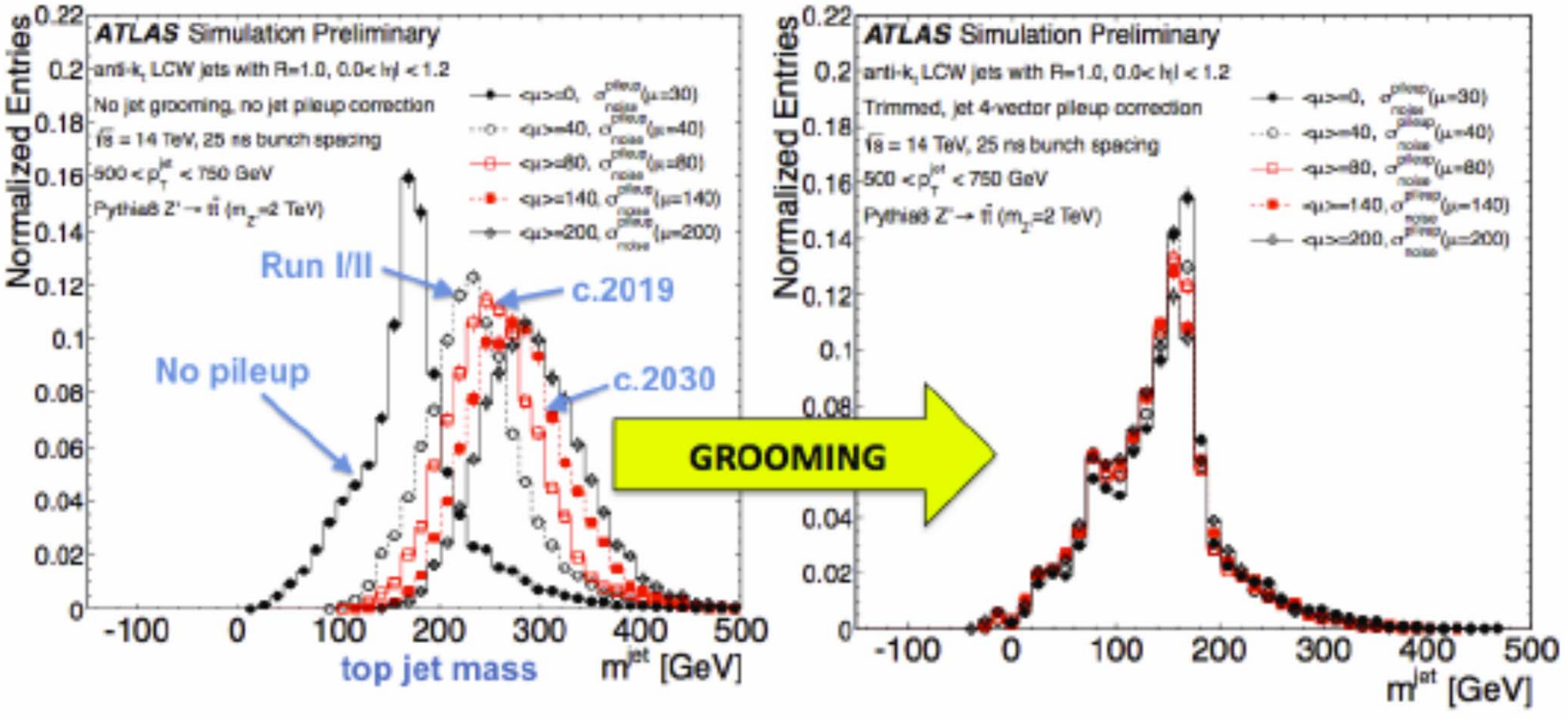
Boosted ttH



Apply jet grooming to get top decay candidates

- **Find hard substructure using mass drop criteria**
- **Undo clustering to keep both subjets**
- **Combinatorics: choose pairing based on kinematic correlation, e.g. top mass, W mass etc.**

Boosted ttH

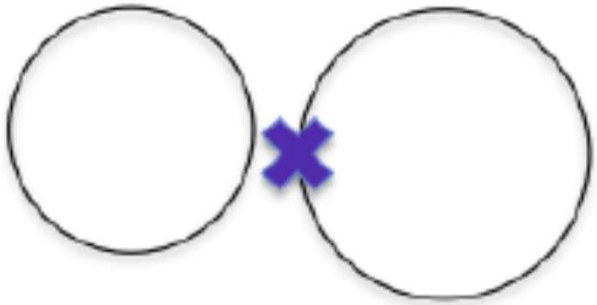


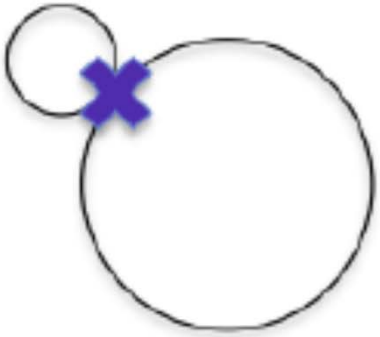
Apply jet grooming to get top decay candidates

- **Grooming also helps to remove pile-up effects**

Boosted ttH

kT's final cluster combines a pair of subjets,

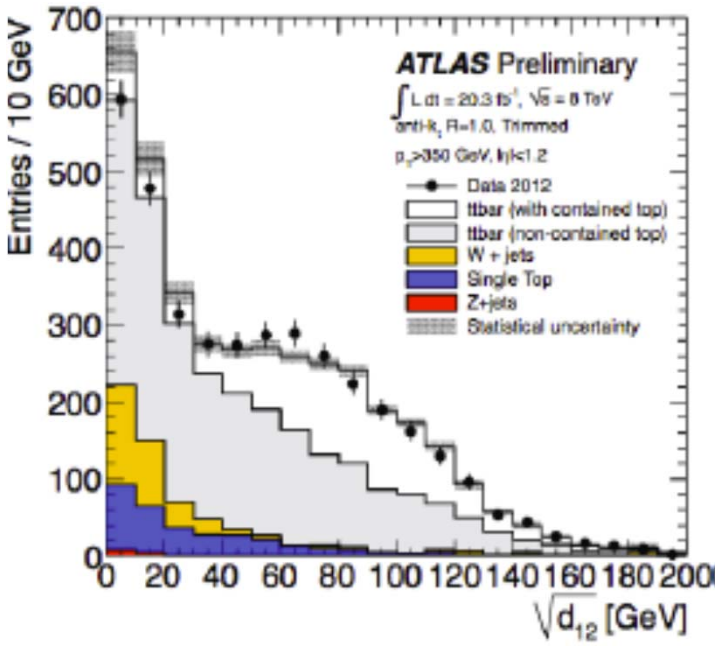


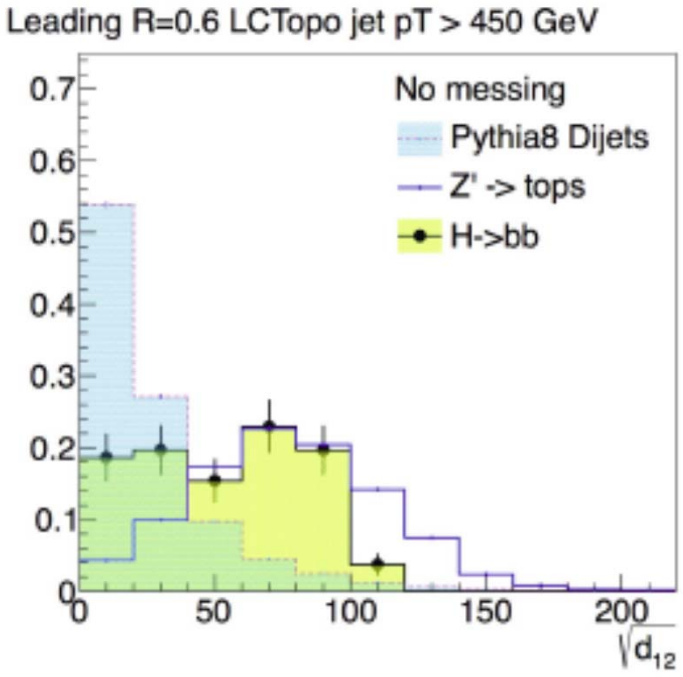


If the position at the last clustering is that of two prongs from a massive particle decay, then $\sqrt{d_{12}} = min(pT^1, pT^2) \times \Delta R^{1,2}$ should be roughly half the mass of the massive particle.

If not, then we should get a meaningless distribution that peaks at zero.

Boosted ttH





Ultimate goal is to develop (boosted) Higgs and top tagger

- **Require bb-jet substructure study and tagging**
- **However not all top and Higgs are boosted**

Summary and Outlook

Top Quark and Higgs Boson Associated Production

- Discovery potential promising
  - 5σ with 100 fb^{-1} 13/14 TeV LHC data
- Understanding Higgs-top Yukawa coupling
  - No sign of anomalous coupling yet
  - Expect 10% precision on Higgs-top coupling with full LHC Run2 data (~100 fb^{-1})
- Understanding boosted particles topology
  - Useful for 13/14 TeV run
  - Critical for future high energy collider

Backup

ttH (H → bb) Systematics

Systematic uncertainty	Type	Components
Luminosity	N	1
Physics Objects		
Electron	SN	5
Muon	SN	6
Jet energy scale	SN	22
Jet vertex fraction	SN	1
Jet energy resolution	SN	1
Jet reconstruction	SN	1
b-tagging efficiency	SN	6
c-tagging efficiency	SN	6
Light jet-tagging efficiency	SN	12
Background Model		
$t\bar{t}$ cross section	N	1
$t\bar{t}$ modelling: p_{T} reweighting	SN	9
$t\bar{t}$ modelling: parton shower	SN	2
$t\bar{t}$+heavy-flavour: normalisation	N	2
$t\bar{t}$+heavy-flavour: HF reweighting	SN	2
$t\bar{t}$+heavy-flavour: generator	SN	5
W+jets normalisation	N	3
W p_{T} reweighting	SN	1
Z+jets normalisation	N	2
Z p_{T} reweighting	SN	1
Multijet normalisation	N	3
Multijet shape dilepton	S	1
Single top cross section	N	1
Dibosons cross section	N	1
$t\bar{t}V$ cross section	N	1
Signal Model		
$t\bar{t}H$ modelling	SN	2

Detector

tt systematics

Minor systematics

ttH + tqH (H →γγ) Systematics

	$t\bar{t}H$ [%]		tHqb [%]		WtH [%]		ggF [%]	WH [%]
	had.	lep.	had.	lep.	had.	lep.	had.	lep.
Luminosity	±1.8							
Photons	±10.0	±10.0	±10.0	±10.0	±10.0	±10.0	±10.0	±10.0
Leptons	< 0.1	±0.7	< 0.1	±0.7	< 0.1	±0.6	< 0.1	±0.7
Jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	±9.1	±1.6	±19	±2.4	±13	±2.9	±30	±10
Bkg. modeling	0.12 evt.	0.01 evt.	applied on the sum of all Higgs boson production processes					
Theory ($\sigma \times$ BR)	+10,−13		+8,−7		+12,−12		+11,−12	+5.5,−5.5
MC Modeling	±11	±3.3	±12	±4.4	±13	±5.2	±130	±100