Status of ttH, H➔bb in ATLAS

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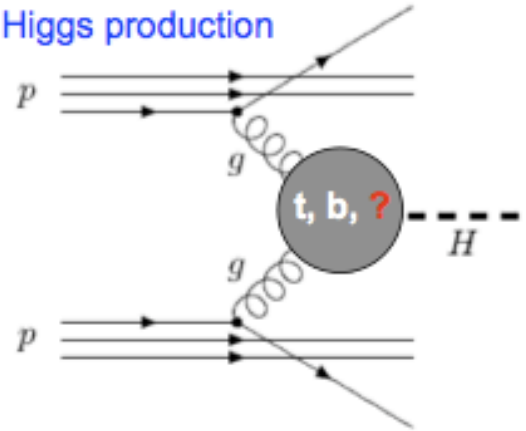
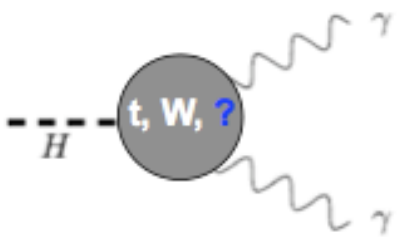
For the ttH analysis group
UK involvement from Gaslgow & RHUL
Thanks to several people for several stolen slides!

Motivation

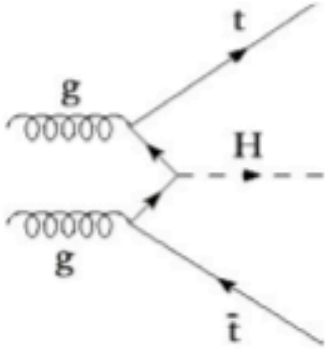
Higgs production



Higgs decay to photons

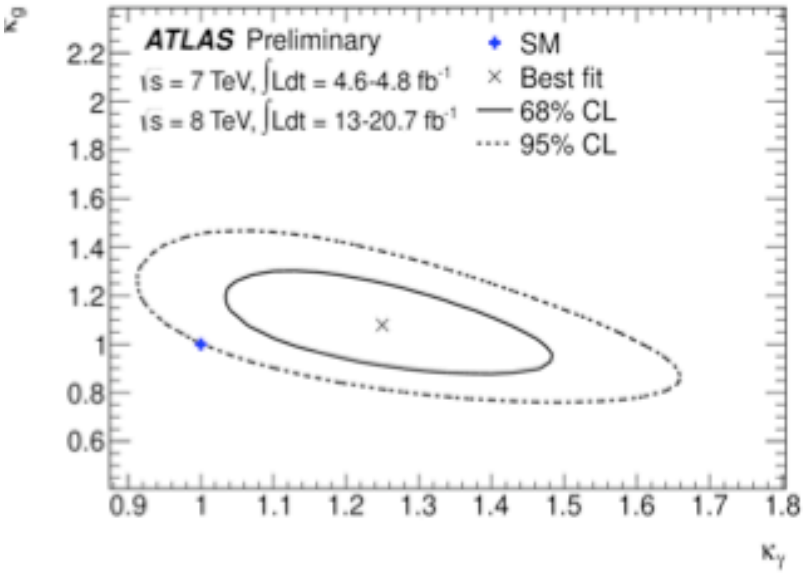


Higgstrahlung from top quark



$$\sigma(t\bar{t}H) \propto g^2_{ttH}$$

ATLAS-CONF-2013-034

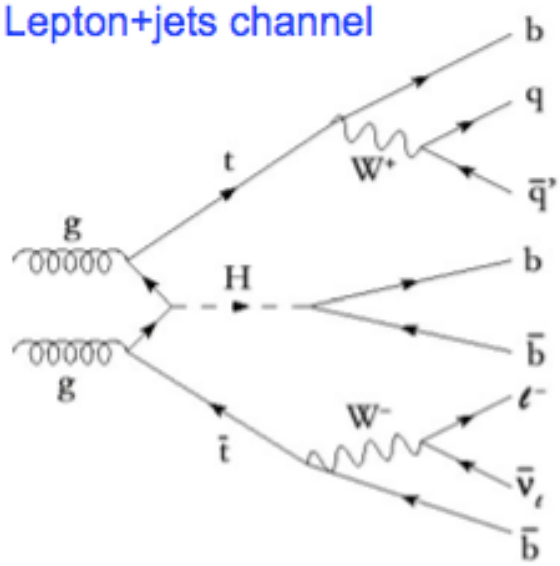


- Indirect constraints on the top-Higgs Yukawa coupling can be extracted from channels involving the ggH and γγH vertices
  - ➔ assumes no new particles.
- Top-Higgs only Yukawa coupling that can be measured directly
  - ➔ allows probing for NP contributions in the ggH and γγH vertices.

Direct ttH searches

Virtues:

- Distinctive final states with high jet/b-tag multiplicity and multiple heavy resonances
  - A priori many handles against backgrounds!
- Possibility to exploit several Higgs decay modes.
  - For m_H=125 GeV, $H \rightarrow b\bar{b}$ dominates although e.g. $H \rightarrow W^+W^-, \tau^+\tau^-$, can also contribute.
  - Other decay modes can be exploited at high integrated luminosity (e.g. $H \rightarrow \gamma\gamma$).



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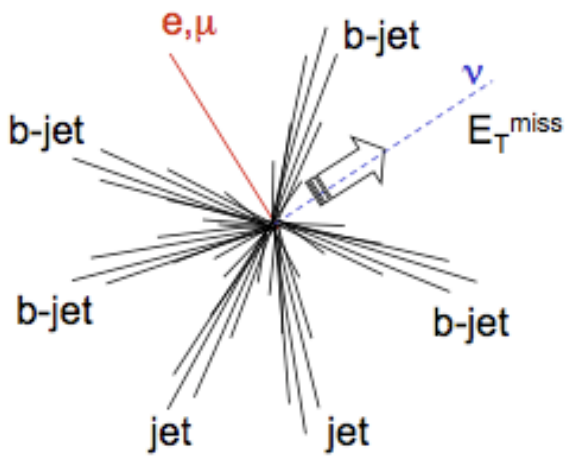
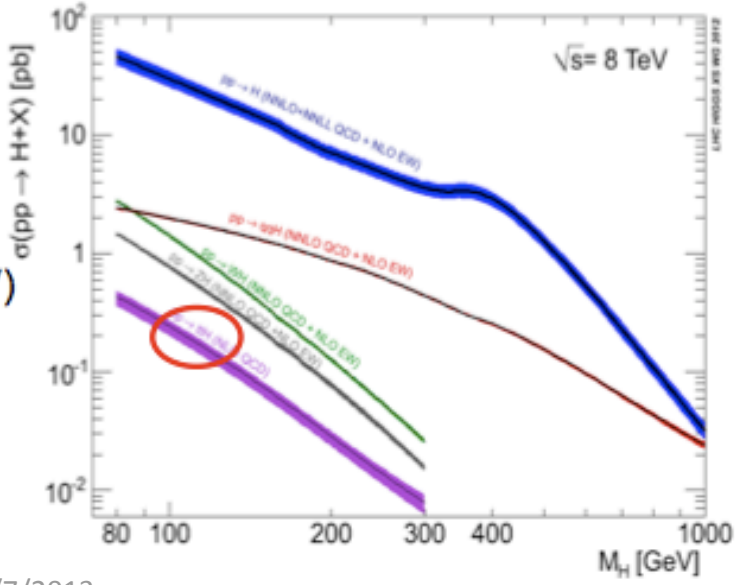
Lepton+jets channel



Challenges:

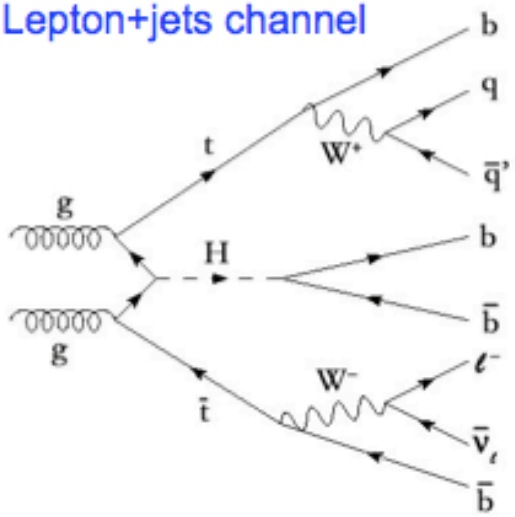
- Very busy events which are hard to reconstruct kinematically (large combinatorial background).
- Low production cross section:
  $\sqrt{s}$=8 TeV: $\sigma(t\bar{t}H)$=130 fb for m_H=125 GeV
  ~x1.5(x4.7) higher(lower) than at $\sqrt{s}$=7 TeV(14 TeV)
- Huge background from $t\bar{t}$+jets affected by large systematic uncertainties, both theoretical and experimental.



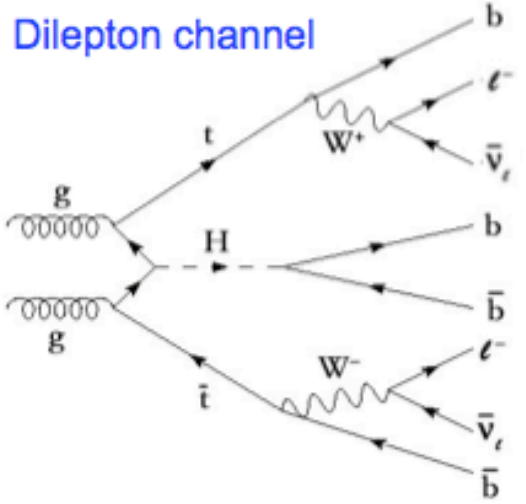
Analysis Strategy

- Select $t\bar{t}$-enriched samples:
  - Lepton+jets and opposite-sign dilepton final states considered so far.
- Pick signals being targeted:
  - Analyses primarily aiming at $H \rightarrow b\bar{b}$ but include contributions from $H \rightarrow WW$ and other subleading decay modes as well.
- Categorize events by jet and b-tag multiplicities:
  - Improve sensitivity by keeping separate high and low $S/\sqrt{B}$ channels.
  - Signal-depleted channels will be exploited to constrain systematic uncertainties.
- For each analysis channel, choose a discriminant variable. Ideally:
  - A simple kinematic variable in signal-depleted channels.
  - A multivariate discriminant in signal-rich channels.
- Hypothesis testing including in-situ constraining of systematic uncertainties.

Lepton+jets channel



Dilepton channel

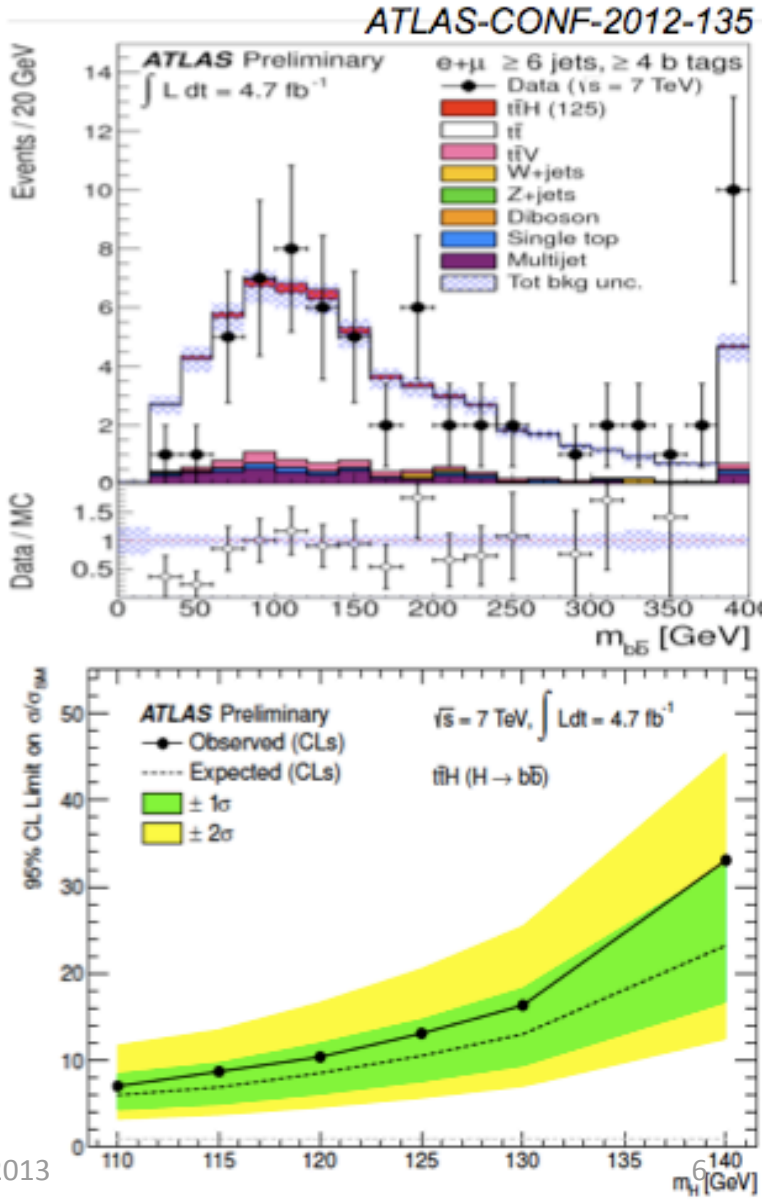


7TeV ATLAS Analysis

- Data: 4.7 fb^{-1} @ 7 TeV
- Only lepton+jets channel analyzed.
- Only H→bb decay mode considered.
- H_{Thad} (scalar sum of jet p_T) and m_{bb} (from kinematic fit) used as discriminant variables
- Fit performed in 9 different channels:

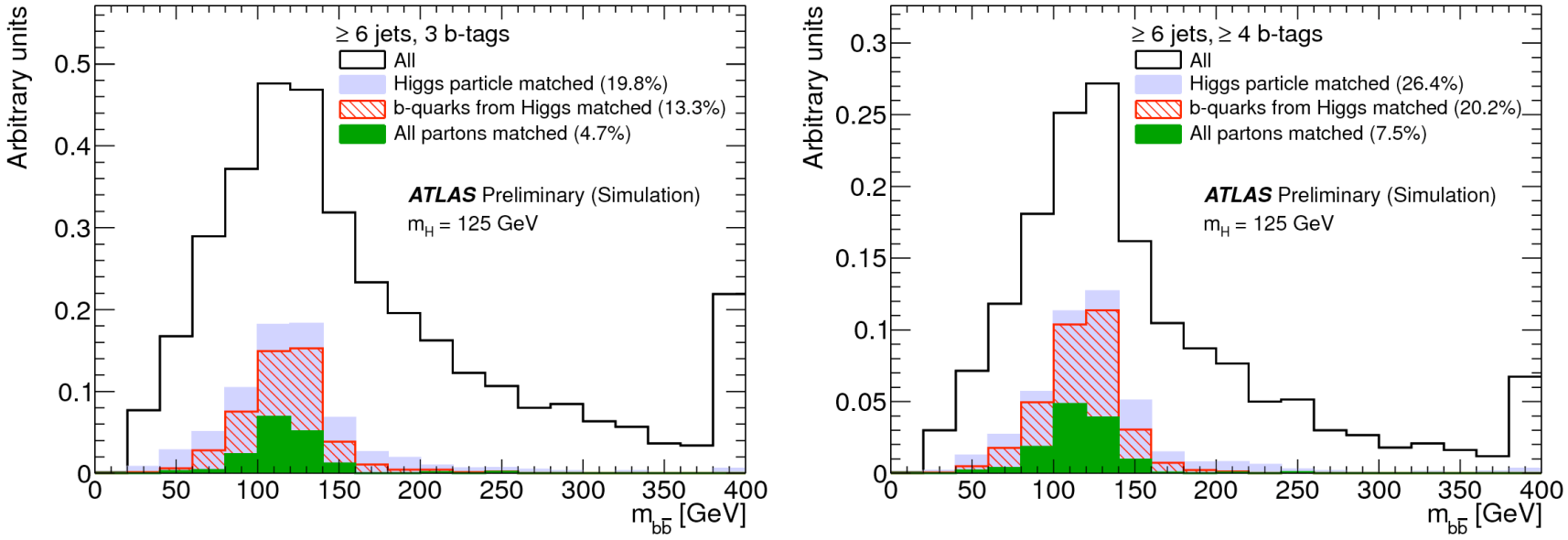
	Validation (not used in fit)		Signal-depleted		Signal-rich
	0 b-tag	1 b-tag	2 b-tags	3 b-tags	≥ 4 b-tags
4 jets	H_{Thad}	H_{Thad}	H_{Thad}		
5 jets	H_{Thad}	H_{Thad}	H_{Thad}	H_{Thad}	H_{Thad}
≥ 6 jets	H_{Thad}	H_{Thad}	H_{Thad}	m_{bb}	m_{bb}

- Observed (expected) limit @ m_H=125 GeV: 13.1xSM (10.5xSM).



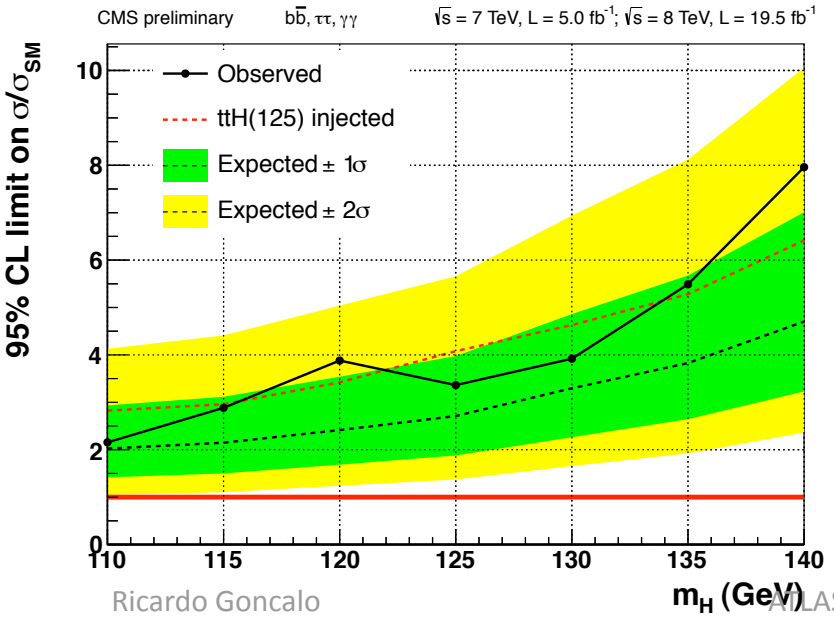
Kinematic Fit

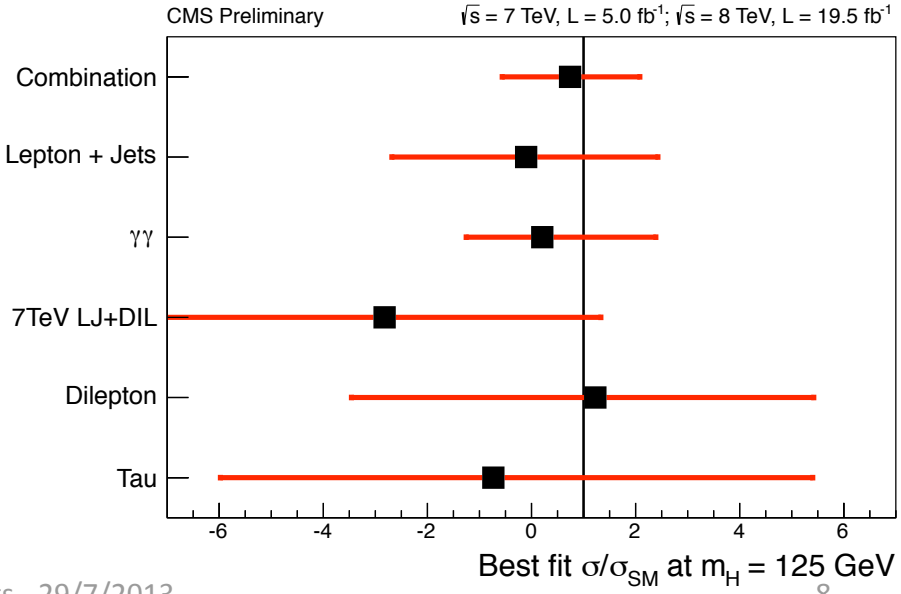
- Implemented in KLFitter – used by several top analyses
- Analysis sensitivity hampered by combinatorial background
- Reject bad combinations – e.g. where b-jet used in W reconstrucion – to reduce impact
- Selection purity still rather low => reconstructed mass spectrum in signal very broad



Recent CMS results

- Recently released an analysis of 8TeV data
  - CMS-PAS-HIG-13-019
  - ttH->bb in lepton+jets and dilepton
  - ttH, H->ττ
- Results:
- Observed 5.2 x σ_{SM} (expected 4.1 x σ_{SM}) 95% CL limits from 8TeV data
- Observed 3.4 x σ_{SM} (expected 2.7 x σ_{SM}) when combining with other ttH results





Event Selection

Lepton+jets

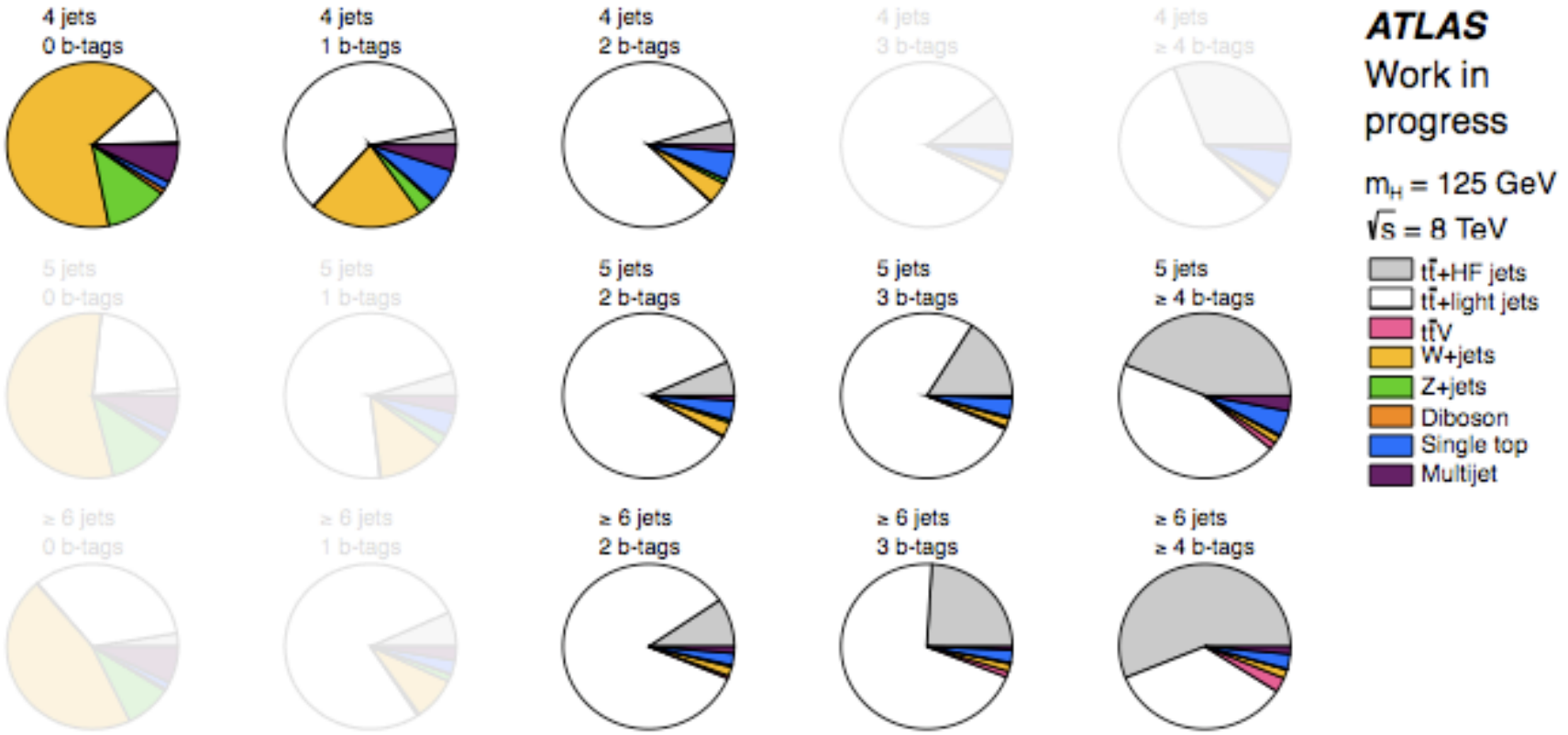
- Exactly 1 isolated lepton (e or μ) with p_T>25 GeV, |η|<2.5 (μ), |η|<2.47 (e) removing crack region (1.37<|η|<1.52)
  [Muon p_T>20 GeV in 7 TeV analysis]
- ≥4 jets with p_T>25 GeV, |η|<2.5
- E_T^{miss} > 20 GeV
- E_T^{miss}+M_{TW}>60 GeV

Dilepton

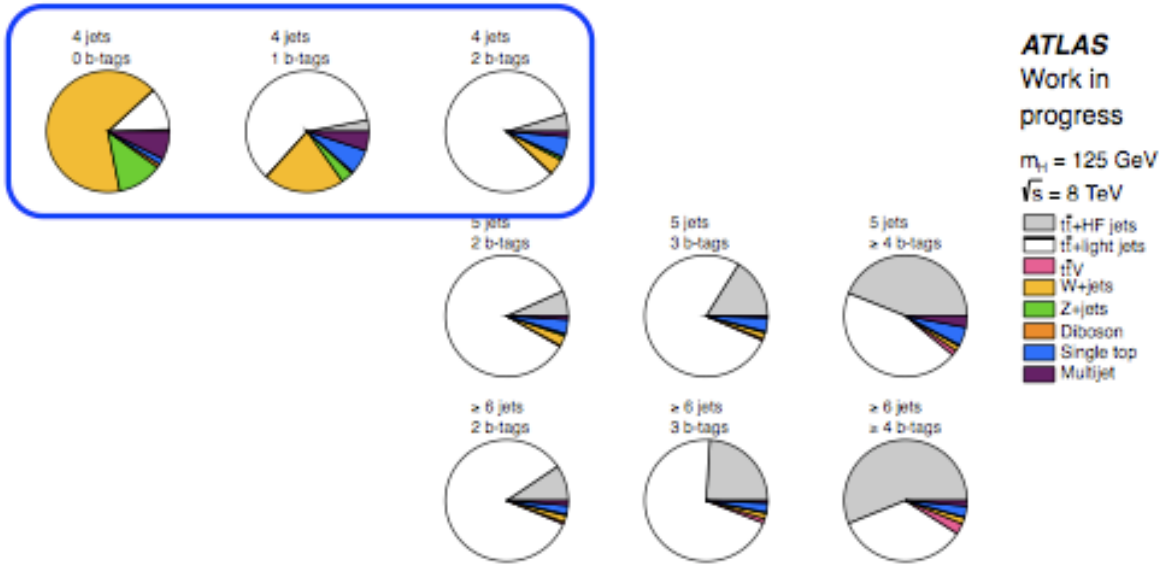
- Exactly 2 isolated opposite-sign leptons (e or μ) with p_T>25 GeV, |η|<2.5 (μ), |η|<2.47 (e) removing crack region (1.37<|η|<1.52)
- ≥2 jets with pT>25 GeV, |η|<2.5
- No cut on E_T^{miss}
- Z mass window cut in ee and μμ: |M(ll)-91|>8 GeV, M(ll)>15 GeV
- H_T>130 GeV in eμ channel

- Events are classified according to the number of jets and b-tags
- B-tagging WP: 70%, p_{Trel}-based calibration in 7 and 8 TeV

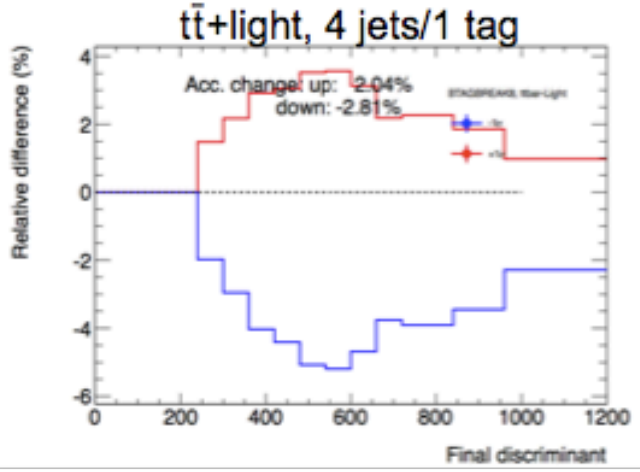
Constraining Uncertainties

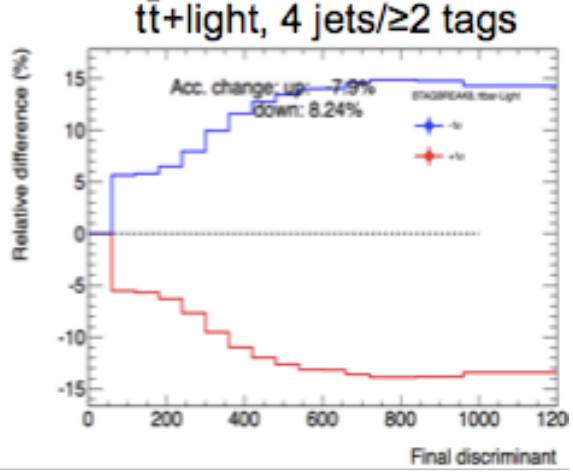


	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}$ + HF
BTAGBREAK0_8TeV	–	–	–
BTAGBREAK1_8TeV	–	–	–
BTAGBREAK2_8TeV	–	–	–
BTAGBREAK3_8TeV	–	–	–
BTAGBREAK4_8TeV	±0.00	–	±0.00
BTAGBREAK5_8TeV	±0.53	–	–
BTAGBREAK6_8TeV	±0.00	±0.00	±0.00
BTAGBREAK7_8TeV	±2.2	±2.1	±2.4
BTAGBREAK8_8TeV	±17.2	±10.4	±14.2
CTAGBREAK0_8TeV	–	±0.57	±0.56
CTAGBREAK1_8TeV	±0.00	±0.68	±0.00
CTAGBREAK2_8TeV	–	±0.51	±0.00
CTAGBREAK3_8TeV	±0.76	±2.8	±2.3
CTAGBREAK4_8TeV	–	±1.2	±1.1
CTAGBREAK5_8TeV	±2.9	±10.1	±9.2
Dibosons_XS	–	–	–
JER_8TeV	±0.61	±4.7	±2.2
JESBREAK1_8TeV	±7.3	±12.9	±9.6
JESBREAK2_8TeV	±1.9	±3.9	±3.0
JESBREAK3_8TeV	±0.71	±1.2	±0.97
JESBREAK4_8TeV	–	±0.67	±0.56
JESBREAK5_8TeV	±1.6	±2.6	±2.2
JESBREAK6_8TeV	±2.1	±6.9	±3.8
JESBREAK7_8TeV	±1.2	±3.9	±2.2
JESBREAK8_8TeV	±3.2	±2.5	±3.2
JVFSF_8TeV	±2.6	±4.3	±4.1
LEPTONSYS_LJET_8TeV	±2.1	±2.1	±2.1
LTAG_8TeV	±2.1	±25.4	±4.6
LUMI_8TeV	±3.6	±3.6	±3.6
QCD_norm_LJET_8TeV	–	–	–
singleTop_XS	–	–	–
ttbar-HFfrac	–	±5.9	±50.0
ttbar-ktfac-HF	–	–	±0.00
ttbar-ktfac-light	–	±0.00	–
ttbar-PartonShower	–	±0.00	±0.00
ttbar-qfac-HF	–	–	±0.00
ttbar-qfac-light	–	±0.00	–
ttbar-RW-eta-1jet	–	–	–
ttbar-RW-eta-2jet	–	±0.00	±0.00
ttbar-RW-HF	–	–	±0.00
ttbar-RW-light	–	±0.00	–
ttbar_XS	–	±10.3	±10.3
ttbar_XS_jet12_LJET	–	±24.0	±24.0
ttbar_XS_jet2_LJET	–	±24.0	±24.0
ttbarV_XS	–	–	–
ttH-Scale_8TeV	±0.65	–	–
WJETS-BBCC4_8TeV	–	–	–
WJETS-BBCC5_8TeV	–	–	–
WJETS-BBCC6_8TeV	–	–	–
WJETS-BBCC_8TeV	–	–	–
WJETS-BBCCC_8TeV	–	–	–
WJETS-C4_8TeV	–	–	–
WJETS-C5_8TeV	–	–	–
WJETS-C6_8TeV	–	–	–
WJETS-CAN_8TeV	–	–	–
WJETS_XS_jet6_8TeV	–	–	–
Zjets_XS_jet4_LJET	–	–	–
Zjets_XS_jet5_LJET	–	–	–
Zjets_XS_jet6_LJET	–	–	–
Total systematics	±20.5	±49.8	±65.2



- B tagging: mainly exploit tag multiplicity spectrum in 4 jet events; also shape of H_{Thad} distribution.





	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}$ + HF
BTAGBREAK0_8TeV	–	–	–
BTAGBREAK1_8TeV	–	–	–
BTAGBREAK2_8TeV	–	–	–
BTAGBREAK3_8TeV	–	–	–
BTAGBREAK4_8TeV	±0.00	–	±0.00
BTAGBREAK5_8TeV	±0.53	–	–
BTAGBREAK6_8TeV	±0.00	±0.00	±0.00
BTAGBREAK7_8TeV	±2.2	±2.1	±2.4
BTAGBREAK8_8TeV	±17.2	±10.4	±14.2
CTAGBREAK0_8TeV	–	±0.57	±0.56
CTAGBREAK1_8TeV	±0.00	±0.68	±0.00
CTAGBREAK2_8TeV	–	±0.51	±0.00
CTAGBREAK3_8TeV	±0.76	±2.8	±2.3
CTAGBREAK4_8TeV	–	±1.2	±1.1
CTAGBREAK5_8TeV	±2.9	±10.1	±9.2
Dibosons_XS	–	–	–
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JESBREAK7_8TeV	±1.2	±3.9	±2.2
JESBREAK8_8TeV	±3.2	±2.5	±3.2
JVFSF_8TeV	±2.6	±4.3	±4.1
LEPTONSYS_LJET_8TeV	±2.1	±2.1	±2.1
LTAG_8TeV	±2.1	±25.4	±4.6
LUMI_8TeV	±3.6	±3.6	±3.6
QCD_norm_LJET_8TeV	–	–	–
singleTop_XS	–	–	–
ttbar-HFfrac	–	±5.9	±50.0
ttbar-ktfac-HF	–	–	±0.00
ttbar-ktfac-light	–	±0.00	–
ttbar-PartonShower	–	±0.00	±0.00
ttbar-qfac-HF	–	–	±0.00
ttbar-qfac-light	–	±0.00	–
ttbar-RW-eta-1jet	–	–	–
ttbar-RW-eta-2jet	–	±0.00	±0.00
ttbar-RW-HF	–	–	±0.00
ttbar-RW-light	–	±0.00	–
ttbar_XS	–	±10.3	±10.3
ttbar_XS_jet12_LJET	–	±24.0	±24.0
ttbar_XS_jet2_LJET	–	±24.0	±24.0
ttbarV_XS	–	–	–
ttH-Scale_8TeV	±0.65	–	–
WJETS-BBCC4_8TeV	–	–	–
WJETS-BBCC5_8TeV	–	–	–
WJETS-BBCC6_8TeV	–	–	–
WJETS-BBCC_8TeV	–	–	–
WJETS-BBCCC_8TeV	–	–	–
WJETS-C4_8TeV	–	–	–
WJETS-C5_8TeV	–	–	–
WJETS-C6_8TeV	–	–	–
WJETS-CAN_8TeV	–	–	–
WJETS_XS_jet6_8TeV	–	–	–
Zjets_XS_jet4_LJET	–	–	–
Zjets_XS_jet5_LJET	–	–	–
Zjets_XS_jet6_LJET	–	–	–
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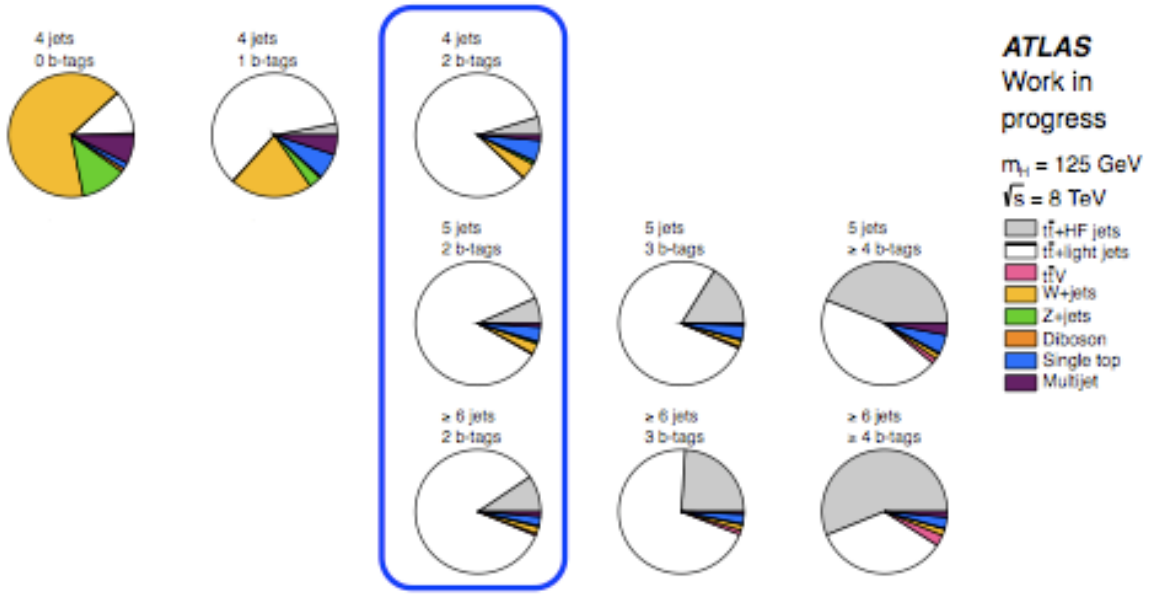
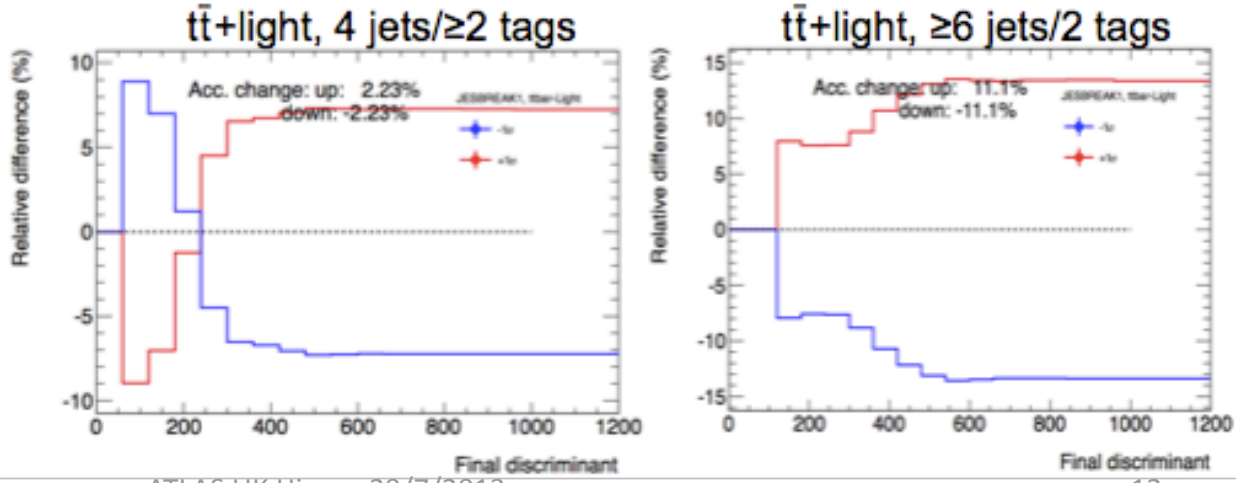


- JES: mainly exploit jet multiplicity spectrum of $t\bar{t}$ in 2-tag samples and shape of H_{Thad} distribution.



	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}$ + $H\bar{F}$
BTAGBREAK0_8TeV	–	–	–
BTAGBREAK1_8TeV	–	–	–
BTAGBREAK2_8TeV	–	–	–
BTAGBREAK3_8TeV	–	–	–
BTAGBREAK4_8TeV	±0.00	–	±0.00
BTAGBREAK5_8TeV	±0.53	–	–
BTAGBREAK6_8TeV	±0.00	±0.00	±0.00
BTAGBREAK7_8TeV	±2.2	±2.1	±2.4
BTAGBREAK8_8TeV	±17.2	±10.4	±14.2
CTAGBREAK0_8TeV	–	±0.57	±0.56
CTAGBREAK1_8TeV	±0.00	±0.68	±0.00
CTAGBREAK2_8TeV	–	±0.51	±0.00
CTAGBREAK3_8TeV	±0.76	±2.8	±2.3
CTAGBREAK4_8TeV	–	±1.2	±1.1
CTAGBREAK5_8TeV	±2.9	±10.1	±9.2
Dibosons_XS	–	–	–
JER_8TeV	±0.61	±4.7	±2.2
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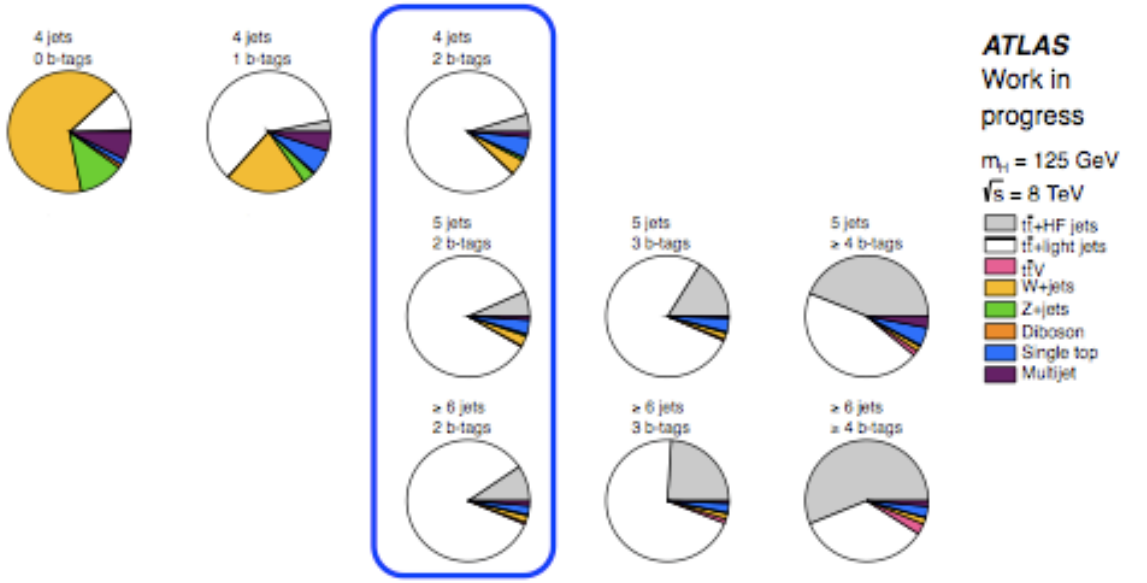
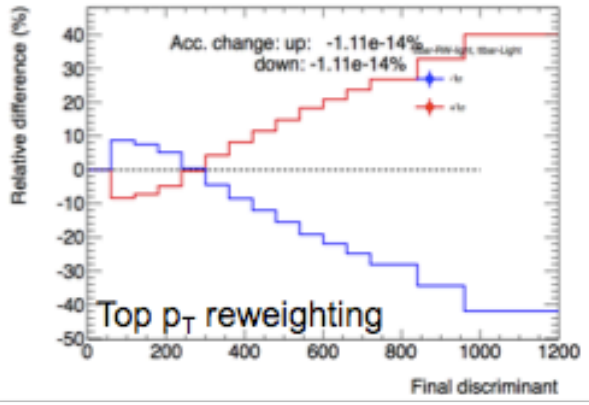
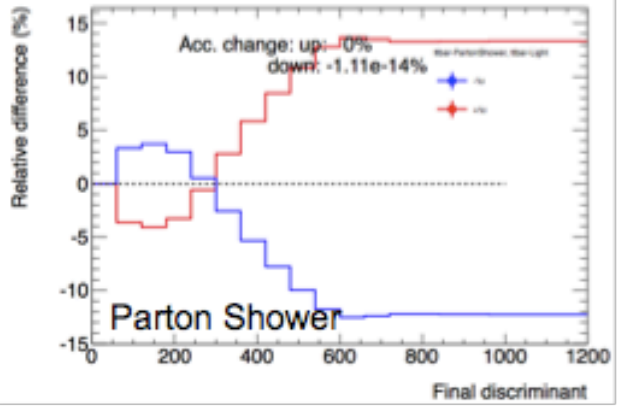
QCD_norm_LJET_8TeV	–	–	–
singleTop_XS	–	–	–
ttbar-HFfrac	–	±5.9	±50.0
ttbar-ktfac-HF	–	–	±0.00
ttbar-ktfac-light	–	±0.00	–
ttbar-PartonShower	–	±0.00	±0.00
ttbar-qfac-HF	–	–	±0.00
ttbar-qfac-light	–	±0.00	–
ttbar-RW-eta-1jet	–	–	–
ttbar-RW-eta-2jet	–	±0.00	±0.00
ttbar-RW-HF	–	–	±0.00
ttbar-RW-light	–	±0.00	–
ttbar_XS	–	±10.3	±10.3
ttbar_XS_jet12_LJET	–	±24.0	±24.0
ttbar_XS_jet2_LJET	–	±24.0	±24.0
ttbarV_XS	–	–	–
ttH-Scale_8TeV	±0.65	–	–
WJETS-BBCC4_8TeV	–	–	–
WJETS-BBCC5_8TeV	–	–	–
WJETS-BBCC6_8TeV	–	–	–
WJETS-BBCC_8TeV	–	–	–
WJETS-BBCCC_8TeV	–	–	–
WJETS-C4_8TeV	–	–	–
WJETS-C5_8TeV	–	–	–
WJETS-C6_8TeV	–	–	–
WJETS-CAN_8TeV	–	–	–
WJETS_XS_jet6_8TeV	–	–	–
Zjets_XS_jet4_LJET	–	–	–
Zjets_XS_jet5_LJET	–	–	–
Zjets_XS_jet6_LJET	–	–	–
Total systematics	±20.5	±49.8	±65.2



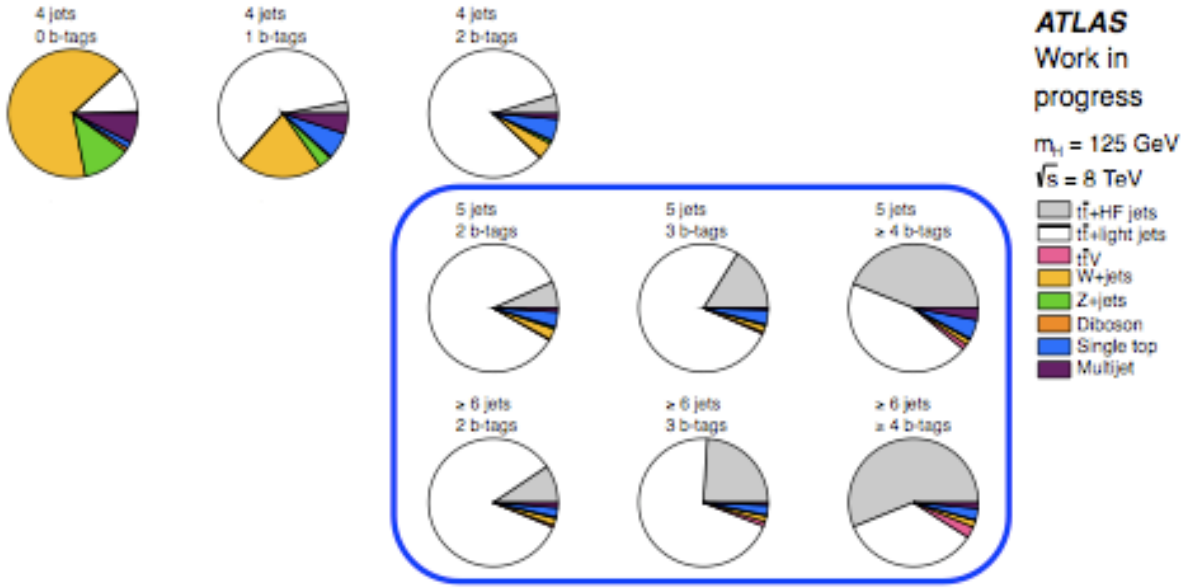
- $t\bar{t}$+light shape modeling: exploit shape of H_{Thad} distribution in $t\bar{t}$+light-dominated samples

$t\bar{t}$+light, 4 jets/≥2 tags





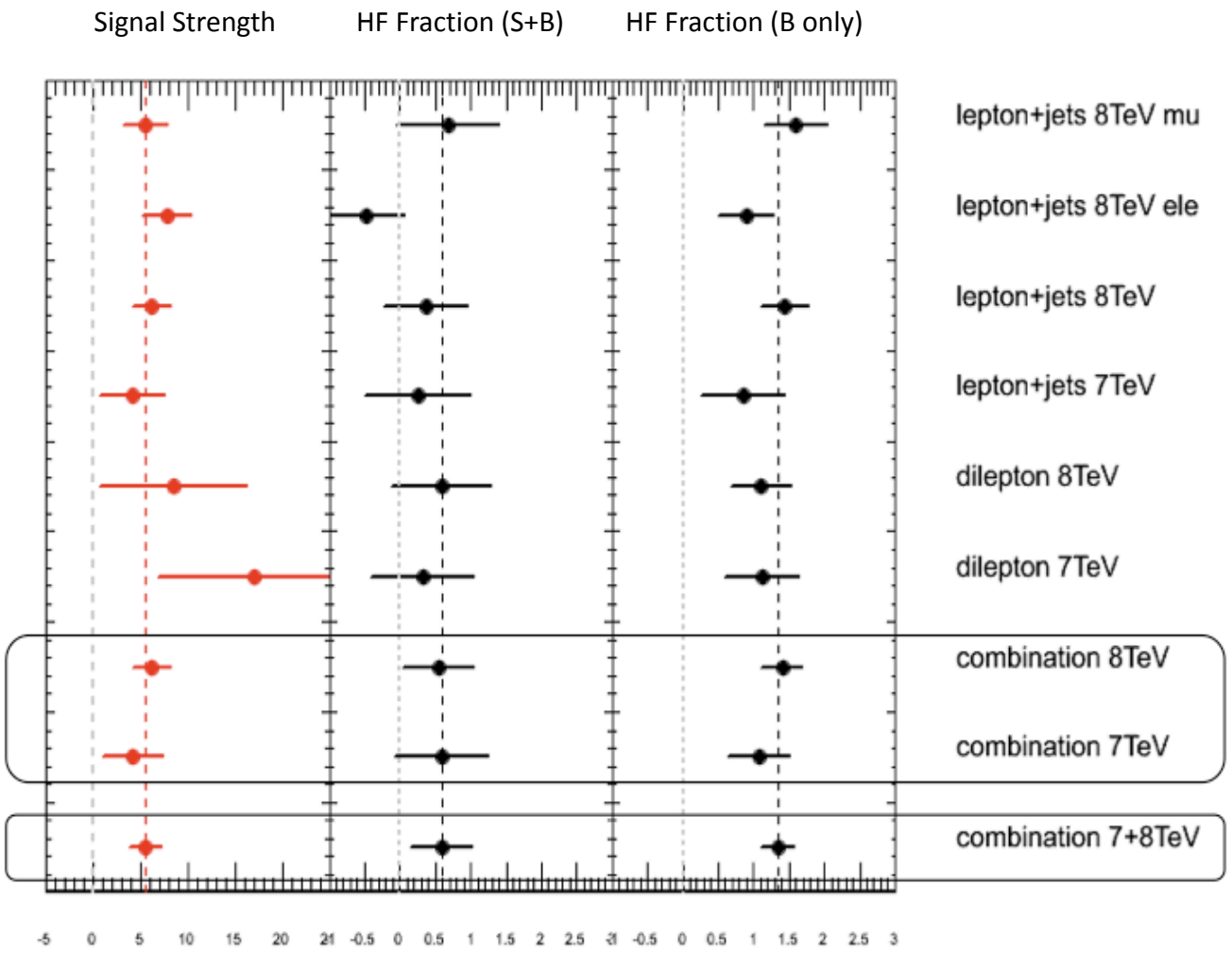
	$t\bar{t}H$ (125)	$t\bar{t}$ + light	$t\bar{t}$ + HF
BTAGBREAK0_8TeV	–	–	–
BTAGBREAK1_8TeV	–	–	–
BTAGBREAK2_8TeV	–	–	–
BTAGBREAK3_8TeV	–	–	–
BTAGBREAK4_8TeV	±0.00	–	±0.00
BTAGBREAK5_8TeV	±0.53	–	–
BTAGBREAK6_8TeV	±0.00	±0.00	±0.00
BTAGBREAK7_8TeV	±2.2	±2.1	±2.4
BTAGBREAK8_8TeV	±17.2	±10.4	±14.2
CTAGBREAK0_8TeV	–	±0.57	±0.56
CTAGBREAK1_8TeV	±0.00	±0.68	±0.00
CTAGBREAK2_8TeV	–	±0.51	±0.00
CTAGBREAK3_8TeV	±0.76	±2.8	±2.3
CTAGBREAK4_8TeV	–	±1.2	±1.1
CTAGBREAK5_8TeV	±2.9	±10.1	±9.2
Dibosons_XS	–	–	–
JER_8TeV	±0.61	±4.7	±2.2
JESBREAK1_8TeV	±7.3	±12.9	±9.6
JESBREAK2_8TeV	±1.9	±3.9	±3.0
JESBREAK3_8TeV	±0.71	±1.2	±0.97
JESBREAK4_8TeV	–	±0.67	±0.56
JESBREAK5_8TeV	±1.6	±2.6	±2.2
JESBREAK6_8TeV	±2.1	±6.9	±3.8
JESBREAK7_8TeV	±1.2	±3.9	±2.2
JESBREAK8_8TeV	±3.2	±2.5	±3.2
JVFSF_8TeV	±2.6	±4.3	±4.1
LEPTONSYS_LJET_8TeV	±2.1	±2.1	±2.1
LTAG_8TeV	±2.1	±25.4	±4.6
LUMI_8TeV	±3.6	±3.6	±3.6
QCD_norm_LJET_8TeV	–	–	–
singleTop_XS	–	–	–
ttbar-HFfrac	–	±5.9	±50.0
ttbar-ktfac-HF	–	–	±0.00
ttbar-ktfac-light	–	±0.00	–
ttbar-PartonShower	–	±0.00	±0.00
ttbar-qfac-HF	–	–	±0.00
ttbar-qfac-light	–	±0.00	–
ttbar-RW-eta-1jet	–	–	–
ttbar-RW-eta-2jet	–	±0.00	±0.00
ttbar-RW-HF	–	–	±0.00
ttbar-RW-light	–	±0.00	–
ttbar_XS	–	±10.3	±10.3
ttbar_XS_jet12_LJET	–	±24.0	±24.0
ttbar_XS_jet2_LJET	–	±24.0	±24.0
ttbarV_XS	–	–	–
ttH-Scale_8TeV	±0.65	–	–
WJETS-BBCC4_8TeV	–	–	–
WJETS-BBCC5_8TeV	–	–	–
WJETS-BBCC6_8TeV	–	–	–
WJETS-BBCC_8TeV	–	–	–
WJETS-BBCCC_8TeV	–	–	–
WJETS-C4_8TeV	–	–	–
WJETS-C5_8TeV	–	–	–
WJETS-C6_8TeV	–	–	–
WJETS-CAN_8TeV	–	–	–
WJETS_XS_jet6_8TeV	–	–	–
Zjets_XS_jet4_LJET	–	–	–
Zjets_XS_jet5_LJET	–	–	–
Zjets_XS_jet6_LJET	–	–	–
Total systematics	±20.5	±49.8	±65.2



- $t\bar{t}$+HF fraction: exploit $t\bar{t}$ yield in different tag multiplicities

Channels	B-only Fit
4 jets/0, 1, ≥2 tags +5 jets/2, 3 tags	0.50
+≥6 jets/2, 3 tags	0.34
+5 jets/≥4 tags	0.29
+≥6 jets/≥4 tags	0.23

Initial Results



- Comparison of fitted parameters from individual fits in semilept and dilept in 7 and 8 TeV and combinations.
- Very consistent picture.
- Full combination (S+B):

  $\mu = 5.6 \pm 1.7$

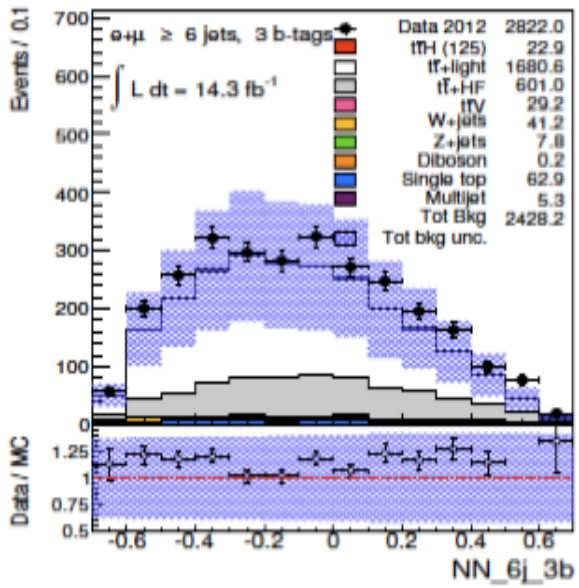
  tt-HF= 0.6 ± 0.4

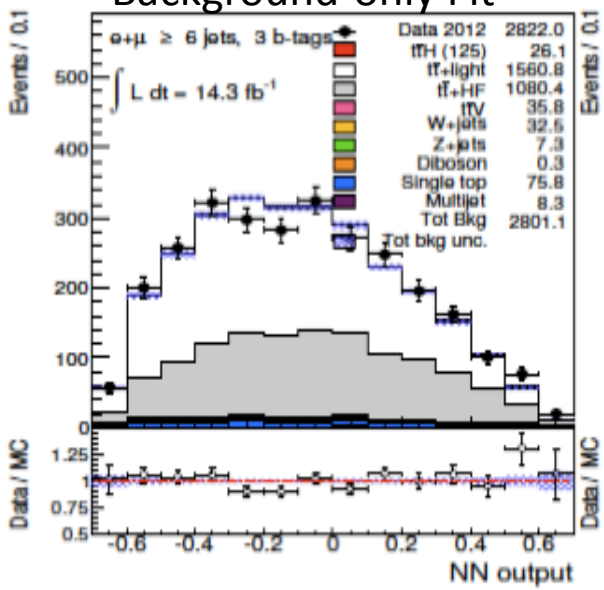
  (corresponds to scaling factor of 1.3 ± 0.2; comparable to that found for W+HF).

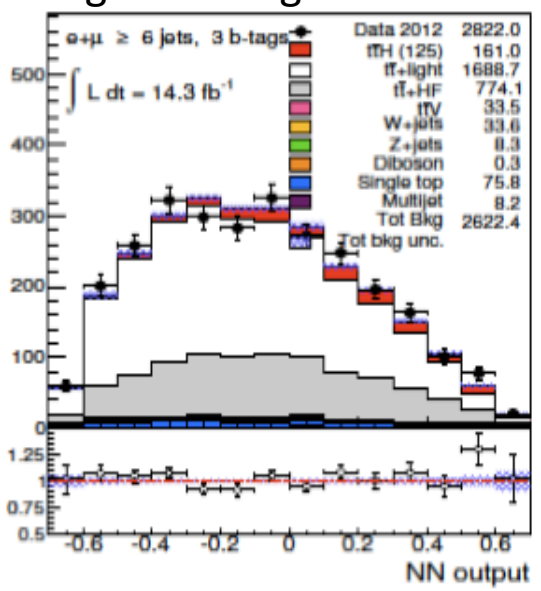
What's Going On?

Pre-Fit | Background-only Fit | Signal+Background Fit

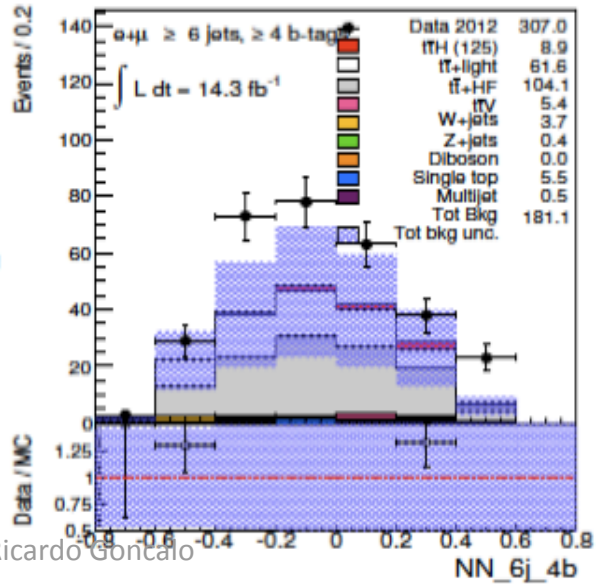
3 b

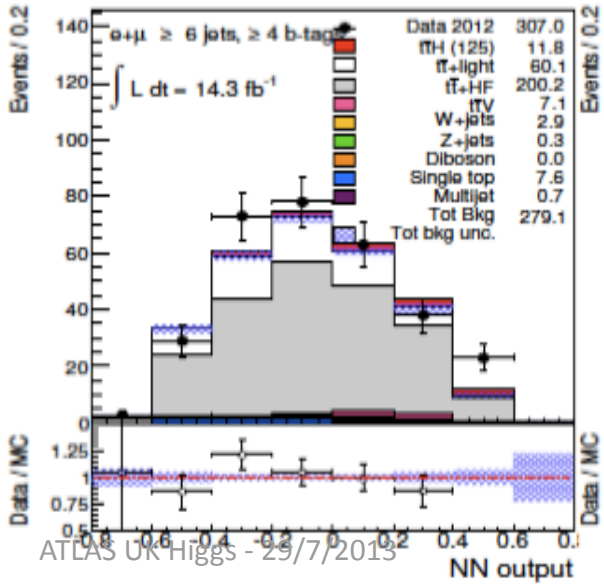


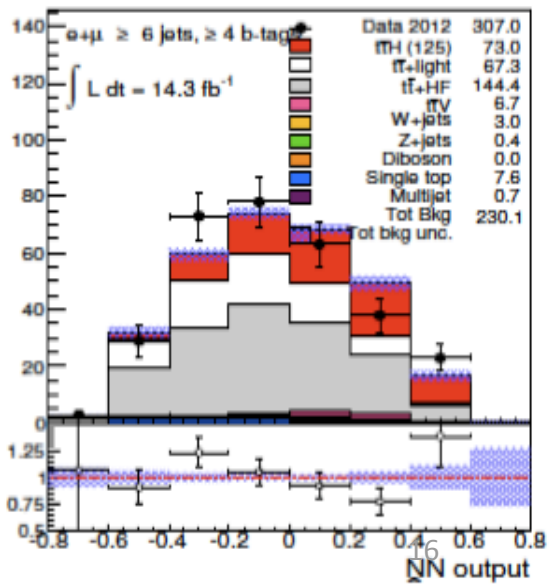




≥4 b







The Story So Far…

- The high value of μ lead us to closely investigate several issues

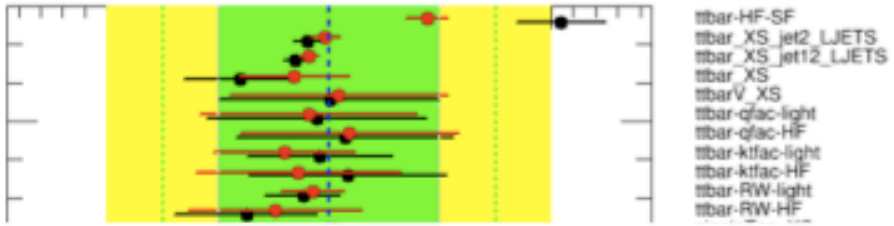
- The modeling of background has many unknowns:
  - tt+HF cross section easily changes by ≥x2 for different theory choices
    - Affects extrapolation from background-dominated regions into signal region
  - The use of HFOR to mix tt+light jets and tt+HF is being investigated
  - Different choice of hard scale:
    - Default: $Q^2 = \mathrm{Sum}(p_T^2 + m^2)$; BDDP: $Q^2 = m_t \sqrt{(p_T^{b1}\, p_T^{b2})}$;

    Mass scale: $Q^2 = m_t\, m_{bb}$; Mass/2: $Q^2 = m_t\, m_{bb}/2$
  - Different theory model in MadGraph
  - b-tagging calibration: we've been starting from pTrel-based calibration
  - Reviewing our fit model (important!)

- Have been in close communication with theorists: workshop in Glasgow with people from IPPP, Edinburgh etc, and others

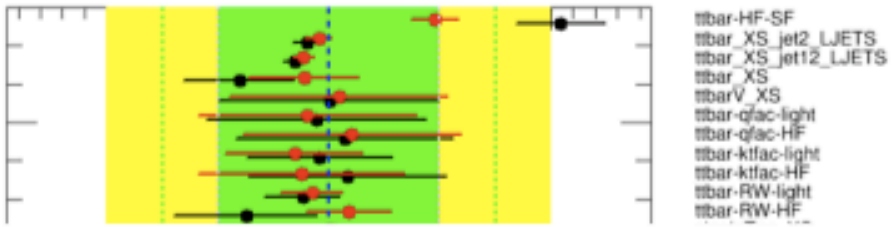
Example: default fit model

- BDDP



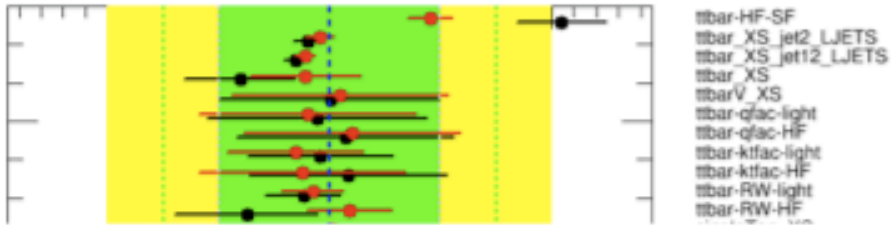
Mu = 4.4+-2.1

- Mbb



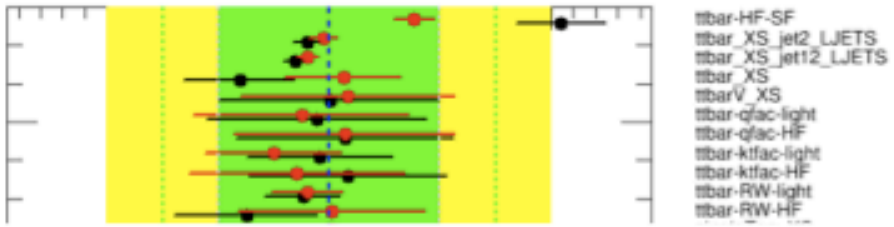
Mu = 2.8+-2.4

- Mbb/2



Mu = 2.9+-2.4

- Mbb/2 no PS



Mu = 6.4+-2.1

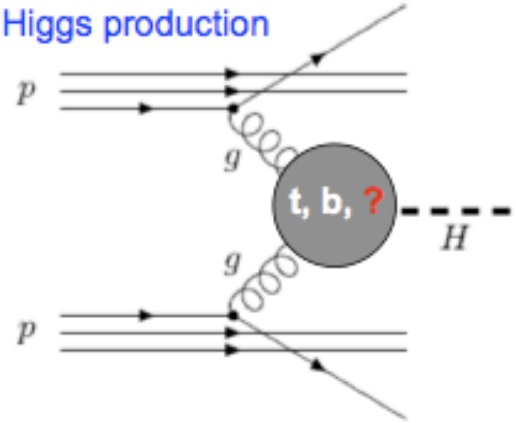
Conclusions

- Very much “work in progress”!
- Now moving to 20/fb 8TeV data
  - Hopefully first plots in Higgs plenary this week
- Aiming at a CONF note in the Fall
- Wish list:
  - Improved theory understanding of background (and NLO signal)
  - Improved fit model
  - Continuous b-tagging: very strong discriminant

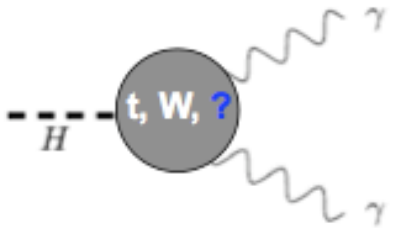
Bonus slides

Motivation

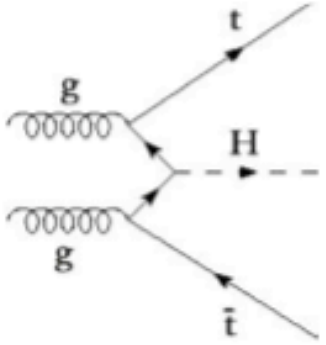
Higgs production



Higgs decay to photons

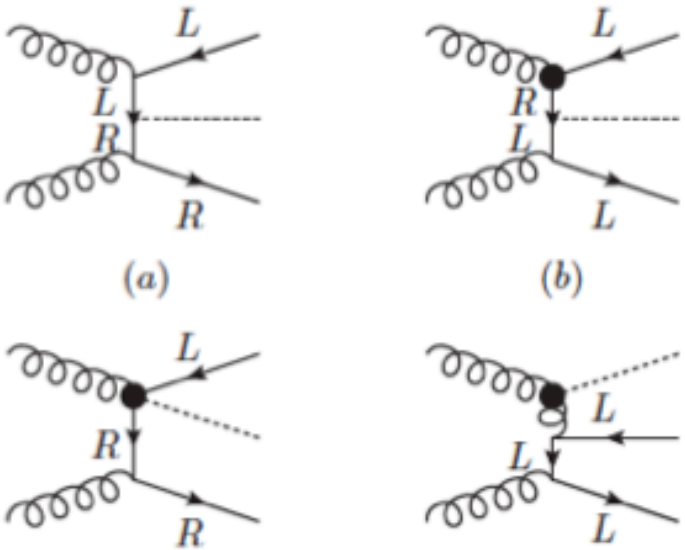


Higgstrahlung from top quark

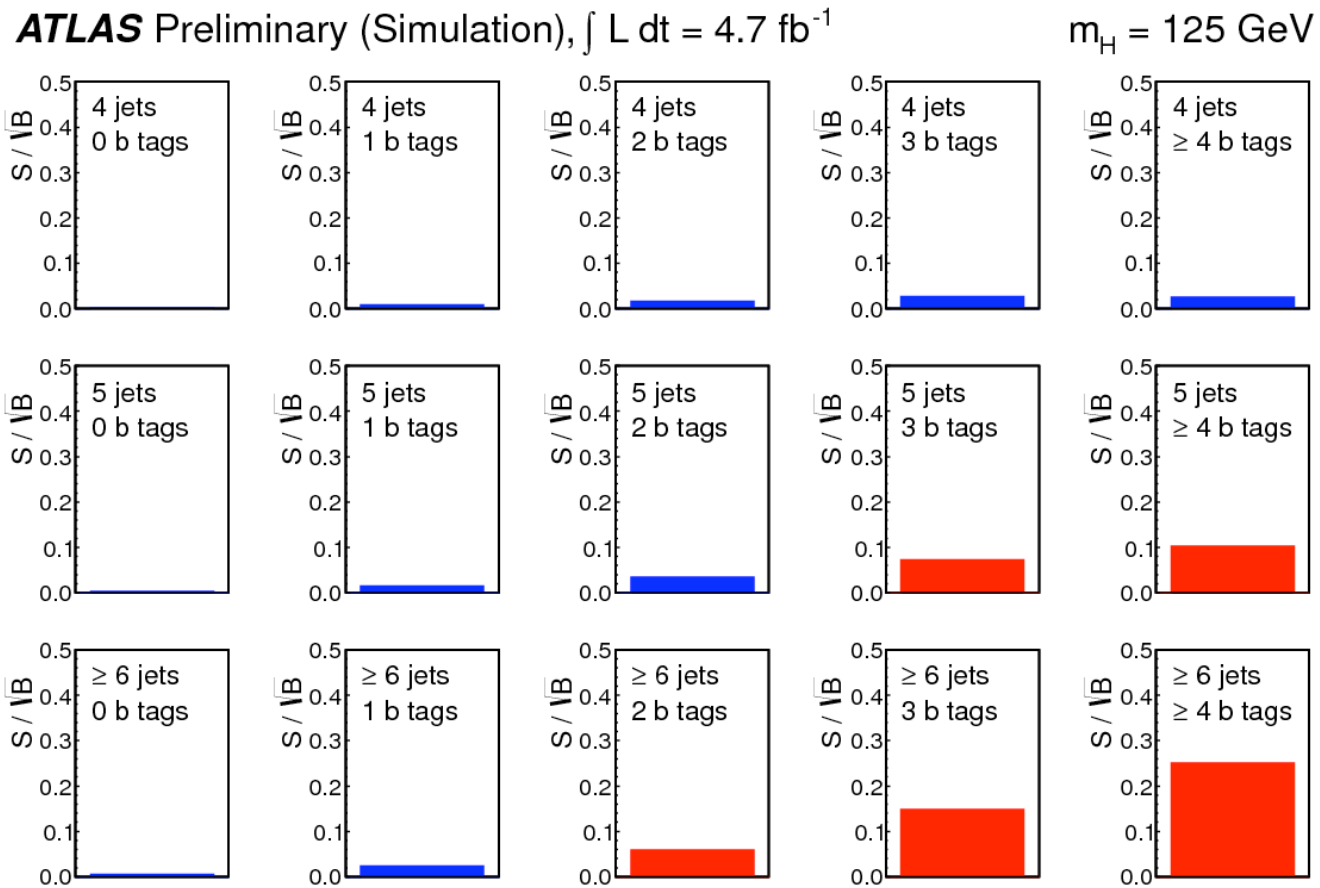


$$\sigma(t\bar{t}H) \propto g^2_{ttH}$$

arXiv:1205.1065



- Effective top-Higgs Yukawa coupling can deviate from SM prediction from new higher-dimension operators that are basically unconstrained.
- Many New Physics models predict signatures of $t\bar{t}$+heavy-flavor jets. E.g.
  - Top-quark compositeness
  - SUSY: $\tilde{g}\tilde{g} \rightarrow (tt\tilde{\chi}_1^0)(bb\tilde{\chi}_1^0)$
  - Charged Higgs: $pp \rightarrow tbH^+ \rightarrow tb(tb)$
  - …


ATLAS Preliminary (Simulation), ∫ L dt = 4.7 fb-1
mH = 125 GeV
S / √B
4 jets 0 b tags
4 jets 1 b tags
4 jets 2 b tags
4 jets 3 b tags
4 jets ≥ 4 b tags
5 jets 0 b tags
5 jets 1 b tags
5 jets 2 b tags
5 jets 3 b tags
5 jets ≥ 4 b tags
≥ 6 jets 0 b tags
≥ 6 jets 1 b tags
≥ 6 jets 2 b tags
≥ 6 jets 3 b tags
≥ 6 jets ≥ 4 b tags
0.0
0.1
0.2
0.3
0.4
0.5