Recent results of searches for beyond Standard Model physics in ATLAS

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on behalf of the ATLAS Collaboration

- Busy last months for the ATLAS Collaboration
  - ✓ Culminating in a multitude of results shown at ICHEP2016 and Top2016 Conferences

- I will present a subset of recent results from the Higgs and Exotics physics group

- Apologies if your favourite BSM search is not shown in this talk!

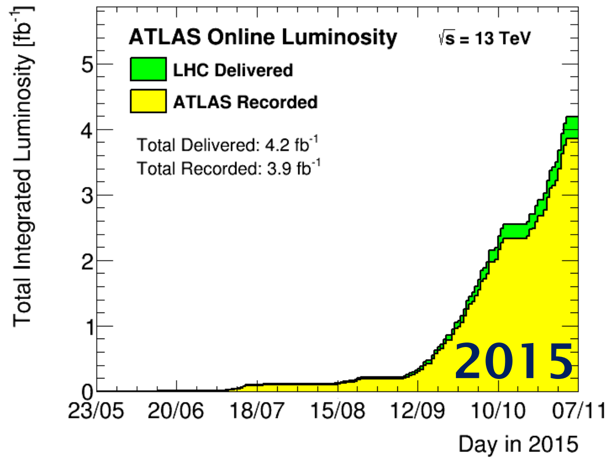
- Focus on BSM physics and top quark, which plays a prominent role in many BSM scenarios

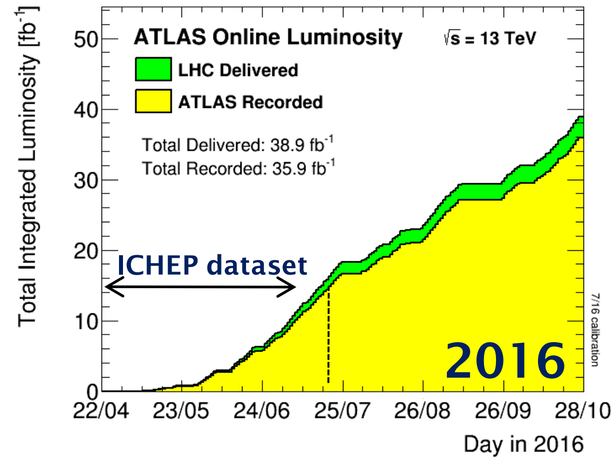
- Look for new phenomena in high jet multiplicity final states:
  - ✓ search for heavy charged Higgs
  - ✓ search for vector-like quarks

- Listing of public ATLAS Higgs and Exotics group results:

  http://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
  http://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

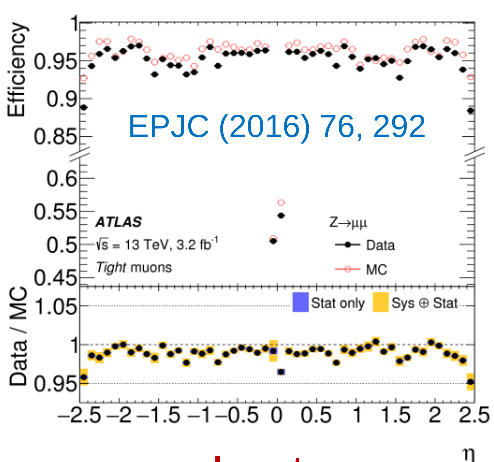
- LHC 2016 proton-proton physics run came to an end, and we have about 10 times more data in 2016 than in 2015!



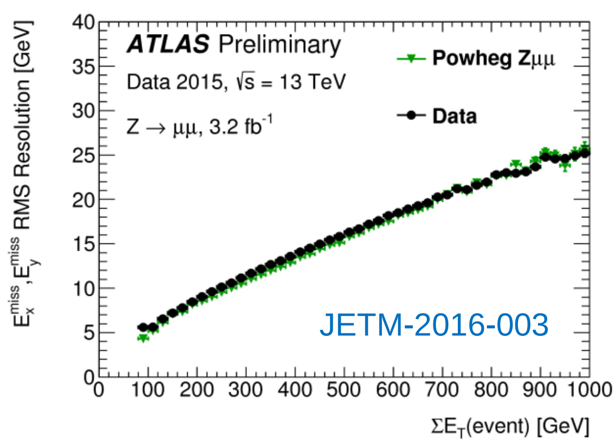


- Results today cover the 2015 dataset (3.2 fb^{-1}) and the “ICHEP2016” dataset (13.2 fb^{-1})

- ATLAS experimental challenges:



Leptons



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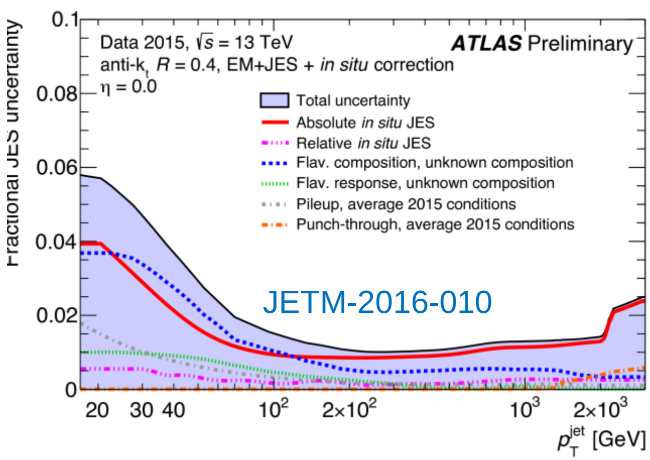
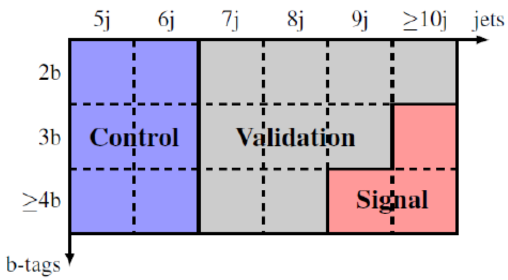
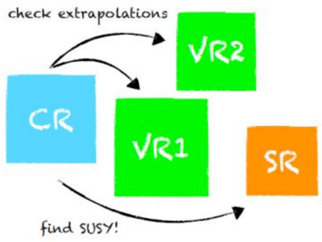


Jets

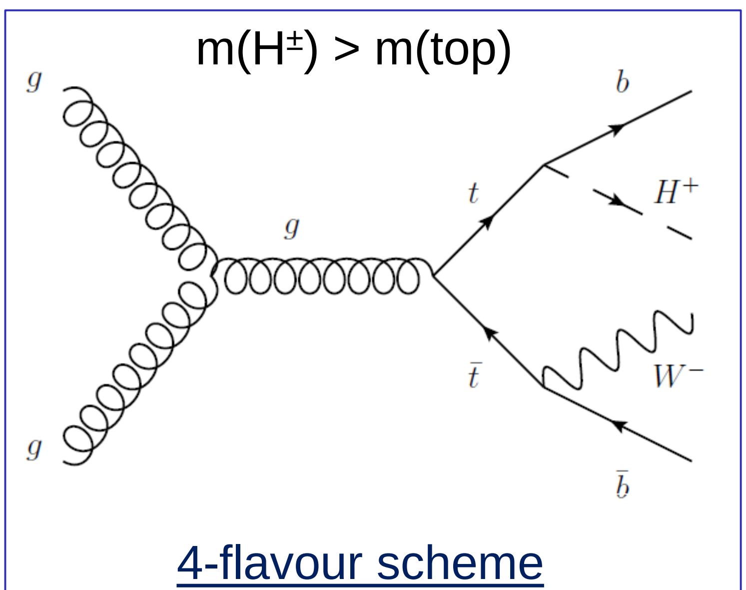
- Strategy for new physics searches (for example, in the case of Higgs boson):
    - Indirectly, by looking for non-standard properties of light Higgs (spin, CP, couplings…)
    - Directly, by explicit search for BSM objects
        - additional Higgs bosons (neutral and charged, decays to SM particles,..)
        - Higgs boson decays to BSM states (light scalar resonances, invisible decays,..)
- In the case of direct searches, define selection based on signal signatures/acceptance and background kinematics
- Compare observed data to Standard Model background (Monte Carlo and data-driven) and MC signal predictions
- Split into control and signal regions, extrapolation checked before unblinding (validation)

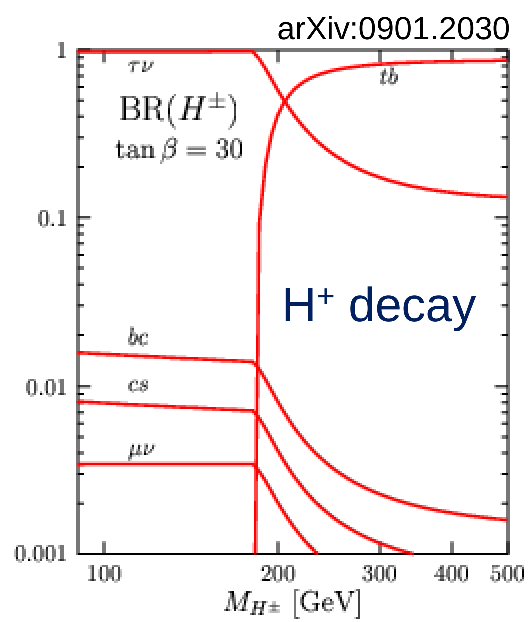


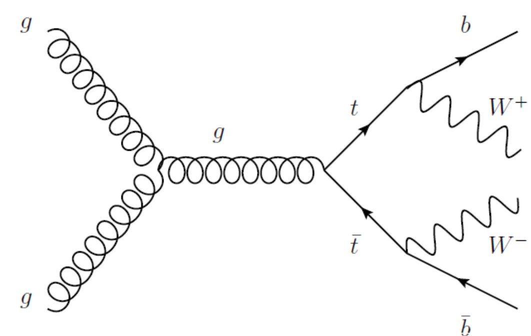


- In the case of no evidence for new physics: set limits on cross-section times branching ratio
- Comparisons provided for specific models, but usually possible to constrain additional models

- No charged scalar bosons exist in SM: many BSM models predict extended Higgs sectors containing charged Higgs bosons (2HDM, Higgs triplets…)
- Example: two-Higgs-doublet model (2HDM) adds 5 physical states (h, H, A, $H^{\pm}$)
- 4 types depending on which fermion couples to which doublet (tan β = $<\Phi_2>/<\Phi_1>$)
    - Minimal Supersymmetric SM is a special case of type II 2HDM, often used as benchmark
- At high $H^{\pm}$ mass, the main production mode of heavy charged Higgs boson at the LHC is in association with a top quark, and $H^{\pm} \rightarrow tb$ is the dominant decay mode
- Focus on final state (4FS): t (→ Wb) b $H^{\pm}$ (→ tb), dominant background is top pairs + jets



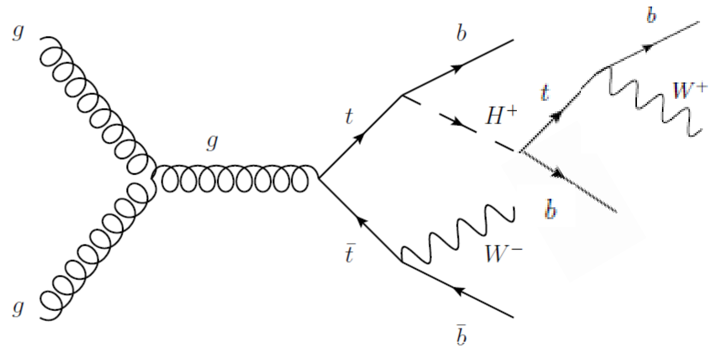




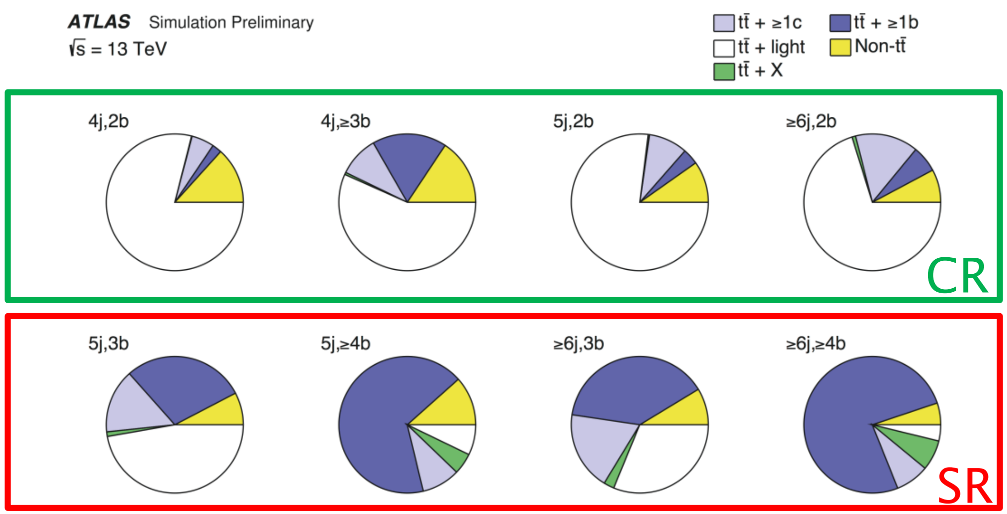
Top-quark pair production

Search for charged Higgs boson in the H→tb decay

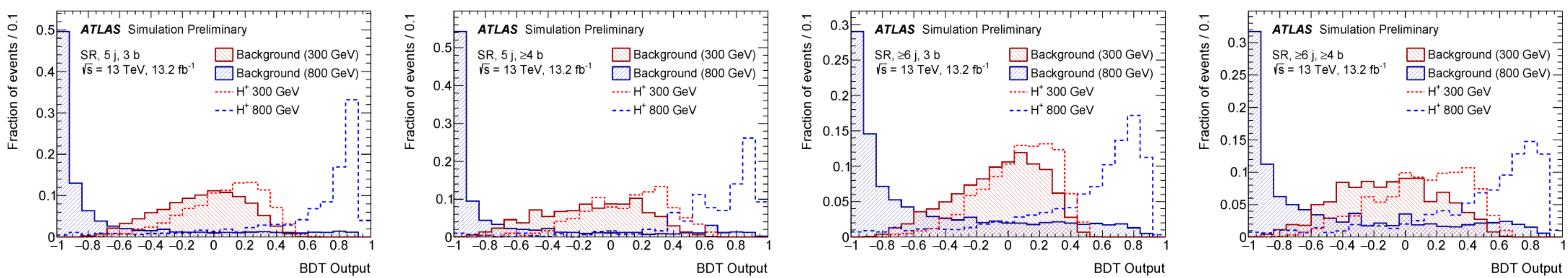
ATLAS-CONF-2016-089 (08/16)



- Single lepton with p_T > 25 GeV, ≥ 4 jets with p_T > 25 GeV and at least 2 b-tagged jets



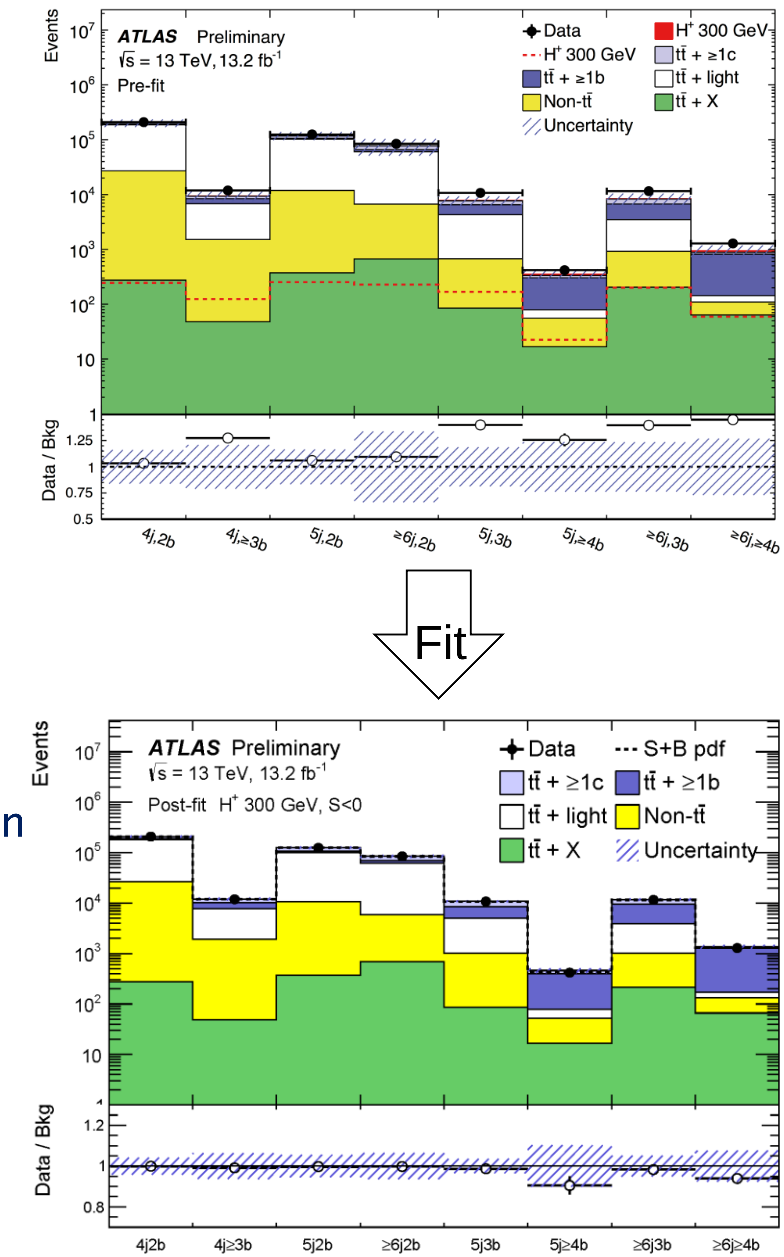
- Split into 4 signal and 4 control regions based on number of jets and b-tagged jets
- Dominant background is top quark pair + heavy flavour jets
- Maximum likelihood fit to all regions based scalar sum of jet p_T in control and boosted decision trees (BDT) output in signal regions as discriminants



Search for charged Higgs boson in the H→tb decay

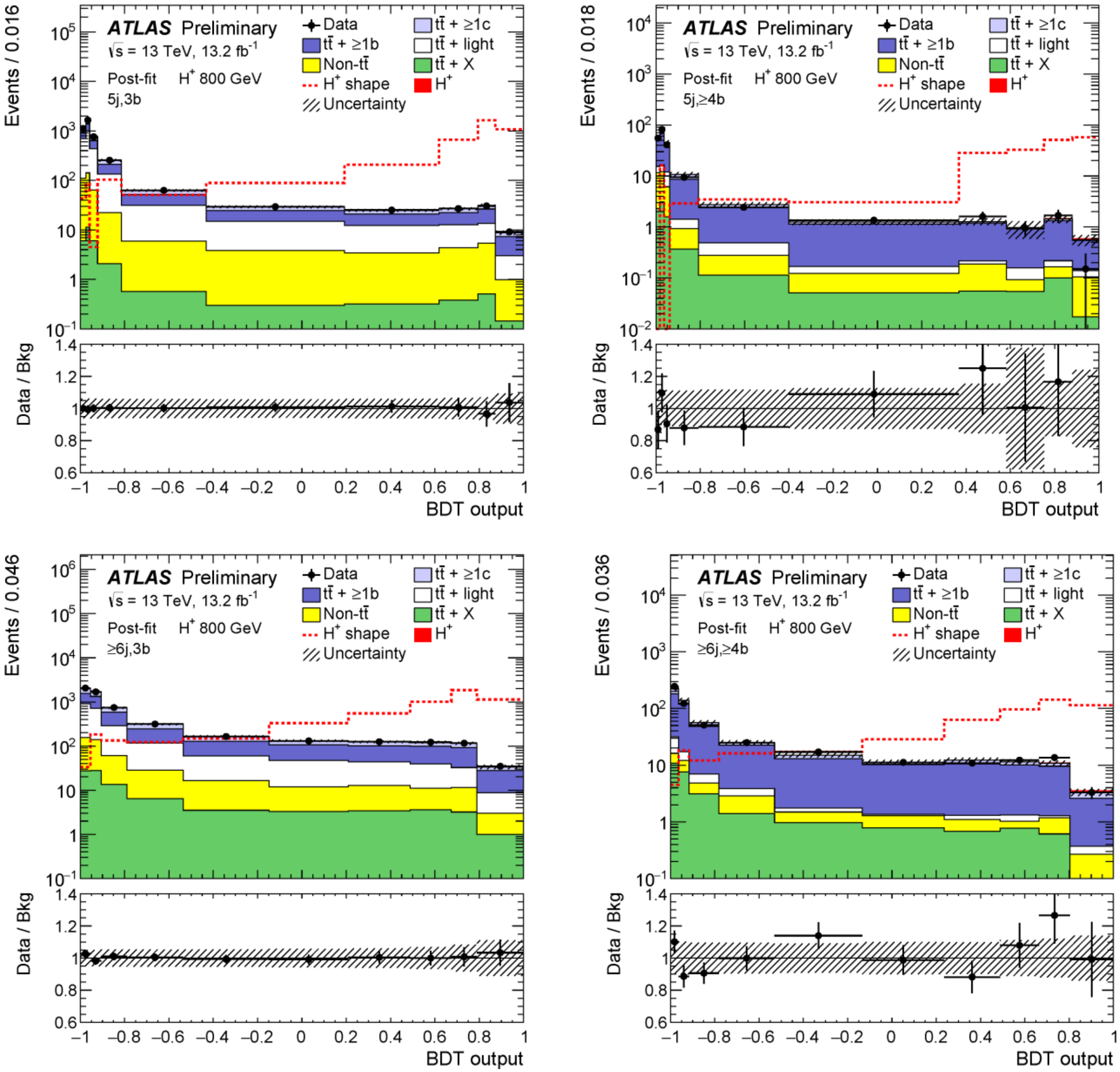
ATLAS-CONF-2016-089 (08/16)

- tt+jets production:
  - split into light/heavy flavour based on extra jets tt+light, tt +≥1c, tt+≥1b
- Rely on MC (Powheg+Pythia6) to describe tt+jets
  - tt+≥1b kinematics reweighted to dedicated NLO Sherpa+OpenLoops prediction
  - tt+light and tt+≥1c reweighted to NNLO prediction for p_T^{tt} and p_T^{top} (arxiv:1606.03350)
  - Normalisation of tt +≥1c and tt+≥1b contributions freely floating in the fit
- BDT trained against:
  - tt+≥1b for $m_{H^\pm}$ < 500 GeV, reduces syst. correlation
  - all the backgrounds for $m_{H^\pm}$ > 500 GeV
- Sources of systematic uncertainty:
  - luminosity measurement
  - reconstruction of physics objects
  - signal/background modelling
  - affect normalisation and/or shapes



Search for charged Higgs boson in the H→tb decay

ATLAS-CONF-2016-089 (08/16)

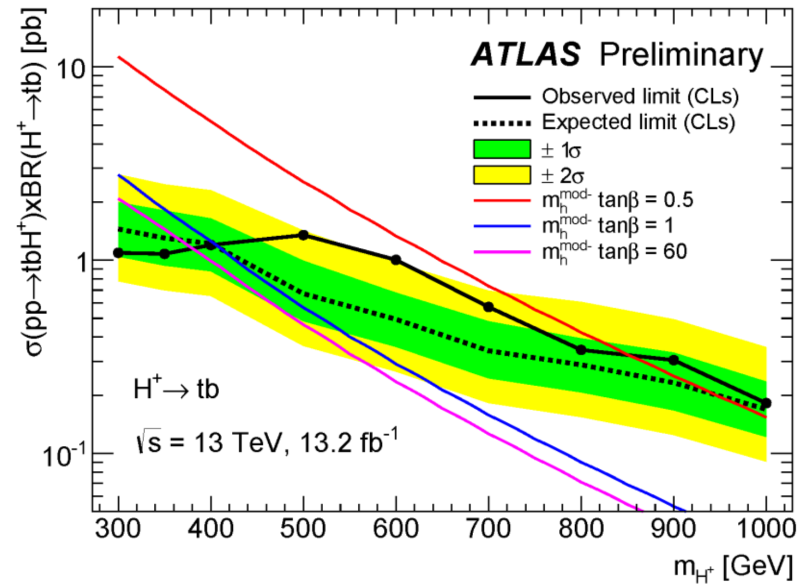


- Signal and control region normalisation and shape well described after fit
- No significant excess observed

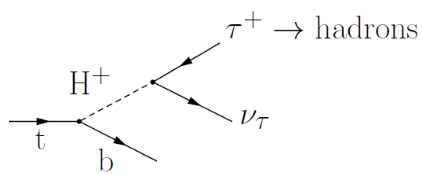
Search for charged Higgs boson in the H→tb decay

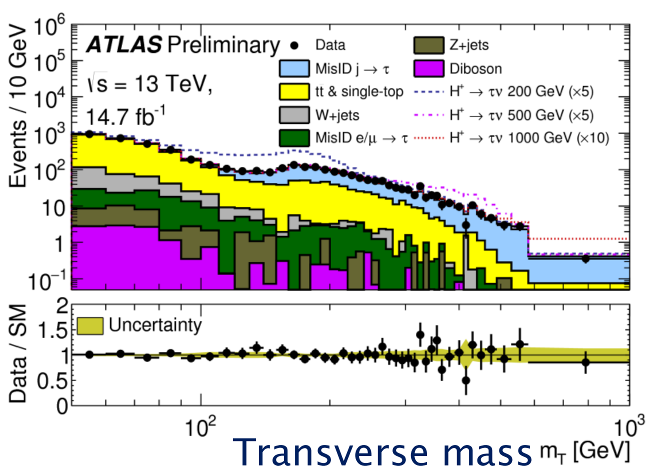
ATLAS-CONF-2016-089 (08/16)

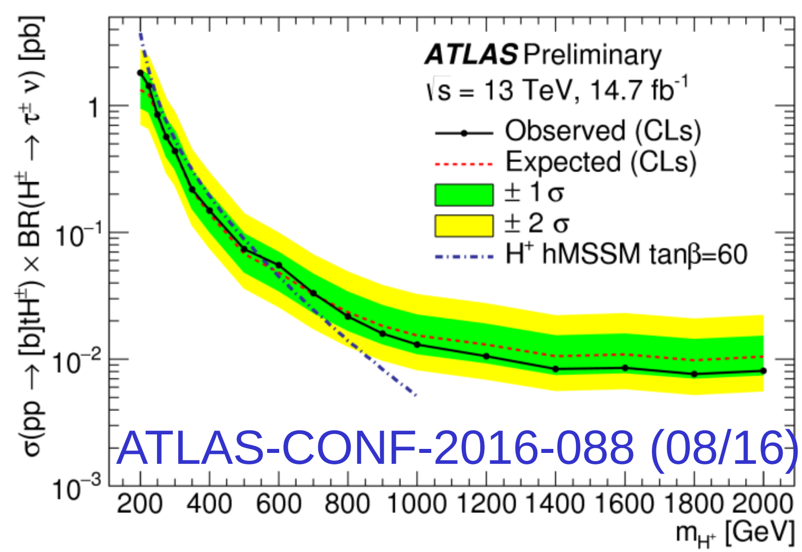
- Observed cross-section times branching ratio limits of the order of 1.1 – 0.18 pb for m(H⁺) range of 300 GeV – 1 TeV
- Unlike Run I, no broad excess
  - observe 2.1σ excess at 600 GeV
- Exclude high values of tan β for m(H⁺) < 380 GeV



- Similar sensitivity as ATLAS search for charged Higgs boson production decaying to τν in the fully hadronic final state







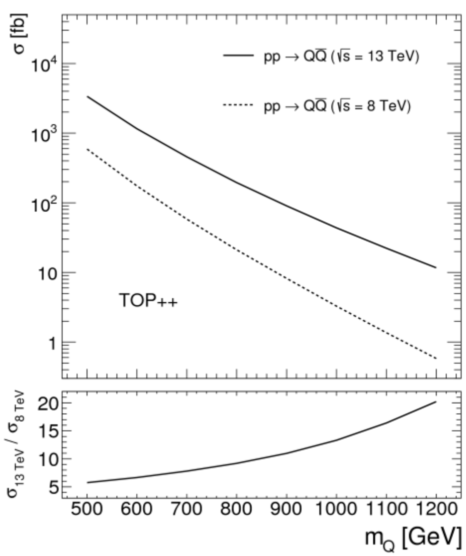
- Chiral 4th quark generation excluded by Higgs boson measurements

- Vector-like quarks (VLQ):
  spin ½, coloured, charged
  LH and RH coupling to charged currents

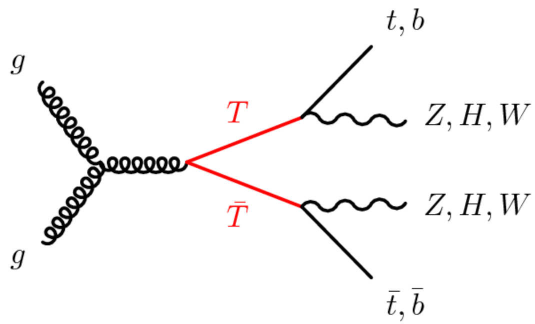
- Arise in little Higgs, composite Higgs, extra dimensions, and GUTs models, naturalness would require $m_Q \leq 2$ TeV

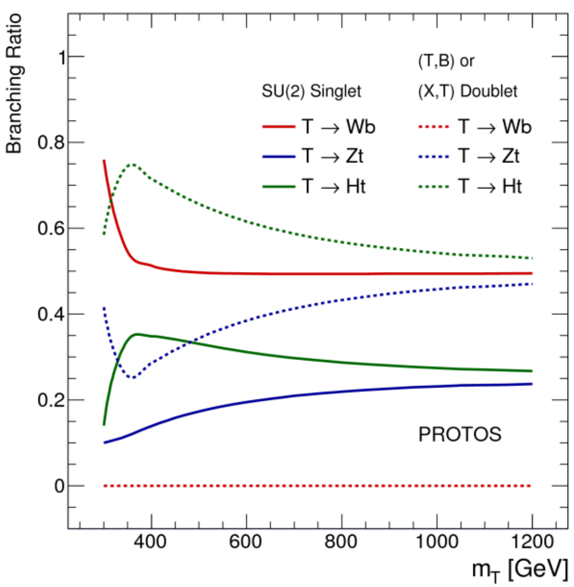
	VLQ	Q [e]	T3
singlets	(T) (B)	+2/3 -1/3	0
doublets	(X,T) (T,B) (B,Y)	+5/3, +2/3 +2/3, -1/3 -1/3, -4/3	± 1/2
triplets	(X,T,B) (T,B,Y)	+5/3, +2/3, -1/3 +2/3, -1/3, -4/3	+1, 0, -1

- Production:
  - strong pair production (less model dependent)
  - single via EW (mixing angles model dependent)

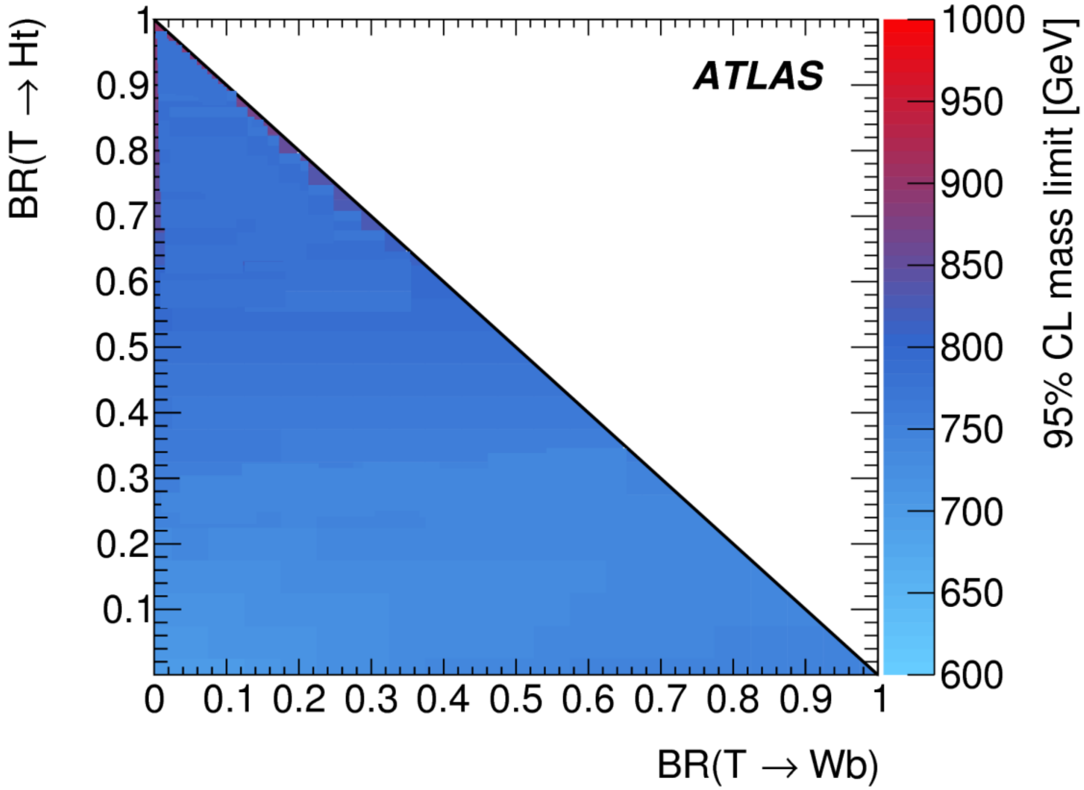


- Decay: usually assume only coupling to 3rd generation:

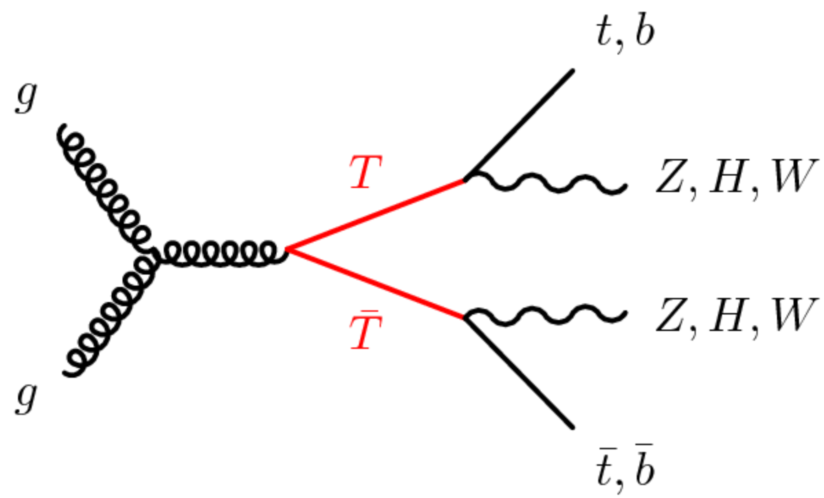


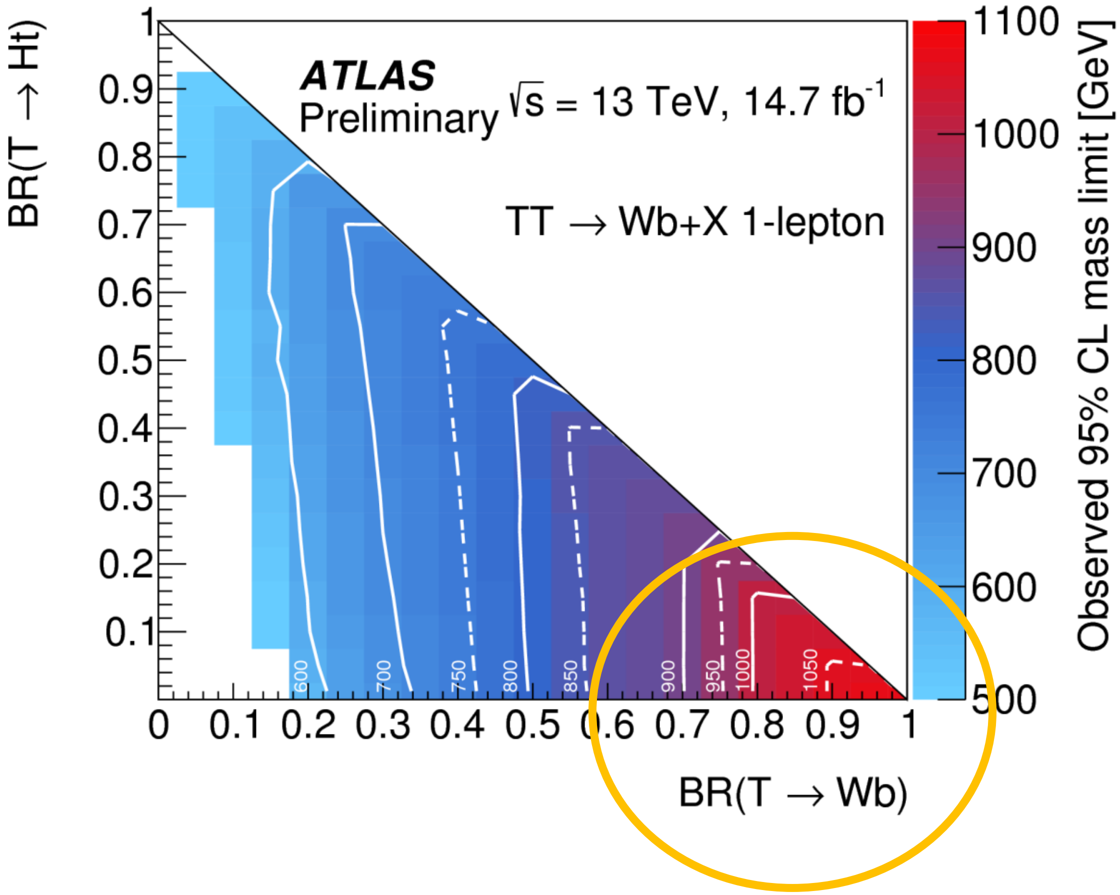


Contour plane of BR(T → Ht) versus BR(T → Wb)



- Multiple final states:





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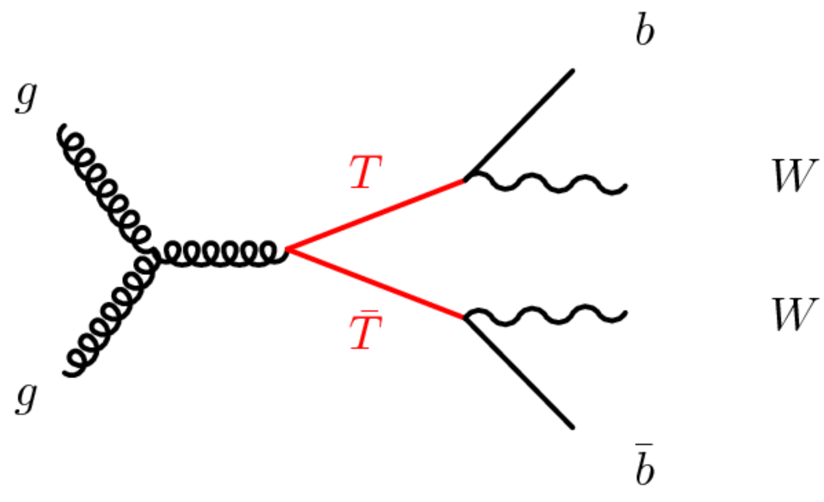
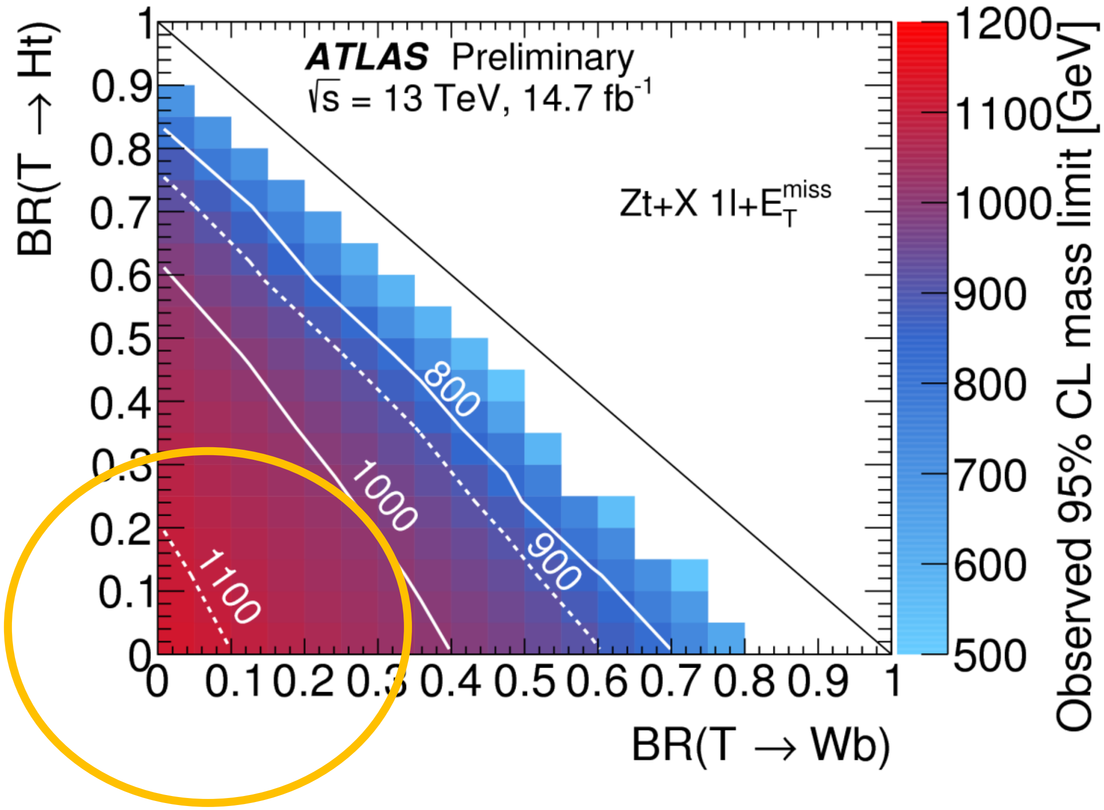
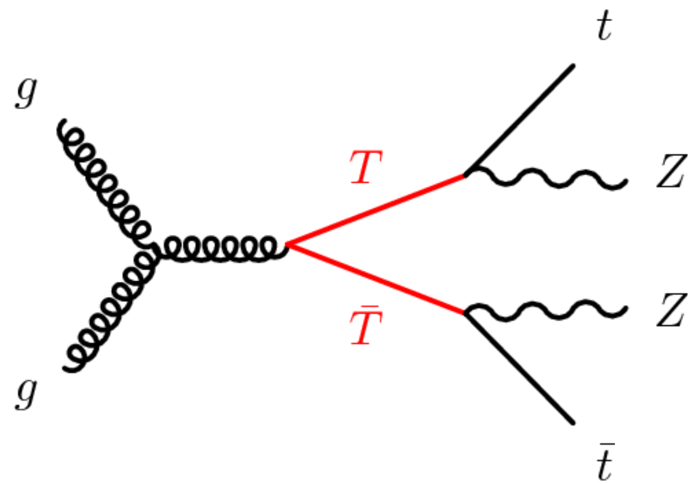


✓ Single-lepton + jets targeting TT → WbWb (ATLAS-CONF-2016-102)

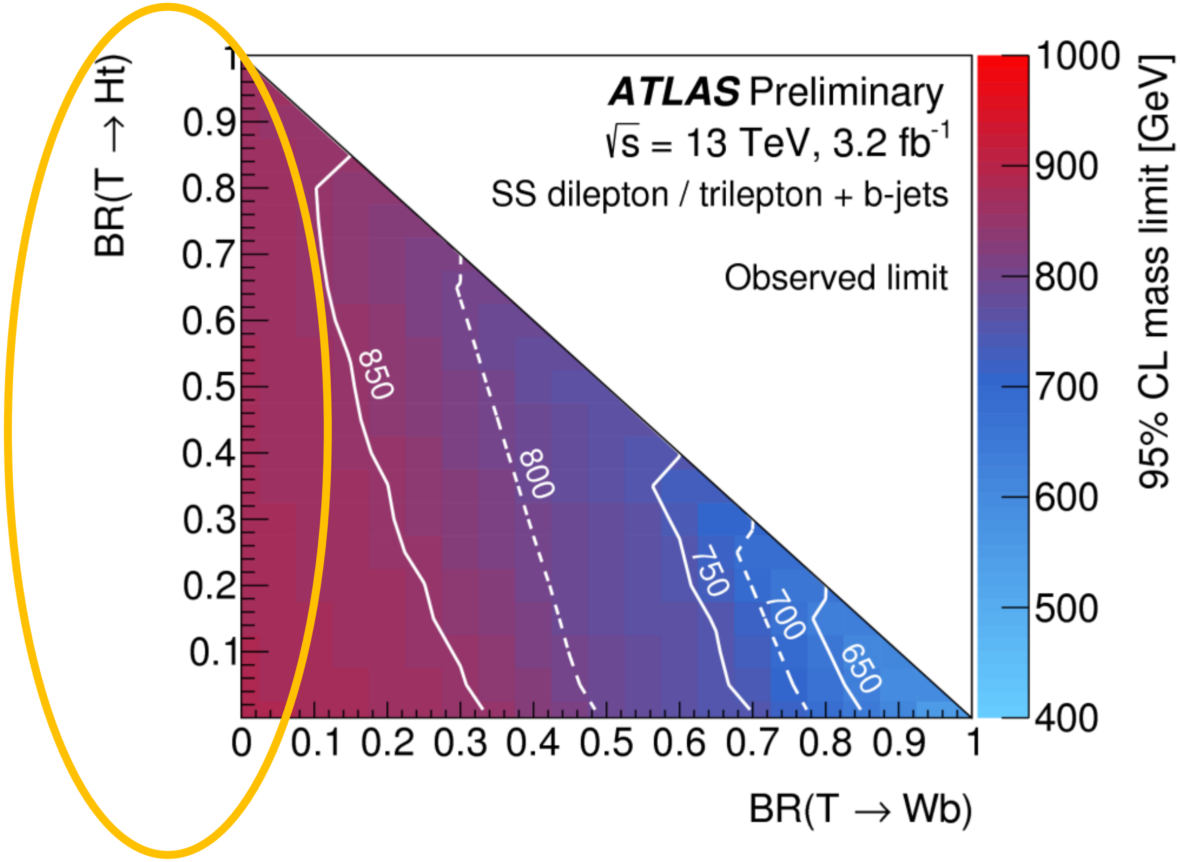


- Multiple final states:

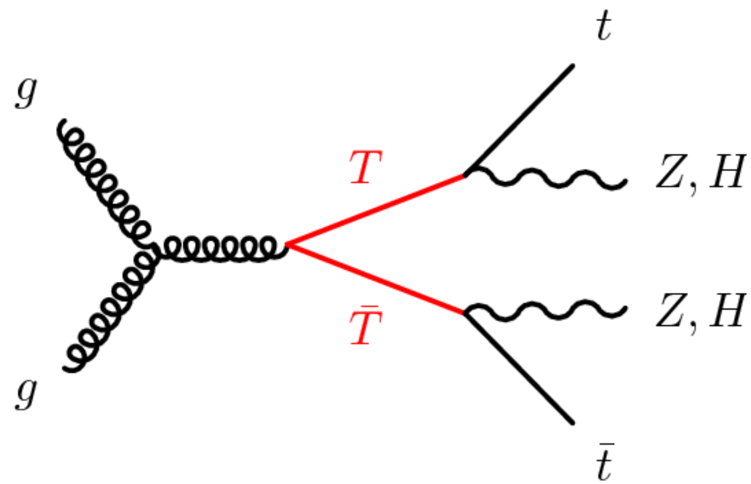


✓ Single-lepton + jets targeting TT → tZtZ (ATLAS-CONF-2016-101)

Contour plane of BR(T → Ht) versus BR(T → Wb)



- Multiple final states:

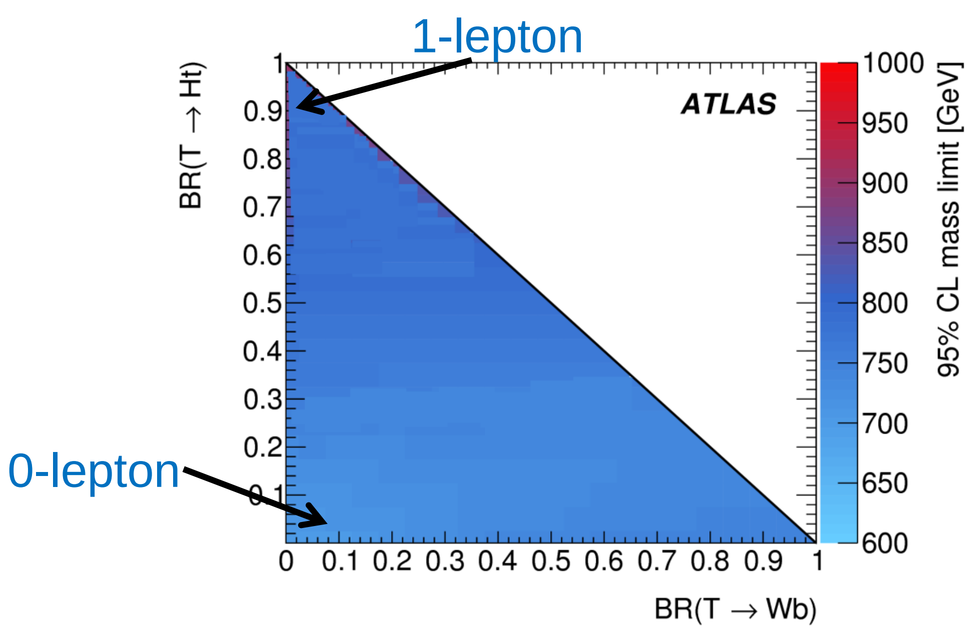


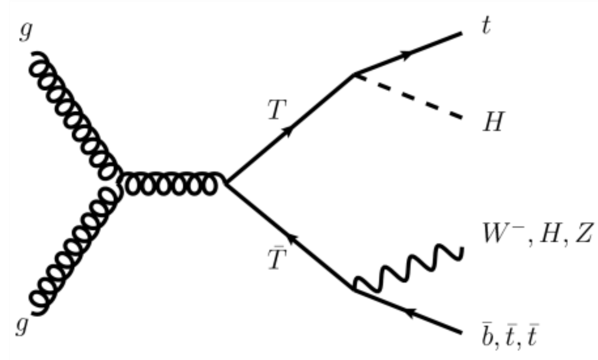
✓ Same-sign leptons targeting TT → tZtZ and TT → tHtH (ATLAS-CONF-2016-032)

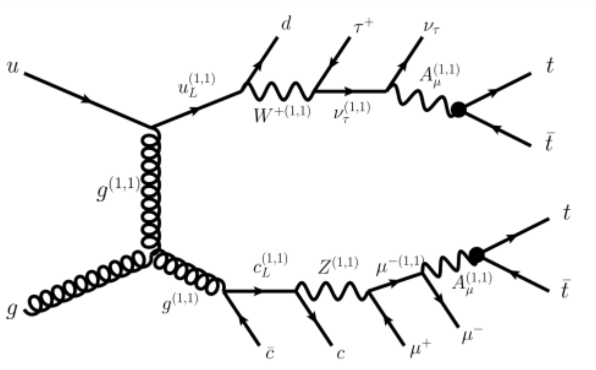
ATLAS-CONF-2016-104 (09/16)

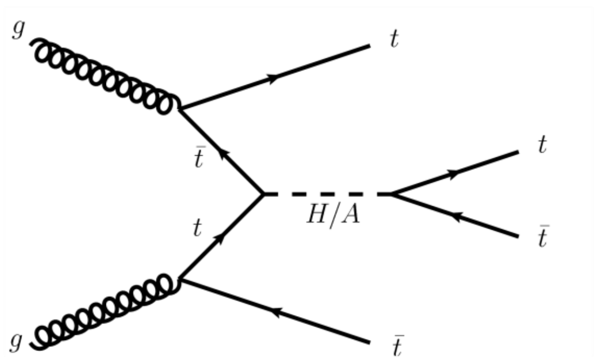
- We can target at once several signal scenarios:
  - ✓ VLQ TT pair production (TT→HtHt, HtZt, HtWb, ZtZt, ZtWb)
  - ✓ 4-top quarks production (SM, 2UED-RPP, EFT)
  - ✓ BSM Higgs (bbH/A(→tt), ttH/A (→tt), tbH+(→tb)

- Orthogonal 1-lepton and 0-lepton analyses probe different corners of branching ratio plane



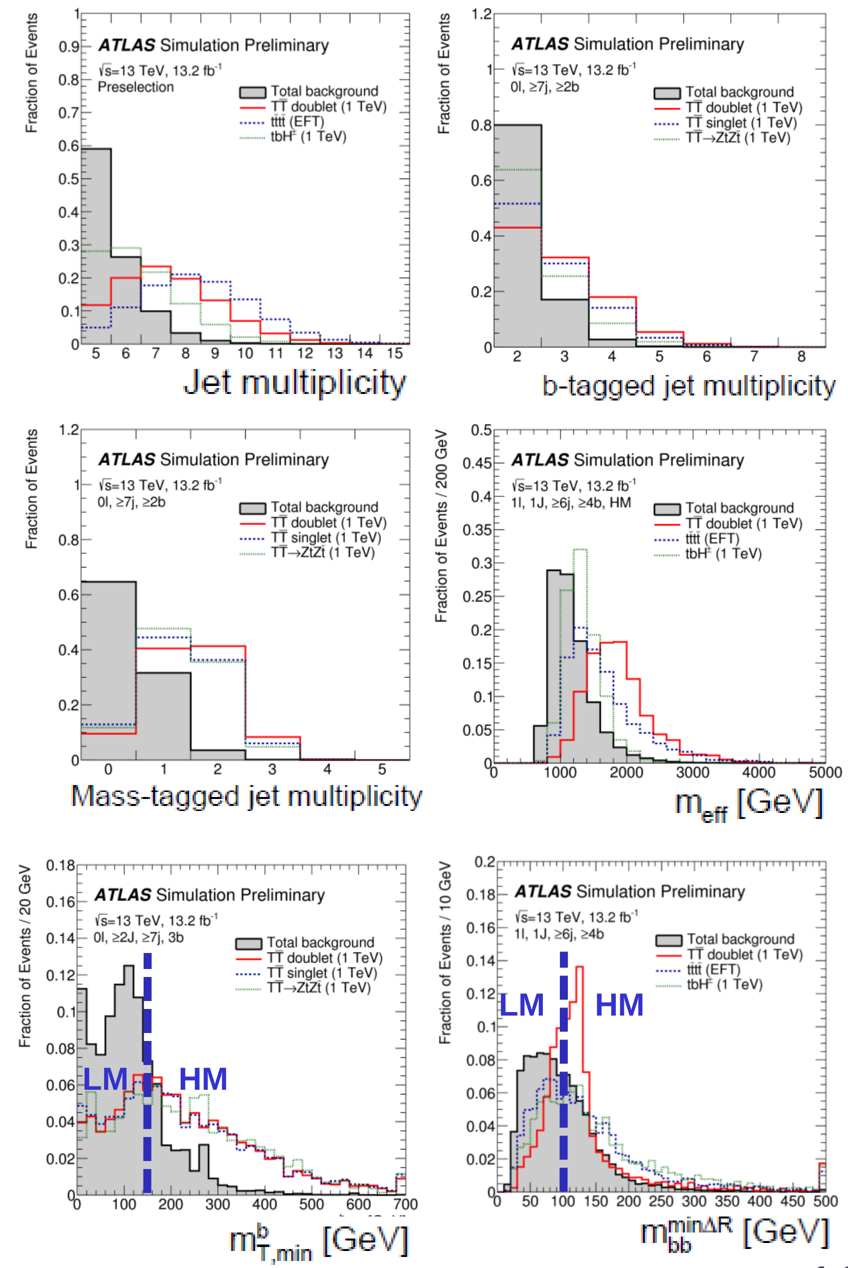






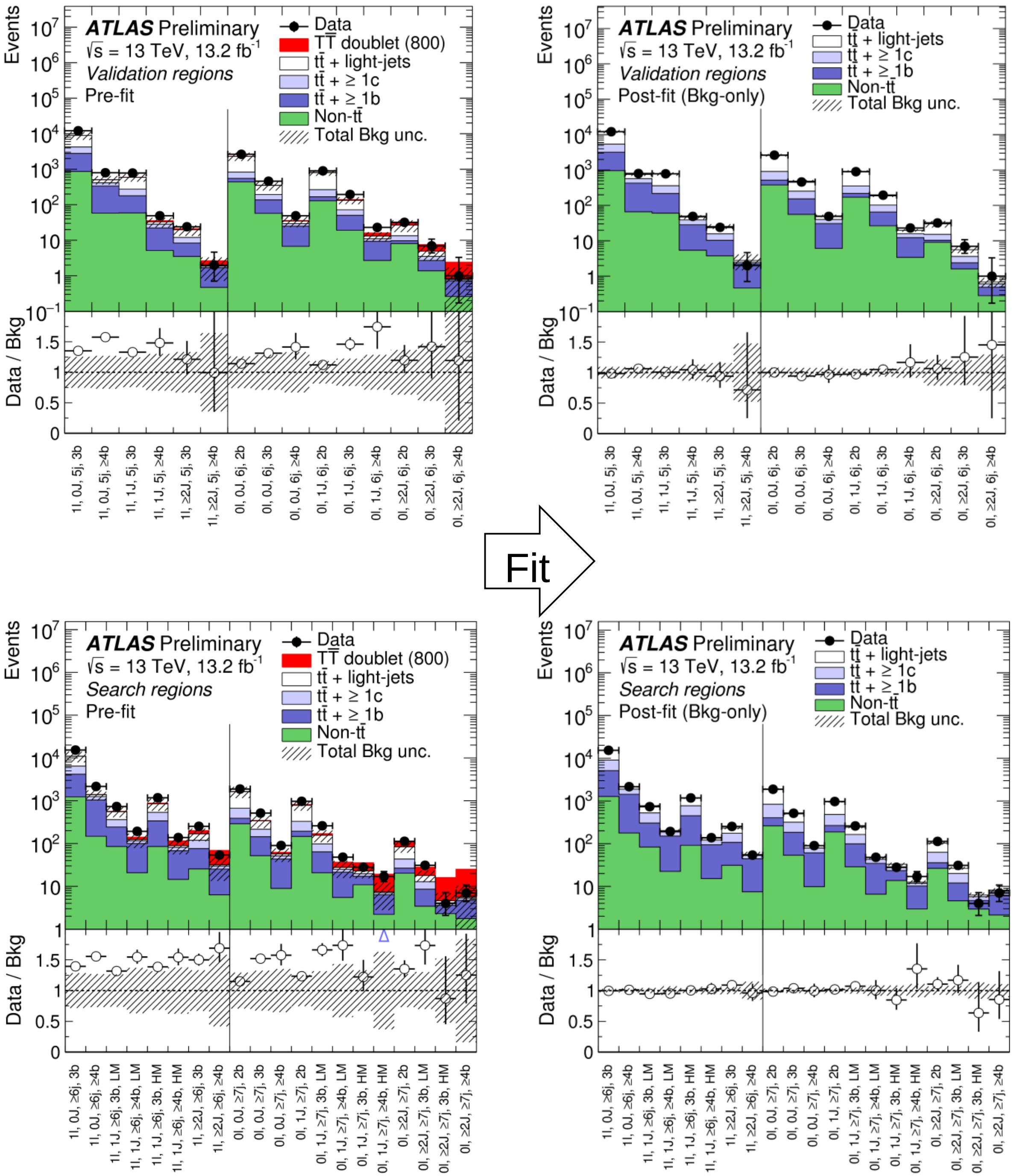
ATLAS-CONF-2016-104 (09/16)

- Analysis pre-selection similar to charged Higgs:
  - 1-lepton channel: 1 lepton with $p_T > 25$ GeV, ≥5 jets with $p_T > 25$ GeV, out of which ≥2 b-tags
  - 0-lepton channel: MET trigger, ≥6 jets with ≥2 b-jets, cut on MET > 200 GeV
- Split by number of jets (5, ≥6), number of b-jets (2, 3, ≥4) and # of mass-tagged jets (0, 1, ≥2)
  - reclustered from calibrated small-R jets with anti-kT R=1.0, M > 100 GeV, and $p_T > 300$ GeV
- Signal discrimination based on shape of effective mass $m_{eff} = \Sigma p_T^{jets} + p_T^{lepton} + MET$ used in a profile likelihood fit performed across signal regions
- Enhance further S/B:
  - 1-lepton channel: high $m_{bb}^{\min\Delta R}$ increases sensitivity to signals with H→bb in final state
  - 0-lepton channel: cut on $m_{T,\min}^{b}$ (min. transv. mass between MET and leading 3 b-jets)



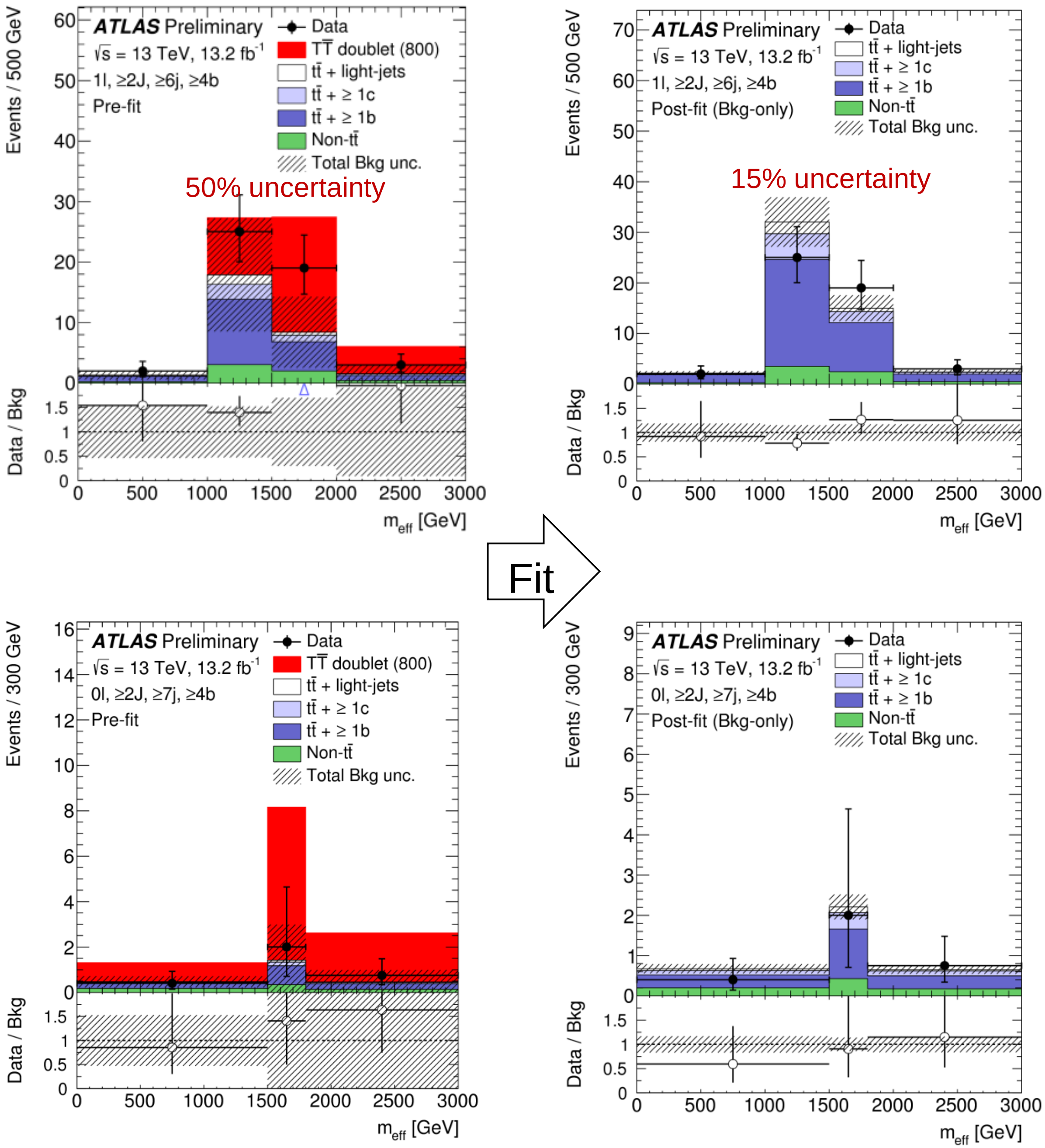
Analysis overview: VLQ/4tops/HBSM

ATLAS-CONF-2016-104 (09/16)



- Total of 8 (12) search regions and 6 (9) validation regions in 1(0)-lepton channel
  - regions with ≥ 6 (7) jets are search regions and with exactly 5(6) jets are validation regions
- Different phase-spaces covered by each channel
- Complex top-quark pair background model (low to high signal purity)

ATLAS-CONF-2016-104 (09/16)



- Shape of effective mass distribution is well described by background-only hypothesis
- No significant excess observed
- Limits sets on several signal models

Analysis overview: VLQ/4tops/HBSM

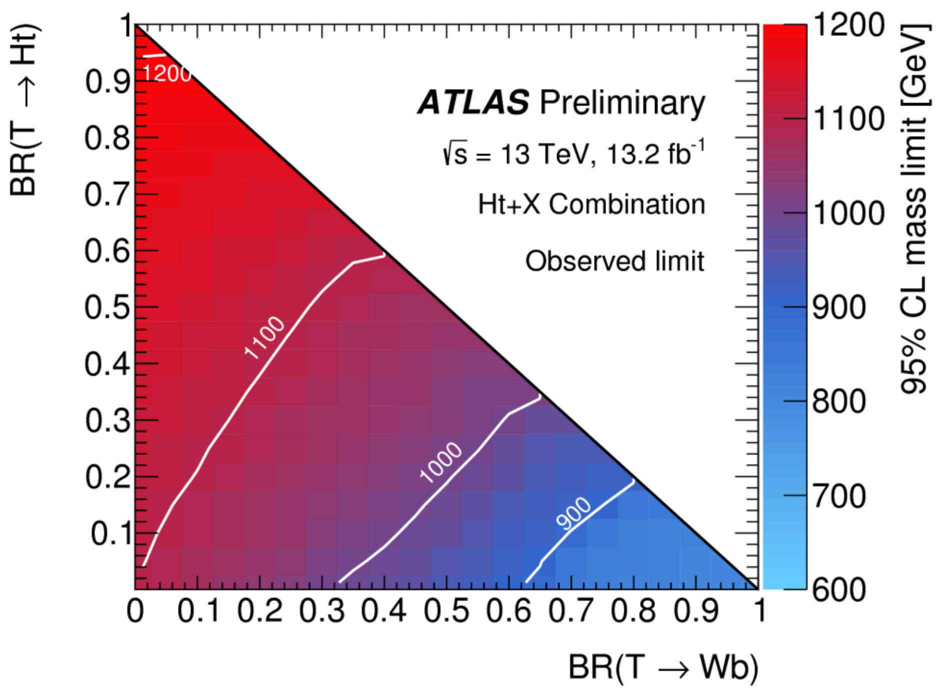
ATLAS-CONF-2016-104 (09/16)

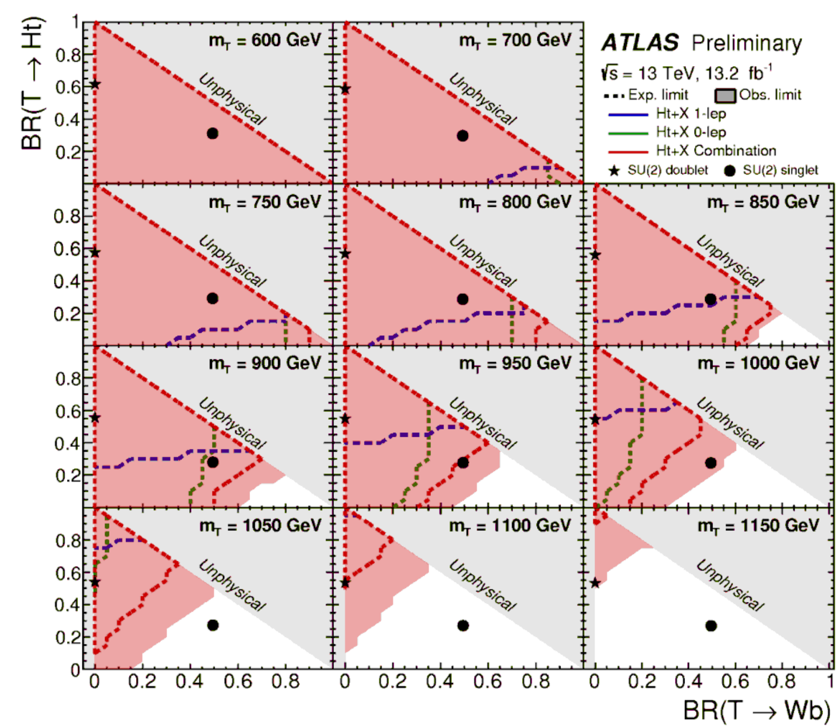
- VLQ scenarios extended sensitivity of previous searches by ~200-300 GeV wrt to previous search
- Model-independent limits on 2D BR plane with good coverage obtained from combination

95% CL lower limits on T quark mass [GeV]				
Search	BR($T \to Ht$) = 1	BR($T \to Zt$) = 1	Doublet	Singlet
1-lepton channel	1180 (1120)	740 (820)	1060 (1000)	900 (880)
0-lepton channel	1090 (1070)	1060 (1010)	1090 (1060)	950 (890)
Combination	1200 (1160)	1100 (1040)	1160 (1110)	1020 (960)

Previous ATLAS $T\bar{T} \to Ht$+X searches (1-lepton)					Ref.
Run 2 (3.2 fb^{-1})	900 (980)	700 (740)	800 (900)	750 (780)	[24]
Run 1	950 (880)	750 (690)	860 (820)	760 (720)	[18]

- Complimentarity of 0-lepton and 1-lepton analyses evident

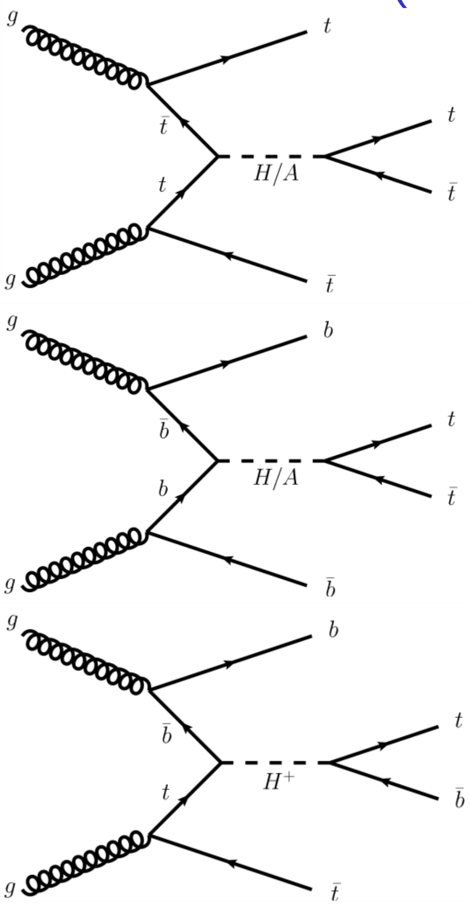


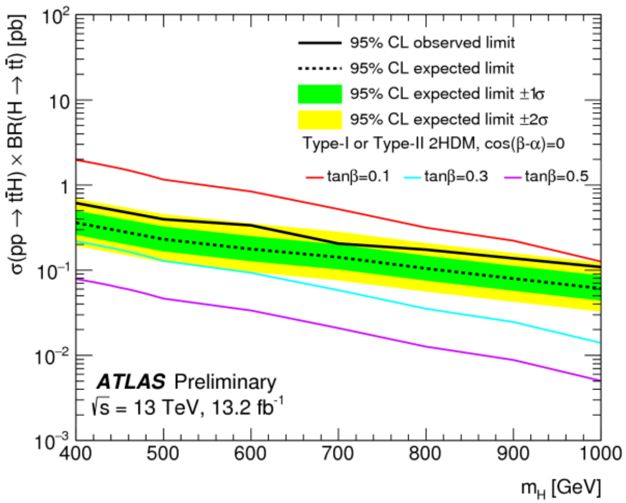


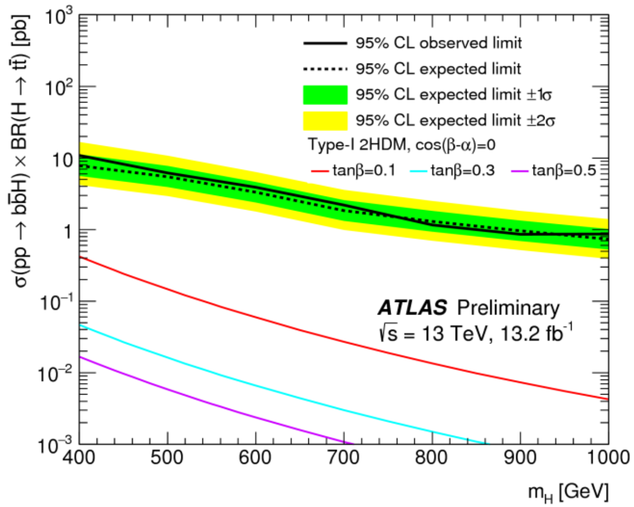
Analysis overview: VLQ/4tops/HBSM

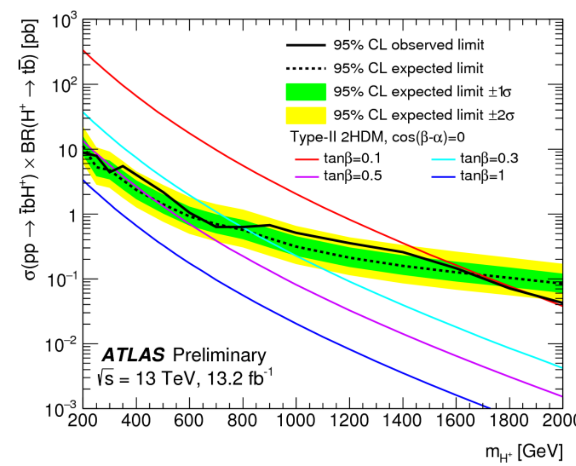
ATLAS-CONF-2016-104 (09/16)

- Extended Higgs sector in 2HDM model, H/A to top-quarks pair decay is dominant for $m_{H/A} > 2m_{top}$
- Type-II 2HDM model: probing masses from 400 GeV to 1 TeV
- Sensitivity in HBSM ttH(tt): excluding tan $\beta < 0.2$
- First limits on bbH(tt): current analysis not optimal for bbH/A(→tt) due to low acceptance of b-quarks
- Sensitivity in $0.3 < m_{H+} < 1$ TeV about twice worse than dedicated H^+ analysis, also sensitive to $m_{H+} > 1$ TeV



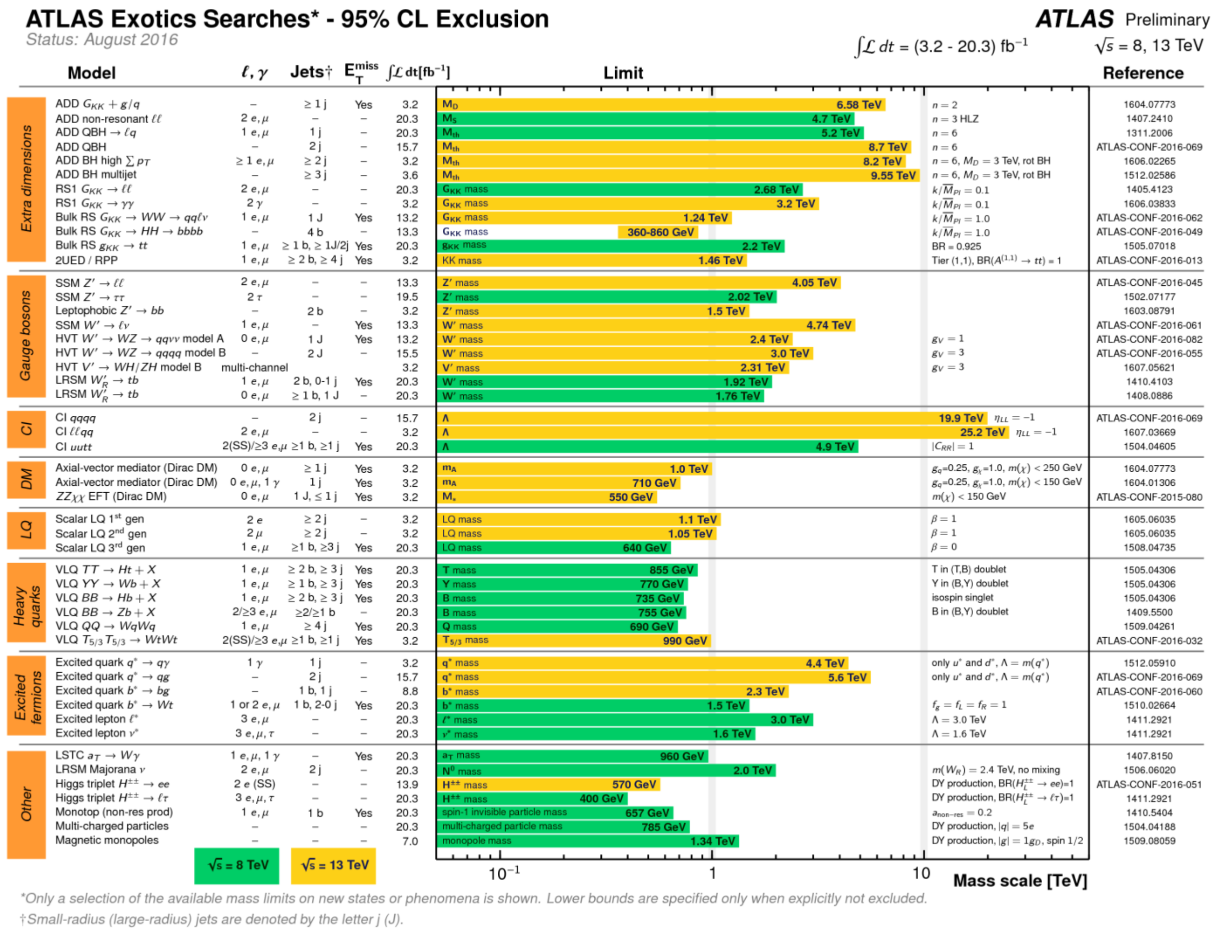






- Several new searches for BSM phenomena with 13 TeV probe a varied range of BSM signals

- Lots of recent results on searches for new states or phenomena:



- Still ~33 fb[-1] of data to analyse ahead of us – let's see…

Muchas gracias por su atención!

Back-up

The variables entering the BDT training are :

- The leading jet p_T.
- The mass of the bb pair with smallest ΔR.
- The p_T of the fifth jet, with the jets ordered by transverse momentum with the b-tagged jets first and then the non-b-tagged jets.
- The second Fox-Wolfram moment calculated using all jets and leptons.
- The average ΔR of all bb pairs.
- The ΔR of the lepton and the bb pair with smallest ΔR.
- The mass of the untagged jet pair with smallest ΔR.
- The scalar sum of E_T calculated using all jets.
- The mass of the bb pair with largest p_T.
- The mass of the bb pair with largest mass.
- The mass of the jet triplet with largest p_T.
- The centrality, defined as the ratio of the scalar sum of the p_T of all jets and leptons over the total visible energy.

Analysis overview: VLQ/4tops/HBSM

Mass-tagged jet multiplicity	b-jet multiplicity	$m_{bb}^{\min\Delta R}$	m_{eff}	Channel name
Search regions (≥6 jets)				
0	3	-	> 400 GeV	0J, ≥6j, 3b
0	≥4	-	> 400 GeV	0J, ≥6j, ≥4b
1	3	< 100 GeV	> 700 GeV	1J, ≥6j, 3b, LM
1	3	> 100 GeV	> 700 GeV	1J, ≥6j, 3b, HM
1	≥4	< 100 GeV	> 700 GeV	1J, ≥6j, ≥4b, LM
1	≥4	> 100 GeV	> 700 GeV	1J, ≥6j, ≥4b, HM
≥2	3	-	-	≥2J, ≥6j, 3b
≥2	≥4	-	-	≥2J, ≥6j, ≥4b
Validation regions (5 jets)				
0	3	-	> 400 GeV	0J, 5j, 3b
0	≥4	-	> 400 GeV	0J, 5j, ≥4b
1	3	-	> 700 GeV	1J, 5j, 3b
1	≥4	-	> 700 GeV	1J, 5j, ≥4b
≥2	3	-	-	≥2J, 5j, 3b
≥2	≥4	-	-	≥2J, 5j, ≥4b

Mass-tagged jet multiplicity	b-jet multiplicity	$m_{\mathrm{T,min}}^{b}$	Channel name
Search regions (≥7 jets)			
0	2	-	0J, ≥7j, 2b
0	3	-	0J, ≥7j, 3b
0	≥4	-	0J, ≥7j, ≥4b
1	2	-	1J, ≥7j, 2b
1	3	< 160 GeV	1J, ≥7j, 3b, LM
1	3	> 160 GeV	1J, ≥7j, 3b, HM
1	≥4	< 160 GeV	1J, ≥7j, ≥4b, LM
1	≥4	> 160 GeV	1J, ≥7j, ≥4b, HM
≥2	2	-	≥2J, ≥7j, 2b
≥2	3	< 160 GeV	≥2J, ≥7j, 3b, LM
≥2	3	> 160 GeV	≥2J, ≥7j, 3b, HM
≥2	≥4	-	≥2J, ≥7j, ≥4b
Validation regions (6 jets)			
0	2	-	0J, 6j, 2b
0	3	-	0J, 6j, 3b
0	≥4	-	0J, 6j, ≥4b
1	2	-	1J, 6j, 2b
1	3	-	1J, 6j, 3b
1	≥4	-	1J, 6j, ≥4b
≥2	2	-	≥2J, 6j, 2b
≥2	3	-	≥2J, 6j, 3b
≥2	≥4	-	≥2J, 6j, ≥4b

Preselection requirements

Requirement	1-lepton channel	0-lepton channel
Trigger	Single-lepton trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
Leptons	=1 isolated e or μ	=0 isolated e or μ
Jets	≥5 jets	≥6 jets
b-tagging	≥2 b-tagged jets	≥2 b-tagged jets
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV
Other $E_{\mathrm{T}}^{\mathrm{miss}}$-related	$E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}^{W} > 60$ GeV	$\Delta\phi_{\mathrm{min}}^{4j} > 0.4$