Search for exotics with top at ATLAS

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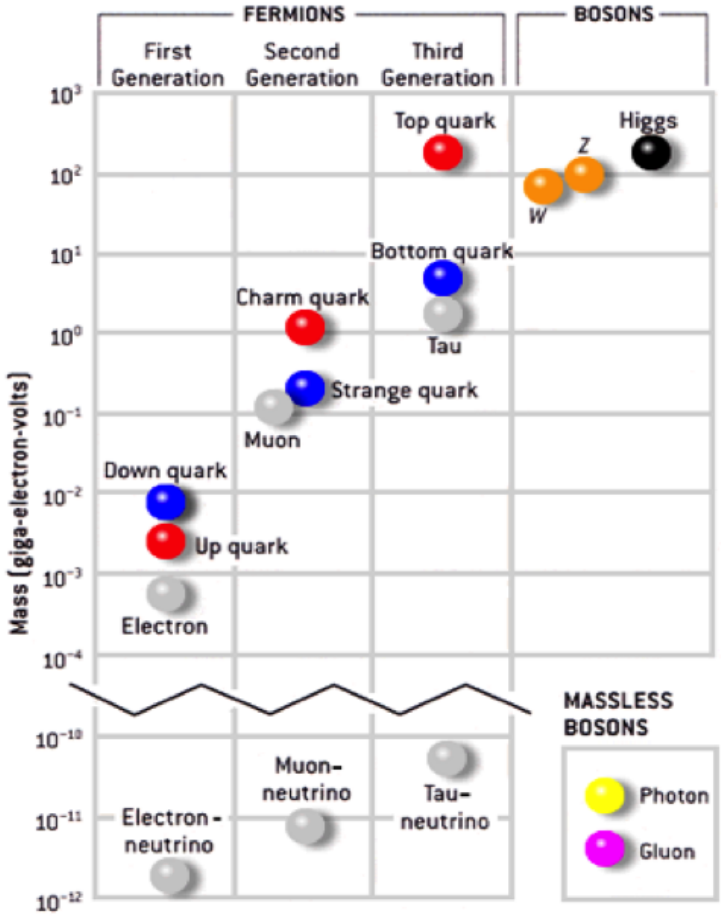
EPSHEP2013, Stockholm

July 18, 2013

Motivation

- Due to its large mass, top quark offers a unique window to search for new physics:
  - $m_t \sim \Lambda_{EWSB}(246\text{GeV})$: top may play a special role in the EWSB
  - Many extensions of the SM explain the large top mass by allowing the top to participate in new dynamics.

- Approaches of new physics search
  - Measure top quark properties: check with SM prediction.
  - Directly search for new particles coupling to top
    - $t\bar{t}$ resonances searches
    - Search for anomalous single top production
    - Vector-like quarks searches
      (Covered in another talk "Searches for fourth generation vector-like quarks with the ATLAS detector")



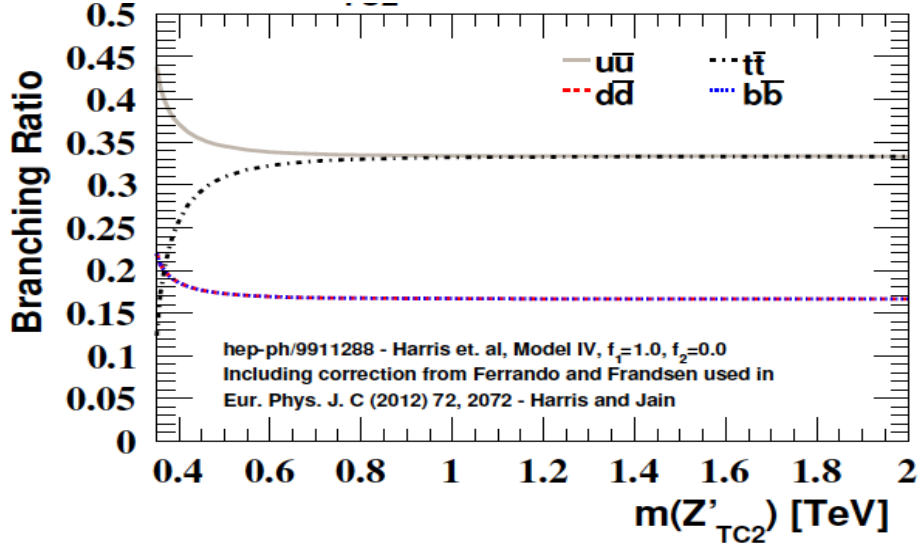
$t\bar{t}$ resonance: benchmark models ATLAS-CONF-2013-052

2 specific models used as examples of sensitivity

- Leptophobic topcolor Z'

  Eur.Phys.J.C72 (2012) 2072

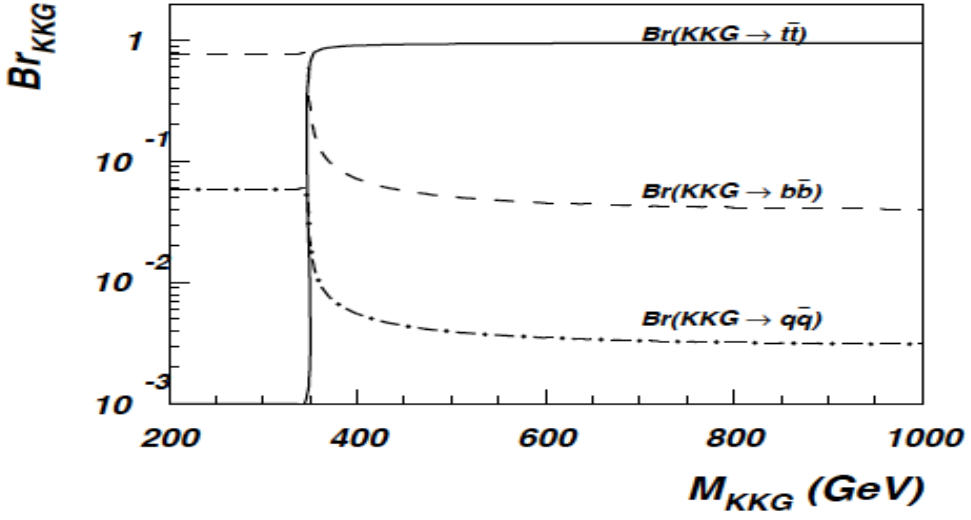
  - Explains the top quark mass and EWSB through top quark condensate
  - Z' couples strongly only to the first and third generation of quarks
  - Narrow resonance: $\Gamma/m \sim 1.2\%$



- Kaluza-Klein gluons

  Phys. Rev. D 77, 015003 (2008)

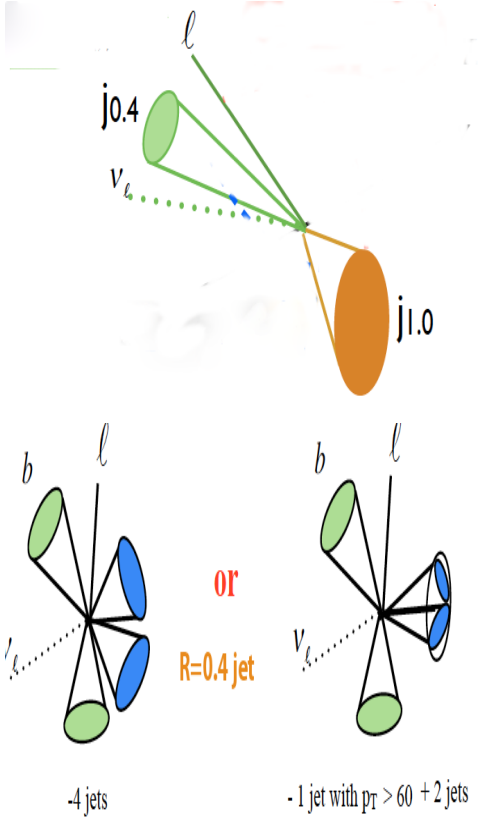
  - Predicted by the Bulk Randall-Sundrum models with warped extra dimension
  - Strongly coupled to the top quark
  - Broad resonance: $\Gamma/m \sim 15\%$



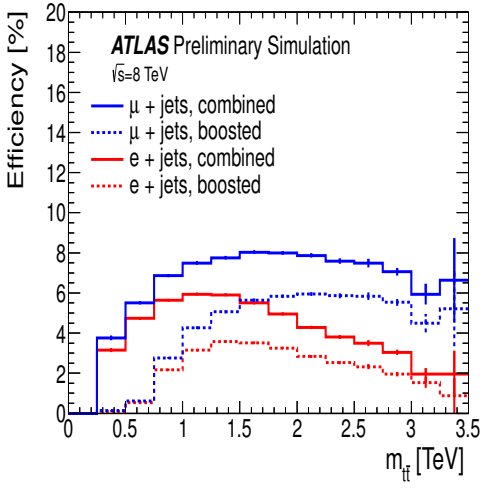
$t\bar{t}$ resonance: lepton+jets(I)

- Backgrounds
  - SM $t\bar{t}$, Z+jets, single top, diboson and W+jets shape: directly from MC
  - W+jets normalization, multijet: estimated from data

- Event selection
  - One top decays hadronically and the other semileptonically.
  - Boosted selection
    - 1 high p_T R=1.0 jet with $m_{jet} > 100$GeV, $\sqrt{d_{12}} > 40$GeV;
      1 R=0.4 jet close to lepton;
      ≥ 1 R=0.4 b-jet(could overlap with the former 2 jets.)
    - 1 isolated lepton; E_T^{miss}.
  - Resolved selection
    - 3 or 4 R=0.4 jets with ≥ 1 b-jet
    - 1 isolated lepton; E_T^{miss}.
      (Same as boosted channel)



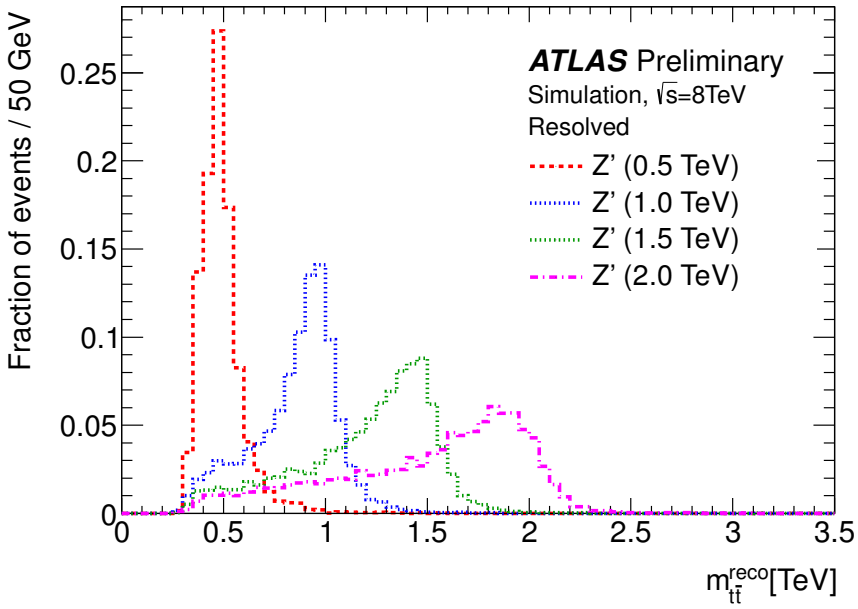
- The boosted selection helps improve efficiency in high signal mass region

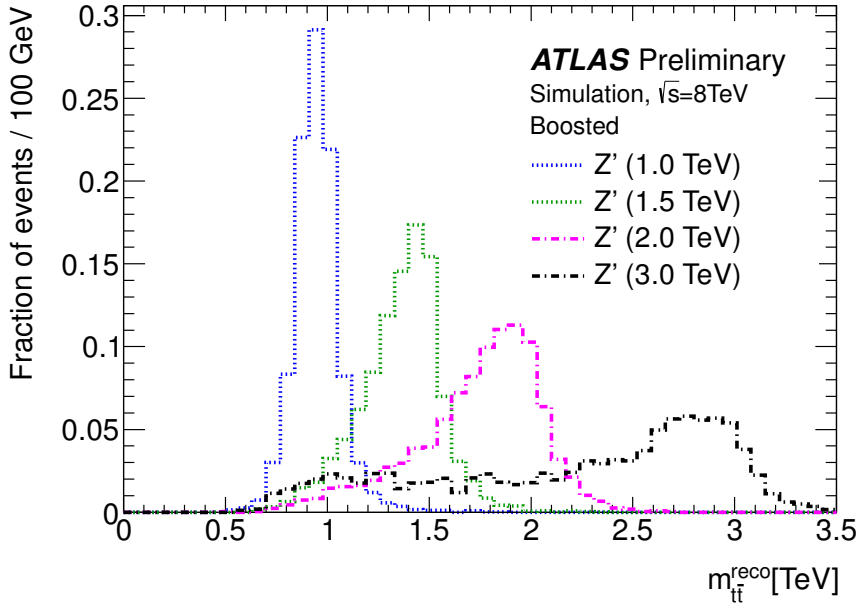


$t\bar{t}$ resonance: lepton+jets(II)

- $t\bar{t}$ invariant mass reconstruction
  - $p_z(\nu)$: from lepton+E_T^{miss} system with m_W constraint

- Resolved: χ^2 algorithm using m_t and m_W, top pair p_T balance as constraint
- Boosted: take R=1 jet as hadronically decaying top; build the other top from ν, lepton and R=0.4 jet





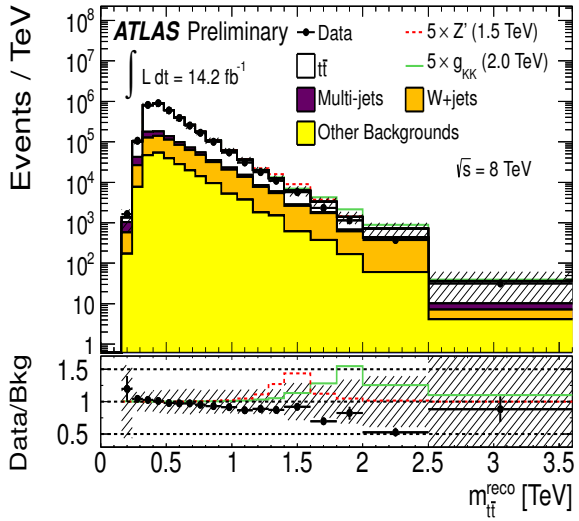
- The $t\bar{t}$ mass spectra are used for statistical analysis

$t\bar{t}$ resonance: lepton+jets(III)

- Dominant systematics on yields

Systematics	Resolved	Boosted
$t\bar{t}$ normalization	8.0%	9.0%
JES of R=0.4 jets	6.0%	0.70%
JES+JMS of R=1. jets	0.30%	17%
b-tag efficiency	4.0%	3.4%
PDF	2.9%	6.0%

- Note: R=1. jet systematics also affect the resolved channel because only events failing the boosted selection will be examined with the resolved selection criteria.

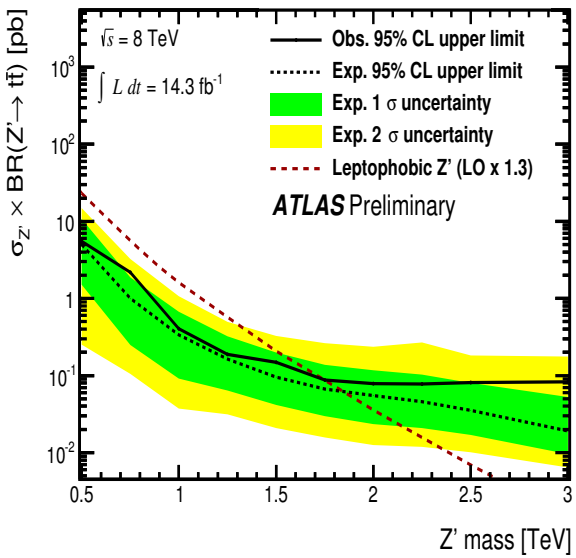


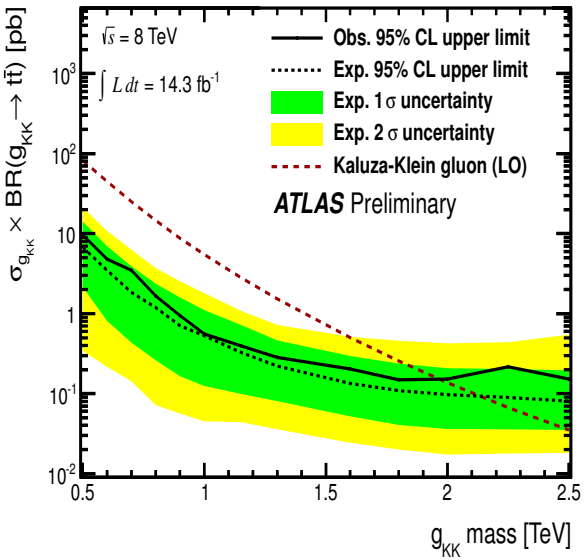
- Exclusion ranges @ 95% C.L.
  - 14.3 fb^{-1} @ 8TeV

Exclusion ranges	Observed
Z'	0.5-1.8TeV
KK gluon	0.5-2.0TeV

  - 4.7 fb^{-1} @ 7TeV arXiv:1305.2756

Exclusion ranges	Observed
Z'	0.50-1.74TeV
KK gluon	0.70-2.07TeV





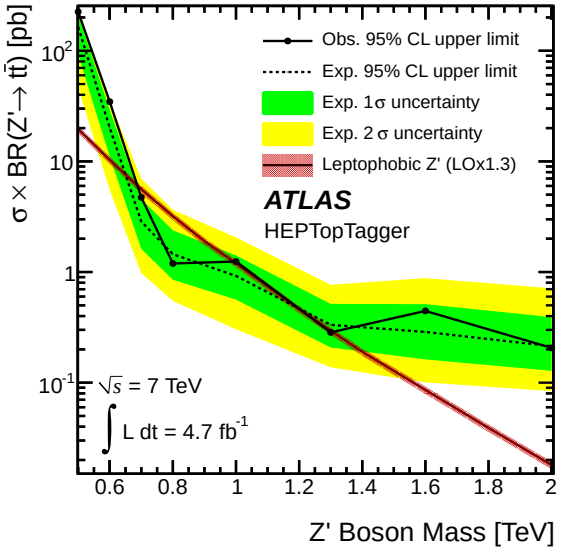
$t\bar{t}$ resonance: full hadronic decays JHEP 1301 (2013) 116

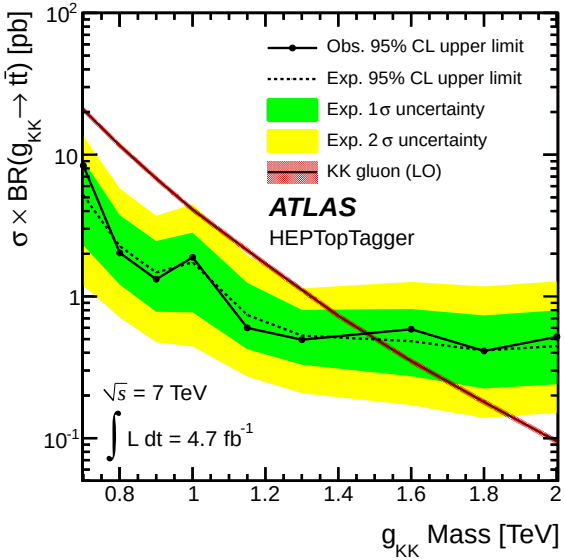
- Two complementary techniques relying on jet substructure are used to identify top:
  - HEPTopTagger
  - Top Template Tagger
- Exclusion ranges @ 95% C.L. with 4.7 fb^{-1} @ 7TeV
- Use HepTopTagger

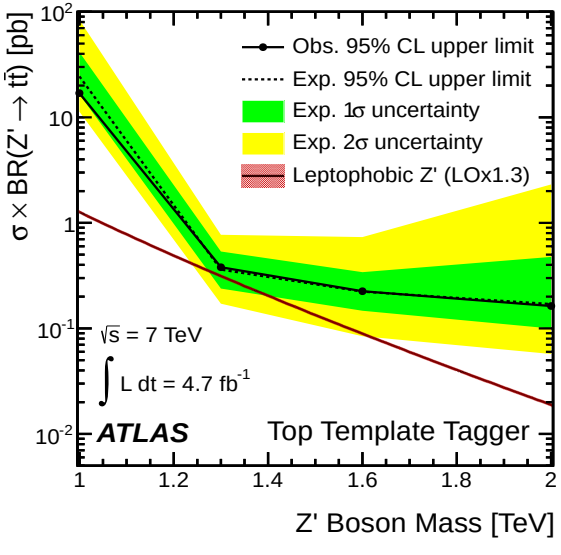
Exclusion ranges	Observed
Z'	0.70-1.00TeV 1.28-1.32TeV
KK gluon	0.70-1.48TeV

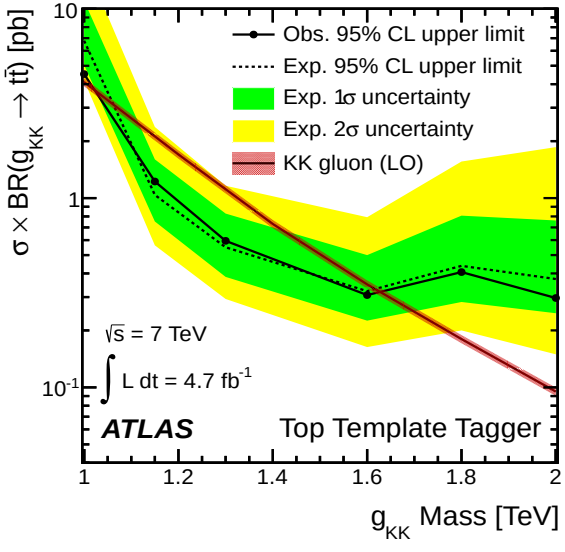
- Use Top Template Tagger

Exclusion ranges	Observed
KK gluon	1.02-1.62TeV







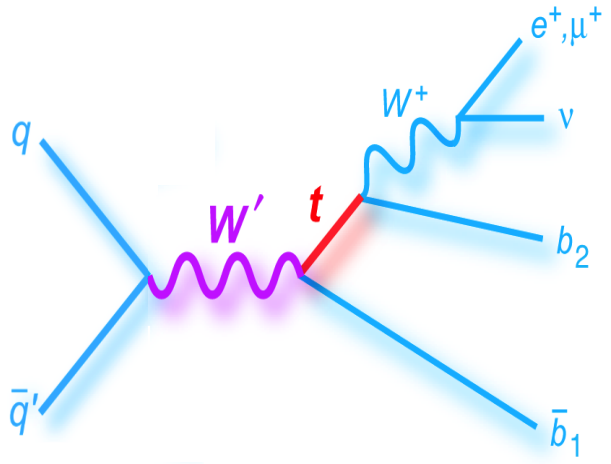


$W' \to tb$: theory ATLAS-CONF-2013-050

- W' carries new charged interaction as a result of enlarged symmetry group.
- Example of phenomenological models
  - Extra dimensions: Kaluza-Klein excitations of SM W
  - Little Higgs: predicts new particles including W'
- Model-independent search
  - Use an effective model describing the coupling of the W' to the fermions.

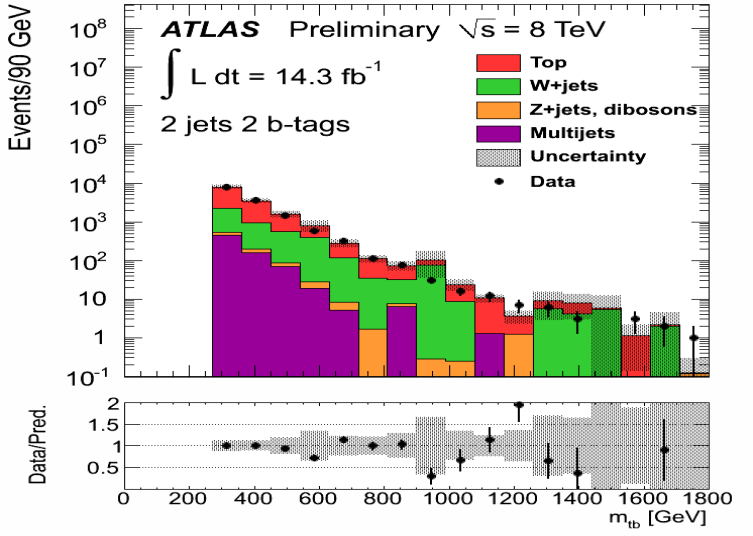
$$L = \frac{V'_{ij}}{2\sqrt{2}} \bar{f}_i \gamma_\mu g'_{R_{ij}} (1+\gamma^5) + g'_{L_{ij}} (1-\gamma^5) W'^\mu f_j + h.c.$$

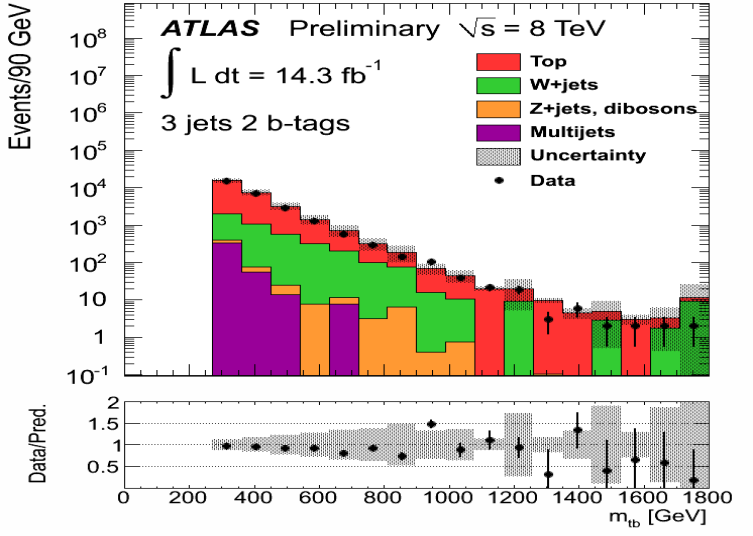
- Search for W' in t+b decay channel
  - Explore models potentially inaccessible to leptonic search ($W' \to l\nu$).
    - W'_R can not decay to a lepton and ν_R if $m_{\nu_R} > m_{W'}$
    - Leptophobic W'
  - W' may couple more strongly to the third generation quarks
  - Can exploit the distinct signature of top quark.



$W' \to tb$: analysis strategy

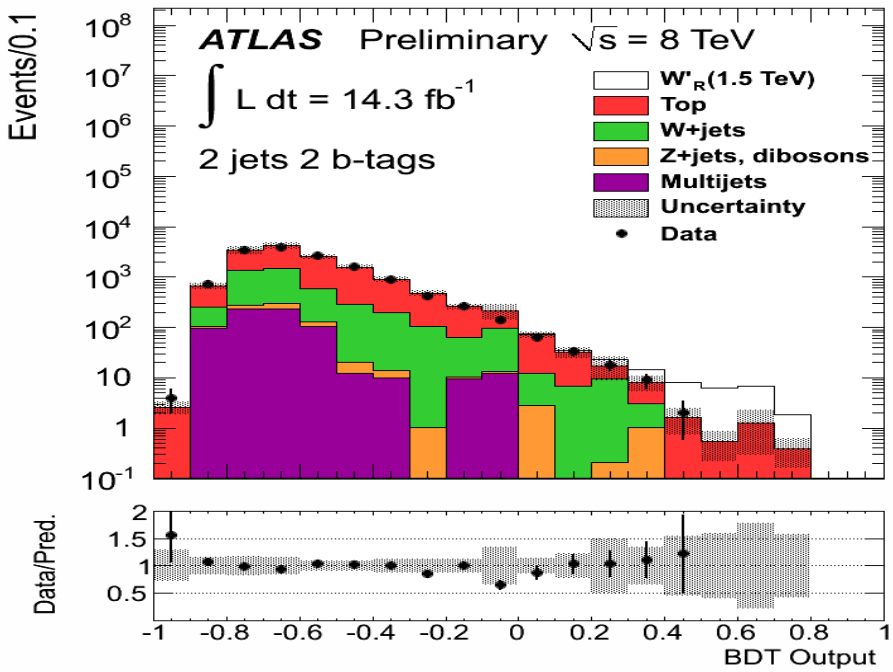
- Background
  - $t\bar{t}$, Z+jets, single top, diboson, W+jets shape: from MC
  - W+jets normalization, multijet: estimated from data
- Event selection
  - Preselection: 1 lepton, E_T^{miss}, 2 or 3 jets with ≥ 1 b-jet
  - Signal region: ≥ 2 b-jets, $M_{W'} \geq 270$GeV
  - Control region:
    - ≥ 2 b-jets, $m_{W'} < 270$GeV: Derive W+jets normalization; verify the variable modeling
    - =1 b-jet: check the modeling of kinematic variables
- tb invariant mass reconstruction
  - $p_z(\nu)$: from lepton+E_T^{miss} system with m_W constraint
  - b from top: the b-jet/jet giving the m_{Wb} closest to m_t
  - b from W': the other b-jet or highest p_T jet

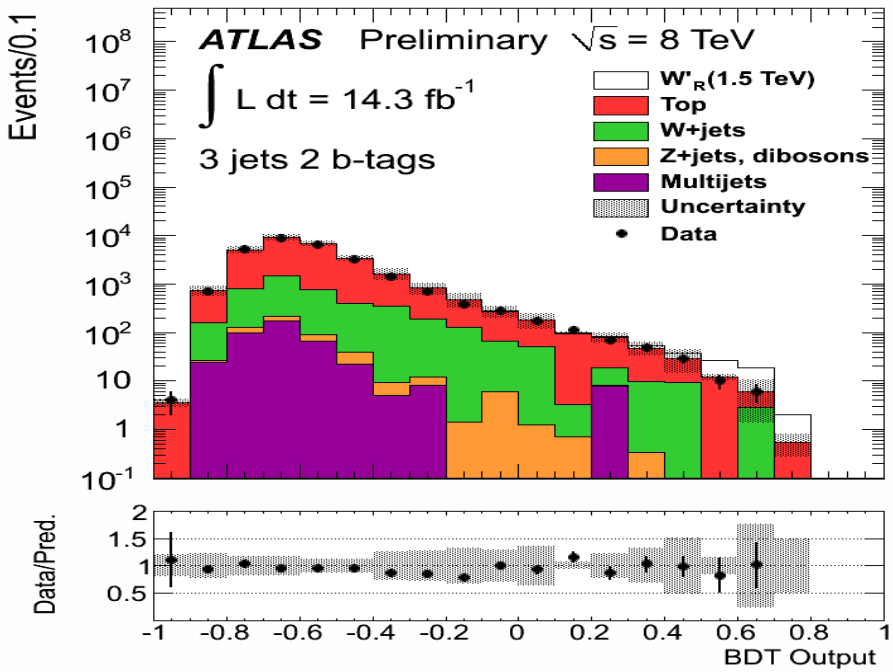




$W' \to tb$: TMVA

- Use Boosted Decision Tree discriminators (BDT)
  - 1 BDT for 2-jet events:
    - 14 variables used for training
    - Most discriminating variables: m_{tb}, $p_T(t)$, $\Delta\phi_{(l,top-jet)}$
  - 1 BDT for 3-jet events:
    - 13 variables used for training
    - Most discriminating variables: m_{tb}, $p_T(t)$, sphericity

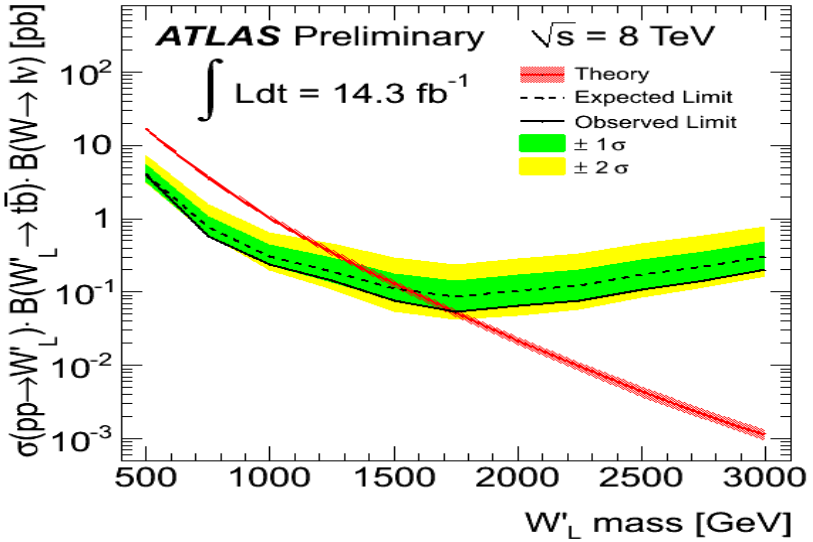


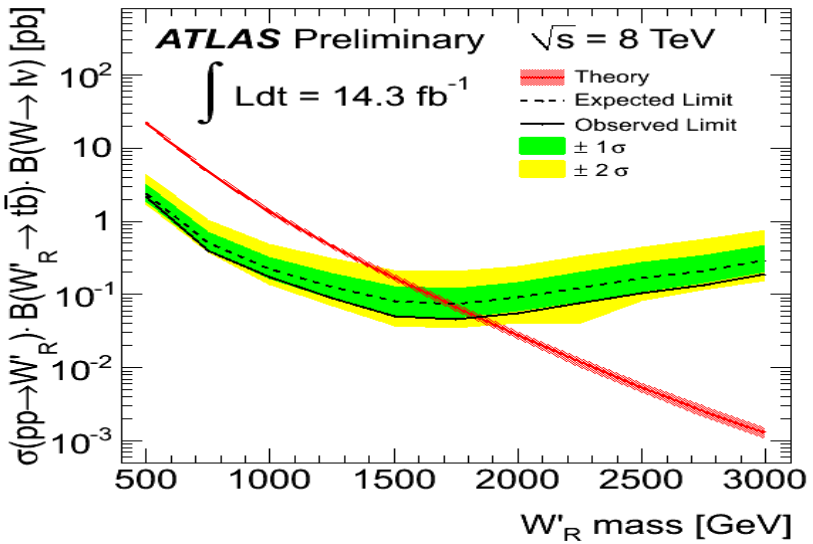


$W' \to tb$: result

- Dominant systematics
  - $t\bar{t}$ MC generator
    - 10%
  - b-tag efficiency
    - 15% – 25% for events with $\geq 2b$
- The BDT output distributions are used for statistical analysis
- Exclusion ranges @ 95% C.L. with 14.3 fb^{-1} @ 8TeV

Exclusion ranges	Expected	Observed
W'_L	< 1.56TeV	< 1.74TeV
W'_R	< 1.72TeV	< 1.84TeV





$b^* \to Wt$: theory PLB 721, 171 (2013)

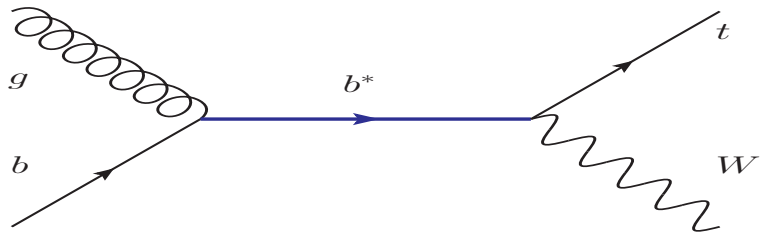
- Phenomenological models
  - Randall-Sundrum models; Composite Higgs models.
- Consider b^* produced singly through its coupling to a b and gluon

$$L = \frac{g_s}{2\Lambda} G_{\mu\nu} \bar{b} \sigma^{\mu\nu} (k_L^b P_L + k_R^b P_R) b_* + h.c.$$

- Exploit the weak coupling of excited-quarks to the third generation quarks

$$L = \frac{g_s}{\sqrt{2}} W_\mu^+ \bar{t} \gamma^\mu (g_L P_L + g_R P_R) b_* + h.c.$$

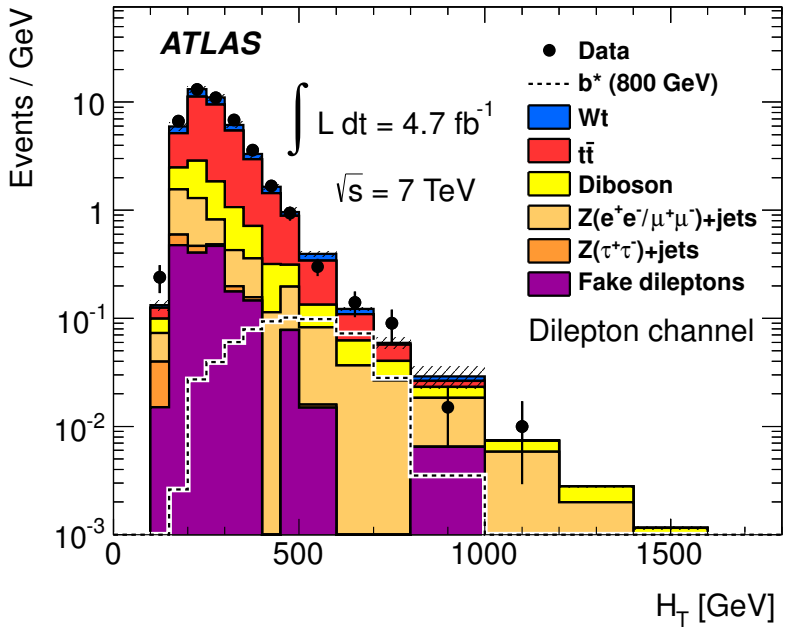
  - b^* can also decay to bZ and bH
  - cross-section and branching ratio of $b^* \to Wt$ depend on the couplings and b^* mass
- general search for Wt resonances under 3 b^* coupling scenarios
  - Left-handed: $k_R^b = g_R = 0$
  - Right-handed: $k_L^b = g_L = 0$
  - Vector-like: $k_L^b = g_L$, $k_R^b = g_R$



$b^* \to Wt$: dilepton channel

- Background
  - $t\bar{t}$, Wt, diboson, Drell-Yan shape: from MC
  - Drell-Yan normalization, and fake dileptons: estimated from data

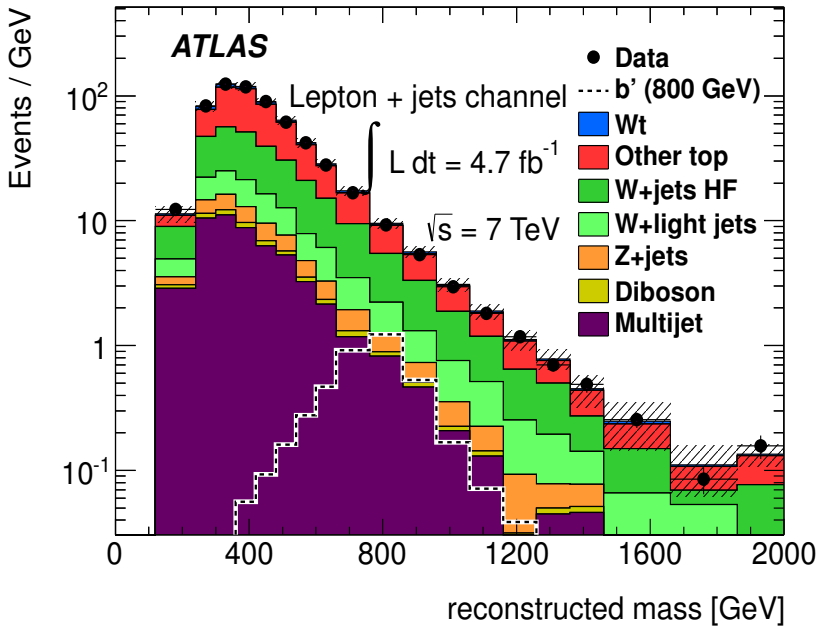
- Event selection
  - 2 leptons with opposite charges, E_T^{miss}, 1 jet
  - ee, $\mu\mu$ channels:
    - $m_{(ll)} < 81\text{GeV}$ or $m_{(ll)} > 101\text{GeV}$
  - Veto to suppress $Z_{\tau\tau}$:
    - $\Delta\phi_{(l_1, E_T^{miss})} + \Delta\phi_{(l_2, E_T^{miss})} > 2.5$
  - Discriminating variable:
    - H_T: $H_T = E_T^{miss} + \sum E_T^{lepton} + E_T^{jet}$



$b^* \to Wt$: lepton+jets channel

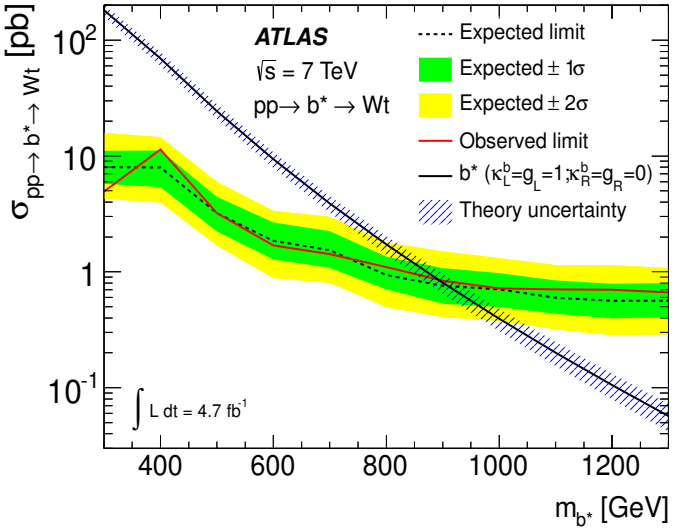
- Background
  - $t\bar{t}$, Z+jets, single top, diboson, W+jets shape: from MC
  - W+jets normalization, multijet: estimated from data

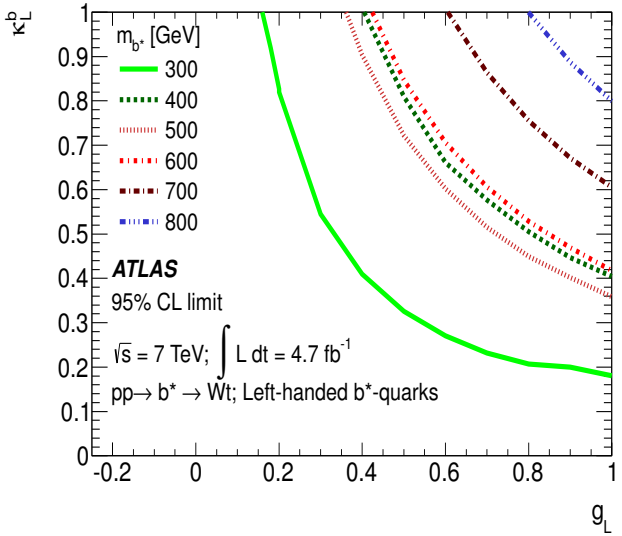
- Event selection
  - 1 leptons, E_T^{miss}, 3 jets with $\geq$ 1b-jet
  - Reject multijet events
    - μ channel: $E_T^{miss} > 25$GeV, $E_T^{miss} + E_T^W > 60$GeV
    - e channel: $E_T^{miss} > 30$GeV, $E_T^W > 30$GeV
  - Discriminating variable:
    - Reconstruct m_{b^*} from lepton, E_T^{miss}, and jets assuming $p_z(\nu)$=0

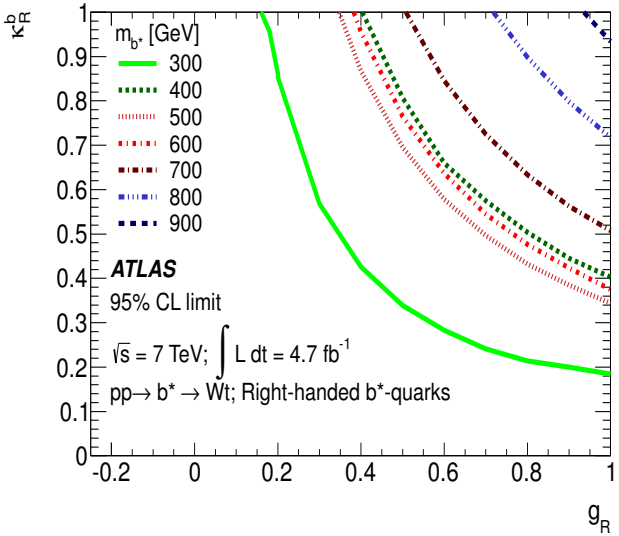


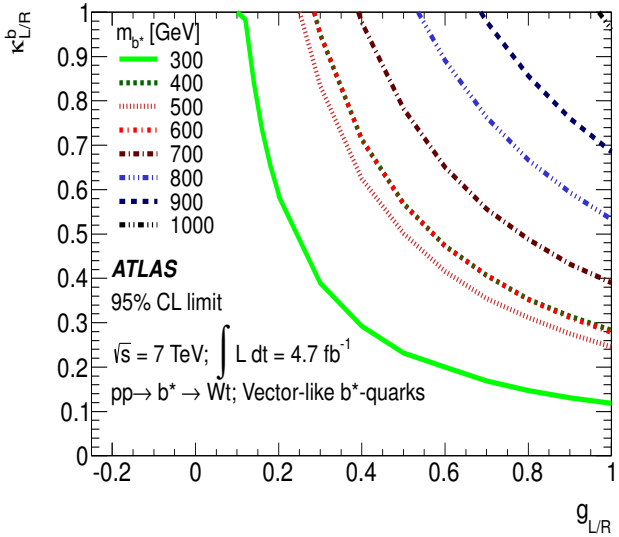
$b^* \to Wt$: result

- Combine 2 channels for statistical analysis.
  - Dilepton channel: use the H_T distribution
  - Lepton+jets channel: use the reconstructed b^* mass spectra
- Cross-section limit @ 95% C.L. as a function of the b^*_L mass($k^b_L = g_L = 1,\ k^b_R = g_R = 0$)
  - Expected limit: $>$ 910GeV; Observed limit: $>$ 870GeV.
- Coupling limits at each mass in 3 scenarios
  - Left-handed; right-handed; vector-like.









Summary

- The search for exotic physics in $t\bar{t}$ pair and single top productions has been presented: $t\bar{t}$ resonances, W', b^*.
- No evidence of new physics has been observed.
- Limits @ 95% C.L. have been placed.

Signal	Limit
Z'	$m_{Z'} > 1.80\text{TeV}$
KK gluon	$m_{g_{KK}} > 2.00\text{TeV}$
W'_L	$m_{W'_L} > 1.74\text{TeV}$
W'_R	$m_{W'_R} > 1.84\text{TeV}$
b^*_L	$m_{b^*_L} > 0.87\text{TeV}$

- Updates with full 2012 dataset will come soon

References I

[1] ATLAS Exotics Public Results

[2] Harris, Robert M. et al
Cross Sections for Leptophobic Topcolor Z' decaying to $t\bar{t}$
Eur.Phys.J.C72 (2012) 2072

[3] K. Agashe, A. Belyaev, T. Krupovnickas, G. Perez and J. Virzi
LHC Signals from Warped Extra Dimensions
Phys. Rev. D 77, 015003 (2008)

[4] ATLAS Collaboration
A search for $t\bar{t}$ resonances in lepton plus jets events with ATLAS using 14 fb^{-1} of proton-proton collisions at $\sqrt{s} = 8$ TeV
ATLAS-CONF-2013-052

[5] ATLAS Collaboration
A search for $t\bar{t}$ resonances in the lepton plus jets final state with ATLAS using 4.7 fb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV
arXiv:1305.2756

References II

[6] ATLAS Collaboration
Search for resonances decaying into top-quark pairs using fully hadronic decays in pp collisions with ATLAS at $\sqrt{s} = 7$ TeV
JHEP 1301 (2013) 116

[7] ATLAS Collaboration
Search for $W' \to tb$ in proton-proton collisions at a centre-of-mass energy of $\sqrt{s} = 8$ TeV with the ATLAS detector
ATLAS-CONF-2013-050

[8] ATLAS Collaboration
Search for single b^*-quark production with the ATLAS detector at $\sqrt{s} = 7$ TeV
PLB 721, 171 (2013)

BACKUP

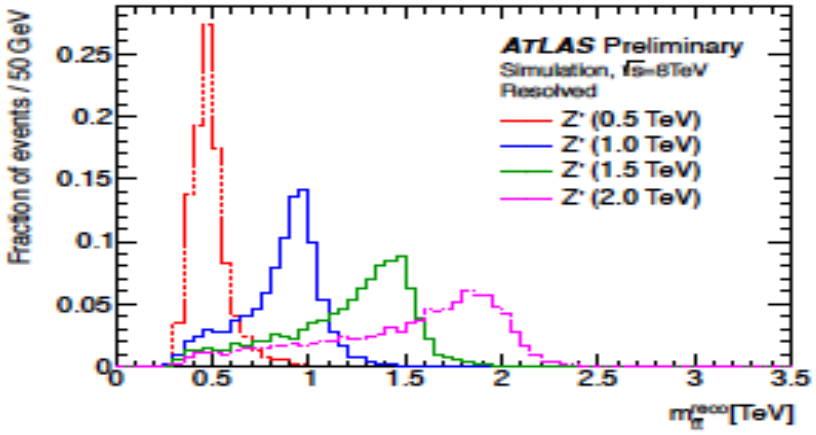
$t\bar{t}$ resonance (lepton+jets): χ^2 algorithm used in event reconstruction

$$\begin{aligned}\chi^2 &= \left[\frac{m_{jj} - m_W}{\sigma_W}\right]^2 \\ &+ \left[\frac{m_{jjb} - m_{jj} - m_{t_h - W}}{\sigma_{t_h - W}}\right]^2 + \left[\frac{m_{j\ell\nu} - m_{t_\ell}}{\sigma_{t_\ell}}\right]^2 \\ &+ \left[\frac{(p_{\mathrm{T},jjb} - p_{\mathrm{T},j\ell\nu}) - (p_{\mathrm{T},t_h} - p_{\mathrm{T},t_\ell})}{\sigma_{\mathrm{diff}\,p_{\mathrm{T}}}}\right]^2,\end{aligned}$$

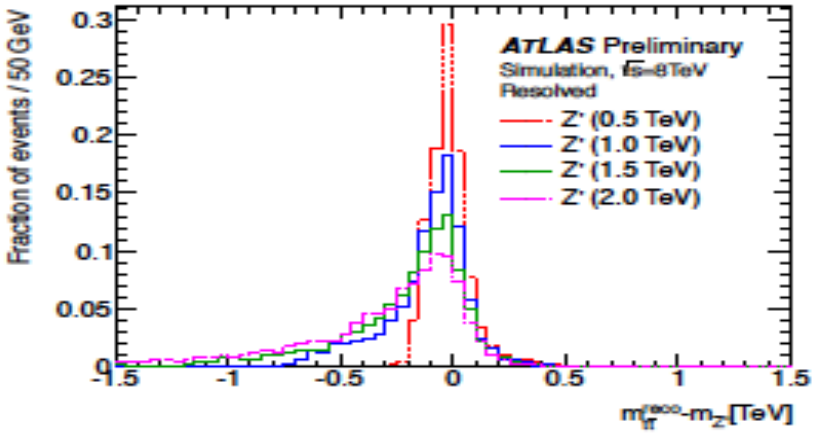
- If one of the jets has $m_{jet} > 60$GeV, the χ^2 is modified:

$$\chi^2 = \left[\frac{m_{jJ} - m_{jJ}^{t_h}}{\sigma_{jJ}^{t_h}}\right]^2 + \left[\frac{m_{j\ell\nu} - m_{t_\ell}}{\sigma_{t_\ell}}\right]^2 + \left[\frac{(p_{\mathrm{T},jJ} - p_{\mathrm{T},j\ell\nu}) - (p_{\mathrm{T},t_h} - p_{\mathrm{T},t_\ell})}{\sigma_{\mathrm{diff}\,p_{\mathrm{T}}}}\right]^2$$

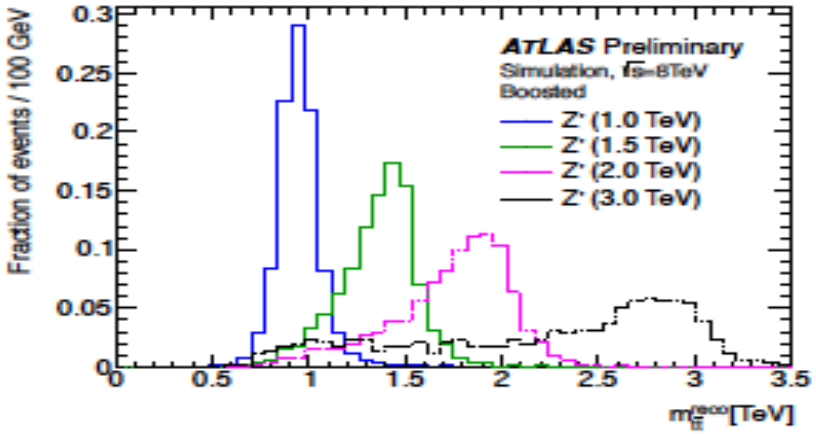
$t\bar{t}$ resonance (lepton+jets): The reconstruction $t\bar{t}$ invariant mass



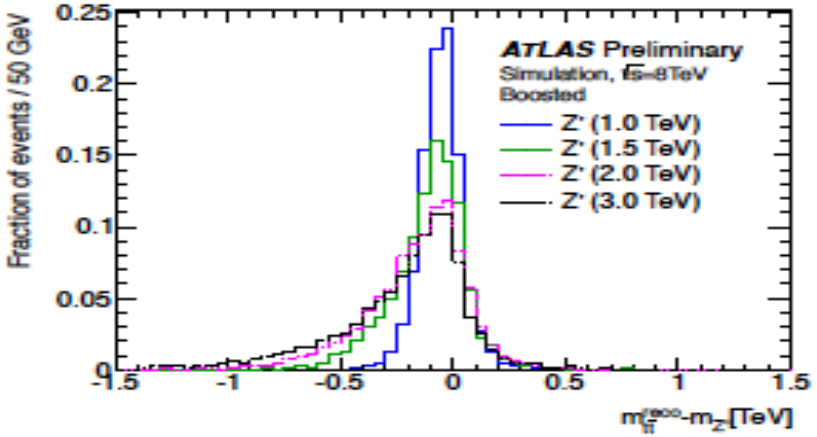
(a) Reconstructed $t\bar{t}$ mass in the resolved selection.



(b) Residuals for the $t\bar{t}$ mass in the resolved selection.

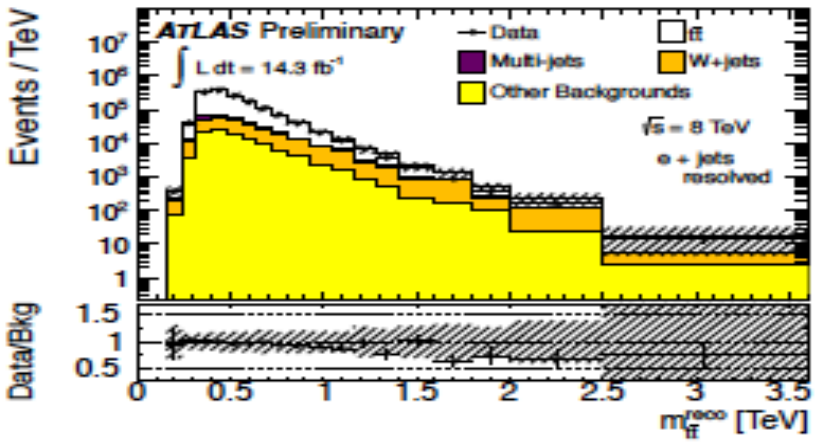


(c) Reconstructed $t\bar{t}$ mass in the boosted selection.

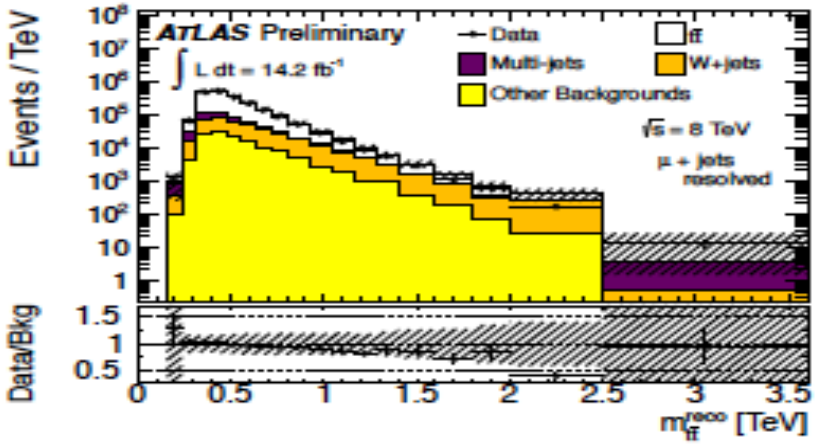


(d) Residuals for the $t\bar{t}$ mass in the boosted selection.

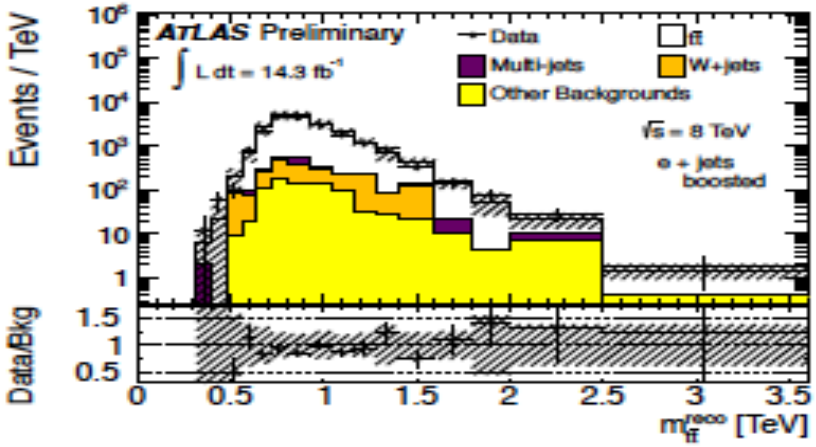
$t\bar{t}$ resonance (lepton+jets): The $t\bar{t}$ invariant mass spectra



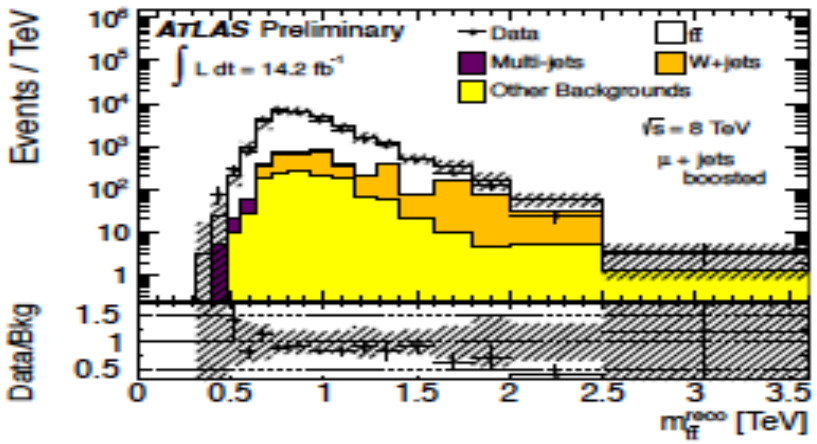
(a) e+jets channel, resolved selection.



(b) μ+jets channel, resolved selection.



(c) e+jets channel, boosted selection.



(d) μ+jets channel, boosted selection.

$t\bar{t}$ resonance (lepton+jets): Average impact of the dominant systematic uncertainties

Table 1: Average impact of the dominant systematic uncertainties on the total background yield and on the estimated yield of a Z' with $m = 1.5$ TeV. The electron and muon channel spectra are added. The shift is given in percent of the nominal value. Certain systematic uncertainties are not applicable to the Z' samples, which is indicated with a bar (–) in the table.

	Resolved selection yield impact [%]		Boosted selection yield impact [%]	
Systematic Uncertainties	total bkg.	Z'	total bkg.	Z'
Luminosity	2.9	4	3.3	4
PDF	2.9	5	6	2.9
ISR/FSR	0.2	–	0.7	–
Parton shower and fragm.	5	–	4	–
$t\bar{t}$ normalization	8	–	9	–
$t\bar{t}$ EW virtual correction	2.2	–	4	–
$t\bar{t}$ Generator	1.5	–	1.6	–
W+jets $b\bar{b}$+$c\bar{c}$+c vs. light	0.8	–	1.0	–
W+jets bb variation	0.2	–	0.4	–
W+jets c variation	1.1	–	0.6	–
W+jets normalization	2.1	–	1.0	–
Multi-Jet norm, e+jets	0.6	–	0.3	–
Multi-Jet norm, μ+jets	1.8	–	0.3	–
JES, small-radius jets	6	2.2	0.7	0.5
JES+JMS, large-radius jets	0.3	4	17	3.3
Jet energy resolution	1.6	0.4	0.6	0.7
Jet vertex fraction	1.7	2.3	2.1	2.4
b-tag efficiency	4	1.8	3.4	6
c-tag efficiency	1.4	0.3	0.7	0.9
Mistag rate	0.7	0.3	0.7	0.1
Electron efficiency	1.0	1.1	1.0	1.0
Muon efficiency	1.5	1.5	1.6	1.6
All systematic uncertainties	14	9	22	9

$t\bar{t}$ resonance (lepton+jets): Data and expected background event yields

Table 2: Data and expected background event yields after the resolved and boosted selections. The uncertainty on the normalization of the expected backgrounds yield is listed.

Resolved selection			
Type	e+jets	μ+jets	Sum
$t\bar{t}$	94000 ± 15000	118000 ± 19000	211000 ± 33000
Single top	6800 ± 800	8400 ± 1100	15200 ± 1900
Multi-jet	3700 ± 1800	10000 ± 5000	14000 ± 6000
W+jets	16000 ± 4000	23000 ± 6000	39000 ± 10000
Z+jets	1800 ± 400	1800 ± 400	3600 ± 800
Di-bosons	230 ± 50	320 ± 60	550 ± 100
Total	121000 ± 17000	162000 ± 23000	283000 ± 39000
Data	119490	160878	280251
Boosted selection			
Type	e+jets	μ+jets	Sum
$t\bar{t}$	2100 ± 500	2800 ± 600	4900 ± 1100
Single top	71 ± 15	105 ± 22	176 ± 34
Multi-jet	39 ± 19	32 ± 16	71 ± 25
W+jets	170 ± 60	310 ± 90	480 ± 140
Z+jets	18 ± 11	33 ± 8	52 ± 15
Di-bosons	2.0 ± 0.8	1.5 ± 1.4	3.5 ± 1.8
Total	2400 ± 500	3300 ± 700	5600 ± 1200
Data	2177	2945	5122

$t\bar{t}$ resonance (lepton+jets): Upper 95% C.L. cross section limits times branching ratio on Z' decaying to $t\bar{t}$

Table 3: Upper 95% CL cross section limits times branching ratio on a leptophobic topcolor Z' decaying to $t\bar{t}$, using the combination of all four samples. The observed and expected limits for each mass point are given, as well as the $\pm 1\sigma$ variation of the expected limit. The second column gives the theoretical predictions with the 1.3 K-factor to account for NLO effects.

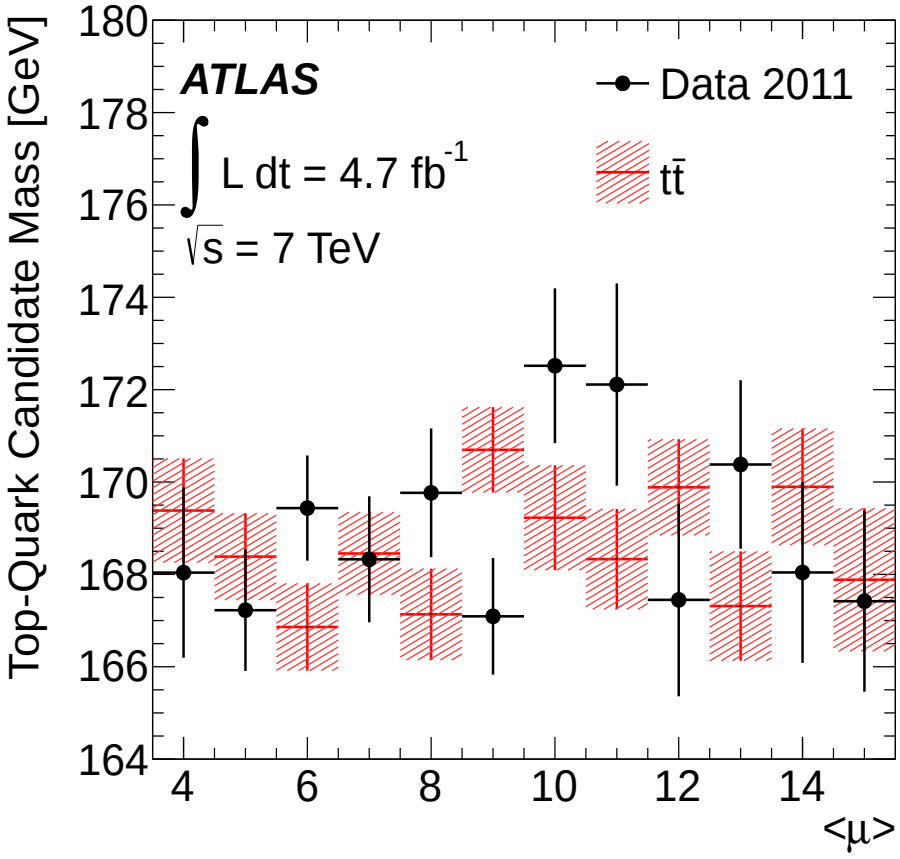
Mass (TeV)	$\sigma\times$ BR $\times$1.3 [pb]	Obs. (pb)	Exp. (pb)	-1σ (pb)	$+1\sigma$ (pb)
0.50	23.	5.30	4.99	1.50	10.7
0.75	5.6	2.17	1.00	0.249	1.87
1.00	1.6	0.406	0.335	0.091	0.674
1.25	0.57	0.187	0.160	0.064	0.323
1.50	2.1×10^{-1}	0.148	0.096	0.041	0.198
1.75		0.087	0.066	0.030	0.137
2.00	3.9×10^{-2}	0.078	0.055	0.023	0.117
2.25		0.078	0.045	0.021	0.103
2.50	6.9×10^{-3}	0.081	0.035	0.017	0.081
3.00	1.5×10^{-3}	0.083	0.019	0.010	0.053

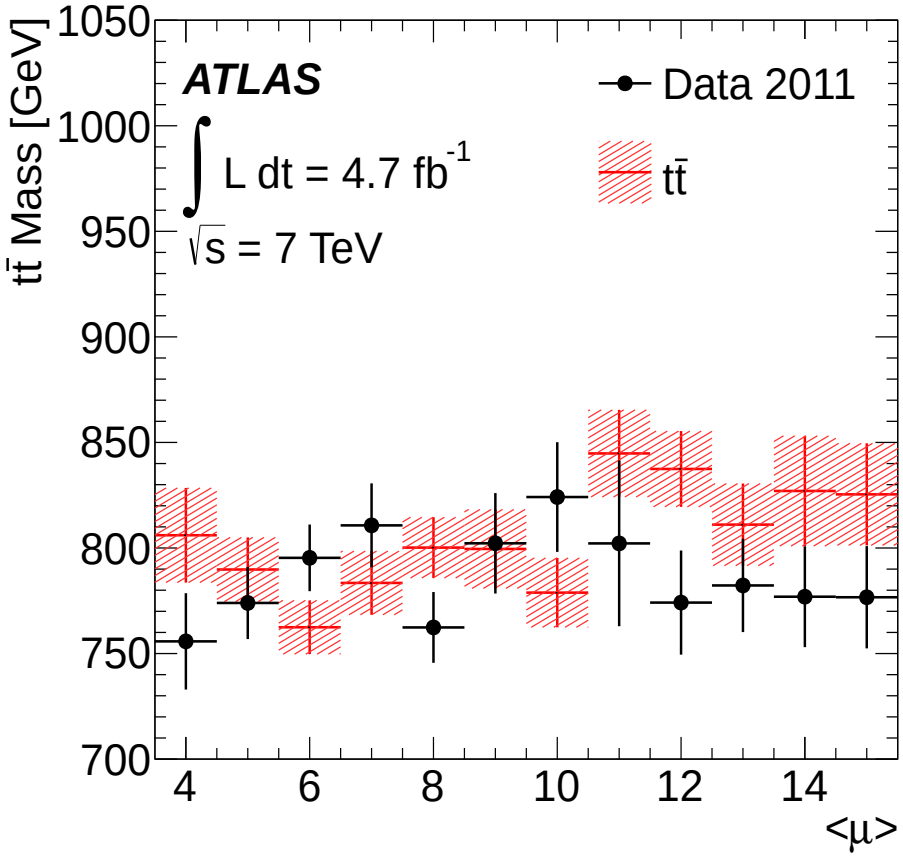
$t\bar{t}$ resonance (lepton+jets): Upper 95% C.L. cross section limits times branching ratio on KK gluon decaying to $t\bar{t}$

Table 4: Upper 95% CL cross section limits times branching ratio on a Kaluza–Klein gluon decaying to $t\bar{t}$, combined samples. The observed and expected limits for each mass point are given, as well as the $\pm 1\sigma$ variation of the expected limit. The second column gives the theoretical predictions.

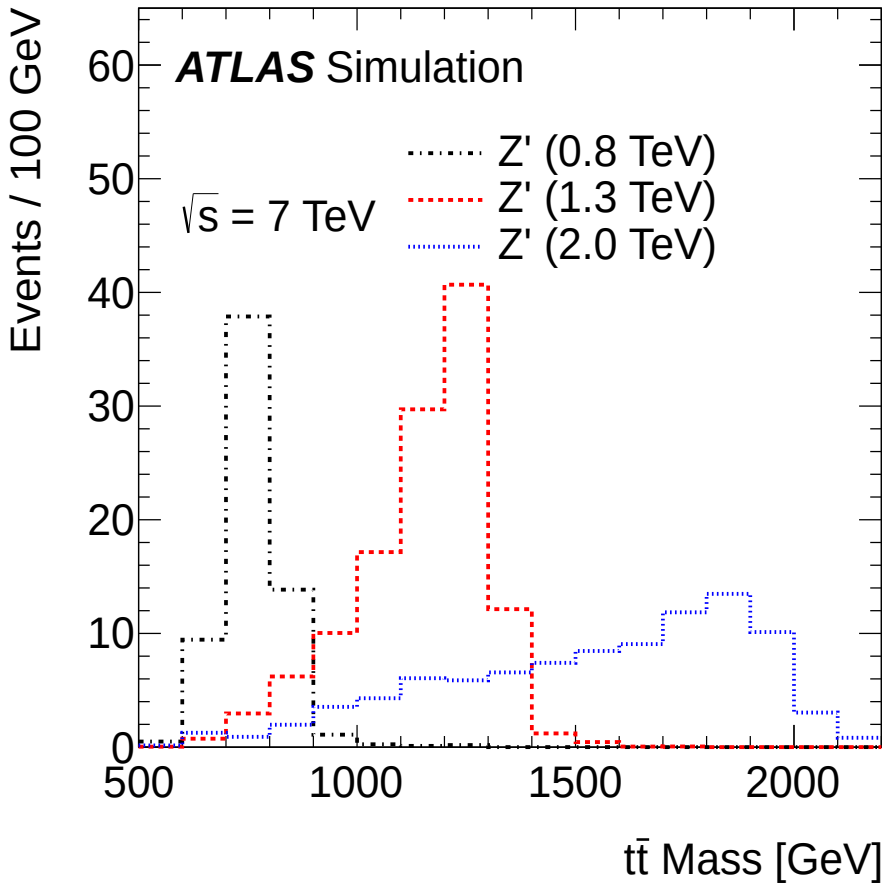
Mass (TeV)	$\sigma\times$ BR [pb]	Obs. (pb)	Exp. (pb)	-1σ (pb)	$+1\sigma$ (pb)
0.50	82.	9.62	6.73	2.15	14.1
0.60	45.	4.79	3.48	0.813	6.98
0.70	25.	3.48	1.84	0.436	3.90
0.80	15.	1.66	1.19	0.262	2.37
0.90	8.8	0.948	0.711	0.165	1.60
1.00	5.5	0.561	0.529	0.125	1.11
1.15	2.8	0.394	0.329	0.100	0.720
1.30	1.5	0.282	0.221	0.081	0.464
1.60	0.50	0.204	0.134	0.052	0.296
1.80	0.26	0.149	0.109	0.041	0.237
2.00	0.14	0.153	0.097	0.036	0.209
2.25	0.067	0.218	0.089	0.036	0.203
2.50	0.035	0.152	0.080	0.035	0.196

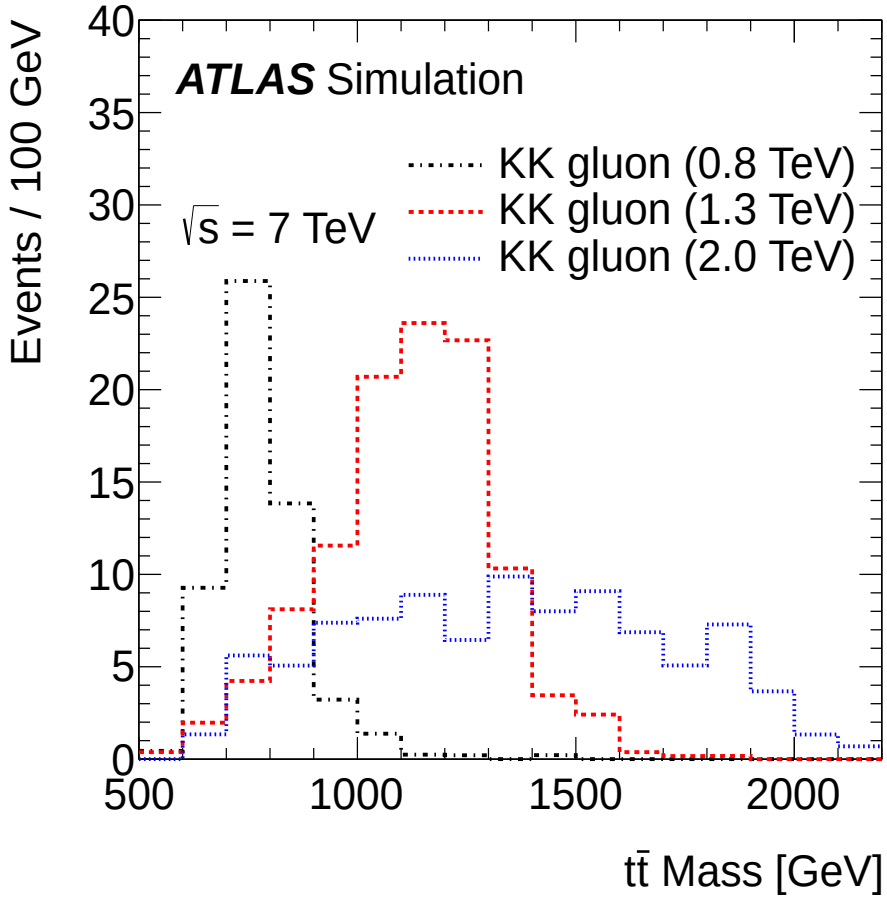
$t\bar{t}$ resonance (full hadronic): HEPTopTagger top-quark candidate mass and reconstructed $t\bar{t}$ mass





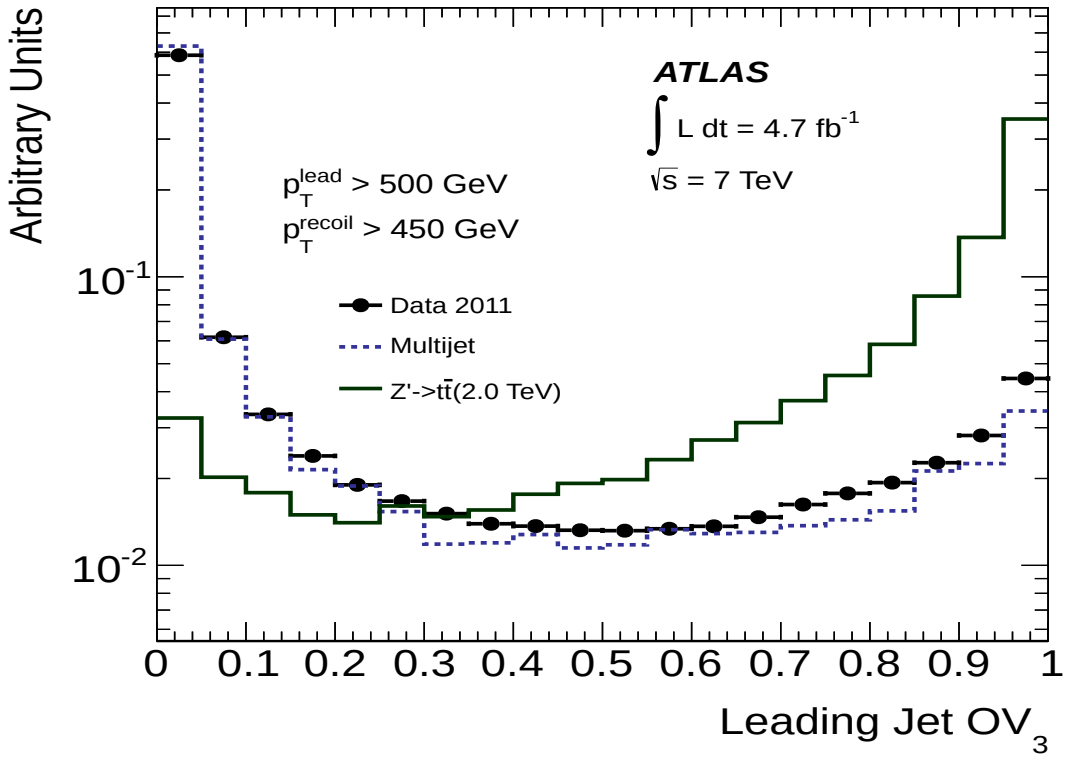
$t\bar{t}$ resonance (full hadronic): the reconstructed $t\bar{t}$ mass for Z' and KK gluon signals in HEPTopTagger analysis





$t\bar{t}$ resonance (full hadronic): OV_3 distributions of Top Template Tagger for the leading jets

$$OV_3 = \max_{\{\tau_n\}} \exp\left[-\sum_{i=1}^{3} \frac{1}{2\sigma_i^2}\left(E_i - \sum_{\substack{\Delta R(\mathrm{topo},i) \\ <0.2}} E_{\mathrm{topo}}\right)^2\right],$$

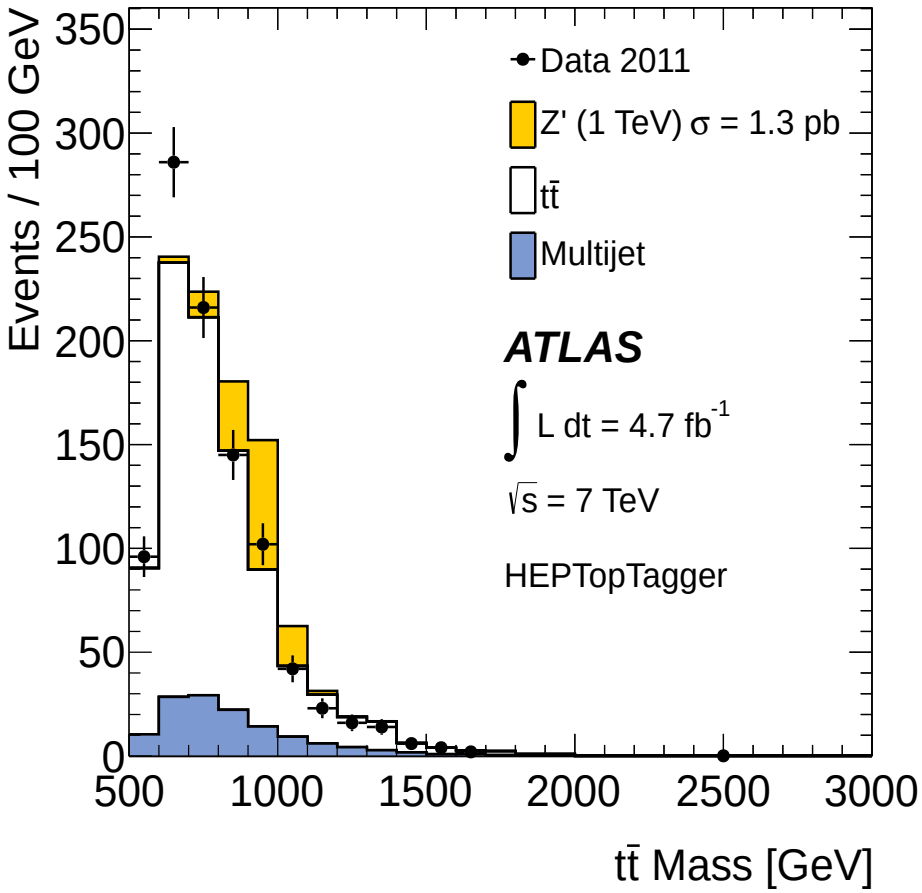


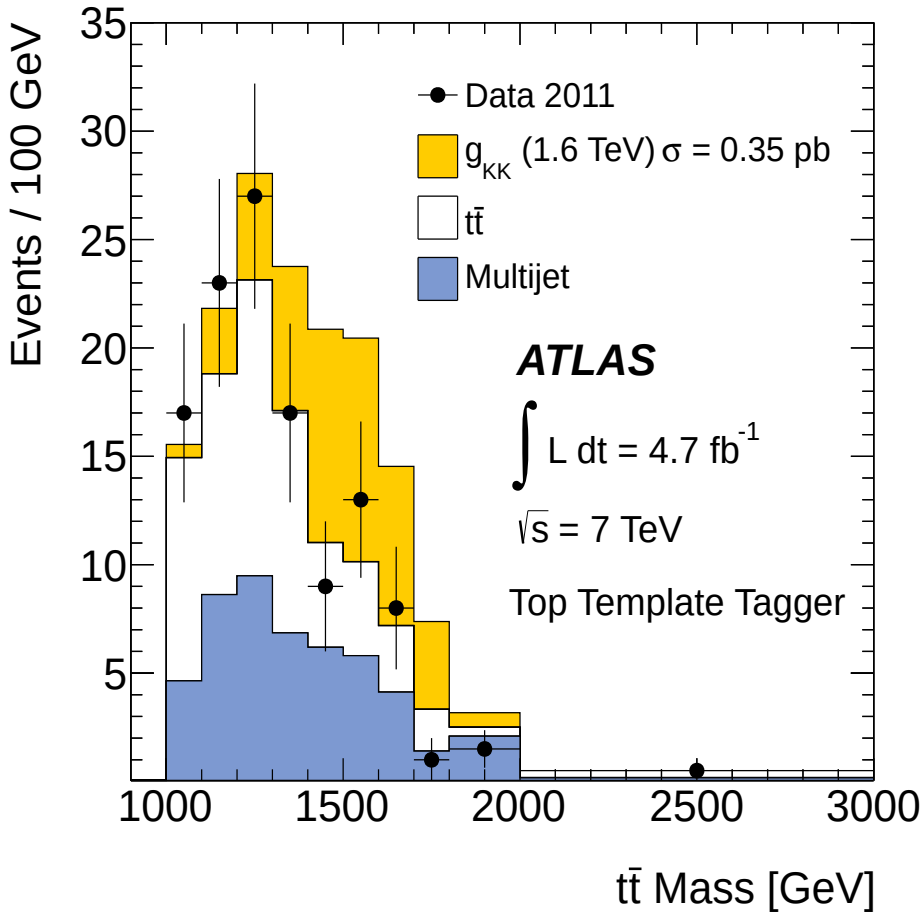
$t\bar{t}$ resonance (full hadronic): $t\bar{t}$ selection efficiency of HepTopTagger and Top Template Tagger

Table 1. Total efficiency (in %) for selecting Z' bosons and KK gluons (g_{KK}) that have decayed to $t\bar{t}$ pairs. These are the efficiencies determined by the MC calculations divided by the SM branching fraction of 46% for both top quarks to decay hadronically. All uncertainties are statistical only.

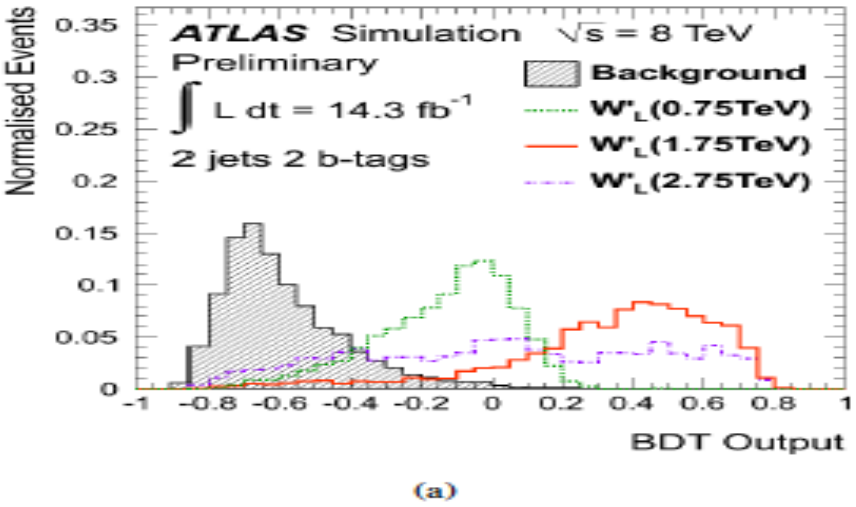
Model	Total Efficiency (%)	
	HEPTopTagger	Template Tagger
Z' (0.5 TeV)	0.03 ± 0.01	–
Z' (0.8 TeV)	2.96 ± 0.08	–
Z' (1.0 TeV)	4.76 ± 0.09	0.48 ± 0.05
Z' (1.3 TeV)	5.67 ± 0.11	6.37 ± 0.13
Z' (1.6 TeV)	5.40 ± 0.10	8.13 ± 0.16
Z' (2.0 TeV)	4.44 ± 0.10	6.26 ± 0.13
g_{KK} (0.7 TeV)	1.70 ± 0.13	–
g_{KK} (1.0 TeV)	4.13 ± 0.21	0.74 ± 0.10
g_{KK} (1.3 TeV)	5.14 ± 0.23	5.02 ± 0.25
g_{KK} (1.6 TeV)	4.72 ± 0.22	6.43 ± 0.26
g_{KK} (2.0 TeV)	4.44 ± 0.22	5.22 ± 0.21

$t\bar{t}$ resonance (full hadronic): distributions of $t\bar{t}$ mass.

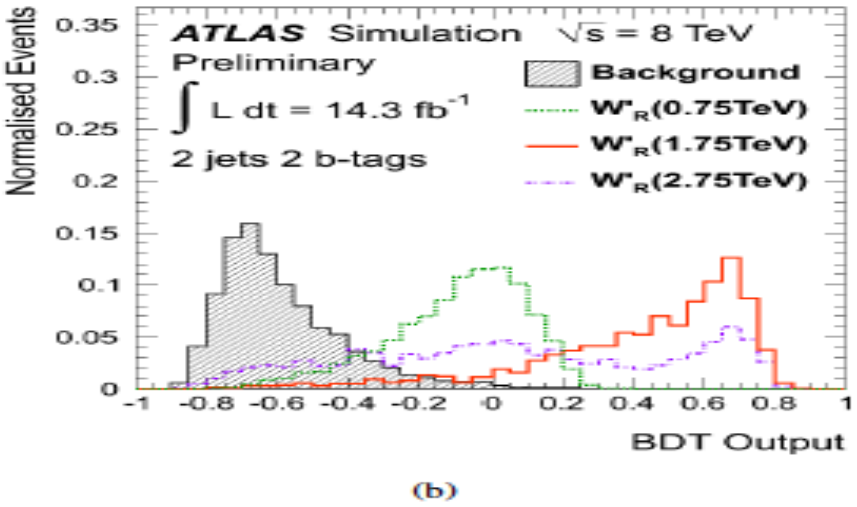




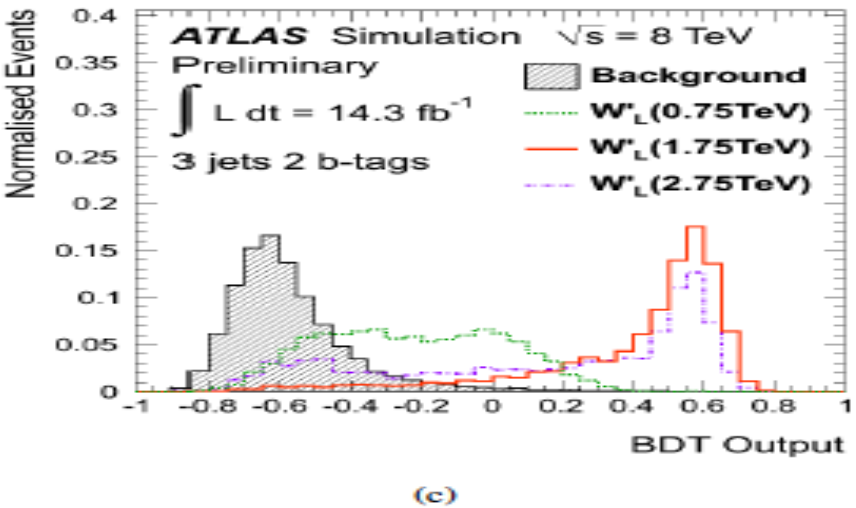
$W' \to tb$: Expected BDT output distributions



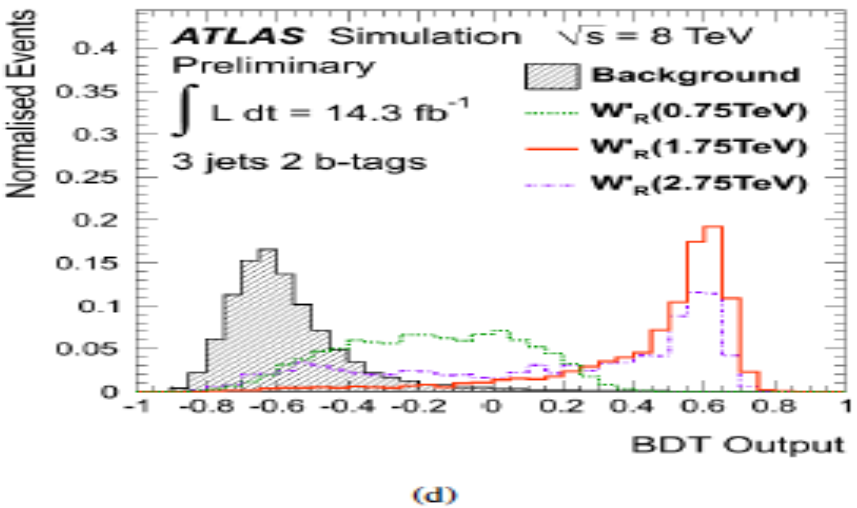
(a)



(b)

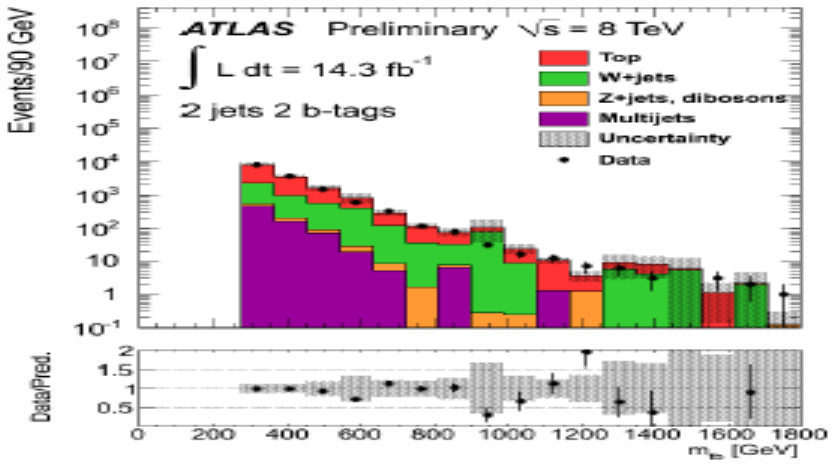


(c)

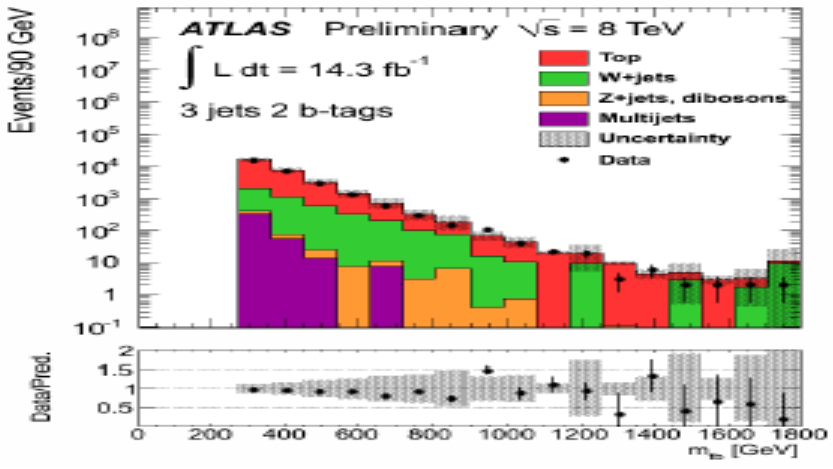


(d)

$W' \to tb$: Disitributions of the reconstructioned $m_{W'}$ and $p_T(top)$



(a)



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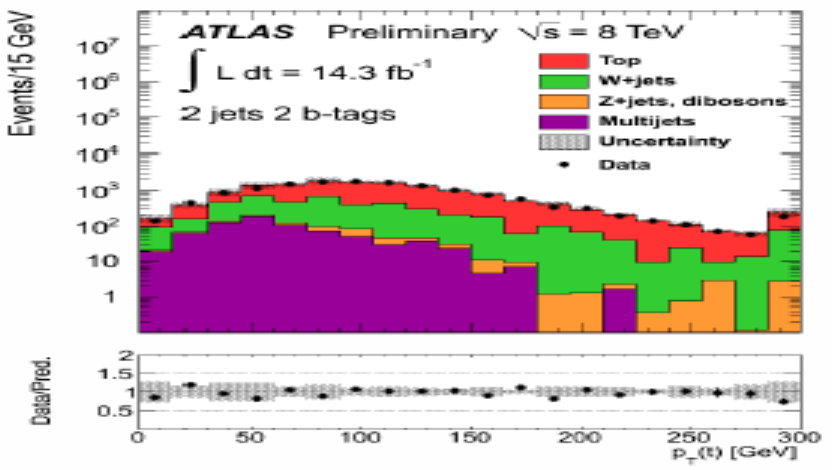
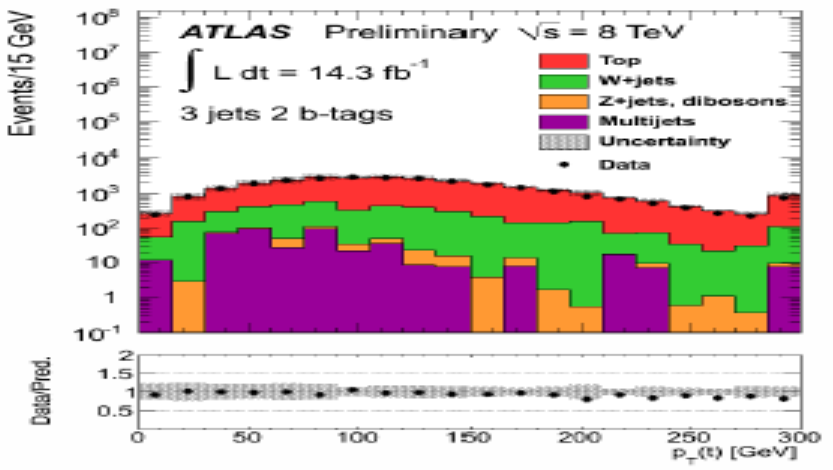


(c)



(d)

$W' \to tb$: Data and expected background event yields

Table 1: Data and expected background events in the signal region. Event yields for several mass hypotheses of the right-handed W' boson are shown. The quoted uncertainties account for all systematic effects as well as for limited statistics in the simulated samples.

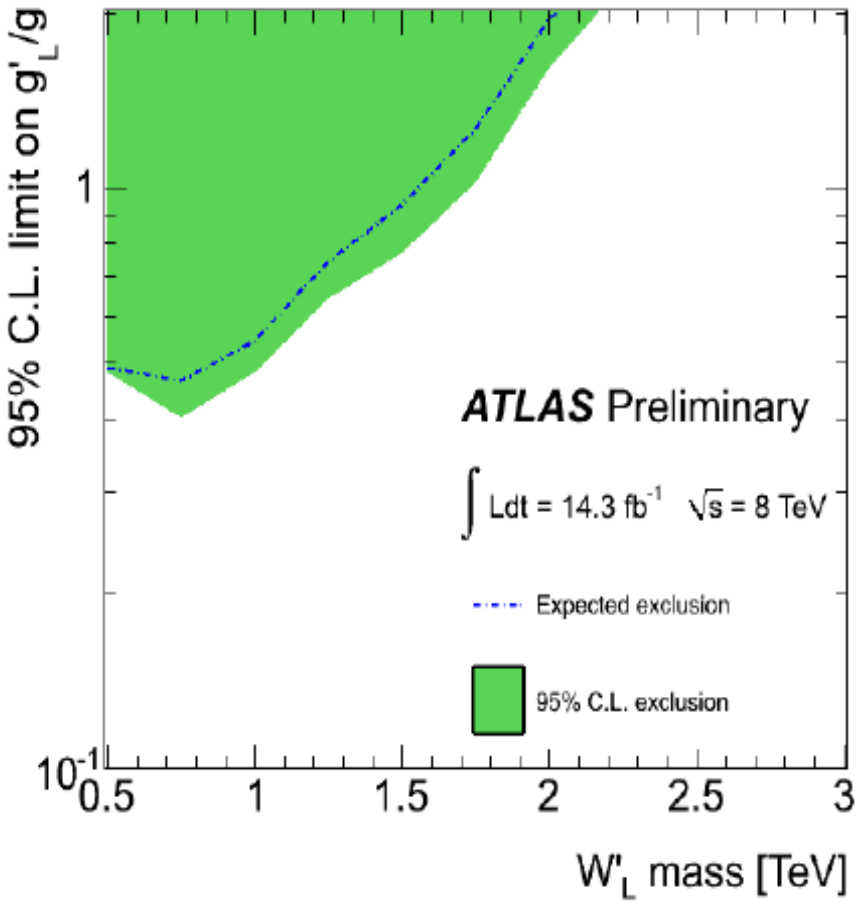
	2-jet 2-tag channel	3-jet 2-tag channel
W'_R (0.5 TeV)	11800 ± 2700	8200 ± 1800
W'_R (1.0 TeV)	600 ± 150	660 ± 160
W'_R (1.5 TeV)	42 ± 11	56 ± 13
W'_R (2.0 TeV)	4.2 ± 1.1	6.2 ± 1.5
W'_R (2.5 TeV)	0.69 ± 0.17	0.87 ± 0.20
W'_R (3.0 TeV)	0.22 ± 0.06	0.25 ± 0.06
$t\bar{t}$	8300 ± 2100	22000 ± 5000
Single-top t-channel	1000 ± 270	1400 ± 400
Single-top Wt	400 ± 80	880 ± 170
Single-top s-channel	310 ± 90	160 ± 50
W+jets	3600 ± 1900	4000 ± 5000
Diboson	130 ± 60	80 ± 40
Z+jets	26 ± 20	42 ± 30
Multijets	710 ± 350	410 ± 210
Total bkg.	14400 ± 3100	29000 ± 7000
Data	14138	27759

$W' \to tb$: Upper 95% C.L. cross section limits times branching ratio on W'_L and W'_R

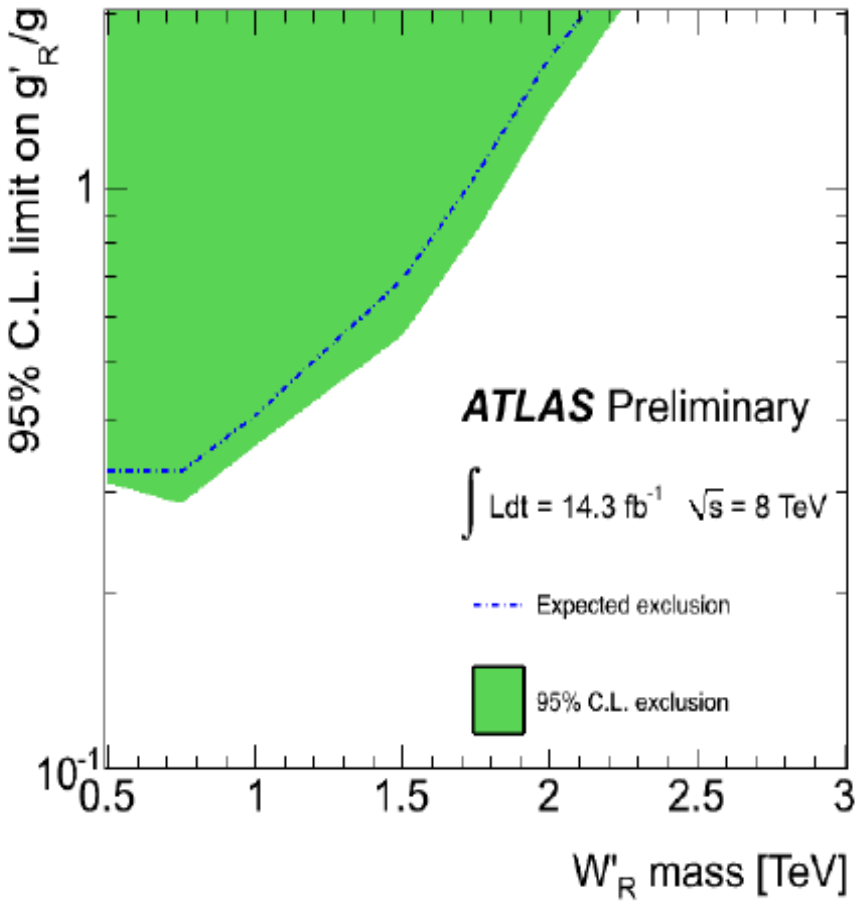
Table 2: Summary table of the W'-boson cross-section times branching ratio theoretical values [6] and observed 95% CL limits (in pb) for left-handed and right-handed W' bosons.

	W'_L		W'_R	
W' mass (TeV)	Theory	Obs. limit	Theory	Obs. limit
0.5	17	4.0	23	2.2
1.0	1.0	0.24	1.4	0.17
1.5	0.13	0.075	0.17	0.051
2.0	0.022	0.064	0.028	0.056
2.5	0.0044	0.11	0.0054	0.10
3.0	0.0011	0.20	0.0013	0.19

$W' \to tb$: Observed and expected 95% C.L. on g'/g as a function of $m_{W'}$ for W'_L and W'_R



(a)



(b)

$b^* \to Wt$: Data and expected background event yields

Table 1
Observed and predicted event yields in the dilepton channel. Only normalisation uncertainties are given. The signal yields are calculated with $\kappa_L^b = g_L = 1$ and $\kappa_R^b = g_R = 0$.

Process	Event yield
b^* (400 GeV)	1250 ± 170
b^* (600 GeV)	211 ± 32
b^* (800 GeV)	41 ± 8
b^* (1000 GeV)	8.9 ± 1.9
b^* (1200 GeV)	2.1 ± 0.5
Wt	293 ± 21
$t\bar{t}$	1380 ± 140
Diboson	255 ± 63
$Z \to e^+e^-$	41 ± 4
$Z \to \mu^+\mu^-$	118 ± 12
$Z \to \tau^+\tau^-$	14 ± 9
Fake dileptons	90 ± 90
Total expected bkg.	2190 ± 180
Total observed	2259

Table 2
Observed and expected event yields in the lepton + jets channel. Only normalisation uncertainties are given. The signal yields are calculated with $\kappa_L^b = g_L = 1$ and $\kappa_R^b = g_R = 0$.

Process	Event yield
b^* (400 GeV)	$12\,100 \pm 1600$
b^* (600 GeV)	1950 ± 300
b^* (800 GeV)	370 ± 70
b^* (1000 GeV)	79 ± 17
b^* (1200 GeV)	20 ± 5
Wt	1660 ± 120
single top s,t-channel	1960 ± 140
$t\bar{t}$	$15\,700 \pm 1600$
W + light jets	3200 ± 400
W + jets HF	$10\,900 \pm 1400$
Diboson	327 ± 16
Z + jets	1300 ± 800
Multijet	3500 ± 1700
Total expected bkg.	$38\,500 \pm 2900$
Total observed	38 175