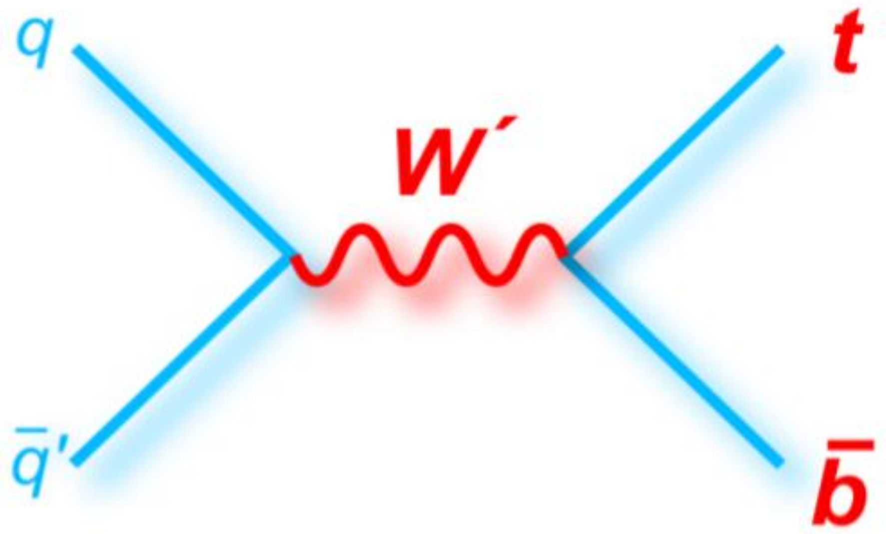
Search for W′ Production in the Single Top Channel with the ATLAS Detector



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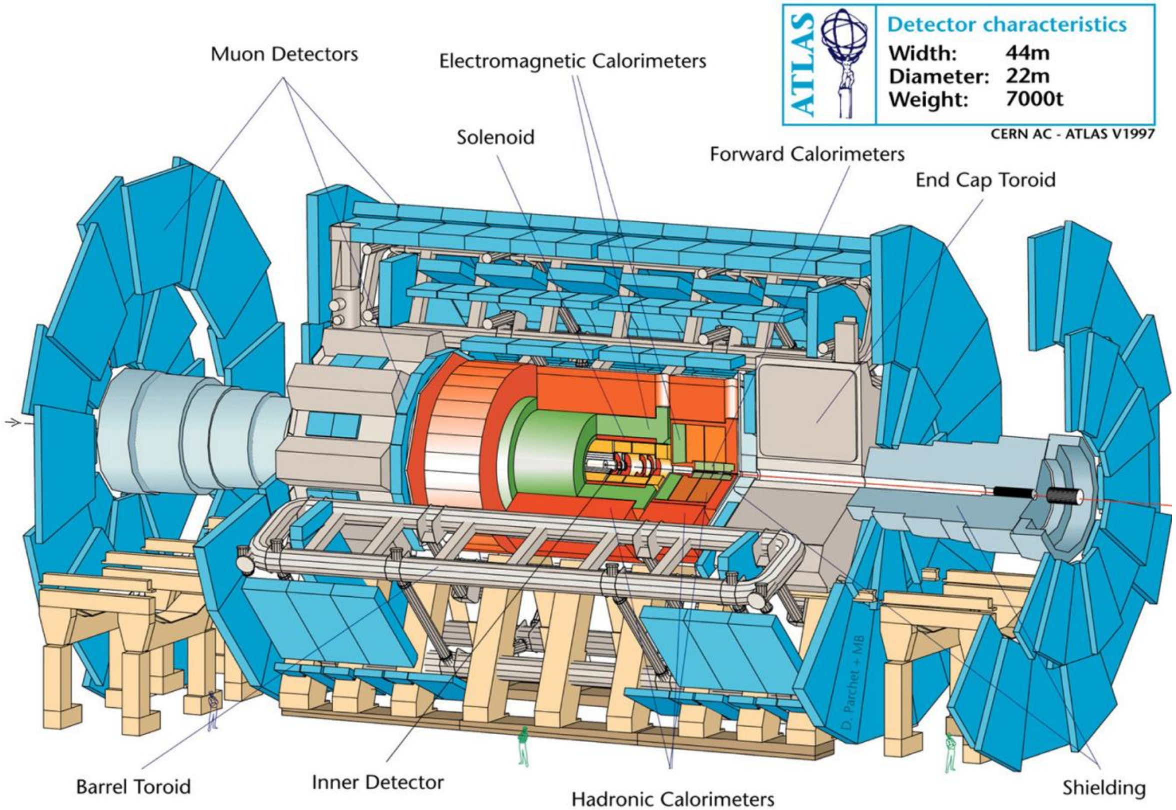
Why W’→tb?

- I am presenting recent results from ATLAS in the search for W′→tb and improvements to the analysis we are currently working on.
  - Most recent result [ATLAS-CONF-2013-050]
- Why look for W′→tb?
  - W’ is a common feature of many new physics models.
  - The W′→tb channel is complementary to the W′→ℓυ search channel.
    - When W′→ℓυ is suppressed, such as when $m_{neutrino} > m_{W'}$, the W′→tb channel has sensitivity competitive with W′→ℓυ.
    - It is also possible that the W' is coupled more strongly to the 3rd generation quarks.

[arXiv:hep-ph/9603349]
[arXiv:hep-ph/9602390]

The ATLAS Detector



- **Information from all of the ATLAS detector systems is used.**
- **In the event selection the jets and leptons are required to be centrally located where the detector has the best resolution.**

Event Selection

- **Two control regions are formed:**
  - **Events that fail the M(W′) cut are used to normalize the W+jets background.**
  - **Single tagged events are used to verify the modeling of kinematic variables.**

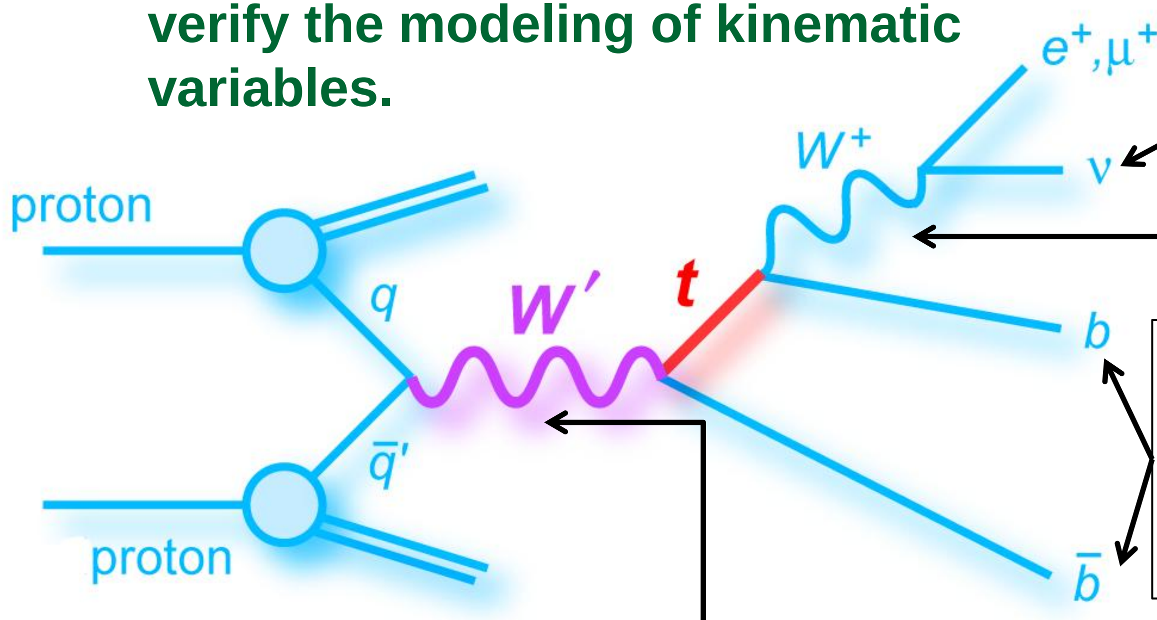
Exactly 1 lepton with p_T > 30 GeV.

- **Electrons: |η| < 2.47 excluding 1.37 < |η| < 1.52**
- **Muons: |η| < 2.5**

MET > 35 GeV.

Triangular cut

M_T(W) + MET > 60 GeV.



2 or 3 jets with p_T > 25 GeV, |η| < 2.5.

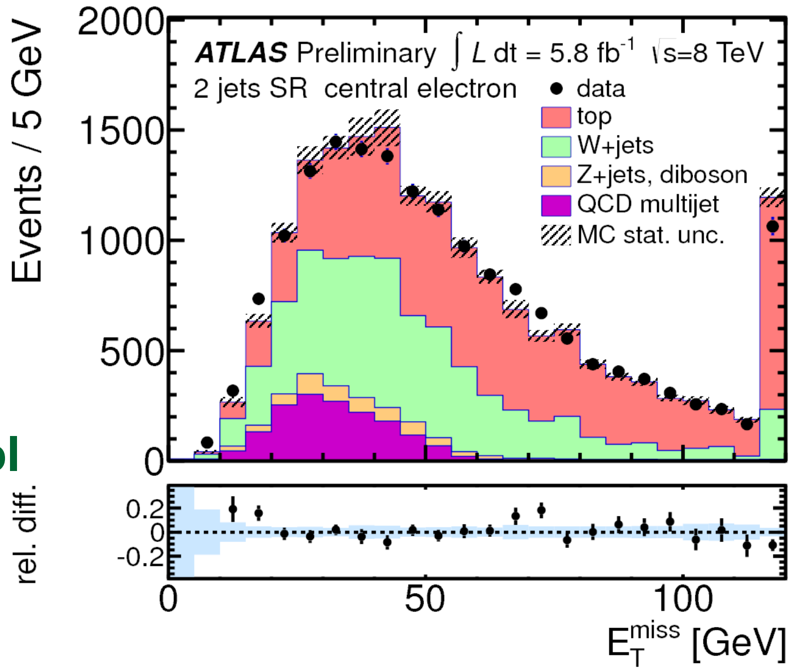
Exactly 2 b-tagged jets with 70% tagging efficiency.

M(W′) > 270 GeV.

Backgrounds

- **Multijet**
  - **Normalized by fitting the MET distribution without the 35 GeV selection cut.**
  - **Shape is obtained by allowing jets to fake electrons in a simulated dijet sample.**
- **W+jets**
  - **Normalized by subtracting all other backgrounds from the data in the control region M(W′) < 270 GeV for each selection channel.**
  - **Shape is taken from Monte Carlo simulation.**

[ATLAS-CONF-2012-132]



Backgrounds

- **The remainder of the backgrounds are modeled in Monte Carlo simulation and are scaled to the theoretical prediction.**

Sample	Generator
ttbar	MC@NLO+HERWIG (Parton Shower and Hadronisation) MC@NLO+JIMMY (Multiple Parton Scattering and Underlying Event)
Single-top t-channel	ACERMC+PYTHIA
Single-top Wt	MC@NLO+HERWIG
Single-top s-channel	MC@NLO+HERWIG
Diboson	HERWIG
Z+jets	ALPGEN+HERWIG
W+jets	ALPGEN+HERWIG
Multijet	PYTHIA
W'	MADGRAPH+PYTHIA

Systematic Uncertainties (1)

- We consider the following uncertainties:
  - Lepton Energy Scale and Resolution
    - The uncertainty in the lepton energy scale and energy resolution are propagated through the analysis.
  - Lepton Identification and Trigger Efficiency
    - The uncertainty in the lepton identification efficiency and the trigger efficiencies are assessed.
  - Jet Energy Scale — One of the dominant systematics
    - The uncertainty in the jet energy scale (JES) is assessed for each jet dependent on its p_T and position in the detector and is propagated to the calculation of the missing transverse energy.
  - Jet Energy Resolution
    - The impact of the jet energy resolution uncertainty is assessed by smearing the jet energy in all samples.
  - Jet Reconstruction Efficiency
    - The uncertainty in the jet reconstruction efficiency is assessed by randomly dropping jets from events.

Systematic Uncertainties (2)

- **b-tagging Performance** One of the dominant systematics
  - **The uncertainty in the b-tagging efficiency and the mistagging rates are estimated from data.**
- **Monte Carlo Generator**
  - **The uncertainty in the ttbar yield due to the Monte Carlo generator is assessed by taking the larger of the differences between the nominal MC@NLO sample and samples produced using POWHEG+HERWIG and ALPGEN+HERWIG.**
- **Parton Shower Modeling**
  - **The uncertainty in the ttbar acceptance due to the parton shower modeling is assessed by taking the difference between samples produced using POWHEG+HERWIG and POWHEG+PYTHIA.**
- **Initial State Radiation/Final State Radiation (ISR/FSR)**
  - **The dependence of the top-quark backgrounds on the ISR/FSR modeling is assessed by taking the largest difference from a set of samples generated using ACERMC+PYTHIA with varying PYTHIA ISR and FSR parameter settings.**

Systematic Uncertainties (3)

- Parton Distribution Function (PDF)
  - The PDF uncertainty is estimated for the top-quark and signal samples normalizing the envelope of CT10, MWST2008NLO68CL, and NNPDF2X at 68% CL to the nominal cross-section.
- Theoretical Cross-section Normalization — One of the dominant systematics
  - For each sample which is normalized to the theoretical cross-section we assess a flat rate uncertainty to account for the scale variations and the uncertainties in α_s and PDFs.
- Multijet Background Normalization
  - We assess a 50% uncertainty on the multijet background rate.
- W+jets Background
  - By propagating the effects of all other systematics in the control region we assess the uncertainty in the W+jets rate. The uncertainty in the modeling is estimated using samples produced while varying the ALPGEN parameters parton p_T and the functional form of the factorization scale.

Systematic Uncertainties (4)

- **Jet Vertex Fraction**
  - **The effects of the uncertainty on the jet vertex fraction is assessed on the rates of all samples.**
- **Luminosity**
  - **The uncertainty in the integrated luminosity used in this analysis is 3.6%, derived from beam-separation scans performed in April 2012.**
- **MC Statistics**
  - **The impact of limited size simulated samples is taken into account.**

Analysis

- **For each channel a Boosted Decision Tree (BDT) is trained using the ROOT Toolkit for Multivariate Data Analysis (TMVA).**
  - **For the training signal the simulation of right handed W′ with a mass of 1750 GeV is used.**
  - **Variables are selected from a long list of kinimatic variables.**
  - **Selected variables are required to have a discriminating power greater than 20%.**
  - **Selected variables must be well modeled in the 1-tag control region.**

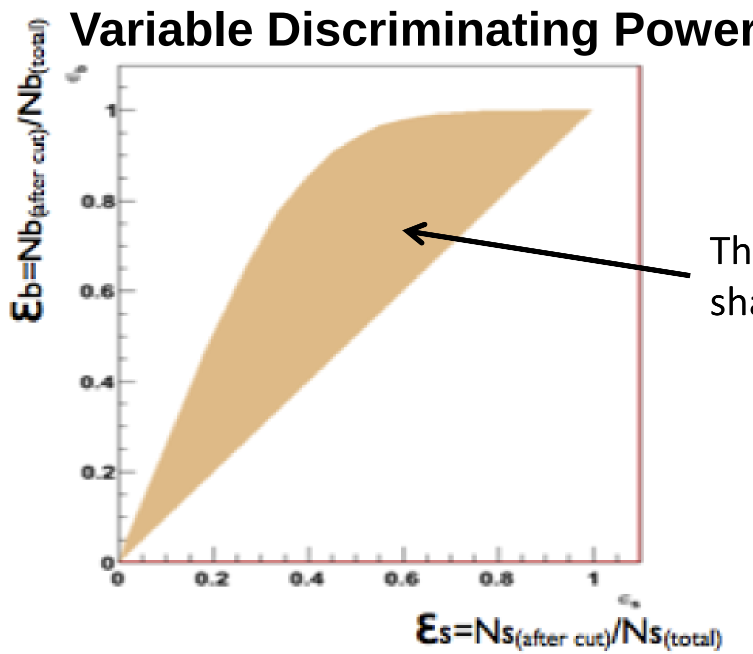
2-Jet 2-Tagged BDT Variables

m_{tb}	$p_T(b_2)$
$p_T(t)$	$p_T(l)$
$\Delta R(l, b_2)$	$\Delta R(l, t)$
$H_T(l, \text{jets}, \text{MET})$	$\Delta R(l, W)$
$m_{b_1 b_2}$	$\Delta R(b_1, b_2)$
$E_T(W)$	sphericity
$p_T(b_1)$	aplanarity

3-Jet 2-Tagged BDT Variables

m_{tb}	$\Delta\eta(l, t)$
$p_T(t)$	$\Delta R(b_1, t)$
sphericity	$\Delta R(b_1, W)$
$p_T(b_1)$	$\Delta R(l, b_1)$
$p_T(l)$	aplanarity
$M_{lb_1 b_2}$	$\Delta\phi(W, t)$
$\Delta\eta(l, W)$	-

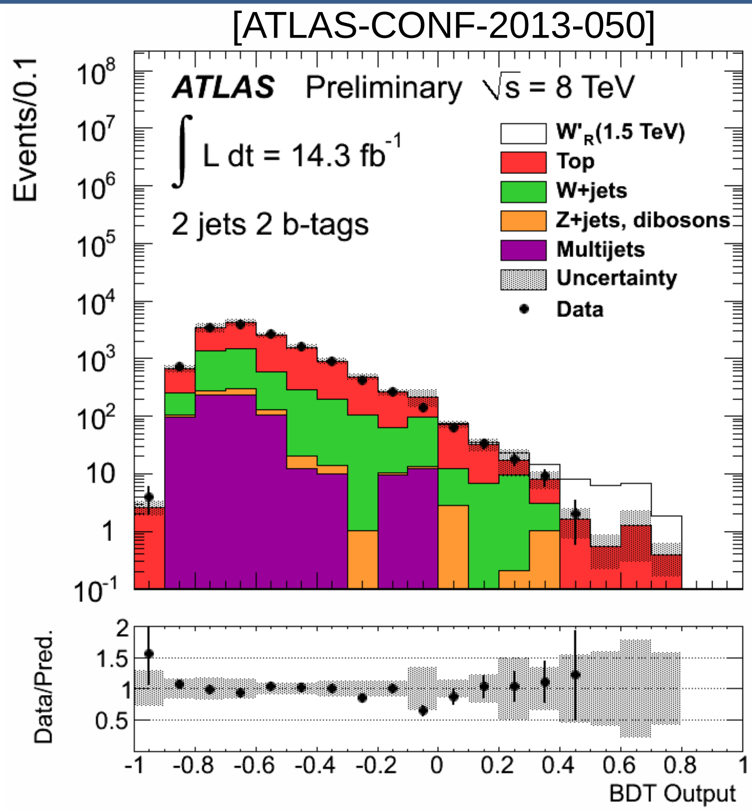
Discriminating Power

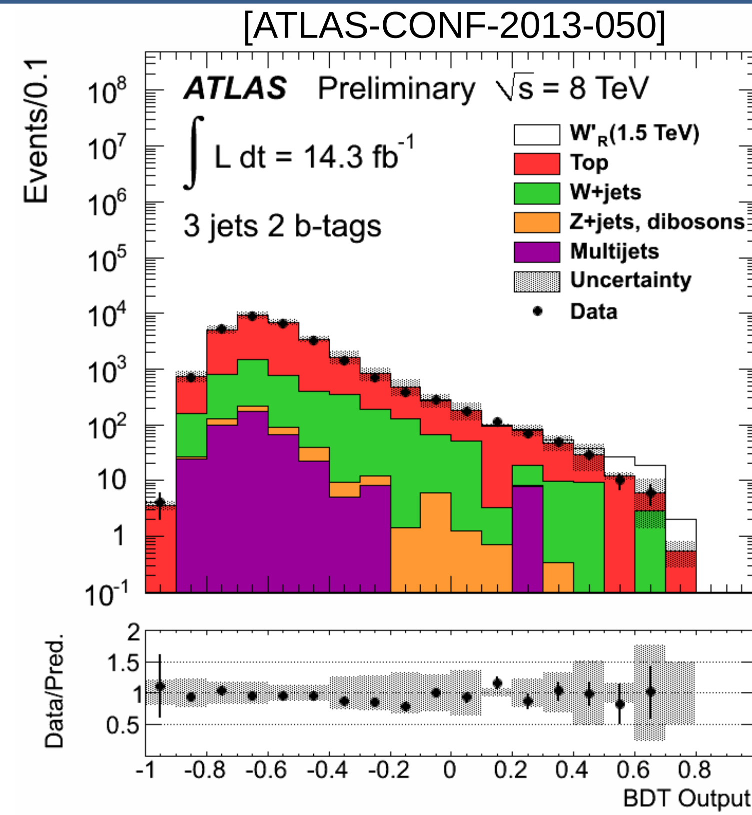


The discriminating power is the shaded area under the curve.

Discriminating power is determined by plotting the background vs. signal efficiencies (ε_B vs. ε_S) for successive cuts on each variable and taking the area between the resulting curve and the line $\varepsilon_B = \varepsilon_S$.

BDT Output





- **The BDT output for the 2 jet and 3 jet selections are above.**
- **A right handed W′ signal with a mass of 1.5 TeV is added to the backgrounds to illustrate what a signal would look like in the analysis.**

Event Yields

	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

- **The final event yields for several right handed W′ signal mass points as well as the backgrounds and data.**

Statistical Analysis (1)

- **With no observed excess in the data we calculate exclusion limits on the production cross-section of the signal as a function of its mass.**
  - **We use the CL_s procedure to calculate exclusion limits at the 95% confidence level using a log-likelihood ratio (LLR) as the test statistic.**

$$LLR = -2\ln\frac{\mathcal{L}(data \mid H_1)}{\mathcal{L}(data \mid H_0)}$$

H_1 is the test hypothesis which includes the signal
H_0 is the null hypothesis which includes no signal

  - **Pseudo-experiments are generated for each hypothesis.**
    - **Statistical fluctuations are treated on a bin-by-bin basis as Poisson fluctuations.**
    - **Systematic uncertainties are treated on a bin-by-bin basis as independent Gaussian fluctuations.**

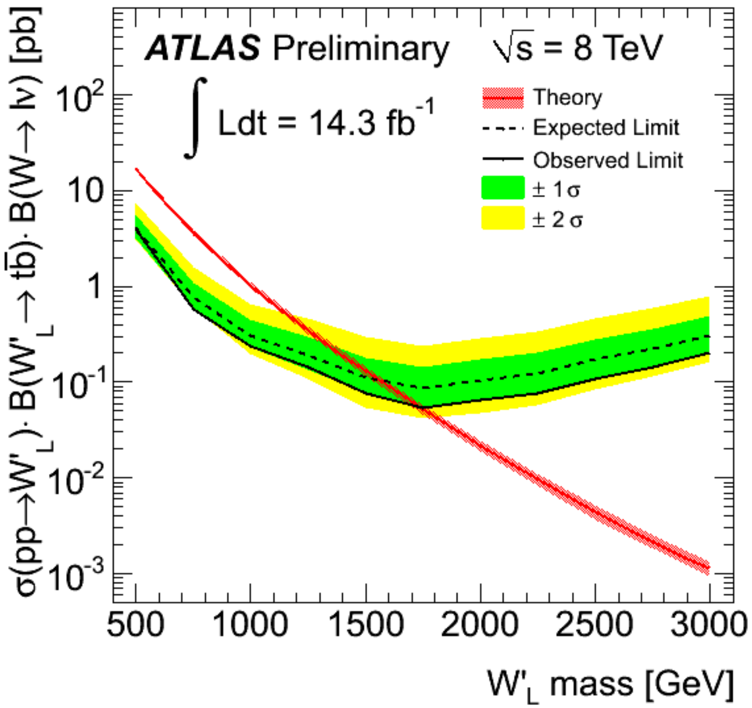
Statistical Analysis (2)

- The bin probabilities are combined into a total probability.
  - Each channel's probability is the product its bins' Poisson probabilities.
  - The total probability is the product of the channels' probabilities.
- CL_{s+b} (CL_b) is defined as the fraction of pseudo-experiments generated with the signal-plus-background (background only) hypothesis with LLR greater than the observed or expected LLR.
- Cross-sections are considered excluded at the 95% confidence level if $CL_s = CL_{s+b}/CL_b < 0.05$.

- To reduce the effects of the systematics on the limit we fit the ttbar yield to data during the statistical analysis.

Mass Limit

[ATLAS-CONF-2013-050]



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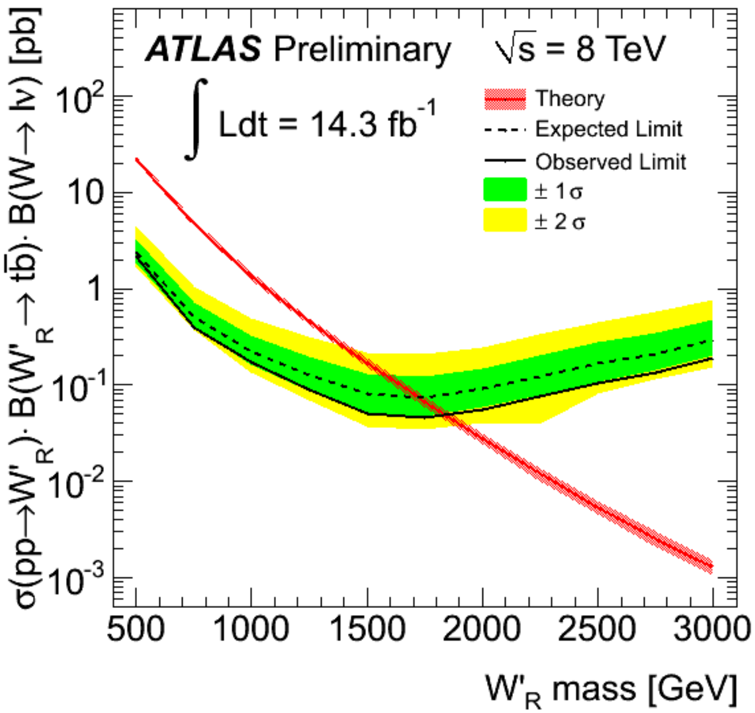


- **Both 2 and 3 jet channels are combined and exclusion limits on the cross-section time branching ratio for each W′ mass are placed.**
- **For a W′ with standard model couplings, the mass lower limits are:**
  - **W'_L > 1.74 TeV**
  - **W'_R > 1.84 TeV**

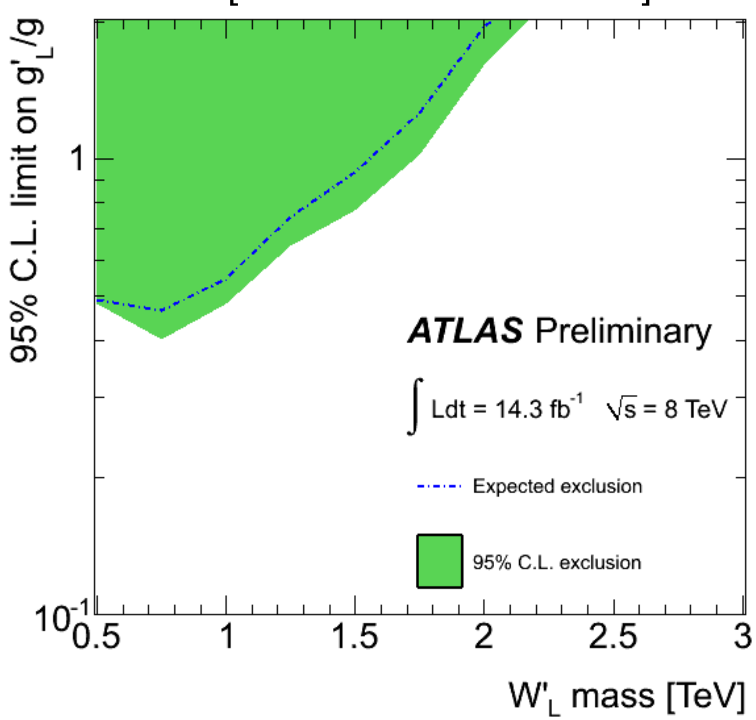
Setting Limits on g’/g

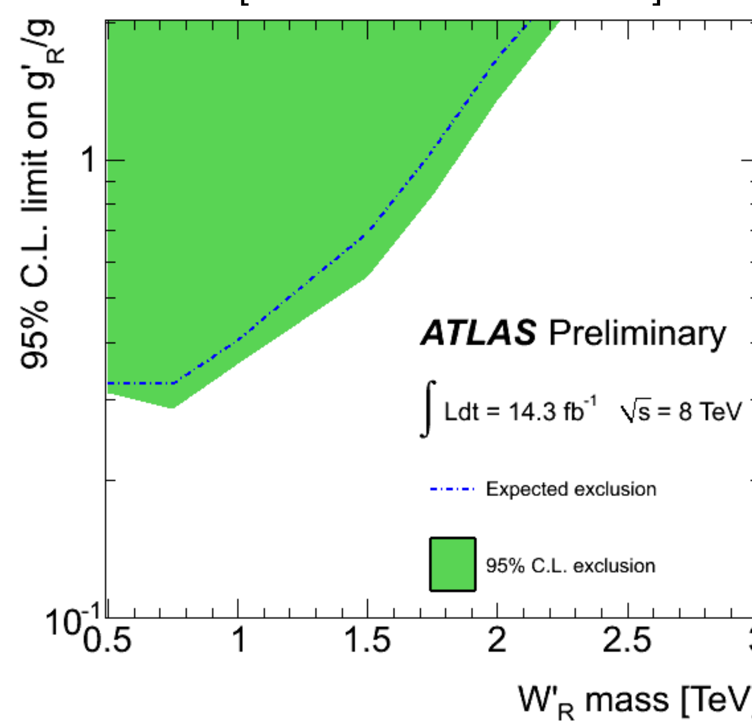
- **Limits can also be set on g’ as a function of W′ mass for models with Lagrangians of the form:**

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

- **The production vertex has a g'^2 dependence.**
  - By taking the ratio of our cross-section limit and the standard model coupling cross-section for each W′ mass, limits on g′/g can be derived.
  - The W′ resonance width, $\Gamma_{W'}$, is also dependent on g'^2 so the cross section is sensitive to the initial-state quark PDFs.
  - The cross-section’s dependence on g′/g and $m_{W'}$ is estimated using MADGRAPH and the effects are found to be at most a few percent for g′/g < 2 and thus they are neglected.

Limits on g′/g





- **Limits on g′/g as functions of W′ mass.**
- **For values of g′/g > 2, the W′ width becomes significant and interactions with the initial state quarks’ PDF must be taken into account.**

Improvements In Progress

- **Update with the full 20.4 fb^{-1} of 8 TeV data.**
  - **This includes updated recommendations from other groups.**
- **Include 1-tag events as an independent channel.**
- **More robust BDT strategy**
  - **Training separate BDTs for left and right handed samples, possibly training different BDTs for different mass ranges.**
- **Improved event selection**
  - **Relaxing the muon isolation requirement increases the signal efficiency by up to ~50%.** [arXiv:1307.1820]
  - **Investigating boosted-b-tagging using soft-lepton-tagging.**
  - **More stringent event selection for 1-tag events may be necessary to control the backgrounds.**

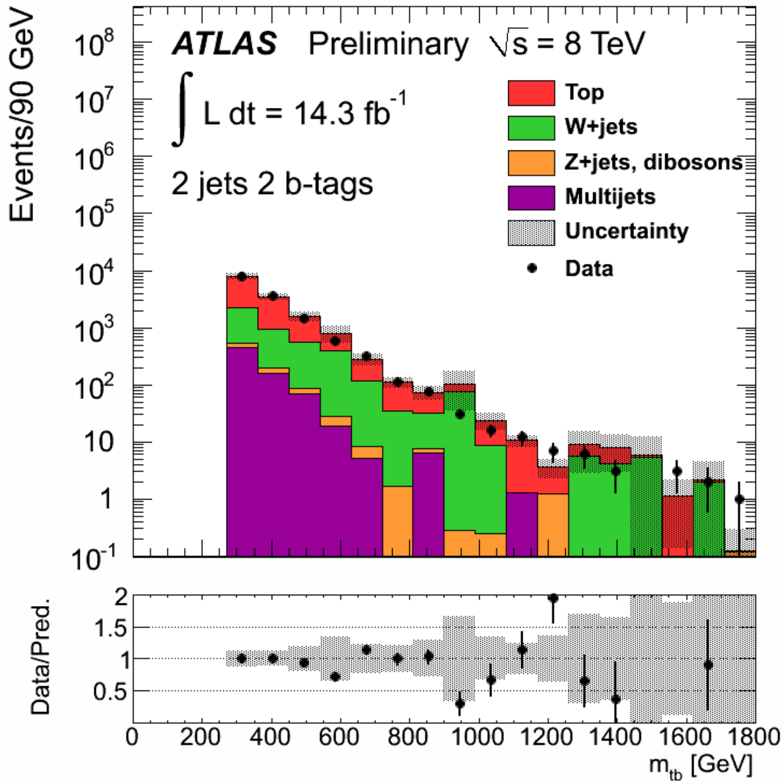
Summary

- We searched for $W' \rightarrow tb \rightarrow l\nu bb$ in 14.3 fb^{-1} by considering events with a single lepton, MET, and 2 b-tagged jets and applying boosted decision trees to construct multivariate discriminants.
- When no excess was observed, limits are placed on the mass of a W′ with standard model couplings of:
  - $W'_L > 1.74$ TeV
  - $W'_R > 1.84$ TeV
- Limits are also calculated for g′/g as a function of W′ mass.
- Our group also has a hadronic analysis in progress.
- Updated results should be available this fall!

Backup Slides

m_{tb} Distribution

[ATLAS-CONF-2013-050]



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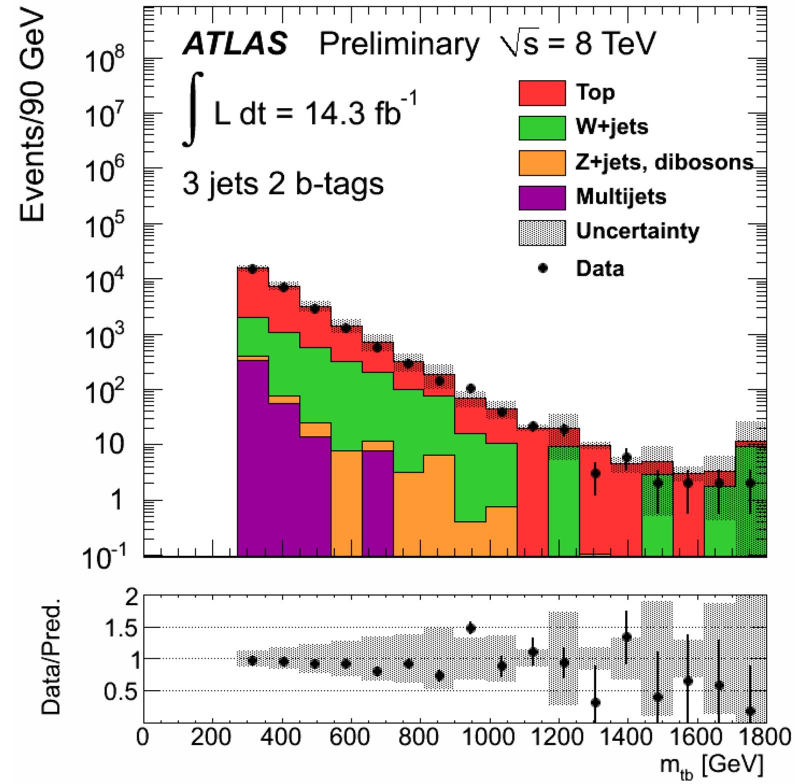
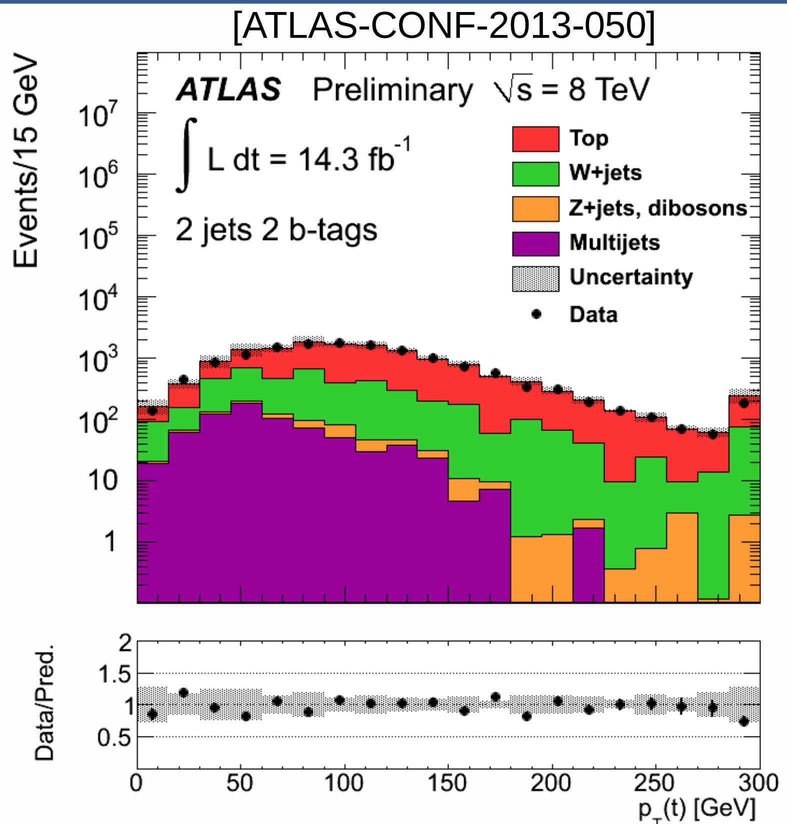
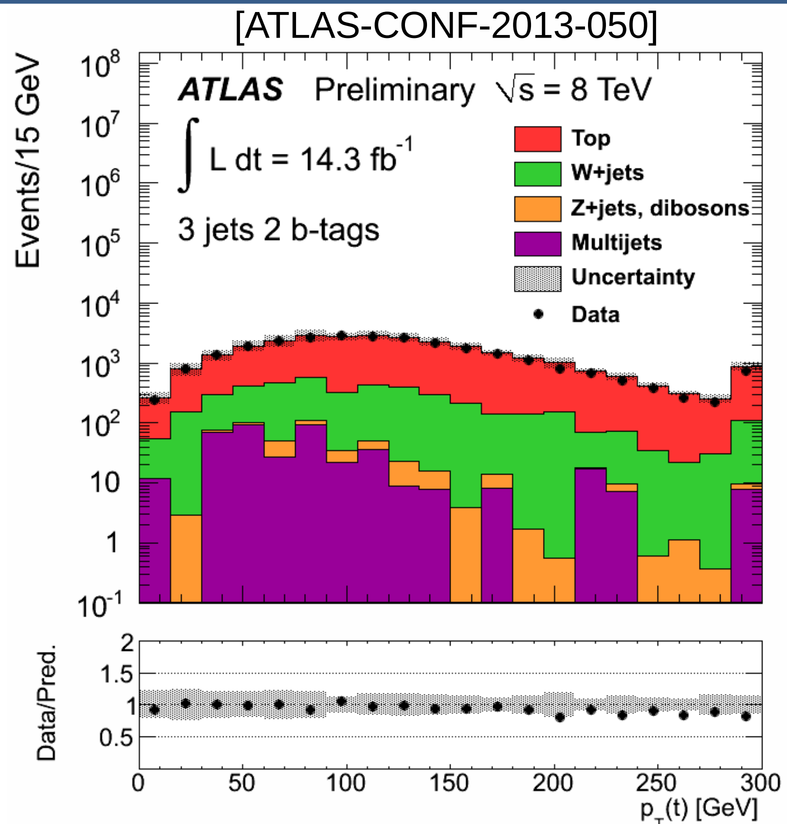


- m_{tb} is the invariant mass of the reconstructed top and bottom quarks, which is the W′ invariant mass.
- This is the most discriminating variable for both selections.

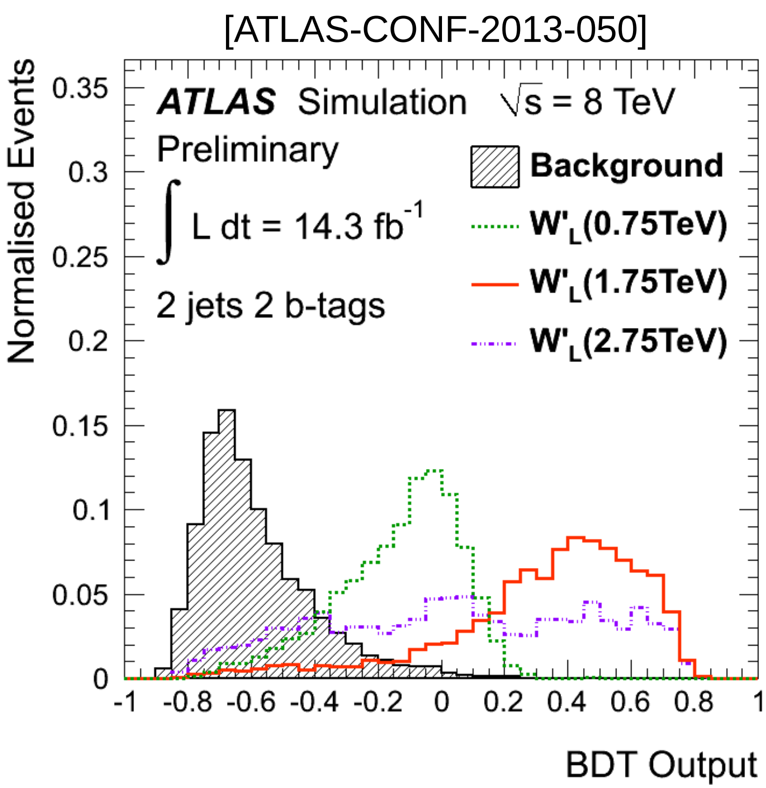
$p_T(t)$ Distribution

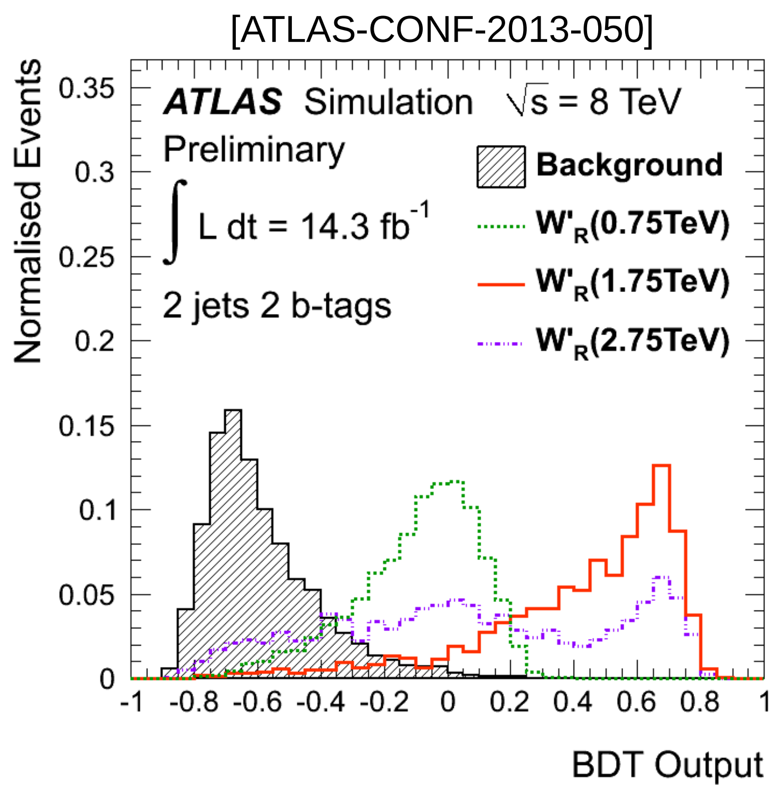




- **$p_T(t)$ is the transverse momentum of the reconstructed top quark.**
- **This is the second most discriminating variable for both selections.**

BDT Distribution 2 Jets





BDT Distribution 3 Jets

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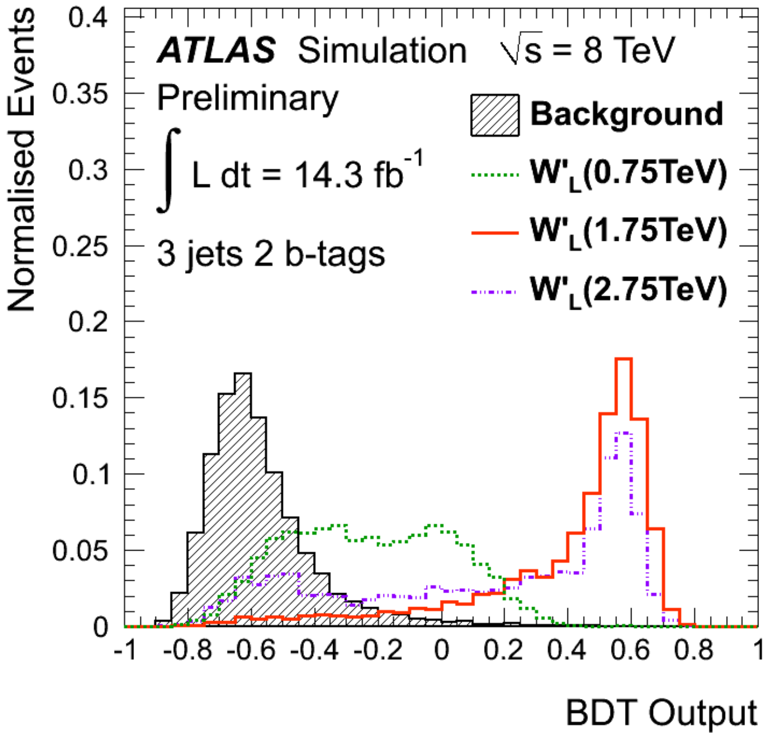

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