Searches in s-channel Single Top Quark Production at ATLAS

Barbara Alvarez Gonzalez
on behalf of the ATLAS Collaboration

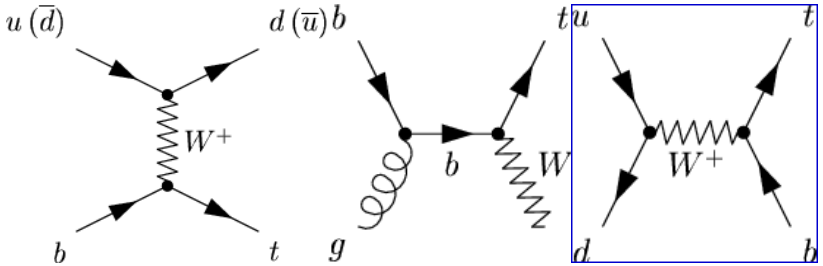
ICHEP, July 6, 2012

OVERVIEW

- Introduction and motivation
- Present the results of two **ATLAS** analyses:
  - *Search for s-Channel Single Top-Quark Production*
    $\Rightarrow$ https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-118/
  - *Search for tb resonances* $\Rightarrow$ http://arxiv.org/abs/1205.1016
- Event selection and background estimation
  - *Shared in both analyses*
- Different techniques for signal extraction:
  - *Cut-based*
  - *Template fit*
- Summary

Introduction and Motivation

- *Single top was first observed at Fermilab in 2009 by* **CDF** *and* **D0**
- *In 2011, t-channel observations by* **ATLAS** *and* **CMS**
- Three production mechanisms:
  - t-channel (σ=65pb @ 7TeV LHC)
  - Wt (σ=16pb @ 7TeV LHC)
  - *s*-channel (σ=5pb @ 7TeV LHC)

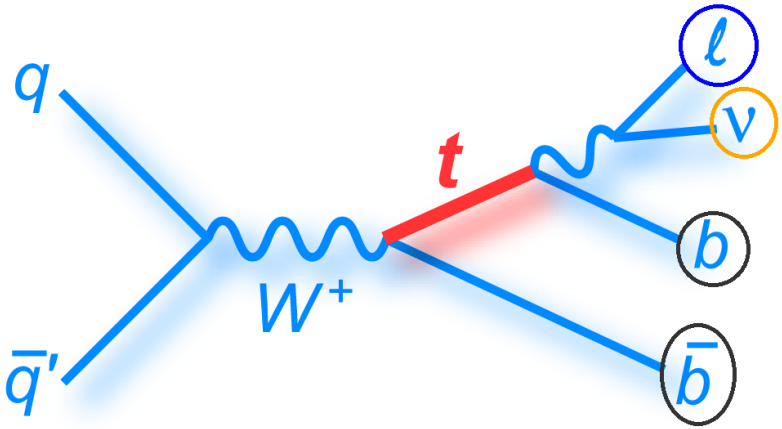


- s-channel single top:
  - Tiny signal, $\sim$ 5 times larger than at Tevatron
  - Very challenging
  - Sensitive probe to new physics processes (W' bosons, charged Higgs bosons,...)

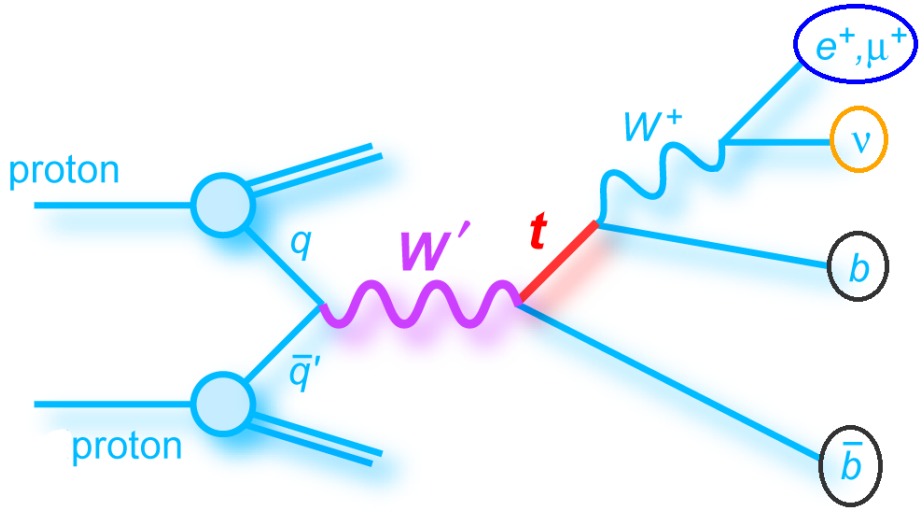
Feynman Diagrams

Use same selection and background estimation in both searches

s-channel single top

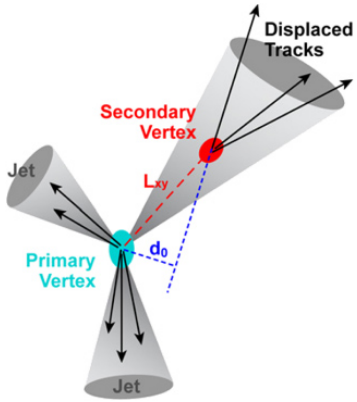


$W' \rightarrow tb$



Key Ingredients

- Lepton identification
- *b*-tagging algorithms
- Jet energy scale



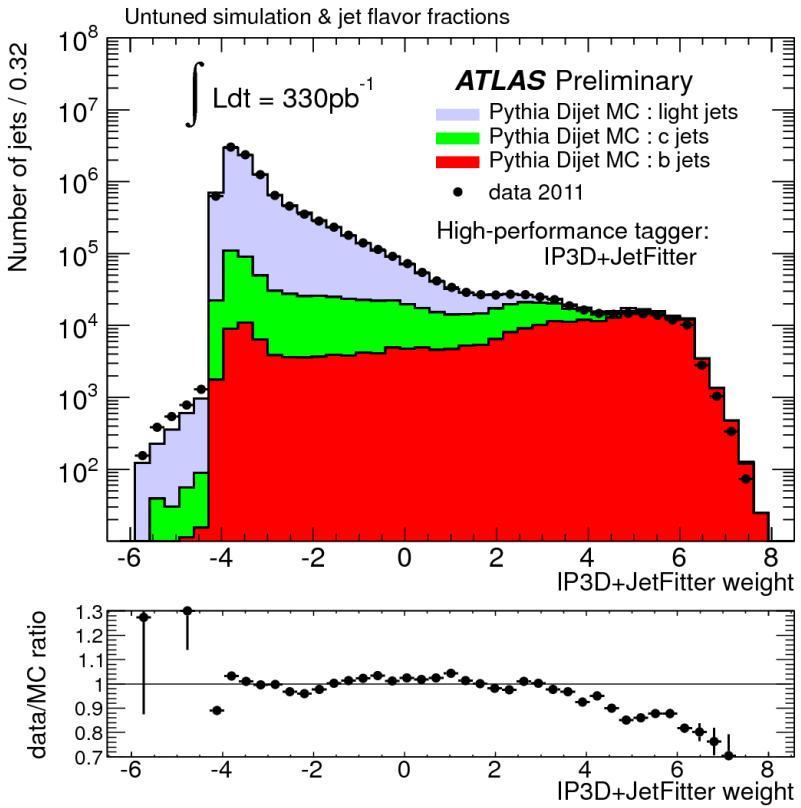
Event Selection

Data

- Single lepton (e/μ) triggers
  - **0.70/1.04 fb^{-1}** of ATLAS data

Event Selection

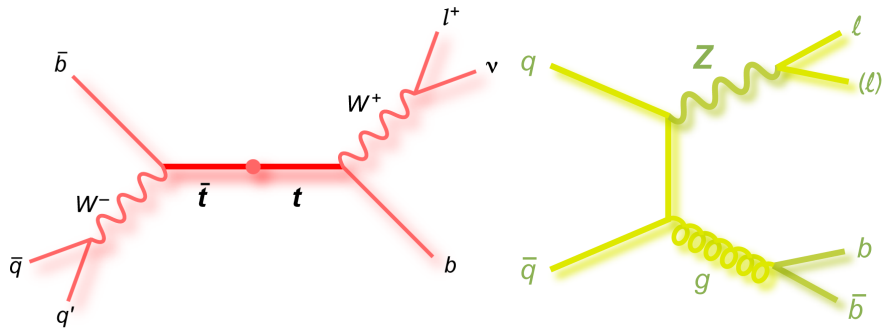
- One isolated **lepton** (e/μ)
  - $p_T > 25$ GeV
  - $|\eta| < 2.47$ electron / $|\eta| < 2.5$ muons
- $\boldsymbol{E_T^{miss}} > 25$ GeV
- Two energetic and central **jets**:
  - $|\eta| < 2.5$
  - $E_T > 25$ GeV
  - At least one *b*-tagged (57% eff.)
- Triangular cut:
  $m_T(W) > 60$ GeV - E_T^{miss}



Background Estimation: Classified in three groups

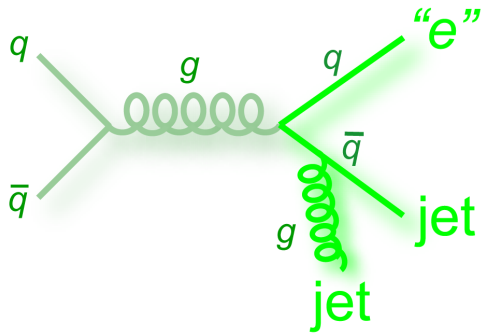
Top and EWK Processes

- Model from simulation
- Normalize to theory:
  $N_{events} = \epsilon_{evt} \sigma \int Ldt$



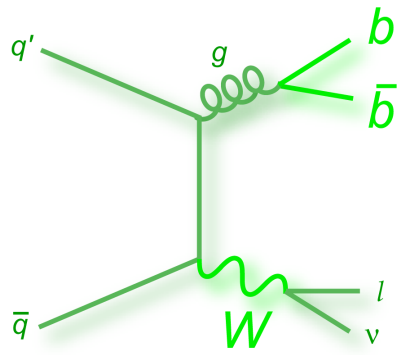
QCD Multijets

- Model from data
- Normalize to data: E_T^{miss} fit

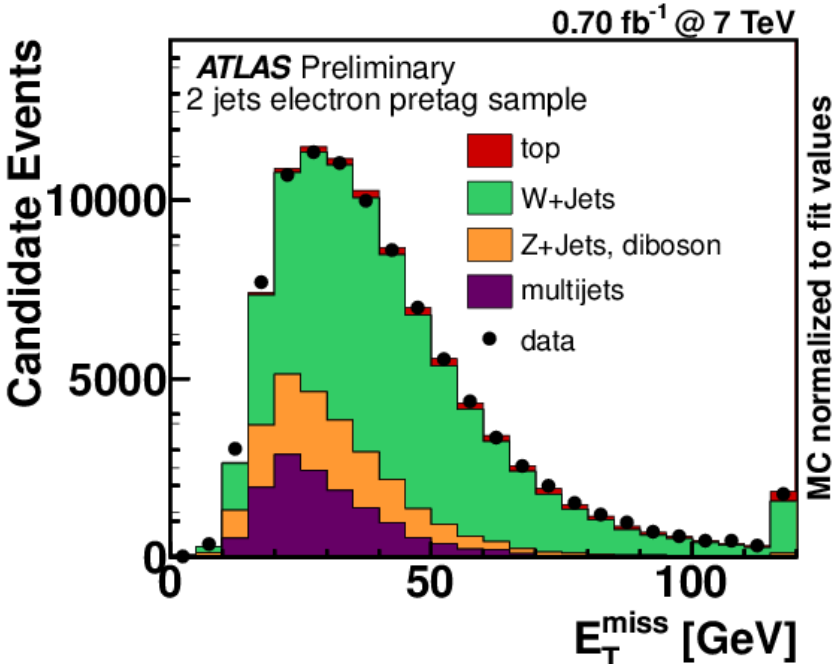


W+jets: W+HF/light

- Model from simulation
- Normalize to data



Background Estimation: QCD and W+jets



QCD Method

- Fitting the E_T^{miss} distribution
- **QCD shape** taken from the **jet-electron** sample

Jet-electron Candidate

- A *jet* is **misidentified** as a lepton
- A *lepton* from **semileptonic decay** of a heavy hadron jet

W+jets Method

- Tag counting method
- The kinematic shape and acceptances are taken from simulation
- The **overall normalization and the flavour composition** are derived from **data**

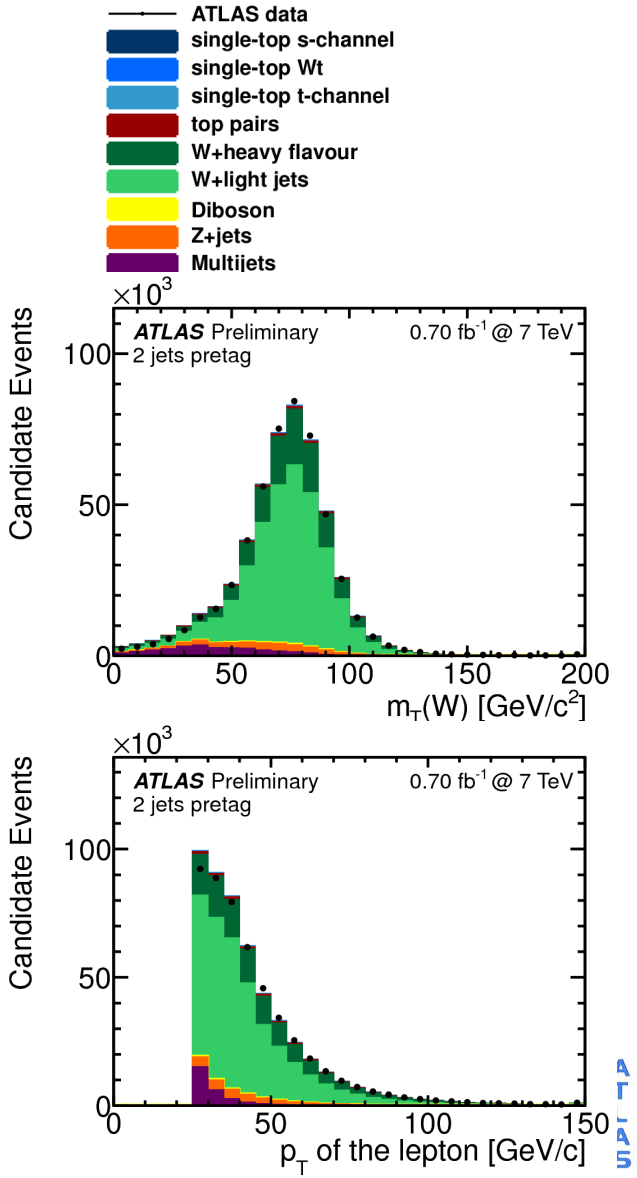
Search for *s*-channel Single Top-Quark Production

Background Modeling and Event Yields

- Signal estimation:
  - Model from simulation
  - Normalize to theory

$$N_{events} = \epsilon_{evt} \sigma_{s-channel} \int Ldt$$

	Pretag events		Single-tagged events	
	Electron	Muon	Electron	Muon
***s*-channel**	**49±5**	**55±6**	**24±2**	**26±3**
t-channel	580±60	630±60	260±30	280±30
Wt	230±20	220±20	90±10	90±9
$t\bar{t}$	1100±90	1200±100	490±40	520±40
W+jets	**38300±10700**	**49700±13900**	250±70	330±90
Wc+jets	10900±2500	12900±3000	**900±210**	**1070±250**
$Wb\bar{b}$+jets	1900±900	2300±1100	490±230	560±260
$Wc\bar{c}$+jets	4800±2200	5900±2700	270±120	340±160
Diboson	690±30	820±40	35±2	40±2
Z+jets	5900±3600	3900±2300	70±40	60±40
Multijets	8100±4100	3700±1900	280±140	320±160
Total Prediction	72600±12500	81400±14800	3200±400	3600±400
Data	**71877**	**82035**	**3242**	**3561**
S/$\sqrt{B}$	**0.18**	**0.19**	**0.42**	**0.44**



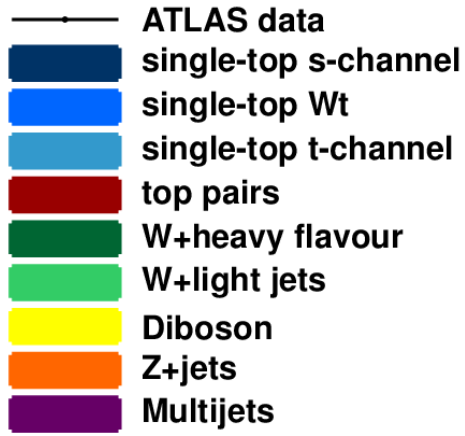
Search for *s*-channel Single Top-Quark Production

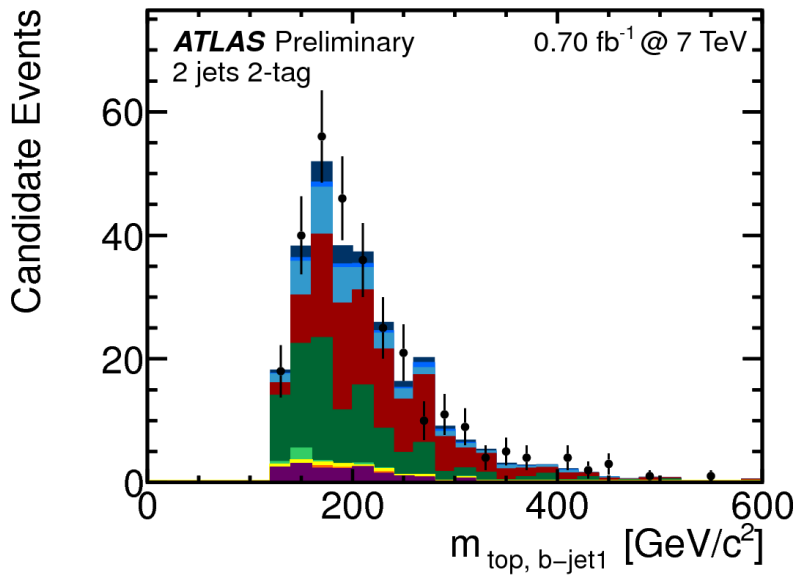
Discriminant Technique

- Sequential cuts applied to isolate the *s*-channel signal
- Used signal/$\sqrt{bkg}$ as **figure of merit**

Cut-based Selection

- **Double-tagged events**
- $30 < \mathbf{m_{top,j2}} < 247$ GeV/c^2
- $\mathbf{p_T(j_1, j_2)} < 189$ GeV/c
- $\boldsymbol{m_T(top)} < 111$ GeV
- $0.43 < \boldsymbol{\Delta R(b - jet_1, b - jet_2)} < 3.6$
- $123 < \boldsymbol{m_{top,j1}} < 788$ GeV/c^2
- $0.74 < \boldsymbol{\Delta R(b - jet_1, lepton)} < 4.68$





Search for *s*-channel Single Top-Quark Production

Result

Results

- 16 signal & 289 background final events, $S/\sqrt{B} = 0.94$
- *Profile Likelihood* used to extract the cross section limit:

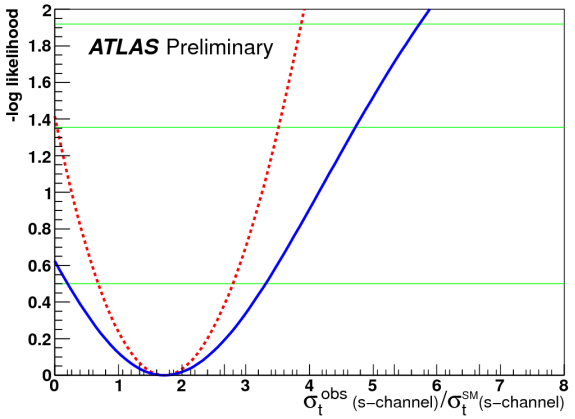
$$\sigma_{s-chan} < 26.5 \text{ pb}$$

Source of Systematic Uncertainties	$\Delta\sigma/\sigma$ [%] cut-based
Data statistics	$\pm$100
MC statistics	$\pm$70
b-tagging	-30/+20
Jet and lepton modeling	-20/+10
MC generator modeling	-60/+20
Multijets normalization	$\pm$40
Others	-10/+30
Luminosity	$\pm$50
All systematics	-110/+90
Total uncertainty	-160/+150

Possible Improvements

- Use the full **LHC dataset**
- Add single-tagged events
- New *b*-tagger (better c separation)
- Reduce systematic uncertainties

Observed

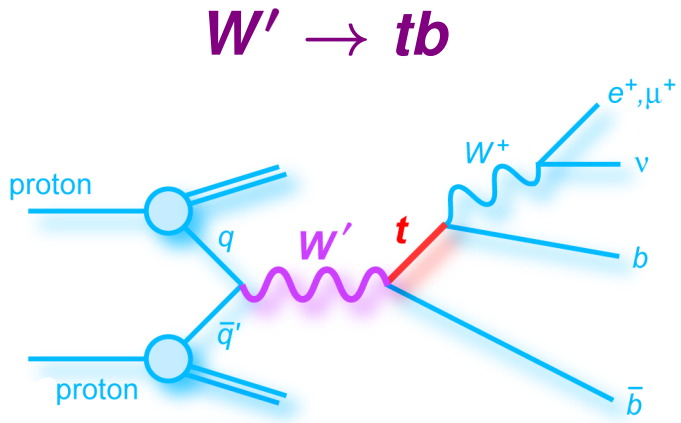


Search for *tb* Resonances

Benchmark Model

Right-handed W'_R

- A **right-handed W'_R** with **Standard Model-like couplings** is chosen as the *benchmark model* for the search for *tb* resonances



- **Next-to-leading-order (NLO) branching ratio and production W'_R cross section values estimated by Zack Sullivan**

$m_{W'_R}$ [GeV]	$\mathcal{B}(W'_R \to tb)$	$\sigma \times \mathcal{B}$ [pb]
500	0.298 ± 0.002	54.6 ± 2.1
750	0.319 ± 0.001	10.9 ± 0.6
1000	0.326 ± 0.001	2.92 ± 0.18
1250	$0.328 \pm < 0.001$	0.91 ± 0.07
1500	$0.330 \pm < 0.001$	0.31 ± 0.03
1750	$0.331 \pm < 0.001$	0.11 ± 0.01
2000	$0.332 \pm < 0.001$	0.044 ± 0.005

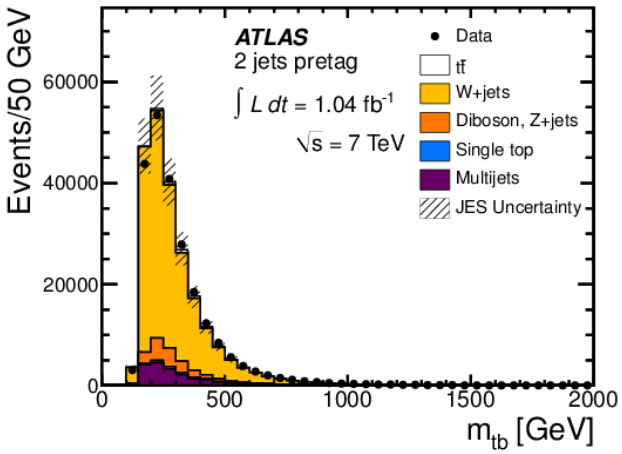
Z. Sullivan, Phys. Rev. D **66**, 075011 (2002) [arXiv:hep-ph/0207290]

Search for *tb* Resonances

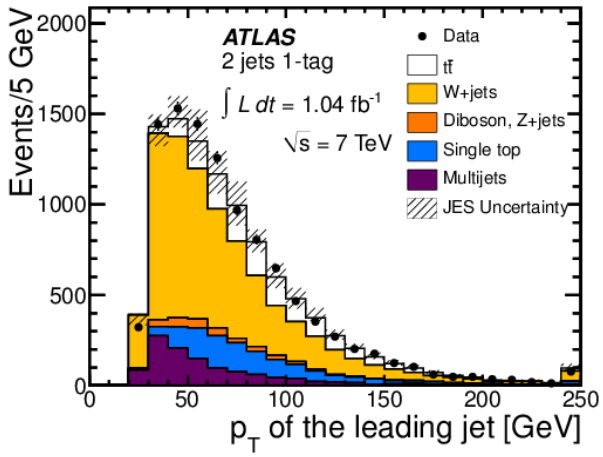
Background Modeling and Event Yields

- *Same event selection and bkg estimation than the s-channel analysis*

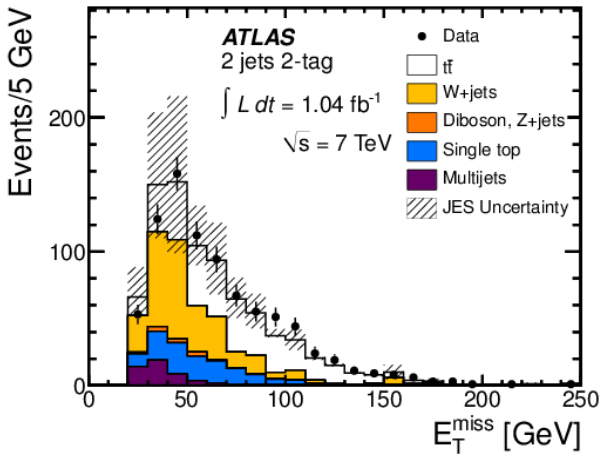
Pre-tagged



Single-tagged



Double-tagged



- **Single- and double-tagged** events used in the analysis

$m_{W'_R}$ [GeV]	Single-tagged	Double-tagged
500	973±37	455±17
750	174±9	77±4
1000	42±3	15±1
1250	11±1	3.9±0.3
1500	3.2±0.3	1.0±0.1
1750	1.0±0.1	0.26±0.03
2000	0.36±0.04	0.09±0.01

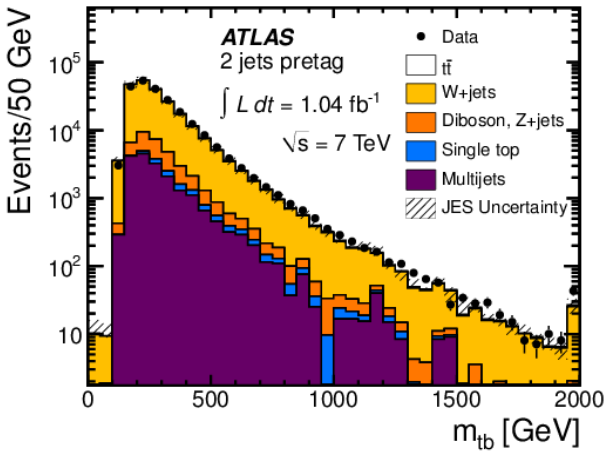
Samples	Single-tagged	Double-tagged
W+ jets	**5970±1000**	290±180
Multijets	1120±560	47±47
$t\bar{t}$	1560±130	**360±30**
Single top	1240±90	120±10
Diboson, Z+jets	320±120	14±2
Total prediction	**10200±1200**	**830±190**
Data	**10428**	**844**

Search for *tb* Resonances

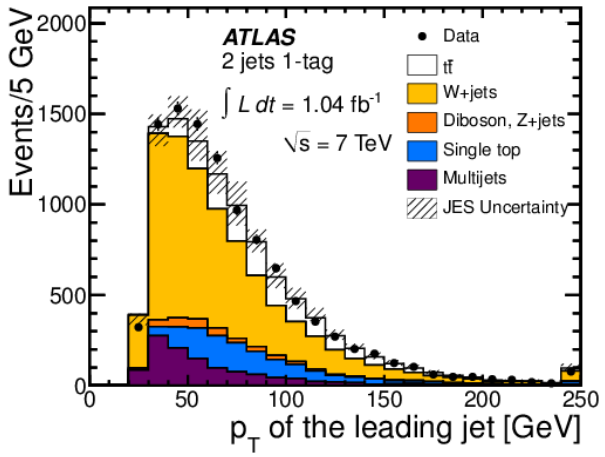
Background Modeling and Event Yields

- *Same event selection and bkg estimation than the s-channel analysis*

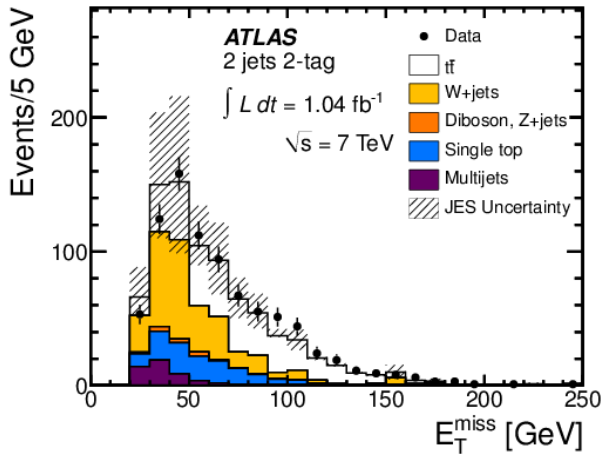
Pre-tagged



Single-tagged



Double-tagged



- **Single- and double-tagged** events used in the analysis

$m_{W'_R}$ [GeV]	Single-tagged	Double-tagged
500	973±37	455±17
750	174±9	77±4
1000	42±3	15±1
1250	11±1	3.9±0.3
1500	3.2±0.3	1.0±0.1
1750	1.0±0.1	0.26±0.03
2000	0.36±0.04	0.09±0.01

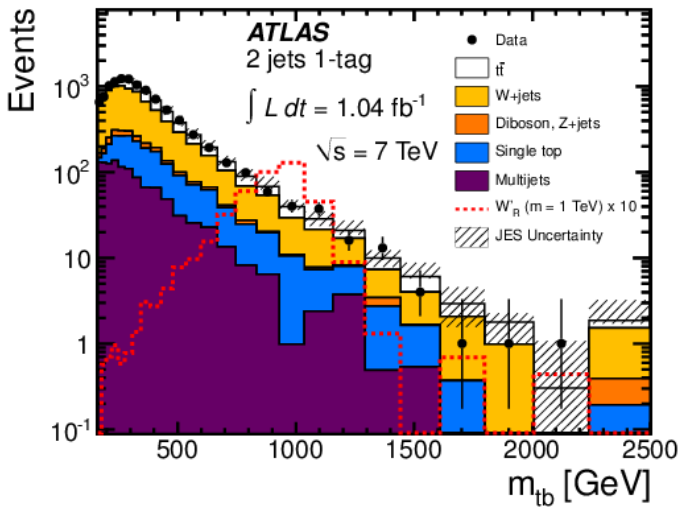
Samples	Single-tagged	Double-tagged
W+ jets	5970±1000	290±180
Multijets	1120±560	47±47
$t\bar{t}$	1560±130	360±30
Single top	1240±90	120±10
Diboson, Z+jets	320±120	14±2
Total prediction	**10200±1200**	**830±190**
Data	**10428**	**844**

Search for *tb* Resonances

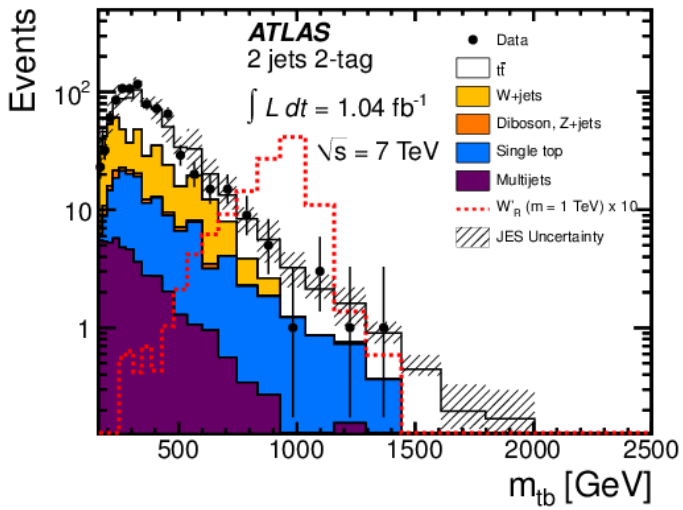
Bumphunter

- The BUMPHUNTER tool is used in this analysis (**http://arxiv.org/abs/1101.0390**) to search for any excess in the data events caused by ***tb* resonances**
- Data and MC comparisons over m_{tb}:
  - One **background template**
  - One **data template**
  - Single and double tagged events separate

Single-tagged



Double-tagged



- **No significant data excess has been identified**

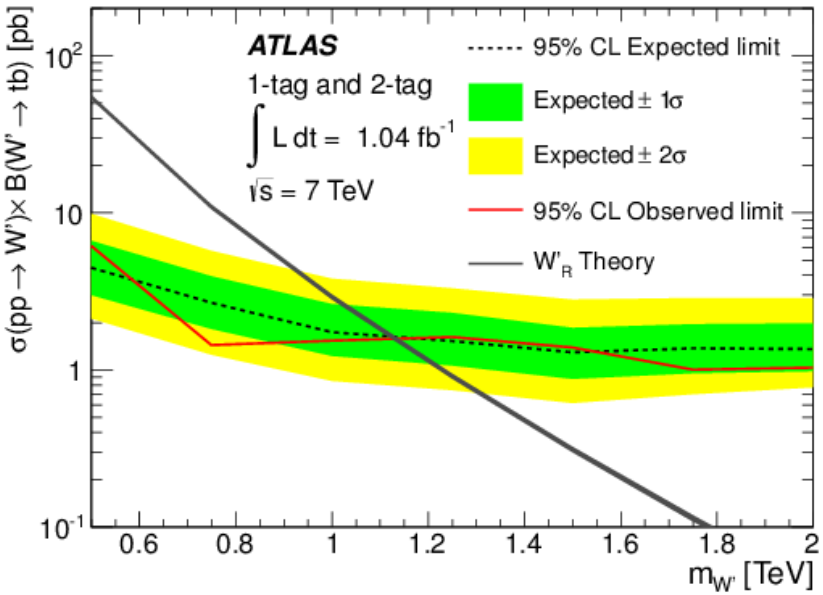
Search for tb Resonances

Results

- **Set limits** on the $\sigma(pp \to W'_R) \times \mathcal{B}(W'_R \to tb)$ at 95% CL
- Determined using Bayesian approach
- The method uses a **Binned Likelihood** function:

$$\mathcal{L}(data|\sigma B, \theta_i) = \prod_{k=1}^{N_{bin}} \frac{\mu_k^{n_k} e^{-\mu_k}}{n_k!} \prod_{i=1}^{N_{sys}} G(\theta_i, 0, 1)$$

- Observed (expected) $\sigma \times B$ limits: 6.1-1.0 (4.5-1.4) pb for W'_R masses from 0.5 to 2.0 TeV
- Observed (expected) lower **mass limit** is: $m_{W'_R} >$ **1.13 (1.13) TeV**



Possible Improvements

- Use the full **LHC dataset**
- Signal optimization
- Search also for left-handed W'

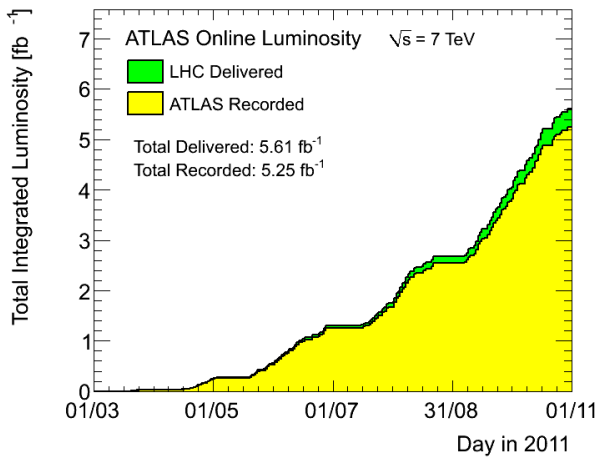
Summary

- Presented the latest ATLAS results on:
  - Search for s-Channel Single Top-Quark with 0.7 fb^{-1}

    $\sigma_{s-chan} < \mathbf{26.5\ pb}$
  - Search for *tb* resonances with 1.04 fb^{-1}

    $m_{W'_R} > \mathbf{1.13\ TeV}$
- Work ongoing to update and improve the results
- **Focus on:**
  - ***b*-tagging algorithms**
  - Optimization to **isolate the signal** (more sophisticated techniques)
  - *Reduce* the impact of systematics

Stay tuned for future results!!



THANK YOU
VERY MUCH
FOR YOUR ATTENTION!!

BACK-UP SLIDES

Documentation

The s-channel single top results presented as a *CONF Note*:

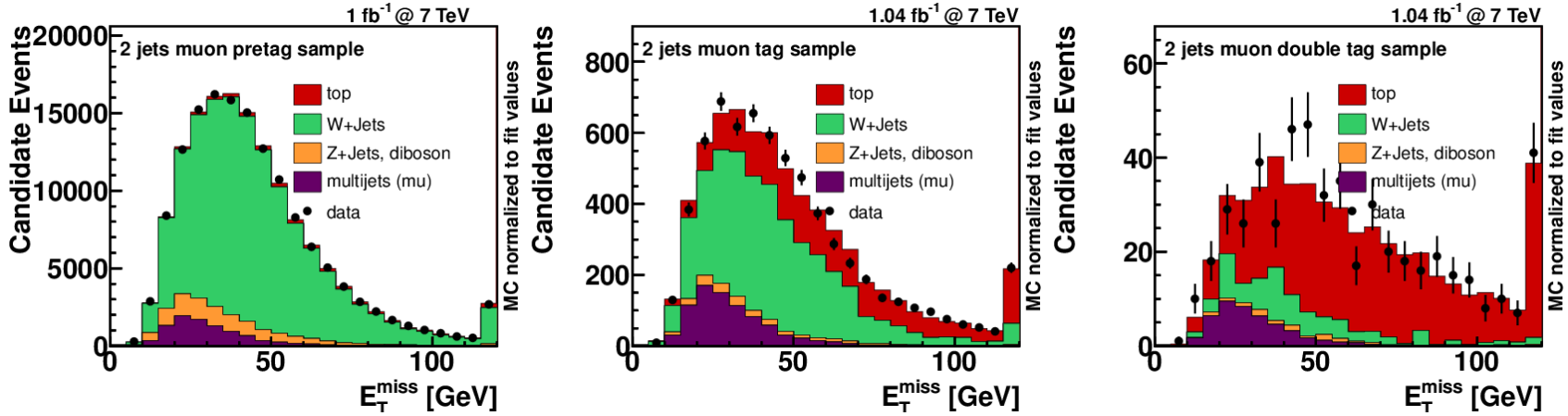
- **Title:** *Search for s-Channel Single Top-Quark Production in pp Collisions at sqrt(s) = 7 TeV*
- **Authors:** ATLAS Collaboration
- **Report-no:** ATLAS-CONF-2011-118
- **Link:** https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-118/

The *tb* resonances research submitted to *PRL*:

- **Title:** *Search for tb resonances in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector*
- **Authors:** ATLAS Collaboration
- **Report-no:** CERN-PH-EP-2012-087
- **Link:** http://arxiv.org/abs/1205.1016

Background Estimation: QCD Muon sample

- E_T^{miss} fitting method used for normalization
  - The **muon QCD shape**, on the fitting, is taken from the jet-electron sample



- The **QCD shape** for the analysis is also taken from the jet-electron sample.

Search for *tb* Resonances

Systematics

- ISR/FSR
- JES, JER, JETreco
- Lepton Scale factors
- PDF, Generator and Parton Shower
- *b*-tagging and Mistag scale factor
- $t\bar{t}$, Wt, t-chan, Z+jets and diboson theory cross section
- QCD normalization (50% and 100%)
- m_{tb} shape
- *W*+jets shape
- *W*+jets normalization
- Lumi 3.7%

Systematic	Background	Signal
MCGen	YES	NO
PartSh	YES	NO
TTbar xs	YES	NO
t-channel xs	YES	NO
Wt xs	YES	NO
Diboson xs	YES	NO
Z+jets xs	YES	NO
QCD	YES	NO
W+jets Shape	YES	NO
W+jets norm	YES	NO
ISRFSR	YES	YES
PDF	YES	YES
Lepton Scales	YES	YES
JER	YES	YES
JET reco	YES	YES
JES	YES	YES
BTAG	YES	YES
LQTAG	YES	YES
m_{tb} shape	YES	NO
LUMI	YES	YES