Measurement of Single-Top Quark Production with the ATLAS Detector

Jenny Holzbauer

On Behalf of the ATLAS Collaboration

DPF Meeting, August 10, 2011

ATLAS-CONF-2011-101 and ATLAS-CONF-2011-104

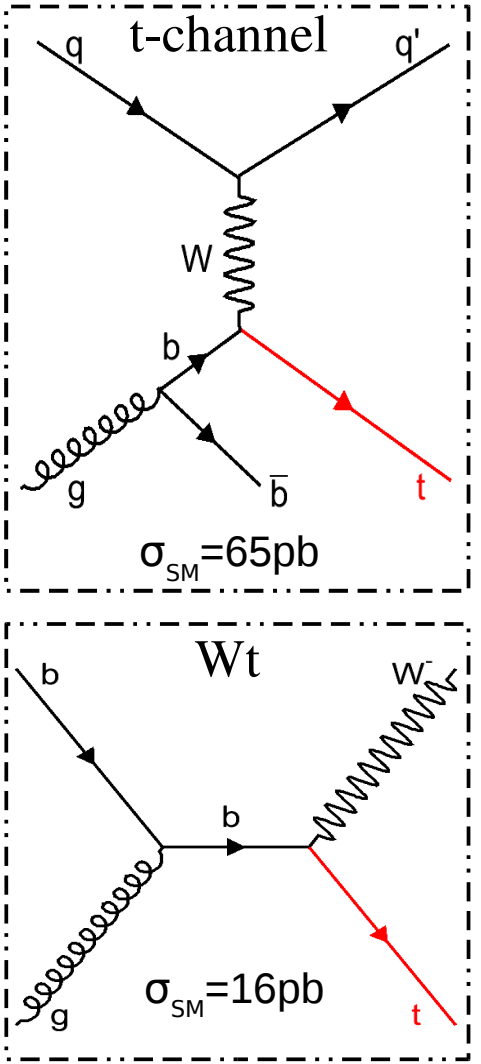
Historical Overview

- **Single-top, electroweak top quark production, first observed at Fermilab in 2009 by D0, CDF[1]**
  - **Just this year, t-channel production observed at Tevatron by D0[2]**
  - **This was followed shortly at the LHC with t-channel evidence by CMS[3] and observation by ATLAS[4]**
  - **ATLAS has also set first limits on Wt[5]**
  - **Very exciting time for single-top!**
- **Reporting updated ATLAS t-channel measurement and Wt limit**

1. D0 Collaboration: Phys.Rev.Lett.103:092001, 2009
   CDF collaboration: Phys.Rev.Lett.103:092002, 2009
2. D0 Collaboration: arXiv:1105.2788v1, submitted to Phys. Lett. B, May 2011
3. CMS collaboration: arXiv:1106.3052v1, accepted to Phys. Rev. Lett.
4. ATLAS collaboration: ATLAS-CONF-2011-088
5. ATLAS collaboration: ATLAS-CONF-2011-027

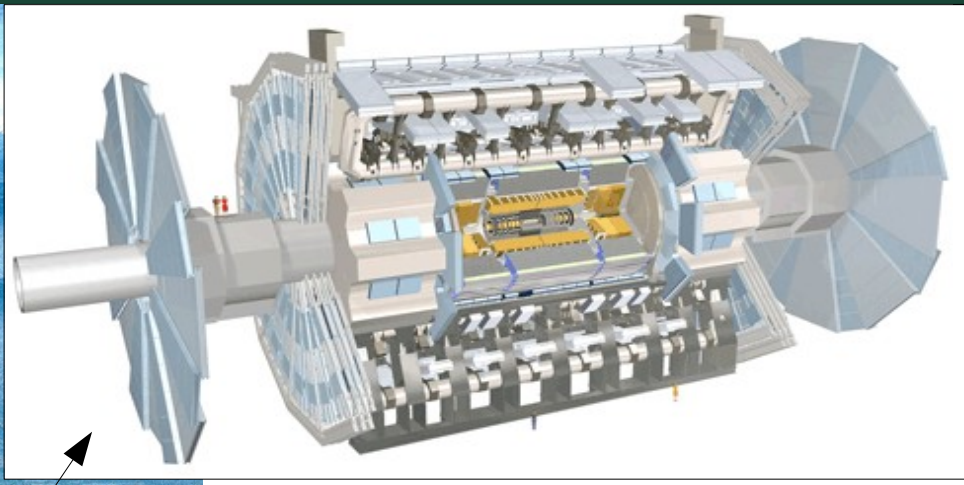
Motivation

- At the LHC, t-channel single-top cross-section is about 30 times larger than at the Tevatron
  - Will allow more precise t-channel measurements and a detailed study of this process
- Single-top is sensitive to any new process that can modify the Wtb coupling (W', FCNC, $H^{\pm}$, etc.)
- Can test of the b-quark structure function
- Wt single-top production cannot be seen at Tevatron, want to look for it at the LHC

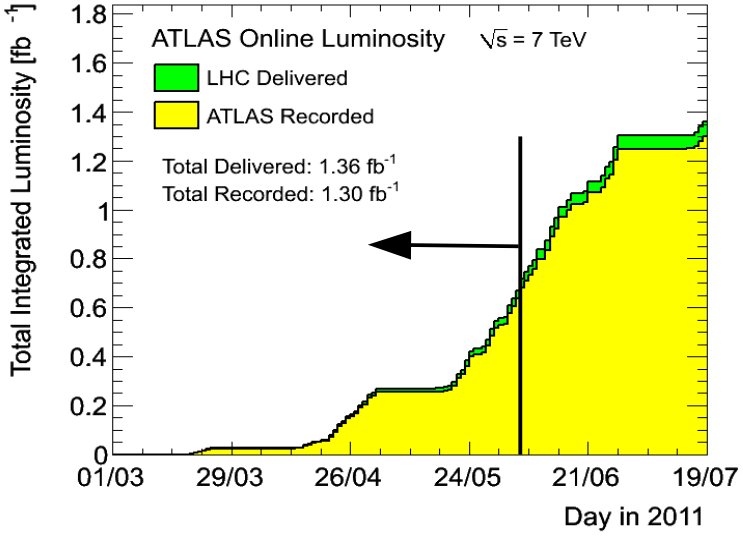


ATLAS at CERN

- Proton-proton collisions
- 7 TeV center of mass energy

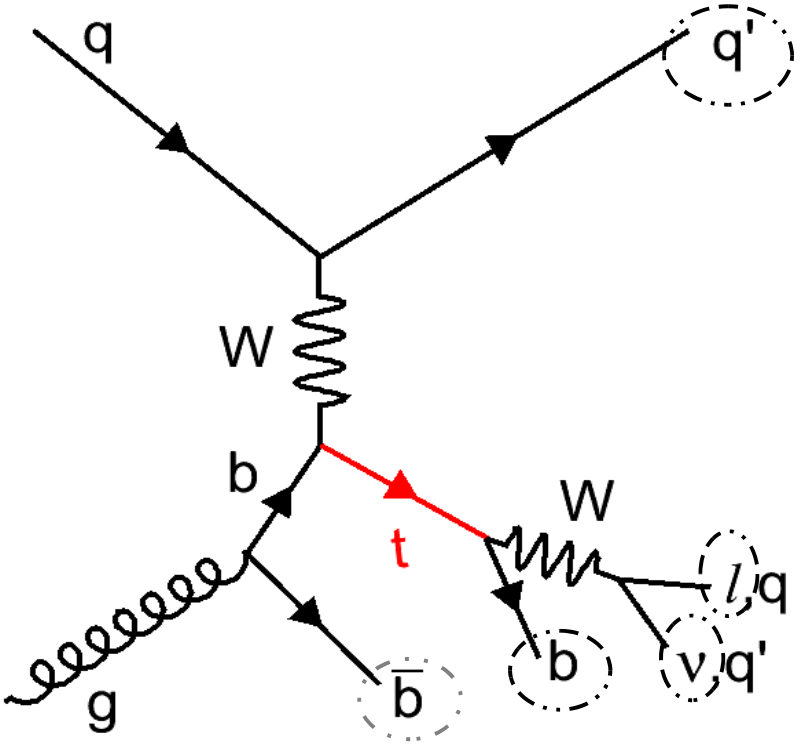


0.70 fb^{-1} used in analyses shown today



t-channel Event Selection

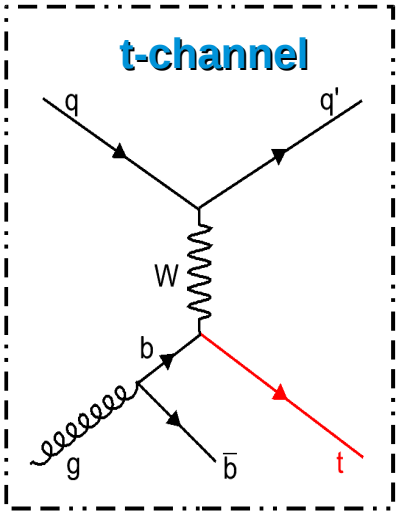
- **Analysis shown uses straight-forward cut-based strategy**
  - **Neural network also performed**
- **t-channel selection to isolate signal-like events:**
  - **2 (or 3) jets, p_T > 25 GeV**
  - **1 jet is b-tagged, 50% efficiency (secondary vertex b-tagger)**
  - **Exactly 1 isolated triggered muon or electron with p_T > 25 GeV and $|\eta| < 2.5$**
  - **E_T^{miss} > 25 GeV**
  - **E_T^{miss} + W_T mass > 60 GeV**
- **S/B is 0.1 after selections**

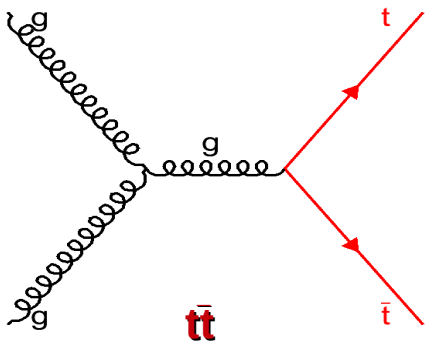


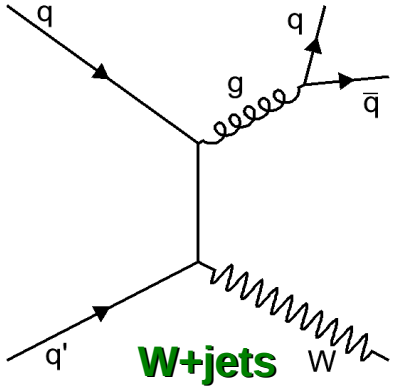
t-channel
σ_{SM}=65 pb

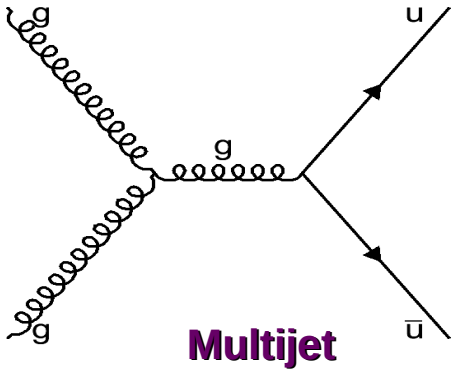
t-channel Backgrounds

- **W+jets is dominant background due to mis-identification of c-quarks as b-quarks**
- **$t\bar{t}$ (lepton + jets), multijet are also large**
  - **Z+jets, diboson, Wt and s-channel are much smaller backgrounds**
- **W+jets normalization and flavor fractions, multijet shape and normalization from data**
  - **Other processes use theory cross-sections**



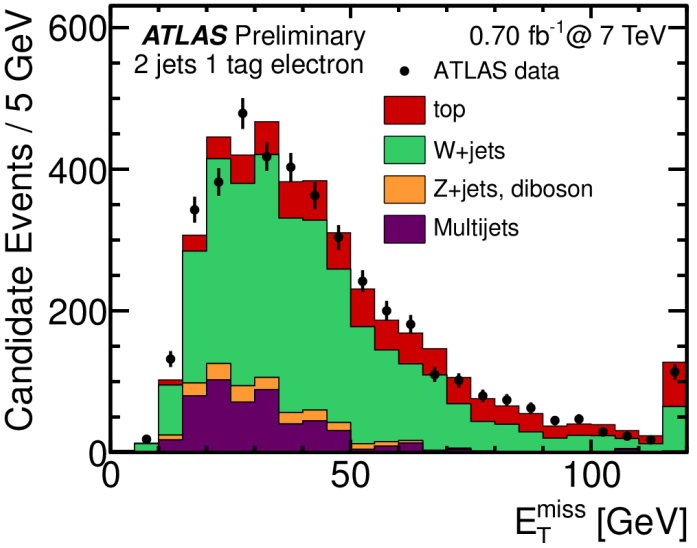


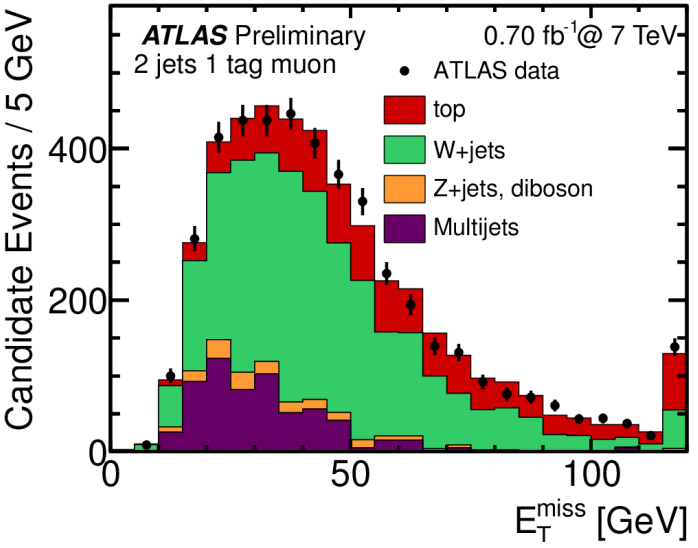




Data-based Background Determination

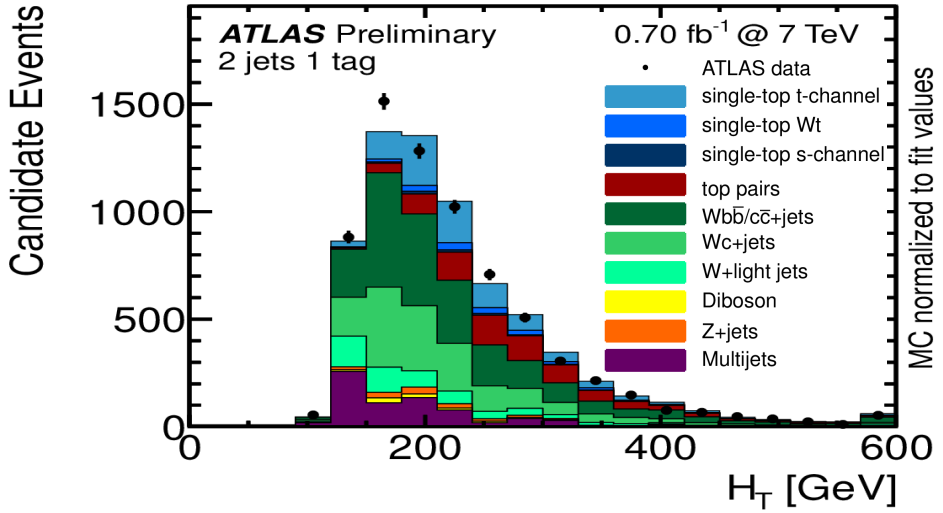
- **Multijet shape and normalization determined via a "jet-lepton" method**
  - **Require jet trigger in place of lepton trigger, veto real leptons**
  - **Binned maximum likelihood fit to E_T^{miss} distribution in data**
- **W+jets normalization and heavy flavor composition:**
  - **Algebraic solution of equations using three off-signal regions for cut based analysis**
  - **Fit to the output distribution for neural network analysis**

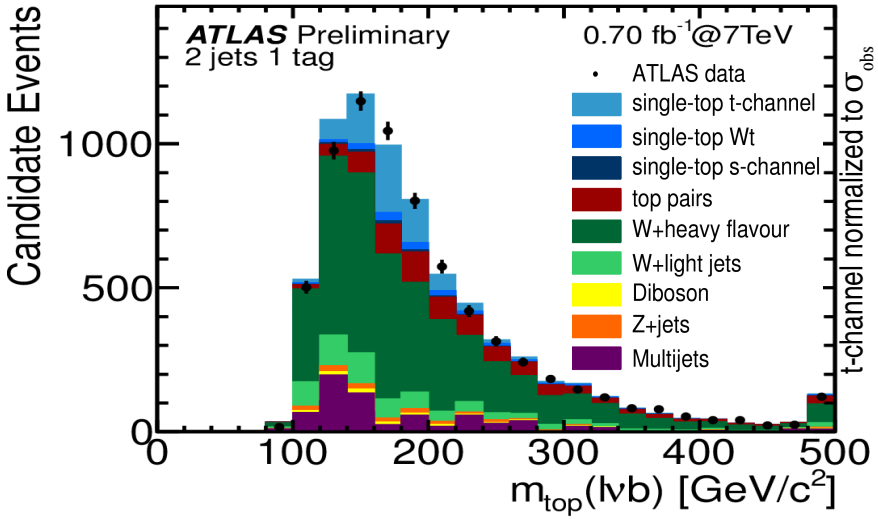


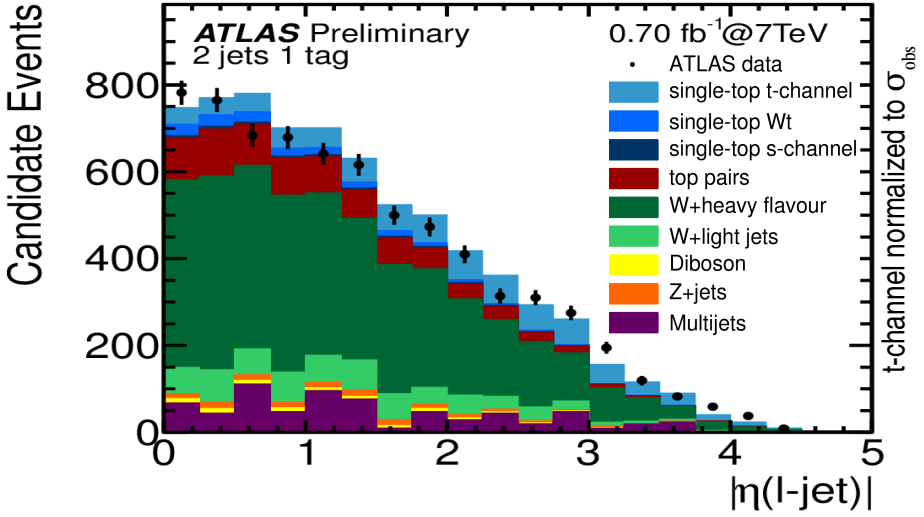


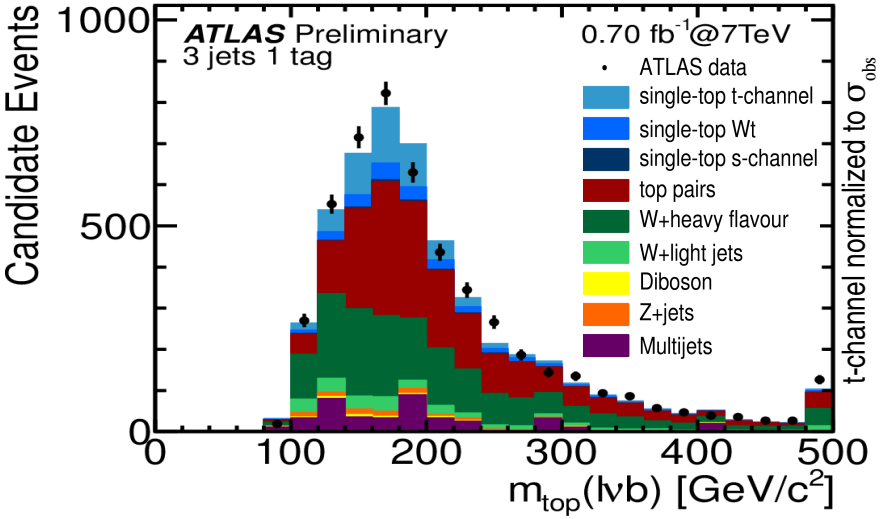
Discriminating Variables

- **Good agreement between Data and Monte Carlo**





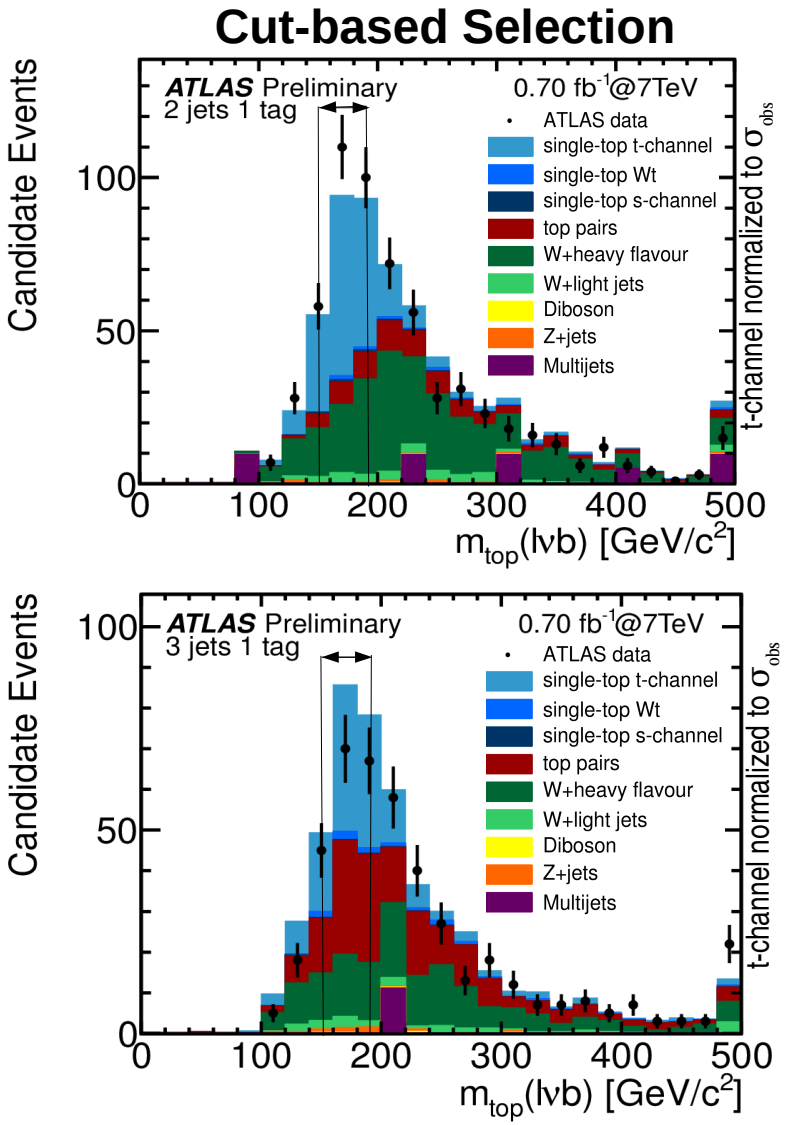




Cut-based Analysis

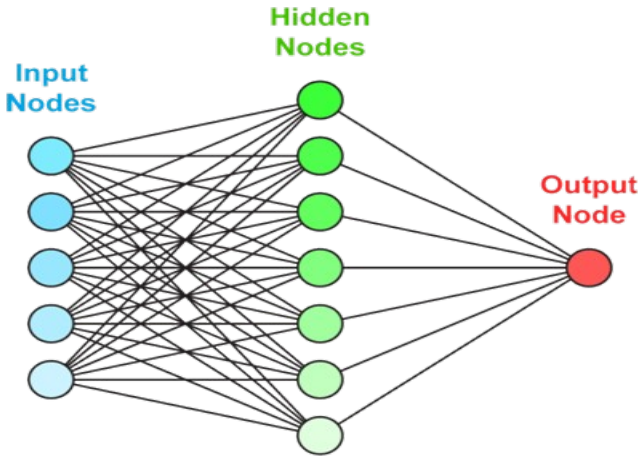
- **Four channels, + or - lepton charge each with 2 or 3 jet events**
  - **Expect asymmetry (protons, uud)**
- **Extra analysis cuts:**
  - **Untagged jet $|\eta| > 2.0$**
  - **$|\Delta\eta$(b-jet, untag jet)$| > 1.0$**
  - **$H_T(jet_1, jet_2, lep., E_T^{miss}) > 210$ GeV**
  - **140 GeV < top mass < 190 GeV**

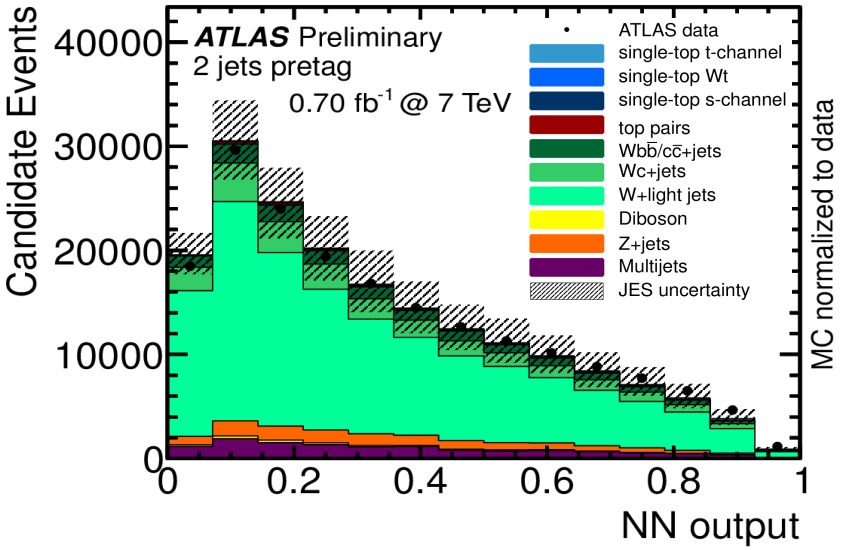
ATLAS Preliminary	Cut-based 2-jet		Cut-based 3-jet	
	Lepton+	Lepton-	Lepton+	Lepton-
single-top *t*-channel	51.8 ± 16.4	23.7 ± 6.5	33.0 ± 7.0	16.3 ± 4.8
TOTAL Expected	94.1 ± 18.4	50.2 ± 8.5	82.6 ± 12.7	57.9 ± 10.1
S/B	1.23	0.89	0.67	0.39
DATA	118	68	74	60

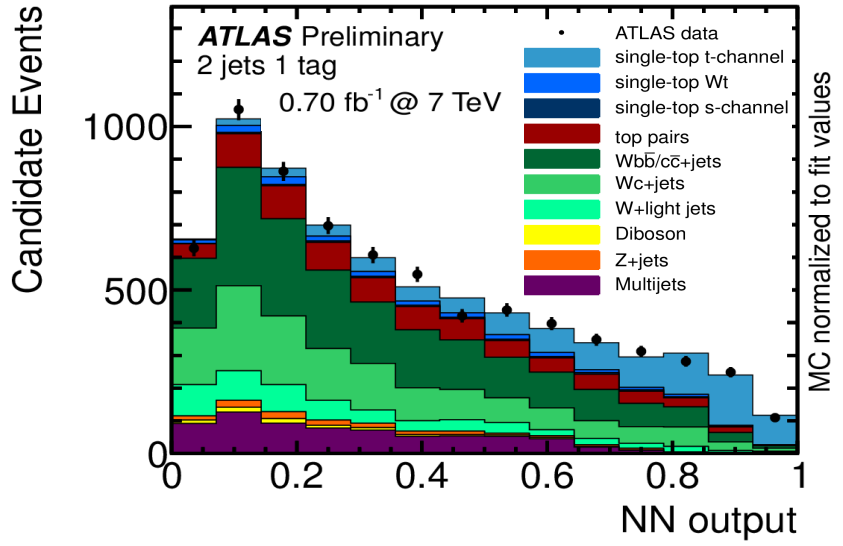


Neural Network Analysis

- **Combine many variables including their correlations into a discriminant**
  - **NeuroBayes program with 13 variables, including cut-based analysis variables**
- **Extract cross section with a binned likelihood fit to the full NN output distribution**
  - **No additional cuts**







t-channel Cross-section Measurement

- **Profile likelihood determines observed cross-section for cut based (CB), maximum likelihood fit determines this for neural network (NN):**
  - **NN 2 jets:** $\sigma_t = 105 \pm 7\,(\text{stat})^{+36}_{-30}\,(\text{syst}) = 105^{+37}_{-31}$ pb (***ATLAS*** Preliminary)
  - **CB 2 jets:** $\sigma_t = 102^{+12}_{-11}(\text{stat})\,^{+38}_{-27}(\text{syst}) = 102^{+40}_{-30}$ pb (***ATLAS*** Preliminary)
  - **CB 3 jets:** $\sigma_t = 50^{+15}_{-14}(\text{stat})\,^{+30}_{-22}(\text{syst}) = 50^{+34}_{-27}$ pb (***ATLAS*** Preliminary)
- **NN and CB 2 jet results, and CB 2 and 3 jet results are consistent**
- **Final result is cut based 2 and 3 jet combination, observed (expected):**

ATLAS Preliminary

$$\sigma_t = 90^{+9}_{-9}(\text{stat})\,^{+31}_{-20}(\text{syst}) = 90^{+32}_{-22}\ \text{pb}\ \left(65^{+28}_{-19}\ \text{pb}\right)$$

t-channel Cross-section Measurement

- **Now dominated by systematic uncertainties**
  - **b-tagging, jet energy scale, and initial/final state radiation uncertainties are particularly large**

ATLAS Preliminary	$\Delta\sigma/\sigma$ [%]	
Source	cut-based combined	NN
Data statistics	± 13	± 10
MC statistics	± 6	± 7
Jet energy scale	+9/-1	+32/-20
b-tagging scale factor	+18/-13	± 13
Generator	+11/-9	± 7
Parton shower	+10/-9	± 6
ISR/FSR	± 14	± 13
Jet η reweighting	+13/-11	+10/-6
Luminosity	+7/-6	± 5
All systematics	+41/-27	+44/-34
Total	+44/-30	+45/-34

***Cut-based result is 2 and 3 jet combination**

Wt-channel Event Selection

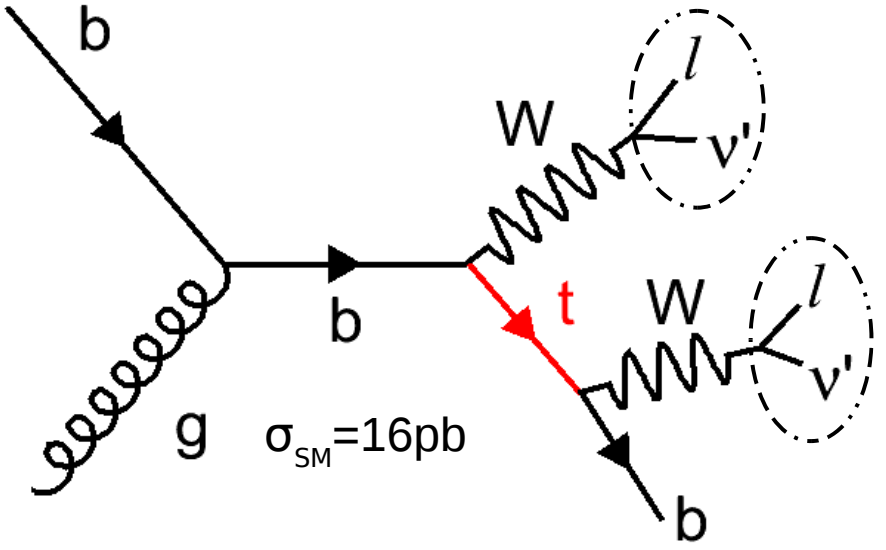
- **General selection:**
  - **Select jets with $p_T > 30$ GeV**
  - **Exactly 2 isolated triggered muons or electrons with $p_T > 25$ GeV and $|\eta| < 2.5$**
  - **$E_T^{miss} > 50$ GeV**
  - **Z to ττ veto:**

$\Delta\Phi(l_1, E_T^{miss}) + \Delta\Phi(l_2, E_t^{miss}) > 2.5$

  - **Z-mass veto (ee/mm only):**

$|M(l_1 l_2) - M(Z)| > 10$ GeV

- **Cut based signal region:**
  - **Exactly 1 jet**



Analysis channels:

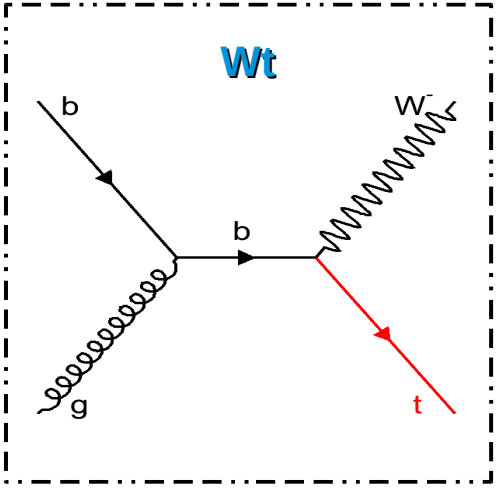
Electron-electron (ee)

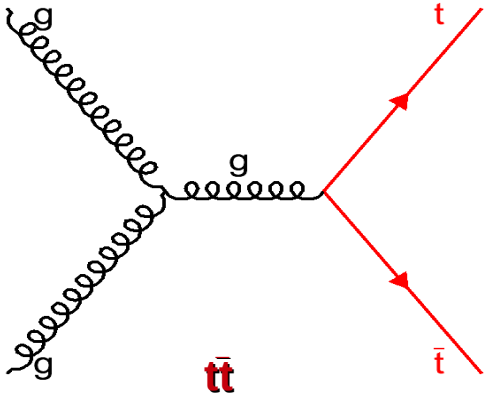
Electron-muon (em)

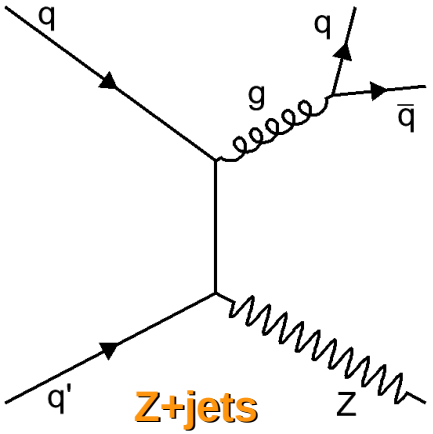
Muon-muon (mm)

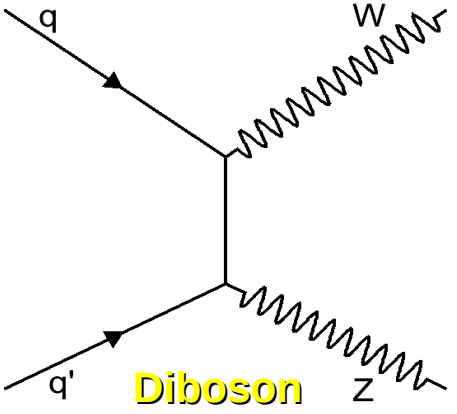
Wt-channel Backgrounds

- $t\bar{t}$ (dilepton) is dominant background due to two real leptons, real tops, and jet mis-reconstruction
- Fake lepton (Multijet and W+jets), Drell Yan, Z to ττ and diboson also large
- All backgrounds have data driven estimations except diboson, for which the theoretical cross-section is used



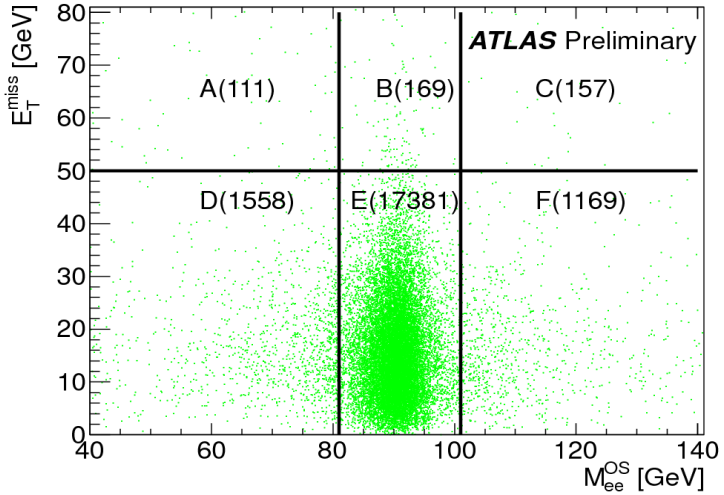






Data-based Fake Lepton and Drell Yan Determination

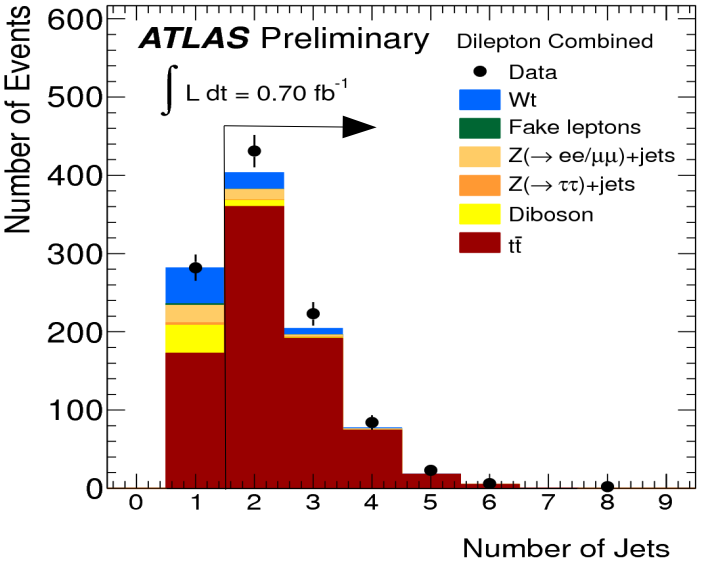
- **"ABCDEF" method is used to determine Drell Yan**
  - **Two uncorrelated variables, dilepton mass and E_t^{miss}**
  - **Use off-signal regions to estimate Drell Yan in signal (A,C) region**
  - **Non-Drell Yan in off-signal region is subtracted, correlations between two variables corrected**
- **Matrix method used to estimate fake lepton (multijet and W+jets) backgrounds**
  - **Four by four matrix with different lepton definitions for the lepton pair**

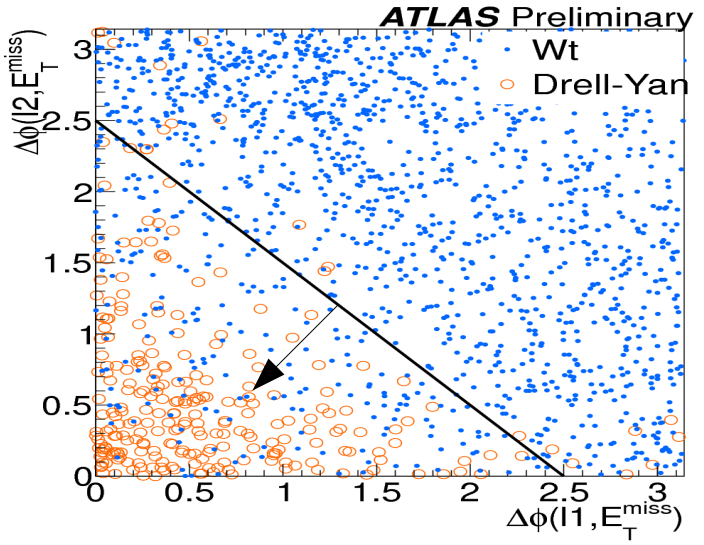


$$N_{A/C}^{predicted} = N_{D/F}^{data} \times (N_B^{data} / N_E^{data})$$

Data-based $t\bar{t}$ and Z to ττ Determination

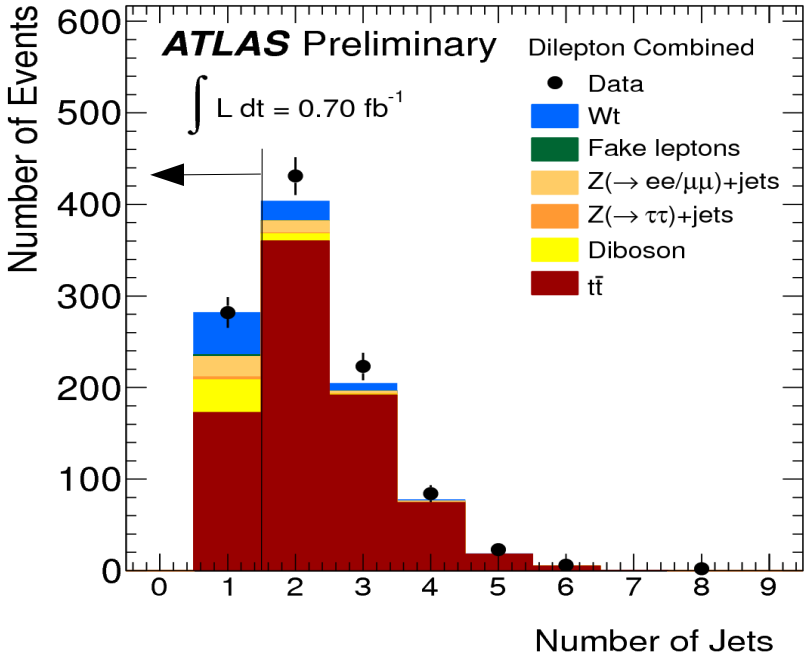
- $t\bar{t}$ estimated using ≥2 jets sample
  - Non-$t\bar{t}$ subtracted from the data in this region and comparing this value to the expected one
  - Result propagated to 1 jet signal region
  - Systematic uncertainties also estimated separately and correlations accounted for
- Z to ττ estimated using
  $\Delta\Phi(l_1, E_T^{miss}) + \Delta\Phi(l_2, E_t^{miss}) < 2.5$ sample
  - Non-Z to ττ subtracted from data in this region and result propagated to 1 jet signal region

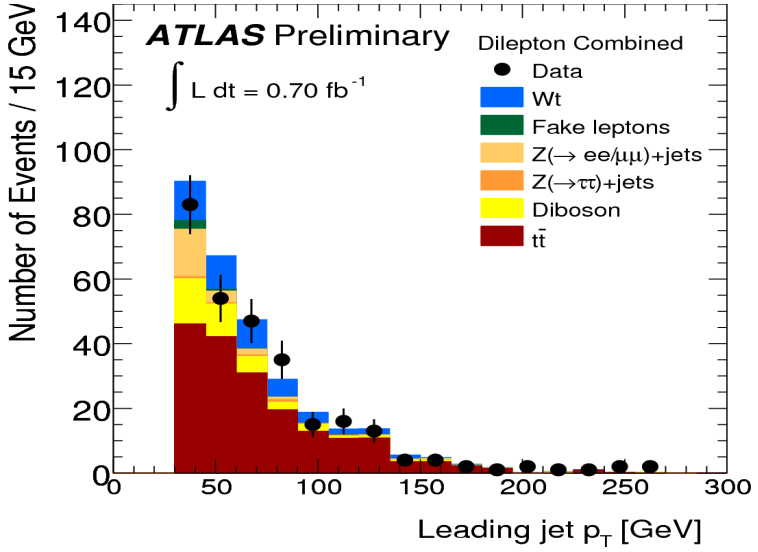


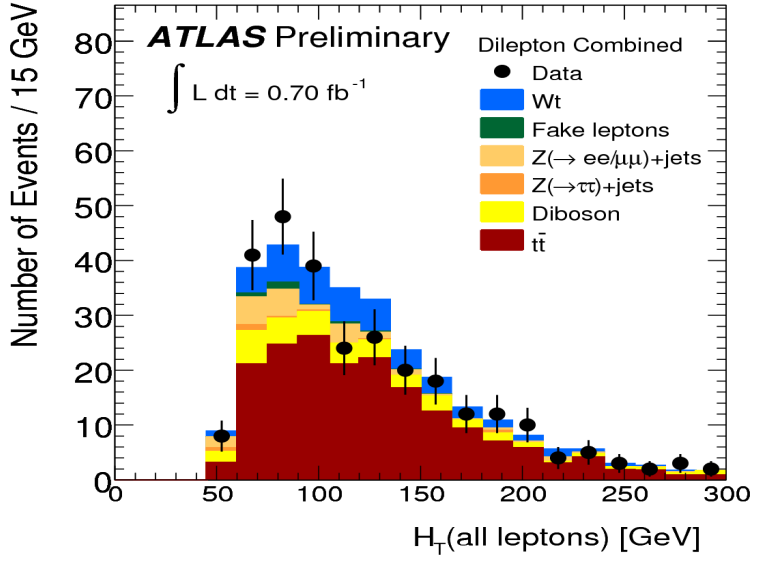


Wt Analysis

- **Dilepton analysis with three channels (ee, eμ, and μμ)**
  - **Cut-based approach, requires extra cut of exactly 1 jet**
  - **Good agreement with expectation in signal region**



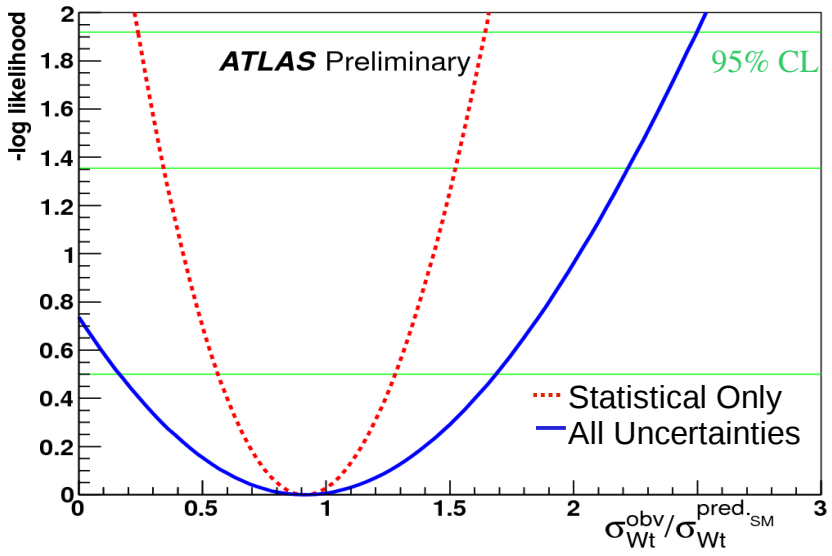




Wt Result

- **Profile likelihood ratio curve used to determine cross-section and limit**
  - $\sigma_{Wt} = 14.4^{+5.3}_{-5.1}(\text{stat})^{+9.7}_{-9.4}(\text{syst})\,\text{pb}$ (***ATLAS*** Preliminary) **observed**
  - **At 95% confidence level, observed (expected) limit is**

    $\sigma_{Wt} < 39.1\,\text{pb}\,(40.6\,\text{pb})$ (***ATLAS*** Preliminary)



Expected Uncertainties

Source ***ATLAS*** Preliminary	$\Delta\sigma/\sigma$ [%]
Data statistics	+37 / -35
MC statistics	+11 / -5.4
Lepton energy scale	+7.0 / -5.4
Lepton energy resolution	+9.0 / -8.9
Lepton efficiencies	+5.3 / -2.9
Jet energy scale	+34 / -35
Jet energy resolution	+29 / -32
Jet reconstruction efficiency	+30 / -33
Top pair scaling factor	+23 / -24
Drell-Yan background estimation	+2.7 / -4.0
Fake lepton background estimation	+4.2 / -4.3
Generator	+16 / -11
ISR/FSR	+6.0 / -1.9
PDF	+5.4 / -2.8
Pileup	+10 / -6.6
Background cross-sections	+6.9 / -6.8
Luminosity	+9.2 / -5.9
All systematics	+68 / -66
Total	+77 / -75

Summary

- **ATLAS single-top results reported for 7 TeV proton-proton collisions at the LHC with 0.70 fb^{-1} of data**
- **Measurement of t-channel cross-section of**
  - $\sigma_t = 90^{+32}_{-22}$ pb (***ATLAS*** Preliminary)**, consistent with the standard model**
- **95% confidence level limit set for Wt of**

  $\sigma_{Wt} < 39.1$ pb (***ATLAS*** Preliminary)
  - **Corresponds to cross-section of**

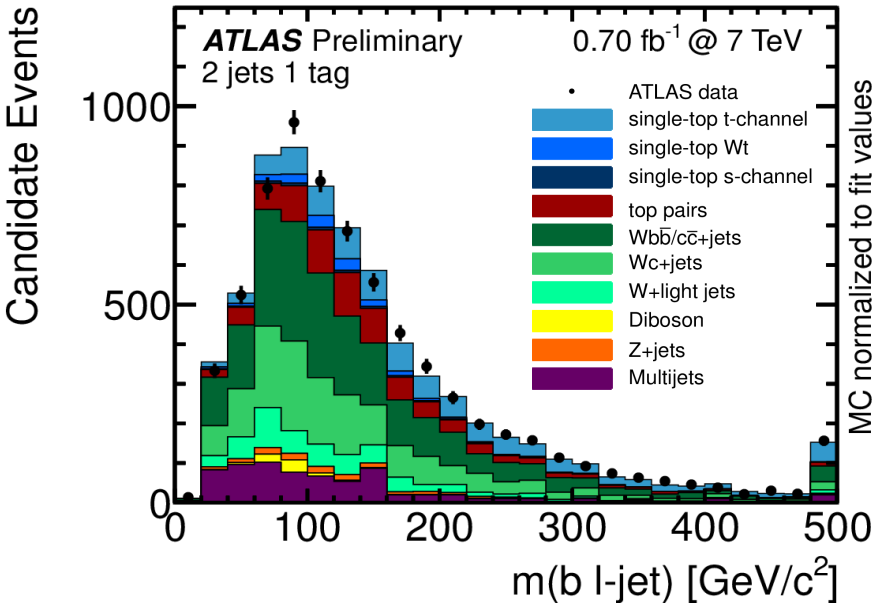
    $\sigma_{Wt} = 14.4^{+5.3}_{-5.1}(\text{stat})^{+9.7}_{-9.4}(\text{syst})$ pb (***ATLAS*** Preliminary)
- **Looking forward to improving the results with the increasing integrated luminosity this year**

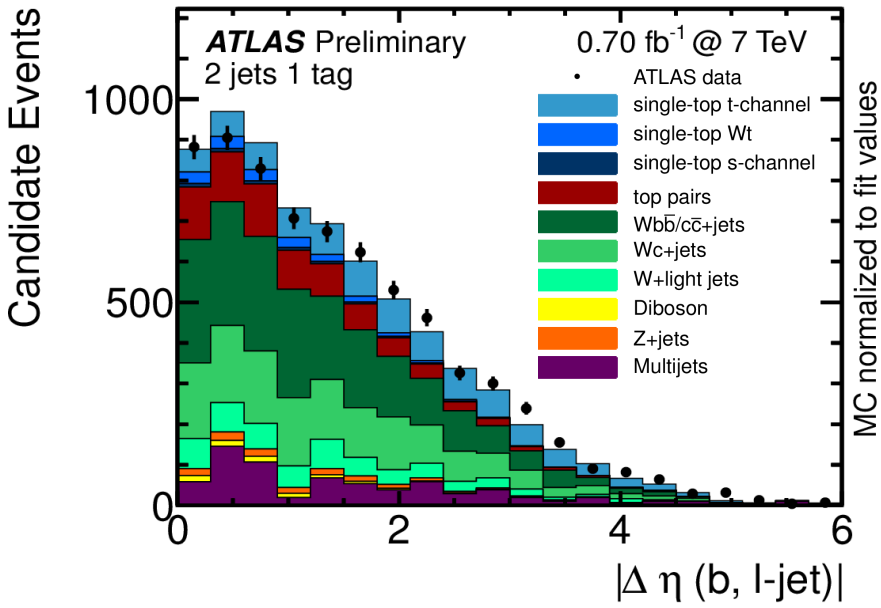
Other Material

Reconstructed Top Quark Mass

- **Top mass variable is one of two final cut-based analysis variables**
  - **Reconstructed top quark formed from the reconstructed W (lepton plus reconstructed neutrino) and the b-tagged jet**
  - **To reconstruct the neutrino, need to determine the neutrino Pz**
    - **Assume the mass of the W boson to be 80.42 GeV**
    - **In the calculation of neutrino Pz there are two solutions and the lowest Pz is chosen**
    - **If there is a negative discriminant ($1+(MET^2*leptonpz^2) < MET^2*leptonE^2$), a null value is taken for this in the calculation**

Additional Discriminating Variables (t-channel)





Wt process Ht(jets) for Event Selection and ≥2 jets

- **General event selection at left, this plus at least two jets at right for Wt analysis**