Single top quarks @ LHC with ATLAS

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on behalf of the ATLAS collaboration

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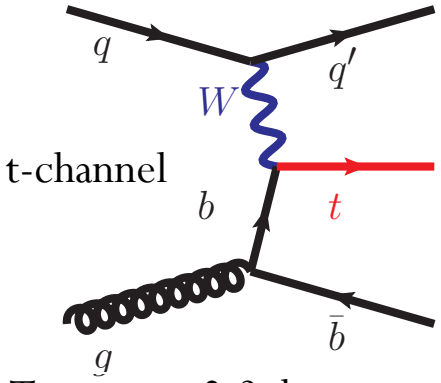
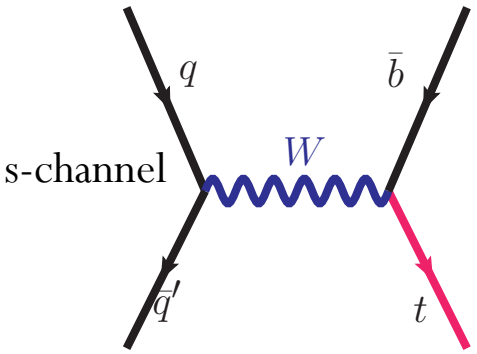
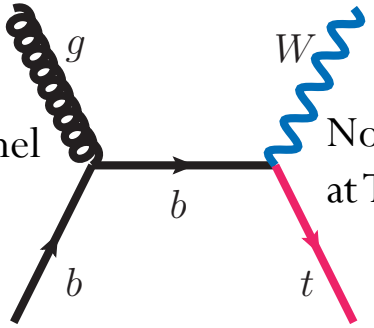
Single top quark



Tevatron: 2.3pb
LHC: $64.6^{+3.2}_{-2.6}$pb



1.1pb
4.6±0.3pb

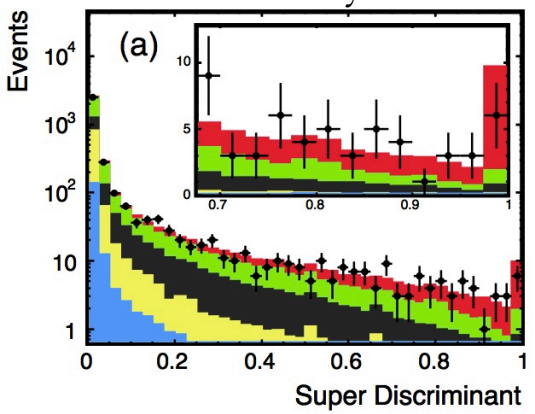


Not accessible at Tevatron

0.2pb
15.7±1.3pb

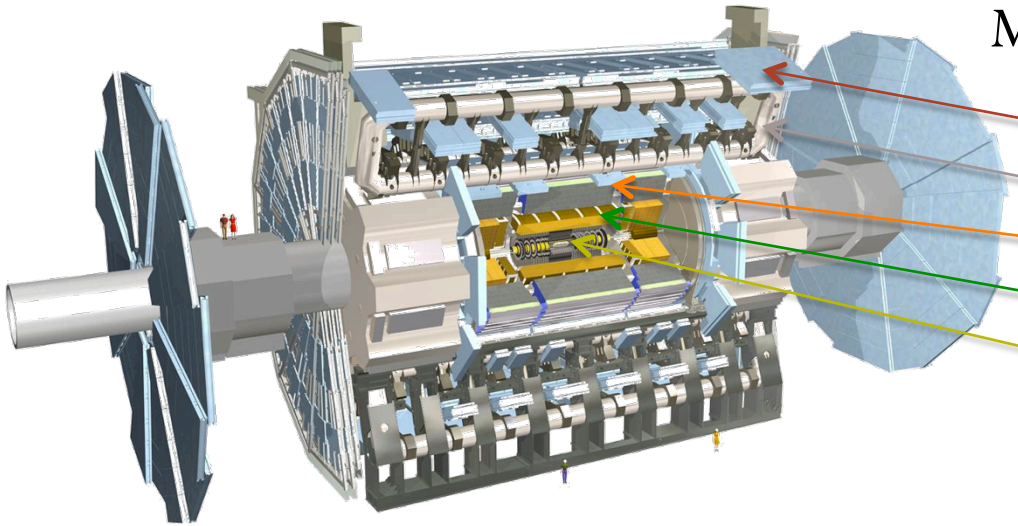
- **Importance of single top**
  - ***Cross section*** αV_{tb}, test of unitarity of CKM
    - 4^{th} generation?
  - Test of b-quark structure function
  - Heavy W', charged H^+
  - Anomalous couplings
  - ***FCNC in single top production***
- **Still a challenge at LHC** *("top factory")***!**

CDF discovery 3.2fb^{-1}



Phys. Rev. Lett. **103**, 092002 (2009)

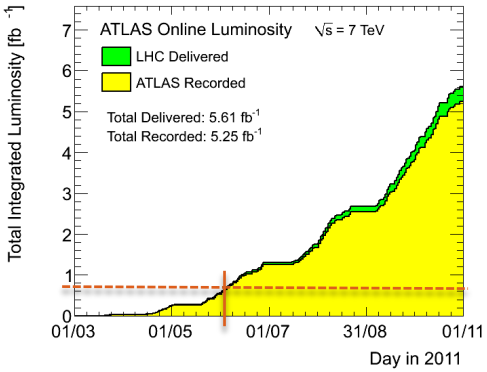
The ATLAS detector

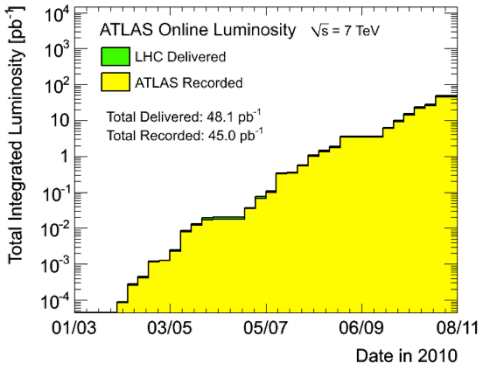


Main detector components

- Muon spectrometer $\Delta p/p<10\%$ up to 1 TeV
- Toroid magnet
- Hadronic calorimeter $\sigma/E \sim 50\%/\sqrt{E} \oplus 3\%$
- EM calorimeter $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
- Inner tracker $\sigma/p_T \sim 0.04\% p_T \oplus 1.5\%$
- Solenoid magnet

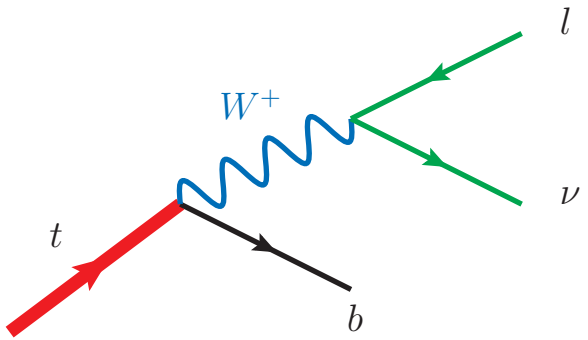
- Analyses presented here with $L=\mathbf{700fb^{-1}}$ for 2011 data ($\mathbf{35pb^{-1}}$ 2010 data)
- $\Delta L=\mathbf{4.5\%}$ (**3.4%**) luminosity uncertainty
- Peak luminosity $\mathbf{1.75\ 10^{33}}$ $cm^{-2}s^{-1}$ ($\mathbf{2.1\ 10^{32}}$ $cm^{-2}s^{-1}$)
- max. **10-12PV (4PV)** per event on average





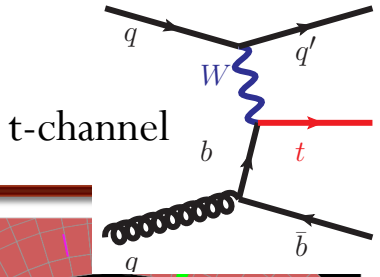
General Object and Event Selection

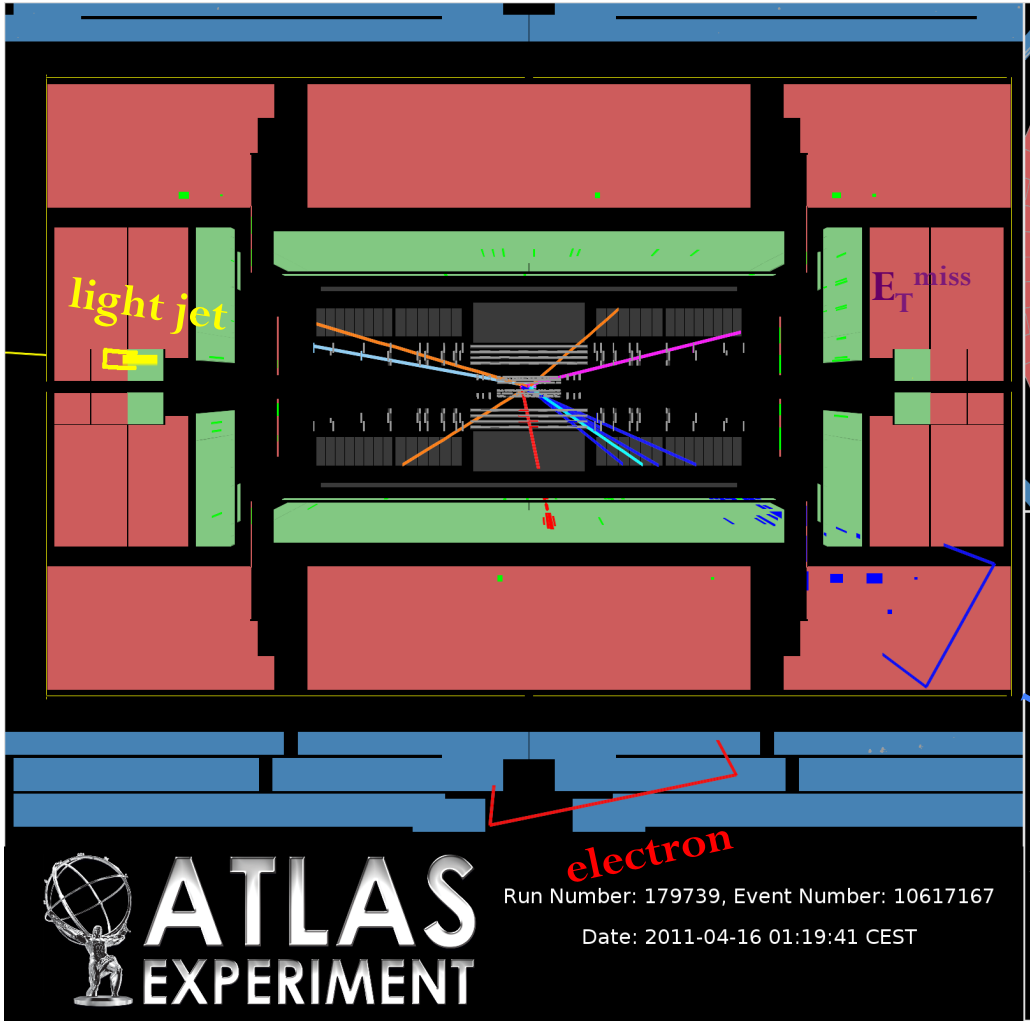
- Analysis mainly in the **lepton decay channel**
  - Trigger on isolated high-p_T lepton at efficiency plateau

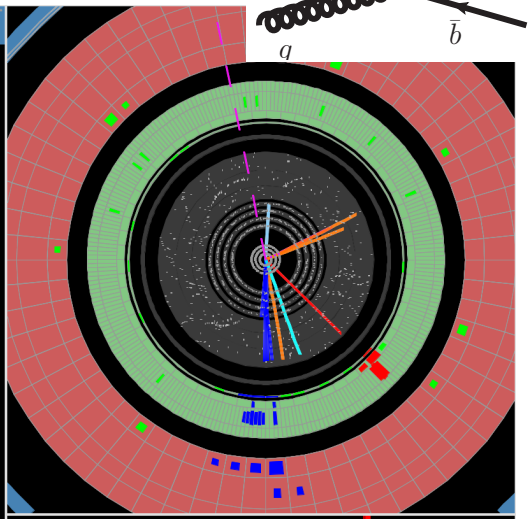


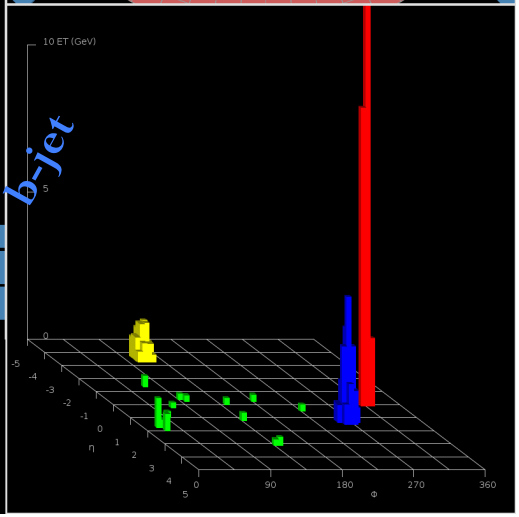
- Signature and selection
  - **Exactly one isolated lepton**
    - within tracker acceptance and p_T>20 GeV
    - relative calorimeter and track isolation
    - electron 'tight' ID selection
    - muon combined from inner tracker and muon spectrometer, track isolation
  - **Jets**, anti-kt (R=0.4), from calorimetric clusters
    - up to $|\eta|$<4.5, p_T>25 GeV
  - ***b*-jets**
    - reconstruct secondary vertex (SV0) @ 50% eff.
  - E_T^{miss} from vector sum of jets, electrons, contribution from muons and unassociated calorimeter cells
    - E_T^{miss} >35 GeV
  - **Transverse mass M_T** from lepton and neutrino
    - $M_T+E_T^{miss}$ >60 GeV
- Main backgrounds: QCD and Z/W+jets (HF), data driven determination

t-channel candidate



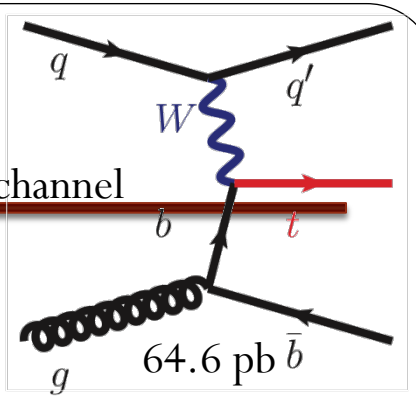




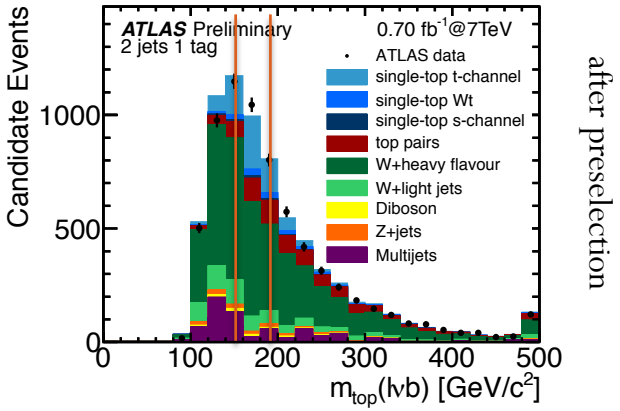


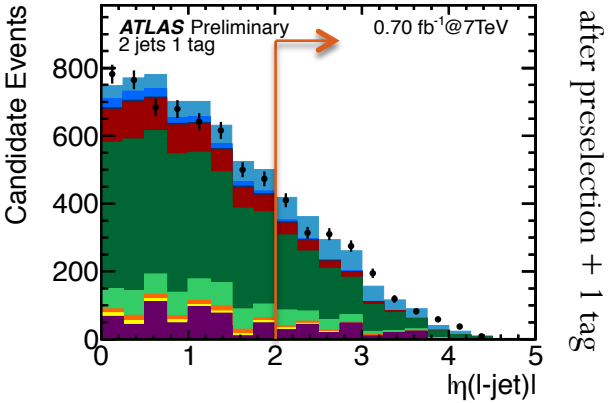
t-channel cross section

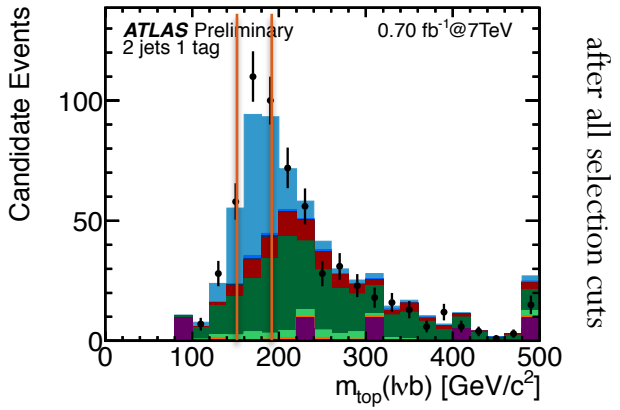
t-channel cross section



- **Cut-based analysis**
  - Exactly one tagged jet
  - 2/3 jet events considered
  - $|\eta_{jet1}|>2.0$ non-tagged jet
  - $H_T>210$ GeV
  - $150\ \text{GeV}<M_{l\nu b}<190\ \text{GeV}$
  - $\Delta\eta(\text{b-jet,jet1})>1.0$

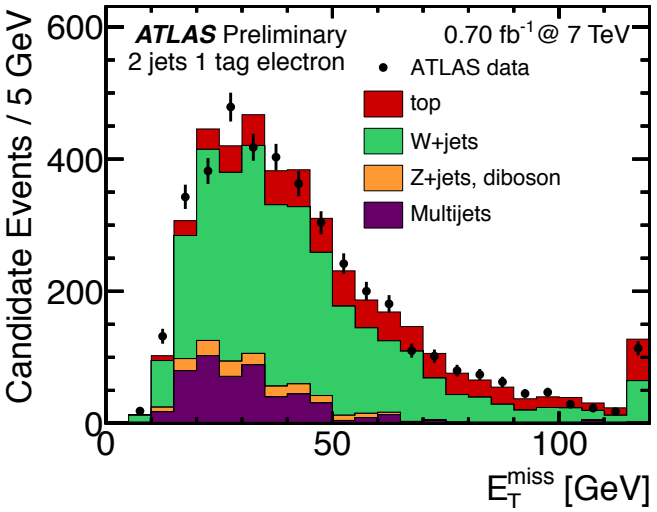


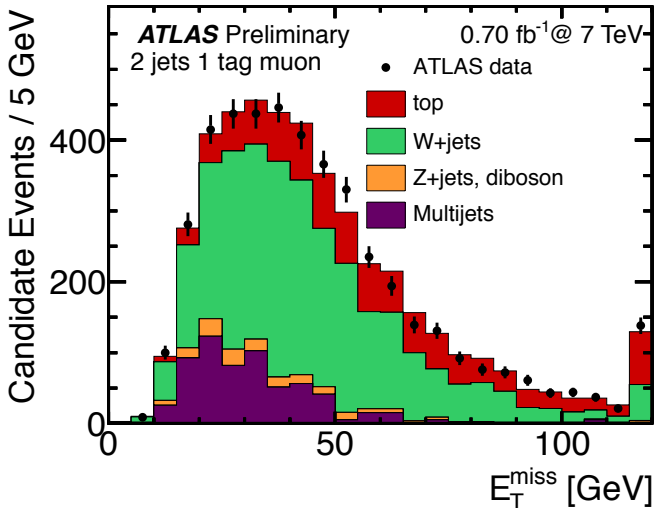




Background estimation

- ***QCD-multijet background*** with jet-electron model:
  - Jets with electron-like properties
  - Normalisation after event selection taken from maximum likelihood fit to E_T^{miss} distribution to data
- QCD fraction 9-10%, cross check with matrix method

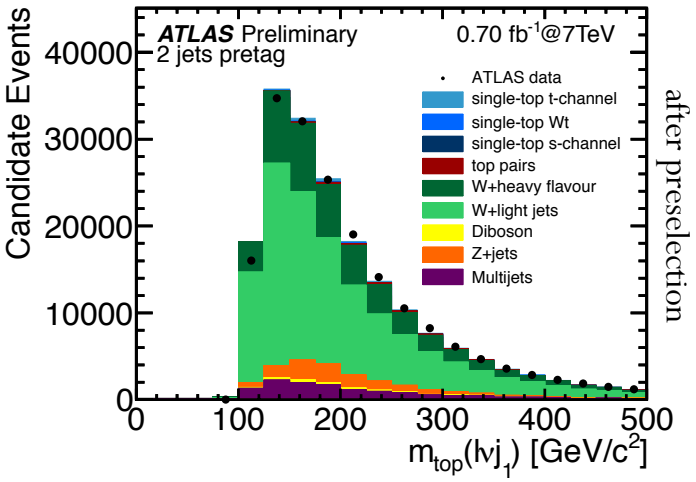




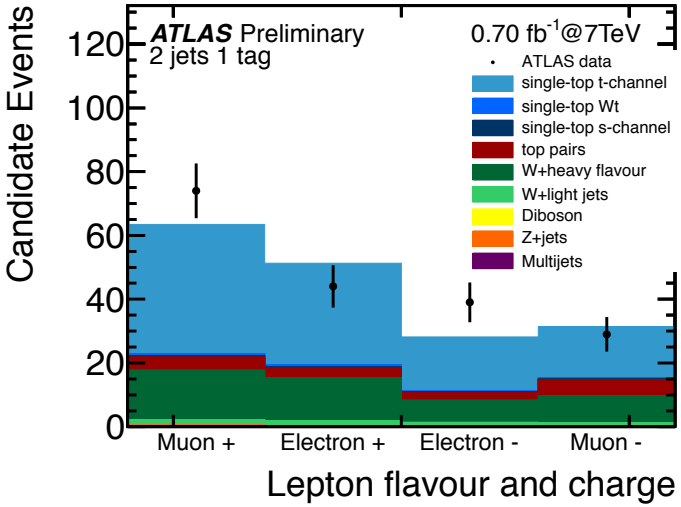
Background estimation

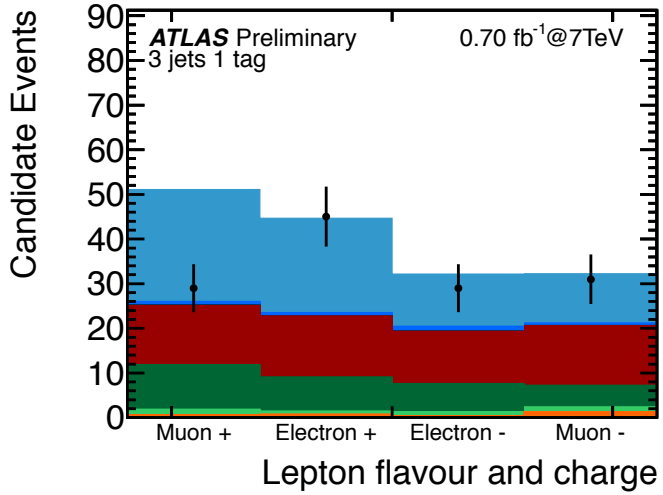
- ***W+jets*** normalisation and heavy-flavour fraction
  - Overall normalisation taken from data events
    - QCD-multijet and other MC backgrounds subtracted
  - Flavour composition from a set of equations and using event yields in 1-jet tag 2-jet tag/pretagged data samples

$$N^{\text{tag}}_{\text{n-jet}} = N^{\text{pretag}}_{\text{n-jet}} \left(\sum_{\text{flav}} k^{\text{flav}}_{\text{n-jet}} F^{\text{flav}}_{\text{n-jet}} P^{\text{flav}}_{\text{n-jet}} \right)$$



t-channel cross section





	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
single-top *Wt*	1.1 ± 0.5	0.6 ± 0.7	1.5 ± 0.6	1.5 ± 1.2
single-top *s*-channel	0.9 ± 0.2	0.6 ± 0.2	0.3 ± 0.1	0.3 ± 0.1
top pairs	7.1 ± 3.2	7.2 ± 2.9	26.8 ± 8.0	25.0 ± 7.6
W+light jets	3.7 ± 1.7	2.6 ± 1.2	2.1 ± 1.5	2.1 ± 1.4
Wc+jets	18.3 ± 3.8	11.7 ± 3.4	7.8 ± 3.0	6.5 ± 2.6
$Wb\bar{b}$+jets	7.7 ± 5.9	2.5 ± 2.5	6.2 ± 5.2	2.9 ± 2.4
$Wc\bar{c}$+jets	3.1 ± 2.4	1.3 ± 1.0	3.6 ± 2.8	1.7 ± 1.4
Diboson	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.1 ± 0.1
Z+jets	0.2 ± 0.4	0.1 ± 0.2	1.0 ± 1.0	1.5 ± 1.3
Multijets	< 0.1	< 0.1	< 0.1	< 0.1
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

- S/B after cuts 0.8 (up to 1.2)
- W+jets (W+c) and top pairs largest backgrounds

t-channel cross section

Source	$\Delta\sigma/\sigma$ [%] cut-based 2-jet	3-jet	combined
Data statistics	± 16	± 24	± 13
MC statistics	± 8	± 11	± 6
Jet energy scale	+7/-5	+10/-1	+9/-1
Jet energy resolution	+6/-4	+8/-7	+6/-1
Jet reconstruction	+2/-1	± 1	± 1
b-tagging scale factor	+17/-12	+21/-14	+18/-13
Mis-tagging scale factor	± 1	± 1	± 1
Lepton efficiencies	+6/-5	+11/-9	+8/-6
Lepton energy scale/resolution	± 1	± 1	+2/-1
Generator	+10/-8	+16/-12	+11/-9
Parton shower	+9/-7	+14/-12	+10/-9
ISR/FSR	+19/-16	± 7	± 14
PDF	+5/-4	+6/-5	± 5
W+jets shape modeling	± 1	± 1	± 1
Jet η reweighting	+12/-10	+18/-14	+13/-11
Background normalization			
QCD normalization	± 4	± 8	± 4
W+heavy flavour normalization	± 2	± 2	± 3
W+light flavour normalization	± 1	± 1	± 1
Theory cross sections	± 7	± 13	± 8
Luminosity	+6/-5	+11/-8	+7/-6
All systematics	+42/-27	+51/-37	+41/-27
Total	+45/-31	+57/-43	+44/-30

- Largest systematics
  - b-tagging efficiency
  - ISR/FSR modeling
- Profile likelihood includes all systematics as nuisance parameters
- 8 channel analysis (2/3 jet, electron/muon, +/- charge) combined
- **Observed cross section**

$$\sigma_t = 90 \pm 9\,(\text{stat.})\,^{+31}_{-20}\,(\text{syst.})\,\text{pb}$$

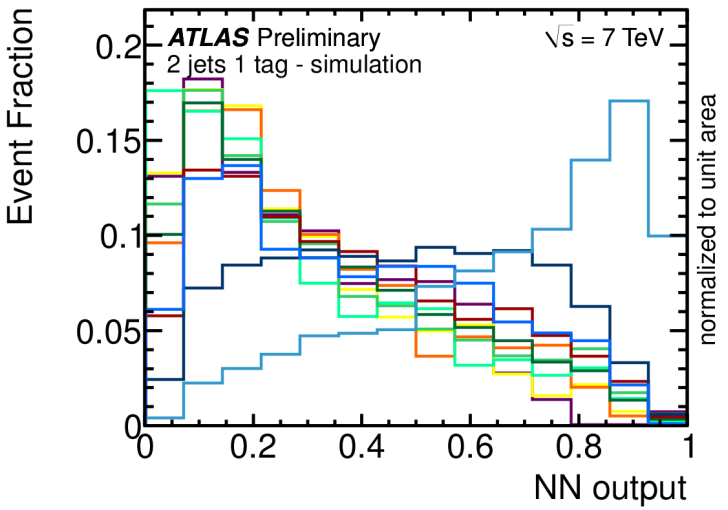
  - **Observed significance 7.6σ**
  - SM: $\sigma_t = 64.5\,\text{pb}$ (result 1.1σ above prediction)

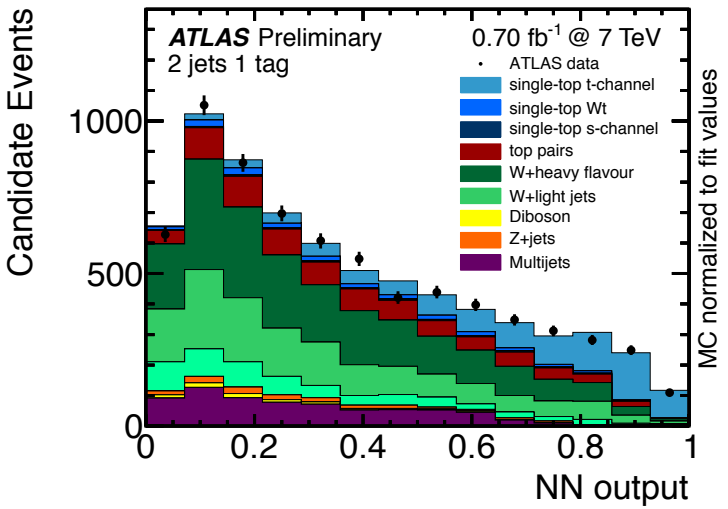
t-channel cross section

- **Neural network analysis**
  - First observation made with 156pb^{-1}
  - Only 2-jet events, 13 input variables, 33 hidden nodes
    - Most important variables: M_{lvb}, $|\eta_{jet1}|$, $E_{T,jet1}$
  - Signal and background (constrained) extracted from maximum likelihood fit to NN output distribution

$$\sigma_t = 105 \pm 7\,(\text{stat.})\,^{+36}_{-30}\,(\text{syst.})\ \text{pb}$$

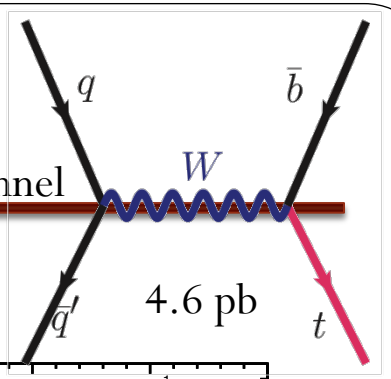
  - Compatible with cut-based result
  - Largest systematic uncertainty
    - JES and b-tagging efficiency





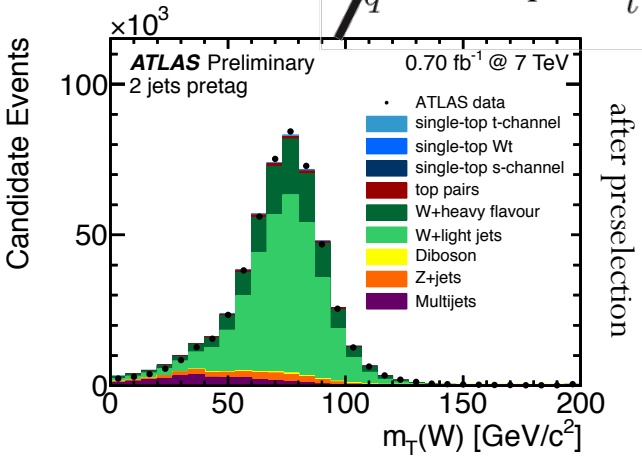
s-channel cross section

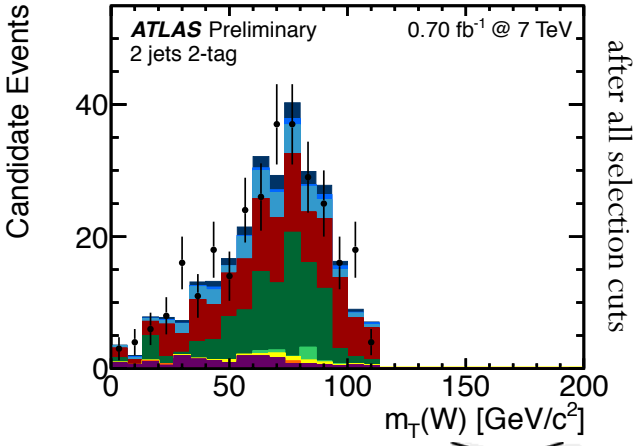
s-channel cross section



- Same event preselection as in t-channel
- Only use central jets ($|\eta|<2.5$)
- Exactly two jets and exactly 2 b-tagged jets

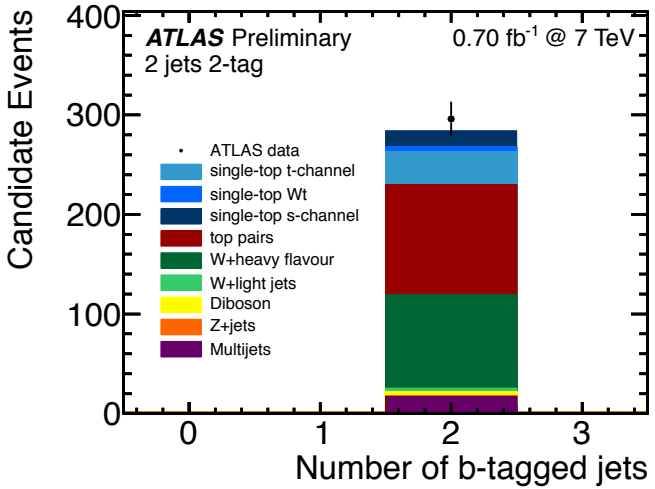
Selection	Signal	Background	S/$\sqrt{B}$
Preselection Only	104	153802	0.26
Number of tagged jets=2	18	415	0.88
30< $m_{top,jet2}$ <247 GeV/c^2	17	349	0.91
$p_T(jet1, jet2)$ <189 GeV/c	17	346	0.91
$m_T(W)$ <111 GeV/c	17	318	0.95
0.43< $\Delta R(b-jet1, lepton)$ <3.6	17	308	0.97
123< $m_{top,jet1}$ <788 GeV/c^2	17	302	0.98
0.74< $\Delta R(b-jet1, b-jet2)$ <4.68	16	269	0.98





s-channel cross section

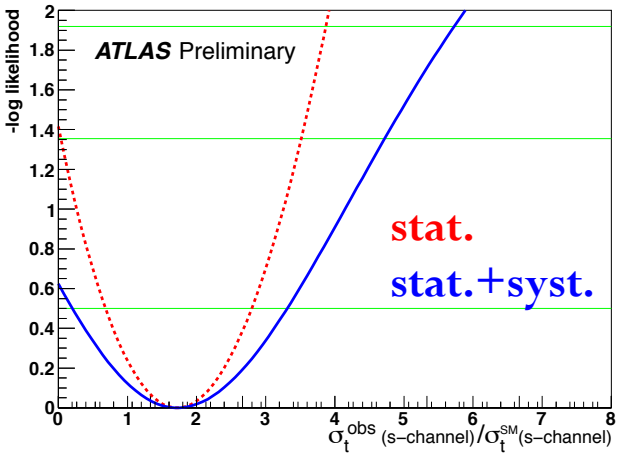
	Final Selection
s-channel	16 ± 6
t-channel	33 ± 13
Wt	5 ± 3
$t\bar{t}$	111 ± 47
W+jets	4 ± 5
Wc+jets	10 ± 8
$Wc\bar{c}$+jets	14 ± 12
$Wb\bar{b}$+jets	70 ± 51
Z+jets	1 ± 1
Diboson	4 ± 1
Multijets	17 ± 10
TOTAL Exp	285 ± 17
$S/\sqrt{B}$	0.98
DATA	296



- Background estimation similar to t-channel
- S/B ~6%
- Top pairs and W+jets dominating backgrounds

s-channel cross section

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

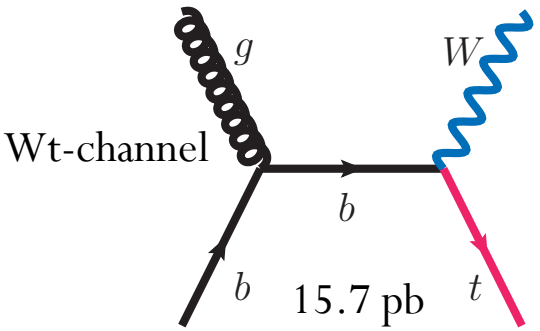


- Measurement statistics and systematics limited
- Extraction of cross section limit with profile likelihood ratio
- **Limit observed** (expected): σ_t**<26.5** (20.5) **pb** ~ 5xσ_{SM} @95%CL

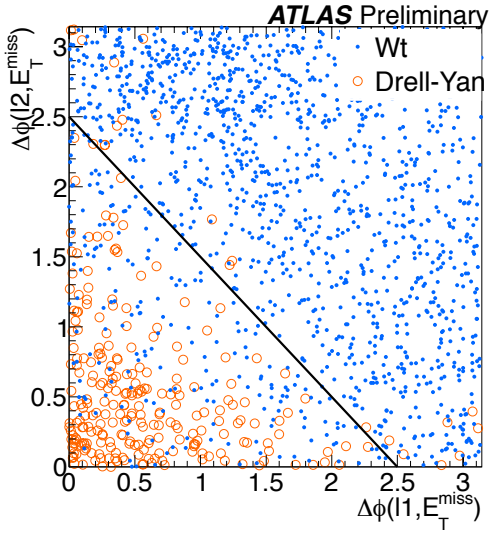
Wt-channel cross section

Wt-channel cross section

- Cut-based selection in the ***dilepton*** channel: ee, μμ, eμ
- Better background suppression against W+jets and QCD multijet



- Event selection
  - Single lepton trigger
  - Exactly two oppositely charged leptons
  - Exactly one jet p_T(jet)>30 GeV
  - E_T^{miss}>50 GeV
  - |M(ll)-M_Z|>10 GeV
  - **Σ**Δφ(lepton, E_T^{miss})>2.5



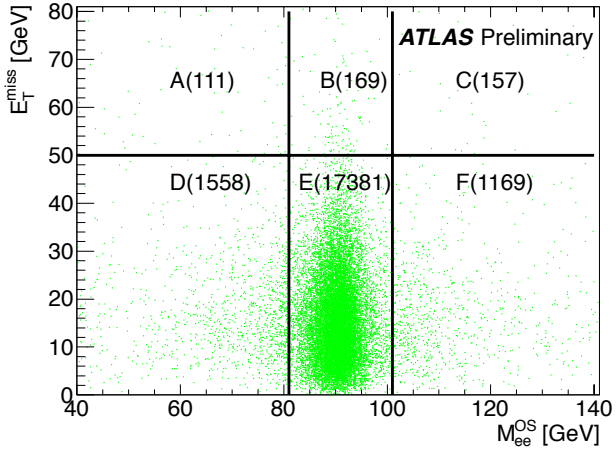
Background determination

- ***QCD-multijet / W+jets***
  - Extended matrix method

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

- ***Drell-Yan***
  - Estimate signal region A/C by ratio of A(C)/D(F)=B/E

$$N_{A/C}^{predicted} = N_f \times \frac{N_B^{data} - k \times N_B^{MCBG}}{N_E^{data} - k \times N_E^{MCBG}} \times (N_{D/F}^{data} - k \times N_{D/F}^{MCBG})$$

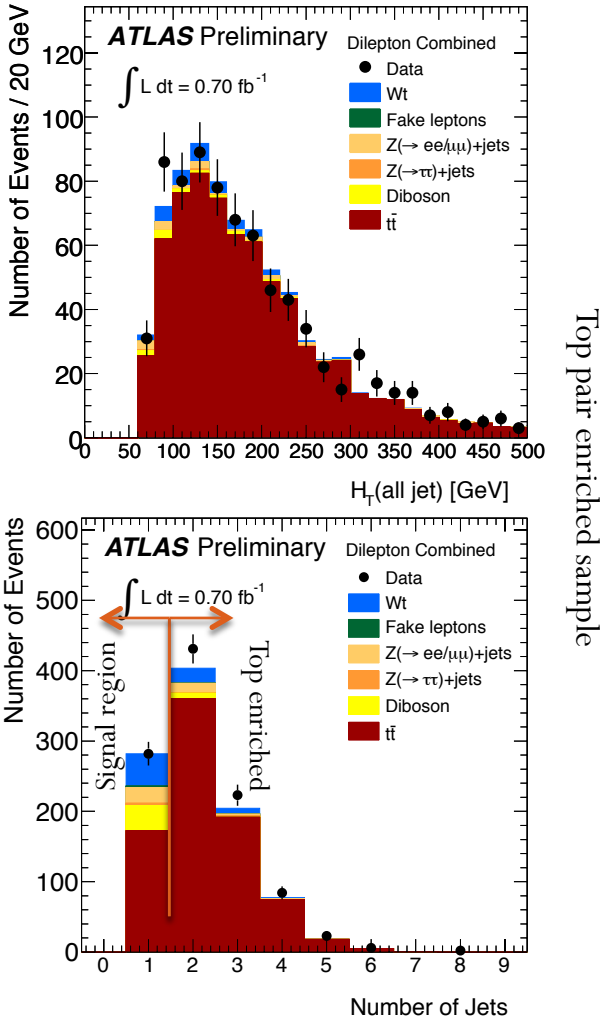


  - Correct for non-Drell-Yan contamination

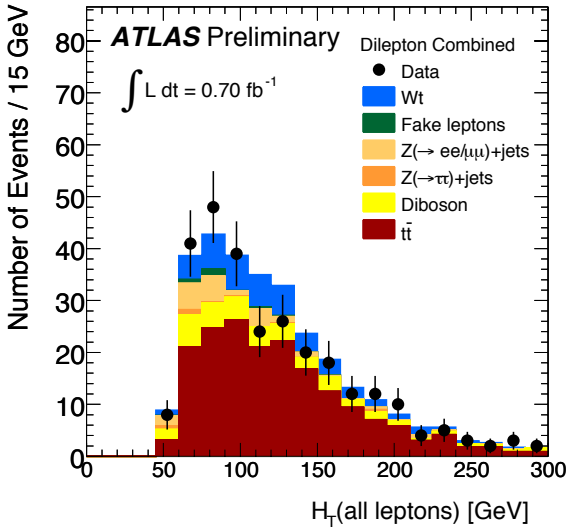
Background determination

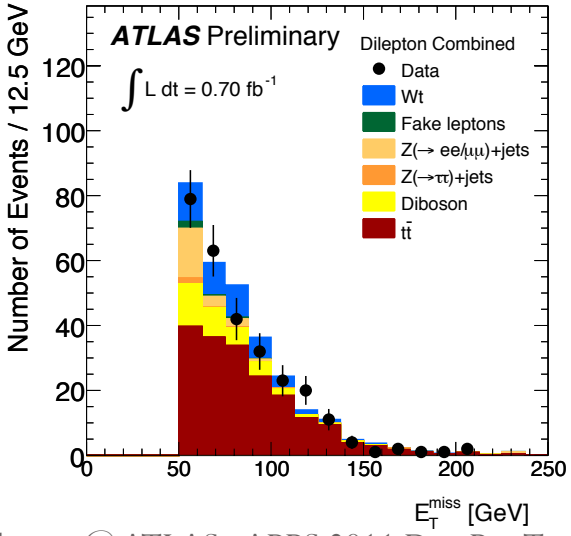
- $Z \rightarrow \tau\tau$
  - Scale background enriched region in $\Delta\varphi(l_{1/2}, E_T^{miss})$ plane by data after non-Z background subtraction

- ***Top quark pairs***
  - Scale factor from CR
    - At least 2 jets p_T>30 GeV



Wt-channel cross section



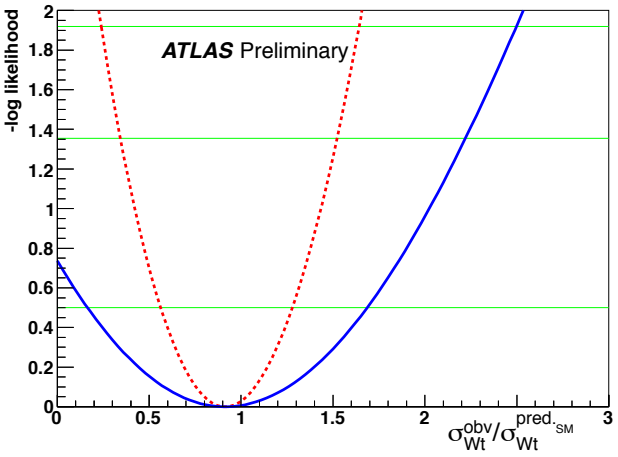


Process	ee	$\mu\mu$	$e\mu$
Wt	8.6 ± 1.6	11.9 ± 1.7	26.6 ± 2.5
$t\bar{t}$	32 ± 6	48 ± 9	105 ± 20
WW	6.0 ± 1.0	8.1 ± 1.2	15.2 ± 1.5
WZ	1.6 ± 0.3	3.0 ± 0.3	2.0 ± 0.3
ZZ	0.2 ± 0.0	1.0 ± 0.1	0.1 ± 0.0
$Z \to ee$	6.2 ± 1.1	0.0 ± 0.0	0.0 ± 0.0
$Z \to \mu\mu$	0.0 ± 0.0	8.4 ± 1.4	0.0 ± 0.0
$Z \to \tau\tau$	0.5 ± 0.3	0.5 ± 0.3	3.9 ± 2.3
Fake lepton	2.3 ± 1.2	0.0 ± 0.6	1.5 ± 0.8
Total Expected	57 ± 7	82 ± 10	154 ± 21
Total observed	62	73	152

- S/B ~20%
- Top pairs largest background

Wt-channel cross section

Source	$\Delta\sigma/\sigma$ [%]
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



- Measurement statistics and systematics limited
- Extraction of cross section limit with profile likelihood ratio
- **Limit observed** (expected): σ_t**<39.1** (40.6) **pb**

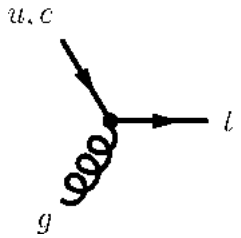
Superseeds limit from lepton+jets σ_t<198pb

FCNC in single top

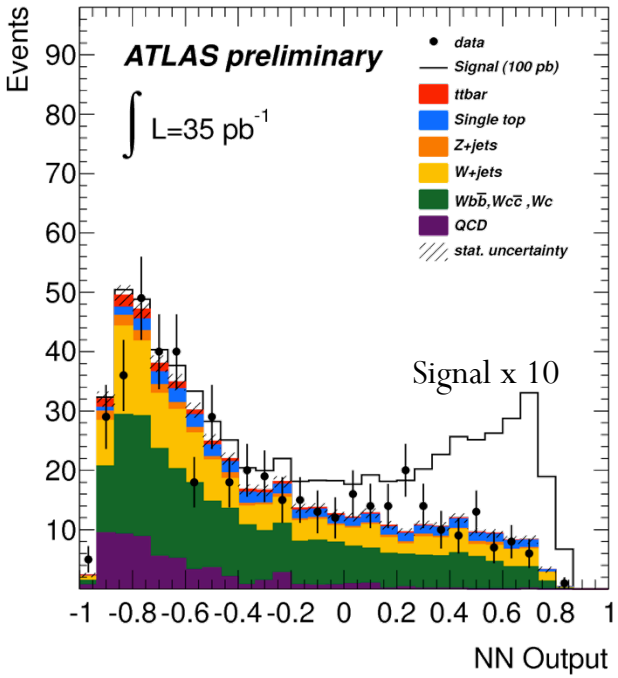
FCNC in single top

- FCNC vertex gq⟶t
  - Anomalous **single top production**
  - Cross section below *Wt*-channel
  - Single top/ single lepton event preselection
    - Softer lepton cut (20 GeV)
    - with exactly one *b*-tagged jet
  - Neural network analysis with 13 input variables
  - Limit on σ(u(c)g⟶t)*BR
    - Upper limit from Bayesian posterior:

      σ(u(c)g⟶t)*BR<17.3pb (obs.)
      σ(u(c)g⟶t)*BR<$17.4^{+8.2}_{-5.4}$ pb (exp.)
  - Systematics from ISR, JES and W+jets HF fraction



σ(u(c)g⟶t) up to10pb

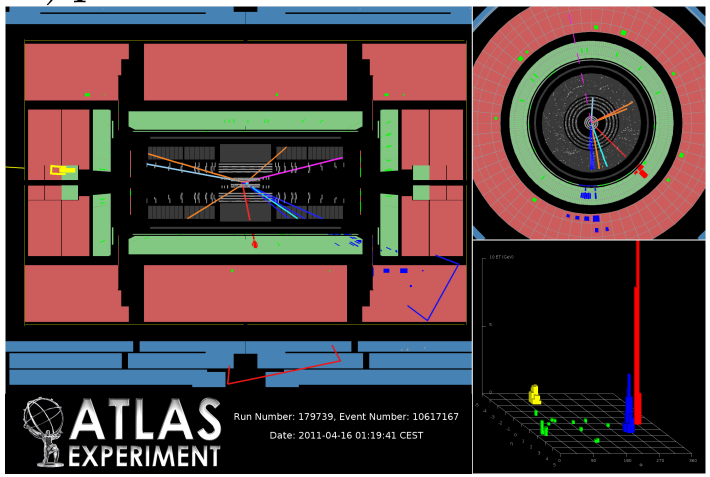


Conclusions

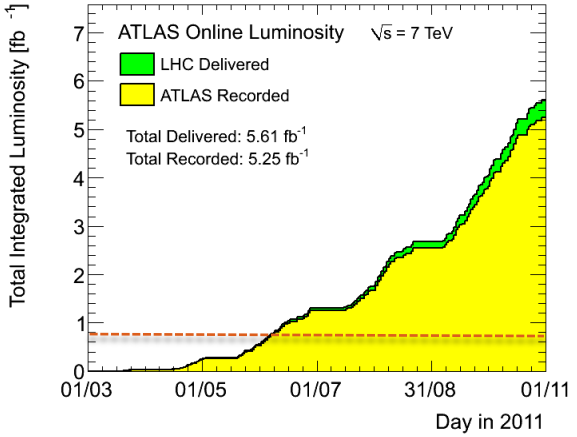
Conclusions

- ATLAS measurement/searches for single top 700pb^{-1}:
  - t-channel: $\sigma_t = 90 \pm 9\,(\text{stat.})\,^{+31}_{-20}\,(\text{syst.})\,\text{pb}$
  - s-channel: $\sigma_t < 26.5\,\text{pb}$
  - Wt-channel: $\sigma_t < 39.1\,\text{pb}$
- FCNC in single top production (35pb-1):
  $\sigma(u(c)g \to t) < 17.3\,\text{pb}$
- t-channel observed with cut-based approach
- Multivariate approached, increase sensitivity
- will eventually observe other single-top channels

t-channel event



- More 2011 data will be analysed
  - Higher statistics (x7)
  - Smaller systematics
- First steps towards new physics taken
  - W', H$^+$, etc…



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References

- t-channel: ATLAS-CONF-2011-101
- s-channel: ATLAS-CONF-2011-118
- Wt-channel: ATLAS-CONF-2011-104, ATLAS-CONF-2011-027
- FCNC: ATLAS-CONF-2011-061

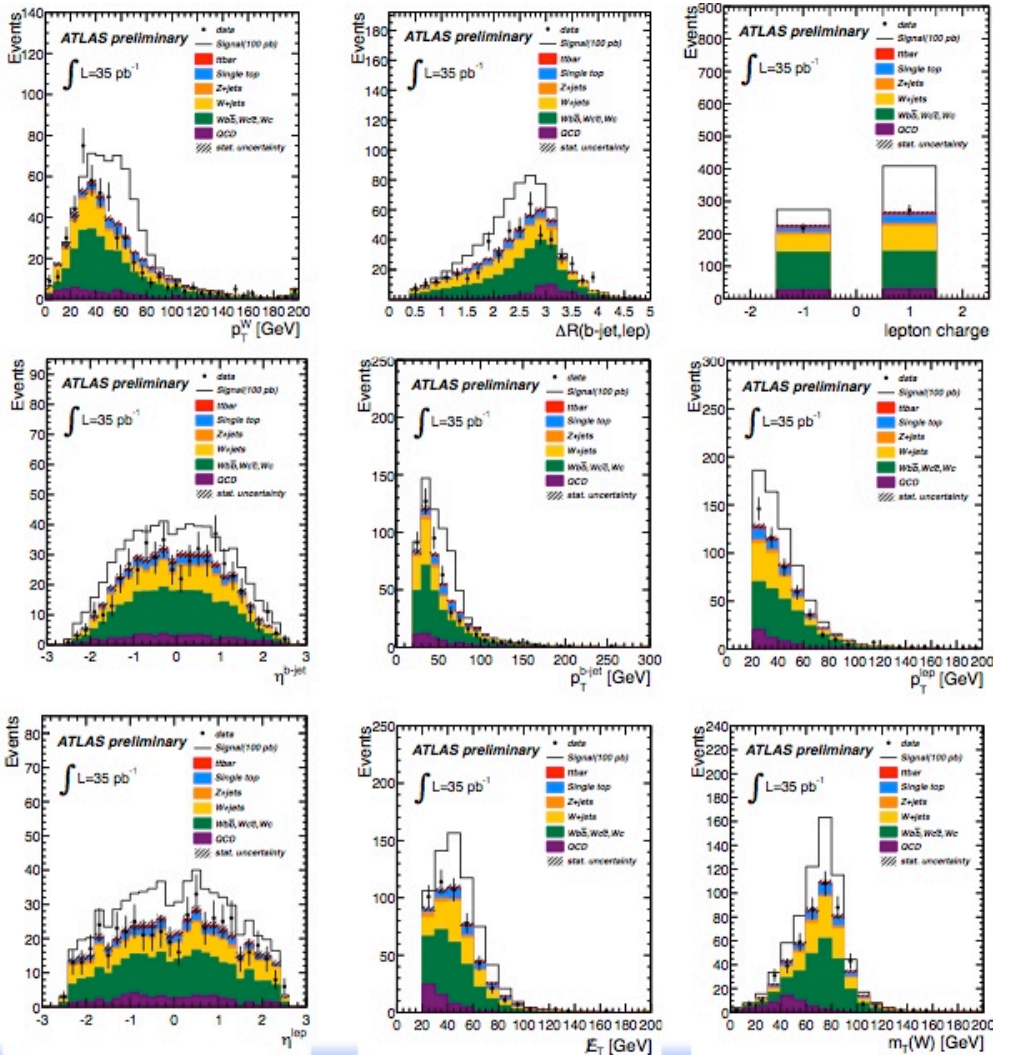
Backup

- FCNC
  - Protos : ξ^{L} and ξ^{R} set to 0.005 and 0, respectively

	t	$\bar{t}$	Total
$ug \to t$	7.30 pb	1.29 pb	8.59 pb
$cg \to t$	0.68 pb	0.68 pb	1.36 pb

- FCNC NN inputs

Variable	Significance (σ)
$p_{T,W}$	66
Δ R(ℓ, b)	29
Lepton charge	22
m_t	20
$\Delta\phi(W, b)$	18
η_b	16
W-boson helicity	10
$p_{T,b}$	9.3
$p_{T,t}$	6.9
η_ℓ	6.6
$\not{E}_T$	3.8
m_T^W	4.3
$\Delta\phi(\ell, b)$	4.2



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