Single top quarks @ LHC

Duc Bao Ta – NIKHEF

on behalf of the
ATLAS and CMS collaboration

TOP 2012

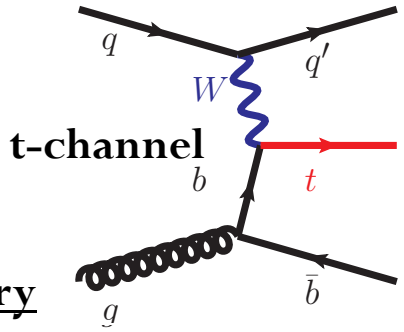
5th International Workshop on Top Quark Physics

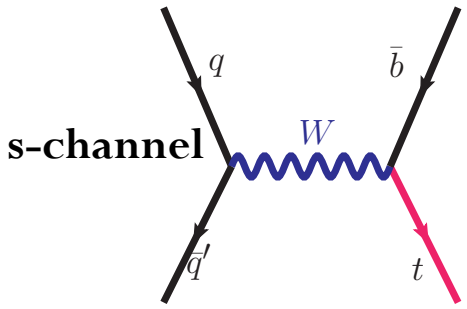
September 16-21, 2012

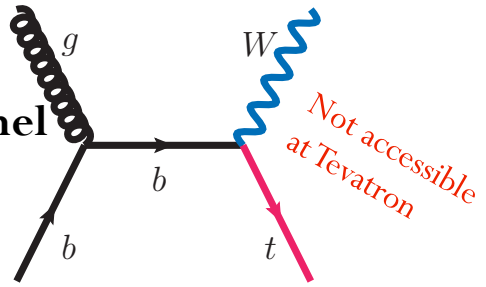
Winchester, U.K.

NIKHEF

Single top quark







SM theory			
Tevatron	**2.3pb**	**1.1pb**	0.2pb
LHC 7TeV	**64.6±2.4pb**	4.6±0.2pb	**15.7±1.1pb**
LHC 8TeV	**87.8±3.4pb**	5.6±0.3pb	**22.4±1.5pb**

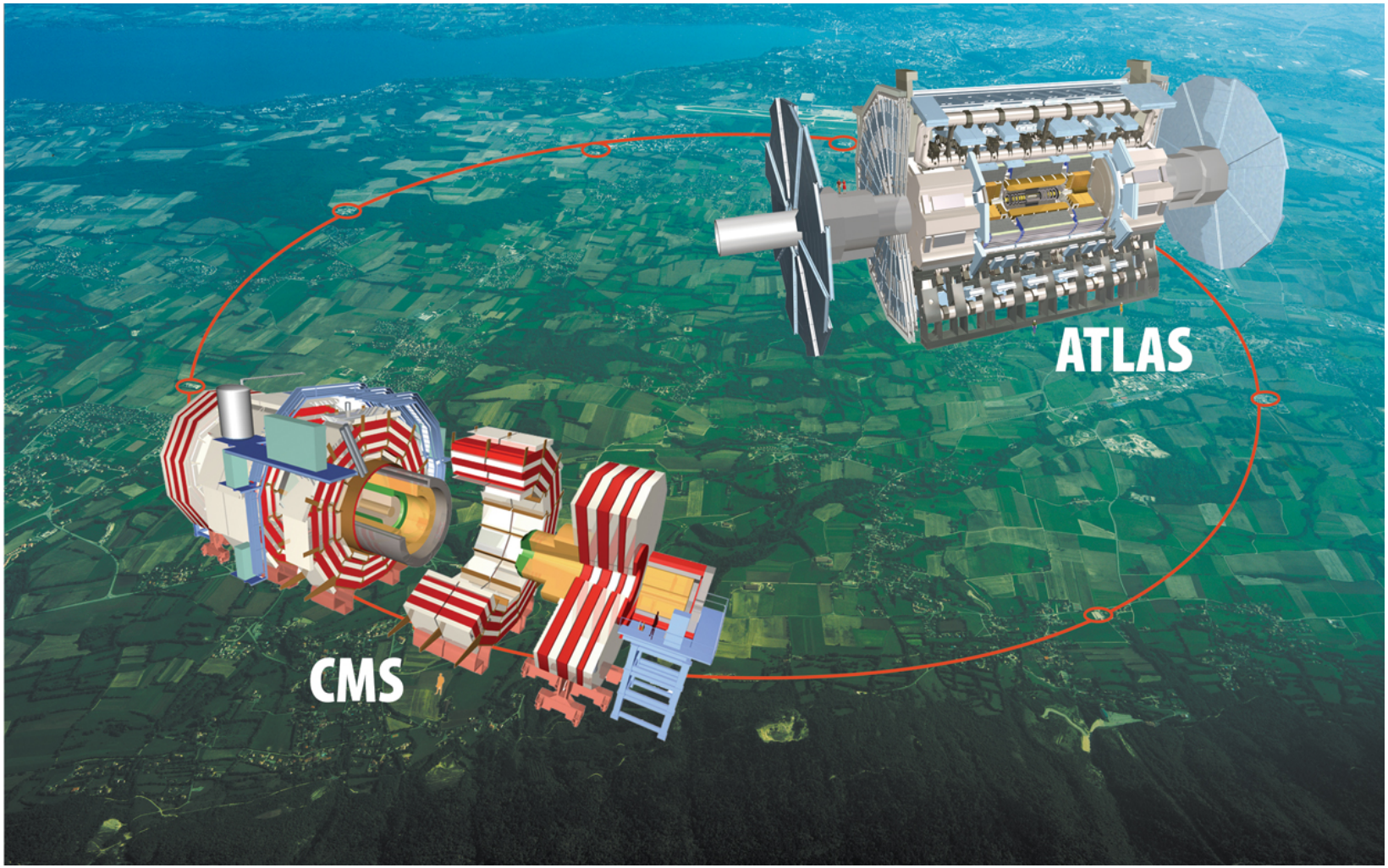
Importance of single top

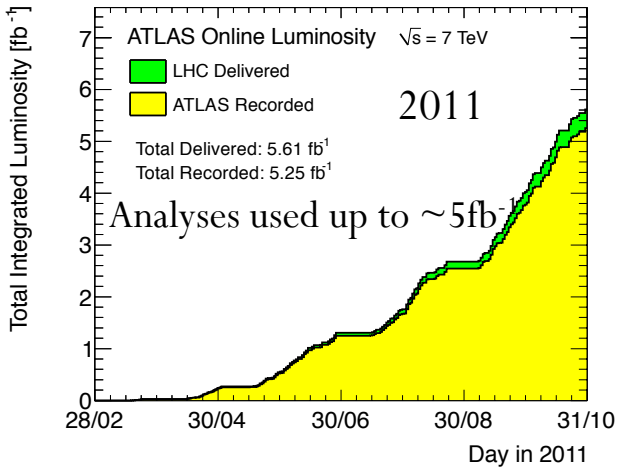
- ***Cross section*** **proportional to V_{tb}, test of unitarity of CKM**
- 4^{th} generation?
- Test of b-quark structure function
- *Heavy W'**, charged H^+
- Anomalous couplings or *FCNC in single top production**

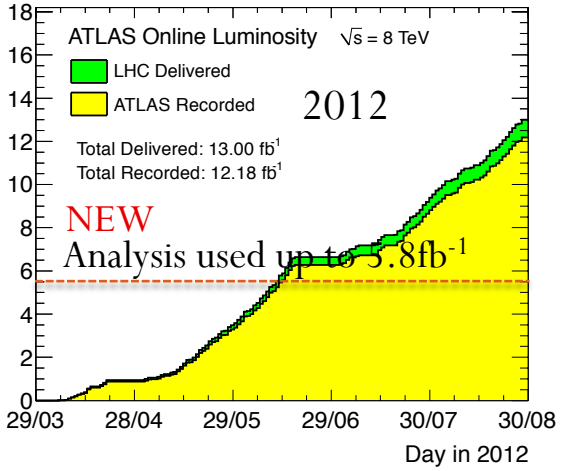
Analysis still a challenge despite the LHC *"top factory"*!

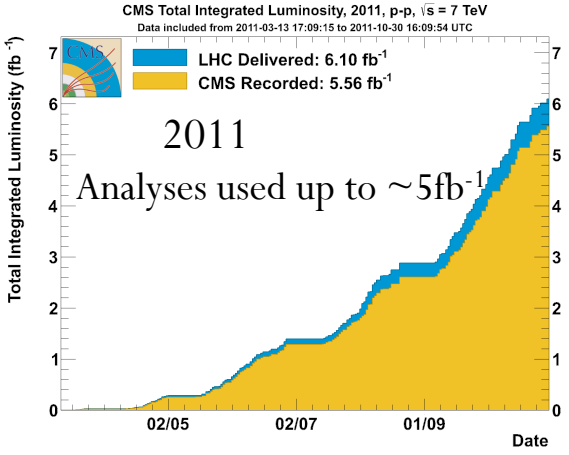
**covered in talk by T. Golling*

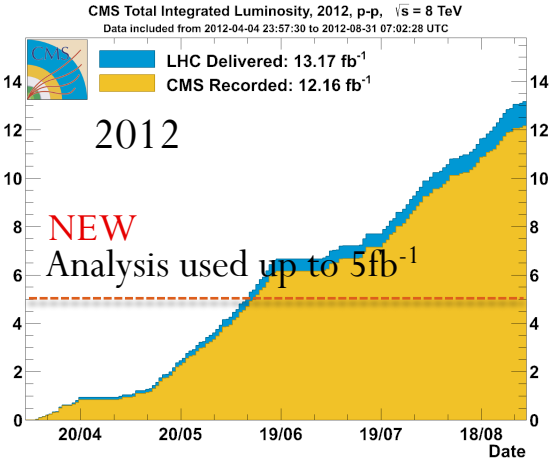
LHC, ATLAS, CMS




ATLAS Online Luminosity √s = 7 TeV
LHC Delivered
ATLAS Recorded
2011
Total Delivered: 5.61 fb-1
Total Recorded: 5.25 fb-1
Analyses used up to ~5fb-1
Total Integrated Luminosity [fb-1]
28/02
30/04
30/06
30/08
31/10
Day in 2011


ATLAS Online Luminosity √s = 8 TeV
LHC Delivered
ATLAS Recorded
2012
Total Delivered: 13.00 fb-1
Total Recorded: 12.18 fb-1
NEW
Analysis used up to 5.8fb-1
29/03
28/04
29/05
29/06
30/07
30/08
Day in 2012


CMS Total Integrated Luminosity, 2011, p-p, √s = 7 TeV
Data included from 2011-03-13 17:09:15 to 2011-10-30 16:09:54 UTC
LHC Delivered: 6.10 fb-1
CMS Recorded: 5.56 fb-1
2011
Analyses used up to ~5fb-1
Total Integrated Luminosity (fb-1)
02/05
02/07
01/09
Date


CMS Total Integrated Luminosity, 2012, p-p, √s = 8 TeV
Data included from 2012-04-04 23:57:30 to 2012-08-31 07:02:28 UTC
LHC Delivered: 13.17 fb-1
CMS Recorded: 12.16 fb-1
2012
NEW
Analysis used up to 5fb-1
20/04
20/05
19/06
19/07
18/08
Date

General Object and Event Selection

Trigger on (isolated) high-p_T lepton at efficiency plateau

Isolated leptons, central, p_T>25GeV
- calorimeter and track isolation

Jets, anti-kt (R=0.4), from calo clusters
- up to $|\eta|$<4.5, p_T>25 (30) GeV

***b*-jets**
- multivariate combination of secondary/tertiary vertex and lifetime information, 50-60% efficiency, ~1/500 lj rejection

E_T^{miss} from vector sum of objects and unassociated calorimeter cells

Isolated single lepton/electron +b-jets/dilepton trigger

Objects from particle flow (PF)

Isolated leptons, central, p_T>20/30GeV
- softer p_T requirement for veto on leptons
- isolation from other PF objects

Jets, anti-kt (R=0.5) from PF particles
- up to $|\eta|$<4.5, p_T>30 GeV

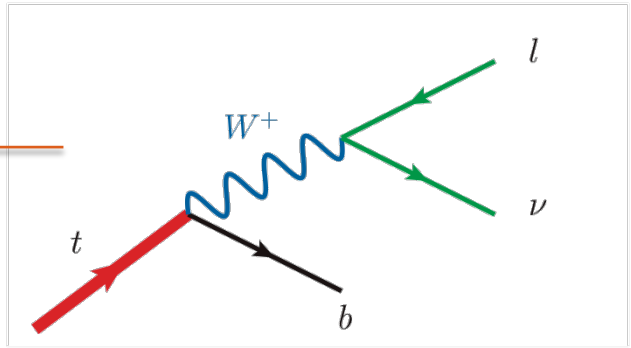
***b*-jets**
- threshold on discriminator based on secondary decay vertex reconstruction, ~60% efficiency, ~1/1000 lj rejection

E_T^{miss} from vector sum of PF objects

Transverse mass M_T from lepton and E_T^{miss} vector

t-channel, s-channel analyses: *single lepton* topology

Wt-channel analyses: *dilepton* topology



Background estimation

W+jets normalisation and heavy-flavour fraction

- In most analyses
  - Obtain directly from shape fit
- Tag counting method
  - Overall normalisation from data after non-W subtraction
  - Flavour composition from a set of equations using tagging probability

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

- Taken from data in sideband
  - Subtract non-W MC from sideband region
  - Take shape and normalisation of sensitive variable from sideband, use in signal region

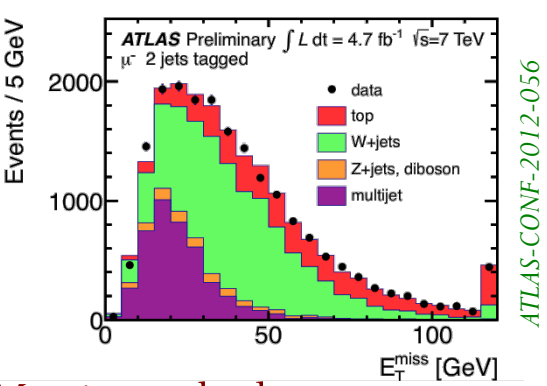
Z+jets normalisation

- Scale MC in E_T^{miss}/M_{ll} grid to data in sideband with corrections from non-Z bkg
- Z+jets correct E_T^{miss} distribution to agree in peak region

Background estimation

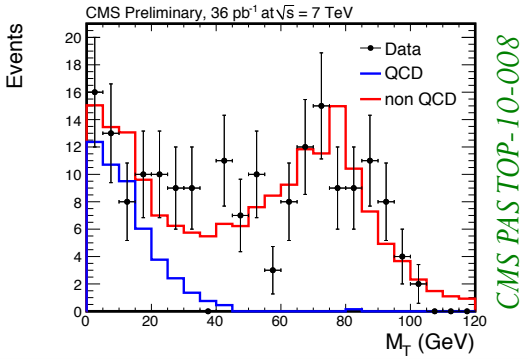
QCD-multijet background

- Jet-electron model
  - Shape: events with jets with electron-like properties
  - Normalisation: max. likelihood fit to E_T^{miss} after event preselection



- Matrix method
  - Combine probability of loosely selected real/background leptons to be selected in the event

- Extrapolation from data
  - Shape: QCD enriched sample with looser lepton selection
  - Normalisation: fit to E_T^{miss} (e), M_T (μ) distribution before cuts



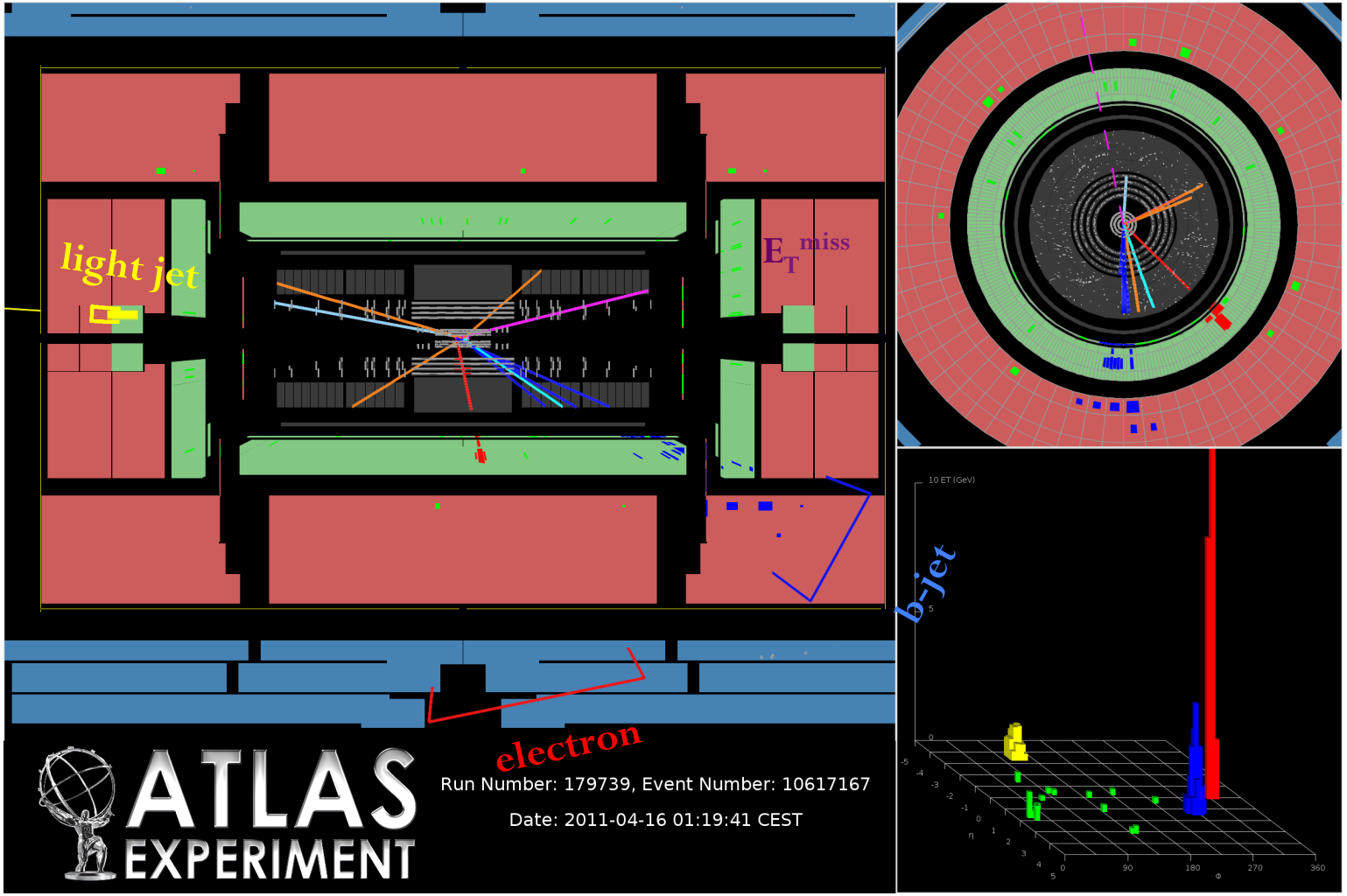
$$N^{\text{tight,loose}} = N^{\text{tight,loose}}_{\text{fake}} + N^{\text{tight,loose}}_{\text{real}}$$

$$N^{\text{tight}}_{\text{fake,real}} = \epsilon_{\text{fake,real}} \cdot N^{\text{loose}}_{\text{fake,real}}$$

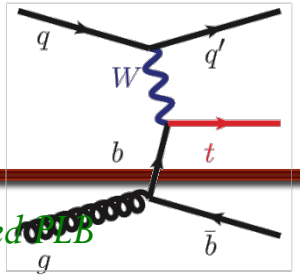
ttbar background

- In analyses with shape fits: fit in ttbar dominated regions, constrained to theory uncertainty

t-channel cross section



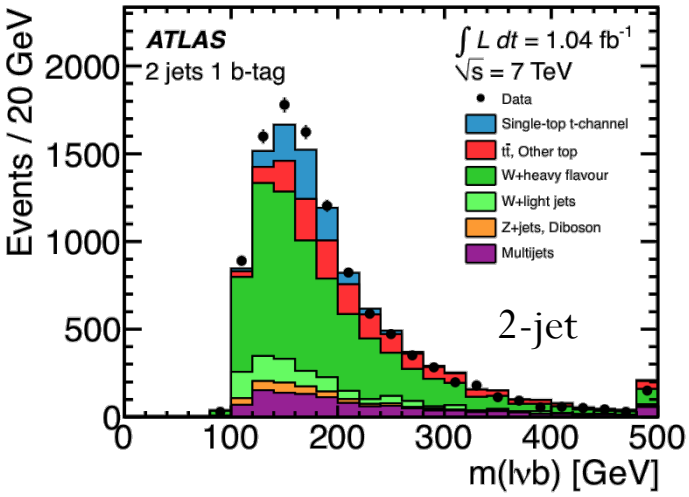
t-channel ATLAS 7TeV

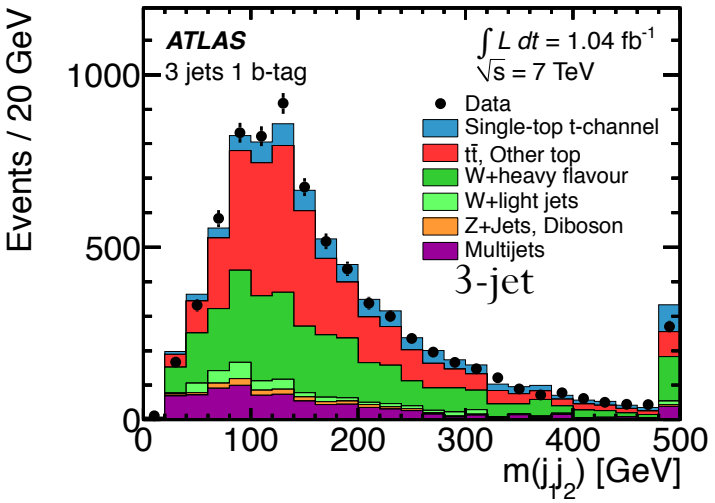


1.04fb^{-1}@7TeV

arXiv:1205.3130, accepted by JHEP

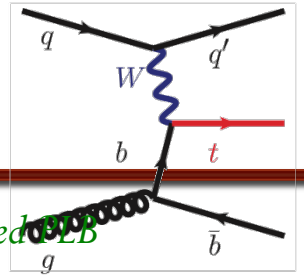
- Typically forward jets, softer b-jet
- Using events with 2/3 jet, exactly one b-tagged jet
- $M_T+E_T^{miss}>60GeV$





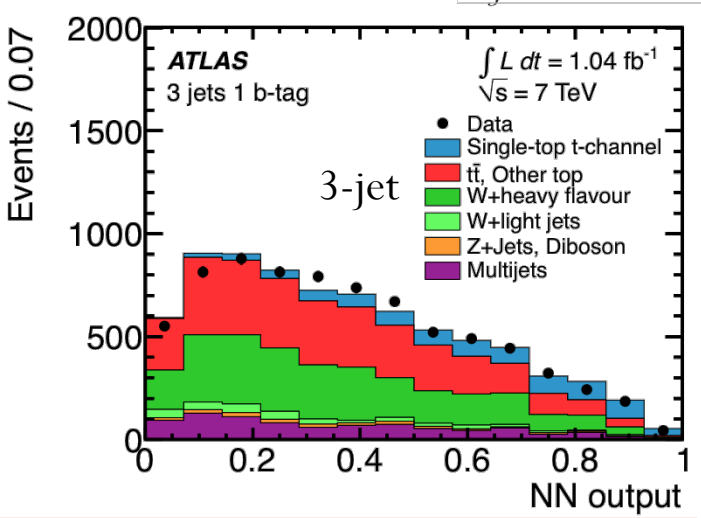
- Background estimation
  - Multijet from jet-electron model
  - W+jets/HF normalisation, ttbar from fit

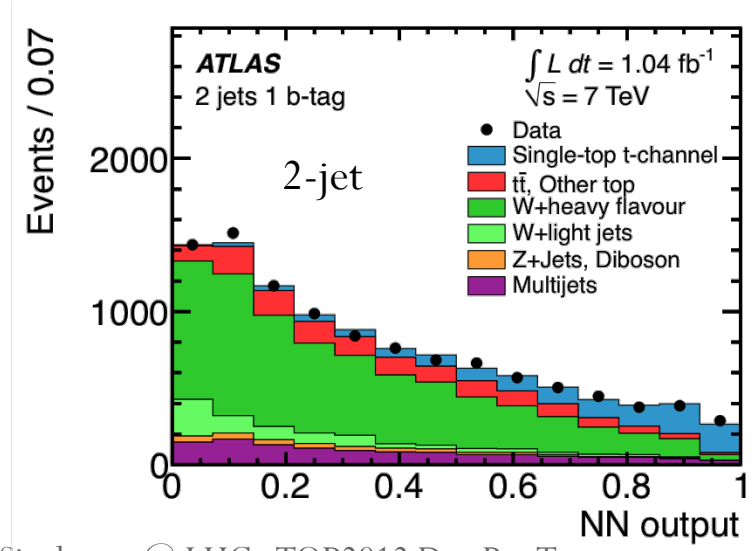
t-channel ATLAS 7TeV



- Multivariate analysis with maximum likelihood fit on full neural network output
  - 12 (18) highest rank variables in 2 (3) jet events
- Cross check with cut&count, BDT

arXiv:1205.3130, accepted by EPJC





$\sigma = 83 \pm 4(\text{stat.}) \pm 20(\text{syst.})$ **pb**

$V_{tb} = 1.13 \pm 0.14$

$V_{tb} > 0.75$ @95%CL for V_{tb} in [0,1]

- Largest systematics
  - ISR/FSR (14%)
  - b-tagging modelling (13%)

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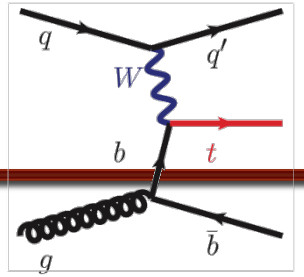
NEW

t-channel ATLAS 8TeV

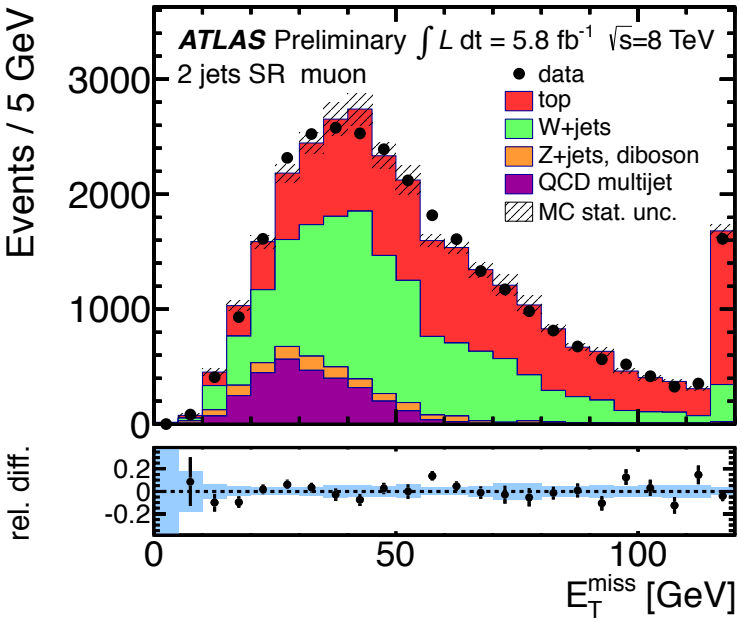


ATLAS-CONF-2012-132

5.8fb^{-1}@8TeV

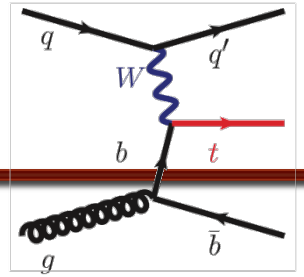
- Cross section increases
  - Signal +35%, ttbar +40%, W+jets +25-35%
- Instrumental changes
  - More difficult pile-up conditions
  - Isolated lepton trigger, harder cuts to reject jets from pile-up
  - QCD fraction seems higher
- Using events 2/3 jets, exactly one b-tagged jet
  - Increase jet p_T>30GeV cut
  - E_T^{miss}>30GeV and harder M_T>50GeV cut

- Background estimation same as 7TeV
  - Jet electron model, W+jet and ttbar from fit



NEW

t-channel ATLAS 8TeV



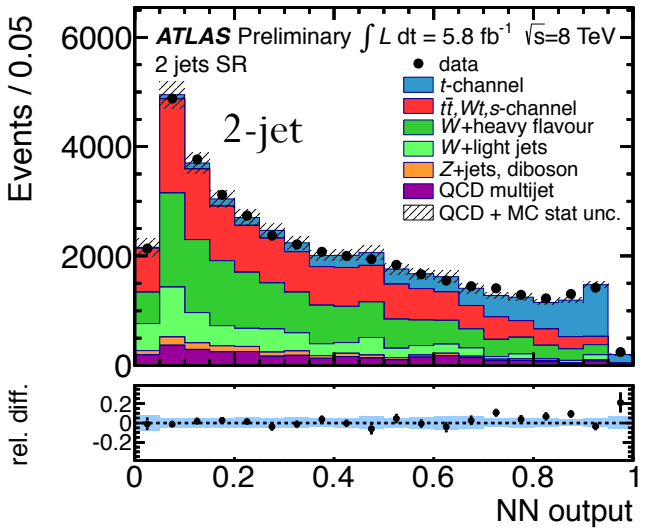
ATLAS-CONF-2012-132

- Multivariate analysis with maximum likelihood fit on full neural network output
  - 11 highest rank variables
  - S/B 12% (was 9% @7 TeV)

$\sigma = 95 \pm 2(\text{stat.}) \pm 18(\text{syst.})$ **pb**

$V_{tb} = 1.04 \pm 0.11$

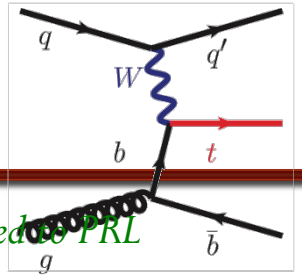
$V_{tb} > 0.80$ @95%CL for V_{tb} in [0,1]



- Largest systematics
  - Same important systematics, reduced effect
  - ISR/FSR, b-tag, jet energy scale (8%-9%)

NEW / UPDATE

t-channel CMS 7TeV

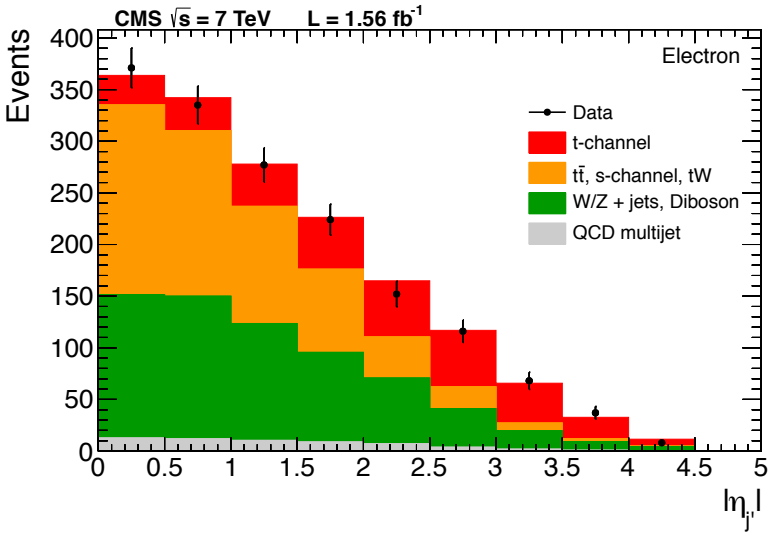


1.17-1.56fb^{-1}@7TeV

CMS TOP-11-021 submitted to PRL

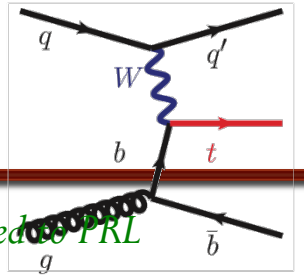
- Signal mostly in events with 2 jets, exactly one b-tagged
- M_T>40GeV(μ), E_T^{miss}>35GeV(e)
- Background estimation
  - Multijet from enriched region, fit to signal region
- Three analysis combined with BLUE
  - $|\eta_{j'}|$ analysis
  - Neural network
  - Boosted decision tree

- Maximum likelihood fit on full $|\eta_{j'}|$ range
  - Signal region 130<m_{lvb}<220GeV
  - W+jets from sideband
  - Top backgrounds, electroweak (W/Z+jets, diboson) and t-channel signal template



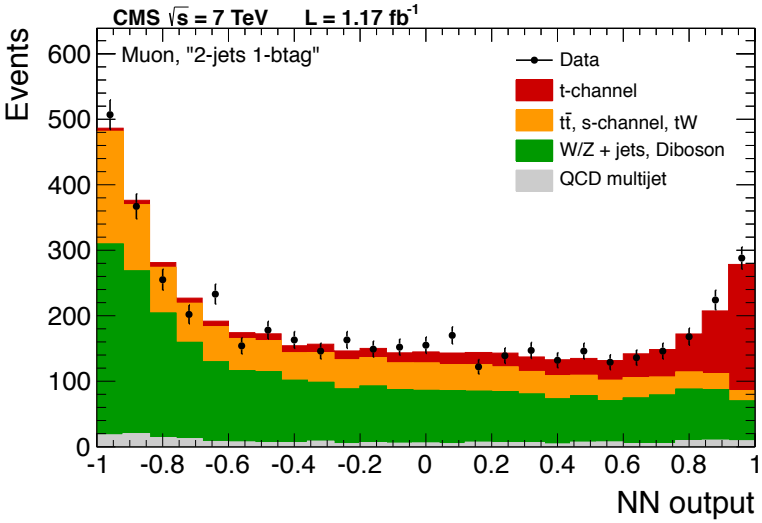
NEW / UPDATE

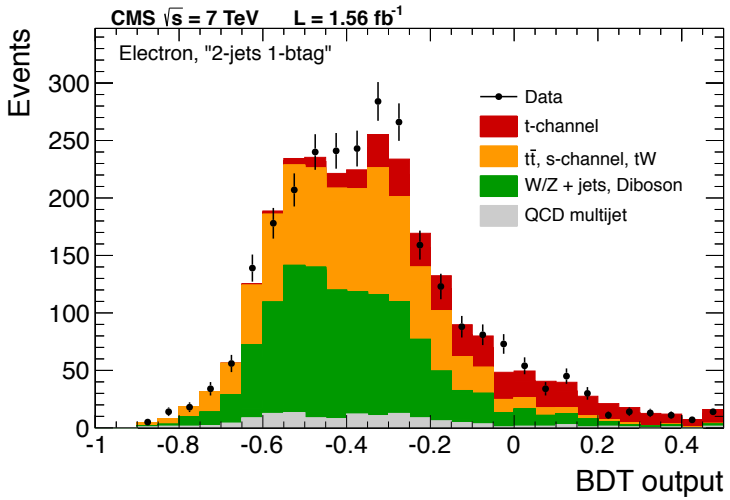
t-channel CMS 7TeV



CMS TOP-11-021 submitted to PRL

- Neural network
  - Using 6 event regions with: 2/3/4 jet events, 1/2 b-tagged jets
  - 37 (38) highest rank variables in two NN for μ (e) events

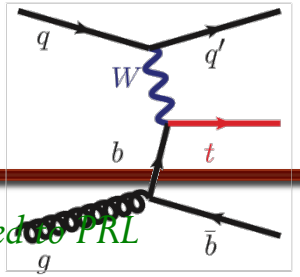




- Boosted decision tree
  - 6 event regions same as NN
  - Training on 2/3 jets, 1 b-tagged jet events muon/electron channel with 11 observables

NEW / UPDATE

t-channel CMS 7TeV



CMS TOP-11-012 submitted to PRL

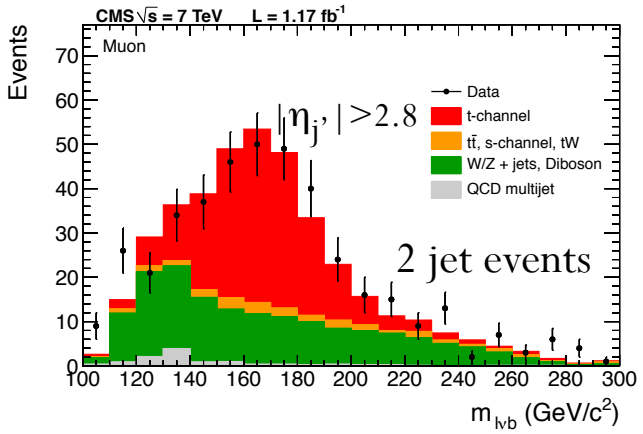
- Cross section determination MVA with marginalizied Bayesian posteriors:

$$p(\mu|\text{data}) \propto \int p'(\text{data}|\mu,\vec{\theta}) \cdot \pi(\mu)\pi(\vec{\theta})\mathrm{d}\vec{\theta}$$

Uniform prior for signal strength μ

Prior for systematic nuisance parameter

  - Theoretical uncertainties not marginalized
- Combination using BLUE
  - 60%-75% statistical correlation between analyses
  - 20% correlation of jet/E_T^{miss} related systematics between MVA and $|\eta_{j'}|$
  - Other taken as 100%



$\sigma = 67 \pm 4(\text{stat.}) \pm 3(\text{syst.}) \pm 4(\text{theo.}) \pm 2(\text{lumi.})$ **pb**

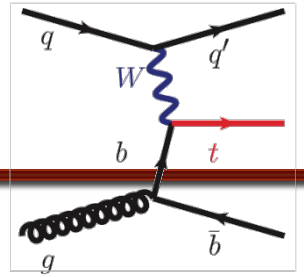
$V_{tb} = 1.02 \pm 0.05 \pm 0.02$ (theo.)

$V_{tb} > 0.92$ @95%CL for V_{tb} in [0,1]

- Largest systematics
  - Statistical uncertainty
  - W+jet normalisation
  - Generator uncertainties

NEW

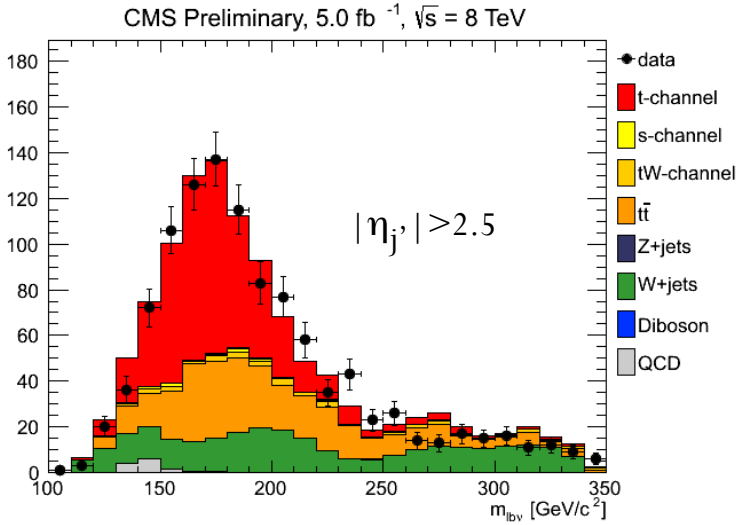
t-channel CMS 8TeV



5.0fb^{-1}@8TeV

CMS PAS TOP-12-011

- Using only single muon topology
- Higher trigger threshold, p_T>26GeV, $|\eta|$<2.1, more isolated muon
- Jet p_T>40GeV
- Harder cut on M_T>50GeV

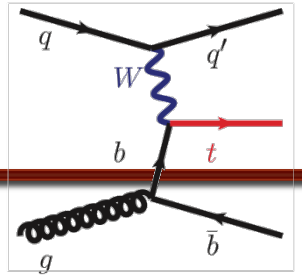


- Can enrich signal by cutting on $|\eta_{j'}|$ light jet

- Background determination
  - Multijet fit in signal and sideband region separately
  - ttbar shape from 3 jets, 2 b-tagged events
  - W+jets shape from sideband subtract ttbar data shape, other MC shapes
  - Z+jets use same scale as for W+jets

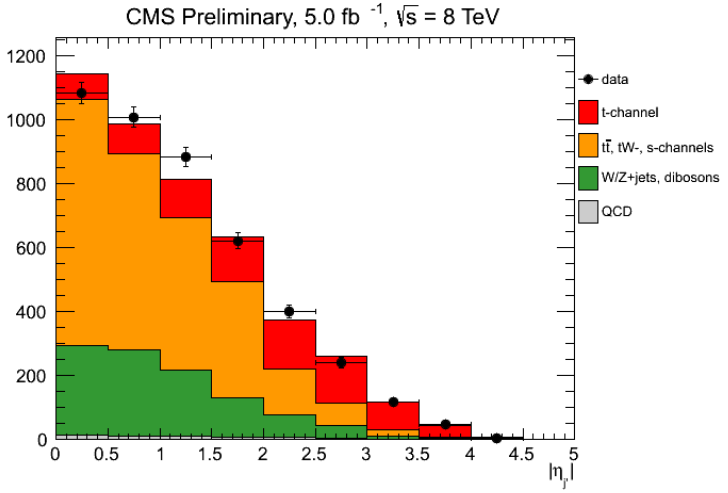
NEW

t-channel CMS 8TeV



- Maximum likelihood fit on full $|\eta_{j'}|$ range
  - events with 2 jet, exactly one b-tagged
  - Signal region $130<m_{l\nu b}<220$GeV
  - Top backgrounds, electroweak (W/Z+jets, diboson) and t-channel signal

CMS PAS TOP-12-011



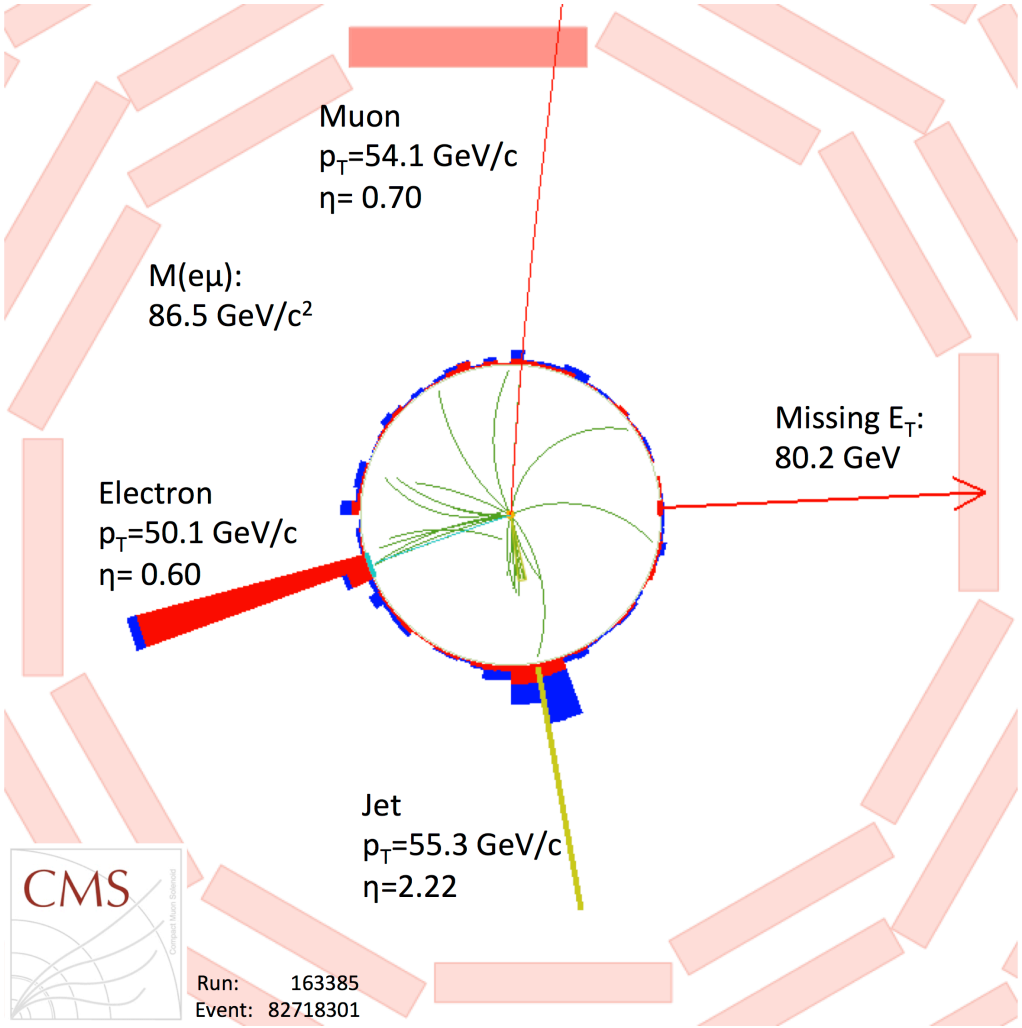
$\sigma = 80 \pm 6(\text{stat.}) \pm 11(\text{syst.}) \pm 4(\text{lumi.})$ **pb**

$V_{tb} = 0.96 \pm 0.08 \pm 0.02(\text{theo.})$

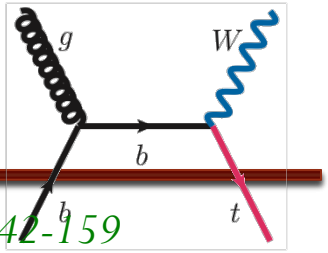
$V_{tb} > 0.81$ @95%CL in [0,1]

- Largest systematics
  - Jet energy scale (9%)
  - Statistics (9%)
  - t-channel generator (6%)

Wt-channel cross section



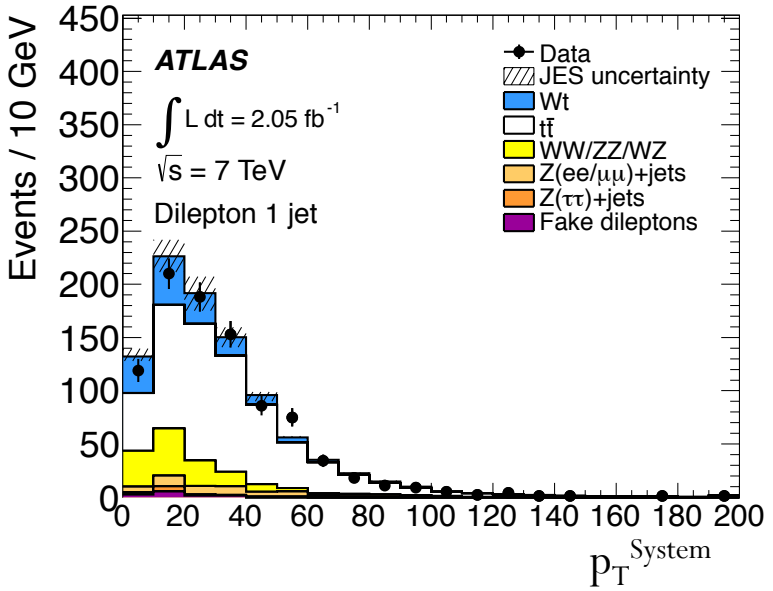
Wt-channel ATLAS 7TeV



Phys. Lett. B 716 (2012) 142-159

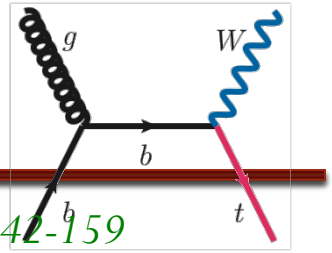
2.05fb^{-1}@7TeV

- Events with at least one central jet, no b-tag requirement
- E_T^{miss}>50GeV, Z-mass window cut (ee, μμ), angular cut against Zττ
- Background estimation
  - Drell-Yan and Zττ, data-driven scaling of data-MC ratio in signal/control region
  - Multijet from matrix method



- Most sensitive variable:
  - p_T^{System}=all object p_T+E_T^{miss}
  - Combine with other variables in MVA

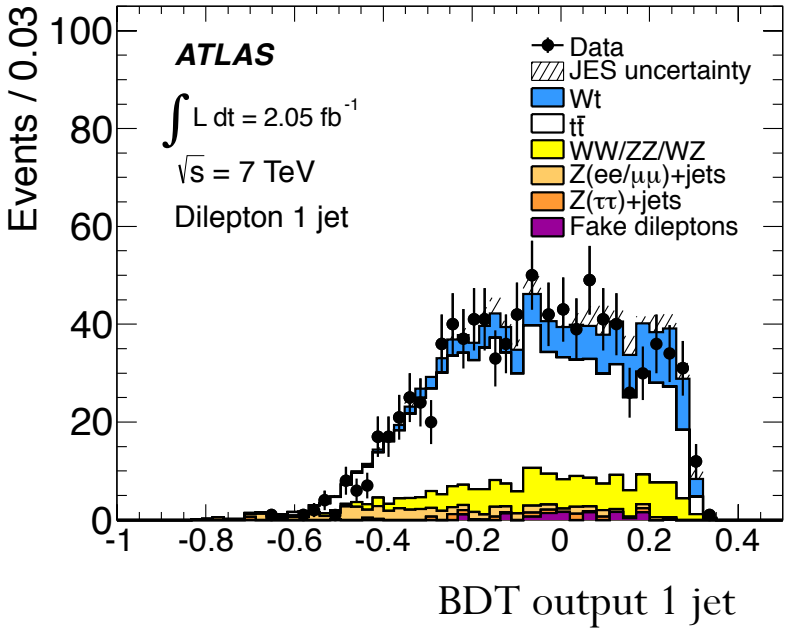
Wt-channel ATLAS 7TeV

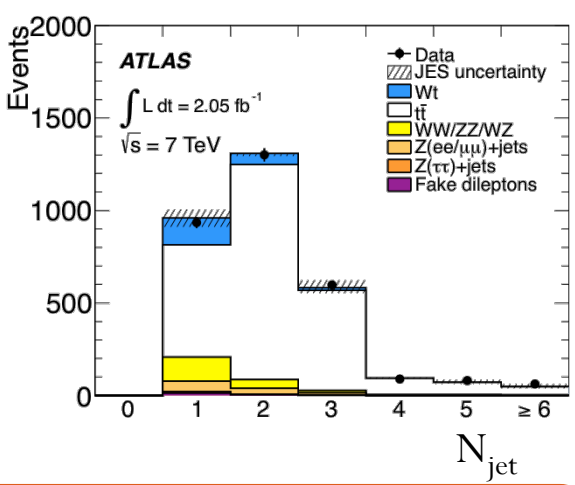


Phys. Lett. B 716 (2012) 142-159

2.05fb^{-1}@7TeV

- Profile likelihood method on boosted decision tree output
  - 1,2,≥3 jet events, training using 22 observables





$\sigma = 17 \pm 3(\text{stat.}) \pm 5(\text{syst.})$ pb

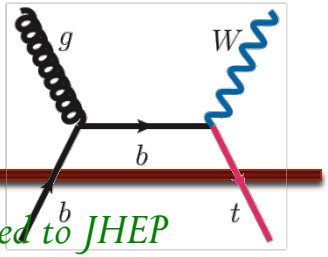
3.3σ level (exp. 3.4σ) evidence

$V_{tb} = 1.03^{+0.16}_{-0.19}$

- Largest systematic
  - Jet energy scale (16%)
  - Parton shower model (15%)
  - Pile-up, Generator (10%)

NEW / UPDATE

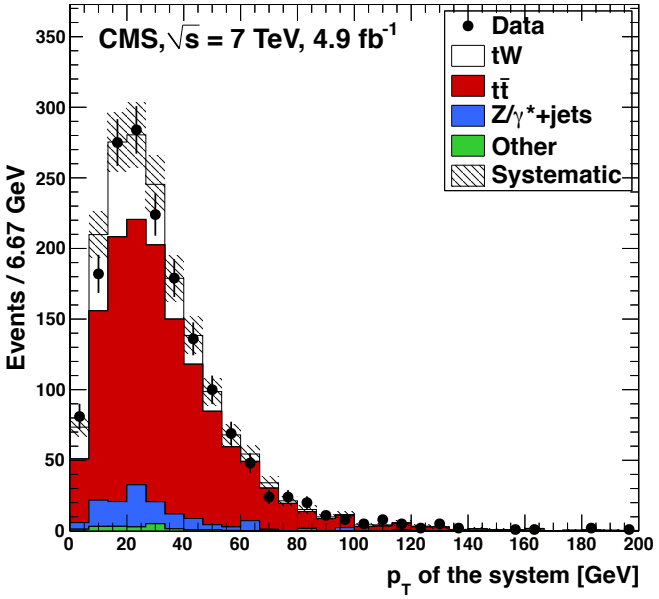
Wt-channel CMS 7TeV

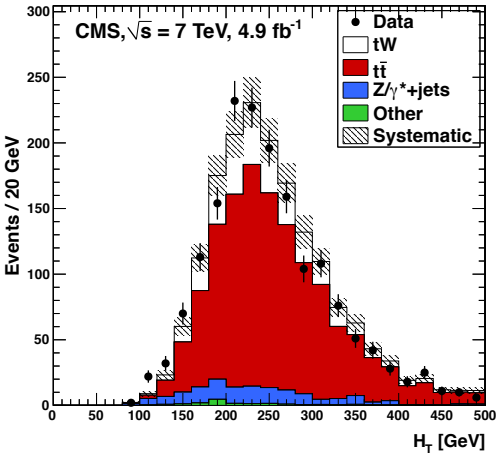


4.9fb^{-1}@7TeV

arXiv:1209.3489, submitted to JHEP

- Events with at least one central jet, at least one b-tagged jet
- E_T^{miss}>30GeV, tracker E_T^{miss}>30GeV
- Z-mass window cut (ee, μμ)

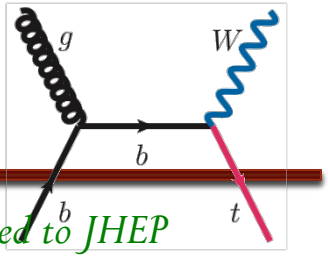




- Background estimation
  - ttbar constrained by using enriched regions (2 jets, 1/2 b-tag) in fit
  - Z+jets correct E_T^{miss} to agree in peak region

NEW / UPDATE

Wt-channel CMS 7TeV



- Binned likelihood fit to BDT output in all channels and signal and control regions

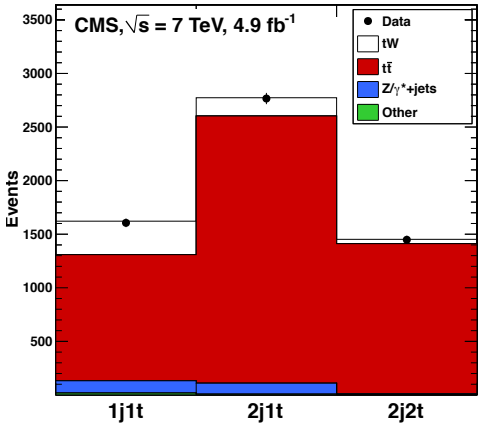
arXiv:1209.3489, submitted to JHEP

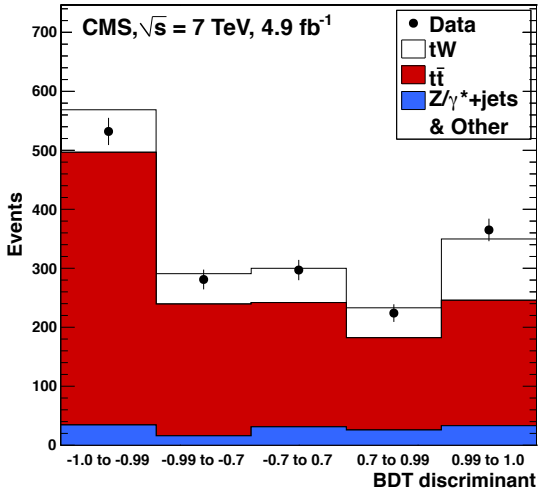
$$\sigma = 16^{+5}_{-4}\,\text{pb}$$

4σ level (exp. 3.6σ)

$$V_{tb} = 1.01^{+0.16}_{-0.13} \pm 0.04(\text{theo.})$$

$$V_{tb} > 0.79 \ @95\%\text{CL for in } [0,1]$$

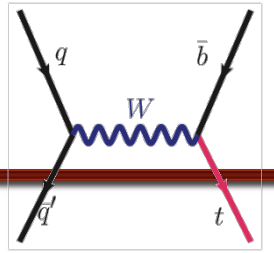




- Cross checked with counting analysis
- Largest systematics on signal
  - Statistical uncertainty (21%)
  - Jet energy scale (15%)
  - ME/PS matching threshold (10%)

s-channel cross section

s-channel ATLAS 7TeV

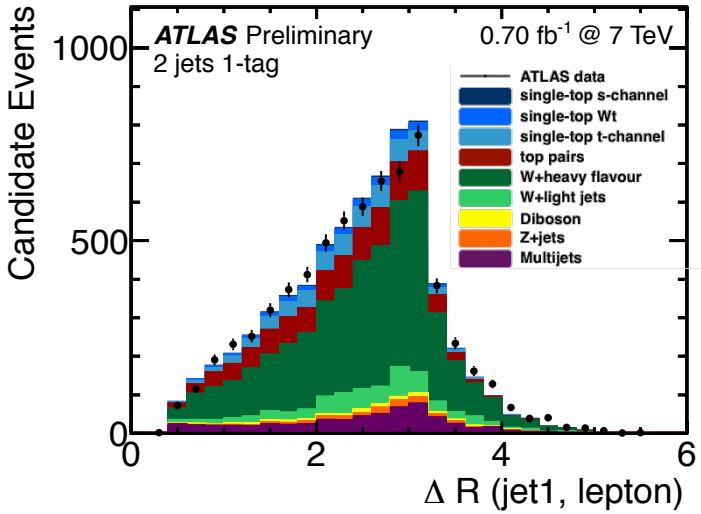


ATLAS-CONF-2011-118

0.70fb^{-1}@7TeV

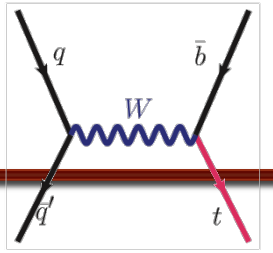
- Events with exactly two central jet events, exactly one b-tagged jet
- E_t^{miss}>25GeV, $M_T+E_T^{miss}$>60GeV

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



- Cut based analysis
- Background estimation
  - Multijet from jet-electron model
  - W+jets (HF) from tag counting

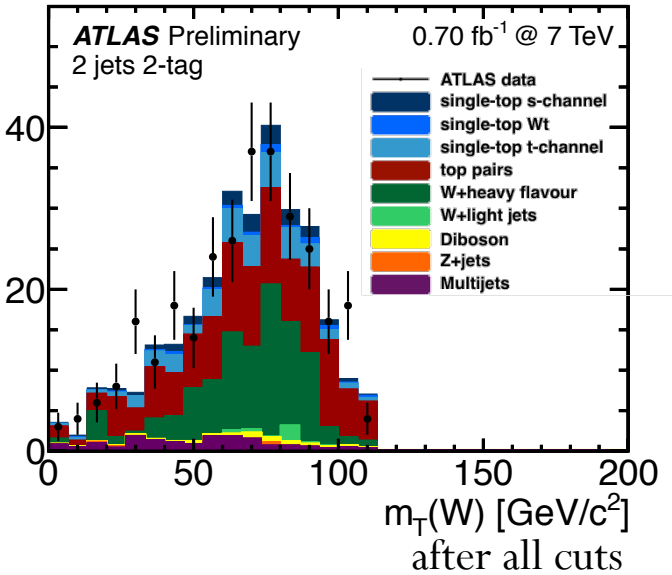
s-channel ATLAS 7TeV



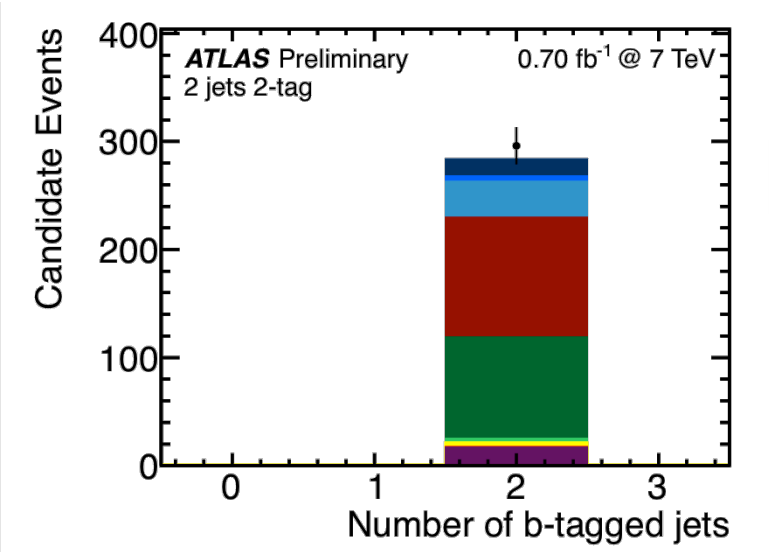
ATLAS-CONF-2011-118

0.70fb^{-1}@7TeV

- Likelihood ratio method on the number of expected events in each channel
  - Expected signal 16±1, expected total 285±17, observed events 296

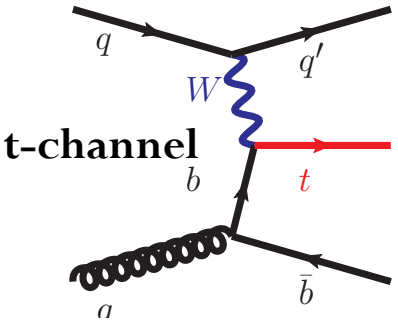


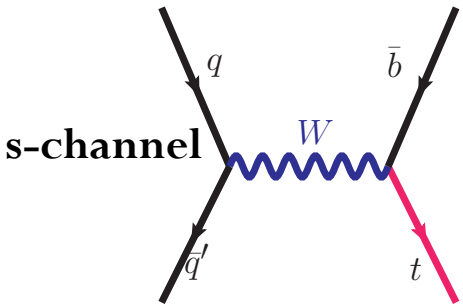
after all cuts

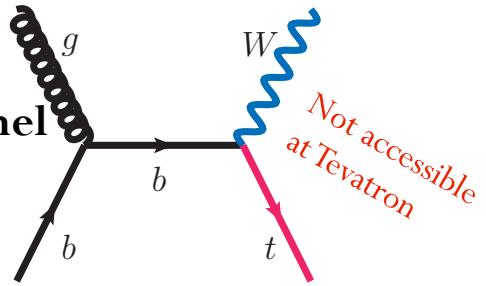


σ<26.5 (20.5) **pb ~ 5xσ$_{SM}$@95%CL**

- Largest systematics
  - Data statistics (100%)
  - MC statistics (70%)
  - MC generator (-60%/20%)







Theory 7TeV	**64.6±2.4pb**	**4.6±0.2pb**	**15.7±1.1pb**
ATLAS 7TeV	83±20pb	<26.5pb	17±6pb @3.3σ
CMS 7TeV	67±6pb	-	16±5pb @4.0σ
Theory 8TeV	**87.8±3.4pb**	**5.6±0.3pb**	**22.4±1.5pb**
ATLAS 8TeV	95±18pb	-	-
CMS 8TeV	80±13pb	-	-

t-channel cross section measured @both CME, **Wt-channel** evidence found, **s-channel** still a challenge

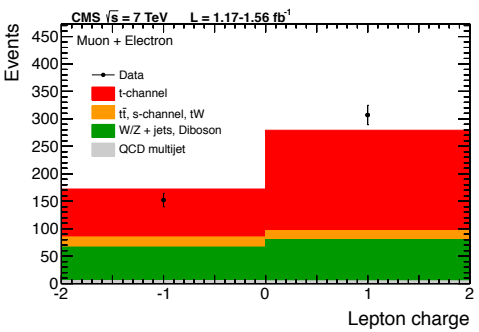
V_{tb} compatible with unity

Cross section ratio ATLAS 7TeV

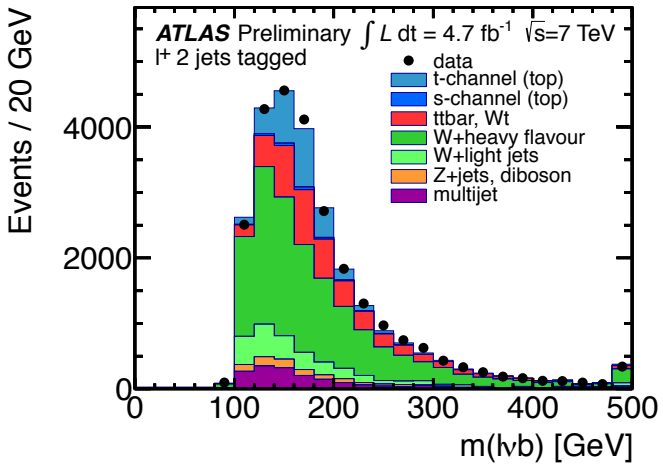
4.7fb^{-1}@7TeV cross section ratio top/antitop in t-channel

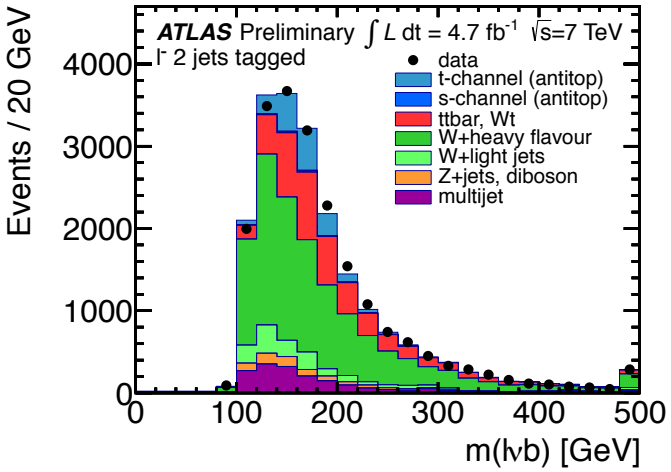
- Expect from SM ~1:2, sensitive to PDFs or new physics
- Similar to t-channel analysis
  - E_T^{miss}>30GeV and M_T>30GeV
  - Jet p_T>30GeV, in forward/barrel transition p_T>50GeV
  - Share background estimation methods
- Ratio reduces systematics
  - Jet energy scale (20% to 4%)
  - Lepton efficiency (3% to 0.2%)
  - Top MC generator (7% to 1%

CMS t-channel cross check



ATLAS-CONF-2012-056



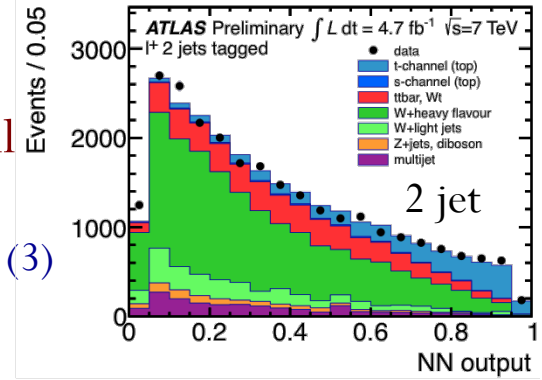


NIKHEF

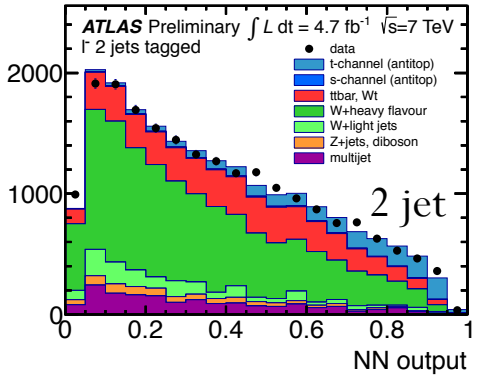
Cross section ratio ATLAS 7TeV

- Using NN on events with 2/3 jets and split in lepton charge
- Multivariate analysis with maximum likelihood fit on full neural network output
  - 15 (19) highest rank variables 2 (3) jet bin
- Total cross section compatible with t-channel result

ATLAS-CONF-2012-056



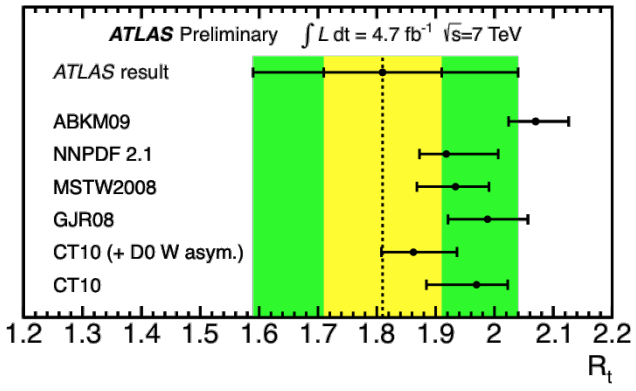
Positive charged lepton



Negative charged lepton

R = 1.81 ±0.10(stat.) **±0.20**(syst.)

- Largest systematics
  - Background normalisation (5%)
  - ISR/FSR, Multijet (4%)
  - Jet energy scale (4%)



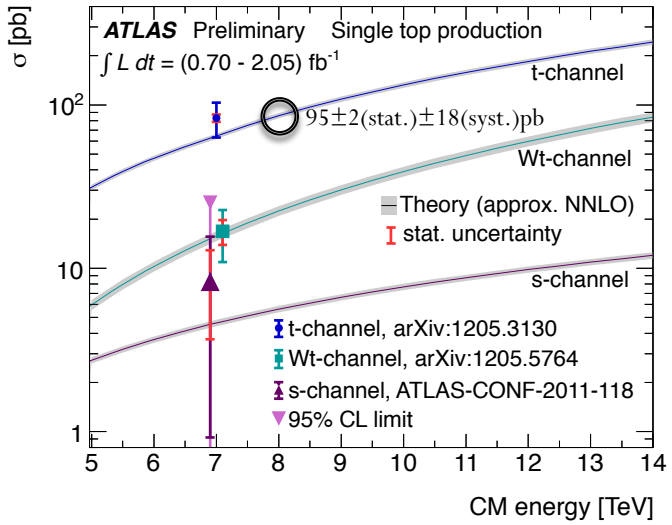
Summary

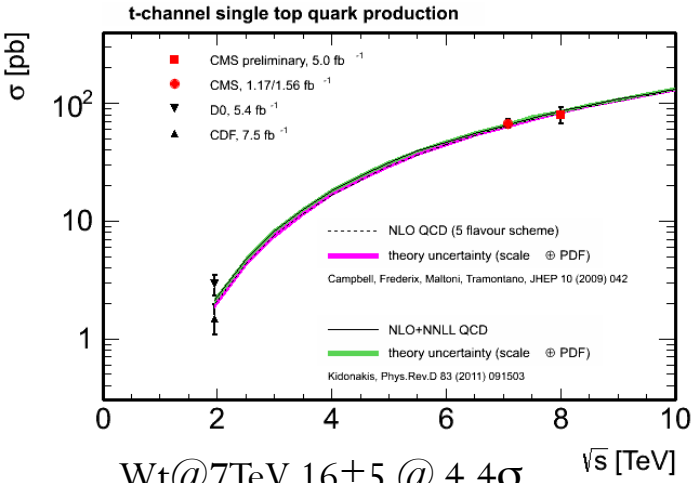
Single top @ LHC established

- t,Wt-channel cross section systematically limited
- s-channel soon be measured?

Single top property measurements will start

New physics searches in single top mode possible





Wt@7TeV 16±5 @ 4.4σ

References

t-channel: arXiv:1205.3130v1, accepted PLB

Wt-channel: Phys. Lett. B 716 (2012) 142-159

s-channel: ATLAS-CONF-2011-118

t-channel, top/antitop xsection: ATLAS-CONF-2012-056

t-channel 8 TeV: : ATLAS-CONF-2012-132

t-channel: CMS TOP-11-021

Wt-channel: arXiv:1209.3489, submitted to JHEP

t-channel 8 TeV: CMS PAS TOP-12-011

Backup slides

t-channel ATLAS 7TeV

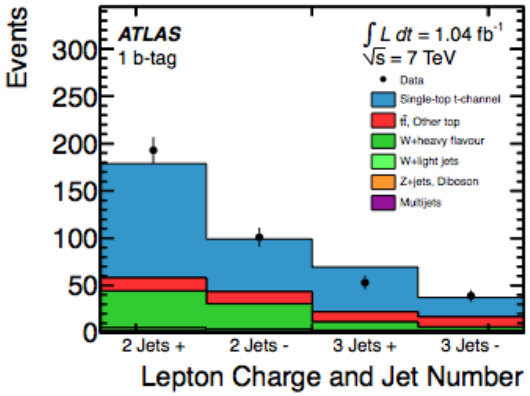
Event yields

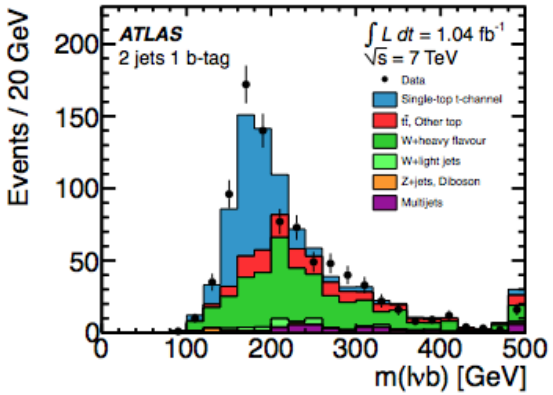
	Electron		Muon	
	2-jet	3-jet	2-jet	3-jet
single-top *t*-channel	447 ± 11	297 ± 7	492 ± 12	323 ± 8
tt, other top	785 ± 52	1700 ± 120	801 ± 53	1740 ± 130
W+light jets	350 ± 100	128 ± 56	510 ± 150	209 ± 91
W+heavy flavour jets	2600 ± 740	1100 ± 400	3130 ± 880	1270 ± 480
Z+jets, diboson	158 ± 63	96 ± 44	166 ± 61	80 ± 31
Multijet	710 ± 350	580 ± 290	440 ± 220	270 ± 140
Total expected	5050 ± 830	3900 ± 520	5530 ± 930	3900 ± 520
Data	5021	3592	5592	3915

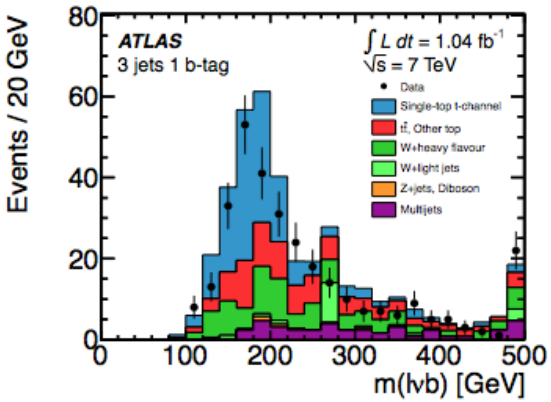
Cut-based

$\sigma = 92^{+29}_{-26}$ pb

	Cut-based 2-jet		Cut-based 3-jet	
	Lepton +	Lepton –	Lepton +	Lepton –
single-top *t*-channel	85 ± 29	39 ± 13	33.6 ± 7.0	14.6 ± 6.2
$t\bar{t}$, other top	14.0 ± 6.4	12.8 ± 4.2	10.5 ± 4.2	10.7 ± 7.9
W+light jets	3.3 ± 1.9	2.0 ± 1.2	0.8 ± 1.3	0.3 ± 0.3
W+heavy flavour jets	39 ± 11	27.1 ± 7.5	8.7 ± 6.0	3.4 ± 3.1
Z+jets, diboson	1.1 ± 0.8	1.0 ± 0.8	0.3 ± 0.2	0.2 ± 0.3
Multijet	0.2 ± 0.2	0.3 ± 0.3	1.5 ± 1.1	3.1 ± 2.0
Total expected	143 ± 31	83 ± 16	56 ± 10	32 ± 11
S/B	1.5	0.9	1.6	1.0
Data	193	101	53	39





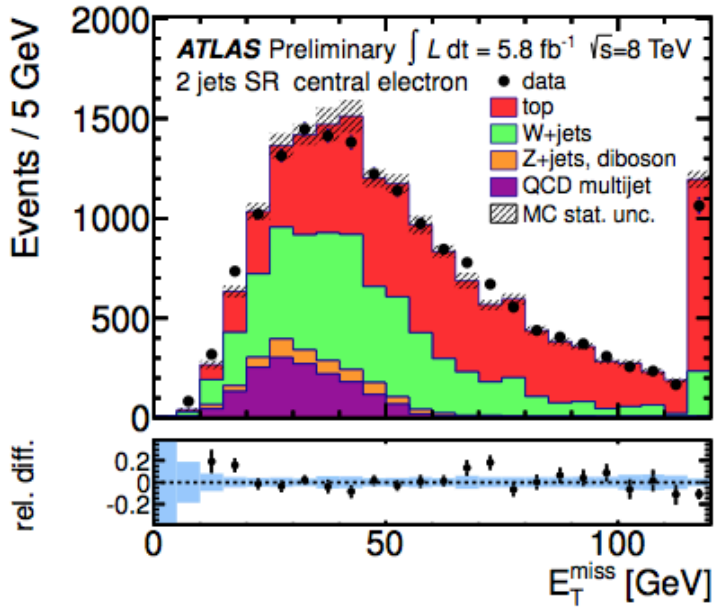


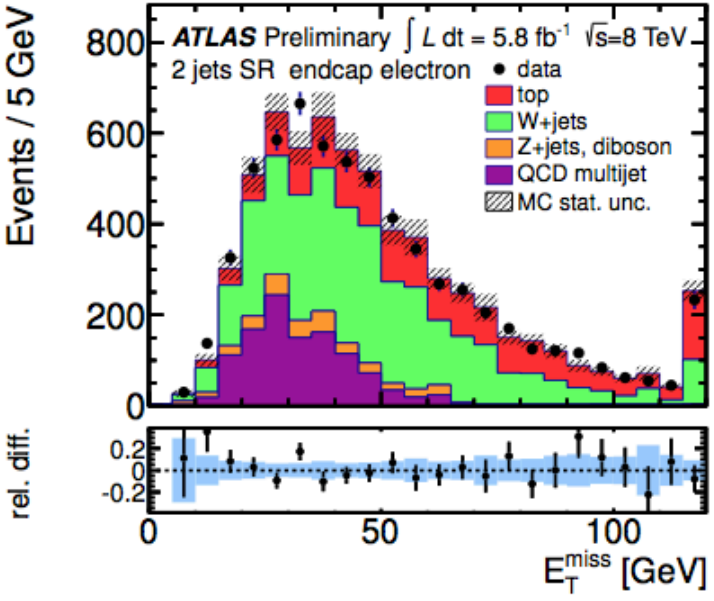
Systematics

Source	$\Delta\sigma_{obs}/\sigma_{obs}$ [%] NN	Cut-based
Data statistics	±5	±8
Detector modelling		
Jets	±6	+3/–4
b-tagging efficiency	±13	±12
Mistagging rate	±1	±1
Lepton	±2	±4
E_T^{miss}, calorimeter readout	±2	±2
Simulation		
PDF	±3	±4
Generator	±4	±7
Parton shower	±5	±11
ISR/FSR	±14	+19/–18
Forward jet modelling	+6/–4	+7/–5
MC statistics	±3	±4
Background normalisation		
Multijets	±4	±2
Other backgrounds	±1	±6
Luminosity	±4	±4
Total systematic uncertainties	+24/–23	+30/–27
Total uncertainty	±24	+31/–28

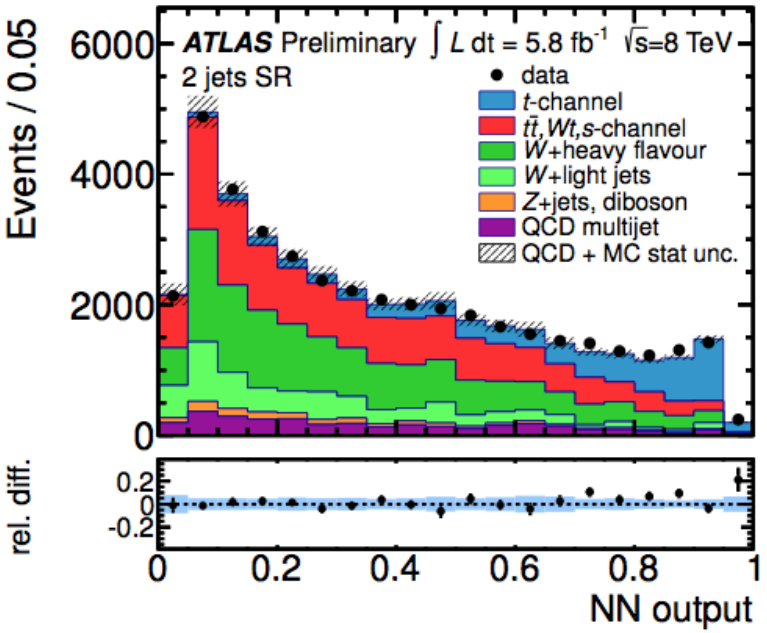
t-channel ATLAS 8TeV

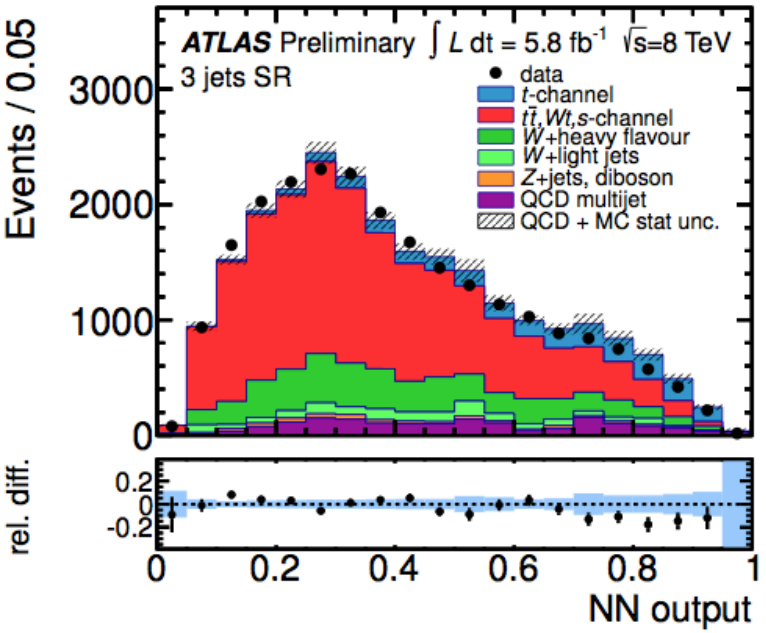
Control region electron





Neural network outputs





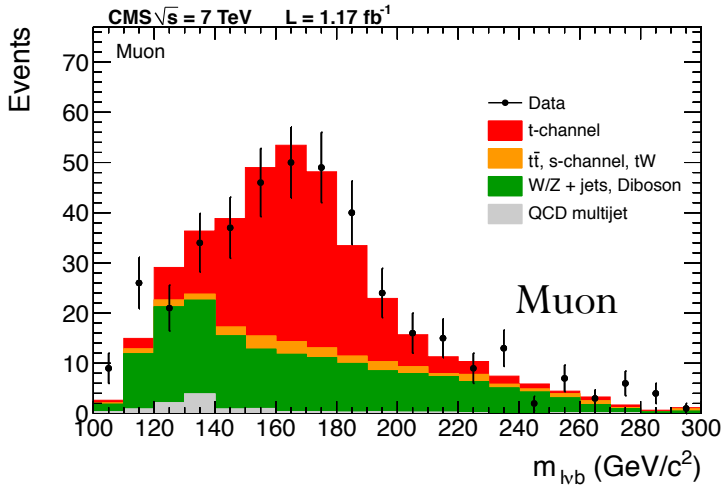
Fit result

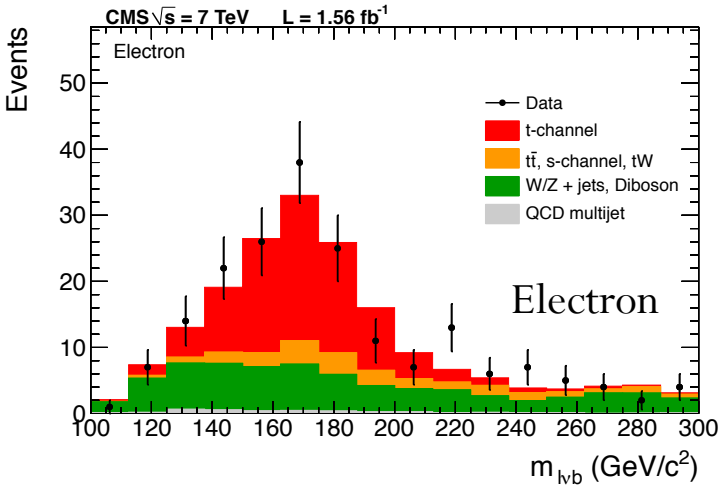
Process	$\hat{\beta}$
t channel	1.08 ± 0.03
W+ heavy flavour	1.04 ± 0.03
W+ light jets	0.93 ± 0.04
Z+ jets, diboson	0.94 ± 0.10
$t\bar{t}$, Wt, s channel	0.88 ± 0.01

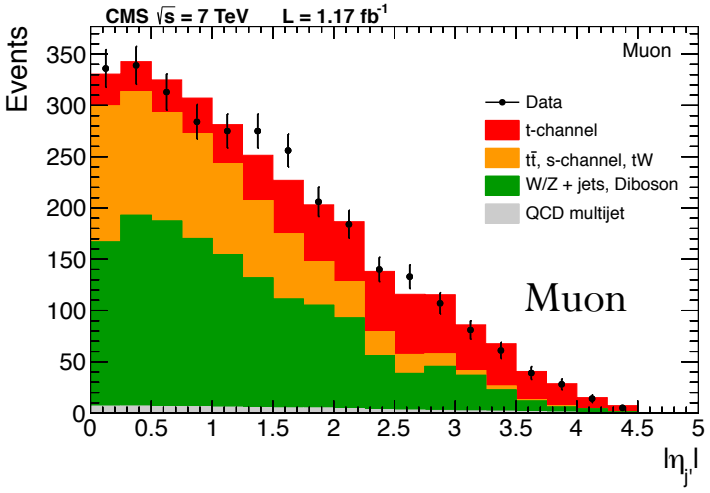
Systematic table

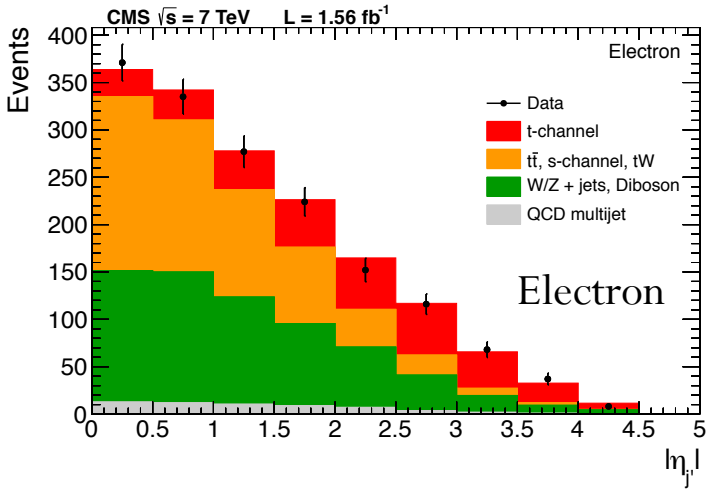
Source	$\Delta\sigma_t/\sigma_t$ [%]
Data statistics	± 2.4
MC statistics	± 2.9
Background normalisation	± 1.5
QCD multijet normalisation	± 3.1
Jet energy scale	± 7.7
Jet energy resolution	± 3.0
Jet reconstruction	± 0.5
Jet vertex fraction	± 1.6
Mistag modeling	± 0.3
c-tagging efficiency	± 0.4
b-tagging efficiency	± 8.5
$E_{\mathrm{T}}^{\mathrm{miss}}$	± 2.3
Lepton efficiencies	± 4.1
Lepton energy resolution	± 2.2
Lepton energy scale	± 2.1
PDF	± 2.8
W+jets shape variation	± 0.3
W+jets extrapolation	± 0.6
t-channel generator	± 7.1
$t\bar{t}$ generator	± 3.3
ISR / FSR	± 9.1
Parton shower	± 0.8
Luminosity	± 3.6
Total systematic	± 18.8
Total	± 19.0

t-channel CMS 7TeV









Event yield $|\eta_{j'}|$

Process	Muon yield	Electron yield
t-channel	617 ± 3	337 ± 2
tW channel	107 ± 1	70.2 ± 0.9
s-channel	25.6 ± 0.5	14.7 ± 0.4
$t\bar{t}$	661 ± 6	484 ± 5
W + light partons	92 ± 7	38 ± 4
$Wc(\bar{c})$	432 ± 14	201 ± 9
$Wb(\bar{b})$	504 ± 14	236 ± 10
Z + jets	87 ± 3	13 ± 1
Dibosons	23.3 ± 0.4	10.7 ± 0.3
QCD	77 ± 3	62 ± 3
Total	2626 ± 22	1468 ± 16
Data	3076	1588

Systematic table

		Uncertainty source	NN	BDT	$\lvert\eta_{j'}\rvert$
Marginalised (NN, BDT)	Experimental uncert.	Statistical	−6.1/+5.5%	−4.7/+5.4%	±8.5%
		Limited MC data	−1.7/+2.3%	±3.1%	±0.9%
		Jet energy scale	−0.3/+1.9%	±0.6%	−3.9/+4.1%
		Jet energy resolution	−0.3/+0.6%	±0.1%	−0.7/+1.2%
		b tagging	−2.7/+3.1%	±1.6%	±3.1%
		Muon trigger + reco.	−2.2/+2.3%	±1.9%	−1.5/+1.7%
		Electron trigger + reco.	−0.6/+0.7%	±1.2%	−0.8/+0.9%
		Hadronic trigger	−1.3/+1.2%	±1.5%	±3.0%
		Pileup	−1.0/+0.9%	±0.4%	−0.3/+0.2%
		$\not{E}_T$ modelling	−0.0/+0.2%	±0.2%	±0.5%
	Backg. rates	W+jets	−2.0/+3.0%	−3.5/+2.5%	±5.9%
		light flavor (u, d, s, g)	−0.2/+0.3%	±0.4%	n/a
		heavy flavor (b, c)	−1.9/+2.9%	−3.5/+2.5%	n/a
		$t\bar{t}$	−0.9/+0.8%	±1.0%	±3.3%
		QCD, muon	±0.8%	±1.7%	±0.9%
		QCD, electron	±0.4%	±0.8%	−0.4/+0.3%
		s-, *t*W ch., dibosons, Z+jets	±0.3%	±0.6%	±0.5%
	Total marginalised uncertainty		−7.7/+7.9%	−7.7/+7.8%	n/a
Not marginalised		Luminosity		±2.2%	
	Theor. uncert.	Scale, $t\bar{t}$	−3.3/+1.0%	±0.9%	−4.0/+2.1%
		Scale, W+jets	−2.8/+0.3%	−0.0/+3.4%	n/a
		Scale, *t*-, *s*-, *t*W channels	−0.4/+1.0%	±0.2%	−2.2/+2.3%
		Matching, $t\bar{t}$	±1.3%	±0.4%	±0.4%
		t-channel generator	±4.2%	±4.6%	±2.5%
		PDF	±1.3%	±1.3%	±2.5%
		Total theor. uncertainty	−6.3/+4.8%	−4.9/+5.9%	−5.6/+4.9%
Syst. + theor. + luminosity uncert.			−8.1/+7.8%	−8.1/+8.4%	±10.8%
Total (stat. + syst. + theor. + lum.)			−10.1/+9.5%	−9.4/+10.0%	±13.8%

t-channel CMS 8TeV

Yields

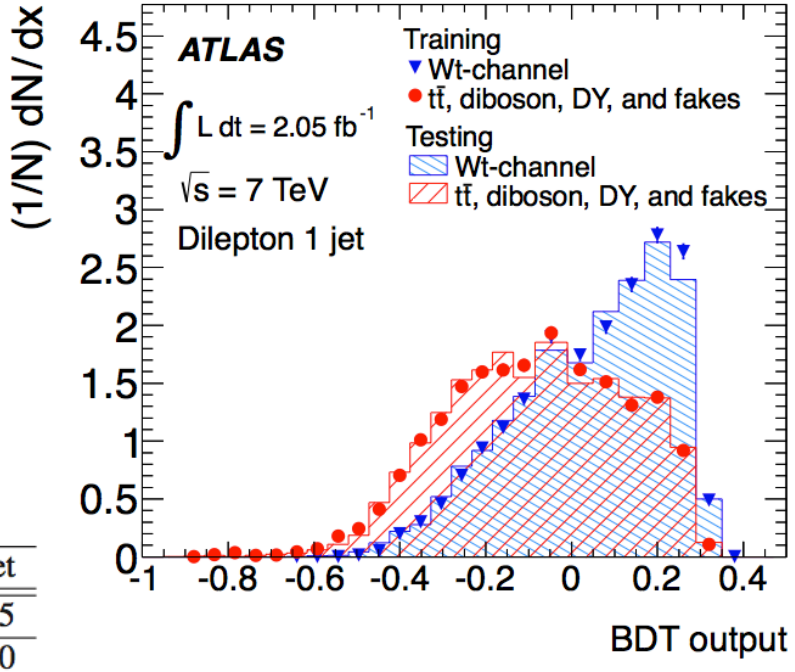
Process	SR	SB
$t\bar{t}$	2196 ± 17	1195 ± 13
W+jets	658 ± 75	867 ± 85
Z+jets	32 ± 16	41 ± 19
QCD	57 ± 24	33 ± 16
Diboson	10 ± 1	16 ± 1
tW-channel	195 ± 4	119 ± 3
s-channel	49 ± 2	19 ± 1
t-channel	915 ± 8	128 ± 3
Total MC	4112 ± 79	2418 ± 89
Data	4403	2618

Systematic table

Uncertainty source	in pb	relative
Statistical	± 5.7	± 7.2 %
W+jets and $t\bar{t}$modeling	± 3.6	$\pm$ 4.5 %
JES	$-$ 6.2 / + 4.7	$-$ 7.8 / + 5.8 %
JER	$-$ 0.8 / + 0.3	$-$ 1.0 / + 0.4 %
Unclustered $\not{E}_T$	$-$ 0.8 / + 0.7	$-$ 1.0 / + 0.9 %
Pileup	$-$ 0.5 / + 0.3	$-$ 0.6 / + 0.4 %
Muon trigger + reconstruction	$-$ 4.1 / + 4.0	$-$ 5.1 / + 5.1 %
Q^2	± 2.5	± 3.1 %
$t\bar{t}$, rate	$-$ 1.5 / + 1.7	$-$ 1.9 / + 2.1 %
QCD, rate	± 0.7	± 0.9 %
$t-$channel generator	± 4.4	± 5.5 %
Other backgrounds, rate	± 0.5	± 0.6 %
b-tagging	± 3.7	± 4.6 %
PDF	$\pm$ 3.7	± 4.6 %
Simulation statistics	± 1.8	± 2.2 %
Total systematics	± 11.0	± 13.7 %
Luminosity uncertainty	± 4.0	± 5.0 %
Total	± 13.0	± 16.3%

Wt-channel ATLAS 7TeV

BDT normalized output



Event yields

	1-jet	2-jet	≥ 3-jet
Wt	147 ± 13	60 ± 9	17 ± 5
tt	610 ± 110	1160 ± 140	740 ± 130
Diboson	130 ± 17	47 ± 5	17 ± 4
$Z \to ee$	20 ± 2	11 ± 2	5 ± 2
$Z \to \mu\mu$	29 ± 3	28 ± 3	12 ± 3
$Z \to \tau\tau$	9 ± 6	4 ± 3	2 ± 1
Fake dileptons	11 ± 11	5 ± 5	negl.
Total bkgd.	810 ± 120	1260 ± 140	780 ± 130
Total expected	960 ± 120	1320 ± 140	790 ± 130
Data observed	934	1300	825

Systematic table

Source	$\Delta\sigma_{Wt}/\sigma_{Wt}$ [%] observed	expected
Data statistics	17	17
MC statistics	< 5	< 5
Lepton energy scale/res.	< 5	< 5
Lepton efficiencies	7	6
Jet energy scale	16	14
Jet energy resolution	< 5	< 5
Jet reconstruction eff.	< 5	< 5
Generator	10	12
Parton shower	15	14
ISR/FSR	5	6
PDF	< 5	6
Pile-up	10	7
tt cross-section	6	6
Diboson cross-section	6	5
Drell-Yan estimate	< 5	< 5
Fake dileptons estimate	< 5	< 5
$Z \to \tau\tau$ estimate	< 5	< 5
Luminosity	7	7
All systematics	29	29
Total	34	33

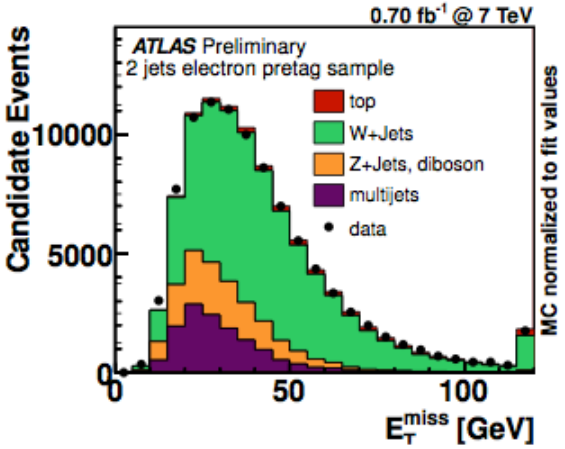
Wt-channel CMS 7TeV

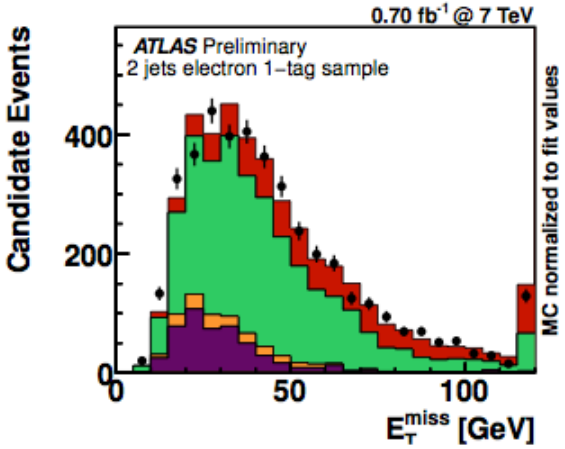
Event yields

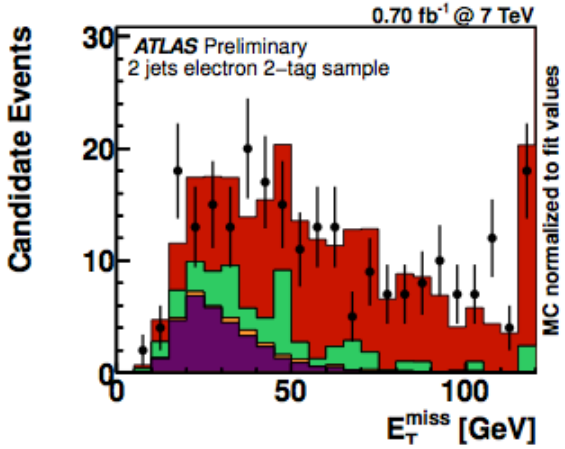
	1j1t	2j1t	2j2t
tW	336±5±16	180±3±16	45±1±6
$t\bar{t}$	1263±19±138	2775±28±205	1488±21±222
$Z/\gamma^{\star}$ +jets	128±12±28	113±10±22	8.5±1.8±1.8
Other	19±3	8.8±0.7±0.2	4±3
Total estimated	1746±23±141	3077±30±207	1546±21±222
Total data	1699	2878	1507

s-channel ATLAS 7TeV

Control plots







Event yields and systematic table

	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

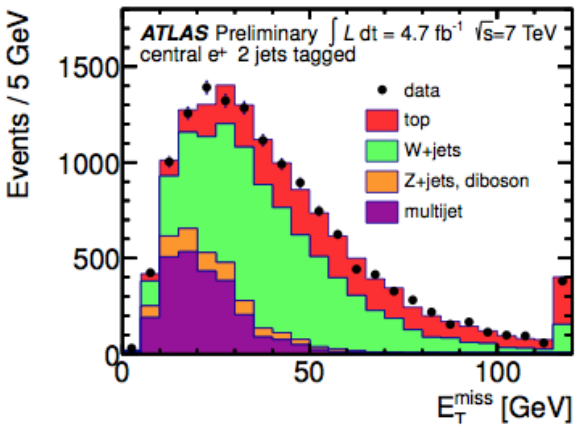
Source	$\Delta\sigma/\sigma$ [%] cut-based
Data statistics	±100
MC statistics	±70
b-tagging	-30/+20
Jet and lepton modeling	-20/+10
MC generator modeling	-60/+20
Multijets normalization	±40
Others	-10/+30
Luminosity	±50
All systematics	-110/+90
Total uncertainty	-160/+150

Cross section ration ATLAS 7TeV

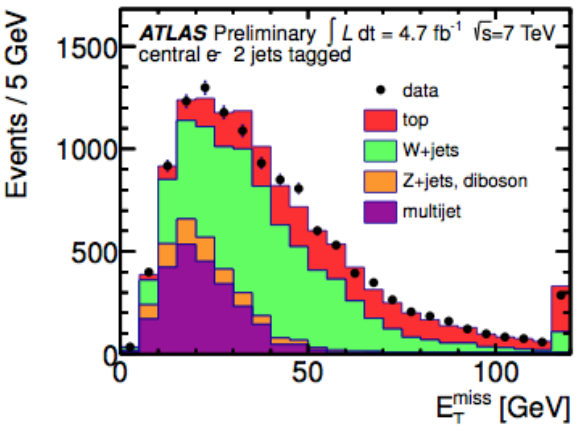
R_t values

PDF set	R_t	stat. unc.	scale unc.	PDF unc.	LHgrid name
CT10	1.97	±1.0%	0.8 % / -2.7 %	3.3 % / -4.0 %	CT10f4
CT10 (+ D0 W asym.)	1.86	±0.9%	3.5 % / 1.0 %	3.5 % / -4.2 %	CT10wf4
ABKM09	2.07	±0.8%	1.9 % / 1.9 %	0.8 % / -0.8 %	abkm09_4_nlo
MSTW2008	1.93	±0.9%	-1.2 % / -2.3 %	3.2 % / -2.6 %	MSTW2008nlo90cl_nf4
NNPDF 2.1	1.92	±1.5%	2.3 % / 3.2 %	1.8 % / -1.8 %	NNPDF21_FFN_NF4_100
GJR08	1.99	±0.9%	-0.5 % / -0.7 %	3.0 % / -2.8 %	GJR08FFnloE

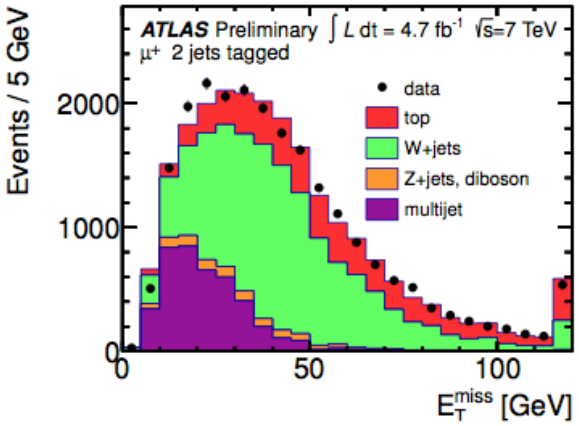
Control plots

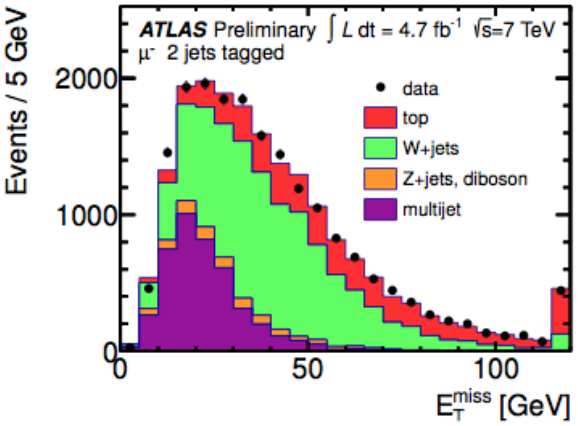


(a)



(b)





Event yields

	2-jets		3-jets	
	ℓ^+	ℓ^-	ℓ^+	ℓ^-
t-channel top	2420 ± 210	4 ± 1	1130 ± 100	2 ± 1
t-channel antitop	2 ± 1	1350 ± 120	1 ± 1	600 ± 50
s-channel top	204 ± 18	$0 \pm {}^{+1}_{-0}$	75 ± 7	$0 \pm {}^{+1}_{-0}$
s-channel antitop	$0 \pm {}^{+1}_{-0}$	92 ± 8	$0 \pm {}^{+1}_{-0}$	32 ± 3
Wt	650 ± 60	650 ± 60	630 ± 50	640 ± 60
$t\bar{t}$	3770 ± 330	3720 ± 320	6290 ± 550	6260 ± 540
W+light	3260 ± 980	1900 ± 570	920 ± 280	690 ± 210
W+heavy flavour	10900 ± 5400	8900 ± 4500	3800 ± 1900	2900 ± 1500
Z+jets, Diboson	760 ± 450	660 ± 400	330 ± 200	300 ± 180
multijet	1710 ± 850	1720 ± 860	840 ± 420	780 ± 390
Total Expectation	23600 ± 5600	19000 ± 4600	14000 ± 2100	12200 ± 1600
Data	25868	20841	14744	12713

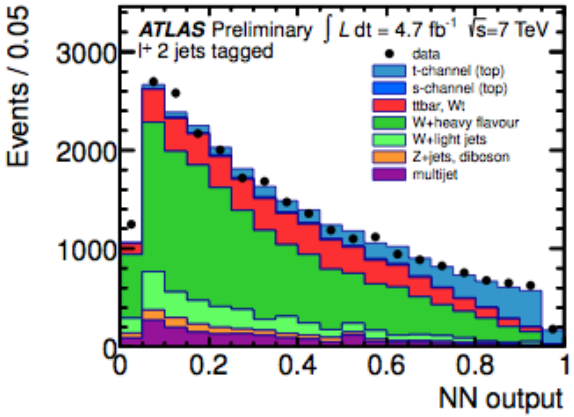
Fit result

Process	$\hat{\beta}$
t channel top	1.27 ± 0.04
t channel antitop	1.30 ± 0.06
W+ heavy flavour	1.21 ± 0.03
W+ light jets	0.74 ± 0.11
Z+ jets, diboson	1.05 ± 0.10
$t\bar{t}$, Wt	1.00 ± 0.02
s channel top	0.98 ± 0.10
s channel antitop	1.00 ± 0.10

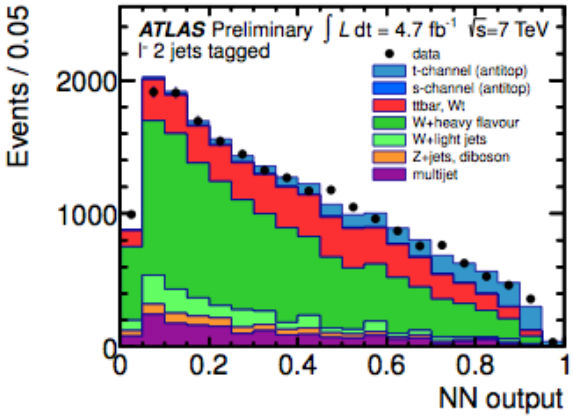
$\sigma_t(t) = 53.2 \pm 1.7\,(\text{stat.}) \pm 10.6\,(\text{syst.})\,\text{pb} = 53.2 \pm 10.8\,\text{pb}$

$\sigma_t(\bar{t}) = 29.5 \pm 1.5\,(\text{stat.}) \pm 7.3\,(\text{syst.})\,\text{pb} = 29.5^{+7.4}_{-7.5}\,\text{pb}.$

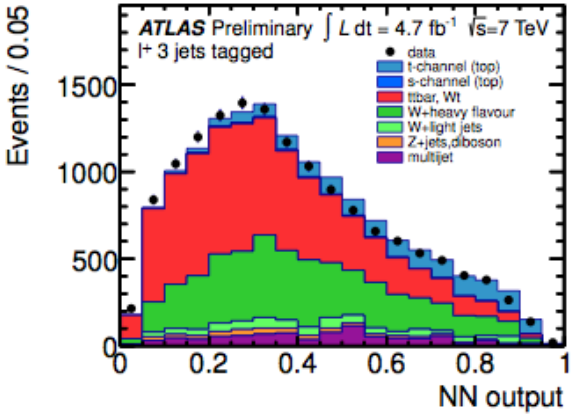
NN outputs

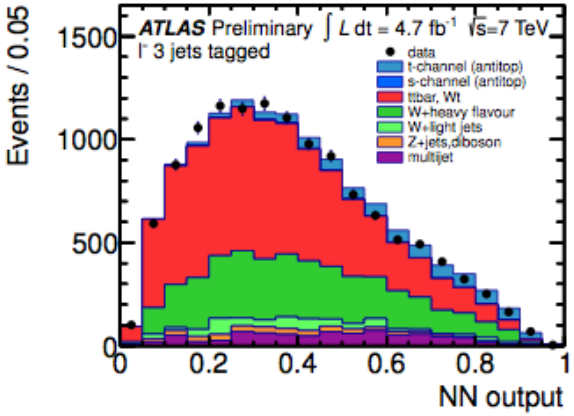


(a)



(b)





Systematic table

Source	$\Delta\sigma_t/\sigma_t(t)$ [%]	$\Delta\sigma_t/\sigma_t(\bar{t})$ [%]	$\Delta R_t/R_t$ [%]
Data statistics	±3.2	±5.0	±5.5
MC statistics	±2.4	±3.7	±3.7
Multijet normalisation	+1.1 / -2.0	+3.1 / -4.2	+3.9 / -3.7
Other background normalisation	±3.4	±1.3	±4.5
Jet energy scale	±16.4	±19.5	+3.7 / -3.6
Jet energy resolution	±3.4	±4.3	±0.8
Jet reconstruction efficiency	+0.7 / -0.4	±0.3	+0.8 / -0.5
b-tagging efficiency scale-factor	±5.9	±8.5	±2.5
Mistag efficiency scale-factor	±0.8	±2.0	±2.7
$b/\bar{b}$ acceptance	±1.0	±1.0	±0.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ modeling	+0.6 / -0.9	+0.9 / -1.3	+0.8 / -0.7
Lepton efficiencies	±2.9	±2.9	±0.3
Lepton energy resolution	+0.5 / -0.8	+1.1 / -1.4	+1.0 / -1.1
Electron energy scale	+0.3 / -0.5	+0.7 / -0.8	±0.6
PDF	±3.3	±4.5	+1.1 / -1.2
W+jets shape variation	+0.6 / -0.5	±0.5	±0.7
Top MC generator	±7.1	±7.1	±0.7
ISR / FSR	±0.7	±3.5	±4.2
Luminosity	±3.9	±3.9	±0.4
Total Systematic	±20.0	+24.7 /-24.9	+11.5 /-11.1
Total	±20.2	+25.2 /-25.4	+12.8 /-12.4