Single-top quark studies in ATLAS

Dominic Hirschbühl

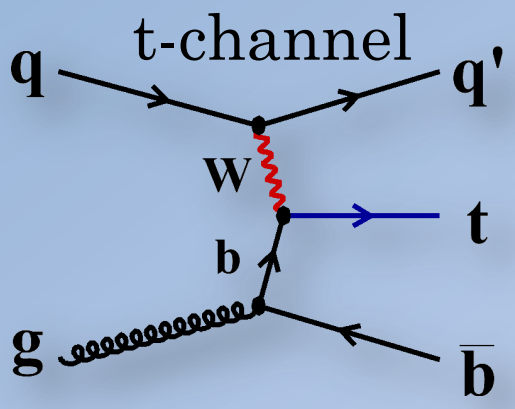
PHYSICS AT THE TERA SCALE Helmholtz Alliance

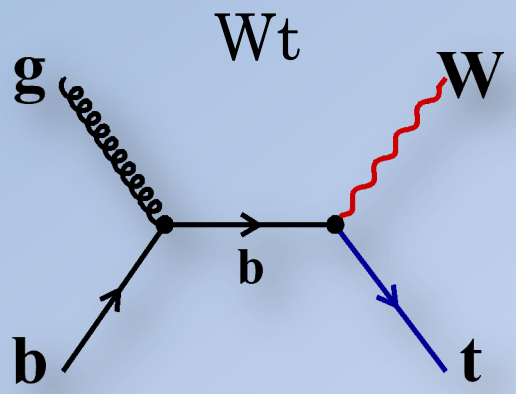
BERGISCHE UNIVERSITÄT WUPPERTAL

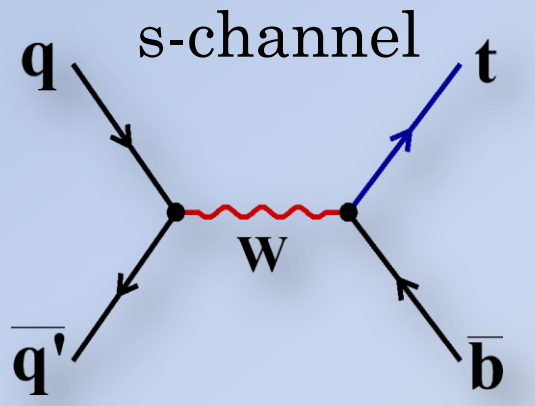
On behalf of the ATLAS collaboration

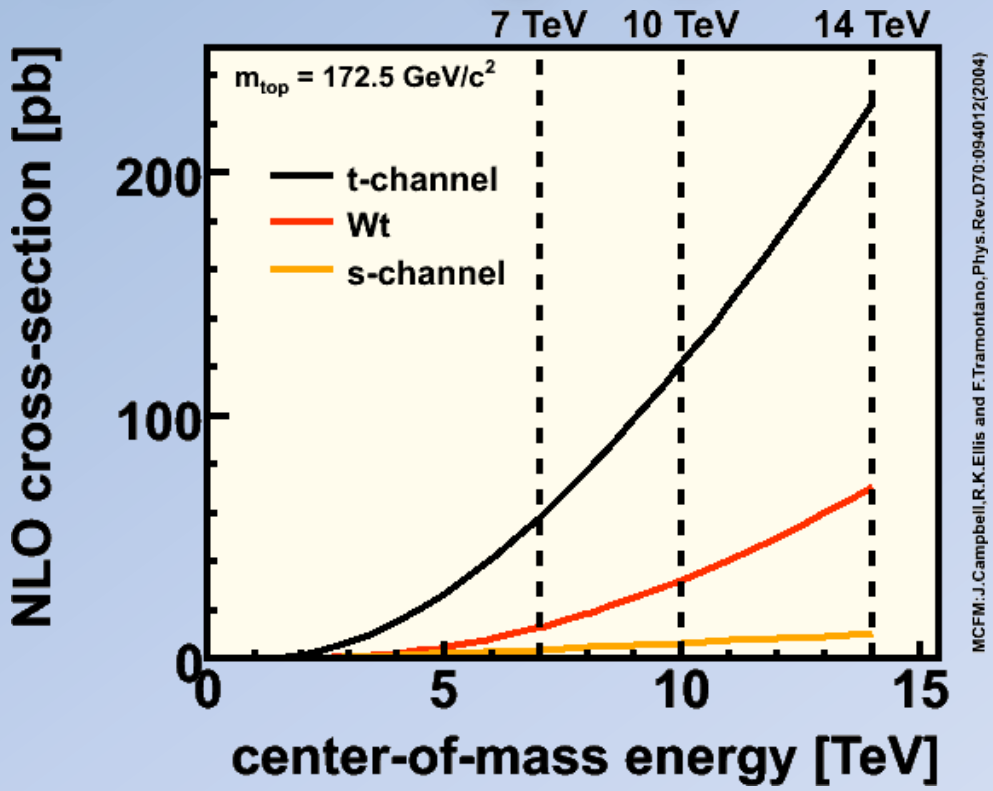
EPSHEP 2011 – Grenoble
21.07.2011

Production of single top quark events







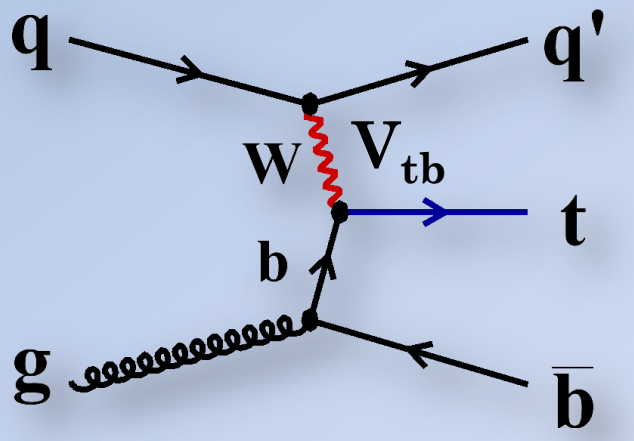


Cross sections @ 7 TeV	
t-channel	$64.6\ ^{+3.2}_{-2.6}$ pb
Wt	15.7 ± 1.3 pb
s channel	4.6 ± 0.3 pb

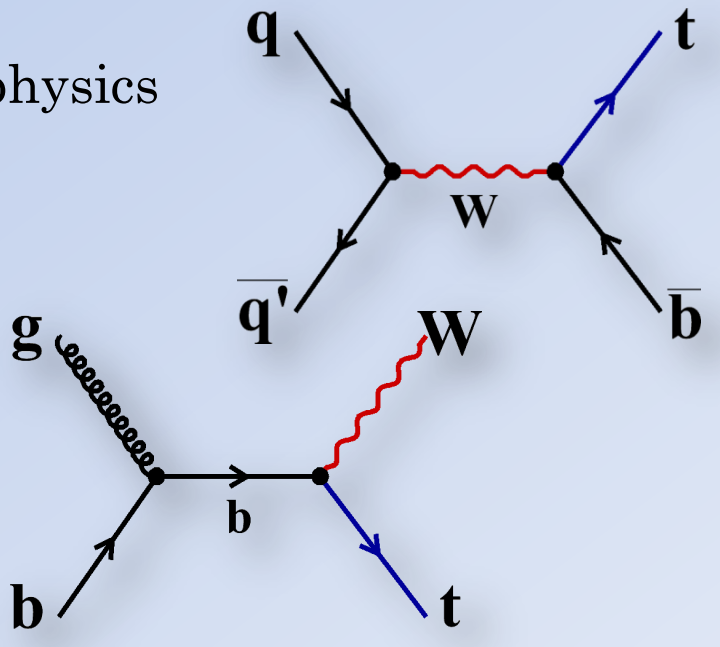
Kidonakis, approx. NNLO

Motivation

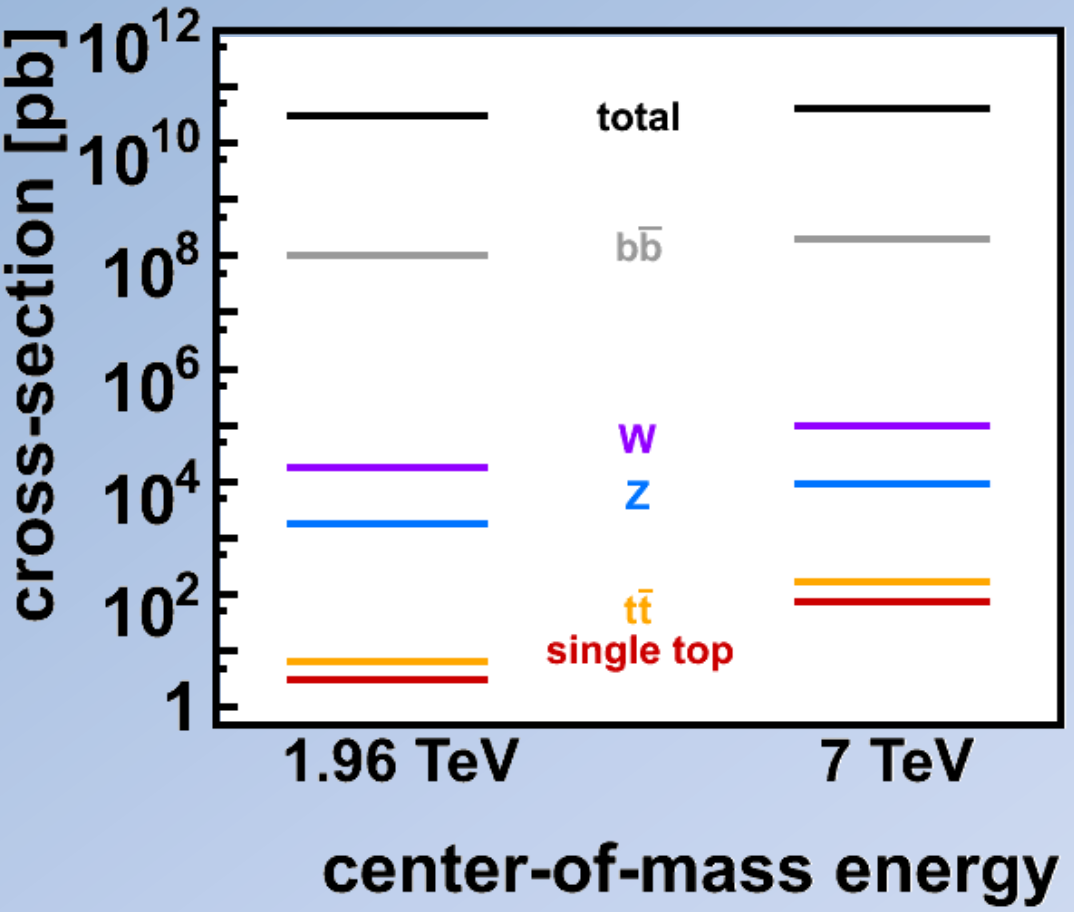
- Test of standard model predictions
  - Cross section $\propto |V_{tb}|^2$
  - Test of the unitarity of the CKM Matrix
    - Hints for existance of a 4th generation
  - Test of the b-quark structure function: DGLAP evolution



- Probe and preparation for searches for new physics
  - charged heavy Bosons W‘, H+ etc.
- Wt process not accessible at the Tevatron
- Measure all three processes independently
  - Access to anomalous couplings



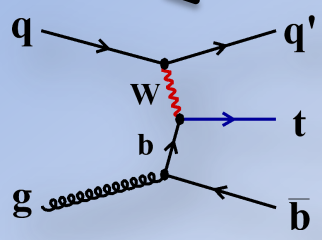
Cross sections @ Tevatron and LHC



- Small S/B compared to tt analyses, because of low number of jets in final state.
- Need to control backgrounds very well.
  - Precise estimation of the rates
  - Good model

Overview

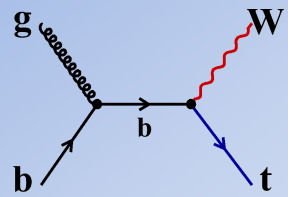
Common object definitions



Lepton+jets channel

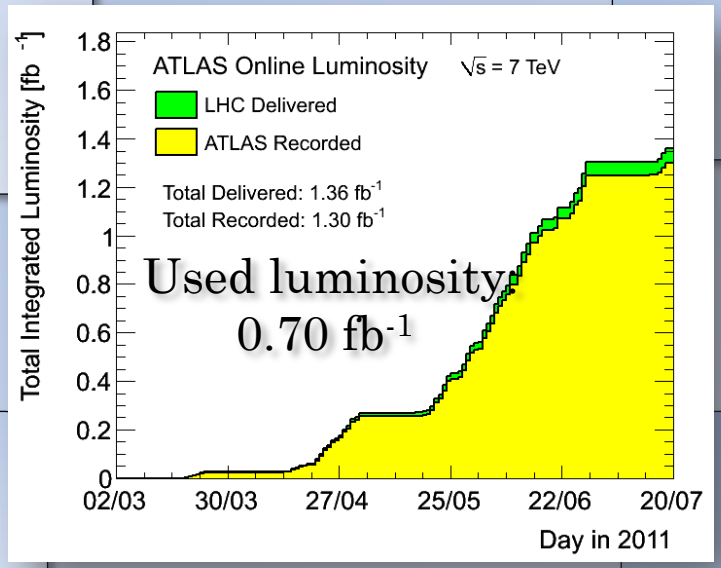
Cut-based

Neural network



Di-lepton channel

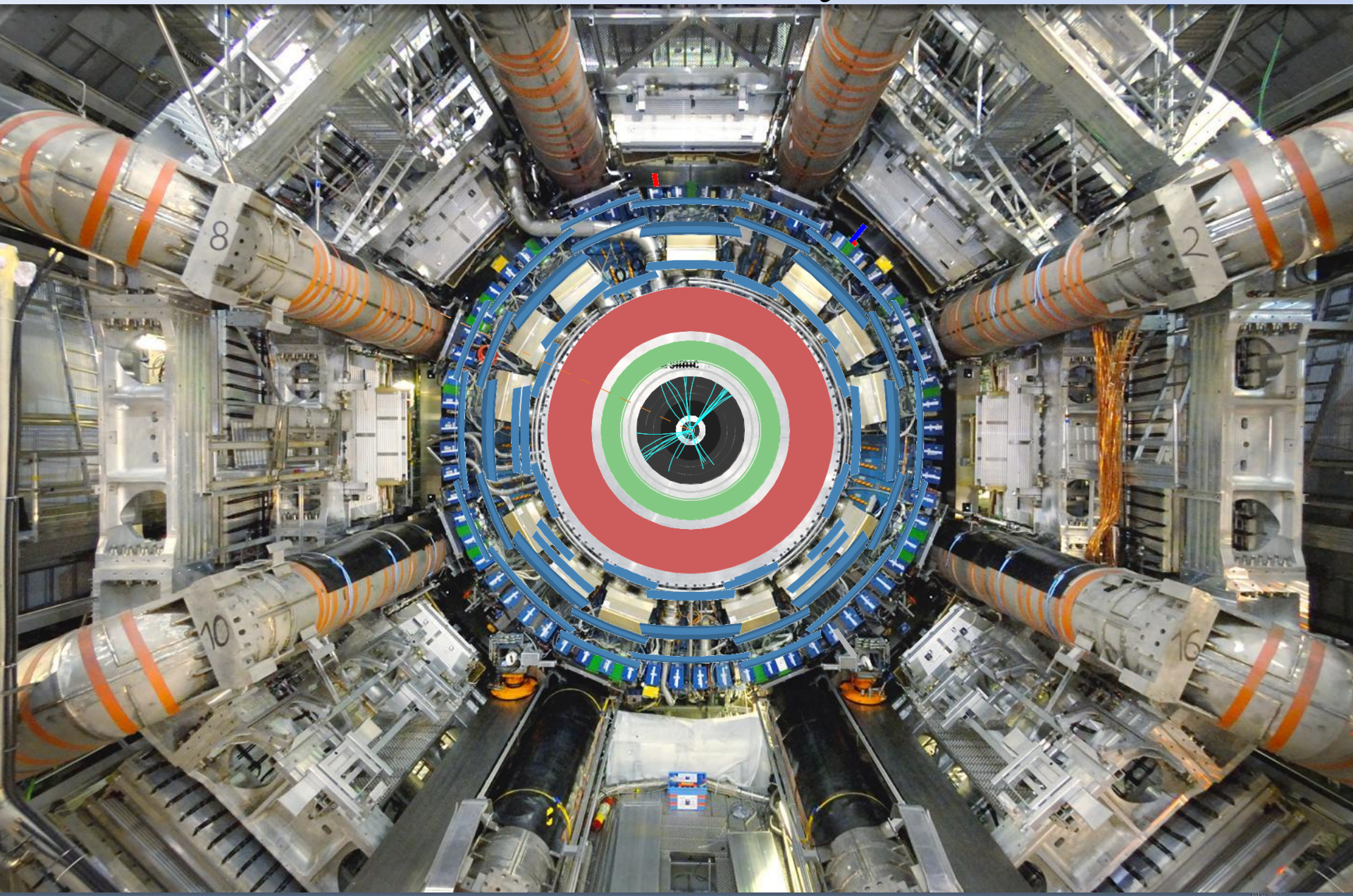
Cut based



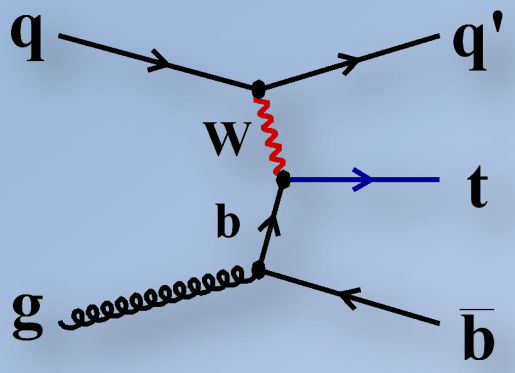
Cross section measurement

Cross section measurement Upper limit

t-channel analyses



t-channel analyses



Biggest cross section of single top processes
Improved S/B ratio compared to Tevatron

Paper with 36 pb^{-1} (3.5 σ)
TOP-10-008

CONF note with 156 pb-1 (6.2 σ)
ATLAS-CONF-2011-088

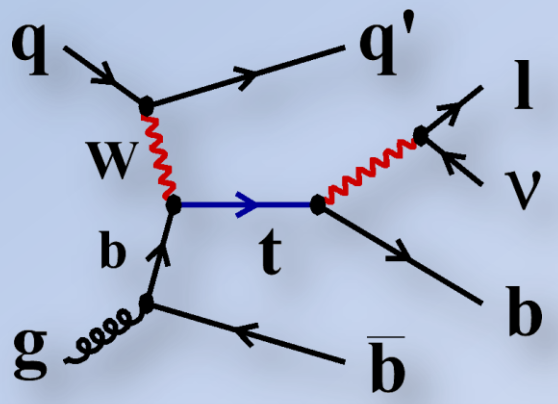
Event signature:

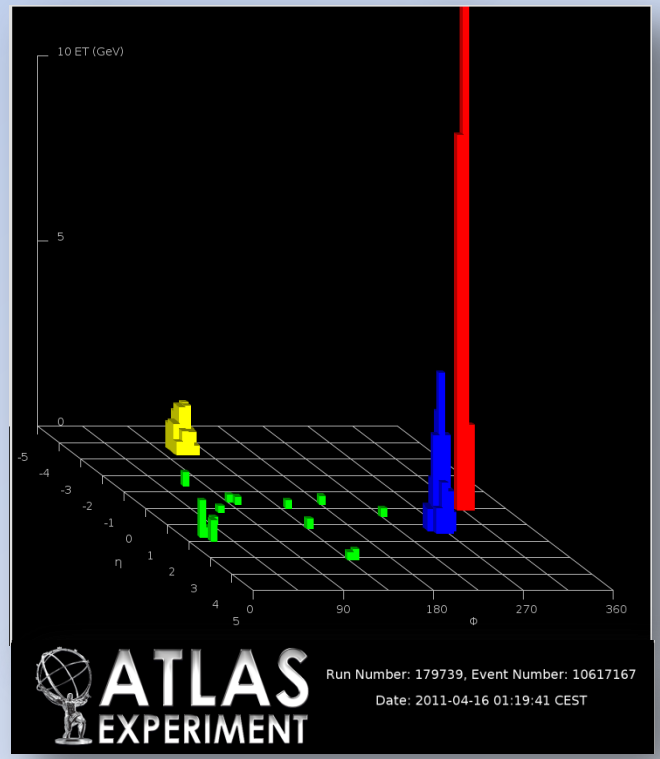
- Real W boson & one high-p_T central b-jet (from top quark)
  - Leptonic decay of W :
    1 electron or muon + missing transverse energy (E_T^{miss})
- 1 or 2 extra forward jet (2^{nd} b-jet, if visible, is also forward)

ATLAS-CONF-2011-101

Event selection

- Lepton selection (electron / muon):
  - $p_T > 25$ GeV
  - $|\eta| < 2.5$
  - Relative Isolation
- Jets
  - Anti-k_T algorithm R=0.4
  - $p_T > 25$ GeV
  - $|\eta| < 4.5$
  - One secondary vertex tag
  - Number of jets
    - NN analysis : 2
    - Cut based: 2 & 3
- Missing transverse energy
  - $E_T^{miss} > 25$ GeV
- QCD multijet veto
  - $M_T(W) > 60$ GeV – E_T^{miss}





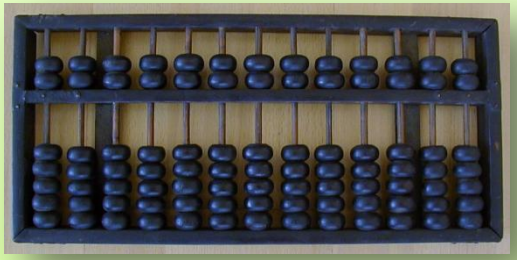
Background estimation - strategy

W+jets (only cut based)

$$N_{W+jets}^{pretag} = N_{data}^{pretag} - N_{qcd}^{pretag} - N_{MC}^{pretag}$$

$$N_{\Phi,n}^{tag} = N^{pretag} F_{\Phi,n}^{pretag} P_{\Phi,n}^{tag} .$$

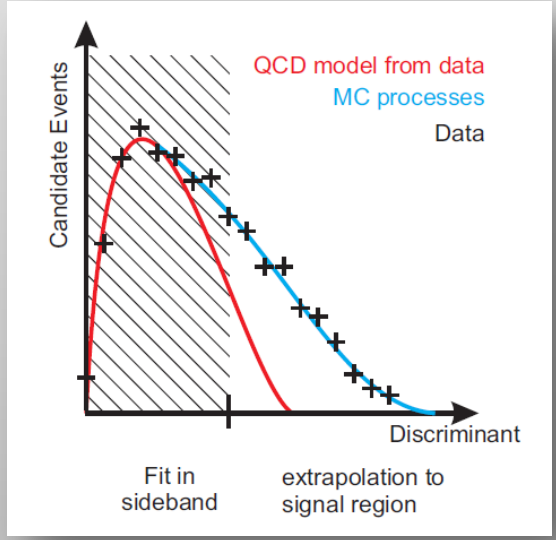
$$N_{data-bkg,2}^{tag} = N_{data-bkg,2}^{pretag} \cdot (F_{bb,2}^{pretag} \cdot P_{bb,2}^{tag} + k_{cctobb}^{pretag} \cdot F_{bb,2}^{pretag} \cdot P_{cc,2}^{tag} + F_{c,2}^{pretag} \cdot P_{c,2}^{tag} + F_{l,2}^{pretag} \cdot P_{l,2}^{tag}) = N_{data-bkg,2}^{pretag} \cdot (k_{bb1to2}^{pretag} \cdot F_{bb,1}^{pretag} \cdot P_{bb,2}^{tag} + k_{cctobb}^{pretag} \cdot k_{bb1to2}^{pretag} \cdot F_{bb,1}^{pretag} \cdot P_{cc,2}^{tag} + k_{c1to2}^{pretag} \cdot F_{c,1}^{pretag} \cdot P_{c,2}^{tag} + k_{l1to2}^{pretag} \cdot F_{l,1}^{pretag} \cdot P_{l,2}^{tag}).$$



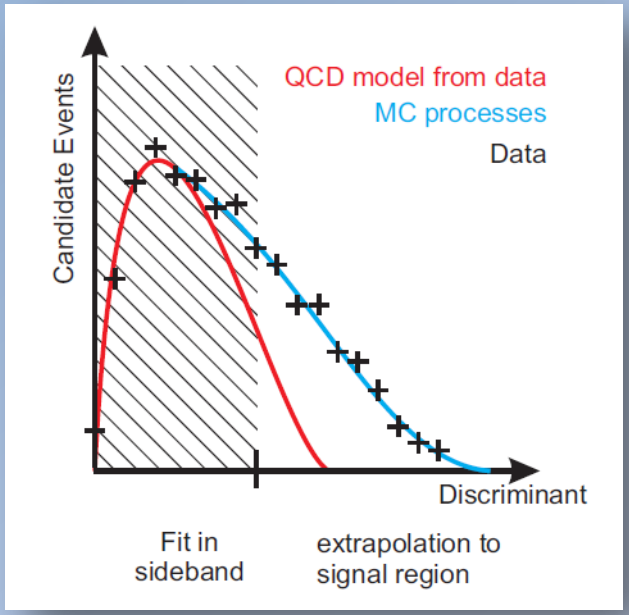
Top processes, Diboson, Z+jets (W+jets – NN)

$$N = \sigma \cdot \varepsilon \cdot \mathcal{L}$$

QCD background E_T^{Miss} fit

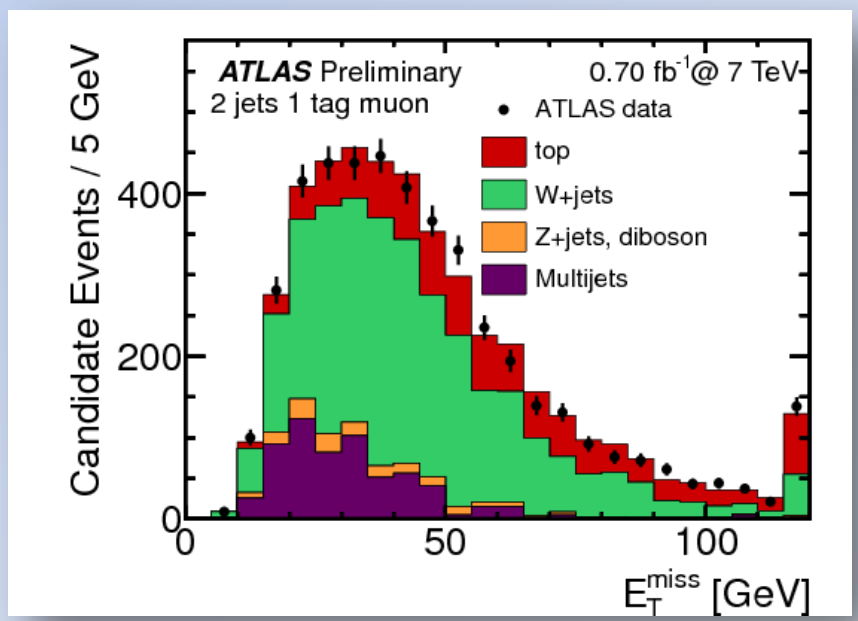


QCD estimate



- Backgrounds with no real W boson
- Huge cross section combined with small fake rate gives sizeable contribution

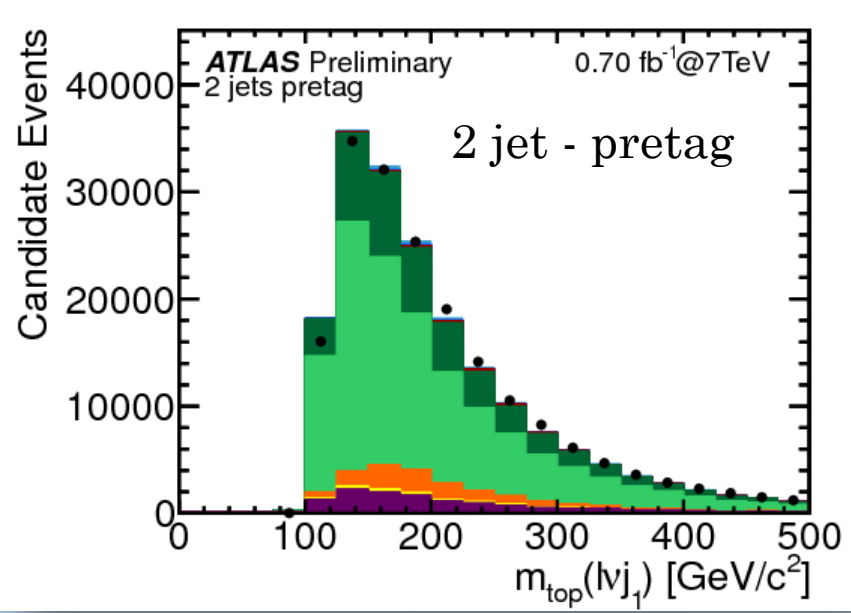
Model :
- Jet trigger data
- Choose jet with high em fraction and more than three tracks

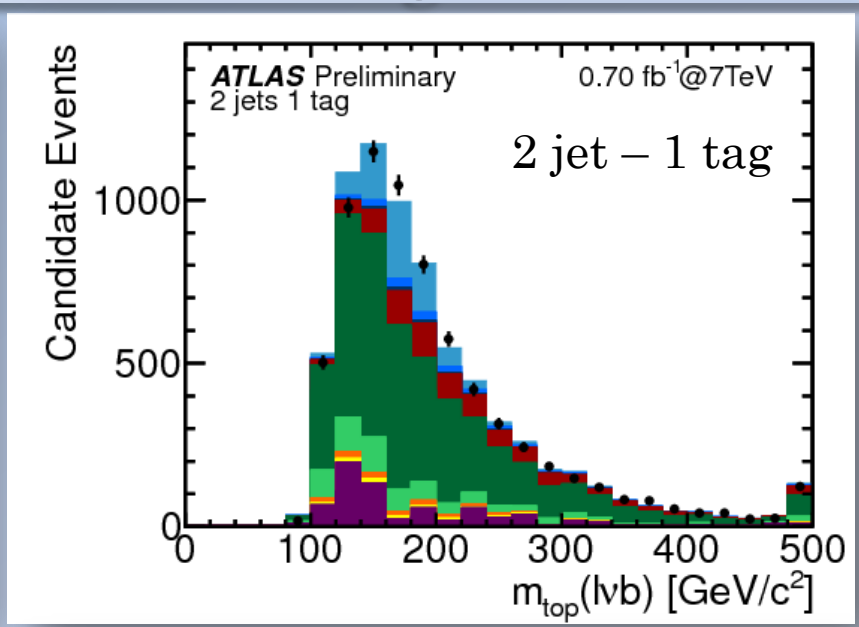


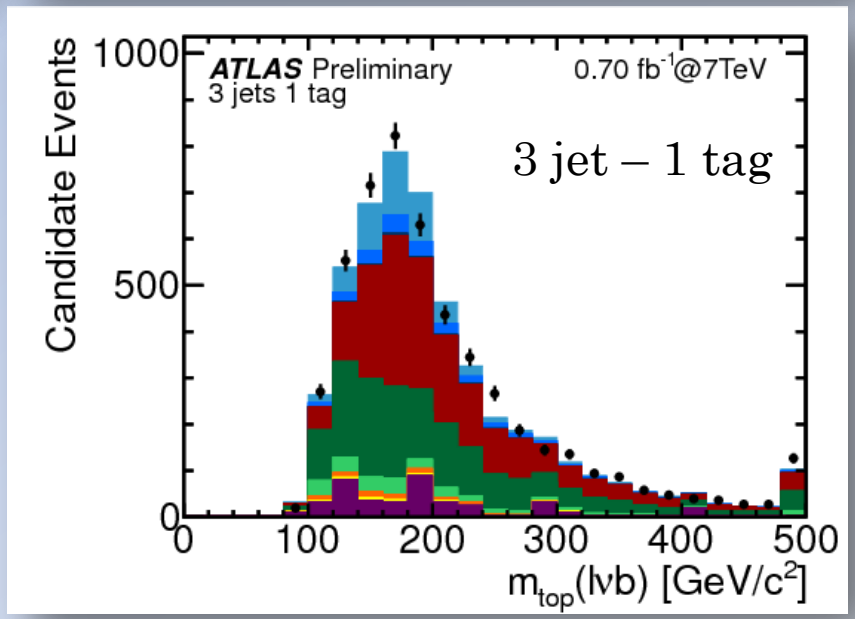
Expected event yield for $L_{int} = 0.70\ fb^{-1}$

	Electron		Muon	
	2-jet	3-jet	2-jet	3-jet
single-top t-channel	267 ± 27	187 ± 19	288 ± 29	198 ± 20
single-top Wt	83 ± 8	112 ± 11	81 ± 8	110 ± 11
single-top s-channel	24 ± 2	11 ± 1	27 ± 2	12 ± 1
top pairs	372 ± 31	912 ± 75	388 ± 32	935 ± 77
W+light jets	278 ± 83	112 ± 55	365 ± 109	148 ± 73
Wc+jets	990 ± 230	330 ± 120	1190 ± 280	340 ± 130
$Wb\bar{b}$+jets	480 ± 330	270 ± 190	560 ± 380	301 ± 220
$Wc\bar{c}$+jets	270 ± 190	150 ± 110	340 ± 240	180 ± 130
Diboson	35 ± 2	16 ± 1	44 ± 2	18 ± 1
Z+jets	68 ± 41	51 ± 31	63 ± 38	39 ± 23
Multijets	310 ± 160	310 ± 150	380 ± 190	103 ± 51
TOTAL Expected	3180 ± 480	2450 ± 310	3730 ± 580	2380 ± 310
DATA	3291	2462	3662	2596

Background modeling





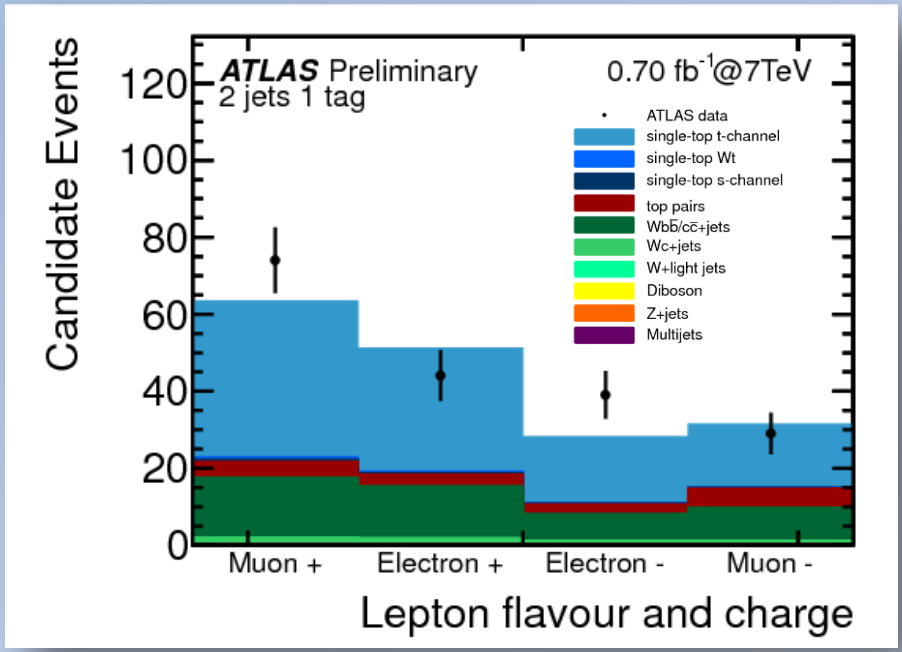


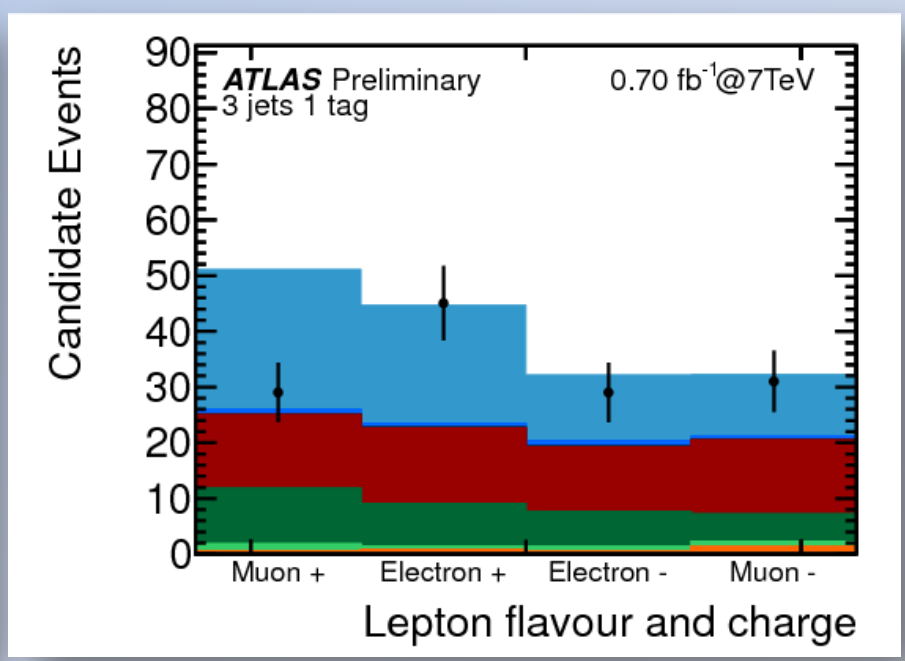
Good agreement between data and background model/ prediction

Cut based analysis

Cut	Value
H_T	> 210 GeV
$M_{l\nu b}$	> 150 GeV & < 190 GeV
$\lvert\eta(\text{light jet})\rvert$	> 2.0
$\lvert\Delta\eta(j1,j1)\rvert$	> 1

Cuts are optimized including systematics





Cut based analysis - Result

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

Statistical analysis:
Profile likelihood using 4 bins:

- electron / muon
- + / - charge

2 channels :

- 2 and 3 jets

Observed cross section:

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

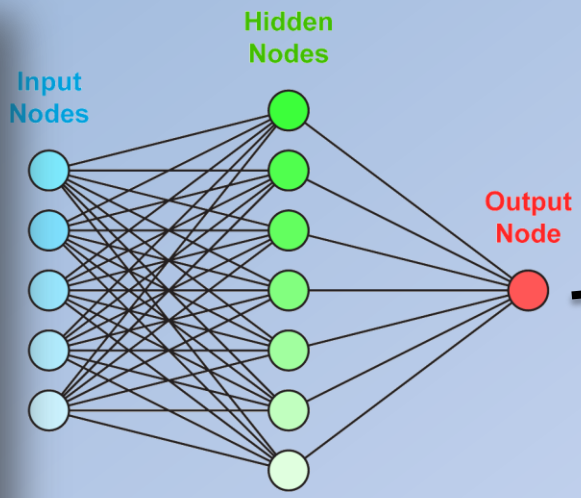
Observed signifance 7.6 σ

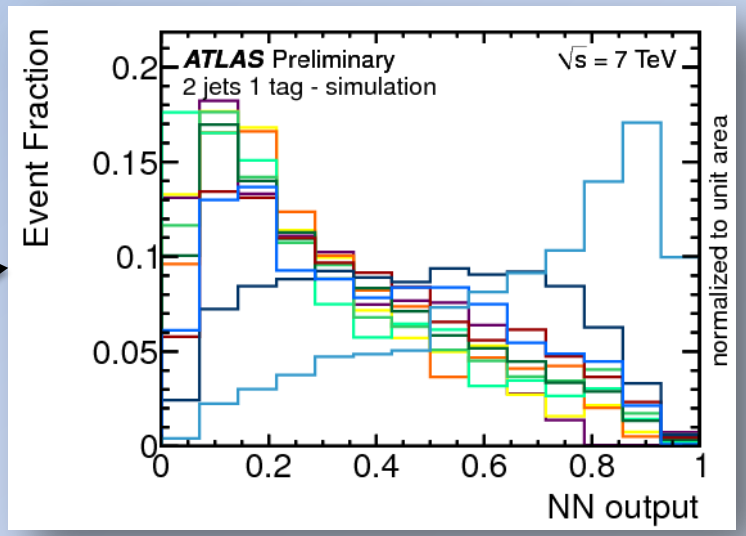
SM: $\sigma_t = 64.5$ pb

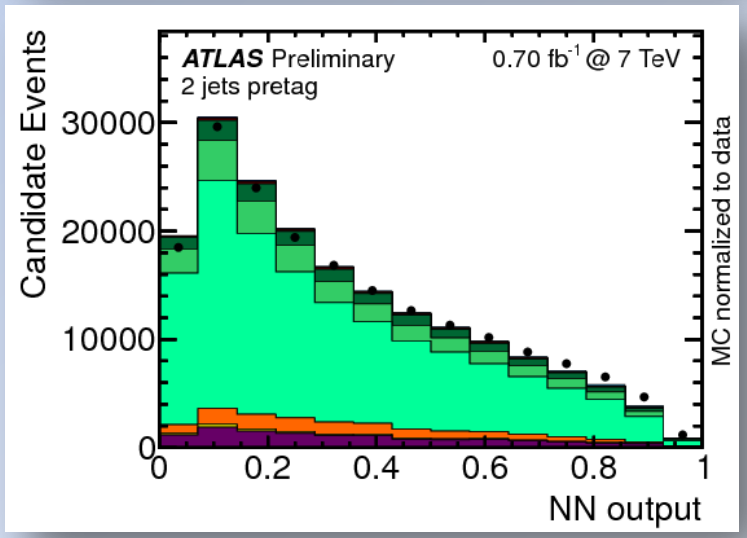
Neural network analysis

Idea: Combine many variables including correlations in one discriminate

Variable
$m(\ell\nu b)$
$\lvert\eta(j_l)\rvert$
$E_{\mathrm{T}}(j_l)$
$\Delta\eta(j_1, j_2)$
$\lvert\Delta\eta(b, \ell\nu)\rvert$
$p_{\mathrm{T}}(\ell)$
$m(b)$
$m_{\mathrm{T}}(W)$
$\eta(\ell)$
$E_{\mathrm{T}}^{\mathrm{miss}}$
polarization
$q(\ell)$
$m(j_1 j_2)$
H_{T}







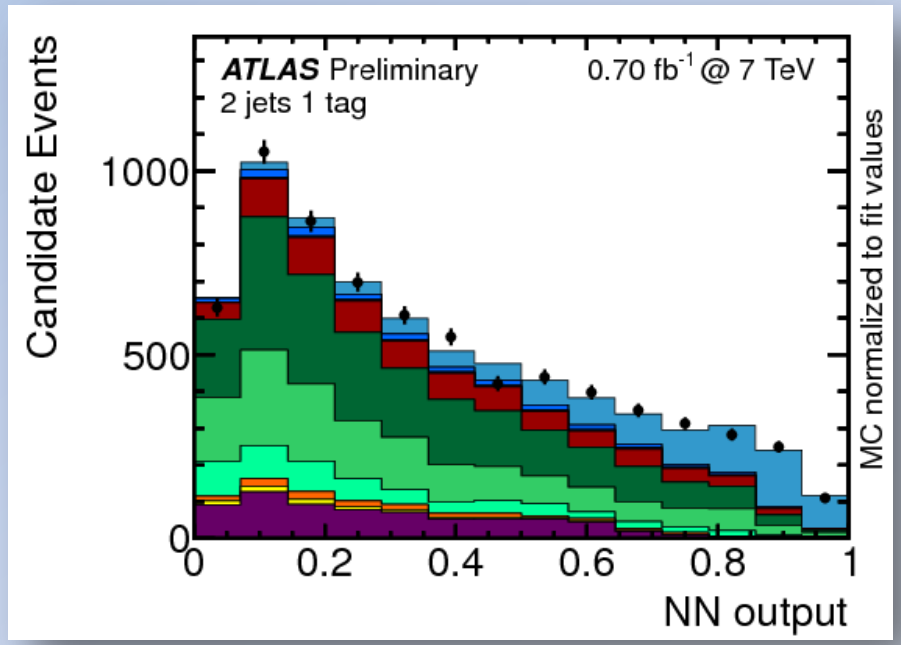
Training:

- Hidden layer: 33 nodes
- Signal/Background 50:50
- Background weighted to exp. number of events

Neural network analysis - Result

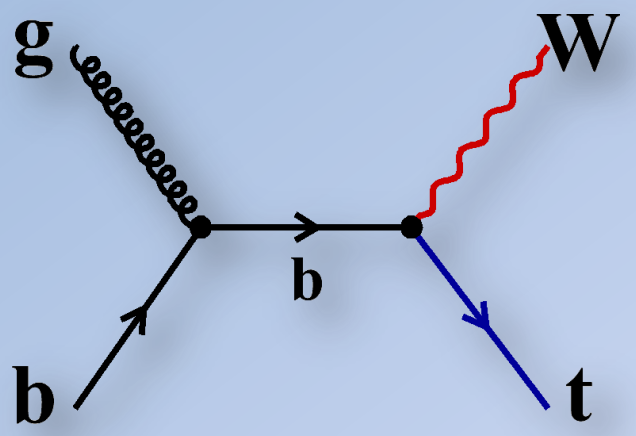
Source	NN
Data statistics	± 10
MC statistics	± 7
Jet energy scale	+32/-20
Jet energy resolution	± 4
Jet reconstruction	+3/-2
b-tagging scale factor	± 13
Mis-tagging scale factor	± 1
Lepton efficiencies	± 5
Lepton energy scale/resolution	± 5
Generator	± 7
Parton shower	± 6
ISR/FSR	± 13
PDF	± 4
W+jets shape modeling	± 1
Jet η reweighting	+10/-6
Background normalization	± 3
QCD normalization	
W+heavy flavour normalization	
W+light flavour normalization	
Theory cross sections	
Luminosity	± 5
All systematics	+44/-34
Total	+45/-34

Statistical analysis:
Maximum likelihood fit using the full output distribution



Observed cross section:
$\sigma_t = 105 \pm 7\ (\text{stat.})\ ^{+36}_{-30}\ (\text{syst.})$
SM: $\sigma_t = 64.5$ pb

Wt - analysis



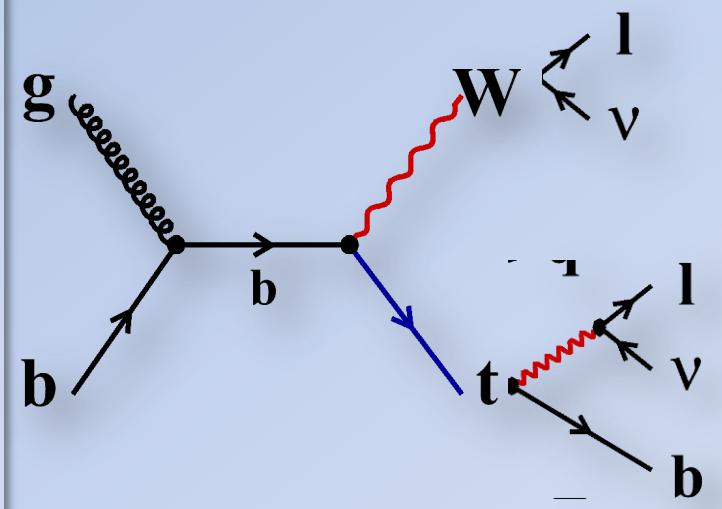
Event signature:
Two real W bosons & one high-P_T central b-jet (from top quark)

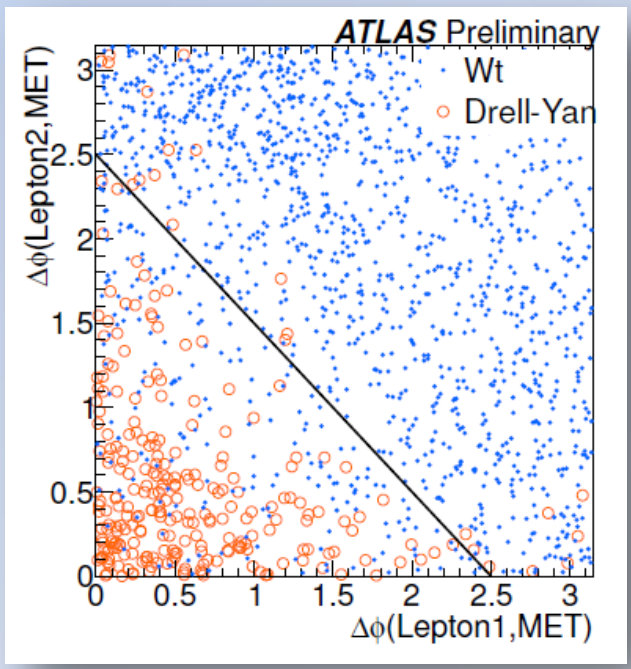
- Leptonic decay of Ws :
  - 2 electrons or 2 muons or 1 electron and 1 muon
  - missing transverse energy (E_T^{miss})

ATLAS-CONF-2011-104

Object selection

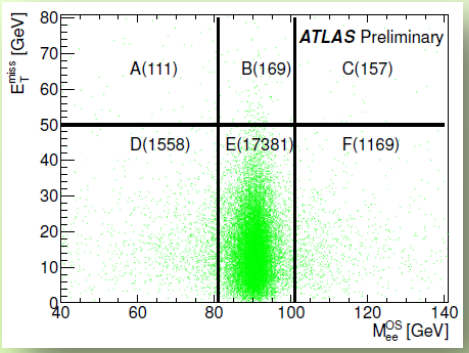
- Lepton selection (electron / muon):
  - $p_T > 25$ GeV
  - $|\eta| < 2.5$
  - Relative Isolation
  - Exactly two leptons (ee / μμ / eμ)
- Jets
  - Anti-k_T algorithm R=0.4
  - $p_T > 30$ GeV
  - $|\eta| < 4.5$
  - Exactly one jet
- Missing transverse energy
  - $E_T^{miss} > 50$ GeV
- Z-mass veto (ee/mm –channel)
  - $|M(ll)-M(Z)| > 10$ GeV
- $Z \rightarrow \tau\tau$ veto
  - $\Delta\Phi(l_1, E_t^{miss}) + \Delta\Phi(l_1, E_t^{miss}) > 2.5$





Background estimation - strategy

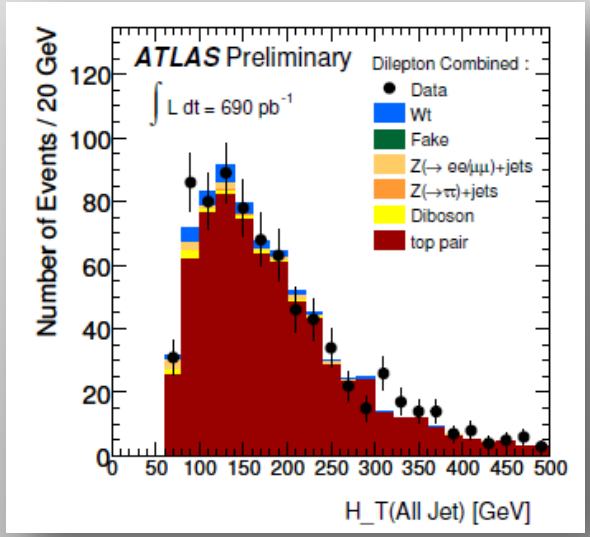
Drell-Yan / QCD
ABCD method



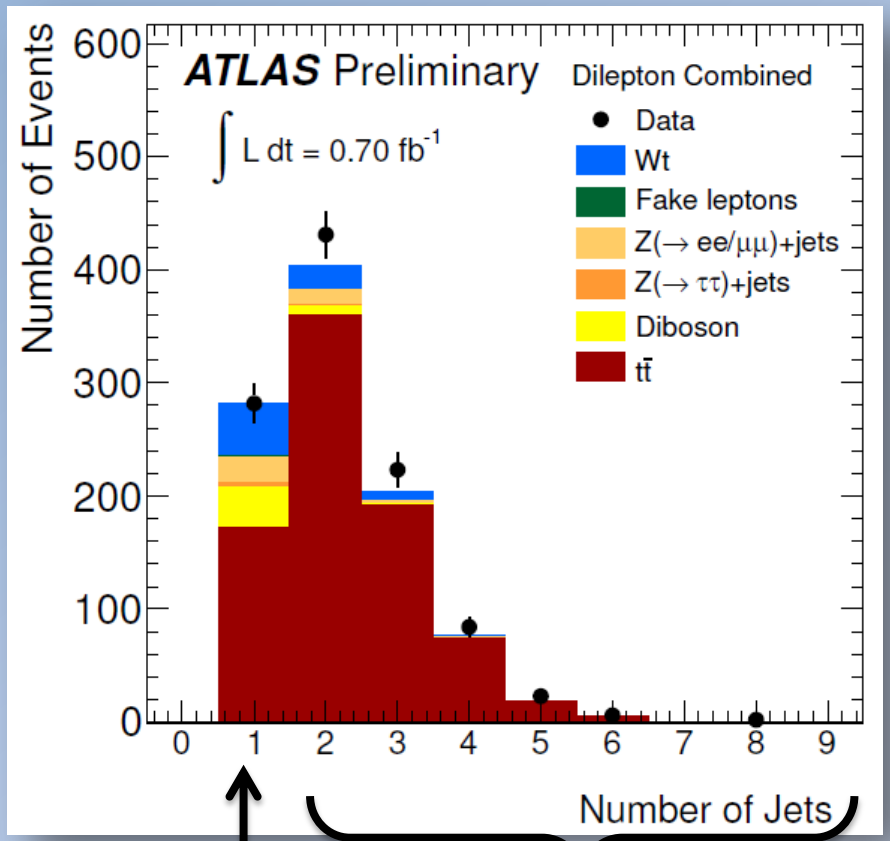
Diboson

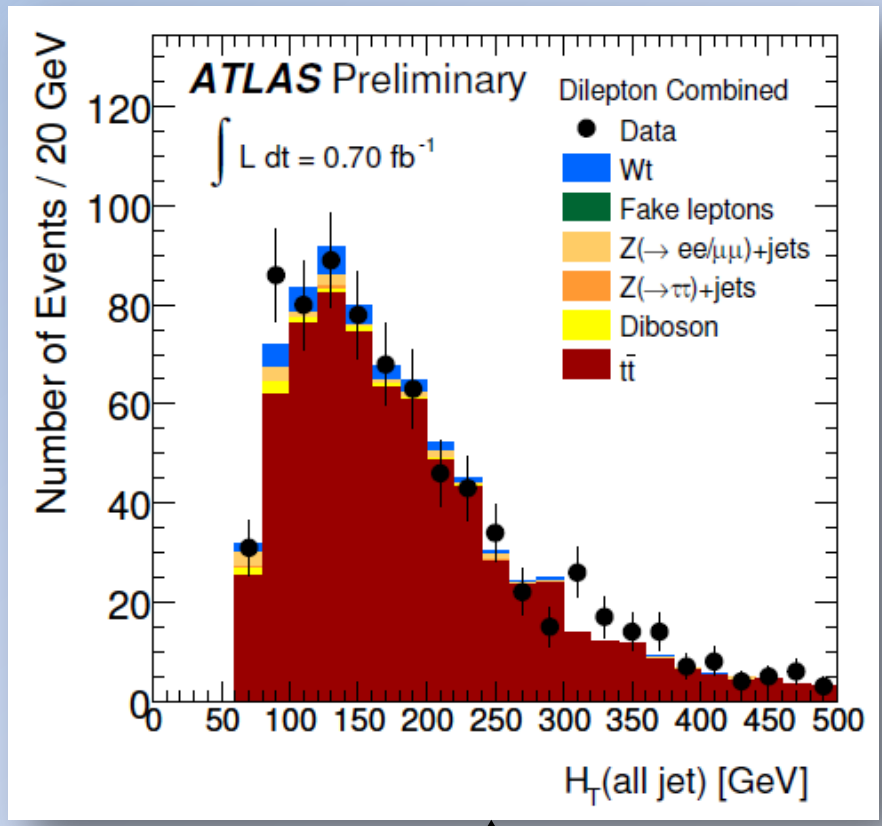
$N = \sigma \cdot \varepsilon \cdot \mathcal{L}$

Top Pair
SF = Data – ΣBkg / MC



Preselection for $L_{int} = 0.70\ fb^{-1}$





Signal sample

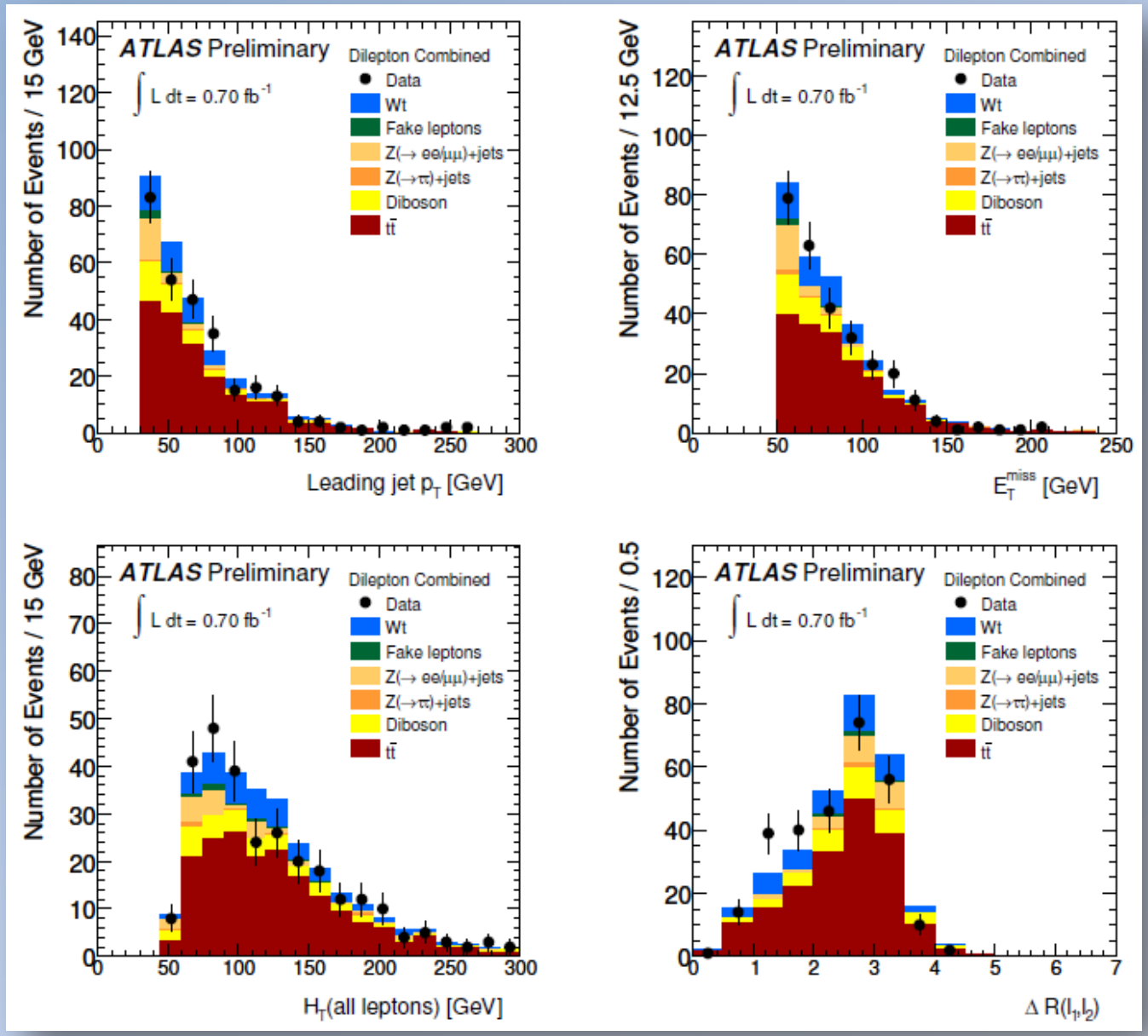
Top quark pair background region

Expected event yield for $L_{int} = 0.70\ fb^{-1}$

Process	ee	$\mu\mu$	$e\mu$
Wt	8.6 ± 1.6	11.9 ± 1.7	26.6 ± 2.5
$t\bar{t}$	31.8 ± 4.5	48.0 ± 7.0	104.7 ± 15.2
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
$Z \rightarrow ee$	6.2 ± 1.1	0.0 ± 0.0	0.0 ± 0.0
$Z \rightarrow \mu\mu$	0.0 ± 0.0	8.4 ± 1.4	0.0 ± 0.0
$Z \rightarrow \tau\tau$	0.5 ± 0.3	0.5 ± 0.8	3.9 ± 1.0
Fake lepton	2.3 ± 1.2	0.0 ± 0.6	1.5 ± 0.8
Total Expected	57.2 ± 5.1	82.1 ± 7.3	154.0 ± 15.4
Total observed	62	73	152

Final selection with njet =1.
Uncertainties include also systematic uncertainties

Kinematic distributions

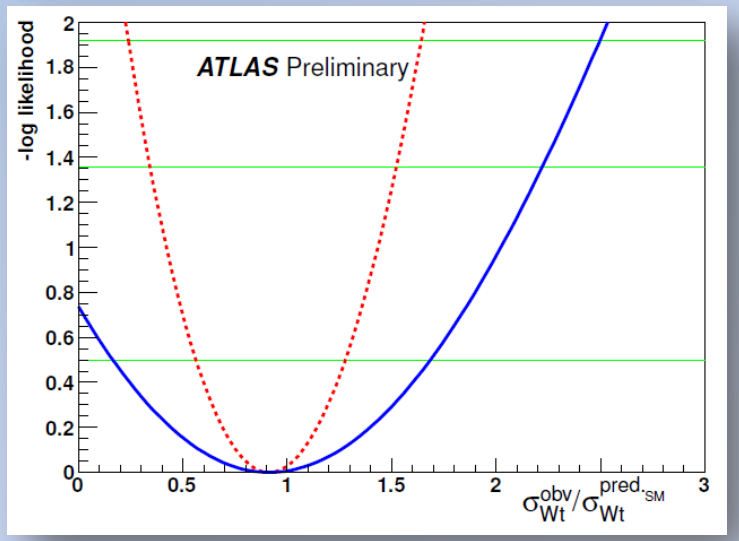


Good agreement between data and background model/ prediction

Wt cut based analysis - Result

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

Statistical analysis:
Profile likelihood



Observed cross section (significance 1.2σ):
$\sigma_{Wt} = 14.4\ ^{+5.3}_{-5.1}\ (stat.)\ ^{+9.7}_{-9.4}$ pb

Observed limit @ 95% C.L.
$\sigma_{Wt} < 39.1$ pb

SM: $\sigma_t = 15.7$ pb

Summary / Conclusion

- Measured single top quark t-channel and Wt cross sections with the 2011 dataset of 0.70 fb^{-1}.
- Both measurements are in agreement with the SM expectations

t-channel: Performed two analyses

- Using a neural network
  $\sigma_t = 107\ ^{+37}_{-31}$ pb

- Cut based approach
  $\sigma_t = 90\ ^{+32}_{-22}$ pb

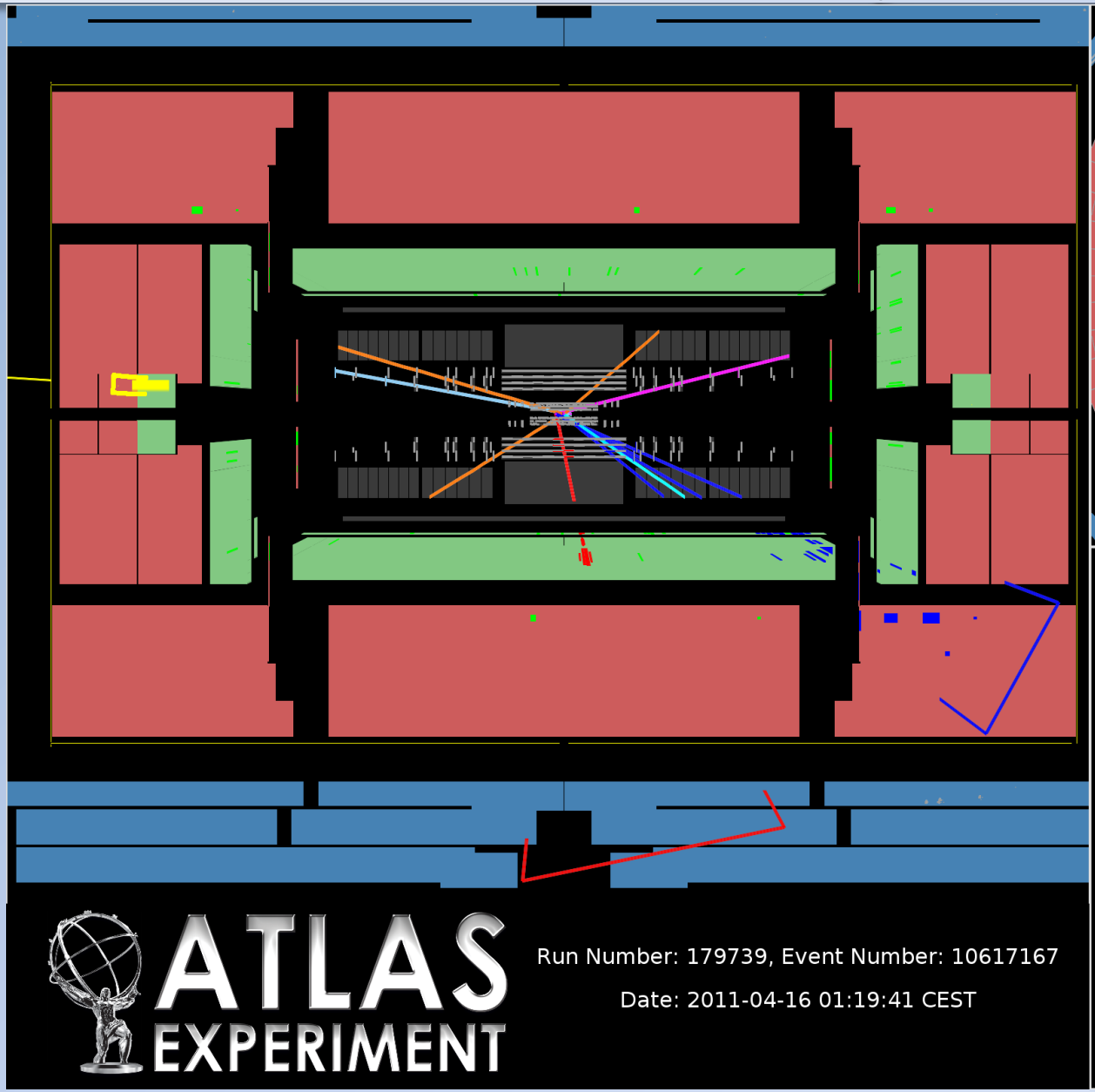
Wt-channel: Performed one analysis

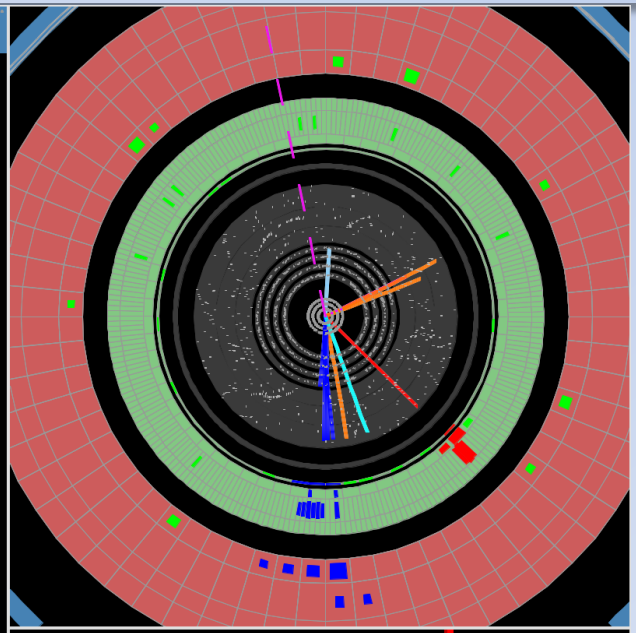
- Cut based approach
  Upper limit: 39pb @ 95% C.L.

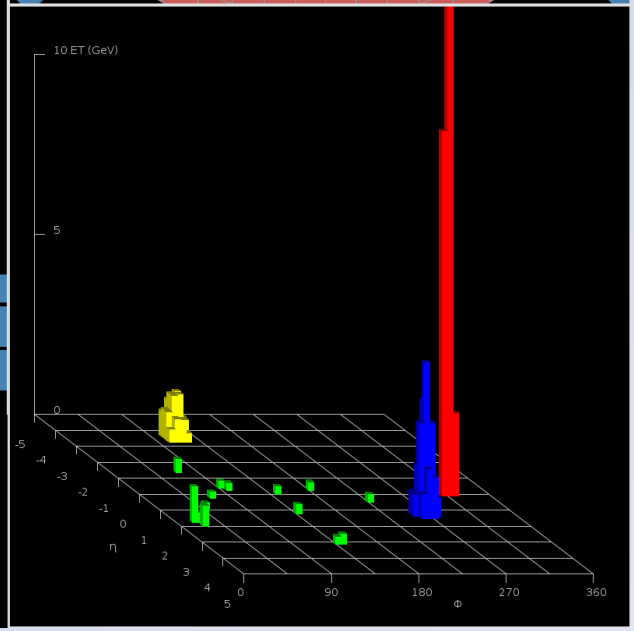
Future:

- Start searching for new physics in the single top sector

Thank you!


ATLAS
EXPERIMENT
Run Number: 179739, Event Number: 10617167
Date: 2011-04-16 01:19:41 CEST




10 ET (GeV)
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
Φ