

Single Top Physics at ATLAS

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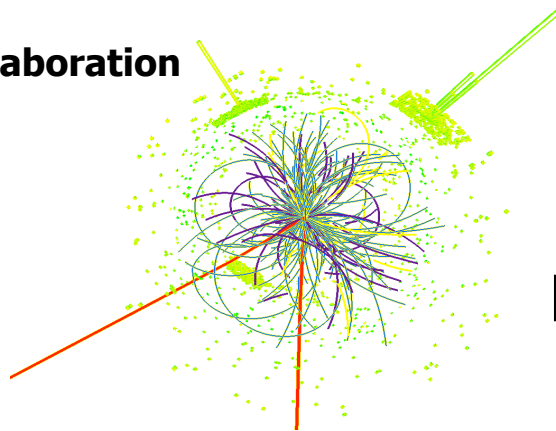
Humboldt-Universität zu Berlin

for the ATLAS Collaboration

GEFÖRDERT VOM



**Bundesministerium
für Bildung
und Forschung**

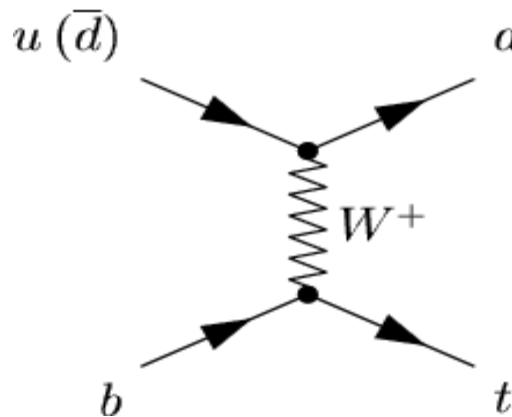


**Rencontres de Moriond,
Electroweak Interactions
and Unified Theories**
March 3rd – March 10th, 2012

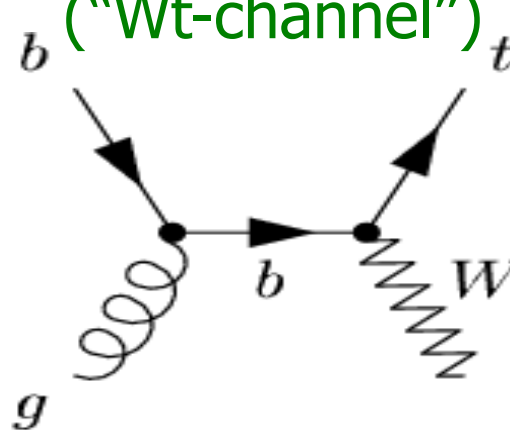
Single Top Production

EW production of top-quarks, three production channels:

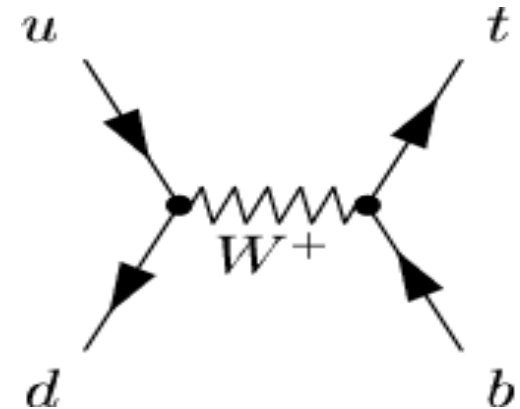
t-channel



Wt associated production
("Wt-channel")



s-channel



predicted cross sections for $\sqrt{s} = 7$ TeV and $m_t = 172.5$ GeV

t-channel: 64.2 ± 2.6 pb

Wt-channel: 15.6 ± 1.3 pb

s-channel: 4.6 ± 0.2 pb

calculations by N. Kinodakis at NLO+NNLL resummation

arXiv 1103.2792, 1005.4451, 1001.5034

Interest in Single Top Production

• Test of SM prediction

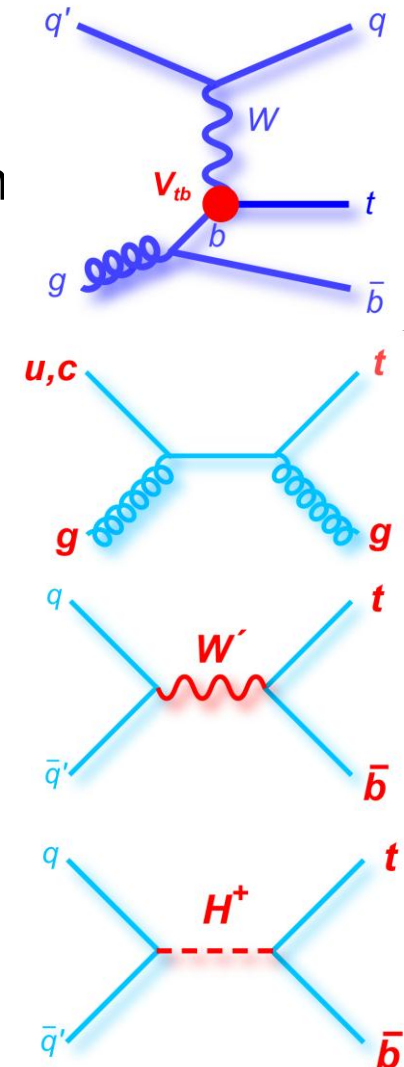
- measurement of the different channels separately
- compare measured cross section with SM prediction
- test of unitarity of CKM matrix
 - ❖ Measurement of V_{tb} , $V_{ub}^2 + V_{cb}^2 + V_{tb}^2 = 1$
 - ❖ hints for a 4th generation?

• Search for phenomena beyond the SM

- search for FCNC, e.g. $ug \rightarrow t$
- search for W' , charged MSSM Higgs $H^\pm$

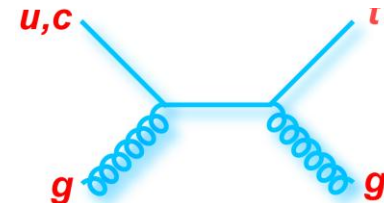
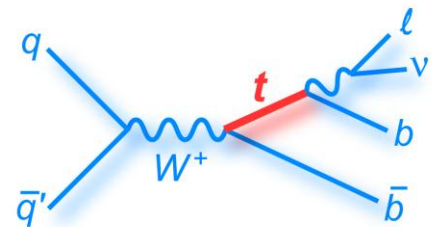
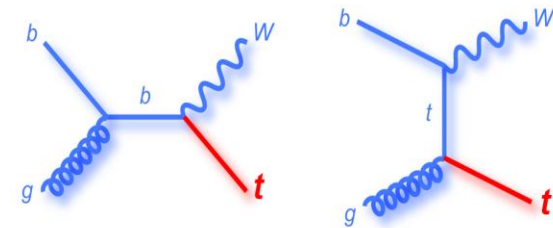
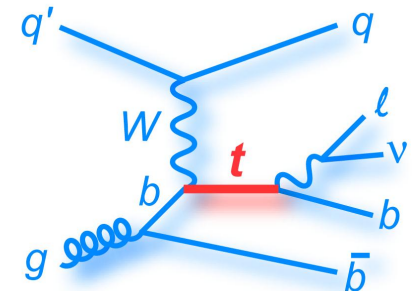
• Experimental benchmark for searches

- object identification
 - ❖ lepton fake rates
 - ❖ QCD Background estimates
 - ❖ b-quark jet identification / b-quark PDF



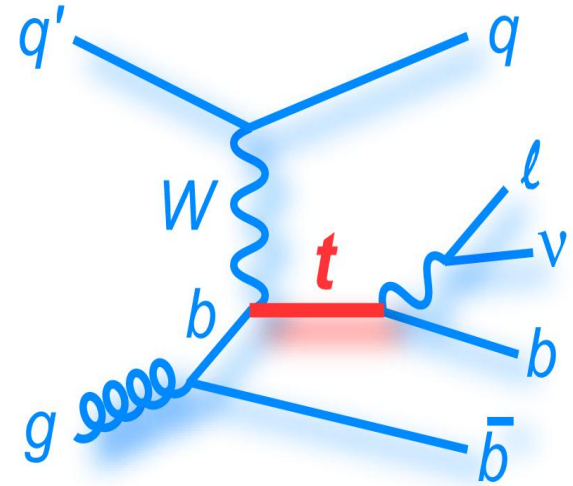
Analyses Performed at ATLAS

- **Standard Model: $L = 0.70 \text{ fb}^{-1}$**
 - **t-channel**
 - ❖ final state: **1 lepton** + 2/3 jets (1 b-jet) + E_T^{miss}
 - ❖ background: top-pair, W/Z+jets, WW, WZ, ZZ, QCD
 - ❖ **ATLAS-CONF-2011-101**
 - **Wt-channel**
 - ❖ final state (di-lepton): **2 leptons** + 1 b-jet + E_T^{miss}
 - ❖ background: top-pair, Z+jets, WW, WZ, ZZ
 - ❖ **ATLAS-CONF-2011-104**
 - **s-channel**
 - ❖ final state: **1 lepton** + 2 jets (2 b-jets) + E_T^{miss}
 - ❖ background: top-pairs, W/Z+jets, WW, WZ, ZZ, QCD
 - ❖ **ATLAS-CONF-2011-118**
- **Beyond SM: $L = 2.05 \text{ fb}^{-1}$**
 - **FCNC**
 - ❖ final state: **1 lepton** + 1 b-jet + E_T^{miss}
 - ❖ background: top-pair, W/Z+jets, SM single top, QCD
 - ❖ **arXiv:1205.0529**



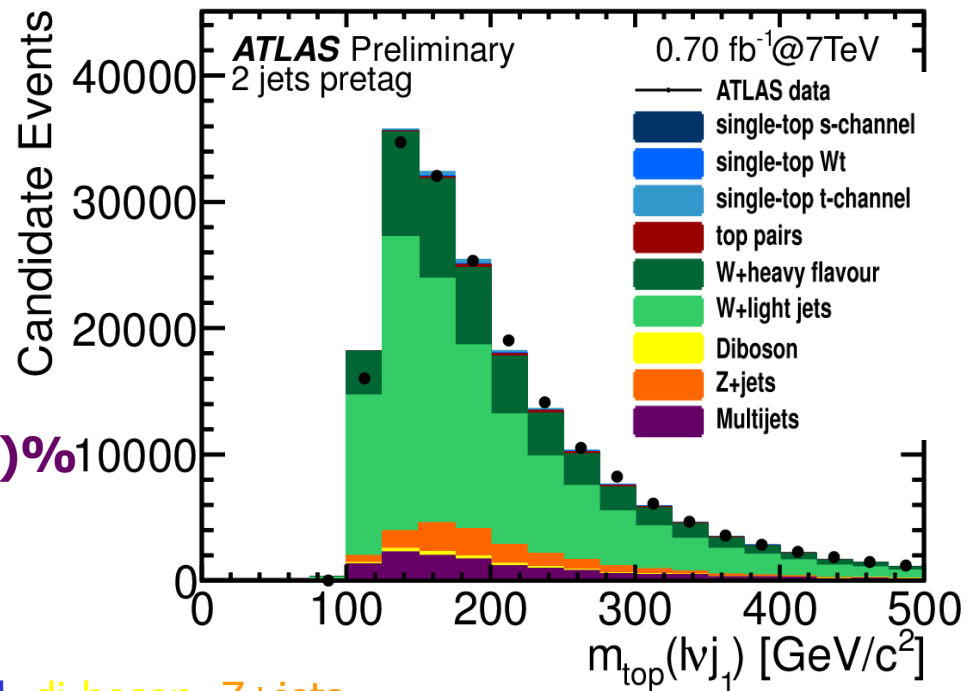
Event Selections (SM Analyses)

- Use single high p_T single lepton trigger
 - **leptonic W-decay**
 - suppression of high QCD background
- Charged lepton (trigger matched)
 - $p_T > 25 \text{ GeV}$, $|\eta| < 2.5$
 - isolation criteria
- Missing transverse energy
 - $E_T^{\text{miss}} > 25 \text{ GeV}$ (t-/s-channel), $E_T^{\text{miss}} > 50 \text{ GeV}$ (Wt-channel)
 - QCD multijet veto: $M_T(W) > 60 \text{ GeV} - E_T^{\text{miss}}$
- Jets
 - anti-kT algorithm, $R=0.4$,
 - $p_T > 25 \text{ GeV}$ (t-/s-channel), $p_T > 30 \text{ GeV}$ (Wt-channel)
 - $|\eta| < 4.5$ (t-channel), $|\eta| < 2.5$ (s-/Wt-channel)
 - if b-tag required: $|\eta| < 2.5$, tagger with $\epsilon_b = 57\%$ (IP and SV based)

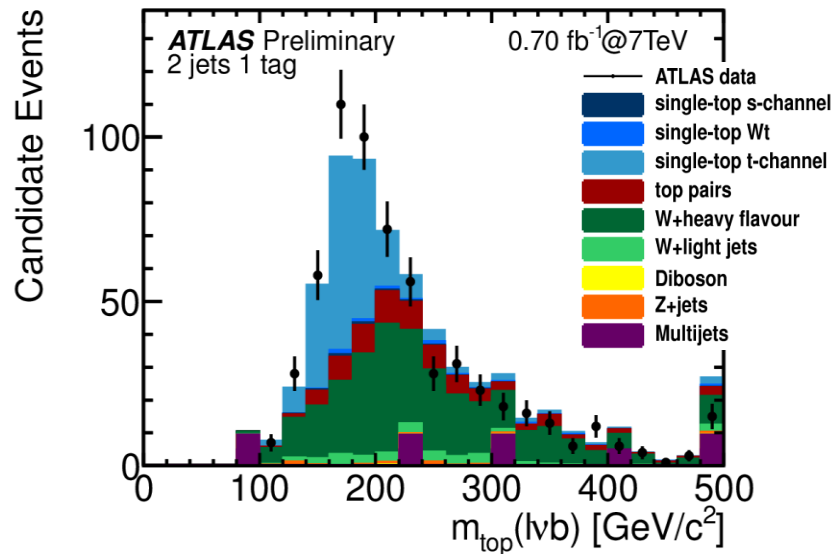


Background Processes (pre-tag)

- **single top:** $\sim 1\%$
- **top-pair:** $\sim 1\%$
- **main background**
 - **W+light jets:** (55-65)%
 - **W+charm jets:** $\sim 20\%$
 - **W+bottom jets:** (2-3)%
- **QCD multijet (fake lepton):** (5-10)%
- **Strategy for BG estimation**
 - MC based: **top-pair**, **Wt**- and **s-channel**, **di-boson**, **Z+jets**
 - ❖ MC normalized to theoretical / measured cross sections
 - ❖ acceptance / efficiencies obtained by MC
 - ❖ $N^{pred} = \sigma^{theo} \varepsilon_{evt} \int L dt, \varepsilon_{evt} = \varepsilon_{evt}^{MC} \varepsilon_{BR} \varepsilon_{corr} \varepsilon_{trig}$
 - estimation from data and reduce as much as possible: **QCD**
 - ❖ data driven event model for multivariate methods (jet electron model)
 - **W+jets:** Alpgen LO+LL predictions with data driven scale factors



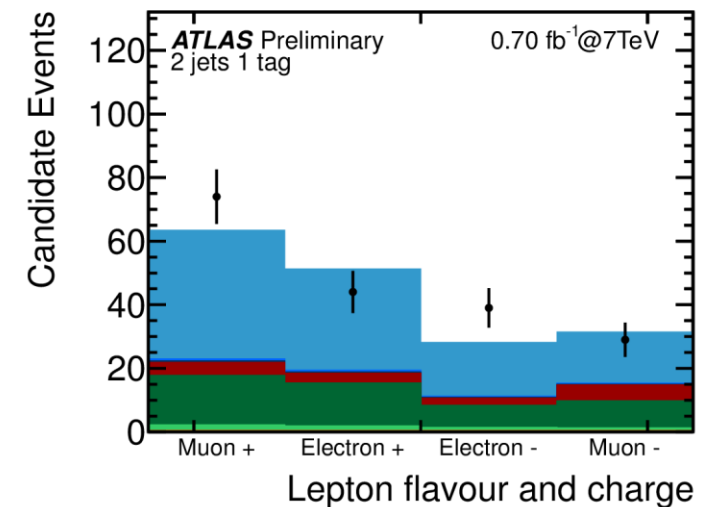
t-Channel Results, cut based



- profile likelihood to evaluate event yields
- separation in lepton flavour and charge
 - optimize statistical power
- **measured cross section:**
 - **90 ± 9 (stat.) $^{+31}_{-20}$ (syst) pb**
- significance in σ :
 - observed: 7.6, expected 5.4
- dominating systematics
 - b-tagging: (+18/-13)%, ISR / FSR: $\pm 13\%$

counting experiment, cuts applied:

- $H_T > 210$ GeV
- $150 \text{ GeV} < M_{lvb} < 190 \text{ GeV}$
- $|\eta(\text{light-j})| > 2.0, |\eta(\text{b-j}, \text{light-j})| > 1.0$
- cuts optimized including systematics
 - reduction of JES uncertainty
- measurement in 2 and 3-jet selection



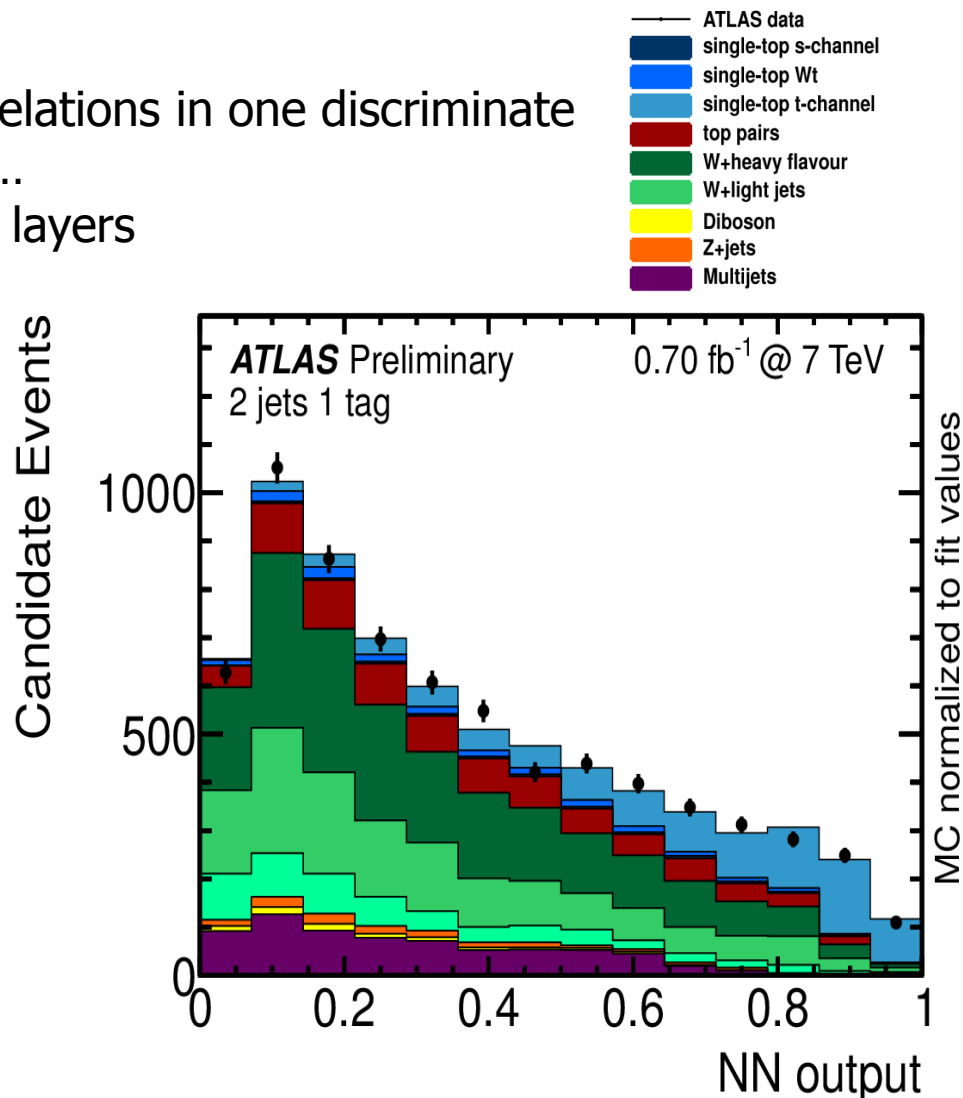
SM: $\sigma = 64.2 \pm 2.6$ pb

t-channel results, NN

- **cross check analysis to cut based**
- combine many variables including correlations in one discriminate
- H_T , E_T , E_T^{miss} , $M(\text{l}\nu\text{b})$, $p_T(\text{l})$, $m_T(\text{W})$, η , ...
- 13 input variables, 33 nodes in hidden layers
- training: 50% signal, 50% BG

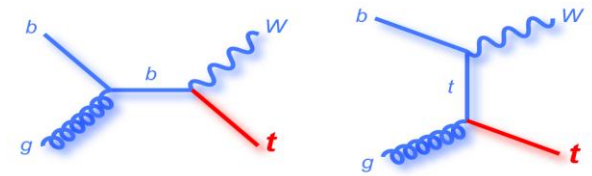
- maximum likelihood fit to NN output
 - simultaneous determination of BG
- frequentist method to estimate systematic uncertainty
- **observed cross section:**
 $105 \pm 7 \text{ (stat.) } ^{+36}_{-30} \text{ (sys) pb}$
- dominating systematics
 JES: (+32/-20)%, b-tag: 13%,
 ISR/FSR: 13%

SM: $\sigma = 64.2 \pm 2.6 \text{ pb}$

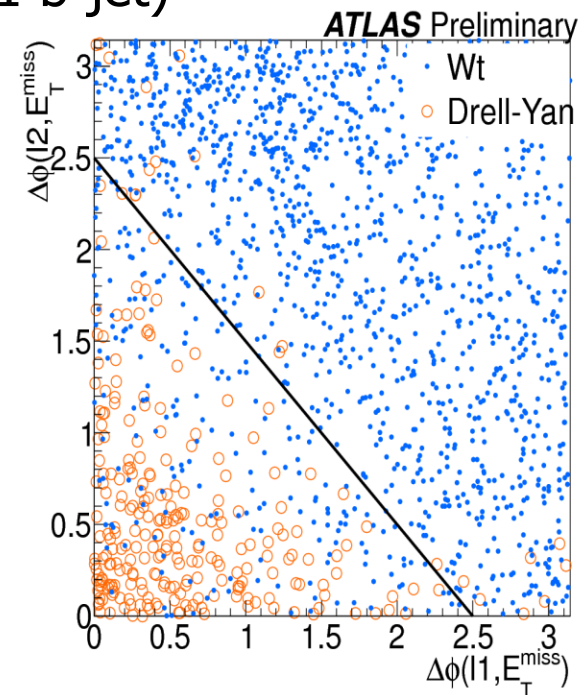


Wt-Channel Analysis

- **Two W-decays $\rightarrow$ two channels**
 - **di-lepton:** both W decaying leptonically
 - ❖ 2 charged leptons, E_T^{miss} and 1 b-jet
 - **lepton+jet:** one W decay leptonically, the other hadronically
 - ❖ 1 charged lepton, E_T^{miss} and 3 jets (with 1 b-jet)

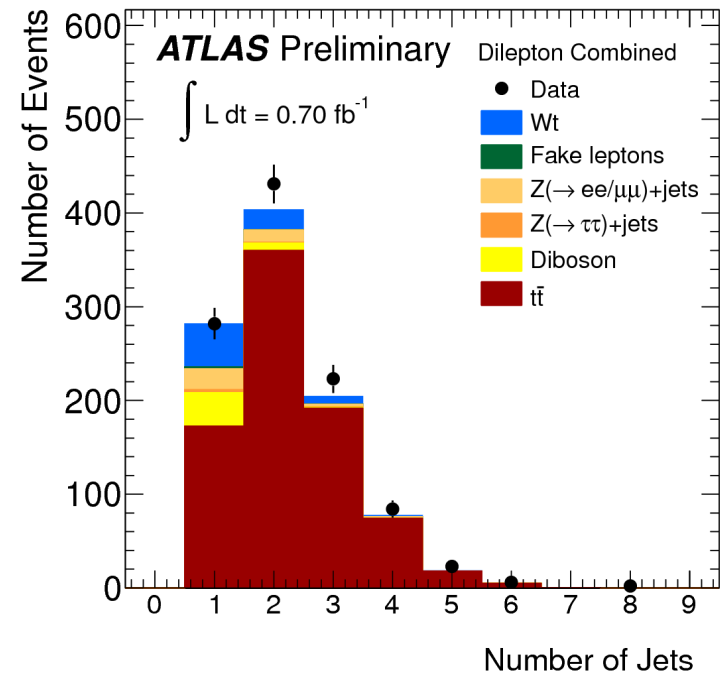
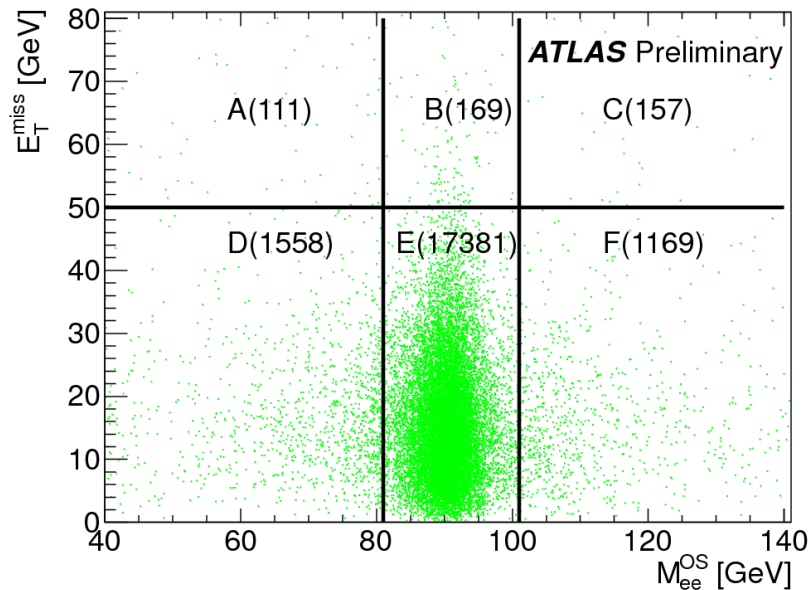


- **Di-lepton channel:**
 - exactly two opposite sign leptons ($e\bar{e}, e\mu, \mu\mu$)
 - exactly one jet, **no b-tagging** requirement
 - Z-mass veto: $|M(\text{ll}) - M(Z)| > 10 \text{ GeV}$
 - $Z \rightarrow \pi\pi$ / DY veto: (triangle cut)
 $\Delta\Phi(l_1, E_T^{\text{miss}}) + \Delta\Phi(l_2, E_T^{\text{miss}}) > 2.5$



Wt-Channel Backgrounds

- **Data driven background estimates:**
 - Drell-Yan and $Z \rightarrow \ell\ell$: estimate with ABCDEF method
 - top-pair: estimate from sidebands (≥ 2 jet region)
 - fake lepton: matrix method



Wt-Channel: Results

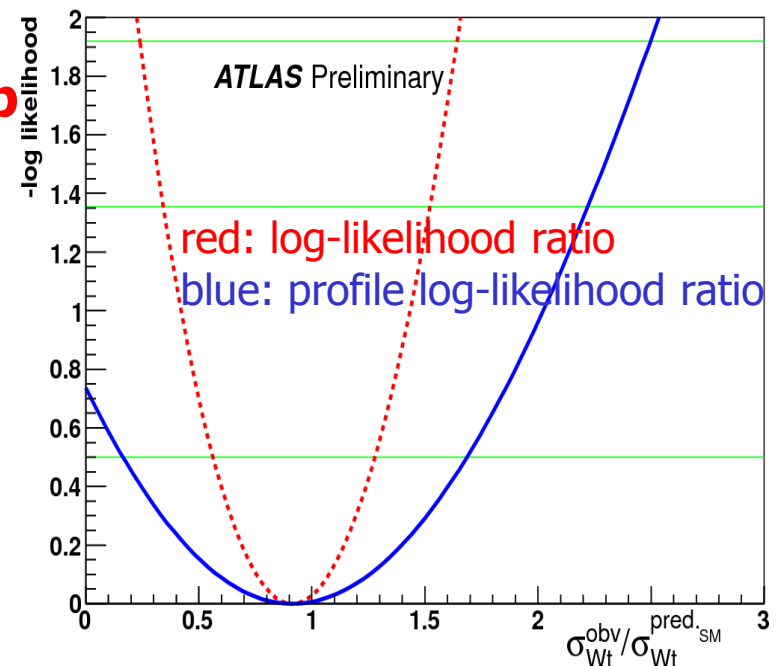
- **Systematic uncertainties**

- jets: JES (+34/-35)%, JER (+29/-32)%, reco ϵ (+30/-33)%
- generator: (+16/-11)%
- all systematics (+68/-66)%, data statistics (+37/-35)%
- **total with statistics (+77/-75)%**

- **Observed cross section**

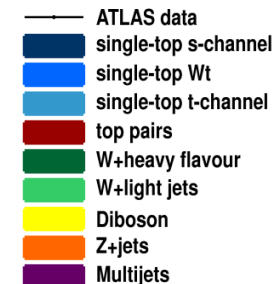
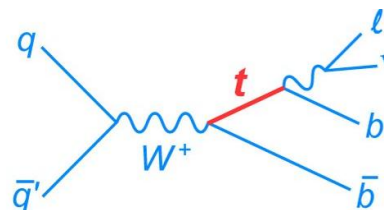
- **$14.4^{+5.3}_{-5.1}$ (stat) $^{+9.7}_{-9.4}$ (sys) pb**
- limits at 95% C.L.
 - ❖ **observed: $\sigma(Wt) < 39.1$ pb**
 - ❖ **expected: $\sigma(Wt) < 40.6$ pb**
- significances are determined with a maximum likelihood ratio

SM: $\sigma = 15.6 \pm 1.3$ pb



s-Channel Analysis

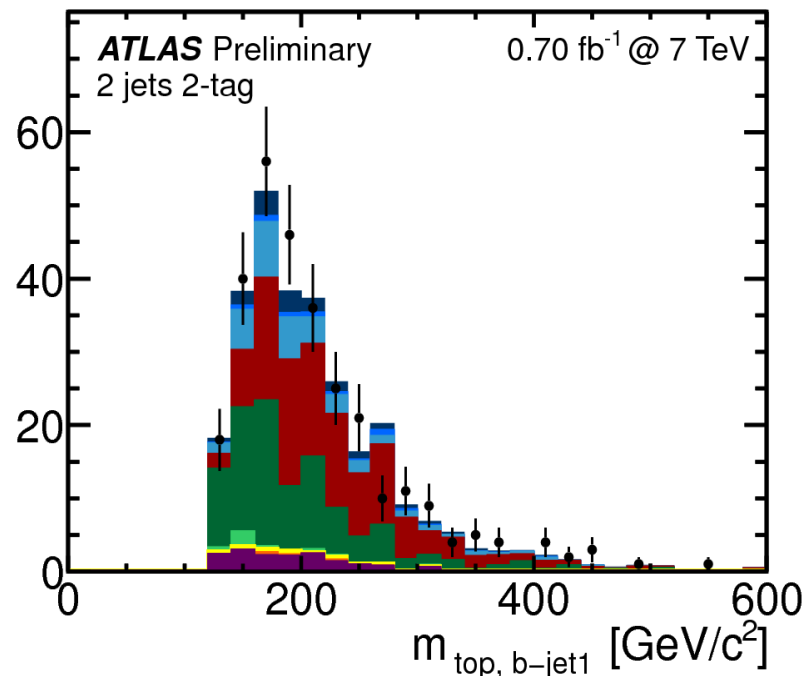
- **Smallest cross section**
- **Similar signature to t-channel**



- **Cut based analysis**

- most efficient cut: **double b-tag**
 - ❖ $S/\sqrt{B}$: $0.26 \rightarrow 0.88$, total 0.98
 - ❖ finally 296 data events (285 ± 17 pred.)
- $m(\text{top}, \text{jet1})$, $m(\text{top}, \text{jet2})$,
- $p_T(\text{jet1}, \text{jet2})$, $m_T(W)$
- $\Delta R(\text{jet1}, \text{lep})$ $\Delta R(\text{jet1}, \text{jet2})$

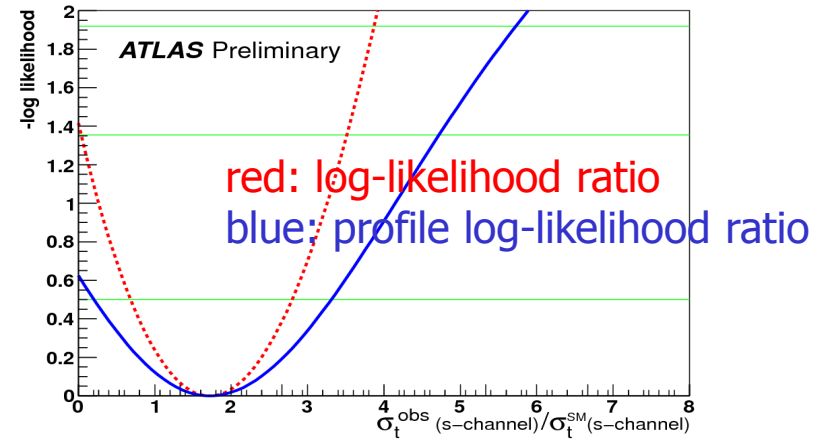
Candidate Events



s-Channel Results

• Main uncertainties

- data statistics $\pm 100\%$
- b-tagging: $(-30/+20)\%$
- luminosity $\pm 50\%$
- MC generator modeling $(-60/+20)\%$
- QCD normalization $\pm 40\%$
- all systematics $(-110/+90)\%$, **total $(-160/+150)\%$**

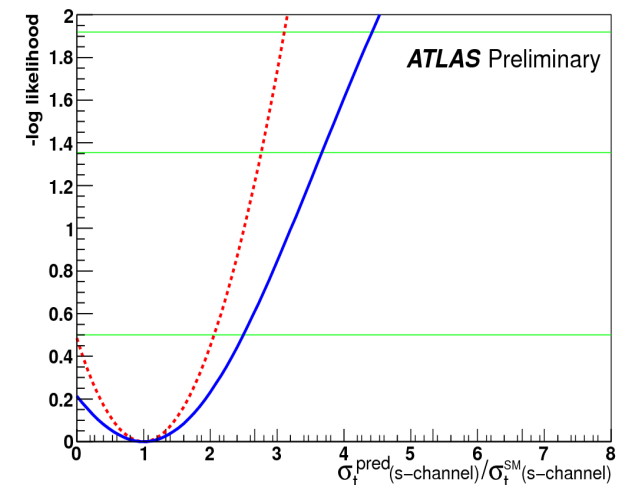


• Counting experiment

- statistical analysis with a profile likelihood

• Limits at 95% C.L.

- **observed $\sigma(\text{s-channel}) < 26.5 \text{ pb}$**
- **expected $\sigma(\text{s-channel}) < 20.5 \text{ pb}$**

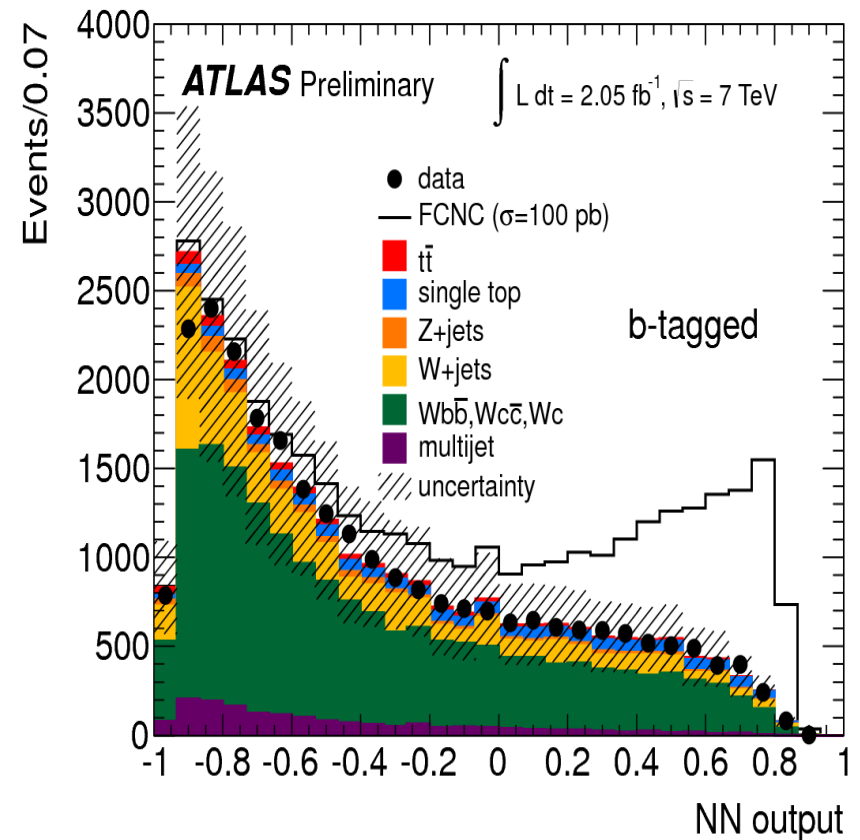
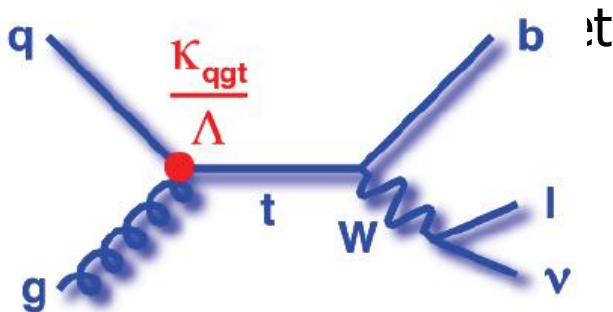


$\text{SM: } \sigma = 4.6 \pm 0.2 \text{ pb}$

Flavour Changing Neutral Currents

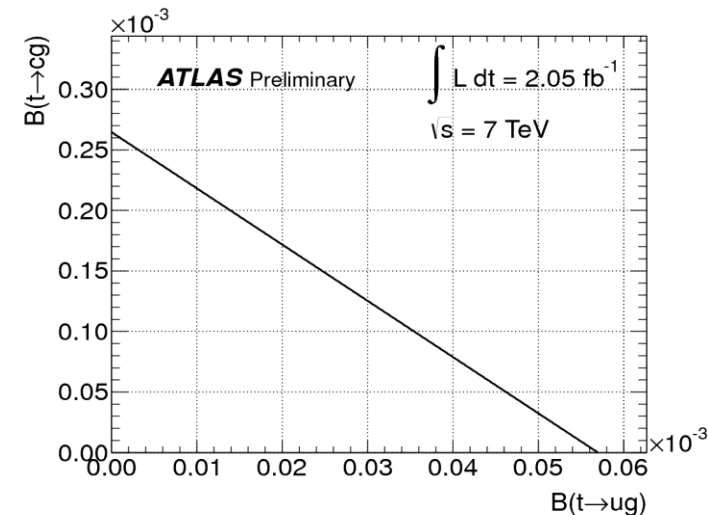
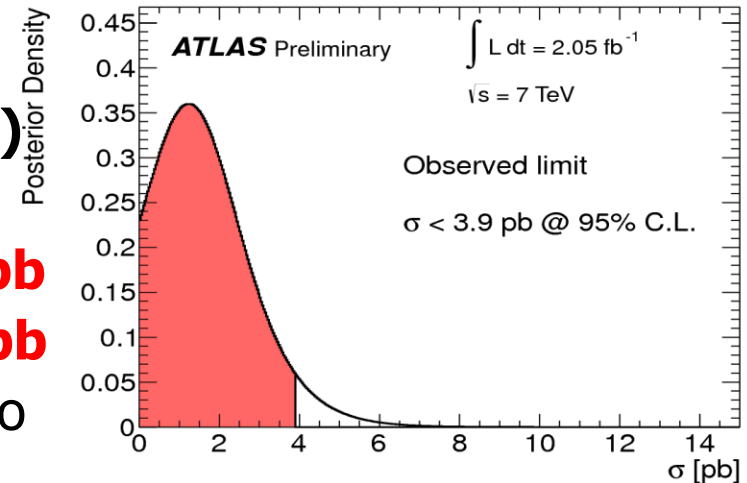
- Search for FCNC in single top production (t-channel)
- Highly suppressed in SM
- Use NN approach
- Event selection (SM decay of top):
 - leptonic W decay (isolated lepton)

- ❖ μ : $E_T^{\text{miss}} > 20 \text{ GeV}$,
 $M_T(W) > (60 \text{ GeV} - E_T^{\text{miss}})$
- ❖ e : $E_T^{\text{miss}} > 35 \text{ GeV}$,
 $M_T(W) > 25 \text{ GeV}$



FCNC Result

- **No evidence of FCNC**
- Upper limits: integrating the PDFs
- **Upper limits at 95% C.L. ($L = 2.05 \text{ fb}^{-1}$)**
 - including all systematic effects
 - expected **$\sigma(\text{FCNC, single top}) < 2.4 \text{ pb}$**
 - observed **$\sigma(\text{FCNC, single top}) < 3.9 \text{ pb}$**
- Using NLO predictions for FCNC converted to limit on coupling constants:
 - **$\kappa_{\text{ugt}}/\Lambda < 6.9 * 10^{-3} \text{ TeV}^{-1} (\kappa_{\text{cgt}} = 0)$**
 - **$\kappa_{\text{cgt}}/\Lambda < 1.6 * 10^{-2} \text{ TeV}^{-1} (\kappa_{\text{ugt}} = 0)$**
- Using NLO calculation upper limits for BR are derived:
 - **$\text{BR}(t \rightarrow \text{ug}) < 5.7 * 10^{-5} (\text{BR}(t \rightarrow \text{cg}) = 0)$**
 - **$\text{BR}(t \rightarrow \text{cg}) < 2.7 * 10^{-4} (\text{BR}(t \rightarrow \text{ug}) = 0)$**



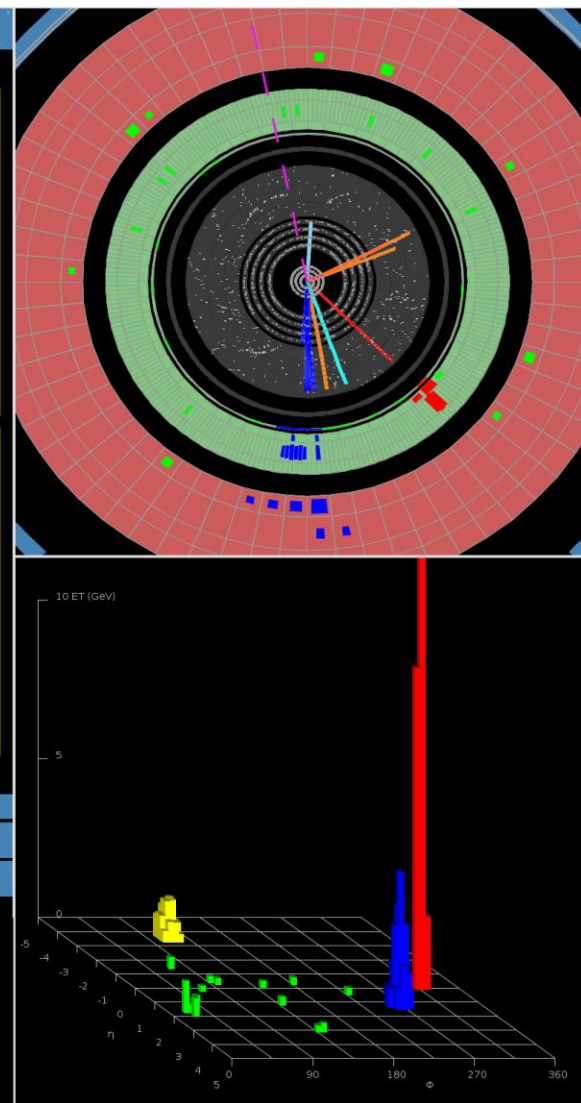
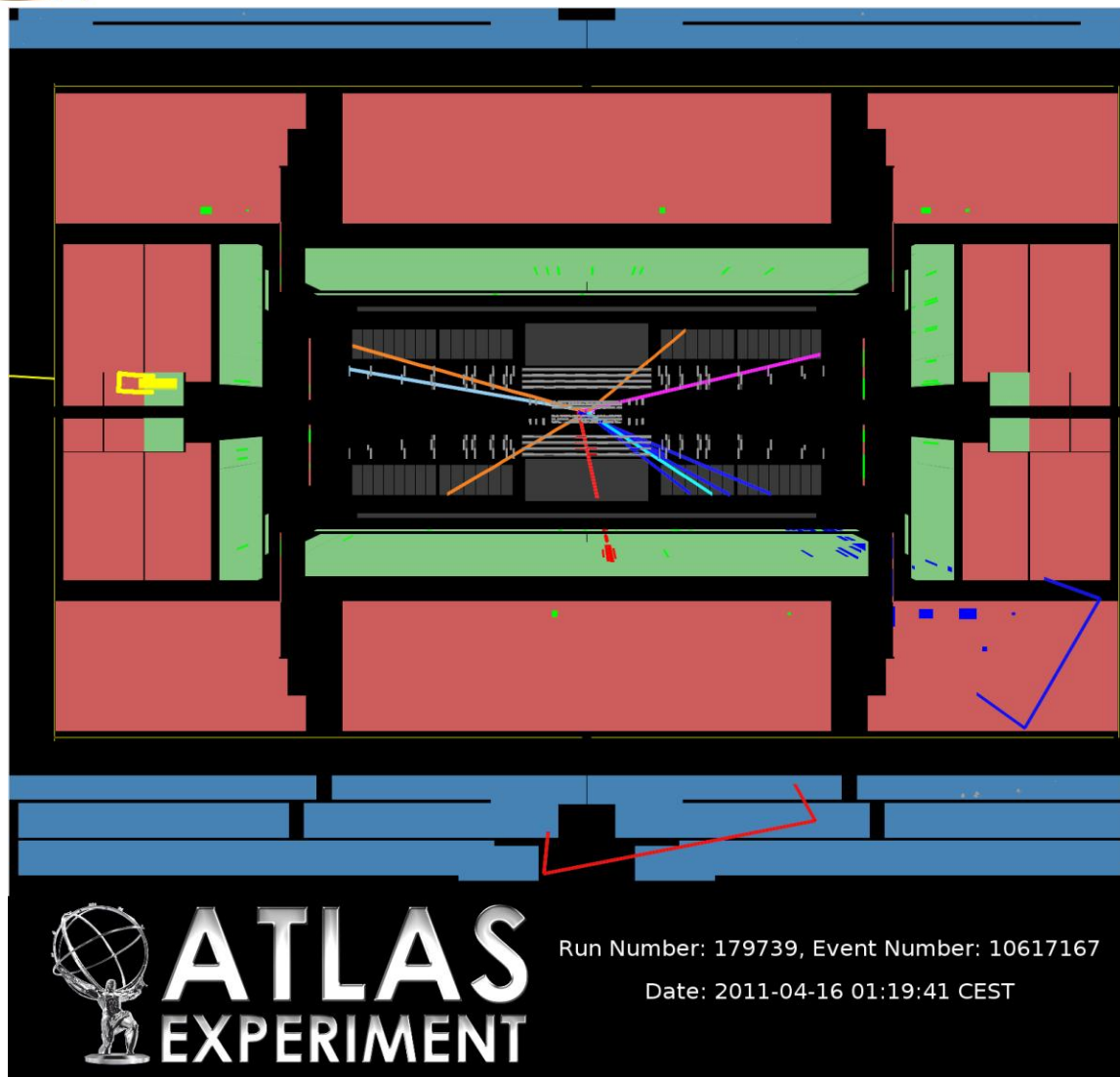
Summary and Outlook

- All single top channels were established at ATLAS
 - cross section measurement for t- and Wt-channel
 - 95% C.L. limit set on s-channel
- Cut based analyses are possible
- Advanced methods based on NN well established
- Data driven background estimations
- All results are compatible with SM expectations
- Next upcoming analyses
 - update to the full 2011 data set of 4.7 fb^{-1}
 - more searches for phenomena beyond the SM
 - ❖ W' , charged Higgs
 - many new beautiful results expected soon!

Backup Slides

- t-channel Event
- NN output for training for the t-channel analysis

t-Channel Event



t-Channel Analysis: NN Output

- single-top t-channel
- single-top Wt
- single-top s-channel
- top pairs
- $Wb\bar{b}/c\bar{c}+\text{jets}$
- $Wc+\text{jets}$
- $W+\text{light jets}$
- Diboson
- $Z+\text{jets}$
- Multijets

