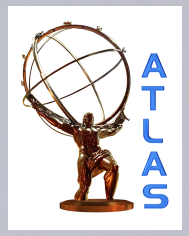
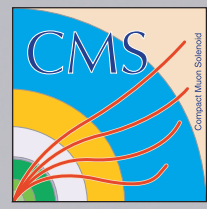




Measurements of Electroweak Top Production at the LHC

Aniello Spiezia

INFN and Università degli Studi di Perugia

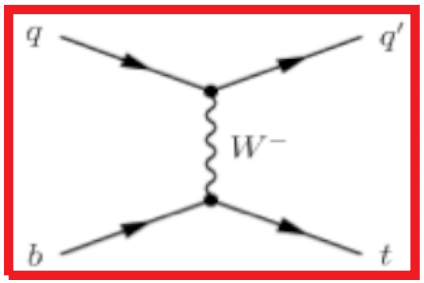
On behalf of CMS and ATLAS Collaborations

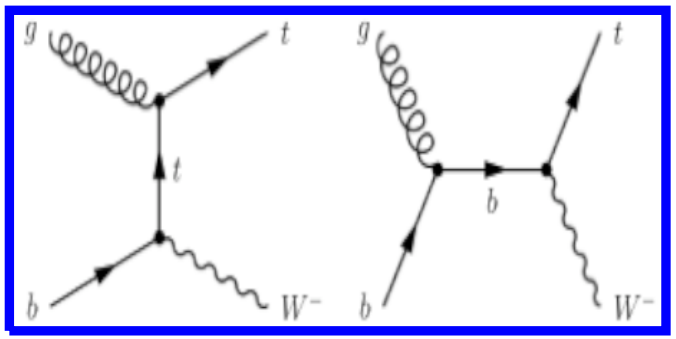
CKM2012: 7th International Workshop on the CKM Unitarity Triangle

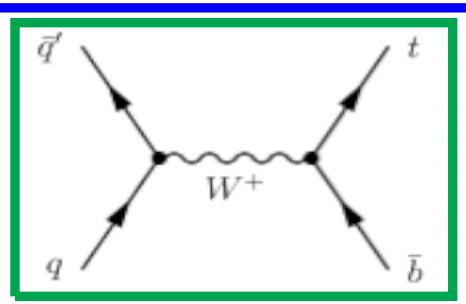
28 Sep-2 Oct 2012, University of Cincinnati

Introduction

- An overview of the measurements made at the LHC for the **single top-quark production** will be given
- There are three processes for the single-top production
- Theoretical values shown calculated with *approximate NNLO* accuracy. Errors due to *scale variation* and *PDF uncertainty*







t-channel single top quark production

$\sigma(\text{pp @ 7TeV}) = 64.6^{+2.7}_{-2.0}$ pb

$\sigma(\text{pp @ 8TeV}) = 87.8^{+3.4}_{-1.9}$ pb

N. Kidonakis, Phys. Rev. D 83 (2011) 091503 [arXiv:1103.2792]

tW single top quark production

$\sigma(\text{pp @ 7TeV}) = 15.7 \pm 1.1$ pb

$\sigma(\text{pp @ 8TeV}) = 22.4 \pm 1.5$ pb

N. Kidonakis, Phys. Rev. D 82 (2010) 054018 [arXiv:1005.4451]

s-channel single top quark production

$\sigma(\text{pp @ 7TeV}) = 4.6 \pm 0.2$ pb

$\sigma(\text{pp @ 8TeV}) = 5.6 \pm 0.2$ pb

N. Kidonakis, Phys. Rev. D 81 (2010) 054028 [arXiv:1001.5034]

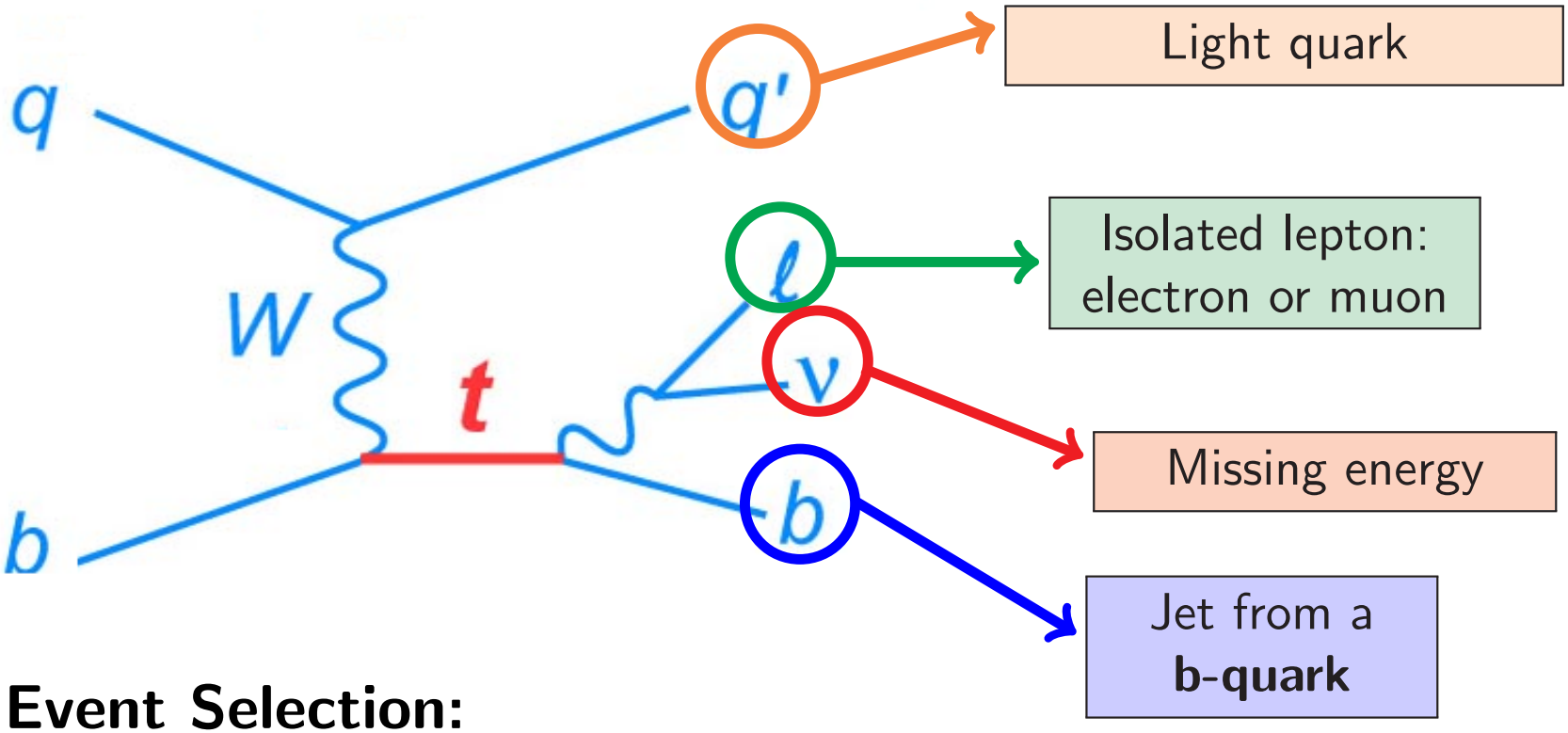
Outline

t-channel production at CMS:

- **Center of mass energy of 7 TeV**
- **Integrated luminosity of 1.17 (1.56) fb^{-1} for muon (electron)**

Measurement of the single top t-channel production cross section - **arXiv:1209.4533**

Event Selection



Event Selection:

- **one** isolated lepton: electron (muon) with $p_T > 30$ (20) GeV
- *veto* on a loose lepton with $p_T > 15$ (10) GeV
- **exactly** two jets
- one of the two jets is **b-tagged**
- $\mathbf{E_T^{miss}}$ ($\mathbf{M_T}$) greater than 35 (40) GeV for the electron (muon) channel
- **top mass window**: 130 GeV $< M_{\ell\nu b} <$ 220 GeV

Analysis Strategy

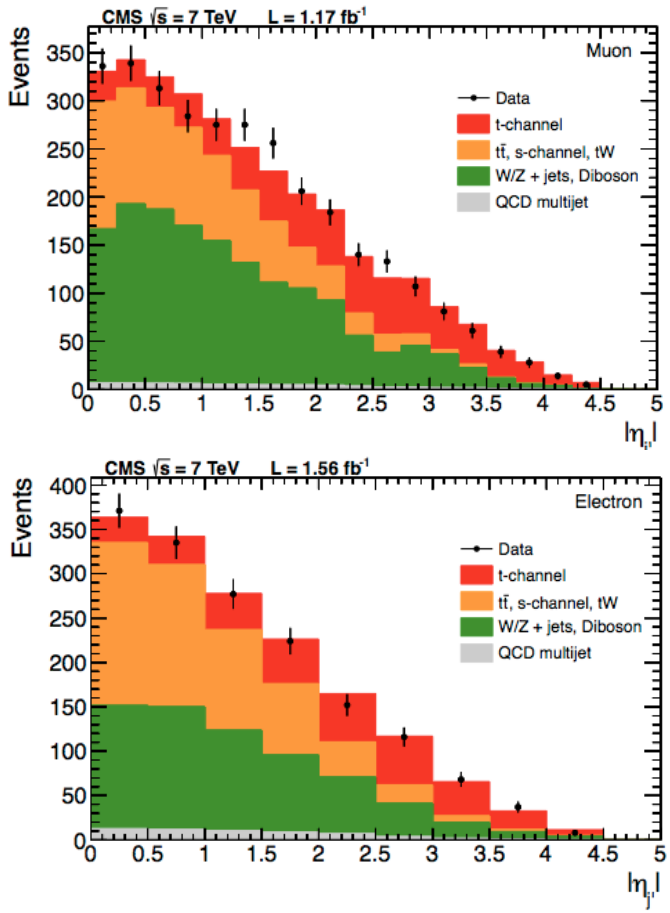
- Three different analyses: one more robust based on the study of the $|\eta_{j'}|$ **distribution**, two more precise, based on **MVA techniques**
- After the selection, the main backgrounds that remain: *top events* ($t\bar{t}$, tW and s-channel single top), QCD events, W + jets and diboson

Background evaluation:

- **QCD events** studied in a control region inverting cuts on the isolation of the leptons
- Control regions to validate the **W+jets** and **$t\bar{t}$**: *2jets-0btags*, *3jets-2btags*, *4jets-1btags* and *4jets-2btags*
- $|\eta_{j'}|$ analysis determines **W+jets** from data: $|\eta_{j'}|$ distribution taken subtracting from data all other processes distributions, in the SB (SideBand, outside the *top mass* $M_{\ell\nu b}$ *window*)
- **Other sources of background** taken from MC

Cross Section measurement - $|\eta_{j'}|$ analysis (I)

- An unbinned maximum likelihood fit is performed on the $|\eta_{j'}|$ distribution
- Simultaneous fit in μ and e channels performed
- Free parameters of the fit are the yields of the signal and background
- QCD yield and template constrained to the one obtained from the control samples in data
- W+jets template taken from data in the SB of $M_{\ell\nu b}$



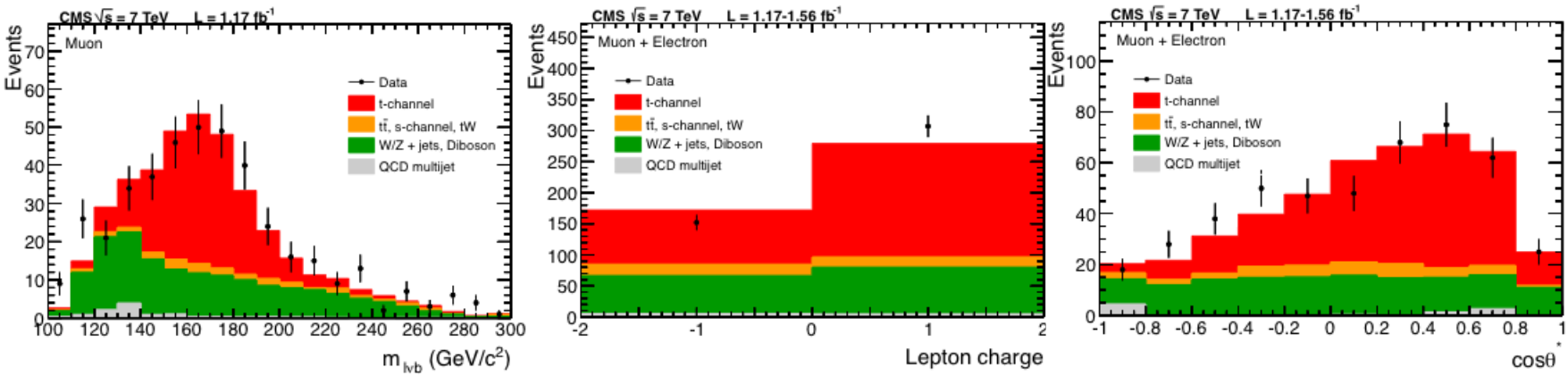
$$\sigma_{t\text{-}channel}(muon) = 73.3 \pm 10.4(stat + syst + lum) \pm 4.0(theor)\ pb$$
$$\sigma_{t\text{-}channel}(electron) = 61.6 \pm 13.9(stat + syst + lum) \pm 3.5(theor)\ pb$$

$$\sigma_{t\text{-}channel}(combined) = 70.0 \pm 6.0(stat) \pm 6.5(syst) \pm 3.6(theor) \pm 1.5(lum)\ pb$$

Cross Section measurement - $|\eta_{j'}|$ analysis (II)

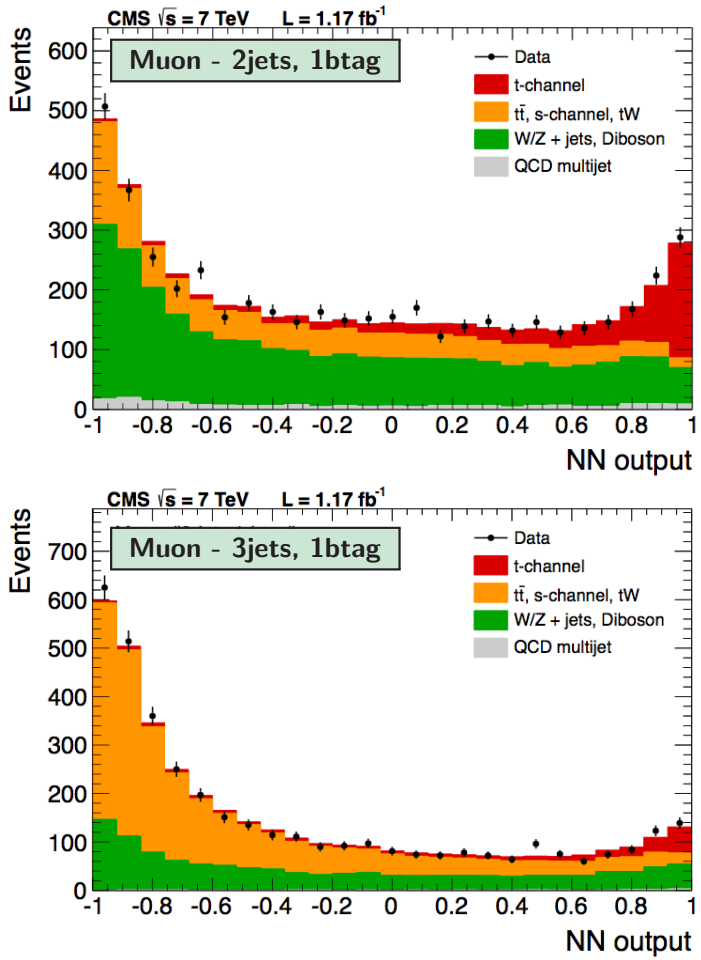
Theory/data agreement tested in a **highly enriched signal region**, i.e. $|\eta_{j'}| > 2.8$

- reconstructed top-quark mass $\mathbf{m_{\ell\nu b}}$
- **charge** of the lepton: the top cross section is $\sim$ a factor two larger than the antitop cross section
- distribution of $\mathbf{\cos\theta^*}$, with θ^* angle between lepton and non-b-tagged jet, in the reconstructed top rest frame: top quarks are almost 100% polarized due to the V-A coupling



Cross Section measurement - **NN analysis**

- Several kinematic variables are combined into a single discriminant by applying an NN technique
- Six categories are simultaneously used for the measurement of the signal cross section: *n-jets m-btag*, with n=2,3,4 and m=1,2
- The variables with the highest ranking are $|\eta_{j'}|$, m_T and the total transverse energy of the event
- Systematic uncertainties marginalized in the fit

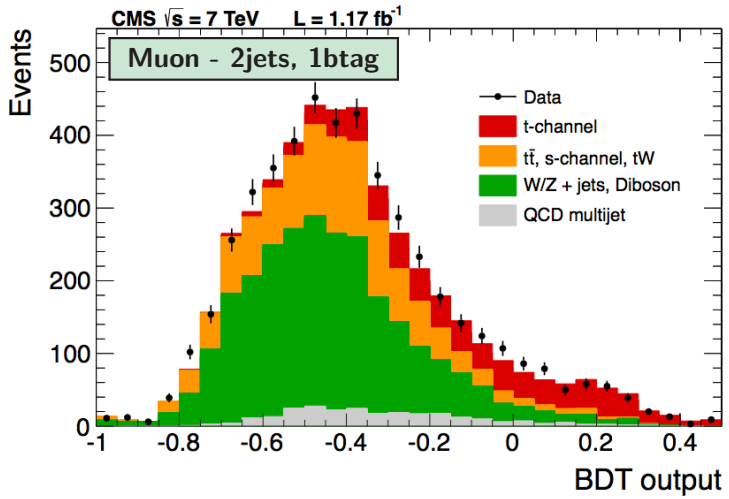


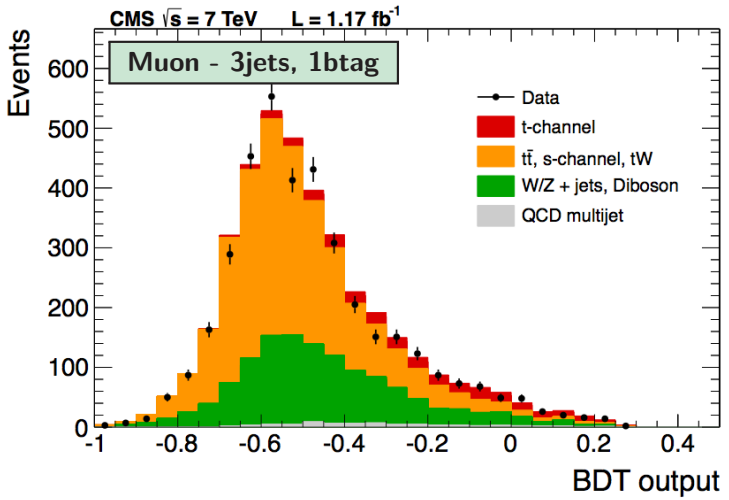
$$\sigma_{t\text{-channel}}(muon) = 66.6^{+7.0}_{-6.6}(stat + syst + lum) \pm^{+6.4}_{-3.5}(theor)\ pb$$
$$\sigma_{t\text{-channel}}(electron) = 66.4^{+8.4}_{-7.9}(stat + syst + lum) \pm^{+5.4}_{-5.4}(theor)\ pb$$

$$\sigma_{t\text{-channel}}(combined) = 66.6 \pm 4.0(stat) \pm 3.3(syst)\ ^{+3.9}_{-3.3}(theor) \pm 1.5(lum)\ pb$$

Cross Section measurement - **BDT analysis**

- Eleven observables are chosen based on their power to discriminate between signal and background events
- Also here the six categories are simultaneously used for the measurement of the signal cross section: *n-jets m-btag*, with n=2,3,4 and m=1,2
- Between the eleven variables: $|\eta_{j'}|$, the invariant mass of the jets of the event, angular separation between the two leading jets
- Systematic uncertainties marginalized in the fit





$$\sigma_{t\text{-}channel}(muon) = 61.6 \pm 13.9(stat + syst + lum) \pm 3.5(theor)\ pb$$
$$\sigma_{t\text{-}channel}(electron) = 73.3 \pm 10.4(stat + syst + lum) \pm 4.0(theor)\ pb$$

$$\sigma_{t\text{-}channel}(combined) = 70.0 \pm 6.0(stat) \pm 6.5(syst) \pm 3.6(theor) \pm 1.5(lum)\ pb$$

Systematic Uncertainties

- **Jet energy Scale**: $\sim 4\%$ for $|\eta_{j'}|$ analysis, up to 1.9% for the NN and $\sim 0.6\%$ for the BDT analyses $\longrightarrow$ evaluated varying the jet 4-momenta in simulated events
- **b-tagging**: $\sim 3\%$ for the $|\eta_{j'}|$ analysis, $\sim 3\%$ for the NN and $\sim 1.6\%$ for the BDT analyses $\longrightarrow$ data/MC scale factors
- **Background normalization**: from theoretical uncertainties for diboson, tW and s-channel processes and from data for $t\bar{t}$, W/Z+jets and QCD events
- **Scale uncertainty** $\longrightarrow$ from dedicated samples in which different scales are used

Combined Result

- The results of the three analyses are combined using the **BLUE (Best Linear Unbiased Estimator) method**
- Statistical correlations between each pair of measurements estimated by generating pseudo-experiments: 60% between NN and $|\eta_{j'}|$, 69% between BDT and $|\eta_{j'}|$, and 74% between NN and BDT
- Correlations for jet energy scale and resolution, b tagging, and E_T^{miss} modelling between $|\eta_{j'}|$ and the two multivariate analyses are taken as 20%
- Other uncertainties taken fully correlated

$$\sigma_{\text{t-channel}} = 67.2 \pm 3.7(\text{stat}) \pm 3.0(\text{syst}) \pm 3.5(\text{theor}) \pm 1.5(\text{lum}) \text{ pb}$$

- Single-top cross section measurement as a test of the CKM matrix unitarity
- Assuming $|V_{td}|$ and $|V_{ts}|$ much smaller than $|V_{tb}|$, this can be measured from $|V_{tb}| = \sqrt{\sigma_{exp}/\sigma_{th}}$ where σ_{th} is the SM prediction with $|V_{tb}| = 1$

$$|f_{LV}\, V_{tb}| = 1.020 \pm 0.046(\text{exp}) \pm 0.017(\text{theor})$$
$$0.92 < |V_{tb}| < 1, \text{ at 95\% CL}$$

with f_{LV} for *anomalous coupling*, =1 in the SM

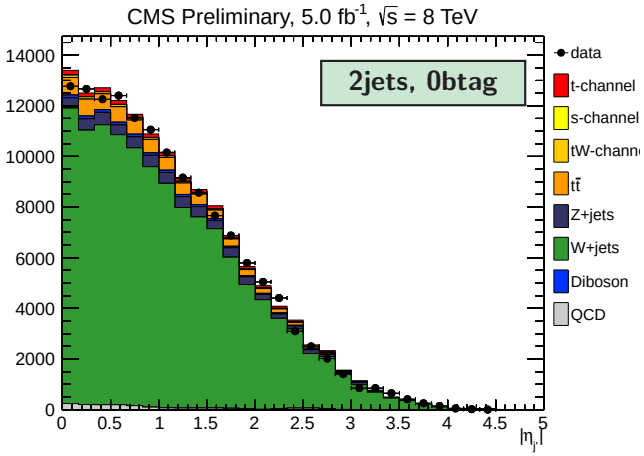
t-channel production at CMS:

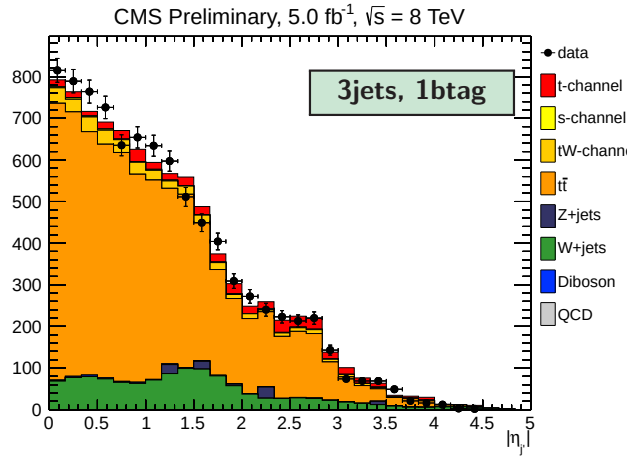
- **Center of mass energy of 8 TeV**
- **Integrated luminosity of 5.0 $\mathbf{fb}^{-1}$**

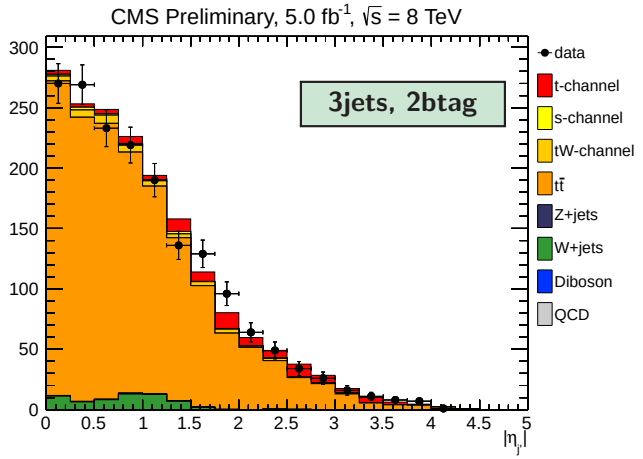
Measurement of the single-top-quark t-channel cross section in pp collisions at $\sqrt{s} = 8$ TeV - **CMS PAS TOP-12-011**

Analysis Strategy

- The analysis strategy follows the $|\eta_{j'}|$ *analysis* just described
- The results presented here focalize on the muon channel only
- Optimization of the signal selection is needed, due to the different center of mass energy, luminosity and to the higher pile-up:
  - the muon must have a p_T greater than 26 GeV
  - the transverse mass $m_T(W)$ is requested to be greater than 50 GeV
- Same background estimation methods as 7 TeV analysis

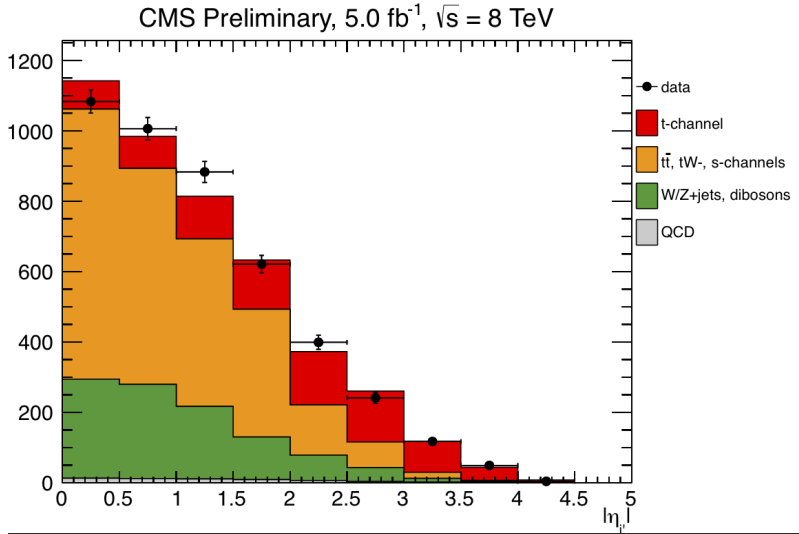


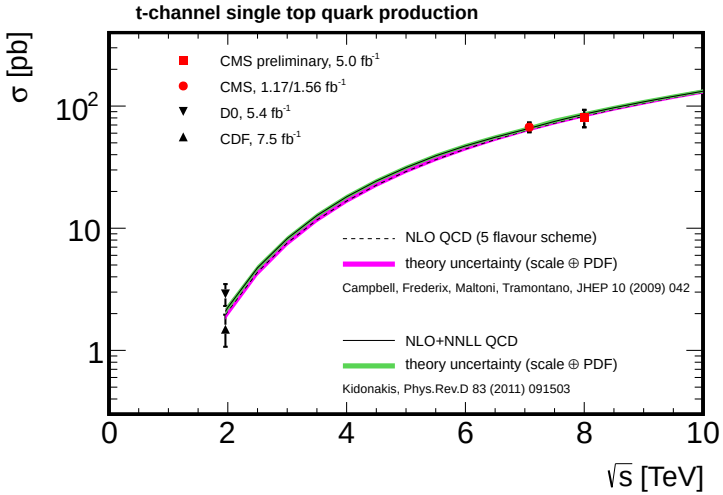




t-channel production at 8 TeV

Signal yield extracted from a fit to the observed $|\eta_{j'}|$ distribution in the *2jet-1tag* region



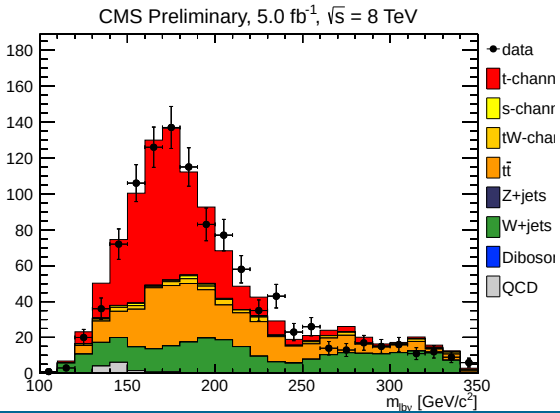


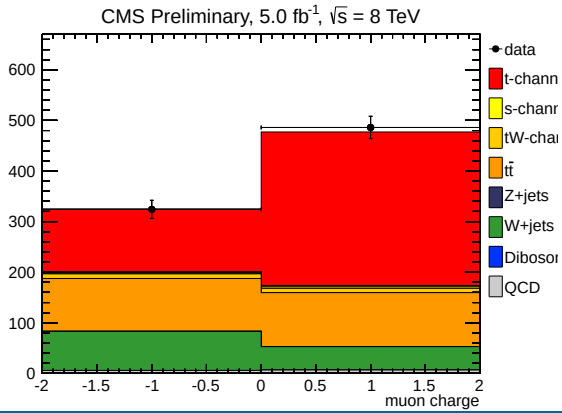
$$\sigma_{\text{t-ch}} = 80.1 \pm 5.7(\text{stat}) \pm 11.0(\text{syst}) \pm 4.0(\text{lum})\ \text{pb}$$

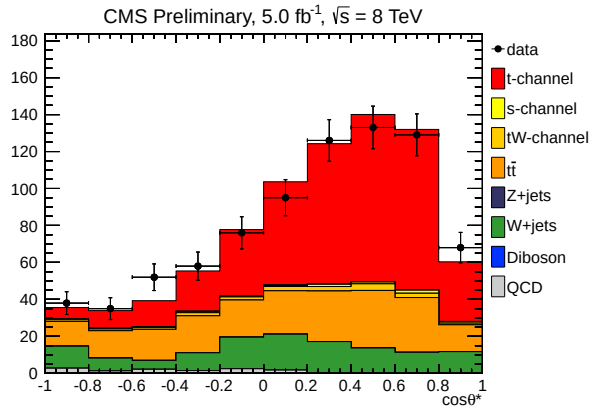
$$|V_{tb}| = 0.96 \pm 0.08(\text{exp}) \pm 0.02(\text{theor})$$

$$0.81 < |V_{tb}| < 1 \text{ at } 95\%\ \text{CL}$$

$$R_{8\text{TeV}/7\text{TeV}} = 1.14 \pm 0.12(\text{stat}) \pm 0.14(\text{syst})$$







t-channel production at ATLAS:

- **Center of mass energy of 7 TeV**
- **Integrated luminosity of 1.04 fb^{-1}**

Measurement of the t-channel single top-quark production cross section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector - **arXiv:1205.3130**

Signal Selection

Measurement performed using a **neural network** and cross-checked with a **cut-based method**

Signal Selection:

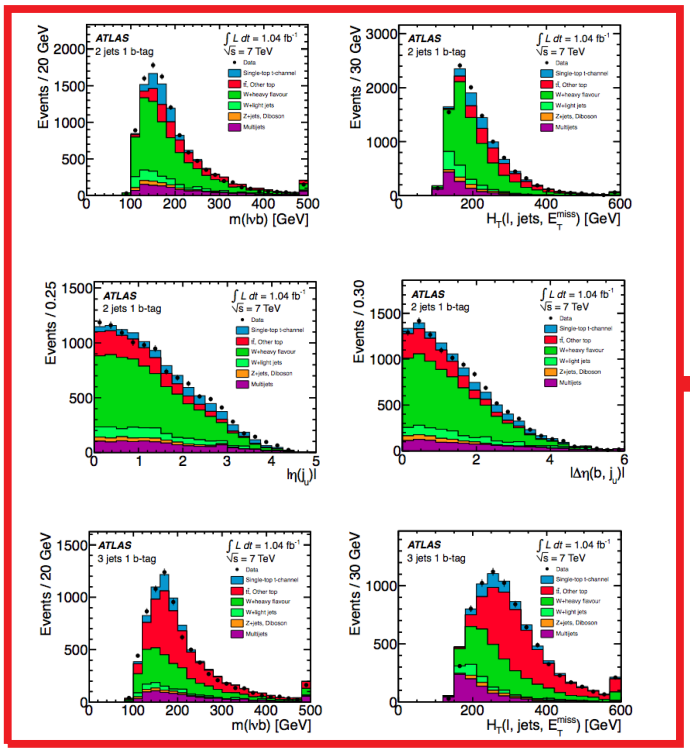
- Exactly one **charged lepton**, e or μ, with a E_T (p_T) greater than 25 GeV for electron (muon)
- Exactly **two or three jets** in which exactly one is *b-tagged*
- Transverse missing energy, $\mathbf{E_T^{miss}}$, greater than 25 GeV
- Cut on the **transverse mass of the W boson**, $m_T(W) > (60\ GeV\ - E_T^{miss})$

Estimation of the background:

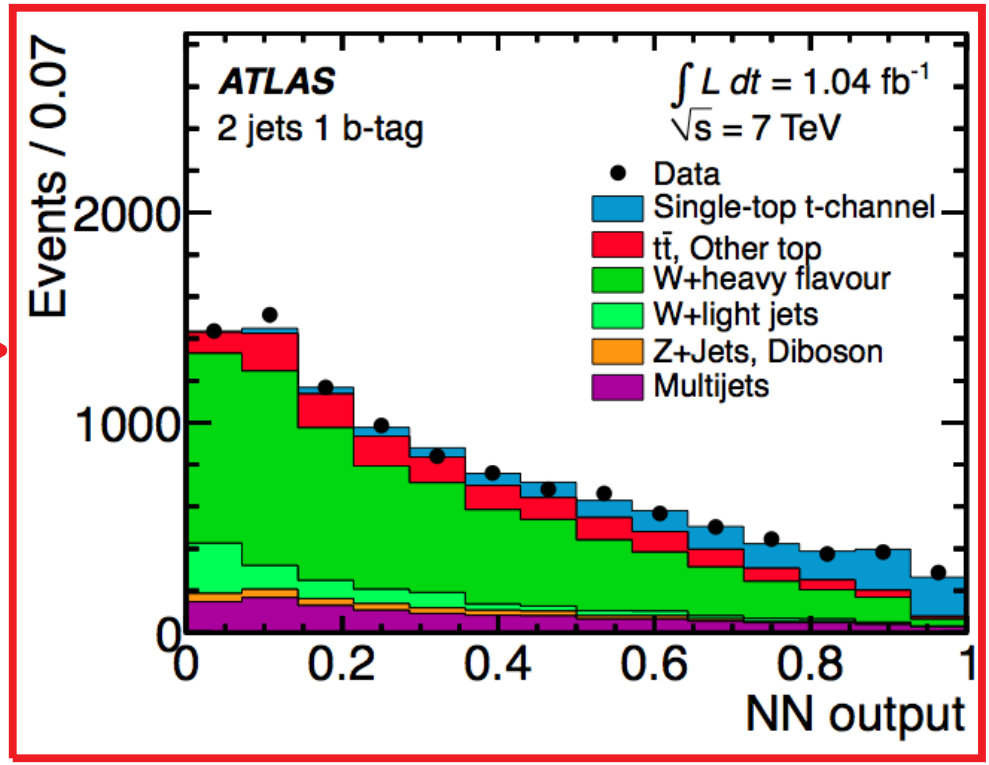
- **QCD events** $\longrightarrow$ binned maximum likelihood fit to the E_T^{miss} distribution in the data
- **W+jets events** $\longrightarrow$ *scale factors* calculated taking the *distributions* from MC and normalization from the NN output fit
- **Other sources of background** (in which the greatest contribution is $t\bar{t}$) $\longrightarrow$ MC samples

Signal and background discrimination

- To **separate** signal from background events **several variables** are combined into one discriminant by employing a **neural network (NN)**
- For 2 jets sample, the most discriminant: $m(\ell\nu b)$, $|\eta(j_u)|$, $E_T(j_u)$
- For 3 jets sample, the most discriminant: $m(j_1, j_2)$, $m(\ell\nu b)$, $|\Delta\eta(j_1, j_3)|$



NN



- 12 variables for the *2 jets tagged* sample
- 18 variables for the *3 jets tagged* sample

Normalized distributions of the neural network output in the *2-jets* (in figure) and *3-jets* samples

Systematic Uncertainties

- **Object modeling**: main sources due to the *jet energy scale*, $\pm 6\%$, and to the *b-tagging efficiency*, $\pm 13\%$
- **Simulation**: evaluated using dedicated samples, the main sources due to the *initial and final state radiations*, $\pm 14\%$
- **Theoretical cross section normalization**: for $t\bar{t}$, tW and s-channel, from theoretical uncertainties
- **Background normalization to data**:
  - $\pm 50\%$ for, QCD evaluated in high pile-up sample
  - $\pm 30\%$ ($\pm 50\%$) for W+light flavour (W+heavy flavour)
- **Luminsity**: uncertainty of $\pm 4\%$

Cross Section measurement

- A binned maximum-likelihood fit to the NN output is performed
- 2-jet and 3-jet samples are fitted simultaneously
- The measured cross section is:

$$\sigma_{\text{t-ch}} = 83 \pm 4(\text{stat})^{+20}_{-19}(\text{syst}) \text{ pb}$$

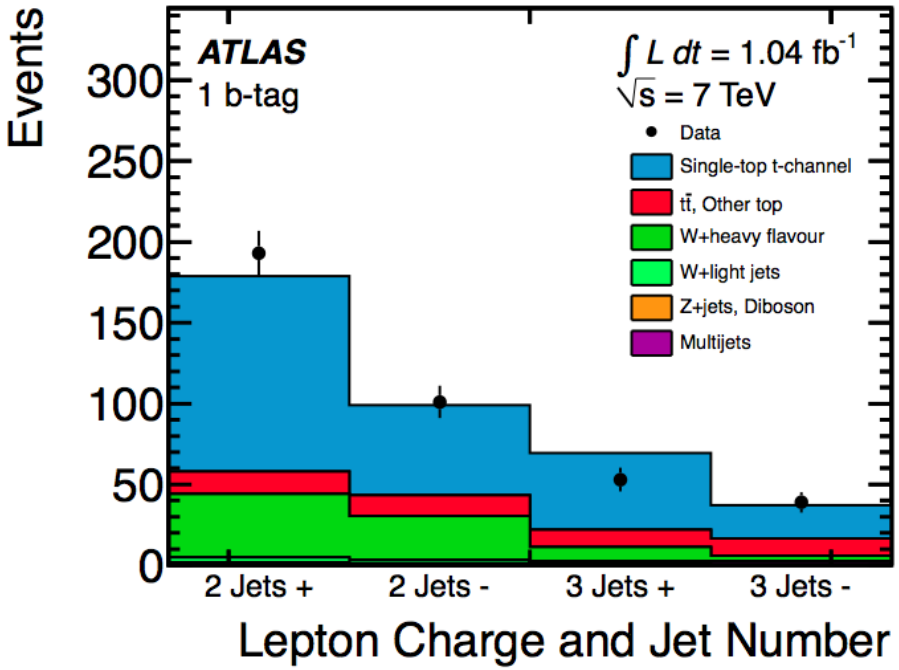
$$|V_{tb}| = 1.13^{+0.14}_{-0.13}(\text{stat}) \pm 0.02(\text{theor})$$

$$0.75 < |V_{tb}| < 1 \text{ at } 95\% \text{ CL}$$

Cut-based method

Additional selections are applied:

- $\eta(\mathbf{j_u}) > \mathbf{2}$, where j_u is the pseudorapidity of the hightest p_T untagged jet
- $\mathbf{H_T} > \mathbf{210GeV}$, where H_T is the scalar sum of the transverse momenta of the lepton, jets, and E_T^{miss}
- $\mathbf{150\ GeV} < \mathbf{m(l\nu b)} < \mathbf{190\ GeV}$
- $|\mathbf{\Delta\eta(b, j_u)}| > \mathbf{1}$ for the 2-jets sample
- $\mathbf{m(j_1, j_2, j_3)} > \mathbf{450\ GeV}$ for the 3-jets sample



Individual measurements of the top-quark and top-antiquark cross sections are provided:

$$\sigma_{\text{t-ch}}(\text{t}) = 59^{+18}_{-16}\ \text{pb}$$

$$\sigma_{\text{t-ch}}(\bar{\text{t}}) = 33^{+13}_{-12}\ \text{pb}$$

$$\sigma_{\text{t-ch}} = 92^{+29}_{-26}\ \text{pb}$$

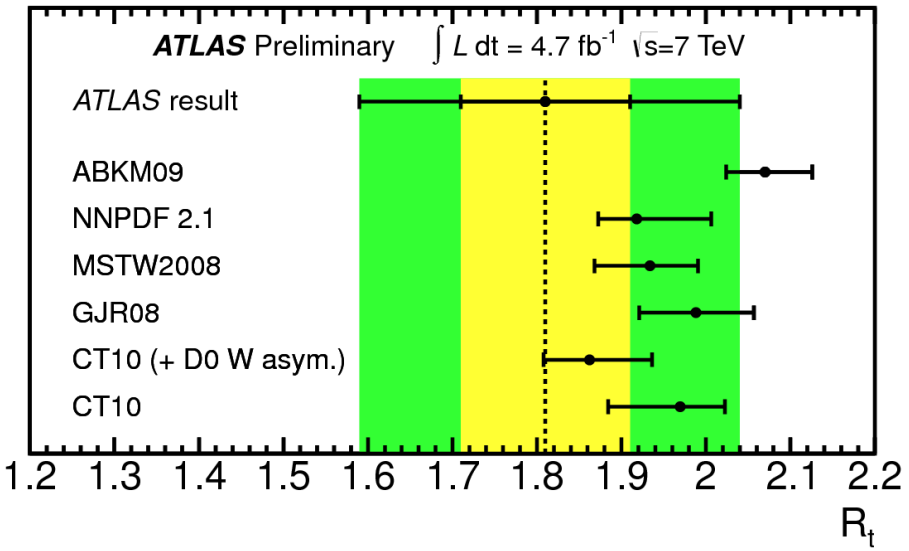
t-channel ratio analysis

- ATLAS provide a measurement of the ratio $\mathbf{R_t = \sigma_{t\text{-}ch}(t)/\sigma_{t\text{-}ch}(\bar{t})}$
- 4.7 fb^{-1} with a center-of-mass energy of 7 TeV
- The analysis strategy follows the NN analysis just described

$$\mathbf{\sigma_{t\text{-}ch}(t) = 53.2 \pm 1.7(stat) \pm 10.6(syst)\ pb}$$
$$\mathbf{\sigma_{t\text{-}ch}(\bar{t}) = 29.5 \pm 1.5(stat) \pm 7.3(syst)\ pb}$$

The **ratio** R_t between the two cross sections is measured to be:

$$\mathbf{R_t = 1.81 \pm 0.10(stat)^{+0.21}_{-0.20}(syst)}$$



Measurement of t-channel single top-quark and top-antiquark cross-sections and their ratio in pp collisions at $\sqrt{s} = 7$ *TeV* - ATLAS-CONF-2012-056

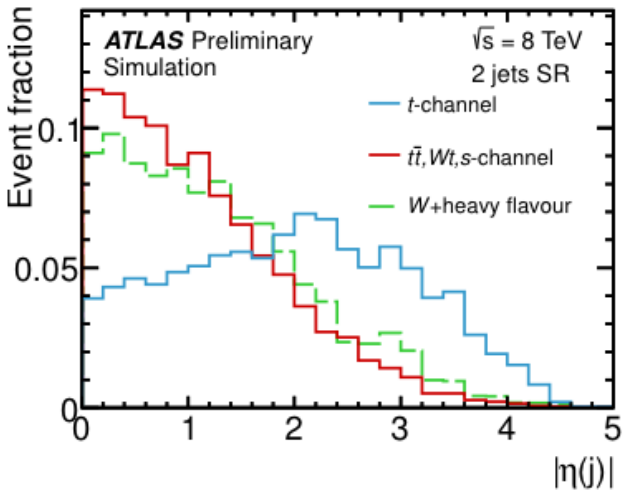
t-channel production at ATLAS:

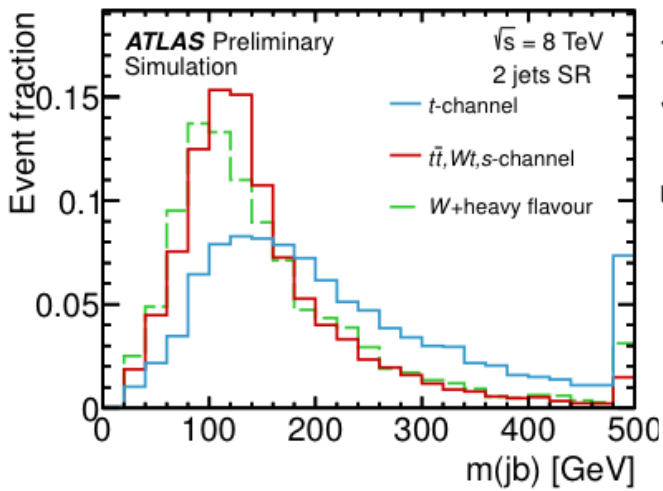
- **Center of mass energy of 8 TeV**
- **Integrated luminosity of 5.8 fb^{-1}**

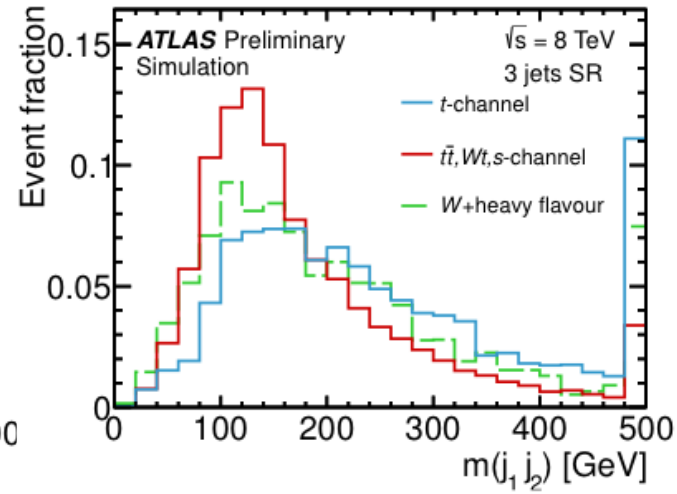
Measurement of t-Channel Single Top-Quark Production in pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector - **ATLAS-CONF-2012-132**

Cross Section at 8 TeV

- Same analysis strategy as just described
- Same object selection as 7 TeV analysis, but:
  - Different cut on the transverse W mass
    $m_T(W) > 50$ GeV
- **Only QCD** events estimated from data-driven study, while the other processes are taken from MC

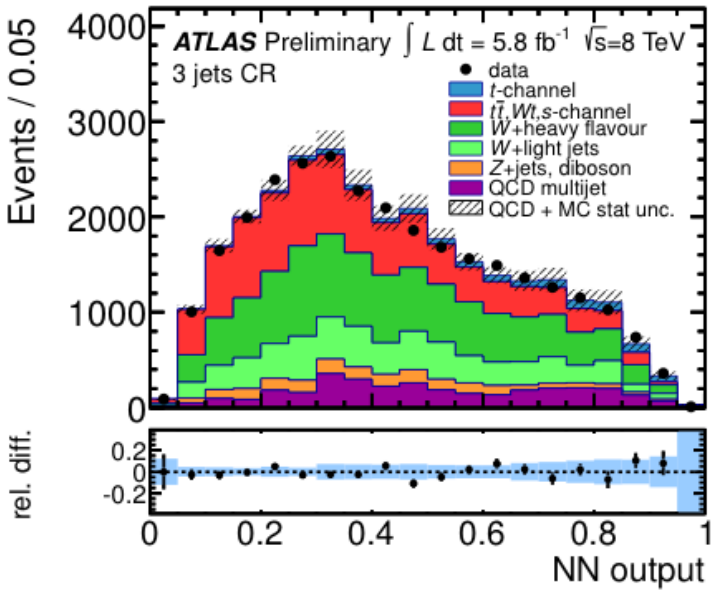


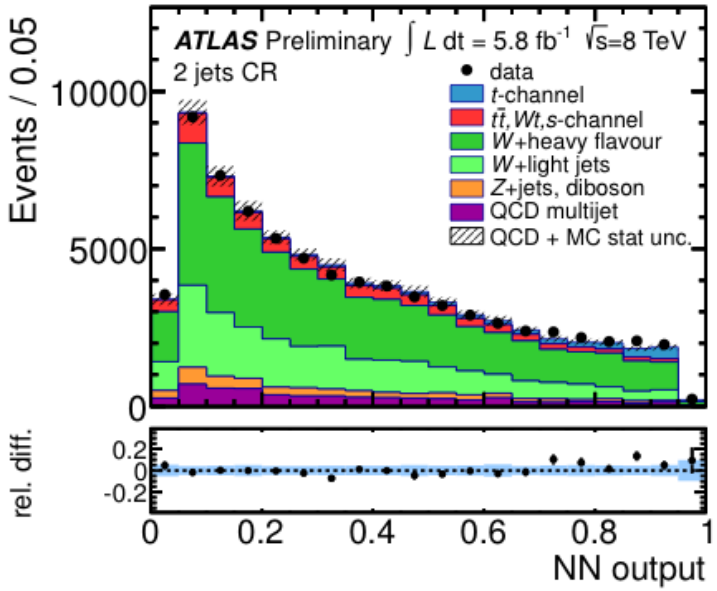




Cross Section at 8 TeV

A binned maximum-likelihood fit to the NN output is performed

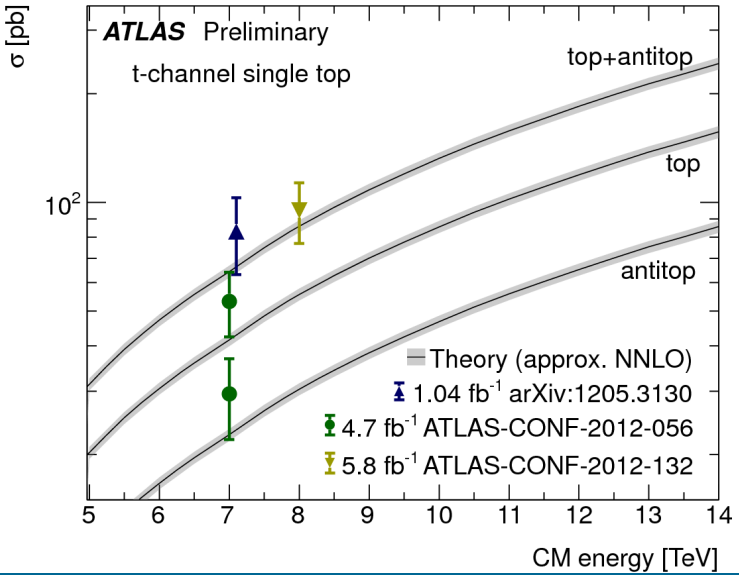




$$\sigma_{\text{t-channel}} = 95 \pm 2(\text{stat}) \pm 18(\text{syst}) \text{ pb}$$

$$|V_{tb}| = 1.04^{+0.10}_{-0.11}$$

$$0.80 < |V_{tb}| < 1 \text{ at 95\% CL}$$



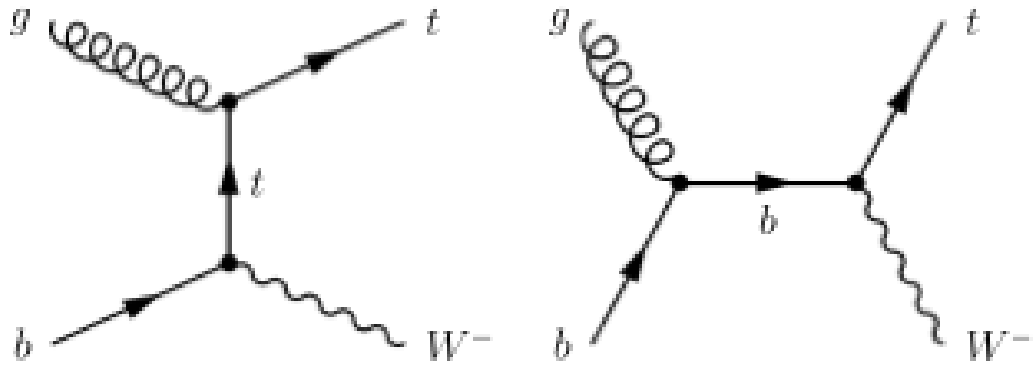
tW production at CMS:

- **Center of mass energy of 7 TeV**
- **Integrated luminosity of 4.9 fb^{-1}**

Evidence for associated production of a single top quark and W boson in pp collisions at 7 TeV - **arXiv:1209.3489**

tW @ CMS

tW channel is inaccessible at Tevatron $\rightarrow$ process observed for the first time at ATLAS and CMS



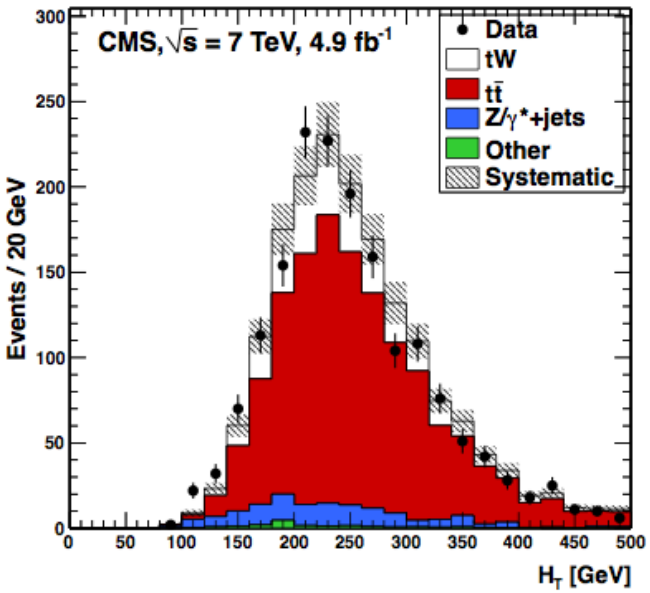
Event Selection:

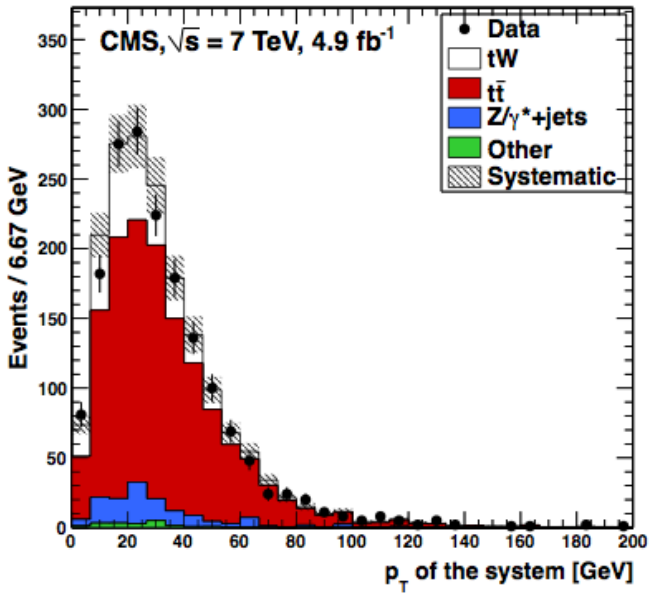
- Exactly **two isolated leptons** with opposite charge, with a p_T greater than 20 GeV $\rightarrow$ three possible channels: ee, $e\mu$ and $\mu\mu$
- Exactly **one b-tagged jet**
- **Transverse missing energy** greater than 30 GeV (for ee and $\mu\mu$ events)
- Transverse missing energy, measured with the only **charged particles**, greater than 30 GeV (for ee and $\mu\mu$ events)
- Cut on events with $M_{\ell\ell} < 20\ GeV$: it **reduces Drell-Yan** events
- Cut on events with M_{ee} or $M_{\mu\mu}$ between 81 and 101 GeV: it **reduces Z** events

Multivariate analysis (I)

A multivariate analysis based on boosted decision trees (BDT) is used, in which four variables are chosen to train the BDT

1. $\mathbf{H_T}$, defined as the scalar sum of the transverse momenta of the leptons, jet and E_T^{miss}
2. $\mathbf{p_T}$ **of the system** formed by the two leptons, the jet and the E_T^{miss}
3. $\mathbf{p_T}$ of the leading jet
4. **the angular distance** between the direction associated to the E_T^{miss} and the closest of the two selected leptons

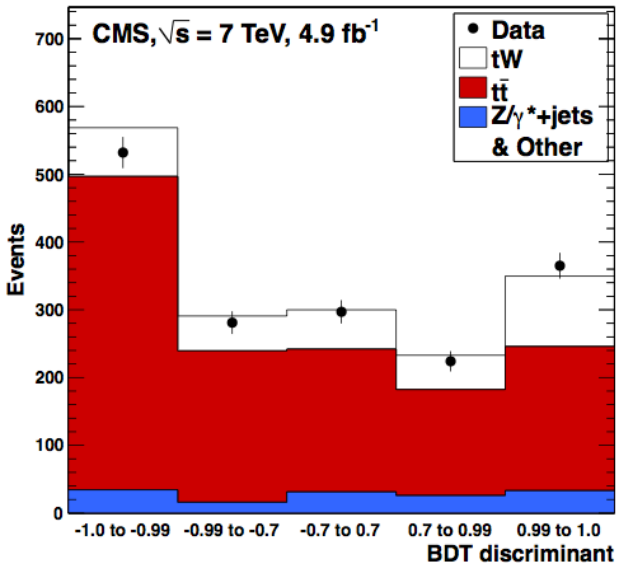




Multivariate analysis (II)

- Two main sources of background that remain after the selection
  1. **Z/γ^* + jets**: data/MC scale factor from E_T^{miss} distribution from events in Z resonance
  2. **$t\bar{t}$**: taken from MC
- A binned likelihood fit is performed on the distributions of the BDT discriminant for each of the three dilepton channels in the signal region (1j1t) and control regions (2j1t and 2j2t)

- Two $t\bar{t}$ enriched regions included to control rate of this background and b-tagging efficiency
- The dominant **systematic uncertainties** are:
  1. **tW**: *b-tagging efficiency* (3-6%)
  2. **$t\bar{t}$**: *b-tagging efficiency* (1.5-4%), *factorization/renormalization scale* (up to 11%) and jet energy scale (7%)



Significance of signal with respect to background-only hypotheses of 4σ

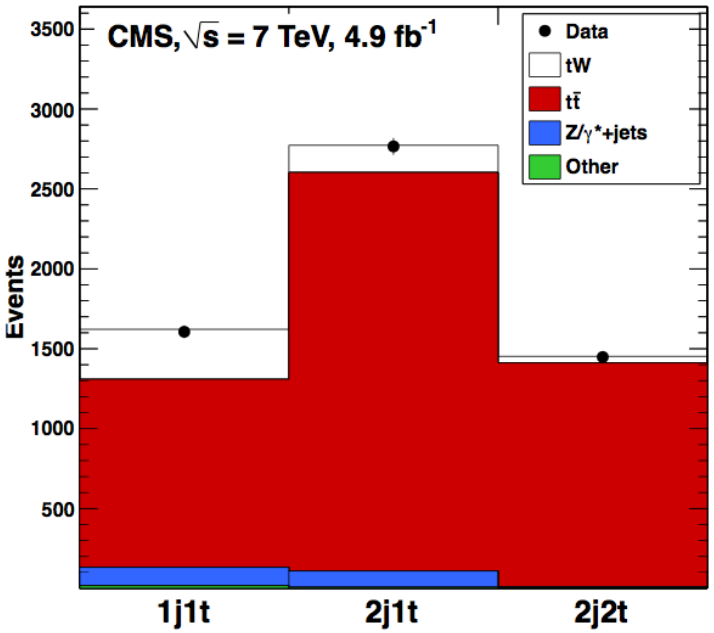
$$\sigma(\mathrm{tW\,production}) = 16^{+5}_{-4}\ \mathrm{pb}$$

$$|V_{tb}| = 1.01^{+0.16}_{-0.13}(\mathrm{exp})^{+0.03}_{-0.04}(\mathrm{th})$$

$$0.79 < |V_{tb}| < 1 \text{ st 90 \% CL}$$

Count-based analysis (cross-check)

- Additional cut of $H_T > 60$ GeV in the $e\mu$ channel
- Fit in the three signal and control samples
- The count-based analysis measures a cross section that **well agrees with the BDT analysis measurement**
- The observed significance of the tW signal with this approach is 3.5σ



The results of this **cross check** is:

$$\sigma(\text{tWproduction}) = 15 \pm 5 \text{ pb}$$

tW production at ATLAS:

- **Center of mass energy of 7 TeV**
- **Integrated luminosity of 2.05 fb^{-1}**

Evidence for the associated production of a W boson and a top quark in ATLAS at $\sqrt{s} = 7$ TeV - **Phys. Lett. B 716 (2012) 142-159**

Signal Selection:

- Exactly two *tight* opposite-sign leptons so that three categories are present: ee, $e\mu$ and $\mu\mu$
- Veto on an additional lepton
- At least one jet in the event
- **NO** b-tagging is applied on the jets
- Missing transverse momentum greater than 50 GeV
- In the ee and $\mu\mu$ events $\rightarrow$ a Z veto is applied
- Veto on the $Z \rightarrow \tau\tau$: $\Delta\phi(\ell_1, \vec{E_T^{miss}}) + \Delta\phi(\ell_2, \vec{E_T^{miss}}) > 2.5$

Estimation of the background:

- $t\bar{t}$, diboson: MC simulation
- Drell-Yan, $Z \rightarrow \tau\tau$, *fake dileptons*: data-driven procedure

Data-driven estimations

Fake dileptons

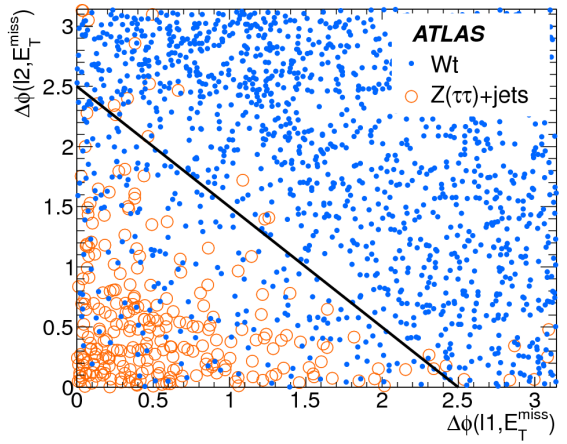
- A *tight-to-loose* method is applied
- Efficiency for *loose* leptons to be reconstructed as *tight* is measured:
  - in a multijet-enriched sample for fake leptons
  - in a $Z \to \ell\ell$ sample for real leptons

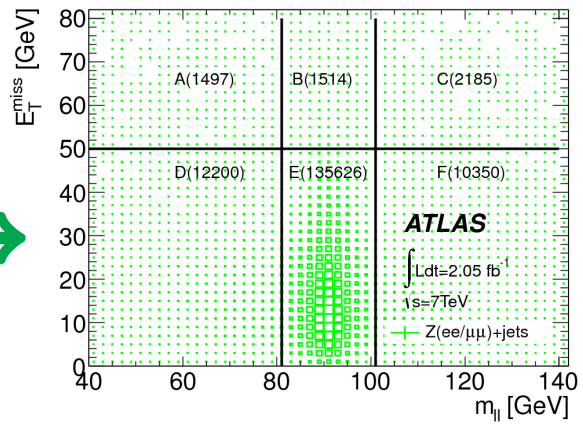
Drell-Yan

- Four background-enriched regions are defined for the ee and $\mu\mu$ events
- These regions are defined applying orthogonal cuts on the $m_{\ell\ell}$ and E_T^{miss} variables
- Scale factor for the signal region is computed from the control regions

$Z \to \tau\tau$ events

A scale factor is measured in a control sample defined exploiting the cut on the sum $\Delta\phi(\ell_1, \vec{E}_T^{miss}) + \Delta\phi(\ell_2, \vec{E}_T^{miss})$



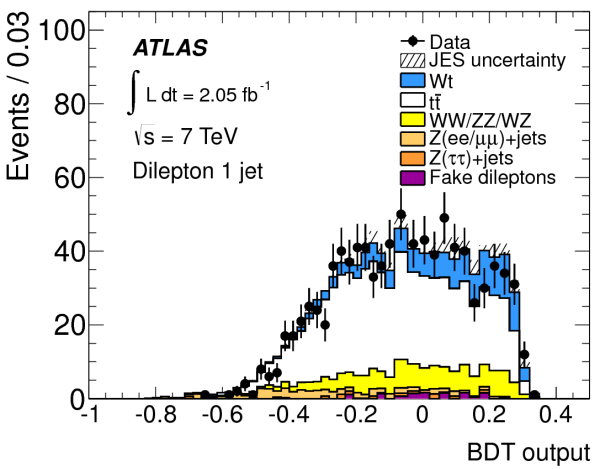


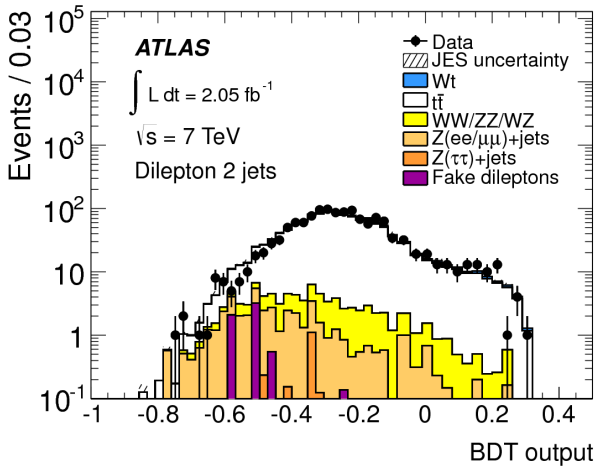
Cross Section measurement

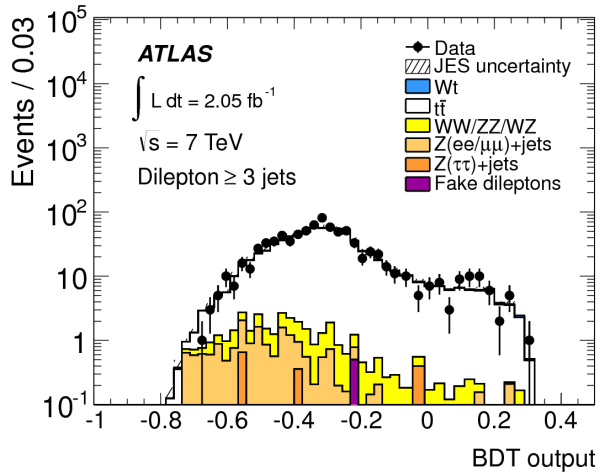
- **Multivariate approach** based on *boosted decision trees* (BDT) is used
- Twenty-two variables used as **input to the BDT**
- **Main systematic** is due to the *jet energy scale* ($\pm 16\%$)
- The **measurement of the cross section** is obtained from a fit to the three BDT output distributions
- Observed significance of 3.3σ

$$\sigma(tW) = 16.8 \pm 2.9(stat) \pm 4.9(syst)\ pb$$

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







s-channel production at ATLAS:

- **Center of mass energy of 7 TeV**
- **Integrated luminosity of 0.70 fb^{-1}**

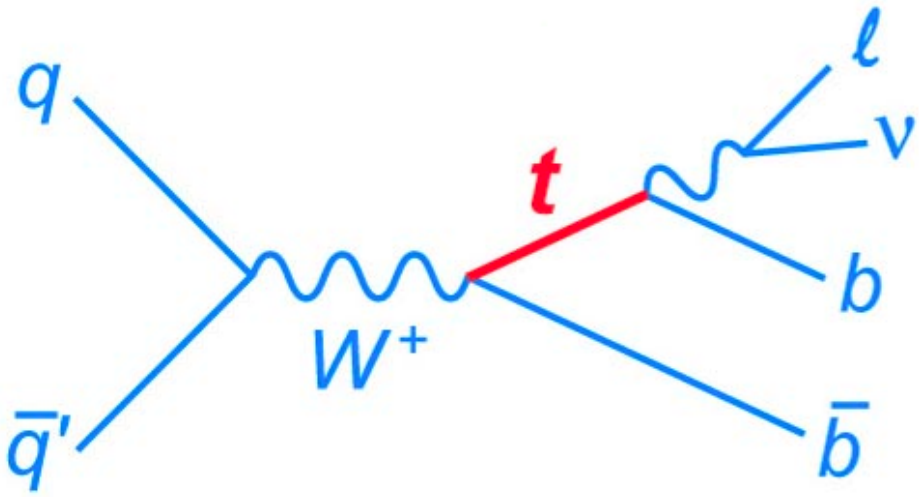
Search for s-channel Single Top-Quark Production in pp Collisions at $\sqrt{s} = 7$ TeV - **ATLAS-CONF-2011-118**

s-channel production

- The s-channel production mode has the lowest cross section between the production modes of the single top quark

$$\sigma(\text{s-ch}) \sim 5\text{pb}$$

- The search for it is interesting since it is sensitive to several models of new physics, like W' bosons or a charged Higgs boson



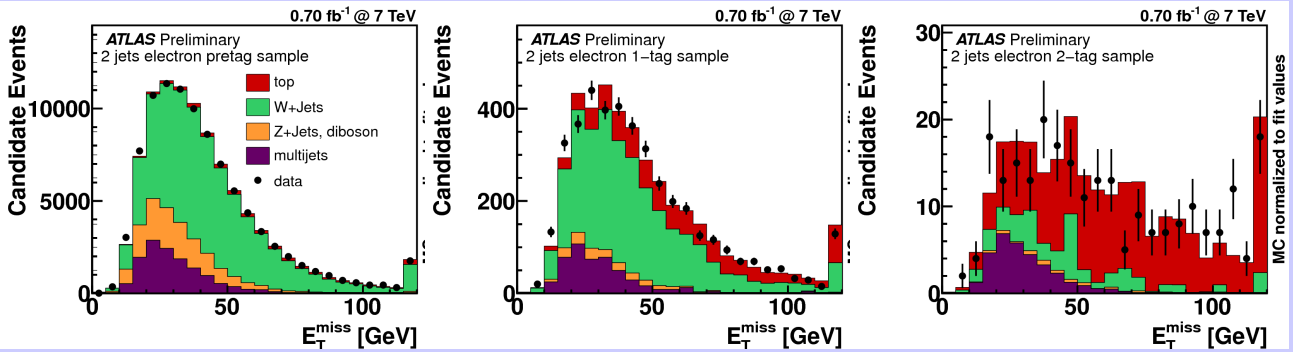
Signal Selection:

- Exactly one electron or muon with a p_T greater than 25 GeV
- Missing transverse energy greater than 25 GeV
- $m_T(W) + E_T^{miss} > 60 GeV$
- Exactly two jets:
  1. **pretag sample**: no b-tagging
  2. **1-tag sample**: only 1 jet b-tagged
  3. **2-tag sample**: both jets b-tagged

Background evaluation

Multijet background:

- **Normalization** taken from a fit to the E_T^{miss} distribution for jet-lepton
- **Shape** taken from the the E_T^{miss} for *non-isolated* lepton events



W+jets background:

- Number of W+jets events in **data** $\rightarrow$ difference between observed data and non-W+jets events from MC, in each jet multiplicity bin
- The **scale factor** is measured as the ratio between number of W+jets in data and number of W+jets in MC

Other background:

Z+jets, WW, WZ and ZZ, the $t\bar{t}$ and the Wt and t-channel single top background contributions are taken from MC

Cross Section determination

- The measurement of the s-channel single top-quark signal is **challenging** since it is **overwhelmed** by large background processes
- After the preselection **tighter requirements** are applied in order to **isolate** the s-channel signal
- Main systematics: MC generator modeling ($-60/+20\%$), multijet normalization ($\pm 40\%$)

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

	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

σ(s-ch) < 26.5 pb at 95% CL

Conclusion

- An overview of the measurements made at the LHC for the **single top-quark production** has been given
- Single top can happen via **three production mechanisms**
- Several analyses have been exploited to separate and measure the three mechanisms
- Measurements of CMS and ATLAS show a good agreement between them and with the SM prediction
- Limits on $|V_{tb}|$ from LHC competitive with those from Tevatron

	Theor.	**CMS**	**ATLAS**
t-channel	$64.6^{+2.7}_{-2.0}\ pb$	$67.2 \pm 6.1\ pb$	$82.7 \pm 18.1\ pb$
t-ch (8 TeV)	$87.8^{+3.4}_{-1.9}\ pb$	$80.1 \pm 13.0\ pb$	$95.1 \pm 18.1\ pb$
tW	$15.7 \pm 1.1\ pb$	$16^{+5}_{-4}\ pb$	$16.8 \pm 5.7\ pb$
s-channel	$4.6 \pm 0.2\ pb$	-	$< 26.5\ pb$

Reference

CMS:

- *Measurement of the single top t-channel production cross section* - arXiv:1209.4533
- *Measurement of the single-top-quark t-channel cross section in pp collisions at* $\sqrt{s} = 8$ *TeV* - CMS PAS TOP-12-011
- *Evidence for associated production of a single top quark and W boson in pp collisions at 7 TeV* - arXiv:1209.3489

ATLAS:

- *Measurement of the t-channel single top-quark production cross section in pp collisions at* $\sqrt{s} = 7$ *TeV with the ATLAS detector* - arXiv:1205.3130
- *Measurement of t-Channel Single Top-Quark and Top-Antiquark Cross-sections and their ratio in pp Collisions at* $\sqrt{s} = 7$ *TeV* - ATLAS-CONF-2012-056
- *Measurement of t-Channel Single Top-Quark Production in pp Collisions at* $\sqrt{s} = 8$ *TeV with the ATLAS detector* - ATLAS-CONF-2012-132
- *Evidence for the associated production of a W boson and a top quark in ATLAS at* $\sqrt{s} = 7$ *TeV* - Phys. Lett. B 716 (2012) 142-159
- *Search for s-channel Single Top-Quark Production in pp Collisions at* $\sqrt{s} = 7$ *TeV* - ATLAS-CONF-2011-118


THANK YOU

BACK UP

$|V_{tb}|$ measurement

Experiment ($\int Ldt$)	Energy	Channel	$\|V_{tb}\|$ unconstrained	$\|V_{tb}\|$ constrained
CDF + D0 (3.2 fb^{-1} and 2.3 fb^{-1}) [19]	1.96 TeV	s+t	$0.88 \pm 0.07(exp) \pm 0.07(th)$	> 0.77 at 95% CL
CDF (7.5 fb^{-1}) [7]	1.96 TeV	s+t	$0.96 \pm 0.09(exp) \pm 0.05(th)$	> 0.78 at 95% CL
D0 (5.4 fb^{-1}) [20]	1.96 TeV	s+t	$1.02^{+0.10}_{-0.11}(exp+th)$	> 0.79 at 95% CL
ATLAS (1.04 fb^{-1}) [9]	7 TeV	t	$1.13^{+0.14}_{-0.13}(exp+th)$	> 0.75 at 95% CL
CMS (1.17 fb^{-1}/ 1.56 fb^{-1}) [10]	7 TeV	t	$1.020 \pm 0.046(exp) \pm 0.017(th)$	> 0.92 at 95% CL
ATLAS (2.05 fb^{-1}) [14]	7 TeV	tW	$1.03^{+0.16}_{-0.19}(exp+th)$	not reported
CMS (4.9 fb^{-1}) [15]	7 TeV	tW	$1.01^{+0.16}_{-0.13}(exp)^{+0.03}_{-0.04}(th)$	> 0.79 at 90% CL
ATLAS (5.8 fb^{-1}) [11]	8 TeV	t	$1.04^{+0.10}_{-0.11}(exp+th)$	> 0.80 at 95% CL
CMS (5.0 fb^{-1}) [12]	8 TeV	t	$0.96 \pm 0.08(exp) \pm 0.02(th)$	> 0.81 at 95% CL

Systematics (I)

Systematics in the **t-channel** analysis at 7 TeV with CMS

		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-, tW 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*-, tW 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%

Systematics (II)

Systematics in the **t-channel** analysis at 8 TeV with CMS

Uncertainty source	in pb	relative
Statistical	± 5.7	± 7.2 %
W+jets and $t\bar{t}$modeling	± 3.6	± 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	± 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%

Systematics (III)

Systematics in the **t-channel** analysis at 7 TeV with ATLAS

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

Systematics (IV)

Systematics in the **t-channel** analysis at 8 TeV with ATLAS

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

Systematics (V)

Systematics in the **tW** analysis with CMS

Systematic Uncertainty (ee/eμ/μμ)	tW (%)	$t\bar{t}$ (%)	Other processes (%)
Luminosity	2.2/2.2/2.2	2.2/2.2/2.2	2.2/2.2/2.2
Pileup modeling	2.1/0.6/0.2	1.0/0.5/0.3	4.9/1.6/3.7
Electron Trigger Efficiency	1.5/1.1/-	1.5/1.1/-	1.5/1.1/-
Muon Trigger Efficiency	-/1.1/1.5	-/1.1/1.5	-/1.1/1.5
Electron Identification	2/2/-	2/2/-	2/2/-
Muon Identification	-/1/1	-/1/1	-/1/1
b-tagging	$^{+2.6}_{-4.0}$ / $^{+4.1}_{-3.7}$ / $^{+4.1}_{-3.3}$	$^{+3.2}_{-1.1}$ / $^{+2.5}_{-3.3}$ / $^{+2.6}_{-3.4}$	$^{+3.9}_{-7.0}$ / $^{+3.4}_{-3.6}$ / $^{+3.2}_{-3.5}$
Jet Energy Scale	$^{-1.1}_{+0.4}$ / $^{-0.6}_{+1.7}$ / $^{-1.8}_{+2.1}$	$^{-4.3}_{+7.6}$ / $^{-4.7}_{+3.7}$ / $^{-3.6}_{+5.5}$	$^{+13.2}_{+1.7}$ / $^{-1.2}_{-0.1}$ / $^{+11.2}_{+10.7}$
Jet Energy Resolution	$^{+1.2}_{+1.4}$ / $^{+0.1}_{+0.2}$ / $^{+0.2}_{+0.8}$	$^{+2.9}_{+0.5}$ / $^{-0.5}_{-2.2}$ / $^{+2.9}_{+0.1}$	$^{+8.0}_{-5.3}$ / $^{-4.4}_{+7.7}$ / $^{+1.4}_{-11.9}$
E_T^{miss} modeling	$^{-0.6}_{+1.0}$ / - / $^{+1.0}_{-0.2}$	$^{+0.2}_{-0.9}$ / - / $^{+0.3}_{+0.5}$	$^{+2.4}_{-7.7}$ / $^{-0.1}_{+0.2}$ / $^{+13.5}_{-2.5}$
Factorization and Normalization scale Q^2	$^{+3.1}_{+0.4}$ / $^{+3.4}_{+0.3}$ / $^{+3.3}_{+0.4}$	$^{+10.0}_{-6.5}$ / $^{+10.1}_{-6.9}$ / $^{+10.1}_{-6.9}$	-/-/-
ME/PS Matching Thresholds	-/-/-	$^{+0.7}_{+2.0}$ / $^{+0.5}_{+1.6}$ / $^{+0.4}_{+1.8}$	-/-/-
tW DR/DS scheme	$^{-5.4}_{-0.5}$ / $^{+6.4}_{-0.5}$ / $^{+1.7}_{-0.5}$	-/-/-	-/-/-
PDF uncertainties	2.2/2.0/2.0	-/-/-	-/-/-
$t\bar{t}$ cross-section	-/-/-	$^{+6.2}_{-5.8}$ / $^{+6.2}_{-5.8}$ / $^{+6.2}_{-5.8}$	-/-/-
Z/γ^* modeling	-/-/-	-/-/-	30.5/1.2/23.5
Simulation Statistics	3.8/1.8/2.7	4.5/2.0/2.9	18.0/12.0/12.4

Systematics (VI)

Systematics in the **tW** analysis with ATLAS

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
$t\bar{t}$ 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

Systematics (VII)

Systematics in the **s-channel** analysis with ATLAS

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