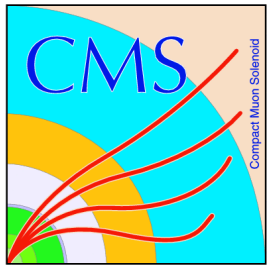


Vrije
Universiteit
Brussel

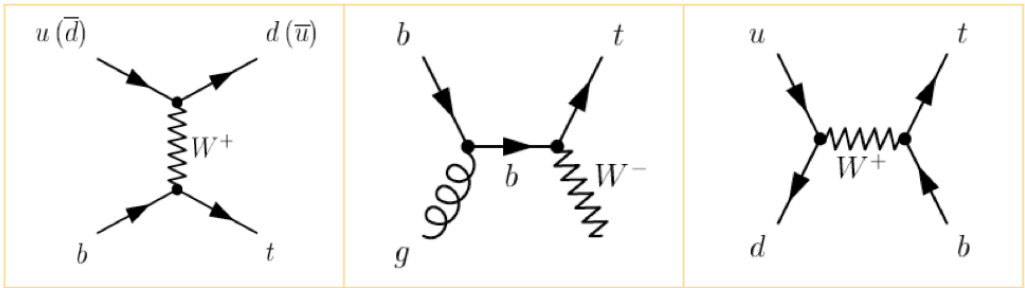
Moriond QCD and High Energy Interactions
March 10th - March 17th 2012

Single Top Production at $\sqrt{s}$=7 TeV

Rebeca Gonzalez Suarez
on behalf of the CMS and ATLAS collaborations

Intro

- **Top quarks** (Tevatron, 1995) in hadron colliders are mostly produced in pairs, via **strong interaction**
- Alternative production: via the **weak interaction**, involving a **Wtb vertex**, leading to a **single top quark final state**:



t-channel	Associated tW production	s-channel
σ = 64.6 +3.3 −2.6 (pb)	σ = 15.7 +1.3 −1.4 (pb)	σ = 4.6 ± 0.3 (pb)

Cross-sections by N. Kidonakis approximate NNLO, $\sqrt{s}$ = 7 TeV (σ_{tt} = 164.6 pb)

- First observed at the Tevatron (2009), in a combination of t/s-channel
- Already observed by the LHC experiments with 2010-2011 data
- Single top-quark processes:
  - are sensitive to many models of **new physics**
  - allow for a measure of $\mathbf{V_{tb}}$ without **assumptions about the number of quark generations**
  - can be used to measure the b-quark parton distribution function (**PDF**)

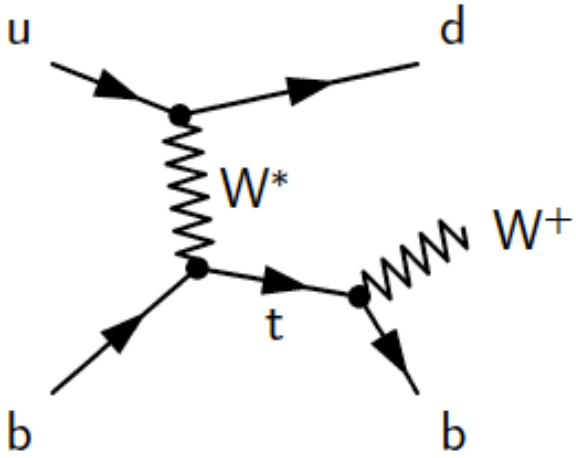
t-channel

- Dominating process with the highest cross section at the Tevatron and the LHC
- **ATLAS** and **CMS** have public results with 2011 data:

ATLAS-CONF-2011-101
July 2011; L = 0.7fb^{-1}

New!
CMS PAS TOP-11-021
March 2012; L = 1.1/1.5fb^{-1}

Updates previous result with 36pb^{-1}
Phys. Rev. Lett. 107 (2011) 091802
arxiv:1106.305



- The final state studied is a **lepton + jets signature**
- Signal events are characterized by:
  - One isolated **muon or electron** and missing transverse energy ($\mathbf{E_T^{miss}}$) (leptonic decay of the W)
  - A central **b-jet** and an additional light-quark jet from the hard scattering process (often forward)
  - Additionally, a second b-jet produced in association to the top quark can be present as well (softer p_T spectrum with respect to the b-jet from top decay)

Selection criteria

- CMS:
  - Exactly 1 isolated lepton (e,μ)
  - 2 jets in the event, 1 b-tagged
  - Muon channel: $m_T(W) > 40$ GeV
  - Electron channel: $E_T^{miss} > 35$ GeV
  - Invariant mass of the reconstructed top quark within (130,220) GeV

- ATLAS:
  - Exactly 1 isolated lepton (e,μ)
  - 2 or 3 jets in the event (NN only 2), 1 b-tagged
  - $E_T^{miss} > 25$ GeV
  - m_T (W) > 60 GeV − E_T^{miss}

Other jet (1-2-3 jets) and b-tagging multiplicities (0-1-2) used in background estimations and control regions

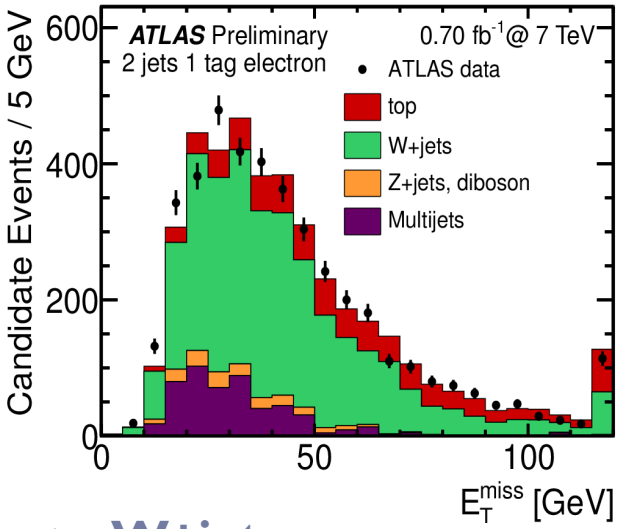
Main backgrounds:

- **W boson production in association with jets** (W+jets)
- **top pair** (tt) production
- **Multijets** (QCD) events

tt and smaller backgrounds from Z+jets, other single-top processes, and diboson production are estimated from simulation and normalized to their theoretical cross-sections.

Background estimation

- The **multijet QCD** contribution is estimated via **maximum likelihood Fit** to MET (e,μ ATLAS, e CMS) / m_T (μ CMS)



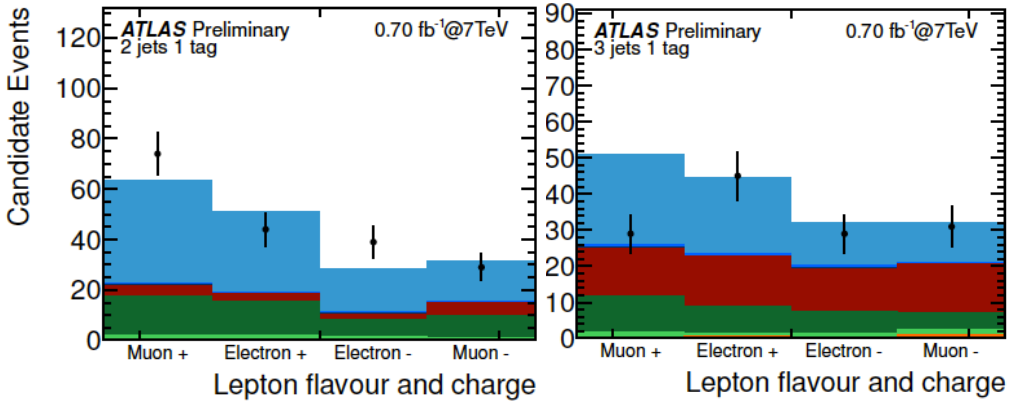
- Template for QCD obtained in data by inverting the isolation on muons and either requiring the electrons to fail some of the quality requirements (CMS), or replacing the electron by a jet passing similar requirements as the electrons (jet-electron model, ATLAS).
- For all other processes (top, W/Z+jets, dibosons), Monte Carlo templates

- **W+jets**
  - **ATLAS:** distributions from Monte Carlo, overall normalization and flavor composition from data (data-driven scale factors)
  - **CMS:** W+jets shapes and normalization extracted from the **reconstructed top quark mass sideband** –events that fail the cut-, subtracting other backgrounds

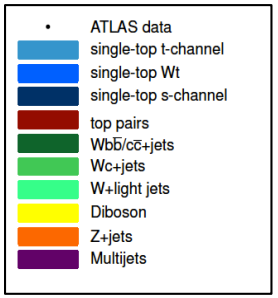
Signal extraction

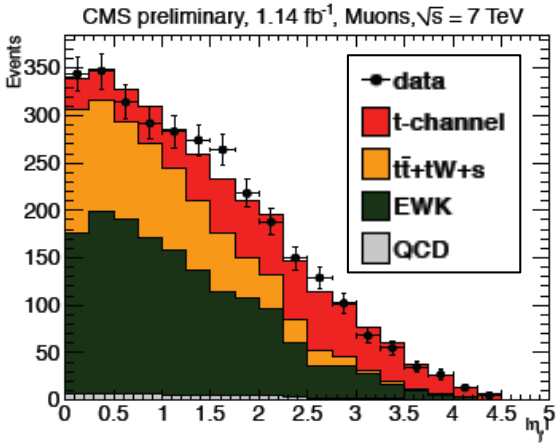
ATLAS: set of discriminant variables
Cut based / Neural Network analysis
Main variables:

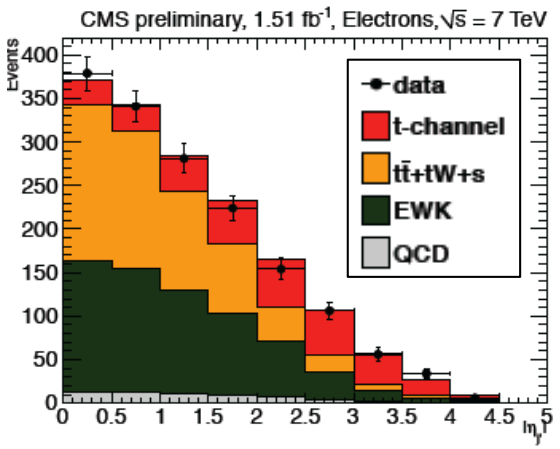
- reconstructed top quark mass
- pseudorapidity of the light (untagged) jet, $|\eta_j'|$
- transverse energy of the light (untagged) jet



Distributions after the cut-based selection, signal contribution normalized to the measured combined cut-based cross section.







CMS: maximum likelihood fit to the distribution of the pseudorapidity of the light (untagged) jet, $|\eta_j'|$

Result of simultaneous fit in the muon and electron decay channel

ATLAS and CMS applied different definitions of theory systematic errors, the discussion is ongoing towards their harmonization

Systematics

- Several sources of systematic uncertainty considered, main ones quoted:
  - **Background normalization to data**
  - **Detector simulation and object modeling**
    - **JES** (~9% ALTAS,CMS), **b-tagging, JER** (18%, 6% ATLAS) (3%, 1% CMS)
  - **Theoretical uncertainties**:
    - **CMS:** renormalization and factorization scale Q^2 (7%)
    - **ATLAS:** generator (11%), parton shower (10%), ISR/FSR (14%)
  - **Monte Carlo generators**
  - **Statistics**
  - **Luminosity**

CMS	[%]
Total	± 17

Full tables in the backup slides

ATLAS	Cut-based [%]			NN [%]
	2-jet	3-jet	combined	
Total	+45/-31	+57/-43	+44/-30	+45/-34

Results

- **ATLAS:** As the cut-based method uses both 2- and 3-jet channels, and has a slightly smaller overall expected uncertainty, it is chosen as the baseline result.

$$\text{(2-jet) } \sigma_t = 102^{+12}_{-11}(stat.)^{+38}_{-27}(syst.) = 102^{+40}_{-30}\text{pb}$$

$$\text{(3-jet) } \sigma_t = 50^{+15}_{-14}(stat.)^{+30}_{-22}(syst.) = 50^{+34}_{-27}\text{pb}$$

$$\text{(NN) } \sigma_t = 105 \pm 7(stat)^{+36}_{-30}(syst) = 105^{+37}_{-31}\text{pb}$$

$$\sigma_t = 90^{+9}_{-9}(stat.)^{+31}_{-20}(syst.) = 90^{+32}_{-22}\text{pb}$$

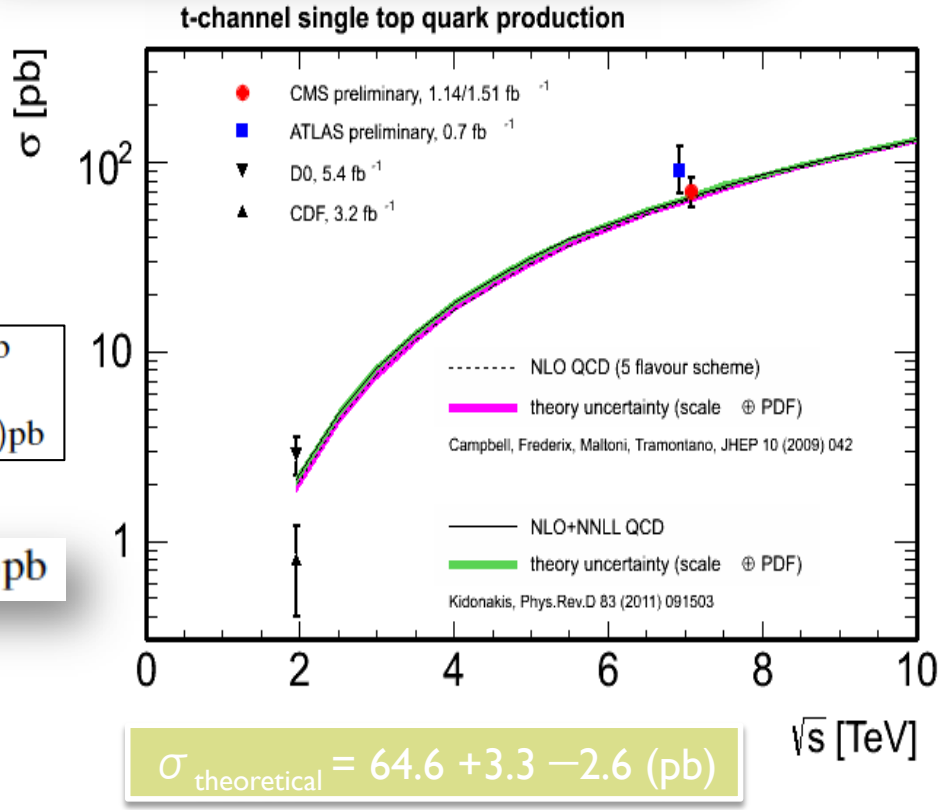
- **CMS:** Results for muon and electron channels and combination

$$\text{(muons) } \sigma_t = 76.9 \pm 6.6(stat.) \pm 11.4(syst.) \pm 3.7(lumi.)\text{pb}$$

$$\text{(electrons) } \sigma_t = 59.3 \pm 8.2(stat.) \pm 11.9(syst.) \pm 2.8(lumi.)\text{pb}$$

$$\sigma_t = 70.2 \pm 5.2(stat.) \pm 10.4(syst.) \pm 3.4(lumi.)\text{pb}$$

$$|V_{tb}| = \sqrt{\frac{\sigma_{t-ch.}}{\sigma^{th}_{t-ch.}}} = 1.04 \pm 0.09\,(\text{exp.}) \pm 0.02\,(\text{th.}),$$



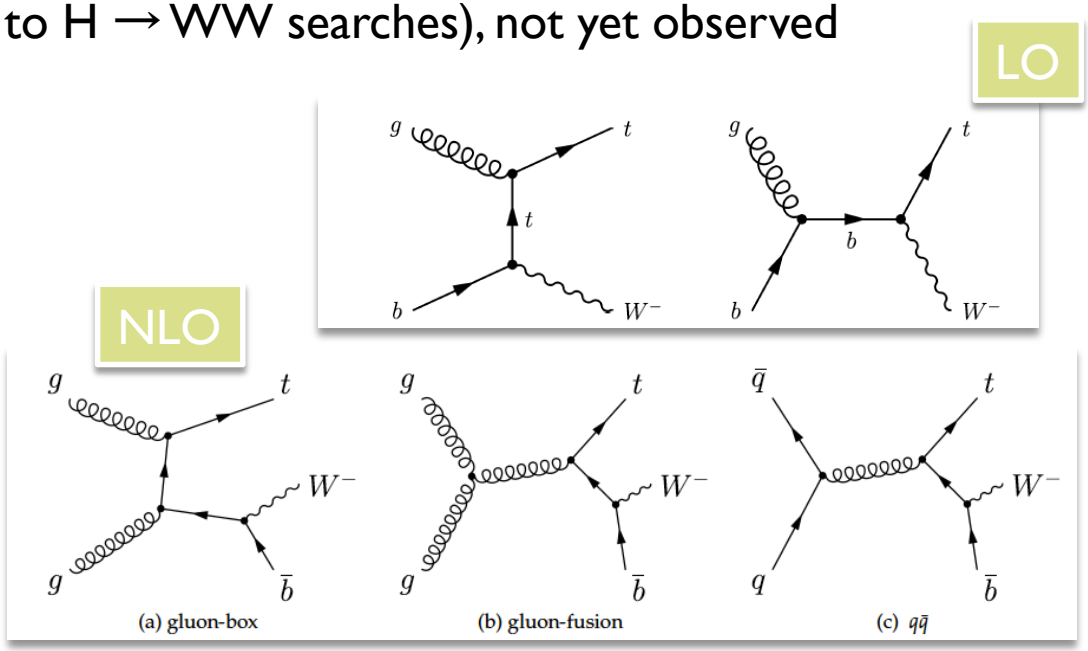
$\sigma_{\text{theoretical}} = 64.6\ ^{+3.3}_{-2.6}$ (pb)

tW associated production

- Interesting topology (background to H → WW searches), not yet observed
- Mixes at NLO with tt production
- Public results with 2011 data:

ATLAS-CONF-2011-104
July 2011; L = 0.7 fb^{-1}

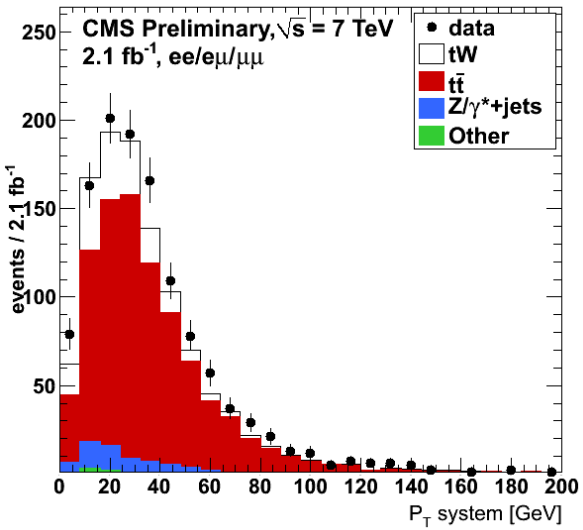
CMS PAS-TOP-11-022
September 2011; L = 2.1 fb^{-1}



- Dilepton final states:
  - 2 leptons, E_T^{miss} and a jet from a b-decay
- Main backgrounds:
  - tt production
  - Z+jets
  - Small contributions from dibosons, other single top channels, W+jets and QCD

Event selection

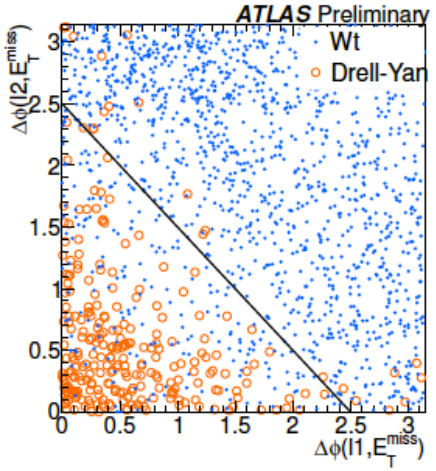
- **ee, eμ** and **μμ** final states (with no extra leptons)
- Jet selection: exactly1 jet (ATLAS/CMS), b-tagged (CMS)
- E_T^{miss} > 50 (ATLAS) 30 (CMS, ee/μμ)
- Anti Z+jets: Remove events in the Z mass window 81 < mll < 101 GeV (ee/μμ)



CMS: Extra variables, **p_T of the system** formed by the leptons, the jet and the E_T^{miss} and **H_T** (scalar sum of the pt of the leptons, jet and MET)

ATLAS: dedicated anti $Z \rightarrow \tau\ \tau$ cut in the selection

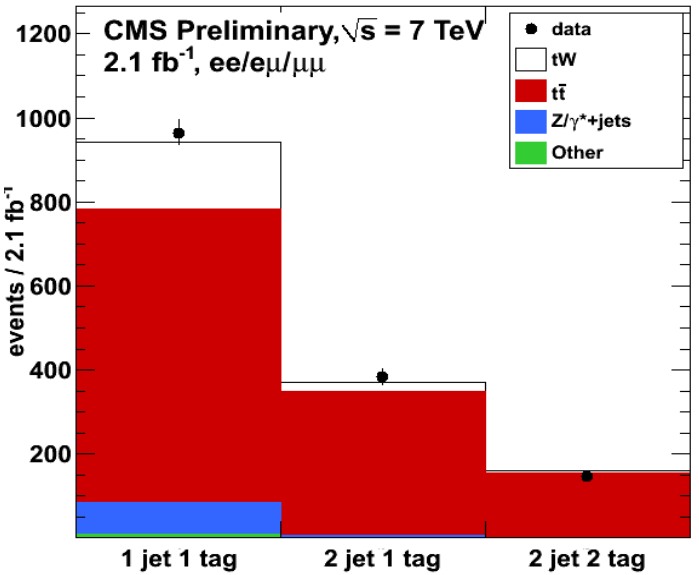
$$\Delta\phi(l_1, E_{\mathrm{T}}^{\mathrm{miss}}) + \Delta\phi(l_2, E_{\mathrm{T}}^{\mathrm{miss}}) > 2.5$$

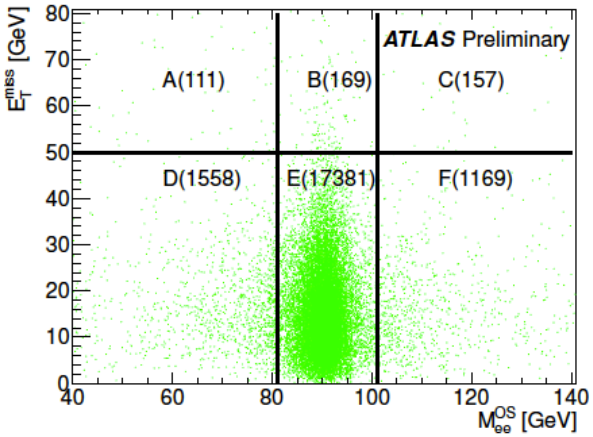


Same structure: Cut-based analysis

Background estimation

- **CMS:**
  - Data-driven estimation of the **Z+jets** background (in/out of the Z mass window)
  - Two **tt enriched control regions** (2j1t, 2j2t) considered in the significance calculation to constrain tt contamination and b-tagging efficiency





$$N_{A/C}^{predicted} = N_{D/F}^{data} \times (N_B^{data}/N_E^{data})$$

- **ATLAS:**
  - Data-driven **Drell-Yan**, using ABCDEF method, orthogonal cuts on 2 variables (m_{ll} and E_T^{miss}) define signal and background enriched regions; used to determine background content in the signal region from data.
  - **Fake lepton** estimation for W+jets (single) and Multijets (double-fake) with matrix method (< 1% effect)
  - Data-driven estimation of **$Z \rightarrow \tau\ \tau$**
  - **Scale factor for tt** obtained from 2j sample

Results

- Main sources of **systematics**:
  - **CMS:** B-tagging (10%) and Q^2 (~10%)
  - **ATLAS:** JES (35%), JER(32%), and background normalization

Tables in the backup slides

ATLAS:

95% CL observed limit on tW production: $\sigma_{tW} < 39.1 (40.6)$ pb obs. (exp.)

Observed significance of $1.2\,\sigma$

With a value of the cross-section:

$\sigma_{tW} = 14\ ^{+5.3}_{-5.1}(\text{stat.})\ ^{+9.7}_{-9.4}(\text{syst.})$ pb

CMS:

Observed (expected) significance of

$2.7\,\sigma$ $(1.8 \pm 0.9\,\sigma)$

Measured value of the cross-section and 68% CL interval:

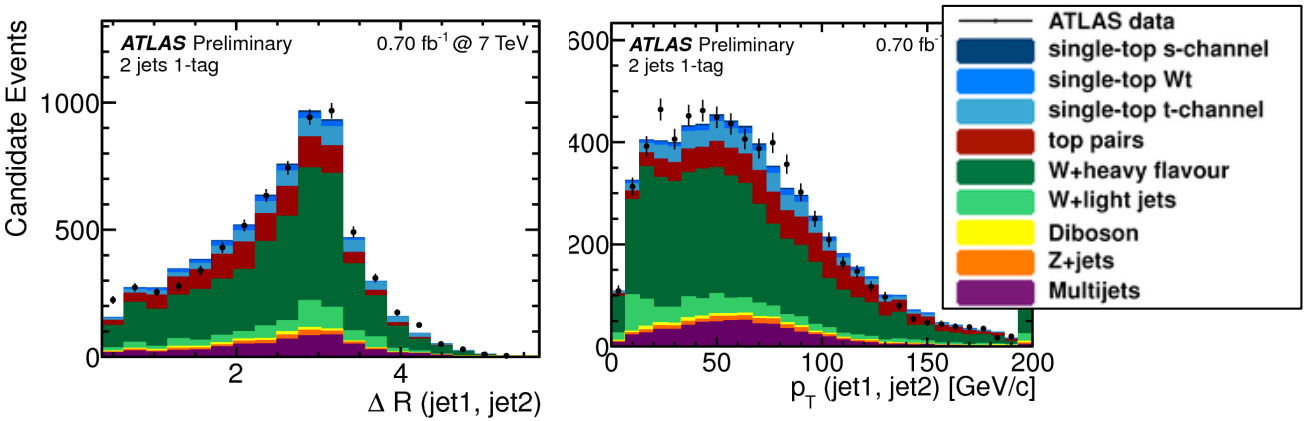
$\sigma_{tW} = 22\ ^{+9}_{-7}$ (stat+sys) pb

ATLAS-CONF-2011-118
August 2011; L = 0.7 fb^{-1}

s-channel

- Sensitive to several models of new physics, like W' bosons or charged Higgs bosons
- Not yet observed
- Signal signature: lepton + jets
  - A lepton (e,μ) and E_T^{miss} from the leptonic decay of a W boson
  - two hadronic jets with high transverse momentum, at least one of which is required to originate from a b-quark
- Backgrounds: tt, W+jets , Multijet + small contributions from other processes
- **Very Challenging**

Same objects and pre-selection as t-channel
Also same background estimations for Multijets and W+jets



After the final selection: signal purity of 6%
Upper limit on the observed production cross-section

Cut-based analysis

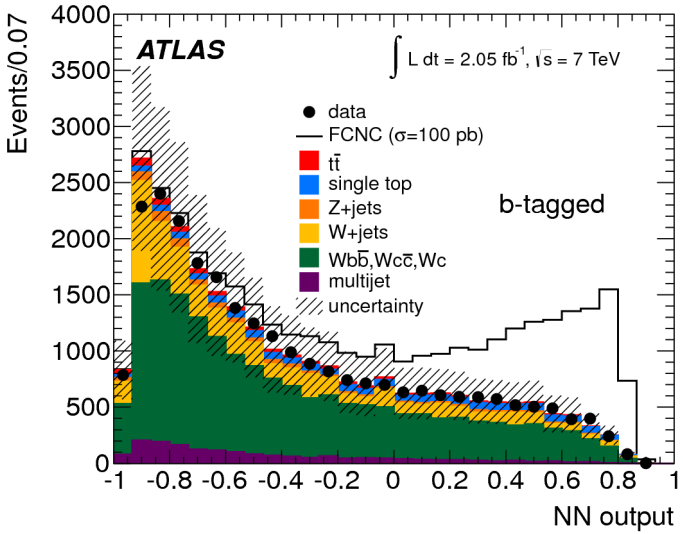
$$\sigma_t < 26.5(20.5)\ \text{pb obs.(exp.)}, 95\%\text{CL}$$

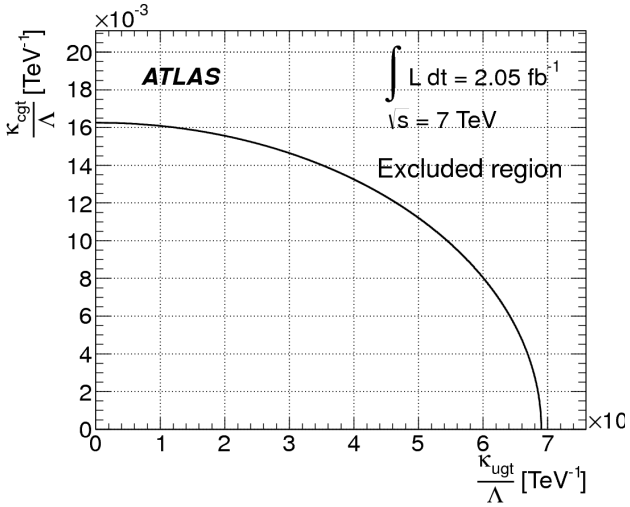
Other single top studies: FCNC single top quark production

New!

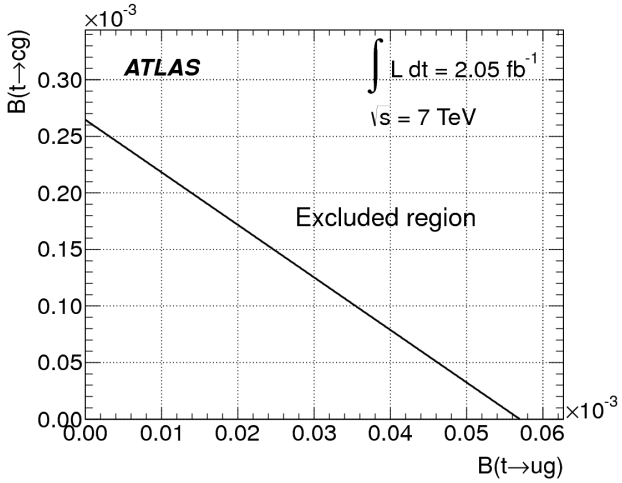
Submitted to Phys. Lett. B
arXiv:1203.0529
Mar 2012; 2.05fb^{-1}

- Analysis strategy:
  - use leptonic decays, 1 jet bin
  - classify events using a neural network
  - most signicant variables: W boson p_T, $\Delta R_{(b\text{-jet,lepton})}$ and lepton charge





Upper limit on the coupling constants κ_{ugt}/Λ and κ_{cgt}/Λ.



Upper limit on the branching fractions t → ug and t → cg

- Results: no observed excess over SM, limits set:

$$\sigma(qg \to t) \cdot B(t \to Wb) < 3.9 \text{ pb (95\% CL)}$$

$$B(t \to ug) < 5.7 \cdot 10^{-5},\ B(t \to cg) < 2.7 \cdot 10^{-4}$$

Summary

- **ATLAS** and **CMS** have a broad program of single top physics
- Window to new physics, key to measurements of electroweak properties of the top quark, background to Higgs and other searches

- Measurement of the **cross-section of t-channel** production with 2011 data
- From t-channel cross section: CMS **measures $|V_{tb}|$** at the **10% level**
- First hints of tW associated production with upper limit on the cross-section (ATLAS) and **significance close to 3 σ** (CMS) in cut based analysis
- First upper limits on s-channel production (ATLAS), challenging final state

- Other single top studies, latest result from ATLAS: **FCNC single top quark production:**
  - The limits set on the coupling constants and the branching fractions are the most stringent to date on FCNC single top-quark production processes for $qg \rightarrow t$ and **improve on the previous best limits set by the Tevatron by factors of 4 and 15, respectively**.

Backup Slides

Systematic uncertainties: t-channel

ATLAS
CONF-2011-101

Source	$\Delta\sigma/\sigma$ [%] cut-based 2-jet	3-jet	combined	NN
Data statistics	± 16	± 24	± 13	± 10
MC statistics	± 8	± 11	± 6	± 7
Jet energy scale	+7/-5	+10/-1	+9/-1	+32/-20
Jet energy resolution	+6/-4	+8/-7	+6/-1	± 4
Jet reconstruction	+2/-1	± 1	± 1	+3/-2
b-tagging scale factor	+17/-12	+21/-14	+18/-13	± 13
Mis-tagging scale factor	± 1	± 1	± 1	± 1
Lepton efficiencies	+6/-5	+11/-9	+8/-6	± 5
Lepton energy scale/resolution	± 1	± 1	+2/-1	± 5
Generator	+10/-8	+16/-12	+11/-9	± 7
Parton shower	+9/-7	+14/-12	+10/-9	± 6
ISR/FSR	+19/-16	± 7	± 14	± 13
PDF	+5/-4	+6/-5	± 5	± 4
W+jets shape modeling	± 1	± 1	± 1	± 1
Jet η reweighting	+12/-10	+18/-14	+13/-11	+10/-6
Background normalization				± 3
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	± 5
All systematics	+42/-27	+51/-37	+41/-27	+44/-34
Total	+45/-31	+57/-43	+44/-30	+45/-34

Systematic uncertainties: t-channel

CMS PAS TOP-11-021

Uncertainty source	in pb	in %
Statistical	±5.2	±7.4%
W+heavy flavours extraction	±5.0	±7.1%
Jet energy scale	−4.4/+6.5	−6.2/+9.2%
Jet energy res.	−0.48/+0.87	−0.69/+1.2%
Unclustered $\not{E}_T$	±0.37	±0.53%
$t\bar{t}$ rate	−2.4/+2.8	−3.5/+4.0%
Q^2, $t\bar{t}$	−2.8/+1.5	−4.0/+2.1%
Q^2, t-channel	±4.9	±7.0%
t-channel generator	±3.5	±5.0%
Muon trigger + reco.	−1.1/+1.2	−1.5/+1.7%
Electron trigger + reco.	−0.53/+0.66	−0.76/+0.94%
Pile up	−0.23/+0.13	−0.33/+0.18%
QCD, muon	−0.67/+0.63	−0.95/+0.89%
QCD, electron	−0.26/+0.21	−0.37/+0.29%
s-, tW-channel, dibosons	±0.38	±0.54%
b-tagging	±2.2	±3.1%
Hadronic trigger	±0.95	±1.4%
PDF	±1.8	±2.5%
Total syst.	±10	±15%
Total	±12	±17%

Systematic uncertainties: tW

ATLAS-CONF-2011-104

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

Systematic uncertainties: tW

CMS PAS TOP-11-022

Systematic uncertainty ($ee/e\mu/\mu\mu$) [%]	signal tW	$t\bar{t}$	$Z/\gamma^{\star}$	other
Luminosity	4.5	4.5	-	4.5
Pile-up multiplicity	0.48/0.55/0.73	$\star$	-	$\star$
Trigger Efficiency	1.5	1.5	-	1.5
Muon reconstruction and identification	- /1/1	- /1/1	-	- /1/1
Electron reconstruction and identification	2/2/ -	2/2/ -	-	2/2/ -
JES	$^{-2.5}_{+1.6}$ / $^{-2.4}_{+0.1}$ / $^{-0.6}_{+1.0}$	$^{-5.6}_{+4.4}$ / $^{-6.0}_{+4.7}$ / $^{-5.9}_{+2.3}$	-	$\star$
JER	1.1/0.5/0.4	3.1/3.9/4.4	-	$\star$
B-tagging	$^{-9.5}_{+10}$ / $^{-9.8}_{+9.8}$ / $^{-9.5}_{+10}$	$^{-8.5}_{+10}$ / $^{-11}_{+10}$ / $^{-9.1}_{+11}$	-	$\star$
Factorization/Normalization Scale (Q^2)	7.7/6/10	7.7/11/12	-	$\star$
ME/PS matching thresholds	-	5.7/0.7/2.3	-	$\star$
ISR/FSR	-	8.9/7.3/7.3	-	$\star$
DR/DS scheme	8.2/9.1/6.6	-	-	$\star$
$E_{\mathrm{T}}^{\mathrm{miss}}$ modeling	2.3/0.9/0.9	$\star$	-	$\star$
PDF uncertainties	4.5/4.5/4.5	$\star$	-	$\star$
Background Normalization	-	15/15/15	50/ 50/ 50	$\star$
Simulation statistics	3.5/1.9/2.7	-	-	17/21/11

"-" means it doesn't apply, and "★" for negligible contributions

Systematic uncertainties: s-channel

ATLAS-CONF-2011-118

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

Background estimation in t-channel CMS

- **QCD multijets** is controlled in the **2 jet 1 tag** sample after fitting the low m_T region for the muon channel/low ET miss region for the electron channel
- Check shape and normalization of $|\eta_j|$ and m_{lvb} in 2 control regions:
  - 2 jets 0 tags: W+light
  - 3 jets 2 tags: ttbar
- **W+ heavy flavor** production is the main background
  - From EWK/ ttbar cross section measurement it is expected to be **1.2 (W+b) / 1.7x (W+c)** larger with respect to MC prediction
  - Control $|\eta_j|$ in the m_{lvb} sidebands
  - Subtract TTbar, single top-s, -tW and dibosons from **prediction**
  - Derive the template for **W+heavy flavor** contribution to be fit in the signal region