

# Measurement of single top quark processes at LHC

*Mario Merola (INFN Napoli)*

*on behalf of the CMS/ATLAS Collaborations*



**SM@LHC**  
Standard Model at LHC

Madrid (Spain), 8-11 April 2014

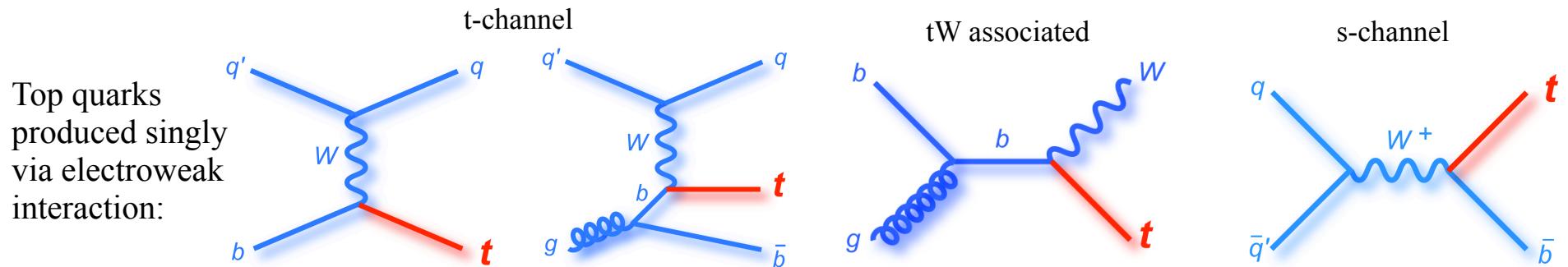
<http://wwwae.ciemat.es/smlhc>



# Intro: single top quark production



2



Cross sections  
(pb)  
(top mass = 173  
GeV)

**t-channel**  
approx. NNLO,  
Phys. Rev. D 83,  
091503 (2011),  
N. Kidonakis

**tW associated  
production**  
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arXiv:1205.3453,  
N. Kidonakis

**s-channel**  
approx. NNLO,  
Phys. Rev. D 81,  
054028 (2010),  
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LHC: pp @ 7 TeV

65.9

15.6

4.56

LHC: pp @ 8 TeV

87.2

22.2

5.55

Tevatron p $\bar{p}$  @  
1.96 TeV

2.08

0.22

1.04

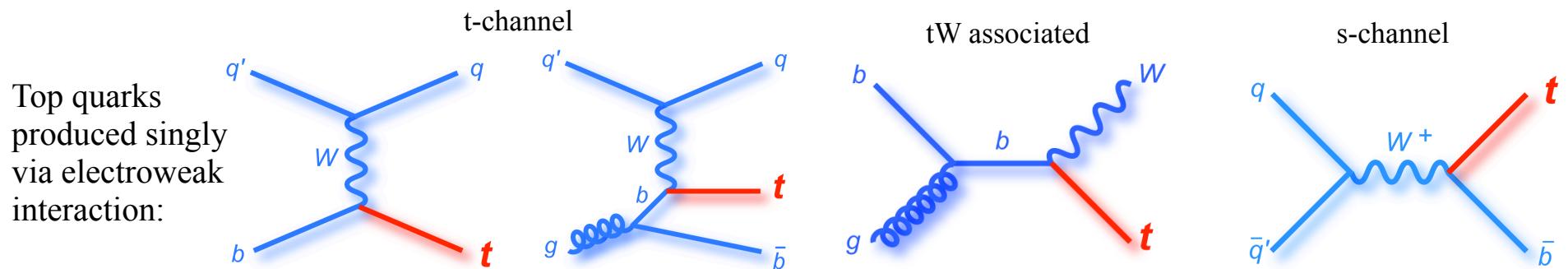
- **Standard model measurements:** inclusive cross sections, top/anti-top charge ratio, top quark polarization, top mass, W-helicity,  $|V_{tb}|$ , PDFs

- **Beyond standard model searches:** FCNC, anomalous couplings, heavy bosons ( $W'$  and charged Higgs), CP violation



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covered by this talk  
not covered but results available  
not yet performed in single top topologies



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# Content



- **t-channel**
  - Inclusive cross section
  - Top charge asymmetry
  - Top polarization
  - CP violation
- **tW associated production**
- **s-channel production**
- **W helicity**
- **Search for FCNC**

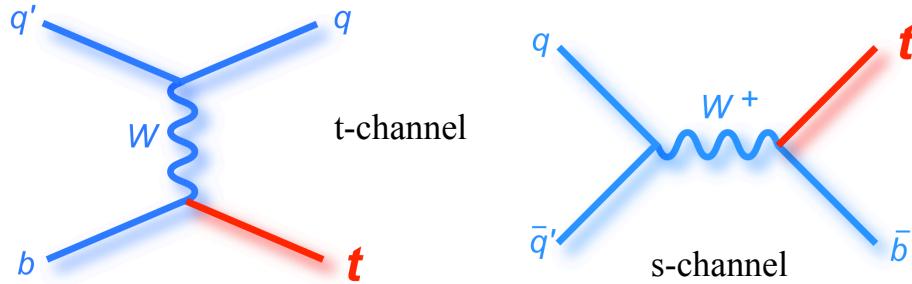


# Single top processes and backgrounds

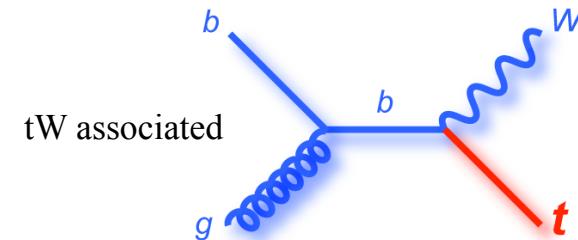
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## SINGLE LEPTON TOPOLOGY

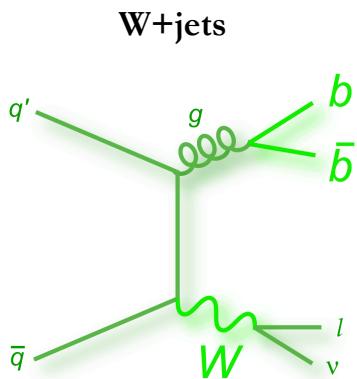
### Signals:



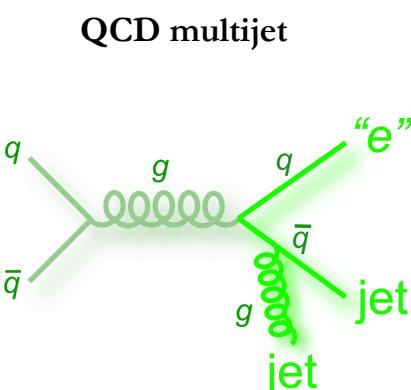
## DILEPTON TOPOLOGY



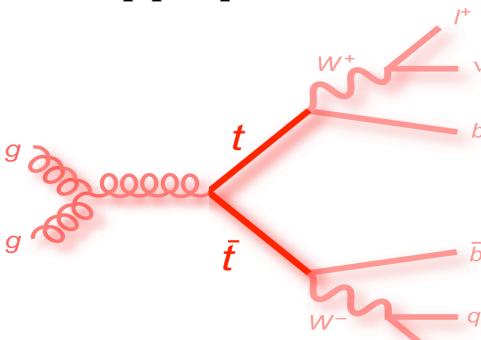
### Main backgrounds (examples):



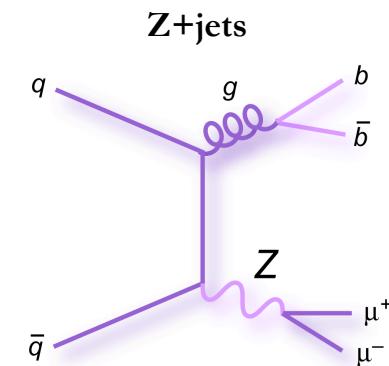
mainly for t- and s-channels



### top pair production



for all three channels



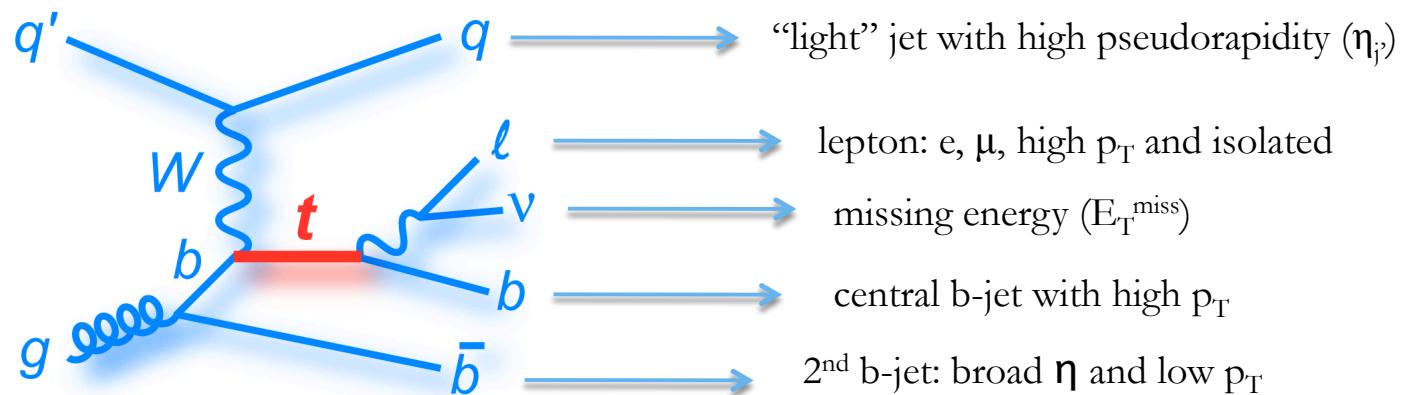
mainly for tW associated production



# t-channel: experimental signature and selection @ 8 TeV



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CMS

$p_T^\mu > 26 \text{ GeV}, p_T^e > 30 \text{ GeV}$

$p_T > 40 \text{ GeV}$

$E_T^{\text{miss}} > 45 \text{ GeV (e)}, m_T^W > 50 \text{ GeV (\mu)}$

**1 muon or electron**

**2 jets 1 b-tagged**

**additional cuts  
(QCD multijet rejection)**

ATLAS

$p_T > 25 \text{ GeV}$

$p_T > 30/35 \text{ GeV}$

$E_T^{\text{miss}} > 30 \text{ GeV}, m_T^W > 50 \text{ GeV}$



# t-channel: inclusive cross section @ 8 TeV

CMS-TOP-12-038

arXiv:1403.7366 ( $\rightarrow$ JHEP)

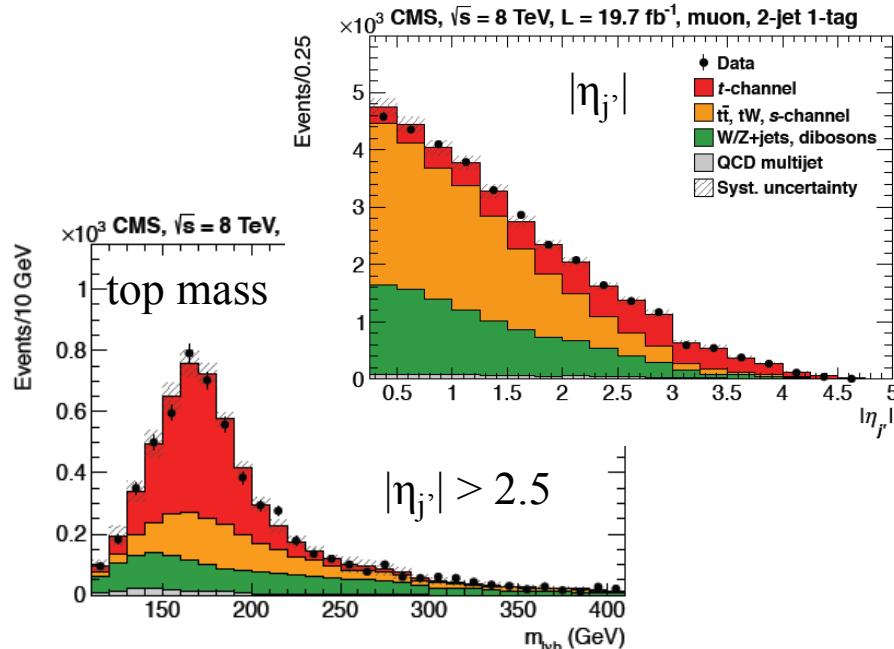
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ATLAS-CONF-2014-007

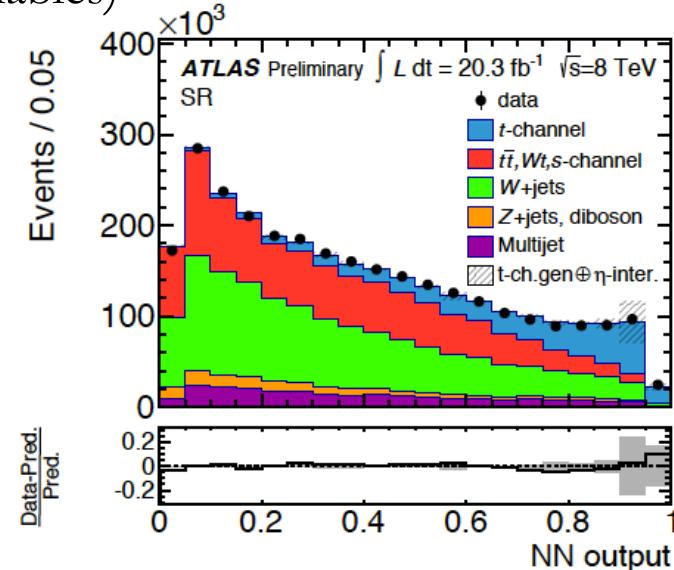
## CMS - Template analysis $|\eta_{j^*}|$

- fit to the pseudorapidity of the recoil jet in the signal region  $130 < m_{\text{top}} < 220$  GeV
- $W/Z+jets$  and  $t\bar{t}$  background shapes are estimated from data (from top mass sideband and 3 jets 2 tags event category)



## ATLAS - Multivariate analysis

- fit to the NN discriminant distribution (14 variables)



- cross section measured in detector fiducial space (reduces generator uncertainties). Full phase space can be obtained by extrapolation using MC generators

# t-channel: inclusive cross section @ 8 TeV



CMS-TOP-12-038

arXiv:1403.7366 (→JHEP)

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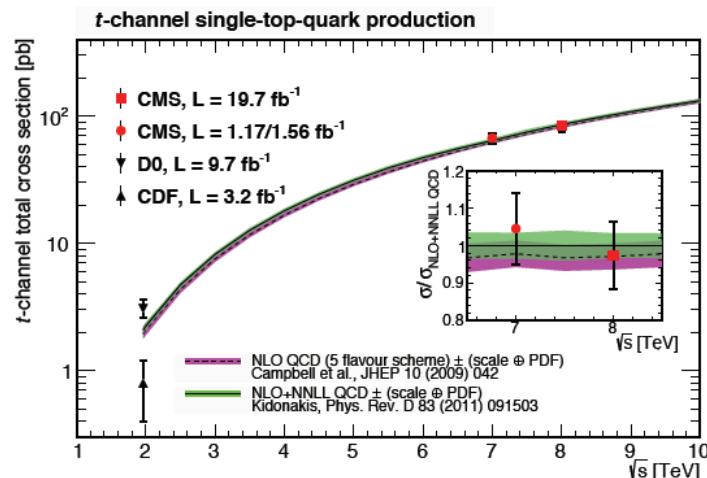
ATLAS-CONF-2014-007

CMS - Template analysis  $|\eta_j|$

$$\sigma_{t\text{-chan}} = 83.6 \pm 2.3(\text{stat.}) \pm 7.4(\text{syst.}) \text{ pb}$$

$$|V_{tb}| = 0.979 \pm 0.045(\text{exp.}) \pm 0.016(\text{theo.})$$

(total unc. 4.9 %)

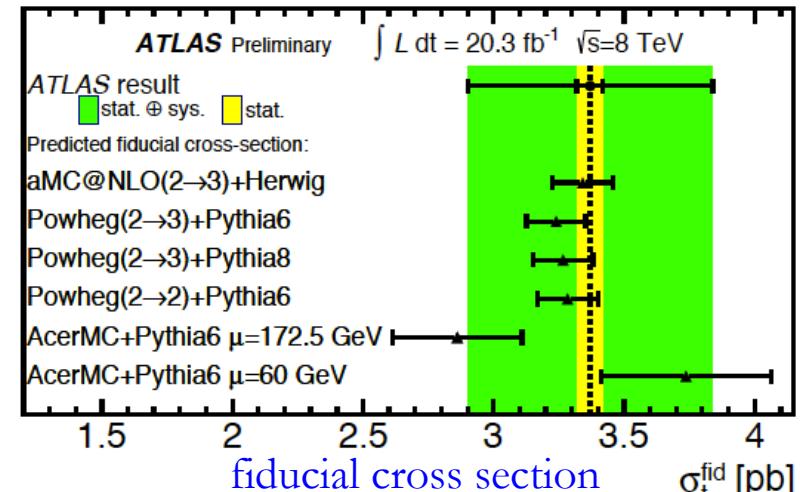


$$|V_{tb}| = 0.998 \pm 0.038(\text{exp.}) \pm 0.016(\text{theo.})$$

7 + 8 TeV CMS combination (total unc. 4.1 %)

ATLAS - Multivariate analysis

$$\sigma_{t\text{-chan}}^{\text{fid}} = 3.37 \pm 0.05(\text{stat.}) \pm 0.47(\text{syst.}) \pm 0.09(\text{lumi.}) \text{ pb}$$



**First fiducial measurement in single top final states:** could be used in the future to improve our MC description of the data

**Main systematics:** signal generator (POWHEG vs COMPHEP for CMS and ACERMC vs aMC@NLO for ATLAS) and Jet Energy Scale (JES)



CMS-TOP-12-038

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arXiv:1403.7366 (→JHEP)



ATLAS-CONF-2012-056

Integrated luminosity =  $19.7 \text{ fb}^{-1}$  (CMS, 8 TeV),  $4.7 \text{ fb}^{-1}$  (ATLAS, 7 TeV)

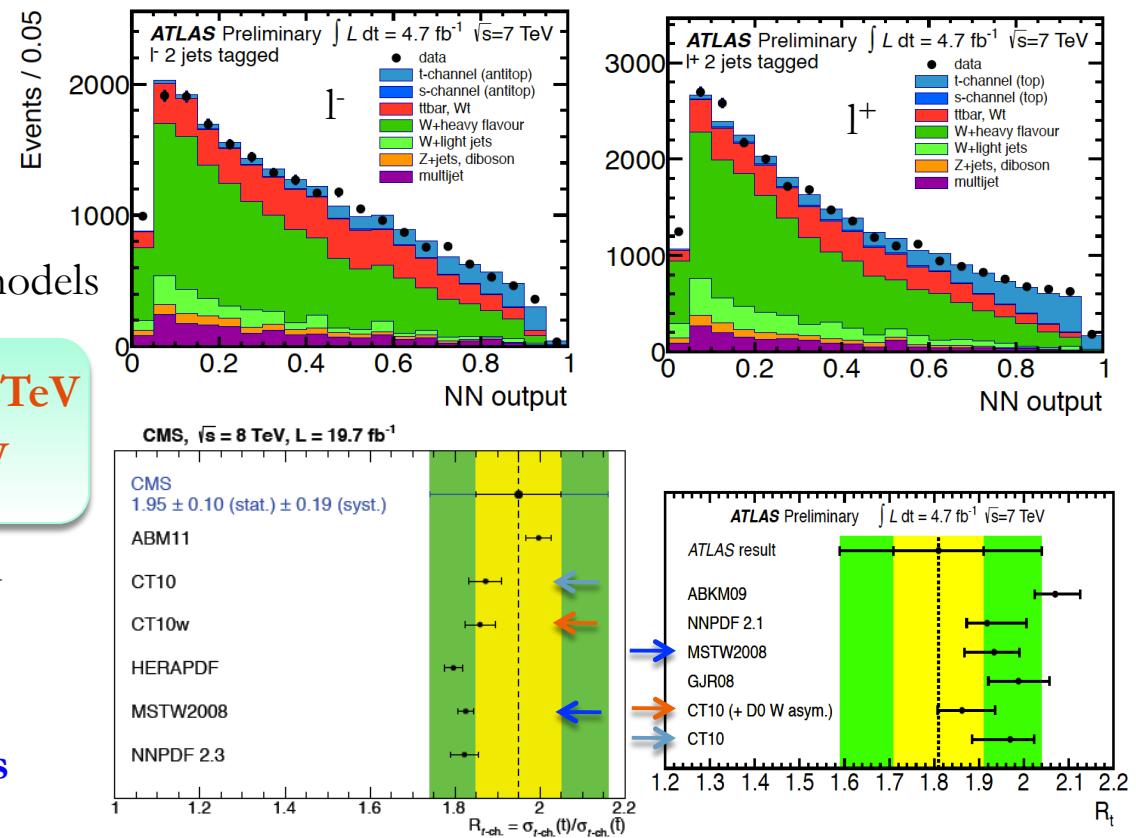
- **Asymmetry in top-antitop production** related to u and d parton distribution functions (PDFs)

- Fit to  $|\eta_{j^{\pm}}|$  (CMS) or NN output (ATLAS) by lepton charge
- W+jets asymmetric,  $t\bar{t}$  symmetric
- $R_t = \sigma(t) / \sigma(\bar{t})$  sensitive to different PDF models

$R_t = 1.81 \pm 0.10(\text{stat})^{+0.21}_{-0.20}(\text{syst})$  ATLAS, 7 TeV

$R_t = 1.95 \pm 0.10(\text{stat}) \pm 0.19(\text{syst})$  CMS, 8 TeV

- **Main systematic uncertainties:** background normalization and JES (ATLAS); PDF and signal modeling (CMS)
- **Improving measurements precision allows to constrain the PDF models**

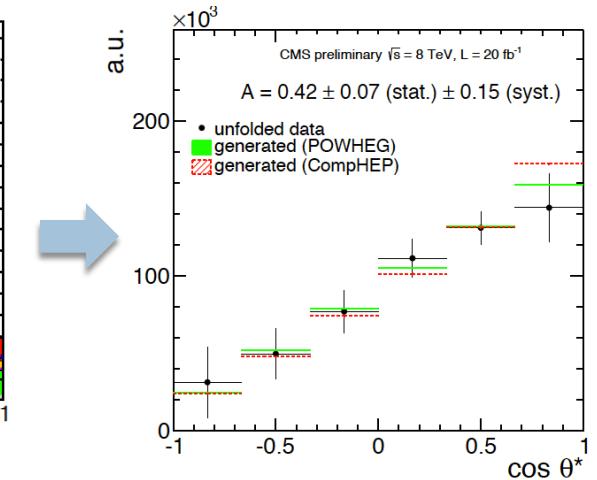
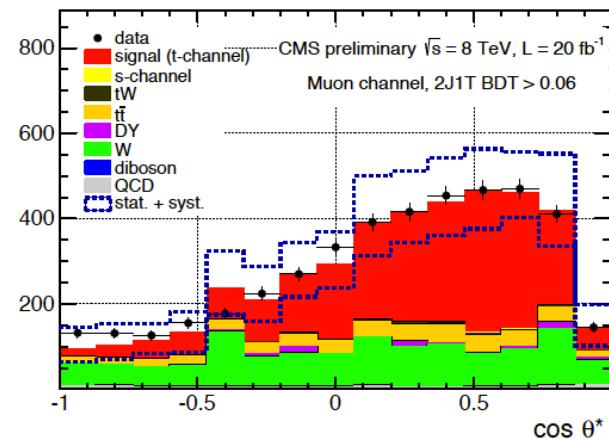


# t-channel: top polarisation @ 8 TeV

- The Standard Model predicts top quarks to be highly polarised in t-channel production
- Measurement of top polarisation allows to **probe the V-A structure** of the electroweak interaction
- From the experimental point of view this translates into the **measurement of the spin asymmetry**

$$A_t \equiv \frac{1}{2} \cdot P_t \cdot \alpha_t = \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}$$

$P_t$  is the top polarisation,  $\alpha_t$  is the spin analyzing power, function of anomalous couplings, and  $N$  are the number of charged leptons aligned or counter-aligned with the top-quark spin axis



$$\frac{d\Gamma}{d\cos\theta^*} = \Gamma \left( \frac{1}{2} + A_t \cos\theta^* \right)$$

$$A_t = 0.41 \pm 0.06(\text{stat}) \pm 0.16(\text{syst})$$

$$P_t = 0.82 \pm 0.12(\text{stat}) \pm 0.32(\text{syst})$$

in agreement with SM expectations,  $A_t \approx 0.5$ ,  $P_t \approx 1$

combined muon and electron channels (with BLUE\*)

First time **negative or null polarized single top quarks are excluded** (at  $2.4\sigma$ )

\*L. Lyons, D. Gibaut, and P. Clifford, Nucl. Instr. and Meth. A 270 (1988) 110



# t-channel: CP violation @ 7 TeV



ATLAS-CONF-2013-032

II

- Test the CP violation by measuring the **forward-backward asymmetry  $A_{FB}^N$** , directly related to the anomalous coupling  $g_R$  in the Lagrangian

$$\mathcal{L}_{Wtb}^{\text{eff}} = -\frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (V_L P_L + V_R P_R) t W_\mu^- - \frac{g}{\sqrt{2}} \bar{b} \frac{i \sigma^{\mu\nu} q_\nu}{m_W} (g_L P_L + g_R P_R) t W_\mu^- + \text{h.c.}$$

- Asymmetry in  $\cos\theta^N$** , where  $\theta^N$  is the angle between the direction of lepton in W rest frame and the direction of  $\mathbf{N}$  in top rest frame

$$A_{FB}^N = 0.031 \pm 0.065(\text{stat.})^{+0.029}_{-0.031}(\text{syst.})$$

Dominant systematics: t-channel and  $t\bar{t}$  modeling, background norm.

$$A_{FB}^N = \frac{3}{4} P_t (F_R^N - F_L^N) \sim 0.64 P_t \text{Im}(g_R)$$

- $\text{Im}(g_R) \neq 0 \rightarrow$  non-SM CP-violating  $Wtb$  vertex

- No CP-violation observed in top quark decays**

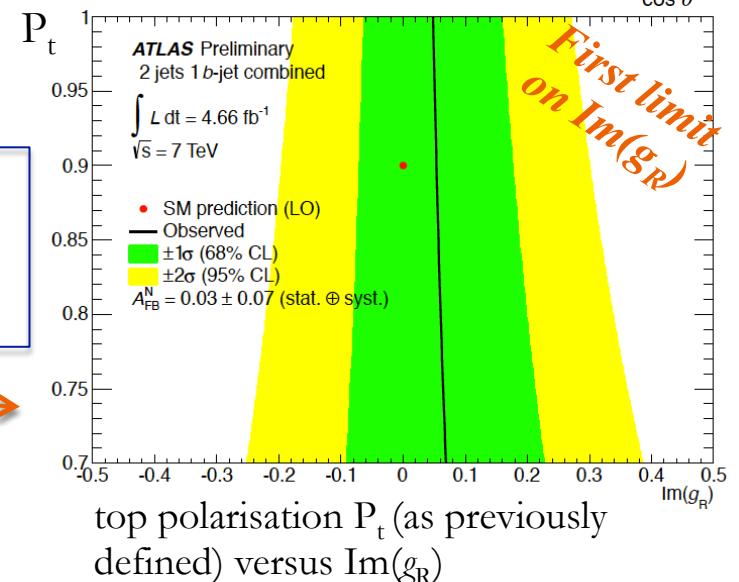
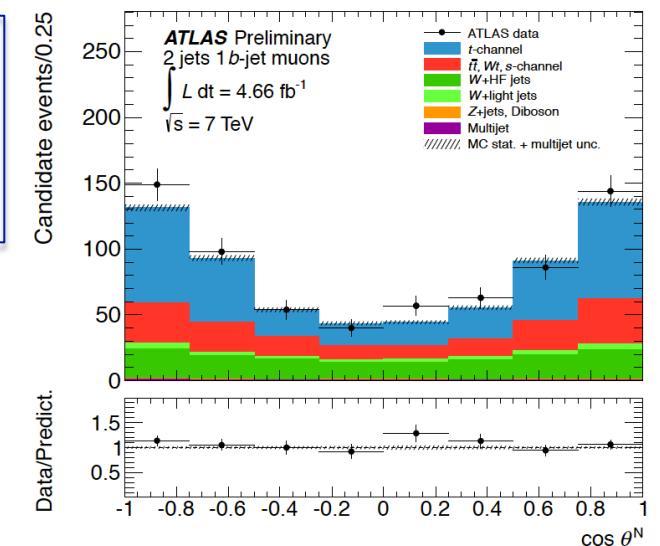
$$\vec{N} = \vec{s}_t \times \vec{q}$$

spin of the top quark

W momentum in top rest frame

$$F_{L,R,0} = \frac{\Gamma_{L,R,0}}{\Gamma(t \rightarrow Wb)} \text{ helicity fractions}$$

Integrated luminosity = 4.66 fb<sup>-1</sup>





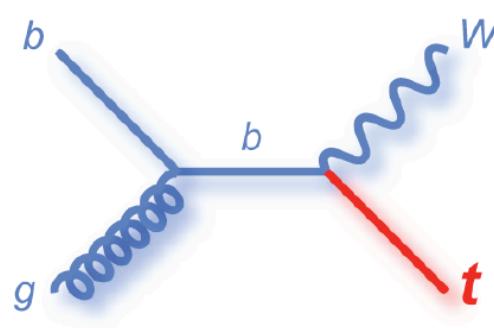
CMS-TOP-12-040

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arXiv:1401.2942 (→PRL)

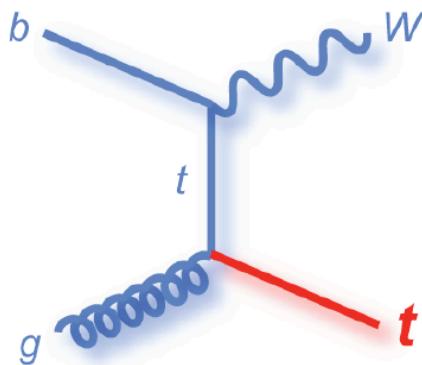


ATLAS-CONF-2013-100



CMS

ee,  $\mu\mu$ , e $\mu$   $p_T^l > 20$  GeV  
 $p_T > 30$  GeV  
 $E_T^{\text{miss}} > 50$  GeV  
 $m_{ll} < 81$  GeV &  $m_{ll} > 101$  GeV



- 2 opposite sign isolated leptons
- Missing energy (2 neutrinos)
- 1 jet (coming from b quark)

ATLAS

**2 opposite-charge leptons**  
(better bkg. rejection)  
**1-2 jets 1-2 b-tags**  
**additional cuts**

e $\mu$ ,  $p_T^l > 25$  GeV  
 $p_T > 30$  GeV

-



# tW associated production: inclusive cross section @ 8 TeV



CMS-TOP-12-040

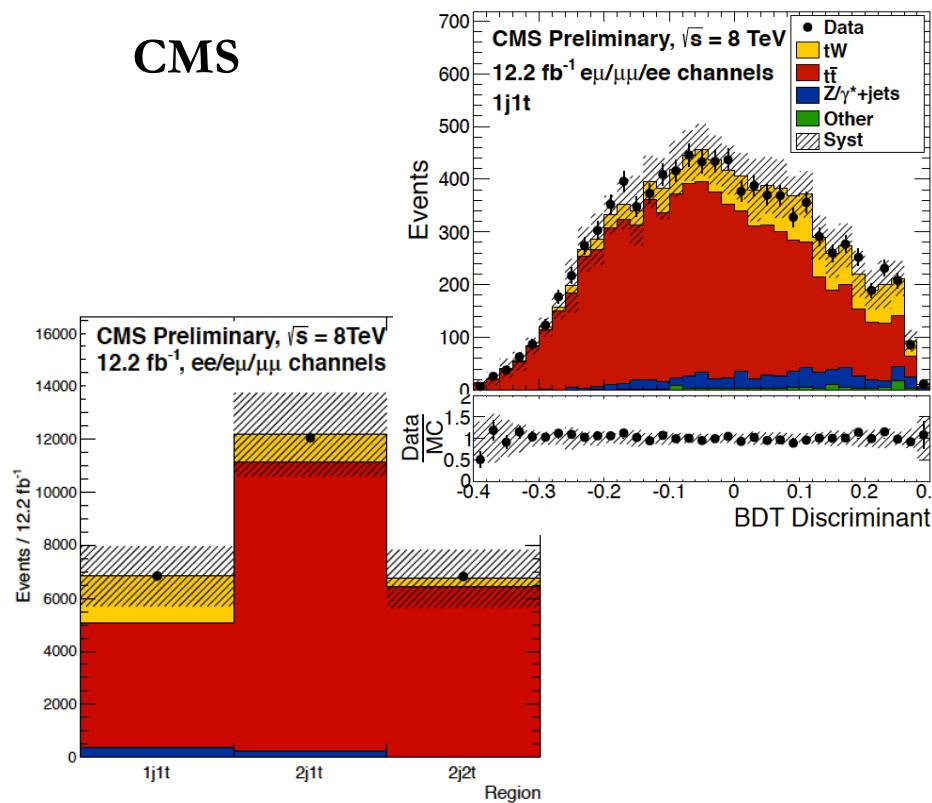
ATLAS-CONF-2013-100

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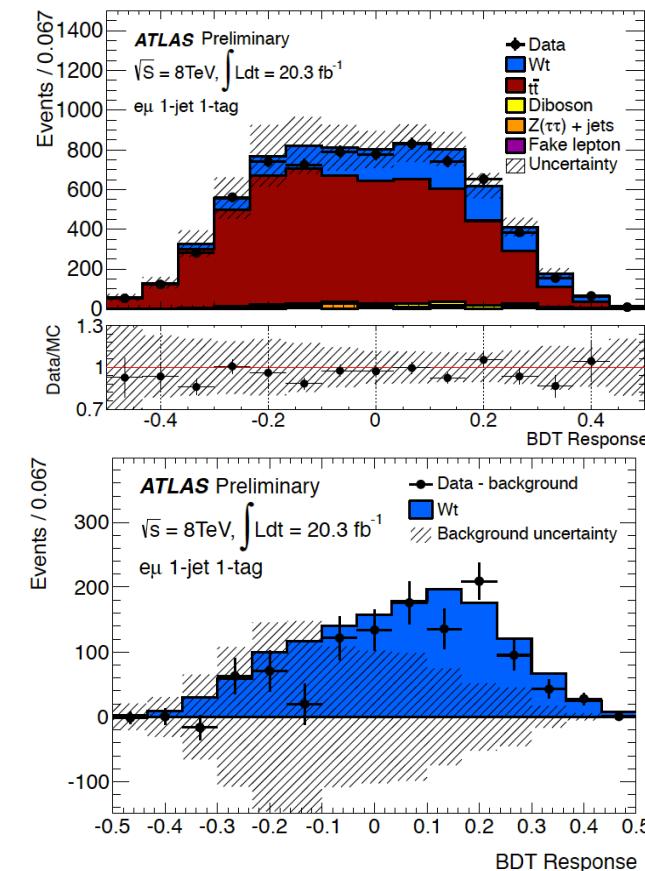
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Fit to BDT discriminant in the signal region (1jet/1btag) and in control regions (2jets/1btag and 2jets/2btags for CMS, 2jets/ $\geq 1$ btag for ATLAS),  $t\bar{t}$  background dominated. The control regions help to constrain the b-tagging and JES uncertainty on the measurement.

CMS



ATLAS



Integrated luminosity = 12.2 fb<sup>-1</sup> (CMS), 20.3 fb<sup>-1</sup> (ATLAS)

4/9/14



# tW associated production: inclusive cross section @ 8 TeV

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CMS-TOP-12-040

arXiv:1401.2942 (→PRL)



ATLAS-CONF-2013-100

CMS

$$\sigma_{tW} = 23.4^{+5.5}_{-5.4} \text{ pb}$$

$$|V_{tb}| = 1.03 \pm 0.12(\text{exp.}) \pm 0.04(\text{th.}),$$

Significance =  $6.1\sigma$  ( $5.4^{+1.5}_{-1.4}\sigma$  expected)

ATLAS

$$\sigma_{tW} = 27.2 \pm 2.8(\text{stat.}) \pm 5.4(\text{syst.}) \text{ pb}$$

$$|V_{tb}| = 1.10 \pm 0.12(\text{exp.}) \pm 0.03(\text{th.}),$$

Significance =  $4.2\sigma$  ( $4.0\sigma$  expected)

$\sigma_{tW} = 22.2 \pm 0.6 \pm 1.4 \text{ pb}$ , SM expectation

The theory shape uncertainties are fixed to the central expected value in the likelihood maximization

- **Main uncertainties:** ME/PS matching thresholds (14%), renormalization/factorization scales (11%), top quark mass (10%)

All the systematic uncertainties are varied in the likelihood maximization

- **Main uncertainties:** signal modeling (11%), JES (10%), b-tagging (8.4%)

Process negligible at Tevatron, LHC evidence at 7 TeV and first observation at 8 TeV



CMS-TOP-13-009

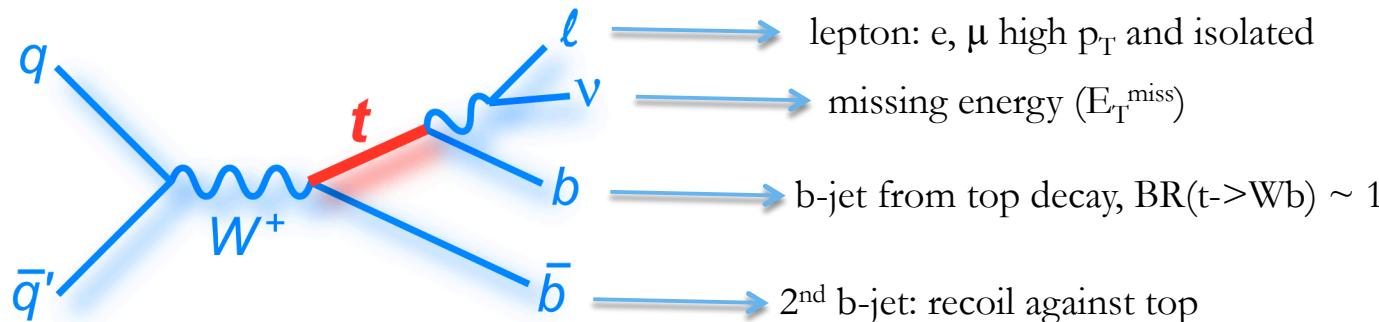
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# s-channel inclusive cross section: intro



ATLAS-CONF-2011-118

- **Smallest cross section at the LHC** among the single top processes
- **Observation at Tevatron** (March 2014, arXiv:1402.5126)



N.B. the jet coming from b-quark has broader  $\eta$  w.r.t. the jet stemming from anti-b-quark

- Choice of b-jet for the top quark reconstruction: the one for which the  $M_{lbv}$  is the closest to the pdf mass 172.5 GeV (**CMS**)
- **Selection**
  - exactly one muon/electron with  $p_T > 26/30$  GeV (**CMS**),  $p_T > 25$  GeV (**ATLAS**)
  - exactly two b-tagged jets with  $p_T > 40$  GeV (**CMS**),  $p_T > 25$  GeV (**ATLAS**)
  - veto other jets with  $p_T > 30$  GeV (**CMS**)



CMS-TOP-13-009

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# s-channel inclusive cross section: analysis and results



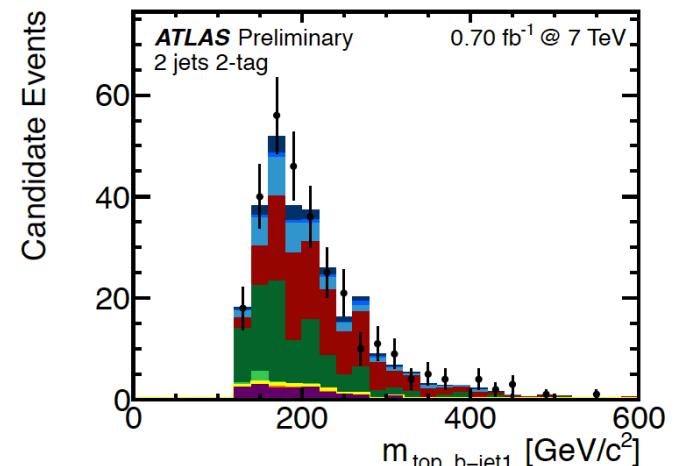
ATLAS-CONF-2011-118

## ATLAS (7 TeV)

- Cut and count analysis

Upper limit:  $\sigma_{\text{s-chan}} < 26.5 \text{ (20.5) pb}$  @ 95% CL, observed (expected)

$\sigma_{\text{s-channel}} = 4.6 \pm 0.3 \text{ pb}$ ,  
SM expectation

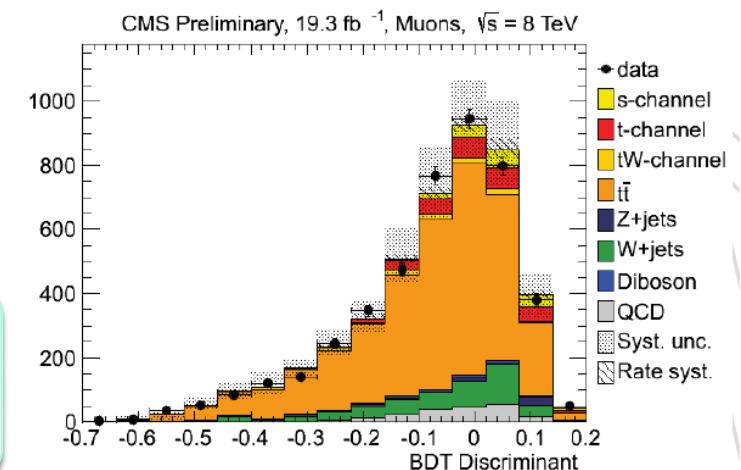


## CMS (8 TeV)

- Multivariate analysis based on Boosted Decision Trees
- Signal extraction: binned maximum likelihood fit to the BDT classifier, in the signal region (2 jets 2 tags) and in the  $t\bar{t}$  control sample (3 jets 2 tags)
- Biggest uncertainty  $t\bar{t}$  ren./fact. scales ( $\sim 80\%$ ) could be improved with NLO MC samples

Upper limit:  $\sigma_{\text{s-chan}} < 11.5 \text{ (17.0, 9.0) pb}$  @ 95% CL,  
observed (expected with SM signal, expected with background only)  
Assuming SM signal  $\sigma_{\text{s-chan}} = 6.2^{+8.0}_{-5.1} \text{ pb}$  (68% FC interval)

$\sigma_{\text{s-channel}} = 5.55 \pm 0.08 \pm 0.21 \text{ pb}$ , SM expectation



Integrated luminosity = 19.3 fb<sup>-1</sup> (CMS, 8 TeV), 0.7 fb<sup>-1</sup> (ATLAS, 7 TeV)

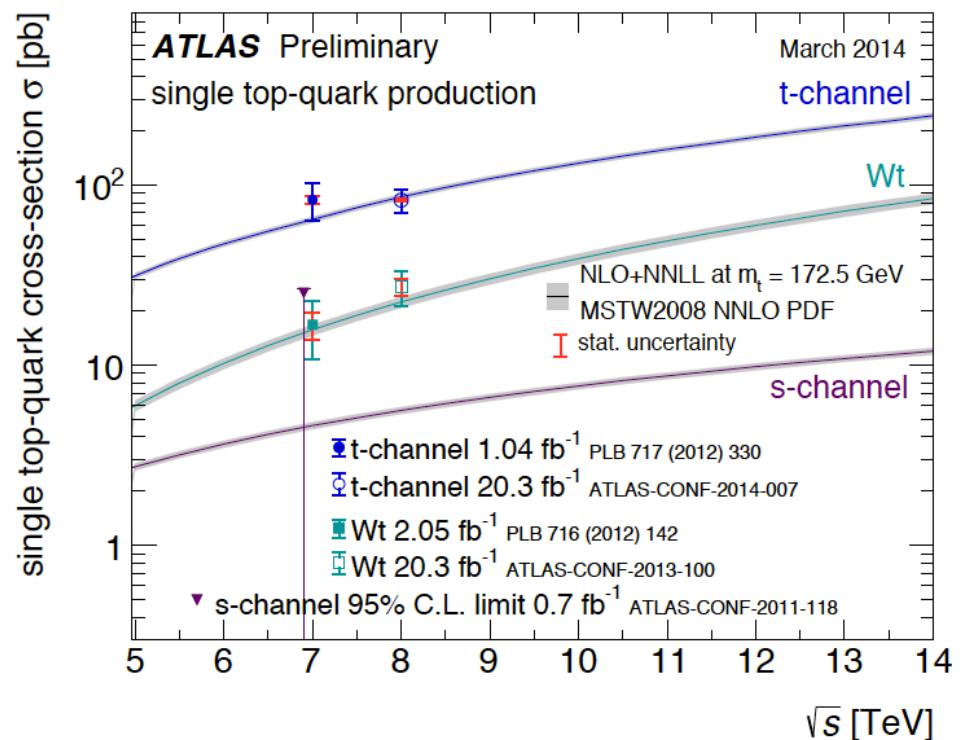
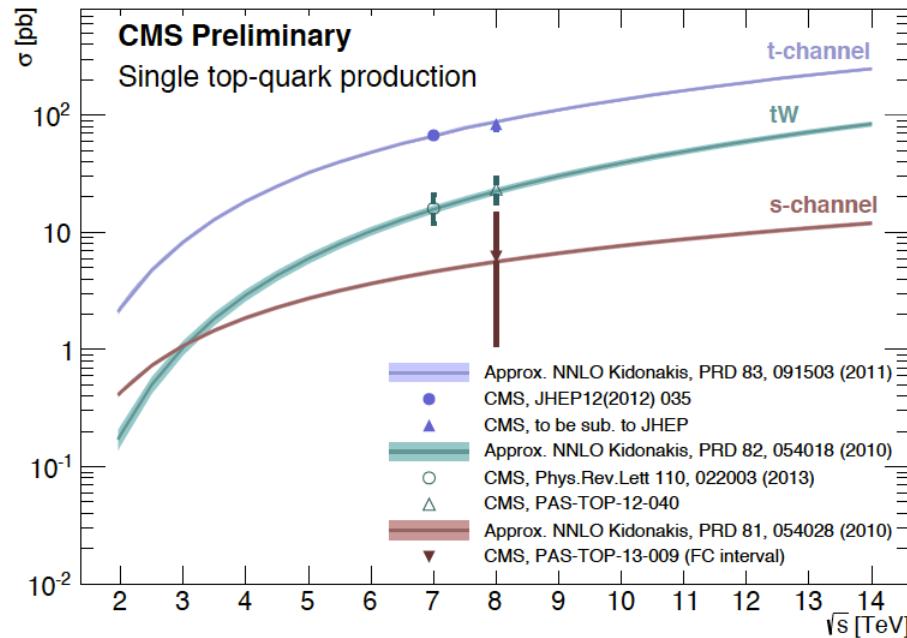
4/9/14



# Single top cross sections

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Good agreement with the approx. NNLO calculation



# W helicity in single top topologies

- Partial width of top quark decay

Integrated luminosity =  $1.14/5.3 \text{ fb}^{-1}$  7/8 TeV

$$\rho(\cos \theta_l^*) \equiv \frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_l^*} = \frac{3}{8}(1 - \cos \theta_l^*)^2 F_L + \frac{3}{8}(1 + \cos \theta_l^*)^2 F_R + \frac{3}{4} \sin^2 \theta_l^* F_0$$

$\theta_l^*$  is defined as the angle between the momentum direction of the lepton and the reversed momentum direction of the b-quark coming from the top, in the W boson rest frame

Less precise than measurement in  $t\bar{t}$  production, but non negligible contribution in future combinations (independent sample; most of the systematic uncertainties are uncorrelated)

- Single top enriched selection: 1 lepton, 2 jets 1 b-tag

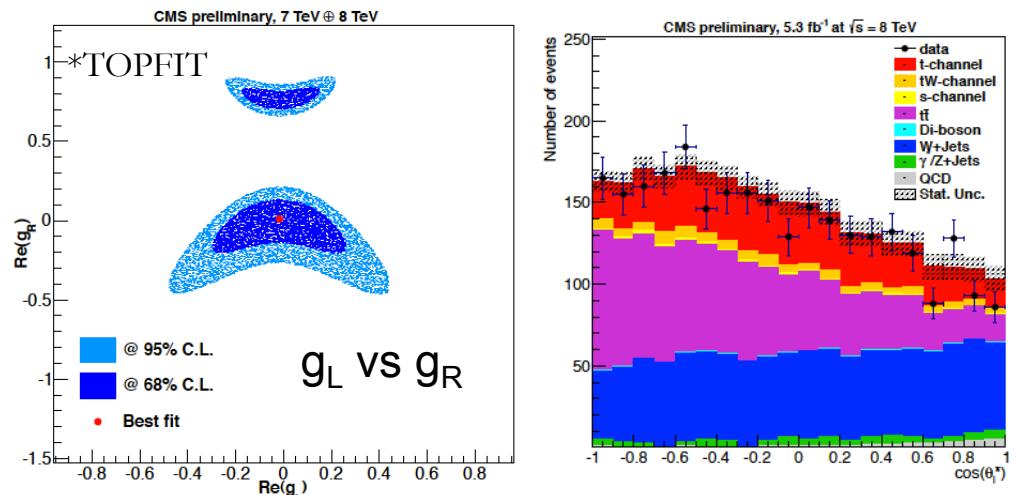
- Binned maximum likelihood fit to  $\cos \theta_l^*$  considering as signal the three single top channels and  $t\bar{t}$

$$\begin{aligned} F_L &= 0.293 \pm 0.069(\text{stat.}) \pm 0.030(\text{syst.}), \\ F_0 &= 0.713 \pm 0.114(\text{stat.}) \pm 0.023(\text{syst.}), \\ F_R &= -0.006 \pm 0.057(\text{stat.}) \pm 0.027(\text{syst.}). \end{aligned}$$

$F_L = 0.311(5)$ ,  $F_0 = 0.687(5)$ ,  $F_R = 0.0017(1)$   
SM expectations with  $m_{\text{top}} = 172.8 \text{ GeV}$ ,  $m_b = 4.8 \text{ GeV}$

Dominant systematic uncertainties:  $E_T^{\text{miss}}$ , JES/JER, factorization/normalization scales

Set exclusion limits on the anomalous couplings  $V_L$ ,  $V_R$ ,  $g_L$ ,  $g_R$ . In the SM  $V_L = V_{tb} \sim 1$ ,  $V_R = g_L = g_R = 0$





CMS-TOP-12-021

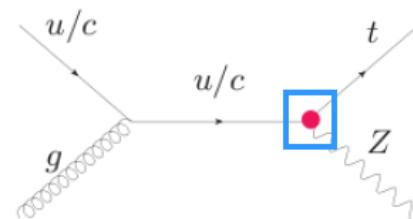
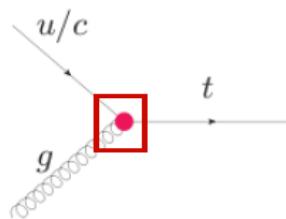
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# FCNC searches



ATLAS-CONF-2013-063

- FCNCs are highly suppressed in the SM
- Searches for FCNC in production:



- tqg coupling best investigated in single top production since the decay topology  $t \rightarrow qg$  can't be easily differentiated from multijets background
- ATLAS searches for  $qg \rightarrow t \rightarrow W (\rightarrow l\nu)b$   
CMS searches for  $qg \rightarrow tZ$  (accesses tqg and tqZ vertices at the same time)
- Limits on  $k/\Lambda$  translates into limits on the BR

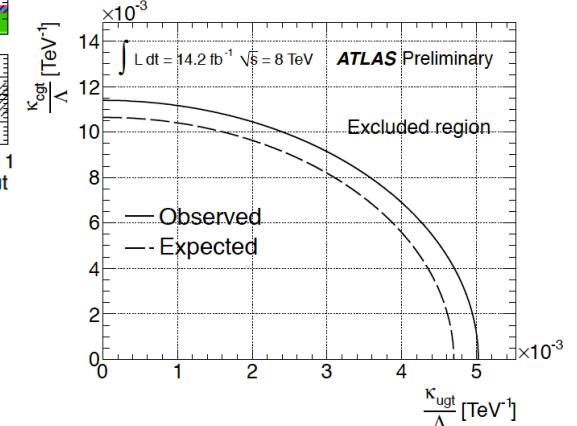
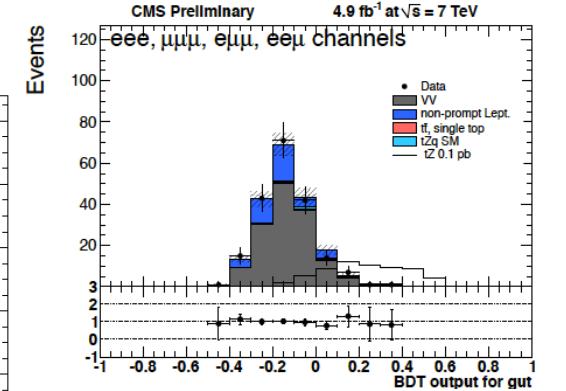
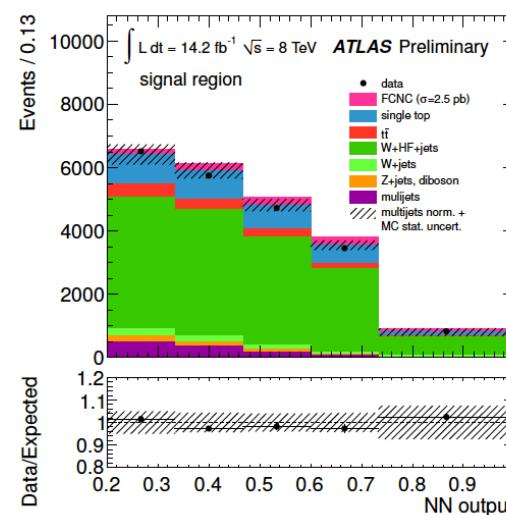
$$\left. \begin{aligned} BR(t \rightarrow ug) &< 3.1 \times 10^{-5} \\ BR(t \rightarrow cg) &< 1.6 \times 10^{-4} \end{aligned} \right\} \text{ATLAS} \quad 8 \text{ TeV}$$

$$\left. \begin{aligned} BR(t \rightarrow uZ) &< 5.1 \times 10^{-3} \\ BR(t \rightarrow cZ) &< 0.11 \end{aligned} \right\} \text{CMS} \quad 7 \text{ TeV}$$

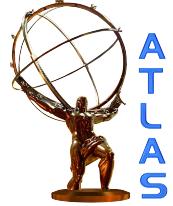
Dominant systematics:

background norm., tagging efficiency, JES/JER

$$\mathcal{L} = \sum_{q=u,c} \left[ \sqrt{2} g_s \frac{\kappa_{gqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} T_a (f_q^L P_L + f_q^R P_R) q G_{\mu\nu}^a \right. \\ \left. + \frac{g}{\sqrt{2} c_W} \frac{\kappa_{Zqt}}{\Lambda} \bar{t} \sigma^{\mu\nu} (\hat{f}_q^L P_L + \hat{f}_q^R P_R) q Z_{\mu\nu} \right] + \text{h.c.}$$



Int. lum. = 4.9  $\text{fb}^{-1}$  (CMS, 7 TeV), 14.2  $\text{fb}^{-1}$  (ATLAS, 8 TeV)



# Conclusions and outlook

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- **Cross section precision measurement:** observation established for t-channel and tW associated production;  $|V_{tb}|$  precise determination; first measurement of fiducial cross section (reduced generator dependency)
  - differential measurements
- **s-channel production upper limit**
  - combination 7+8 TeV data, move to NLO  $t\bar{t}$  generators to benefit from reduced scale uncertainty
- **Top quark production features and properties investigated:** top anti-top charge asymmetry, top polarization and CP violation
  - top mass measurement
- **W helicity:** set limits on anomalous couplings in the  $Wtb$  vertex
  - combination with measurements in  $t\bar{t}$  channels
- **FCNC:** limits on  $qg$ ,  $qZ$  top quark decay modes
- Other **new physics searches** ongoing:  
 $W' \rightarrow tb$  (ATLAS/CMS),  $b^* \rightarrow Wt$  (ATLAS), ...



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*THANKS !*



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# Backup



# t-channel: inclusive cross section @ 7 TeV

- **Selection**

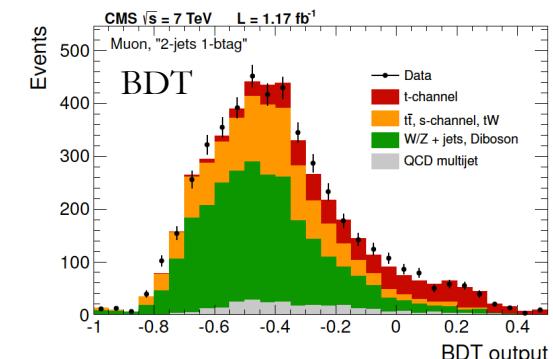
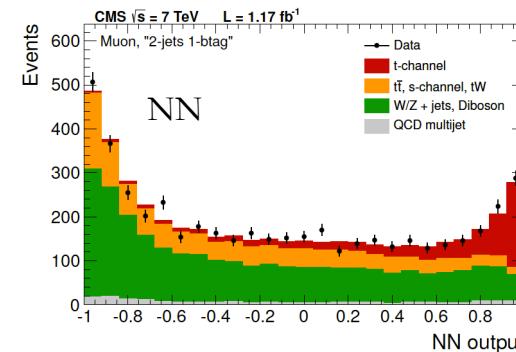
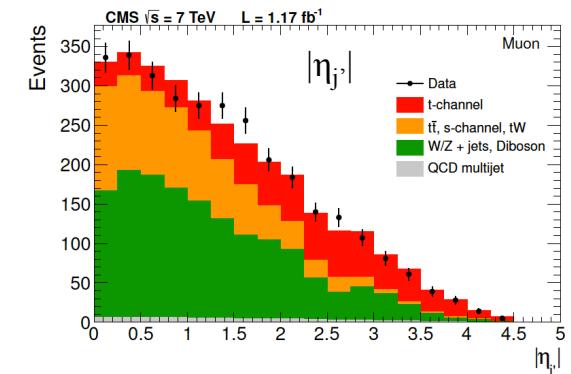
- exactly one lepton with  $p_T > 20/30$  GeV (muon/electron)
- at least two jets ( $\text{anti-}k_T$ ) with  $p_T > 30$  GeV + b-tagging
- $m_T(W) > 40$  GeV ( $\mu$ );  $E_T^{\text{miss}} > 25$  GeV ( $e$ )

- **Template fit** analysis  $|\eta_j|$

- Fit to the pseudorapidity of the recoil jet in the signal region  $130 < m_{\text{top}} < 220$  GeV
- Data-driven W+jets shape
- Low model dependence

- **Boosted Decision Trees** and **Neural Network** analyses

- Most precise measurement
- Exploit the knowledge of electroweak top quark production
- Experimental and cross section uncertainties constrained by data using exclusive phase space regions ( $2j1t, 3j1t, 4j1t, 2j2t, 3j2t, 4j2t$ )





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# t-channel: inclusive cross section @ 7 TeV

Integrated luminosity = 1.17/1.56 fb<sup>-1</sup> (muons/electrons)

Cross section measured by **individual analyses**:

$|\eta_j|$ :  $\sigma_{t\text{-channel}} = 70.0 \pm 6.0(\text{stat}) \pm 6.5(\text{syst}) \pm 3.6(\text{th}) \pm 1.5(\text{lumi}) \text{ pb}$

NN:  $\sigma_{t\text{-channel}} = 68.1 \pm 4.1(\text{stat}) \pm 3.4(\text{syst})^{+3.3}_{-4.3}(\text{th}) \pm 1.5(\text{lumi}) \text{ pb}$

BDT:  $\sigma_{t\text{-channel}} = 66.6 \pm 4.0(\text{stat}) \pm 3.3(\text{syst})^{+3.9}_{-3.3}(\text{th}) \pm 1.5(\text{lumi}) \text{ pb}$

**Analyses combination** performed using BLUE method\*:

$$\begin{aligned}\sigma_{t\text{-channel}} &= 67.2 \pm 3.7(\text{stat.}) \pm 3.0(\text{syst.}) \pm 3.5(\text{theor.}) \pm 1.5(\text{lumi.}) \text{ pb} \\ &= \mathbf{67.2 \pm 6.1 \text{ pb}}\end{aligned}$$

Assuming the CKM matrix elements  $|V_{td}|$ ,  $|V_{ts}| \ll |V_{tb}|$  and allowing for the presence of an anomalous form factor  $f_{L_V}$  in the Wtb coupling:

$$|f_{L_V} \bullet V_{tb}| = \sqrt{\sigma/\sigma_{\text{th}}} = 1.020 \pm 0.046(\text{exp.}) \pm 0.017(\text{th.}), \text{ constrained } |V_{tb}| > 0.92 \text{ at 95% CL}$$

\*L. Lyons, D. Gibaut, and P. Clifford, Nucl. Instr. and Meth. A 270 (1988) 110



# t-channel inclusive cross section @ 8 TeV ATLAS

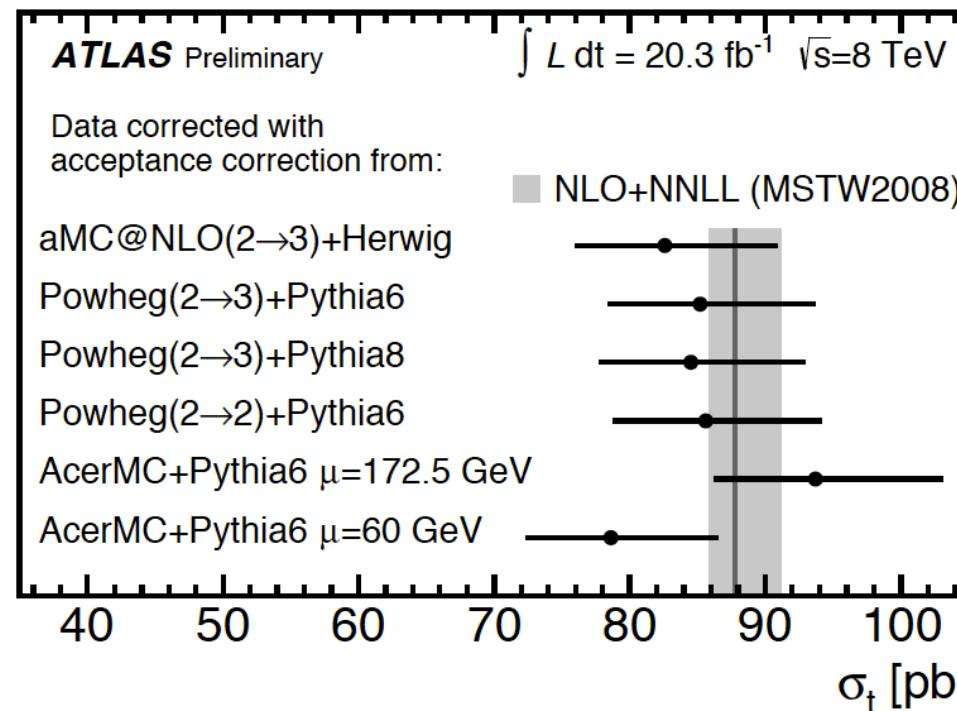


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$$\sigma_{\text{t-channel}} = 82.6 \pm 1.2(\text{stat.}) \pm 11.4(\text{syst.}) \pm 3.1(\text{PDF}) \\ \pm 2.3(\text{lumi.}) \text{ pb (aMC@NLO + Herwig)}$$

$$|V_{tb}| = 0.97^{+0.06}_{-0.07}(\text{exp.}) \pm 0.06(\text{gen. + PDF + theo.}) \\ (\text{total unc. 9.8 \%})$$



# tW associated production: inclusive cross section @ 7 TeV

- **Selection**

- exactly two opposite-charge isolated leptons (ee, e $\mu$ ,  $\mu\mu$ ) with  $p_T > 20$  GeV
- exactly one jet (anti- $k_T$ ) with  $p_T > 30$  GeV, b-tagged
- veto events with  $81 < m_{ll} < 101$  GeV
- min ( $E_T^{\text{miss}}$ , tracker  $E_T^{\text{miss}}$ )  $> 30$  GeV

- **Fit to a BDT multivariate discriminant** simultaneously in the signal region (1j1t) and in control regions (2j1t, 2j2t), background dominated.

- **Main systematic uncertainties:** jet energy scale, matching thresholds

- **Results**

$$\sigma_{tW} = 16^{+5}_{-4} \text{ pb}$$

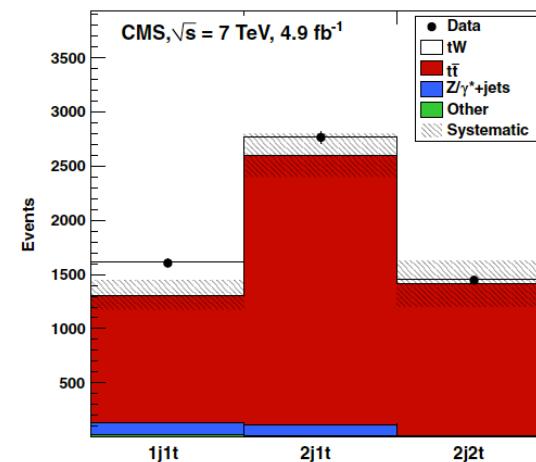
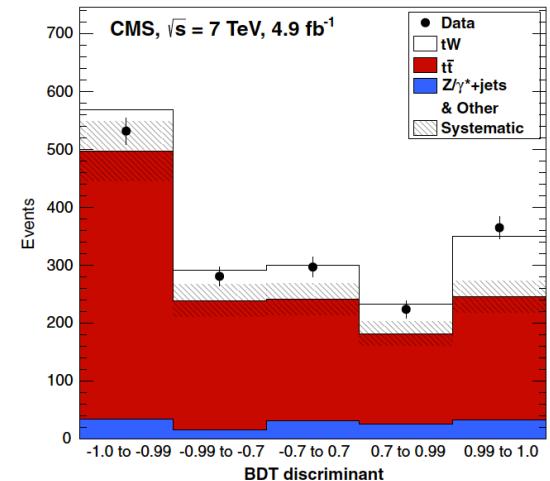
$$|V_{tb}| = 1.01^{+0.16}_{-0.13} (\text{exp.})^{+0.03}_{-0.04} (\text{th.}),$$

constrained  $|V_{tb}| > 0.79$  at 90% CL

Significance =  $4.0\sigma$  ( $3.6^{+0.8}_{-0.9}\sigma$  expected)

SM expectation  
 $\sigma_{tW} = 15.6 \pm 0.4 \pm 1.1 \text{ pb}$

Integrated luminosity =  $4.9 \text{ fb}^{-1}$





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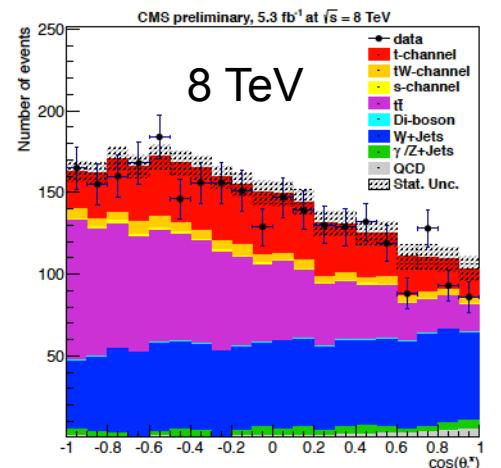
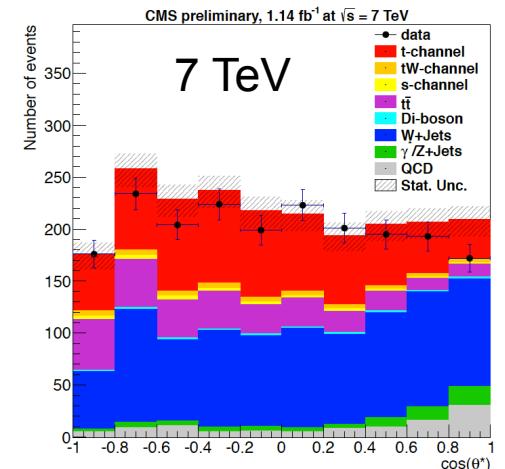
# W helicity in single top topologies: analysis



Integrated luminosity = 1.14/5.3 fb<sup>-1</sup> 7/8 TeV

## • Selection 7/8 TeV (single top enriched)

- exactly one muon with  $p_T > 20/26$  GeV
- exactly two jets ( $\text{anti-}k_T$ ) with  $p_T > 30/60$  GeV, 1 b-tagged
- **Signal:** single top and top pair production (dominant)  
**Main background:** W+jets



## • Reweighting procedure

- weight function  $W = \rho^{\text{non-SM}} / \rho^{\text{SM}}$
- probability of final state  $\cos\theta_{l,\text{reco}}^* =$   
 $= \rho(\cos\theta_{l,\text{reco}}^* | \vec{F}) \propto \int d\cos\theta_{l,\text{gen}}^* W_{\text{gen}} \cdot \rho(\cos\theta_{l,\text{gen}}^* | \vec{F}^{\text{SM}}) \cdot \mathcal{R}(\cos\theta_{l,\text{gen}}^*, \cos\theta_{l,\text{reco}}^*)$



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# W helicity in single top topologies: results



- **Dominant systematic uncertainties:** MET, JES/JER, factorization/normalization scales, simulation and W+jets shape

Integrated luminosity =  $1.14/5.3 \text{ fb}^{-1}$  7/8 TeV

- **Binned maximum likelihood fit results**

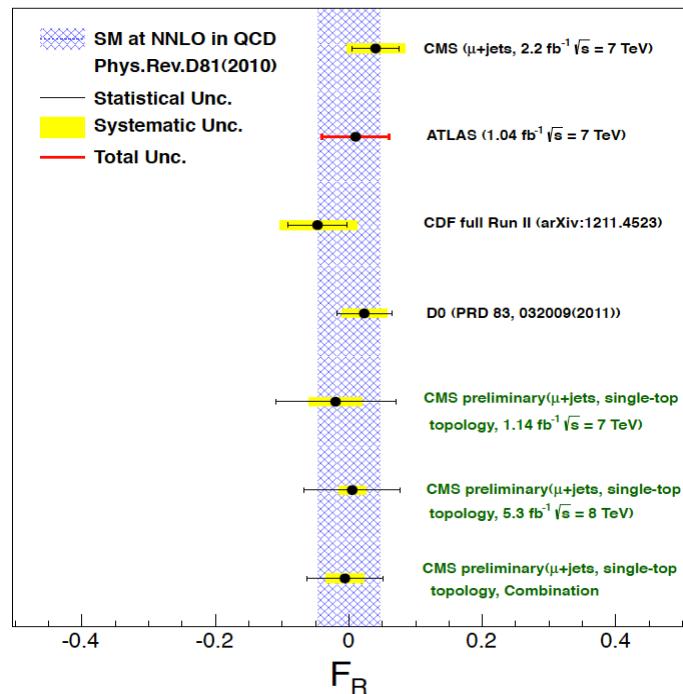
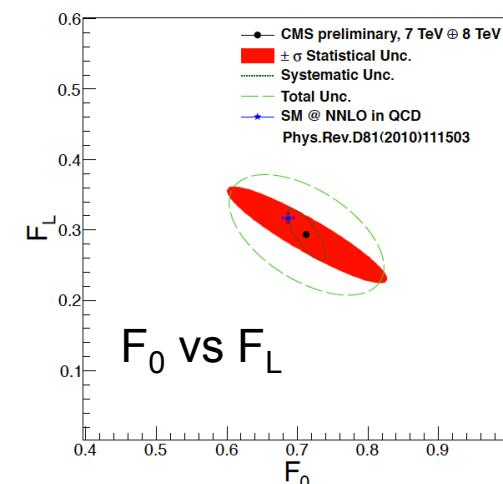
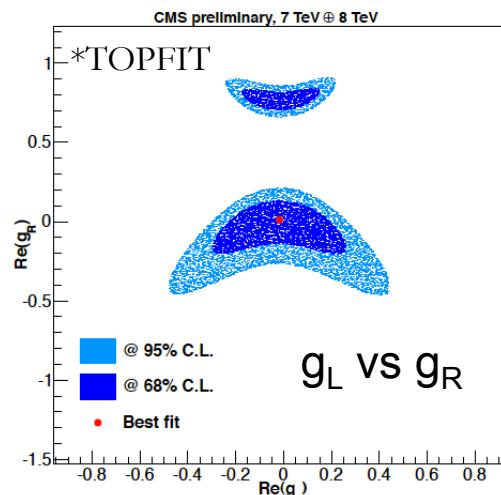
$$F_L = 0.293 \pm 0.069(\text{stat.}) \pm 0.030(\text{syst.}),$$

$$F_0 = 0.713 \pm 0.114(\text{stat.}) \pm 0.023(\text{syst.}),$$

$$F_R = -0.006 \pm 0.057(\text{stat.}) \pm 0.027(\text{syst.}).$$

$$F_L = 0.311(5), F_0 = 0.687(5), F_R = 0.0017(1)$$

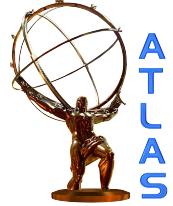
SM expectations with  $m_{\text{top}} = 172.8 \text{ GeV}$ ,  $m_b = 4.8 \text{ GeV}$





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arXiv:1403.7366 ( $\rightarrow$ JHEP)

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# t-channel charge ratio

## Systematic uncertainties tables

CMS

Uncertainty source	$\sigma_{t\text{-ch.}}(t) \text{ (%)}$	$\sigma_{t\text{-ch.}}(\bar{t}) \text{ (%)}$	$R_{t\text{-ch.}} \text{ (%)}$
Statistical uncertainty	$\pm 2.7$	$\pm 4.9$	$\pm 5.1$
JES, JER, MET, and pileup	$\pm 4.2$	$\pm 5.2$	$\pm 1.1$
b-tagging and mis-tag	$\pm 2.6$	$\pm 2.6$	$\pm 0.2$
Lepton reconstruction/trig.	$\pm 0.5$	$\pm 0.5$	$\pm 0.3$
QCD multijet estimation	$\pm 1.6$	$\pm 3.5$	$\pm 1.9$
W+jets, t̄t estimation	$\pm 1.7$	$\pm 3.6$	$\pm 3.0$
Other backgrounds ratio	$\pm 0.1$	$\pm 0.2$	$\pm 0.6$
Signal modeling	$\pm 4.9$	$\pm 9.4$	$\pm 6.1$
PDF uncertainty	$\pm 2.5$	$\pm 4.8$	$\pm 6.2$
Simulation sample size	$\pm 0.6$	$\pm 1.1$	$\pm 1.2$
Luminosity	$\pm 2.6$	$\pm 2.6$	-
Total systematic	$\pm 8.2$	$\pm 13.4$	$\pm 9.6$
Total uncertainty	$\pm 8.7$	$\pm 14.2$	$\pm 10.9$
Measured cross section or ratio	$53.8 \pm 4.7 \text{ pb}$	$27.6 \pm 3.9 \text{ pb}$	$1.95 \pm 0.21$

ATLAS

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



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# t-channel top polarisation – CMS, 8 TeV

## Systematic uncertainties table

Uncertainty source	$\delta A_L^\mu$	$\delta A_L^e$
generator	0.025	0.009
$Q^2$ scale $t$ -channel	0.024	0.055
$Q^2$ scale, $t\bar{t}$	0.015	0.005
$Q^2$ scale, $W+jets$	0.036	0.038
top quark mass	0.058	0.042
$W+jets$ shape	0.016	0.007
$W+jets$ flavour	0.005	0.008
top $p_T$ , $t\bar{t}$	0.010	0.025
matching, $t\bar{t}$	0.028	0.052
matching, $W+jets$	0.025	0.038
PDF	0.013	0.014
JES	0.074	0.074
JER	0.016	0.179
unclustered $E_T$	0.013	0.006
lepton ID and isolation	0.001	0.002
lepton trigger	0.001	0.002
pileup	0.015	0.002
b tagging	0.007	0.009
mistagging	0.001	0.003
lepton weight	0.001	0.009
anti-isolation range of QCD	0.010	0.053
QCD fraction	0.092	0.028
background fractions	0.007	0.018
unfolding bias	0.002	0.003
total systematics	0.15	0.23
statistical	0.07	0.11
total	0.17	0.26



# Search for FCNC - ATLAS, 8 TeV

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## Systematic uncertainties table

Systematic	Signal	$W + \text{jets}$	$W + \text{HF+jets}$
Jet energy scale	< $\pm 1\%$	$\pm 13\%$	$\pm 3\%$
Jet energy resolution	$\pm 4\%$	$\pm 20\%$	$\pm 3\%$
$b$ -tagging efficiency	$\pm 5\%$	$\pm 1\%$	$\pm 1\%$
$c$ -tagging efficiency	< $\pm 1\%$	$\pm 3\%$	$\pm 20\%$
Mistag rate	< $\pm 1\%$	$\pm 26\%$	< $\pm 1\%$
Muon momentum scale	< $\pm 1\%$	< $\pm 1\%$	< $\pm 1\%$
Muon identification	$\pm 1\%$	$\pm 1\%$	$\pm 1\%$
Electron energy scale	< $\pm 1\%$	< $\pm 1\%$	< $\pm 1\%$
Electron identification	$\pm 1\%$	$\pm 1\%$	$\pm 1\%$
Missing transverse momentum	< $\pm 1\%$	< $\pm 1\%$	< $\pm 1\%$
PDF	$\pm 3\%$	$\pm 4\%$	$\pm 8\%$
$W + \text{jets}$ modelling	—	< $\pm 1\%$	< $\pm 1\%$
Cross section	—	24%	55%
Systematic	$t\bar{t}$	single-top	$Z + \text{jets}$
Jet energy scale	$\pm 13\%$	$\pm 4\%$	$\pm 4\%$
Jet energy resolution	$\pm 1\%$	$\pm 2\%$	$\pm 6\%$
$b$ -tagging efficiency	$\pm 5\%$	$\pm 5\%$	$\pm 4\%$
$c$ -tagging efficiency	< $\pm 1\%$	< $\pm 1\%$	$\pm 5\%$
Mistag rate	< $\pm 1\%$	< $\pm 1\%$	$\pm 3\%$
Muon momentum scale	< $\pm 1\%$	< $\pm 1\%$	< $\pm 1\%$
Muon identification	$\pm 1\%$	$\pm 1\%$	$\pm 1\%$
Electron energy scale	< $\pm 1\%$	< $\pm 1\%$	< $\pm 1\%$
Electron identification	$\pm 1\%$	$\pm 1\%$	< $\pm 1\%$
Missing transverse momentum	< $\pm 1\%$	< $\pm 1\%$	$\pm 3\%$
PDF	$\pm 4\%$	$\pm 2\%$	$\pm 5\%$
ISR/FSR	$\pm 3\%$	$\pm 5\%$	—
Cross section	8%	10%	24%