Single top measurements (and V_{tb}) at the LHC

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for the CMS collaboration
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7th International Workshop on Top Quark Physics Physics,
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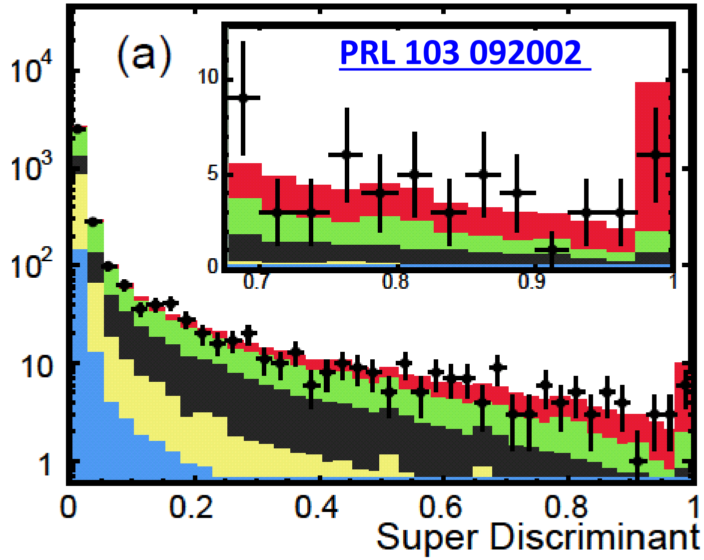
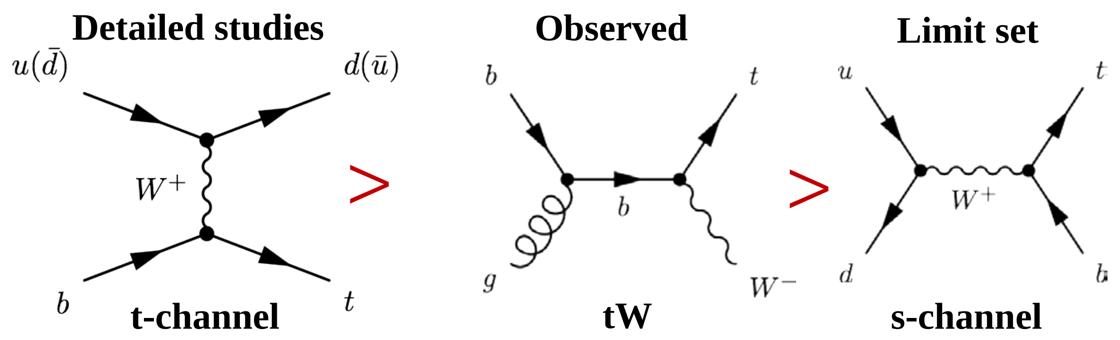
Introduction



- **At hadron colliders:**
- **Dominant: Pair production via strong interactions**
- **Sub-dominant: single production via EWK interaction**



Discovery at Tevatron via Super Discriminant while LHC is a top factory

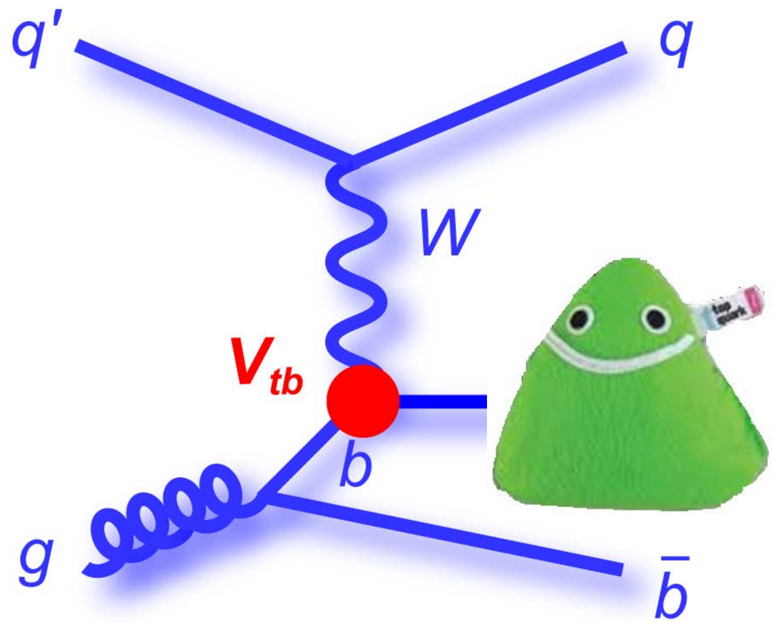
Why single-top?

- Sensitive to **new physics**!
  - FCNC, Anomalous couplings
  - New particles (W', $H^{\pm}$)
- Characteristic scenario for **SM measurements**
  - Top polarization, W helicity, top mass, $|V_{tb}|$
- **Background** in searches
  - SUSY, Higgs

We will look at production cross sections (all), $|V_{tb}|$ (t-, tW-channel), properties (t-channel)

Cross section

Properties



Differential

Wtb couplings

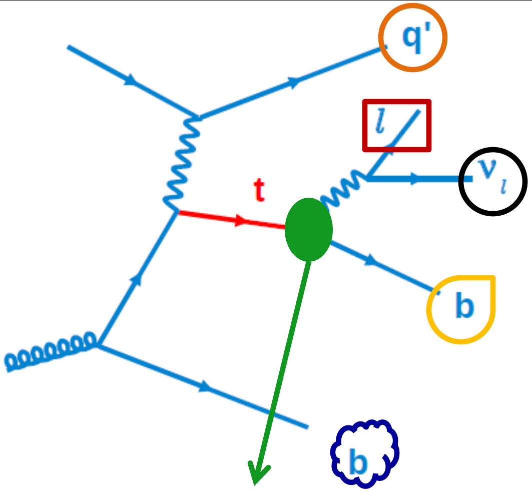
T-CHANNEL

FOCUS ON NEW RESULTS

N. Kidonakis (Phys. Rev. D 83 2011):

- 8 TeV: $87.8^{+3.4}_{-1.9}$ pb
- 7 TeV: 64.6 ± 3.4 pb

t-channel cross section

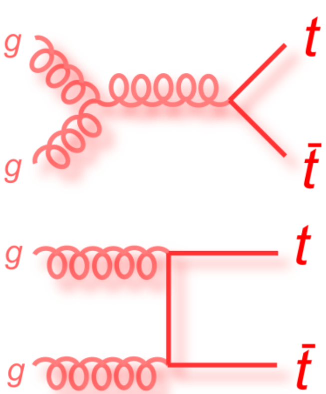


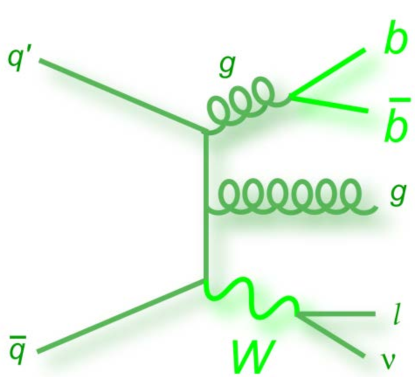
σ(t) depends on $|V_{tb}|$

- Light jet (j') with large pseudorapidity, $\eta_{j'}$
- High p_T lepton (μ, e)
- Missing transverse energy (MET)
- b-quark jet, high p_T, in the central part of the detector
- Additional soft b-quark jet with broader η

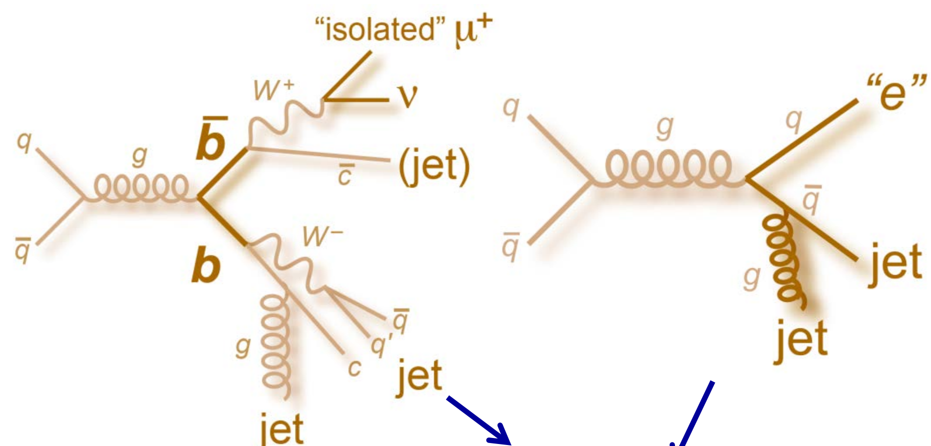
Generic Selection:
1 lepton + **2 J**et , **1** is b-**T**agged + MET-related criteria

Backgrounds:



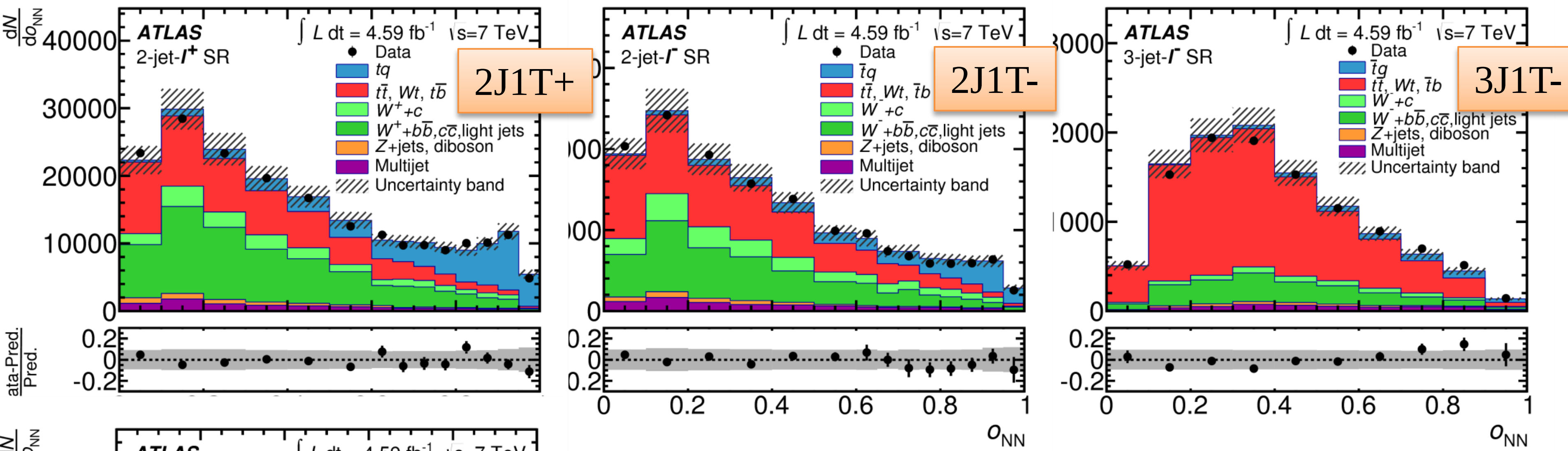


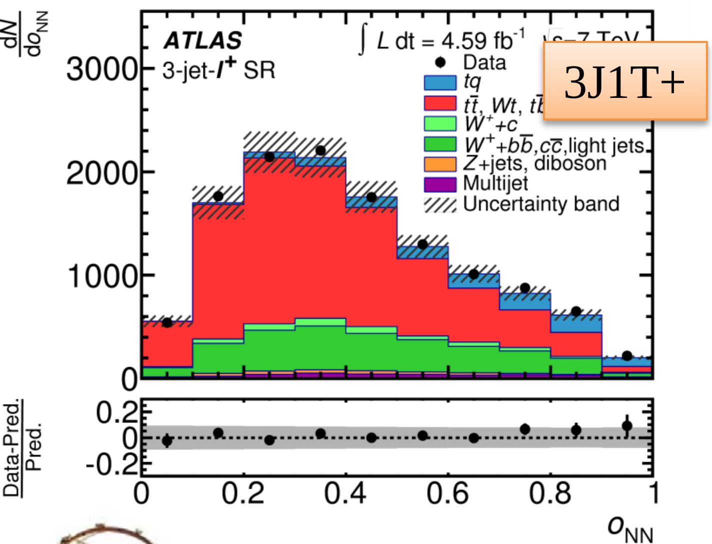
norm. from data



Shape and norm. from data

t-channel cross sections at 7 TeV (4.6 fb^{-1})





1406.7844v1, (to PRD)

- Generic selection and a topological cut against QCD multijets (see backup).
- 4 signal categories: 2J1T (ℓ^+ , ℓ^-) and 3J1T (ℓ^+ , ℓ^-)
  - Looser b-tagging to validate backgrounds (tight b's vetoed)
- A 3J2T to control b-tagging efficiency
- Simultaneous fit to NN output in 4 regions
- Systematic uncertainties from pseudo-experiments

$m_t = 172.5$ GeV

t-channel cross sections at 7 TeV (4.6 fb^{-1})

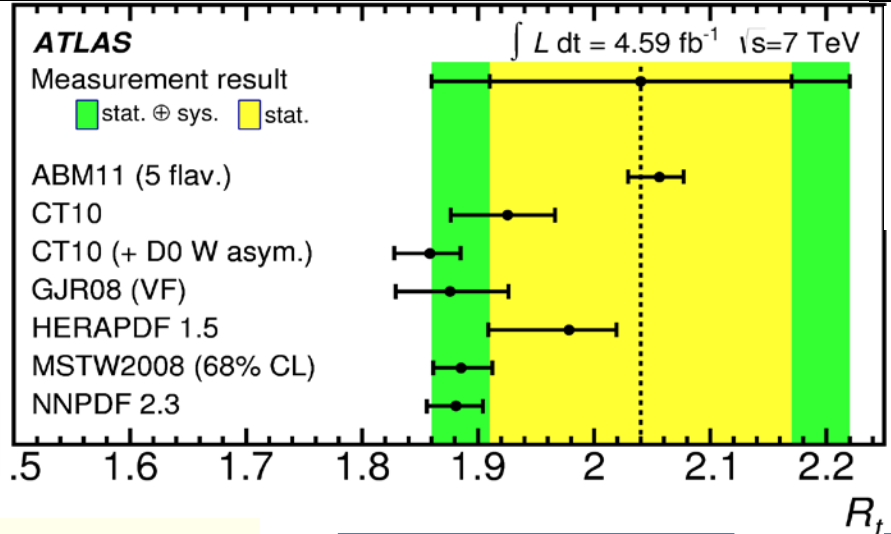
NEW

Theory

(N. Kidonakis, Phys. Rev. D 83 (2011)):

$$\sigma(tq) = 41.9^{1.8}_{-0.9}\ \text{pb}$$

$$\sigma(\bar{t}q) = 22.7^{0.9}_{-1.0}\ \text{pb}$$

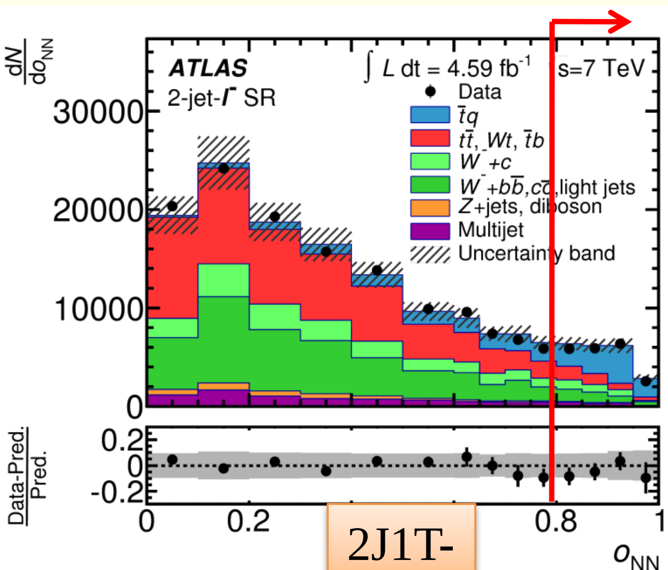


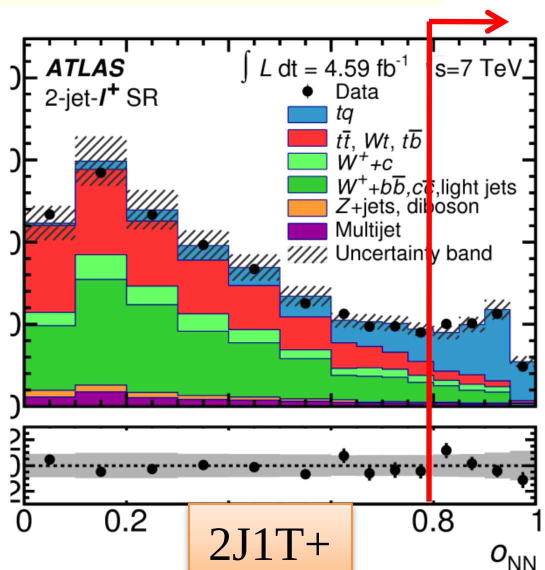
Dominated by systematics → JES

$$\frac{\sigma(tq) = 46 \pm 6\,\text{pb}}{\sigma(\bar{t}q) = 23 \pm 4\,\text{pb}} = R_t = 2.04 \pm 0.18$$

Mainly statistical → PDF

Correlations accounted for





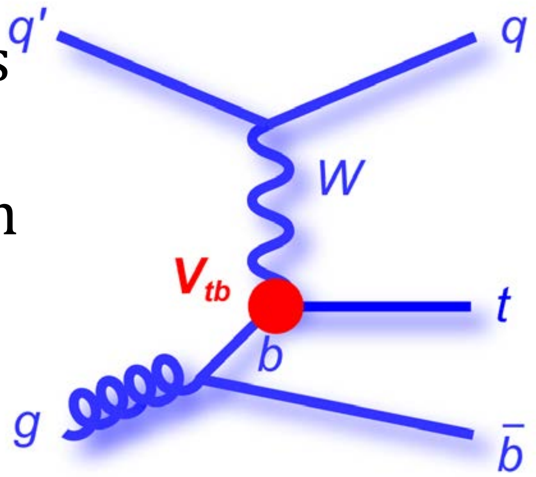
- High purity region for differential measurements
- See C. D. Pardos talk

t-channel cross sections: $|V_{tb}|$ in 7 TeV

	Theory PRD 83 (2011)	ATLAS 4.6 fb^{-1} 1406.7844v1	CMS 1.14 fb^{-1} JHEP12(2012) 035
σ (t-chan)	64.6 ± 3.4 pb	68 ± 8 pb	67.2 ± 6.1 pb

- With tWb vertex in production, t-channel cross section depends on $|V_{tb}|$
- Assuming $|V_{td}|$, $|V_{ts}| << |V_{tb}|$ and the interaction being purely left-handed

$$|V_{tb}| = \sqrt{\frac{\sigma_{meas}}{\sigma_{theo}}}$$



ATLAS: $|V_{tb}| = 1.02 \pm 0.07$

$|V_{tb}| < 1$ ➡ $0.88 < |V_{tb}| <= 1$ @ 95% C.L.

CMS: $|V_{tb}| = 1.020 \pm 0.049$

$|V_{tb}| < 1$ ➡ $0.92 < |V_{tb}| <= 1$ @ 95% C.L.

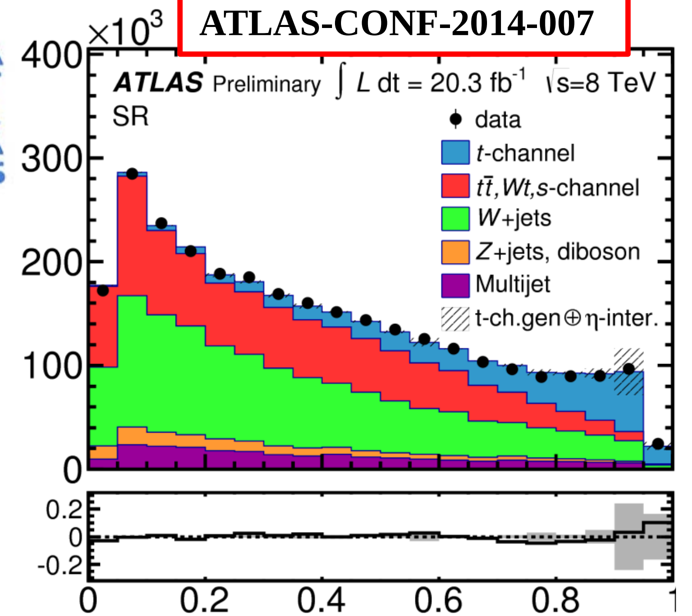
$m_t = 172.5$ GeV

t-channel cross sections at 8TeV (20.3 fb^{-1}) NEW

- Measurement in a fiducial volume

- Fit to NN output in the signal (2J1T) region
- Backgrounds as constrained nuisance parameters
  - Validated in 2J2T ($t\bar{t}$) and 2J0T (W+jets)
- Systematics from pseudo-experiments

ATLAS-CONF-2014-007



- **How? A truth (fiducial)** phase space close to ***selected data***
  - Truth objects (leptons, jets,…) defined close to reco. ones using final state particles.

$$\sigma_{\mathrm{fid}} = 3.37 \pm 0.05(\mathrm{stat.}) \pm 0.47(\mathrm{syst.}) \pm 0.09(\mathrm{lumi.})\ \mathrm{pb}$$

Signal generator

JES

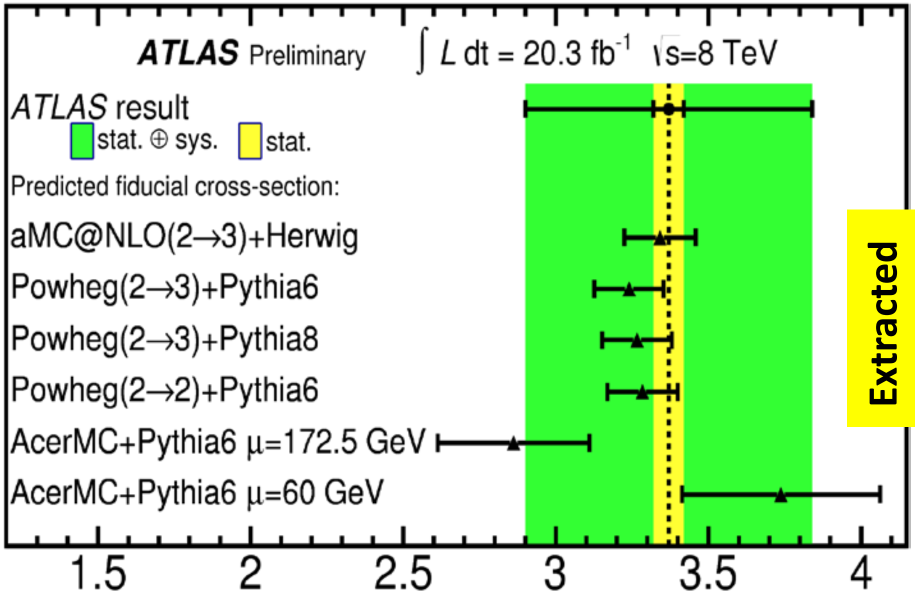
- **Main benefit:**
  - Marginal effect due to acceptance
  - Affected mainly by efficiencies so less model-dependent

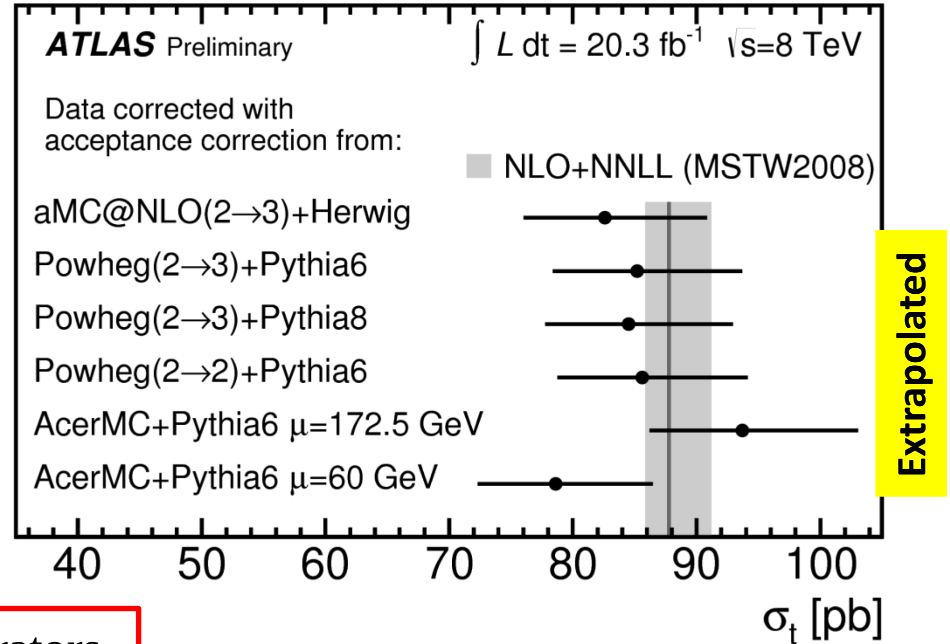
	Generator	PDF	Total
Fiducial	8%	1%	14%
Inclusive	13%	4%	17%

  - Understand the acceptance in comparison with the inclusive measurement

t-channel cross sections at 8TeV (20.3 fb^{-1})

NEW





ATLAS-CONF-2014-007

With different generators

$$\sigma = \frac{1}{\epsilon_{fid}} . \sigma_{fid}$$

Model-dependence $\gg \delta_{th}$

aMC@NLO + Herwig

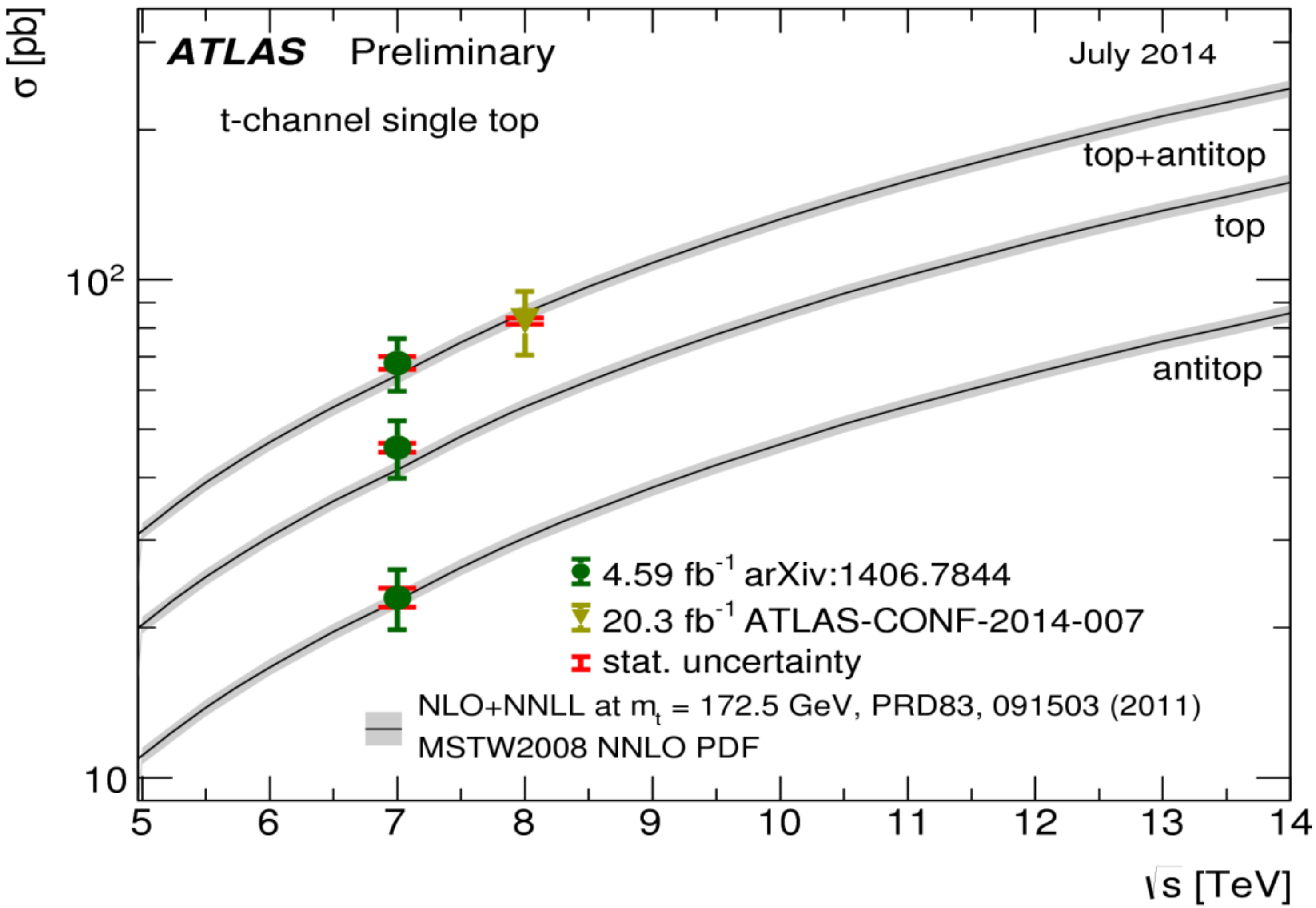
$$\sigma = 82.6 \pm 1.2(\text{stat.}) \pm 11.4(\text{syst.}) \pm 3.1\ (\text{PDF}) \pm 2.3\ (\text{lumi.})$$

$$|V_{tb}| = 0.97^{+0.09}_{-0.1}$$

Assuming $m_t = 172.5$ GeV

t-channel cross sections at 8TeV (20.3 fb^{-1})

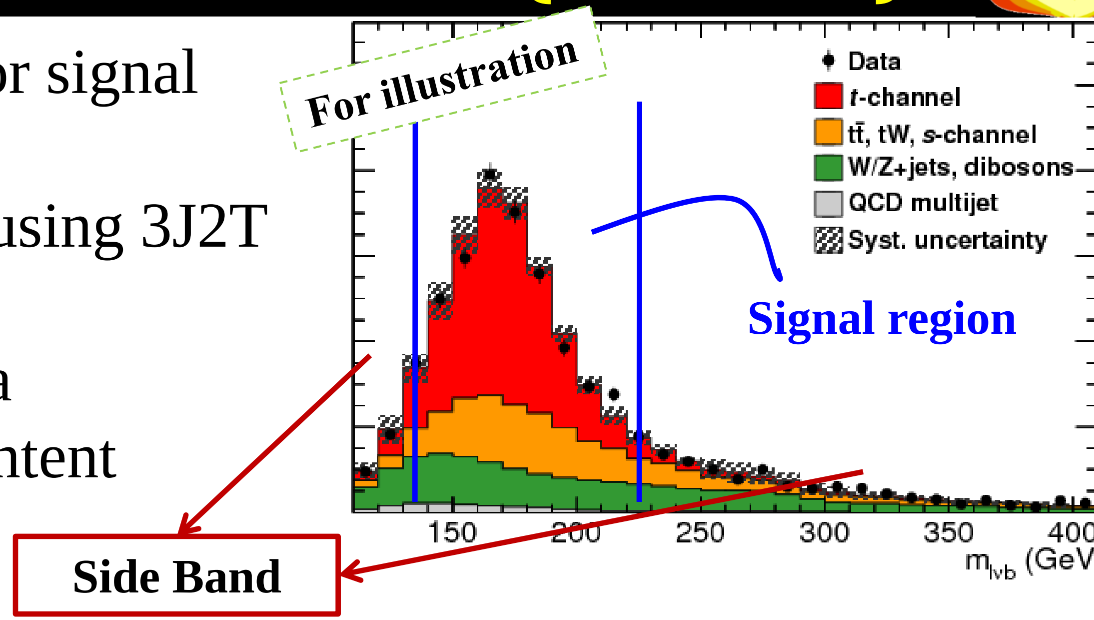
NEW



ATLAS-CONF-2014-007

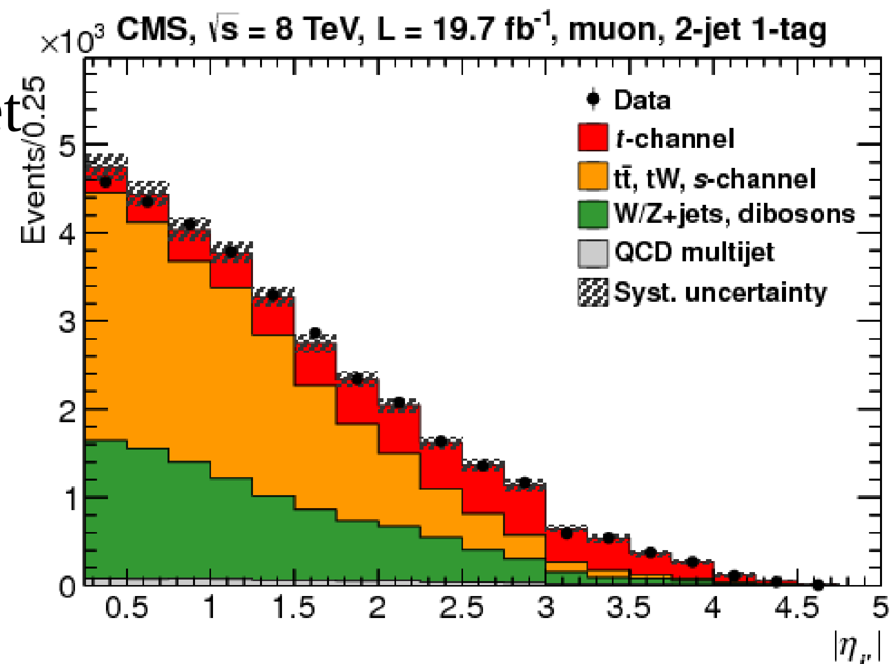
t-channel cross sections at 8TeV (19.7 fb^{-1}) NEW

- Generic selection in 2J1T for signal
- $t\bar{t}$ background is corrected using 3J2T
- W/Z+jets validated in 2J0T
- Shape is taken from SB data
    - Similar heavy-flavor content



JHEP06(2014)090

- Template fit to |η| of the non-tagged jet
- Backgrounds treated as constrained parameters
- Other systematics from pseudo-experiments
- Fit is done inclusively and for ℓ^+ and ℓ^-



t-channel cross sections at 8TeV (19.7 fb^{-1})

NEW

- Template fit to |η| of the non-tagged jet

JHEP06(2014)090

$$\sigma_{tot} = 83.6 \pm 2.3\,(\text{stat.}) \pm 7.4\,(\text{syst.})\ \text{pb}$$

$$\sigma_{t} = 53.8 \pm 1.5\,(\text{stat.}) \pm 4.4\,(\text{syst.})\ \text{pb}$$

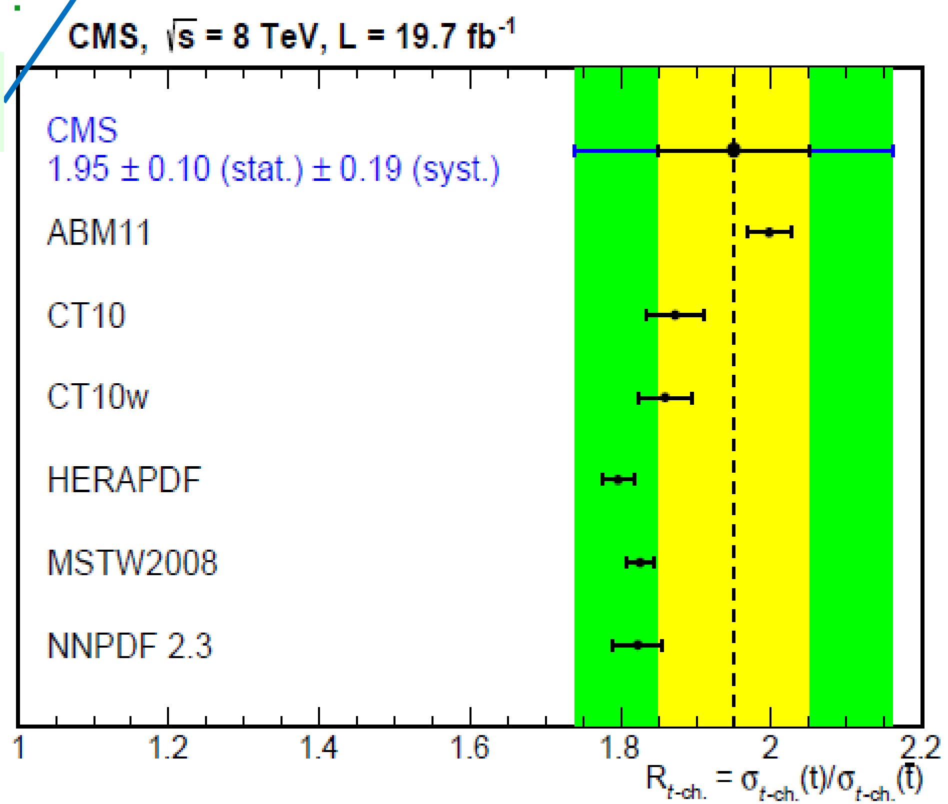
$$\sigma_{\bar{t}} = 27.6 \pm 1.3\,(\text{stat.}) \pm 3.7\,(\text{syst.})\ \text{pb}$$

Signal modeling

$$R_{t-ch} = 1.95 \pm 0.1\,(\text{stat.}) \pm 0.19\,(\text{syst.})$$

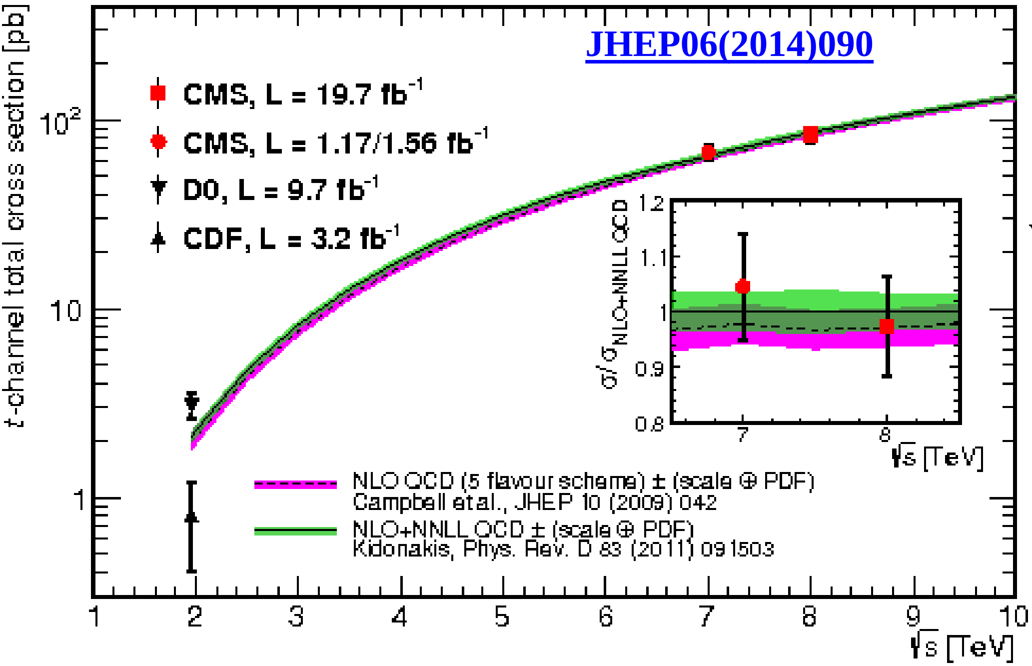
$m_t = 172.5$ GeV

PDF



t-channel cross sections at 8TeV (19.7 fb^{-1})

NEW



$$R_{8/7} = \frac{\sigma_{8TeV}}{\sigma_{7TeV}}$$
$$= 1.24 \pm 0.08\,(\text{stat.}) \pm 0.12\,(\text{syst.})$$

With $|V_{tb}| \gg |V_{ts}|, |V_{td}|$

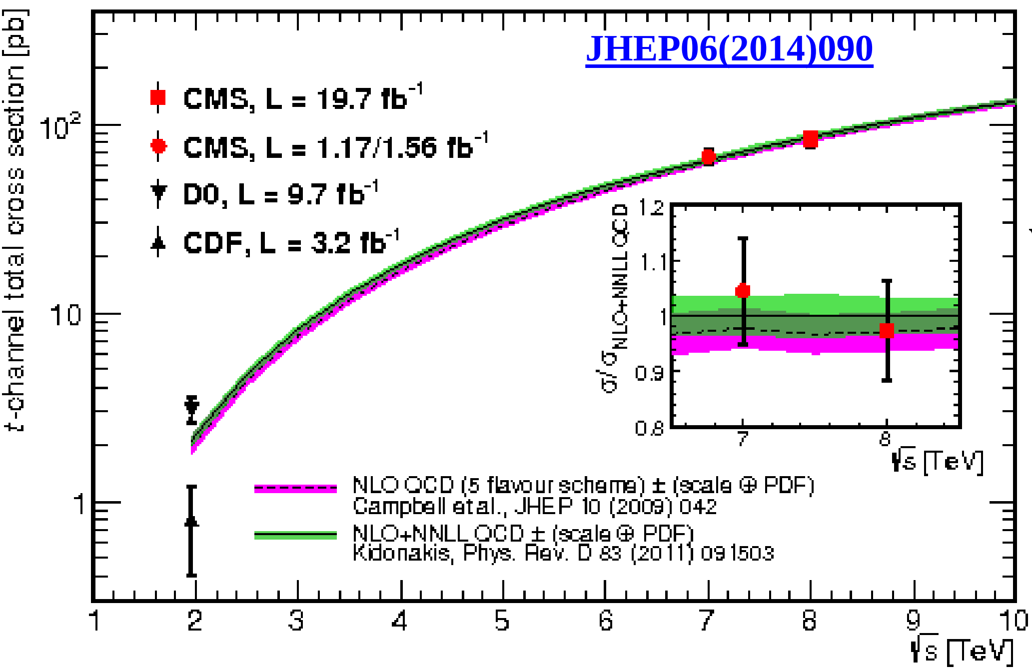
$$\left|f_V^L V_{tb}\right| = 0.998 \pm 0.038\,(\text{exp.}) \pm 0.016\,(\text{th.})$$

7 ⊕ 8

PDG: **0.89 ± 0.07**

t-channel cross sections at 8TeV (19.7 fb^{-1})

NEW



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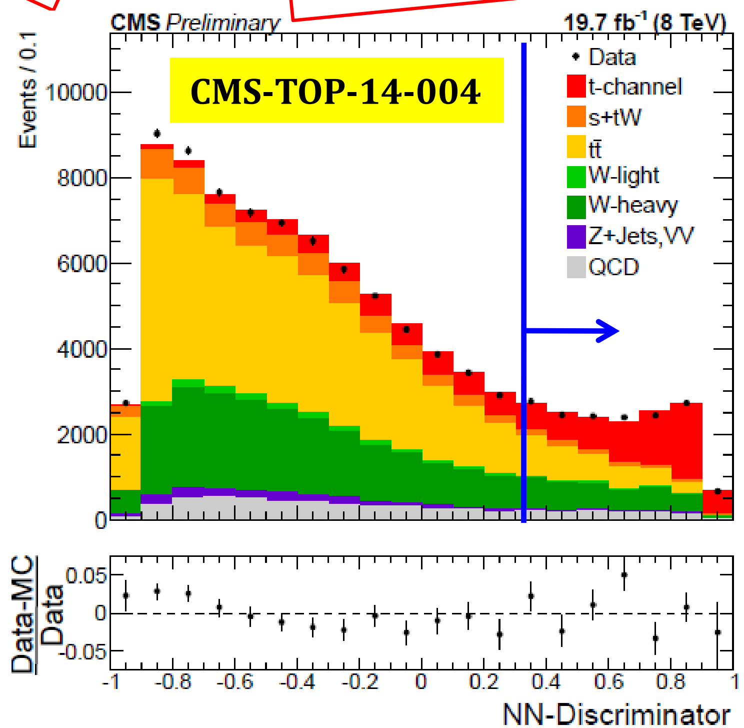


- A similar selection without $m_{lb\nu}$
- NN is trained for t-channel signal in 2J1T
- Fit to NN-disc. with background as constrained parameters
- A high purity sample by a cut on NN-disc. for differential cross section.
- See details in C. D. Pardos talk ….

NEW

Anomalous tWb couplings in t-channel

NEW

- Deviations from SM in the **tWb** structure affects the single-top cross section

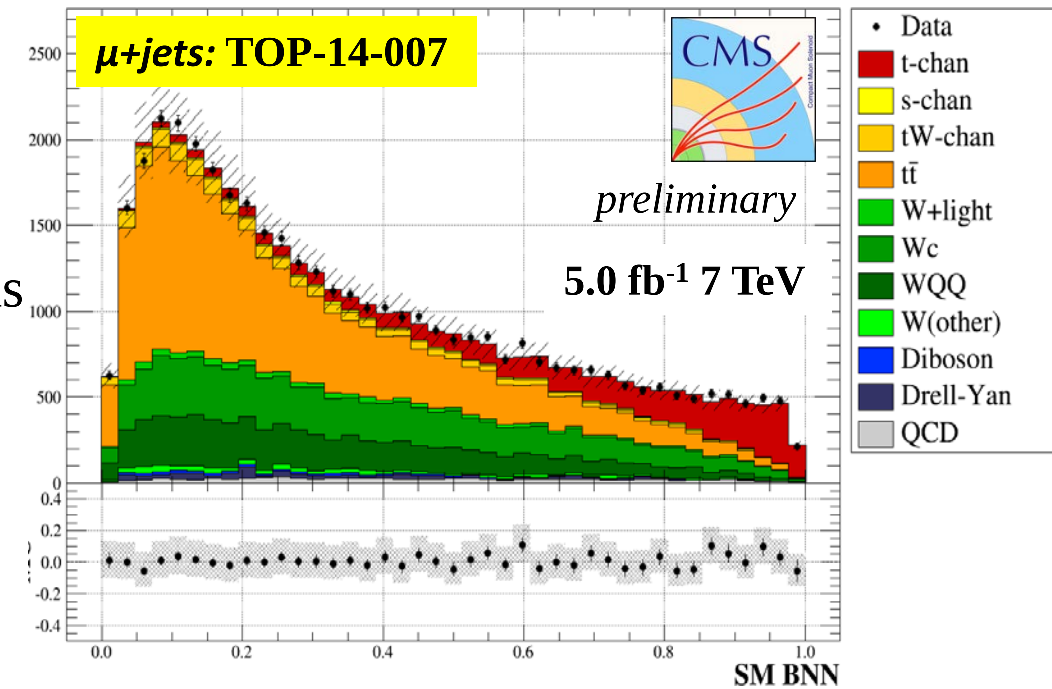
$$L = -\frac{g}{\sqrt{2}}\,\bar{b}\,\gamma^{\mu}(f_V^L\,P_L + f_V^R\,P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\,\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(f_T^L\,P_L + f_T^R\,P_R)tW_{\mu}^{-} + \text{h.c.}$$

- Dedicated search for anomalous couplings in the ***production*** and ***decay***
- Early ATLAS result, $-0.20 < \mathrm{Im}(f_T^R) < 0.3$ @95% CL (ATLAS-CONF-2013-032)

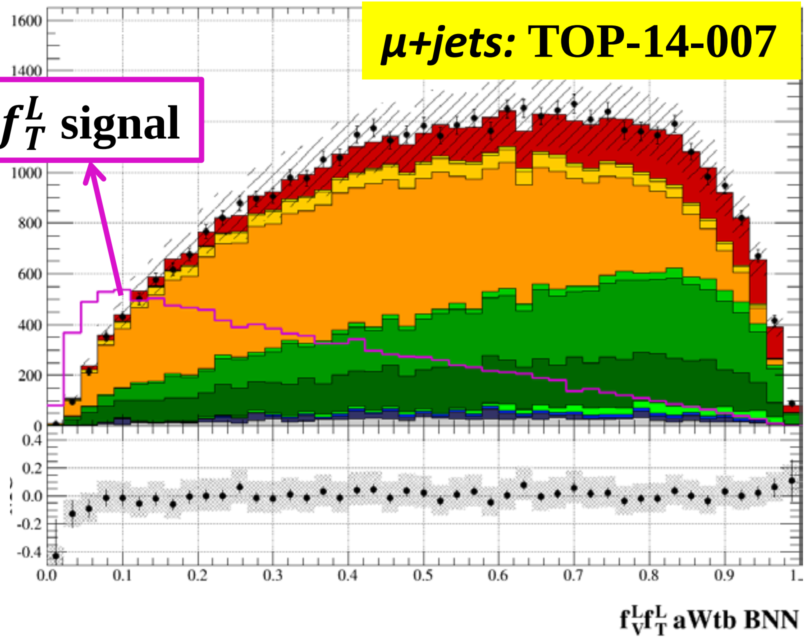
- Generic selection and a cut on a **QCD BNN** against QCD (see backup)
- **Signal categories**, used in statistical analysis: 2J1T, 3J1T, 3J2T
- **Background modeling**: 2J0T and 3J0T (W+jets), 4J2T ($t\bar{t}$), normalization as constrained nuisance parameters

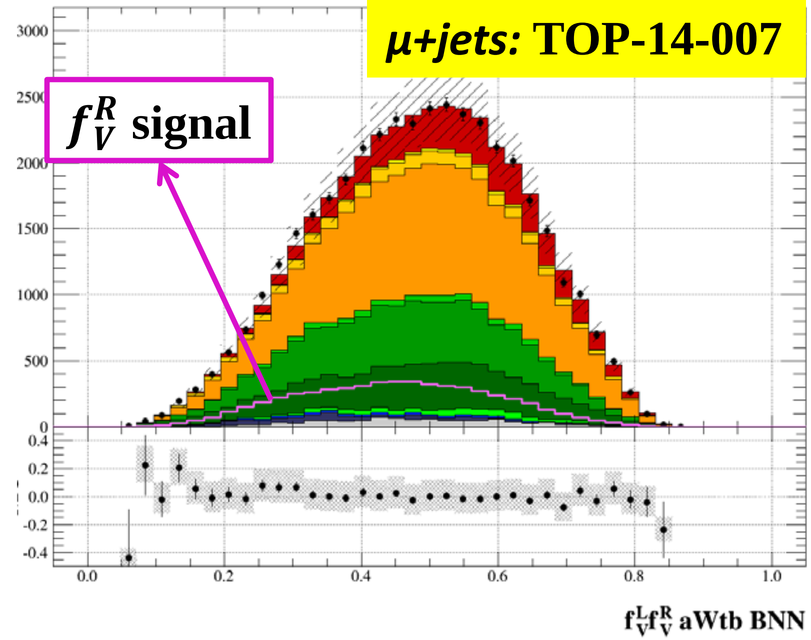
- Two types of MVA used
  - **SM BNN** discriminates SM single-top from SM backgrounds
  - **aWtb BNN,** extracted from the model, used against all SM to limit f_V^R or f_T^L separately

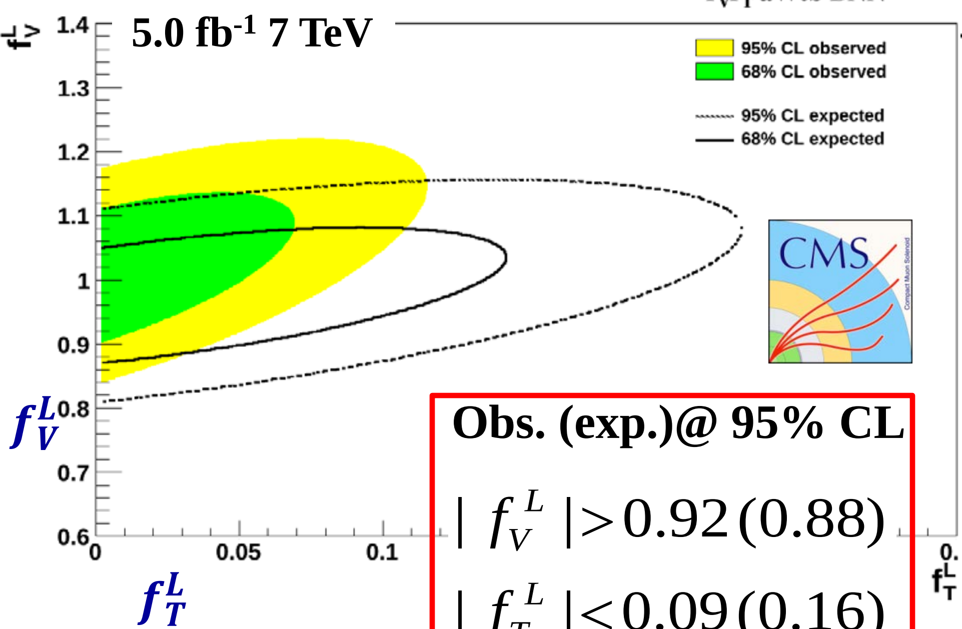
- A 2D fit to both MVA's



Anomalous tWb couplings in t-channel



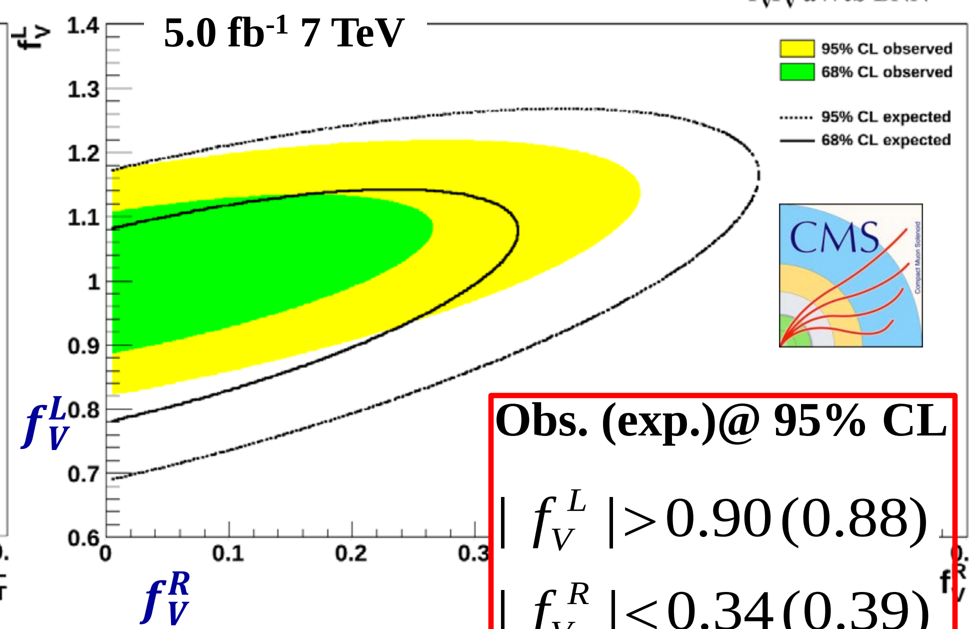




Obs. (exp.)@ 95% CL

$|f_V^L| > 0.92\,(0.88)$

$|f_T^L| < 0.09\,(0.16)$

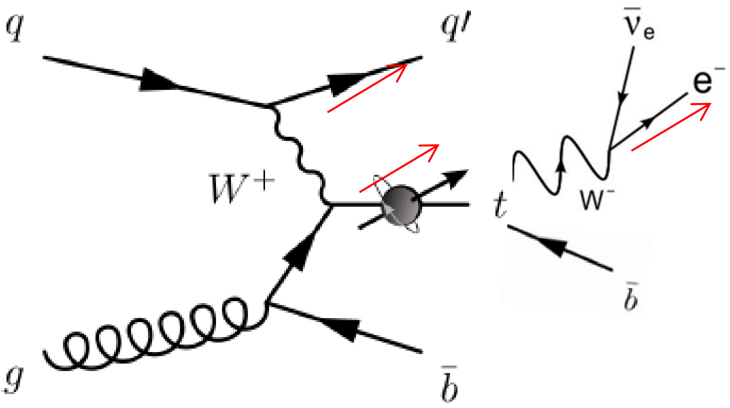


Obs. (exp.)@ 95% CL

$|f_V^L| > 0.90\,(0.88)$

$|f_V^R| < 0.34\,(0.39)$

Top quark polarization



New physics in tWb vertex alters the top polarization

Single-top quark in t-channel:
produced 100% polarized in the direction of charged lepton due to V-A coupling

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{1}{2}(1 + P_t \alpha_l \cos\theta^*)$$

top polarization

$\theta^* \equiv \measuredangle(l, q')$ in top rest frame

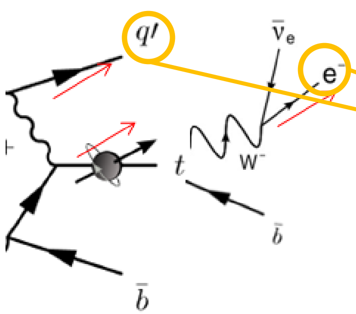
Correlation degree or spin analyzing power
SM: $\alpha_l \approx 1$ for charged lepton

CMS-TOP-13-001

- The sample is statistically a mix of ↑ and ↓ top quarks
- We measure the spin asymmetry:

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

Experimentally:
we select the t-channel event: 1 lepton + 1 light jet + 1 b-tagged jet + …



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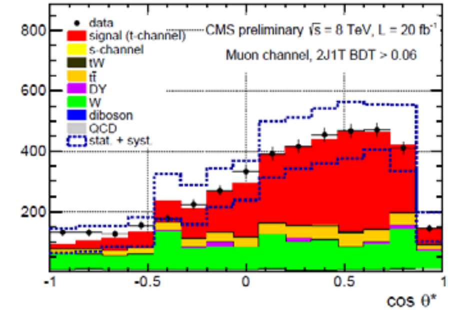
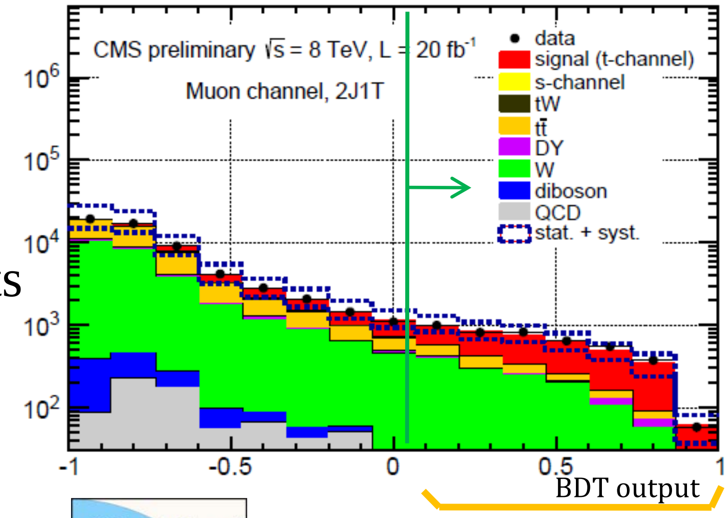


Top quark polarization

The output of a Boosted Decision Tree is used to

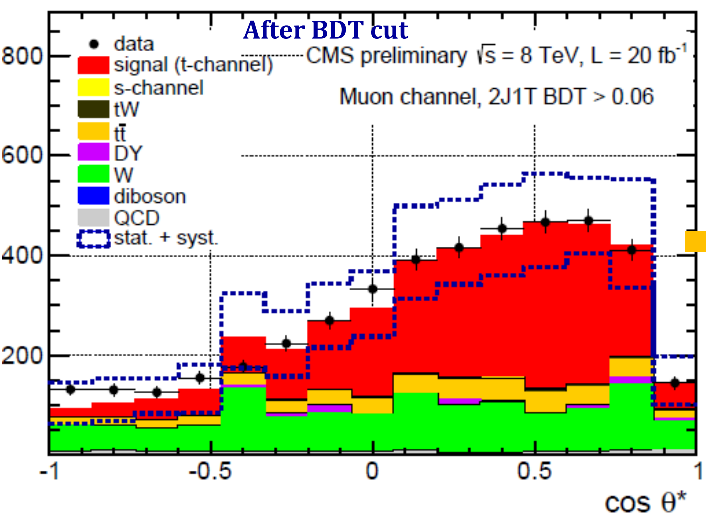
1. Determine the background contributions
2. Enrich the signal sample

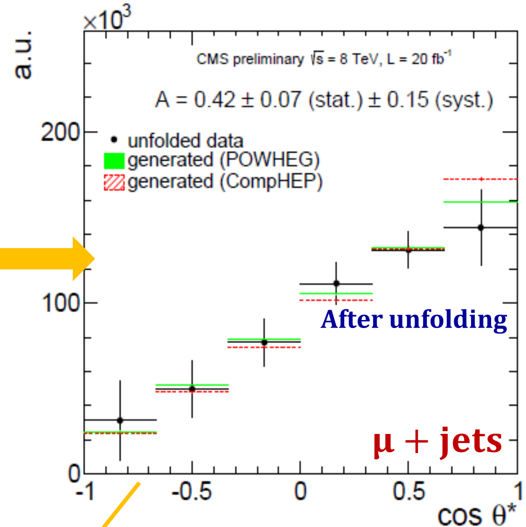


Background validation: 3J1T, 3J2T ($t\bar{t}$), 2J0T W+jets

MadGraph **W+jets shape** is corrected with **SHERPA**

The detector effects are resolved via **unfolding**





Combination

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

$$A_l \equiv \frac{1}{2} P_t \cdot \alpha_l \quad \text{and } \alpha_l \approx 1$$

JEC

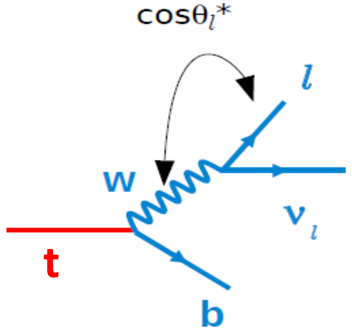
Muon $A_l = 0.42 \pm 0.07(\text{stat.}) \pm 0.15(\text{syst.})$

Electron $A_l = 0.31 \pm 0.11(\text{stat.}) \pm 0.23(\text{syst.})$

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

CMS-TOP-13-001

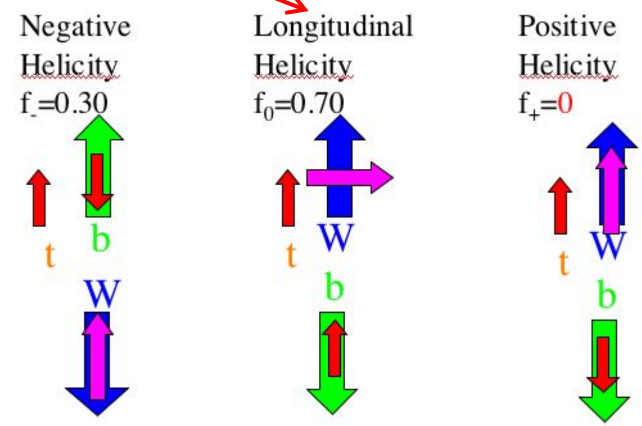
W-helicity, single-top topology



- Partial decay of top quark with $\mathbf{F_i} \equiv \frac{\Gamma_i}{\Gamma}$

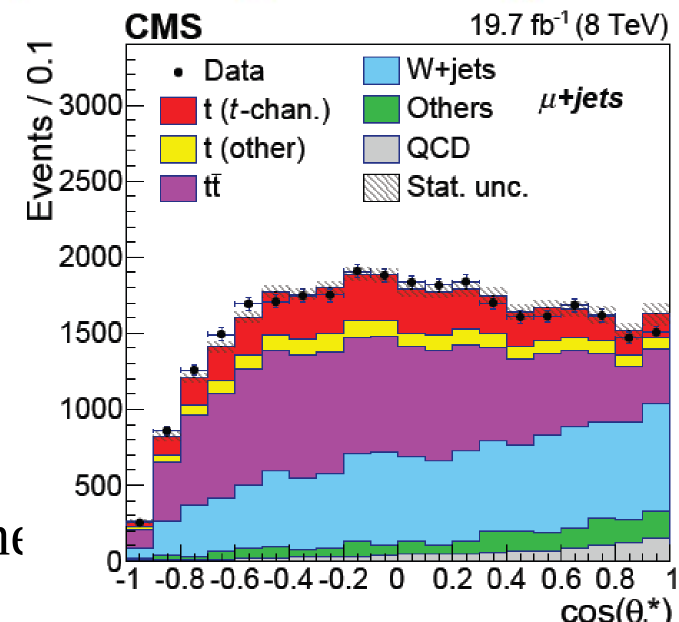
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l^*} = \frac{3}{8}(1-\cos\theta_l^*)^2\,\mathbf{F_L} + \frac{3}{4}\sin\theta_l^*\,\mathbf{F_0} + \frac{3}{8}(1+\cos\theta_l^*)^2\,\mathbf{F_R}$$

CMS-TOP-12-020



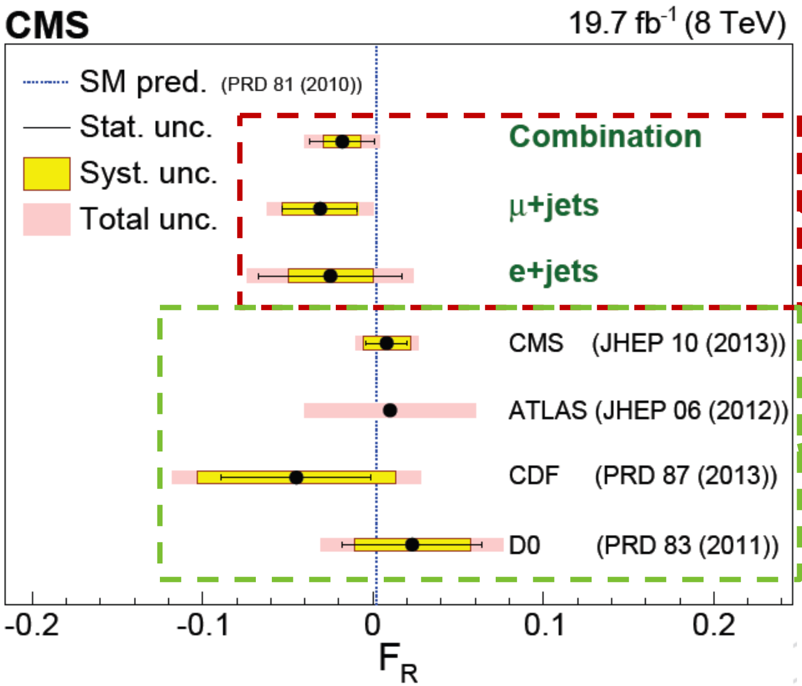
$$\boxed{\begin{aligned}\Gamma_{0\,(L,R)} \propto \frac{m_t^2}{m_W^2}\left[\left|f_V^L\right|^2 + \left|f_V^R\right|^2\right]\mathcal{F}_{1\,(2)}\left(m_W^2, m_b^2\right) \\ + \left[\left|f_T^L\right|^2 + \left|f_T^R\right|^2\right]\mathcal{F}_{2\,(1)}\left(m_W^2, m_b^2\right) + \cdots\end{aligned}}$$

- tWb anomalous couplings are reflected in angular decay distribution of $\cos\theta_l^*$
- First measurement of W-helicity in single-top
- A reweighting method employed in a binned likelihood fit using $\cos\theta_l^*$
- Simultaneous measurement of W+jets background
- Signal is every process that includes $t \to b\ell\nu$
    - Contributions from $t\bar{t}$ are taken into account
- Results at e- and μ-channels are combined using the likelihoods



W-helicity, single-top topology

NEW



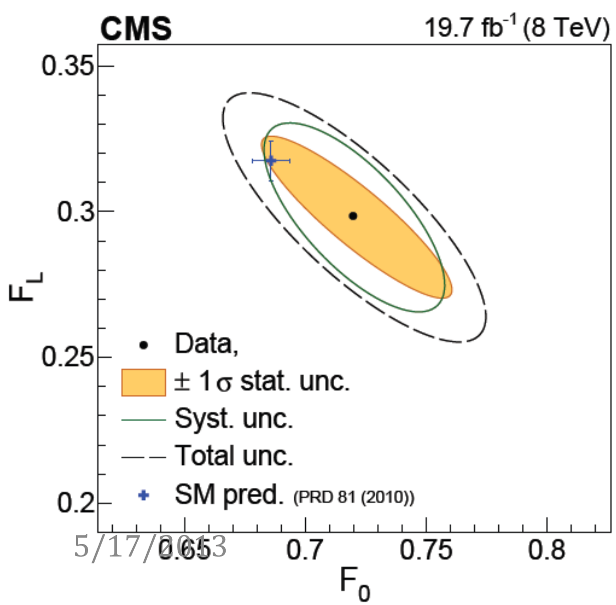
top-pair

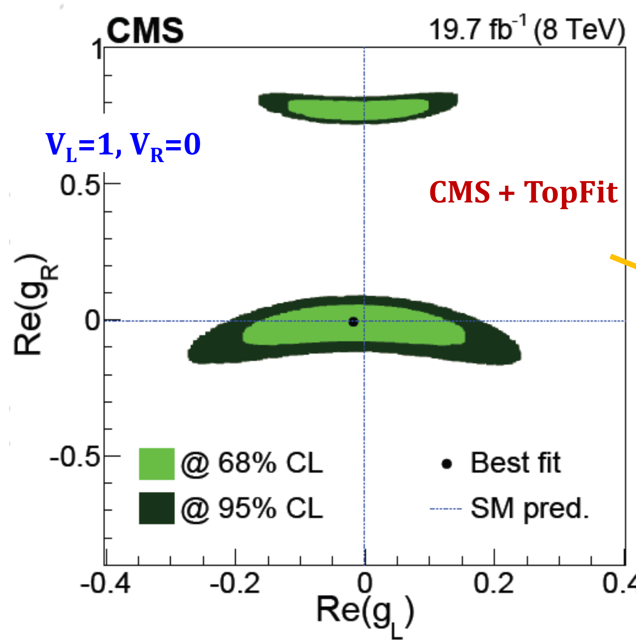
Results from single-top are competitive, despite smaller statistics
Single-top and top-pairs: independent datasets: gain in combination.

e + μ: consistent with SM

$$F_L = 0.298 \pm 0.028\,(\text{stat.}) \pm 0.032\,(\text{syst.}),$$
$$F_0 = 0.720 \pm 0.039\,(\text{stat.}) \pm 0.037\,(\text{syst.}),$$
$$F_R = -0.018 \pm 0.019\,(\text{stat.}) \pm 0.011\,(\text{syst.})$$

Signal modeling

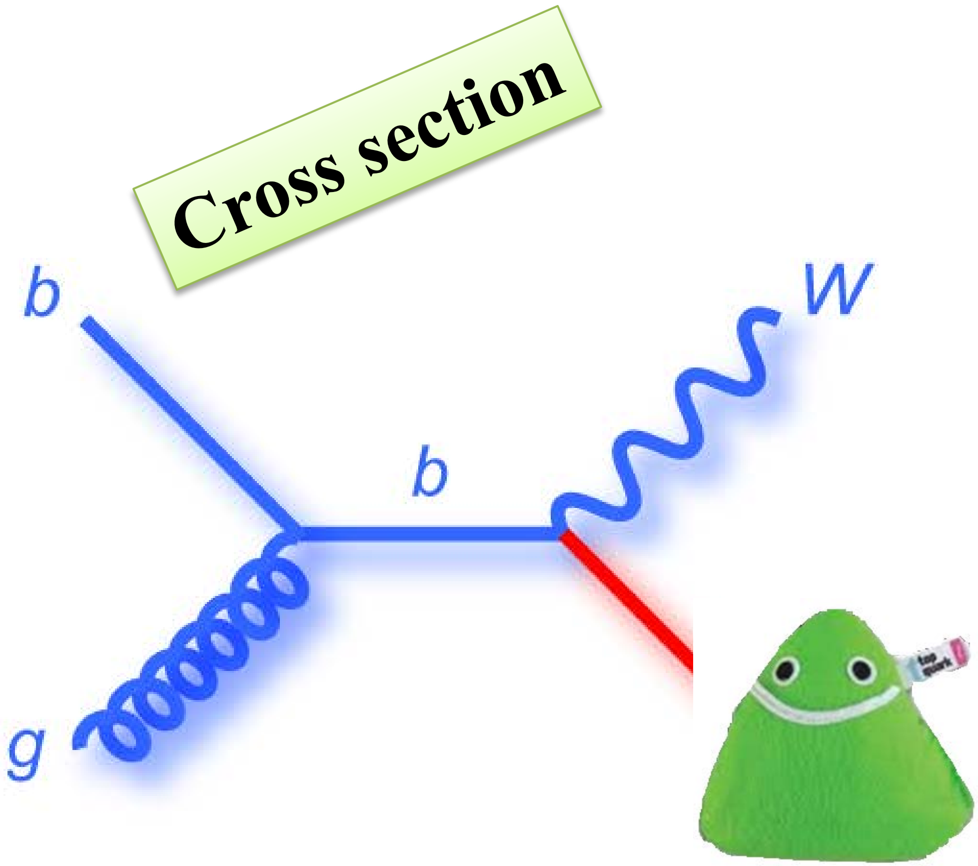


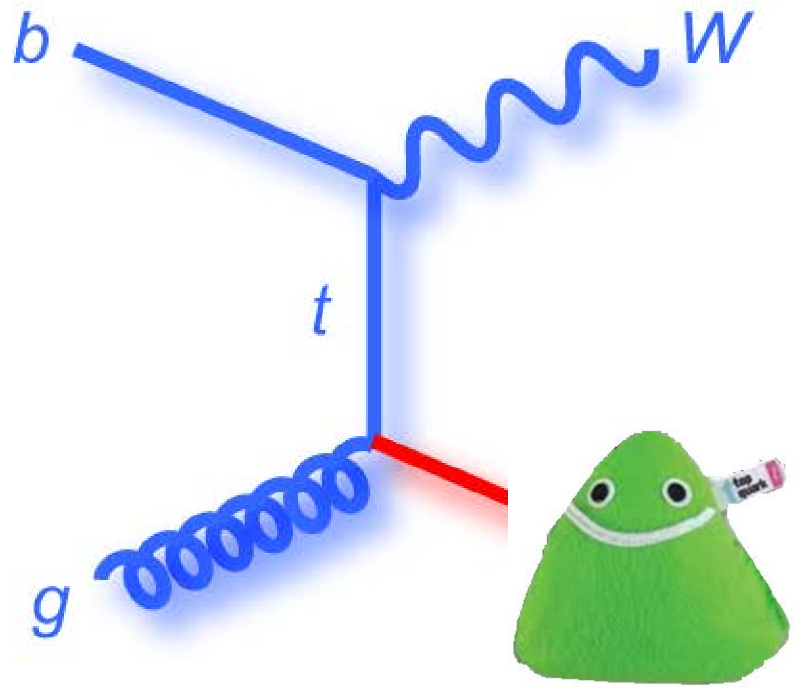


Best fit values:

g_L = -0.017, g_R = -0.008

CMS-TOP-12-020





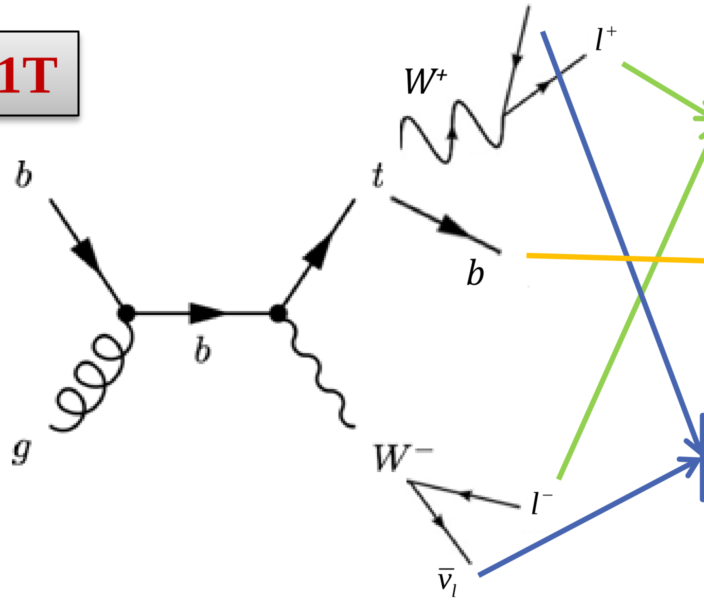
TW-CHANNEL

FOCUS ON NEW RESULTS

σ_{th}: 22.2 ± 0.6 ± 1.4 pb
Kidonakis, arXiv:1210.7813

tW cross section

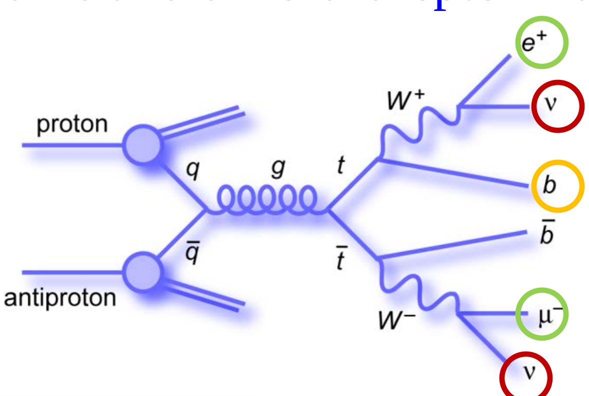
1J1T



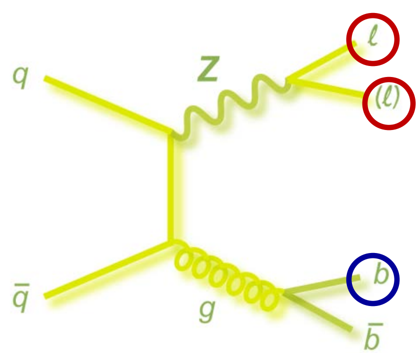
- Two isolated leptons (μμ, eμ, ee)
- One b-jet from top decay b-quark (1j1t)
- Missing energy from two neutrinos (MET)

MET ambiguity: Not possible to fully reconstruct the top quark or W-boson

Same and different lepton flavor



Same lepton flavor



- Remove the Z-peak
- Apply the MET cut
- correct the yield using events inside Z-peak

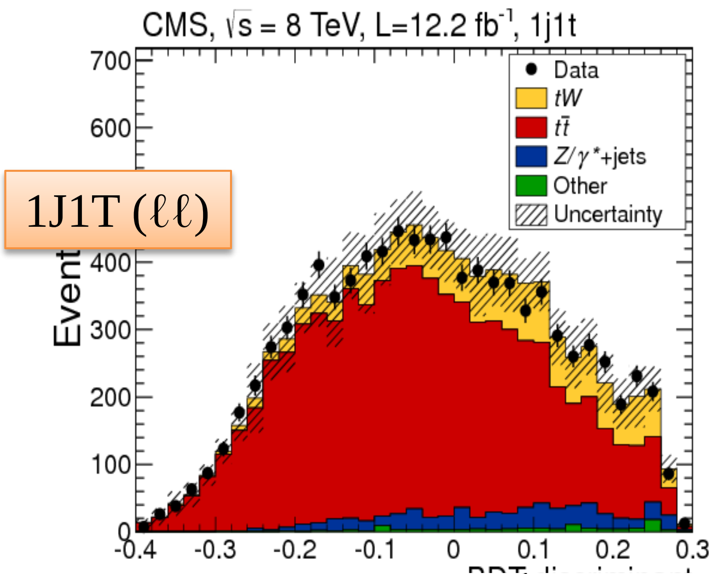
Small contribution from fake leptons, i.e. QCD , W+jets

2J1T, 2J2T to control tt

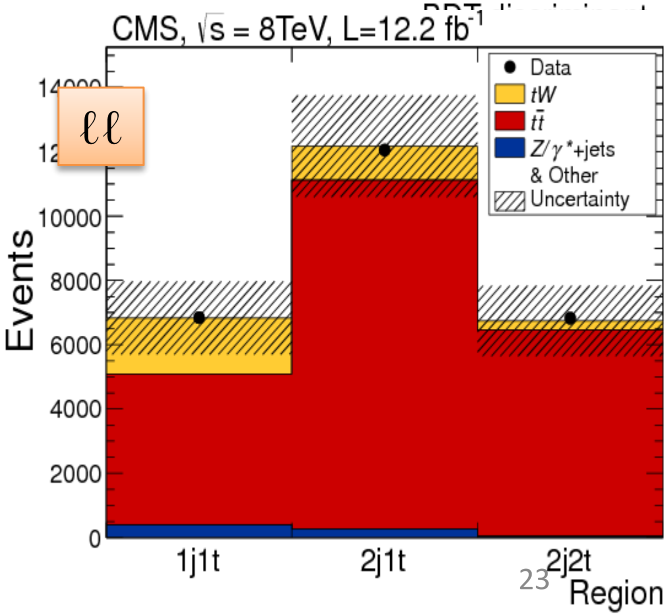
tW cross section at 8 TeV (12.2 fb^{-1})

NEW

- A **Likelihood fit** is performed on a **BDT (13 var.)** output over all three channels (μμ, eμ, ee) and all three regions (1j1t, 2j1t, 2j2t)
- **Templates** for signal and background taken from **simulation**
- **Uncertainties** as nuisance parameters in the fit
  - All constrained with data except **theory** and **luminosity**
  - **Main:** modeling of $t\bar{t}$ and scale



Phys. Rev. Lett. 112



Significance: 6.1σ (expected: 5.4 ± 1.4)

Cross section: 23.4 ± 5.4 pb *(th. : 22.2 ± 0.6 ± 1.4 pb)*

$|V_{tb}|$: 1.03 ± 0.12(exp.) ± 0.04(th.) $(|V_{tb}| \gg |V_{ts}|, |V_{td}|)$

Constrained $|V_{tb}| < 1$: $|V_{tb}| > 0.78$ @95% C.L.

tW cross section at 8 TeV (20.3 fb^{-1})

- A **Likelihood fit** is performed on a **BDT (19 var.)** output over eμ channel and the two regions (1j1t, 2j≥1t)
- **Templates** for signal and background taken from **simulation**
- **Normalization for fake** from data
- **Uncertainties** estimated using pseudo-experiments
    - **Main:** Wt and $t\bar{t}$ modelling

ATLAS-CONF-2013-100

Significance: 4.2σ (expected: 4.0)

Cross section (tW+X):

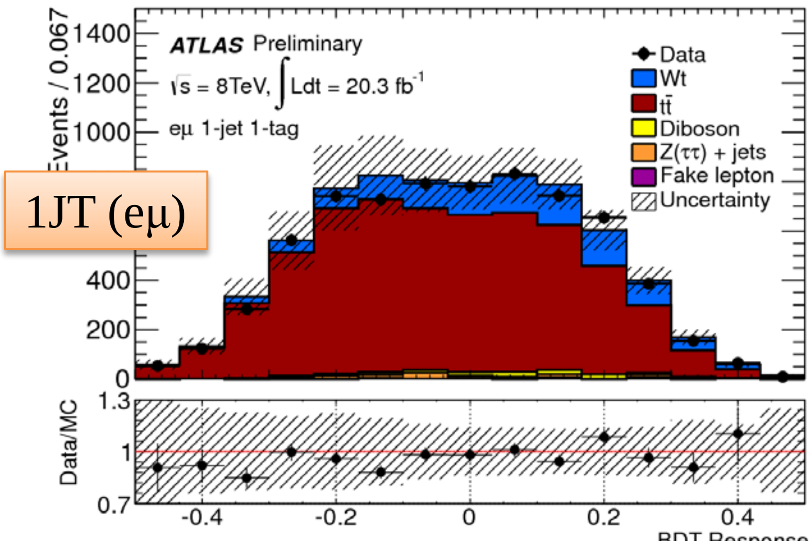
27.2 ± 2.8 (stat.) ± 5.4 (syst.) pb

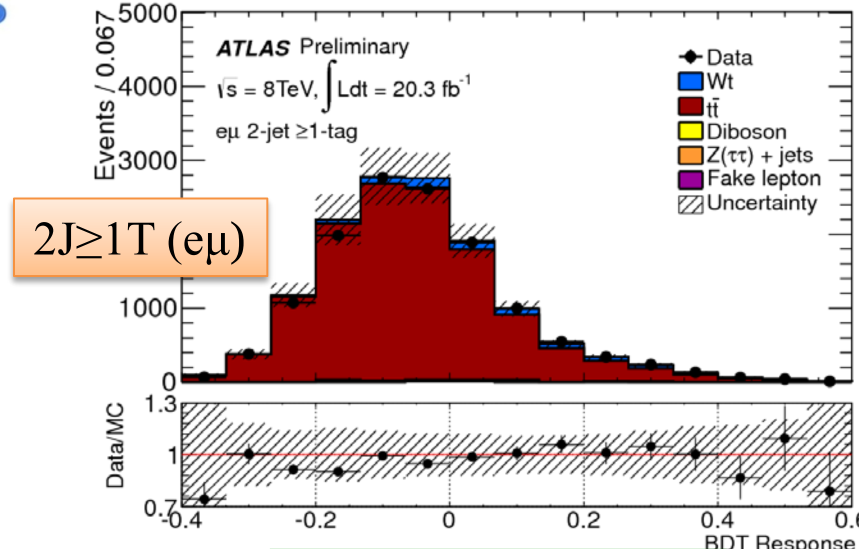
(th. : 22.2 ± 0.6 ± 1.4 pb)

With $|V_{tb}| \gg |V_{ts}|, |V_{td}|$:

$|f_V^L V_{tb}|$: 1.10 ± 0.12(exp.) ± 0.03(th.)

Constrained $|f_V^L|$ = 1: $|V_{tb}|$ > 0.72 @95% C.L.





Assuming m_t = 172.5 GeV

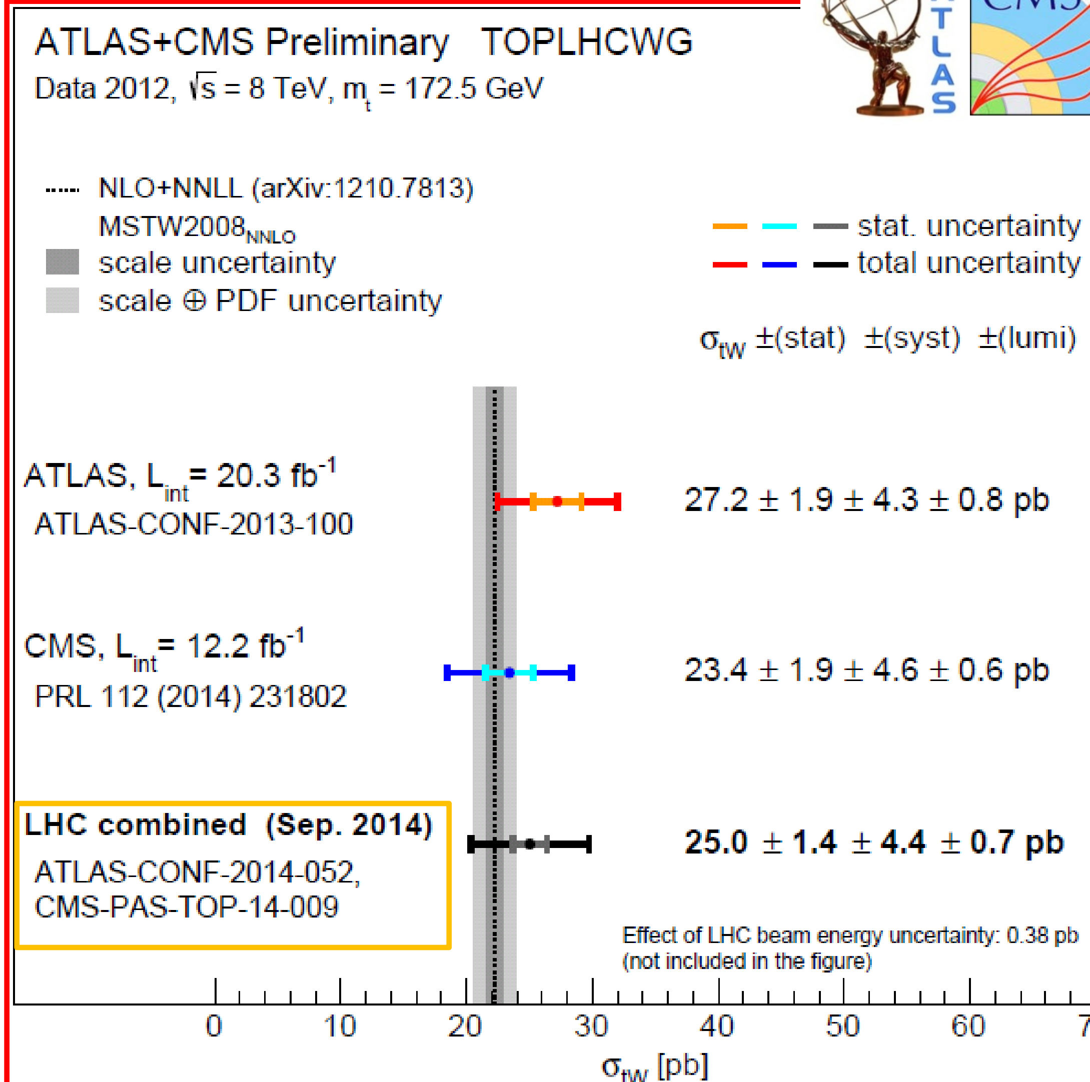
tW cross section at 8 TeV (combination)

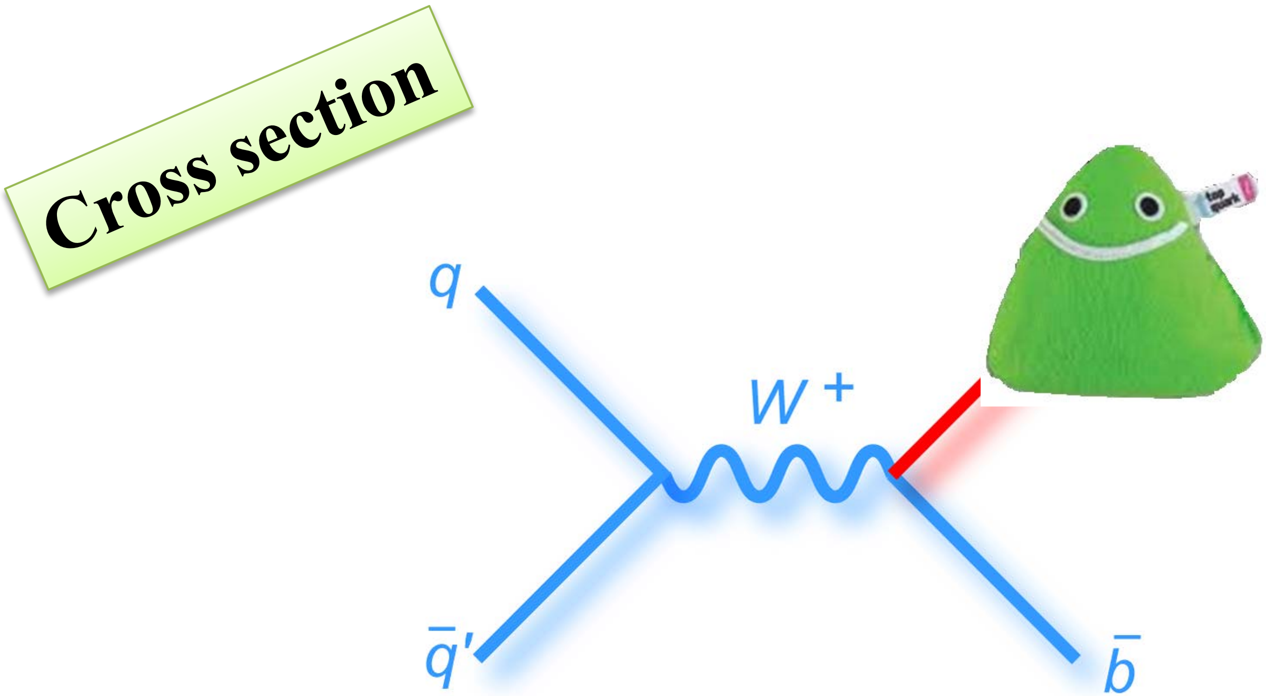
- The results of the two experiments are combined using BLUE

- **Correlated systematics**
  - Theory modeling (ρ =1)
  - Luminosity (ρ =0.31)
  - B-tagging (ρ =0.5)
- Stability checked for different ρ assumptions
- **Dominant systematic:**
  - Theory modeling

- $|f_V^L V_{tb}|$: 1.06 ± 0.11

- **Constrained $|f_V^L|$ = 1 & $|V_{tb}| \leq 1$:**
  $|V_{tb}| > 0.79$ @95% C.L.

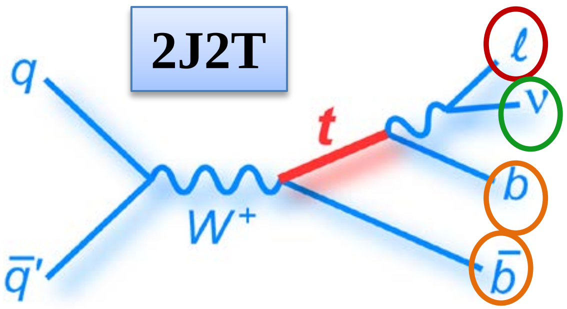




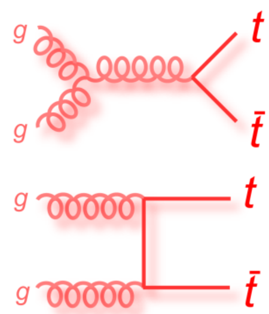
S-CHANNEL

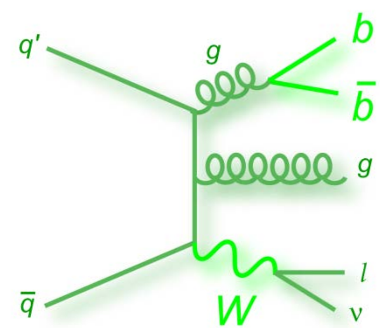
FOCUS ON NEWER RESULTS

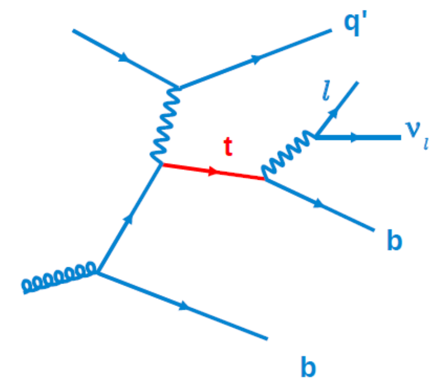
s-channel cross section



- **Signature:** 1 lepton + 2 b-jets + MET-related quantities
- **Backgrounds:** tt, W+jets, t-channel



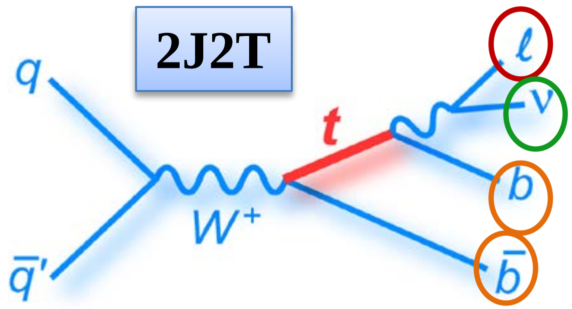




- **SM expectation at 8 TeV:**
  $\sigma_{s\text{-ch}} = 5.55 \pm 0.08 \pm 0.21$ pb
  N. Kidonakis (1205.3453)

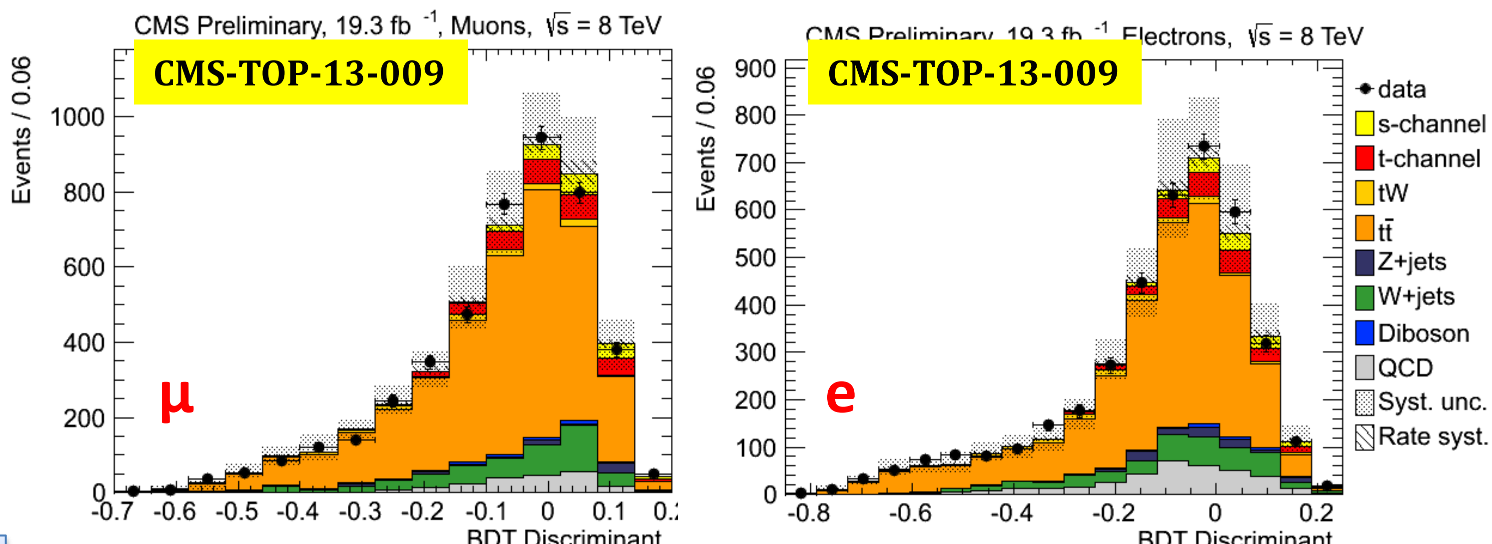
- **ATLAS:** set the first upper limit at 7 TeV
  $\sigma_{s\text{-ch}} < 26.5\ (20.5)$ pb (4.6 pb SM)

s-channel cross section at 8 TeV (19.3 fb^{-1})



- **Signature:** 1 lepton + 2 b-jets +MET-related quantities
- **Backgrounds:** tt, W+jets, t-channel
- **SM expectation at 8 TeV:** $\sigma_{s\text{-}ch} = 5.55 \pm 0.08 \pm 0.21$ pb

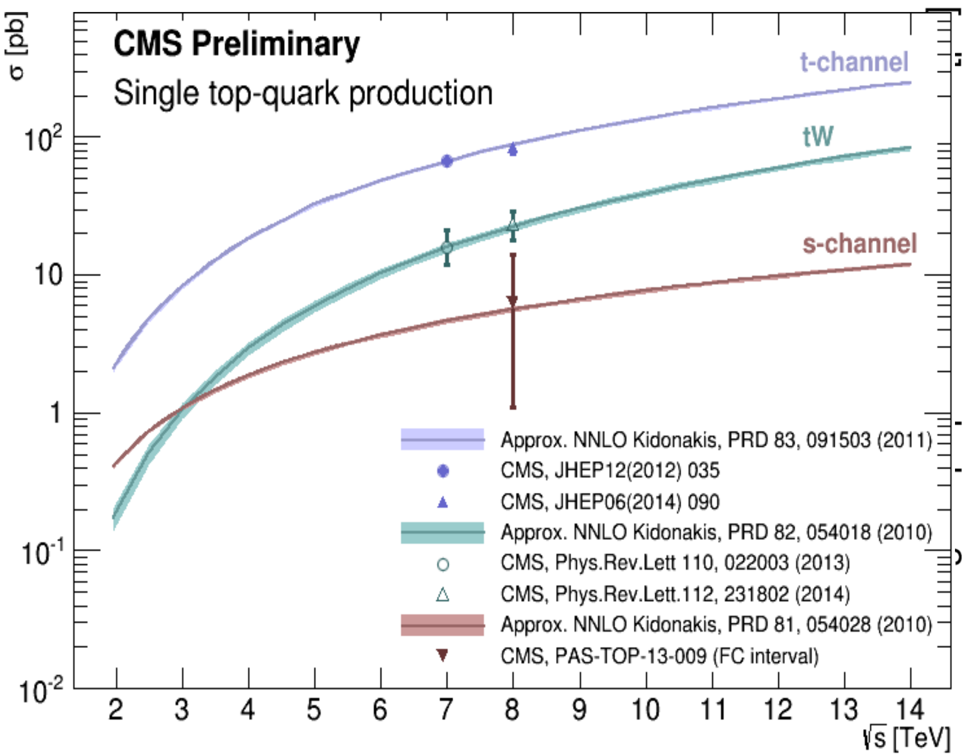
- A **likelihood fit** on the **BDT output** in signal (2J2T) and tt (3J2T) control regions
- **Backgrounds** (tt, W+jets) are constrained in the fit
- Pseudo experiments for theory and instrumental systematics

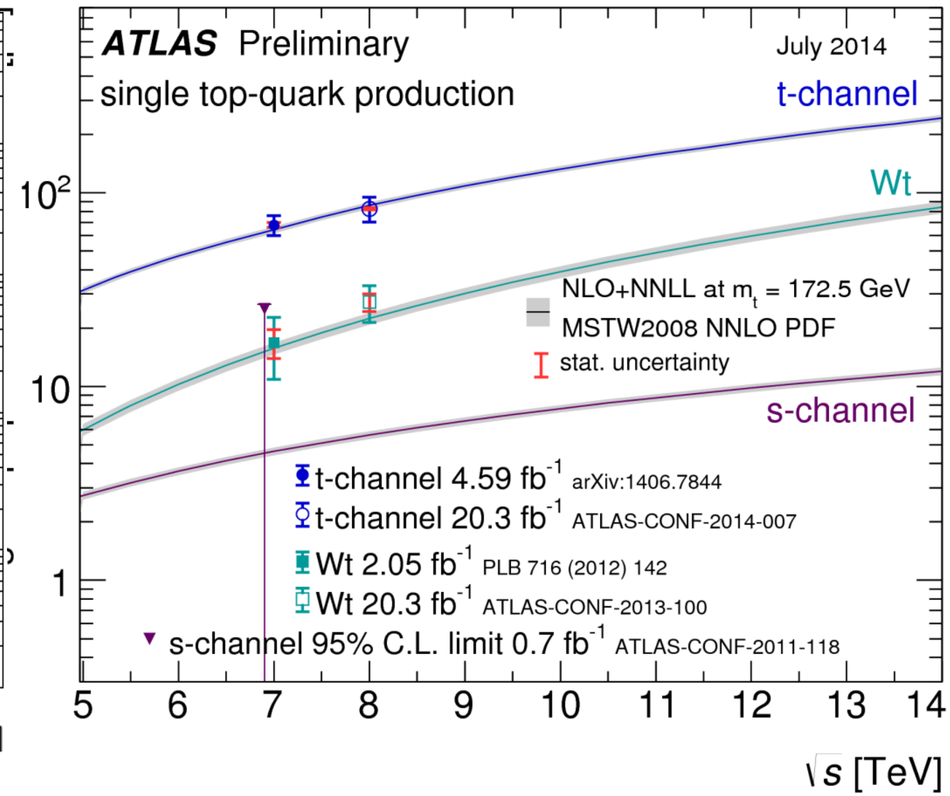


Scale

- **Observed @ 95% CL :** $\sigma_{s\text{-}ch.} < 11.5$ pb
- **Expected @ 95% CL :** $\sigma_{s\text{-}ch.} < 17.0$, 9.0 pb (SM sig., bkg.)

Summary on single-top cross sections





Summary

- **LHC experiments** are performing extensive studies in single-top events

- First property measurements and searches are conducted using t-channel

- Observations of single-top in tW-channel are reported

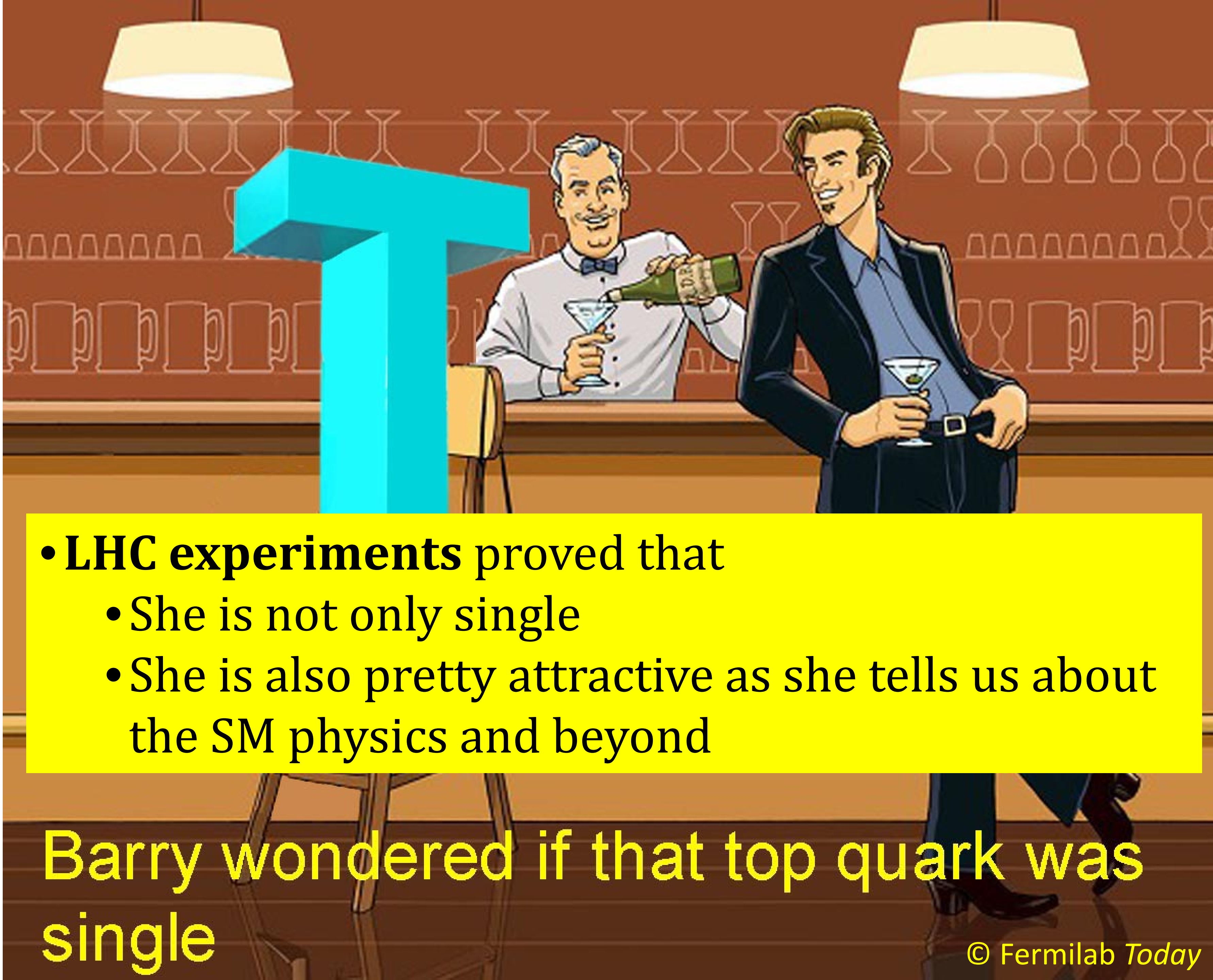
- Limits are set on the s-channel production

- All measurements so far are consistent with the SM predictions
- No sign of new physics yet

- More measurements and updates with the full LHC datasets are underway

- Stay tuned
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopCONFnotes


Barry wondered if that top quark was single
© Fermilab *Today*



- **LHC experiments** proved that
  - She is not only single
  - She is also pretty attractive as she tells us about the SM physics and beyond

BACKUP

Additional information on 1406.7844 (7 TeV)

- **Electron:**
  - $E_T > 25\ GeV, |\eta_{cl}| < 2.47$ exclusing , $1.37 < |\eta_{cl}| < 1.52$
  - A cut on Σp_T^{calo} in $\Delta R < 0.2$ and a cut on Σp_T^{trk} in $\Delta R < 0.3$ excluding electron constit
  - Σp_T^{calo} is corrected for pile-up
  - Thresholds changes wrt η, p_T and number of vertices such that the efficiency for $Z \to ee$ and $W \to e\nu$ is 90%
- **Muon:**
  - $p_T > 25\ GeV, |\eta| < 2.5$
  - $\Sigma p_T^{calo} < 4$ GeV in $\Delta R < 0.2$
  - $\Sigma p_T^{trk} < 2.5$ GeV in $\Delta R < 0.3$
  - Isolation efficiency: 95%-97%depending on data-taking period (T&P)
- **Jet:**
  - $p_T > 30\ GeV,\ |\eta| < 4.5$
    - For $2.75 < |\eta| < 3.5$, $p_T > 35\ GeV$
  - Lepton overlap removal, identification criteria
- **b-tagging:**
  - 54% efficiency for b-quark jets, 4.8% for c-quark jets
- $E_T^{miss} > 30\ GeV, m_T(W) > 30\ GeV$

Additional information on 1406.7844 (7 TeV)

- Dedicated cat to reject QCD in most of ATLAS analyses:

$$p_T(\ell) > 40\ GeV\left(1 - \frac{\pi - |\Delta\phi(j_1,\ell)|}{\pi - 1}\right)$$

- Simultaneous fit to NN discriminant in 2 and 3 jets (1b)
- 3jet2tag to constrain the b-tagging efficiency unc.
- QCD from data:
- Electron channel: jet-lepton method, making a sample with jets that are passing electron selections
- Muon channel: matrix method, estimation based on loose-tight isolation of muons
- Wjets: shape taken from simulation. Norm in the same fit as data
- Backgrounds are constrained in the fit
- Signal is generated with PowHeg BOX
- Rt is mostly independent of top mass

	p_1 [pb/GeV]	p_2 [pb/ GeV^2]
$\sigma(tq+\bar{t}q)$	-0.46	-0.06
$\sigma(tq)$	-0.27	-0.04
$\sigma(\bar{t}q)$	-0.19	-0.02

A quadratic m_t dependence is assumed

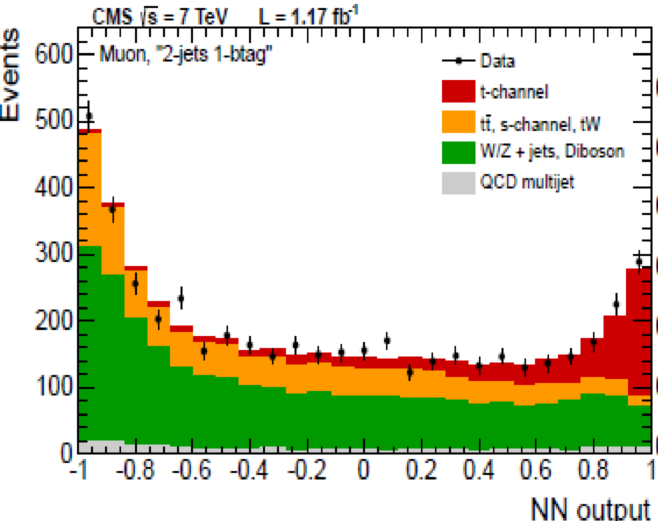
Additional information on 1406.7844 (7 TeV)

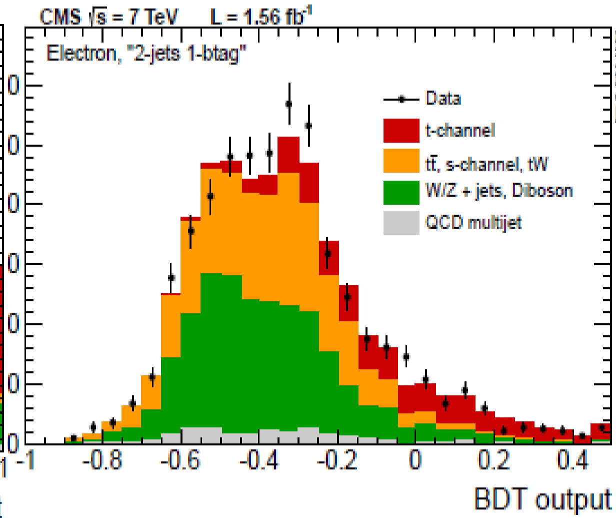
Source	$\Delta\sigma(tq)/\sigma(tq)$ [%]	$\Delta\sigma(tq)/\sigma(tq)$ [%]	$\Delta R_t/R_t$ [%]	$\Delta\sigma(tq+tq)/\sigma(tq+tq)$ [%]
Data statistical	±3.1	±5.4	±6.2	±2.7
Monte Carlo statistical	±1.9	±3.2	±3.6	±1.9
Multijet normalization	±1.1	±2.0	±1.6	±1.4
Other background normalization	±1.1	±2.8	±1.9	±1.6
JES detector	±1.6	±1.4	<1	±1.4
JES statistical	<1	<1	<1	<1
JES physics modeling	<1	<1	<1	<1
JES η intercalibration	±6.9	±8.4	±1.8	±7.3
JES mixed detector and modeling	<1	<1	<1	<1
JES close-by jets	<1	<1	<1	<1
JES pile-up	<1	<1	<1	<1
JES flavor composition	±1.4	±1.4	±1.2	±1.6
JES flavor response	<1	<1	±1.0	<1
b-JES	<1	<1	<1	<1
Jet energy resolution	±2.1	±1.6	±1.0	±1.9
Jet vertex fraction	<1	<1	<1	<1
b-tagging efficiency	±3.8	±4.1	<1	±3.9
c-tagging efficiency	<1	±1.4	<1	<1
Mistag efficiency	<1	<1	<1	<1
$b/\bar{b}$ acceptance	±1.0	<1	<1	$--$
$E_{\mathrm{T}}^{\mathrm{miss}}$ modeling	±2.3	±3.4	±1.6	±2.6
Lepton uncertainties	±2.8	±3.0	±1.0	±2.8
PDF	±3.2	±5.8	±2.5	±3.2
W+jets shape variation	<1	<1	<1	<1
tq generator + parton shower	±1.9	±1.6	<1	±1.9
tq scale variations	±2.6	±3.0	<1	±2.6
$t\bar{t}$ generator + parton shower	<1	±2.1	±1.6	<1
$t\bar{t}$ ISR / FSR	<1	<1	±1.0	<1
Luminosity	±1.8	±1.8	±0.5	±1.8
Total systematic	±12.0	±14.9	±6.1	±12.1
Total	±12.4	±15.9	±8.7	±12.4

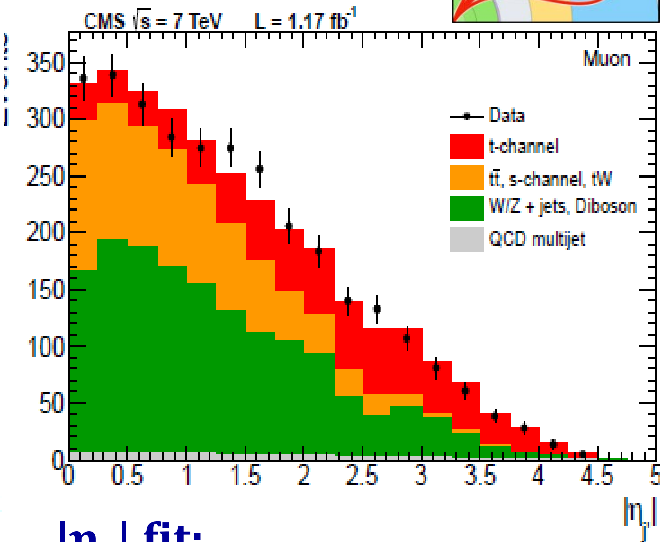
t-channel cross sections at 7 TeV (~1. fb^{-1})

JHEP12(2012) 035

- Generic selection (see backup).
- Different categories number of jets and b-tagged jets







Neural Network:
- Backgrounds and systematics as nuisance parameters
- Signal: 2J1T, 3J1T
- Constraining backgrounds, b-tag efficiency, etc.: 4J1T, 2J2T, 3J2T, 4J2T

Boosted Decision Tree:
- Backgrounds and systematics as nuisance parameters
- Signal: 2J1T, 3J1T
- Constraining backgrounds, b-tag efficiency, etc.: 4J1T, 2J2T, 3J2T, 4J2T

$|\eta_{j'}|$ fit:
- Template fit with data-driven backgrounds
- Signal: 2J1T
- Check the modeling of backgrounds: 3J2T, 2J0T

t-channel cross sections at 7 TeV (~1. fb^{-1})

		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 flavour (u, d, s, g)	−0.2/+0.3%	±0.4%	n/a
		heavy flavour (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%

t-channel cross sections ATLAS Fiducial

- **Electron:**
  - $E_T > 25\ GeV, |\eta_{cl}| < 2.47$ exclusing , $1.37 < |\eta_{cl}| < 1.52$
  - A cut on Σp_T^{calo} in $\Delta R < 0.2$ and a cut on Σp_T^{trk} in $\Delta R < 0.3$ excluding electron constituents
  - Thresholds changes wrt η, p_T and number of vertices such that the efficiency is uniformed
- **Muon:**
  - $p_T > 25\ GeV, |\eta| < 2.5$
  - Cone size of isolation depends on muon p_T $(\frac{10\ GeV}{p_T(\mu)})$
  - Isolation/$p_T(\mu) < 0.05$
- **Jet:**
  - $p_T > 30\ GeV,\ |\eta| < 4.5$
    - For $2.75 < |\eta| < 3.5$, $p_T > 35\ GeV$
  - Lepton overlap removal, identification criteria
- **b-tagging:**
  - 50% efficiency for b-quark jets in $t\bar{t}$, 3.7% for c-quark jets and 0.1% for light jets
- $E_T^{miss} > 30\ GeV, m_T(W) > 50\ GeV$

Uncertainties in predictions are scale & PDF

t-channel cross sections ATLAS Fiducial

Source	$\Delta\sigma_{\text{fid}}/\sigma_{\text{fid}}$ [%]
Data statistics	±1.5
MC statistics	±1.1
Multijet normalisation	$+2.3$ -1.4
Other background normalization	±0.8
JES η intercalibration	±7.9
JES physics modelling	±3.0
JES detector	< 0.5
JES statistical	< 0.5
JES mixed detector and modelling	< 0.5
JES single particle	< 0.5
JES pile-up	< 0.5
JES flavor composition	±0.8
JES flavor response	±0.5
b-JES	< 0.5
Lepton uncertainties	±2.9
$E_{\mathrm{T}}^{\mathrm{miss}}$ modelling	±3.0
b-tagging efficiency	±3.5
c-tagging efficiency	< 0.5
Mistag efficiency	< 0.5
Jet energy resolution	±1.7
Jet reconstruction eff.	< 0.5
Jet vertex fraction	< 0.5
t-channel generator	±7.9
W+jets generator	±1.4
PDF	±1.1
$t\bar{t}$, Wt and s-channel generator	< 0.5
ISR / FSR ($t\bar{t}$)	< 0.5
Total Systematic	±14

Object	Cut
Electrons	$p_{\mathrm{T}} > 25$ GeV and $\lvert\eta\rvert < 2.5$
Muons	$p_{\mathrm{T}} > 25$ GeV and $\lvert\eta\rvert < 2.5$
Jets	$p_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 4.5$
	$p_{\mathrm{T}} > 35$ GeV, if $2.75 < \lvert\eta\rvert < 3.5$
Lepton (ℓ), Jets (j_i)	$\Delta R(\ell, j_i) > 0.4$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV
Transverse W-boson mass	$m_{\mathrm{T}}(W) > 50$ GeV
Lepton (ℓ), jet with the highest p_{T} (j_1)	$p_{\mathrm{T}}(\ell) > 40\ \mathrm{GeV}\left(1 - \frac{\pi - \lvert\Delta\phi(j_1,\ell)\rvert}{\pi - 1}\right)$

Uncertainties in predictions are scale & PDF

t-channel cross sections CMS 8 TeV

μ and e combined

Uncertainty source	$\sigma_{t\text{-ch.}}$ (%)
Statistical uncertainty	$\pm$ 2.7
JES, JER, MET, and pileup	$\pm$ 4.3
b-tagging and mis-tag	$\pm$ 2.5
Lepton reconstruction/trig.	$\pm$ 0.6
QCD multijet estimation	$\pm$ 2.3
W+jets, $t\bar{t}$ estimation	$\pm$ 2.2
Other backgrounds ratio	$\pm$ 0.3
Signal modeling	$\pm$ 5.7
PDF uncertainty	$\pm$ 1.9
Simulation sample size	$\pm$ 0.7
Luminosity	$\pm$ 2.6
Total systematic	$\pm$ 8.9
Total uncertainty	$\pm$ 9.3
Measured cross section	83.6 $\pm$ 7.8 pb

Uncertainty source	$\sigma_{t\text{-ch.}}(\mathrm{t})$ (%)	$\sigma_{t\text{-ch.}}(\bar{\mathrm{t}})$ (%)	$R_{t\text{-ch.}}$ (%)
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, $t\bar{t}$ 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 pb	27.6 $\pm$ 3.9 pb	1.95 $\pm$ 0.21

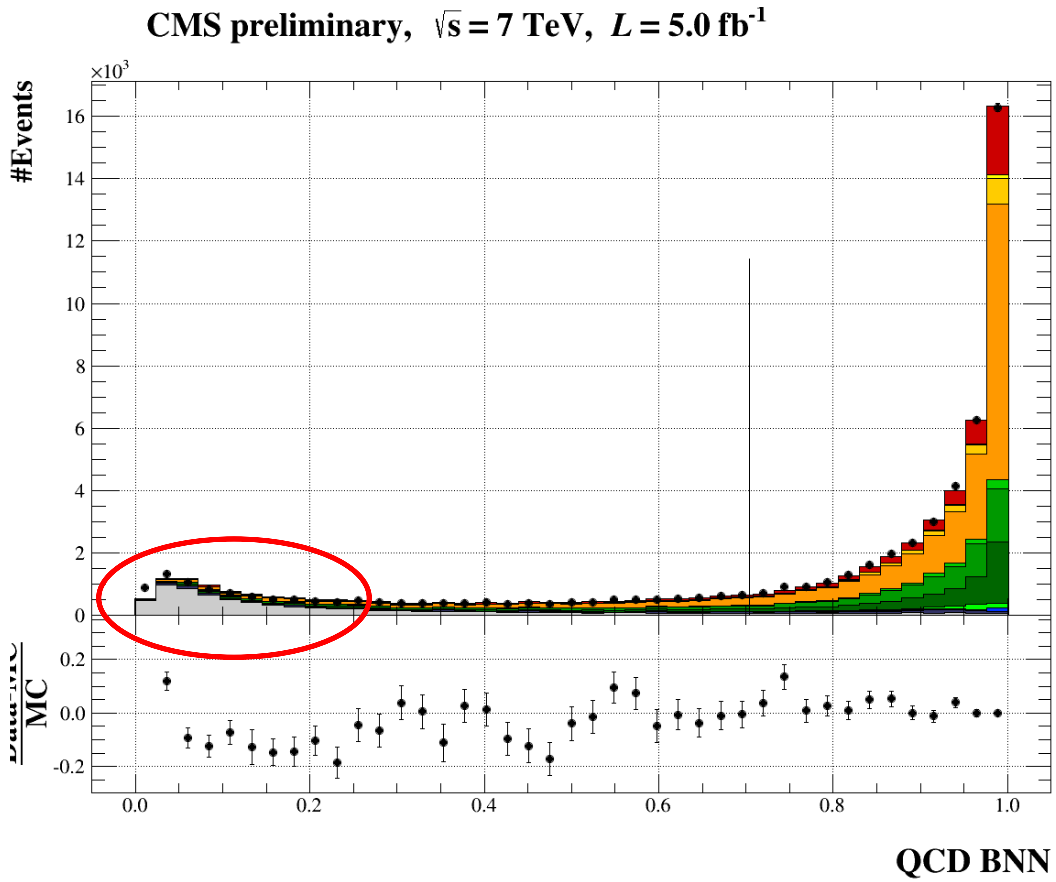
$$\sigma^{\text{theo.}}_{t\text{-ch.}}(\mathrm{t}) = 56.4^{+2.1}_{-0.3}\,(\text{scale}) \pm 1.1\,(\text{PDF})\,\text{pb},$$

$$\sigma^{\text{theo.}}_{t\text{-ch.}}(\bar{\mathrm{t}}) = 30.7 \pm 0.7\,(\text{scale})^{+0.9}_{-1.1}\,(\text{PDF})\,\text{pb}.$$

$$\sigma^{\text{theo.}}_{t\text{-ch.}} = 87.2^{+2.8}_{-1.0}\,(\text{scale})^{+2.0}_{-2.2}\,(\text{PDF})\,\text{pb},$$

N. Kidonakis, 1205.3453

t-channel anomalous tWb CMS



Marginalized systematics: JES, JER, b-jet identification, pileup, E_T^{miss}

Unmarginalized: The rest, via pseudo-experiments

The most significant: signal modeling

t-channel top polarization CMS

Similar processes in shape are combined:

- **tt, s, tW QCD 20% constraint**
- **VV and V+jets (unconstrained)**

Wjets systematics:

- **light of 11%,**
- **reweighting 50%,**
- **HF 0.5 and 2**

Constant unfolding bias treated as systematic

Combination with BLUE

Only lepton efficiencies uncorrelated

Uncertainty source	δA_l^{μ}	δA_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 $\not{E}_T$	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

tW-channel ATLAS

Source	$\Delta\sigma/\sigma$ [%] observed	expected
Data statistics	7.1	8.6
MC statistics	2.8	3.5
Experimental uncertainties		
Lepton modeling	2.4	2.4
Jet identification	0.2	0.6
Jet energy scale	10	12
b-jet energy scale	5.0	6.3
Jet energy resolution	0.7	0.2
E_T^{miss} scale	4.1	5.0
E_T^{miss} resolution	4.5	5.3
Flavor tagging	8.4	9.4
Theory uncertainties		
$Wt/t\bar{t}$ overlap modeling	1.4	1.6
PDF	2.5	3.2
Background normalization	3.6	4.4
ISR/FSR	5.9	6.0
Wt generator and PS	11	11
$t\bar{t}$ generator and PS	7.5	9.2
Luminosity	3.7	3.9
Total (syst)	20	23

Several uncertainties are constrained with data (profiled):

- Background normalization
- Individual components for jet energy correction
- B-tagging
- Missing transverse energy

tW-channel CMS

Systematic uncertainty	$\Delta\sigma$ (pb)	$\Delta\sigma/\sigma$	Notes
ME/PS matching thresholds	3.3	14%	Matching threshold 2× and 1/2× nominal 20 GeV value in $t\bar{t}$ simulation
Renormalization/factorization scale	2.9	12%	Scale value 2× and 1/2× nominal value of $m_t^2 + \sum p_T^2$ in $t\bar{t}$ and tW simulation
Top-quark mass	2.2	9%	m_t varied in tW and $t\bar{t}$ simulation by ± 2 GeV
Fit statistical	1.9	8%	Remaining uncertainty in fit when all other systematic uncertainties are removed
Jet energy scale	0.9	4%	Jet energy scale varied up/down
Luminosity	0.7	3%	2.6% uncertainty in the measured luminosity
Z+jets data/simulation scale factor	0.6	3%	Varying scale factors used for correcting Z+jets E_T^{miss} simulation
tW DR/DS scheme	0.5	2%	Difference between DR and DS scheme used for defining tW signal
$t\bar{t}$ cross section	0.4	2%	Uncertainty in the cross section of $t\bar{t}$ production
Lepton identification	0.4	2%	Uncertainty in scale factors for lepton efficiencies between data/simulation
PDF	0.4	2%	From choice of PDF
Jet energy resolution	0.2	1%	Energy resolution for jets varied up/down
b-tagging data/simulation scale factor	0.2	<1%	Variations in scale factors
$t\bar{t}$ spin correlations	0.1	<1%	Difference between $t\bar{t}$ simulation with/without spin correlations
Pileup	0.1	<1%	Varying effect of pileup
Top-quark p_T reweighting	0.1	<1%	Uncertainty due to differences in top quark p_T between data and $t\bar{t}$ simulation
E_T^{miss} modeling	0.1	<1%	Uncertainty in amount of unclustered E_T^{miss}
Lepton energy scale	0.1	<1%	Uncertainty in energy of leptons
Total	5.5	24%	

tW-channel combination

ATLAS and CMS have similar event yields for signal and background. However, the discriminant distributions in the signal-dominated one-jet region differ. CMS has more expected signal events in the high-discriminant region, and more bins in that region than ATLAS.