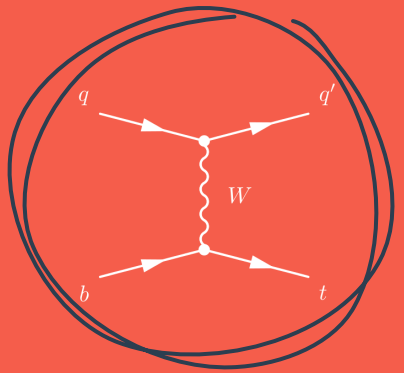
On behalf of the ATLAS and CMS collaborations
LHCP 15, St. Petersburg

Single Top t-Channel



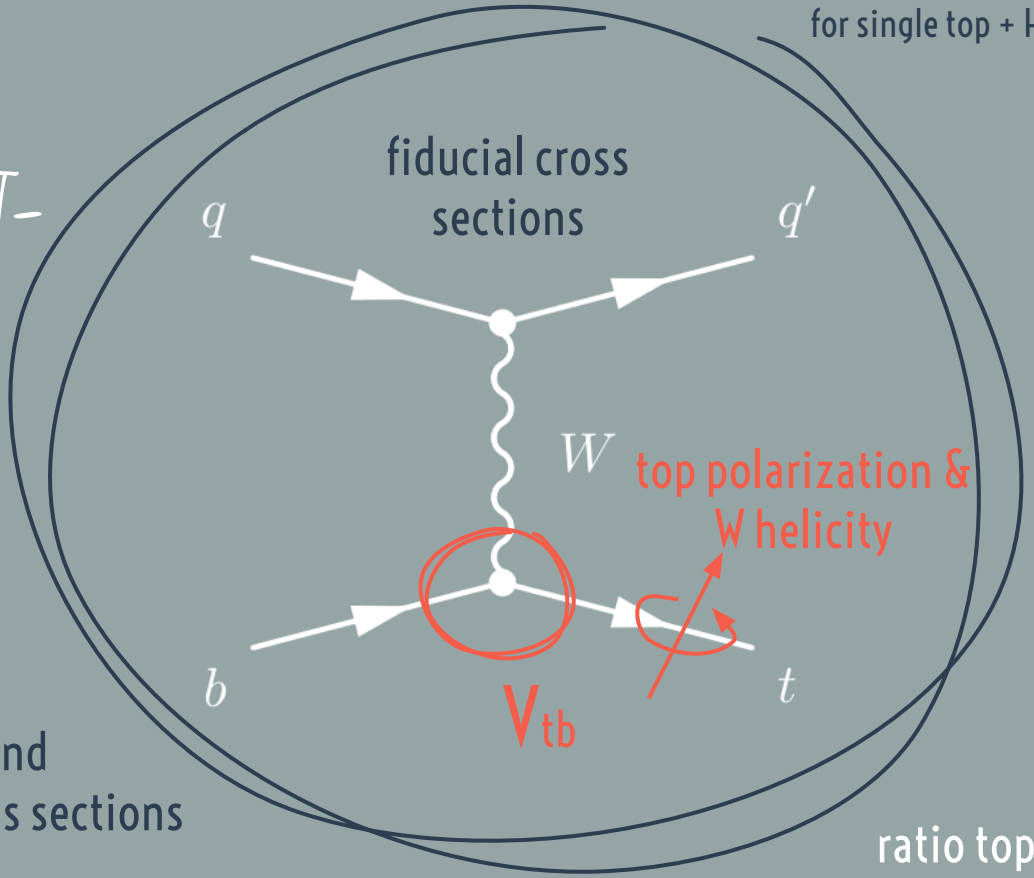
Benedikt Maier

Institute for Experimental Nuclear Physics

Karlsruhe Institute of Technology

Things to Measure in t-channel

for FCNCs: see talk by Boris Lemmer
for mass: see talk by Nathan Mirman
for single top + Higgs: see my poster :p



inclusive and differential cross sections

ratio top over antitop …
top mass …
probing MC simulations and PDFs …

→ **Perfect place to probe SM parameters and modelling!**

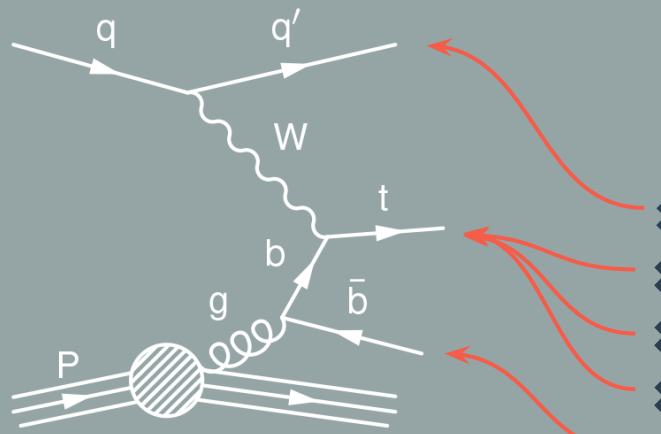
Experimental signatures

main backgrounds

top quark pairs

W+jets

QCD multijet



- ✖ light quark jet with large $|\eta|$
- ✖ isolated lepton (e or μ)
- ✖ missing transverse energy
- ✖ central high-p_T b jet
- ✖ (extra b jet, broad $|\eta|$, low p_T)

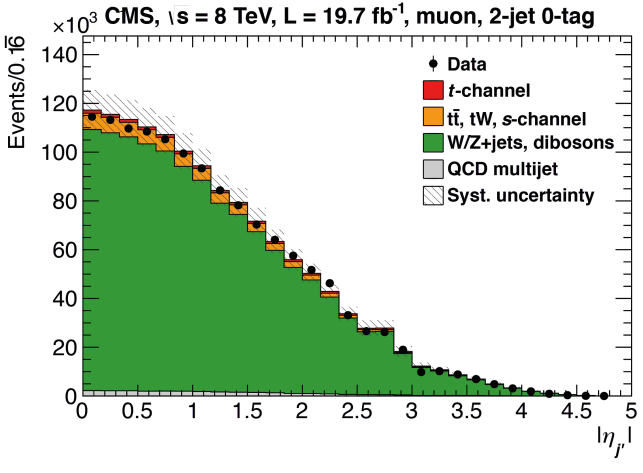
1. Cross sections

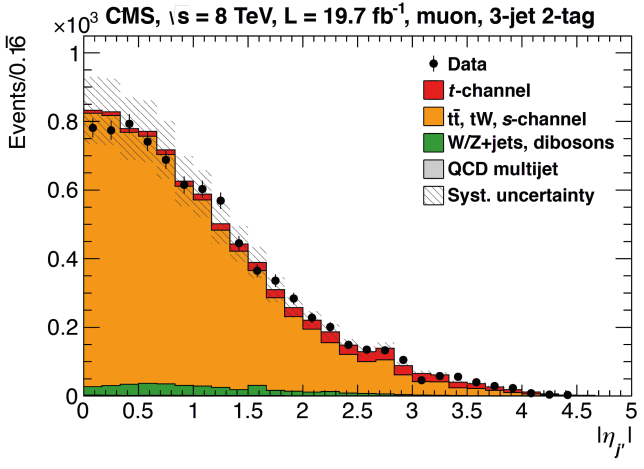
Inclusive. Fiducial. Differential.

JHEP 06 (2014) 090

Cross section at 8 TeV

- Typical **2j1t** selection (i.e. two jets, one of which is b tagged)
- Template analysis in $|\eta_{j'}|$
- Divide 2j1t region into signal region (SB, 130<m_{top}<220 GeV) and sideband (SB) outside this range
- Background estimation:
  - Correct **ttbar** shape/normalization using 3j2t events
  - Validate shape of **Wjets** in 2j0t
    - Extrapolate shape from SB to SR





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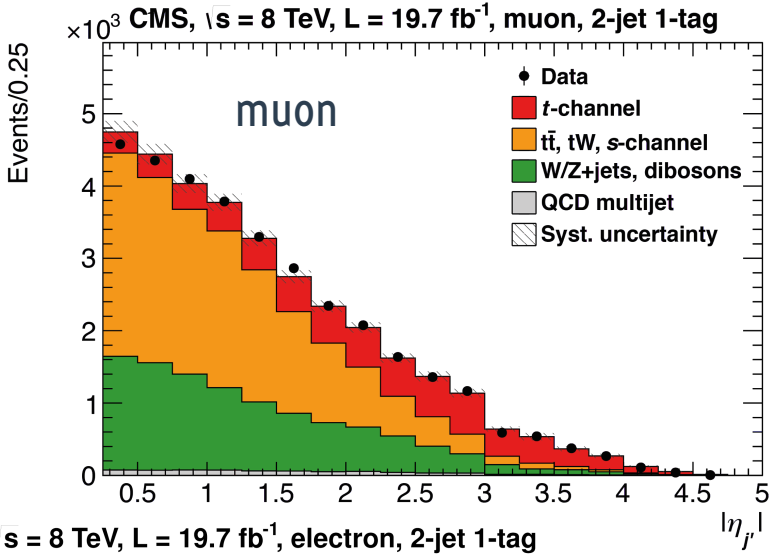
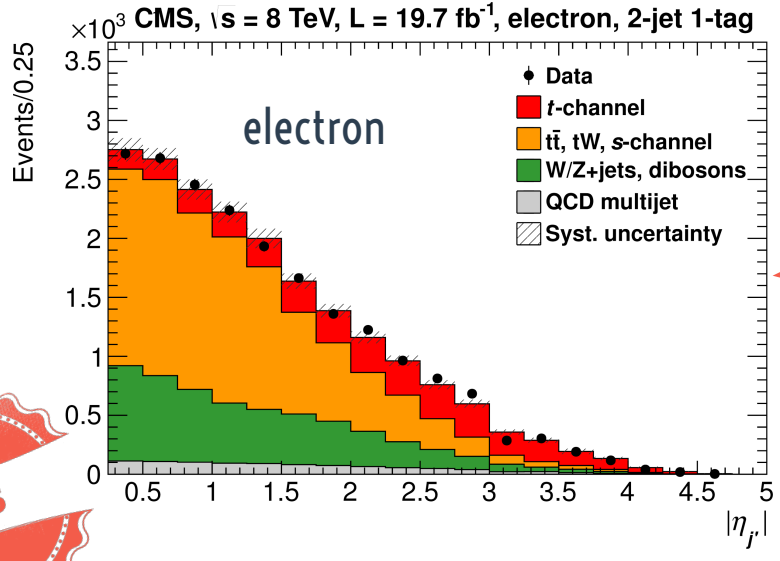
Cross section at 8 TeV





post fit distributions

- Fit to $|\eta_{j'}|$ shape in SR, simultaneously done in muon + electron channels
  - Background normalization constrained using data
  - Signal left free to float

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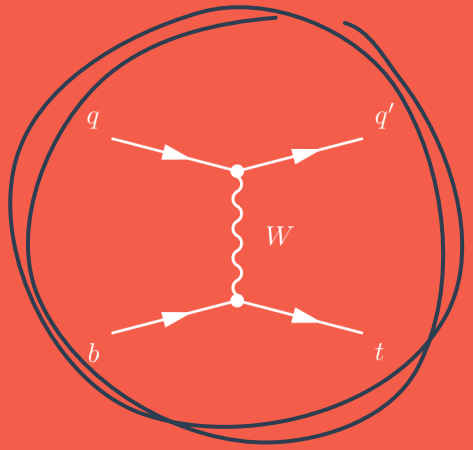
Cross section at 8 TeV: results



inclusive cross-section

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

Theories say:

$83.9\ ^{+0.8}_{-0.3}$ pb

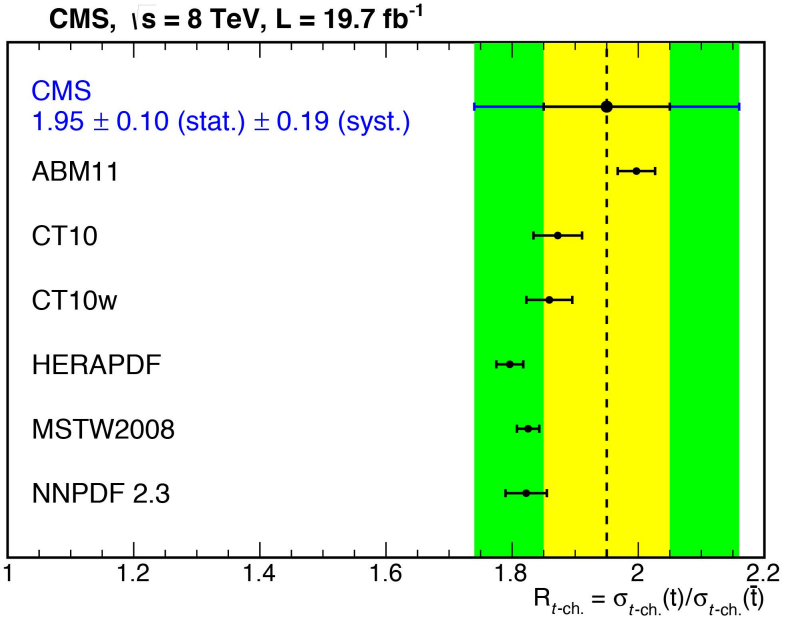
NNLO QCD, arXiv:1404.7116, Bruchseifer, Caola, Melnikov

$84.7\ ^{+3.8}_{-3.2}$ pb

NLO QCD, Hathor 2.1, reference x-sec of the TopLHCWG

Main uncertainties: signal modelling & JES/JER/MET

CMS



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PROBING PDFs

$\sigma_t = 53.8 \pm 1.5(\text{stat.}) \pm 4.4(\text{syst.})$

$\sigma_{tbar} = 27.6 \pm 1.3(\text{stat.}) \pm 3.7(\text{syst.})$

- Separation by **lepton charge** allows drawing conclusions on σ_t / σ_{tbar}
- This ratio R is dependent on **PDFs**

Main uncertainties: PDF

$R = \sigma_t / \sigma_{tbar} = 1.95 \pm 0.10(\text{stat.}) \pm 0.19(\text{syst.})$

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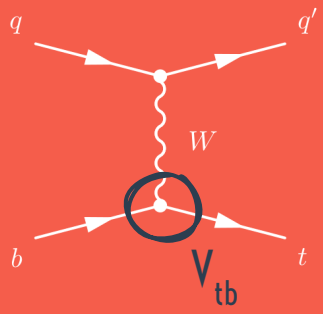


Measuring V_{TB}

Extraction of $|f_{Lv}V_{tb}| = \sqrt{(\sigma_{t\text{-ch.}} / \sigma^{\text{theor.}}_{t\text{-ch.}})}$

Assuming BR($t \to Wb$)~1 and $|V_{tb}| \gg |V_{ts}|, |V_{td}|$.

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

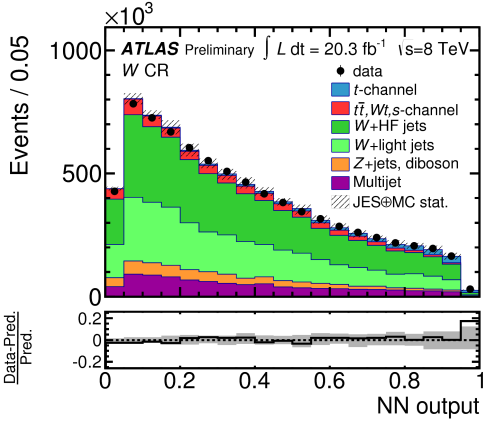
Combination of 8 and 7 TeV data:

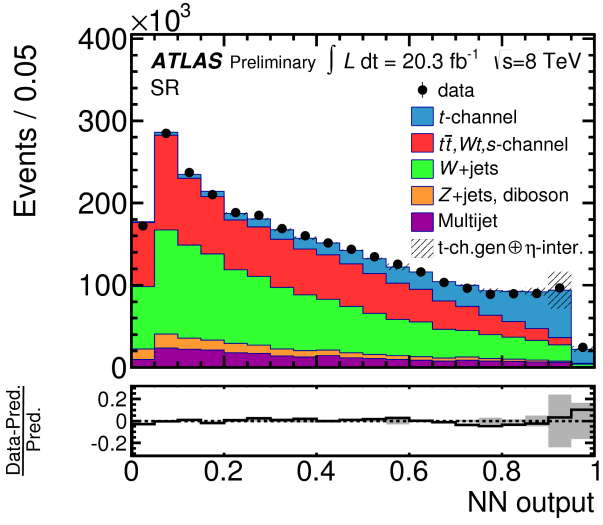
$$|f_{Lv}V_{tb}| = 0.998 \pm 0.038(\text{exp.}) \pm 0.016(\text{th.})$$

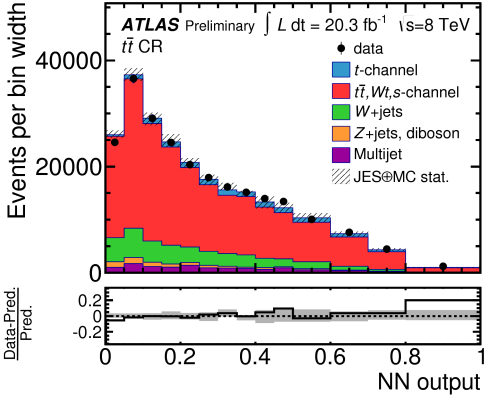
CMS

ATLAS-CONF-2014-007

Fiducial cross section at 8 TeV







- Typical **2j1t** selection
- NN to separate between signal and background
  - $|\eta_j|$, rec. top mass, mass of jet pair **most important**
- Background shape taken from MC, normalized to (N) NLO calculations
  - Data-driven QCD
- Validate shape of backgrounds in 2j0t and 2j2t regions
  - Nice agreement found

ATLAS-CONF-2014-007

How: Define a fiducial volume with selections **cuts on truth objects** in simulation close to cuts reconstructed ones

- Cuts on stable particles, clustered jets → again a typical 2j1t selection, but on MC truth
- B hadron matching to identify b jets

Why fiducial?

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

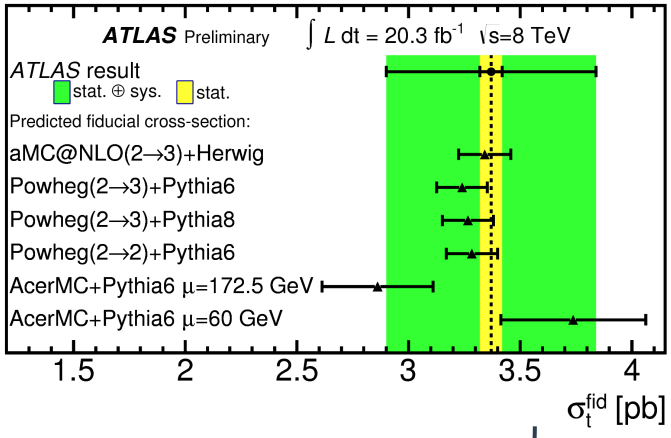
Main uncertainties: signal modelling, JES η calibration

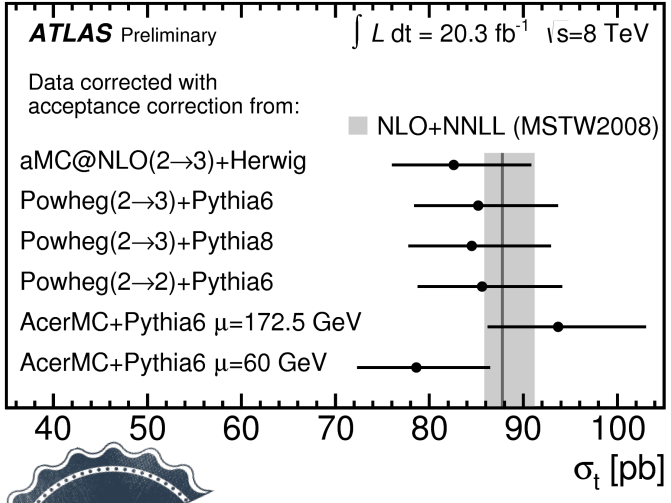
Why:

- Reducing dependence of measurement on extrapolation
- Differences connected with event generation can be reduced to differences within fiducial volume
- Later re-interpretation w/ better MC generators possible

ATLAS-CONF-2014-007

Fiducial cross section at 8 TeV





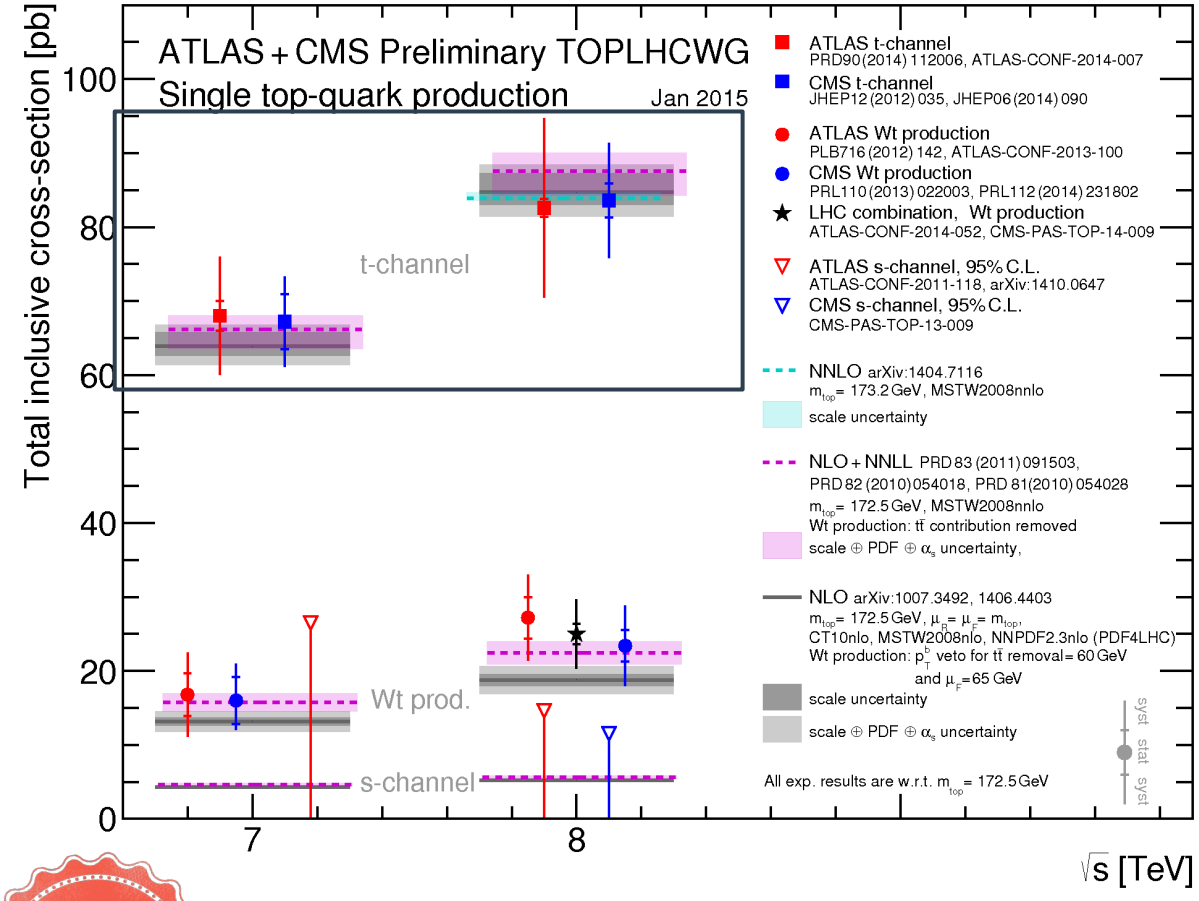
$$\sigma = \frac{1}{\varepsilon_{fid}} \sigma_{fid}$$

Uncert.'s	Generator	PDF	Total
Fiducial	8%	1%	14%
Inclusive	13%	4%	17%

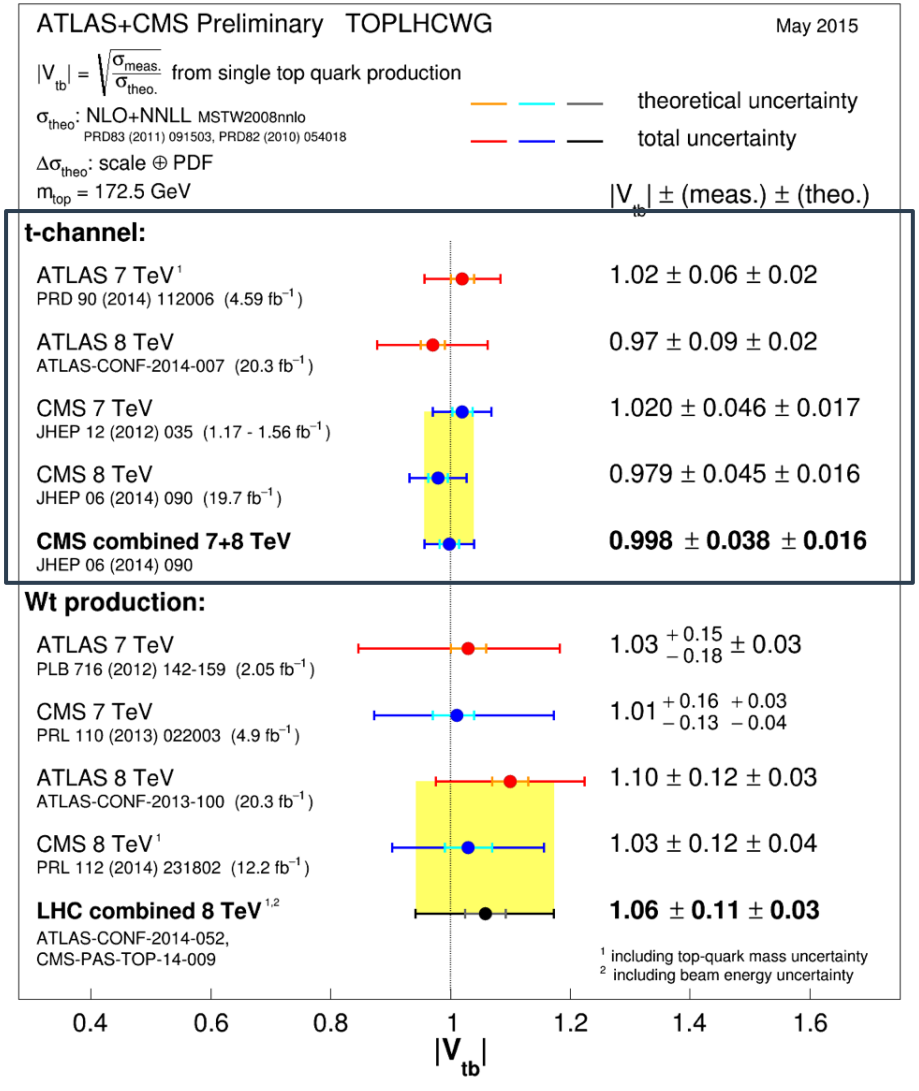
$$|V_{tb}| = 0.97^{+0.09}_{-0.10}$$

$$\sigma_{t\text{-ch.}} = 82.6 \pm 1.2(\text{stat.}) \pm 11.4(\text{syst.}) \pm 3.1(\text{PDF}) \pm 2.3(\text{lumi})\ \text{pb}$$

LHCTopWG Summary Plots



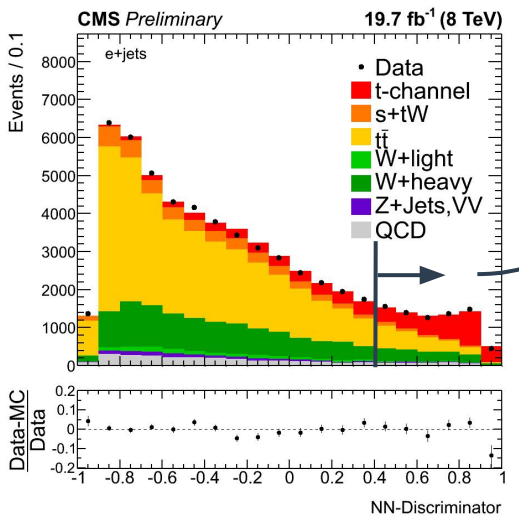
LHCTopWG Summary Plots

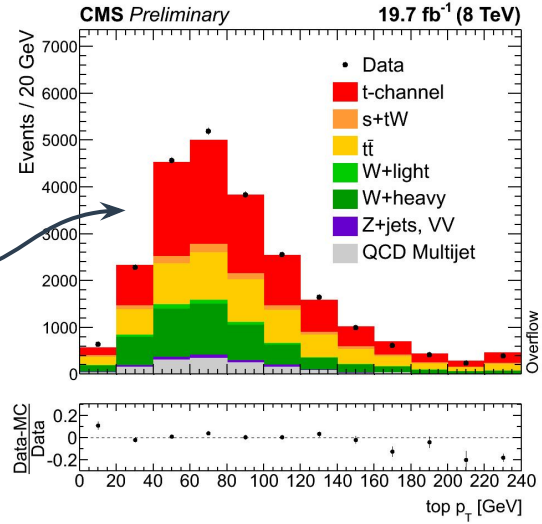


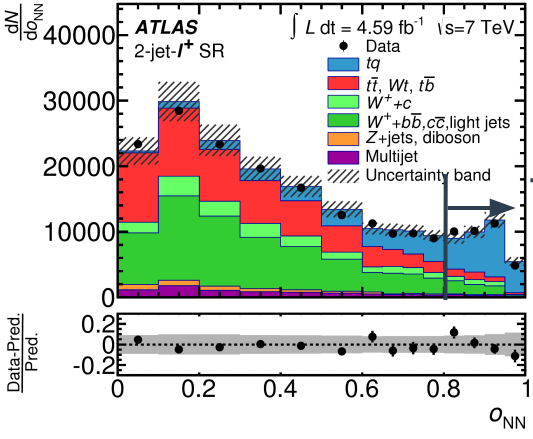
CMS-PAS-TOP-14-004
Phys. Rev. D 90, 112006 (2014)

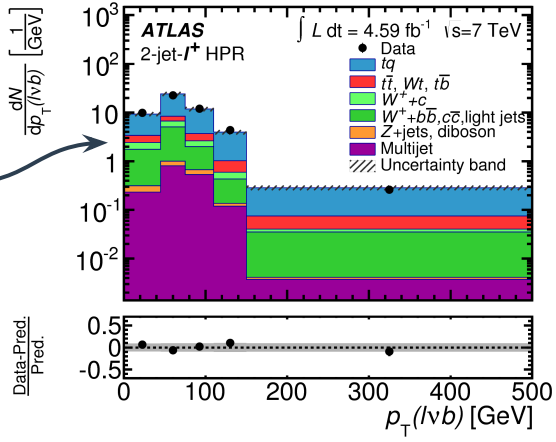
Differential cross sections

- Typical **2j1t** selection
- Train neural network with variables uncorrelated to top p_T
- Cut on NN-Discriminator to obtain a signal-enriched sample
- Perform background subtraction



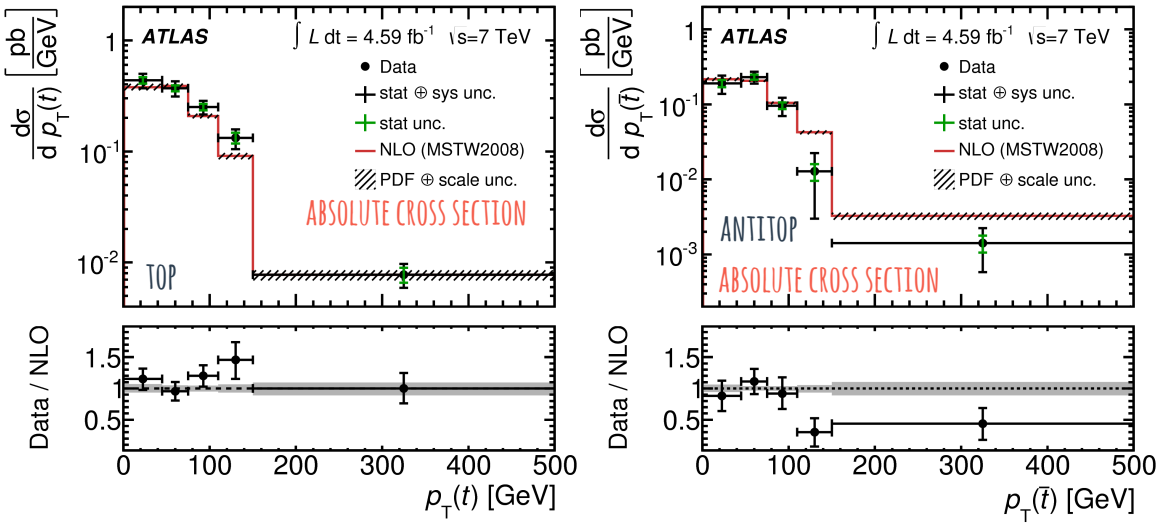


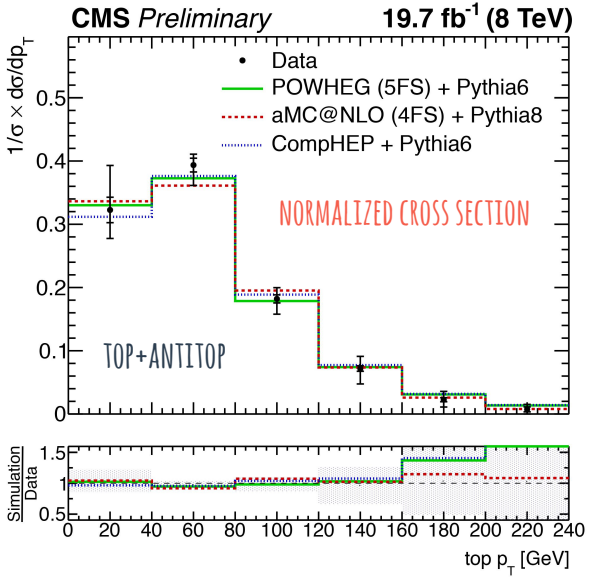




CMS-PAS-TOP-14-004
Phys. Rev. D 90, 112006 (2014)

CROSS SECTIONS DIFFERENTIAL IN P_T



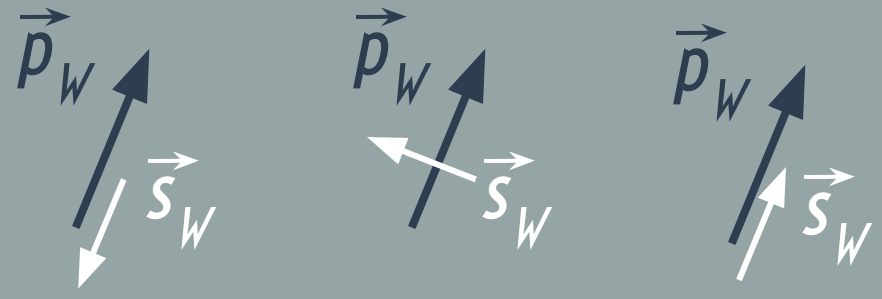


- Unfolded data distributions compared to different MC predictions
- ATLAS: good agreement with absolute MCFM prediction and t/tbar rates
- CMS: aMC@NLO 4FS + Pythia8 gives better description in tail of p_T

2. Properties

Helicity. Polarization.

W BOSON HELICITY

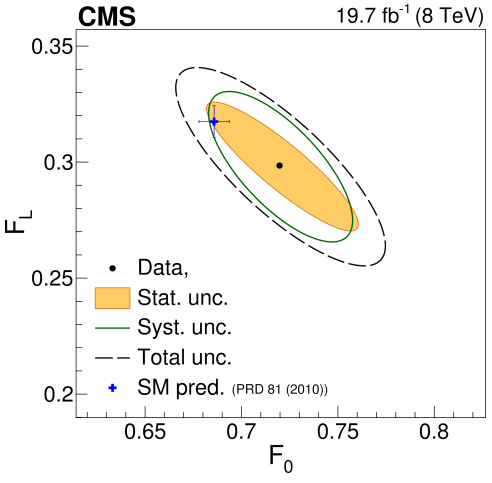


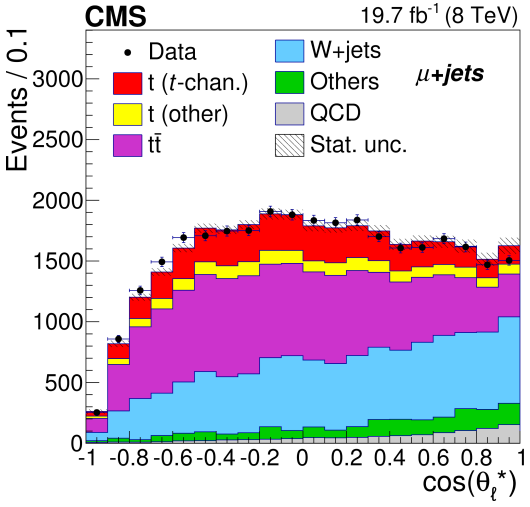
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell^*} = \frac{3}{8}(1-\cos\theta_\ell^*)^2 F_L + \frac{3}{4}\sin\theta_\ell^* F_0 + \frac{3}{8}(1+\cos\theta_\ell^*)^2 F_R$$

obtained from $\Sigma F_i = 1$

θ_ℓ^*: angle between **W in top rest frame** and ℓ **in W rest frame**

- **to be extracted from the fit (Powheg simulation for SM: F_L=0.3, F_0=0.7, F_R=0)**
- Can be used to set limits on anomalous vector & tensor couplings in tWb vertex





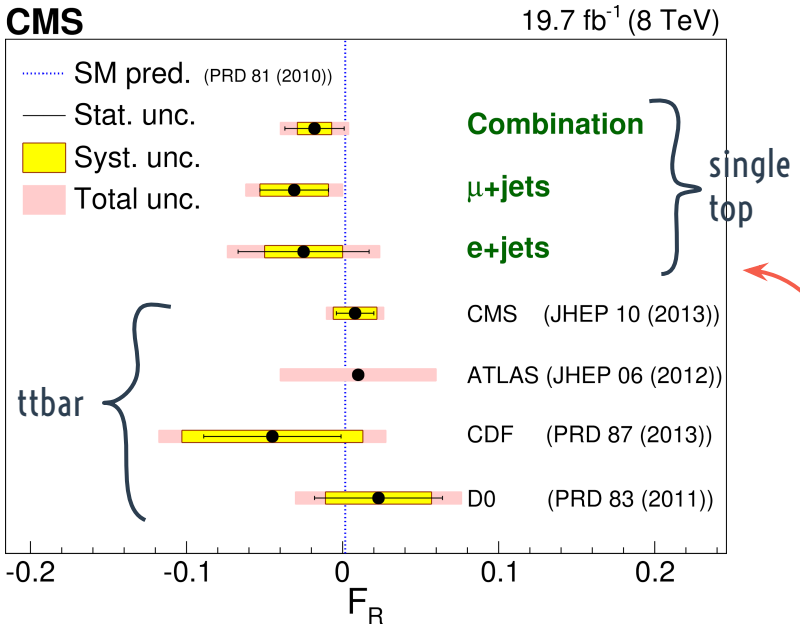
JHEP 01 (2015) 035

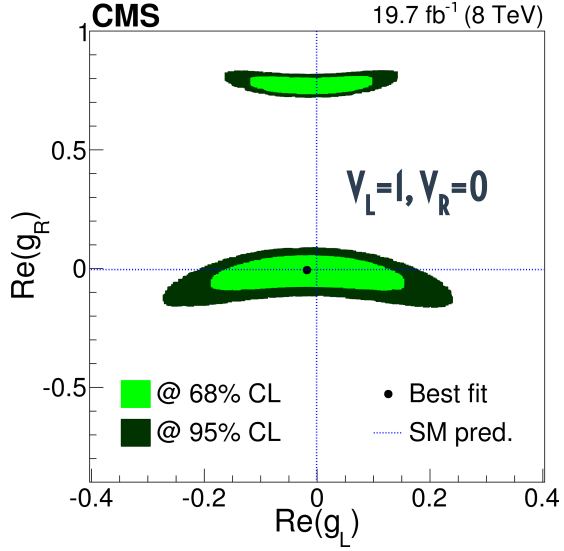
W BOSON HELICITY

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

Main uncertainties: signal modelling

- Typical **2j1t** selection
- Each process with t⟶ Wb considered as signal, i.e. also ttbar
- Fit to θ_ℓ^*: F_L, F_0 and β_{Wjets} treated as free parameters
- normalization of all other processes (including signal) fixed to values from *t*-channel xsec. measurement





JHEP 01 (2015) 035

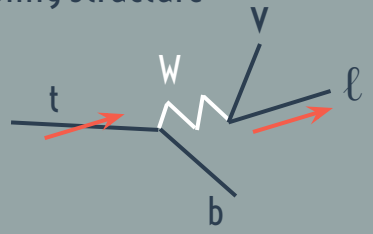
W BOSON HELICITY

- This first single top measurement can compete with ttbar, despite smaller statistics
- Combination with ttbar possible because of orthogonal datasets

- Interpreting results in terms of anomalous, real tensor couplings
- Best fit values: g_L=-0.017, g_R=-0.008

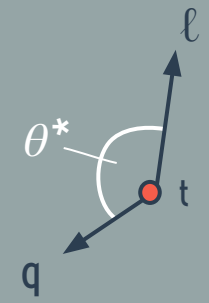
Top polarization in the t-channel

- **SM**: top quarks **100% polarized** in direction of charged lepton due to V-A coupling structure



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

Variable **sensitive** to top quark polarization: $\cos\theta^*$



$$A_\ell = \frac{N(\cos\theta^*>0)-N(\cos\theta^*<0)}{N(\cos\theta^*>0)+N(\cos\theta^*>0)} = \frac{1}{2}P_t\cdot\alpha_\ell$$

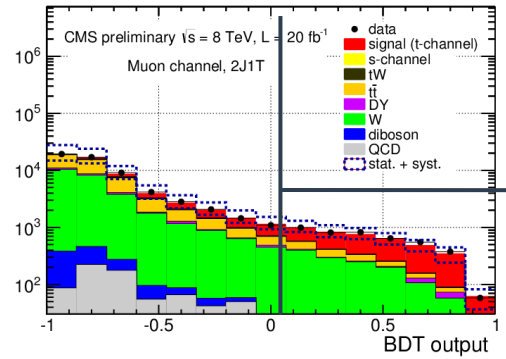
top polarization

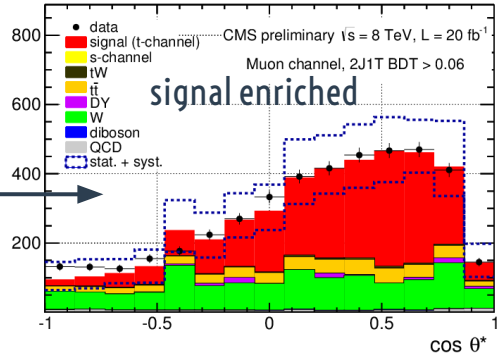
θ^*: $\measuredangle$ (ℓ, light quark) in top quark rest frame

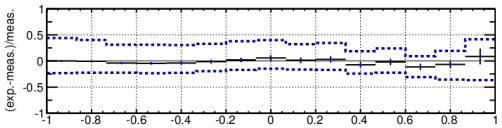
α_ℓ=1 for SM (at LO)
Anom. couplings can change value

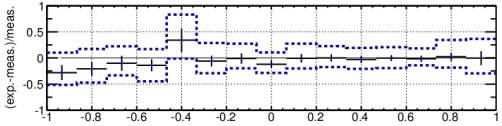
CMS-PAS-TOP-13-001

TOP POLARIZATION

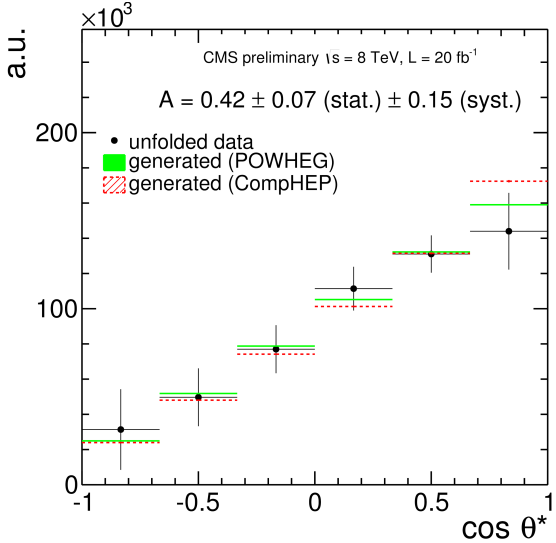








unfolding



- Typical **2j1t** selection
- Background validation:
  - data driven QCD from MET and $M_{T,W}$ (inverting ℓ isolation)
  - Validate Wjets in 2j0t, correct MadGraph with Sherpa
- **Train BDT** & **fit discriminant** to determine signal & background yields
- **Cut on BDT** to enrich signal process
- **Unfold** to correct for detector effects

Main uncertainty: JES

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

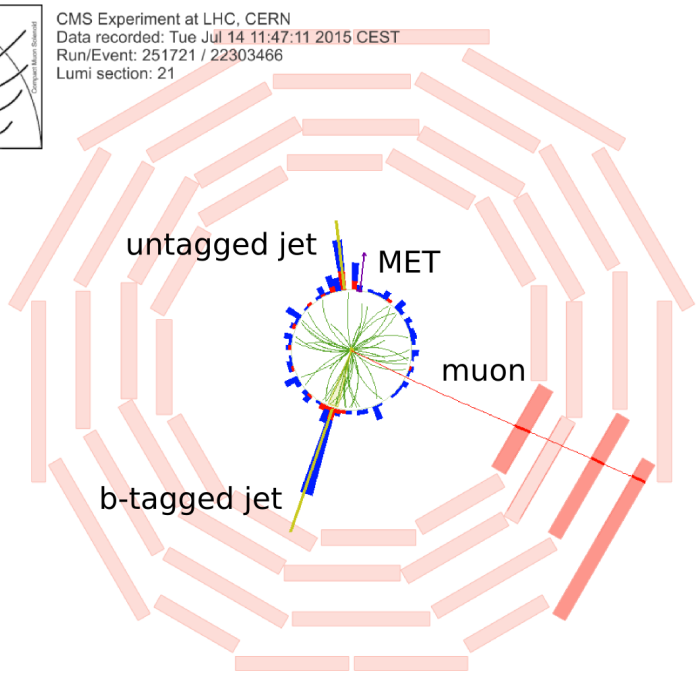
$\alpha_\ell = 1$

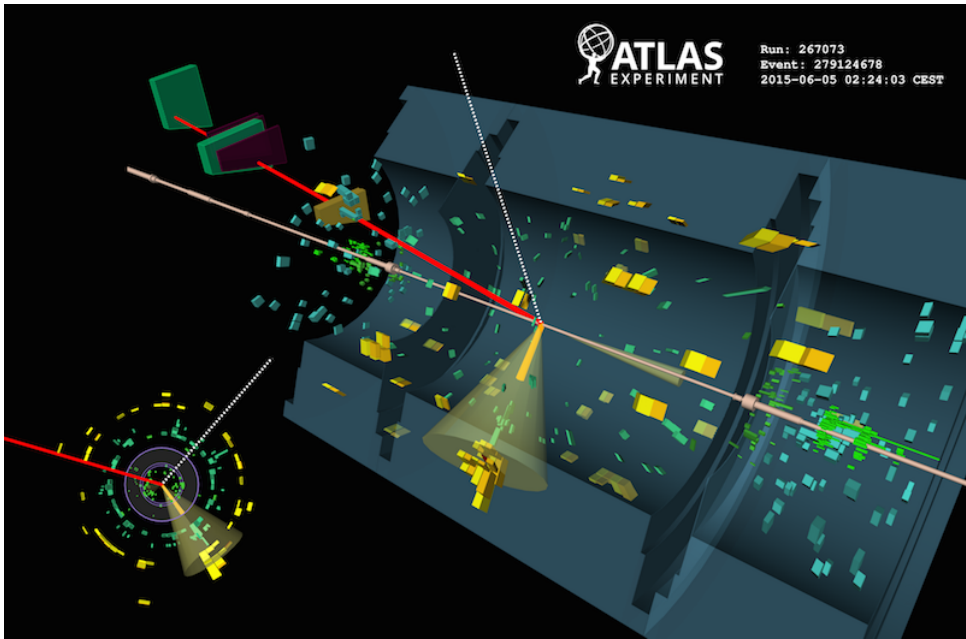
$P_t = 0.82 \pm 0.12(\text{stat.}) \pm 0.32(\text{syst.})$

Compatible with SM (P_t=1)!

CMS

13 TeV single top events





How cool the *t*-channel looks at 13 TeV!

Summary

The *t*-channel has the **largest cross section** of single top production at the LHC.

This makes it a unique place to probe the SM, study V-A interactions and look beyond for new physics.

ATLAS and **CMS** have so far found no deviations from SM when analysing:

- ✖ Inclusive, differential & fiducial cross sections
- ✖ Properties of the tWb vertex and the coupling structures

All the more, so far we have **learned a lot about the SM**, its parameters, modelling aspects and (via the TopLHCWG and talks like this) the collaboration between ATLAS and CMS … we are looking forward to more 13 TeV data!

Thank you.