Single top cross section measurements

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Top LHC-France meeting
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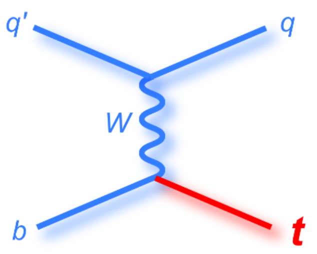
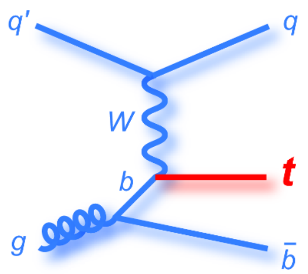
Single top production processes

Three processes in LO



2 → 2 process (5FS)



2 → 3 process (4FS)

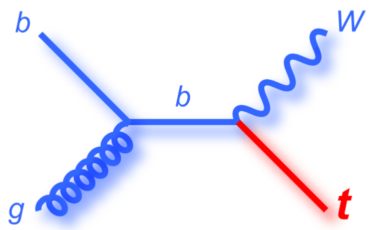
t-channel

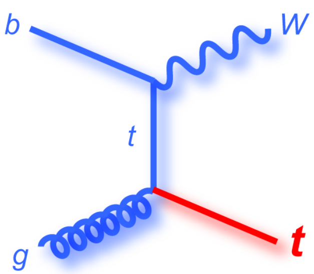
$\sigma_t(8\,TeV) = 85\,pb \pm 4.4\%$

$\sigma_t(13\,TeV) = 217\,pb \pm 4.1\%$

$R_{13/8} = 2.6$

Dominant process





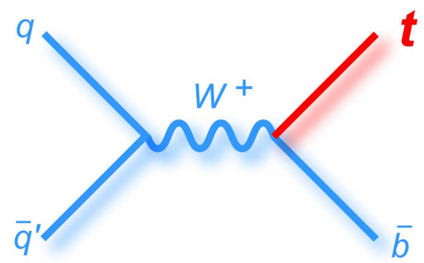
Associated Wt production

$\sigma_{Wt}(8\,TeV) = 22.4\,pb \pm 6.8\%$

$\sigma_{Wt}(13\,TeV) = 71.7\,pb \pm 5.3\%$

$R_{13/8} = 3.2$

Process not observed in $p\bar{p}$ collisions



s-channel

$\sigma_s(8\,TeV) = 5.2\,pb \pm 4.2\%$

$\sigma_s(13\,TeV) = 10.3\,pb \pm 3.9\%$

$R_{13/8} = 1.9$

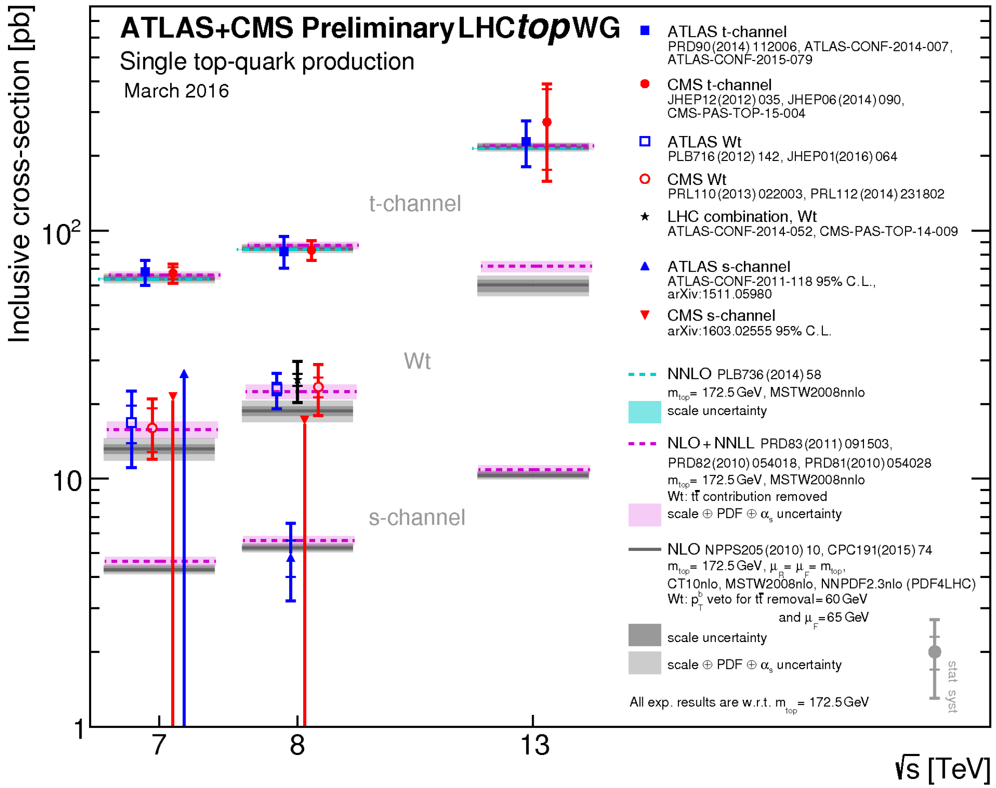
Rare process in pp collisions σ grows much slower with $\sqrt{s}$ than the other top production modes

NLO predictions arXiv:1406.4403
NLO+NNLL predictions arXiv:1311.0283

Inclusive cross sections - Summary of ATLAS+CMS measurements

Motivation for inclusive/fiducial cross section measurements in single top production

- Testing the EW couplings
- Precision measurements to check the SM predictions
- Direct test of the PDFs
- Direct determination of the CKM matrix element V_{tb}



All measurements are in agreement with the SM predictions
Only the t-channel process probed at the three energies

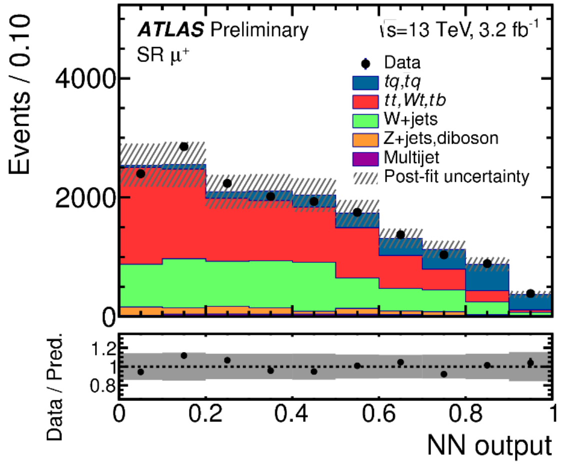
t-channel at 13 TeV – Inclusive cross sections

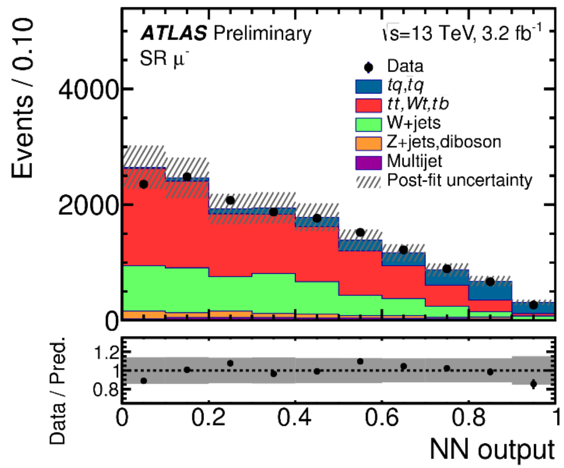
ATLAS-CONF-2015-079

- t-channel exchange leads to a light (spectator) jet scattered into the forward region
- Event selection: 1 isolated muon, 1 b-tagged jet + 1 non-tagged jet with $|\eta| < 3.5$, both with a high p_T, $m_T\,(W) > 50$ GeV; selection dominated by $t\bar{t}$ and W+jets backgrounds
- Signal discrimination with a multivariate analysis (NN): $m_t, m_{jb}, m_T(W), \eta(j)$ are the most relevant
- Fit of the multivariate discriminator to get the signal strength $\beta = \sigma/\sigma_{th}$, the background normalization is constrained

$$\sigma_t(t) = 133 \pm 25\,pb \quad \sigma_t(\bar{t}) = 96 \pm 24\,pb$$
$$\sigma_t = 229 \pm 48\,pb \quad \Delta\sigma_t/\sigma_t = 20\%$$

Source	$\Delta\sigma\ (t)/\sigma$	$\Delta\sigma\ (\bar{t})/\sigma$
Statistics	5%	5%
Luminosity	5%	5%
MC statistics	6%	6%
Jet/MET	8%	6%
b-tagging	7%	8%
Theory model	13%	18%





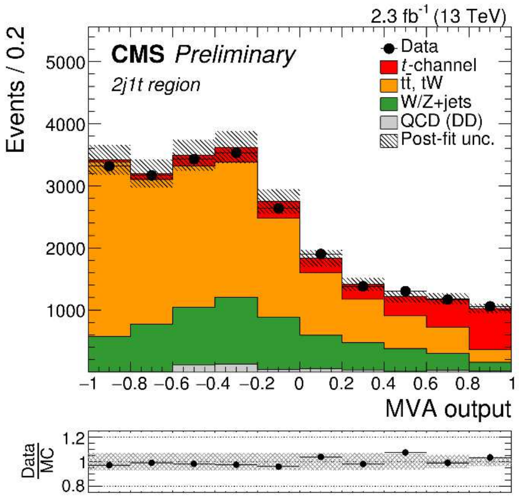
t-channel at 13 TeV – Inclusive cross sections and ratio

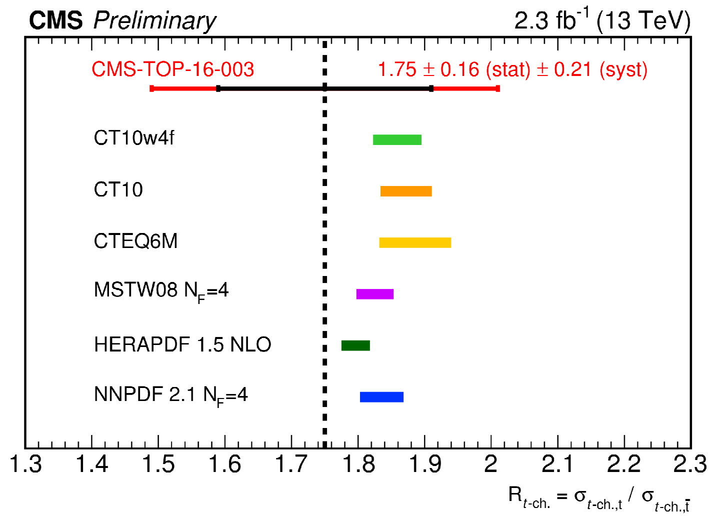
- Similar event selection (jet with $|\eta| < 4.7$) and signal discrimination procedure
- Simultaneous fit of the multivariate discriminators in the signal and 2 control regions

Cross section ratio in agreement with the SM prediction

Potential to discriminate between the different PDF sets when better precision achieved

$$\sigma_t(t) = 141.5^{+22.8}_{-23.0}\ pb$$
$$\sigma_t(\bar{t}) = 81.0^{+22.8}_{-23.0}\ pb$$
$$R_t = \sigma_t(t)/\sigma_t(\bar{t}) = 1.75 \pm 0.16(stat) \pm 0.21(syst)$$
$$\Delta R_t/R_t = 15\%$$





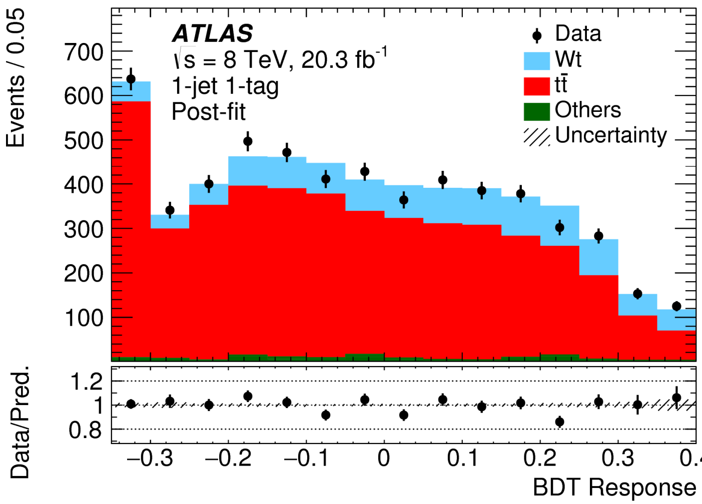
CMS-PAS-TOP-15-003

Associated Wt production at 8 TeV – Inclusive cross section

JHEP 01 (2016) 064 (ATLAS)
PRL 112 (2014) 231802 (CMS)

- Selection from the cleanest final state: 2 opposite-sign leptons, 1 or 2 jets, 1 or 2 b-tagged jets, and $E_T^{miss} > 40\ GeV (ee, \mu\mu), > 20\ GeV\ (e\mu)$
- Background from non-resonant ($WWb/WWbb$) and double resonant ($t\bar{t}$) productions
- Fitted multivariate discriminators combining different variables optimised depending on numbers of N_{jets} and N_{bjets}

$$\sigma_{Wt} = 23.0 \pm 1.3(stat)^{+3.2}_{-3.5}\ (syst) \pm 1.1(lumi)\ pb \quad \Delta\sigma_{Wt}/\sigma_{Wt} = 16\%$$



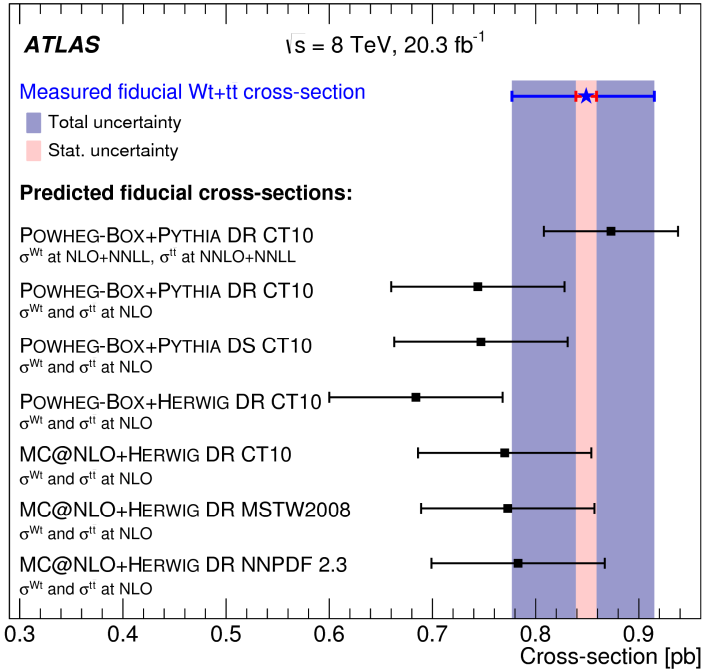
Source	$\Delta\sigma_{Wt}/\sigma_{Wt}(\%)$
Statistics	5.8
Luminosity	4.7
Theory model	9.9
Jet/MET	10.9
b-tagging	3
Lepton eff.	1

Associated Wt production at 8 TeV – Fiducial cross section

- Cross section measurement in a fiducial region for a more robust comparison to the theory: this reduces the sensitivity to theory modelling uncertainties
- The fiducial acceptance requires 2 leptons and 1 b-jet at the particle level
- Combined $t\bar{t}$ and Wt measurement from the fit in the 1-jet 1-btag region only

$$\sigma_{t\bar{t}+Wt,fid.} = 0.85 \pm 0.01(stat)^{+0.06}_{-0.07}(syst) \pm 0.03(lumi)\ pb$$
$$\Delta\sigma_{t\bar{t}+Wt,fid}/\sigma_{t\bar{t}+Wt,fid} = 8\%$$

Source	$\Delta\sigma_{t\bar{t}+Wt}/\sigma_{t\bar{t}+Wt}$(%)
Statistics	1
Luminosity	3.1
Theory model	4.9
Jet/MET	5.2
b-tagging	2.3
Lepton eff.	2.3

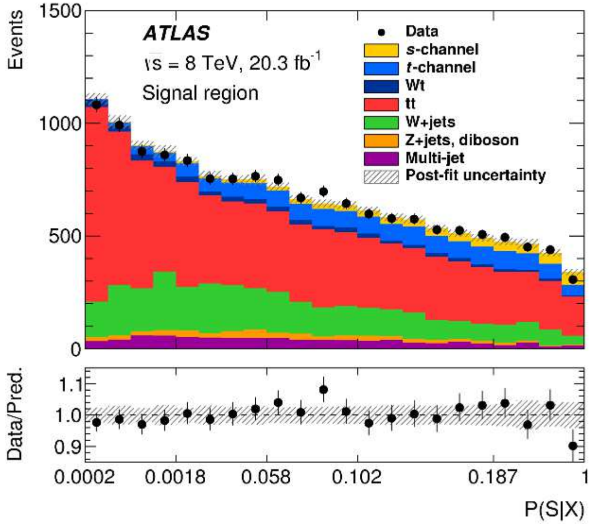


JHEP 01 (2016) 064 (ATLAS)

Search for s-channel production at 8 TeV

- Selection: 1 isolated lepton, 2 b-tagged jets and large E_T^{miss}; the main background is $t\bar{t}$
- Signal discrimination based on the matrix element method (ATLAS) or using a multivariate discriminator (CMS)
- Fit of the discriminator to get the signal strength β with the background contrained through control regions

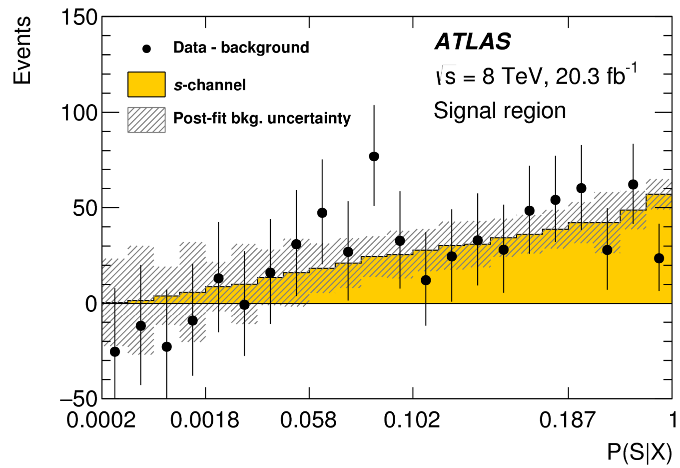
$$\sigma_s = 4.8 \pm 0.8(stat)^{+1.6}_{-1.3}(syst)\ pb$$
$$\Delta\sigma_s/\sigma_s = 37\%$$



Evidence

3.2σ observed

3.9σ expected

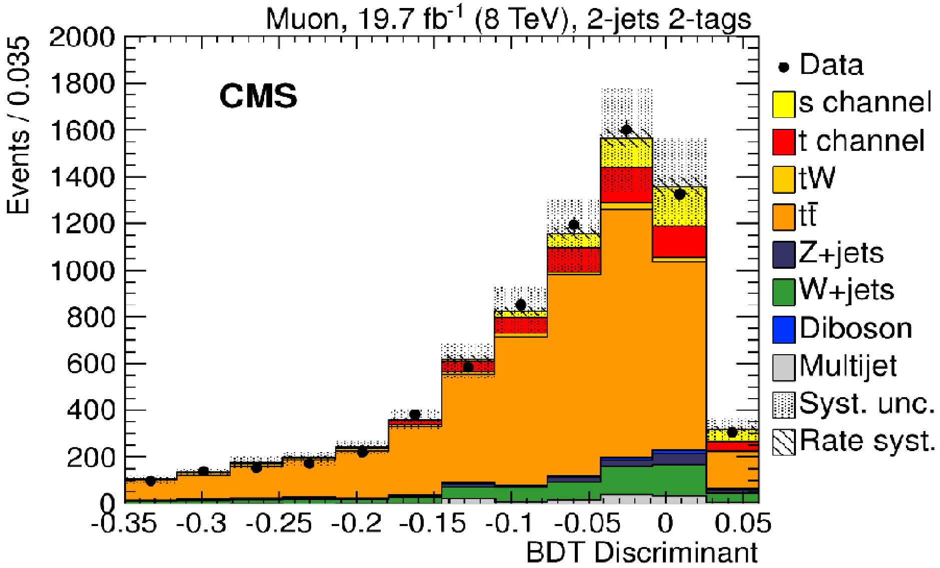


Phys. Lett. B756 (2016) 228 (ATLAS)

Search for s-channel production at 8 TeV

$\sigma_s = 13.4 \pm 7.3\ pb$
$\Delta\sigma_s/\sigma_s = 54\%$

2.5σ observed
1.1σ expected



$\Delta\sigma_s/\sigma_s(\%)$

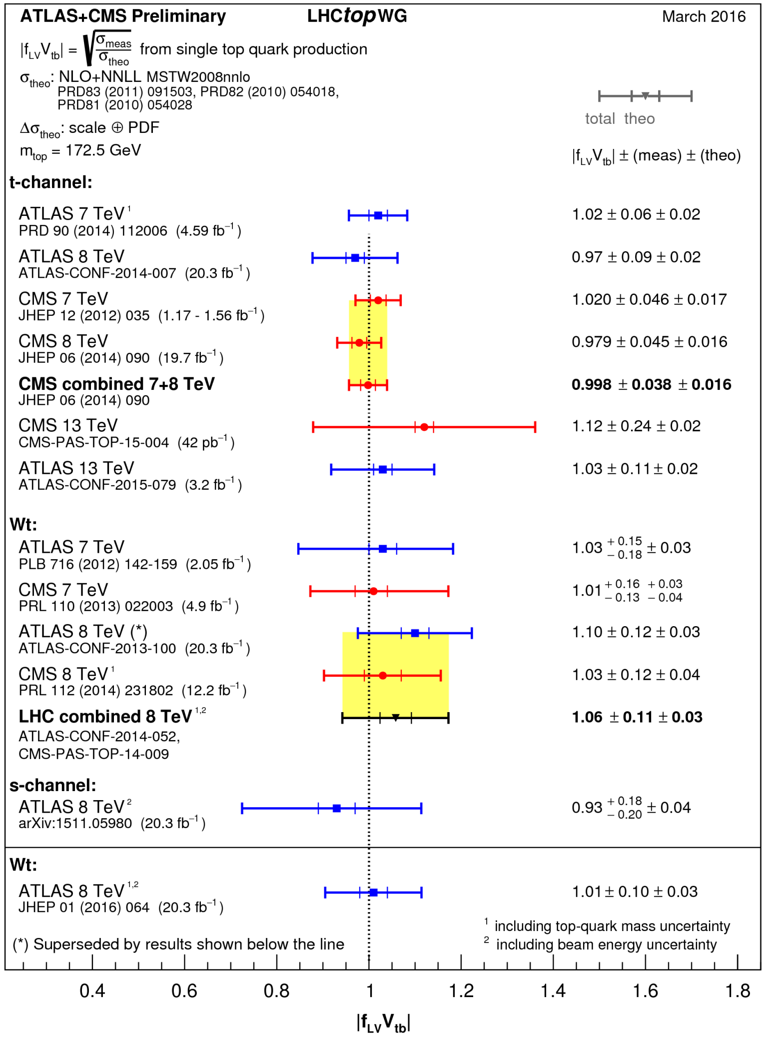
Source	ATLAS	CMS
Statistics	12	11
Luminosity	5	6
MC statistics	12	-
Jet/MET	13	19
b-tagging	8	16
Backgrounds	8	19
Theory model	13	33

arXiv:1603.02555 (CMS)

From cross sections to EW couplings

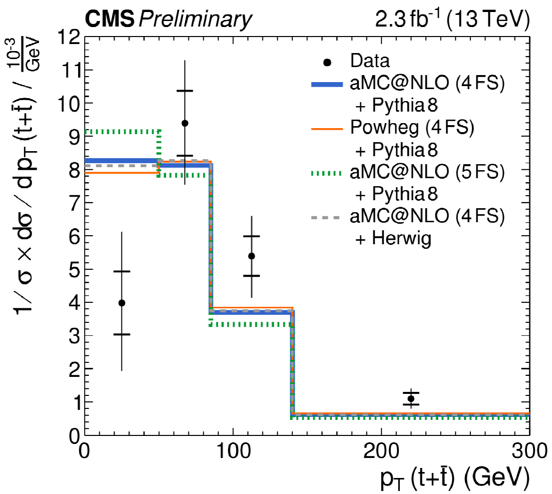
- The CKM matrix elements V_{tq} enter in the production and decay Wtb vertices
- Anomalous Wtb couplings are parameterized through the left-handed form factor f_{Lv} (in SM $f_{Lv} = 1$)
- In the approximation $|V_{td}|, |V_{ts}| \ll |V_{tb}|$ and full left-handed decay to Wb one get

$$|f_{Lv}\, V_{tb}| = \sqrt{\sigma/\sigma^{theo}}$$



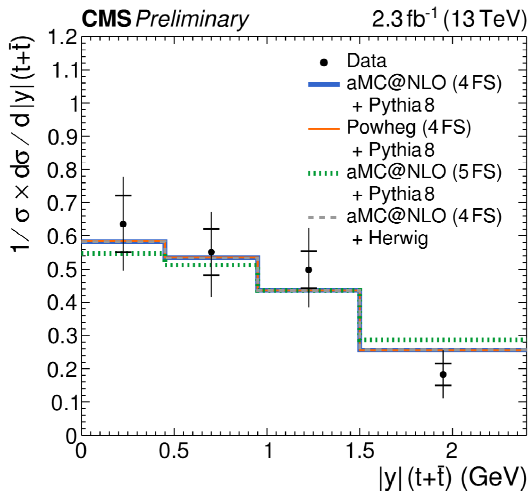
t-channel differential cross sections at 13 TeV

- Differential measurements are particularly well suited to assess the validity of the predictions
- Normalized differential cross sections measured as a function of the top p_T and $|y|$
- Event selected with 1 isolated muon, 2 jets ($|\eta| < 4.7$) with 1 b-tagged, and $m_T(W) > 50\ GeV$
- Signal discrimination with a multivariate analysis: $\eta(j), m_t, \Delta R(j,b), |\Delta\eta(b,\mu)|, m_T(W)$
- Discriminator fitted to extract separately the signal yields in each bin of top p_T and $|y|$
- Unfolding to parton level with the TUNFOLD algorithm



Good agreement with the theoretical description within the uncertainties

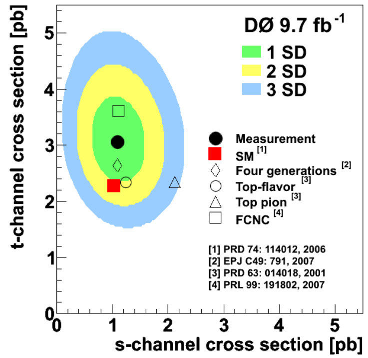
CMS-PAS-TOP-16-004



Summary and perspectives

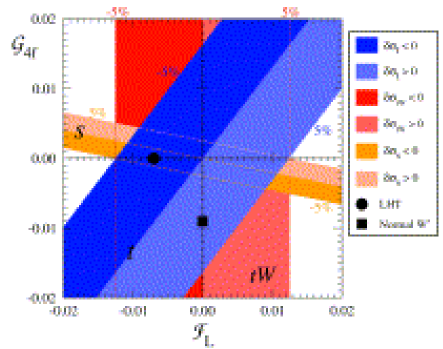
- Overall good agreement with the Standard Model predictions of the inclusive, fiducial and differential cross sections measured for the three single top processes
- Also good agreement for the derived values of the CKM matrix element $|V_{tb}|$
- More results will come to complete the scan of all energies
- Combination of the three processes for BSM searches through:
  - Direct model comparison

Fermilab-Pub-13-252-E (DØ)



  - Determination of effective couplings

$$\sigma_t = \sigma_t^0(1 + 4\mathcal{F}_L - 3.06\mathcal{G}_{4f})$$
$$\sigma_s = \sigma_s^0(1 + 4\mathcal{F}_L + 19.69\mathcal{G}_{4f})$$
$$\sigma_{Wt} = \sigma W_t^0(1 + 4\mathcal{F}_L)$$



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