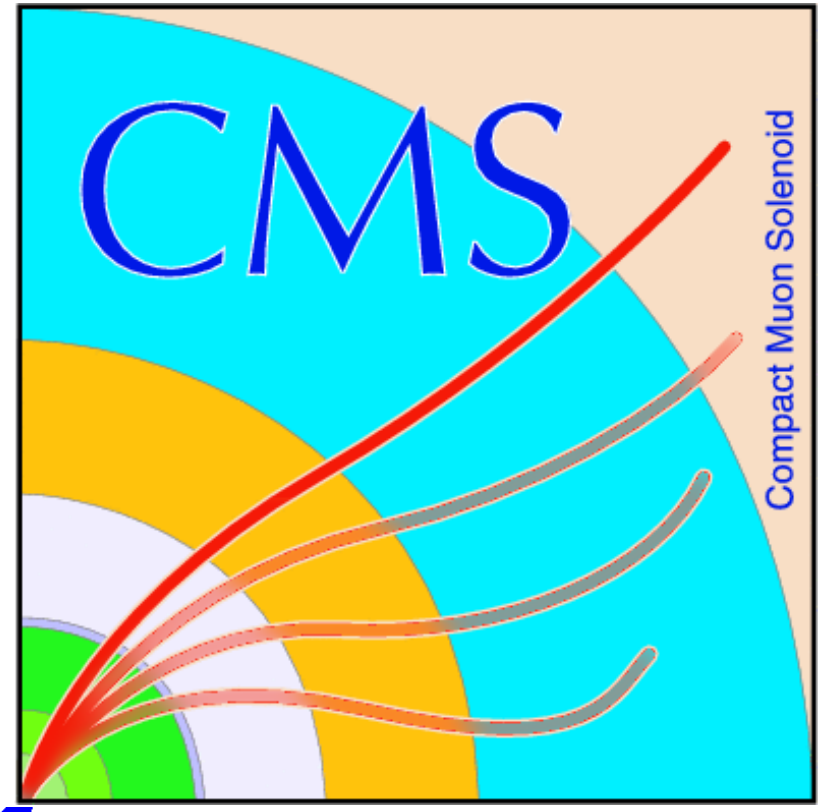
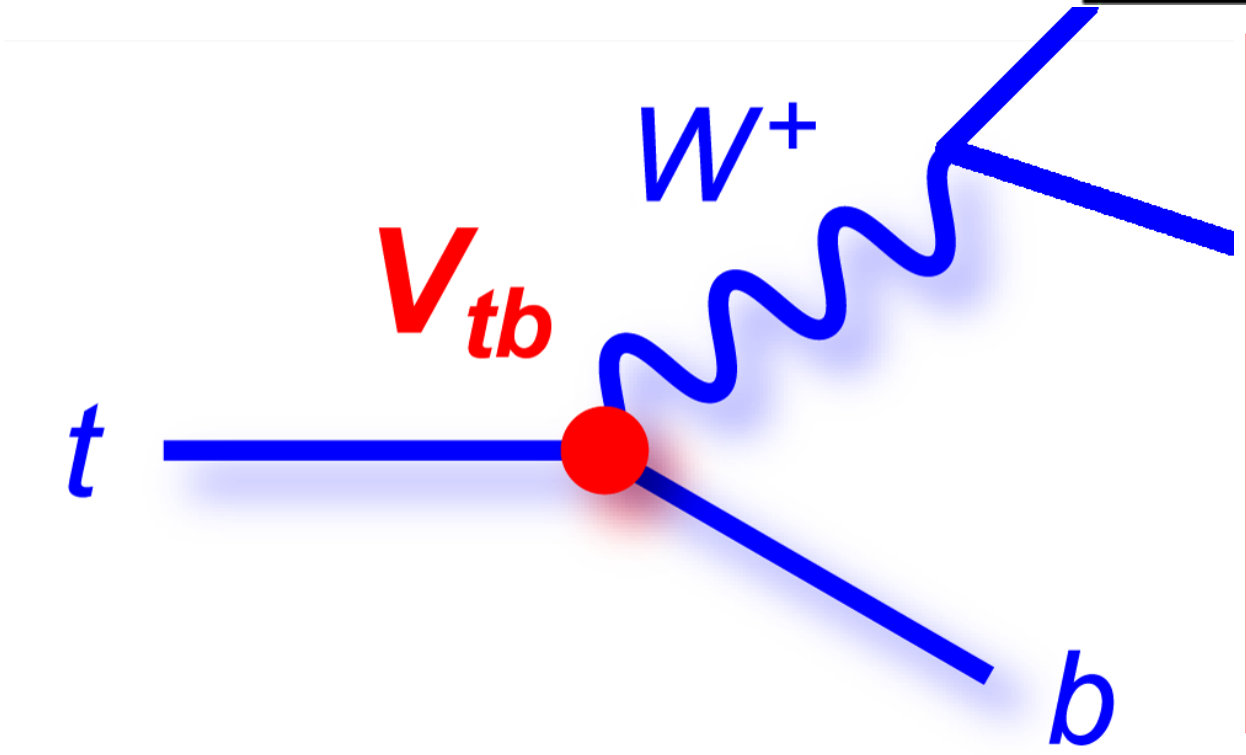
Single top quark production measurements in **CMS**





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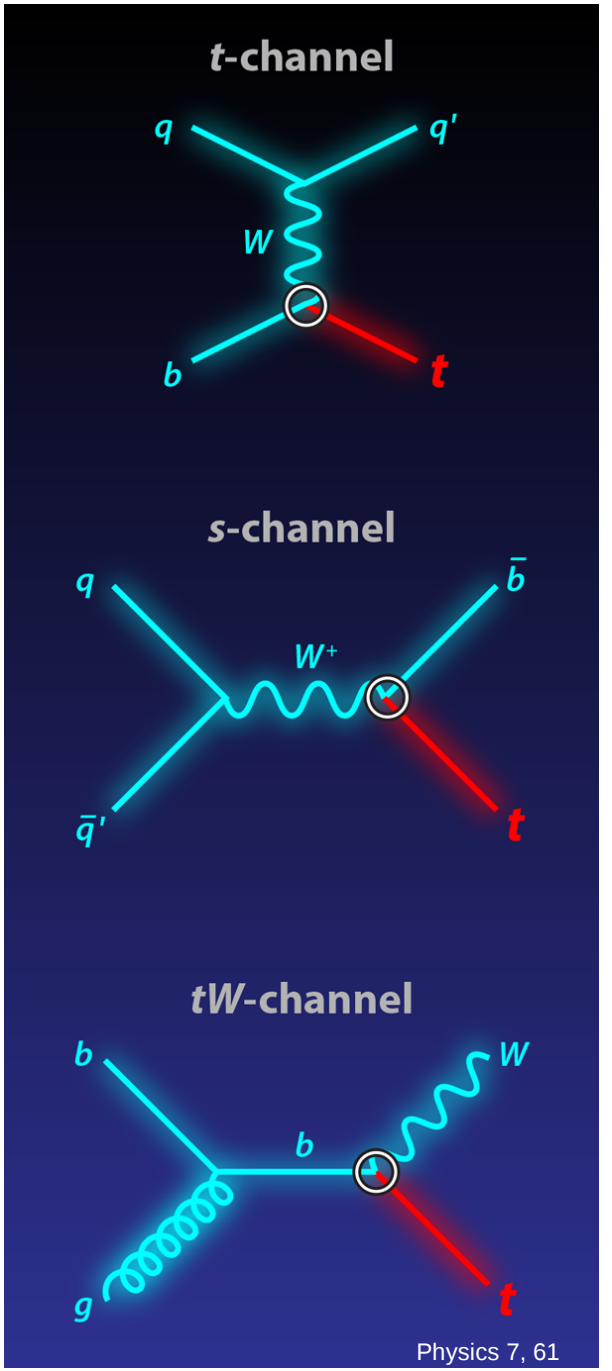
On behalf of the CMS collaboration

August 2016, ICHEP

Single top production

- three production channels :
  - **t-channel**
  - **tW channel**
  - **s-channel**
- Production via charged current interaction
  - direct probe to tWb coupling
  - **measurement of $|V_{tb}|$**
  - study of top quark polarization
- **sensitive to quark PDF**
- sensitive to new physics :
  - anomalous couplings (FCNC)
  - 4th generation
  - charged Higgs ($H^{\pm}$) interaction

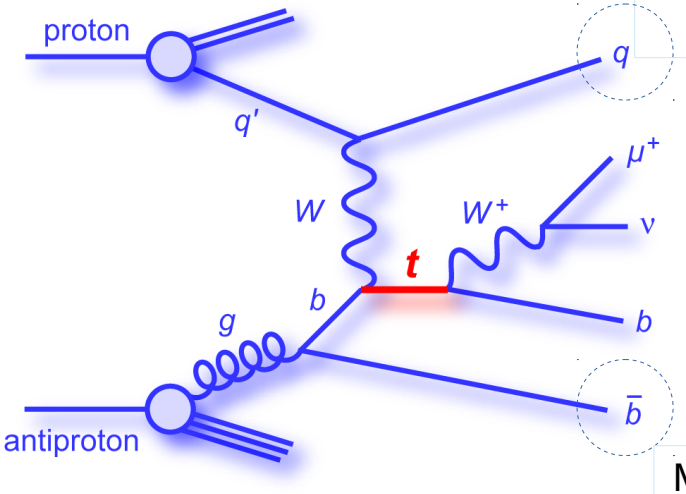


t-channel

➔ Highest cross section

Most recent CMS results :

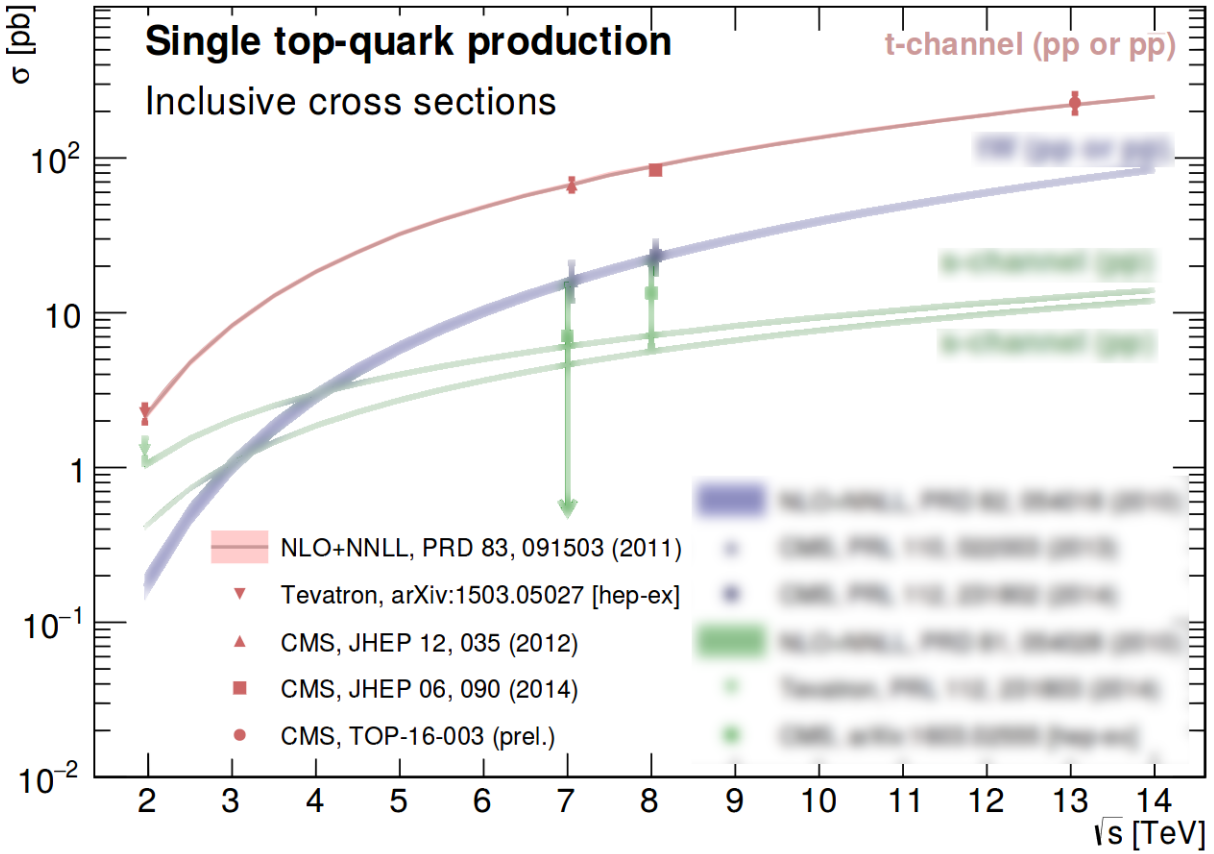
Differential cross section @ 13 TeV (Top-16-004)
Inclusive cross section @ 13 TeV (Top-16-003)
Fiducial cross section @ 8 TeV (Top-15-007)



Forward & light jet

Signature (2J1T)
2Jets , 1b-tagged

Mostly out of acceptance



Top-16-003

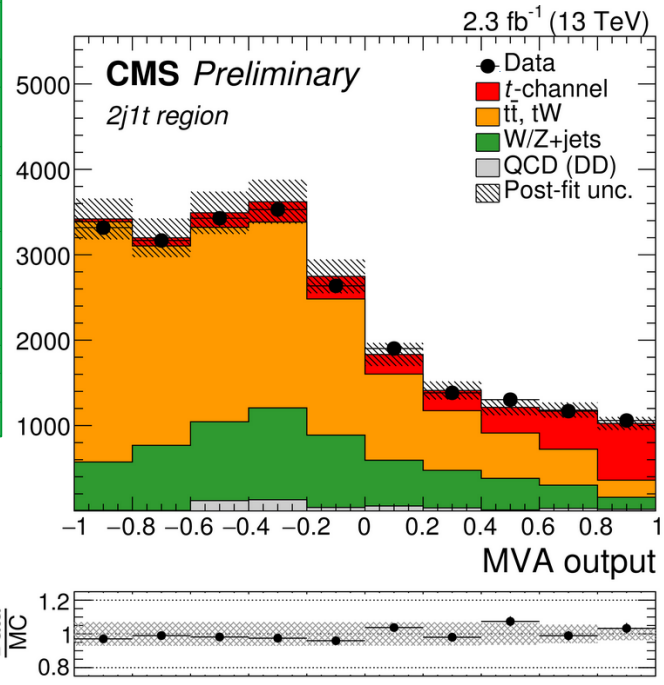
t-channel cross-section @ 13TeV

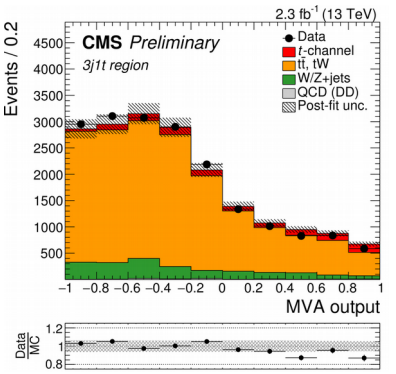
- Exactly one Isolated muon
  - pt > 22 GeV
  - Non-isolated muons used for QCD estimation
- M_T > 50 GeV
  - Low M_T for QCD control region
- Central high-p_T b-jet
  - 2J1T : Signal Region
  - 3J(1/2)T : $t\bar{t}$ Control Region
  - 2J0T : W-Jet control region

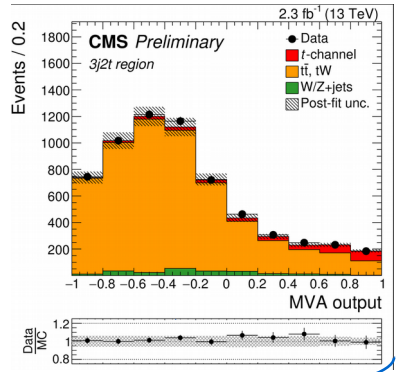
    QCD Method validation

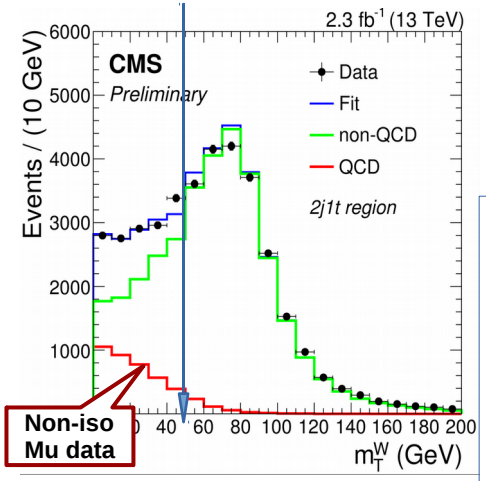
Variable
light quark $\lvert\eta\rvert$
top quark mass
dijet mass
transverse W boson mass
jet-p_T sum
$\cos\theta^*$
hardest jet mass
ΔR (light quark, b quark)
light quark p_T
light quark mass
W boson $\lvert\eta\rvert$

Neural Network









Simultaneous fit in 3 regions

$$\sigma(t+\bar{t}) = 228 \pm 4\%\ (\text{stat.}) \pm\ 6\%\ (\text{exp.}) \pm 12\%\ (\text{theo.})\ \pm 3\%\ (\text{lumi.})\ \text{pb}$$

$$228 \pm 15\%\ \text{pb}\ \left[\sigma^{\text{SM}} = 217^{+9}_{-8}\ \text{pb}\right]$$

- largest single uncertainty: signal modeling (aMC@NLO ↔ Powheg)

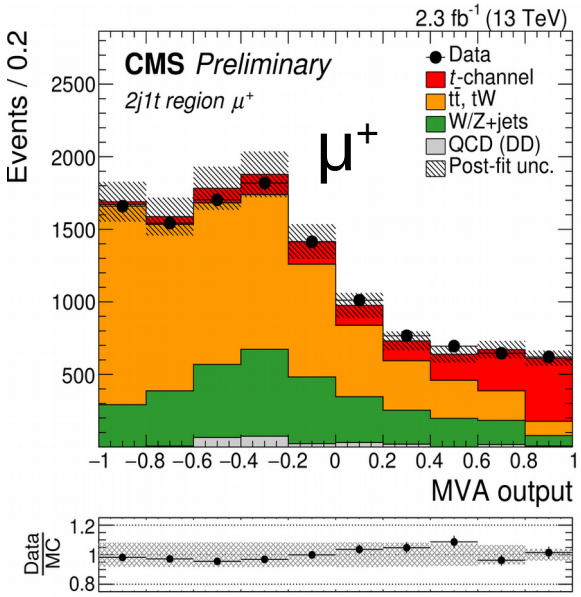
- CKM V_{tb} element (assuming $|V_{tb}| >> |V_{td}|, |V_{ts}|$)

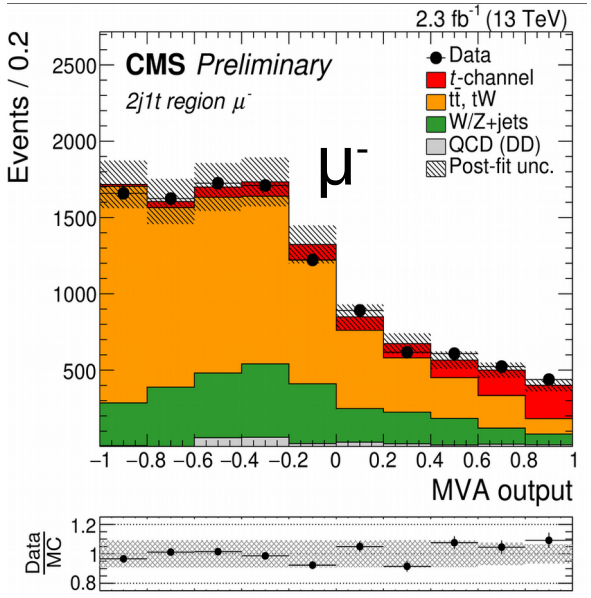
$$|f_{LV} V_{tb}| = 1.02 \pm 0.07\ (\text{exp.}) \pm 0.02\ (\text{theo.})$$

Top-16-003

top antitop cross-section ratio @ 13 TeV

- Repeating the same analysis, separately for positive and negative muons

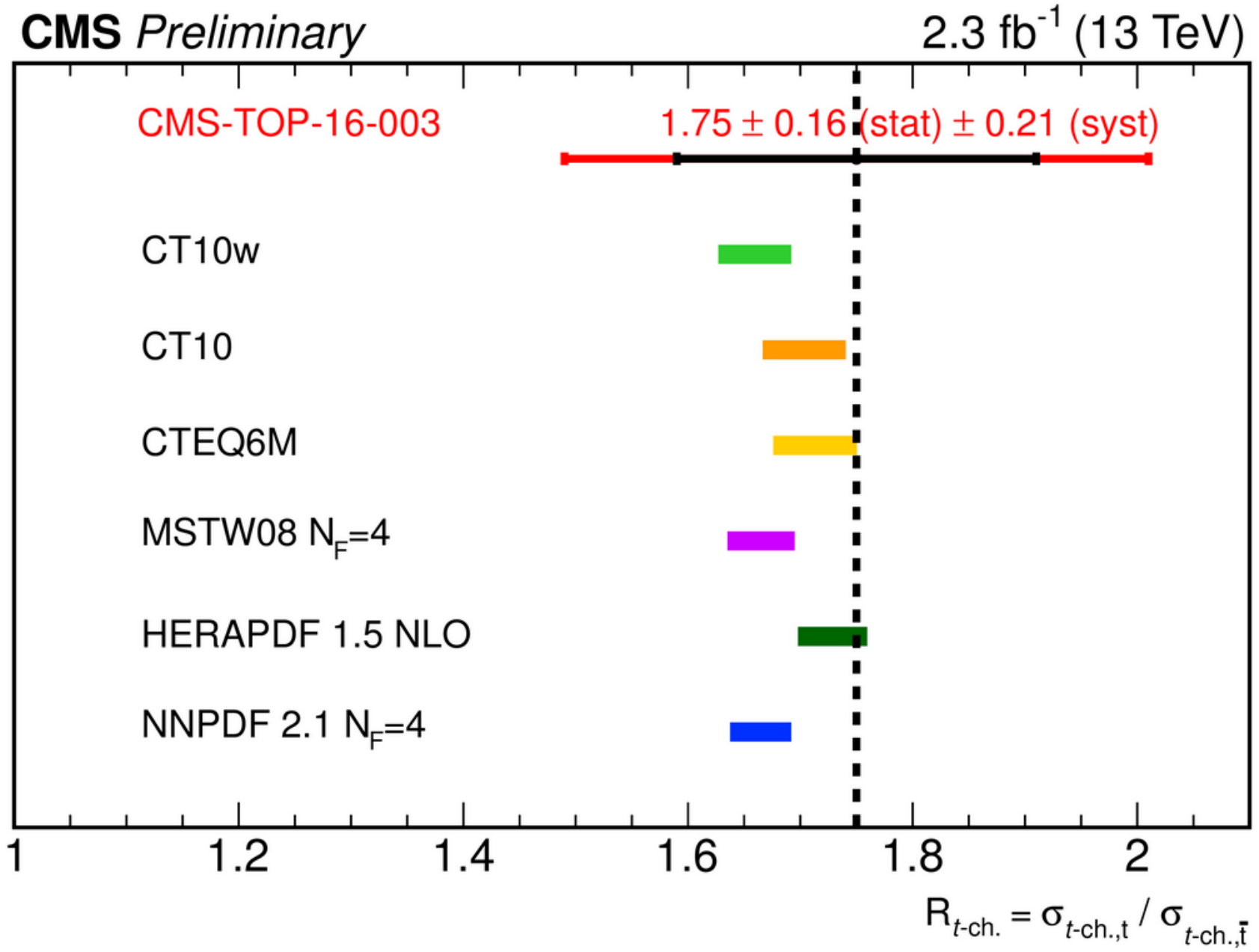




$$= \frac{141.5\,^{+22.8}_{-23.0}\,\text{pb}}{81.0\,^{+15.1}_{-15.1}\,\text{pb}} = 1.75 \pm 0.16\,(\text{stat.}) \pm 0.21\,(\text{syst.})$$

Top-16-003

top antitop cross-section ratio @ 13 TeV



Top-16-004

t-channel differential cross-section @ 13TeV

2.2 fb^{-1} of 2015 data is enough to start differential measurements vs. p_T and rapidity

BDT discriminator :

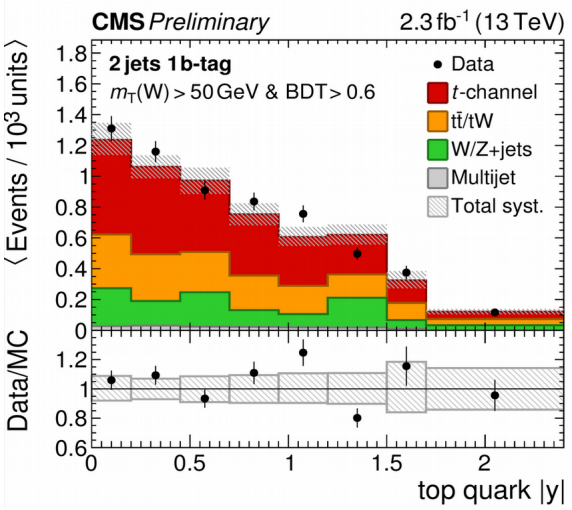
Based on variables uncorrelated to top pt and rapidity

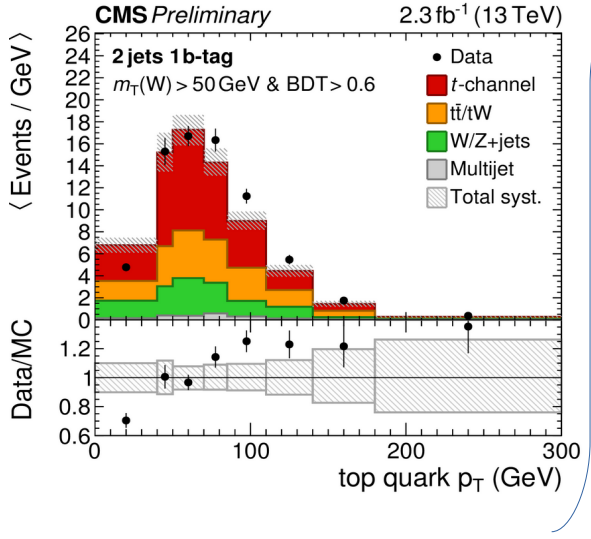
Fit to

m_T shape for m_T < 50 GeV

BDT otherwise

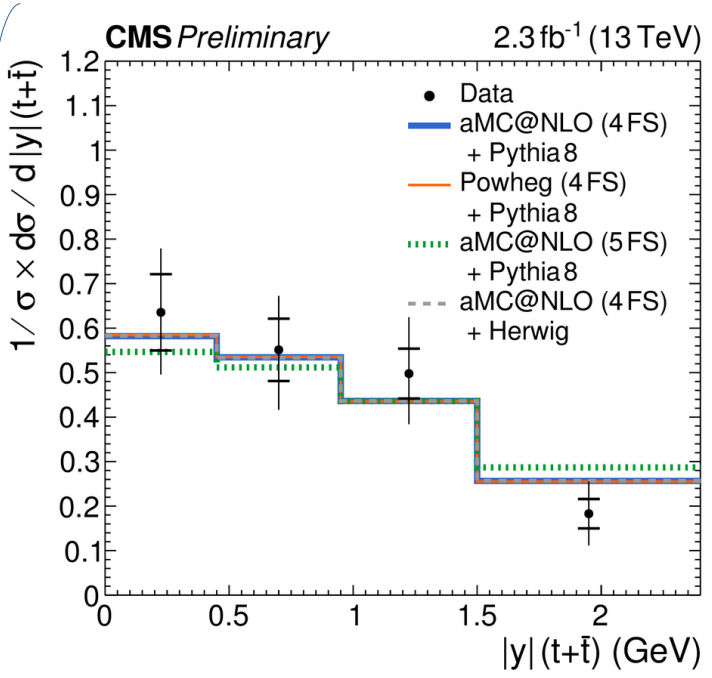
m_T > 50 GeV & BDT > 0.6

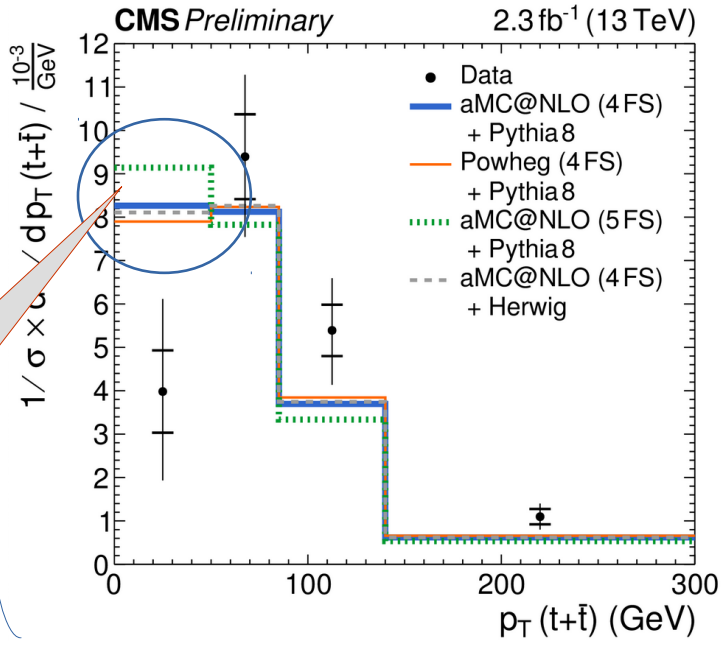




Unfolded to parton level

low acceptance & high sensitivity to modeling





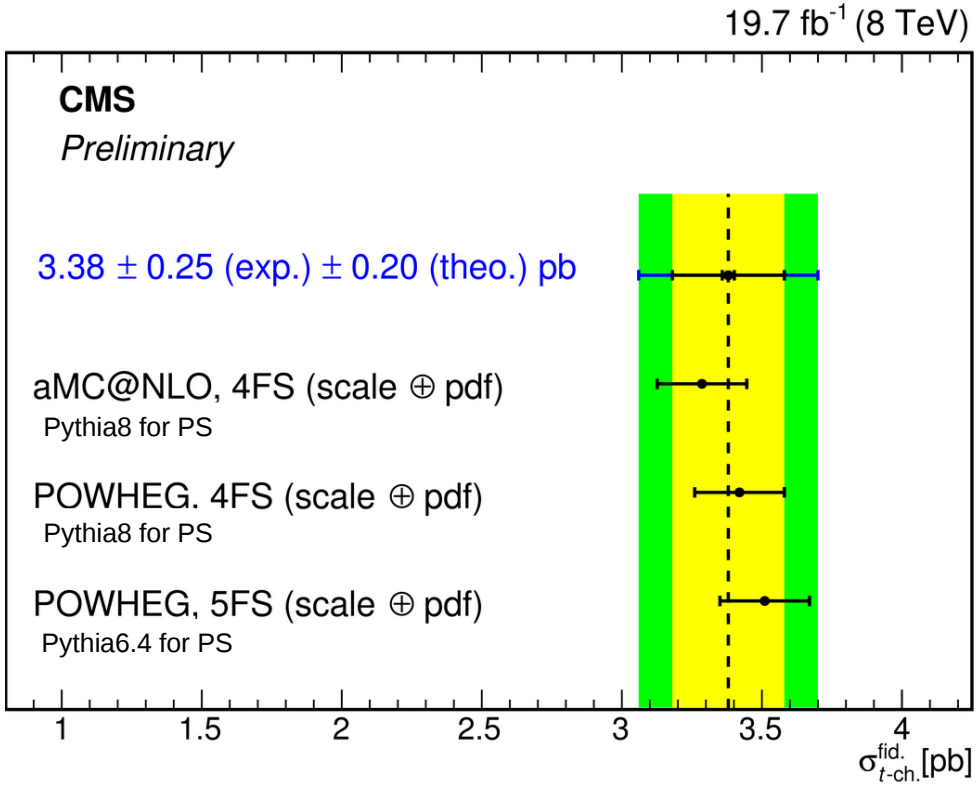
Top-15-007

t-channel fiducial cross-section @ 8TeV

$$\sigma^{\text{fid}}_{t\text{-ch}} = \sigma_{t\text{-ch}} \cdot A^{\text{fid}} \quad A^{\text{fid}} = \frac{\sigma^{\text{fid,MC}}_{t\text{-ch}}}{\sigma^{\text{MC}}_{t}}$$

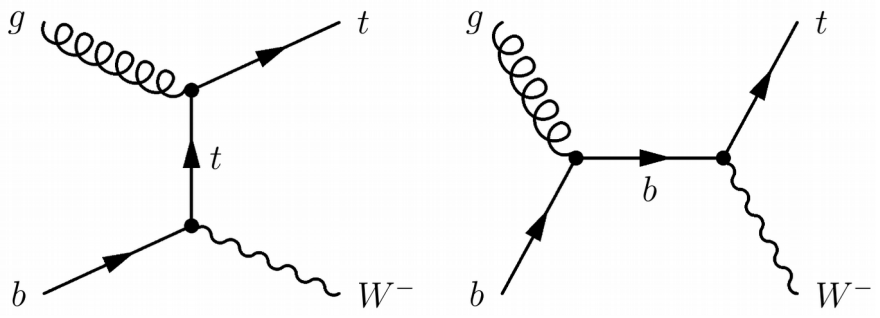
- Same selection as the 8TeV cross section measurement
  [JHEP06(2014)090]
- Similar cuts at the generator level

Object	Kinematic cuts at detector level	Cuts at particle level	number required
Tight Muon	$p_T > 26$, $\|\eta\| < 2.1$, $I_{rel} < 0.12$	$p_T > 30$, $\|\eta\| < 2.4$	exactly 1 (or 1 Ele)
Tight Electron	$E_T > 30$, $\|\eta\| < 2.4$, $I_{rel} < 0.1$	$p_T > 30$, $\|\eta\| < 2.4$	exactly 1 (or 1 Mu)
Veto Muon	$p_T > 10$, $\|\eta\| < 2.4$, $I_{rel} < 0.2$	-	0
Veto Electron	$E_T > 20$, $\|\eta\| < 2.4$, $I_{rel} < 0.15$	-	0
Jets	$p_T > 40$, $\|\eta\| < 4.7$	$p_T > 40$, $\|\eta\| < 5.0$	exactly 2
B-tagging	1 jet is tagged	$\|\eta\| < 2.4$, b-hadron	exactly 1
m_T (muons)	$m_T > 50$	-	-
$\not{E}_T$ (electrons)	$\not{E}_T > 45$	-	-

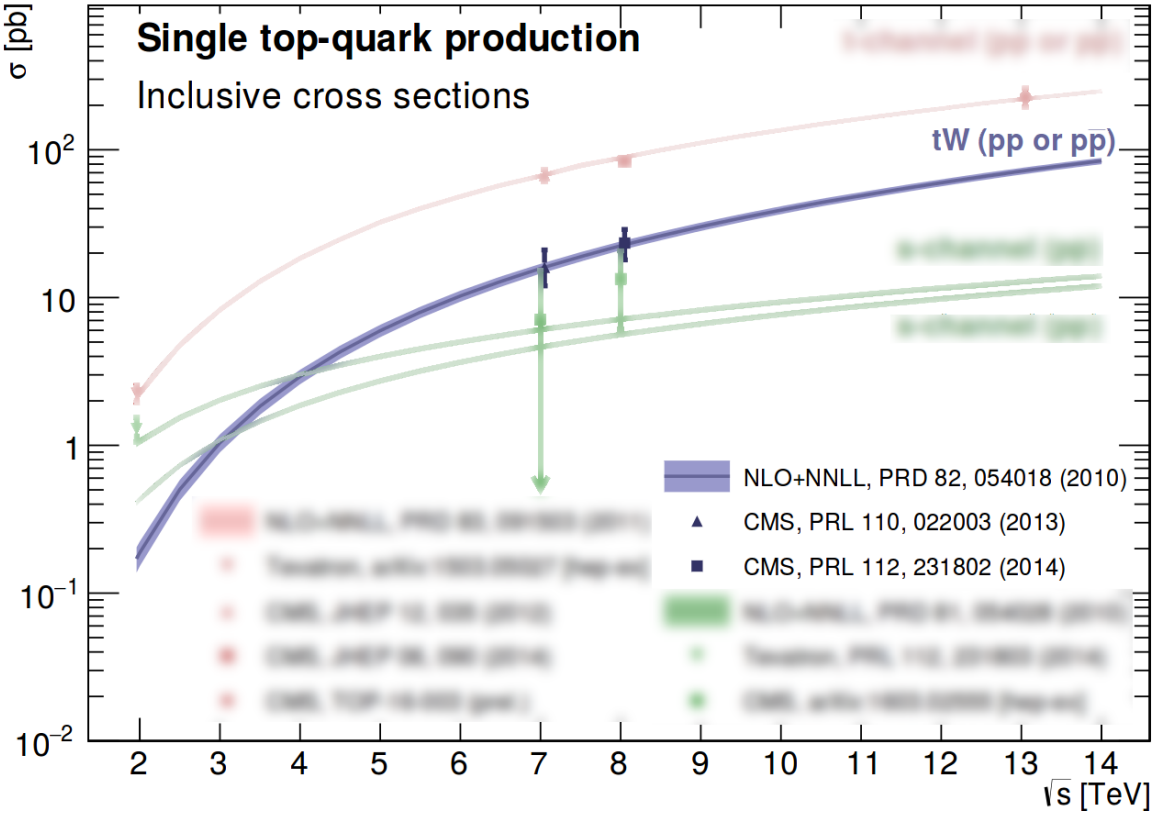


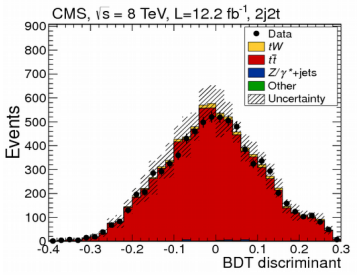
tW channel

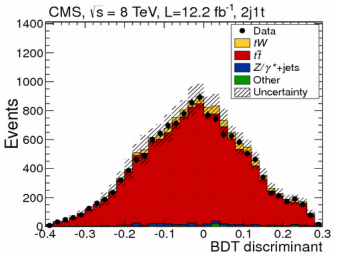
Observation @ 8 TeV :
PRL 112 (2014) 23180

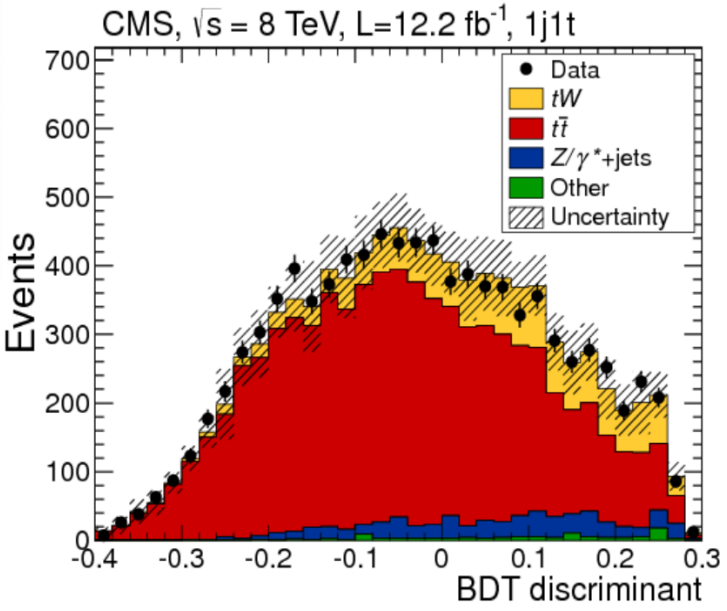


- di-lepton final states are considered
- Signal region : 1Jet-1bTagged
- Fit BTD discriminant to extract σ_{tW}
  - Simultaneously in signal region, 2J1T and 2J2T to control $t\bar{t}$







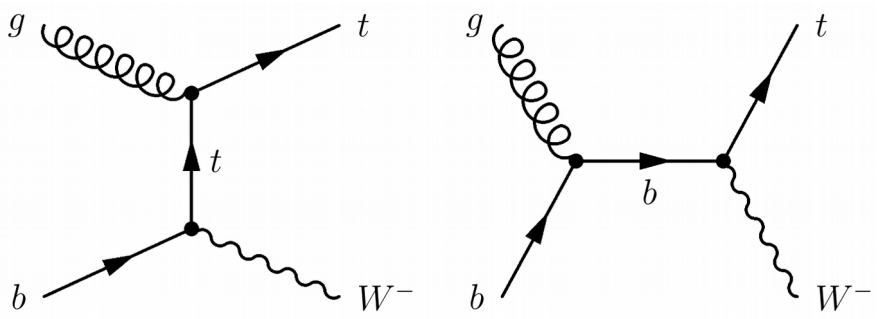


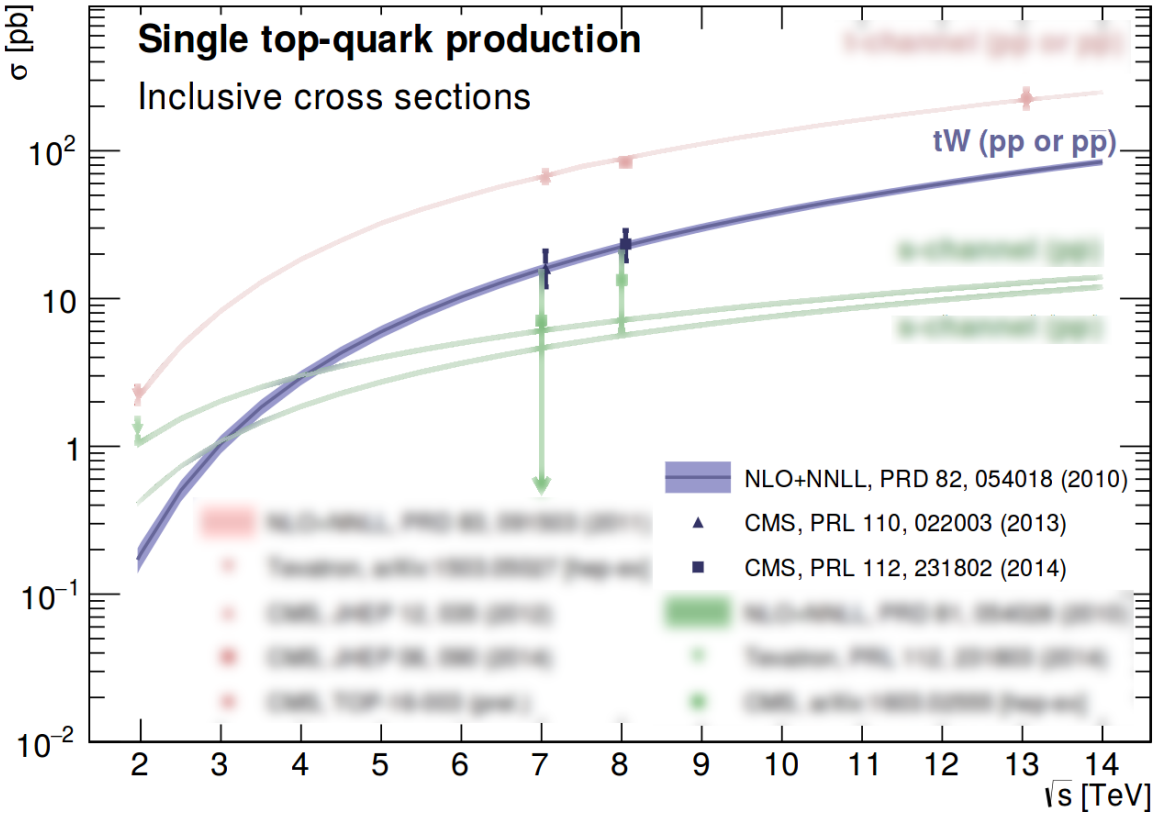
- σ_{tW} = 23.4 ± 5.4 pb
- Significance = 6.1 (5.4) σ obs. (exp.)
- Assuming $|f_{LV}|$=1 :

$$|V_{tb}| = \sqrt{\frac{\sigma_{tW}}{\sigma_{tW}^{th}}} = 1.03 \pm 0.12(exp.) \pm 0.04(th.)$$

tW channel

Observation @ 8 TeV :
PRL 112 (2014) 23180

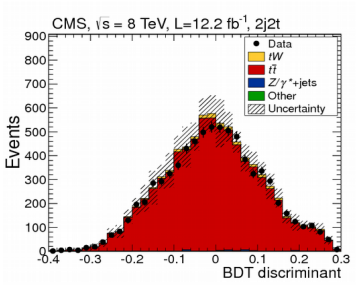


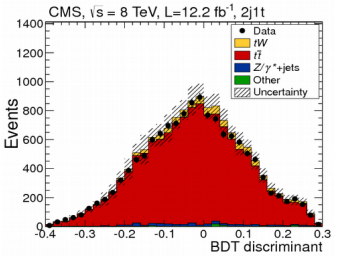


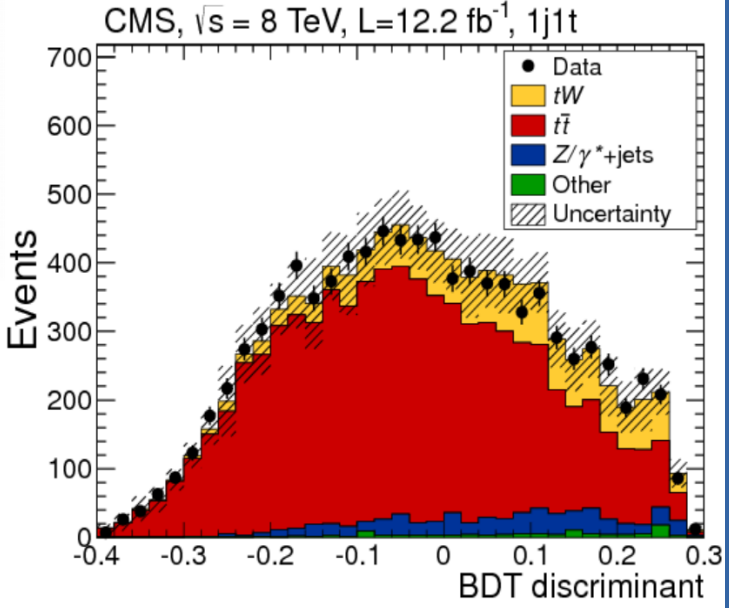
di-lepton final states are considered
Signal region : 1Jet-1bTagged
Fit BTD discriminant to extract σ_{tW}
Simultaneously in signal region, 2J1T and 2J2T to control $t\bar{t}$

σ_{tW} = 23.4 ± 5.4 pb

Significance = 6.1(5.4)σ







Combination with ATLAS (CMS-TOP-15-019)

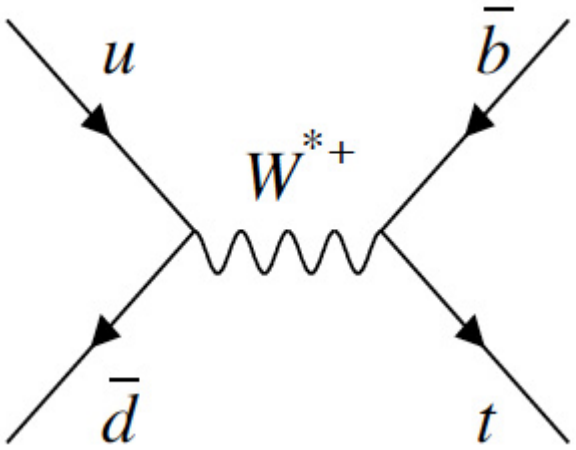
$$\sigma_{Wt} = 23.1 \pm 1.1\ (\text{stat.}) \pm 3.3\ (\text{syst.}) \pm 0.8\ (\text{lumi.})\ \text{pb}$$

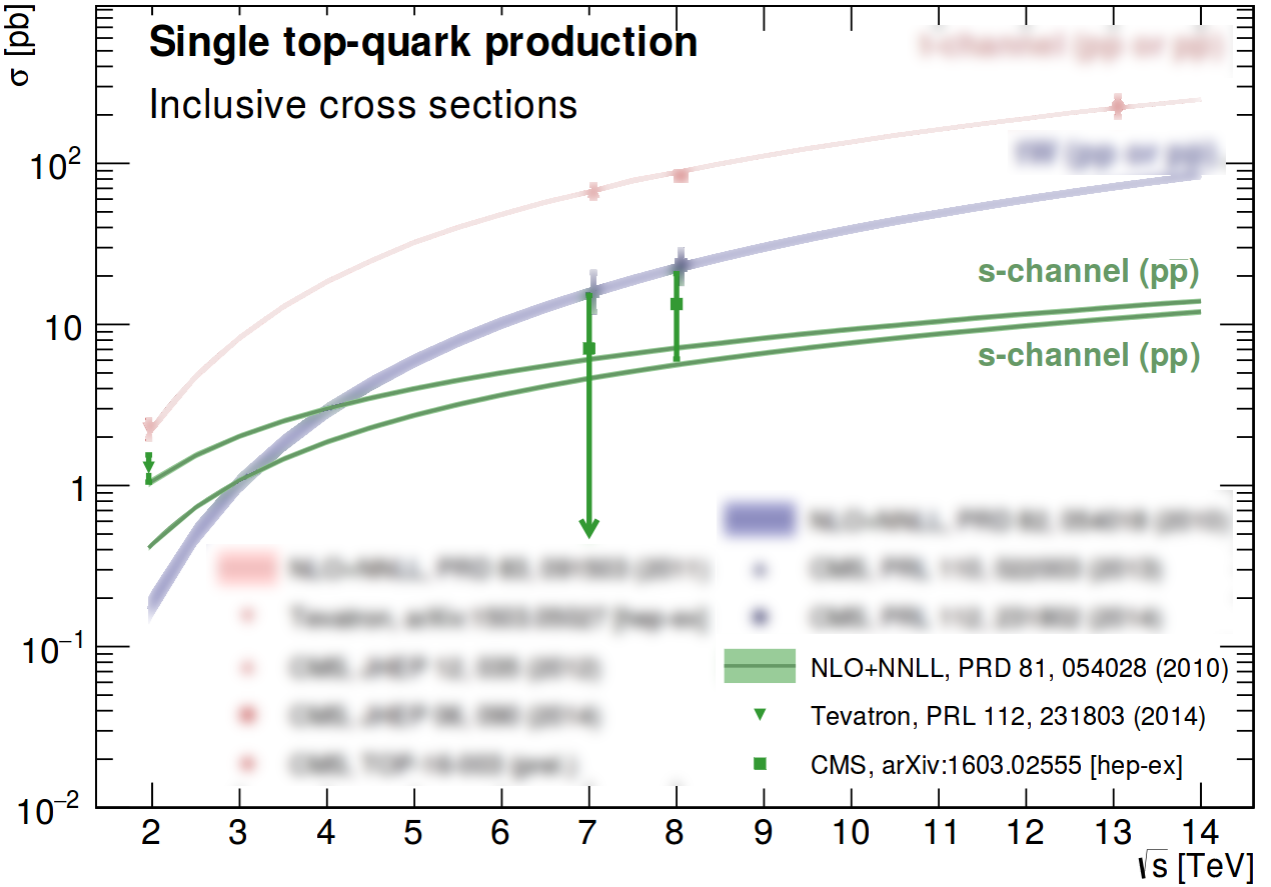
$$= 23.1 \pm 3.6\ \text{pb}$$

Source	Uncertainty (%)	Uncertainty (pb)
Data statistics	4.7	1.1
Simulation statistics	0.8	0.2
Luminosity	3.6	0.8
Theory modelling	11.8	2.7
Background normalization	2.2	0.5
Jets	6.2	1.4
Detector modelling	4.9	1.1
Total systematics (excl. lumi)	14.4	3.3
Total systematics (incl. lumi)	14.8	3.4
Total uncertainty	15.6	3.6

s-channel

arXiv:1603.02555
submitted to JHEP

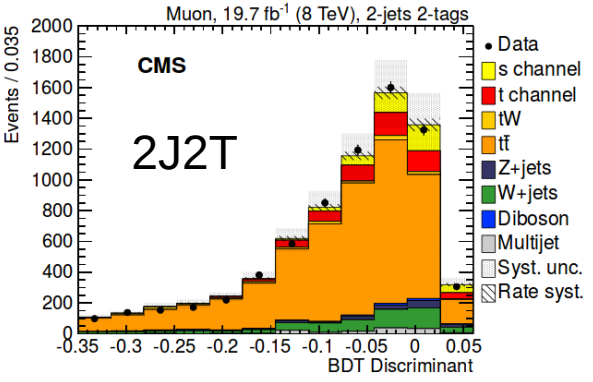


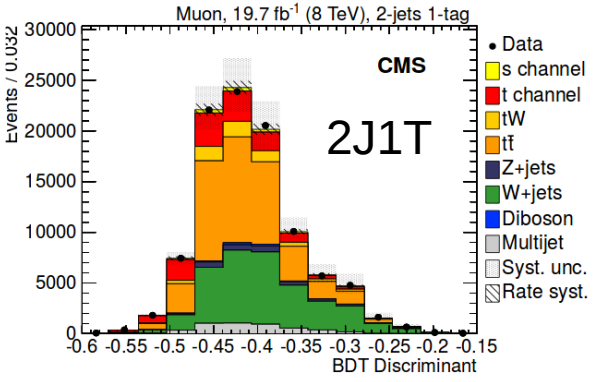


Leptonic decay of top :
- 1Lepton + 2b-jets

Measured at 7TeV and 8TeV
Main backgrounds : $t\bar{t}$, t-channel, Wbb
BDTs trained in 2J2T and 3J2T
- s-channel vs rest in 2J2T
- $t\bar{t}$ vs rest in 3J2T

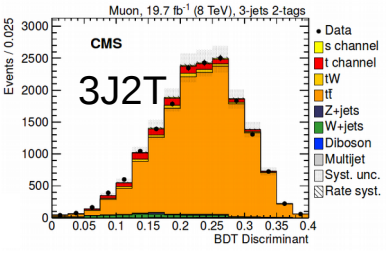
Likelihood fit to BDTs
Main systematic uncertainties :
- Theory modeling
- JES/JER





Channel	Observed UL	Expected UL—SM signal	Expected UL—no signal
μ, 7 TeV	31.4 pb	25.4 [19.0, 36.6] pb	20.2 pb
μ+e, 8 TeV	28.8 pb	20.5 [13.4, 26.7] pb	15.6 pb
7+8 TeV	4.7	3.1 [2.1, 4.0]	2.2

(Simultaneous fit)



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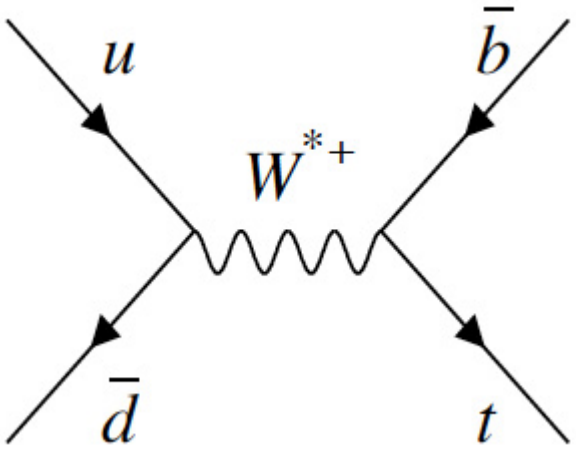

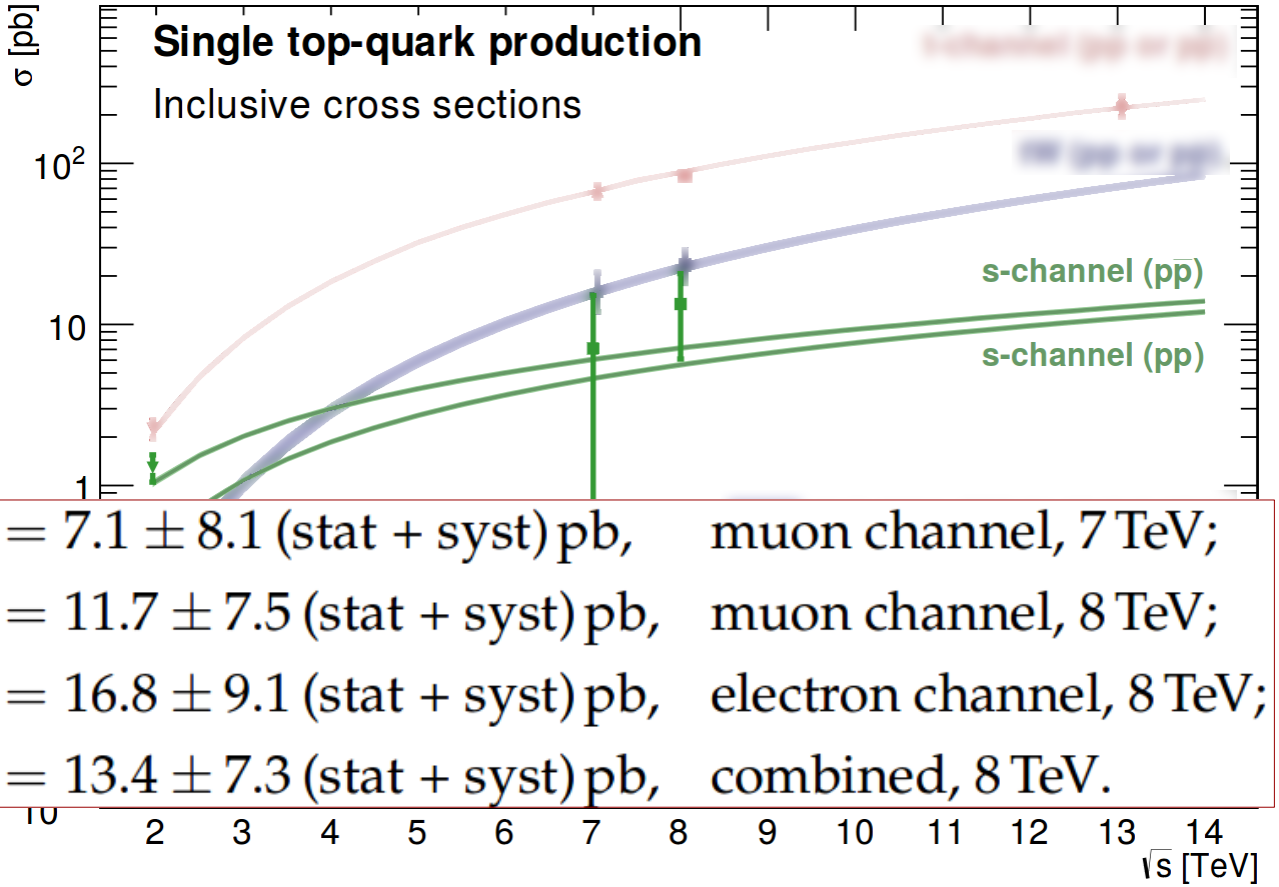

$$\sigma_s = 7.1 \pm 8.1\,(\text{stat} + \text{syst})\,\text{pb}, \quad \text{muon channel, 7 TeV;}$$
$$\sigma_s = 11.7 \pm 7.5\,(\text{stat} + \text{syst})\,\text{pb}, \quad \text{muon channel, 8 TeV;}$$
$$\sigma_s = 16.8 \pm 9.1\,(\text{stat} + \text{syst})\,\text{pb}, \quad \text{electron channel, 8 TeV;}$$
$$\sigma_s = 13.4 \pm 7.3\,(\text{stat} + \text{syst})\,\text{pb}, \quad \text{combined, 8 TeV.}$$

Leptonic decay of top :
- 1Lepton + 2b-jets

Measured at 7TeV and 8TeV
Main backgrounds : $t\bar{t}$, t-channel, Wbb
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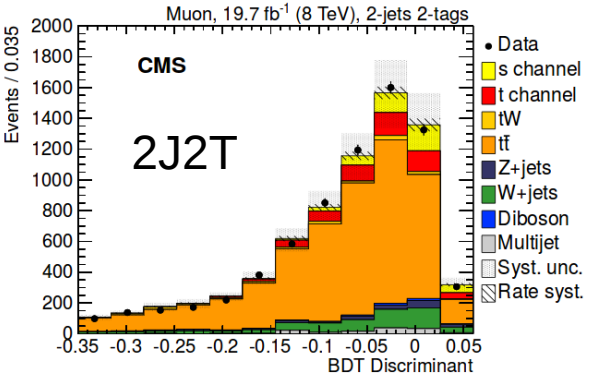

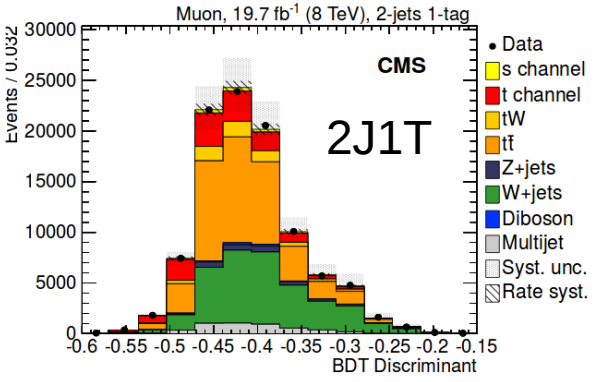

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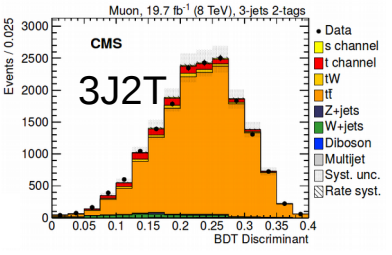
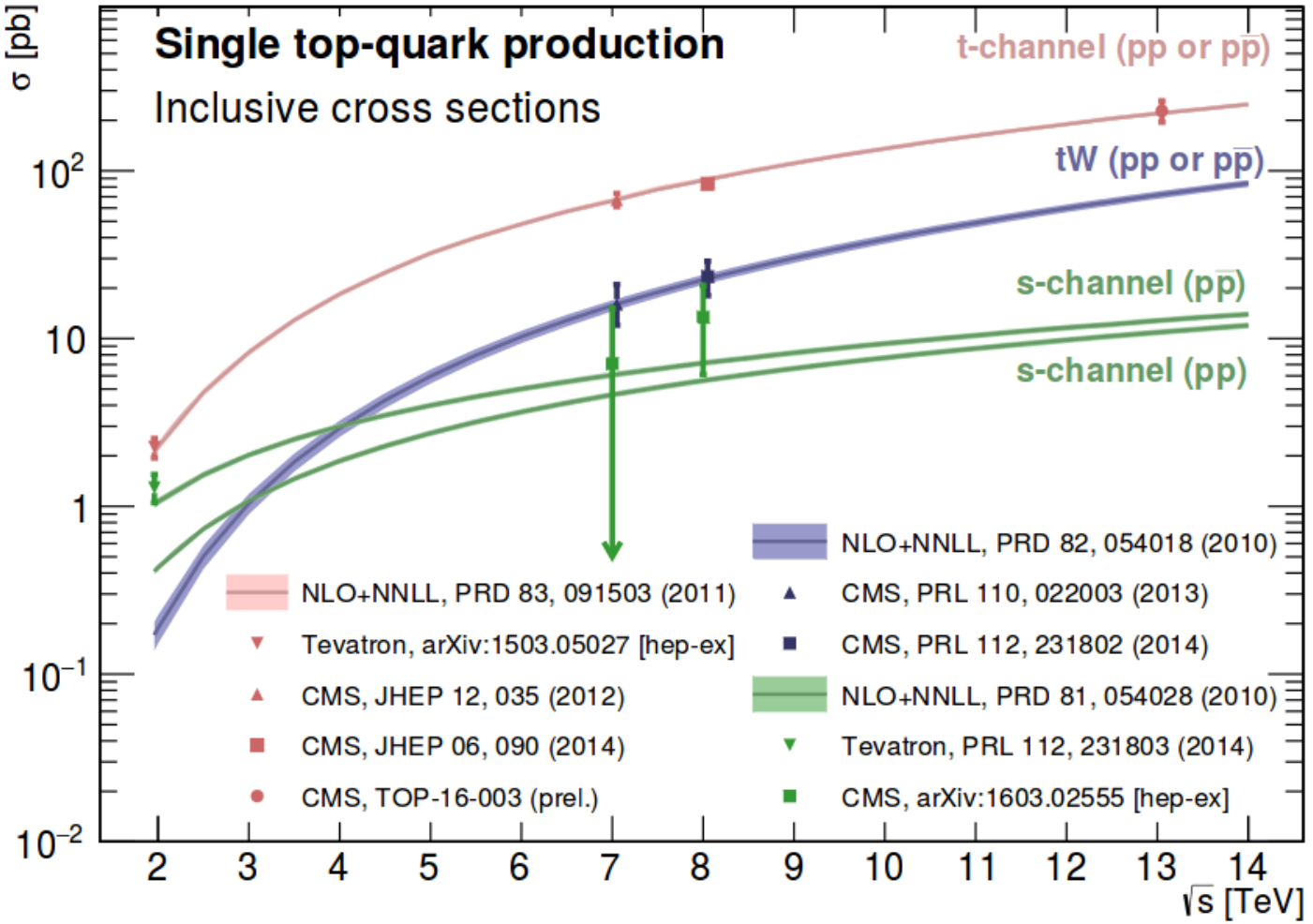


Summary

- CMS has measured the electroweak production of the Top quark in different production modes at 7,8 and 13 TeV



- Stay tuned for more precise measurements from analyzing 2016 data set.

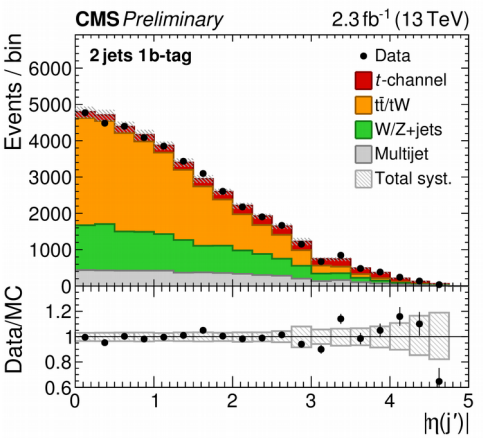
Backup slides

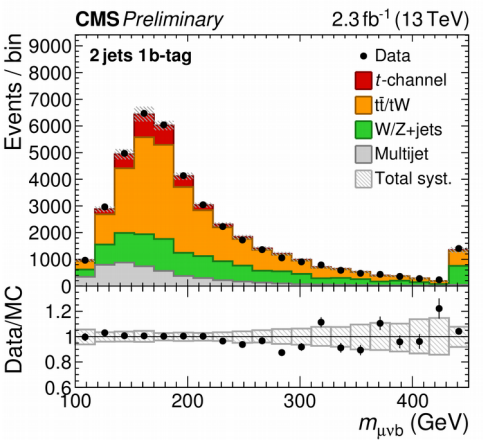
t-channel systematics

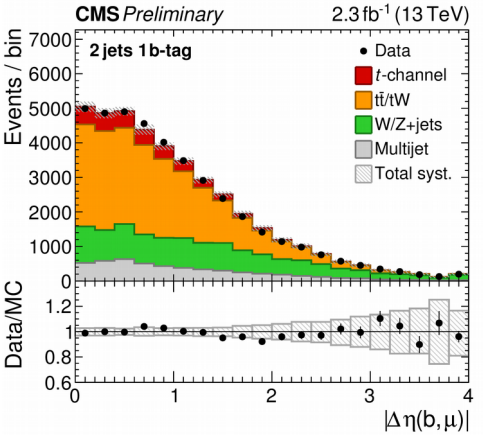
uncertainty source	$\Delta\sigma_{t-\text{ch.},t+\bar{t}}/\sigma^{\text{obs}}_{t-\text{ch.},t+\bar{t}}$	$\Delta\sigma_{t-\text{ch.},t}/\sigma^{\text{obs}}_{t-\text{ch.},t}$	$\Delta\sigma_{t-\text{ch.},\bar{t}}/\sigma^{\text{obs}}_{t-\text{ch.},\bar{t}}$
uncertainty of the fit (stat. + prof. unc.)	±6.8%	±7.4%	±11.9%
statistical uncertainty	±4.0%	±4.7%	±7.6%
profiled uncertainties	±5.5%	±5.7%	±9.2%
MC statistics	±2.8%	±3.4%	±4.0%
pileup	-0.2/+0.1%	-0.5/+0.4%	-0.1/+0.7%
experimental uncertainty	-6.2/+6.2%	-6.7/+6.7%	-10.0/+10.0%
Signal modeling	±7.9%	±10.1%	±8.2%
$t\bar{t}$ modeling	±4.3%	±3.9%	±4.6%
W+jets modeling	-2.1/+1.7%	-1.6/+1.1%	-2.8/+2.3%
Q^2 scale t-channel	-5.7/+7.0%	-7.1/+5.1%	-6.1/+6.9%
Q^2 scale $t\bar{t}$	-2.7/+4.1%	-2.5/+4.0%	-3.9/+3.4%
Q^2 scale tW	-0.3/+0.5%	-0.4/+0.3%	-1.1/+0.4%
Q^2 scale W+jets	-2.7/+3.0%	-2.5/+4.2%	-5/+2.4%
PDF uncertainty	-3.0/+2.6%	-3.1/+3.2%	-3.7/+4.2%
top p_{T} modeling	±0.1%	±0.1%	±0.2%
total theory uncertainties	-12.1/+12.6	-13.8/+13.6	-13.5/+13.4%
luminosity	±2.7%	±2.7%	±2.7%
total uncertainty	-14.5/+14.8%	-16.3/+16.1%	-18.6/+18.6%

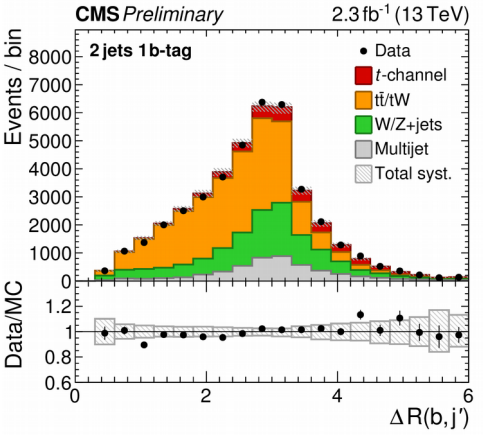
uncertainty source	$\Delta\sigma_{t-\text{ch.},t+\bar{t}}/\sigma^{\text{obs}}_{t-\text{ch.},t+\bar{t}}$	$\Delta\sigma_{t-\text{ch.},t}/\sigma^{\text{obs}}_{t-\text{ch.},t}$	$\Delta\sigma_{t-\text{ch.},\bar{t}}/\sigma^{\text{obs}}_{t-\text{ch.},\bar{t}}$
JES	±4.9%	±5.6%	±3.7%
JER	±0.7%	±0.2%	±1.5%
b-tagging efficiency	±2.3%	±2.1%	±1.6%
mis-tagging efficiency	±0.8%	±1.2%	±0.4%
lepton reconstruction/trigger	±2.5%	±2.0%	±2.9%

Differential measurement input variables to BDT

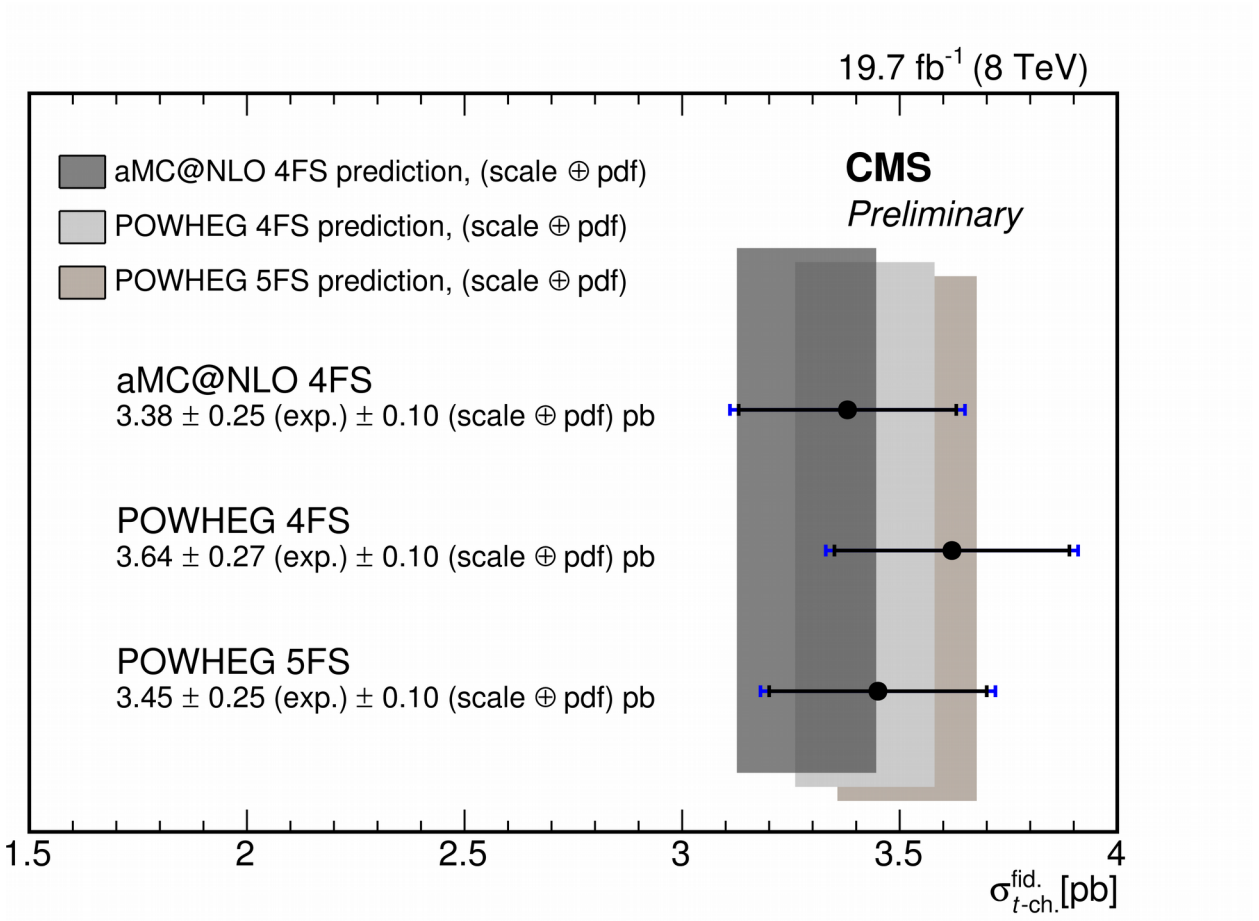








Fiducial : More Comparisons



tW channel systematics

Systematic uncertainty	$\Delta\sigma$ (pb)	$\Delta\sigma/\sigma$	Notes
ME/PS matching thresholds	3.3	14%	Matching threshold $2\times$ and $1/2\times$ nominal 20 GeV value in $t\bar{t}$ simulation
Renormalization/factorization scale	2.9	12%	Scale value $2\times$ and $1/2\times$ 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%	

s-channel systematics

Source	Uncertainty (%)				
	μ, 7 TeV	μ, 8 TeV	e, 8 TeV	μ + e, 8 TeV	7+8 TeV
Statistical	34	15	14	10	11
$t\bar{t}$, single top quark rate	29	15	14	12	14
W/Z+jets, diboson rate	23	11	13	12	12
Multijet rate	9	3	5	2	2
Lepton efficiency	14	1	2	1	3
Hadronic trigger	5	—	—	—	1
Luminosity	10	5	6	4	6
JER & JES	66	39	29	34	18
b tagging & mistag	34	15	14	14	16
Pileup	6	11	7	9	7
Unclustered $\not\!\!E_T$	5	8	2	6	5
μ_R, μ_F scales	54	34	31	30	28
Matching thresholds	43	11	12	7	17
PDF	12	8	7	7	9
Top quark p_T reweighting	3	5	7	6	6
Total uncertainty	115	64	54	55	47