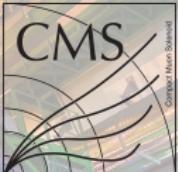




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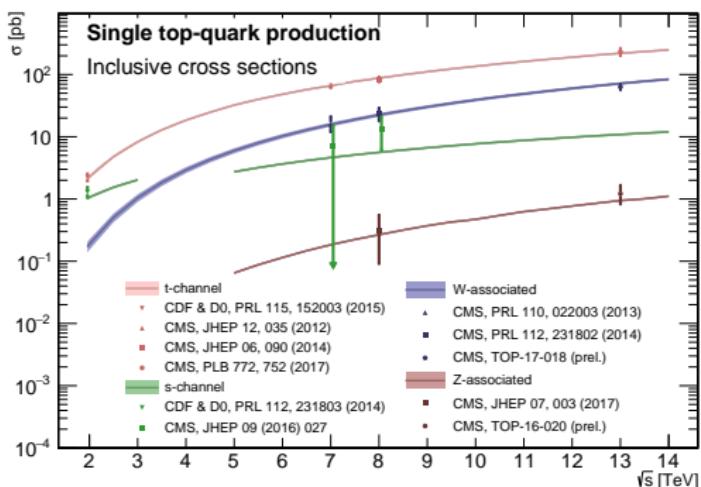
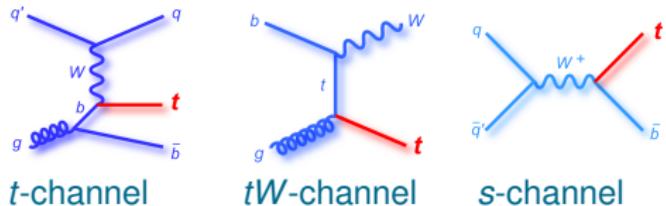
SERGIO SÁNCHEZ CRUZ

TQP@PF 2018, Fermilab (US)

SINGLE TOP QUARK CROSS SECTIONS AT CMS

SINGLE TOP PHYSICS

- ▶ Production modes at LHC:
 - ▶ t -channel
 - ▶ W associated (tW -channel)
 - ▶ s -channel
- ▶ Production through electroweak interactions
 - ▶ Sensitive to the V_{tb} matrix element
 - ▶ Study of the Wtb coupling
- ▶ Sensitive to PDFs
- ▶ Sensitive to new physics models and background for precision $t\bar{t}$ physics
- ▶ I will focus in the latest released result on each channel



Channel and dataset

- ▶ Measurement performed in the single μ channel
- ▶ Using the 2015 dataset (2.2 fb^{-1})

Lepton selection

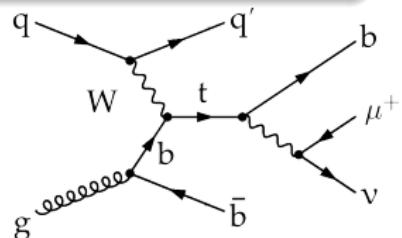
- ▶ Isolated muon ($p_T > 22 \text{ GeV}$)

Jet selection

- ▶ Using jets with $p_T > 40 \text{ GeV}$, $|\eta| < 4.7$
- ▶ b -tags: MVA based on secondary vertices ($\epsilon_b \approx 45\%$, $\epsilon_{fake} \approx 0.1\%$)

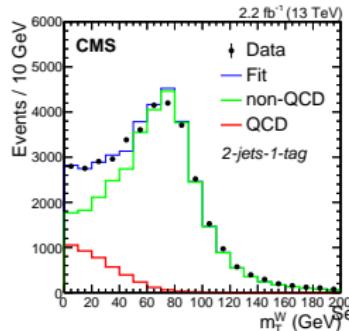
Event selection

- ▶ $m_T(W) > 50 \text{ GeV}$
- ▶ Measurement regions employed:
2j1b (single top), 3j1b, 3j2b ($t\bar{t}$),
2j0b (W+jets)



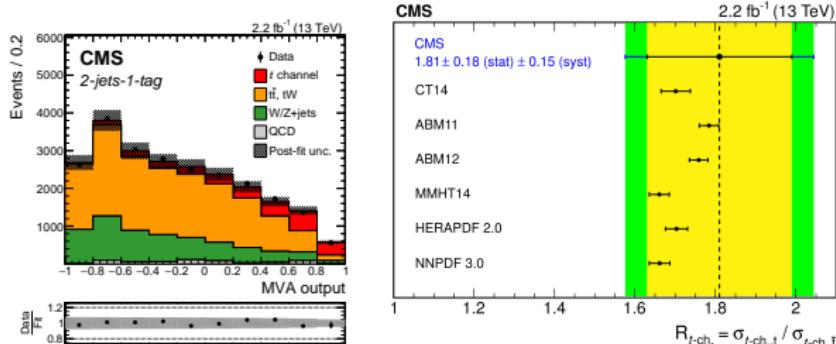
Background estimation

- ▶ $t\bar{t} + tW \Rightarrow \text{MC simulations}$
- ▶ $W+\text{jets} \Rightarrow \text{MC simulations}$
- ▶ QCD normalization determined in a data-driven way



t -CHANNEL

- ▶ Signal is extracted from a likelihood fit to a ANN distribution
- ▶ Fit performed simultaneously in categories 2j1b, 3j1b and 3j2b \otimes charge of the muon
- ▶ Free parameters of the fit: μ_{t-ch} , R_{t-ch}



- ▶ Result compatible with SM expectations

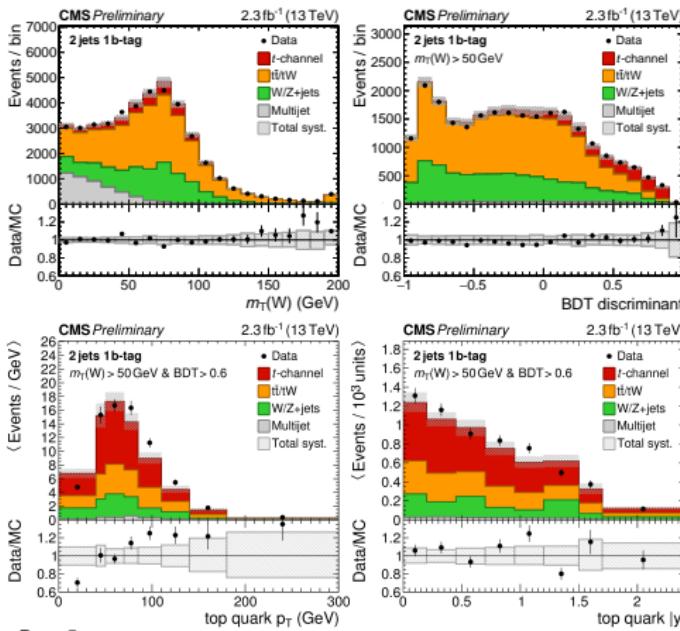
$$\begin{aligned}\sigma_{t-ch.} &= 238 \pm 5\% \text{ (stat.)} \pm 5\% \text{ (exp.)} \pm 11\% \text{ (theo.)} \pm 2\% \text{ (lumi.) pb} \\ &= 238 \pm 13\% \text{ pb} \quad [\sigma^{\text{SM}} = 217^{+9}_{-8} \text{ pb}]\end{aligned}$$

- ▶ CKM element V_{tb} assuming $|V_{tb}| \gg |V_{td}|, |V_{ts}|$

$$|f_{LV} V_{tb}| = 1.05 \pm 0.07 \text{ (exp.)} \pm 0.02 \text{ (theo.)}$$

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- ▶ Identical event selection to the inclusive result
- ▶ Signal is extracted through a ML fit to each of the bins of top quark p_T and rapidity
- ▶ BDT instead of ANN is used



In situ determination of the QCD background:

- ▶ Shape extracted from antiisolated μ data sample
- ▶ Fit performed to shape of $m_T(W)$ for events $m_T(W) < 50$ GeV and BDT for events with $m_T(W) > 50$ GeV

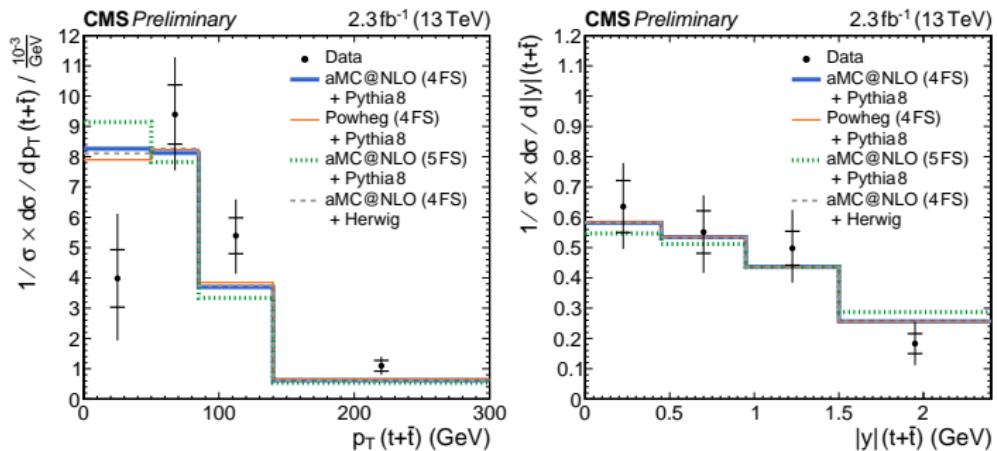
Validation of modeling in signal-enhanced region

- ▶ Models predict softer p_T spectrum than what is observed in data

t -CHANNEL (DIFFERENTIAL)

CMS-PAS-TOP-16-004

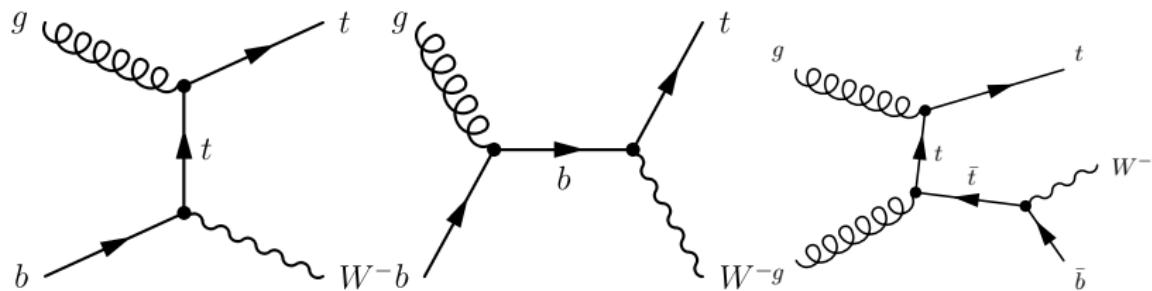
- Results unfolded to parton level:



- Uncertainties: data statistics (10%-25%), μ_R/μ_F scales (10-15%), m_t (10%-20%) and jet energy corrections (10%-15%)
- First top-quark p_T bin has lower signal acceptance and is more affected by systematic uncertainties
- Data is described by theoretical predictions

tW -CHANNEL

- ▶ Represents $\sim 25\%$ of the total single top production at LHC
- ▶ It is an excellent probe of the V_{tb} matrix element
- ▶ It is the main background in $t\bar{t}$ precision measurements and also a potential background in BSM searches
- ▶ Its production interferes with $t\bar{t}$ production at NLO
 - ▶ Two configurations to subtract overlapping diagrams: diagram subtraction and removal



tW -CHANNEL AT 13 TeV

Channel and dataset

- ▶ 13 TeV analysis targets dileptonic channel
 - ▶ $e\mu$ channel is more background free
- ▶ Using the 2016 dataset (35.9 fb^{-1})

Event selection

Lepton selection

- ▶ Isolated electron and muon ($p_T > 25(20) \text{ GeV}$)

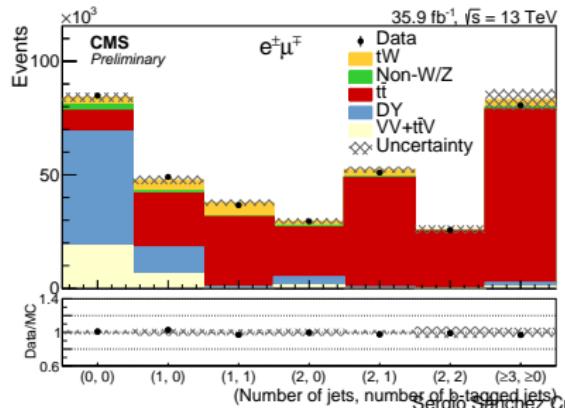
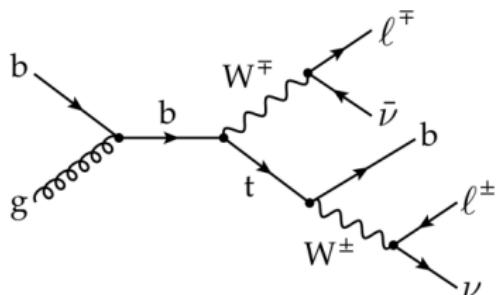
Jet selection

- ▶ Using jets with $p_T > 30 \text{ GeV}$, $|\eta| < 2.4$
- ▶ b -tags: MVA based on secondary vertices ($\epsilon_b \approx 70\%$, $\epsilon_{fake} \approx 1\%$)
- ▶ “Additional” loose jets $20 < p_T < 30 \text{ GeV}$

CMS-PAS-TOP-17-018

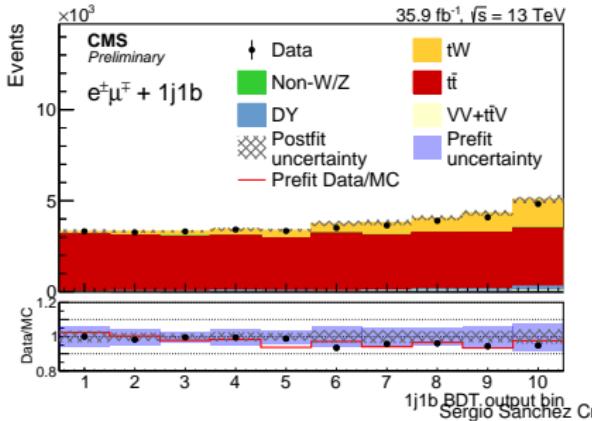
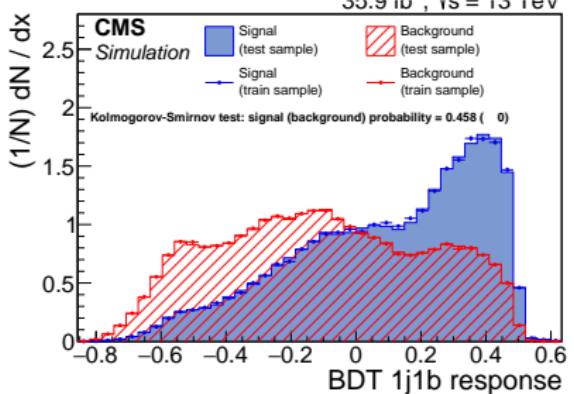
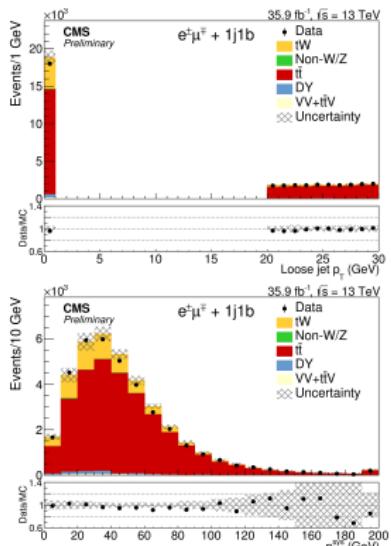
Classes

- ▶ Three regions defined: 1j1b, 2j1b, 2j2b



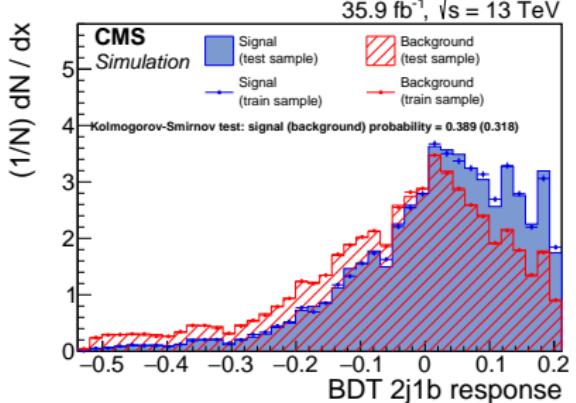
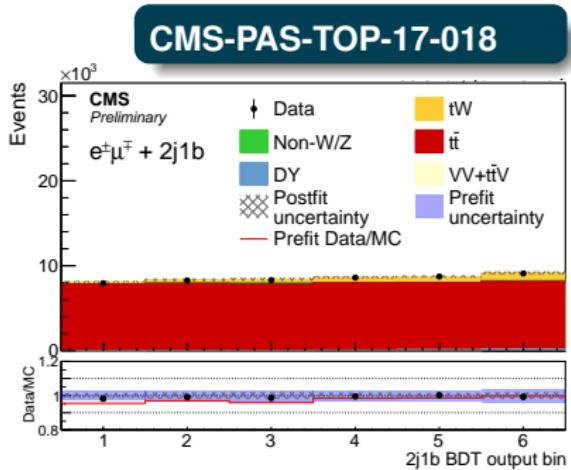
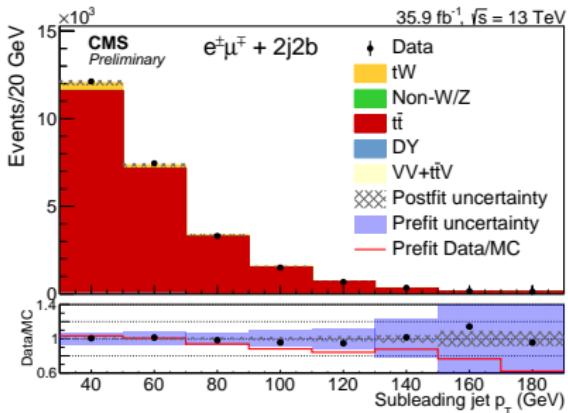
tW-CHANNEL

- ▶ Overwhelming $t\bar{t}$ contribution in every measurement region
- ▶ BDT discriminator in the 1j1b region exploits topological differences
 - ▶ Lost jet in $t\bar{t}$ events
 - ▶ Overall higher transverse boost in $t\bar{t}$ events



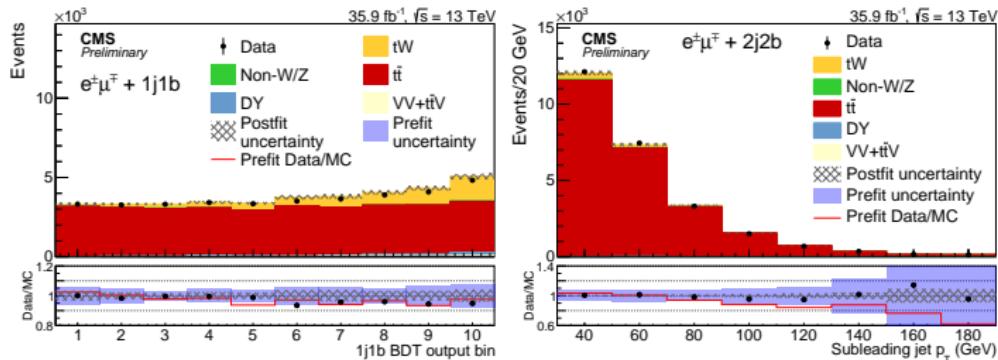
tW-CHANNEL

- ▶ Further exploit the presence of signal in the 2j1b region with a dedicated BDT
 - ▶ Input variables are angular correlations among jets and leptons
- ▶ We additionally use the **subleading jet p_T distribution in the 2j2b region** to further constrain systematic uncertainties



RESULTS

- ▶ Signal strength determined from a ML fit to BDT distribution in the 1j1b and 2j1b regions and subleading jet p_T in 2j2b
- ▶ Result consistent with SM expectations within the $\mathcal{O}(10\%)$ uncertainty



- ▶ Experimental uncertainties: pile-up (3.3%), jet energy scale (3.2%), electron/muon efficiencies (3.3%/3.1%), trigger efficiencies (2.7%), ... \Rightarrow mostly due to their effect in $t\bar{t}$
- ▶ Theoretical uncertainties: μ_R/μ_F scale (2.5%), color reconnection (2.0%), ME/PS matching (1.8%), ...

$$\sigma_{tW} = 63.1 \pm 3\% \text{ (stat.)} \pm 9\% \text{ (syst)}$$

$$\pm 3\% \text{ (lumi) pb}$$

$$\sigma_{tW} = 63.1 \pm 6.6 \text{ pb}$$

$$\left[\sigma_{tW}^{\text{SM}} = 72 \pm 2 \text{ (scale)} \pm 3 \text{ (PDF) pb} \right]$$

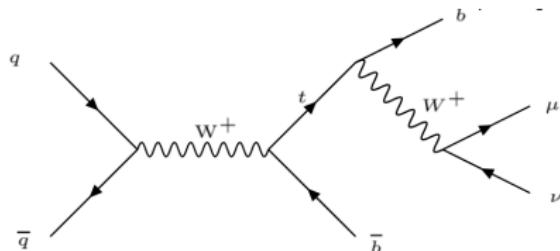
s-CHANNEL

- ▶ Search for s-channel at 7 and 8 TeV
- ▶ Challenging channel at LHC as it is suppressed in pp collisions
- ▶ Also a probe of the V_{tb} matrix element

8 TeV 19.7 fb^{-1}

- ▶ Isolated electron ($p_T > 30$) or muon ($p_T > 26$)
- ▶ Jets with $p_T > 40 \text{ GeV}$, $|\eta| < 4.7$
- ▶ Zero jets with $20 < p_T < 40 \text{ GeV}$ in signal region
- ▶ b -tagging: MVA based on secondary vertices $\epsilon_{fake} \approx 0.1\%$

JHEP 09 (2016) 027



7 TeV 5.1 fb^{-1}

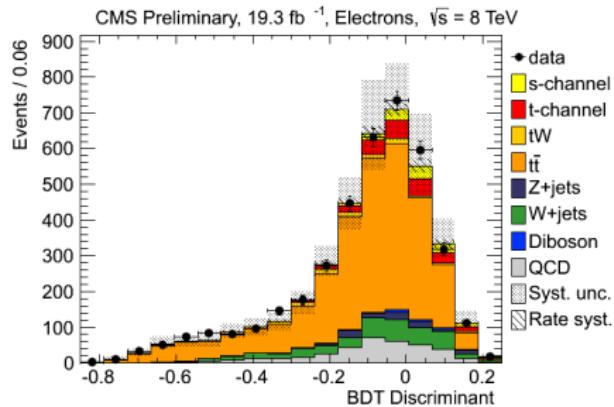
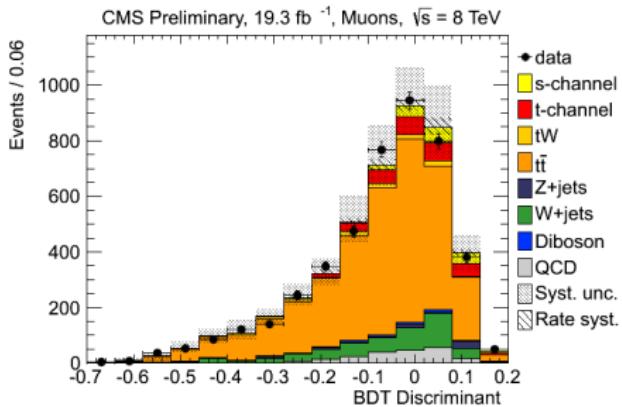
- ▶ Isolated muon ($p_T > 20$)
- ▶ Jets with $p_T > 40 \text{ GeV}$, $|\eta| < 4.7$
- ▶ b -tagging: MVA based on secondary vertices $\epsilon_{fake} \approx 0.1\%$

Measurement regions

- ▶ 2j2b: signal region
- ▶ 3j2b: $t\bar{t}$ control region
- ▶ 2j1b: t -channel and $W+\text{jets}$ control region
- ▶ 2j0b: $W+\text{jets}$ control region

S-CHANNEL

- ▶ Signal is extracted by performing a ML fit to BDT distributions in 2j2t, 2j1t and 3j2t
- ▶ Main uncertainties: μ_R/μ_F scales (28%), JES/JER (18%), b -tagging (16%)

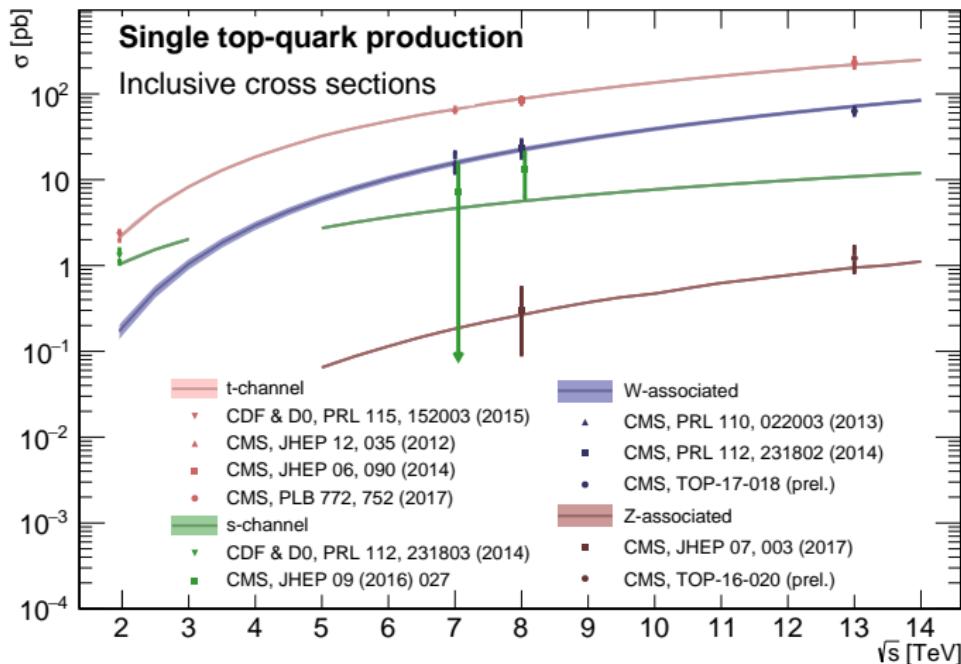


	Exp. significance	Obs. significance
7 TeV (muon)	0.5	0.9
8 TeV (el + mu)	0.8	2.3
Combined 7 + 8 TeV	1.1	2.5

	Exp. upper limit	Obs. upper limit
7 TeV (muon)	25.4 [19.0, 36.6] pb	31.4 pb
8 TeV (el + mu)	20.5 [13.4, 26.7] pb	28.8 pb
Combined 7 + 8 TeV (on μ)	3.1 [2.1, 4.0]	4.7

CONCLUSIONS

- ▶ Overview of the latest CMS results on single top production



- ▶ Keep tuned for interesting and more precise results!

Back-up

t -CHANNEL SYSTEMATICS

Uncertainty source	$\Delta\sigma_{t\text{-ch}, t+\bar{t}}/\sigma_{t\text{-ch}, t+\bar{t}}^{\text{obs}}$	$\Delta\sigma_{t\text{-ch}, t}/\sigma_{t\text{-ch}, t}^{\text{obs}}$	$\Delta\sigma_{t\text{-ch}, \bar{t}}/\sigma_{t\text{-ch}, \bar{t}}^{\text{obs}}$	$\Delta R_{t\text{-ch}}/R_{t\text{-ch}}$
Statistical uncert.	$\pm 5.5\%$	$\pm 5.3\%$	$\pm 11.5\%$	$\pm 9.7\%$
Profiled exp. uncert.	$\pm 5.2\%$	$\pm 5.7\%$	$\pm 4.9\%$	$\pm 3.3\%$
Total fit uncert.	$\pm 7.6\%$	$\pm 7.8\%$	$\pm 12.5\%$	$\pm 10.3\%$
Integrated luminosity	$\pm 2.3\%$	$\pm 2.3\%$	$\pm 2.3\%$	—
Signal modelling	$\pm 6.9\%$	$\pm 8.2\%$	$\pm 8.5\%$	$\pm 5.3\%$
$t\bar{t}$ modelling	$\pm 3.9\%$	$\pm 4.3\%$	$\pm 4.5\%$	$\pm 4.0\%$
W + jets modelling	$-1.8/+2.1\%$	$-1.6/+2.3\%$	$-2.5/+2.3\%$	$-1.7/+2.0\%$
μ_R/μ_F scale t -channel	$-4.6/+6.1\%$	$-5.7/+5.2\%$	$-7.2/+5.1\%$	$-0.7/+1.2\%$
μ_R/μ_F scale $t\bar{t}$	$-3.5/+2.9\%$	$-3.5/+4.1\%$	$-4.7/+3.1\%$	$-1.1/+1.0\%$
μ_R/μ_F scale tW	$-0.3/+0.5\%$	$-0.6/+0.8\%$	$-1.1/+0.7\%$	$-0.2/+0.1\%$
μ_R/μ_F scale W + jets	$-2.9/+3.7\%$	$-3.5/+3.0\%$	$-4.9/+3.8\%$	$-1.2/+0.9\%$
PDF uncert.	$-1.5/+1.9\%$	$-2.1/+1.6\%$	$-1.8/+2.1\%$	$-2.2/+2.5\%$
Top quark p_T modelling	$\pm 0.1\%$	$\pm 0.2\%$	$\pm 0.2\%$	$\pm 0.1\%$
Total theory uncert.	$-10.7/+11.1\%$	$-12.2/+12.1\%$	$-13.6/+12.9\%$	$\pm 7.5\%$
Total uncert.	$-13.4/+13.7\%$	$\pm 14.7\%$	$-18.7/+18.2\%$	$\pm 12.7\%$

t-CHANNEL EXPERIMENTAL SYSTEMATICS

Uncertainty source	$\Delta\sigma_{t\text{-ch},t+\bar{t}}/\sigma_{t\text{-ch},t+\bar{t}}^{\text{obs}}$	$\Delta\sigma_{t\text{-ch},t}/\sigma_{t\text{-ch},t}^{\text{obs}}$	$\Delta\sigma_{t\text{-ch},\bar{t}}/\sigma_{t\text{-ch},\bar{t}}^{\text{obs}}$	$\Delta R_{t\text{-ch}}/R_{t\text{-ch}}$
MC samples size	$\pm 3.4\%$	$\pm 4.1\%$	$\pm 3.8\%$	$\pm 3.2\%$
JES	$\pm 4.1\%$	$\pm 4.7\%$	$\pm 3.5\%$	$\pm 2.1\%$
JER	$\pm 1.7\%$	$\pm 1.2\%$	$\pm 2.4\%$	$\pm 0.6\%$
b tagging efficiency	$\pm 1.9\%$	$\pm 2.0\%$	$\pm 1.8\%$	$\pm 1.4\%$
Mistag probability	$\pm 0.9\%$	$\pm 0.6\%$	$\pm 0.8\%$	$\pm 0.5\%$
Muon reco./trigger	$\pm 2.0\%$	$\pm 2.3\%$	$\pm 1.9\%$	$\pm 1.8\%$

tW -CHANNEL SYSTEMATICS

Source	Uncertainty (%)
Trigger efficiencies	2.7
Muon efficiencies	3.1
Electron efficiencies	3.2
Jet energy scale	3.2
Jet energy resolution	1.8
b tagging efficiency	1.4
Mistagging rate	0.2
Pileup	3.3
$t\bar{t}$ μ_R and μ_F scale	2.5
tW μ_R and μ_F scale	0.9
Underlying event	0.4
ME/PS matching	1.8
Initial state radiation	0.8
Final state radiation	0.8
Color reconnection	2.0
PDF	1.5
DR-DS	1.3
VV normalization	0.4
Drell-Yan normalization	1.1
Non-W/Z leptons normalization	1.6
$t\bar{t}V$ normalization	0.1
MC statistics	1.6
Full phase space extrapolation	2.9
Total systematic (excluding integrated luminosity)	9.5
Integrated luminosity	3.3
Statistical	2.8
Total	10.5

S-CHANNEL SYSTEMATICS

Source	Uncertainty (%)				
	$\mu, 7 \text{ TeV}$	$\mu, 8 \text{ TeV}$	$e, 8 \text{ TeV}$	$\mu + e, 8 \text{ TeV}$	$7+8 \text{ TeV}$
Statistical	34	15	14	10	11
$t\bar{t}$, single top quark normalization	29	15	14	12	14
W/Z+jets, diboson normalization	23	11	13	12	12
Multijet normalization	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 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