Single Top Quark Production at CMS

Enrique Palencia Cortezón

(on behalf of the CMS Collaboration)

Universidad de Oviedo

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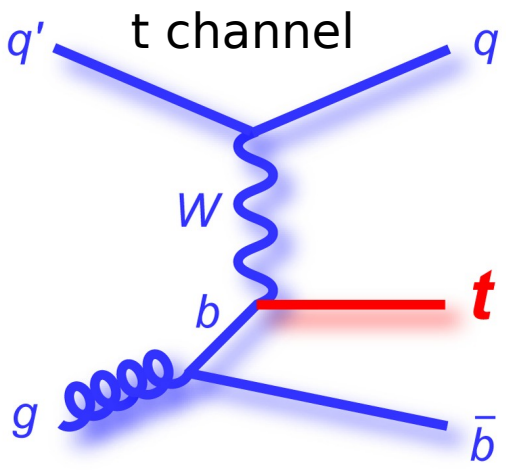
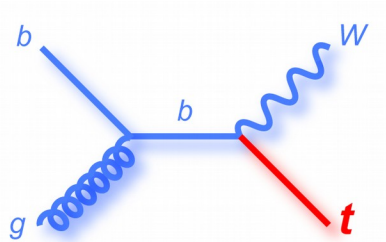
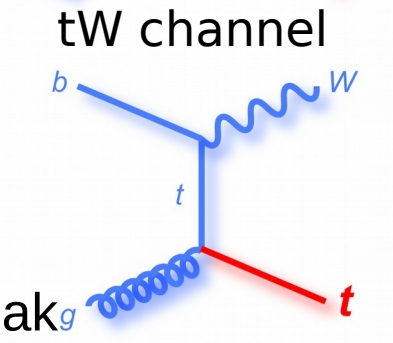
Universidad de Oviedo

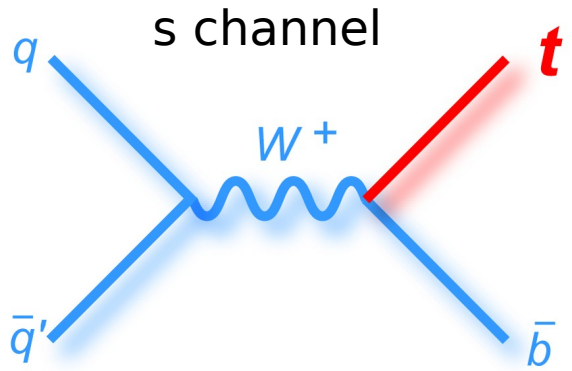
Single Top Quark Physics

- Single top quarks are produced through EW interactions. Three main modes:









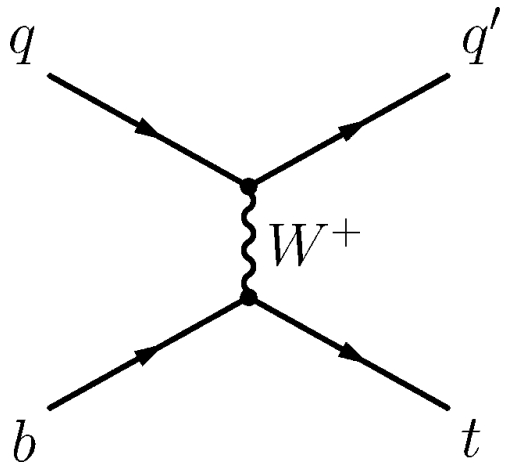
- Crucial insight into the electroweak processes of the SM

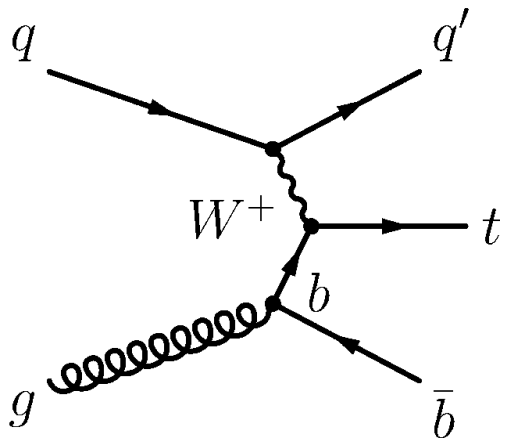
- Sensitive to
  - the V_{tb} matrix element. Study of the V_{tb} coupling
  - PDFs
  - new physics model (large couplings to exotic particles)

	σ (pb)		
CME	t-channel	tW	s-channel
7 TeV	63.9	15.7	4.3
8 TeV	84.7	22.2	5.6
13 TeV	217.0	71.2	11.4

- Background for precision tt physics and many BSM searches

t channel Production





- Represents ~73% of the total single top production at the LHC
  - Distinct signature: light quark recoiling against the top quark
  - Differential measurements are possible
- Can be used for a direct measurement of the Cabibbo–Kobayashi–Maskawa (CKM) matrix element V_{tb}

t channel @ 13 TeV (2.2 fb^{-1})

- Signature: 1 μ, 2 jets, 1 b tag, MET

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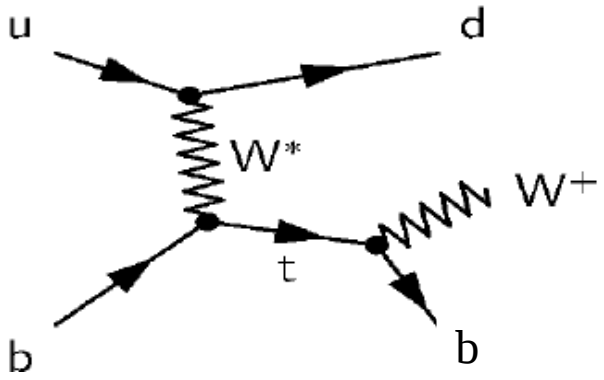
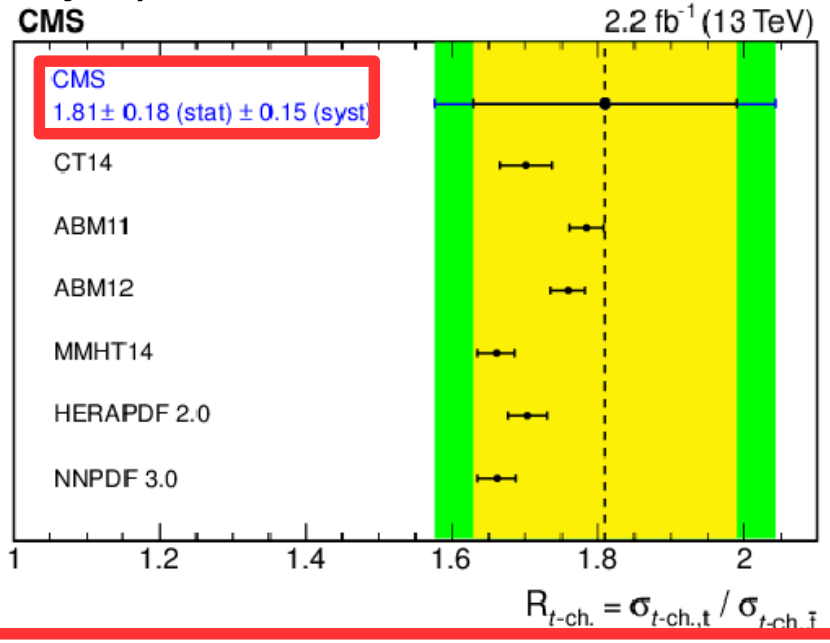
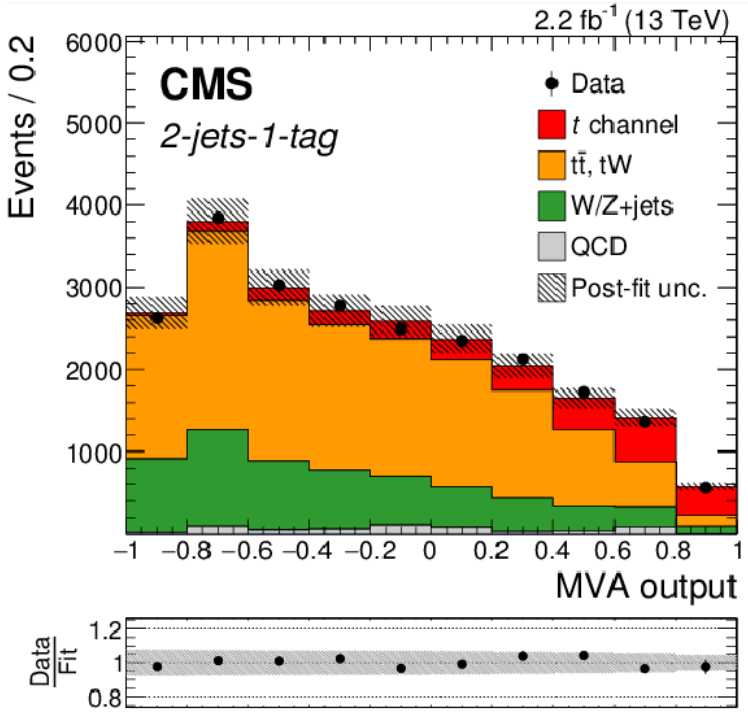


- Signal extraction: binned likelihood fit on the MVA output based on 11 kinematic variables
- Simultaneous fit to the signal region (2j1b) and the two tt bkg regions (3j1b, 3j2b)
  - t channel signal strength and $R_{t\text{-ch}} = \sigma_{top}/\sigma_{antitop}$ free parameters
- Main systematic
  - Signal modeling



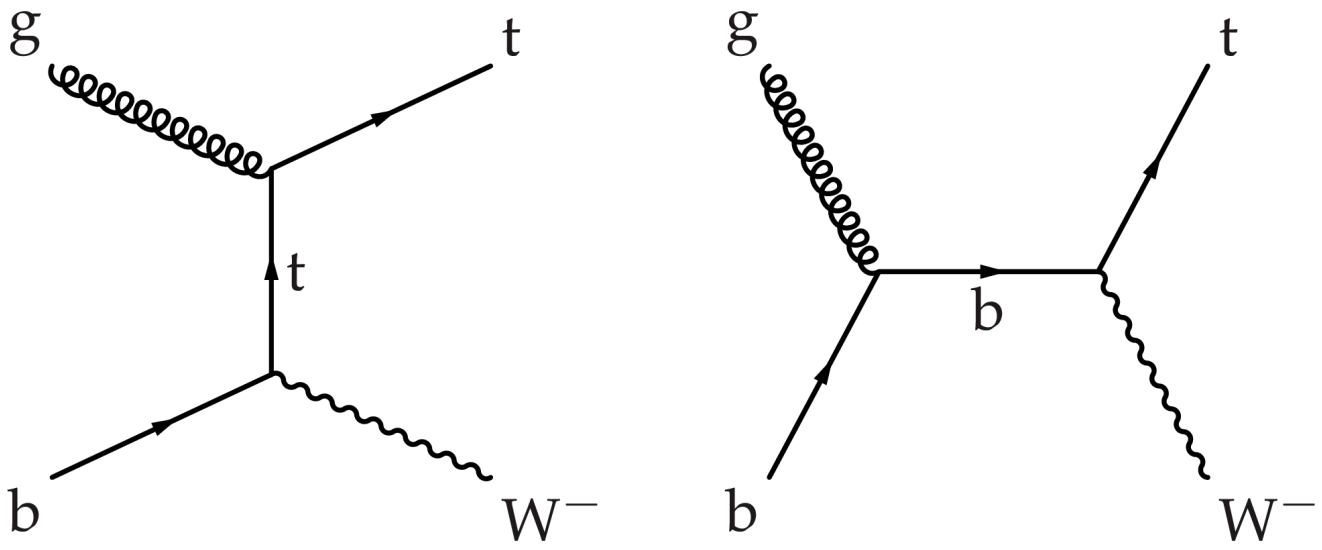


$$\sigma_{t\text{-ch.},t+\bar{t}} = 238 \pm 13\,(\text{stat}) \pm 12\,(\text{exp}) \pm 26\,(\text{theo}) \pm 5\,(\text{lumi})\ \text{pb}$$

$$\sigma^{\text{th}}_{t\text{-ch.},t+\bar{t}} = 217.0^{+6.6}_{-4.6}\,(\text{scale}) \pm 6.2\,(\text{PDF}+\alpha_S)\ \text{pb (NLO)}$$

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

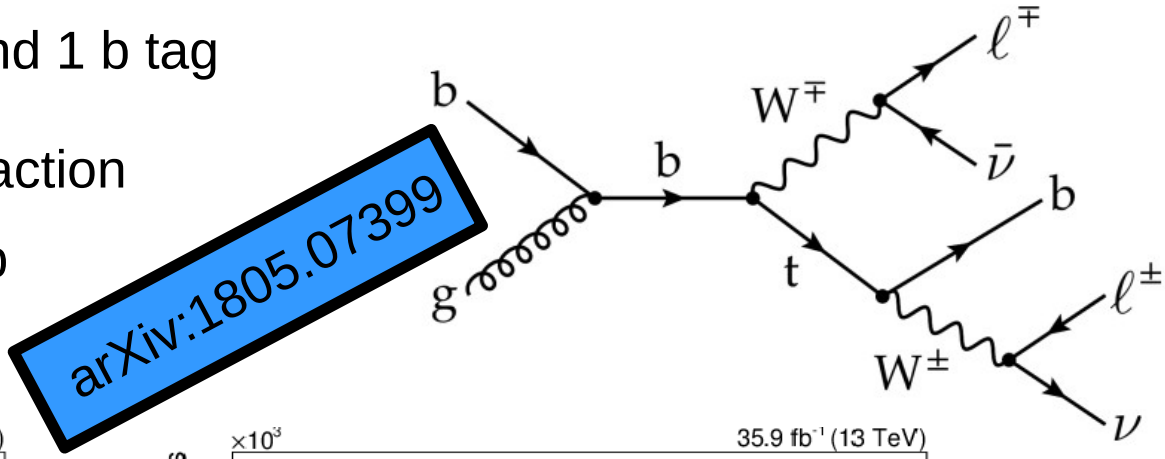
tW Production

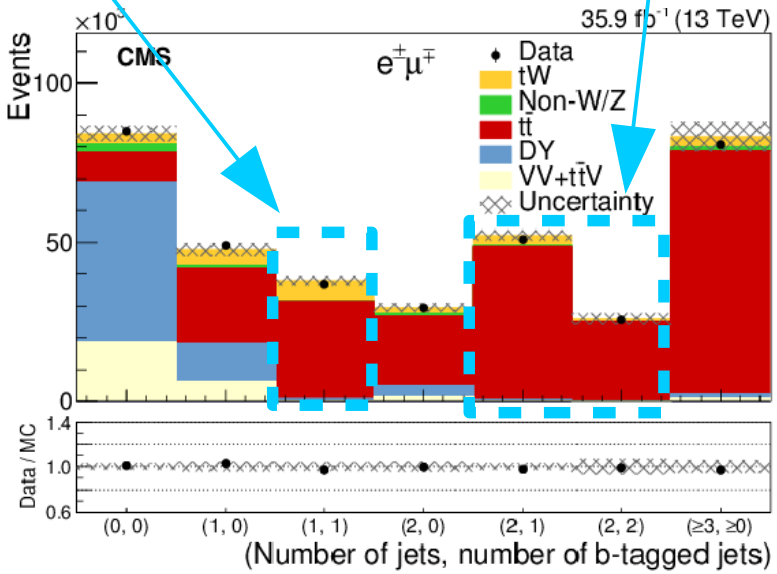


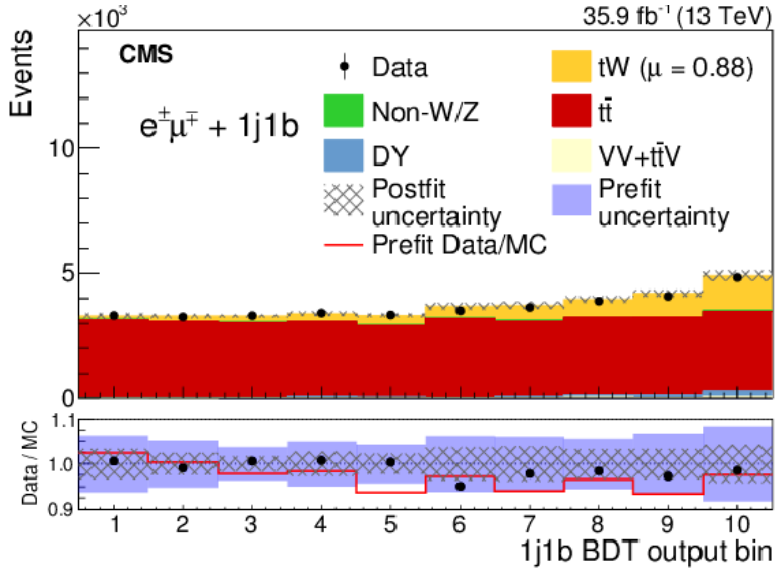
- Represents ~25% of the total single top production at the LHC
- Its production interferes with tt production at NLO (same final state)
  - Two configurations to subtract overlapping diagrams: diagram subtraction and diagram removal

tW channel @ 13 TeV (35.9 fb^{-1})

- Signature: 2 OS leptons (eμ), 1 jet and 1 b tag
- Three regions defined for signal extraction
  - 1j1b (main signal region), 2j1b, 2j2b
- Huge tt contribution in all the regions





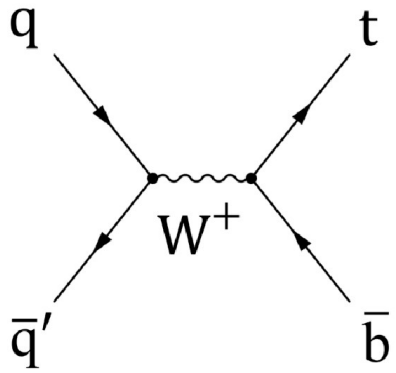


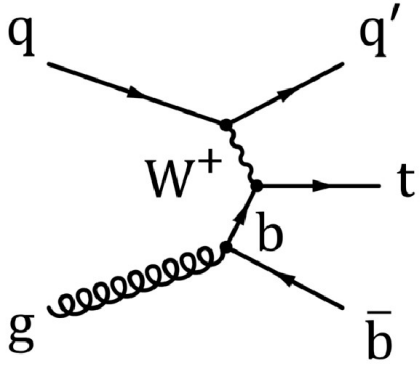
- Signal strength determined from a ML fit to BDT distribution in the 1j1b and 2j1b regions and subleading jet p_T in 2j2b
- Main uncertainties
  - JES, lepton identification, tt modeling

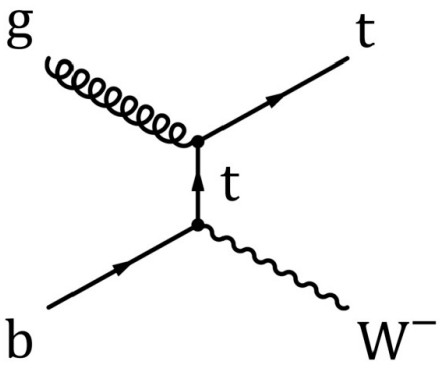
$$\sigma_{tW} = 63.1 \pm 1.8\ (\text{stat}) \pm 6.4\ (\text{syst}) \pm 2.1\ (\text{lumi})\ \text{pb}$$

σ_{tW}(NNLO) = 71.7 ± 1.8 (scale) ± 3.4 (PDF) pb

s channel Production







- Extremely challenging final state
  - Rare process: ~3% of the total single top production at the LHC
  - Grows much slower with CME than other top production modes (@13 TeV, S/B does not improve...)
- Sensitive to new physics (W', charged Higgs)

s channel @ 7 and 8 TeV (5.1 and 19.7 fb^{-1})

- Signature: 1 lepton, 2 jets, 2 b tags
- Binned likelihood fit on the BDT output in 3 different regions: 2j2b (signal), 3j2b (tt), 2j1b (t channel and W+jets)
- Observed significance (combination): 2.5σ
- Main systs: JES, generator, b-tagging

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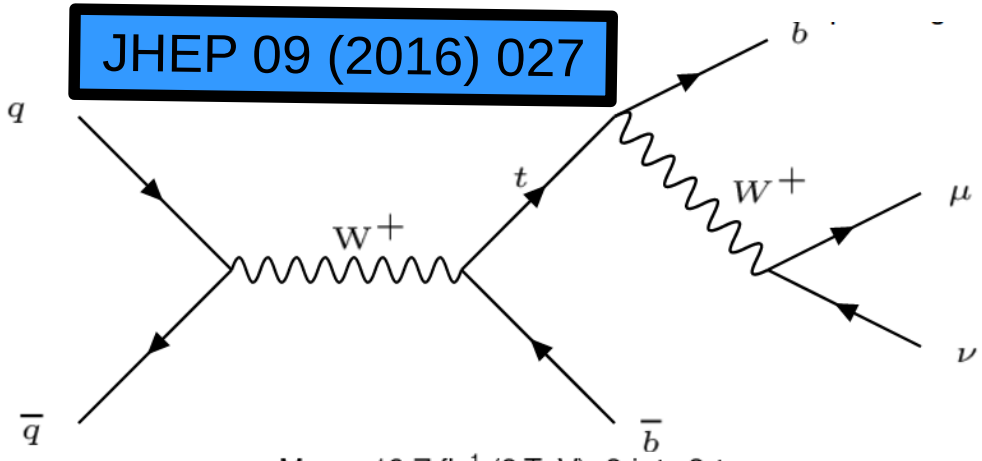
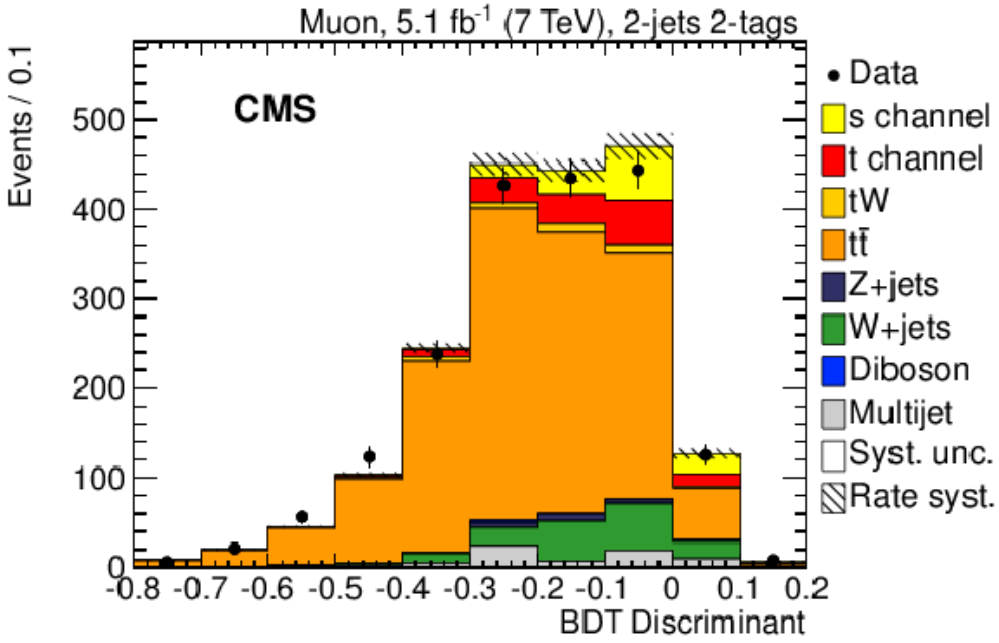
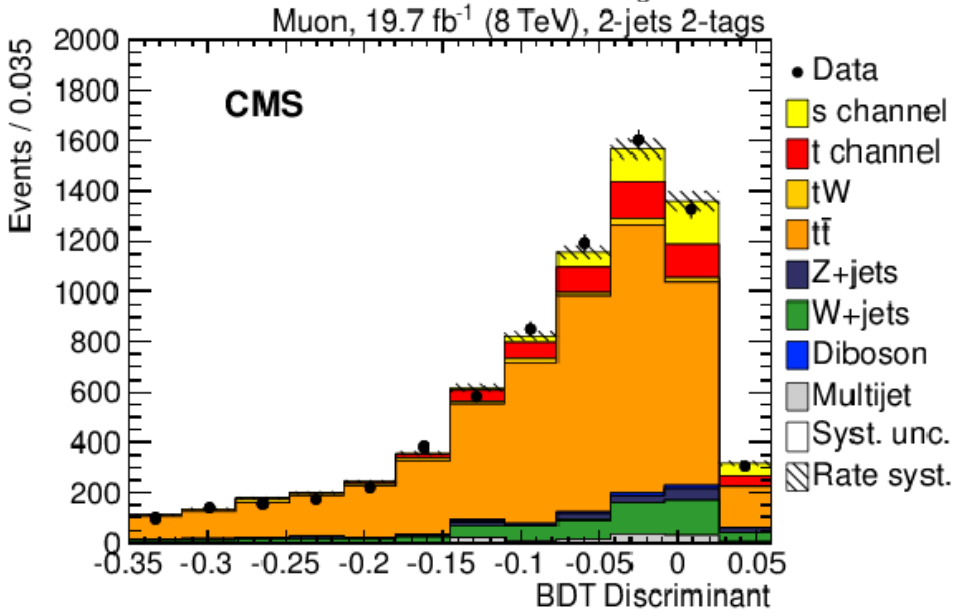






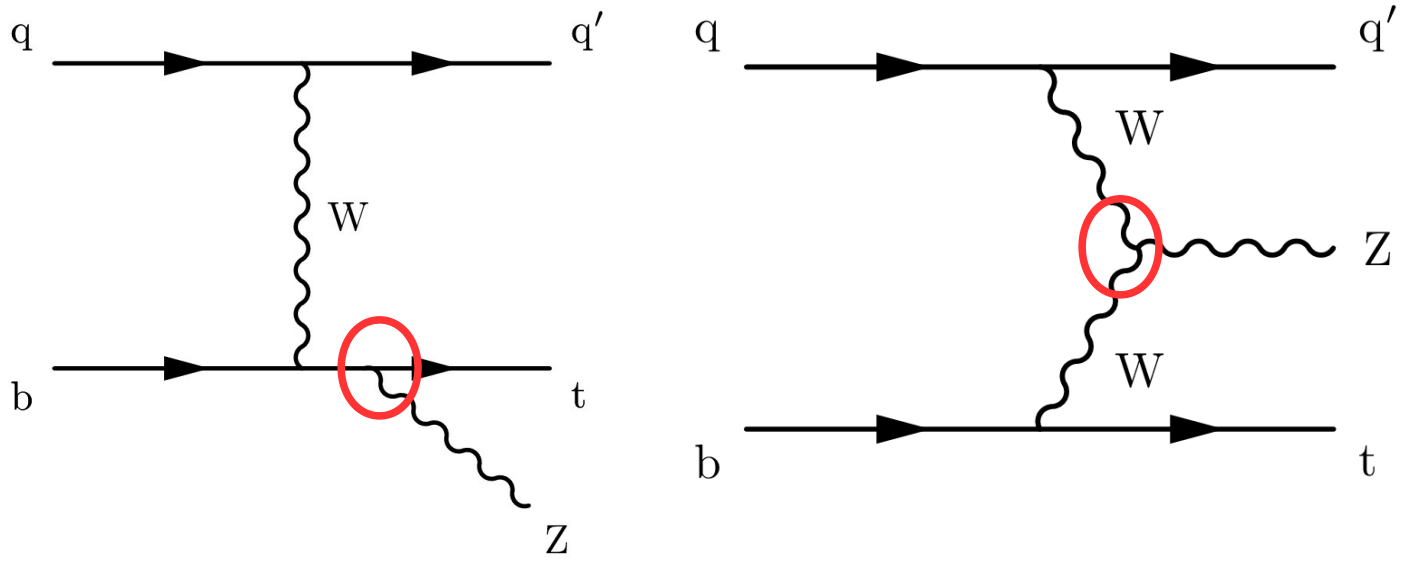
$\sigma_{s\text{-ch}}(7\ \text{TeV}) = 7.1 \pm 8.1\ (\text{stat+syst})\ \text{pb}$

$\sigma_{s\text{-ch}}(8\ \text{TeV}) = 13.4 \pm 7.3\ (\text{stat+syst})\ \text{pb}$

$\sigma_s(7\ \text{TeV}) = 4.56 \pm 0.07\ (\text{scale}) \pm 0.17\ (\text{PDF})\ \text{pb}$

$\sigma_s(8\ \text{TeV}) = 5.55 \pm 0.08\ (\text{scale}) \pm 0.21\ (\text{PDF})\ \text{pb}$ (NNLO)

tZ Production



- Extremely rare process: 2 orders of magnitude smaller than tW
- Sensitive to top-Z and triple gauge boson WWZ couplingst
  - Possible deviations may indicate physics BSM (FCNC, anomalous couplings)
- Typically studied decay mode: 3 isolated high-p_T leptons, 1 b tagged jet
  - Small BR but much cleaner than 1 and 2 leptons channels
- Main backgrounds from ttV, WZ and non-prompt lepton production

tZ @ 13 TeV (35.9 fb^{-1})

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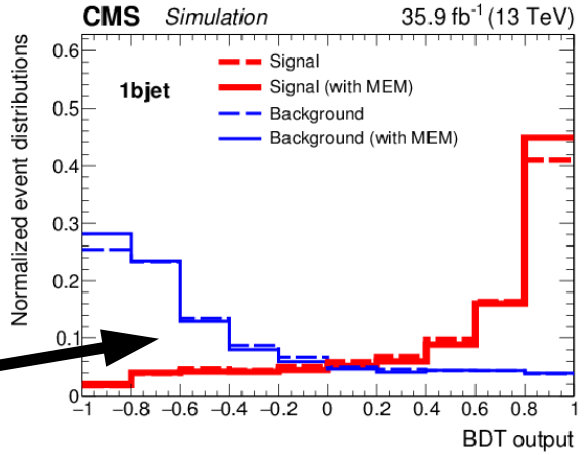
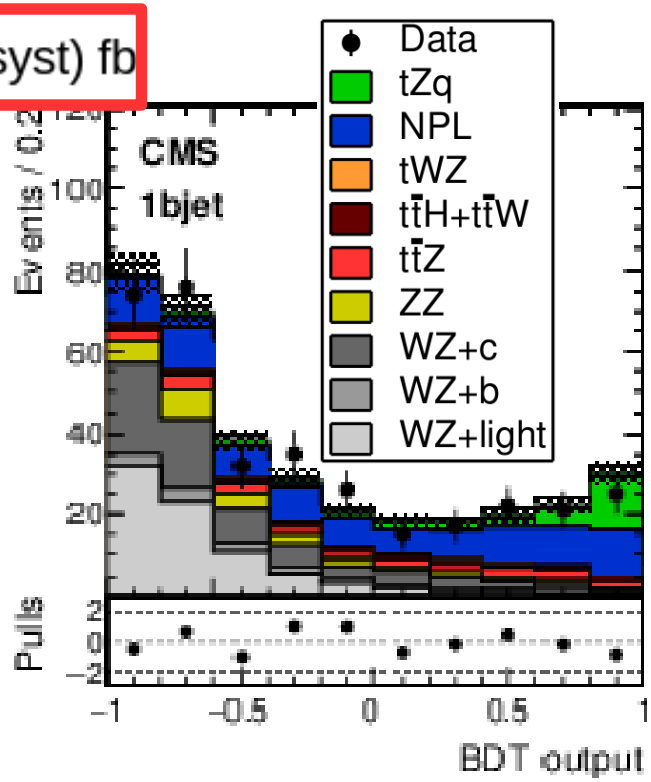
- 3 leptons and Z candidate (2 OS leptons within ±10 GeV around Z mass)
- Three regions of interest: 1 b tag jet (SR), 2 b tag jets (ttZ) and 0 b tagged jets (non-prompt leptons)
- BDT trained against WZ, ttV and ZZ using top and Z reconstruction
  - ME weights added to increase performance

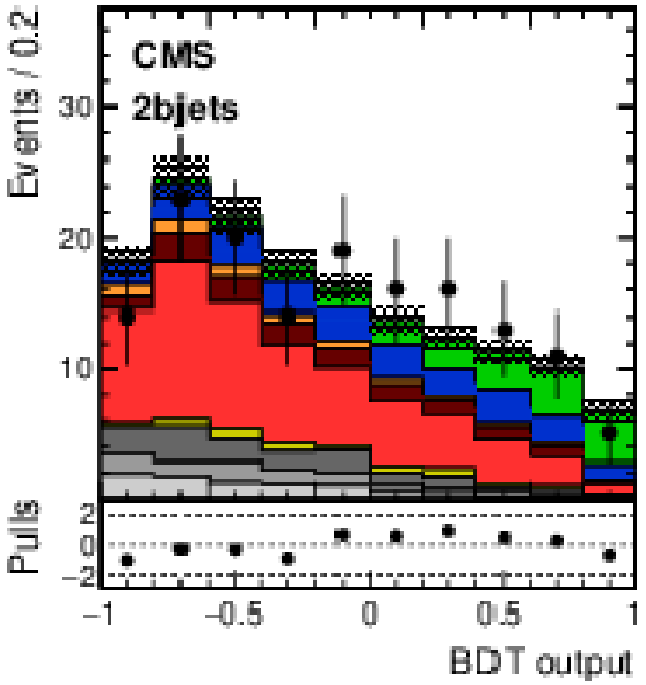


$$\sigma(t\ell^+\ell^-q) = 123^{+33}_{-31}\ (\text{stat})\ ^{+29}_{-23}\ (\text{syst})\ \text{fb}$$

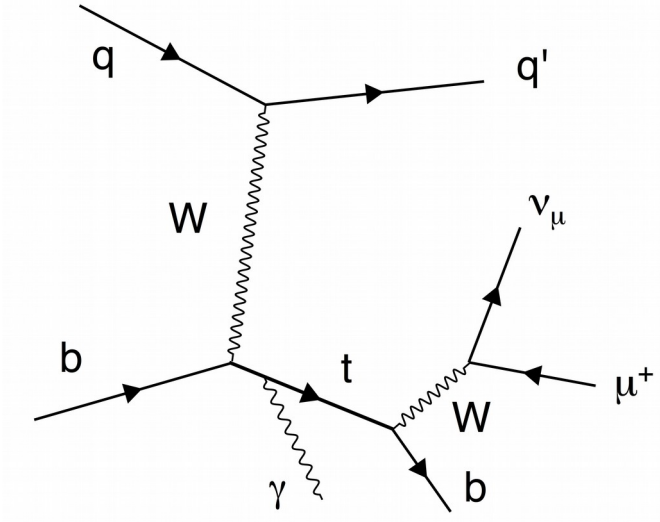
$\sigma_{tZ(ll)q}$(NLO) = 94.2 ± 3.1 fb

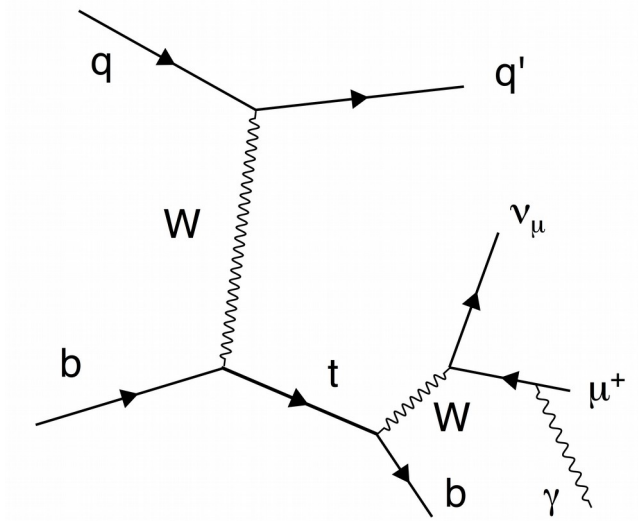
- Observed (expected) significance: 3.7 (3.1)σ
- Main systematics
  - Bkg. normalization
  - Signal modeling

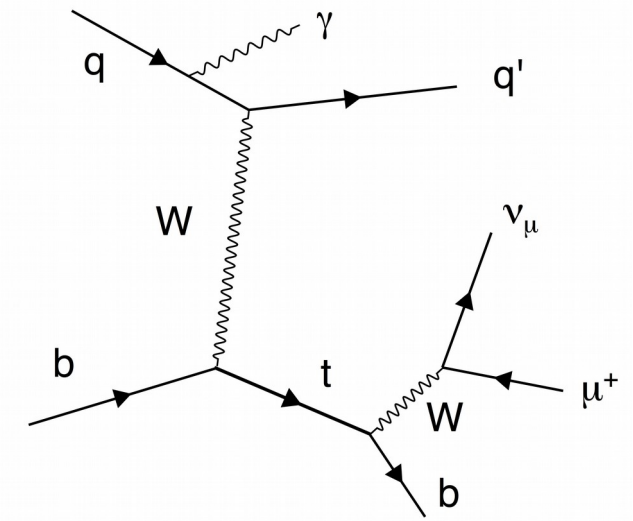




tγ Production





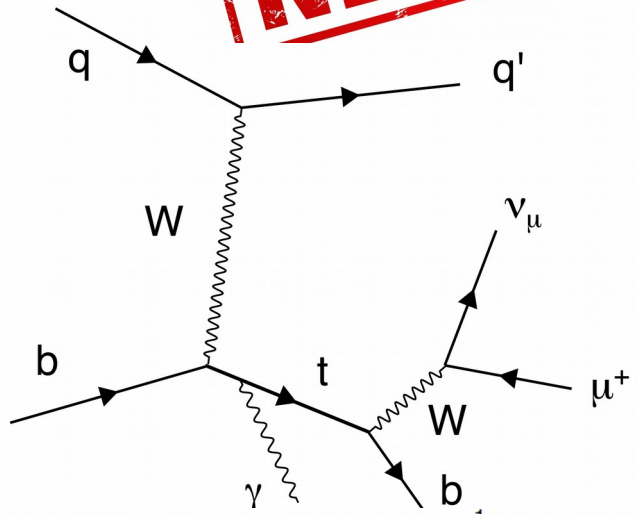


- Extremely rare process
- Sensitive to the top quark charge and the top quark electric and magnetic dipole moments

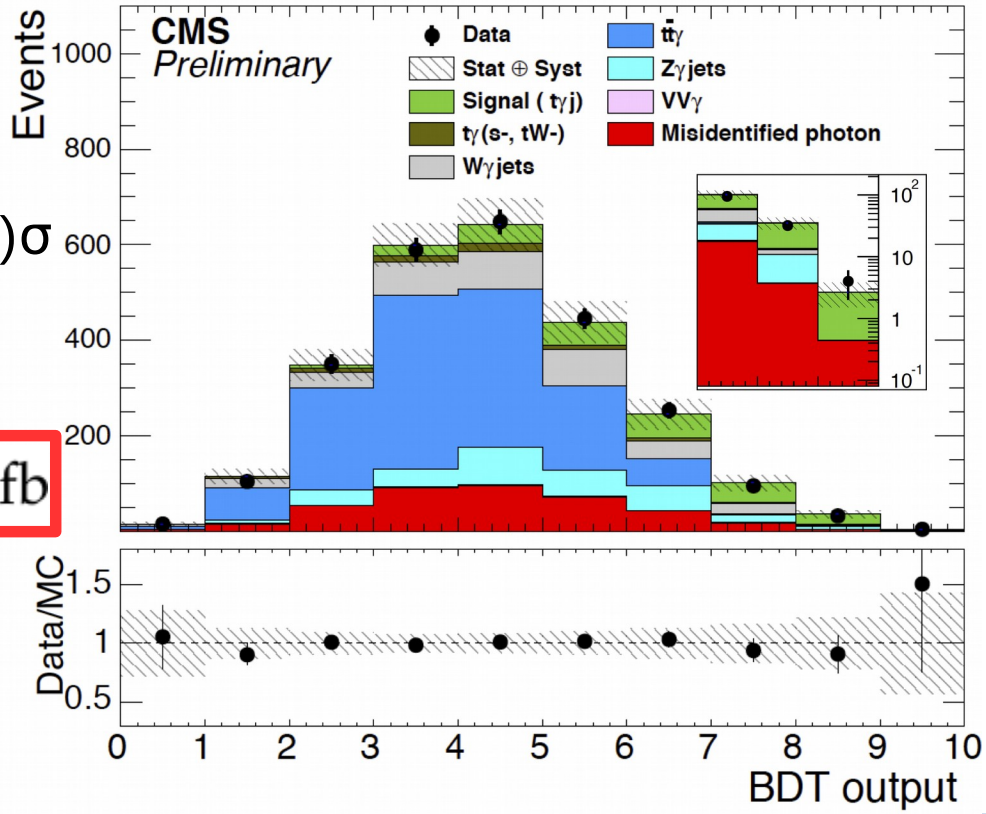
tγ @ 13 TeV (35.9 fb^{-1})

NEW

CMS-PAS-TOP-17-016



- t-channel: 1 μ, 1 γ, MET, ≥ 2 jets, 1 b tagged jet
- BDT based on topological and kinematic properties
  - Light jet η, cos (μ, light jet), muon η, ΔR(light jet, γ), top mass, jet multiplicity, W transverse mass, μ charge
- Binned likelihood fit is performed to the BDT in the SR and the tt+γ CR (2 b tagged jets)
- Observed (expected) significance of 4.4 (3.0)σ
  - First evidence of this process!

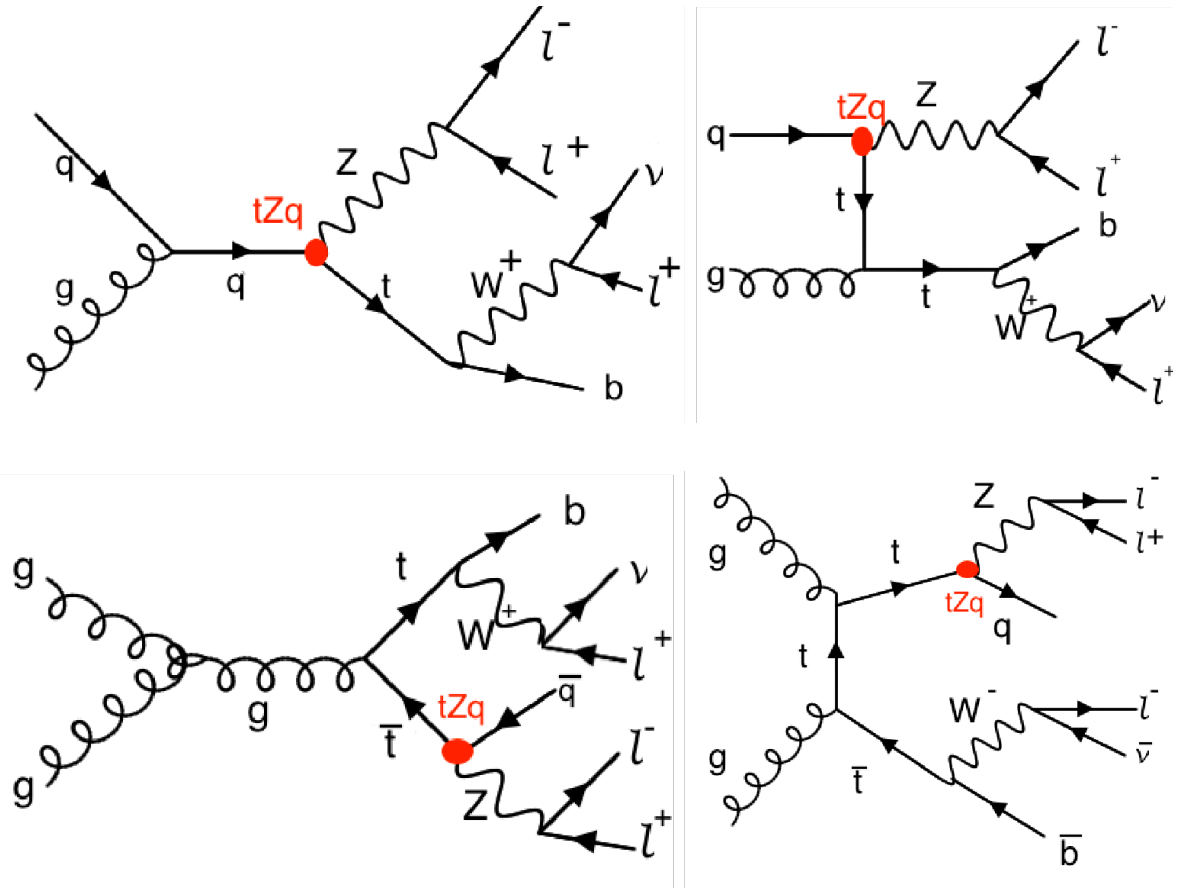


$$\mathcal{B}(t \to \mu\nu b)\sigma(t\gamma j) = 115 \pm 17(\text{stat})^{+33}_{-27}(\text{syst})\ \text{fb}$$

$\sigma_{t\gamma}$(NLO) = 81 ± 4(scale+PDF) fb

- Main systematics
  - JES and signal modeling

FCNC tZq



- In SM, FCNC are forbidden at tree level and highly suppressed at higher order
  - BR(t → u/c Z) ≈ 10^{-14}
- Several SM extensions enhance these BRs and can be proved

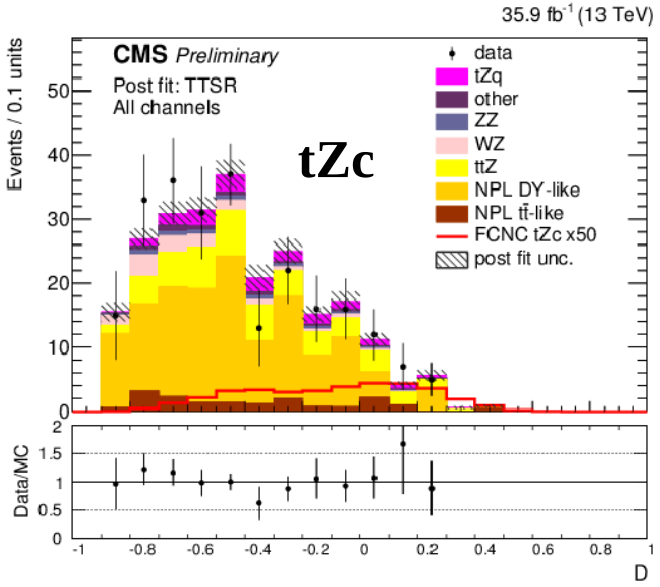
FCNC tZq @ 13 TeV (35.9 fb^{-1})

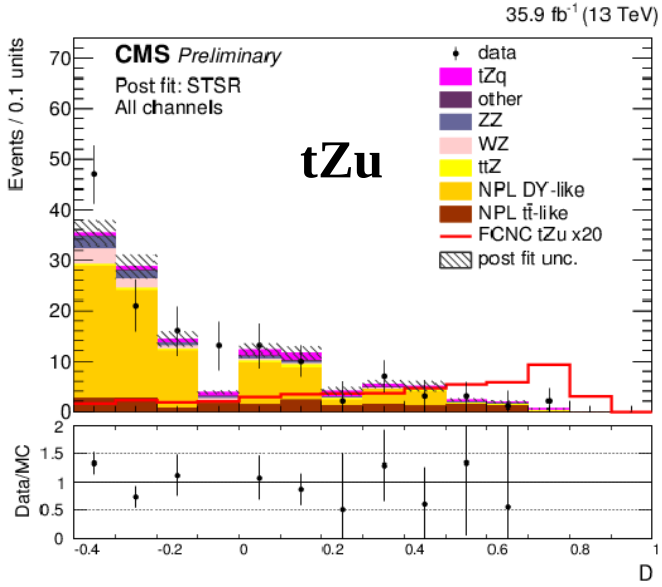
- Search focused on single top and tt FCNC interactions observable in 3l final states
  - the FCNC interaction might happen at the production or at the top quark decay
- Same selection as tZq analysis

CMS-PAS-TOP-17-017

- Two BDTs: one for single top and another one for tt FCNC
- 4 lepton channels and 5 regions used
- Main systematics
  - modeling, JES, b-tagging

	WZ control region (WZCR)	single top quark signal region (STSR)	top quark pair signal region (TTSR)	single top quark control region (STCR)	top quark pair control region (TTCR)
Number of jets	$\geq 1, \leq 3$	1	$\geq 2, \leq 3$	1	$\geq 2, \leq 3$
Number of b jets	0	1	≥ 1	1	≥ 1
$\lvert M(Z_{reco}) - M_Z \rvert < 7.5$ GeV	Yes	Yes	Yes	No	No





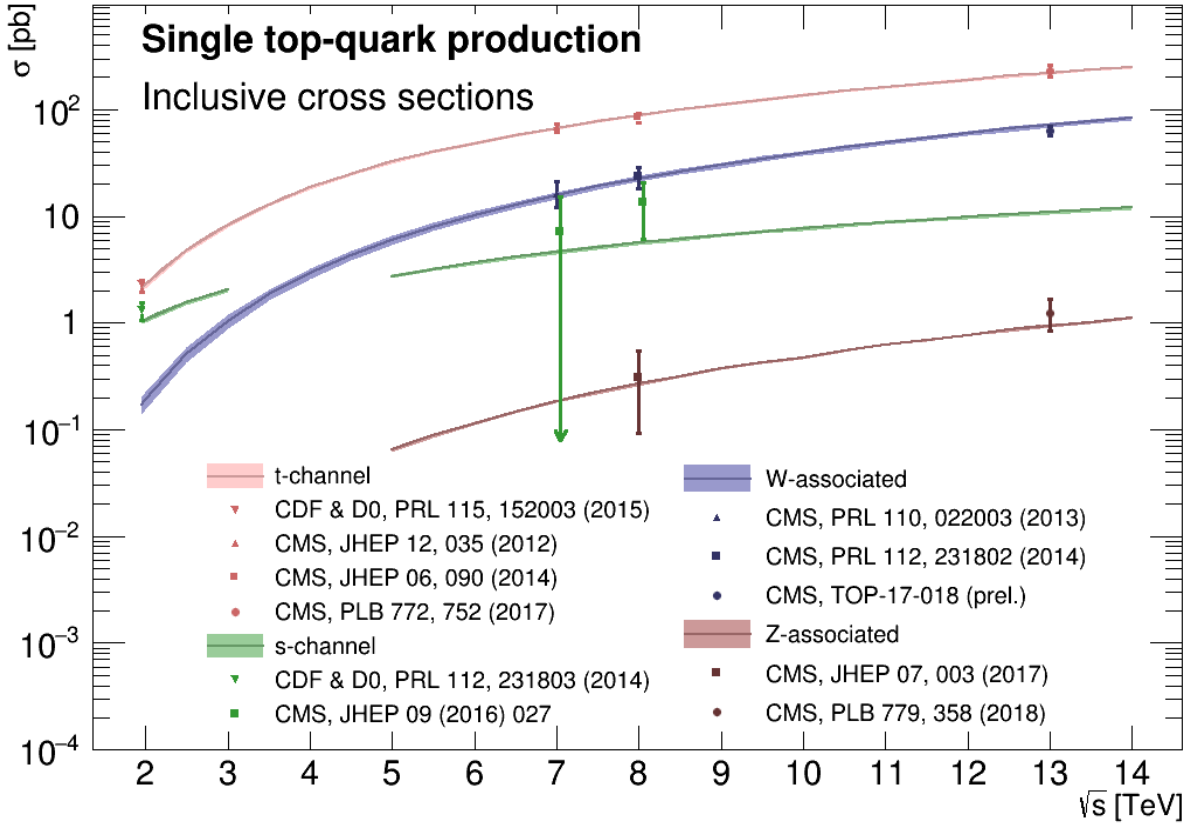
$B(t \longrightarrow uZ) < 0.024\ (0.015)\%$

$B(t \longrightarrow cZ) < 0.045\ (0.037)\%$

Obs. (exp.)

Summary

- CMS single top covers a broad range of analysis
- From precission measurements
  - t and tW channels
- To evidences of new processes
  - s channel, tZq and tgamma
- And searches for BSM processes
  - FCNC
- 2017 dataset is in the pipeline
  - New results are coming soon



Thank you for your attention!

http://cms-results.web.cern.ch/cms-results/public-results/publications/TOP/SGLTOP.html

Back-up Slides