Single-top quark production at CMS

Priyanka

(On behalf of CMS Collaboration)

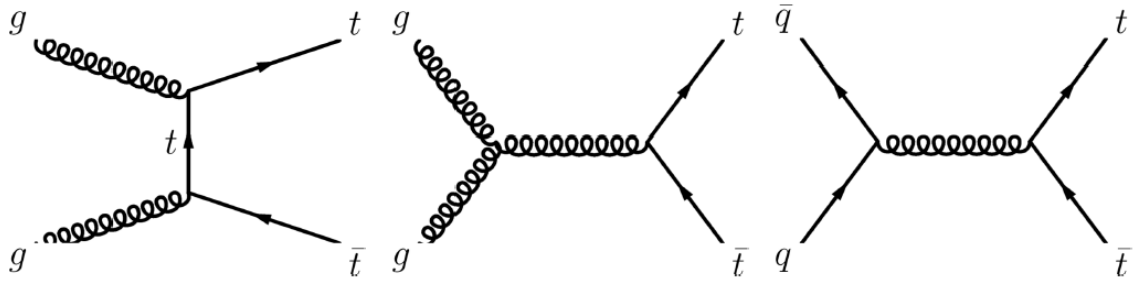
Dept. of Physics & Astrophysics, University of Delhi

7th International Conference on New Frontiers in Physics (ICNFP2018)
4 - 12 July 2018, Kolymbari, Creta, Greece.

Introduction to top quark

TOP quark decay predominantly (~100%) to a W Boson and a b-quark

- Discovered by the CDF and DØ collaborations at the Tevatron in 1995 in pair production (strong interaction).
- Dominantly produced via strong interaction.



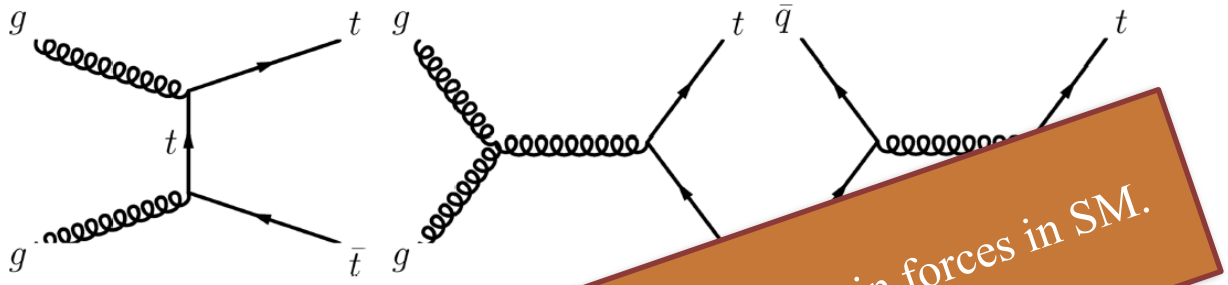
- It is the heaviest elementary particle.
- Short Lifetime=>decay before hadronizing:

  unique way to observe a bare quark.
- Electroweak (single top) production discovered by the CDF and DØ collaborations at the Tevatron in 2009 (evidence by DØ in 2006).

Introduction to top quark

TOP quark decay predominantly (~100%) to a W Boson and a b-quark

- Discovered by the CDF and DØ collaborations at the Tevatron in 1995 in pair production (strong interaction).
- Dominantly produced via strong interaction.



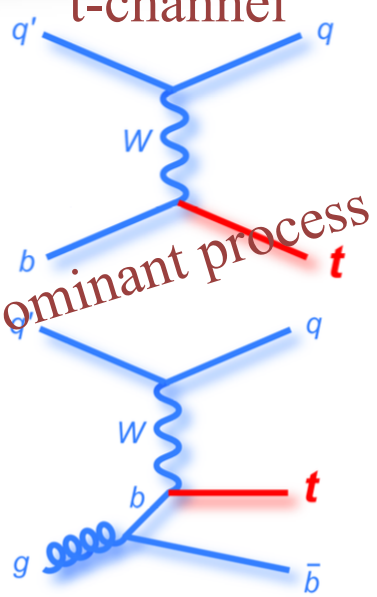
top quark => provides important tests of two main forces in SM.

- It is the heaviest elementa
- Short Lifetim izing:

  uniqu bare quark.
- Electrow gle top) production discovered by the CDF and DØ collaborations at the Tevatron in 2009 (evidence by DØ in 2006).

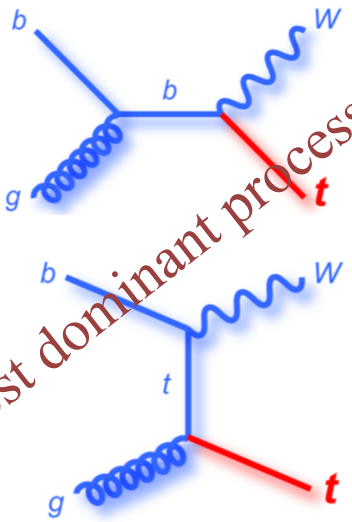
Single top-quark production at LHC

t-channel



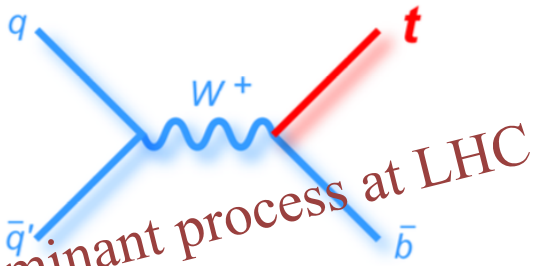
Dominant process

tW-channel



2nd most dominant process at LHC

s-channel

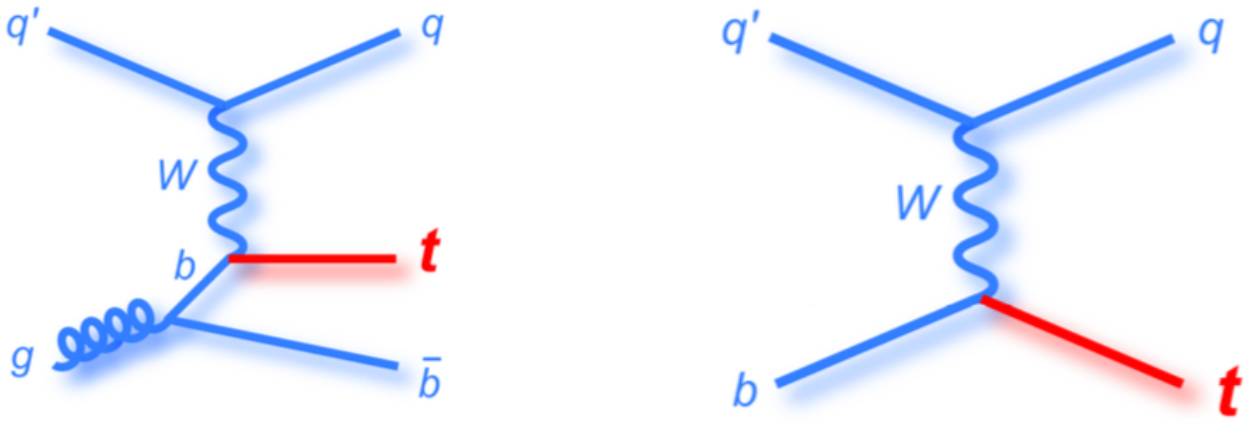


Least dominant process at LHC

Center of mass Energy	t-Channel (NNLO) (in Pb)	s-Channel (NNLO) (in Pb)	tW-Channel (NNLO) (in Pb)
Tevatron (ppBar) 1.96TeV	2.08	1.05	0.22
LHC (pp) 7TeV	63.89	4.29	15.74
LHC (pp) 8TeV	84.69	5.24	22.37
LHC (pp) 13TeV	216.99	10.32	71.7

- Cross-section of Single top quark production $\Rightarrow |V_{tb}|$ matrix element of CKM matrix.
- Sensitive to non-SM couplings of Wtb vertex.
- Background for precision tt physics and many other BSM searches.

t-channel



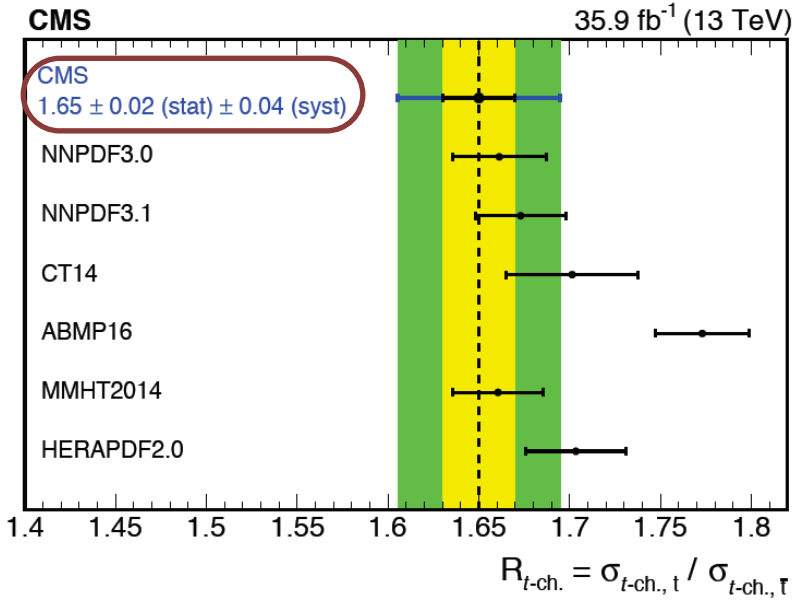
- Contains ~73% of the total single top quark production at LHC.
- Direct measurement of $|V_{tb}|$ matrix element of CKM matrix.
- New physics beyond the SM would alter the couplings and affect the polarisation.
- Also suited for testing the proton PDF and comparing the various models with data.

CMS-PAS-TOP-17-011

t-channel@13TeV

HOT NEWS

Singnature: 1lepton(e/μ), 2 jets, 1 b tag,MET



$$\sigma_{t-ch.,t+\bar{t}} = 219.0 \pm 1.5(stat) \pm 32.9(syst)pb$$
$$|f_{LV}V_{tb}| = 1.01 \pm 0.05(exp) \pm 0.02(theo)$$

With

$$\mathcal{B}(\mathrm{t} \to \mathrm{Wb}) \approx 1 \Rightarrow f_{\mathrm{LV}}^2 \mathrm{V}_{\mathrm{tb}}^2 = \sigma_{\mathrm{meas.}}/\sigma_{\mathrm{theo.}}$$

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

☞R's exp. uncertainty~PDF model's theoretical uncertainties: proton structure

- Simultaneous ML fit on multivariate discriminators, separately for signal region(2j1t) and 2 control regions (3j1t,3j2t) NjMt region, lepton flavour, and lepton charge (12 discriminator distributions fitted simultaneously).

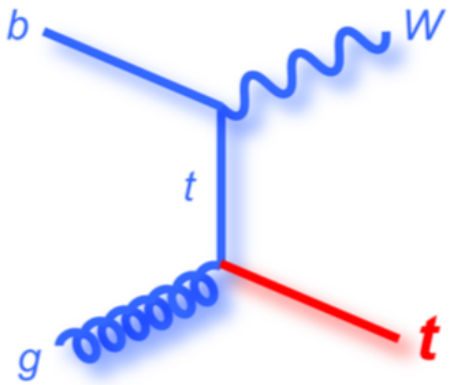
➢Fit repeated two times:

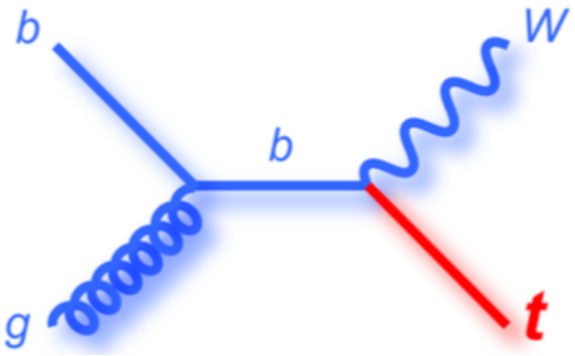
1)First fit: top channel signal strength and anti-top channel signal strength are free parameters.

2)Second fit: Anti-top channel signal strength and $R_{t\text{-ch}}$ free parameters.

- Main systematic: Signal modeling.

tW-channel





- Contains ~25% of the total single top quark production at LHC.

- Challenge for tW-Channel: Interference at NLO level with top-quarks pair production for extraction of tW signal.

➢ Two configurations to subtract overlapping diagrams: diagram subtraction(DS) & diagram removal(DR)

DR

DS

$$\mathcal{M} = \mathcal{M}^{(tw)} + \mathcal{M}^{(tt\sim)}$$

$$|\mathcal{M}|^2 = |\mathcal{M}^{(tw)}|^2 + 2\mathrm{Re}\{\mathcal{M}^{(tw)}\mathcal{M}^{(tt\sim)*}\} + |\mathcal{M}^{(tt\sim)}|^2$$

tW-channel@13TeV

arXiv:1805.07399

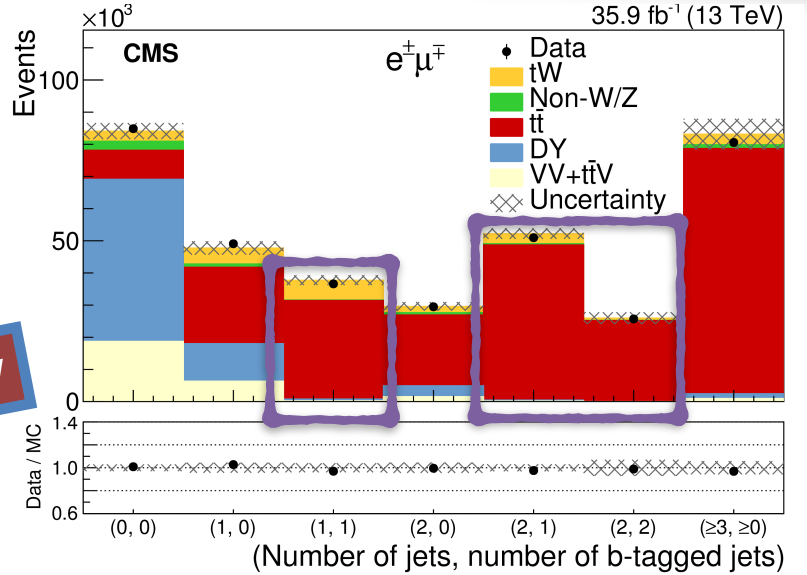
submitted to JHEP

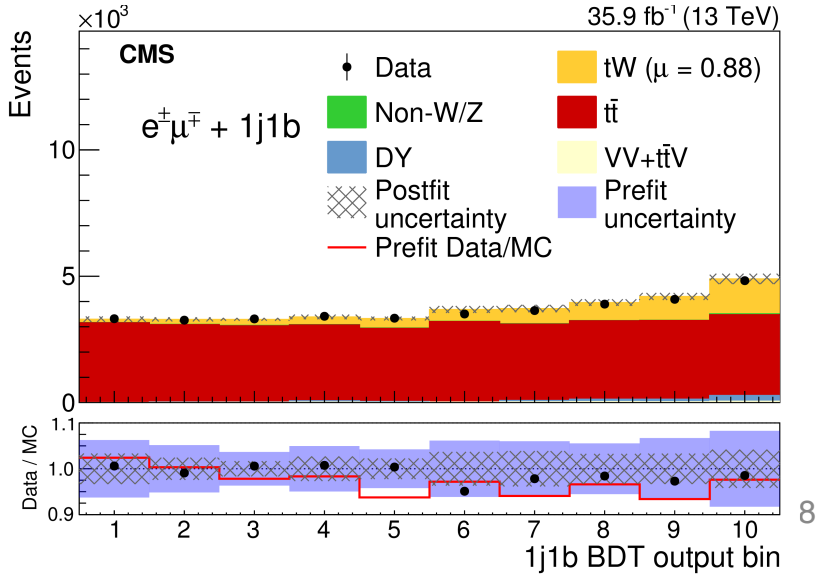
- Signature: 2 OS leptons (eμ), 1 jet, 1 b-tag
- Three regions defined for signal extraction: 1j1t (main signal region), 2j1t, 2j2t
- Signal strength determined from a ML fit to BDT distribution in 1j1t and 2j1t regions and sub-leading jet p_T in 2j2t.
- Main systematic: JES, lepton identification, tt modeling.

First measurement at 13TeV

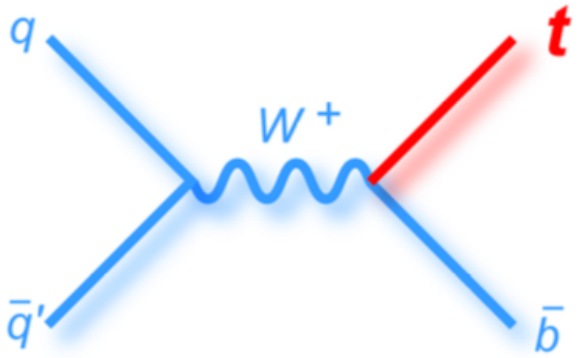
σ_{tW} = 63.1 ± 1.8 (stat) ± 6.4 (syst) ± 2.1 (lumi) pb

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





s-channel



- Contains ~3% of the total single top quark production at LHC $\Rightarrow$ Challenging final state.
- Grows much slower with CME than other top production modes.
- Sensitive to new physics (Searches for W', charged Higgs).

JHEP 09 (2016) 027

s-channel@7&8TeV

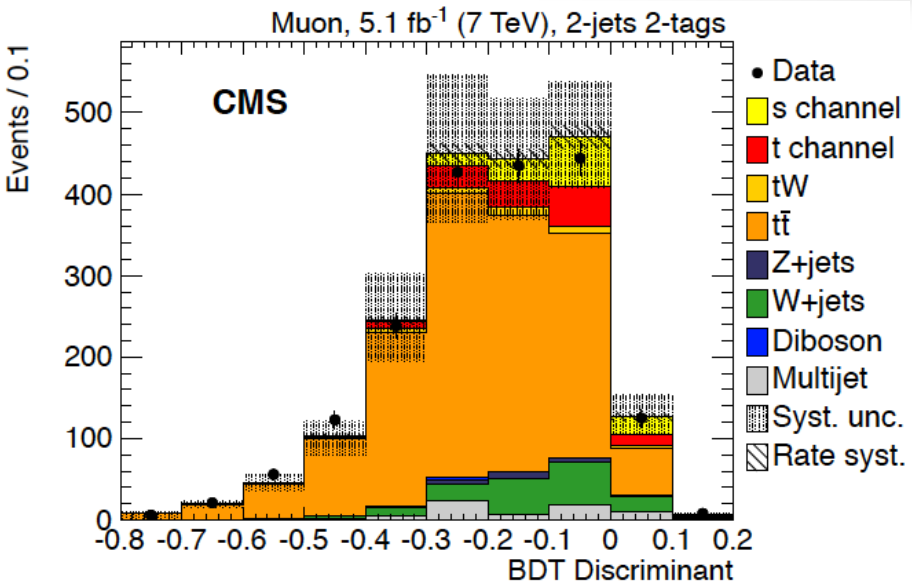
- Signature: 1 lepton, 2 jets, 2 b-tag
- Binned likelihood fit on BDT output in 2j2t (signal), 3j2t (tt) and 2j1t (t-channel and w+jets) regions.
- Observed(expected) significance (combination): 2.5(1.1) σ
- Main systematic: JES, generator, b-tagging.

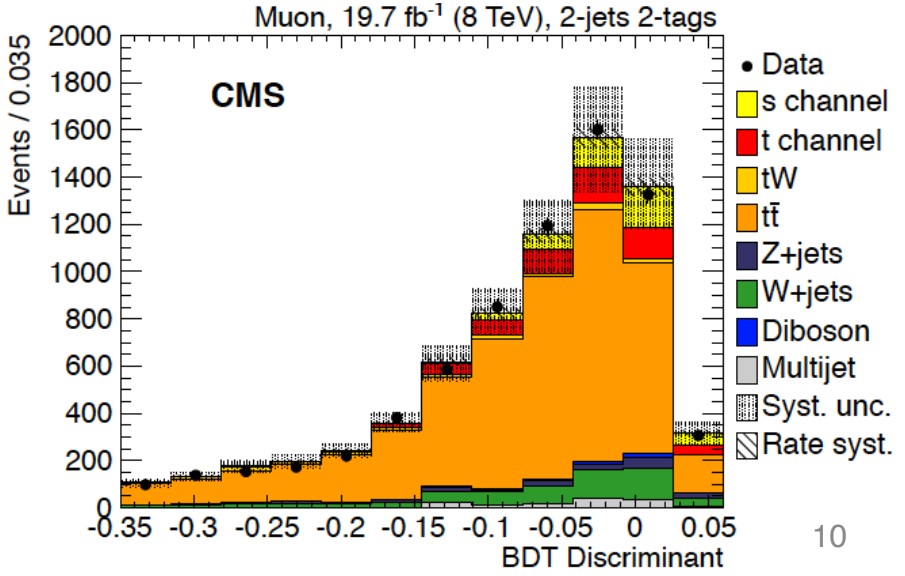
$\sigma_{\text{s-ch}}(7\ \text{TeV}) = 7.1 \pm 8.1\ (\text{stat+syst})\ \text{pb}$

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

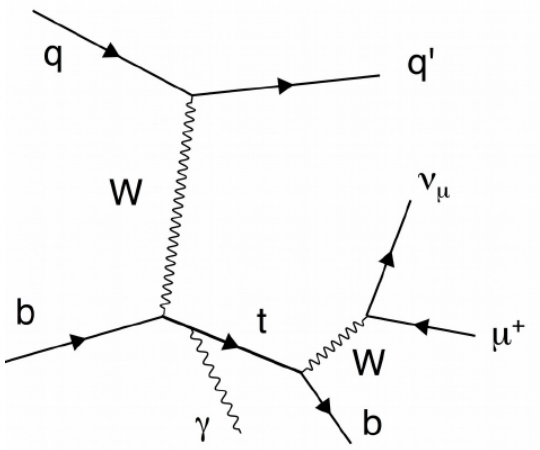
$\sigma_s(7\ \text{TeV}) = 4.56 \pm 0.07\ (\text{scale}) \pm 0.17\ (\text{PDF})\ \text{pb}$

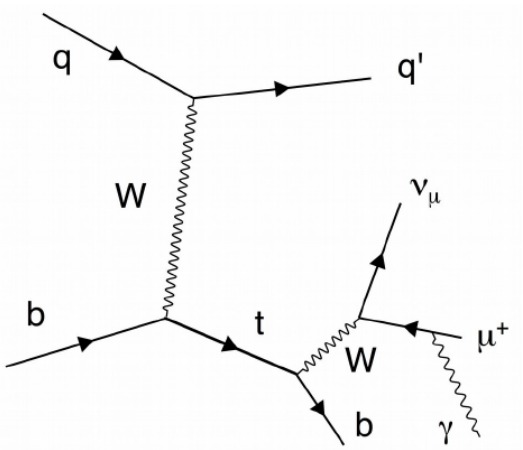
$\sigma_s(8\ \text{TeV}) = 5.55 \pm 0.08\ (\text{scale}) \pm 0.21\ (\text{PDF})\ \text{pb}$ (NNLO)

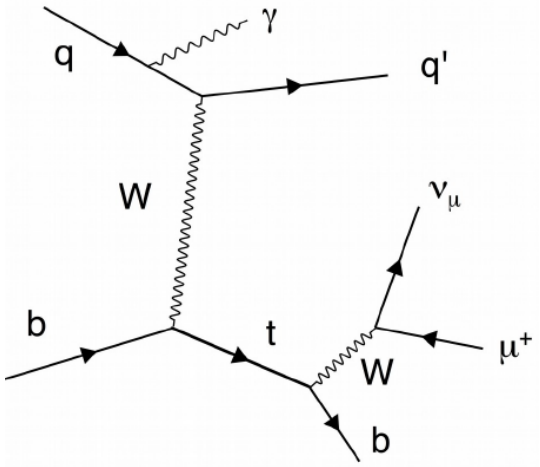




tγ-production in t-channel mode







- Extremely rare process: couplings through electroweak loop corrections opens up the possibility to search for new physics in the top quark sector.

- Sensitive to the top quark electric charge and the top quark electric and magnetic dipole moments.

CMS-PAS-TOP-17-016

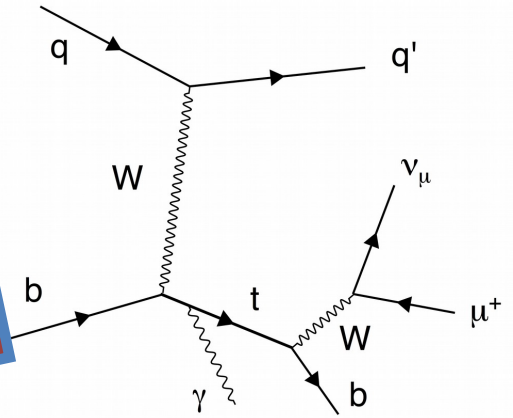
tγ@13TeV

I'M NEW

- Signature: t-channel 1μ, 1γ, MET, ≥ 2 jets, 1 b tagged jet

- Binned likelihood fit on BDT output on signal 1-tag region and control 2-tag region tt+γ.

First evidence of process!

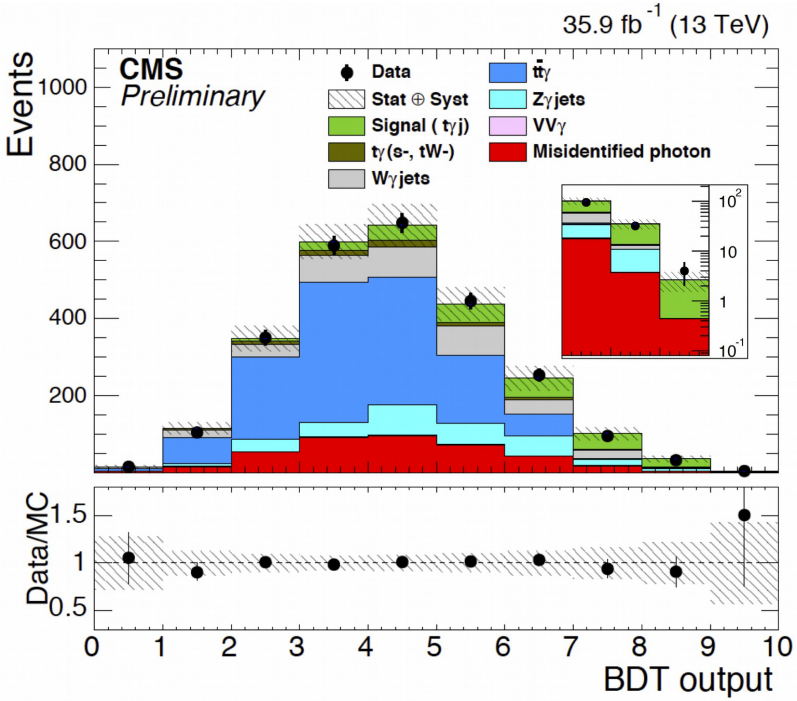


- Observed(expected including all sources of systematic uncertainties) significance: 4.4(3.0) σ

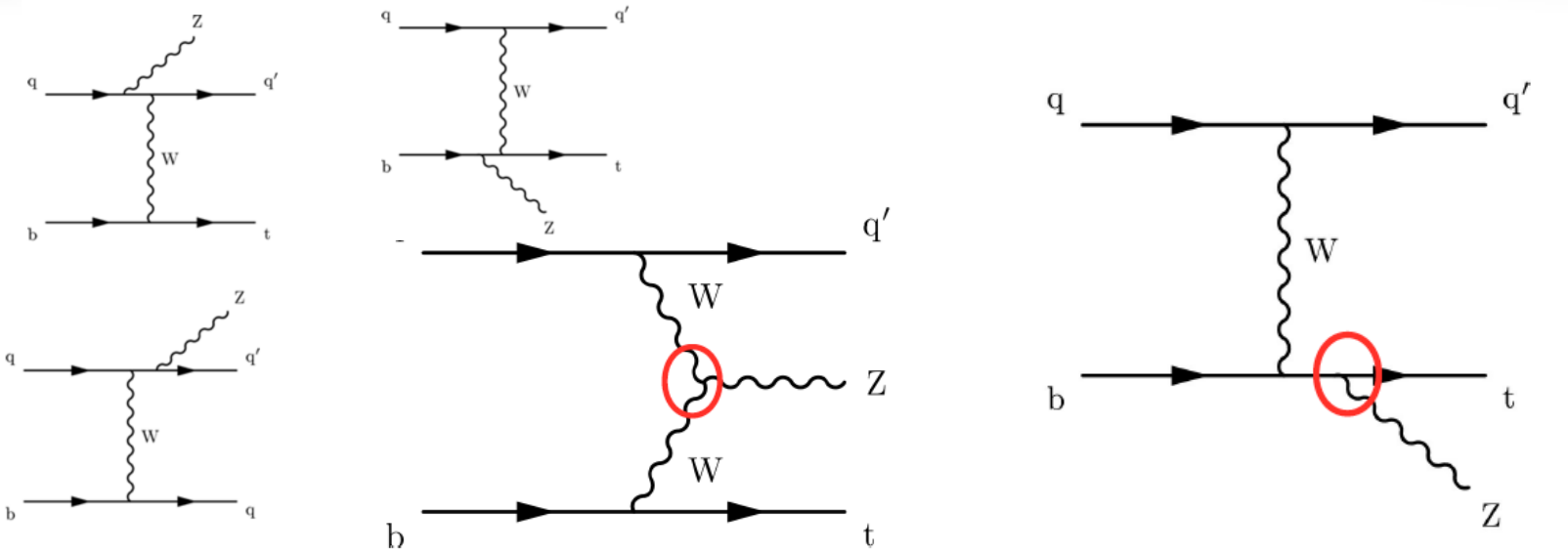
- Main systematic: JES and signal modeling.

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

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



tZ-production in t-channel mode

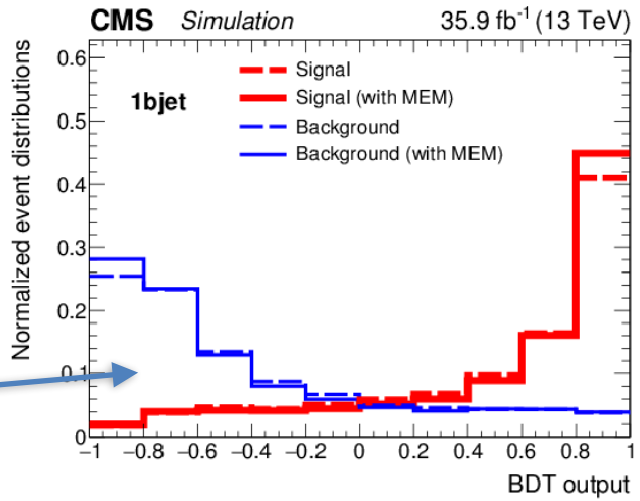


- Extremely rare process: 2 orders of magnitude smaller than tW.
- Sensitive to ttZ and triple gauge boson (WWZ) couplings: possible deviations may indicate physics BSM.
- Main backgrounds from ttV, WZ and non-prompt lepton production.

PLB 779 (2018) 358

tZ@13TeV

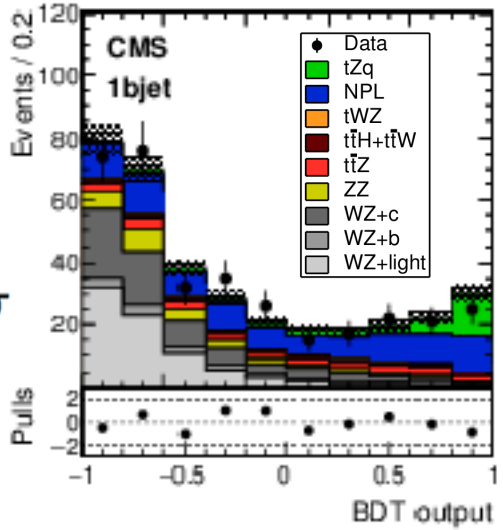
- Signature: 3 leptons (2 OS leptons within ±10GeV around Z mass)
- Three regions defined for binned maximum-likelihood fit to 12 distributions: 1b-tag (main signal region), 2b-tag (ttZ) and 0b-tag (non-prompt leptons)
- BDT trained against WZ, ttV and ZZ using top and Z reconstruction: ME weights added to increase performance

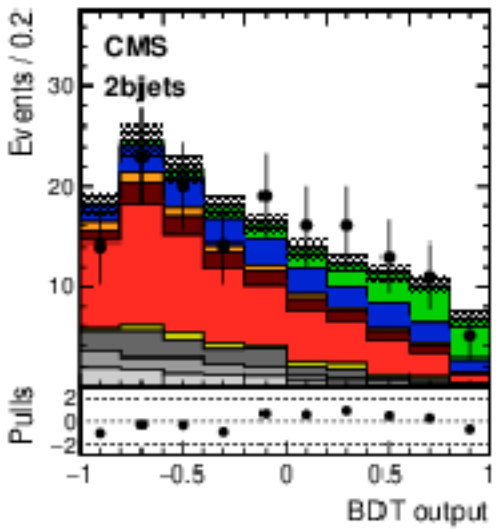


$$\sigma(t\ell^+\ell^-q) = 123^{+33}_{-31}\ (\text{stat})\ ^{+29}_{-23}\ (\text{syst})\ \text{fb}$$

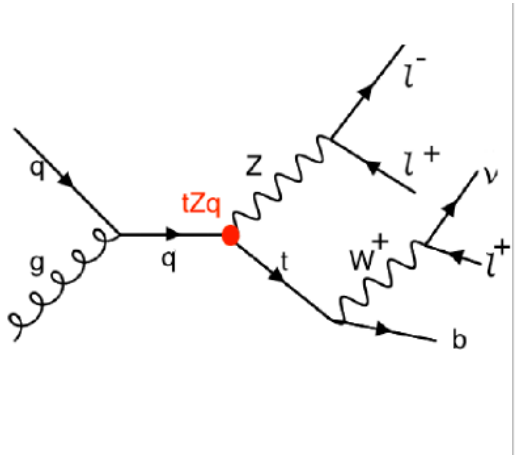
$\sigma_{tZ(ll)q}$(NLO) = 94.2 ± 3.1 fb

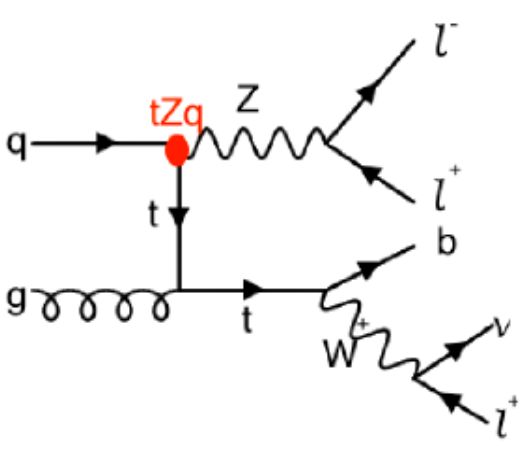
- Observed(expected) significance: 3.7(3.1)σ
- Main systematic: Background normalization and signal modeling.

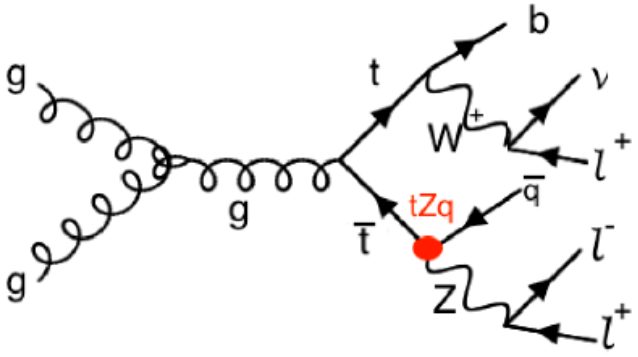


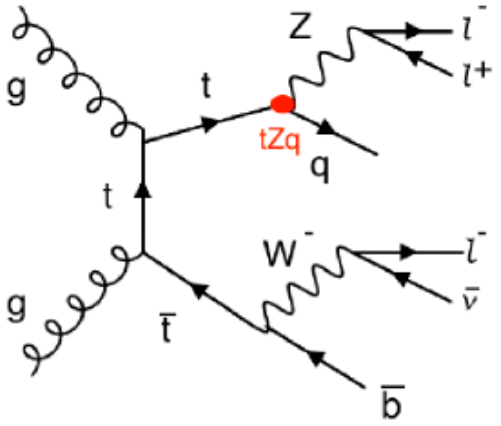


FCNC tZq









- Flavour changing neutral current transitions are interaction processes where a fermion undergoes a change of flavour without the alternation of its charge.

- In SM, FCNC are forbidden at tree level and highly suppressed at higher order

➢ BR(t → u/c Z) ≈ 10^{-14}

FCNC interaction might happen at the production or at the top quark decay.

- Several SM extensions enhance these BRs.

CMS-PAS-TOP-17-017

FCNC tZq@13TeV

- Search focused on single top & tt FCNC interactions observable in 3l final states, FCNC interaction happens at the production or at the top quark decay.
- Same selection as tZ analysis.
- Two simultaneous likelihood fits: one for single top and another one for tt FCNC.
- 4 lepton channels and 5 regions used.

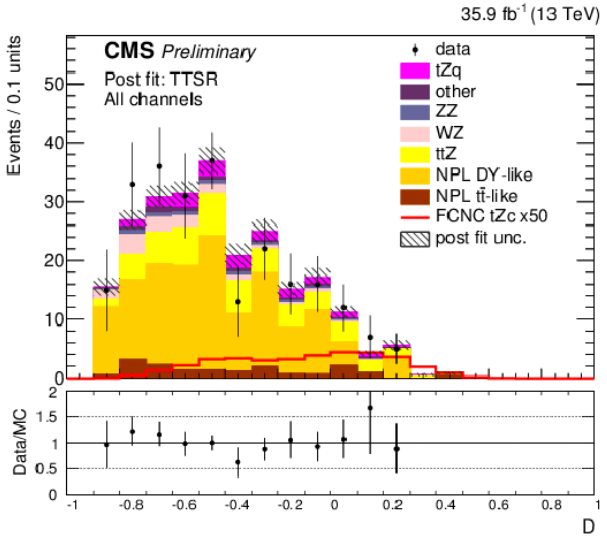
	WZ control region (WZCR)	single top quark signal region (STSR)	top quark pair signal region (TTSR)	single top quark control region (STCR)	top quark pair control region (TTCR)
Number of jets	$\geq 1, \leq 3$	1	$\geq 2, \leq 3$	1	$\geq 2, \leq 3$
Number of b jets	0	1	≥ 1	1	≥ 1
$\lvert M(Z_{reco}) - M_Z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

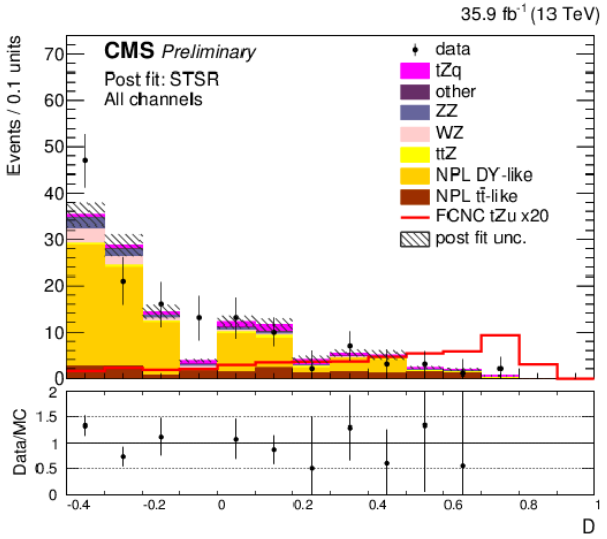
$B(t \longrightarrow uZ) < 0.024\ (0.015)\%$

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

Obs. (exp.)

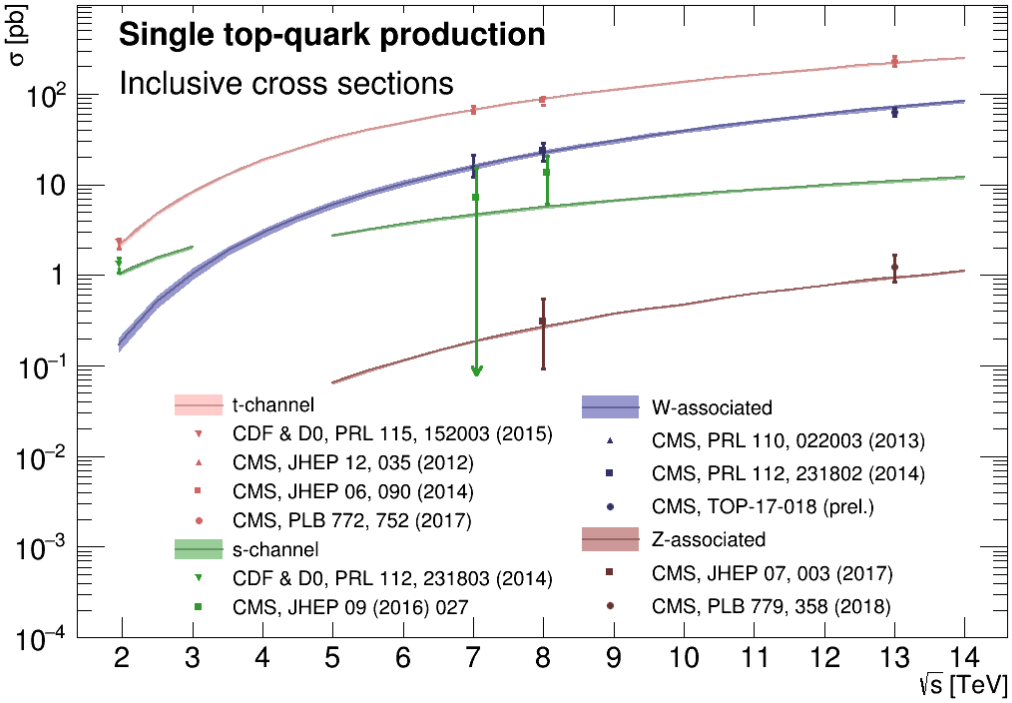
- Main systematic: modeling, JES, b-tagging





Summary

- CMS single top covers a broad range of analysis.
- From precission measurements: t and tW channels.
- To evidences of new processes: s channel, tZ and tgamma.
- And searches for BSM processes: FCNC.
- Many more new results are coming soon.



Acknowledgement

- Thanks to Single top and Top group convenors and Single top team.
- Thanks to conference organisers.
- Thanks to my supervisors (Prof. Kirti Ranjan, Dr. Ashutosh Bhardwaj).
- Special thanks to Larissa and Sonia for an unforgettable help.

Thank you for your kind attention!