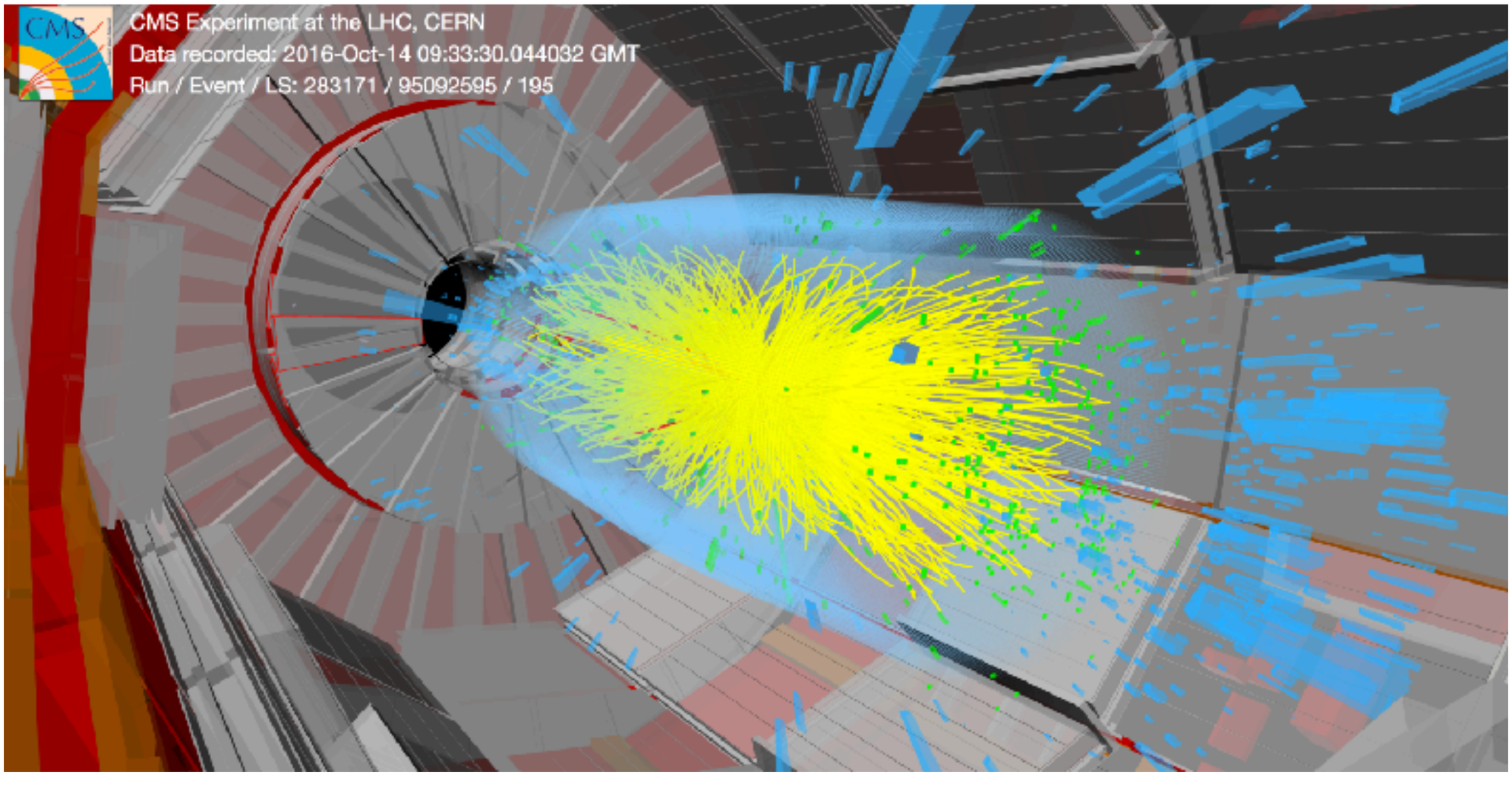
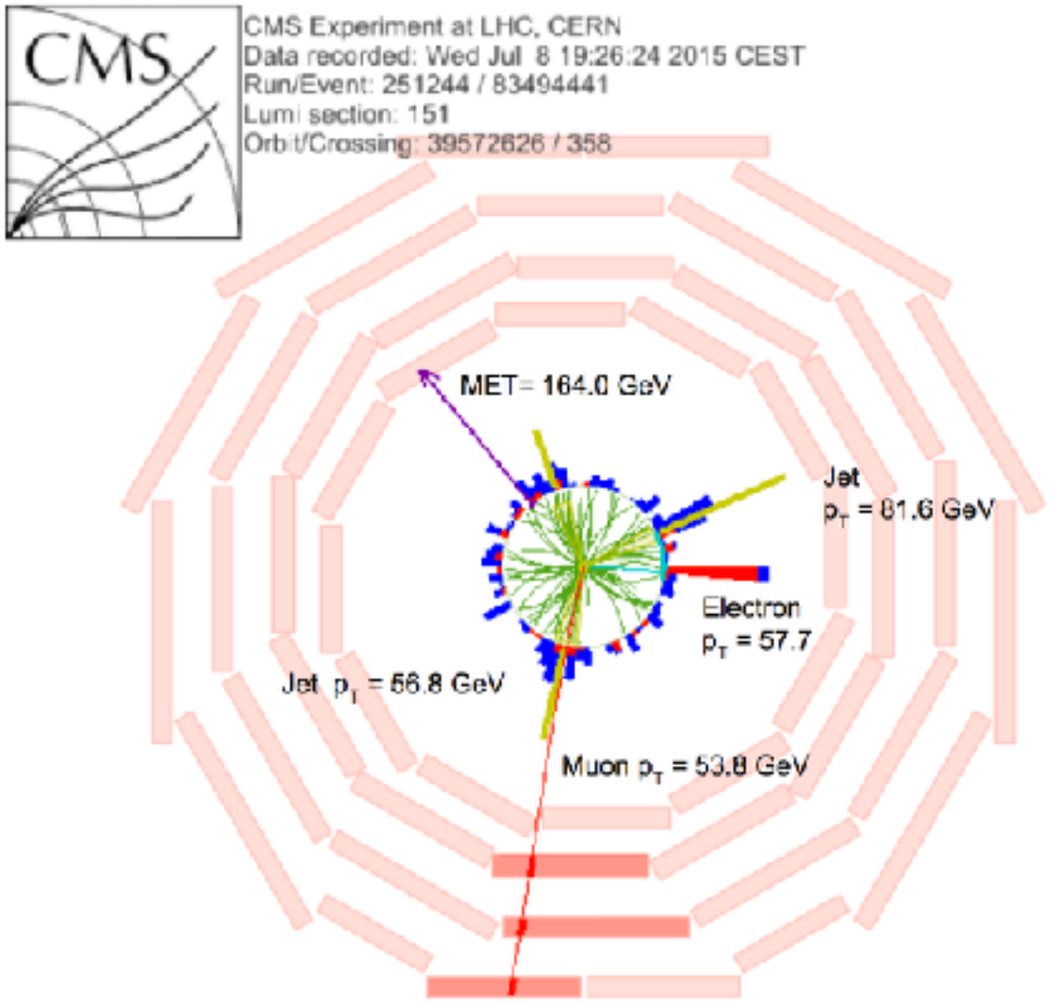
New Physics Searches in the Top Quark Sector at Hadron Colliders

Pallabi Das
TIFR, Mumbai

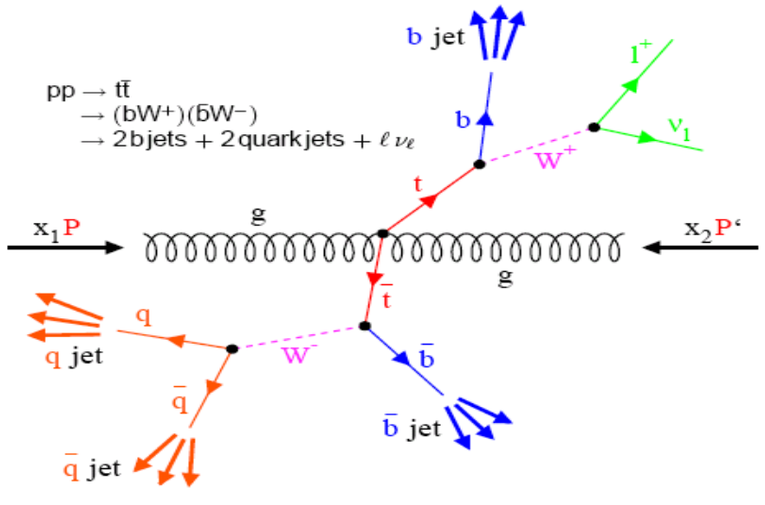


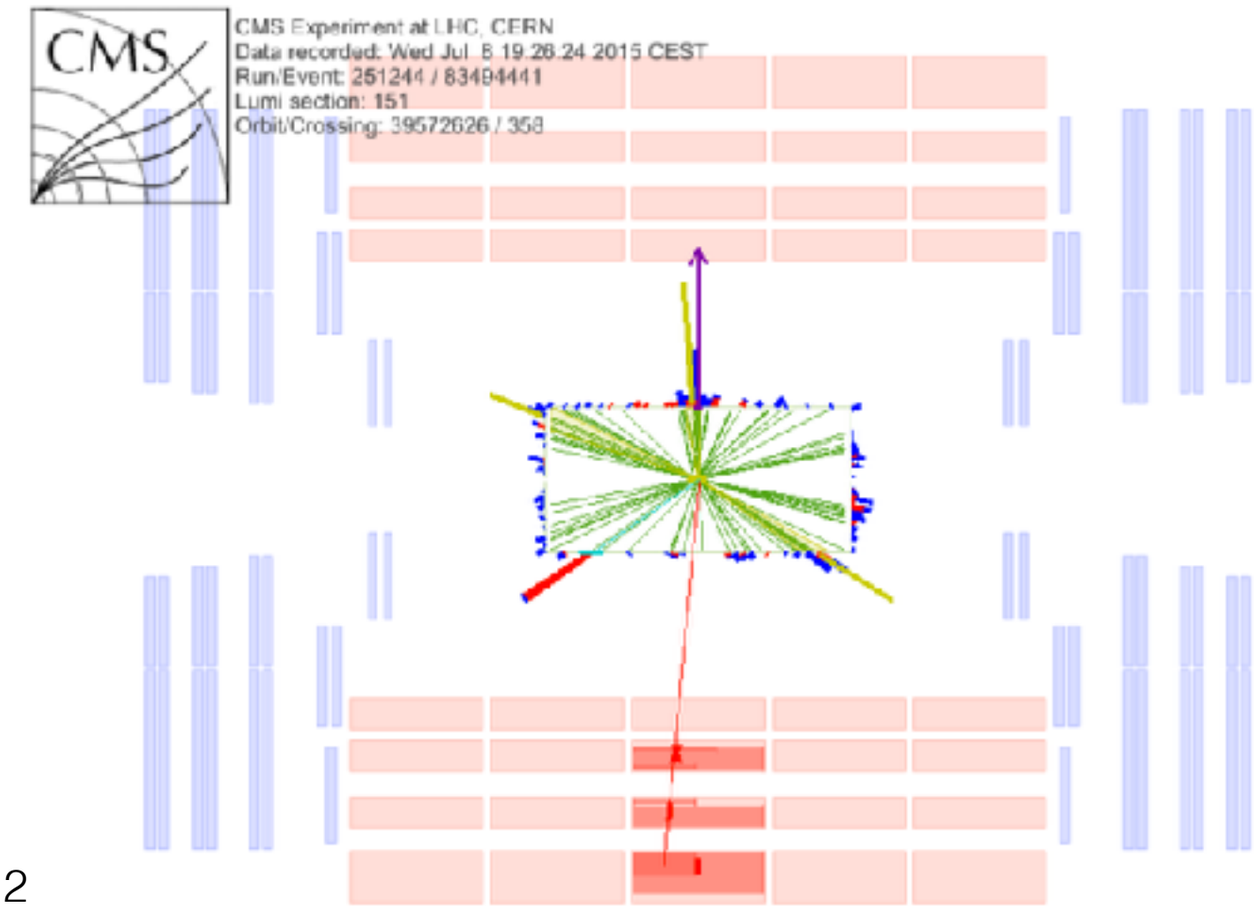
CKM 2016

Top Pair Event at LHC



t->Wb, W->lν or W->qq̄

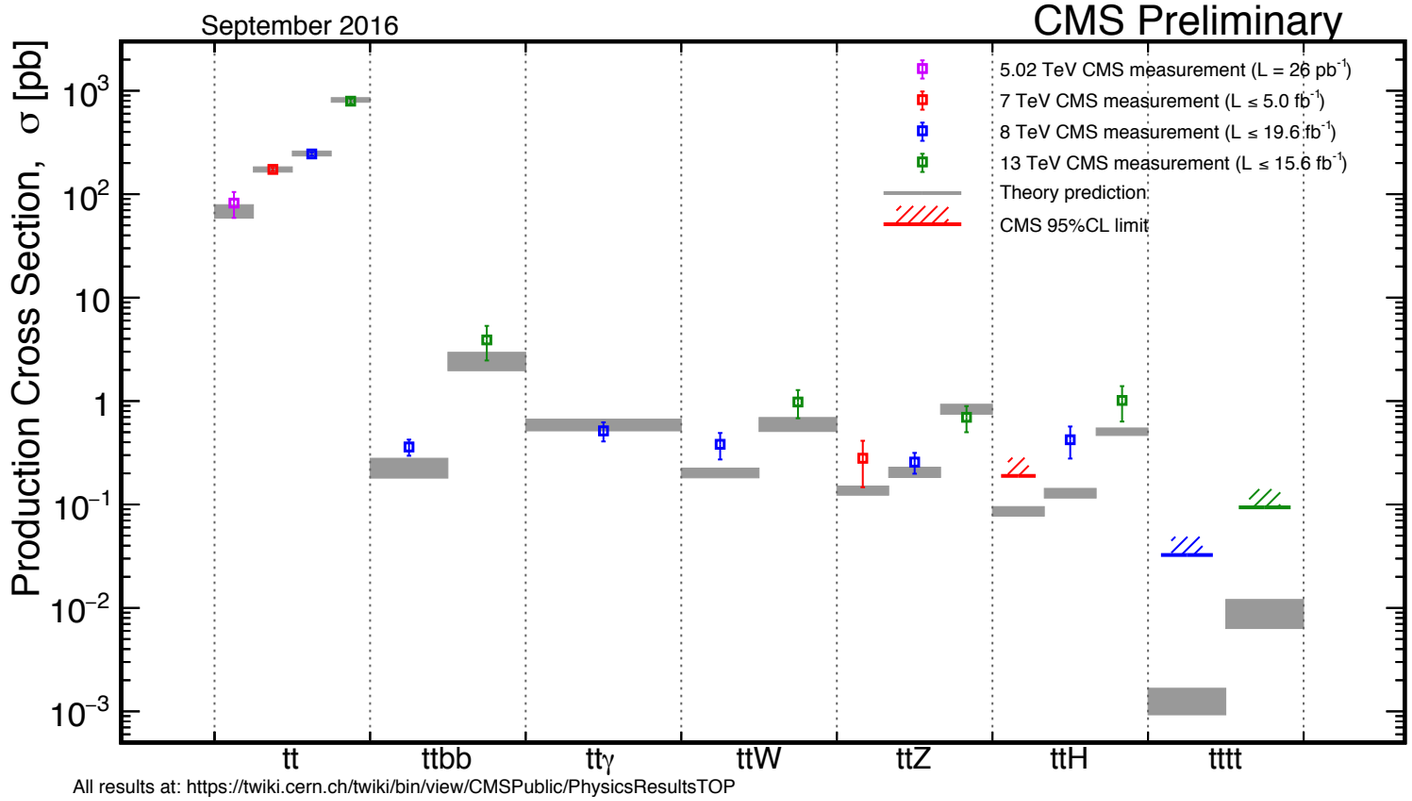


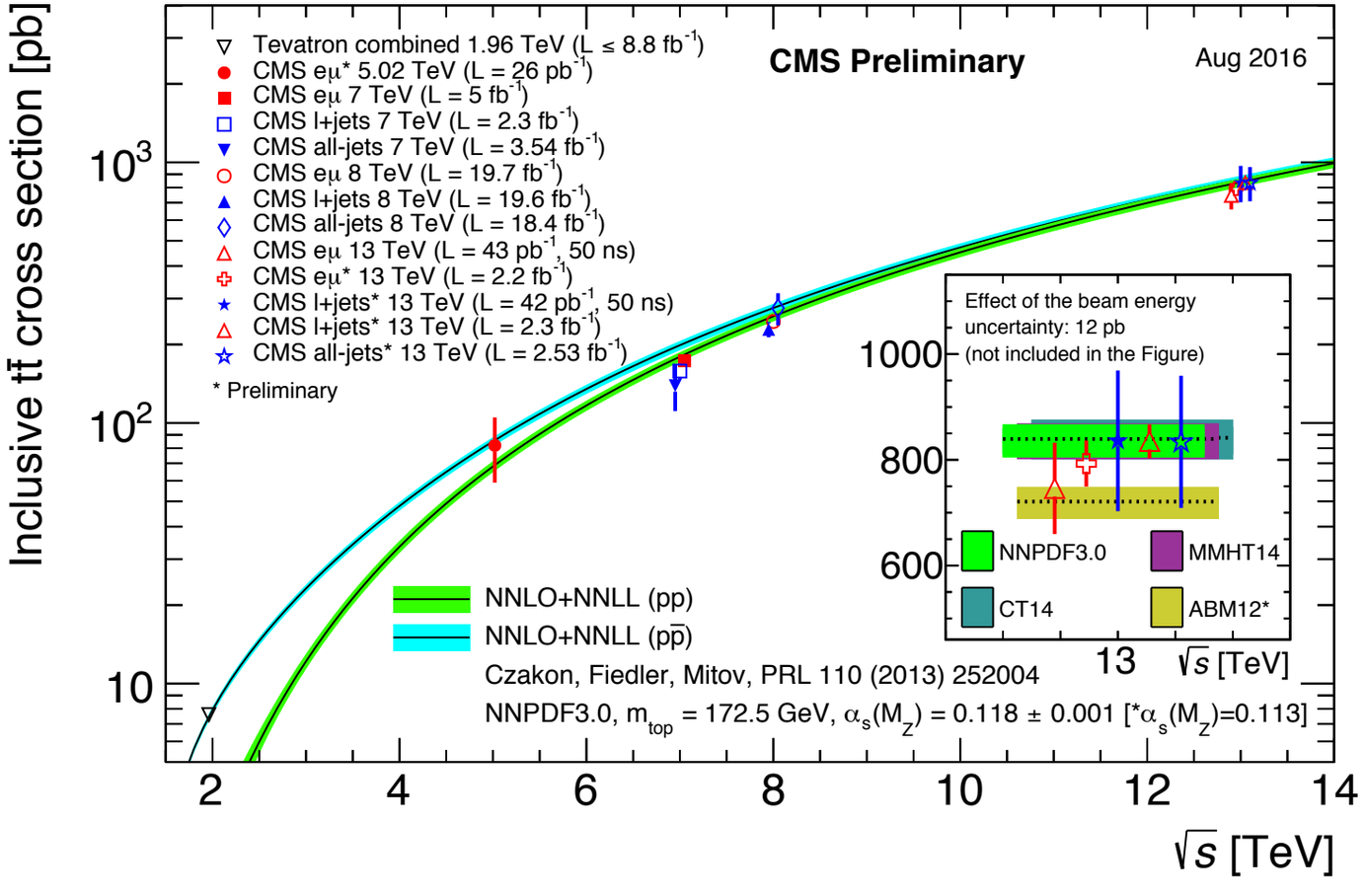


LHC pp collisions

Run I: $\sqrt{s}$ = 7 & 8 TeV

Run II: $\sqrt{s}$ = 13 TeV





Scope for many measurements in the top sector.

Physics Beyond the Standard Model

- Standard Model (SM) as a theory is successful, but not the ultimate.
- Models beyond the SM invoke new and heavy particles which have not yet been observed.
- These heavy particles are likely to decay, sometimes even preferentially, through the heavy top quark.
- This implies that the new particles can have large couplings with the top quark, making it suitable for the search of new physics.
- Note: LHC is a top factory, with production rate (~10 top pairs/s at 13TeV).
- High potential for interesting physics at hadron colliders!

Search Strategies with Top Quark

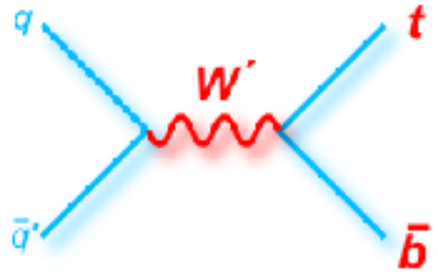
- Via study of Top production (single and pair):
  - Associated production with particle X

    -> look for deviation from SM

  - FCNC production mode
- Via study of Top decays (pair produced where one top decays a la SM):
  - MSSM decays to charged Higgs boson ($H^{+/-}$)
  - FCNC decay to up type quarks
- Massive particles decaying to top quark pairs
- Vector like quarks decaying through top quarks

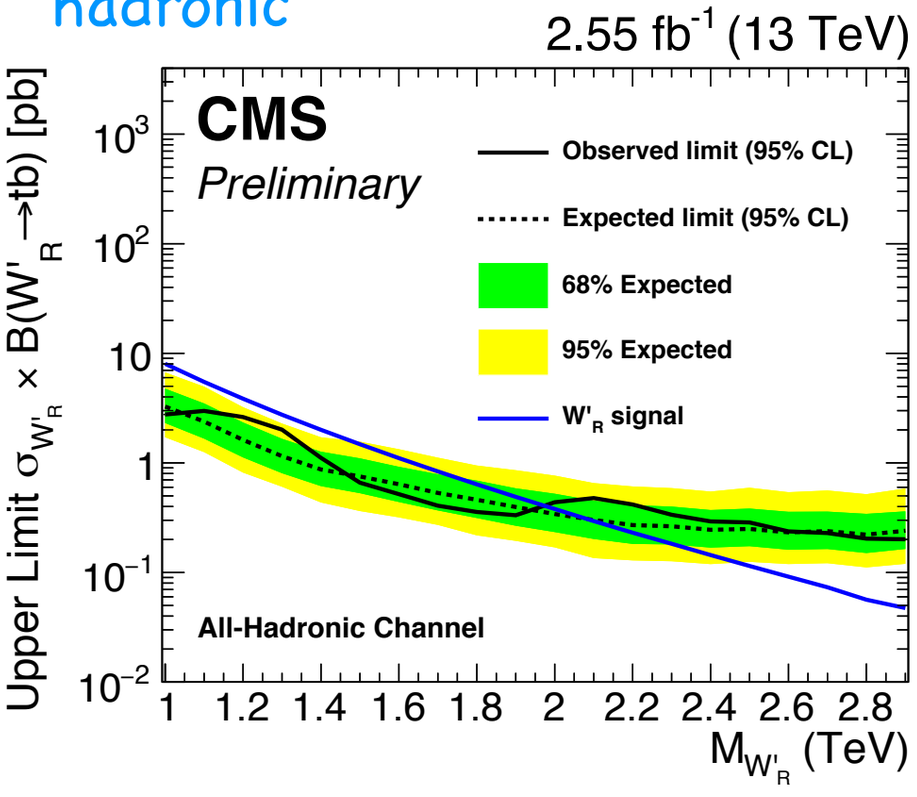
Top in Massive Vector Boson Decays

Massive Charged Gauge Boson Decay to Top



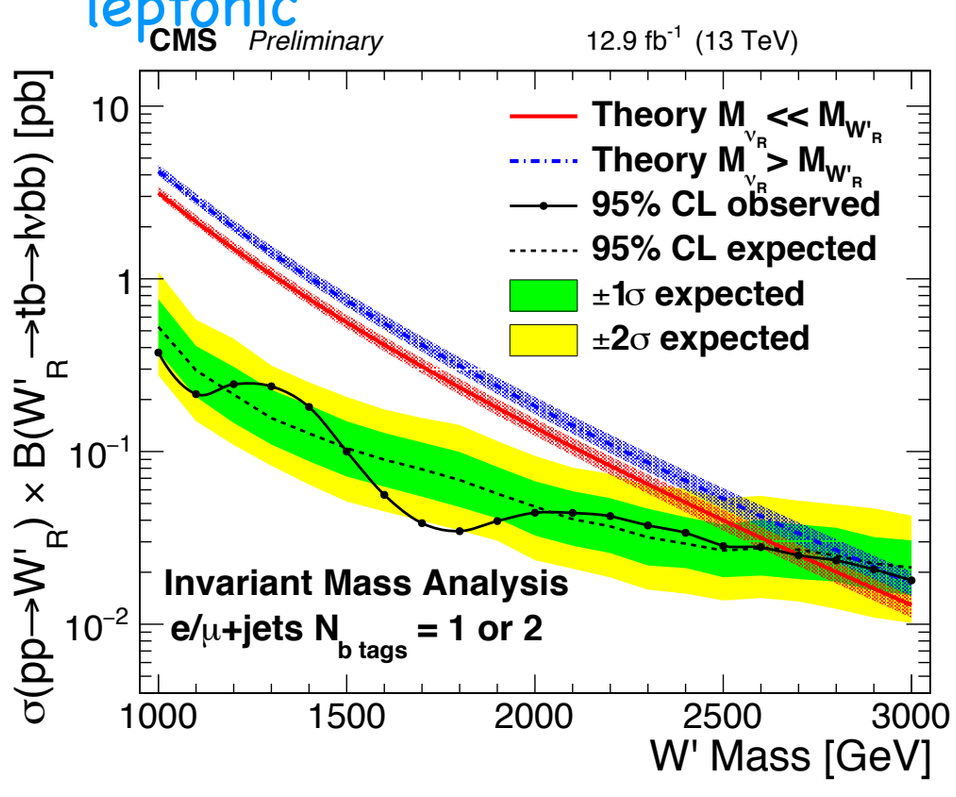
- W'->tb->qqbb and lepton plus jets final state
- tb invariant mass is reconstructed, search for excess over SM expectation.

hadronic



M(W'R) > 2.0 GeV

leptonic

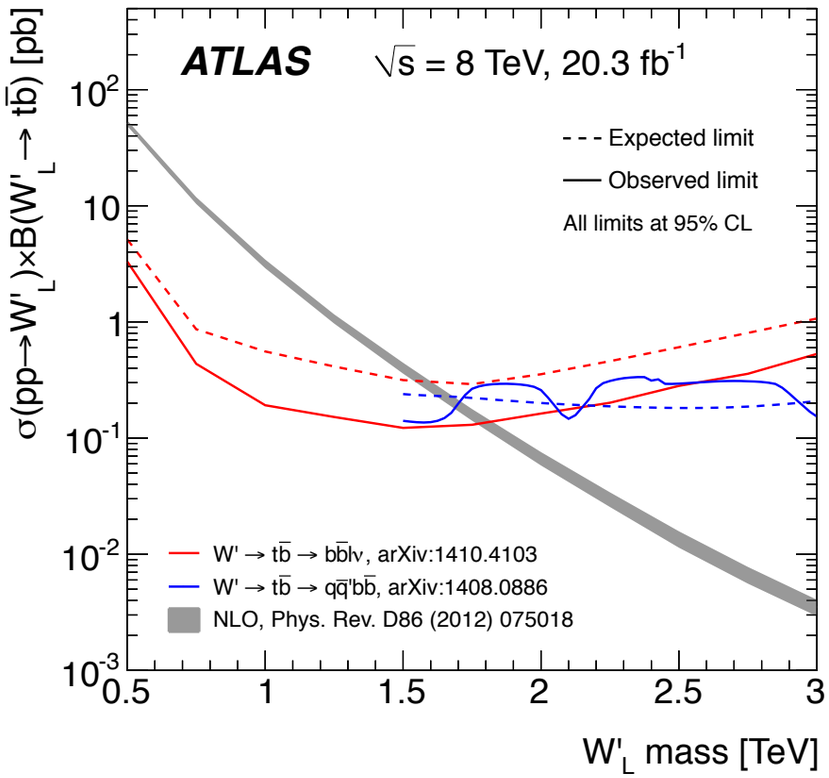


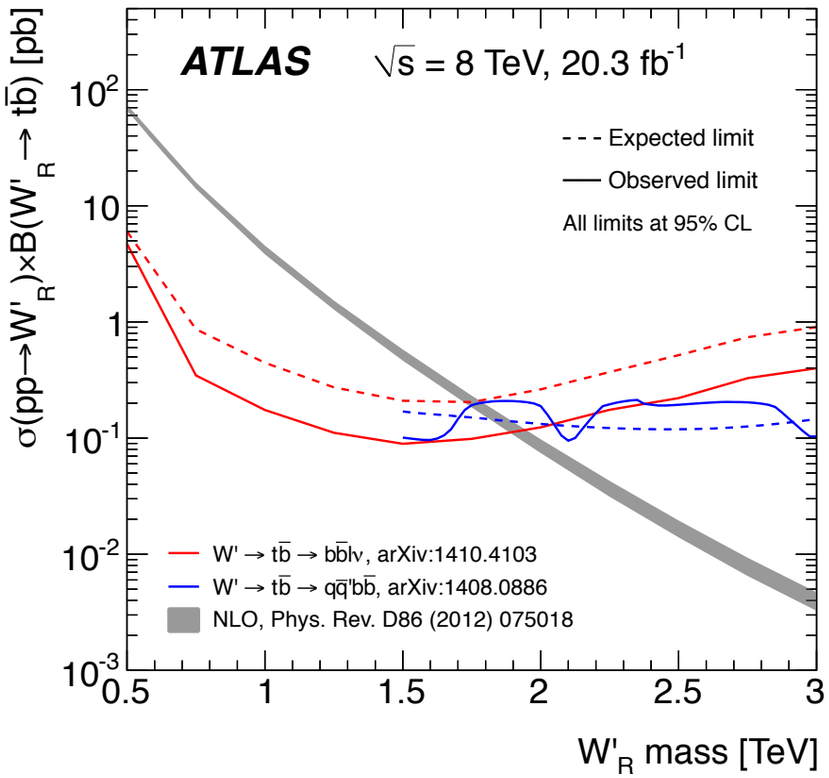
M(W'R) > 2.67 GeV

Refer: CMS PAS B2G-16-009, B2G-16-017

ATLAS Massive Charged Gauge Boson Decay to Top

- W'->tb in lepton plus jets and hadronic final states.
- No excess is observed in data over background within the mass range 0.5-3.0 TeV.
- BDT discriminant used to find exclusion limit.





$M_{W'} > 1.92$ TeV assuming right handed coupling

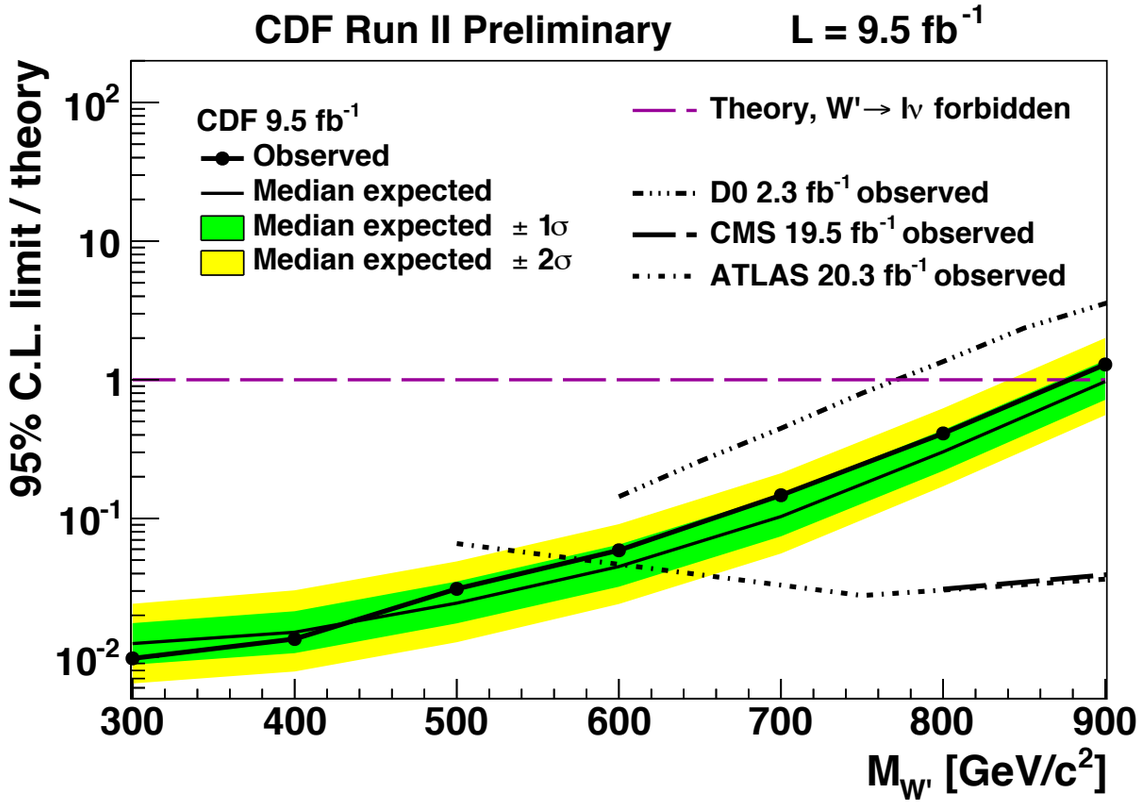
$M_{W'} > 1.8$ (1.7) TeV assuming left handed coupling, without (with) interference with SM tW

Refer: EPJC (2015) 75:165 and PLB 743 (2015) 235-255

TEVATRON

Massive Charged Gauge Boson Decay to Top

- Charged massive resonance $W^{+/-\prime}$->tb, when t->Wb->lνb.
- Events categorized by jet multiplicities and presence of e/mu.
- MVA discriminant is used for analysis.



$M_{W'}$ > 860 GeV
for right handed W'

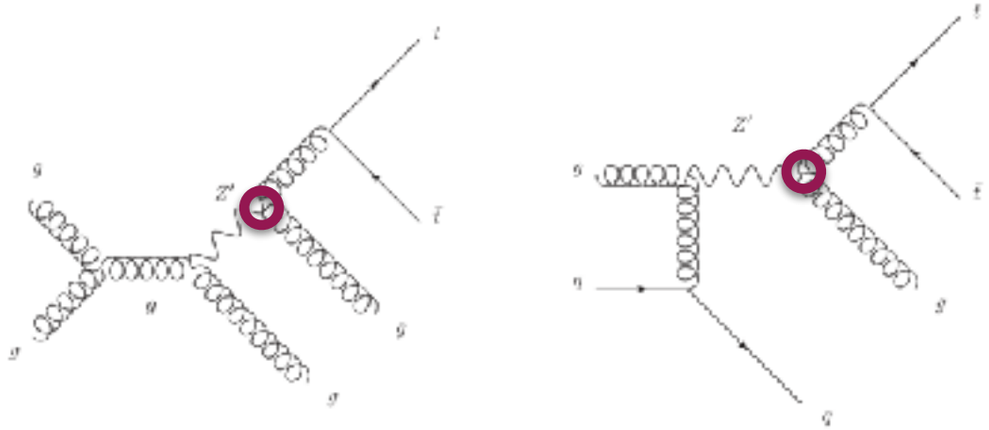
Refer: PRL 115 061801 (2015)

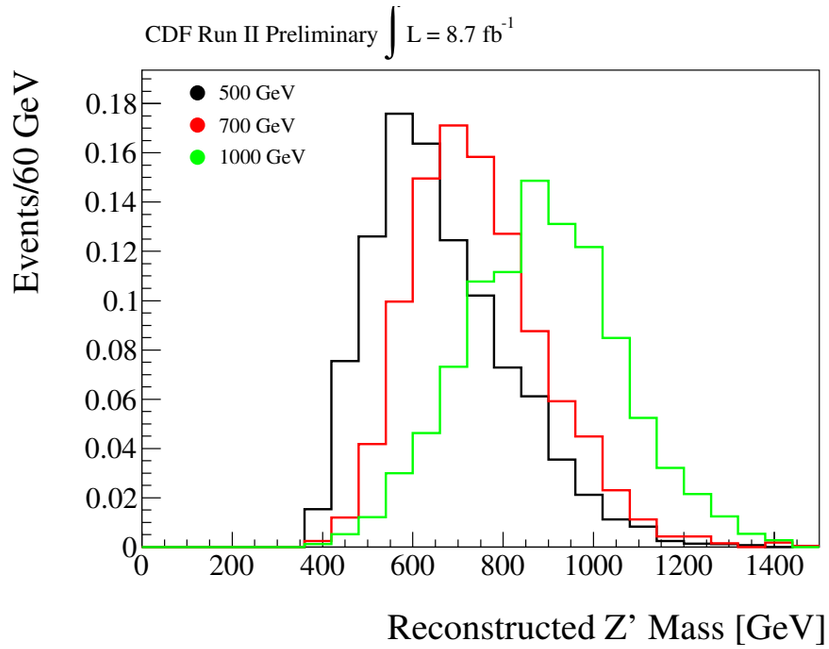
TEVATRON

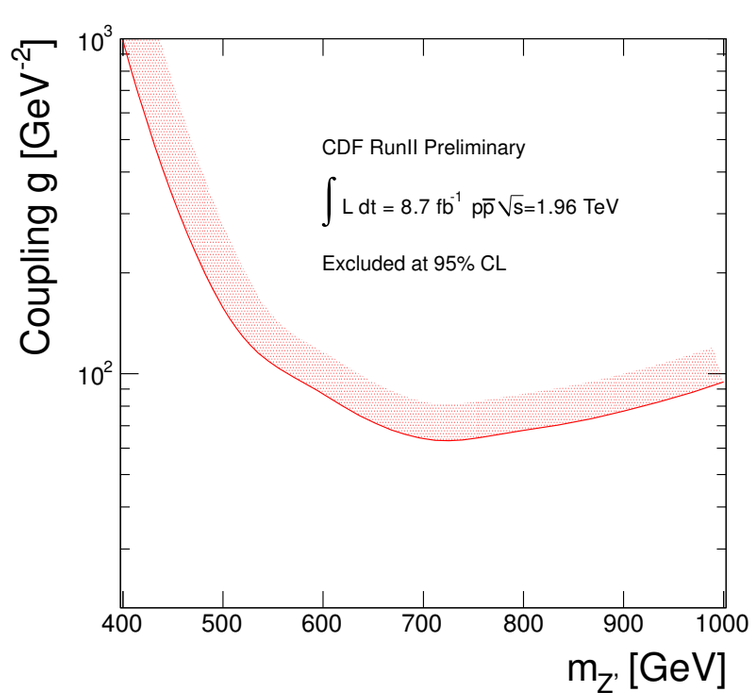
Chromophilic Heavy Gauge Boson

- Z′->g*g, where g*->$t\bar{t}$, leading to the $t\bar{t}g$ final state.

- Z′ mass reconstructed in semi-leptonic final state.







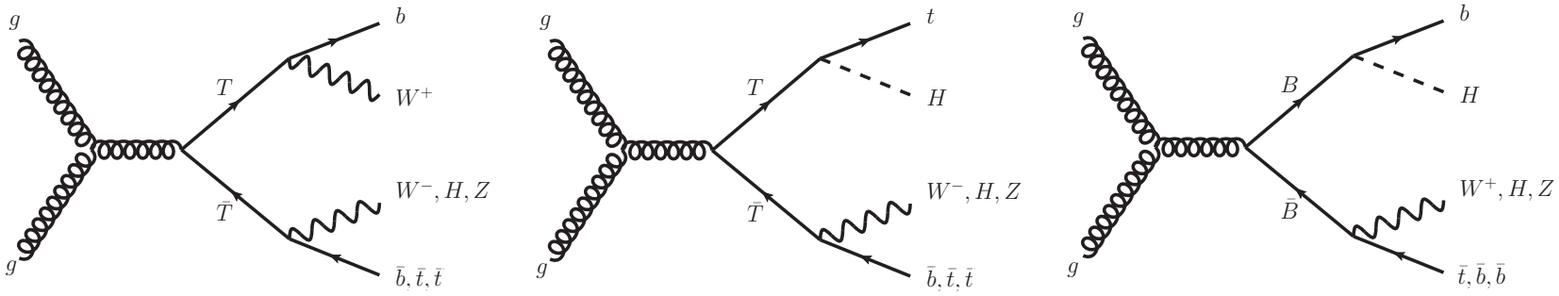
40 fb < σ < 300 fb
for resonances with mass
500-1000 GeV/c^2.

Refer: PRD 86 112002

Search for Vector Like Quarks and Invisible Particles

Search for VLQs

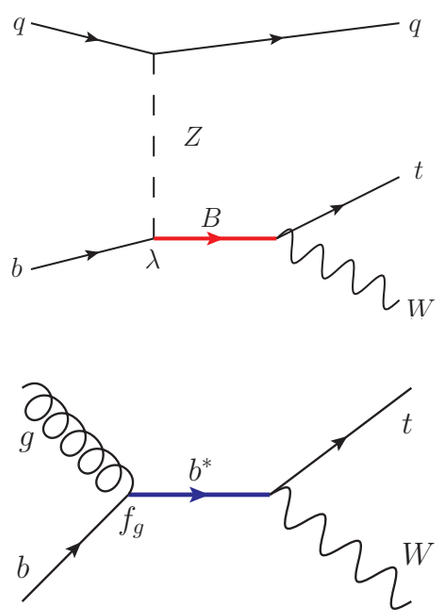
- Pair produced VLQs decaying via $T\bar{T}$->Ht+X, $T\bar{T}$->Wb+X, $B\bar{B}$->Hb+X in the lepton plus jets final state.

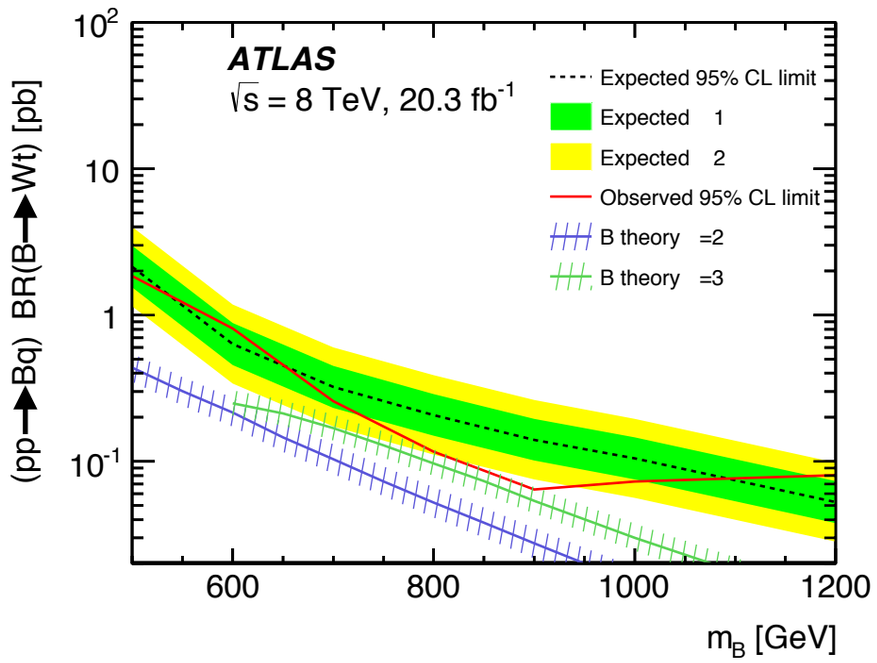


M_T > 730-950 GeV

M_B > 575-813 GeV

- Singly produced VLQs or excited quarks decaying through top quark.





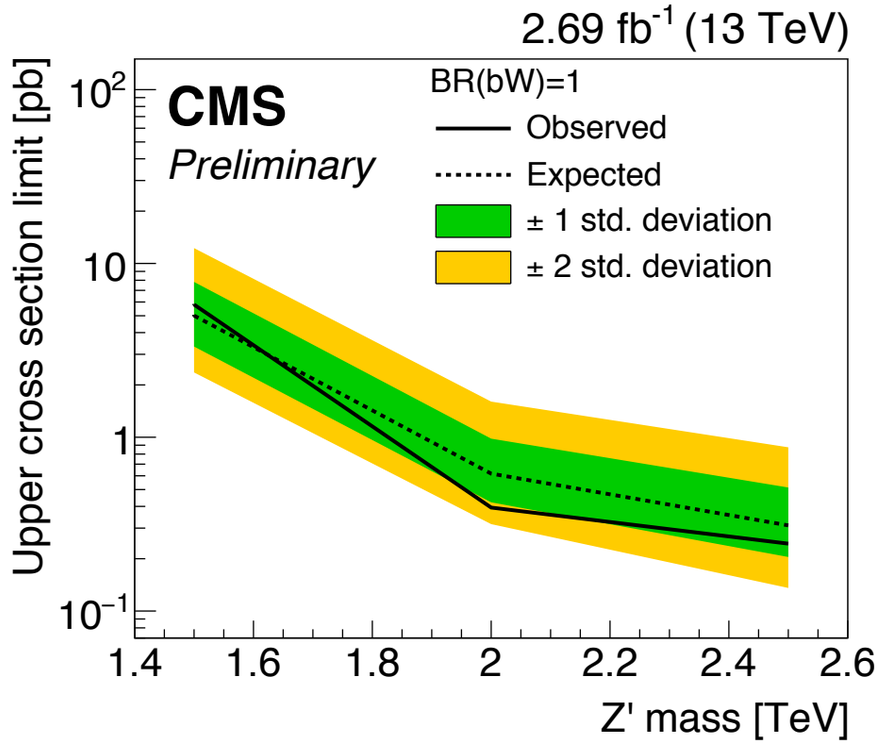
M_{b^*} > 1.5 TeV

Refer: JHEP 08 (2015) 105, JHEP 02 (2016) 110

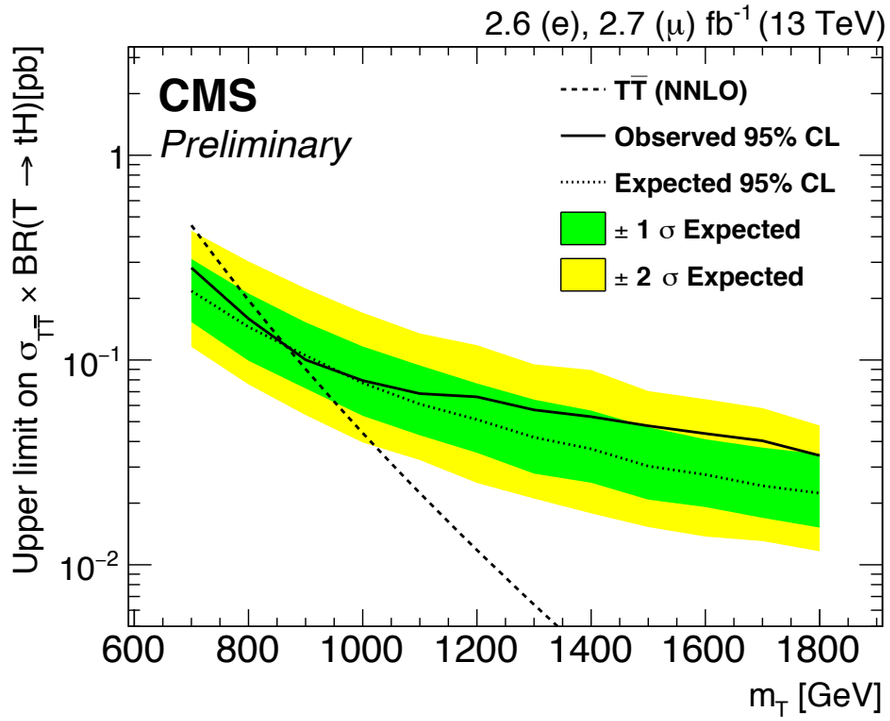
Search for VLQs

- Z'->T't->WbWb, where T' is a heavy vector like top partner.

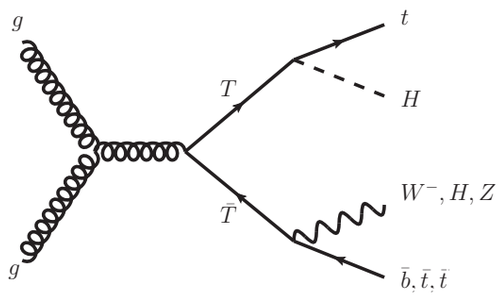
- T' and Z' invariant mass reconstructed in all hadronic final state.



σ < 0.13–11 pb



- Pair produced VLQs decaying via TT̄->Ht+X.



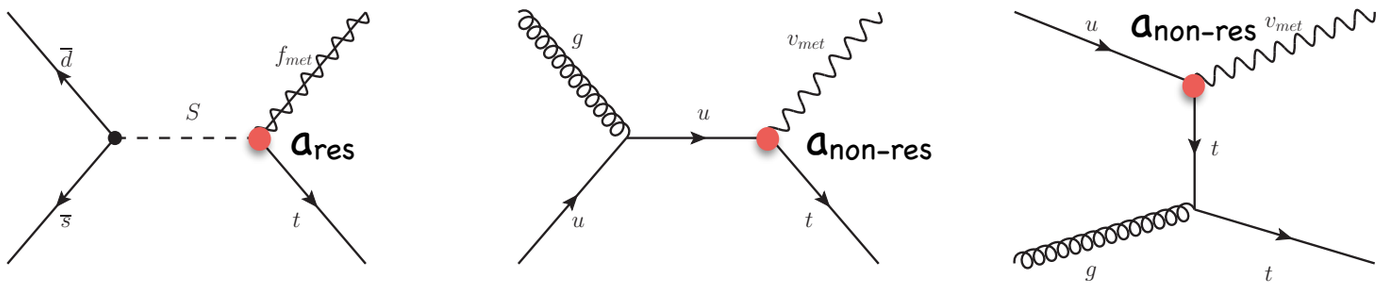
M_T > 860 GeV

Refer: CMS PAS B2G-16-011, B2G-16-013

Search for Invisible Particle Produced with Single Top Quark

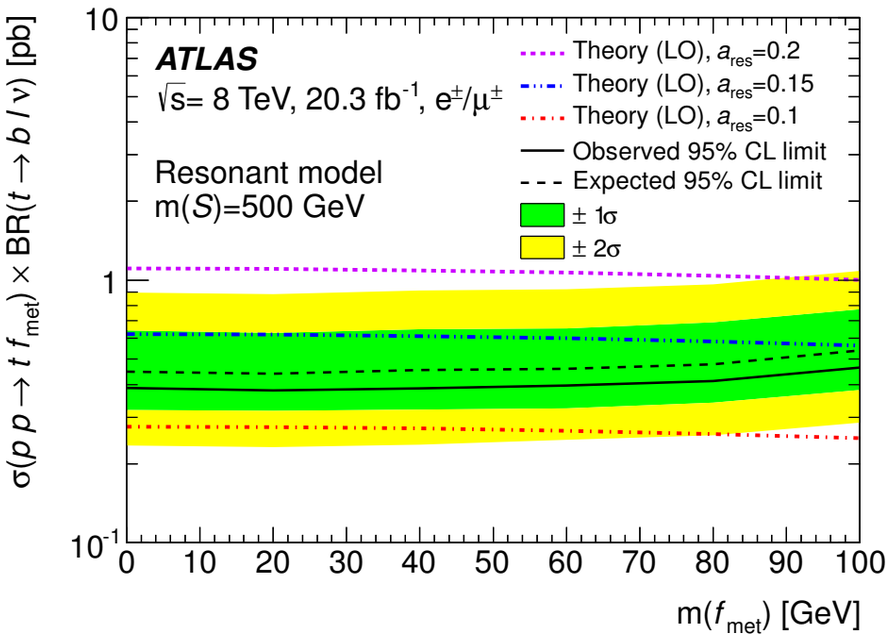
- Single top quark produced in association with MET studied in semi-leptonic final state.

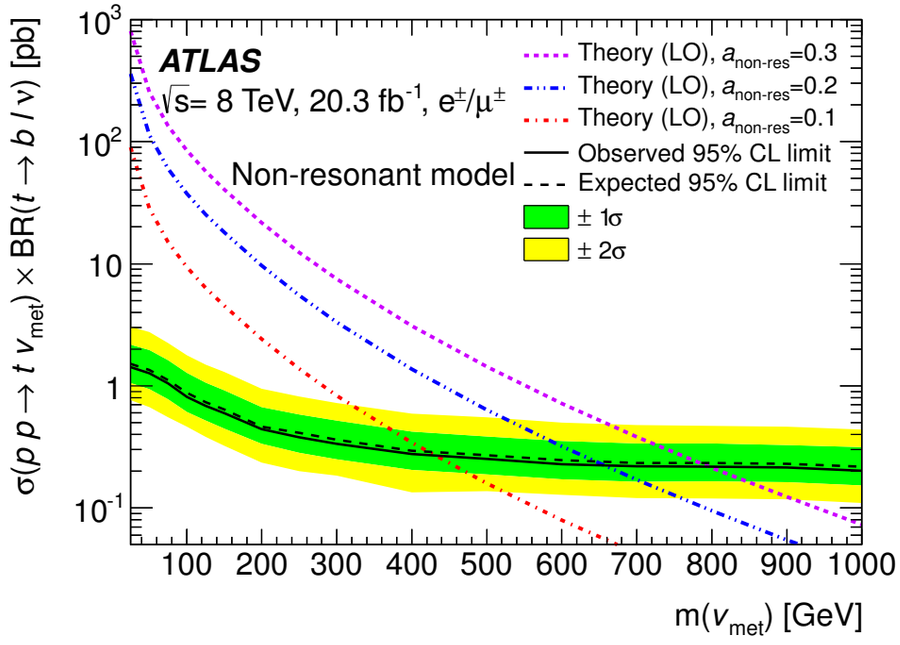
- Upper limits on production x-section are set.



a_{res} = 0.2 excluded up to $m(f_{met})$ = 100 GeV

$a_{non-res}$ = 0.2 excluded up to $m(v_{met})$ = 657 GeV

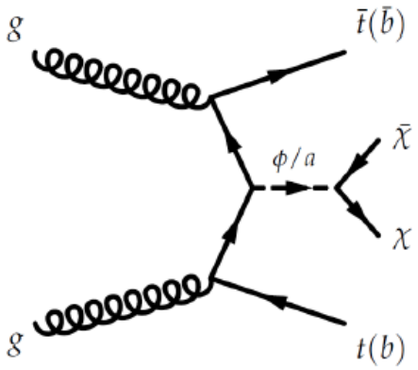


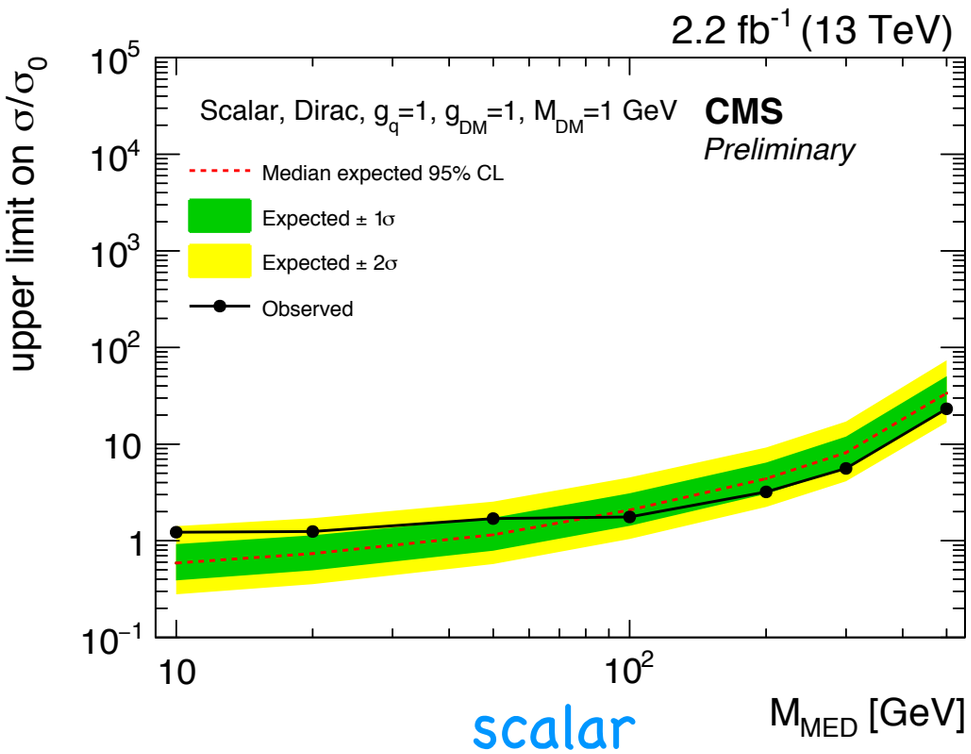


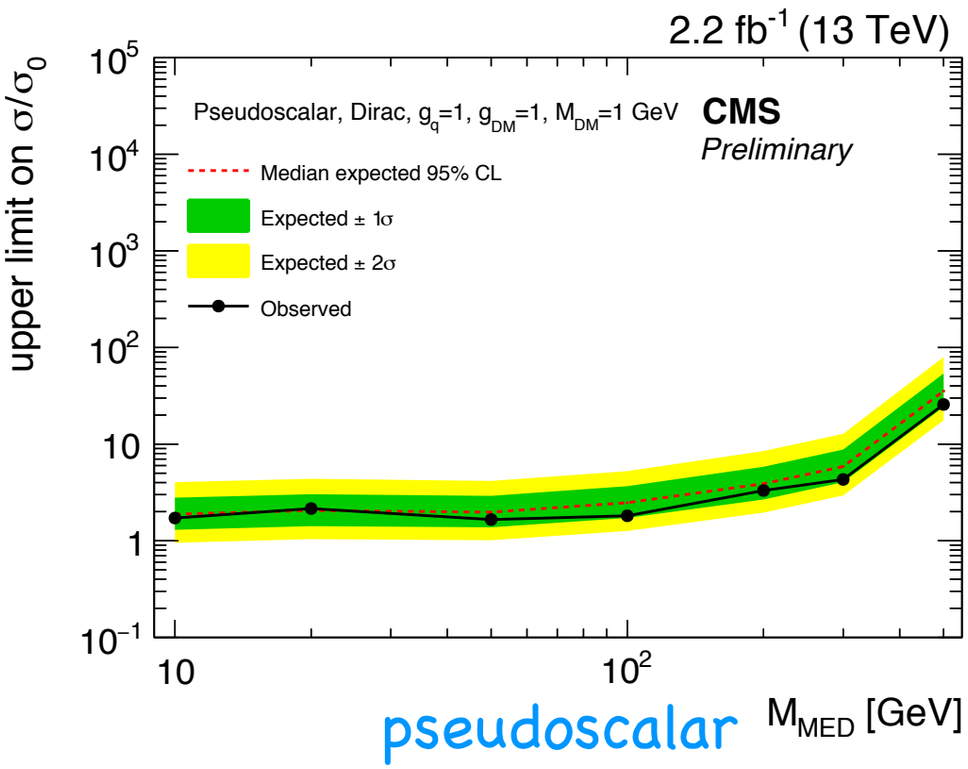
Refer: EPJC (2015) 75:79

Production of Dark Matter with Top pair

- Dark matter particle produced in association with top quark pair.
- Dilepton final state.







M(φ/a) > 39 GeV,
with M(DM) = 1 GeV and $g_q = g_{DM} = 1$

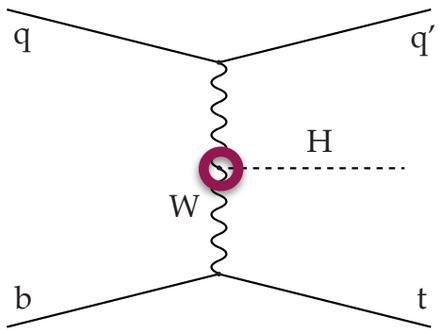
Refer: CMS PAS EXO-16-028

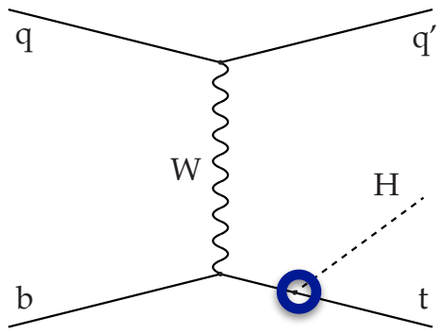
Search for Anomalous Couplings and Four Tops

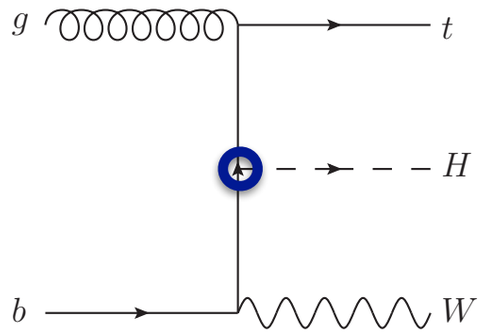
CMS ATLAS Higgs Production with Single Top

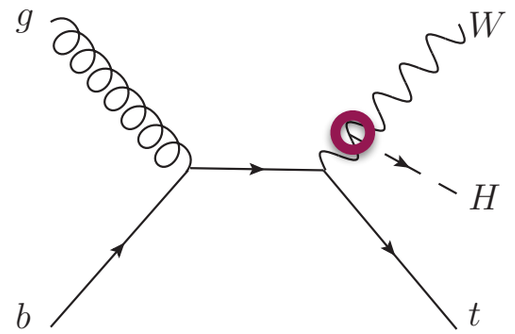
- Higgs production with a single top studied in both experiments to find deviations in couplings as predicted by SM.

- Interference between contributing diagrams -> hints at anomaly.

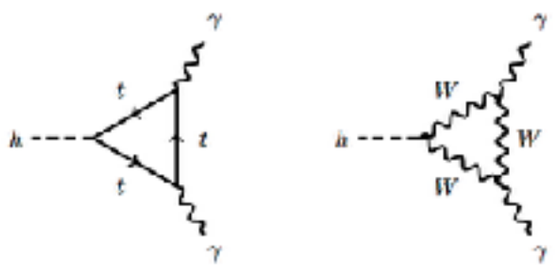


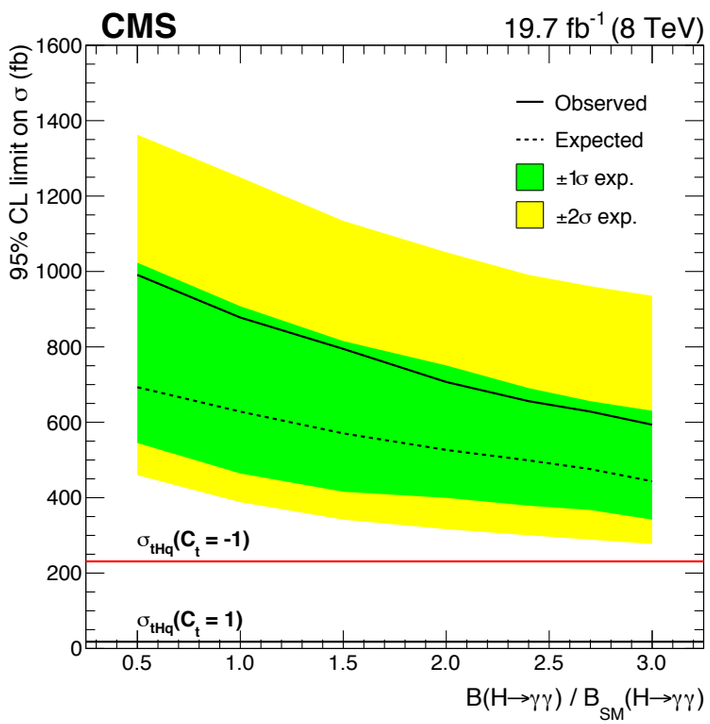




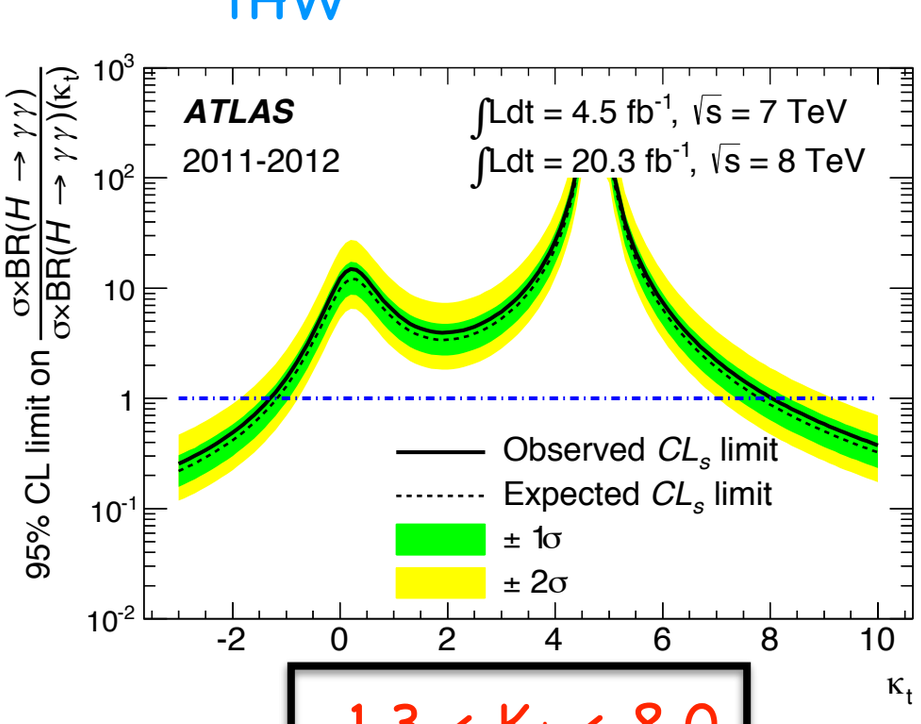


tHq





tHW

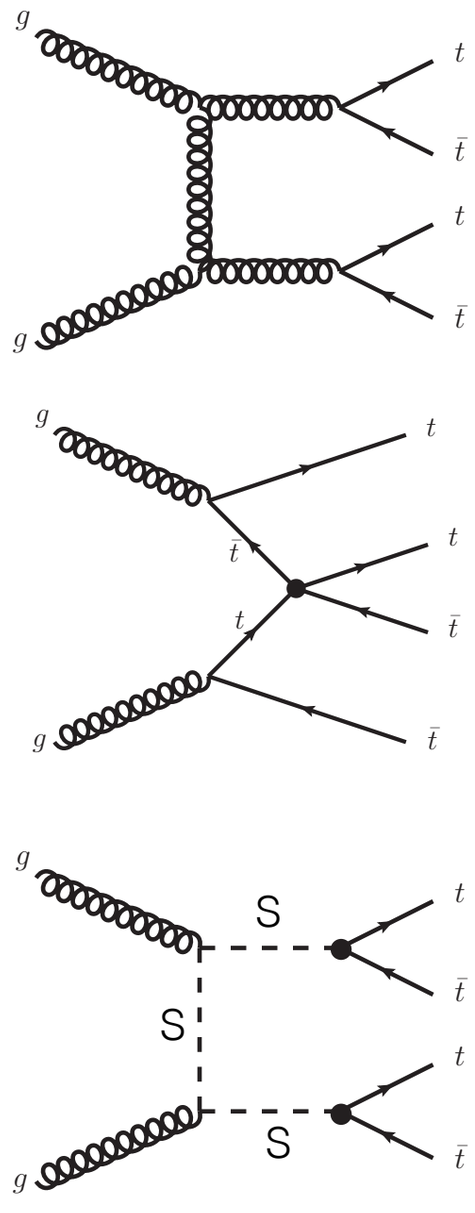


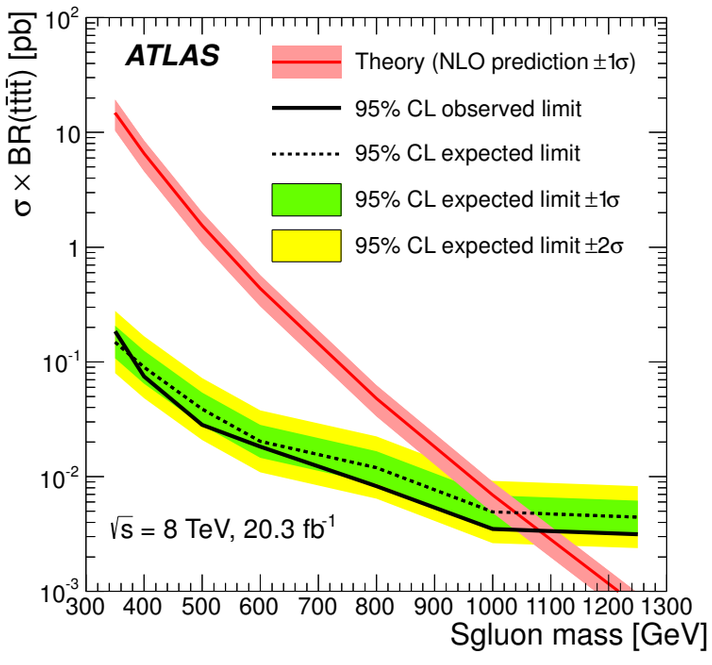
-1.3 < K_t < 8.0

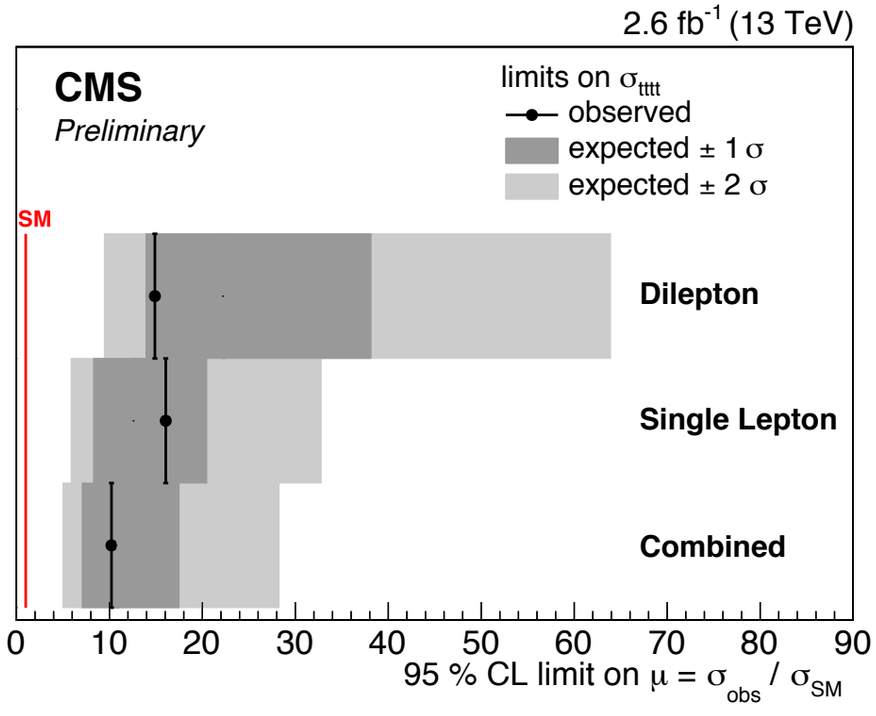
Refer: JHEP 06 (2016) 177,
PLB 740 (2015) 222-242

Production of Four Tops

- $t\bar{t}t\bar{t}$ production (σ_{SM}~1 fb at 8 TeV) in lepton plus jets final state
- ATLAS limit on cross section: ~23σ_{SM}
- CMS limit on cross section at 13TeV: ~10σ_{SM}







Refer: JHEP 08 (2015) 105, CMS PAS TOP-16-016

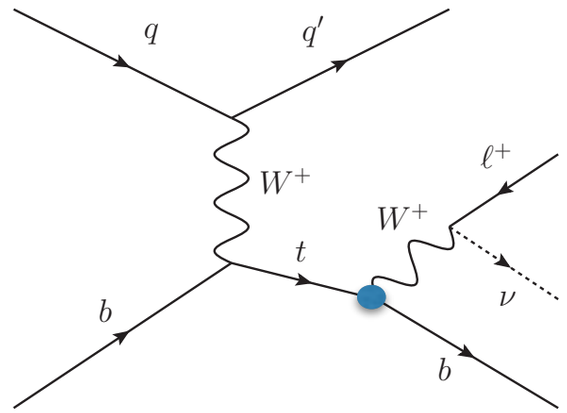
Anomalous Couplings to Gauge Bosons

ATLAS

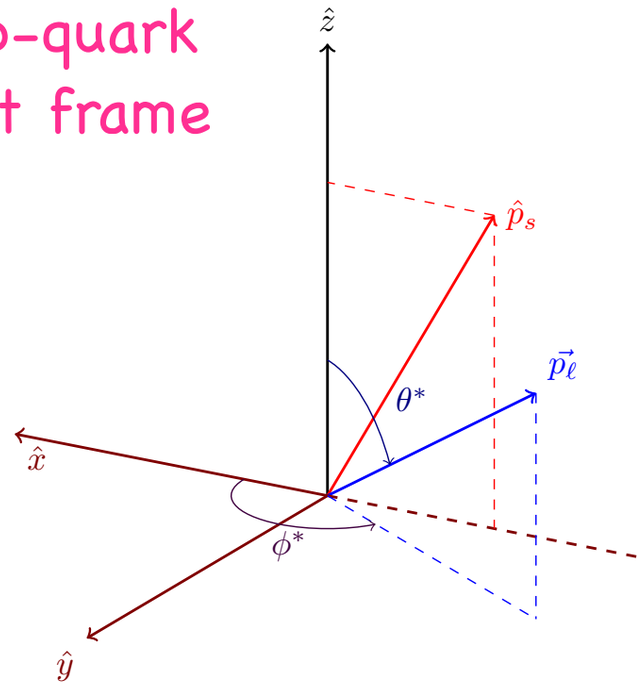
Anomalous Wtb Coupling

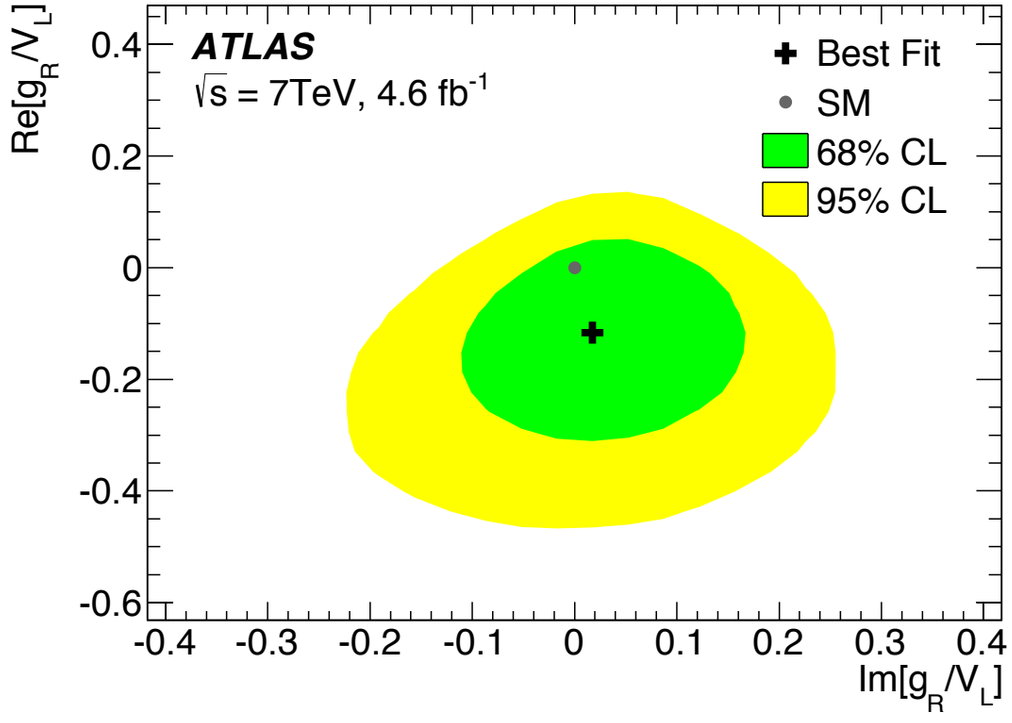
- Study of the angular properties of the top decay products to constraint the polarization fractions.

- Final state: exactly one charged light lepton, exactly one b tagged jet and exactly one untagged jet.



top-quark rest frame



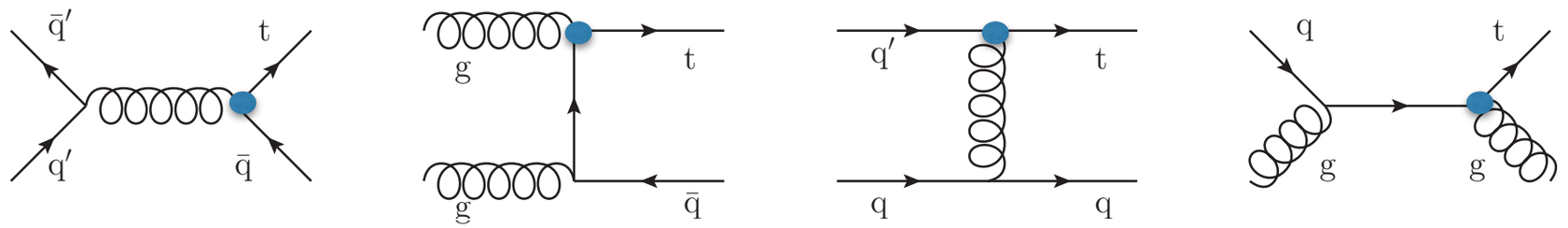


Watch out for Run II analysis.

Refer: JHEP 04 (2016) 023

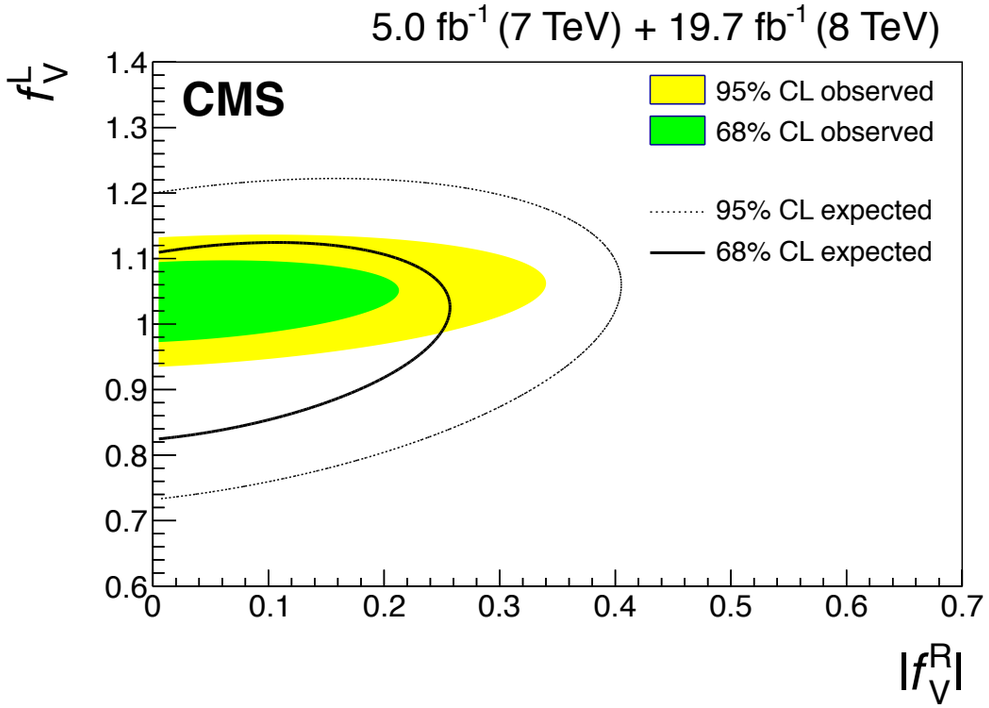
Anomalous Wtb Coupling

- Single top production in t-channel or in FCNC with one muon and two/three jets in the final state -> Bayesian Neural network analysis.



$$L = (g/\sqrt{2})\bar{b}\gamma^{\mu}(f^{L}_{V}P_{L}+f^{R}_{V}P_{R})tW^{-}_{\mu} - (g/\sqrt{2})\bar{b}(i\sigma^{\mu\nu}\partial_{\nu}W_{\mu}^{-}/M_{W})(f^{L}_{T}P_{L}+f^{R}_{T}P_{R})t$$

$$\sigma = ((f^{L}_{V})^{2}A_{p}+(f^{R}_{V})^{2}B_{p})BR(t\to l,\nu,b)$$



$BR(t\to ug) < 3.55\times10^{-4}(1.58\times10^{-4})$
$BR(t\to cg) < 3.44\times10^{-3}(1.05\times10^{-3})$

Limits on anomalous coupling:
$f^{L}_{V} > 0.98$, $|f^{R}_{V}| < 0.16$,
$|f^{L}_{T}| < 0.057$, $-0.049 < f^{R}_{T} < 0.048$

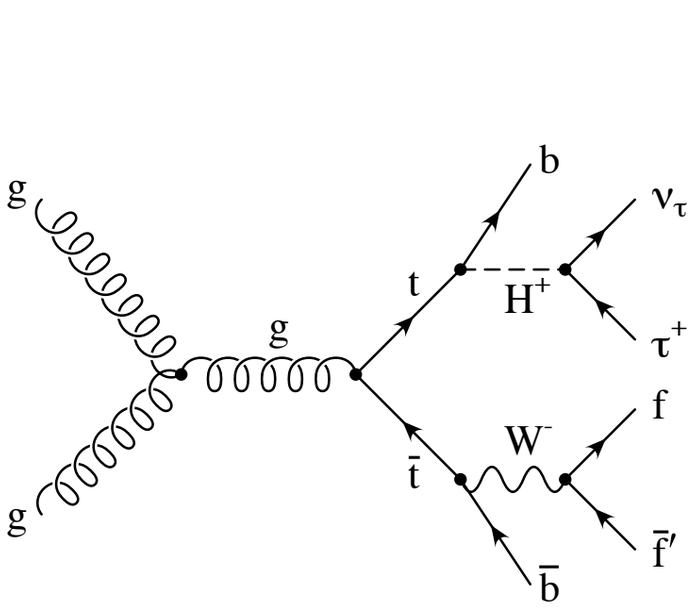
Refer: CMS PAS TOP-14-007

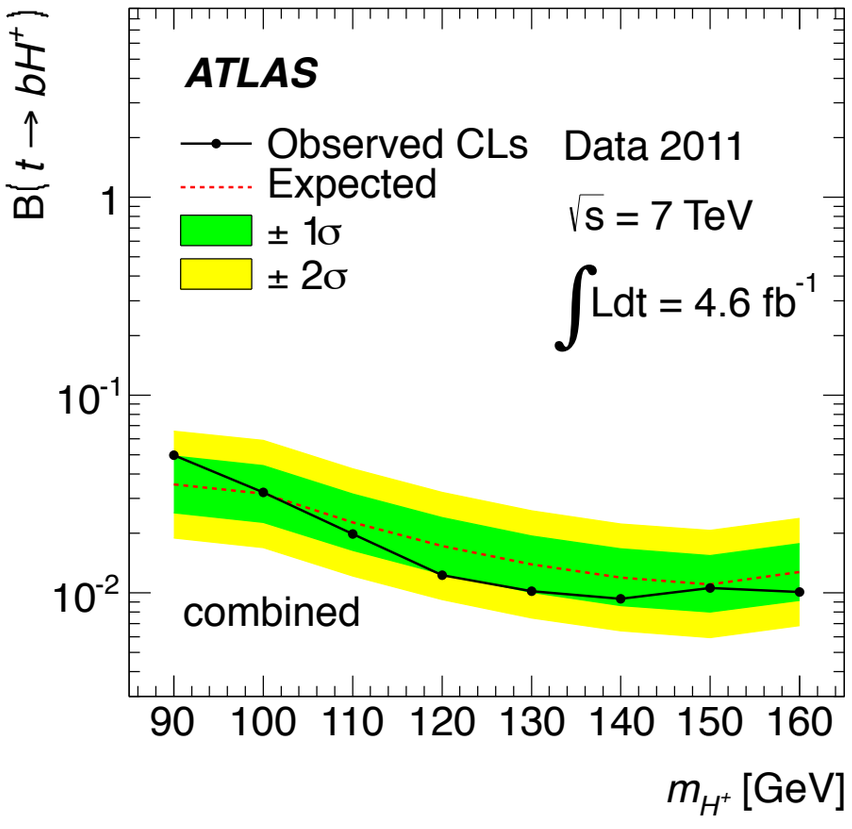
Top Decays to Light Charged Higgs

Light Charged Higgs in Top Decay

- $t\bar{t}$ production with one t->Wb, another t->H^+b, with H^+->$\tau\nu$.

- Three final states with different decay combinations of W and τ (all hadronic, semi-leptonic, fully leptonic).



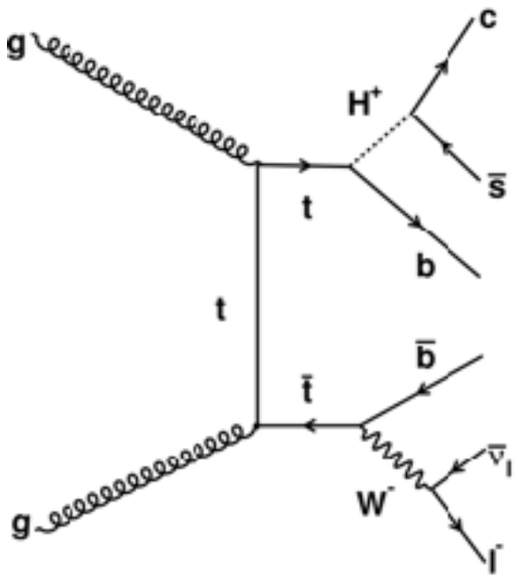


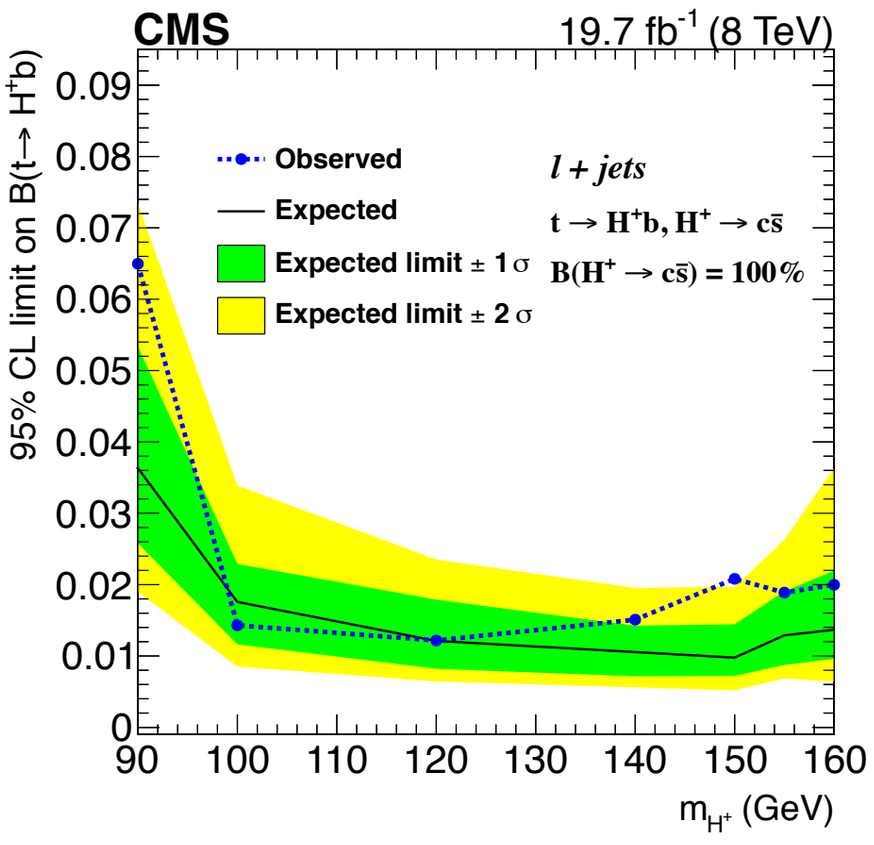
BR(t->H^+b) < 0.01-0.05
assuming BR(H^+->$\tau\nu$)=1

Refer: JHEP 06 (2012) 039

Light Charged Higgs in Top Decay

- $t\bar{t}$ production with one t->Wb, another t->H^+b, with H^+->$c\bar{s}$.
- Final state: isolated lepton, at least four jets and large MET.





BR(t->H^+b) < 0.012-0.065
assuming BR(H^+->$c\bar{s}$)=1

Refer: JHEP 12 (2015) 178

Summary

- Top events at hadron colliders are great place to search for new physics.
- Results from mainly Run I data are presented.
- Till now Standard Model holds strong.
- Large statistics will improve the measurements.
- Stay tuned for Run II results!

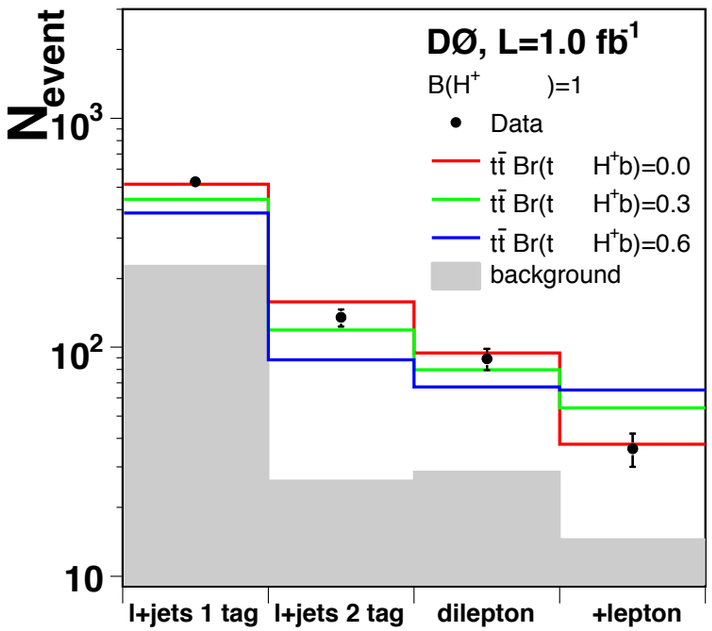
Thank You.

Back Up

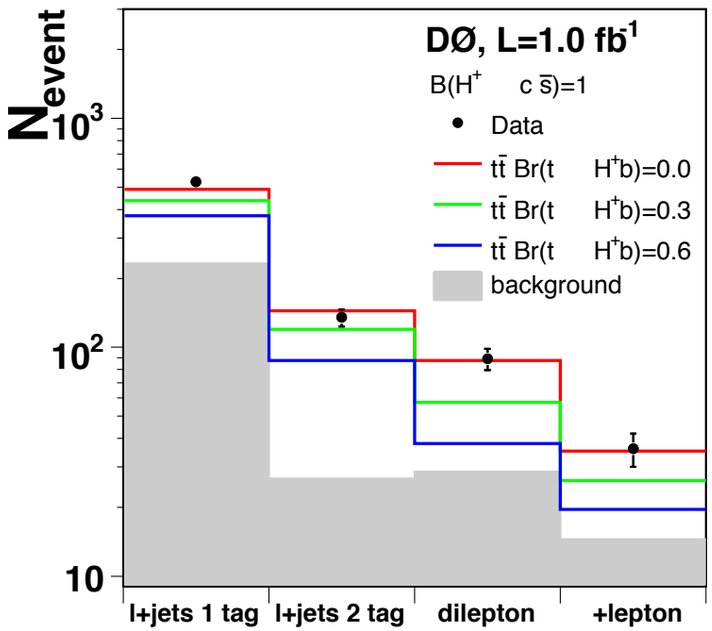
TEVATRON

Light Charged Higgs in Top Decay

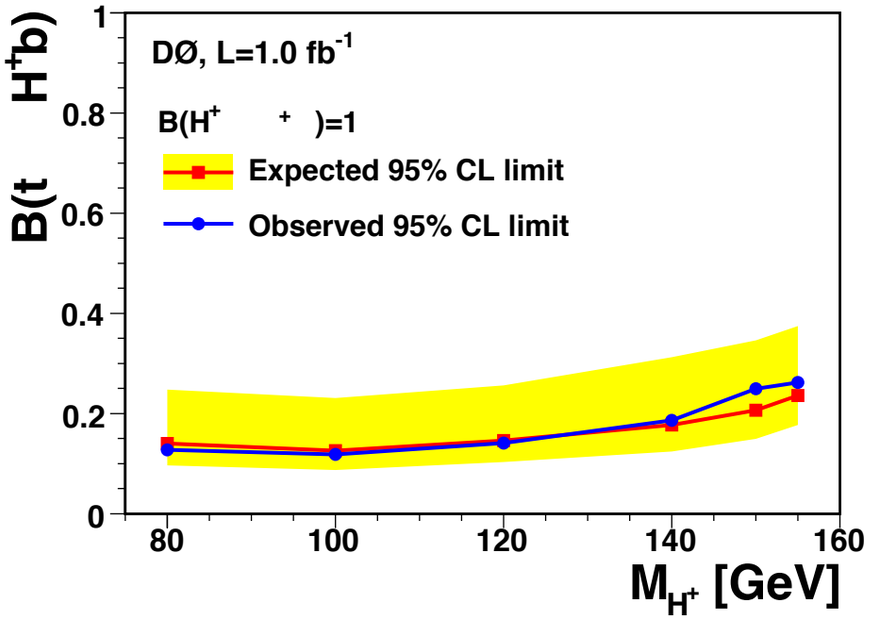
- $t\bar{t}$ production with one top decaying through t->Wb, another t->H^+b.
- H^+->$c\bar{s}$, H^+->$\tau\nu$ channels.



Purely tauonic H^+ decay
BR(t->H^+b) < 0.15-0.19



Purely hadronic H^+ decay
BR(t->H^+b) < 0.22

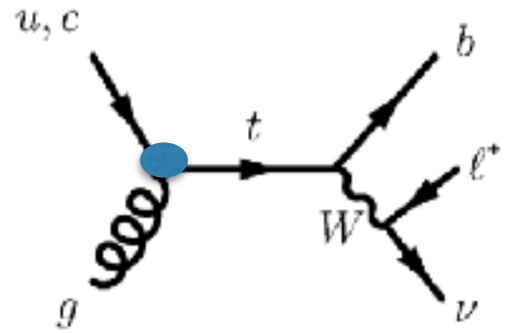


BR(t->H^+b) < 0.12-0.26

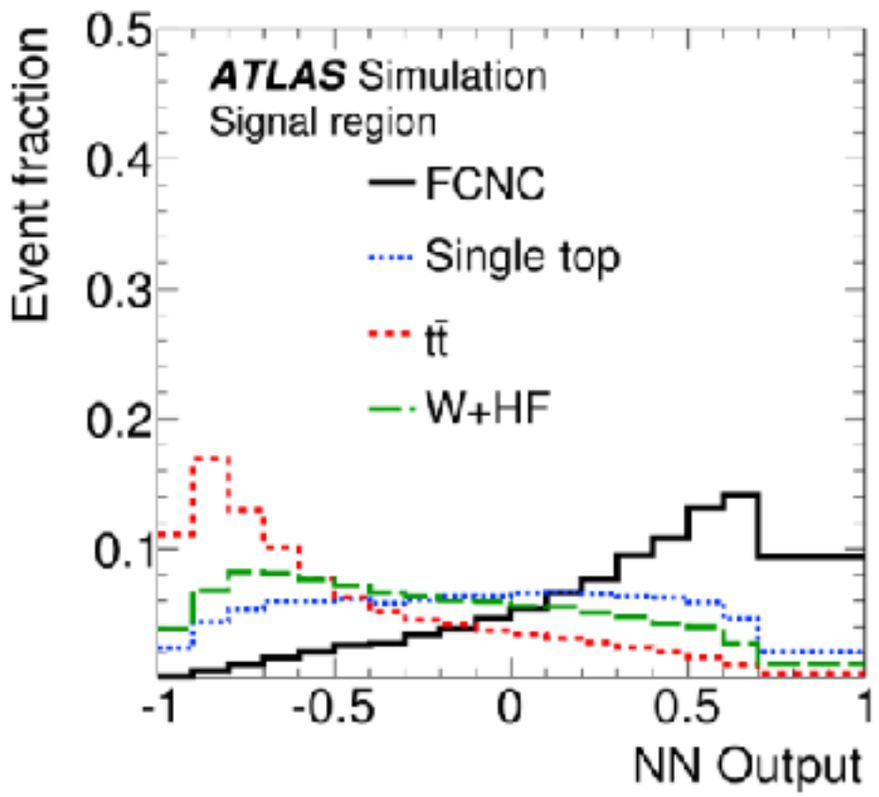
Refer: PLB 682, 278 (2009)

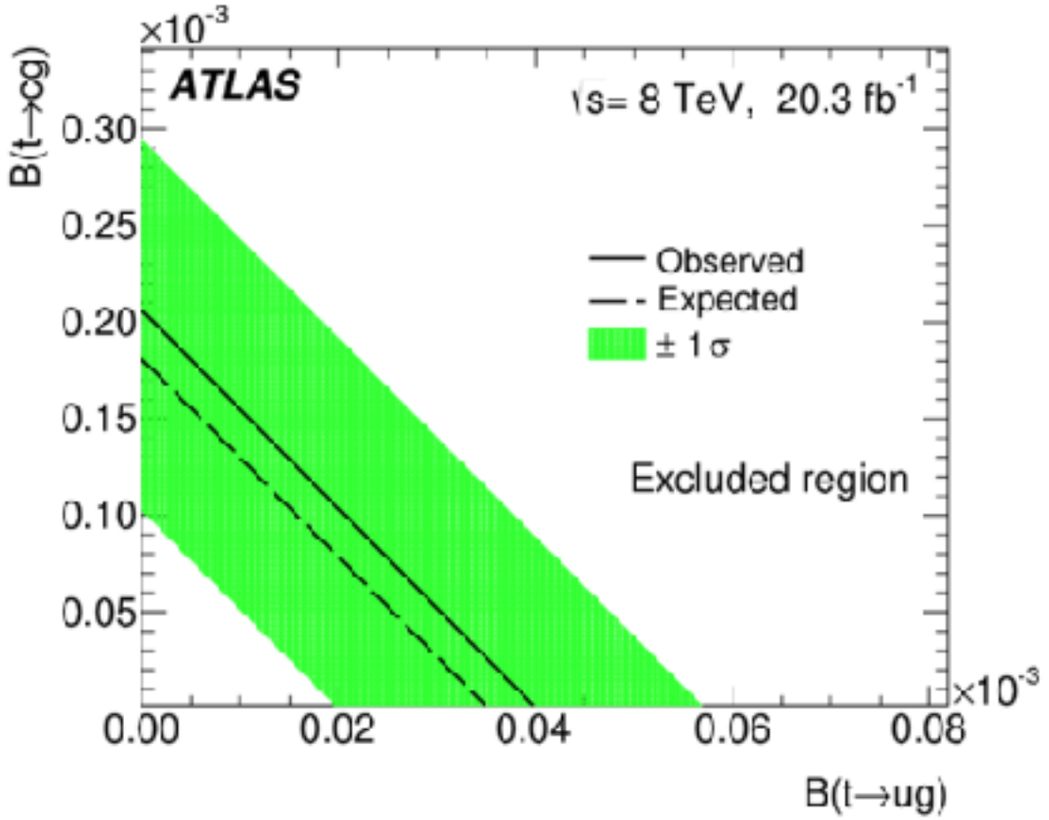
Single Top Production with FCNC

- Study in leptonic final state.



- Neural network analysis.



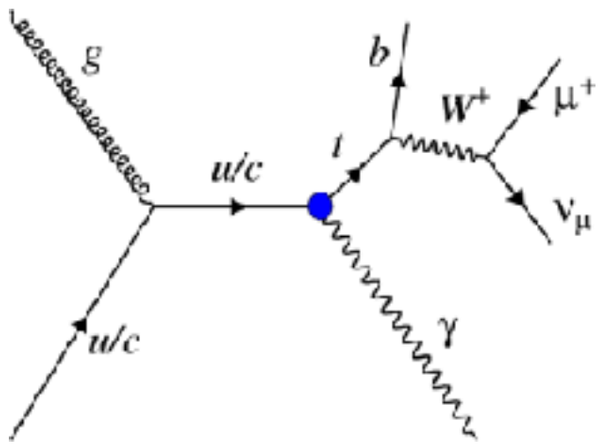


No significant rate of FCNC single top production is observed.
Upper limit is set on BR using Hypothesis test.

Refer: Eur. Phys. J. C (2016) 76:55

Anomalous Single Top Production with Photon

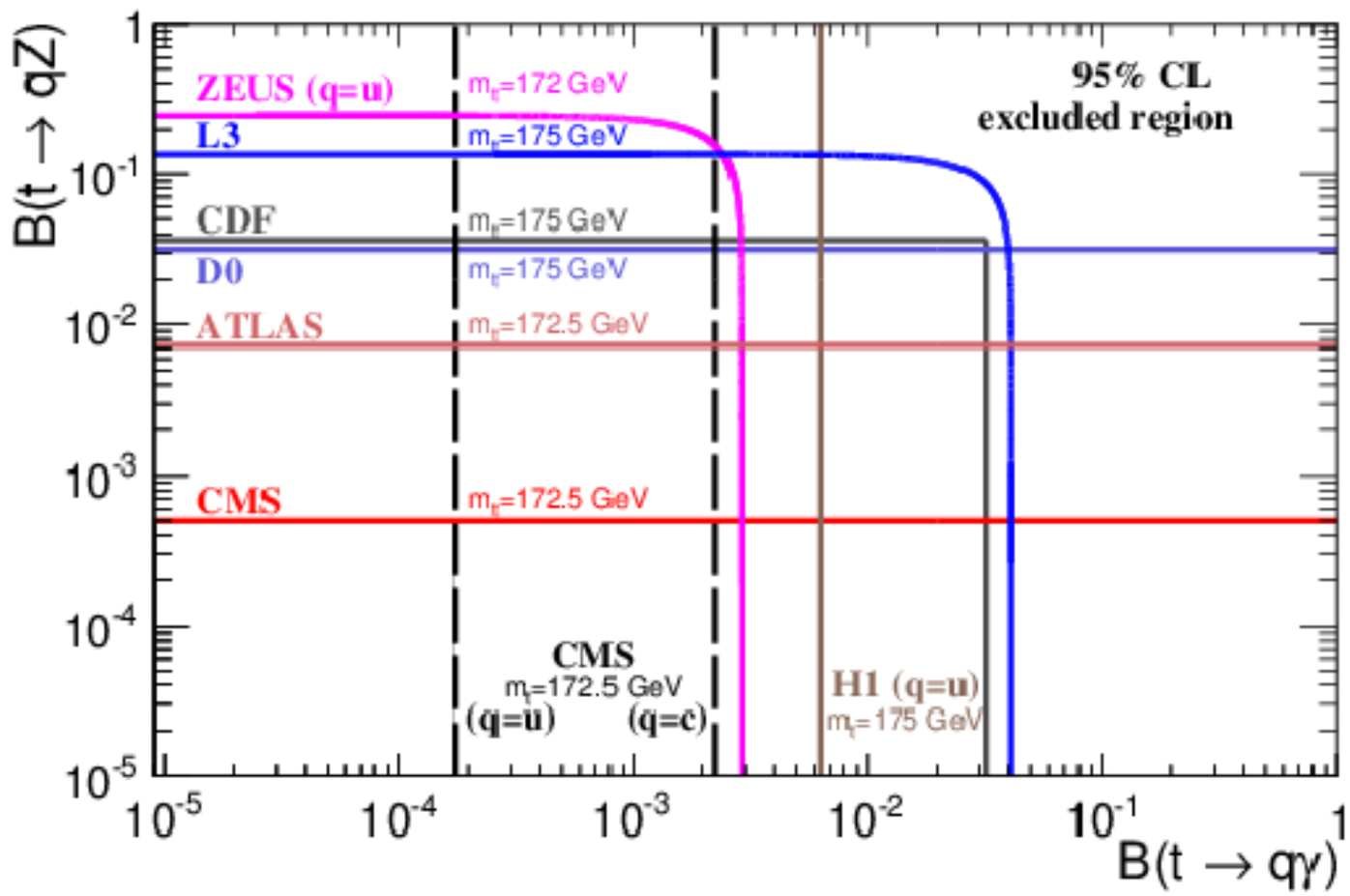
- Search for FCNC in single top production in association with γ.
- No evidence of the FCNC production is observed.
- Upper limit on $tu\gamma$ and $tc\gamma$ anomalous couplings.



Highest constraint put on BR.

$BR(t\to u\gamma) < 1.3\times10^{-4}$

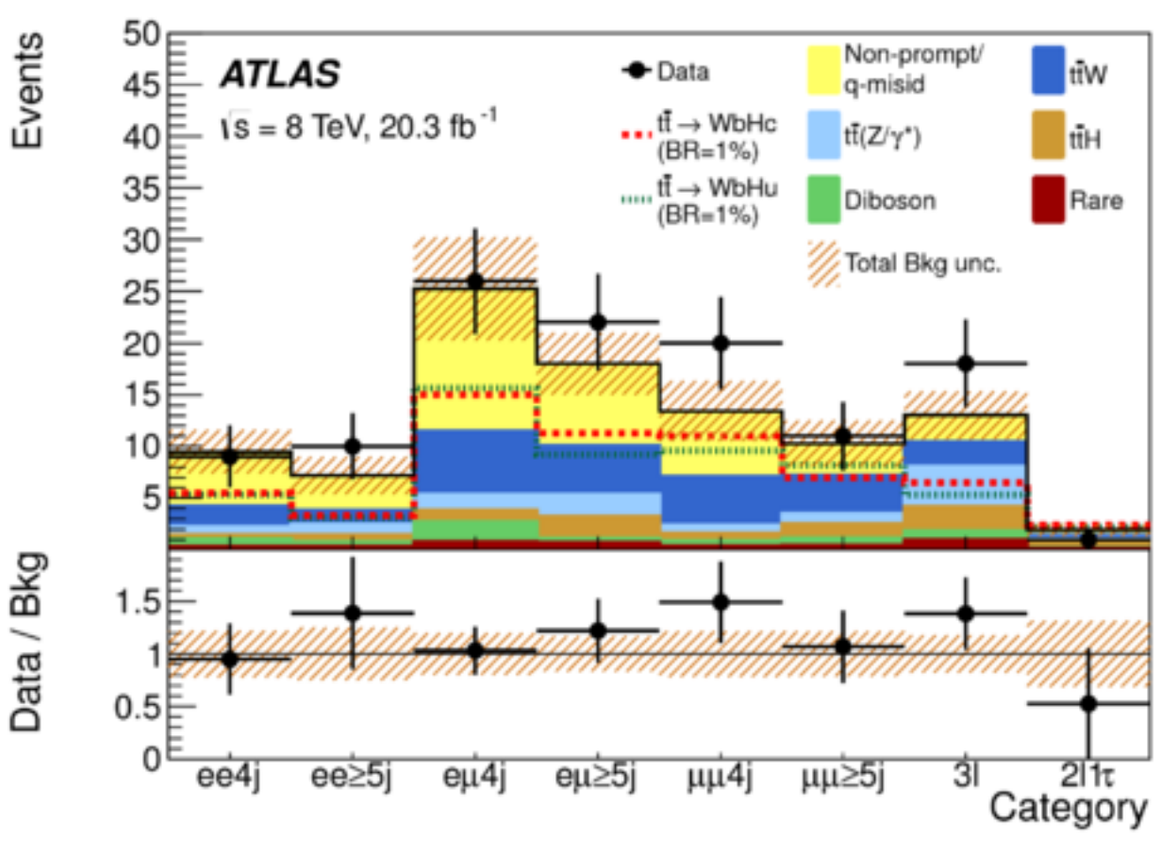
$BR(t\to c\gamma) < 1.7\times10^{-3}$

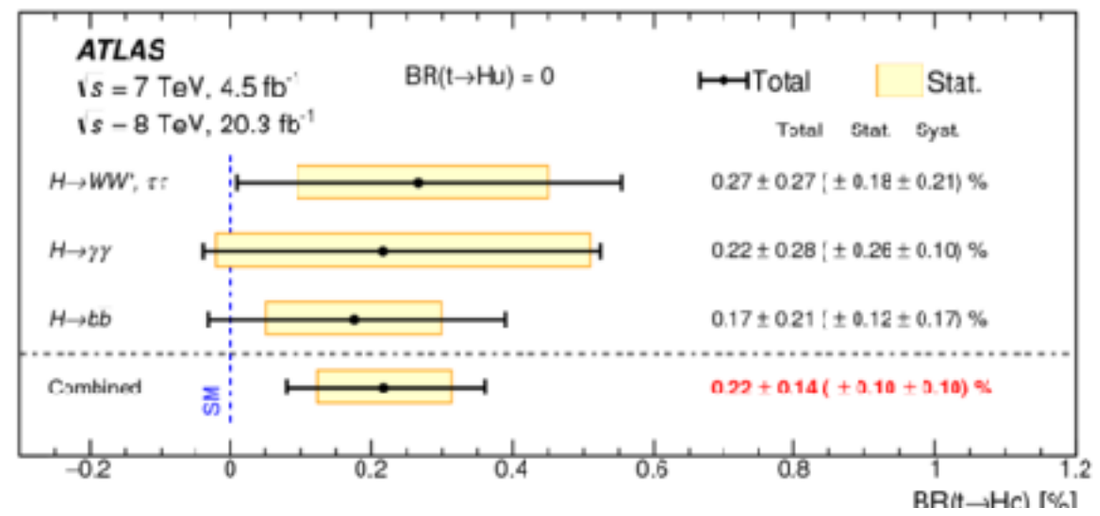


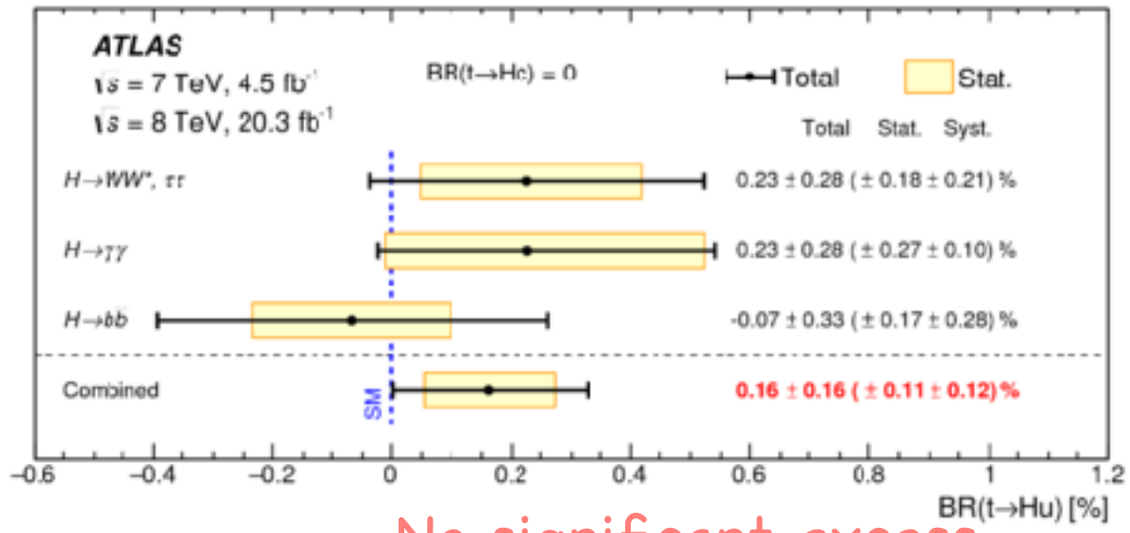
Refer: JHEP 04 (2016) 035

Top FCNC Decay to Hq

- Pair produced tt->WbHq, H->bb.
- Final state categorized based on number of jets and leptons.
- A discriminant based on probability is used to compare the shape of signal and background.







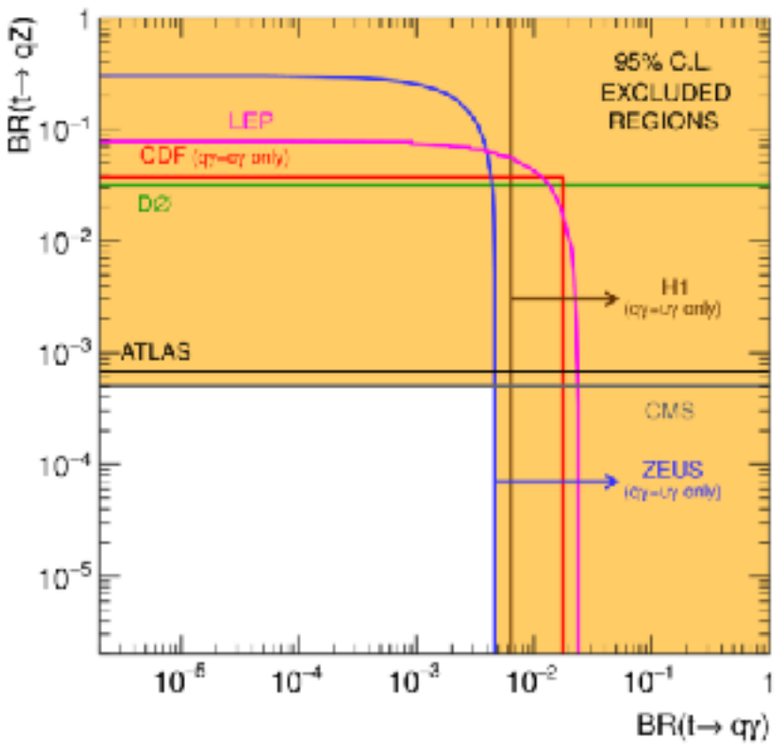
Refer: JHEP 12 (2015) 061

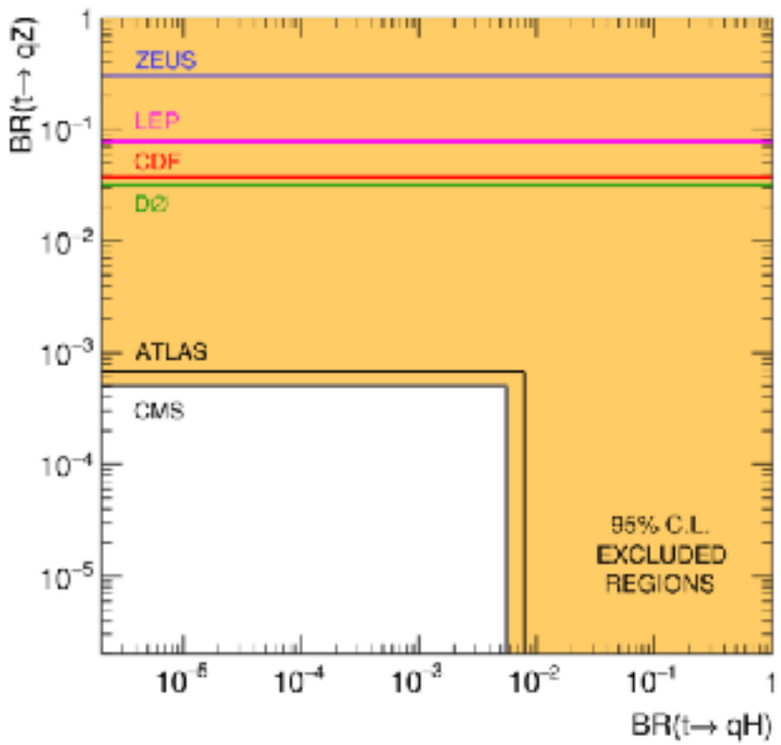
No significant excess.

ATLAS

Top FCNC Decay to Zq

- Pair produced tt->WbZq, with Z->ll, W->lν.
- Top and Z mass are reconstructed after final selection for comparing the data and expected SM background.
- Run I analysis statistics limited.
- Run II results expected soon.





Refer: EPJC 76 (2016) 12

No significant excess.

Top FCNC Decay to Hq

- Pair produced tt->HqWb, with H->WW, ZZ and $\tau\tau$ channels.

- Neural network analysis used.

	$\mathcal{B}_{obs}(t \to Hc)$	$\mathcal{B}_{exp}(t \to Hc)$	$\mathcal{B}_{exp}+\sigma$	$\mathcal{B}_{exp}-\sigma$
Trilepton	1.26	1.33	1.87	0.95
Same-sign dilepton	0.99	0.93	1.26	0.68
Multilepton combined	0.93	0.89	1.22	0.65
Diphoton hadronic	1.26	1.33	1.87	0.95
Diphoton leptonic	0.99	0.93	1.26	0.68
Diphoton combined	0.47	0.67	1.06	0.44
b jet + lepton	1.16	0.89	1.37	0.60
Full combination	0.40	0.43	0.64	0.30
	$\mathcal{B}_{obs}(t \to Hu)$	$\mathcal{B}_{exp}(t \to Hu)$	$\mathcal{B}_{exp}+\sigma$	$\mathcal{B}_{exp}-\sigma$
Trilepton	1.34	1.47	2.09	1.05
Same-sign dilepton	0.93	0.85	1.16	0.62
Multilepton combined	0.86	0.82	1.14	0.60
Diphoton hadronic	1.26	1.33	1.87	0.95
Diphoton leptonic	0.99	0.93	1.26	0.68
Diphoton combined	0.42	0.60	0.96	0.39
b jet + lepton	1.92	0.84	1.31	0.57
Full combination	0.55	0.40	0.58	0.27

$|\lambda^{H}_{tc}|^2 < 6.9\times10^{-3}$ and $|\lambda^{H}_{tu}|^2 < 9.8\times10^{-3}$

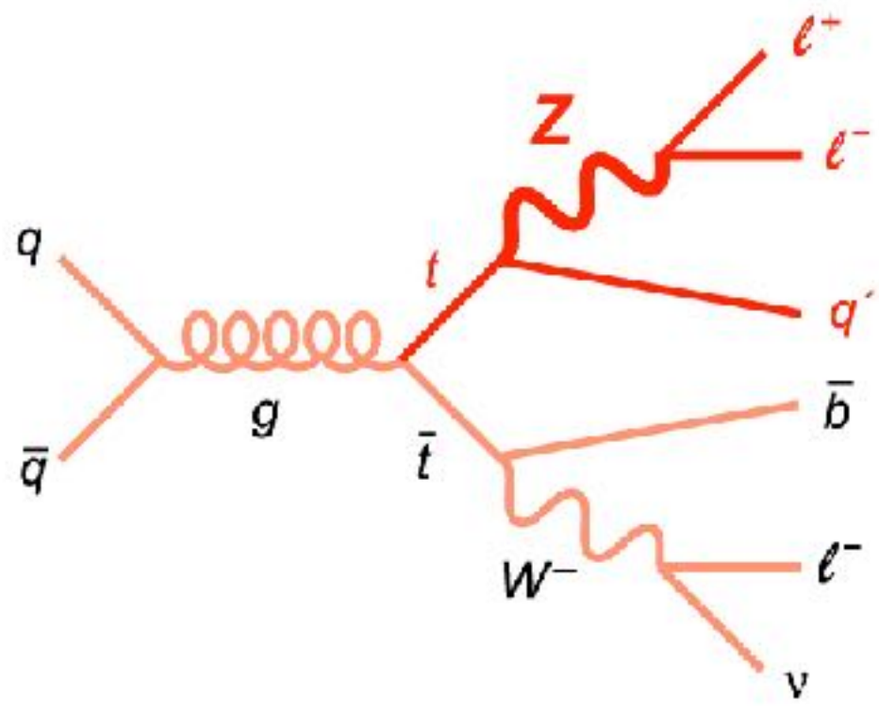
Refer: arXiv:1610.04857

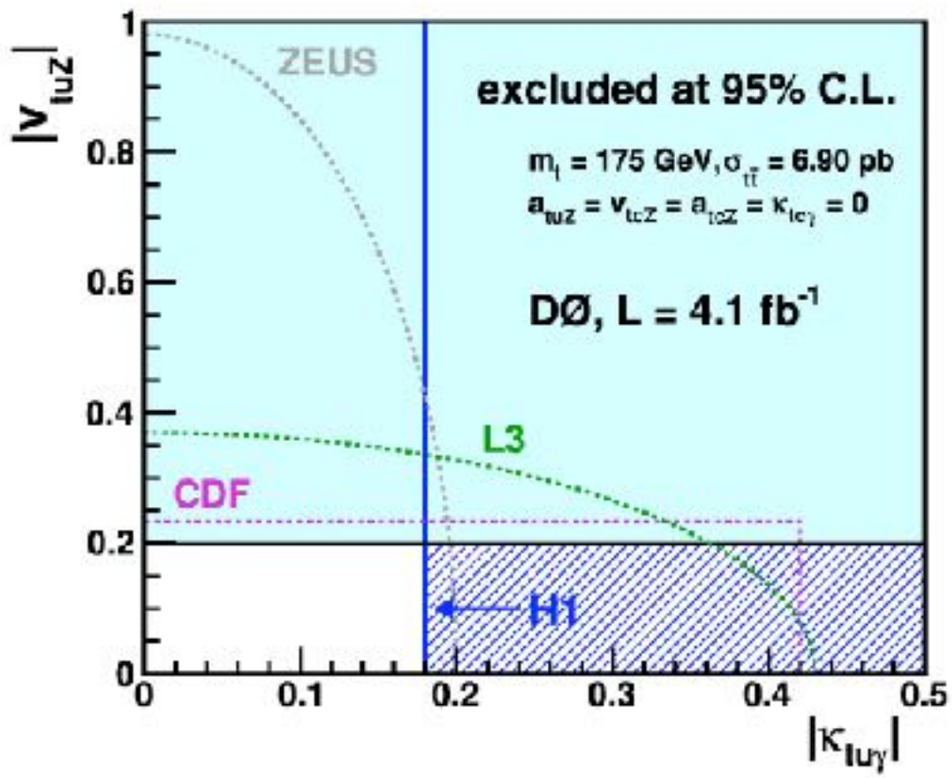
TEVATRON

Top FCNC Decay to Zq

- tt->WbZq, Z->ll and W->lν.

- No anomalous coupling observed in tuZ, tcZ.

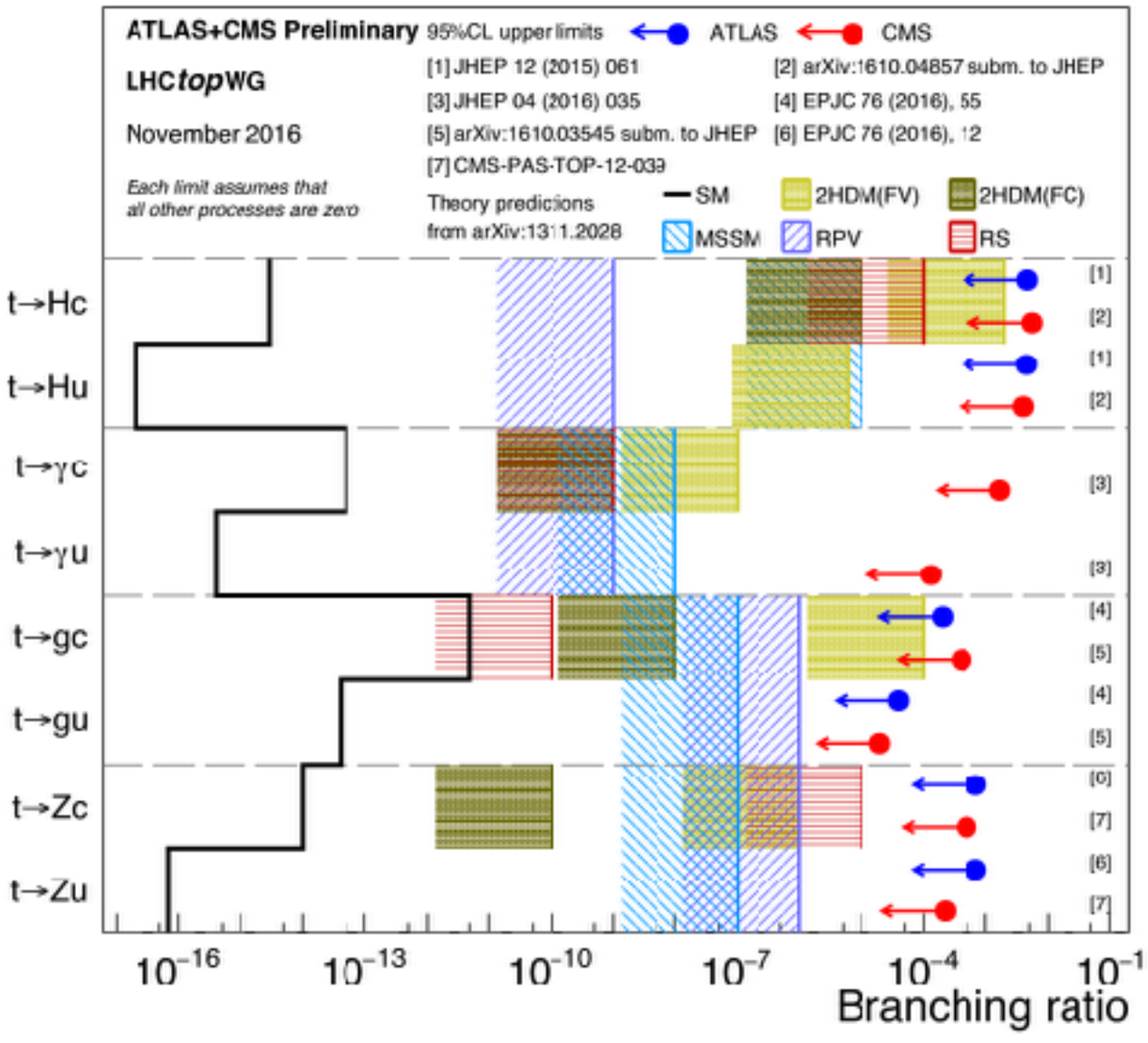


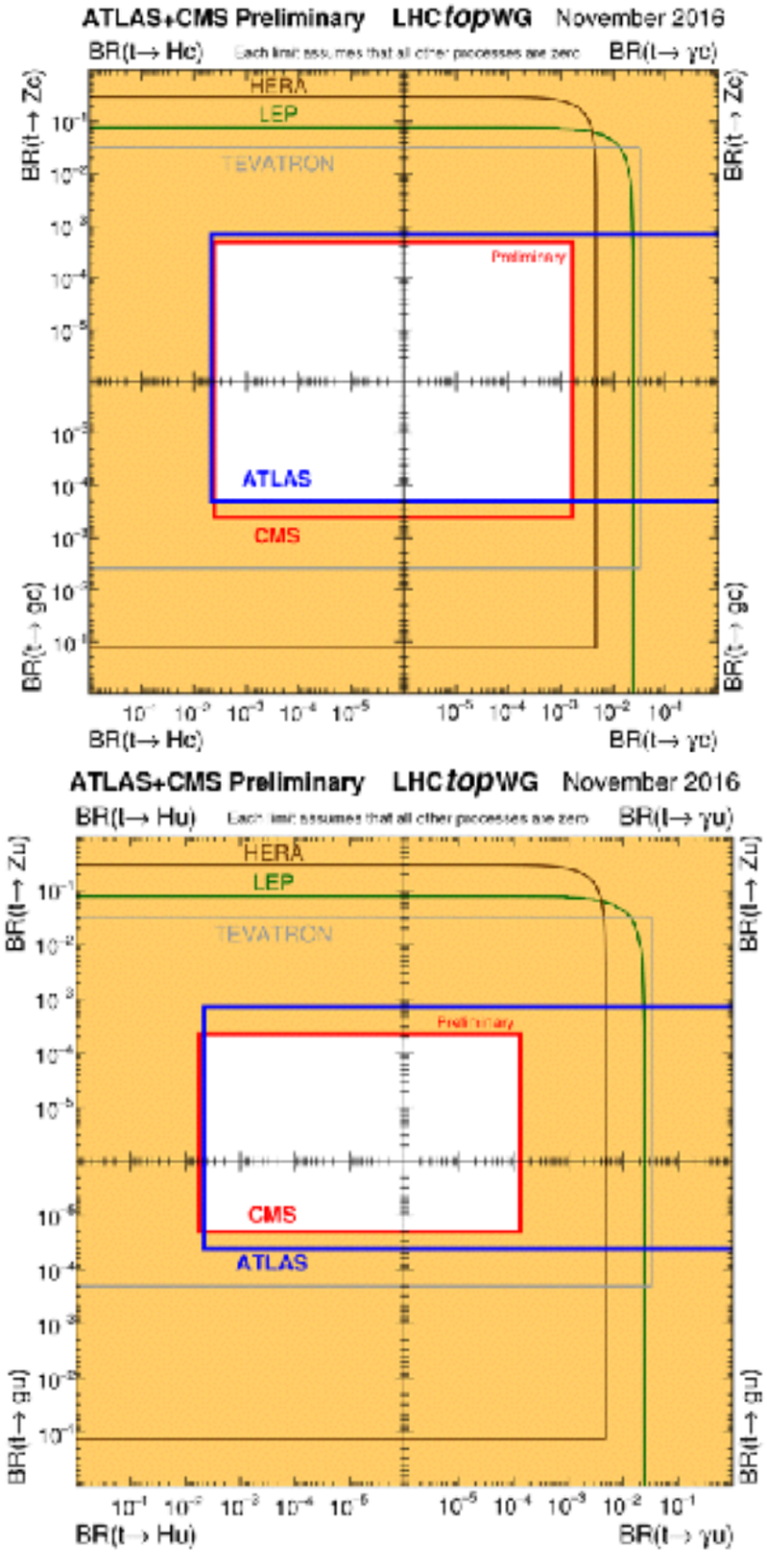


No significant excess.

Refer: PLB 701, 313 (2011), PRL. 101, 192002 (2008)

Top FCNC Decay



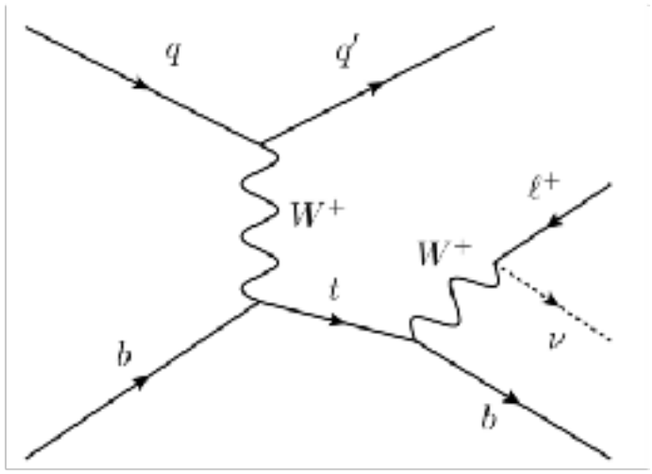


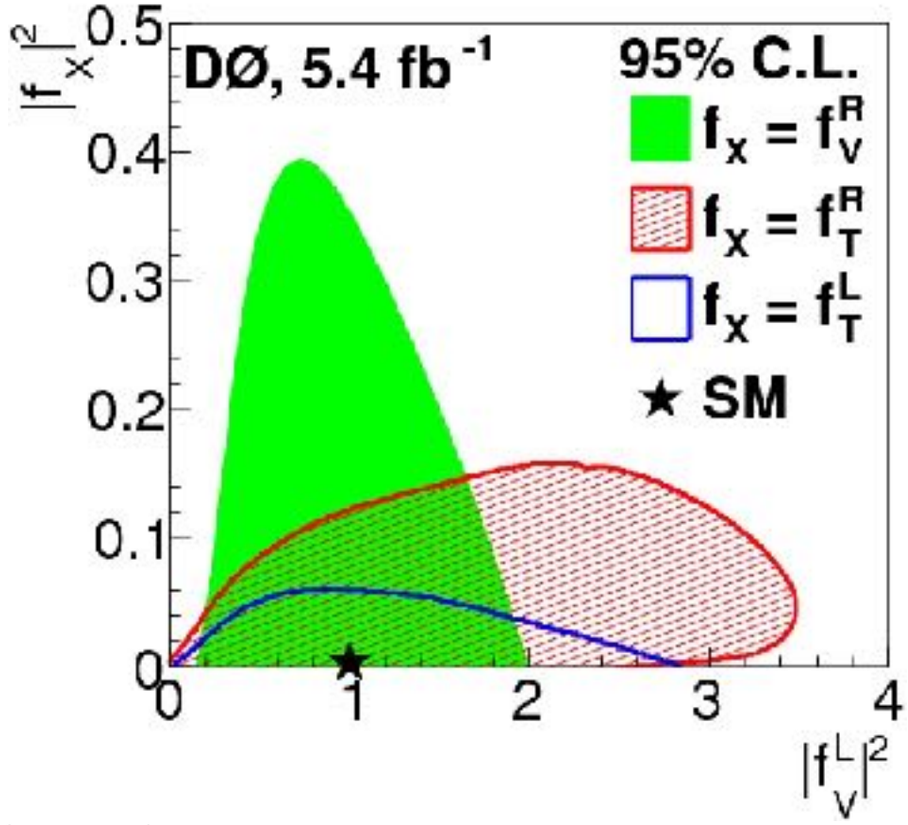
TEVATRON

Anomalous Wtb Coupling

- Study of the angular properties of the top decay products to constraint the polarization fractions with the D0 experiment.

- The analysis is performed in both the leptons plus jets and dilepton final state.





95% C.L. limit contours for the combination of W boson helicity and single top quark measurements for anomalous tWb coupling form factors.

Refer: PLB 713, 165 (2012)