UNIVERSITEIT GENT

Flavor Changing Neutral Currents in Top Production and Decay

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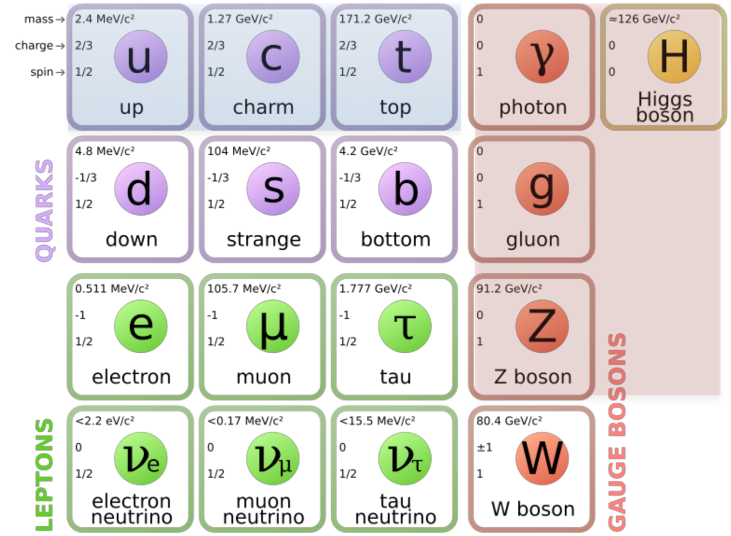
Top 2013: 6th International Workshop on Top Quark Physics
18 September 2013 Durbach, Germany

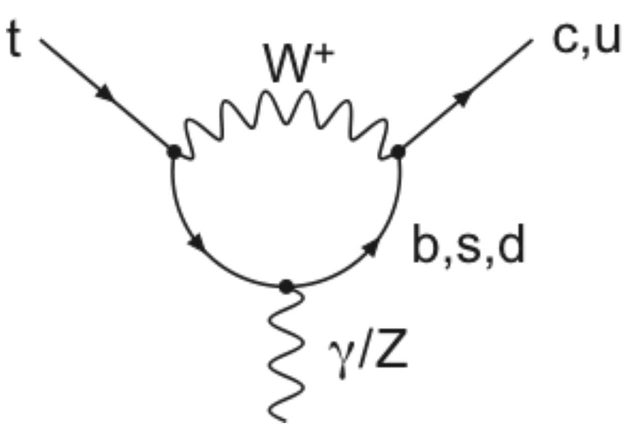
FCNCs

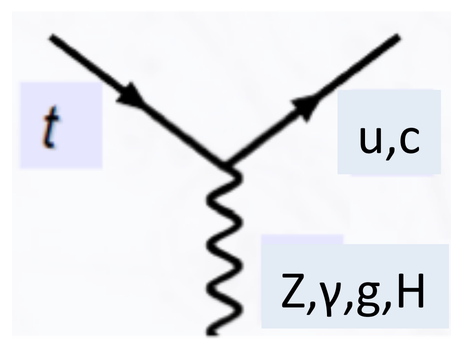
- Transitions that change the flavor of a fermion without changing its charge.
- Forbidden at tree level in the SM
- Suppressed at higher orders due to GIM mechanism.
- Occurs only at the level of quantum loop corrections with $\mathcal{B}(t \rightarrow Xq) \sim 10^{-17} - 10^{-12}$, X=H,γ,Z,g



in BSM:
$\mathcal{B}(t \rightarrow Zq) \sim 10^{-9} - 10^{-3}$

→ any evidence of FCNC will indicate the existence of new physics.





FCNC

Branching ratios for top FCN decays in the SM, models with $Q = 2/3$ quark singlets (QS), a general 2HDM, a flavour-conserving (FC) 2HDM, in the MSSM and with R parity violating SUSY.

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	–	–	2×10^{-6}	3×10^{-5}
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	–	–	2×10^{-6}	1×10^{-6}
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	–	–	8×10^{-5}	2×10^{-4}
$t \to uH$	2×10^{-17}	4.1×10^{-5}	5.5×10^{-6}	–	10^{-5}	$\sim 10^{-6}$
$t \to cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}
$t \to cH$	3×10^{-15}	4.1×10^{-5}	1.5×10^{-3}	$\sim 10^{-5}$	10^{-5}	$\sim 10^{-6}$

Aguilar-Saavedra, ACTA Phys. Pol. B 35 (2004)

- In this talk: “model independent” searches using effective models.

Outline

- Search for FCNC in
  - ttbar events
    - t→Zq decays
    - t→Hc decays
  - single top quark events
    - pp→t
    - pp→t+q/g
    - pp→t+Z
    - t-channel cross section
  - same sign top quark production

FCNC in t→(Z, γ,H)q Decays in ttbar Events

	BR limits @ 95% CL (%)	
ppbar @ 1.8 TeV	**t→Zq**	**t→qγ**
CDF[1] (~110/pb) *dilepton+4j*	33	3.2
ppbar @ 1.96 TeV		
CDF[2] (1.9/fb) *dilepton+4j*	3.7	x
D0[3] (4.1/fb) *trileptons*	3.2	x
pp @ 7 TeV		
ATLAS[4] (2.1/fb) *trileptons*	0.73	x
CMS[5] (5/fb) *trileptons*	0.21	x
pp @ 8 TeV		
CMS[6] (19.5/fb) *trileptons*	0.07	x

1) PRL 80 (1998) 2525
2) PRL 101 (2008) 192002
3) PRL 701 (2011) 313
4) JHEP 90 (2012) 139
5) PLB 718 (2013) 1252
6) CMS-PAS-TOP-12-037

B(t→cH) < 0.83 % @ 7 TeV in H→γγ [ATLAS-CONF-2013-081].

B(t→cH) < 2.7 % @ 7 TeV [Craig et al. arxiv:1207.6794].
re-interpreting a CMS anomalous multi-lepton (≥3 leptons) search [CMS, JHEP 06 (2012)169].
B(t→cH) < 0.31 % @ 8 TeV in H→WW,ττ,ZZ [CMS-PAS-SUS-13-002].

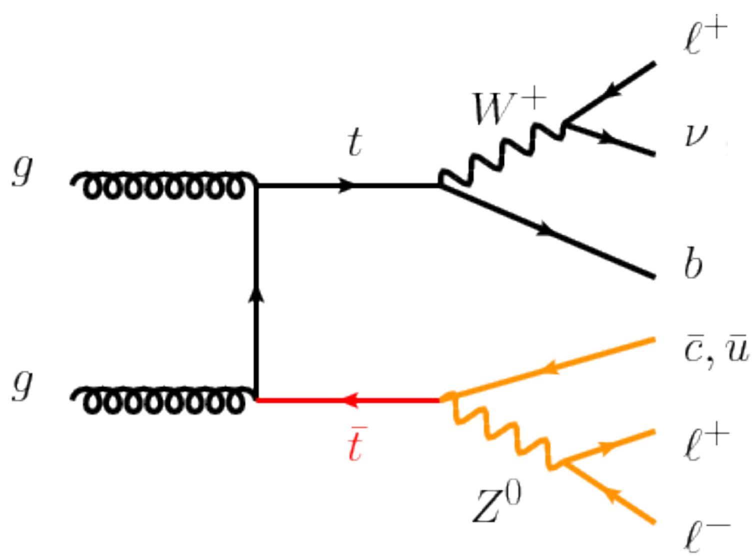
FCNC in t→Zq Decays in ttbar Events

Aguilar-Saavedra,
ACTA Phys. Pol. B 35 (2004)

Assuming NP involves particles with m > $m_{t,}$
effective Lagrangian up to dim 5:

$$-\mathcal{L}^{\rm eff} = \frac{g}{2c_W} X_{qt}\, \bar q \gamma_\mu (x_{qt}^{\rm L} P_{\rm L} + x_{qt}^{\rm R} P_{\rm R}) t Z^\mu + \frac{g}{2c_W} \kappa_{qt}\, \bar q (\kappa_{qt}^v + \kappa_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t Z^\mu$$
$$+ e\lambda_{qt}\, \bar q (\lambda_{qt}^v + \lambda_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t A^\mu + g_s \zeta_{qt}\, \bar q (\zeta_{tq}^v + \zeta_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} T^a q G^{a\mu}$$
$$+ \frac{g}{2\sqrt{2}} g_{qt}\, \bar q (g_{qt}^v + g_{qt}^a \gamma_5) t H + \text{H.c.}\,,$$

N.B.: Implementation of each term might differ for each measurement – results not perfectly comparable.

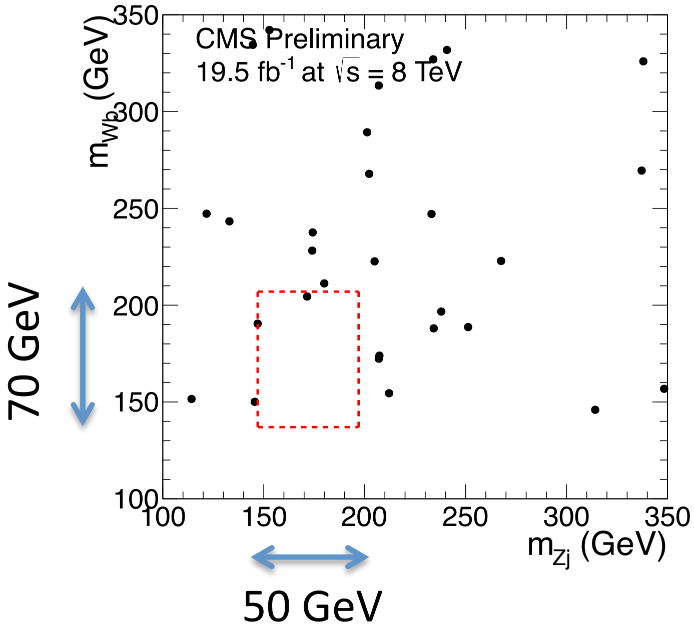


- Trilepton final state
  - Two isolated opposite charged leptons in a Z mass window.
  - Another isolated lepton.
  - No 4th lepton.
  - Large MET.
  - At least two jets (exactly 1 b-jet)

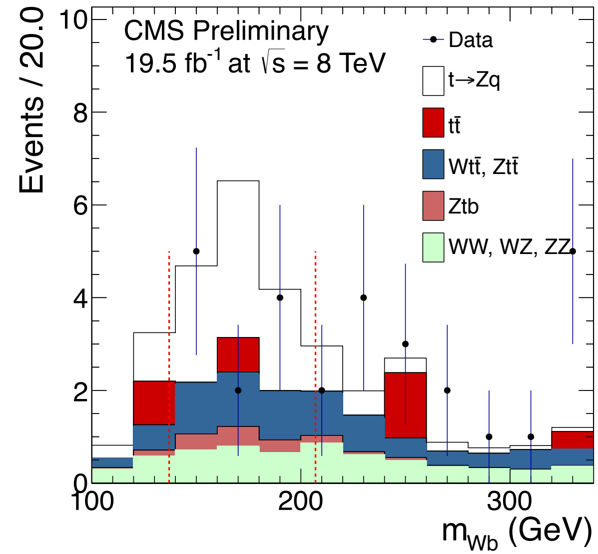
CMS-PAS-TOP-12-037

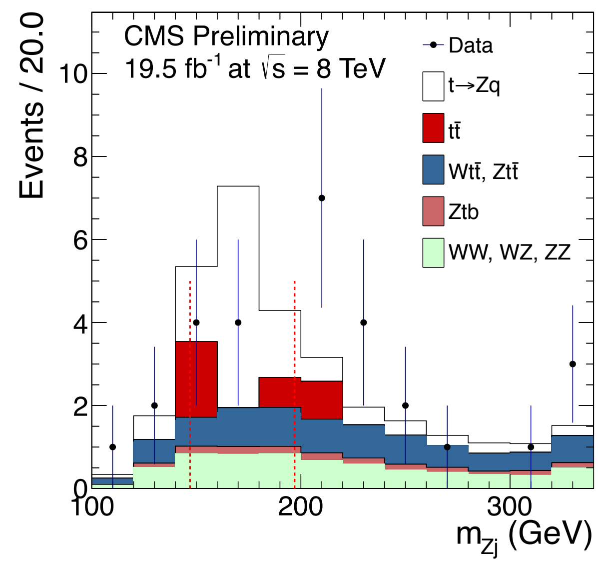
FCNC in t→Zq Decays in ttbar Events

- Zj and Wb pairing to reconstruct top quarks.
- ϕ(max) between t(Wb) and t(Zj) by examining all Zj pairings.
- Signal: MadGraph+PYTHIA
- Backgrounds: data-driven.



CMS-PAS-TOP-12-037





Br(t→Zq)=0.1%

- Dominant systematic uncertainties: factorization and renormalization scales, PDFs and σ_{ttbar}.

No excess of events over the SM background.
$\mathcal{B}$(t → Zq) > 0.07 % is excluded at the 95 % C.L.

FCNC in t→cH(γγ) Decays in ttbar Events

Branching ratios for top FCN decays in the SM, models with $Q = 2/3$ quark singlets (QS), a general 2HDM, a flavour-conserving (FC) 2HDM, in the MSSM and with R parity violating SUSY.

	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY
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ACTA Phys. Pol. B 35 (2004)

ATLAS-CONF-2013-081

- Signal: PROTOS+PYTHIA
- one top quark in the hadronic or leptonic channel + Higgs(→γγ).
  - backgrounds for non-resonant γγ final state are small after ttbar selection.

- Hadronic channel
  - ≥ 4 jets (≥ 1 b-jet)
  - reject leptons
  - $156 < m_{\gamma\gamma j} < 191$ GeV
  - $130 < m_{jjj} < 210$ GeV

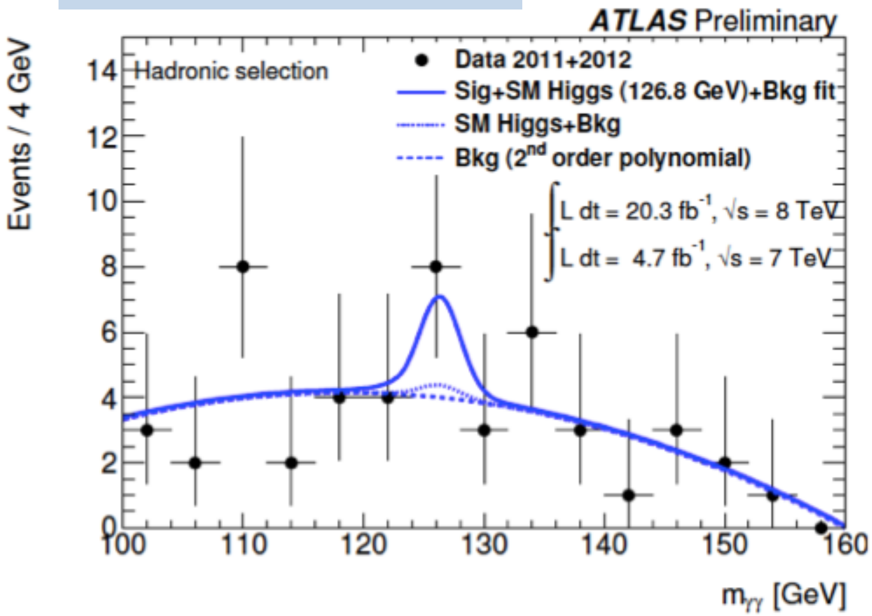
- Leptonic channel
  - exactly 1 lepton
  - m_T(lep,MET) > 30 GeV
  - ≥ 2 jets (≥ 1 b-jet)
  - $156 < m_{\gamma\gamma j} < 191$ GeV
  - $135 < m_{jjj} < 205$ GeV

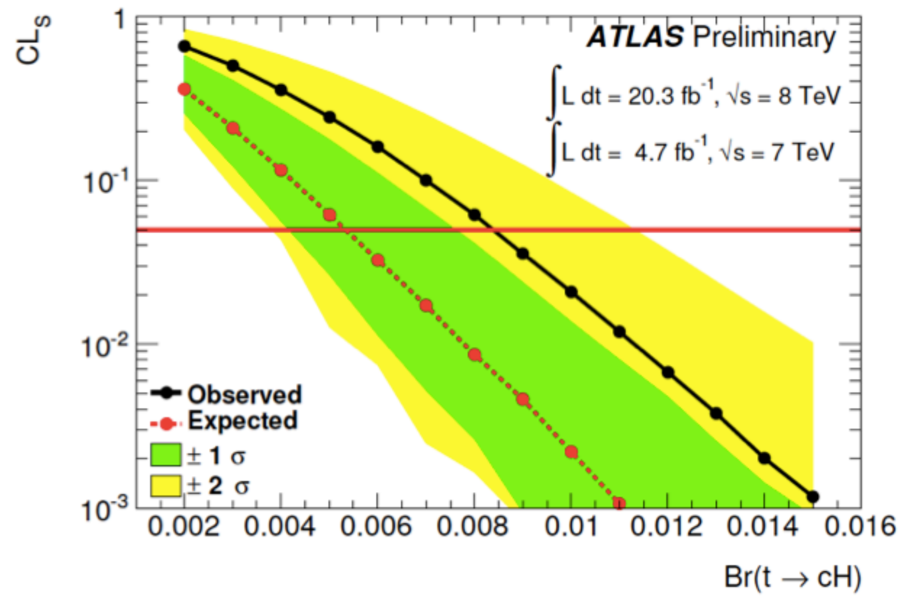
- Higgs
  - 2 high-p_T: 40 and 30 GeV well identified and isolated photons

FCNC in t→cH(γγ) Decays in ttbar Events

$N(had + lep) = 3.7^{+4.4}_{-3.7}$

ATLAS-CONF-2013-081





SM Higgs bkg: ggF, VBF, WH, ZH, ttH, tH.

No excess of events over the SM background.

$\mathcal{B}$(t→cH) < 0.83 % @ 95% CL for m_H=126.8 GeV
→ limit on tcH coupling: $\lambda_{tcH} = 1.91 \sqrt{\mathcal{B}} < 0.17$

- Dominant systematic uncertainties: photon ID and isolation, JES, b-tagging.

FCNC in t→cH Decays Reinterpreted from Inclusive Multilepton Search

$t\bar{t}$ production followed by

$$t \to ch,\ t \to b(W \to \ell\nu)$$

$$h \to WW^* \to \ell\nu\ell\nu,$$

$$h \to \tau\tau,$$

$$h \to ZZ^* \to jj\ell\ell, \nu\nu\ell\ell, \ell\ell\ell\ell.$$

10 most sensitive signal regions for t→ch

OSSF pair	E_T^{miss} [GeV]	H_T [GeV]	b-tag	data	background	signal
below Z	0–50	> 200	✓	5	9.4 ± 2.6	12.3 ± 3.2
below Z	50–100	> 200	✓	10	9.3 ± 3.6	12.7 ± 3.4
below Z	50–100	0–200	✓	48	51 ± 25	39.5 ± 9.9
below Z	0–50	0–200	✓	35	43 ± 12	23.9 ± 5.2
n/a	50–100	0–200	—	29	28 ± 14	21.8 ± 4.6
below Z	50–100	0–200	—	146	125 ± 29	41 ± 11
n/a	0–50	0–200	✓	30	24 ± 11	16.1 ± 3.8
above Z	0–50	0–200	✓	17	18.5 ± 6.7	10.8 ± 2.7
on Z	50–100	0–200	✓	58	44 ± 13	16.0 ± 3.5
below Z	50–100	> 200	—	11	11.0 ± 3.8	7.1 ± 2.1

BR(t→ch = 1 %) and ordered by sensitivity.

All signal regions: = 3 leptons (no hadronic τ), no OSSF pair or an OSSF pair off Z, and a b-tag.

Higgs Decay Mode	obs	exp	1σ range
$h \to WW^*$ (BR = 23.1 %)	1.58 %	1.57 %	(1.02–2.22) %
$h \to \tau\tau$ (BR = 6.15 %)	7.01 %	4.99 %	(3.53–7.74) %
$h \to ZZ^*$ (BR = 2.89 %)	5.31 %	4.11 %	(2.85–6.45) %
combined	1.28 %	1.17 %	(0.85–1.73) %

$$\sqrt{|\lambda_{tc}^h|^2 + |\lambda_{ct}^h|^2} < 0.21$$

- Complementary to h→γγ

CMS-PAS-SUS-13-002

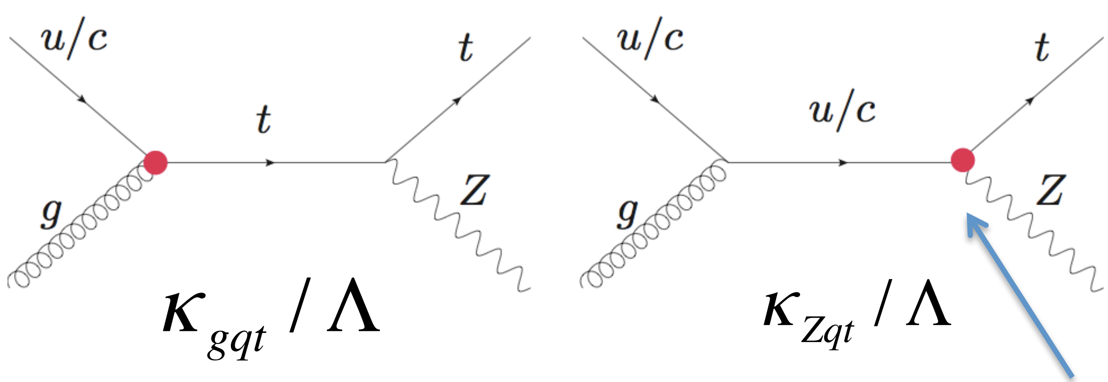
Single Top FCNC Searches

t→qg impossible to differentiate from multijets background; look for anomalous top quark production: qg→t

ppbar @ 1.96 TeV	ℬ(t→gu) %	ℬ(t→gc) %	ℬ(t→Zu) %	ℬ(t→Zc) %
CDF[1] (2.2/fb) *pp→t*	0.039	0.57		
D0[2] (2.3/fb) *pp→t+g/q*	0.02	0.39		
pp @ 7 TeV				
ATLAS[3] (2.05/fb) *pp→t*	0.0057	0.027		
CMS[4] (4.9/fb) pp→t+Z	0.56	7.12	0.51	11.40
pp @ 8 TeV				
ATLAS[5] (14.2/fb) *pp→t*	0.0031	0.016		

1) PRL 102 (2009) 151801
2) PLB 693 (2010) 81
3) PLB 712 (2012) 351
4) CMS-PAS-TOP-12-021
5) ATLAS-CONF-2013-063

FCNC in Single Top t+Z Events



Also probed by FCNC ttbar

Agram, Andrea et al. arxiv:1304.5551v2

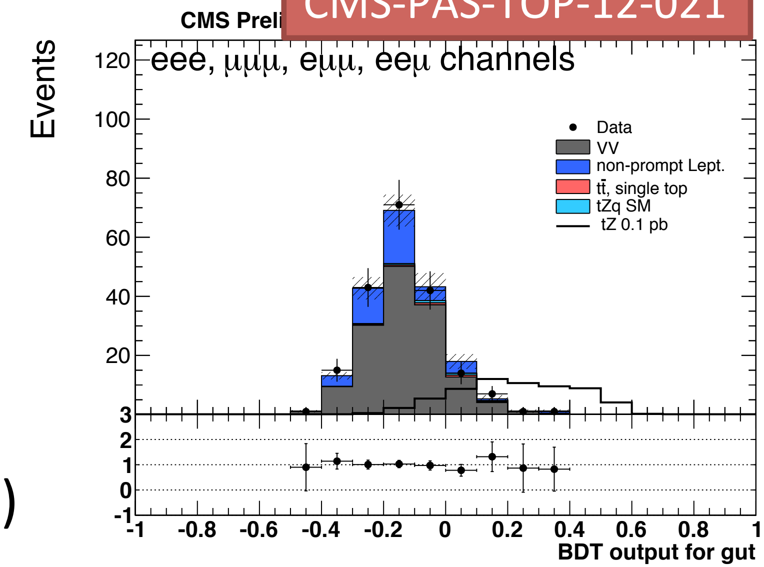
assumed in CMS-PAS-TOP-12-021.

$$-\mathcal{L}^{\rm eff} = \frac{g}{2c_W} X_{qt}\, \bar{q}\gamma_\mu (x^{\rm L}_{qt} P_{\rm L} + x^{\rm R}_{qt} P_{\rm R}) t Z^\mu + \frac{g}{2c_W}\kappa_{qt}\, \bar{q}(\kappa^v_{qt} + \kappa^a_{qt}\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} t Z^\mu$$
$$+ e\lambda_{qt}\, \bar{q}(\lambda^v_{qt} + \lambda^a_{qt}\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} t A^\mu + g_s\zeta_{qt}\, \bar{q}(\zeta^v_{tq} + \zeta^a_{qt}\gamma_5)\frac{i\sigma_{\mu\nu}q^\nu}{m_t} T^a q G^{a\mu}$$
$$+ \frac{g}{2\sqrt{2}} g_{qt}\, \bar{q}(g^v_{qt} + g^a_{qt}\gamma_5) t H + {\rm H.c.}\,, \qquad (1)$$

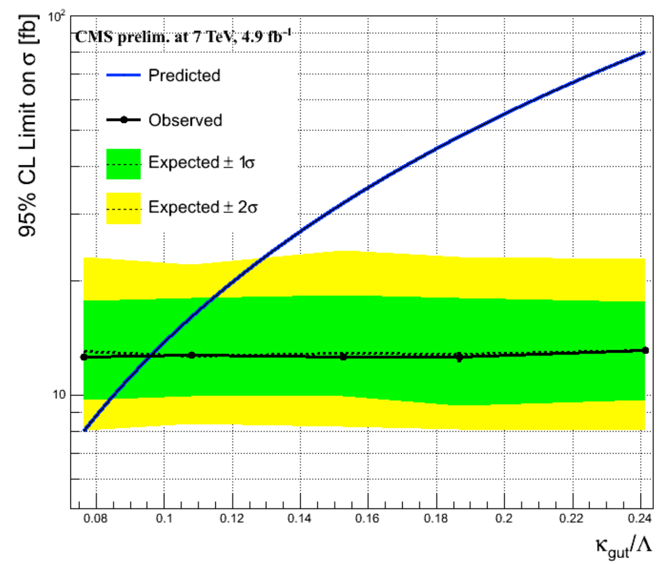
FCNC in Single Top t+Z Events

CMS-PAS-TOP-12-021

- 3 isolated leptons + 1 b-jet
- Signal: MadGraph+Pythia
- Signal extraction: using kinematic variables and b-tagging info, combined using a Boosted Decision Tree (BDT)
  - BDT shapes: from data for Z+jets, inverting third lepton isolation + low MET.
  - Other shapes: from simulation.
- Main background from fake leptons (Z+jets)
- Other backgrounds : ZZ+jets, ttbar, tZq.



couplings	Expected (TeV^{-1})	Observed (TeV^{-1})	$\mathcal{BR}(t \to gq/Zq)$
κ_{gut}/Λ	0.096	0.096	0.56 %
κ_{gct}/Λ	0.427	0.354	7.12 %
κ_{Zut}/Λ	0.492	0.451	0.51 %
κ_{Zct}/Λ	2.701	2.267	11.40 %

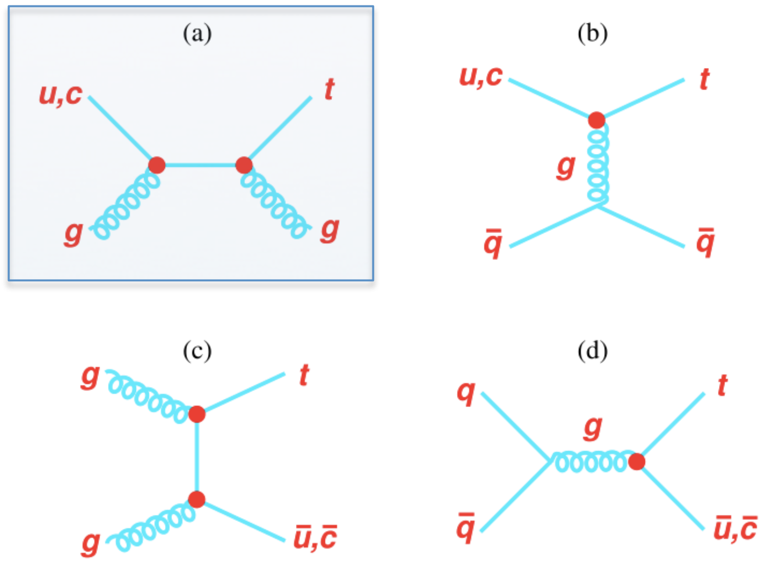


FCNC in Single Top t+g Events

D0, PLB 693 (2010) 81

- Top quark + an additional jet.
- Final state ~ SM t-channel single top quark production.
- Dominant background: W+jets.
- Signal background separation by Bayesian Neural Networks (BNN).
- Signal and single top background by SINGLETOP MC.

largest contribution

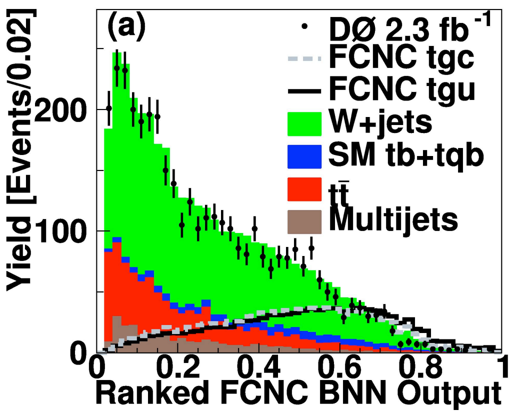


$$
\begin{aligned}
-\mathcal{L}^{\mathrm{eff}} = & \frac{g}{2c_W} X_{qt}\, \bar{q}\gamma_\mu (x^{\mathrm{L}}_{qt} P_{\mathrm{L}} + x^{\mathrm{R}}_{qt} P_{\mathrm{R}}) t Z^\mu + \frac{g}{2c_W} \kappa_{qt}\, \bar{q}(\kappa^v_{qt} + \kappa^a_{qt}\gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t Z^\mu \\
& + e\lambda_{qt}\, \bar{q}(\lambda^v_{qt} + \lambda^a_{qt}\gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t A^\mu + \boxed{g_s \zeta_{qt}\, \bar{q}(\zeta^v_{tq} + \zeta^a_{qt}\gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} T^a q G^{a\mu}} \\
& + \frac{g}{2\sqrt{2}} g_{qt}\, \bar{q}(g^v_{qt} + g^a_{qt}\gamma_5) t H + \mathrm{H.c.}\,, \qquad (1)
\end{aligned}
$$

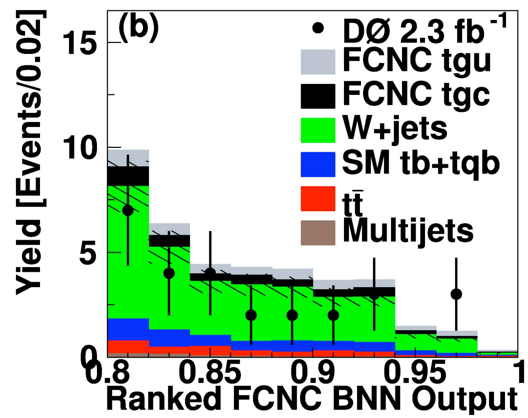
FCNC in Single Top t+g Events

D0, PLB 693 (2010) 81

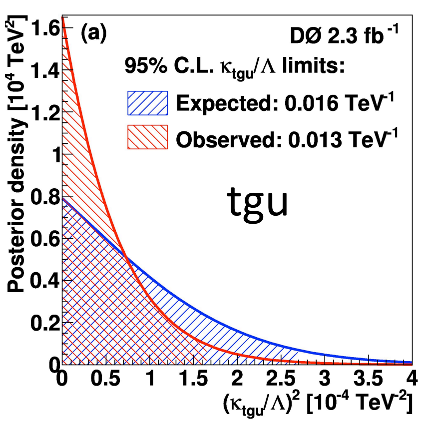
- 54 variables in BNN (a subset of the single-top measurement variables + variables from the previous FCNC analysis).
  - individual object and event kinematics, top reconstruction, jet width, angular correlations.
- Bins ordered by signal/background ratio

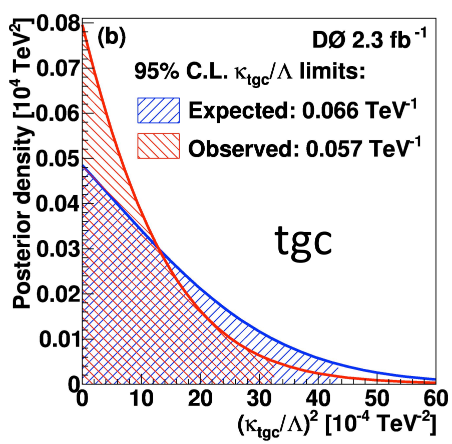


FCNC signals normalized to 5 pb.



FCNC signals normalized to their observed limits.



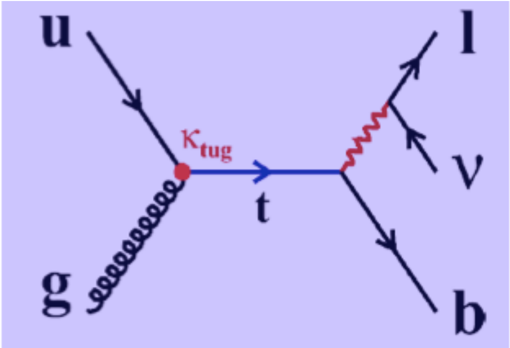


- Dominant uncertainties: jet energy scale and b-tag modeling.

	tgu	*tgc*
Cross section	0.20 pb	0.27 pb
κ_{tgf}/Λ	0.013 TeV^{-1}	0.057 TeV^{-1}
$\mathcal{B}(t \to fg)$	2.0×10^{-4}	3.9×10^{-3}

FCNC in Single Top (gq→t) Events

- Main differences of gq→t from SM:
  - top quark is produced with almost zero p_T
    → p_T(FCNC) < p_T(SM) → W and b from the top quark are almost back-to-back.
  - p_T(W) > p_T(V+jets) and p_T(diboson) → decay products of the W have small opening angles.
  - Different charge asymmetry.



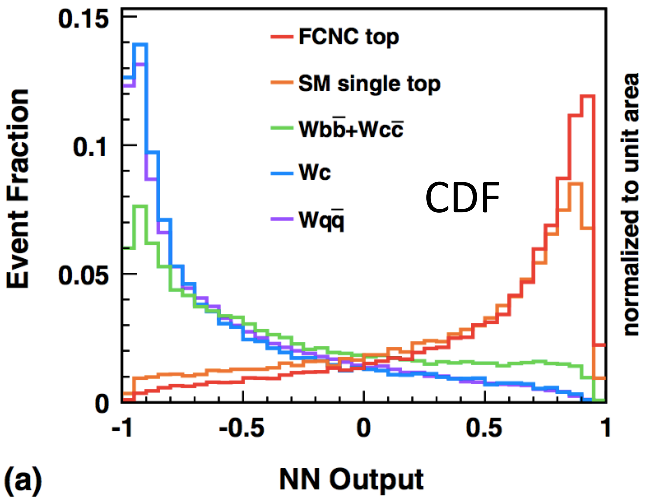
ATLAS, PLB 712 (2012) 351
ATLAS-CONF-2013-063 [8 TeV]

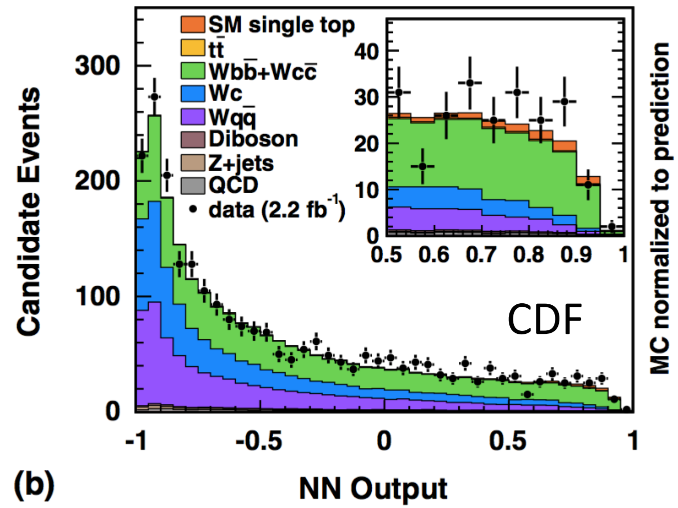
CDF, PRL 102 (2009) 151801

- Signal: PROTOS (ATLAS, 7 TeV), TOPREX (CDF)
- Signal: ME_{TOP} → A new generator for FCNC at approx. NLO (ATLAS, 8 TeV)
- Bayesian Neural Network to discriminate signal and background (W+jets and multijets)
- Binned maximum likelihood fit to the NN output distributions.

$$
\begin{aligned}
-\mathcal{L}^{\text{eff}} &= \frac{g}{2c_W} X_{qt}\, \bar{q}\gamma_\mu (x_{qt}^{\text{L}} P_{\text{L}} + x_{qt}^{\text{R}} P_{\text{R}}) t Z^\mu + \frac{g}{2c_W} \kappa_{qt}\, \bar{q}(\kappa_{qt}^v + \kappa_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t Z^\mu \\
&+ e\lambda_{qt}\, \bar{q}(\lambda_{qt}^v + \lambda_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} t A^\mu + g_s \zeta_{qt}\, \bar{q}(\zeta_{tq}^v + \zeta_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu} q^\nu}{m_t} T^a q G^{a\mu} \\
&+ \frac{g}{2\sqrt{2}} g_{qt}\, \bar{q}(g_{qt}^v + g_{qt}^a \gamma_5) t H + \text{H.c.}\,, \qquad (1)
\end{aligned}
$$

FCNC in Single Top (gq→t) Events



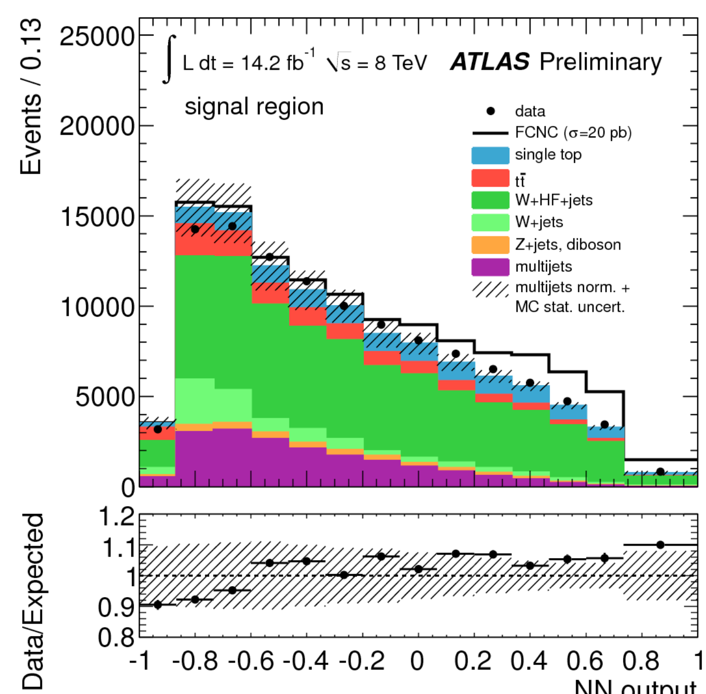


→ CDF, PRL 102 (2009) 151801
→ ATLAS, PLB 712 (2012) 351
→ ATLAS-CONF-2013-063 [8 TeV]

$$\sigma(u,c+g \to t)\times B(t \to Wb)$$
$$< 1.8\ pb@95\%\ CL\ (CDF)$$
$$< 3.9\ pb@95\%\ CL\ (ATLAS, 7\ TeV)$$
$$< 2.5\ pb@95\%\ CL\ (ATLAS, 8\ TeV)$$

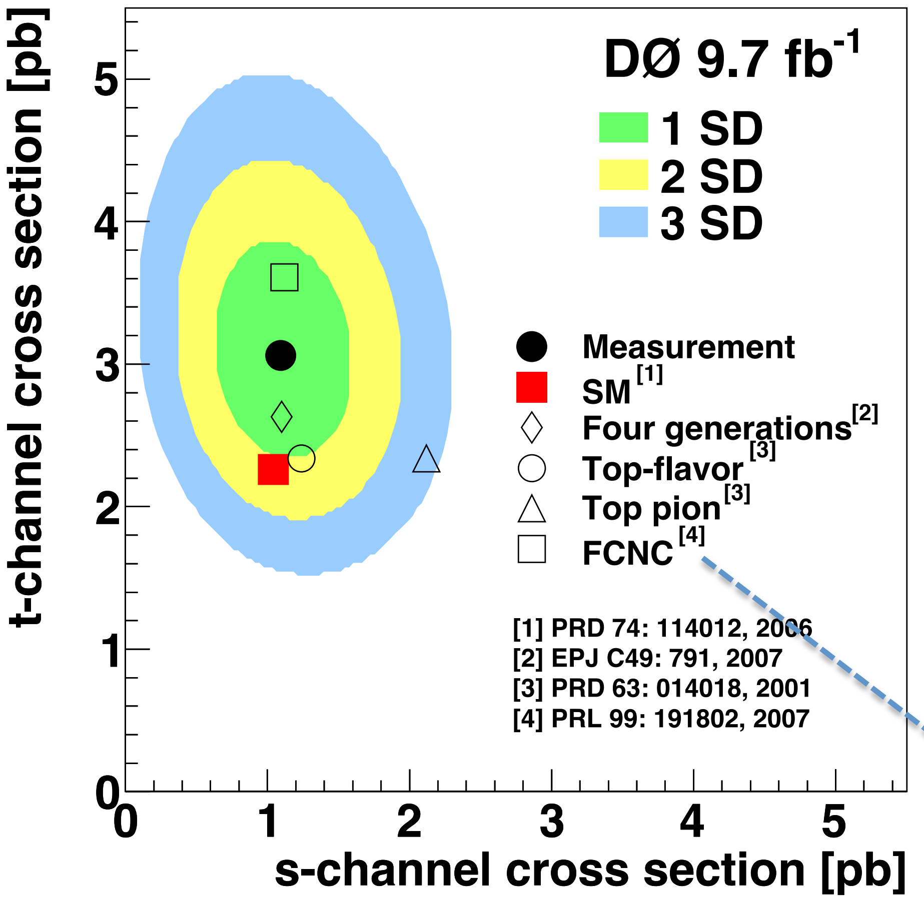
Best limits:
$\mathcal{B}(t \to u + g) < 3.1\times10^{-5}$ (ATLAS, 8 TeV)
$\mathcal{B}(t \to c + g) < 1.6\times10^{-4}$ (ATLAS, 8 TeV)

Dominant systematic uncertainties (for ATLAS, 8 TeV): JES/JER, b-tag efficiency, PDFs.



Single Top t-channel Cross Section and FCNC

D0, arXiv: 1307.0731, submitted to PLB



- FCNC modifies t-channel production rate.

Tait and Yuan, PRD 63 (2000) 014018

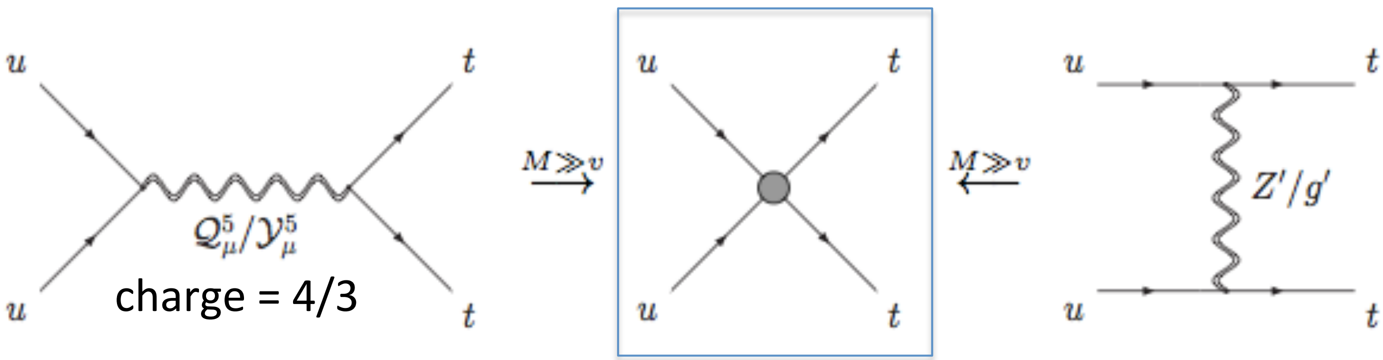
FCNC model
with $\mathbf{k_{tug}/\Lambda}$ = 0.036.

dominant systematic uncertainties: multi-jet normalization, W/Z+jets heavy flavor correction, ISR/FSR, ttbar cross-section, b-tagging.

Same-sign Top Quark Production

- Same-sign top pair production involving double top flavour violation.
- Sensitive to new heavy resonances
  - e.g. flavour-violating Z' ← *a possible explanation for A_{FB}(ttbar) discrepancy in Tevatron*

- Effective model independent approach (Aguilar-Saavedra, Nucl. Phys. B843 (2011) 638)



(scalars can also be exchanged in both s and t channels)

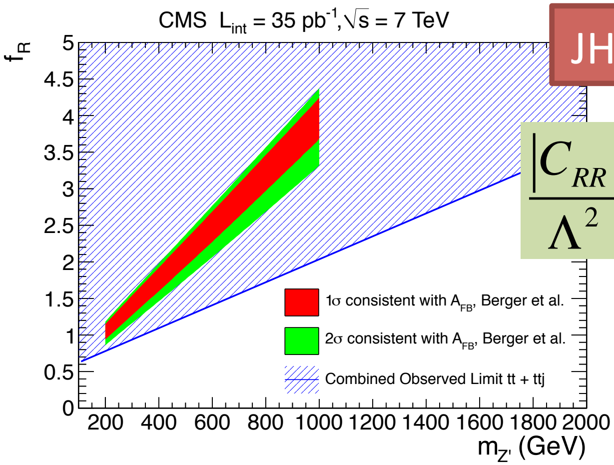
M(boson) >> EWSB scale

$$\mathcal{L}_{4F} = \frac{1}{2}\frac{C_{LL}}{\Lambda^2}(\bar{u}_L\gamma^\mu t_L)(\bar{u}_L\gamma_\mu t_L) + \frac{1}{2}\frac{C_{RR}}{\Lambda^2}(\bar{u}_R\gamma^\mu t_R)(\bar{u}_R\gamma_\mu t_R) - \frac{1}{2}\frac{C_{LR}}{\Lambda^2}(\bar{u}_L\gamma^\mu t_L)(\bar{u}_R\gamma_\mu t_R) - \frac{1}{2}\frac{C'_{LR}}{\Lambda^2}(\bar{u}_{La}\gamma^\mu t_{Lb})(\bar{u}_{Rb}\gamma_\mu t_{Ra}) + \text{h.c.}\,,$$

C_{xx}: dimensionless consts.
Λ: scale of new physics.

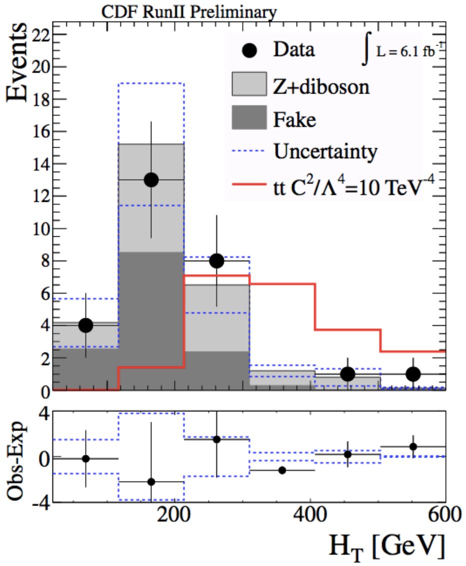
Same-sign Top Quark Production

- Same-sign dilepton events + ≥ 2 jets.
- Dominant backgrounds: misidentified leptons, charge mis-id



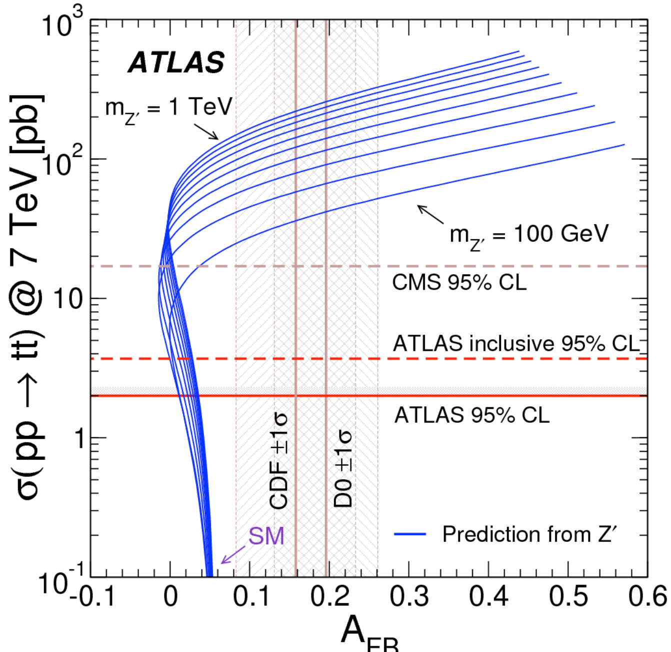
JHEP 08 (2011) 005

$$\frac{|C_{RR}|}{\Lambda^2} < 2.7\ TeV^{-2}$$



$$\frac{|C_{RR}|}{\Lambda^2} < 3.7\ TeV^{-2}$$

CDF/PHYS/EXO/PUBLIC/10466



$$\frac{|C_{RR}|}{\Lambda^2} < 0.35\ TeV^{-2}$$

ATLAS, 7 TeV, fb^{-1}

JHEP04(2012)069

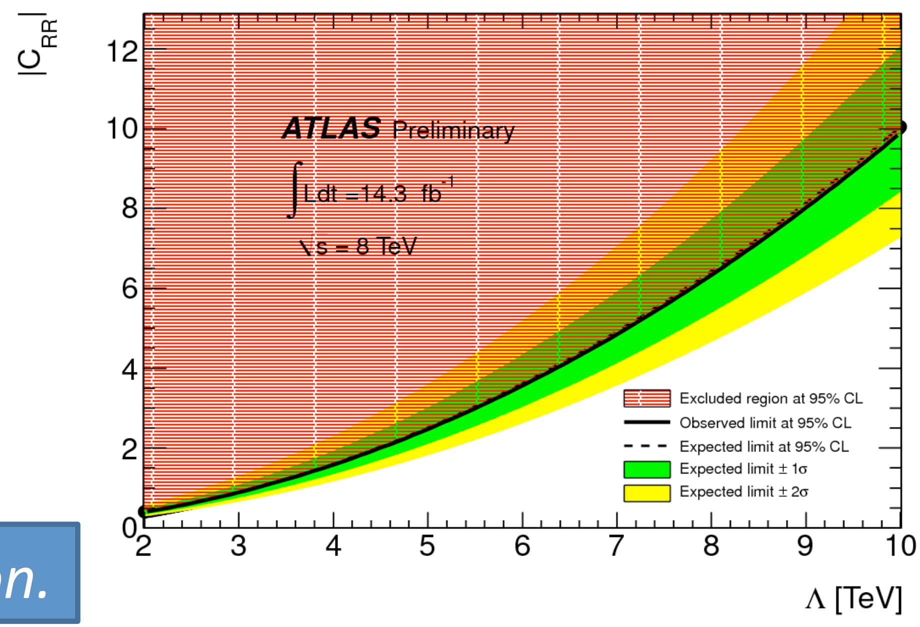
No same-sign top quark production.
→ FCNC interpretation of Tevatron A_{FB} is disfavored

Same-sign Top Quark Production

- Same-sign dilepton events + jets (w/ ≥ 1 b-jet)
  - MET > 40 GeV
  - H_T > 550 GeV
- Signal: PROTOS
- Dominant backgrounds: misidentified leptons, charge mis-id, ttW+jets

No same-sign top quark production.

ATLAS-CONF-2013-051



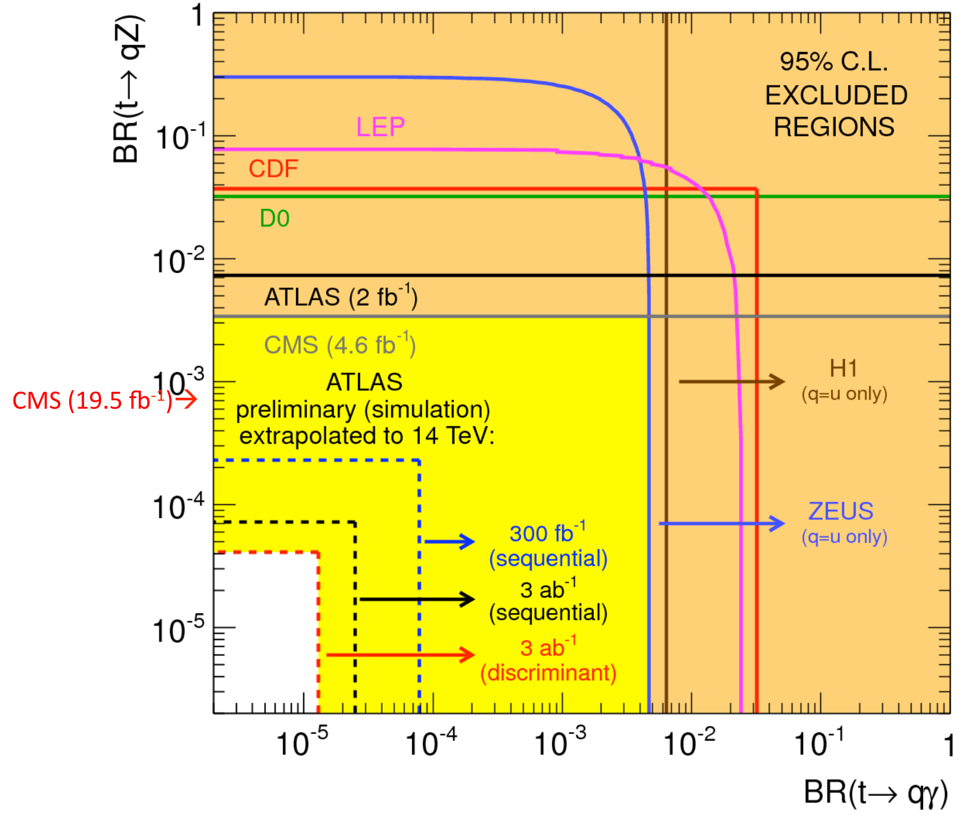
	95% C.L. upper limit		
	$\sigma(pp \to tt)$ [pb]		$\lvert C\rvert/\Lambda^2$ [TeV^{-2}]
Chirality configuration	Expected 1σ range	Observed	Observed
Left-left	0.14-0.28	0.19	0.092
Left-right	0.15-0.30	0.20	0.271
Right-right	0.15-0.32	0.21	0.099

Summary

- No sign of FCNC in ttbar, single top and same sign top quark processes.
  - No FCNC from other processes either (e.g. $B_s^0 \rightarrow \mu^+\mu^-$).
- Limits getting closer to the predictions from specific models.
- First limits on t→cH
  - almost at 2HDM prediction.

- At the 13/14 TeV LHC run, ATLAS and CMS expect the limits to be an order of magnitude smaller:
  - ATLAS: Br(t→Zq) >~ 2×10^{-4} with 300 fb^{-1} *[ATLAS-PHYS-PUB-2012-001]*
  - CMS: Br(t→Zq) >~ 10^{-5} with 300 fb^{-1} *[CMS-Note-2013-002]*

ATLAS-PHYS-PUB-2012-001



Tevatron and LHC Public Results

- ATLAS:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
- CDF
  - http://www-cdf.fnal.gov/physics/new/top/top.html
  - http://www-cdf.fnal.gov/physics/exotic/
- CMS
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
- D0
  - http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.htm

BACKUP

Effective Lagrangian up to Dim. 5

Aguilar-Saavedra, ACTA Phys. Pol. B 35 (2004)

Assuming NP involves particles with m > m_t.

$$-\mathcal{L}^{\rm eff} = \frac{g}{2c_W} X_{qt}\, \bar{q}\gamma_\mu (x_{qt}^{\rm L} P_{\rm L} + x_{qt}^{\rm R} P_{\rm R}) t Z^\mu + \frac{g}{2c_W} \kappa_{qt}\, \bar{q}(\kappa_{qt}^v + \kappa_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu}q^\nu}{m_t} t Z^\mu$$
$$+ e\lambda_{qt}\, \bar{q}(\lambda_{qt}^v + \lambda_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu}q^\nu}{m_t} t A^\mu + g_s \zeta_{qt}\, \bar{q}(\zeta_{tq}^v + \zeta_{qt}^a \gamma_5) \frac{i\sigma_{\mu\nu}q^\nu}{m_t} T^a q G^{a\mu}$$
$$+ \frac{g}{2\sqrt{2}} g_{qt}\, \bar{q}(g_{qt}^v + g_{qt}^a \gamma_5) t H + \text{H.c.}\,, \qquad (1)$$

$q^\nu = (p_t - p_q)^\nu$: boson momentum

$\bar{q},\ t$: quark fields

Couplings are constants and normalized to:

$$\left|x_{qt}^L\right|^2 + \left|x_{qt}^R\right|^2 = 1,\ \left|\kappa_{qt}^L\right|^2 + \left|\kappa_{qt}^R\right|^2 = 1,\ \ldots\ with\ X_{qt}, \kappa_{qt}, \lambda_{qt}, \zeta_{qt}, g_{qt} \in \Re^+$$

→ Model-independent framework.

Coefficients can be constrained from direct and indirect measurements.

N.B.: Implementation of each term might differ for each measurement – the results not perfectly comparable.

FCNC in t→Zq Decays

CMS-PAS-TOP-12-037

- Background Estimation
  - Derived using data using b-tagging information.
  - Events with different number of b-tags (all, 0, and 1) are correlated with the efficiencies and fake rates.

$$\begin{pmatrix} N_{all} \\ N_{0b} \\ N_{1b} \end{pmatrix} = \mathrm{T} \begin{pmatrix} N_{VV} \\ N_{FCNC} \\ N_{XTT} \end{pmatrix}$$

Events with 0 b-jets are dominated by VV processes.
Events with 1 b-jet should be consistent with FCNC signal.
Events with ≥ 2 b-jets dominated by Wttbar, Zttbar, tbZ, ttbar.

Number of events for each category is estimated by inverting the above matrix and counting the number of events in each b-tag category.

FCNC in t→cH(γγ) Events

- BR to tcH coupling:

ATLAS-CONF-2013-081

$$\Gamma_{t\to cH} = \frac{\alpha}{32\sin^2\theta_W} g_{tcH}^2 m_t \left(1 - \frac{m_H^2}{m_t^2}\right)^2$$

$$\Gamma_{t\to bW} = \frac{\alpha}{16\sin^2\theta_W} \left|V_{tb}\right|^2 \frac{m_t^2}{m_W^2}\left(1 - 3x^4 + 2x^6\right) \ \ with \ \ x = m_W / m_t$$

Neglecting $\Gamma_{t\to cH}$ in Γ_{tot}:
$$Br = \frac{g_{tcH}^2}{2} x^2 \left(1 - 3x^4 + 2x^6\right)^{-1}\left(1 - \frac{m_H^2}{m_t^2}\right)^2 = 0.028 g_{tcH}^2$$

$$\to g_{tcH} = 5.98\sqrt{Br}$$

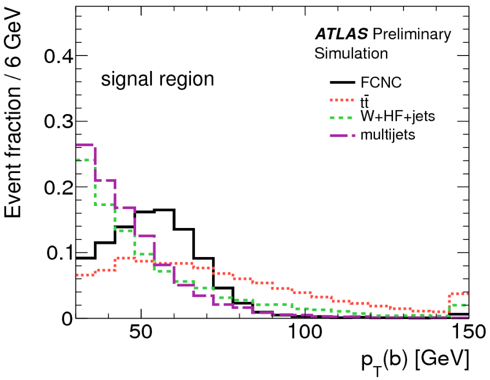
λ_{tcH} = 1.91√Br (directly comparable to the ttH coupling given by $\lambda_t = \sqrt{2} m_t / v$)

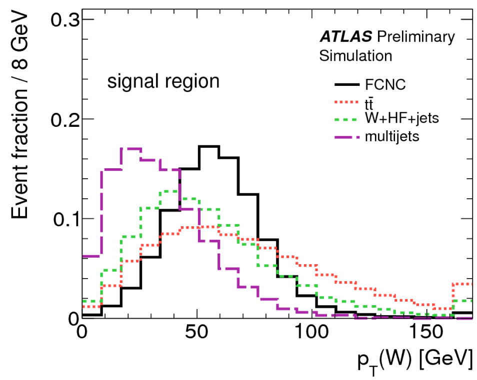
FCNC in Single Top tZ Events

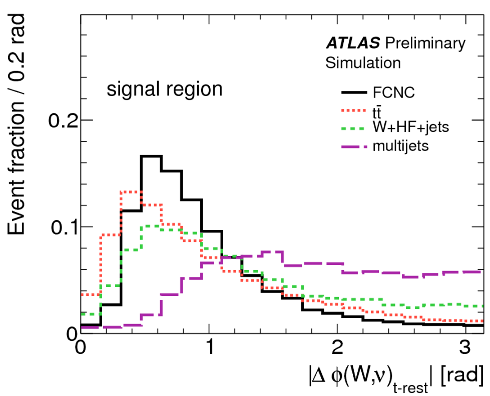
- Variables used in BDT

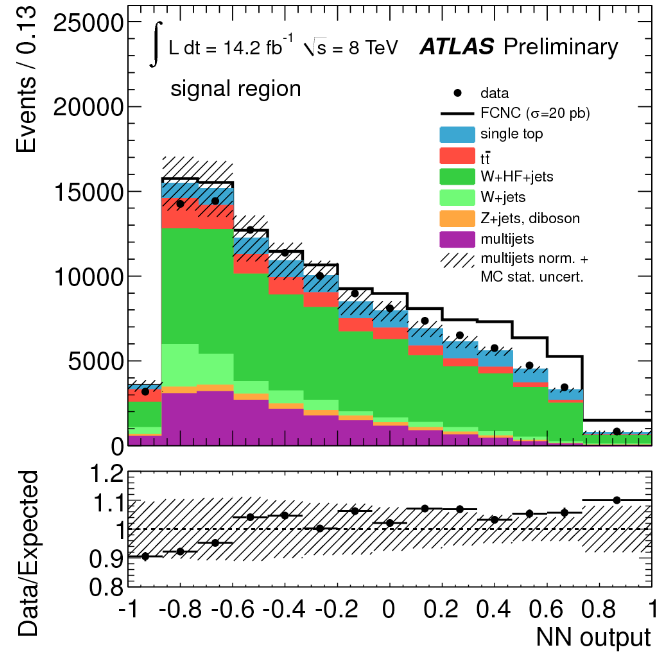
  - reconstructed top-quark mass,
  - $\Delta\varphi(l_W - b)$, azimuthal angle between the lepton from the W candidate and the b-jet candidate,
  - $q|\eta|$, with q the charge of the W candidate,
  - p_T of the Z boson candidate,
  - η of the Z boson candidate,
  - selected jet multiplicity,
  - selected b-tagged jet multiplicity,
  - $\Delta\varphi(Z{-}\not{E}_T)$, azimuthal angle between the Z candidate and the direction of the $\not{E}_T$ vector,
  - CSV discriminator,
  - η of the leading jet,
  - $\Delta\varphi(l_W - Z)$, azimuthal angle between the lepton from the W candidate and the Z candidate,

FCNC in Single Top (gq→t) Events









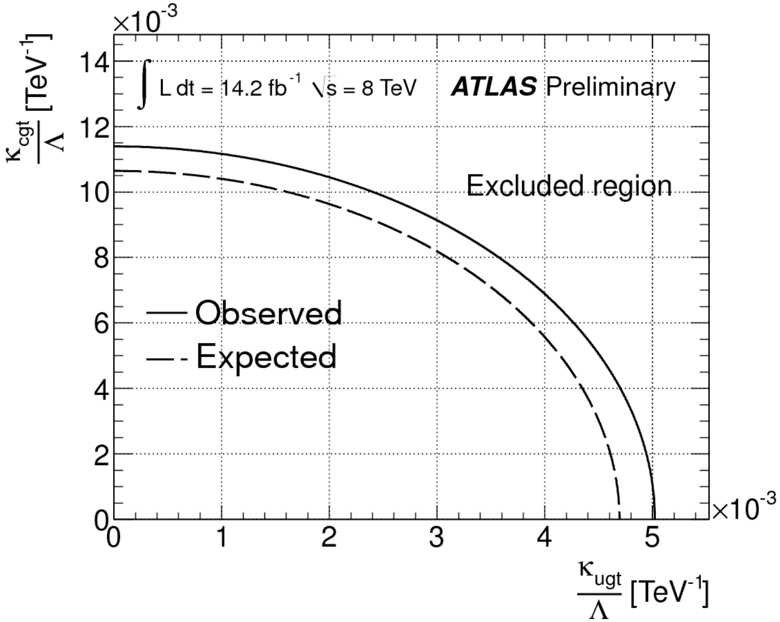
No evidence for FCNC process

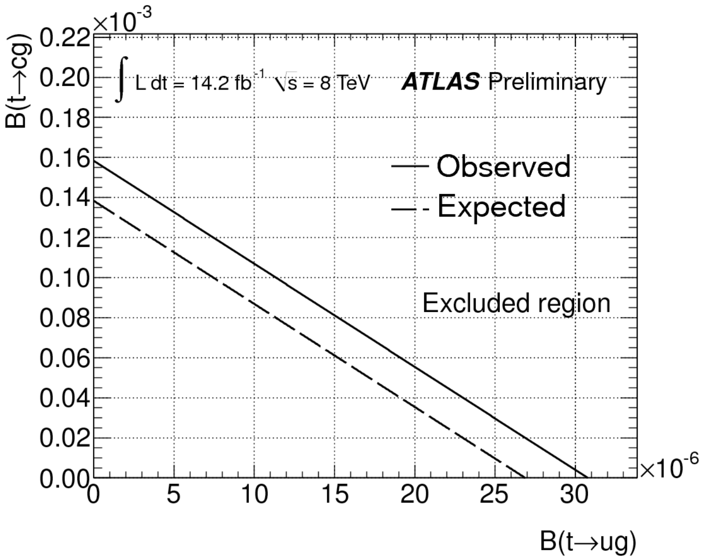
$$\sigma(u,c+g\rightarrow t)\times B(t\rightarrow Wb)$$
$$<1.8\ pb@95\%\ CL\ (CDF)$$
$$<3.9\ pb@95\%\ CL\ (ATLAS,7\ TeV)$$
$$<2.5\ pb@95\%\ CL\ (ATLAS,8\ TeV)$$

CDF, PRL 102 (2009) 151801
ATLAS, PLB 712 (2012) 351
ATLAS-CONF-2013-063 [8 TeV]

FCNC in Single Top (gq→t) Events

CDF, PRL 102 (2009) 151801
ATLAS, PLB 712 (2012) 351, ATLAS-CONF-2013-063 [8 TeV]





$\kappa_{cgt} = 0:$

$\kappa_{ugt} / \Lambda < 0.018\ TeV^{-1} (CDF)$

$\kappa_{ugt} / \Lambda < 0.0069\ TeV^{-1} (ATLAS,\ 7\ TeV)$

$\kappa_{ugt} / \Lambda < 0.0051\ TeV^{-1} (ATLAS,\ 8\ TeV)$

$\kappa_{ugt} = 0:$

$\kappa_{cgt} / \Lambda < 0.069\ TeV^{-1} (CDF)$

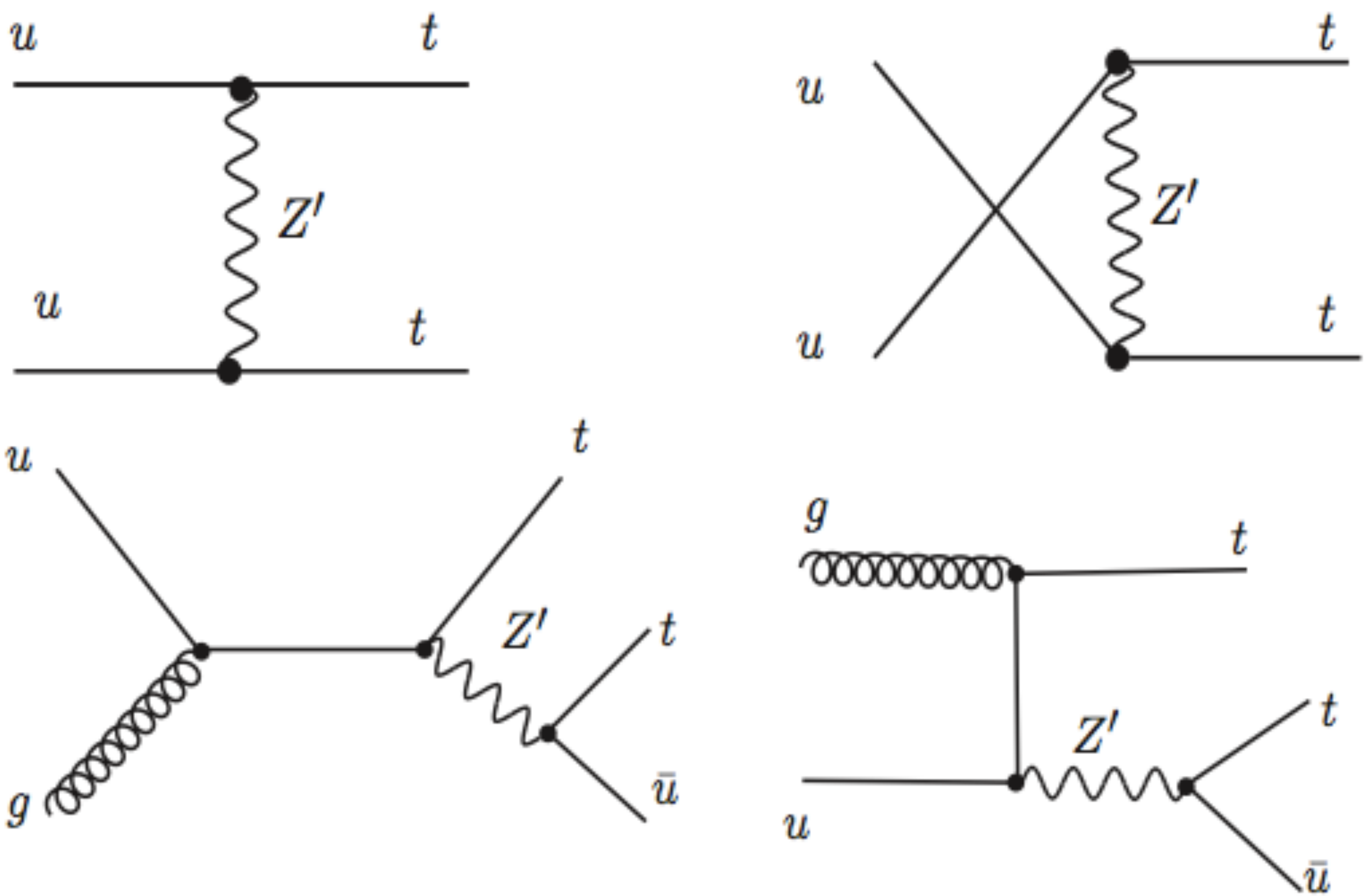
$\kappa_{cgt} / \Lambda < 0.016\ TeV^{-1} (ATLAS,\ 7\ TeV)$

$\kappa_{cgt} / \Lambda < 0.011\ TeV^{-1} (ATLAS,\ 8\ TeV)$

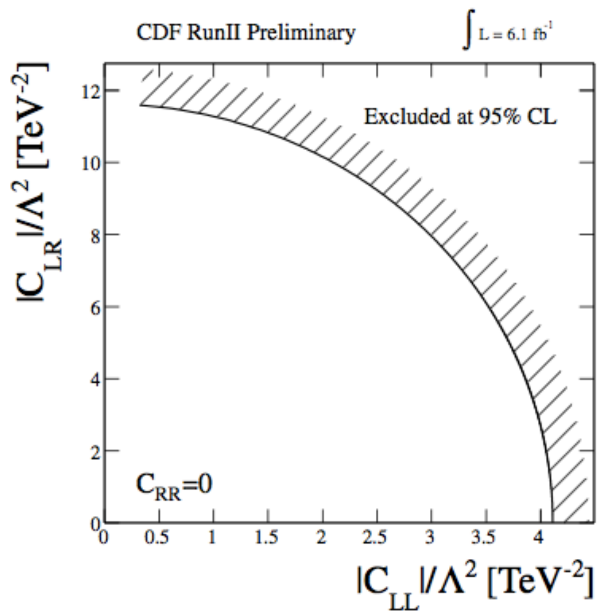
$\mathcal{B}$(t → c + g) = 0
$\mathcal{B}$(t → u + g) < 3.9x10^{-4} (CDF)
$\mathcal{B}$(t → u + g) < 5.7x10^{-5} (ATLAS, 7 TeV)
$\mathcal{B}$(t → u + g) < 3.1x10^{-5} (ATLAS, 8 TeV)

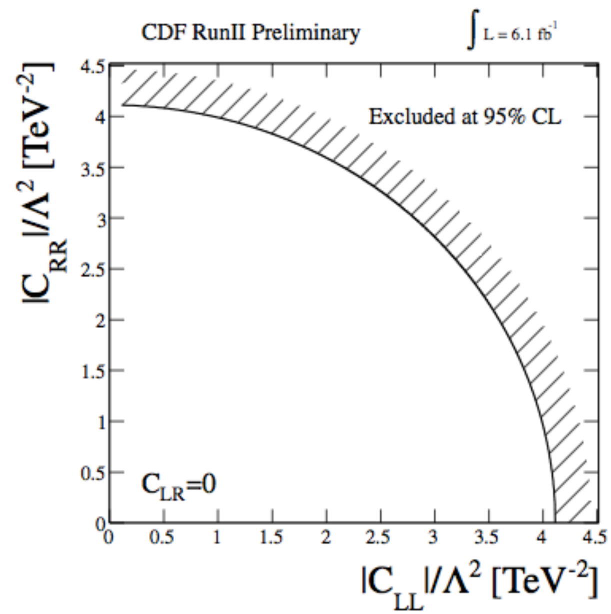
$\mathcal{B}$(t → u + g) = 0
$\mathcal{B}$(t → c + g) < 5.7x10^{-3} (CDF)
$\mathcal{B}$(t → c + g) < 2.7x10^{-4} (ATLAS, 7 TeV)
$\mathcal{B}$(t → c + g) < 1.6x10^{-4} (ATLAS, 8 TeV)

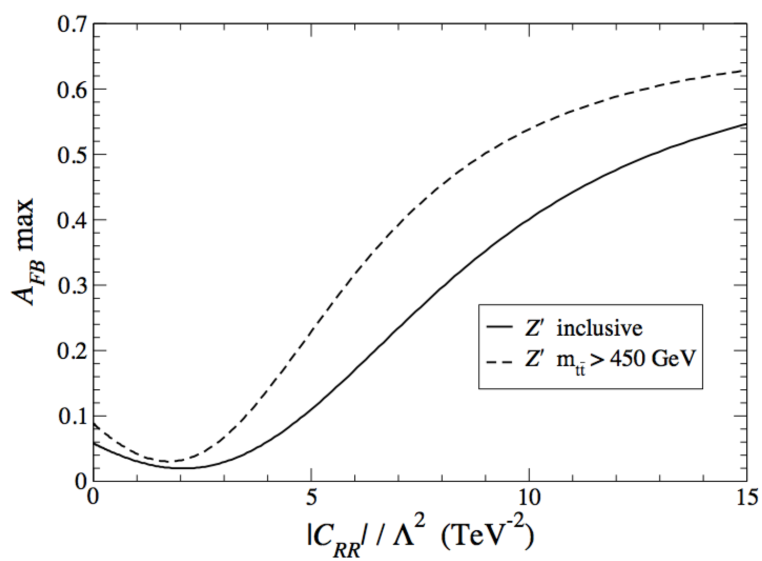
Same-sign Top Quark Production



Same-sign Top Quark Production







CDF/PHYS/EXO/PUBLIC/10466

Same-sign Top Quark Production

ATLAS, 7 TeV, fb^{-1}

JHEP04(2012)069