Top Quark Forward-Backward Asymmetry and Single-top

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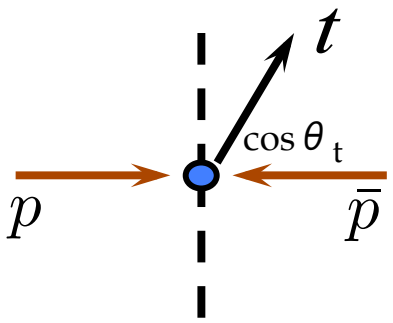
1205.****
w/ I. Low and H. Zhang

Tevatron has observed top quark Forward-Backward Asymmetry in t tbar production about $\geq 2\sigma$ away from SM.

Many explanations are proposed:
color-octet G', color singlet Z', W', ...

How can we test (quickly)
same-sign top, t tbar + 1jet, single-top

Top quark A_{FB}



$$A_c = \frac{N_t(p) - N_{\bar{t}}(p)}{N_t(p) + N_{\bar{t}}(p)}$$ Charge Asymmetry

$$N_{\bar{t}}(p) = N_t(\bar{p})$$ (C)

$$A_{fb} = \frac{N_t(p) - N_t(\bar{p})}{N_t(p) + N_t(\bar{p})}$$

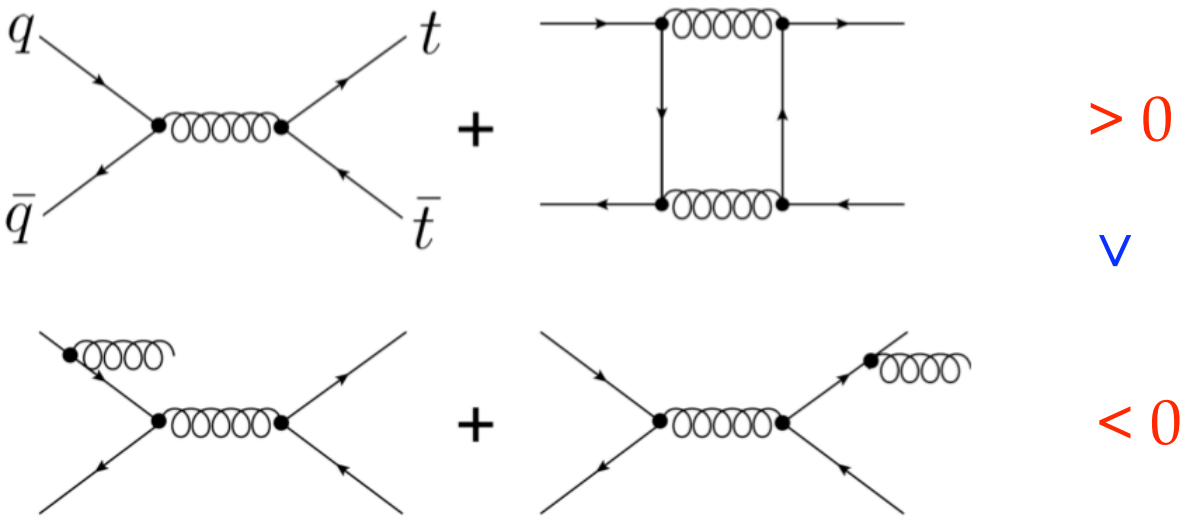
Lab frame $$A_{fb}^{p\bar{p}} = \frac{N(cos\theta_t > 0) - N(cos\theta_t < 0)}{N(cos\theta_t > 0) + N(cos\theta_t < 0)}$$

$$\Delta y = y_t - y_{\bar{t}} = 2 \cdot \tanh^{-1}\left(\frac{\cos(\theta_{t\bar{t}})}{\sqrt{1 + \frac{4m_t^2}{\hat{s} - 4m_t^2}}}\right)$$

c.m. frame $$A_{fb}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N_t(\Delta y < 0)}$$

SM NLO:

Kühn and Rodrigo,1998, 2011



> 0

V

< 0

$$A_{FB}^{p\bar{p}(SM)} = 0.056(7)$$ (QCD+EW, normalized to LO)

$$A_{FB}^{t\bar{t}(SM)} = 0.087(10)$$

MCFM

$$A^{p\bar{p}} \sim 0.038$$

$$A^{t\bar{t}} \sim 0.058 \xrightarrow[\text{EW}]{+\sim 26\%} 0.073$$

POWHEG

$$A_{FB}^{t\bar{t}} = 0.066$$ (QCD+EW)

Exp. Results

$$A_{fb}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N_t(\Delta y < 0)}$$

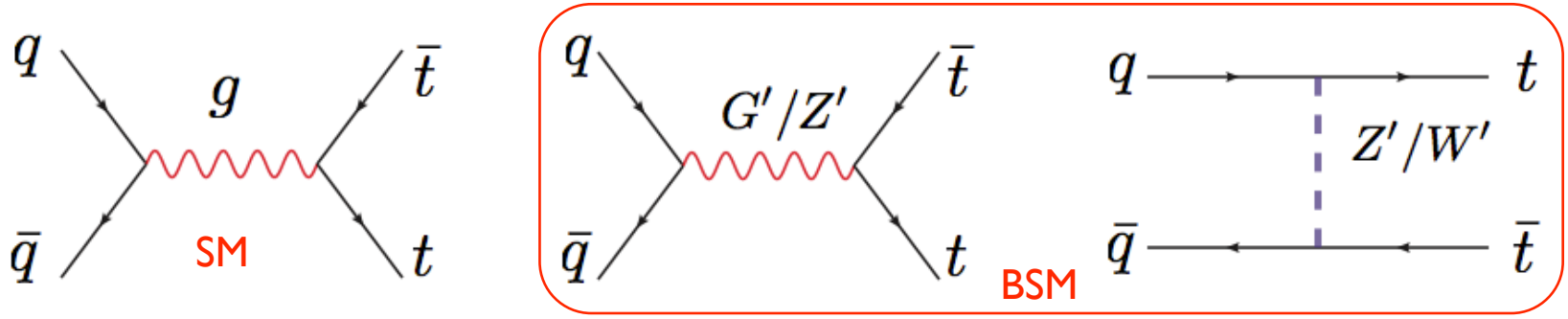
DZero	$0.12 \pm 0.08(\text{stat}) \pm 0.01(\text{sys})$	0.9 fb^{-1}
	$0.08 \pm 0.04(\text{stat}) \pm 0.01(\text{sys})$	4.3 fb^{-1}
PRD84:112005,2011	$0.196 \pm 0.065(\text{stat + sys})$	5.4 fb^{-1}
CDF	$0.24 \pm 0.13(\text{stat}) \pm 0.04(\text{sys})$	1.9 fb^{-1}
	$0.158 \pm 0.072(\text{stat}) \pm 0.017(\text{sys})$	5.3 fb^{-1}
	$0.162 \pm 0.047(\text{stat + sys})$	8.7 fb^{-1}

$$A_{fb}^{p\bar{p}} = \frac{N(cos\theta_t > 0) - N(cos\theta_t < 0)}{N(cos\theta_t > 0) + N(cos\theta_t < 0)}$$

CDF	$0.17 \pm 0.07(\text{stat}) \pm 0.04(\text{sys})$	1.9 fb^{-1}
	$0.193 \pm 0.065(\text{stat}) \pm 0.024(\text{sys})$	3.2 fb^{-1}
PRD83:112003,2011	$0.15 \pm 0.05(\text{stat}) \pm 0.024(\text{sys})$	5.3 fb^{-1}

possible explanations from new physics

NP models can be divided into two classes



s-channel: extra octet vector gluon (*axigluon*, ...)

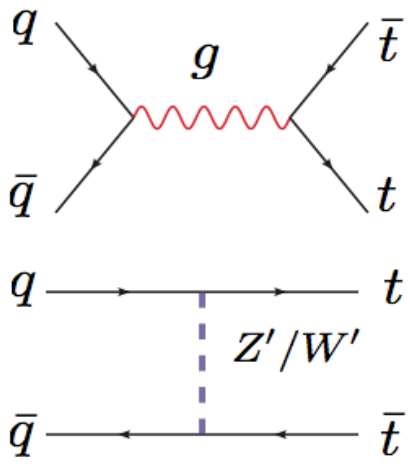
- "small" couplings to the first two generations: dijet constraints at 7 TeV.
- large couplings to third generation: to generate large $A_{FB.}$
- heavy resonances: $M_{t\bar{t}}$ spectrum constraints.
- broad width: to interfere with the SM amplitude.

t-channel: flavor changing interaction

- color singlet: *Z'-u-t* , W'^{+}-d-t
- color sextet or triplet

[Jung,Murayama,Pierce,Wells, arXiv:0907.4112]
[Cheung,Keung,Yuan, arXiv:0908.2589]
[Shu,Tait,Wang, arXiv:0911.3237]

Flavor-violating Z'/W'



$$\mathcal{L} = g_W \bar{u}/\bar{d}\gamma^\mu (f_L P_L + f_R P_R) t Z'_\mu/W'_\mu + h.c.$$

$$\frac{d\sigma}{d\cos\theta} = \mathcal{A}_{SM} + \mathcal{A}_{INT} + \mathcal{A}_{NPS}$$

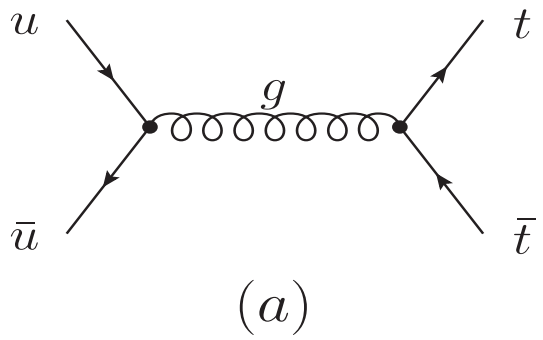
$$\mathcal{A}_{SM} = \frac{\beta g_s^4}{144\pi\hat{s}}(2 - \beta^2 + \beta^2\cos^2\theta)$$

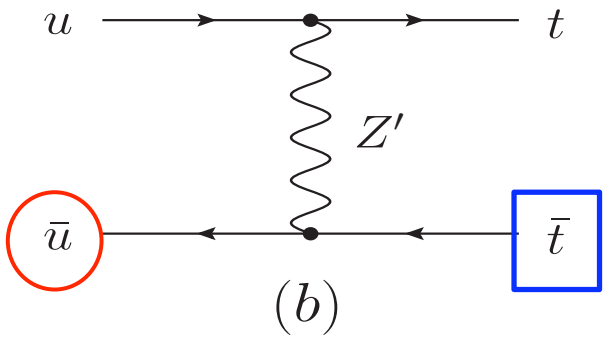
$$\mathcal{A}_{INT} = \frac{\beta g_s^2 g_W^2}{72\pi\hat{s}} \frac{f_R^2}{\hat{s}(\hat{t} - m^2_{Z'/W'})} \left[2(\hat{u} - m_t^2)^2 + 2\hat{s}m_t^2 + \frac{m_t^2}{m^2_{Z'/W'}}((\hat{t} - m_t^2)^2 + \hat{s}m_t^2)\right]$$

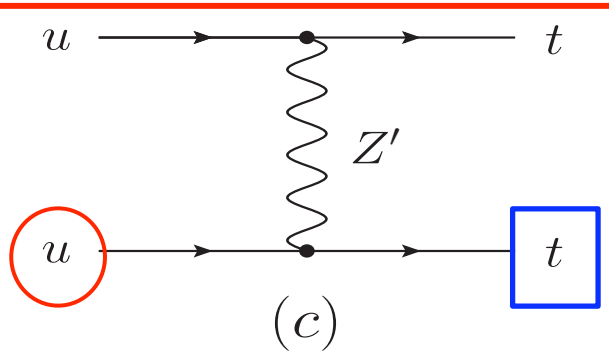
$$\mathcal{A}_{NPS} = \frac{\beta g_W^4}{128\pi\hat{s}} \frac{f_R^4}{(\hat{t} - m^2_{Z'/W'})^2} \left[4(\hat{u} - m_t^2)^2 + \frac{m_t^4}{m^4_{Z'/W'}}(4\hat{s}m^2_{Z'/W'} + (\hat{t} - m^2_{Z'/W'})^2)\right]$$

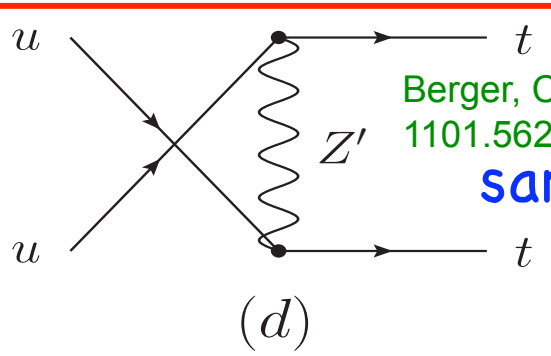
- INT contribution is negative.
- NPS contribution is positive.
- For heavy Z'/W', one needs a large f_R such that NPS contribution dominates over INT contribution to produce positive A_{FB}.

Flavor-violating Z′ model



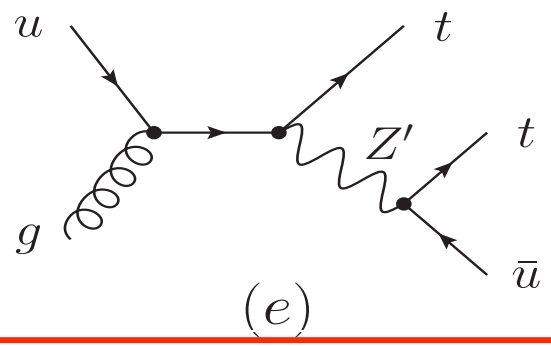


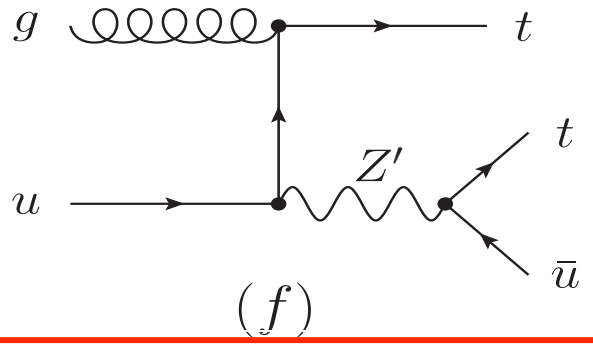




Berger, Cao, CRC, Li, Zhang, 1101.5625

same-sign top

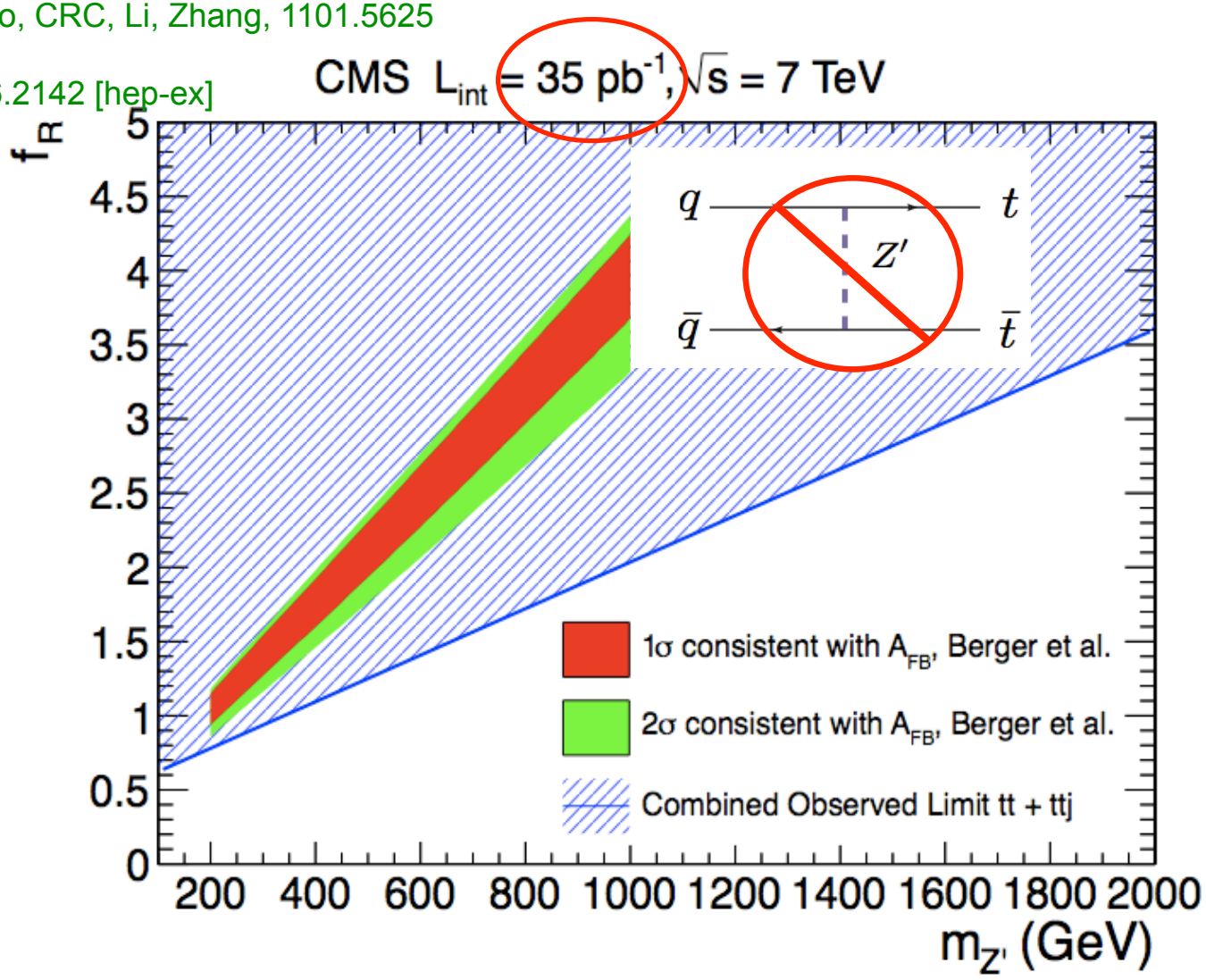




CMS same-sign search

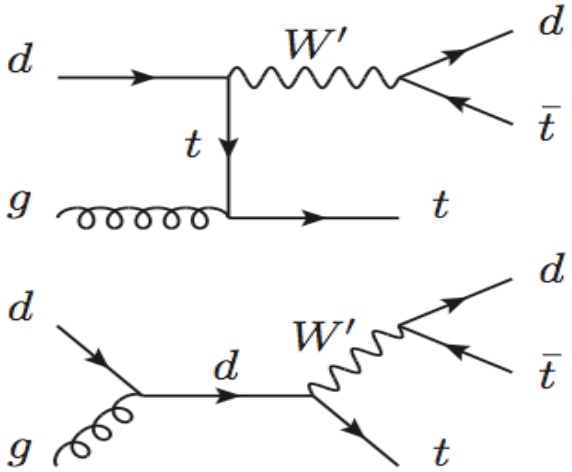
Berger, Cao, CRC, Li, Zhang, 1101.5625

CMS, 1106.2142 [hep-ex]

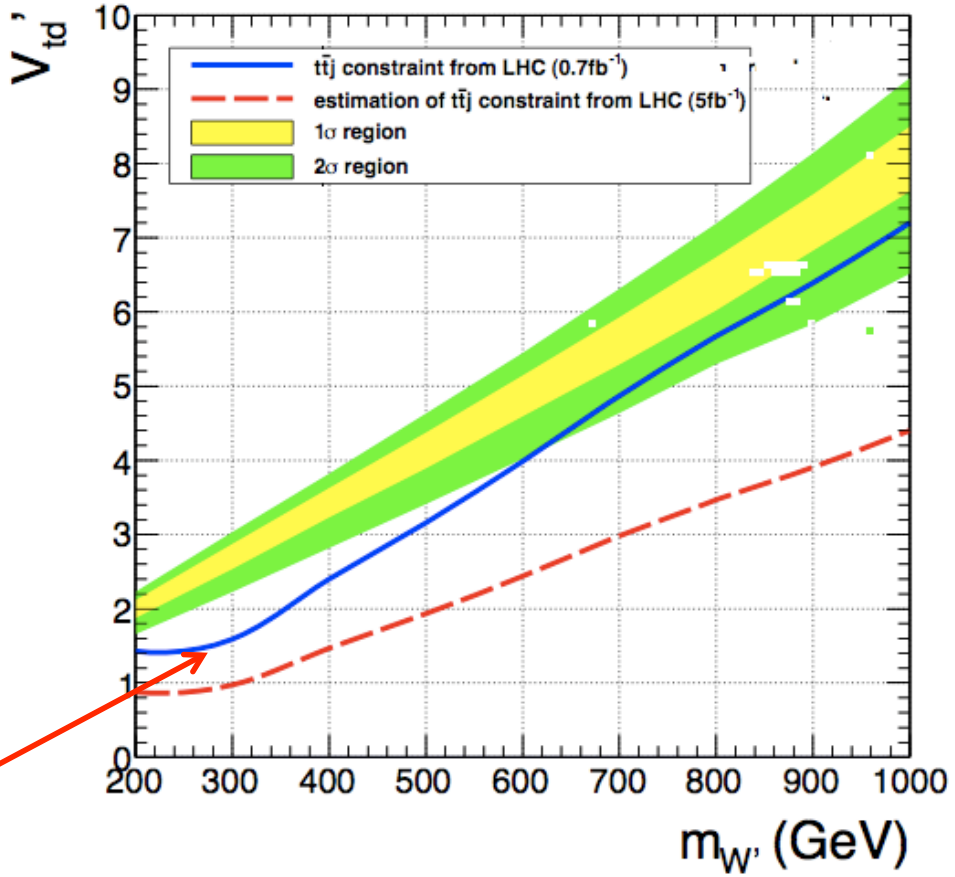


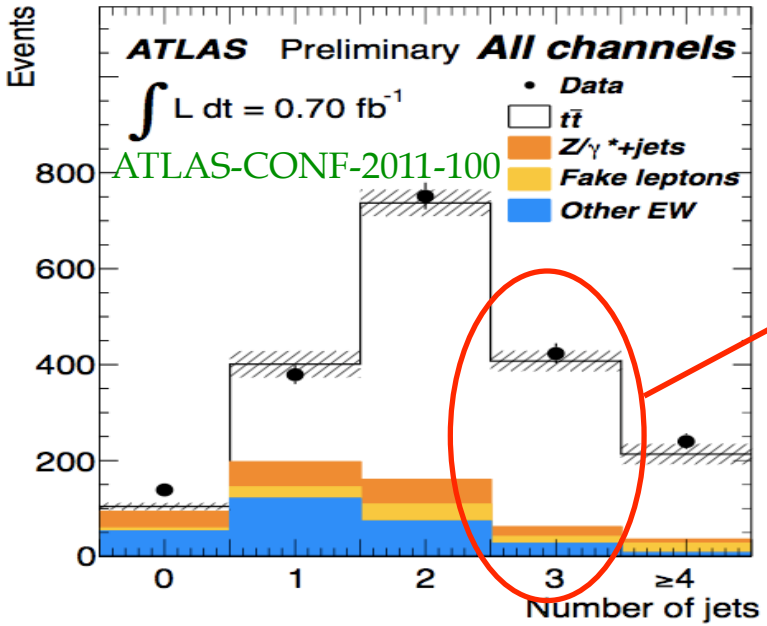
W′ and ttbar+1jet

See Hao Zhang's talk



Duffty, Sullivan, Hao, 1203.4489 [hep-ph]

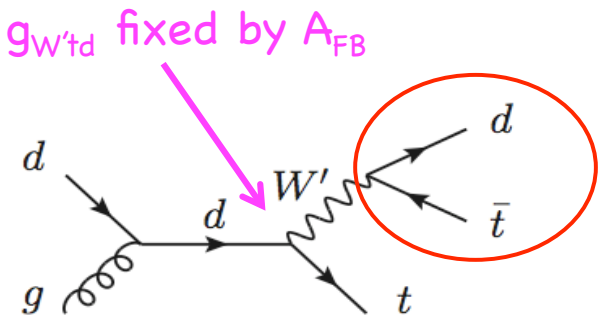




$m_{W'}$ < 600 GeV is currently excluded by 2σ

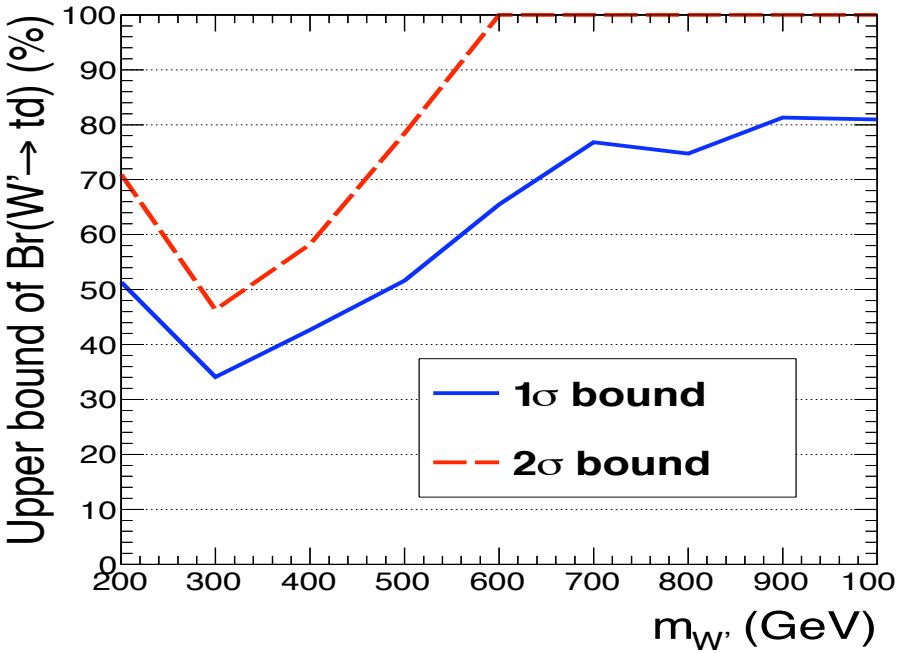
5 fb^{-1} data set can explore whole region

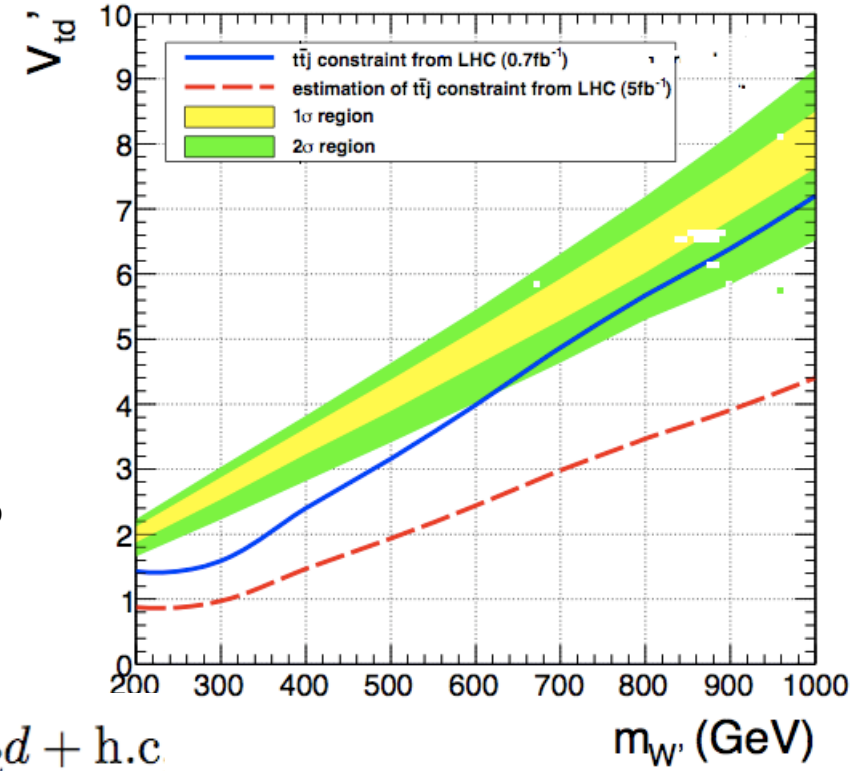
How can we get around the $t\bar{t} + jets$ constraints?



Duffty, Sullivan, Zhang, 1203.4489 [hep-ph]

➡ reduce Br($W' \to td$)





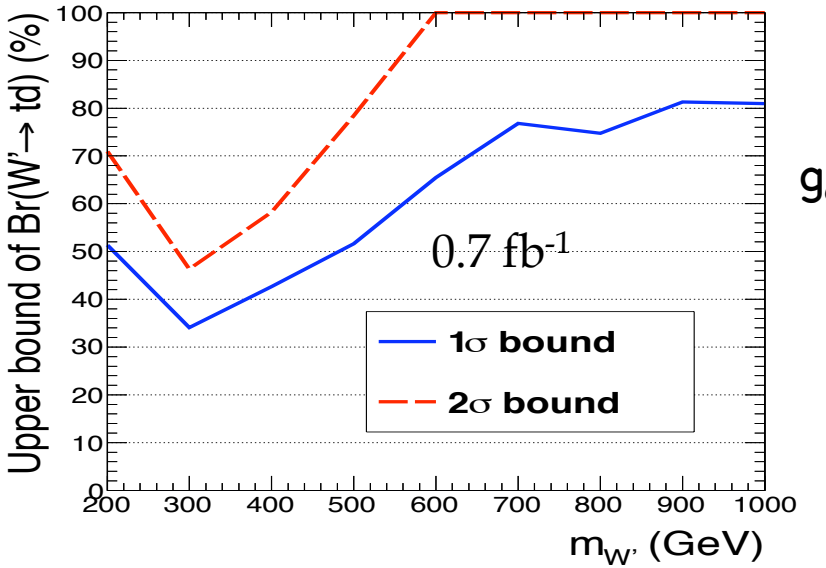
➡ open light quark decay mode

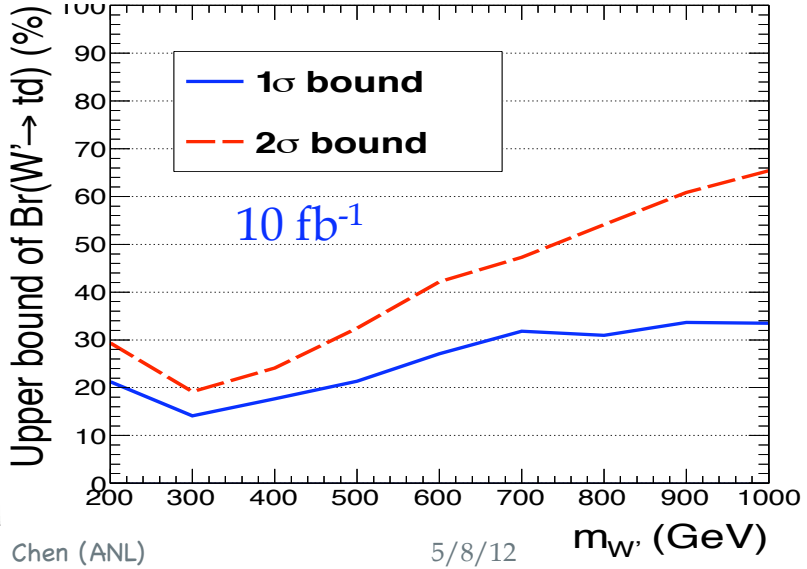
$$\mathcal{L} = g_2 g_{qq'} W'_\mu \bar{q} \gamma^\mu P_R q' + g_2 g_{td} W'_\mu \bar{t} \gamma^\mu P_R d + \text{h.c}$$

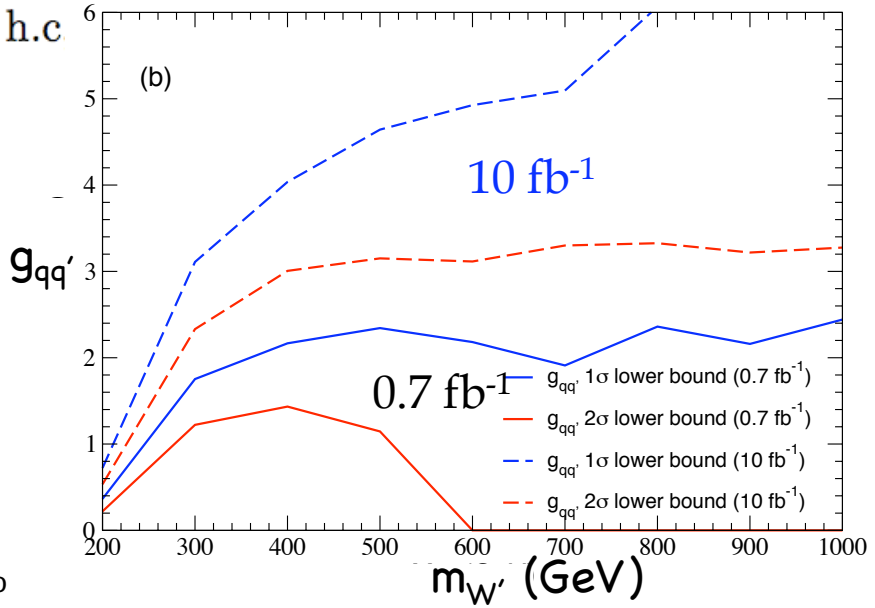
CRC, Low, Zhang (work in progress)

W′ and single-top

$$\mathcal{L} = g_2 g_{qq'} W'_\mu \bar{q} \gamma^\mu P_R q' + g_2 g_{td} W'_\mu \bar{t} \gamma^\mu P_R d + \text{h.c}$$







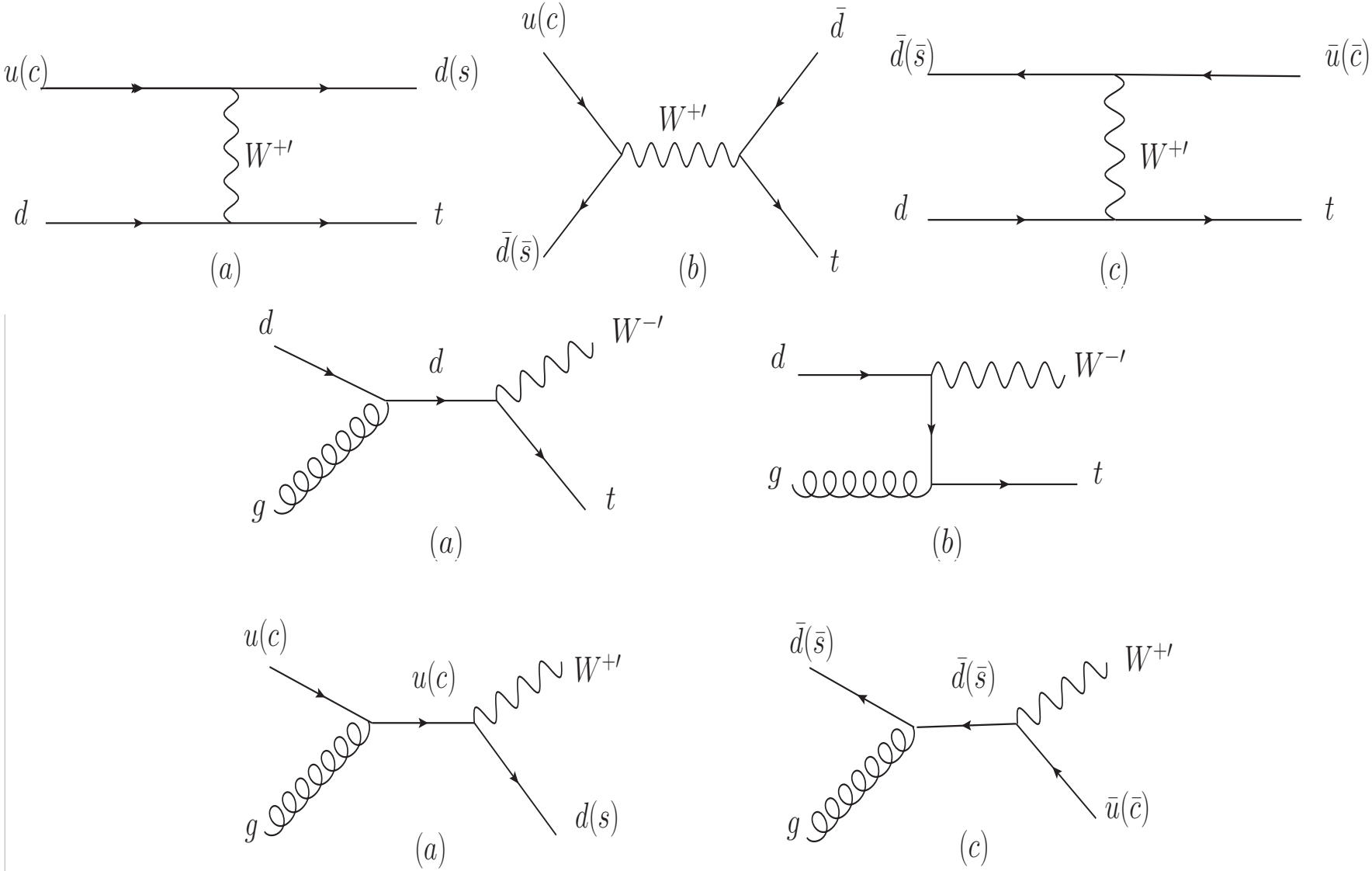
- agree with $t\bar{t}j$ in 95% C.L.

w/ 0.7 fb^{-1}, Br(W'-> td) < 35%~80%, if explain $A_{FB}^t + \sigma(t\bar{t})$ in 1σ;
no constraint when $m_{W'}$ > 600 GeV for 2σ.

w/ 10 fb^{-1}, Br(W'-> td) < 15%~35%, if explain $A_{FB}^t + \sigma(t\bar{t})$ in 1σ;
Br(W'-> td) < 20%~65% for 2σ.

$$\mathcal{L} = g_2 g_{qq'} W'_\mu \bar{q} \gamma^\mu P_R q' + g_2 g_{td} W'_\mu \bar{t} \gamma^\mu P_R d + \text{h.c}$$

We consider (q,q') = (u,d)&(c,s)



ATLAS search for (tch)single-top

one isolated charged lepton, missing energy, exact 2 or 3 j, one b-tagging

$$p_T^{\ell} > 25 \text{ GeV}, \ |\eta^{\ell}| < 2.5, \ p_T^{j} > 25 \text{ GeV}, \ |\eta^{j}| < 4.5,$$

$$|\eta^{\text{b-jet}}| < 2.5, \ E_T^{\text{miss}} > 25\text{GeV}, \ M_T(W) > (60 \text{ GeV} - E_T^{\text{miss}})$$

$$|\eta^{\text{jet1}}| > 2.0, \ H_T > 210 \text{ GeV},$$

$$150 \text{ GeV} < M_{\ell\nu b} < 190 \text{ GeV}, \ \Delta\eta(b-jet, jet1) > 1.0$$

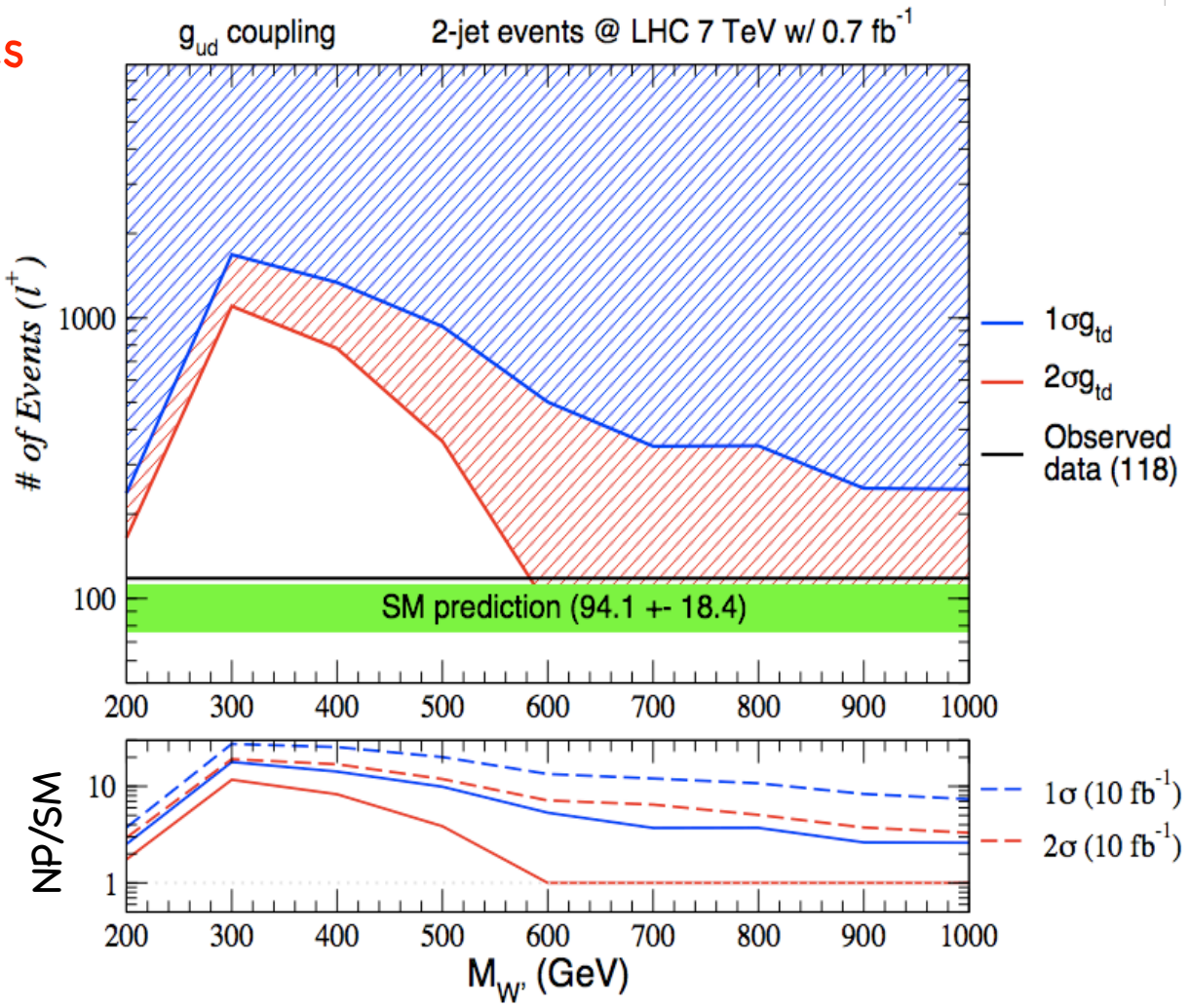
	Cut-based 2-jet		Cut-based 3-jet	
	Lepton+	Lepton-	Lepton+	Lepton-
single-top t-channel	51.8 ± 16.4	23.7 ± 6.5	33.0 ± 7.0	16.3 ± 4.8
TOTAL Expected	94.1 ± 18.4	50.2 ± 8.5	82.6 ± 12.7	57.9 ± 10.1
S/B	1.23	0.89	0.67	0.39
DATA	118	68	74	60

ATLAS-CONF-2011-101

W' and single-top

W'ud coupling generates too much more events
(1σ: > 3xSM;
2σ: >2xSM for
$m_{W'}$ < 600 GeV)

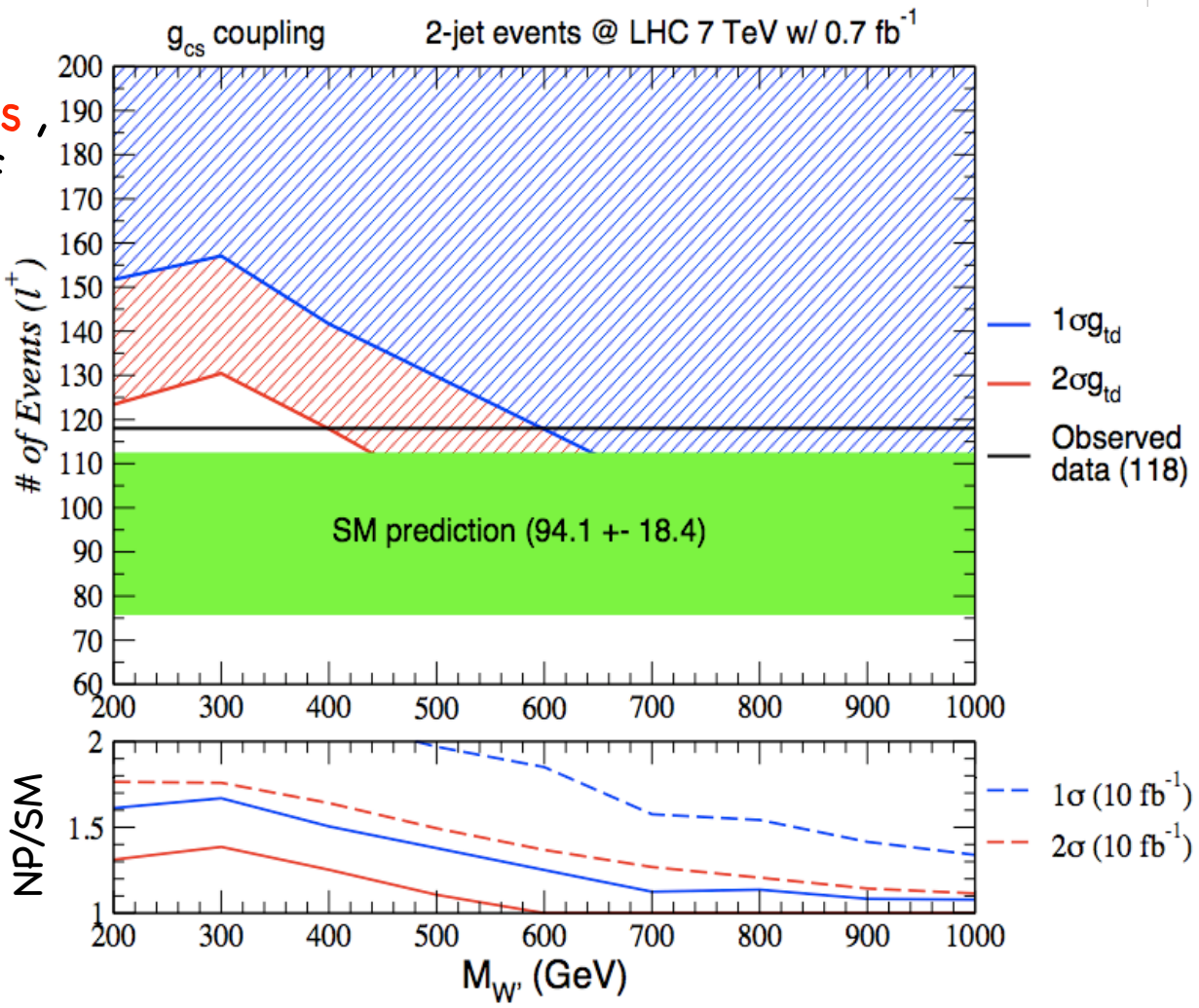
w/ 10 fb^{-1}, 2σ case can also be explored!



W' and single-top

weak constraints on W'cs , given the uncertainty of ~40% in data.

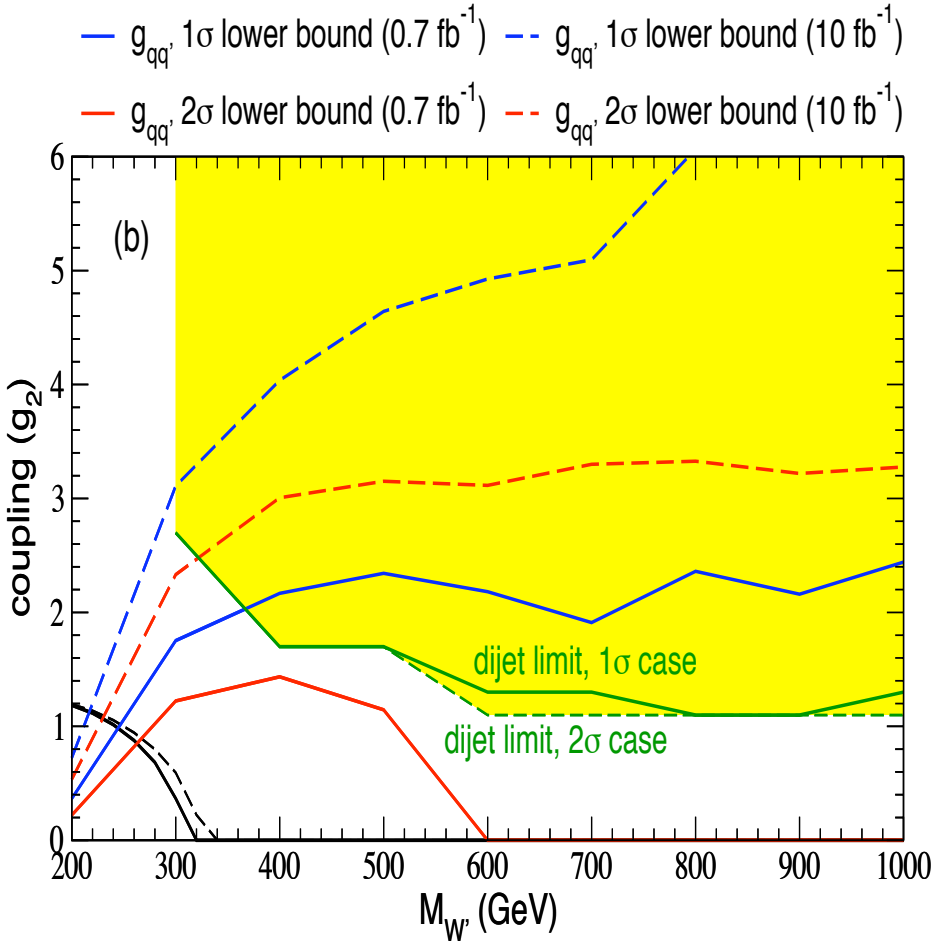
w/ 10 fb^{-1}, expect ~10% uncertainty, W'cs could be explored, assuming data = SM

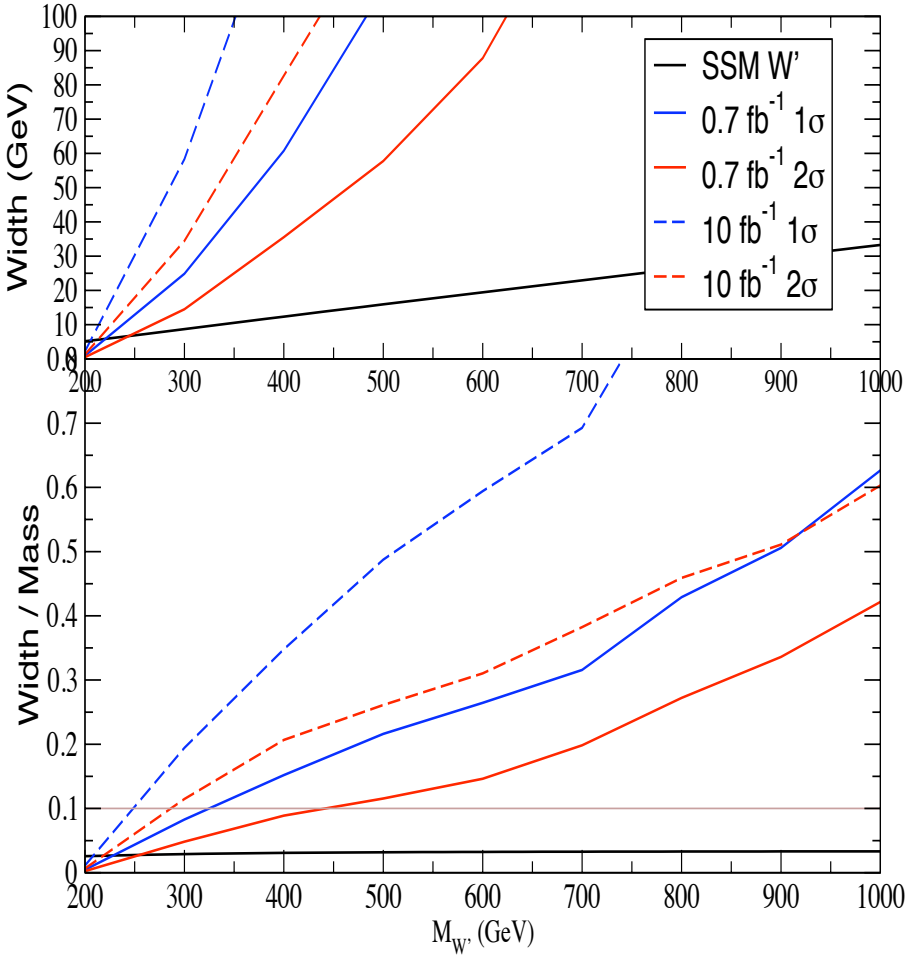


Conclusion

- Top quark A_{FB} is found to be larger than SM prediction at Tevatron; may indicate NP.
- FC Z′ model is excluded by CMS same-sign top data.
- W′ suffers from either $t\bar{t}j$ or single-top.
- W′ couples to ud is not allowed.
- 10fb^{-1} data set at 7 TeV LHC can explore W′ model in single-top search

Backup


$g_{qq'}$ 1σ lower bound (0.7 fb^{-1})
$g_{qq'}$ 1σ lower bound (10 fb^{-1})
$g_{qq'}$ 2σ lower bound (0.7 fb^{-1})
$g_{qq'}$ 2σ lower bound (10 fb^{-1})
(b)
dijet limit, 1σ case
dijet limit, 2σ case
coupling (g_2)
$M_{W'}$ (GeV)


SSM W'
0.7 fb^{-1} 1σ
0.7 fb^{-1} 2σ
10 fb^{-1} 1σ
10 fb^{-1} 2σ
Width (GeV)
Width / Mass
$M_{W'}$ (GeV)