Multi-lepton signals from the top-prime quark at the LHC

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with KC Kong and Graham Wilson JHEP 1204 (2012) 079 (arxiv:1112.3041)

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What do we mean by "multi-lepton"?

• Prehistoric mathematics

- Our prehistoric ancestors would have a general sensibility about amounts, and would have instinctively known the difference between "one" and "two" sabre-tooth tigers. But the intellectual leap from the concrete idea of two things to the invention of a symbol or word for the abstract idea of "two" took many ages to come about.
- Even today, there are isolated hunter-gatherer tribes in the Amazon which only have words for "one", "two", and "many"
- Who are we to argue with such a simple numbering system?
- In this talk, "multi" means 3 or more

The model

- SM + T', G' (Dobrescu, Kong, Mahbubani)
 - arxiv:0902.0792
- Start by adding a "vector-like" top quark with quantum numbers (3, 1, 2/3) under SM

$$\mathcal{L} \supset -\left(\bar{u}_L^3, \bar{\chi}_L\right) \left(\begin{array}{cc} \lambda_t (h+v)/\sqrt{2} & 0\\ M_0 & M_\chi \end{array}\right) \left(\begin{array}{c} u_R^3\\ \chi_R \end{array}\right)$$

- $\begin{pmatrix} t_{L,R} \\ t'_{L,R} \end{pmatrix} = \begin{pmatrix} \cos \theta_{L,R} & -\sin \theta_{L,R} \\ \sin \theta_{L,R} & \cos \theta_{L,R} \end{pmatrix} \begin{pmatrix} u_{L,R}^3 \\ \chi_{L,R} \end{pmatrix}$
 - The masses of the top eigenstates relates the left and right mixing angles

Gluon Prime

• Extend the SM color gauge group $SU(3)_1 \times SU(3)_2 \rightarrow SU(3)_c$

$$\left(\begin{array}{c} G^1_\mu \\ G^2_\mu \end{array} \right) = \frac{1}{\sqrt{h_1^2 + h_2^2}} \left(\begin{array}{cc} h_2 & -h_1 \\ h_1 & h_2 \end{array} \right) \left(\begin{array}{c} G_\mu \\ G'_\mu \end{array} \right)$$

- Massless state becomes the SM gluon, massive state is our gluon prime
- After the breaking of the SU(3)xSU(3) the strong couplings are parameterized by gs and r (the ratio of G' to G coupling)

Interactions

• EW bosons and T-prime $\frac{g}{\sqrt{2}}W^+_{\mu}\bar{b}_L\gamma^{\mu}(c_Lt_L+s_Lt'_L)+H.c.$

$$\frac{g}{\cos\theta_W} Z_\mu \left[\left(\frac{c_L^2}{2} - \frac{2}{3} \sin^2 \theta_W^2 \right) \bar{t}_L \gamma^\mu t_L + \left(\frac{s_L^2}{2} - \frac{2}{3} \sin^2 \theta_W \right) \bar{t'}_L \gamma^\mu t'_L + \frac{s_L c_L}{2} (\bar{t'}_L \gamma^\mu t_L + H.c.) \right] \\ \frac{-1}{v_h \sqrt{2}} h(c_L^2 m_t \bar{t}_L t_R + s_L^2 m_{t'} \bar{t'}_L t'_R + c_L s_L m_{t'} \bar{t}_L t'_R + c_L s_L \bar{t'}_L t_R) + H.c.$$

• quarks and gluon-prime

$$g_s r G'^a_{\ \mu} \bar{q} \gamma^\mu T_a q$$

• tops and gluon-prime $g_s G'^a_{\ \mu} [\bar{t}\gamma^\mu (g_L P_L + g_R P_R)T^a t + \bar{t'}\gamma^\mu (g''_L P_L + g''_R P_R)T^a t']$ $g_s G'^a_{\ \mu} \bar{t}\gamma^\mu (g'_L P_L + g'_R P_R)T^a t'$

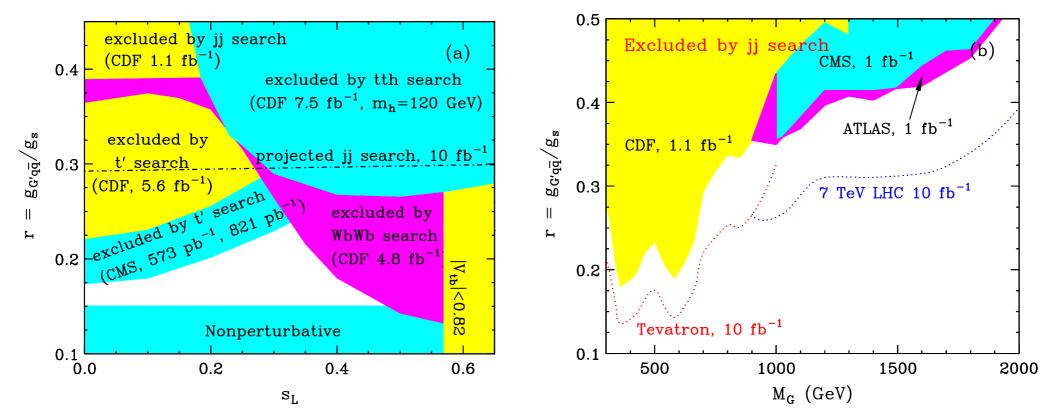
• Total of 4 parameters: T', G' masses, sL and r

Why the t'/G' model?

- Numerous studies have been done analyzing the multi-lepton prospects of common BSM models
- If we do start seeing multi-lepton signals then the next step is to actually figure out what model this signal came from.
- This model is fully described by four parameters outside of the SM.
 - not many places in parameter space to hide

Constraints

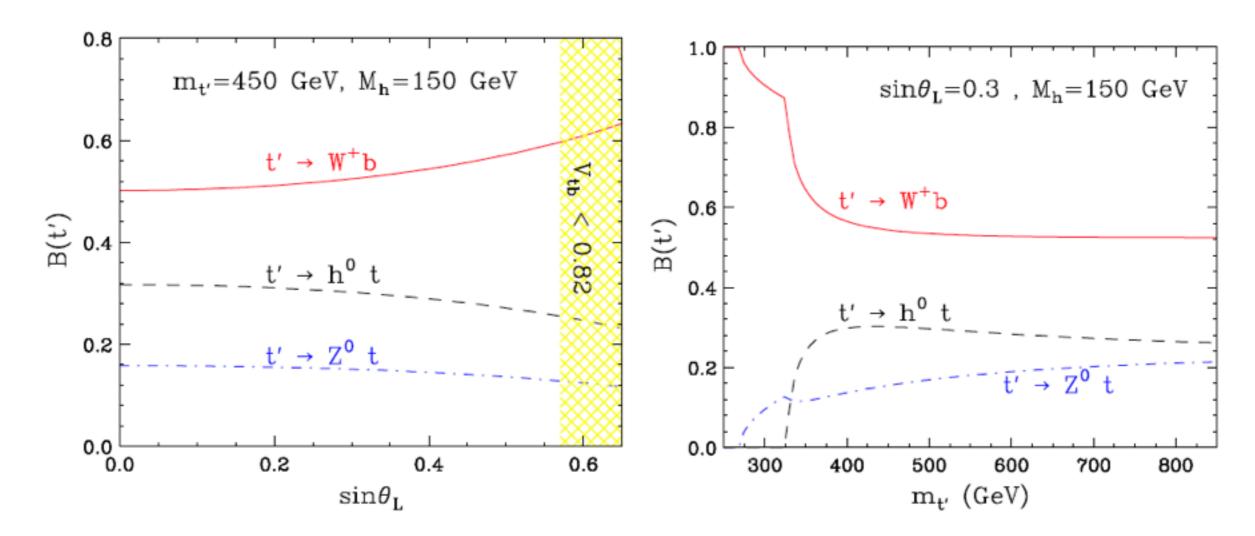
 One goal was to update the constraints using up to date LHC and Tevatron data.



• T' = 450 GeV, G' = I TeV

• The available parameter space for this point is quickly evaporating

Decays of the t'



Taken from Dobrescu, Kong, and Mahbubani

if
$$m_{t'} >> m_t$$
 $B(t' \to W^+ b) = \frac{1}{1 + c_L^2} \ge$

$$B(t' \to Zt) = B(t' \to ht) = \frac{c_L^2}{2(1 + c_L^2)} \le 25\%$$

50%

Multi-lepton signals

N_ℓ	$t\bar{t}' + t'\bar{t}$	$t' \overline{t}'$
0	$0.57 \ b_{Zt} + 0.61 \ b_{Wb}$	$(0.72 \ b_{Zt} + 0.78 \ b_{Wb})^2$
1	$0.32 \ b_{Zt} + 0.34 \ b_{Wb}$	$2 \times (0.21 \ b_{Zt} + 0.22 \ b_{Wb})$
		$\times (0.73 \ b_{Zt} + 0.78 \ b_{Wb})$
		$(0.21 \ b_{Zt} + 0.22 \ b_{Wb})^2$
2	$0.086 \ b_{Zt} + 0.048 \ b_{Wb}$	$+ 2 \times (0.052 \ b_{Zt})$
		$\times (0.73 \ b_{Zt} + 0.78 \ b_{Wb}$)
		$2 \times (0.0147 \ b_{Zt})$
3	$0.023 \ b_{Zt}$	$\times (0.73 \ b_{Zt} + 0.78 \ b_{Wb})$
		$+2 \times (0.052 \ b_{Zt})$
		$\times (0.21 \ b_{Zt} + 0.22 \ b_{Wb})$
		$2 imes (0.015 \ b_{Zt})$
4	$0.0032 \ b_{Zt}$	$\times (0.21 \ b_{Zt} + 0.22 \ b_{Wb})$
		$+(0.052 \ b_{Zt})^2$
5	0	$2 \times (0.052 \ b_{Zt})$
		$\times (0.015 \ b_{Zt})$
6	0	$(0.015 \ b_{Zt})^2$

-We look at pair and associated t' production -Sacrificing the total cross section we can get events with up to 6 leptons

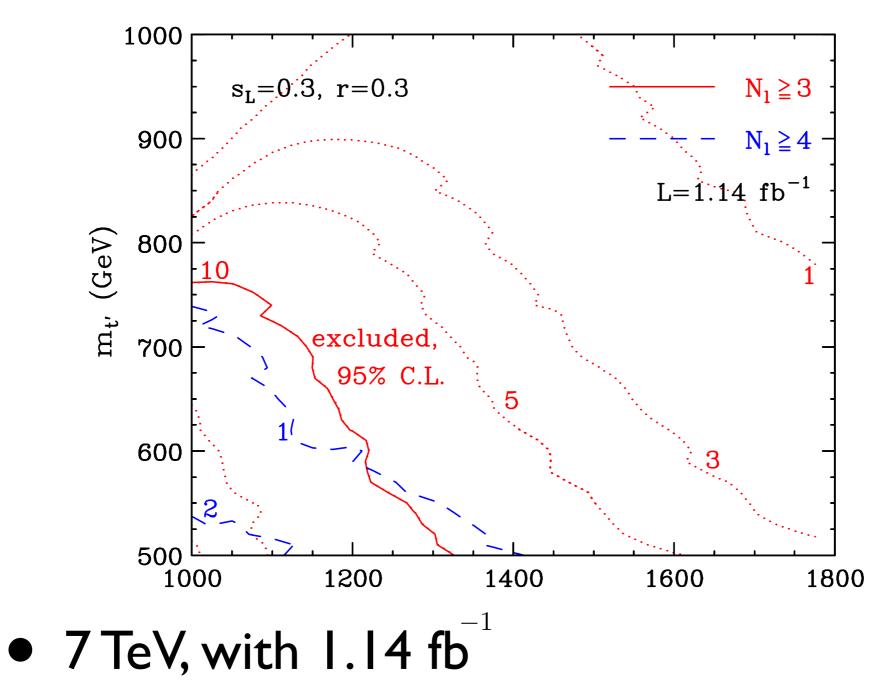
$$b_{Zt} = BR(t' \to Zt),$$

$$b_{Wb} = BR(t' \to Wb),$$

$$b_{Z,2l} = BR(Z \to \ell^+ \ell^-) = 0.067,$$

$$b_{W,1l} = BR(W^+ \to \ell^+ \nu_\ell) = 0.22.$$

LHC Reach



CMS collaboration: arxiv: 1109.4985

The Next Step

- Once more of these multi-lepton events are found, more work needs to be done to distinguish between which model it came from
 - e.g. SUSY, UED decay chains
- One can look at kinematic distributions which could change depending on the intermediate particles
 - Invariant mass, MT2, etc.

Conclusion

- The t'/G' model is easily described by only four extra parameters
- We can get some very interesting multilepton signals
- As easy as it is to describe, it is just as easy to rule out with standard LHC searches as well as multi-lepton searches

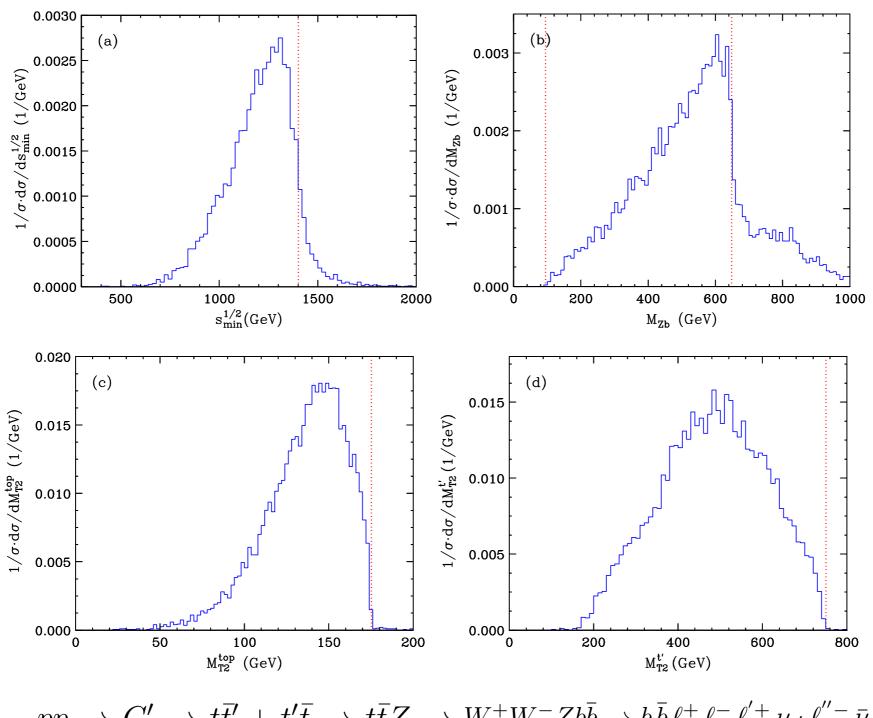
The End



Backup slides

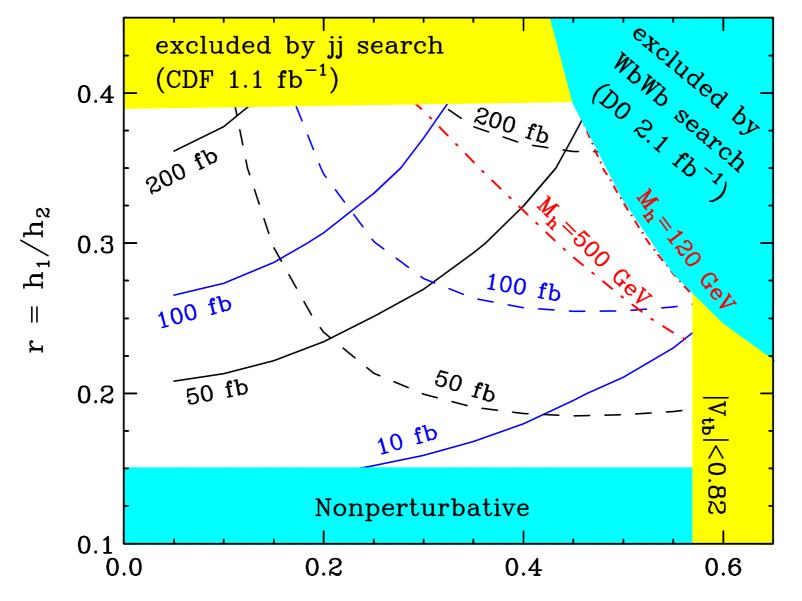
transform under the extended gauge group as shown in Table 1. end the model \mathfrak{g}_{h} section $2\sqrt{k}$ including a $SU_3(3)_{1}$ with $SU_4(3)_{2h}$ gauge symmetry ectione Subly ibediteled draws with the States and the states of states and the satisfied of the states of the sta netownoft@Che clais gun of CD. G. while the exthogonal combination of the cobr-octet boson sprantieldy Σ breaks for many enals bilinear the static two Σ (3) groups. Σ may ntary scalar spitheat the the presence of here is senor malizable and simple, at degrees of where h_1 and h_2 are the $SU(3)_1 \times SU(3)_2$ gauge couplings, the follows. The quarks in the mass eigenstate basis for the fermions and gauge bosons, the gluon interactions nderithen Standed sauseastellerines have in Table the total age soupling $SU(3)_{2}$ $SU(3)_{1}$ $SU(2)_{\rm M}$ gæge grðiFivassbævtiónaFablehle gange SM quarks: q_L^i , u_R^i , d_R^i , $di G_{na}^2 mix [the]^n$ orthogonal combination G'_{r} is a color, octet boson ion. of QCD. Getti le linear combina scalar with d mass M_{G} is the orthogonal combination G'is a color-octet boson wectorlike quark: $\chi_L, \chi_R / 2$ +2/3 $^{1}-h_{1}$ G_{μ}^{-1} $^{3}h_{\gamma}$ scalar with γ'^1 $= \frac{1}{\frac{h}{h}} \frac{1}{h} \frac{h}{h} \frac{h}$ rks are vectorlike and have a strength set by the QCD gauge coupling for the fermions and gauge bosons, the gluon interactions nd have a strength set by the OCD gauge coupling

Distributions



 $pp \to G' \to t\bar{t}' + t'\bar{t} \to t\bar{t}Z \to W^+W^-Zb\bar{b} \to b\bar{b}\,\ell^+\,\ell^-\,\ell'^+\,\nu_{\ell'}\,\ell''^-\,\bar{\nu}_{\ell''}$ [112.3041, Kong, McCaskey, Wilson]

Previous exclusion



 s_L