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

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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

$$\mathcal{L} \supset -(\bar{u}^3_L, \bar{\chi}_L) \begin{pmatrix} \lambda_t(h+v)/\sqrt{2} & 0 \\ M_0 & M_\chi \end{pmatrix} \begin{pmatrix} u^3_R \\ \chi_R \end{pmatrix}$$

$$\begin{pmatrix} t_{L,R} \\ t'_{L,R} \end{pmatrix} = \begin{pmatrix} \cos\theta_{L.R} & -\sin\theta_{L,R} \\ \sin\theta_{L,R} & \cos\theta_{L,R} \end{pmatrix} \begin{pmatrix} u^3_{L,R} \\ \chi_{L,R} \end{pmatrix}$$

- The masses of the top eigenstates relates the left and right mixing angles

Gluon Prime

- Extend the SM color gauge group

$$SU(3)_1 \times SU(3)_2 \to SU(3)_c$$

$$\begin{pmatrix} G_\mu^1 \\ G_\mu^2 \end{pmatrix} = \frac{1}{\sqrt{h_1^2 + h_2^2}} \begin{pmatrix} h_2 & -h_1 \\ h_1 & h_2 \end{pmatrix} \begin{pmatrix} G_\mu \\ G'_\mu \end{pmatrix}$$

- 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 $\frac{g}{\sqrt{2}} W_\mu^+ \bar{b}_L \gamma^\mu (c_L t_L + s_L t'_L) + H.c.$

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

$$\frac{-1}{v_h\sqrt{2}} h (c_L^2 m_t \bar{t}_L t_R + s_L^2 m_{t'} \bar{t'}_L t'_R + c_L s_L m_{t'} \bar{t}_L t'_R + c_L s_L \bar{t'}_L t_R) + H.c.$$

- quarks and gluon-prime

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

- tops and gluon-prime

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

$$g_s G'^a_\mu \bar{t}\gamma^\mu (g'_L P_L + g'_R P_R) T^a t'$$

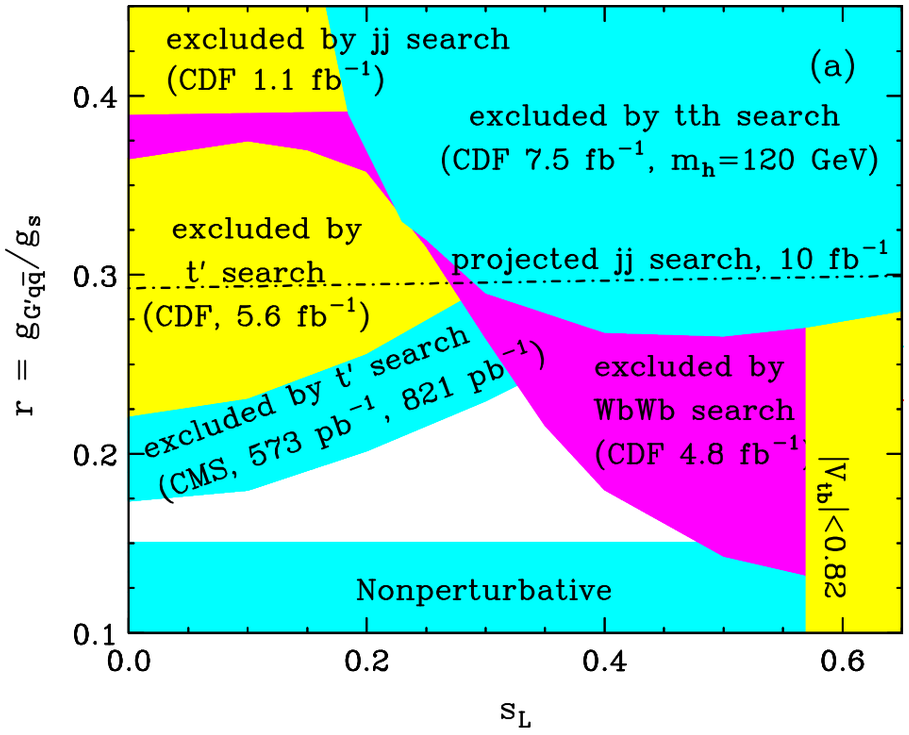
- Total of 4 parameters: T', G' masses, sL and r

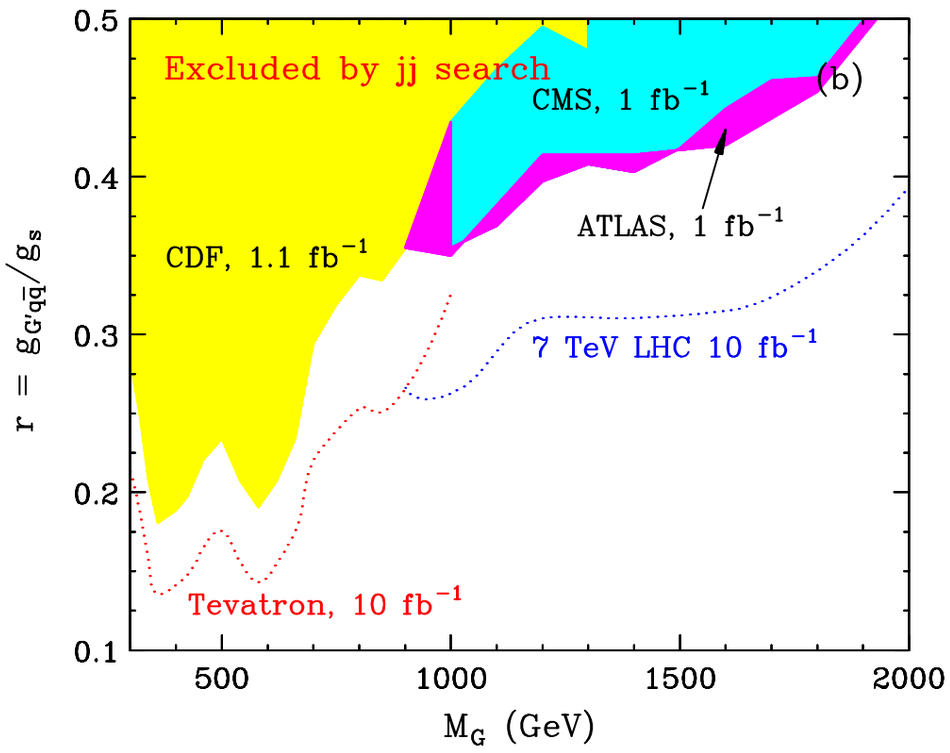
Why the t'/G' model?

- 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

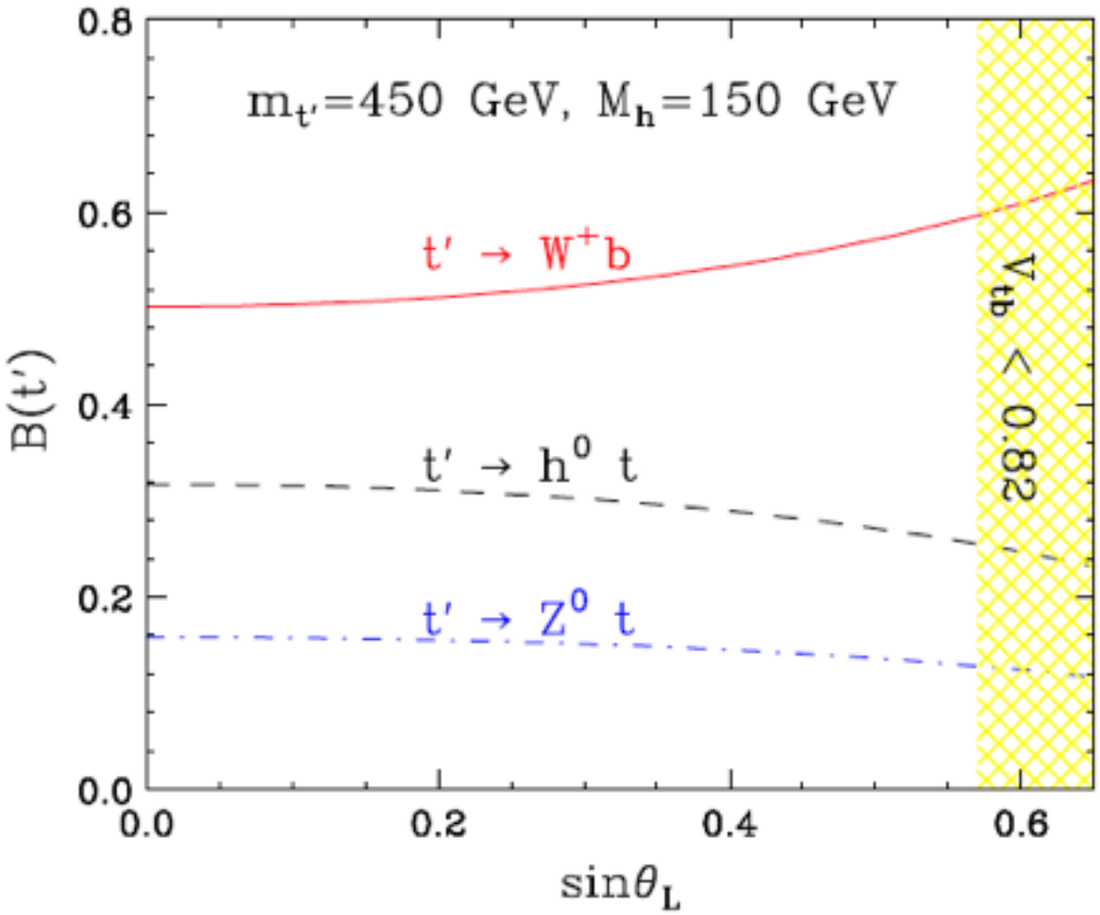
- One goal was to update the constraints using up to date LHC and Tevatron data.

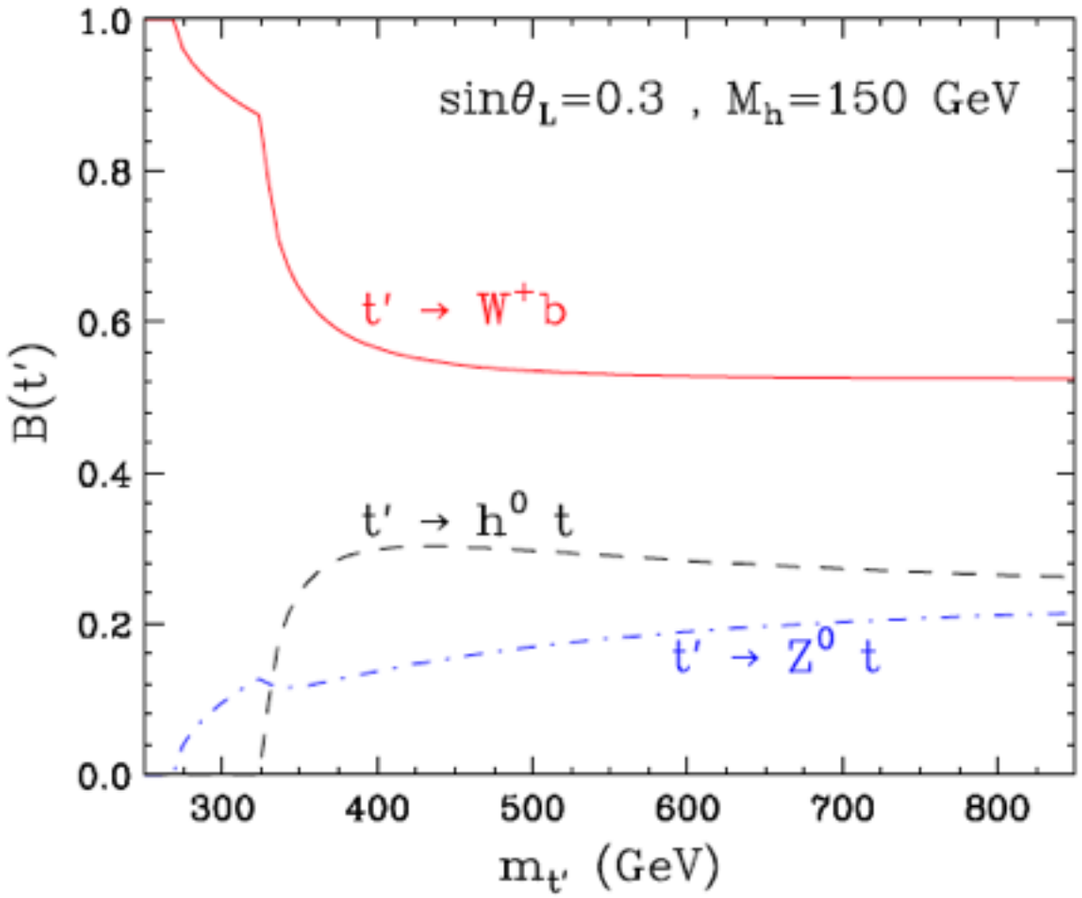




- T' = 450 GeV, G' = 1 TeV
- The available parameter space for this point is quickly evaporating

Decays of the t'





- Taken from Dobrescu, Kong, and Mahbubani

if $m_{t'} >> m_t$

$$B(t' \to W^+ b) = \frac{1}{1 + c_L^2} \geq 50\%$$

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

Multi-lepton signals

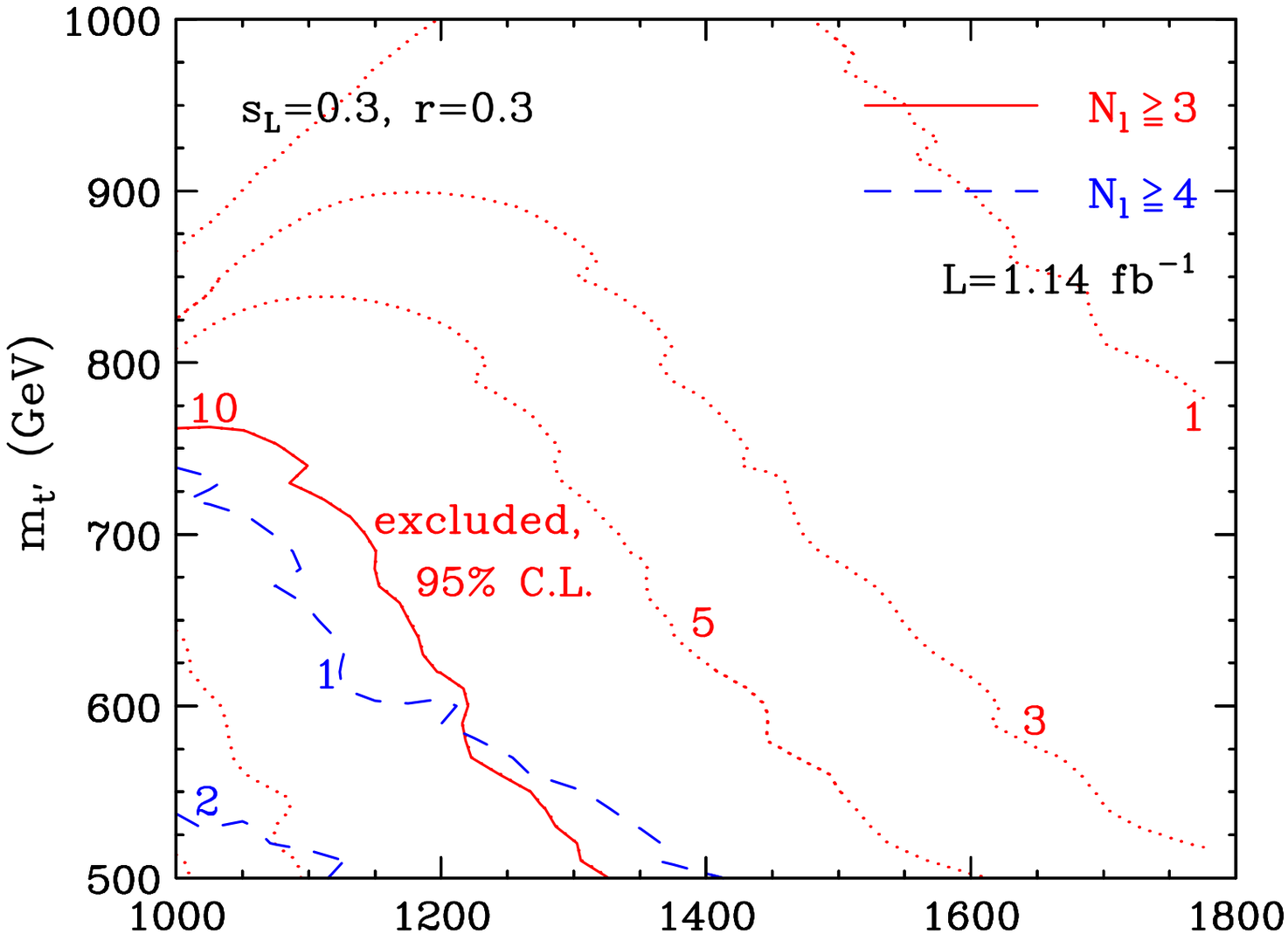
N_ℓ	$t\bar{t}' + t'\bar{t}$	$t'\bar{t}'$
0	$0.57\ b_{Zt} + 0.61\ b_{Wb}$	$(0.72\ b_{Zt} + 0.78\ b_{Wb})^2$
1	$0.32\ b_{Zt} + 0.34\ b_{Wb}$	$2 \times (0.21\ b_{Zt} + 0.22\ b_{Wb})$ $\times(0.73\ b_{Zt} + 0.78\ b_{Wb})$
2	$0.086\ b_{Zt} + 0.048\ b_{Wb}$	$(0.21\ b_{Zt} + 0.22\ b_{Wb})^2$ $+ 2 \times (0.052\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



- 7 TeV, with 1.14 fb^{-1}
- 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 multi-lepton 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

- Thank you!

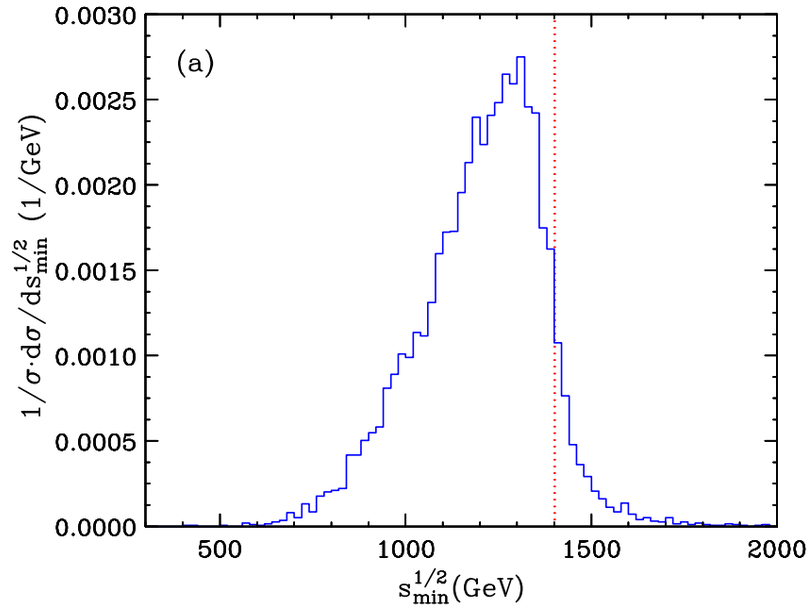
Backup slides

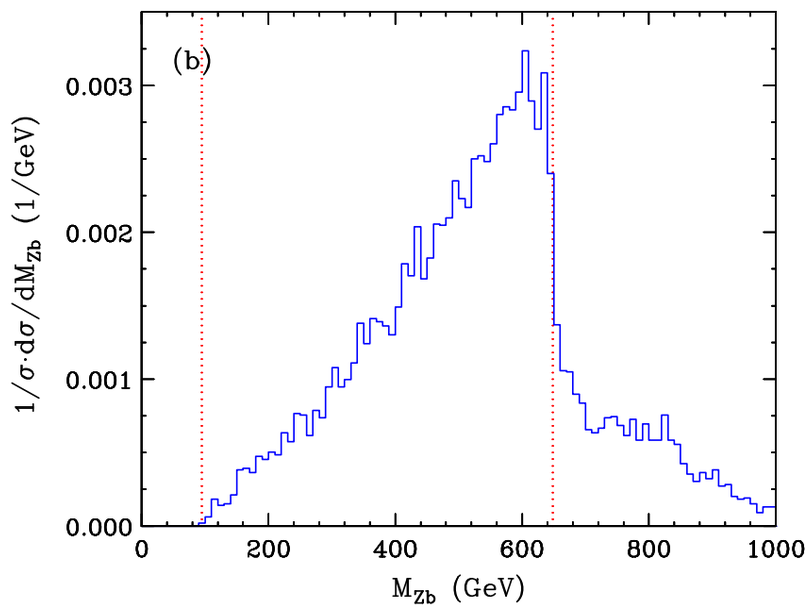
Quantum Numbers

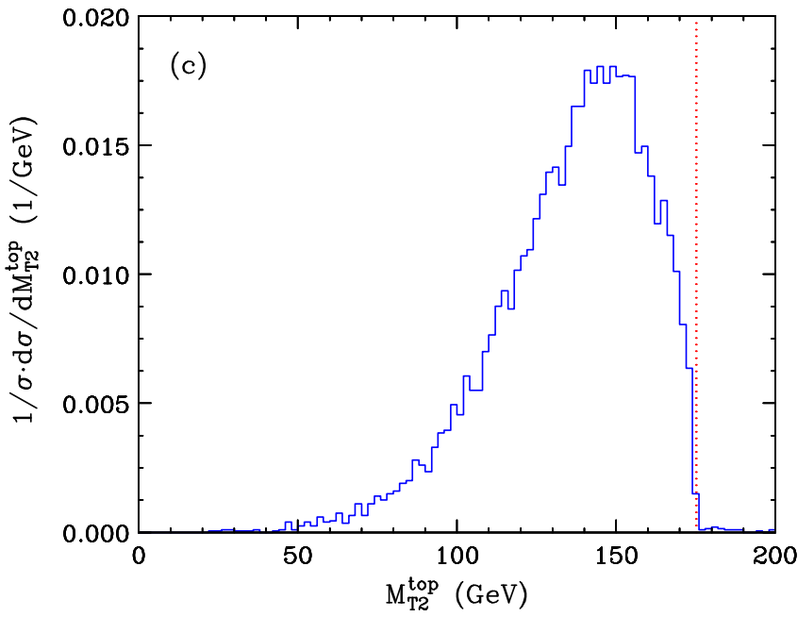
	$SU(3)_1$	$SU(3)_2$	$SU(2)_W$	$U(1)_Y$
SM quarks: $q_L^i,\ u_R^i,\ d_R^i$	3	1	2, 1, 1	$+1/6,\ +2/3,\ -1/3$
vectorlike quark: $\chi_L,\ \chi_R$	1	3	1	$+2/3$
scalar with VEV: Σ	3	$\overline{3}$	1	0

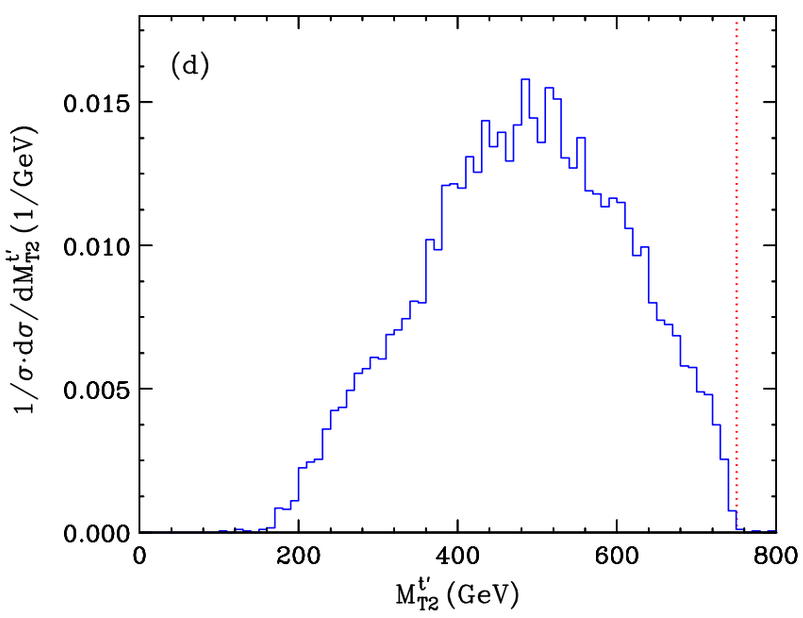
The scalar $\sum$ gets a vev to break the SU(3)xSU(3) to give the gluon prime it's mass

Distributions









$$pp \to G' \to t\bar{t}' + t'\bar{t} \to t\bar{t}Z \to W^+W^-Zb\bar{b} \to b\,\bar{b}\,\ell^+\,\ell^-\,\ell'^+\,\nu_{\ell'}\,\ell''^-\,\bar{\nu}_{\ell''}$$

1112.3041, Kong, McCaskey, Wilson

Previous exclusion