Higgs production through Top-Prime decays at the LHC

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Motivation

- Top-prime decaying to Standard Model (SM) Higgs and the top is an interesting channel for Higgs search.
- The heavier top, top-prime, is vector-like in nature.
- Vector-like quarks appear in Little Higgs models along with additional fields such as massive gauge fields.
- In the present framework, we look at the minimal extension of the standard model involving a vector-like quark.
- We look at the QCD production of such a quark and also introduce a massive gluon to enhance top prime pair production cross sections.

The Model [0902.0792]

- A vector-like quark χ is considered, which transforms as (3, 1, 2/3) under the $SU(3)_c \times SU(2)_W \times U(1)_Y$ gauge group.
- This additional quark χ may mix with the SM top. Interactions with the first two generations are neglected.
- On imposing electroweak symmetry breaking, the quark mass matrix takes the following form:

$$\mathcal{L} = -\begin{pmatrix} \bar{u}_L^3, & \bar{\chi}_L \end{pmatrix} \begin{pmatrix} \lambda_t(v_H + H/\sqrt(2)) & 0 \\ M_0 & M_x \end{pmatrix} \begin{pmatrix} u_R^3 \\ \chi_R \end{pmatrix} + h.c. \tag{1}$$

- u^3 is the up type quark of the third generation. H is the Higgs boson and VEV, $v_H \approx 174$ GeV.
- M_0, M_χ and the λ_t Yukawa couplings are real.

The Model

- Transformation equations between gauge and mass eigenstate basis:

$$\begin{pmatrix} t_{L,R} \\ t'_{L,R} \end{pmatrix} = \begin{pmatrix} \cos\theta_{L,R} & -\sin\theta_{L,R} \\ \sin\theta_{L,R} & \cos\theta_{L,R} \end{pmatrix} \begin{pmatrix} u^3_{L,R} \\ \chi_{L,R} \end{pmatrix} \tag{2}$$

- Here t is the standard model top, hence m_t is 173 GeV. t' is the new quark.
- The mixing angles θ_L and θ_R are defined as :

$$\theta_L = \frac{1}{2}\tan^{-1}\left(\frac{2M_0\lambda_t v_H}{M_\chi^2 + M_0^2 + \lambda_t^2 v_H^2}\right) \tag{3}$$

$$\theta_R = \sin^{-1}\left(\sqrt{\frac{\sin^2\theta_L m_{t'}^2}{\sin^2\theta_L m_{t'}^2 + \cos^2\theta_L m_t^2}}\right) \tag{4}$$

The Interaction Terms

- The interaction of the W and Z boson with the t' quark is described through the following terms [0902.0792]:

$$\frac{g}{\sqrt{2}} W_\mu^- \bar{b}_L \gamma_\mu (\cos\theta_L t_L + \sin\theta_L t'_L) + h.c \quad (5)$$

$$\frac{g}{\cos\theta_W} Z_\mu \left[\left(\frac{\cos\theta_L}{2} - \frac{2}{3}\sin^2\theta_W \right) \bar{t}_L \gamma_\mu t_L + \quad (6)$$

$$\left(\frac{\sin\theta_L}{2} - \frac{2}{3}\sin^2\theta_W \right) \bar{t'}_L \gamma_\mu t'_L + \frac{\sin\theta_L \cos\theta_L}{2} \left(\bar{t'}_L \gamma_\mu t_L + h.c \right) \right]$$

- The Z boson interaction also includes a flavor changing $t - t'$ neutral current.

The Interaction with the Higgs

- The Yukawa coupling with t and t' is :

$$\frac{-1}{v_H\sqrt(2)}h^0(\cos\theta_L^2 m_t \bar{t}_L t_R + \sin\theta_L^2 m_{t'}\bar{t'}_L t'_R + \tag{7}$$

$$\cos\theta_L \sin\theta_L m_{t'}\bar{t}_L t'_R + \cos\theta_L \sin\theta_L m_t \bar{t'}_L t_R) + h.c.$$

- This model has three parameters : $\sin\theta_L$, mass of the top prime and mass of the Higgs.

Branching Fractions

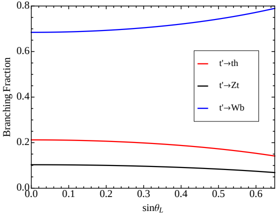

Figure: Branching Fraction as a function of mixing angle ($\sin\theta_L$). For top primes pair produced through QCD processes, we choose $\sin\theta_L = 0.3$ at a top prime mass of 300 GeV

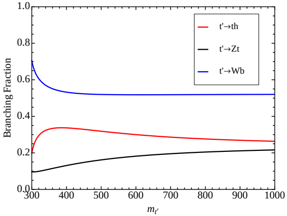

Figure: Branching Fraction as a function of top-prime mass for $\sin\theta_L = 0.3$.

Pair Production of t'

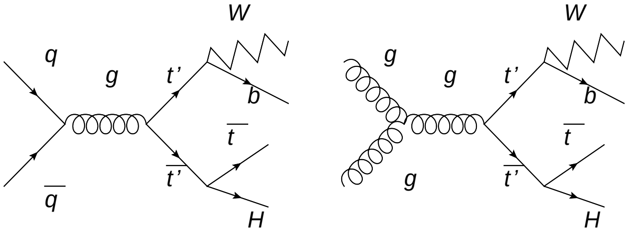

Figure: Top prime pair production through QCD. Top prime decays to Wb and tH followed by Higgs decays to $b\bar{b}$ at 120 GeV and all possible W decay modes. Higgs to W^+W^- is an interesting decay mode considered later. These are representative Feynman diagrams.

Cross section versus Top prime mass

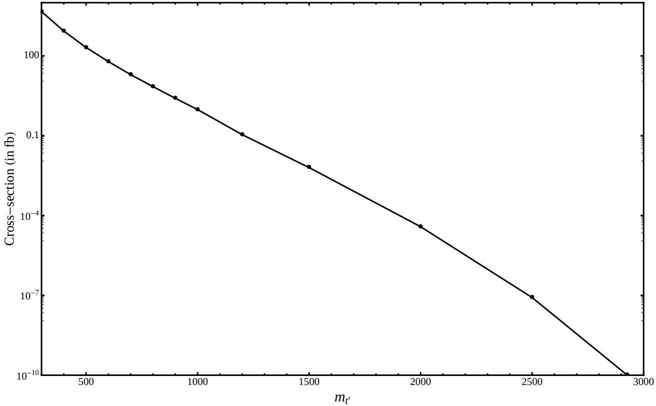

Figure: Cross section at 7TeV. The cross-sections of the top-prime were calculated using MadGraph. Here the leading order cross-sections are plotted as a function of the top prime mass.

Signal Processes : Semileptonic decay modes

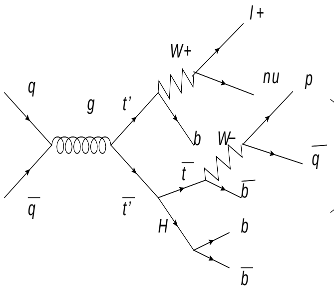

Figure: Signal processes for the present analysis. Two different Higgs decays are considered. In the $H \rightarrow W^+W^-$ decay channel, existence of same signed dilepton pairs are taken into account. These processes are as model independent as possible. The value of the mixing angle $\sin\theta_L$ is chosen to be 0.3, a region where model dependence is minimal.

Backgrounds

- Major irreducible background is $t\bar{t}$ + jets.
- Another important background is W^+W^- + jets.
- Background discrimination method :
  - For $H \rightarrow b\bar{b}$ decays, we ask for 3 b-jets and a lepton to discriminate between $t\bar{t}$ backgrounds and signal.
  - For $H \rightarrow W^+W^-$ decays, we ask for same signed dileptons to discriminate between $t\bar{t}$ backgrounds and signal.
- Other standard model backgrounds may contribute to the $H \rightarrow W^+W^-$, where we look at 4W + 2b final state. These backgrounds are $t\bar{t}W^+W^-$ or $W^+W^-W^+W^-$. These processes have very low cross sections because they are suppressed by powers of $1/M_W$.

Cuts Applied

- For Higgs to $W+W-$ decays, the following cuts were applied:
  - Jet $p_T > 30$ GeV
  - Lepton $p_T > 25$ GeV
- These cuts are rather low. They were chosen so that the number of signal events could be maximized. The dominant background is $t\bar{t}W^+W^-$ which has a very low cross section.

Signal events generated	Events that pass cuts (Kinematic and analysis specific)
50000 (400 GeV)	48232
50000 (500 GeV)	48407

Table: Events passing the cuts

Results at 7 TeV with 150 GeV Higgs

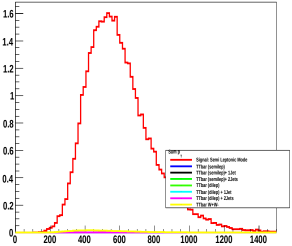

Figure: Sum p_T plot for a 400 GeV top prime, giving rise to a 150 GeV Higgs.

Luminosity in fb^{-1}	Predicted signal events 400 GeV top-prime	Predicted background events $t\bar{t}$ and W^+W^- and $t\bar{t}W^+W^-$
1	4.4	0.04
5	22	0.22
10	44	0.45

Table: Predicted and expected events for a 400 GeV top prime decaying to a 150 GeV Higgs

Results at 7 TeV with 140 GeV Higgs

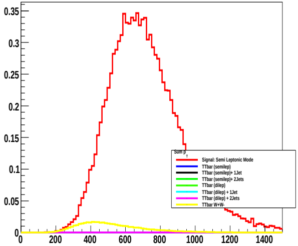

Figure: Sum p_T plot for a 500 GeV top prime, giving rise to a 140 GeV Higgs.

Luminosity in fb^{-1}	Predicted signal events 500 GeV top-prime	Predicted background events $t\bar{t}$ and W^+W^- and $t\bar{t}W^+W^-$
5	5.5	0.22
10	11	0.45

Table: Predicted and expected events for a 500 GeV top prime decaying to a 140 GeV Higgs

Inclusion of gluon-prime [0902.0792]

The top-prime model may be extended by including a $SU(3)_1 \times SU(3)_2$ gauge symmetry which is spontaneously broken down to $SU(3)_c$.

$$\begin{pmatrix} G^1_\mu \\ G^2_\mu \end{pmatrix} = \frac{1}{\sqrt{h_1^2 + h_2^2}} \begin{pmatrix} h_2 & -h_1 \\ h_1 & h_2 \end{pmatrix} \begin{pmatrix} G_\mu \\ G'_\mu \end{pmatrix} \tag{8}$$

The gluon-prime interaction with t and t' quarks is chiral and given by :

$$g_s G'^a_\mu [\bar{t}\gamma^\mu (g_L P_L + g_R P_R) T^a t + \bar{t'}\gamma_\mu (g''_L P_L + g''_R P_R) T^a t'] \tag{9}$$

and the flavor changing terms,

$$g_s G'^a_\mu \bar{t}\gamma^\mu (g'_L P_L + g'_R P_R) T^a t' + h.c \tag{10}$$

Here, $P_{L,R} = (1 \pm \gamma_5)/2$, $g_L = r\cos\theta_L{}^2 - \frac{\sin\theta_L{}^2}{r}$, $g''_L = r\sin\theta_L{}^2 - \frac{\cos\theta_L{}^2}{r}$, $g'_L = \left(r + \frac{1}{r}\right)\cos\theta_L \sin\theta_L$ and $r \equiv \frac{h_1}{h_2}$. The right handed couplings are analogous to the left handed couplings with $\theta_L \to \theta_R$.

Higgs production channels through the gluon prime

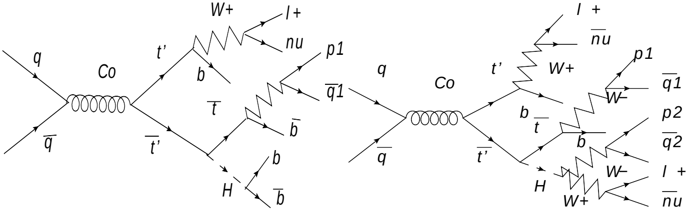

Figure: Higgs decay modes considered. These processes are mediated by the gluon prime.

Cuts Applied

- The following cuts were applied for a 120 GeV Higgs ($H \to b\bar{b}$):
  - Lepton $p_T > 30$ GeV
  - Jet $p_T > 50$ GeV
  - $|\eta| < 2.4$

Signal events generated	Events that pass cuts (Kinematic and analysis specific)
50000 (300 GeV)	38993

Table: Events passing the cuts

- The following cuts were applied for a 150 GeV Higgs ($H \to W^+W^-$):
  - Lepton $p_T > 25$ GeV
  - Jet $p_T > 30$ GeV
  - $|\eta| < 2.4$

Results at 7 TeV with 120 Higgs

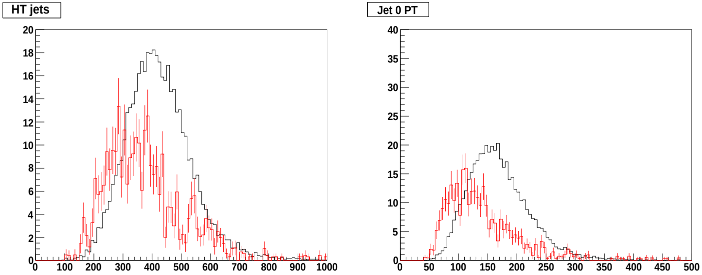

Figure: Sum p_T and p_T of the highest p_T jet in an event for a 300 GeV top prime, with cross section enhanced by a gluon prime, giving rise to a 120 GeV Higgs. This process has a production cross section of 22.8 pb^{-1}. Here, $\sin\theta_L = 0.02$ and $r = 0.2$.

Luminosity in fb^{-1}	Predicted signal events 300 GeV top-prime	Predicted background events $t\bar{t}$ and W^+W^-
1	466	295
5	2330	1475

Table: Predicted and expected events for a 300 GeV top prime decaying to a 120 GeV Higgs

Results at 7 TeV with 150 Higgs

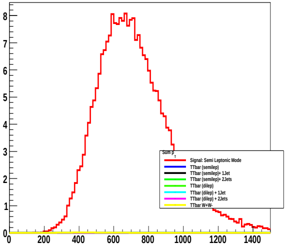

Figure: Sum p_T plot for a 500 GeV top prime, with cross section enhanced by a gluon prime, giving rise to a 140 GeV Higgs.

Luminosity in fb^{-1}	Predicted signal events 400 GeV top-prime	Predicted background events $t\bar{t}$ and W^+W^- and $t\bar{t}W^+W^-$
1	26	0.04
5	130	0.22
10	260	0.45

Table: Predicted and expected events for a 400 GeV top prime decaying to a 150 GeV Higgs

Conclusion

- Hints of new physics observed at 7 TeV LHC with $1fb^{-1}$ of data.
- Higgs of masses 120, 140 and 150 GeV have been considered.
- Top primes of masses 300, 400 and 500 GeV have been considered.
- This is work in progress and a wider mass range for top primes will be looked into.

Experimental exclusion

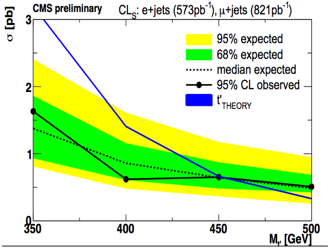

Figure: Experimental exclusion plot

- The experimental exclusion plot from CMS provides stringent conditions on the cross section of top-prime production.
- However, the branching fraction of the top-prime to *Wb* is assumed to be 100% here, but within the framework of our model the branching fractions vary between 71% to 50%. Since top-primes are pair produced this branching fraction is eventually squared and hence the cross section of pair production in the present framework would be much smaller that what this curve excludes.
- We consider non-QCD modes of top-prime production which decouple from QCD for small $\sin\theta_L$. Here $\sin\theta_L$ is chosen to be 0.02.