Finding a Bouncing Higgs with Top Quarks at the LHC

(And 100TeV colliders vis-a-vis BICEP2.)

Joseph Bramante – University of Notre Dame
Finding how the electroweak scale is tuned to low mass, the stability of the Higgs potential, and any deviations from a second order EWSB all require precision measurements of the top Yukawa.
CMS search for pp → tth in the isolated same sign dilepton channel
CMS search for pp → tth in the isolated same sign dilepton channel
• Cut on isolated same charge dileptons
LHC $tth$ to same sign dilepton

CMS search for $pp \rightarrow tth$ in the isolated same sign dilepton channel
• Cut on isolated same charge dileptons
• Require $\sim 20$ GeV missing transverse energy
CMS search for pp →tth in the isolated same sign dilepton channel

- Cut on isolated same charge dileptons
- Require ~20 GeV missing transverse energy
- Require 4 jets, with 2 Light CSV b-tags or 1 Medium CSV b-tag
We parameterize UV physics with up to Dimension 6 couplings to the Higgs boson.
Restrict attention to strongly-coupled and top quark operators. LHC is, after all, a hadron machine.

\[ \mathcal{O}_{HG} = \frac{c_{HG}}{\Lambda^2} (H^\dagger H) G_a^{\mu\nu} G_\mu^a G_\nu^a \]

\[ \mathcal{O}_{hgt} = \frac{c_{ht}}{\Lambda^2} (\bar{Q}_L H) \sigma^{\mu\nu} T^a t_R G_\mu^a \]

\[ \mathcal{O}_{cHq} = (\bar{Q}_3 L \gamma^\mu Q_3 L)(H^\dagger \not{D}_\mu H), \quad \mathcal{O}_{c' Hu} = (\bar{Q}_3 L \sigma_i \gamma^\mu Q_3 L)(H^\dagger i \not{D}_\mu H), \quad \mathcal{O}_{cH u} = (\bar{t}_R \gamma^\mu t_R)(H^\dagger \not{D}_\mu H) \]

and \[ \mathcal{O}_{y_u} = H^\dagger H \bar{Q}_3 L H^c t_R. \]
Only two operators contribute to $tth$ at leading order in the strong coupling, and have a different momentum structure than the Standard Model.

\[
O_{HG} = \frac{c_{HG}}{\Lambda^2} (H^\dagger H) G_\alpha^{\mu\nu} G^{\alpha}_{\mu\nu}
\]

\[
O_{hgt} = \frac{c_{hgt}}{\Lambda^2} (\bar{Q} L H) \sigma^{\mu\nu} T^a t_R G^{a}_{\mu\nu}
\]
Different kinematic dependence, for example there is a new gluon s-channel. Compare to the SM process whose relative amplitude goes as $\sim 1/P(\text{top})$. 

\[
\mathcal{O}_{HG} = \frac{c_{HG}}{\Lambda^2} (H^\dagger H) G^{\mu\nu}_a G^a_{\mu\nu} \\
\mathcal{O}_{hgt} = \frac{c_{hgt}}{\Lambda^2} (\bar{Q} L H) \sigma^\mu\nu T^a t_R G^a_{\mu\nu}
\]
Bounds on Dim-6 $tth$ Kinematic Operators

Higgs Production

$0.8 < \mu_h < 1.2$
The distribution of tops and Higgs in the detector shift for boosted Higgs events.
A typical event with Standard Model couplings.

\[ c_{gh} = -0.75 \]

\[ c_{GH} = 0.083 \]

\[ (\mu_{th} \approx \mu_h \approx 1) \]
A typical event with NP boosted dim-6 couplings.

\[
\begin{align*}
  c_{ght} &= -0.75 \\
  c_{GH} &= 0.083 \\
  (\mu_{th} \approx \mu_h \approx 1)
\end{align*}
\]
To find new physics in the kinematic effective field theory, define new collider observables using the angles between collider objects. In pp→tth→dilepton, these will be angles between three objects.

Missing transverse energy (MET) is energy lost in the detector, mostly to neutrinos.

Same charge dileptons.

B-tagged jets (Medium, Light b-tags).
\[ L_{pT} = \sum_{\text{isolated leptons}} p_T^\ell \]

Same charge dileptons.
$c_{hgt} = -0.5, c_{HG} = 0.055$

SM $t\bar{t}h + \text{bkgds}$

14 TeV
100 fb$^{-1}$

Precuts

Events/50 GeV

Sum of Lepton $p_T$
Missing transverse energy (MET) is energy lost in the detector, mostly to neutrinos.

\[ B_\phi = \sum_{b\text{-tagged jets}} p_{T}^b \times |\Delta \phi_{E_T, b}| \]
$t\bar{t}j$  
$ttW$  
$c_{hgt}=-0.5, c_{HG}=0.055$  
SM $t\bar{t}h + $ bkgds

14 TeV, 100 fb$^{-1}$  
MET $>$ 100 GeV  
$L_{pt} > 150$ GeV  
$B_\phi > 200$ GeV

Events/50 GeV vs Sum of Lepton $p_T$
Missing transverse energy (MET) is energy lost in the detector, mostly to neutrinos.

Same charge dileptons.
Good at cutting backgrounds even for SM tth searches

$\delta_{ht} = -0.5, \delta_{HG} = 0.055$

14 TeV
$100 \text{ fb}^{-1}$
Precuts
**Kinematic Reach for 14 TeV LHC**

<table>
<thead>
<tr>
<th>Condition</th>
<th>$tt + jets$</th>
<th>$ttW^\pm + jets$</th>
<th>SM Signal</th>
<th>NP Signal</th>
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<tbody>
<tr>
<td>SSDL preliminary cuts only</td>
<td>697</td>
<td>185</td>
<td>128</td>
<td>114</td>
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<tr>
<td>$L_\phi &lt; 250$</td>
<td>428</td>
<td>107</td>
<td>106</td>
<td>91</td>
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<tr>
<td>$L_{pT} &gt; 200$</td>
<td>124</td>
<td>51</td>
<td>8</td>
<td>13</td>
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<tr>
<td>$L_{pT} &gt; 200$, $L_\phi &lt; 250$</td>
<td>10.9</td>
<td>8.1</td>
<td>2.3</td>
<td>4.1</td>
</tr>
<tr>
<td>$E_T &gt; 80$, $L_\phi &lt; 100$, $B_\phi &gt; 150$, $\Delta R_{\ell_b} &gt; 150$</td>
<td>8.1</td>
<td>5.9</td>
<td>4.5</td>
<td>6.0</td>
</tr>
<tr>
<td>$E_T &gt; 100$, $L_{pT} &gt; 150$, $B_\phi &gt; 200$</td>
<td>28</td>
<td>18</td>
<td>4.8</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\sqrt{s} = 14$ TeV, 100 fb$^{-1}$, parameter points listed</th>
<th>$\mu_{t\bar{t}h}$</th>
<th>events after $E_T &gt; 100$, $L_{pT} &gt; 150$, $B_\phi &gt; 200$</th>
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<td>Standard Model</td>
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<tr>
<td>$c_{hgt} = -0.75$, $c_{HG} = 0.083$</td>
<td>1.5</td>
<td>24</td>
</tr>
<tr>
<td>$c_{hgt} = -0.75$, $c_{HG} = -0.13$</td>
<td>1.4</td>
<td>15</td>
</tr>
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<td>$c_{hgt} = -0.5$, $c_{HG} = 0.055$</td>
<td>0.99</td>
<td>10</td>
</tr>
<tr>
<td>$c_{hgt} = -0.5$, $c_{HG} = -0.16$</td>
<td>0.95</td>
<td>8.2</td>
</tr>
<tr>
<td>$c_{hgt} = 0.25$, $c_{HG} = -0.028$</td>
<td>1.2</td>
<td>12</td>
</tr>
</tbody>
</table>
This statement was only a hope.
This statement was only a hope. Until BICEP2! It is Incredible we found it: New scalar potential at $\sim 10^{-2}$ Planck mass!
Is Higgs Inflation Dead?
Jessica L. Cook, Lawrence M. Krauss, Andrew J. Long, Subir Sabharwal
Comments: 6 pages, 2 figures
Subjects: Cosmology and Nongalactic Astrophysics (astro-ph.CO); High Energy Physics (hep-th)

We consider the status of Higgs Inflation in light of the recently announced results from the BICEP2 collaboration. In order for the primordial B-mode signal to be observable by future experiments, Higgs Inflation generally predicts a small amplitude of tensor perturbations, around $10^{-10}$, which we find is essentially no, unless one considers either extreme fine tuning of models with attractive features of the original idea. We also explore the possible importance of the effective potential used in calculating inflationary observables, e.g. $n_S$, and the effects of Higgs mass uncertainties and other observables already considered to be small to remove the apparent incompatibility between the BICEP2 observation and Planck constraints.

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P. H. R. S. Moraes, J. R. L. Santos
Subjects: General Relativity and Quantum Cosmology (gr-qc); High Energy Physics (hep-th)

One possible description for the current accelerated expansion of the universe is a scenario driven by a scalar field. In this work we present some interesting features of these models in a flat space-time. This effective model was constructed by coupling two single fields and analyzing their dynamic properties to compute analytical cosmological parameters. The behavior of the model is discussed in detail.

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Comments: 7 pages, 3 figures

The observed value of the Higgs mass indicates that the Higgs potential becomes flat at a Higgs inflation scenario proposed by Bezrukov and Shaposhnikov. It turns out, however, that Higgs inflation is still alive. For example, $|\chi|=7$ corresponds to the tensor-to-scalar ratio $r\sim 10^{-10}$.
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Dead....................................Alive

![Graph showing Higgs mass and inflation scale](image)
In order to wring LHC data dry of top yukawa physics —

use kinematic EFT and angular variables!
Center for Future High Energy Physics

http://cfhep.ihep.ac.cn/
HEP
Jim Parsons on What Makes *The Big Bang Theory* So Big

By Amanda Dobbins

wanted anyway, because he’s won three Emmys and because *The Big Bang Theory*, is watched by 23.4 million people...
$10^{16} \text{GeV}$

$\text{SU}(3) \times \text{SU}(2) \times \text{U}(1)$
$10^{16}$ GeV

SU(3) $\times$ SU(2) $\times$ U(1)
\[ r = 0.2^{+0.07}_{-0.05} \]

\[ N_e = \int \frac{da}{a} = \int \frac{da}{dt} \frac{dt}{a} = \int Hdt \]

\[ = \int \frac{H M_p}{\phi} \frac{d\phi}{M_p} = \sqrt{8} r^{\frac{4}{3}} \Delta \phi \]

Using

\[ r = \frac{\gamma s}{ss} = \frac{\text{tensor}}{\text{Scalar}} = \frac{H^2}{M_p^2} = \frac{H^4}{\dot{\phi}^2} \]