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Tests of top compositeness at hadron colliders

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Summary. — Top pair production can be used to probe composite top models. Associated with 4-top and $t\bar{t}b\bar{b}$ productions, it can be used to distinguish different hypotheses.

PACS 14.65.Ha – Top quarks.
PACS 12.60.Rc – Composite models.

1. – Introduction

The effects of top compositeness can be parametrized by adding order by order higher-dimensional operators to the SM Lagrangian,

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2}\sum_i c_i \mathcal{O}_6^i + \mathscr{O}\left(\frac{1}{\Lambda^4}\right). \qquad (1)$$

There are two main reasons to do so. On the one hand, the usual perturbative expansion cannot be used because the new interaction is strong. On the other hand, this effective approach is able to describe a large class of models even beyond composite top models. Naive dimensional analysis (NDA) [1] has been used to classify the operators. Each coefficient c_i is then a function of ξ, with $\xi \sim 4\pi$ for strongly coupled theories.

2. – Top pair production

2·1. *Lagrangian.* – Only a few operators contribute to the top pair production [2]:

$$\mathcal{L}_{t\bar{t}} = \mathcal{L}_{t\bar{t}}^{\rm SM} + \frac{1}{\Lambda^2}\left[g_h\mathcal{O}_{hg} + c_R\mathcal{O}_{Rg} + a_R\mathcal{O}_{Ra}^8 + \text{h.c.} + (R \leftrightarrow L)\right], \qquad (2)$$

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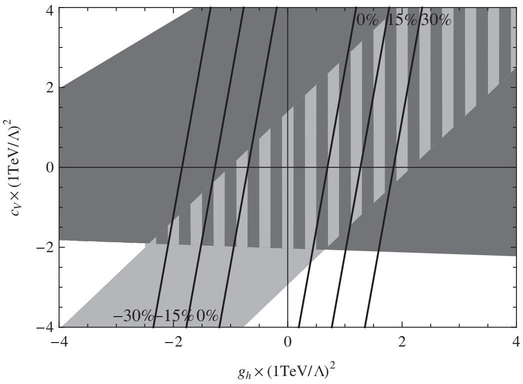

Fig. 1. – In light (dark) gray, Tevatron allowed region by the total cross-section measurement (the M_{tt} distribution). LHC allowed regions if the measured total cross-section is the one predicted by the SM are delimited by the thick black lines.

where

$$(3)\qquad \mathcal{O}_{hg} = \left[\left(H\bar{Q}\right)\sigma^{\mu\nu}T^A P_R t\right] G^A_{\mu\nu}, \qquad \mathcal{O}^8_{Ra} = \left[\bar{t}\gamma^\mu T^A P_R t\right] \sum_q \left[\bar{q}\gamma_\mu T^A \gamma_5 q\right],$$

$$(4)\qquad \mathcal{O}_{Rg} = \left[\bar{t}\gamma^\mu T^A D^\nu P_R t\right] G^A_{\mu\nu}.$$

If only t_R is composite, $c_R \sim a_R \sim 1$, $c_L = a_L = 0$ and $g_h \sim 1/\xi$. If, on the contrary, only Q_L is composite, $c_L \sim a_L \sim 1$, $c_R = a_R = 0$ and $g_h \sim 1/\xi$. If both chiralities are composite, $c_R \sim a_R \sim c_L \sim a_L \sim g_h \sim 1$. So, the magnitude of g_h compared to the other coefficients counts the number of composite fields.

2˙2. *Total cross-section and M_{tt} distribution.* – These observables only depend on g_h and the combination $c_V \equiv c_R + c_L$. The $t\bar{t}$ production via gluon fusion only depending on g_h, the Tevatron and the LHC are rather complementary as shown in fig. 1. The distortion of the invariant mass distribution is mainly due to the operators $\mathscr{O}_{R,Lg}$ and is thus less visible at the LHC. It should be noted that, for low values of Λ, Tevatron measurements already imply that $g_h \sim c_V$, and suggest 2 composite fields.

2˙3. *Forward-backward asymmetry.* – The forward-backward asymmetry measured at the Tevatron, $A^t_{\rm FB} = 0.19 \pm 0.065(\text{stat}) \pm 0.024(\text{syst})$ [3], is about 2σ away from the SM value, $A^t_{\rm FB} = 0.05 \pm 0.015$. This large deviation could be explained by the compositeness of the top if $\Lambda \sim 1\,\text{TeV}$ and $a_A \equiv a_R - a_L$ is $\mathscr{O}(1)$:

$$(5)\qquad \delta A^t_{\rm FB} = 0.0342^{+0.016}_{-0.009}\, a_A \left(\frac{1\,\text{TeV}}{\Lambda}\right)^2.$$

2˙4. *Spin correlation.* – Left- and right-handed composite top cannot be distinguished using only kinematic observables. Fortunately there is a strong correlation between the top spin and the direction of the lepton coming from its decay [4]. We have shown that the distribution as a function of the charged leptons directions is not only sensitive to g_h and c_V but also to the combination $c_A \equiv c_R - c_L$ and is thus able to disentangle between the left- and right-handed composite top.

3. – 4-top and $t\bar{t}b\bar{b}$ productions

Contrary to top pair production, the 4-top one can probe the dominant $\mathscr{O}(\xi^2)$ operators for a right-handed composite top,

$$\mathcal{O}_R = [\bar{t}\gamma^\mu P_R t]\,[\bar{t}\gamma_\mu P_R t] \tag{6}$$

and for a left-handed composite top,

$$\mathcal{O}_L = \left[\bar{Q}\gamma^\mu P_L Q\right]\left[\bar{Q}\gamma_\mu P_L Q\right], \qquad \mathcal{O}_L^8 = \left[\bar{Q}\gamma^\mu T^A P_L Q\right]\left[\bar{Q}\gamma_\mu T^A P_L Q\right]. \tag{7}$$

When both chiralities are composite, there are 2 additional operators:

$$\mathcal{O}_S = \left[\bar{Q}^\alpha P_R t\right]\left[\bar{t} P_L Q^\alpha\right], \qquad \mathcal{O}_S^8 = \left[\bar{Q}^\alpha T^A P_R t\right]\left[\bar{t} T^A P_L Q^\alpha\right]. \tag{8}$$

In the above expresssions, we have assumed that $SU(2)_L$ is unbroken by the new interaction, *i.e.* the full doublet, including b_L, is composite. Yet, all these operators lead to similar cross-sections between 2 and 20 pb for $g = 4\pi$ and $\Lambda = 1\,\text{TeV}$. They can thus all fit any measurement by a slight change of their coefficient g^2/Λ^2 since $\sigma \sim \left(\frac{g}{\Lambda}\right)^4$. If Q_L is composite, there will also be a modification of $t\bar{t}b\bar{b}$ cross-section. The ratio of the 2 processes can be used to identify the operator because it is independent of g/Λ but strongly dependent on the operator. Its coefficient can then be extracted.

4. – Conclusion

Top pair production is a good probe for new physics. First, the total cross-section and the invariant mass distribution can pin down the number of composite fields. Secondly, the forward-backward asymmetry could be the first hint of top compositeness from which we can estimate the scale. Thirdly, the spin correlation differentiates left- from right-handed composite top. The $t\bar{t}t\bar{t}$ and $t\bar{t}b\bar{b}$ productions can probe the hierarchy among the dominant and subdominant operators.

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