HIGGS BOSONS IN $t\bar{t}$ PRODUCTION

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Abstract

The top quark has a large Yukawa coupling with the Higgs boson. In the usual extensions of the standard model the Higgs sector includes extra scalars, which also tend to couple strongly with the top quark. Unlike the Higgs, these fields have a *natural* mass above $2m_t$, so they could introduce anomalies in $t\bar{t}$ production at the LHC. We study their effect on the $t\bar{t}$ invariant mass distribution at $\sqrt{s} = 7$ TeV. We focus on the bosons (H,A) of the minimal SUSY model and on the scalar field (r) associated to the new scale f in Little Higgs (LH) models. We show that in all cases the interference with the standard amplitude dominates over the narrow-width contribution. As a consequence, the mass difference between H and A or the contribution of an extra T-quark loop in LH models become important effects in order to determine if these fields are observable there. We find that a 1 fb^{-1} luminosity could probe the region $\tan\beta \leq 3$ of SUSY and $v/(\sqrt{2}f) \geq 0.3$ in LH models.

1 Introduction

The main objective of the LHC is to reveal the nature of the mechanism breaking the electroweak symmetry. This requires not only a determination of the Higgs mass and couplings, but also a search for additional particles that may be related to new dynamics or symmetries present at the TeV scale. The top-quark sector appears then as a promising place to start the search, as it is there where the EW symmetry is broken the most. Generically, the large top-quark Yukawa coupling with the Higgs boson (h) also implies large couplings with the extra physics. For example, in SUSY extensions h comes together with neutral scalar (H) and pseudoscalar (A) fields [1]. Or in Little Higgs (LH) models, a global symmetry in the Higgs and the top-quark sectors introduces a scalar singlet and an extra T quark [2, 3]. In all cases these scalar fields have large Yukawa couplings that could imply a sizeable production rate in hadron collisions and a dominant decay channel into $t\bar{t}$.

2 Top quarks from scalar Higgs bosons

The potential to observe new physics in $m_{t\bar{t}}$ at hadron colliders has been discussed in previous literature [4, 5]. In general, any heavy s–channel resonance with a significant branching ratio to $t\bar{t}$ will introduce distortions. In the diagram depicted in fig.1 the intermediate scalar is produced at one loop, but the gauge and Yukawa couplings are all strong.
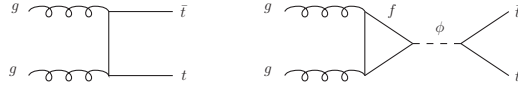

Figure 1: *Diagrams that interfere in $t\bar{t}$ production.*

In [6] we give the expressions for the leading-order differential cross section for $gg \to t\bar{t}$ through a scalar and a pseudoscalar, ϕ. To have an observable effect it is essential that the width Γ_ϕ is small. This is precisely the reason why the effect on $m_{t\bar{t}}$ of a very heavy standard Higgs h would be irrelevant. A 500 GeV Higgs boson would couple strongly to the top quark, but even stronger to

itself. Its decay into would-be Goldstone bosons would then dominate, implying a total decay width of around 60 GeV.

To have a smaller width and a larger effect the mass of the resonance must *not* be EW. In particular, SUSY or LH models provide a new scale and massive Higgses with no need for large scalar self-couplings.

3 SUSY neutral bosons

SUSY incorporates two Higgs doublets, and after EWSB there are two neutral bosons (H and A) in addition to the light Higgs. The mass of these two fields is not EW, so they are *naturally* heavy enough to decay in $t\bar{t}$. Their mass difference depends on the μ parameter and the stop masses and trilinears in addition to $\tan\beta$ [7]. Varying these parameters, for $m_A = 500$ GeV we obtain typical values of $m_H - m_A$ between -2 and $+10$ GeV.
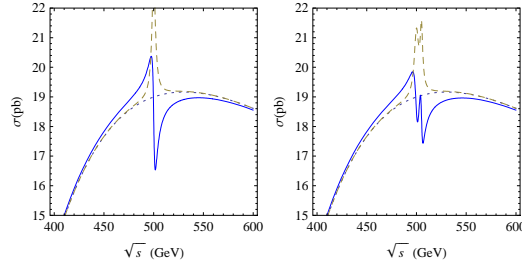

Figure 2: $\sigma(gg \to t\bar{t})$ *for* $\tan\beta = 2$ *and SUSY bosons of mass* $m_A = m_H = 500$ *GeV (left) or* $m_A = 500$, $m_H = 505$ *GeV (right). Dashes provide the narrow-width approximation and dots the standard model cross section.*

In fig.2-left we observe an average 5.5% excess and 8.1% deficit in the 5 GeV intervals before and after $\sqrt{s} = 500$ GeV, respectively. There the position of the peaks and dips caused by H and A overlap *constructively*. In contrast, in fig.2-right their mass difference implies a partial cancellation between the dip caused by A and the peak of H.
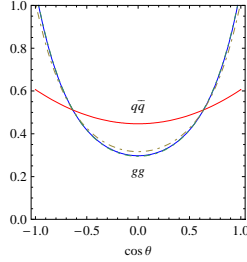
Figure 3: *Standard angular distribution for the t quarks from $q\bar{q}$ and gg collisions at $\sqrt{s} = 500$ GeV. We include (dashes) the distribution from gg at the peak and the dip of fig.2-left.*

From fig.3 we argue that different cuts could be applied to reduce the background for $t\bar{t}$ production at the LHC or even to optimize the contribution from gg versus $q\bar{q}$, but not to enhance the relative effect of the scalars on $\sigma(gg \to t\bar{t})$.

4   Little Higgs boson

In LH models the Higgs appears as a pseudo-Goldstone boson of a global symmetry broken spontaneously at the scale $f > v/\sqrt{2} = 174$ GeV. The global symmetry introduces an extra T quark and a massive scalar singlet r, the *Higgs* of the symmetry broken at f. Once the electroweak VEV is included the doublet and singlet Higgses mix [8, 9].

The extra Higgs r is somehow similar to the heavier scalar in a doublet plus singlet model, with the doublet component growing with $s_\theta = v/(\sqrt{2}f)$. If s_θ is sizeable so is its coupling to the top quark. The coupling to the extra T quark is stronger, but if r is lighter than $2m_T$ then its main decay mode will be into $t\bar{t}$. Therefore, r is a naturally heavy ($m_r \approx f$) but narrow scalar resonance with large couplings to quarks and an order one braching ratio to $t\bar{t}$.

In [6] we examine this case in detail. The results are similar to the ones obtained for SUSY bosons of the same mass.

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5 Signal at the LHC

Let us now estimate the invariant mass distribution of $t\bar{t}$ events ($m_{t\bar{t}}$) in pp collisions at the LHC. We will take a center of mass energy of 7 TeV and 1 fb^{-1} luminosity and we will not apply any cuts . At these energies the cross section $pp \to t\bar{t}$ is dominated by gg fusion (90%).

In fig.4 we observe a 5% excess followed by a 9% deficit, with smaller deviations as $m_{t\bar{t}}$ separates from the mass of the extra Higgs bosons. In fig.5 we find that changing the binning is important in order to optimize the effect.
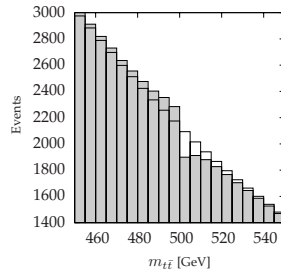

Figure 4: *Number of $t\bar{t}$ events in pp collisions at 7 TeV and 1 fb^{-1} for $m_A = m_H = 500$ GeV and $\tan\beta = 2$ distributed in 5 GeV bins.*
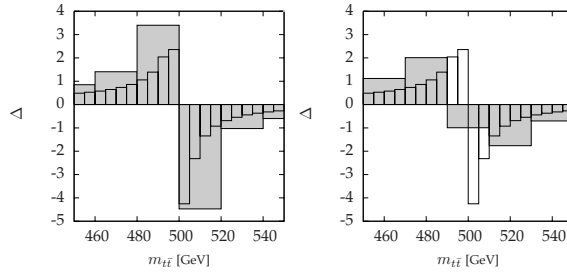

Figure 5: *Deviation $\Delta = (N - N_{SM})/\sqrt{N_{SM}}$ in the number of events respect to the standard prediction for two different binning ($m_A = m_H = 500$ GeV and $\tan\beta = 2$).*

6 Summary and discussion

In models with an extended Higgs sector the extra bosons tend to have large couplings with the top quark that imply a sizeable one-loop production rate at hadron colliders. If the mass of these bosons is not EW but comes from a new scale (*e.g.*, the SUSY or the global symmetry-breaking scales), then they may decay predominantly into $t\bar{t}$. We have studied their effect on the $t\bar{t}$ invariant mass distribution at 7 TeV and 1 fb^{-1}. We have considered the deviations due to the neutral bosons A and H of the MSSM, and to the scalar r associated to the scale f in LH models. In all cases the interference dominates, invalidating the narrow-width approximation.

References

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