Four-top events at the LHC

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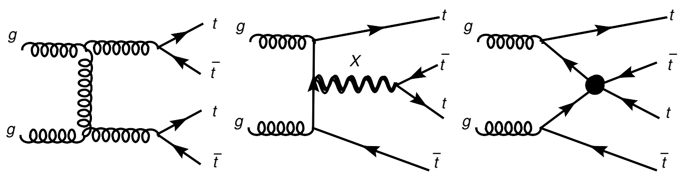
DOI: http://dx.doi.org/10.3204/DESY-PROC-2010-01/251

Four-top production is a spectacular final state and a sensitive probe of new physics that is relatively unconstrained by precision measurements at LEP or resonance searches at the Tevatron. Examples are models where the top quark is composite or where a new heavy particle couples strongly or exclusively to top quarks. We report preliminary results of a first detailed simulation and estimate the LHC sensitivity in the same-sign dilepton channel.

1 Introduction

Four top production occurs in the Standard Model (SM) through diagrams like the one in figure 1(a) [1]. The total $pp \to t\bar{t}t\bar{t}$ cross-section at 14 TeV is 7.5 fb in the SM and is dominated by gluon-initiated diagrams. On the other hand, in many SM extensions the top quark plays a special role. New particles X with a preference for the top quark could yield a sizeable $t\bar{t}t\bar{t}$ cross-section through processes like that depicted in Fig. 1(b). Note that this diagram involves only couplings of X to top quarks. In particular, X does not have to couple to light quarks or gluons to be produced at the LHC. If X is too heavy, the resonance is replaced by a contact interaction like in Fig. 1(c). Well-motivated examples are models where the top quark is composite [2, 3], in which the top quark acquires its large mass (after electroweak symmetry breaking) through large mixing with composite states in a new strong sector, as in 4D duals to Randall-Sundrum (RS) models. In this approach, most of the SM is fundamental but with the right-handed top quark and the Higgs that couple strongly to composite fields and the amount



(a) (b) (c)

Figure 1: (a): Standard Model diagram that give rise to the $t\bar{t}t\bar{t}$ final state. (b-c): Two diagrams involving new physics, that yield to a non-zero event rate even if the new particle does not couple to light quarks. (b) represents s-channel (resonant) $t\bar{t}$ production. The effective four-top interaction in (c) can result from integrating out a heavy particle.

of composite admixture in a given SM fermion determines its mass [4].

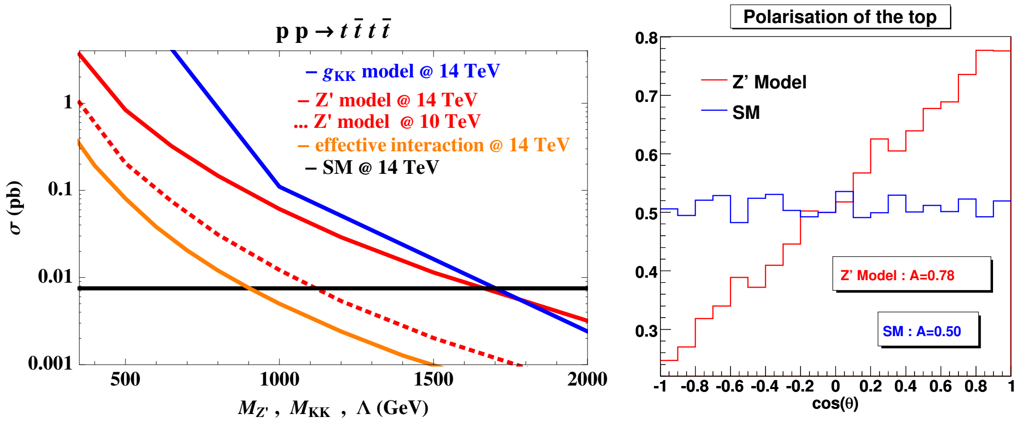


Figure 2: Left: Four-top production cross section at the LHC, mediated by a Kaluza–Klein gluon (in blue) or a Z' (in red). The orange curve refers to the effective 4-fermion interaction $(\bar{t}_R\gamma_\mu t_R)(\bar{t}_R\gamma^\mu t_R)/\Lambda^2$ leading to Fig. 1(c). Right: Angular distribution for the leptons of the top decay in the Z' model with $M_{Z'}$ =800 GeV compared to the SM.

To estimate the LHC sensitivity to this final state, we introduce a generic and very simple effective theory in which the SM is supplemented by a new heavy particle Z' having a large coupling to the right-handed (RH) top quark ($g_{t_R}^{Z'} = 3$) but suppressed couplings to the light SM fermions. In Fig. 2 we show the leading order cross section at the LHC for $t\bar{t}t\bar{t}$ production as calculated by MadGraph. In Fig. 3(a), we present the $M_{t\bar{t}}$ distributions of the $t\bar{t}$ pair emitted by a Z' with $M_{Z'} = 1.2$ TeV, of the spectator $t\bar{t}$ pair, which peaks around 500 GeV, and of the $t\bar{t}$ pair produced by the effective 4-fermion contact interaction. We compare as well with the $M_{t\bar{t}}$ from the SM four-top events, which peaks close to 600 GeV. We also display in (b) the maximum of the $t\bar{t}$ pair transverse energy distribution as a function of $M_{Z'}$.

2 Top polarisation

An interesting way to probe the properties of the top interactions relies on measuring the top polarization [3]. The SM four top production being dominated by parity invariant QCD processes, we expect to generate an equal number of left and right-handed pairs. However, in the new physics models discussed here, there is a strong bias towards RH tops. The angular distribution of the leptons from the top decays enables to analyze the polarisation of the top quarks. The differential cross section can be written as

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \frac{A}{2}(1+\cos\theta) + \frac{1-A}{2}(1-\cos\theta) \tag{1}$$

where θ is the angle between the direction of the lepton in the top rest frame and the direction of the top polarization. The corresponding distribution is illustrated in Fig. 2.

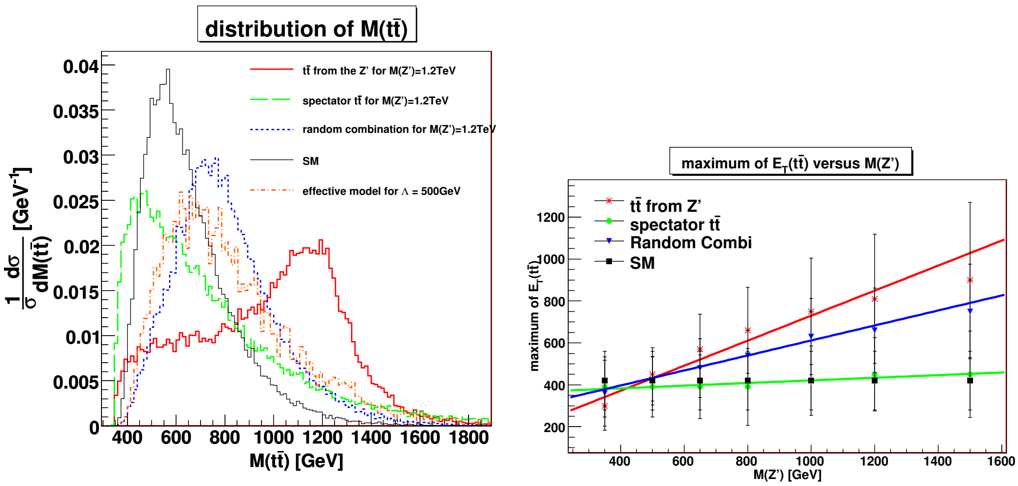


Figure 3: (a) Invariant mass distributions of the top pairs; (b) Position of the maximum of the E_T distribution of the $t\bar{t}$ pair as a function of $M_{Z'}$.

3 Same-sign dilepton channel

The strategy to extract the new physics signal from the SM background consists in requiring two leptons $e^{\pm}$ or $\mu^{\pm}$ with the same sign. Thus, $t\bar{t}$+jets production is effectively reduced. The power of selecting same-sign dilepton events to study $t\bar{t}WW$ final states from pair-production of heavy quarks was shown in detail in [5] and recently applied by CDF to put a strong bound on the mass of fourth generation down-type quarks (b') [6]. In this channel, the main backgrounds to be considered are then $t\bar{t}W$+jets, $t\bar{t}WW$+jets and $t\bar{t}$+jets where the charge of one lepton is

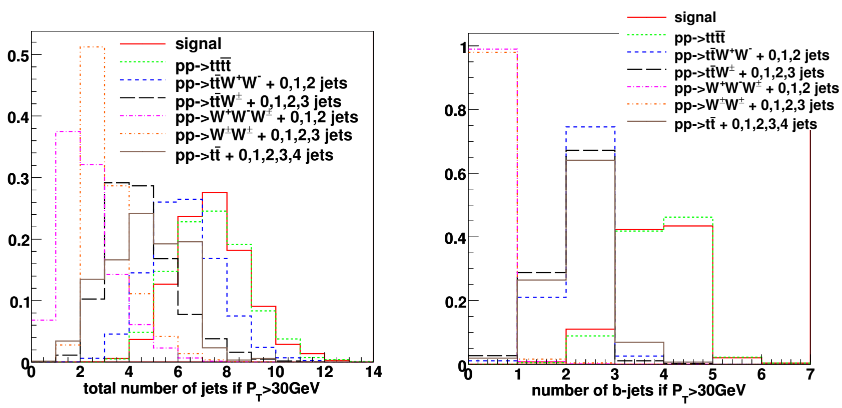


Figure 4: Fractions of signal and background events with a given number of jets with $p_T > 30$ GeV in the same-sign dilepton channel, after Pythia and jet reconstruction with a jet cone size $\Delta R = 0.4$.

misidentified. Signal and background were generated with MadGraph/MadEvent and passed through Pythia. Jets have been reconstructed using a cone size $\Delta R = 0.4$. The distribution of events with a given number of jets is represented in Fig. 4.

Given the complexity of our final state, in a first stage, the minimal approach to reconstruction is to study the scalar sum of the transverse energy of all final state objects. The H_T distribution for a 500 GeV (first panel) and 1 TeV (second and third panels) Z' are shown in Fig. 5 for respectively 10 and 100 fb^{-1} of data. For a 500 GeV mass, the signal is overwhelming after making only a very basic selection on the number of jets $n_j \geq 6$ and $p_T > 30$ GeV. A further and crucial experimental signature of the four-top final states is the large b-jet multiplicity, see Fig. 4(b), which can be used as a powerful tool to extract the signal even coming from a heavy resonance as shown in the third panel of Fig. 5. Reconstruction of (some of) the top quarks in the event can provide additional handles to reduce the background. More details and references can be found in Section 12 of [7] and in the upcoming publication [8].

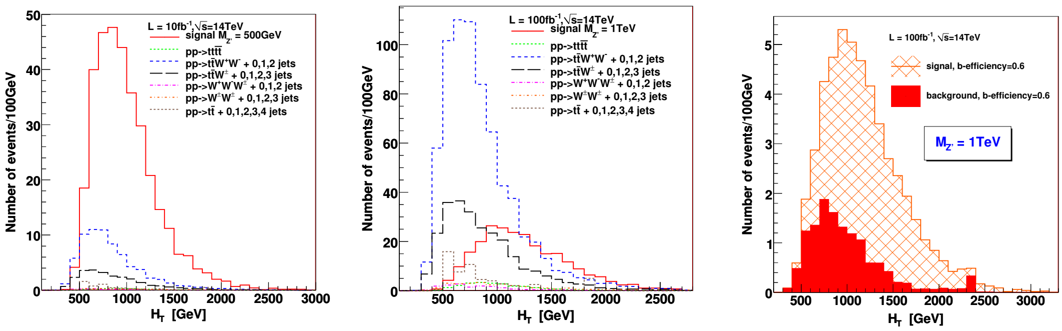


Figure 5: Total transverse energy after demanding $n_j \geq 6$, $p_T > 30$ GeV (first two plots) and in addition $n_{b-jet} \geq 3$ (third plot). In first plot, $M_{Z'} = 500$ GeV, in last two plots $M_{Z'} = 1$ TeV.

4 Acknowledgments

The work of G.S. is supported by the European Research Council Starting Grant Cosmo@LHC.

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