The use of machine learning to understand the excess of events in SS and 3 lepton events with b-jets

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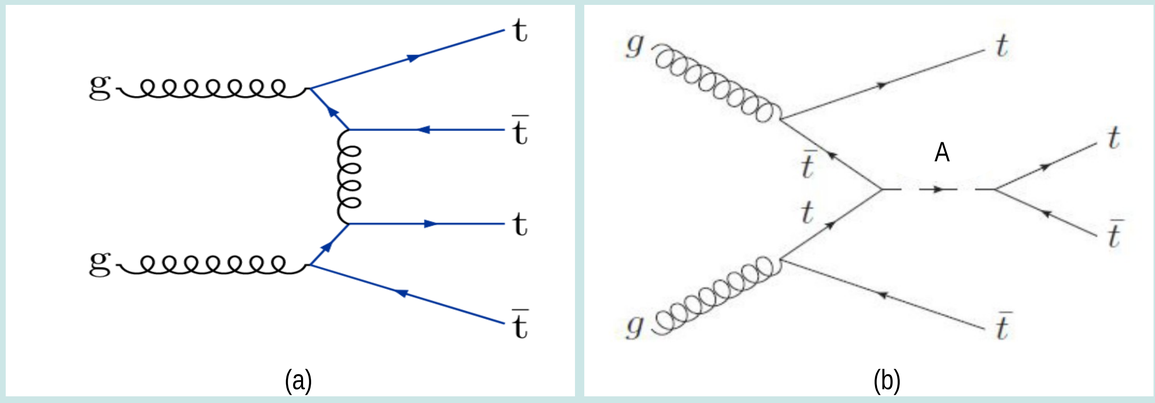
Introduction

The exploration of a Higgs boson (h) at the Large Hadron Collider (LHC) expanded a new window of opportunity for the community of particle physics. Signatures with multi leptons final states have emerged in light of addition of hypothetical scalar bosons to the Standard Model (SM), as predicted in Ref [1]. The SM is not able to accommodate excesses in the data (Ref. [2]), which include elevated rates of leptons in association with b-tagged jets, a scalar singlet S was introduced in conjunction with a 2HDM model in Ref. [1], referred to here as the 2HDM+S model. In this study we expand on the phenomenology expressed in [1,3], we evaluate the the significance of the proposed choice of parameter space for the heavy pseudo-scalar and the charged scalar.

Motivation

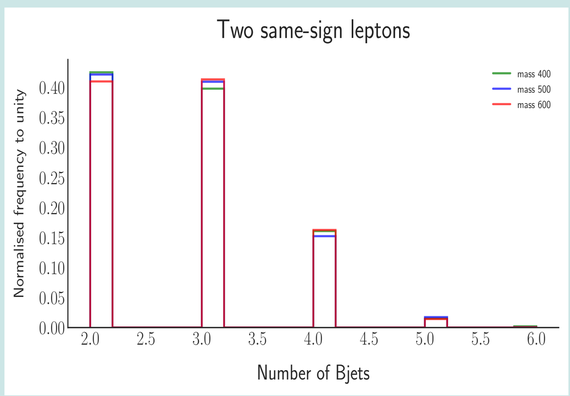
The addition of a Higgs-doublet to the SM results in the scalar spectrum being populated with two CP-even (h, H), one CP-odd (A) and charged scalar bosons ($H^{\pm}$), thus leaving room to study the characteristics on the scalar spectrum. Our interest is on investigating the CP-odd scalar in the 2HDM+S model, by studying the production of A in association with two top-quarks and its decay into $A \to t\bar{t}$ channels. This composition leads to an excess of interesting final states containing b-tagged jets and leptons produced by four top-quarks. This process modifies the four top-quark cross section, where an excess is seen in the data. In this setup we elaborate on the resulting characteristics corresponding to the production of two same-sign leptons and three leptons in association with b-tagged jets.

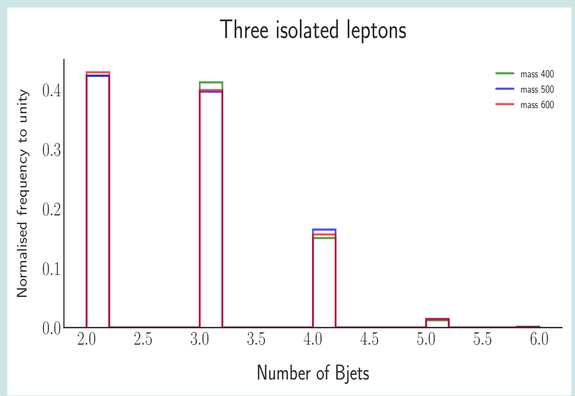
Four top-quark Feynman's diagrams



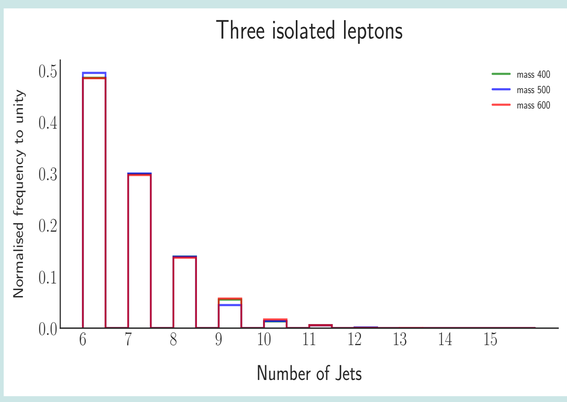
Feynman diagrams for the production of $t\bar{t}t\bar{t}$ from the SM represented by figure (a) and beyond the SM (BSM) represented by figure (b).

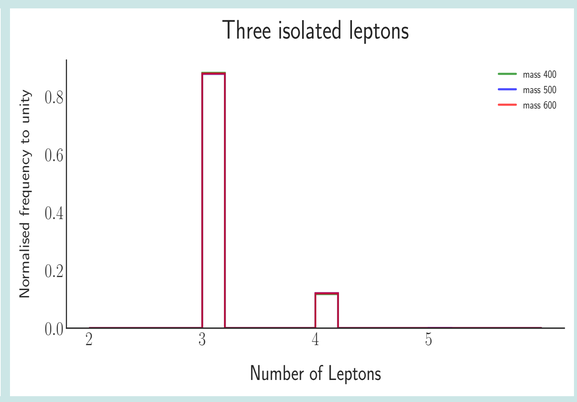
Multi-lepton signatures in four top-quark production





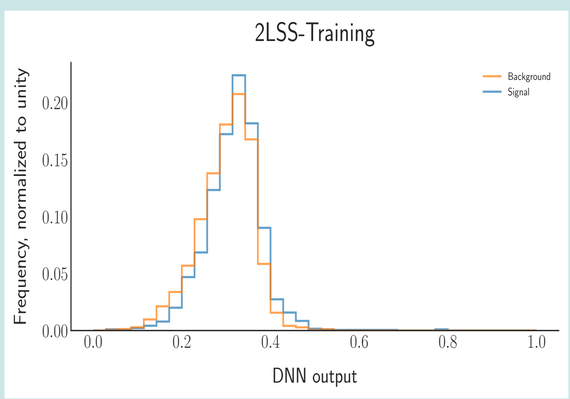
The signature that will be used to explain the excess of events with b-jets follows the decay mechanism : the decay of A from two top quarks with pseudo-scalar at the set parameters mentioned in the motivation. The expected yield from this decay would result in four top quarks ($pp \to t\bar{t}A \to t\bar{t}t\bar{t}$) in its final state. These 4 top-quark give rise to an excess of multi lepton final states associated with b-tagged jets as seen in the two channels of interest displayed in the distributions above for the different masses of A.

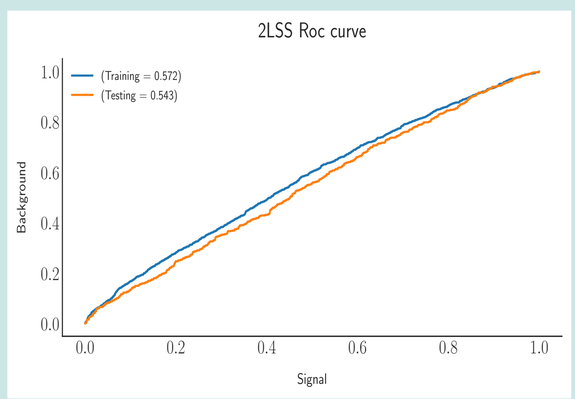




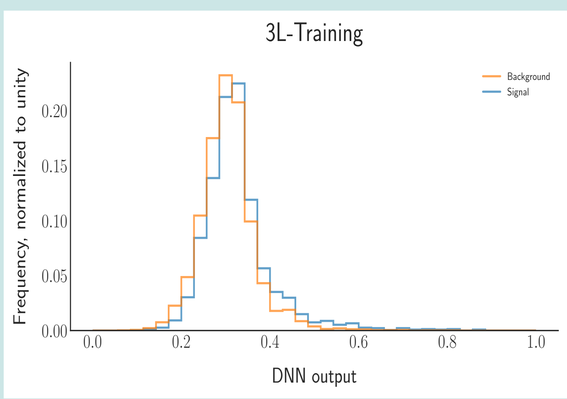
For illustrative purposes, we show the distributions of number of jets together with the number of leptons to highlight the excess of multi leptons in the final state of the signature that we are focusing on. The distributions are for the three isolated channel. Based on the distributions show above, we can conclude that 2HDM+S model provides final states with multi leptons associated with b-tagged jets as proposed in [1].

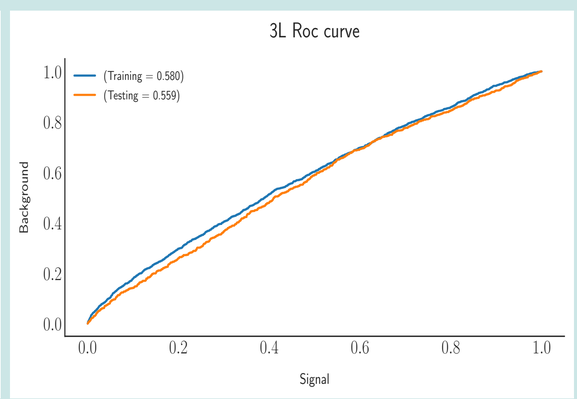
Machine Learning results





The process of 4 top-quarks is a rare process. With the difficulty on separating the background noise from signals, machine learning techniques are needed to help separate the signal from the background. A multivariate model in developed with 12 discriminating variables is used for separation and the resulting DNN output for same-sign lepton together with its ROC curves are shown.





The training of the DNN provides an efficiency of above 65% classification, with the ROC curve being above 50% as seen above. The results for the three isolated leptons are shown above as well. The DNN seems to have an efficiency of above 50%. The BSM signal with the mass range studied here is difficult to distinguish from the SM background. The excess concern to the data is compatible with this observation.

References

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[2] S. Buddenbrock, A.S. Cornell, Y. Fang, A. Fadol Mohammed, M. Kumar, B. Mellado, K.G. Tomiwa, JHEP1910, 157 (2019).arXiv:1901.05300[hep-ph]
[3] von Buddenbrock, S., Cornell, A. S., Iarilala, E. D., Kumar, M., Mellado, B., Ruan, X., Shrif, E. M. (2018).arXiv:1809.06344[hep-ph]