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Recommendations for the search of the Anomalous Wtb interactions in the tW-associated Single Top Quark Production

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Abstract. There are no experimental bounds for the anomalous Wtb couplings provided in the tW-associated single top quark production in the final signature with lepton plus jets so far. The main reason for the situation is the difficulties with the modeling of such a process. Different schemes of the tW-associated single top quark production modeling have different sensitivity to the anomalous Wtb couplings and prospective their constraints are strongly scheme-dependent. The most preferable is the usage of the full gauge-invariant set of the diagrams. However one needs to discriminate the different phase space regions in this case anyway. In the article the separation between top pair and tW-associated single top quark production processes with the help of Neural Network technique is presented. The full scheme with the complete gauge invariant set of Feynman diagrams is used.

Introduction

Due to its unique properties top quark is one of the most interesting particle for the searches of the physics beyond of the Standard model (SM). There are three well-known single top quark production processes at hadron colliders, they are $s-$channel, $t-$channel and $tW-$associated ones. First two of them were observed first at the Tevatron collider [1],[2],[3]. Because of its tiny cross section at the Tevatron energies, $tW-$associated single top quark production was observed only recently [4] at the LHC, and the normalized differential cross-section measurement in a fiducial phase-space region was provided [5].

Physics beyond the SM can manifests in the modification in the predicted by the SM values of some of the couplings. As for anomalous Wtb couplings, SM predicts the following set of coupling values: $f_{\mathrm{V}}^{\mathrm{L}} = V_{\mathrm{tb}}, f_{\mathrm{V}}^{\mathrm{R}} = f_{\mathrm{T}}^{\mathrm{L}} = f_{\mathrm{T}}^{\mathrm{R}} = 0$ in the most general, lowest dimension, CP conserving Lagrangian

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for the Wtb vertex [6, 7]:

$$\mathfrak{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(f_{\rm V}^{\rm L}P_{\rm L} + f_{\rm V}^{\rm R}P_{\rm R}\right)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}\partial_{\nu}W_{\mu}^{-}}{M_{\rm W}}\left(f_{\rm T}^{\rm L}P_{\rm L} + f_{\rm T}^{\rm R}P_{\rm R}\right)t + h.c. \tag{1}$$

where $P_{\rm L,R} = \frac{1\mp\gamma_5}{2}$, $\sigma_{\mu\nu} = \frac{i}{2}(\gamma_{\mu}\gamma_{\nu} - \gamma_{\nu}\gamma_{\mu})$, form factor $f_{\rm V}^{\rm L}$ ($f_{\rm V}^{\rm R}$) represents the left-handed (right-handed) vector coupling, $f_{\rm T}^{\rm L}$ ($f_{\rm T}^{\rm R}$) represents the left-handed (right-handed) tensor coupling. Therefore any of the deviations from the SM values listed above for these couplings may be considered as a manifestation of some new physics. There are direct searches for the anomalous operators in the t-channel single top production [8], [9], [10]. The first search for new physics that uses the tW process is performed by the CMS collaboration [11] in the events with two opposite-sign isolated leptons.

1 Different schemes of the tW-associated production and their sensitivity to the anomalous Wtb couplings.

The next-to-leading order corrections to the leading order tW process is conditioned by the additional b-quark to the tW process. The final signature of the NLO process tWb is similar to the final signature of the top-pair ($t\bar{t}$) production processes. The top pair production processes are the dominant ones. Moreover the cross terms between tW and $t\bar{t}$ do appear and also have significant contribution. In Fig. 1 all the diagrams of $gg \to t\bar{b}W^-$ subprocess for the tWb final state are listed as an example.

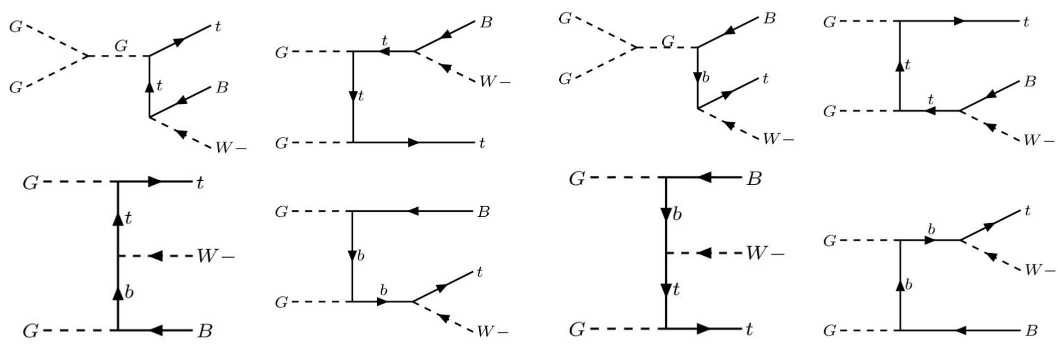

Figure 1: Diagrams for the process $gg \to t\bar{b}W^-$.

One or another schemes are used for tW processes highlighting on the simulation level. The most known (and often used) are *Diagram Removal* scheme [12],[13] (where all top pair production diagrams are removed and the other diagrams are considered in the analyses), *Diagram Subtraction* scheme [13],[14] (with the deletion of the top pair production diagrams after the squaring all the diagrams), scheme with artificially introduced local subtraction term [15] and others.

The question arises, which simulation scheme of the tW processes should be chosen for the task of the searches for the anomalous Wtb couplings. Different schemes of the tW processes modeling have different sensitivity to the anomalous Wtb couplings. Even if some of the tW simulation scheme is used and the analysis is provided, the constraints on the anomalous Wtb couplings can't be considered in the way as it may be considered in the case where artificial procedure with some or another diagrams deletion is not used. Moreover, top pair production processes also have the sensitivity to the anomalous Wtb couplings and the deletion of the top pair diagrams leads to loss of an information.

The above was demonstrated in [16] with the final statement that the usage of the gauge-invariant full set of the diagrams from Fig.1 is the most preferable for the anomalous Wtb couplings searches. But the question is how to separate the top pair and tW-associated processes phase space regions still exists. The idea is to use Neural Networks (NN) for such a separation [17].

2 Neural Network implementation for the $t\bar{t}$ and tW phase space separation

The first NN should be trained for the separation between top pair and tW-associated phase space regions. For such a purposes the variables with different behavior for $t\bar{t}$ and tW have been chosen. These variables (see Fig. 2), like a cosine of angle between a lepton from a first top decay and a jet from a second top decay in one of the two top quarks rest frame (10 in total), have been extracted from the specially generated two sets of events. For the NN training the following event samples were used. First set of events contain the processes with top pair production only and the second set of events contain the processes with tW-associated single top production provided in DR scheme. In this way the different kinematic properties of the separated processes are revealed in the chosen variables more expressly.

First, the NN has been trained with the set of chosen variables to distinguish the top pair phase space region. On the left plot of Fig. 3 one can see that the events with top pair processes only (from the training set of events with top pair production) have been classified by the NN as they are. One can observes the same thing on the right plot of Fig. 3 where the events with single top processes only (from the corresponding training set of events) have been classified by the NN as the tW events.

And the second, the NN, which has been trained to distinguish top pair and single top events, is applied to the full simulation scheme with complete gauge invariant set of diagrams for $t\bar{t}+tW$ events, where top pair, tW single top and its interference is included. One can see the result in Fig. 4. On the left side on the plot there are events classified by the NN as the events with top pair production and on the right side there are events classified as the events from tW single top quark production. The interference is ”smeared “between the highlighted classes of events.

Conclusion

In the article we formulate recommendations how to increase the sensitivity of the search for the anomalous contribution to the Wtb interactions in the processes of tWb production. The recent measurements of the differential cross section for tWb process [5] confirms rather high uncertainties (up to 30%) due to the simulation issues in tWb processes. We recommend to use full scheme with the simulation of the complete set of gauge invariant set of Feynman diagrams. Direct implementation of the full scheme leads to decreasing of the sensitivity for the Wtb interactions, since the main contribution comes from the pair QCD top quark production. The recommendations are simple, need to prepare correct simulation with full scheme and separate QCD (pair, double resonant) and electroweak (single resonant) contribution by dedicated NN. The interference is correctly taken in to account and the systematic uncertainty has minimized. Such NN to separate top pair and tW-associated single top production phase spaces has been prepared. It was shown that good separation between $t\bar{t}$ and tW phase spaces is achieved. At the next step one can create additional NNs to distinguish the anomalous Wtb contribution separately from the events similar to $t\bar{t}$ and tW due to the different properties in each case. The described scheme of the simulation and separation between phase spaces can be used in the experimental searches for the anomalous contributions to the Wtb vertex as well as for the measurements of the tW-associated single top quark production process parameters.

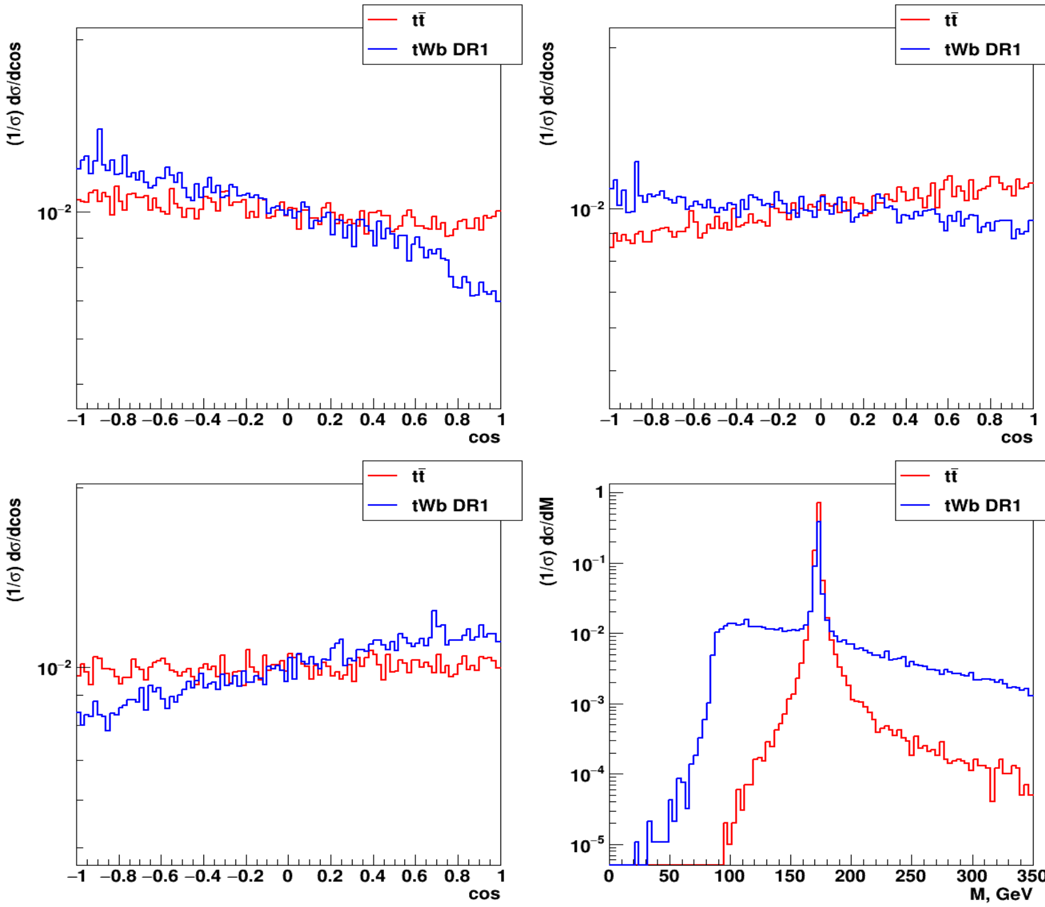

Figure 2: The distributions of some kinematic variables which have been chosen for training of the NN for the separation between top pair and single top processes phase space

Acknowledgments

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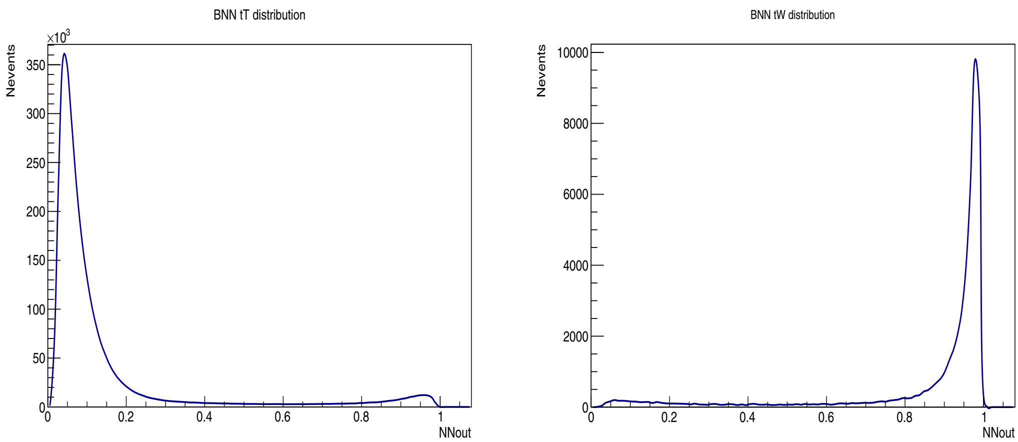

Figure 3: The NN output after the training. The events from the training event set with top pair (tW-associated single top) production have been classified by the NN as the events with top pair (tW-associated single top) production on the left (right) plot.

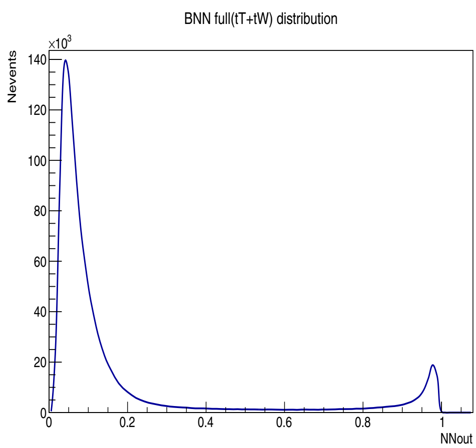

Figure 4: The NN output for the full set of $t\bar{t} + tW$ events.

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