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The recipe to search for anomalous Wtb couplings in tWb associated production process.

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Abstract. The impact of anomalous Wtb couplings on tWb process of the single top quark production has been probed in different schemes of tWb modeling. A special attention devotes to influence of the particular schemes to the anomalous couplings sensitivity. The distributions of representative variables demonstrate different behaviour in different simulation schemes, therefore the correct probe for anomalous Wtb couplings require specific approach to simulate BSM contribution. Special approach to search for BSM contribution in the off-shell tWb process is proposed in this paper. The approach is based on the kinematic separation of the double and single resonant contributions by means of neural network. The specific BSM properties are considered separately for the double and single resonant events. Such approach allows to add information on the anomalous Wtb coupling from simultaneous consideration of the $t\bar{t}$ (double resonant) and tWb (off-shell, single resonant) contribution of tWb processes and therefore can improve the sensitivity to the anomalous Wtb couplings.

Introduction

There are three processes of a single top quark production at hadron colliders, they are known as s-channel, t-channel and tW-associated single top production [1]. All of them, except the last one, have been observed at Tevatron collider [2],[3],[4]. Due to its tiny cross section at the Tevatron collider tW-associated production is a process of interest only at the LHC collider and it has been observed recently [5].

For modern tasks in high energy physics accounting the next-to-leading order corrections to the main leading order process is very important. For tW process one needs to take into account the process with additional b-quark appearance in the final state, that is to say tWb processes. The final state of tWb process has the same signature as the pair top quark

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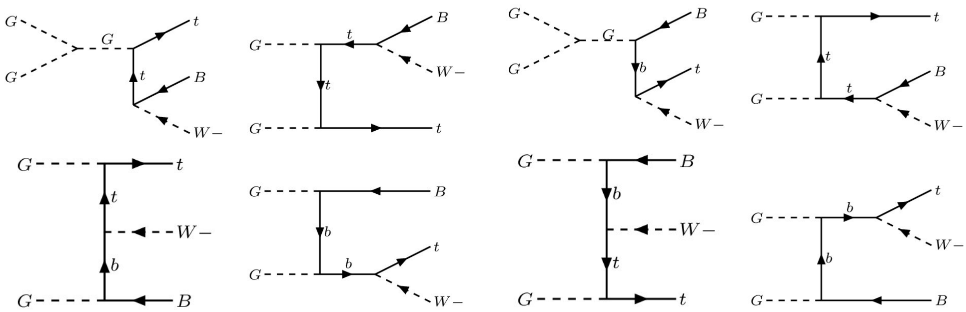

Figure 1: Diagrams for the process $gg \to t\bar{b}W^-$.

production and the Feynman diagrams of pair and single top quark production processes contribute to the same gauge invariant set. The full process $pp \to t\bar{b}W^-$ contains subprocesses with two quarks or two gluons in the initial state and the last ones are dominant. In Fig. 1 all the diagrams of $gg \to t\bar{b}W^-$ subprocess with subsequent lepton channel decay of W-boson are listed.

Three diagrams from Fig. 1 with two top quarks are the diagrams of the double top production; other five diagrams correspond to the single top production. If one studies the tWb processes in the experimental analyses the task of separation between double and single top quark production processes arises. Different schemes of tWb modeling highlight the single top production in some or another way. In the following we use the notations from [6]. For example, in so-called $DR1$ scheme (known as *Diagram Removal* in a past, [7],[8]) all three double resonant top quark production diagrams are removed and the rest of diagrams are considered. In this case the interference between double top and single top production diagrams has not been taken into account. In the $DR2$ scheme (*Diagram Subtruction* [8],[9]) deletion of the double top production diagrams is performed after the squaring all of the diagrams. In this case the interference terms between double and single top quark production diagrams are kept, however this procedure leads to significant part of the simulated events with negative weights.

The search for anomalous operators in the Wtb vertex is one of the most important tasks in top physics due to direct impact of the anomalous operators to the cross sections and kinematic distributions of the single top quark production processes. There are direct searches for the anomalous operators in the t-channel single top production [10],[11],[12] however the experimental searches for the anomalous operators in the tWb process of single top production have not been provided so far. The short phenomenological study of the influence of the anomalous operators in the Wtb vertex in a different schemes of the tWb processes modeling has been provided in [13].

1 Anomalous structure of the Wtb vertex.

The most general, lowest dimension, CP conserving Lagrangian for the Wtb vertex has the following form [16, 17]:

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

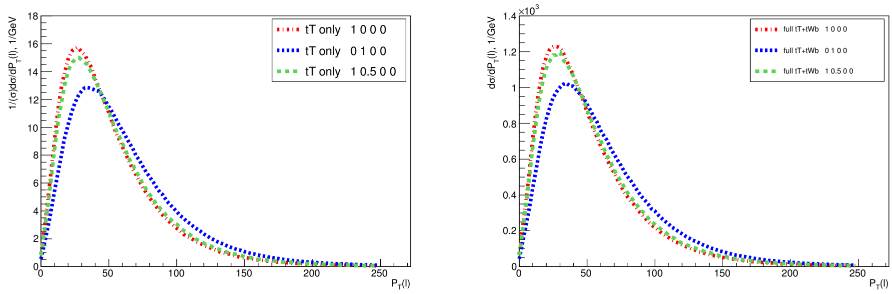

Figure 2: Transverse momentum of a lepton from $W-$boson decay for double top production (left) and for full set of diagrams from Fig.1 (right) for different values of anomalous Wtb couplings values from (1)

where $P_{\mathrm{L,R}} = (1 \mp \gamma_5)/2$, $\sigma_{\mu\nu} = \frac{i}{2}(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)$, form factor $f_{\mathrm{V}}^{\mathrm{L}}$ ($f_{\mathrm{V}}^{\mathrm{R}}$) represents the left-handed (right-handed) vector coupling, $f_{\mathrm{T}}^{\mathrm{L}}$ ($f_{\mathrm{T}}^{\mathrm{R}}$) represents the left-handed (right-handed) tensor coupling. The SM has the following set of coupling values: $f_{\mathrm{V}}^{\mathrm{L}} = V_{\mathrm{tb}}, f_{\mathrm{V}}^{\mathrm{R}} = f_{\mathrm{T}}^{\mathrm{L}} = f_{\mathrm{T}}^{\mathrm{R}} = 0$.

The short phenomenological study of the influence of the anomalous operators in the Wtb vertex in a different schemes of the tWb processes modeling has been provided in [13]. It was shown that even double top quark production process is sensitive to the anomalous Wtb couplings (it is not very obviously due to the presence of anomalous operators in top quark decay only in comparison with single top production processes where Wtb vertex appears twice, in production and decay of top quarks); so it is understandably that double top quark production process is less sensitive to the anomalous Wtb couplings than single top quark production one. Proceeding from the foregoing one can conclude that for anomalous Wtb operators searches in tWb processes the usage of the full gauge invariant set of the diagrams from Fig. 1 without deletion of some of them is more justified.

2 Discrimination between double top quark production and single top quark production

As one can see from Fig. 2, due to huge contribution of double top production processes [14], the kinematic distributions of the full tWb process and double top production look identical to each other. It arises a task of distinguishing of the double resonant top quark production part in the full set of diagrams from the other contributions, which corresponds to the single top quark production and cross terms between double and single top quark production processes. The idea is to construct a Deep Learning Neural Network (DNN) for such a discrimination. In Fig. 3 distributions on some of the kinematic variables are shown; one can see the difference in behaviour of the curves for double top production in comparison to $DR1$ (single top production), all these variables can be chosen as an input variables for a DNN.

3 Anomalous Wtb couplings in double top quark production processes.

As it was presented in Fig. 1, all diagrams for double top quark production diagrams have only one Wtb vertex in the decay of top quark. It's reasonable to suggest that some angular

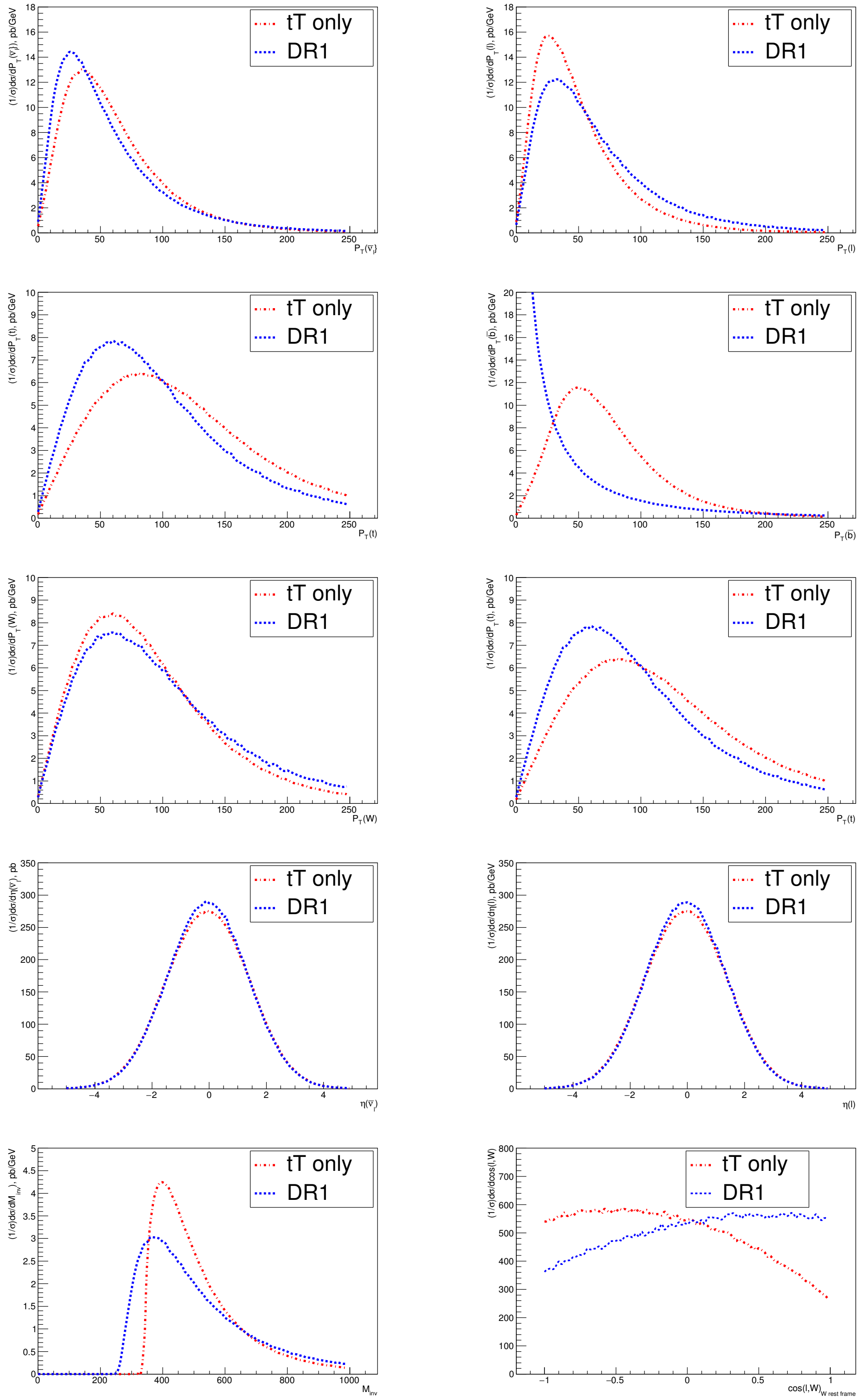

Figure 3: Distributions on some kinematic variables for double top production and single top production in *DR*1 scheme.

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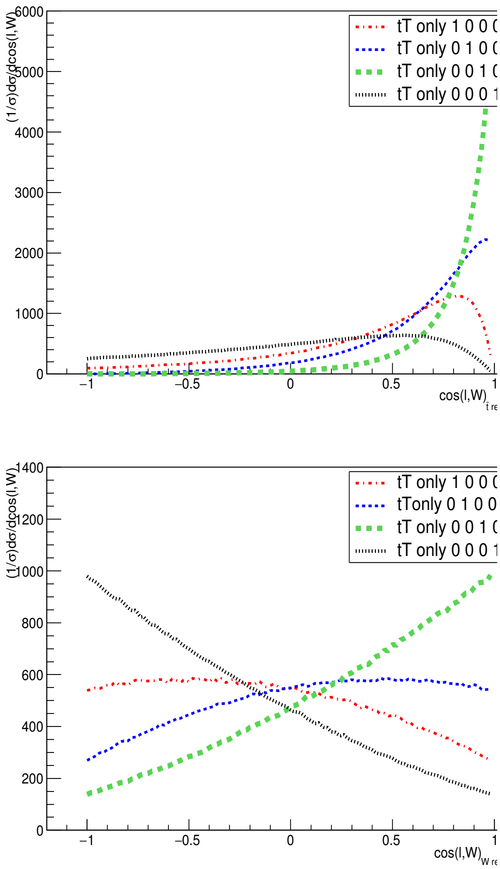

Figure 4: The cosine of angle between lepton from W-boson decay and W-boson itself in the top quark rest frame (top) and in the W-boson rest frame (bottom) for the top-pair production processes and different scenarios of interaction in the *Wtb* vertex

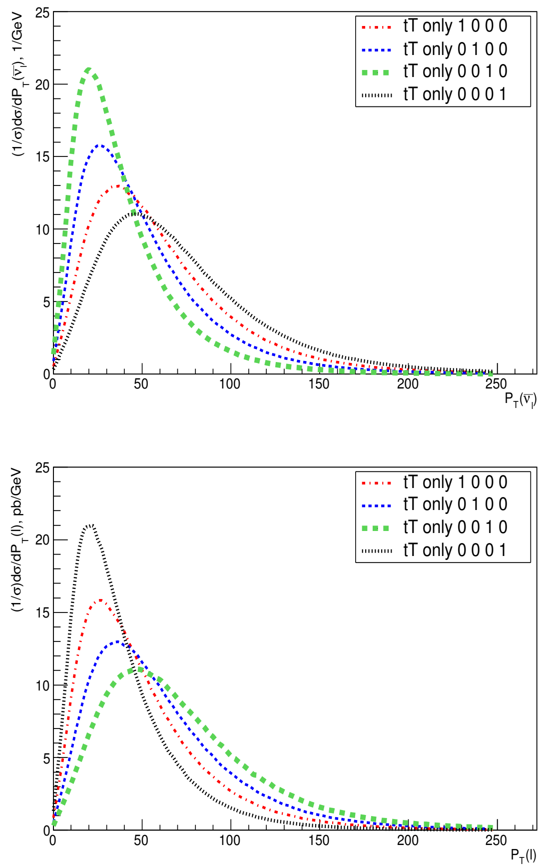

Figure 5: The distribution of the neutrino (top) and lepton from W-boson decay (bottom) momenta for the top-pair production processes and different scenarios of interaction in the *Wtb* vertex

variables of the top quark decay products like angle between two their four-momentum or transverse momentum are the most sensitive to anomalous *Wtb* vertex variables. In Fig. 4 and 5 the distributions for some of such kind of variables are shown for pure left- and right-handed vector and left- and right-handed tenzor interactions. For example the "1 0 0 0" notation means that the distribution is achieved with values of couplings from 1 are equal to $f_V^L = 1, f_V^R = f_T^L = f_T^R = 0$. As expected, there are differences in the distributions for different values of the anomalous *Wtb* couplings. Such kind of variables can be used for training a DNNs for the discrimination between different scenarios of anomalous *Wtb* interactions.

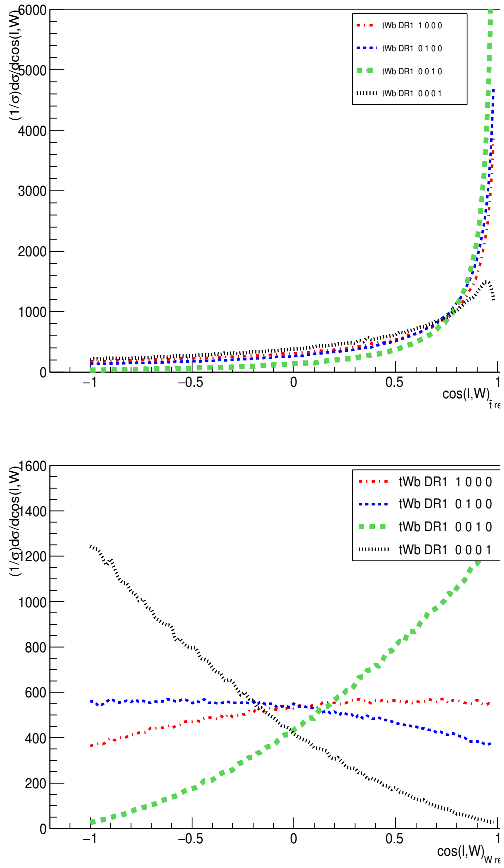

Figure 6: The cosine of angle between lepton from W-boson decay and W-boson itself in the top quark rest frame (top) and in the W-boson rest frame (bottom) for the DR1 scheme and different scenarios of interaction in the Wtb vertex

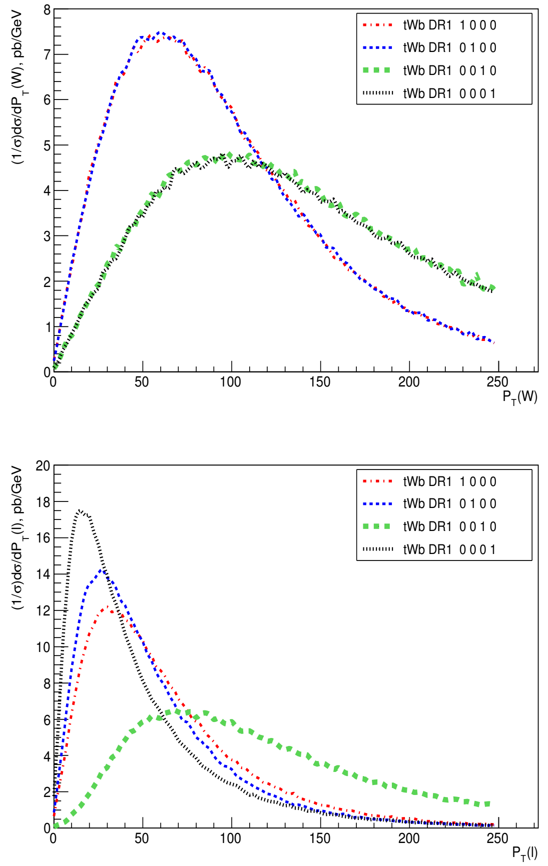

Figure 7: The distribution of the W-boson (top) and lepton from W-boson decay (bottom) momenta for the DR1 scheme and different scenarios of interaction in the Wtb vertex

4 Anomalous Wtb couplings in single top quark production processes.

Single top quark processes have two Wtb vertices in a corresponding Feynman diagrams (Fig.1). After the discrimination of single top events with the help of the DNN using the variables which are described in Sec.2 other DNNs should be constructed in the same way with the variables described in Sec.4. Those "BSM DNNs" should have a possibility to discriminate the contributions from different operators in 1. It's reasonable to use $DR1$ or $DR2$ schemes to highlight the impact of the anomalous operators in single top processes. One can expect that the angular variables have the higher sensitivity to the anomalous operators. In Fig. 6, 7 distributions for some of the angular variables are shown for the contributions of different operators into Wtb vertex for $DR1$ and in Fig. 8, 9 for $DR2$ scheme. Listed

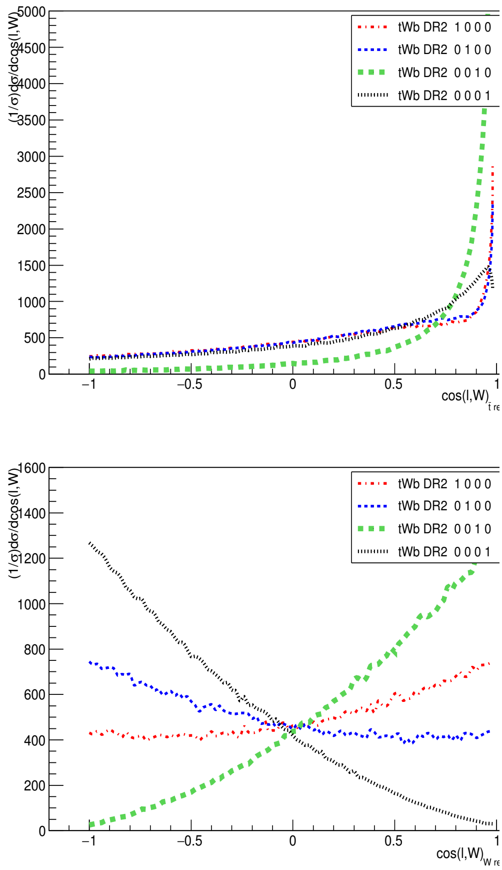

Figure 8: The cosine of angle between lepton from W-boson decay and W-boson itself in the top quark rest frame (top) and in the W-boson rest frame (bottom) for the DR2 scheme and different scenarios of interaction in the Wtb vertex

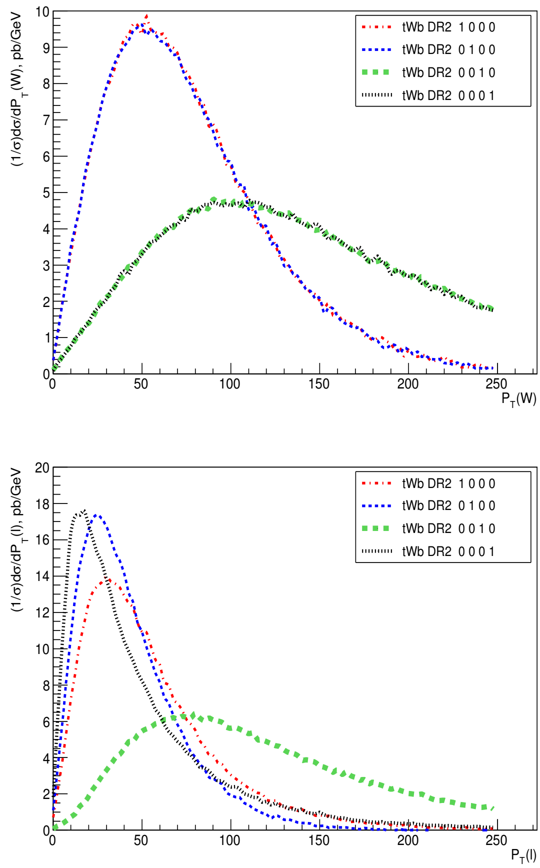

Figure 9: The distribution of the W-boson (top) and lepton from W-boson decay (bottom) momenta for the DR2 scheme and different scenarios of interaction in the Wtb vertex

variables can be used for training the "BSM DNNs" to discriminate different contributions of the anomalous Wtb operators.

Conclusion

The paper describes recipe of the complete analysis to search for the anomalous Wtb operators in the tWb process. The most correct way to search for the anomalous Wtb operators in the Wtb vertex is a usage of the full scheme of tWb process with the simultaneous simulation of double and single resonant top quark production in one gauge invariant set of Feynman diagrams. For a distinguishing of the double and single resonant top quark contributions the Deep Learning Neural Network is applied in order to perform kinematic separation and taking into account interference terms without negative weights of the events. The set of variables for the DNN is also suggested in the paper. At the next step, additional BSM DNNs are needed to highlight the contribution of the anomalous operators in the *Wtb* vertex, the set of corresponding variables for BSM DNNs is proposed as well. The quantitative estimation of the expected significance requires statistical analysis of the BSM DNN outputs and will be performed in the future paper.

Acknowledgments

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