Optimizing the sensitivity to the Di-Higgs search in $bbW^{+}W^{-}$ final state using machine learning methods

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Abstract

A study of optimization of signal sensitivity in the search for the Di-Higgs event in the ATLAS experiment is presented where one of the Higgs bosons decays via the $H \rightarrow b\bar{b}$ channel and the other via $H \rightarrow W^{+}W^{-}$ with $b\bar{b}lvqq$ as the final state. Large irreducible background contamination from $t\bar{t}$ decay significantly decreases the signal sensitivity in the Di-Higgs search. We employ ROOT's built-in Multivariate analysis tool (TMVA) to train new physics-motivated variables along with currently trained variables. An increment in the rejection of $t\bar{t}$ background while keeping the signal efficiency high is observed.

Introduction: Di-Higgs

What is Di-Higgs?

➢ **Simply a pair of Higgs boson formed in high energy collision!**

Why do we care about Di-Higgs?

➢ One of the consequence of the Brout–Englert–Higgs (BEH) mechanism in the Standard Model (SM) is that it requires the self-coupling of the Higgs boson. And we have yet to verify this experimentally!

❑ **Studying Di-Higgs production at the ATLAS experiment can help us probe the Higgs self-coupling.**

❑ **Measuring the Higgs self-coupling will in turn help in reconstructing the Higgs Potential.**

Higgs Potential

$$V \approx V(v) + \frac{1}{2}m_H^2 h^2 + \underbrace{\frac{m_H^2}{2v}}_{\lambda_{HHH}} h^3 + \frac{m_H^2}{8v^2}\, h^4$$

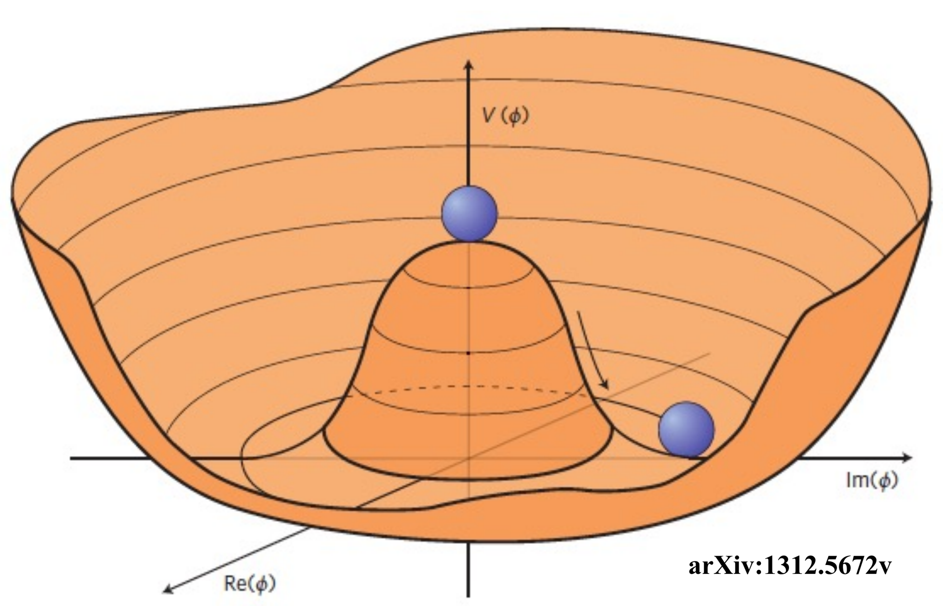


Figure 1. Shape of the SM Higgs Potential

Di-Higgs production at the LHC

Production Mode	Cross Section
$ggf - hh$	~33 fb
$VVF - hh$	~ 2 fb
$hhZ - hh$	~0.4 fb

More than 90% of SM Di-Higgs is produced via ggF, which is only accounted for in this analysis. There are two ways in which Di-Higgs is formed from ggF, as shown in figure 2. Their amplitudes interfere destructively, resulting to a production cross-section of ≈ 31 fb at $\sqrt{s}$ =13 TeV [1] .

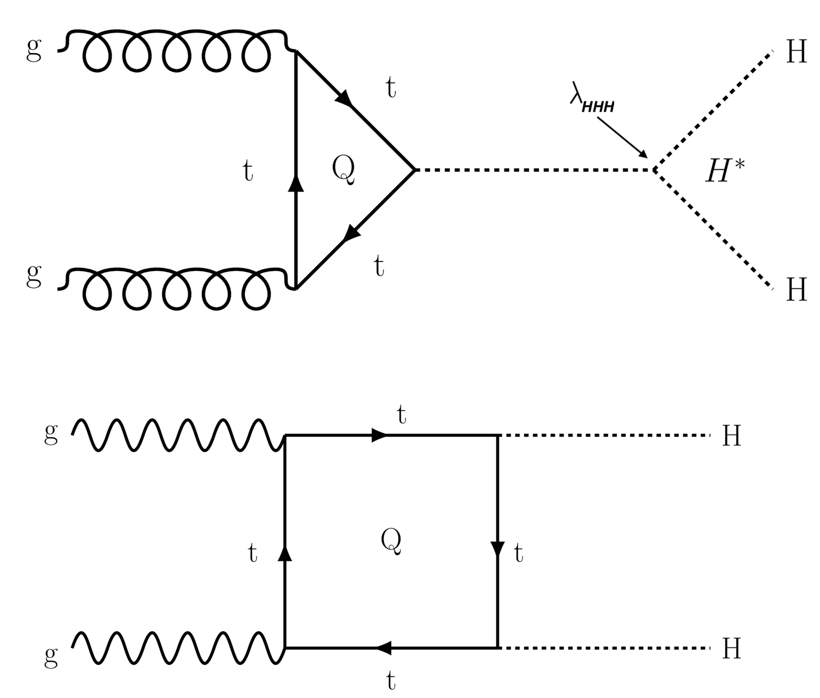


Figure 2. Feynman diagrams showing the production of SM Di-Higgs through gluon-gluon fusion. The figure in the top has the Higgs trilinear self-coupling, whereas the figure in bottom does not.

Di-Higgs Signal and background ($b\bar{b}\ W^{+}W^{-}$)

Di-Higgs Signal:

$pp \rightarrow HH \rightarrow b\bar{b}\ W^{+}W^{-} \rightarrow b\bar{b}lvqq$

Background: $(t\bar{t}\ ,\ t\bar{t}\,W,\ t\bar{t}\,Z,\ W$+jets, Z + jets...)

$t\bar{t} \rightarrow b\bar{b}\ W^{+}W^{-} \rightarrow b\bar{b}lvqq$

➢ Since $t\bar{t}$ accounts for > 80% of background, only its contribution is accounted for the machine learning modelling.

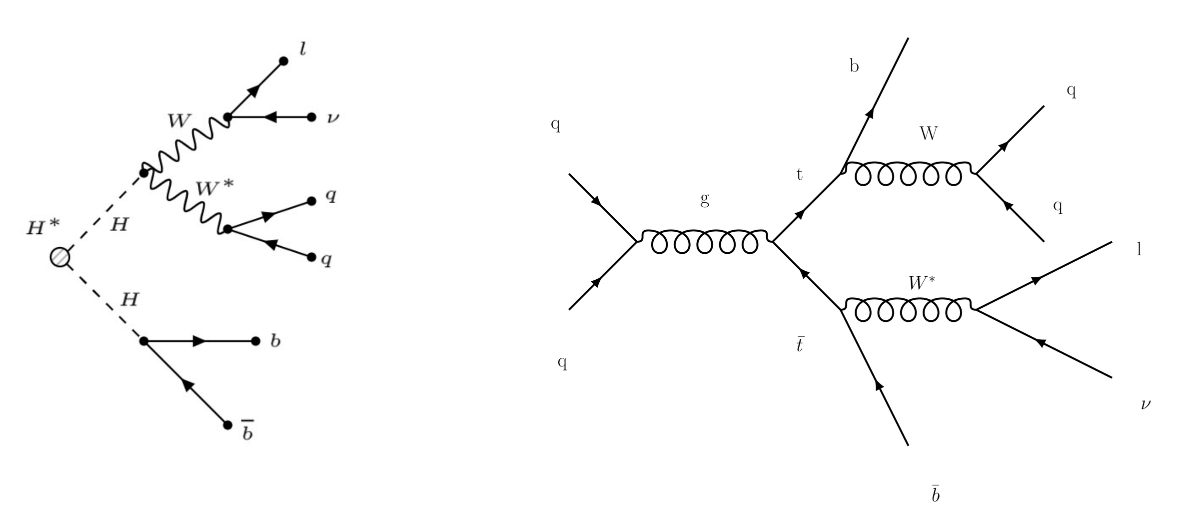


Figure 3: Di-Higgs decaying to $b\bar{b}lvqq$ (left), and $t\bar{t}$ decaying to $b\bar{b}lvqq$ (right), making the background irreducible.

Project description:

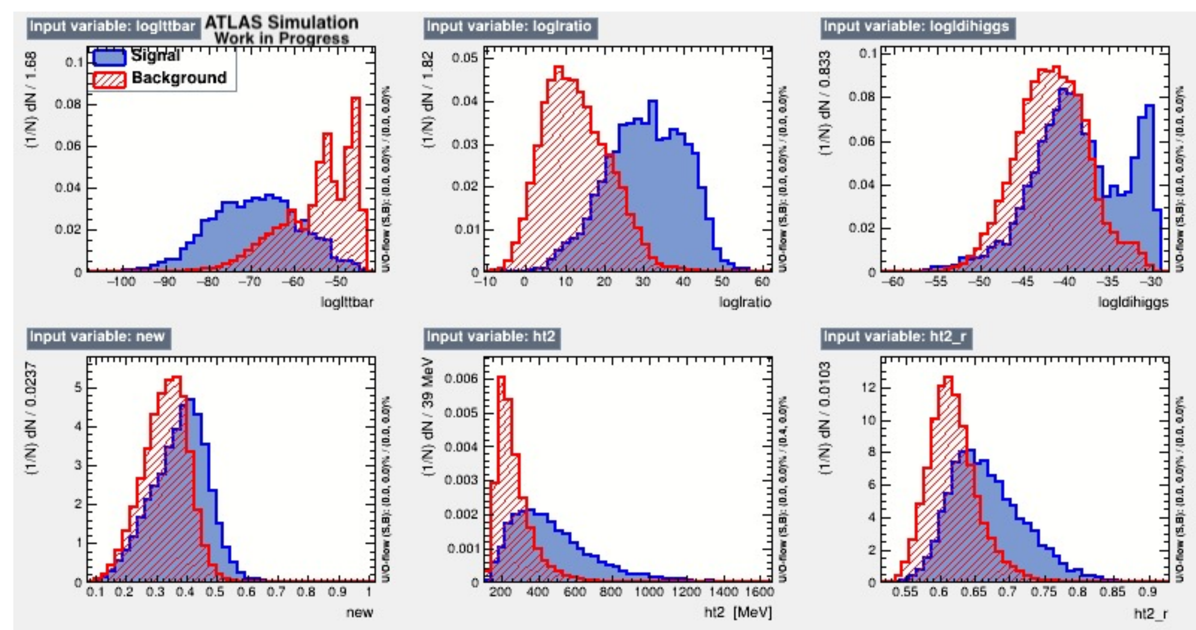
- Increase the discrimination of the background from signal for MC simulated data based on the signal significance, defined as $\frac{S}{\sqrt{S+B}}$

How?

- Introduce new kinematic variables, train machine learning algorithms (BDT and DNN) as implemented in ROOT's TMVA.

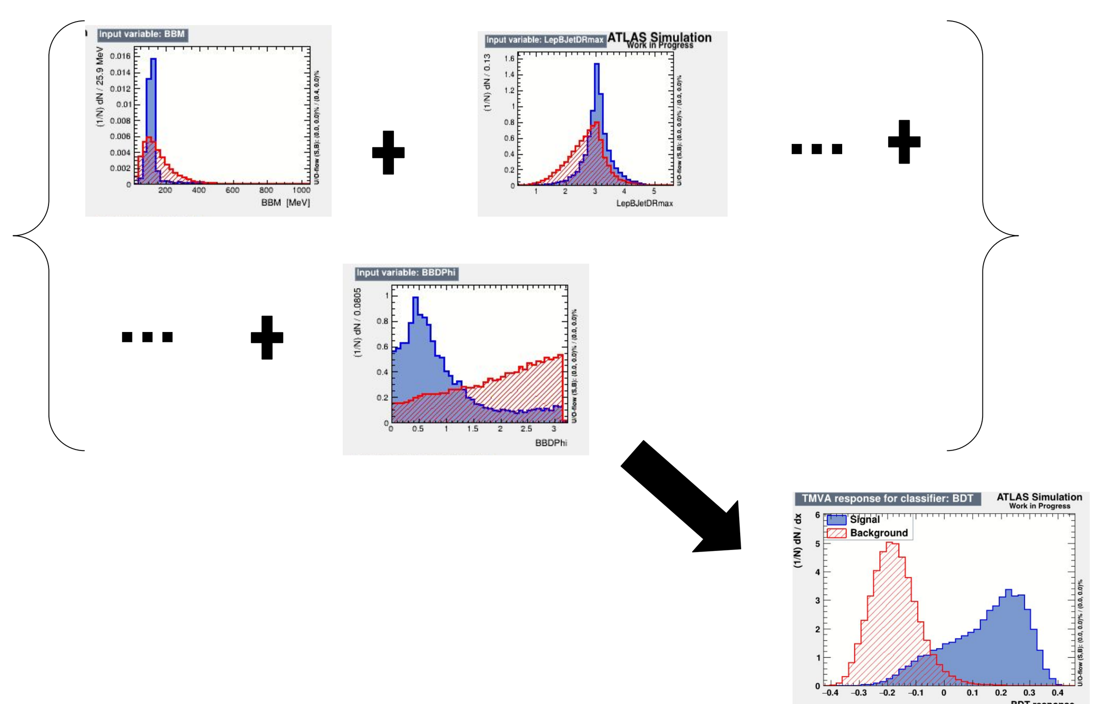
Data and methods

- 43 Kinematic Variables obtained from Monte Carlo Simulation of pp collision.



Machine Learning methods

- Deep Neural Network (DNN) algorithm,
- Boosted Decision Tree (BDT) algorithm
  - Many decision trees are trained together and integrated to form a "forest".
  - Several weak classifiers are amalgamated to construct a strong classifier.



Results

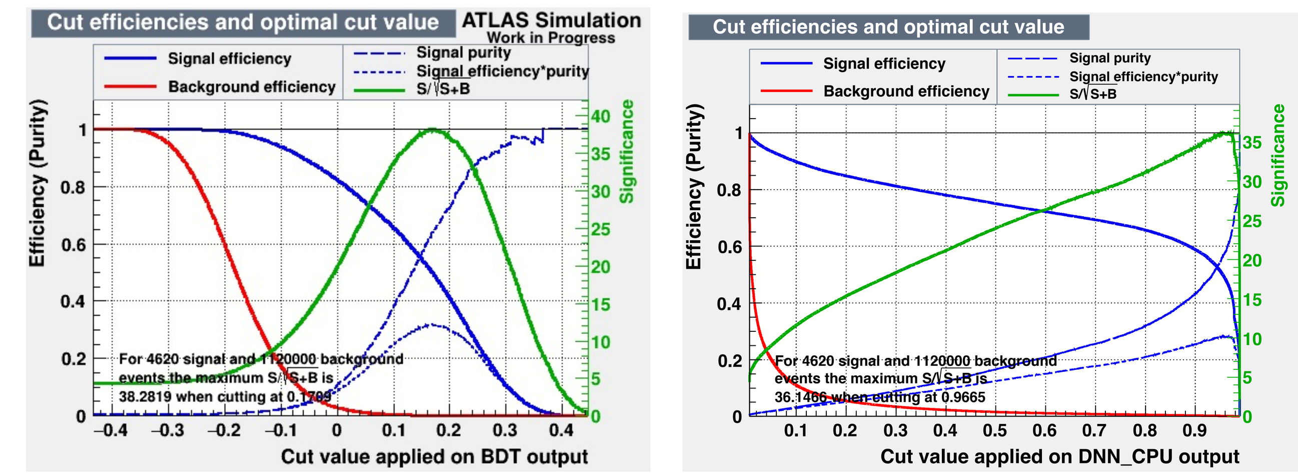


Figure 4: Signal Significance peaked at 38.2819, and 36.1466 for 43 BDT trained kinematic variables (left) and DNN trained variables (right) for 4620 signal and 1120000 background events.

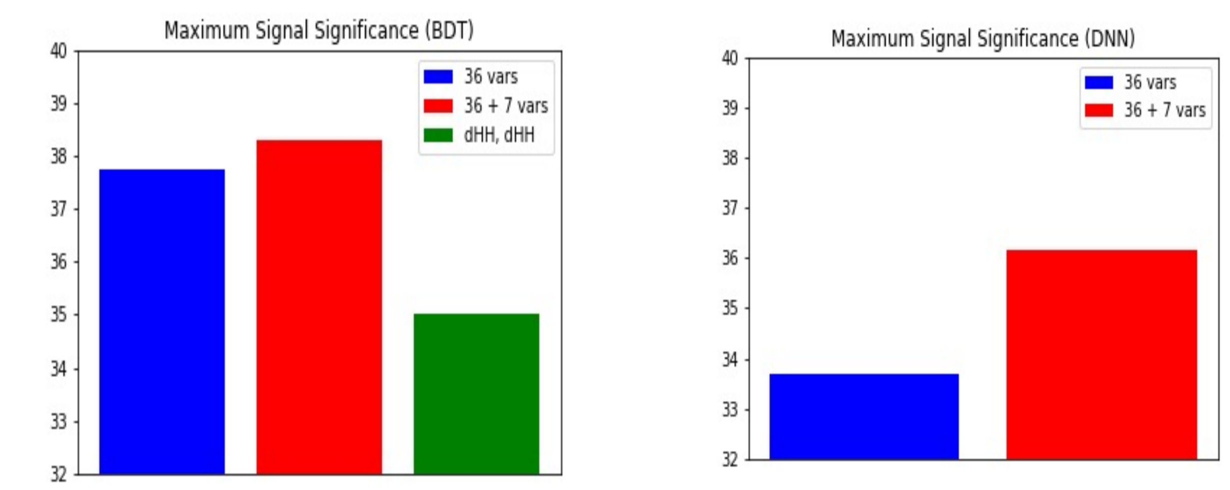


Figure 5: Comparison of performance of BDT (left) and DNN (right) performance on previously trained variables and (previously trained variables + new Kinematic variables) .

Conclusions

❑ **Adopting kinematic variables from similar channels and training machine learning models increased the signal significance,**

❑ **BDT algorithm performed better than DNN algorithm for a same number of input kinematic variables.**

References

1. LHC Higgs Cross Section HH Sub-group
2. P. Kafle, Optimization of sensitivity for the Di-Higgs search in $b\bar{b}lvqq$ final state in the LHC data recorded by the ATLAS detector in pp collisions at $\sqrt{s}$ =13 TeV, (2021)
3. ATLAS Collaboration, "Combination of searches for Higgs boson pairs in pp collisions at $\sqrt{s}$ =13 TeV with the ATLAS Detector," Physics Letters B800, 135103 (2020)

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