A Search for Exotic Higgs Decay to the 4b Final State

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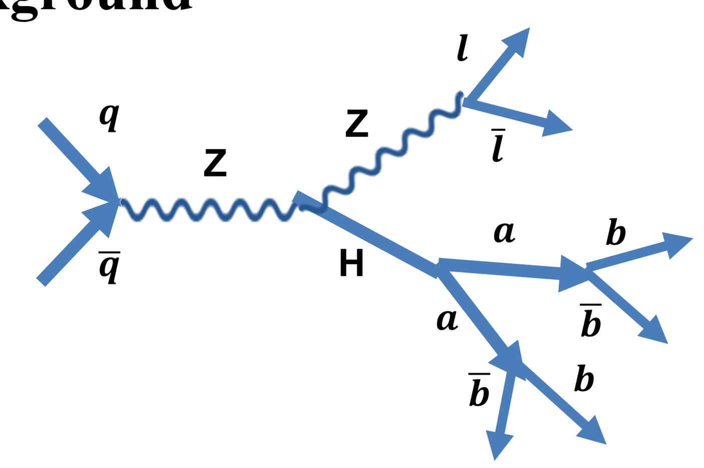
Motivation

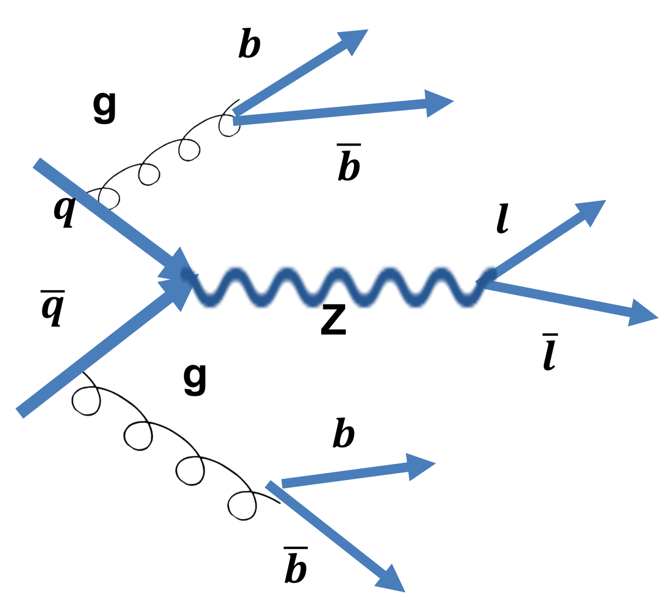
The Higgs Mechanism is theorized to be the method behind which particles gain their mass and where the theory of the Higgs Boson comes from. However, the Higgs Boson discovered in 2012 does not currently fit completely with the theory. The question, and motivation for this project, becomes: does such a Higgs Boson exist?

Signal vs. Background

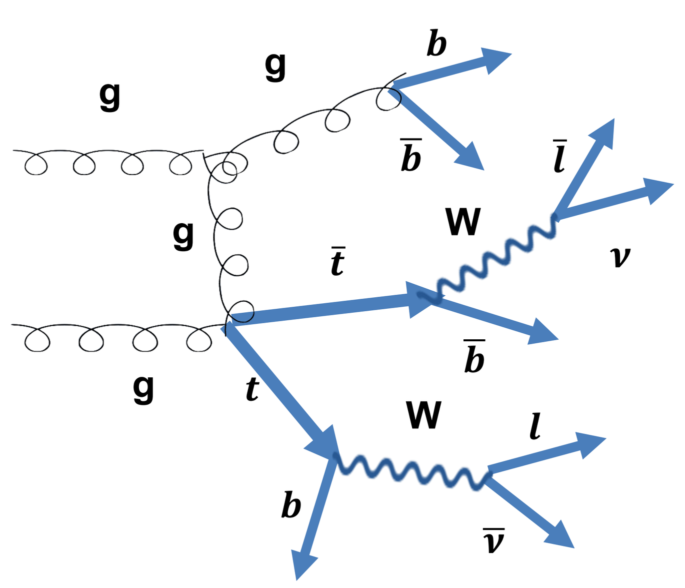
While not the only theory, this project focuses on the idea of a new Higgs particle, a, which most likely decays from the known Higgs Boson into four b quarks.



But with the current technologies, the ATLAS detector can only see the four b quarks, meaning that on first look, all of these decay patterns are the same.



Z-Jet Background



ttbar Background

Goals and Objectives

This project worked to create a machine learning algorithm to discriminate between signal $H \rightarrow aa \rightarrow b\bar{b}b\bar{b}$ and other background processes. It includes:

- A detailed study of observables in special relativity adapted for the kinematics of this specific type of event
- Development of a Binary Decision Tree (BDT) to perform the discrimination

The outcomes of this project will be used to further investigate these signal events to see if such an "a" boson does exist

Investigation of the Kinematics

In order to distinguish background and signal, we first need to understand the characteristics that separate the two by completing an analysis of the kinematics of each possible decay pattern.

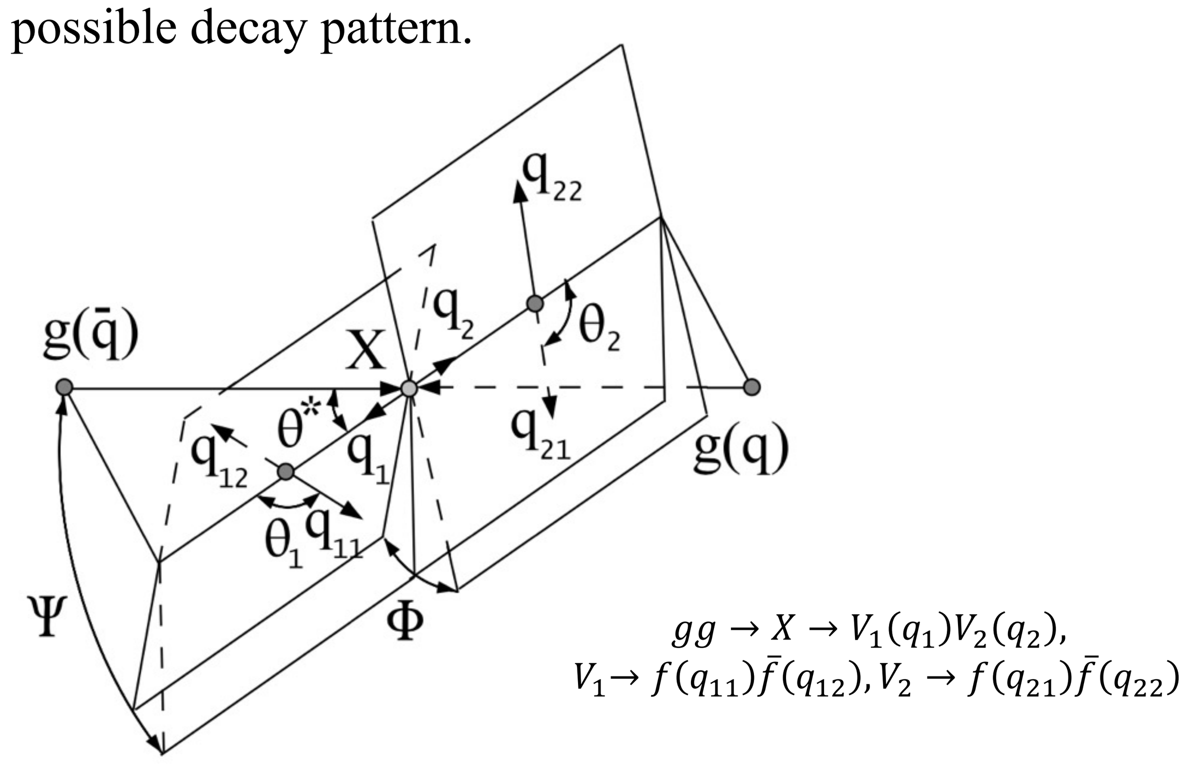


Diagram of the variables present in the given general decay sequence (Bolognesi et al., 2012)

$$\theta_1 = \cos^{-1}\left(-\frac{\boldsymbol{q}_2 \cdot \boldsymbol{q}_{11}}{|\boldsymbol{q}_2||\boldsymbol{q}_{11}|}\right) \qquad \theta_2 = \cos^{-1}\left(-\frac{\boldsymbol{q}_1 \cdot \boldsymbol{q}_{21}}{|\boldsymbol{q}_1||\boldsymbol{q}_{21}|}\right)$$

$$\hat{q}_1 = (\sin\theta^* \cos\Phi^*,\ \sin\theta^* \sin\Phi^*, \cos\theta^*)$$

Each of the angles shown in the diagram and described in equation form can be calculated by the momentum components of the decayed particles $q_{11}, q_{12}, q_{21}, \& \ q_{22}$ and where $q_1 = q_{11} + q_{12}$ and $q_2 = q_{21} + q_{22}$ They are all taken from and derived in-depth in Bolognesi et al.

With this investigation, we determined eight variables with which we could accurately distinguish between signal and background.

MET, Higgs mass (m_H), Higgs momentum (p_T^H), Z Boson cos $\theta_{CS}^{\ell\ell}$, a boson mass ($m_a^{(1)}$), a boson mass ($m_a^{(2)}$), Higgs cosθ^*, Event Quality

The Implementation of Machine Learning

Because of the shear amount of data collected by the ATLAS detector, it would be impossible to manually comb through all of it looking for specific parameters. By using machine learning techniques, we are able to

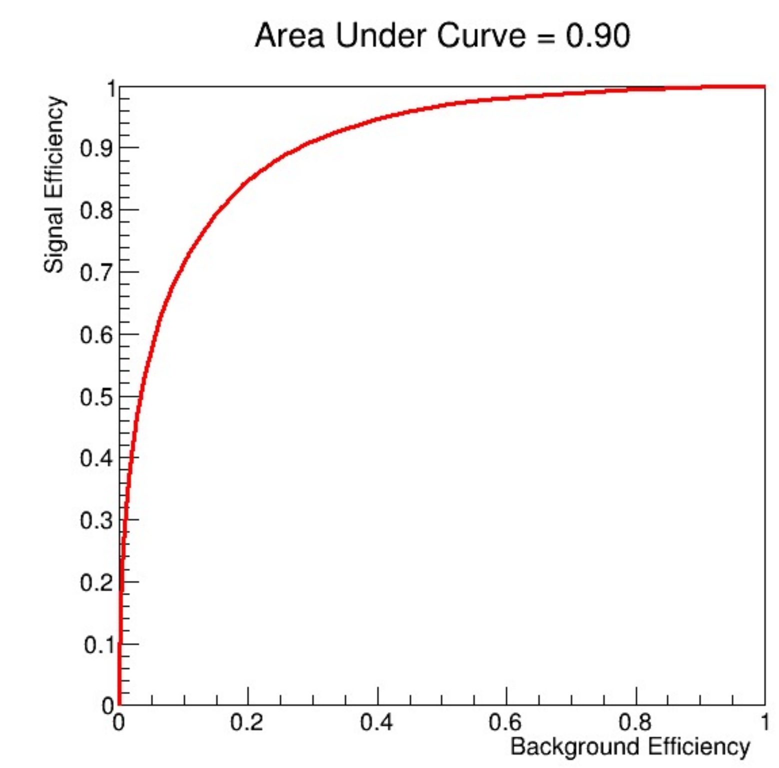
Run large amounts of data

Adapt in real time

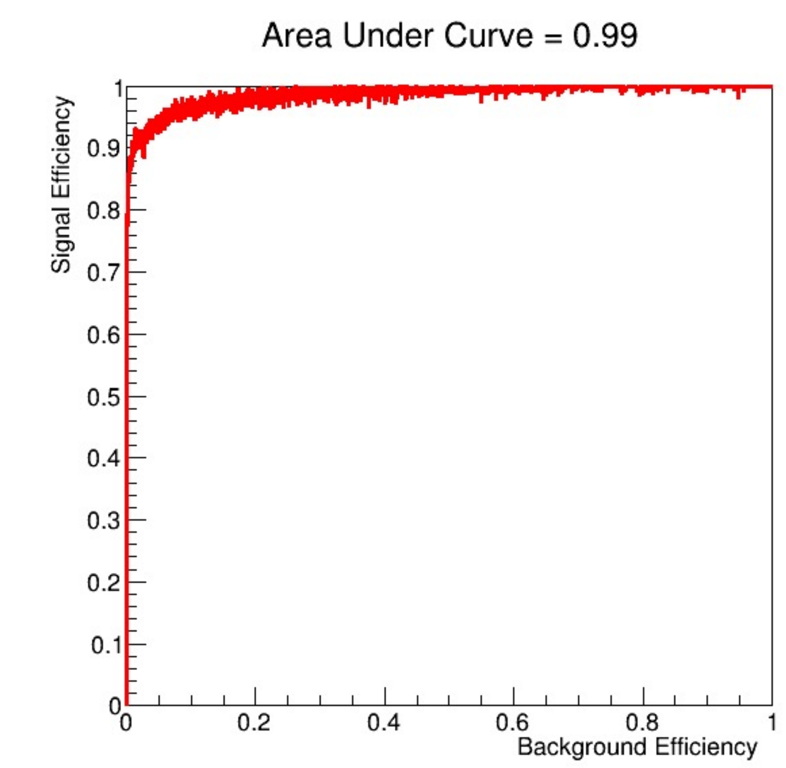
For this project, we used a Binary Decision Tree (BDT).

Results

Using a combination of build-in machine learning techniques from ROOT and python, we trained a BDT to successfully distinguish signal and background events in a simulated set of data. In each of these graphs, the y-axis represents the efficiency of the algorithm to accurate select signal and the x-axis represents the same for the background. This a perfect distinction would appear as a step function with an Area under the Curve (AUC) equal to 1.



This graph details the results of running the algorithm over a singular background set (Z-jets)



This graph details the results of running the algorithm over all known background

Next Steps

Test & Refine BDT

Try other types of algorithms

Run over Real Data

Acknowledgments

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References

[1] S. Bolognesi, Y. Gao, A. V. Gritsan, K. Melnikov, M. Schulze, N. V. Tran, and A. Whitbeck, Phys. Rev. D 86, (2012).