

# Project 1 on Machine Learning team Yoor

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**Abstract**—A classification dataset from the Large Hadron Collider simulations is being studied. First, the data is thoroughly explored using visual aids. After that, several basic Machine Learning methods are applied on preprocessed data. Results are evaluated using cross-validation. Model overview is given for each considered algorithm and the best model is chosen.

## I. INTRODUCTION

The Higgs boson is a famous elementary particle which was first predicted in 1960s and then discovered in 2012 [1]. Its famousness is due to two facts, first being the colossal amount of effort put into construction of the Large Hadron Collider and conducting the ATLAS experiment and the second being the fact that the Higgs boson is considered to be connected to the fact that particles have a mass.

The ATLAS experiment consists of protons colliding at near-relative speed. After collision, the resulting particles sometimes contain the Higgs boson. Itself, it is not detectable by LHC. However, it is possible to detect the particles that it is decaying to.

The data being studied comprises of 250 000 objects (train) each having 30 features:  $\{(x_i, y_i)\}_{i=1}^N$ ,  $x_i \in \mathbb{R}^D$ ,  $N = 250000$ ,  $D = 30$ . Each object represents a collision of a stream of protons. The data was not obtained during the ATLAS experiment, but rather from the simulation [2]. Features represent properties of detected particles. It is required to determine if the particles represent the Higgs boson. The dataset has two classes: signal/noise.

The following paper claims that it is possible to use simple methods, such as Linear and Logistic Regressions to classify the data. In the following sections, the data is thoroughly studied and then the model is chosen based on reasoning and cross-validation.

## II. MODELS AND METHODS

Table I: Feature processing tricks and linear regression

Feature trick added	Test accuracy
Constant feature	0.745
Standardization	0.745
Imputation	0.747
Binarization	0.747
Degree 3 poly	0.785

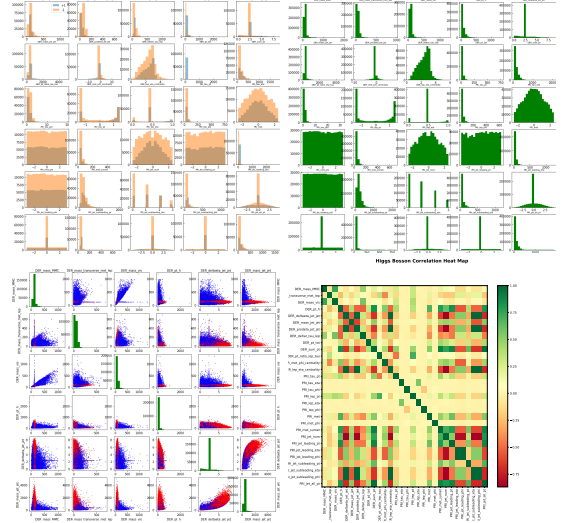


Figure 1: Exploratory data analysis using charts

First, the exploratory data analysis shows that most of the features (except one) are real-valued 1, 1-2. Moreover, it is also can be seen that the test distribution does not differ from the train one 1, 1. Scatter plots 1, 3 show dependencies between features, as well as the correlation plot 1, 4.

To begin with, a simple linear regression model is used on raw data (with a constant feature added), with 5-fold cross-validation to control overfitting. The results of each subsample are averaged to provide train/test accuracy. However, the model gives unsatisfying results on the hold-out dataset. As a means to deal with this issue, feature imputation and feature engineering is used: missing features are imputed with mean values (and ‘missing value’ feature is added), categorical features are binarized. Moreover, it has been discovered that some of the features represent particle’s mass, momentum or energy. Using the fact that squaring these quantities would make linear combinations of them meaningful in terms of physics ( $E^2 = m^2 + p^2$ ), we introduce the polynomial basis. Table I shows the respective effects of these tricks.

Applying ridge regression, it might be seen that it does not overfit in terms of accuracy (but does in terms of MSE 2) on the dataset given even for the 6th degree, meaning that there is no significant difference between the test and the train accuracies. Applying it for different degrees, one

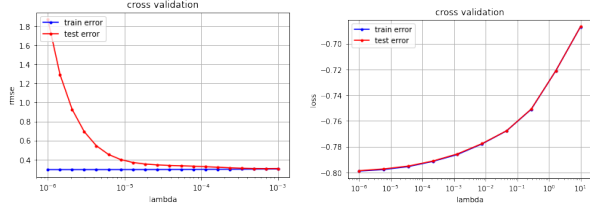


Figure 2: Degree 6 basis, MSE and Accuracy metrics

obtains results shown in the Table II. It can be seen that

### III. MODELS AND METHODS

Table II: Polynomial basis and linear regression,  $\lambda = 0$

Degree	Test accuracy	MSE Test	MSE Train	$\lambda$ best
1	0.7470	0.3378	0.3377	$10^{-6}$
2	0.7737	0.3483	0.3158	$10^{-2}$
3	0.7850	0.3060	0.3040	$10^{-4}$
4	0.7937	0.3030	0.3010	0.0004
5	0.7971	0.3050	0.3010	0.0006

As can be seen in the figures and results, while train MSE is continuously decreasing because of over-fitting, there is no significant change in test error after third degree polynomial basis. Therefore, feature extraction using polynomial basis does not seem to work for higher degrees. Furthermore, the accuracy of the model in Kaggle is not as good as what we expected (below 0.8), so that we decided to switch logistic regression since it uses a loss function tailored for the purpose of classification.

Applying logistic regression to the dataset, we have found out that it is crucial to implement the Newton's method since gradient update rule is taking too much time since final iterations are going with a small step size. Moreover, we discovered that the magnitude  $\gamma$  of the gradient step depends on the size of the dataset. Therefore, we use batched version of stochastic gradient descent for logistic regression as the optimizer to stabilize the size of the dataset the optimizer uses for training.

### IV. RESULTS

We have presented an application of linear, ridge and logistic regression to the dataset. The best model was logistic regression with best accuracy of 0.81.

### V. DISCUSSION

Despite thorough analysis, our project lacks further consideration in the following directions. First, it can be seen that some of the features do not look alike the Gaussian distribution. It might prove beneficial to split such features into two using a certain threshold.

### VI. SUMMARY

We have shown that it is possible to detect the Higgs boson using linear methods and feature augmentation.

### REFERENCES

- [1] [en.wikipedia.org/wiki/Higgs\\_boson](https://en.wikipedia.org/wiki/Higgs_boson)
- [2] Experiment and feature description
- [3] EPFL ML Project 1