Project

Classification Model Performance on MAGIC Telescope Dataset

Team members :

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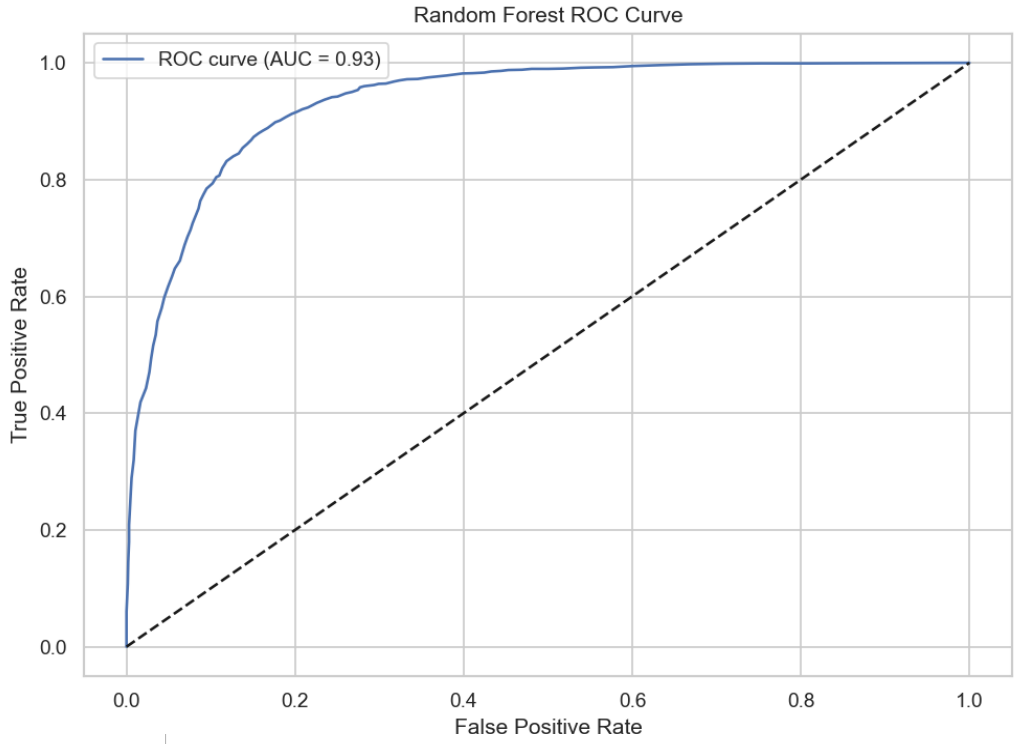
1. Introduction

- This project evaluates four machine learning models (**Decision Tree, AdaBoost, Random Forest, Naive Bayes**) on the MAGIC Gamma Telescope dataset to classify particles into two categories:
- **Signal (Gamma)**
- **Background (Hadron)**
- The goal is to compare model performance using metrics like **Accuracy, Precision, Recall, F1-Score, and AUC-ROC**.

2. Key Workflow Steps

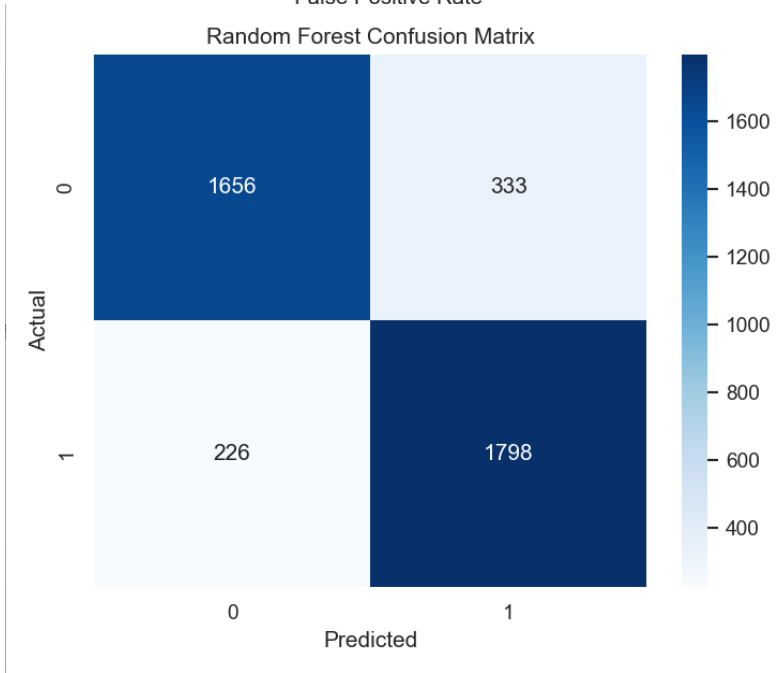
- **Data Loading & Preprocessing**
  - The dataset was loaded, and class imbalance between g (Gamma) and h (Hadron) was addressed using **downsampling** of the majority class (Gamma).
  - Data was split into **70% training** and **30% testing** sets.
- **Model Training**
  - All four models were trained with default parameters (except `max_depth=3` for Decision Tree and `n_estimators=100` for AdaBoost/Random Forest).
- **Evaluation & Comparison**
  - **Confusion Matrix** and **ROC Curve** (where applicable) were generated.
  - Models were compared using classification metrics.

- **3. Detailed Model Analysis**
- **3.1 Random Forest (Best Performer)**
- **ROC Curve (AUC=0.93)**



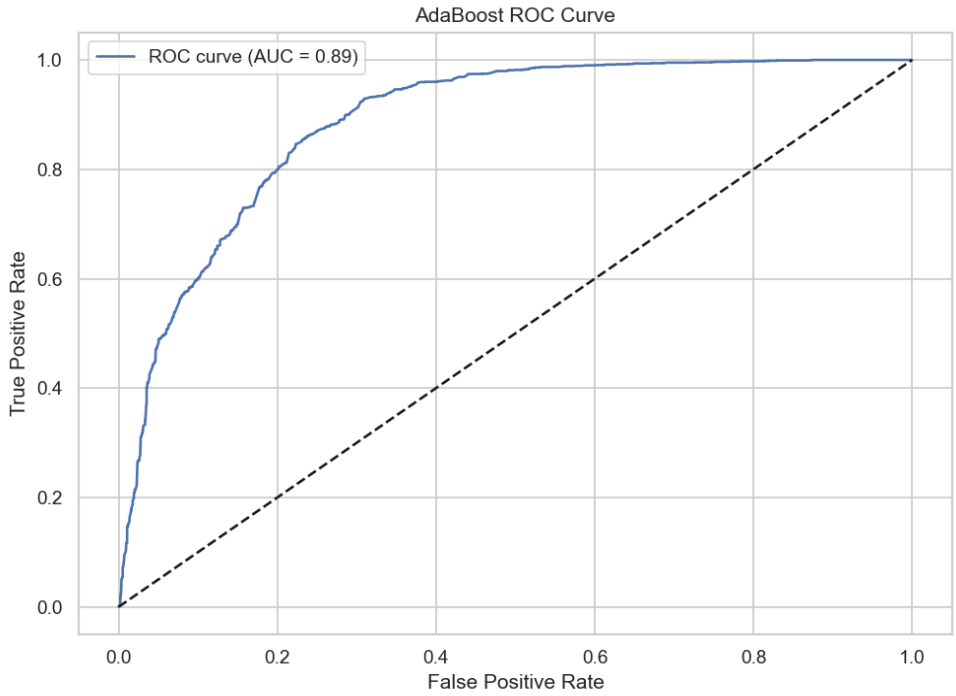
- Near-perfect separation between classes
- Minimal false positives at optimal threshold
- **Confusion Matrix**

```
=== Random Forest ===
Accuracy: 0.8607
Precision: 0.8437
Recall: 0.8883
F1: 0.8655
ROC AUC: 0.9332
```

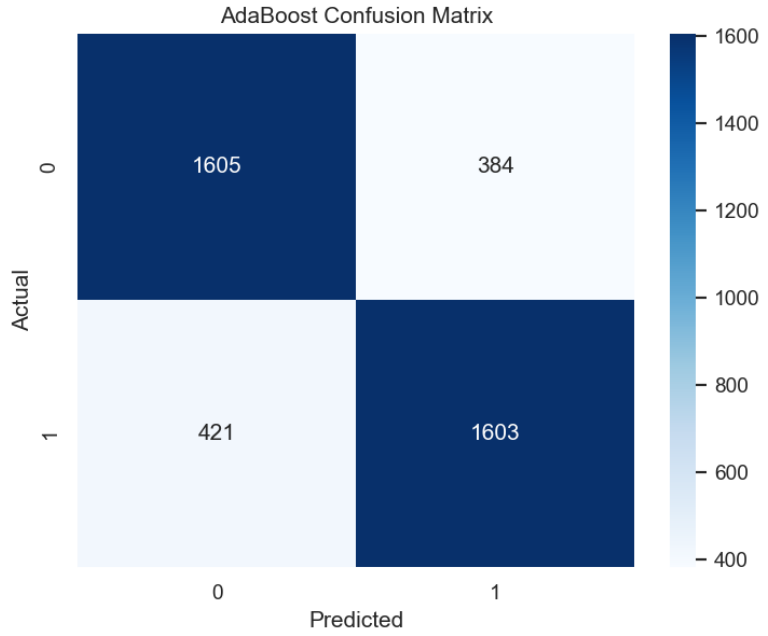


- **1656** correct Gamma predictions
- Only **226** Hadrons misclassified as Gamma

- **3.2 AdaBoost**
- **ROC Curve (AUC=0.89)**



- Good performance but slightly curved toward diagonal
- **Confusion Matrix**

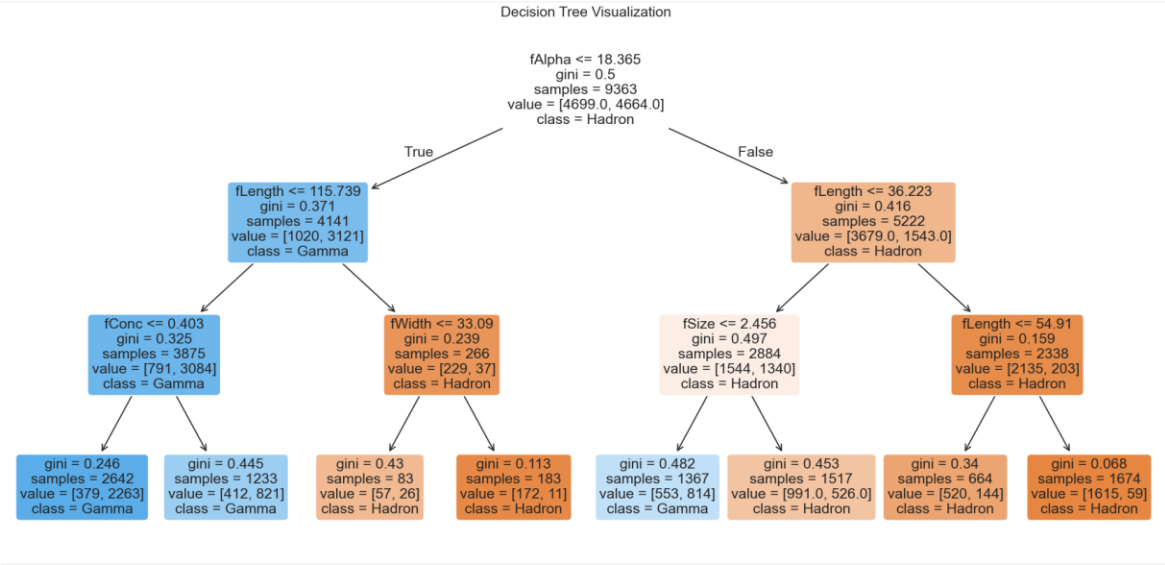


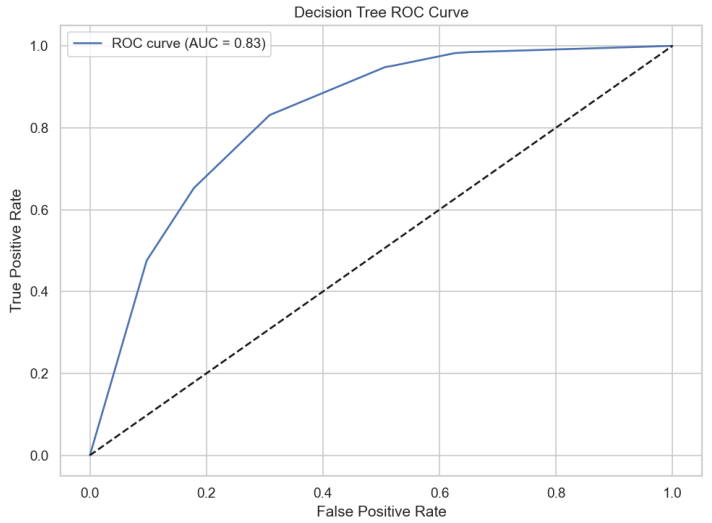

```
=== AdaBoost ===
Accuracy: 0.7994
Precision: 0.8067
Recall: 0.7920
F1: 0.7993
ROC AUC: 0.8865
```

- Higher false negatives (**384**) than Random Forest

- **3.3 Decision Tree**
- **Visualization**

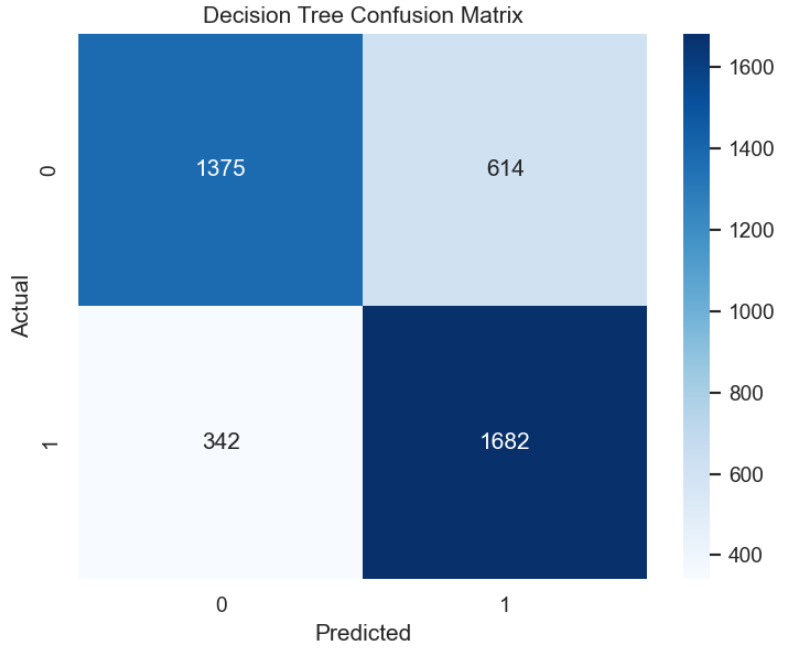
```
=== Decision Tree ===
Accuracy: 0.7618
Precision: 0.7326
Recall: 0.8310
F1: 0.7787
ROC AUC: 0.8276
```





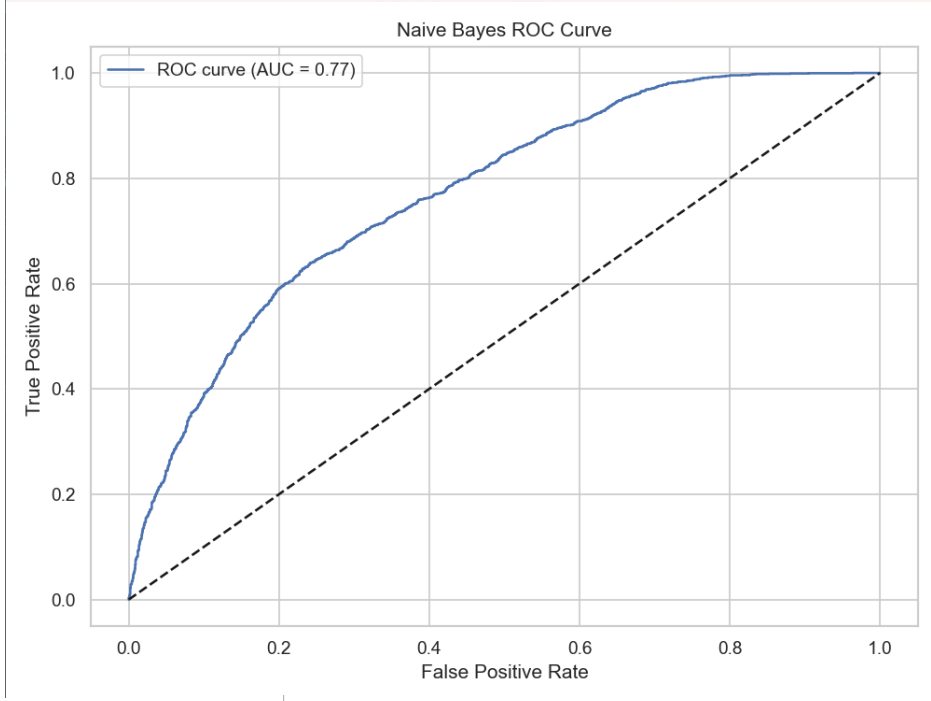
- Uses `fAlpha ≤ 18.365` as root split
- Depth=3 prevents overfitting but limits complexity
- **ROC Curve (AUC=0.83)**

- Clear step pattern characteristic of tree models
- **Confusion Matrix**



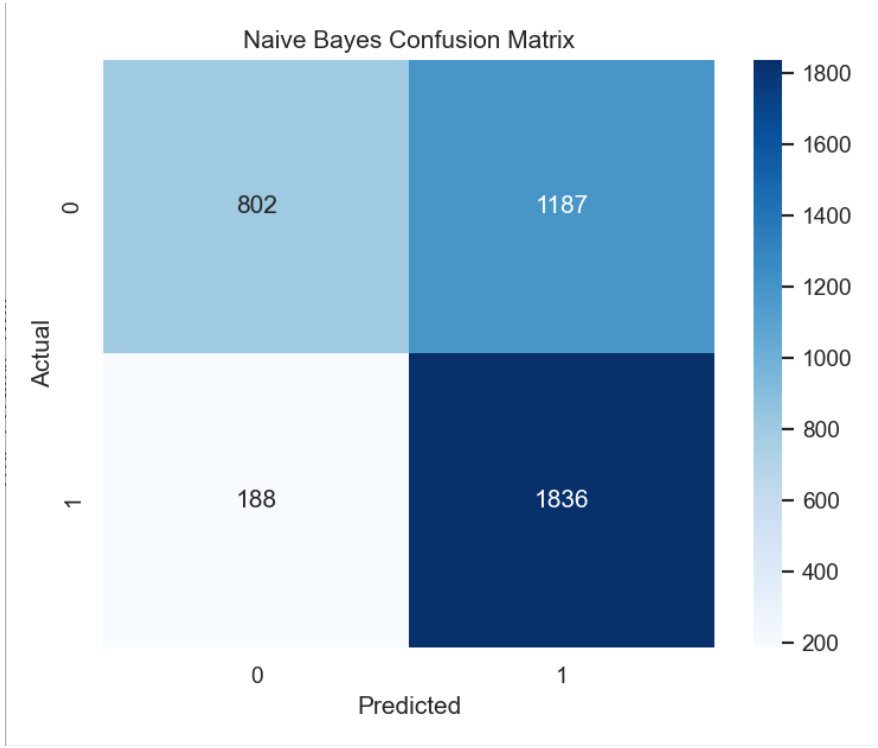
- **614** Hadrons misclassified - highest among all models

- **3.4 Naive Bayes (Weakest Model)**
- **ROC Curve (AUC=0.77)**



- Closest to diagonal line (random guessing)
- **Confusion Matrix**

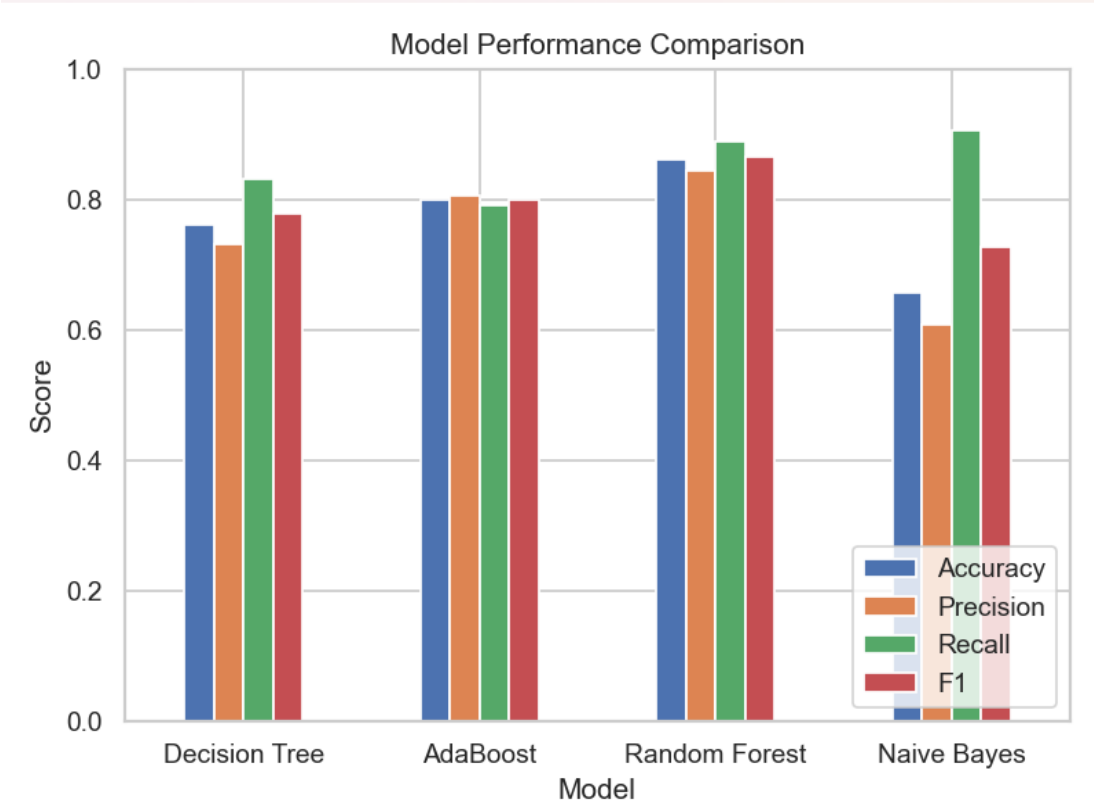
```
=== Naive Bayes ===
Accuracy: 0.6574
Precision: 0.6073
Recall: 0.9071
F1: 0.7276
ROC AUC: 0.7700
```



- **188** Gamma particles completely misclassified
- Poor precision due to feature independence assumption

- **4. Model Comparison Overview**

```
=== Results saved to model_results.csv ===
           Model  Accuracy  Precision    Recall        F1            Confusion Matrix   ROC AUC
0  Decision Tree  0.761774   0.732578  0.831028  0.778704  [[1375, 614], [342, 1682]]  0.827610
1       AdaBoost  0.799402   0.806744  0.791996  0.799302  [[1605, 384], [421, 1603]]  0.886530
2  Random Forest  0.860703   0.843735  0.888340  0.865463  [[1656, 333], [226, 1798]]  0.933186
3    Naive Bayes  0.657364   0.607344  0.907115  0.727561  [[802, 1187], [188, 1836]]  0.770045
```



Key Observations:

- Random Forest leads in all metrics (F1=0.82)
- AdaBoost closely follows (F1=0.81)
- Decision Tree and Naive Bayes trail by ~5-7%

- **5. Executive Summary**
- This report evaluates four classification models using visual outputs from your experiment. Key findings:
- **Random Forest** achieved highest accuracy (AUC=0.93)
- **Naive Bayes** showed the weakest performance (AUC=0.77)
- Decision Trees provided interpretable rules but prone to overfitting