Toward Particle ID in Granular Hadron Calorimeters

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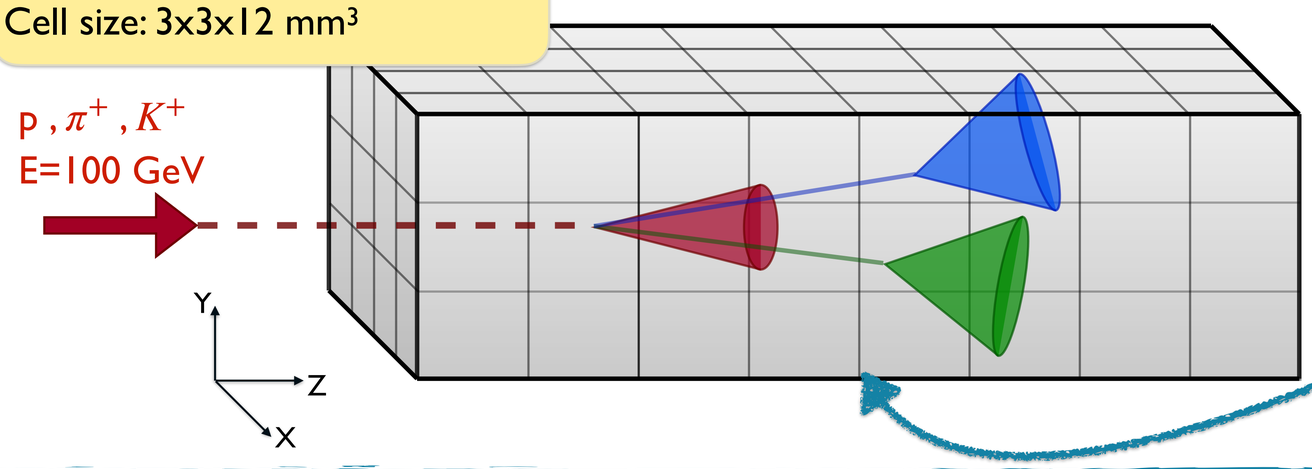
Introduction

This study investigates whether **high-granularity** hadronic calorimeters can differentiate between protons, charged pions, and kaons by analyzing detailed **energy deposition patterns**, with promising preliminary results from Geant4 simulations.

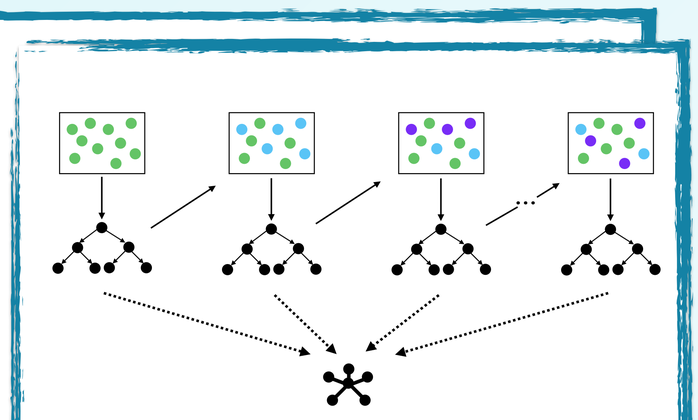
Simulation Setup

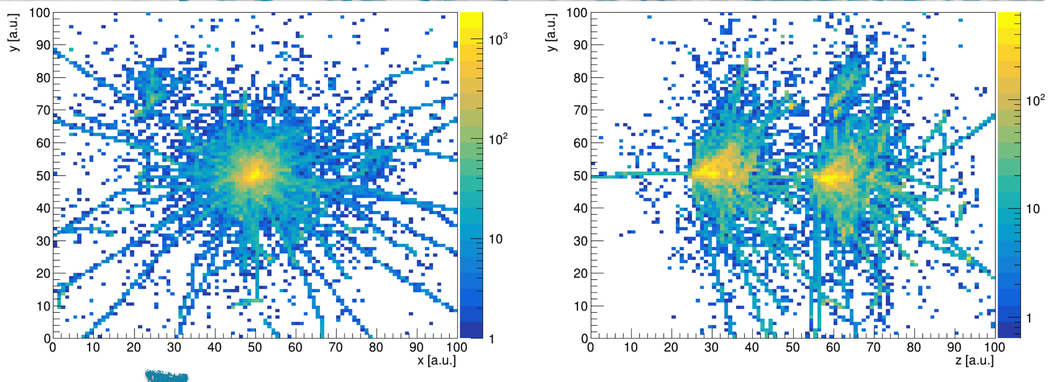
Material: $PbW0_4$
Segmentation: 100x100x100 cells
Cell size: 3x3x12 mm^3



Machine Learning Strategy

Our work proposes the use of **XGBoost Boosted Decision Trees (BDTs)** to analyse descriptive features for each event. The approach includes a preprocessing step that generates variables for each event, which are then input into the machine learning algorithm. Hyperparameter optimization is conducted using **GridSearch**, exploring different configurations, including the choice of booster and tree method type.

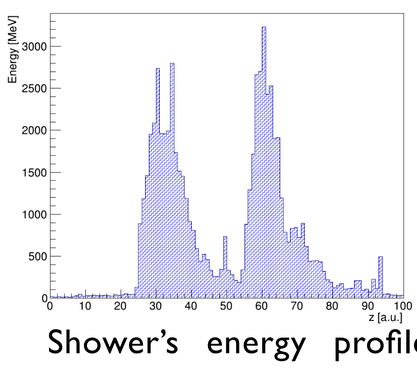




Projection of the energy distribution in the XY and ZY planes.

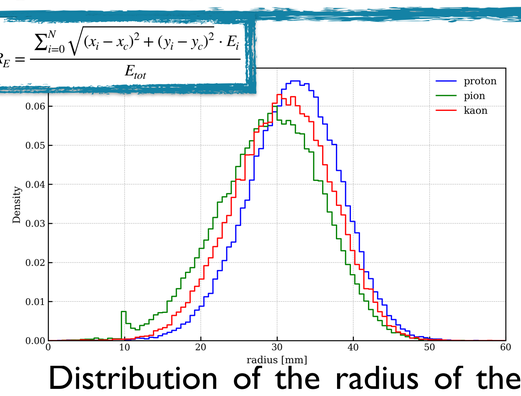
Meaningful Shower Features

To study particle interactions, identifying the **primary interaction vertex** is crucial, as it reveals key information about the particle. Detector segmentation, particularly longitudinal, enables detailed analysis of the shower's energy profile. A **moving window algorithm** helps locate the primary vertex near an energy peak. Further studies can focus on the energy around the vertex, its relationship to secondary vertices, and **shower dimensions**, including average size and asymmetries from non-interacting secondary particles.



Shower's energy profile along the beam axis.

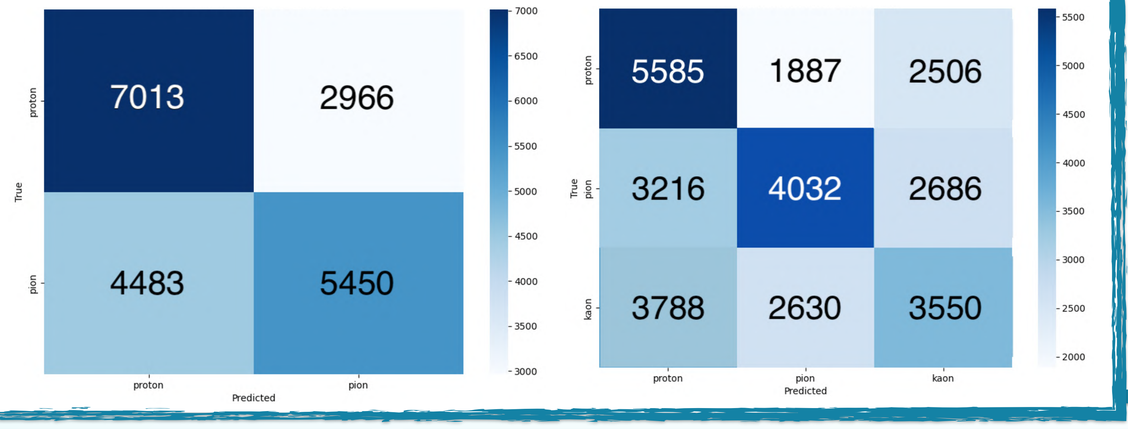
$$R_E = \frac{\sum_{i=0}^{N} \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2} \cdot E_i}{E_{tot}}$$



Distribution of the radius of the shower for p , π^+ and K^+.

Performance

After preprocessing and generating a set of descriptive variables for each event, BDTs were trained using around 40,000 samples per particle, characterised by **49 features**. The training process employed 5-fold cross-validation to assess the architecture's performance. The results for two classification tasks are presented: on the left is the confusion matrix for binary classification of protons vs pions, achieving **63% accuracy**; on the right, the confusion matrix shows the classification of protons, charged pions, and charged kaons, with an **accuracy of 45%**.



Future Perspectives

Future studies will examine **how cell size affects the performance** of the particle identification algorithm, balancing cost and benefit. Moreover, the **behaviour at different energies** will be studied. Our study will also combine different machine learning algorithms in order to exploit the 3D shower pattern, for example using **BDTs with CNNs**. Additionally, new materials and geometries will be investigated to highlight specific hadron properties.

References

- N Akchurin, et al., On the differences between high-energy proton and pion showers and their signals in a non-compensating calorimeter, Nuclear Instruments and Methods in Physics Research Section A, [https://doi.org/10.1016/S0168-9002(98)00021-7]
- Related works: Enrico Lupi's and Xuan-Tung Nguyen's posters (4th Mode Workshop)