Toward Particle ID in Granular Hadron Calorimeters

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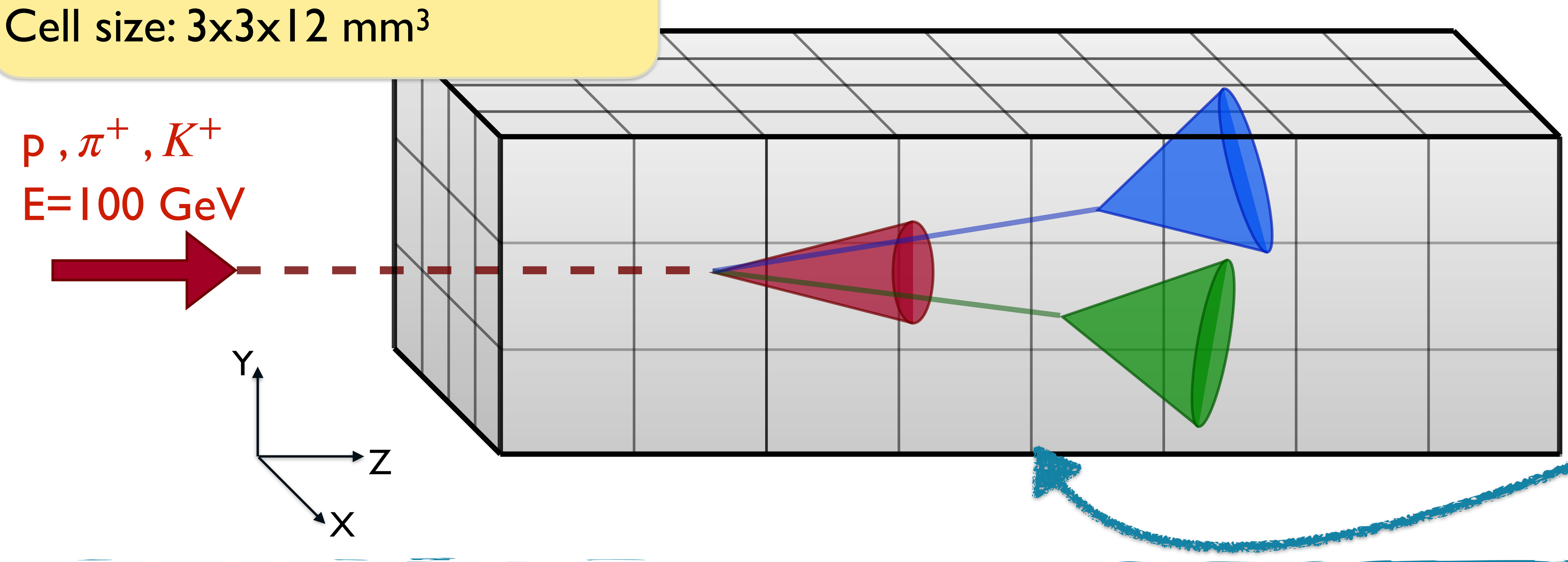
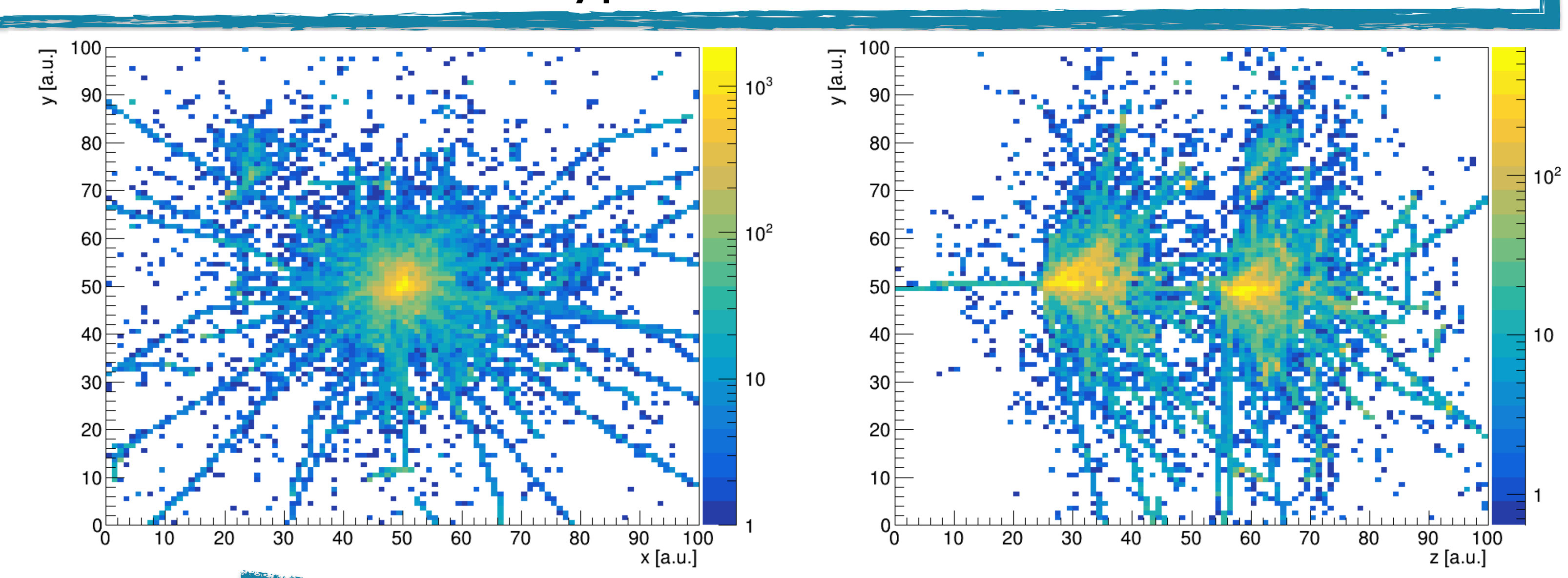
Introduction

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: $PbWO_4$
Segmentation: 100x100x100 cells
Cell size: 3x3x12 mm^3

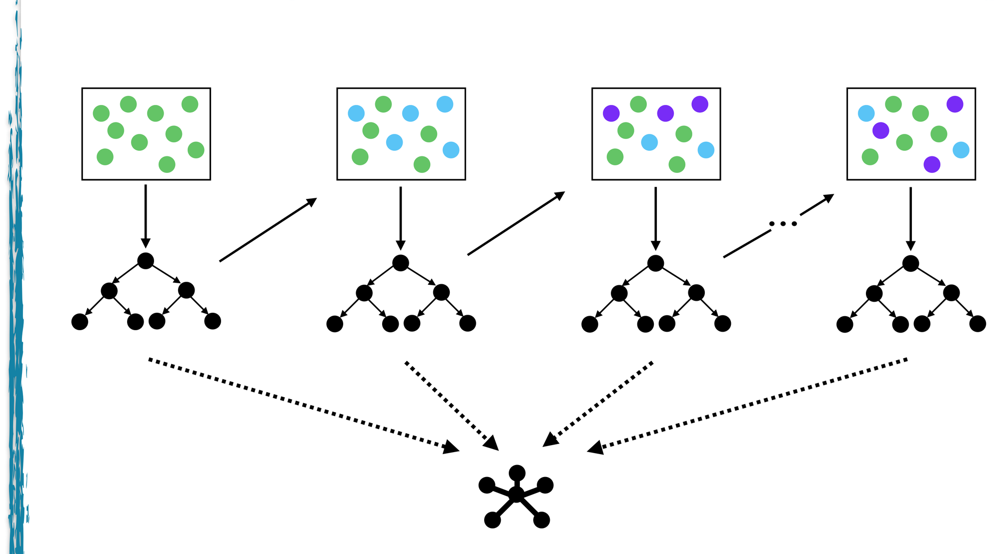




Projection of the energy distribution in the XY and ZY planes.

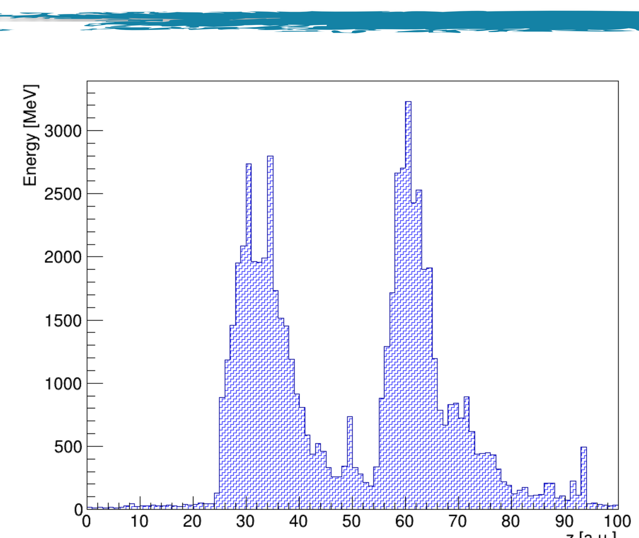
Machine Learning Strategy

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.

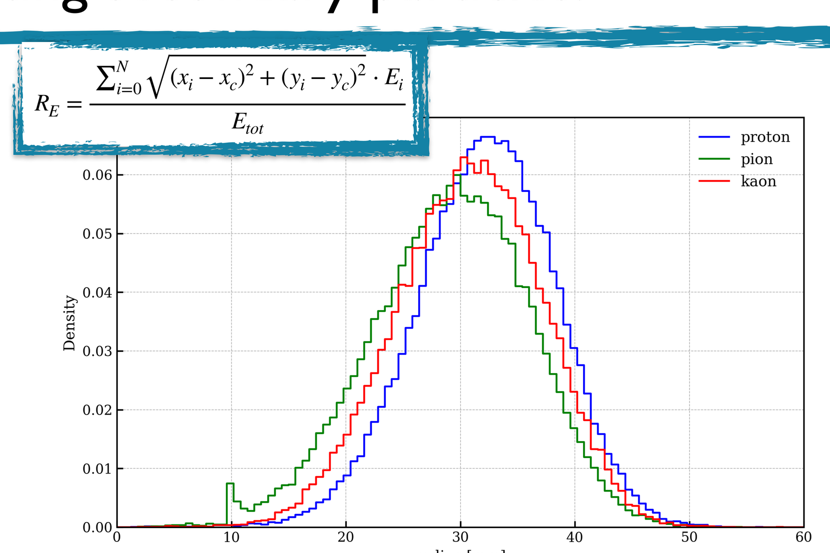


Meaningful Shower Features

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.



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%**.

True \ Predicted	proton	pion
proton	7013	2966
pion	4483	5450

True \ Predicted	proton	pion	kaon
proton	5585	1887	2506
pion	3216	4032	2686
kaon	3788	2630	3550

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)