Towards the Increase in Granularity for the Main Hadronic ATLAS Calorimeter: Exploiting Deep Learning Methods

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Introduction

Tile Calorimeter

- Principal hadronic calorimeter in ATLAS experiment.
- Consist of a sampling plastic scintillator/iron detector.
- It is divided into three cylindrical sections, referred to as the barrel and extended barrel.
- Has fixed segmentation often reported in terms of pseudo-rapidity regions.

3 Radial Layers

A (Δη = 0.1)
BC (Δη = 0.1)
D (Δη = 0.2)

Tile Long Barrel (LB)  
|η| < 1.0

Tile Extended Barrels (EB)  
0.8 < |η| < 1.7
Objective

Granularity Increase

- Technical possibility to increase the spatial resolution of the Tile Calorimeter.
- Dividing the BC layer into two separate sublayers B and C will provide more information on the longitudinal shower profile.
- Splitting the A layer along the direction of pseudo-rapidity should help gain more information on the transverse profile of a particle shower.
Motivation

Jets in the Upgrade Regime

- Higgs, W and Z decay to narrow jets with radius smaller than 0.4 in the $\eta \times \phi$ frame.
- Quarks produced with a boost in its momentum.
- The products of its decay are collimated into a structure which contains 2 or 3 sub-jets.
- TileCal cell size becomes comparable with typical separation between two quarks from $W$ decay for transverse momentum higher than 600 GeV.

Improvements of TileCal
- Angular position of jets and single hadrons.
- Reconstruction of physical objects and jet properties.
- Precise lifetime measurements of long lived particles.
New Granularity

Calibration System

- Each part of the calorimeter readout is calibrated by a particular system.
- The calibration of optic components of TileCal and PMTs is performed using a moveable Cesium radioactive source.
- Our dataset will consist of data collected during the calibration of the calorimeter tiles.

- The Cesium system is used for cell response equalization. (PMT gain and optics).
New Granularity

Multi-Anode PMT

- Increase detector granularity by reading individual signals from each fiber present in the bundle using a Multi-Anode Photomultiplier Tube (MA-PMT).

- Associate the image patterns formed in the MA-PMT grid of pixels into specific sub-regions inside the cells of the calorimeter.

- Increase granularity, in pseudo-rapidity, without change the mechanical structure of the TileCal by developing an algorithm to associate an image pattern to a cell subregion.

Multi-Anode PMT
- Hammamatsu 64-MA-PMT
- Pixel Grid: 8 x 8
- Pixel Size: 2.35mm x 2.35mm

Fiber Bundle
- Fiber Diameter: 1.00 mm
The Cesium scan acts like a cell x-ray.
The A12 cell has 9 tiles in each of its 3 tubes.
The passage of the Cesium source through one of the tubes produces 9 peaks in its signal profile (green line).
New Granularity

Multi-Anode PMT

- Readout electronics acquire integrated currents from one channel connected to the single-anode PMT and 48 channels to the MA-PMT.
- Both PMTs, single and multi-anode, are connected to the same calorimeter cell from different sides.

This allows us to compare the time-dependent response curves of the single-anode PMT with the images produced on the MA-PMT grid of pixels.
We separate the image patterns from subcells B and C using the information of the detector geometry alongside with time response from the cesium scan.

- B cell has tubes 4, 5 and 6.
- C cell has tubes 7, 8 and 9.
Longitudinal Granularity Increase

Separate B and C Cells

- We separate the image patterns from subcells B and C using the information of the detector geometry alongside with time response from the cesium scan.
  - B cell has tubes 4, 5 and 6.
  - C cell has tubes 7, 8 and 9.

|        | B cell | C Cell | Total |
|--------|--------|--------|-------|
| Entries| 1647   | 1951   | 3598  |

Low statistics!
Difficult to use these samples in most supervised classification model.
Generative Adversarial Networks

Increase Statistics

- Use a generative model in order to increase the number of samples in the dataset.
- Generative Adversarial Networks (GAN) is a framework based in game theory.
- Two models (Deep Neural Networks) compete with each other.
- **Generator Model**: creates synthetic images that look like the real ones.
- **Discriminator Model**: Tells whether an image produced by the generator model is real or fake.

\[
J(D) = -\frac{1}{2} \mathbb{E}_{x \sim p_{data}} \log D(x) - \frac{1}{2} \mathbb{E}_z \log(1 - D(G(z)))
\]

\[
J(G) = -J(D)
\]
• We used a DCGAN for producing synthetic images of each subcell.
• After generate the synthetic images we feed them into a Convolutional Neural Network in order to train our classifier.
• In the end of the whole process we use the real images evaluate the classification model.
\section*{BC Cell Results}

\subsection*{B Cell Images}

\begin{itemize}
    \item Real Data
    \item Relative Difference
    \item Synthetic Data
\end{itemize}

\textbf{Biggest difference around 11\%}


### BC Cell Results

**C Cell Images**

The images show the results of ATLAS Preliminary Tile Calorimeter C Subcell Real Images compared to synthetic images. The relative difference is noted, with the biggest difference around 14%.
Relative Difference Between Subcells

Real Data

Synthetic Data
## BC Cell Results

### Binary Classification Model

|                 | B cell | C Cell | Total |
|-----------------|--------|--------|-------|
| **Real Data**   | 1647   | 1951   | 3598  |
| **Synthetic Data** | 100k   | 100k   | 200k  |

|                | B cell Prediction | C Cell Prediction |
|----------------|-------------------|-------------------|
| **B cell**     | 1647              | 0                 |
| **C cell**     | 50 (~3%)          | 1901              |

Training Accuracy = 0.9886 ± 0.0027

Test Accuracy = 0.9861
Conclusions

- It is possible to increase the statistics of the dataset using a generative model.
- With this, we can look at the increase of granularity as a supervised learning problem.
- The combination of these two techniques made the binary classification possible.
- The first results showed a longitudinal granularity increase in cell BC1 by a factor of two, with 98% of accuracy in the test set.
- We also tested the A12 cell for transverse granularity (left and right subcells of A12) and achieved an accuracy of 96% in the test set.
- This is encouraging for a possible solution of such an important step in calorimeter upgrade in the ATLAS experiment.

Future Work

- Reconstruct the energy of the single-anode PMT using pixels of the MA-PMT.
- Test different GAN architectures.
Thank you!