Advanced ML Techniques and Hybrid Dual-Readout Systems for Electroweak Jet Identification and Particle Flow Enhancement in Future Collider Detectors

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Short Review

This project explores advanced calorimetry techniques to enhance energy measurement precision in particle showers. A hybrid dual-readout system measures Cherenkov and scintillation light to separate electromagnetic and hadronic components. Segmented crystal calorimeters capture energy at different depths to determine photon direction. Simulations using GEANT4 and machine learning improve the determination of centroids position resolution in the SCEPCal calorimeter.

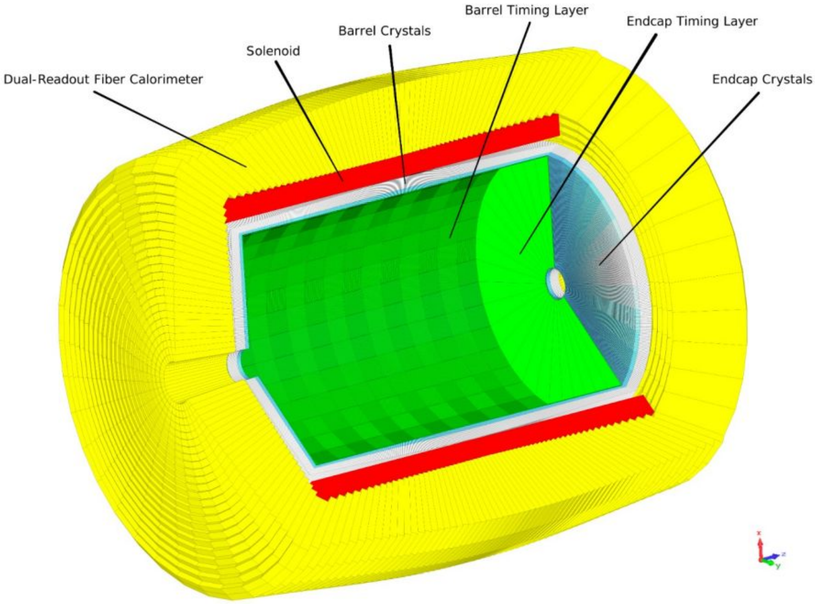

Figure 1: Dual readout calorimeter structure [1:p.17]

Machine learning architecture and complex choice

The CNNs are designed to capture the spatial data, but without corresponding mapping, there are two more options for predicting z-positions of centroids in electromagnetic showers - RNNs and FNNs. Unlike FNNs, which treat inputs independently, RNNs capture sequential energy patterns across calorimeter layers, resulting in more accurate predictions. This makes them good for handling complex, non-linear data from SCEPCal.

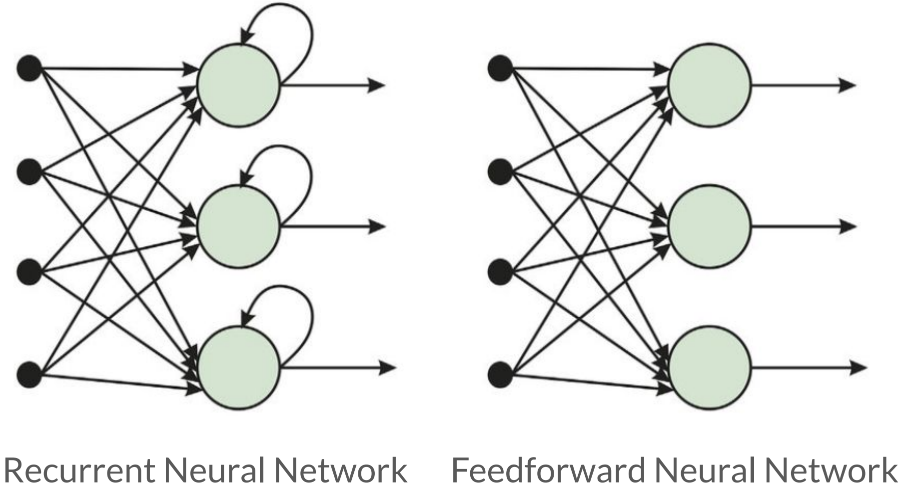

Figure 2: The diagram for comparison of RNN and FNN architectures. [2]

Results: Barrel and Endcap crystal layers

Initial results are promising with the Feedforward Neural Network (FNN), achieving 0.02 mm resolution for 5 mm crystals. While this suggests FNN might be sufficient, it may also show signs of bias and overfitting due to its algorithm of processing. The Recurrent Neural Network (RNN), despite initial deviations, better models temporal dependencies and energy propagation, offering a potentially more accurate and robust solution in the long term.

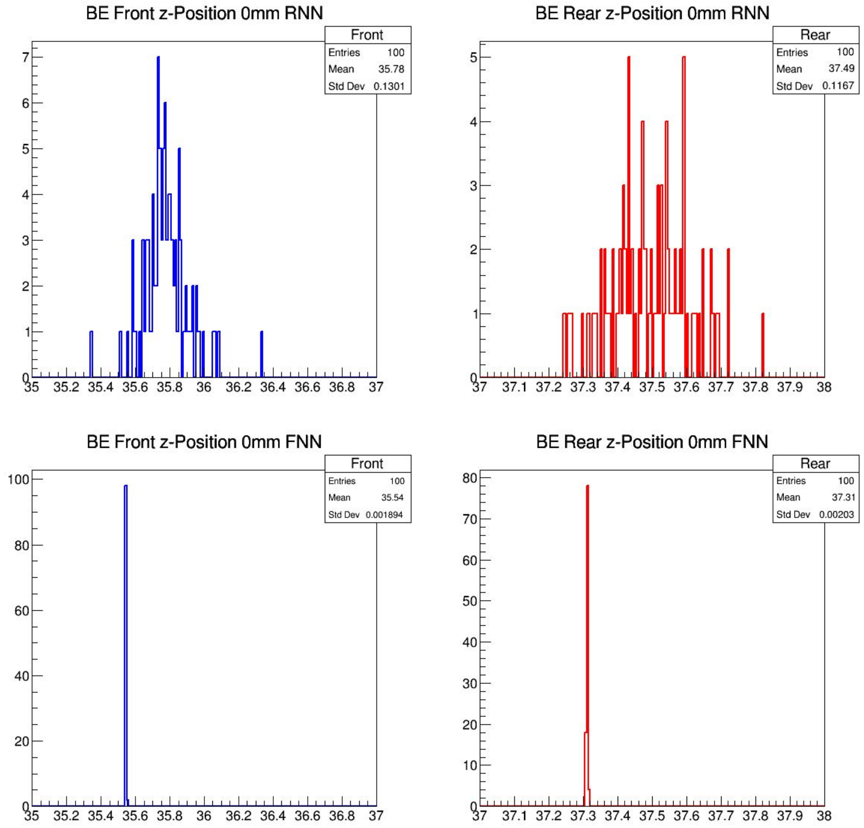

Figure 3: The z-positions of centroids in the Barrel and Endcap crystal layers according to the FNN and RNN models.

Results: Timing layers

The timing layer results demonstrate the RNN model's superior consistency compared to the FNN model. While the FNN initially achieved around 0.8 mm resolution for 5 mm crystals, it struggles with accurately capturing complex energy propagation due to its treatment of features independently. However, it does not correspond to the analytical approach. The RNN excels in modeling temporal dependencies and sequential interactions, resulting in more reliable predictions. As the SCEPCal data simulator develops, treating all timing layers simultaneously will further improve model accuracy.

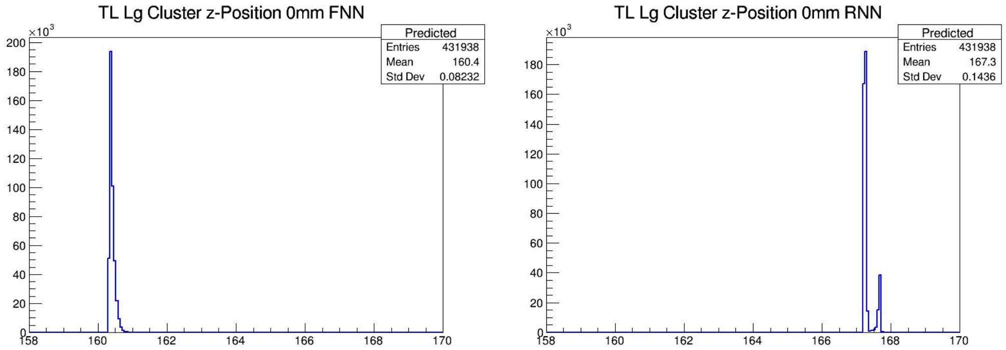

Figure 4: The z-positions of centroids in the Longitudinal Gain of the Timing layer according to FNN and RNN models. The true value is 167.32 +- 0.11 cm

End of the Beginning: Next phase of the development

The exploration with RNNs has revealed both challenges and promising directions. To enhance impact point precision, the design of the detector has to be implemented to the code to improve and simplify the neural network's learning process. This shift aims for sub-1mm precision and 20ps timing accuracy, marking the start of an exciting new phase with refined goals and future innovations in particle detection and machine learning.

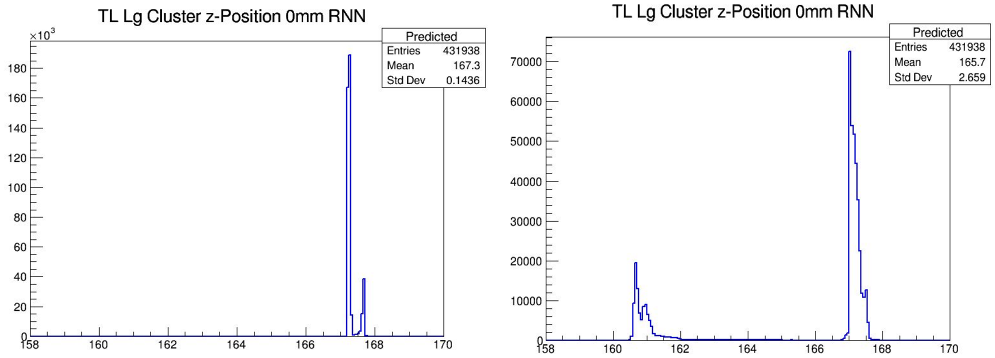

Figure 5: The z-positions of centroids according to RNN. On the left hand side, the training and validation data were the same. On the right hand side, they are different.

References

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