Deep Learning for Pion Identification and Energy Calibration with the ATLAS Detector

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2020-018/

Dilia María Portillo Quintero [1], Alison Lister [2], Max Swiatlowski [1], Wojtek Fedorko [1], Russell Bate [1,2]

[1]TRIUMF, [2]UBC

Separating charged and neutral pions as well as calibrating the pion energy response is a core component of reconstruction in the ATLAS calorimeter.

Deep learning techniques can be used for pion classification and energy calibration tasks by representing the signal in the ATLAS calorimeter layers as pixelated images.

Hadronic Calibration in ATLAS

Hadronic showers are mostly composed of pions

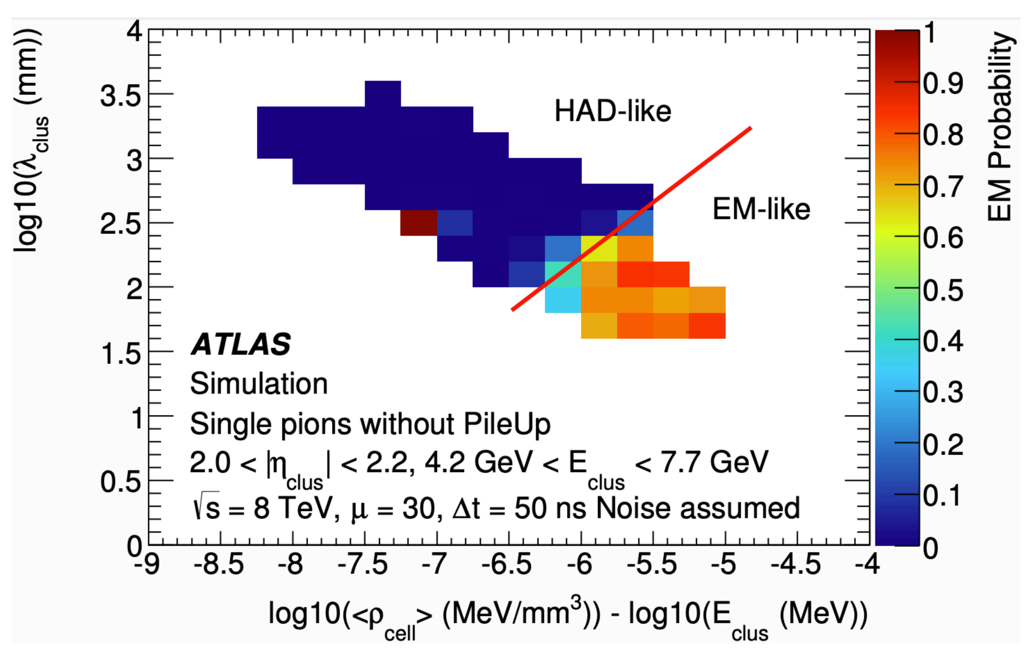
- π^0: Captured by the electromagnetic calorimeter
- $\pi^\pm$: Require the dense material in the hadronic calorimeter to be stopped

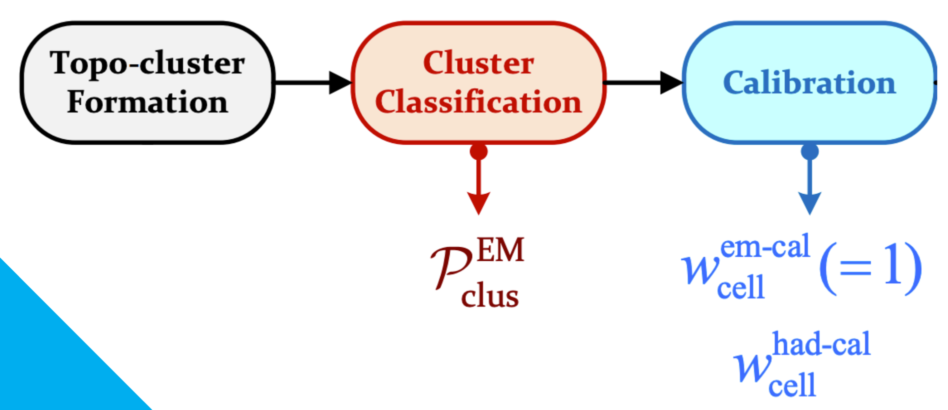
Different detector response and measurement for π^0 vs. $\pi^\pm$ showers

Topo-clusters: Baseline hadronic reconstruction in ATLAS, uses 3-D clusters of noise-suppressed calorimeter cells.

Topo-cluster calibration:

1) Clusters are classified as electromagnetic (EM) or hadronic (HAD) calculating the EM Probability $\mathcal{P}^{EM}_{clus}$
2) Cluster energy is calibrated by weighting the cells energy

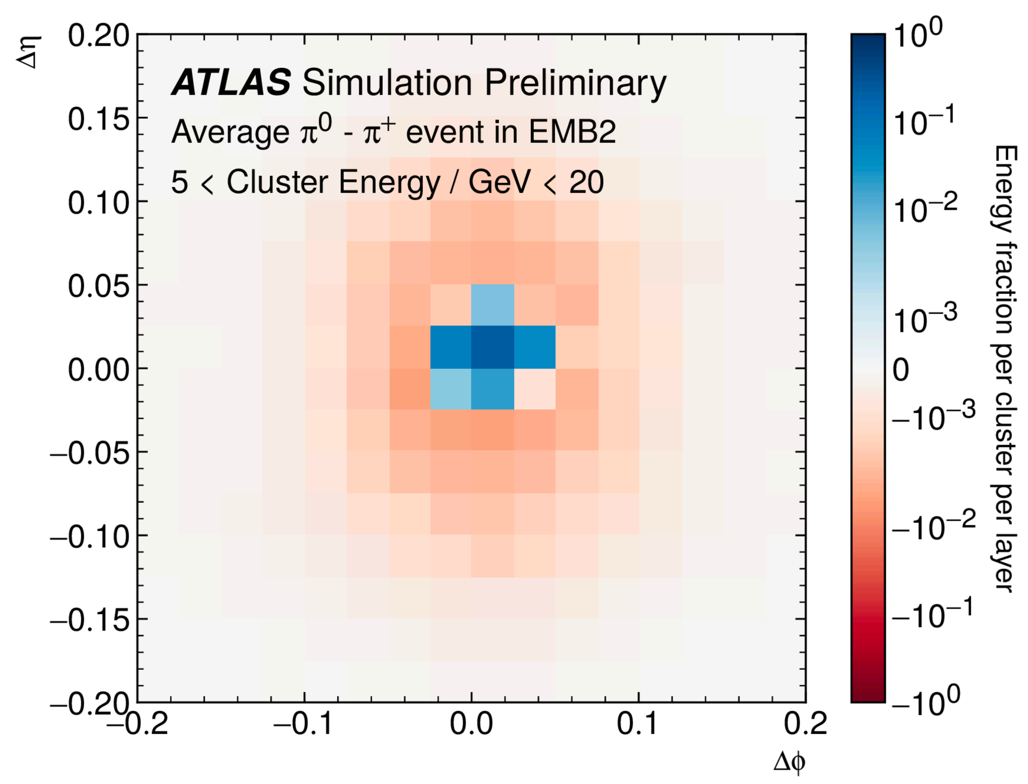




Topo-Cluster Images and Neural Networks

Represent each cluster as an image per calorimeter layer using the appropriate cell granularity in ATLAS.

Using single-particle Monte Carlo simulations.



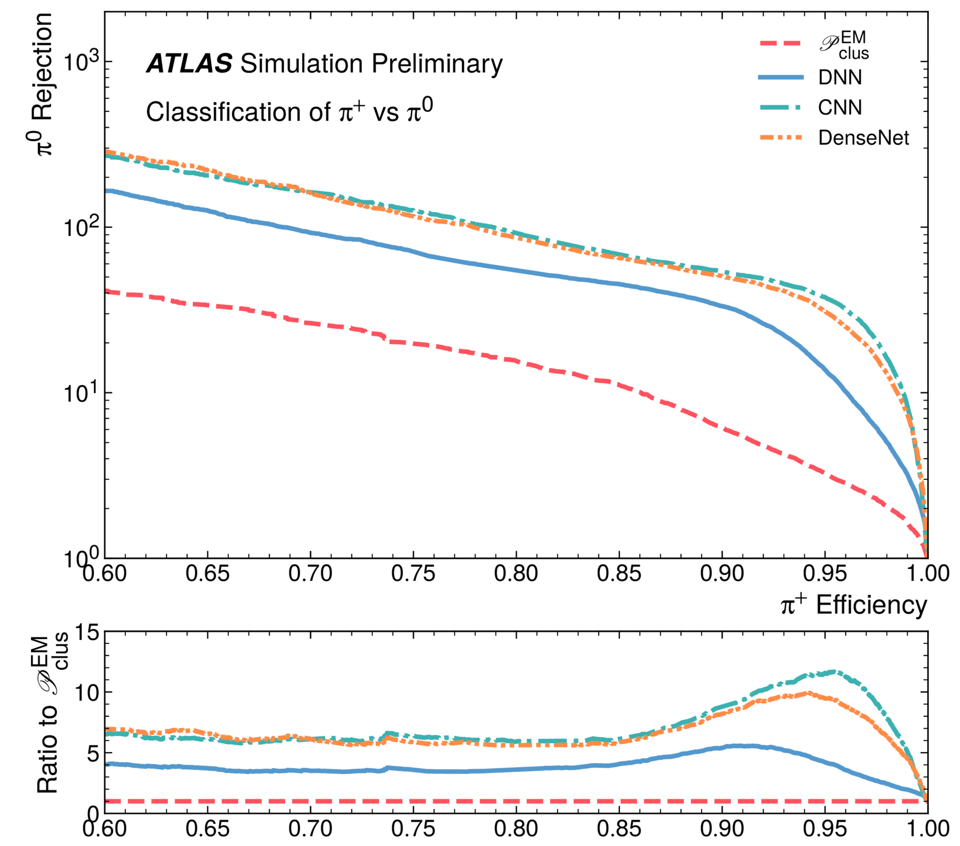
Architectures

- CNN (Convolutional Neural Networks): Use ‘convolutions’ to extract useful features from different portions of the image
- DNN (Dense Neural Networks): Large, deep networks with cells as direct inputs
- DenseNet: Industry-designed, sophisticated CNN with sophisticated information propagation

Pion Classification

The ML techniques all do an excellent job of distinguishing π^0 from $\pi^\pm$ showers

DenseNet and CNN architectures have ≈ 8 times better background rejection compared to $\mathcal{P}^{EM}_{clus}$



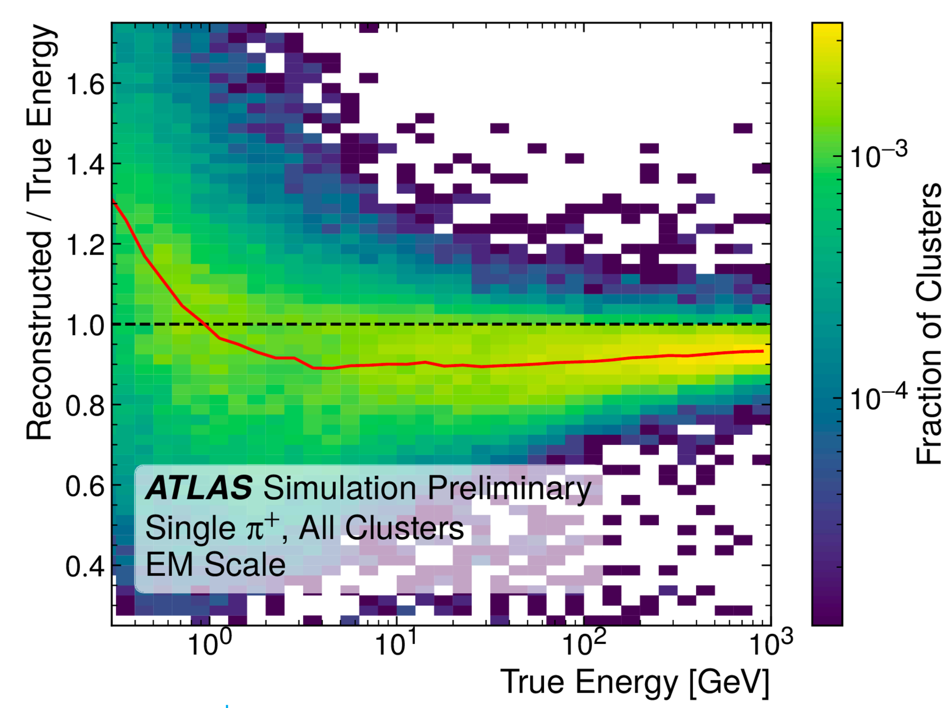
π^+ vs. π^0 classification

Pion Energy Regression

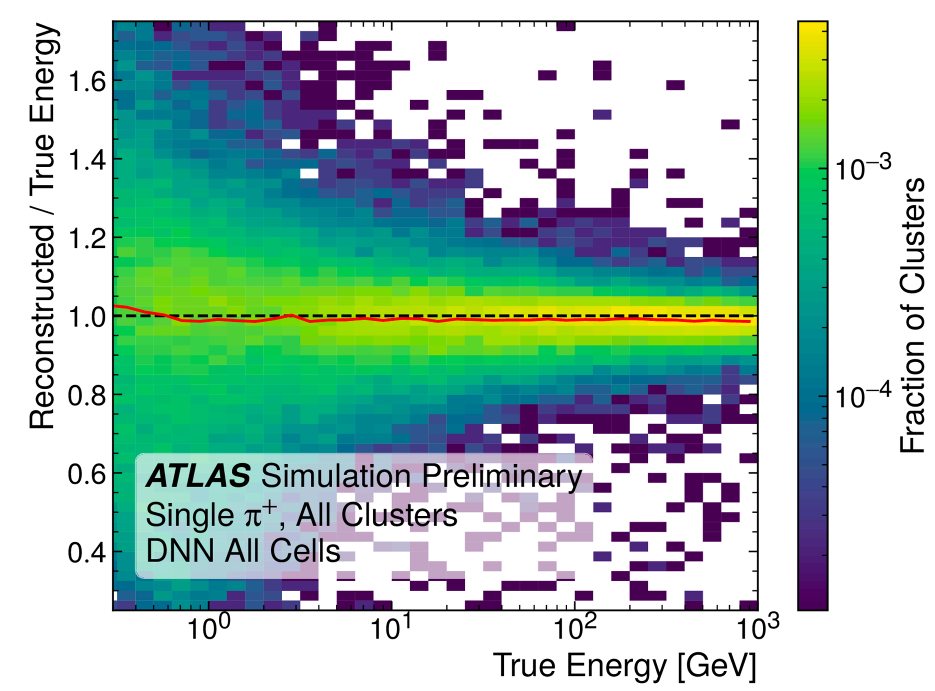
Goal: Predict the true energy deposited in the cluster

Energy Response:

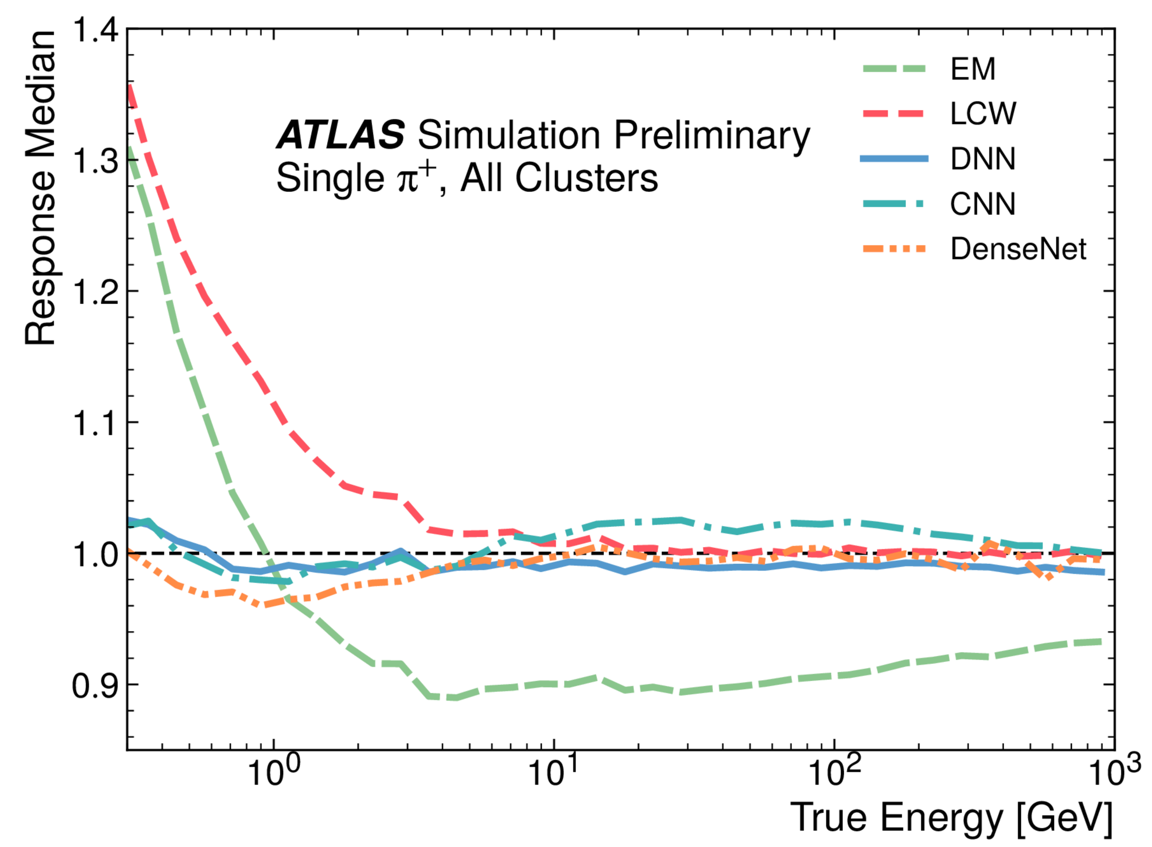
$Response = E^{Measured}/E^{true}$ ~ 1 after calibration



π^+ response before calibration



π^+ response after calibration with DNN



π^+ Mean response after calibration schemes

CONCLUSION

Deep learning approaches outperform the classification applied in the baseline local hadronic calibration and are able to improve the energy resolution for a wide range in particle momenta, especially for low energy pions. This work demonstrates the potential of deep-learning-based low-level hadronic calibrations to significantly improve the quality of particle reconstruction in the ATLAS calorimeter.

Discovery, accelerated