Improving ATLAS Hadronic Object Performance with ML/AI Algorithms

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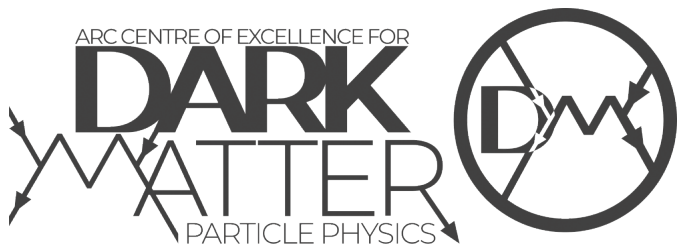
on behalf of the ATLAS Collaboration



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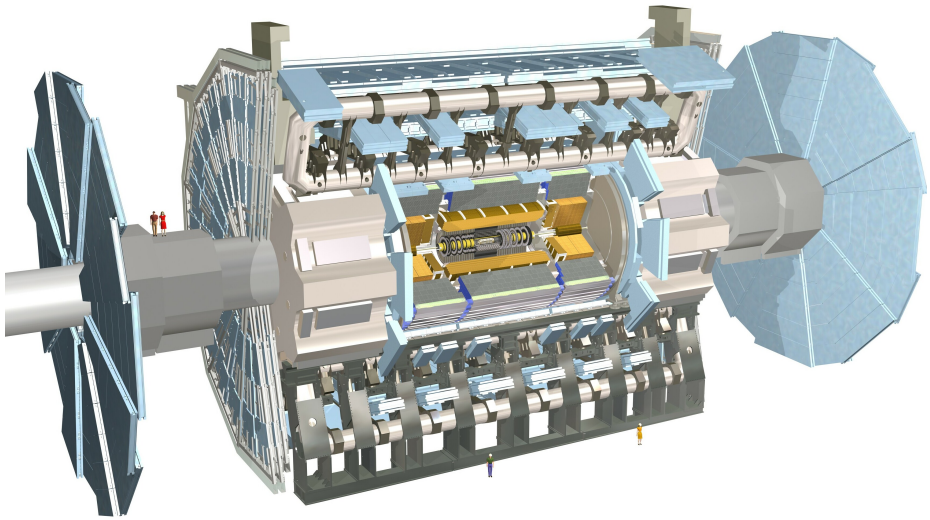
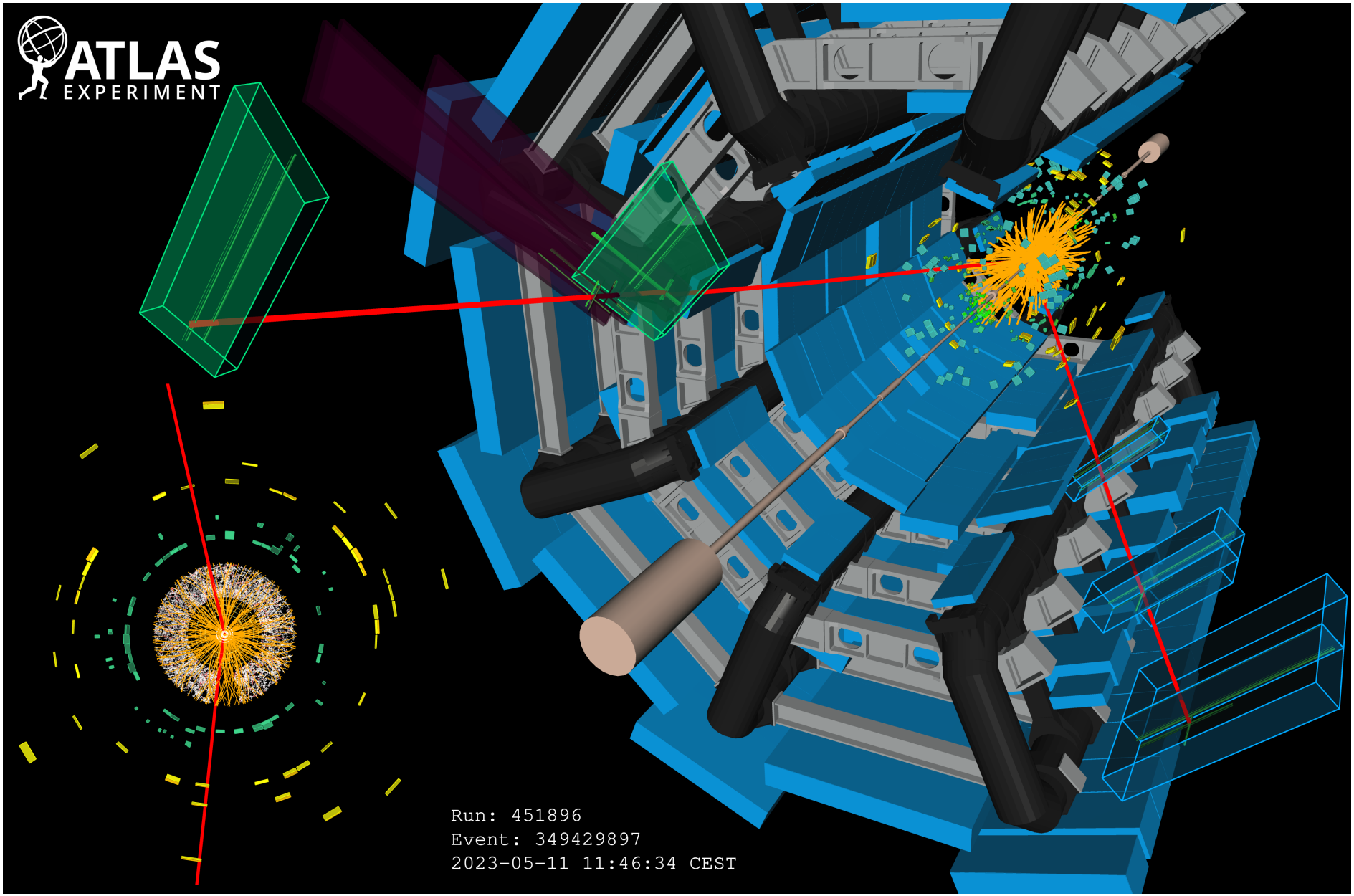
The LHC and the ATLAS Experiment

The Large Hadron Collider delivers proton-proton collisions to several experiments situated around its ring

Detectors record the path of produced particles and their deposited energy



Event Reconstruction



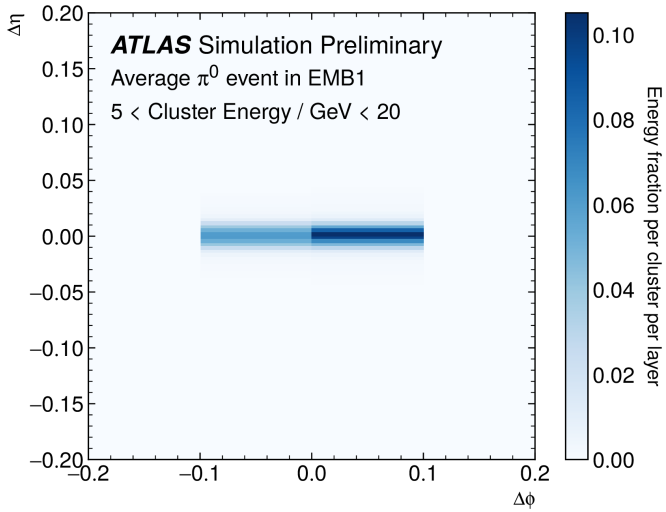
Event Reconstruction

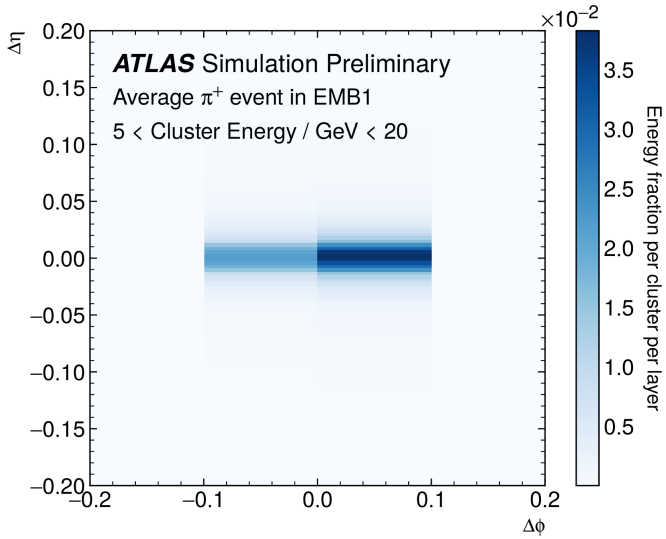
- Pions are the most abundant particle produced in LHC proton-proton collisions
- Understanding how to reconstruct pions is essential!
- Goals: improve classification and energy scale calibration of pions using ML techniques
- Many tasks already make use of machine learning - plenty of prior work to build on
- Lots of information in shower shape and depth to leverage

Datasets

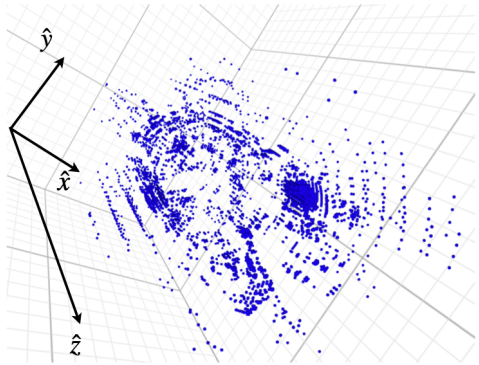
Explored deep learning techniques using two different types of datasets:

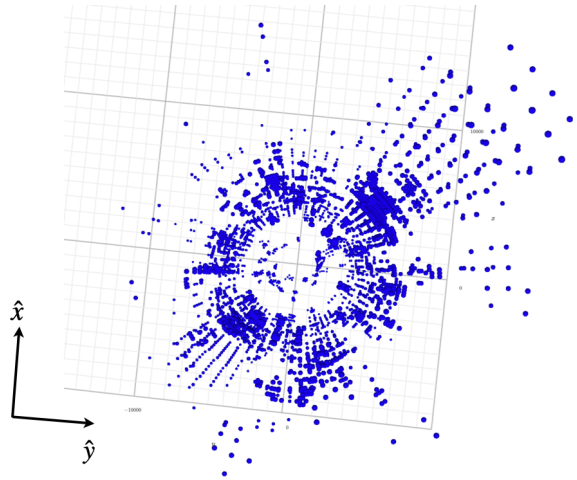
Image based



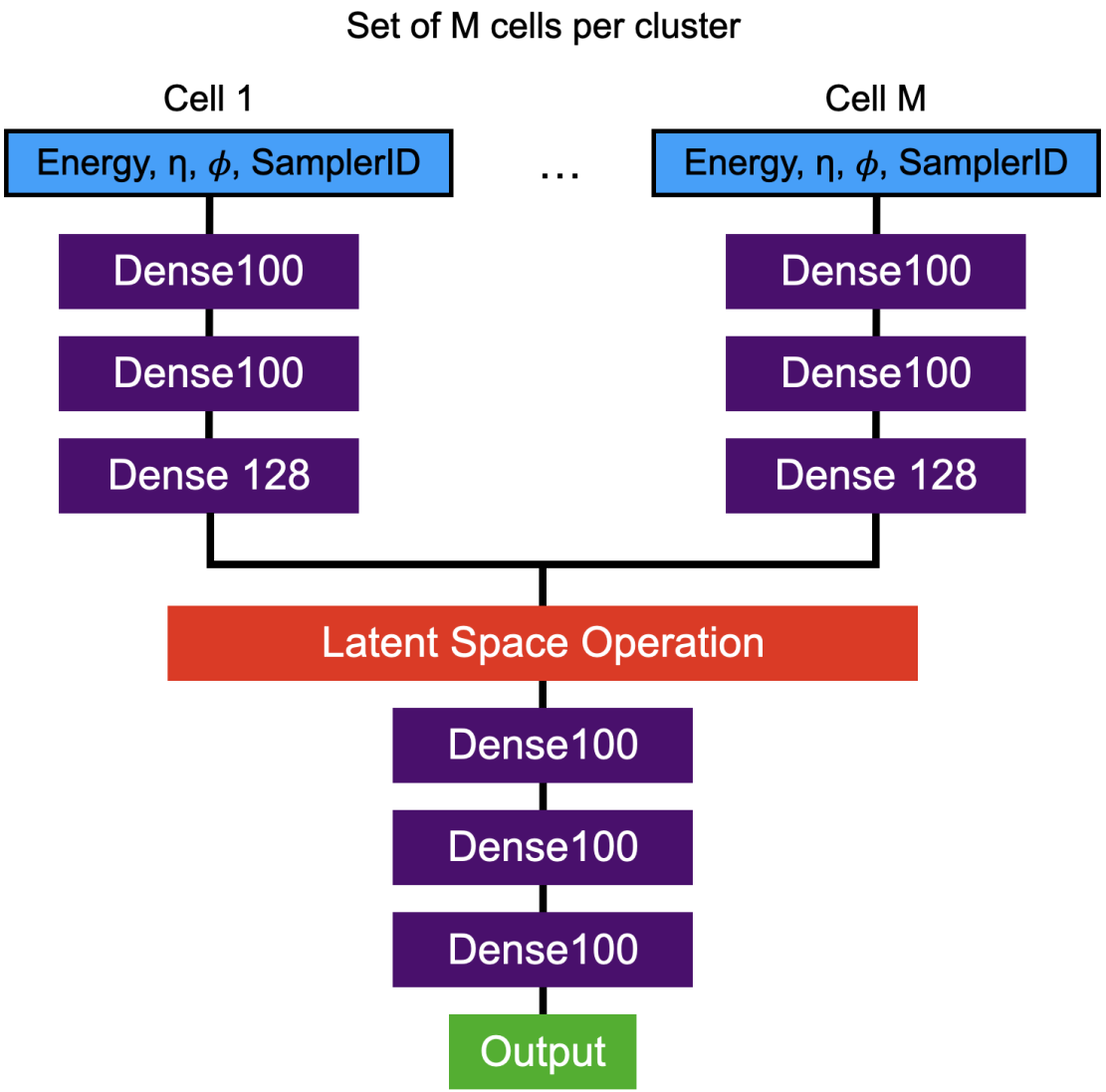


Point cloud





Machine Learning Architectures: Deep Sets

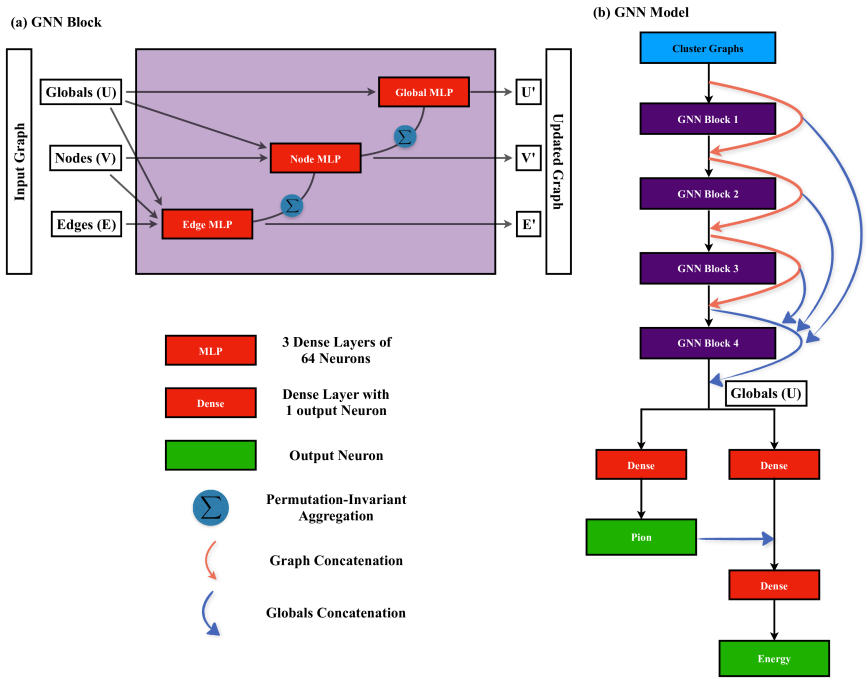


- Deep Set Theorem: can parameterise any observable of variable-length sets of particles using particle properties
- Using Particle Flow (specialised Deep Set framework for use in particle physics)
- Input features are (log) cell energy, sampling layer, η, and ϕ

Machine Learning Architectures: Graph-based Networks

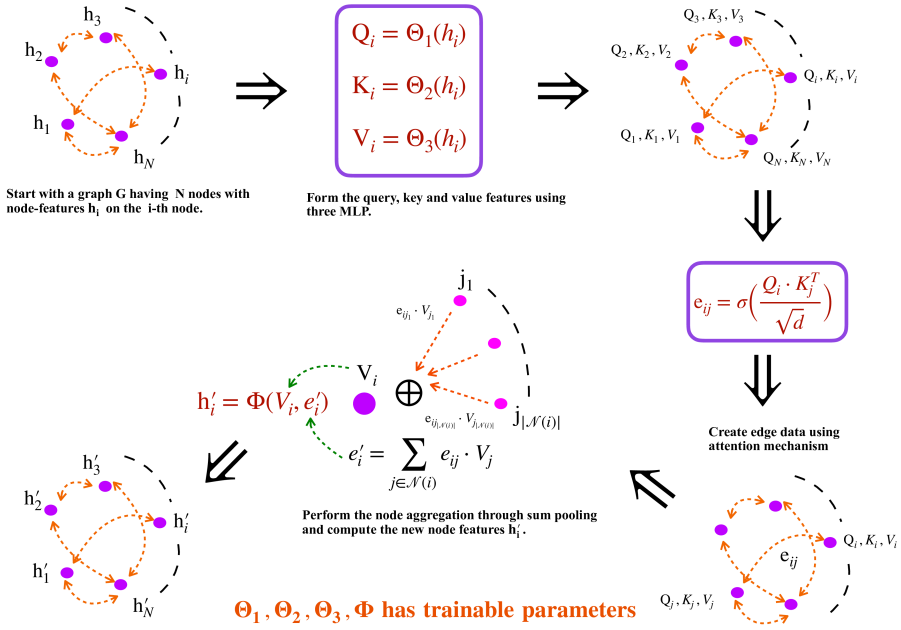
Graph Neural Network

Edges set by detector geometry



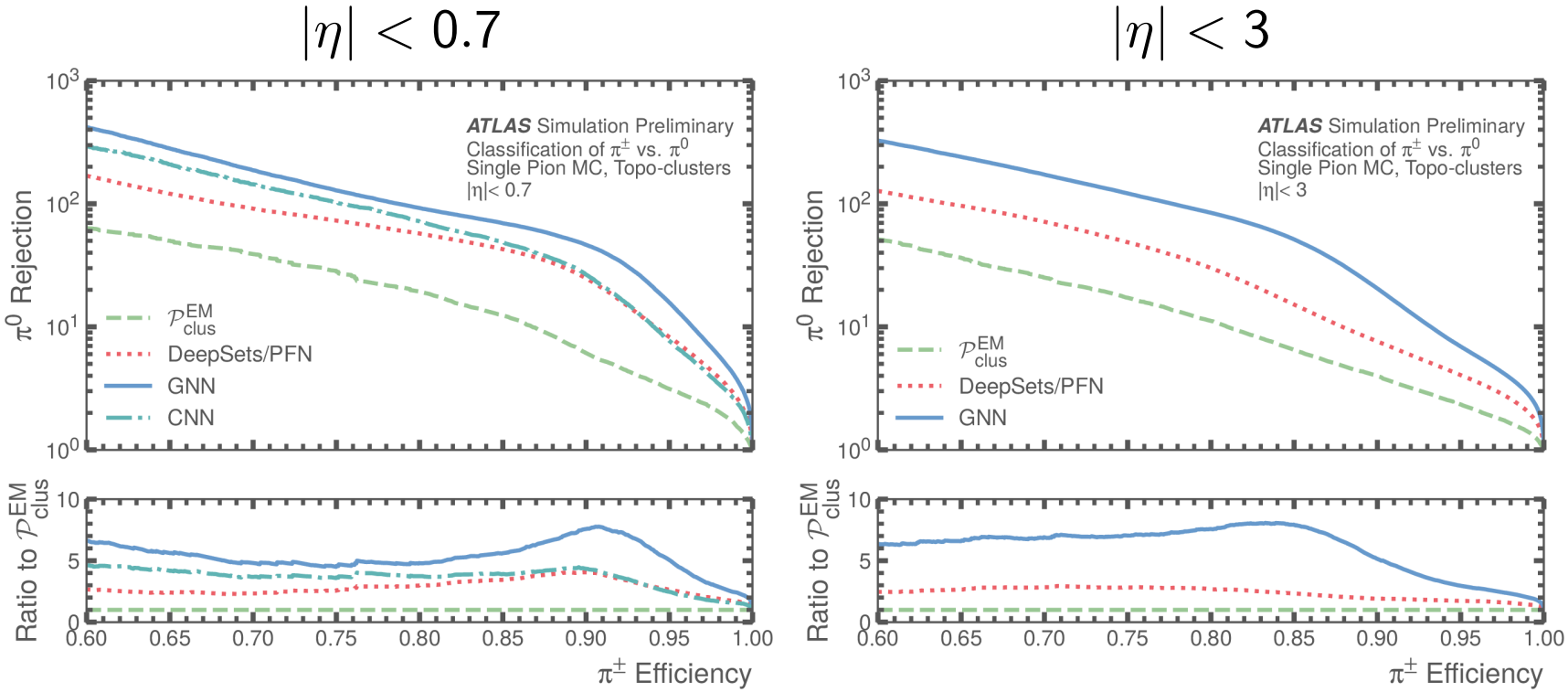
Transformer Network

Edges set by self-attenuation



Node features: cell energy, sampling layer, η, $\Delta\eta$, ϕ, $\Delta\phi$, and minimum radial distance of cell to shower axis $r_\perp$

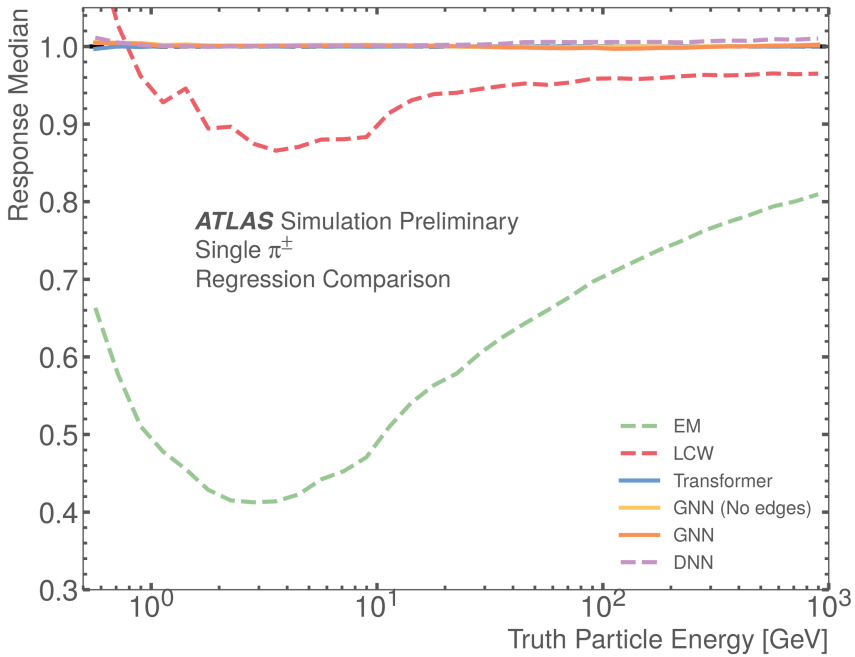
Classification Results



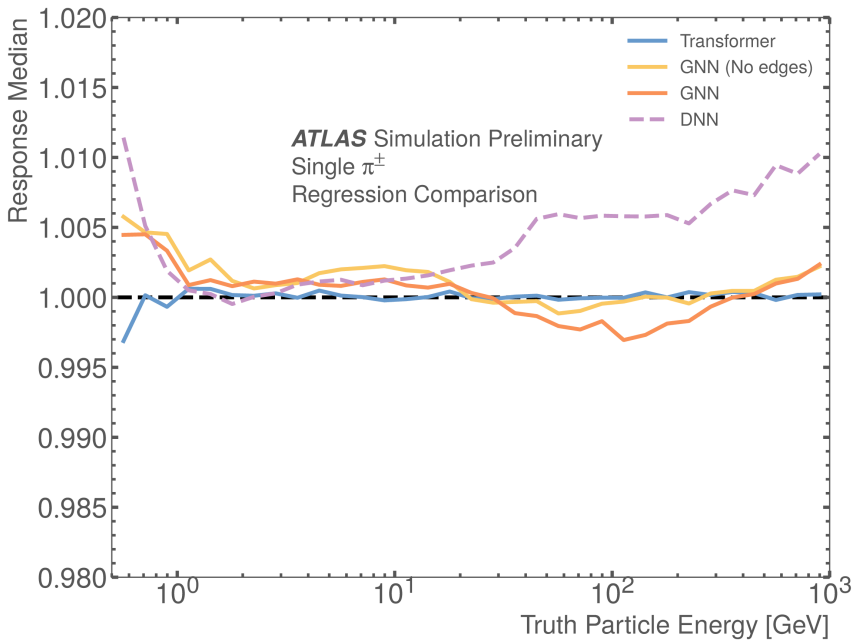
- Using only calorimeter information
- Higher values of rejection show better performance for the same selection efficiency

Regression Results

All models



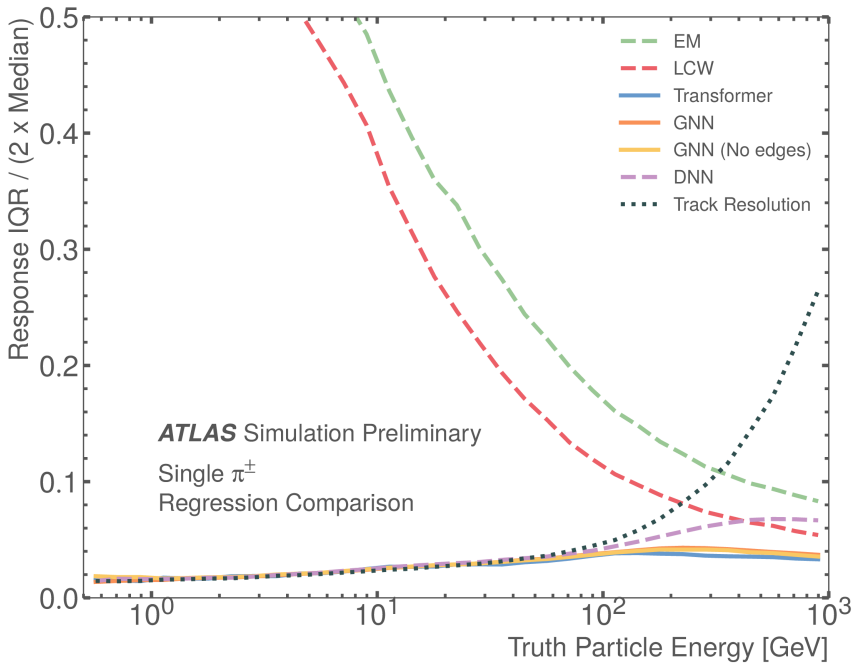
ML models only



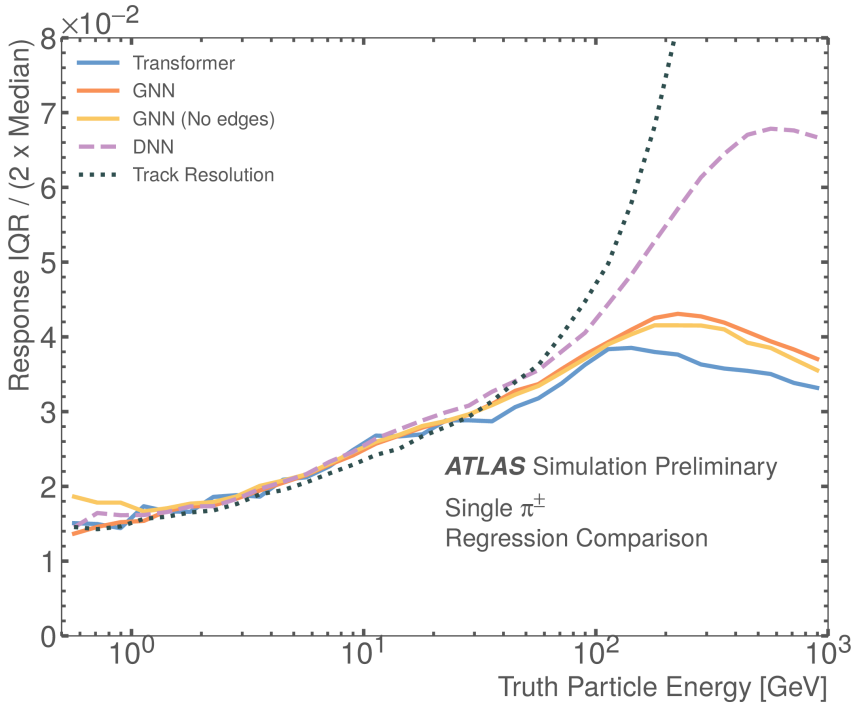
- Using both calorimeter and tracking information
- Ideal value is a response of 1 across the entire energy range

Regression Results

All models



ML models only



- Lower values of IQR/Median correspond to better resolution
- Network combines good calorimeter performance at high energy with good track resolution at low energy

Conclusion

- Neural networks to classify pions as charged or neutral - great performance improvement over traditional methods
- Neural networks to perform energy calibration - significant improvement in both energy scale and resolution for classified topo-clusters
- All of this possible by better leveraging the information contained in the shapes of showers as they pass through the various calorimeter layers