Pion reconstruction in the ATLAS detector using Graph Neural Networks

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June 3, 2022

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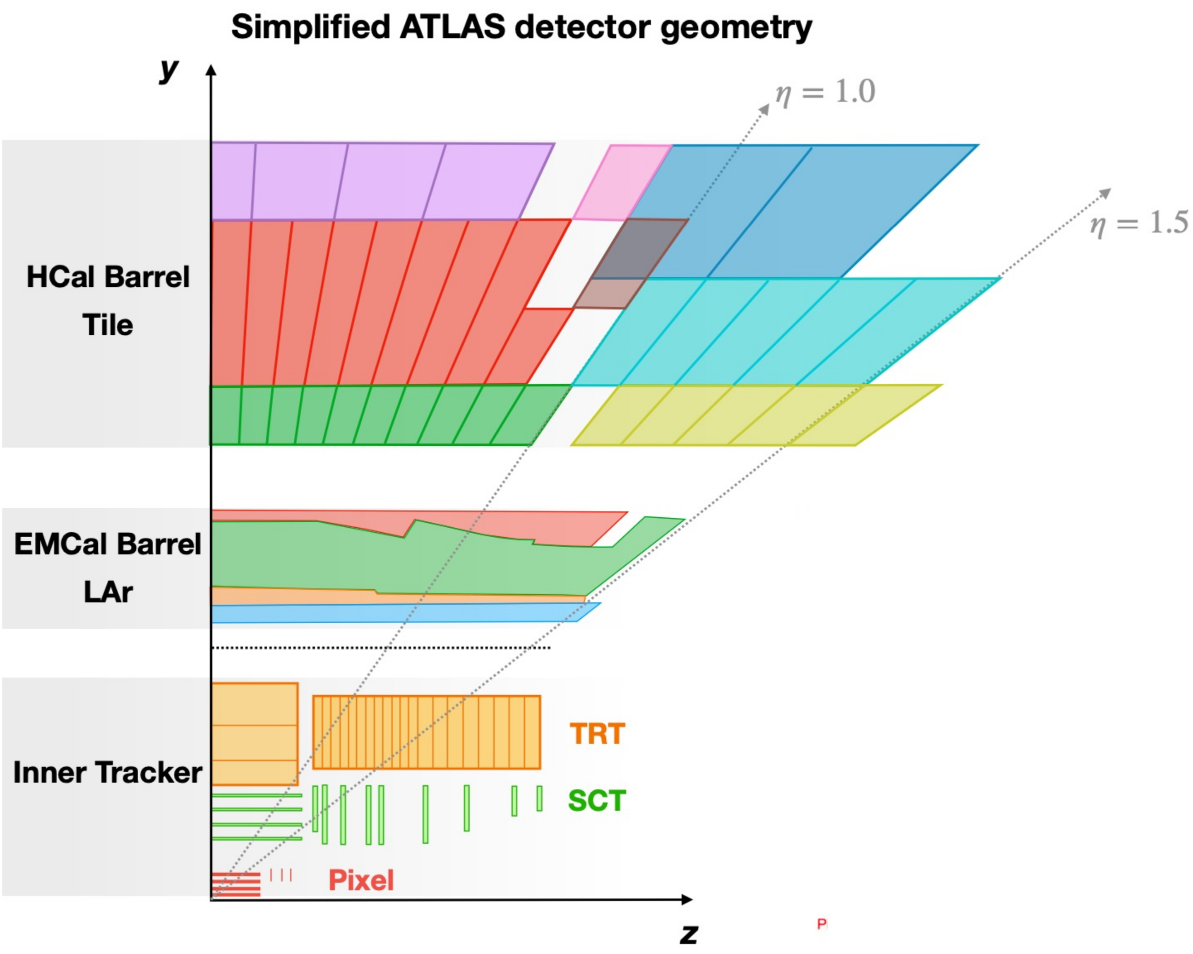
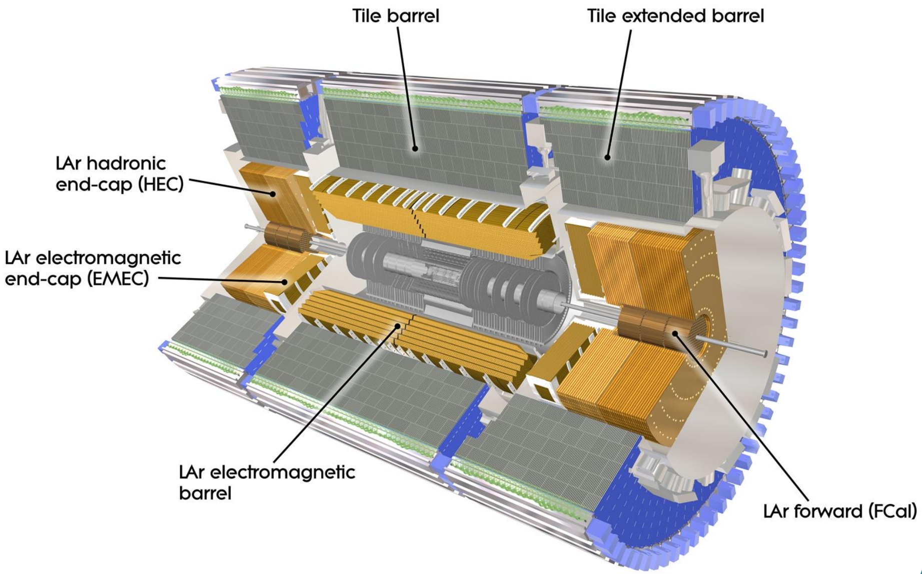
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

ATLAS Detector Geometry



Calorimeter Layer	$\Delta\eta$ Granularity	$\Delta\phi$ Granularity	Interaction Lengths
EMB1	$0.025/8 = 0.003125$	$\pi/32 \approx 0.1$	$\approx 4X_0$
EMB2	0.025	$\pi/128 \approx 0.025$	$\approx 16X_0$
EMB3	0.05	$\pi/128 \approx 0.025$	$\approx 2X_0$
Tile0	0.1	$\pi/32 \approx 0.1$	$\approx 1.5\lambda$
Tile1	0.1	$\pi/32 \approx 0.1$	$\approx 4\lambda$
Tile2	0.2	$\pi/32 \approx 0.1$	$\approx 2\lambda$



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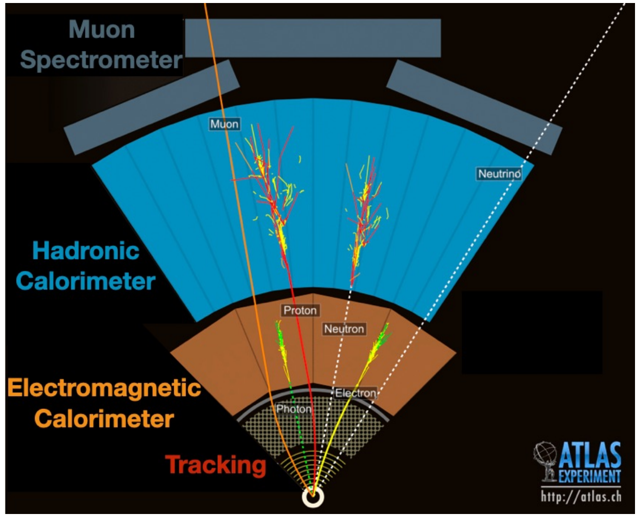
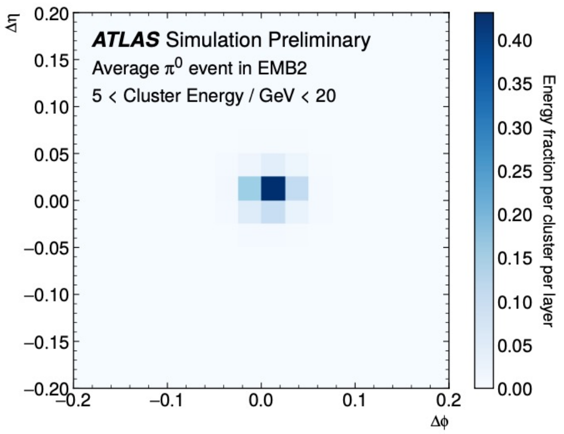
Dataset and ML Problem

- Dataset:
  - Simulated single pion showers (π^0 and π^+)
  - Topo-clusters: 3D objects representing local particle showers
  - Previous approach: image representation of each layer of calorimeter

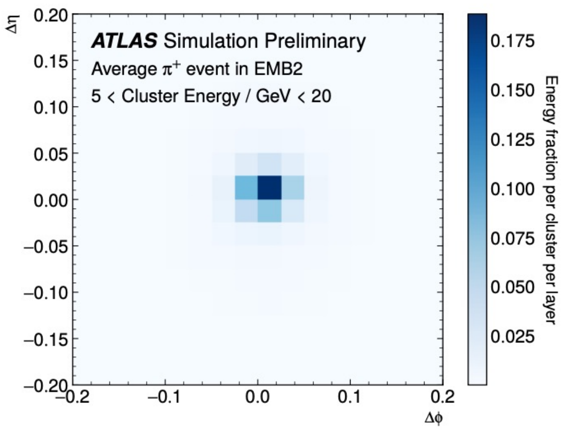


- ML Problems:
  - Pion classification: π^0 or π^+
  - Energy regression: pion energy

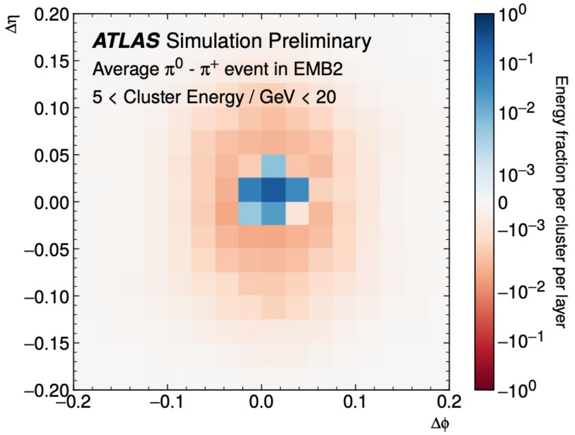
Neutral pions



Charged pions



Difference



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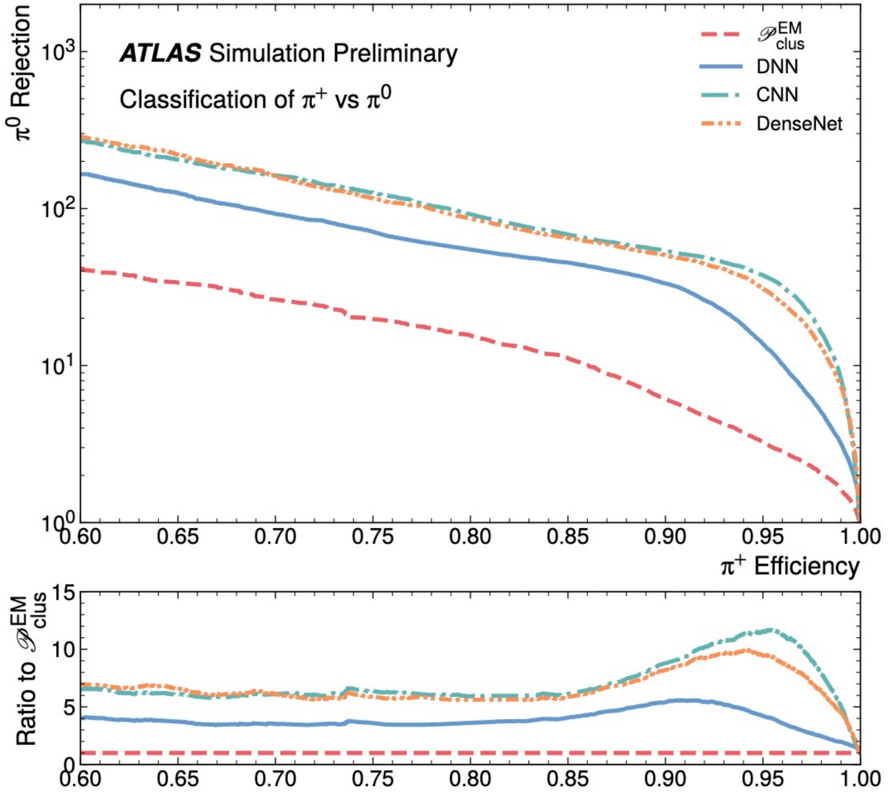
Results: Image-based approach

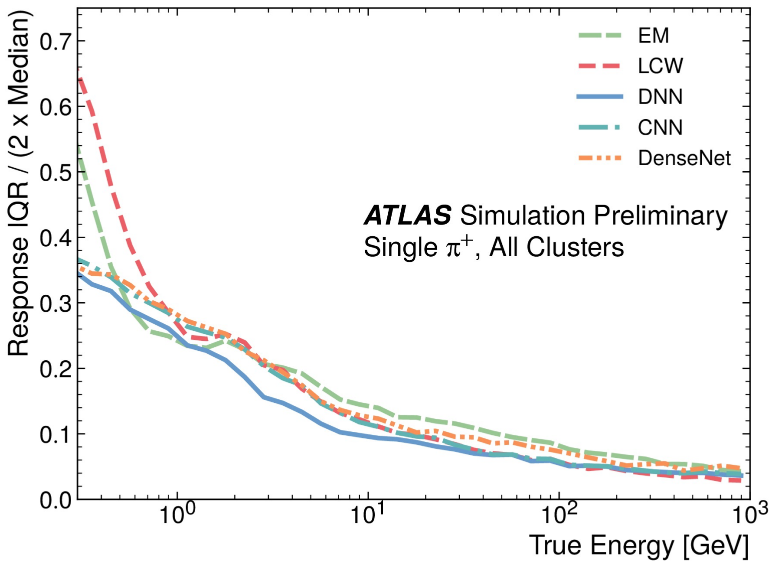
- Image-based methods outperform the baseline classification and energy calibration methods.
- Drawbacks: Sparse images of varying dimensions, restricted η range (|η| < 0.7) due to changes in detector geometry.

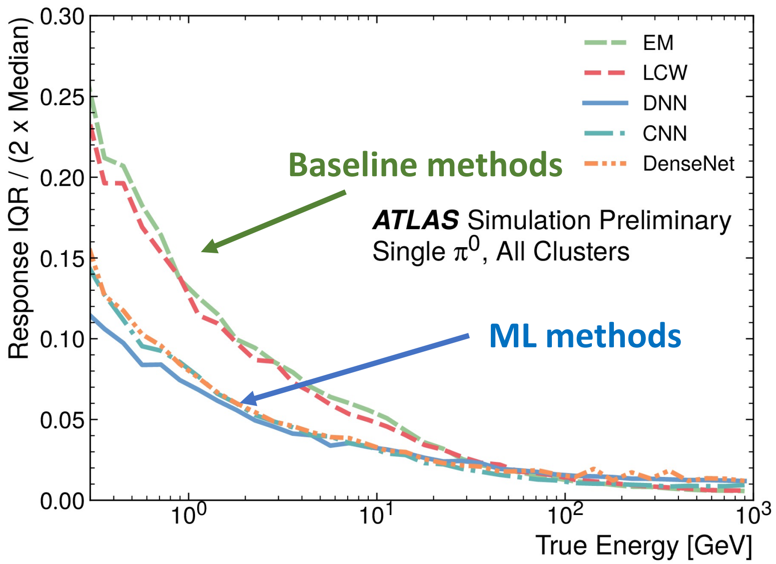
Classification



Regression

Inter-Quantile Range (IQR)





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Graph Neural Network Approach

- Representing topo-clusters as graphs is more suited to handle its non-uniform 3D structure compared to a series of calorimeter images
- More flexibility to include different calorimeter layer geometries/granularities
- Improved ability to perform cluster classification and energy calibration out to forward regions

Topo-cluster

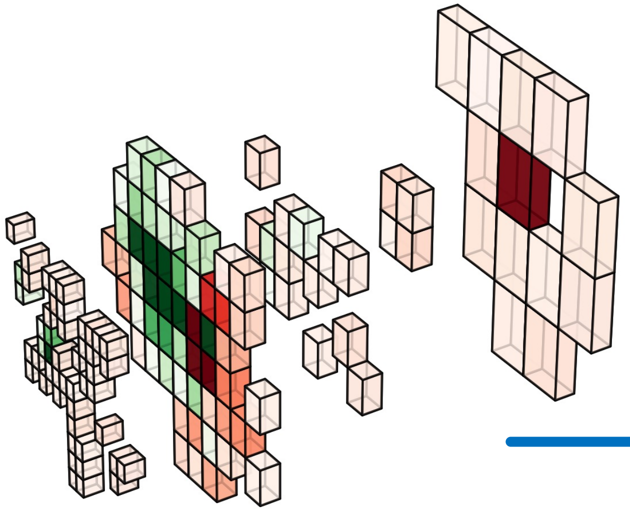

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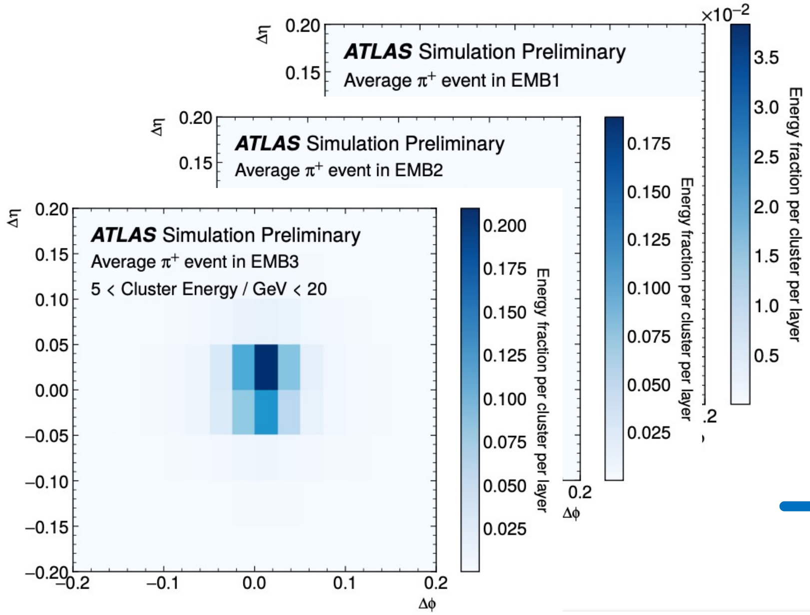
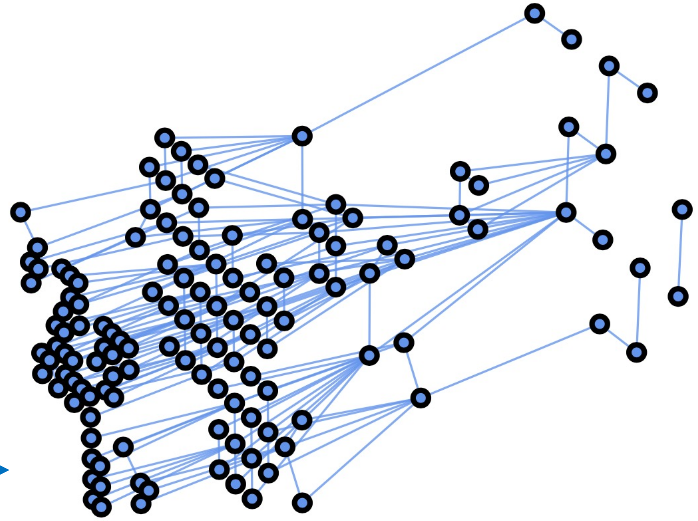
Image-based representation



Graph-based representation



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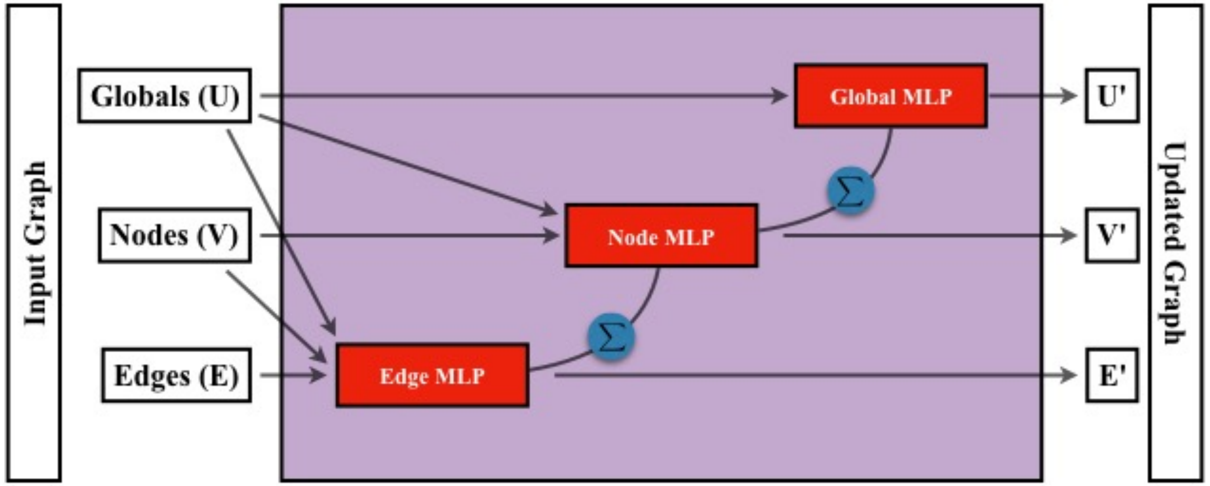
Topo-Cluster Graph Representation

- **Nodes**: Cells from the topo-cluster with features such as
  - cell energy
  - sampling layer
  - cell location (η, φ)
  - cell size
- **Edges**: One-hot encoded vector defining geographical connections between nodes
- **Global Node**: total cluster energy

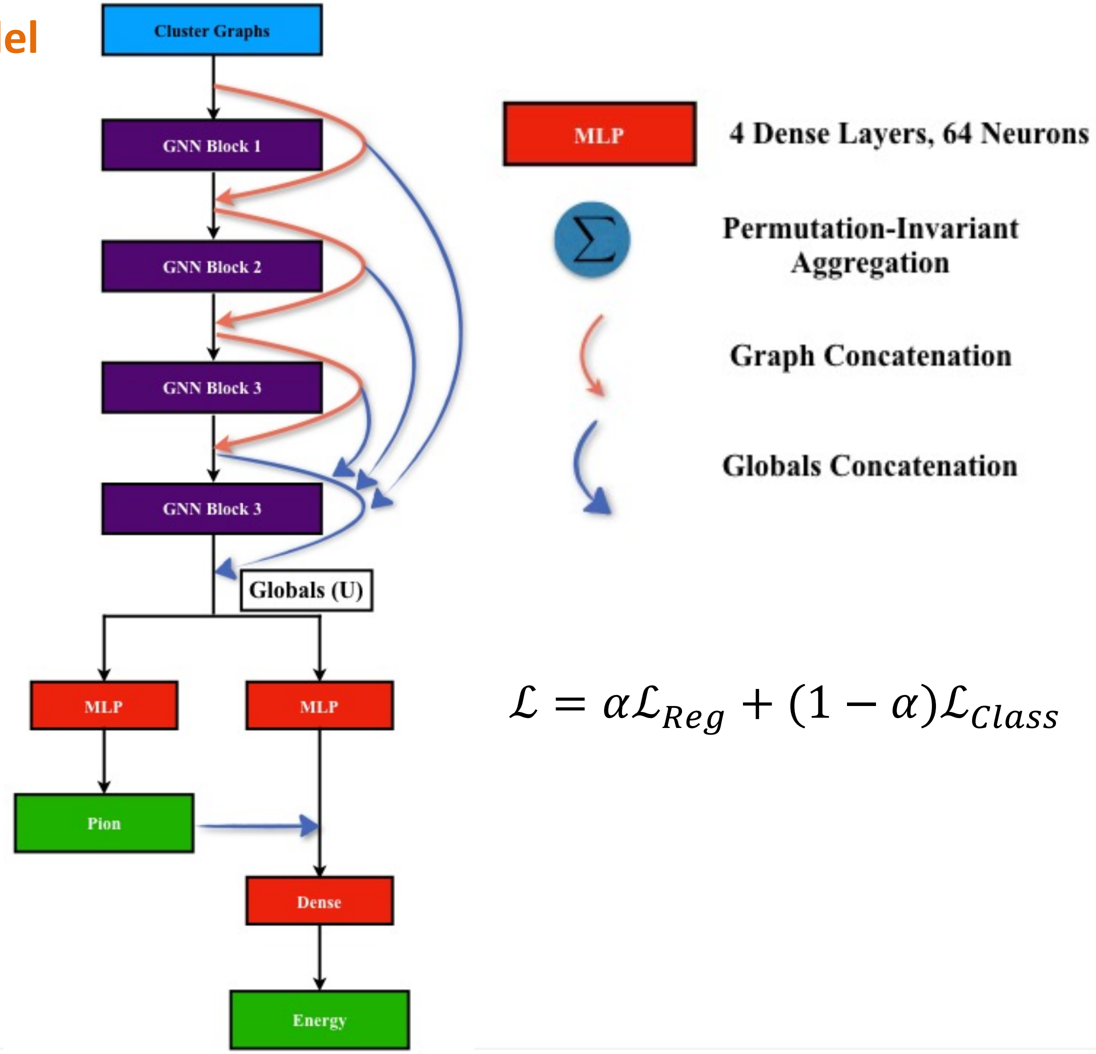
GNN Model

- Graph Nets library by DeepMind
  - Highly customizable graph blocks
  - Lightweight
  - Not actively developed or widely used

FullGNN Block



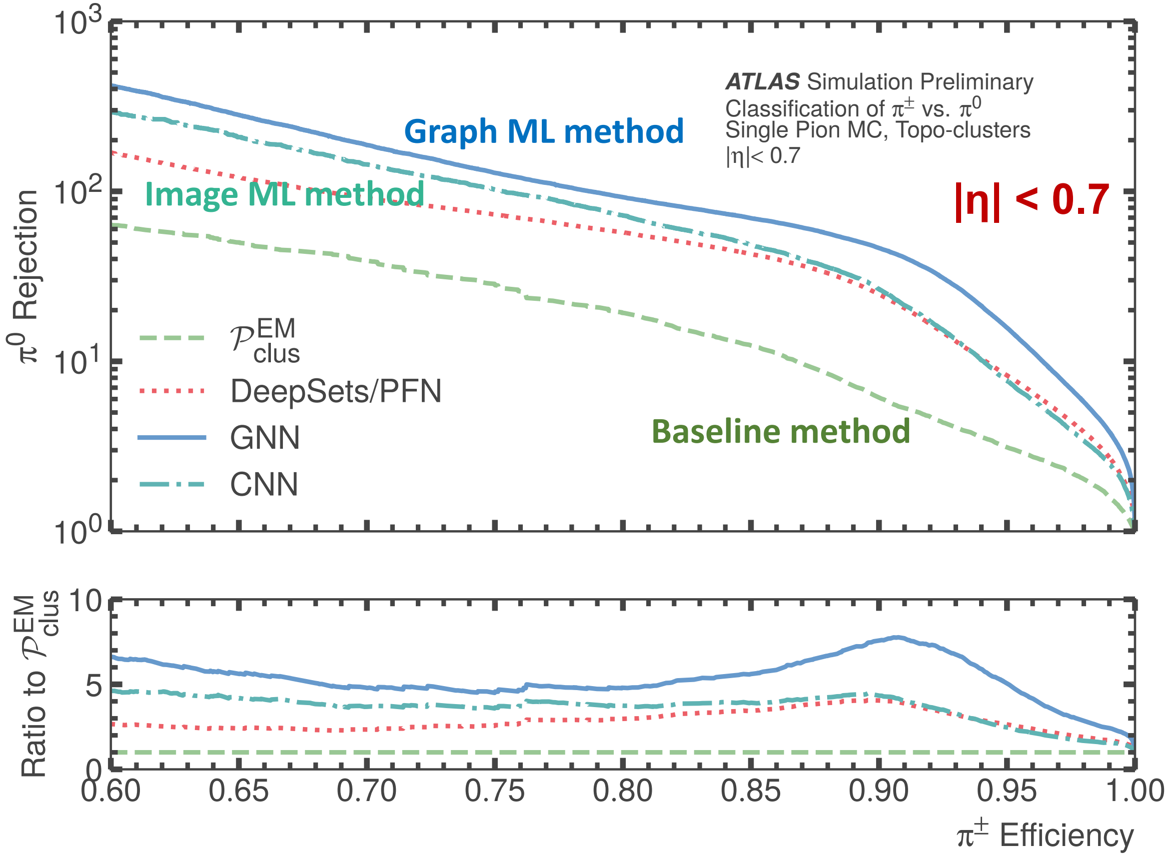
Model



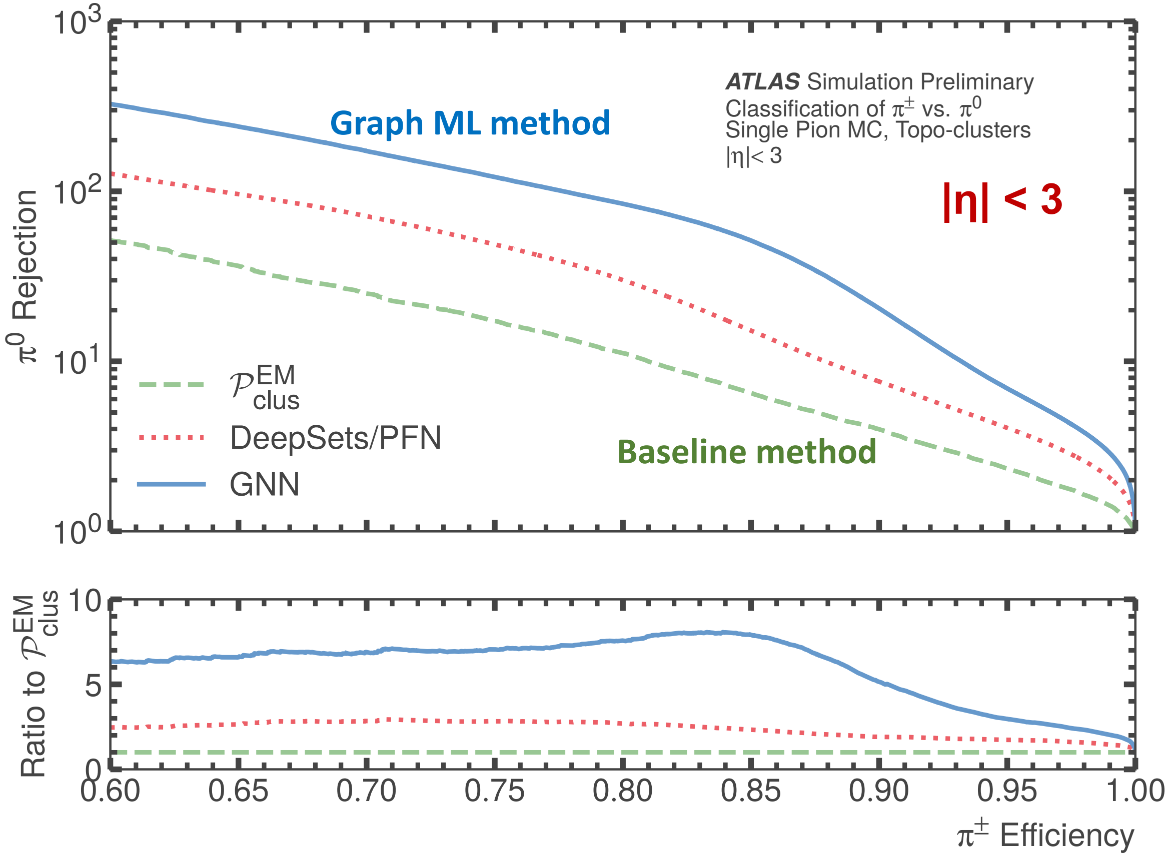
$$\mathcal{L} = \alpha \mathcal{L}_{Reg} + (1 - \alpha)\mathcal{L}_{Class}$$

GNN Results: Classification

Comparison with Image-based approaches



Performance on expanded Detector Regions



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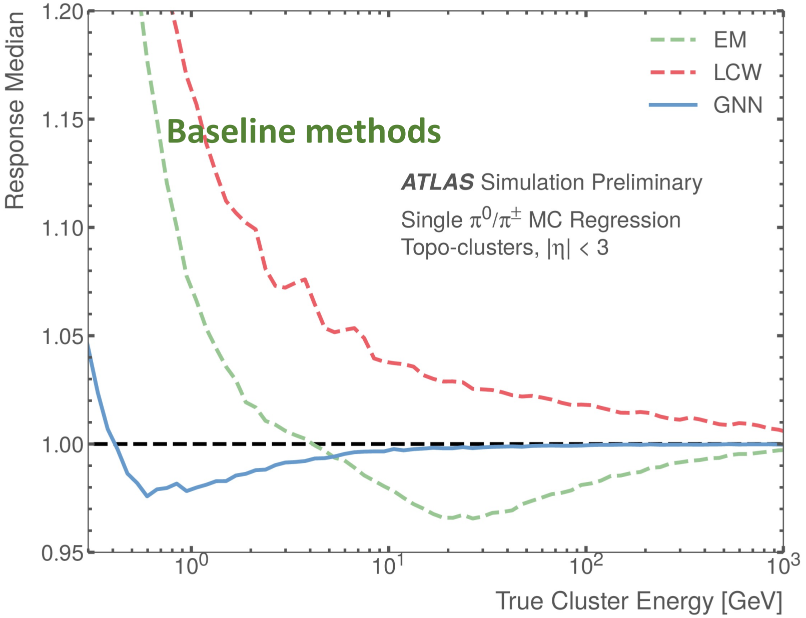
GNN Results: Regression

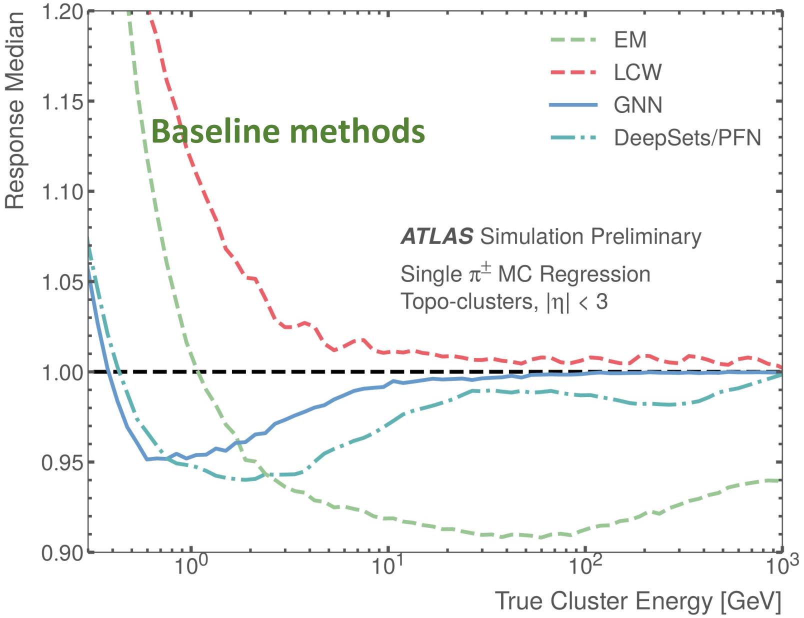
Significant improvement in the cluster energy response using the GNN model compared to EM and LCW scales

Response Medians

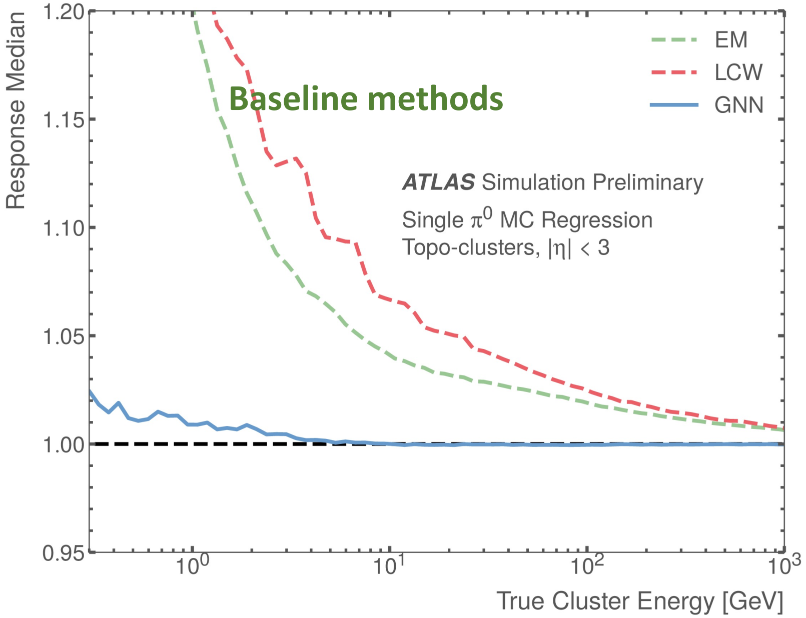
Mixed Neutral and Charged Pions



Charged Pions



Neutral Pions



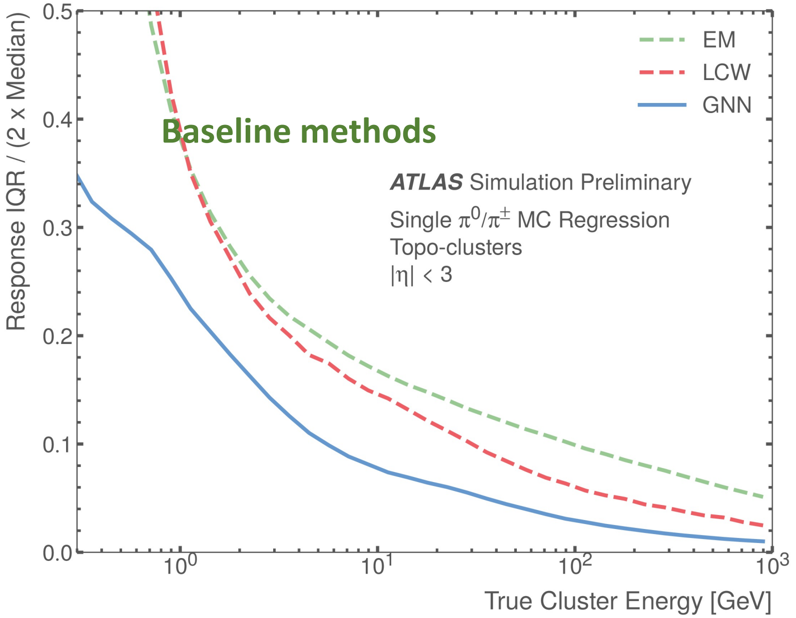
ATLAS-JETM-2022-002

GNN Results: Regression

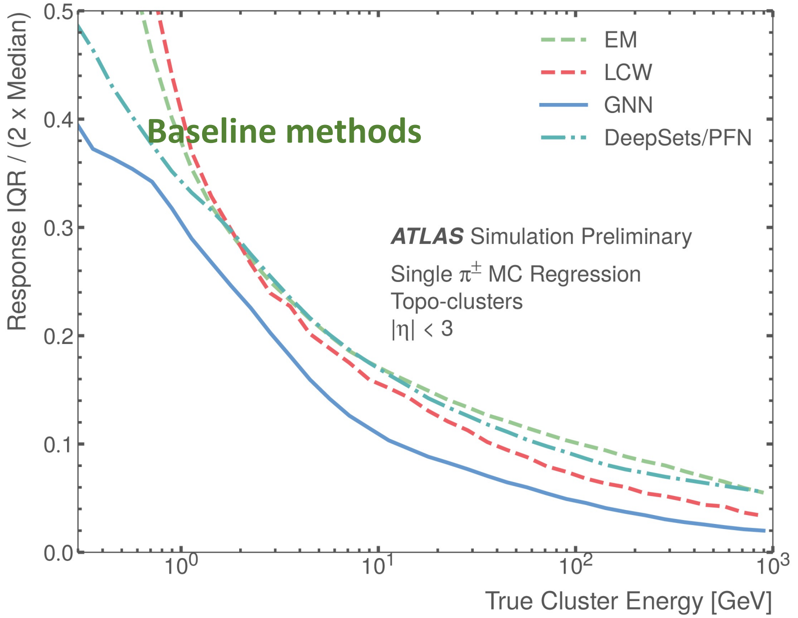
Significant improvement in the cluster energy response using the GNN model compared to EM and LCW scales

Inter-Quantile Range (IQR)

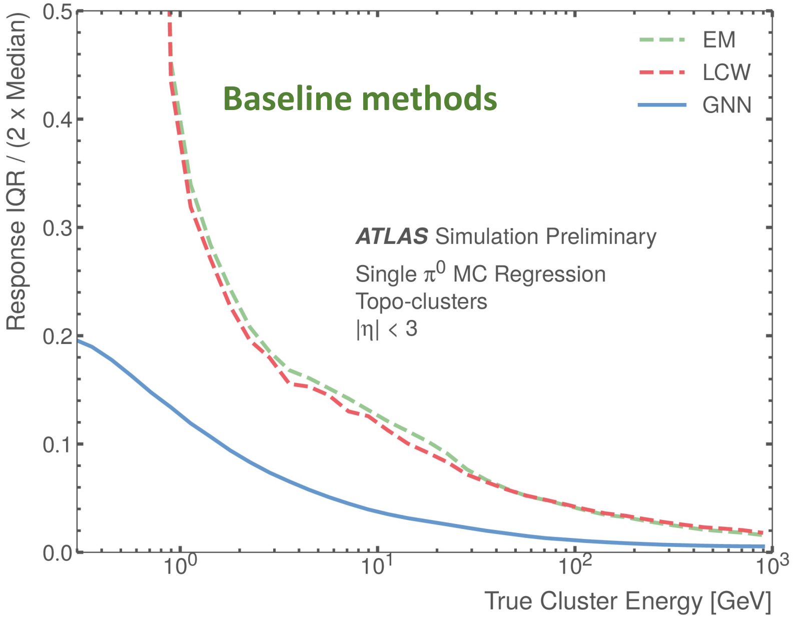
Mixed Neutral and Charged Pions



Charged Pions



Neutral Pions



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Next Steps

- Addition of tracks to graph-based representations of topo-clusters as additional inputs
- Use trained GNN models for inference within the ATHENA framework
  - involves conversion to ONNX model
  - successfully implemented this previously with the image-based models

ATLAS-JETM-2022-002