Graph Neural Network to label particle hits in Liquid Argon Time Projection Chamber

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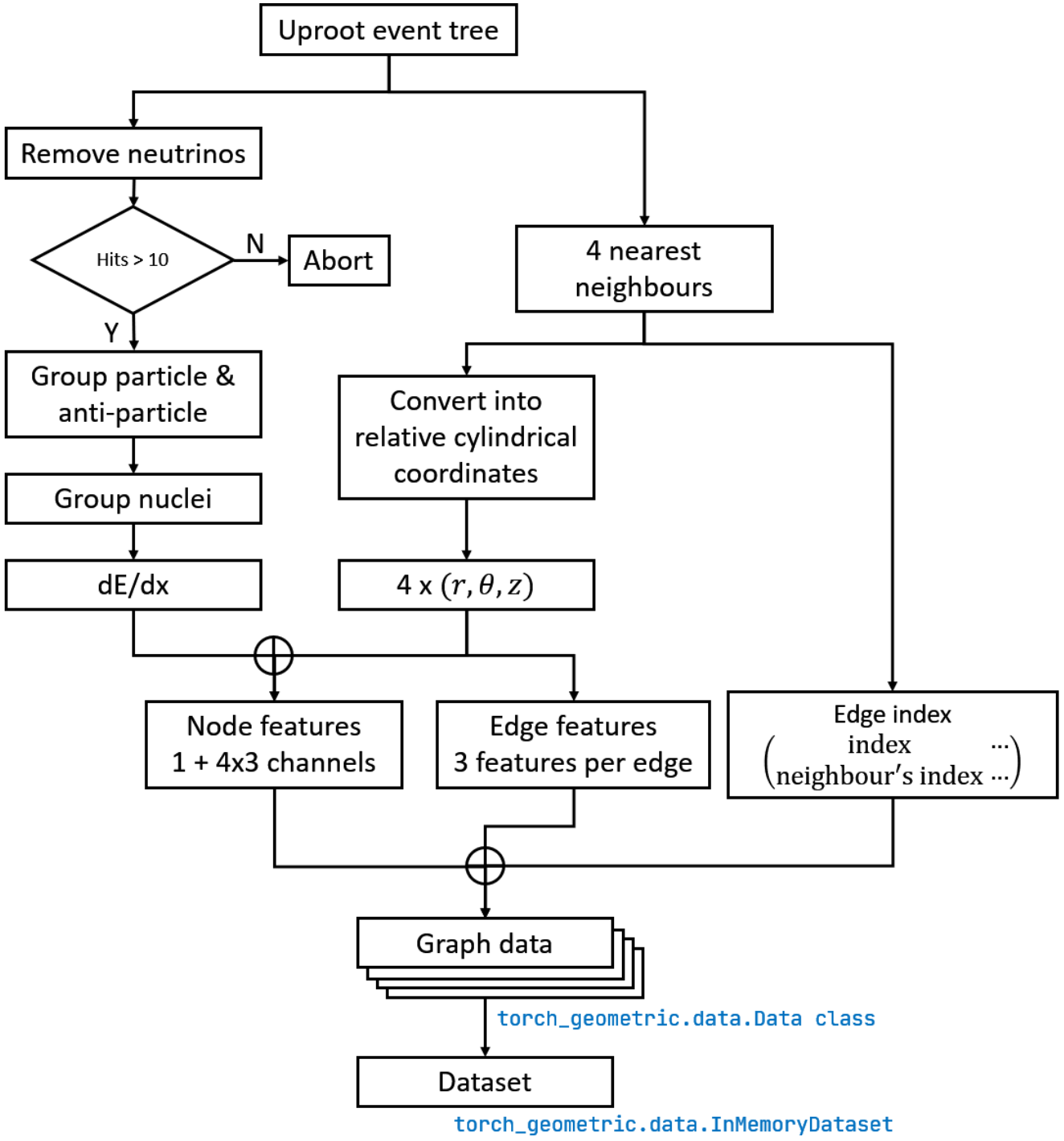
Why Graph Neural Network?

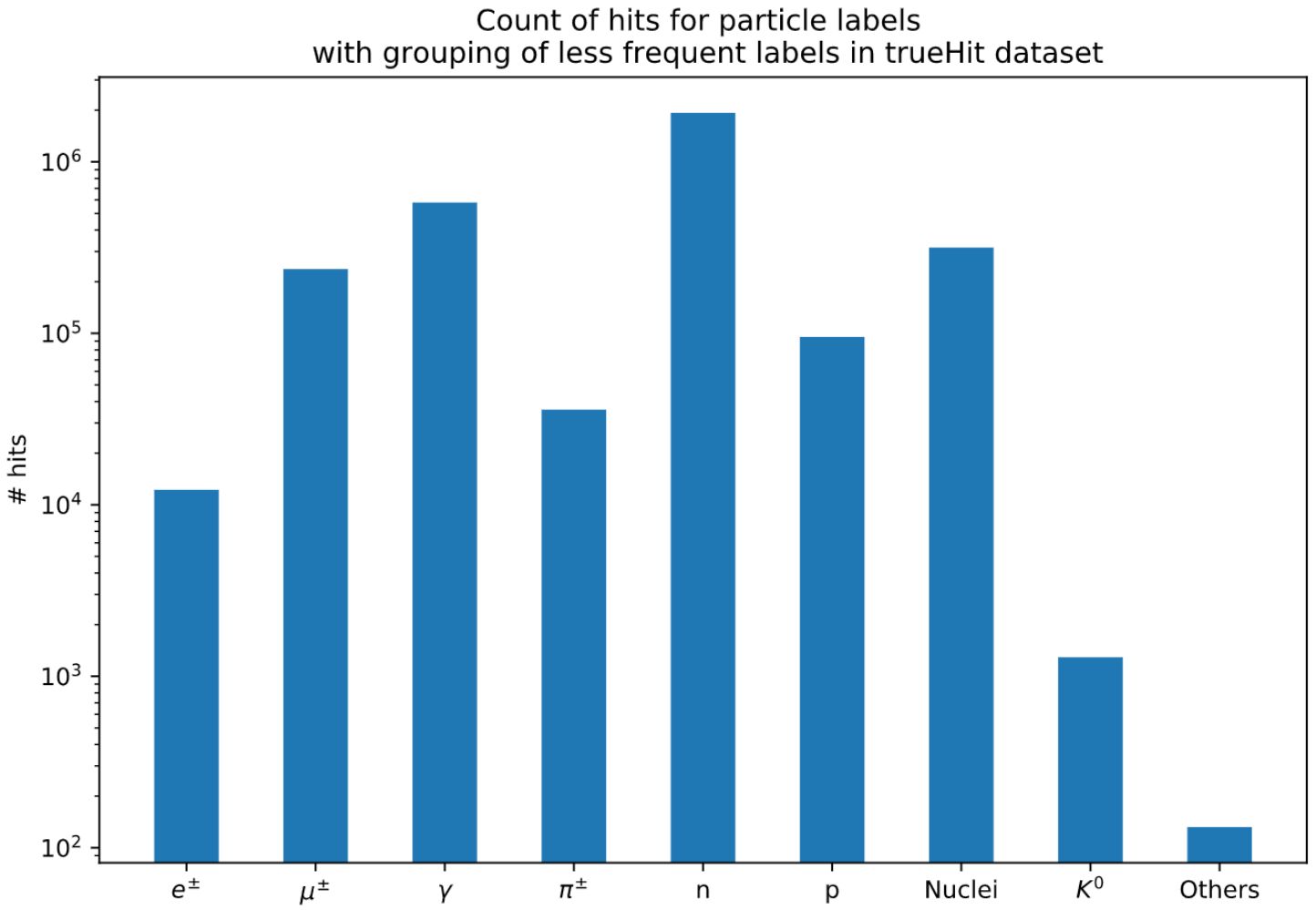
- Sparse-like particle events
  - Large area of background for 2D/3D CNN
  - Convolution kernel hardly covers a whole track
- GNN for manifolds
  - Even detectors in irregular shape, GNN can still identify particles
- Graph (Nodes + Edges)
  - Give the chance to identify each nodes (=hits)
  - Topology properties of interactions and vertices

Dataset generation

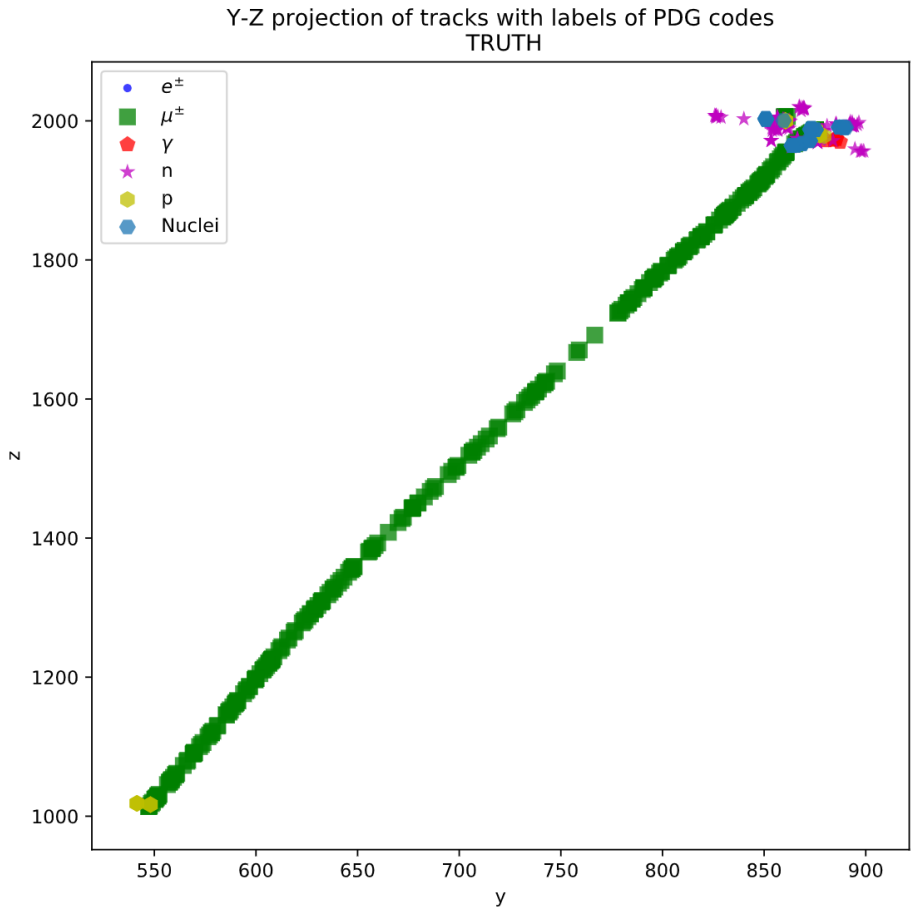
- From particle simulation
- Node = hits in the detector
- Node feature = dE/dx
- Edges = nearest neighbours (tried 4 and 10, chose 4)
- Edges feature = cylindrical coordinates of the neighbour

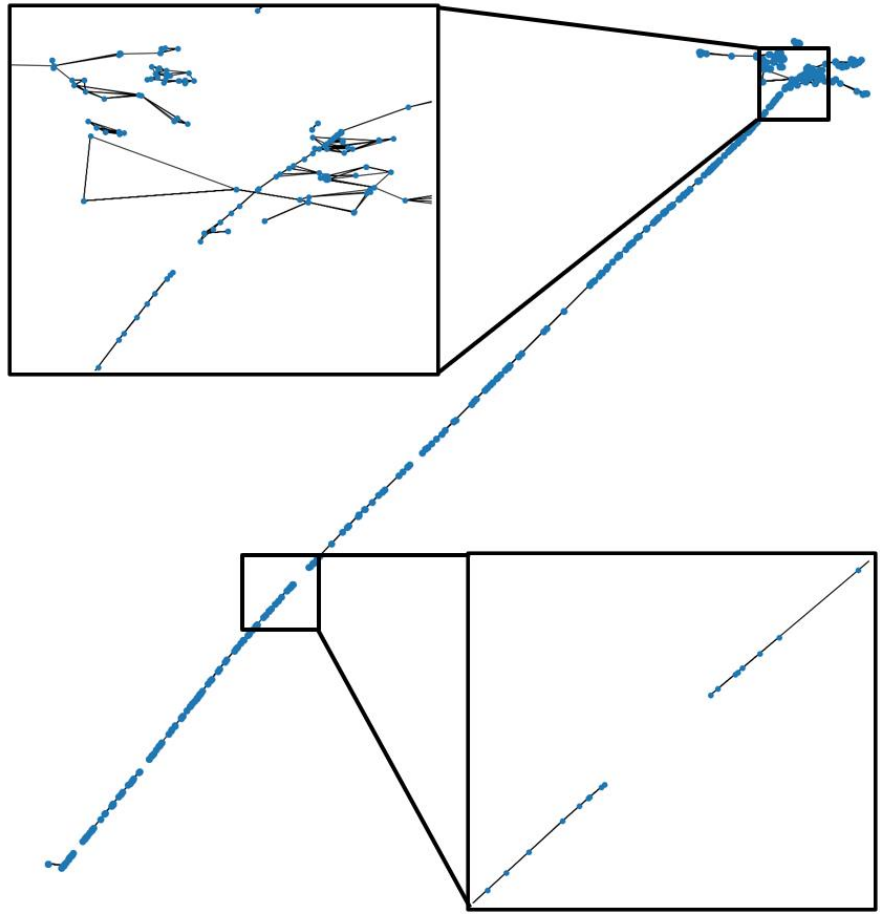


Particle labels in category



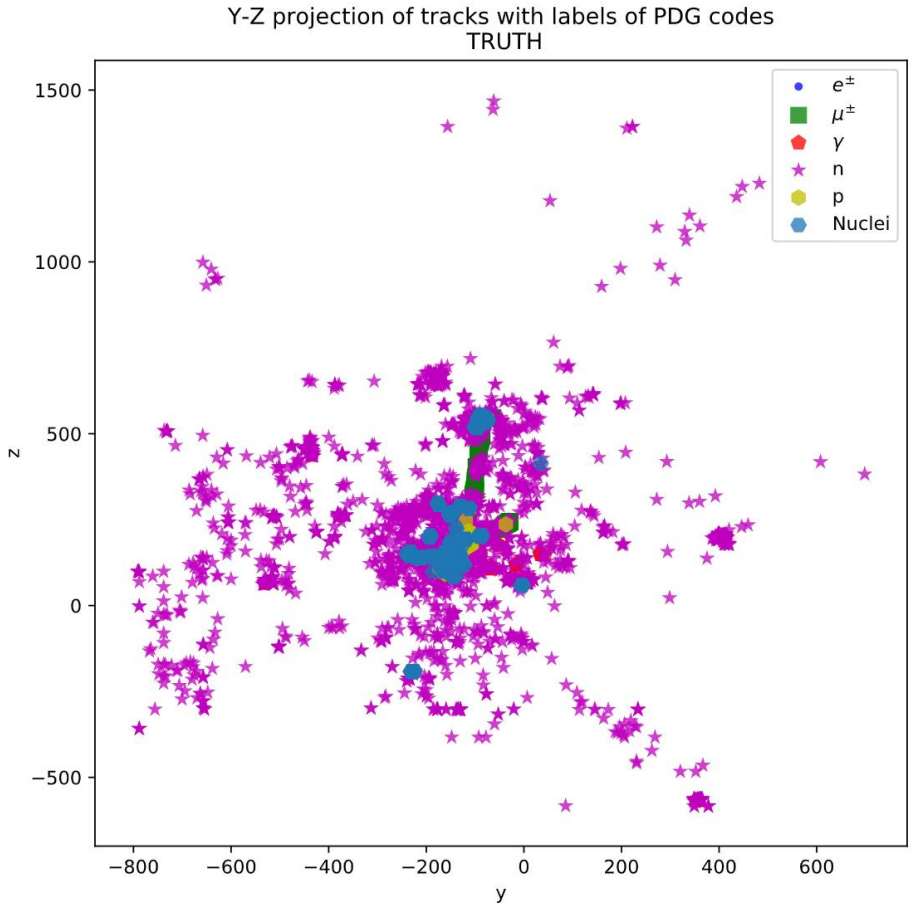
Some of the graphs in the dataset

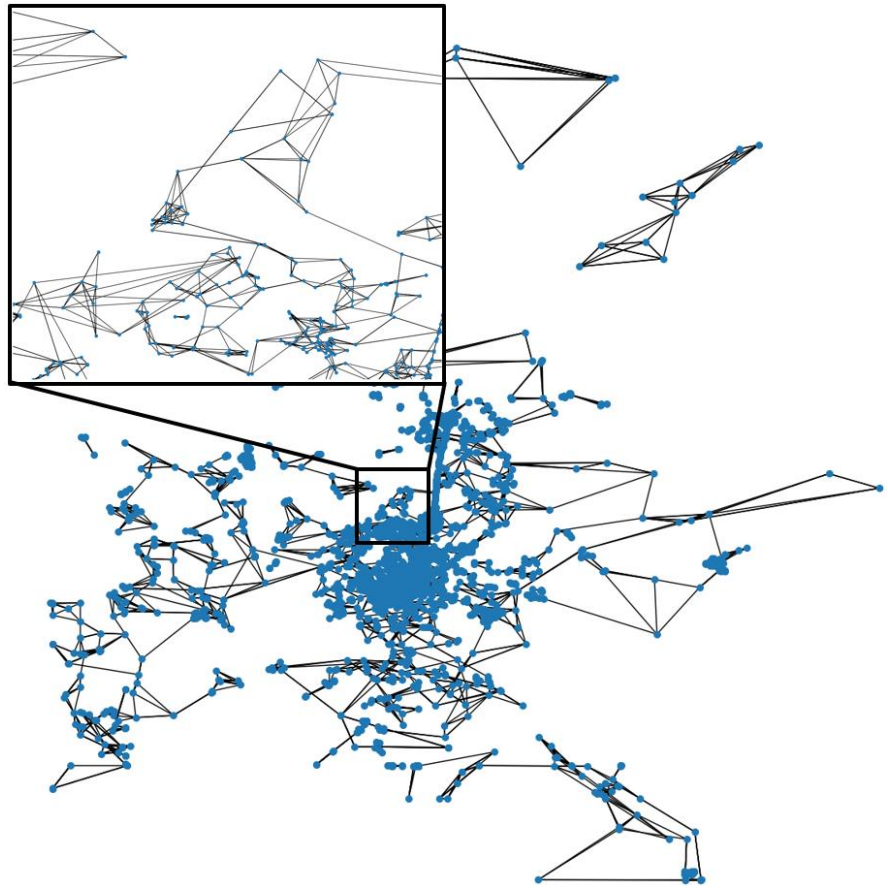




Track-like (muon)

Some of the graphs in the dataset

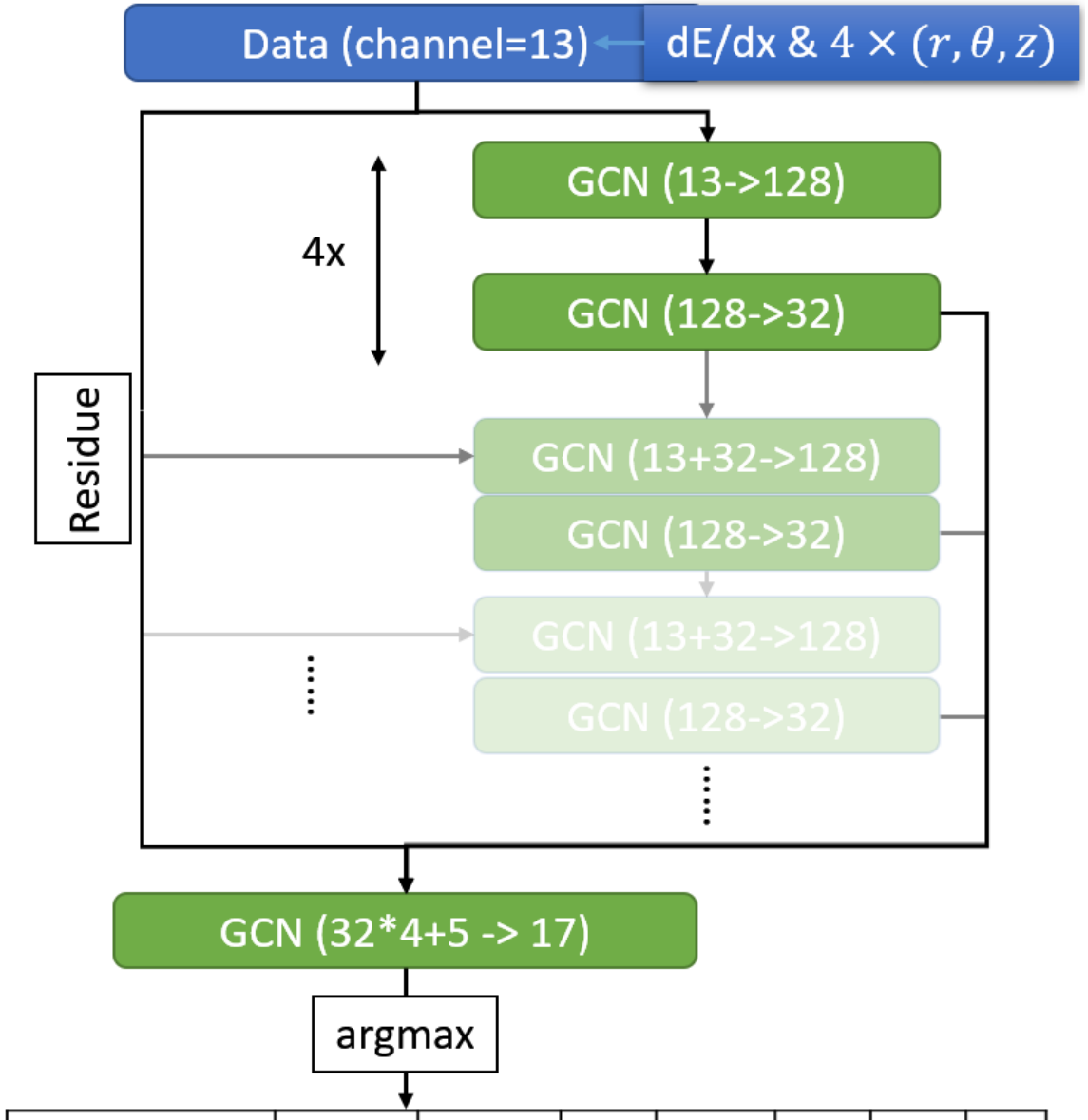




Cluster-like (neutron, muon, nuclei, proton)

GCN model

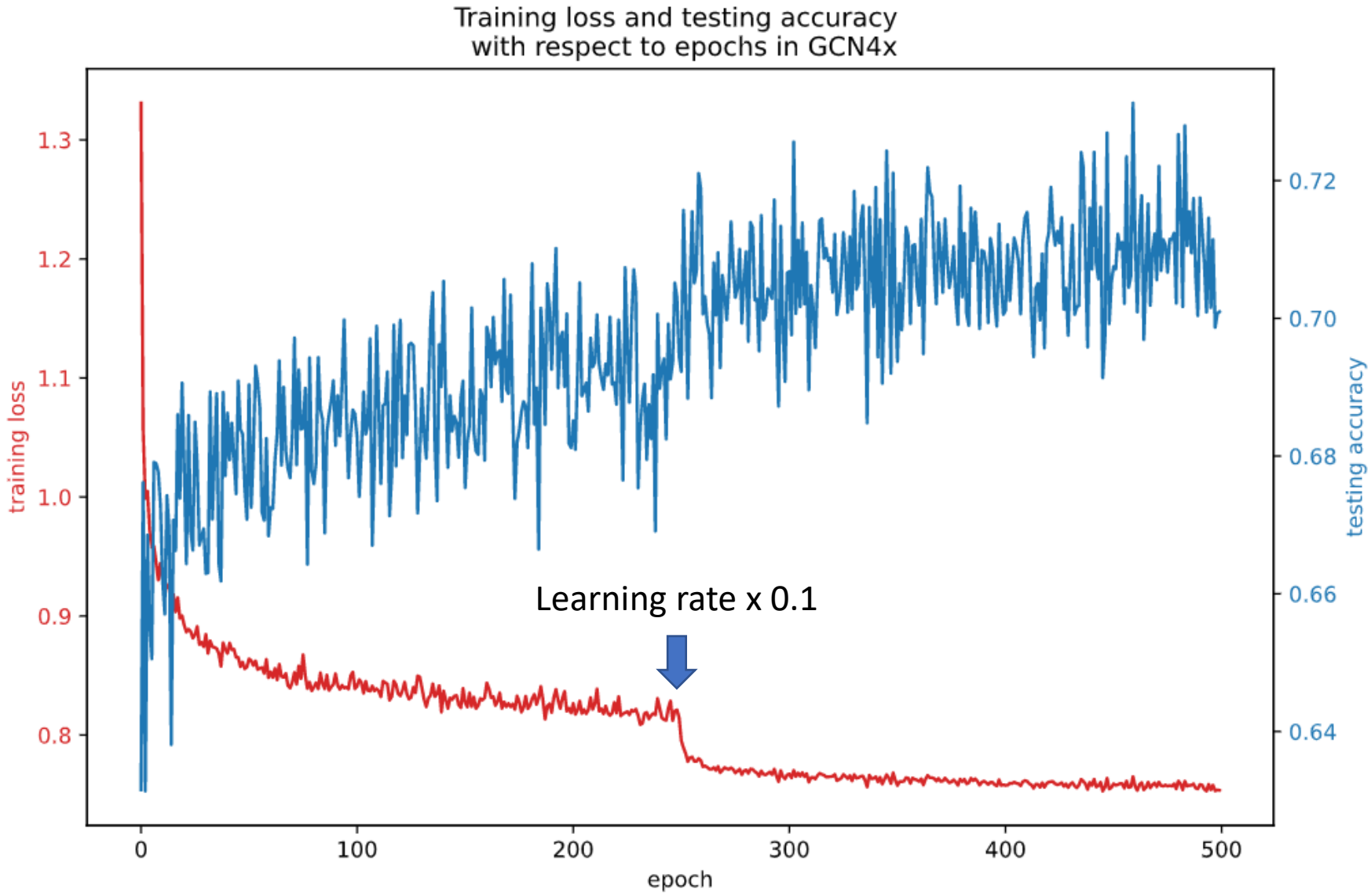
- Residue to smooth the gradient
- Node feature involved cylindrical coordinates, reasonable?



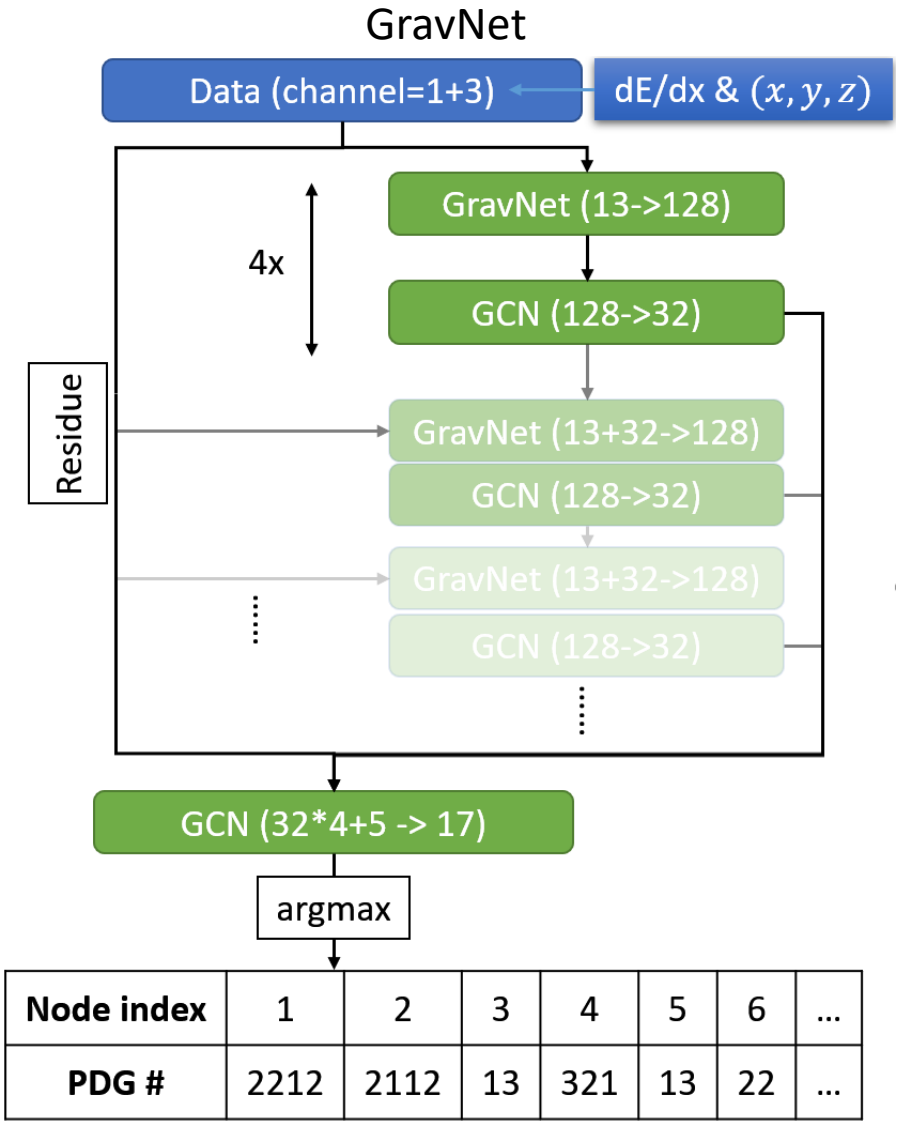
Node index	1	2	3	4	5	6	...
PDG #	2212	2112	13	321	13	22	...

GCN model - result

- Stayed around 0.68-0.72.
- Learning rate too low? 1e-3
- Tried lr_scheduler but not much effective.

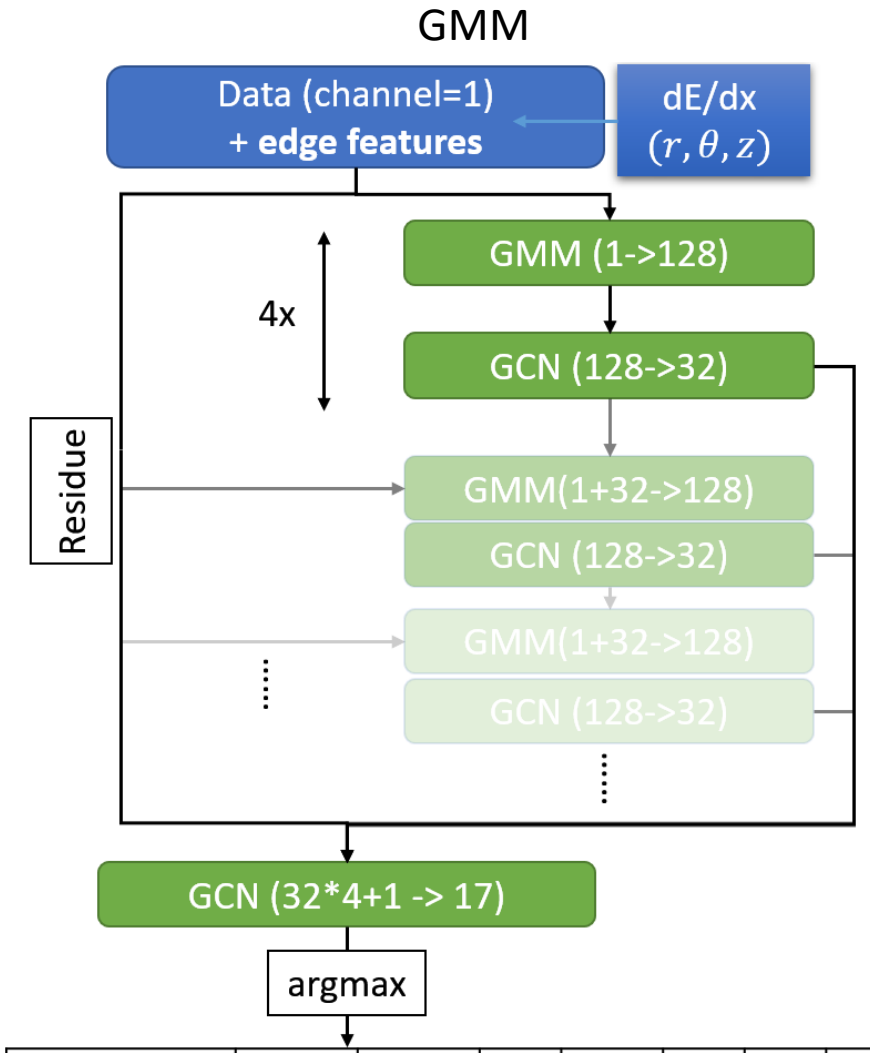


Other models – GMM and GravNet



Node index	1	2	3	4	5	6	...
PDG #	2212	2112	13	321	13	22	...

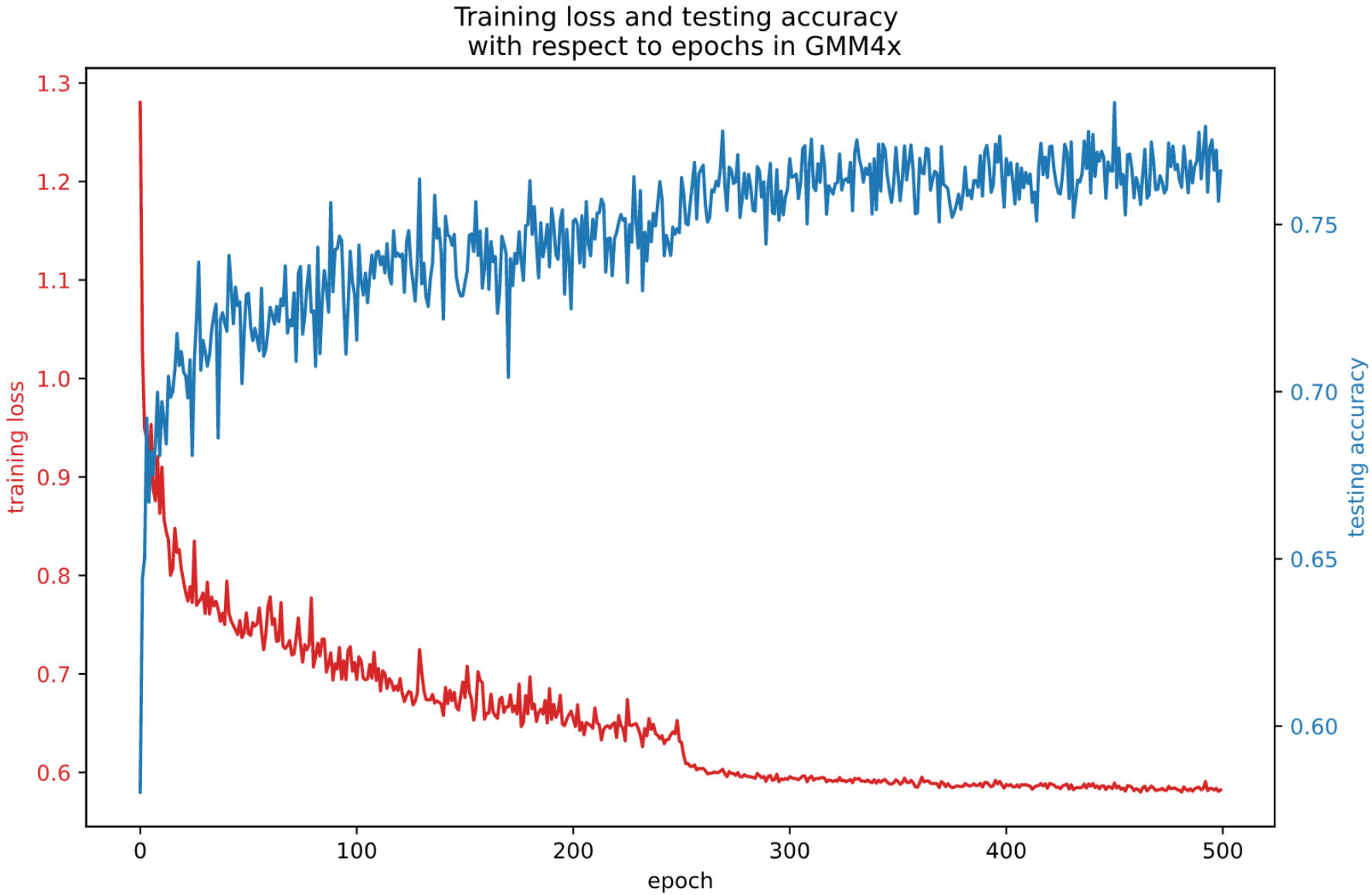
- GMM: Gaussian Mixing Model that could learn edge features
- GravNet: Learn edges
- Want to see how these to go beyond GCN model



Node index	1	2	3	4	5	6	...
PDG code	2212	2112	13	321	13	22	...

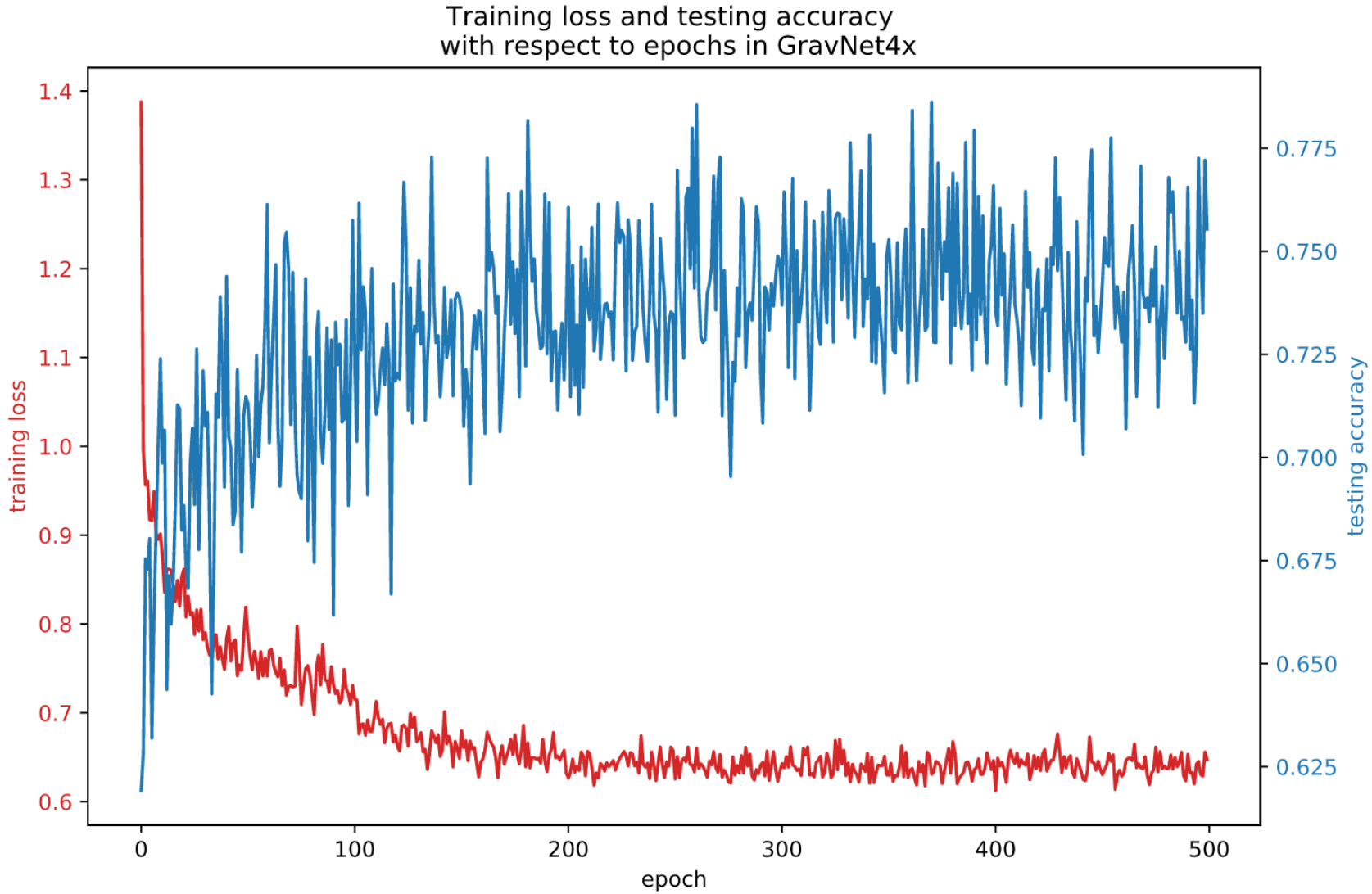
GMM model - Result

- Slightly better than GCN (+0.1)
- Similar training time as GCN model
- Detail on label-wise accuracy



GravNet model - Result

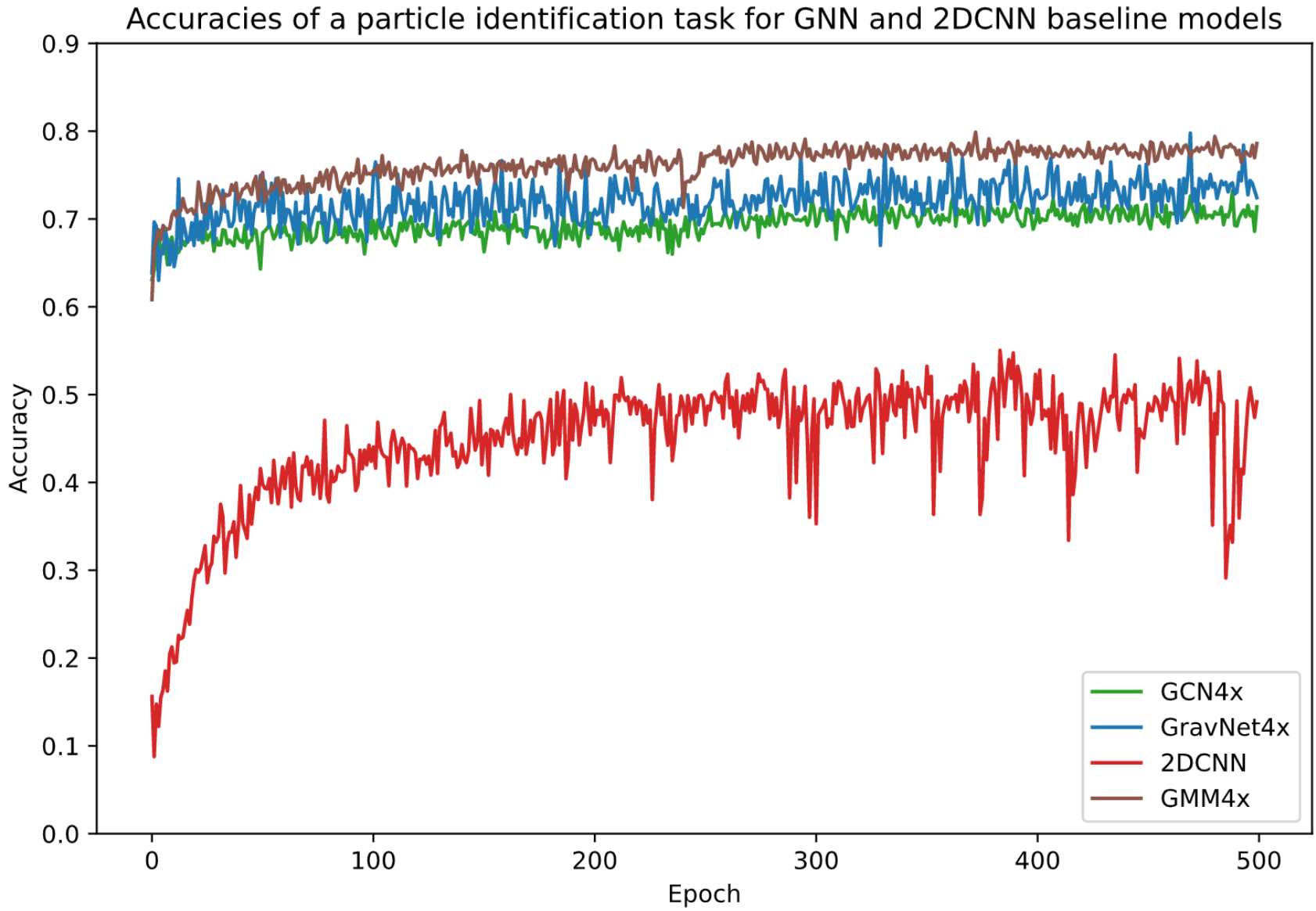
- Very unstable: smaller batch size (200 comparing to 500).
- Very slightly better than GCN (+0.05)
- Time consumption is much higher than other models (10-15 hours 500 epochs).



Comparing with 2D CNN

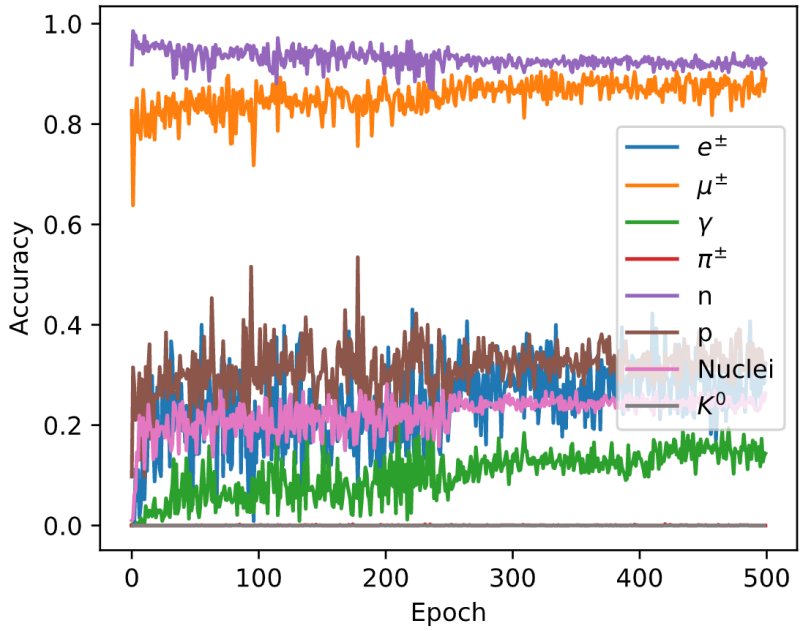
@ 500 epoch

Model	Time usage (hours)	Accuracy
2D CNN	7.67	0.49 ± 0.02
GCN4x	1.33	0.71 ± 0.01
GMM4x	1.86	0.786 ± 0.007
GravNet4x	14	0.72 ± 0.02

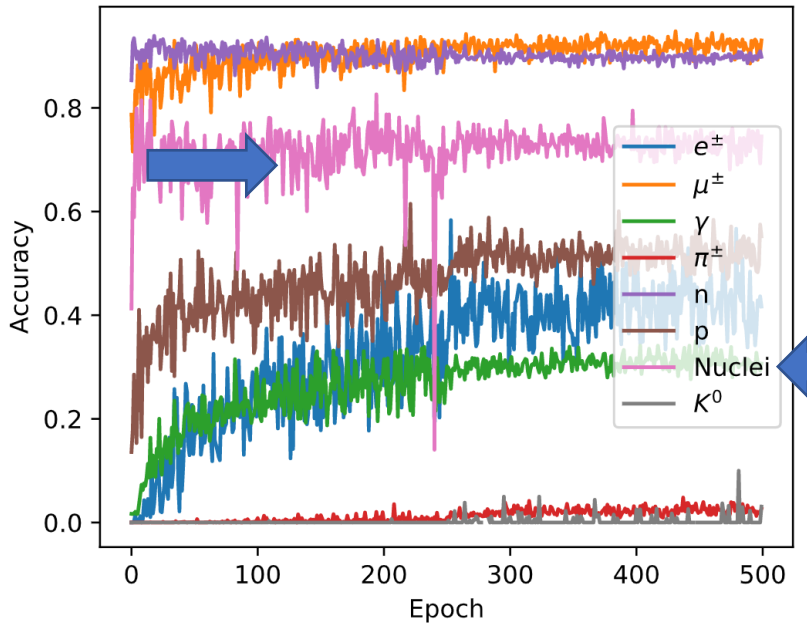


GCN/GMM/GravNet label-wise accuracy

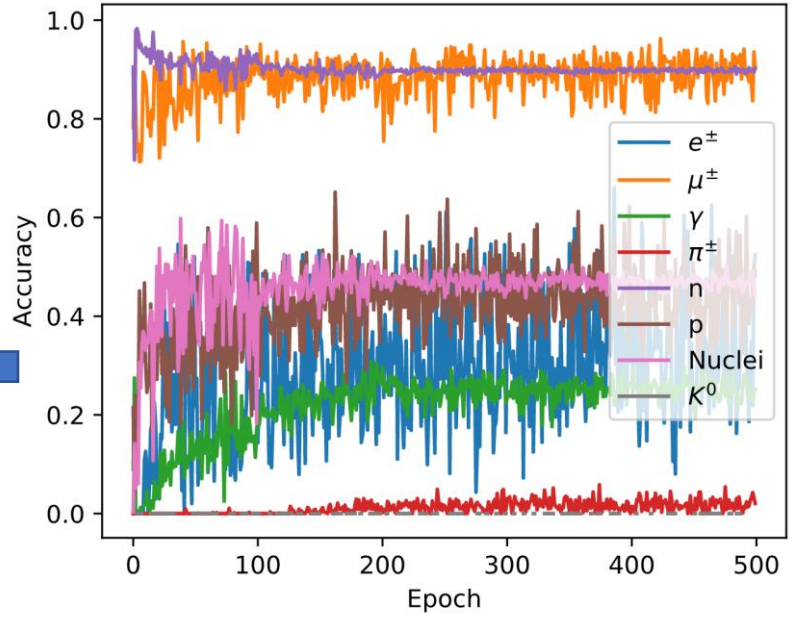
GCN



GMM



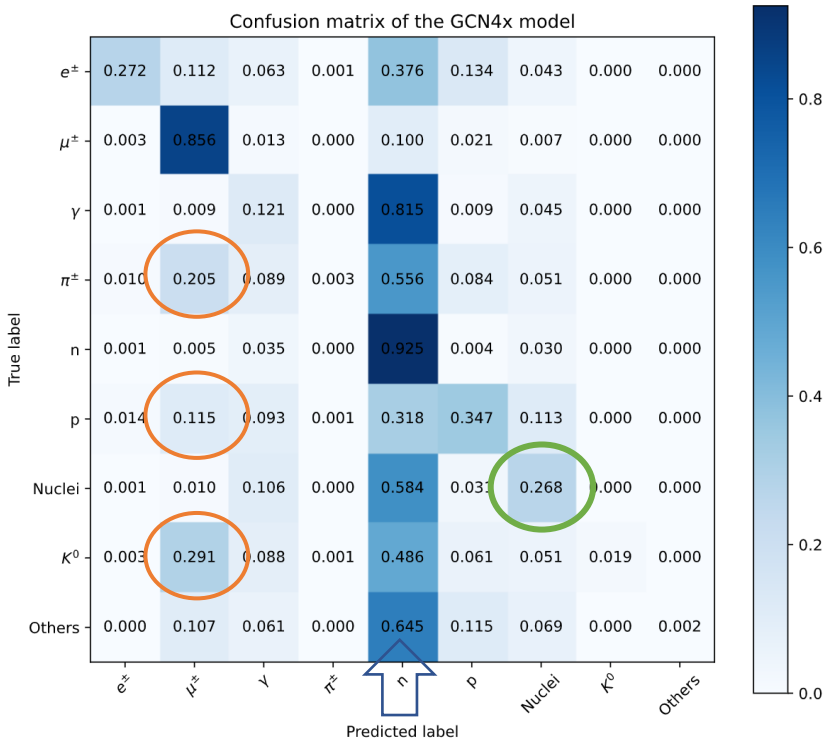
GravNet



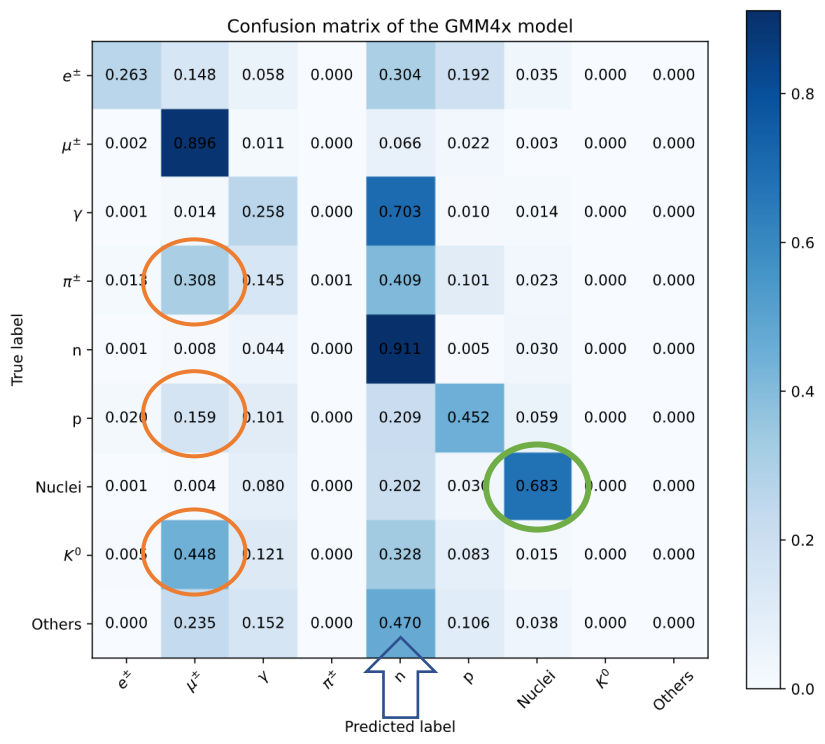
- Muon tracks and neutron clusters are OK.
- Pion track was rare in dataset, not identified by any model.
- Nuclei clusters were identified but slightly wrong size.

GCN/GMM/GravNet confusion matrix

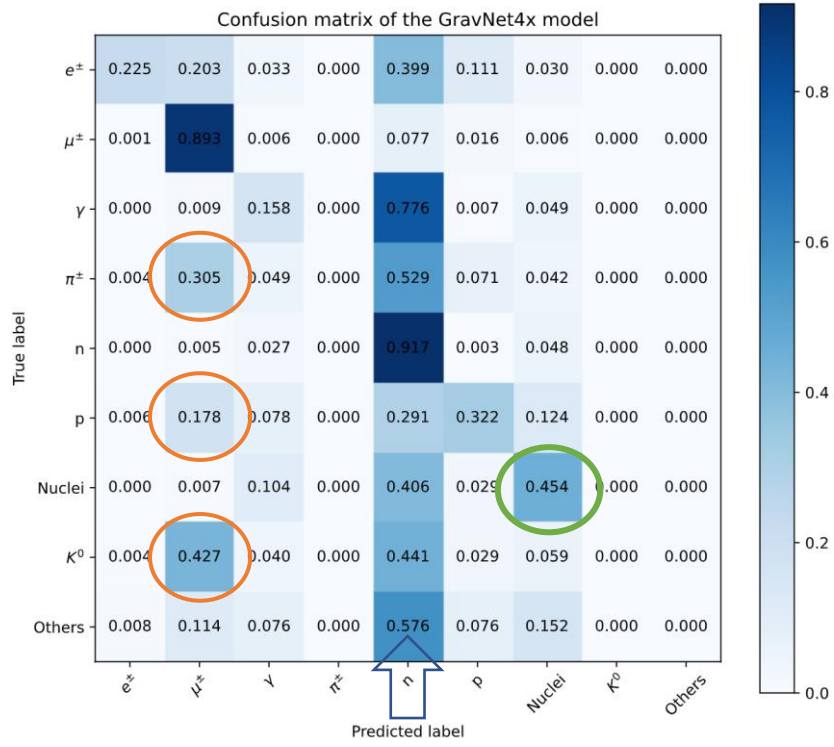
GCN



GMM



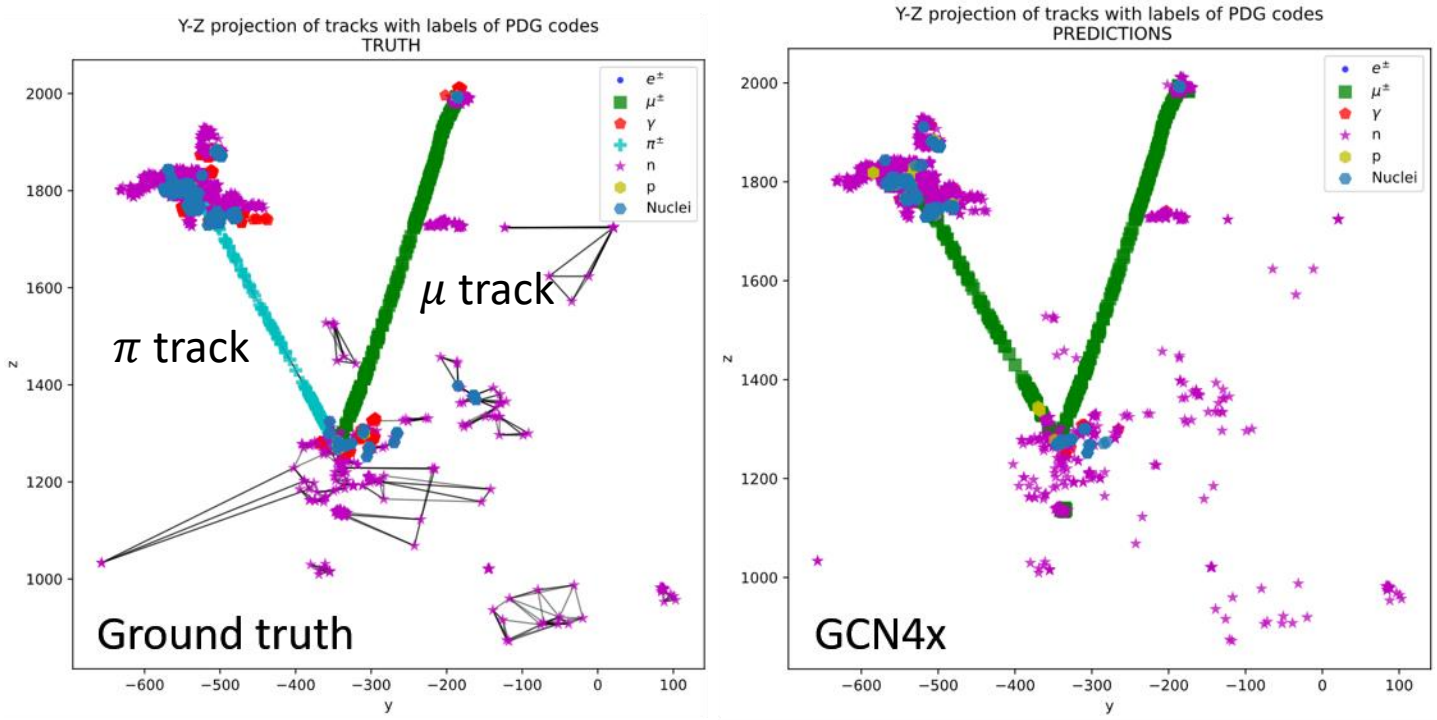
GravNet



- Muon hits high false positive rate.
- Pion, proton and kaon tracks mistakenly predicted as muon.
- Nuclei well predicted by GMM

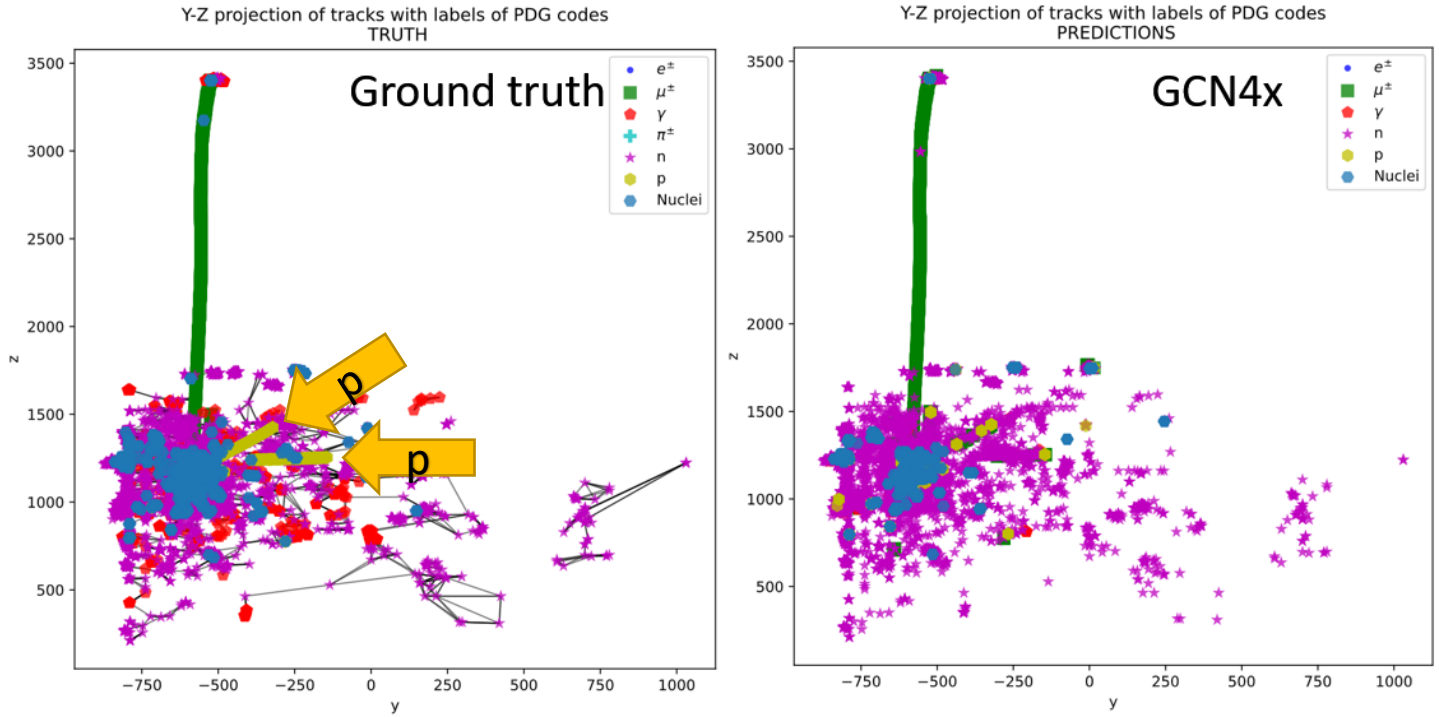
Event-wise analysis on tracks

- Muon tracks and neutron clusters are OK.
- π track was rare in dataset, not identified by any model.
- Nuclei clusters were identified but slightly wrong size.



Event-wise analysis on clusters

- Muon tracks OK.
- Proton tracks embedded inside neutron clusters and were hardly identified in GCN4x or GMM4x. GravNet4x almost got one of the tracks.
- GCN4x underestimated nuclei clusters size.



Limitations

- Graph construction (edges)
  - Dynamic graphs/ differential graph generation
  - Minimum spanning tree to force connections
- Neural network layers
  - Try Graph Attention Network
- Dataset
  - Involve more events (currently 880)
  - Realistic data, e.g. uncertainty in measurements
  - Semi-supervised training (no ground truth if from detectors)

Thank you

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