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ESS neutrino Super Beam plus

Co-funded by the European Union

Classification of ESSνSB WC Near Detector Events Using Graph Neural Networks

ν_μ- and ν_e-events for neutrino oscillation studies

Kaare Endrup Iversen - Lund University

GNN Classification of ESSνSB events

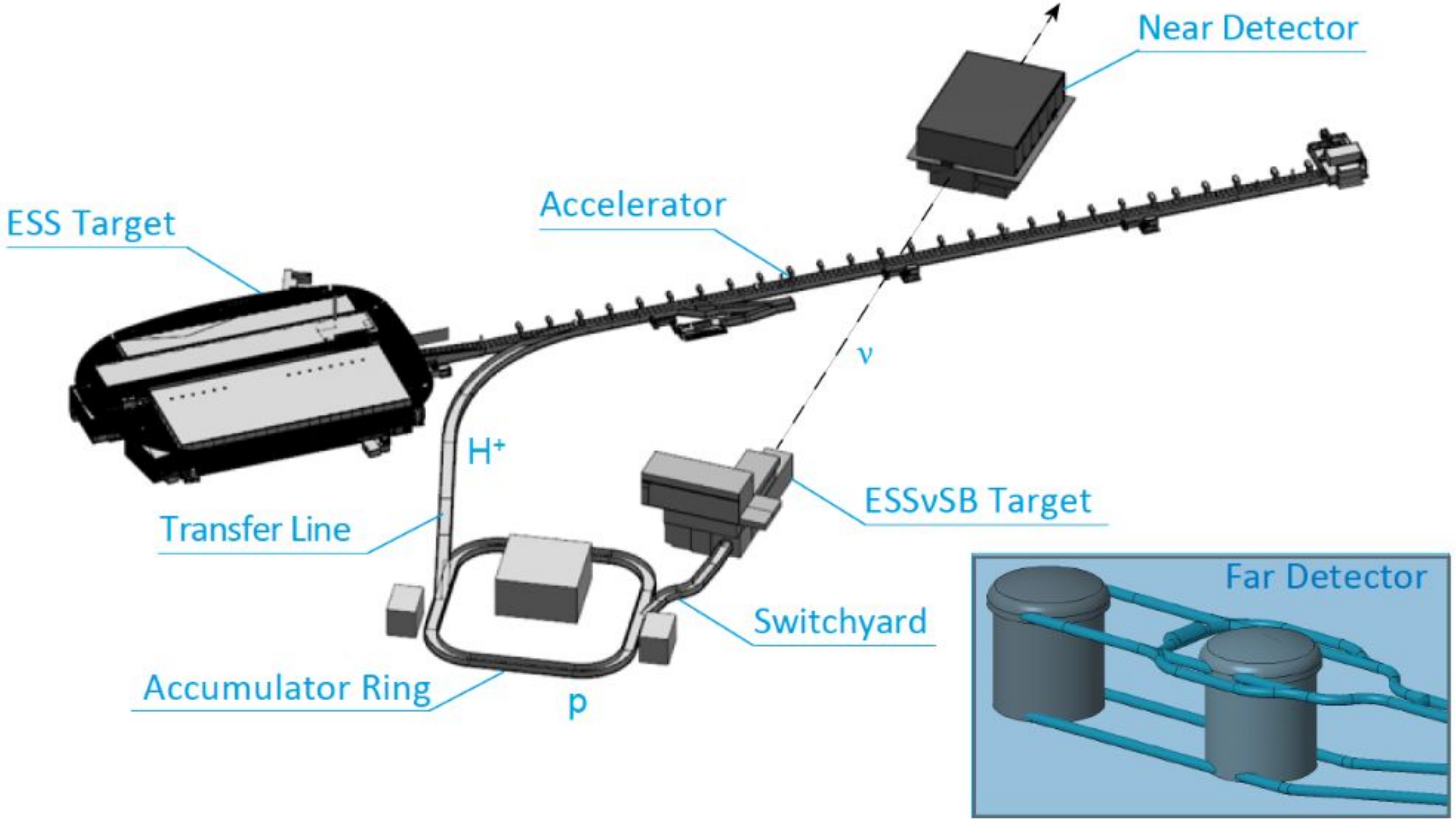
- ESSνSB - An accelerator neutrino experiment in Sweden
- Current framework and motivation
- Graph neural networks and implementation

- Classification performance
- Generalisation

Motivation

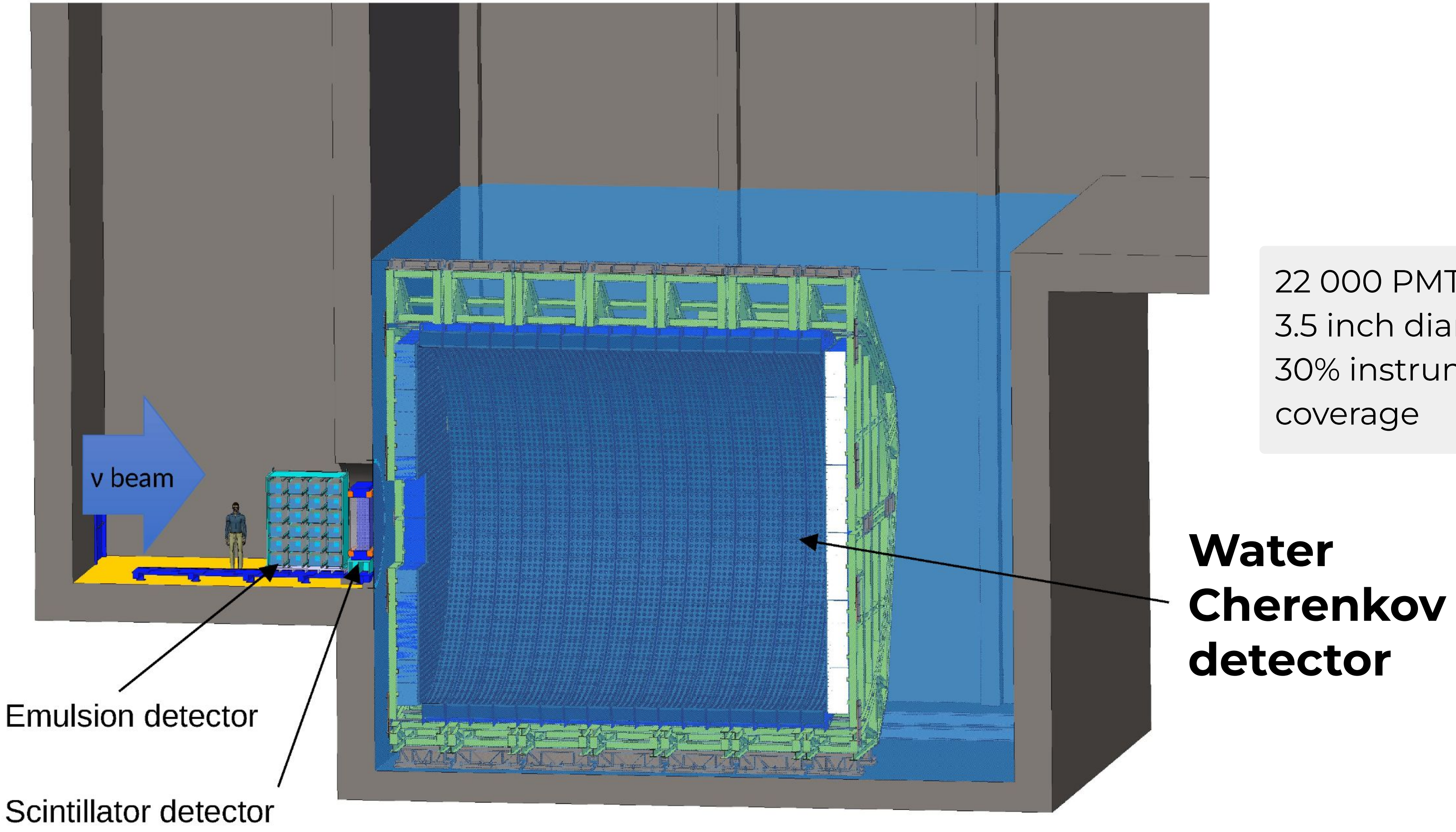

ess

ESSnuSB - Detectors



The European Spallation Source neutrino Super Beam Conceptual Design Report

ESSnuSB - Near Detectors



22 000 PMTs
3.5 inch diameter
30% instrumentation coverage

[The European Spallation Source neutrino Super Beam Conceptual Design Report]

Current Framework

Charged Lepton Simulations

WCSIM
https://github.com/WCSim/WCSim

Neutrino Interaction Simulations

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Generator. Nucl. Instrum. Meth. A 614:87–104, 2010

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LLH Based Reconstruction

fiTQun
J. Phys.: Conf. Ser. 888 012066, 2017

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- Likelihood reconstruction takes ~1 CPU min/event
- To explore different detector proposals, fast reconstruction is crucial

Why Do We Need GNN Reconstruction?

- Fast and reliable event reconstruction enables testing of different detector layouts
- LLH-based methods are accurate, but reconstruction is slow
- Multiple reconstruction methods provides a way to cross check and find systematic errors

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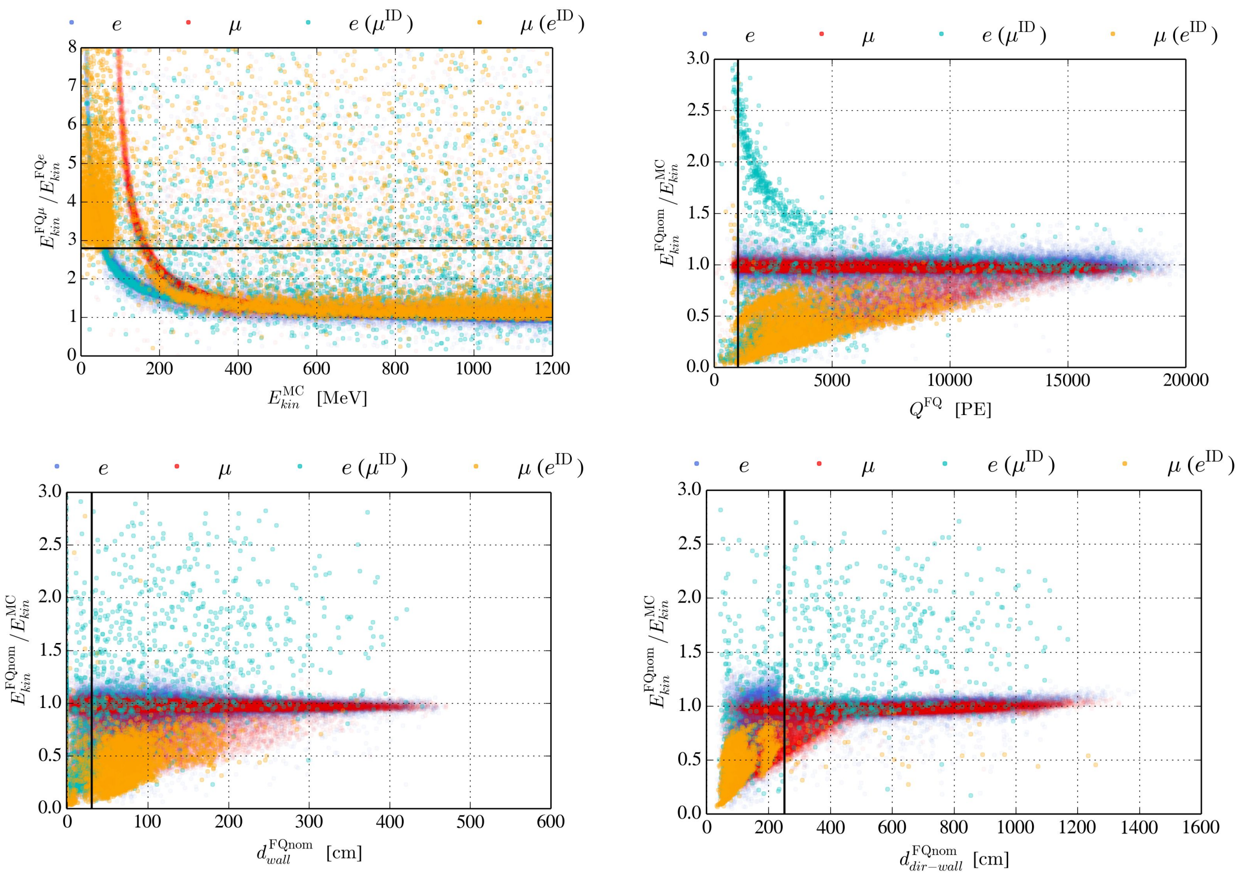
Data processing

- Cuts based on **reconstructed variables**
- Removes events that are **hard to classify**
- Reduces number of events by a **factor ~2**



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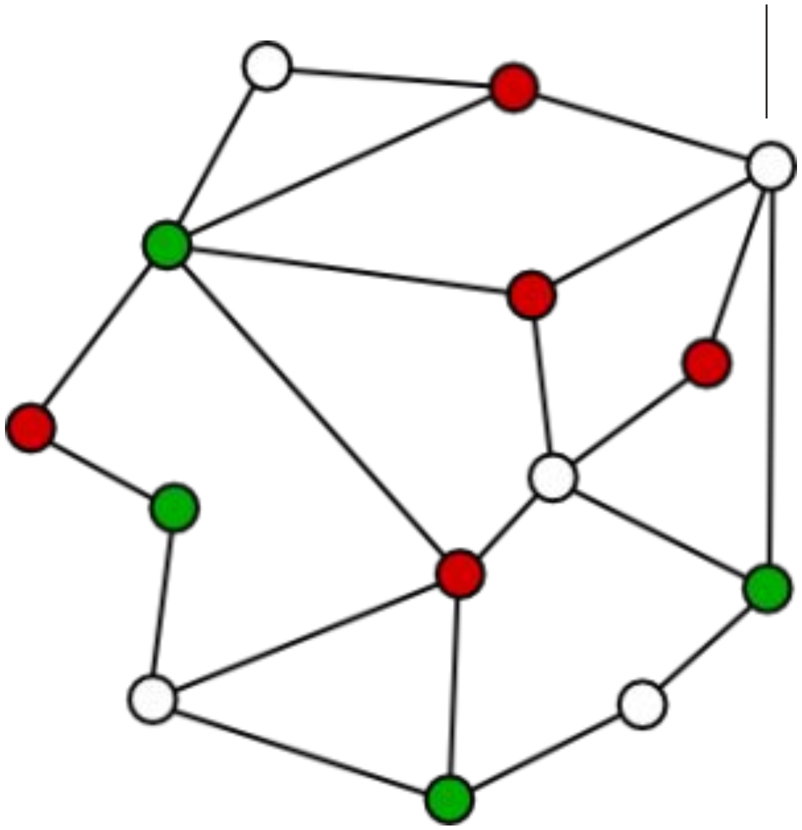
Graph Neural Networks

Graph Neural Networks

- Based on graph theory
- Each **graph** is a **neutrino event**
- Each **PMT hit** is a **node**
- A node features: **xyz, time, charge**

- Suited for non-euclidian data

Node = Data point
In our case a DOM hit



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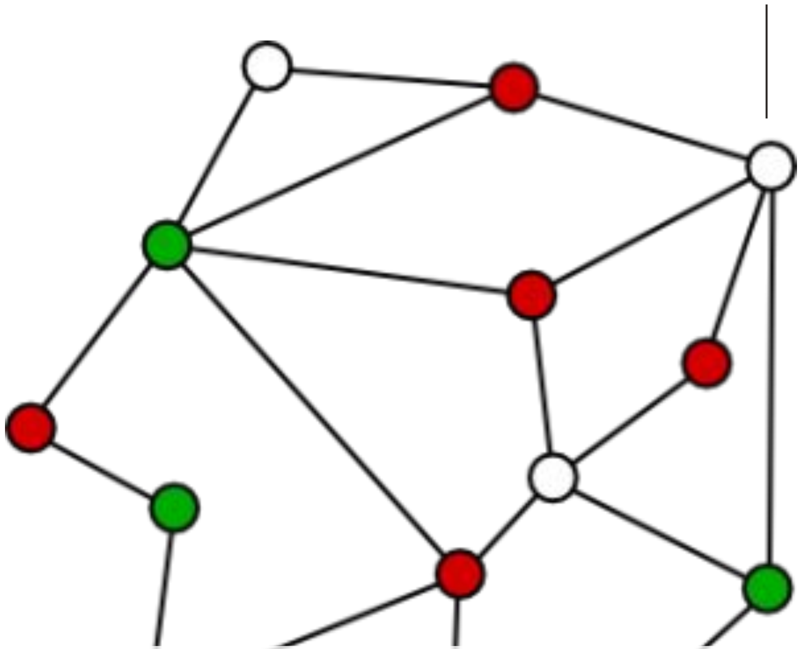

GraphNeT - Graph Neural Networks for Neutrino Telescopes

https://github.com/graphnet-team/graphnet

GraphNeT: Graph neural networks for neutrino telescope event reconstruction (Søgaard et al)

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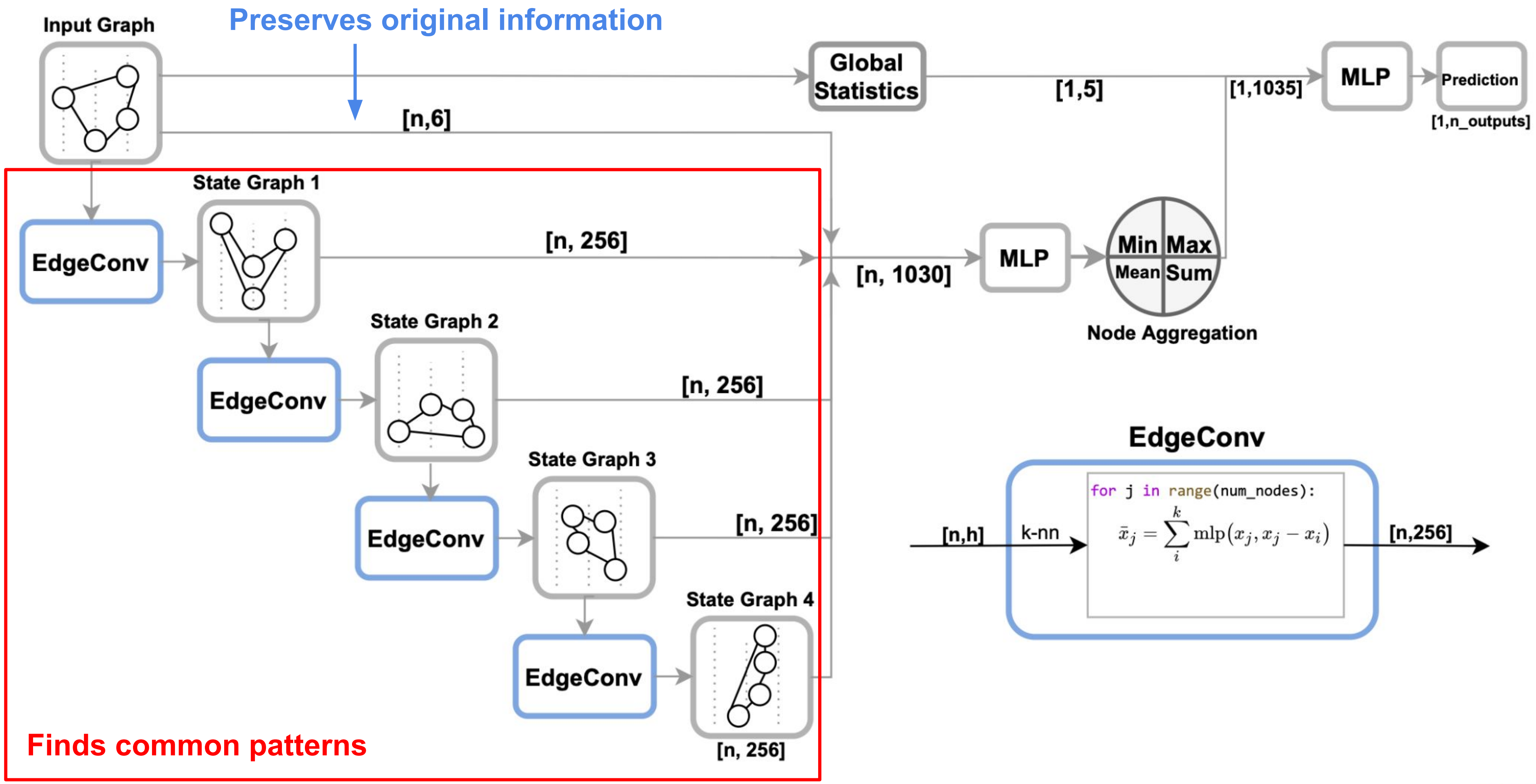
Graph Neural Networks - Architecture



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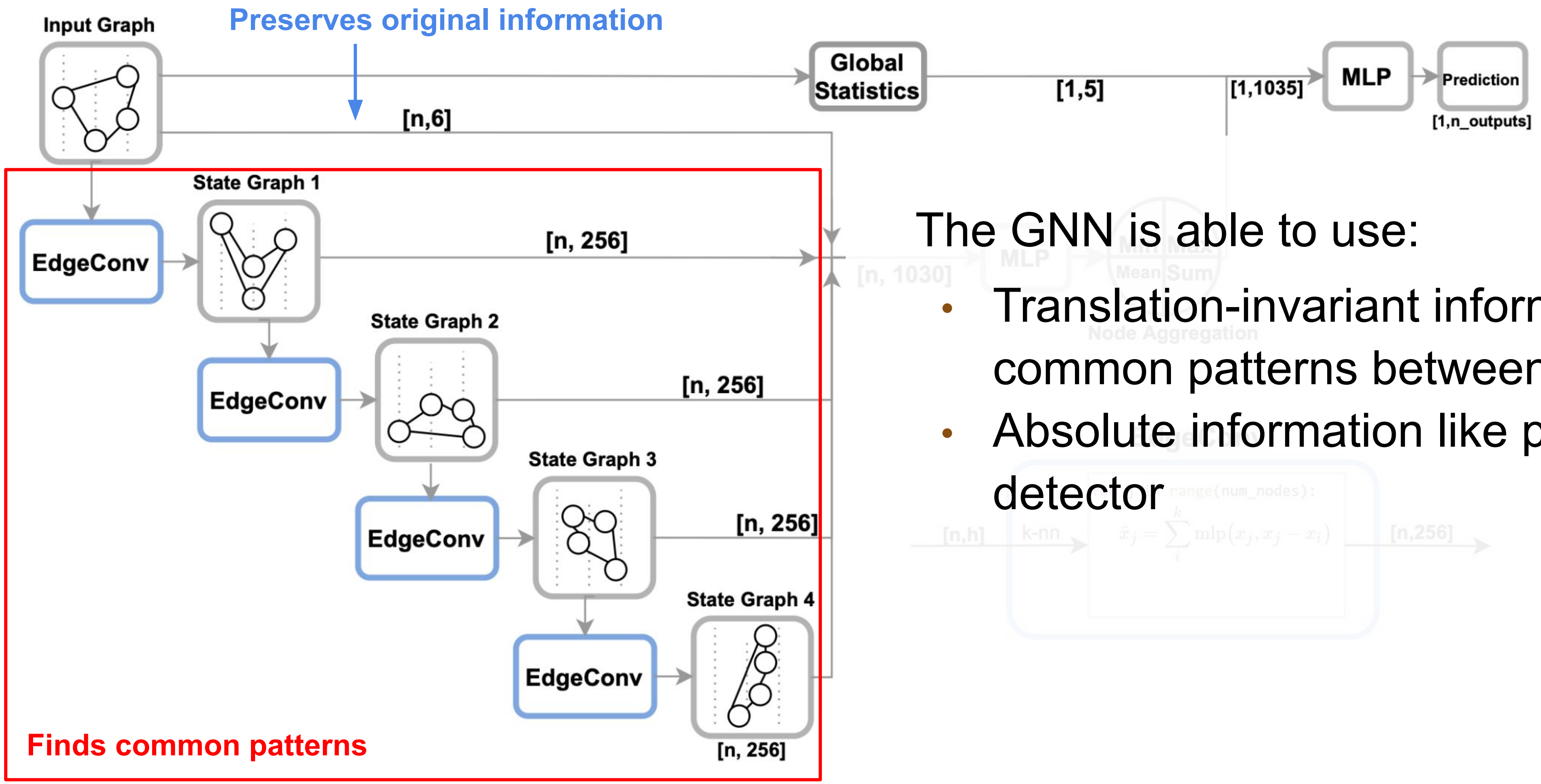
Graph Neural Networks - Architecture



The GNN is able to use:

- Translation-invariant information about common patterns between events
- Absolute information like position in the detector

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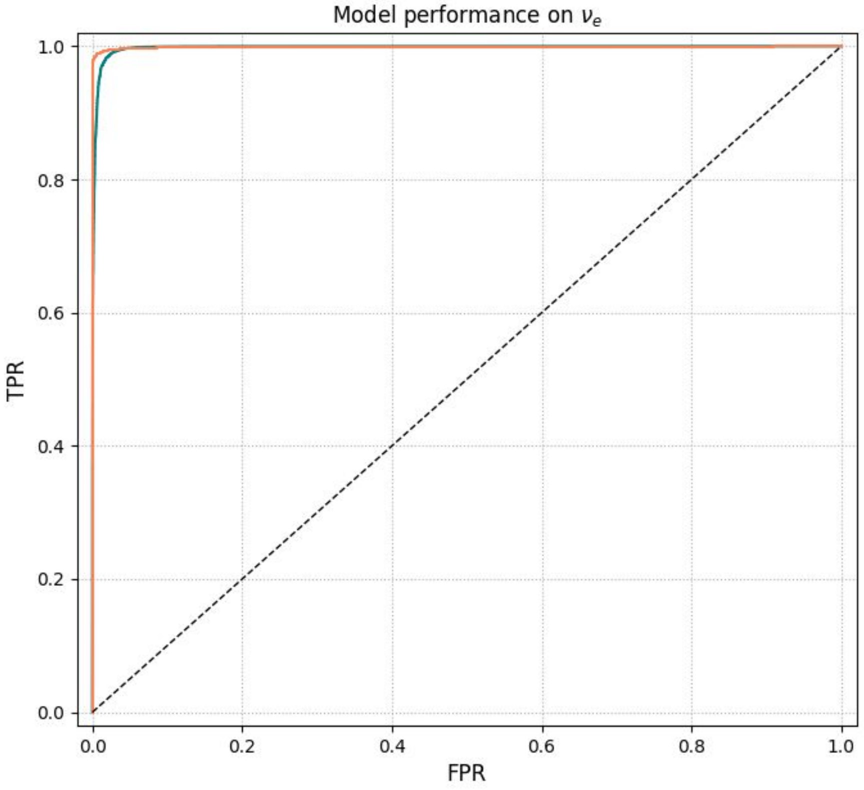
Classification Performance

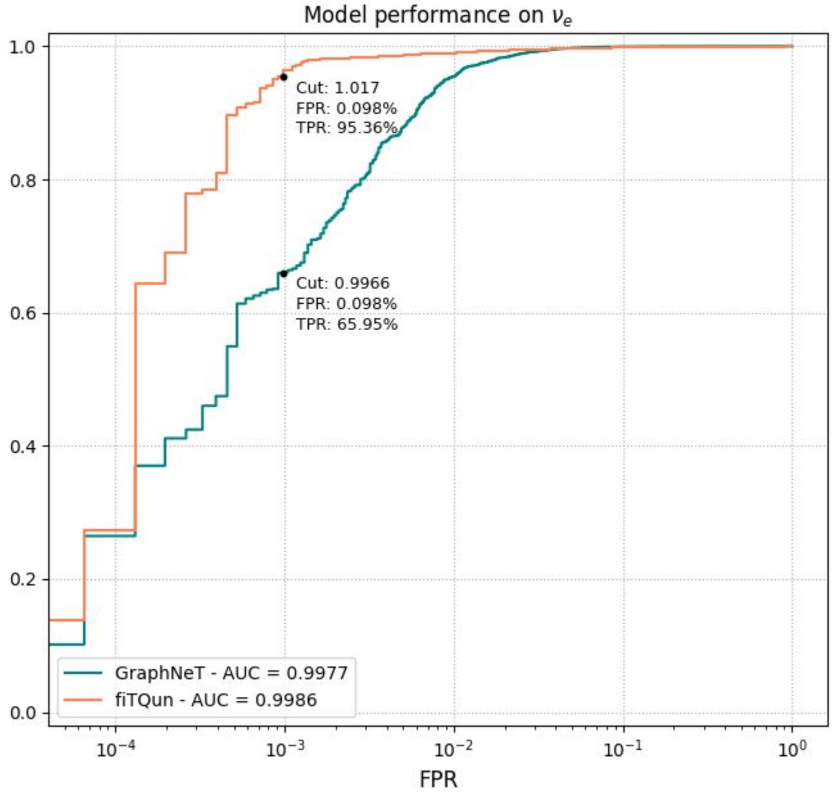
Event Classification Performance

With cuts

ROC Curve



ROC Curve with logarithmic x axis



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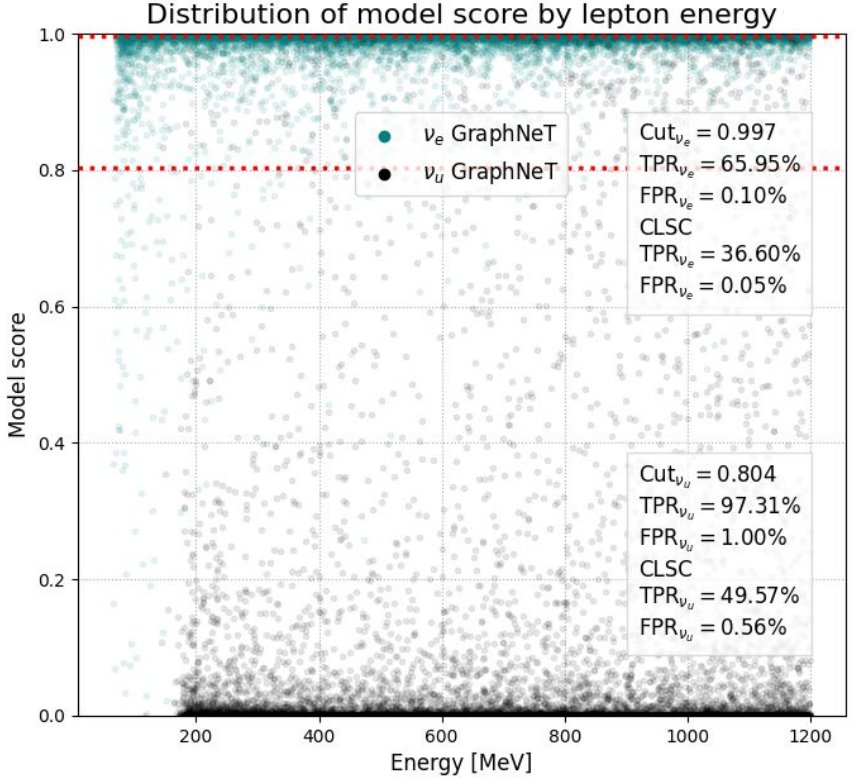
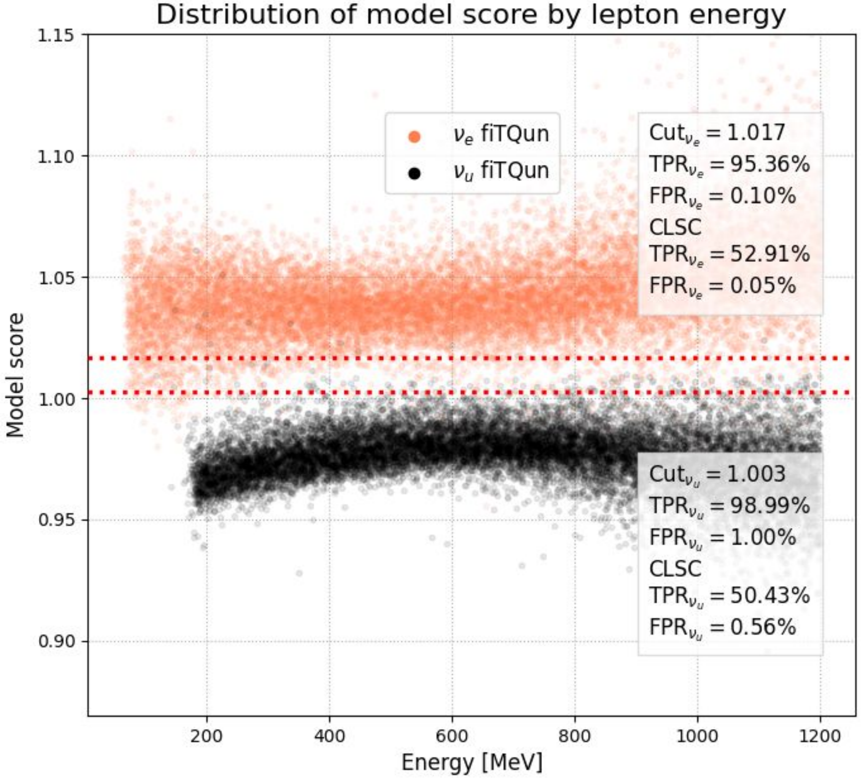
Event Classification Performance

With cuts

GraphNeT performance



fiTQun performance



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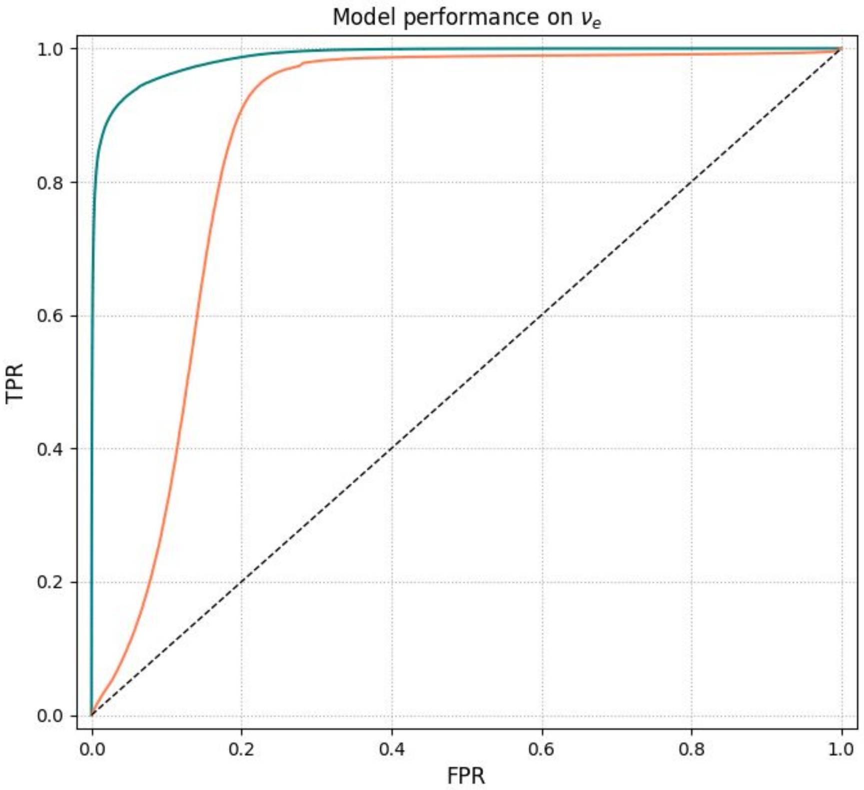
Event Classification Performance

Without data cuts

ROC Curve



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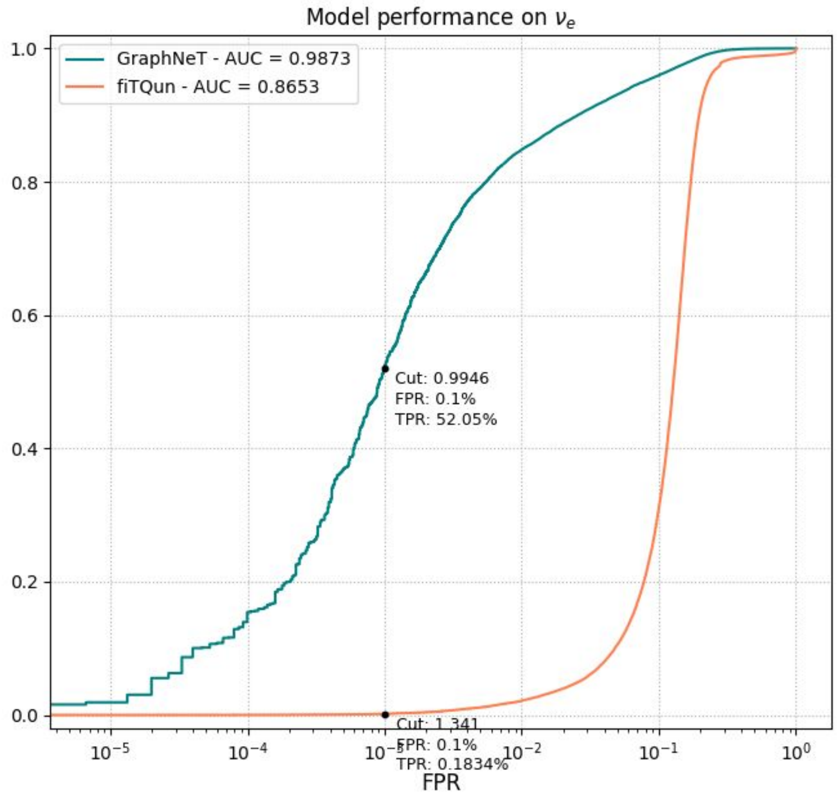
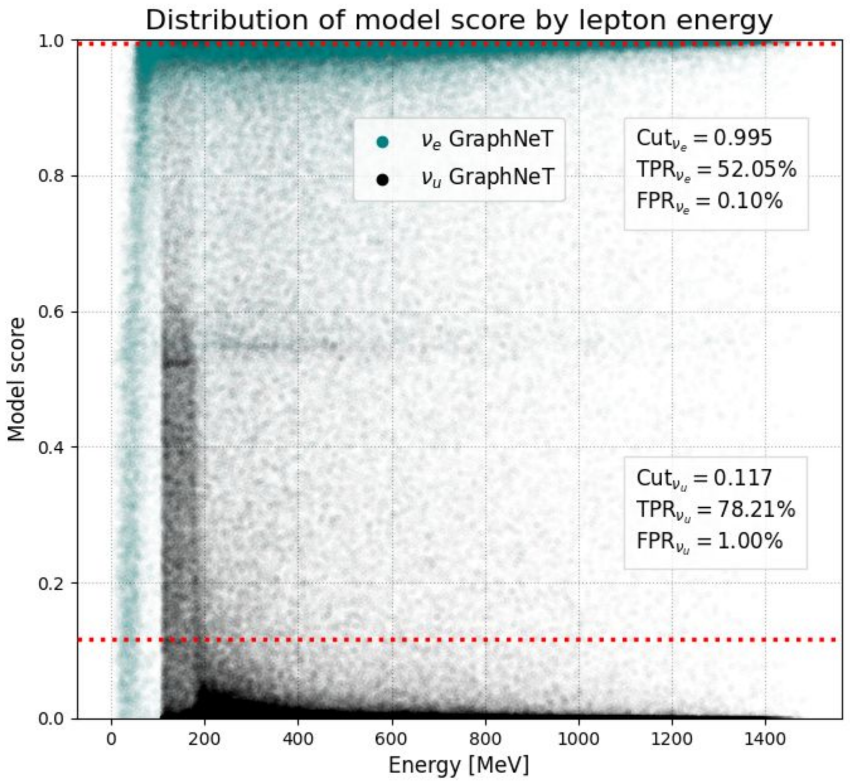


Event Classification Performance

Without data cuts

GraphNeT performance



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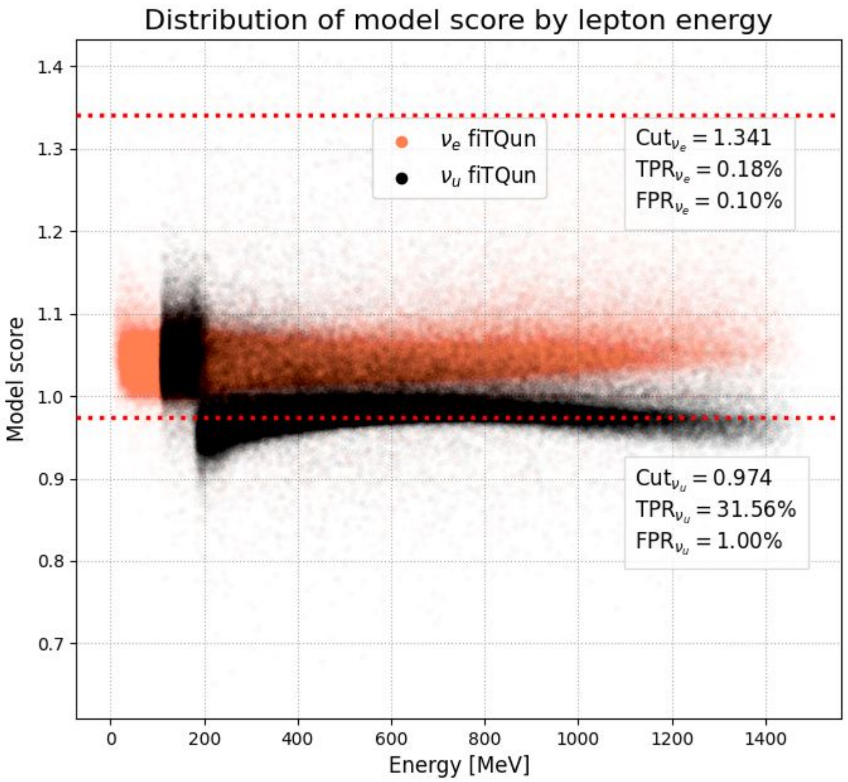

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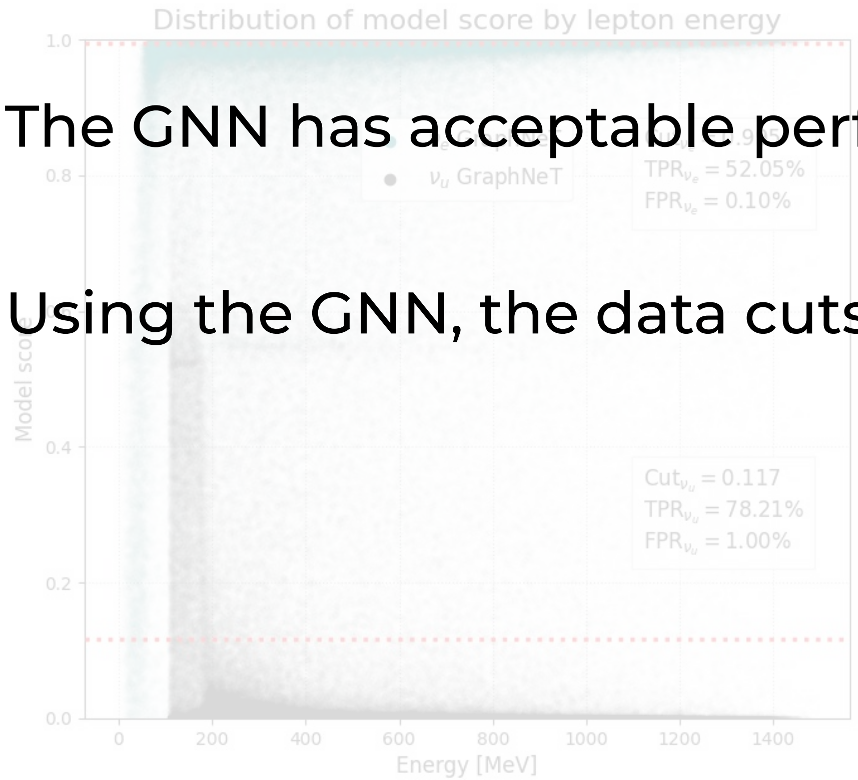
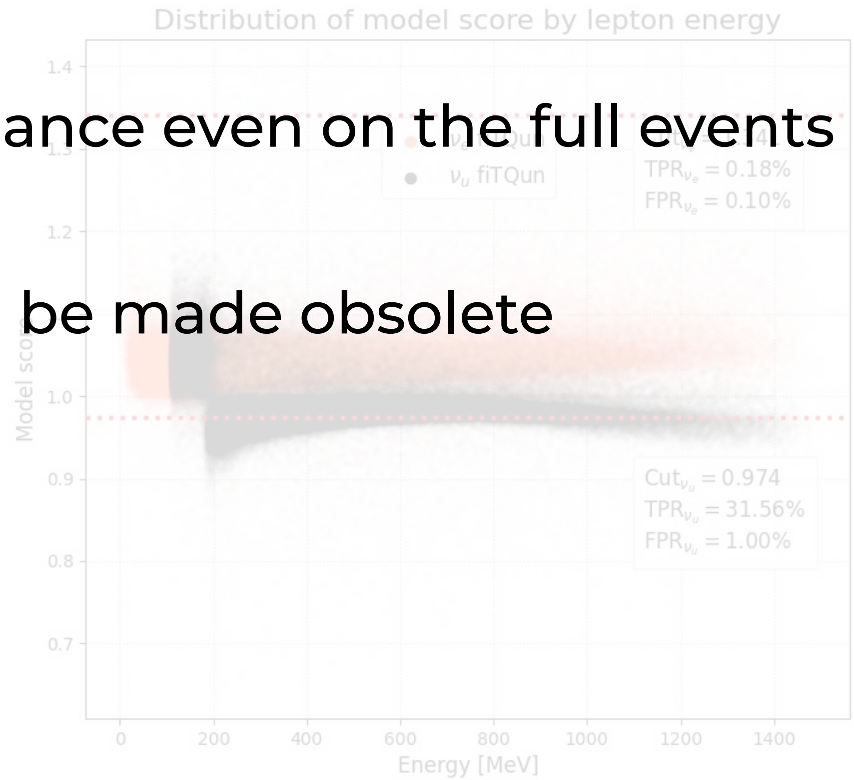
Event Classification Performance

- The GNN has acceptable performance even on the full events
- Using the GNN, the data cuts can be made obsolete





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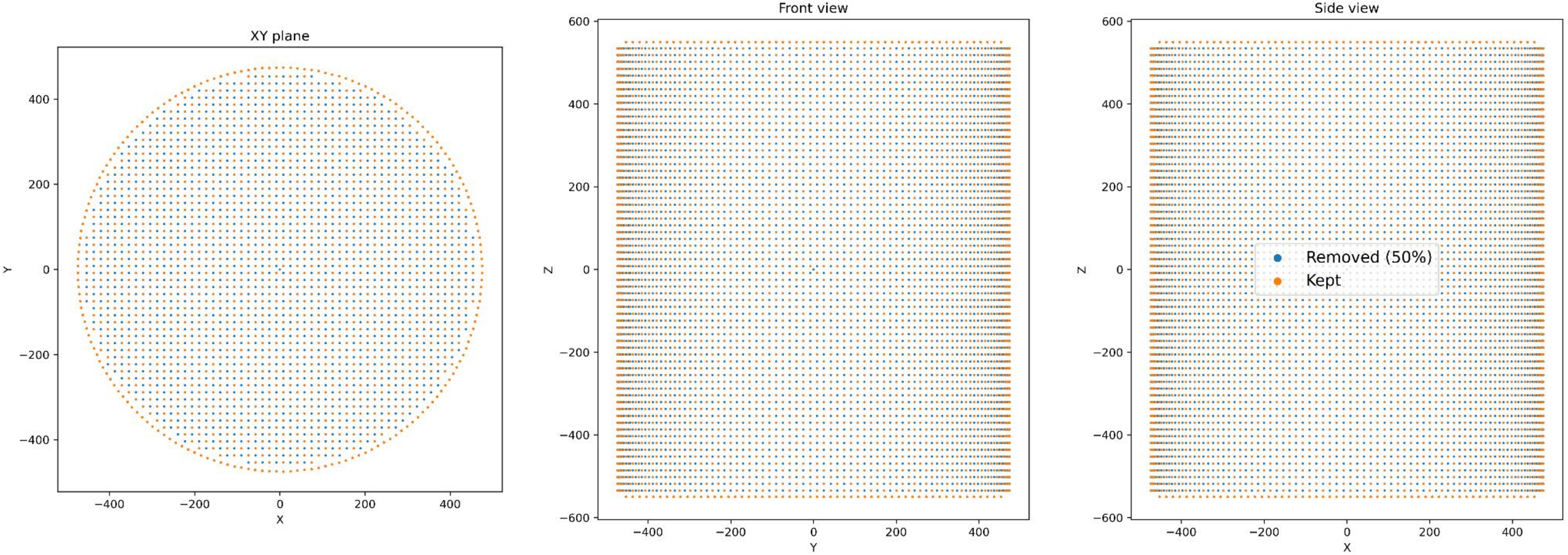
Generalisation

Generalisation



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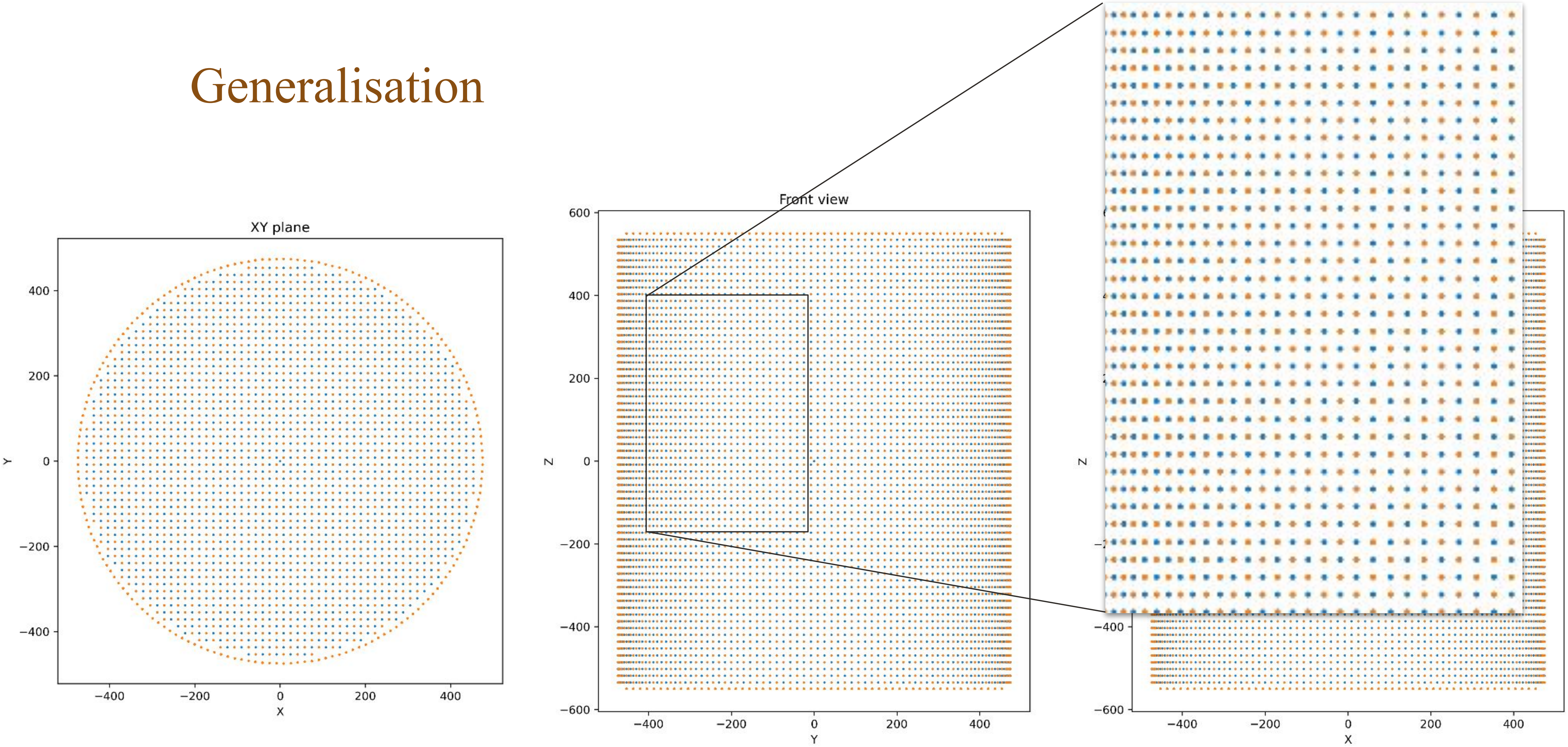

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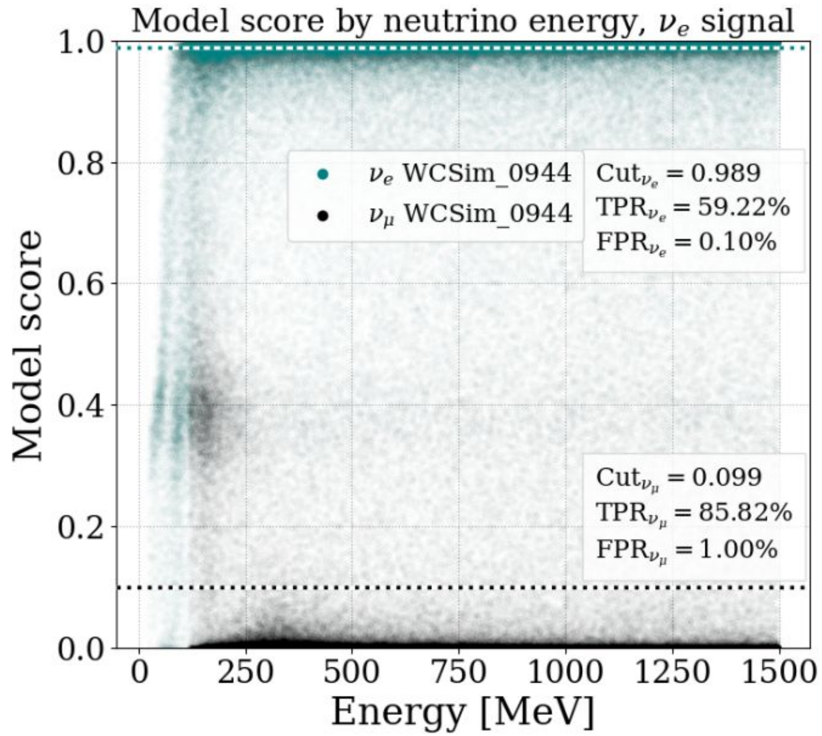
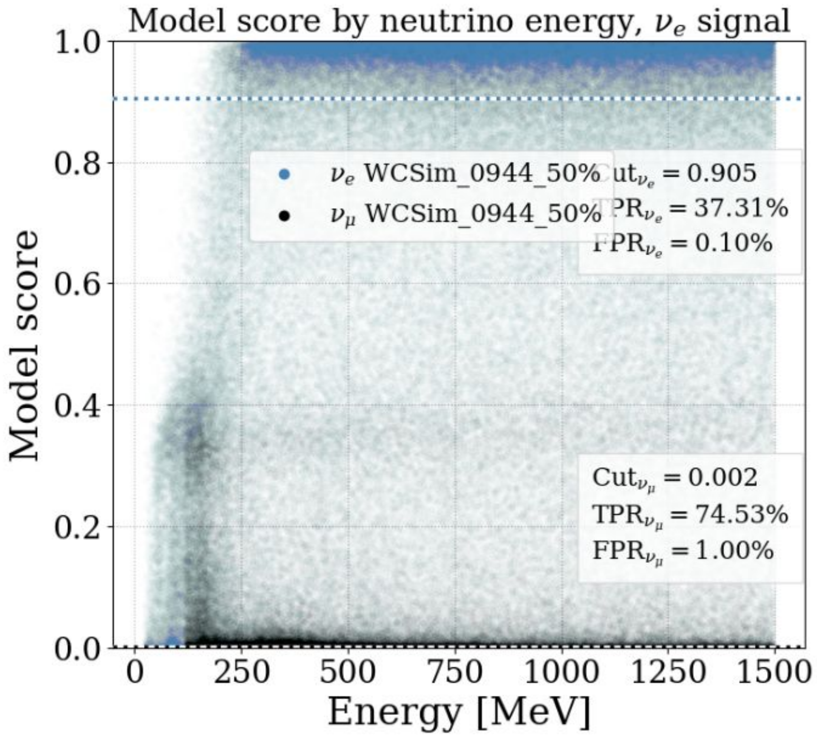
Generalisation

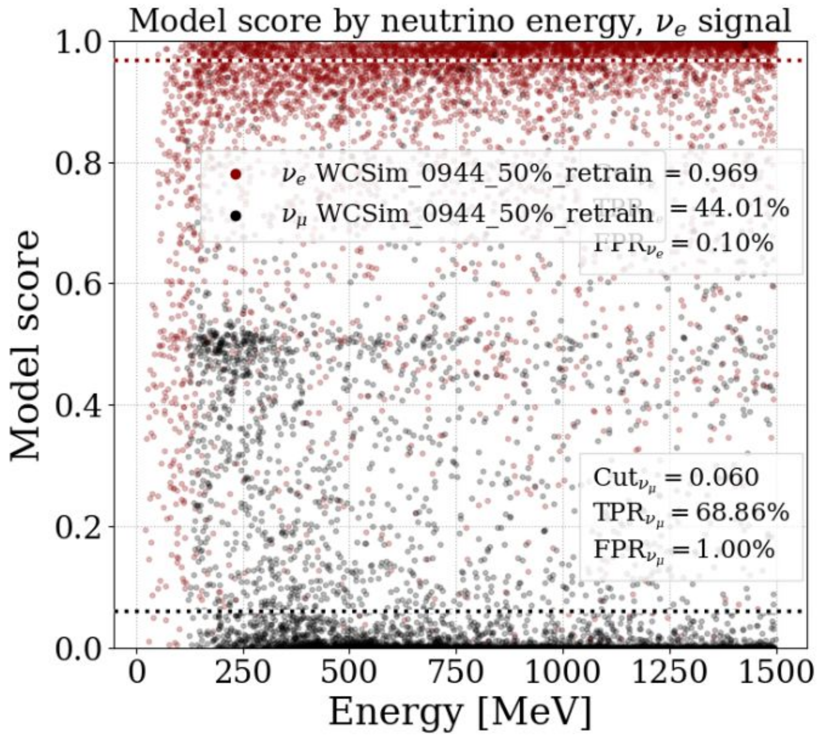
Original PMTs



50% PMTs
Original model



50% PMTs
Retrained model



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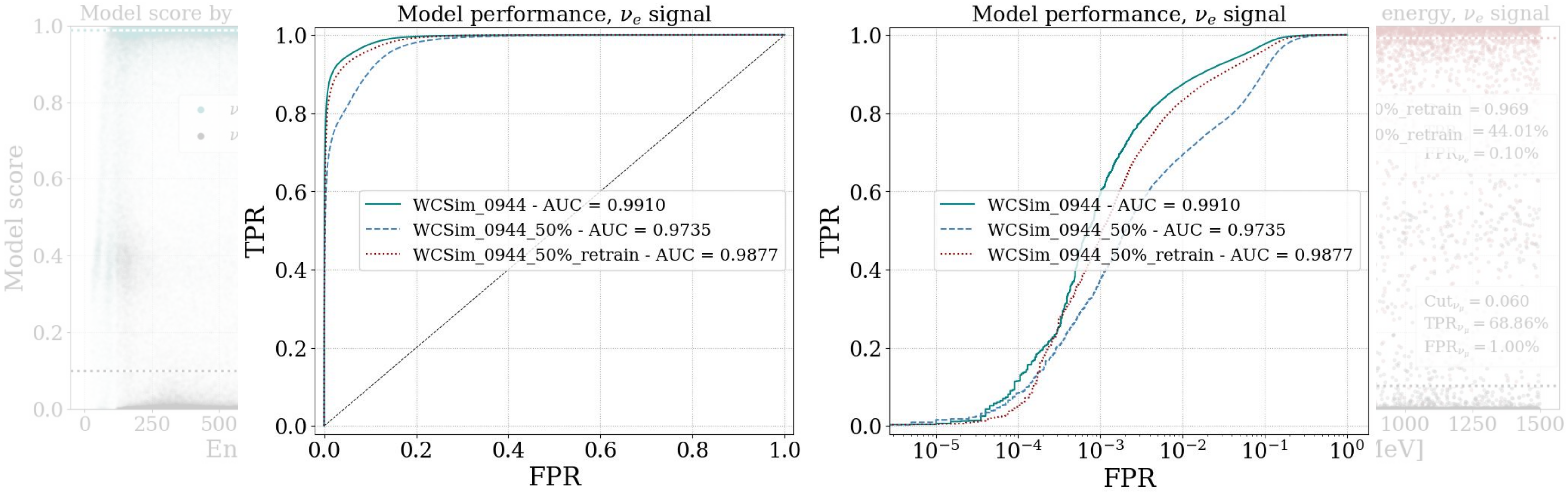

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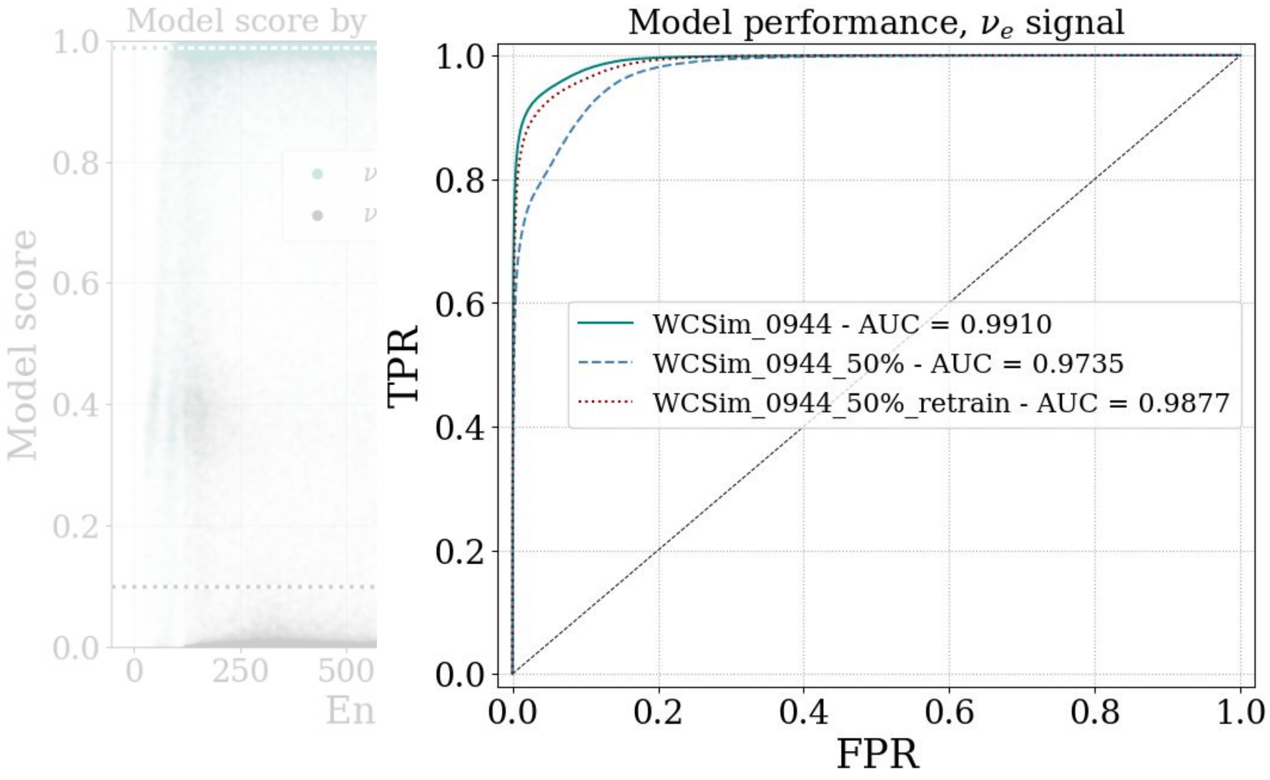

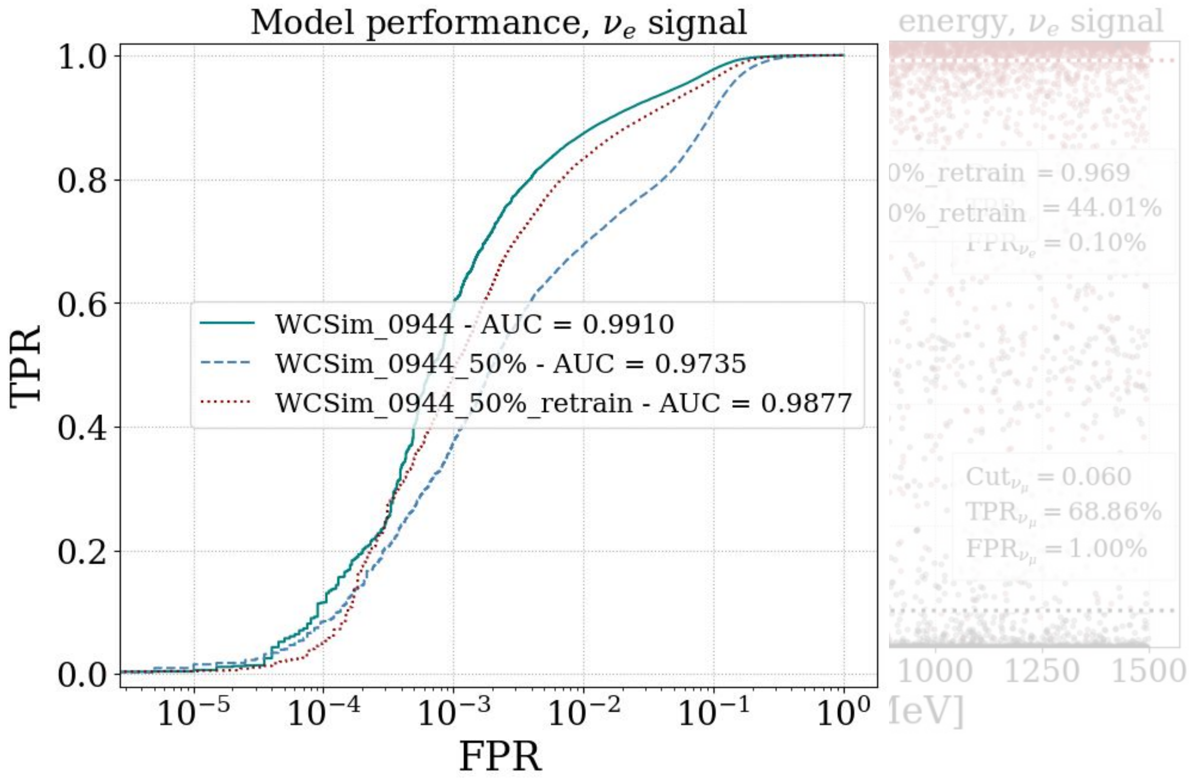

What if we don't switch off all PMTs uniformly?

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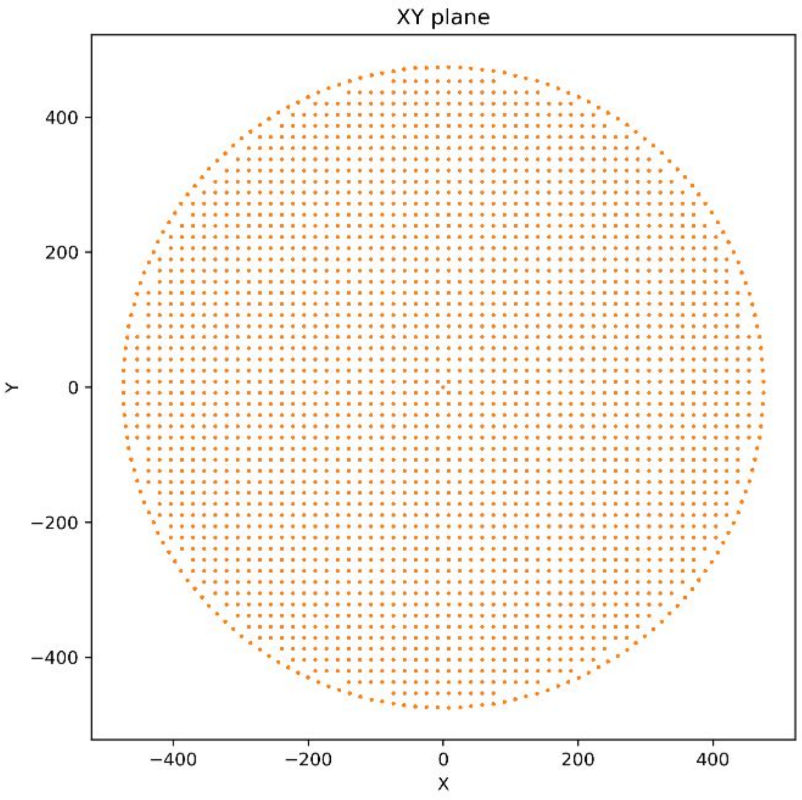
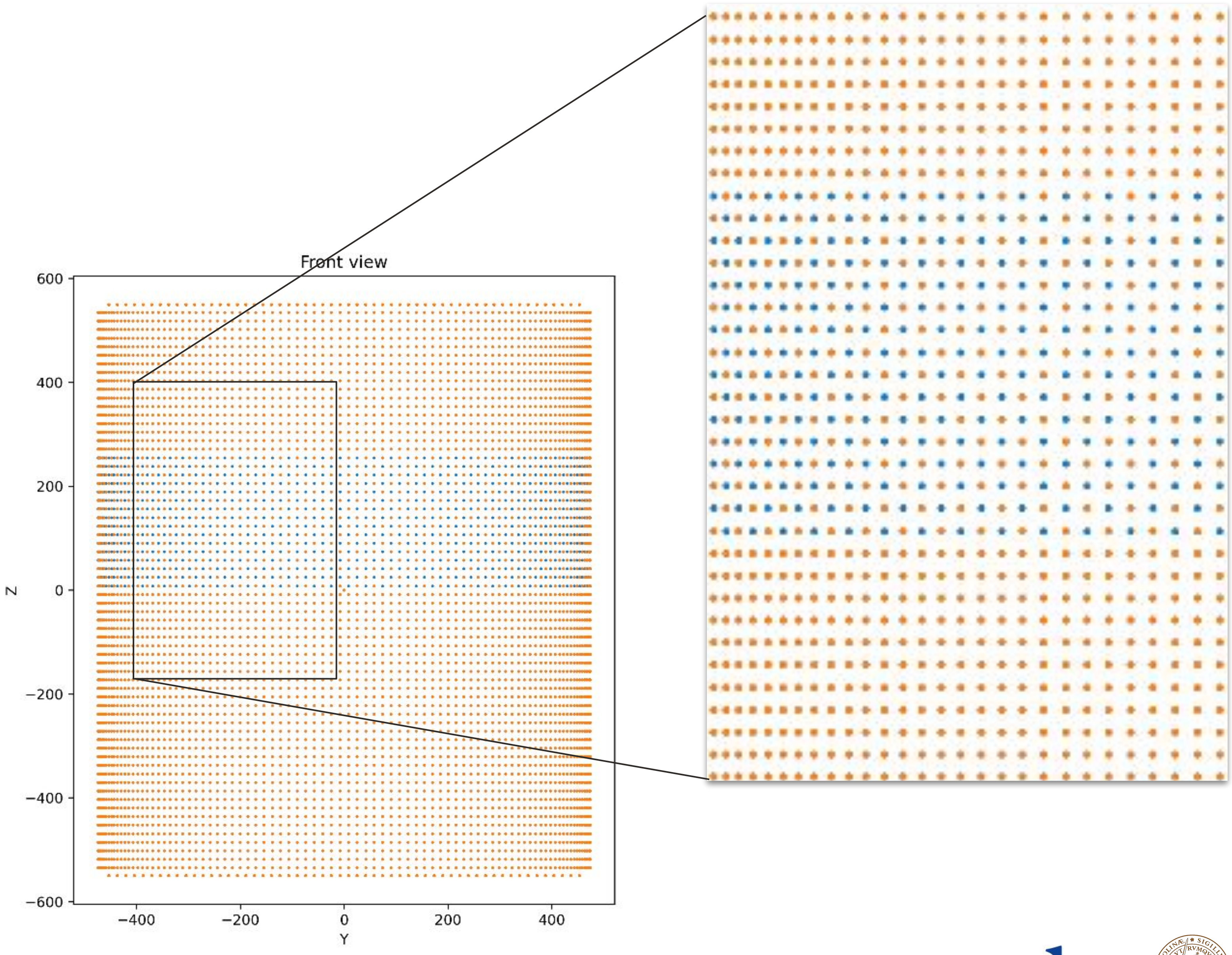
Generalisation





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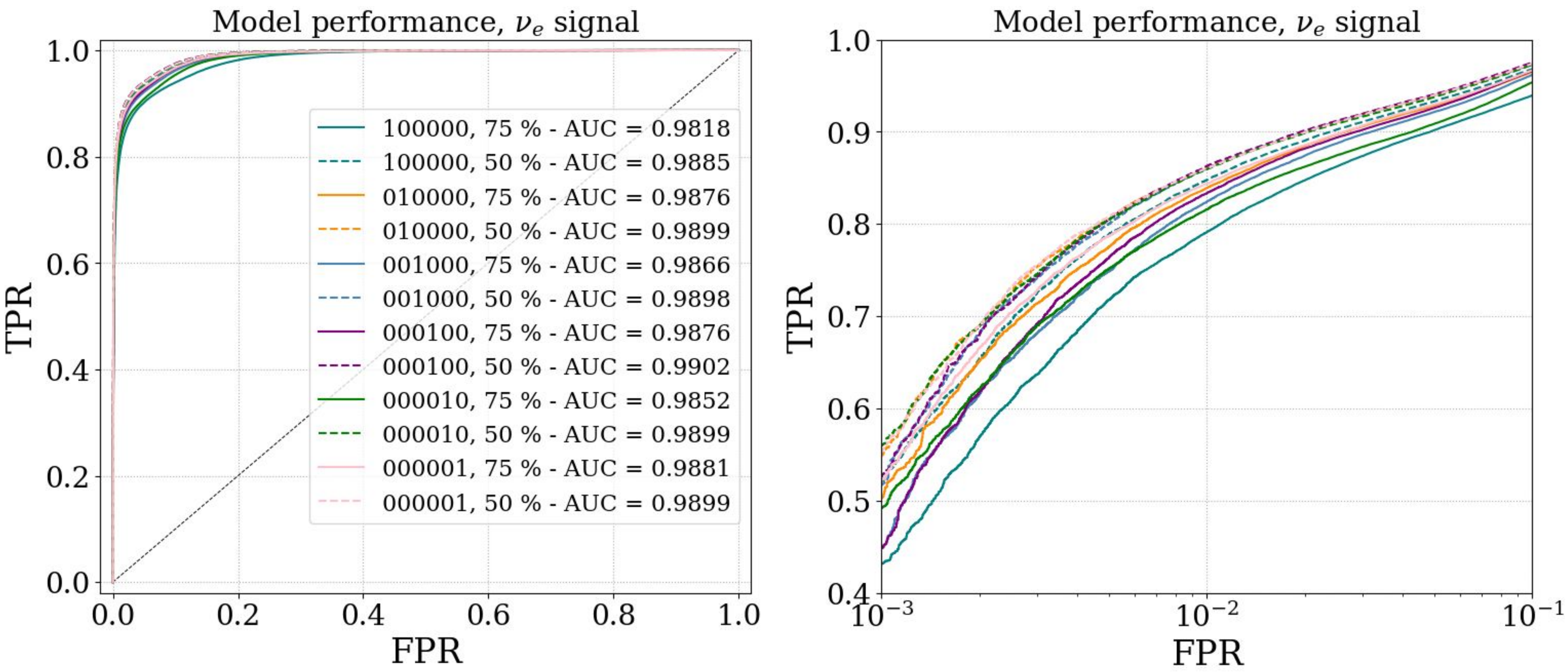

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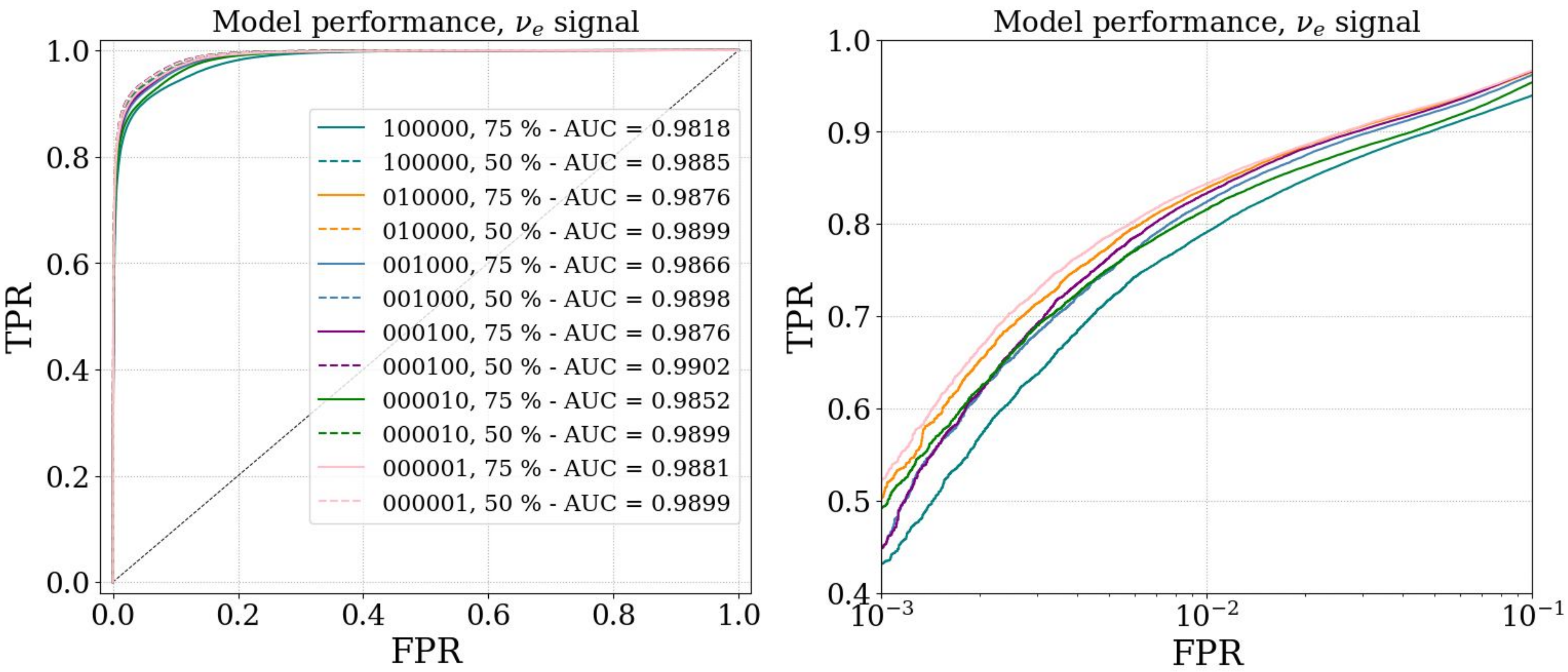

Summary

- GNNs can match fiTQun and outperform on difficult topologies
- Fast reconstruction can aid detector design

  - **not all PMTs are created equal**

Next steps

- Qualify PMT importance with simulation information
- Use more complex schemes to adjust PMTs
- Investigate event topologies of “difficult” events

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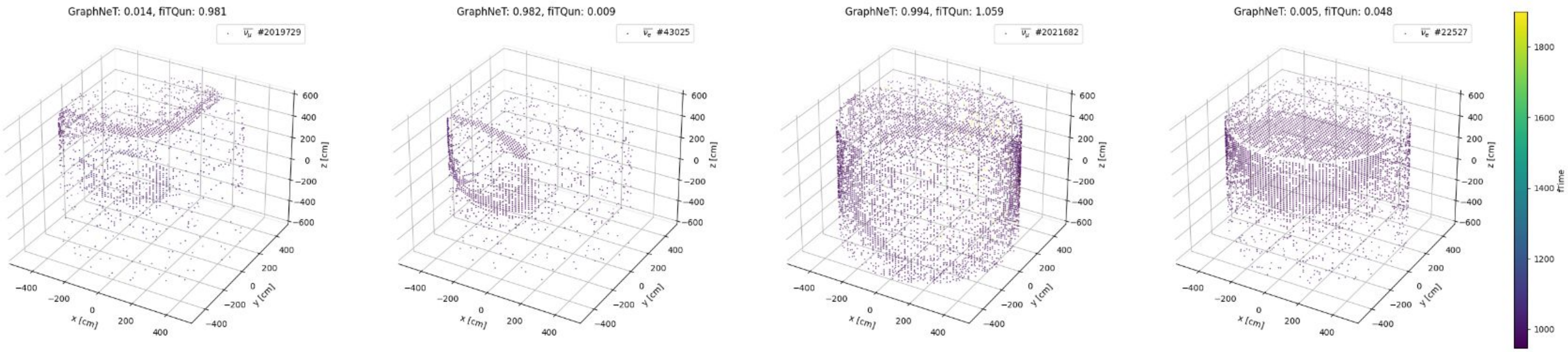
Thank you!

Backup Slides

Factors impacting performance - multiple charged lepton signatures

Neutrino event simulations - **with** data cut



GNN > fiTQun

fiTQun > GNN

Both wrong

Both correct

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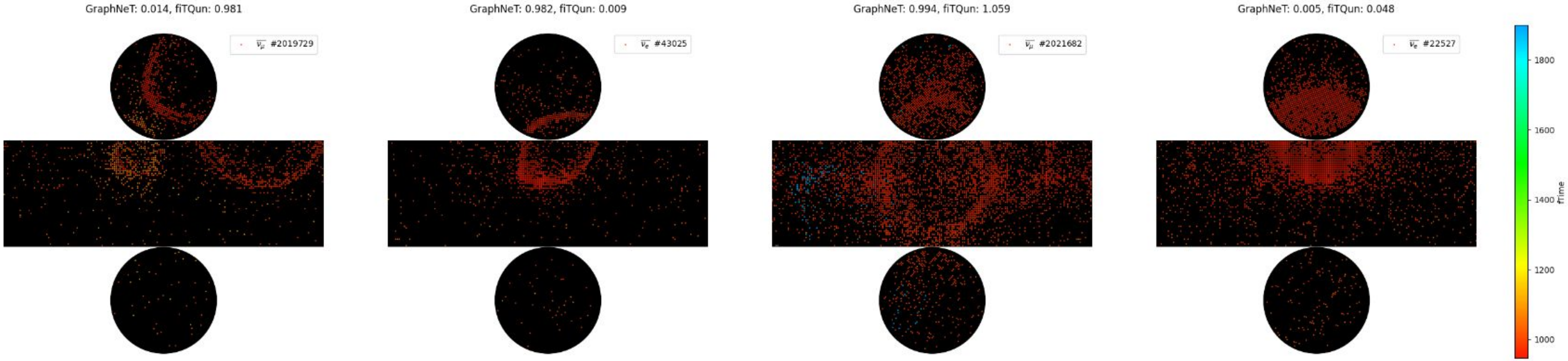

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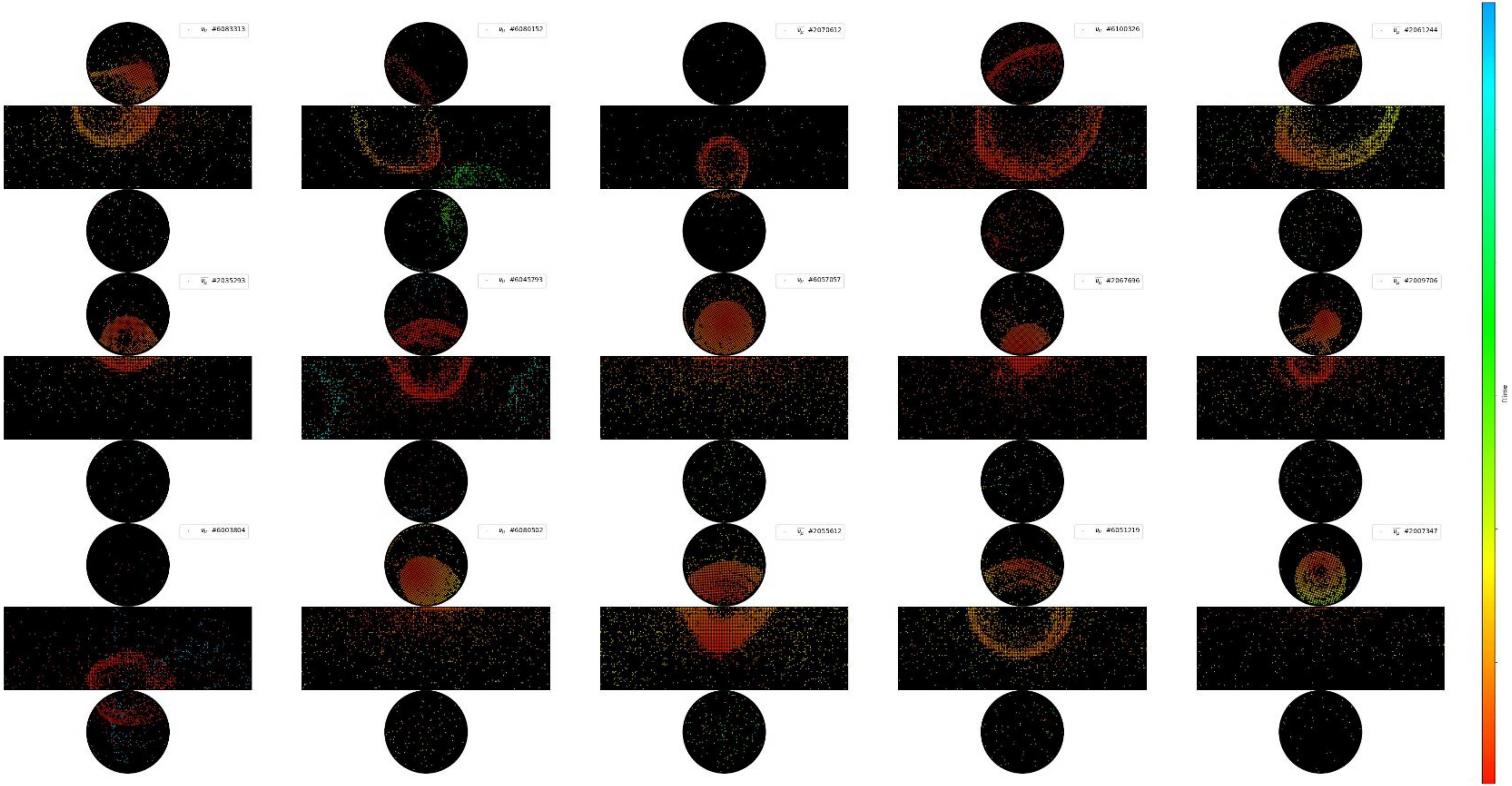
Event for which GraphNeT performs significantly better than fiTQun



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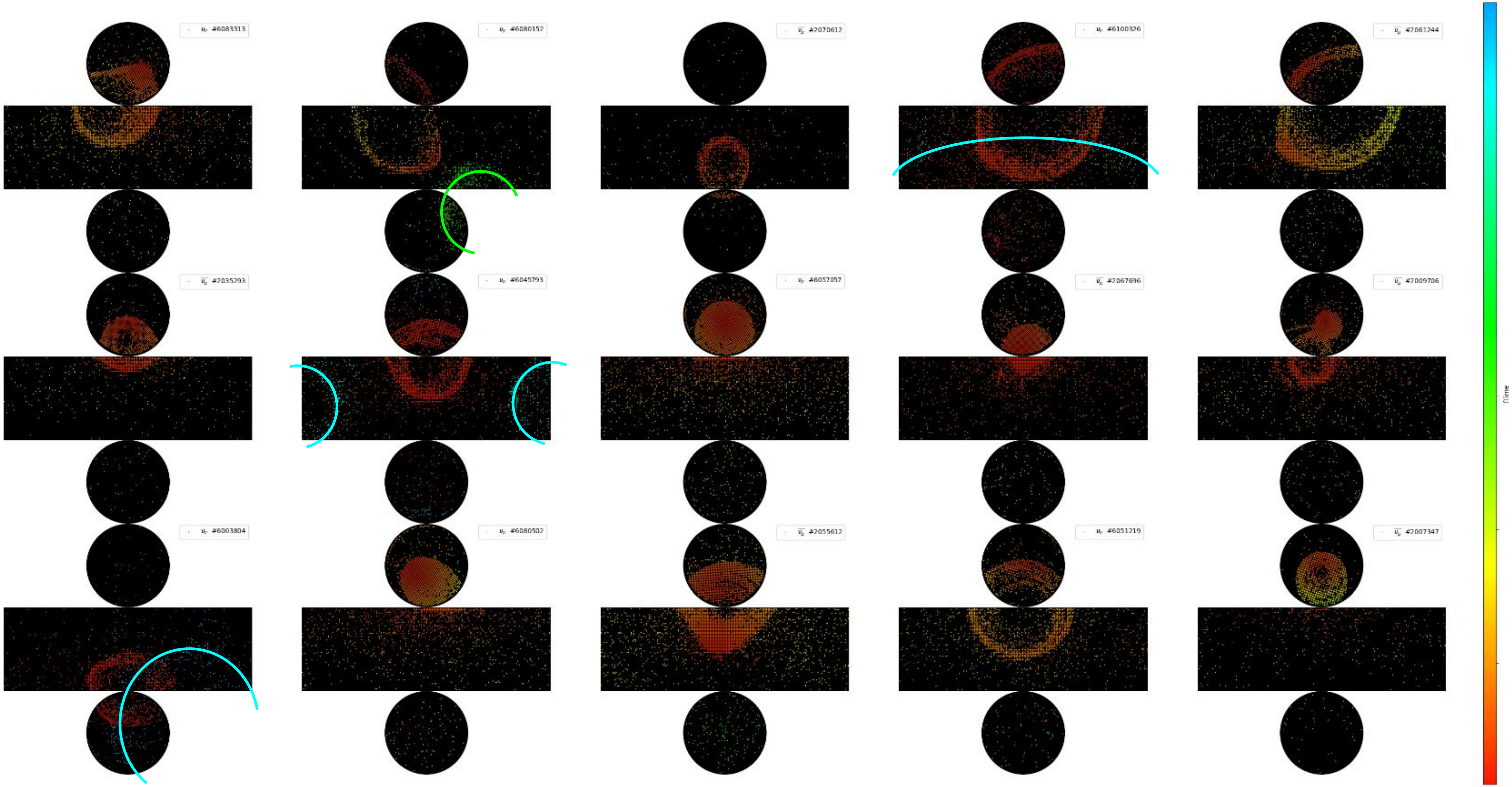
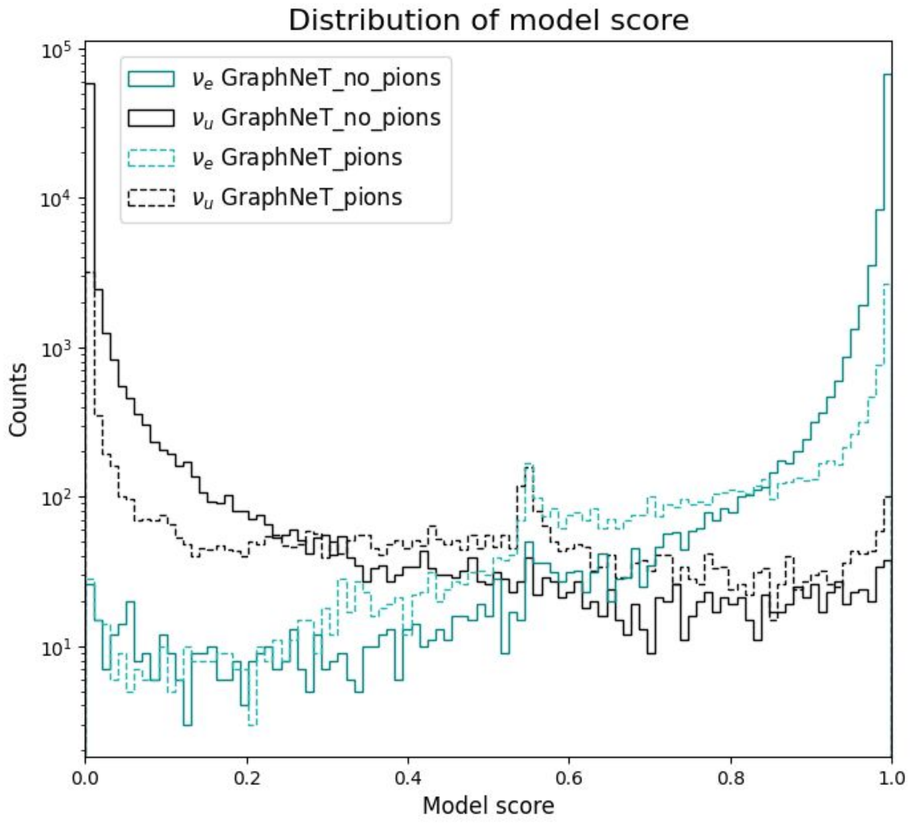


Factors impacting performance - pion creation
Neutrino event simulations - with data cut

GraphNeT performance with logarithmic x axis



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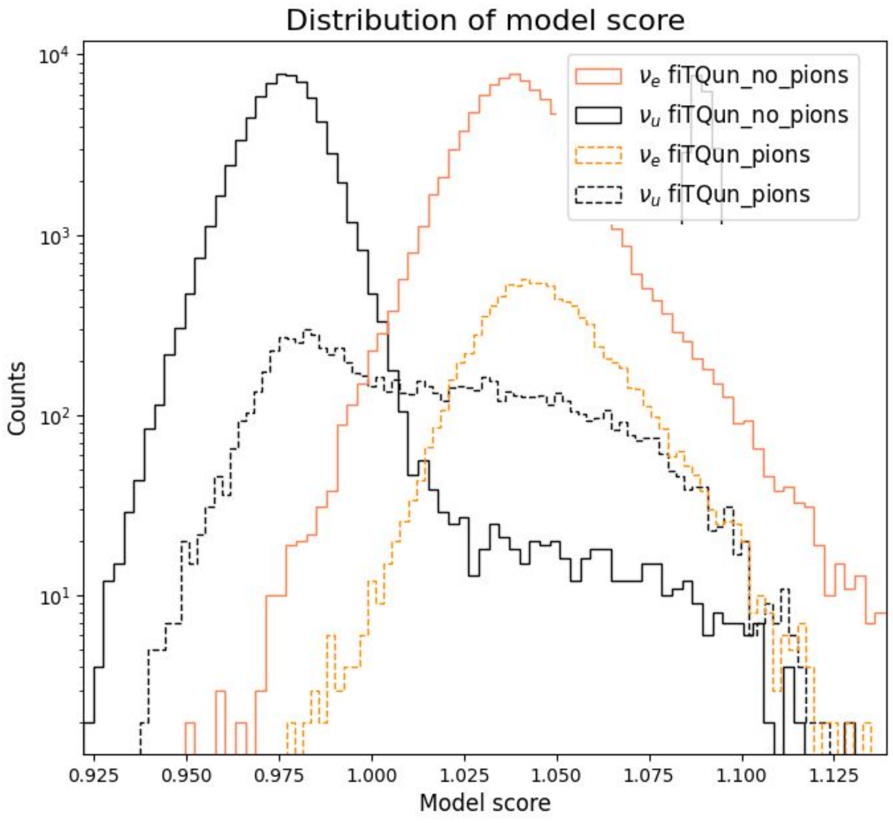

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Factors impacting performance - pion creation

Neutrino event simulations - with data cut

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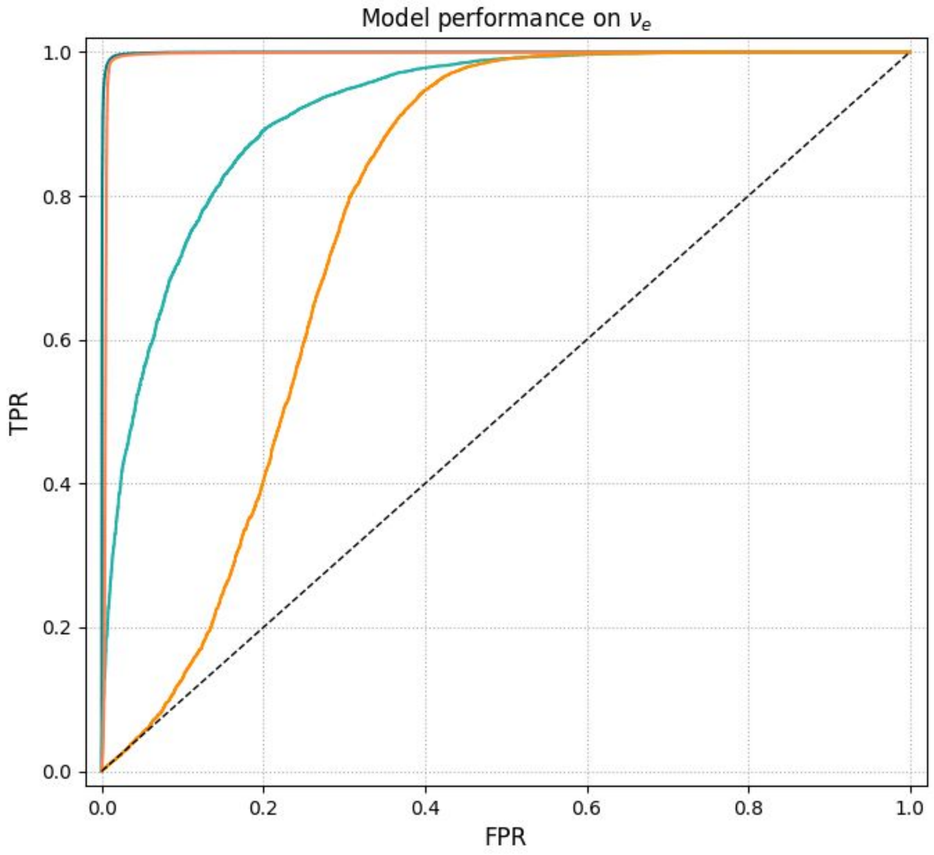

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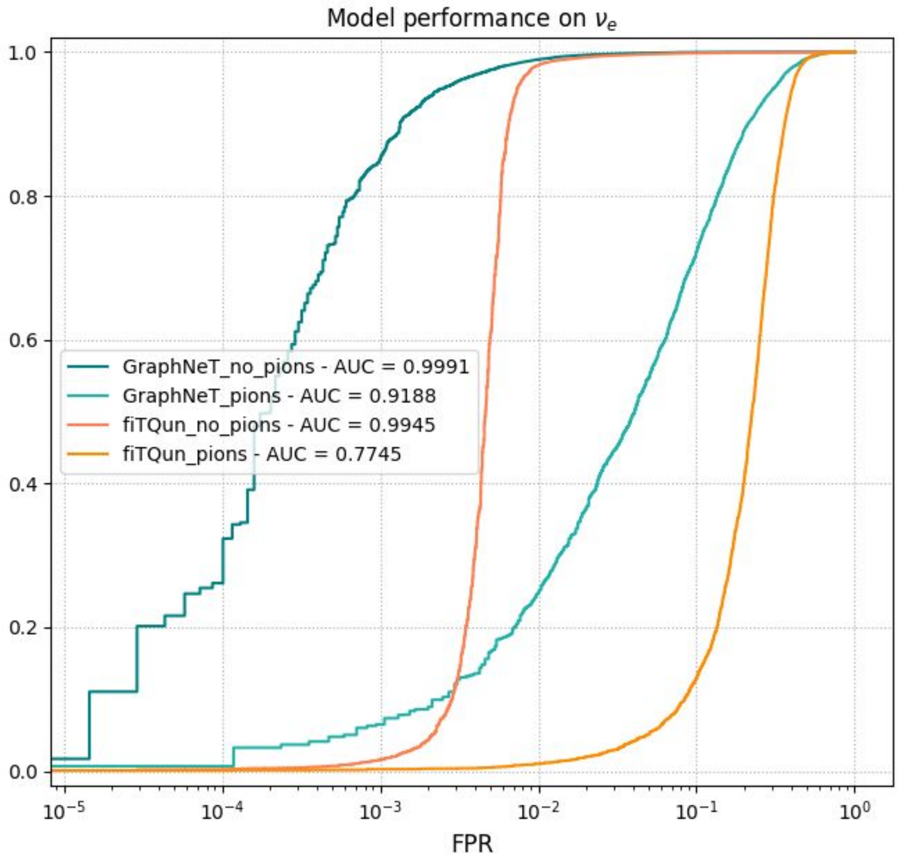

Event Classification - Performance Measures

The neutrino beam will consist of > 98 % muon neutrinos (at the near detector)

- We can allow more electron neutrino events to be misidentified and still have a pure muon neutrino event sample

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False positive rate (FPR) is the ratio of undesired events are identified as the desired type

- Example: The **FPR** for **electron neutrino** events is the number of **muon neutrino** events identified as **electron neutrinos**, divided by the total number of **muon neutrino** events

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We select samples that yield FPRs of:

- **1 % for muon neutrinos**
- **0.1 % for electron neutrinos**

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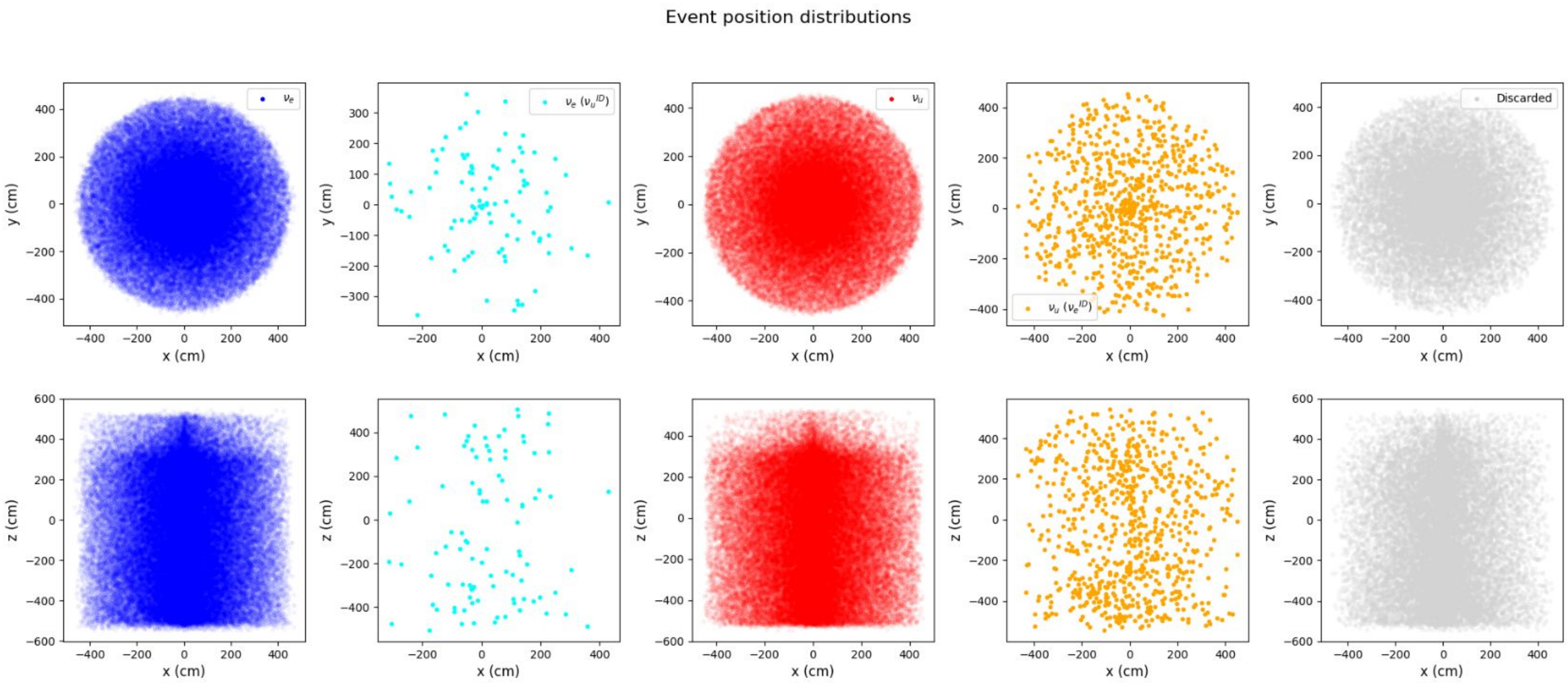
Relation between interaction position and reconstruction performance

Neutrino event simulations - with data cut



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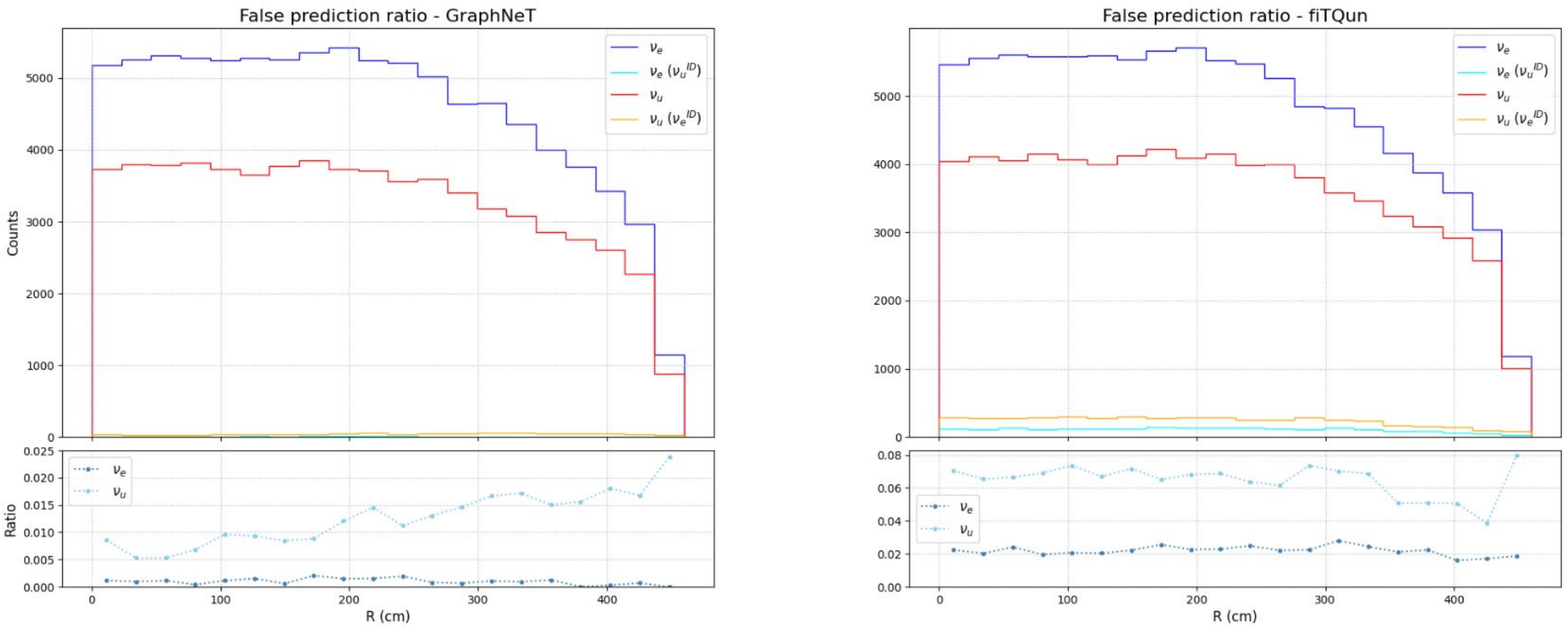

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