Application of machine learning methods for the identification of proton decay in liquid argon detector

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Questions

- What was the universe like back then?
- Why is there more matter than antimatter in the universe?
- How many forces are present in the nature?
- Is the Standard model enough?

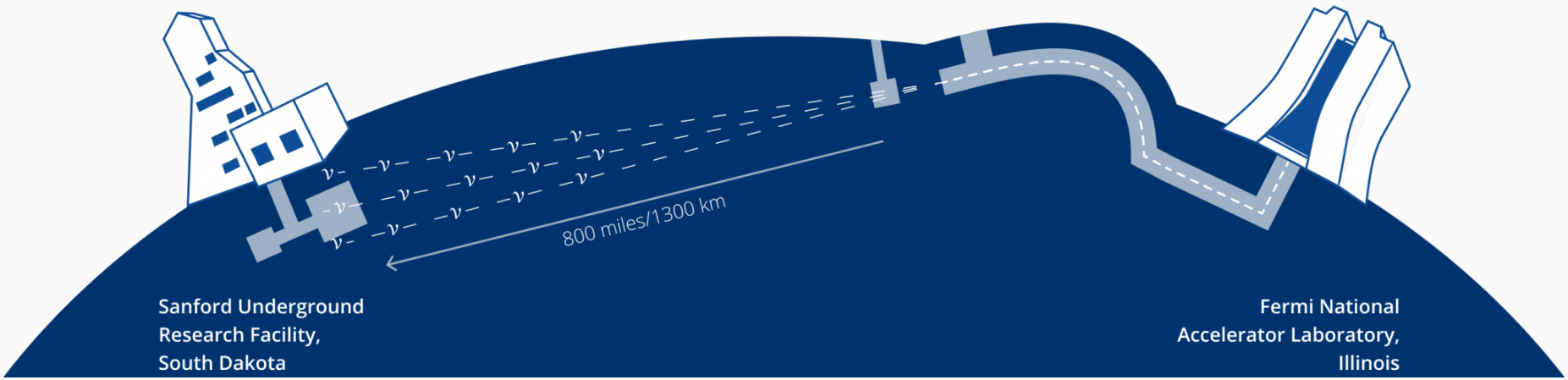
The Deep Underground Neutrino Experiment

DUNE

The Deep Underground Neutrino Experiment (*DUNE*) is a neutrino experiment under construction hosted by U.S. Department of Energy's *Fermilab*.

Main goals:

- exploration of neutruno oscillations
- studies of supernovae and the formation of neutron stars and black holes
- search for proton decay



DUNE detectors

The far detector: 4×10 kt LArTPC[1] modules & cryogenics
The near detector: LArTPC *ArgonCube* & HPgTPC

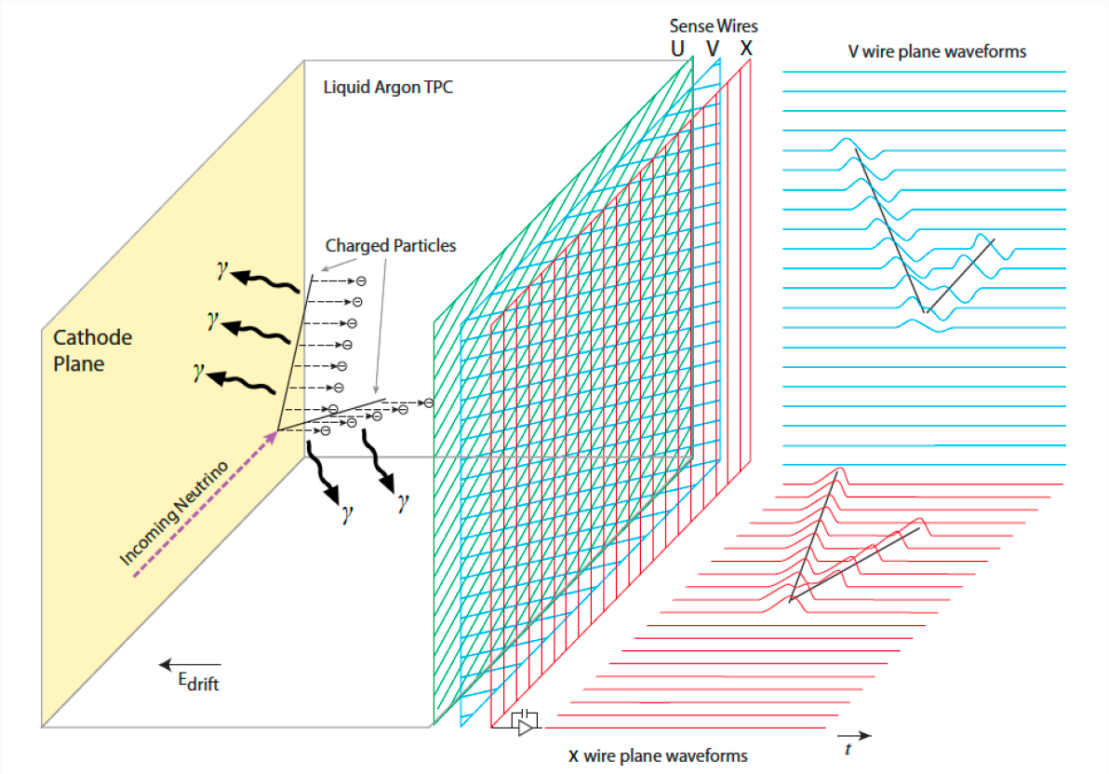


Figure 1: The general operating principle of the SP LArTPC. Negatively charged ionization electrons from the neutrino interaction drift horizontally opposite to the **E** field in the LAr and are collected on the anode, which is made up of the *U*, *V* and *X* sense wires. The right-hand side represents the time projections in two dimensions as the event occurs.

[1] Liquid Argon Time Projection Chamber

Detector APA

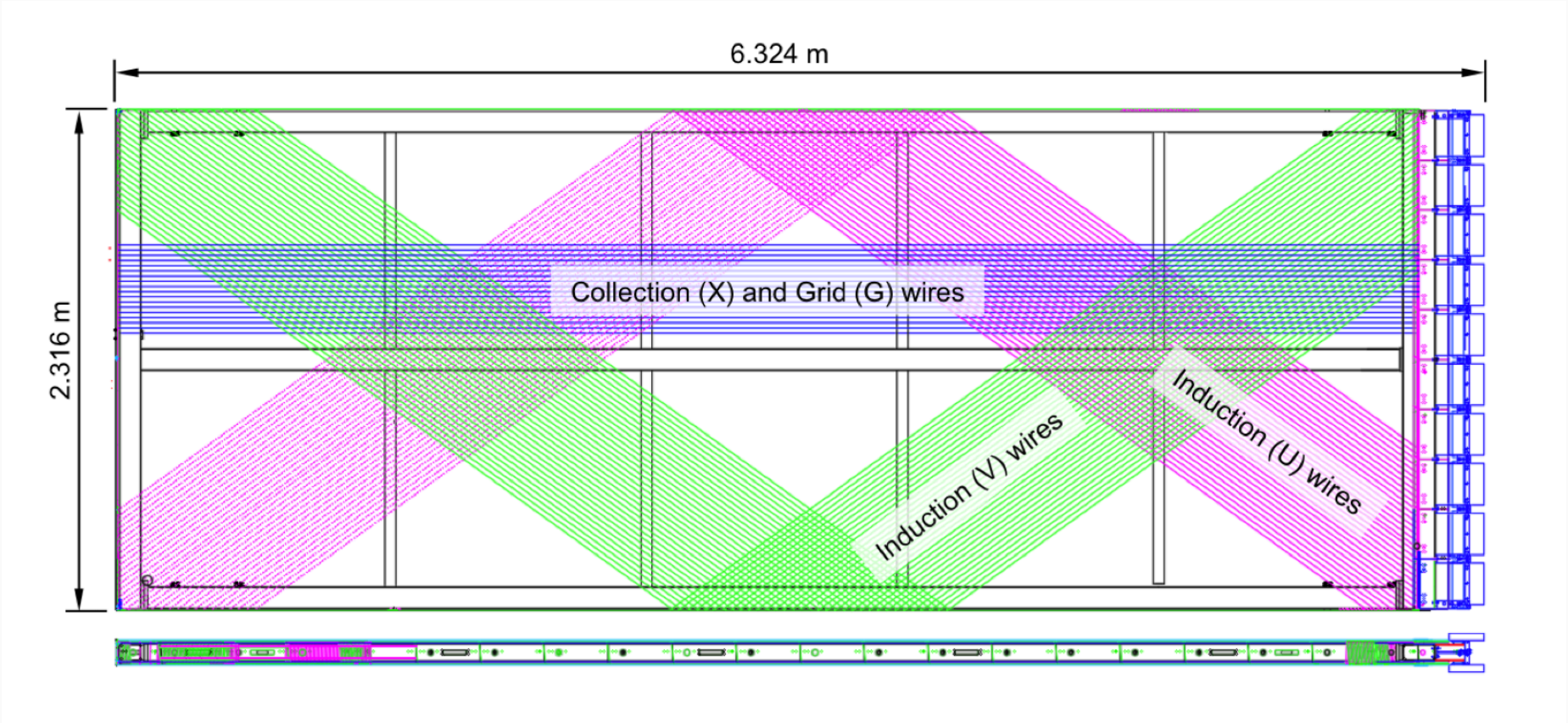


Figure 2: Illustration of the DUNE APA wire wrapping scheme showing small portions of the wires from three signal planes (*U*, *V*, *X*). The TPC electronics, shown in blue no the right, mount directly to the frame and process signals from both the collection and induction channels.

Data Acquisition and Interpretation

Simulated signal time projections

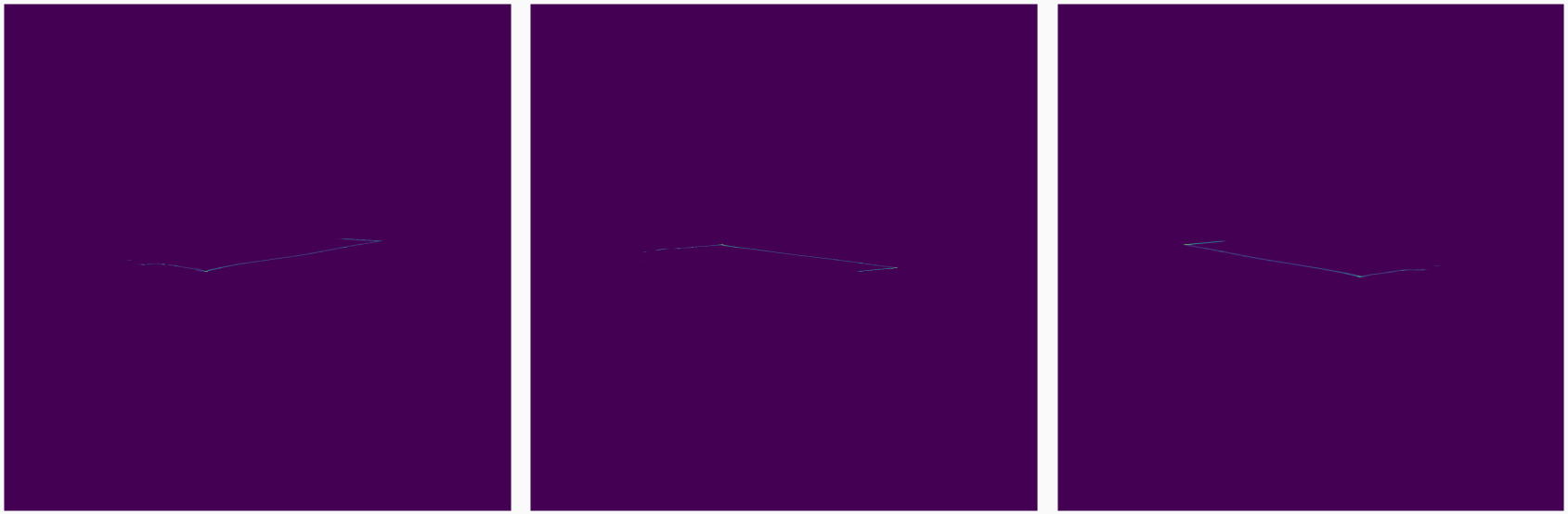


Figure 3: Illustration of the signal time projections to induction planes *U* and *V* and the collection plane *X*, from left to right respectively.

Main decay modes

decay mode	expected fraction	observed fraction
$K \to \mu_+ \nu$	63,6 %	61,77 %
$K \to \pi_+ \pi_0$	20,7 %	19,3 %
$K \to 2\pi_+ 1\pi$	5,58 %	4,16 %
$K \to \pi_0 e \nu$	5,1 %	7,2 %
$K \to \pi_0 \mu \nu$	3,3 %	3,04 %
$K \to 1\pi_+ 2\pi_0$	1,76 %	0 %

Table 1: Main modes of K decay.

Data preprocessing

- ROI extraction and centering
- image production
- categorizing images based on decay mode
- transforms and standardization

Essential Machine Learning Techniques

Artificial neural networks

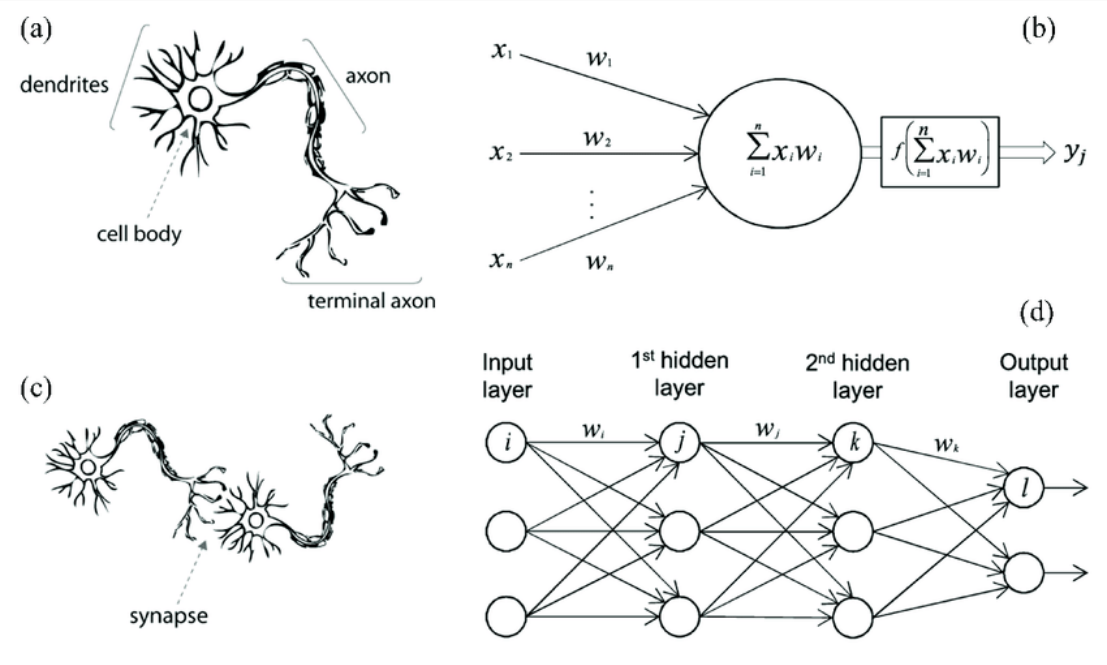


Figure 4: Illustration of an artificial neuron function as compared to neuron in a biological brain.

$$y_j = f\left(\sum_{k=0}^{n} w_{jk} x_k\right)$$

y_j ... the j-th output,
w_{jk} ... the k-th component of the j-th weight vector,
x_k ... the k-th input

Artificial neural networks

Neural network is a sequence of layers made of neurons, where:

- neurons of one layer connect only to neurons of the immediately preceding and immediately following layers
- *input layer* receives external data and *output layer* produces the ultimate result
- *hidden layers* in between
- layers can be *fully connected* or *pooling*

EfficientNet and ransfer learning

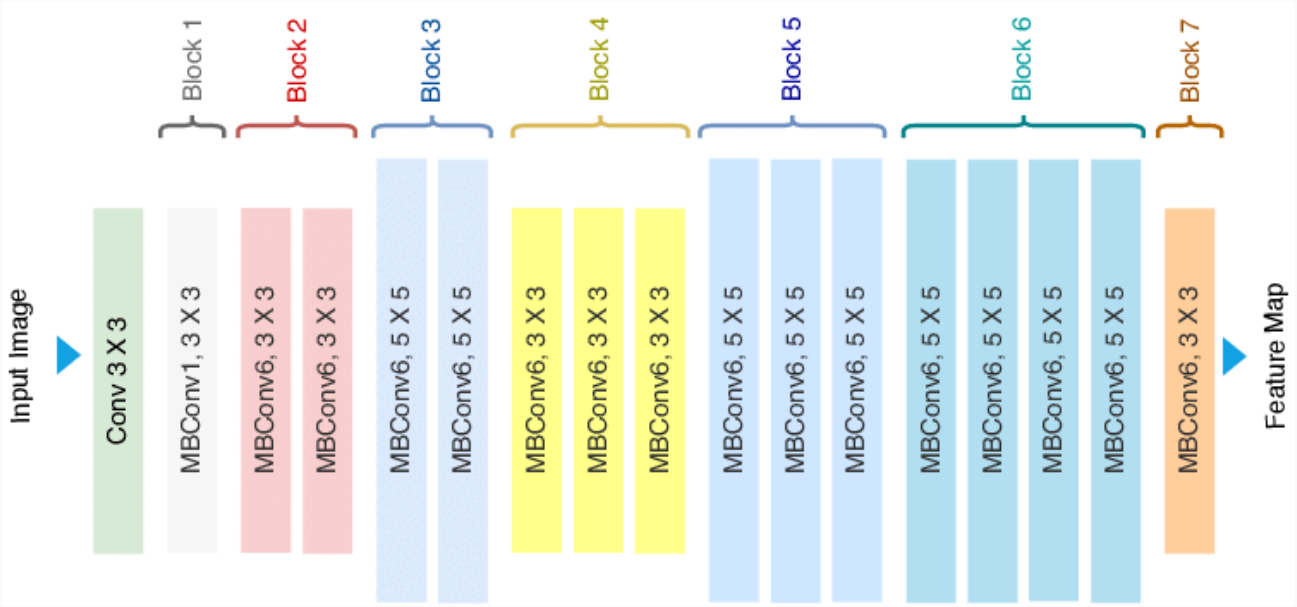


Figure 4: Architecture of EfficientNet B0 neural network.

Recent Results

Resulting ROC

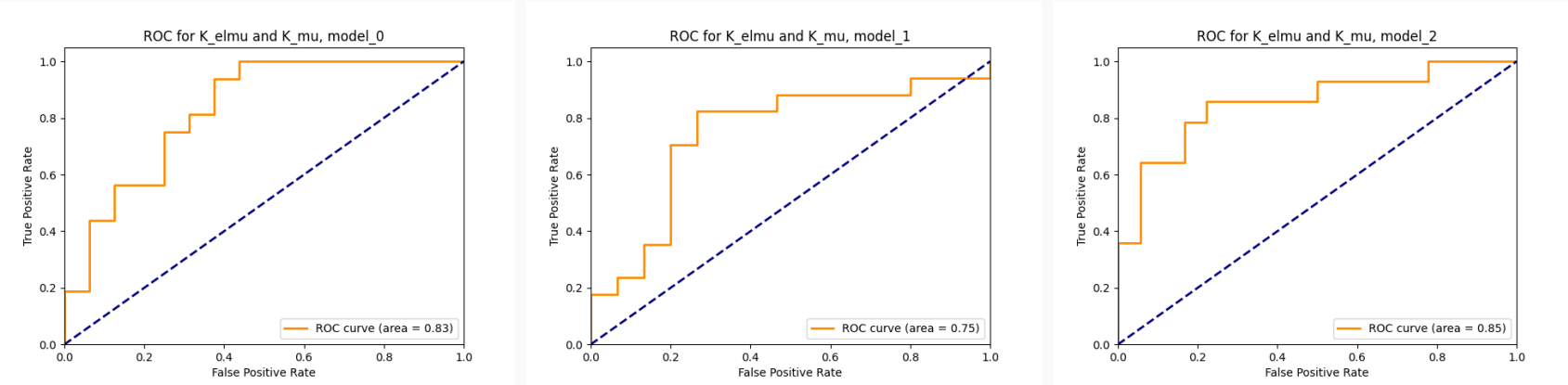
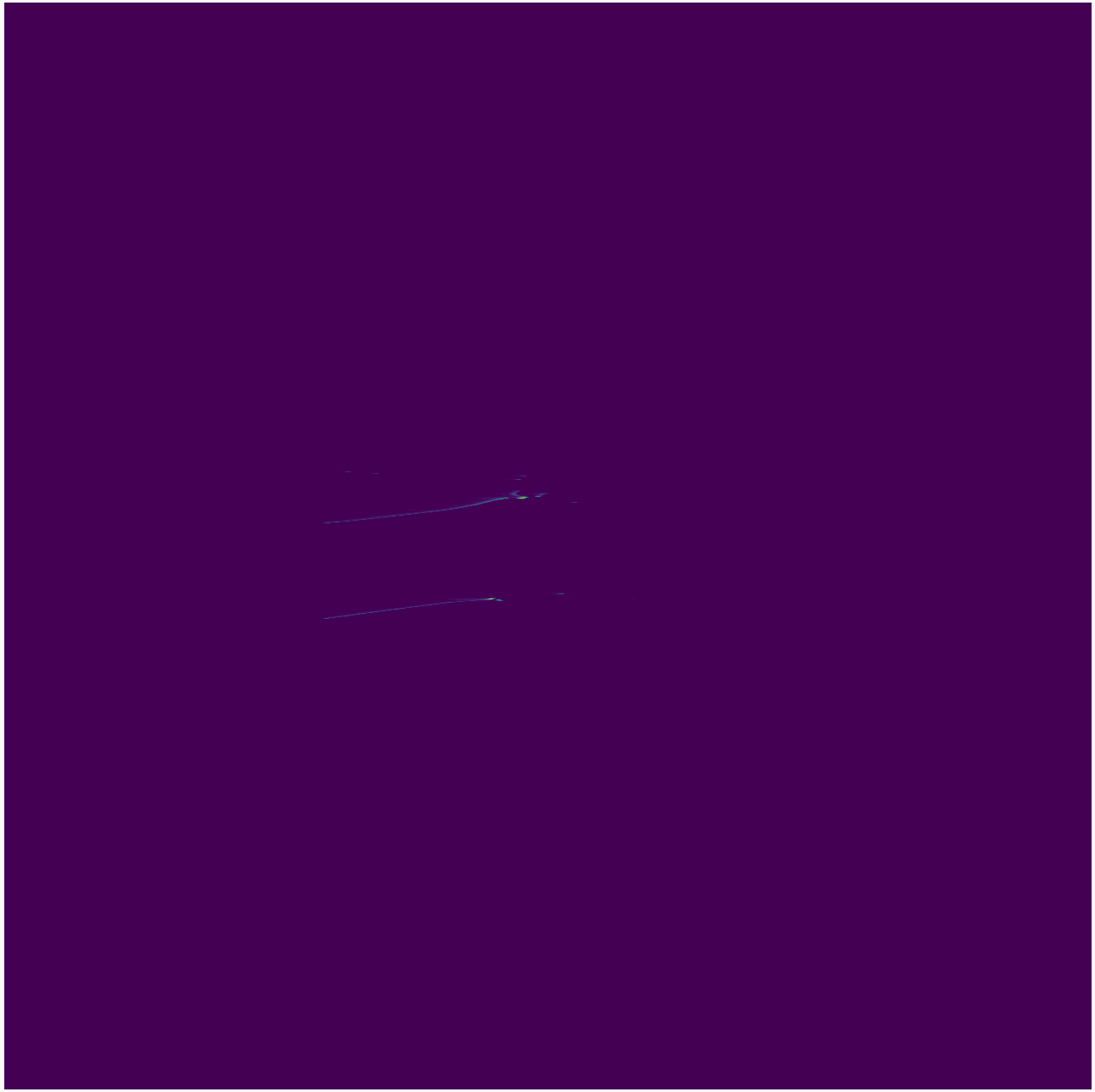


Figure 5: Receiver operating characteristics and area under ROC curve for models trained on signal and background time projections.

Problems and conclusions



Questions?