Applying Machine Learning to Vertex Recognition for Neutrino Interactions

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MINERvA

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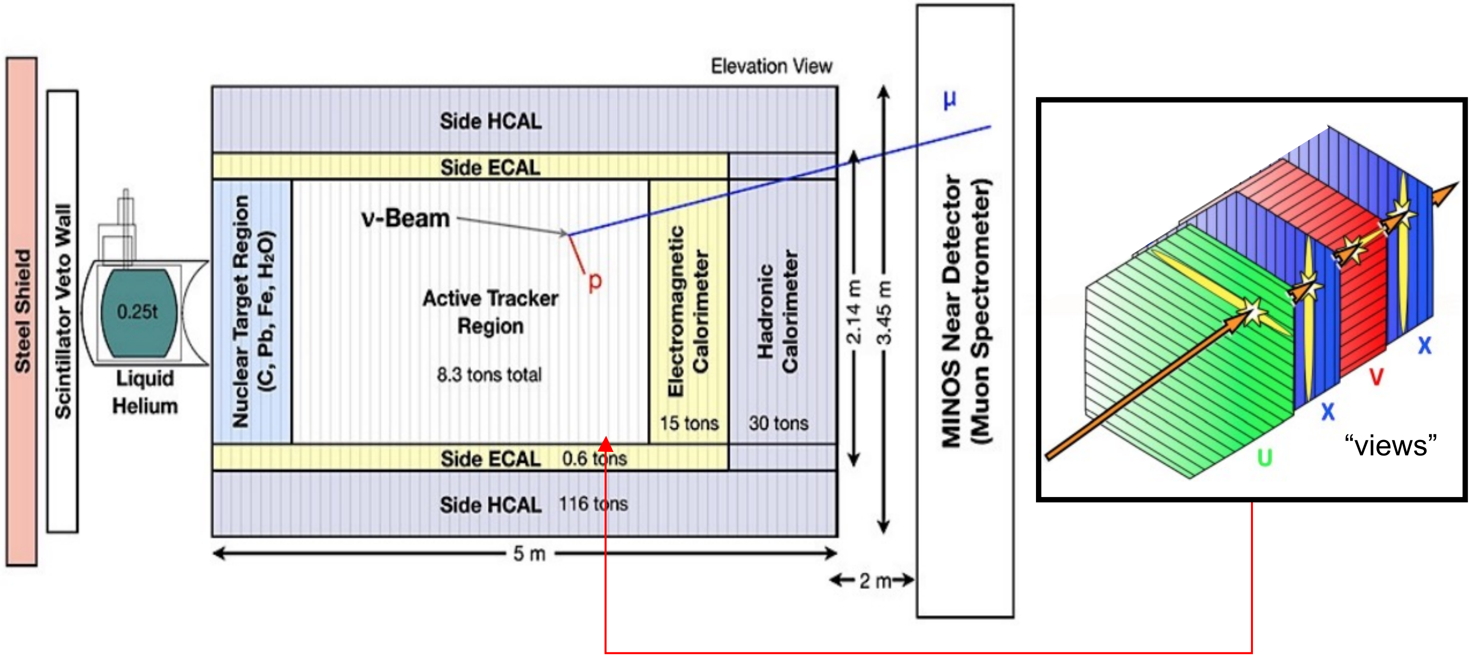
New perspectives, Fermilab

MINERνA

- The Main INjector ExpeRiment for ν-A scattering. Made to study neutrino cross sections with different nuclei (https://minerva.fnal.gov/).

Active material is made of triangular shaped charged particle detector strips arranged in planes at 3 orientations (views).

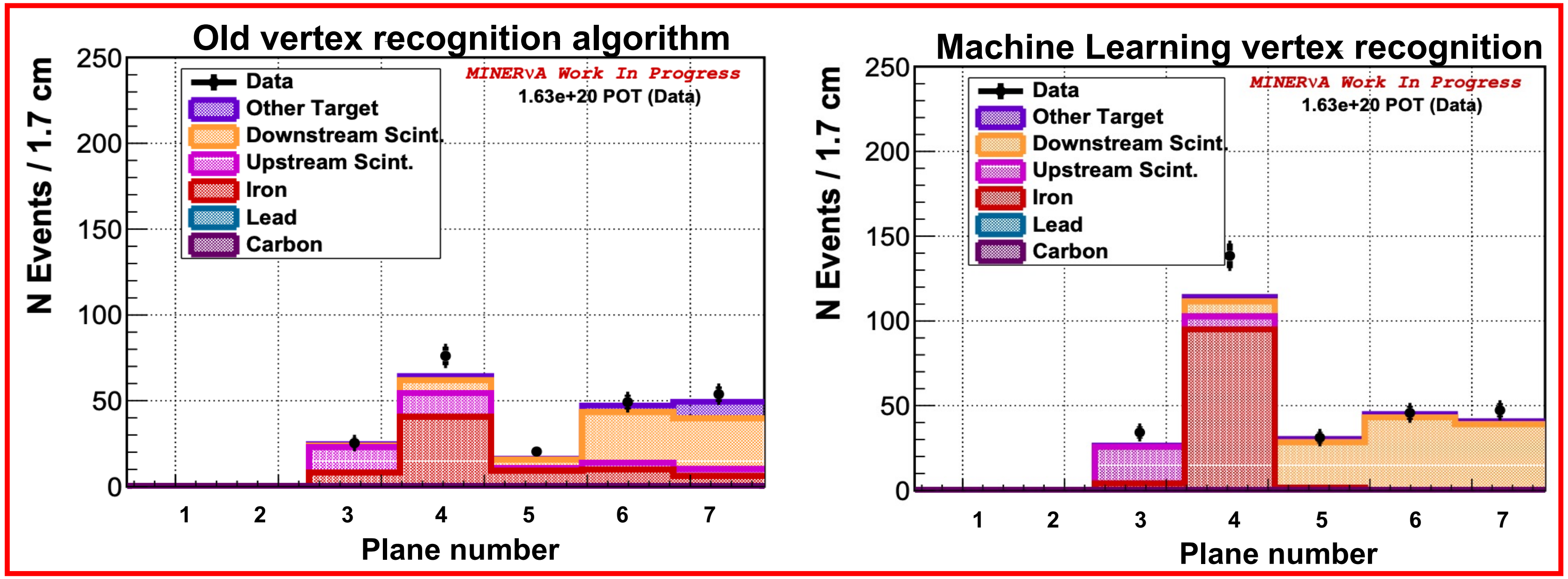


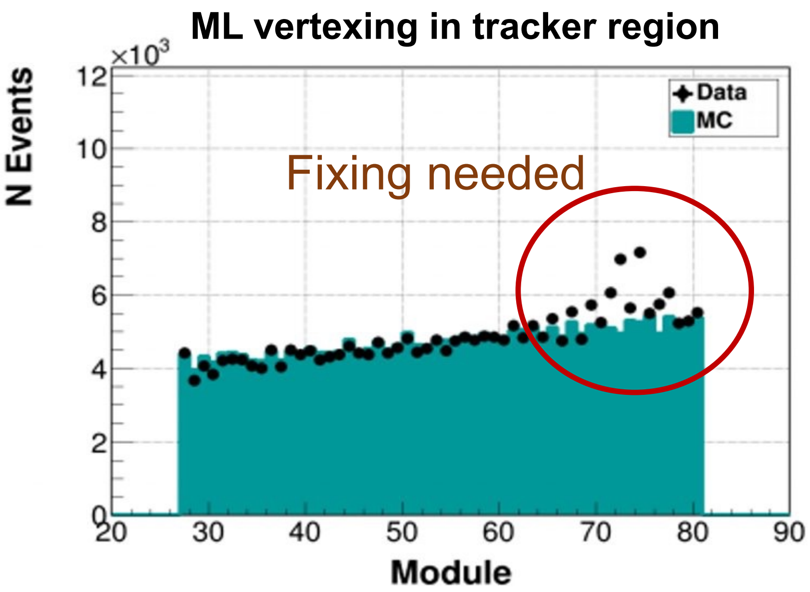
Minerva detector

- Electromagnetic Calorimeter (ECAL) is made of plastic scintillator and **lead** planes.
- Hadronic calorimeter (HCAL) is made of charged particle detectors and iron planes.

Motivation

- Previous work successfully done.
  - *"Vertex finding in neutrino-nucleus interaction: a model architecture comparison"* (JINST 17 (2022) 08, T08013)

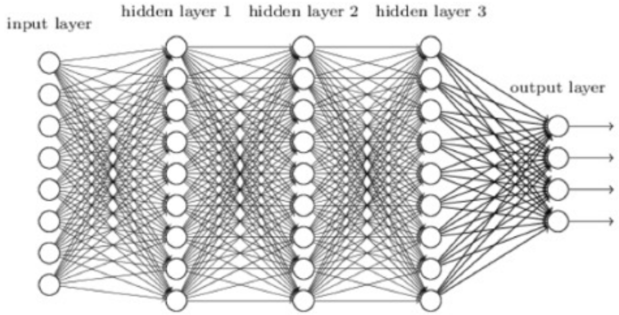


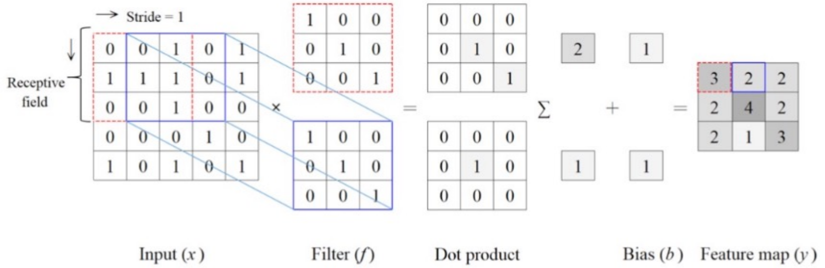


- Those ML models are limited to the nuclear target and tracker region. The Monte Carlo in the downstream tracker region does not match with the data
- The **lead located in the ECAL is a promising candidate for neutrino analysis** due to its superior acceptance and nuclear mass compared to the lead in the nuclear target.
- It is necessary to developed new ML models that incorporate the ECAL and enhance the downstream tracker region.

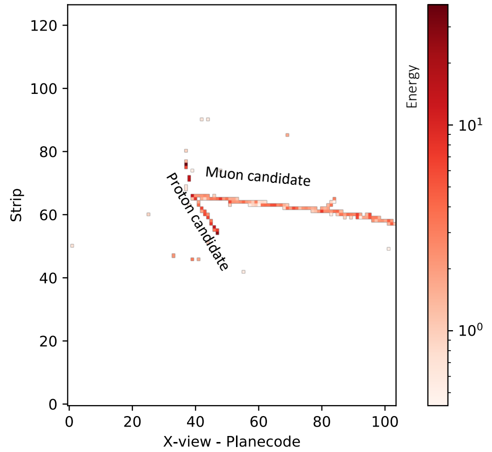
Deep Convolutional Neural Networks (DCNN)

- Algorithms designed to mimic pattern-based data through processes like the human brain.
- In DCNN the inputs of each layer are mapped into outputs by convoluting small kernel, this is the technique to analyze images.
- DCNN can be used to create vertex recognition models for neutrino interactions.
- This is applied to data from the **MINERνA experiment.** Learn as function of the plane of the vertex.





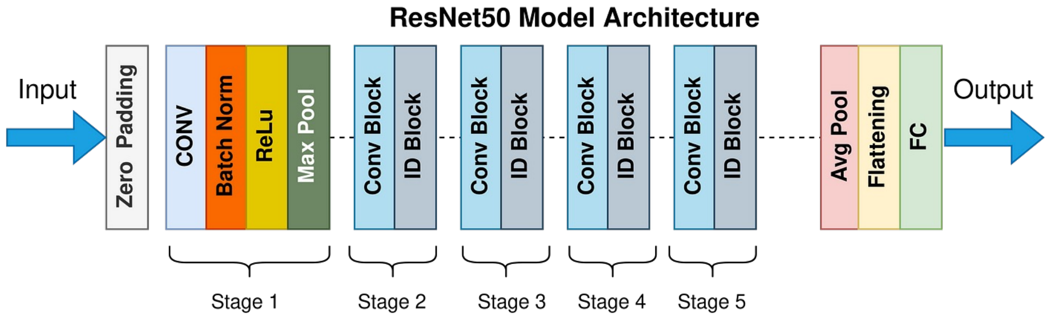
[Fan, C.-L.; Chung, Y.-J. Design and Optimization of CNN Architecture to Identify the Types of Damage Imagery. Mathematics 2022]

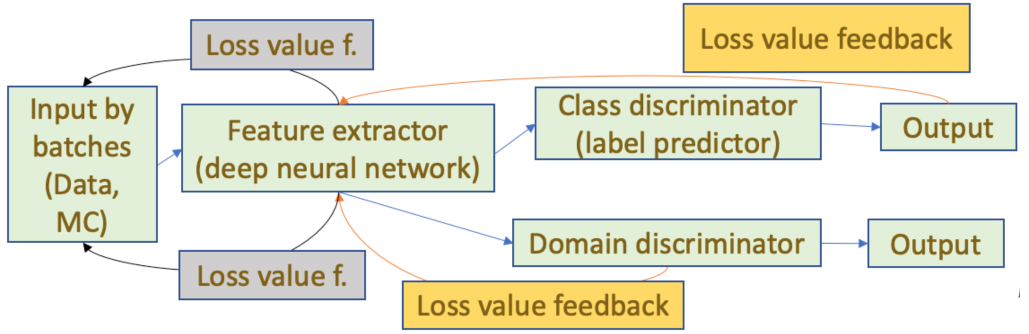


Neutrino interaction from the MINERvA detector

Project Evolution

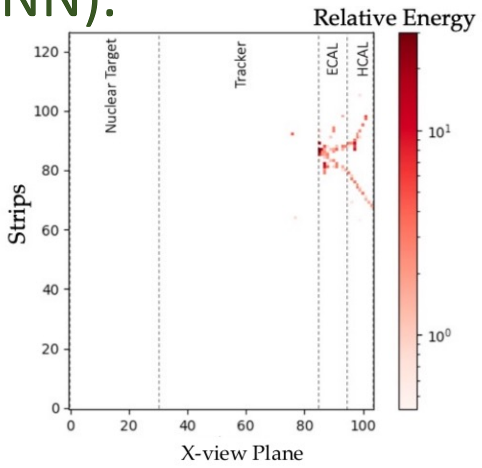
- Features improved.
  - Adding HCAL activity.
    - Extension of neutrino analysis in ECAL region.
  - Including images with interaction in the ECAL.
    - Simulated data in the ECAL.
  - Different architecture.
    - 20 layers DCNN to ResNet-50 (arXiv:1512.03385).
  - Domain Adversarial Neural Network (DANN).



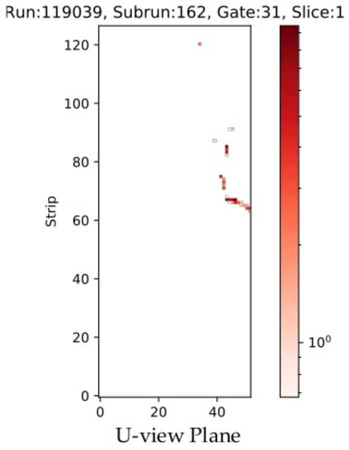


Domain Adversarial Network Architecture

Dataset used contains:
- 10 millions of images of simulated data
- 2.5 millions of images from real data.



104x127 image size



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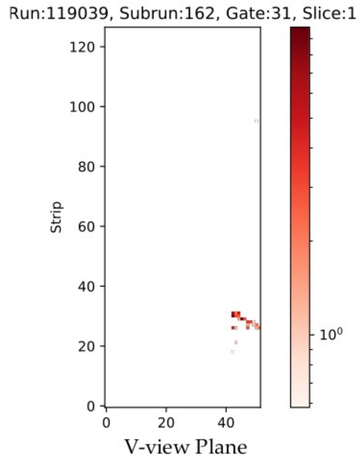

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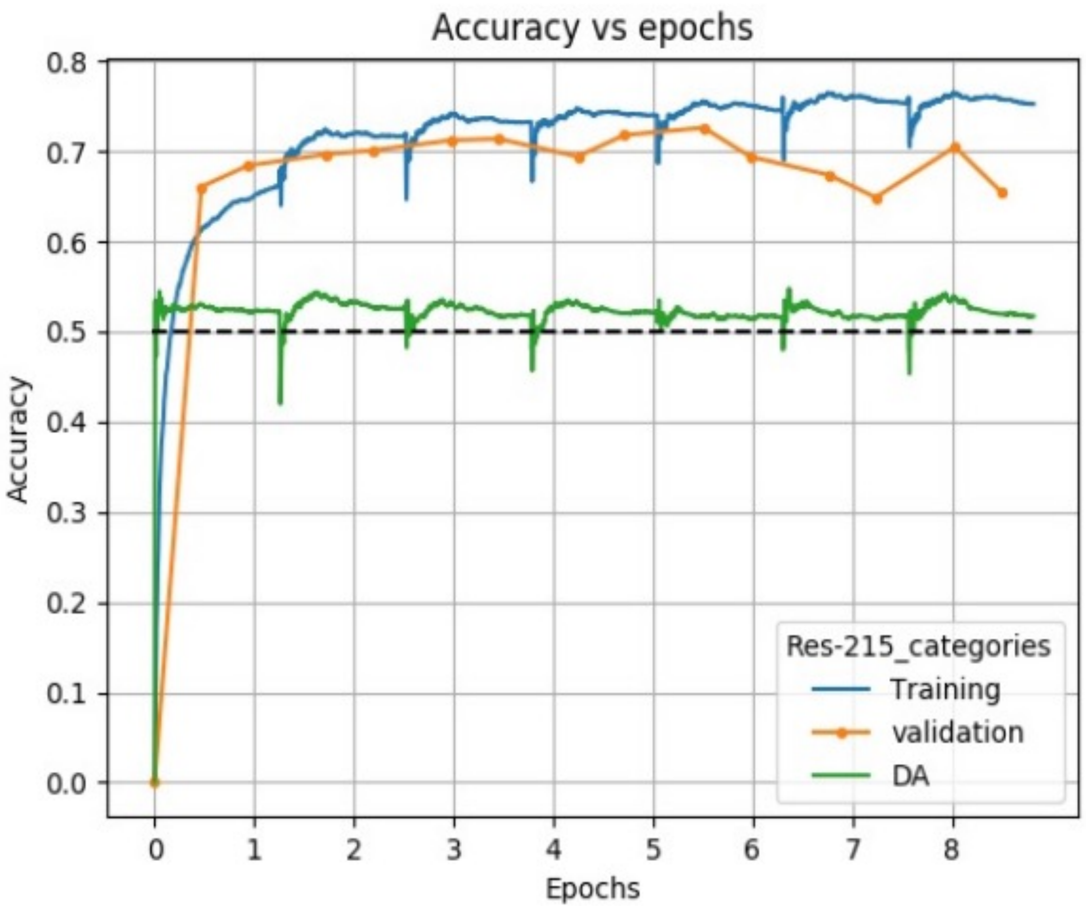
Training and testing models

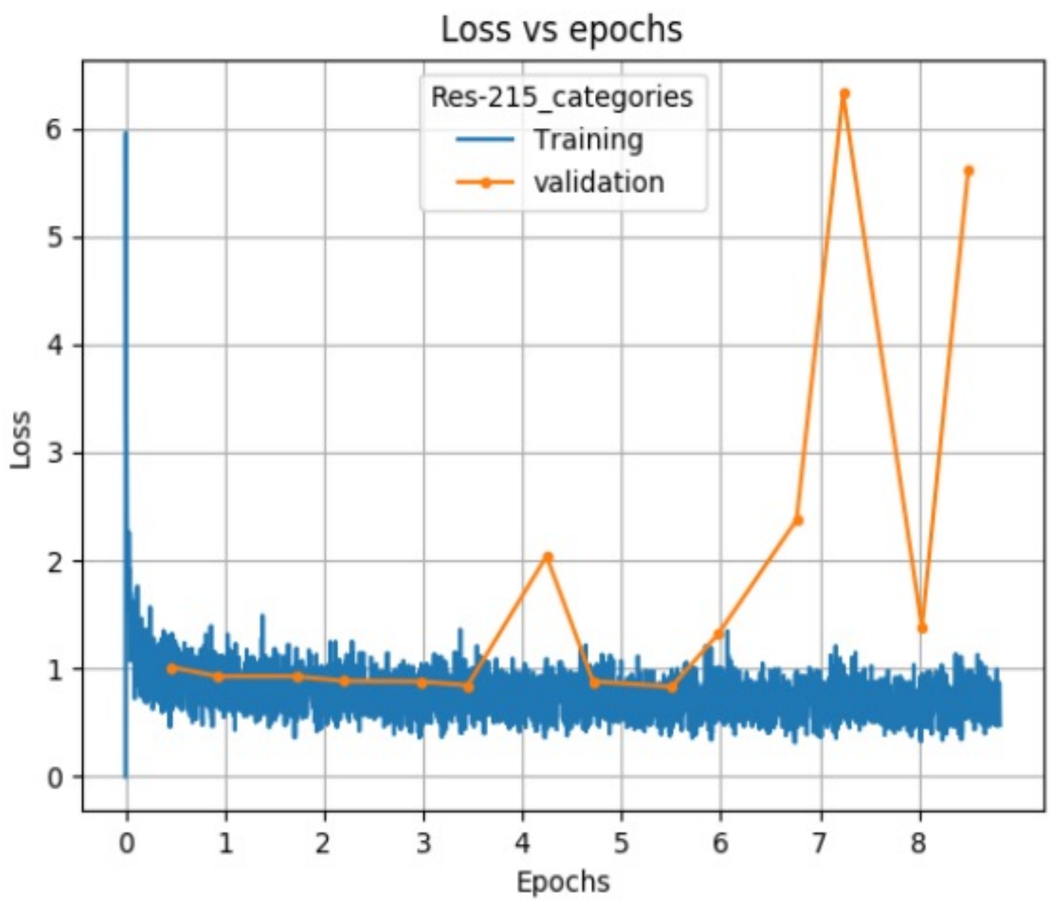
- MC dataset is separated into 3 sets.
  - Training (80%).
  - Validation (10%).
  - Test (10%).

- All sets but test are using for the "learning" process, training models.
  - Whole set passes through the algorithm several times, each time is called epoch.
  - Metric used to evaluate the assessment of the training:
    - Accuracy: Closeness between a measurement and its true value.
    - Loss function (cross entropy): Evaluates differences between true values and classified values; closer to zero the better.

Training and testing models

Note: Training using the entire detector. Target region, tracker region, and Calorimeters.



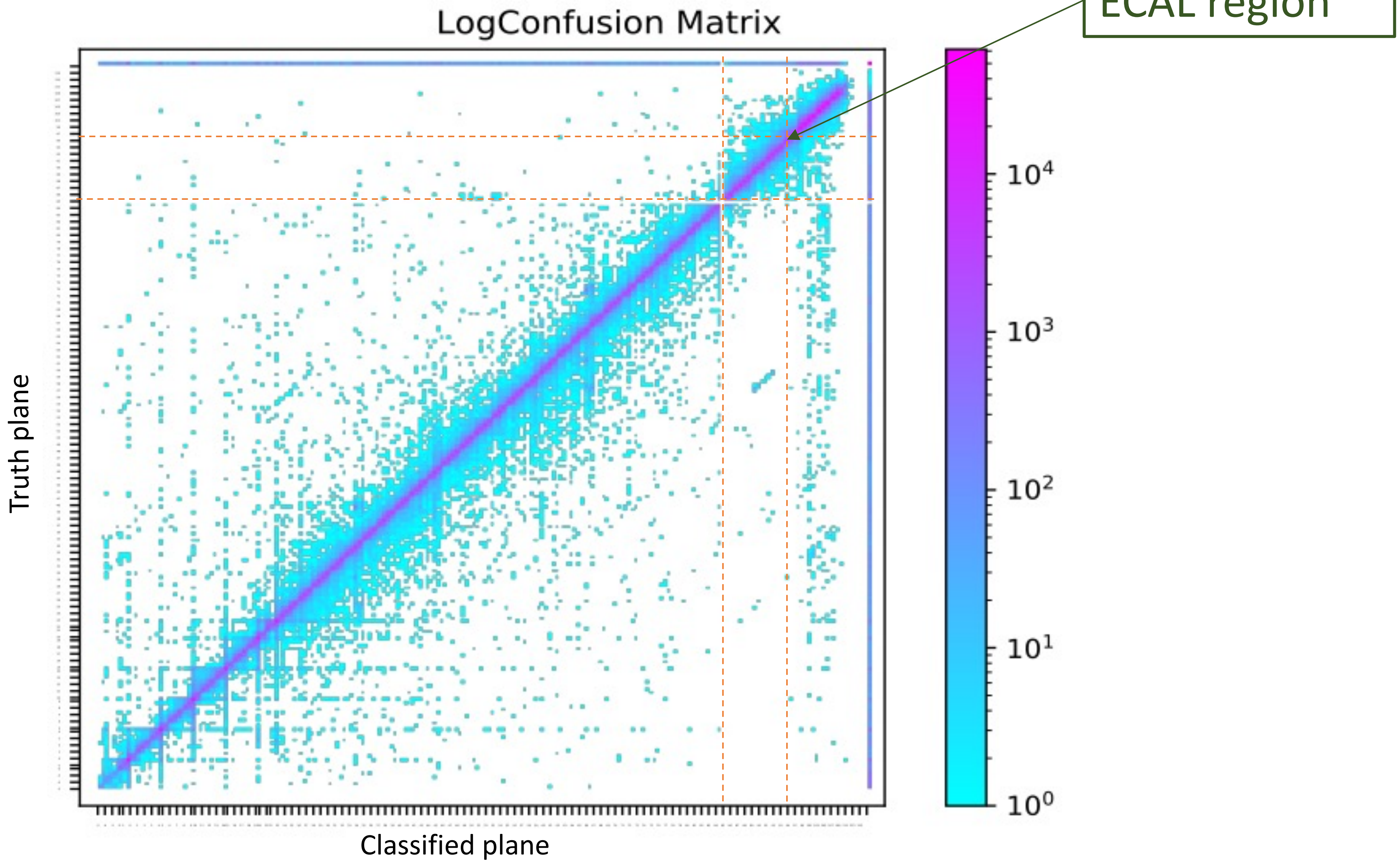


Testing the models generated in the training stage using a different dataset

Epoch	1.8	2.5	3.1	3.7	4.4	5.0	5.6
Accuracy	0.707	0.702	0.715	0.718	0.715	0.723	0.723
Loss	0.841	0.869	0.811	0.820	0.904	0.809	1.285

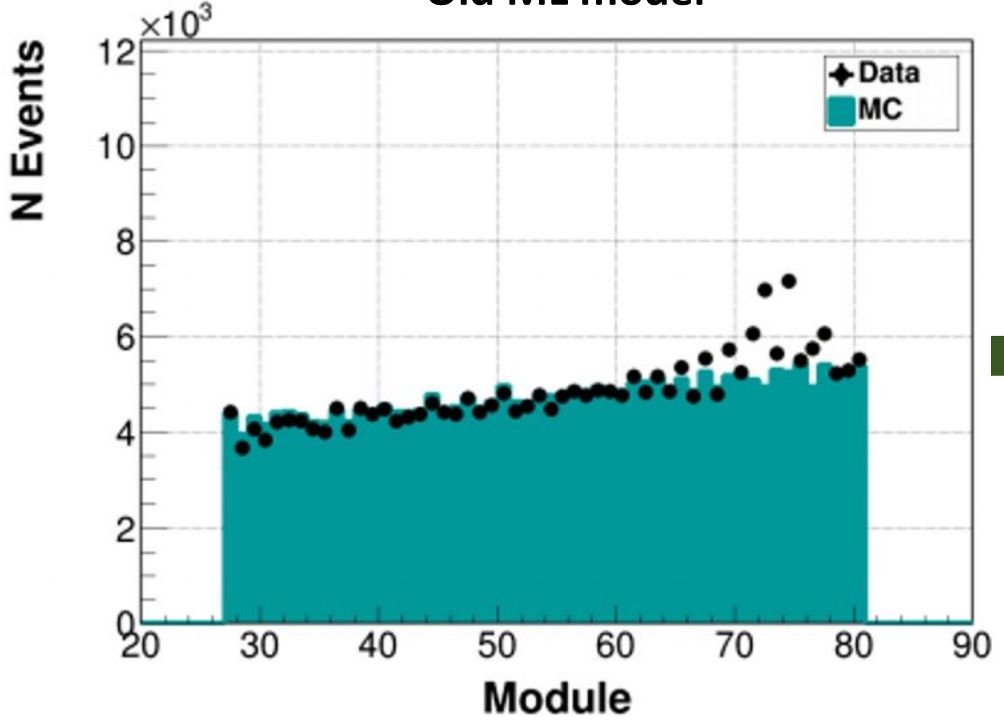
Confusion Matrix

- MINERvA has 214 planes along all the detector



Comparing MC with Data Old/New ML model

Old ML model

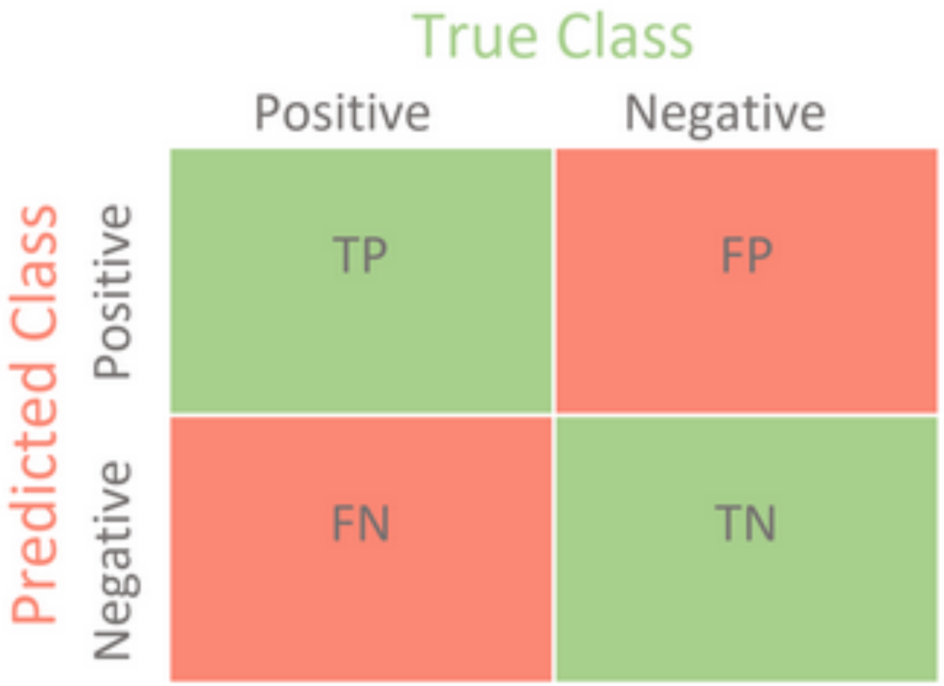


New ML model

2 planes are equivalent to 1 module in the MINERνA experiment

Metrics for model performance

- Multi-class classification.
  - Models trained for 215 classes. x-view + u view + v view planes + background events.
- Traditional metric is used: precision, recall, F1 score.

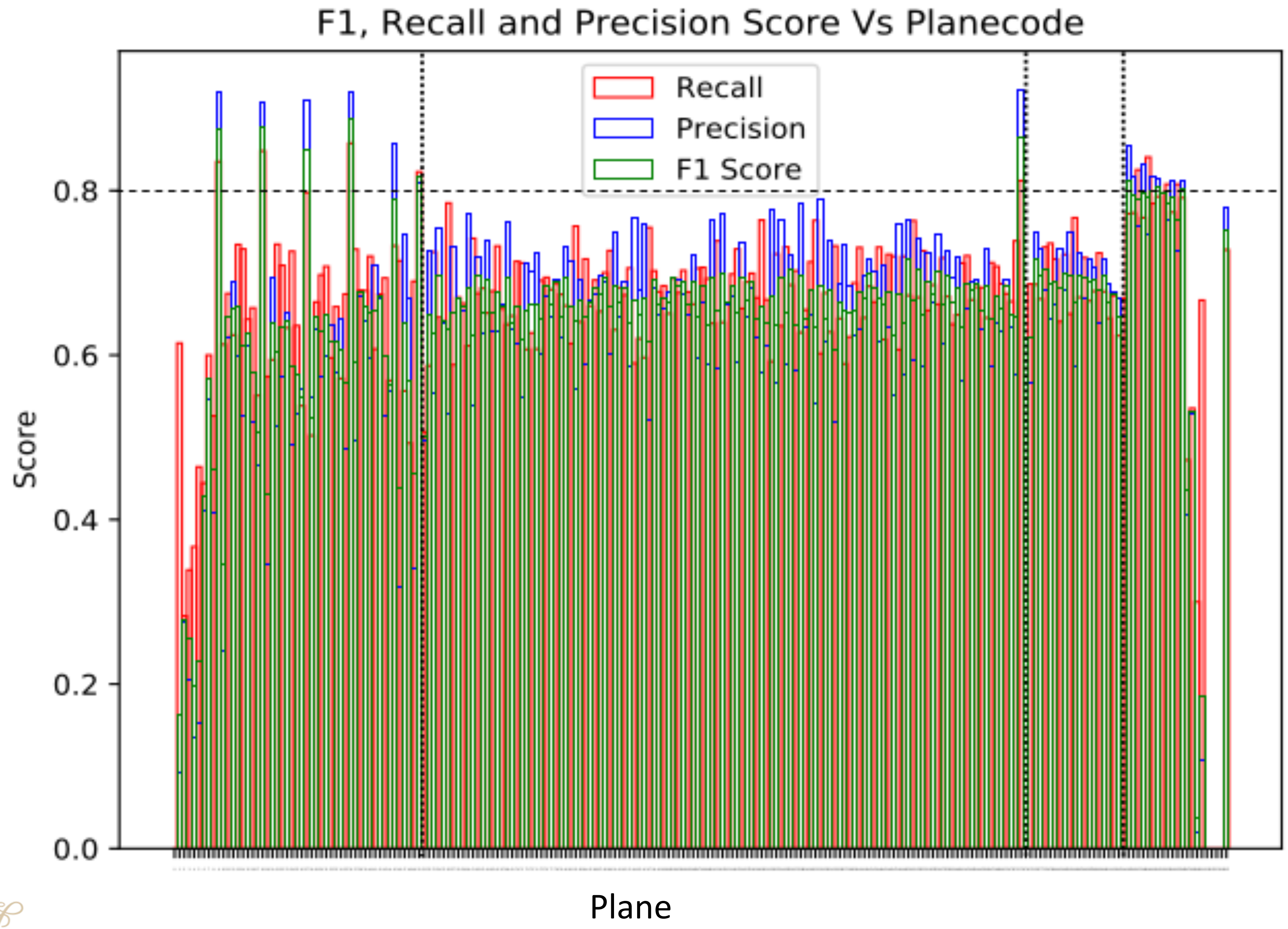


$$precision\ (purity) = \frac{TP}{TP + FP}$$

$$F1 = \frac{2(recall)(precision)}{recall + precision}$$

$$recall\ (efficiency) = \frac{TP}{TP + FN}$$

Results



$$F1 = \frac{2(recall)(precision)}{recall + precision}$$

Region	F1 mean
Target	64.4%
Tracker	67.1%
ECAL	71.3%
HCAL	72.4%

Comments and conclusions

- Machine learning model has been successfully trained.
- Domain Adversarial Network is implemented on simulated mc with data.
- New models will allow neutrino analysis in the Electromagnetic calorimeter.

Thanks


The End?
John Voirin
Tim Griffin
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Andrew Lathrop
Chris Richardson
Jesse Chvojka
David Martinez

Back Up

Plane distribution