Study of a Deep Learning (DL) model for Particle Classification in DUNE FD

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Goal

- e^- (signal) / π^0 (Background) separation in the DUNE Single Phase Far Detector (Ultimate goal)

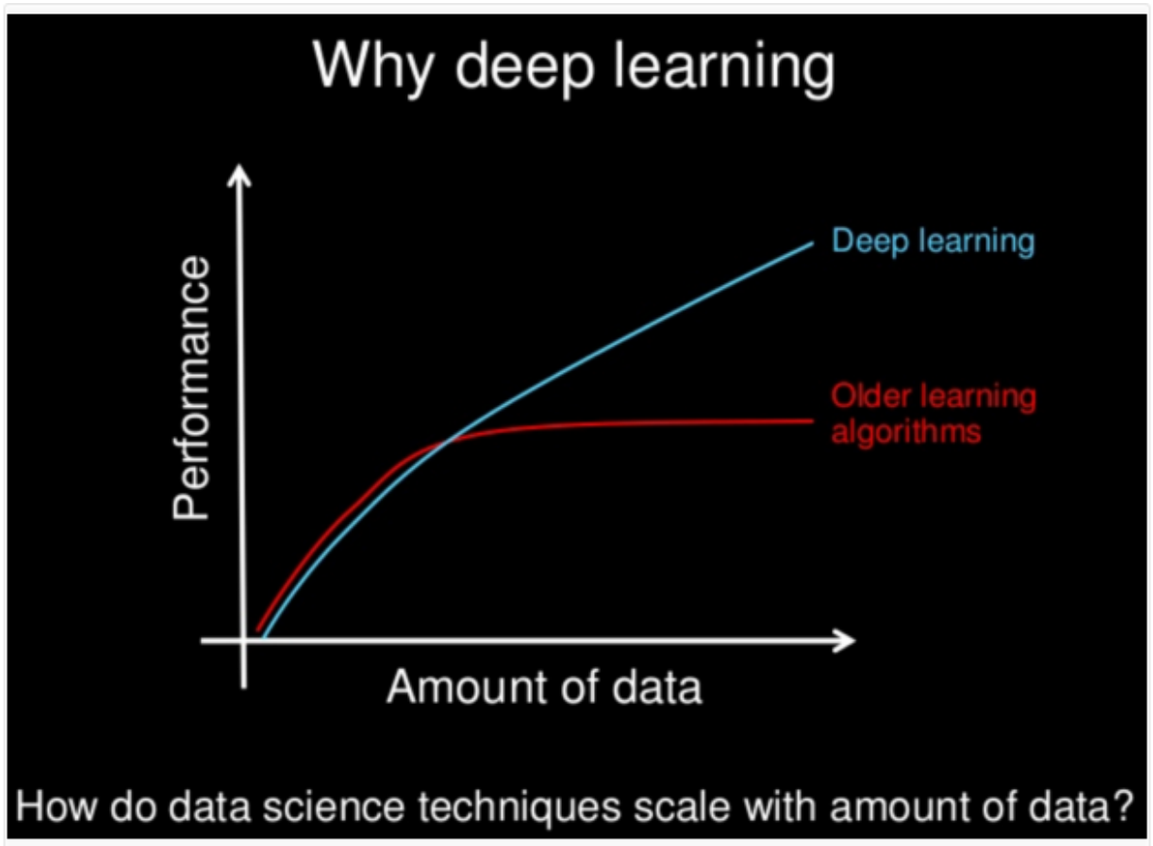
- Particle classification (first step)

- Neutrino event classification for background subtraction study (second step)

- The aim of the first study is to check the feasibility of the method (Proof of concept)

- The method is Convolutional Neural Network (CNN) used for Computer Vision.

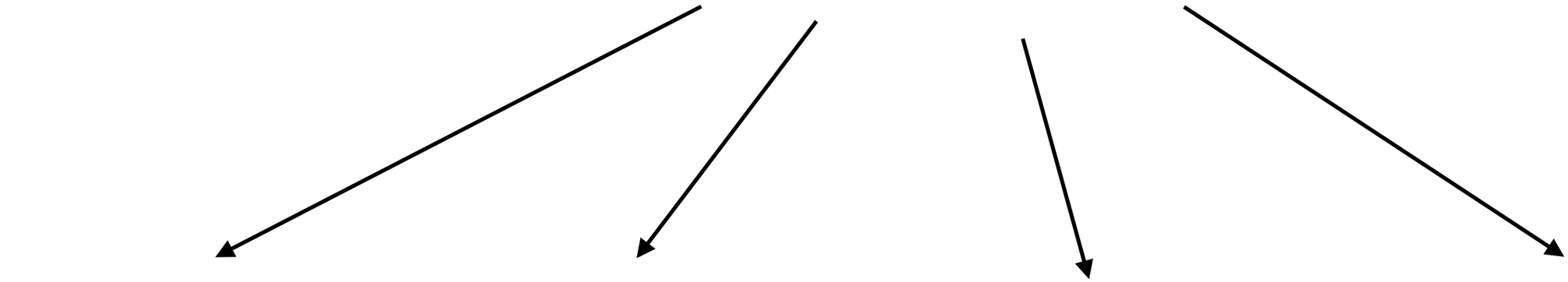
Deep Learning



Why Deep Learning?

DL is a subfield of Machine Learning.

Computer Vision with DL



- ResNet50

ResNet50 (pre-trained model)

- Residual nets achieve 3.17% error on the ImageNet test set
- The model is previously trained on a dataset and contains the weights and biases
- Learned features are often transferable to another data (Saving time)

For state-of-the-art studies, models, papers, etc:
https://paperswithcode.com/sota

Particle Classification Scenario

- The method: Image Classification using Deep Learning (Transfer learning)
- The model: **ResNet50**
- Dataset (80% Train + 20% Validation) Preparation
    - single particle generation via LArSoft and Geant4 (e^-, π^0, p, μ^-, K^+)
        - Text files generated with Evt #, Space point (SP), ADC, # of SP, momentum information
        - 80k Train data + 20k data validation data (each particle has 20k images in total) are generated
        - 3-in-1 Image generation (size: 224x224 pixels)
- Train ResNet50 model with train dataset
- Test the model with validation dataset and obtain results for 5 particles class (5c), 4c and 3c

MC Single Particle Generation

- **Detector:** DUNE Single Phase Far Detector - isotropic - 10kt - 1x2x6 m^3

- **Dataset:** Total 100k events generated via LArSoft and Geant4 classified into 5 categories: e^-, π^0, p, μ^-, K^+ as TRAIN data with 80K events and TEST data with 20K events in total. Each particle has 16k train and 4k test data. All information related to generated single particles is stored in the root files. (/pnfs/dune/scratch/fbay/)

- **Particle momentum:** Between 0.1 - 2.0 GeV (except e^- with 0.1 - 5.0 GeV). All momentum distribution of the particles generated are flat.

Image Generation

1. Generate text files from the root files including information as Evt #, Space Point (X, Y, Z), ADC, # of Space Point (SP) and Momentum.

2. Put a Space Point CUT (> 350) in order to reject events without an image.

3. Use ADC values for each point to create colourful points depending on energy deposit.

4. Create 2D images (224x224 pixels) with 3 views (2D) in 1 image. The views are XY, XZ, YZ.

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1 342.151 317.899 975.719 72.5761 2284 1.515
1 342.18 317.598 976.078 74.6677 2284 1.515
1 342.139 317.299 976.437 64.2498 2284 1.515
1 342.2 317.245 976.498 77.8101 2284 1.515
1 342.176 317.897 976.51 206.486 2284 1.515
1 342.187 317.246 976.535 83.2714 2284 1.515
1 342.189 317.438 976.538 95.2156 2284 1.515
1 342.195 317.841 977.019 199.504 2284 1.515
1 342.195 316.651 977.079 78.6248 2284 1.515
1 342.217 316.998 977.14 92.8011 2284 1.515
1 342.178 316.356 977.578 68.0617 2284 1.515
1 342.22 316.955 977.591 86.6226 2284 1.515
1 342.206 315.555 977.717 64.1844 2284 1.515
1 342.262 317.668 977.823 61.8104 2284 1.515
1 342.235 317.283 977.948 178.91 2284 1.515
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1 342.28 316.084 979.02 75.1911 2284 1.515
1 342.285 315.484 979.123 49.2913 2284 1.515
1 342.3 315.233 979.509 49.7656 2284 1.515
1 342.322 315.414 980.045 88.8186 2284 1.515
1 342.342 315.083 980.132 91.0397 2284 1.515
1 342.352 315.339 980.426 74.2892 2284 1.515
1 342.349 314.827 980.464 193.102 2284 1.515
1 342.348 314.907 980.542 75.4531 2284 1.515
1 342.346 315.296 980.573 167.731 2284 1.515
1 342.382 314.375 981.155 76.719 2284 1.515
1 342.395 314.161 981.555 80.4195 2284 1.515
1 342.411 315.129 981.632 55.7226 2284 1.515
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1 342.44 315.03 982.239 59.7527 2284 1.515
1 342.429 314.117 982.398 55.8875 2284 1.515
1 342.44 314.628 982.399 53.5654 2284 1.515
1 342.424 313.755 982.58 74.1598 2284 1.515
1 342.441 313.151 982.804 179.198 2284 1.515
1 342.454 313.209 982.843 79.3513 2284 1.515
1 342.449 313.918 982.861 68.3982 2284 1.515
1 342.448 313.511 983.013 50.4851 2284 1.515
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Image Generation II

3 views (2D) in 1 image (224x224 pixels) are generated from txt file

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1 342.151 317.899 975.719 72.5761 2284 1.515
1 342.18 317.598 976.078 74.6677 2284 1.515
1 342.139 317.299 976.437 64.2498 2284 1.515
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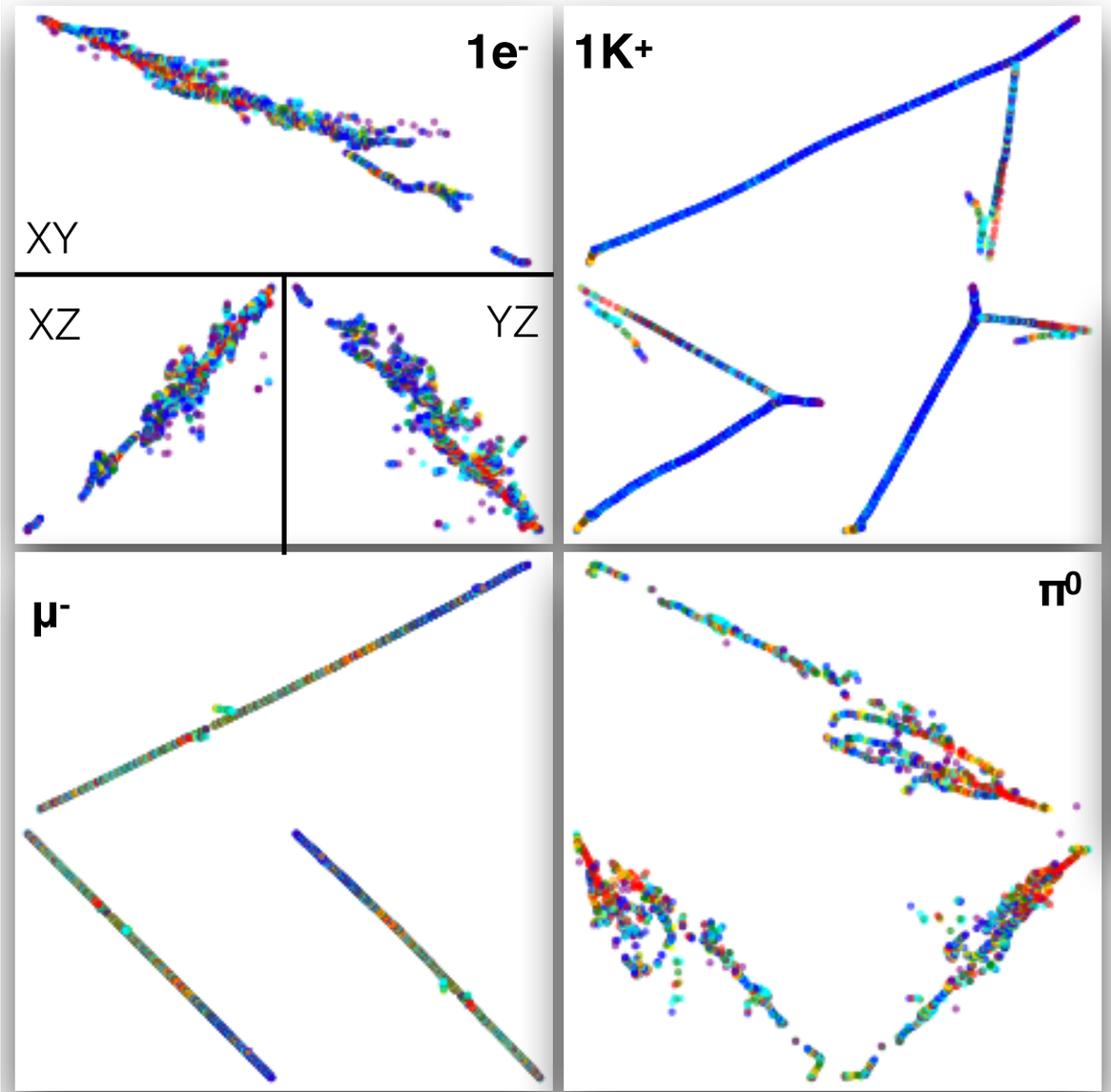
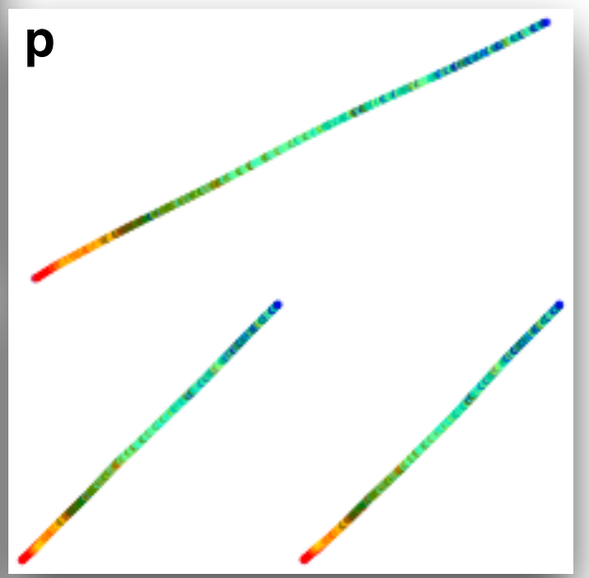
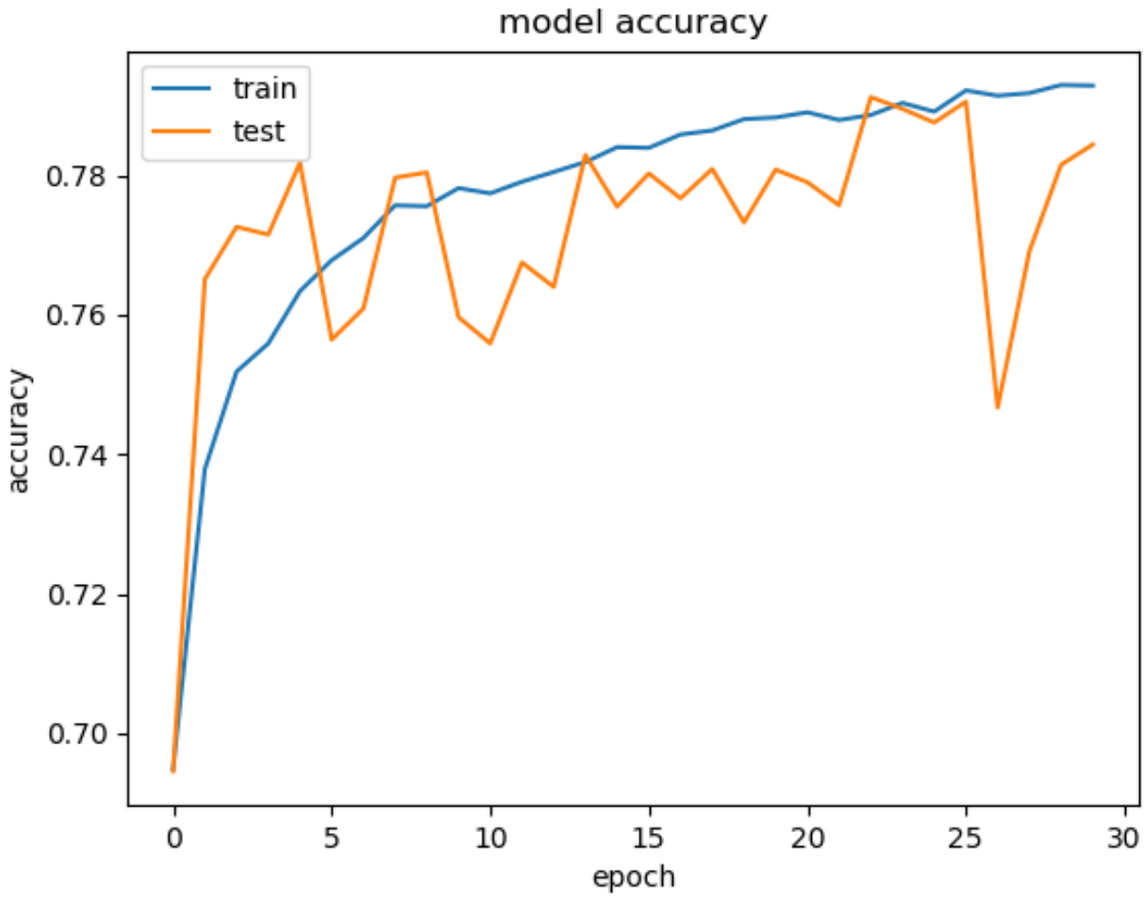
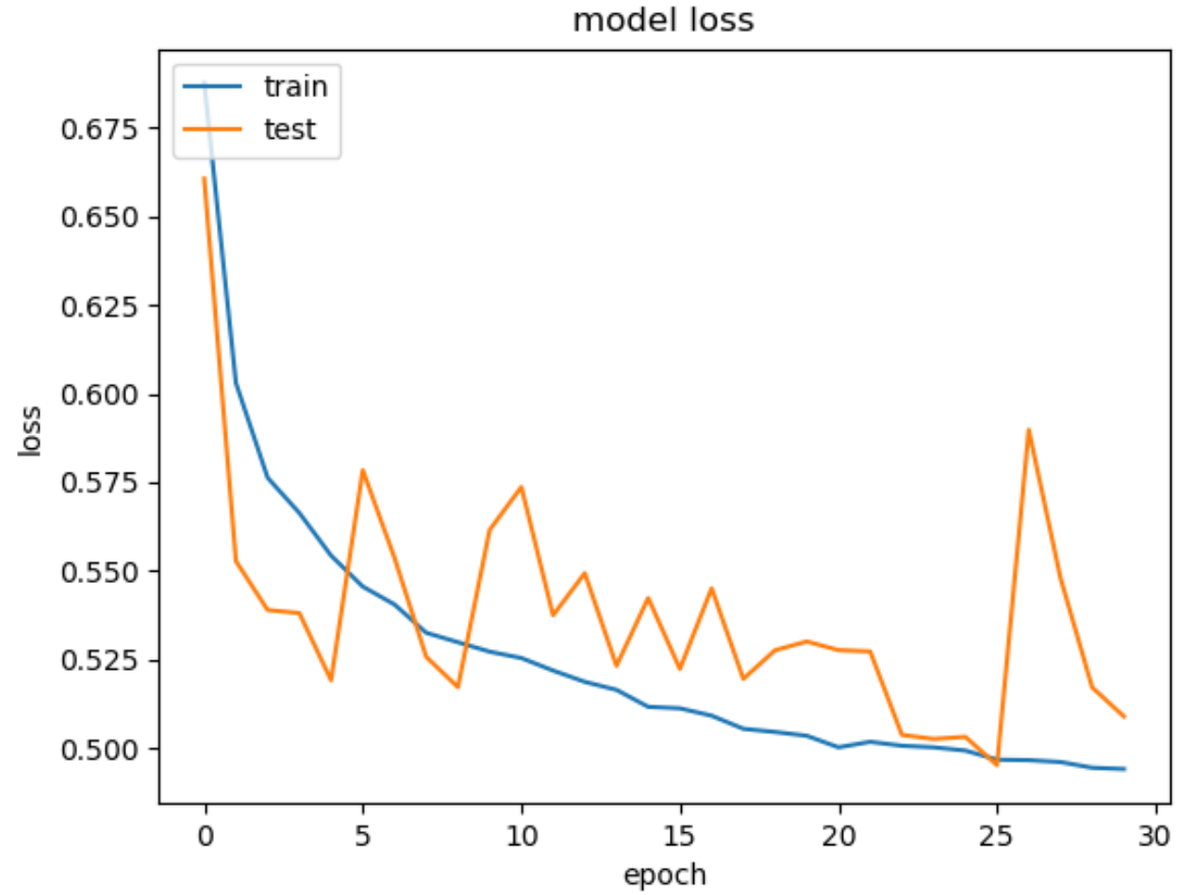




100K 224D 5C Results

ResNet50



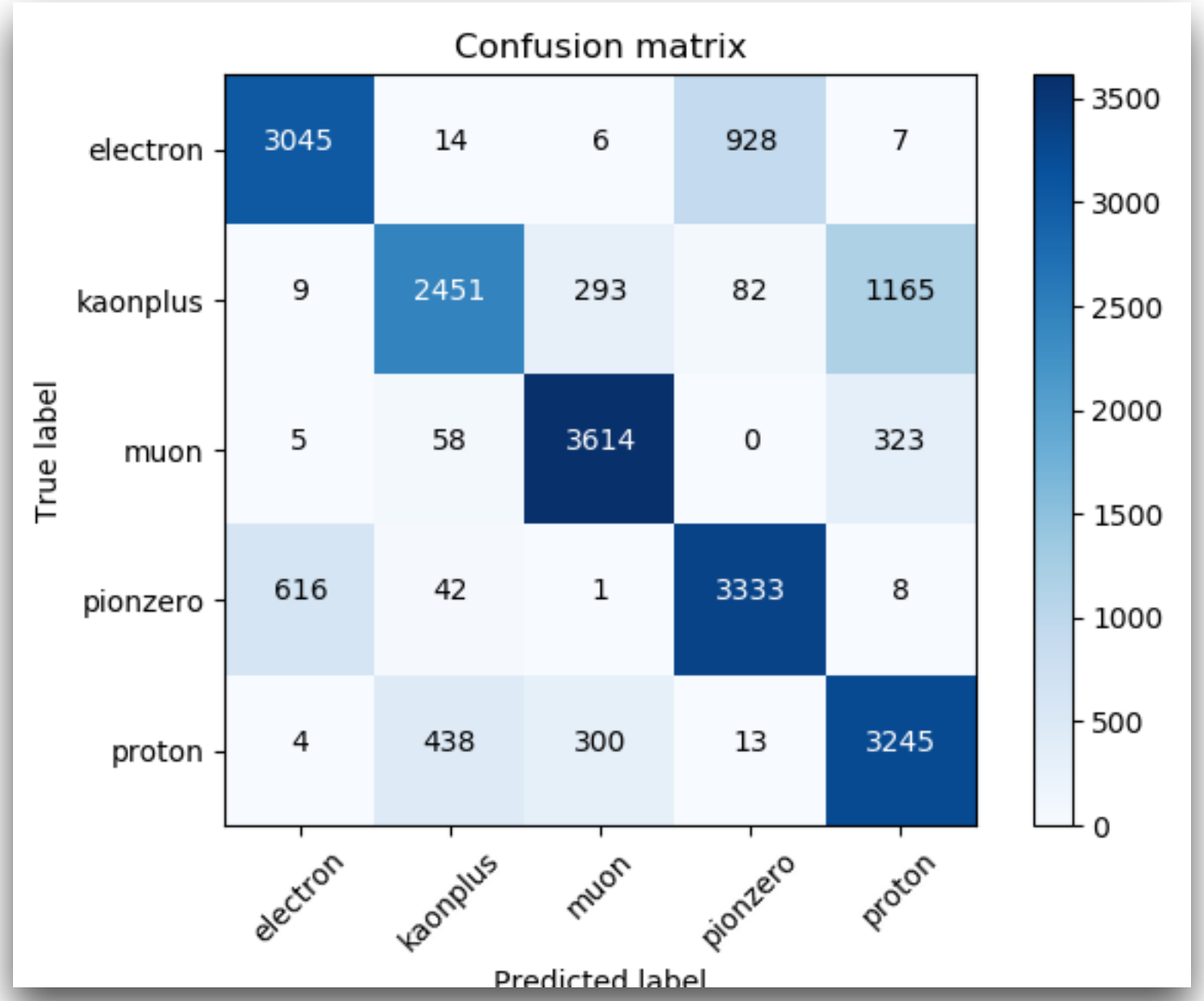


Accuracy: Correctly found image fraction

Loss: a value about how your prediction is well.

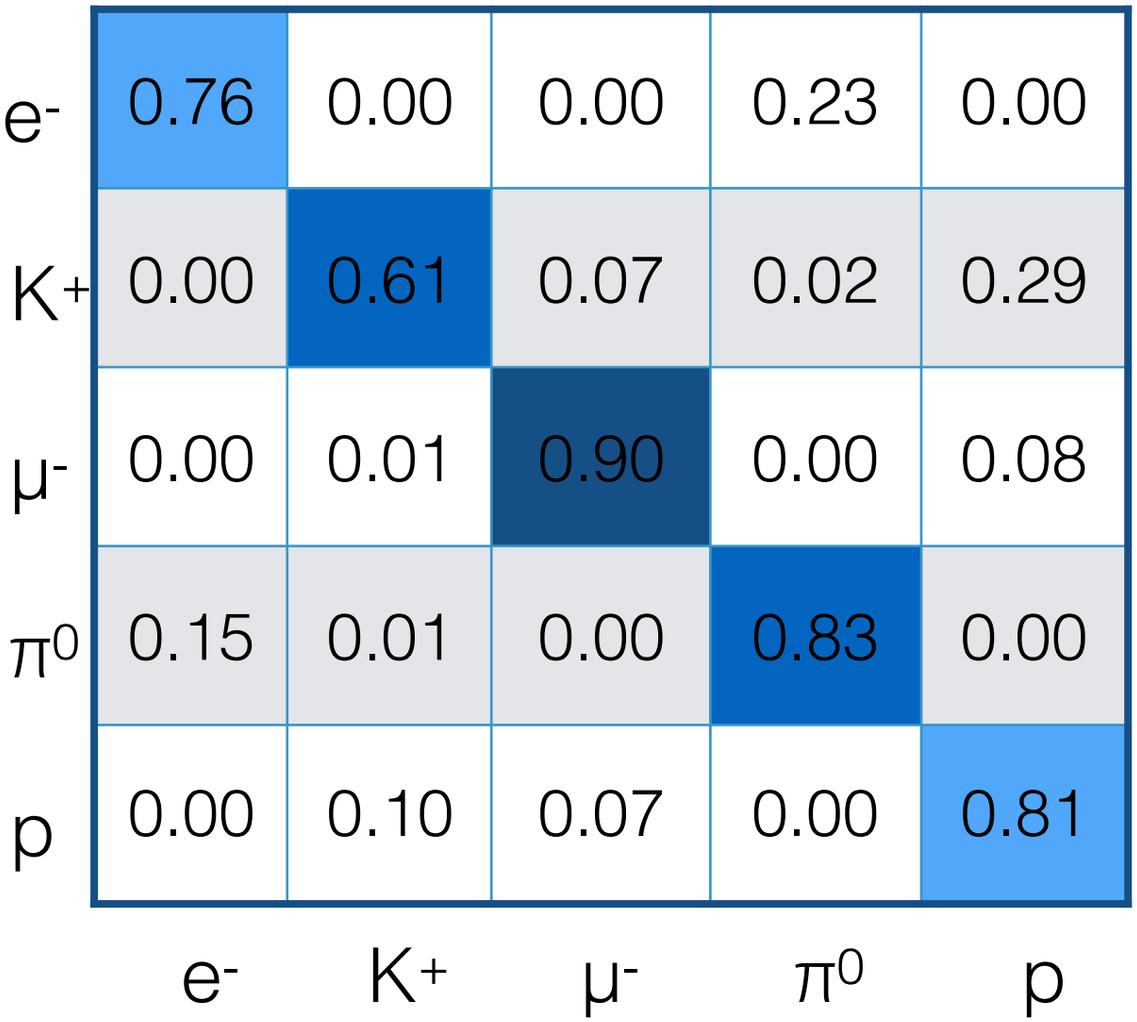
1 epoch: a process passing over all data (train+test) once

100K 224D 5C Results over Confusion Matrix



5 particles classification performance

Normalized Confusion Matrix

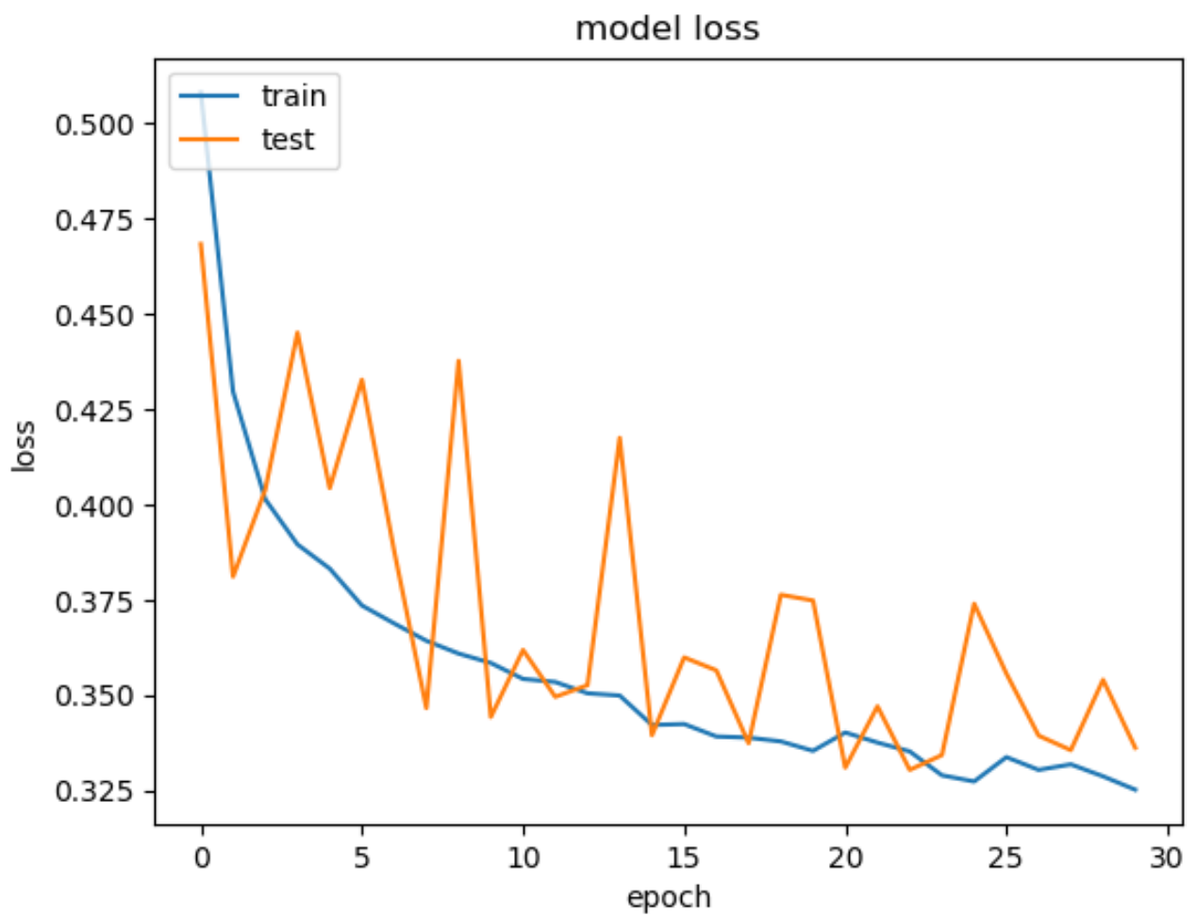


Diagonal Entries: Correct prediction fraction
Off-Diagonal Entries: Misidentification fraction

Particles	Correct Fraction [%]	Mis-Id [%]
e^-	0.76	0.23 (π^0)
K^+	0.61	0.29 (p)
μ^-	0.90	0.08 (p)
π^0	0.83	0.15 (e^-)
p	0.81	0.10 (K^+)

80K 224D 4C Results

ResNet50

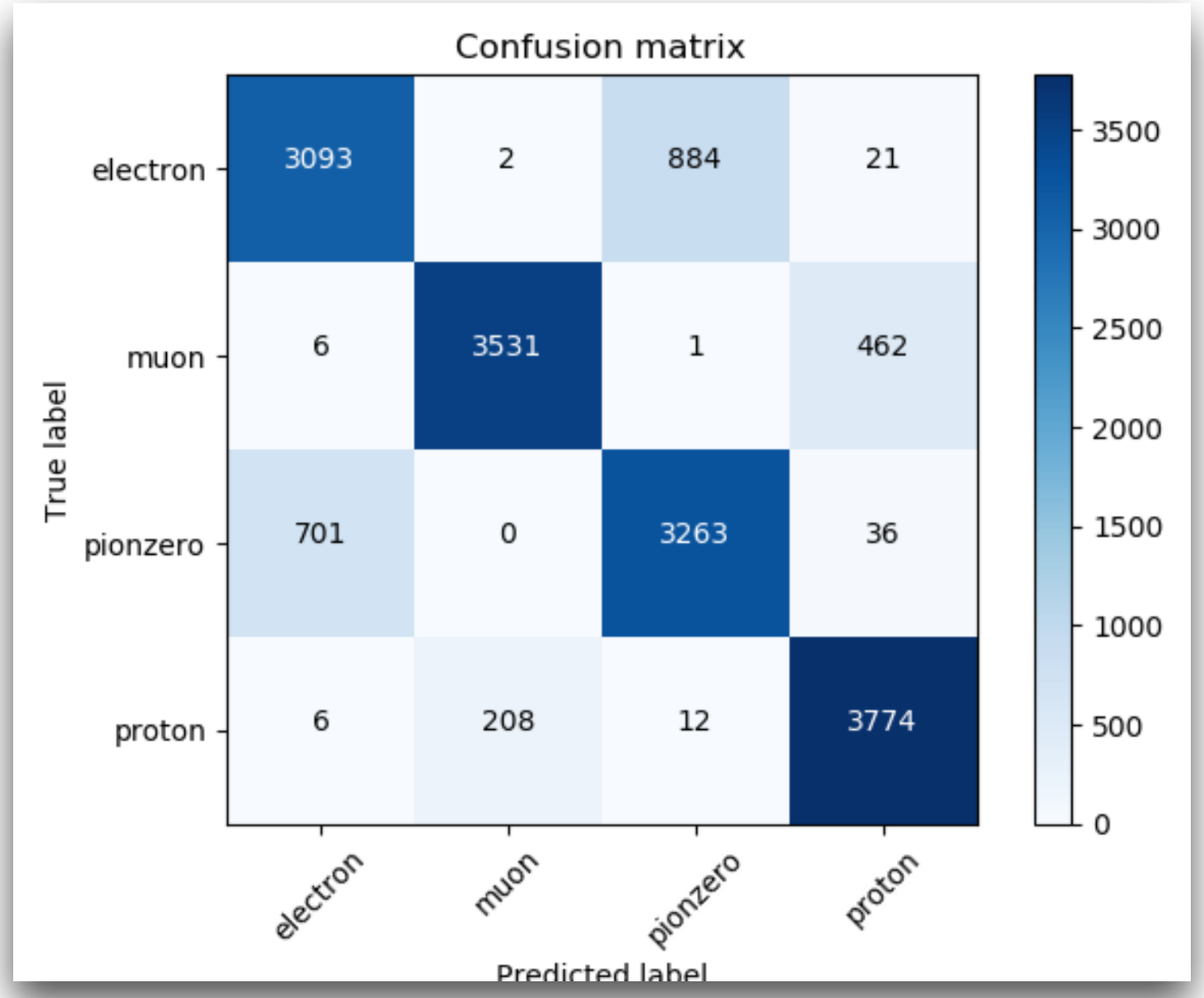


Accuracy: Correctly found image fraction

Loss: a value about how your prediction is well.

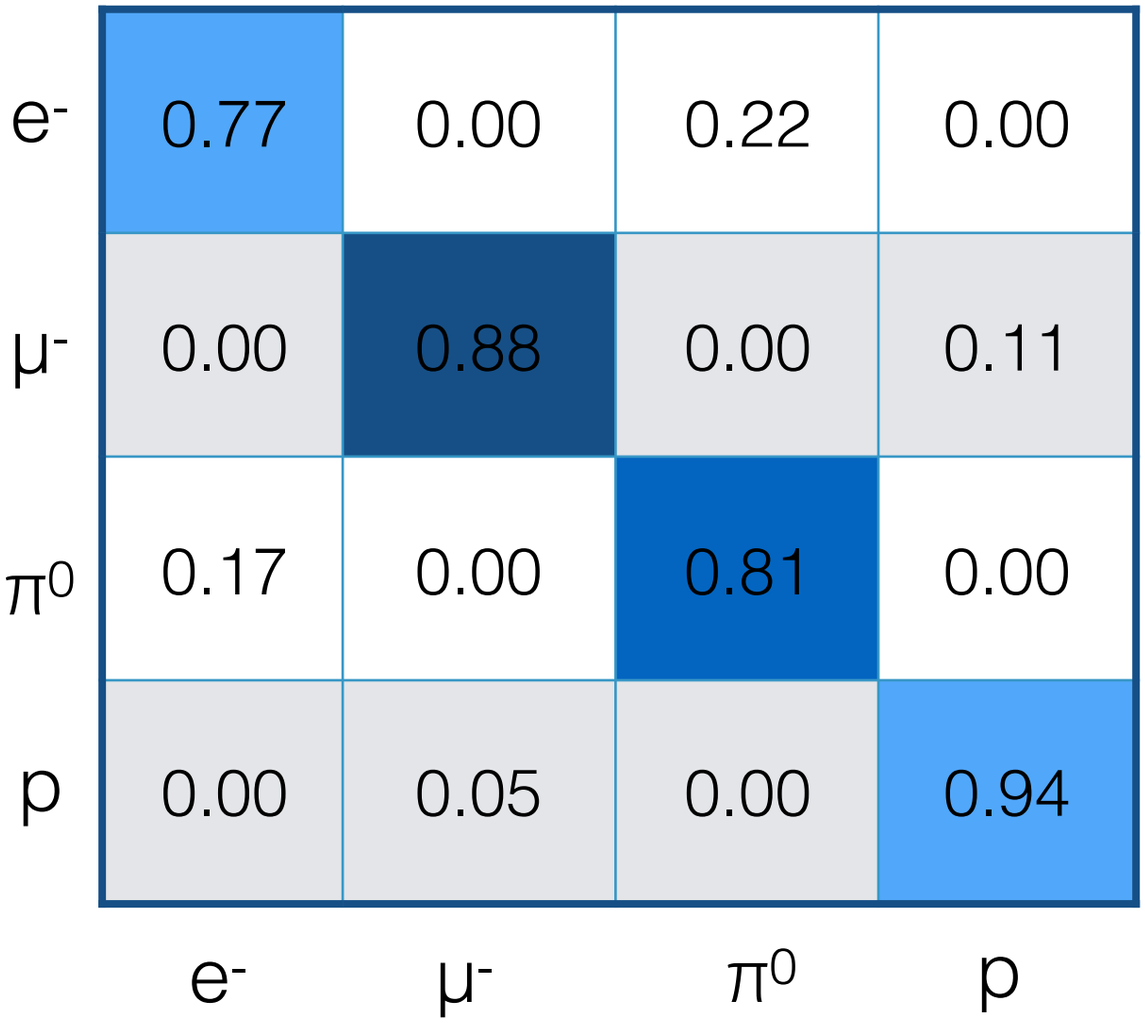
1 epoch: a process passing over all data (train+test) once

80K 224D 4C Results over Confusion Matrix



4 particles classification performance

Normalised Confusion Matrix

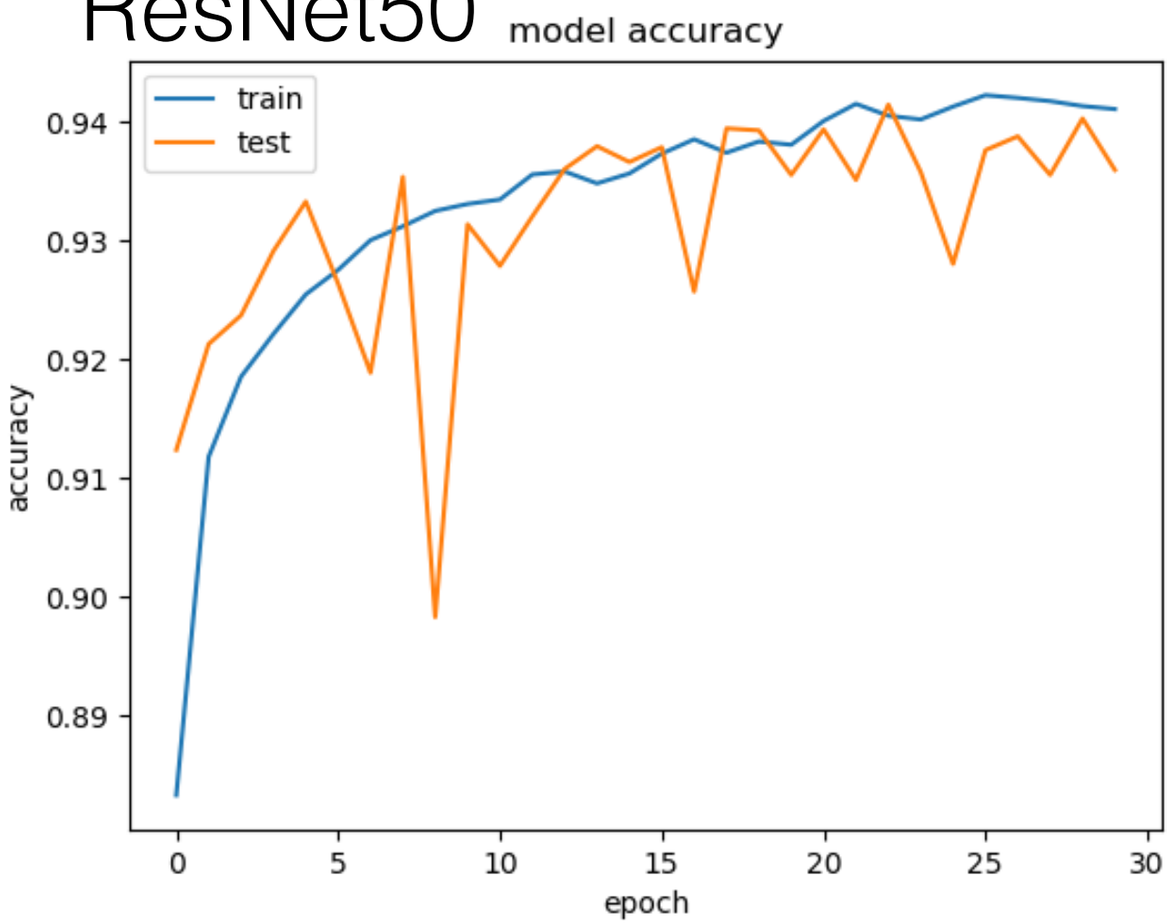


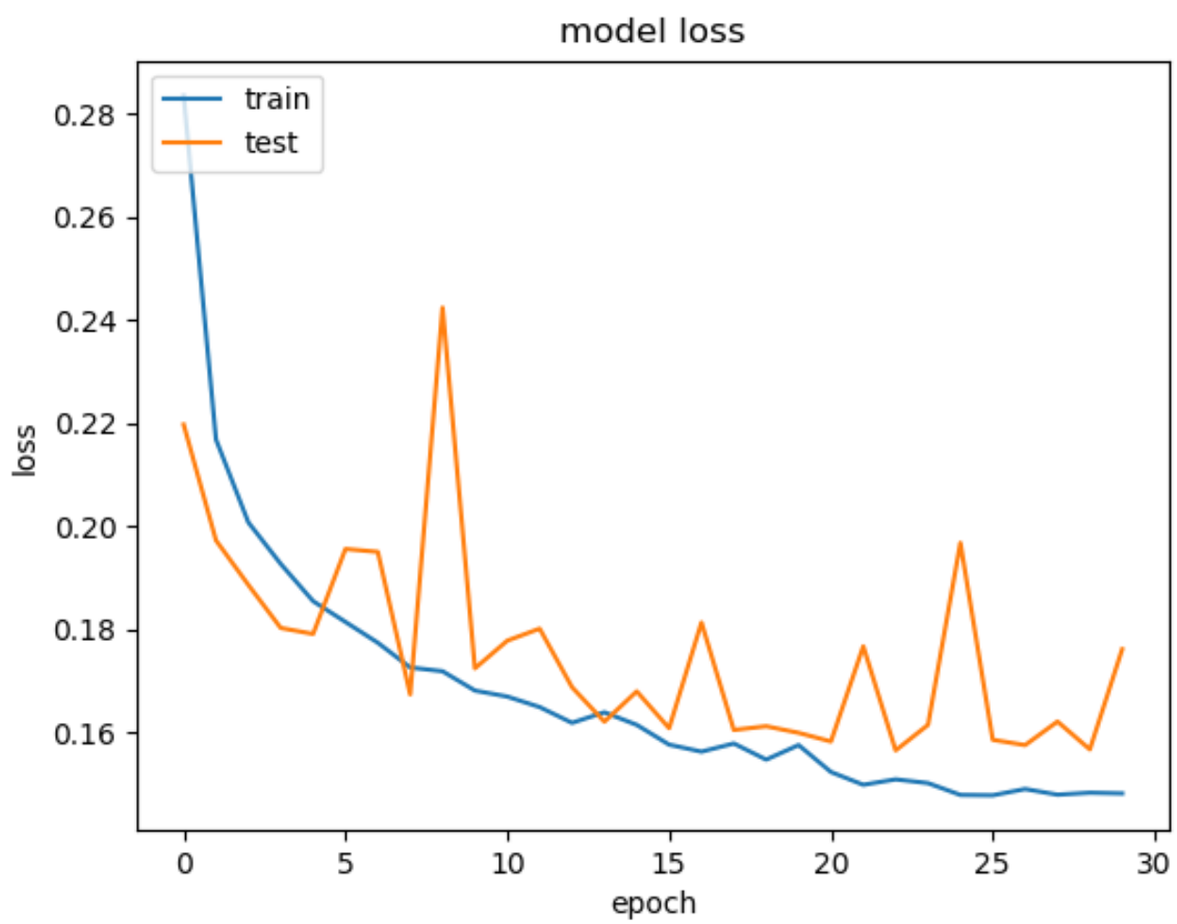
Particles	Correct Fraction [%]	Mis-Id [%]
e^-	0.77	0.22 (π^0)
μ^-	0.88	0.11 (p)
π^0	0.81	0.17 (e^-)
p	0.94	0.05 (μ^-)

Diagonal Entries: Correct prediction fraction
Off-Diagonal Entries: Misidentification fraction

60K 224D 3C Results

ResNet50



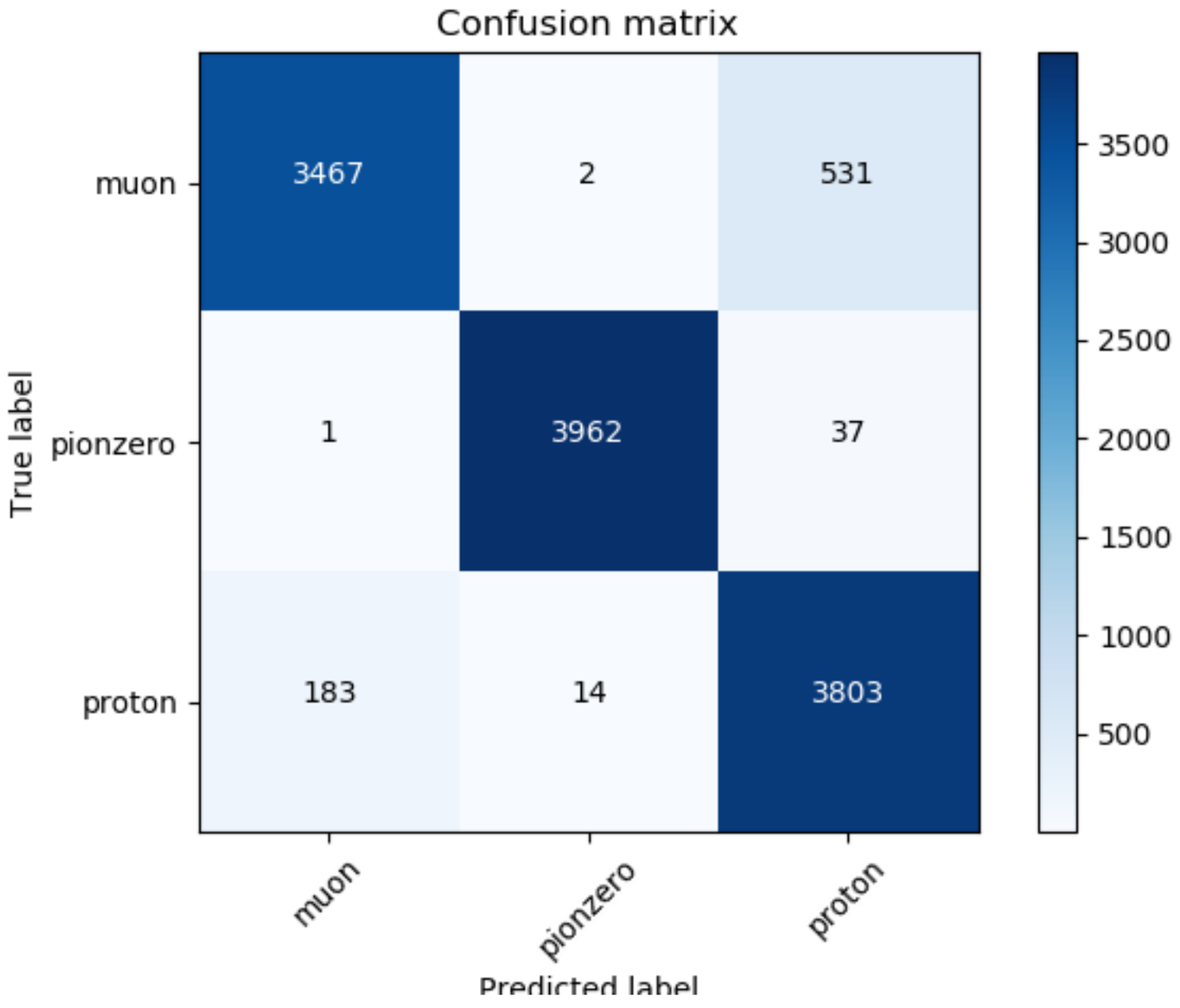


Accuracy: Correctly found image fraction

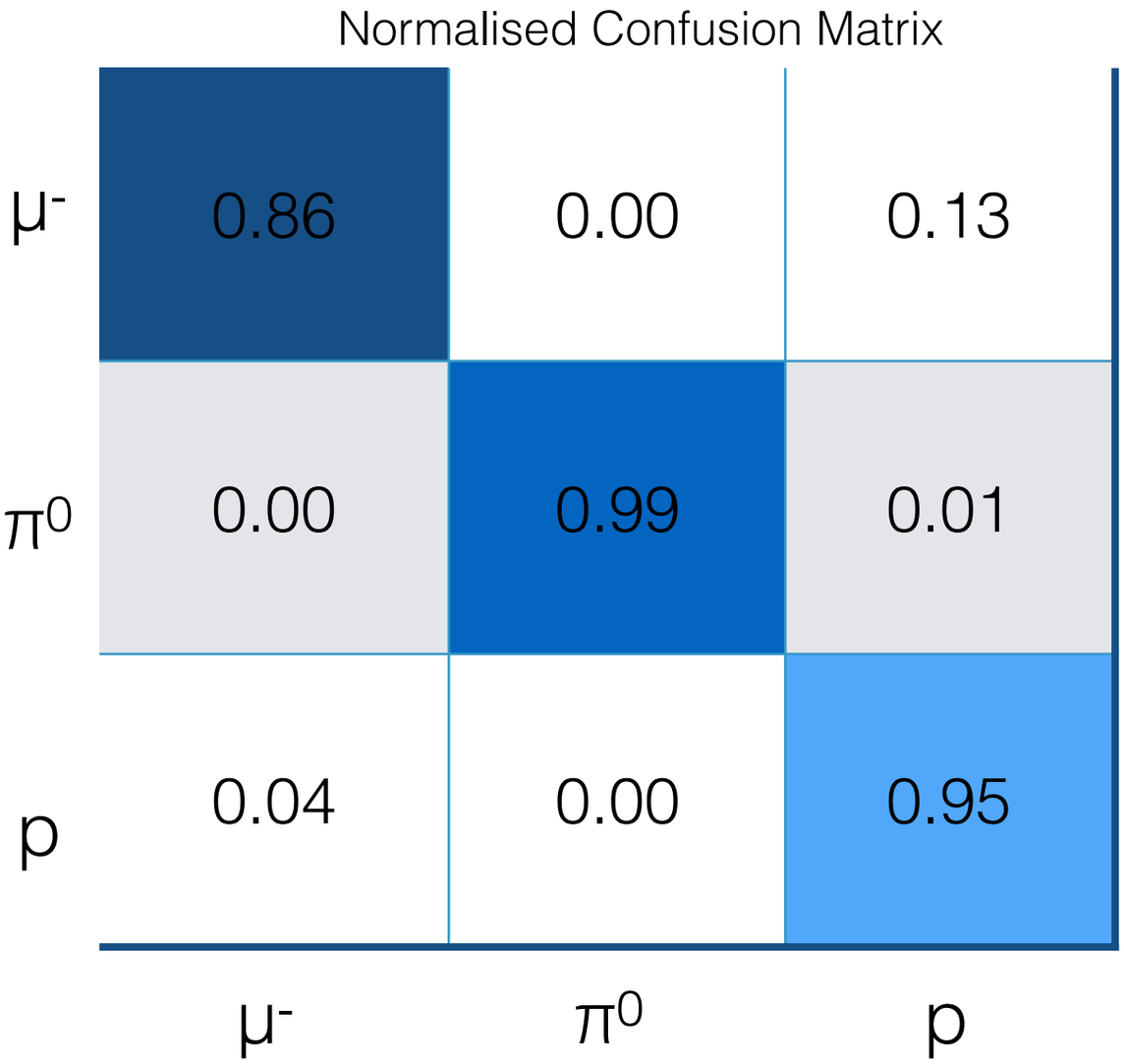
Loss: a value about how your prediction is well.

1 epoch: a process passing over all data (train+test) once

60K 224D 3C Results over Confusion Matrix



3 particles classification performance



Diagonal Entries: Correct prediction fraction
Off-Diagonal Entries: Misidentification fraction

Particles	Correct Fraction [%]	Mis-Id [%]
μ^-	0.86	0.13 (p)
π^0	0.99	0.01 (p)
p	0.95	0.04 (μ^-)

Possible Improvements

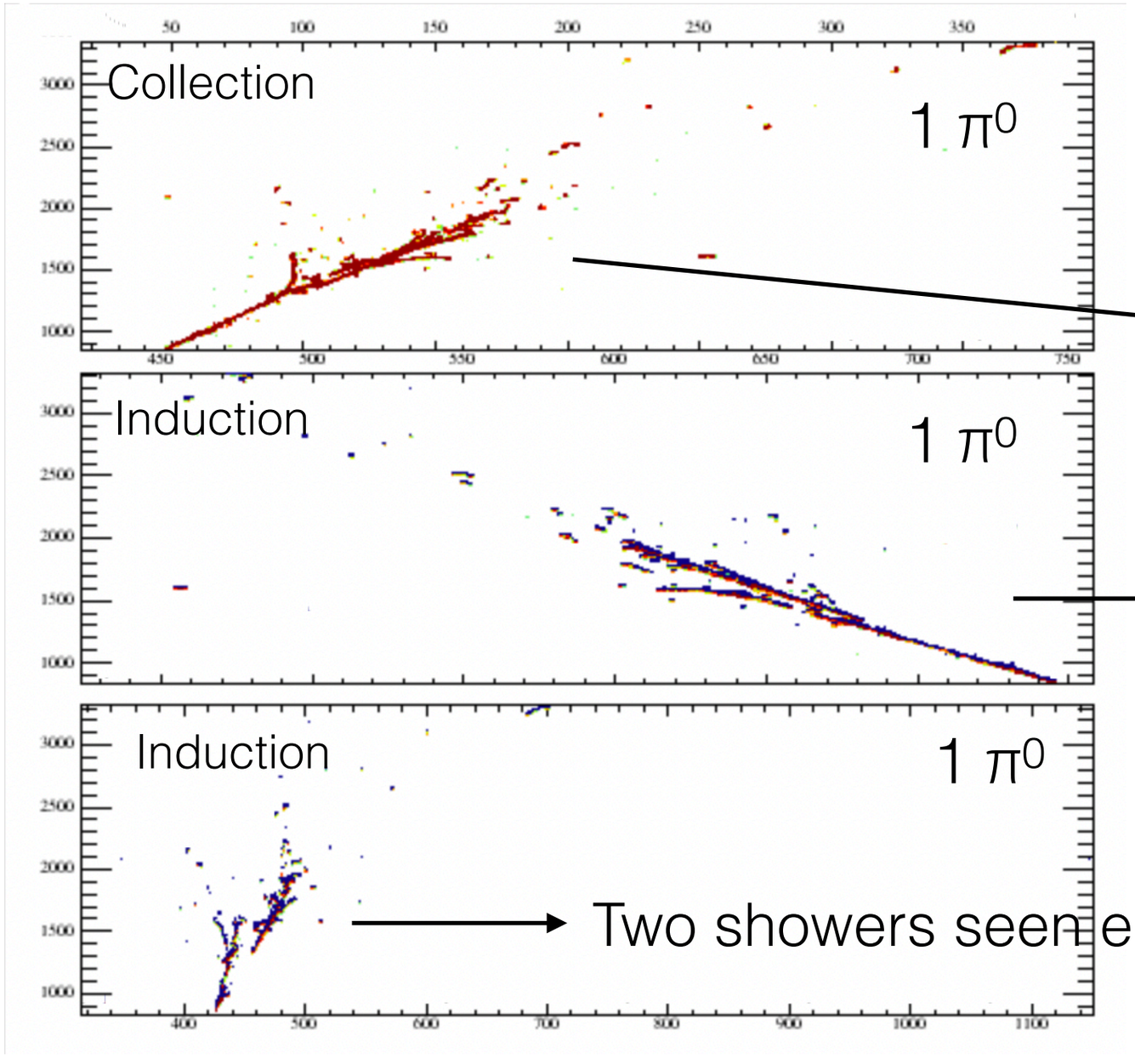
- Consider Hadronic Interactions.
- Additional cuts/methods can be studied for accuracy improvement.
- Data can be increased to get better accuracy results.
- Find efficiency performance as a function of kinematic variables.

Conclusion

- 100K MC single particle generation was realised with the help of the LArSoft including Pandora codes for Space Point reconstruction and Geant4.
- Transfer learning and three 2D images-in-one image with 224x224 pixels were employed.
- As Image generation optimised, 3-in-1 images give better test accuracy results.
- For 5C, 4C and 3C particle classification with the help of ResNet50 model, the test accuracy results were obtained as ~0.80, ~0.86 and ~0.94, respectively.
- The more data, the more performance (Deep Learning).
- The results are promising for neutrino event classification in the LArTPC of DUNE FD which is excellent imaging calorimeter.

BACKUP

Possible Classification Mistakes



Looks like electron

Looks like electron

Two showers seen easily