Deep Learning MicroBooNE

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New Perspectives 06/14/2016

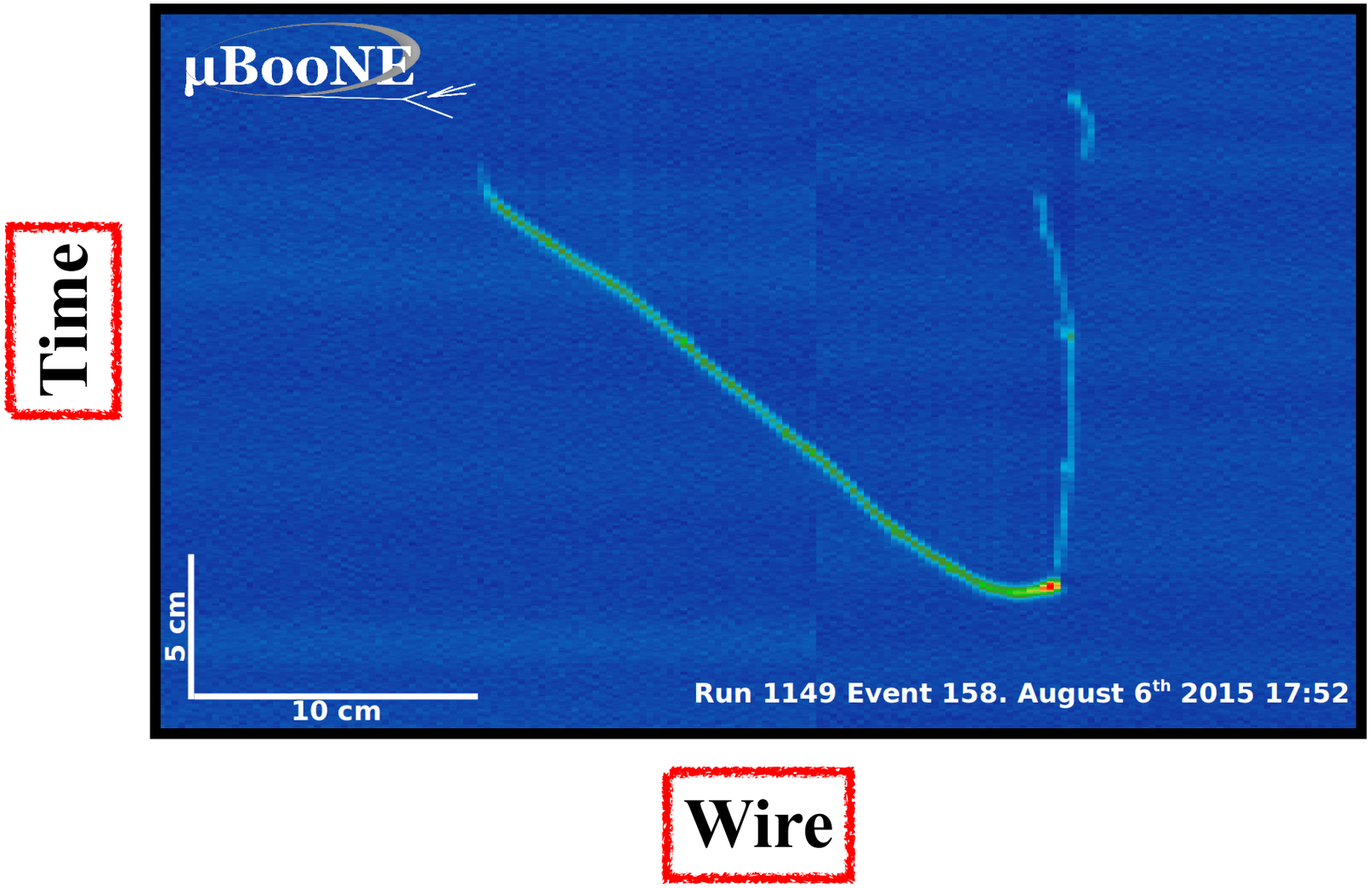
Summary

1. Motivation
2. Deep Learning overview
3. Single particle classification and detection
4. Nu detection in event image

Motivation

- Current reconstruction for **LArTPC** is a lot of pattern recognition
  - We design new features in algorithms most appropriate for the task at hand, usually to capture a specific particle signature
    - ex: cosmics rays, muon decay, neutral pion decay, and neutrino!

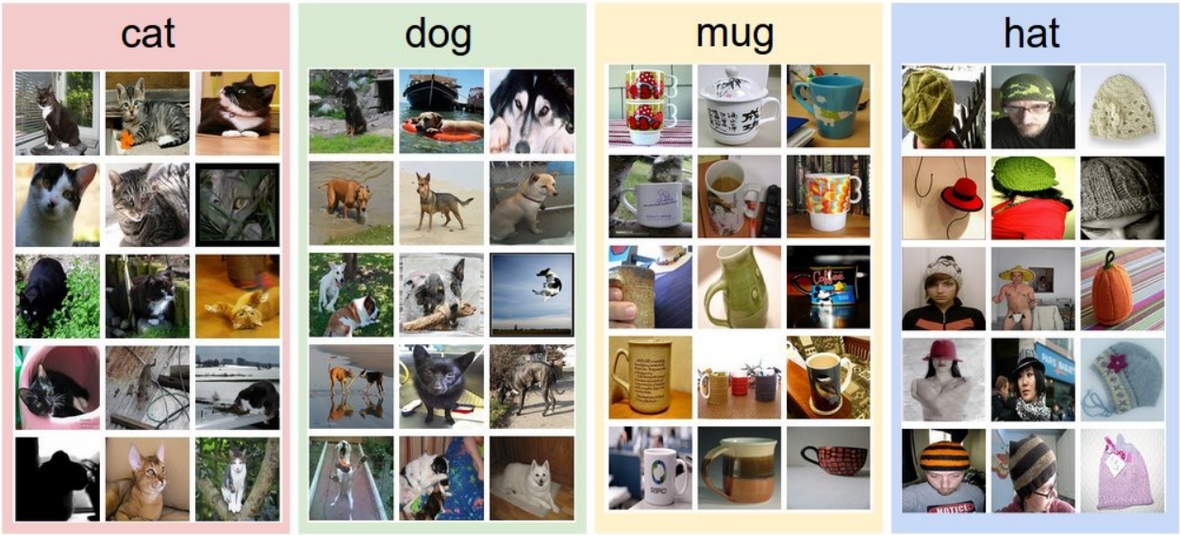
- Our **data** can be represented as **images**



Likely muon decays to electron!

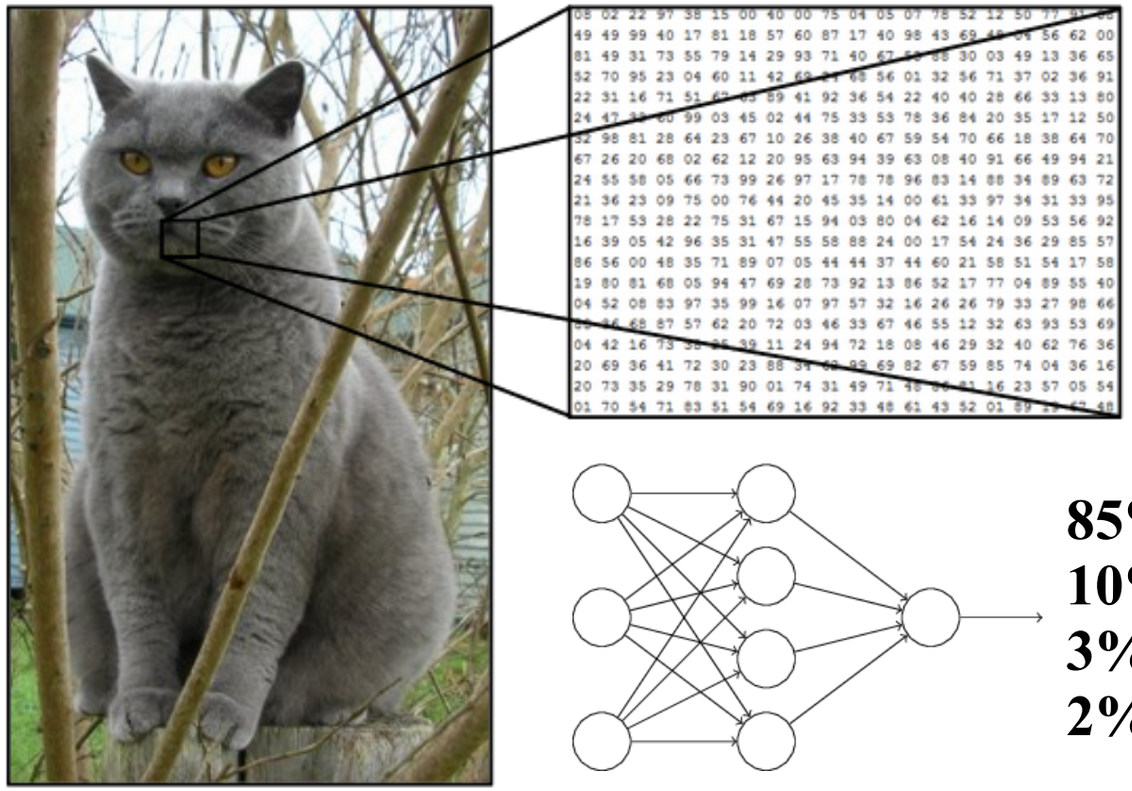
Deep Learning Overview

A problem in **Computer Vision** is image classification



Given an input image, assign **one** label from a fixed set of categories

How to design an algorithm that can classify images into district categories?



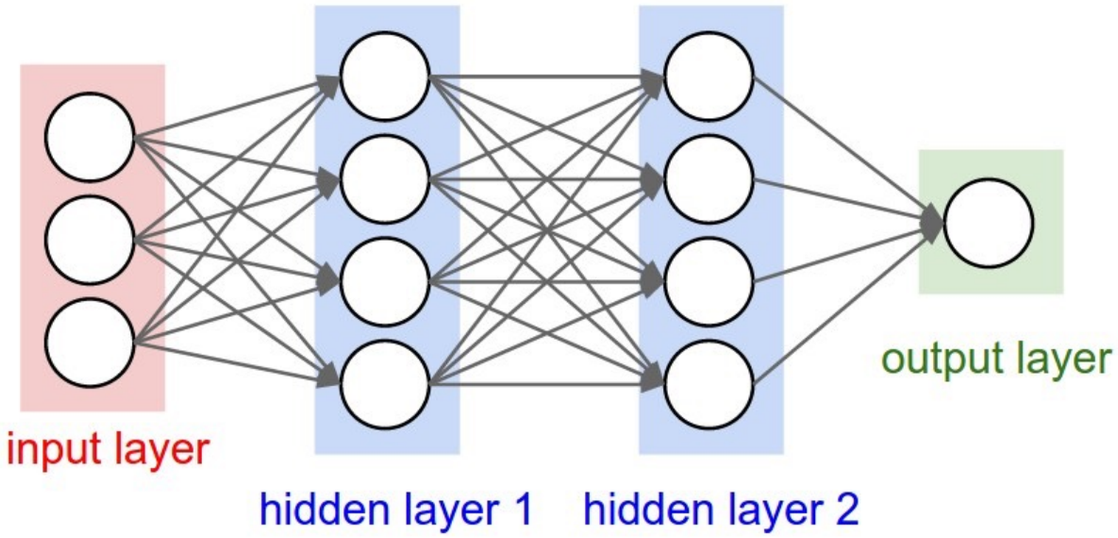
Collection of numbers to a computer

85%	**cat** ✓
10%	**dog**
3%	**hat**
2%	**mug**

Deep Learning Principle

Provide the computer with **many examples** of each class and then develop a function that maps an image a list of class scores. Tell computer when it's **right** and **wrong** how to **improve.**

Convolutional Neural Networks are similar to artificial neural networks — they are made up of neurons that have learnable weights and biases.



Introduction to CNNs

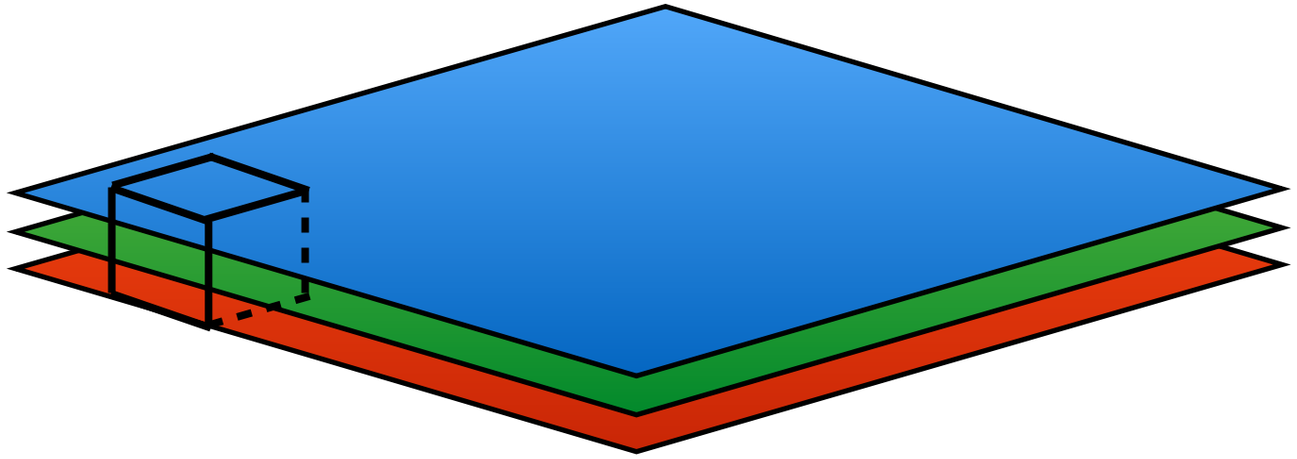
Filter

1	0	-2	0
2	1	-1	-1
0	3	-3	-1
-1	0	1	0

1	0	2	1
1	1	1	-1
0	1	0	-1
-1	-1	-1	1

0	0	-2	0
1	-1	0	1
0	1	-3	-1
-1	1	-2	1

weights



Image

Introduction to CNNs

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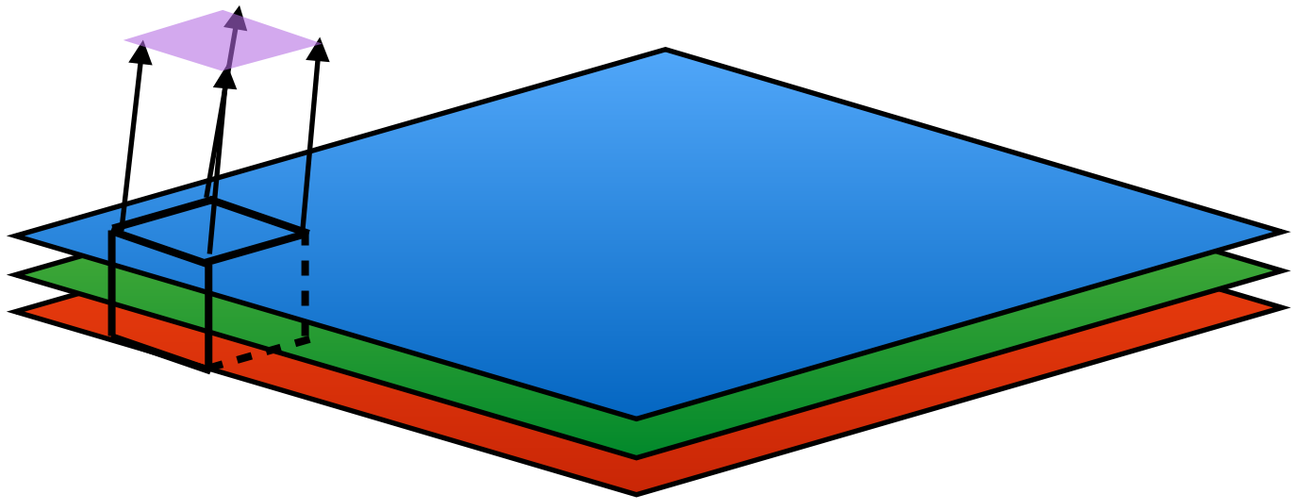
weights

Dot product, add bias



Image

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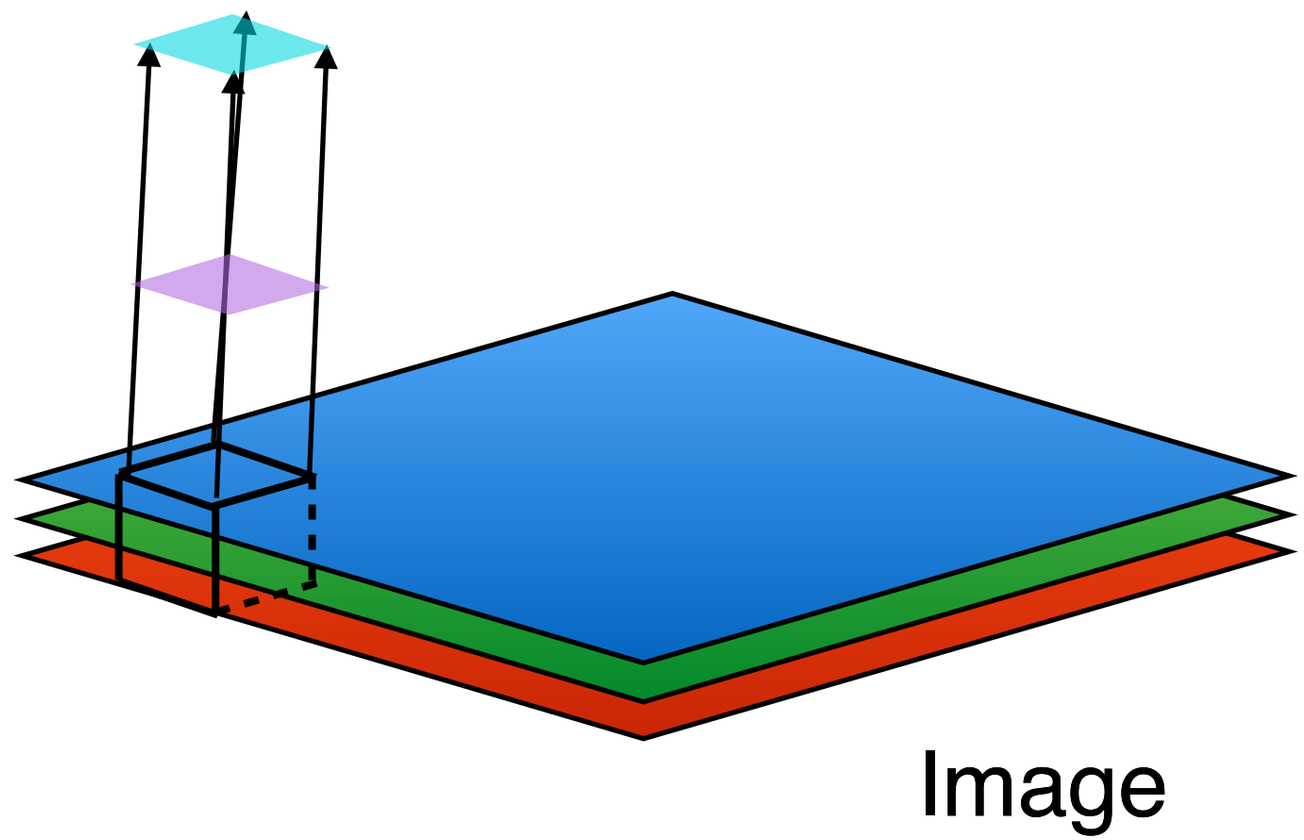
weights

Activation function

Dot product, add bias



Introduction to CNNs

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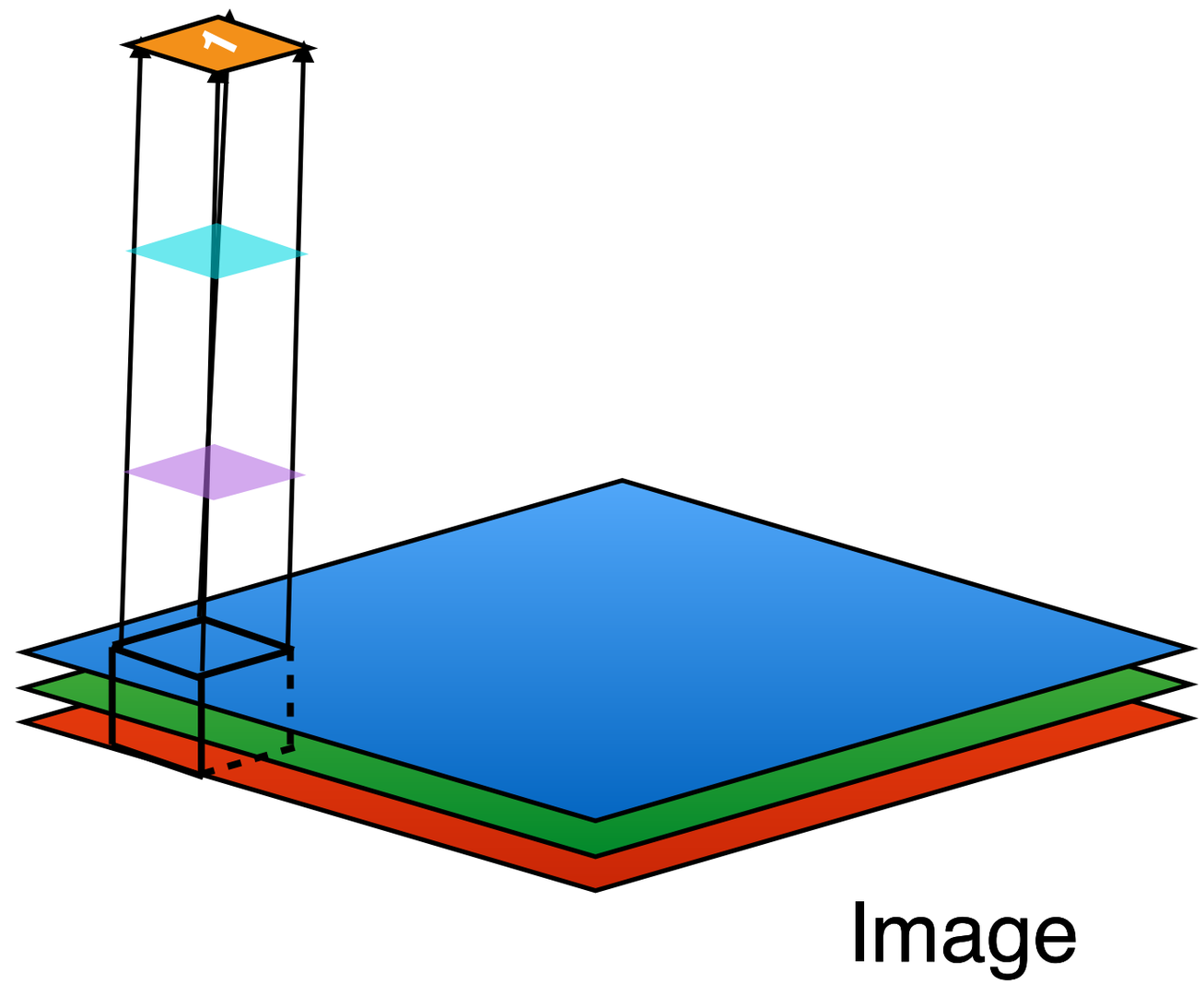
weights

Neuron output

Activation function

Dot product, add bias



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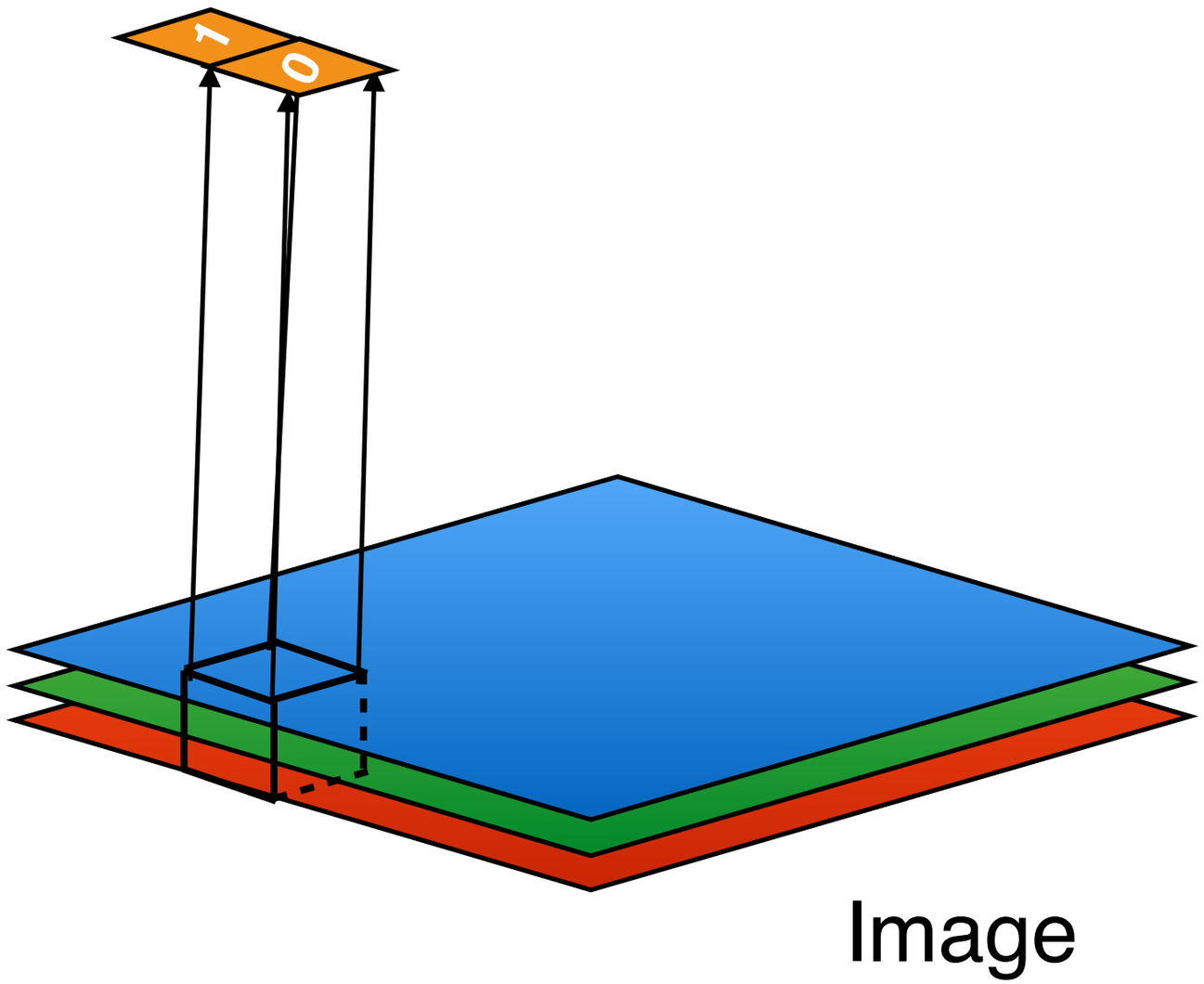

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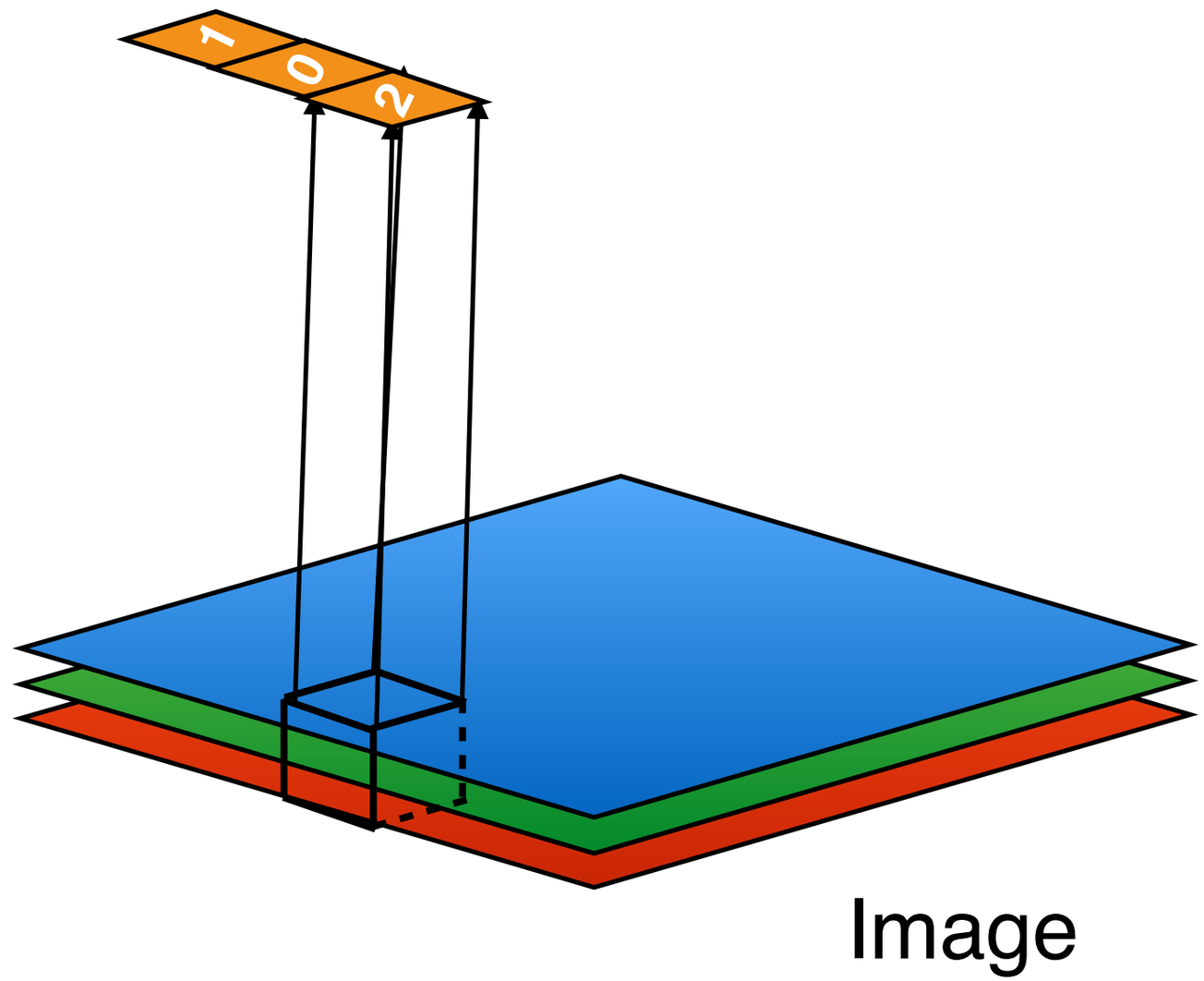

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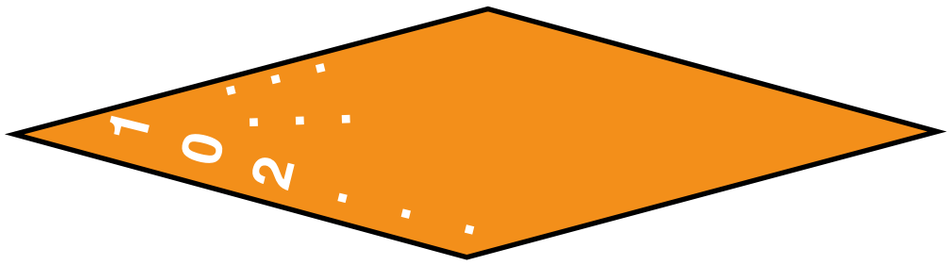
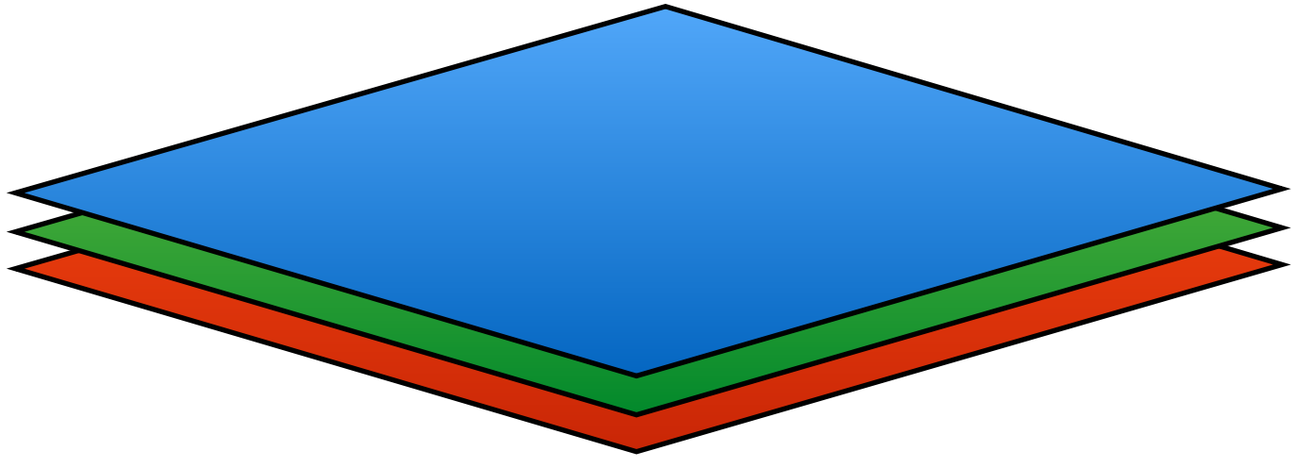
0	0	-2	0
1	-1	0	1
0	1	-3	-1
-1	1	-2	1

weights

Feature Map

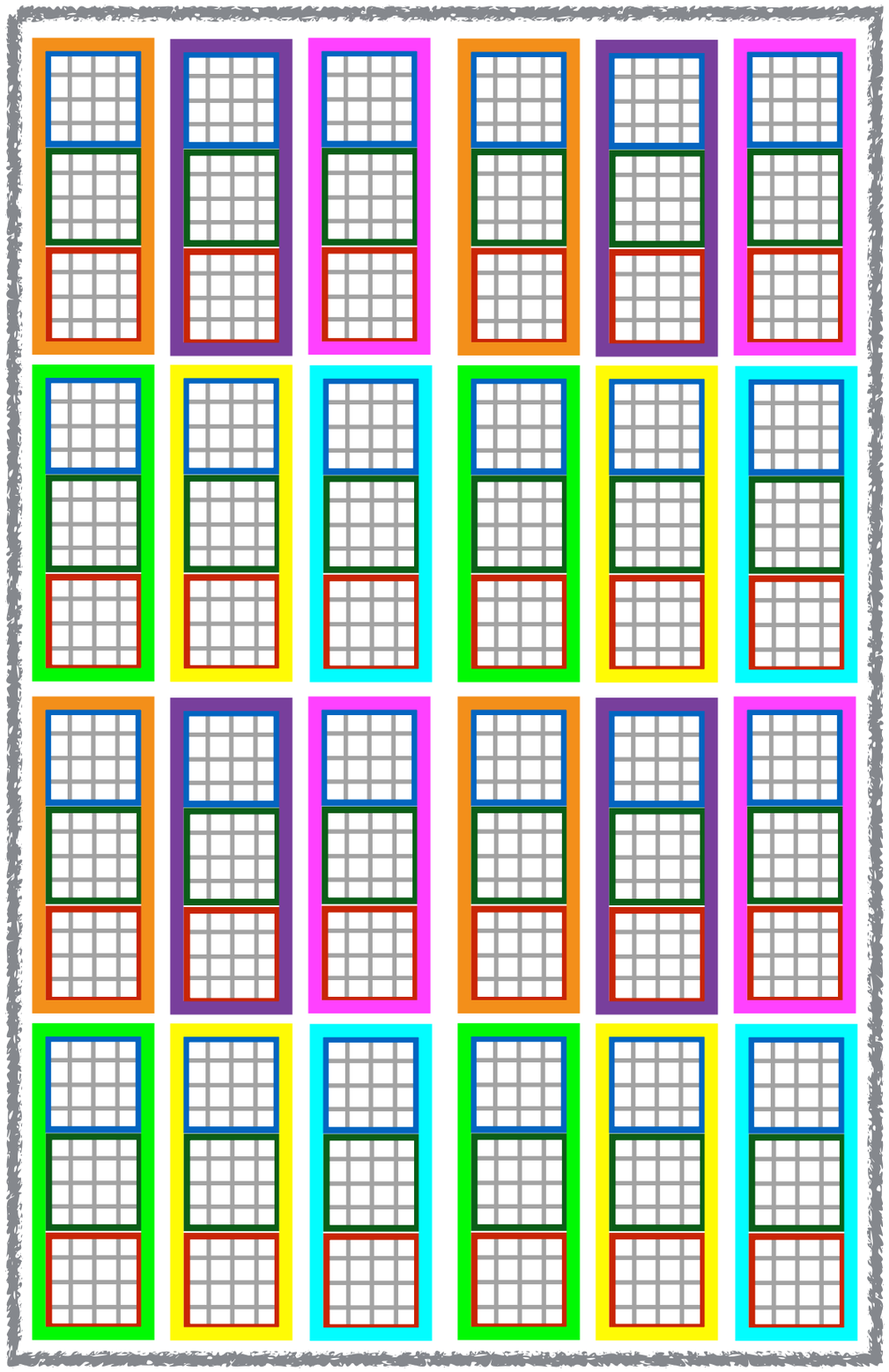




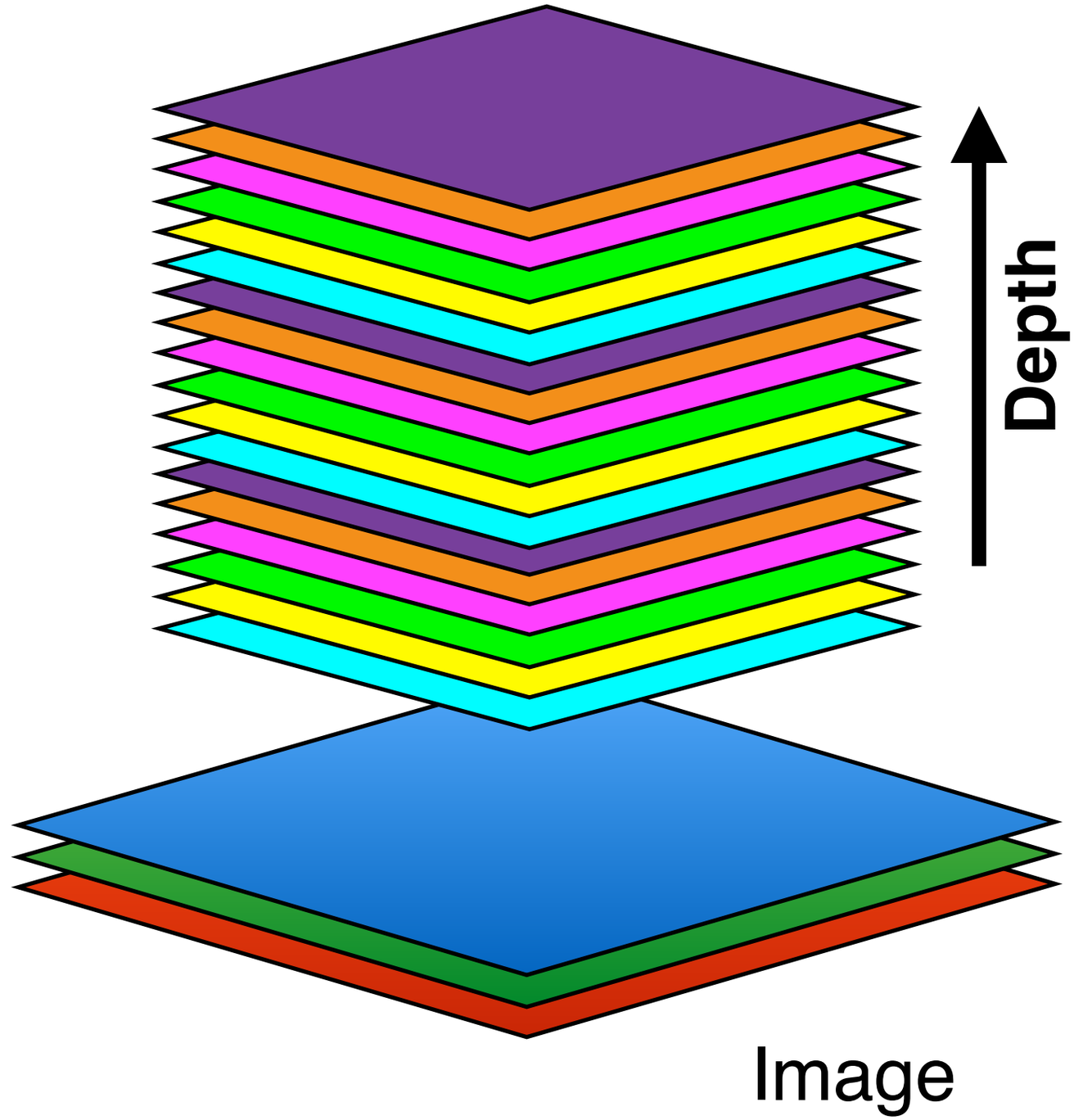
Image

Introduction to CNNs

N Filters

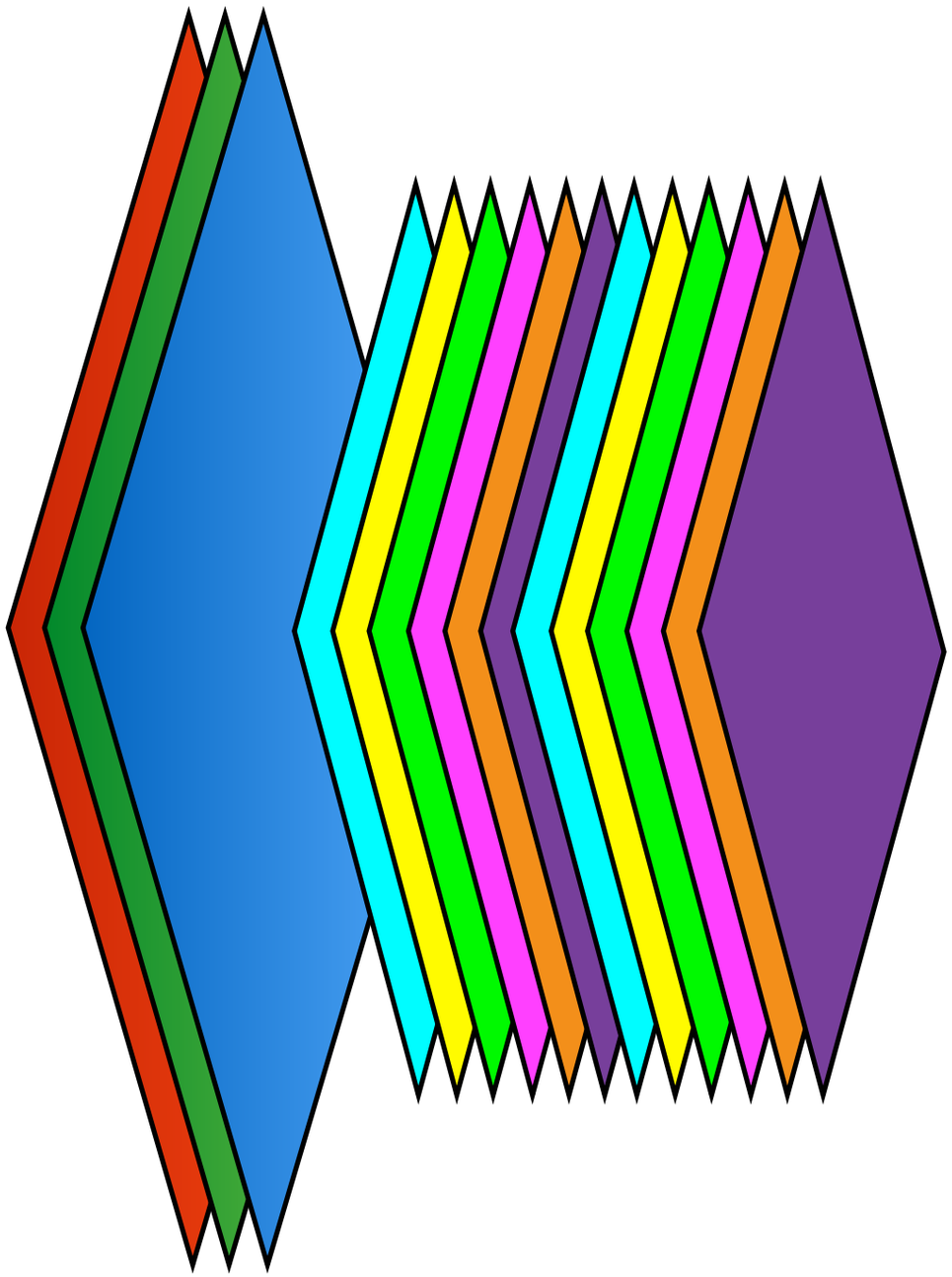


Feature Maps



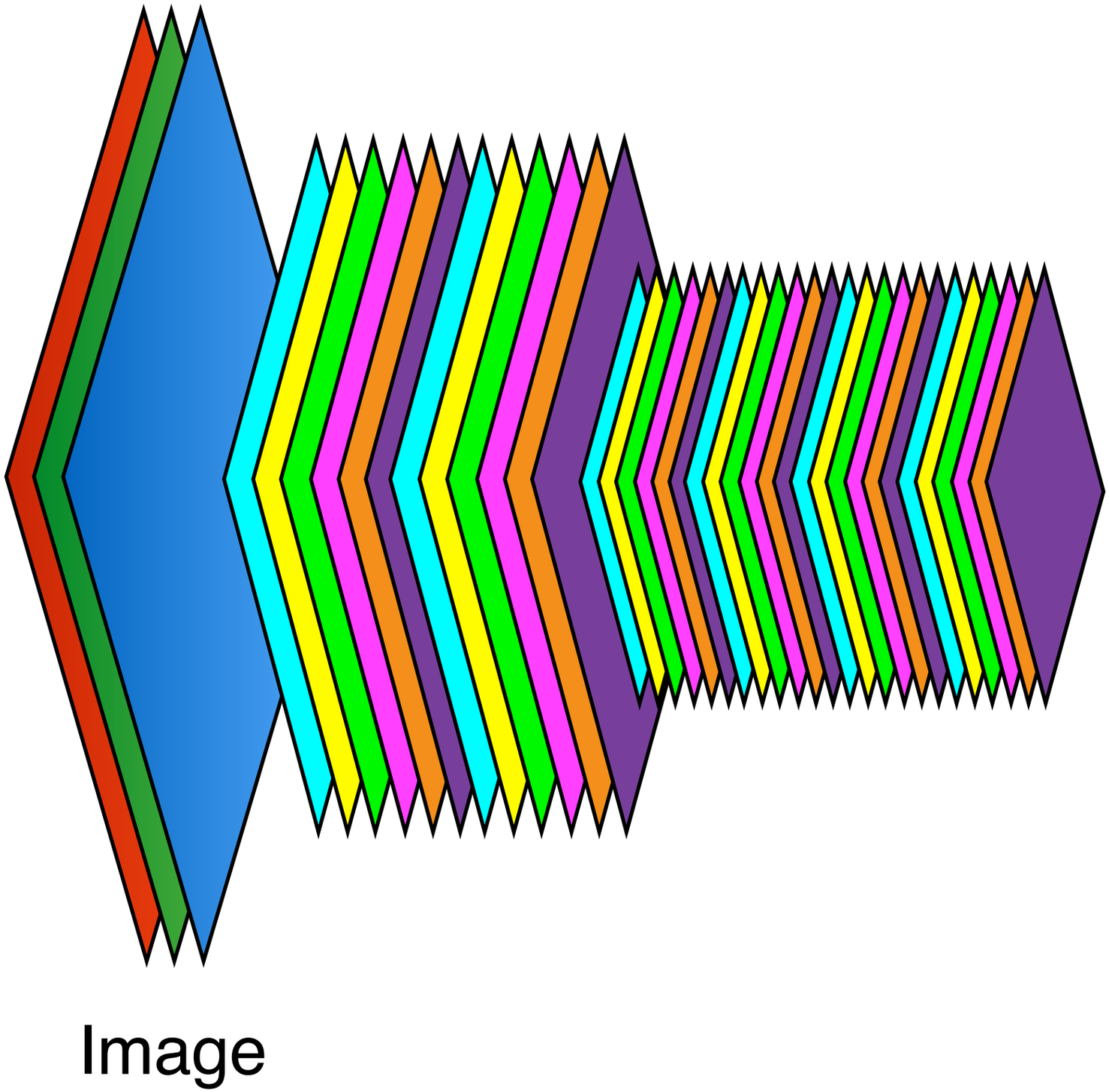
many weights!

Introduction to CNNs

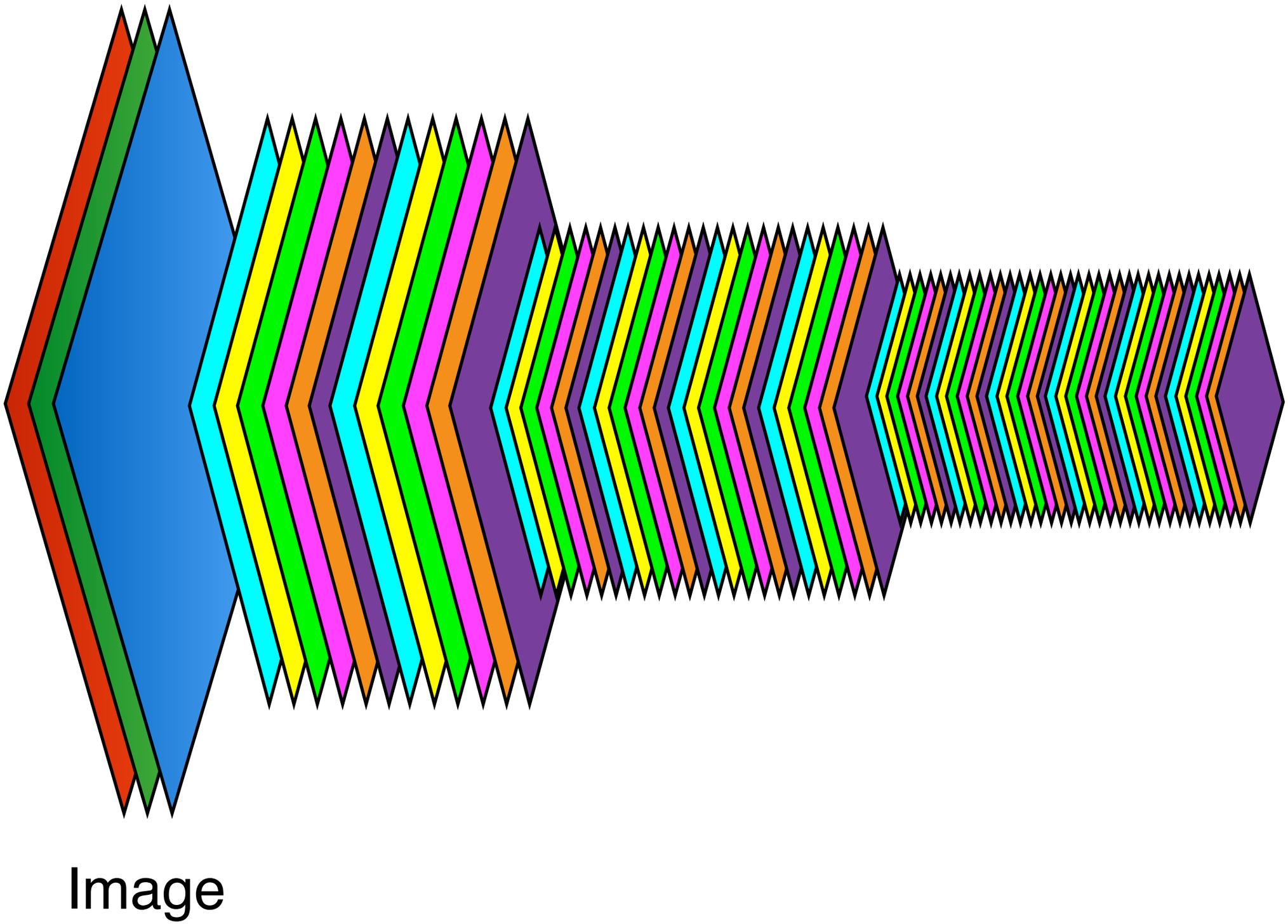


Image

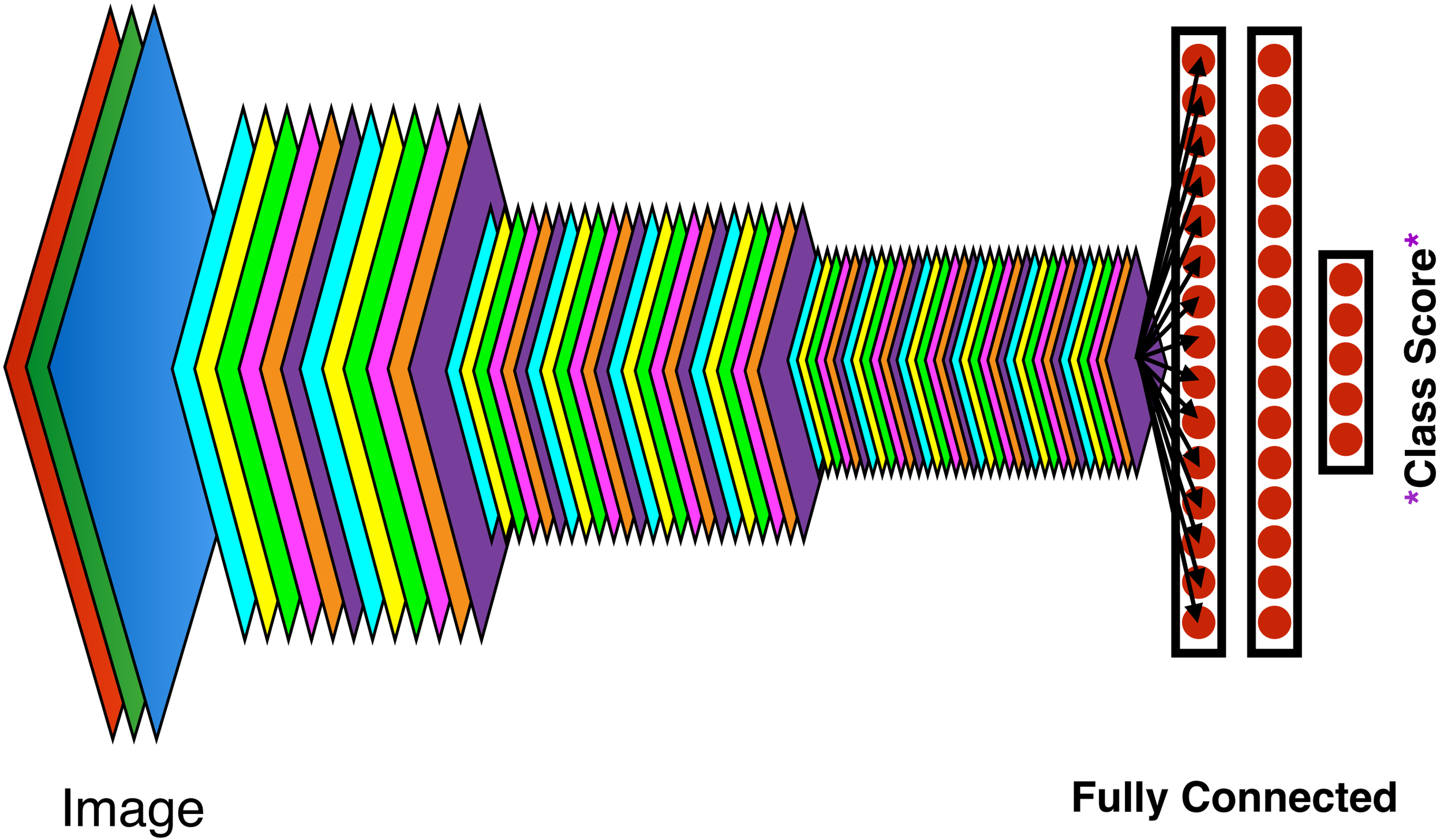
Introduction to CNNs



Introduction to CNNs



Introduction to CNNs



CNN Research & Industry

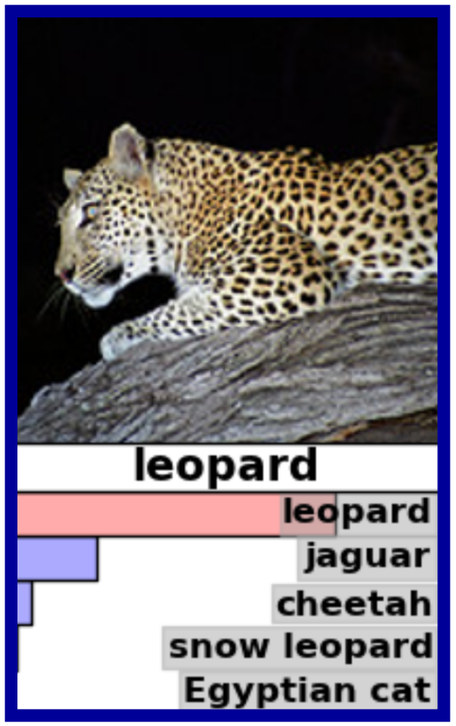
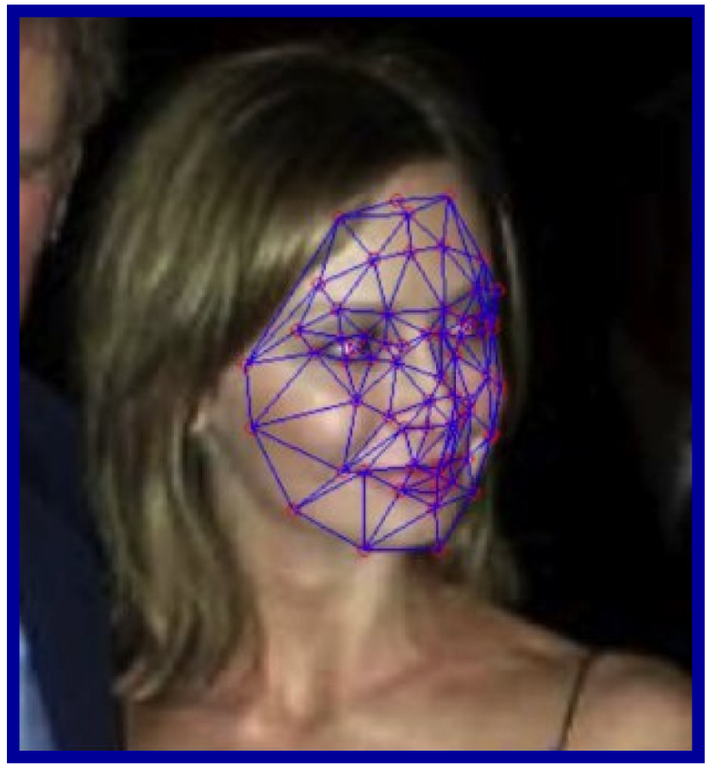
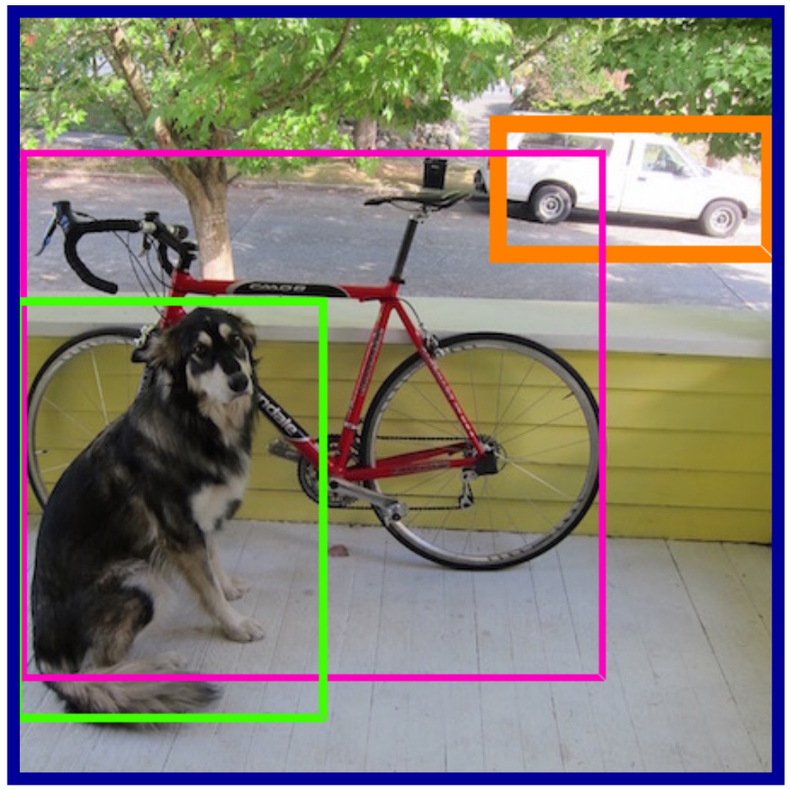


Image classification



Facebook's DeepFace



Object Detection

Car vision

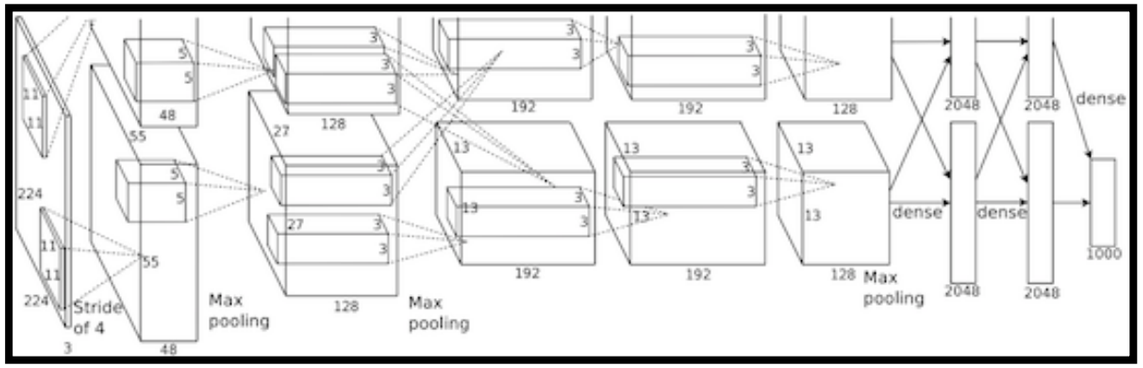
Image captioning

Particle Classification

We have trained **two** types of industrial deep networks that serve as benchmarks against deeper and more elaborate models.

1. AlexNet

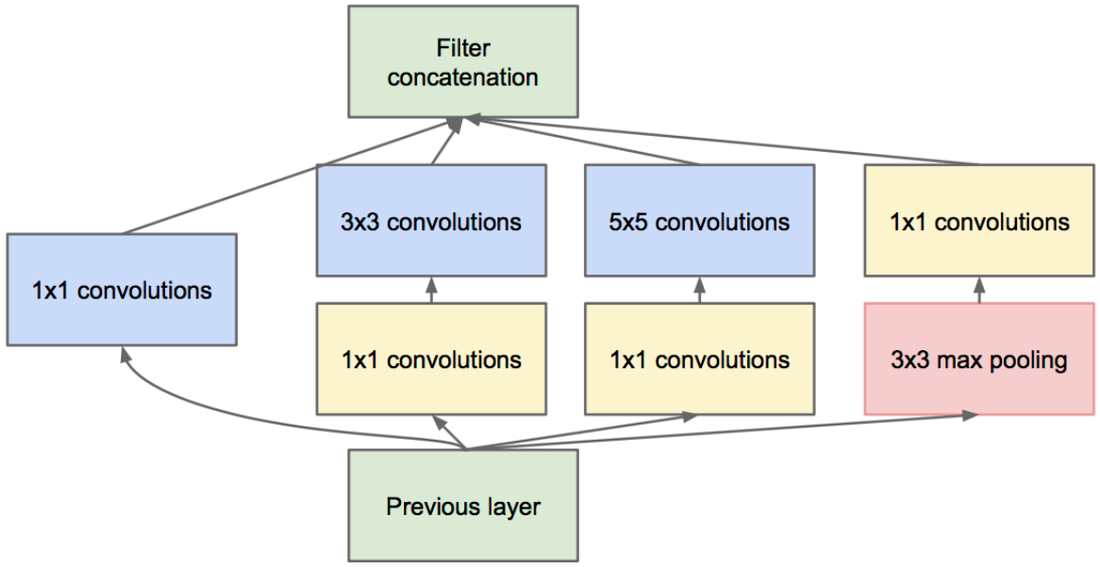
- First very successful, deep, CNN model for image classification
- Versatile, easy to understand and piggy-back higher level layers (such as object detection)



5 convolutional layers + **3** FC layers

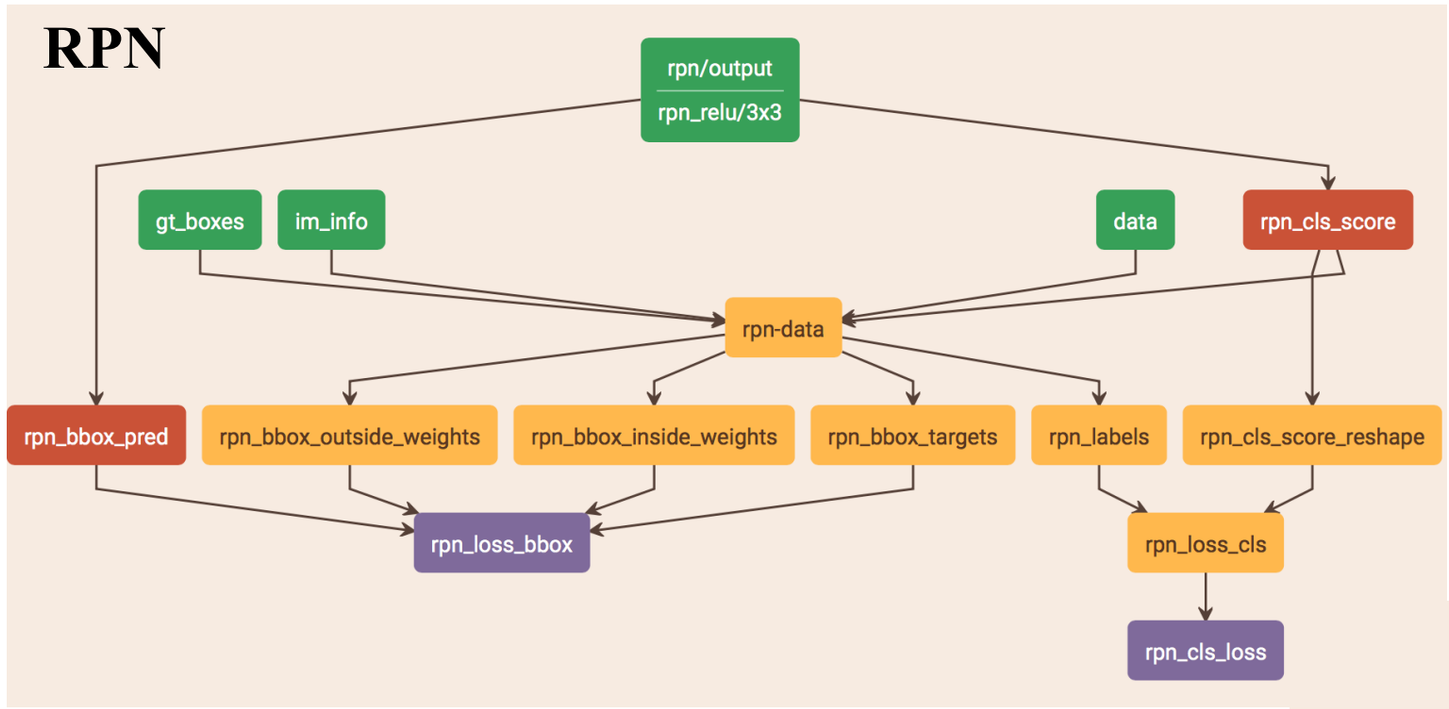
2. GoogLeNet

- Features 22 layers of depth with *parallel* convolutional layers (so-called inception architecture)
- ***More layers, more features!***



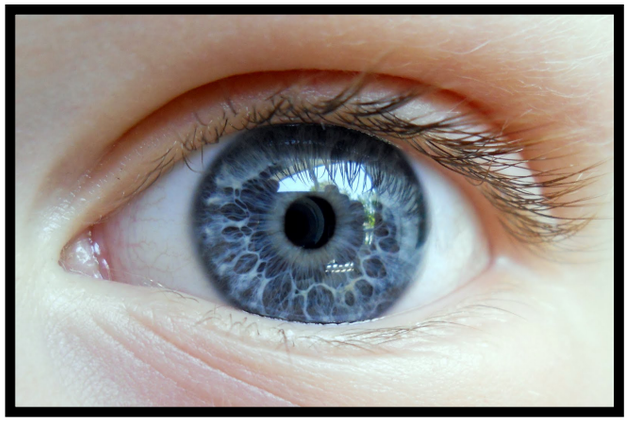
Particle Detection

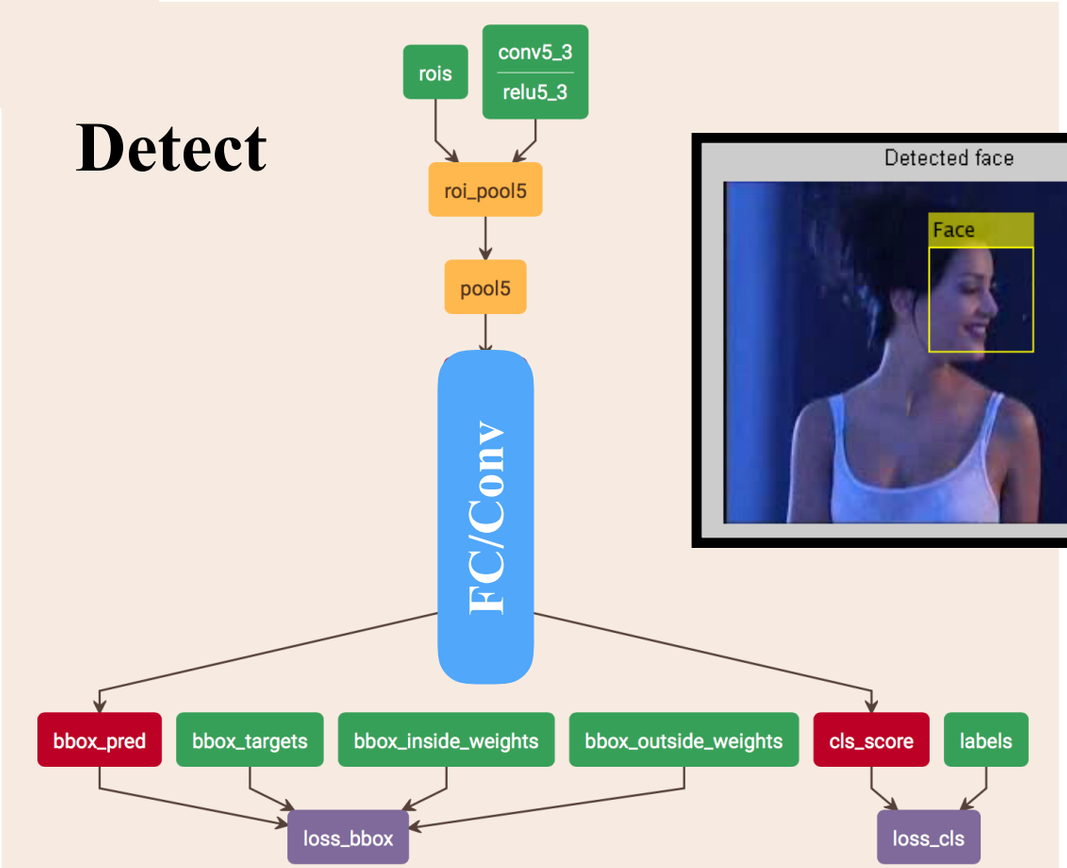
Trained an object detector called **Faster-RCNN**



Detector network takes the region proposals, classifies them, then regresses the proposed regions to generate a bounding box

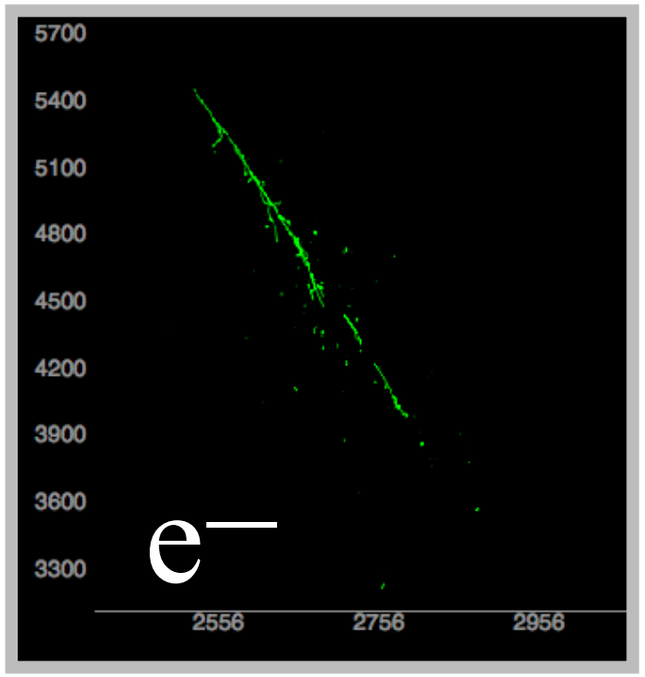
Region proposal network is like the "eyes" and reports a set of regions for objects

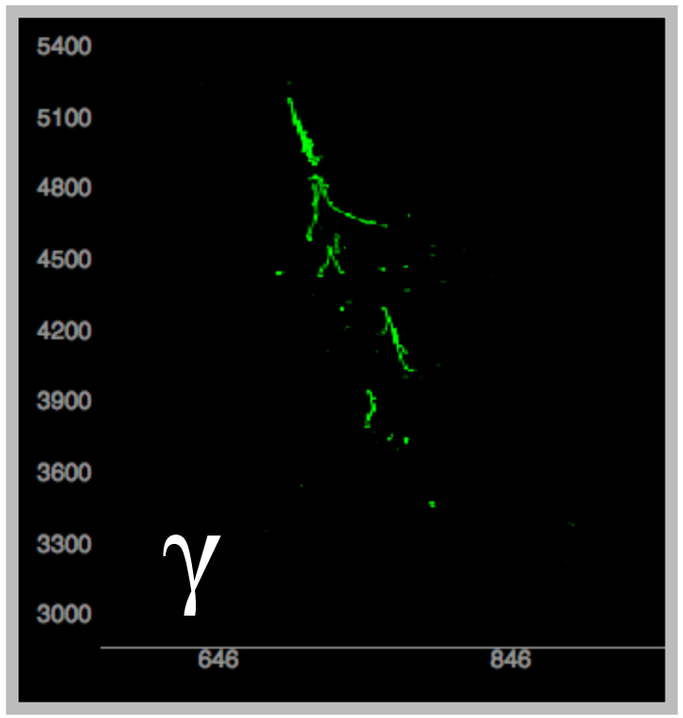




Single Particles

MicroBooNE Simulation In Progress

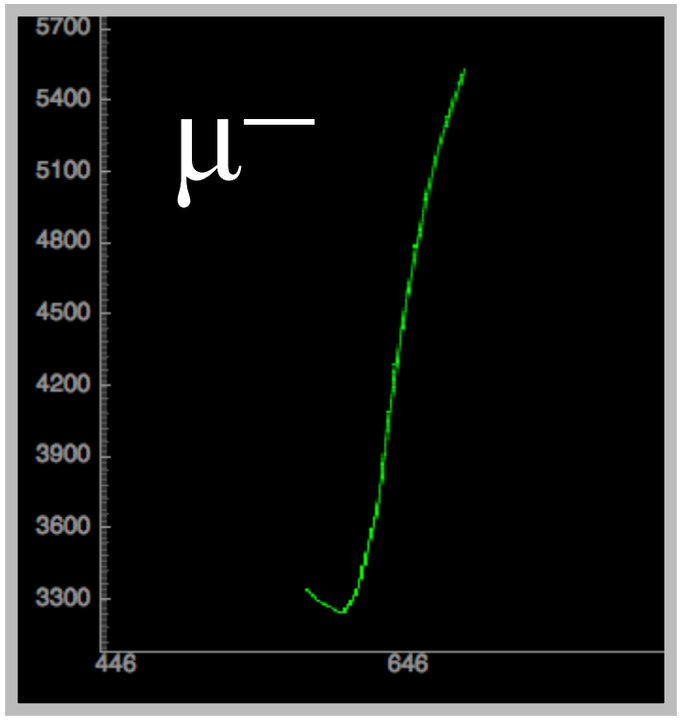


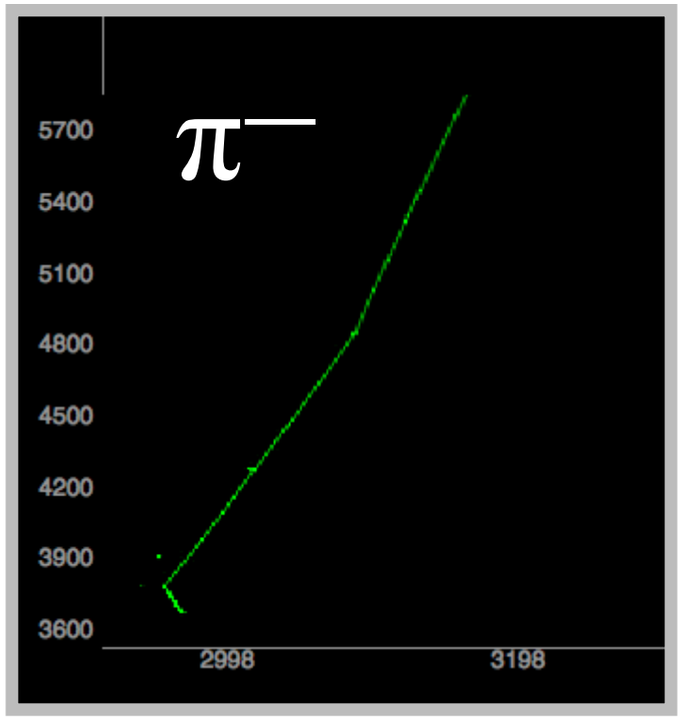


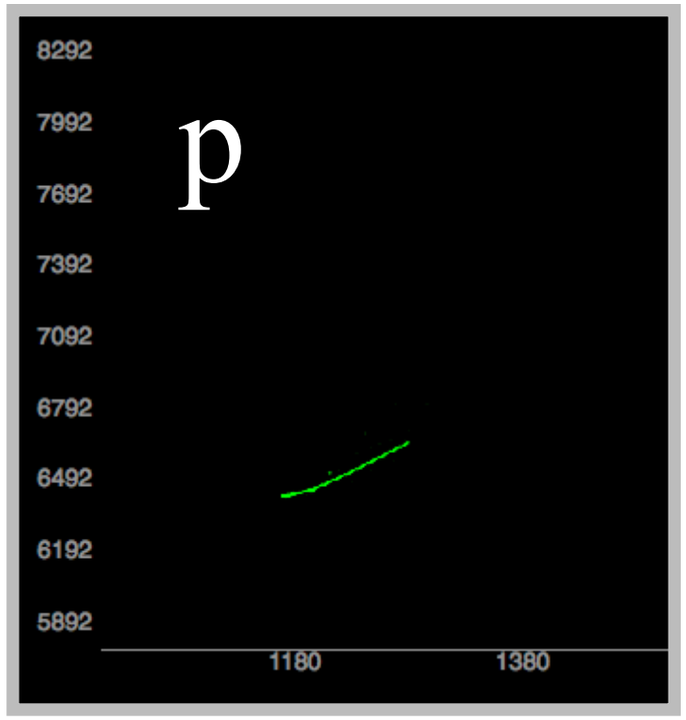
5 particle types:

e, γ, μ-, π-, p

Our classes!







Single Particles

5 particle types: ***e, γ, μ-, π-, p***

576 by **576**

``HiRes"

- **Single plane** readout of 3456 wires and 6048 time ticks

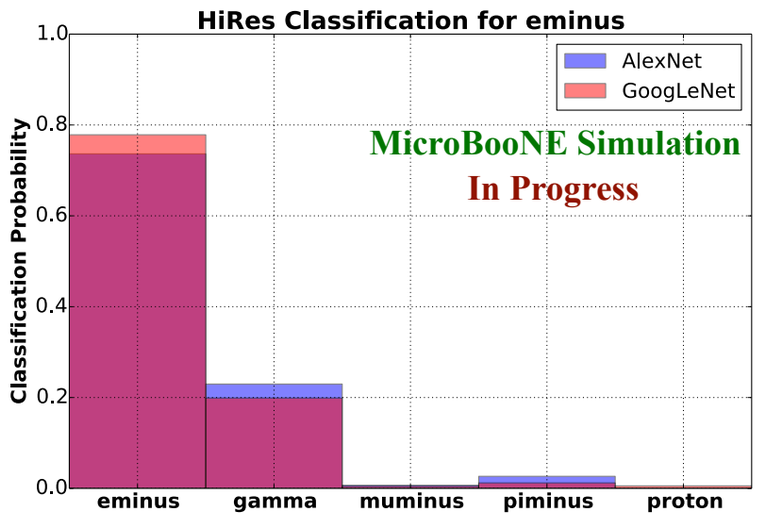
  → Apply a compression factor of **2 in wire** and **6 in time**

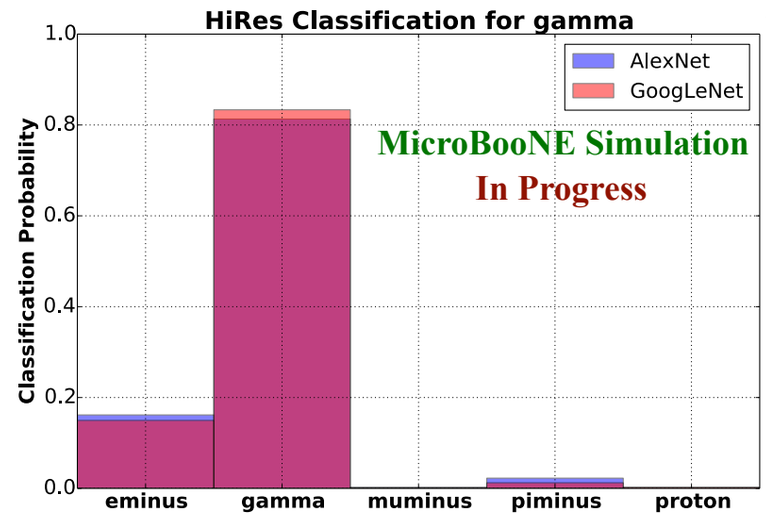
- **Crop** the region on the collection plane that contains the particle

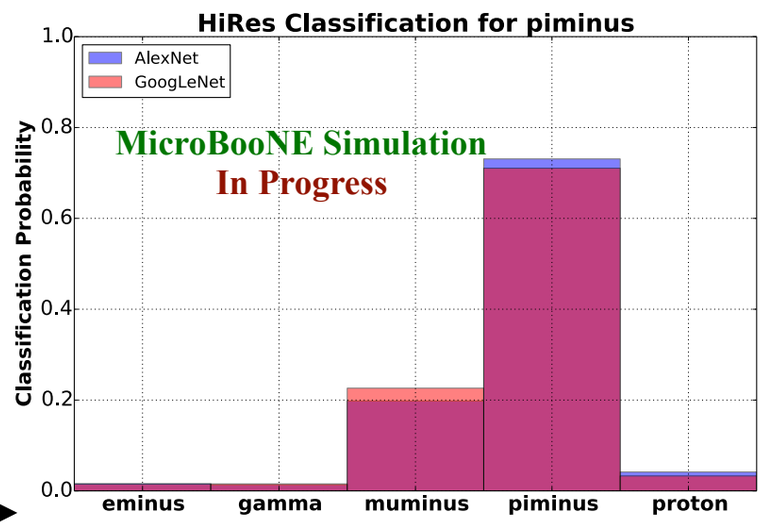
Compare AlexNet and GoogLeNet

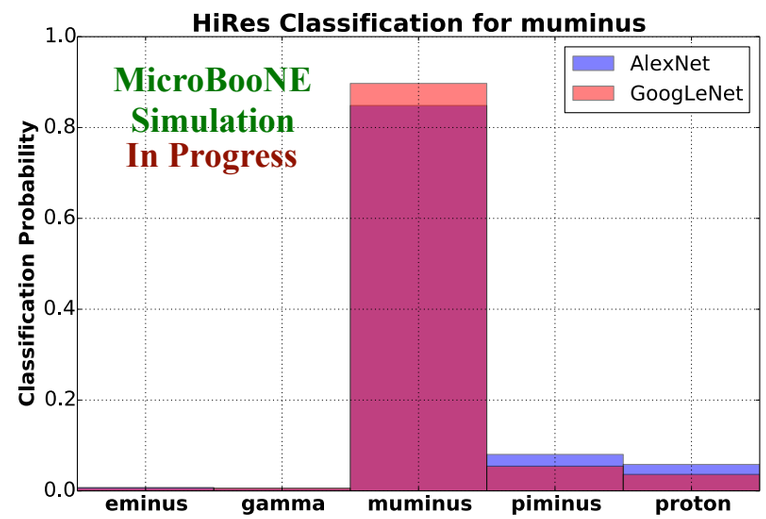
Single Particles

Particle type

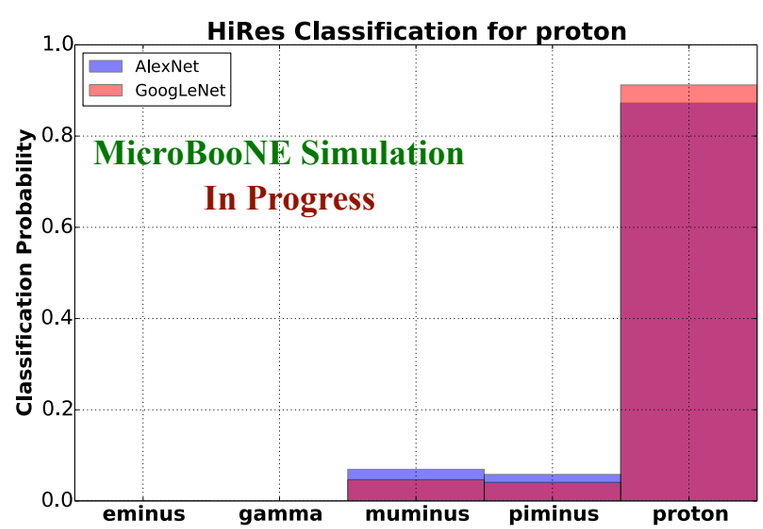




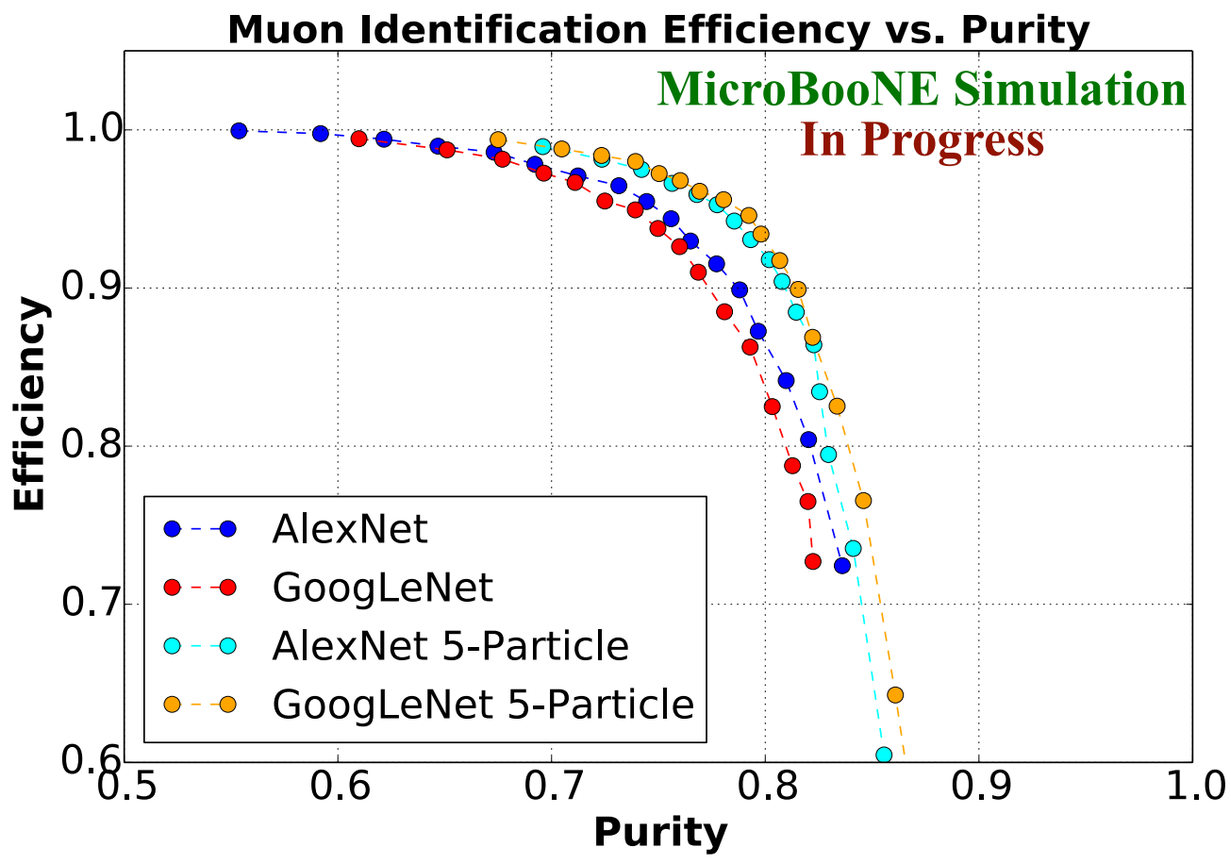


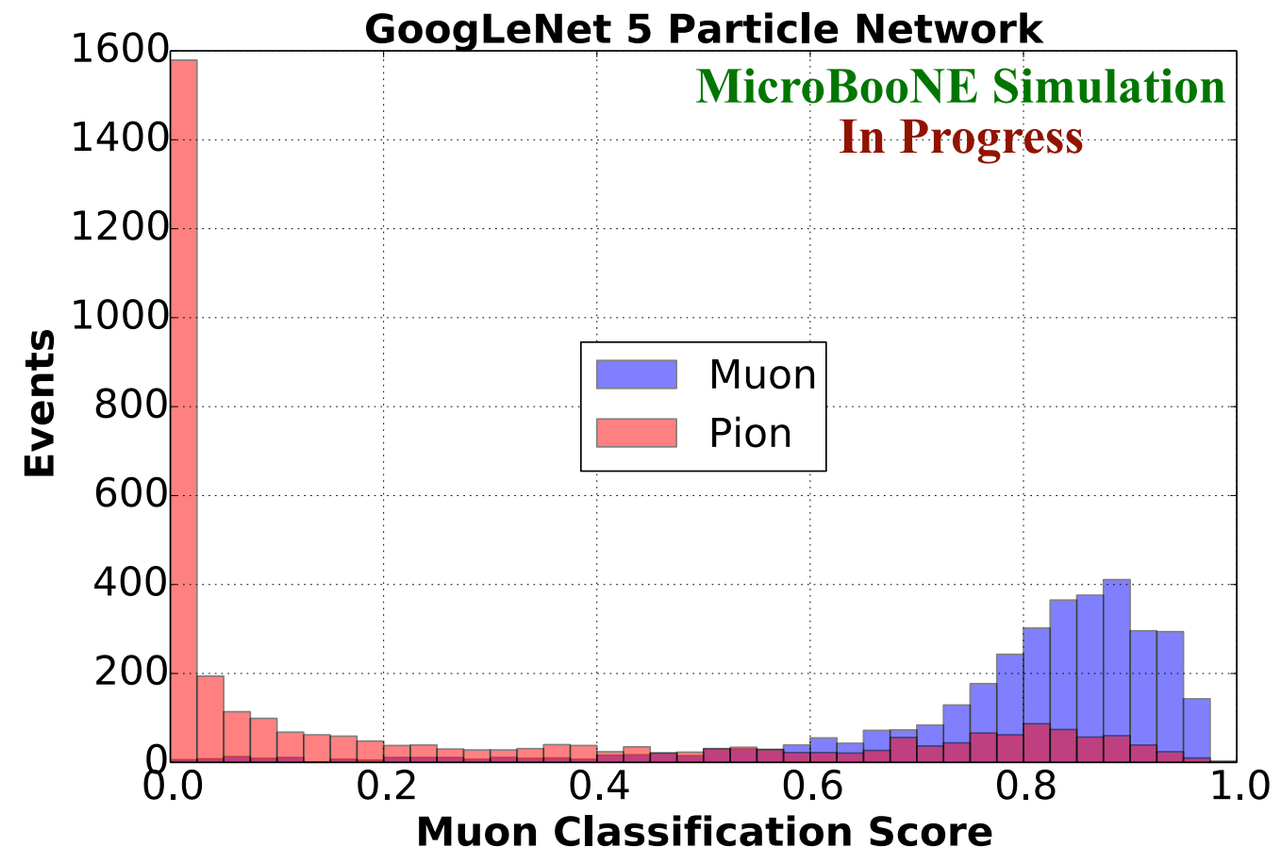


Network classifications



Single Particles — μ- vs. π-



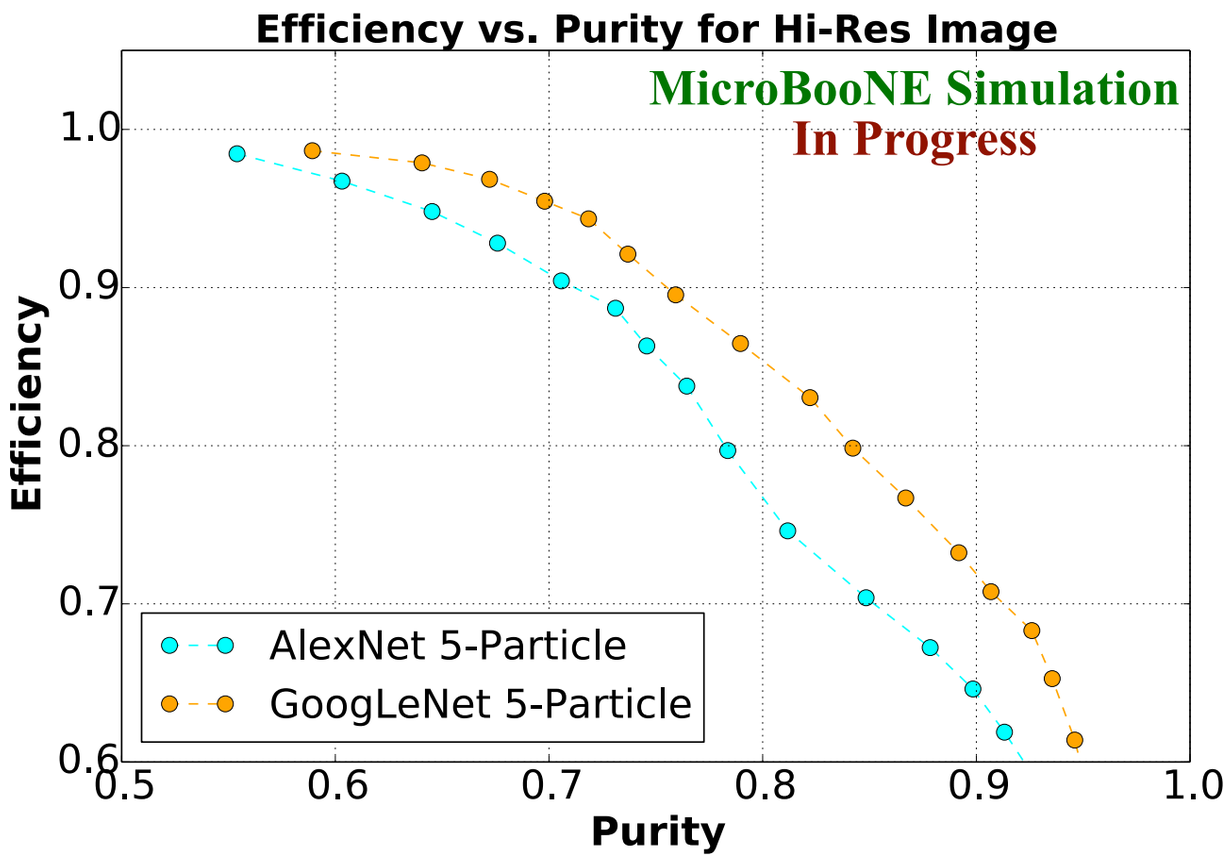


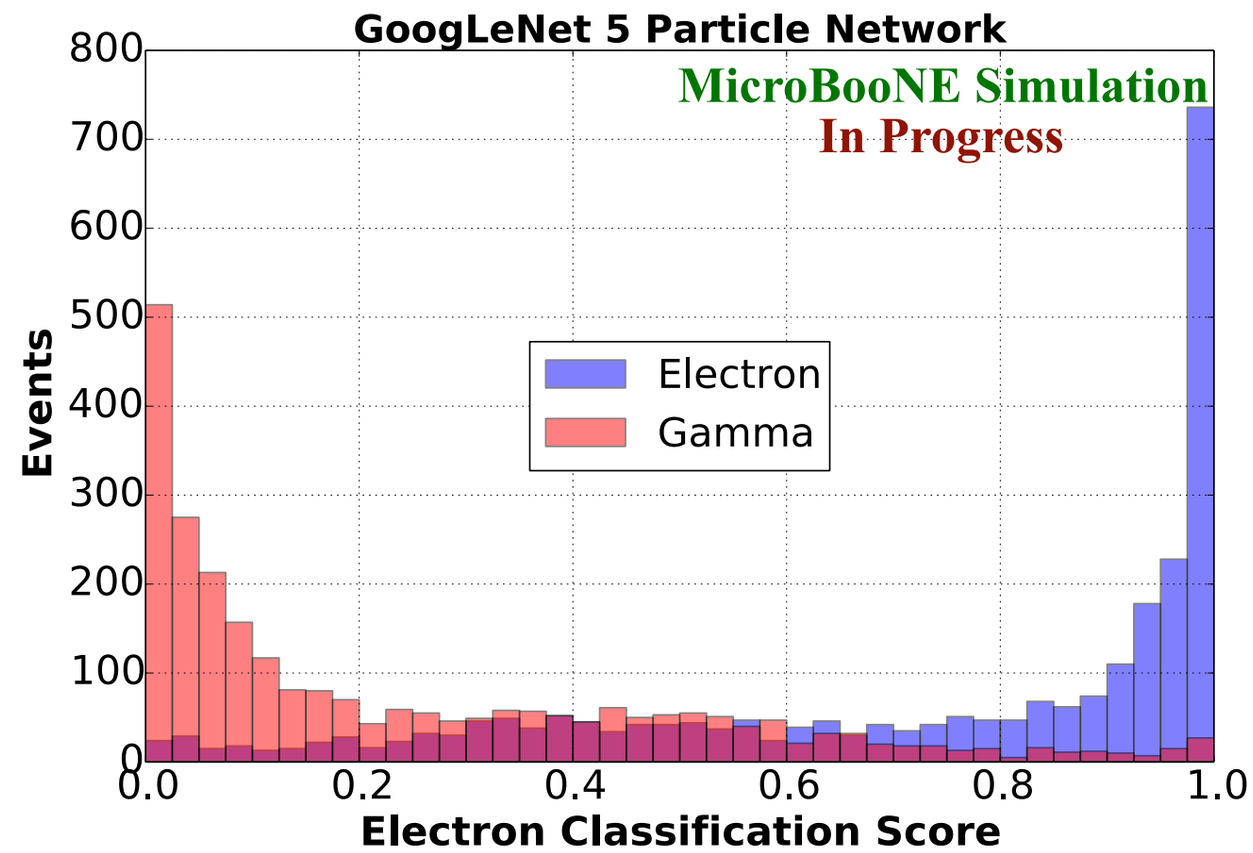
Muon selection EP curve for muon/pion **2**-particle sample (blue & red curve)

Network trained for **5** particle class has a better performance with more learned features!

Muon/pion separation in the network score

Single Particles — e- vs. γ





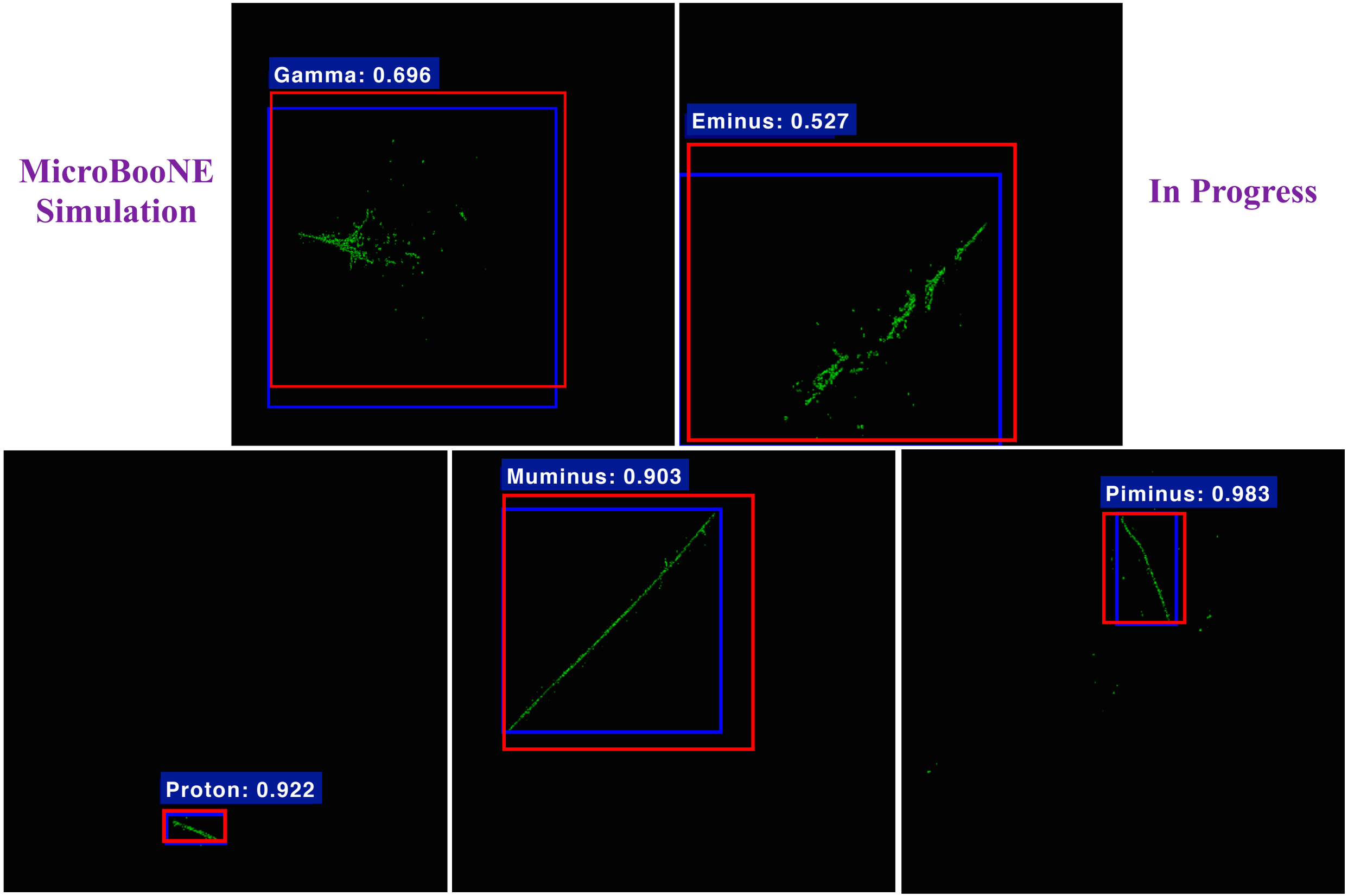
Electron selection EP curve for the 5-particle classification

GoogLeNet provides better separation!

Electron/gamma separation in the network score

Single Particle Detection

MicroBooNE Simulation



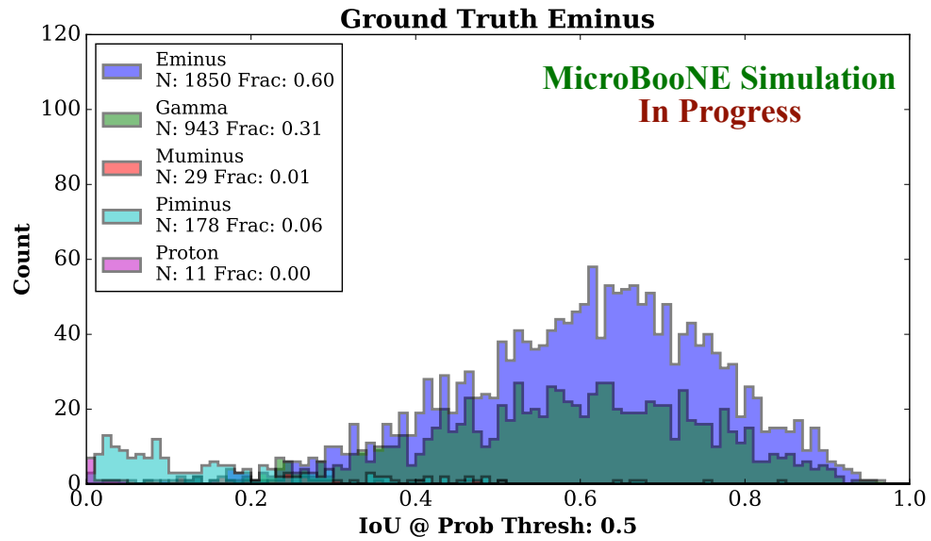
In Progress

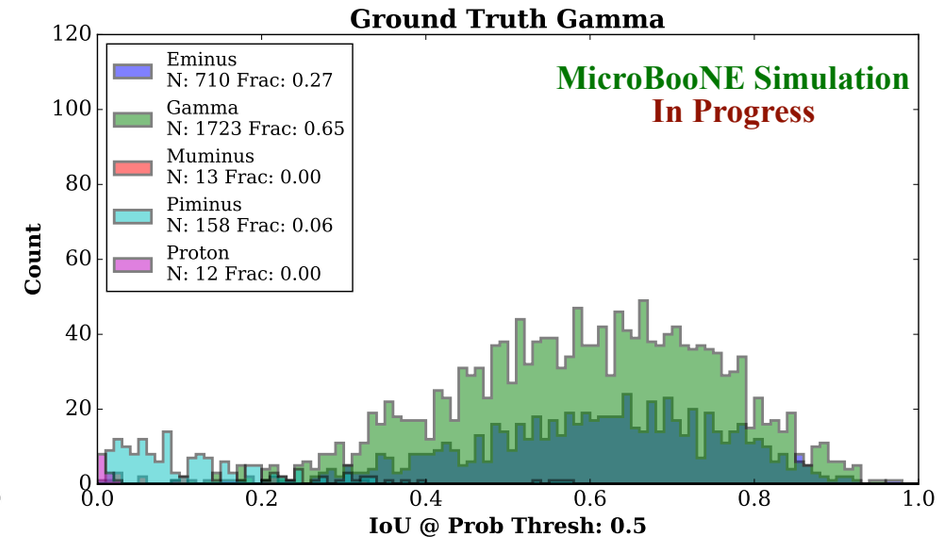
Single Particle Detection

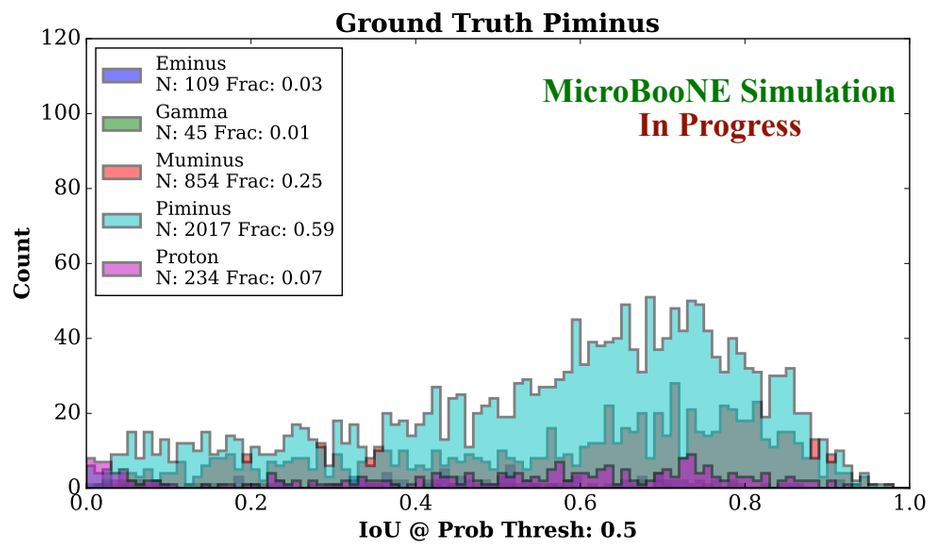
Intersection over Union

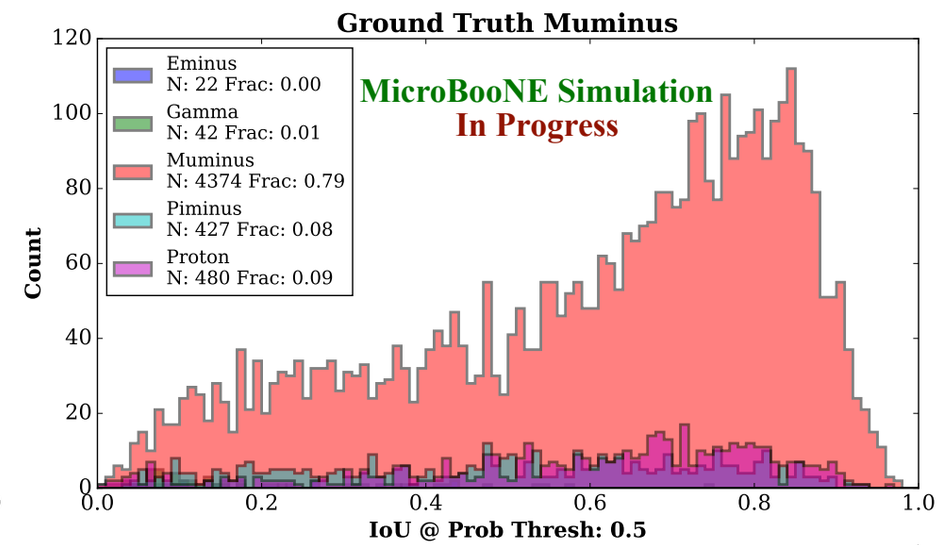
(IoU)

How well the <u>detected box</u> overlaps the <u>MC box</u>

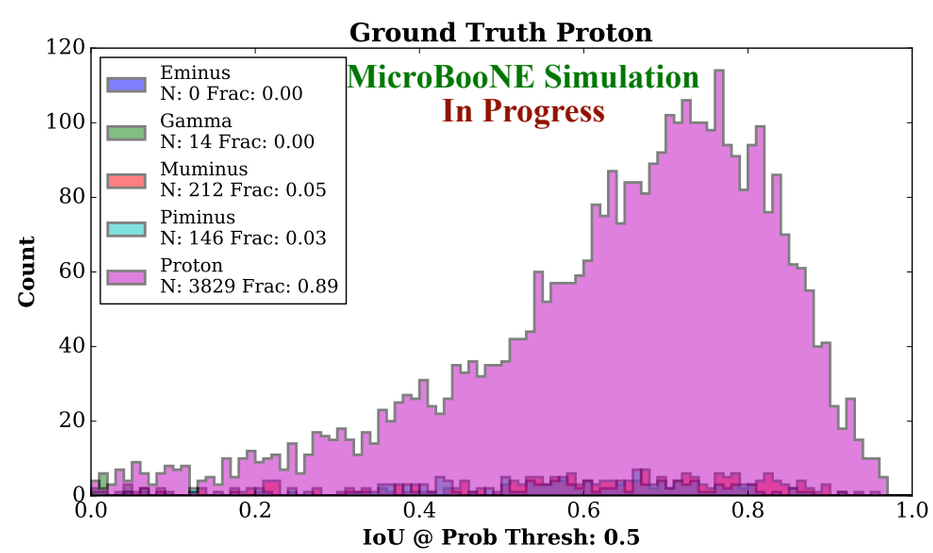








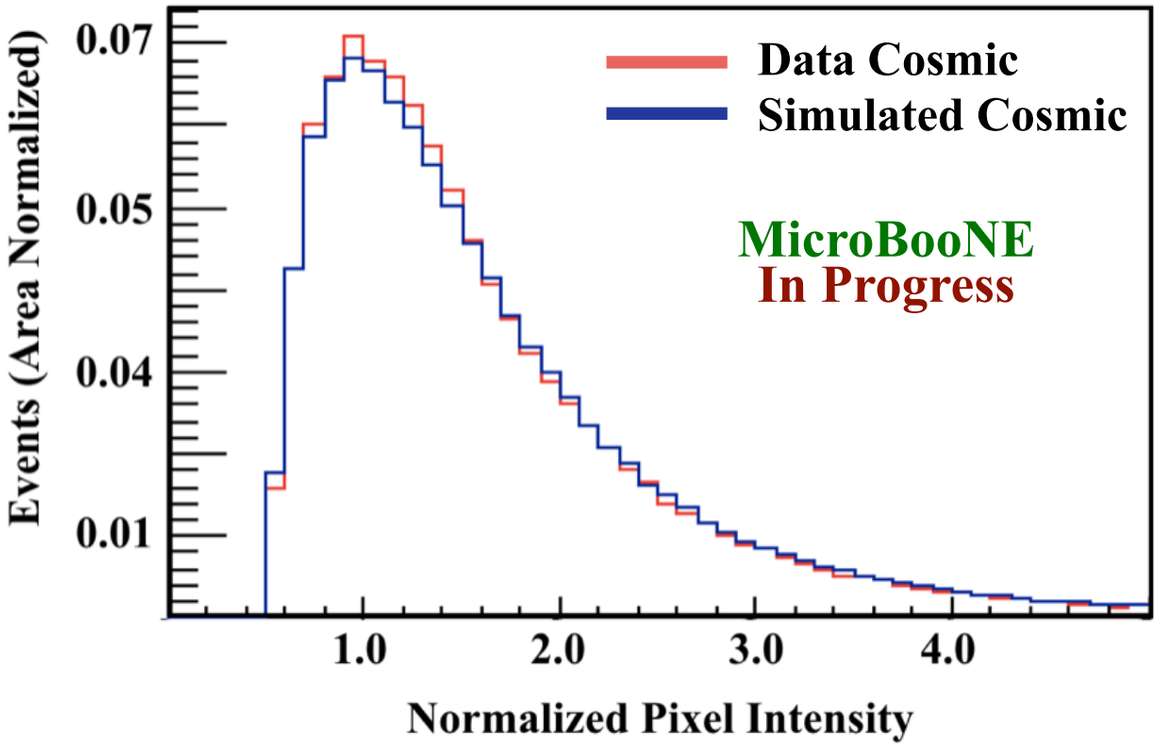
No overlap



Perfect overlap

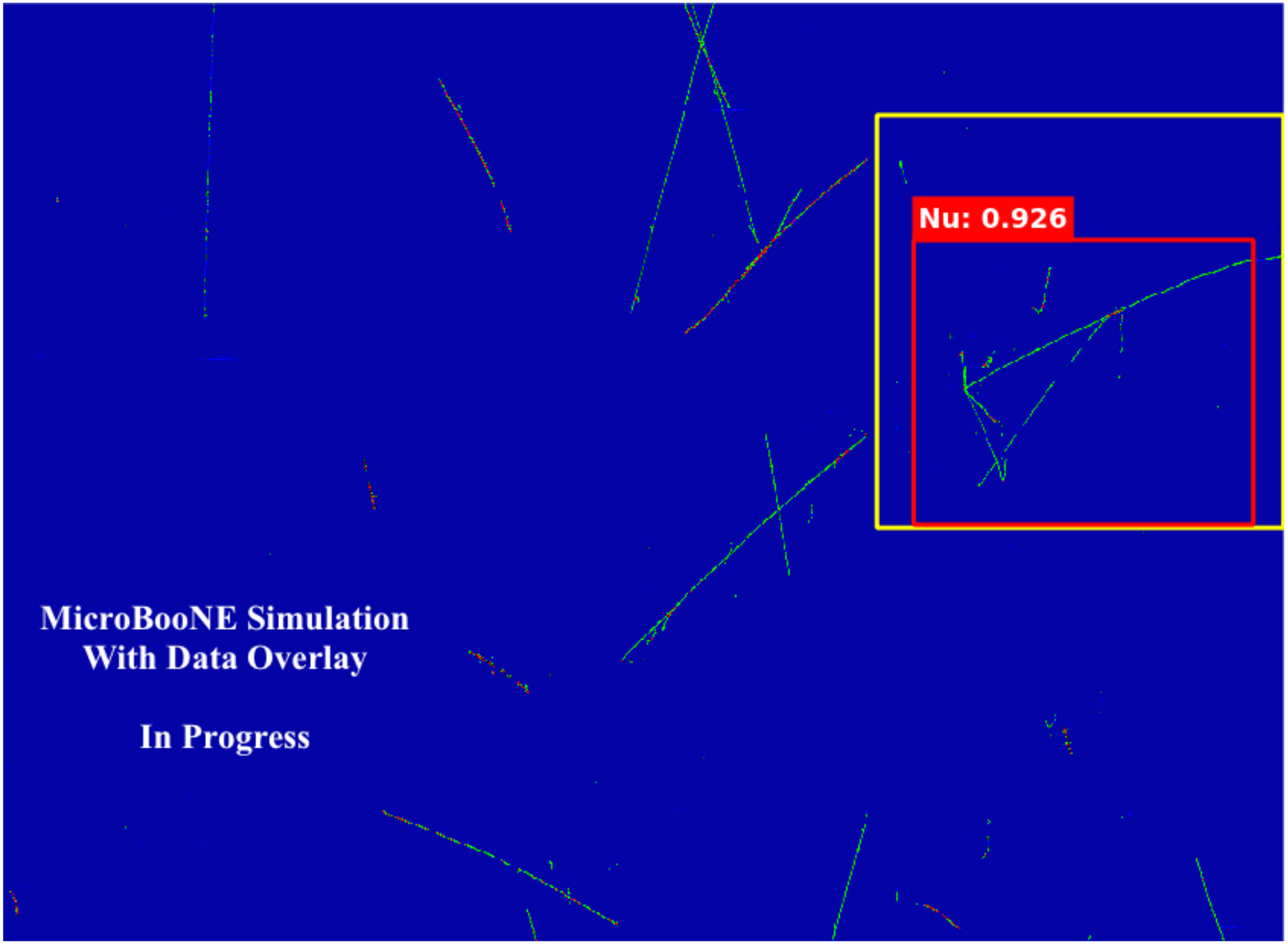
Nu Detection

Train a detection network with **MC neutrino** interaction image **overlaid with data cosmic ray background**.

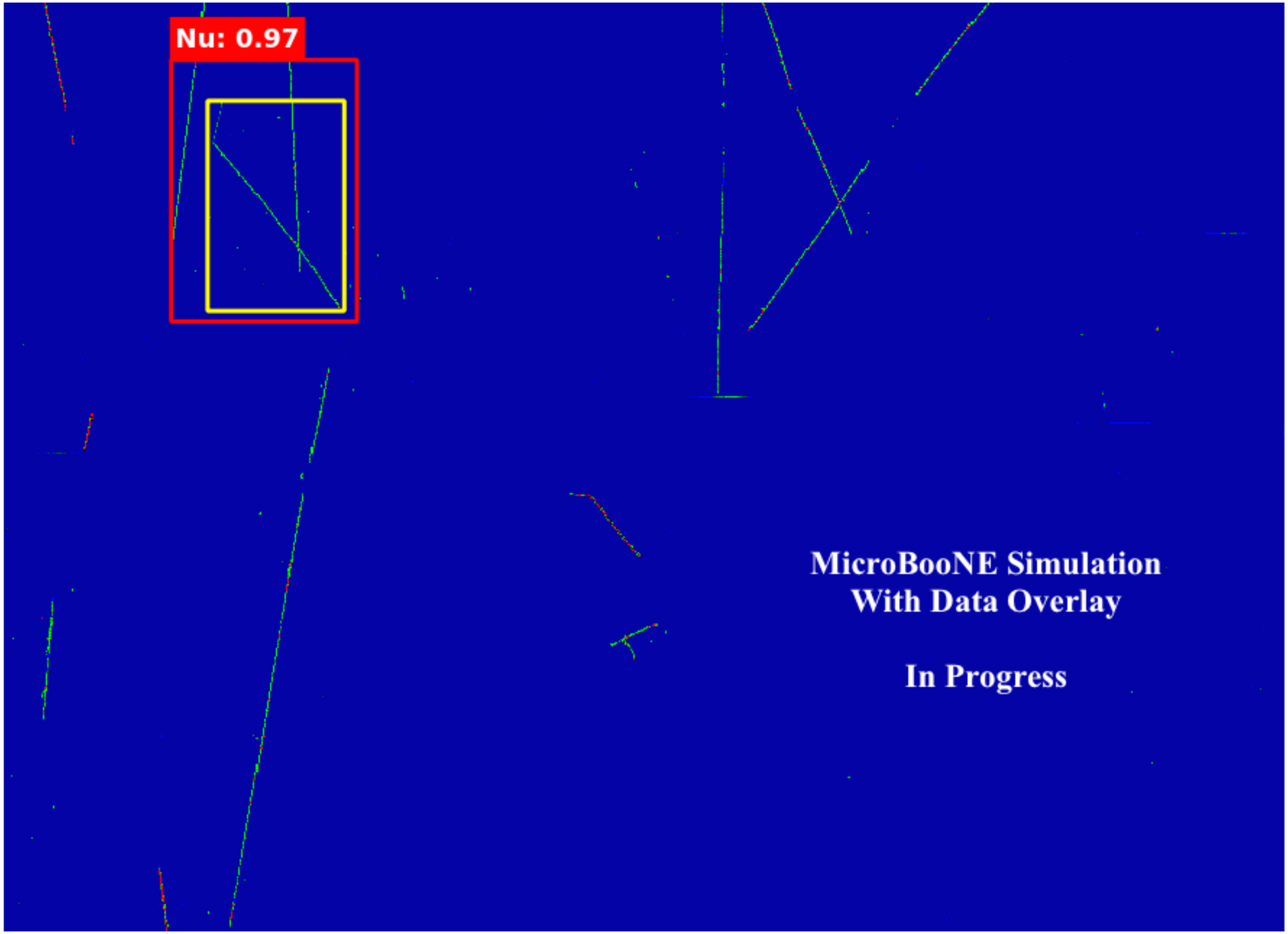


- High resolution event image of size 756x864
- Scaled the pixel intensity between the data cosmic and simulated neutrino

Nu Detection



Nu Detection



Summary

Deep Learning **can learn** features in LArTPC images for

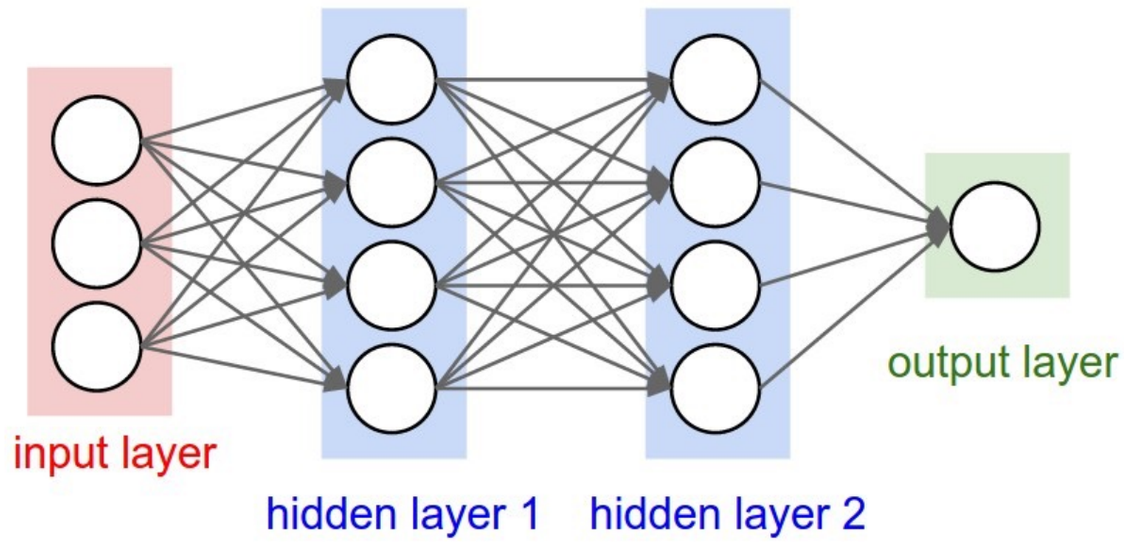
- Single particle classification, and detection
- Neutrino detection of monte-carlo neutrino with cosmic overlay

Thanks!

Backup

``Artificial" Neural Network

Input set of parameters for a single class



Class score, inference

Each "hidden" layer is…

- **dot product between internal set of weights, and the input**
- **adding a bias term**
- **passing the output through a activation function**

Single Particles

MicroBooNE Simulation In Progress

Particle type

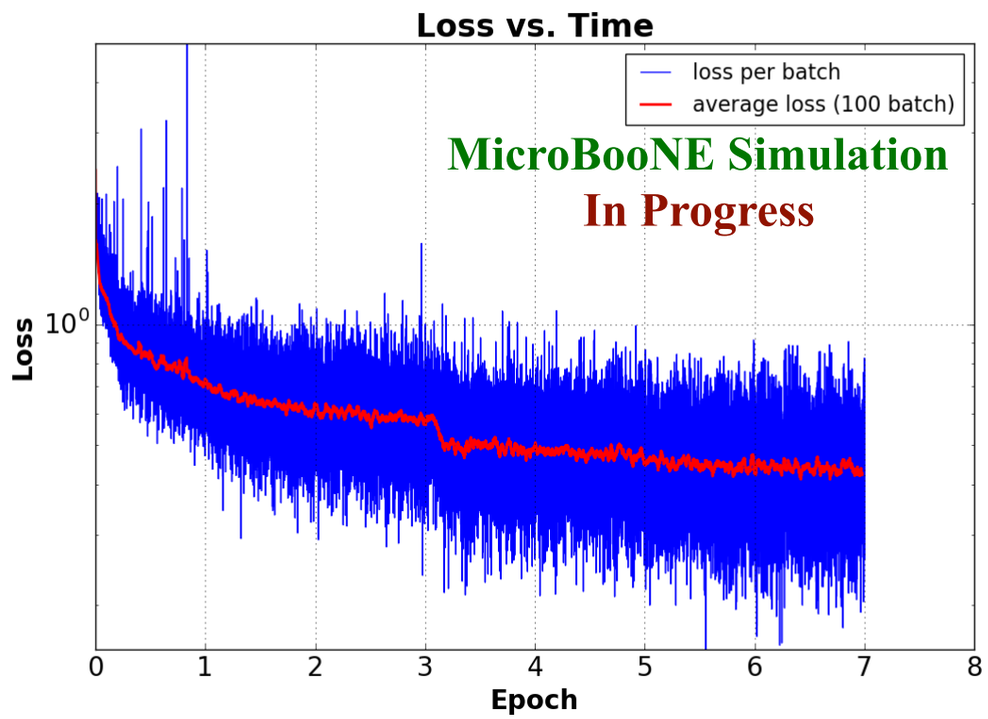
Image, Network	Classified Particle Type				
	e^- [%]	γ [%]	μ^-	π^-	proton
HiRes, AlexNet	73.6 (γ 23.0)	81.3 (e^- 16.2)	84.8 (π^- 8.0)	73.1 (μ^- 19.8)	87.2 (μ^- 7.0)
HiRes, GoogLeNet	77.8 (γ 19.9)	83.4 (e^- 15.0)	89.7 (π^- 5.4)	71.0 (μ^- 22.6)	91.2 (μ^- 4.6)

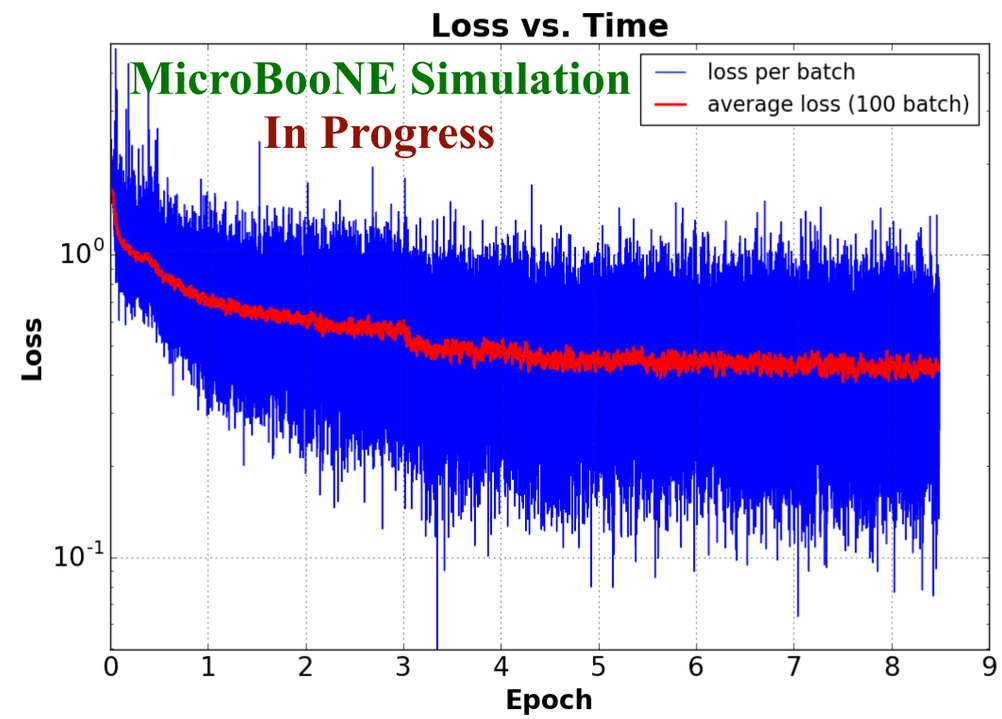
Classification percentage

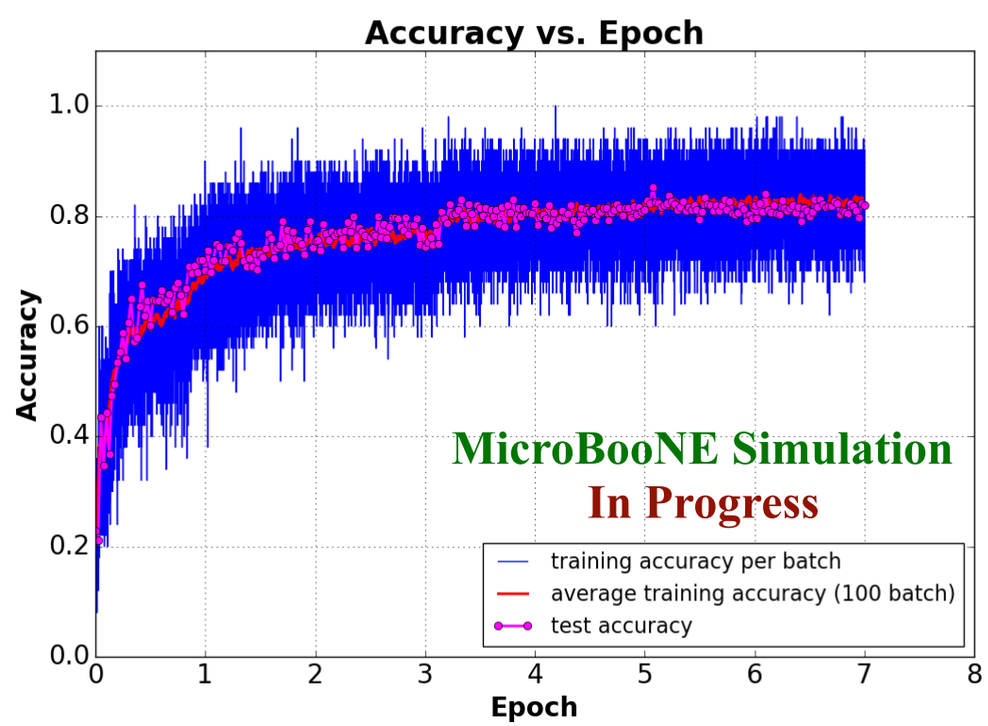
Most common misclassification

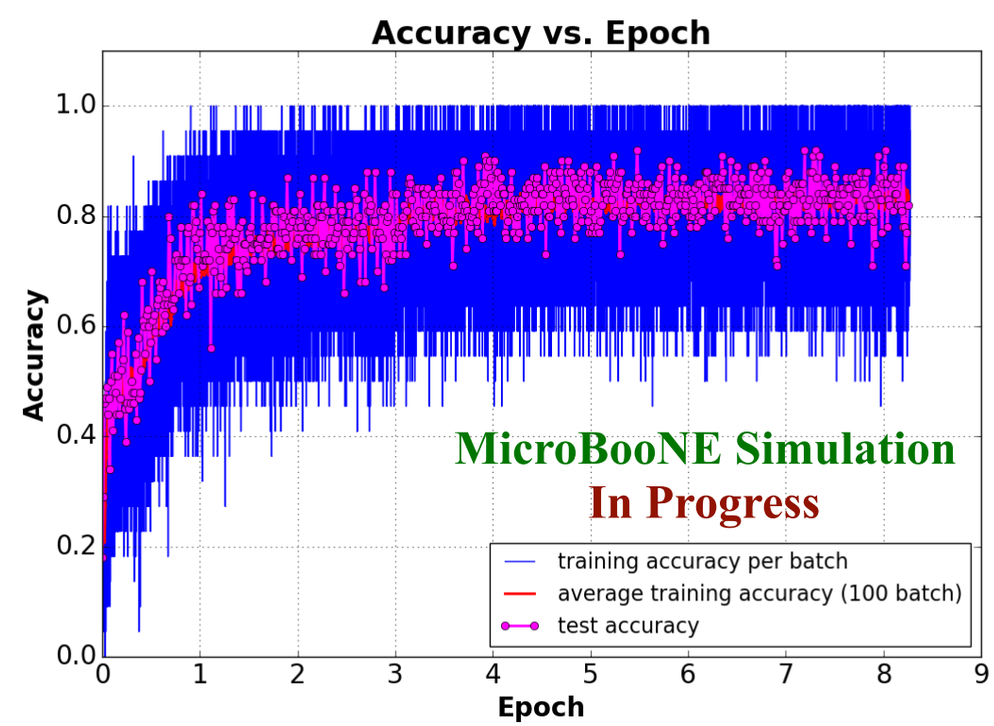
Single Particle Training

How we track the progress of **learning**









Deep Learning References

- AlexNet — *famous!*
  - https://papers.nips.cc/paper/4824-imagenet-classification-with-deep-convolutional-neural-networks.pdf
- GoogLeNet — *depth!*
  - http://www.cs.unc.edu/~wliu/papers/GoogLeNet.pdf
- Tech report on Faster-RCNN
  - http://arxiv.org/abs/1506.01497
- To-be-published book on DL — *recommend!*
  - http://www.deeplearningbook.org
- Stanford introduction to visual recognition with neural nets — *highly recommended!*
  - http://cs231n.github.io
- Caffe framework for DL
  - http://caffe.berkeleyvision.org
- Faster-RCNN framework
  - https://github.com/rbgirshick/py-faster-rcnn
- LArbys LArCV
  - https://github.com/LArbys/LArCV