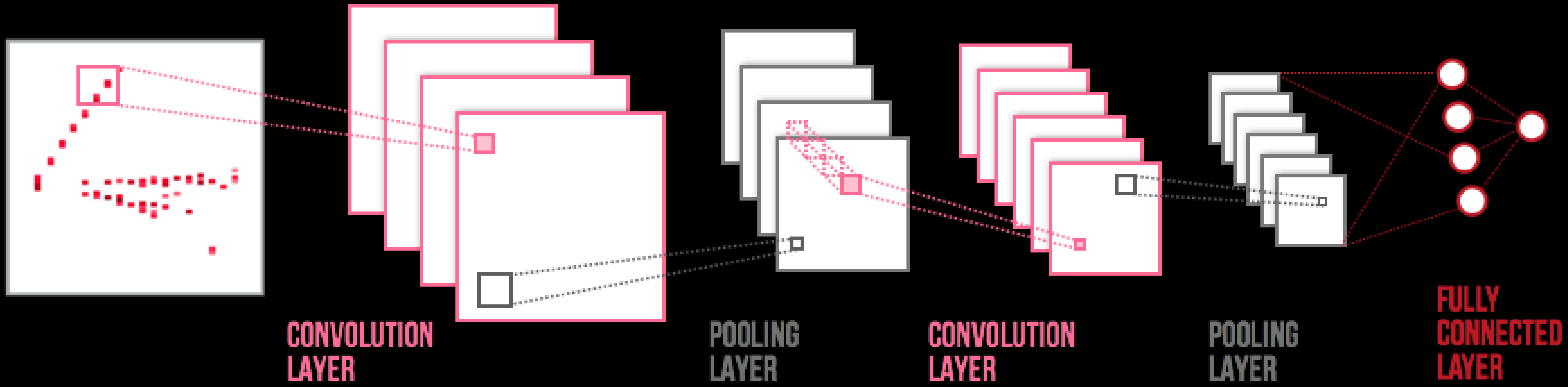
FERMILAB-SLIDES-18-075-ND

NOvA Reconstruction using Deep Learning

Micah Groh



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Convolutional Neural Nets

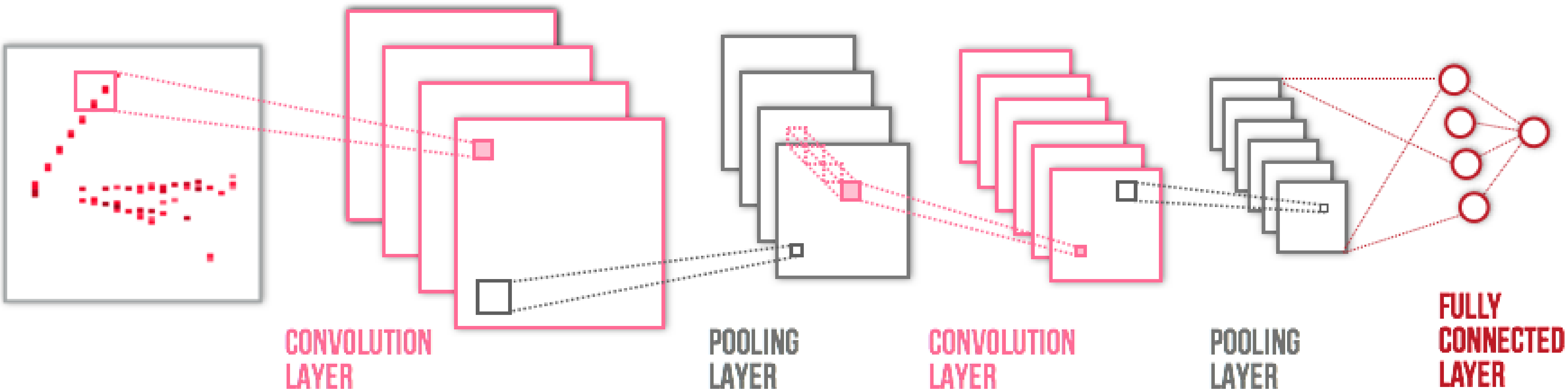
Method: Use convolutional neural networks (CNN) to extract features from then classify a “pixel map” made using detector hits from an event.

Why use CNNs?:

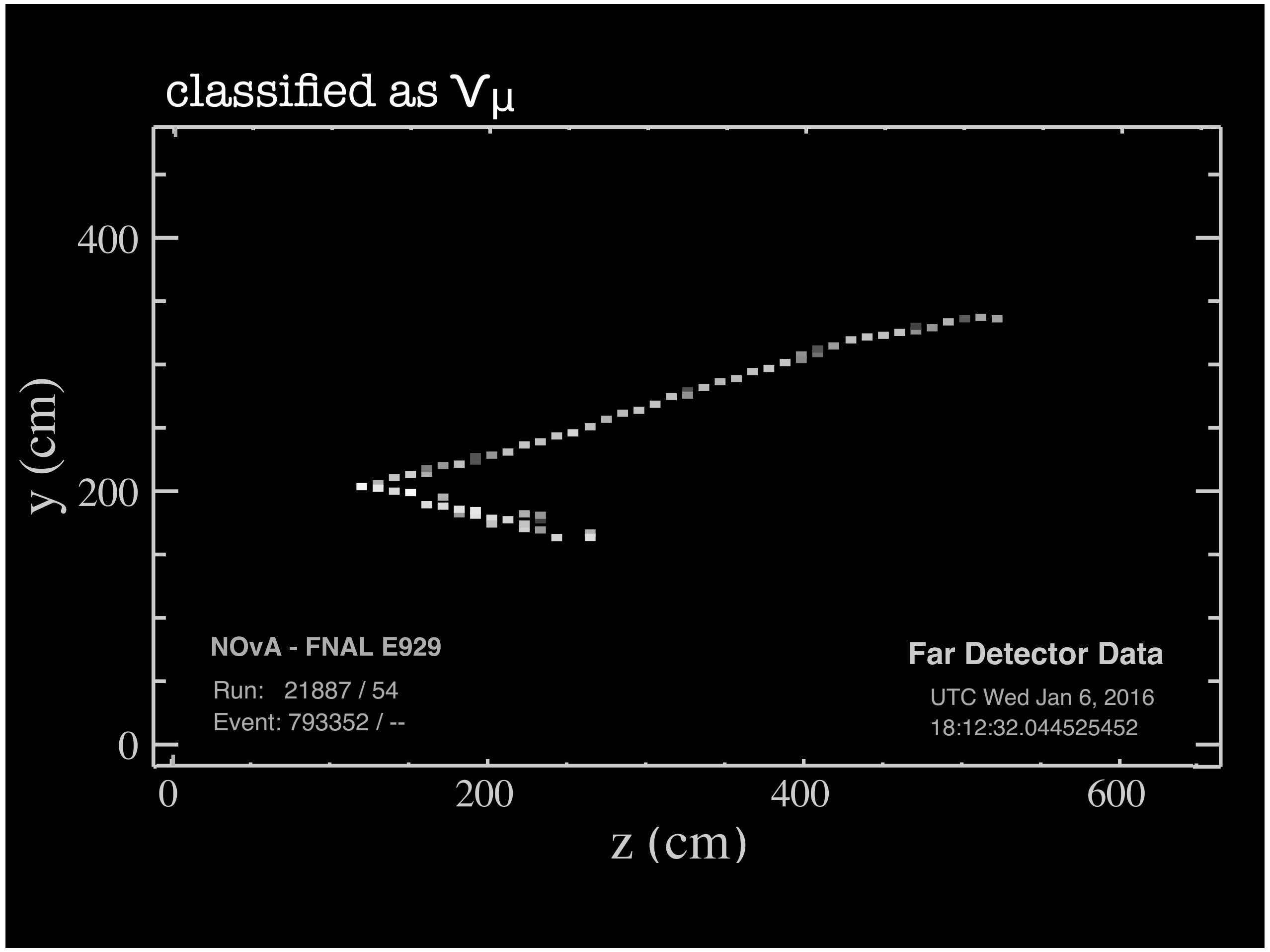
1. Designed to optimally use topological features

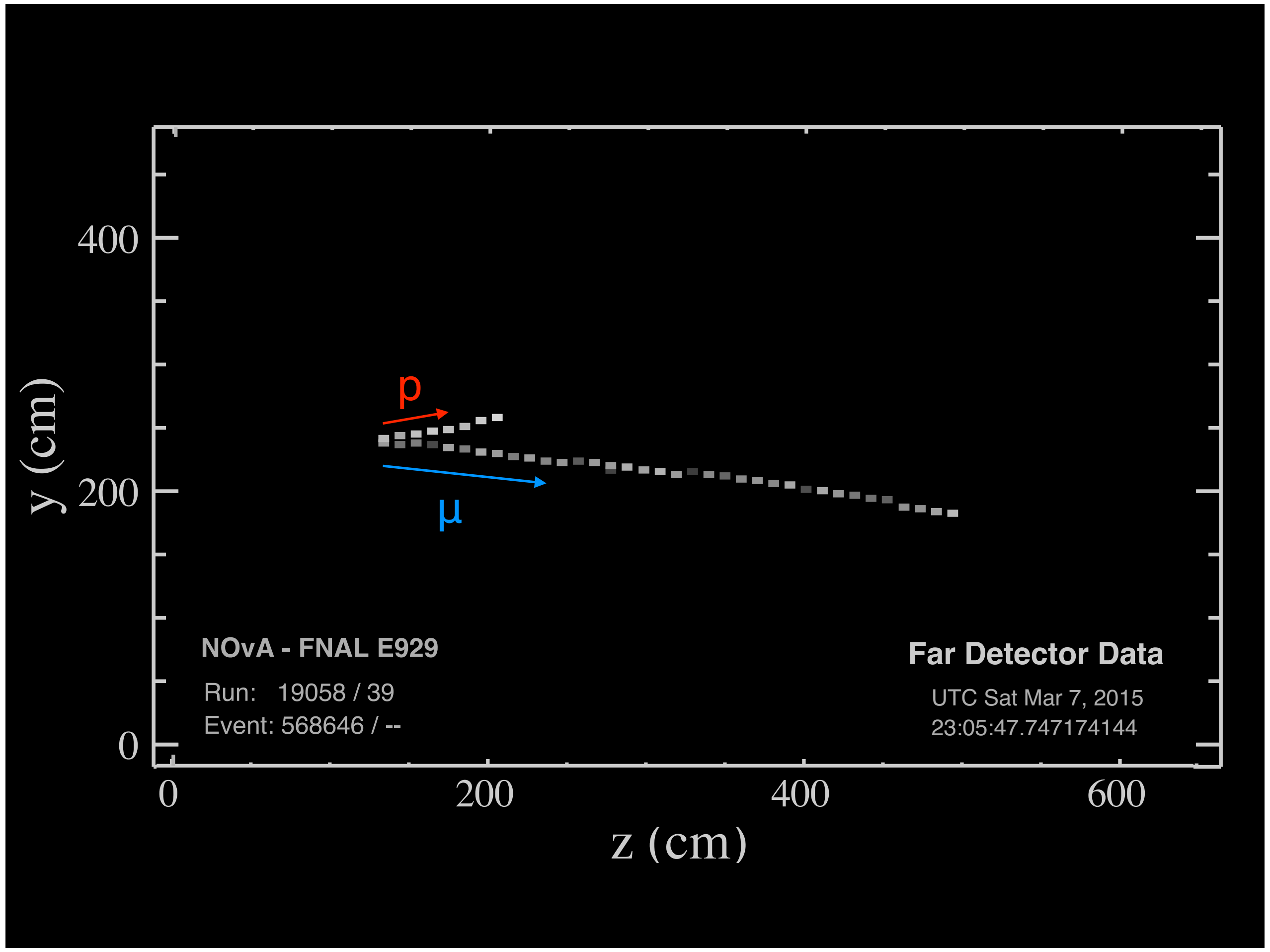
2. Learn which features have the best discrimination power

3. Decouples the task of classification from the reconstruction inefficiencies



Reconstruction Goals





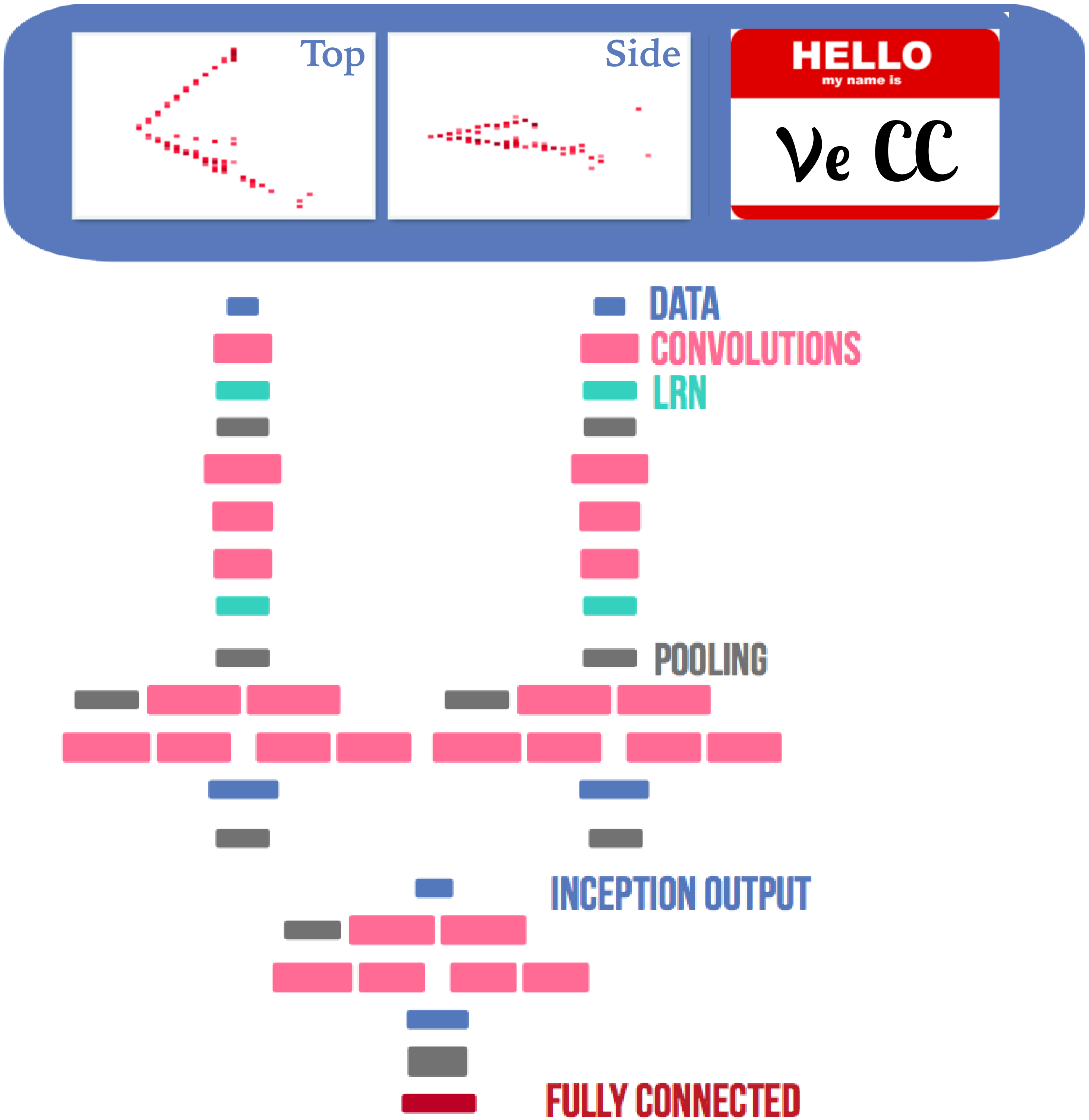
Identify the **flavor** of a neutrino interaction

Applications:
- Numu Disappearance
- Nue Appearance
- NC Disappearance

Classify **particles** from a neutrino interaction

Applications:
- Nue Energy Estimator
- Pi0 Mass Peak
- Cross Section Measurements

Event Classification



F. Psihas, Ph.D. thesis, Indiana University, 2018, doi:10.2172/1437288.

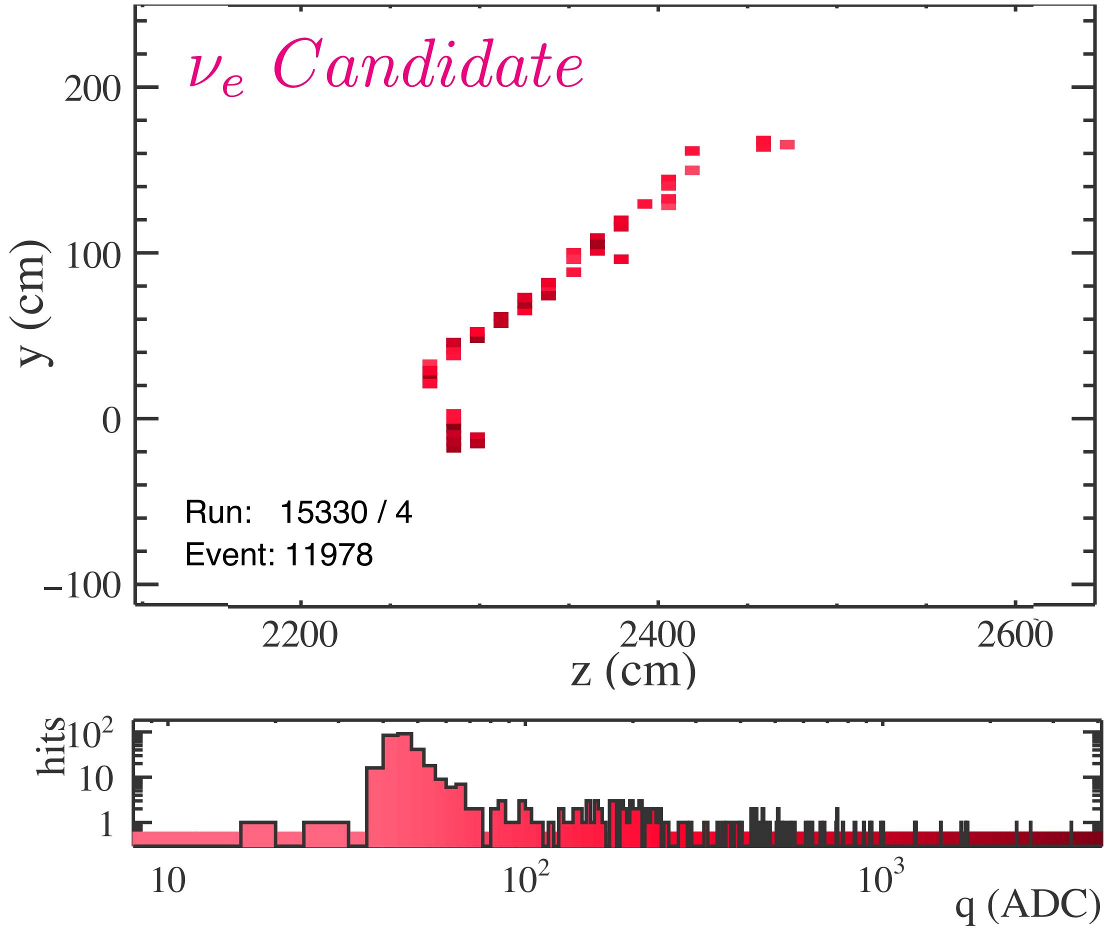
Classify neutrino events using two tower network, **Convolutional Visual Network**.

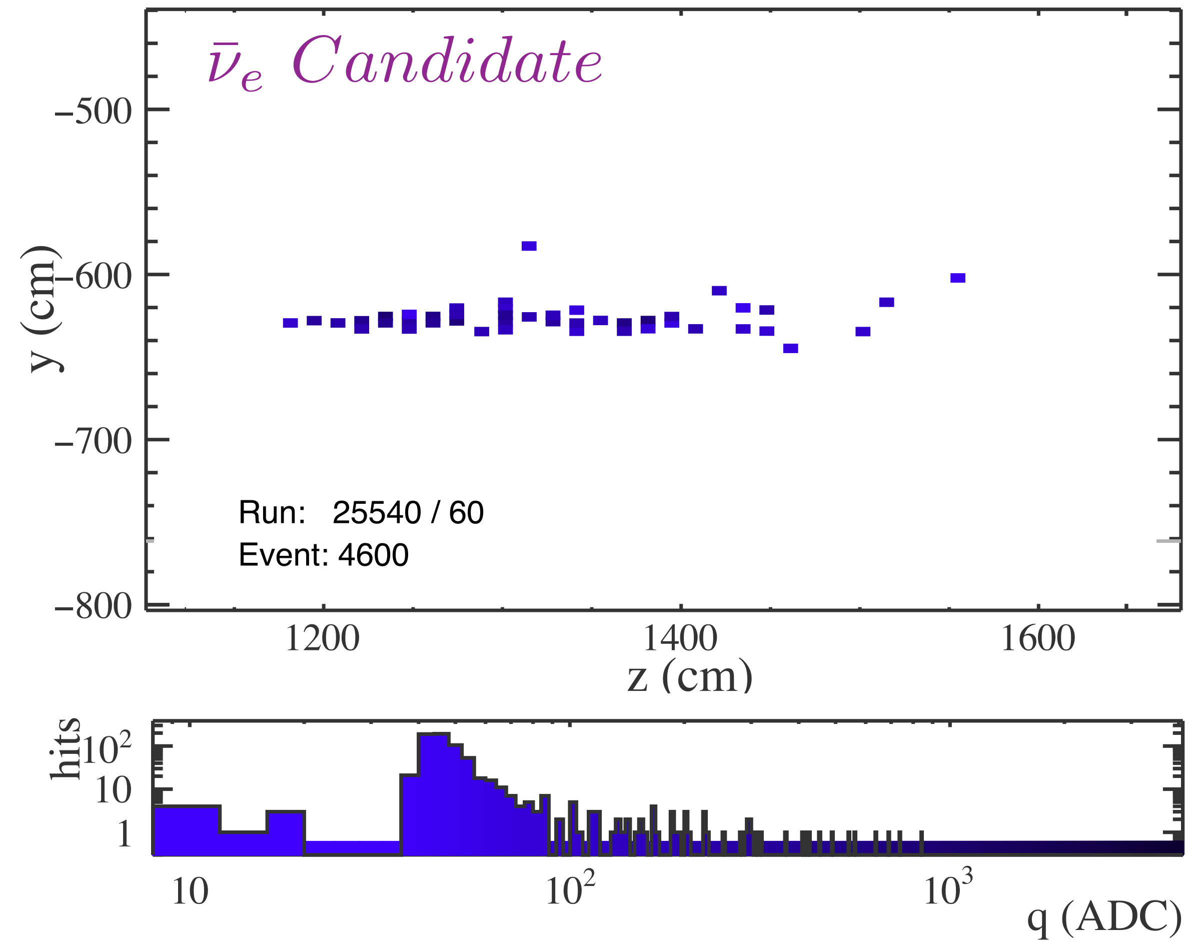
Each view of the event is examined separately for most of feature extraction.

New this analysis:

- **Updated simulation.**
- **Classification is done using final states.**
- **Network optimizations.**
- **Separate neutrino and anti-neutrino training.**

Event Classification



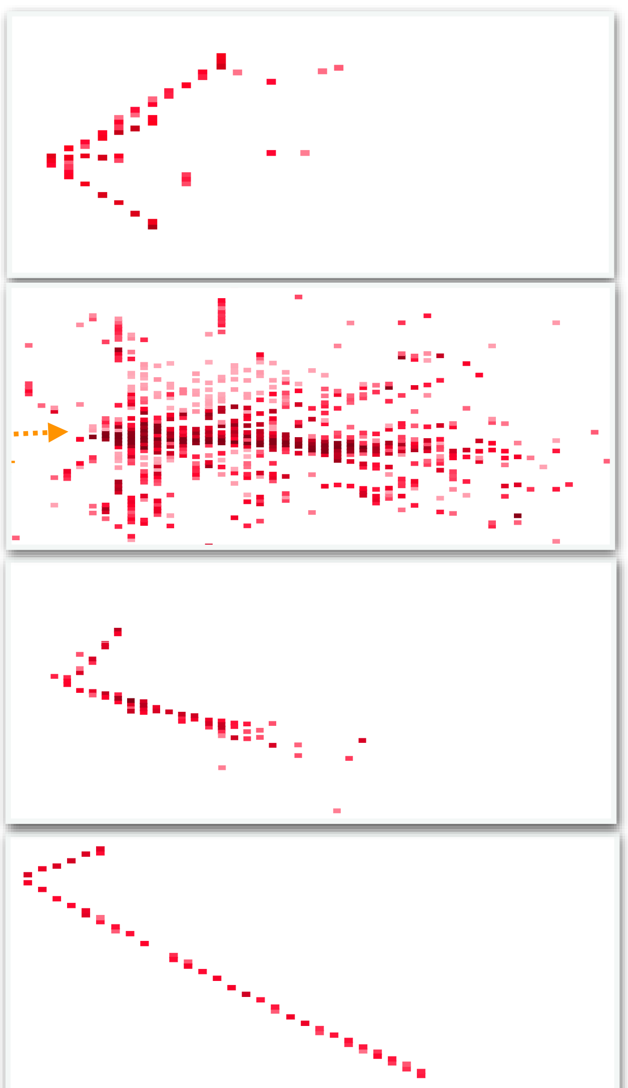


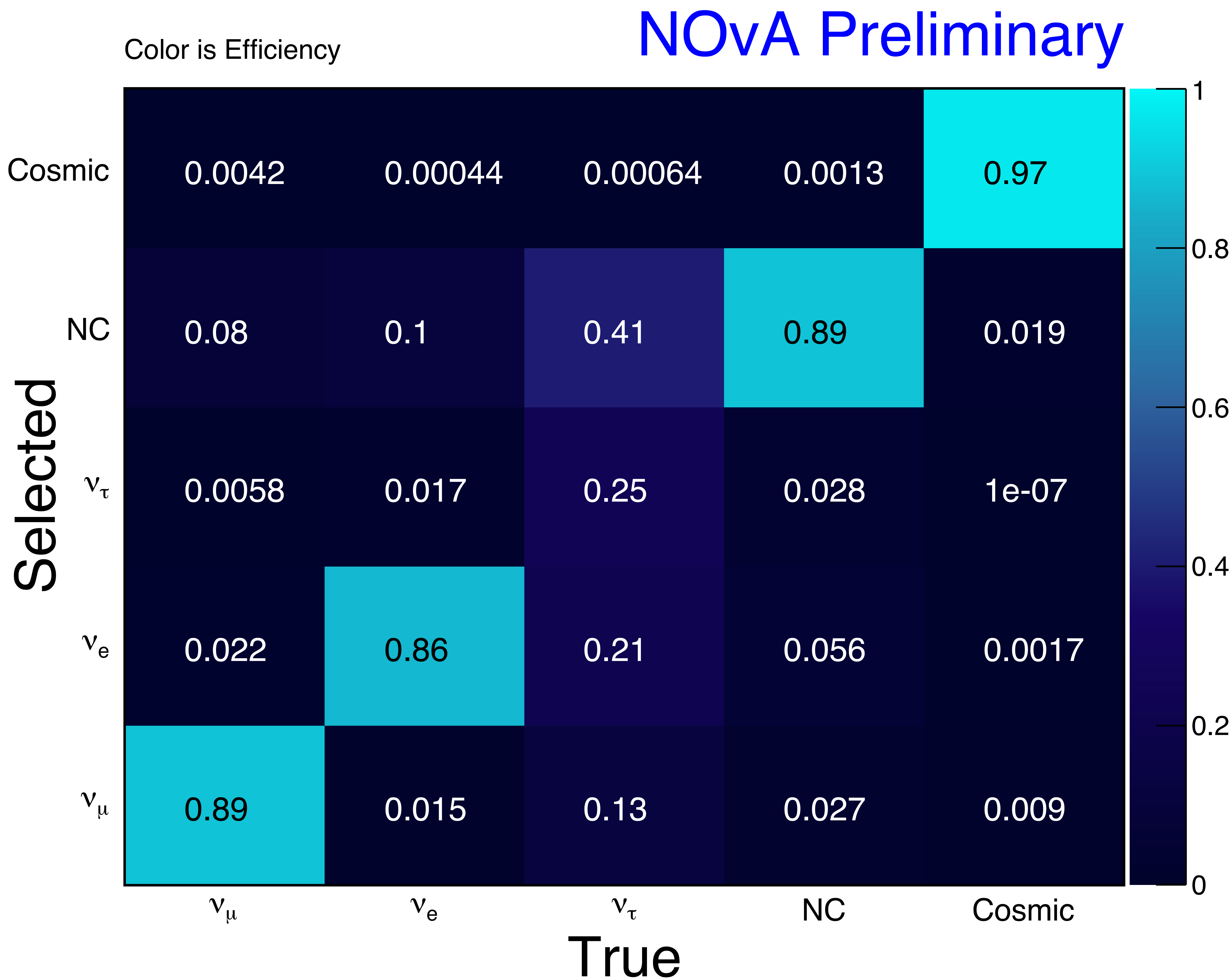
Train on neutrino beam and anti-neutrino beams separately.

Utilize differences in event topology.

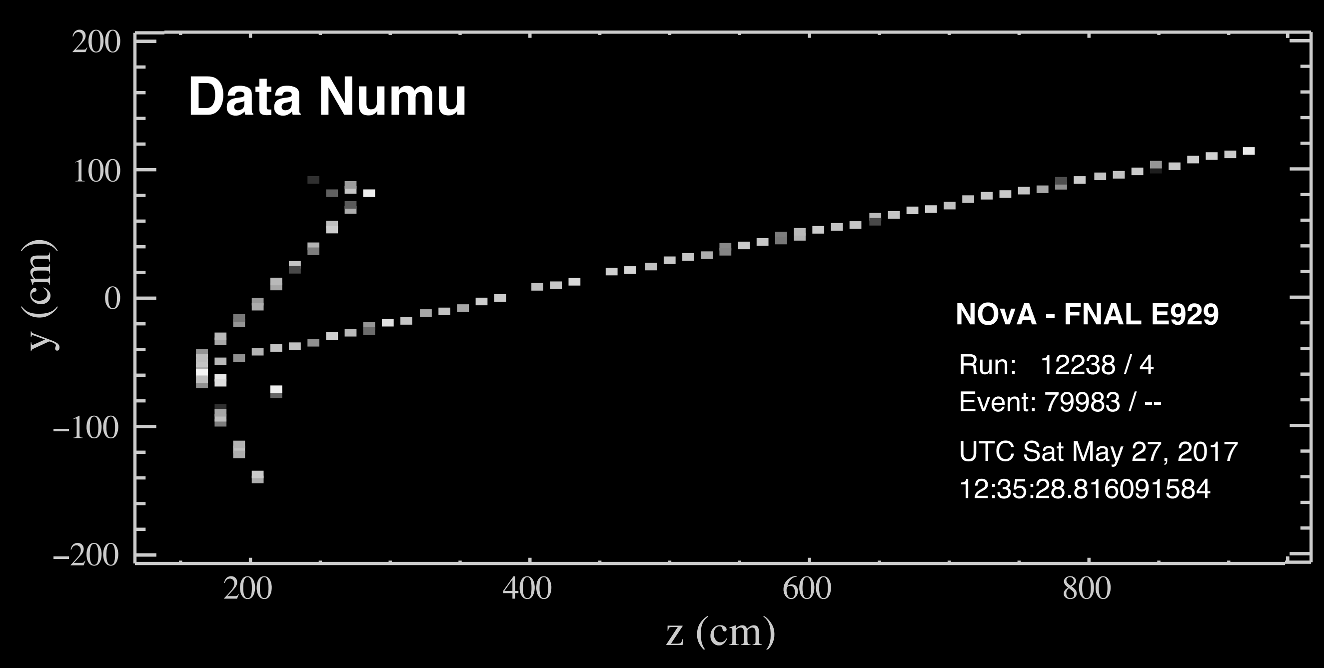
$\bar{\nu}$ **Efficiency Improvement** Training Sample (ID > 0.9)		
$\bar{\nu}_e$ CC Signal	$\bar{\nu}_\mu$ CC Signal	$\bar{\nu}$ NC Signal
14%	6%	10%

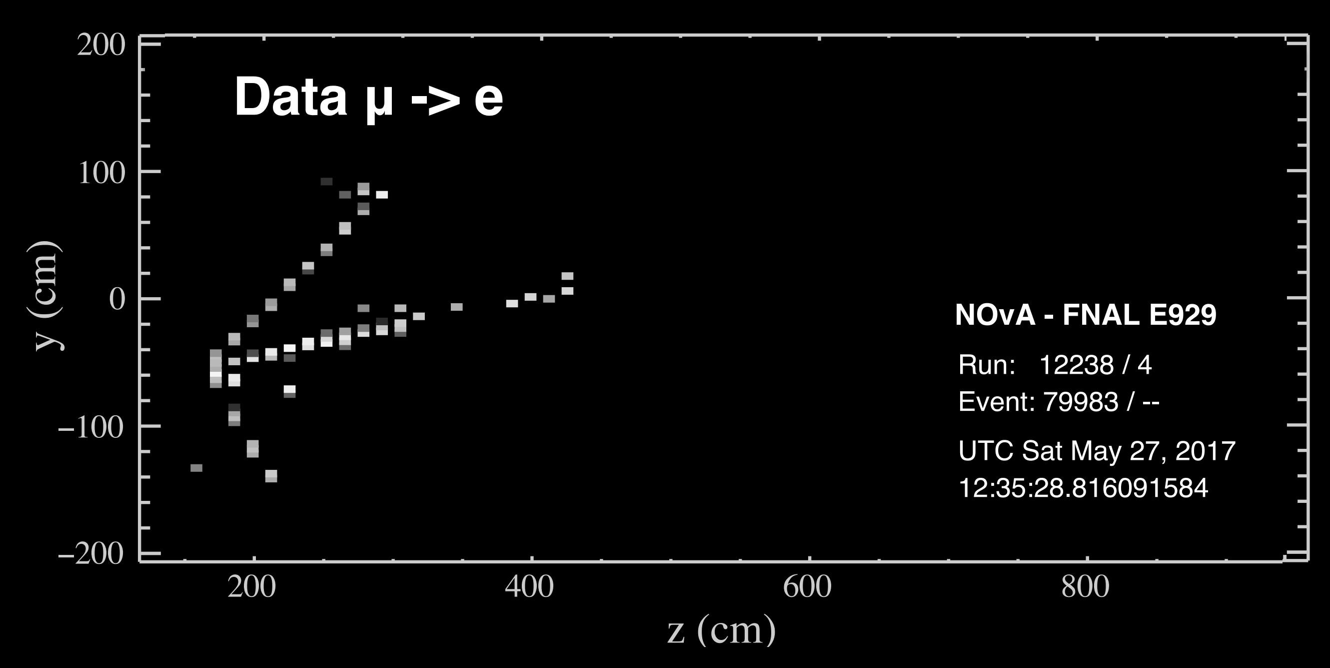
Event Classification

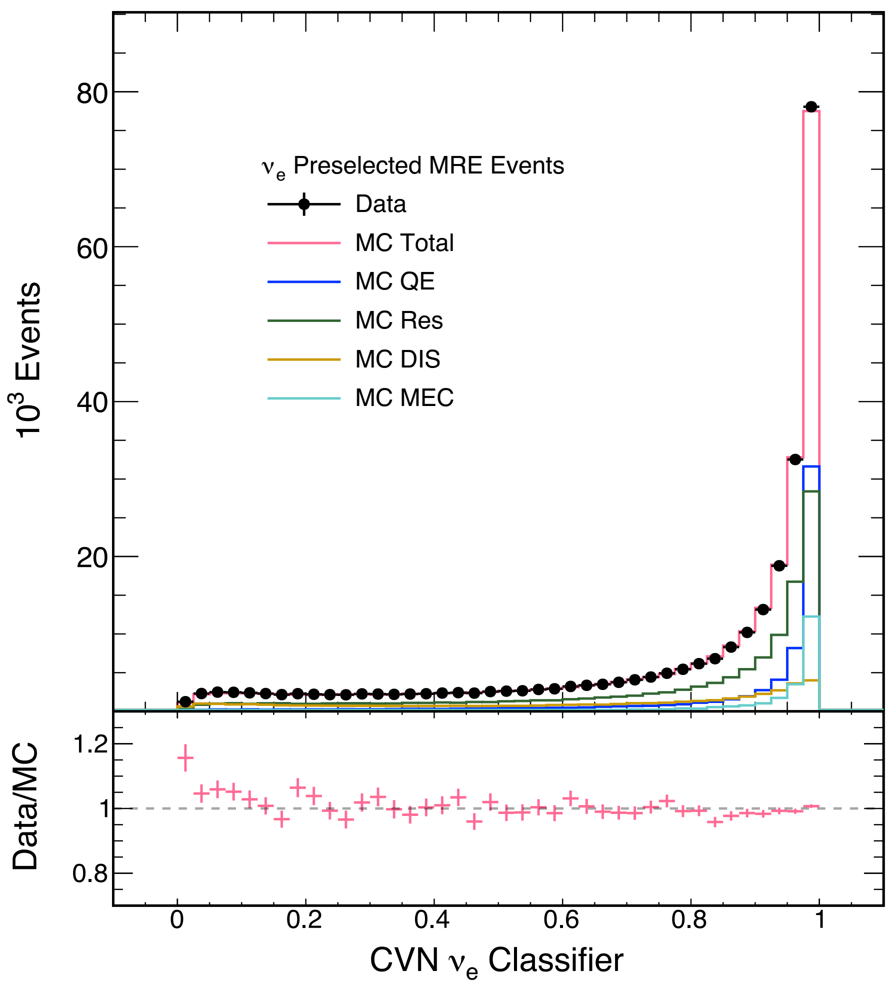




Example Data Check: MRE







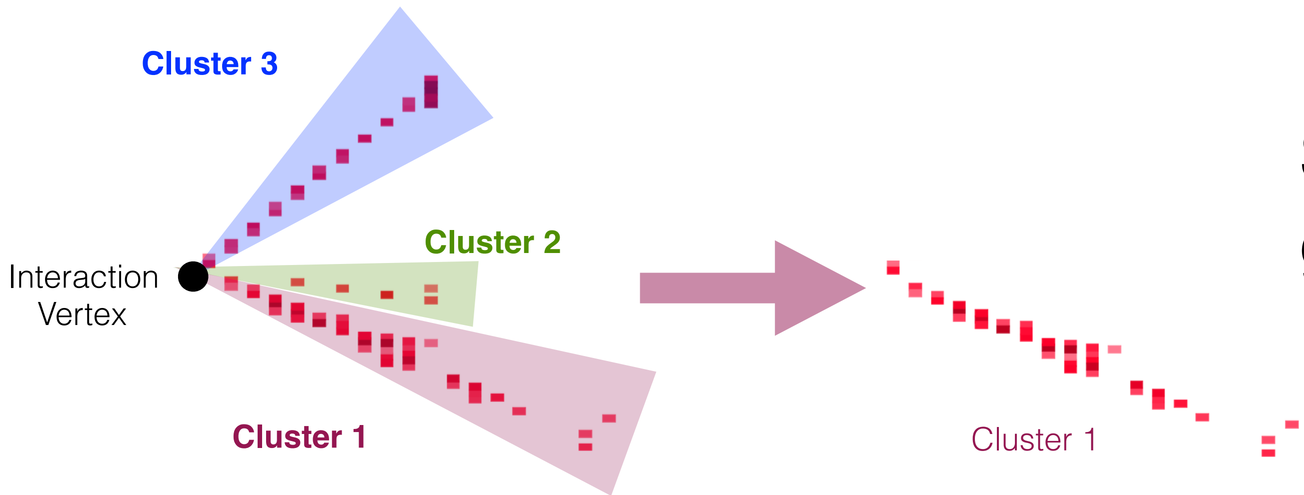
Muon Removed - Electron:

Select a muon neutrino interaction.

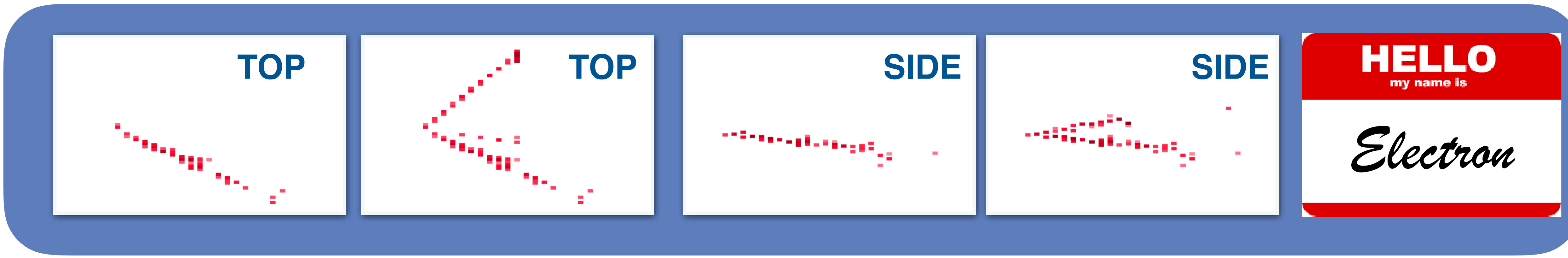
Remove the muon hits and replace with a simulated electron.

Data/MC comparisons show good agreement.

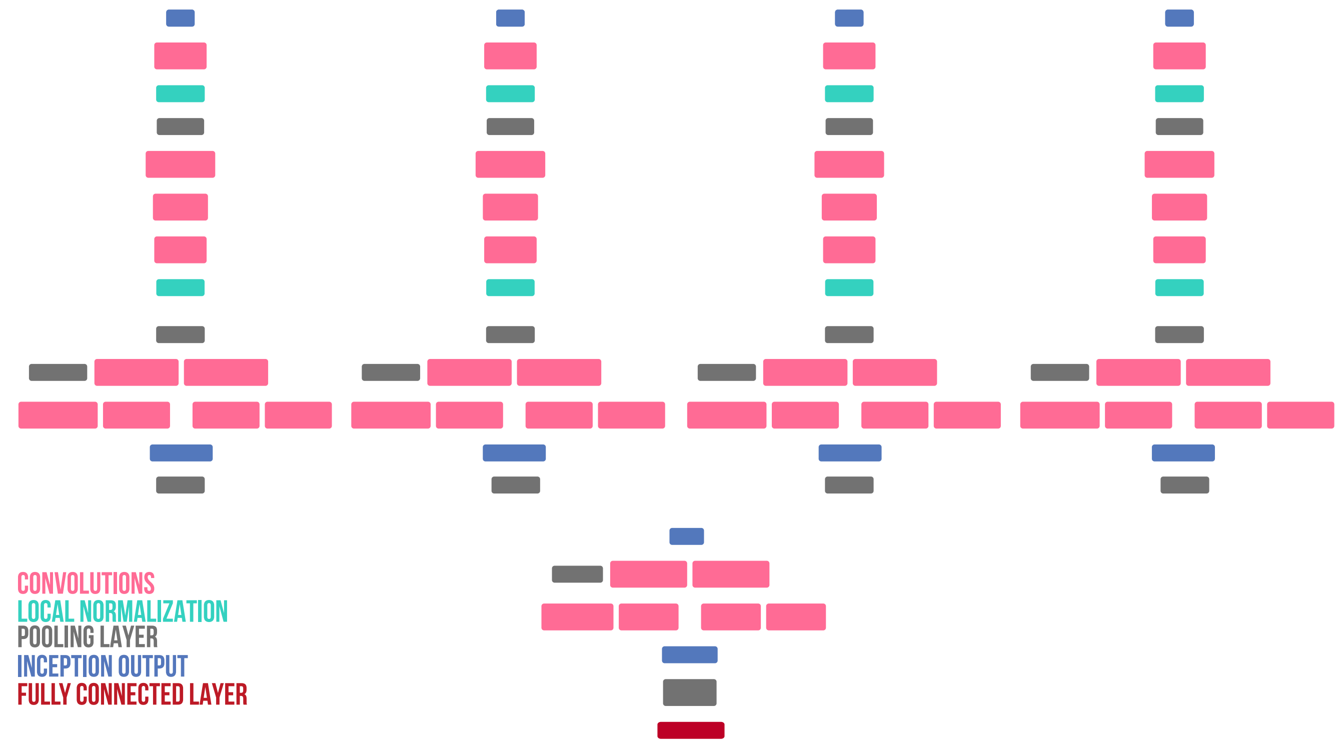
Particle Classification



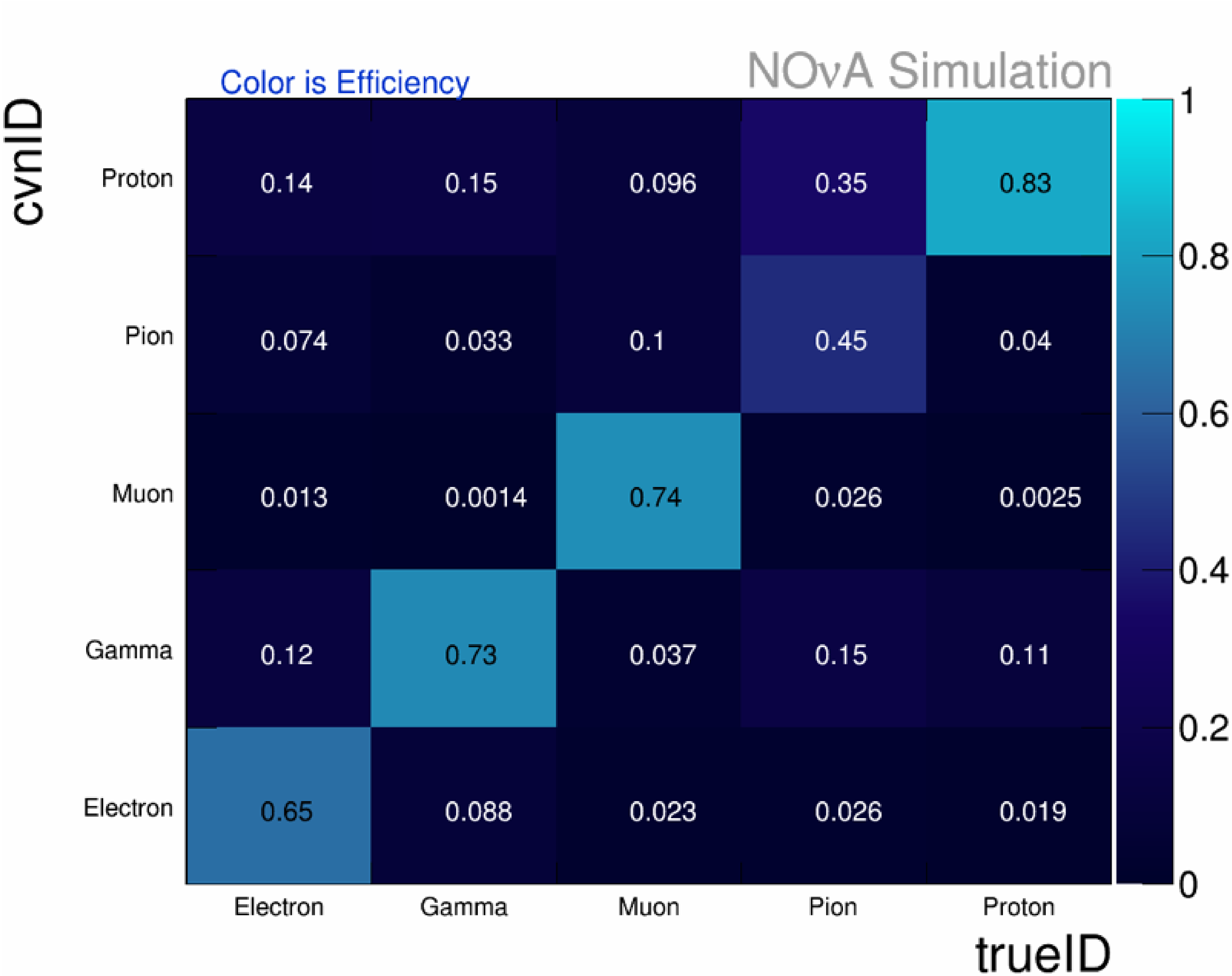
Single particles are separated using geometric reconstruction methods.



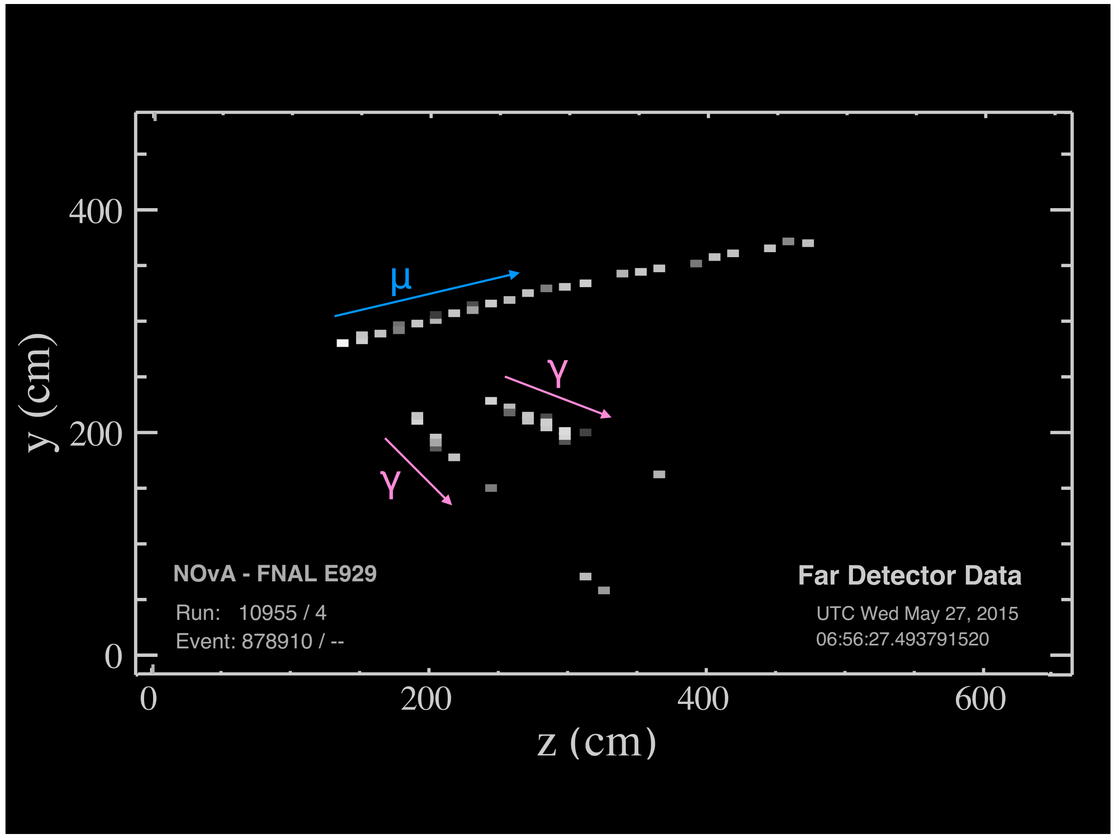
Classify particles using both views of the particle and both views of the entire event.



Particle Classification

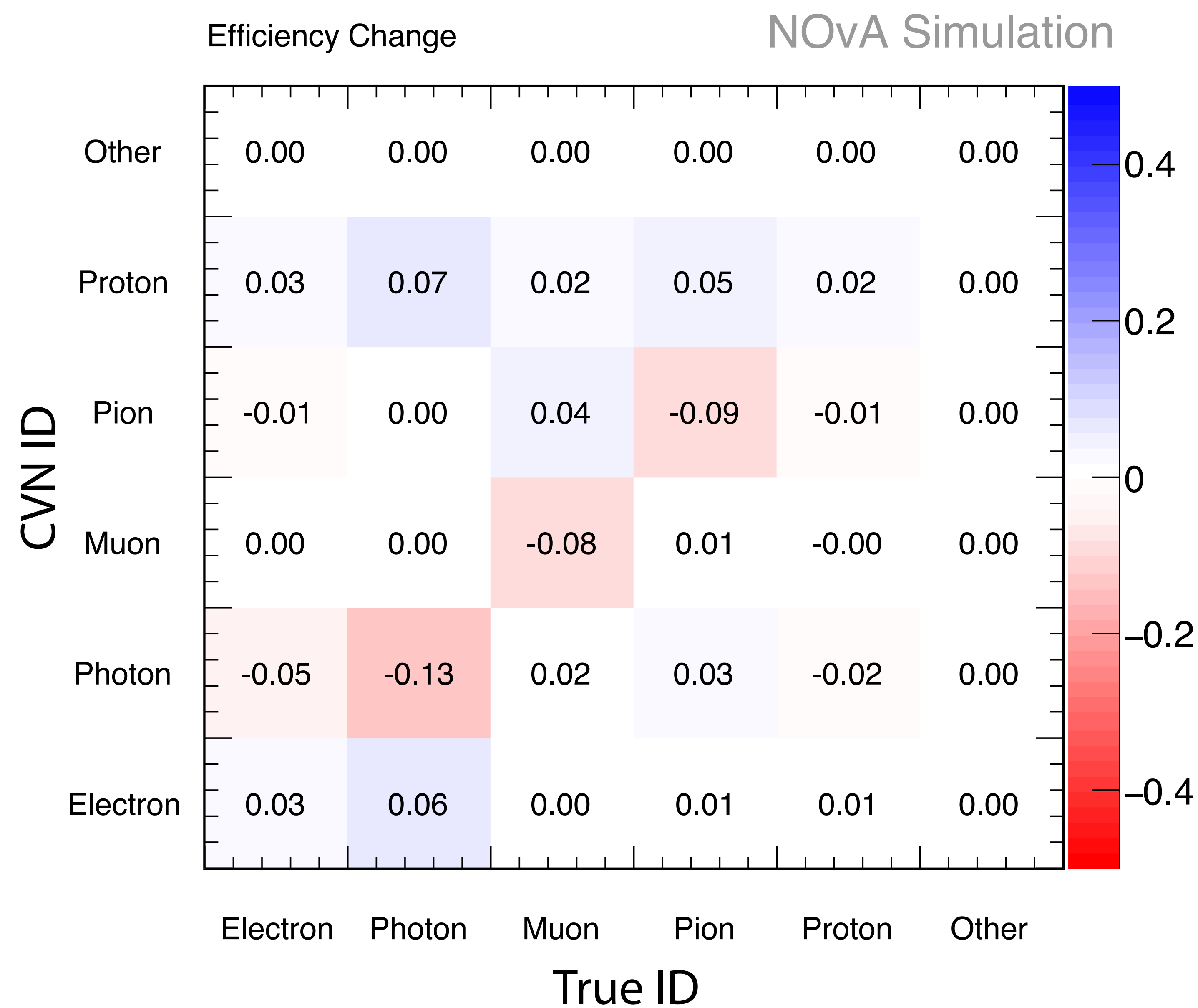


Utilizing Context



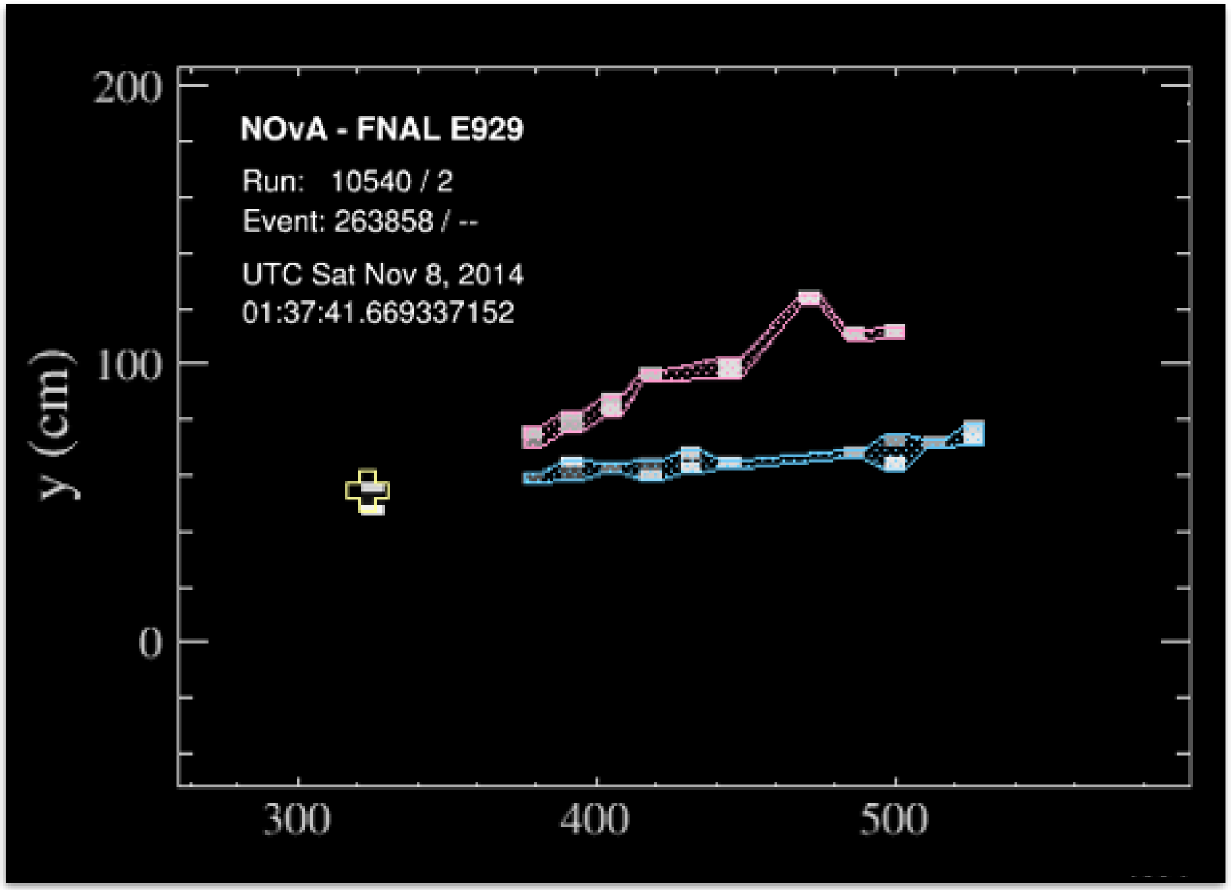
Showing the network the entire event teaches the network **contextual** information.

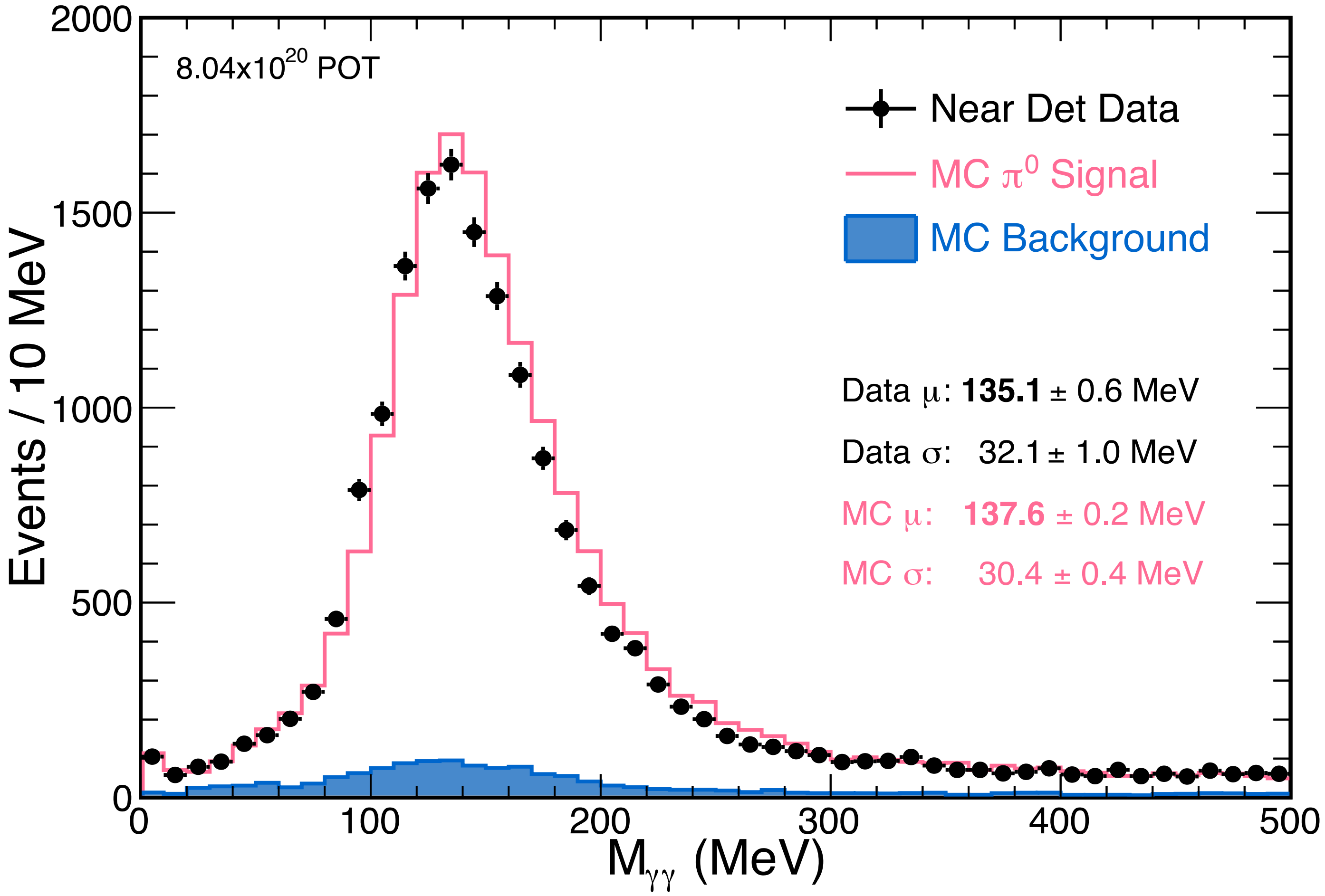
Particularly useful in the classification of photons.



The change in efficiency for each category from removing context information.

Example Data Check: π^0 Mass Peak

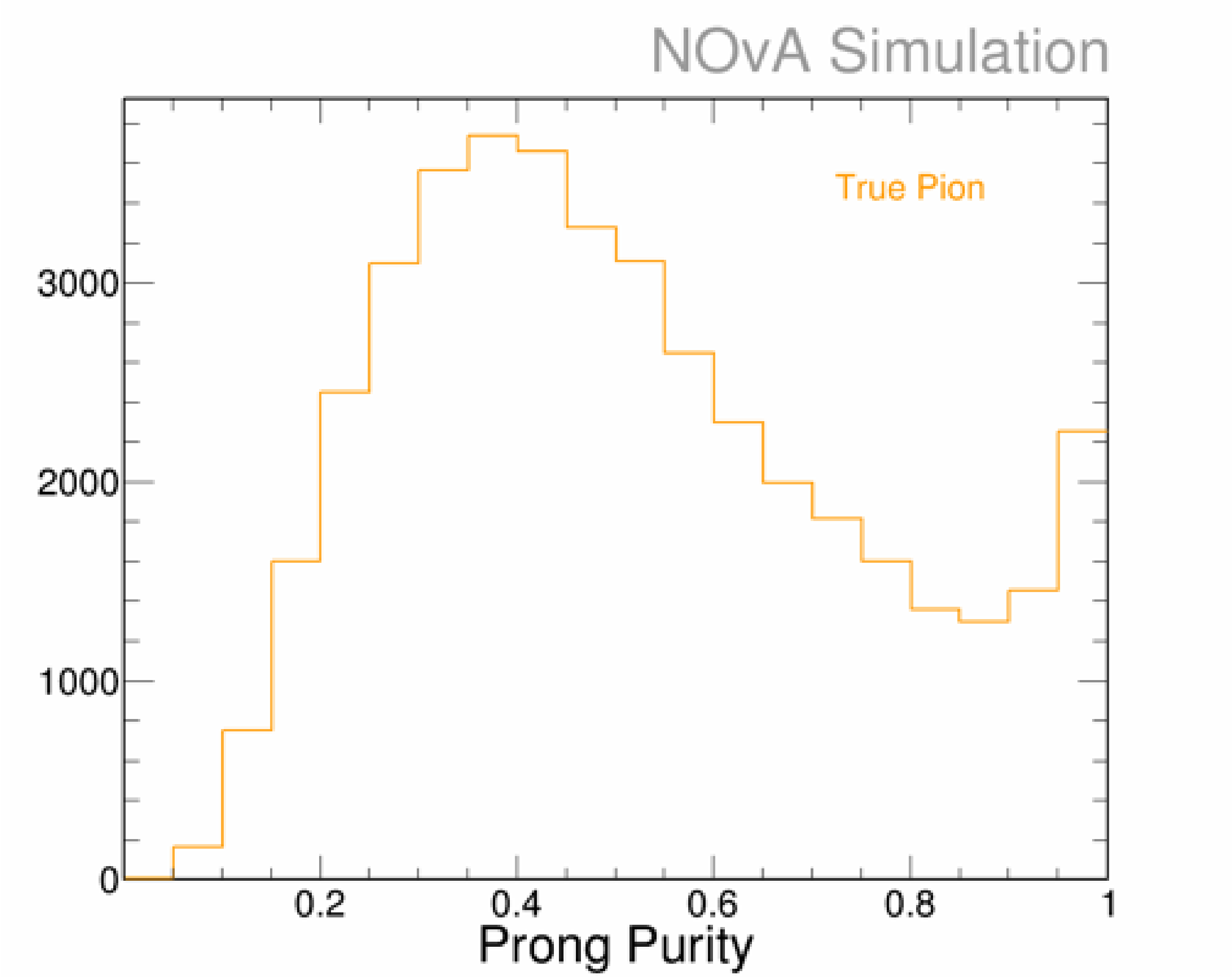


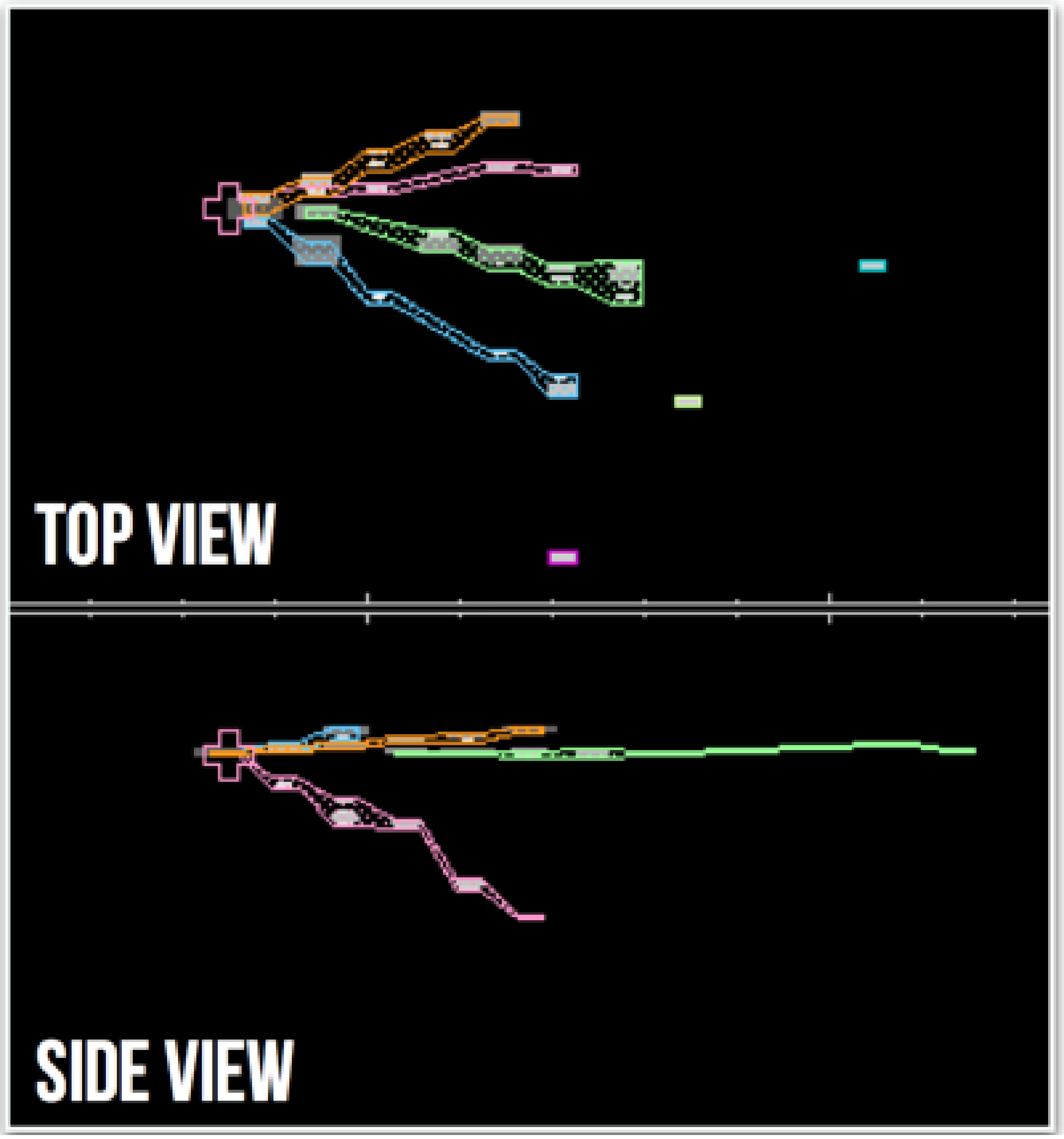


π^0 mass reconstructed using invariant mass of pairs of photons identified using the single particle classifier.

Reconstruction Caveats

Single particle classifier is dependent on the quality of the already existing clusters.





Full Event Reconstruction

Cluster and **classify** particles simultaneously using **instance aware semantic segmentation.**

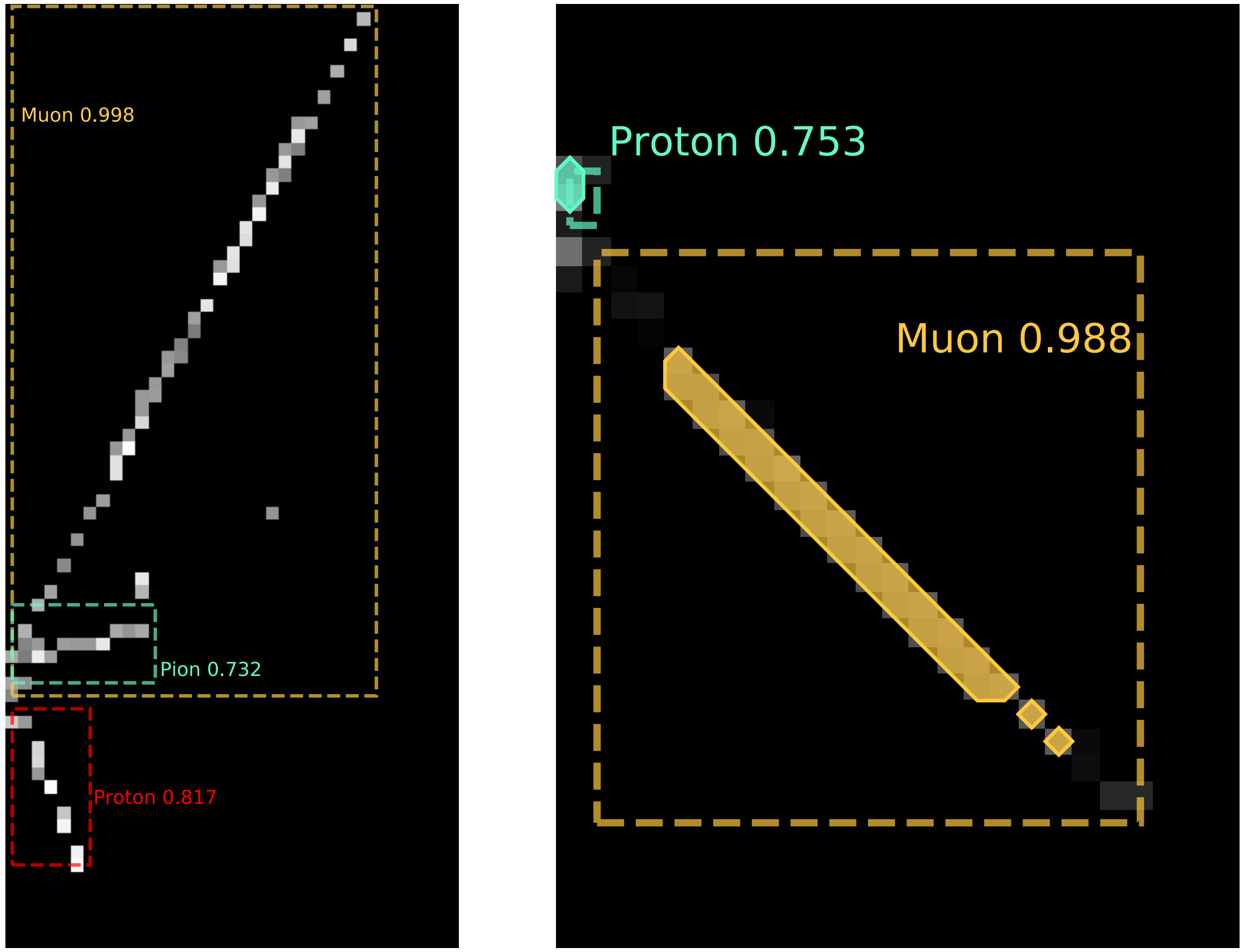
A network reconstructs an event **hit by hit**.

Bounding Boxes - builds bounding boxes aiming to contain a single particle.

Labels - A softmax function is used to classify the particle in each box.

Clustering - Pixel by pixel clusters are defined to closely contain single particles.

Exploring different inputs to the network to improve clustering performance.



Kaiming He and (2017). Mask R-CNN. CoRR, abs/1703.06870.

Conclusion

Training on neutrinos and anti-neutrinos separately yields the largest improved for event classification.

Giving contextual information improves performance of single particle classification.

Data-driven methods are used to check the performance of the networks.

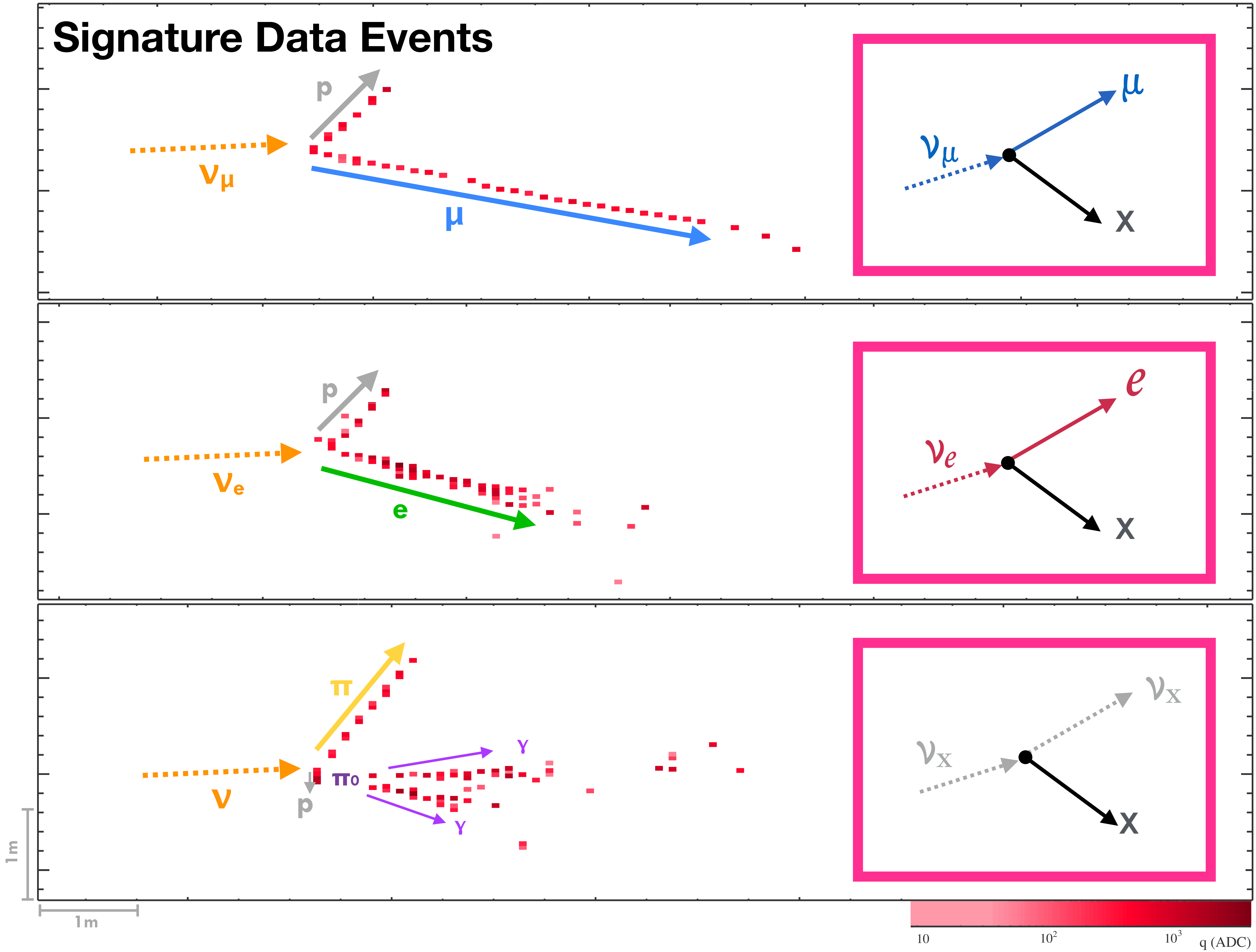
Developing a network for full event reconstruction.

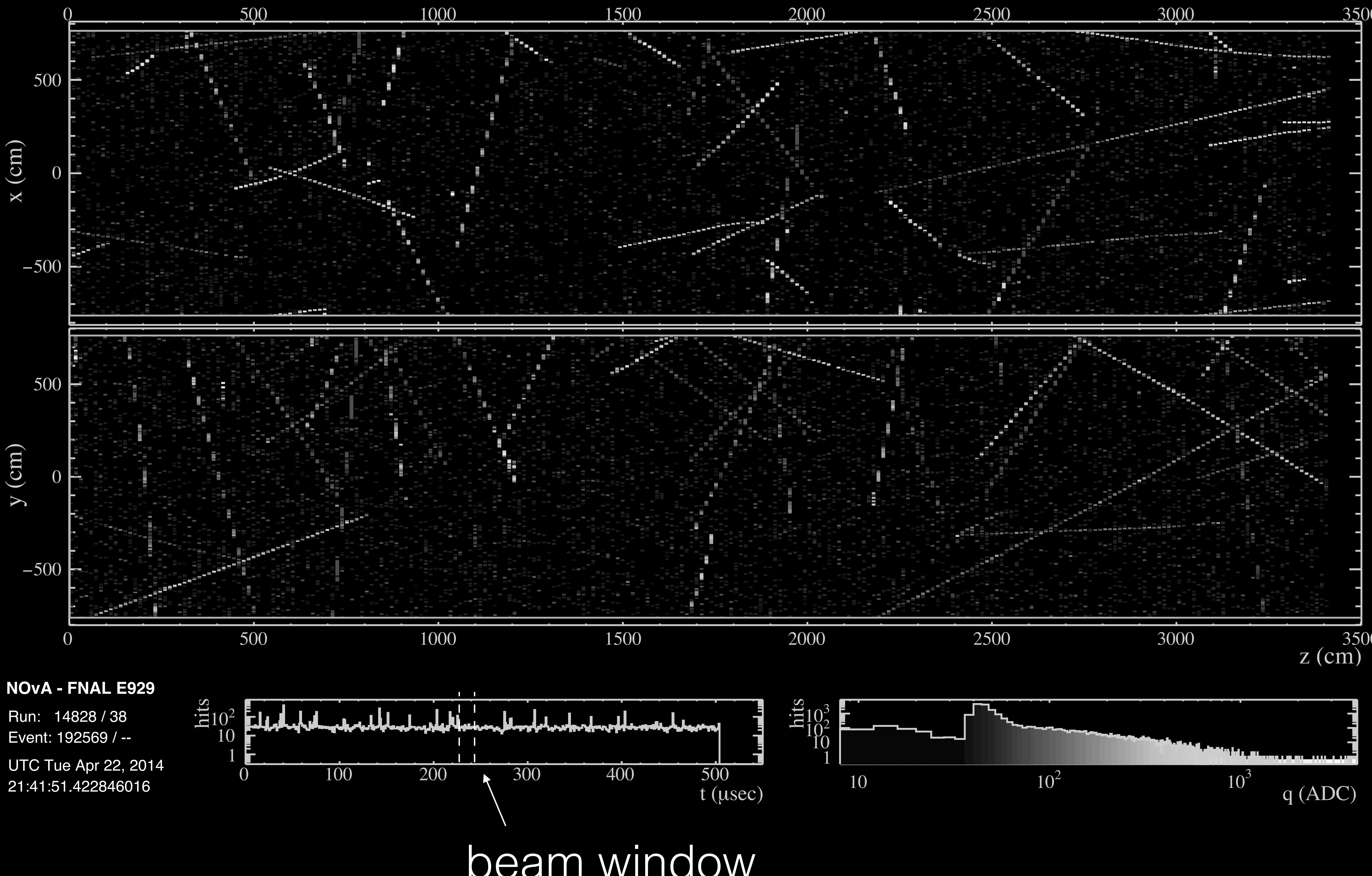
http://nusoft.fnal.gov/nova/public/nova-events/

Can you beat our neural nets?

Backup

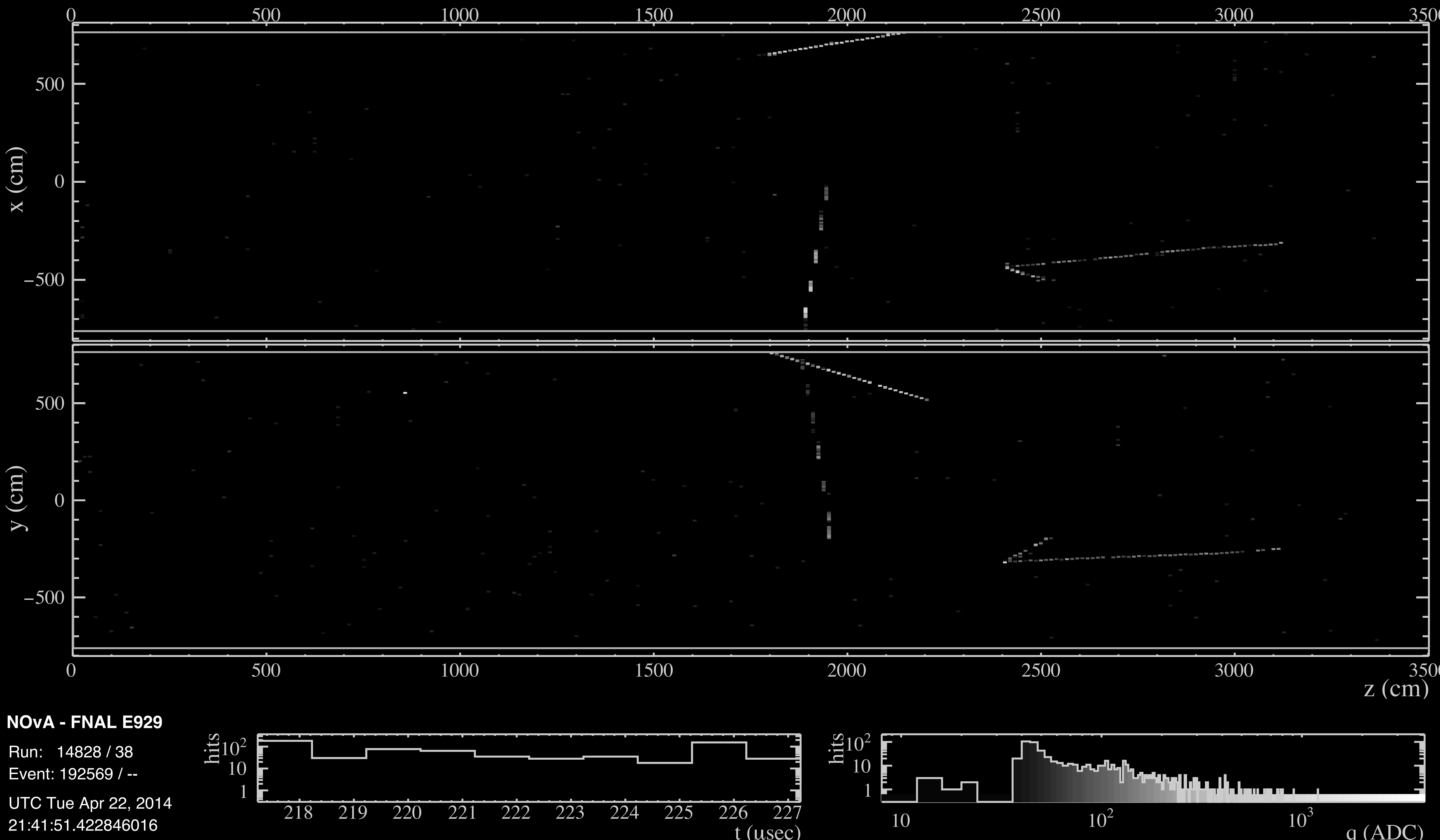
Signature Data Events



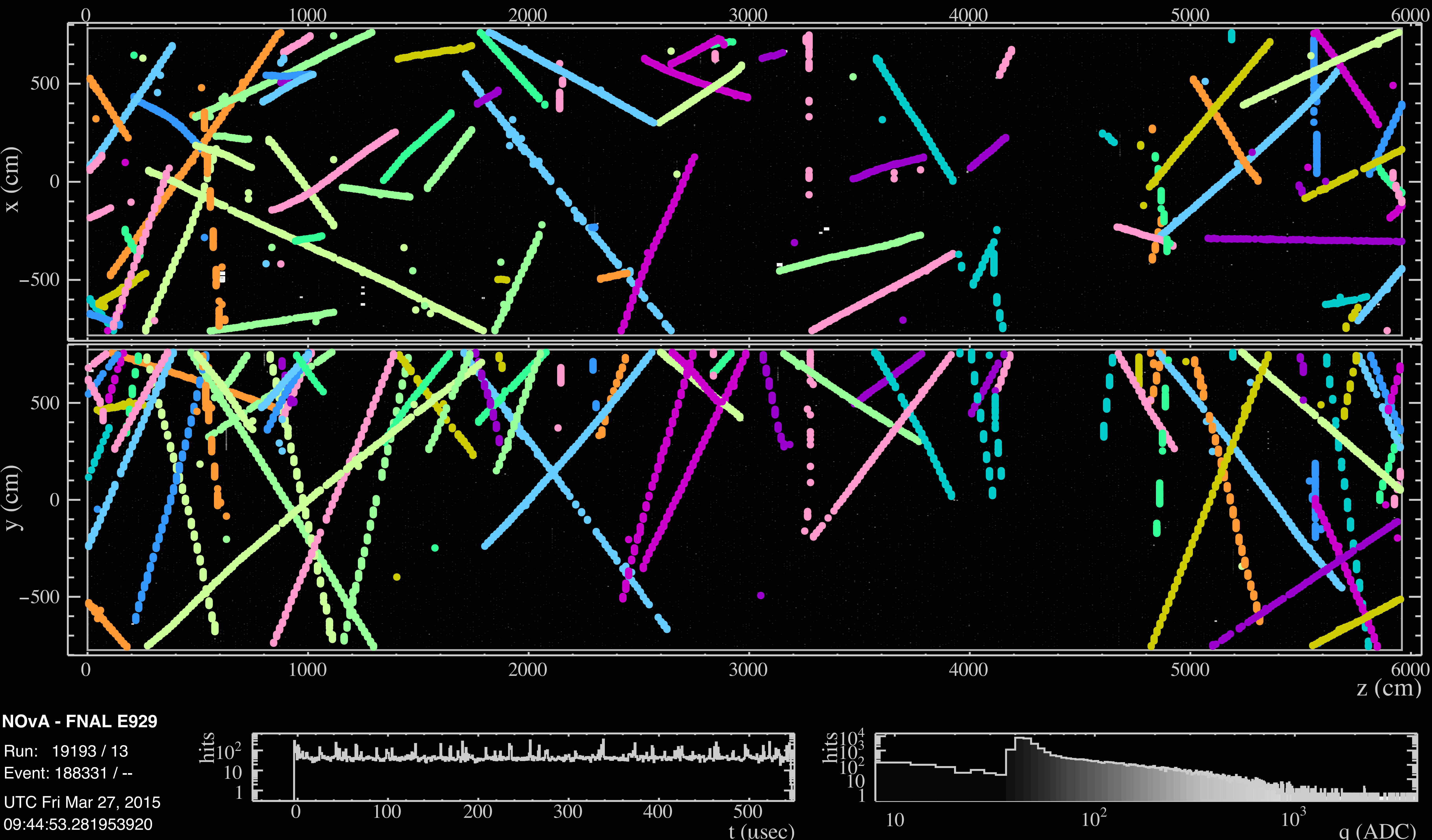

0
500
1000
1500
2000
2500
3000
3500
x (cm)
500
0
−500
y (cm)
500
0
−500
z (cm)
NOvA - FNAL E929
Run: 14828 / 38
Event: 192569 / --
UTC Tue Apr 22, 2014
21:41:51.422846016
hits
t (μsec)
hits
q (ADC)
beam window

NOvA Events

Separate hits by time and space

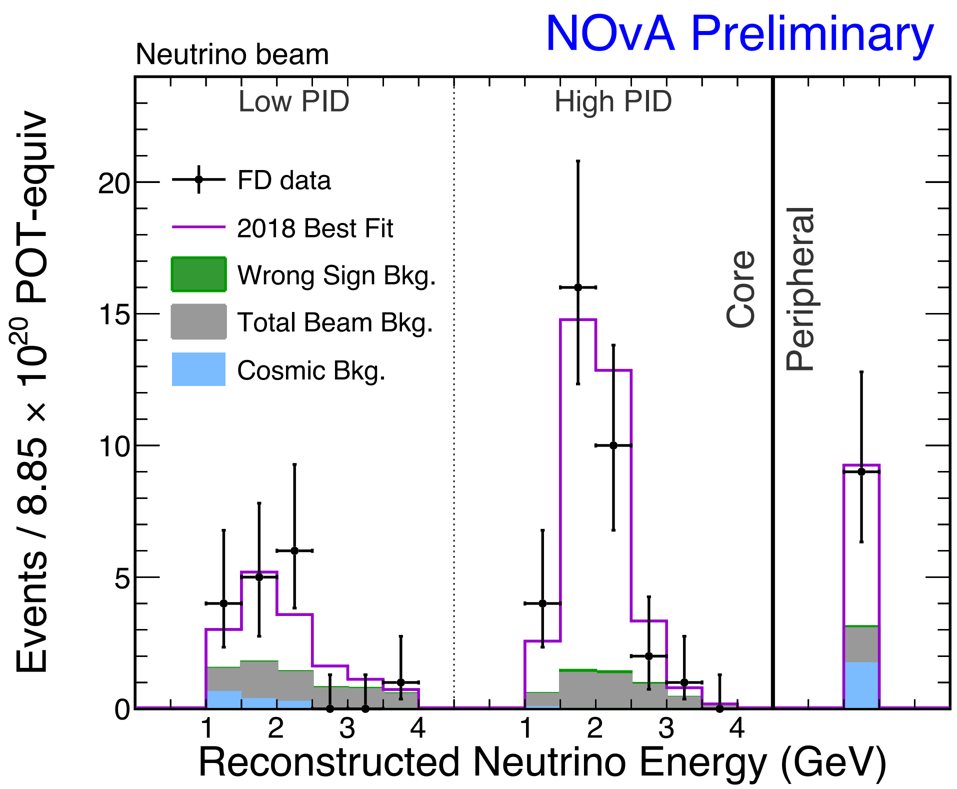


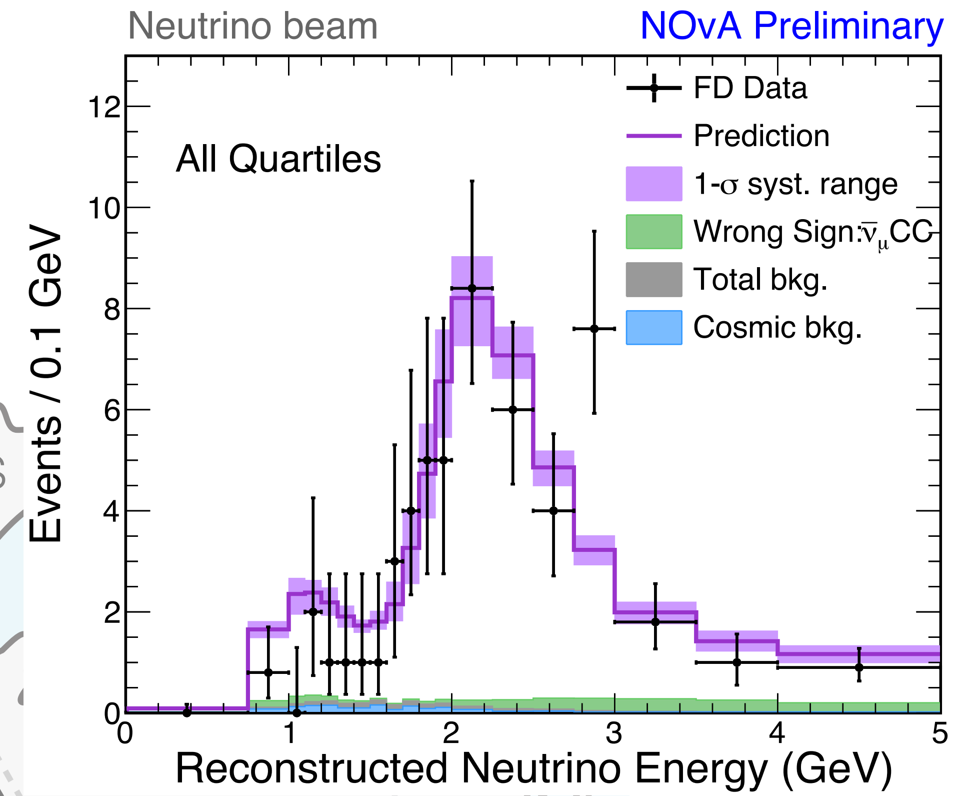
Beam window only.

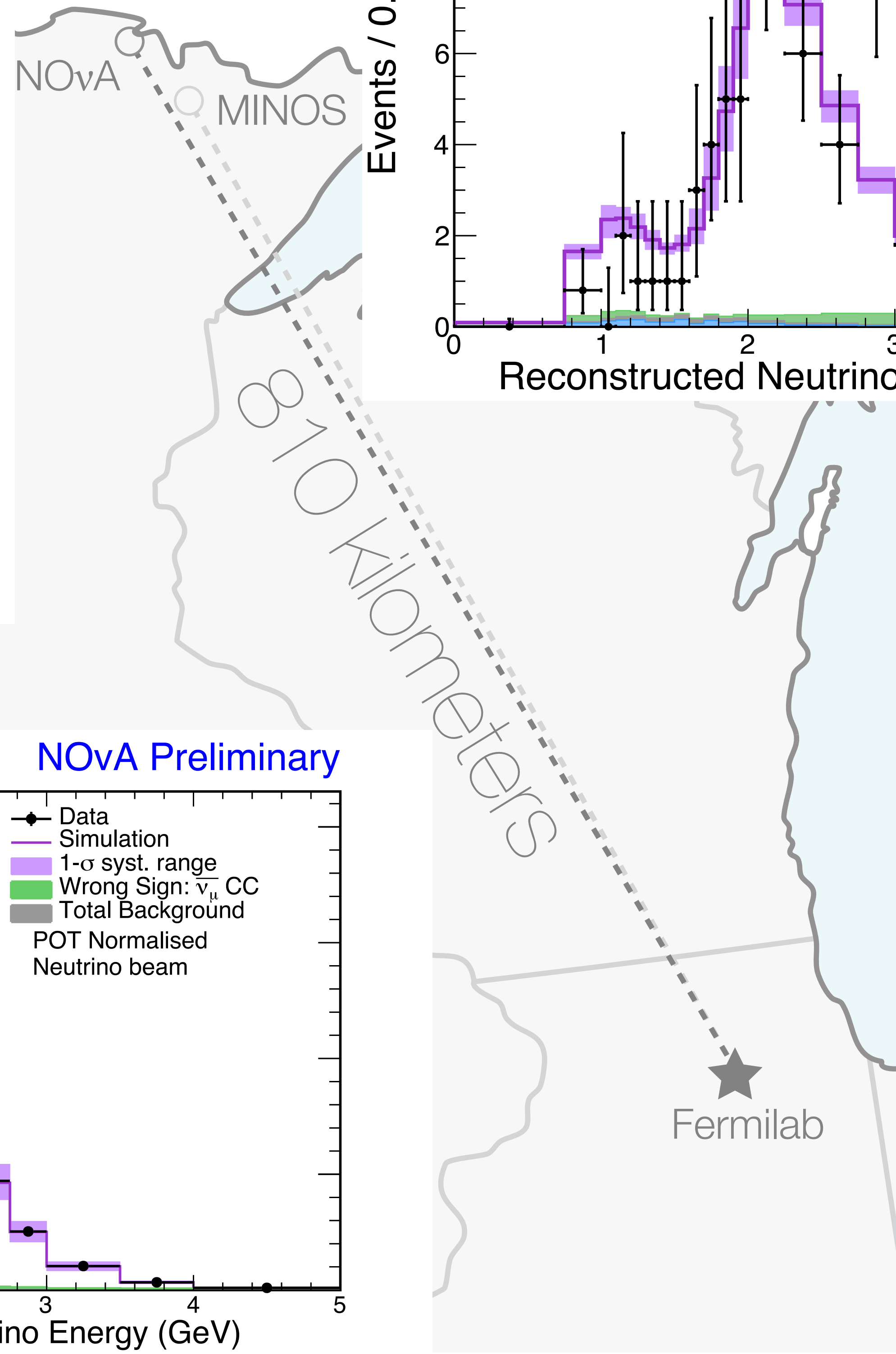


0
1000
2000
3000
4000
5000
6000
500
0
−500
x (cm)
y (cm)
z (cm)
NOvA - FNAL E929
Run: 19193 / 13
Event: 188331 / --
UTC Fri Mar 27, 2015
09:44:53.281953920
hits
t (μsec)
q (ADC)

NOvA Analysis

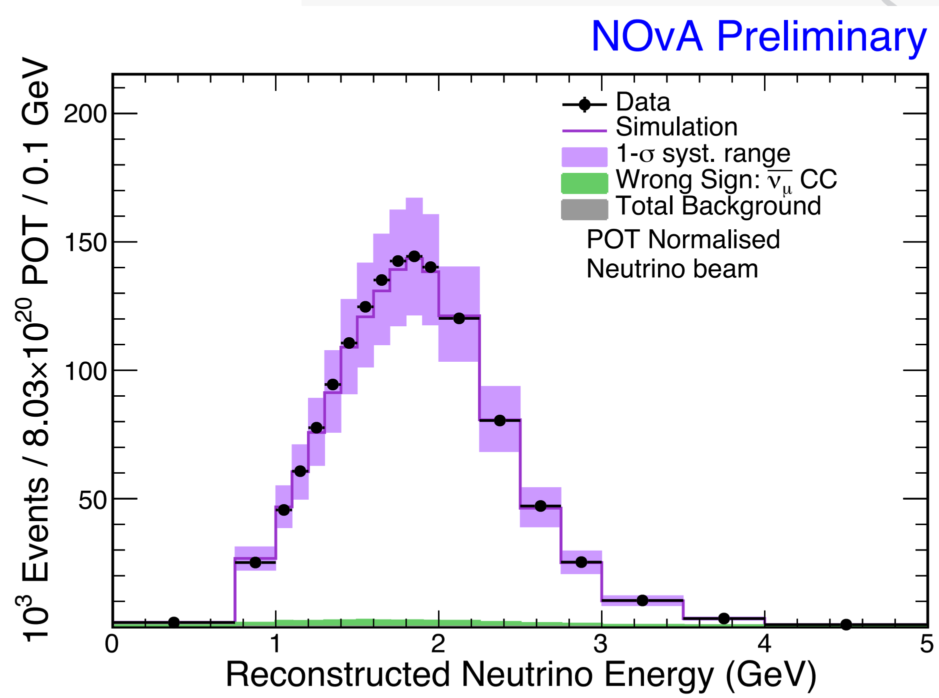




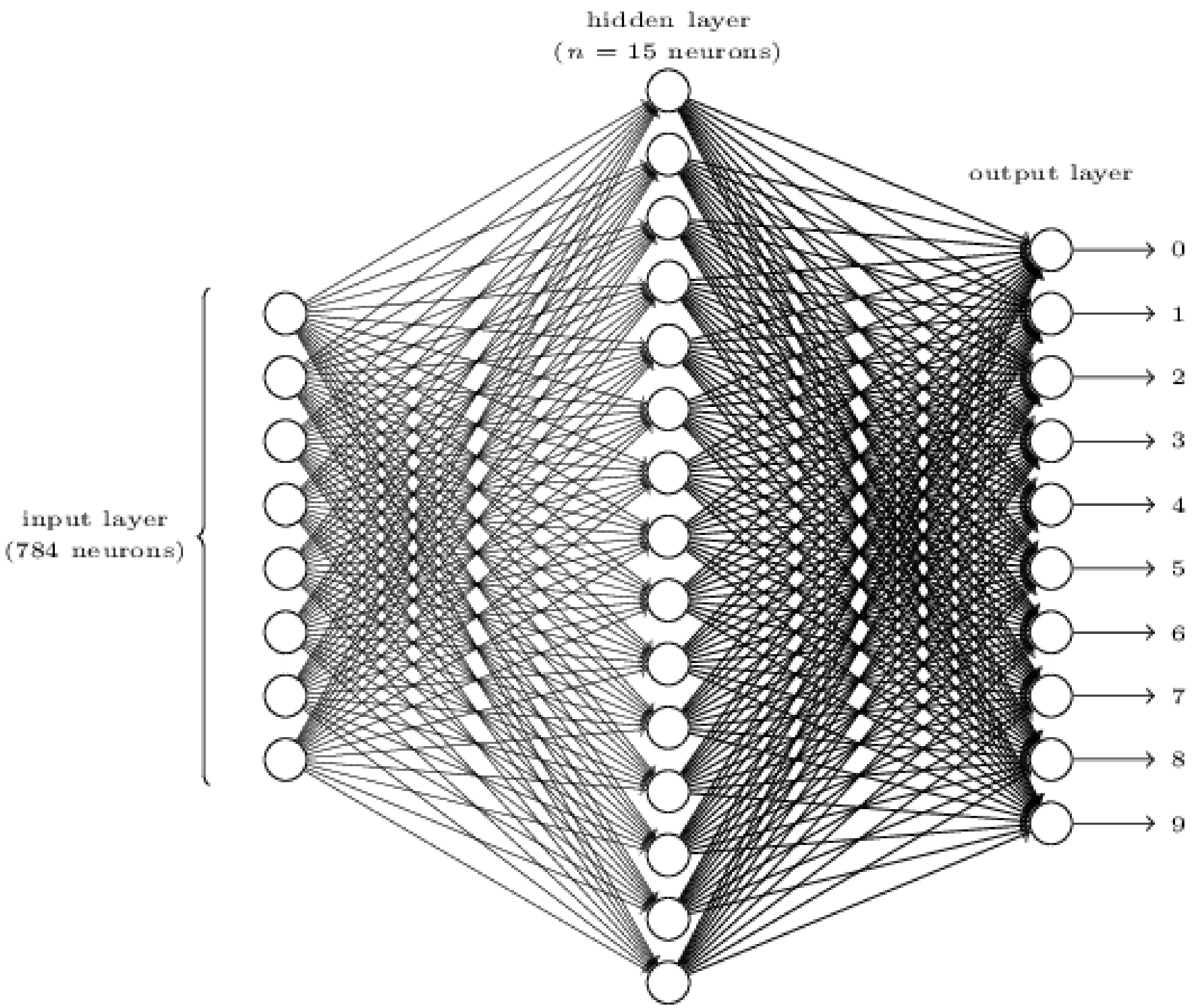


Measurables:

An energy spectrum of each neutrino flavor at each detector.



Neural Networks



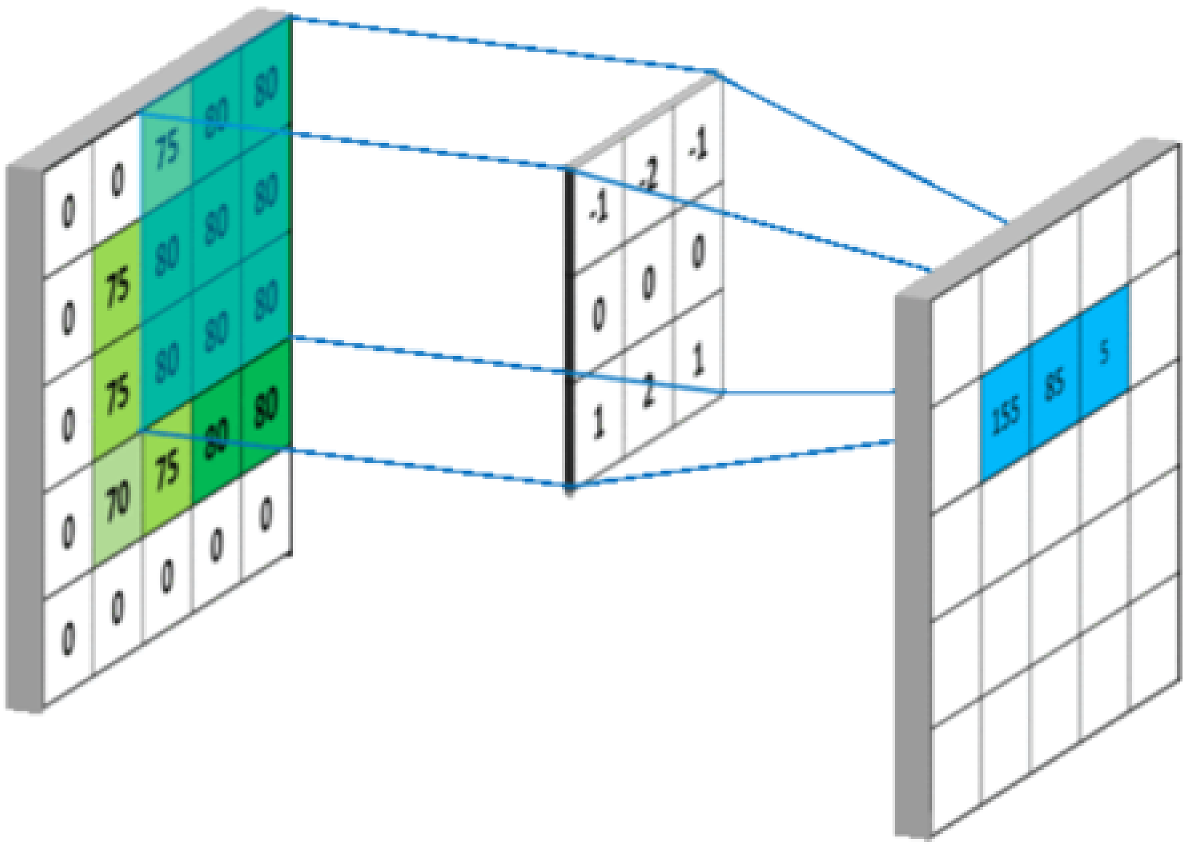
Identify neutrino flavor using neural networks.

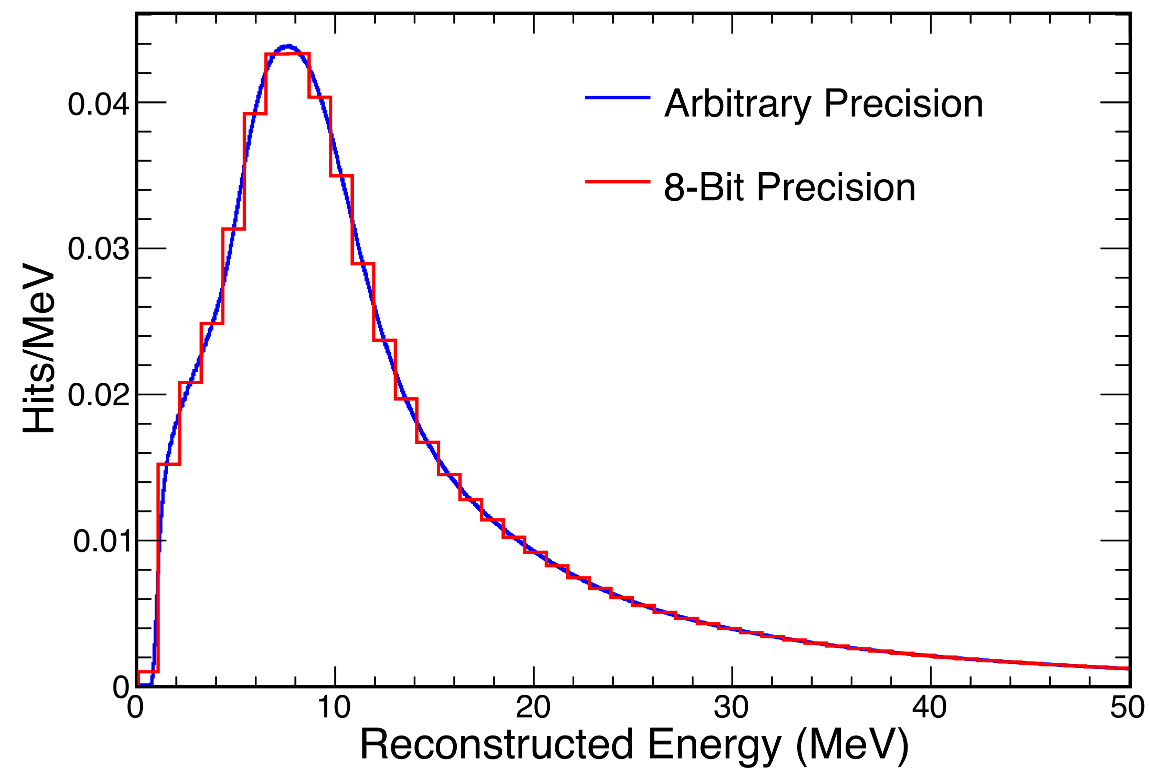
Artificial Neural Network (ANN) consists of multiple layers of neurons.

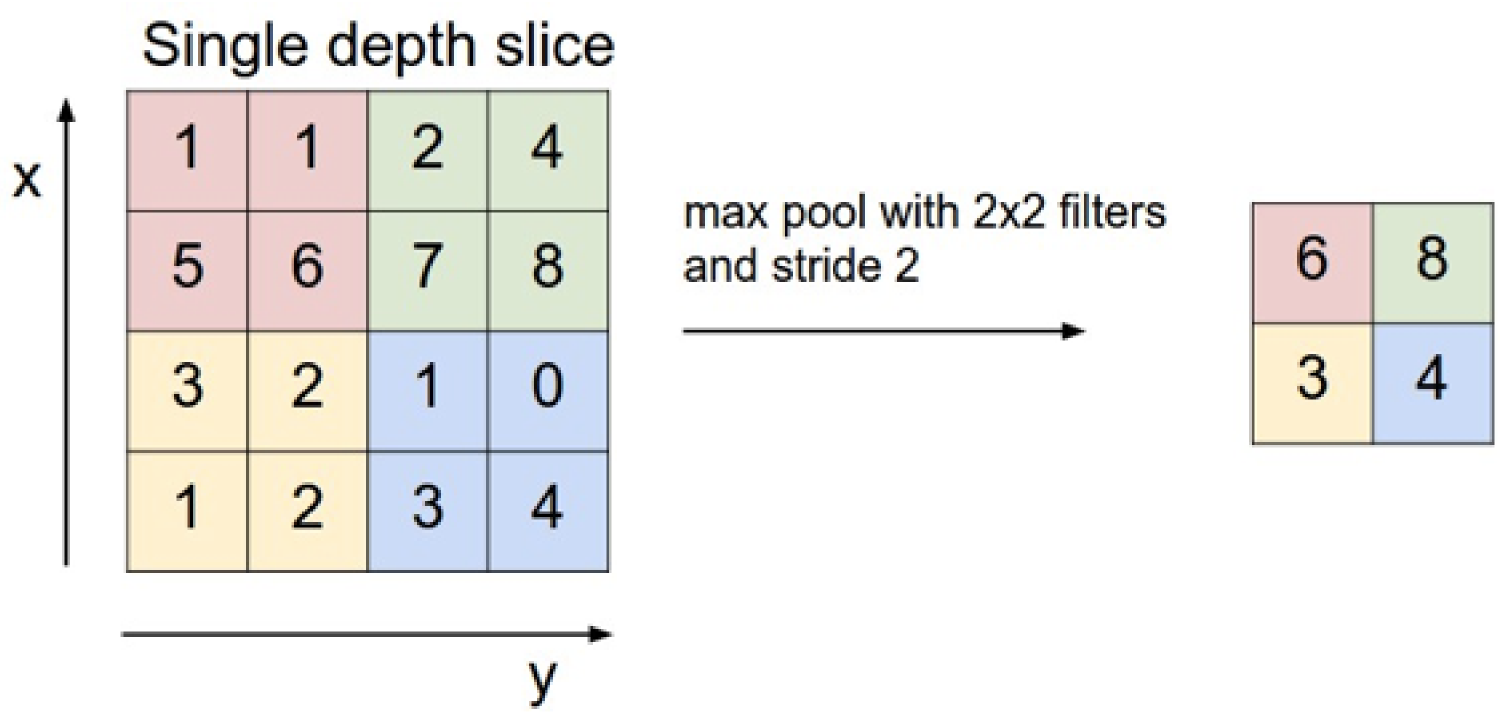
Each neuron represents a function using the values from the previous layer.

Output layer has scores for each category.

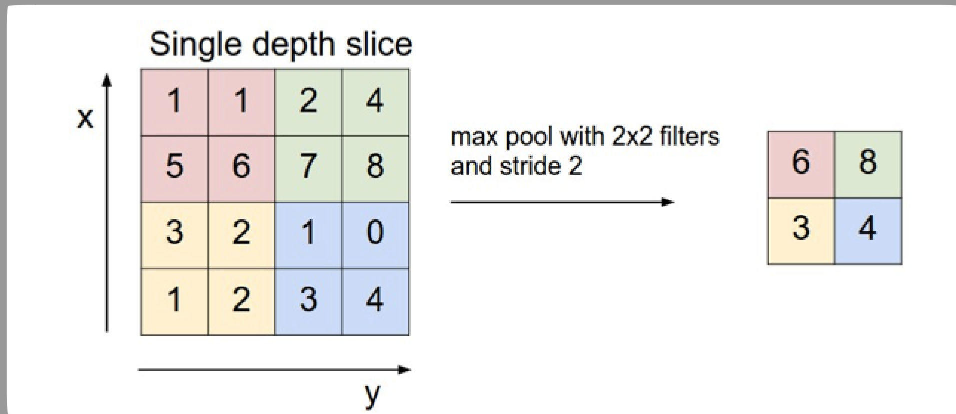
Convolutions and Pooling



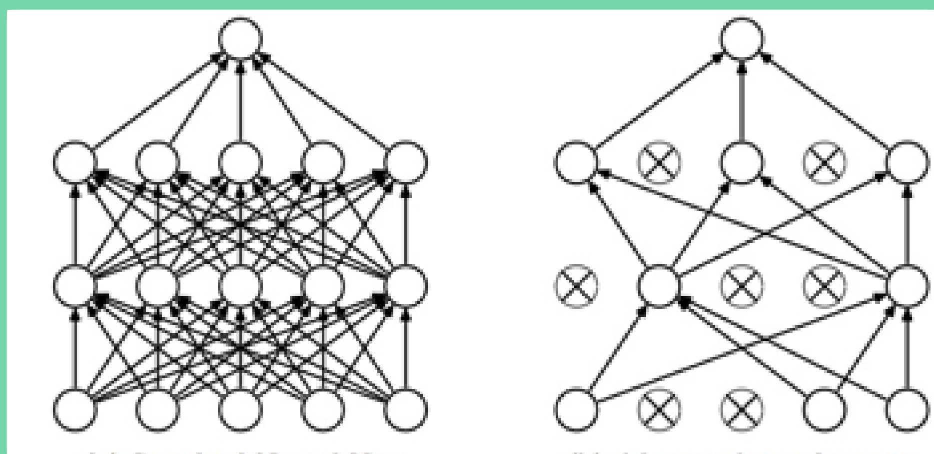




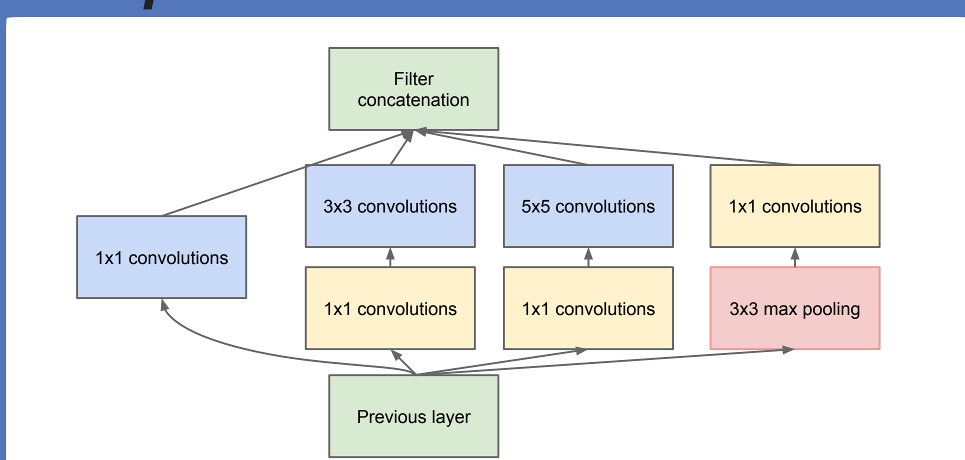
Pooling



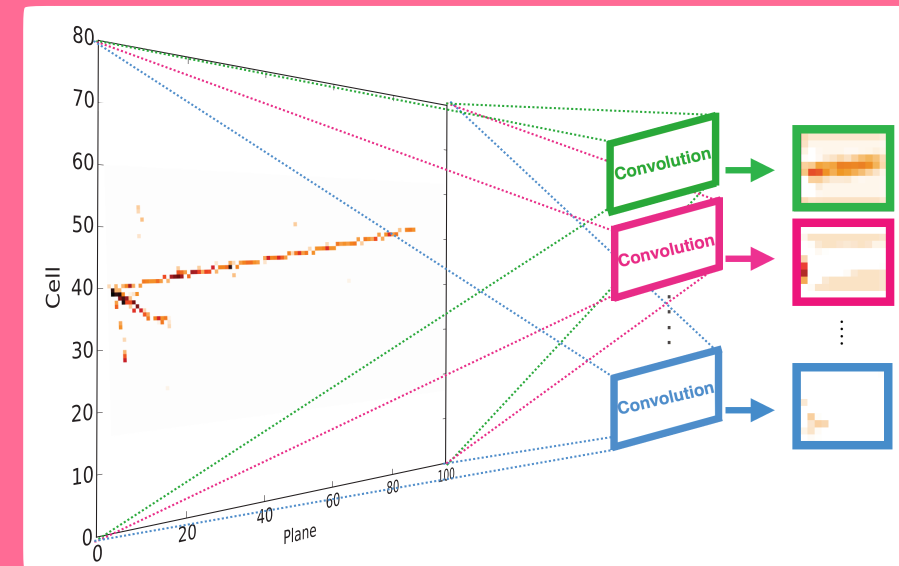
Dropout



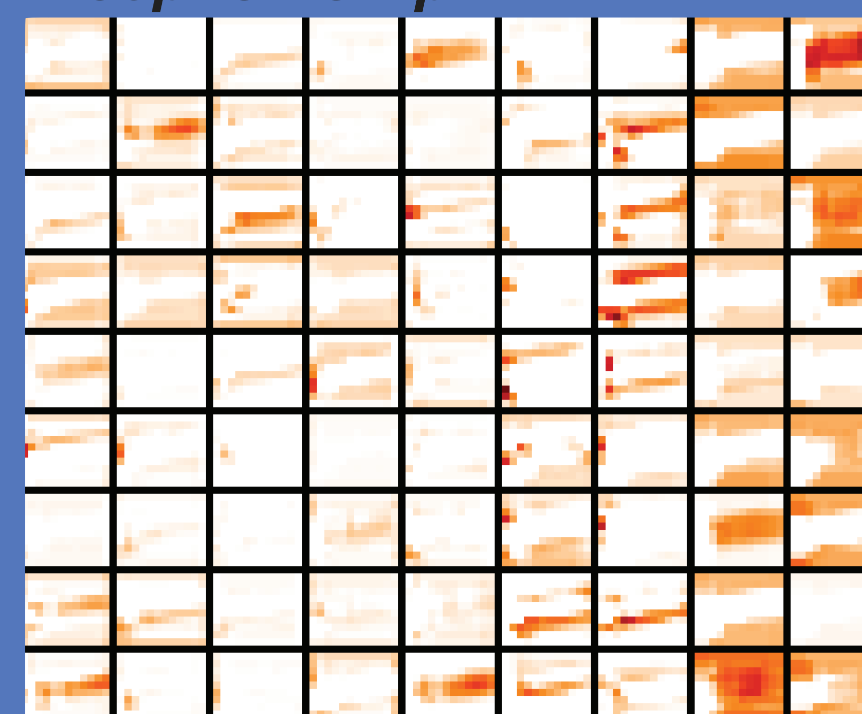
Inception module



Convolution

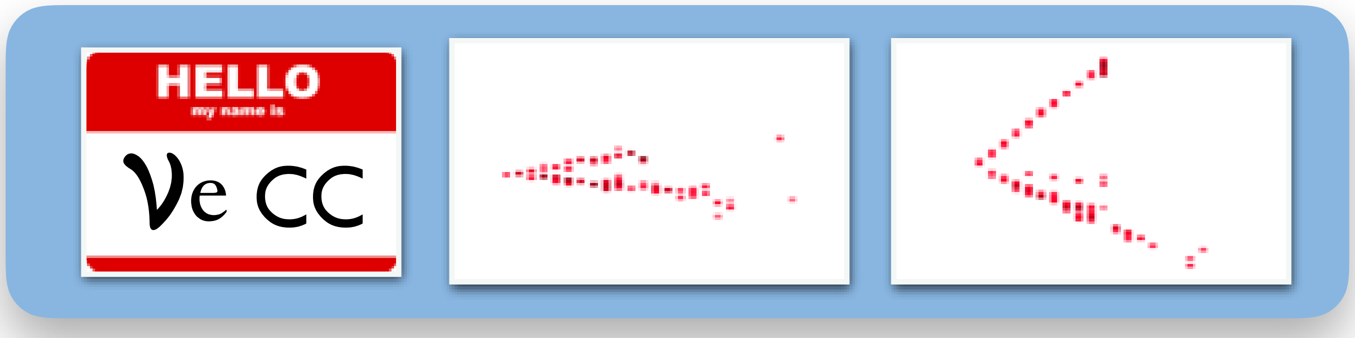


Inception output



Training

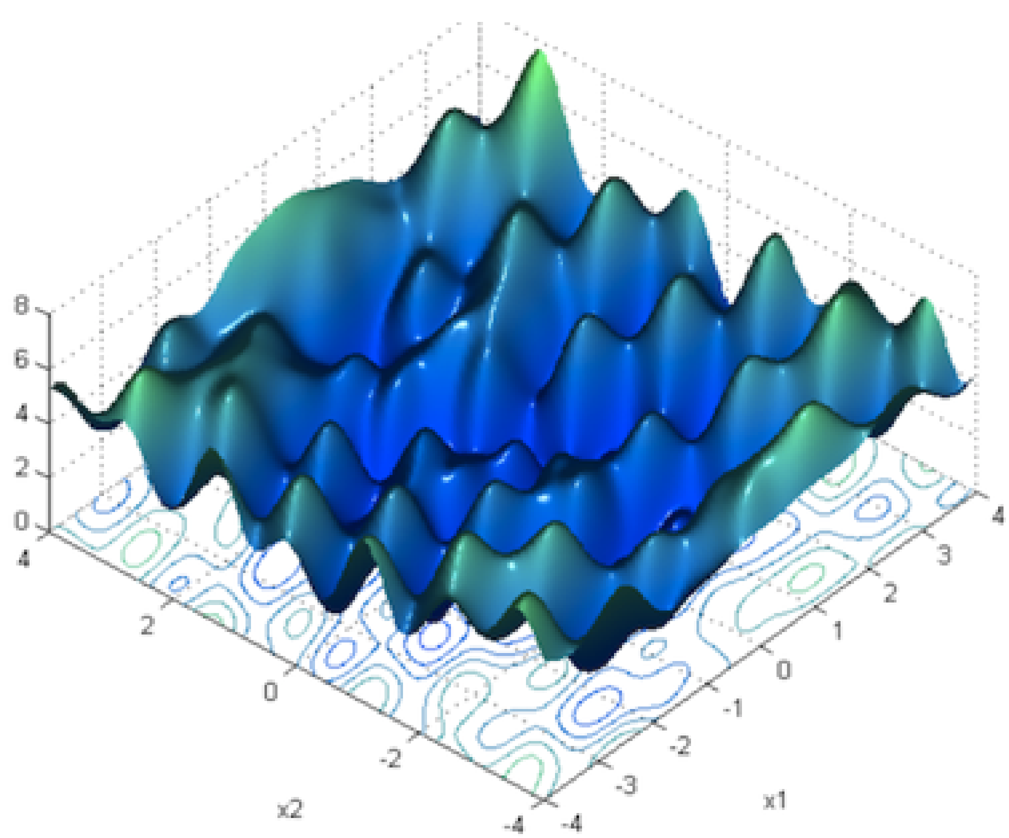
x4.7 million

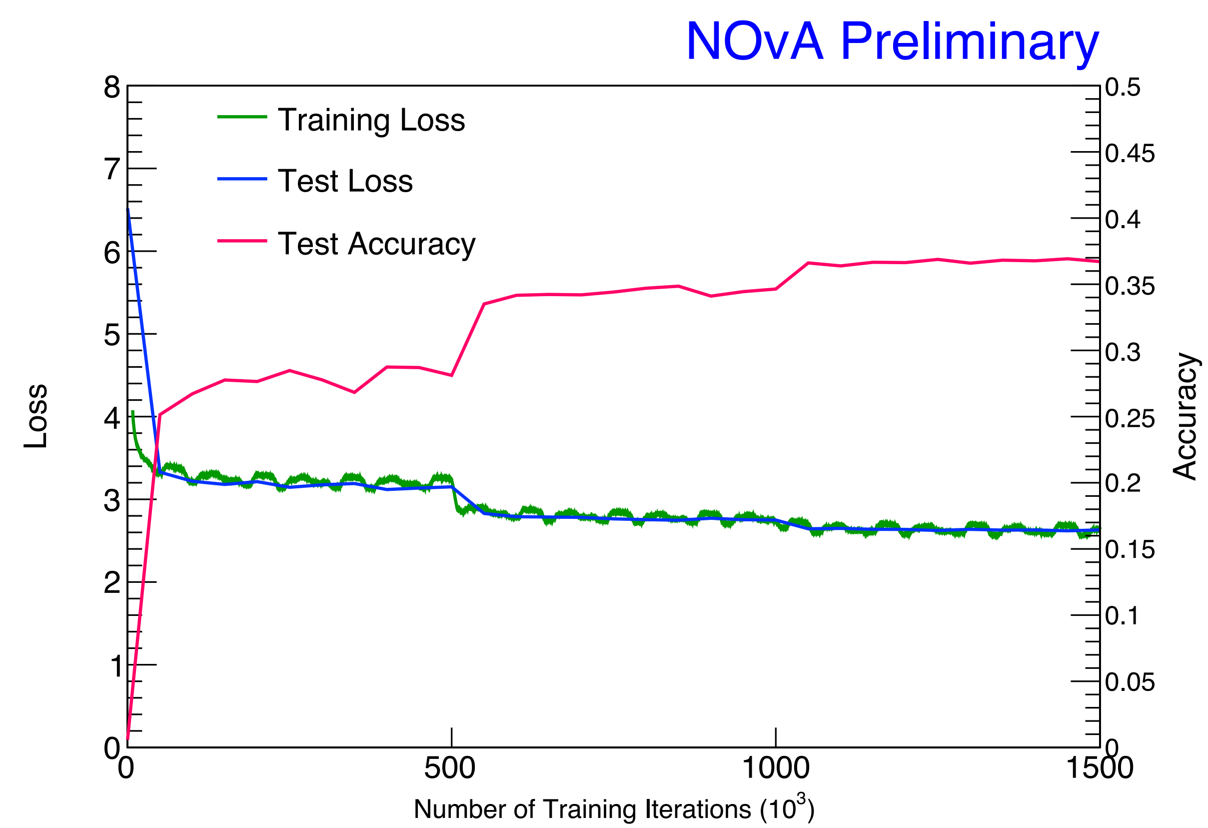


Training Sample

Test Sample

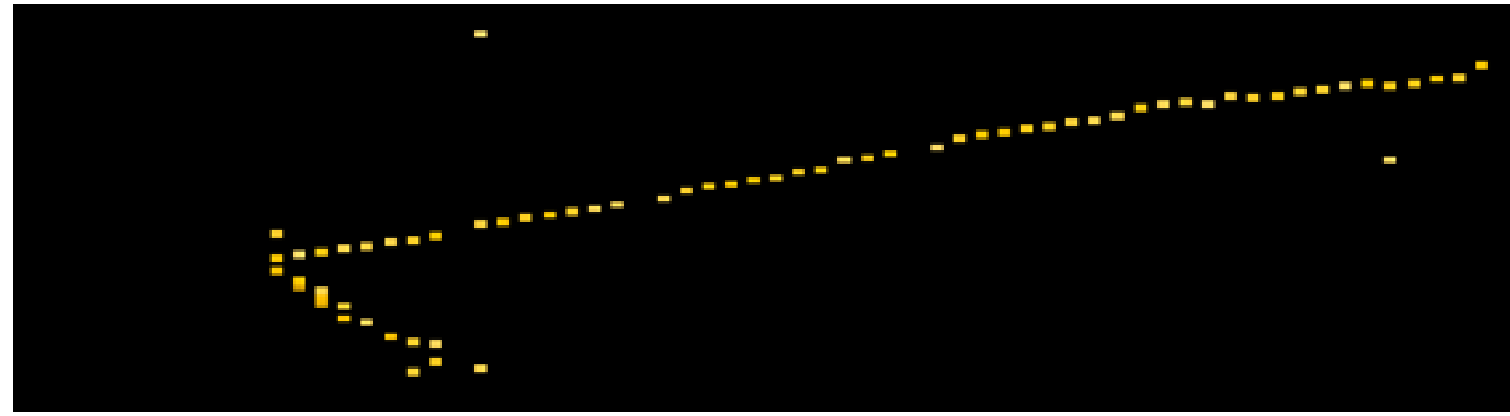
Weights are learned through a process to minimize the loss function.



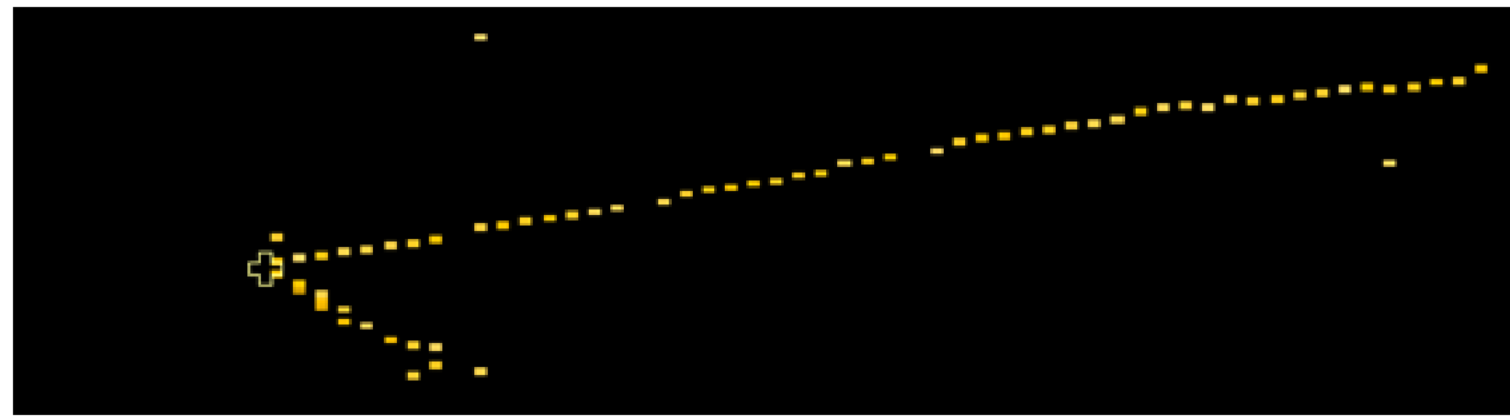


Traditional Reconstruction

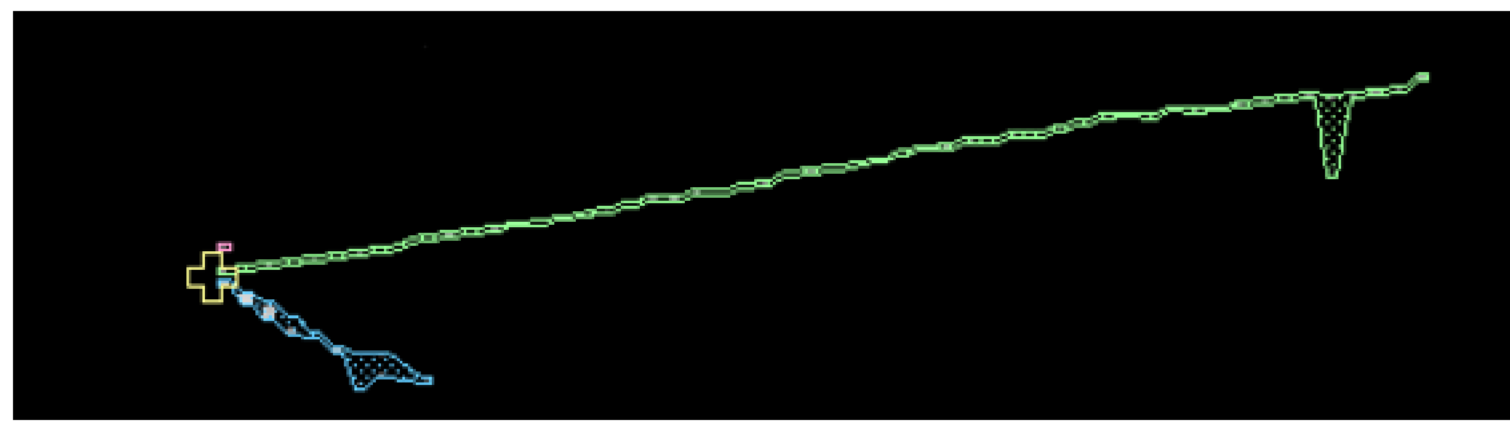
Group all hits with a common origin, the same neutrino interaction or cosmic.



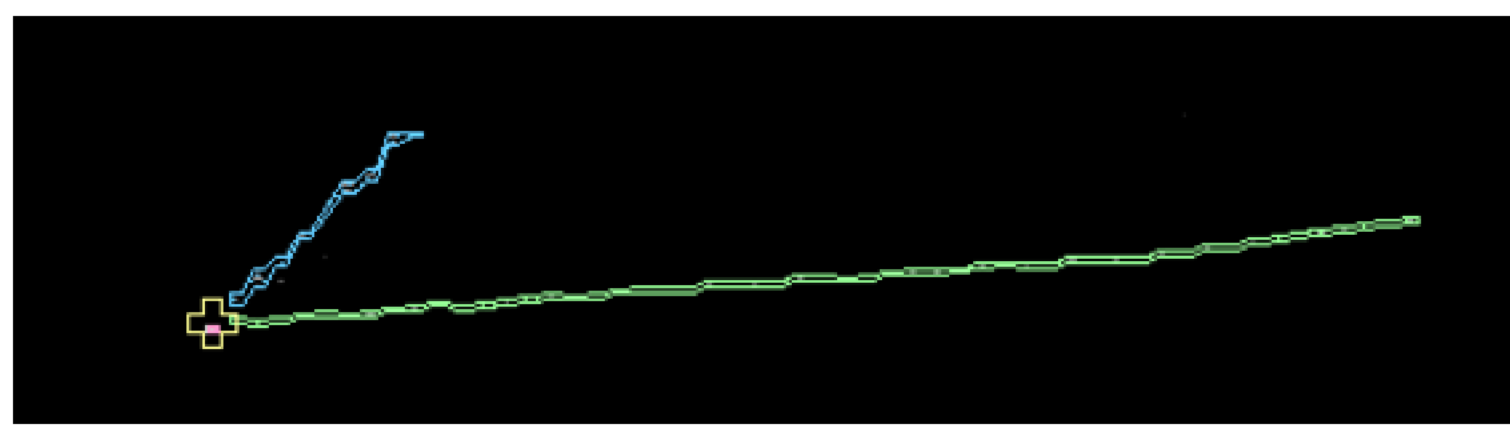
Reconstruct the global interaction vertex.



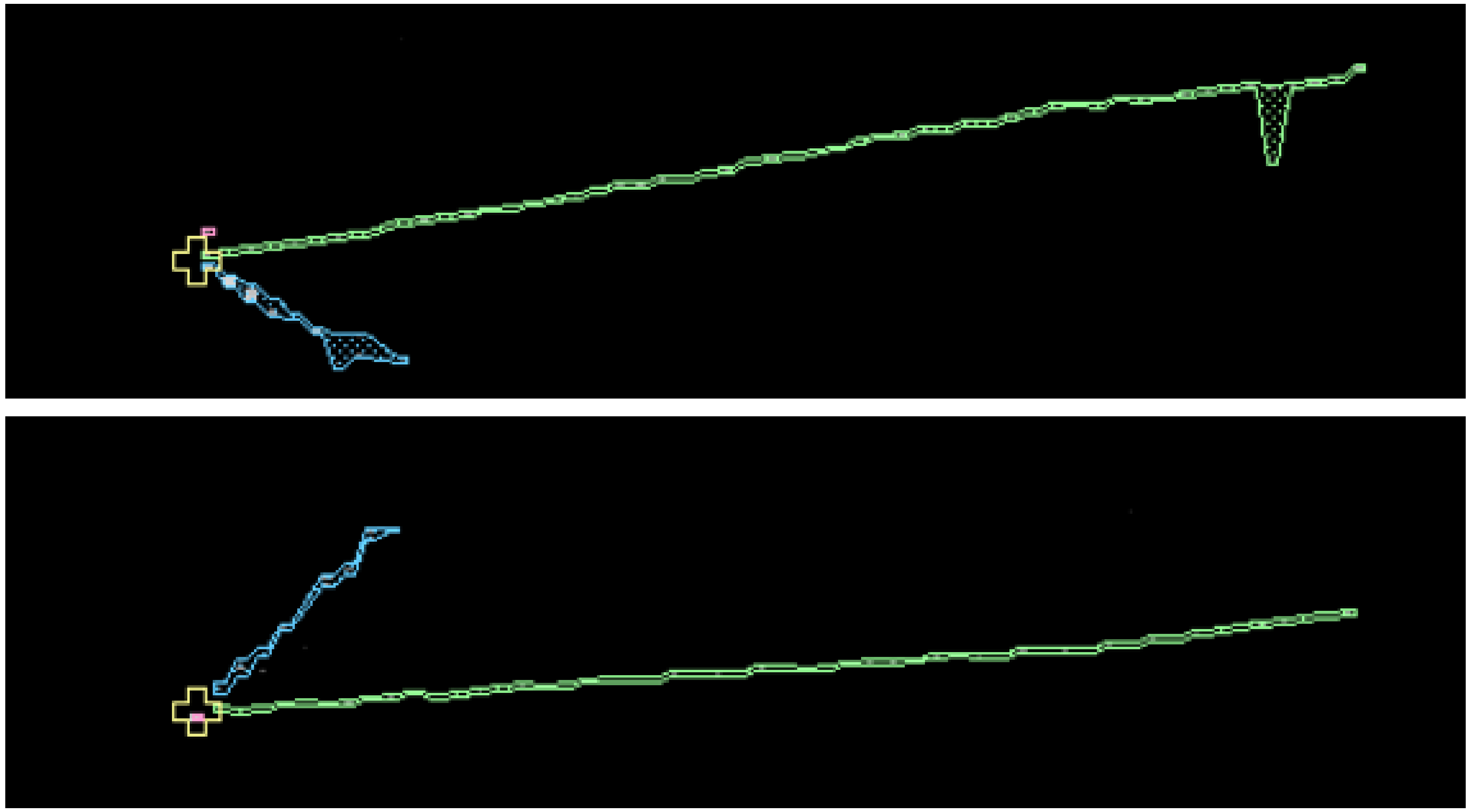
Cluster hits belonging to the same particle.

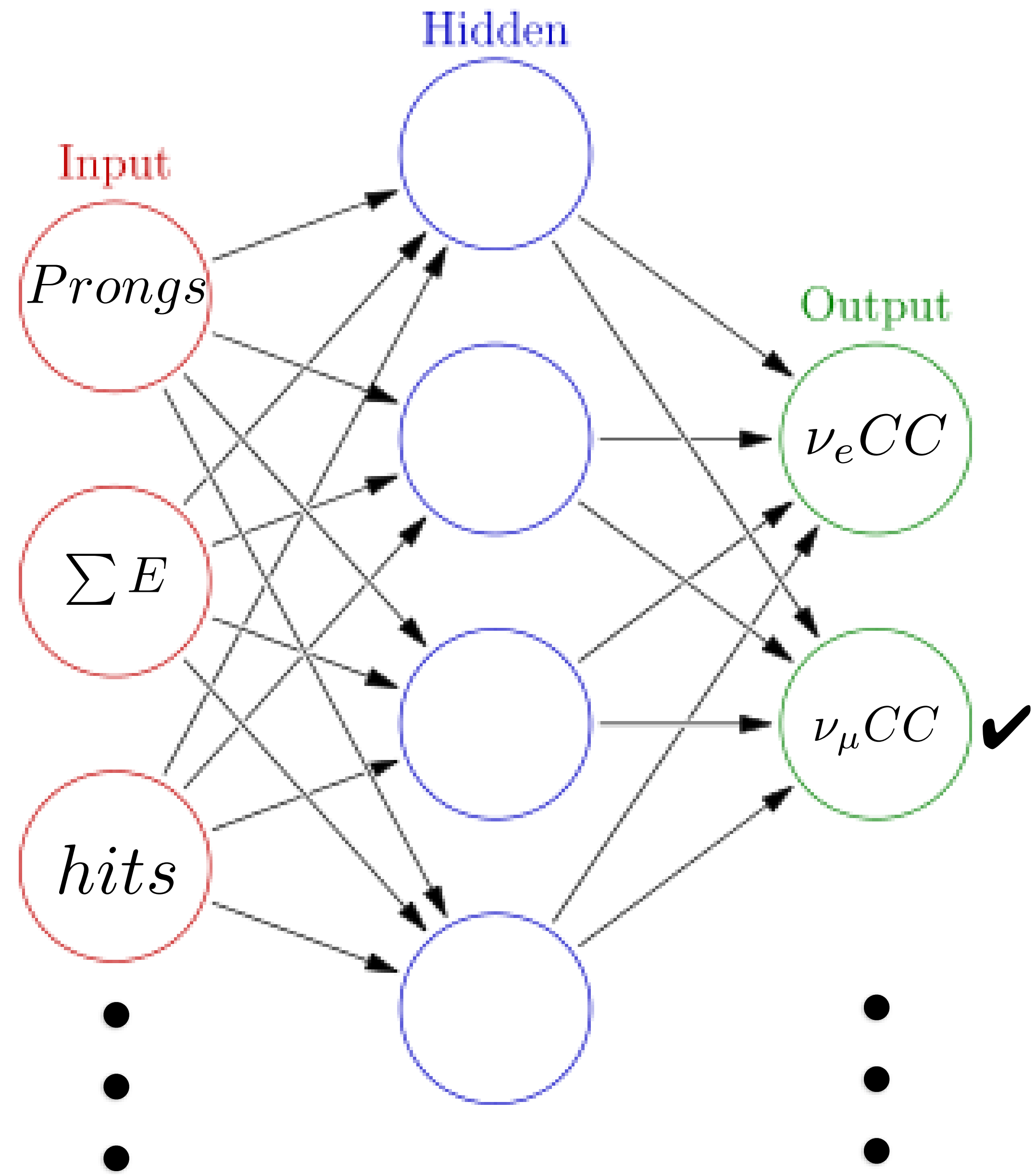


Match clusters across views to make 3D prongs



Event Identification

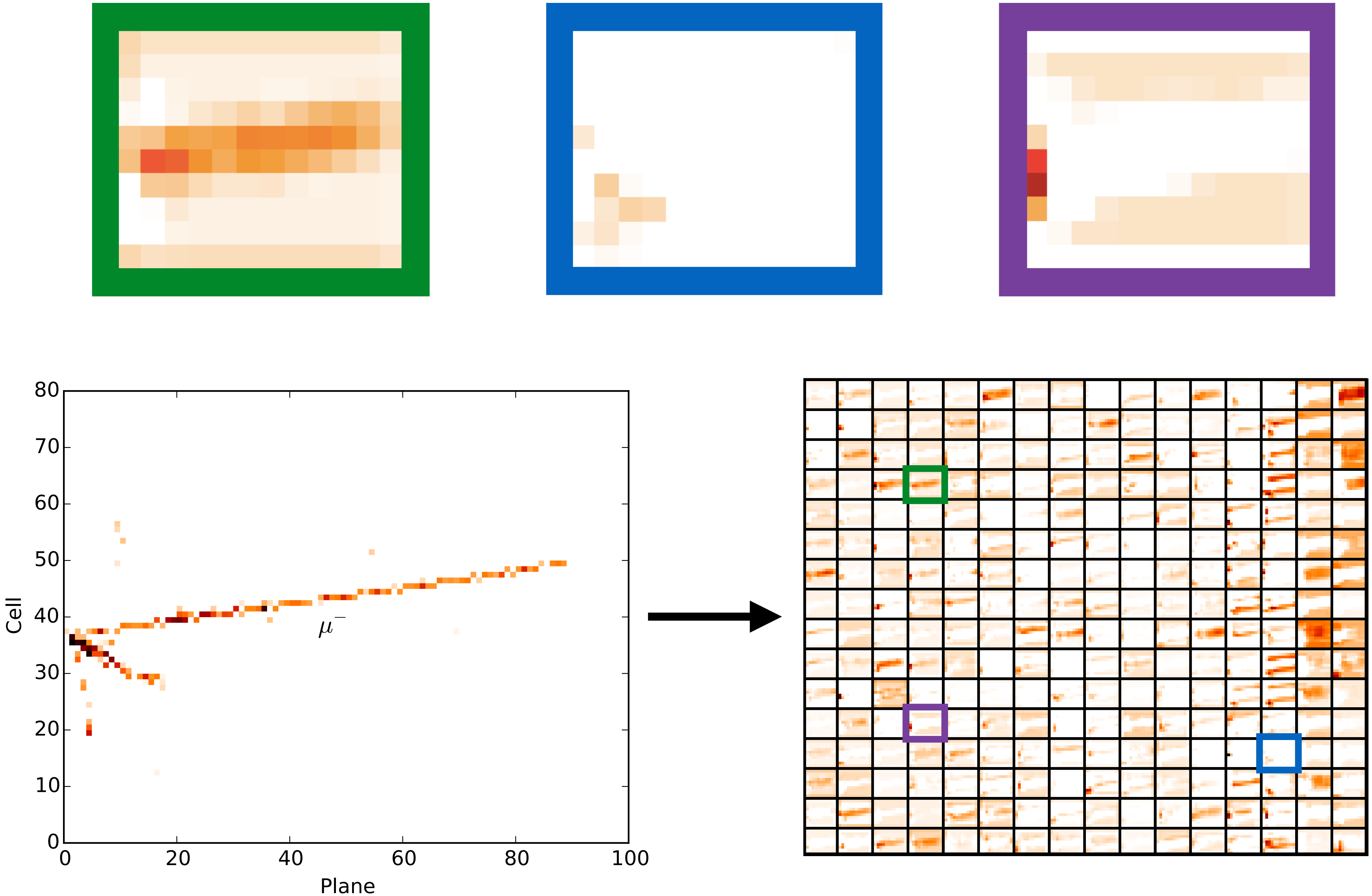




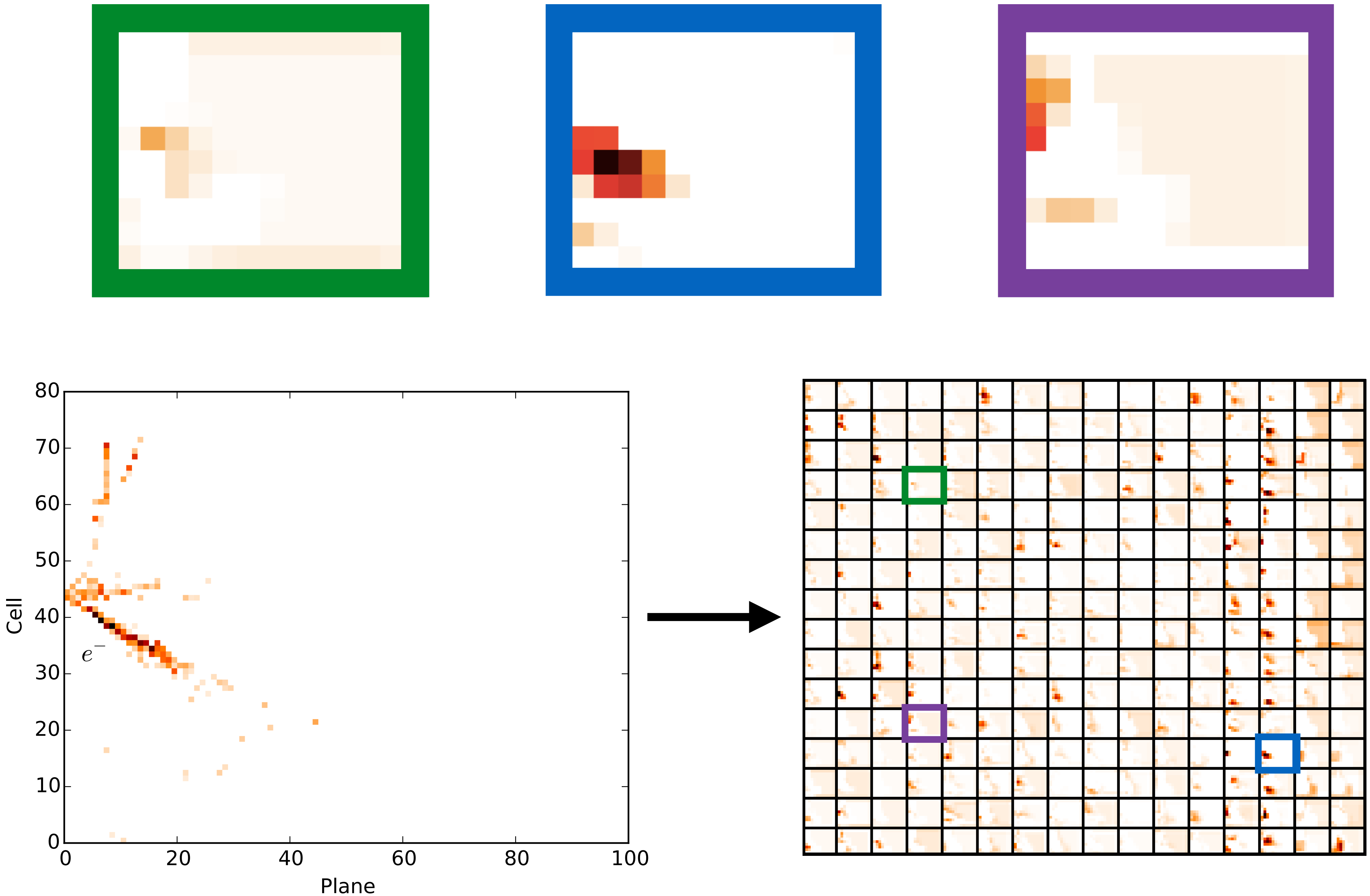
Extracted features from geometrical reconstruction used in a neural net.

Output is the interaction type.

NOvA Features

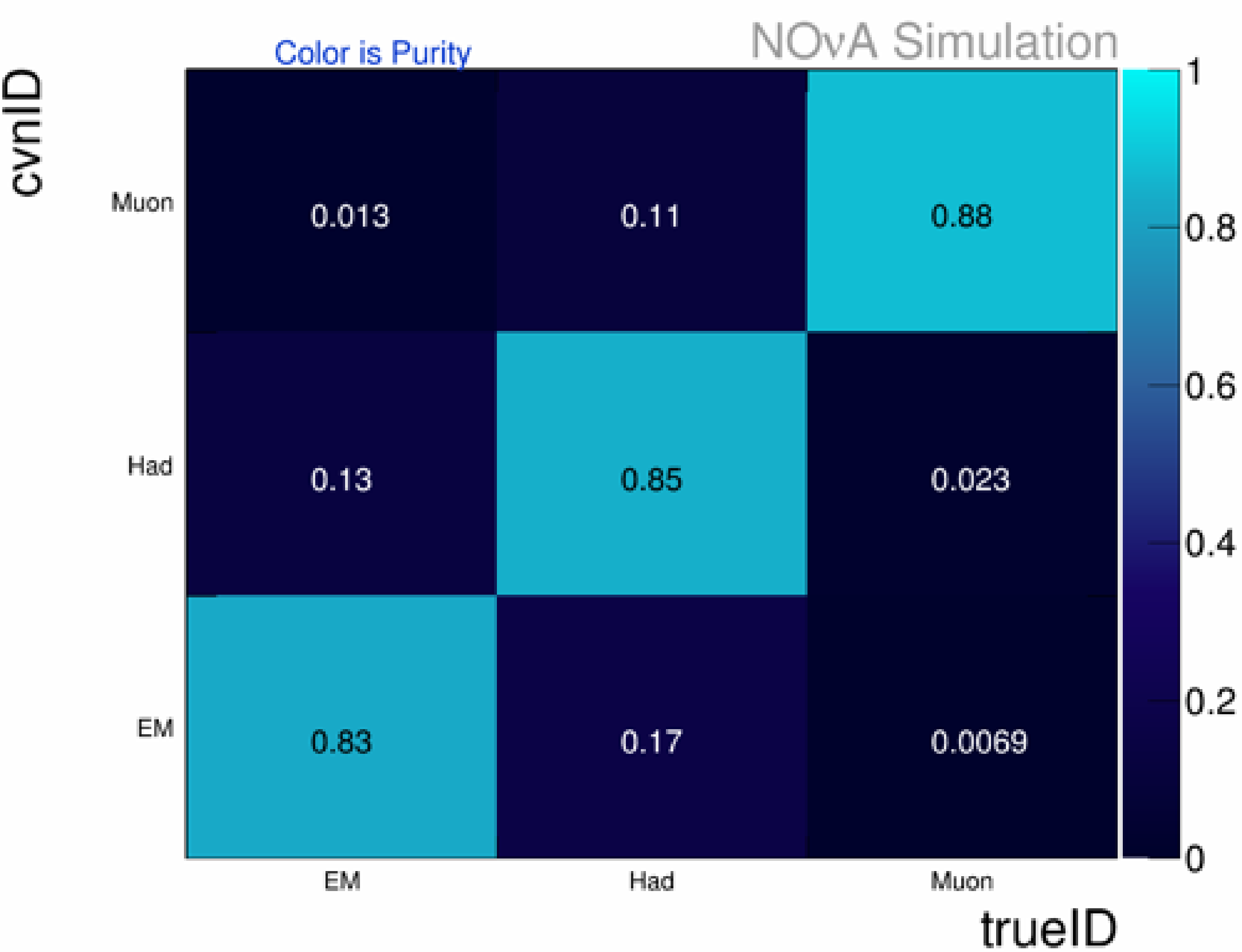


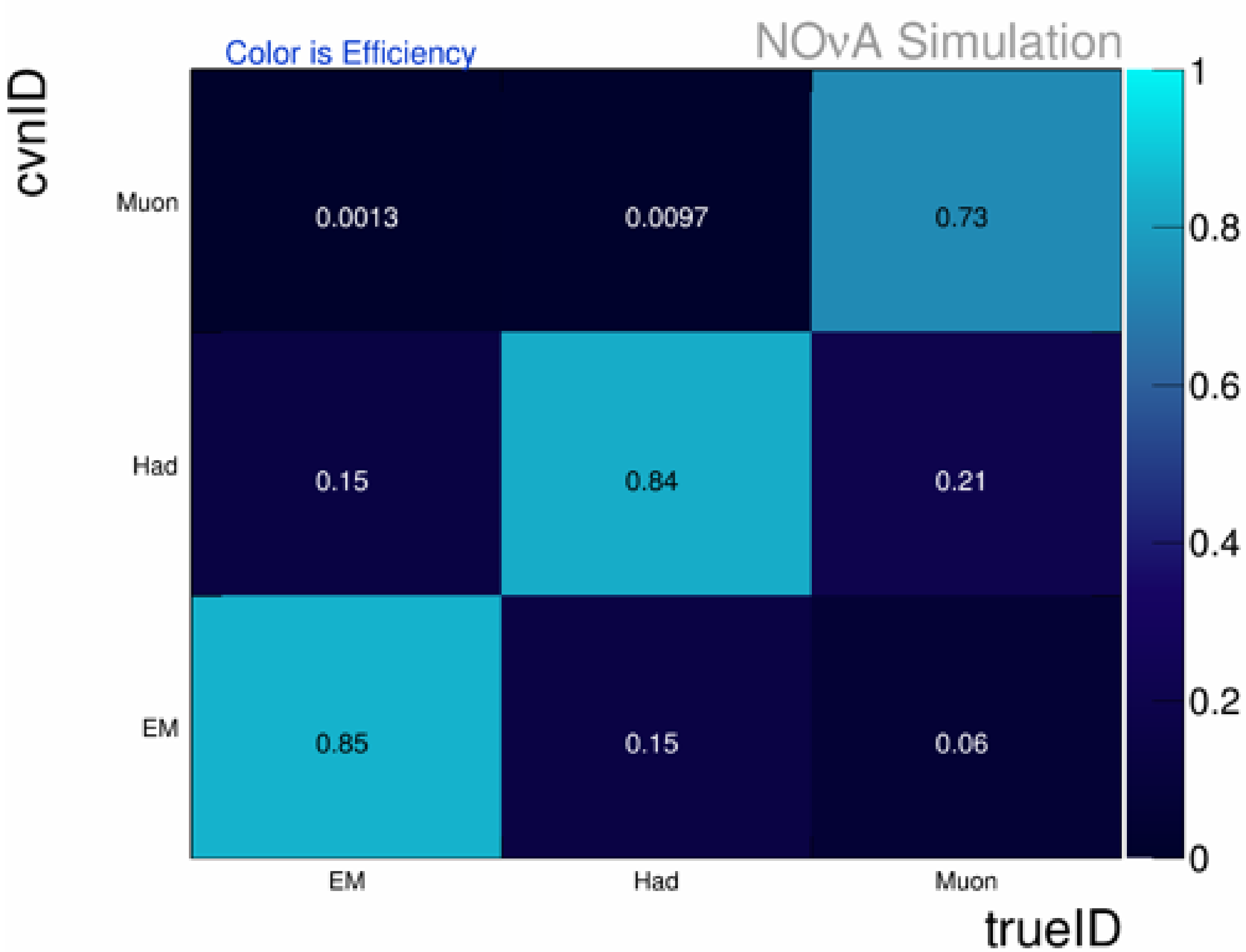
NOvA Features



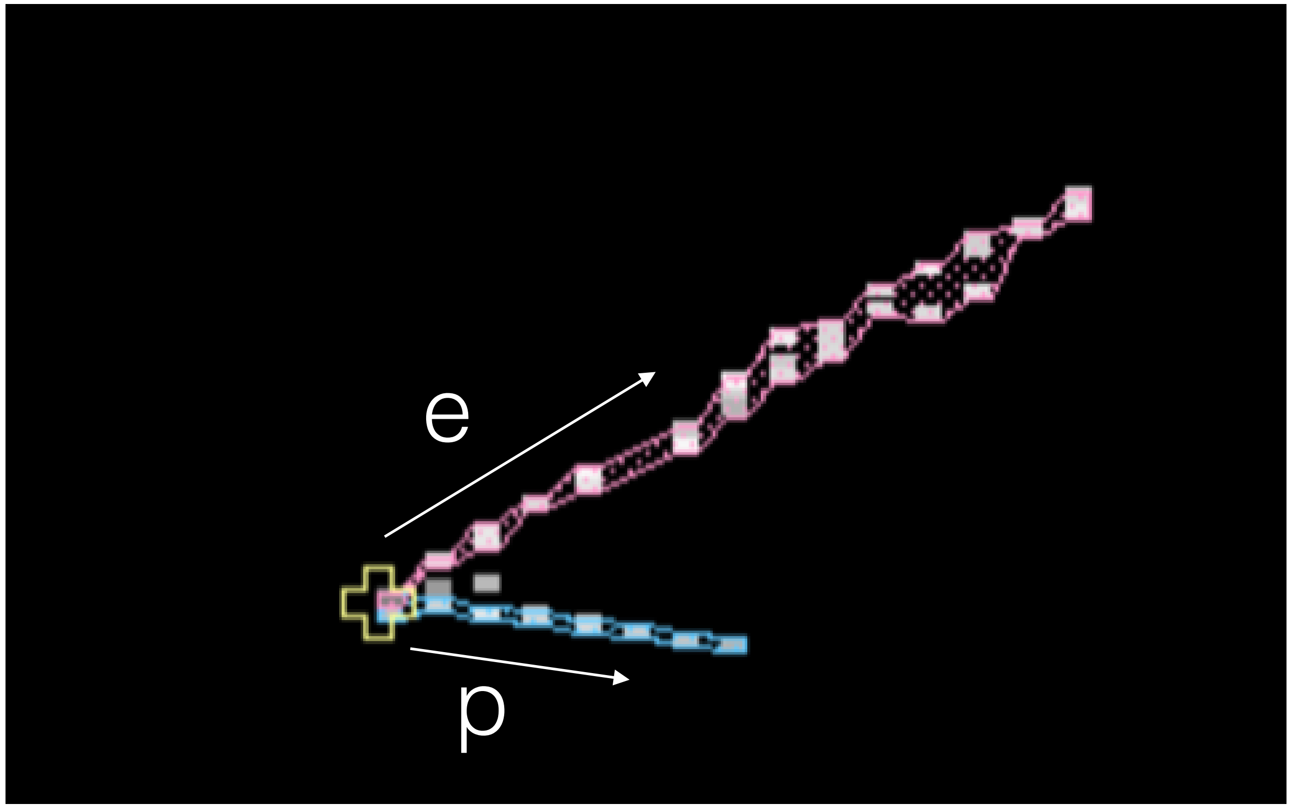
Prong CVN

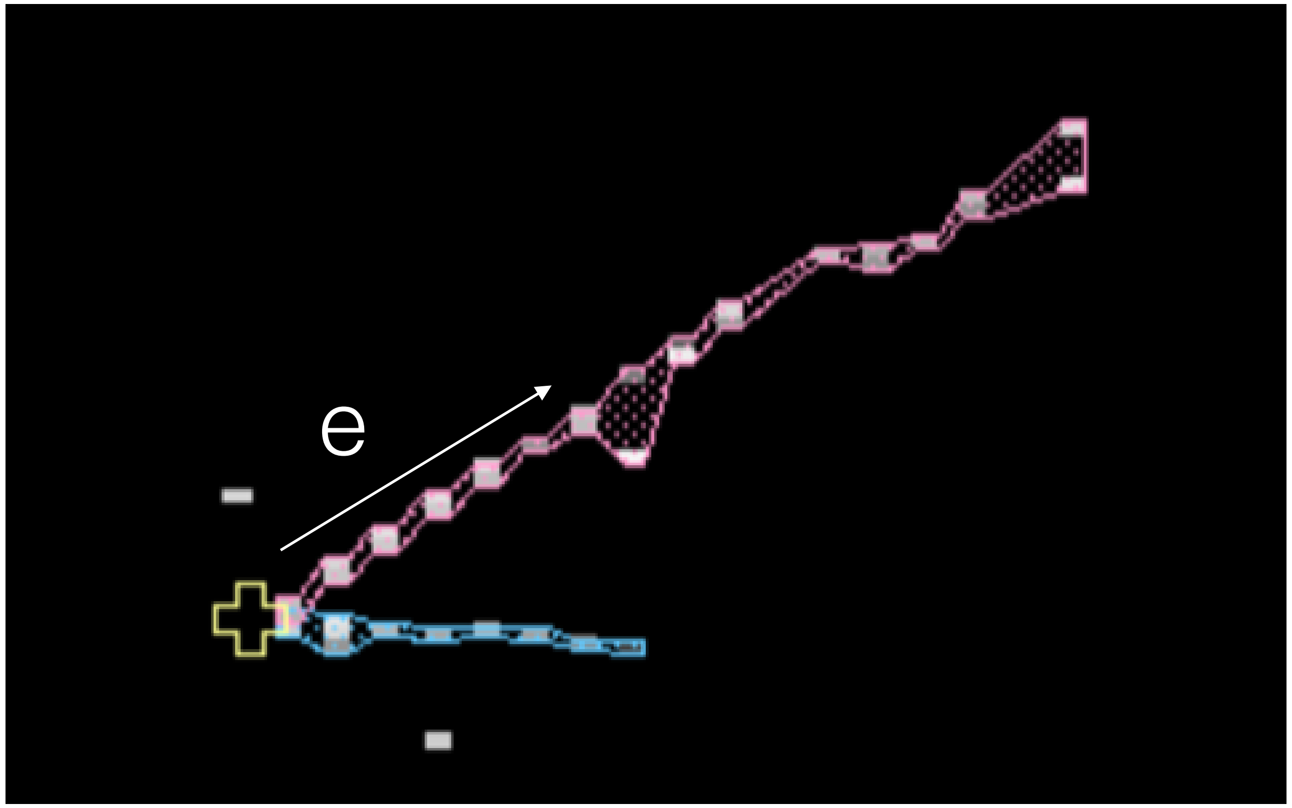
Broad categories looking at just electromagnetic and hadronic particles as well as muons.

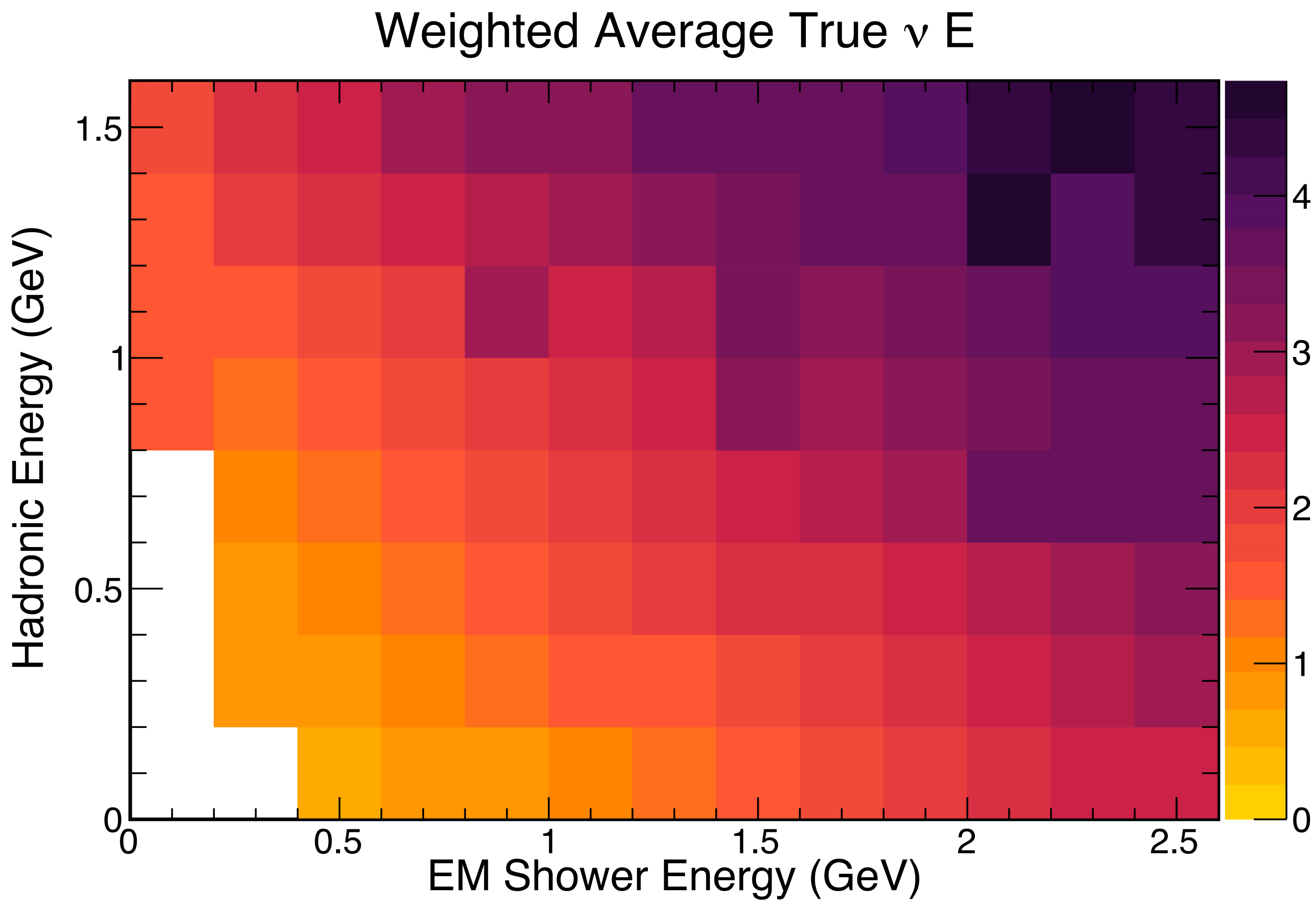




Nue Energy Estimator







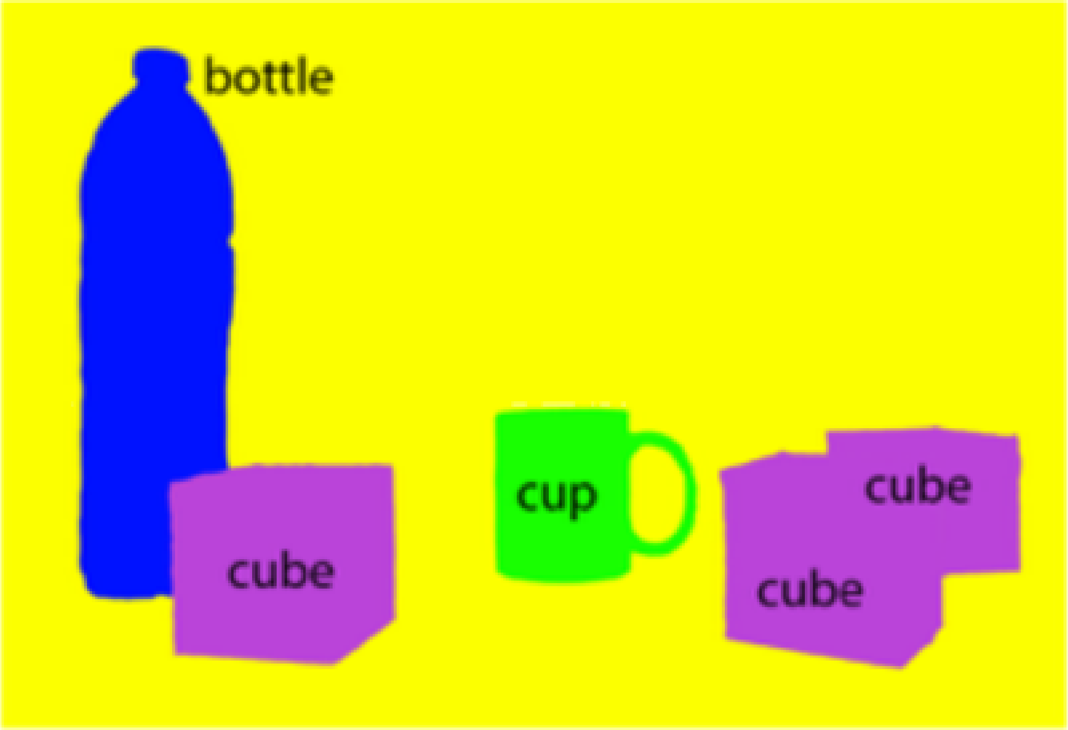
$$E_\nu = f(E_{EM}, E_{had})$$

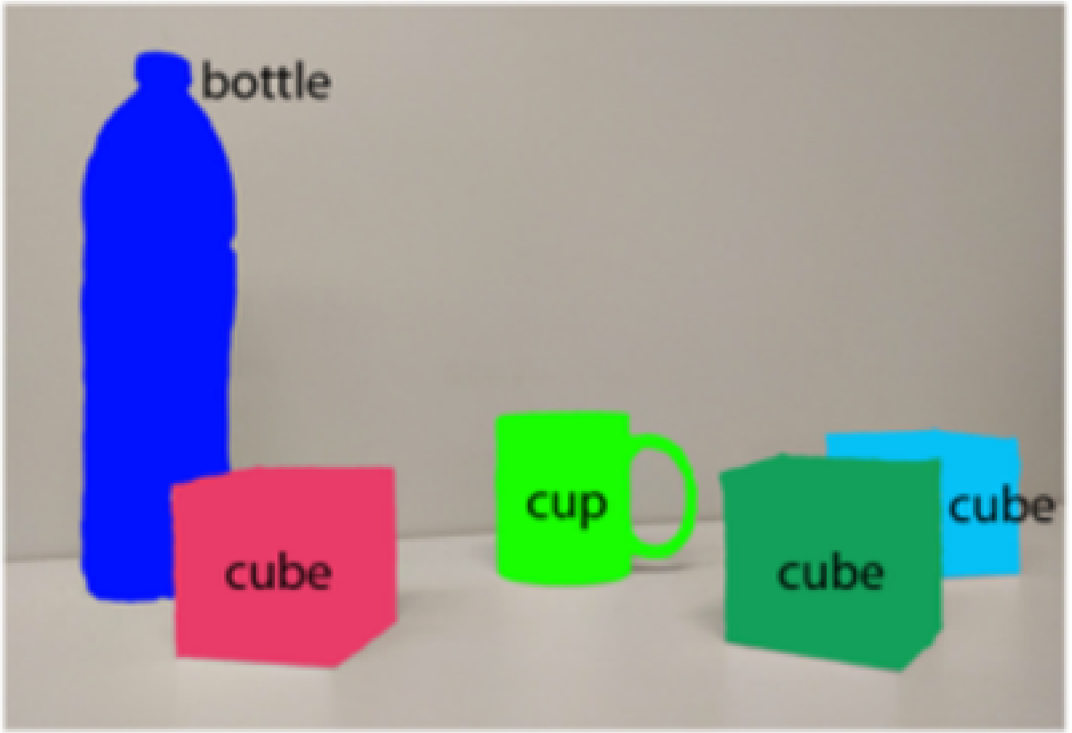
The neutrino energy is estimated as a fit to the total EM energy and the total hadronic energy in the event.

The energy resolution is ~10%.

~20% improvement from first analysis.

Full Event Reconstruction





Semantic Segmentation

Train a network for pixel by pixel classification

Instance Segmentation

Network clusters hits and assigns a label to each cluster