# Overview of Rebooted Reconstruction Group and the DL Gen2 Framework

MicroBooNE Collaboration Meeting

10/20/2023

Matthew Rosenberg

# Outline

- Introduction to new (re-launched) reco group
  - On behalf of reco conveners: Andy Chappell, Maria Brigida Brunetti, and myself
- Highlight results from reco parallel session
  - DL vertexing in Pandora (Ryan Cross)
  - $\Sigma^0$ production cross section studies (Isobel Mawby)
  - Hit-based 3D GNN reconstruction (Giuseppe Cerati)
- Overview of DL Gen2 reconstruction framework

# The Reco Group

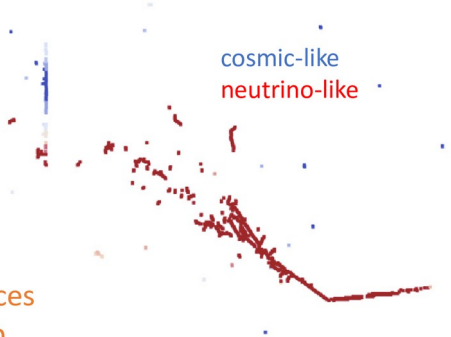
- Our role in MicroBooNE:
  - Developing new and applying existing reconstruction tools to current and emerging MicroBooNE analyses, working with analysis teams toward optimizing physics capabilities
  - Facilitating the sharing of tools and techniques in the broader community, including integration into the latest Fermilab computing environment
  - Implementing procedures and tools for cross-comparisons of reconstruction approaches
  - Ensuring reconstruction tools are integrated in MicroBooNE's workflow as well as defining best practices for large-scale deployment of algorithms using HTC and HPC computing resources, in consultation with the Data Management Conveners and HPC Coordinator
- Group Meetings:
  - Biweekly on Wednesdays at 9:00am CT
  - Please join us!
    - No need for polished presentations/analyses, informal discussions welcome
    - Let us know if there are any reco-related improvements needed for your analysis!
- Mailing list: microboone_reconstruction@fnal.gov

# Current Reconstruction Projects

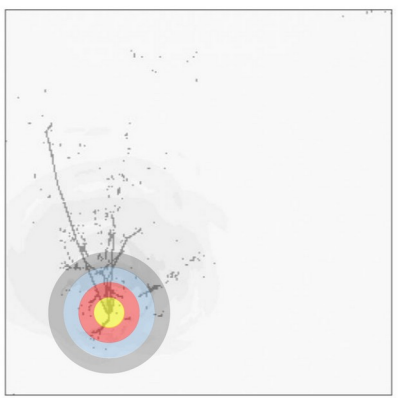
- Aim to support all existing reconstruction frameworks
  - Wire Cell: currently not collaborating with group on new developments
  - Pandora: work ongoing to incorporate new developments made since 2019 variant currently used in MicroBooNE
    - Deep neural networks for vertex finding
      - More general support for deep learning in Pandora via LibTorch
    - Vertex refinement algorithm based on nearby cluster directions
    - Shower refinement (adds missing MIP-like stub to primary electrons)
    - Improved Michel and Delta-ray reconstruction in cosmic pass
    - Calorimetric matching when only two good views are available
    - BDTs for track/shower characterization
    - PFP refinement algorithms to improve PFP completeness
    - Algorithms to extract tracks clustered into showers
    - Clustering algorithms incorporating hit width information
  - DL Gen2: new framework in place, much more on this later
- And new tools as well!
  - E.g. Giuseppe and collaborators' work on a new GNN reconstruction

# Pandora DL Vertexing (from Ryan Cross)

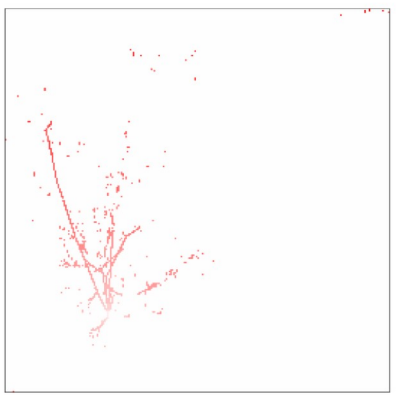
- Andy Chappell developed DL vertexing approach in Pandora for Dune
- Ryan Cross working on porting this to MicroBooNE
  - Network also retrained to tag cosmic vs. neutrino hits in neutrino slice!
- See Ryan's presentation from Wednesday (DocDB 40891) for much more detail!




Hits are assigned a class according to distance from true vertex



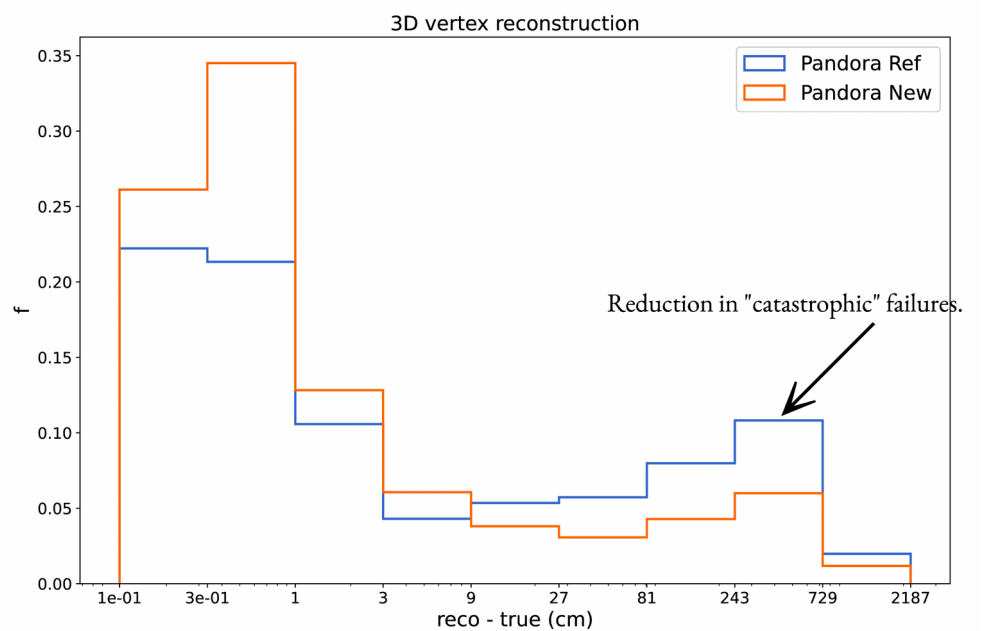
Network trained to learn those distances from input images



Network infers hit distances and resultant heat map isolates candidate vertex

# Pandora DL Vertexing (from Ryan Cross)

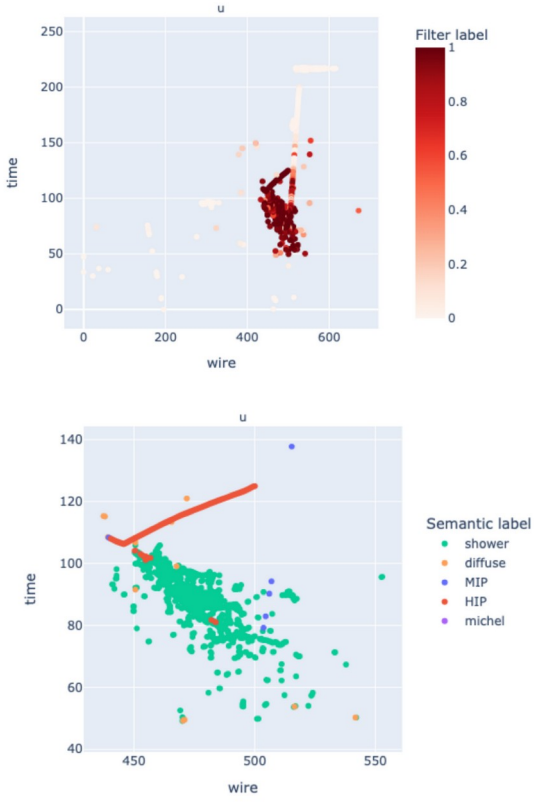
- Network does better at avoiding large errors
- See Ryan's presentation from Wednesday (DocDB 40891) for much more detail!




| Distance | % Events Default | % Events DL |
|---|---|---|
| 1cm | 53.3 | 62.8 |
| 2cm | 61.5 | 72.1 |
| 3cm | 63.9 | 75.6 |
| 5cm | 66.0 | 78.8 |
| 10cm | 68.6 | 82.2 |

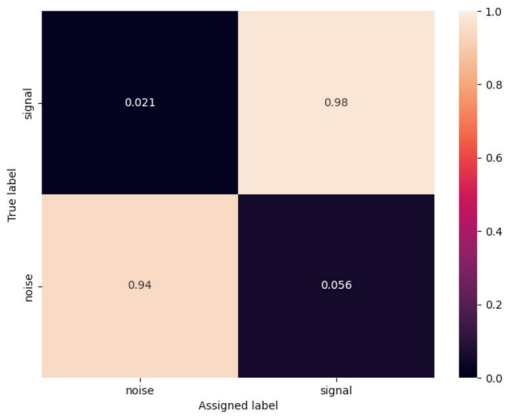
# Graph Neural Networks for 3D Reconstruction in LarTPCs (from Giuseppe Cerati)

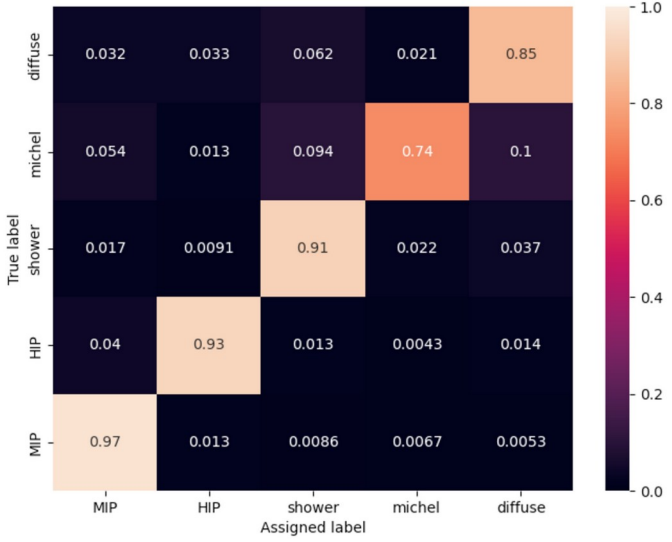
- In collaboration with Exa. TrkX collaboration, Giuseppe has developed a GNN for LArTPC event reconstruction using MicroBooNE open data
- Graph connects hits within planes and to 3D space points
  - Currently using recob::Hits from Pandora neutrino slice as input
- Network trained to:
  - Classify hits as either neutrino induced or noise / cosmic induced
  - Classify neutrino-induced hits further as MIP, HIP, EM shower, Michel, or diffuse
  - Locate 3D neutrino vertex
- Lightweight, very fast network: 0.12 seconds / event on CPU
- See Giuseppe's presentation from Wednesday (DocDB 40980) for much more detail!

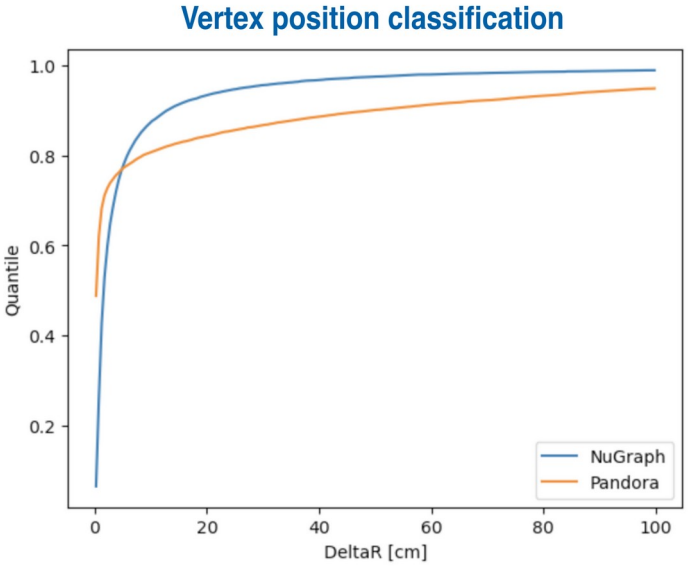


# Graph Neural Networks for 3D Reconstruction in LarTPCs (from Giuseppe Cerati)

- Hit classification very accurate!
- Vertex reconstruction reduces chance of large errors
- Paper currently in preparation
- See Giuseppe's presentation from Wednesday (DocDB 40980) for much more detail!



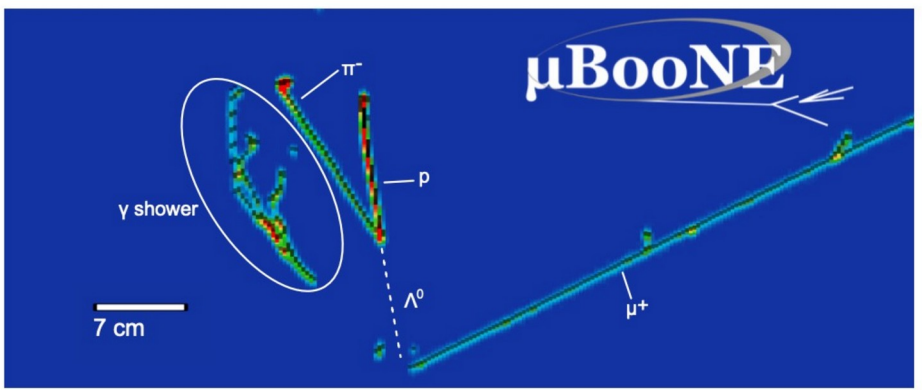



# $\Sigma^0$ Production Cross Section Analysis (from Isobel Mawby)

- Very rare process (~40 events expected)
- Analysis using Pandora
- Very important to avoid or overcome efficiency losses from issues in reconstruction
- Identify aspects of reconstruction that affect analysis performance, identify ways to address shortcomings on both the reconstruction side and analysis side
  - For example, improve neutrino slicing or analyze other slices for signal
- See Isobel's presentation from Wednesday (DocDB 40940) for much more detail!

$$\begin{aligned} \bar{\nu}_\mu + p \rightarrow \quad & \Sigma^0 + \mu^+ & \\ \Sigma^0 \rightarrow \quad & \Lambda + \gamma & (\sim 100\%) \\ \Lambda \rightarrow \quad & p + \pi^- & (63.9\%) \end{aligned}$$



# DL Gen2: A New Reconstruction Framework from the Tufts Deep Learning Group

- First: overview of reco framework
- Then: inclusive CCnue selection results, comparison to Wire Cell
  - See my parallel talk from yesterday (DocDB 41015) or backup slides for more detail

# DL Gen2 Overview

Updates to reconstruction are required to move beyond 1e1p, 1μ1p topologies and analyze additional channels

**Common Input Preparation**
- Optical filter, good runs, noise filtering, signal processing, PMT trigger

**DL 2D Image Generation**
- larcv images produced
- Pixels classified with SparseSSNET
- Cosmic-ray tagging, removal with wire-cell charge-light matching

Gen1

**Vertex Finding**
- Cluster in 2D, “vee” shaped 1e1p/1μ1p search

**Track, Shower Reco**
- Tracks: step in 3D, project to 2D
- Showers: cluster in 2D, find 3D direction

**Selection**
- Pre-cuts, BDT cuts, MPID network cuts

Gen2

**3D Point Reconstruction with LArMatch network**
- find 3D points from 2D pixels, assign true point score
- find keypoints and assign ν, track start/end, etc. scores

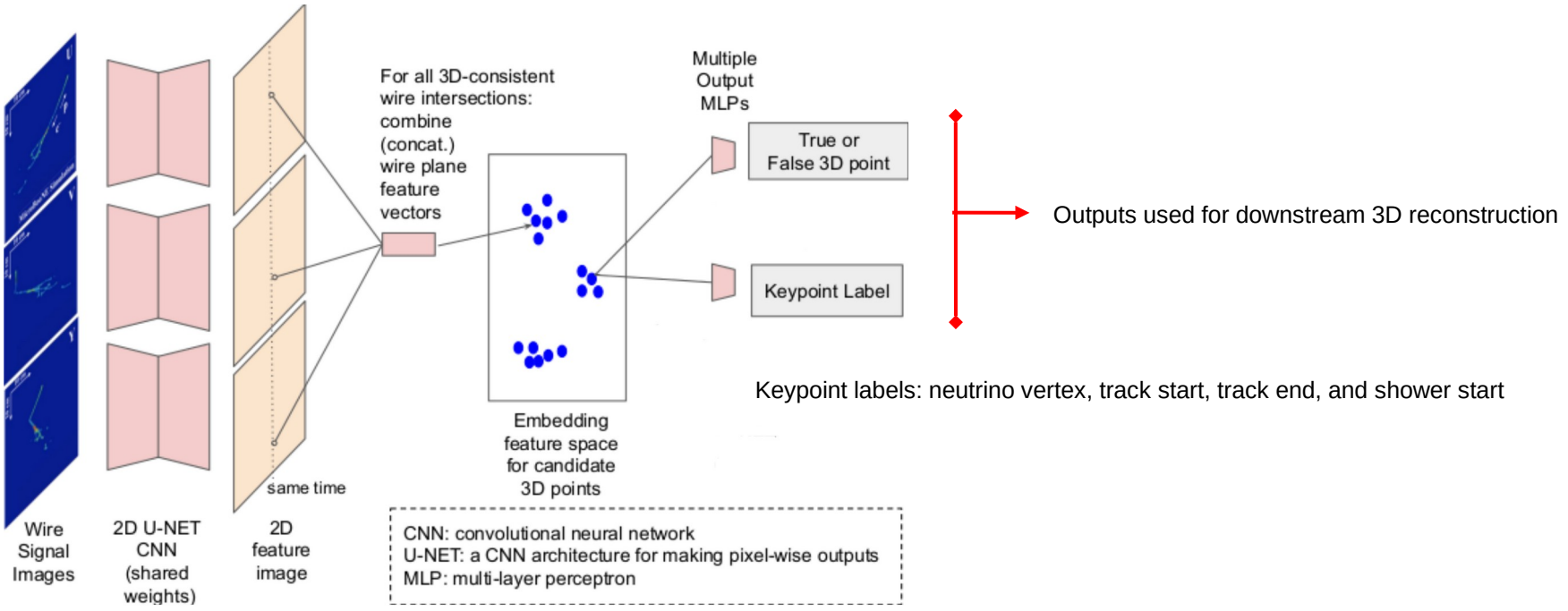
**Track, Shower Reco**
- Cluster in 3D, reconstruct from 3D clusters

**LArPID Network**
- Classify each prong as electron, photon, muon, pion, or proton
- Classify prongs as primary or secondary (with charged or neutral parent)
- Predict completeness (fraction of true particle that was reconstructed)
- Predict purity (fraction of reconstructed prong that is from true particle)

**Selection**
- Use particle ID for selection
- Good results with cuts on prong CNN particle scores

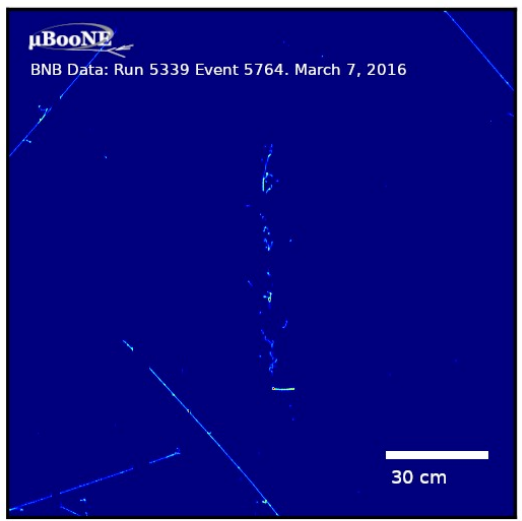
# The LArMatch Network

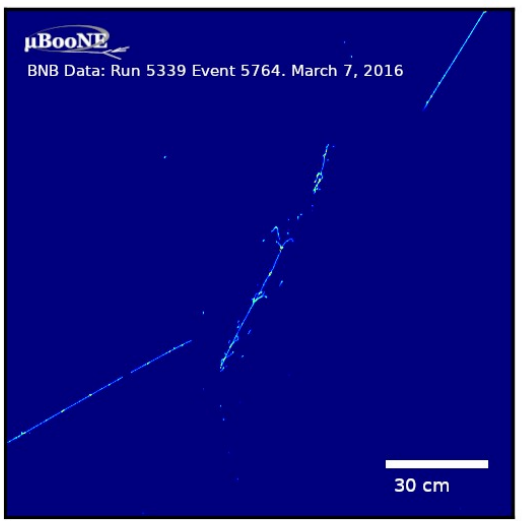
- A U-NET CNN developed by Taritree to find 3D energy-deposition points from 2D images

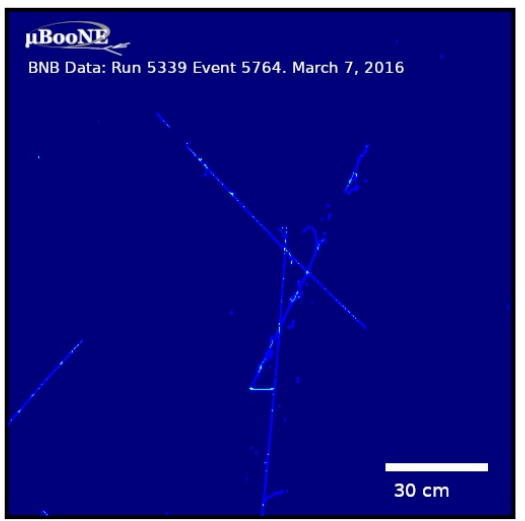


# Reconstruction Example: LArMatch Input

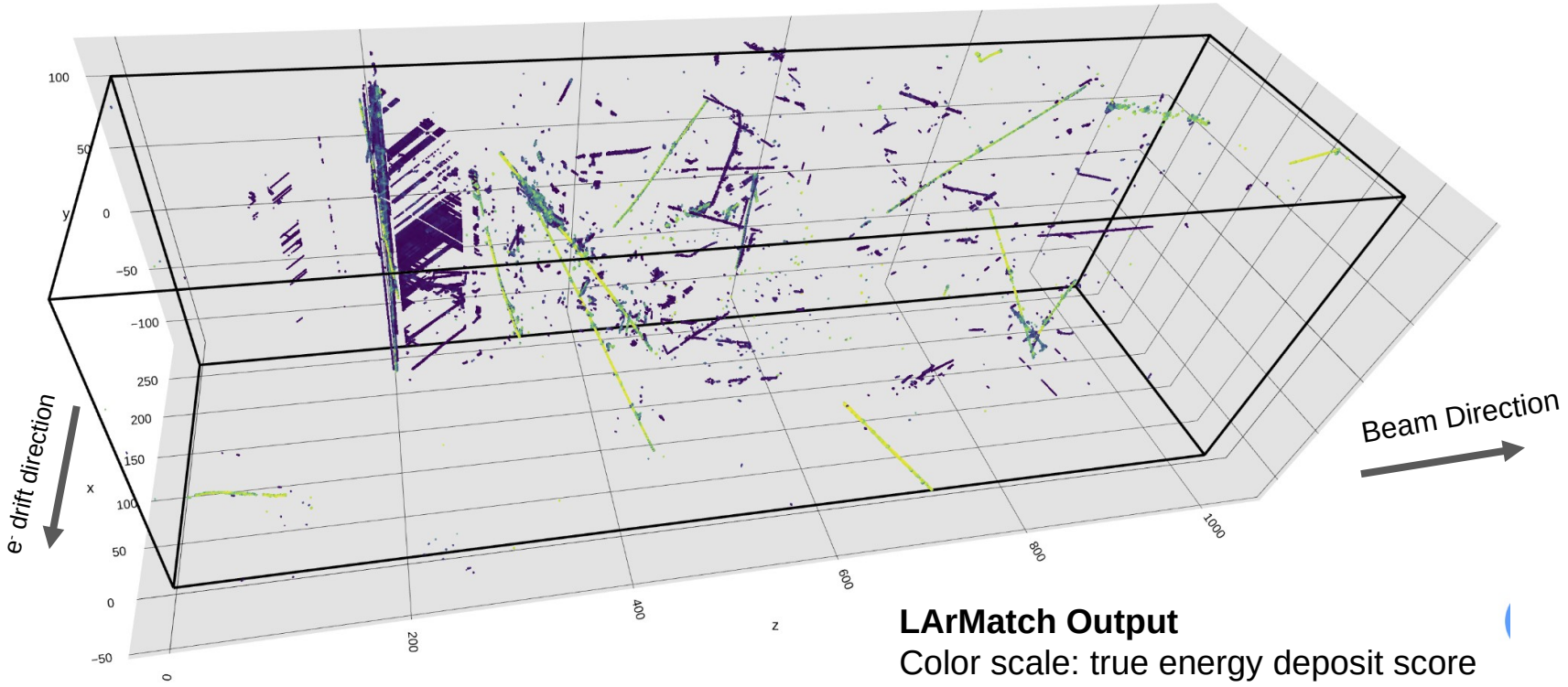
Zoomed in view of probable CC $\nu_e$ interaction from open data:



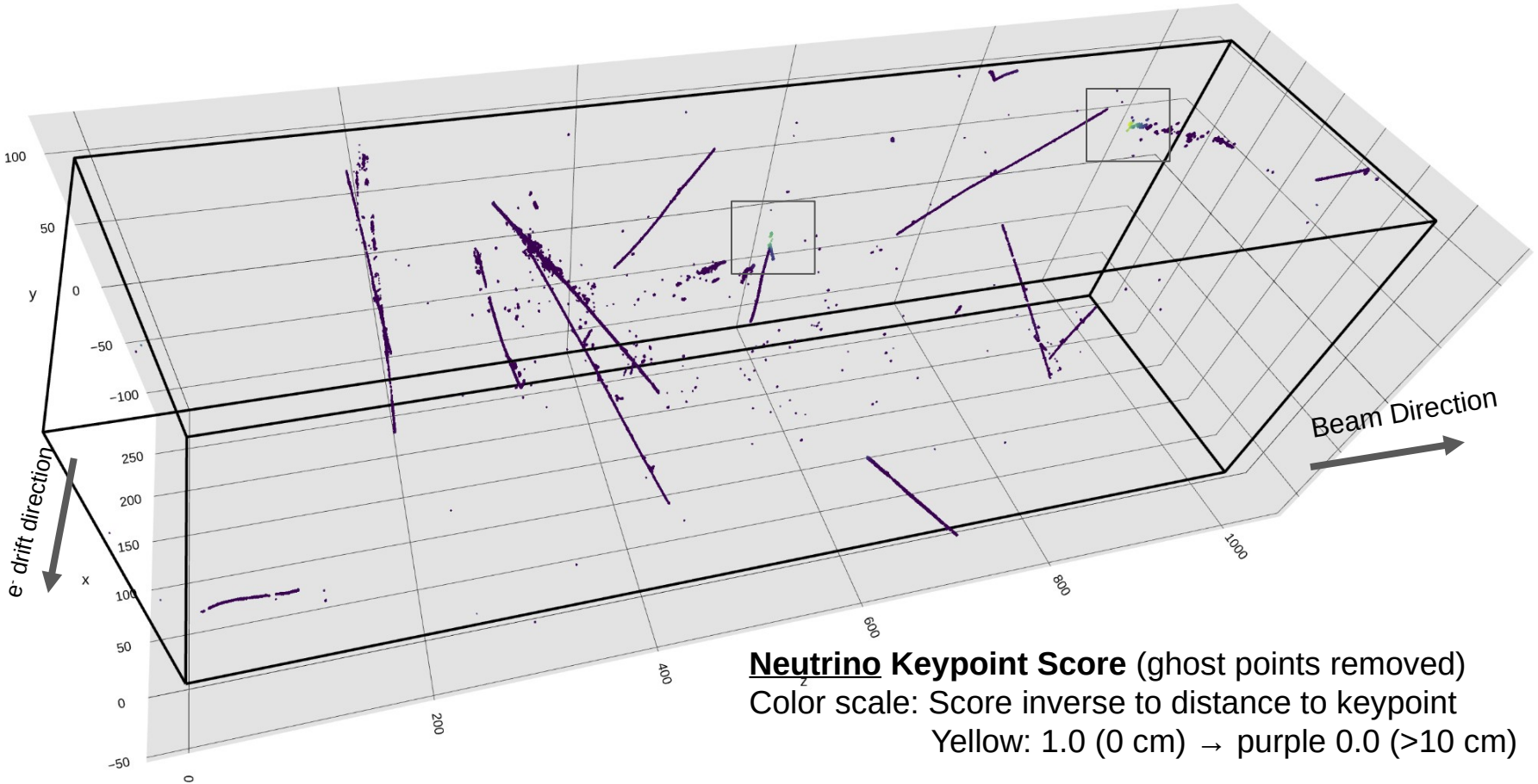



# Reconstruction Example: LArMatch True Energy Deposit Output




**LArMatch Output**
Color scale: true energy deposit score
Purple:0.0 → Yellow: 1.0

# Reconstruction Example: LArMatch Neutrino Keypoint Score Output

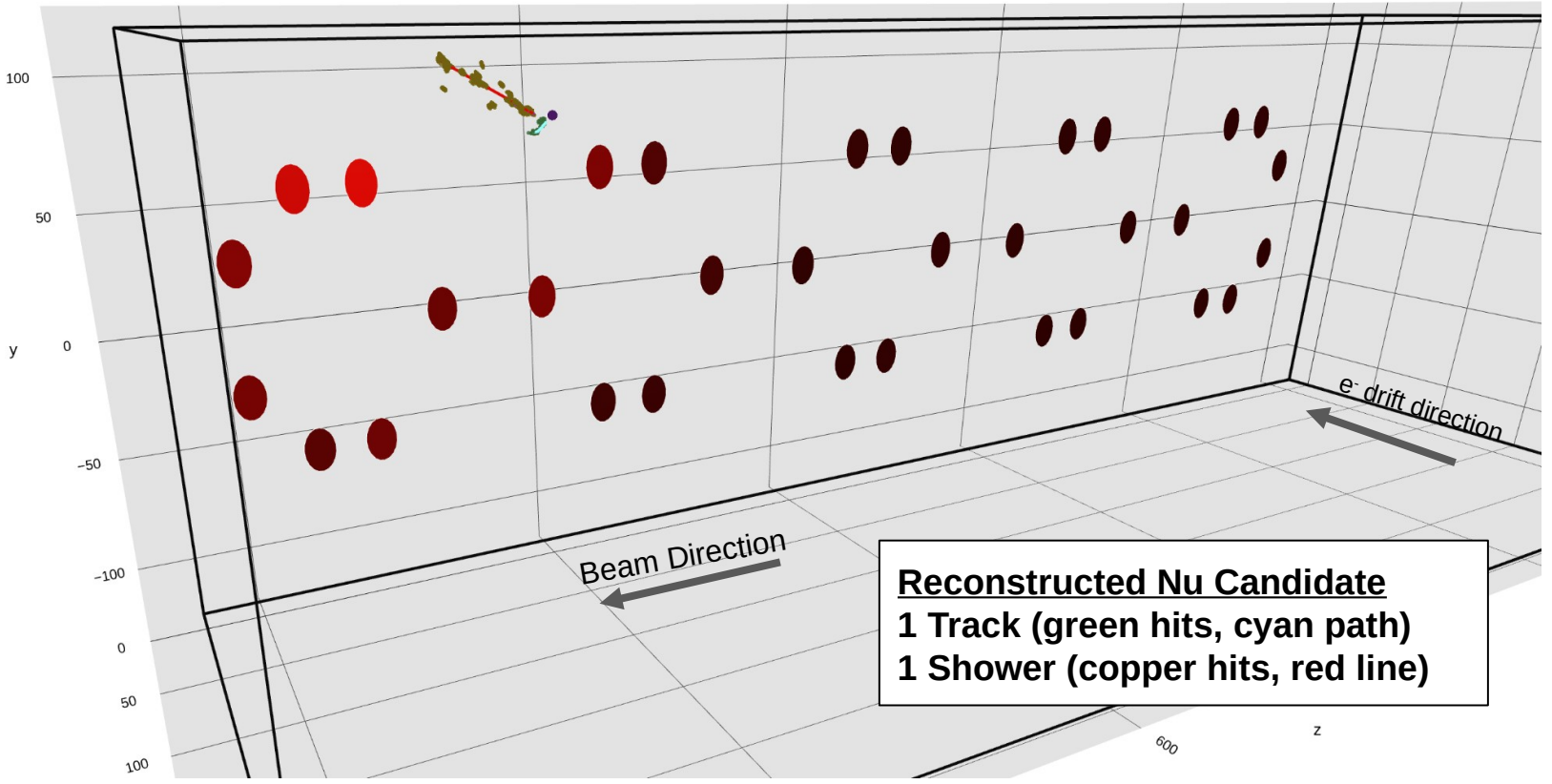



**<u>Neutrino</u> Keypoint Score** (ghost points removed)
Color scale: Score inverse to distance to keypoint
Yellow: 1.0 (0 cm) → purple 0.0 (>10 cm)

See backup slides 29 – 31 for track start, track end, and shower start scores

# Reconstruction Example: Vertexing & Track/Shower Clustering

Shower trunk obscured in both U and V plane → leads to missing shower trunk in 3d hits, but seen by 2D CNN in Y plane

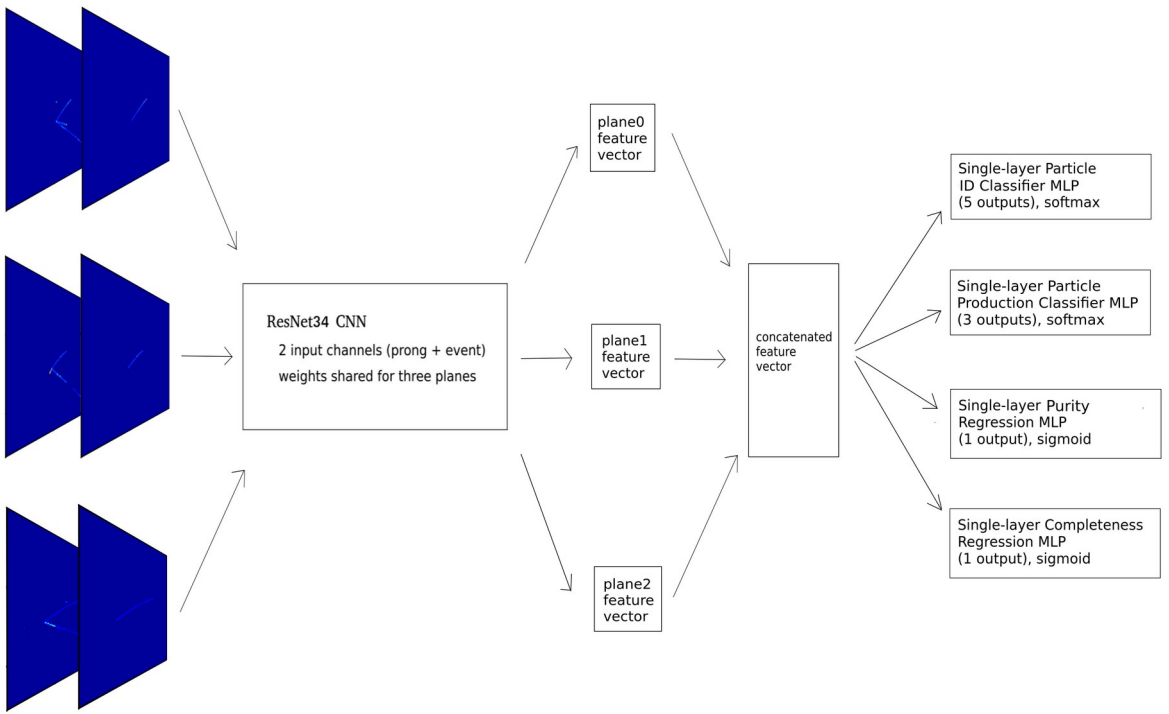


# The LArPID Network

- A CNN to classify reconstructed 3D tracks and showers
  - Inputs: 2D larcv images (select pixels associated with 3D points in reco prong)
  - Trained on tracks and showers attached to LArMatch-identified neutrino vertices from neutrino MC (run3 overlay samples)
- Does particle identification
  - Outputs five score indicating how likely it is that the input is a muon, pion, proton, photon, or electron
- Outputs reconstruction quality metrics
  - Completeness prediction: fraction of true particle reconstructed in input track/shower
  - Purity prediction: fraction of reconstructed track/shower that was created from true particle
- New: particle production process classifier
  - Outputs three scores indicating how likely is is that the input is a primary particle from a neutrino interaction, a secondary with a charged parent, or a secondary with a neutral parent

# LArPID: Network Architecture

- Provide network both prong images and full event (context) images for each wire plane
- Use tried and tested ResNet architecture (arXiv:1512.03385), limit CNN depth to 34 layers due to computational constraints
- See slides 32 – 36 for additional details



# LArPID: Particle ID Classification Results

- Results shown with true prong purity > 60% cut for accurate labels
- Overall validation accuracy: 91.8%

Validation Sample Accuracy Statistics

| | True electrons | True photons | True muons | True pions | True protons |
|---|---|---|---|---|---|
| Fraction classified as electrons | **84.5%** | 5.2% | 0.1% | 0.5% | 0% |
| Fraction classified as photons | 12.7% | **94.3%** | 0.2% | 0.2% | 0.1% |
| Fraction classified as muons | 0.4% | 0.1% | **93.9%** | 11.5% | 0.3% |
| Fraction classified as pions | 2.3% | 0.3% | 5.6% | **86.5%** | 1.6% |
| Fraction classified as protons | 0.1% | 0.1% | 0.2% | 1.4% | **97.9%** |

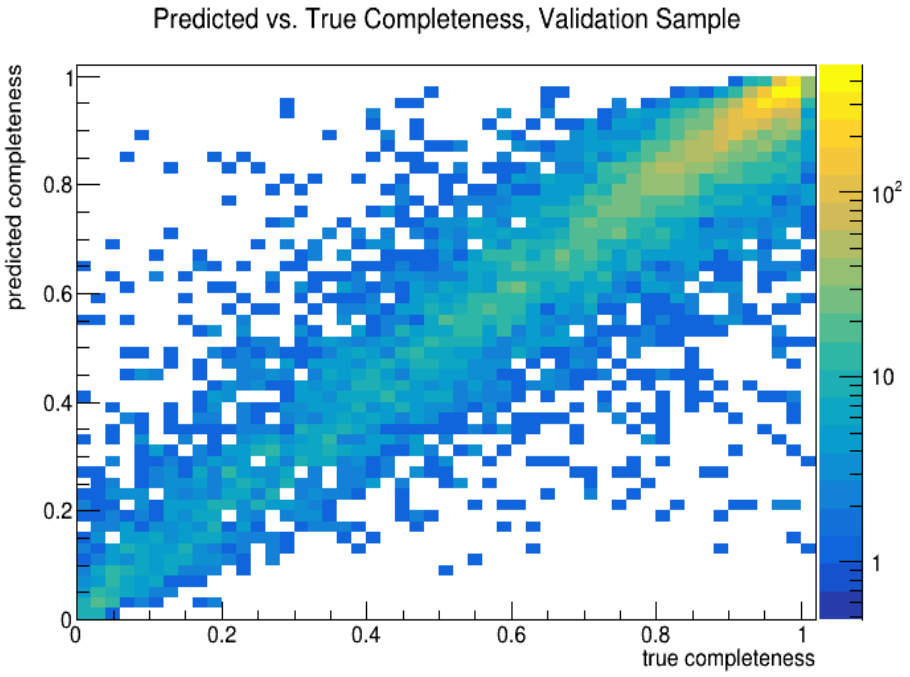
# LArPID: Particle Production Process Classification Results

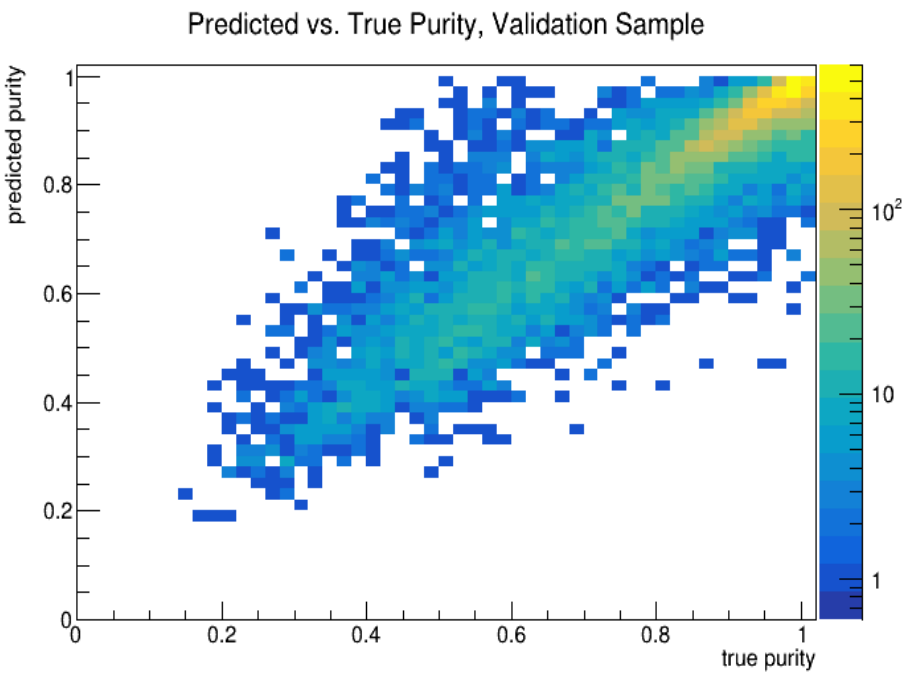
- Results shown with true prong purity > 60% cut for accurate labels
- Overall validation accuracy: 89.0%

Validation Sample Accuracy Statistics

| | True primary | True neutral parent | True charged parent |
|---|---|---|---|
| Fraction classified as primary | **87.8%** | 3.4% | 6.5% |
| Fraction classified as neutral parent | 2.9% | **93.6%** | 6.9% |
| Fraction classified as charged parent | 9.3% | 3.0% | **86.7%** |

# LArPID: Completeness and Purity Results



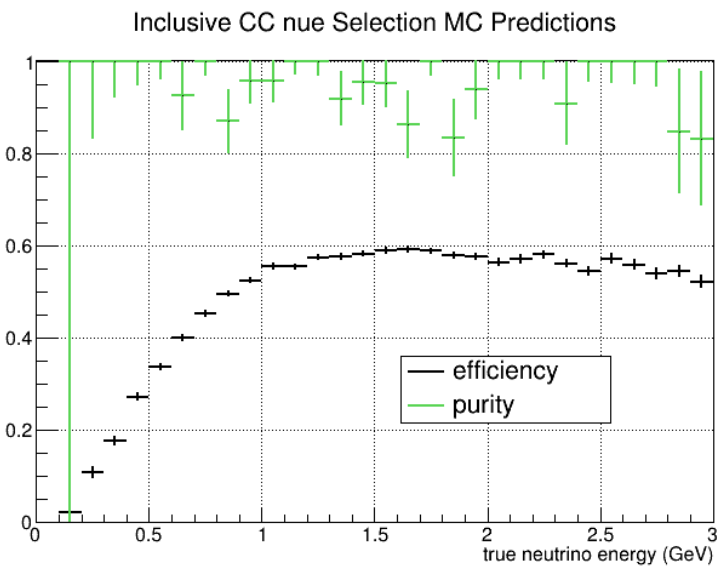
# DL Gen2 Inclusive CCnue Selection

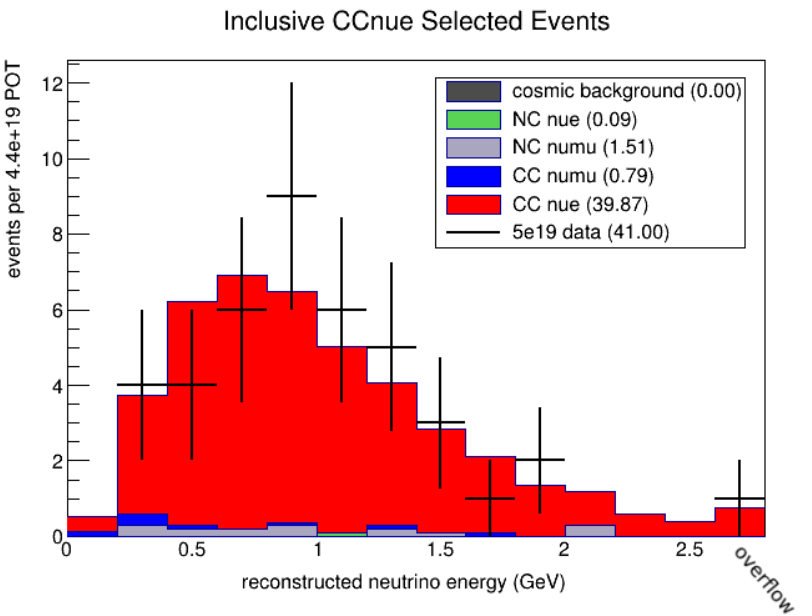
- Use some basic reconstruction quality cuts and output of LArPID network (primary electron identified) to select inclusive CCnue events
  - See my parallel talk from yesterday (DocDB 41015) or backup slides (37 - 44) for much more detail
- What's new since last presentation (DocDB 40651):
  - Implemented Wire Cell's 3cm to effective TPC boundary fiducial volume cut
    - Can now compare directly to Wire Cell's inclusive CCnue selection
  - Re-optimized selection criteria including the output of the particle production process classifier

# Inclusive CCnue Selection Results

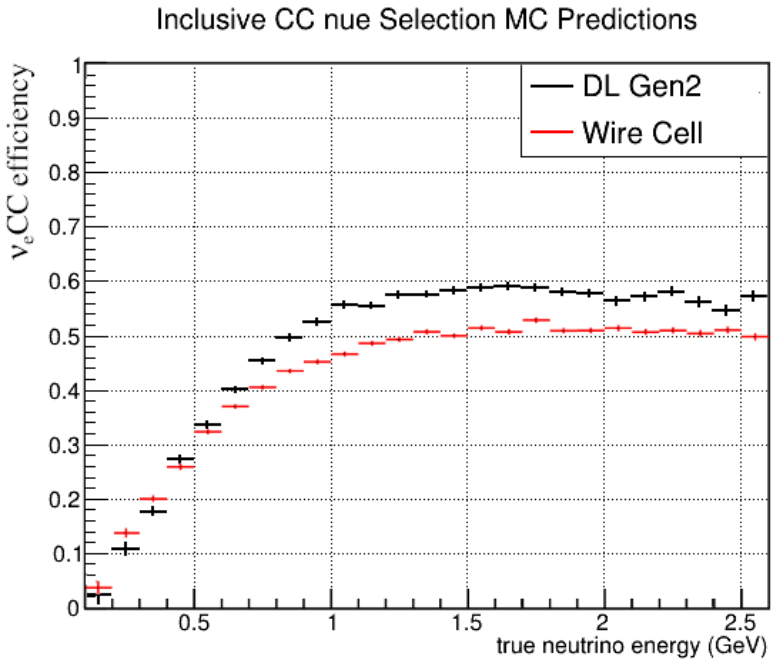
- Predictions for run1 open data (4.4e+19 POT):
  - Overall efficiency 51.5%, overall purity: 94.3%
  - Total events: 42.3
  - Signal events: 39.9

- Observed for run1 open data (4.4e+19 POT):
  - Total events: 41
  - Estimated (from hand scans) signal events: 39-40



# Comparison to Wire Cell (MC Predictions)




Overall Selection Statistics

| | DL Gen2 | Wire Cell |
|---|---|---|
| Efficiency | 51.5% | 46% |
| Purity | 94.3% | 82% |

# Comparison to Wire Cell (5e19 Results)

- Comparing selected events in run1 open data (4.43e+19 POT), all manually hand scanned
  - One wire cell only event was not present in DL sample, have not yet tracked down an event display to classify it
  - One DL gen2 only event was a toss up, hence the uncertainty in signal and background counts
- Number of probable signal events found by DL Gen2 but not Wire Cell: 10
- Number of probable signal events found by Wire Cell but not DL Gen2: 8
- Event displays for selected DL gen2 and wire cell events can be found starting on slide 46

| | DL Gen2 Data Hand Scan Estimate | DL Gen2 MC Prediction | Wire Cell Data Hand Scan Estimate | Wire Cell MC Prediction |
|---|---|---|---|---|
| Total Events | 41 | 42.3 | 40 | 41.2 |
| Signal Count | 39-40 | 39.9 | 37-38 | 33.8 |
| Background Count | 1-2 | 2.4 | 2-3 | 7.3 |
| Purity | 95% - 98% | 94% | 93% - 95% | 82% |

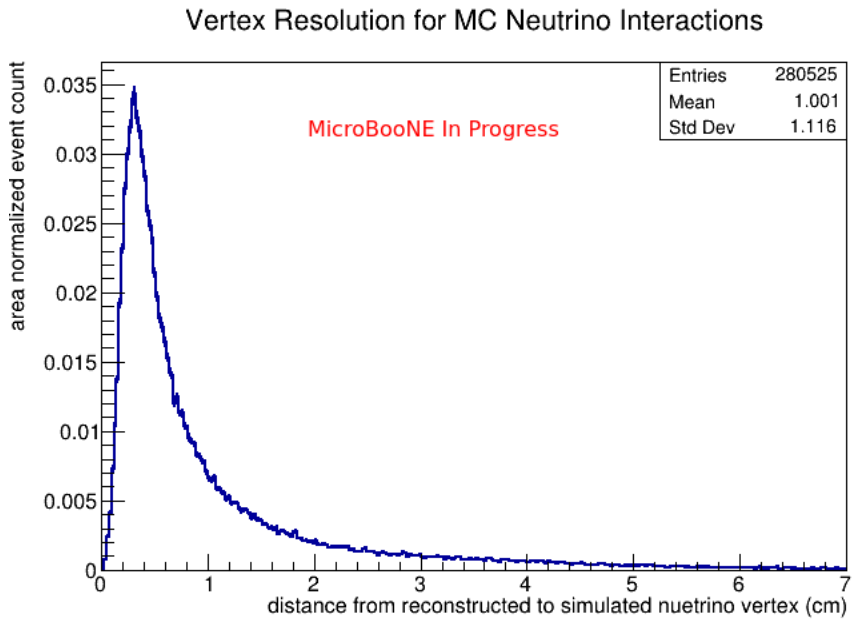
# Conclusions

- DL Gen2 reconstruction is mature and operational
- New tools provide a very competitive CCnue selection and the potential to improve the sensitivity of future analyses
- We’re planning on implementing DL Gen2 at Fermilab and working on a DL Gen2 inclusive CCnue eLEE analysis
- But the LArPID network can be implemented (and processed at the ntuple stage) in other frameworks!
  - Wanwei Wu is working on implementing LArPID in Pandora
  - Jessie Micallef is working on implementing LArPID in Wire Cell

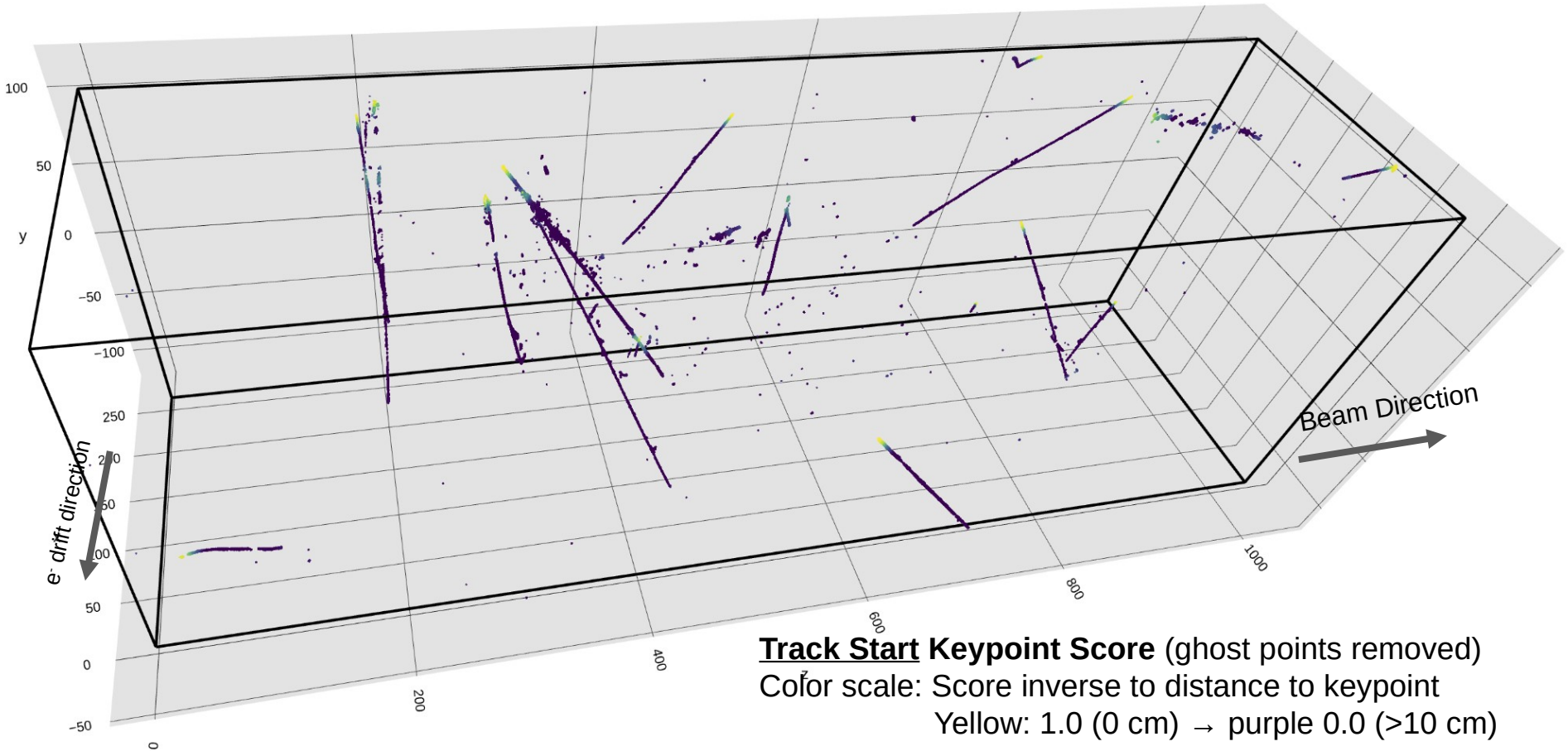
# Backup Slides

# LArMatch Neutrino Vertex Resolution

- In MC, 68% of reconstructed neutrino vertices are within 9.2mm of simulated interaction position (within 3 wires)

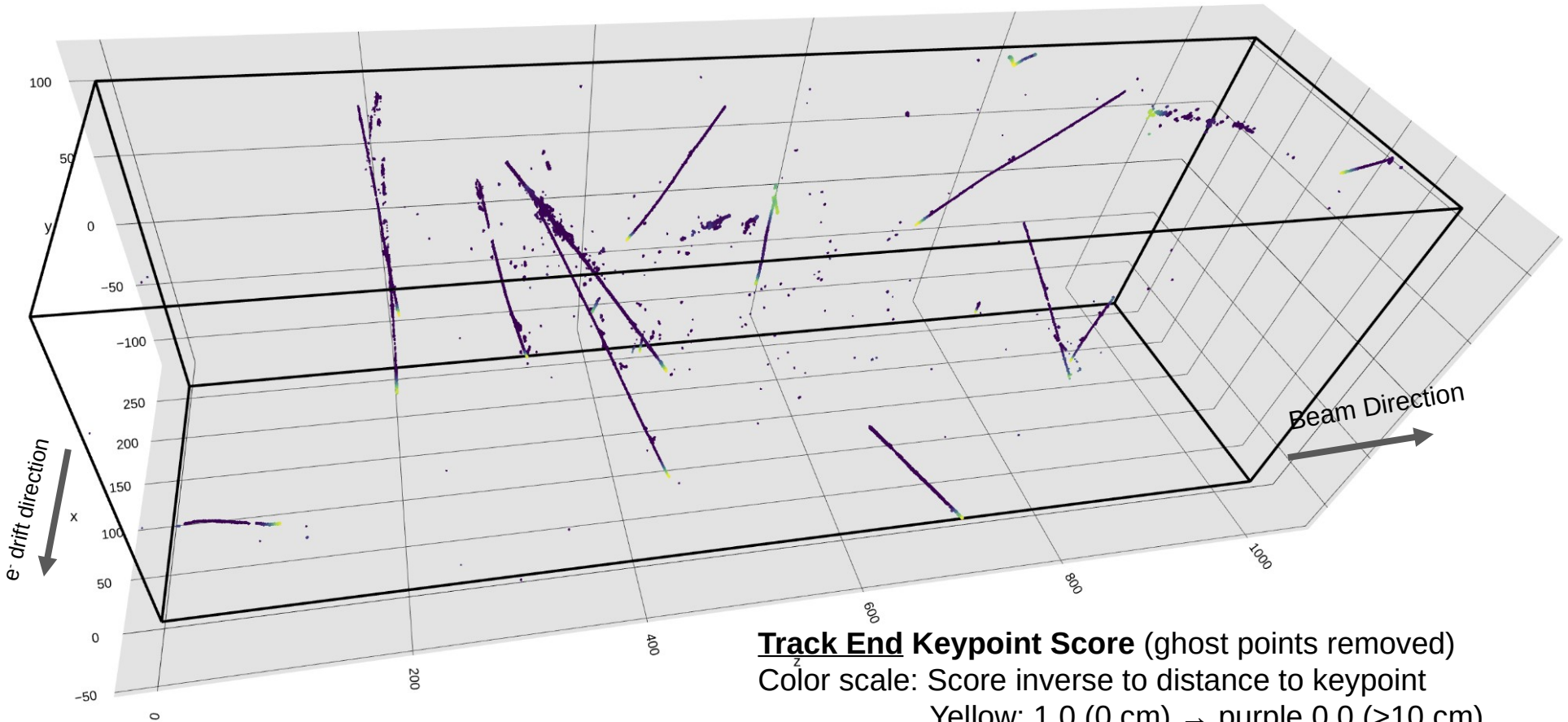


# Reconstruction Example: LArMatch Track Start Score Output



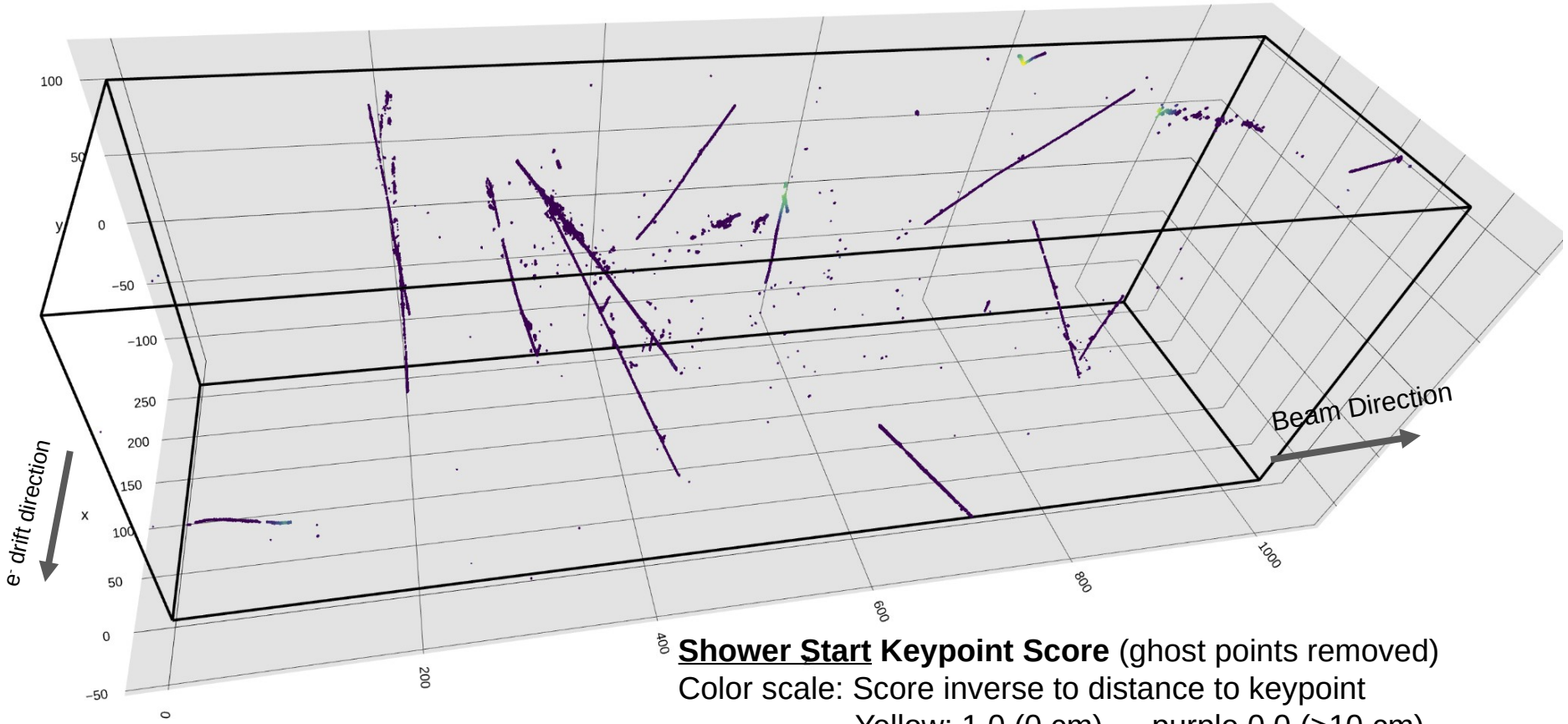

**<u>Track Start</u> Keypoint Score** (ghost points removed)
Color scale: Score inverse to distance to keypoint
Yellow: 1.0 (0 cm) → purple 0.0 (>10 cm)

# Reconstruction Example: LArMatch Track End Score Output




**<u>Track End</u> Keypoint Score** (ghost points removed)
Color scale: Score inverse to distance to keypoint
Yellow: 1.0 (0 cm) → purple 0.0 (>10 cm)

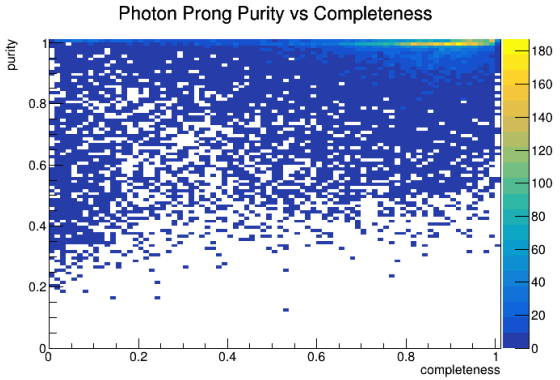
# Reconstruction Example: LArMatch Shower Start Score Output

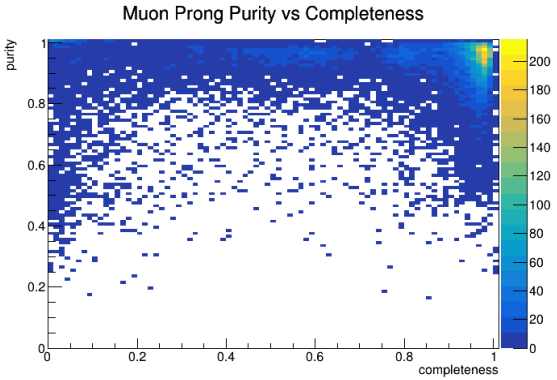


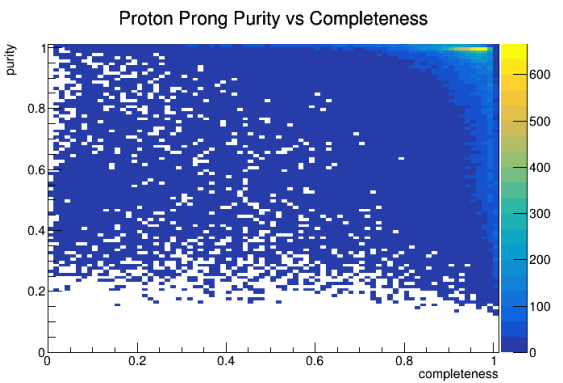

**<u>Shower Start</u> Keypoint Score** (ghost points removed)
Color scale: Score inverse to distance to keypoint
Yellow: 1.0 (0 cm) → purple 0.0 (>10 cm)

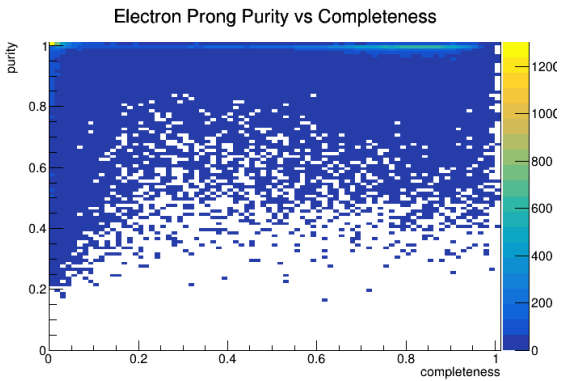
# LArPID Training Sample Selection

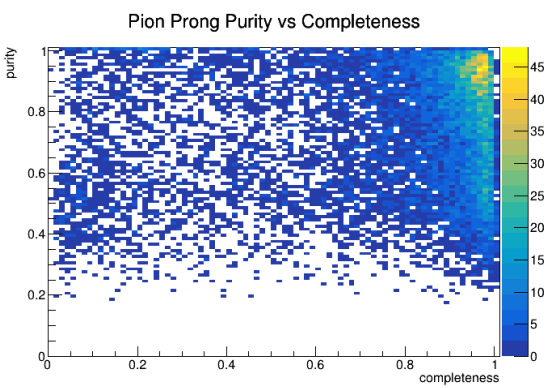
- Select reconstructed tracks and showers attached to neutrino vertices (identified by the LArMatch network) from run3 overlay samples
- Only include prongs with at least 10 above-noise-threshold pixels in all three wire planes
- No more than 20% of prong can be reconstructed from cosmic-ray contamination



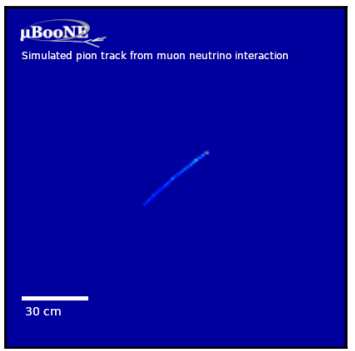



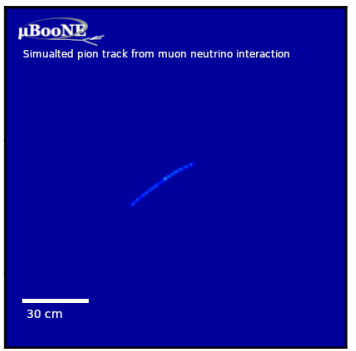
# LArPID: Image Preprocessing

- In 2D images, select all pixels included in 3D prong hits
- Crop to 512 x 512 window. Center prong in image if it fits, otherwise crop around prong end point (if it's a track) or start point (if it's a shower)
- Normalize pixel values (subtract mean, divide by standard deviation)
- Provide full event images (with cosmics removed) along with prong images

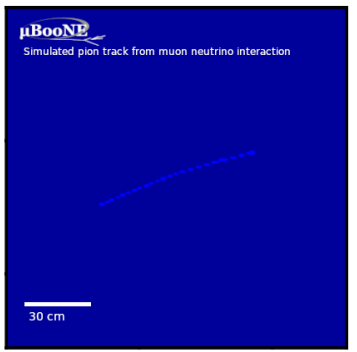
plane 0 prong



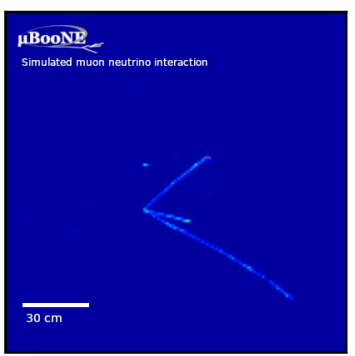

plane 1 prong



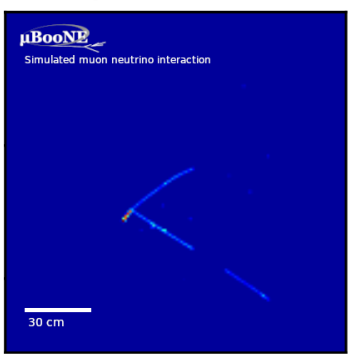

plane 2 prong



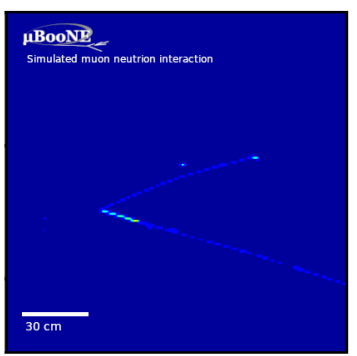

plane 0 all




plane 1 all

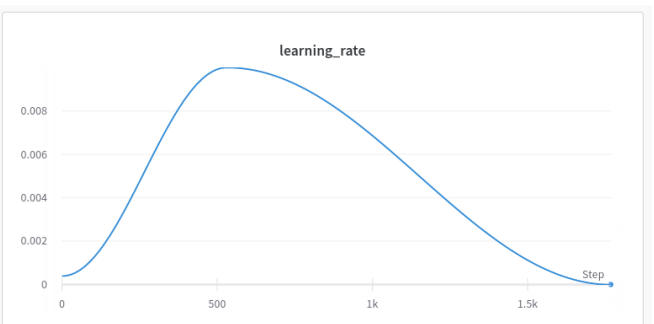



plane 2 all



# LArPID: Training

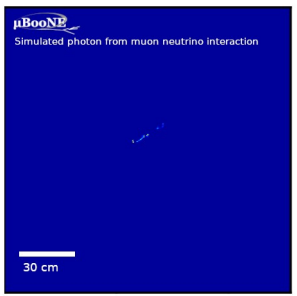
- Use learned weights to combine losses from three tasks (arXiv:1705.07115)
  - Loss = $\exp(-s_{cr})L_{cr} + \exp(-s_{pr})L_{pr} + 2\exp(-s_{pc})L_{pc} + 2\exp(-s_{pp})L_{pp} + s_{cr} + s_{pr} + s_{pc} + s_{pp}$
    - $L_{cr}$ = mean square error **c**ompleteness **r**egression loss
    - $L_{pr}$ = mean square error **p**urity **r**egression loss
    - $L_{pc}$ = cross entropy **p**article ID **c**lassification loss
    - $L_{pp}$ = cross entropy **p**article **p**roduction process classification loss
- Training sample: on the order of 100k prongs (tracks/showers) of each particle type (electrons, photons, muons, pions, and protons)
  - Weight $L_{pc}$ and $L_{pp}$ contributions to account for class imbalances
- Validation sample:
  - 10k prongs, 2k per particle type
- Training
  - Data augmentation: randomly flip input images
  - Trained for 20 epochs with a variable learning rate scheduler:



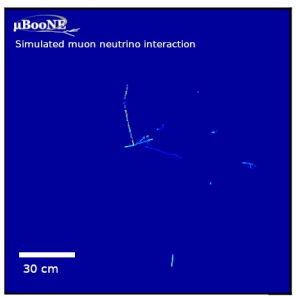
# LArPID: Interpreting the Model

- In progress: image manipulation studies designed to understand what information the model is using to make decisions

plane 1 prong

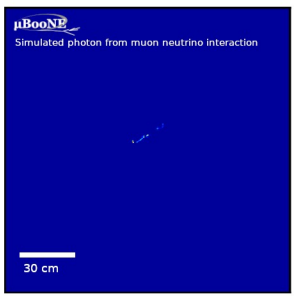



plane 1 all

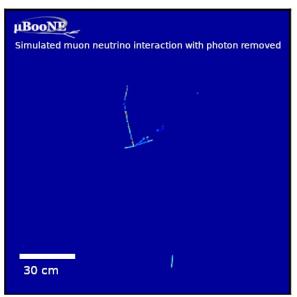



electron score = -3.63, photon score = -0.03

plane 1 prong




plane 1 all



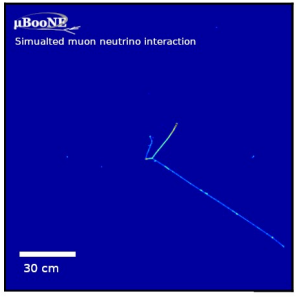

electron score = -1.53, photon score = -0.25

# LArPID: Interpreting the Model

- In progress: image manipulation studies designed to understand what information the model is using to make decisions

plane 0 prong

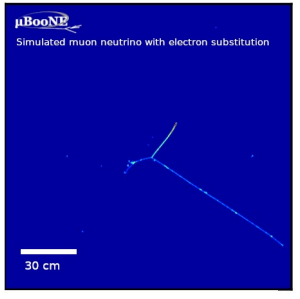

plane 0 all




electron score = 0, photon score = -7.02,
pion score = -6.02

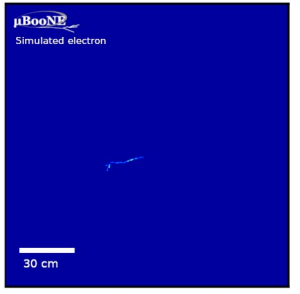
plane 0 prong


plane 0 all

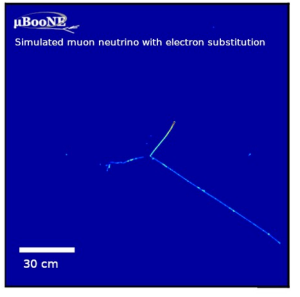



electron score = -0.01, photon score = -5.03,
pion score = -8.63

plane 0 prong



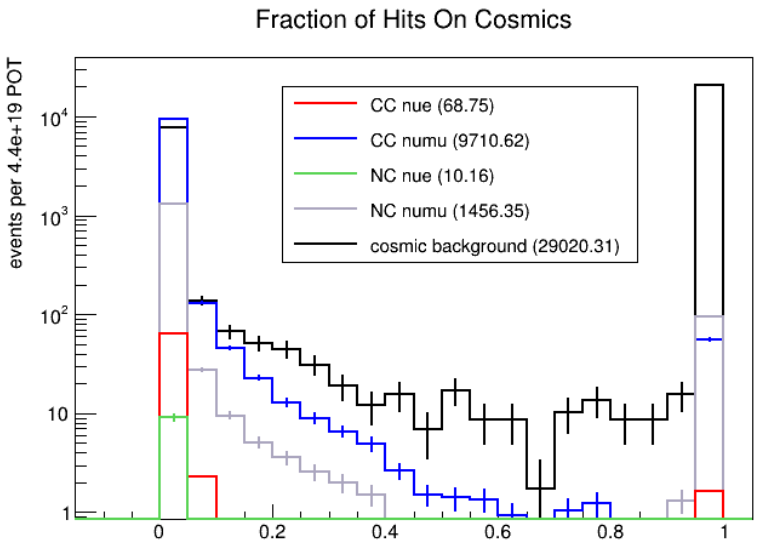

plane 0 all




electron score = -7.87, photon score = 0,
pion score = -12.84

# Inclusive CCnue Selection Cuts

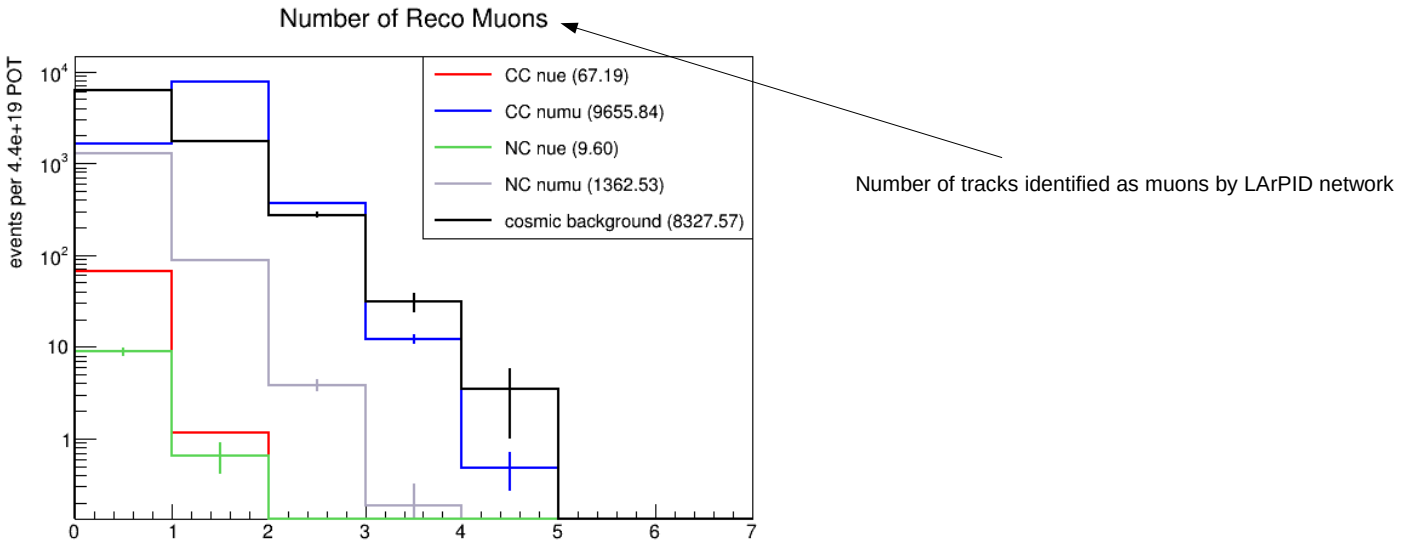
- Total predicted signal: 77.4 events per 4.4e19 POT
- Cuts so far:
  - found neutrino vertex (from LArMatch) inside fiducial volume




Add: fraction on cosmics < 1

# Inclusive CCnue Selection Cuts

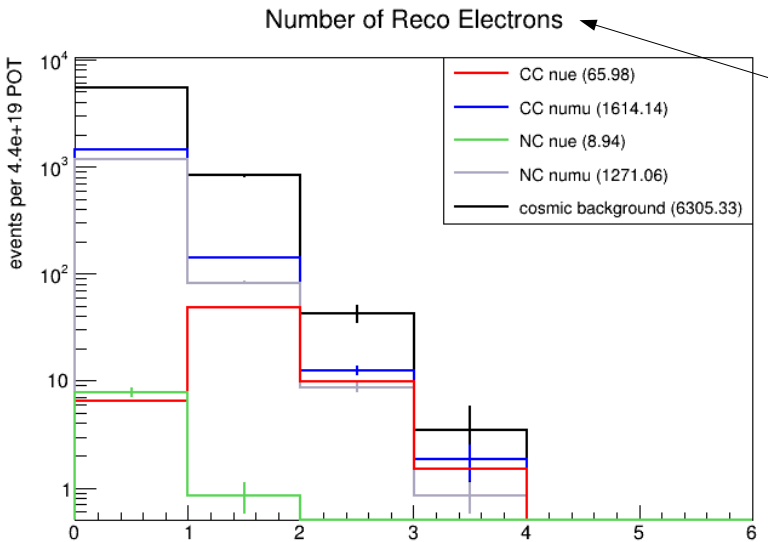
- Total predicted signal: 77.4 events per 4.4e19 POT
- Cuts so far:
  - found neutrino vertex (from LArMatch) inside fiducial volume
  - Fraction of hits on cosmics < 1




Add: number of reco muons = 0

# Inclusive CCnue Selection Cuts

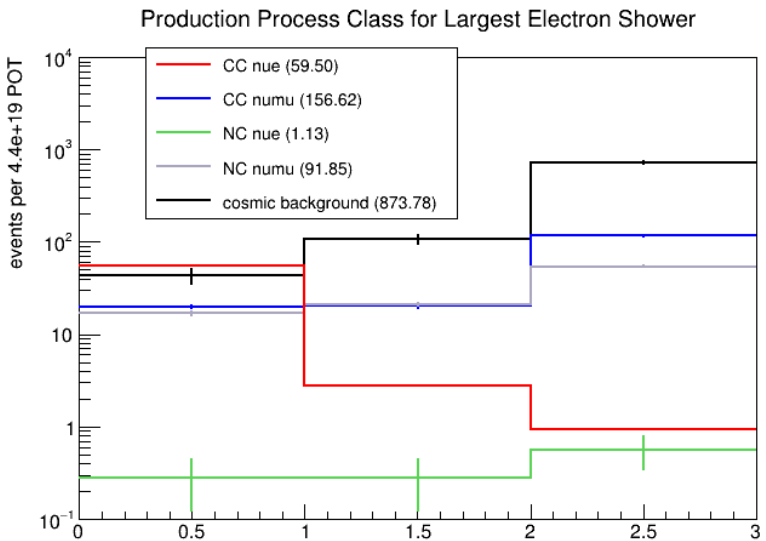
- Total predicted signal: 77.4 events per 4.4e19 POT
- Cuts so far:
  - found neutrino vertex (from LArMatch) inside fiducial volume
  - Fraction of hits on cosmics < 1
  - Number of reco muons = 0




Add: number of reco electrons >= 1

# Inclusive CCnue Selection Cuts

- Total predicted signal: 77.4 events per 4.4e19 POT
- Cuts so far:
  - found neutrino vertex (from LArMatch) inside fiducial volume
  - Fraction of hits on cosmics < 1
  - Number of reco muons = 0, number of reco electrons >= 1

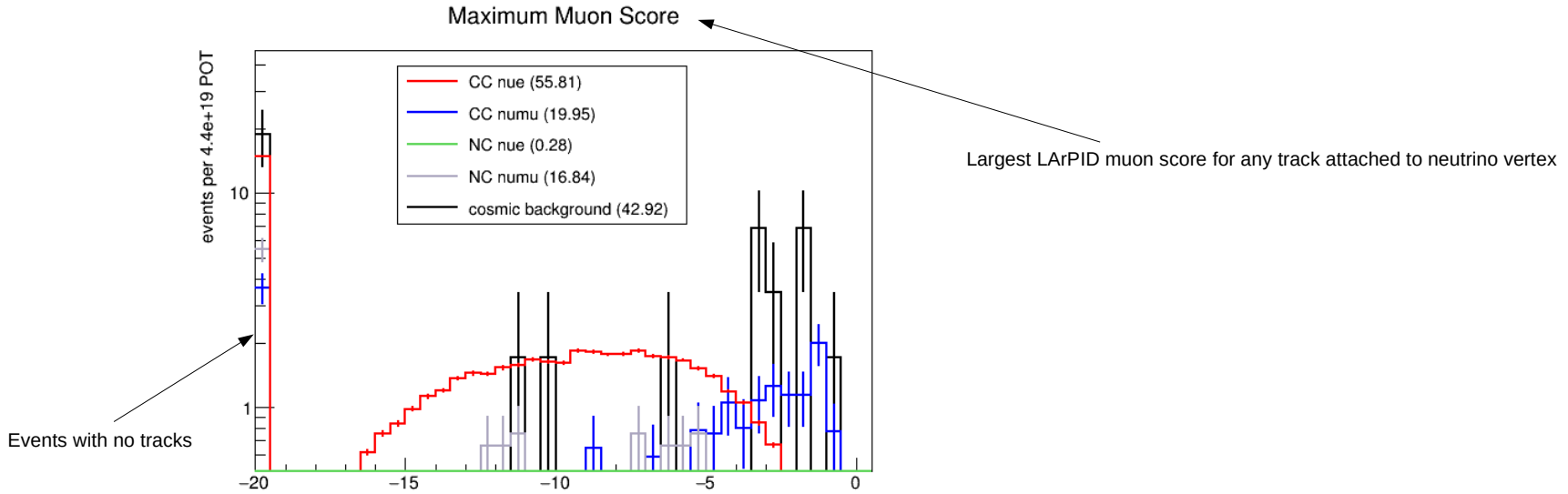



Particle production classes:
0: primary particle from neutrino interaction
1: secondary particle with neutral parent
2: secondary particle with charged parent

Add: largest reco electron classified as primary

# Inclusive CCnue Selection Cuts

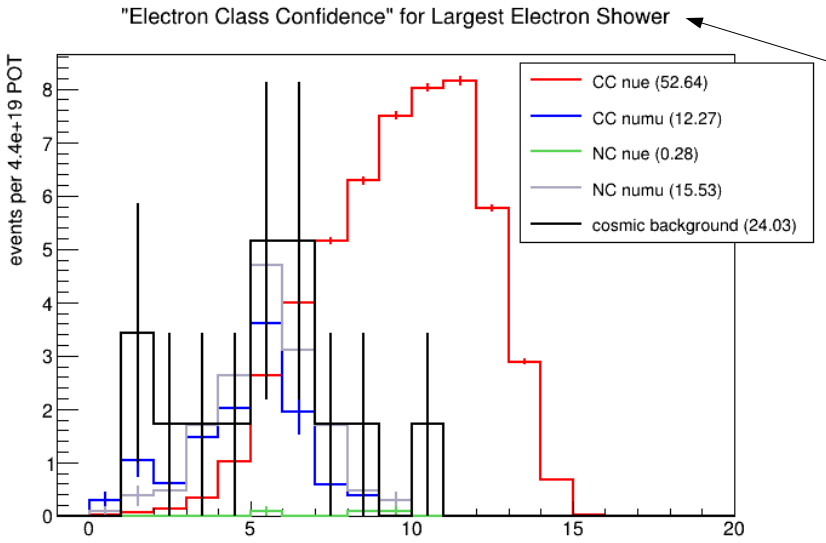
- Total predicted signal: 77.4 events per 4.4e19 POT
- Cuts so far:
  - found neutrino vertex (from LArMatch) inside fiducial volume
  - Fraction of hits on cosmics < 1
  - Number of reco muons = 0, number of reco electrons >= 1
  - Largest reco electron classified as primary




Add: maximum muon score of any track < -3.7

# Inclusive CCnue Selection Cuts

- Total predicted signal: 77.4 events per 4.4e19 POT
- Cuts so far:
  - found neutrino vertex (from LArMatch) inside fiducial volume
  - Fraction of hits on cosmics < 1
  - Number of reco muons = 0, number of reco electrons >= 1
  - Largest reco electron classified as primary
  - Maximum muon score of any track < -3.7

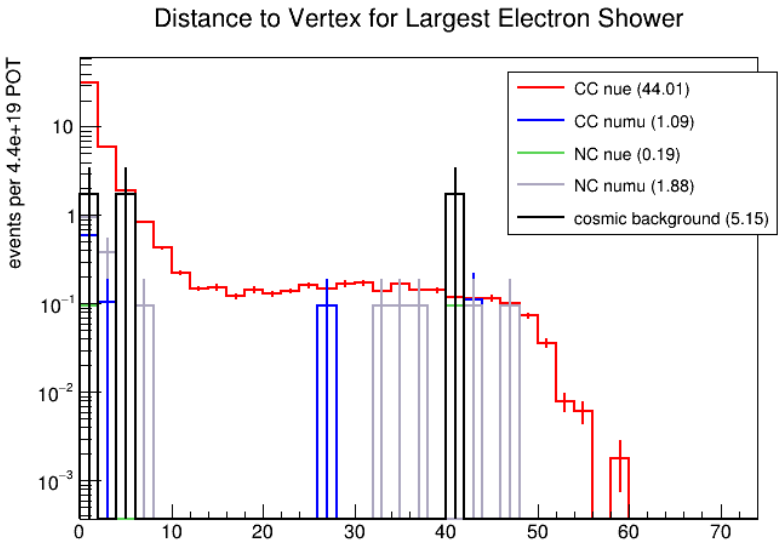


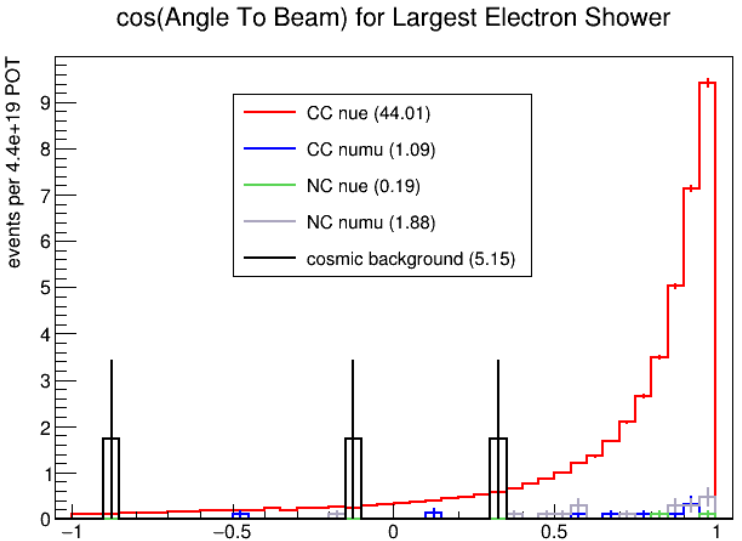

Electron class confidence = electron_score – (pion_score + photon_score)/2

Add: electron confidence score for largest reco electron > 7.1

# Inclusive CCnue Selection Cuts

- Total predicted signal: 77.4 events per 4.4e19 POT
- Cuts so far:
  - found neutrino vertex (from LArMatch) inside fiducial volume
  - Fraction of hits on cosmics < 1
  - Number of reco muons = 0, number of reco electrons >= 1
  - Largest reco electron classified as primary
  - Maximum muon score of any track < -3.7
  - Electron confidence score for largest reco electron > 7.1



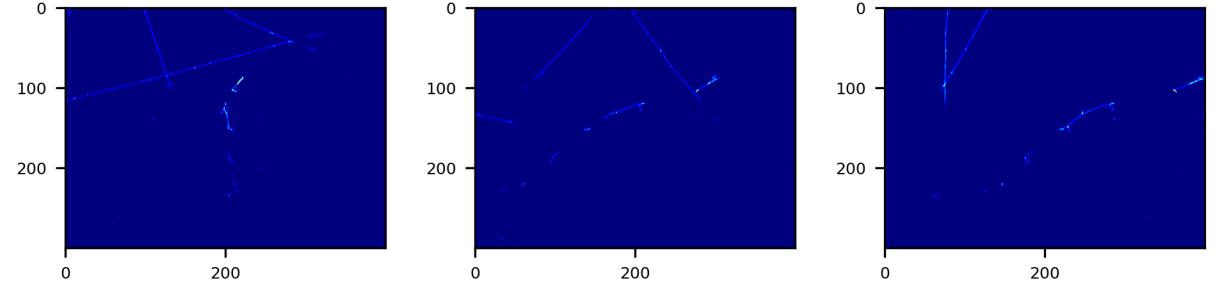

Add: cos(angle to beam) for largest electron shower > -0.07 (-4 degrees)
Add: Distance of largest electron shower start to vertex < 35cm

# “Final” Cut Set

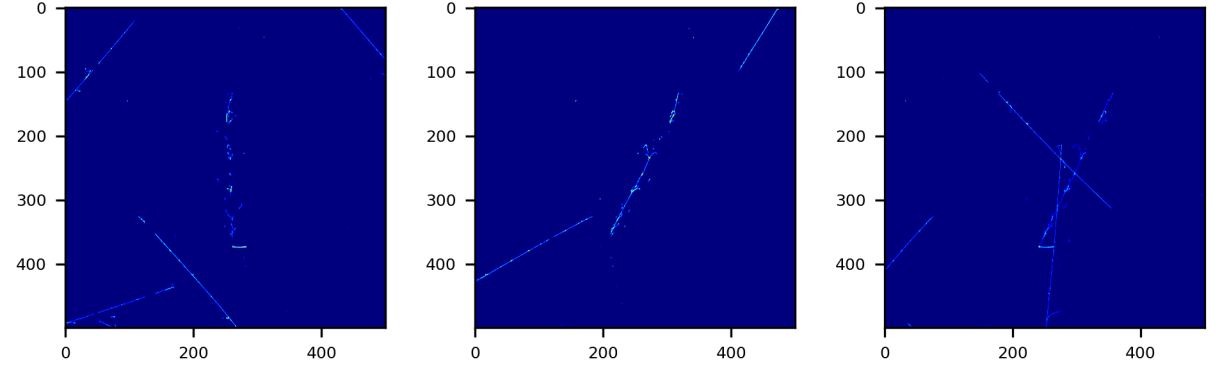
- Cuts:
  - found neutrino vertex (from LArMatch) inside fiducial volume
  - Fraction of hits on cosmics < 1
  - Number of reco muons = 0, number of reco electrons >= 1
  - Maximum muon score of any track < -3.7
  - Largest reco electron:
    - classified as primary
    - Has electron confidence score > 7.1
    - Has cos(angle to beam) > -4 degrees
    - Has start position < 35cm from neutrino vertex
- Results:
  - Completely removes cosmics
  - Gives predicted purity of 94.3% and efficiency of 51.5%

# Run1 Open Data Event Displays

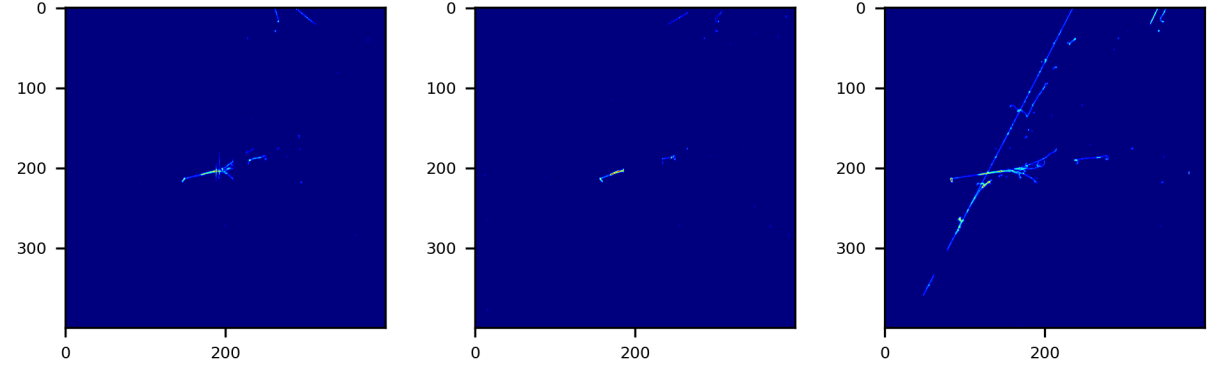
run 5375 subrun 2 event 150
DL Gen2 reco neutrino energy: 271.83 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



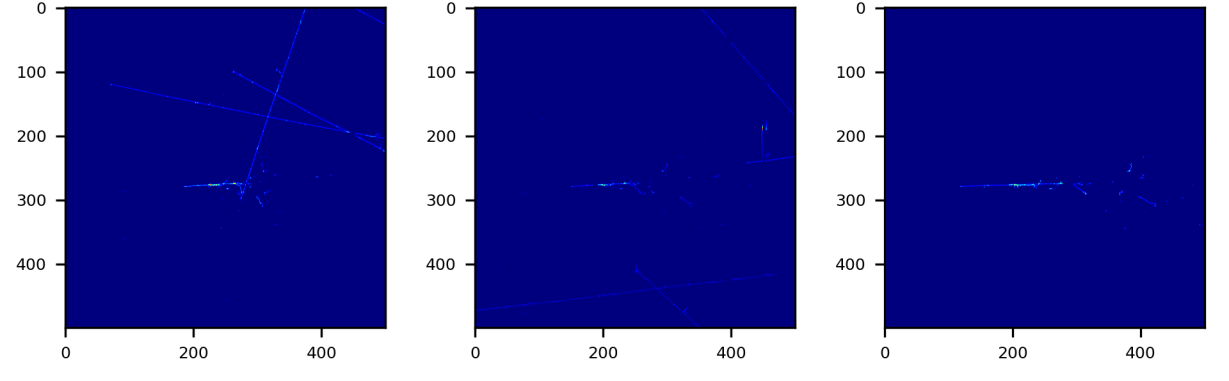
run 5339 subrun 115 event 5764
DL Gen2 reco neutrino energy: 305.64 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



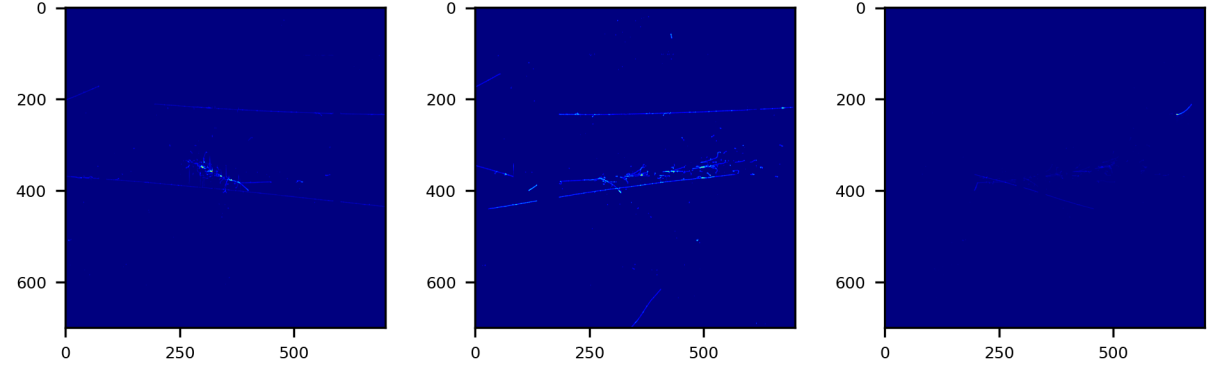
run 5703 subrun 66 event 3345
DL Gen2 reco neutrino energy: 318.57 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



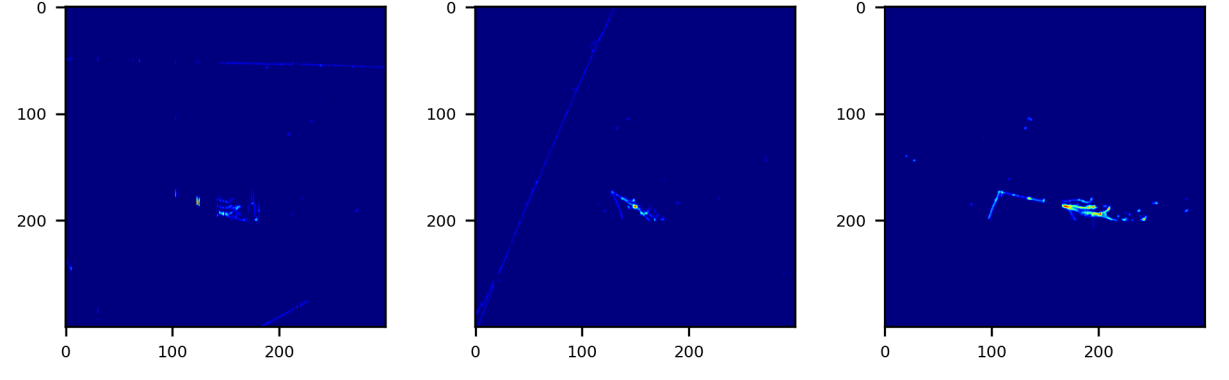
run 5187 subrun 182 event 9135
DL Gen2 reco neutrino energy: 370.17 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



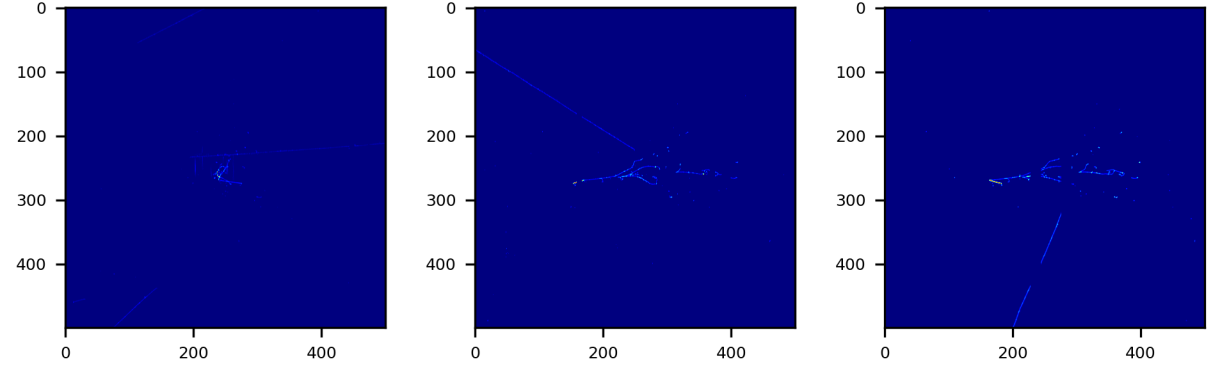
run 5147 subrun 55 event 2797
DL Gen2 reco neutrino energy: 411.39 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



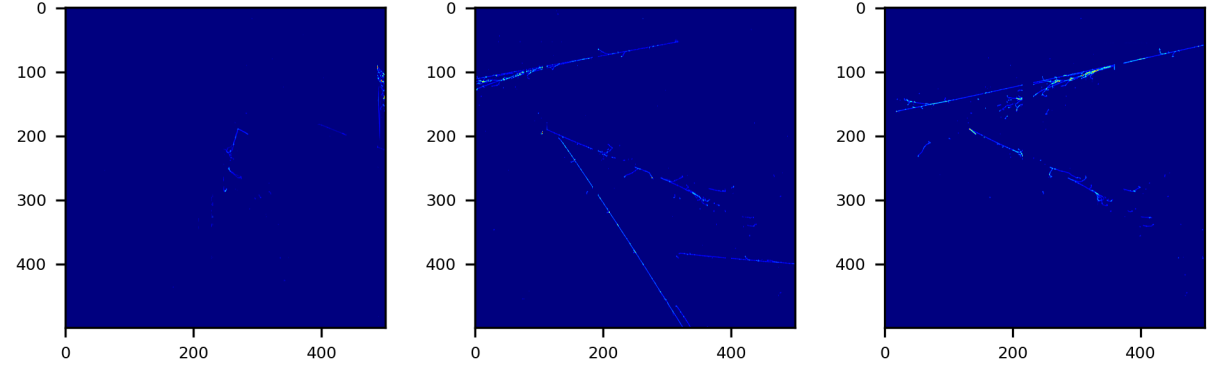
run 5371 subrun 47 event 2391
DL Gen2 reco neutrino energy: 411.76 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



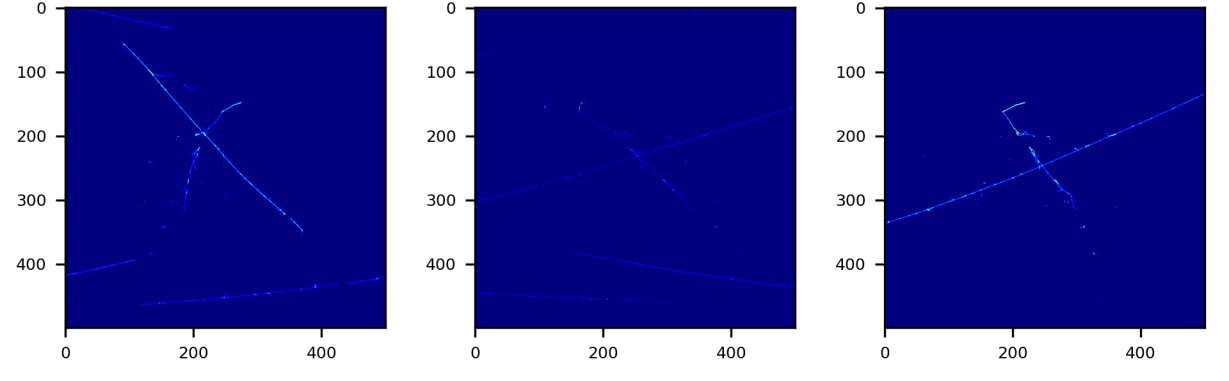
run 5328 subrun 30 event 1515
DL Gen2 reco neutrino energy: 512.14 MeV
Wire Cell reco neutrino energy: 686.93 MeV
found in DL Gen2: Yes
found in wire cell: Yes



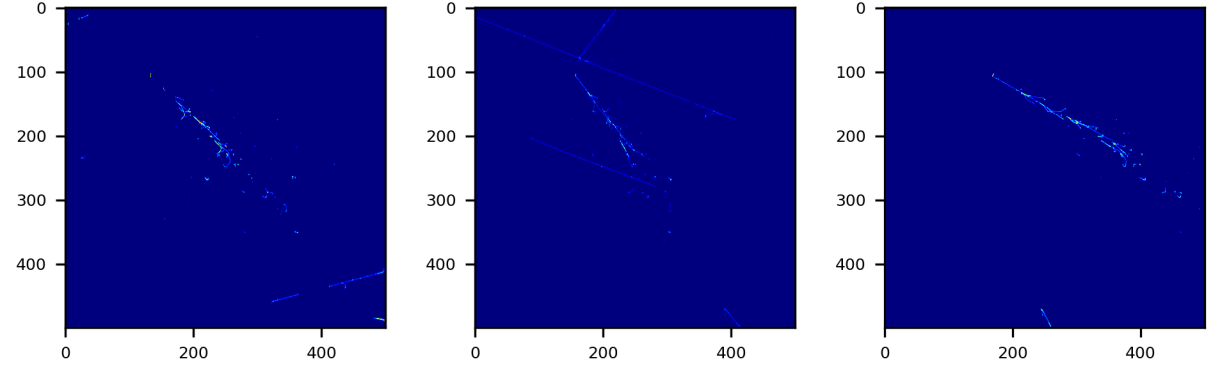
run 5195 subrun 15 event 755
DL Gen2 reco neutrino energy: 567.30 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



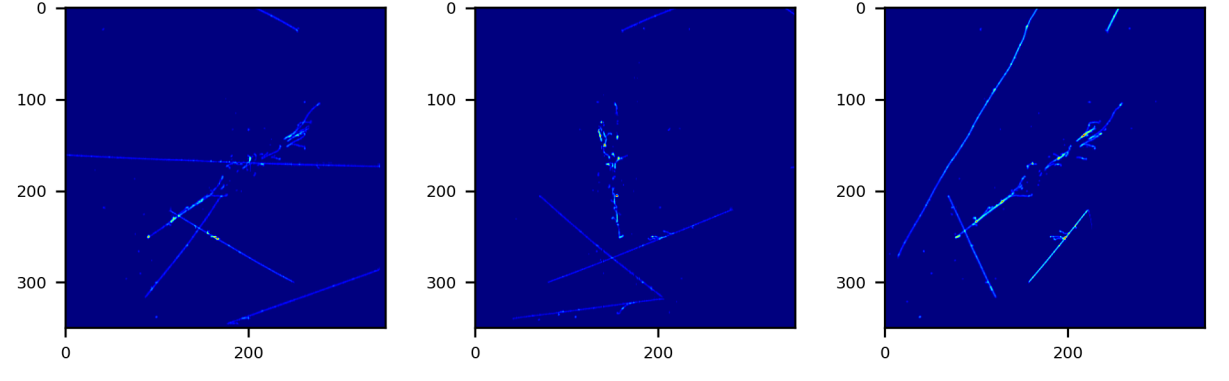
run 5774 subrun 74 event 3718
DL Gen2 reco neutrino energy: 601.60 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



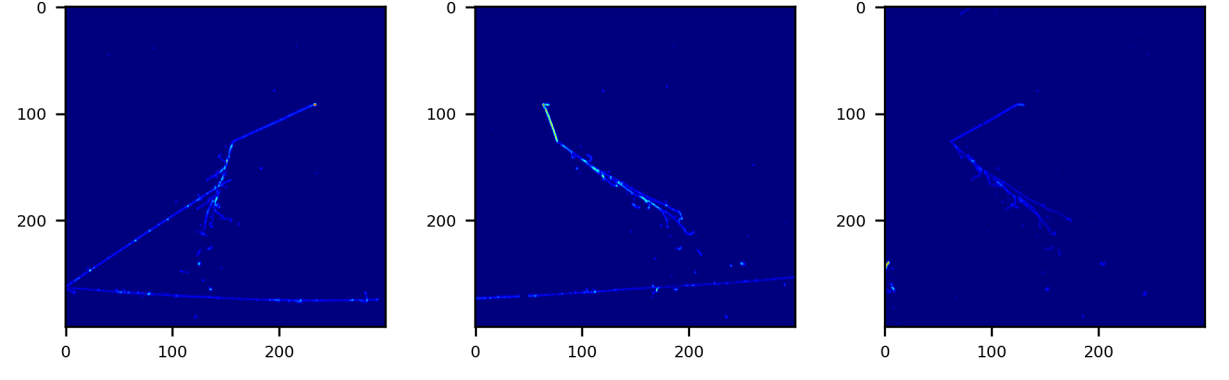
run 5382 subrun 47 event 2372
DL Gen2 reco neutrino energy: 646.35 MeV
Wire Cell reco neutrino energy: 807.17 MeV
found in DL Gen2: Yes
found in wire cell: Yes



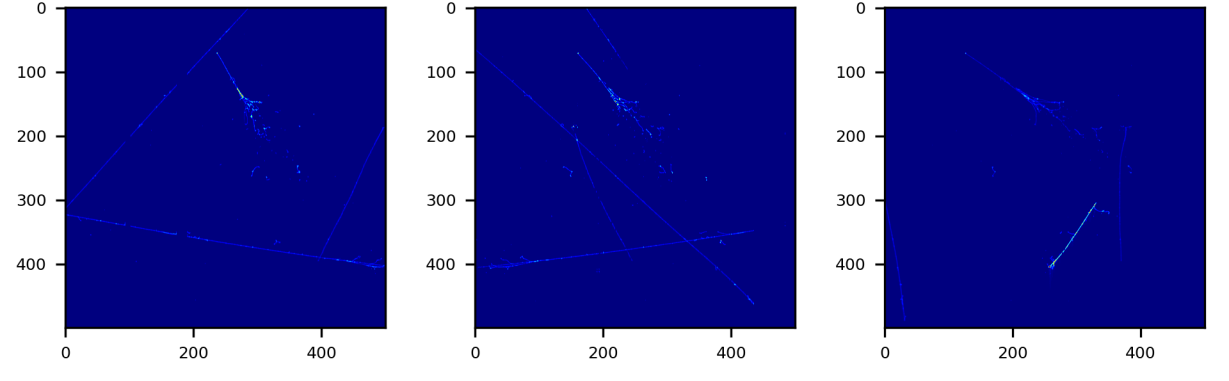
run 5938 subrun 5 event 281
DL Gen2 reco neutrino energy: 699.35 MeV
Wire Cell reco neutrino energy: 797.40 MeV
found in DL Gen2: Yes
found in wire cell: Yes



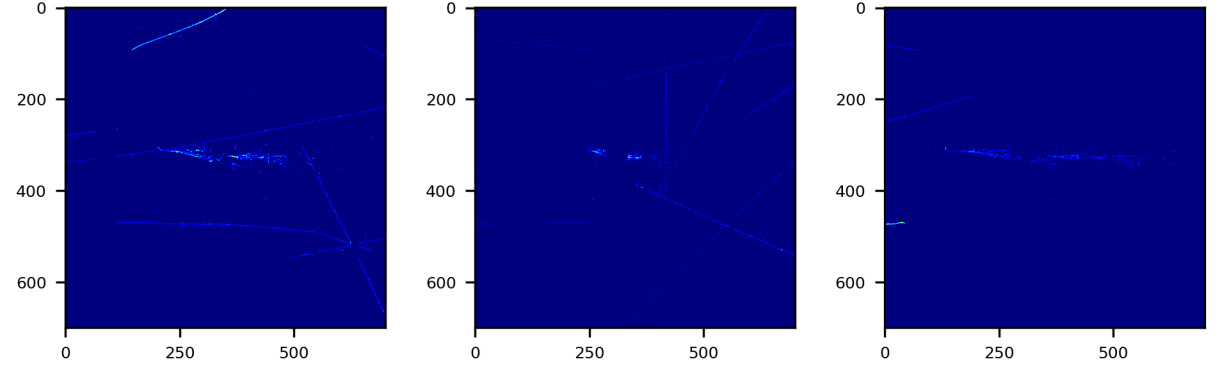
run 5385 subrun 194 event 9704
DL Gen2 reco neutrino energy: 725.63 MeV
Wire Cell reco neutrino energy: 741.22 MeV
found in DL Gen2: Yes
found in wire cell: Yes



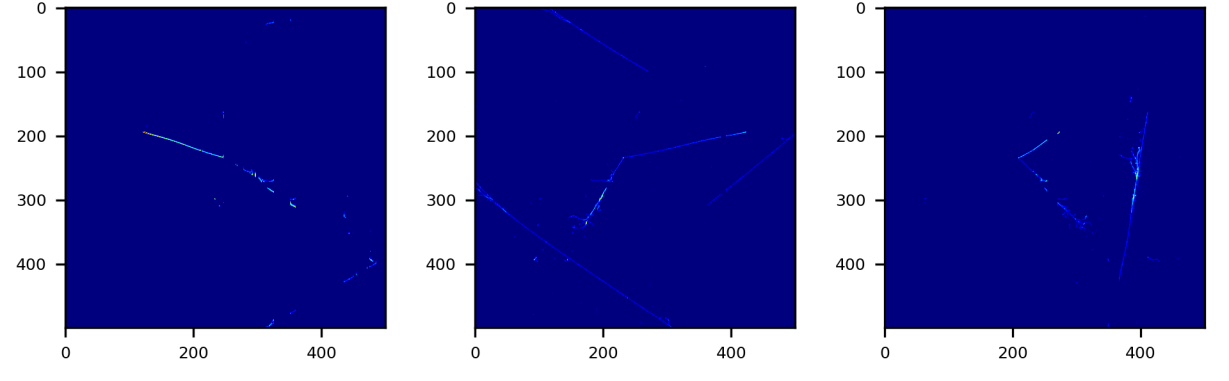
run 5705 subrun 197 event 9869
DL Gen2 reco neutrino energy: 729.29 MeV
Wire Cell reco neutrino energy: 756.24 MeV
found in DL Gen2: Yes
found in wire cell: Yes



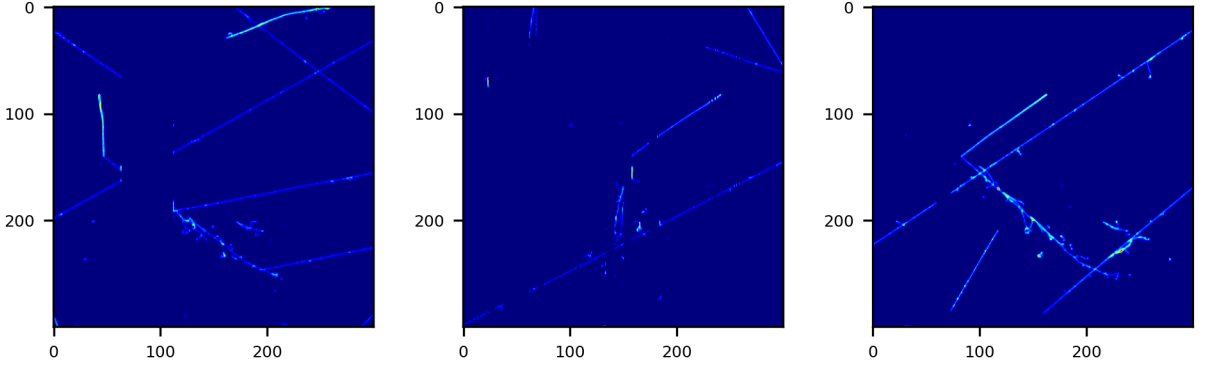
run 5147 subrun 55 event 2800
DL Gen2 reco neutrino energy: 744.70 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



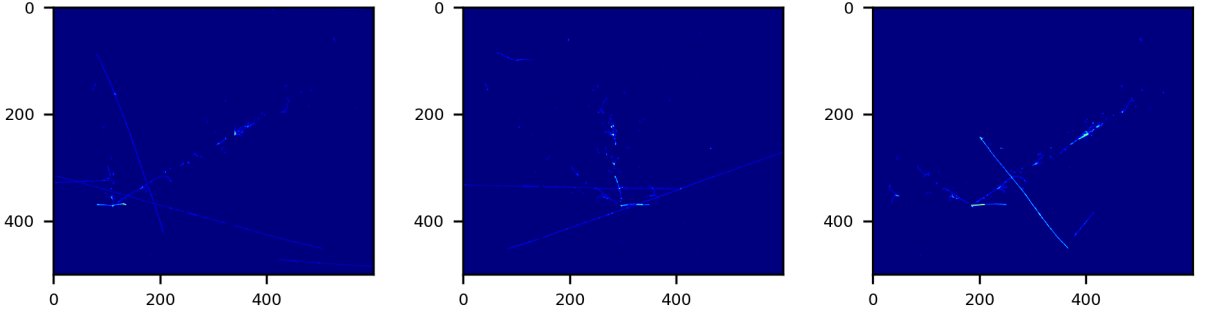
run 5891 subrun 150 event 7507
DL Gen2 reco neutrino energy: 805.45 MeV
Wire Cell reco neutrino energy: 937.33 MeV
found in DL Gen2: Yes
found in wire cell: Yes



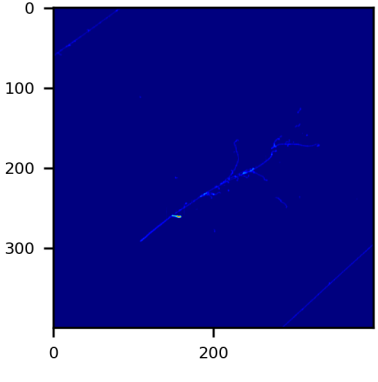
run 5581 subrun 47 event 2377
DL Gen2 reco neutrino energy: 816.54 MeV
Wire Cell reco neutrino energy: 945.91 MeV
found in DL Gen2: Yes
found in wire cell: Yes

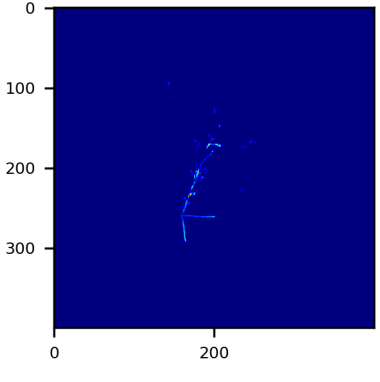


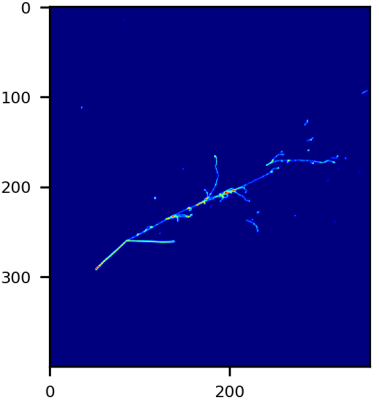
run 5211 subrun 99 event 4994
DL Gen2 reco neutrino energy: 851.63 MeV
Wire Cell reco neutrino energy: 1351.99 MeV
found in DL Gen2: Yes
found in wire cell: Yes



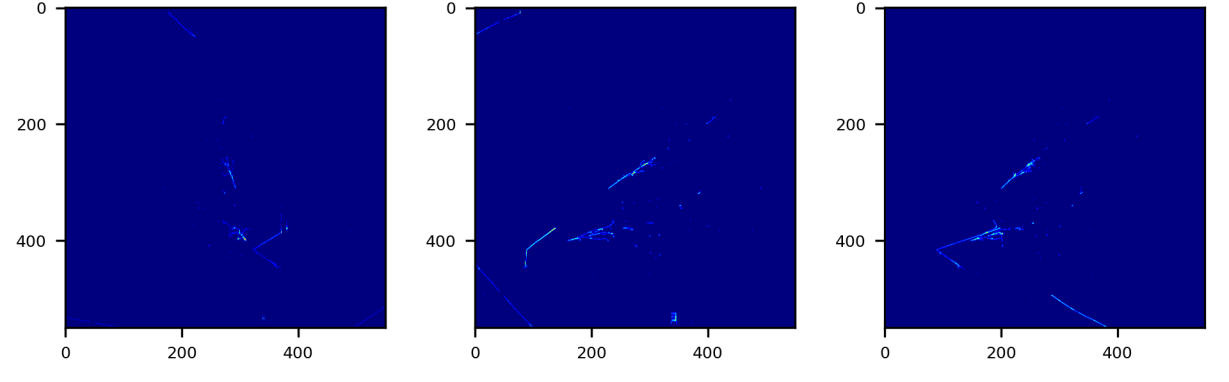
run 5695 subrun 8 event 409
DL Gen2 reco neutrino energy: 859.77 MeV
Wire Cell reco neutrino energy: 929.06 MeV
found in DL Gen2: Yes
found in wire cell: Yes



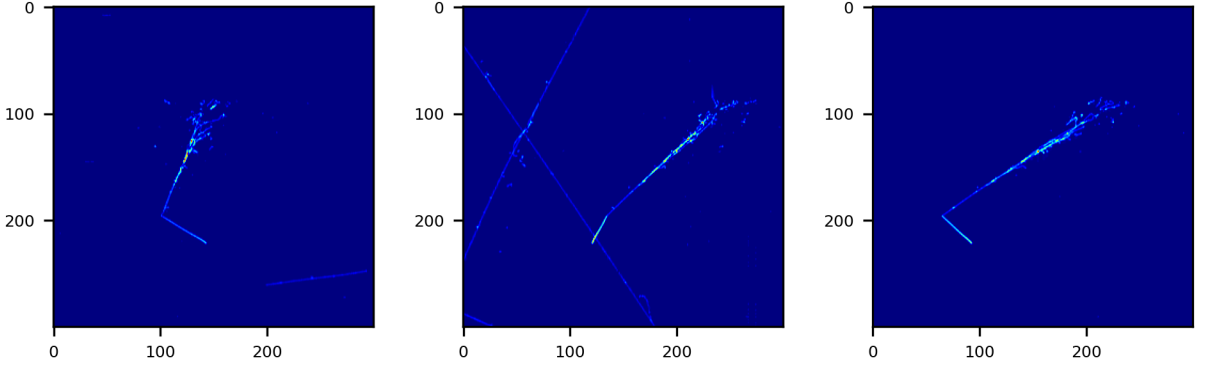



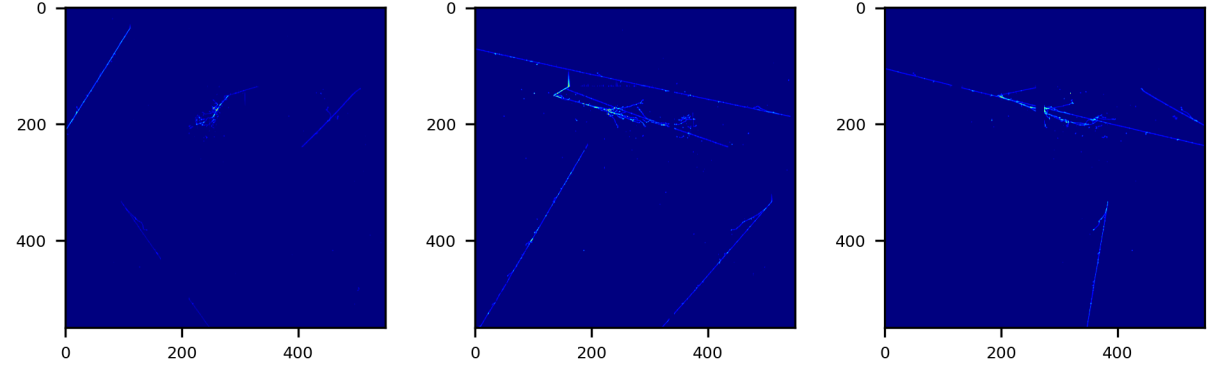
run 5607 subrun 14 event 747
DL Gen2 reco neutrino energy: 860.66 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



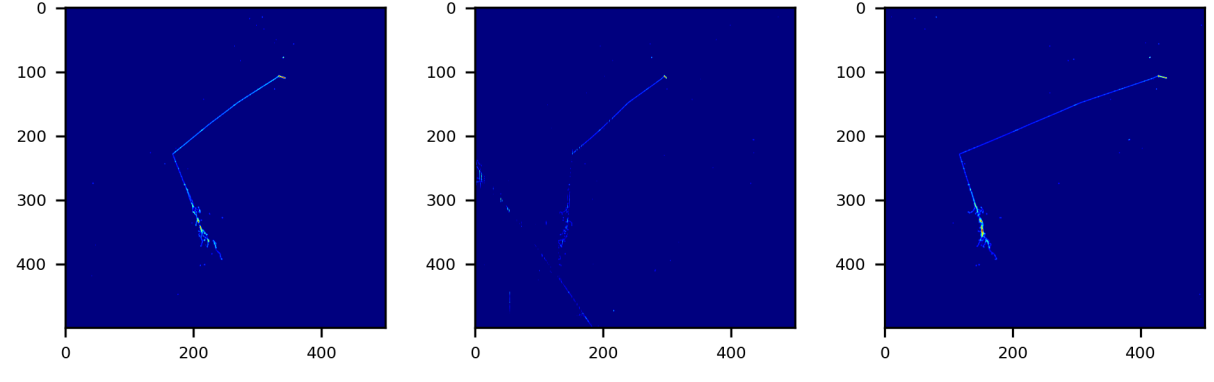
run 5783 subrun 46 event 2342
DL Gen2 reco neutrino energy: 895.68 MeV
Wire Cell reco neutrino energy: 855.36 MeV
found in DL Gen2: Yes
found in wire cell: Yes



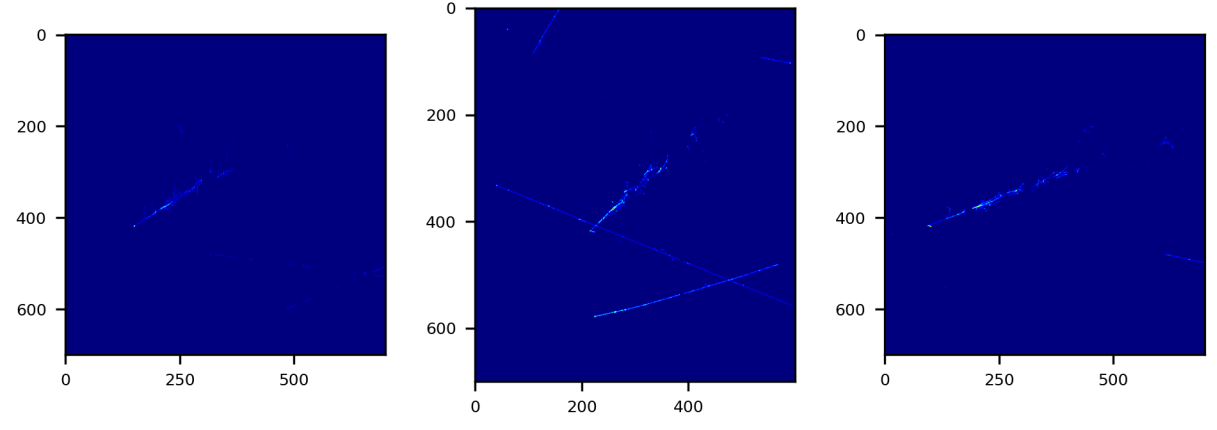
run 5617 subrun 10 event 512
DL Gen2 reco neutrino energy: 932.89 MeV
Wire Cell reco neutrino energy: 1710.92 MeV
found in DL Gen2: Yes
found in wire cell: Yes



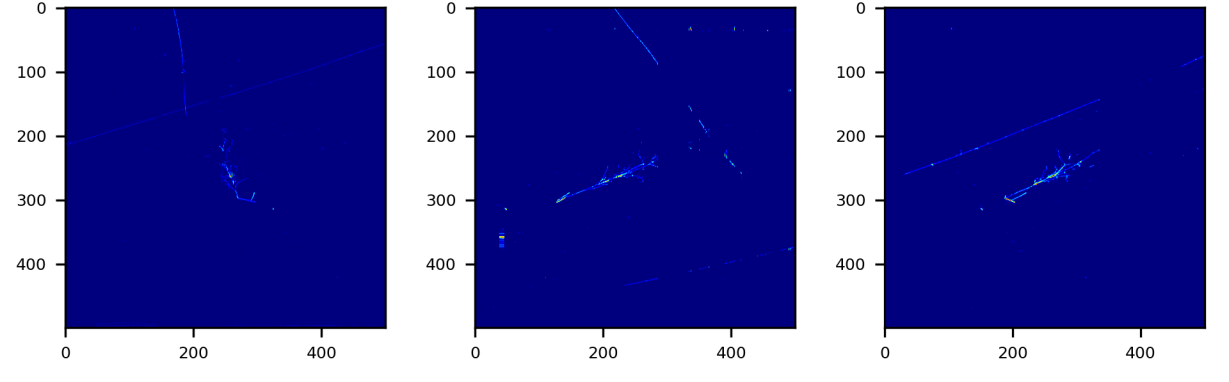
run 5360 subrun 0 event 45
DL Gen2 reco neutrino energy: 939.33 MeV
Wire Cell reco neutrino energy: 927.08 MeV
found in DL Gen2: Yes
found in wire cell: Yes



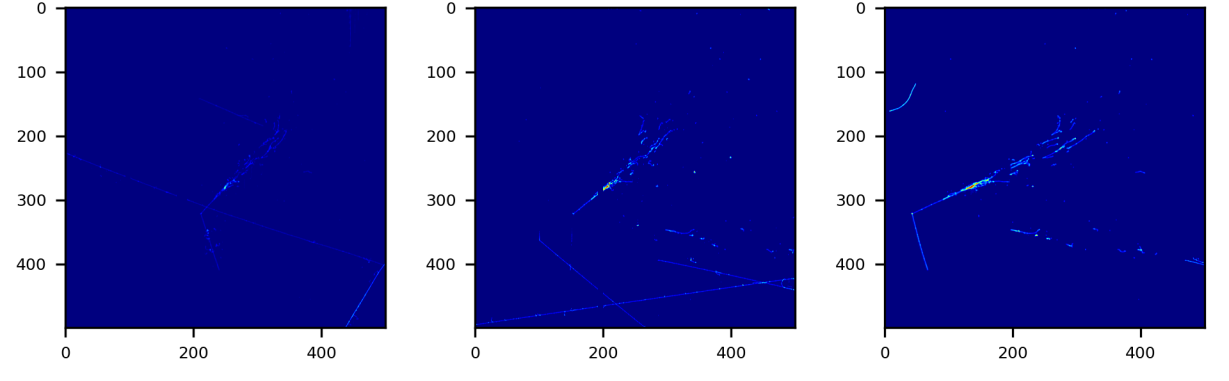
run 5513 subrun 0 event 31
DL Gen2 reco neutrino energy: 994.50 MeV
Wire Cell reco neutrino energy: 1425.07 MeV
found in DL Gen2: Yes
found in wire cell: Yes



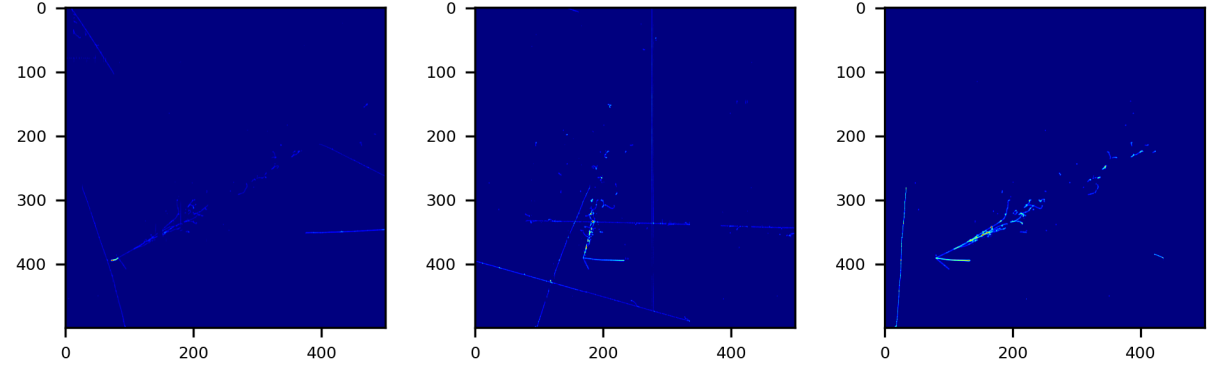
run 5729 subrun 121 event 6086
DL Gen2 reco neutrino energy: 1025.12 MeV
Wire Cell reco neutrino energy: 1183.91 MeV
found in DL Gen2: Yes
found in wire cell: Yes



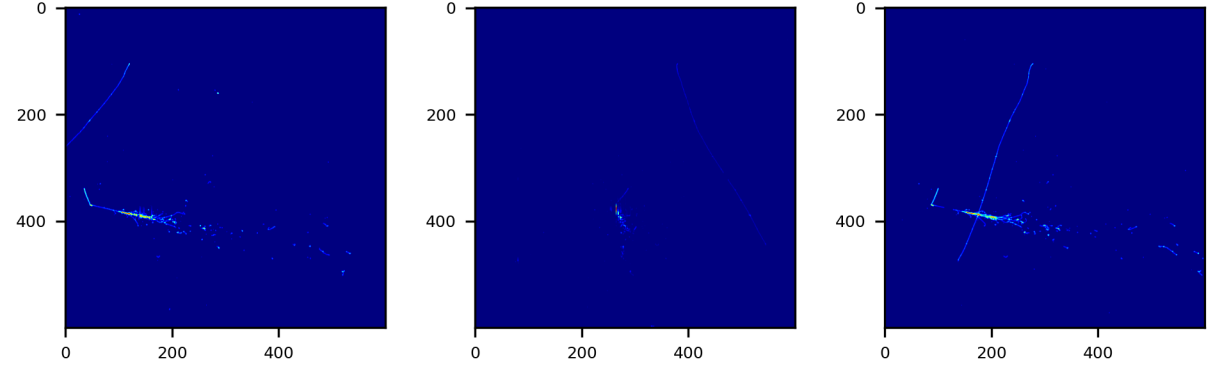
run 5761 subrun 11 event 582
DL Gen2 reco neutrino energy: 1049.61 MeV
Wire Cell reco neutrino energy: 1536.06 MeV
found in DL Gen2: Yes
found in wire cell: Yes



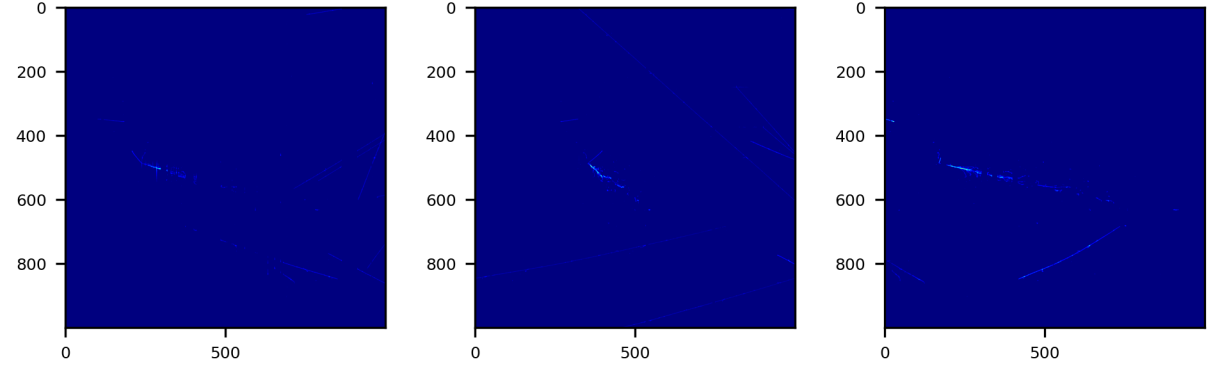
run 5229 subrun 65 event 3279
DL Gen2 reco neutrino energy: 1071.38 MeV
Wire Cell reco neutrino energy: 1069.22 MeV
found in DL Gen2: Yes
found in wire cell: Yes



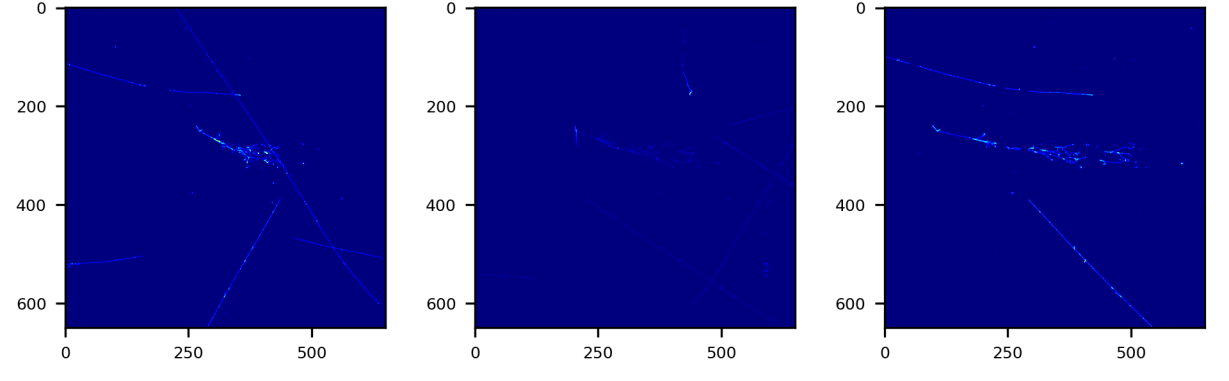
run 5606 subrun 74 event 3708
DL Gen2 reco neutrino energy: 1071.96 MeV
Wire Cell reco neutrino energy: 1568.46 MeV
found in DL Gen2: Yes
found in wire cell: Yes



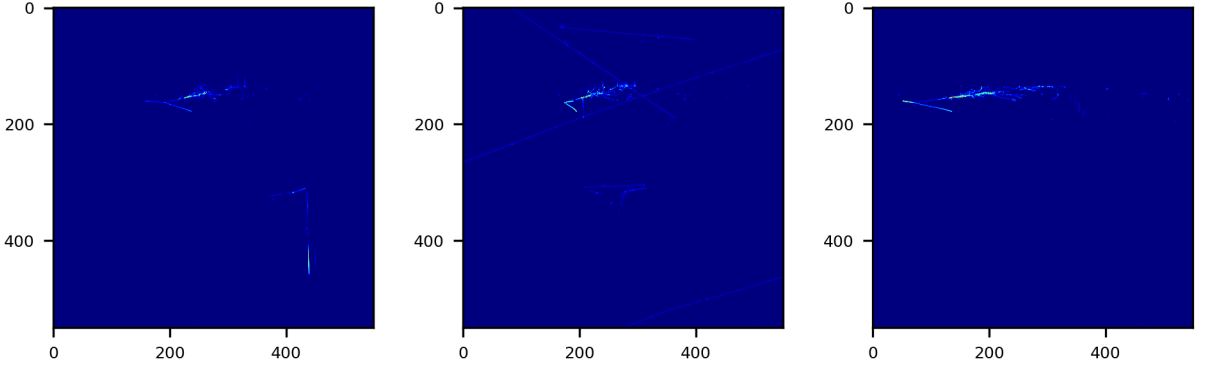
run 5197 subrun 8 event 412
DL Gen2 reco neutrino energy: 1149.39 MeV
Wire Cell reco neutrino energy: 2405.42 MeV
found in DL Gen2: Yes
found in wire cell: Yes



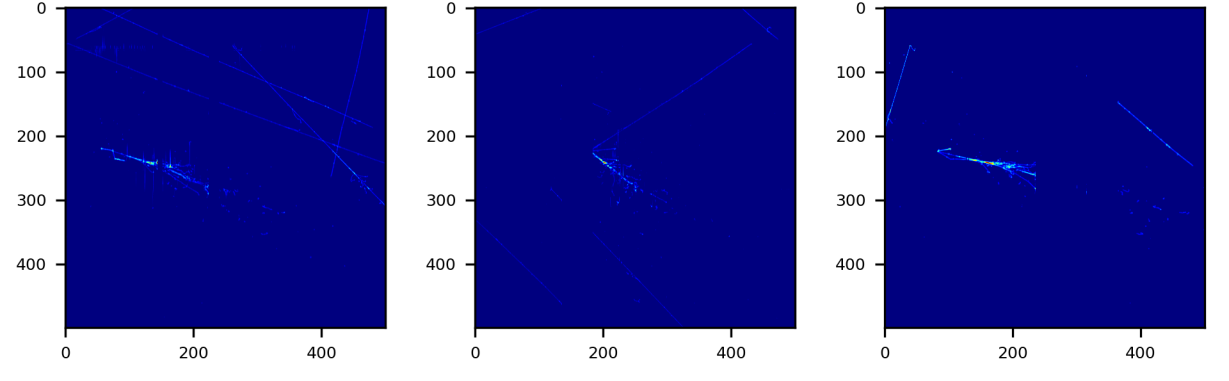
run 5161 subrun 8 event 447
DL Gen2 reco neutrino energy: 1180.47 MeV
Wire Cell reco neutrino energy: 1404.92 MeV
found in DL Gen2: Yes
found in wire cell: Yes



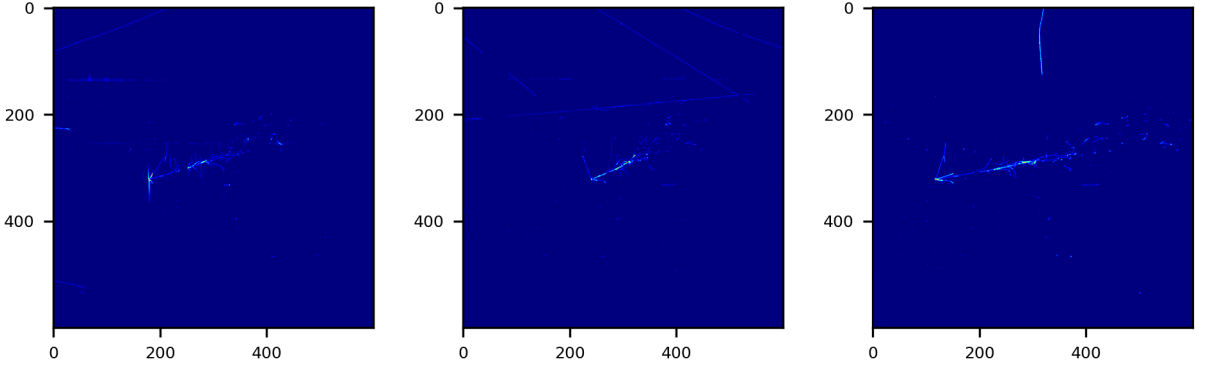
run 5583 subrun 13 event 692
DL Gen2 reco neutrino energy: 1217.68 MeV
Wire Cell reco neutrino energy: 1453.91 MeV
found in DL Gen2: Yes
found in wire cell: Yes



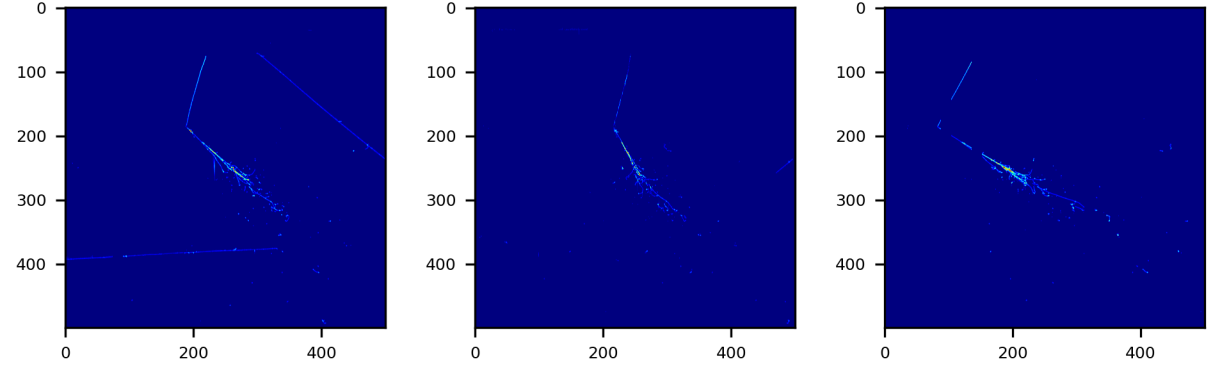
run 5280 subrun 97 event 4861
DL Gen2 reco neutrino energy: 1341.46 MeV
Wire Cell reco neutrino energy: 1655.72 MeV
found in DL Gen2: Yes
found in wire cell: Yes



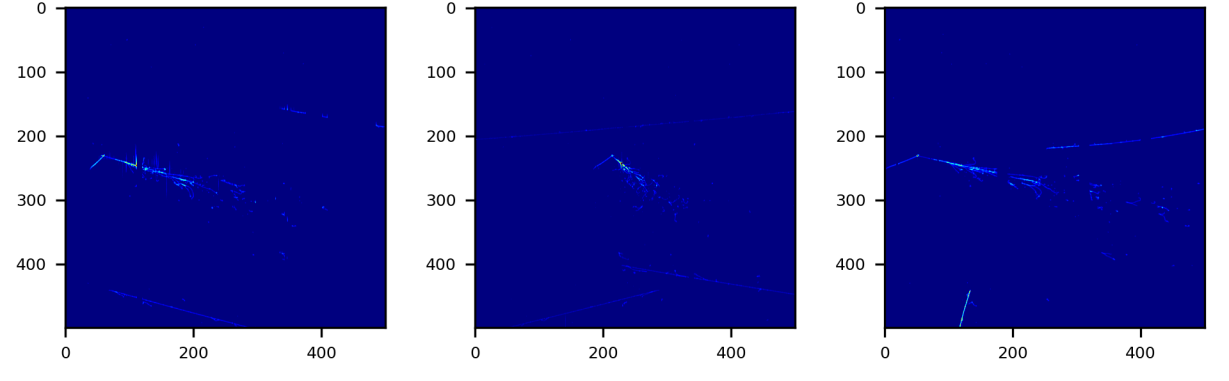
run 5444 subrun 1 event 87
DL Gen2 reco neutrino energy: 1372.67 MeV
Wire Cell reco neutrino energy: 2197.98 MeV
found in DL Gen2: Yes
found in wire cell: Yes



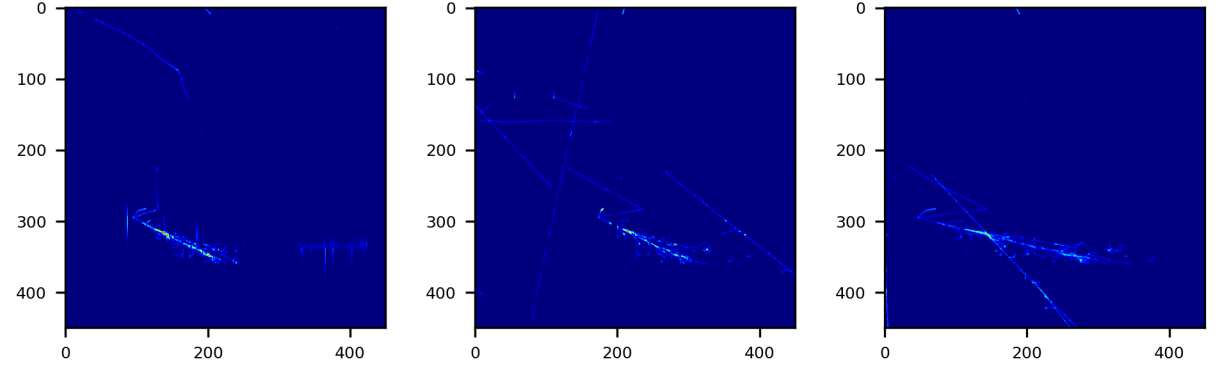
run 5906 subrun 74 event 3710
DL Gen2 reco neutrino energy: 1377.54 MeV
Wire Cell reco neutrino energy: 1432.80 MeV
found in DL Gen2: Yes
found in wire cell: Yes



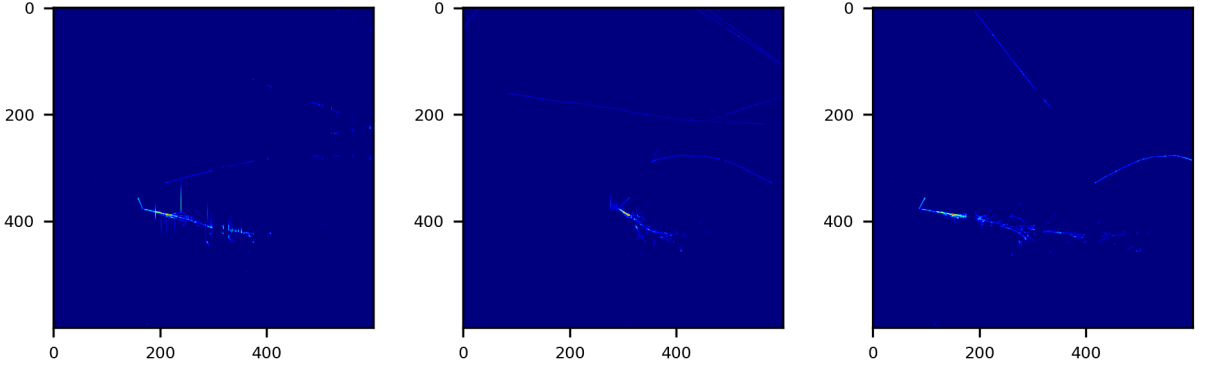
run 5501 subrun 64 event 3226
DL Gen2 reco neutrino energy: 1385.24 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



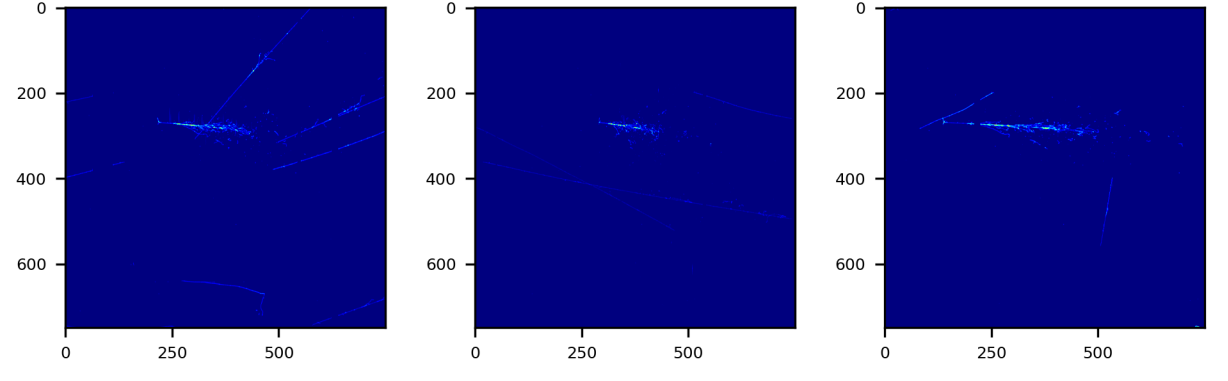
run 5709 subrun 74 event 3719
DL Gen2 reco neutrino energy: 1551.27 MeV
Wire Cell reco neutrino energy: 1903.41 MeV
found in DL Gen2: Yes
found in wire cell: Yes



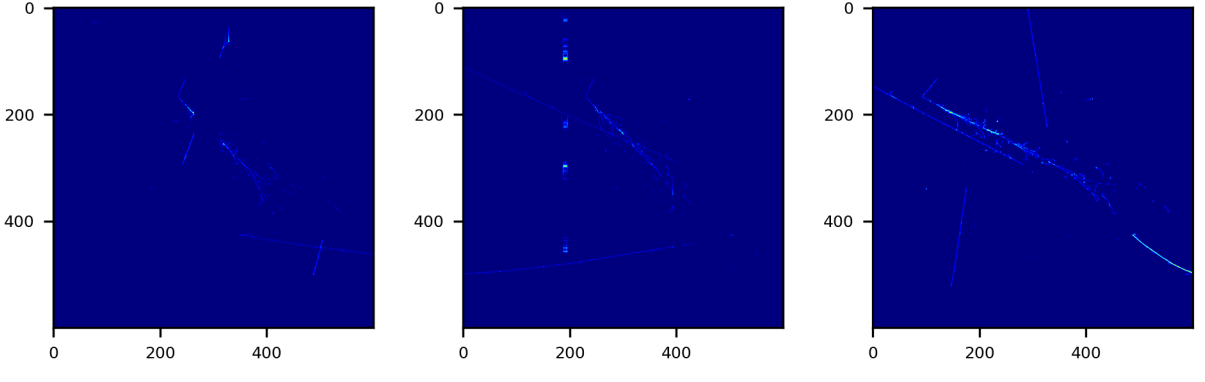
run 5334 subrun 14 event 709
DL Gen2 reco neutrino energy: 1566.82 MeV
Wire Cell reco neutrino energy: 1859.82 MeV
found in DL Gen2: Yes
found in wire cell: Yes



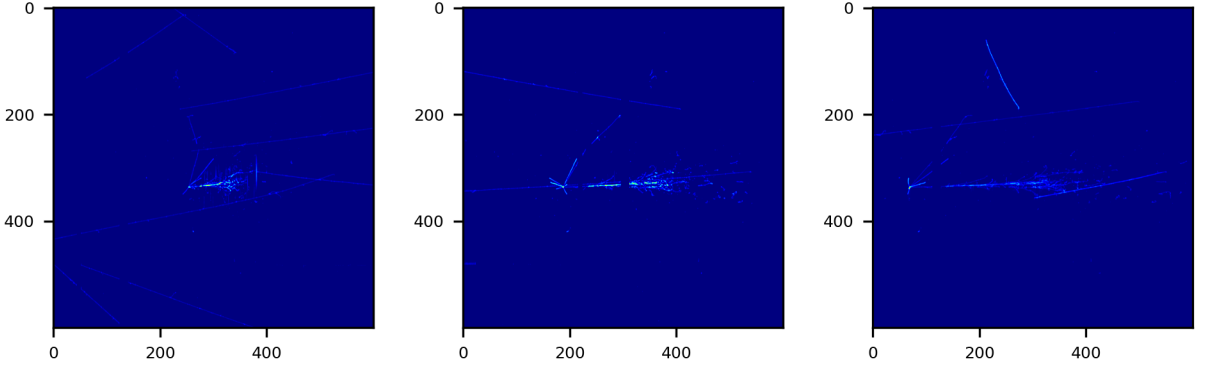
run 5322 subrun 14 event 730
DL Gen2 reco neutrino energy: 1581.57 MeV
Wire Cell reco neutrino energy: 2392.96 MeV
found in DL Gen2: Yes
found in wire cell: Yes



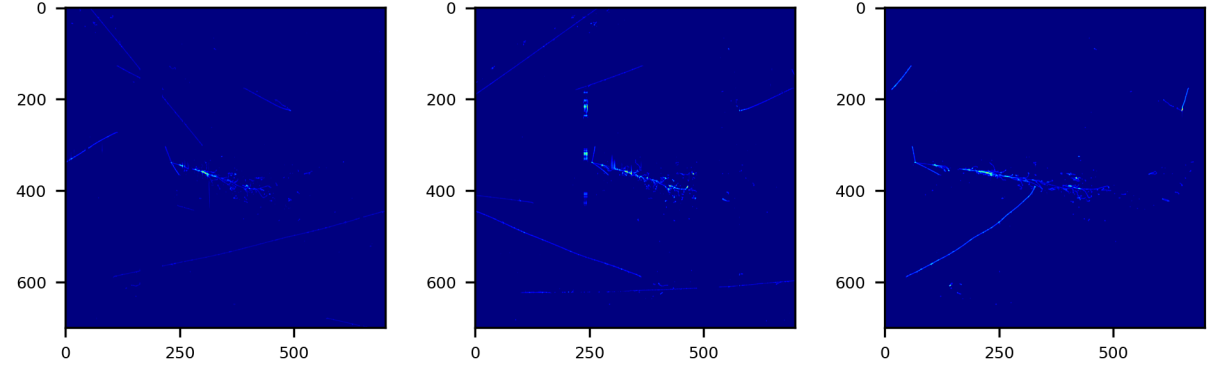
run 5462 subrun 62 event 3136
DL Gen2 reco neutrino energy: 1651.30 MeV
Wire Cell reco neutrino energy: 1712.93 MeV
found in DL Gen2: Yes
found in wire cell: Yes



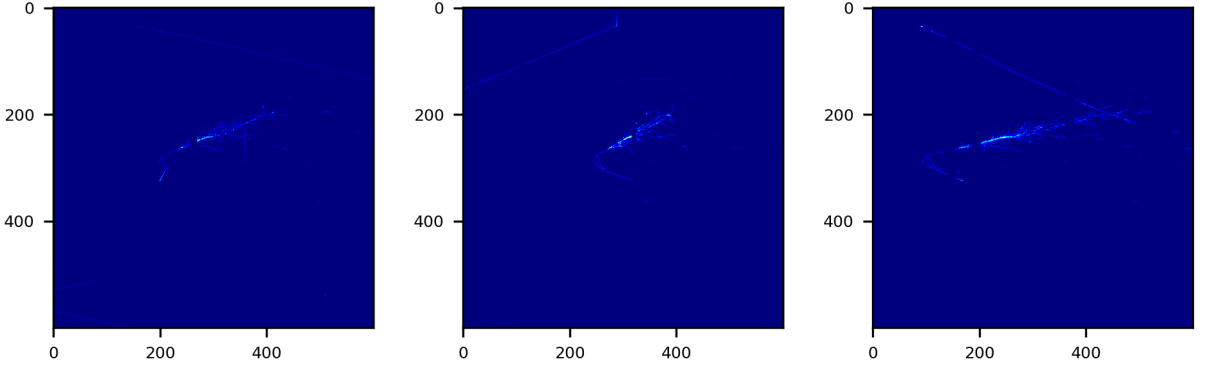
run 5924 subrun 2 event 109
DL Gen2 reco neutrino energy: 1882.50 MeV
Wire Cell reco neutrino energy: ?
found in DL Gen2: Yes
found in wire cell: No



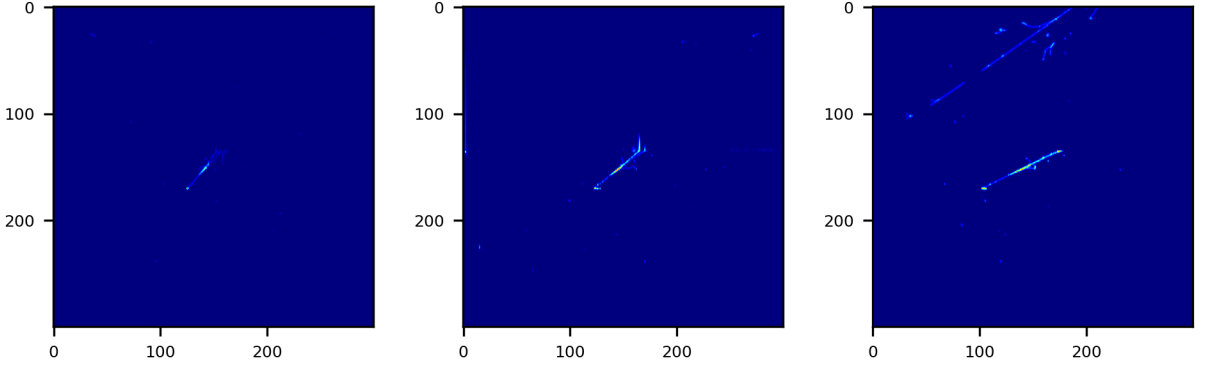
run 5607 subrun 15 event 796
DL Gen2 reco neutrino energy: 1998.50 MeV
Wire Cell reco neutrino energy: 2766.99 MeV
found in DL Gen2: Yes
found in wire cell: Yes



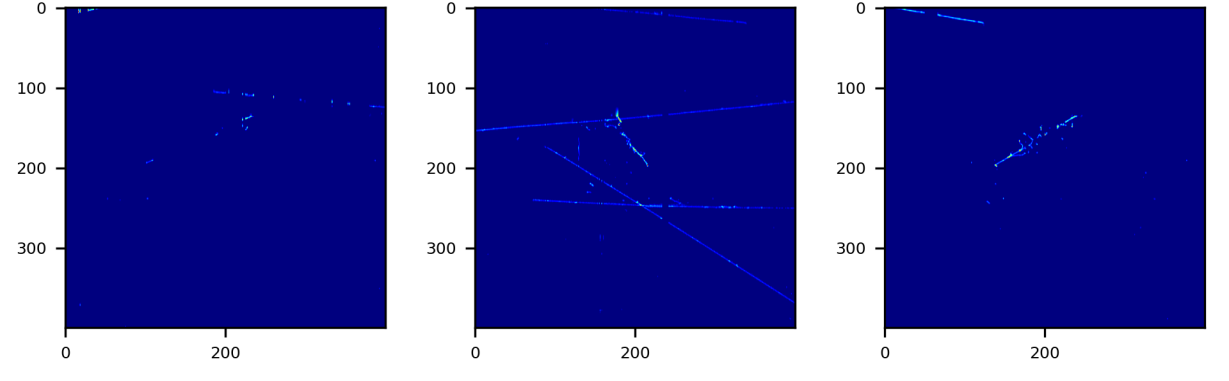
run 5607 subrun 7 event 358
DL Gen2 reco neutrino energy: 3316.72 MeV
Wire Cell reco neutrino energy: 3869.03 MeV
found in DL Gen2: Yes
found in wire cell: Yes



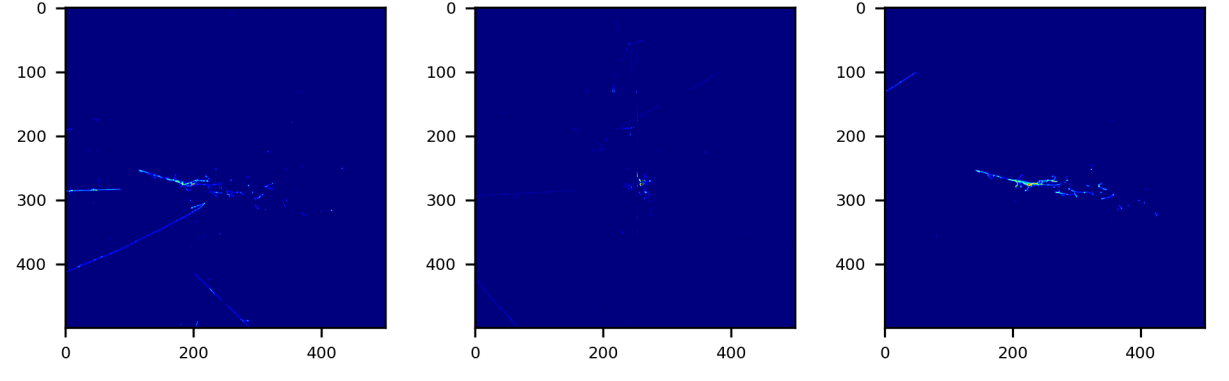
run 5332 subrun 13 event 652
DL Gen2 reco neutrino energy: ?
Wire Cell reco neutrino energy: 236.07 MeV
found in DL Gen2: No
found in wire cell: Yes



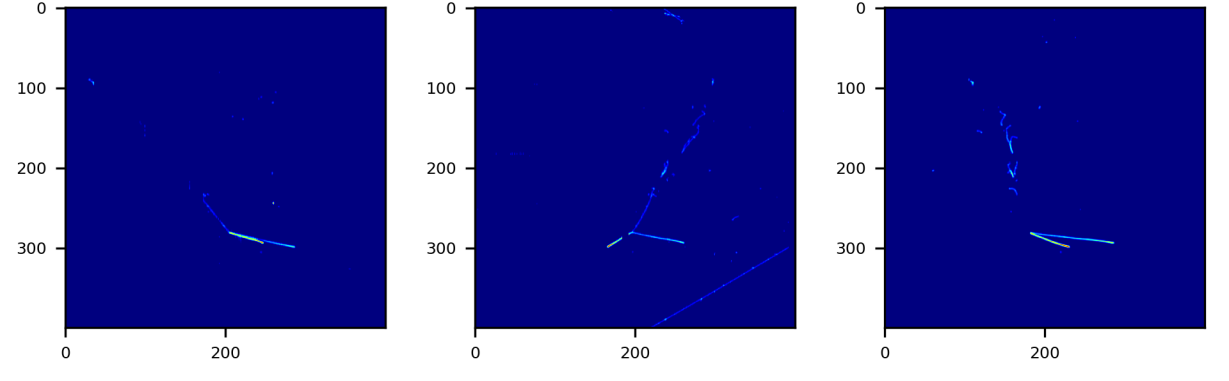
run 5521 subrun 29 event 1484
DL Gen2 reco neutrino energy: ?
Wire Cell reco neutrino energy: 289.00 MeV
found in DL Gen2: No
found in wire cell: Yes



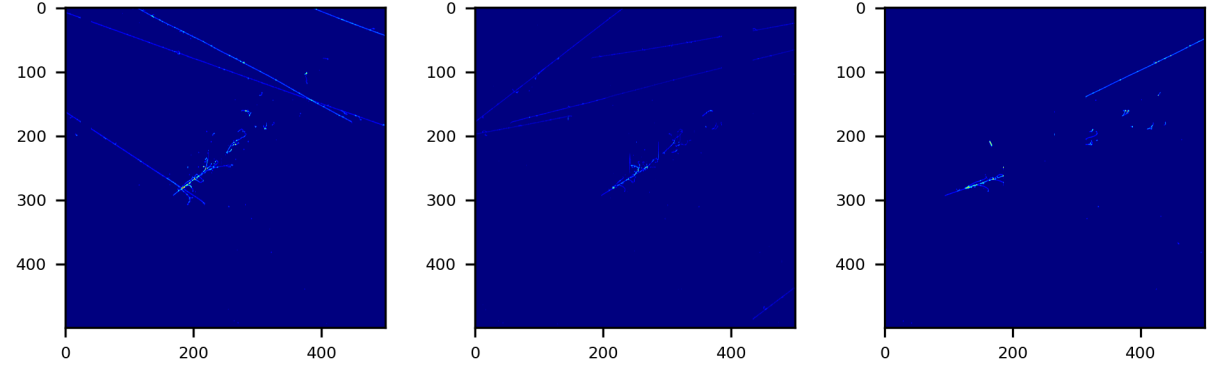
run 5215 subrun 43 event 2167
DL Gen2 reco neutrino energy: ?
Wire Cell reco neutrino energy: 699.03 MeV
found in DL Gen2: No
found in wire cell: Yes



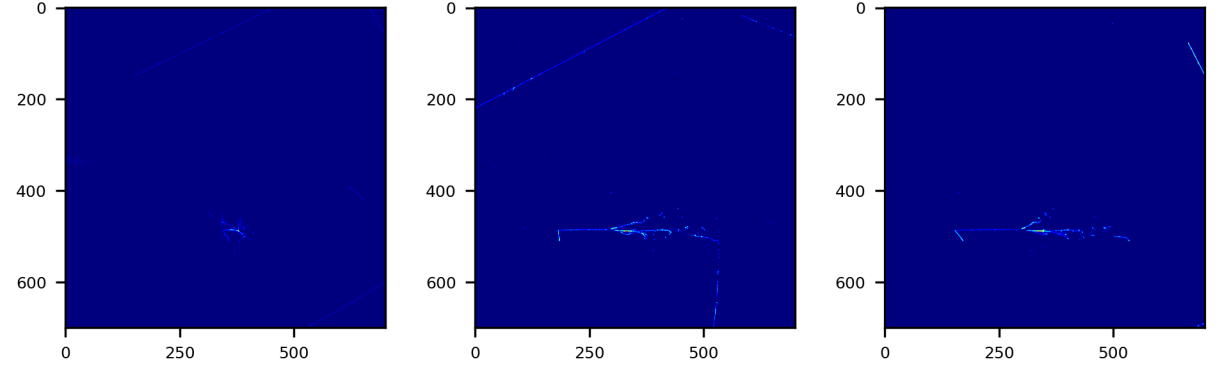
run 5216 subrun 59 event 2981
DL Gen2 reco neutrino energy: ?
Wire Cell reco neutrino energy: 767.06 MeV
found in DL Gen2: No
found in wire cell: Yes



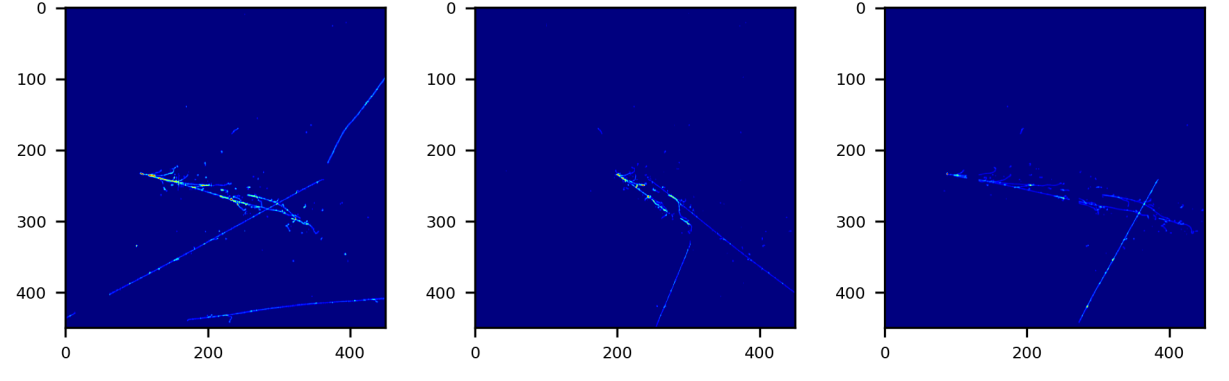
run 5904 subrun 22 event 1128
DL Gen2 reco neutrino energy: 454.99 MeV
Wire Cell reco neutrino energy: 777.99 MeV
found in DL Gen2: No
found in wire cell: Yes



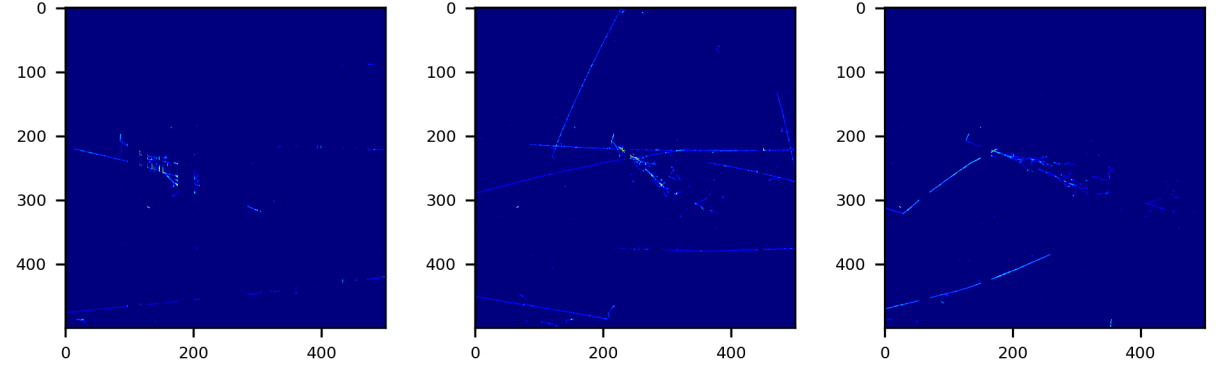
run 5433 subrun 147 event 7362
DL Gen2 reco neutrino energy: 859.33 MeV
Wire Cell reco neutrino energy: 846.06 MeV
found in DL Gen2: No
found in wire cell: Yes



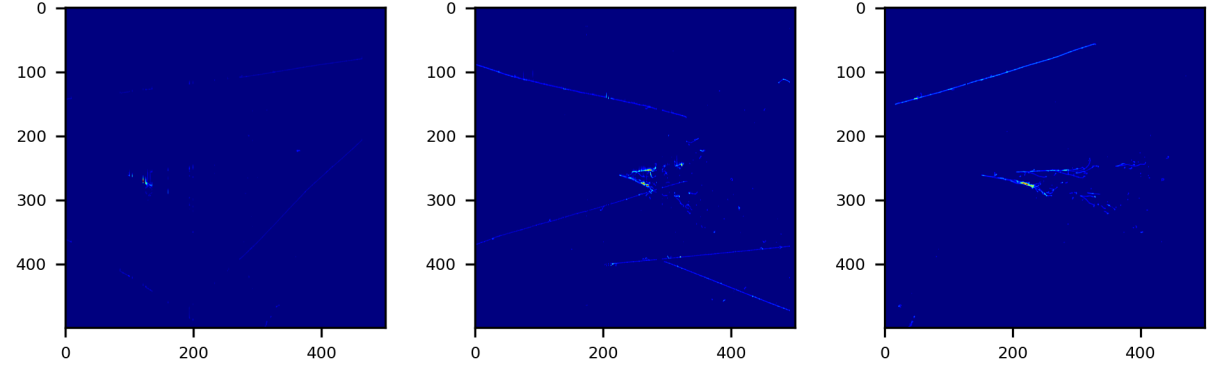
run 5897 subrun 18 event 924
DL Gen2 reco neutrino energy: ?
Wire Cell reco neutrino energy: 882.97 MeV
found in DL Gen2: No
found in wire cell: Yes



run 5418 subrun 119 event 5988
DL Gen2 reco neutrino energy: 684.65 MeV
Wire Cell reco neutrino energy: 1096.28 MeV
found in DL Gen2: No
found in wire cell: Yes



run 5508 subrun 83 event 4173
DL Gen2 reco neutrino energy: 798.31 MeV
Wire Cell reco neutrino energy: 1177.00 MeV
found in DL Gen2: No
found in wire cell: Yes



run 5353 subrun 15 event 783
DL Gen2 reco neutrino energy: 1335.48 MeV
Wire Cell reco neutrino energy: 1956.90 MeV
found in DL Gen2: No
found in wire cell: Yes