# Shower Vertex CNN Update

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ProtoDUNE Reconstruction Meeting

26/07/17

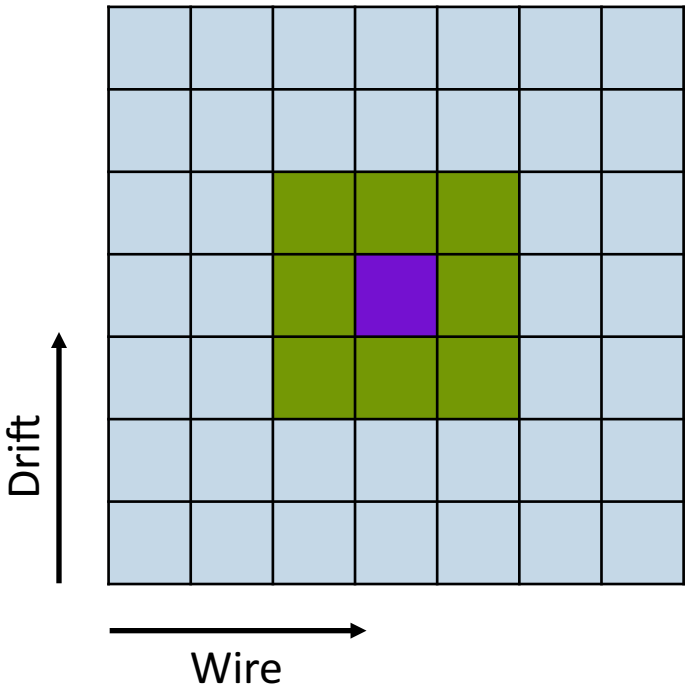
# Introduction

- Previously showed some evidence of the shower vertex CNN working in single event displays
- I put this on the backburner since the code inside LArSoft was slow if I wanted it to be able to find vertices efficiently
- Now tensorflow is in LArSoft, have picked this effort up again
  - Retrained the network using tensorflow
  - Updated the LArSoft implementation of the ShowerVertexFinder module to take advantage of the much higher speed of tensorflow
    - Can afford to be a bit greedier with my searching for identified vertices

Training details can be seen here: https://indico.fnal.gov/event/14798/contribution/1/material/slides/0.pdf

# Being greedy

- Wanted to have a little wriggle-room in identifying a hit as a vertex candidate
  - For each hit, look at nine pixels from the CNN, including the eight neighbours
  - With neighbouring hits, take account of potential overlaps to avoid too many calls to the CNN
- Option to ignore hits from:
  - Track-like clusters from the EM/Track CNN
  - Tracks tagged as cosmic
  - Tracks over a certain length

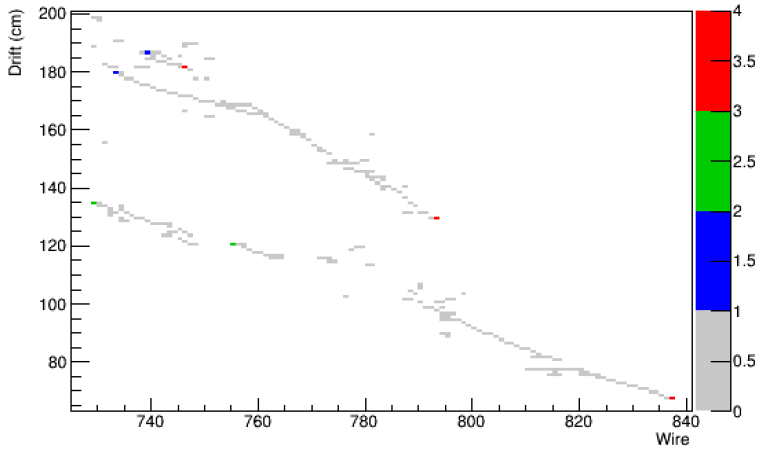


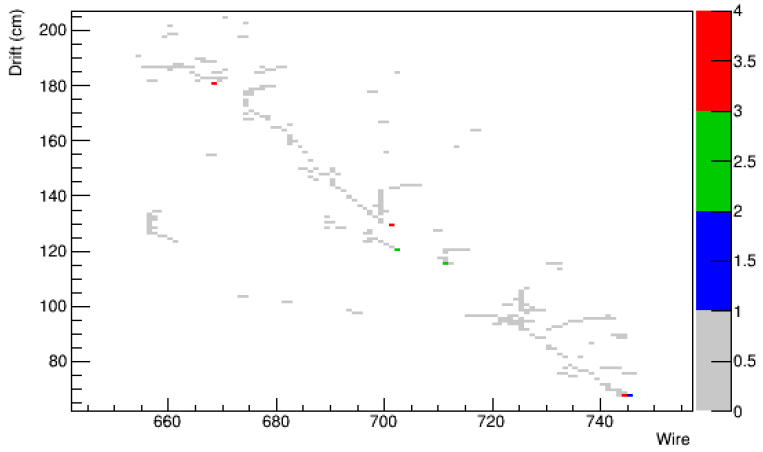
# Methodology

- CNN is applied to each view individually, and gives us a list of identified vertex candidates for each view
- Use the time coordinate (converted to drift position) to match between the three views
  - Require drift coordinate to agree within 1 cm for a match
- Allow matches between all three views and two views to be considered
  - Two view matches subject to finding a hit close to the projection of the vertex into the third view

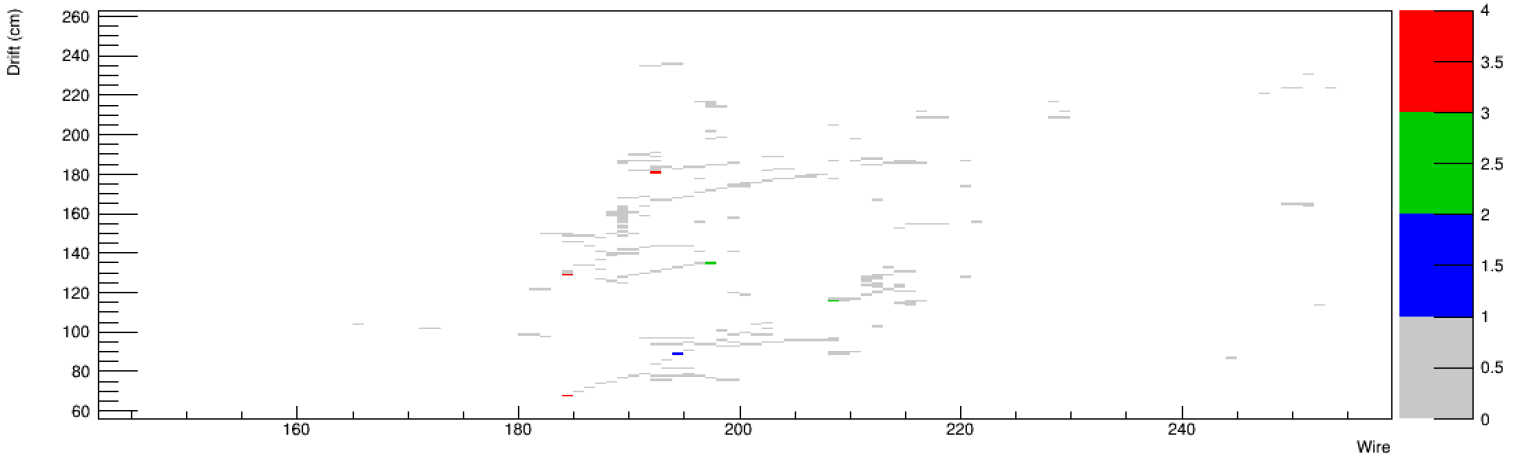
# Matched vertices

- Plot below shows all vertices found in the three views




All considered hits | Unmatched vertices | 2-view matched vertices | 3-view matched vertices



# Testing sample

- The results I present today are based on the following:
  - 1000 pi-zero decays in protoDUNE-SP
  - Energies Gaussian around 500 MeV
    - Somewhat representative of pi-zero energies expected from interactions in the Far Detectors

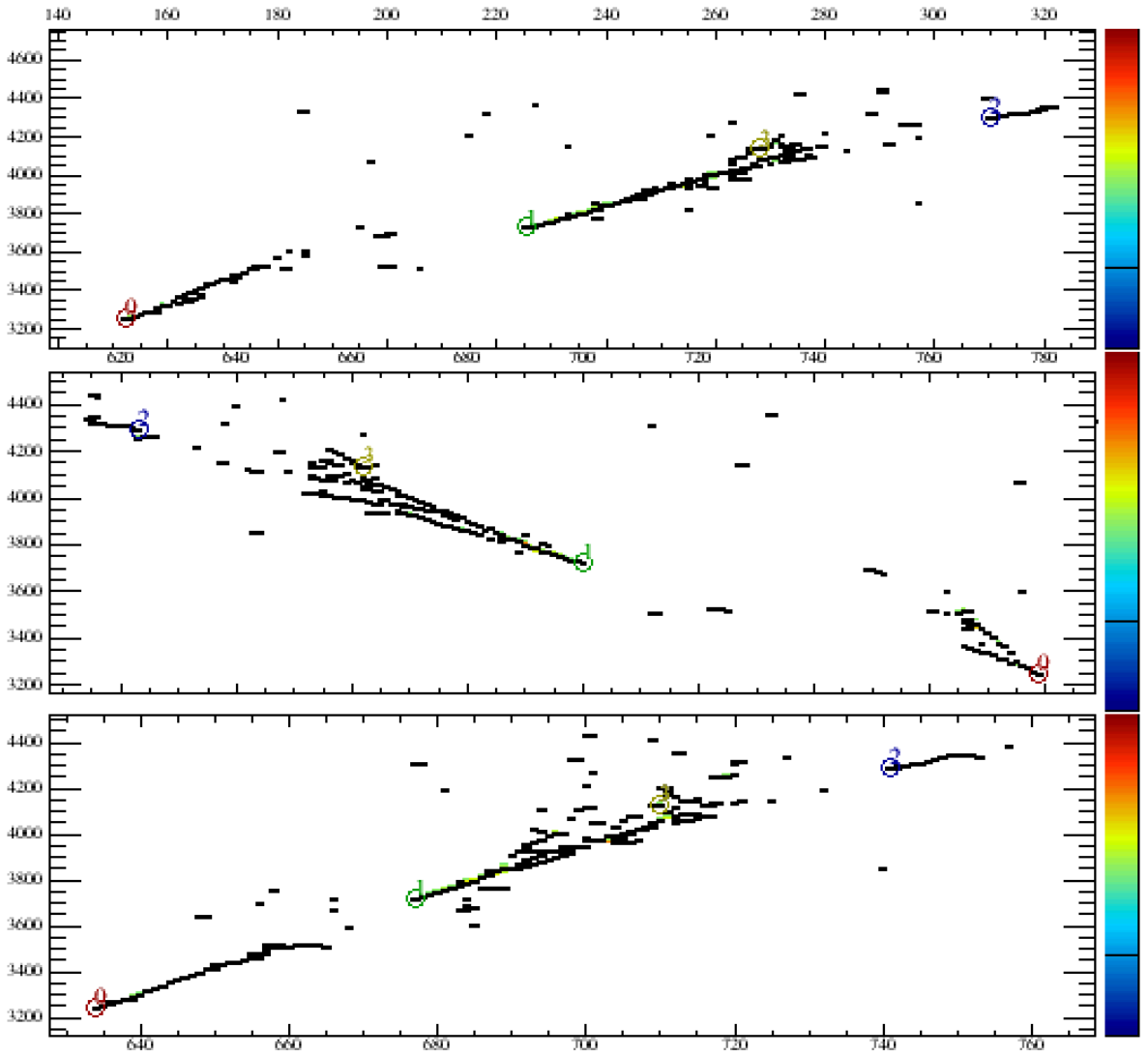
```
physics.producers.generator.PDG: [111]    # Particle ID
physics.producers.generator.PDist: 1    # Momentum distribution (0=uniform, 1=gaussian)
physics.producers.generator.P0: [0.5]     # Central value of momentum (GeV)
physics.producers.generator.SigmaP: [0.50]    # Width of momentum distribution

# This block defines starting parameters for protodune_v2_2.gdml geometry
physics.producers.generator.PosDist: 0    # Position distribution (0=uniform, 1=gaussian)
physics.producers.generator.X0: [0.0]  # Starting position (cm)
physics.producers.generator.Y0: [300.0]
physics.producers.generator.Z0: [300.0]
physics.producers.generator.SigmaX: [300.0]
physics.producers.generator.SigmaY: [300.0]
physics.producers.generator.SigmaZ: [300.0]

physics.producers.generator.AngleDist: 0    # Angle distribution (0=uniform, 1=gaussian)
physics.producers.generator.Theta0XZ: [0.0] # Starting angles (degrees)
physics.producers.generator.Theta0YZ: [0.0]
physics.producers.generator.SigmaThetaXZ: [90.]
physics.producers.generator.SigmaThetaYZ: [90.]
```

# Event display example

- Vertices shown as numbers on the wire, time space
- Vertices 0 and 1 correspond to the photon conversion points
- Vertices 2 and 3 indicate other similar features

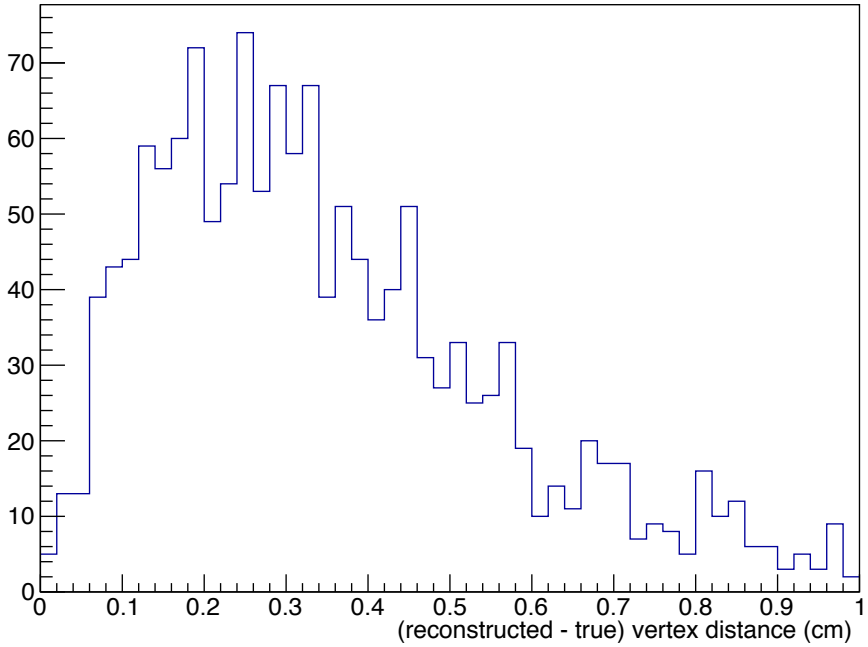


# Performance

- The module can also use truth information to match the reconstructed vertices to the true photon conversion points
- I define a match when the (reconstructed – true) positions agree to within 1 cm
- Not expected to find a match for any true photon that converted outside of the detector (or close to the edge and travelling outwards)
- Next few slides show the quality and efficiency of the algorithm

# Quality of matching

- Plot shows the distribution of the distance between the true and reconstructed shower vertex point

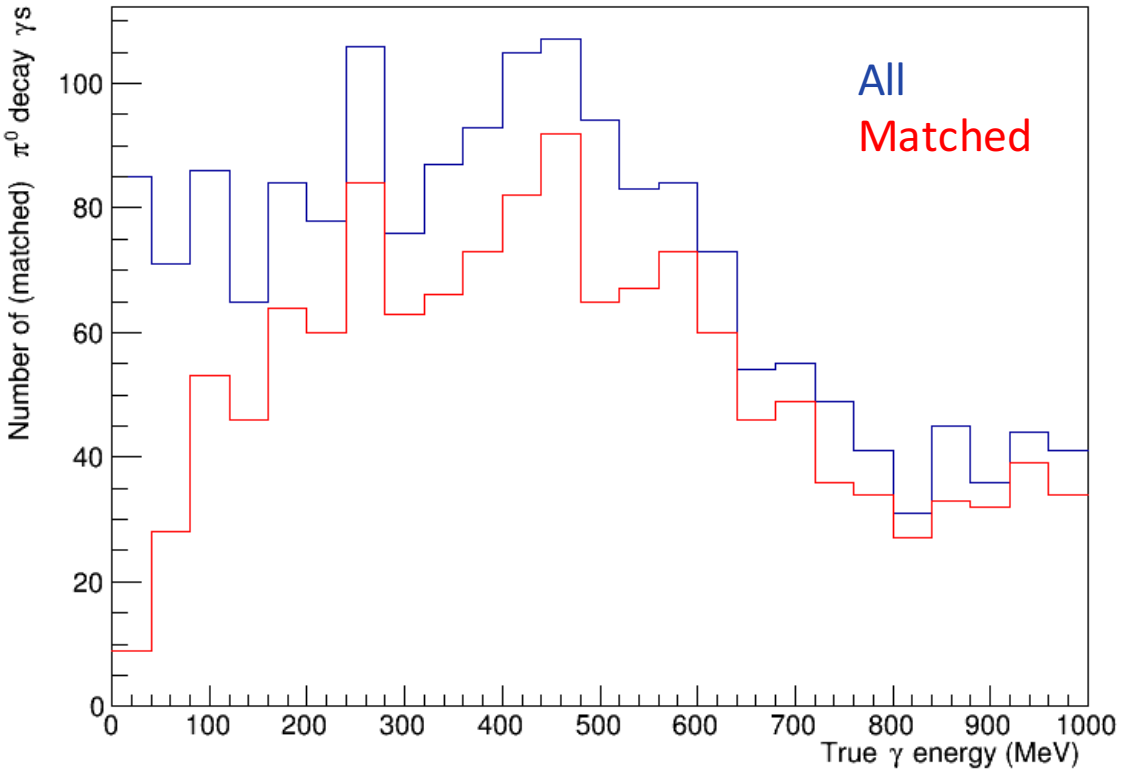



- Integrating from 0, the 68% C.L. width = 0.43 cm
- Gaussian fit (above 0.1): mean = 0.17 cm, sigma = 0.37 cm

# Photon efficiency

- The efficiency calculated using each decay photon individually as a function of the photon energy

- Take the ratio of the photon energy distribution from all photons and those matched to an identified vertex

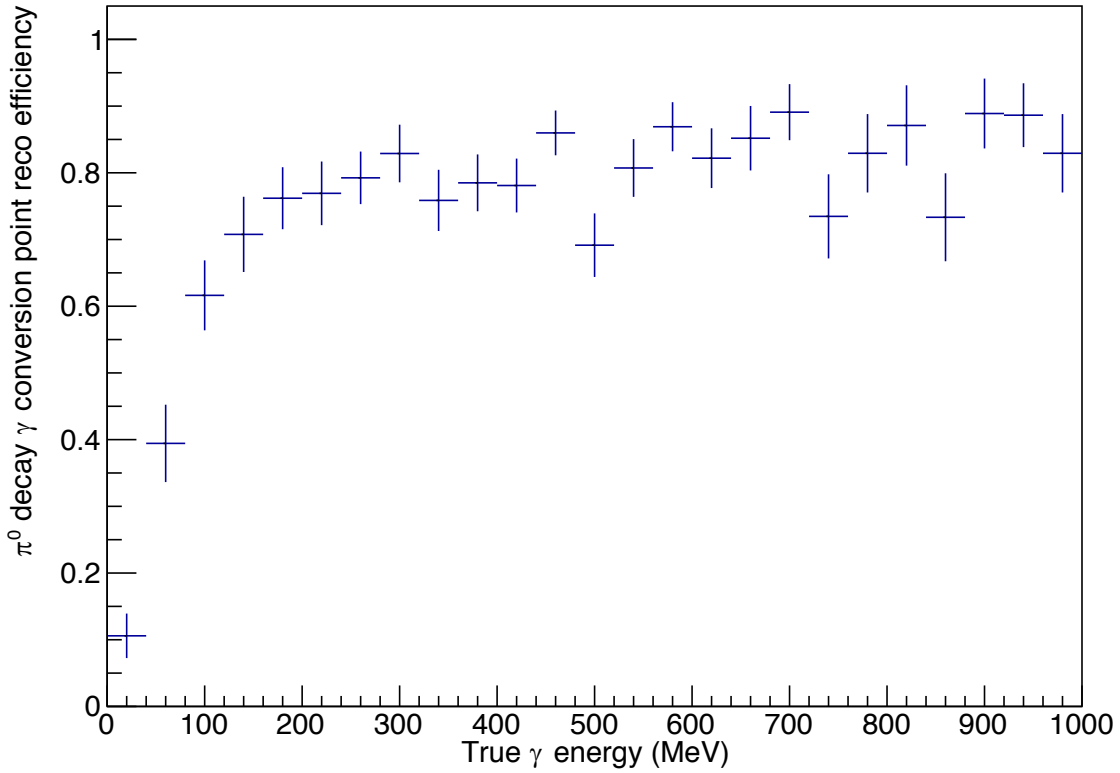


# Photon efficiency

- The efficiency calculated using each decay photon individually as a function of the photon energy

- Integrated efficiency:
  - 75%

- Fitted with pol0 above 200 MeV:
  - 82%



# Photon efficiency

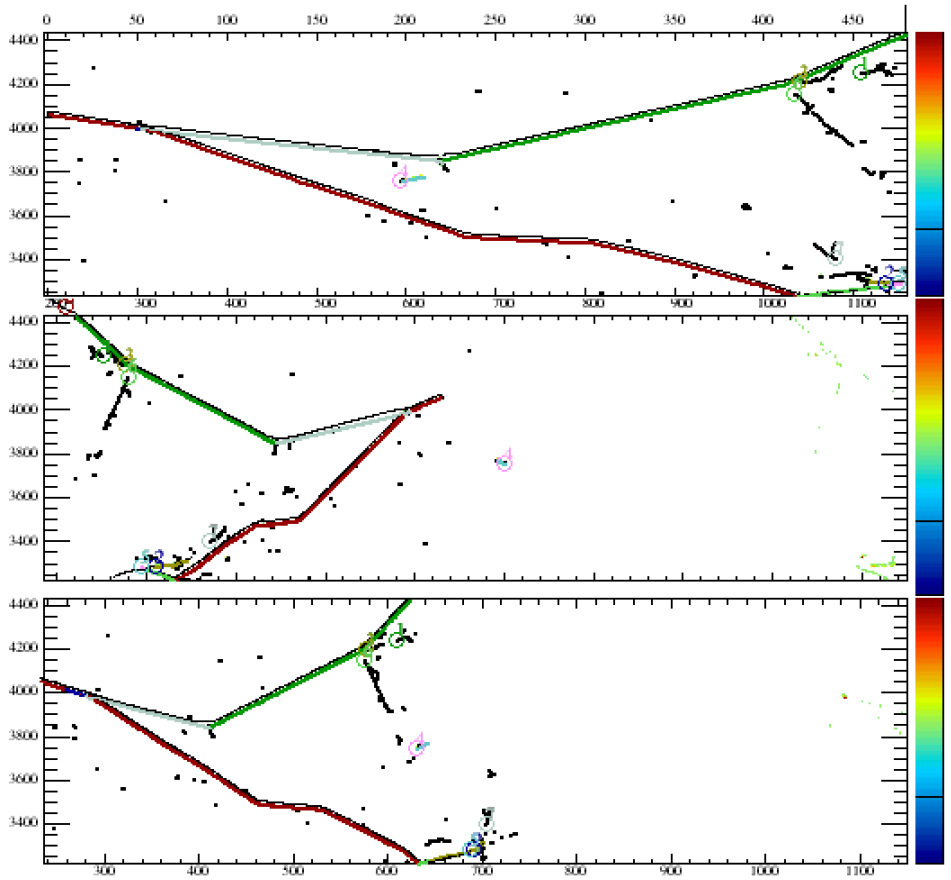
- The low efficiency in the lowest energy bins can be simply explained by the low energy photons producing very few hits

- The plateau does not occur at 100% efficiency mostly due to the topology of some interactions
  - Photons having very similar vertex positions
  - One photon shower is completely buried within the other

- There are some failures where by eye it should work, but most fall into the above categories.
  - These failures are often in interactions where the shower direction is parallel to the readout wires
  - Effectively reduces the number of useful wire planes

# Pizeros in charged particle interactions

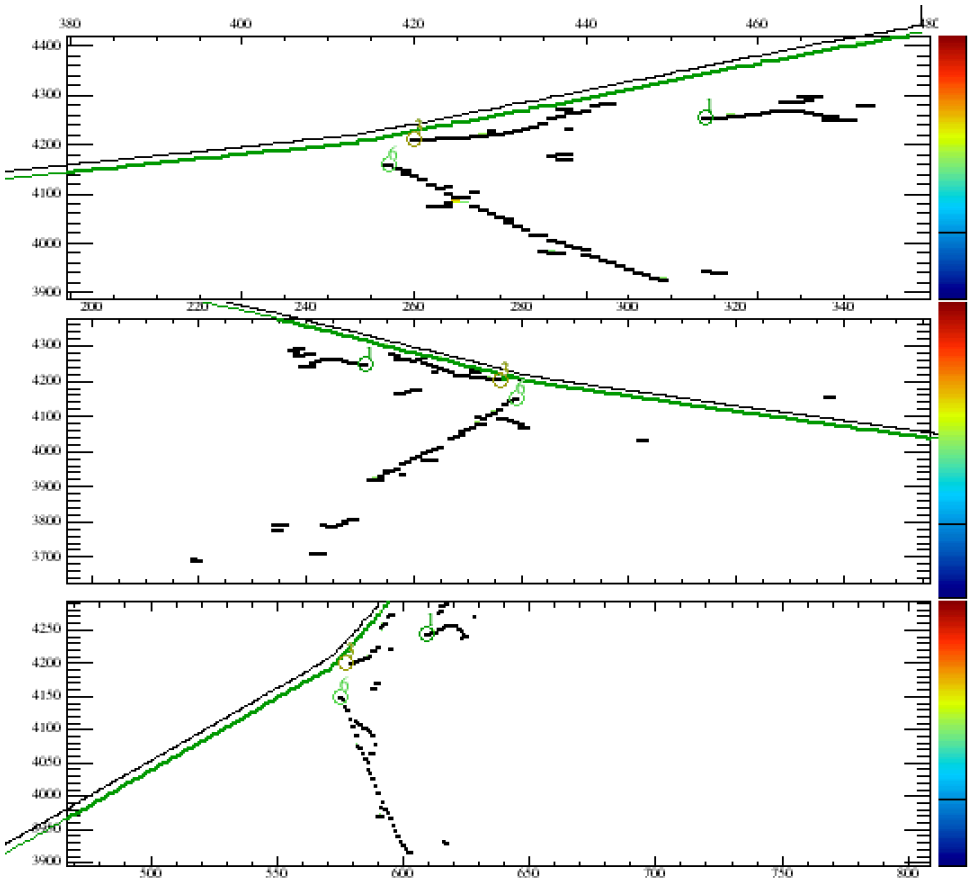
- 3 GeV pion interaction
- Two pi-zeros produced in this event.



```
Found true pi-zero decay at point (372.772, 228.639)
Found true pi-zero decay photon at end point (365.246, 225.071) with energy 226.738
Found true pi-zero decay photon at end point (379.747, 219.868) with energy 33.0249
Found true pi-zero decay at point (424.31, 197.92)
Found true pi-zero decay photon at end point (424.08, 200.354) with energy 148.006
Found true pi-zero decay photon at end point (423.744, 201.889) with energy 118.017
Matched a true vertex (365.246, 225.071) to a reco vertex (365.848, 225.017)
Didn't find a match for true vertex (379.747, 219.868)
 - True position corresponds to wires 664.671, 300.581, 457.655
Matched a true vertex (424.08, 200.354) to a reco vertex (424.115, 200.387)
Matched a true vertex (423.744, 201.889) to a reco vertex (424.515, 201.824)
```

# Pizeros in charged particle interactions

- 3 GeV pion interaction
- Two pi-zeros produced in this event.
- Reconstruct three of the photon vertices here
  - Final one is very low energy and not seen



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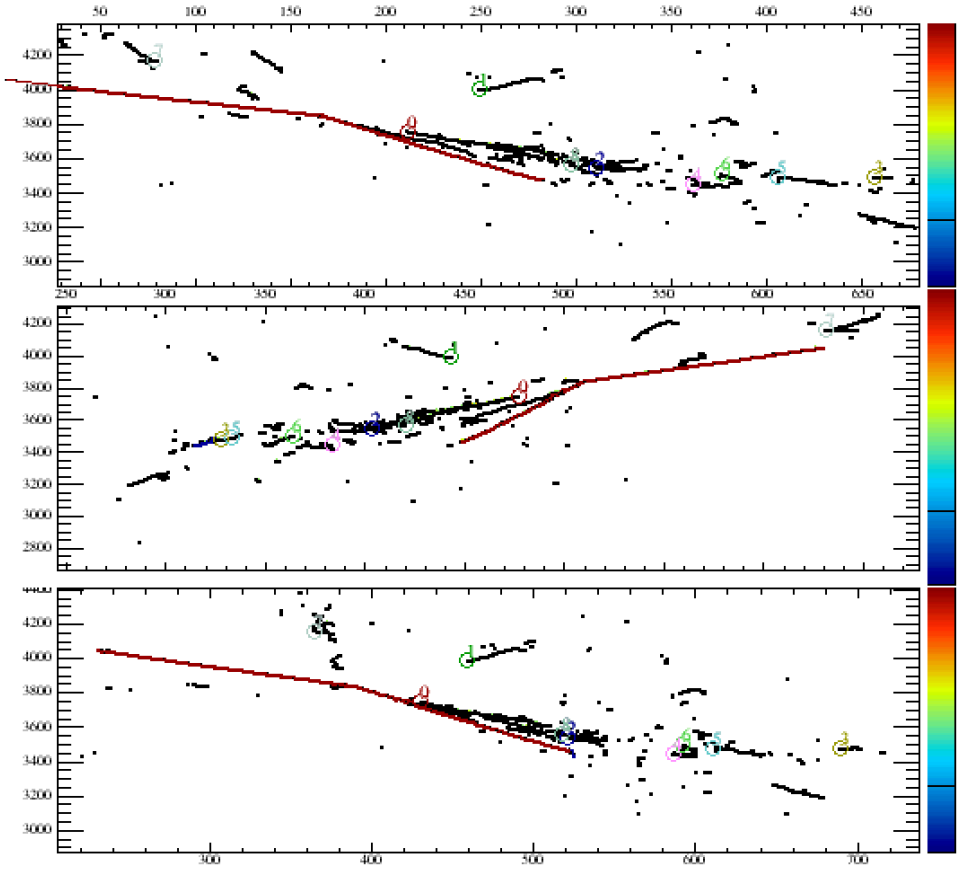
```

# Pizeros in charged particle interactions

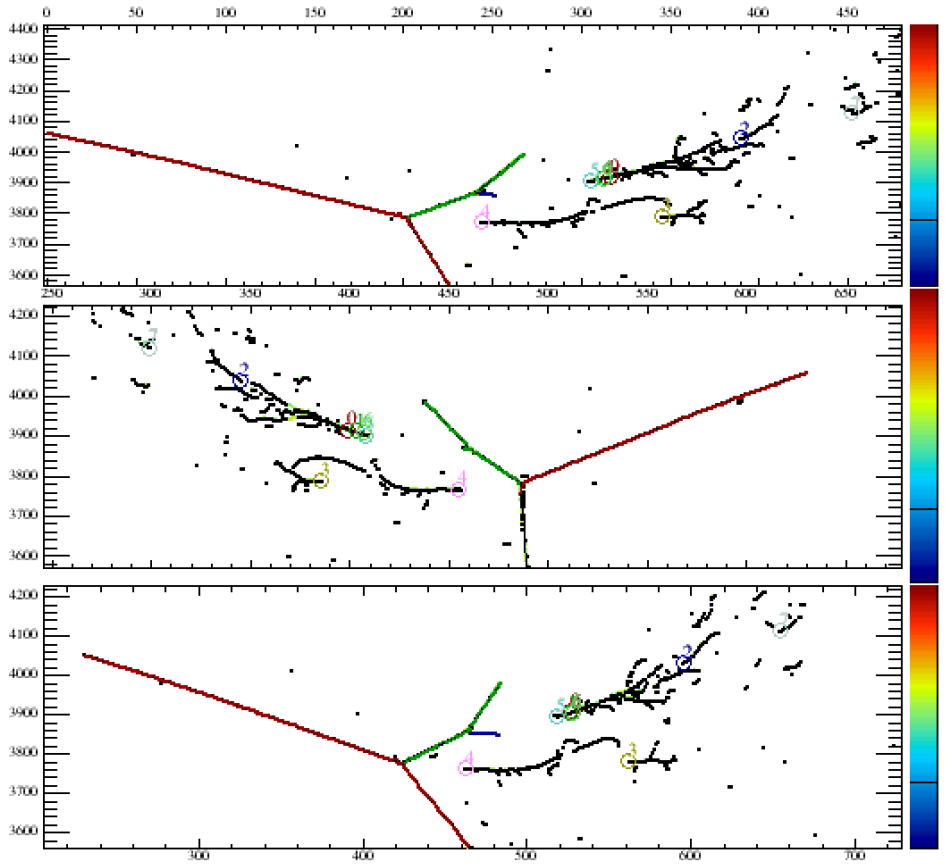
- 3 GeV pion interaction
- Three pi-zeros produced in this event.
  - Only reconstruct two photons here (vertices 0 and 1)
  - One collinear with track, one buried in the big shower, others quite low energy



```
Found true pi-zero decay at point (406.105, 80.7176)
Found true pi-zero decay photon at end point (402.515, 89.1164) with energy 239.459
Found true pi-zero decay photon at end point (402.93, 101.675) with energy 1190.29
Found true pi-zero decay at point (406.105, 80.7176)
Found true pi-zero decay photon at end point (477.677, 35.3669) with energy 51.0811
Found true pi-zero decay photon at end point (391.18, 63.2007) with energy 131.782
Found true pi-zero decay at point (406.105, 80.7176)
Found true pi-zero decay photon at end point (401.569, 70.1212) with energy 82.0241
Found true pi-zero decay photon at end point (404.931, 119.898) with energy 95.1742
Didn't find a match for true vertex (402.515, 89.1164)
 - True position corresponds to wires 408.811, 499.517, 184.8
Matched a true vertex (402.93, 101.675) to a reco vertex (403.047, 101.682)
Didn't find a match for true vertex (477.677, 35.3669)
 - True position corresponds to wires 221.378, 499.042, 72.6347
Didn't find a match for true vertex (391.18, 63.2007)
 - True position corresponds to wires 377.909, 558.759, 130.719
Didn't find a match for true vertex (401.569, 70.1212)
 - True position corresponds to wires 376.958, 533.736, 145.16
Matched a true vertex (404.931, 119.898) to a reco vertex (405.047, 119.794)
```

# Pizeros in charged particle interactions

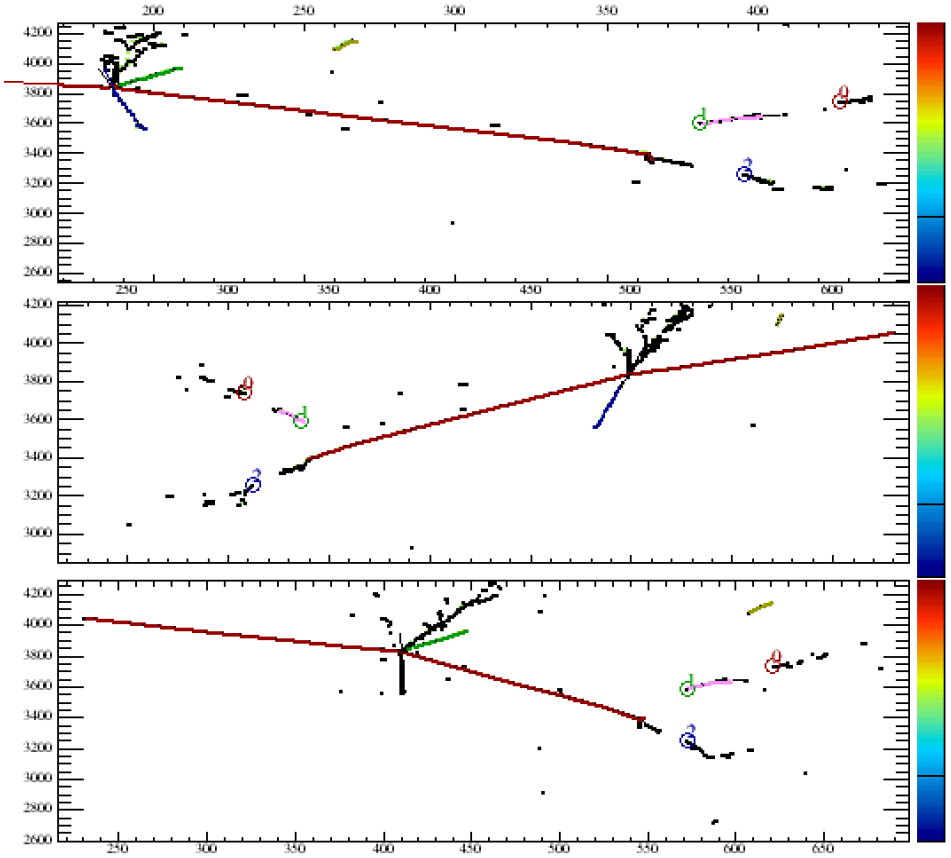
- 3 GeV proton interaction
- Generally see lower pi-zero multiplicities
- Single pi-zero with both photons clearly visible and identified



```
Found true pi-zero decay at point (402.166, 97.059)
Found true pi-zero decay photon at end point (398.996, 117.102) with energy 356.204
Found true pi-zero decay photon at end point (395.107, 146.425) with energy 830.387
Matched a true vertex (398.996, 117.102) to a reco vertex (399.047, 117.207)
Matched a true vertex (395.107, 146.425) to a reco vertex (395.447, 146.819)
```

# Pizeros in charged particle interactions

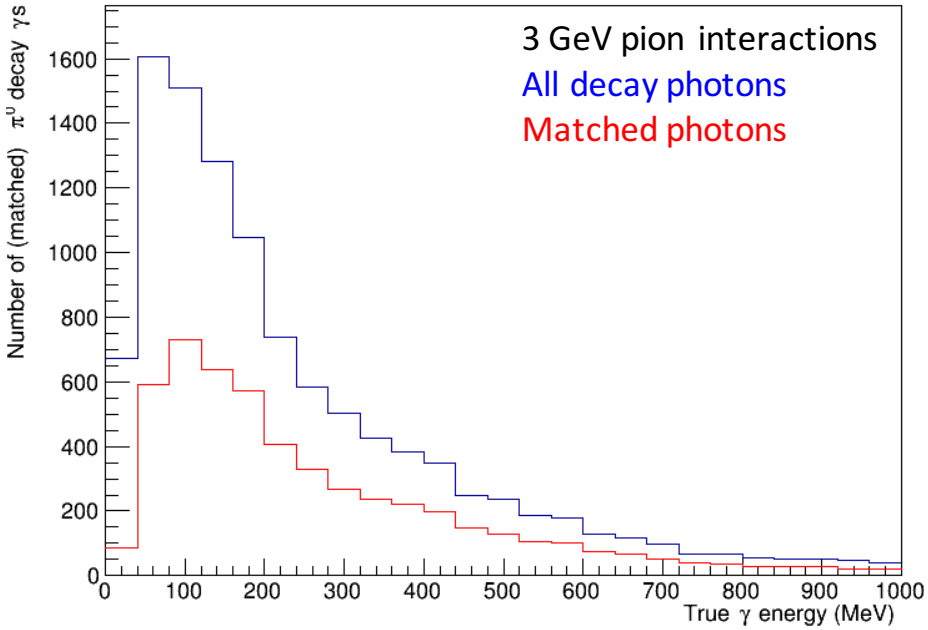
- 3 GeV proton interaction
- Two pi-zeros here
- Two photons convert right in the vertex so are missed
- Other photon missed as it extends the red track

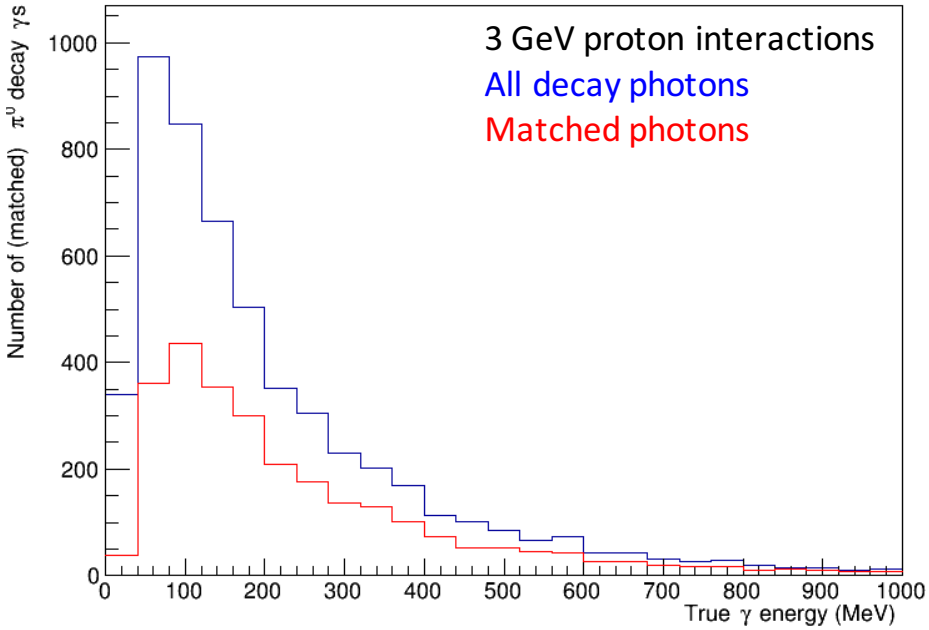


```
Found true pi-zero decay at point (402.895, 89.6609)
Found true pi-zero decay photon at end point (405.951, 88.9142) with energy 41.8474
Found true pi-zero decay photon at end point (402.416, 89.7494) with energy 384.11
Found true pi-zero decay at point (410.193, 162.882)
Found true pi-zero decay photon at end point (411.538, 176.246) with energy 117.021
Found true pi-zero decay photon at end point (402.514, 182.999) with energy 141.802
Didn't find a match for true vertex (405.951, 88.9142)
 - True position corresponds to wires 404.164, 495.574, 184.378
Didn't find a match for true vertex (402.416, 89.7494)
 - True position corresponds to wires 410.036, 498.541, 186.121
Didn't find a match for true vertex (411.538, 176.246)
 - True position corresponds to wires 549.063, 336.707, 366.622
Matched a true vertex (402.514, 182.999) to a reco vertex (402.647, 183.043)
```

# Photon efficiency

- The efficiency calculated using each decay photon individually as a function of the photon energy



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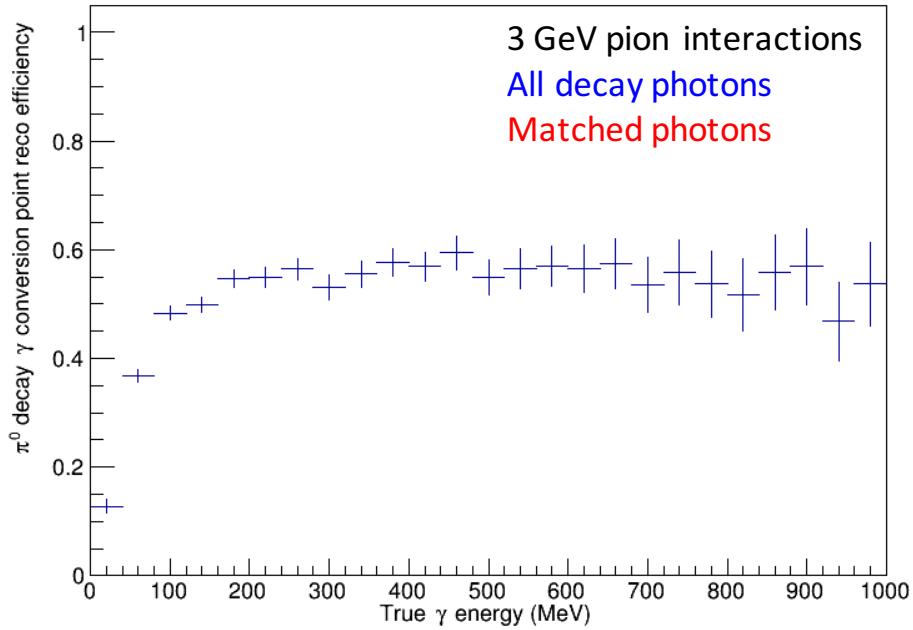
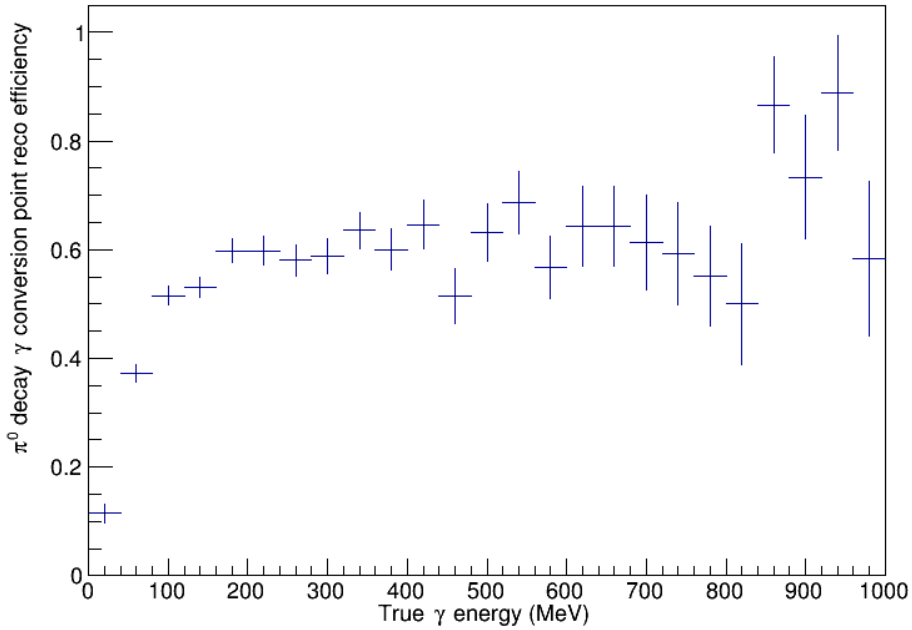



Efficiency = 49% (56% above 200 MeV)




Efficiency = 51% (61% above 200 MeV)

- Pion events typically busier (and a higher number of pizeros)

# Summary

- The shower vertex finding looks to work very well on a sample of pi-zero decays
  - Efficiency is 74% (80% for E > 200 MeV)
- For beam events (pion and proton at 3GeV), efficiency drops to roughly 50% (60% above 200 MeV)
- Still the absolute efficiency isn't necessarily the right metric, we just need to know whether a given shower was due to an electron or not (gap detection)
- Need to test on some full protoDUNE beam + cosmic samples…

# DUNE physics week

- Samples for the Physics week…
- /pnfs/dune/persistent/users/lwhite86/analysisweek/showervertex/
  - pizero/ - The 1000 events presented here
  - pion3GeV/ - The 5000 events presented here
  - proton3GeV/ - The 5000 events presented here
  - beam3GeVCosmic/ - In progress
  - fdNeutrino/ - Hope to start soon
- I will provide a code snippet showing how to access the vertices
- Next slide shows how to run the module

# Running the module

- The code lives in a feature branch at the moment
  - lhw_shwVtxCNN
- Example .fcl file: /dune/app/users/lwhite86/cnnOutput/runShowerCNNReco.fcl

```
#include "protoDUNE_reco.fcl"

process_name: Reco

physics.producers.pmtrack.HitModuleLabel:                       "linecluster"
physics.producers.pmtrack.ClusterModuleLabel:                   "emtrkmichelid:emtrkmichel"
physics.producers.pmtrack.PMAlgTracking.TrackLikeThreshold:     0.63
physics.producers.pmtrack.PMAlgTracking.MinSeedSize2ndPass:     3
physics.producers.pmtrack.PMAlgTracking.Validation:             "adc"
physics.producers.pmtrack.PMAlgTracking.AdcValidationThr:       [0.8, 0.8, 1.0]
physics.producers.pmtrack.PMAlgTracking.RunVertexing:           true
physics.producers.pmtrack.PMAlgTracking.FlipToBeam:             true
physics.producers.pmtrack.PMAlgTracking.MatchT0inCPACrossing:   true
physics.producers.pmtrack.PMAlgCosmicTagging.TagOutOfDriftTracks: true
physics.producers.pmtrack.PMAlgCosmicTagging.TagFullHeightTracks: true
physics.producers.pmtrack.PMAlgCosmicTagging.TagNonBeamT0Tracks:  true
physics.producers.pmtrack.PMAlgCosmicTagging.TagTopFrontBack:   true
physics.producers.pmtrack.PMAlgCosmicTagging.TagApparentStopper:  true
physics.producers.pmtrack.PMAlgCosmicTagging.VetoActualStopper:   false
physics.producers.pmtrack.PMAlgCosmicTagging.StopperBuffer:     2

physics.producers.showervertexfinder:                          @local::standard_showervertexfinder
physics.producers.showervertexfinder.PointIdAlg.NNetModelFile: "/dune/app/users/lwhite86/cnnOutput/showerVtxCNN_TF.proto.pb"
physics.producers.showervertexfinder.PointIdAlg.PatchSizeW:    44
physics.producers.showervertexfinder.PointIdAlg.PatchSizeD:    48
physics.producers.showervertexfinder.PointIdAlg.DriftWindow:   6
physics.producers.showervertexfinder.PointIdAlg.DownscaleFn:   "mean"
physics.producers.showervertexfinder.HitModuleLabel:           "linecluster"
physics.producers.showervertexfinder.InputMVALabel:            "emtrkmichelid:emtrkmichel"
physics.producers.showervertexfinder.Views:                    []
physics.producers.showervertexfinder.InputMVACut:              0.99
physics.producers.showervertexfinder.VertexMVACut:             0.90
physics.producers.showervertexfinder.CalcPiZeroEfficiency:     true
physics.producers.showervertexfinder.CosmicModuleLabel:        "pmtrack"
physics.producers.showervertexfinder.IgnoreCosmics:            true
physics.producers.showervertexfinder.IgnoreLongTracks:         true
physics.producers.showervertexfinder.LongTrackCut:             1.0
physics.producers.showervertexfinder.TruthMatchDist:           1.0

physics.reco: [ rns, caldata, gaushit, hitfd, linecluster, pandora, pandoracalo, pandorapid, emtrkmichelid, pmtrack, showervertexfinder, pmtrackcalo, pmtrackpid ]
```