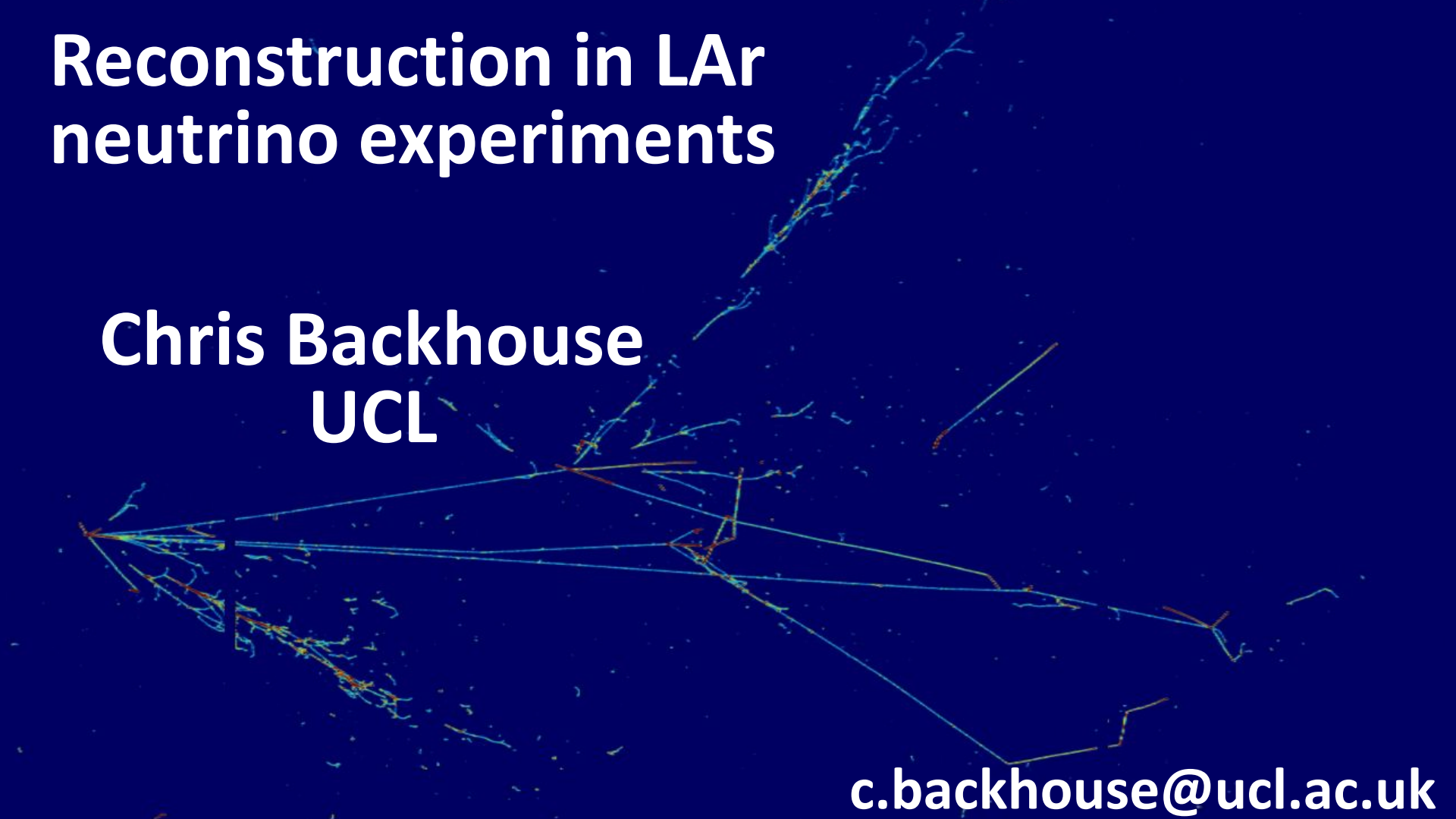
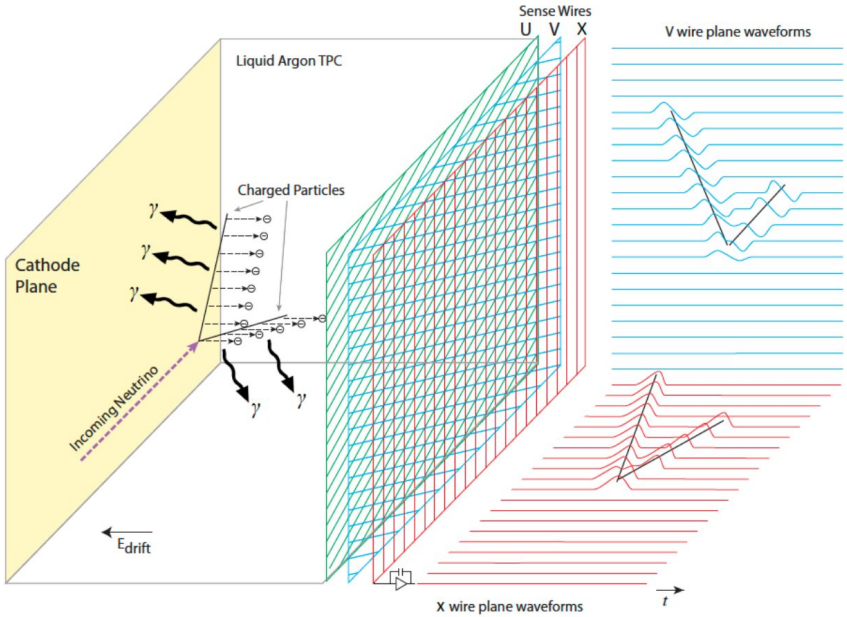
Reconstruction in LAr neutrino experiments



Chris Backhouse
UCL

c.backhouse@ucl.ac.uk

Introduction



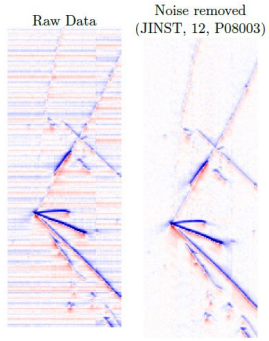
- Thanks to Andy Chappell (Warwick) for many of these slides
- Need to reconstruct the flavour and energy of the incident neutrino
- Ideally reconstruct detailed final state
- Other event sources
  - Cosmic rays, SN neutrinos, nucleon decay, atmospheric neutrinos, calibration sources...

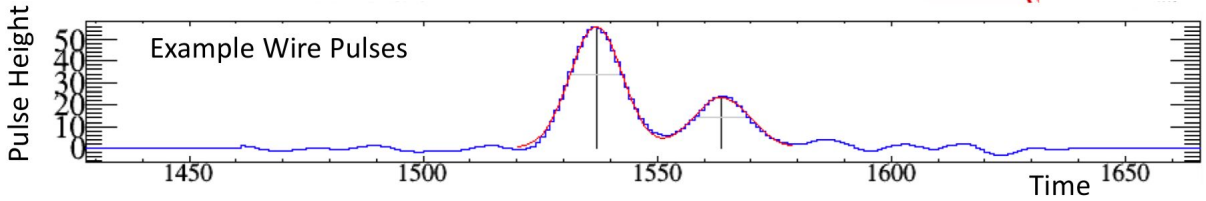
- I am presenting with a DUNE-oriented bias, but there is a whole family of LArTPC neutrino experiments:
  - DUNE (HD, VD, ND), ArgoNeuT, MicroBooNE, SBND, Icarus…
- Lots of shared infrastructure and cross-pollination
  - nutools, larsoft, wirecell, pandora...

μBooNE
SHORT-BASELINE NEAR DETECTOR
SBND
IMAGING COSMIC AND RARE UNDERGROUND SIGNALS
ICARUS
ArgoNeuT
DUNE

Reconstruction stages

- "DataPrep" - remove pedestals, correlated noise, etc
  - Eminently parallelizable
- Deconvolution - map bipolar induction signals to unipolar
  - Lots of Fourier transforms
- Hit finding
  - Also needs to happen online for trigger
- **Pattern recognition**
- Event ID
  - Traditional MVAs based on reconstructed particles, or full event image CNN (CVN)





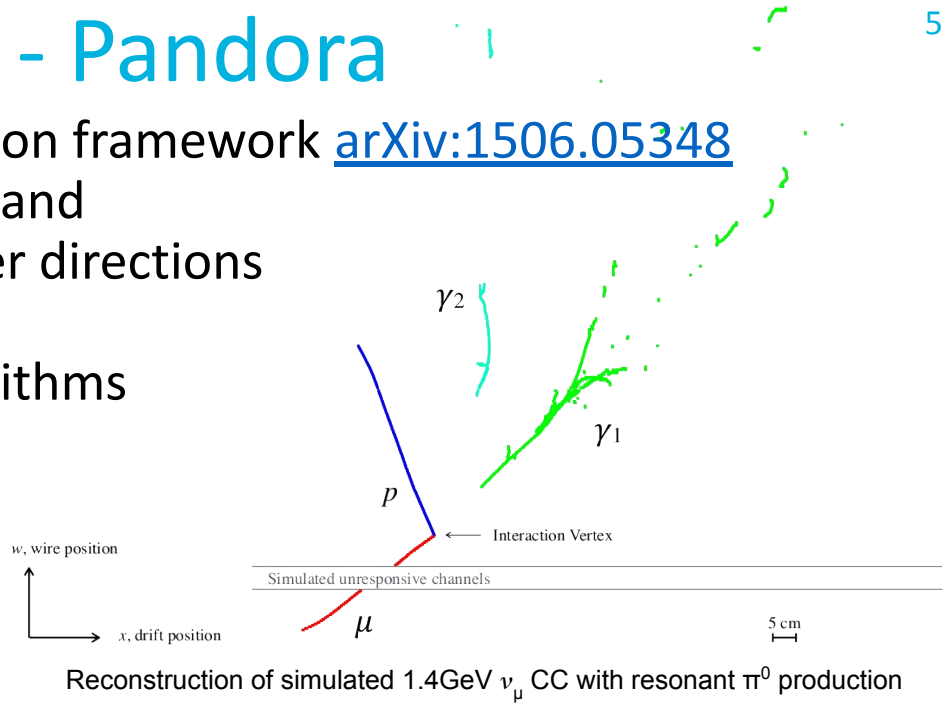
Documentation

- MicroBooNE have done a great job documenting their analysis. Some highlights:
  - “Wire-Cell 3D Pattern Recognition Techniques for Neutrino Event Reconstruction in Large LAr TPCs”, arXiv:2110.13961
  - “Cosmic Ray Background Rejection with Wire-Cell LAr TPC Event Reconstruction in the MicroBooNE Detector”, arXiv:2101.05076
  - “Semantic Segmentation with a Sparse Convolutional Neural Network for Event Reconstruction in MicroBooNE”, arXiv:2012.08513
  - “Neutrino Event Selection in the MicroBooNE LArTPC using Wire-Cell 3D Imaging, Clustering, and Charge-Light Matching”, arXiv:2011.01375
  - ”A Convolutional Neural Network for Multiple Particle Identification in the MicroBooNE LArTPC”, arXiv:2010.08653
  - “Vertex-Finding and Reconstruction of Contained Two-track Neutrino Events in the MicroBooNE Detector”, arXiv:2002.09375
  - “A Deep Neural Network for Pixel-Level Electromagnetic Particle Identification in the MicroBooNE LArTPC”, arXiv:1808.07269
  - “The Pandora Multi-Algorithm Approach to Automated Pattern Recognition of Cosmic Rays and Neutrinos in MicroBooNE”, arXiv:1708.03135
  - “Convolutional Neural Networks Applied to Neutrino Events in a LArTPC”, arXiv:1611.05531

- Other experiments
  - “Cosmic Background Removal with Deep Neural Networks in SBND”, arXiv:2012.01301
  - “Neutrino interaction classification with a convolutional neural network in the DUNE far detector”, arXiv:2006.15052

Pattern recognition - Pandora

- Pandora is a widely-used reconstruction framework arXiv:1506.05348
- Goal is to cluster hits by true particle and reconstruct track trajectories / shower directions
- Multi-algorithm approach
- Mostly “classical” so far, but ML algorithms can slot in where appropriate
- Focus on two today:
  - Track/shower CNN
  - Vertex CNN

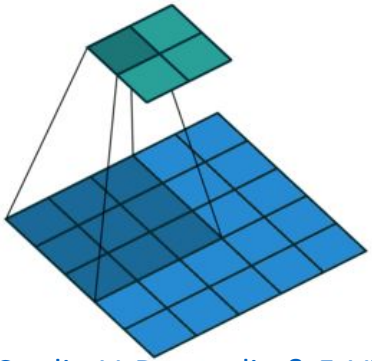


Reconstruction of simulated 1.4GeV ν_μ CC with resonant π^0 production

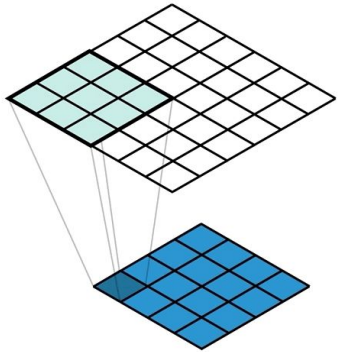
- Other event reconstruction approaches exist
- e.g. the three strands of the recent MicroBooNE result used
  - Semantic segmentation
  - Pandora
  - WireCell https://lar.bnl.gov/wire-cell/

Track / shower separation

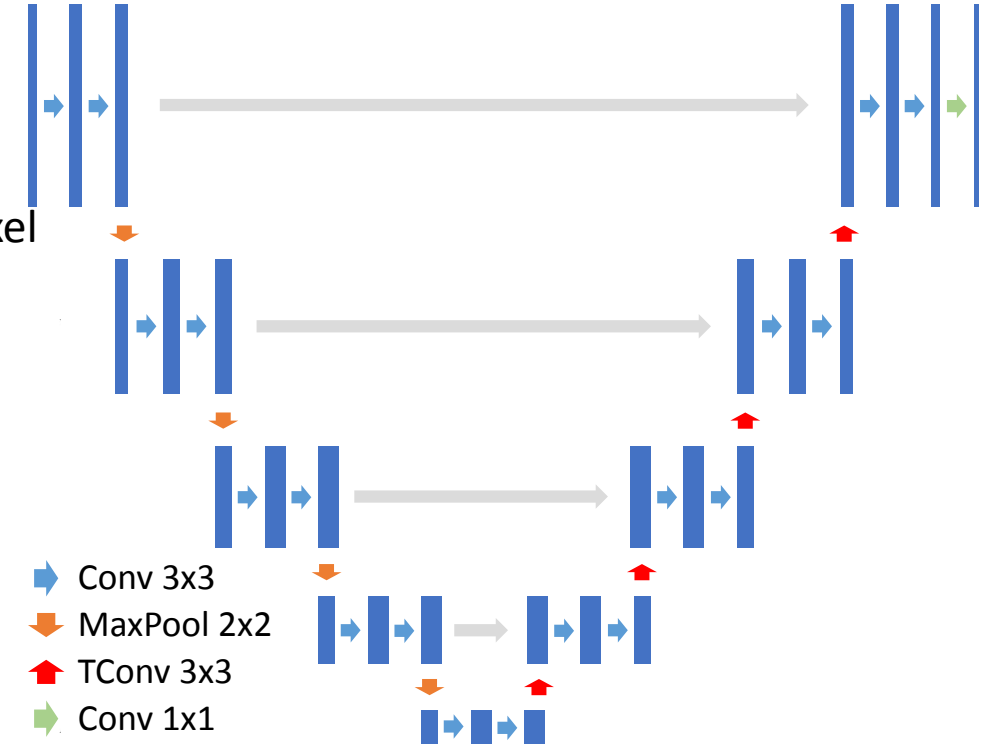
- Different algorithms are appropriate for track-like and shower-like parts
- Classify hits up-front using a network
- U-Net architecture developed for biomedical image segmentation in 2015 arXiv:1505.04597
  - Downsampling convolutions
  - Upsampling transpose convolutions
  - Skip connections
  - Assign track/shower prob. to each pixel



Credit: V. Dumoulin & F. Visin

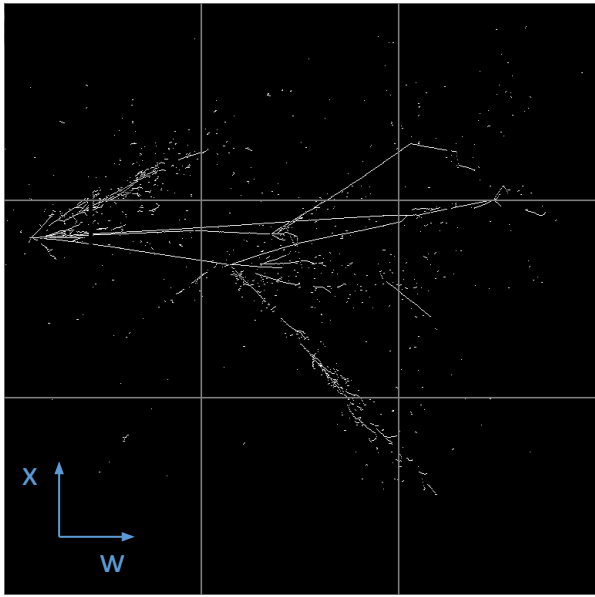


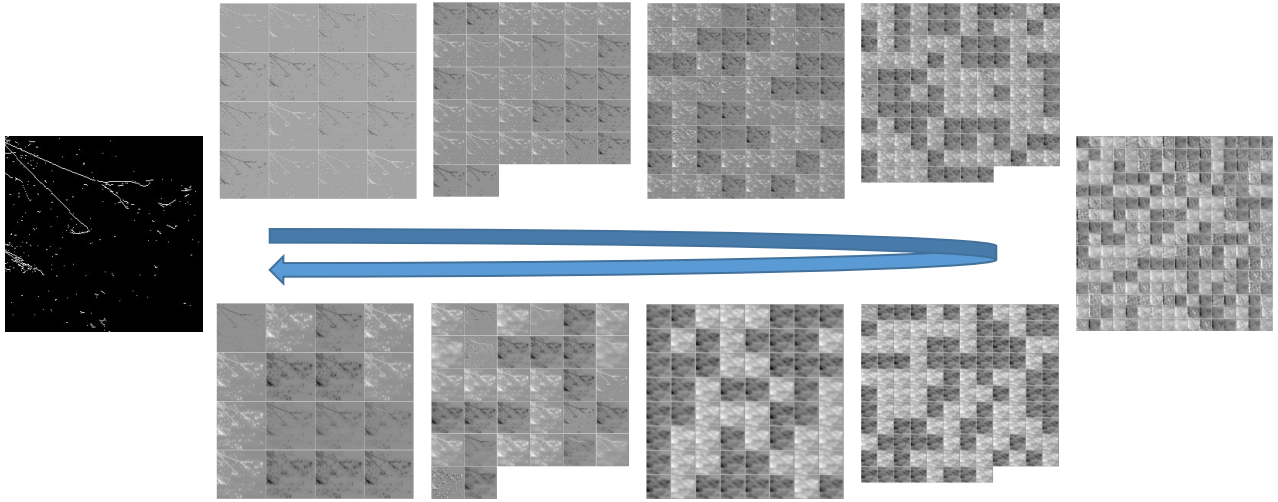
Credit: T. Lane



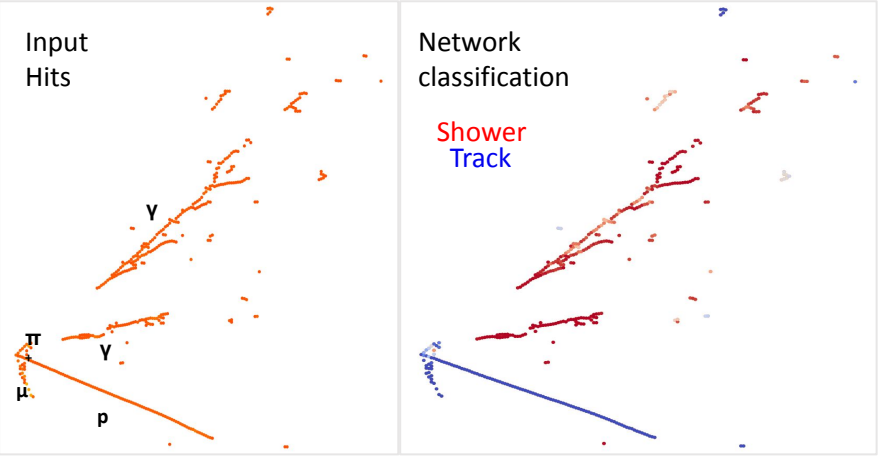
Track / shower separation

- Train on 100k simulated neutrino interactions
- Break image into 256^2 pixel tiles
- Allows a degree of sparsification (skip empty tiles)





Track / shower separation

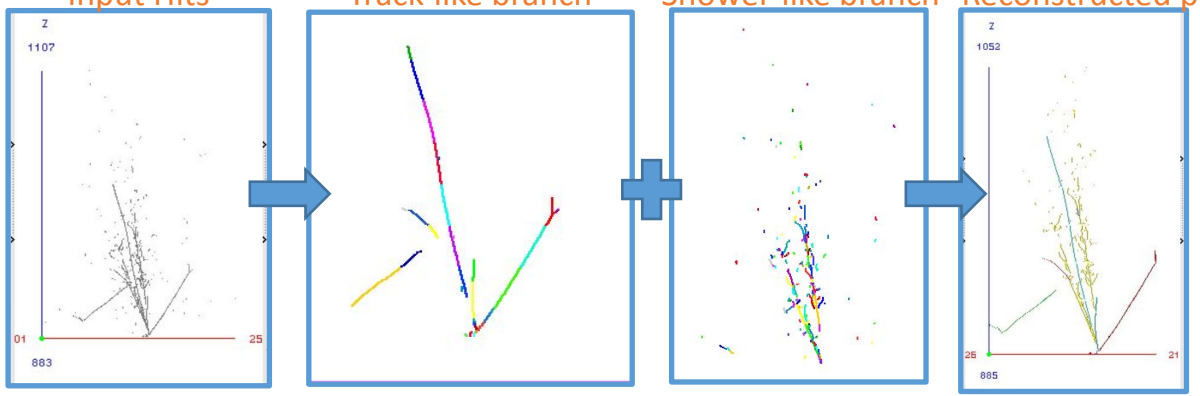


True\Net	Shower	Track
Shower	95.0%	3.9%
Track	5.0%	96.0%
Σ	100%	100%

Confusion matrix for W view

- Pandora algorithms provide initial clusters
- Classify clusters based on majority vote of hit-level classification
- Algorithms can target separated track and shower topologies

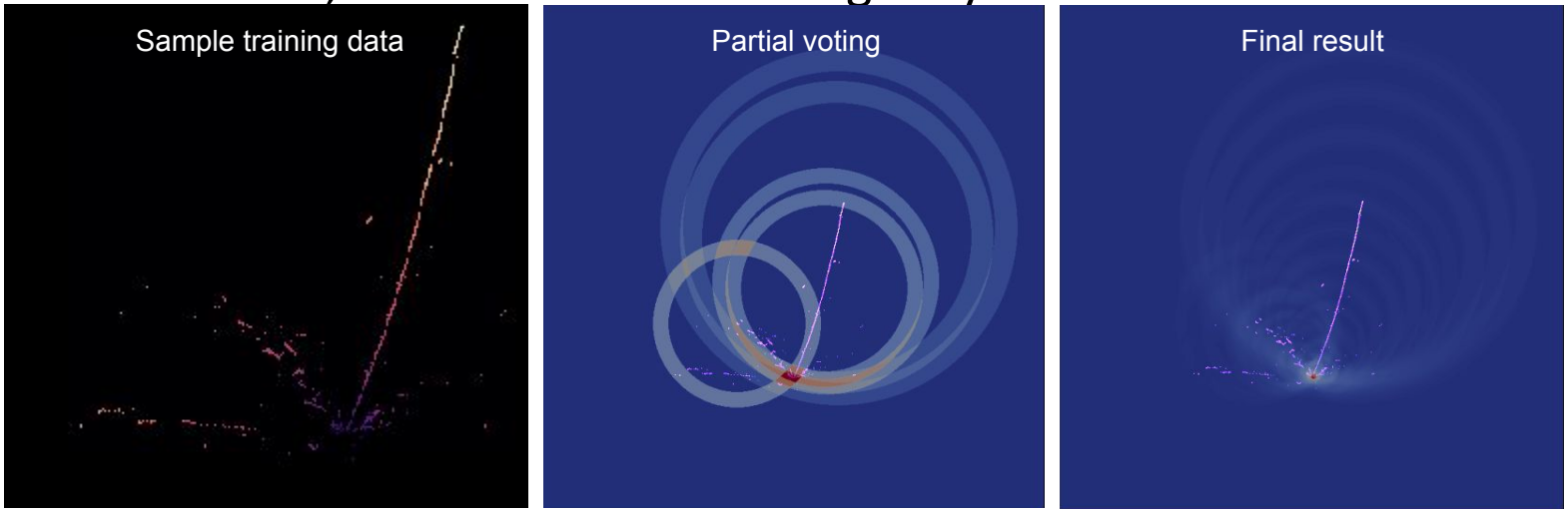
Example ~2 GeV CC DIS interaction



- Executed on CPU in production contexts
- Some experimentation with GPU-as-a-service
- Wrapper around NVidia's Triton API

Vertex finding

- Location of neutrino interaction vertex is an important reconstruction hint
  - Reconstruct showers directed away from the vertex
  - Be less willing to merge reco objects close to the vertex
- Regression networks exist for vertex position, neutrino energy, lepton angle arXiv:2012.06181
- Pandora experimenting with differently-designed DL vertexing algorithm
- Rather than regressing single vertex position, network predicts distance of each hit to vertex, result based on a Hough-style vote



Conclusion

- Low level data processing ripe for parallelization / acceleration
- Full-event classification and regression networks trivially so
- My impression: neutrino reconstruction less “monolithic” than colliders, no single algorithm that should be obsessively optimized
- Reconstruction is often using hybrid of traditional approaches with DL elements
  - Highlighted a couple of examples here
  - Interesting challenge to make efficient use of acceleration for small subsets of the workflow
- Other whole-event approaches exist, both for classification/characterization and full reconstruction
  - Graph networks
  - 3D sparse convolutions

  ....