Atmospheric neutrino reconstruction with Pandora

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10 November 2021 / Institute of Physics / Opportunities with Atmospheric Neutrinos workshop

DEEP UNDERGROUND NEUTRINO EXPERIMENT

WARWICK
THE UNIVERSITY OF WARWICK

Outline

- Aim of this presentation: provide **initial thoughts on atmospheric neutrino reconstruction in a LArTPC** using **Pandora**
- Atmospheric neutrinos will be **first DUNE neutrino dataset**
- Pandora for accelerator nu good starting point for atmospheric nu reco
- Differences between beam and atmospheric neutrinos
- First look at atmospheric neutrino reconstruction with Pandora
- Reconstruction development plans

Many thanks to the Pandora team, and especially Andy Blake*, for recent discussion

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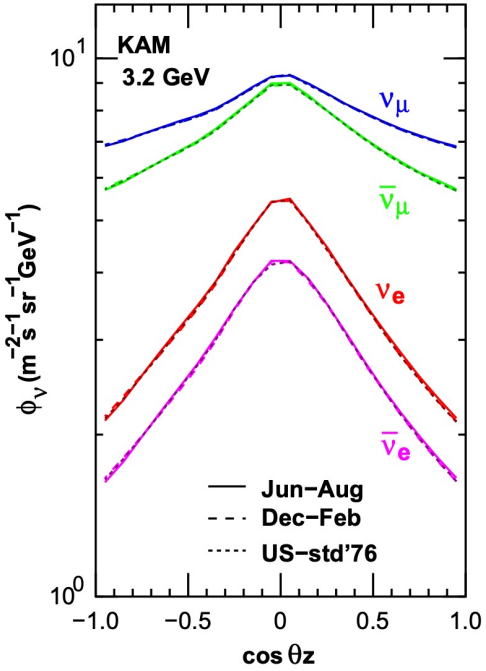
Beam vs atmospheric neutrinos

- Different energy spectrum
- Completely different angular distribution
- Different flavour composition (e.g. υ_e/υ_μ ratio is very different)
- Different mix of neutrinos and antineutrinos (no neutrino or antineutrino modes!)
- Different oscillations. Atmospheric neutrinos:
  - can be used to probe matter effects and MSW resonance
  - have much broader range of L/E
  - Can be used to access more oscillation modes such as tau neutrino appearance.



Arrival zenith angle dependence of atmospheric neutrino fluxes averaged over all azimuth angles at 3.2 GeV.
M. Honda, M. Sajjad Athar, T. Kajita
arXiv:1502.03916v2

Pandora for atmospheric neutrinos

- Advanced accelerator neutrino reconstruction with Pandora
- What needs adjusting for atmospheric neutrinos?
  - Our transverse reconstruction must be as good as our longitudinal reconstruction

- We can't utilise any beam-related constraints within the reconstruction
  - e.g. cannot expect interaction vertex to be upstream in beam direction
- In most cases, we need an input T0 from an external (photon) detector

Physics-driven requirements

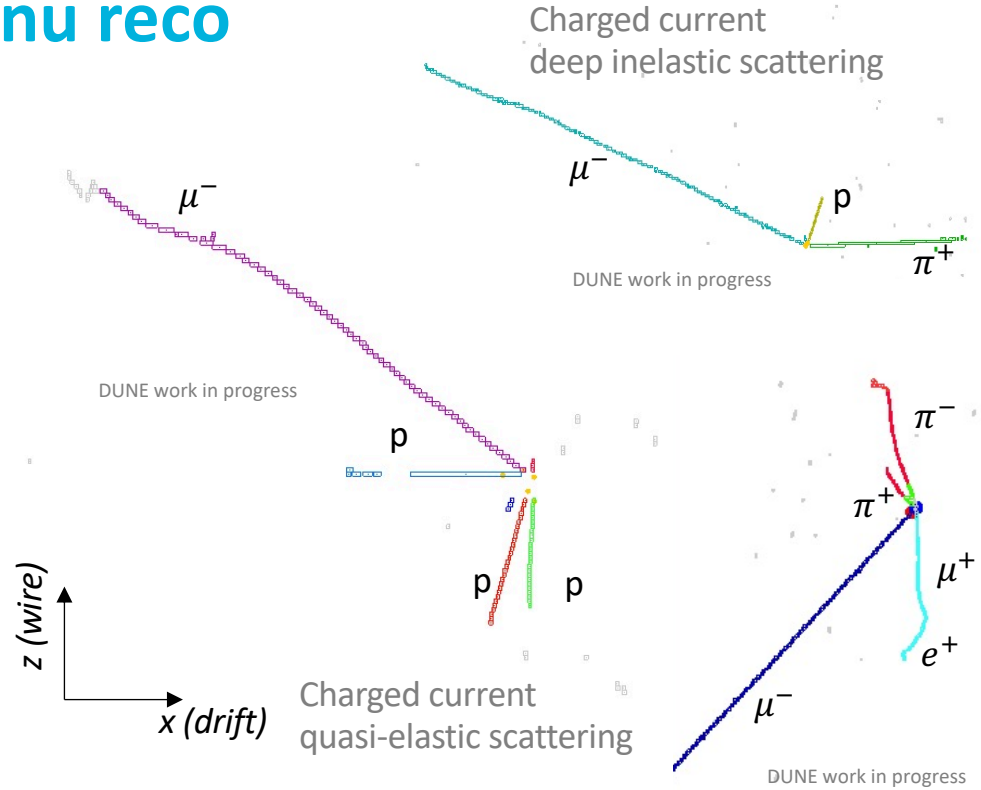
- Good reconstruction of neutrino direction is important
  - Both angle and propagation direction (i.e. forward vs backward)
  - Direction of the incident neutrino, not just the final-state lepton
- Separate neutrinos and antineutrinos

  e.g. by analysing mix of final-state particles, or from presence of Michel electrons
- Beside the golden $\upsilon_\mu \rightarrow \upsilon_e$ appearance channel, $\upsilon_\mu \rightarrow \upsilon_\mu$ disappearance also important for atmospheric neutrinos
  - A lot of oscillation physics from energy vs angle plot for $\upsilon_\mu \rightarrow \upsilon_\mu$ disappearance
- Atmospheric neutrinos are an excellent source of tau neutrinos
  - Need to be able to reconstruct the hadronic decays of tau leptons
- Atmospheric neutrinos background to baryon number violation searches

First look at atmospheric nu reco

Sample specifications

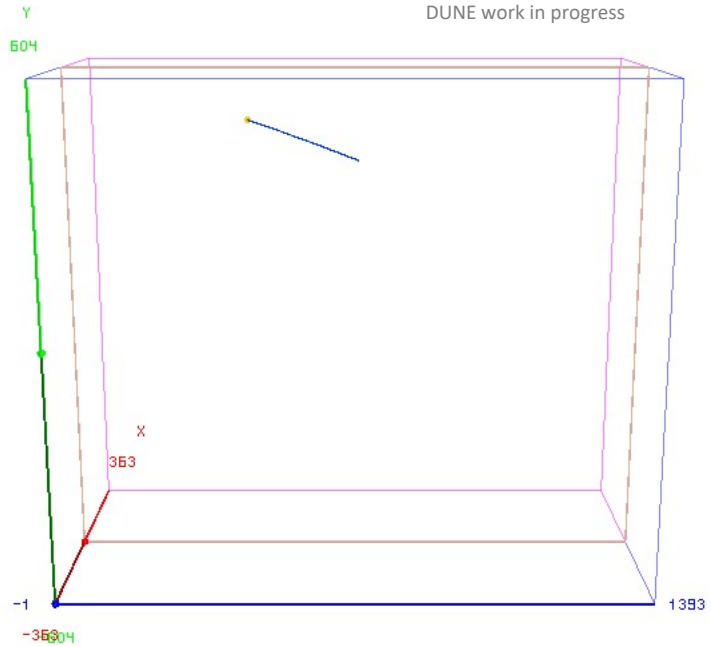
- DUNE Far Detector
  Smaller geometry, 12% of FD fiducial mass
- Simulation by J. Barrow based on Honda flux models
- Energy: 0.1-100 GeV
- Solar cycle maximum. several additional factors modelled



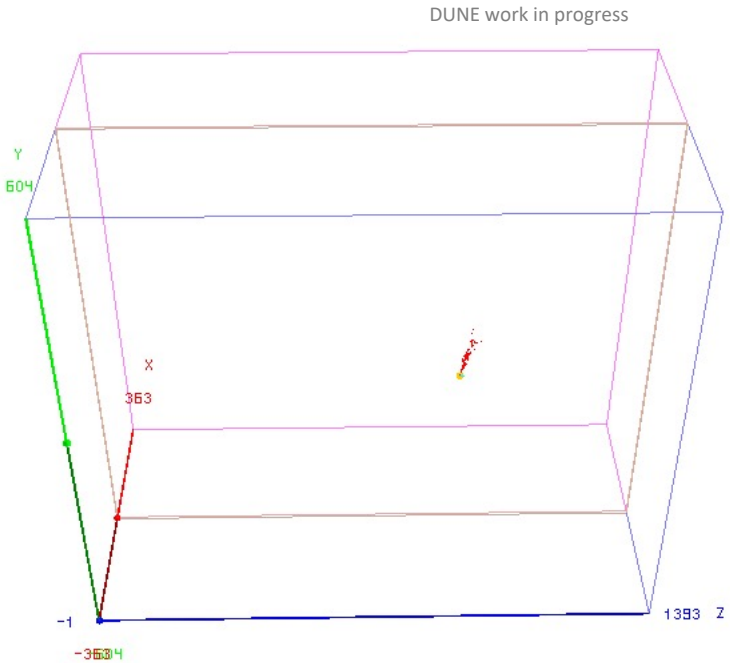
Examples of well-reconstructed events

Honda flux calculation: *Phys.Rev.D* 92 (2015) 2, 023004
https://www.icrr.u-tokyo.ac.jp/~mhonda/nflx2014/index.html
J. Barrow's PhD dissertation:
https://trace.tennessee.edu/utk_graddiss/6617

First look at atmospheric nu reco (2)



1.59 GeV muon



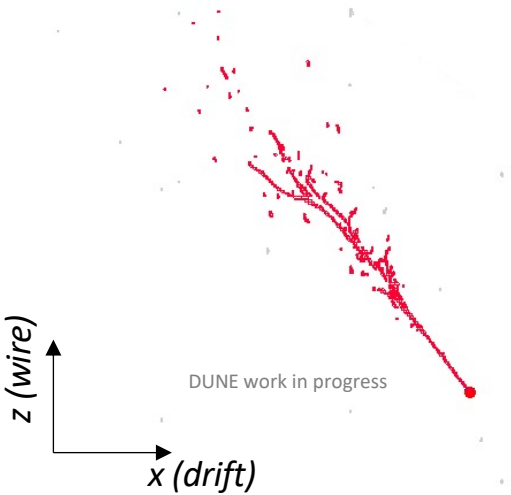
0.54 GeV electron

The importance of vertex placement

- Pandora's vertexing MVAs pick vertex candidate with best score among many
- Optimised for beam particles, preference for low z vertex candidates

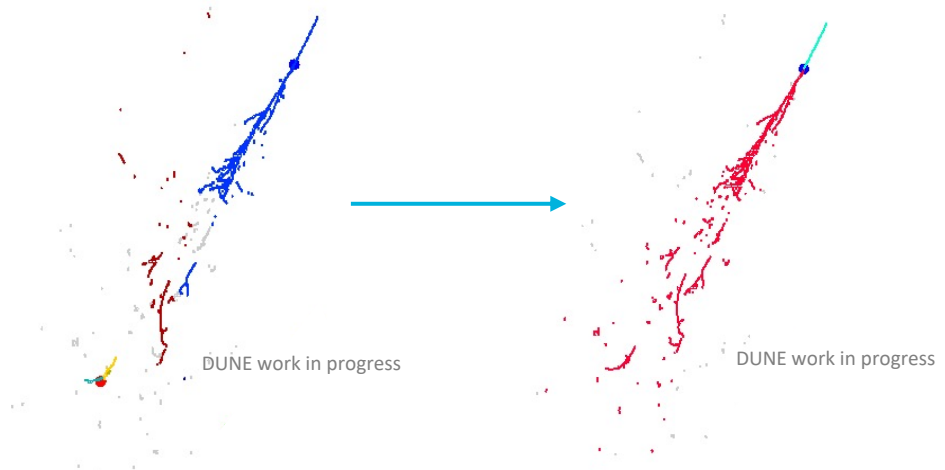
Example of **forward-going** shower

Pandora for accelerator



Example of **backward-going** shower

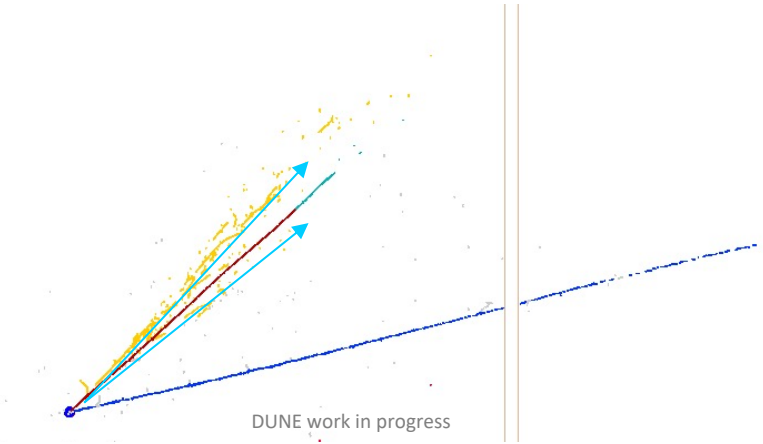
Pandora for accelerator **with true vertex**

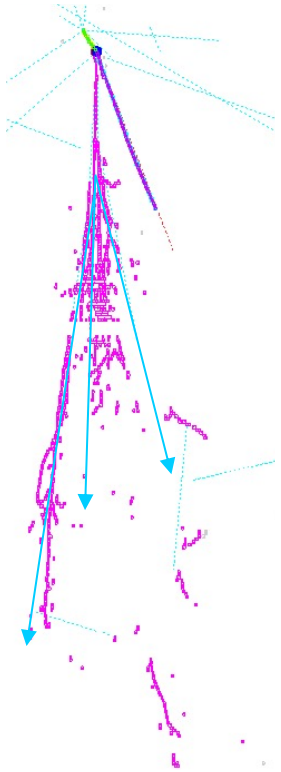


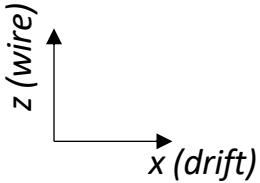
Understood effect of bad vertex placement

Shower merging

- Two or more particle showers are merged
- Affects both forward and backward-going cases
- Planned area of investigation for beam neutrino reconstruction; improvements will benefit atmospheric reconstruction as well







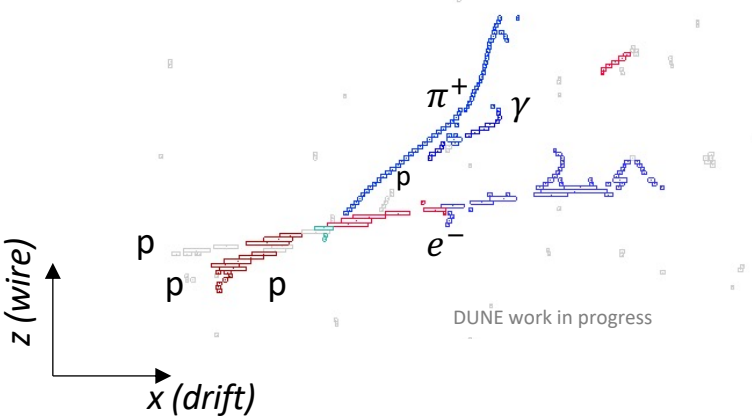
Integration of deep learning techniques

- We are integrating deep learning techniques in Pandora reconstruction chains for accelerator neutrinos
- Some are of direct relevance to atmospheric neutrino reconstruction, others will benefit all reconstruction chains
- Using deep learning to carefully steer some key decisions, rather than to try to solve entire problem space in one go
- A couple of examples in the next slides:
  - Track/shower streaming
  - Vertex reconstruction → affecting hierarchy reconstruction

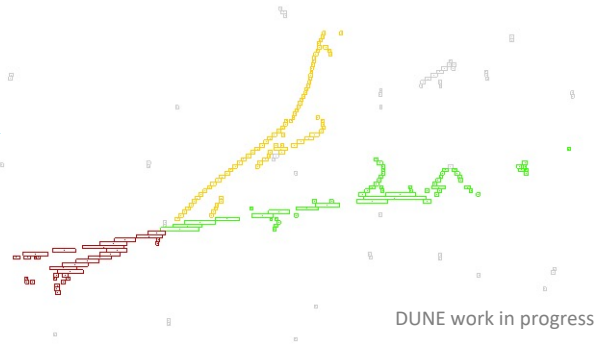
Track-shower streaming with deep learning

- Hit-based track/shower separation
- Allows reconstruction of tracks and showers in different “streams” that can connect and disconnect
- Aims at reducing track/shower contamination. Currently under development, promising initial results

Accelerator neutrino reconstruction



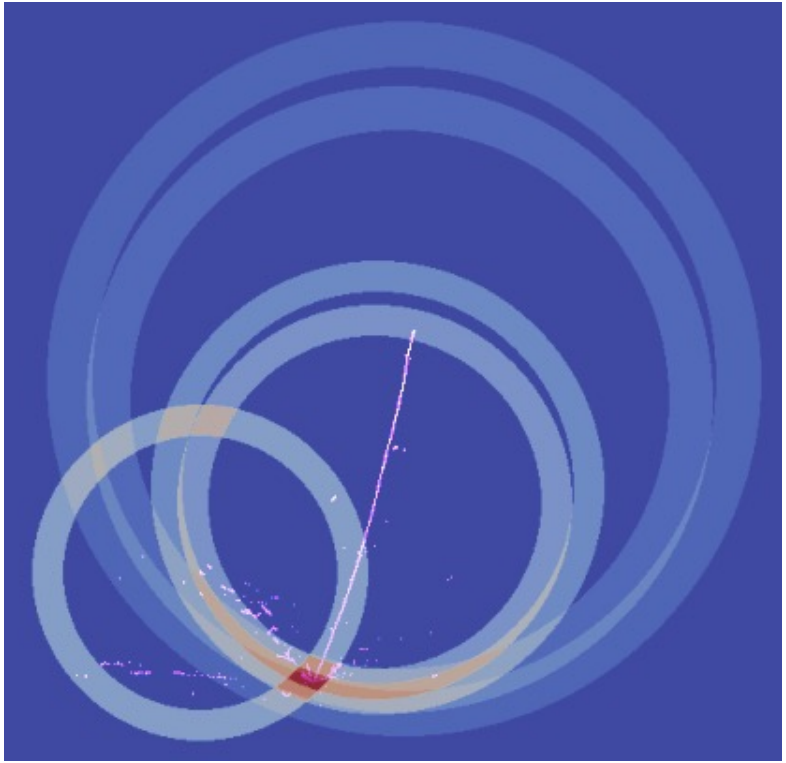
With track/shower streaming



Electron shower has been reconstructed as single particle!

Vertexing with deep learning

- The distance from each hit to the primary vertex is calculated and assigned by neural network to one of 19 classes
- Need to process the output to determine the likely vertex location via consensus
- For each hit, draw a ring using lower and upper distance bounds
- The shaded region contains the set of candidate vertices according to central hit
- After processing many hits, overlapping rings isolate the likely vertex location



DUNE work in progress

Conclusions

- Atmospheric neutrinos part of the DUNE physics programme
- First neutrino dataset → important commissioning tool
- Atmospheric neutrino reconstruction part of upcoming Pandora milestones
- Pandora for accelerator neutrinos good day-0 reconstruction for atmospheric neutrinos
- The different spectra and topologies require targeted improvements, particularly to vertexing
- Future PhD students will be focusing their efforts on event reconstruction of atmospheric neutrinos
- Many ongoing and planned features, and promising initial results