

Atmospheric neutrino reconstruction with Pandora

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



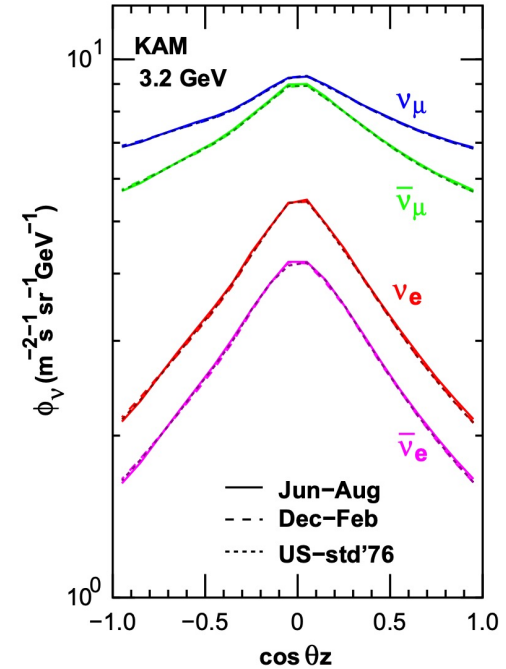
Outline

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

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

Beam vs atmospheric neutrinos

- Different **energy spectrum**
- Completely different **angular distribution**
- Different **flavour composition**
(e.g. ν_e/ν_μ ratio is very different)
- Different **mix of neutrinos and antineutrinos**
(no FHC or RHC 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 $\nu_\mu \rightarrow \nu_e$ appearance channel, $\nu_\mu \rightarrow \nu_\mu$ **disappearance** also important for atmospheric neutrinos
 - A lot of oscillation physics from energy vs angle plot for $\nu_\mu \rightarrow \nu_\mu$ 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

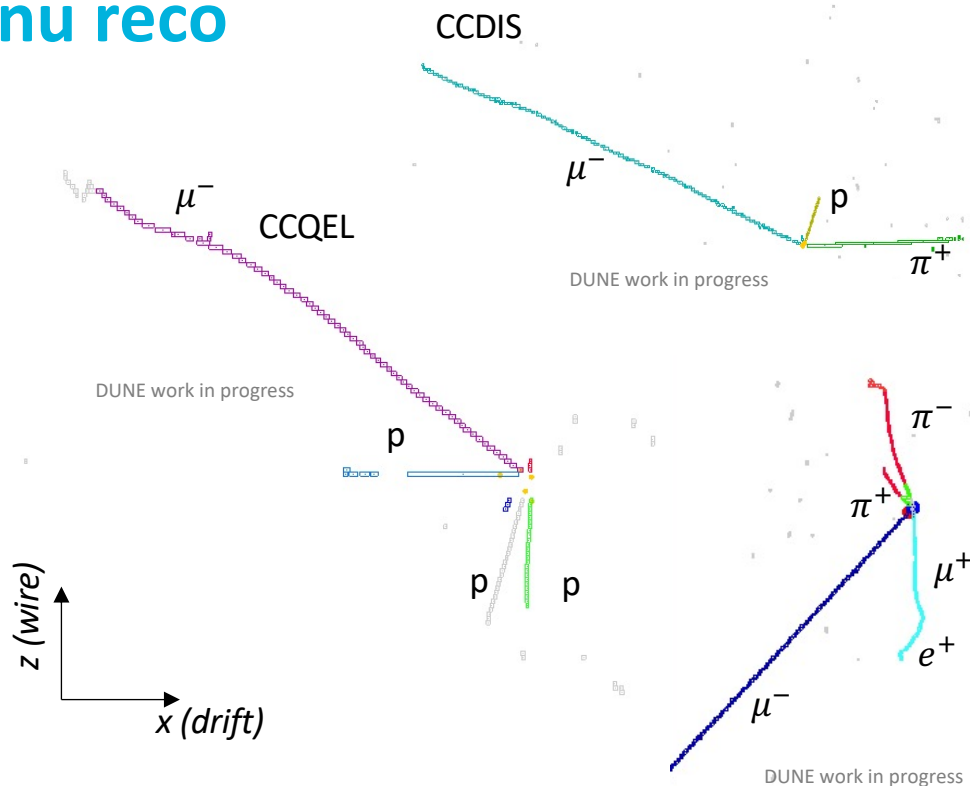
Sample specifications

- DUNE Far Detector
 - Small geometry with 12 drift regions defined by 12 external CPAs and 6 central APAs
- Simulation by J. Barrow based on Honda flux models
- Energy: 0.1-100 GeV
- Solar cycle maximum. several additional factors modelled

Honda flux calculation: [arXiv:1502.03916v2](https://arxiv.org/abs/1502.03916v2)

J. Barrow's PhD dissertation:

https://trace.tennessee.edu/utk_graddiss/6617



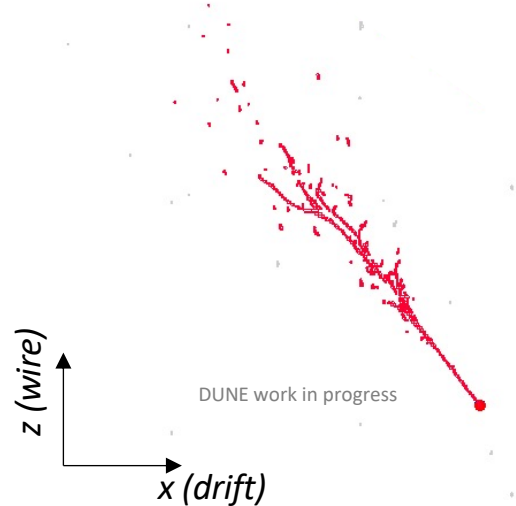
Examples of well-reconstructed events

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

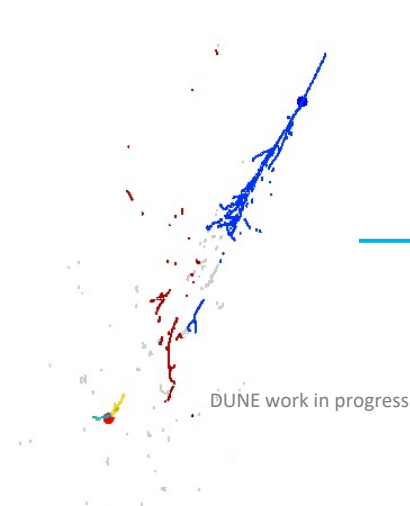
Example of **forward-going** shower

Pandora for accelerator

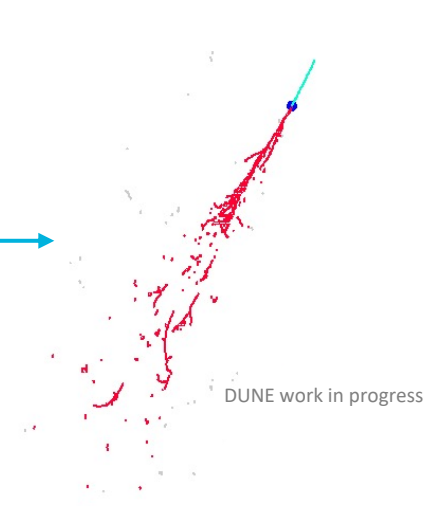


Example of **backward-going** shower

Pandora for accelerator



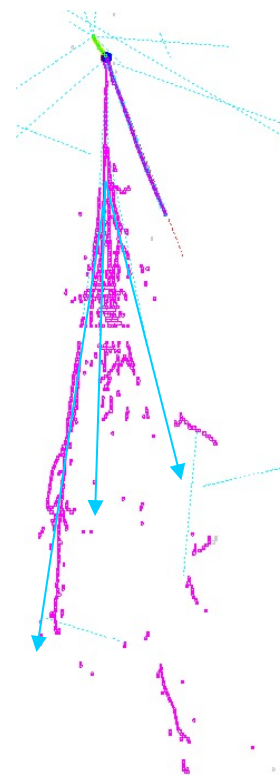
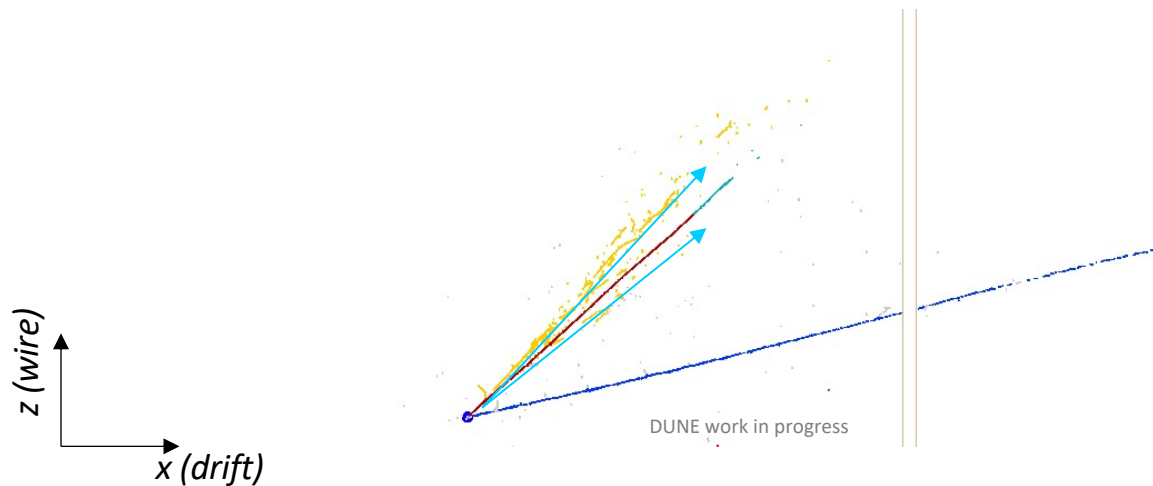
with true vertex



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



DUNE work in progress

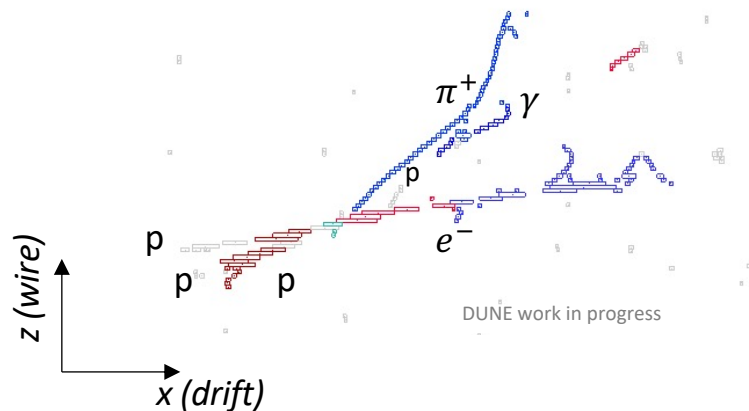
Integration of deep learning techniques

- 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

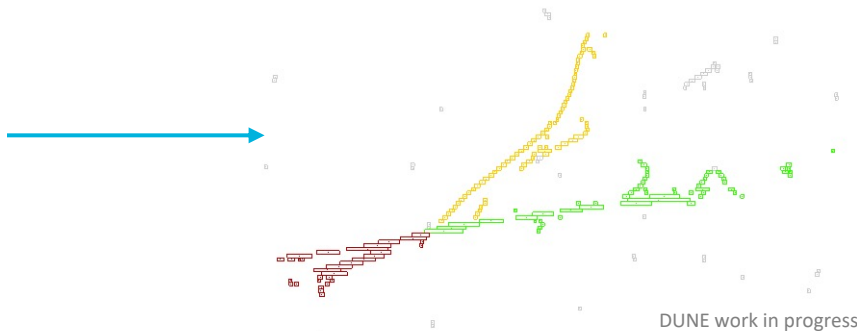
Track-shower streaming with deep learning

- Hit-based track/shower separation with semantic segmentation
- 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



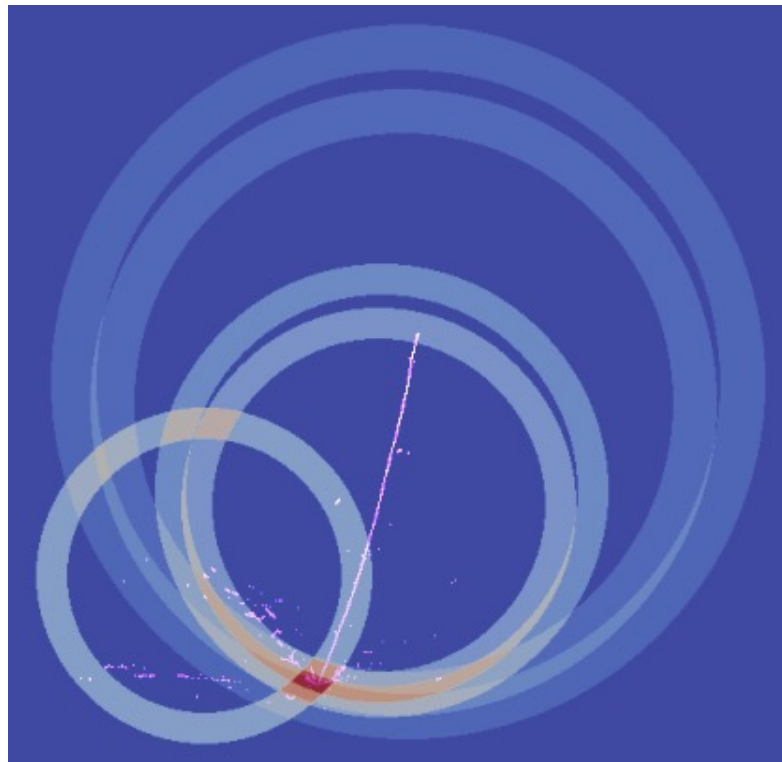
With track/shower streaming



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 to one of 19 classes by the network
- 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



Conclusions

- Atmospheric neutrinos part of the DUNE physics programme and 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**