Pandora Reconstruction

Steven Green on behalf of the Pandora Team
ProtoDUNE Sim/Reco
29th November 2017
Aims:

* Give an overview of the Pandora multi-algorithm approach to event reconstruction in LArTPCs.

* Outline the strategy for developing Pandora for protoDUNE. Including fhicl configuration examples

* Get feedback from protoDUNE analysers on the best way to format the Pandora output.
LArTPCs provide “photograph quality” images of the particles produced in neutrino/beam interactions. These images contain a wealth of information for use in physics analyses.

Whereas the human brain can excel at identifying features in recorded events, it is a significant challenge to develop an automated, algorithmic solution.

MicroBooNE Simulation:
1.4 GeV $\nu_\mu$ CC RES $\mu, p, \pi^0$

DUNE FD: 17 GeV $\nu_\mu$ CC DIS

Zoom in around vtx

~60m
Multi-Algorithm Pattern Recognition

- Single clustering approach is unlikely to work in a complex topology:
  - Mix of track-like and shower-like clusters

- Pandora replaces this with a multi-algorithm approach:
  - Build up events gradually
  - Each step is incremental - aim not to make mistakes (undoing mistakes is hard…)
  - Deploy more sophisticated algorithms as picture of event develops
  - Build physics and detector knowledge into algorithms
The benefits of the multi-algorithm philosophy of Pandora is showcased in the treatment of cosmic rays. Pandora reconstructs LArTPC events by dividing up the event into “slices” and reconstructing each slice using two different hypotheses:

1) Hits in a slice originate from cosmic rays.
2) Hits in a slice originate from a neutrino/test beam.

Pandora then compares these two different cases to determine, which is most likely.
Pandora contains chains of algorithms that are optimised for the reconstruction of cosmic rays and neutrinos.

- **Pandora Cosmic**: Optimised for identification of cosmic rays.
- **Pandora Neutrino**: Optimised for the identification of neutrinos.

Development of an algorithm chain focused on the reconstruction of beam particles will be vital for protoDUNE.
* Vetoing clear cosmic rays as a first step aids reconstruction of neutrino/beam particles by creating a **cleaner working environment**.

1 GeV beam event with cosmics.

Before the initial cosmic ray removal

After the initial cosmic ray removal
- Clear cosmic ray candidates have been rejected
The use of Pandora for event reconstruction at MicroBooNE is well understood and has been documented in:

arXiv:1708.03135

The Pandora multi-algorithm approach to automated pattern recognition of cosmic-ray muon and neutrino events in the MicroBooNE detector


(Submitted on 10 Aug 2017)

The development and operation of Liquid–Argon Time–Projection Chambers for neutrino physics has created a need for new approaches to pattern recognition in order to fully exploit the imaging capabilities offered by this technology. Whereas the human brain can excel at identifying features in the recorded events, it is a significant challenge to develop an automated, algorithmic solution. The Pandora Software Development Kit provides functionality to aid the design and implementation of pattern-recognition algorithms. It promotes the use of a multi-algorithm approach to pattern recognition, in which individual algorithms each address a specific task in a particular topology. Many tens of algorithms then carefully build up a picture of the event and, together, provide a robust automated pattern-recognition solution. This paper describes details of the chain of over one hundred Pandora algorithms and tools used to reconstruct cosmic-ray muon and neutrino events in the MicroBooNE detector. Metrics that assess the current pattern-recognition performance are presented for simulated MicroBooNE events, using a selection of final-state event topologies.

MicroBooNE pattern-recognition paper has completed internal collaboration review, posted to arXiv. Minor revisions just submitted to EPJC.
Present the fraction of events deemed “correct” by Pandora performance metrics:

- Consider exclusive final-states where all true particles pass simple quality cuts (e.g. nHits)
- Correct means exactly one reco primary particle is matched to each true primary particle
- Well defined assessment of pattern recognition

E.g. MicroBooNE Simulation

MicroBooNE Simulation

Missing parent-daughter link: $\pi^+$ split

CCRES w/ $\pi^+$

CCRES w/ $\pi^0$
The MicroBooNE Pandora paper shows several of these metrics to fully determine the quality of the event reconstruction.

Next milestone → Replicate similar studies at protoDUNE.

Fraction of events with exactly one reco particle matched to each target MCParticle.
From MicroBooNE to ProtoDUNE

From a pattern recognition point-of-view, the important differences between MicroBooNE and ProtoDUNE are:

- Multiple drift volumes for protoDUNE.
- Different event topologies due to the increased energy.
- Target particles to reconstruct are beam particles and not neutrinos.

By addressing each of these differences we will make the transition to ProtoDUNE.

Very first step: Get a working reconstruction chain for ProtoDUNE using Pandora and the MicroBooNE algorithm logic ✔

ProtoDUNE, 1 GeV Test Beam + Cosmics

MicroBooNE, BNB Beam + Cosmics

~6m

~2.3m

~10.4m
Currently the master branch of dunetpc, protoDUNE_reco.fcl uses a single pass of Pandora.

In this pandoracosmic pass, all particles are reconstructed as cosmic rays.

This approach was inherited from MicroBooNE where a two pass approach was used:

1. Reconstruct everything as cosmic rays. Then remove clear cosmic rays.
2. Reconstruct the remaining event as neutrinos.
The latest pandora developments provide a consolidated reconstruction.

This reconstruction runs both cosmic and neutrino/beam passes and uses the multi-algorithm approach to decide the best outcome.

Cosmic ray tagging is applied to remove clear cosmic ray candidates from the neutrino/beam reconstruction.

In the consolidated output, ambiguous cosmic rays will still be tagged as beam/neutrino particles, but we are developing a more sophisticated approach to beam particle ID that will resolve this issue.

We are working to bring these updates to dunetpc in the near future.
In the current incarnation, Pandora produces a neutrino candidate that includes primary particles produced from the neutrino interaction and a candidate vertex position.

We would appreciate feedback on preferences for the formatting of the output from Pandora.

For example, are there any specific conventions required for particle ID (cosmic rays vs beam) and particle hierarchy?

If you think of something at a later date please contact myself or any of the Pandora team (see backup for contact details).
The Pandora team is working on bringing the latest and greatest reconstruction to ProtoDUNE SP very soon.

We are developing beam particle ID for protoDUNE with a view to showing performance in the near future.

Thank you for your attention.
Questions?
Pandora Team

Pandora is an open project and new contributors would be extremely welcome. We’d love to hear from you and we will always try to answer your questions!

Contact details:

Framework development

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ProtoDUNE

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Please visit https://github.com/PandoraPFA
Clean topology: $\nu_\mu$ CC QE interactions with exactly one reconstructable muon and one reconstructable proton in visible final state:

$\nu_\mu + \text{Ar} \rightarrow p + \mu^-$

<table>
<thead>
<tr>
<th>#Matched Particles</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3+</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>1.3%</td>
<td>95.8%</td>
<td>2.9%</td>
<td>0.1%</td>
</tr>
<tr>
<td>$p$</td>
<td>8.9%</td>
<td>87.3%</td>
<td>3.6%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

53,168 events, 86.0% have exactly one reco particle matched to each target.

MicroBooNE Simulation

ProtoDUNE Sim/Reco
BNB CC RES: $\nu_\mu + Ar \rightarrow \mu^- + p + \pi^+$

Three-track topology: CC $\nu_\mu$ interactions with resonant charged pion production:

<table>
<thead>
<tr>
<th>#Matched Particles</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3+</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>3.5%</td>
<td>95.1%</td>
<td>1.4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>$p$</td>
<td>9.0%</td>
<td>86.8%</td>
<td>4.0%</td>
<td>0.3%</td>
</tr>
<tr>
<td>$\pi^+$</td>
<td>6.9%</td>
<td>80.9%</td>
<td>11.4%</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

47,754 events, 70.5% have exactly one reco particle matched to each target.
Two-photon topology: CC $\nu_\mu$ interactions with resonant neutral pion production:

<table>
<thead>
<tr>
<th>#Matched Particles</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3+</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>3.7%</td>
<td>94.8%</td>
<td>1.5%</td>
<td>0.0%</td>
</tr>
<tr>
<td>$p$</td>
<td>9.9%</td>
<td>85.5%</td>
<td>4.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>6.8%</td>
<td>88.0%</td>
<td>4.8%</td>
<td>0.4%</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>29.9%</td>
<td>66.4%</td>
<td>3.6%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

17,939 events, 49.9% have exactly one reco particle matched to each target.

$#\text{hits } \gamma_1 > #\text{hits } \gamma_2$