Michel Electron Reconstruction

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  • Radiated energy deposits

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Motivation and Goals

• In ProtoDUNE–SP Michel electrons provide a O(100) Hz source of tens of 0-50 MeV electrons with characteristic energy spectrum

Motivation

• Understand detector response to tens of MeV electrons
  • Improve $\nu$ energy reconstruction
  • Supernova Neutrinos

Goal

• Measure energy resolution and scale for tens of MeV electrons
A Michel electron is an electron produced when a muon decays at rest

\[ \mu \rightarrow e + \nu_e + \nu_\mu \]

Three body decay kinematics lead to a characteristic spectrum

- Steep cut-off at 53 MeV corresponding to \( M_\mu / 2 \)
Michel Electrons in LAr

In LAr the Michel electron spectrum is modified by radiative corrections

- Negative muons can be captured by the nucleus
- Electron couples to nucleus via a photon at decay

Michel spectrum changed

- Peak moves to lower energies
- Tail extends to $\mu_{5/2}$
Muon lifetime much shorter than readout window

- See muon track and Michel as one object
- Incoming muon stops with a Bragg peak
- Electron emitted isotropically

At $O(10)$ MeV electron stopping power similar for radiation and collisions

- Critical value $\sim 45$, on top of peak in spectrum

Therefore Michel electrons have a unique topology

- Track + Shower
MC Truth Study
Stopping Muon Sample

- Study the ionisation energy deposition at a truth level to inform reconstruction
- Sample of individual particle gun muons
- 40,000 $\mu^+$ generated at 400MeV
- Retain shower daughters
  - Study details of the radiated energy

![Graph of True energy of Michel Electrons]

<table>
<thead>
<tr>
<th>h_michel_true_energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Std Dev</td>
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</tbody>
</table>
Michel tracks can be quite reliably recognised (e.g. MicroBooNE)

- Radiated energy is much harder, particularly in noisy environments

So a track only energy reconstruction would be simple...

...but the track only energy deposition has large stochastic variations
Radiated Photons

- Multiple photons radiated for each Michel electron
- Stochastic nature of brem radiation increases with Michel energy
- Can carry a significant energy away from the initial track
- Need to associate deposits from brem photons with primary track
Geometry of Radiation

- Some radiation can travel a reasonable distance before converting into ionisation
- Absorption length \( \sim 20 \text{cm} \)
- Mostly confined within 30–60 degrees of Michel momentum
- Need to associate deposits to the initial track
Ionisation Energy Deposition

Track Only

True Michel energy vs ionisation energy from Michel only

40 cm, 30 degrees

Ionisation within 40.000000cm of vertex and 0.500000Rad of Momentum

Primary Electron Track Only

Ionisation within 40cm of Vertex and 30 Degrees of Michel Track

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Reconstruction
Beam + Cosmics Sample

- Reconstruction tested on Beam + Cosmics samples from MCC9
- Cosmic MC provides a more realistic sample on which to test reconstruction
- \(O(10,000)\) Michel electrons in each sample
Hit Tagging

The plan is to aid reconstruction with hit tagging from a CNN.

The CNN is trained on 48×48 images of the detector readout from each plane.

The images provide context for the network to identify the central hit:

- **Target**: classify what caused the central hit in the image
- **EM, Track, None, Michel**
Network Architecture

The network has a simple architecture with a single convolutional layer

- 1 convolutional layer
  - 48 5x5 filters
- 2 dense layers
- Two output layers: [em, trk, none], [michel]

Dropout between each layer to control overtraining

O(10,000,000) images used in training, generated from simulation

- Cosmics, Muon beam, Hadron beam
Michel Hit Tagging Performance

- Tested CNN’s on a sample of beam + cosmic simulation and compared to previous network
  - Pion beam at 2.5GeV
- Hit tagging performance test: ROC curve
  - True positive vs false positive rates for Michel hits

**Michel Classification**

![ROC curve for Michel Classification](image)

**EM Classification**

![ROC curve for EM Classification](image)
Event Selection Method

Event selection: search for a cluster of Michel tagged hits near the end of a reconstructed track

In each plane
  • Loop over hits and check
    • Michel output of CNN \(>\) CNN Thresh
    • Distance from track end \(<\) Radius Thresh
  • Count these hits

Selection criteria
  • Number tagged hits in each plane \(>\) Number Thresh
Event Selection Performance

- Event selection was tested on the reconstructed sample used for the hit tagging test.
- Tested hyperparameters on 10% of data.
- Best performance on full data:
  - Purity: 98%
  - Efficiency: 3%
Energy Reconstruction Ideas

Based on the initial tagged hits

- Create track from initial Michel hits
- Produce a cone parallel to the initial Michel track
- Extend the cone to a collection radius $\sim 50$ cm
- Collect any Michel–like or EM–like hits within the cone
- Use these hits as input into energy reconstruction
Energy Reconstruction Ideas

Based on the initial tagged hits

- Create track from initial Michel hits
- Create a rectangle with the Michel electron track at the bottom left corner
- Produce a grayscale image based on all Michel–like or EM–like hits within the image
- Use these images as input into CNN which is trained to reconstruct Michel energy
Challenges

- To get clean images for energy reconstruction need Michel electrons in empty region of the detector
- ... or need a way to get rid of unrelated hits
- Initial naive attempt seems to deal with tracks but not local EM activity, including that near tracks e.g. deltas
Challenges

EM Hits
Challenges

Delta Hits
Challenges

Clean Event
Summary

- Michel electrons provide an abundant source of tens of MeV electrons
- Useful tool to study detector response to low energy electron events
  - Supernova neutrinos
- Truth level MC study into ionisation energy deposition from Michel electrons
  - Large variation in radiated energy deposits $\rightarrow$ need to collect radiated energy
- Event selection based on CNN tagged Michel–like hits at very high purity
- Beginning to work on Energy reconstruction
  - Use hits tagged during event selection to define a cone for hit collection
  - Use hits tagged during event selection to define images for energy reconstruction with CNN