Michel Electron Reconstruction

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Outline

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  - Michel electrons in LAr
- Monte Carlo Truth Study
  - Track–like energy deposition
  - Radiated energy deposits
- Reconstructing Michel electrons in ProtoDUNE-SP
  - Hit Tagging
  - Event Selection
  - Energy Reconstruction

Motivation and Goals

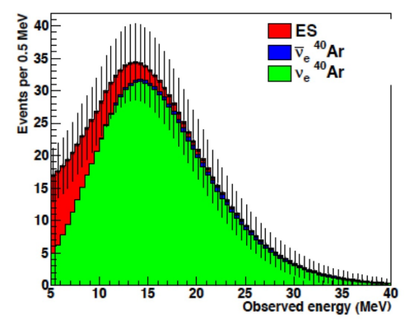
- In ProtoDUNE–SP Michel electrons provide a O(100) Hz source of tens of 0-50 MeV electrons with characteristic energy spectrum

Motivation

- Understand detector response to tens of MeV electrons
  - Improve ν energy reconstruction
  - Supernova Neutrinos

Goal

- Measure energy resolution and scale for tens of MeV electrons



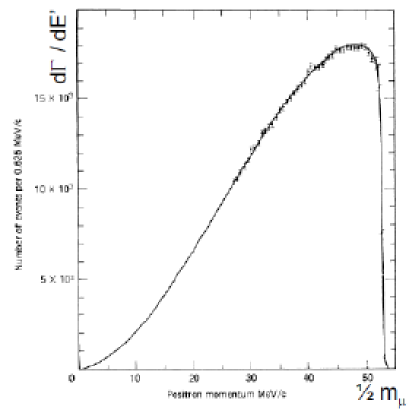
Michel Electrons

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 $M_\mu/2$



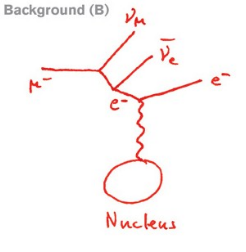
Michel Electrons in LAr

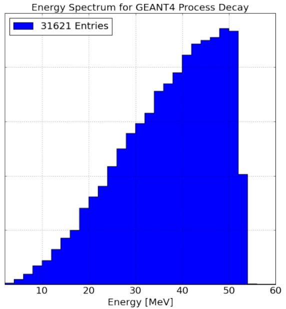
In LAr the Michel electron spectrum is modified by radiative corrections

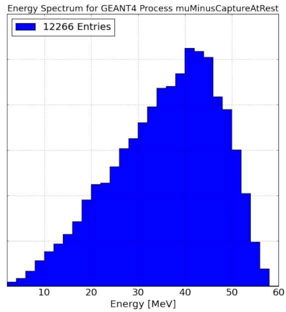
- Negative muons can be captured by the nucleus
- Electron couples to nucleus via a photon at decay

Michel spectrum changed

- Peak moves to lower energies
- Tail extends to M_μ







Energy Deposition in LAr: What Does a Michel look like?

Muon lifetime much shorter than readout window

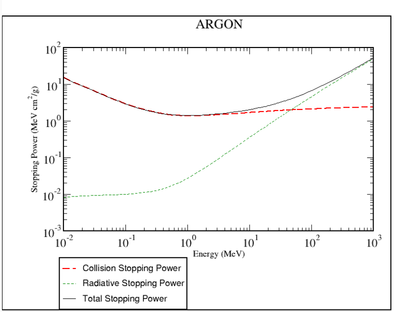
- See muon track and Michel as one object
- Incoming muon stops with a Bragg peak
- Electron emitted isotropically

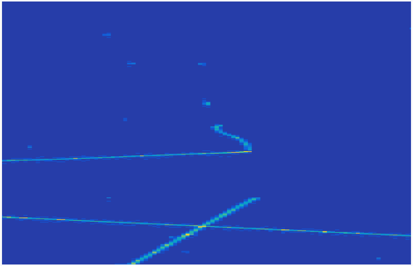
At O(10) MeV electron stopping power similar for radiation and collisions

- Critical value ∼45, on top of peak in spectrum

Therefore Michel electrons have a unique topology

- Track + Shower

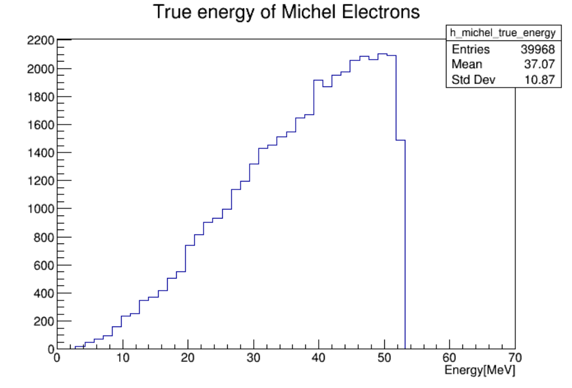




MC Truth Study

Stopping Muon Sample

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



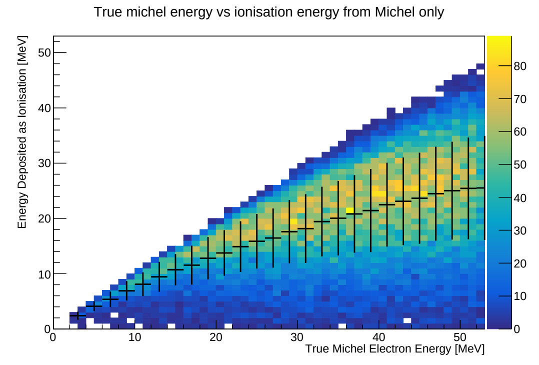
Track–like Energy Deposition

Michel tracks can be quite reliably recognised (e.g. MicroBooNE)

- Radiated energy is much harder, particularly in noisy environments

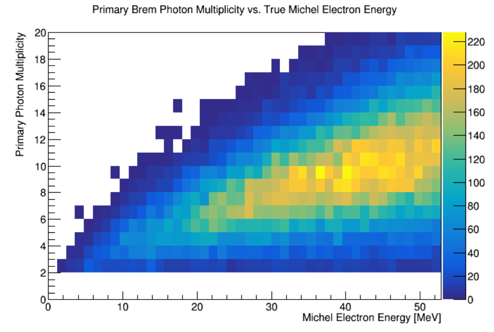
So a track only energy reconstruction would be simple...

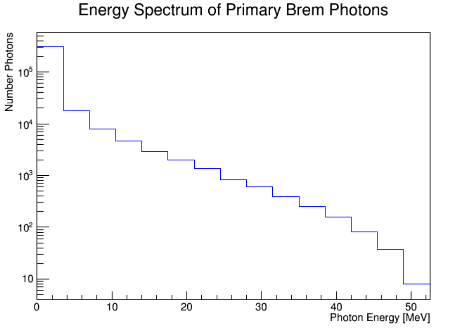
...but the track only energy deposition has large stochastic variations



Radiated Photons

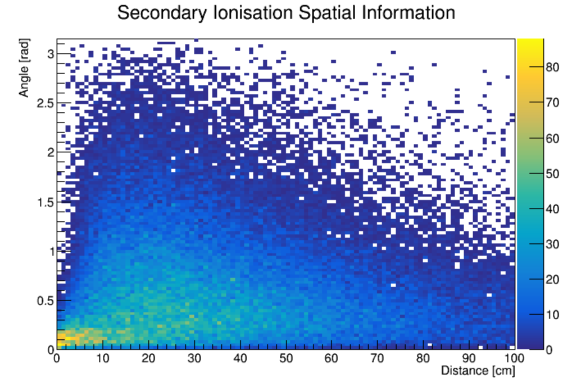
- Multiple photons radiated for each Michel electron
- Stochastic nature of brem radiation increases with Michel energy
- Can carry a significant energy away from the initial track
- Need to associate deposits from brem photons with primary track





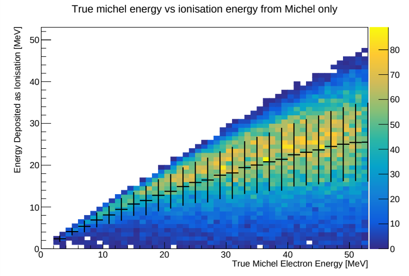
Geometry of Radiation

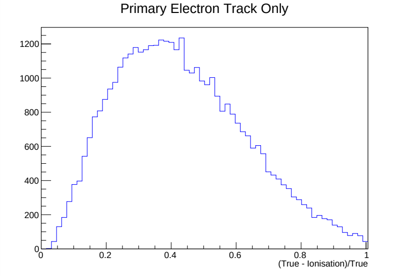
- Some radiation can travel a reasonable distance before converting into ionisation
- Absorption length $\sim 20cm$
- Mostly confined within 30–60 degrees of Michel momentum
- Need to associate deposits to the initial track



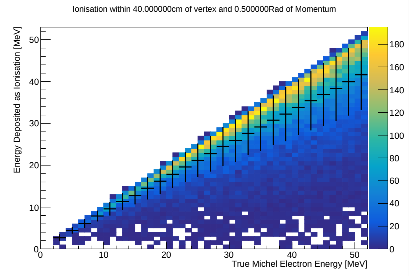
Ionisation Energy Deposition

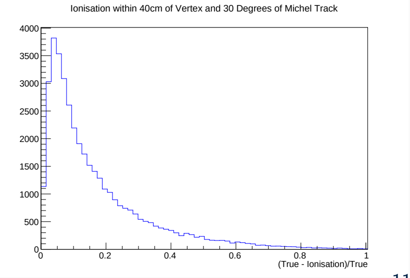
Track Only





40 cm, 30 degrees

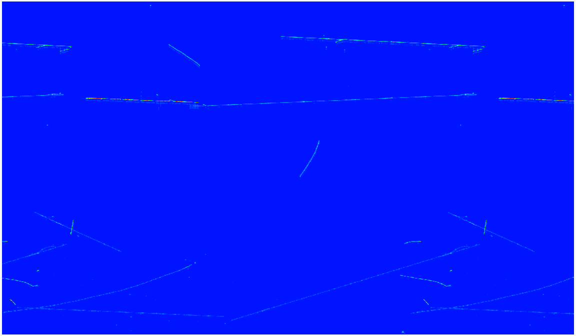




Reconstruction

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



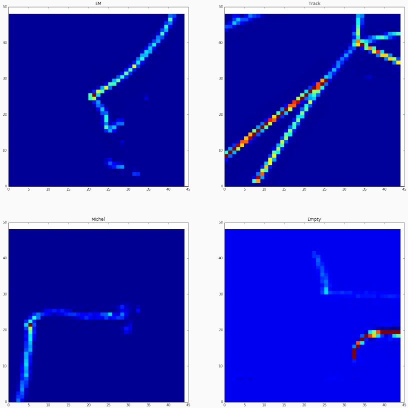
Hit Tagging

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

The CNN is trained on 48x48 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

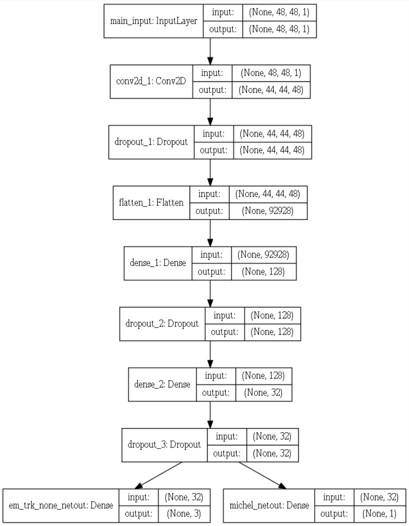
The network has a simple architecture with a single convolutional layer

- 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

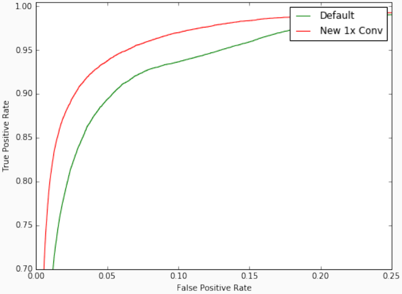
- Cosmics, Muon beam, Hadron beam



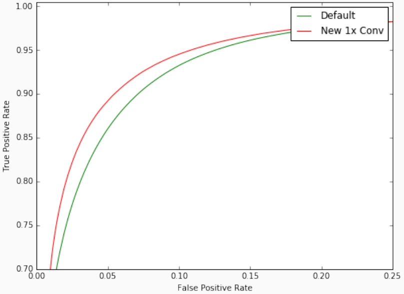
Michel Hit Tagging Performance

- 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



EM Classification



Event Selection Method

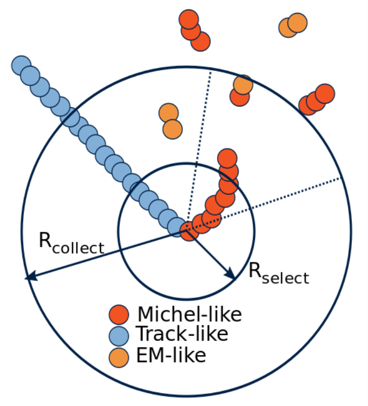
Event selection: search for a cluster of Michel tagged hits near the end of a reconstructed track

In each plane

- Loop over hits and check
  - Michel output of CNN > CNN Thresh
  - Distance from track end < Radius Thresh
- Count these hits

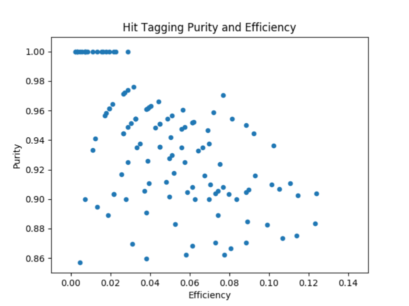
Selection criteria

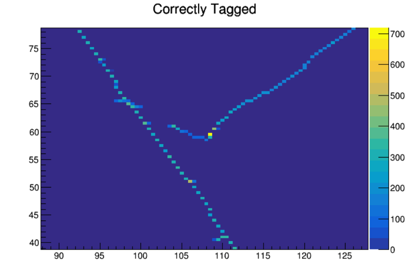
- Number tagged hits in each plane > Number Thresh

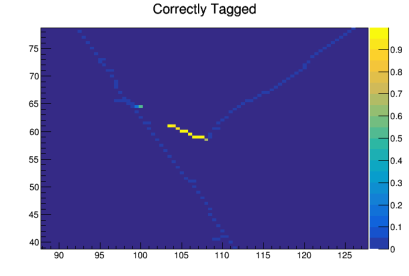


Event Selection Performance

- 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%



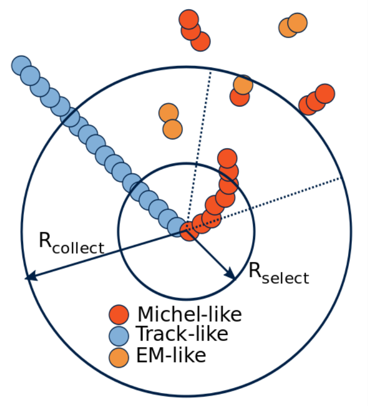




Energy Reconstruction Ideas

Based on the initial tagged hits

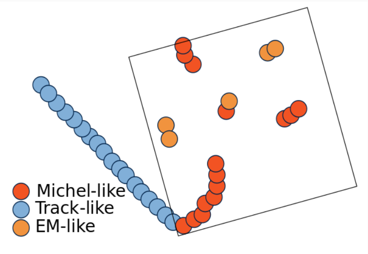
- Create track from initial Michel hits
- Produce a cone parallel to the initial Michel track
- Extend the cone to a collection radius $\sim$ 50 cm
- Collect any Michel–like or EM–like hits within the cone
- Use these hits as input into energy reconstruction

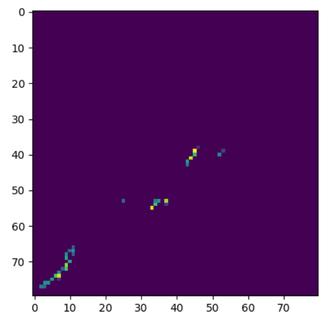


Energy Reconstruction Ideas

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



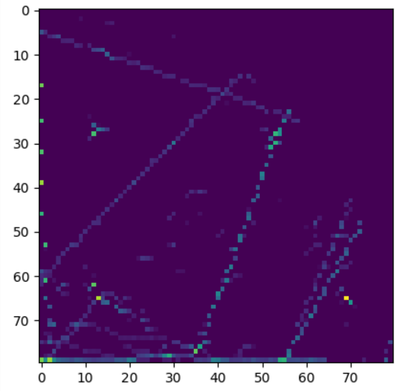


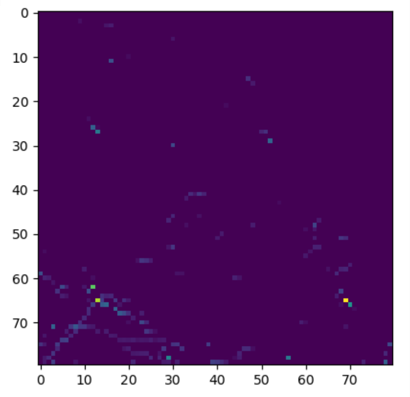
Challenges

- 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

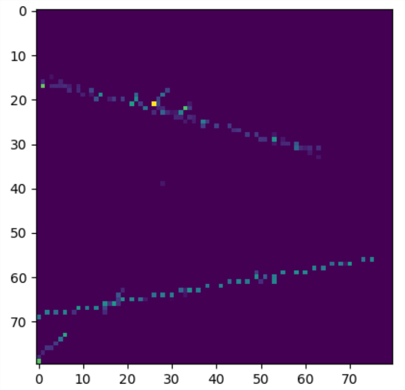
EM Hits

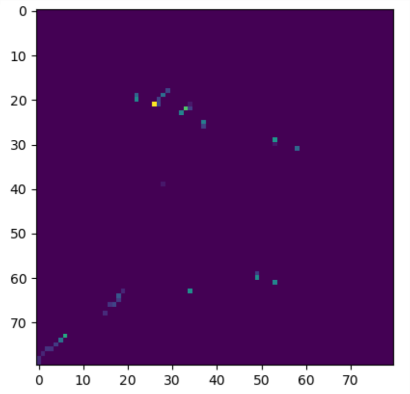




Challenges

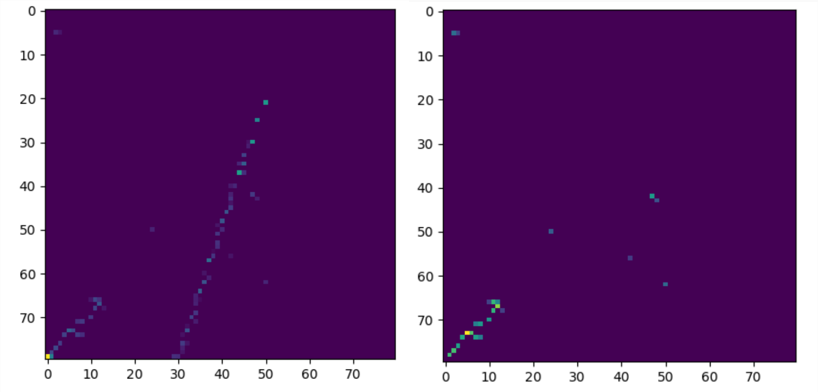
Delta Hits





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