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Michel Electron Reconstruction Using the MicroBooNE LArTPC Cosmic Data

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Abstract. MicroBooNE is a Liquid Argon Time Projection Chamber (LArTPC) neutrino detector located in the Booster Neutrino Beamline at Fermilab which began collecting neutrino data in October 2015. MicroBooNE aims to explore the low energy excess in the ν_e spectrum reported by MiniBooNE as well as perform ν -Ar cross-section measurements. In this note, we present the current status of reconstructing Michel electrons from cosmic ray muons in the MicroBooNE detector. These electrons are distributed uniformly inside the detector, and serve as a natural and powerful sample to study the detector's response for low energy (tens of MeV) interactions as a function of position. We have developed a reconstruction software tool to identify such Michel electrons which could be of benefit to LArTPC experiments generically.

1. Introduction

The MicroBooNE experiment is a Liquid Argon Time Projection Chamber (LArTPC) sitting on the Booster Neutrino Beamline (BNB) at the Fermi National Accelerator Laboratory aiming to study neutrino interactions at the $\mathcal{O}(1 \text{ GeV})$ energy range. Charged particles deposit energy as they traverse the TPC volume ionizing the argon, and the ionization charge is detected on closely spaced sense wires over three planes, which produce a high-resolution image conveying topological and calorimetric information from the interaction.

In this work we take advantage of the many cosmic ray muons entering the TPC to isolate a sample of electrons produced from muon decay (Michel electrons). These electrons have a well characterized energy spectrum [1] and can provide us with a valuable sample to use to study the detector response to tens of MeV electrons. We explore the details of how electrons in this energy range deposit energy in argon, and the impact this has on the topological signature of these electrons in a LArTPC, and consequently on the ability to tag and reconstruct their energy.

The full details of this analysis can be found in Ref. [2].

2. Michel Electron Energy Deposition in Liquid Argon

Michel electrons are in an interesting energy range because contributions to energy loss in argon from ionization and radiative photon production are similar (see Fig. 1 left). Furthermore, photons in liquid argon can travel up to tens of centimeters before pair-producing or Compton-scattering. As a consequence Michel electrons will manifest themselves neither as a continuous track of ionization, nor as a fully developed electromagnetic shower but rather as a short ($\approx 10 \text{ cm}$) linear segment of ionization, with up to several small (consisting of a few to tens of



MeVs of deposited energy) clumps of charge deposited by photons further away from the muon decay point. Fig. 1 (right) shows an example candidate Michel electron from data, in which this complex topology can be seen. In order to recover the full energy deposited by an electron it is necessary to successfully tag the radiated photons. This can become challenging, particularly in a surface detector in which accidental cosmic activity is present.

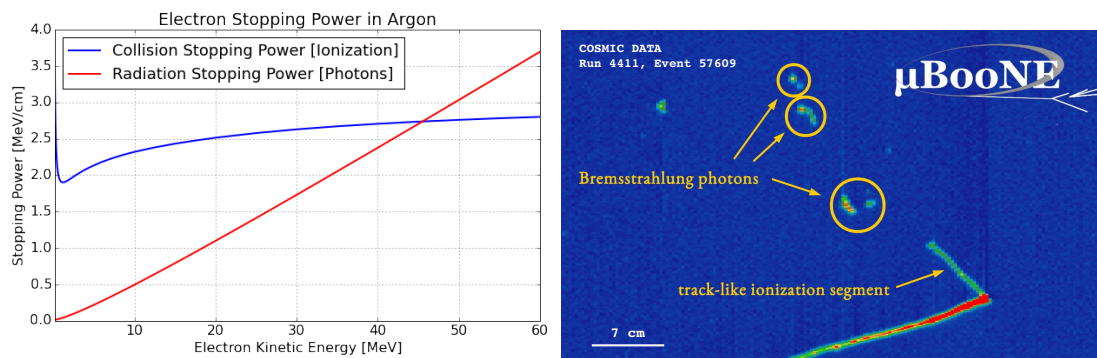


Figure 1. Left: stopping power as a function of energy for electrons in argon from NIST [3]. Right: event display showing a tagged Michel electron on the MicroBooNE collection plane. The x-axis denotes the wire-number and the y-axis the drift-time. Color associated to signals is representative of the amount of charge collected.

3. Reconstruction Algorithm

The approach to reconstruction employed in this analysis only utilizes information from MicroBooNE's collection plane. Signals from collection plane wires are processed through a noise-filtering and signal deconvolution process [4]; two dimensional hits are then identified in association to pulses on the wires, giving information on the 2D position of charge deposits. Hits are then clustered based on their spatial arrangement in order to isolate charge associated to each cosmic ray muon present in the event. At this point hits from each muon are spatially sorted and this ordered set of hits is used to produce a charge and linearity profile of the muon. By scanning the charge profile we can identify a muon's stopping point by searching for a Bragg peak. Similarly the linearity profile is used to identify significant kinks in the track, consistent with a muon decay producing an electron coming out in a different direction. By requiring a coincidence between the Bragg peak and a kink we can isolate a very pure sample of Michel electrons. Once a Michel electron candidate is identified, we extend the search for deposited charge further out in the TPC in order to try and collect some of the charge deposited by radiated photons.

4. Energy Reconstruction

To reconstruct the energy of a Michel electron candidate we integrate the measured charge from the hits tagged as belonging to a Michel electron. We then account for the electronics response and signal processing to convert from an ADC scale to charge using gain calibration measurements performed by injecting test pulses of known charge into the TPC channels. To go from measured charge collected on the wires to deposited energy we account for a constant recombination factor calculated using the Modified Box model as parametrized by the ArgoNeuT collaboration [5], applied at MicroBooNE's electric field for a value of dE/dx of 2.3 MeV/cm. We account for the effect of charge quenching due to impurities as the electrons drift through the argon by correcting for the average effect of an 8 ms electron lifetime over the entire 2.56 m

drift-distance. Following this procedure we calculate a preliminary calibration to obtain a value of reconstructed energy in MeV. Applied to our sample of over 5,000 tagged Michel electrons this produces the Michel electron energy spectrum shown in Fig. 2 (left).

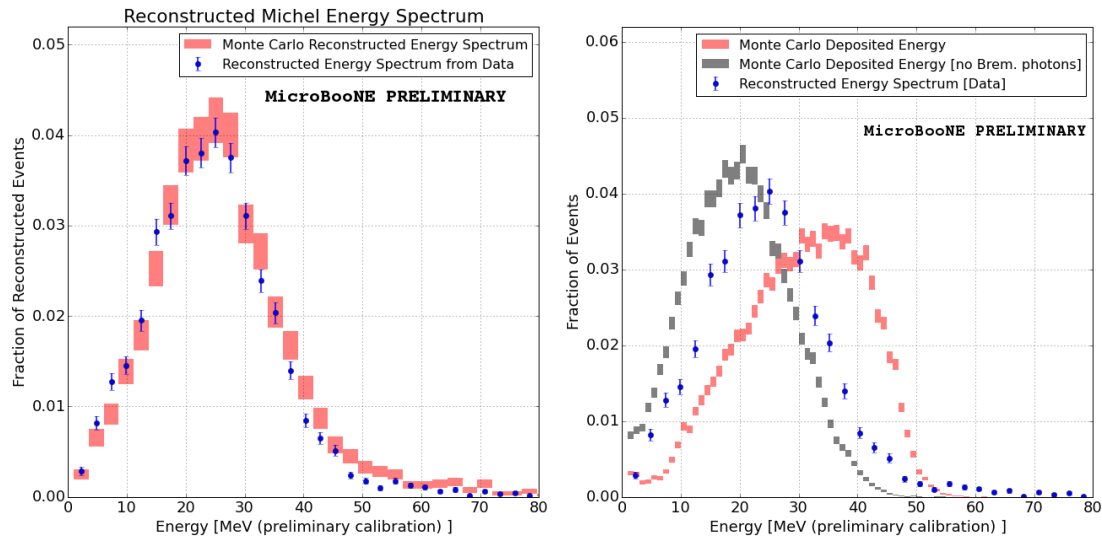


Figure 2. Left: reconstructed energy spectrum for tagged Michel electrons using data and Monte Carlo. Right: comparison of the reconstructed energy spectrum for data with a study of the same energy reconstruction definition applied to a Monte Carlo simulation in which only ionization energy (black) and ionization and radiative contributions (red) from Michel electrons are used. Error bars are statistical only.

5. Discussion

The reconstructed energy spectrum is clearly shifted to lower energies with respect to the true spectrum. This is an artifact of the reconstruction and a consequence of the difficulty of tagging all the energy carried by radiated photons. The fact that the contribution of radiative photons to the total energy loss increases at larger electron energies leads to the peak-like structure seen in Fig. 2. The reconstructed energy spectrum is also shown on the right-hand-side of Fig. 2 compared to a MC simulation in which the same energy reconstruction definition is applied to Michel electrons for which all (red) and no (black) radiative photons are considered for the energy calculation. One sees that if all energy from radiative photons can be successfully recovered, the energy spectrum recovers much of its true distribution. The reconstruction approach used for this effort lies somewhat in between the extreme cases, and can be improved in the future with advances in the reconstruction.

- [1] Marcel Bardon, et. al., PRL, 14, 449 (1965).
- [2] MicroBooNE Public Note 1008 (2016) <http://www-microboone.fnal.gov/publications/publicnotes/>
- [3] National Institutes of Standards and Technology, ESTAR.
- [4] MicroBooNE Public Note 1016 (2016) <http://www-microboone.fnal.gov/publications/publicnotes/>
- [5] The ArgoNeuT collaboration, Journal of Instrumentation (JINST), 2013 JINST Vol. 8 P08005