8 Conclusion

The Deep Underground Neutrino Experiment (DUNE) is a next generation neutrino oscillation experiment, which aims to make precision measurements of neutrino oscillation probabilities, in order to search of CP–violation in the lepton sector. In addition, DUNE provides an opportunity to study the mechanisms involved in supernova bursts through the measurement of supernova neutrinos. To achieve these goals, the charged particles in the DUNE detectors will have to be accurately reconstructed, in order to allow the details of the neutrino interactions to be determined. This thesis presented the results of the development of two reconstruction algorithms in the ProtoDUNE–SP detector, which is a surface level proto–type for the DUNE far detector modules.

In this thesis, the development of a hit tagging algorithm for track, shower, and Michel electron hit classification was discussed in Chapter 6. This algorithm is based on convolution neural networks, with a small patch approach. In terms of track–shower discrimination, the algorithm was shown to reduce the false–positive rate for all particle species, with a reduction of more than a factor of 10 in some cases. In addition, this algorithm was shown to give a good agreement, of around 1–3%, between data and simulation for hit–by–hit event selection. This algorithm is now seeing significant use within ongoing ProtoDUNE–SP data analyses, including pion cross–section analyses and detector calibrations. Additionally, this network was used as part of the Michel electron event selection algorithm, which was discussed in Chapter 7 of this thesis.

A sample of Michel electrons from the ProtoDUNE–SP detector was used to study Michel electron reconstruction in LArTPCs, and to estimate the energy resolution and bias of ProtoDUNE–SP for electrons in the tens of MeV range. Michel electron events where selected based on a new algorithm, which combined the clustering of Pandora with the output of the hit classification CNN to select clusters with a high fraction of Michel–like hits. This algorithm was shown to agree well between data and simulation, with around a 2% difference between the selected fraction in data and simulation. The simulation was used to estimate the purity and efficiency of the event selection algorithm, which were found to be around 98% and 6% respectively. This represents an improvement in both purity and efficiency over similar LArTPC Michel electron studies from other experiments, such as MicroBooNE.

The Michel electron sample was used to investigate a novel reconstruction technique, which was based on the semantic segmentation of images with a convolutional neural network. A U–Net architecture was used to perform the segmentation, and the results were promising, however, more work is required to improve the performance of this algorithm across the whole energy range.

In the 0–25 MeV region, where the performance of the U–Net algorithm was good, the ionisation energy resolution for Michel electrons based on this algorithm was found to be around 10–12%, and the bias was less than 5%. This represents an improvement over the measured Michel electron ionisation energy resolution of MicroBooNE, which is the closest comparison to ProtoDUNE–SP in terms of Michel electron reconstruction. Above 25 MeV, the reconstruction algorithm began to develop as significant tail in the fractional difference distribution. This tail represents the tendency of the algorithm to under–reconstruct the Michel electron ionisation energy, and is a result of a drop in hit selection efficiency above 25 MeV. Therefore, some additional work is required to improve the performance of this algorithm, but the excellent performance in the low energy region shows that this is a promising approach. A similar approach could be developed for other low–energy reconstruction tasks in LArTPCs, such as the reconstruction of supernova neutrinos in the DUNE far detector.

The DUNE experiment will use a liquid argon time projection chamber to make precision studies of neutrino oscillations, supernova neutrinos, and beyond the standard model phenomena. The development of effective reconstruction algorithms and understanding the detector response are both crucial components of understanding particle interactions in the DUNE detector. In this thesis we have presented the results of various studies into electromagnetic interactions in the ProtoDUNE–SP detector, focussing on the application of convolutional neural networks to event reconstruction in LArTPCs. The results of these analyses are being used to assist in physics measurements based on ProtoDUNE–SP data, and can also be used to guide further development of reconstruction strategies for LArTPC detectors.