Single and Double Electron Event Classification Using Machine Learning for the MAJORANA DEMONSTRATOR

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Abstract

Signals generated by single and double electron events are found in the dataset of the MAJORANA DEMONSTRATOR (MJD). MJD is searching for a signal due to a double electron event, so we would like to be able to filter out single electron events that pollute our signal. We show that through the use of a 10 layer convolutional neural network (CNN) in PyTorch, we can identify single and double electron waveforms generated by MaGe [2]. The best networks have an AUC of 0.822, meaning 82.2% of the time they are correctly ranking a double electron event differently than a single electron event.

Introduction

- MJD [1] is neutrinoless double beta decay experiment ($0\nu2\beta$)
- Theoretical decay process that is sensitive to neutrino mass
  - Decay process is possible in Ge-76
  - Feynman diagram provided in figure 1
  - Neutrino mass indicates physics beyond the standard model, means neutrino is a “Majorana” particle
- MJD has 40kg of P-Type Point Contact (PPC) Ge detectors (figure 2), with 30kg being enriched Ge-76

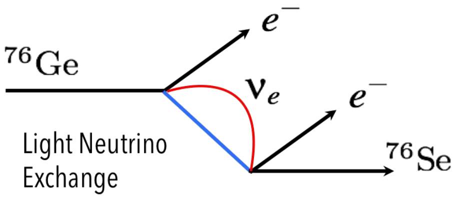

Figure 2: $0\nu2\beta$ Feynman diagram in Ge-76. Decay is mediated by the W boson.

- $0\nu2\beta$ results in the emission of two electrons at 2039 keV total
- MJD also picks up single electron events at 2039 keV, from cosmic rays or impurities in detectors
  - Single electron events degrade our ability to detect $0\nu2\beta$
- Use a convolutional neural network (CNN) to identify single and double electron events in order to filter out the single electron events, increasing our sensitivity to $0\nu2\beta$

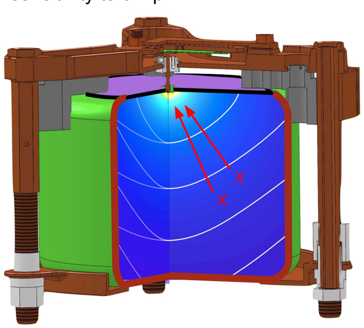

Figure 2: PPC detector. Point contact is at top, which generates a potential across the detector volume. The two “x” show the emission of two electrons in a $0\nu2\beta$ event. The electrons form “charge clouds” which drift towards the contact. These clouds are collected at different times due to their spatial separation.

Procedure

- 10 layer CNN used separate simulated single and double electron events based on their waveforms alone, CNN structure given in figure 3
- Output is a number between 0 and 1, ranking a probability of how sure the network is that the event was a single electron event (0) or double electron event (1)
- Simulated data is purely the physics of interactions in order to show this separation is possible, future research will add in electronics effects and random noise
- Simulated data made using MJD’s MAGE [2] software
  - Generated $0\nu2\beta$ and single electron events uniformly throughout PPC detector volume at 2039 keV
  - Waveform had 2016 points to match real detectors output
  - 100,000 waveforms generated in total
  - Split into 80,000 test waveforms and 20,000 validation waveforms for
  - Simulated data shown in figure 4

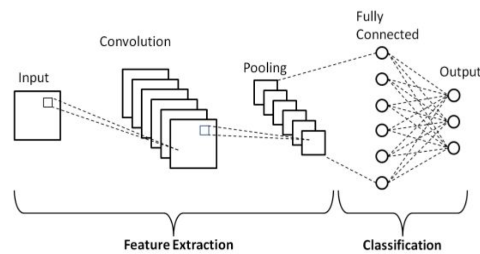

Figure 3: CNN structure. Our CNN has a single output value instead of 3.

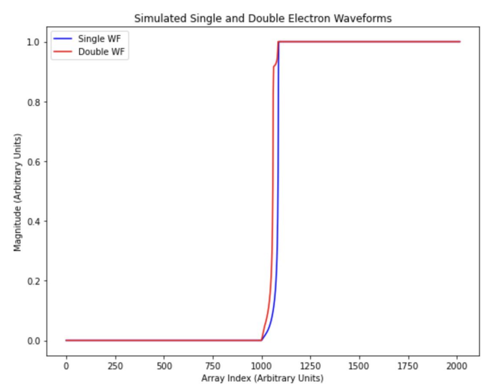

Figure 4: Simulated single (blue) and double (red) wave-forms. Notice the kink in the double event from the two charge clouds being collected at different times.

- After building the CNN in PyTorch [3], hyperparameter search done with Ax
- Best model and hypersearch code is provided online in the author’s GitHub repository [3]

Analysis and Results

- CNNs analyzed with ROC curves (plots TPR against FPR, figure 5) and AUC (area under ROC curve)
  - Double electron event is background, single electron event is signal
  - Get pairs of TPR and FPR for various classification thresholds
- Best model has AUC of 0.822, meaning single electron event classified with lower value than double electron event 82.2% of the time

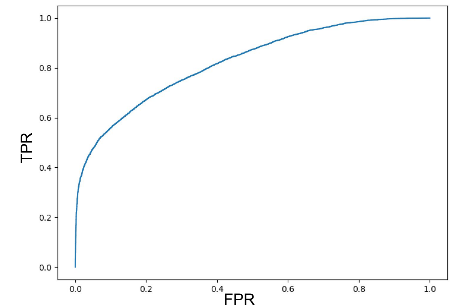

Figure 4: ROC curve for the best CNN. AUC = 0.822.

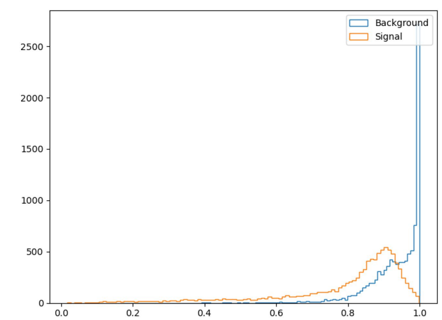

Figure 5: Distribution of how the classifier ranked the single electron events (signal) and double electron events (background). Recall that a classification of 0 corresponds to single electron events, and a classification of 1 corresponds to double electron events.

Acknowledgements

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References

[1] N. Abgrall, *et al.* (2014). The MAJORANA DEMONSTRATOR Neutrinoless Double-Beta Decay Experiment. Advances in High Energy Physics, vol. 2014.
[2] M. Boswell, *et al.* (2011). MAGE - a GEANT4-Based Monte Carlo Application Framework for Low-Background Germanium Experiments. IEEE TNS.
[3] https://github.com/stew31415/electron_classification.git