A 1D CNN Algorithm for Low Background β Detection with Time Projection Chamber

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Introduction

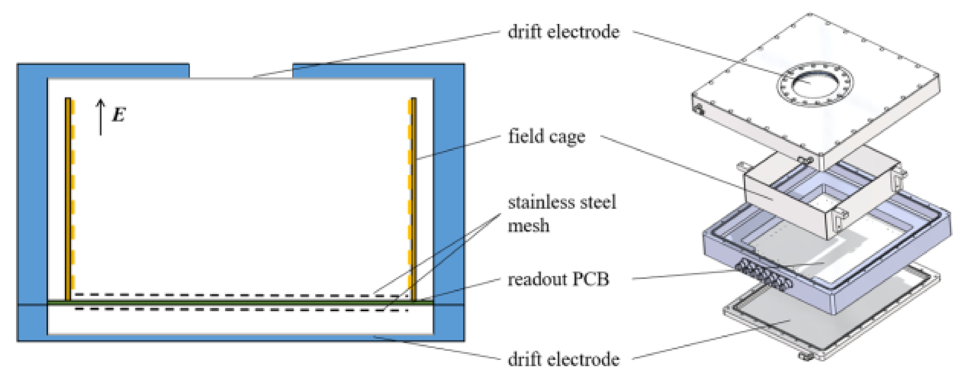
- Removing the thick lead shielding from mainstream α and β detection schemes can significantly reduce the size and weight of instrumentation, facilitating their use in confined spaces.
- The reconstruction capability of ***Time Projection Chambers (TPC)*** facilitates lead-free, low-background detection of α and β particles. Manual multi-feature selection based on TPC has shown effective performance in low-background alpha detection
- The ***one-dimensional convolutional neural network (1D CNN)*** algorithm contributes to effectively discriminating between background and β events in lead-free TPC detectors, achieving high background rejection while retaining the majority of β data.

Detection System

TPC System

The TPC system consists of a main TPC detector and an anti-coincidence detector, allowing for the exclusion of cosmic muons through anti-coincidence measurements.

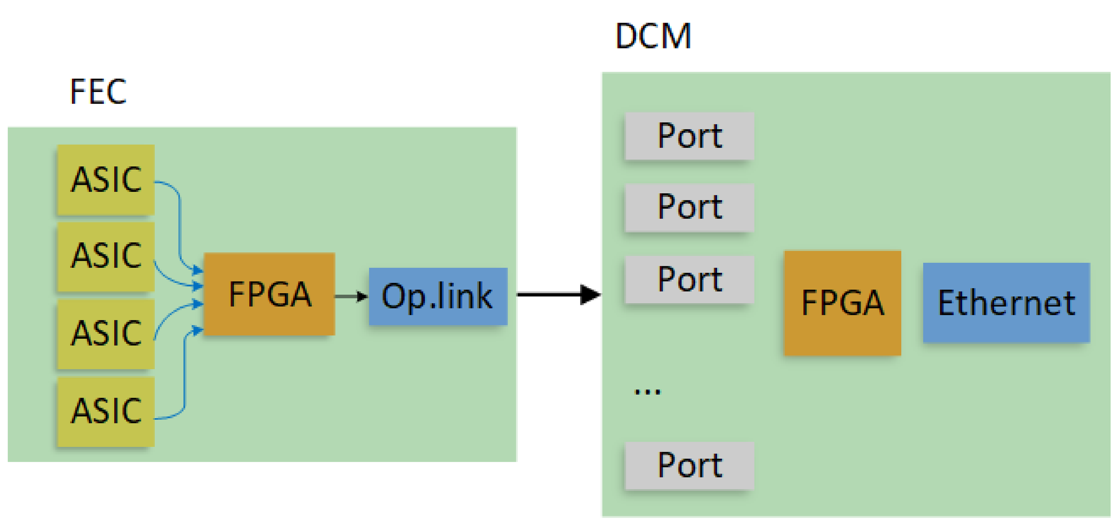
- The TPC main detector utilizes a readout configuration of 120 × 120 strips
- The veto detector employs a 4 × 4 PAD readout configuration
- A total of 256 signal channels are read out using a PCB anode board with a sensitive area of 150mm × 150mm
- The detector casing is crafted from aluminum and includes a radiation entrance window for samples, measuring 70mm×70mm on its surface



Readout Electronics

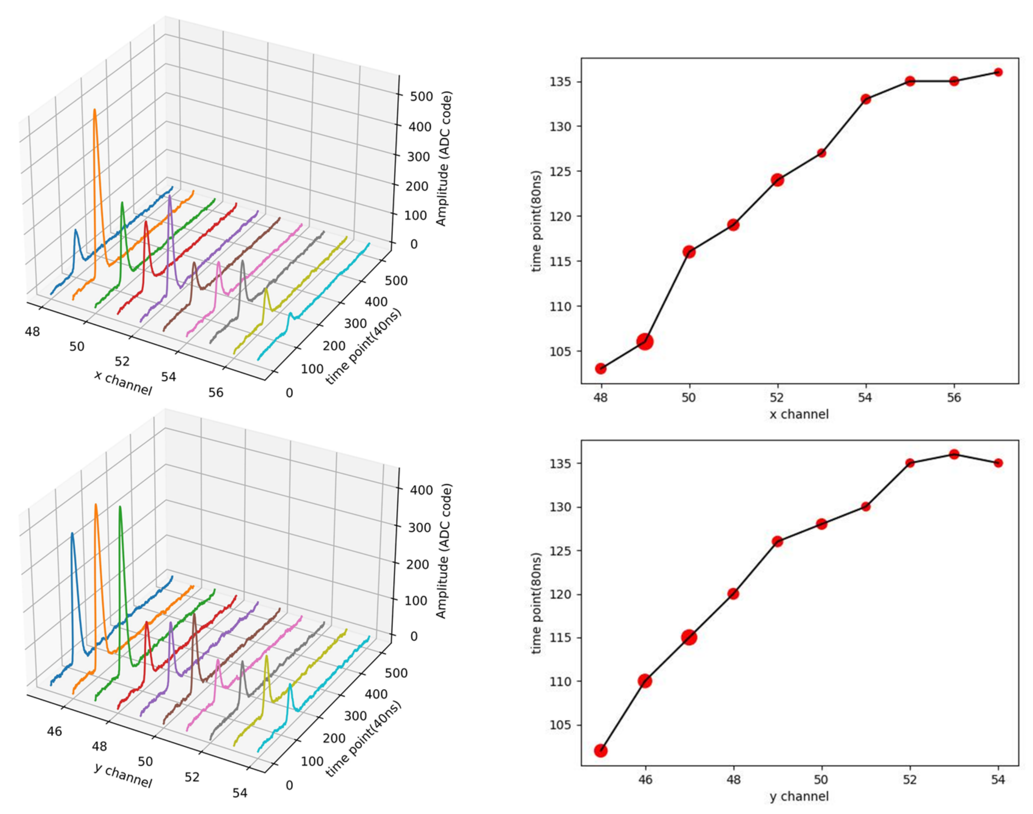
The readout electronics comprise two components: the Front-End Card (FEC) and the Data Collection Module (DCM), this algorithm is not constrained to this particular system.

- The Front-End Card (FEC) amplifies and filters the charge signals obtained from the anode board and transmits them to the Data Collection Module (DCM) via optical fibers.
- The Data Collection Module (DCM) gathers and transmits data to PC via Ethernet



Feature Reconstruction

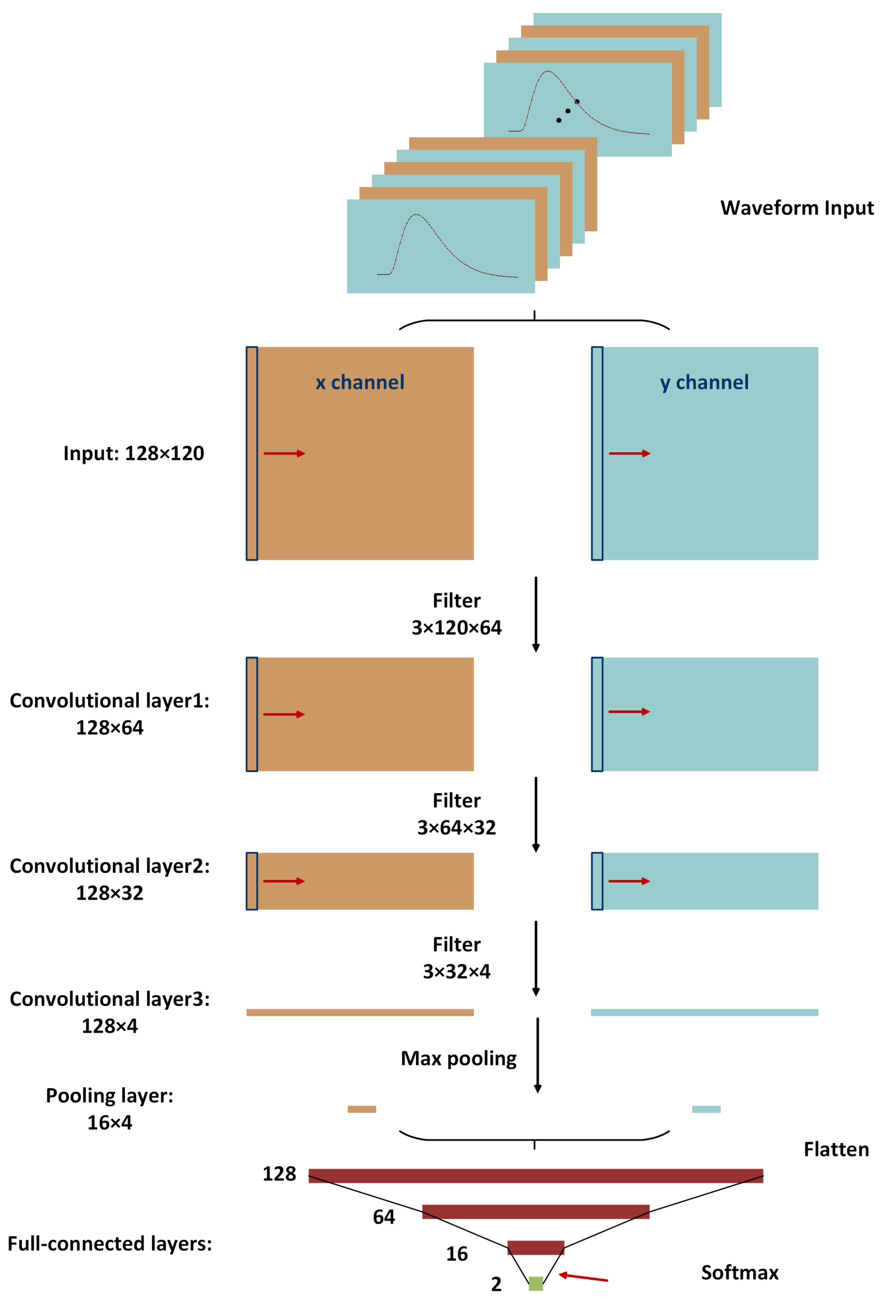
Using waveform data, it's possible to reconstruct the three-dimensional trajectory and energy deposition of particles, allowing for the reconstruction of additional features. For example, the starting point of the trajectory represents the particle's hit position.



Algorithm Design

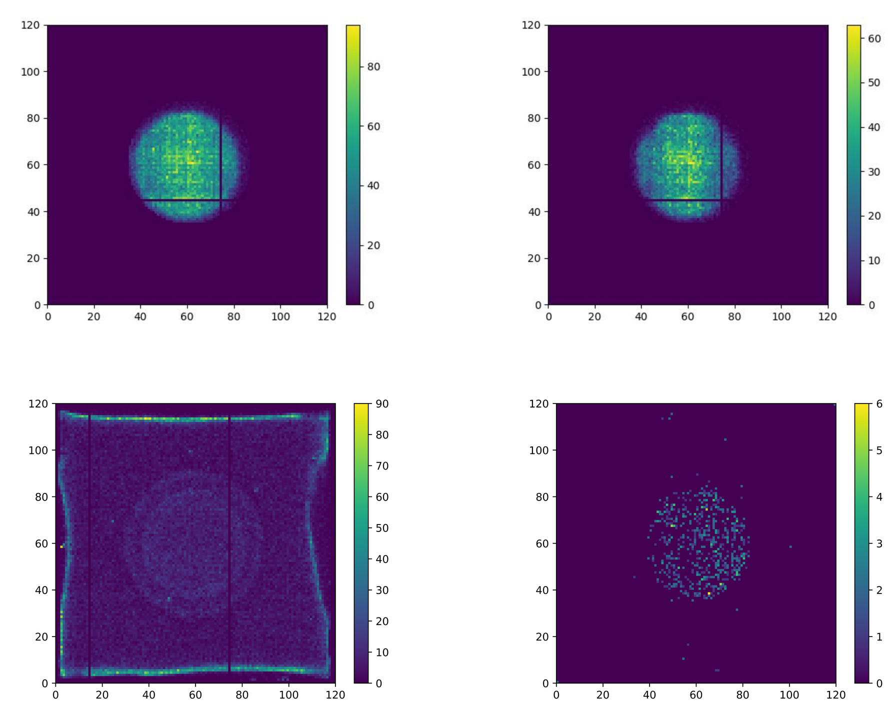
Network Architecture

The neural network comprises convolutional layers and fully connected layers. The last layer of the fully connected layers is a softmax function, producing a two-dimensional probability vector as output.



Test Result

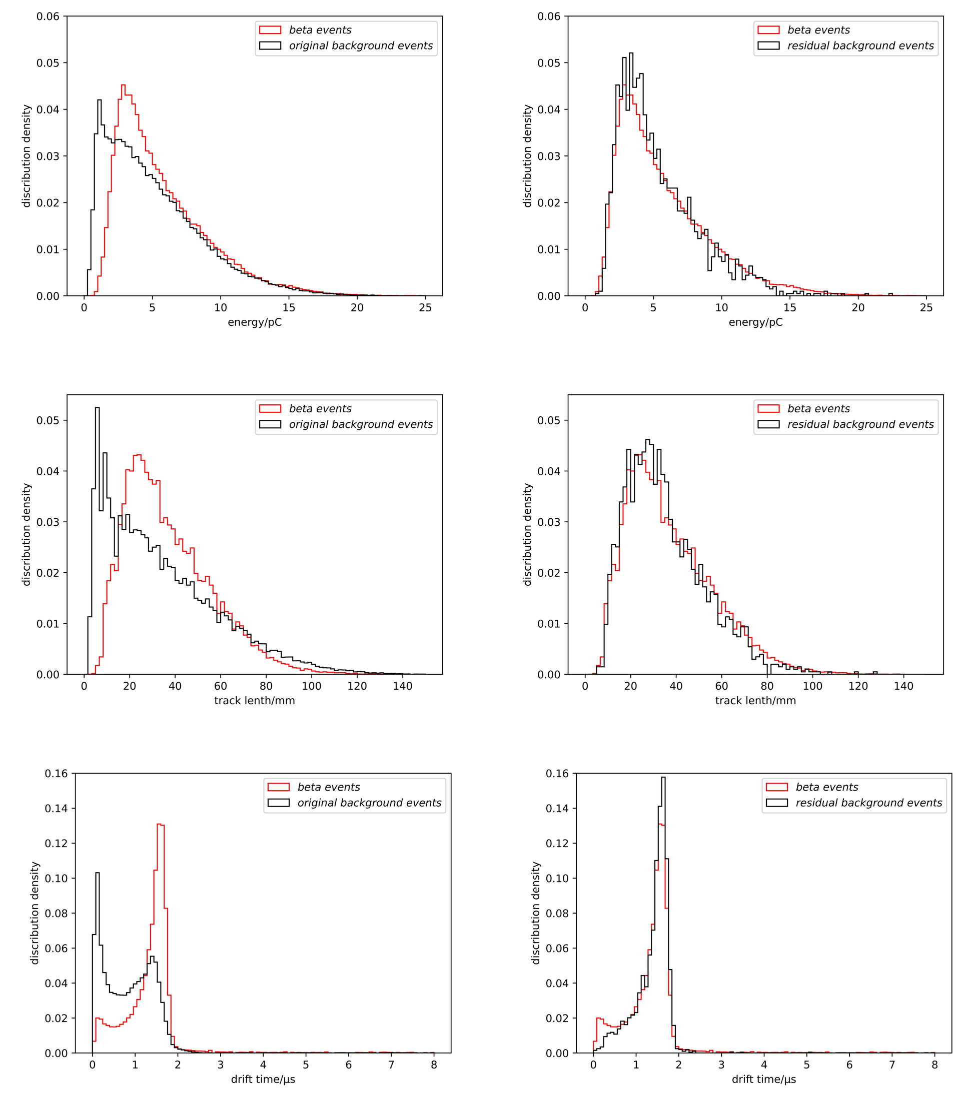
In the test set, there are a total of 83,470 β events over 4 minutes and 69,875 background events over 2 hours. Using the neural network to set the output threshold for filtering, the rejection rates are 44.53% for β events and 99.15% for background events. The following figures displays the distribution of trajectory starting points before and after filtering for β and background events.



The test results reveal a significant disparity in the algorithm's filtering performance between the β and background datasets. Furthermore, based on the rejection rates, it's possible to eliminate the vast majority of background events while preserving a large portion of β events.

Algorithm Evaluation

In order to evaluate the algorithm from a physics standpoint, we conducted a statistical analysis of the distributions of common physical quantities before and after filtering including energy loss, drift time, and trajectory lengths. The results of these distributions demonstrate the similarity between the remaining background events and true β events, providing evidence for the algorithm's superiority over manual selection.



Conclusion

- This algorithm is applicable for low-background beta detection within lead-free shielded environments using TPC systems.
- This algorithm enables the utilization of more lightweight and adaptable instruments across a broader spectrum of detection scenarios.
- Currently, with a β event retention rate of over 55%, we have achieved a 99.15% background rejection rate.

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