Institute of Research into the Fundamental laws of the Universe

Nuclear Physics Department

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The neutrino nature through the study of the Xenon 136 double-beta decays on the PandaX-III experiment

The search for neutrinoless double-beta decay (0νββ) is crucial for advancing our understanding of physics and exploring physics beyond the Standard Model. However, this pursuit is incredibly challenging due to the decay's extreme rarity, requiring profound interpretation and reliance on experimental constraints and theoretical nuclear models. The PandaX-III experiment is dedicated to the search for 0νββ in ^{136}Xe.
It is a high-pressure gaseous Time Projection Chamber (TPC) with Micromegas detectors. This design choice is made to maximize the particle track detection and discrimination 0νββ signal vs. gamma background capabilities. One of the main challenges of the 0νββ search is the discrimination between the signal and background events, which contaminate the region of interest (ROI). The strip readout system of the Micromegas detectors (a combination of 52 of them form a readout plane) allows for the precise 2D reconstruction of the ionization tracks together with the charge and time information. This allows for studying the electron tracks' energy and topology and ultimately discriminating the signal from the background. To suppress the scintillation light and rely only on the ionization signal, a 90% enriched ^{136}Xe is mixed with 1% trimethylamine (TMA) quencher. The current energy resolution of the PandaX-III experiment is 3% for the 2457 keV energy of the 136 Xe 0νββ decay, envisioned to be improved to 1%. However, several factors can degrade the energy resolution, such as the presence of dead channels, gain inhomogeneities in the Micromegas detectors, or electron attachment in the TPC.

This Ph.D work presents a study on the impact of missing channels on the energy and topology reconstructions in the PandaX-III experiment. The results of the Blob charge determination do not provide the desired possibility of reconstituting the part of the blob energy that would have been lost due to missing channels in XZ from YZ projections of reconstructed event tracks and vice versa. However, the study gave insight into employing machine learning (ML) algorithms to mitigate the impact of missing channels on energy and topology reconstructions. A Convolutional Neural Network (CNN) model was developed to predict the true energy of the electrons from the simulated data collected by the Micromegas with missing channels. The final results show that the CNN model predicts the true energy of the events recorded by the Micromegas with missing channels with a good energy resolution. We observe an improvement in the detection efficiency of the Monte Carlo 0νββ signal in the ROI from 69% to 89% after applying the CNN model, in comparison to the direct approach of directly summing amplitudes of the signals from the Micromegas with missing channels.
Another CNN model was also used to classify the two-electron events from the single-electron events in the Monte Carlo data affected by missing channels. The model is capable of rejecting 99% of the background events while maintaining a 26% efficiency for the 0νββ signal in the ROI.

The results of this work are promising and pave the way for further studies to improve the energy resolution and background rejection in the PandaX-III experiment.
