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Missing data reconstruction using Machine Learning techniques in the gaseous TPC PandaX-III experiment

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The PandaX-III experiment aims to detect the Neutrinoless Double-beta decay (NLDBD), a hypothetical process where only two electrons are emitted from the atomic nucleus. Since the Q-value of the decay is divided only between charged particles, the electron sum energy spectrum of the NLDBD would show a single peak at the Q-value point. While only a few isotopes undergo double-beta decay with the emission of two anti-neutrinos, Xe-136 was chosen for the experiment due to its high natural abundance and suitability for use in gaseous TPC detectors. However, the Q-value for Xe-136 (~2.5MeV) can be contaminated by background radiation, which needs to be distinguished from the signal.
The PandaX-III experiment uses a Time Projection Chamber (TPC) detector filled with 10 bar gaseous Xe-136 and a readout plane consisting of 52 Thermal-bonded Micromegas modules (TBMM) [1], each with readout pixels connected in channels. There are 128 readout channels per module: 64 per X and Y directions. Therefore, XZ and YZ projections of the initial decay event track represent the detector output. It stores not only the amplitudes of the signal deposited by ionized particles inside the gas but also the topology of the event. Thus, such data configuration is beneficial for background discrimination from the signal [2]. In NLDBD searches, the experiment requires excellent energy resolution to discriminate signals from the background, and the PandaX-III experiment design aims to achieve better than 3% at 2.5 MeV. However, in the real-world experiment, readout channels may be disconnected due to physical damage, the appearance of sparks, high dark currents, and other factors, resulting in losses in energy measurement and track reconstruction. In addition, the signal gain may be inhomogeneous on the Micromegas modules, further degrading the energy reconstruction. To improve the measurement quality, registered data should be corrected for missing channels and inhomogeneities.
In this project, Machine Learning techniques have been implemented to predict the total energy of events detected by TBMM modules that have missing channels. Additionally, event classification was studied to differentiate between NLDBD events and background events based on their topology. To conduct the analysis, Monte-Carlo simulations were performed using REST software based on the Geant4 and ROOT libraries. Multiple Neural Network (NN) architectures were tested to find the most optimal configuration that yields the best predictions. The results indicate an improvement in the detection efficiency of an NLDBD signal when NN is applied to correct missing energy compared to direct signal detection with missing energies. Finally, discrimination of the background using NN demonstrates noticeable results, helping select events that require reconstruction due to detector flaws. In low-rate experiments (NLDBD, Dark-matter searches, etc.), the high energy resolution is crucial, and the loss in detection capability may drastically reduce the effectiveness of the detector. Therefore, such a technique shows high potential to be implemented in Xe-based experiments. After having presented the experiment and the status of the MM readout, the methodology of the ML studies will be described along with the corresponding results.

References

[1] J. Feng et al., A thermal bonding method for manufacturing Micromegas detectors, Nuclear instruments & methods in physics research. Section A, Accelerators, spectrometers, detectors and associated equipment 989 (2021) 164958
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