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#4-249 Techniques for Accurate Energy Calibration in Reactor Neutrino Detectors

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Recent years have seen significant advancements in neutrino physics, particularly in the study of reactor neutrinos, which have played a key role in resolving the long-standing reactor neutrino anomaly. Accurate calibration of detectors in reactor neutrino experiments is essential for measuring reactor antineutrino interactions and understanding neutrino oscillations, key phenomena in particle physics. This paper focuses on the calibration techniques used to establish a reliable energy scale for detecting neutrinos through inverse beta decay (IBD), a crucial process for reactor monitoring and neutrino physics. Several calibration methods are employed, including the use of scintillators, radioactive sources (both gamma and neutron emitters), cosmic muon detection, neutron capture events (such as those from AmBe sources), and LED light injection to calibrate the photomultiplier tubes (PMTs) and monitor the linearity of the electronics. These techniques play a critical role in ensuring an accurate energy scale, which is fundamental for precise neutrino measurements. Scintillators and radioactive sources are used to inject known signals into the detector, enabling direct calibration of the energy scale and control detector response stability. Cosmic muon detection helps to understand the spatial response and efficiency of the detector, while neutron capture events provide additional insight into the detector's nuclear response. Additionally, advanced simulations using Geant4, FIFRELIN, and Monte Carlo methods help to correct for energy nonlinearity, model complex gamma cascades, and improve neutron capture efficiency, further reducing uncertainties in energy reconstruction. These methods significantly enhance energy resolution and reduce systematic errors, resulting in more accurate reactor neutrino measurements. The combined application of these techniques improves data accuracy for reactor antineutrino spectra analysis and enables better interpretation of neutrino energy distributions, offering deeper insights into reactor operations and the properties of neutrinos. These advancements not only enhance the sensitivity of ongoing and future neutrino experiments but also contribute to the optimization of reactor monitoring and neutrino oscillation studies. Ultimately, improved calibration methods are crucial for advancing research in both particle physics and nuclear science.

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