EUROPEAN AI FOR FUNDAMENTAL PHYSICS CONFERENCE EuCAIFCon 2025

Contribution ID: **108** Type: **Poster + Flashtalk**

Semi-Supervised Density Estimation for Suppressing ^{42}Ar/^{42}K Surface Beta Events in LEGEND

The LEGEND experiment aims to detect neutrinoless double-beta ($0\nu\beta\beta$) decay using high-purity germanium detectors (HPGes) enriched in ^{76}Ge, immersed in instrumented liquid argon (LAr). Atmospheric LAr contains the cosmogenically activated isotope ^{42}Ar, whose decay progeny, ^{42}K, can undergo beta decay ($Q_\beta = 3.5$ MeV) on the HPGe surface. Without the baseline mitigation strategy—using underground-sourced LAr (UGLAr) depleted in ^{42}Ar—this decay would become the dominant background at the $0\nu\beta\beta$ Q-value ($Q_{\beta\beta} = 2.039$ MeV) in LEGEND-1000. Given the non-negligible risk that UGLAr may not be available in time for LEGEND-1000, alternative approaches are being explored, such as optically active enclosures combined with machine-learning-based pulse-shape discrimination (ML-PSD), to distinguish between $0\nu\beta\beta$ signals and background events. To develop and evaluate novel ML-PSD techniques, we operated high-purity germanium (HPGe) detectors in ^{42}Ar-enriched LAr at the SCARF LAr test facility at TU Munich, generating a dataset enriched in ^{42}K surface beta events.

In this work, we investigate the construction of a latent representation of raw HPGe waveform data using variational inference. Unlike conventional PSD parameters, the latent vectors are designed to fully utilize the high-level features of the waveforms. By constraining the latent space with a predefined prior, we estimate the data density corresponding to a signal proxy derived from ^{228}Th calibration data. This is achieved by first employing a classifier neural network to estimate the posterior probability of class labels for samples drawn from both the latent prior and the signal-proxy distribution and then applying Bayes'rule to compute the likelihood of the data under the signal-like hypothesis.

We use the resulting density estimate to classify events as signal- or background-like at a specified significance level. Our evaluation demonstrates promising suppression of ^{42}K surface beta events, providing a pathway for density-based PSD that utilizes the complete raw waveform information from HPGe detectors.

This work was supported by the Cluster of Excellence ORIGINS (EXC 2094-39078331), funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy, and by the DFG Collaborative Research Center SFB1258-283604770.

AI keywords

variational inference, anomaly detection, pattern recognition

Primary author: LAY, Niko Nanda Putra Nila (Technical University of Munich)

Co-authors: LEONHARDT, Andreas (Technical University of Munich); Dr HASHEMI, Baran (Technical University of Munich); Dr HACKETT, Brennan (Max Planck Institute for Physics); Dr MAJOROVITS, Béla (Max Planck Institute for Physics); VOGL, Christoph (Technical University of Munich); Dr GUSEV, Konstantin (Technical University of Munich); Prof. HEINRICH, Lukas (Technical University of Munich); Dr SCHWARZ, Mario (Technical University of Munich); NEUBERGER, Moritz (Technical University of Munich); RUMYANTSEVA, Nadezda (Technical University of Munich); Dr KRAUSE, Patrick (Technical University of Munich); Prof. SCHÖNERT, Stefan (Technical University of Munich); Dr COMELLATO, Tommaso (Technical University of Munich)

Presenter: LAY, Niko Nanda Putra Nila (Technical University of Munich)

Track Classification: Inference & Uncertainty