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Graph Neural Networks and Multi-Objective Optimization for Coded-Mask Prompt-Gamma Imaging within the SiFi-CC Collaboration

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Background and Aims: This study introduces graph neural networks (GNNs) to improve prompt-gamma imaging for a 1D coded-mask gamma camera developed by the SiFi-CC collaboration for proton therapy verification.

Methods: The coded-mask detector features LYSO:Ce,Ca scintillating fibers with dual-ended readouts. Coincident detector signals are aggregated into event representations and subsequently into cluster representations to capture spatial, temporal, and energy information. A graph-based learning model infers interaction positions and energies from these representations, feeding the output into a Maximum-Likelihood Expectation-Maximization (MLEM) algorithm for depth profile reconstruction. Finally, image reconstruction parameters are optimized using an NSGA-III multi-objective genetic algorithm within the Optuna framework.

Results: For a dataset of 10^{10} protons, the optimized pipeline demonstrated sub-millimeter beam range accuracy, achieving a root-mean-square error (RMSE) below 0.6 mm.

Conclusions: Combining graph-based event reconstruction with targeted image optimization significantly improves the resolution of coded-mask prompt-gamma imaging detectors.

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