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Machine Learning Approaches for Metallic Magnetic Calorimeters

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Metallic magnetic calorimeters (MMCs) of the maXs-series, developed within the SPARC collaboration, offer exceptional energy resolving power (up to $E/\Delta E \approx 6000$ at 60 keV) [1] over a broad spectral range (1–100 keV) with high quantum efficiency and linearity [2], making them ideal for high-precision X-ray spectroscopy in fundamental atomic physics. Their operation, however, requires intricate per-pixel optimization of hardware parameters - such as SQUID array tuning - and extensive manual steps in the analysis of raw detector pulses [3]. These procedures, while manageable for current small-scale arrays, become infeasible for future MMC developments with orders of magnitude more pixels.

We present first results of applying machine learning (ML) methods to automate MMC signal classification and feature extraction, thereby improving scalability and robustness. Classical techniques such as principal component analysis combined with clustering were evaluated for reliable pulse shape classification. More advanced architectures, in particular convolutional variational auto-encoders (CVAEs) coupled with multilayer perceptrons (MLPs), were trained on synthetic MMC pulses to embed them into a low-dimensional latent space and reconstruct physical pulse parameters (e.g., amplitude, trigger time, decay time). Notably, neural networks trained solely on synthetic data successfully reconstructed calibration spectra from real measurements, surpassing traditional finite response filter performance.

These results demonstrate the feasibility of incorporating ML into MMC analysis pipelines, paving the way for automated operation. Future developments will explore fine-tuning with real data, improved artifact simulation for temperature drift correction, and reinforcement learning for autonomous hardware optimization.

References

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