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Automated Data/MC Tuning via Phase-Space Optimization

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High-fidelity Monte Carlo simulations (e.g., Geant4, CORSIKA, Pythia) are indispensable in high-energy and medical physics. However, aligning simulated and experimental distributions remains a laborious task, traditionally relying on manual selection tuning or computationally expensive grid scans. This challenge is compounded when quality selection cuts must be jointly optimized across a high-dimensional phase space containing correlated detector observables.

An automated, domain-independent framework designed to efficiently optimize multi-variable quality selection criteria is introduced. Utilizing a pure-Julia architecture leveraging automated optimization engines, the pipeline simultaneously minimizes binned shape discrepancies while applying density-based regularizations to preserve overall statistical efficiency. The methodology is evaluated using both synthetic and publicly available data. The high performance of Julia's compilation ecosystem enables end-to-end multi-dimensional optimization over millions of events in seconds. Foreseen future applications of this framework include the optimization of complex data pipelines for large-scale neutrino observatories like KM3NeT, as well as next-generation medical workflows such as the 3Dπ liquid argon PET scanner. The resulting open-source toolkit provides an effective approach to simulation tuning for both complex physical event analyses and precision medical imaging workflows.

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