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Improved Probabilistic Event Weighting via Covariance-Corrected Q-Factors for Signal Isolation

In complex particle physics analyses where signal and background events are intertwined across multidimensional phase space, statistically consistent event-by-event weighting is indispensable for unbiased extraction of signal observables. However, many widely used methods can often fail to correctly estimate this separation, particularly in the presence of statistically independent variables or when key model assumptions fail.

We assess the limitations of these standard techniques with particular focus on Q-factors – an adaptive local fitting method based on k-nearest neighbors. Although Q-factors offer enhanced flexibility over global fits, it inherently assumes statistical dependence between discriminating and weighted variables, leading to a bias when this condition is violated. To address this, we introduce a corrected formalism, ${}_{s}Q$ -factors (pronounced /*skju:*/, as in "*skew*"), which integrates the local adaptivity of Q-factors with the covariance-based corrections from ${}_{s}\mathcal{P}$ lot. This hybrid approach restores statistical consistency across dimensions while still preserving local sensitivity, enabling unbiased signal extraction in complex, multidimensional analyses. Through Monte Carlo simulations, we demonstrate that ${}_{s}Q$ -factors consistently outperform traditional methods in both signal recovery and physics parameter estimation. These studies highlight the robustness and accuracy of the method in high-dimensional analyses.

Secondary track

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