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Unbinned inclusive cross-section measurements with machine-learned systematic uncertainties

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We introduce a novel methodology for addressing systematic uncertainties in unbinned inclusive cross-section measurements and related collider-based inference problems. Our approach incorporates known analytic dependencies on parameters of interest, including signal strengths and nuisance parameters. When these dependencies are unknown, as is frequently the case for systematic uncertainties, dedicated neural network parametrizations provide an approximation that is trained on simulated data. The resulting machine-learned surrogate captures the complete parameter dependence of the likelihood ratio, providing a near-optimal test statistic. As a case study, we perform a first-principles inclusive cross-section measurement of $H \to \tau\,\tau$ in the single-lepton channel, utilizing simulated data from the FAIR Universe Higgs Uncertainty Challenge. Results in Asimov data, from large-scale toy studies, and using the Fisher information demonstrate significant improvements over traditional binned methods. Our computer code "Guaranteed Optimal Log-Likelihood-based Unbinned Method"(GOLLUM) for machine-learning and inference is publicly available.

Our submission won first place ex aequo in the FAIR Universe Higgs Uncertainty Challenge and is available at https://arxiv.org/abs/2505.05544.

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