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Beyond the Standard Model Searches for Dark Vector Bosons: A Comparison of BDT and Parametric Neural Networks

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\usepackage{parskip}
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hidelinks
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\begin{document}

\noindent{\large\textbf{Beyond the Standard Model Searches for Dark Vector Bosons: A Comparison of BDT and Parametric Neural Networks}}

\vspace{0.5em}

The search for exotic Higgs boson decays to pairs of dark vector bosons,  $H \rightarrow Z_d Z_d \rightarrow 4\ell$ , where each  $Z_d$  decays to a pair of same-flavour opposite-sign leptons, presents a significant multivariate classification challenge due to the continuous and unknown mass of the dark vector boson  $Z_d$ . Traditional approaches based on Boosted Decision Trees (BDTs) require separate training at each signal mass hypothesis, limiting sensitivity interpolation across the mass spectrum and increasing computational overhead. Parametric Neural Networks (pNNs) offer an alternative by conditioning the classifier on the signal mass hypothesis as an additional input, enabling a single unified model to provide optimised discrimination across the full  $Z_d$  mass range. In this work, we present a systematic comparison of BDT and pNN classifiers for the  $H \rightarrow Z_d Z_d \rightarrow 4\ell$  search using ATLAS Run 3 proton-proton collision data at  $\sqrt{s} = 13.6$  TeV. We evaluate both approaches in terms of signal-to-background discrimination, sensitivity as a function of  $Z_d$  mass, computational cost, and interpolation behaviour between trained mass points  $m_{Z_d} \in [15, 60]$  GeV.

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