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Multi-scale cross attention transformer encoder for τ lepton pair invariant mass reconstruction

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With the observation of the Standard Model Higgs boson (H) by the CMS and ATLAS experiments in 2012, the last missing elementary particle predicted by the Standard Model of particle physics was found. Since then, extensive measurements in various decay channels of the Higgs boson have been performed. One of them is the decay into a pair of τ leptons. It is the decay channel of the Higgs boson into fermions with the second-largest branching fraction, only surpassed by the decay into a pair of bottom quarks.
In such analyses, the reconstructed invariant mass of the di-τ pair is an important discriminant to separate signal (H) from background events, which can be reconstructed starting from the decay products of each τ lepton. However, the presence of neutrinos in the final state determines a lack in terms of energy which leads to an underestimation of the invariant mass itself.
The proposed work consists in a Deep Learning (DL) model that, instead of just regressing the mass, estimates the full four-vector of each τ of the system before decay for a high-resolution reconstruction of the invariant mass and therefore retrieve information about the kinematics of the parent particle.
The implemented model is a multi-scale cross attention transformer encoder (a DL model, born for Natural Language Processing tasks and now demonstrating its power as a universal architecture). This multi-modal network can extract information from the substructure of the di-τ products and the kinematics of the reconstructed taus through self-attention transformer layers. The learned information is subsequently integrated to improve regression performance using an additional transformer encoder with cross-attention heads. H $\rightarrow \tau\tau$ process together with the main backgrounds are used as a benchmark to measure the performance of the new algorithm with respect to the currently used one in CMS (SVFit).

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