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Particle Decay Tree Reconstruction with Graph Neural Networks

Learning the hierarchy of graphs is relevant in a variety of domains, as they are commonly used to express the chronological interactions in data structures. One application is in Flavor Physics, as the natural representation of a particle decay process is a rooted tree graph.
Analyzing collision events involving missing particles or neutrinos requires knowledge of the full decay tree. However, the experimental reality is that only part of the tree can be measured, as heavy particles produced in the collisions decay rapidly. This continues with additional intermediate decays until the daughter particles of these decay chains, referred to as final state particles, are stable enough to reach the detector. In the tree graph structure these represent the leaf nodes. The challenge is then to reconstruct the tree graph structure using only the available information of the final state particles, resulting in a large combinatorial complexity as they can often number over 20 particles. The reconstruction algorithm must therefore learn and apply physical laws to predict the number and hierarchy of intermediate parent particles.

To learn the decay tree graph structure from these available sets of leaf nodes, we introduce an approach to encode the entire structure of the rooted trees as a lowest common ancestor generation matrix. We use a graph neural network, namely a neural message passing mechanism, which considers relations between the leaf nodes. This method is then applied to simulated collision data of the Belle II experiment to evaluate the efficiency of this approach compared to the existing reconstruction algorithm.

Significance

We offer a novel approach to deal with scenarios where the structure of the rooted tree graph representing a particle decay is unknown. Namely, we demonstrate a method of encoding the entire decay tree structure into a single matrix which relies on minimal assumptions about the number of intermediate particles. As far as the authors are aware, this is the first time a single training target for applying machine learning methods has been shown, allowing for a single, end-to-end-trained solution for particle decay reconstruction.

References

Speaker time zone

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