Muon bundle reconstruction with KM3NeT/ORCA using graph convolutional networks

Executive summary

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KM3NeT/ORCA is a water-Cherenkov neutrino detector, currently under construction in the Mediterranean Sea at a depth of 2450 meters. The project's main goal is the determination of the neutrino mass hierarchy by measuring the energy- and zenith-angle-resolved oscillation probabilities of atmospheric neutrinos traversing the Earth. Additionally, a large amount of atmospheric muons is observed in the detector, which can be used to study extensive air showers generated by cosmic ray particles.

Reconstructing the properties of atmospheric muons can prove challenging. Especially if there are multiple muons crossing the detector at the same time (muon bundles), the signature left behind in the detector can be very complex. Deep Learning methods can drastically simplify this process by providing a universal and simple way of reconstructing any observable. Since the data recorded by KM3NeT closely resembles point clouds, graph convolutional networks are a natural choice for the architecture.

This work describes the first application of graph networks in KM3NeT, and the first application of deep learning methods on our measured data. The networks are used to reconstruct the zenith angle, the muon multiplicity and the diameter of atmospheric muon bundles. Simulations and measured data from an early four line stage of the detector are used to evaluate the performance. This novel method provides a zenith reconstruction consistent with an established classical algorithm on both data and simulations for single muon events. Furthermore, it shows improvements for multi-muon events, and allows for an investigation of the cosmic ray composition via the reconstructed bundle properties.