

The Measurement and Modelling of Cosmic Ray Muons at KM3NeT Detectors

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Abstract

Atmospheric muons are the most frequently observed form of cosmic radiation. Despite this, the existence of the muon flux component produced in decays of short-lived parent particles, called prompt muon flux still awaits experimental confirmation. This contribution to the muon flux is expected to start dominating at high energies, around PeV, since many of the prompt parent particles are heavy hadrons, containing charm and strange quarks. The aim of this thesis was two-fold: to evaluate the possibility of observing the prompt muon flux and to validate the performance of the KM3NeT detectors.

The KM3NeT experiment is a research network of underwater Cherenkov neutrino telescopes, currently under construction at two different locations in the Mediterranean Sea. The ARCA detector, dedicated to high-energy neutrino astronomy, is located near the coast of Italy at Portopalo di Capo Passero. The second one is ORCA, and it focuses on the low-energy atmospheric neutrino physics and is built offshore Toulon, in France. Even in their intermediate configurations, the KM3NeT detectors collect vast amounts of muon data. This work makes use of the muon data to evaluate the current operation of KM3NeT/ARCA and KM3NeT/ORCA and estimate their future potential.

To study the performance of KM3NeT detectors, an extensive Monte Carlo (MC) simulation of the muon events has been produced using the CORSIKA code, coupled with a chain of KM3NeT processing software. It was possible through significant improvements in the open-source KM3NeT application, responsible for the transport of simulated particles to the detector.

The MC simulation was put to use in the reconstruction of several observables: muon bundle energy, total primary energy and muon multiplicity. The regression of energy and multiplicity was carried out utilising machine learning tools. The bundle energy reconstruction beat the standard KM3NeT energy reconstruction by a large margin. Obtaining predictions of total primary energy and muon multiplicity allowed for the first measurements of such quantities by an underwater neutrino telescope.

The developed reconstruction was directly applied in the main physics analysis, which investigated the potential of KM3NeT detectors to observe the prompt atmospheric muon flux. The complete KM3NeT detectors should be able to confirm the prompt signal within 4–6 years of operation, possibly even sooner if their measurements are combined. Currently, the sensitivity is strongly limited by systematic uncertainties, which may be reduced by the time ARCA and ORCA are completed.