T 4: Cosmic rays 1

Time: Monday 16:00–18:00 Location: Geb. 20.30: 2.059

T 4.1 Mon 16:00 Geb. 20.30: 2.059

Investigations of Photon-Hadron Separation at the Pierre Auger Observatory using Monte Carlo Simulations — •Fiona Ellwanger for the Pierre-Auger-Collaboration — Karlsruhe Institut für Technologie, Karlsruhe, Germany

Cosmic ray detectors like the $3000\,\mathrm{km}^2$ surface array of the Pierre Auger Observatory are capable of observing high-energy photons in the range of 10^{18} to 10^{20} eV if the flux is sufficiently high. Since the mean free path of the photons increases with energy in the ultra-high energy range, extragalactic sources can be probed up to distances of few Mpc. However, no clear candidates for ultra-high energy photons have been identified yet, so simulations must be used to study typical trigger patterns and observables for discriminating photons from hadrons.

Neural networks show promise of improved discriminating variables but require the training data to be very well understood. In contrast to hadron showers, photon-induced showers are expected to penetrate deeper in the atmosphere and have a steeper lateral distribution function, since the secondary particles almost exclusively belong to the electromagnetic component. Therefore, a number of elements in the the existing simulation and reconstruction chain, which has been developed and tuned for hadron-induced showers, need to be revisited for the case of ultra-high energy photons. In this contribution, we examine the parameters used to define how particle thinning in Corsika shower simulations is done and discuss implications for classical and machine learning based shower reconstruction algorithms.

T 4.2 Mon 16:15 Geb. 20.30: 2.059

Gamma-Hadron Separation at the IceCube Neutrino Observatory — •Federico Bontempo for the IceCube-Collaboration — KIT, Karlsruhe, Germany

The IceCube Neutrino Observatory is located at the geographic South Pole and composed of two detectors: the surface array, called IceTop, is made of ice-Cherenkov tanks, and the in-ice array made of optical detector modules deep in the ice. The two detectors can be combined for the study of cosmic rays. This work will primarily focus on low energy air-showers. It will use the IceTop response, mainly dominated by the electromagnetic component of cosmic-ray and gamma-ray air showers, for the reconstruction of the air-showers quantities, such as direction or energy. The in-ice array is used to ensure the presence of high energy muons, produced primarily in hadronic air-shower. At PeV energies, only a small fraction of gamma-ray induced showers produce an in-ice signal, but almost all hadronic showers feature an in-ice muon signal. Thus, the in-ice array can be exploited for gamma-hadron separation and the search for primary astrophysical PeV photons.

T 4.3 Mon 16:30 Geb. 20.30: 2.059

Estimation of cosmic ray mass by correlating muon signals extracted from surface detector stations of the Pierre Auger Observatory using neural networks — •Steffen T. Hahn, Markus Roth, David Schmidt, and Darko Veberic for the Pierre-Auger-Collaboration — KIT IAP, Karlsruhe, Germany

To fully understand the acceleration and propagation physics of cosmic rays at the highest energies, it is necessary to have an accurate knowledge of their mass composition. However, since information on the mass and energy is degenerate and a direct measurement of the mass is impossible, obtaining information about the composition is non-trivial. One of the observables that break this degeneracy is the number of muons produced during the particle cascade induced by a cosmic ray interacting with the Earth's atmosphere.

The Pierre Auger Observatory is the largest cosmic ray detector on Earth. One of its central components is its surface detector array consisting of uniformly spaced hybrid detector stations. These stations measure time traces of particles produced in the shower cascade.

This contribution presents a method of estimating the number of muons from these signals using machine learning techniques. The signal trace from a single station and a fixed set of shower parameters are used as input of a neural network to infer the fraction of the signal that is due to muons. The fractions obtained from several stations can be spatially correlated to estimate the mass of the primary cosmic ray. Eventually, the estimated muon content of recorded air showers will be presented including a study of systematic uncertainties.

T 4.4 Mon 16:45 Geb. 20.30: 2.059

Event-by-event reconstruction of air-shower events with IceCube using a two component lateral distribution function — •Mark Weyrauch for the IceCube-Collaboration — Karlsruhe Institute of Technology (KIT), Institute for Astroparticle Physics (IAP),

The IceCube Neutrino Observatory, located at the geographic South Pole, consists of a surface detector comprised of ice-Cherenkov tanks, IceTop, and an optical in-ice array. This combination allows for coincident measurements of the low-energy ($\sim$ GeV) and high-energy ($\gtrsim 400\,\mathrm{GeV}$) muon component in cosmic-ray air shower events. An event-by-event GeV muon estimator can constitute a useful tool for, amongst others, cosmic ray composition analyses and, in combination with the TeV muon component, strongly constrain hadronic interaction models. However, since IceTop does not feature dedicated muon detectors, an estimation of the GeV muon component on basis of individual air showers is challenging. One possibility for an event-by-event estimation of low-energy muons is given by the two component lateral distribution function (two component LDF), combining an analytical description for the electromagnetic and muon lateral distribution of the full detector signal.

T 4.5 Mon 17:00 Geb. 20.30: 2.059

Sub-PeV Cosmic-Ray Measurements at IceCube — •Julian Saffer for the IceCube-Collaboration — Institut für Experimentelle Teilchenphysik, Karlsruher Institut für Technologie (KIT)

The surface array of the IceCube Neutrino Observatory is able to record cosmic-ray induced air showers with a primary energy in the range from a few hundred TeV to EeV. Composition analyses at IceCube highly benefit from its multi-detector design. Combining the measurement of the electromagnetic shower component and low-energy muons at the surface with the response of the in-ice array to the associated high-energy muons improves the directional reconstruction accuracy and opens unique possibilities to extract the primary particle's mass. The analysis of air showers below PeV energies provides the potential to test the validity of hadronic interaction models at low energies but also requires special treatment in the event processing. In this talk, a new methodical approach to reconstruct the elemental composition of these low-energy air showers with a convolutional neural network is presented. The achieved performance in primary mass discrimination and energy reconstruction of air-shower events is discussed.

T 4.6 Mon 17:15 Geb. 20.30: 2.059

An analysis concept to measure atmospheric prompt muons with IceCube — •Pascal Gutjahr and Mirco Hünnefeld — TU Dortmund University, AG Rhode, Dortmund, Germany

When cosmic rays hit the Earth's atmosphere, extensive air showers are initiated. The secondary particles produced are divided into two components: long-lived, light mesons such as pions and kaons referred to as conventional particles and short-lived, heavy charmed and unflavored mesons referred to as prompt particles. Both components decay further into muons and neutrinos, which are detected with cherenkov and neutrino telescopes. In several air shower experiments, muons have been observed more frequently than expected based on simulation. To understand this discrepancy, also referred to as the muon puzzle, the ratio of pions and kaons may be studied. This ratio can be analyzed by measuring the atmospheric muon and neutrino flux, as muon production is dominated by pions and neutrino production is dominated by kaons. Additionally, hadron production in forward direction and at energies of PeV and above are not well constrained by particle accelerator experiments, leading to large uncertainties in hadronic interaction models. Analyses of the atmospheric muon and neutrino fluxes will provide crucial measurements in this phase space.

In this contribution, a first step towards these goals is presented by a concept to measure the atmospheric muon flux at high energies using the IceCube Neutrino Observatory. The main objective is to measure the normalization of the prompt component to constrain the uncertainties in the hadronic interaction models.

T 4.7 Mon 17:30 Geb. 20.30: 2.059

Towards the depth-dependent energy spectrum using stopping muons in IceCube — •Deborah Kramps and Lucas Wit-

thaus for the IceCube-Collaboration — Astroparticle Physics WG Rhode, TU Dortmund University, Germany

The IceCube Neutrino Observatory is a cubic-kilometer-scale detection sys- tem located in the Antarctic ice, dedicated to the study of neutrinos. However, the predominant signal comes from atmospheric muons produced in extensive air showers in the atmosphere. These muons traverse the ice at speeds greater than the speed of light, producing Cherenkov light that is captured by optical modules. The muon energies can be reconstructed based on the recorded light patterns.

This talk presents a Monte-Carlo study aimed at unfolding the depth- dependent energy spectrum of atmospheric muons. It is based on a subset of single muons that stop within IceCube's instrumented volume. Deep neural networks are used to perform the event classification and reconstruction tasks.

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T 4.8 Mon 17:45 Geb. 20.30: 2.059

Unfolding the Atmospheric Muon Spectrum Using Stopping Muons in IceCube — •Lucas Witthaus and Karolin Hymon for the IceCube-Collaboration — Astroparticle Physics WG Rhode, TU Dortmund University, Germany

The IceCube Neutrino Observatory is a neutrino detector built into the ice sheet near the South Pole. Despite its main objective, the observation of neutrinos, most of the detected events are caused by atmospheric muons produced in cosmic-ray-induced air showers in the upper atmosphere. When entering the Antarctic ice, muons experience significant energy losses due to interactions with surrounding matter, which limits their propagation length. This talk presents the unfolding of the stopping muon depth intensity, providing information about the abundance of atmospheric muons in the South Pole ice. The study focuses on a subset of events that includes single muons that stop inside the IceCube detector. Event classification and reconstruction tasks are performed using deep neural networks.

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