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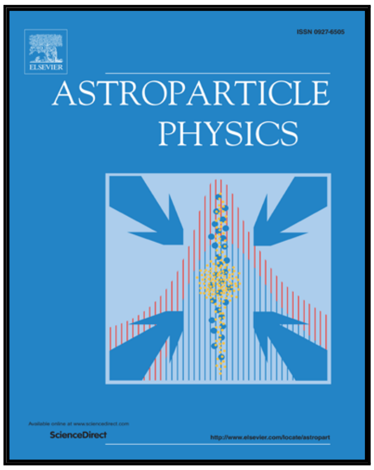

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Impact of muon detection thresholds on the separability of primary cosmic rays

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Abstract

Knowledge of the mass composition of cosmic rays in the transition region of galactic to extragalactic cosmic rays is needed to discriminate different astrophysical models on their origin, acceleration, and propagation. An important observable to separate different mass groups of cosmic rays is the number of muons in extensive air showers. We performed a CORSIKA simulation study to analyze the impact of the detection threshold of muons on the separation quality of different primary cosmic rays in the energy region of the ankle. Using only the number of muons as the composition-sensitive observable, we find a clear dependence of the separation power on the detection threshold for ideal measurements. Although the number of detected muons increases when lowering the threshold, the discrimination power is reduced. If statistical fluctuations for muon detectors of limited size are taken into account, the threshold dependence remains qualitatively the same for small distances to the shower core but is reduced for large core distances. We interpret the impact of the detection threshold of muons on the composition sensitivity in terms of a change of the correlation of the number of muons n_μ with the shower maximum $X_{\max}$ as function of the muon energy as a result of the underlying hadronic interactions and the shower geometry. We further investigate the role of muons produced in a shower by photon-air interactions and conclude that, in addition to the effect of the $n_\mu - X_{\max}$ correlation, the separability of primaries is reduced as a consequence of the presence of more muons from photonuclear reactions in proton than in iron showers.

Keywords: Ultra high energy cosmic rays, mass composition, muon detectors, detection thresholds, depth of shower maximum

1. Introduction

The cosmic ray energy spectrum shows three main features [1]: the “knee” at $10^{15.6}$ eV [2], the “ankle” at $10^{18.6}$ eV [3] and a flux suppression at ultra-high energies above $10^{19.6}$ eV [4, 5]. If the knee is related to the drop-out of predominantly light elements, then the heavy elements of this population are expected to drop out at the so-called “second knee” at about $10^{17.5}$ eV [6]. Whether this population is followed by another galactic population of higher energy is subject of an ongoing debate [7]. To discriminate between different physics scenarios, a precise measurement of the mass composition of cosmic rays in the transition region of galactic to extragalactic cosmic rays up to ultra-high energies is necessary.

The Telescope Array [8] and the Pierre Auger Collaborations [9] have obtained composition results in the energy range of the ankle by fluorescence measurements of the depth of shower maximum [10, 11]. Several astrophysical models attempt to describe these results, however, composition analyses depend highly on the employed hadronic interaction models for simulations of cosmic ray induced extensive air showers [12–19].

In addition to the depth of shower maximum, the number of muons in an extensive air shower is a crucial mass related observable since heavier cosmic ray particles produce a significantly larger muon content [20, 21]. Important results by means of muon detection techniques with air shower arrays have been obtained by Haverah Park [22–24], Yakutsk [25–27] and AGASA-Akeno [28–30], and more recently by the EAS-TOP [31, 32], EAS-MSU [33–36], KASCADE [2, 37, 38], and KASCADE-Grande [39, 40] experiments. Currently, both the Pierre Auger and the Telescope Array Collaborations are planning to extend their experiments by muon detectors of different types. After completion, both ground-based detector systems will be able to estimate the energy of the primary particle producing

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