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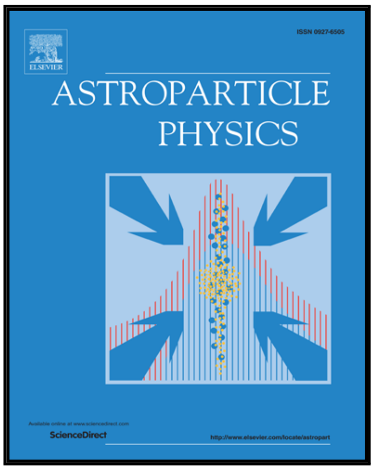

Shower Center of Gravity and Hadronic Interaction Characteristics

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Shower Center of Gravity and Hadronic Interaction Characteristics

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Abstract

The system of equations for the center of gravity of the shower initiated in the atmosphere by high-energy proton is derived and solved under certain assumptions for the case of logarithmically decreasing interaction length of hadrons in the air. The obtained expression splits into two terms. One term represents the center of gravity of the purely electromagnetic cascade at the primary proton energy and another one is a modification of that by hadronic cascading. This expression provides a transparent view of the way in which hadronic interaction characteristics define the longitudinal shower development.

1. Introduction

One of the crucial point in the air shower description is to establish a connection of the shower longitudinal profile, in particular, the depth of the shower maximum (Xmax), with hadronic interaction characteristics. Much study has been done with Monte Carlo simulations [1, 2, 3]. However, there is still a need in a transparent analytic view on that connection. Several approaches have been tried, from toy models to extensions of the Heitler model, designed for the electromagnetic shower [4], to the hadronic shower [5, 6, 7]. Nevertheless, no satisfactory description has been obtained on the quantitative level.

A direct way to establish the connection is use of the cascade theory. A problem is that the shower maximum is an inconvenient quantity for treatment by cascade equations. Much more viable quantity is the shower center of gravity (CG).

A shortcoming of CG is that it characterises the whole cascade, including a long tail, which is determined by multiple secondary particle interactions, whereas Xmax is insensitive to the tail and thus is defined by much less number of particle generations. Mainly due to this, the present study does not pretend on fully quantitative conclusions. Nevertheless we hope that the solution of equations for CG would allow us to look in detail into the dynamics of the shower longitudinal development which governs both Xmax and CG. And one could explicitly trace how interaction characteristics define that dynamics.

To obtain the solution of equations for CG in a compact and transparent form, the following simplifications are made:
(i) cascading only two types of hadrons - baryons (nucleons) and pions - is considered,
(ii) production of nucleons by pions is neglected,
(iii) charged pion decay is neglected,
(iv) Feynman scaling for the energy distributions of secondary particles is assumed,
(v) the energy-dependence of the interaction cross sections is taken into account.

Feynman scaling approximation is justified by the fact that the shower longitudinal development is basically defined by the forward spectra of the produced particles which have a much weaker energy dependence than, e.g., the total multiplicity.

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