New Astronomy 44 (2016) 45–50

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

# Measurement of muon production depth in cosmic ray induced extensive air showers by time structure of muons at observation level

Gohar Rastegarzadeh*, Sahar Khoshabadi

*Faculty of Physics, Semnan University, Semnan, Iran*

## HIGHLIGHTS

- Muon production depth (MPD) of shower is measured from time structure of muons at observation level.
- MPD' dependence on the $X_{max}$ and $X_{max_\mu}$, and so primary mass of cosmic ray is investigated.
- A new method for calculating MPD is presented.
- Ability of MPD as a mass discriminating parameter between primaries have been investigated.

## ARTICLE INFO

*Article history:*
Received 17 October 2014
Revised 15 July 2015
Accepted 18 September 2015
Available online 9 October 2015

Communicated by Dr. G. Brunetti

*Keywords:*
Cosmic ray
Mass composition
Maximum depth of development of Electrons and muons
MPD

## ABSTRACT

In the present work, muon production depth (MPD) of extensive air showers (EASs) are measured from time structure of muons at the observation level. A new method for calculating MPD is presented. Based on its relation to the maximum depth of development of electrons and muons ($X_{max}$ and $X_{max_\mu}$), this parameter has been used as a mass discriminator factor. Using CORSIKA simulation, different simulations for proton and iron primaries in the energy range of $10^{14}$–$10^{15}$ eV are presented. It is found that MPD distribution is strongly related to $X_{max}$ and $X_{max_\mu}$. These are mass sensitive parameters and their potential as mass discriminator parameters between light and heavy primaries for ALBORZ prototype array and some arbitrary arrays are investigated.

© 2015 Elsevier B.V. All rights reserved.

## 1. Introduction

The measurement of the mass composition is one of the most challenging topics in the study of high energy cosmic rays. It is difficult to establish composition of the primaries that initiates air showers from the average properties of the data (Kampert and Unger, 2012). It can be studied only indirectly through the extensive air showers they produced in the Earth atmosphere, with the parameters which can be found from experimental data like time ($t$), number of detected electrons ($N_e$), and density of detected particles ($\rho$) (Antoni et al., 2003). The study of the muon component at the observation level is a method to evaluate information about composition and hadronic interactions of the primaries. Time structure of muons at ground level gives valuable information about the longitudinal development of the hadronic component in EASs. Investigations of muonic component in EAS are of a great importance for understanding air shower physics (Kampert and Unger, 2012). Muons carry nearly undistorted information about their parent particles to the observati on level. They are the most numerous products of the hadronic interactions that are responsible for the development of the showers in the atmosphere. It is possible to reconstruct the muon production depth (MPD) distribution, using the signals collected by the surface detector arrays (Heck et al., 1998). This allows investigating the longitudinal development of the muonic component, and due to its close relation to EAS hadrons, the development of showers (Arsene et al., 2012; Brancus, 2002,). In this work, simulated data were used to determine the MPD. A new method for calculating MPD is presented and compared with the former method. Finally this method is examined as mass discriminator parameter for a rescaled ALBORZ prototype array. The CORSIKA (version 7400) (Dova et al., 2004), with the hadronic interaction models generator QGSJET-II-04 and DPMJET for simulating hadronic collisions at high energies, and GHEISHA_2002d at low energies (in an energy range from $10^{14}$ eV to $10^{17}$ eV), are used for simulating 500 showers.

### 1.1. MPD reconstruction

References Cazon et al. (2004) and Cazon et al. (2005) propose a model at which infers the muon production distance, $z$, along the

* Corresponding author. Tel.: +98 2333654102; fax: +98 2333654102.
*E-mail address:* grastegar@semnan.ac.ir (G. Rastegarzadeh).

http://dx.doi.org/10.1016/j.newast.2015.09.004
1384-1076/© 2015 Elsevier B.V. All rights reserved.

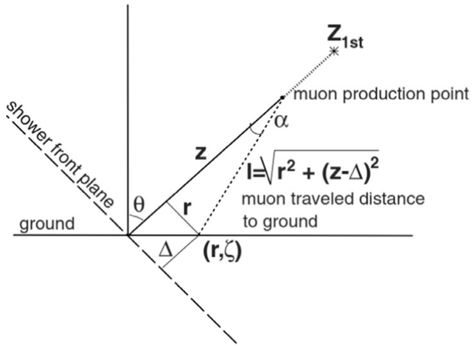


**Fig. 1.** Picture of the geometry used to obtain the muon traveled distance, *z*, and the geometrical delay (van Buren, 2007).

shower axis. In Fig. 1, assuming muons travel non-deflected at the speed of light, *c*, it is possible to derive muon production distance ($z$) from Garcia-Gamez (2013):

$$z = \frac{1}{2}\left(\frac{r^2}{ct_g} - ct_g\right) + \Delta \quad (1)$$

where $t$ is geometrical delay (time delay with respect to the arrival of the shower front plane), $r$ and $\Delta$ are distances from the point at ground to the shower axis and to the shower plane respectively (Garcia-Gamez, 2013). The shower front plane is defined as the plane perpendicular to the shower axis, and moving at speed of $c$ along to the shower axis direction (van Buren, 2007). The production distance can be easily related to the total amount of traversed matter $X^{\mu}$, using:

$$X^{\mu} = \int_{z}^{\infty} \rho(\acute{z})d\acute{z}$$

where $\rho$ is the atmosphere density and the $X^{\mu}$ is referred to MPD. The relation between altitude and depth is shown in Figs. 2 and 3, respectively. A simplified model of above integral for different depth,

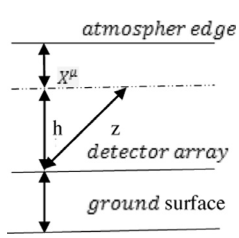


**Fig. 2.** The relation between altitude and depth of a shower for an incident and a vertical shower (Abbasi et al., 2013).

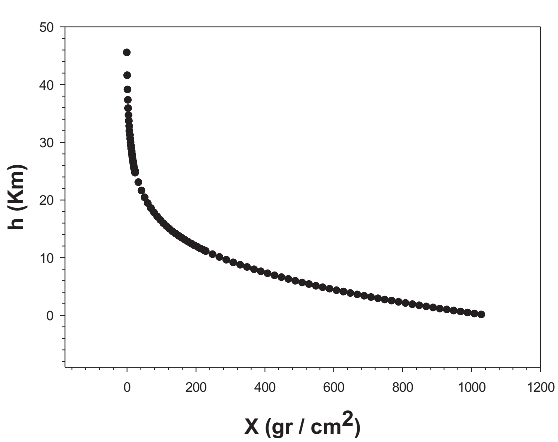


**Fig. 3.** The relation between altitude and depth according to Eq. (2).

becomes (Gaisser, 1990):

$$h(\text{km}) = \begin{cases} 47.05 + 6.9\ln X^{\mu} + .299\ln^2\left(\frac{X^{\mu}}{10}\right) & X^{\mu} < 25\ \text{g/cm}^2 \\ 45.5 - 6.34\ln X^{\mu} & 25 < X^{\mu} < 230 \\ 44.34 - 11.861\left(X^{\mu\,0.19}\right) & X^{\mu} > 230 \end{cases} \quad (2)$$

In general, the relation between vertical altitude ($h$) and distance up the trajectory ($z$) is: (for $\frac{z}{R_E} \ll 1$) (Gaisser, 1990).

$$h = z\cos\theta + \frac{z^2}{2R_E}\sin^2\theta$$

where $\theta$ is zenith angle, and $R_E$ is the radius of the earth, and for ($z < R_E$), then, $h = z\cos\theta$ (Gaisser, 1990).

The shape of the MPD-distribution contains relevant information about the development of the hadronic cascade and the maximum depth of shower development ($X_{max}$) (Garcia-Gamez, 2013).

## 2. Energy and mass dependence of MPD

Cosmic ray nuclei share their energy amongst $A$ nucleons, where $A$ is atomic number. Therefore, their showers can be described as a superposition of $A$ nucleon-induced sub-showers with an energy of $E/A$ each. Thus, showers of heavy primaries are less penetrating, tending to develop higher up in the atmosphere than nucleon showers of the same energy. On the other hand $X_{max}$ and $X_{max_{\mu}}$ are the slant depth, at which the number of electrons and muons, respectively reaches their maximum. They are mass sensitive parameters, and modified in terms of the number of particles. Proving any relationship between $X^{\mu}$, and $X_{max}$ and $X_{max_{\mu}}$, this parameter ($X^{\mu}$) could be easily used as a mass discriminator. $X_{max}$ has a strong connection to the primary mass (Kampert and Unger, 2012). Additionally, $X_{max}$ depends on energy. The higher the energy, the longer the shower and the deeper is $X_{max}$. MPD-distribution has its own maximum ($X^{\mu}_{max}$), and this maximum correlates with $X_{max}$. As mentioned above, the $X^{\mu}_{max}$ is sensitive to $X_{max}$, and so to the primary mass and energy. The histogram of calculated muon production distance for simulated vertical proton primary in the energy of $10^{14}$ eV at 1200 m observation level is shown in Fig. 4. It is virtually depict able that there is a maximum for calculated muon production distance ($z_{max}$). It is related to real $X_{max}$, obtained by CORSIKA, since it refers to a place which the most muons come from. As most of the muons produced at shower's $X_{max}$, $X^{\mu}_{max}$ and $X_{max}$ are almost equal. For all primary masses, $X^{\mu}_{max}$ increases with increasing energy (as a result of increasing $X_{max}$ by energy increasing). Also, for all primary energies, it decreased, with increasing primary mass (as

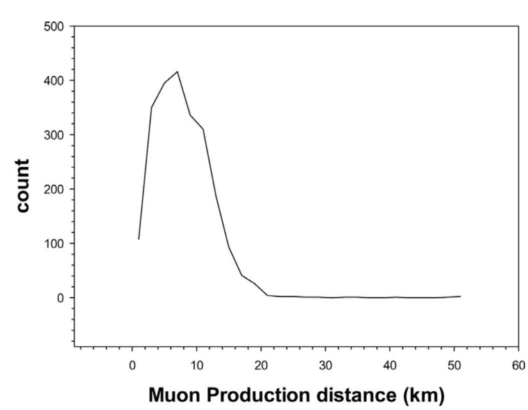


**Fig. 4.** Muon production distance distributions ($z$) for a vertical Proton shower with primary energy of $10^{14}$ eV simulated with CORSIKA at 1200 m observation level (ALBORZ).

Download English Version:

https://daneshyari.com/en/article/1778817

Download Persian Version:

https://daneshyari.com/article/1778817

Daneshyari.com