30TH INTERNATIONAL COSMIC RAY CONFERENCE

Muons in the Cosmic Radiation

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Abstract: A review of measurements of the high muon energy spectra for altitudes close to the sea level and different directions performed with devices placed at various geomagnetic latitudes is presented. The muon spectra and the muon charge ratio, defined as the ratio of positive to negative muon fluxes, are discussed.

Introduction

Cosmic-ray muons originate from the decay of pions and kaons produced by the interactions of high-energy primary nuclei, A_{cr}, with atmospheric ones, A_{air}:

$$A_{cr} + A_{air} \rightarrow \pi^{\pm}, K^{\pm}, K^{0}\ldots$$

$$\pi^{+}\ (63\%\ K^{+}) \rightarrow \mu^{+} + \nu_{\mu}$$
$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu}$$
$$\pi^{-}\ (63\%\ K^{-}) \rightarrow \mu^{-} + \bar{\nu}_{\mu}$$
$$\mu^{-} \rightarrow e^{-} + \bar{\nu}_{e} + \nu_{\mu}$$

Much experimental work has been done to measure muon intensities at the sea level. The zenith angular dependence of muon fluxes have been measured from the vertical direction to near-horizontal in the momentum region $5\cdot10^{4}$ GeV/c.

A considerable volume of work by different authors has been reported to review the existing experimental information. The aim of the present work is to explore all old and new high energy muon data and to give as far as possible a coherent view of the present knowledge.

The absolute differential muon fluxes for zenithal angles between 0 and 75 degree

The absolute differential muon fluxes are presented in Figures 1 up to 6 [1-34]. All data are fitted by the function (1):

$$j(E_{\mu}) = p1\cdot E_{\mu}^{-2.65}\cdot\left(\frac{1}{1+\frac{p2\cdot\cos\Theta\cdot E_{\mu}}{115}}+\frac{p3}{1+\frac{p4\cdot\cos\Theta\cdot E_{\mu}}{850}}\right),$$

where muons' energies are in GeV.
Formula 1 has a theoretical origin, Gaisser [35], from the numerical integration of the analytical cascade equations.
The coefficients p1, p2, p3 and p4 are listed in the Table 1.

Parameter	*Near vertical $\Theta=0^{\circ}$*
p1	$8.961\cdot10^{-3}$
p2	1.
p3	0.05
p4	1.

Table 1: The values of the coefficients p1 up to p4, used in the Equation (1) for near vertical muons.

Parameter p1 is proportional to the energy spectrum of the primary nucleons. Parameters p2 and p4 are related to the spectrum of secondary particles (pions and kaons) produced in the high energy interactions in the air and to the slope of the primary nucleon spectra.

Parameter p3 gives the muons contribution from the decay of the mainly charged kaons.

The formula proposed (with parameters listed in the Table 1) fits very well the experimental high energy muons data for different azimuthal angles. For the $\Theta=75^\circ$ highest muon data are also well fitted by functions suggested.

The muon charge ratio

Measurements of the muon spectra at different geomagnetic latitudes aim at studies of the influence of the Earth's magnetic field on cosmic rays. The majority of reported results of the muon charge ratio $R(\mu^+/\mu^-)$ is in good agreement for muon energies higher than 5 GeV.

The measured charge ratio (1.27±0.07) seems to be well established. But the new L3 + C data shows for muons with energy higher than 20 GeV up to 3000 GeV value R is 1.285±0.022.
Inside one σ both results agree very well.

Conclusions

In the present paper the analysis of atmospheric differential muon spectra for various angles from 0 to 75 degree in the Earth's atmosphere and near the sea level has been presented.

The results of the fitting procedure by the formula which has the theoretical origin have been presented for different angles. All data, ald and new, are in very good agreement with the formula (1). For E_μ > 200 GeV the formula still is working pretty well, also for 75 degrees.

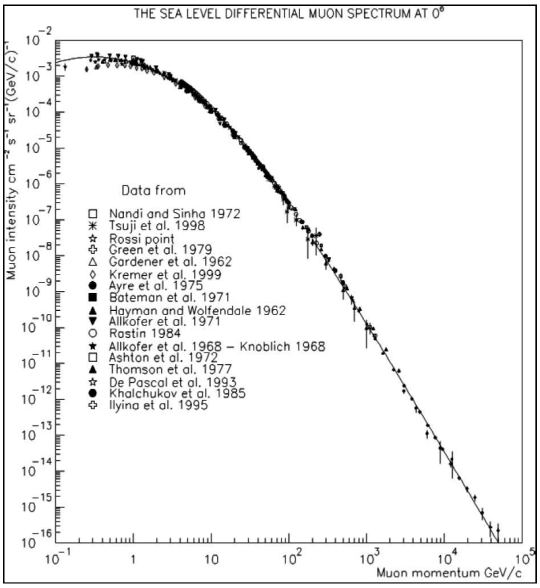

Figure 1: The sea level differential muon intensities versus muon momentum at 0 degrees

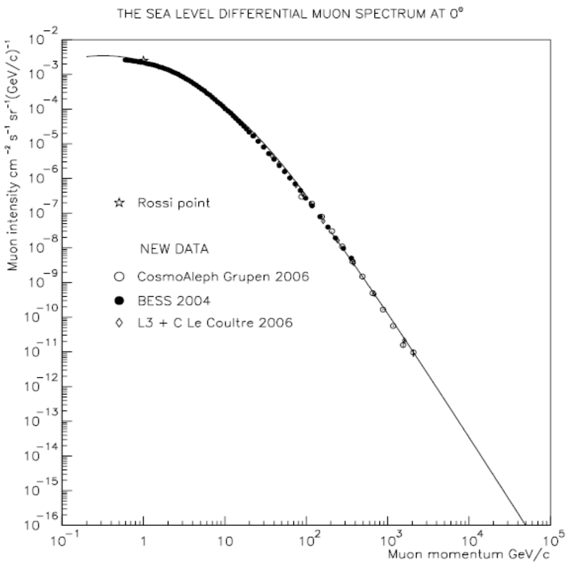

Figure 2: The sea level differential muon intensities versus muon momentum at 0 degrees – the New Data

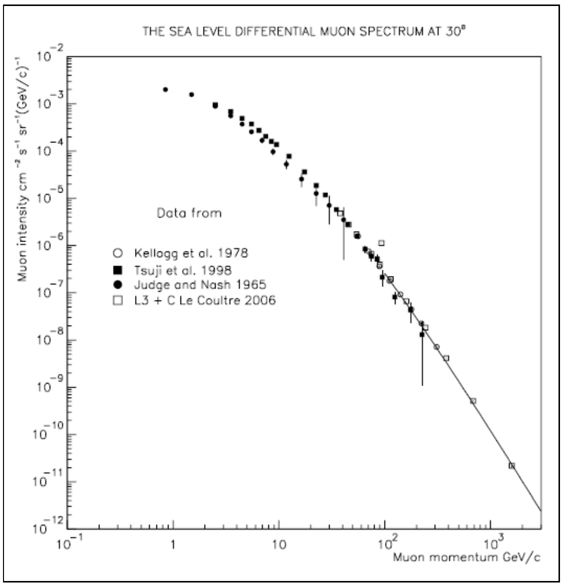

Figure 3: Differential muon intensities versus muon momentum at 30 degrees.

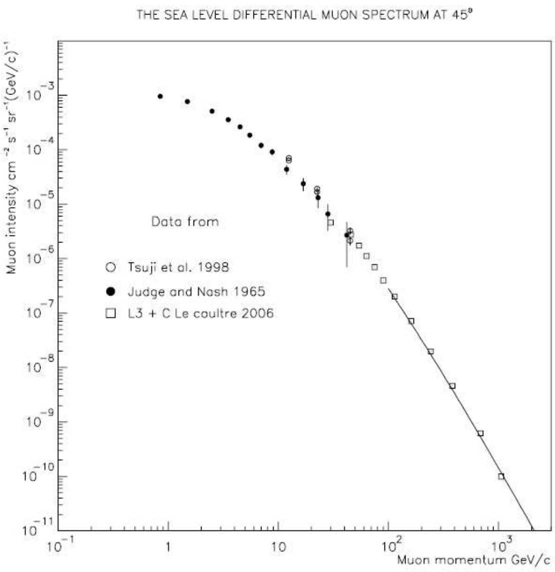

Figure 4: Differential muon intensities versus muon momentum at 45 degrees.

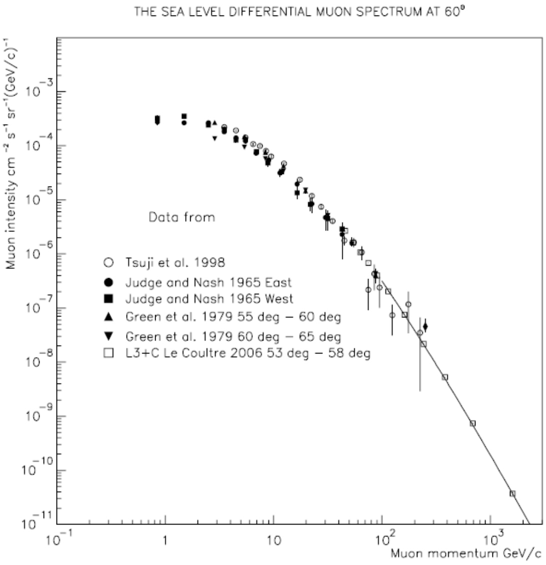

Figure 5: Differential muon intensities versus muon momentum at 60 degrees.

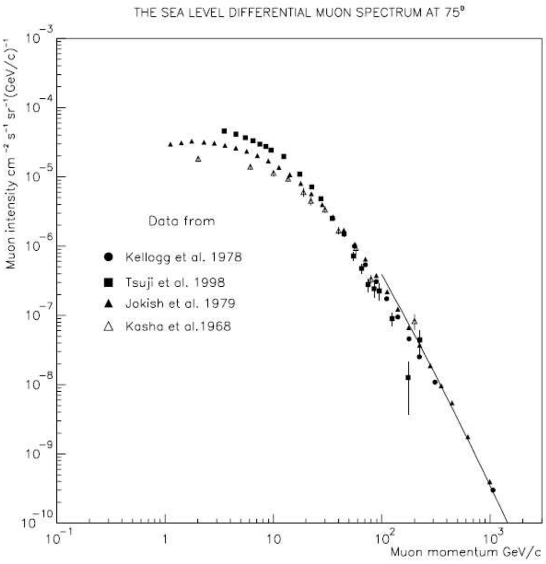

Figure 6: Differential muon intensities versus muon momentum at 75 degrees.

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