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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-5-7. Directional and Momentum Dependence of the Positive Excess of the Cosmic-Ray Mesons

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A magnetic spectrometer using solid iron electromagnet was constructed to observe the charge and momentum of mu-mesons at large zenith distance, and at various azimuth, with the momentum range 5–100 Gev/c. From this observation, the azimuthal and momentum dependence of positive excess were obtained. The positive excess was small or negative at East direction and large at West especially in low energy and this difference was found to be in agreement with the result of calculation considering only pi-mu-process.

The positive excess at the production layer was obtained considering the trajectories of mu-mesons in the atmosphere and was about 25% in this momentum range.

§ 1. Introduction

Since April 1954, using the narrow angle G-M counter telescopes, the observation of the intensity of high energy mu-mesons at the zenith distance 80° has been continued at Nagoya, 25°N geomagnetic latitude. In this observation, East-West asymmetry of about 10% was found in the cosmic-ray intensities. The deflections of primary cosmic-rays before their entry into the earth's atmosphere can not explain this asymmetry, since the average momentum of the primary particle effective for this observation is estimated to be 300±100 Gev/c. This asymmetry was interpreted[1] by considering the geomagnetic deflection of secondary mesons during their passage through the atmosphere and the positive excess of mesons at their production layer. The observed asymmetry quantitatively agreed with the theoretical value obtained by assuming about 20% of the positive excess of mesons at their production layer which seemed to be plausible.

We are continuing the observation of cosmic-ray intensity distribution with the narrow angle telescope. To determine the directions of the cosmic rays before entering to the earth's magnetic field, it is necessary to consider not only the geomagnetic deflection of the primaries, but also that of the secondary mu-mesons. Thus, the observation of the charge and the momentum of mu-mesons becomes necessary.

Apart from this observation of the intensity distribution of cosmic rays the charge and momentum spectrum of mu-mesons from large zenith distance 80° was observed at various azimuthal angles. From those data, we attempt to investigate the directional and momentum dependence of the positive excess of cosmic-ray mesons. Although the statistical accuracy is not yet sufficient, the observed value seemed to agree with calculated value by assuming the positive excess of mesons at their production layer which were derived from the observations by various workers[2].

§ 2. Apparatus

The apparatus consists of a solid iron electromagnet, a neon hodoscope, trigger system and a camera system. They are on altazimuth mounting which allow them to be inclined

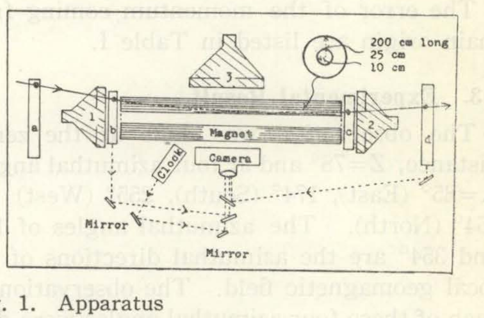

Fig. 1. Apparatus
a, b, c, d; Neon trays.
1, 2 ; Scintillation counter for detection.
3 ; Scintillation counter for side shower.

Table I. The error of the momentum.

Momentum %	Error of the momentum in Gev		
	due to finite diameter of neon tube	Scattering	Total
5.5 Gev		$+1.4\sim-1.4$	$+1.4\sim-1.4$
10 〃	$+2\sim-.1$	$+2.5\sim-1.8$	$+2.5\sim-1.8$
50 〃	$+4.7\sim-3.8$	$+12.9\sim-8.2$	$+13.7\sim-8.2$
100 〃	$+22\sim-14$	$+24\sim-16$	$+33\sim-21$

Table II. The positive excess at N, E, S and W.

Momentum Range (Gev/c)	Positive Excess $2\left(\frac{\mu^+-\mu^-}{\mu^++\mu^-}\right)$			
	N	E	S	W
$5.5\sim10$	0.37 ± 0.15	-0.18 ± 0.18	0.21 ± 0.14	0.72 ± 0.13
$10\sim30$	0.47 ± 0.12	0.07 ± 0.10	0.36 ± 0.09	0.42 ± 0.10
$30\sim100$	0.39 ± 0.14	-0.01 ± 0.13	0.27 ± 0.15	0.27 ± 0.14

through zenith distance from 75° to 90°. The solid iron magnet is a hollow cylinder with the length of 2 meters. The excitation current of 30 ampere is used, thus the magnet is maintained at a saturated induction of about 20 kilo gauss.

In this condition, the angle due to the multiple scattering is about 1/5 of the magnetic deflection. The lower limit of the determination of the momentum is about 5 Gev/c which is due to the absorption of the 1500 g/cm² iron and blocking off of the magnet.

The momentum of a particle was determined using the difference between the direction cosines of the particle before and after penetrating through the magnetic field in the iron core.

The maximum detectable momentum is about 100 Gev/c which is limited by the finite diameter of the neon tube.

The error of the momentum coming from main origin are listed in Table I.

§ 3. Experimental Result

The observation was done at the zenith distance, Z=78° and at four azimuthal angles, A=85° (East), 174° (South), 255° (West) and 354° (North). The azimuthal angles of 174° and 354° are the azimuthal directions of the local geomagnetic field. The observations at each of these four azimuthal angles were done every day. In order to compensate between the focussing effect for positive and negative

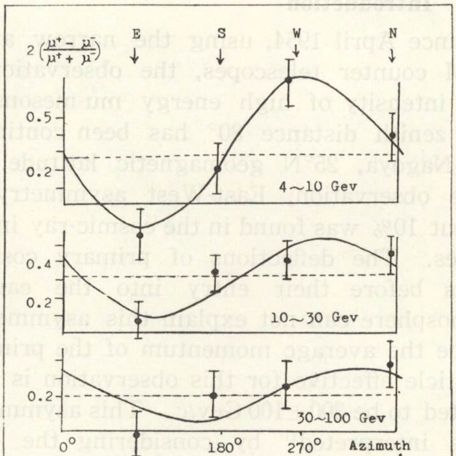

Fig. 2. Azimuthal dependence of positive excess at sea level Z~78°.

particles, the excitation current was reversed once in every day. The results of observation are shown in Table II. Thus, the azimuthal and momentum dependence of positive excess are obtained as shown in Fig. 2. The averages of the positive excess over a wide range of the momentum were plotted because of the statistical error, although the accuracy for the determination is better than the range.

§ 4. Discussion

The deflection of the meson in the atmosphere has the opposite direction between μ^+

and μ^-. So if we observe at one direction, the trajectories of them are different to each other. Therefore, the difference of the path length between μ^+ and μ^- having the same momentum becomes larger according as the direction of the observation approach E or W and as the zenith distance becomes larger. We first discuss the positive excess at the production layer and then study the large difference between the positive excesses at E and W.

1. *Positive excess at production layer*

The positive excesses observed at N and S can be regarded to be equal to the positive excess at the production layer, because the path length of μ^+ and μ^- mesons are almost the same. On the contrary, the positive excesses at E and W can not be considered like this owing to the large difference of path length.

But the trajectory of μ^+ from East direction and that of μ^- from West direction have the similar form, so that the positive excess at the production layer is obtained by comparing the $\mu_E{}^+$ with $\mu_W{}^-$ or $\mu_W{}^+$ with $\mu_E{}^-$ respectively, where $\mu_E{}^+$ is the intensity of μ^+ at East direction and so on.

Thus the positive excess at the production layer is obtained as shown on Fig. 3, together with other data, as the function of the energy of mesons at their production layer. As seen

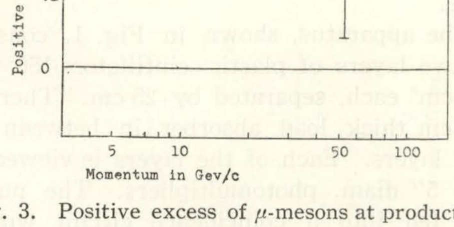

Fig. 3. Positive excess of μ-mesons at production layer, $2\,(\mu^+ - \mu^-)/(\mu^+ + \mu^-)$.

⊙ Our data
● Greisen *et al*
■ Owen and Wilson
▽ Filosofo *et al*
○ Brode and Webber
▲ Beretta *et al*

from it, our data are not inconsistent with other data, and we can not say that it is shown to exist in the decrease of the positive excess with momentum.

2. *Azimuthal dependence of the positive excess*

The positive excesses observed at E and W were calculated using the value of 25% for the positive excess at the production layer in the momentum range of 15 Gev/c ~100 Gev/c. The survival probability of mu-mesons was obtained by the numerical computation considering i) the deflection of path due to the earth's magnetic field, ii) the production layer at 100 g/cm^2 along the path from the top of the atmosphere, and iii) the ionization loss. The result of this calculation is shown in Fig. 4. Thus, the large difference of the positive excess at E and W was found to be in agreement with the result of calculation.

The data by Moroney *et al.* observed at zenith distance 60° are also shown in Fig. 4 and they explained it sufficiently considering the positive excess at the production layer, pi-mu decay process and survival probability of mu-mesons in the atmosphere. Our data was observed at zenith distance 78° and the momentum range is one order higher. This figure shows that at this higher momentum

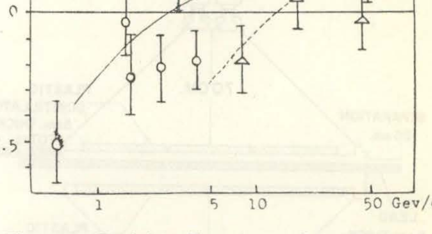

Fig. 4. Positive Excess at Sea Level

Our data Z 78°
▼ N ▲ S △ E ▽ W

Moroney and Parry Z 60°
● W ○ E

———————— Calculated

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region, the same explanation as Moroney *et al* can be possible.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-5-8. Intensity of μ-mesons at Depths Greater than 2000 MWE

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An experiment is in progress in Kolar Gold Mines (India) to measure μ-meson intensities underground at great depths and the results obtained so far at 816, 1812, 3410 and 4280 mwe have been given. The depth intensity curve of μ-mesons is converted to the integral energy spectrum of μ-mesons at sea level and it is found that the energy spectrum can be expressed in the form $N(>E)\propto E^{-(2.9\pm0.33)}$ in the range 600 Gev $<E_{\mu}$ $<$2600 Gev. From this, the production spectrum of pions has been inferred and compared with the other cosmic ray data.

The energy spectrum of μ mesons at sea level, besides being of interest in itself, may throw some light on the nuclear interactions in which the parents of μ mesons are produced. The simpler method to extend the energy spectrum of μ mesons would be to measure the cosmic ray intensities at depths $>$2000 mwe, with large aperture cosmic ray telescopes. The depth-intensity curve of cosmic ray underground can then be converted to the integral energy spectrum of μ mesons by means of a suitable range-energy relation. With a view to extend the μ meson energy spectrum to energies much greater than 5000 Gev, we have undertaken an experiment to measure the intensity of cosmic ray μ mesons at great depths ($>$2000 mwe) in the Kolar Gold Mines in India. The results obtained so far will be presented here.

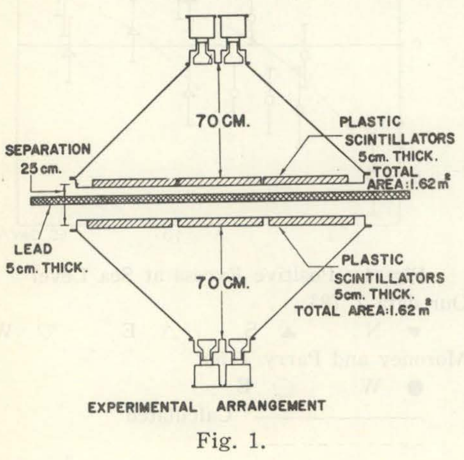

Fig. 1.

The apparatus, shown in Fig. 1, consists of two layers of plastic scintillators $156\times104\times5$ cm^3 each, separated by 25 cm. There is a 5 cm thick lead absorber in between the two layers. Each of the layers is viewed by two 5″ diam. photomultipliers. The pulses are fed into a coincidence circuit with a resolving time 3 μ sec. With this system, we can observe cosmic ray counting rates as low as 1/day without being affected by chance coincidences due to photomultiplier noise and background radio activity. The counting rate of our telescope at the surface of the mines