

COMITATO NAZIONALE PER L'ENERGIA NUCLEARE
Laboratori Nazionali di Frascati

LNF - 70/32
10 Luglio 1970

C. Castagnoli, E. Etim and P. Picchi: A DISCUSSION ON
SOME RECENT RESULTS ON COSMIC RAY MUONS. -

LNF - 70/32

Nota interna : n. 484
10 Luglio 1970

C. Castagnoli^(x), E. Etim^(o) and P. Picchi : A DISCUSSION ON SOME RECENT RESULTS ON COSMIC RAY MUONS. -

The existence of the μ -meson, as a heavy electron, is in itself an "anomaly" but perhaps not the only one since some unexpected results of recent experiments^(1,2) on cosmic ray muons of very high energy indicate anomalies in our understanding of this particle.

This circumstance has led to speculations about possible anomalous couplings of the μ -meson and or the existence of a new type of particle as for instance the SU_3 triplets or some others like the intermediate vector bosons. A less drastic interpretation of these results but one no less important than the hypothesis of exotic particles and interactions takes the view that the results of some of these experiments may be witness to a significant departure of very high energy QED from the predictions of familiar approximation schemes such as the vector meson dominance model. In the following pages we study the results of the experiments mentioned herein above and the consistency of some of their interpretations. We find that although these interpretations cannot be dismissed outright as untenable, their physical bases will have to await more refined data, desirably from many experimental groups, before they can be finally established.

1. - MUOPRODUCTION

In the analysis of muoproduction data the vector meson dominance model has been extensively used. According to this model the photon exchanged between the muon and the proton is a vector meson (see

(x) Laboratorio di Cosmo-geofisica del CNR, Torino.

(o) Istituto di Fisica Teorica dell'Università, Napoli.

2.

Fig. 1) (or better a number of such mesons) in disguise; from⁽³⁾ this follows that the total photoabsorption cross-section $\sigma_{\gamma p}(\nu)$ is given by

$$(1) \quad \sigma_{\gamma p} = \alpha \left\{ \left(\frac{16\pi}{2} \right) \frac{\gamma_{\rho}}{\gamma_{\rho}} \sigma_{\rho} + \left(\frac{4\pi}{2} \right) \frac{\gamma_y}{\gamma_y} \left[\sin^2 \theta_y \sigma_{\omega p} + \cos^2 \theta_y \sigma_{\phi p} \right] \right\}$$

where $\gamma_{\rho}, \gamma_y, \theta_y$ give the couplings of the photon to the neutral vector mesons ρ^0, ω, ϕ and $\sigma_{\nu p}$ ($\nu = \rho^0, \omega, \phi$) can be calculated from the diffractive production of these mesons.

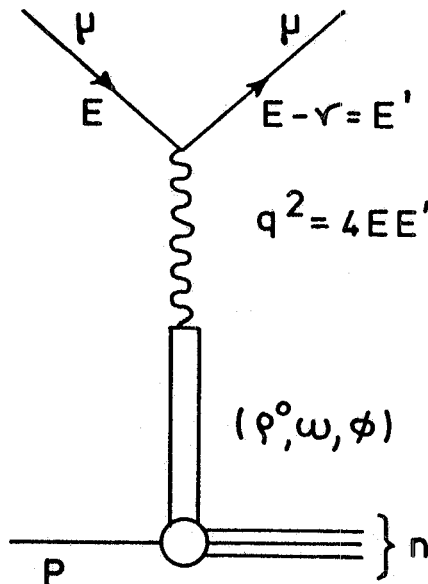


FIG. 1 - Muoproduction in the vector dominance model.

The application of the vector meson dominance hypothesis to high energy e-p and μ -p scattering is however not very successful. The general⁽⁴⁾ expression for the differential inelastic cross section in terms of the form factors $W_1(q^2, \nu), W_2(q^2, \nu)$ is

$$(2) \quad \frac{d^2\sigma}{dq^2 d\nu} = \frac{4\pi\alpha^2}{q^4} \frac{1}{E^2} \left[\frac{1}{2} q^2 W_1(q^2, \nu) + (E^2 - E\nu - \frac{1}{4} q^2) W_2(q^2, \nu) \right]$$

where W_1 and W_2 are related to the cross-sections σ_t, σ_l for the absorption of transversally and longitudinally polarized photons respectively

$$(3) \quad W_1 = \frac{1}{4\pi^2\alpha} (q^2 + \nu^2)^{1/2} \sigma_t(q^2, \nu)$$

$$(3) \quad W_2 = \frac{1}{4\pi^2\alpha} \frac{q^2}{(q^2 + v^2)^{1/2}} \left[\sigma_t(q^2, v) + \sigma_l(q^2, v) \right]$$

The vector meson dominance parametrization of σ_t and σ_l is usually

$$(4) \quad \sigma_t = \sigma_{\gamma p}(v) \left(\frac{m_p^2}{m_p^2 + q^2} \right)^2; \quad \sigma_l = 0$$

Substituting from (3) and (4) into (2) gives

$$(5) \quad \frac{d^2\sigma}{dq^2 d\nu} = \frac{\alpha}{\pi} \frac{1}{q^2 E^2} \left[\frac{1}{2} (q^2 + v^2)^{1/2} + \frac{(E^2 - E\nu - \frac{1}{4}q^2)}{(q^2 + v^2)^{1/2}} \right] \sigma_{\gamma p}(v) \left(\frac{m_p^2}{m_p^2 + q^2} \right)^2$$

If the contribution of σ_l is included as was shown by Sakurai⁽⁵⁾ one has

$$(3') \quad W_1 = \frac{(v^2 + q^2)^{1/2}}{4\pi^2\alpha} \sigma_{\gamma p}(v) \left(\frac{m_p^2}{m_p^2 + q^2} \right)^2$$

$$W_2 = \frac{q^2}{4\pi^2\alpha (v^2 + q^2)^{1/2}} \sigma_{\gamma p}(v) \frac{m_p^2}{m_p^2 + q^2}$$

and eq. (2) becomes

$$(5') \quad \frac{d^2\sigma}{dq^2 d\nu} = \frac{\alpha}{\pi} \frac{1}{q^2 E^2} \left[\frac{1}{2} (q^2 + v^2)^{1/2} \frac{m_p^2}{m_p^2 + q^2} + \frac{E^2 - E\nu - 1/4 q^2}{(q^2 + v^2)^{1/2}} \right] \sigma_{\gamma p}(v) \left(\frac{m_p^2}{m_p^2 + q^2} \right)^2$$

The cross-section $\sigma_{\gamma p}(v)$ has been measured by various groups⁽⁶⁾ and some theoretical calculations of it are also available. As seen

from Table I $\sigma_{\gamma p}(\gamma)$ is approximately constant for γ above 1 GeV. We shall take for the constant value $\sigma_{\gamma p}(\gamma) = 125 \mu\text{b}$.

TABLE I

Reference 6	Technique used	Photon energy GeV	$\sigma_{\gamma p}(\gamma) \mu\text{b}$
ABHHM Collaboration	Bubble chamber photoproduction	$3.5 < \gamma < 5.4$	116 ± 17
J. BALLAM et al.	Bubble chamber photoproduction	$7 < \gamma < 8$	126 ± 17
D. O. CALDWELL et al.	Counters	$7.4 < \gamma < 9.4$	118.8 ± 2.6
"	"	$12 < \gamma < 15.2$	114 ± 2.8
"	"	$14.4 < \gamma < 18.3$	113 ± 2.5
M. DAVIER et al.	Vector dominance model	$\gamma = 9$	130 ± 30
G. KNIES	Quasi elastic optical theorem	$3 < \gamma < 5$	99 ± 12
Buccella and Colocci	Regge Pole theory	$\gamma > 5$	130

The comparison of eqs. (5) and (5') with experiment is displayed in Table II where the experimental entries are from Kirk et al. (7). What seems noteworthy about the vector meson dominance model is that recent data by Wilson (8) et al. and by Perl (9) et al. are better fitted with eq. (5') than by eq. (5). It must be remembered though

TABLE II

Muon energy	Cross section per nucleon in μ b meson production events		
	experimental	eq (5)	eq (5')
2.5 GeV/c	3.6 ± 0.7	5.22	5.6
5 GeV/c	5.1 ± 0.5	7.83	8.37
10.5 GeV/c	11.4 ± 1.4	10.8	11.5

that eq. (5') was motivated by the failure of eq. (5) to fit high-energy (10) e-p data and that one consistency test of eq. (5'), namely the ratio between the longitudinal and transverse cross-sections σ_L, σ_T predicted to be proportional to q^2/m^2 by Sakurai has been contradicted in e-p (11) scattering.

Information on μ -p scattering in cosmic rays comes mainly from measurements underground. Such measurements are plagued by large uncertainties due to experimental difficulties especially that of distinguishing between nuclear and electromagnetic showers.

In fig. (2) we have plotted the shower cross-section defined by

$$(6) \quad \sigma_{Sh}(x) = \int_{E(\min)}^{\infty} F(E, x) dE \int_{\nu_{\min}}^{E-m_{\mu}} \frac{d\sigma}{d\nu}(E, \nu) / \int_{E(\min)}^{\infty} F(E, x) dE$$

where $F(E, x)$ is the muon-spectrum at a depth x underground against x using eq(5) and (5') to get $d\sigma/d\nu$. For ν_{\min} we have used 2 and 5 GeV.

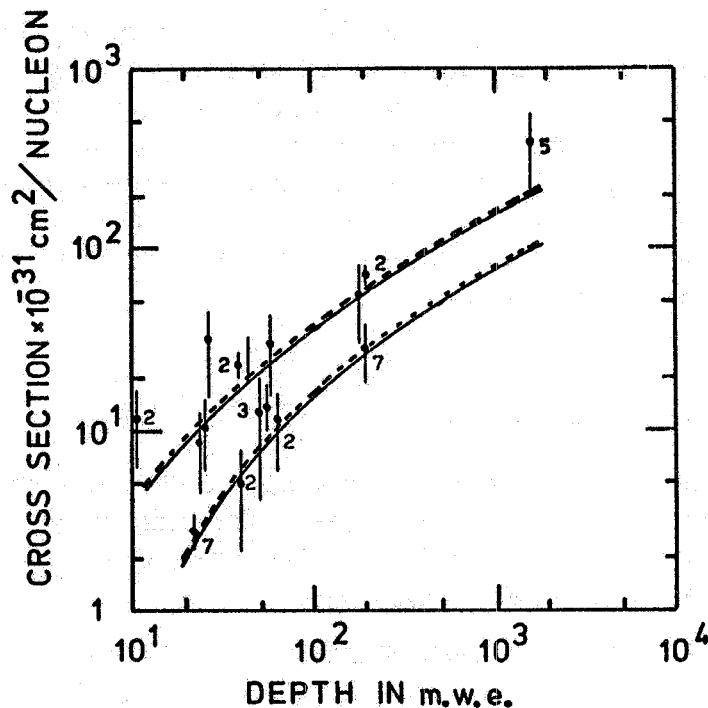


FIG. 2 - Cross section for shower production under-rock. The solid and dashed lines are obtained using eq. (5) and eq. (5') respectively with $\nu_{\min} = 2$ and 5 GeV. The value of ν_{\min} in each experiment, which differs from 1 GeV is given near to experimental point.

Eqs. (5) and (5') are in agreement with these data⁽¹²⁾. In Table (3) the predictions of vector dominance after normalization at

TABLE III

$q^2(\text{GeV})^2$	eq (5)	eq (5')	Experimental (Higashi)
2	10	10	10 ± 2
5	.97	3.95	5 ± 1.4
10	.0098	1.13	2.3 ± 1.1

$q^2 = 2(\text{GeV}/c)^2$ have been compared with the measurements of Higashi⁽¹³⁾ et al. of the integral muon-spectrum with respect to q^2 for $\nu \geq 5 \text{ GeV}$. There is a marked preference for eq. (5') instead of eq. (5).

The above discussed agreement of the vector meson dominance model with cosmic ray data is to be contrasted with the fact that recent measurements underground⁽¹⁴⁾ show an anomalous behaviour with respect to it. The same is true of a muoproduction event of energy transfer $\nu \approx 300 \text{ GeV}$ observed by Higashi⁽¹⁵⁾ et al. during a year and a half of observation. The frequency of this anomalous event taking account of the experimental geometry is about ten times what one would expect from either eqs. (4), eq. (5) or (5'). The comparison of the sea level muon energy spectrum with the depth-intensity curve through dE/dx can give little information on μ -p scattering because of the errors in the relevant experimental parameters (exponent of the spectrum, bremsstrahlung, pair production) and also because the large part of energy loss is due to interactions with small q^2 and ν . In conclusion it is clear from the above that eq. (5') fits better the high energy cosmic ray muon data than eq(5) suggesting that for high energy transfer, ν , there is a possible anomalous increase in the muon-nucleon cross-section with respect to the conventional picture.

2. - HORIZONTAL AIR SHOWERS

The frequent extensive horizontal air showers observed by the Tokio⁽¹⁾ group and later confirmed by Wolfendale et al.⁽¹⁷⁾ are of considerable interest to muon physics. The characteristic properties of these horizontal air showers (HAS) are:

- i) The primaries of HAS for zenith angle $\theta > 70^\circ$ are clearly different from those for $\theta < 55^\circ$.
- ii) The zenith angle distributions for $60^\circ \leq \theta \leq 75^\circ$ follows the $\sec \theta$ law exactly as for muons.
- iii) There is a significant departure from the $\sec \theta$ law for $\theta > 75^\circ$; the corresponding attenuation length is between 2000-1000 gm/cm^2 .
- iv) The exponent of the spectrum of the HAS in function of the energy transfer (size) is $-2,8 \pm 0,3$ for $\theta > 70^\circ$.
- v) A large percentage of HAS nuclear cascade showers is observed in HAS.

These properties, especially (v), point to two possible facts:

- (a) The μ -p cross-section increases at high energy ($E > 10^3 \text{ GeV}$)
- (b) The primaries of the HAS are not muons but another type of particle with a strong coupling.

These two possibilities and their consequences are discussed below.

2.1. - Inapplicability of the Vector Meson Dominance Model

In Sect. (1) we have seen that although cosmic ray data on μ -p scattering are in accord with the vector meson dominance model for relatively low energy they suggest that at high energy there could be an anomalous increase in the μ -p cross-section.

If the HAS are due to muons then from their properties listed above they are the first experimental information on muoproduction with $\gamma > 10^3$ GeV and a large cross section which disagrees with the vector meson dominance model equations (5) and (5'). In fact the use of eqs(5) and (5') to compute the integral flux of HAS

$$(7) \quad J(\gamma_{\min}) = \int_{\gamma_{\min}}^{\infty} dE M(E) \int_{\gamma_{\min}}^{\infty} d\gamma \frac{d\sigma}{d\gamma} N \Delta X$$

gives very poor result as seen by the dashed curve in fig. (3).

In eq. (7) $M(E)$ is the conventional differential muon spectrum, N Avogadro's number and $\Delta X = 400 \text{ gm cm}^{-2}$ is the mean distance between the point of origin of the event and that of observation.

The minimum and maximum values of q^2 used are:

$$q_{\min}^2 = \gamma^2 m_{\mu}^2 / [E(E-\gamma)] \quad q_{\max}^2 = 2M_N \gamma$$

A fait de mieux we have adopted the parametrisation

$$(8) \quad W_2(\gamma, q^2) = \frac{C}{\gamma} = \frac{0,3}{\gamma}$$

of γW_2 found to fit the SLAC-MIT data for $\gamma/q^2 \geq 5 \text{ GeV}^{-1}$ and for both γ and q^2 separately large (minimum value of $q^2 \simeq 0,5 \text{ GeV}^2$) in eq. (7) and the resultant form of $J(\gamma_{\min})$ is the full curve in fig. (3) which as seen is quite close to the experimental points. This agreement of eq. (8) with the HAS data is rather surprising since q^2 for these events is small and we know both theoretically and experimentally for γ up to 20 GeV that $\gamma W_2 \propto q^2 \sigma_t$ tends to zero for $q^2 \rightarrow 0$. If the HAS are due to muons then the agreement of eq. (8) with experiment implies ipso facto a break-down of the Weizsacker-William's approximation following which $\sigma_t(\gamma, q^2)$ for $q^2 \ll m_p^2$ can be expanded in a convergent series about $q^2=0$

$$(9) \quad \sigma_t(\gamma, q^2) = \sigma_{\gamma p}(\gamma) (1 + aq^2 + bq^4 \dots \dots \dots)$$

Eq. (8), on the other hand, gives

$$(10) \quad \sigma_t(\gamma, q^2) = \frac{4\pi\alpha^2}{q^2} C$$

even for small q^2 provided γ is large $\gamma \rightarrow \infty$.

A conclusion that can be drawn from the above comparison of eqs. (9) and (10) with experiment for large γ and small q^2 is that high energy QED may differ from what, out of habit, is expected of it on the basis of familiar approximation methods.

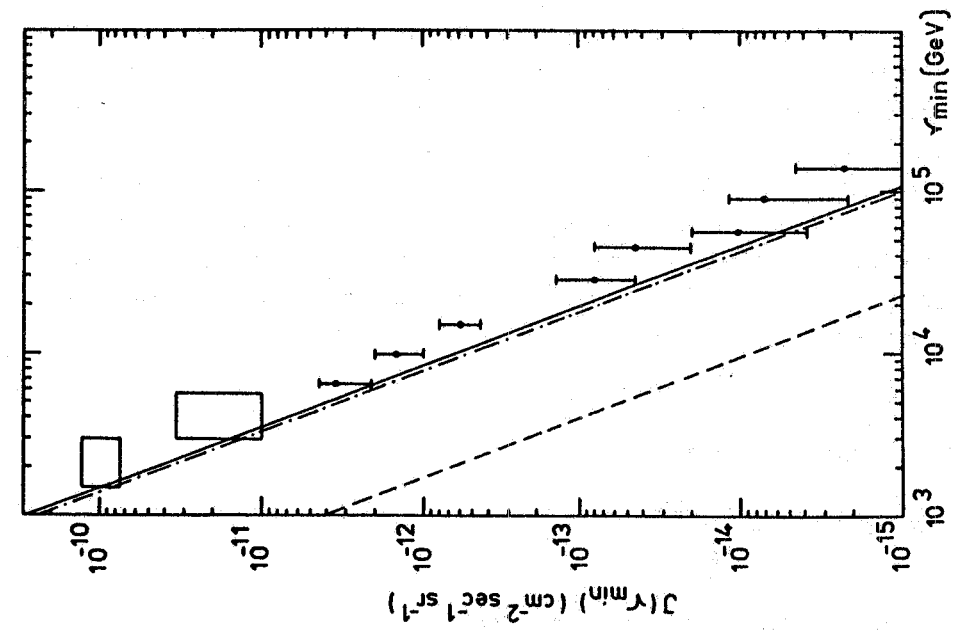


FIG. 3 - Plot of the integral flux $J(\nu_{\min})$ against the minimum energy transfer ν_{\min} . The dash-dot curve is the result of eqs. (5) and (5'); the full and dash-dot curves are drawn using the parametrization eq. (8) in the two extreme cases $\overline{\sigma}_t(\overline{\sigma}_t + \overline{\sigma}_p)$ equal to one and zero.

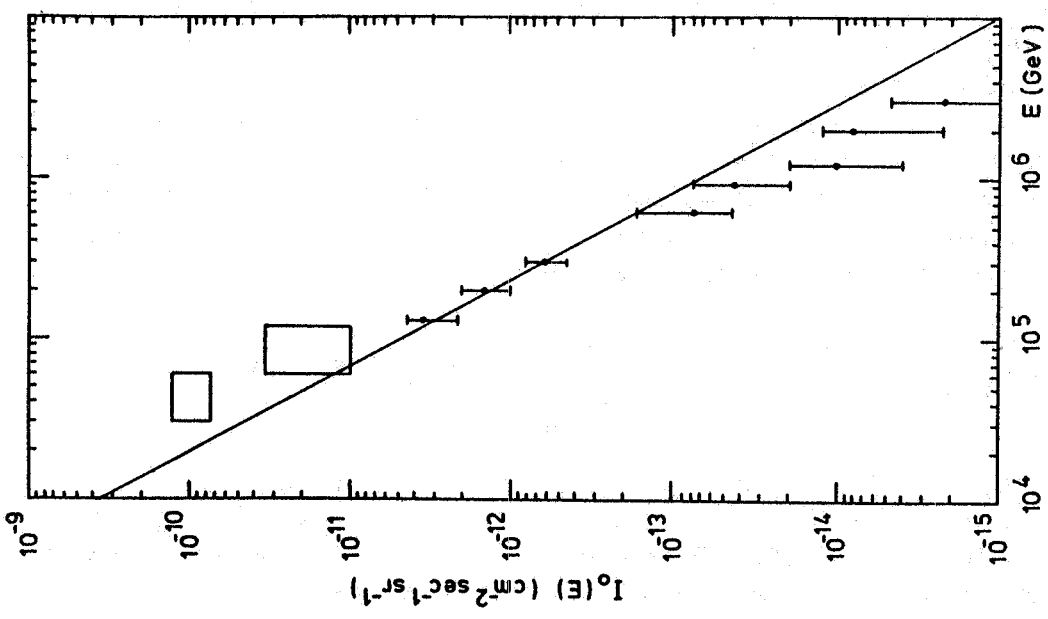


FIG. 4 - Integral vertical sea level flux $I_0(E)$ of heavy primaries against energy E . The experimental data have been obtained using the HAS data. The straight line is from eq. (12).

2.2.- SU3 triplet particles

If the HAS are not from muon parents one is forced to conclude that they are produced by strongly interacting parents⁽²¹⁾. Since such strongly interacting parents cannot be nucleons (the inelasticity K_N of nucleons is 0.5 and are therefore absorbed at large zenith angle) it must be supposed that they are particles heavier than the nucleon and therefore with a small inelasticity K_T . This hypothesis would fit in well with the properties (iii) and (v) of the HAS. The likely candidates could be the massive particles whose possible existence is a consequence of the SU(3) symmetry. We have examined the data of Dardo⁽²²⁾ et al. on triplets whose mass m_T should be between 10 and 15 GeV and whose mean free path λ_T is between 2 and 3 times that of the nucleon λ_N . The value of λ_T given by Dardo et al. is just about what one would expect theoretically.

The inelasticity K_T can be calculated from the relation

$$K_T M_T \simeq K_N M_N.$$

Using the formula:

$$(11) \quad J(\gamma) = I_0(E_{\min}) \Delta x / \lambda_T$$

to calculate the integral flux $I_0(E_{\min})$ of the assumed heavy primaries with energy $E > E_{\min}$ ($E_{\min} = \gamma_{\min}/K_T$) from the integral flux $J(\gamma_{\min})$ of the HAS with energy $\gamma > \gamma_{\min}$ we find the result displayed in fig. (4) (the horizontal flux has been converted to the vertical using the experimental ratio from Dardo et al.). Starting, from the experimental flux ($\sim 10^{-7} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$) of Dardo et al. referring to a triplet energy near threshold, $3 \frac{M_T^2}{M_N}$, one can obtain the flux in the energy interval concerned:

$$(12) \quad I_0(E) = 10^{-7} (E/3 \frac{M_T^2}{M_N})^{-\gamma}$$

with $\gamma = 1, 6$ the exponent of the primary spectrum. Eq. (12) is a straight line which passes very close the I_0 values obtained from the HAS data with corresponding errors.

3. - ZENITH ANGLE DISTRIBUTION OF HIGH ENERGY MUONS

In a series of underground experiments the Utah group⁽²⁾ has provided evidence that the intensity of ultra-high energy muons ($E > 10^{12} \text{ eV}$) does not show the $\sec \theta$ enhancement that is expected of it if the main source of muons is the decay of pion and Kaon parents. The almost isotropic zenithal angle distribution reported points to the existence of muons that are produced directly, either in the nucleon-nucleon collision in the atmosphere or through an intermediary of very short life-time itself produced in the N-N collision; the overall muon spectrum is best fitted by

the formula:

$$(13) \quad M(E) = C_{\pi} E^{-\gamma-1} r^{\gamma} K(E, \theta) B(E \cos \theta^* + B)^{-1} + \\ + RC_{\pi} E^{-\gamma-1} (\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} (\text{GeV})^{-1})$$

in which the first term represents the conventional muon spectrum of π -K derived muons and the second term is the contribution from the direct process; the parameter $R \simeq 0,02$ which fixes the direct spectrum is simply the ratio of muons derived from the direct process to the total number of pions of the same energy. $C_{\pi} = 0,225$, $\gamma = 1,7$, $B = 90$ GeV and the factor $K(E, \theta)$ which varies between 1,16 and 1,38 corrects for the ratio of kaons to pions of all charges.

Suggestions as to the origin of the direct process are many and varied: Callan⁽²³⁾ and Glashow have argued that not all the particles observed underground are muons but that there is a new type of stable particle, the \mathcal{U} -particle, which arrives at the detector from the top of the atmosphere without interacting. The \mathcal{U} -particle hypothesis is in conflict with the experimentally⁽²⁴⁾ confirmed fact that the penetrating component of cosmic rays consists only of muons.

On the basis of the disagreement between the measurement of Farley et al. of the muon g-factor

$$(14a) \quad a_{\mu}^{(\text{expt})} = \frac{1}{2} (g-2)_{\mu} = (11664,5 \pm 33) \cdot 10^{-7}$$

and the then theoretical value

$$(14b) \quad a_{\mu}^{(\text{th})} = \frac{1}{2} (g-2)_{\mu} = (116564 \pm (10-20)) \cdot 10^{-8}$$

Neito⁽²⁵⁾ pointed out that the deviation of (14a) from (14b) which could be explained by postulating the existence of a neutral vector boson whose coupling constant f to the muon is related to its mass M by:

$$(15) \quad \frac{1}{M^2} \left(\frac{f^2}{4\pi} \right) \simeq (33 \text{ GeV})^{-2}$$

is consistent with the direct production mechanism since if such a boson is exchanged between an incoming and an outgoing muon it can also decay into a muon pair. However with the recent measurements of Farley⁽²⁶⁾ et al.

$$(16a) \quad a_{\mu}^{(\text{expt})} = \frac{1}{2} (g-2)_{\mu} = (116616 \pm 31) \cdot 10^{-8}$$

and of the detailed calculations of $a_{\mu}^{(\text{th})}$ by Aldins et al.⁽²⁷⁾

$$(16b) \quad a_{\mu}^{(\text{th})} = \frac{1}{2} (g-2)_{\mu} = (116587 \pm 3,4) \cdot 10^{-8}$$

the discrepancy between theory and experiment is essentially eliminated and the small difference between (16a) and (16b) could most probably be due to experimental and theoretical uncertainties. In this case the near agreement between (16a) and (16b) places a stringent limit on the electromagnetic coupling to the higher mass hadrons which can contribute to the muon g-factor through vacuum polarization. The general formula⁽²⁸⁾ for the hadronic contribution to a_μ is

$$(17) \quad a_\mu \text{ (hadrons)} = 4 \alpha^2 \int_0^\infty \frac{\rho(x) K(x)}{x^2} dx$$

where the spectral function $\rho(q^2)$ is related to the total cross-section $\sigma_h(e^+e^-)$ for e^+e^- annihilation into hadrons by

$$(18) \quad \sigma_h(e^+e^-) = \frac{16\pi^3 \alpha^2}{q^4} \rho(q^2)$$

and $K(q^2)$ is a slowly varying function defined by the integral

$$(19) \quad K(q) = \int_0^1 dz \frac{z^2(1-z)}{z^2 + (1-z)\frac{q^2}{m_\mu^2}} \approx \frac{m_\mu^2}{3q^2}$$

with m_μ the muon mass. Substituting from (18) and (19) into (17) and simplifying gives:

$$(20) \quad a_\mu \text{ (hadrons)} \approx \frac{m_\mu^2}{12\pi^3} \int_0^\infty \frac{dx \sigma_h(e^+e^-)}{x}$$

It follows from (20) that if the small difference δa_μ between (16a) and (16b) is regarded as the upper limit of the theoretical error of having neglected the contribution of higher lying hadrons with mass greater than $\sqrt{x_0} > m_\phi$ then eq (20) implies

$$(21) \quad \int_{x_0}^\infty \frac{dx}{x} \sigma_h(e^+e^-) < \frac{12\pi^3}{m_\mu^2} \delta a_\mu = 8.2 \mu\text{b}$$

Thus a reduction of the experimental errors apart from confirming the QED calculation would seriously limit the cross-section for e^+e^- annihilation into hadrons. An upper bound similar to (21) is placed on whatever hypothetical coupling is held responsible for the small difference δa_μ . In the case of the vector boson considered above one would have⁽²⁹⁾:

$$(22) \quad 0 \leq \left(\frac{f^2}{4\pi}\right) \frac{1}{M^2} \leq (45 \text{ GeV})^{-2}$$

Other particles such as the SU3 triplets or a new class of hadrons capable of decaying into hadrons states containing muons have come under examination for their possible responsibility for the direct mechanism of muon production. Whatever hypothesis advanced in support of the direct production mechanism comes under two serious tests:

i) To find a physical explanation for the large cross-section $\sigma(pp \rightarrow x)$, which would be between 10^{-26} and 10^{-28} cm^2 , where x is the intermediary in the chain $p + \text{atmospheric Nucleus} \rightarrow x \rightarrow \mu^+$?

ii) With the new muon spectrum in eq. (13) determined to within the parameter R one must obtain the depth-intensity curve of muon underground which is known to be in agreement with the conventional pion and Kaon derived muon spectrum at sea level.

As to the first difficulty one can, at least for the moment, overlook it since anomalously large cross-sections are nothing new to cosmic ray events. It is sufficient to remember that the large cross-section for nucleon pair production in extensive air showers with energy greater than 100 GeV is very much greater than the geometrical cross-section $\sigma_{\bar{p}} = \pi \lambda_p^2$ ($\lambda_p = h/M_p c$ is the Compton wavelength of the proton) while that for the production of \bar{p} at 30 GeV ($\sigma_{\bar{p}} \sim 10^{-30} \text{ cm}^2$) is approximately equal to the geometrical cross-section, the corresponding cross-sections for the productions of π , K and p in p-p collisions follow the geometrical law as originally suggested by Adair and Price⁽³⁰⁾. The second difficulty is more demanding since one must find an additional mechanism of energy loss by muons in order to consistently take account of those directly produced. One way of circumventing this difficulty was suggested by Bergeson⁽³¹⁾ et al. and consists in assuming that the photo-nuclear cross-section $\sigma_{\gamma p}(\gamma)$ increases with the energy transfer γ in such a way that eq. (13) matches the depth-intensity curve. Using the formula

$$-\left(\frac{dE}{dx}\right)_{\text{Nucl}} = b_{\text{Nucl}} E$$

one finds under this assumptions that b_{nucl} increases up to a factor six above the normal value. This large increase is however not observed in underground experiments because the events characterized by high muon energy and very large energy transfer ($\gamma > 10^3 \text{ GeV}$) which should give rise to it are rare deep underground.

However if the HAS are muon-produced then from the work of the last section we have an example of individual interactions with large energy transfer γ characterized by an anomalous increase in the cross-section which can account for the needed energy loss necessary to match eq.(13) with the depth-intensity curve.

New leptonic interactions such as those illustrated in Figs. (5a), (5b) and (5c) have come under consideration through the possible existence of the intermediate vector bosons W^\pm as likely mechanisms of the muon energy loss. The diagrams in Figs. (5a) and (5b) can be evaluated and shown to give cross-sections of the order of 10^{-37} cm^2 at most. Diagrams of the type in Fig. (5c), although possible are mainly speculations.

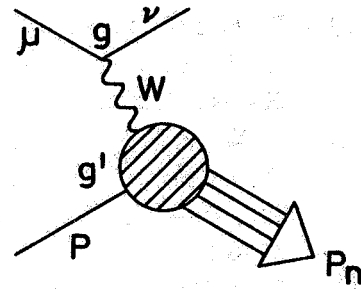
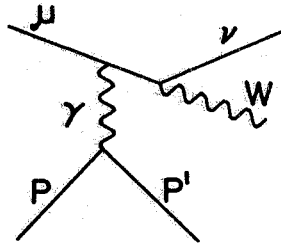
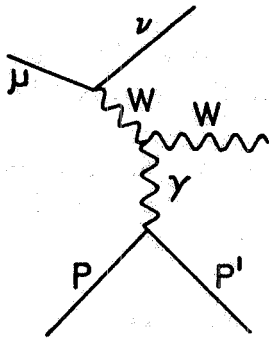
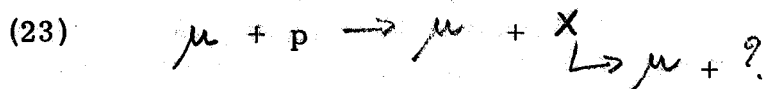


FIG. 5 a), b) - Muoproduction of W .

Fig. 5 c) - Muoproduction of strong W .

A possible experiment to detect a possible anomalous interaction giving rise to two muon secondaries in the final state following the chain



is an underground measurement at different depths of the ratio S of the number of decaying muons to the total number of incident ones. If interactions such as (23) do not exist then S should fall-off precipitously with the depth as the mean muon energy increases. But if (23) exists with significant probability then S would have a slower fall-off with increased depth by reason of the added secondaries.

CONCLUSION. -

High energy physics, because of its very nature and the speculations which go into making it does not permit an easy interpretation of or conclusions on its results even those obtained experimentally. For instance the work of Aldin et al. has almost completely destroyed any basis for hope in explaining many experimental facts such as direct muon production by arguments based on the possible existence of W^\pm . Nonetheless the HAS, the experiments of the Utah group and that of the Torino group on triplets combine to feed the suspicion that there is something new happening in the ultra-high energy region. To have definitive answers to the problems which have been touched upon above more and new data, especially those from visual techniques, are greatly needed.

REFERENCES. -

- (1) - T. Hara, S. Kawaguchi, S. Mikano, M. Nagano, K. Suga, M. Takano, G. Tanahashi and T. Matano, Eleventh Intern. Conf. on Cosmic Rays, Budapest (1969), EAS-22.
- (2) - J. W. Keuffel, J. L. Osborne, G. L. Bolingbroke, G. W. Mason, M. O. Larson; G. H. Lowe, J. H. Parker, R. O. Sternerson and H. E. Bergeson, Eleventh Intern. Conf. on Cosmic Rays, Budapest (1969), MU-31.
- (3) - R. Wilson, Comm. Nuclear Part. Phys. (1968), pag. 169.
- (4) - S. Drell and J. Walecka, Ann. Phys. 18, 28 (1964).
- (5) - J. J. Sakurai, Phys. Rev. Letters 22, 981 (1969).
- (6) - Aachen-Berlin-Bonn-Hamburg-Heidelberg-Munich Collaboration, Phys. Letters, 27B, 474 (1968); J. Ballam, G. B. Chadwick, Z. G. T. Guirangossian, P. Klein, A. Levy, M. Menke, E. Pickup, P. Seyboth, T. H. Tan and G. Wolf, Phys. Rev. Letters 21, 1544 (1968); M. Davier, I. Derardo, D. Drickey, D. Fries, R. Mozley, A. Odian, F. Villa and D. Yount, SLAC-PUB-503 (1968); G. Kneis, Phys. Letters 27B, 288 (1968); F. Buccella and M. Colucci, Phys. Letters 24B, 61 (1967); D. O. Cadwell, V. B. Elings, W. P. Hesse, G. E. Jahn, R. J. Morison, F. V. Murphy and D. E. Yount, Phys. Letters 23, 1256 (1969); C. Castagnoli, M. Muchnik, G. Ghigo and R. Rinzivillo, Nuovo Cimento 19, 683 (1960).
- (7) - J. A. Kirk, D. M. Cottrél, J. J. Lord and R. J. Piserchio, Nuovo Cimento 40A, 523 (1965); R. L. Thompson, J. J. Lord, J. A. Kirk, M. E. Nelson and R. J. Piserchio, Preprint (unpublished).
- (8) - C. M. Hoffman, A. D. Lieberman, E. Engels Jr., D. C. Imrie, P. G. Innocenti, R. Wilson, C. Zajde, W. A. Blampied, D. C. Stairs and D. Drickey, Phys. Rev. Letters 22, 659 (1969).
- (9) - B. D. Dieterle, T. Braunstein, J. Cox, F. Martin, W. T. Toner, M. L. Perl, T. F. Ziph, W. L. Lakin and H. C. Bryant, Phys. Rev. Letters 23, 1187 (1969); M. L. Perl, T. Bramstein, J. Cox, F. Martin,

- W. T. Toner, B. D. Dieterle, T. F. Zipf, W. L. Lakin and H. C. Bryant, *Phys. Rev. Letters* 23, 1191 (1969).
- (10) - E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, G. Miller, L. W. Mo, R. E. Taylor, M. Briedenbech, J. I. Friedman, B. C. Hartmann and H. W. Kendall, *Phys. Rev. Letters* 23, 935 (1969); M. Briedenbach, J. I. Friedman, H. W. Kendall, E. D. Bloom, D. H. Coward, H. DeStaebler, J. Drees, L. W. Mo and R. E. Taylor, *Phys. Rev. Letters* 23, 939 (1969).
- (11) - W. Albrecht, F. W. Bresse, H. Dorner, W. Flauger, KH. Frank, J. Gayler, H. Hultschig, V. Korbel, J. May and E. Ganssauge, Preprint DESY-69/46 (1969).
- (12) - D. Kessler and R. Maze, *Physica* 22, 69 (1956); E. Amaldi, C. Castagnoli, A. Gigli and S. Sciuti, *Nuovo Cimento* 9, 969 (1952); S. Higashi, et al., *Nuovo Cimento* 5, 592 (1957); N. Chandhuri and M. S. Sinha, *Nuovo Cimento* 57, 573 (1968).
- (13) - S. Higashi et al., *J. Phys. Soc. Japan*, 17, Suppl. A-III, 362 (1962).
- (14) - Eleventh Intern. Conf. on Cosmic Rays, Budapest (1969), EAS-22.
- (15) - S. Higashi et al., *Nuovo Cimento* 22, 304 (1961); S. Higashi et al., *Nuovo Cimento* 38, 107 (1965); S. Chin et al., *Can. J. Phys.* 46, 5112 (1968).
- (16) - C. Castagnoli, P. Picchi and R. Scrimaglio, *Nuclear Phys.* 87, 641 (1967).
- (17) - D. Alexander et al., Eleventh Intern. Conf. on Cosmic Rays, Budapest (1969), MU-35.
- (18) - C. Castagnoli, E. Etim and P. Picchi, *Lettere al Nuovo Cimento* 2, 595 (1969).
- (19) - J. Bjorken, *Phys. Rev. Letters* 16, 408 (1966); SLAC-PUB-510 (1968).
- (20) - V. Weisskopf, *Comm. Nuclear Part. Phys.* (1969), pag. 1.
- (21) - C. Castagnoli, E. Etim and P. Picchi, *Nuovo Cimento* 1, 197 (1969).
- (22) - M. Dardo, P. Penengo and K. Sitte, *Nuovo Cimento* 58 A, 59 (1968).
- (23) - C. G. Callan Jr. and S. L. Glashow, *Phys. Rev. Letters* 20, 779 (1968).
- (24) - W. R. Kropp Jr., F. Reines and R. W. Woods Jr., *Phys. Rev. Letters* 20, 1256 (1968).
- (25) - M. M. Neito, *Phys. Rev. Letters* 21, 488 (1968).
- (26) - J. Bayley et al., *Phys. Letters* 28B, 287 (1968).
- (27) - J. Aldins, T. Kinoshita, S. J. Brodsky and A. J. Dufner, *Phys. Rev. Letters* 23, 441 (1969).
- (28) - E. Etim and P. Picchi, Frascati report LNF-69/33 (1969).
- (29) - I. Yu. Kobzarev and L. B. Okun', *Soviet Phys. -JETP* 14, 859 (1962); S. J. Brodsky and E. deRafael, *Phys. Rev.* 168, 1620 (1968).
- (30) - R. K. Adair and N. J. Price, *Phys. Rev.* 142, 844 (1966).
- (31) - H. E. Bergeson, J. W. Keuffel, M. O. Larson, G. W. Mason and J. L. Osborne, *Phys. Rev. Letters* 21, 1089 (1968).