What is the difference between neutral-nucleon, and proton-nucleon interaction cross sections?

McCusker: We cannot measure the interaction mean free path of neutral secondaries directly. From the distributions in n_s I would infer that the K and π interaction cross sections are not very different. The number of events, however, is not very big as yet. The ICEF results should greatly improve the position.

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III-4-34. The Conclusion Speech

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All speakers of this plenary session have made such good jobs and prepared such complete and fruitful reports that it is quite unnecessary for me to make my conclusion long. Besides, during ordinary sessions, such a wide range of problems concerning extensive air showers was discussed that it is impossible even to enumerate them in a short speech. Really at our sessions much was said both about details of interactions of most and even on the methods of future experiments on observations of non-atmospheric showers on the moon.

The only thing I want to do is to emphasize the progress achieved in the study of extensive air showers after the Moscow Conference.

One has to admit that in this field no extraordinary discoveries have been made, which could astound a layman.

But from a specialistic point of view very much has been done. A lot of data were obtained on the anisotropy of primaries at superhigh energies, on the energy spectrum in this region and on its upper limit; the systematic work was started on primary γ-rays of very great energies and on local sources; very great attention was paid to μ-meson component and to μ-meson beams in extensive air showers.

Very many data were accumulated on spatial and energy distribution of different components of showers, on their altitude dependence, on the core structure and so on.

In other words a great and fruitful work is being done in accumulating experimental materials and on its interpretation and, what is especially important, on obtaining fully reliable and indisputable data.

I think that we can strongly believe that this work will give its fruits, that the obtained data will lead us to a new stage in our knowledge of processes at the greatest energies occurring in nature (that is some joules per one individual particle) and will help us understand the phenomena in our and other galaxies, in bursts of supernova in interstellar space.

III-5. Mu-Mesons

Chairman: H. MESSEL
Secretary: T. KITAMURA

Date	Time	Paper Numbers
Sept. 11	15 : 30 – 17 : 30	from III-5-1 to III-5-11
Sept. 12	15 : 30 – 17 : 30	from III-5-12 to III-5-20
Sept. 14	12 : 00 – 13 : 30	from III-5-21 to III-5-24

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III-5-1. The Polarization of Cosmic Ray Mu-Mesons*

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The polarization of cosmic ray mu mesons which come to rest in a brass absorber has been measured at sea level with 12, 700, and 3700 gm/cm^2 (air equivalent) of cover above the absorber. According to the theory of Hayakawa,[1] and independently of Fowler *et al*,[2] and Gol'dman,[3] the measured polarization depends, in part, upon the proportion of K mesons among the parents of stopped muons. It has therefore been possible to determine a K/π production ratio for primary interaction energies up to 100 Bev. The results at 12 gm/cm^2 and about one half of the data at 3700 gm/cm^2 were previously reported.[4]

The muon polarization was determined from a measurement of the flux of decay electrons emerging from the brass absorber in the downward direction with and without a precessing magnetic field of about 83 gauss. The field was cycled ON and OFF automatically with a 10 minute period. The experimental configurations for the three runs are summarized in Table 1 and are shown in figures 1, 2, and 3. The runs are designated A, B, and C in order of increasing cover. The four detectors had a total sensitive area of ten square meters. This large area made it possible to accumulate the above data in five months of running time. The incoming mu mesons were defined by a coincidence between the outputs of the photomultipliers U and U' (see Fig. 1) and an anti-coincidence with the photomultiplier, D. This event is labeled $UU'\bar{D}$. Similarly decay electrons which strike the lower scintillator are selected by the requirement, $DD'\bar{U}$. The UU' and DD' coincidence eliminate a large number of pulses due to noise. After a passive delay of 0.70 sec., the pulses representing $UU'\bar{D}$ start a 5.6 μ sec gate pulse.

* This research has been performed under a joint program of research supported by the Atomic Energy Commission, the Office of Naval Research, and the Office of Scientific Research of the Air Force.

Table I. Summary of Conditions for the Three Runs

Run	Cover-gm/cm² air equivalent	Experimental Arrangement	Number of Muons	Number of Accidentals
A	12	one detector-Fig. 1.	195,000	80,000
B	700 (Fe, Pb)	telescope-Fig. 2.	75,000	8,100
C	2700 (rock)	four detectors Fig. 1 and 3.	410,000	33,000

This gate pulse is then put in coincidence with DD'U. The output of this delayed coincidence is stored in either an ON or an OFF register depending upon the state of the magnetic field. An additional set of scalers and registers in parallel with the first guarantees against failure in these critical components. The registers and two running-time clocks (ON and OFF) were photographed once an hour. In addition, six other rates (e.g. UU') were similarly monitored in OFF and ON channels. It was found in these cases that the ON and OFF rates differed

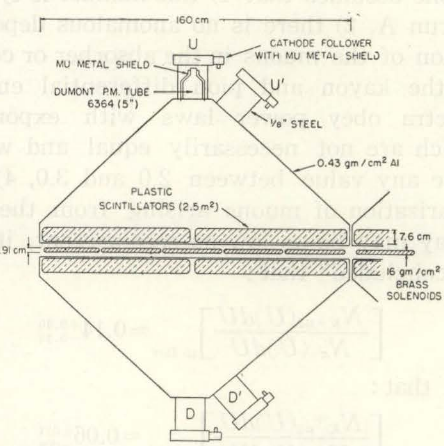

Fig. 1. One of the four detectors.

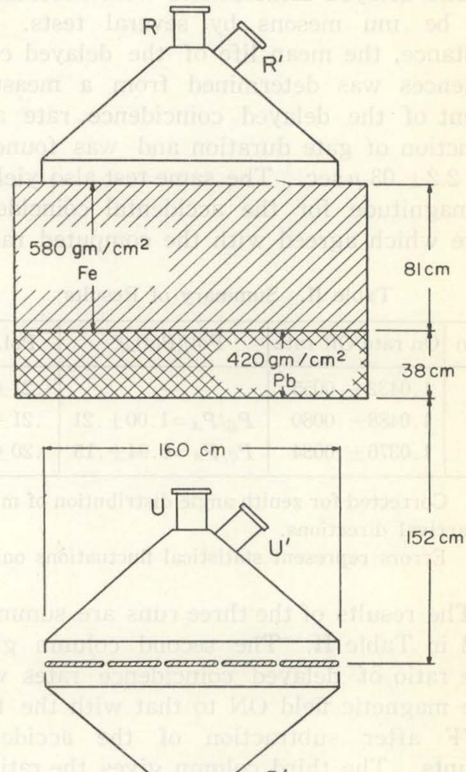

Fig. 2. Telescope for measurement of 1.5 Bev muons.

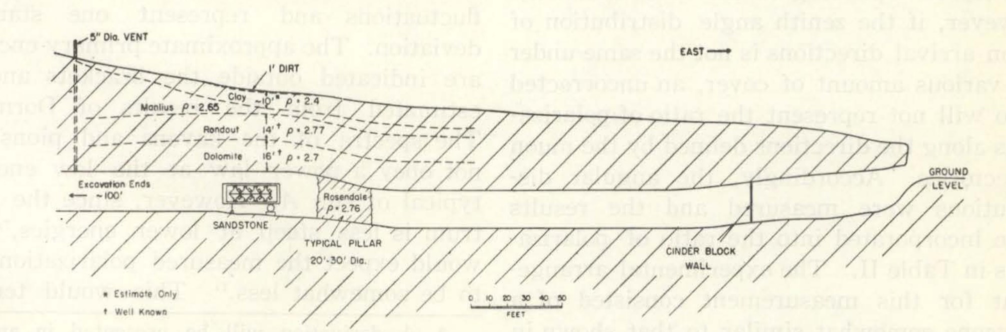

Fig. 3. Underground polarization experiment-location south binnewater mine-typical profile.

by less than 0.2% which indicates that the magnetic field did not significantly affect the sensitivity of the system. Also, the continuous record of these additional rates made possible an accurate determination of the accidental delayed coincidences rates. During run B a coincidence between the phototubes R and R' (See Fig. 2) was required before the delayed coincidence event would be accepted.

The delayed coincidences were ascertained to be mu mesons by several tests. For instance, the mean life of the delayed coincidences was determined from a measurement of the delayed coincidence rate as a function of gate duration and was found to be $2.2\pm.03$ μsec. The same test also yielded a magnitude for the accidental coincidence rate which agreed with the computed race.

Table II. Summary of Results

Run	On rate/Off rate	Pol/(Pol)$_A$*	Pol.**
A	$1.0432\pm.0055$	—	$.21\pm.03$
B	$1.0488\pm.0080$	$P_B/P_A=1.00\pm.21$	$.21\pm.04$
C	$1.0376\pm.0034$	$P_C/P_A=0.94\pm.15$	$.20\pm.02$

* Corrected for zenith angle distribution of muon arrival directions.

** Errors represent statistical fluctuations only.

The results of the three runs are summarized in Table II. The second column gives the ratio of delayed coincidence rates with the magnetic field ON to that with the field OFF after subtraction of the accidental counts. The third column gives the ratio of the polarization at 700 or 3700 gm/cm^2 to that at 12 gm/cm^2. This ratio is insensitive to most of the systematic errors which affect a single measurement of the polarization (e. g. electron scattering in the brass absorber). However, if the zenith angle distribution of muon arrival directions is not the same under the various amount of cover, an uncorrected ratio will not represent the ratio of polarizations along the directions defined by the muon trajectories. Accordingly, the angular distributions were measured and the results were incorporated into the ratio of polarizations in Table II. The experimental arrangement for this measurement consisted of a telescope somewhat similar to that shown in Fig. 2, though without the lead and iron absorber. The delayed coincidence rates with and without an associated signal from the highest scintillators were compared.

The ratios P_B/P_A and P_C/P_A in Table II were used to obtain an estimate of the K/π production ratios at the primary energies represented by runs B and C. Since the K/π production ratios determined from a single polarization measurement contain large systematic errors it was necessary to take, as a reference, a K/π production ratio for the energy represented by run A from a recent machine experiment. The relative numbers of K^+ to π^+ mesons at the target was found to be about .25 in a 2.08 Bev/c secondary beam which was produced by 25 Bev protons impinging on an alumium target.[5] From the known branching ratio, one obtains the relative numbers of $K^+_{\mu 2}$ mesons to π^+ mesons in the total energy interval dU at U

$$\left[\frac{N_{K^+\mu 2}(U)dU}{N_{\pi^+}(U)dU}\right]_{25\text{ Bev}} \cong 0.14 \qquad (1)$$

If one assumes that 1) this number is typical of run A, 2) there is no anomalous depolarization of the muons in the absorber or cover, 3) the kayon and pion differential energy spectra obey power laws with exponents which are not necessarily equal and which have any value between 2.0 and 3.0, 4) the polarization of muons arising from the $K^+_{\mu 3}$ decay may be as low as zero percent, it can be concluded* that:

$$\left[\frac{N_{K^+\mu 2}(U)dU}{N_{\pi^+}(U)dU}\right]_{40\text{ Bev}} = 0.14^{+0.49}_{-0.14} \qquad (2)$$

and that:

$$\left[\frac{N_{K^+\mu 2}(U)dU}{N_{\mu^+}(U)dU}\right]_{100\text{ Bev}} = 0.06^{+024}_{-006} \qquad (3)$$

The limits of error are due to statistical fluctuations and represent one standard deviation. The approximate primary energies are indicated outside the brackets and are estimated from the results of Dorman.[6] The spectra of the kayons and pions may not obey a power law at the low energies typical of run A. However, since the spectrum is less steep at lower energies,[7] one would expect the measured polarization, P_A, to be somewhat less.[1] This would tend to

* A derivation will be presented in another publication.

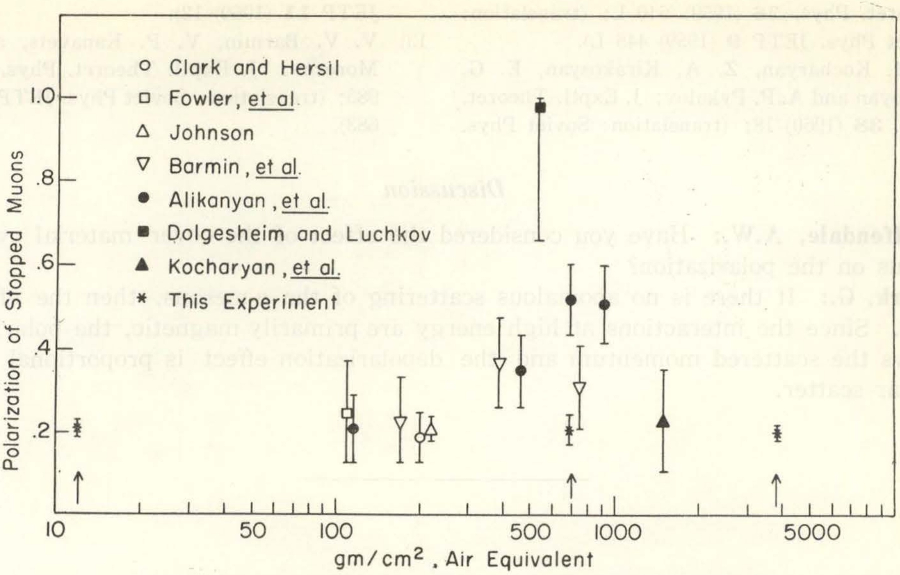

Fig. 4. Reported polarization of stopped muons vs material over absorber (not including atmosphere).

indicate, falsely, the presence of additional K mesons at high energies. In this event the results presented in equations (2) and (3) should be decreased. However, since the errors in these expressions represent only an upper limit, they need not be changed.

Despite certain systematic errors, estimates of the absolute polarizations have been made using a method similar to that of Clark and Hersil,[8] wherein the scattering of the electrons was neglected. The results are given in Table II and the errors given include only the statistical fluctuations. The discrepancy with the previously reported value for run A is due to a numerical error in the earlier work* and to a revised estimate of one of the systematic errors. For comparison with other experiments[2,8,9,10,12,13], these results are plotted in Fig. 4. It is apparent from this figure that all of the published results are consistent with there being no change in the polarization as the cover over the absorber is varied from 12 gm/cm² to 3700 gm/cm², air equivalent.

The authors are grateful to Mr. Robert Mudge, Mr. Charles Reed, and Mr. James Nottingham whose assistance at the experimental sites proved invaluable. The extensive film scanning and computations were ably performed by Mr. Allen Krieger, Mr. Bonnard Teegarden, and (Mrs.) Dorothy Bradt. Finally, the authors would like to thank the stuff of the Laboratory for Nuclear Science for their support throughout the course of the experiment.

* Reference 4 should be corrected to read $P_u = P_s = .22 \pm .03$.

References

1) S. Hayakawa: Phys. Rev. **109** (1957) 1533.
2) J. M. Fowler, H. Primakoff and R. D. Sard: Nuovo Cimento, **9** (1958) 1027.
3) I. I. Gol'dman: J. Exptl. Theoret. Phys. **34** (1958) 1017; (translation: Soviet Phys. JETP **7** (1958) 702).
4) H. V. Bradt and G. W. Clark: Bull. Am. Phys. Soc. Ser. II, **6** (1961).
5) V. T. Cocconi, T. Fazzini, G. Fidecaro, N. H. Lipman and A. W. Merrison: Phys. Rev. Letters **5** (1960) 19.
6) L. I. Dorman: *Cosmic Ray Variations*, State Publishing House for Technical and Theoretical Literature, Moscow.(1959) translation: Technical Documents Liaison Office, Wright-Patterson Air Force Base, Ohio).
7) S. Olbert: Phys. Rev. **96** (1954) 1400.
8) G. W. Clark and J. Hersil: Phys. Rev. **108** (1957) 1538.
9) C. S. Johnson: Phys. Rev. **122** (1961) 1883.
10) A. I. Alikanyan, B. A. Dolgeshein B. I. Luchkov and V. I. Ushakov: Proceedings of the Moscow Cosmic Ray Conference, **1** 318 Moscow (1960).
11) B. A. Dolgeshein and B. I. Luchkov: J. Exptl.

Theoret. Phys. **36** (1959) 640 L; (translation: Soviet Phys. JETP **9** (1959) 445 L).
12) N. M. Kocharyan, Z. A. Kirakosyan, E. G. Sharoyan and A. P. Pykalov; J. Exptl. Theoret. Phys. **38** (1960) 18; (translation: Soviet Phys. JETP **11** (1960) 12).
13) V. V. Barmin, V. P. Kanavets, and V. V. Morozov: J. Exptl. Theoret. Phys. **39** (1960) 986; (translation: Soviet Phys. JETP **12** (1961) 683).

Discussion

Wolfendale, A.W.: Have you considered the effect of the cover material over apparatus on the polarization?

Clark, G.: If there is no anomalous scattering of the μ-mesons, then the effect is small. Since the interactions at high energy are primarily magnetic, the polarization follows the scattered momentum and the depolarization effect is proportional to the angular scatter.

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III-5-2. Polarization of Cosmic Ray Muons

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It has been calculated[1-8] and established experimentaly, that the cosmic ray muons are partially polarized in longitude. According to the theoretical estimations the measured polarization depends on the energy spectrum of π-mesons and, in part, on the ratio of the productions of the K^+-mesons and π^+-mesons. The dependence of the cosmic ray muons polarization on their energies has been investigated in the paper[9]. But our prelimenary data given in the above-mentioned paper have a large statistical errors. We continued our measurements of the cosmic ray muons polarization underground with a larger and improved arrangement shown in Fig. I, to get more precise data.

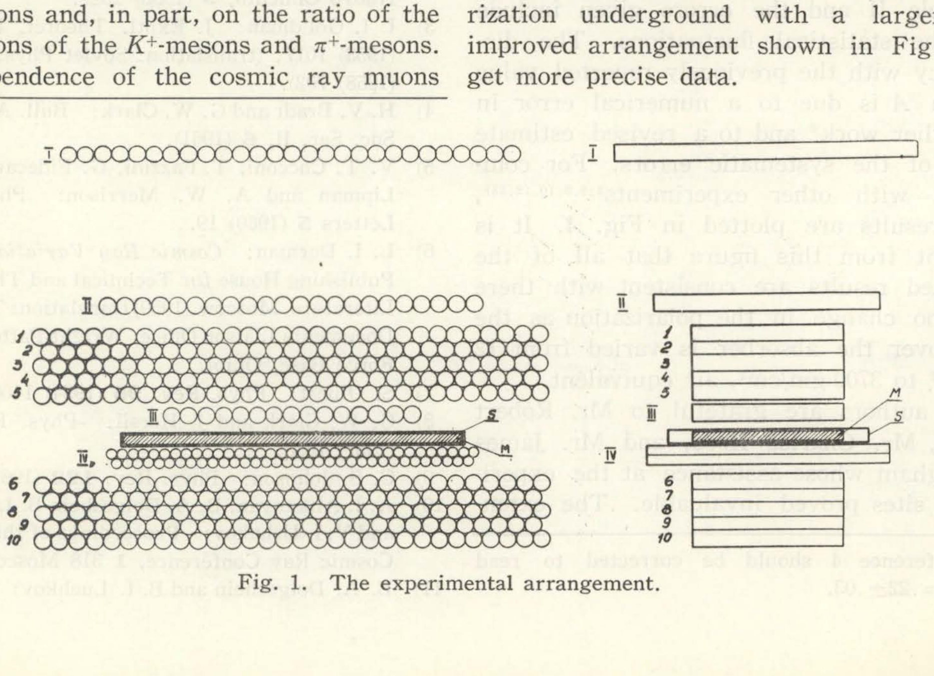

Fig. 1. The experimental arrangement.