JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-6-15. High Energy Gamma-Rays and Jet Showers*

M. BOWLER, J. DUTHIE, P. FOWLER, A. KADDOURA, D. PERKINS, K. PINKAU and W. WOLTER

H. H. Wills Physics Laboratory, Univesrity of Bristol, United Kingdom

1. Results are described and analyzed of an investigation into the spectrum of gamma-rays and total energy release into pi-zero mesons of local nuclear interactions recorded in 4 stacks of emulsion and heavy material flown at about 220 g/cm², and 3 stacks of similar composition flown on balloons at altitudes ranging from 8 to 28 g/cm².

2. Both, nuclear events and gamma-rays are detected and their energy is determined in a similar way. Only after dividing the events into two classes according to the position of origin inside the stack, and investigating the events under the microscope, do the following differences in the spectra of events appear according to their nature:

a. The energy spectrum for the energy release into pi-zero mesons at balloon and aeroplane altitudes is similar, both follow rather closely a law of $E^{-2.0}$. (Figs. 1 and 2)

b. The spectrum of gamma-rays at balloon altitudes follows a similar law of $E^{-2.0}$. (Fig. 3)

c. The spectrum of gamma-rays at 220 g/cm² is steeper than that for nuclear events (Fig. 4). In fact, some 11 should have been observed at energies larger than the highest energy gamma-ray recorded. The experimental points are best fitted by a line of slope −2.3 from 400 to 1500 Bev, and a slope of −2.8 above 1500 Bev. The changing slope however complicates the comparison of our data with other results. Therefore, one line with slope −2.5 is fitted to the data.

3. From an evaluation of the flying time,

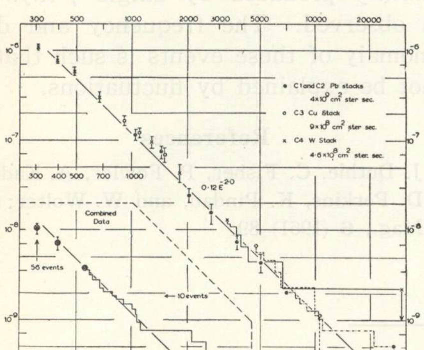

Fig. 1. Integral energy spectrum of electromagnetic cascades initiated by local nuclear interactions in Comet stacks (220 g/cm²).

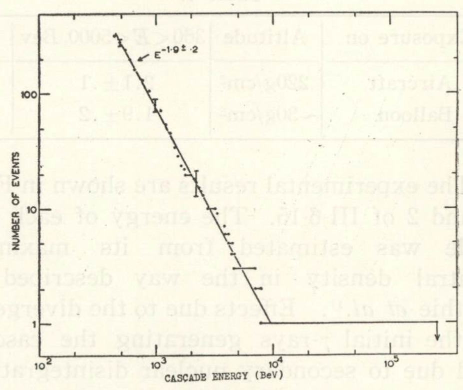

Fig. 2. Integral energy spectrum of nuclear events in balloon stacks.

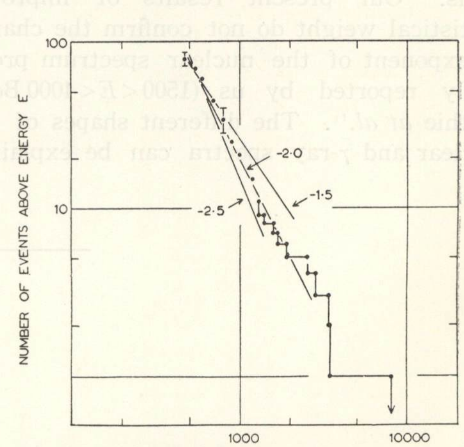

Fig. 3. Integral energy spectrum of γ-rays in balloon stacks.

* This paper was read by K. Pinkau (now at Kiel University, Germany.).

height-time-curve, and size of the stacks, absolute intensities for the gamma-rays and local nuclear events can be obtained. The data for nuclear events releasing more than 470 Bev into pi-zero mesons, and gamma-rays above the same energy are shown in Fig. 5. We conclude that the nuclear-active component is attenuated according to a law $e^{-x/125\ g/cm^2}$.

The flux at the top of the atmosphere is about 3.10^{-6} particles/cm²·sec·steradian. Assuming that only 50% of the particles incident on the stacks interacted, a flux of $6\cdot10^{-6}$ particles is obtained from the MIT-data above 5000 Bev, indicating that some 10% of the energy is released into pi-zero mesons in nuclear interactions of this energy.

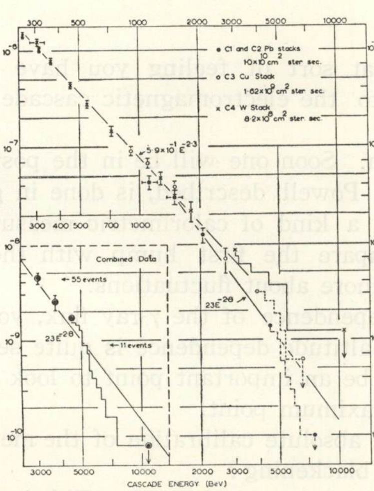

Fig. 4. Integral energy spectrum of γ-rays and/or electrons in Comet stacks (220 g/cm²).

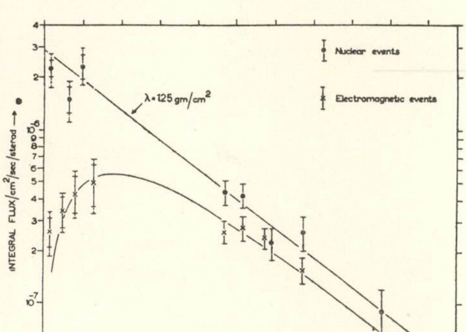

Fig. 5. Flux of cascades with energy exceeding 470 BeV as a function of mass of overlying air.

4. We know that the energy spectrum of gamma-rays is not altered during cascade processes. Thus the spectrum of gamma-rays at production will have the same slope as that recorded in our stacks. If gamma-rays are produced in nuclear interactions only, the altitude dependence of the source distribution will have the same exponential law as that found experimentally for nuclear events. The cascade processes, which the gamma-rays will undergo between the point of production and entry into our stacks, are described by the so-called "stationary solutions" of cascade theory. We thus obtain the lower curve of Fig. 5, and the normalization of the curve gives us the rate of production of gamma-rays. There is a possible flux of gamma-rays at the top of the atmosphere of several 10^{-7}, and this must be compared with several 10^{-4} for protons at the same energy.

5. From the rate of production of gamma-rays, we can calculate the expected muon spectrum if both components result from the charge independent production and decay of

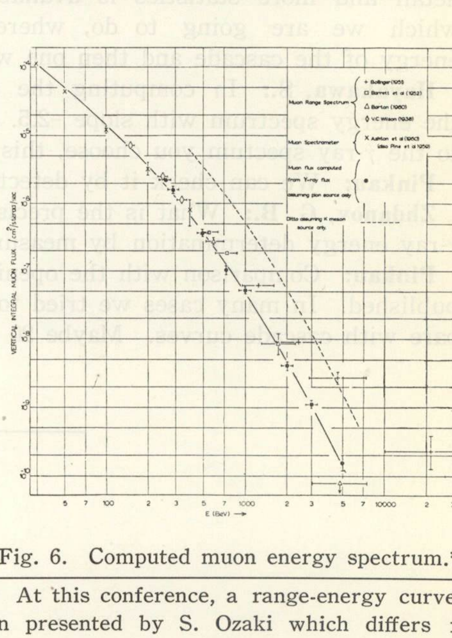

Fig. 6. Computed muon energy spectrum.*

* At this conference, a range-energy curve has been presented by S. Ozaki which differs from the one used in this figure to obtain the energy spectrum of muons from underground measurements. If Ozaki's curve is used, all points have to be shifted to the left, the shift increasing with energy. As a result, the points of the muon spectrum agree then very well within the statistical errors with our points derived from the gamma-ray spectrum.

pions. The results are shown in Fig. 6 in comparison with measurements of the muon spectrum. Up to about 1000 Bev, the muon results are magnetic spectrometer results from Durham, beyond that energy they are computed from the depth-intensity curve according to the range-energy relation. No discrepancy appears between the data due to the large scatter of the muon data.

If one assumes that both muons and the gamma-rays result from the decay of K-mesons, our points should give higher values by one order of magnitude. Thus, the proportion of K-mesons produced appears to be very small.

6. A real discrepancy arises if one tries to reconcile our results with these presented by the Japanese group (III-6-16) about the production of pions in high energy interactions. Their spectra show, going from lower to higher primary energies, that more and more of the total energy released is given to a few very high energy secondary particles. The conclusions to be drawn from our results indicate the opposite, that the energy of the highest energy secondary particles increases only with some power smaller than one of the primary energy. The Japanese result would mean, that the gamma-ray spectrum should have a slope equal to or be flatter than that of the spectrum of nuclear-active particles. This is contray to our findings. One might hope, however, that future experiments will solve the discrepancy.

Discussion

Yamaguchi, Y.: I would like to know what sort of feeling you have on the fluctuation in the fractional energy going into the electromagnetic cascade at the nuclear collision.

Pinkau, K.: This is very difficult to establish. Soon one will be in the position to do more about this, once the analysis, Prof. Powell described, is done in greater detail and more statistics is available. It is a kind of calorimetric measurement which we are going to do, where we compare the first hump with the total energy of the cascade and then one will know more about fluctuations.

Hayakawa, S.: In computing the altitude dependence of the γ-ray flux, you used the energy spectrum with slope –2.5. Since the altitude dependence is quite sensitive to the γ-ray spectum you choose, this seems to be an important point to look at.

Pinkau: We can check it by detecting the maximum point.

Zhdanov, G. B.: What is the precision of the absolute calibration of the method of γ-ray energy determination by measurement of blackening?

Pinkau: Comparison with the openig angle gave the error of $\sim$10%. This is already published. In many cases we tried to measure the density at several depths to compare with cascade curves. Maybe 20 or 30% is the good measure of the error.