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-2-14. The Possible Existence of Photon Initiated EAS

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Results for a period of 15 months obtained with the Lodz experiment indicate an anomalous frequency of EAS events giving the penetrating multiplicity zero as compared to the frequency of EAS giving small multiplicity. It is shown that the effect is well explained by a background if abnormal showers equal to 30/1000 of the total frequency.

In a previous pepar[1)] we described a method enabling the detection of a possible trace primary photons of very high energy through the investigation of large EAS, abnormally poor in penetrating particles. These primary cosmic photons may be produced indirectly in p-p collisions of protons with the diffused matter of the Universe.

Here are some details about the experimental equipment used in Lodz.* The detector for the density analysis of penetrating particles Δ_p consists of a total of $M=56$ groups of 5 counters, each group with an area of $s_p=0{,}136\,\text{m}^2$.** (Henceforth, we shall refer to $x=\Delta_p \cdot s_p$). The whole is shielded by a thickness of 30 cm Pb+12 cm Fe. The device for the selection of the elctronic density Δ_e consists of a total of $K=72$ unshielded counters, each with an area of $s_e=0{,}0125\,\text{m}^2$, divided into 8 groups at the two extremities of the lead tray (the diameter of the device is equal to 10 m.). Any unshielded counter hit in any of these groups sets up an eightfold master coincidence. The registration of the whole is made by hodoscope, which enables the numbers k and m of the hit counters (unshielded and under lead) to be ascertained. As the master frequency is equal to 10 per hour, we are interested only in that part of the registrations which correspond to huge electronic densities (e.g. from $100\,\text{m}^{-2}$). The phenomena observed filling this condition on a basis of $100\,\text{m}^2$ cannot therefore relate to a merely localized event. Therefore, the registration of a high electronic density with a simultaneous lack of registration of penetrating particles (high value of k, with $m=0$) would suggest the existence of a pure cascade due to a primary photon; the size of this cascade cannot be inferior to 10^5 particles.

The initial period of registration latsted 15

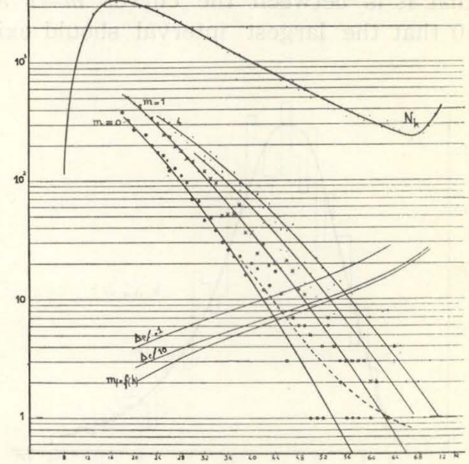

Fig. 1.

* This experiment is being performed in collaboration by the Nuclear Research Institute of the Polish Academy of Sciences (laboratory at Lodz) and the Cosmic Physics Laboratory of the French National Centre for Scientific Research in Paris.

** Recently, two additional detectors, each of $3{,}25\,\text{m}^2$, have been brought into use. The total effective area is now equal to $14{,}1\,\text{m}^2$ divided into 104 parts.

months. The top curve in Fig. 1 shows the frequency variation of the electronic registrations N_k (as a function of k), whatever m may be. Starting from the point at which $k=66$, a rise is noticeable due to the registration of the integral part of the electronic spectrum (a small number of counters in anticoincidence). As Δ_e increases with k, according to the equation $\Delta_e=80\ln(K/K-k)$, an increase in the meson multiplicity average become noticeable and therefore, the disapperance of very small m multiplicities. This increase is obviously linked with the continued increase of the meson and electron densities. For a given value of k, it is observed that the frequency of penetrating particles reaches a maximum m_f (m at its highest frequency) varying with k in accordance with the curve $m_f=f(k)$, as illustrated in Fig. 2. The curve Δ_p on Fig. 1 is calculated in accordance with the equation $(\Delta_p)_f=7.4\ln(M+1/M-m)$, which approximately defines the mean value of $(\Delta_p)_f$. It will be seen that the two curves Δ_e and Δ_p are more or less parallel. It is then ascertained that the value $R_f=(\Delta_p)_f/\Delta_e$ is constant and equal to 0.015 from the point at which $k=20$, $m_f=2$, up till the highest values of k and m_f.

The same figure shows the histograms of the penetrating events where m is constant and k variable, which are obtained where $m=0$, 1 and 4 and the average of the cases in which $m=2$ and 3. These distributions may be represented by a coherent network of regular curves, the interval between which increases as k augments and m diminishes, so that it is between the curves $m=1$ and $m=0$ that the largest interval should exist.

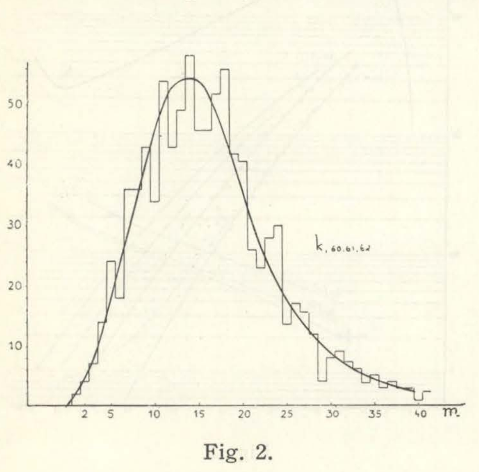

Fig. 2.

We shall describe this important question of spacing which allows extrapolation in a realm where statistics are few and also the detection of the abnormal frequency in the cases where $m=0$ by comparison.

The ratios of the numbers of penetrating events can be calculated if the spectrum of the penetrant component $f(\Delta_p, k)$ or $f(x, k)$ imposed by the device for detecting the electronic component is known. As an example, Fig. 2 shows a histogram of the frequencies $f(m)$ by combining the values where $k=60$, 61 or 62, in order to improve the statistics at the price of a larger width (the regular curve corrects the maximum dispersal slightly). This histogram is obviously due to a spectrum of the penetrating particles $f(x, k)$, passing through a maximum value for x_f.* If we know the spectrum $f(x)$, we should be able to calculate the ratios between the number of penetrating events of the consecutive multiplicities in accordance with the equation:

$$\frac{N_{m+1}}{N_m}=\frac{\binom{M}{m+1}\int_0^\infty(1-e^{-x})^{m+1}\cdot e^{-(M-m-1)x}f(x)dx}{\binom{M}{m}\int_0^\infty(1-e^{-x})^{m}\cdot e^{-(M-m)x}f(x)dx} \tag{1}$$

By the systematic use of the relation $x=\ln\{(M+1)/(M-m)\}$ to convert $f(m)$ into a density spectrum $f(x)$ through altering the variable, we can trace the curve corresponding to this spectrum. At the same time, we shall be sure of magnifying the lowest values of x, something which is fairly important, as we shall show. If we want to reconstitute

* The problem of the spectrum of penetrating particles is treated in this paper in a purely formal way. We are concerned merely with finding the simplest possible analytical expression to depict conveniently the ratios between the different multiplicities m. This function is devoid of any physical meaning. However, we are in the process of studying the physical significance of a "true" meson spectrum. The subject is linked only indirectly with the question of photon EAS, but it is nevertheless important with regard on the one hand to the dependency between the meson density and the size of an EAS (which is certainly not linear) and on the other with the radial (spatial) structure of the penetrating component of the EAS. It will be possible to develop the subjects mentioned by making use of the statistical material collected during our registration experiments. We intend dealing with it later in a separate paper.

the total histogram of the frequencies N_m, we would be obliged to find a form very close to the reality of the complete shape of the spectrum $f(x)$ for every value of k. But as we are interested only in weak multiplicities (*e.g.*, where m varies between 0 and 4), we are not forced to know the overall form of the spectrum, and it is sufficient to find a simple analytical function coming near to the initial part thereof. It can even be shown that, in calculating weak multiplicities, it is unnecessary to bear in mind the position of the maximum point of the spectrum proposed, as it is solely its left-hand slope (the front of the spectrum) which is decisive.

Various analytical functions have been adapted for the calculation of the ratios N_{m+1}/N_m through integration with small values of m, by studying more particularly the preponderant influence of the low-density tail and also that of a possible inferior density limit x_0 (by integrating from x_0 to infinity). The result is that the ratios calculated vary little as long as x descends towards zero regularly. We stress this because we have tried to apply several expressions, even without a maximum, where the spectrum goes to infinity and is cut only by the term of anticoincidence. The ratios of the combination terms $\binom{M}{m}$ being respectively 56, 27.5, 18, 13.5 where $m=0$, 1, 2, 3, 4, their role is extremely important and decisively determines a discontinued distribution of the multiplicities N_m. On the other hand, the ratios of the integrals rise only by 10–15% when m gains one unit.

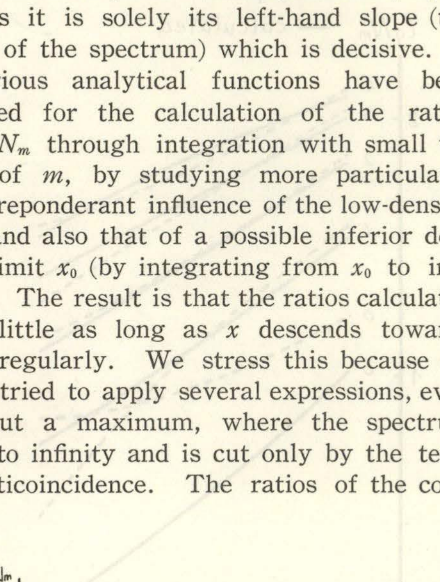

Fig. 3.

All these considerations apply equally well where a spectrum of penetrating particles is imposed not by a differential band of electron densities, *e.g.*, where $k \geq 60$. The example is given in Fig. 3 which depicts the histogram of N_m frequencies where $k \geq 60$. A study of the front of the integral spectrum has certain advantages principally because of the possibility of working with far more statistics and of applying the method of area variations described below.

We have then chosen an expression of the $\Delta_p{}^n e^{-\alpha\Delta p}$ type and we are convinced that this type of spectrum certainly overestimates the low densities. In other words, it is preservative, giving an excess of low densities, which is expressed by a surplus of weak multiplicities and, more particularly, of zeros. This fact puts us in a situation where we have a large safety margin in so far as the problem which we are studying is concerned.

It is possible to carry out a more detailed analysis of the registration of the weak multiplicities m and so to derive important additional information with regard to the slope at the front of the spectrum. For this purpose we divide the effective area of the meson detector into several sections, *e.g.*, seven. We then continue so as to obtain experimental results corresponding to a given multiplicity m=cts, but belonging to the growing number S of sections; in other words, we read the change of frequency of a selected and fixed multiplicity when the area of the detector increases. In this way it is possible to draw up a frequnecy table $N_{m,S}$ which corresponds to the different values of m and S (*e.g.*, where S varies from 4 to 7 and m from 0 to 4). In considering the weak multiplicities m, we are far from the maximum of the spectrum and decreasing values $N_{m,S}$ are observed when S increases and m=cts, because part of these cases are changed into the multiplicities $m+1$, $m+2$, etc. The contribution of m derived from the cases $m-1$, $m-2$, etc. (when S increases) is smaller than the loss referred to and is nothing where $m=0$! Thus the consecutive disappearance of the weak multiplicities may be expected, in the order $m=0$, $m=1$, etc. This method extends the previously performed analysis of the multiplicities observed over the total area of the detector. The area increase in the case of constant multiplicity corresponds in a way to the decline in multiplicity where the area is constant, but on the one hand the procedure is not carried out by such sudden jumps and on the other (and this is most important), we arrive at an analysis of the curve shape of the "zeros", which is impossible otherwise. It is then possible to determine very sensitively the slope of the beginning of the spectrum. The change in the frequencies $N_{m,S}$ is represeuted by expressions similar to (1). For given values of S and m there are (every section contains 8 hodoscopic elements):

$$A\binom{8S}{m}\int_0^\infty (1-e^{-x})^m \cdot e^{-(8S-m)x} \cdot f(x)dx\,, \quad (2)$$

where A is a normalisation constant such, for example, as the sum of the integrals considered (for m varying from 0 to 4, S from 4 to 7 there are 20 integrals), which must be equal to the sum of the experimental registrations of the corresponding cases. The choice of the parmeters n and α (of the function $\Delta_p{}^n e^{-\alpha\Delta p}$) should satisfy as well as possible the condition of this normalisation. By carrying out several trials on an integral electronic band where $k\geq 60$, we obtained values of $n=5$ and $\alpha=3.8$. The Table I represent (a) experimental values* and (b) calculated values. It will be seen that the values in (a) agree with those in (b) except where $m=0$. On the graphs (Fig. 4) it will be noticed that the calculated curves (continuous) and the experimental curves (dotted) are superimposed and form a coherent network, while the experimental curve where $m=0$ deviates appreciably from the corresponding calculated curve. This anomaly may derive only from a subsistant background of zeros. On subtracting at every point a value equal to 6 or 7, we pass from the real to the expect-

Table I. k≥60 a. Experimental

m \ S	4	5	6	7
0	17 ±3.1	10.5±2.7	7.8±2.7	7±2.7
1	38.4±4.7	17.6±3.5	8.7±2.8	3±1.7
2	70.7±6.3	39.7±5.3	19.2±4.0	14±3.7
3	106.7±7.8	61.8±6.6	38.7±5.7	19±4.4
4	128.6±8.5	81.6±7.6	52.1±6.6	39±6.2

b. Calculated

m \ S	4	5	6	7
0	10.4	4.7	2.3	1.2
1	35.7	18.0	9.7	5.3
2	67.8	38.2	21.4	12.8
3	101.8	62.3	40.1	23.9
4	124.6	84.2	58.9	33.7

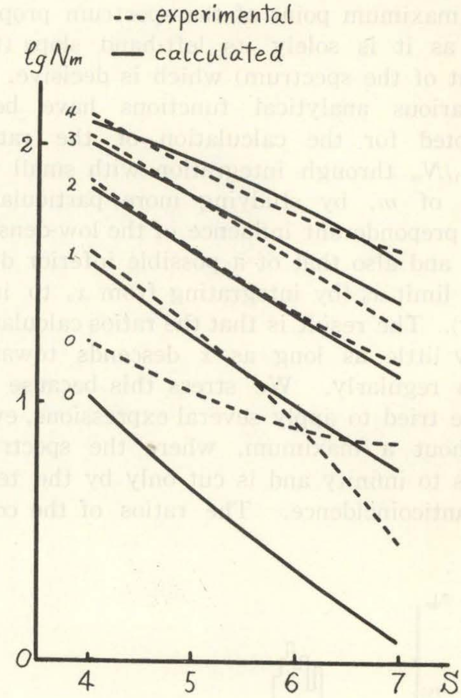

Fig. 4.

* Several readings of different combinations of the experimental values were taken. The values given in the table are the mean values. Statistical experimental errors are calculated by taking into account only independent readings (attention must be given to this because most of the readings are interdependent).

ed curve.*

A similar procedure can be used by employing a greater statistical series (than where $k \geq 60$), *e.g.*, where $k \geq 50$. The calculation of these results needs far more time but we have fairly reliable indications that the function best adapted for the cases where $k \geq 50$ is $\Delta_p^5 e^{-4.9\Delta p}$. The Table II represents the results observed and calculated. It will be seen that there is a surplus of 12 zeros which corresponds well with the surplus of from 6 to 7 zeros where $k \geq 60$ (the statistical series being roughly double).

Taking into account all these indications (supplying the values of the relationships N_{m+1}/N_m for high values of k), the extrapolation of the frequency curves $f(k)$ where m $=$cts, as indicated in Fig. 1, can be confirmed. Thus, in tracing the curve $m=0$ (a full curve), we estimate that it represents the frequency of normal cases. The real distribution of multiplicities other than zero are coherent and show no anomalies, but starting with $k=36$ the frequencies of zeros alone appears to deviate increasingly from the normal as

Table II

k>50

m	Experim.	Calcul.
0	25±5	13
1	52±7	52
2	105±10	97

k increases. For $k=36$ we count 172 normal zeros and 229±15 experimental zeros. This difference is 3.7 times standard deviation (or, according to Pearson's χ^2 test, a confidence coefficient of 0.0002). It will also be seen that where $k \geq 60$ there are more zeros than units (7 "0", 3 "1") and in spite of the small statistical series, this enables us to expect confidently an experimental curve of $m=0$ that will intersect the curve of $m=1$ at the point where $k \simeq 60$.

The dotted curve was obtained by adding to the curve considered as normal a fraction of zeros which was constant and equal to 3/1000 of the total frequency N_k. This seems to give a good explanation of the experimental deviation and indicates the probable existence of anomalous EAS at the rate of some thousandths, as would happen with a detectable trace of primary photons.

It will be seen that the effective area of the detector (7.6 m²) of the penetrating component is still too small to bring out clearly, as we had intended, the existence of a peak of zeros followed by a hollow in the integral histogram $f(m)$[1]. However, we consider these preliminary results most encouraging and are therefore continuing the experiment, using a detector with an effective area of 14.1 m² divided into 104 parts.

References

1) R. Maze and A. Zawadzki: Nuov. Cim. **17** (1960) 625.

* The normalisation constant A is calculated indeed after subtracting these values (4 times 6): the sum of experimental events is equal to 781, but the calculated one is 757.