OBSERVATION OF μ-MESON BURSTS IN A SET OF IONIZATION CHAMBERS

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Bursts due to high-energy ($E \gtrsim 10^{11}$ ev) μ mesons moving at a small angle to the horizontal plane were observed with the aid of a set of cubic ionization chambers. It is shown that with a set of ionization chambers similar to that described in the paper, but somewhat modified, it should be possible to study the angular distributions of high-energy μ mesons.

APPARATUS

THE apparatus was designed for the study of the cores of extensive atmospheric showers and contained two layers of ionization chambers (see references 1 and 2). The chambers were placed side by side and formed an area $2 \times 2\text{m}^2$. A vertical section through the apparatus is shown in Fig. 1.

Each layer consisted of 64 chambers of cubic shape. The chambers were connected to separate channels of amplification and pulse registration. The range of the registered pulses corresponded to the passage of from 5 to 4×10^4 relativistic particles through the chamber volume. The registration of the pulses took place whenever the total ionizing burst in all chambers exceed a value corresponding to 1000 relativistic particles.

Working together with the apparatus was a system of a large number of Geiger-Müller counters arranged in groups at various distances.

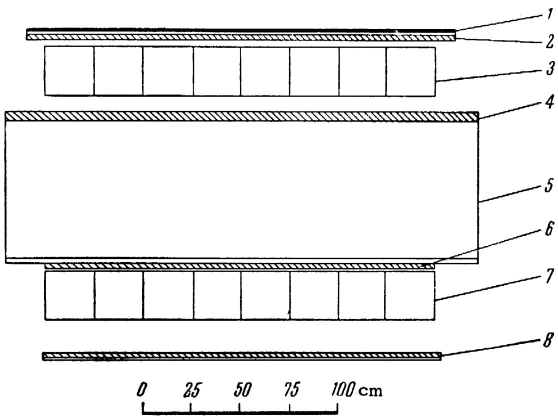

FIG. 1. Cross section of the apparatus: 1 – Al, thickness 0.3 cm; 2, 4, 6, 8 – Pb, thickness 2.5, 5, 2.5, 2 cm, respectively; 3, 7 – ionization chambers; 5 – graphite, thickness 73 cm.

RESULTS

A large part of the events registered by the apparatus was produced by air showers consisting both of electron–photon components and nuclear-active particles. The showers observed with the aid of the chambers were accompanied in most cases by the triggering of the counters located above the apparatus and around it. These cases have been analyzed previously.[1,2]

Among the registered events, however, there are cases similar to those shown in Fig. 2. The group of chambers with approximately the same size of bursts were located along a straight line forming an ionization distribution in the chambers that was "extended" in shape. The number of events of this type turned out to be the same for the upper and lower rows of the chamber. As a rule, such events are not accompanied by the triggering of the hodoscopic counters placed around the apparatus. The triggering of the counters (sometimes a few) was observed mainly when the shower intersected the upper row of ionization chambers. It is of interest that in this case the triggered counters were situated in a narrow strip in the direction of the extended distribution of the ionizing bursts. Evidently, the shower particles are scattered on the unshielded lead surface and enter the counters. The cases of the "extended" distribution of bursts in the chambers differ from the ordinary ones also in the fact that the passage of the particles is registered only in one of the layers during the total absence of bursts in the other, since the usual burst in one row of chambers, in a considerable part of the cases, is accompanied by bursts in the other row.

The character of the events do not allow them to be identified with air showers. Such events may be showers of relativistic particles generated in the lead over the chambers by single particles traveling at a small angle to the horizontal plane. Particles generating such showers cannot be nuclear-

		20	40	8000	22,000	450	90
		25	40	7000	20000	300	60
		25	140	5000	15000	150	30
		15	80	17000	5000	90	40
		15	60	10000	2000	50	20
			35	100	45	30	15
					15		

a

	25	400	15			25	40
10	70	700	40			20	100
30	200	30	25				160
60	400	70	20			30	100
90	250	40	15			60	40
200	150	30	15		15	100	30
200	30				15	20	20
150	20				20	30	15

b

FIG. 2. Examples of the distribution of ionization in the layer of ionization chambers in the cases of the registration of showers from oblique μ mesons; a represents the largest burst recorded by us; b is one of the two cases of registration of μ-meson double showers. The layout of a row of ionization chambers is shown; the numbers in the squares give the sizes of the burst in the given chamber (in numbers of relativistic particles).

active particles, since the intensity of the N component drops with an increase in the angle θ to the vertical as $\exp\{-\mu x(\sec\theta - 1)\}$, where for sea level $\mu x = 8$. For angles $\theta > 75°$ the intensity of the N component attains only the value $\sim 10^{-10}$ times the intensity along the vertical.

A quantitative analysis of the recorded events indicates that the observed bursts with an ionization distribution of "extended" shape may be explained as radiation showers from μ mesons. The analysis was made in the following way. We selected cases satisfying two conditions:

1. The ionization was concentrated only in one row of ionization chambers, and its total size corresponded to the passage of > 1000 relativistic particles.

2. There were four or more chambers, situated in a row along one line, in which ionization of comparable size was observed (no more than 1.5 times as great).

The number of relativistic particles in the shower was taken from the sum of the ionization produced in the chambers situated along a line perpendicular to the direction of propagation of the shower. The maximum sum from several measurements (along the shower) was taken. For each event the value of the total ionization was found in all chambers of a given row. It turned out that the number of cases selected in this way was 0.25 ± 0.03 per hour for each row of chambers (a total of 190 cases were recorded in both rows of chambers). In all cases, except one, the bursts in one row of chambers were not accompanied by bursts in the other row.

According to the data of Schein and Gill,[3] for a spherical chamber covered by 12 cm of lead, the number of μ-meson bursts caused by showers of 400 or more particles per cm² of chamber was $1.36 \times 10^{-6}\,\mathrm{cm}^{-2}\,\mathrm{min}^{-1}$.

The expected number of μ-meson showers in our arrangement can be roughly estimated, according to the data of Schein and Gill,[3] if it is assumed that the high-energy μ mesons have an isotropic distribution and that we recorded only μ meson bursts for which $\theta \geq 75°$ ($\tan\theta \gtrsim 4$), where θ is the angle between the trajectory of the meson and the vertical. It turned out that the experimental value was less than three times the calculated value. This should be regarded as satisfactory agreement if it is considered that there is a possibility of an appreciable increase in the number of particles in the shower as a result of the method we employed to determine it and also if one takes into account the large undefined effective area and effective solid angle for the cases we selected.

We note that, according to the estimate, the total number of μ-meson showers with a given number of particles passing through the apparatus is more than twenty times the measured value in the selected angular interval.

Shown in Fig. 3 is the integral spectrum of the observed showers obtained from the number of particles. Also shown there is the integral spectrum of these events under the condition that the number of particles in the shower was measured from the total ionization produced in all chambers.

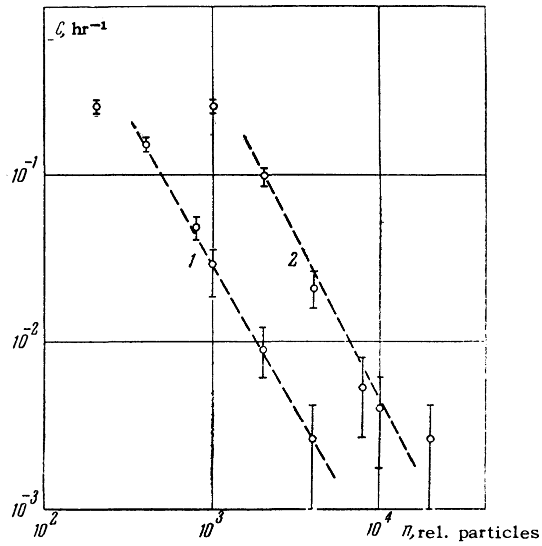

FIG. 3. Integral spectrum of the showers: 1 — from the number of relativistic particles in the shower; 2 — from the total ionization (in relativistic particles) in a row of ionization chambers. The number of showers recorded in one hour by one row of chambers is marked off on the axis of ordinates. The curves were constructed from the data obtained during 370 hours of operation of the apparatus.

The observed bursts should refer to μ mesons of energy of the order of 10^{11} ev and above. The results indicate that the number of bursts greater than a given size (n) decreases in accordance with a law of the n^{-2} type or somewhat more steeply.

It is seen from Fig. 3 that the number of showers of a given size measured from the total ionization produced by a shower in the entire layer of chambers is appreciably greater than the number of showers with the given number of particles. This results from the fact that a shower with n particles, in crossing the chambers at an angle θ to the vertical, produces in them a total burst corresponding to $n/\cos\theta$ particles, which, in the spectrum of bursts of the n^{-2} type, should cause the number of bursts to increase as $\cos^{-2}\theta$.

Curve 2 of Fig. 3 gives the number of bursts due only to μ mesons at an angle of inclination $\theta \geq 75°$. The total number of particles due to μ mesons from all directions should be several times greater. This should be borne in mind when an apparatus with large plane systems of chambers is used to determine the direction of the particle stream. At sea level the oblique μ-meson showers in such systems resemble the arrival of a "young" atmospheric shower[4] or nuclear-active particles of high energy.

Besides the described bursts in the form of single showers there were recorded, during a period of 370 hr of operation, two cases in which two, almost parallel showers were observed simultaneously. Since the probability for the formation of a radiation shower is very small ($\sim 10^{-3}$), the simultaneous observation of two showers suggests that the passage of two high-energy mesons at a small distance from one another is not a rare event.

The results obtained indicate that by means of the system of ionization chambers it is possible not only to measure the size of the showers produced by μ mesons, but also to find the direction of these showers. High-energy μ-meson showers arise primarily from bremsstrahlung photons. In the selection of showers of a given energy the effective energy of the μ meson proved to be very close to the energy of a bremsstrahlung photon whose direction of travel almost coincides with the direction of the μ meson. Therefore, the use of the system of ionization chambers, which allows a good determination of the direction and energy of the μ meson showers, makes it possible to obtain the angular distribution of μ mesons of different energies ($E > 10^{11}$ ev). It is necessary here to place the apparatus under a layer of ground sufficient to absorb the nuclear-active particles (5 — 8 m water equivalent).

The investigation of the angular distribution of showers produced by μ mesons of different energies may give important information as regards the mechanism of the μ-meson generation.[5] The investigation of events involving the simultaneous passage of high-energy μ mesons is also of great interest.

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