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AN EMULSION CHAMBER FOR THE INVESTIGATION OF THE VERY HIGH ENERGY PARTICLES INTERACTIONS

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I

The emulsion chamber method has become recently one of the modern methods in the investigation of the secondary particles produced in the interactions of very high energy primary particles with the nuclei of some different matter placed in the way of those particles. An emulsion chamber consists of thin emulsion layers (of the thickness of 30—100 μ) placed horizontally one above another and separated by lead layers of the thickness of .5—2 cm (1—4 c. u.).

The energy of a cascade can be accurately estimated by means of cascade curves of Nishimura [1], [2], [3].

Having found these and bearing in mind that the energy of the cascade is equal to the energy of the photon by which the given cascade was initiated, one gets the photon energy and at the same time that of the Π^0 meson.

Charged particles produced in the interactions (mostly pions) are passing through the chamber and their tracks are observed in the emulsion plates. Nevertheless — due to the small number of these tracks as well as to their small length (the emulsion plates are very thin) — it is impossible to distinguish them from the background. If the thickness of the chamber is comparable with the mean free path for an interaction in lead (160 g/cm² = 14 cm Pb) the electron-photon cascades initiated by the neutral pions coming from the secondary interactions of the charged particles, can still be observed in the lower layers of the chamber.

Probability for the detection of all charged particles in such a way depends on the thickness of the chamber and obviously increases with it.

In this way using the thin chamber (6 cm of lead) the target diagrams can be obtained and the energy of the neutral pions produced in the primary interaction can be exactly estimated. In addition to that target diagrams and the approximate energies of the charged particles can be found in the case of the thick chamber (20 cm of Pb).

Knowing the place of the primary interaction (which in most cases appears to be possible), the angular distribution of the produced particles can be found.

The angular and energy distributions of the secondary particles produced in a given interaction provide the necessary information for almost full description of an elementary act of interaction (the exact value of the energy of the primary particle remains unknown).

II

A thin emulsion chamber for the investigation of the N-N type of the interactions was designed (Fig. 1).

A graphite absorber was placed above the chamber and it served as a target for the incident „primary" particles. The sidecut of the apparatus is presented in Fig. 1a. The area of the horizontal emulsion layer is equal to 2.1 m². The chamber consists of 90 elements, each of the area of 130 × 180 cm. A considerably magnified area is shown in Fig. 1b. As it is seen, it contains 6 emulsion plates, each wrapped in a black paper and placed inside a polyethylene bag in order to maintain constant humidity of the emulsion.

A photon entering the chamber initiates an electron-photon cascade in the first lead layer. This cascade develops in the further lead layers reaching the maximum even in the case of a very energetic cascade (of the order 10^{12} eV) [4].

Owing to the 6 separated emulsion layers one is able to find the number of the electrons at six different depth levels in the chamber; this provides 6 different points on the cascade curve and ensures high accuracy in the estimation of the cascade and the photon energy.

The thickness of the lead absorber was suitably chosen so as to ensure that the above mentioned points should determine the right shape of the cascade curve and reach the maximum of its development for the energy of 10^{12} eV.

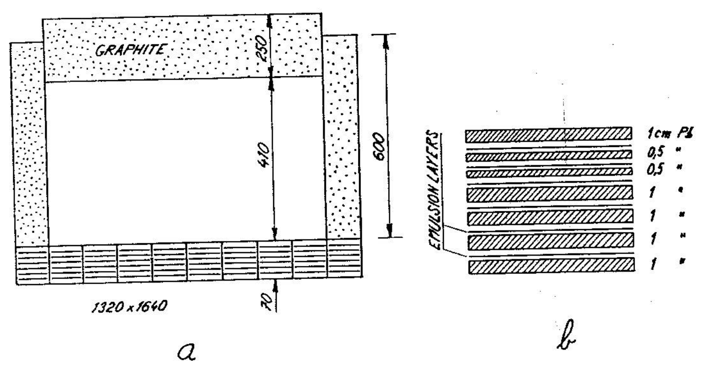

Fig. 1.

The total thickness of the lead absorber is equal to 5 cm. For the photons coming into the chamber vertically this represents about 10 c. u.

Above the emulsion chamber (in this case a photon detector) the graphite absorber was placed. This absorber becomes a source of the nuclear interactions. Its thickness was $.5\ \lambda_i$ (the mean free path for nuclear interaction in the graphite is equal to $\lambda_i = 80$ g/cm^2).

Consequently, the probability of an interaction in the absorbent of the thickness $x = .5\ \lambda_i$ is equal to

$$p_1 = xe^{-x} = .303$$

and the probability of the observation of more than one interaction can be expressed as follows:

$$p_{>1} = 1 - e^{-x} - xe^{-x} = .09.$$

In this way about 30 % of all the incident nuclear particles initiate only one interaction and 9 % initiate more than one interaction in the graphite absorber. The multiple interactions are not the wanted ones because they spoil the picture of the primary collision due to the mixing of particles coming from the different interactions. In our case the efficiency of the graphite absorber was of the order of 30.

The graphite absorber was placed about 40 cm above the detector (the emulsion chamber) in order to ensure sufficient separation in space between the photons coming from the decay of Π° meson generated in graphite. This is necessary if one wants to distinguish between two cascades initiated by these photons. The minimum value of the angle between two photons (in the case of their sharing equally the energy between them) can be found from the equation

$$\Theta = \frac{2m_{\pi^\circ}C^2}{\Sigma_{\pi^\circ}}.$$

As we have found in our experiment one can expect the maximum value of the Π° meson energy of the order $E_{\pi^\circ} = 4.10^{12}$ eV [5]. Then the minimum distance between the axes of the two cascades is (Fig. 2)

$$d \geqslant \frac{2hm_{\pi^\circ}C^2}{E_{\pi^\circ}} \approx 30\mu.$$

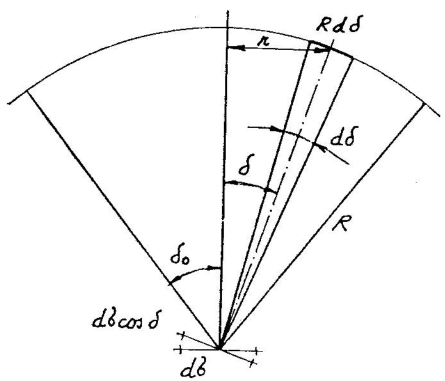

Fig. 2.

It is evident that this value of d represents really the minimum distance necessary for the proper distinction.

III

As mentioned in the introduction a threshold in the cascade energy for the detection by means of the emulsion chamber is of the order of 10^{11} eV. If one wants to detect all the Π° mesons through the observation of the electron-photon cascades (assuming the mean value of the inelasticity coefficient for Π° mesons to be equal to .1) the total inelasticity coefficient of ($k = .3$) the primary interacting particle must have the energy of the order $E \geqslant 7.10^{13}$ eV. For the estimation of the number of interesting interactions it is necessary to know the intensity of the nuclear component of cosmic radiation at the level of the chamber exposition.

Using the optimal data determined by the satellite experiments in the upper strata of our atmosphere the intensity of the protons with an energy above 10^{13} eV is equal to

$$J_0 \approx 2.10^{-2} \frac{1}{\text{m}^2\text{sec sterad}}.$$

In our case the expected threshold energy is of the order of 7.10^{13} eV.

Thus, assuming the exponent of the integral energy distribution for the protons to be equal to $\gamma = 2$, one gets for the intensity of the protons with an energy above 7.10^{13} eV in the upper strata of the atmosphere the value

$$I_1 = 4.10^{-4} \frac{1}{\text{m}^2 \text{ sec sterad}}.$$

At the altitude of 760 g/cm^2 (Lomnický štít 2640 m above sea level) one gets for the vertical intensity of protons with an energy above 7.10^{13} eV the following equation (assuming the attenuation length for protons in air is equal to 125 g/cm^2):

$$I_L(0) = I_1 . e^{-\frac{760}{125}} = 10^{-6} \frac{1}{\text{m}^2 \text{ sec sterad}}. \qquad (1)$$

The intensity of protons for which the line of flight forms an angle ϑ with the vertical direction can be represented by the following equation for the same altitude as before:

$$I_L(\vartheta)\ \text{d}\vartheta = I_L(0) \cos^7\vartheta\ \text{d}\vartheta. \qquad (2)$$

The number of protons impinging on an element area $d\sigma$ at an angle $(\vartheta, \vartheta + d\vartheta)$ per sec is equal to (Fig. 3):

$$dn(\vartheta) = I_L(\vartheta)\, d\sigma \cos\vartheta\, d\vartheta,$$

$$dn(\vartheta) = I_L(\vartheta)\, d\sigma \cos\vartheta \frac{2\pi r R\, d\vartheta}{R^2},$$

$$dn(\vartheta) = 2\pi I_L(\vartheta) \sin\vartheta \cos\vartheta\, d\sigma\, d\vartheta.$$

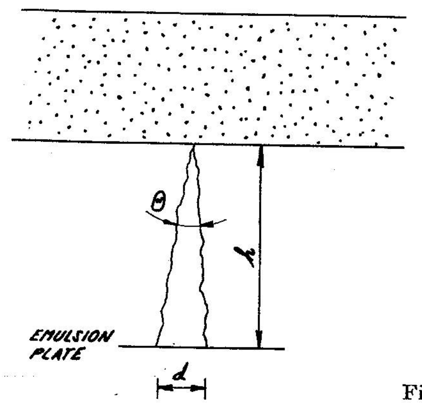

Fig. 3.

For the finite area F one has to integrate the above equation in order to get the total number of protons intersecting it. Thus:

$$dN(\vartheta) = \int_F 2\pi\, I_L(\vartheta) \sin\vartheta \cos\vartheta\, d\,\sigma\, d\vartheta,$$

$$dN(\vartheta) = 2\pi\, F I_L(\vartheta) \sin\vartheta \cos\vartheta\, d\,\vartheta.$$

If the maximum angle for which we can still detect protons is equal to ϑ_0 then the total number of protons passing through our apparatus in 1 sec with the condition $\vartheta \leqslant \vartheta_0$ can be evaluated by means of the formula

$$\int_0^{\vartheta_0} dN(\vartheta) = 2\pi F \int_0^{\vartheta_0} I_L(\vartheta) \sin\vartheta \cos\vartheta\, d\,\vartheta. \quad (3)$$

In our case for the maximum angle ϑ_0 the value of 30° has been accepted because any higher value makes an estimation of the cascade energy developing at this angle very difficult. From equations (3) and (2) one can obtain the total number of protons with an energy above 7.10^{13} eV each, coming into our apparatus in one sec, as equal to

$$N = 2\pi F I_L(0) \int_0^{30^\circ} \cos^8\vartheta \sin\vartheta\, d\vartheta = F I_L(0)\, .0{,}506 \text{ sterad}.$$

Thus, using our apparatus of the total detection area of 2.1 m^2 and a graphite generator with the efficiency of $\eta = .3$ during the period of four months we should observe the following number of the interactions with an energy above 7.10^{13} eV:

$$N = F\eta t I_L(0)\, .0.506 \text{ sterad} = 3.3.$$

IV

The above described emulsion chamber has been installed at the laboratory on the summit of Lomnický štít (2640 m). The chamber enclosed inside the wooden case has been placed on the roof of the laboratory building. The chamber filled with the Ilford G 5 emulsion plates of the size 5″ × 7″ and emulsion thickness 50 μ has been exposed in 1964 for four months.

The fourth row of the emulsion plates (placed inside the chamber under a 3 cm thick lead layer) was scanned under a microscope with the magnification of 120. Three data have been found. They represent the interactions of particles with an approximate energy above 10^{13} eV, which confirms our prediction. A detailed analysis of these interactions is being made. In 1965 the chamber has been exposed again, this time with the Soviet emulsion plates of the type R and the size of 13 × 18 cm.

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