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ELECTROMAGNETIC CASCADES PRODUCED BY GAMMA-QUANTA WITH THE ENERGY $E_\gamma = 100 - 3500$ MeV
V. FLUCTUATIONS

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1. INTRODUCTION

Fluctuations are characteristic feature of an electromagnetic cascade process (ECP or e.m.shower) as a stochastic process produced by high energy gamma-quanta (GQ) or electrons in dense enough media. A thorough knowledge of them is very important for reliable, to the necessary degree, measurement of energy of inducing ECP primary particles, especially when they are detected within limited volume of absorbent and/or at not too high energies (for example, up to some GeV). In the first place of principal interest are fluctuations of such parameters of e.m.showers which are used for determining the energy and position of hard GQ (or electrons). For this purpose it is not enough to know the fluctuations of the number of shower particles at a fixed depth along the shower axis (SA) only which have been well studied in literature /1-8/ or even the ones concerning the longitudinal energy distribution but obtained in a simplified way and so being of very limited application.

From practical point of view it turned out suitable, as firstly shown in /7/ and next papers /10, 11/ such quantities as a relative standard deviation (RSD) σ_A/A of the part A of ionization loss released within a certain volume of absorbent limited by some depth t_A measured from the conversion point of a primary GQ along the SA or by two mutually parallel planes each being parallel to the SA and separated by a distance p_A away from it. Moreover, these quantities as a function of A show interesting properties of approximate scaling and are useful when applied in various methods of registration of high energy GQ, particularly in xenon bubble chambers (XeBC) /12/. So do the similar shower parameters as $S_t/\bar{t}$ and $S_p/\bar{p}$ describing the longitudinal and lateral spread of e.m.showers respectively /11/.

All aforesaid quantities are analysed in this work using pictures of the 180 l XeBC of ITEP (Moscow) /13/. It is well known that because of relatively low value of radiation length (r.l.) of liquid xenon (1 r.l. ≅ 4 cm /15/) and good quality of image of electron trajectories this chamber is very fit for such investigation. On the whole 908 events of e.m. showers produced by GQ of energy E_γ = 100-3500 MeV and registered on the pictures which have been selected and analyzed /14/ are used to this end. As is described previously /14/, the ranges of shower electrons (SER) with the energy greater than 0.5-1.5 MeV within each square of $\Delta t \Delta p$ = 0.6x0.3 r.l.^{2} at the depth t and the width p were measured in the projection plane (PP) for all intervals of energy E_γ. In the work the maximum value of p is equal to 5 r.l. whereas the relevant value of t changes from 11 r.l. at $E_\gamma = 100 \pm 10$ MeV to 24 r.l. at $E_\gamma = 3375 \pm \pm 125$ MeV /14/. The SER are determined, on the average, to within the accuracy of about 20%. Note at last that plane SER are approximately proportional to the relevant ionization loss, at least within the central shower region in which more than 90% of the total cascade energy is deposited /16/.

2. LONGITUDINAL FLUCTUATIONS

Figure 1 shows the longitudinal distribution of the RSD $\sigma_{A(\bar{t}_A)}/A$ plotted with steps of A = 0.1 for 6 among 22 intervals of energy E_γ analysed in the work. Here $\sigma_{A(\bar{t}_A)}$ means the sample standard deviation of the part A of ionization loss of shower electrons deposited, on the average, within an absorbent layer of thickness t_A along the SA, so that for a given value of E_γ we have

$$A(\bar{t}_A) = \frac{1}{E_\gamma} \int_0^{\bar{t}_A} f(E_\gamma, t) \cdot dt, \qquad (1)$$

where $f(E_\gamma, t)$ is the longitudinal profile of average ionization loss /17/. One can observe that the behaviour of

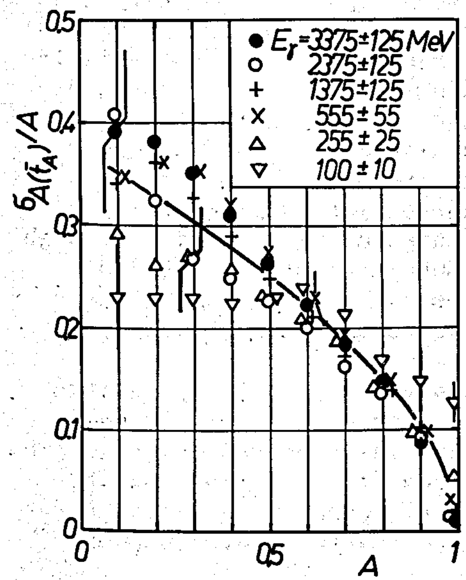

Fig.1. Coefficients of variation $\sigma_{A(\bar{t}_A)}/A$ of the part A of the shower electron ionization loss released within a liquid xenon layer of thickness $\bar{t}_A$ (measured along the shower axis) at which, on the average, some fixed part $A(\bar{t}_A)$ of this loss is deposited. Experimental data at $E_\gamma \geq 555$ MeV are fitted to the function (2) shown as the solid line.

$\sigma_{A(\bar{t}_A)}/A$ as a function of A is independent of E_γ, within statistical errors, at $E_\gamma \geq 500$ MeV. It can be simply parametrized as follows:

$$\sigma_{A(\bar{t}_A)}/A = \sqrt{a^2 + \beta(\gamma - A)} - a. \qquad (2)$$

Here $a = 0.038 \pm 0.001$, $\beta = 0.166 \pm 0.005$ and $a = 1.01 \pm 0.01$. The solid curve in fig.1 displays this parametrization.

3. LATERAL FLUCTUATIONS

Lateral fluctuations are defined as a sample standard deviation $\sigma_{A(\bar{p}_A)}$ about the sample mean $\bar{p}_A$ measured on the PP when the distance p_A from the SA is taken to be always positive, independently whether it is to the left or right side of the SA. As has been pointed out earlier between two mutually parallel planes each being as well parallel to the SA and separated from it by a distance p_A the part A of the total ionization loss of shower electrons is deposited. All aforesaid

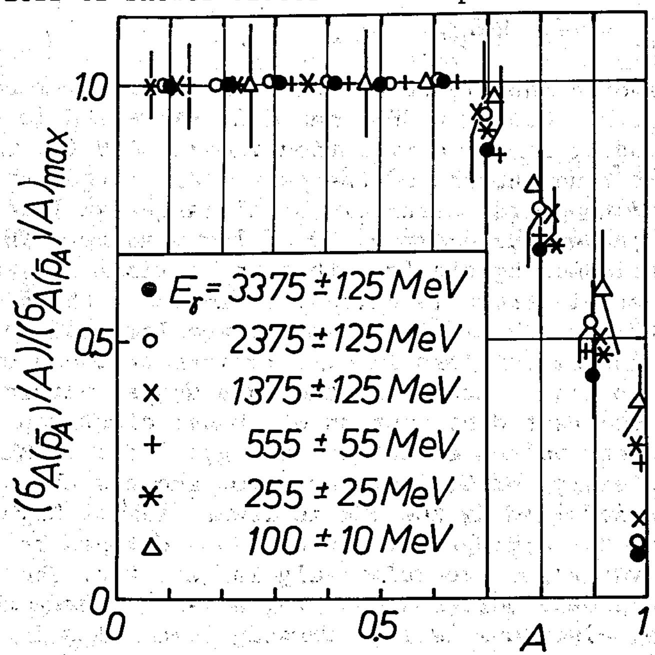

Fig.2. Same as fig.1, for lateral shower development normalized to maximum values of relevant coefficients of variation. $\bar{p}_A$ is the distance between two parallel planes one of which is drawn through the SA so that within them, on the average, the part A of the total shower electron ionization loss is deposited.

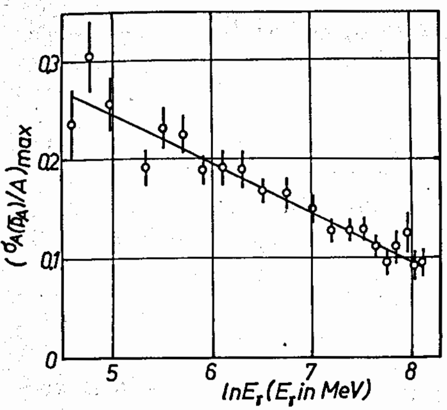

Fig.3. Maximum value of the coefficient of variation $(\sigma_{A(\bar{p}_A)}/A)_{max}$ for lateral e.m. shower spread as a function of primary GQ energy E_γ.

concerns a given individual shower event whereas $\bar{p}_A$ refers to the sample mean at a fixed interval of primary GQ energy E_γ.

In fig.2 the coefficients of variation $\sigma_{A(\bar{p}_A)}/A$ normalized to their maximum values $(\sigma_{A(\bar{p}_A)}/A)_{max}$ are displayed as a function of A for the same as in fig.1 six values of energy E_γ. Fig.3 shows the energy dependence of the maximum coefficient of variation. This dependence may be depicted by the following linear function of $\ln E_\gamma$

$$(\sigma_{A(\bar{p}_A)}/A)_{max} = a + b \cdot \ln E_\gamma , \qquad (3)$$

which is drawn in the figure as the straight line. Here a = = 0.48 ± 0.02, b = 0.048 ± 0.003 when E_γ is expressed in MeV and the corresponding linear correlation index r ≅ 0.95. One can perceive that fluctuations of the part A are larger at lower energy E_γ and they are relatively still larger at lateral edges of e.m. showers produced by GQ of lower energy. This can be easily explained by the fact that the visible ionization loss of shower electrons is closely connected with the number of these electrons. Thus, for example, the longitudinal distribution of ionization loss in e.m. showers produced by 1600 MeV GQ in liquid xenon has the same shape, within the error, as the relevant distribution of shower electrons numbers at two different values of cut-off energy: 3 and 33 MeV /18/. So, at lower energy of GQ inducing e.m. showers, the number of electrons involved in the ECP is lower than at higher energy. Therefore the appropriate fluctuations defined as the coefficients of variation are relatively larger, too. The same concerns the shower peripheries, i.e. at A ≅ 1 where the number of shower electrons is considerably lower than in the centre.

Figure 4 presents the dependence on E_γ of the coefficients of variation $S_p/\bar{p}$ and $S_t/\bar{t}$ about the sample mean of the lateral ($\bar{p}$) and longitudinal ($\bar{t}$) shower dimensions, it being borne

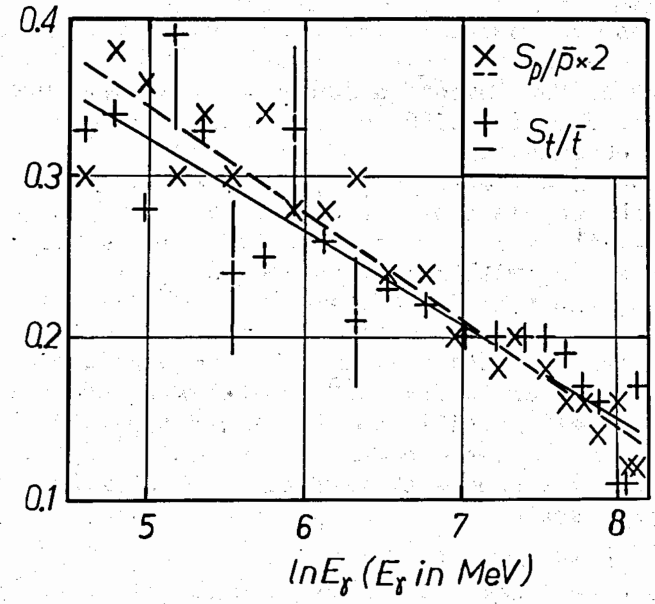

Fig.4. Energy dependence of the coefficients of variation in longitudinal ($S_t/\bar{t}$) and plane lateral ($S_t/\bar{p}$) spread of e.m. showers about their relevant average values: $\bar{t}$ and $\bar{p}$. Experimental data are fitted to functions (4) displayed by straight lines.

in mind that $\bar{p}$ is an estimator of the average distance from the SA. It is clearly seen that both the coefficients rapidly decrease with E_γ increasing and that, on the average, $S_p/\bar{p} \simeq \frac{1}{2} S_t/\bar{t}$ within all energy interval cosidered. The energy dependence of the coefficients was fitted to the linear functions of $\ln E_\gamma$ as follows:

$$S_t/\bar{t} = 0.61 - 5.77\cdot 10^{-2} \ln E_\gamma ,$$
$$r = 0.90, \qquad (4)$$
$$S_p/\bar{p} = 3.38 - 3.33\cdot 10^{-2} \ln E_\gamma ,$$
$$r = 0.95,$$

where r denotes the correlation coefficient, E_γ in MeV. The relative dependence is shown in fig.4 as straight lines: the solid line corresponds to the longitudinal dimension and the dashed one concerns the lateral spread of e.m. showers.

IV. CONCLUSIONS

As a result of the investigation of e.m. showers produced by GQ of energy E_γ = 100-3500 MeV in liquid xenon one can draw the following conclusions:

1. The standard deviation $\sigma_{A(\bar{t}_A)}$ of the part A of ionization loss of shower electrons at various depths $\bar{t}_A$ at which, on the average, the part A of this energy loss is deposited, may be simply scaled with regard to the energy E_γ as a function of A using the relation (2) at $E_\gamma \geq 500$ MeV. At lower energy this dependence is somewhat different (fig.1).

2. The standard deviation $\sigma_{A(\bar{p}_A)}$ of the part A of shower energy deposited as an ionization loss between two parallel planes being as well parallel to the SA and separated a distance $\bar{p}_A$ from it may be represented as a function of A in the form approximately scaled with respect to E_γ (fig.2) when the factor of energy scale $(\sigma_{A(\bar{p}_A)}/A)_{max}$ is a linear function of $\ln E_\gamma$ (2), as demonstrated in fig.3.

3. The relative spread of the average longitudinal $S_t/\bar{t}$ and lateral $S_p/\bar{p}$ shower dimensions as defined in the text falls with increasing primary GQ energy. This dependence may be fitted reliably enough to the linear functions of $\ln E_\gamma$ (3). In all investigated energy region $S_p/\bar{p} \cong \frac{1}{2} S_t/\bar{t}$, i.e. the relative longitudinal fluctuations of ionization loss in e.m.showers are nearly twice as large as the lateral ones.

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