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ELECTROMAGNETIC CASCADES PRODUCED BY GAMMA-QUANTA WITH THE ENERGY E_γ = 100-3500 MeV
3. LATERAL DEVELOPMENT

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1. Introduction

The great practical importance of the knowledge of the lateral (or transversal) spread of an electromagnetic cascade process (ECP or e.m. shower) produced by high energy gamma quanta (GQ) in dense enough media can be easily appreciated, for instance, by simple inspection of fig.1 where two e.m. showers arising from the decay of π^0 meson of about 3 GeV energy are recorded on a picture of the 180 l xenon bubble chamber (XeBC) of ITEP (Moscow). As has been pointed out earlier [1] this chamber with its large dimensions 25.7x11x10 in units of radiation length (RL) is perhaps the unique one which enables it to obtain detailed and various experimental information about e.m. showers up to some GeV of primary GQ energy.

One can see on the picture (fig.1) that two neighbouring cascades would be erroneously taken as a single one if an angle between their shower axes (SA) is sufficiently small as is often the case at high energies. The problem of the GQ detection becomes even more complicated when the process of multiple production of π^0 (or/and η^0) mesons or other particles

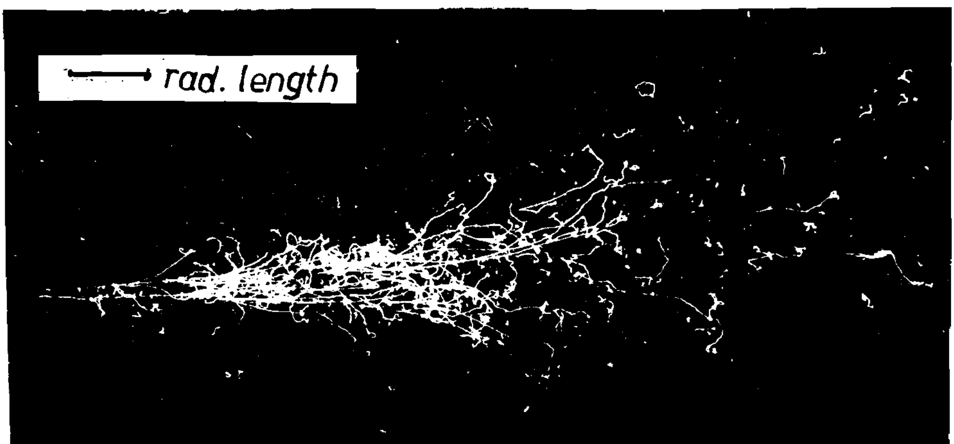

Fig.1. Two neighbouring e.m. showers initiated by gamma quanta, each having of about 1.7 GeV energy, from the decay of a π^0 meson produced in π^-Xe interaction at 3.5 GeV/c (180 l xenon bubble chamber of ITEP, Moscow).

being a source of hard photons is to be investigated as well as direct production of high energy GQ is analysed. Nevertheless, in contrast with the problem of the longitudinal development of a shower which is well studied in literature the knowledge of the lateral spread of the ECP is so far rather scarce because the relevant experiments are much more difficult. Now one can believe to be shown [2] that the distribution of shower energy in transverse direction (or profile) is independent of the absorbent when expressed in Moliere units $R_M = 21$ MeV Xo/Eo, where Xo is the value of the RL and Eo is the critical energy. The lateral profile is sometimes described by a single/double slope exponential decay [3].

In this paper the investigation of the transverse development of e.m. showers created by GQ with energies of 100-3500 MeV in liquid xenon was carried out using 220 thousand pictures of the 180 l XeBC of ITEP (Moscow) exposed to the beam of π^- mesons at 3.5 GeV/c. From among 1657 shower events selected during the scanning, 908 only fulfilling the condition of minimum risk to be cut off by the chamber [1,4] have been used for further analysis and grouped into 22 bins of primary GQ energy E_γ. The number of events in a bin varied from 11 to 86 [1].

For each selected event the summary projection ranges of shower electrons (SER), $\Delta\Sigma r_e(t,p|E_\gamma)$ in a picture plane were measured using grid with the dimensions of the elementary square $\Delta t = 0.6$ RL along the SA (which is in the picture plane, according to the selection criteria) and $\Delta p = 0.3$ RL in its transversal direction. Minimum value of electron range to be discerned reliably enough on a picture corresponds to their cut off energy of 0.5-1.5 MeV. As has been shown by means of the computer modeling [5] the SER are proportional, on the average, to the relevant ionization loss of shower electrons $f(p|E_\gamma,t) \equiv \Delta\Sigma E(E_\gamma,t,p)/\Delta t\Delta p$ within about 3%. Other details of the method used in the work are described in [1] and references quoted herein.

2. Plane Lateral Distribution

Figure 2 presents, as an example, one among 22 bins obtained in the lateral distribution of average electron ionization loss measured on the picture plane in step of 1.2 RL along the SA for e.m. showers produced in liquid xenon by GQ with the energy $E_\gamma = 1125 \pm 125$ MeV. Experimental data are fitted for all bins of energy by common least-squares techniques to the simplest exponential function, i.e.

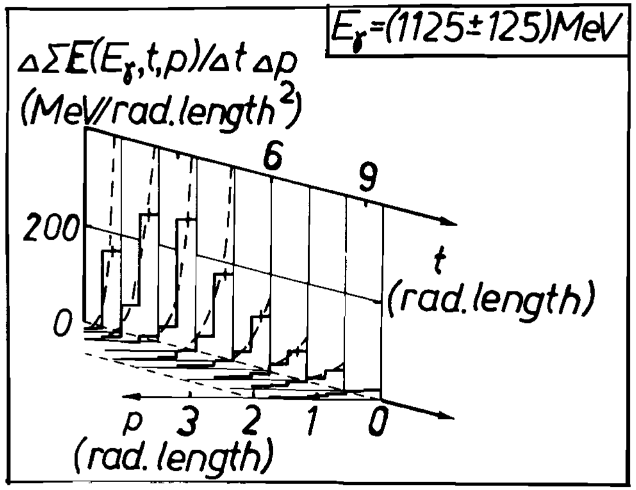

Fig.2. Plane lateral distribution of the ionization loss of electrons in e.m. showers produced in liquid xenon by gamma quanta of $E_\gamma = 1125 \pm 125$ MeV energy (t is the shower depth measured in step of 0.6 rad. length along the shower axis from the conversion point of a primary photon). The best fit to the form (1) is superimposed (dashed lines).

$$\frac{\Delta\Sigma E(E_\gamma,t,p)}{\Delta t\,\Delta p} = A_1 \exp(-p/A_2), \qquad (1)$$

where $A_2 = A_2(t|E_\gamma)$ is the free parameter depending on the shower depth t at a given value of E_γ. The fitted values of the parameter A_2 are shown in figs.3a-3c for all 22 intervals of primary photon energy.

One can see that displayed points are markedly collimated along some straight line, at least at lower values of t. Therefore, it is reasonable to approximate the t dependence of A_2 to the linear function as

$$A_2 = \alpha + \beta t, \qquad (2)$$

where α and β are free parameters.

But when the shower depth t increases the spread of A_2 values increases too, mainly because of relative low statistics of event available. That's why the parameters α and β have been evaluated for two intervals of t: 0-6 RL, 0-12 RL and for all values of t. Figs.4 and 5 present the relevant results as a function of $\ln E_\gamma$, respectively. From the observation of these figures conclusion arises that within the er-

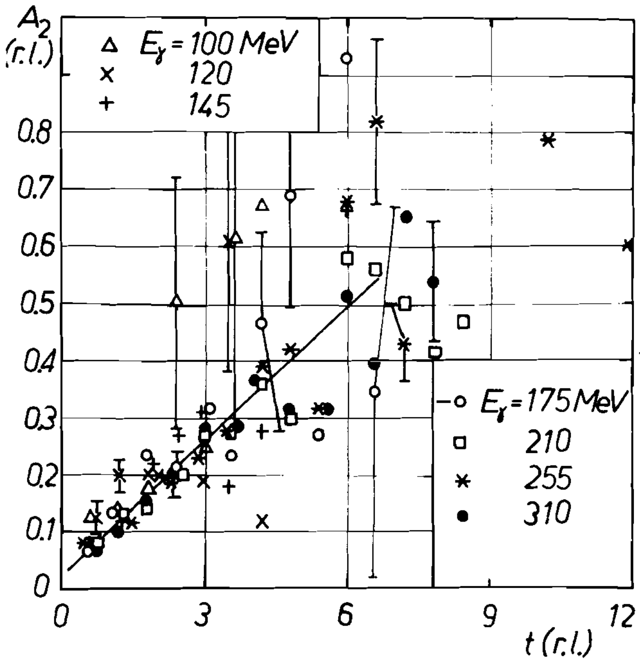

Fig.3a. Dependence on t of the slope parameter A_2 of the function (1) within the interval of the primary photon energy E_γ = = 100-310 MeV.

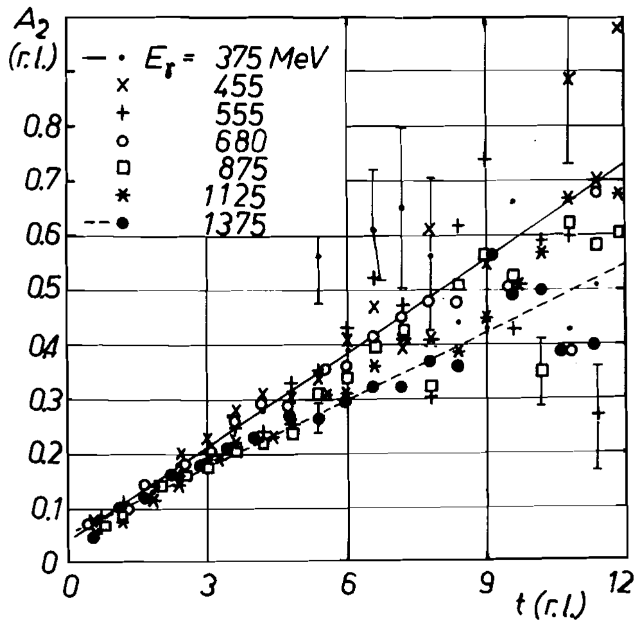

Fig.3b. Same as fig.3a, for a primary photon energy of 373-1375 MeV.

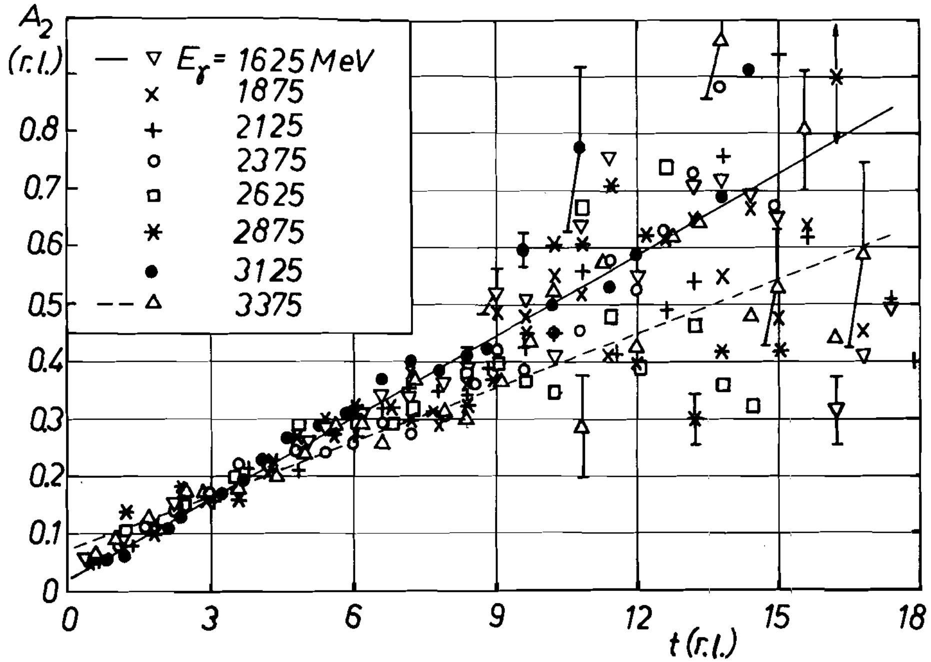

Fig.3c. Same as fig.3a, for a primary photon energy of 1625-3375 MeV.

rors achieved in the work the parameter α does not depend on LnE_γ and is equal to 0.042 ± 0.015 RL whereas the $\ln E_\gamma$ dependence of β is a linear one at least at $E_\gamma \geq 175$ MeV. So, we have

$$\beta = a + b \ln E_\gamma , \tag{3}$$

where the fitted values of the parameters a and b are given in the table for three ranges of t.

Table

Fitted values of parameters a and b corresponding to the three ranges of t at $E_\gamma \geqq 175$ MeV (both the parameters are dimensionless)

t(RL)	a	-b
0-6	0.067±0.004	0.0053±0.0005
0-12	0.072±0.003	0.0062±0.0004
all	0.075±0.003	0.0066±0.0004

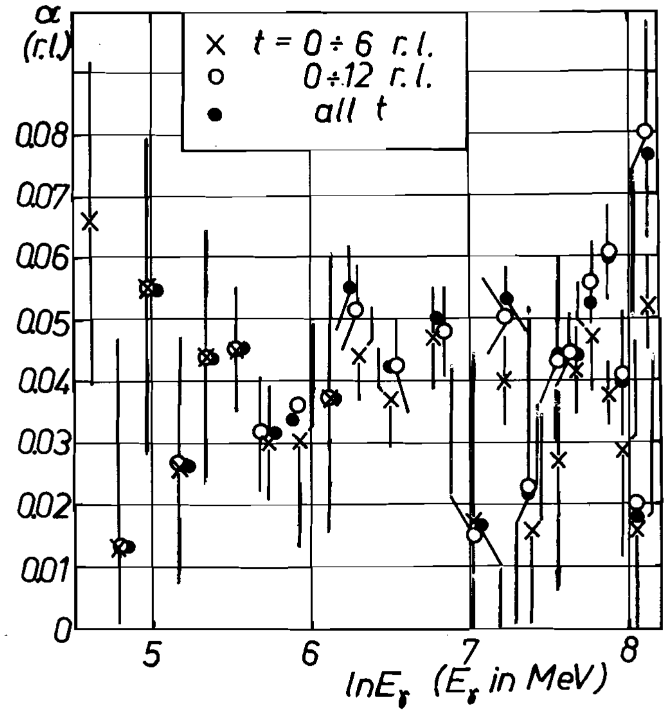

Fig.4. Energy dependence of the parameter α of the eq.(2).

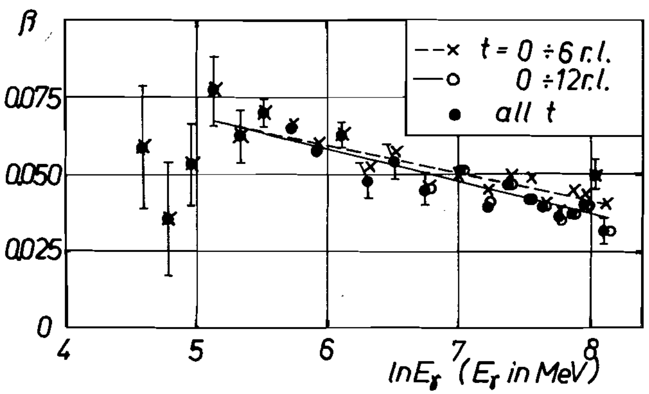

Fig.5. Energy dependence of the parameter β of the eq.(2) within the two intervals of t and for all values of t. Solid and dashed lines display the eq.(3) for two intervals of t, respectively.

3. Radial Distribution

As has been shown earlier[6] the average radial distribution of ionization loss in e.m. showers $F(r|E_\gamma,t)$ is related with the corresponding plane distribution $f(p|E_\gamma,t)$, measured in this experiment, by means of the following integral equation:

$$f(p|E_\gamma,t) = 2\int_p^\infty \frac{F(r|E_\gamma,t)}{\sqrt{1-(p/r)^2}}\,dr . \qquad (4)$$

In general, the solution of this equation is of the form[7]:

$$F(r|E_\gamma,t) = -\frac{1}{\pi r^2}\int_\infty^r \frac{d}{dp}(pf(p|E_\gamma,t))\,\frac{dp}{\sqrt{1-(r/p)^2}} . \qquad (5)$$

Unfortunately, although the plane distribution $f(p|E_\gamma,t)$ is a simple exponential function (1), the form of the radial distribution $F(r|E_\gamma,t)$ is much more complicated. Its numerical values one can obtain using the computer techniques. Another way is to express the solution by means of the McDonald function Ko as proposed in[8]:

$$F(r|E_\gamma,t) = \frac{1}{2\pi r^2}\cdot Ko\left(\frac{r}{A_2}\right) . \qquad (6)$$

Then, for example, such useful characteristic of the ECP as the root-mean-square value of the shower radius can be easily obtained as

$$(\bar{r}^2)^{1/2} = \left\{\int_0^\infty r^2 F 2\pi r dr \Big/ \int_0^\infty F 2\pi r dr\right\}^{1/2} = 2A_2 . \qquad (7)$$

So, the fraction η of energy released inside a cylinder of a radius of $2A_2$ around the SA $\eta = 1 - 2K_0(2)$ was estimated to be equal to $\eta \approx 0.72$ [8].

4. Conclusions

The results of our investigation of the lateral development of e.m. showers produced by GQ with the energy E_γ=100-3500 MeV in liquid xenon are as follows:

1. The projected (plane) lateral distribution of shower electron ionization loss can be parametrized by an exponential

function (1), where the slope A_2 is approximately a linear function of the absorber depth t and proportional to the logarithm of the primary GQ energy E_γ.

2. The radial distribution of ionization loss in e.m. showers is much more complicated and can be estimated either from the eq.(5) using the computer techniques or from eq.(6) proposed in ref.[8].

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Словинский Б. E1-89-789
Электромагнитные ливни, образованные гамма-квантами с энергией E_γ = 100-3500 МэВ
3. Поперечное развитие

Изучается поперечное развитие электронно-фотонных ливней, создаваемых в жидком ксеноне гамма-квантами (ГК) с энергией E_γ=100-3500 МэВ. Исходным экспериментальным материалом были снимки с 180-литровой ксеноновой пузырьковой камеры ИТЭФ (Москва), облученной в пучке π^--мезонов с импульсом 3,5 ГэВ/с. Получены распределения средних ионизационных потерь ливневых электронов в плоскости снимков с шагом 0,6 рад.ед. вдоль оси ливня. Они аппроксимированы экспоненциальной функцией с параметром наклона, линейно зависящим от глубины ливня и логарифма энергии E_γ первичных ГК. Приведен также общий вид радиального распределения ионизационных потерь в исследуемых ливнях.

Работа выполнена в Лаборатории высоких энергий ОИЯИ и в Институте физики Варшавского политехнического института.

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Słowinski B. E1-89-789
Electromagnetic Cascades Produced by Gamma-Quanta with the Energy E_γ = 100-3500 MeV
3. Lateral Development

Experimental studies of lateral spread of electromagnetic showers created in liquid xenon by gamma-quanta (GQ) of 100-3500 MeV, using pictures of the 180 l xenon bubble chamber of ITEP (Moscow), are made. The distribution of the average ionization loss of shower electrons measured on the picture plane in step of 0.6 radiation length along the shower axis was obtained and fitted to the exponential function, where the slope has turned out to be linearly dependent on the shower depth and proportional to the logarithm of GQ energy E_γ. General form of the radial spread of ionization loss expressed by the plane distribution is reported too.

The investigation has been performed at the Laboratory of High Energies, JINR and at the Institute of Physics of the Warsaw University of Technology.

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