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FLUCTUATION OF ELECTROMAGNETIC CASCADE AXIS IN DENSE AMORPHOUS SEGMENTED MEDIA

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The investigation of fluctuation of the so-called energy cascade axis around the geometry cascade axis for electromagnetic cascade produced in liquid xenon by gamma quanta within the energy interval 100–3500 MeV has been performed. As a basis the previously obtained experimental data [1] from the 180-liter Xenon Bubble Chamber of ITEP (Moscow) [2] were used. Our results may be helpful for the construction and further enhances of the characteristics of electromagnetic calorimeters with fine-segmented active absorbers such as PANDA (GSI, Darmstadt) and SPHERE (LHE, JINR, Dubna).

Проведены исследования флуктуации так называемой энергетической оси относительно геометрической оси электромагнитных ливней, вызванных в жидком ксеноне гамма-квантами с энергией в интервале 100–3500 МэВ. В качестве исходного экспериментального материала использованы ранее полученные результаты измерений ливней, зарегистрированных в 180-литровой ксеноновой пузырьковой камере ИТЭФ (Москва) [2]. Приведенные данные могут быть полезны при сооружении и дальнейшем совершенствовании электромагнитных калориметров с тонко сегментированной активной средой, таких как ПАНДА (GSI, Дармштадт) и СФЕРА (ЛВЭ ОИЯИ, Дубна).

1. MOTIVATION

Although the information, both experimental and numerical, about basic characteristics of electromagnetic (em) cascades (EMCs), mostly integral ones, like average longitudinal and lateral profiles, produced in dense amorphous materials by high enough energy photons and electrons (and positrons) has been collected for many years (for example, [1]), nevertheless our present knowledge of many other practically important features of this process is insufficient till now. This is especially true in regard to fluctuations and correlations of various traits of EMCs. In particular, for the purpose of designing new detectors of hard em radiation, i. e., electromagnetic calorimeters (ECs) based on segmented active absorbers or to improve the characteristics of already existing detectors, of great importance are the knowledge on fluctuations of the so-called energy axis of the cascade (ECA) around its geometric axis (GCA). Note that as distinct from track detectors in ECs, the GCA is not determined directly. Therefore the question of estimation of fluctuations of the (experimentally reconstructed) GCA around the ECA (not observed in ECs) is still an acute question. For example, an effective

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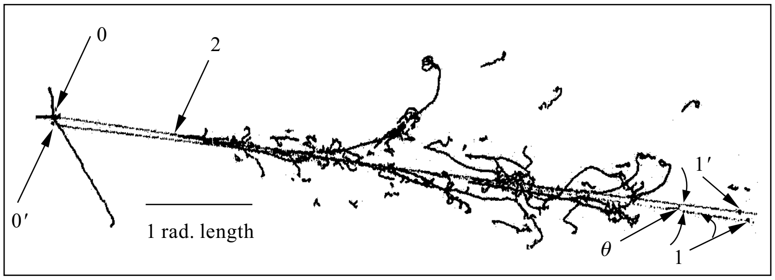

Fig. 1. An event of an electromagnetic cascade induced by a gamma quantum of energy $E_\gamma \approx 1.5$ GeV registered in the 180 XeBC of ITEP (Moscow) [2]

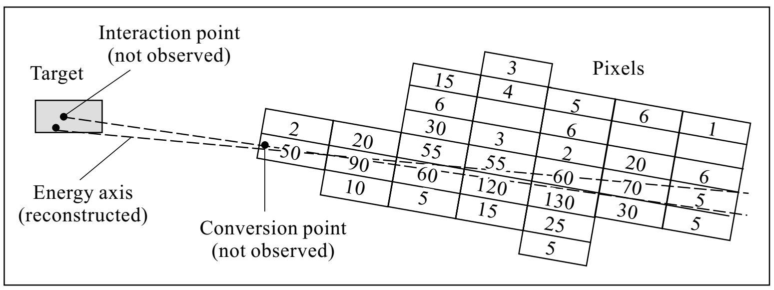

Fig. 2. Same as in Fig. 1 but presented as being detected in a typical fine-segmented em calorimeter (plane projection). Numbers indicate the energy release both in the form of ionization and Cherenkov radiation (in arbitrary units)

mass $m_{\gamma\gamma}$ of two gamma quanta is of the form: $m^2_{\gamma\gamma} = 2(1 - \cos\Theta_{\gamma\gamma})E_{\gamma_1}E_{\gamma_2}$, where E_{γ_1} and E_{γ_2} are the energy values of each gamma quantum, and so the error of the determination of the angle $\Theta_{\gamma\gamma}$ between them may be as large as several percents or even larger.

In Fig. 1 an event of the EMC (plane projection) registered in the 180-liter Xenon Bubble Chamber (XeBC) of ITEP (Moscow) [2] is shown. The following designations are used: 0 — the interaction point; 2 — the conversion point of the photon producing the EMC; (0, 1) — the GCA; (0′, 1′) — the ECA, Θ is an angle between the GCA and ECA. The same event but registered in a typical EC, as a set of signals presented by numbers in arbitrary units is demonstrated in Fig. 2 (plane projection). The precise determination of the (veritable) emission angle of shower creating gamma quanta (i. e., their shower axes) is of grate importance for further processing of experimental information about every event of high-energy nuclear collision. But the only quantity that can be obtained in the EC is the ECA.

Below we present the results of investigation of GCA fluctuations in EMCs produced in liquid xenon by gamma quanta of energy ranging from 100 MeV to 3.5 GeV. Our investigation is based on the experimental material taken from the 180XeBC [2] exposed to the beam of 3.5 GeV/c π^- mesons.

2. FLUCTUATION OF ENERGY CASCADE AXIS

Using our data base [1] containing 918 events of EMCs produced in the 180XeBC [2] by gamma quanta of energy from 100 MeV to 3.5 GeV divided into 21 intervals, the analysis of ECA fluctuations around their GCA has been performed. The measurements were made on condition that the used grid has the segmentation cells of dimensions $\Delta t = 0.6$ r. l. along the cascade depth and $\Delta p = 0.3$ r. l. in its lateral direction (see [1, p. 189]). Notice also that the cut-off energy for electrons and positrons in liquid xenon is $E_c \approx 1 \div 1.5$ MeV [1]. The experimental data on ECAs were fitted to the following linear dependence

$$p(t|E_\gamma) = a(E_\gamma)\,t + b(E_\gamma) \qquad (1)$$

by the least-squares techniques. Here $p(t|E_\gamma)$ is the lateral deviation of weighted energy release at the cascade depth t from geometric axis, whereas the coefficients $a(E_\gamma)$ and $b(E_\gamma)$ were calculated as a result of the fit to experimental results at all energy values E_γ. Note that $a(E_\gamma) = \tan\Theta(E_\gamma)$, where $\Theta(E_\gamma)$ is the average angle between GCA and ECA at the energy E_γ as pointed out in Fig. 1, and $b(E_\gamma)$ is a typical uncertainty of the conversion point determination. The energy dependence of these coefficients is presented in Fig. 3. All length parameters: $p(t|E_\gamma)$, t, and $b(E_\gamma)$ are expressed in units of radiation length. For liquid xenon 1 r. l. $\approx$ 4 cm [1]. For other absorbers being of interest, for example, for PANDA EC (GSI, Darmstadt) 1 r. l. equals: 1.85 cm for CsI(Ti), 1.68 cm for CeF_3, and 0.89 cm for $PbWO_4$. The energy dependence of these parameters can be described by the following simple functions: $a(E_\gamma) = \beta E_\gamma^{-\alpha}$, where $\ln\beta = 1.88 \pm 0.47$, $\alpha = 0.74 \pm 0.08$, and $b(E_\gamma) = (-0.043 \pm 0.008)\ln E_\gamma + (0.50 \pm 0.05)$, E_γ is in MeV, $b(E_\gamma)$ is in r. l.

Fluctuations of coefficients $a(E_\gamma)$ and $b(E_\gamma)$ are adequately described by the (non-weighted) root mean square (r. m. s.) of these quantities. They are depicted in Fig. 4.

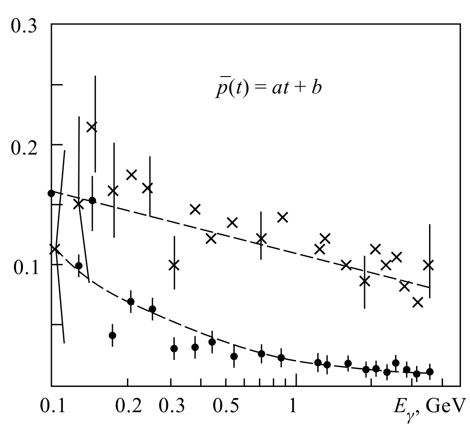

Fig. 3. The fitted parameters $a = \tan\Theta$ (•) and b (×) (in r. l.) of the energy shower axis indicated in Figs. 1 and 2. Drawn are the relevant approximation functions

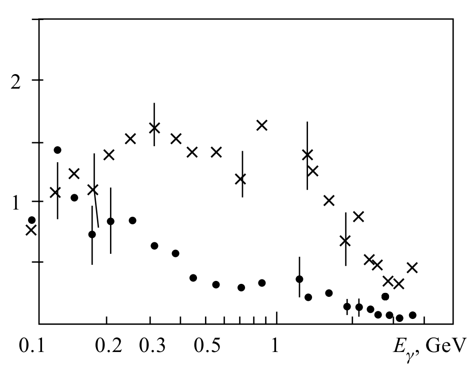

Fig. 4. Energy dependence of r. m. s. values of the coefficients $a(E_\gamma)$ (•) and $b(E_\gamma)$ (×) (in r. l.)

CONCLUSIONS

The results obtained in the work can be summarized as follows:

1. The investigated fluctuations of the ECA around the GCA become less than $\sim 1.5^\circ$ at $E_\gamma \approx 500$ MeV and decrease to about 0.6° at $E_\gamma \approx 2$ GeV (Fig. 1) on condition that the chosen segmentation of active absorber (liquid xenon) is as $\Delta t \times \Delta p = 0.6 \times 0.3$ r.l.^{2}. It means that the accuracy of identification of the lightest particles decaying into two gammas — π^0 mesons — is about 10 % when the accuracy of energy determination is not worse than 20 %.

2. At lower energies, i.e., when $E_\gamma \leqslant 100$ MeV, these fluctuations rapidly increase because the process of EMC is much less outlined and the notion of ECA loses its practical sense.

3. The real situation is somewhat worse when the GCA is directed not exactly along the longitudinal segmentation of the active absorber.

4. The fluctuations under investigation diminish when the dimensions of pixels are lower and lower, and they increase at larger pixels.

5. The coefficients $a(E_\gamma)$ and $b(E_\gamma)$ (and their r.m.s. estimates) depend not only on the pixels dimensions but also on the cut-off energy E_c in such a way that the fluctuations decrease with the decreasing E_c. In our approximation of $a(E_\gamma)$ it means that the parameter α increases with the decreasing E_c. The exhaustive qualitative analysis of these dependences is available with the help of computer EMC process simulation only. It can be done, for example, using the EGS4 code [3] and GEANT.

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