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LONGITUDINAL SHOWER PROFILES IN DIFFERENT MATERIALS

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I. INTRODUCTION

The longitudinal distribution of average ionization loss of electrons and positrons in electromagnetic showers, often called a longitudinal shower profile, is commonly considered as the most important characteristic of this phenomenon, being at the same time the simplest one, among all its basic features, for experimental determination. It also has been noticed that this characteristic reveals interesting and practically useful scaling property when the depth of a shower is expressed in units of its average depth depending, in turn, on energy of a primary particle initiating the shower and parameters of the material in which it develops [1]. Moreover, the average shower depth (ASD) can be determined experimentally much more precisely than remaining similar parameters, such as the location of the shower maximum or its median and other quantiles which also may be used as scaling parameters [1].

In the present work we investigate the experimental data concerning the longitudinal profiles (LP) of showers produced by electrons of energy from 2 GeV to 200 GeV in lead [2,3] and from 4 GeV to 49 GeV in tungsten [4]. The goal of the work is to study the scaling behaviour of these profiles and to analyse the energy and material dependence of the ASD as a scaling parameter.

II. SCALING BEHAVIOUR OF LONGITUDINAL SHOWER PROFILES

In our previous work it has been pointed out that the LP of showers created in liquid xenon by gamma quanta with energy E_γ greater than ~500 MeV do not depend on E_γ (within experimental errors) when a shower depth t is expressed by the dimensionless parameter $x = t / t(E_\gamma)$ [1], where $t(E_\gamma)$ is just the ASD at energy E_γ. An example of relevant distributions is shown in Fig.1. Therefore, the energy dependence of LPs is contained in $t(E_\gamma)$ as demonstrated in Fig.2. The straight line in this figure represents the approximating function [1]:

$$t(E_\gamma) = (-4.8 \pm 0.1) + (1.32 \pm 0.03) \ln E_\gamma, \tag{1}$$

where E_γ is in MeV and t is in radiation length (r.l.).

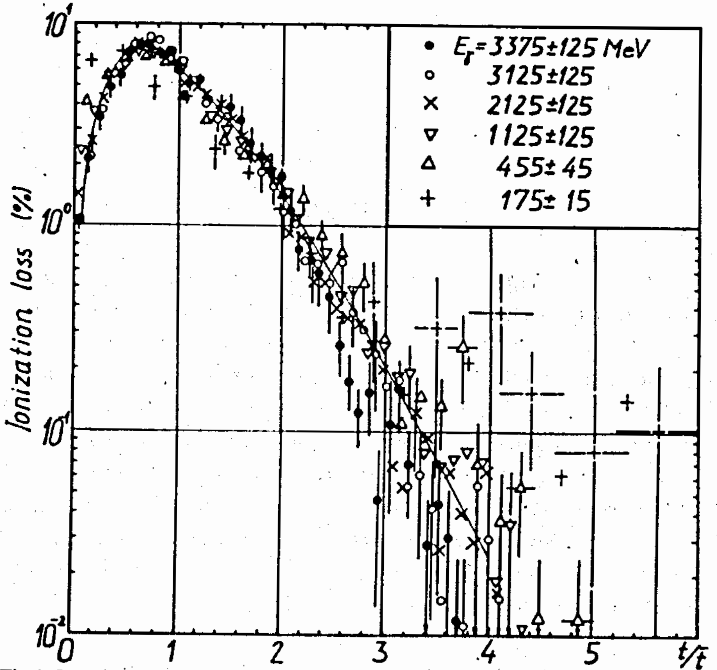

Fig.1. Longitudinal distribution of average ionization loss in showers produced by gamma quanta with energy E_γ in liquid xenon: $t(E_\gamma)$ is the average depth of a shower with energy E_γ [1]

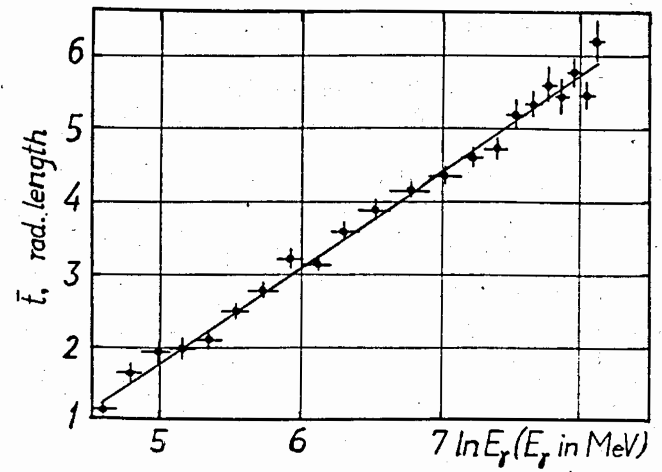

Fig.2. Dependence of the average shower depth on energy E_γ of gamma quanta producing showers in liquid xenon. The straight line represents the approximating function (1) (E_γ is in MeV)

The analogous analysis of the experimental data pertaining to LPs of showers produced by electrons of energy E = 2—15 GeV [2] and E = 25—200 GeV [3] in lead, as well as electrons of energy E = 4—49 GeV in tungsten [4] led to the similar property within the whole examined interval of primary electron's energy E: the LPs as a function of dimensionless depth cease to depend on with an average accuracy of several per cent.

III. ENERGY-DEPENDENCE OF AVERAGE SHOWER DEPTH

Since the ASD $t(E_\gamma)$ turned out to be a suitable scaling parameter for LPs, it is interesting to investigate its dependence on energy of particles initiating showers, and on the parameters describing the properties of material in which this process occurs. Such an energy dependence is shown in Figs.3 and 4 for lead and tungsten, correspondingly. The former experimental results have been obtained from [2—4]. In these figures overimposed are the approximating functions:

$$t(E) = (-1.5 \pm 0.5) + (1.01 \pm 0.03) \ln E \qquad (2)$$

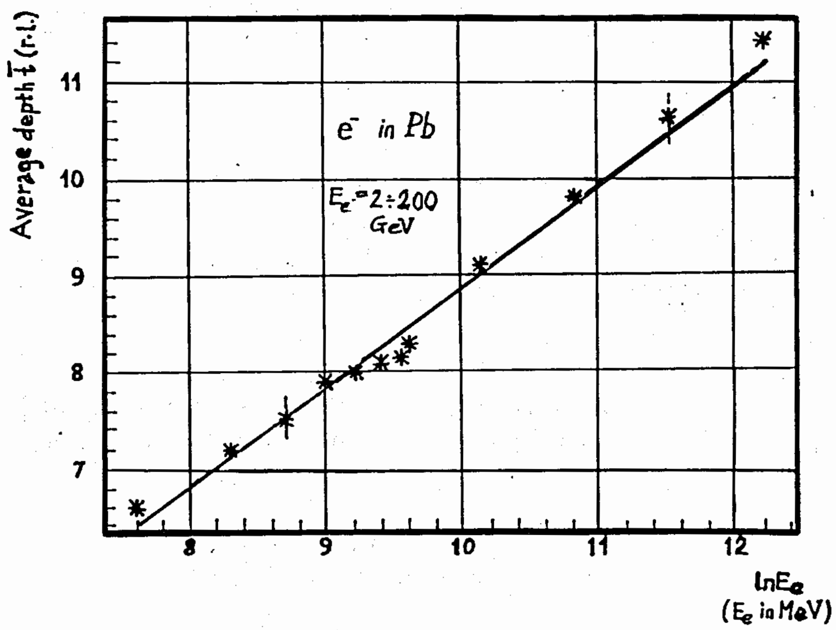

Fig.3. The same as in Fig.2 for electrons creating showers in lead [2,3]. The straight line shows the approximating function (2) (E is in MeV)

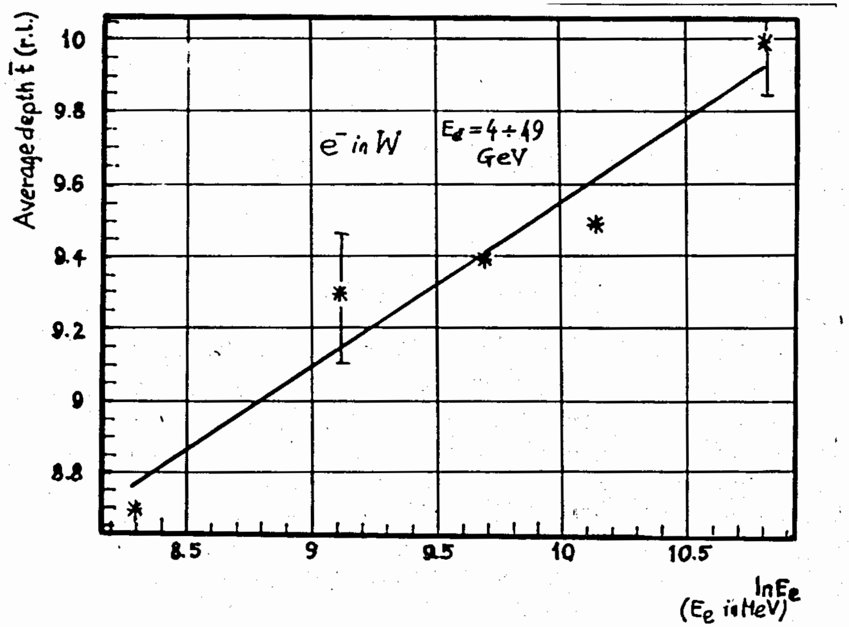

Fig.4. The same as in Fig.2 for electrons initiating showers in tungsten [4]. The straight line shows the approximating function (3) (E is in MeV)

for lead [2,3] and

$$t(E) = (8.4 \pm 0.5) + (0.45 \pm 0.17)\ln E \qquad (3)$$

for tungsten [4]. Here E is in MeV and t is in r.l.

It should be mentioned too that the linear dependence between the ASD and $\ln E$, i.e., the dependence of the form

$$t(E) = a_t + b_t \ln E, \qquad (4)$$

comes from the approximation B of cascade theory [5], although this approximation is limited to very high energies of the particles creating showers in light enough materials ($Z < 20$—30).

IV. MATERIAL DEPENDENCE OF AVERAGE SHOWER DEPTH

In the formulas (1)—(3), having the form (4), the slope parameter contains information about the material in which a shower develops. So, it is interesting to examine the dependence of b_t on ρZ and $\rho Z/A$, where ρ is the density of the

material, Z and A are its nuclear electric charge and nuclear mass number. Such distributions are displayed in Figs.5 and 6. One can easily notice that the investigated parameter b_t, and accordingly the ASD, rapidly decrease with the electron density ρZ and relative electron density $\rho Z/A$ of shower absorbers.

V. CONCLUSION

The results of the analysis of experimental data pertaining to the longitudinal development of showers created by gamma quanta of energy between ~500 and 3500 MeV in liquid xenon, and electrons with energy in the interval 2—200 GeV in lead [2,3], as well as electrons of energy 4—49 GeV in tungsten [4] show that:

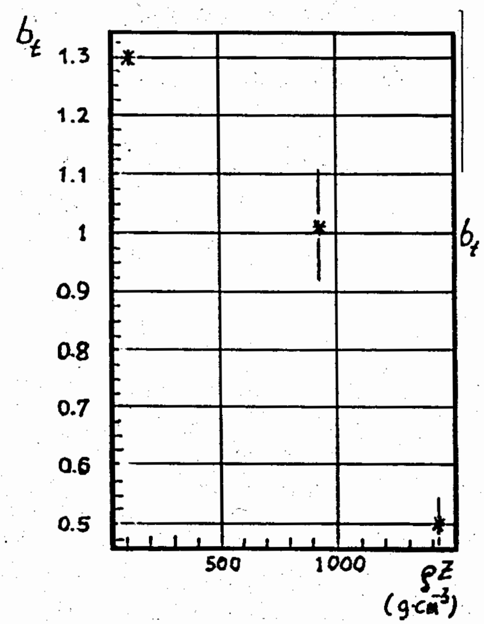

Fig.5. Dependence of the slope parameter b_t of the formula (4) on the electron density of shower absorber ρZ

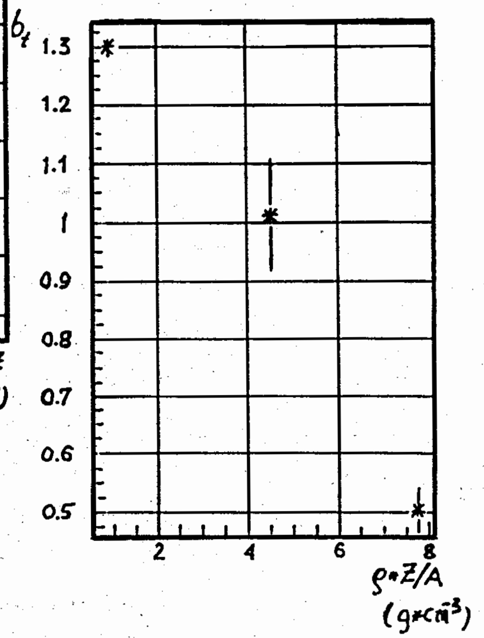

Fig.6. The same as in Fig.5 but as a function of relative electron density $\rho Z/A$

1. The average shower depth is a fairly suitable scaling parameter for longitudinal shower profiles within such a large interval of energy of primary particles making these profiles to be energy independent with a good enough accuracy.

2. The scaling parameter rapidly decreases (approximately linearly) with relative electron density of the absorber in which the shower occurs.

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