LPM EFFECT AND PRIMARY ENERGY ESTIMATIONS

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1. Introduction

The distortion of the electron cascade development under LPM effects is now currently admitted (1, 2, 3) ; it consists in an increase of depths of showers origin, of shower maximum T_{max}, a decrease of the number of particles at maximum N_{max} and results in a flattening and a widening of the cascade transition curve. Connected with the influence of multiple Coulomb scattering on basic electromagnetic processes (bremstrahlung, pair production), this effects appears at high energy with a threshold dependent on the density of the medium (more than 10 TeV for lead, more than 10^6 TeV in air).

We examine here, consequently, the electromagnetic components of hadron induced showers in lead and EAS in air, calculated for the same hadronic cascades in the different alterlative, including or not LPM effect.

2. Analytical representation of cascade curve

We have used in lead our Monte-Carlo data (1) to estimate from numerical values of γ-induced showers the different moments at fixed primary photon energy E_o

$$p_n(E_o) = \int_0^\infty t^n N_e(E_o,t)\, dt$$

The longitudinal spread τ and the integral track length S_o have therefore been obtained from the relations between appropriate moments

$$[\tau(E_o)]^2 = \frac{p_2(E_o) - [p_1(E_o)]^2/p_o(E)}{p_o(E)}$$

and

$$S_o(E_o) = \sqrt{2\pi}\,\tau(E_o)N_{max}(E_o) = \int_o^\infty p(E_o,t)\, dt$$

We found convenient to describe the data including LPM effect by the following formula (replacing Greisen's formula when $E_o > 1$ TeV in lead) :

$$N_e(E_o,t) = 15.3[1+ \alpha_2 B_o^{\beta_2}]^{-1} E_o^{0.9773} \exp[-(t-T_o)^2/2\tau^2]$$

with $T_o = T^{LPM}_{max}$, $\tau = \tau^{LPM}$ and $B_o = \mathrm{Ln}\,(E_o/10^3)$, where

$$T^{LPM}_{max} = 4.98 + \mathrm{Ln}\,E_o + \alpha_1[\mathrm{Ln}\,E_o]^{\beta_1} \quad (\alpha_1 = 0.0001477,\ \beta_1 = 4.64)$$

and

$$\tau^{LPM} = 3.78(1 + \alpha_2 B_o^{\beta_2})\, E_o^{\delta} \quad (\alpha_2 = 0.008446\ ;\ \beta_2 = 2.7936)$$

This formula is inserted in our Monte-Carlo programm of hadronic cascade for all γ rays of different energy emitted at different depth.

Similar procedure has been adopted for air, from Monte-Carlo data (2) leading to the formula for $E_o \geqslant 10^5$ TeV

$$N_e(E_o,t) = 0.00825\ E_o(100.-0.88B_o-1.62B_o^2)\ \exp\left[-(t-T_o)^2/2\tau^2\right]$$

$$\text{where}\quad B_o = \mathrm{Ln}\ (E_o/10^8)\qquad ,\ T_o = 1.363B_o + 21.09$$

$$\tau = 5.2\quad \text{if } E_o \leqslant 10^{10}\ \text{GeV}$$

$$\tau = 5.2 - 0.426\ \mathrm{Ln}\ (E_o/10^{10})\quad \text{if } E_o \geqslant 10^{10}\ \text{GeV}$$

(E_o in GeV, t in c.u.). This formula is also inserted in our hydrid Monte-Carlo-analytic simulation in air in place of Greisen's formula.

3.Simulation in lead calorimeters

The model used for production of secondary hadrons is SBM extended in lead following HE 4.1-9 with $< \nu > = 3.2$. The energy lost in disintegration of the struck nucleus is $E_D(\mathrm{MeV}) = 124\ N_H+30$, the number of tracks N_H being obtained from $N_H = 3.46E^{0.33}A^{0.19}$(4). The Monte Carlo procedure gives the quantities E_{ion}, E_d, E_{out} at different depth of a calorimeter 1000 g/cm^{-2} deep built with lead plates of 50 $g.cm^{-2}$.

$$E_{ion} = (N_1 + N_2 + 0.75\ N_3)\ 32 \times 7.4\ (\mathrm{MeV})$$

$$(N_1 = ½(N(100+N(200))\ ,\ N_2 = ([N(300)+N(400)]/2)...)$$

is the energy lost by secondary particles and γ initiated cascades, E_D is the total energy spent by disintegration, E_{out} is the energy leaking out the considered slide (or the bottom of the calorimeter) estimated as the sum of the individual energies of outgoing hadrons. The behaviour of those quantities with depth are given in fig. 1 for incoming protons of 10^5 GeV. E_{ion} is given with and without LPM. It can be ascertained that for short calorimeters ($\sim 3\lambda$) E_{ion} is 1.6 times lower at 10^6 GeV when LPM is taken into account and a systematic underestimation, rising with energy, occurs when the primary E_o is estimated from E_{ion} without consideration of LPM. A first approach of the amended Grigorov spectrum is shown in fig. 2. Similar consequences will also be detailed for emulsion chamber data.

4. EAS with LPM

EAS induced by proton have been simulated between 10^9-10^{11} GeV, for scaling model (5) and CKP model. For 1st model according to the small number of more energetic secondaries secondaries an important distorsion occurs in cascade curve (fig. 3 - 4) at 10^{10} and 10^{11} GeV. The discrepancy is not visible at 10^9 GeV. For CKP model, LPM can be neglected even at 10^{10} GeV. If we postulate, following (6) the validity of scaling at such energies, the primary energy near 10^{11} GeV estimated from the Fly's eye could be underestimated by 30% without LPM correction.

5. Conclusion

LPM effect implies higher intensities near 10^6 GeV, estimated from direct measurements. The tendancy of fig. 2 where Grigorov

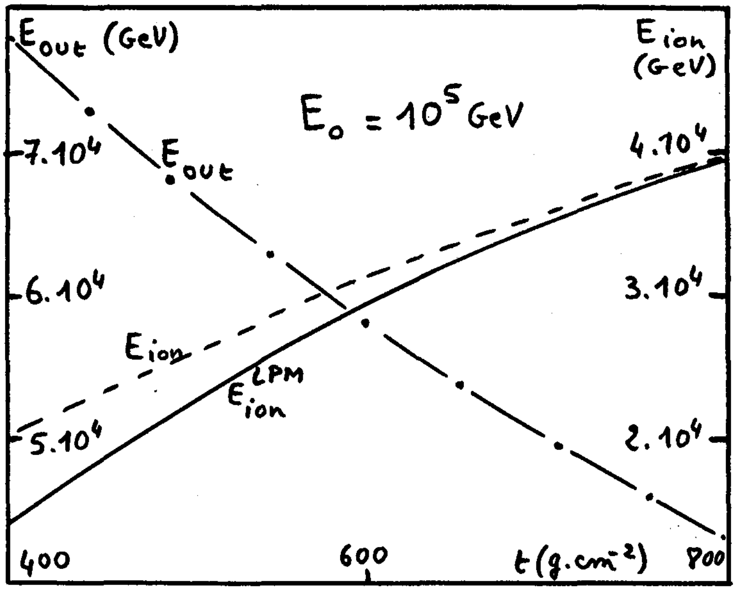
E_{out} (GeV)
E_{ion} (GeV)
$E_o = 10^5$ GeV
7.10⁴
6.10⁴
5.10⁴
4.10⁴
3.10⁴
2.10⁴
E_{out}
E_{ion}
E_{ion}^{LPM}
400
600
800
t (g.cm⁻²)

Fig. 1

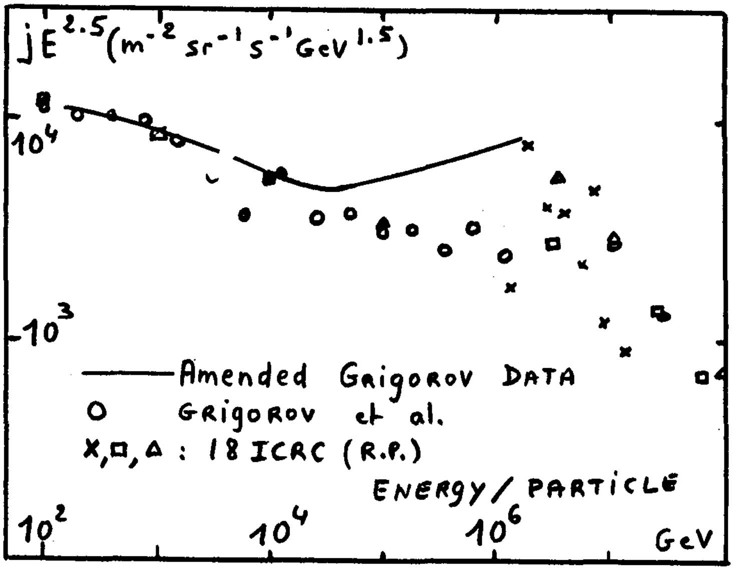
jE^{2.5} (m⁻² sr⁻¹ s⁻¹ GeV^{1.5})
10⁴
10³
Amended Grigorov DATA
○ Grigorov et al.
X, □, △ : 18 ICRC (R.P.)
ENERGY/PARTICLE
10²
10⁴
10⁶
GeV

Fig. 2

amended spectrum is nearer of EAS data (7) could be stronger, if we consider in nuclear model the decrease of inelasticity with primary energy (HE 4.1-9,10). In atmosphere, it's difficult to know at present if scaling model is valid at so high energy, but we have considered here at least, the extremal distorsion due to LPM.

References

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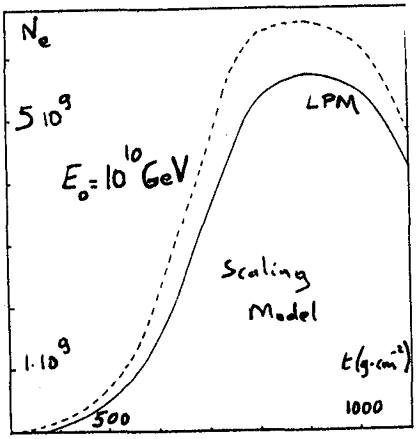

Fig. 3

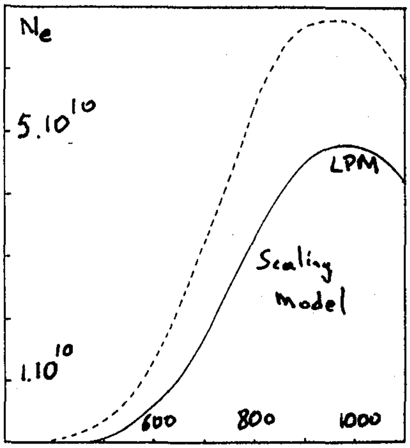

Fig. 4