On the characteristics of the LPM showers traversing the atmosphere

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Abstract. **The LPM showers traversing the atmosphere are expected to behave differently from the usual LPM showers in the medium with constant density, because they traverse the atmosphere where the air density change in location to location, and as the LPM effect depends strongly on the density of the medium. In this paper, we examine the behaviors of the LPM showers whose minimum energies are relatively high, say, 10^{16}eV in order to clarify the character of the fluctuation in the LPM showers in the atmosphere.**

***Keywords*: LPM effect, LPM Shower, Neutrino**

I. Introduction

Now, it is well known that the LPM shower(due to Landau, Pomeranchuk and Migdal[1]) showers at extremely high energies[3][4] behave quite differently from the BH (Bethe-Heitler)showers[2].

Although the LPM effect is essentially the density effect and it influences strongly the shapes of the electron showers in the high density material, such as lead, and it affects even the electron showers in the atmosphere with rather low density if the primary energies are so high, 10^{21}eV or more.

If extremely high energy electron neutrinos coming from the universe really exist, such the electron neutrinos can be detected as the LPM showers in the atmosphere. The LPM showers in the atmosphere have another characteristics which the usual LPM shower in the matter with the constant density have not. Because they develop in the atmosphere where the density changes in location to location and the LPM effect strongly depend on the medium.

In the present paper, we restrict our interest in the diversity of the LPM showers and , therefore, pay our attention to high threshold energy, say, 10^{16}eV , which is too high energy to apply to the real experiment for the space shuttle, something like EUSO. A tentative application to the plausible experiment is given in an another paper by the same authors in this conference[5].

II. Cross sections for the bremsstrahlung and pair production

The electron showers are generated due to the processes of bremsstrahlung and pair production.

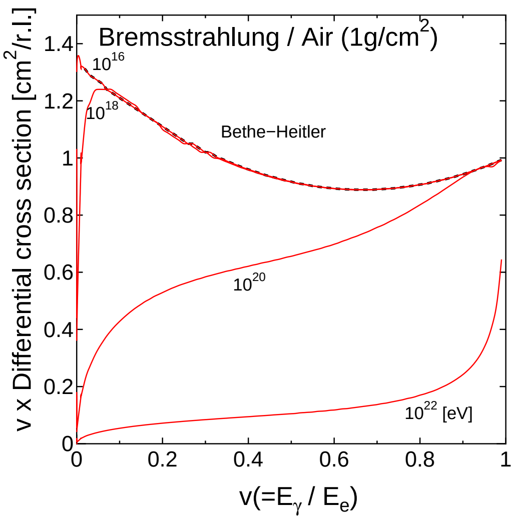

Fig. 1. Differential cross section for bremsstrahlung at the height of 1g/cm^2

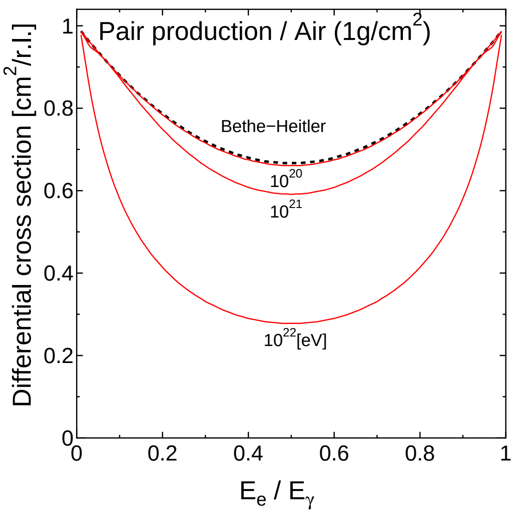

Fig. 2. Differential cross section for pair production at the height of 1g/cm^2

In Fig.1 we give the differential cross sections of bremsstrahlung at the height of 1g/cm^2. In Fig.2, we give the differential cross section of pair production in the same height as in Fig.1. It is understood from Fig.1 and Fig.2 that even lower density of the air, such as 1g/cm^2, the LPM effect begins to be effective at extremely high

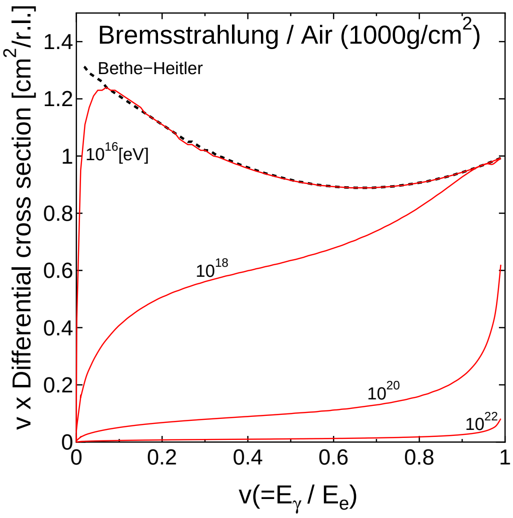

Fig. 3. Differential cross section for bremsstrahlung at the height of $1000\mathrm{g/cm}^2$

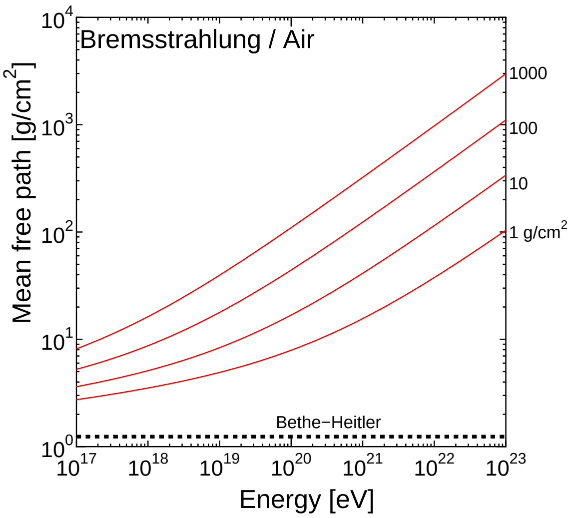

Fig. 5. Mean free path of the electron for bremsstrahlung

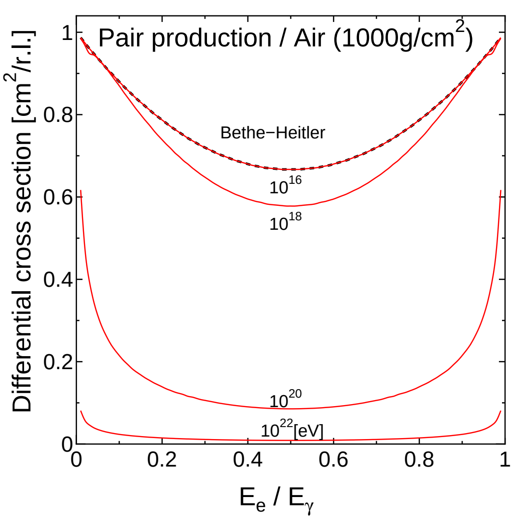

Fig. 4. Differential cross section for pair production at the height of $1000\mathrm{g/cm}^2$

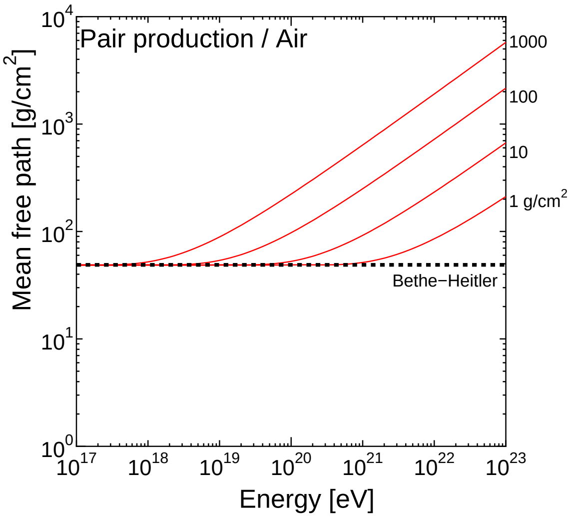

Fig. 6. Mean free path of the photon for pair production.

energies.

In Fig.3 we give the corresponding quantities as Fig.1 at the height of $1000\mathrm{g/cm}^2$, the highenst density in the asmosphere and in Fig.4, and give the corresponding quantities as Fig.2 at the height of $1000\mathrm{g/cm}^2$. Comparing Fig.1 with Fig.3 and Fig.2 with Fig.4, respectively, then we can see that the effective energies from the LPM effect at lower atmosphere is lower than those at higher atmosphere, as they must be.

Also, it should be noticed from these Fig.s that the unbalanced energy distribution between electrons and positrons are enhanced greatly as the increase of the primary energy. This is one of the reasons which produce diversity among the LPM showers compared with the BH showers.

In Fig.5, we give the primary energy dependence on the mean free paths of electrons for bremsstrahlung, while we give the corresponding quantities for pair production in Fig.6. These remarkable prolongation of the mean free paths of electrons and photons produce the prolongation of the electron showers as their primary energies increase. Furthermore, the existence of the change of the density in the location to location in the atmosphere makes the structure of the LPM showers concerned complicate.

However, it should be noticed that we cannot imagine the real behaviors of the LPM shower well from the first impression of the differential and integral cross sections, because the shower structure is very complicated.

III. The exact treatment on the LPM showers

The remarkable fluctuation is one of the most biggest characteristics of the LPM showers. Even if their primary energies are same, each of electron showers may behaves quite differently from their averaged ones do. Therefore, we must carefully treat the LPM showers without killing the fluctuation. For the purpose, we

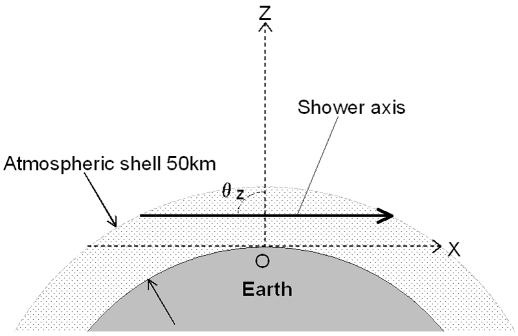

Fig. 7. Schematic view on the direction of the shower development

utilize the exact Monte Carlo method in which we treat exactly the stochastic character in the physical processes involved without any approximation.

The exact treatment to the LPM showers was carried out by Konishi *et al.* in both one-dimensional and three-dimensional case without ionization loss by the full Monte Carlo method[3]. They firstly clarified the peculiarities of the LPM showers compared with usual electron showers(BH showers). Misaki calculated the LPM showers with and without ionization loss in one-dimensional way by the numerical method and verified the clear difference between the LPM showers and BH showers [4]. Furthermore, Konishi *et al.* [6] first clarified that the LPM showers have the mutlti-peak structures which produce the diversity among electron showers. This is never imagined in the BH showers. In the present paper, we adopt 10^{16}eV as the minimum energy of the LPM shower. Above this energy, we treat all the stochastic processes in the LPM showers as exactly as possible without any introduction of the approximations.

IV. THE DIVERSITY AMONG THE LPM SHOWERS

We calculate the LPM showers traversing the atmosphere by the full Monte Carlo method, taking into consideration of the change of air density.

Our LPM showers develop along the x-axis in Fig.7 at the height of z=0.5 km and 5 km($\theta_Z = 90°$,zenith angle) from the surface of the Earth.

In Fig.8, we give the development of the LPM shower whose primary energy is 10^{21}eV at the height of 5km.

Five sets of the LPM showers with different starting points are given. The starting points for the LPM showers are -20.0kg/cm^2, -12.8kg/cm^2, 0.0kg/cm^2, 12.7kg/cm^2, 18.9kg/cm^2, respectively. They are measured from z axis just above where we can imagine EUSO or something like this (see, Fig.7). Each sets consist of five sampled showers.

The dotted curves with arrow indicating the right axis show the relation between the depth for shower development and atmospheric depth there.The depths are expressed in g/cm^2 and are measured from z=0.

From the Fig.8, we can point out the multi-peak structures of the shower. The electron showers which start at -20.0 kg/cm^2 (the edge of the atmosphere)

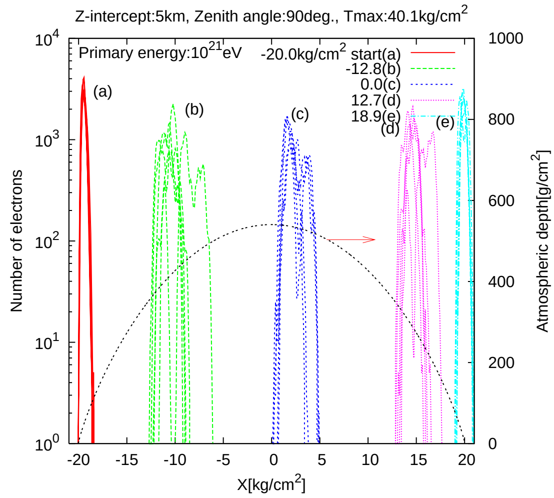

Fig. 8. 10^{21}eV LPM showers at the height of 5km, with different starting point. The depth is measured in kg/cm^2.

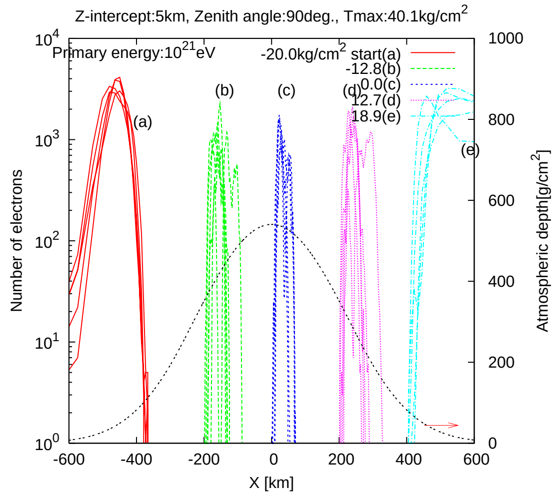

Fig. 9. The same showers in Fig.8, measured in km.

traverse the atmosphere where density of the air is extremely low, and therefore the LPM effect is not effective . Consequently, these showers (a) cannot be the LPM shower, remains to the BH showers. Thus, such the showers (a) have no fluctuation among five sampled showers compared with three sets of showers (b), (c) and (d).

In Fig.9, the same showers are expressed in km. The Tmax of 40.1 kg/cm^2 in the Figs. 8 and 9 denote the total amount of the atmosphere along the shower axis(x-axis in the present case) at the height of 5 km. In other words, we can utilize 40.1 kg/cm^2 as the maximum producer for the development of electron showers along the shower axis at the height of 5 km.

In Figs.10 and 11, we give the similar quantities as shown in Figs.8 and 9, but with the different height of 0.5 km. The meaning of the Tmax of 67.7 kg/cm^2 is same as in the explanation in Figs.8 and 9

Compared Fig.10 with Fig.8, we can tentatively conclude that for 10^{21}eV, there is not so appreciable difference between the LPM showers which traverse in lower densities and the corresponding ones which traverse in higher density, namely the LPM effect is effective at primary energy 10^{21}eV.

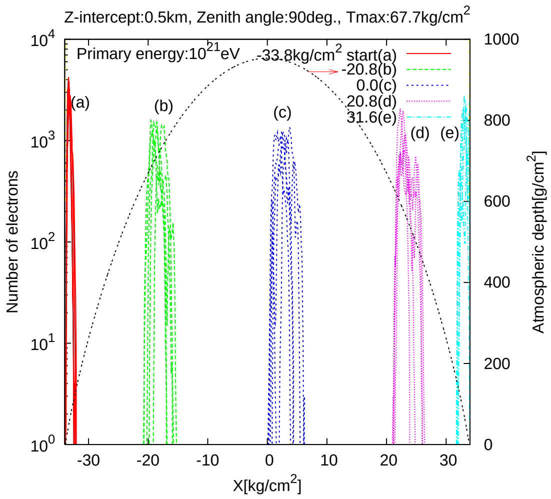

Fig. 10. 10^{21}eV LPM showers at the height of 0.5 km, different starting point. The depth is measured in kg/cm^2.

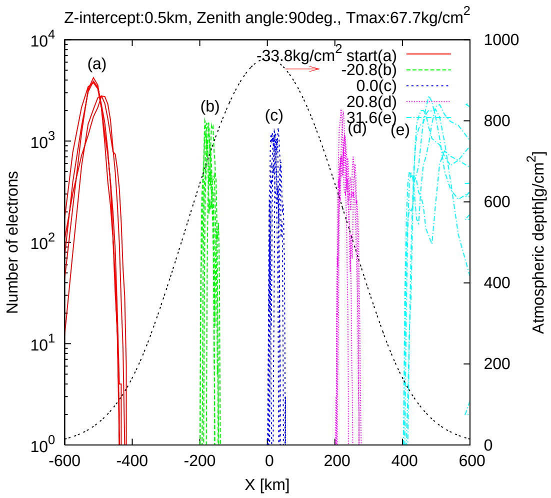

Fig. 11. The same showers in Fig.10, measured in km

V. Conclusions

The LPM showers traversing the atmosphere behave in more complicated manner than usual LPM showers in the medium with constant density, reflecting from the situation that LPM effect strongly depends on the density of the medium.

Also, above 10^{21}eV, in spite of lower density in the atmosphere, the LPM showers in the atmosphere are expected to be active, showing their complicated structure which are not appear in the ususl LPM showers.

References

[1] L.D.Landau and J.Ja.Pomeranchuk, Dok.Akad.Nauk SSSR, **92**(1953)535,735, A.B.Migdal,Phys.Rev.**103**(1957)1811
[2] B.Rossi and K.Greisen, Rev.Mod.Phys.**13**,240(1941)
[3] E.Konishi, A.Misaki and Fujimaki, Nuovo Cimento,**A44**,(1978)509C,(1990)783, A.Misaki, Fortsch.d. Phys.,**38**(1990)413
[4] A.Misaki, Phys.Rev.**D40**,(1990)3086, A.Misaki, Nuovo Cimento,**13C**,(1990)783, A.Misaki,Fortsch.d.Physa.,**38**((1990)413
[5] K.Miyazawa, K.Higashide,N.Inoue,I.Nakamura,K.Kato and A.Misaki, present proceeding.
[6] E.Konishi,A.Adachi, N.Takahashi and A.Misaki, Jour.Phys.G **17**,(1990)719