Characteristics of the LPM shower in the Atmosphere and Comments to the Thinning Method

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The role of the LPM effect in the cascade shower is strongly emphasized. The LPM effect gives distinguished diversity over the cascade shower development in heavy substance ,which has never been imagined in the conventional cascade shower. As the LPM effect is a kind of the density effect, the effect appear strongly in the cascade shower in heavy substances. However, the LPM effect surely influence even cascade shower in the atmosphere, if primary energies are enough high . In this paper, we demonstrate wider diversity of the LPM shower in lead and we show behavior of individual LPM shower in the atmosphere which are deviate from their aberage behavior. Also, we mention to the validity of the thinning method and show some results by the thinning method, comparing with the results by the full Monte Carlo method and discuss around them.

KEYWORDS: cascade shower,air shower,LPM effect,Monte Carlo simulation,thinning method,hybrid method

§1. Introduction

For our presentation, Nagano and Masaike has given following crucial questions and comments:
Nagano's questions are as follows: [1] Even if the LPM effect is really effective over cascade showers, this effect is restricted to the early development of cascade showers, because the average energy of shower particles rapidly decrease due to its multiplication. [2] Whenever we utilize the technique of the thinning method, we always consider the effect of fluctuations. In this sense, we need not discriminate the LPM effect from any other effect. [3] We adopt 10^{-6} as the decramatic energy, therefore, we are completely free from fluctuation due to the LPM effect.

We would like to answer his questions in the following:
[1] Such comment had been made in the famous review paper on the Nishimura-Kamata theory by Nishimura and Kamata forty years before. In this paper, they mention to the LPM effect (LP effect at that time) in the following:
"Recently the limit of applicability of the complete screening cross sections at very high energies has been critically discussed by Landau and Pomeranchuk. They pointed out that,at very high energy, the path length of an electrin which is effective in the collision process become so long that the interference effects of the adjacent atoms should be taken into account, and that the cross section should decrease in the high energy region. Even if the cross section should fall off at very high energies, the average energy of shower particles would soon decrease by order of magnitude by the rapid multiplication of particles, Thus these effects,if exists any,should concern only the beginning stage of shower development and overall behavior should suffer little change." [1)]

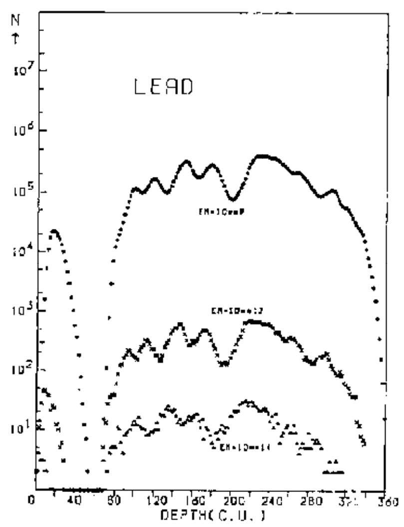

Fig. 1. Number N of electrons in a photon-initiated shower of primary energy $E_0 = 10^{17}$eV in lead as a function of depth in the absorber. The three curves refer to three different values of cutoff energy Em,10^9 ,10^{12} and 10^{14}eV.

However, we have clarified such surmise by Kamata and Nishimura doen't hold. In Figure 1, we give behavior of individual shower obtained by the full Monte Carlo method for different threshold enengies.[2)] We should notice that shower structure with different threshold are essentially same. The threshold energy 10^9eV is so small that we could neglect the LPM effect completely. However, the cascade shower with so low threshold energy maintain original structure of the cascade shower with high threshold(10^{14}eV). This means that fundamental structure of the LPM shower are essentially governed by the accidental energy configuration of small number of shower particle with extremely high energies in the early stage of shower development. [2] One of the defect of the thinning method produces artificial fluctuation which never exists in real physical processes. Consequently, the thinning method is not adequate means by which we analyze individual behavior of the LPM shower, because one of the distinguished characteristics of the LPM shower is wide diversity on the shower development. If we analyze physical events whose fluctuation is not so large, we could utilize the thinning method even in the analysis of individual event. [3] If you apply thinning method to the analysis of the LPM shower with the decramatic energy of 10^{-6}, then you have no problem, because the distinguished fluctuation is essentially generated in extremely high energies, keeping original character even on the latter stage of the shower development and such small decramatic energy guarantee that essential calculation for the LPM shower could be carried out in the part of the full Monte Carlo method.

On the other hand, Masaike has given the following questions: It seems strange for him that our assertion that we could expect big fluctuation in the extremely high energy air shower due to the LPM effect. In his understanding, there may be three possibilities for producing 'strange situation ' . [1] Such strange assertion may be due to wrong calculation. [2] As the Monte Carlo simulation is essentially the approximated calculation, some reasons due to miscalculation enhance situation to appear as the 'fluctuation', which may be related to 'fluctuation' in the early development of air shower. [3] Possibly, it may be really strange new phenomena. For example, it is hardly to imagine that air shower may behave something like CHAOS. Nevertheless, it is worthy examining them.

Our answer to Masaike's remarks are as follows: [1] Our calculation should be one of the most rigorous one among similar calculations. Our calculation is carried out by full Mote Carlo method. The Monte Carlo method may be most dangerous one and unreliable method and may produce everything which they want to get, if we doesn't carefully check the structure of the Monte Carlo method which we now utilize and don't prove the validity of the method utilized. Why could we say our Monte Carlo rigorous one? The reasons are as follows: The fundamental structure of our full Monte Carlo method for cascade shower simulation was originally developed for the calculation of cascade shower under Approximation A.[3] The results obtained are compared with analytical solution under Approximation A, which prove the validity of our method. The same structure of the Monte Carlo method is applied to the calculation of the LPM shower. The results obtained by are compared with the solution of the LPM shower which are numerically obtained , solving the transport equation for the LPM shower and agreement between them is excellent.[4] Thus, our results are proved to be accurate, comparing our result with results obtained by methodologically independent methods. [2] Methodologically speaking, the Monte Carlo method, particularly, the full Monte Carlo method is the most rigorous one for understanding toward stochastic processes of physical events against Masaike's recognition.The full (exact) Monte Carlo method) is never the approximated method, rather perfect method. However, as previously stated, there are too much wrong "Monte Carlo " method which is never interested in their validity. Our Monte Carlo method is rather perfect method which is quite different pseudo Monte Carlo method. There fore, our method could not produce wrong results. [3] Our results which show wider diversity over the development of the cascade shower are never strange, rather rational. Also, these are not related to something like CHAOS.

§2. The characteristics of the LPM shower

The characteristics of the LPM shower is summarized as follows: [1] The average behavior of the LPM shower is quite different from that of the BH shower.[4–7] [2] Individual behavior of the LPM shower is quite different from average behavior of the LPM shower.[2] To demonstrate the distinguished characteristics of individual LPM shower, we give some examples of individual LPM shower in lead for same primary energy and minimum energy. We never imagine wider diversity over the shower developments in the sense of the conventional cascade shower(the BH shower) in Figure 2 to Figure 5.

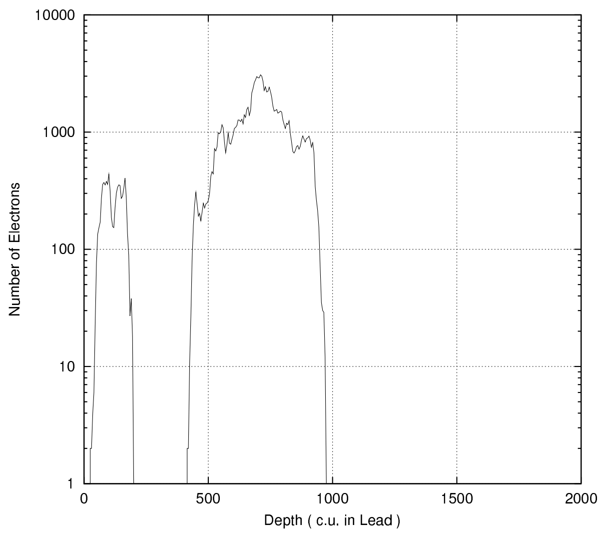

Fig. 2. Sample of The transition curve of electrons produced by photon caluculated by full Monte Carlo method.
$E_0 = 10^{18}$eV,$Emin = 10^{12}$eV

Such wider diversity denotes that the developments of the LPM shower in the latter stage are essentially decided by the accidental energy configuration where fluctuation is too big among shower particles in the very early stage of the shower development.

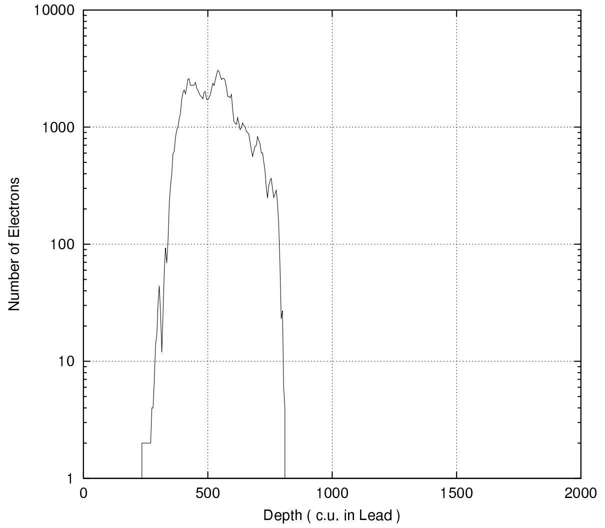

Fig. 3. Sample of The transition curve of electrons produced by photon caluculated by full Monte Carlo method.
$E_0 = 10^{18}$eV,$Emin = 10^{12}$eV

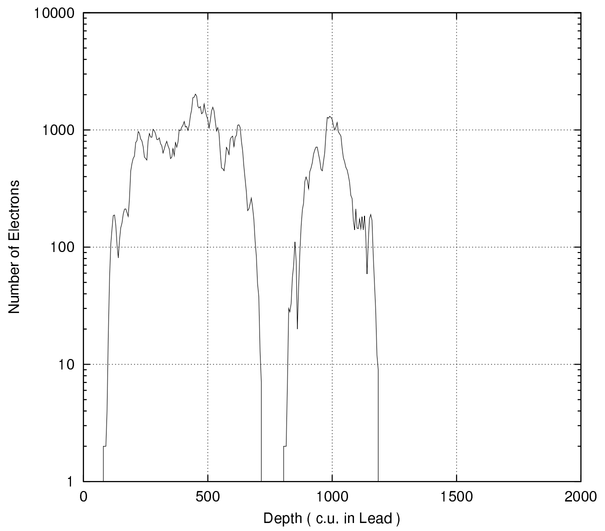

Fig. 4. Sample of The transition curve of electrons produced by photon caluculated by full Monte Carlo method.
$E_0 = 10^{18}$eV,$Emin = 10^{12}$eV

As the LPM effect is a kind of the density effect, the effect is too effective in heavy material something like lead. Therefore, the LPM effect in the atmosphere is very weak compared with lead. Nevertheless, the LPM begin to be effective above 10^{19} eV or so and influence over the shower development totally. Furthermore, the density of the atmosphere change position to position and the LPM effect change position to position in the atmosphere. We should calculate differential and integral cross sections for bremsstrahlung and pair production processes with the LPM effect, taking into account the change of the density in the atmosphere for real LPM

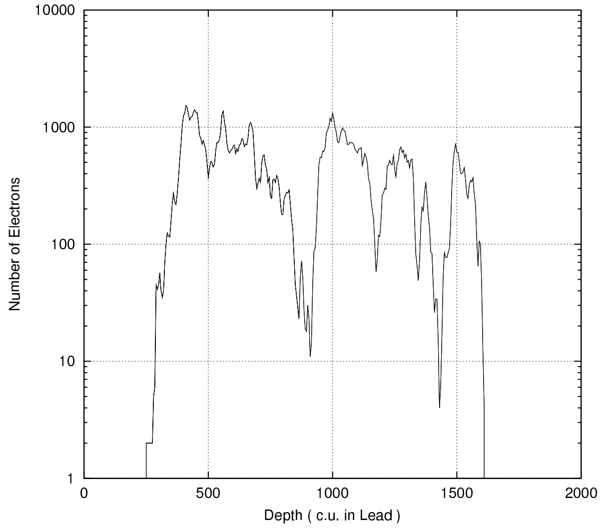

Fig. 5. Sample of The transition curve of electrons produced by photon caluculated by full Monte Carlo method.
$E_0 = 10^{18}$eV,$Emin = 10^{12}$eV

shower in the atmospher. In Figure 6 and 7, we give the differential cross section for bremsstrahlung and pair production processes in the atmosphere for primary incident energy of 10^{16}eV.

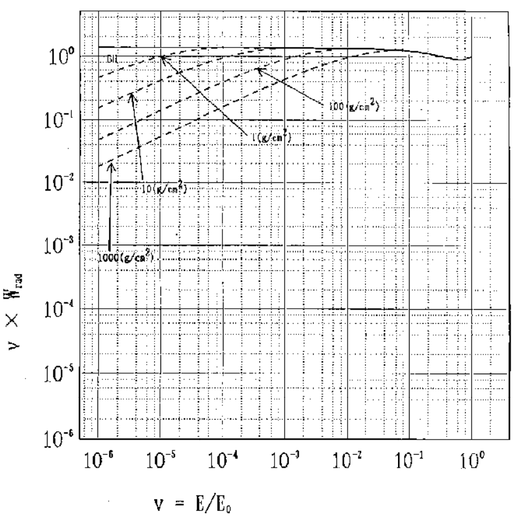

Fig. 6. Differential cross section for bremsstrahlung in the atmosphere with the LPM effect for different densities. Primary energy is 10^{16}eV.

From Figure 6 and 7, it is understood that the LPM effect could be negligible below 10^{16}eV in the atmosphere. Namely, we could say that cascade showers develop as the BH shower. Below 10^{16}eV. Also, we give corresponding cross sections for primary energies of 10^{19}eV and 10^{23}eV in Figures 8 to 11. From these figures, it is easily under-

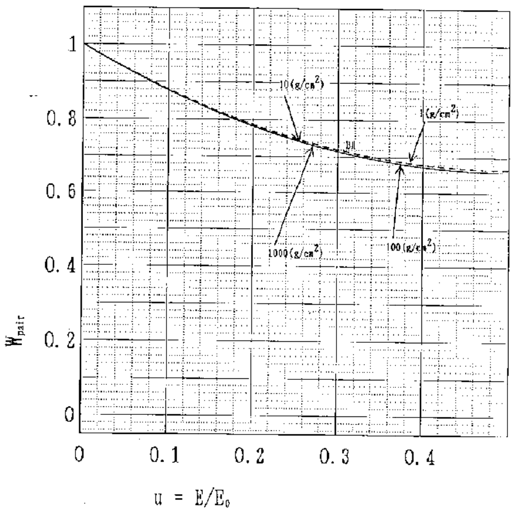

Fig. 7. Differential cross section for pair production in the atmosphere with the LPM effect for different densities. Primary energy is 10^{16}eV.

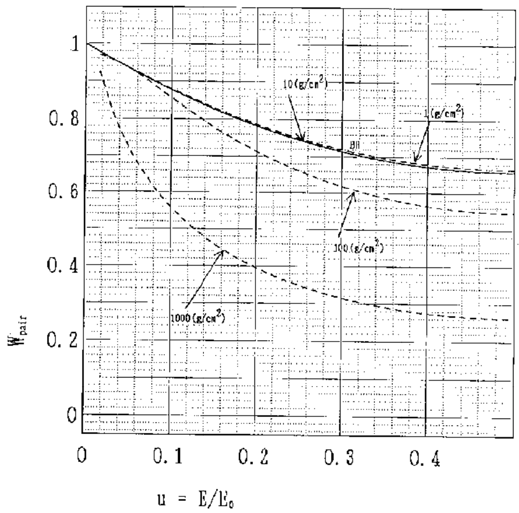

Fig. 9. Differential cross section for pair production for primary energy of 10^{19}eV.

stood that the LPM effect becomes effective much more as primary energy increases and density of the atmosphere increases.

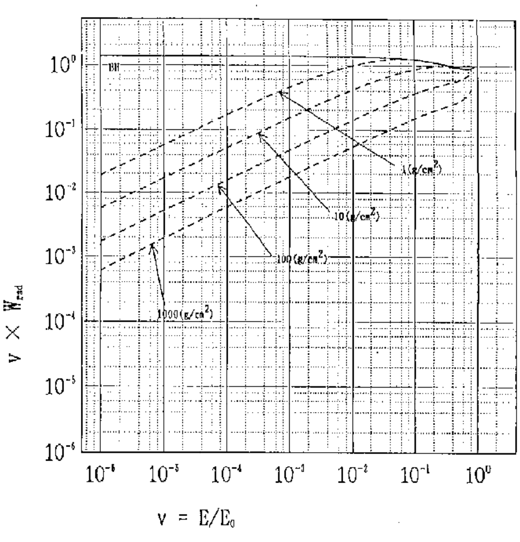

Fig. 8. Differential cross section for bremsstrahlung for primary energy of 10^{19}eV.

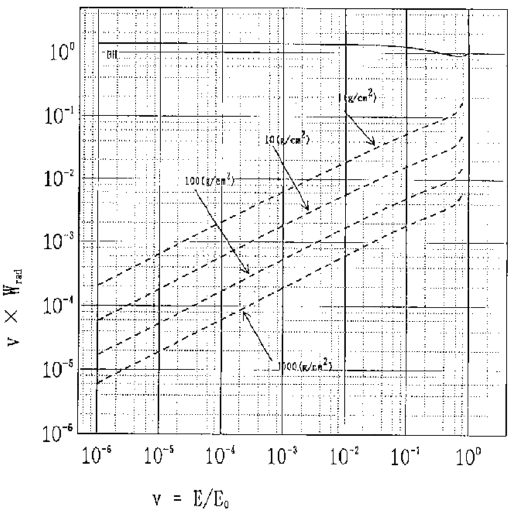

Fig. 10. Differential cross section for bremsstrahlung for primary energy of 10^{23}eV.

§3. What is the second best? Hybrid method or Thinning Method

The most exact method for the calculation of electromagnetic cascade shower is the full(exact)Monte Carlo method. However, it is impossible still now for us to solve extremely high energy air shower by the full Monte Carlo even if we could utilize the highest level of supercomputers. Then, we are forced to adopt the second best. The hybrid or thinning ? It depends on kinds of the problems to be solved. For example, if you are interested in individual behavior of the LPM shower, you are suggested to utilize the hybrid method for their analysis. Because we could minimize ambiguity around fluctuation by utilizing the hybrid method which is shown in the following. If you are interested in the average picture of air showers, you are suggested to utilize thinning method. Because thinning method could give rather precise picture of the

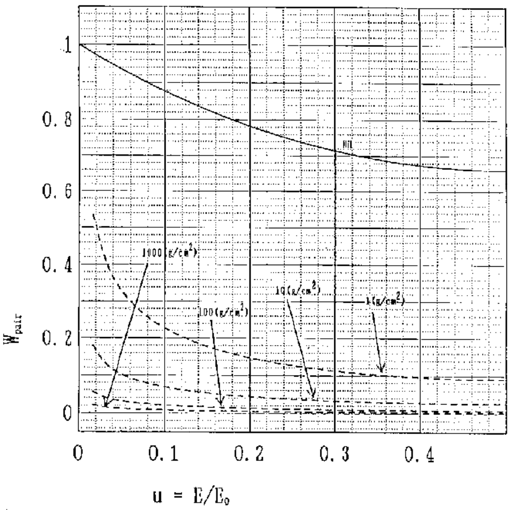

Fig. 11. Differential cross section for pair production for primary energy of 10^{23}eV.

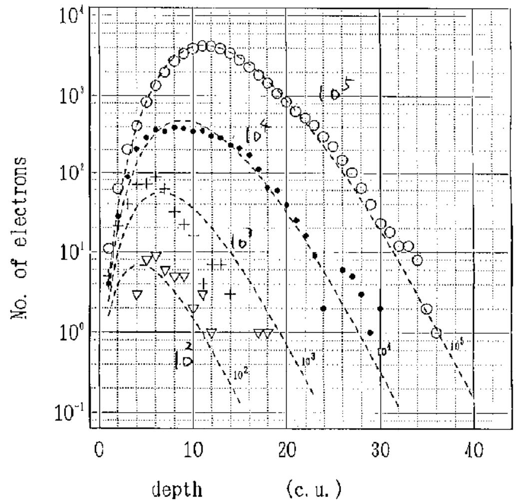

Fig. 12. Comparison of exactly simulated one sampled shower with their averaged showers over different energy ratio from 10^2 to 10^5 with definite minimum energy 10^{10}eV for the BH showers

averaged.

Our Hybrid method is as follows: We simulate cascade shower exactly by full Monte Carlo method, when the energies of shower particles are above 10^{16}eV. We utilize differential and integral cross sections for bremsstrahlung and pair production procees in which the density of the atmosphere is taken into account. When energies of shower particle are fall down 10^{16}eV, we treat the cascade shower as the BH shower. We calculate the averaged BH shower under Approximation B,[3] in stead of individual BH shower to save computing time.

In Figure 12,[9] we give the comparison between individual BH shower and the corresponding average BH shower for different energy combination. It is easily understood that individual BH shower approaches to the averaged one for lager energy ratio, indicating less fluctuation. On the other hand, the situation in the LPM shower is different from that of the BH shower. In Figure 13,[9] we give the corresponding figure in the LPM shower to the BH shower. It is easily understood that individual LPM shower never approaches to the averaged LPM shower, even if shower particles are more larger. Namely, we could approximate individual BH shower to the averaged BH shower, while we couldn't approximate individual LPM shower to the averaged LPM shower, This is the just reason why we adopt the averaged BH shower instead of individual BH shower below 10^{16}eV where the LPM effect could be negligible in our hybrid method.

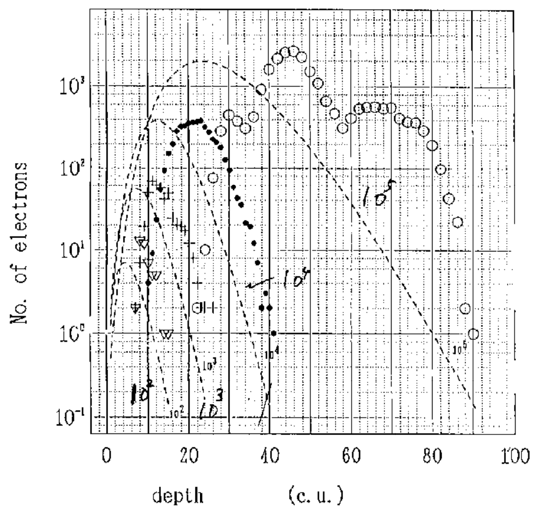

Fig. 13. Comparison of exactly simulated one sampled shower with their averaged showers over different energy ratio from 10^2 to 10^5 with definite minimum energy 10^{10}eV for the LPM showers

As we mentioned to earlier, the LPM effect is rather weak in the atmosphere compared with the lead, we could not expect strong diversity in the atmosphere as shown in lead in Figure 2 to Figure 5. Nevertheless, we could expect individual LPM shower in the atmosphere which is far from the averaged LMP shower. In Figure 14 ,15 and 16, we give individual LPM shower whose starting points are $1g/cm^2$,$10g/cm^2$, $100g/cm^2$,respectively.

We give cascade shower whose energy is larger than 10^{16}eV by full Monte Carlo Method in the lower part of these figures and cascade shower whose energy is larger than 10^{16}eV by the hybrid method in lower part of these figures. It is very clear from these figures that behavior of "total number " of shower particles are essentially governed by the full Monte Carlo part of the cascade

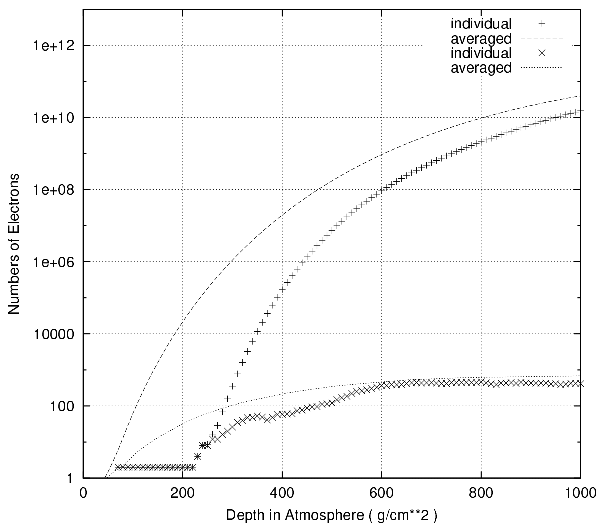

Fig. 14. Example of individual LPM shower in the atmosphere for primary energy of 10^{21}eV. Starting point is $1g/cm^2$

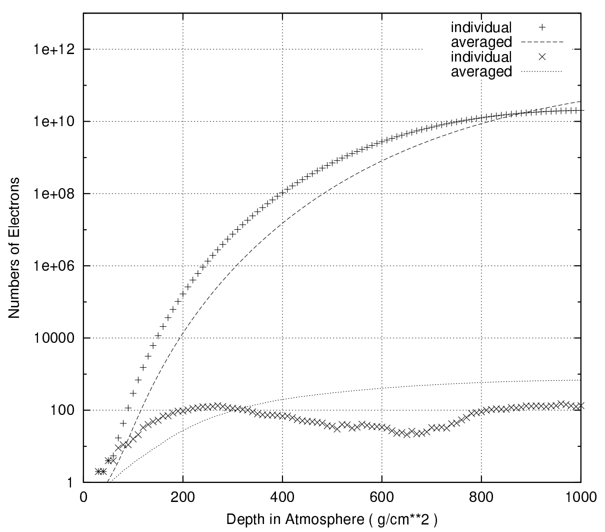

Fig. 15. Example of individual LPM shower in the atmosphere for primary energy of 10^{21}eV. Starting point is $10g/cm^2$

shower.

In Figures 17,18,19, we give the average transition curves for total number of electron starting at different depths of the atmosphere. On the contrary to the transition curves of the BH shower, primary energy dependence on the transition curves are very complicated. The LPM shower with higher primary energy are slowly developed due to the LPM effect compared with the LPM shower with lower primary energy. Particularly, the LPM shower with starting point of $100g/cm^2$ develop more slowly compared with other LPM shower with the starting point of thinner densities.

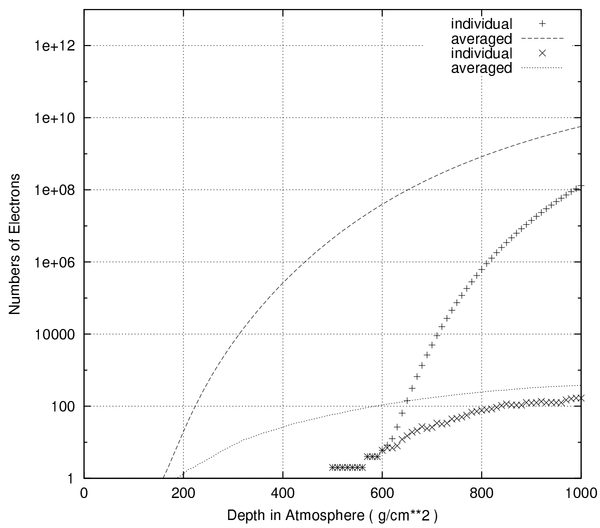

Fig. 16. Example of individual LPM shower in the atmosphere for primary energy of 10^{21}eV. Starting point is $100g/cm^2$

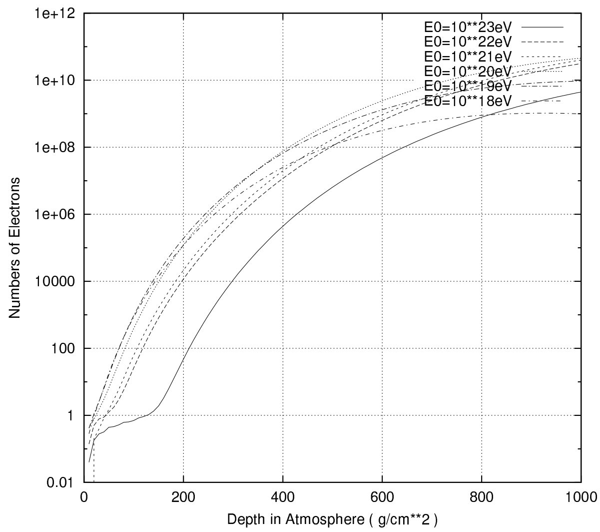

Fig. 17. The average transition curves for total number of electrons in the LPM shower induced by photon with starting point $1g/cm^2$, Primary energy are 10^{23}, 10^{22}, 10^{21}, 10^{20}, 10^{19},and 10^{18}eV, $E_{min} = 10^6$eV.

§4. Comments to the thinning method

The thinning method has been widely utilized for the analysis for air shower mainly due to save the computer time. citerf:8 The most important defect of thinning method is to introduce artificial fluctuation into cascade

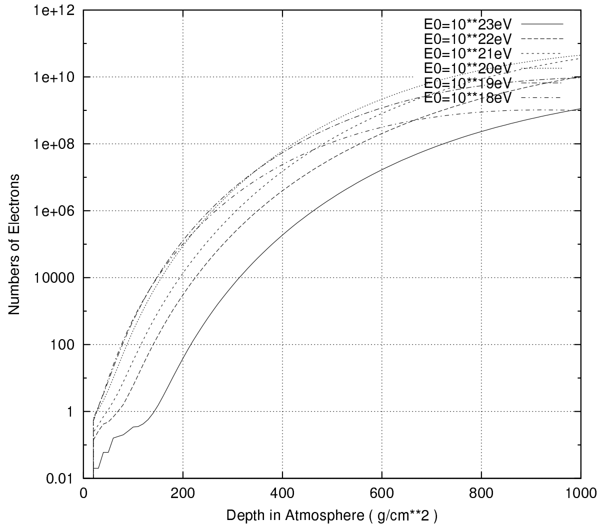

Fig. 18. The average transition curves for total number of electrons in the LPM shower induced by photon with starting point $10g/cm^2$. Primary energy are 10^{23}, 10^{22}, 10^{21}, 10^{20}, 10^{19},and 10^{18}eV, $E_{min} = 10^6$eV.

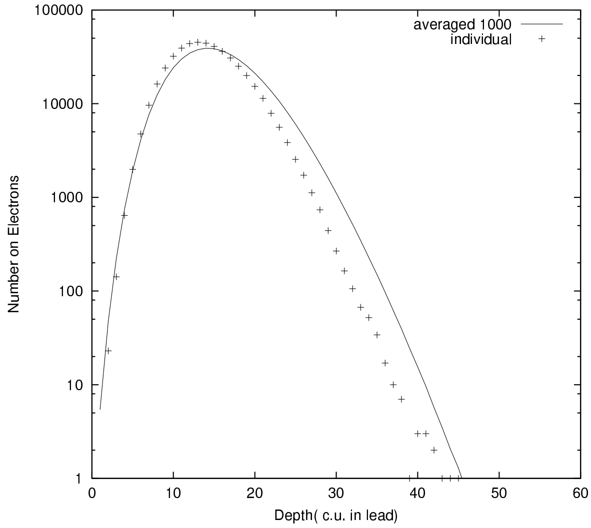

Fig. 20. Comparison between the averaged BH shower and individual BH shower by full Monte Carlo method in lead. Primary photon energy is $E_0 = 10^{18}$eV, $E_{min} = 10^{12}$eV.

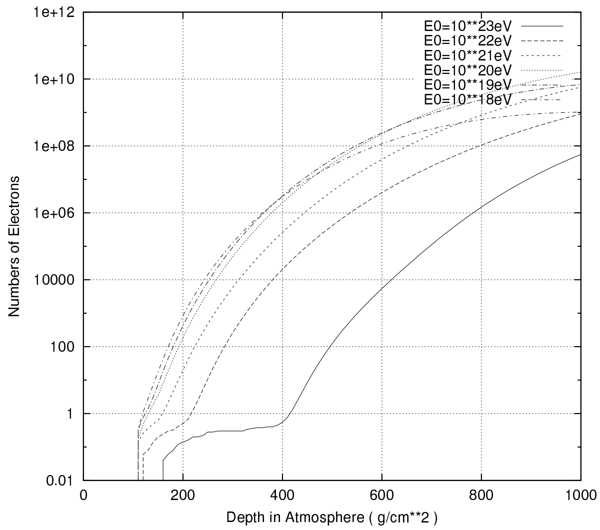

Fig. 19. The average transition curves for total number of electrons in the LPM shower induced by photon with starting point $100g/cm^2$. Primary energy are 10^{23}, 10^{22}, 10^{21}, 10^{20}, 10^{19},and 10^{18}eV, $E_{min} = 10^6$eV.

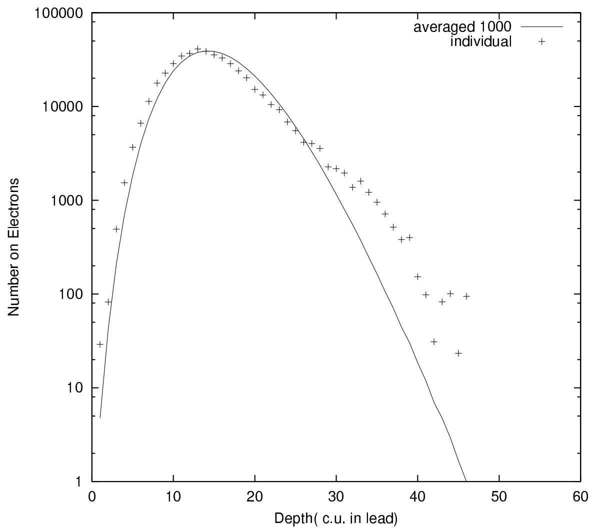

Fig. 21. Comparison between the averaged BH shower and individual BH shower by the thinning method in lead. Primary photon energy is $E_0 = 10^{18}$eV,$E_{min} = 10^{12}$eV, Demacation energy is $E_{de} = 10^{14}$eV.

shower. There may be , however, situations in which the effect of the fluctuation could be neglected. In this case, the thinning method is very powerful means for the physical . In other words, if we are exclusively interested in the average behaviors of physical events, the thinning method becomes very powerful means for the analysis of the problem. It is well known that the BH shower is less fluctuated compared with the LPM shower. In Figure 20 we give comparison between the averaged BH shower and individual BH shower by the full Monte Carlo method. The agreement between them is rather nice, which denotes small fluctuation in the BH shower. We give the same average behavior of the BH shower by the thinning method in Figure 21. It is well understood that thinning method give correct average value. In Figure 22, we compare averaged transition curves of the LPM shower in lead which show strong fluctuation with that by the thinning method. As far as the averaged value concerned, agreement betwenn the result obtained by the full Monte Carlo method and that by thinning method is excellent. We could save comput-

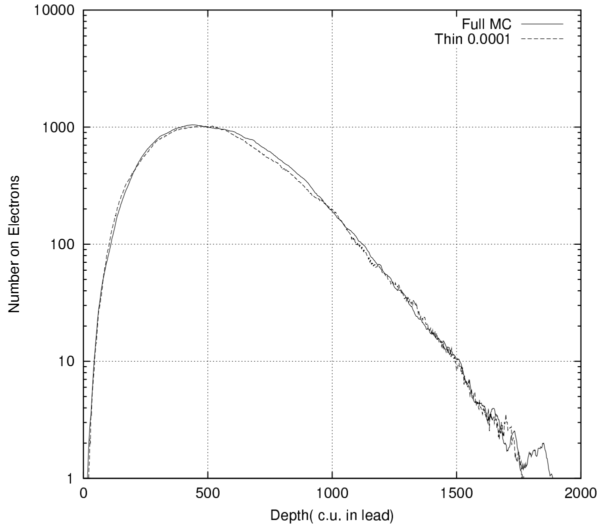

Fig. 22. Comparison of the transition curves by full Monte Carlo method with that by the thinning method in lead. Primary photon energy is $E_0 = 10^{18}$eV, $E_{min} = 10^{12}$eV,Demacation energy is $E_{de} = 10^{14}$eV.

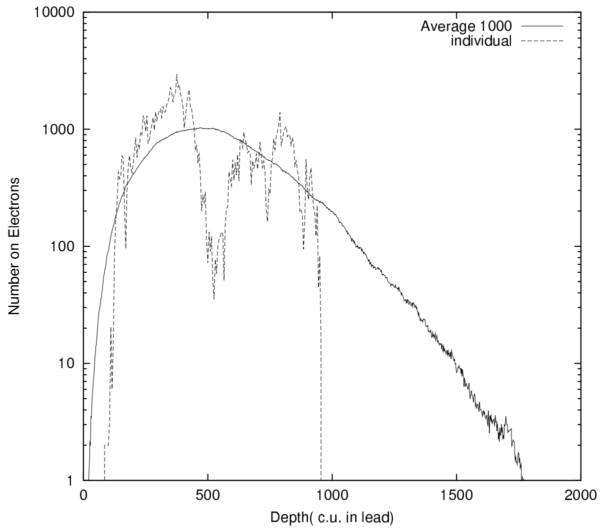

Fig. 23. Individual LPM shower in lead by the thinning method shown with the averaged shower. Primary photon energy is $E_0 = 10^{18}$eV,$E_{min} = 10^{12}$eV,Demacation energy is $E_{de} = 10^{14}$eV.

ing time much by utilizing computing time. This is the merit of the thinning method. Finally, we show individual LPM shower by the thinning method in Figure 23. In this case, the fundamental structure of the LPM shower essentially has been kept in the thinning method, although the artificial fluctuation is added, because decramatic energy ratio so small that the thinning method is almost same as the full Monte Carlo method.

Acknowledgements

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