THE HUMP IN THE CERENKOV LATERAL DISTRIBUTION OF GAMMA RAY SHOWERS

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ABSTRACT

The lateral distribution of atmospheric Cerenkov photons emitted by gamma ray showers of energy 100 GeV is calculated. The lateral distribution shows a characteristic hump at a distance of $\sim$ 135 meter from the core. The hump is shown to be due to electrons of threshold energy 1 GeV, above which the mean scattering angle becomes smaller than the Cerenkov angle.

Introduction : We have reported earlier[1] the calculation of the lateral distribution of Cerenkov radiation at sea-level emitted by showers initiated by gamma rays of energy 100 GeV incident at the top of the atmosphere. The lateral distribution shows a characteristic shoulder at a distance of $\sim$ 125 m from the core. This shoulder has been seen by various authors [2-4] but not by Browning and Turver[5] . Our calculation did not include the effect of Rayleigh and aerosol scattering and ozone absorption on the Cerenkov photons and the effect of the geomagnetic field on the electrons. Also the effect of temperature variation in the atmosphere was not included in this calculation.

Further calculations were done in which the effect of Rayleigh, aerosol scattering and ozone absorption have been included but not the geomagnetic field as the effect due to this is found to be small [4] . Also the effect of temperature variation is now included. The resulting lateral distribution still shows the hump at a distance of $\sim$135 m from the shower core. Investigations on the nature and origin of the shoulder are reported in the present paper.

Method of Calculation

The treatment of the soft cascade is essentially similar to calculations of Vatcha[6] . For photons both pair production and Compton scattering processes are considered while for electrons bremmstrahlung, multiple Coulomb scattering and ionisation losses are taken into account.

Everywhere corrections have been applied for the screening effect. The value of the radiation length in air used is 37.2 gms/cm^2. For the atmosphere a realistic model is taken. The relation between the height h (in meters) and the depth x (gms/cm^2) in the atmosphere is given by

$$h = (6740 + (2.5 \ln X) \ln (1030/X)$$

The scale height is thus dependent on depth

The most important effect is that of multiple Coulomb scattering. Both the single and multiple Coulomb scattering are considered for particles of energy below 1 GeV and for particles with energy above 1 GeV only the multiple Coulomb scattering is taken into account since inclusion of single scattering term for these particles has negligible effect on the

Cerenkov photon lateral distribution. The refractive index, n, of air is given by

$n = 1 + 0.0002926\ (X/1030)\ (273.2/\ T\ )$ where T, the atmospheric temperature (^{o}k) is

$$T = 204 + 0.091\ X$$

Each photon and electron (or positron) is treated by Monte Carlo method from the point of its production to the next interaction point until either one of the following conditions is satisfied (a) its energy falls below 1 MeV, (b) it starts moving horizontally or backwards, or (c) it emerges below the observation level.

For the calculation of the Cerenkov emission it is assumed that the electron moves in a straight path to a certain distance (this distance varied for different sets of calculations) and does not suffer any energy loss in between. This energy loss, is, however, taken into account for following the electrons in the cascade.

The Cerenkov photon lateral distribution is calculated in the following manner . For each straight section of the electron path the Cerenkov photons emitted are confined between two cones having vertices at the two ends of the straight section. These two cones intersect the observation plane in two ellipses. The Cerenkov photon density is calculated by assuming uniform distribution within the two ellipses and is accumulated at some fixed points which happen to fall in between the two ellipses. The points lie along the X-axis at distances from 10 m to 220 m from the core. The average Cerenkov lateral distribution at sea-level for the wave length interval 300 nm to 650 nm is obtained, from a total of 100 showers.

Different sets of calculations have been carried out with and without including the effect of Rayleigh, aerosol scattering and ozone absorption of the Cerenkov photons. For this purpose, the data given by Eltermann [7] is used. A fourth degree polynomial is fitted to Eltermann's data for interpolation to intermediate distances.

Results

The lateral distribution without absorption (a) and with absorption (b) are shown in Fig.1. The lateral distribution shows the characteristic hump at $\sim$ 135 m from the core. It is quite clear that inclusion of the effect of absorption does not reduce the prominence of the hump at all.

Such a hump in the lateral distribution was noticed in the calculations of Zatsepin and Chudakov and Patterson and Hillas whereas it is absent in that of Browning and Turver. The hump present in the calculation of Zatsepin and Chudakov is less prominent than in ours and Patterson and Hillas see a hump whose height is intermediate between ours and that of Zatsepin and Chudakov.

Patterson and Hillas suggest that the extraordinary prominence of the hump in our first calculation may result because of the fact that we have taken very large slab thickness ($5 \times 10^{-4} \times E$ for E less than 1 MeV, 1 radiation length above 1 GeV) while treating the Coulomb scattering. In our present calculations we have used very small slab thickness, sometimes as small as 0.003 radiation length. Still the shape of the hump remains unchanged. (Fig.2)

We have calculated the Cerenkov photon lateral distribution produced by particles with energy greater than 1 GeV and by particles with energy less than 1 GeV separately (Fig.2). The lateral distribution due to lower energy particles shows a very weak shoulder. The lateral distribution due to particles having energy greater than 1 GeV shows a very strong shoulder. These are the particles for which the r.m.s. scattering angle due to Coulomb scattering is less than the Cerenkov emission angle. The contribution to the lateral distribution from different depths in the atmosphere from electrons of energy greater than 1 GeV and less than 1 GeV is shown in Fig.3 (a) and (b) respectively.

The product of the height of production of the Cerenkov photons from electrons of energy greater than 1 GeV and the Cerenkov angle remains almost constant (between 110 and 140 m) for a fairly large range of the height of production of the Cerenkov photons (between 7 and 20 Km). The hump is essentially a consequence of this and is due to the contribution from particles of energy of greater than 1 GeV where the scattering angle becomes smaller than the Cerenkov angle.

Conclusions

We have shown that the hump in lateral distribution of Cerenkov photons at sea level in electromagnetic cascades of energy 100 GeV, remains essentially unaffected even after taking into account the Rayleigh and aerosol scattering and ozone absorption, and reducing the atmospheric slab thickness to very small values in the treatment of scattering of high energy electrons. The hump is essentially due to particles of energy greater than 1 GeV where the mean scattering angle becomes smaller than the Cerenkov angle.

References

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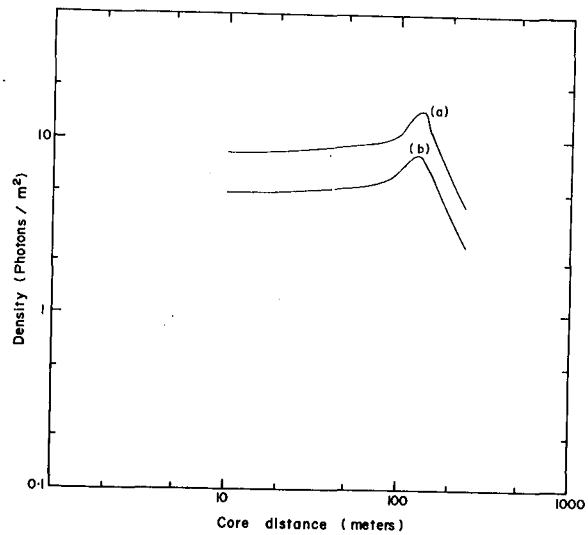

Fig.1. Lateral distribution of Cerenkov photons (a) without absorption, (b) with absorption

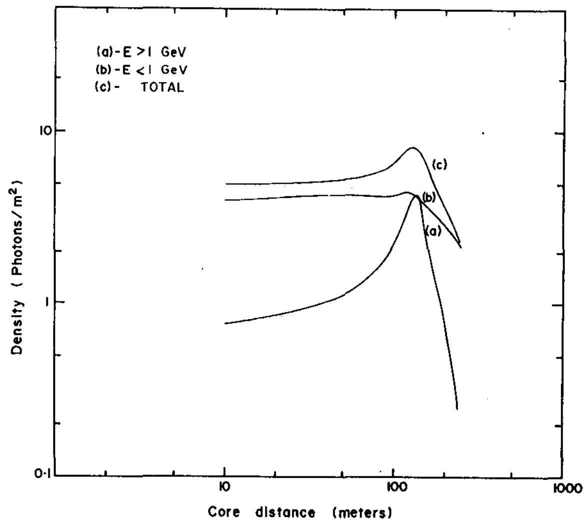

Fig.2. Lateral distribution of Cerenkov photons due to particles of energy (a) > GeV (b) < 1 GeV and (c) total

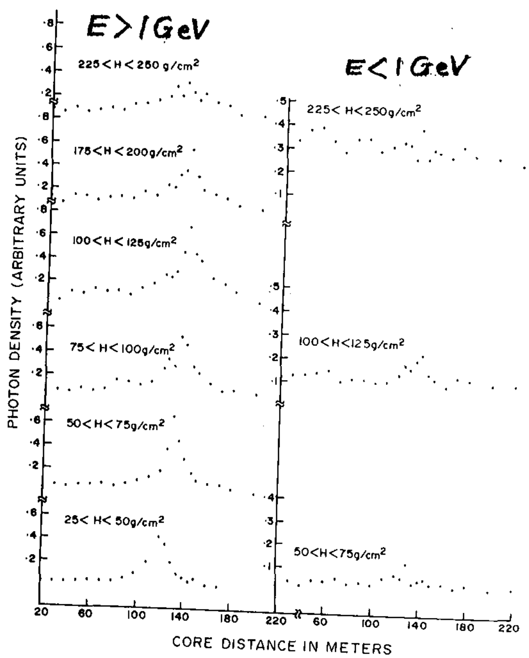

Fig.3 Contribution to lateral distribution of Cerenkov photons from different depths in the atmosphere due to particles having energy (a) > 1 GeV (b) < 1 GeV.