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The Multi-scattering effect and lateral density distribution of Cherenkov photons from the individual muon

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The muons, which are created during hadronic shower development, may play important role in a detection by Cherenkov telescope (see MAGIC documentation). The reason of it is simple - the cross section is small, it means that they can pass by whole atmosphere and hit the ground. They produce Cherenkov light, however: for muons the energy threshold of Cherenkov effect is more than 4 GeV at sea level. The number of Cherenkov photons per 1 g/cm^2 is 350. This value is height independent. It seems to be interesting to see how lateral density distribution looks like in the case of individual muon passing through the atmosphere. The ionization energy looses are not taken into account in all the results presented below.

In the first approximation, I supposed that muons at fixed energy and zenith angle 0 deg.,are hitting the top of atmosphere and reach the ground without changing the direction. Cherenkov photons were created if energy was higher than energy threshold for Cherenkov effect in each height of the atmosphere. The direction of the photons was supposed to be Cherenkov angle. The lateral density distribution of all Cherenkov photons was calculated for energies: 6 GeV, 10 GeV, 30 GeV and 100 GeV (see Fig.1). All distributions are the same for low distances. We can see the so called 'hump' around 120 m - this distance corresponds to the maximum of function R=H*tan(θ_{Ch}). There are presented similar distributions for photons, which have an angle less than opening angle of camera - saying exactly only this part of camera which is involved in hardware trigger (it is 0.95 deg. for MAGIC telescope). The fact, that a major part of Cherenkov light can not be detected if axis of telescope is parallel to direction of muon, has an explanation in Fig. 2. The solid lines show the dependence of Cherenkov angle on thickness of atmosphere for all investigated energy. It is visible that close to the observation level the Cherenkov angle is higher then 0.95 deg and in this case can not give any contribution to the trigger.

In the second approximation I have added an additional effect: multi-scattering of muons. Moliere's theory says that the angle after multiple Coulomb- scattering has (for low angles) a two dimensional Gaussian distribution with an RMS which depend on the momentum of particle and the thickness (expressed in rad. lengths) which particle passes. Higher angles are described by Rutherford formula. You can find this characteristic angle (RMS of the Gaussian distribution) in Fig.3 (all dashed lines). This angle is much higher for low energy muon than for high energy in the case of the same material traversed (rad. lengths). The lateral density distributions, which are shown in Fig.4, were calculated such that before the Cherenkov photons were created, the angle of muon direction was changed according to Moliere theory. The differences between Fig. 1 and Fig. 4 are larger for low energy muons, which was to be expected. The lateral density distributions in Figure 5 were obtained from photons which are in the field of view of trigger part of camera. If you compare Fig. 2 and 5 you can simply conclude that multi-scattering effects play a very important role in the calculation of accidental triggering the low energy muons which is at the beginning parallel to the MAGIC telescope axis.

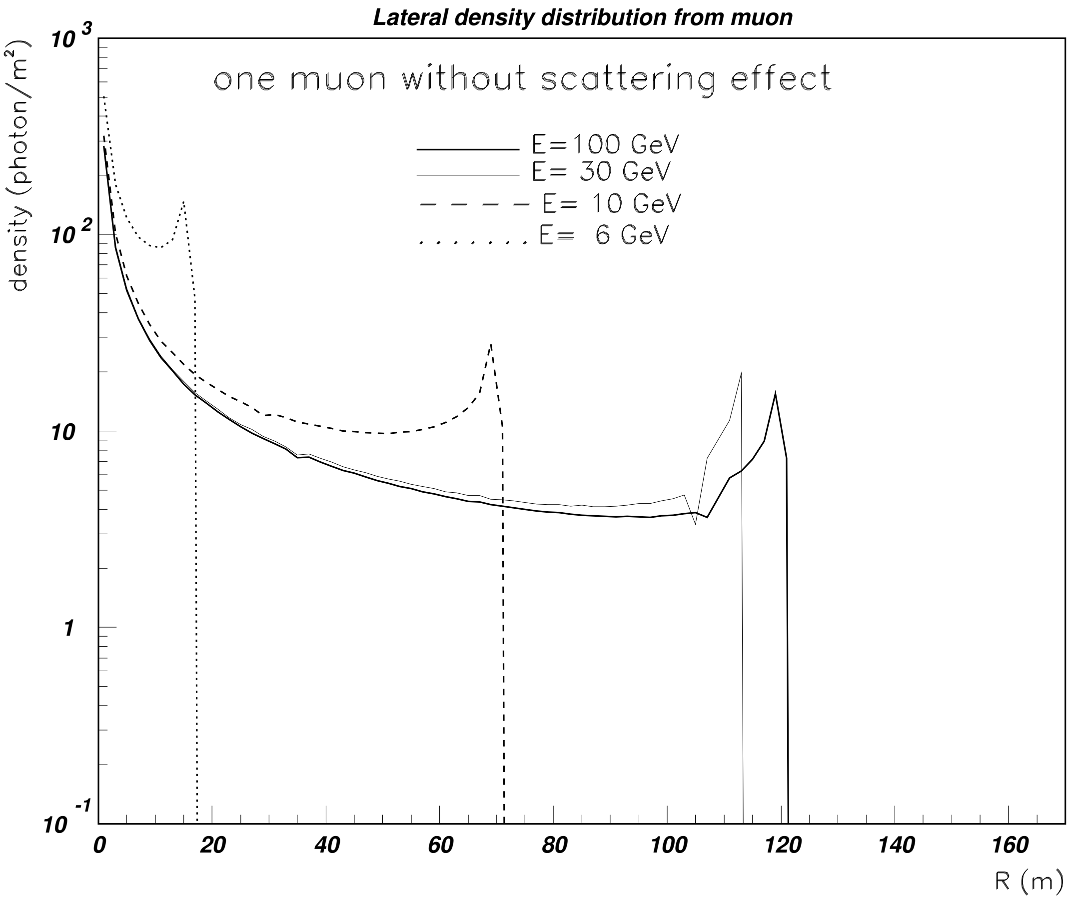

Figure 1: The lateral density distribution from individual muon, which doesn't change direction (all Cherenkov photons).

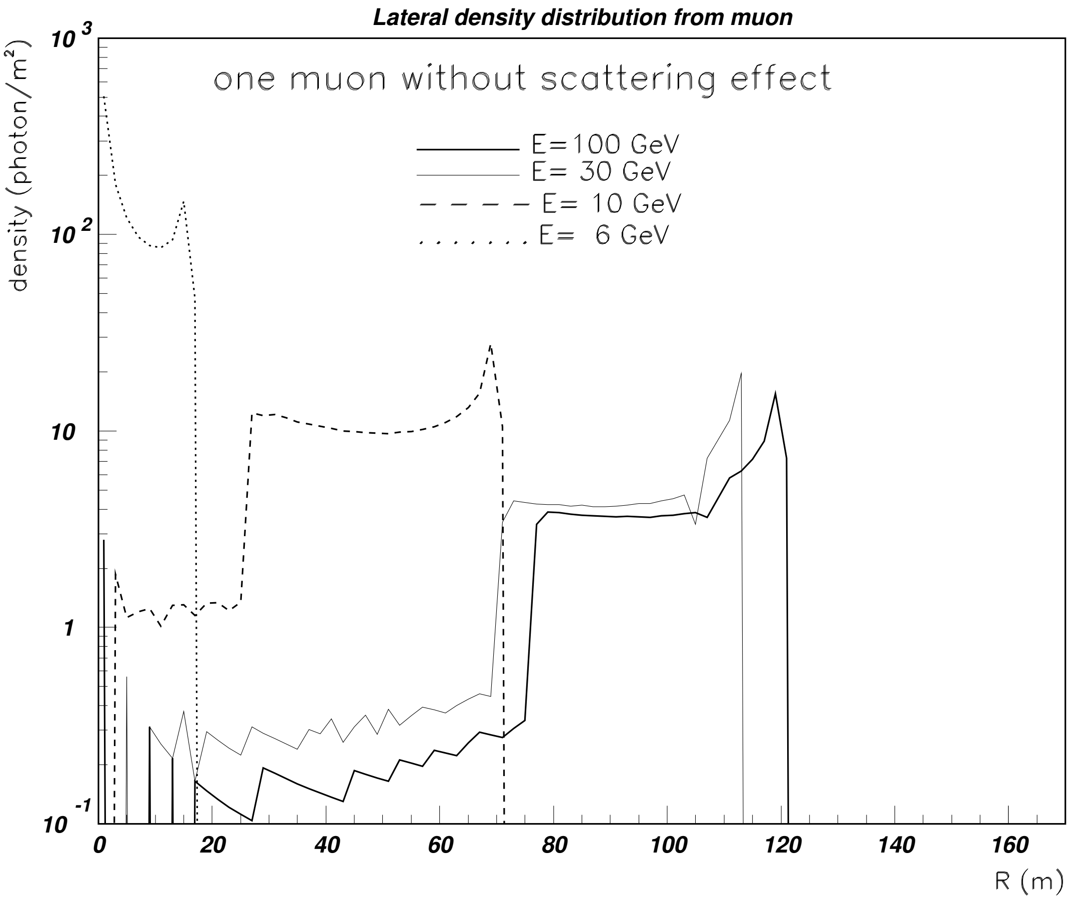

Figure 2: The lateral density distribution from individual muon, which doesn't change direction (all Cherenkov photons).

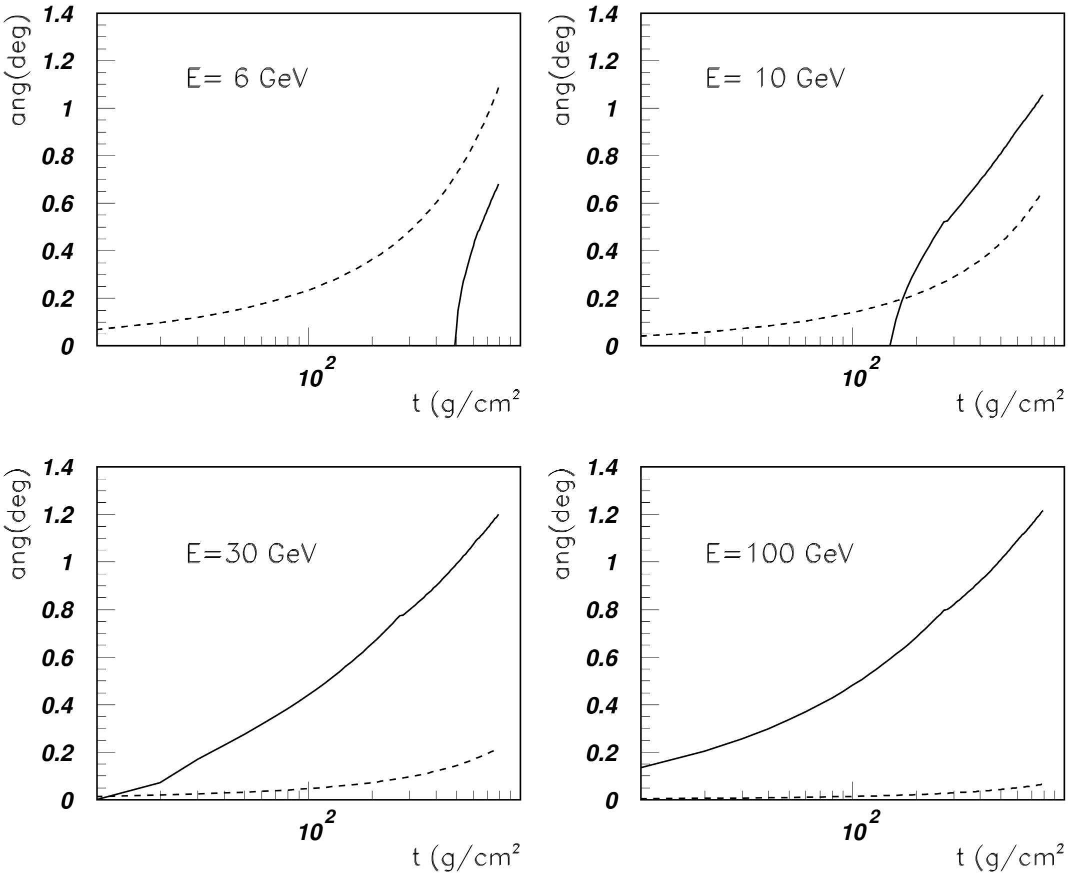

Figure 3: The Cherenkov angle (solid lines) and RMS of distribution of of angle after multi-scattering (dashed lines).

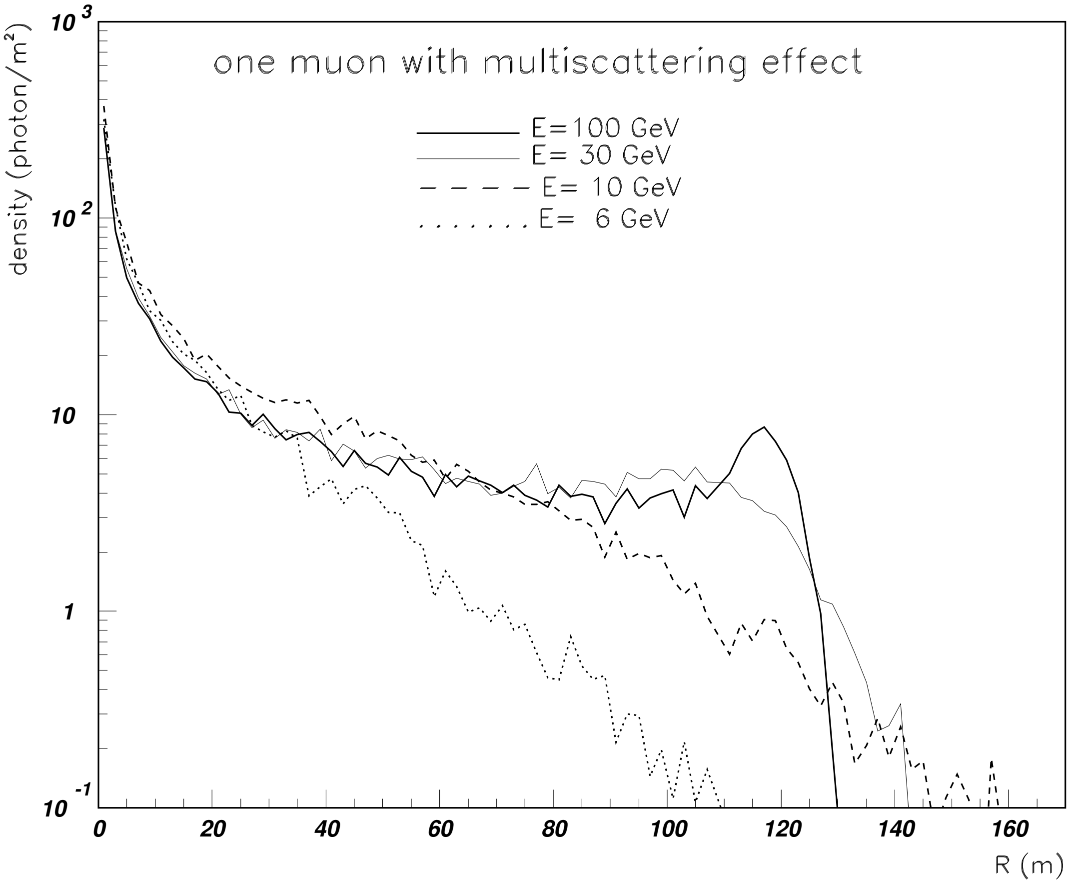

Figure 4: The lateral density distribution from individual muon (all Cherenkov photons) multi-scattering is taken into account

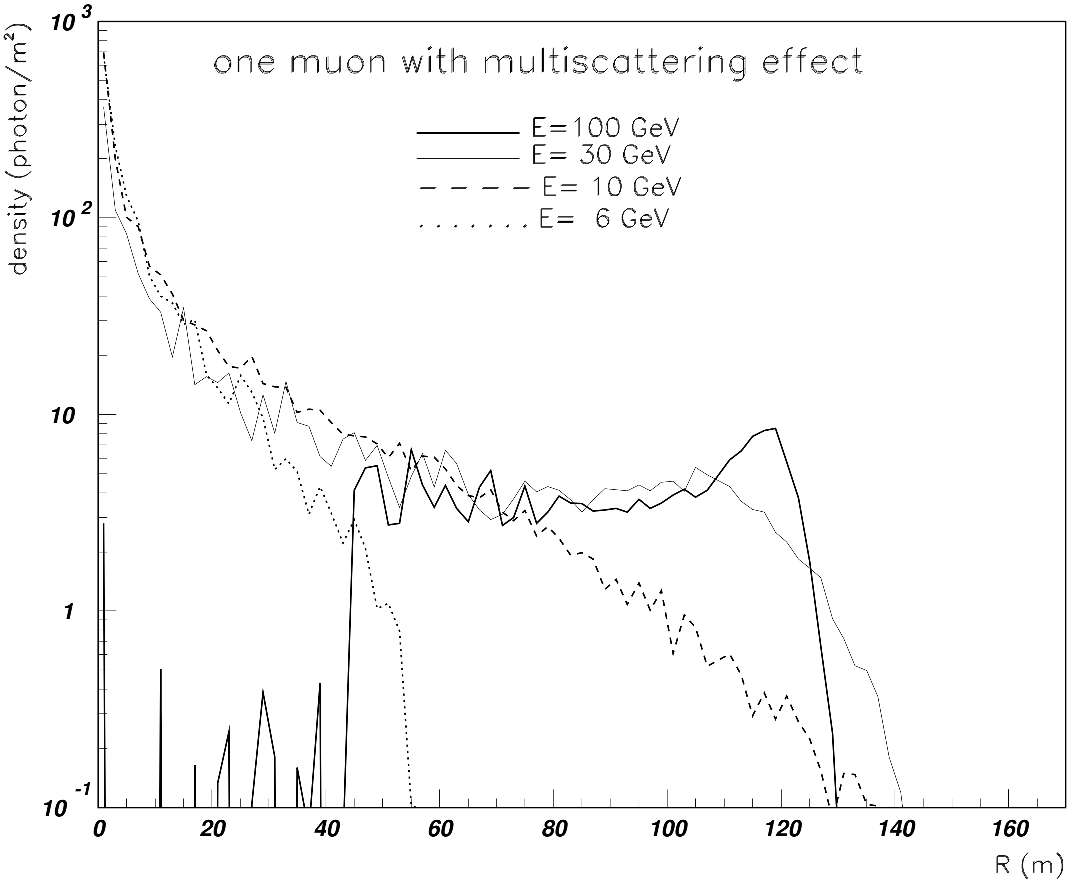

Figure 5: The lateral density distribution from individual muon Cherenkov photons with angle ¡0.95 deg) multi-scattering is taken into account