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Characteristics of a few GeV γ showers

Dorota Sobczyńska
<ds@kfd2.fic.uni.lodz.pl>

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Abstract

In Cherenkov experiments a possibility of the detection the γ initiated shower is connected with the density of the Cherenkov photons on the ground and also the area of telescope dish. A main characteristics of a few energy γ cascades are a longitudinal development and lateral density distribution. This is also very important to know how large are the fluctuations of the density. All distributions are shown and discussed in this paper.

Contents

Table 1: The average total number of the created Cherenkov photons in γ cascade is given in millions. The last column is the number of simulated events for each zenith and each primary energy.

E(GeV)	$zen = 0^o$	$zen = 25^o$	$zen = 40^o$	$zen = 50^o$	$zen = 70^o$	N_{sim}
5	0.22	0.21	0.20	0.19	0.15	5000
10	0.46	0.44	0.42	0.40	0.32	5000
20	0.94	0.92	0.87	0.83	0.68	4000
50	2.44	2.40	2.27	2.16	1.78	1000
100	5.02	4.90	4.67	4.45	3.66	1000

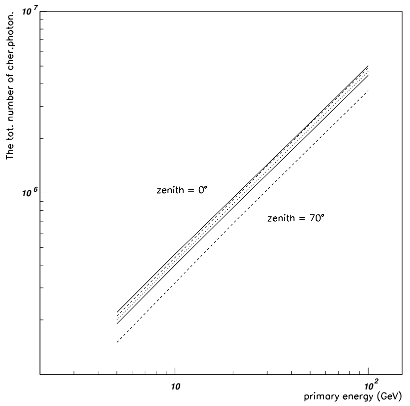

Figure 1: The total number of Cherenkov photons as a function of γ's primary energy for few zenith angles.

1 Introduction

A few GeV γ cascades may be detected by Cherenkov telescopes with a large area of the mirror dish like MAGIC or ECO1000. Understanding of the features described in this note may be very useful in data analysis. To simulate a detailed shower development in the atmosphere we are using a CORSIKA program version 6.019 [1], which may be used also in large zenith simulations. Small changes in standard code were done and are described in [2]. The simulations of showers coming from the South direction were done for five fixed primary energy and for five fixed different zenith angles. The observation level was chosen to La Palma with its magnetic field. An average total number of created Cherenkov photons in a shower one may find in the **Tab.1**. The last column show the number of simulated events. The average total number of Cherenkov photons in the shower is dependent on zenith angle and it increases with the primary energy (it is linear function of the primary energy not only in log log scale), see **Fig.1**.

2 The longitudinal development

The average longitudinal development of the shower one may find in figures **Fig. 2a,2c,3a,3c**, where the number of charge particle is plotted as a function of the height (or thickness) in the atmosphere. The height and the thickness as well are always given in vertical direction to make a comparison between different zenith angles more clear. The charge particles with energy above threshold are the source of Cherenkov light production and one may see in **Fig.2b,2d,3b,3d** from which part of the atmosphere is coming most of light. Two investigated energies are presented: the smallest 5 GeV and the highest 100 GeV, because the distributions are smoothly changing between them. In the 5 GeV case **.Fig.2a, 2c** there is not charge particles on the observation level (even below 5 km a.s.l) and what is consistent on this level there is not Cherenkov photons creation. The distance between shower maximum and the observer is increasing with the zenith angle for the same primary energy. In vertical 100 GeV γ **Fig.3a,3c** one charged particle (in average) is reaching the telescope level and in consequence also just above a ground Cherenkov light is created. For larger zenith angles (40^o and more) shower developed up to the end in the thicker atmosphere.

3 The lateral density distribution

The information provided by the CORSIKA code on the Cherenkov light from the shower gives us a possibility to calculate lateral density distribution. Atmospheric absorptions [3] (Mie, Reylegh and Ozone) were taken into account for each individual photon. There is average spectrum of Cherenkov light in **Fig.4a**, which we may expected on observation level in comparison with created spectrum. As an example 5 GeV γ was chosen. The average total transmission for all simulated energies and zenith angles were calculated and plotted in **Fig.4b**. The simulations show that average total transmission of the light from the shower is almost energy independent on investigated energy range, but it decreases with zenith angle (form 0.7 for vertical up to 0,4 for 70^o zenith angle). The average lateral density distributions were calculated on the plane perpendicular to the axis of shower for distances up to 600 m from the core. A three kinds of fluctuations were tested for three different area of the mirror dish: $1m^2$, MAGIC - $225m^2$ and $729m^2$. In each case the RMS of the density have been obtained from the total number of photons which hit detector at fixed position. In **Fig.5, 6** one may find examples of the results for γ at primary energy 5 GeV and 100 GeV respectively The fluctuations are higher in $1m^2$ case then in the mirror Magic case as it was expected, but there is almost no differences between 225 and 729 m^2. Increasing the area of the telescope dish form 225 m^2 up 729 m^2 does not make a fluctuations of the density smaller. For the primary energy 100 GeV the fluctuations are higher close to the core for low zenith angles. This fact can be explain by the longitudinal development of the shower. Additional fluctuations come from the light created close to observation level - they are connected with occurrence of some charge particles at the detector level. There is (if accidentally something survived) only a few of them, but they already change the slope of the lateral density close to the shower axis.

3.1 The comparison of lateral density at the same zenith angle

Figure 7 show the comparison between lateral density distributions obtained from simulation at the same zenith angles. Shapes of the distributions are similar for one zenith angle and the curves seems to be parallel on logarithmic scale. The distance to a peak position is increasing with zenith angle from 120 m for vertical cascades up to more them 300 m for zenith 70^o. The relative fluctuations of the density calculated from the 729 m^2 detector are plotted next figure **Fig.8**. This quantity is smaller for higher primary energy at the distances larger then peak position. In smaller distances case the relative fluctuations may be larger for higher energies if some charge particle can reach a ground. This effect is visible for 0^o and 25^o for 100 GeV and 50 GeV only.

3.2 The comparison of lateral density at the same primary energy

The influence of zenith angle on lateral density distribution is included in **Fig.9**. The flat part of the density is decreaasing with the zenith because of two reasons. First because shower has developed higher in the atmosphere and second because the atmospheric absorption is stronger for larger zenith angles. The relative fluctuations of the lateral density at the same energy have been compared in **Fig.10**. The results look quite strange, at large distances for one primary energy, relative fluctuations are comparable for simulated zenith angles (except 70^o) and they are getting smaller for higher energy (from level 0.7 for 5 GeV up to 0.2 at 100 GeV. Distances below a peak do not show this variability even for very low energy (when there are not charge particles close to telescope). Why the relative fluctuctions level is higher for lower zenith angle? Because the influence of Earth magnetic Field on the shower is not negligible. The shower has been more effected by Magnetic Field (MF) if its axis has been more inclined from direction of MF. The direction of MF on La Palma is about 38^o from horizon , it means that this is 52 deg from zenith direction. Simulations were done for 0, 25, 40, 50 and 70deg zenith angle and 0 deg azimuth angle what correspond to 52,27,12,2 and 18 deg angle between MF and shower axis respectively (see also **Fig.11e**. The relative fluctuations at the same energy are strongly correlated with this angle and one may conclude that they are the smallest for zenith angle around 50^o . The effect of MF influence on fluctuations of lateral density distribution is better visible for very low energy (like 5 or 10 GeV), for higher energy the shower development plays essential role (see **Fig.10e** and compare 0 and 25^o - they almost do not differ. The role of MF in lateral density distribution of Cherenkov photons was investigated by Raquel de los Reyes and Luis Jose Contreras and the same results were obtained also now (**Fig.11a,b,c,d**), where for four zenith angles four different azimuth were simulated. The lateral density in the flat part of distribution dependent on angle between MF and shower axis.

4 Conclusions

For very low energy γ there is any charge particles on the observation level, so we may say that atmosphere seems to be "full calorimeter"for this kind of cosmic rays. One may find some charge particles at low zenith angles for primary energy starting from 50 GeV. The total number of Cherenkov photons created in the atmosphere is proportional to the primary energy and also depend on zenith angle - for large zenith angle secondary electrons and positrons which penetrate atmosphere may be below a threshold for Cherenkov light production. The simulations show that average total transmission of all the photons in the shower is almost energy independent in investigated energy range, but it decreases with zenith angle. The average lateral density distributions calculated from simulations have shapes like they were expected. The fluctucions of Cherenkov photons density obtained from Magic and $729m^2$ are almost the same. The relative fluctuations of the density (for fixed direction of the shower) are higher for lower energy if distances are below peak position. In the smaller distances case the level of this fluctuations depend on possibility of existing charge particle on telescope level. For fixed primary energy we may conclude: the fluctuations are determined by zenith angle throw:
- the longitudinal development,
- influence of Earth Magnetic Field.

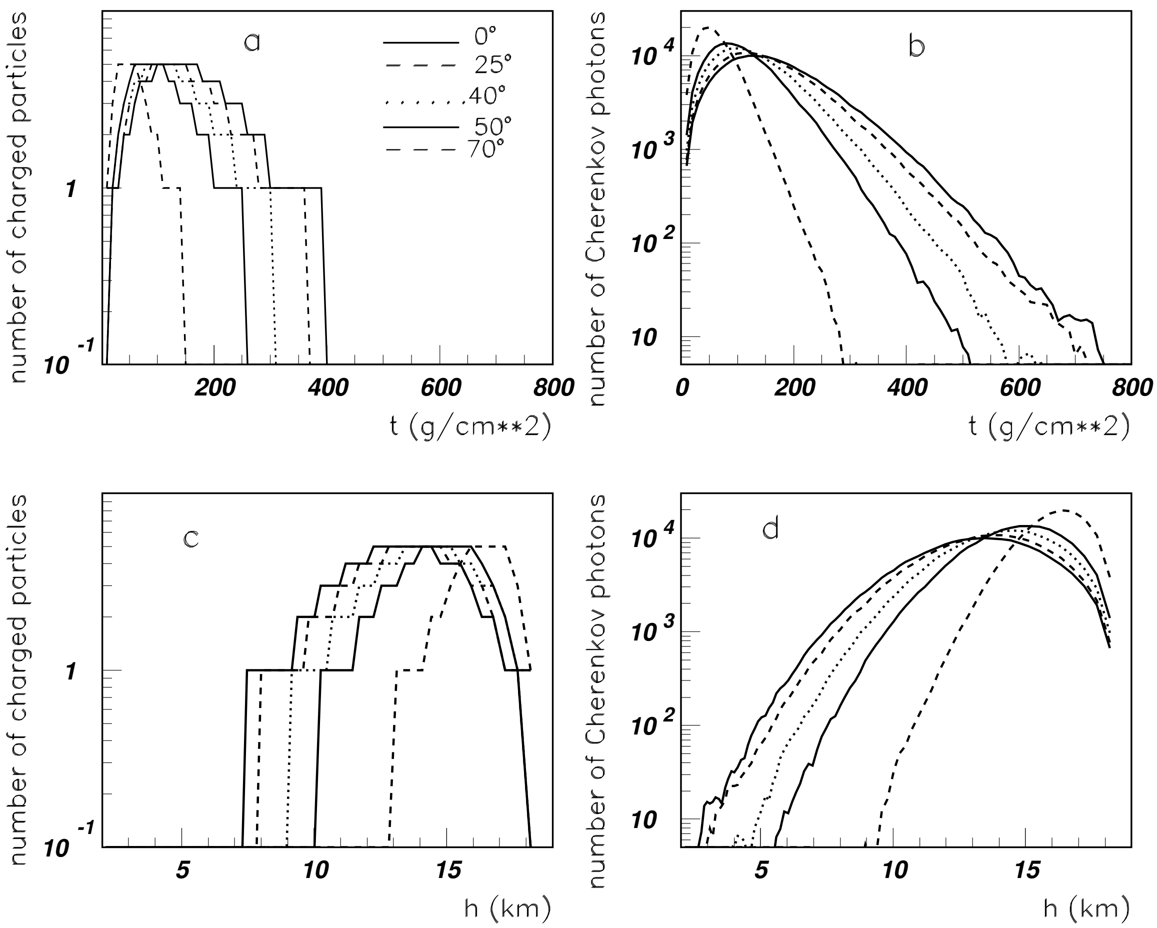

Figure 2: The longitudinal distributions for 5 GeV γ for a few zenith angles : **a)** the average number of charge particles versus thickness; **b)** the average number of Cherenkov photons versus thickness; **c)** the average number of charge particles versus height; **d)** the average number of Cherenkov photons versus height in the atmosphere. Thickness and height are measured in vertical direction.

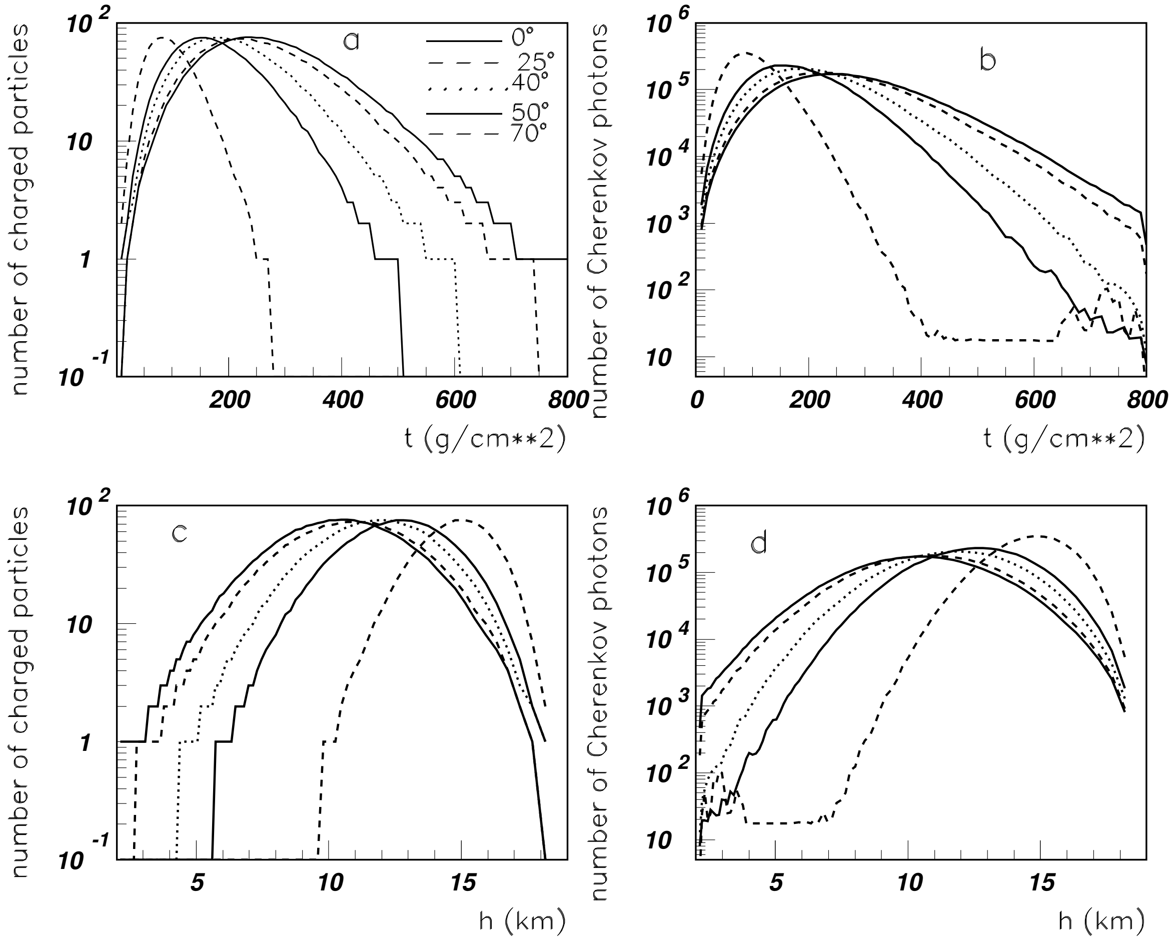

Figure 3: The longitudinal distributions for 100 GeV γ for a few zenith angles : **a)** the average number of charge particles versus thickness; **b)** the average number of Cherenkov photons versus thickness; **c)** the average number of charge particles versus height; **d)** the average number of Cherenkov photons versus height in the atmosphere. Thickness and height are measured in vertical direction.

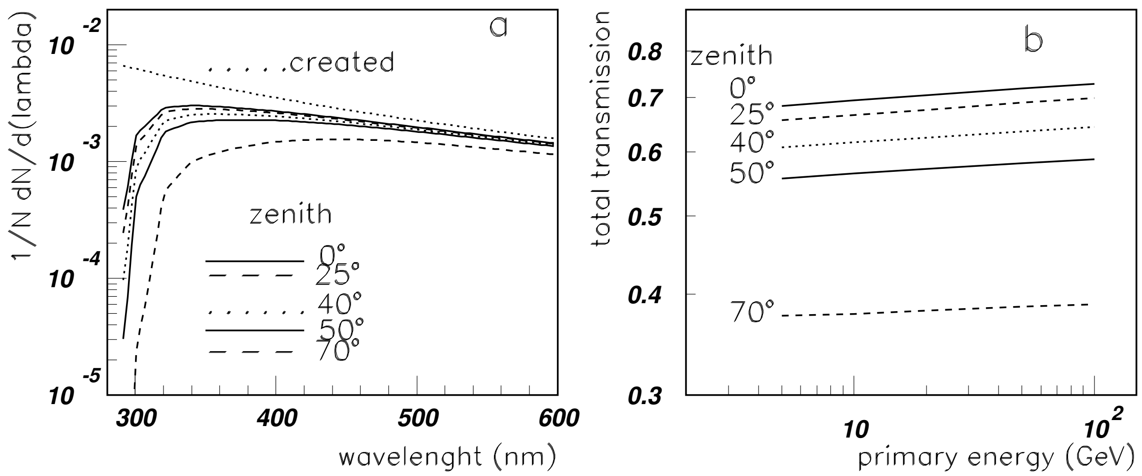

Figure 4: **a)** The average spectrum of Cherenkov photons after atmospheric absorption from 5 GeV γ at different zenith angles . **b)** The average total transmission versus the primary energy at different zenith angles.

References

[1] D. Heck and J. Knapp, EAS Simulation with CORSIKA: A User's Manual, 2002.

[2] Sobczyńska D. Mmcs from CORSIKA 6.014MAGIC TDAS 02-10, 2002

[3] Moralejo A. Reflector Simulation program - MAGIC TDAS 02-05, 2002

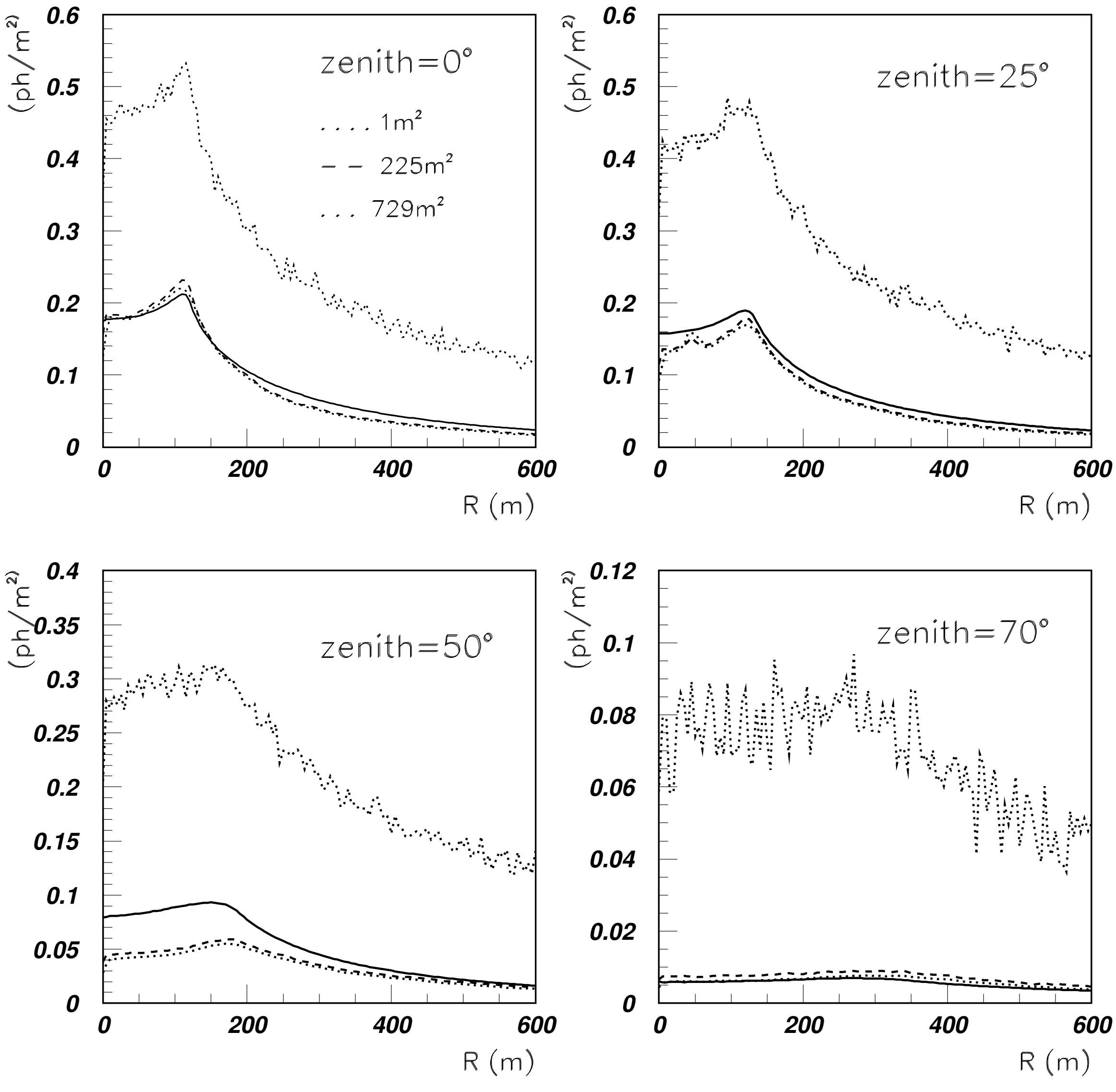

Figure 5: The average lateral density distributions from 5 GeV γ at different zenith angles (solid lines) and the calculated RMS of the density obtained from different area detectors.

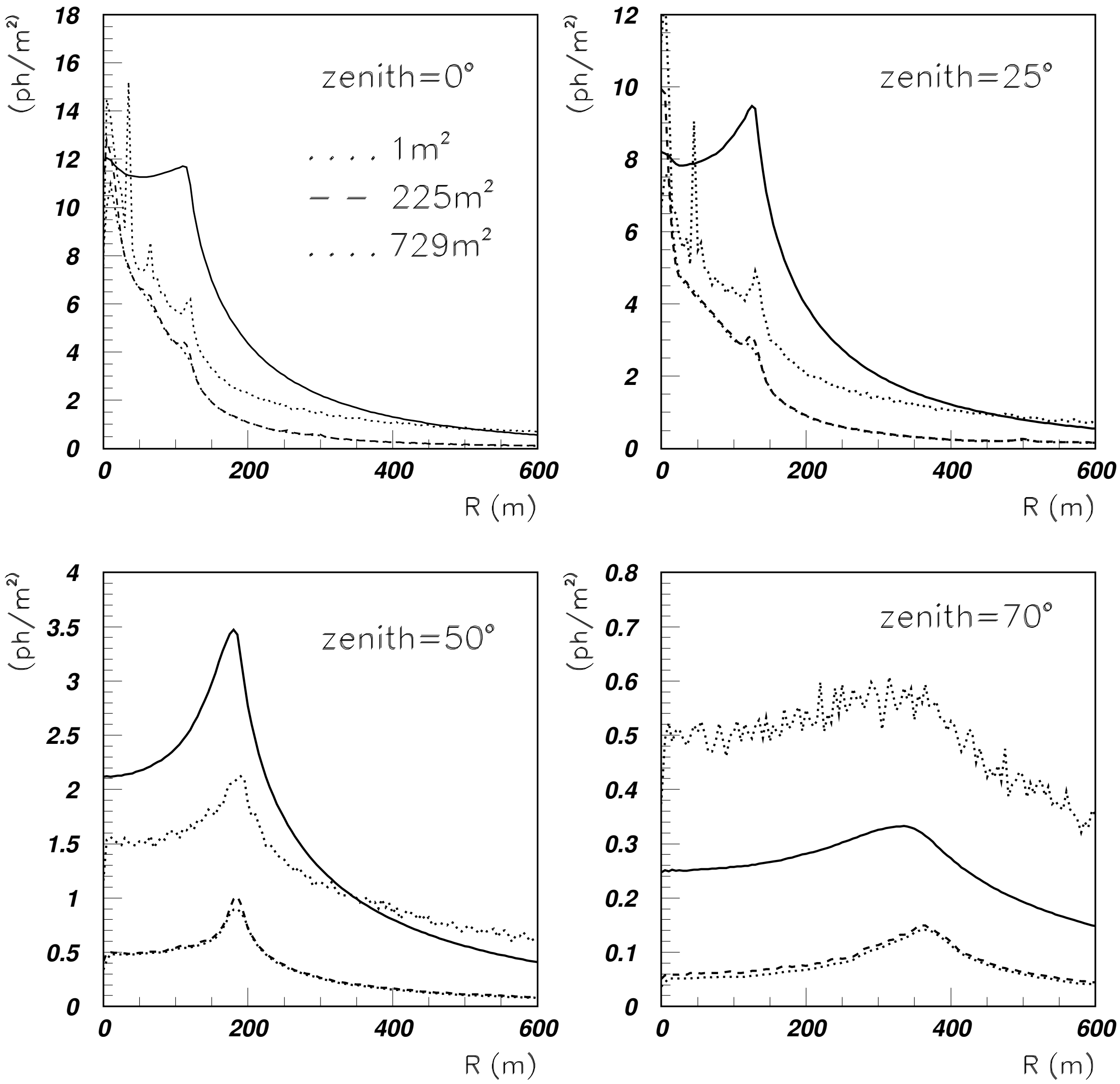

Figure 6: The average lateral density distributions from 100 GeV γ at different zenith angles (solid lines) and the calculated RMS of the density obtained from different area detectors.

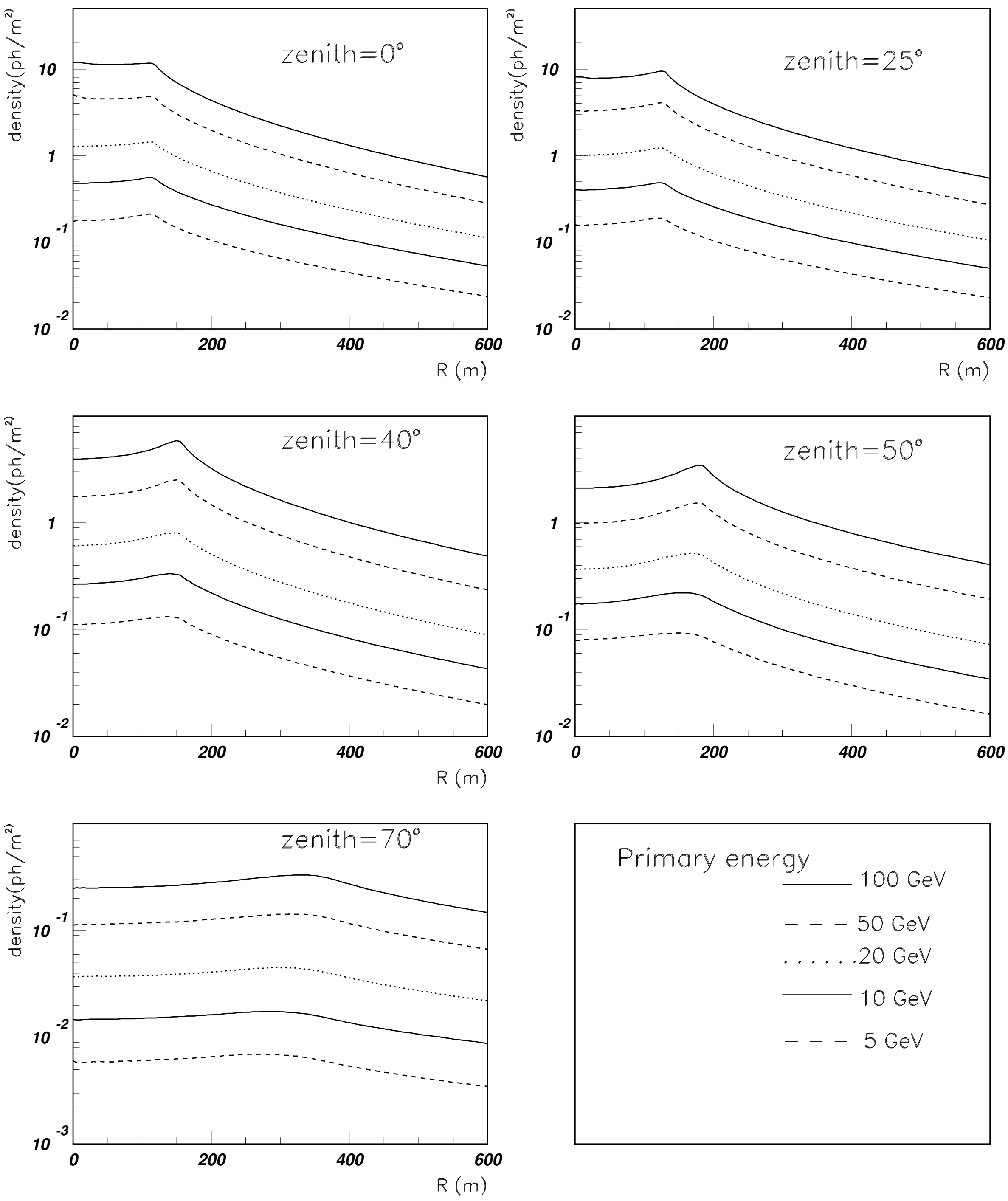

Figure 7: The average lateral density distributions from γ's at fixed zenith angles.

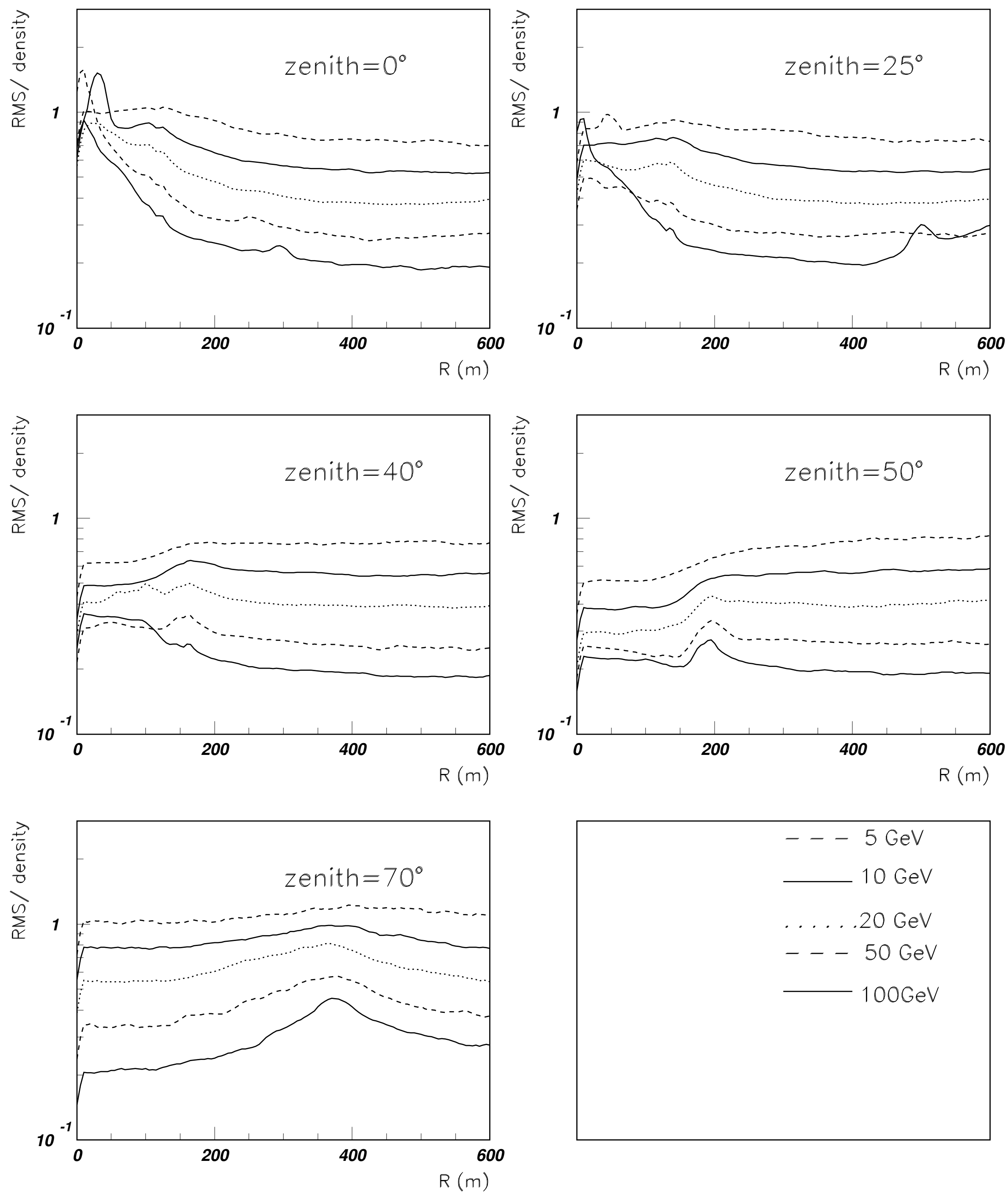

Figure 8: The relative fluctuations of the density obtained from telescope (area 729 m^2) at fixed zenith angles.

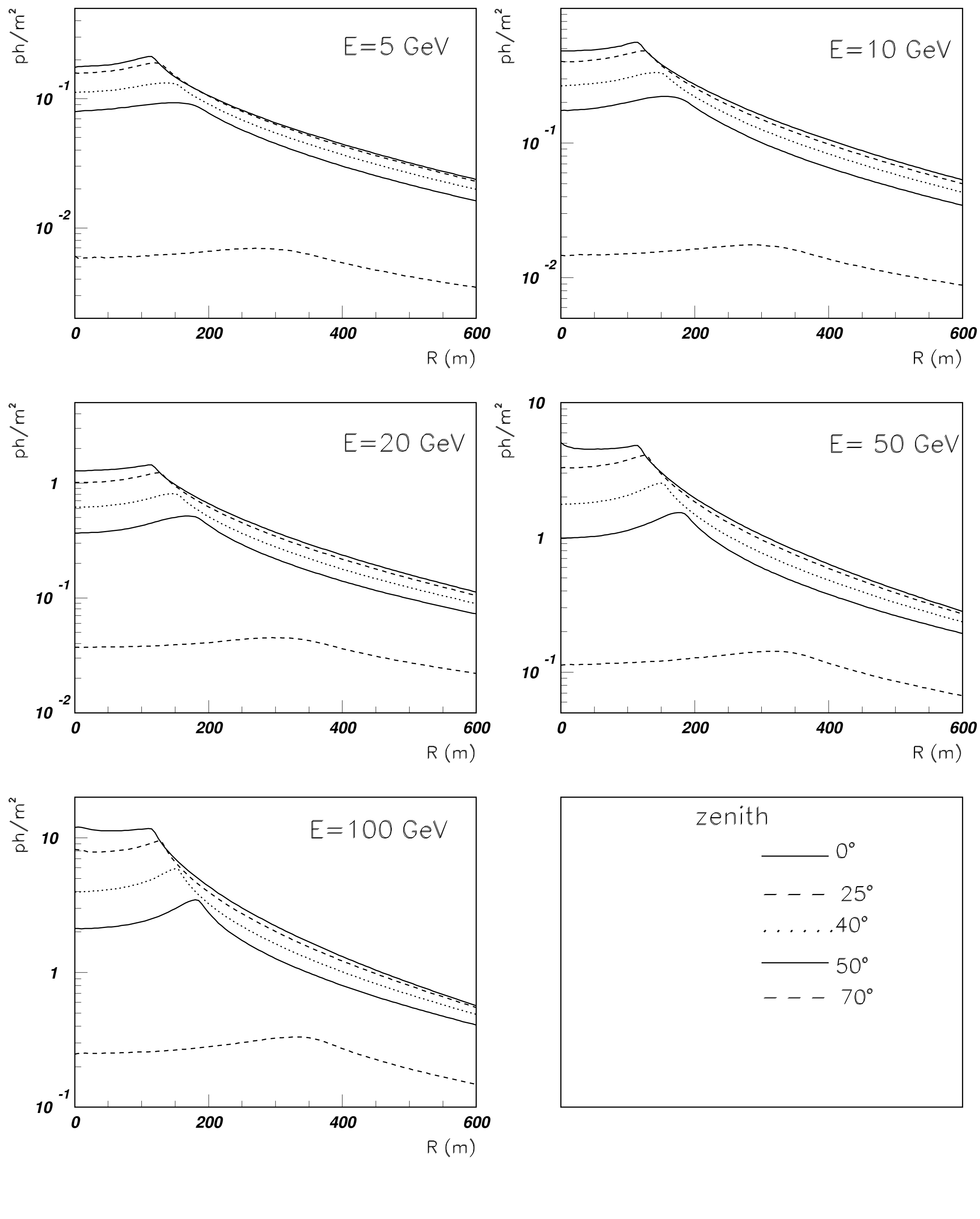

Figure 9: The average lateral density distributions at fixed energy for different zenith angles

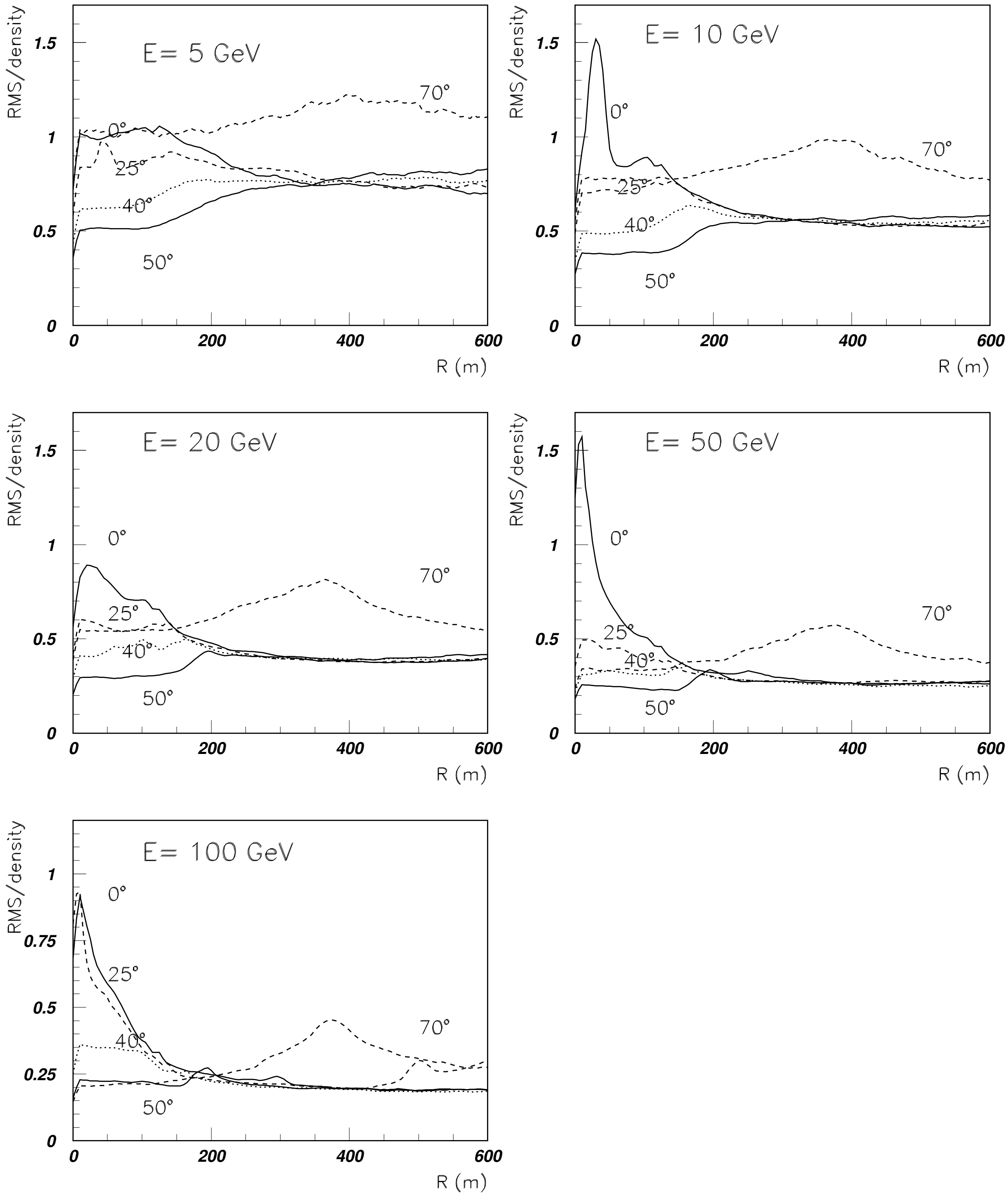

Figure 10: The relative fluctuations of the density obtained from telescope (area 729 m^2) at fixed primary energies.

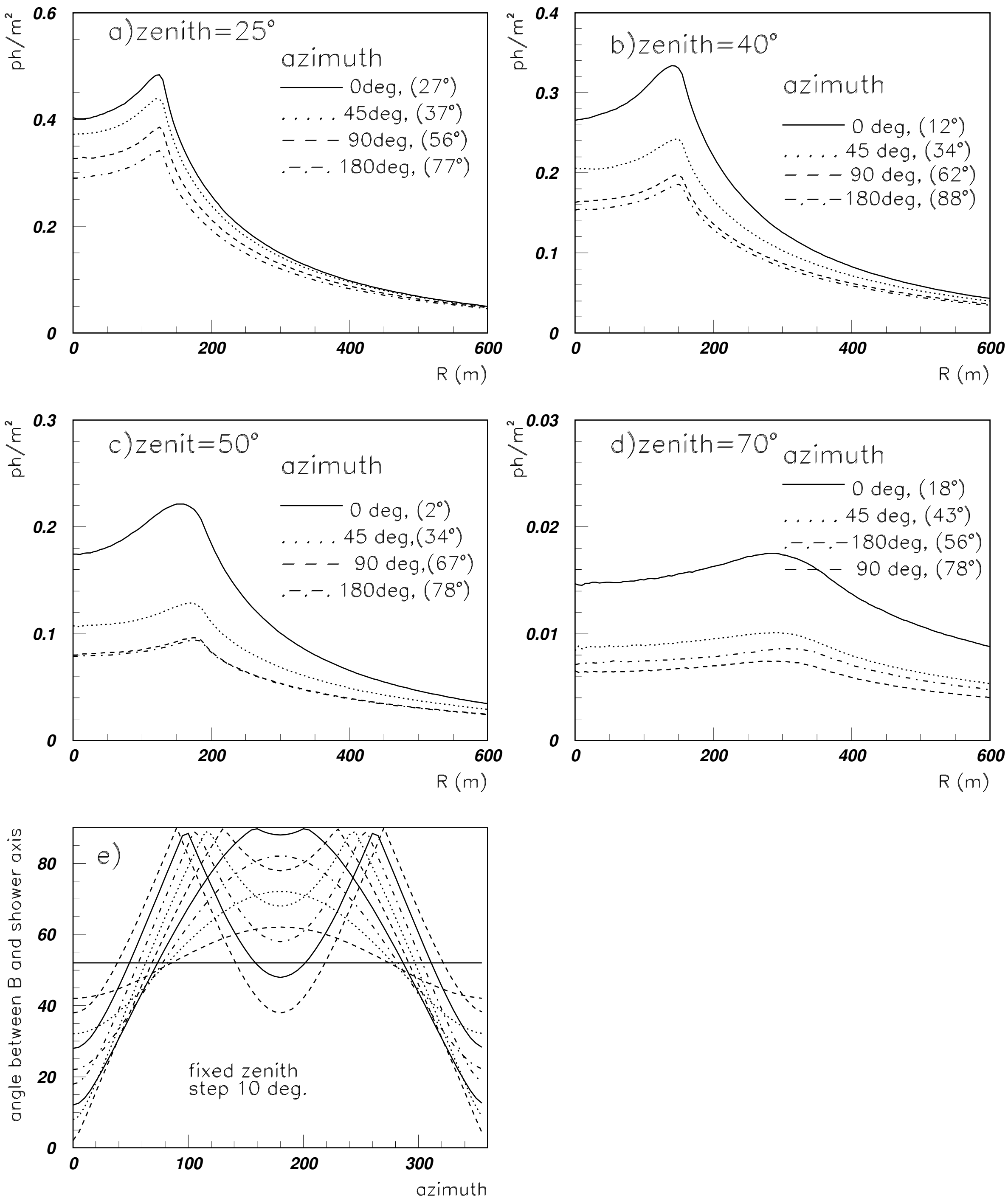

Figure 11: The average lateral density distribution for 10 GeV γ's coming from different directions (**a, b, c, d**). Values in the brackets show to angle between MF and shower axis. **e)**The angle between magnetic field direction on La Palma and shower axis versus azimuthal angle for fixed zenith.The horizontal solid line is done for vertical cascades, the rest is made with 10^o step of zenith.