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Fluctuations of particle density in Giant Air Showers

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Abstract. We had performed simulations of shower development using CORSIKA v.5.624 code for primary protons, iron nuclei and gammas with energies 10^{11} GeV/nucleon with thinning factor 10^{-6}. We studied fluctuations of main Giant Air Showers (GAS) components density and their dependence on the distance from the shower core. Consequences for future UHE showers measurements are discussed.

1 Introduction

Basing on the simulation results we examine fluctuations of density distribution of different particle types in GAS. We present lateral distribution of fluctuations between particle densities from different GAS. We acknowledge the $\varrho(600\,m)$ as a practical "energy estimator" (Hillas (1971)).

2 Simulations

We have performed simulations for primary proton, iron and gamma with energy 10^{11} GeV, 10 GAS for each zenith angle $0°$, $10°$, $20°$, and $40°$. We use CORSIKA code version 5.624 with the thinning factor 10^{-6}. All those showers have been simulated with the Quark Gluon String Model (see Capdevielle et al. (2000) for details). The respective energy thresholds were 3 MeV for electrons and photons and 300 MeV for muons. Observation level has been chosen at 1400 m a.s.l. Lateral density distribution in $log_{10}(r/1m)$ scale was obtained using relation:

$$\varrho(r) = \frac{1}{2\pi} \cdot \frac{1}{ln10} \cdot \frac{\Delta N}{\Delta(log_{10} r)} \cdot \frac{1}{r^2} \qquad (1)$$

We use $\Delta(log_{10} r) = 0.1$.
The variance σ^2 was calculated in every distance bin in classical way

$$\sigma^2 = \frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(\varrho_i(r) - \overline{\varrho(r)}\right)^2$$

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where $\overline{\varrho(r)}$ is an average density for all n showers in a distance bin. We do not include statistical variations which depend on the average predicted number of particle in the detector (product of detector size and particle density). Statistical variations might dominate GAS development variation at large distances from shower core.

3 Fluctuations of GAS components

In the Figure 1 we present an example of density distribution of e^+e^-, muons, gammas and all charged ($e^+e^- + \mu$) together with their fluctuation (σ) and relative fluctuation for the case of primary particles being protons with energy 10^{20} eV and the zenith angle $\theta = 10°$. The relative fluctuations are small for distances less then about 1000 m from the GAS core. This is generaly true for all set of simulations (primary protons, iron nuclei and gammas) and simulated zenith angles ($\theta \leq 40°$), but for primary gammas the relative fluctuations are larger at all distances. In the Figure 2 we compare the relative fluctuations (in case of primary protons) of the total number of particles in showers and of densities at distances of 600 m and 1500 m from the core. In the Figures 3 and 4 the fluctuations for muons and all charged paricles are presented for primary iron nuclei and gammas.
From our simulation results we conclude that at distances of 600 m and more, only registration of muon component (separately from electromagnetic (E-M)) can provide an opportunity to have energy estimator with an accuracy of 15% (or better in the iron case). However, as sometimes is suggested, if the higest energy C.R. are gammas then the muon content is much lower and the E-M component fluctuations exceed 50% for small zenith angles.

References

Hillas, A. M., Proc. 12^{th} ICRC, Hobart, vol. 3, p. 1001, 1971.
Capdevielle, J. N., et al,, Astroparticle Physics, 13, 259, 2000.

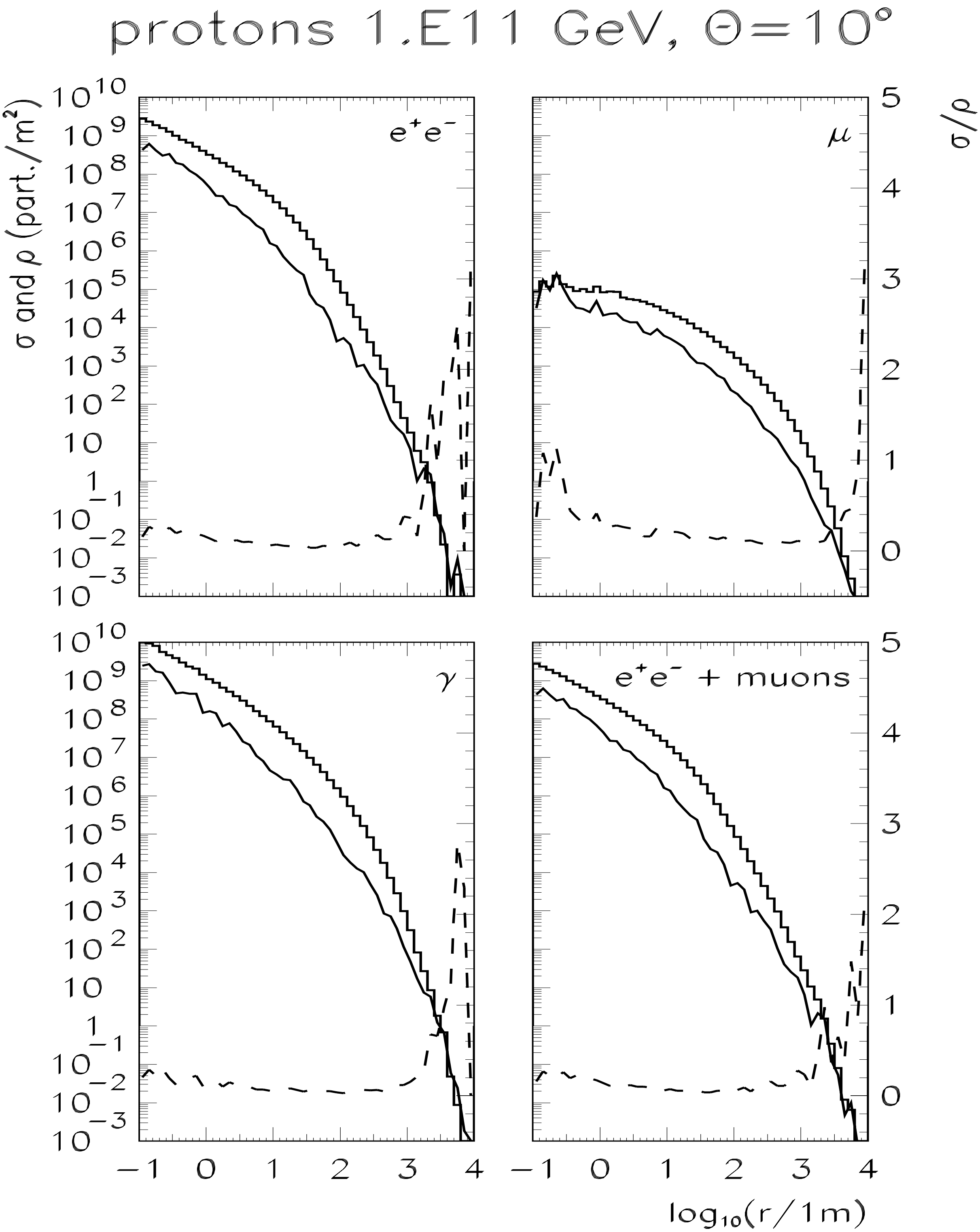

Fig. 1. Mean density ϱ (upper curves) and its fluctuation σ (lower curves) as a function of distance from the core for different GAS components; right scale and broken lines denote relative fluctuations σ/ϱ.

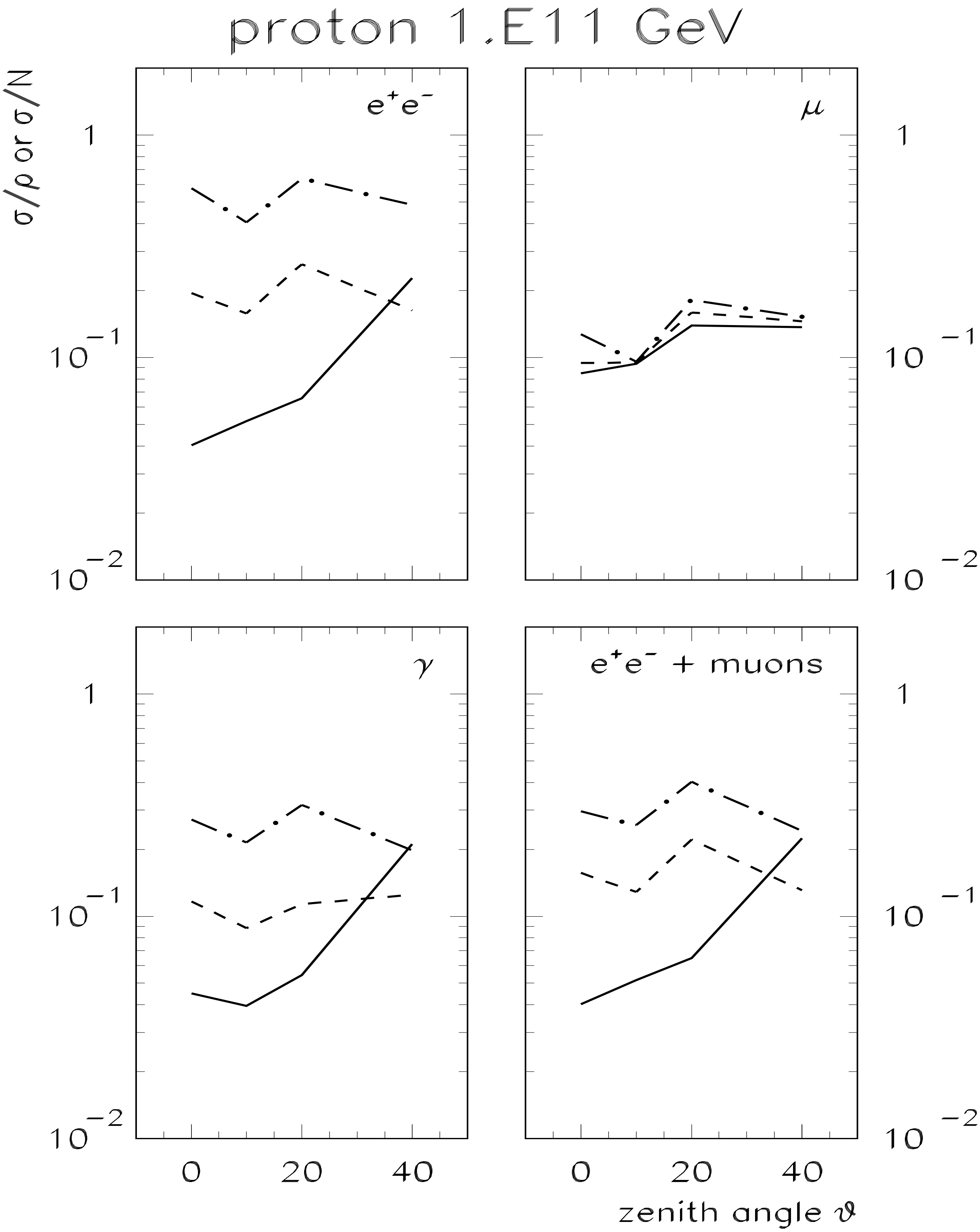

Fig. 2. Relative fluctuations vs. zenith angle. Figure presents comparison of relative fluctuations for number of particles (solid line), particle density at 600 m (short dashed line), and particle density at 1500 m (dashed–dotted line). Particle types and primary particle are indicated. Statistical variations were not included.

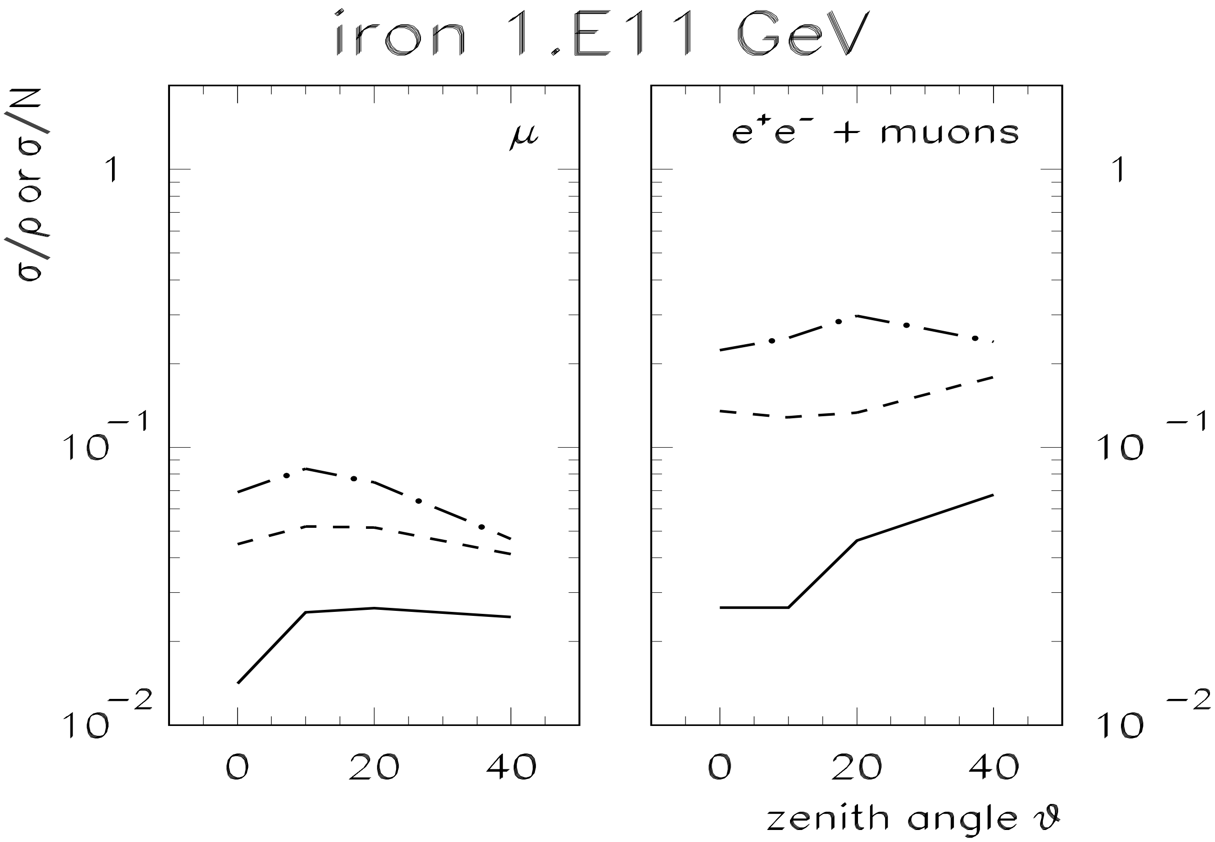

Fig. 3. Fluctuations for primary iron nuclei. Lines as in the Figure 2.

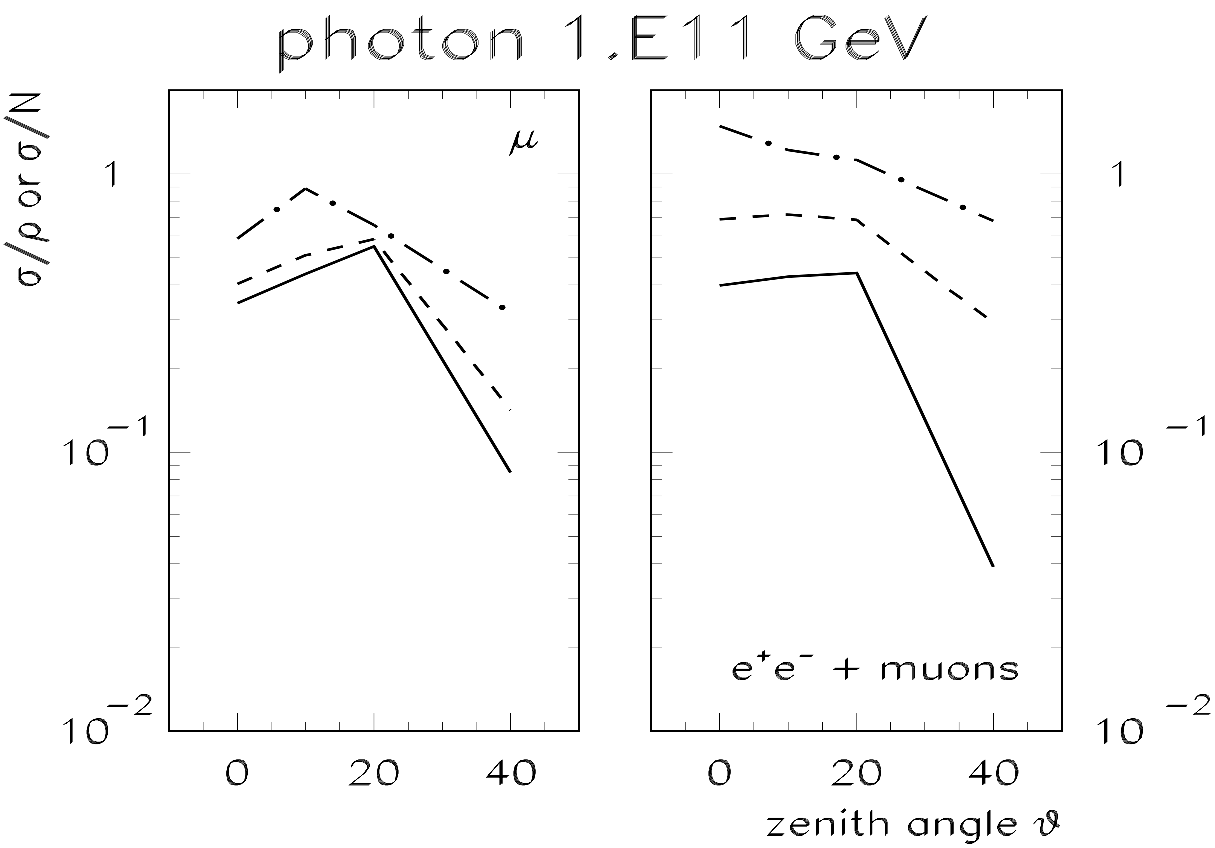

Fig. 4. Fluctuations for primary gammas. Lines as in the Figure 2.