Multiproduction at UHE and Simulation of Giant EAS

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Abstract

Simulations carried out with CORSIKA (Le Gall, 1999) in the energy range 1-100 EeV, including LPM effect show that γ's initiated showers exhibit muon electron abundances at large distances($\geq 1.5Km$ from axis) tending to be comparable at UHE to hadronic showers (compensation between the enhancement versus energy of photoproduction cross section and of the decrease of both pair production cross section and the bremsstrahlung cross section, with LPM effect). Another tendancy is the local contrast in the abundance of positive and negative muons (with a possible ellipticity in the lateral muon distribution) induced by the geomagnetic field, especially visible for some azimutal and zenith angles ; those distorsions more intense for heavy primaries can be exploited on the most favourable horizontal axis or areas, for the discrimination between nuclei and protons.

1 Introduction:

We have used the version CORSIKA 5.62 (Capdevielle et al, 1992, Heck et al.,1998) with the option QGSJET as the unique hadron interaction model. This preference is justified by an acceptable agreement of this model with several shower features, such as the depth of the maximum, the muon- electron abundance and the longitudinal shower profile, when compared to Fly's Eye's results(Kalmykov et al.,1997).
To limit in reasonable proportions the CPU time, we have selected the CORSIKA versions with the "thining" option. The factor defining the energy fraction, below which the thining algorithm taking into account the anterior experience with MOCCA program (Hillas, 1997) is activated, has been set at 10^{-4} , 10^{-5} , 10^{-6} and 10^{-7}. The thining procedures are used both in the EGS program and in the hadronic cascade.
As we deal with electrons and photons above 10^8 GeV, the LPM effect has been involved into the EGS option (EGS4 standard program modified for high energy cascades in the atmosphere) ; the cross sections of Bethe-Heitler for pair production and bremsstrahlung have been corrected using Migdal's formula .

2 LPM effect and muon-electron abundance

2.1 Cross sections for photoproduction and pair production One advantage of CORSIKA is that the procedure of photoproduction is added to EGS and coupled with the hadron cascade generation, using the form:

$$\sigma_{\gamma-p} = (73.7s^{0.073} + 191.7/s^{0.602})\sqrt{(1 - s_0/s)}$$

(1)

where s and s_0 are respectively the squared CMS energy and the squared threshold energy for pion production.$\sigma_{\gamma-p}$ is converted to $\sigma_{\gamma-air}$ by multiplication with $A^{0.91} = 11.44$ for Air. Branching ratio and single or multiple pion generation are taken into account as well as subsequent charge exchange and resonance production. A new equilibrium is established in the UHE asymptotic region where the photopion production becomes quite more important than at lower energies reaching in air 25 % of the pair production cross section(at an altitude of 20 Km)

2.2 Lateral spread For longitudinal components, the simulation confirms the results obtained by previous authors (maximum shifted deeper in pure e.m. cascades and small consequences on hadron or nuclear showers). It is interesting to underline, here, that a traditionnal criterium, used to distinguish γ from hadron

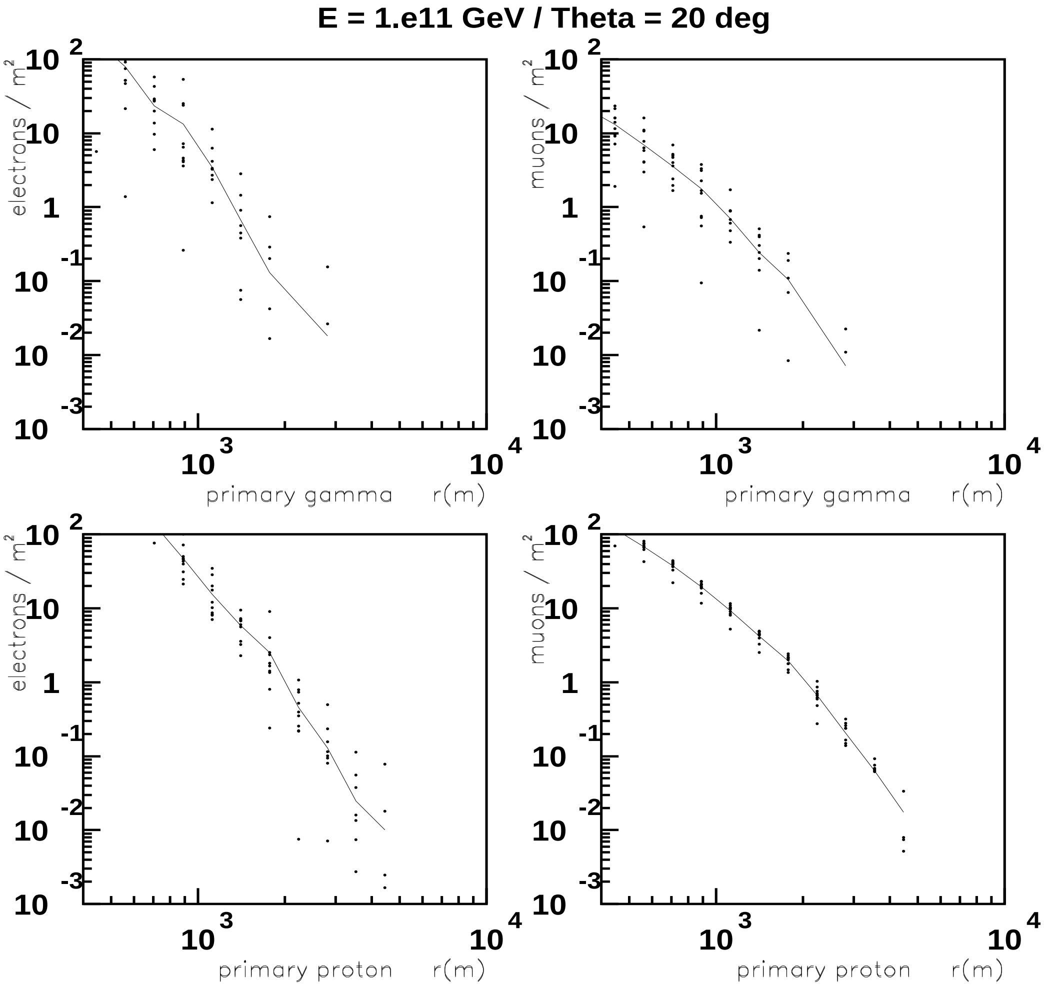

Figure 1: lateral electron and muon distributions for 10 EAS at 100 EeV

primaries, the muon poor abundance, will not work in reason of the LPM effect decreasing the lateral electron densities ; if the shower densities are collected at large distance (this is the case for giant EAS, especially for arrays with grid enlar ged up to 1500m,), the ratio of muon to electron densities are comparable. On fig.1, we can ascertain 25 % of muons (e.m.shower) at 1Km , against 30 % for a proton shower.

When very high electron densities are observed (fig.2a), the primary hadronic contribution is well separated. This corresponds to the rare circumstances where the axis is not so far from one detector (at this energy, 100 $el./m^2$ are associated respectively to core distances of 700 and 1000m) ; in ge neral, the observation will be more similar to the situation of fig. 2b (densities between 100 and $1part./m^2$).

A new equilibrium between hard and soft component is then appearing at UHE in pure e.m. shower in reason of the LPM effect, giving equivalent observable muon-electron ratio (even if the ratio of the tota l muon-electron sizes remain quite different) and the discrimination of an hypothetic e.m. background will require additive criteria , derived from the lateral electron profile or from the fluorescence.

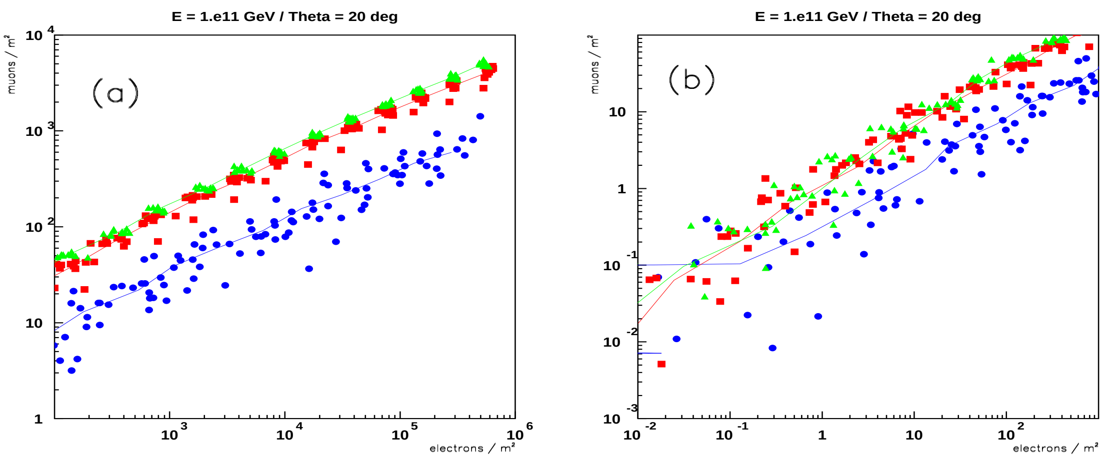

Figure 2: scatter plot of muon and electron densities for 10 EAS at 100 EeV for γ primaries ($\circ$), proton ($\triangle$), iron ($\Box$) primaries

3 Muon component and geomagnetic field

One advantage of CORSIKA is that particles and antiparticles are followed individually : such is the case of positive and negative muons that we can distinguish during the propagation in the atmosphere, as well as at the arrival of the penetrating component at ground level. The deflection of the muons during their propagation involves the multiple Coulomb scatte ring and the curvature of the trajectories, as for all the charged particles of the simulation, in the Earth's magnetic field.

In order to point out some typical signature of the primary particle in the contrast of the proper ties of positive and negative particles, we have calculated in each shower the coordinates of positive and negative particles barycenters, $\delta_{\mu\mu}$, and the orientation, $\phi_{\mu\mu}$ for muons , of this dipole in azimutal angle. Any kind of coherence is destroyed in the case of the soft component , the lateral spread being dominated by the multiple coulomb scattering, preventing any possibility of sorting in the magnetic field ;

On the contrary, for muons, especially for heavy nuclei initiated showers, where the muons start at higher altitude, with comparatively, lower energies than for proton primaries, one barycenter separation by 200m has been obtained at UHE, for vertical showers and iron primaries, using a thining factor 10^{-6}. This separation, more clear in the case of nuclei, appears also connected with the statistical reduction of the fluctuations of showers initiated by nuclei.

To eliminate any possible bias generated by the thining technique and understand more rapidly the benefit of this geomagnetic effect, a sample of several hundred showers without thining, for muons with energies exceeding 300 MeV, has been simulated and some systematic features have emerged. For near vertical showers , at $10^6 GeV$, the orientation to East-West direction of the dipole and the net barycenter separation by 100m in favour of iron initiated showers is clear, whatever may be the azimutal incidence.

For a zenith angle of $40°$, the situation is emphasized with a separation of 200 m for showers coming from East or West.

One tremendous barycenter separation by 500m is obtained in the case of very inclined showers ($\Theta = 55°$).

Complementary simulations up to $10^9 GeV$ without thining confirmed those general circumstances, the separation δ, being divided by about a factor 2 when rising the energy on those 4 decades f or both iron and proton primaries (in reason of the increase of the average muon longitudinal momentu m).

The discrimination between heavy and light nuclei at UHE can be carried on both directions:

- ratio of μ^+,μ^- at convenient distances
- ellipticity of the muon component

.At PAO energies, we can make a rapid illustration of the geomagnetic effect of the muon component using the muon lateral distribution function $\rho_\mu(r)$ employed for giant showers in Akeno , assuming that one half of the muon content (positive and negative) is distributed around each barycenter with a cylindrical symmetry For $\delta_{\mu\mu} = 200m$, the average ratio of positive to negative muons densities on the axis defined by the dipole will give one charge excess characterized by a factor 3 at 500m from axis, decreasing slowly to an excess by a factor 2 near 1000m and an excess of 60% at 2000m (turning to a symetric excess of negative muons in the opposite direction and equal charge densities on the axis perpendicular to the dipole). Those charge excess are emphasized for inclined showers propagating near a vertical East-West plane where we obtain for $\delta_{\mu\mu} = 400m$ respective ratio of 9.5, 4.8 and 2.5.
Alternatively, in the absence of detectors for muon charge identification, we introduce the ellipticity factor $\epsilon(r) = \rho_{\mu//}(r)/\rho_{\mu\perp}(r)$, ratio of total muon densities at the same dist ance from the shower axis , on one axis oriented along the muonic dipole and on the axis perpendicular in t he core center. For $\delta_{\mu\mu} = 200m$, ϵ is equal respectively to 1.53 , 1.19, 1.10 at 2 50, 500, 1000m from the shower axis.Again, for inclined showers of incoming directions close to a vertical East-West plane, when $\delta_{\mu\mu} = 400m$,ϵ rises respectively to 6.0, 1.92, 1.39, remaining larger than 1.35 at 2000m. All the muon densities and distances have been taken here in the plane perpendicular to the shower axis.

At present, we have confirmed this synopsis inspired by the analytical approach by our Monte Carlo data , after comparing the positive (or negative) muon charge excess in 4 sectors delimited by the diagonals in the frame determined by the muonic dipole and the axis perpendicular in shower axis ; the demonstration of the elliptical properties or of the e xistence of typical delays in signals correlated with positive and negative muons require a larger statistics with a s maller (or without) thining.

4 Conclusion

The special phenomenology devoted to the propagation of UHE particles, including the LPM effect, indicates some limitations in the case of γ's initiated showers ; at large distance from axis, the ratio of muon to electron densities becomes comparable and it becomes more difficult to have a reliable estimator of primary energy. This difficulty is reduced as far as primary γ's at UHE are not expected to penetrate in the atmosphere.
Another interesting observation is that the geomagnetic field can help the discrimination between heavy nuclei and proton by the lateral muon distribution ellipticity and the charge excess in muon densities. This requests observations in two pairs of sectors (both centered on shower axis),the former oriented along the dipole defined by the barycenters of positive and negative muons, the latter perpendicular ; such topologic discrimination will become more efficient by selecting the proportion of showers with incoming direction close to the vertical plane perpendicular to the Earth magnetic field .

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