1η ΗΜΕΡΙΔΑ ΠΑΡΟΥΣΙΑΣΗΣ ΕΡΕΥΝΗΤΙΚΩΝ ΔΡΑΣΤΗΡΙΟΤΗΤΩΝ ΠΜΣ ΤΜΗΜΑΤΟΣ ΦΥΣΙΚΗΣ

Καταιγισμοί ατμοσφαιρικών σωματιδίων

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Τομέας Πυρηνικής Φυσικής και Φυσικής Στοιχειωδών Σωματιδίων

Numerical study of the electron lateral distribution in atmospheric showers of high energy cosmic rays

The study of the lateral distribution of electrons in an atmospheric cascade can lead to useful conclusions on the mass and energy of the primary cosmic particle. In this work we compare the results we get from simulations by the CORSIKA program, with the theoretical NKG function expressing the lateral distribution of electrons. We then modify the original NKG function to fit better the data of the simulation. Finally, we propose this procedure as a method to approach the mass of the primary particle which started the atmospheric cascade.

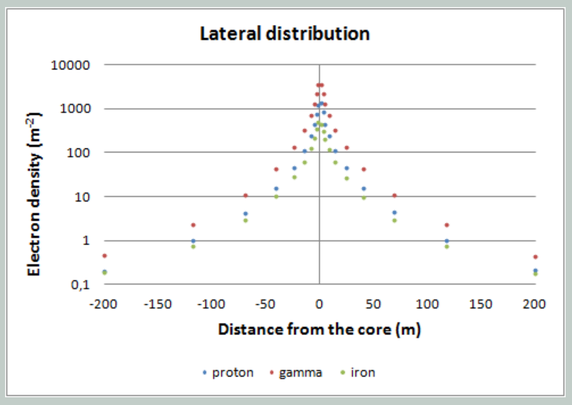
The Simulation

In this paper, for each entry angle we ran 100 simulations with fixed primary particle energy and of zenith angles varying from 0 to 75 degrees. The results obtained as the mean value of all simulations for each particle. The corresponding errors are due to the limited number of events in the Monte Carlo simulation.
The cutoff energy for the particles, i.e. the energy under which the program stops giving the particle interactions, was 0.3 GeV (hadrons, muons) and 0.015 GeV (electrons, photons).
The lateral distribution of the electrons has been measured from the core of the cascade at an altitude of 110 m above sea level (observation level).
The first section of the present study was made for particles with primary energy 10^7 GeV (proton, photon and iron nuclei) and for different zenith angles θ.
The azimuth angle was kept constant (φ = 0 degrees, φ =20 degrees and φ =60 degrees). The second section of the present study was made for particles with primary energy 10^7 GeV (proton and nuclei of helium, oxygen, silicon, calcium and iron) and for entry zenith angle 20 degrees. The azimuth angle was kept constant (φ = 0 degrees) in all cascades. In this section, we modified the NKG function to fit best to our results and drew conclusions about the dependence of the exponent s from the mass of the primary particle.

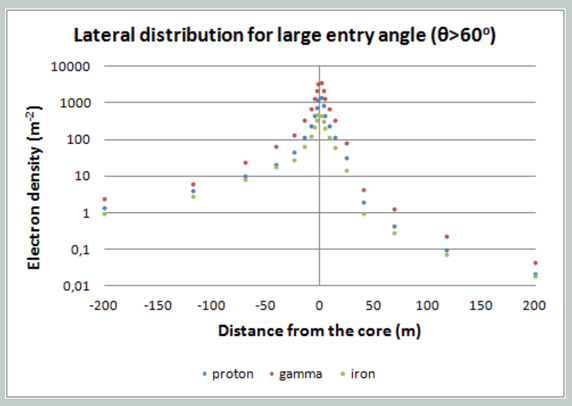
Results

Compare of the lateral distribution of electrons for different primary particle and at different angles.

When the entry angle θ is small $0^o<\theta<20^o$ the differences of lateral distribution (of electrons arriving at the observation plane and the electrons arriving at the plane perpendicular to the axis of the cascade) are small. The diagram below shows that there is symmetry around the center of the cascade (in a plane perpendicular to the axis of the cascade).

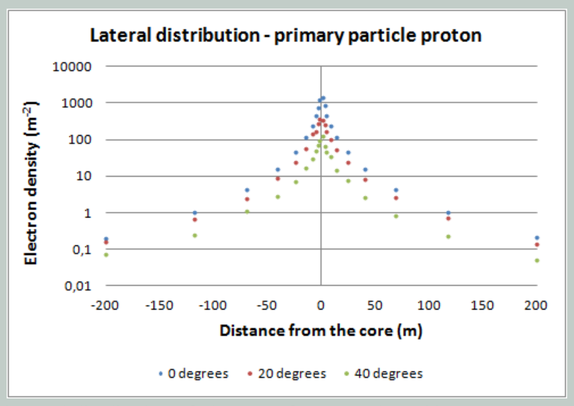


Lateral distribution of electrons for cascades of primary particles proton, photon and iron nuclei with primary energy 10^7 GeV and entry angle 0 degrees.



In large entry angles θ>60° for electrons arriving at observation level there is no symmetry. The cascade develops differently in the lateral plane.

Compare of the lateral distribution of electrons on the same original particle and at different angles.



Lateral distribution of electrons for cascades with a proton primary particle with primary energy 10^7 GeV and entry angles 0, 20 and 40 degrees.

Electromagnetic Shower

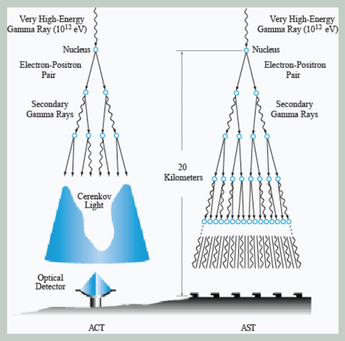
Atmospheric shower simulation with Corsika

- Primary particle – gamma ray photon.
- Three sets of showers. Every set has 10 showers.
- The primary particle energy is.

First set →	10 TeV
Second set →	40 TeV
Third set →	70 TeV

- Zenith angle → 20 deg.
- Azimuth angle → from -180 to 180 deg.
- Observation level → 110m above sea level.
- The results are average values for each set of shower.

Detection



✓ Interact in the upper atmosphere

✓ Generates an atmospheric shower

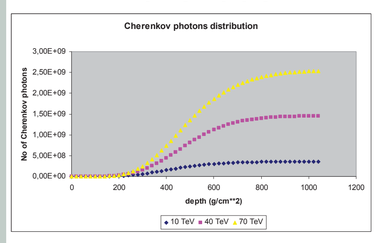
✓ Consisting mainly of electrons, positrons and photons

✓ Production of Cherenkov photons

✓ Detection of Cherenkov photons

✓ Detection of charged particles

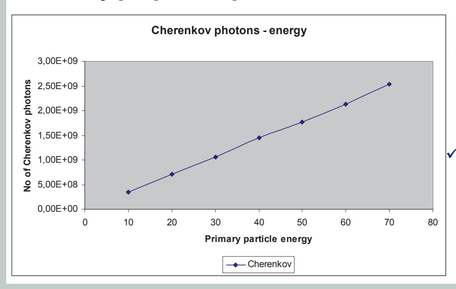
Παραγωγή φωτονίων Cherenkov



✓ Φωτόνια Cherenkov που παράγονται σε όλα τα ύψη φτάνουν στο επίπεδο παρατήρησης

✓ Σε μεγάλα βάθη ο αριθμός των φωτονίων Cherenkov που δημιουργείται είναι μικρός και έτσι ο ολικός αριθμός τείνει να γίνει σταθερός

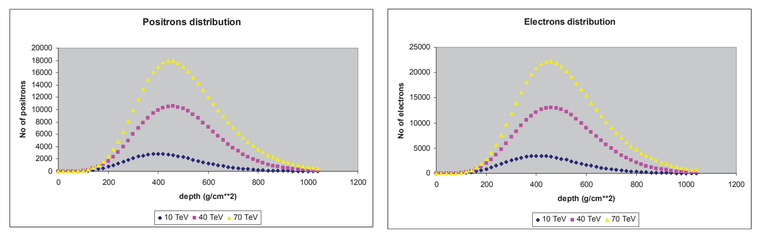
Αύξηση των φωτονίων Cherenkov με την ενέργεια



✓ Αριθμός των φωτονίων Cherenkov που φτάνουν στο επίπεδο παρατήρησης

✓ Η αύξηση των φωτονίων Cherenko σε σχέση με την ενέργεια του αρχικ σωματιδίου είναι σχεδόν γραμμική

Κατανομή ηλεκτρονίων - ποζιτρονίων



✓ Παραγωγή ηλεκτρονίων - ποζιτρονίων

✓ Αύξηση σε ποζιτρόνια και ηλεκτρόνια

↓

Μέχρι το μέγιστο του καταιγισμού

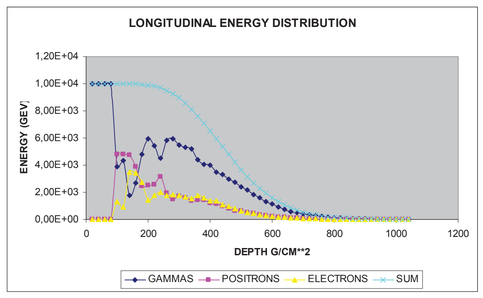
✓ Μεγάλη αρχική ενέργεια

↓

Περισσότερα ηλεκτρόνια και ποζιτρόνια

Το μέγιστο πηγαίνει βαθύτερα

Κατανομή ενέργειας



✓ Η ενέργεια του καταιγισμού

↓

Το άθροισμα των ενεργειών των σωματιδίων

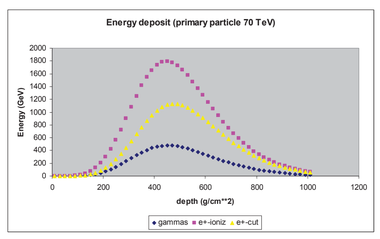
✓ Συνεχής μείωση της ενέργειας του καταιγισμού

✓ Απώλεια ενέργειας

↓

Απόθεση ενέργειας στον αέρα

Απόθεση ενέργειας



Απόθεση ενέργειας στον αέρα

✓ Σωματίδια γ (cut energy)

✓ Ηλεκτρόνια και ποζιτρόνια (ιονισμός)

✓ Ηλεκτρόνια και ποζιτρόνια (cut energy)

✓ Μέγιστο του καταιγισμού

↓

Μέγιστη απόθεση ενέργειας

Conclusions

✓ VHE cosmic gamma ray physics consolidating as a new research field in the frontier of High Energy Astrophysics and Particle Physics

✓ New installations (eg CTA) starting or in progress for the near future

✓ Hundreds of new sources expected to be discovered → High Energy Gamma-Ray Astronomy

✓ There is a broad and exciting program of High Energy Astrophysics and Fundamental Physics studies just around the corner…

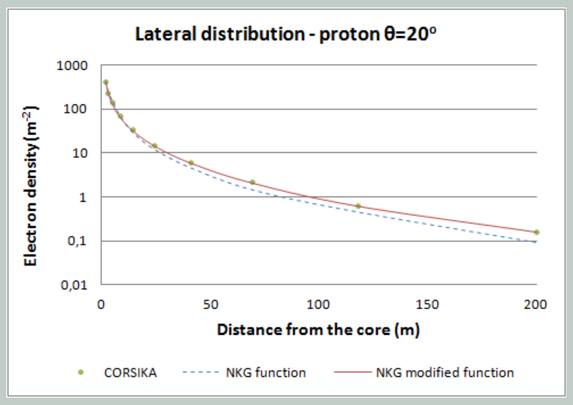
✓ In the long term, observatories based on large arrays of Cherenkov Telescopes (CTA, AGIS), should improve the sensitivity and the angular resolution, opening the way to the discovery of new types of cosmic accelerators

The NKG function

$$\rho(r) = N_e C(s)\left(\frac{r}{r_M}\right)^{s-2}\left(1+\frac{r}{r_M}\right)^{s-4.5}$$

The modified NKG function

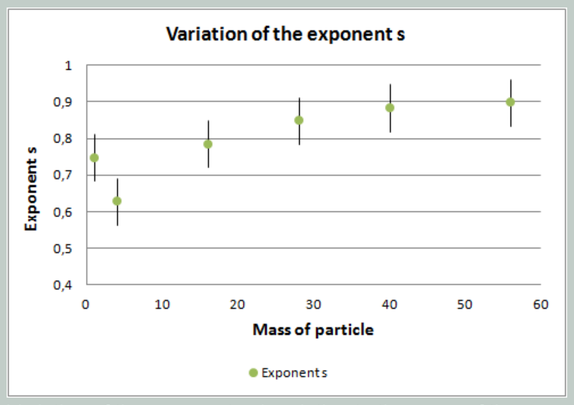
$$\rho = C\left(\frac{r}{r_o}\right)^{s-1,8}\left(1+\frac{r}{r_o}\right)^{2s-3,8}$$



Lateral distribution of electrons for cascades with a primary particle proton having primary energy 10^7 GeV and entry angle 20 degrees. The solid line represents the fitted function while the dashed represents the original.

Values of the exponent s

Particle - Nucleus	exponent s
proton	0,75±0,06
helium	0,63±0,06
oxygen	0,79±0,06
silicon	0,85±0,06
calcium	0,89±0,06
iron	0,90±0,06



Variation of the exponent s, in relation to the mass of the primary particle.

Conclusions

There is symmetry in the density of the lateral distribution of the electrons in relation to the axis of the cascade. For heavier primary nuclei the electron density decreases but the symmetry remains. But as the entry angle increases, the symmetry on a plane perpendicular to the axis of the cascade remains, while on the observation plane there is no longer symmetry on both sides of the axis of the cascade.

The lateral electron density decreases for larger entry angles. This is due to the higher absorption of electrons because of the lateral distance traveled until they reach the ground as well as the greatest height of the first interaction.

The initial NKG function describes well the lateral distribution of electrons in smaller distances from the core of the cascade. For larger distances we propose a modified NKG function.
With this modified function we can achieve better fit also at the greater distances from the core of the cascade.

Finding the parameter s of the modified NKG function that adjusts the simulation data better, we can make conclusions for the primary mass of the particle. It appears that the exponent s varies with the mass of the primary particle up to Z ≈ 18, remaining nearly constant for heavier nuclei.