# DISTINCTION BETWEEN A COSMIC RAY IRON NUCLEUS AND A PROTON BY SIMULATING EAS WITH AIRES PROGRAM

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## Abstract

The Linsley standard atmospheric model is used to simulate the atmospheric EAS due to the passage of an Ultra High Energy Cosmic Ray (UHECR, Linsley, 1977). Adopting the AIR shower Extended Simulation (AIRES) program we derived the longitudinal and lateral distribution of the secondary particles produced in the atmosphere along the path of the primary. From these distributions one can distinguish between protons and ions as an UHECR.

## Energy Spectrum of C.R.

One of the primary purposes of the Pierre Auger Project and Observatory is to study the masses of ionizing radiation, cosmic rays, which are constantly striking the earth. Due to the high occurrence of low-energy cosmic rays, they have become relatively well understood in the 80 years since the discovery of cosmic rays. However, cosmic rays at higher energies are much rarer. Also, primary cosmic rays can never be directly observed, and must be studied through the properties of the air showers which they cause in the upper atmosphere.

The Pierre Auger Observatory project (PAO) is an international collaboration of 19 countries to study the highest energy cosmic rays and explore the upper energy region of the cosmic ray energy spectrum (Fig. 1) in which the presence of cosmic ray protons and ions is prohibited according to the Greisen- Zatsepin -Kuzmin theory (Fig. 2, Greisen, 1965). Due to the fact that in this energy region about ten cosmic ray particles are observed the last decade, the PAO with its high statistics will shed light in this controversy (Dova, 2001).

Two giant detector arrays, each covering 3000 square kilometers, will be constructed in the Northern and Southern Hemispheres. The PAO has been designed to work in a hybrid detection technique.Each will consist of 1600 water cherenkov detectors and three atmospheric fluorescence detectors. The objective of the arrays is to measure the arrival direction, energy, and mass composition of cosmic rays above $10^{19}$ eV.

The first being constructed in Mendoza province, Argentina. This site is especially interesting since it will make possible to explore the part of the sky not explored yet, with a preferential view to the Galactic Center. A giant array of particle detectors will measure the lateral and temporal distribution of shower particles at ground level (Fig. 3). Air fluorescence detectors (FD) will measure the longitutinal development of the shower in the atmosphere above the surface array. The combination of both kinds of detectors to measure simultaneously the shower parameters of a subset of showers will allow higher precision in the energy and arrival direction determination and aimes at a better separation of heavy nuclei, protons and gammas.

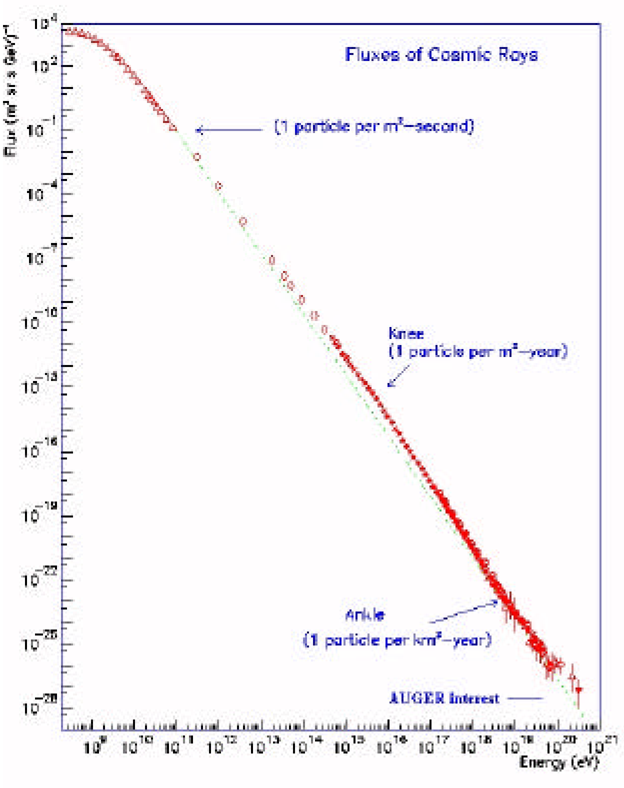


Fig. 1. The cosmic ray energy spectrum from very low to very high energies. Energies above 5x$10^{19}$ eV will explore the PAO (Hillas, 1981).

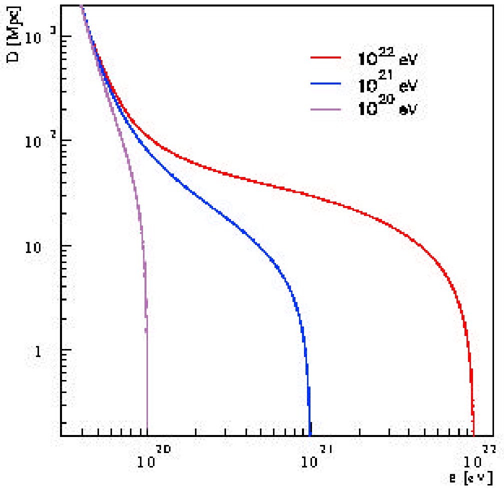


Fig. 2. Due to the fact that very high energy cosmic protons and ions loose energy interacting with the microwave background radiation giving pions, there is an energy degradation as a function of distance to the observer for 3 different injection energies (Hojvat, 1997).

## The AIRes simulation technique

A practical method to determine the shower parameters is a fitting procedure; the experimental data for a specific shower will be fitted with Monte Carlo simulated event (f. ex. with AIRES). The critical parameters (primary energy, direction and mass composition) of the simulated event will be modified untill the fit gives best results. The whole evolution of an EAS due to the high energy primary interactions with the atmospheric air is here simulated by the AIRes technique (Sciutto, 1999). The simulation takes into account among others, about 50 possible interactions, decays and energy losses of particles evolved (Fig. 4).

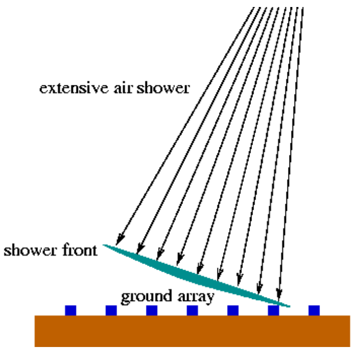
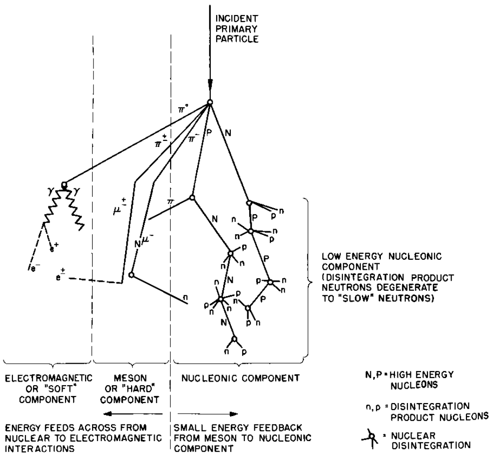


Fig. 3. The shower front considered as spherical, triggers the ground array.



Schematic Diagram of Cosmic Ray Shower

Fig. Fig. 4. The EAS which is simulated by the AIRES technique

In particular, the AIRES program takes into account the pair production, electron-positron annihilation, bremsstrahlung, Compton and photoelectric effects, Landau-Pomeranchuk-Migdal effect, particle decays, such as pions, muons; hadronic processes, such as inelastic collisions hadron-nucleus and photon-nucleus, photonuclear reactions, nuclear fragmentation, elastic and inelastic propagation of particles, such as losses of energy in the medium (ionization), multiple Coulomb scattering and geomagnetic deflections. In the present analysis 100 EAS are simulated all produced by a primary proton and iron of an energy of 100 EeV with vertical direction and zero azimuth and elevation angle. The number of 100 EAS is taken in order to reduce fluctuations. For such high energies the results are not much different for vertical directions above Mendoza. The simulations are shown in figures 5, 6 and 7.

## How can we distinguish a shower created by a primary iron nucleus or proton?

Due to the larger interaction cross section of iron nuclei with the atmosphere, the corresponding maximum of the created shower is at lower atmospheric depths compared with the maximum of the shower created by a proton. In addition, fluctuations in an iron shower longitudinal profiles are much less than for proton showers. At any fixed energy, an ensemble of proton showers must exhibit a broad range of $X_{max}$ values than an ensemble of iron showers. Information about the isotopic composition can therefore be extracted both from the mean of the $X_{max}$ distribution and from its width (Sommers, 1995). By simulating 100 iron nuclei and proton showers with an initial energy of 100 EeV, one can obtain this difference (Figs. 5 and 6).

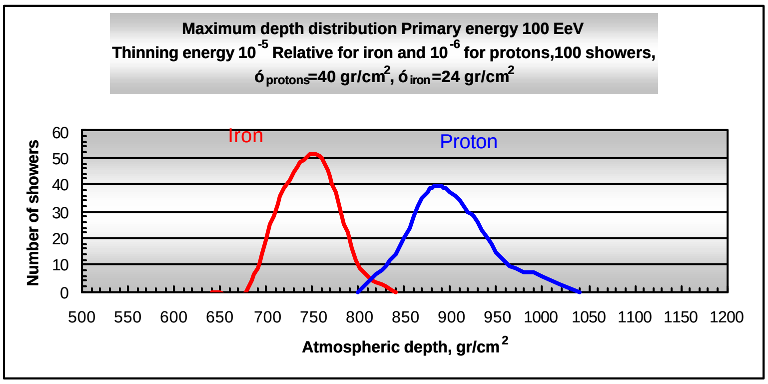


Fig. 5. The mean maximum $X_{max}$ of the iron showers is at lower atmospheric depth (750 gr/cm$^2$), while for proton of the same energy is deeper in the atmosphere (900 gr/cm$^2$).

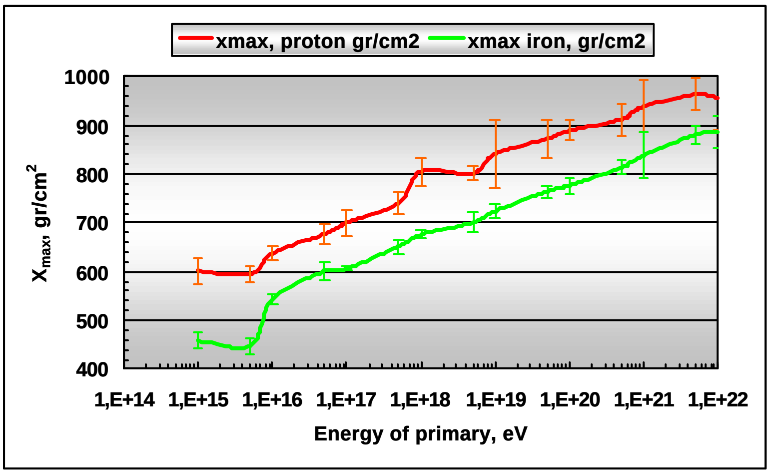


Fig. 6. The difference of $X_{max}$ for iron and proton showers is more or less constant for an energy range from $10^{14}$ - $10^{22}$ eV.

## Arrival time of particles on ground at the shower front

The shower front arriving on the ground has a thickness of few meters. Therefore, from the time delay of striking the Cherenkov detectors one can estimate the orientation of the primary particle.and its direction of origin. For a vertical primary, if we measure the arrival time of the shower front (Fig. 3) at different radial distances from the core, we would observe the white curve (Fig. 7) as the time delay of muons (the fastests). Due to the fact that muons arrive later on ground (read curve), means that the shape of the shower front is not spherical but elipsoid. Other particles arrive later (electrons and positrons) and gammas arrive even later (Fig. 7).

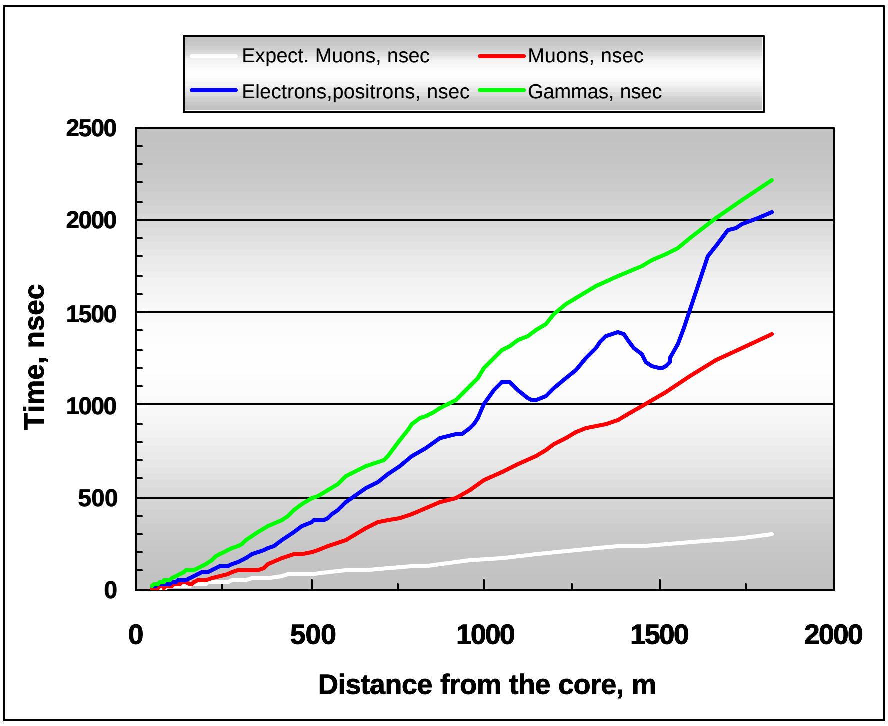


Fig. 7. The arrival time of different particles of the shower front as a function of the distance from the shower core

## Conclusions

By estimating $X_{max}$ we have given some simulation examples, which clearly distinguish primary heavy nuclei from protons. Additionally, the fact that EAS front has an ellipsoid rather than a spherical shape, should be taken into account on the estimation of the direction of the primary. The AIRes simulation program is a powerful tool to identify the energy of the detected by the PAO Ultra High Energy.

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