Ultra high energy cosmic rays simulation with CONEX code

M.C. TALAI* and **G. LAKEL**

Department of Physics, Badji Mokhtar University, B.P. 12, 23000 Annaba, Algeria.

* talai.mc@univ-annaba.org

Abstract

Nowadays, ultra high energy cosmic rays are subject to intense research of great interest. All current investigations (Auger observatory , Telescope Array experiment and soon Jem-Euso experiment) try to answer some relevant questions: What are they? Where do they come from? How do they acquire such colossal energies?

In this work, detailed simulations of extensive air showers have been carried out with the CONEX program version 2r6.40 in order to evaluate the slant depth of the shower maximum and the charged particles number. These parameters and their fluctuations are very sensitive to the primary particle mass and energy. The obtained results are compared for proton and iron primaries at the energy range $10^{18} – 10^{21}$ eV.

Introduction

The origin of the ultra high energy cosmic rays (UHECR) with energies above the GZK cutoff (5 10^{19} eV) remains unknown. The discovery of their sources will certainly reveal the most energetic astrophysical accelerators in the universe. The identity of UHECR is also unknown When they penetrate in the Earth atmosphere, they produce a large cascade of secondary particles called Extensive Air Shower. This extensive shower can mainly be simulated with the CORSIKA and CONEX codes. Our Simulations were carried out using CONEX program coupled to different hadronic interaction models.

CONEX

- **Hybrid simulation code that is suited for fast one dimensional of shower profiles, including fluctuations [1,2]**
- **Combines Monte Carlo simulation of high energy interactions with a fast numerical solution of cascade equations for the resulting distributions of secondary particles**
- **Gives primary mass, energy, and zenith angle. The energy deposit profile as well as charged particle and muon longitudinal profiles are calculated**
- **An extended Gaisser – Hillas fit is performed for each shower profile similar to what is implemented in CORSIKA [3]**
- **Shower simulation parameters, profiles and fit results are written to a ROOT file**

Longitudinal profile

The longitudinal development of EAS depends on the energy and type of incident primary particle. One of its characteristics, the atmospheric depth of shower maximum (X_{max}), which is often used to reconstruct the elemental composition of primary cosmic rays (identification).

The Gaisser Hillas formula gives the approximate number of charged particles as a function of atmospheric depth along the shower axis[4]:

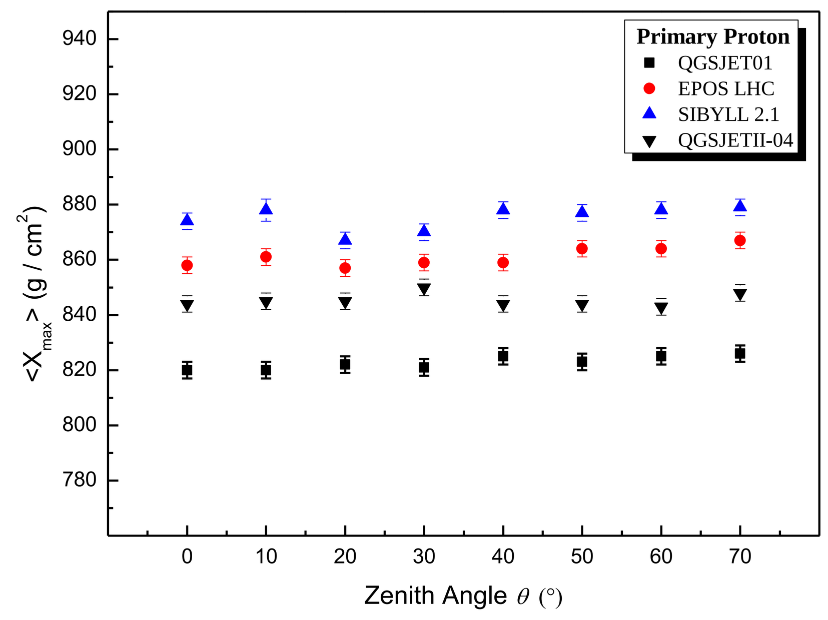
$$N_X = N_{\max}\left(\frac{X}{X_{\max}}\right)^{X_{\max}/\lambda} exp\left(\frac{X_{\max}-X}{\lambda}\right)$$

X : the atmospheric depth (g/cm²), X_{max} : the depth shower maximum(g/cm²)

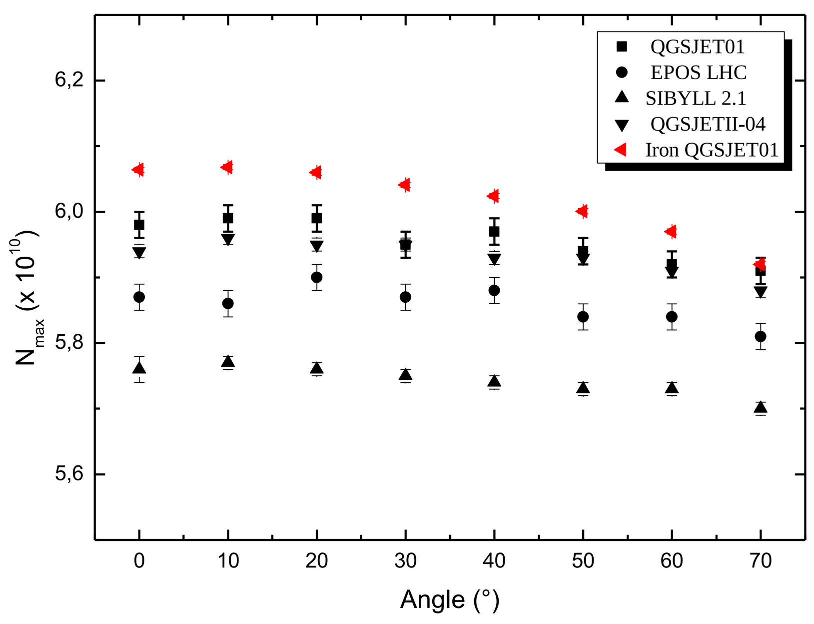
N_{max} : the maximum profile of charged particles , λ: is a characteristic length parameter

Simulations

- Extensive air shower simulation carried out with CONEX program for different zenith angle values
- Hadronic interaction model: QGSJET01, EPOS LHC , SIBYLL 2.1, QGSJETII-04
- Primary particle: Proton, Iron
- Primary particle energy : $10^{18} – 10^{21}$ eV
- Analysis concentrated on : X_{max} & N_{max}
- Energy cutoff : Default Values
- Event number: 500 – 1000

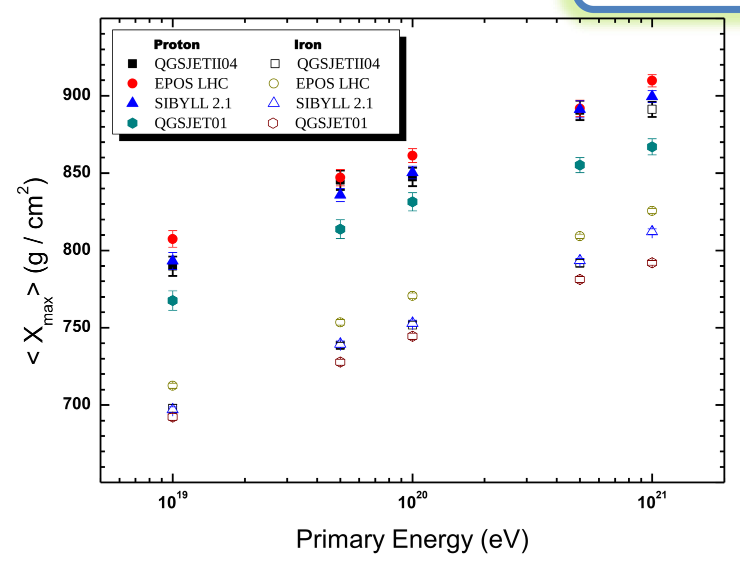


$<X_{max}>$ is influenced by the choice of hadronic model. The discrepancy, in case of primary proton, between the different models is about 60 g/cm².

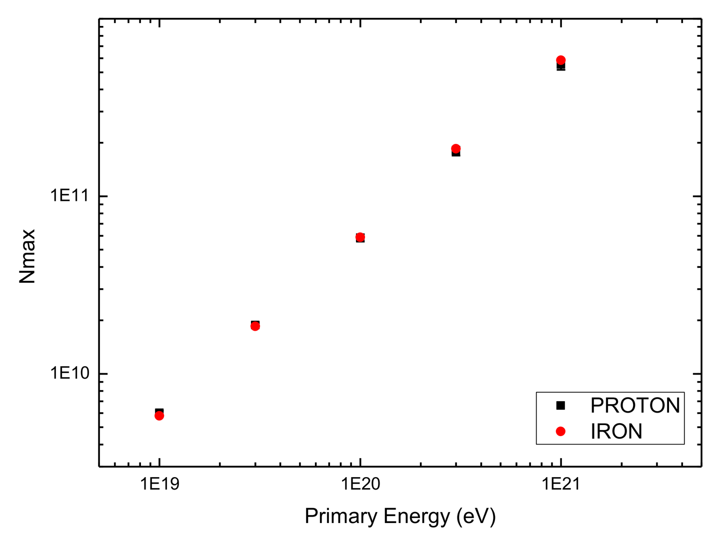


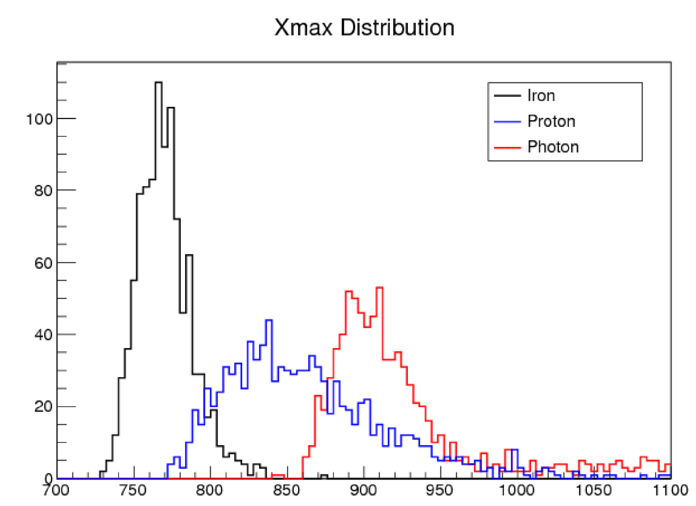
However, the discrepancy between the different models regarding the $<N_{max}>$ parameter is negligible (<5%)

Preliminary Simulation Results

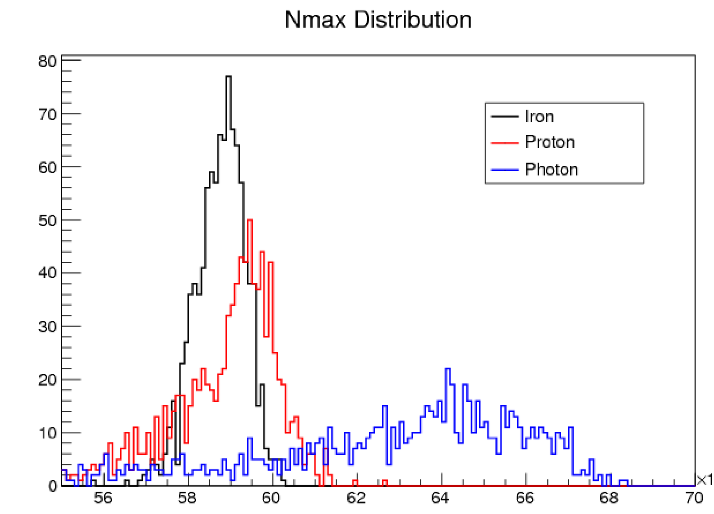


- **As known, proton primaries give greater value for X_{max} than iron primaries. The difference is about 100 g/cm².**
- **In All cases X_{max} increases with the primary energy**





The X_{max} distribution for primary proton, photon and iron (primary energy = 10^{20} eV)



The N_{max} distribution for primary proton, photon and iron (primary energy = 10^{20} eV

Conclusion

- **For a better understanding of the properties of UHECR, we have used CONEX code to simulate the interaction with atmosphere of primary nuclei (iron, proton) and photon with energy range 10^{19} to 10^{21} eV.**
- **The most interesting quantities for this purpose are the distributions of the X_{max} parameter and the number of charged particles**
- **X_{max} depends strongly on the high energy hadron interaction models which induce large uncertainties in primary particle identification**
- **The next step is to use our recorded data (CONEX) as input ones for the Jem-Euso experiment simulation code (Offline).**
- **The study of the fluorescence signal intensity profile will shed more light on the primary mass and energy.**

References

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[2]: T. Pierog and others, Nucl. Phys. Proc. Suppl., 151 (2006)
[3]: D. Heck et al., Forschungszentrum Karlsruhe Report (1998)
[4]: T.K. Gaisser and A.M. Hillas, *Proc.* 15th Int. Cosmic Ray Conf., 8(1977) 353