Analysis of the depth of shower maximum and its fluctuation using air shower simulations

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Abstract: The study of depth of shower maximum, Xmax, has crucial importance in the estimation of the energy and of mass composition of cosmic rays. Recently, the RMS of the Xmax distribution has been also shown to be an important and indepentent composition parameter. In this study, we used CORSIKA and CONEX simulation programs to run 490,000 showers in the energy range from 10^{17} to $10^{20.4}$ eV and for several primary particle types. We present a detailed comparison of $\langle$Xmax$\rangle$ as its RMS as a function of primary composition and energy for diferent hadronic interaction models. The influence of diferent simulation models on experimental results is also going to be discussed.

Keywords: Depth of the showers maximum, fluctiations, RMS of Xmax, Monte Carlo, mass composition.

1 Introduction

The importance of studying the mass composition of ultra high energy cosmic rays is directly related to understanding of the characteristics of its source, acceleration and propagation through the galactic and extragalactic medium. Among the possible analysis of an Extensive Air Shower - EAS, a highly promising method is to measure the depth of shower maximum, called Xmax. This parameter is defined as the atmospheric depth, in slant depth, of a EAS in development where it reaches the maximum number of particles. Natural fluctuations in the development of a EAS (figure 1) are very relevant and force us to rethink averages and work with statistical analysis. The average of this parameter according to the primary energy is known as elongation rate, figure 2. The simulations for different hadronic models show a strong dependence on energy and mass of the primary, as shown in Figure 2.

This study arose as a way of representing the elongation rate in energy. Until then prescedentes studies were made with small range of the spectrum (between 10^{19} and $10^{9.19}$) in log_{10}(EeV). In this work we use the energies between 10^{17} and $0^{20.4}$ with bins of 0.1 in log_{10}(EeV). We simulated 490,000 events with the hadronic model SYBIL by two simulators, CORSIKA [1] and CONEX [2, 3]. The masses were chosen so as not to take into account the nuclear structure, but the model of superposition, so they are between 1 and 55 protons, with the addition of 10 protons at each change of mass. A simulation with shower of 5 protons was made too. All events were simulated with 60 degrees of inclination, θ.

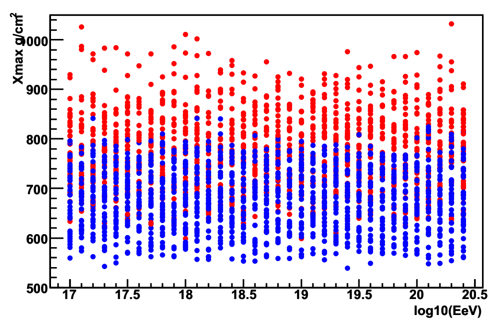

Figure 1: Here we simulated 7000 events of proton and iron to show the natural fluctuations of the parameter Xmax.

2 Comparation of the RMS values between the two simulators

The work is focused on the RMS values of the parameter Xmax. The RMS values for different energy and mass compositions are shown below. The graphs refer to CONEX (figure 3) and CORSIKA (figure 4), respectively. A first observation we can see directly the differences between the two simulators.

The CONEX present a certain stability in the slope, where all are decreasing to the primary energy, and the RMS values are between 20 and 60 g/cm2.

The CORSIKA curves exhibit a same behavior of change inclination related to energy and there are a litle difference with the CONEX. The RMS is between 20 and 65 g/cm2.

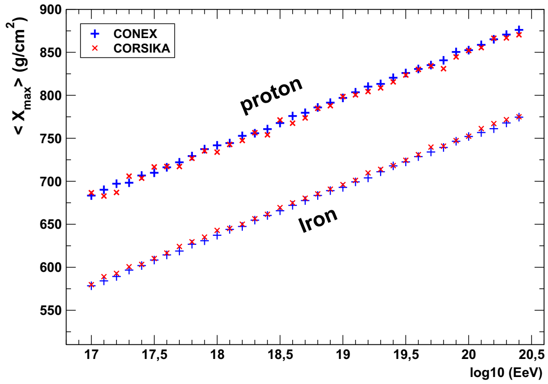

Figure 2: Its the average, in bins of energy, of the graph above, called Elongation rate, that is showing a dependency in energy and mass.

All curves of both simulators present a kind of energy modulation in function of energy.

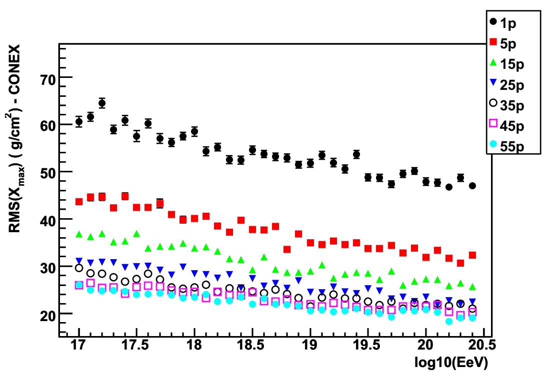

Figure 3: RMS of Xmax simulated with CONEX.

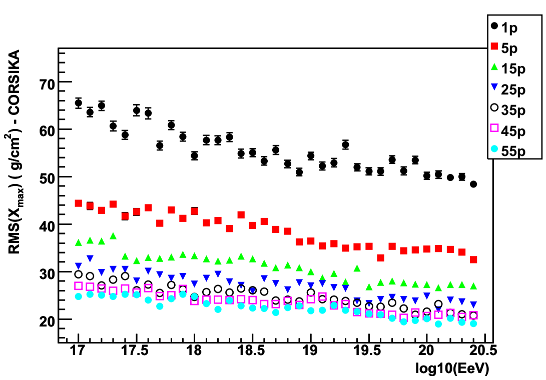

Figure 4: RMS of Xmax simulated with CORSIKA.

3 Percentual graphic

One way to compare the curves of both simulators is work with a graph of percentage (figure 5), where the values of each point were reweighted by values related to CONEX.

Here we can see that this difference, between them, is in the order to -10% up to 10% with a large fluctuation.

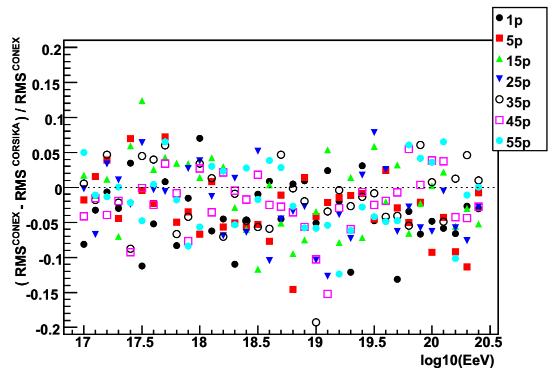

Figure 5: Percentual graphic to the two simulators.

4 Conclusions

- The graphics presented during the conference showed a large difference between CONEX and CORSIKA, but with help of Tanguy Pierog we discovered that this was caused by an inconsistence of the SLANT configuration together with the atmosphere profile number 22 in the CORSIKA. This problem is being corrected in the moment. For this new graphics we used SLANT configuration with atmosphere profile 1 - US-standard.
- A detailed study into energy bins shows that the curves have some sort of modulation along the energy, and therefore more statistical studies are needed to understand this new issue.

5 Acknowledgments

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