Composition Studies using Depth of Shower Maximum with the High-Resolution Fly's Eye (HiRes)

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***Abstract*. The depth of shower maximum or X_{max} of extensive airshowers is a sensitive probe of the chemical composition of ultra-high energy cosmic rays. Both the evolution of mean X_{max} with energy and the width of the X_{max} distribution can provide clues as to the species of the particles initiating the airshowers. Here, we report the results of composition studies using X_{max} with data collected in stereoscopic mode by the High-Resolution Fly's Eye observatory.**

***Keywords*: Ultra-High Energy Cosmic Rays, Chemical Composition, Nitrogen Fluorescence**

I. Introduction

Chemical composition studies are crucial to a complete understanding of Ultra-High Energy Cosmic Rays (UHECR). At the highest energies, an understanding of the composition is required to confirm whether the observed spectral cutoff [1] is indeed due to the GZK mechanism [2]. At lower energies, any interpretation of spectral features such as the "ankle" and "second knee" must simultaneously explain observed changes in composition, or the lack of such changes [3].

An important clue to chemical composition which is accessible to nitrogen fluorescence observatories is the depth of shower maximum X_{max} of cosmic ray induced extensive airshowers. Heitler [4] first described the development of electromagnetic cascades. With some simplifying assumptions Heitler's model can be generalized to showers induced by atomic nuclei [5]. We expect the average value of *airshower maximum* $<X_{max}>$ to follow the relation

$$<X_{max}> = \lambda_r \left(\ln \frac{E}{\xi_c^e} - \ln A \right) + C \qquad (1)$$

where λ_r is the radiation length of the medium (air), ξ_c^e the critical energy (at which radiative energy loss equals collisional energy loss), and E and and A are respectively the energy and atomic mass of the primary cosmic ray. C is model-dependent, and approximately independent of energy.

Differentiating this relation we obtain the *elongation rate* Λ_A

$$\Lambda_A = \frac{d <X_{max}>}{d \log E} \approx \lambda_r \left(2.3 - \frac{d \ln A}{d \log E} \right) \qquad (2)$$

which is a robust indicator of changes in chemical composition because of its simple dependence on changes in A.

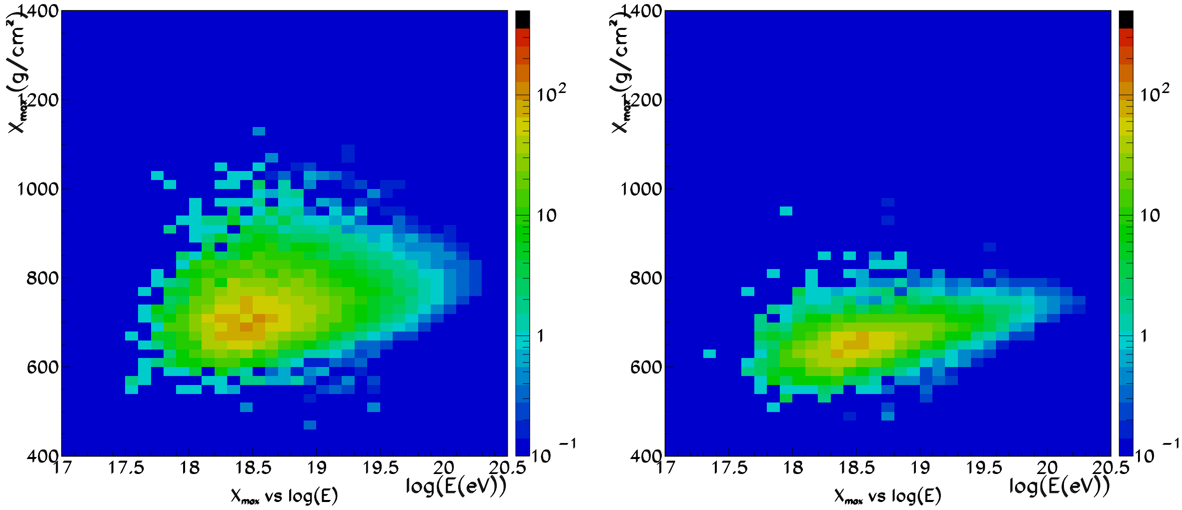
Figure 1 illustrates that in addition to $<X_{max}>$, the *width* of the X_{max} distribution at a given energy is also sensitive to the composition of the primary particle. Specifically, heavier nuclei will tend to exhibit narrower spreads in X_{max}. In this talk, we will investigate both the mean value of X_{max} and the width of the X_{max} distribution using data collected in stereoscopic mode by the High-Resolution Fly's Eye observatory.

II. The High-Resolution Fly's Eye

The High Resolution Fly's Eye (HiRes) observatory was operated from May 1997 to April 2006 on the Dugway Proving Grounds in Utah, U.S.A. HiRes consisted of two nitrogen fluorescence detectors: HiRes-I at (40.2° N, 112.8° W, 1597 meters M.S.L.) and HiRes-II at (40.1° N, 113.0° W, 1553 meters M.S.L.), separated by approximately 13 km.

HiRes-I consisted of a single ring of fluorescence cameras viewing elevation angles from 3° to 17°. HiRes-II, which became operational in December 1999, consisted of two rings of cameras viewing elevation angles from 3° to 31°. Each camera consisted of a 16×16 array of photomultiplier tubes (PMTs) at the focus of a 4 m^2 spherical mirror. HiRes-II also made use of a 100 ns clock flash ADC aystem [6], which allowed grouping of PMT pulse-height information from different tubes with the same hit times. This feature played an important role in the analysis described in this paper

Reconstruction of airshower events proceeds by using the fluorescence light signal to infer the number of charged particles as a function of depth in the atmosphere (Figure 2). By comparing the profiles of observed events to CORSIKA [7] simulated airshower events, primary particle energy and airshower characteristics (including X_{max}) are estimated.



(a) Proton-Induced Airshowers (b) Iron-Induced Airshowers

Fig. 1. *Left:* X_{max} versus $\log E$ for QGSJET01 proton-induced showers passed through HiRes detector simulation. *Right:* Similar plot for iron-induced showers.

III. HiRes X_{max} Results

The results of X_{max} studies with the HiRes stereoscopic data set will be presented at the 31^{st} International Cosmic Ray Conference.

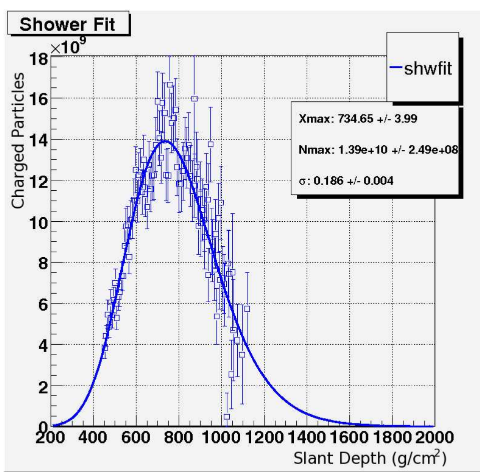


Fig. 2. Shower profile of HiRes stereoscopic event. Phototube pulses are sorted into time bins, the y-axis is converted from fluorescence light output (proportional to energy deposition) to the number of charged particles assuming an average energy deposition per particle of 2.4 MeV/g cm^2.

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