Testing The HiRes Detector Simulation Against UHECR Data

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Abstract

The High Resolution Fly's Eye Experiment uses a realistic Monte Carlo program to determine its aperture and resolution. We have developed a detailed simulation of the detector response, which allows us to generate events that can be compared directly against real data by reconstructing them with the same analysis programs. We use a library of proton- and iron-induced air showers, generated with the CORSIKA [1] and QGSJet [2] programs, plus a database where conditions that change on a night-to-night basis are tabulated, to simulate the exact data set under study. Background light is added to make pattern recognition and event reconstruction be directly comparable to the data. We present a detailed set of comparisons between Monte Carlo generated events and actual data taken by the HiRes-2 FADC detector.

1. Introduction

The two air fluorescence detectors of the HiRes experiment, located at Dugway Proving Ground in the desert of Utah, observe cosmic rays of the highest energies ($> 10^{17} eV$) by collecting UV scintillation photons from the giant air showers that primary particles induce in the atmosphere. In the ultra high energy end of the cosmic ray spectrum direct observation as well as direct comparison with accelerator data is impossible. Thus computer simulations of the underlying physical processes and the detector response play a decisive role in the data analysis.

We rely on realistic Monte Carlo programs to determine the aperture of our detectors. The simulations also help us to understand the geometrical and energy resolution of our detectors and to determine appropriate cuts for event selection in our analysis of the energy spectrum, anisotropy and composition of the cosmic ray particles.

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2. HiRes-2 Detector Simulation

We have developed complete simulation programs for both detectors. Here, we will focus on the newer detector, HiRes-2, which is using Flash ADC (FADC) electronics instead of the sample and hold electronics of HiRes-1.

The detector simulation includes: the generation of air showers with the help of a CORSIKA shower library; the propagation of photons through the atmosphere; ray tracing and simulation of the optical components of the detector, including mirrors, filters and photomultiplier tubes; the electronics of the data acquisition and the trigger system. Conditions that change on a nightly basis, e.g. the aerosol profile of the atmosphere and trigger DAC settings, are recorded in databases and sampled by the detector simulation programs to generate Monte Carlo (MC) events with the specific conditions that match a certain time period of events under analysis. Background light is added from the measured distribution of the same time period to achieve a realistic simulation of the trigger response. MC events are stored in the same format as actual data so that both can be reconstructed using the exact same routines.

3. Shower Library

In order to preserve event-to-event fluctuations in the charged particle profiles of simulated air showers, we use CORSIKA to generate individual showers instead of relying on parameterizations of average profiles. However, simulating each single shower with CORSIKA would require too much CPU time for the generation of a statistically significant sample. Thus, we have created a library of shower profiles that can be used repeatedly with various geometries. Giant air showers have been generated with CORSIKA and the hadronic interaction codes QGSJet and SIBYLL [3] at five fixed energies for proton and iron primary particles. Each shower profile is characterized by the four parameters of a fit to a Gaisser-Hillas [4] type function.

We have found strong correlations between the fit parameters and the energy of the primary particle; this allows us to scale library showers to the energies we sample from a continuous spectrum in the detector Monte Carlo.

4. Atmospheric Database and Trigger Conditions

We store parameters that vary during the observation periods in database files, from where they can be accessed by the detector simulation. An atmospheric database records parameters describing the aerosol profile for each hour of detector ontime. The aerosol distribution is probed with a steerable laser system: scattered light from periodic laser shots at different elevation and azimuthal angles is recorded by our detectors and can be analyzed to retrieve information about the horizontal extinction length, phase function and the scale height of scattering due to aerosol. Changes in the aerosol profile account for the largest uncertainty in our experiment and therefore have to be well understood.

A separate database contains nightly information about the detector on-time and about non functioning phototube clusters, a flag for the trigger algorithm in use and lists with the varying trigger gains for each mirror. The trigger gains determine the sensitivity of our FADC detector and are adjusted to keep the level of triggers caused by background noise low. During the lifetime of the HiRes-2 detector several changes have been made to optimize the required trigger pattern. We have divided our data into periods with unchanging trigger algorithms and analyze each set of data separately. MC events are generated using the databases to take the actual trigger and atmospheric conditions of each night in the data set into account.

5. Comparisons of Data with Monte Carlo Events

Once we have selected clear nights for a data set and generated MC events with realistic atmospheric parameters and trigger settings, we analyze the real and simulated events with the same reconstruction programs. The recorded or simulated FADC times and pulses are used to reconstruct the geometry, shower profile and finally the energy of each event. Detailed comparisons between real and MC events provide a tool to test our understanding of the HiRes detectors and the physics of air showers. These comparisons are applied to geometric quantities of showers, trigger characteristics of events, features of the recorded tracks and shower profile, reconstructed energies, etc.

The figure on the next page is an example from our set of comparisons: the semi-logarithmic histogram in the top plot shows the distributions of events over total number of photoelectrons per degree of recorded shower-track. There are about four times more simulated events (open squares) than real events in this data sample (filled squares). Both distributions are normalized to cover the same area. The lower plot shows the ratio of real events over MC events and a linear fit to this ratio. As can be seen, the simulated amount of light and the light recorded by the FADC detector are in very good agreement.

6. Conclusion

We have carefully simulated our experiment and have undertaken extensive tests of our simulation programs against data sets with different trigger logics. Data-MC comparisons prove that our simulations are realistic; hence we are confident that we can trust the calculated aperture and resolution of the HiRes experiment.

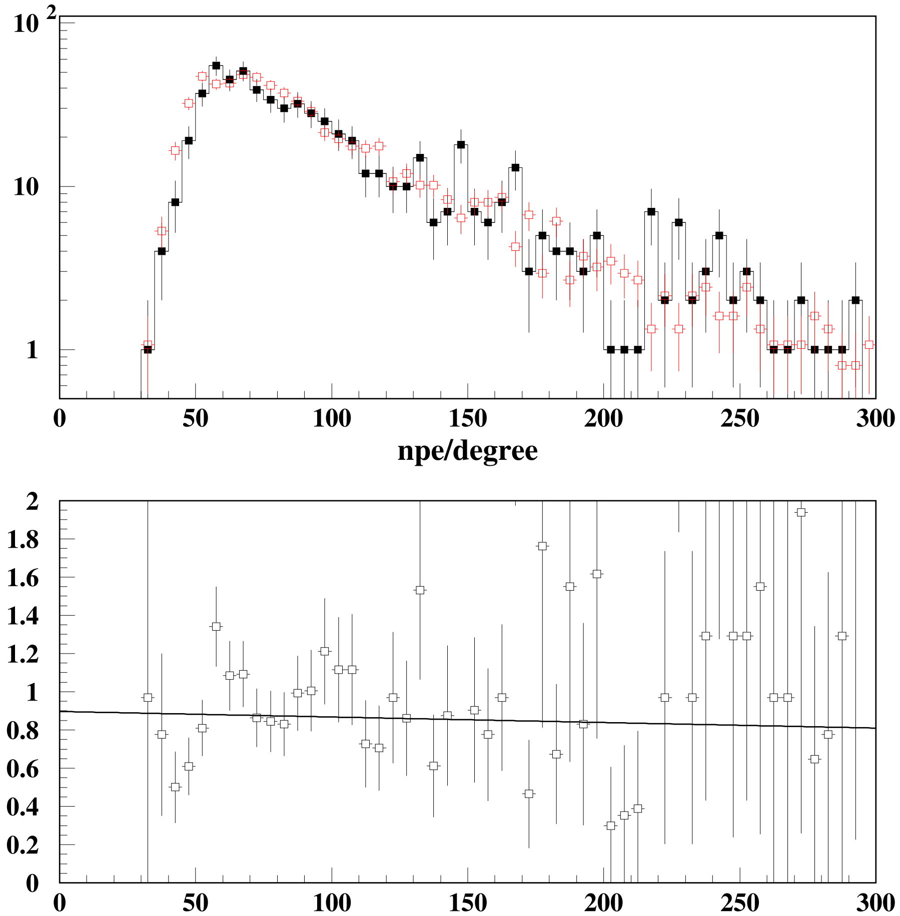

Fig. 1. top: Distributions of number of photoelectrons per degree of track. (Open squares: MC , filled squares: data) ; bottom: Ratio of data over MC.

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