A Top-Down Technique as an Analysis Tool for Auger Fluorescence Data

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Abstract

The Auger Observatory aims at the detection of Ultra-High-Energy Cosmic-Rays by employing an array of ground-particle counters overviewed by atmospheric fluorescence telescopes -a mini prototype of which has been operative since 12/2001 near the town of Malargue in the province of Mendoza, Argentina. Conventional bottom-up fluorescence data analyses techniques convert photons entering the telescope's diaphragm to shower size; energy and primary composition are then estimated by fitting a Gaisser-Hillas distribution. In this paper we discuss the potential capabilities of a top-down technique based on a robust primary energy estimator. Such technique uses hundreds of very fast-simulated shower longitudinal profiles and calculates their corresponding photon profiles seen by the telescopes. Primary energy and composition follow from maximum likelihood or chi-squared analyses.

1. Introduction

Bottom-up methods currently used in Fluorescence Detector (FD) analysis convert ADC-raw data as function of time to shower size as function of traversed atmospheric depth. This is done in two steps: 1) Conversion of ADC(t) to photons(t) entering the diaphragm, and 2) conversion of diaphragm photons(t) to shower size(depth). Primary energy and composition follow from a fit to a Gaisser-Hillas function.

In this paper we present an alternative stand-alone method for analysis of FD data, and demonstrate that FD data in individual showers can be reproduced (up to inevitable fluctuations in the detection) by thorough simulations of air showers with atmospheric propagation and detector response.

2. The Method

A flow-chart diagram of the method is shown on Fig. 1, and can be summarized as follows:

- Raw ADC-data are extracted for all relevant pixels. Pulse finding and

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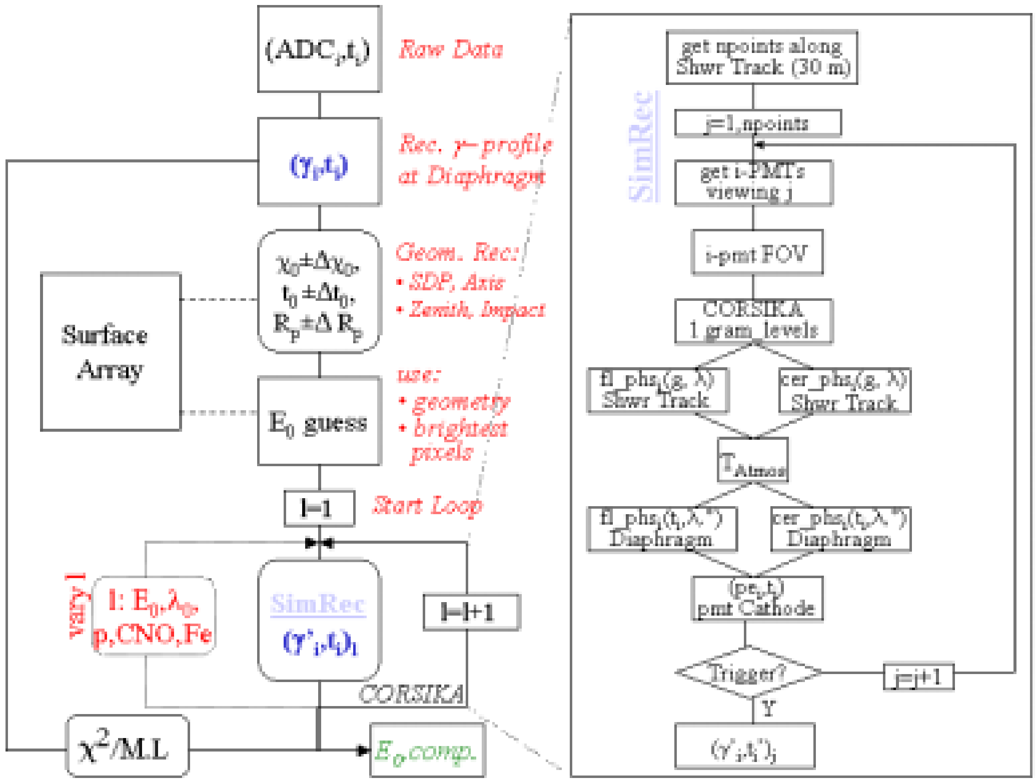

Fig. 1. Flow-chart diagram of the Top-Down FD-analysis technique.

pedestal subtraction algorithms are applied. A gaussian is fit to each pulse to get a better pulse centroid (for asymmetric pulses). Pulse-shape- and time-Vs.-elevation cuts are applied to discriminate random pulses.

- Calibration files are applied to convert ADC(t) to photons(t) entering the diaphragm.
- Shower Detector Plane, axis, zenith, azimuth, and core are calculated.
- A fast energy guess is made by taking into account the signal at the brightest camera row and the reconstructed shower geometry.
- Taking the energy guess and reconstructed shower geometry as reference, hundreds of simulated shower longitudinal profiles are fastly generated [1], each corresponding to a unique combination of primary energy, composition, and first interaction length.
- For each simulated shower profile, the atmospheric fluorescence yield is calculated and transmitted through the atmosphere down to the FD telescopes, producing both simulated photon(t) and ADC(t) profiles. (See next section on photon(t) profile simulation).
- Maximum likelihood techniques are used to compare both raw and simulated profiles in order to extract primary energy and composition.

2.1. Photon(t) Profile Simulation

Photon(t) profile simulation follows directly from the flow-chart diagram shown on the right-hand side of Fig. 1. In very general terms it can be described as follows:

- A shower-axis vector of vertical length 90 km is constructed and divided into 30 m steps (100 ns time-intervals along shower-axis).
- For each point along the axis, one identifies the pixel(s) viewing the point.
- Fluorescence yield and Cherenkov light are calculated for all points within the PMT's FOV by using the fastly simulated longitudinal shower profiles.
- All fluorescence and Cherenkov photons are transmitted through the atmosphere using realistic atmospheric models for the site, and followed down to the detector which is also modeled. A photon(t) (and ADC(t)) profile is saved for all triggered pixels.

3. Example of Event Reconstruction

We have analyzed 25 Auger Engineering Phase (EP) hybrid events. During the EP a $\sim 80km^2$ mini surface array (MSA) overviewed by two fluorescence telescopes ~12 km away, was operative between 12/2001 and 3/2002. In Fig. 2, we plot the deviation of our energy guesses with respect to those calculated using a full bottom-up reconstruction method for the 25 hybrid events. The deviation is quite small, proving the goodness of the energy guess algorithm. In order to visualize the capabilities of the method we show, in Fig. 3, an example of a simulated Auger hybrid event.

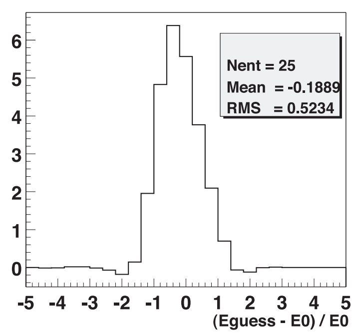

Fig. 2. Primary energy-guess deviation.

We throw a nearly vertical 1.5 EeV iron primary in the the middle of the MSA (see figure captions). From the photomultiplier trigger times we reconstruct the shower axis. Knowing this, we use the Bartol code [1] to generate 100 iron and 100 proton shower longitudinal profiles with energies distributed around the energy guess of 1.7 EeV. From these we follow all steps previously described in order to simulate their corresponding photon profiles entering the telescope's diaphragm. The fact that the profiles start and end precisely with the raw signal is indicative of the goodness of the geometrical reconstruction. The best fitted profile corresponds to a 1.5 EeV iron primary with $X_{max} = 693\ g \cdot cm^{-2}$, in accordance with simulated primary parameters. Inevitable fluctuations in the detection in real events may make such reconstruction not so accurate, yet the observed shift on simulated signal maxima between proton and iron primaries can be used to extract statistically more significant information on primary energy and composition than that obtained with bottom-up methods. The entire reconstruction process takes just under 4 hours on a 1GHz Linux machine.

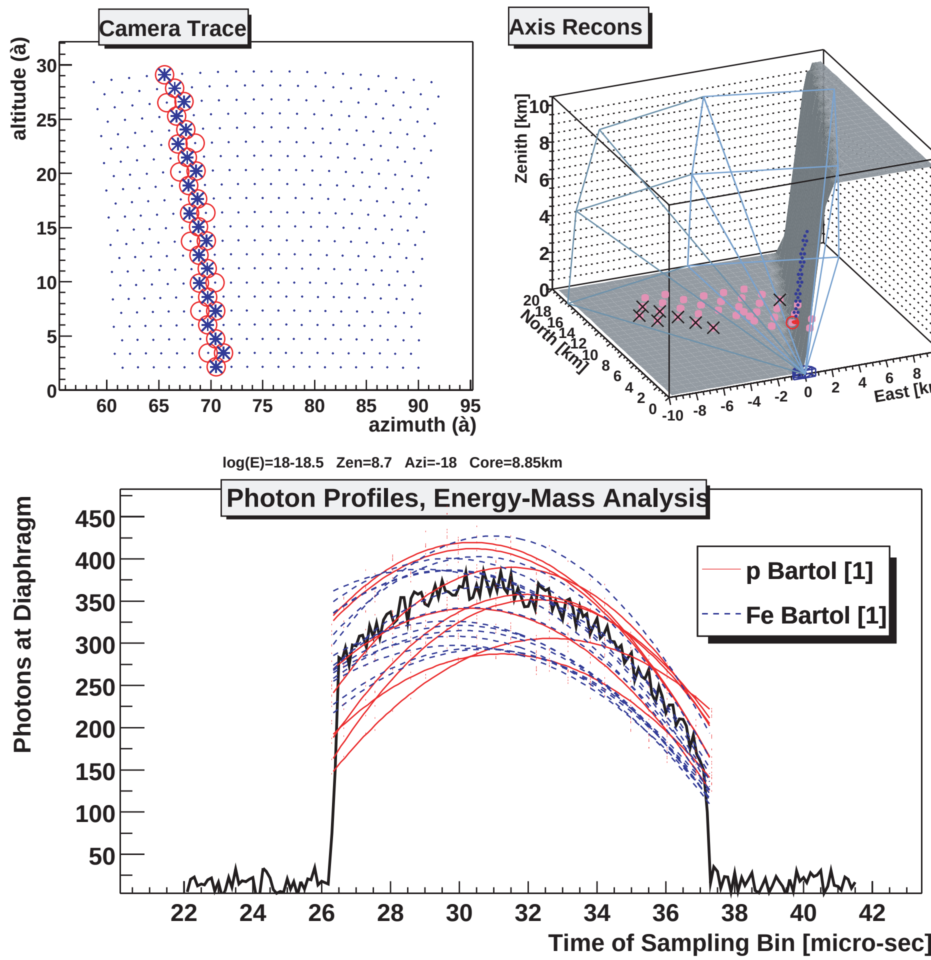

Fig. 3. Example of reconstruction of a simulated Auger Engineering-Array Hybrid Event landing 8.85 km from the telescope, with 8.7° zenith angle, for which the energy guess was 1.7 EeV. Upper left: Circles (stars): simulated triggered camera pixels (reconstructed shower-axis projected on camera's FOV). Upper right: 3D graph showing position of fluorescence telescope (origin), of operative water Cherenkov tanks (those not crossed out), of simulated triggered tank (encircled one), of reconstructed shower-axis (string of dots), and of reconstructed impact point (single dot). Lower: A sample of simulated proton (continuous lines) and iron (dashed) photon profiles entering the telescope's aperture superimposed on the simulated raw photon profile (continuous thick line). These (sample) profiles were generated according to the method described in the text, and corresponding to primaries with energies distributed between $(1-3)$ EeV. The best fitted profile corresponds to a 1.5 EeV iron primary with $X_{max} = 693$ $g \cdot cm^{-2}$ in accordance with simulated primary parameters.

4. References

1. Alvarez-Muniz, J. et al. 2002, Phys. Rev. D 66, 033011.