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Track Reconstruction in Imaging Fluorescence Signals Induced by Extreme Energy Cosmic Ray Particles.

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Abstract

The Extreme Energy Cosmic Ray particles interact with the atmosphere inducing fluorescence light as the end-result of a complex relativistic cascade process. The fluorescence signal can be detected as a track whose duration, position and intensity are related to the arrival direction and energy of the primary particle. This detection technique is used by the OWL-AIRWATCH space mission.

We present here a reconstruction procedure for typical signals, aiming to extract the useful track from the sky background and to estimate the arrival direction of the primary particle. The efficiency of the procedure has been checked on simulated OWL-AIRWATCH data and preliminary results are reported.

1 Introduction:

Extreme Energy Cosmic Ray (EECR) particles interact with the Earth atmosphere inducing fluorescence light as result of a relativistic cascade process giving rise to a propagating shower of particles. The fluorescence signal can be detected as a more or less complex track whose duration, position, and intensity are related to the arrival direction and energy of the primary EECR particle. This detection technique is used by the OWL-AIRWATCH mission (Scarsi et al., 1998, Scarsi et al., 1999) aimed to observe the atmosphere looking down toward the Earth nightglow from a low orbit space platform (from a distance of ~500 Km). To do this, a wide-angle optics with large collecting surface and single-photon counting with fast detectors (Stalio et al., 1999) and fast read-out electronics (Catalano et al., 1999) are required. The detector at the focal plane will record the shower emitting the fluorescence light characteristic of the atmospheric Nitrogen, and the resulting event will look like a single narrow track. The tracks are observed in presence of the intrinsic atmospheric background which strongly depends on various parameters related to the observation conditions as, for example, moon exposure, geographical position, orbital altitude, meteorological conditions (Barbier et al., 1999).

We present here an off-line reconstruction procedure for typical fluorescence signals induced by EECR particles, aiming to extract the useful track from the sky background and to estimate the arrival direction of the primary particle. The procedure makes use of cluster analysis and simple computational geometry techniques; its efficiency has been checked on OWL-AIRWATCH data simulated at various values of energy and arrival direction of the primary, and preliminary results are reported.

2 Off-line Event Reconstruction:

In the currently planned configuration of the OWL-AIRWATCH payload, the detector at the focal plane presents a modular structure: it can be viewed as a X-Y matrix of "macrocells" where each macrocell is formed by a X-Y matrix of pixels, and each pixel corresponds to a single sensor unit. When a fluorescence signal is revealed in the detection area and triggered by the on-board electronics system, position and arrival time of the detected photoelectrons are registered at rate of Gate Time Units (GTU) as defined by the read-out electronics (Catalano et al., 1999). The image of the event on the X-Y detector plane and its representation along to the two time-space projection planes will look like in Fig.1.

In the projection plane representation the abscissa refers to the spatial position (X or Y) of the event in the detector plane; its scale unit is the pixel and its scale extension refers to the entire detector plane size.

The ordinate stands for the time independent variable; its scale unit is the GTU and its scale extension depends on the duration (persistence) of the track in the detection area and then it depends on the event arrival direction and energy. The information related to the two projection planes is all what we need to perform the arrival direction reconstruction of the primary particle.

In the following we consider the detector plane as formed by a set of 5x5 macrocells containing 48x48 pixels each, for a total of 240x240 single sensor units. The pixel is assumed to be a square element with a size corresponding to 1 Km^2 on the Earth while the GTU time unit is set to 833 ns. The GTU can be expressed in the same units of the spatial coordinates; in fact, given the event is moving at the speed of light, it goes through 0.25 Km in a time interval of 833 ns and this implies that a spatial pixel in our configuration corresponds to ~ 4 GTU units.

Moreover, to simplify the geometrical parameterization of the system, we will assume here that pixels and macrocells are strictly contiguous without gaps between them; we note also that the information related to only adjacent macrocells with higher integral of counts is sufficient to reconstruct the arrival direction of the primary.

The procedure is performed in three steps:

1. extract the significant track,
2. determine the geometrical parameters of the significant track, and
3. reconstruct the arrival direction of the primary particle.

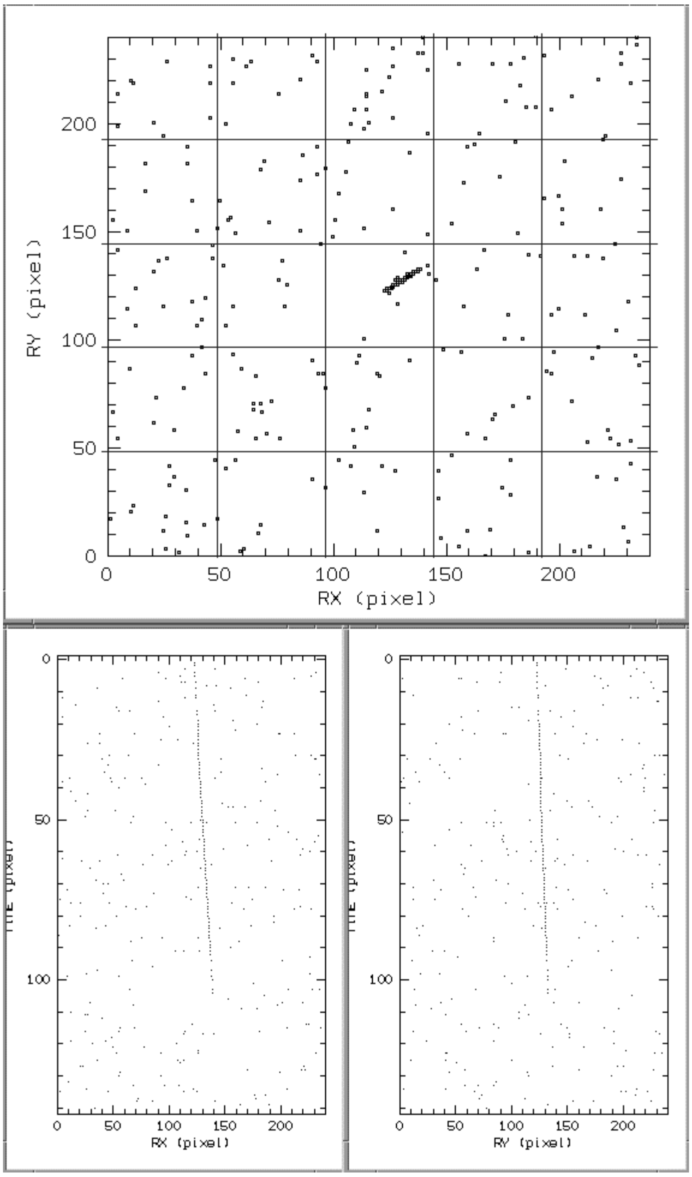

Figure 1: Visualization of a fluorescence signal. At the top: image of the event on the X-Y detector plane. At the bottom: the signal as viewed along the two projection planes (Time-X and Time-Y).

2.1 Extraction of the Significant Track:

The first step of the off-line event reconstruction concerns the extraction of the useful track with respect to the residual background as viewed along the two projection planes (Catalano et al., 1998). The technique here adopted is based on a simple two-dimensional single-link clustering algorithm (Di Gesù and Maccarone, 1986): the data are seen as a random graph where the weight is the Euclidean distance between the nodes. Given a suitable threshold, defined as Euclidean distance in the space of each projection plane, a cluster track will be identified by all those pixels whose inter-distances are less than the threshold; the track will be considered significant if it contains more than a minimum number of points. Clustering threshold and significant number of points depend on the statistics of the data set; in our application, a spatial pixel corresponds to four GTU units and therefore the minimum clustering threshold must be at least 4.

To simplify the description of the method, we will assume in the following that a significant set of points forming a single track has been extracted by the cluster procedure in each projection plane. Fig.2 shows the set of points belonging to the significant clusters extracted from data presented in Fig.1.

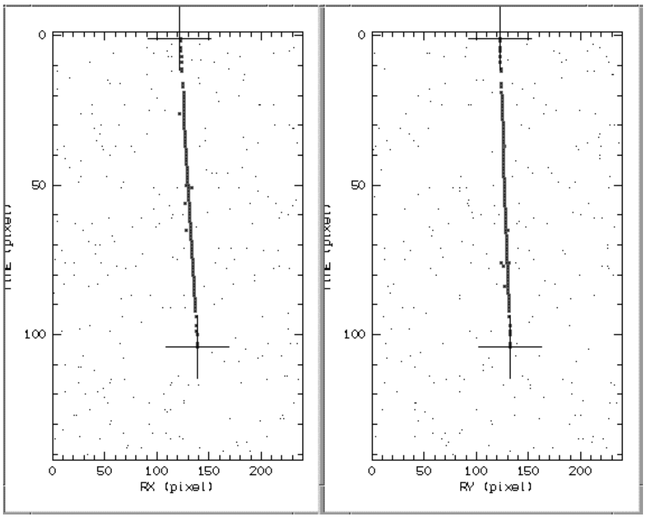

Figure 2: The significant set of points obtained from data shown in Fig.1 as clusterized at distance threshold equal to 5 pixels along each projection plane.

2.2 Determination of the Geometrical Parameters of the Significant Track:

The significant track can now be modeled as a simple straight line to evaluate its slope along each projection plane. These slopes constitute the necessary information to reconstruct the arrival direction of the primary particle. The geometrical parameters of each straight line are evaluated via a fitting procedure that minimizes the absolute deviation from the median. This robust estimation method allows us to exclude from the final computation those pixels that were activated very near to the track due to the residual background or to signals split in two contiguous pixels (some of these spurious pixels are present in the clusters shown in Fig.2). The extremes of each fitted straight line are marked with a cross in Fig.2.

2.3 Arrival Direction Reconstruction:

The primary arrival direction (zenith θ, and azimuth ϕ angles) is derived by a geometrical combination of the slopes ($Slope_X$, $Slope_Y$) of the linear tracks along the two projection planes, taking into account the kinematics of the particle moving at the speed of light. The angles and their components along X and Y are computed as:

$$\phi = tg^{-1}\left(\frac{Slope_Y}{Slope_X}\right) \qquad \theta = 2 \cdot tg^{-1}\left(A \cdot \sqrt{(Slope_X)^2 + (Slope_Y)^2}\right)$$

$$\theta_X = tg^{-1}(tg\theta \cdot \cos\phi) \qquad \theta_Y = tg^{-1}(tg\theta \cdot sin\phi)$$

where A is a constant related to the speed of light and depending on the pixel size and on the time unit; in our application its value is ~ 4.

3 Results:

The track reconstruction procedure presented here has been checked on a set of fluorescence signals (100 for each energy, 100 for each arrival direction) simulated as induced by EECR primaries at energies from $3x10^{19}$ to $1x10^{21}$ eV; all signals were simulated with arrival direction defined by azimuth angle ϕ_0=33° and zenith angles θ_0=30°, 45°, 60°, and 75°, respectively (a more statistically significant set of samples will be presented at the time of the ICRC conference). Moreover, the OWL/AIRWATCH payload was considered at the height of 500 Km from Earth, with no clouds present in the atmosphere. Preliminary results are shown in Fig.3 in the form of angular resolution defined as the angular distance between simulated and reconstructed direction. The angular resolution is strictly related to the length of the track, and this length depends on the energy as well as on the inclination of the arrival direction of the primary. Results shown in Fig.3 confirm our expectation: at higher energies the angular resolution improves reaching values of the order of 2.5°, 0.5°, and 0.2° for simulated zenith angles equal to 45°, 60°, and 75°, respectively.

Work is in progress to improve the off-line event reconstruction in all its steps. The procedures to reconstruct energy and height of the shower are in progress, too.

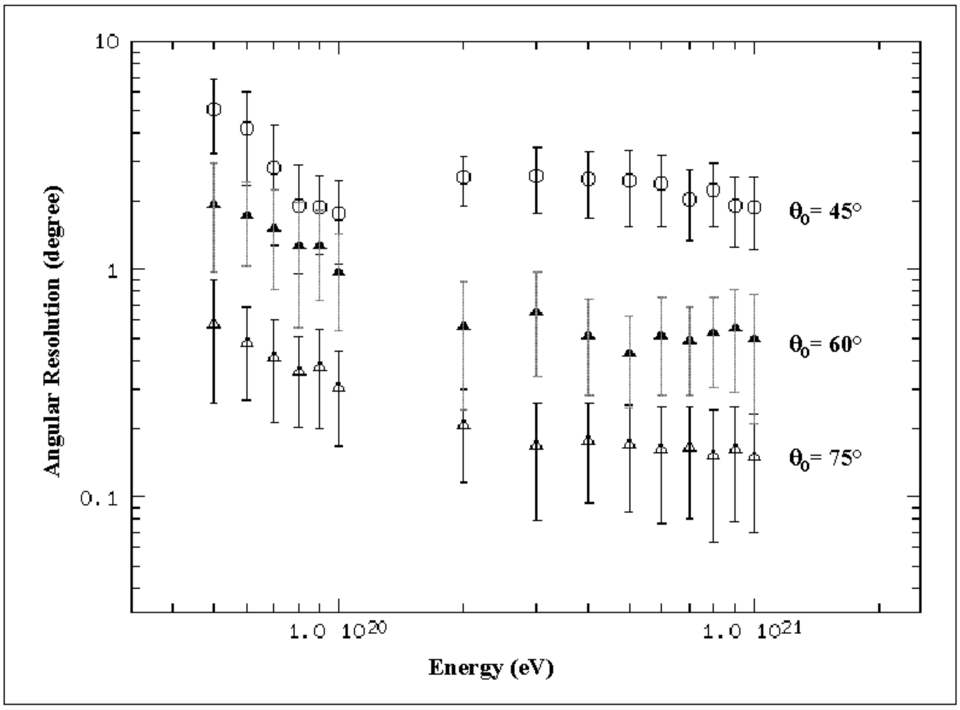

Figure 3: Results of the off-line event geometrical reconstruction. Angular resolution versus energy for events simulated at azimuth angle ϕ_0=33°, and zenith angle θ_0=45°, 60°, and 75°, respectively.

References

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