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Time Offset Effects and its Off-line Calibration in EAS Experiments

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In EAS experiments, the space-time information of the secondary particles is used to reconstruct the primary direction, which is greatly affected by the hit time offset. Usually absolute manual calibration is used, which takes time and man power and is dependant on the environment. A new term named Characteristic Plane is introduced to analyze the hit time offset effects such as the quasi-sinusoidal modulation on azimuth angle distribution, with the results checked by Toy MC. The Characteristic Plane method is developed to off-line calibrate the time offset of the detector units in an EAS array. Taking ARGO experiment as an example, a MC simulation was done to verify the above mentioned method, which shows the Characteristic Plane method is sufficient enough to calibrate an EAS array time by time (under different environment) just using the run data without disturbing the normal run.

1. Introduction

In EAS (Extensive Air Shower) experiments, the space-time information of the secondary particles is used to reconstruct the primary direction, where the space information refers to the detector position while the time information is achieved usually by TDC. The former is easy to measure and stable in a long period, while the latter depends on the detector, cable, electronics, etc, and usually varies with time and environment. The time offset refers to the relative time difference between detector units, which leads to worse angular resolution, and more seriously, wrong primary direction which leads to the quasi-sinusoidal modulation on the azimuth angle distribution [1], so its calibration is very important for the primary direction reconstruction in gamma ray astronomy. Usually absolute manual calibration using a probe detector to calibrate relatively all the detectors in an EAS array is used to do that, which takes time and man power. Currently the number of detectors in an EAS array is getting larger and larger which leads to the difficulty of manual calibration. Taking the ARGO experiment [2] as an example which has totally 18480 detector units (called PADs), it takes months to calibrate such an array manually, while the time variance is still not considered. That means effective off-line calibration is greatly needed in such experiments.

2. Characteristic Plane

For an EAS event i, the position (x_{ij}, y_{ij}) and time t_{ij} information for each fired detector j are measured in EAS experiments. Taking into account the detector time offset δ_j, the primary direction cosines $l_i = sin\theta_i cos\phi_i$ and $m_i = sin\theta_i sin\phi_i$ (θ_i and ϕ_i are the azimuth and zenith angles) can be reconstructed by planar fit:

$$c(t_{ij} - \delta_j - t0_i) = l_i x_{ij} + m_i y_{ij} \quad (1)$$

where c is the light velocity, and $t0_i$ is constant. If the detector time offset is not known, the planar fit goes like:

$$c(t_{ij} - t0'_i) = l'_i x_{ij} + m'_i y_{ij} \quad (2)$$

giving the fake direction cosines $l'_i = sin\theta'_i cos\phi'_i$ and $m'_i = sin\theta'_i sin\phi'_i$. From Eq.1 and Eq.2, one can reach:

$$c(\delta_j - \delta_{0i}) = a_i x_{ij} + b_i y_{ij} \quad (3)$$

where $a_i = l'_i - l_i$, $b_i = m'_i - m_i$, and $\delta_{0i} = t0'_i - t0_i$. $a_i = sin\theta_{0i}cos\phi_{0i}$ and $b_i = sin\theta_{0i}sin\phi_{0i}$ defines a plane in the (x, y, δ) space, i.e. the Characteristic Plane (CP), which depends only on the fired detectors, representing the difference between the reconstructed plane without considering the time offset (FP: Fake Plane) and the real one (RP: Real Plane). Events firing different sets of detectors have different CP's, while events firing the same set of detectors have the same CP, thus the difference between the FP and RP is the same. The CP of an EAS array (with the direction cosines $a =< l' > - < l >= sin\theta_0 cos\phi_0$, $b =< m' > - < m >= sin\theta_0 sin\phi_0$) represents the mean difference between the FP and RP of all acquired events. There exists a systematic deviation between FP's and RP's.

3. Quasi-Sinusoidal Modulation

Using the term of CP, one can deduce that the reconstructed azimuth angle of the primary distributes quasi-sinusoidally when θ_0 is small enough and the correlation between θ' and ϕ' is ignored, with the first harmonic goes like:

$$f'(\phi') = 1 - sin\theta_0 < \frac{1}{sin\theta} > cos(\phi' - \phi_0) \tag{4}$$

A fast Monte Carlo simulation was done to check the above conclusion: the azimuth angle was sampled uniformly and zenith angle from EAS experiment data (with $< \frac{1}{sin\theta} >= 3.53$), a CP with θ_0 and ϕ_0 was assumed, then $sin\theta_0 cos\phi_0$ and $sin\theta_0 sin\phi_0$ were subtracted from the original direction cosines respectively thus forming the new ones. Fig.1 shows the resulting azimuth angle ϕ' distribution together with the sinusoidally fitted curve ($\theta_0 = 5^o$, $\phi_0 = 45^o$ in this example), from which one can see that the phase (p1=0.776$\pm$0.005) and modulation amplitude (p2=0.305$\pm$0.001) of the first harmonic agree with Eq.4.

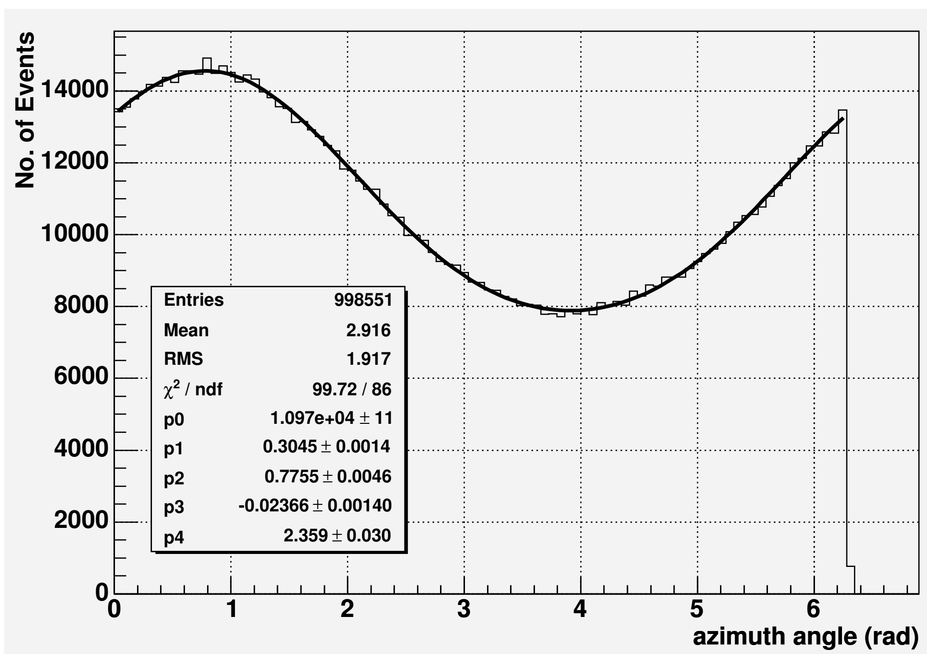

Figure 1. Azimuth angle distribution fitted with the first and second harmonics.

4. Characteristic Plane Method

According to Eq.1, if l_i and m_i were exactly known, then any event can be used to relatively calibrate all the detector units fired by that event. Surely that's not true, but $l'_i - a$ and $m'_i - b$ can be taken as unbiased estimation to l_i and m_i, then for each event i, the time offset δ_{ij} of each fired detector j can be estimated, and with large amount of events, $\delta_j =< \delta_{ij} >_i$. What one needs to know is just a and b, i.e. the CP of the EAS array. Suppose that the azimuth angle of the primary is independent on the zenith and distributes uniformly, then:

$$< l >= 0 \tag{5}$$

$$< m >= 0 \tag{6}$$

thus

$$a =< l' > - < l >=< l' > \tag{7}$$

$$b =< m' > - < m >=< m' > \tag{8}$$

which means that the CP of an EAS array can be calculated from the mean values of the direction cosines of FP's. .

Taking ARGO experiment as an example, a full Monte Carlo simulation for proton primaries (energy: 1TeV-5TeV, spectrum index: -2.7, azimuth angle: $0^o - 360^o$, zenith angle: $0^0 - 60^o$) was done using CORSIKA562 (QGSJET, GHEISHA, and EGS4 were used for hadronic and electromagnetic interaction respectively) [3] and ARGOG-V131 (trigger multiplicity: LM6, no noise, sample area: 200m×200m) [4]. For each PAD, the time offset was preset according to various rules. Characteristic Plane Method was used to recalculate the time offsets which were compared with the preset ones. Fig.2 shows one of the difference distributions between the time offset by CP method and the preset one for PAD's in the central area and for PAD's in the guarding ring (PAD's in the central area participate trigger while PAD's in the guarding ring not) together with the gaussian fitted curves. The mean value is meaningless while the width shows that the CP method is very effective.

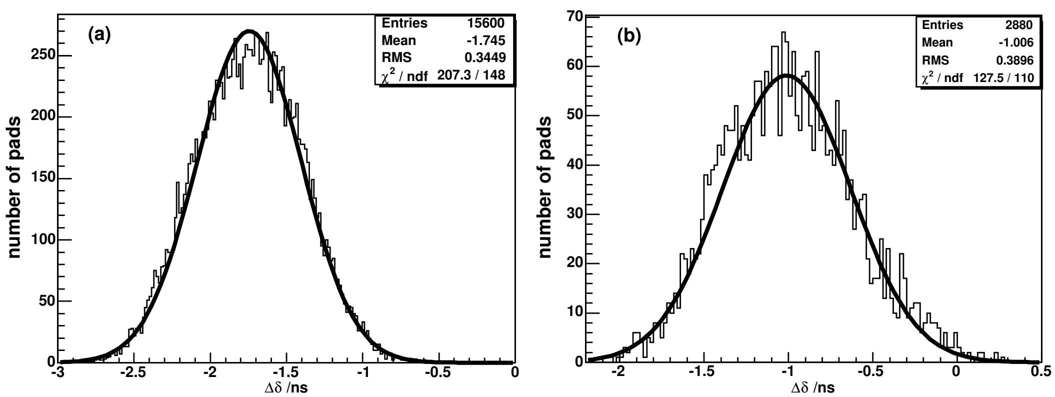

Figure 2. The Difference between the time offset by CP method and the preset one for PAD's in the central area (a) and for PAD's in the guarding ring (b).

300 PAD's (10 from each of the 30 CLUSTER's) were sampled and calibrated manually using a standard probe detector. Fig.3 shows the difference distribution between off-line calibration and manual calibration. Again the mean value is meaningless, and the width of 1.28ns is good enough for the ARGO experiment compared with the detector time resolution of 2ns[5].

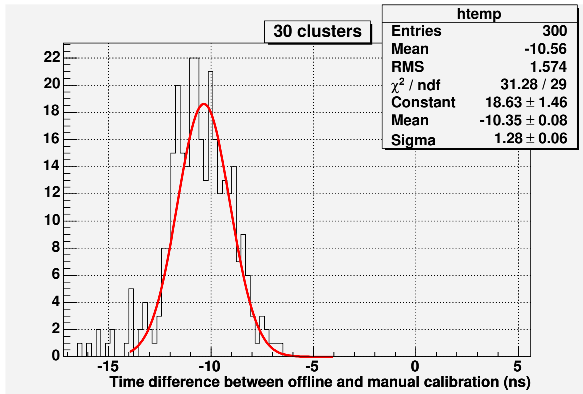

Figure 3. Time offset difference between off-line and manual calibrations.

5. Discussion

The CP makes it easier to understand the detector time offset effects in EAS experiments, and the CP Method makes the off-line calibration possible. The only assumption for this method is that the primary direction cosines has zero mean values which is in fact not true. For example, the geomagnetic effect leads to quasi-sinusoidal modulation on the azimuth angle distribution resulting that the mean values of the direction cosines are not zero [6]. A uniform distribution of the azimuth angle on which the CP method works well can be achieved by selecting special event sample in different EAS experiments (see [7] for ARGO consideration).

6. Acknowledgements

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