Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B (Proc. Suppl.) 175–176 (2008) 435–438
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
www.elsevierphysics.com

Characteristic Plane Method with Conical Correction

S. Z. Chen [a*†]

[a]Key Laboratory of Particle Astrophysics, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 10049, Beijing, China

In ground-based cosmic ray experiments, the equalization of the transit time of signals coming from different parts of the apparatus is of crucial importance for the improvement of the angular resolution and accuracy. In the ARGO-YBJ experiment, this is achieved using the Characteristic Plane Method with conical correction, studied by both Monte Carlo simulation and real data and also checked with manual absolute calibration on a portion of the detector. By introducing conical correction in primary direction reconstruction, the systematics error existing in the off-line calibration with planar fit is successfully removed. Two subsequent construction phases of the detector have been considered: ARGO-42 and ARGO-104. During the calibration of ARGO-104, events with more than 1000 hits and with the core reconstructed inside the carpet were used in order to achieve a good reconstruction of the shower, that is the arrival direction and the core position. The results of the calibration concerning the two configurations, ARGO-42 and ARGO-104, are compared and discussed.

1. Introduction

In ARGO-YBJ experiment, the space-time information of the secondary particle is used to reconstruct the primary direction. The space information refers to the detector position which can be easy measured while the time information is got by TDC, which depends on the detectors, cables, electronics, etc, and also varies with time and environment. The time offset refers to the relative time difference between detector units, and it would lead to bad angular resolution, and more seriously, wrong primary direction which leads to the quasi-sinusoidal modulation on the azimuth angle distribution [1,2], so the time calibration of the detectors, that is the equalization of the transit time of signals coming from different parts of the apparatus, should be done before the primary direction reconstruction.

Having so many detectors it's unpractical to do manual absolute calibration, and from the front end electronics to the chamber it's irrealizable to do online calibration, therefore, Off-line calibration becomes very important in ARGO-YBJ Experiment. Character Plane (CP) method, which was developed to off-line calibrate the time offset of the detector units in an EAS array, was first used in ARGO off-line calibration without conical correction [2,3], but now it is checked out with systematic error due to detector different position in the carpet when studied in detail in the ARGO-42 with Monte Carlo (MC) simulation data. To remove the systematic error, conical correction is added into the CP method, after that, the systematic error approximately disappears.

2. CP method with conical correction

The CP method with planar fit has been fully discussed in [2,3], so only a simple review is given here. 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 experiment. Knowing the detector time offset δ_j, primary direction cosine $l_i = \sin\theta_i \cos\phi_i$ and $m_i = \sin\theta_i \sin\phi_i$ (θ_i and ϕ_i are the azimuth and zenith angles), we can get the real direction reconstruction 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. With the time offset unknown, the planar fit goes like:

$$c(t_{ij} - t0_i^{'}) = l_i^{'} x_{ij} + m_i^{'} y_{ij} \quad (2)$$

*speaker: S. Z. Chen(chensz@mail.ihep.ac.cn)
†on behalf of the ARGO-YBJ collaboration

0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2007.11.046

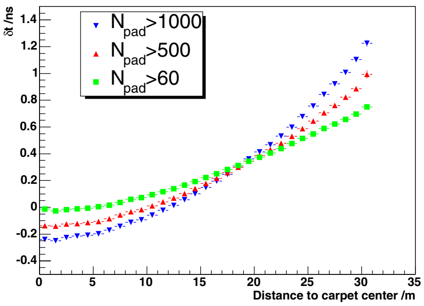

Figure 1. 42 clusters simulation: The residual vs detector distance to the carpet center in different events selection using planar fit.

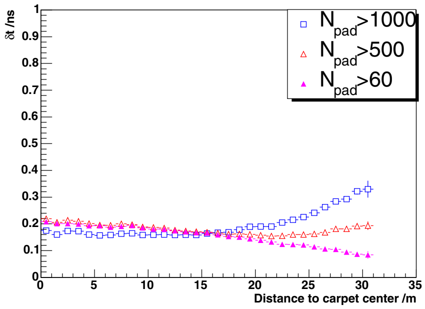

Figure 2. 42 clusters simulation: The residual vs detector distance to the carpet center in different events selection using conical fit.

From Eq.1 and Eq.2, the calibration form can be got finally:

$$< \delta_j > = < t_j > -((< l'_j > x_j + < m'_j > y_j)/c + < t0' >) + (ax_j + by_j)/c \quad (3)$$

where $a = < l' > - < l >$ and $b = < m' > - < m >$. And the plane defined by a and b in the (x, y, δ) space is called the CP. Usually we assume $< l > = 0$ and $< m > = 0$.

The time profile of a EAS front is not a plane but has curvature, therefore, when Eq.1 is used for direction reconstruction, the residual, which refers to the difference between the measured time and the fitted time, will be related to the detector distance R_{ij} from the shower axis. So this will introduce systematic error in CP method, and the systematic error can be completely displayed by later ARGO-42 MC calibration as shown in Fig.1. A simple calculation can show that the max effect of the systematic error on direction reconstruction is about $0.8°$, so a new method must be used to remove it, and this is always achieved by adding the conical correction. After adding the conical correction, the calibration equation Eq.3 is changed to:

$$< \delta_j > = < t_j > -((< l'_j > x_j + < m'_j > y_j + < \alpha R_j >)/c + < t0' >) + (ax_j + by_j)/c \quad (4)$$

where α is the slope parameter of EAS time profile, and is always fixed to 0.03 in direction reconstruction.

2.1. Checking in MC

To test the above conclusion, a full MC simulation for proton primaries (energy:100GeV-100Tev, spectrum index: -2.7, azimuth angle: $0° - 360°$, zenith angle: $0° - 60°$) was done using CORSIKA6203(QGSJET, GHEISHA, and EGS4 for hadronic and electromagnetic interaction respectively)[4] and ARGOG-V138 (trigger multiplicity: LM60, noise: 400, sample area: $200m \times 200m$, detector: 6×7 clusters)[5]. When we used Eq.3 to calibrate the ideal detectors, we clearly saw the systematics error as shown in Fig.1. When checking CP with conical correction, we used events with reconstructed core located inside the carpet, to achieve a good core resolution [6]. The systematic error mentioned above was successfully removed after introducing conical correction with event selection $N_{pad} > 500$ and fixing the slope parameter $\alpha = 0.03$, which can be clearly seen in Fig.2.

When the time offset of each detector was preset according to various rule and recalculated using CP method with conical correction, the distribution of the differences between the time offset obtained by CP method and the preset one was same as the result shown in Fig.2 without regard to the geomagnetic effect, which shows that the CP method with conical correction is very effective.

2.2. Checking in ARGO-42

In real detector time calibration, we used two methods: CP method with planar fit and CP

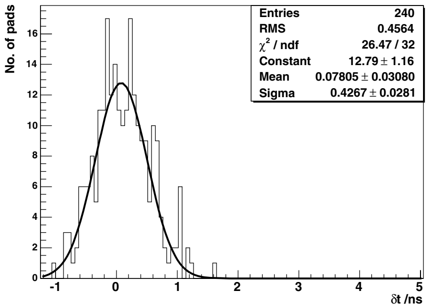

Figure 3. The difference between the off-line calibration with conical fit and the manual calibration, which is fitted with Gaussian.

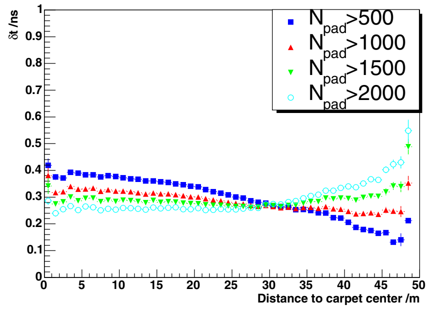

Figure 4. 104 clusters simulation: The residual vs detector distance to the carpet center with different events selection. $N_{pad} > 500$, $N_{pad} > 1000$, $N_{pad} > 1500$, $N_{pad} > 2000$.

method with conical fit for one data sample with events $N_{pad} > 500$ which was collected with 42 clusters (trigger LM 60) from 1-6 Jan 2005. The difference between the results of the two methods is much similar to that shown in MC calibration.

After conical correction introduced, the σ of the difference between the off-line calibration and sample manual calibration decreased from 0.7ns to 0.4ns, shown in Fig.3, which is good enough for the ARGO experiment.

3. CP method with conical correction in ARGO-104

3.1. MC calibration

From ARGO-42 calibration we know that when fixing $\alpha = 0.03$ we should choose appropriate event selection to achieve the best. To study the ARGO-104 time calibration, a full MC simulation for proton primaries was done using CORSIKA6203 [4] and ARGOG-V138 [5]. With this MC data the difference between different events selection was studied in CP with conical correction. According to Fig.4, the event selection $N_{pad} > 1500$ and $N_{pad} > 1000$ are better than other selections like $N_{pad} > 500$, $N_{pad} > 2000$ and so on. But no matter which selection is used, $N_{pad} > 1500$ or $N_{pad} > 1000$, its max effect on direction reconstruction is very little, less than $0.15°$.

3.2. Off-line calibration for ARGO-104

To calibrate the ARGO-104, a data sample of 892,000 events with $N_{pad} > 1000$, which was collected on March 3-4 2006 when the array run steadily and nothing was changed, was used.

Fixing $\alpha = 0.03$ and keeping TDC value within the range 1000-1500ns, we used Eq.4 to calibrate each detector. Since the number of hits on each detector was more than 10000 and the σ of the time offset distribution was less than 5ns, the statistic error of time offset for each detector was less than 0.1ns (2σ).

After the time calibration procedure was iterated 6 times, the distribution of residuals became much better and the Quasi-Sinusoidal Modulation, the amplitude of which was about 6% before calibration, approximately disappeared, as shown in Fig.5.

4. Discussion

4.1. The times of iteration

Due to the trigger system problem, there were 10 clusters, which were different from others by about 10ns, both in Argo-42 and Argo-104. To study the effect of this phenomenon, we preset the corresponding detector's time offset in Argo-42 MC calibration with the time offset got from real data calibration. In this MC calibration we clearly saw that the difference between the preset one and the one got by CP method decreased with the times of iteration. In real data calibration, we

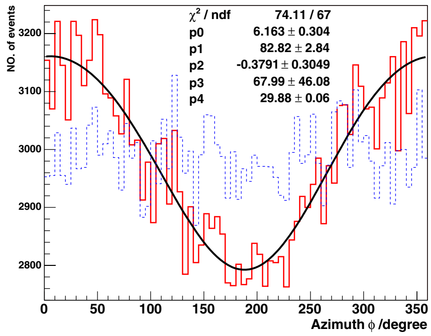

Figure 5. 104 clusters real data: The azimuth distribution before calibration(real line), which is fitted with: $(p0\sin(\phi+p1)+p2\sin(2\phi+p3)+100)p4$. The dotted line is the azimuth distribution after calibration.

decided the times of iteration by comparing result with that got from last time.

4.2. Comparison between ARGO-42 and ARGO-104

When the time offset of the ARGO-42 was compared with the corresponding 42 clusters in ARGO-104, 10 clusters were found very different from others in ARGO-42, but now in ARGO-104 this has changed. When the data was checked in detail, the time when the change took place was found, July 21 2005. This change was due to an adjustment of trigger system electronics, and the common stop signal given to the 10 clusters was always delayed by about 10ns in Argo-42, but in Argo-104 the electronics has been changed. But this delay was steady, for the sigma of their time offset distribution was not bigger than that of others. So this problem will not have effect on direction reconstruction after time calibration. Therefore we concluded that it is necessary to check the TDC stability and to update the calibration files for different data-taking periods.

4.3. The effect of the geomagnetic field

In the full paper above we didn't mention the hypothesis that the azimuth angle of the primary is uniform on which the CP method works well. But, due to the effect of the geomagnetic field it is not true, that is to say $< l >\neq 0$ and $< m >\neq 0$. According to the study and theory in [2,3,8], its effect on direction reconstruction is about 0.3° when we assume the amplitude of asymmetry 2%, which is much less than 6% before calibration. To check and correct the off-line calibration, sample manual absolute calibration should be done for ARGO-104, and Moon shadow analysis will also be helpful. According to our latest study this correction can also be hopefully reached by off-line method.

5. Conclusions

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 and easy to do. By introducing the conical correction with suitable event selection, the systematic error existing in off-line calibration with planar fit has been successfully removed.

6. Acknowledgements

This work is supported in part by NSFC (10120130794), the Chinese Ministry of Science and Technology, the Chinese Academy of Sciences, the Key Laboratory of Particle Astrophysics, IHEP, CAS, and INFN, Italy.

REFERENCES

1. A.M. Elo et al. Proc. Of the 26th ICRC, Salt Lake city, 5(1999):238.
2. H.H. He et al. Proc. of the 29th ICRC, Pune, 5(2005):143-146.
3. P. Bernardini et al. Proc. of the 29th ICRC, Pune, 5(2005):147-150.
4. J.N. Capdevielle et al. KfK Report 1992, No.4998.
5. D. Martello et al. ARGO Detector with GEANT3 package, 2000.
6. Carla Bleve, PH.D thesis.
7. G. Di Sciascio et al. Proc. of the 29th ICRC, Pune, 6(2005):33-36.
8. H.H. He et al. Proc. of the 29th ICRC, Pune, 6(2005):5-8.