Study on the Performance of YBJ 50m² RPC Carpet *

YBJ-ARGO Collaboration

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Abstract The characteristics of a 50m² RPC carpet(prototype of YBJ-ARGO experiment) was analyzed using its test run data. A correction method of the systematic time error is suggested, and non-uniform azimuthal angle distribution possibly due to direction reconstruction error on an asymmetric carpet is reported.

Key words gamma ray astronomy, EAS, RPC

1 Introduction

The Sino-Italian collaboration YBJ-ARGO experiment (Yangbajing Astrophysical Radiation with Ground-based Observatory)[1] located at Yangbajing(90°31′50″E, 30°6′38″N, 4300m a.s.l.)

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is under its way. The goal of the experiment is to study cosmic rays, mainly γ ray point sources (>100GeV) and gamma ray burst(>10GeV) from the northern hemisphere in the declination band $-10° < \delta < 70°$, by means of detecting small size EAS(extensive air shower) using a full coverage $10000m^2$ RPC(resistive plate chamber)[2] carpet.

Since it is the first time using RPC detector at high altitude in EAS experiments in the world, a $50m^2$ prototype RPC carpet[3] was setup and tested at Yangbajing in 1998—1999 to investigate the performance and characteristics of RPC carpet at 4300m a. s. l. Here we present the results from the test run, including detector calibration, azimuthal angle distribution, zenith angle distribution, angular resolution, etc.

2 Experiment Setup and Run

The carpet consists of 3×5 RPCs, $280\times112cm^2$ each. It covers a total area of $8.6\times6.0m^2$ with active area of $45.8m^2$, about 90% coverage, due to 10cm gap between neighborhood RPCs. One chamber consists of 2×5 the smallest detector units so-called PADs, each $56\times56cm^2$ with 16 readout strips($3.3cm\times56cm$). The PADs with a 2mm gas gap are built with bakelite plates of volume resistivity in the range$(0.5—1)\times10^{12}\Omega\cdot cm$. Fig. 1 shows the layout of the carpet, with PAD No. defined by $i\times16+j$, where j increases from 0 to 14 along y direction while i increases from 0 to 9 along x direction.

The RPCs were operated under streamer mode[4] with gas mixture of argon(15%), isobutane (10%) and tetrafluoroethane $C_2H_2F_4$(75%) at high voltage of 7400V, about 500V above the plateau knee, where the efficiency was >95% and the time resolution was about 1ns. Signals from strips of each PAD are FAST-ORed, so position resolution is one PAD size. Triggered signal, requiring at least 6 PADs fired within 100ns, was shaped to 1.5μs pulse time width to inhibit after-pulses, then was sent to TDCs. TDCs working in COMMON STOP mode record the signal time of the fired PADs. For every event the raw data consist of recorded TDC time and channel numbers from which fired PAD positions can be retrieved. More than 380,000 EAS events were collected with the most probable multiplicity (the number of PADs fired by one event) to be about 36(Fig. 2). Since 30 PADs were not working, the maximum multiplicity was 120.

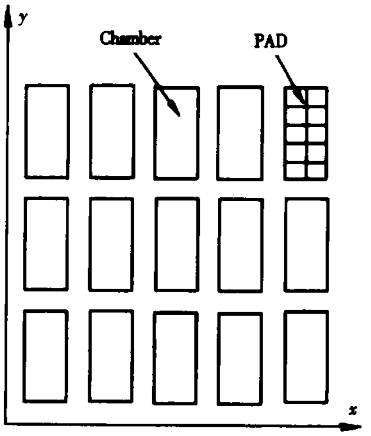

Fig. 1 Layout of the prototype RPC carpet.

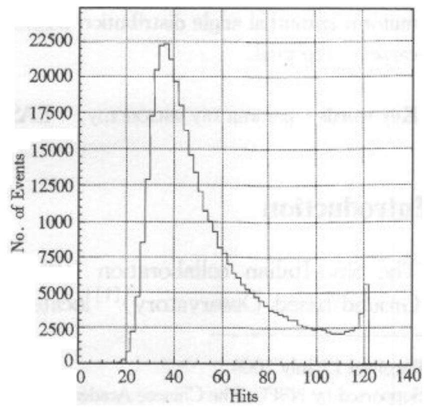

Fig. 2 Event multiplicity distribution.

3 Data Analysis

3.1 Time Correction

Raw data correction is always the first and most important step in data analysis. In our case systematic error comes mainly from the time offset of different PAD signals for the detected particle, which will determine the reconstruction accuracy of the source arrival direction. The time offset includes fluctuation of time response of RPC detector, cable delay, electronic delay(i.e. TDC channel variation), etc. Since the online calibration of the time offset was not done in the test run, difficult for the large number of PADs in YBJ-ARGO experiment, offline time correction should be used to deal with the raw data. That was done in the following way.

Taking the central PAD as the first reference, every PAD is calibrated based on the inner neighborhood PAD, the time distributions of the two PADs were built up by adding all the time of the events fired both PADs. Since the size of the carpet is relatively small(less than 5 meters from the center) compared with shower lateral development(~100m from the core), the position difference can be discarded. The 2 neighborhood PADs should have same time distribution over all the events hitting both of them, so the difference between the medians represents the time offset of one PAD over another. At last all PADs were calibrated based on the central one. Fig.3 shows the time offset for PADs while No.96—126 were not working.

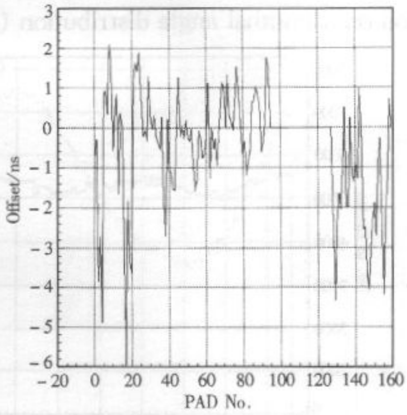

Fig.3 PAD time offset.

3.2 Event Reconstruction

EAS particles are concentrated in a front of parabolic shape. A good approximation for particles not far from the shower core is represented by a cone-like shape. Since in this test the signals being sent to TDCs are shaped to 1.5μs, only the time of the first particle hitting each PAD is recorded. Due to the relatively small size of the carpet, the time profile of the shower front sampled by the carpet is expected to exhibit a planar shape. In this approximation the expected particle arrival time is a linear function of the position,

$$(\boldsymbol{r}_i - \boldsymbol{r}_0)\cdot \boldsymbol{n} = c(t_i - t_0), \tag{1}$$

where $(\boldsymbol{r}_i, t_i)$ and $(\boldsymbol{r}_0, t_0)$ represent the position and time information of the ith and 0th hit respectively, $\boldsymbol{n}$ is the direction vector of the EAS front plane, and c is light velocity. To avoid the error introduced by $(\boldsymbol{r}_0, t_0)$, the following transform of the above formula was used:

$$Ax_i + By_i + C = ct_i, \tag{2}$$

where(x_i, y_i) is the coordinate of the fired PAD, A and B are direction cosines of $\boldsymbol{n}$ along x, y coordinates, and C should be constant related to the time when the shower front passes the origin of the observation plane. The algorithm that reconstructs the arrival direction of the shower fits the time and position of each hit to a plane by χ^2 minimization. Outlying hits were rejected by means of a $k\cdot\sigma$ cut where σ is the standard deviation of the time distribution around the fitted plane. The fit was iterated until all remaining hits meet the cut condition(if the remaining hit number is <6, the event is discarded). k is determined to be about 2.2 when the best reconstruction efficiency is achieved.

4 Results

4.1 Azimuthal Angle Distribution

Uniform azimuthal angle distribution is important for background estimation while searching gamma-ray point sources in EAS experiments. Usually two methods, equal-zenith angle method and equal-declination method, are used. For the former uniform distribution of azimuthal angle is strongly recommended. Background source direction should be uniformly distributed along azimuthal angle, but due to time offset, we found quasi-sinusoidal modulation on azimuthal angle distribution (period 360°)[5]. After time correction, that modulation

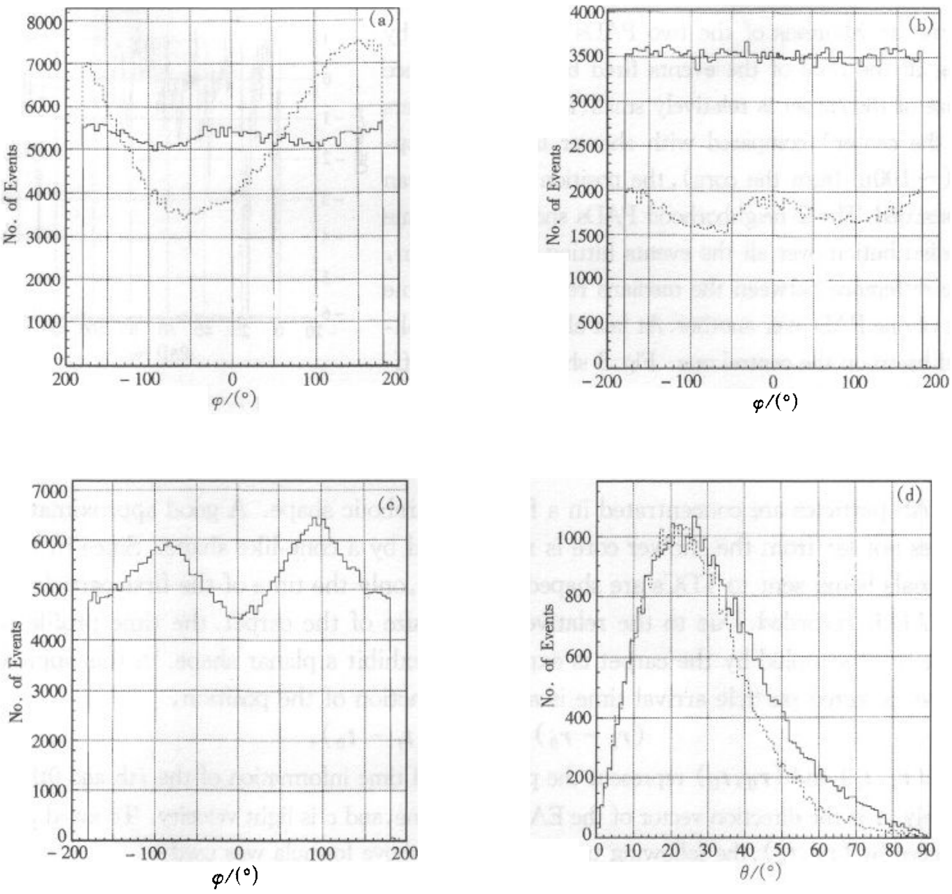

Fig.4 (a) Azimuthal angle distribution before(dotted line) and after(solid line) time offset correction for all events; (b) Azimuthal angle distribution for events with $\theta<30°$ (solid line) and $\theta>30°$ (dotted line); (c) Azimuthal angle distribution reconstructed using PADs with $y<350$cm; (d) Zenith angle distribution reconstructed using PADs with $y<350$cm for events within $\pm 10°$ near x (dotted line) and y axis (solid line).

disappears. Fig. 4(a) shows the azimuthal angle distribution for all events before and after time offset correction, from which we still found ~10% difference between x and y directions (also quasisinusoidal modulation but with period 180°). For $\theta<30°$, we got a uniform distribution (Fig. 4(b)), but for large zenith angles, the distribution shows an increase at x direction ($\phi=0°$ or $180°$) compared with that at y direction ($\phi=\pm 90°$) (Fig. 4(b)). If part of the y PADs were cut off the events along y direction increased after reconstruction (Fig. 4(c)), while the reconstructed zenith angle distribution for events along y direction is wider than that for events along x direction (Fig. 4(d)). Simulation on the same detector setup shows no trigger bias but the same modulation on azimuthal angle distribution after direction reconstruction. Here we reach the conclusion that the non-uniform azimuthal angle distribution is due to reconstruction error on asymmetric carpet. In our case, carpet size alone x coordinates is smaller than that along y coordinates. Due to the fluctuations of the arrival times of shower particles, for events along x direction compared with those along y direction, the reconstructed zenith angle will have bigger error, so the reconstructed zenith angle distribution will be wider. That will lead to the non-uniform azimuthal angle distribution for events with large zenith angles.

4.2 Zenith Angle Distribution

Due to atmospheric absorption, the zenith angle θ distributes like

$$\frac{dN}{d\sec\theta} \propto \frac{e^{-n\sec\theta}}{\sec^3\theta}, \quad (3)$$

with n related to the mean attenuation length λ of EAS,

$$n = \frac{x_0}{\lambda}. \quad (4)$$

where x_0 is the atmospheric depth at observation level (606g/cm² at Yanbajing). n is found to be 5.0 ± 0.5, with λ to be about (121 ± 12)g/cm² (Fig. 5).

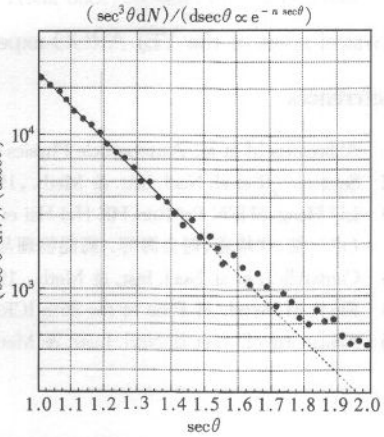

Fig. 5 Zenith angle distribution.

4.3 Angular Resolution

The angular resolution of the carpet has been estimated by dividing the detector into two independent sub-arrays, odd PADs and even PADs, and comparing the two reconstructed shower directions (chessboard method). These two subarrays overlap spatially so that they sample the same portion of the shower. The space angle α between these directions is shown in Fig 6. The carpet angular resolution σ_α can be estimated by the following relation:[6]

$$\sigma_\alpha = \frac{M_\alpha}{1.177\times 2}, \quad (5)$$

where M_α is the median of the α distribution. σ_α is found to be 2.4° for events with hits>80.

5 Conclusions and Discussions

Result of the test run shows the importance of time correction for data analysis, and a correction

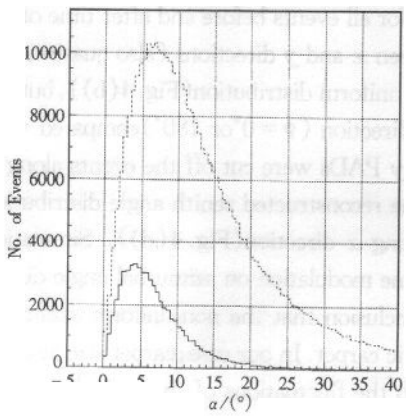

Fig.6 Space angle distribution, for all events (dotled line) and events with hits>80(solid line).

method is suggested. For YBJ-ARGO experiment, since the size of the carpet will be comparable with the lateral development of EAS, PAD time offset correction using the method described in section 3.1 will introduce error due to position difference between PADs and the method should be further modified. For example, since in the YBJ-ARGO experiment the event core may be well reconstructed, the above problem can be solved by selecting those events in the same core distance region. The non-uniform azimuthal angle distribution of the test run shows the importance of symmetry for small size arrays. For YBJ-ARGO experiment, we hope that doesn't occur due to its large size. Simulation on that is undergoing. Anyway, the performance of the prototype RPC carpet shows good and stable characteristics of RPC carpet at YBJ condition with the physical goals of the YBJ-ARGO experiment to be hopefully fulfilled.

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羊八井50m² RPC地毯性能研究*

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摘要　利用羊八井50m² RPC地毯(YBJ-ARGO实验原型)的测试数据对其性能进行了分析研究,包括原初粒子方位角分布、天顶角分布、地毯的角分辨、探测时间系统误差对方位角分布的正弦调制、探测时间系统误差的离线修正、几何不对称的小型地毯探测器上原初粒子到达方向重建误差造成的方位角分布的不均匀性等.

关键词　γ射线天文　广延大气簇射　RPC

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