Status of the ARGO-YBJ experiment

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Abstract. The ARGO-YBJ experiment, under construction at the Yangbaijing Laboratory (P.R. China, 4300 m a.s.l.), is a full coverage detector of dimension 74×78 m^2 made by a single layer of Resistive Plate Counters. About 10% of the final active area ($\sim$ 700 m^2) is in stable operation to check the detector performance and the reconstruction algorithms. In this paper the status of the experiment and the analysis of the first data are presented.

THE DETECTOR

The ARGO-YBJ experiment is under construction at the YangBaJing High Altitude Cosmic Ray Laboratory (Tibet, P.R. China, 4300 m a.s.l.) with the aim of studying cosmic rays, mainly cosmic γ-radiation, at an energy threshold of a few hundreds of GeV. The site location (latitude $30^\circ\ 06'\ 38''$ N, longitude $90^\circ\ 31'\ 50''$ E) will allow the monitoring of the Northern hemisphere in the declination band $-10^\circ < \delta < 70^\circ$.

The apparatus consists of a full coverage array of dimension 74×78 m^2 composed by a single layer of Resistive Plate Counters (RPCs), 280×125 cm^2 each. The area surrounding this central detector, up to 111×99 m^2, is partially ($\sim$ 50%) instrumented with RPCs in order to improve the apparatus performance in the detection of external events (see Fig.1). A lead converter 0.5 cm thick will cover uniformly the RPCs plane in order to improve the angular resolution. The RPC signals are picked up by means of 6.7×62 cm^2 strips. These (a total of 124800 in the carpet) are the basic elements which define the space pattern of the shower. The fast-OR signals of 8 strips are used for time measurements and trigger purposes. These OR-ed strips define a logical pad of area 56 $\times$ 62 cm^2 (a total of 15600 in the carpet) which is the basic element providing the time pattern of the shower. This digital response of the detector can be used up to energies of a few hundreds of TeV. In order to extend the dynamic range, a charge read-out has been implemented by adding to each RPC two large size pads of dimension 140×125 cm^2 each [1].

The time resolution ($\sim$ 1 ns) and the small temporal (the pad) and spatial (the strip) pixels, allow to image the shower front with an unprecedented space-time granularity. An example of the high accuracy sampling capability of the ARGO-YBJ carpet is shown in the left side of Fig.2, where the picture of an air shower event recorded by the pad system of 16 Clusters is displayed.

The basic detection unit is the Cluster, a set of 12 contiguous RPCs. The signals from each Cluster are organized by a front-end pre-processing electronics ("Local Station", LS) in order to give a continuous counting of the fired pads ("pad multiplicity") in a narrow time window (Δt = 150 ns). This information is transferred to the "Central

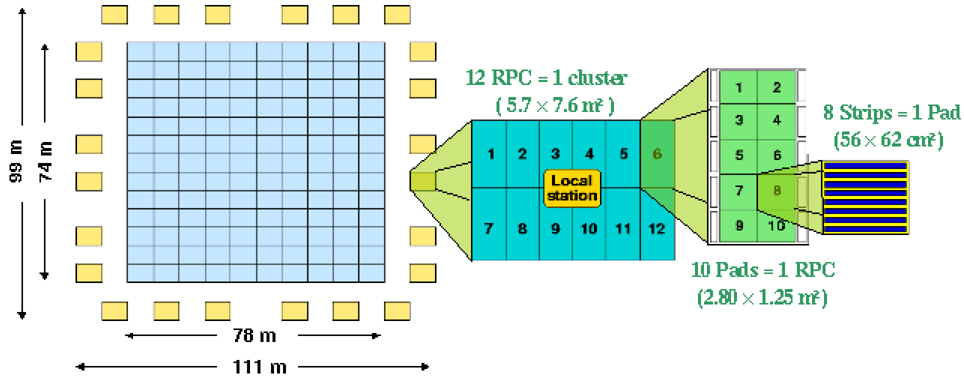

FIGURE 1. Layout of the ARGO-YBJ array, showing definitions of Cluster, RPC, Pad, Strip.

Station" for trigger purposes. At any trigger occurrence, the space and time information from each LS is collected and elaborated in the Central Station for event building and storage.

The physical goals of the experiment require the ability to study with high efficiency both low energy (with a few hits on the carpet) and very high energy (with thousands of fired pads) showers. Therefore, three different trigger subsystems have been implemented: (1) Low Multiplicity Trigger (LMT), (2) Fast Trigger (FT), (3) High Multiplicity Trigger (HMT). All these triggers are based on the hit counters generated by the LSs on a given number of Clusters. These counters are two and they are used for trigger purposes with the following scheme: LMT and FT (from ≥ 1 to ≥ 6), HMT (≥ 7, ≥ 16, ≥ 32, ≥ 64). The Fast Trigger, which sums up the counts of 4 Clusters (a "Supercluster") greater than a selected threshold, is very efficient for low energy events.

Separate from the three former trigger subsystems, the single rate data acquisition system consists of a VME crate with a custom 80-channels scaler board. The absolute time is given by a GPS clock with an accuracy $< 1\ \mu$s. A reference frequency of 10 MHz, provided by the GPS clock, is sent to the same board to check the counting duration, that can be software-selected to 50 or 500 ms.

A detailed description of the trigger and DAQ setup can be found in [2], while the operation in *scaler mode* is reported in [3]. The detector status is continuously monitored for what concerns the high voltage power supply, the current drawn by each RPC, the gas temperature and humidity, and the environmental parameters like atmospheric pressure and external air temperature [4].

An upgrade of the detector by (1) extending the central carpet to include the guard ring, for a total of 14×17 Clusters, and (2) the construction of a large muon detector, is now under study (see [5] for details).

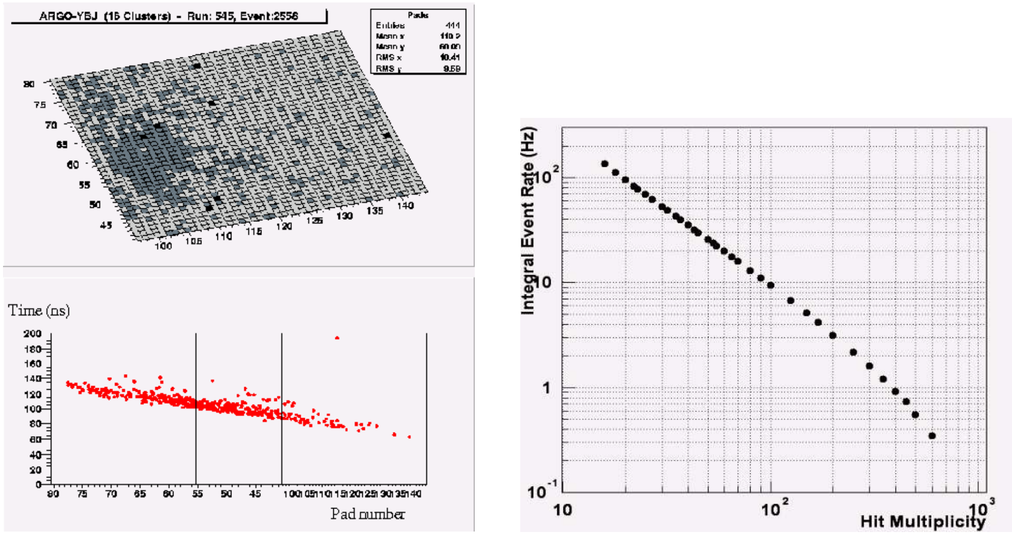

FIGURE 2. Left plot: an air shower event recorded by the pad system of 16 Clusters. The lower panel shows the space-time projected view (the full length of x-axis corresponds to $\sim$ 30 m). Right plot: integral trigger rate vs. pad multiplicity.

OBSERVATIONAL TECHNIQUES

The full coverage approach and the high altitude location allow the study of many physics items in the field of low energy cosmic rays. As a consequence, two main operation modes have been designed for the ARGO-YBJ detector:

a) *Shower technique*
Based on the requirement that a minimum number of pads (N_{pad}) must be fired in the central carpet with the proper space-time pattern. For these events the position and time of any fired pad will be recorded to reconstruct the shower parameters (core position, arrival direction and shower size). The shower data will be used in γ-ray astronomy and in cosmic ray studies. The expected trigger rate is $\sim 2 \cdot 10^4$ ev s^{-1}, for $N_{pad} \geq 50$.

From Monte Carlo simulations we infer that the trigger condition $N_{pad} \geq 50$ corresponds to explore a Crab-like γ-ray source spectrum with energy threshold $\sim$ 200 GeV and median energy $\sim$ 500 GeV, by selecting internal events. With such a multiplicity threshold ARGO-YBJ can achieve a pointing accuracy better than 1°, and a sensitivity to such a point source of at least 8 σ in 1 year of data taking (without considering any quality factor coming from γ/hadron primary discrimination).

b) *Single particle technique*
The counting rate of the single particles hitting the detector is recorded at fixed time intervals. An excess is registered if the counting rate is significantly higher than the background. This simple technique allows the detection of secondary particles from very low energy showers ($E >$ 10 GeV) that reach the ground in a number insufficient to trigger the detector operating in *shower mode*, however the arrival direction is not measured. The single rate measurement will be used to search for low energy transient phenomena such as GRBs or Solar Ground Level Enhancements, and to study cosmic

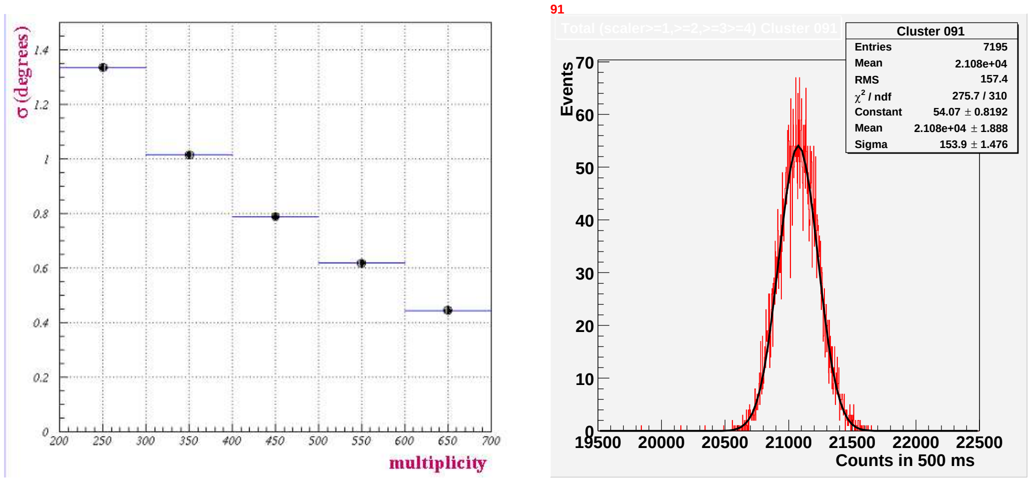

FIGURE 3. Left plot: angular resolution vs. pad multiplicity, measured on 6 Clusters via the even-odd method. Right plot: the counting rate spectrum of Cluster 91 during 1 hour of data taking.

ray modulations due to solar activity. Moreover, the same data can be used to check the detector stability. The expected rate is $\sim 5 \cdot 10^6$ events s^{-1}.

STATUS OF THE EXPERIMENT

Presently 40 Clusters of the central detector carpet (corresponding to a total instrumented area of ~ 1700 m^2) have been installed and put into operation for debugging, calibration and checking of the reconstruction algorithms.

Shower mode

Each Cluster has been individually operated by using the different *shower mode* triggers to test the performance of the single components, the uniformity of their response and the time alignment of all the electronics channels. Several runs with high multiplicity triggers (≥ 64 fired pads) have been devoted to the single Cluster calibrations.

The integrated operation of the detector components has been tested by running 16 Clusters ($\sim 10\%$ of the final active area) with the *shower mode* triggers in the last 2 years. In the right plot of Fig.2 the integral rate of events on 16 Clusters is plotted as a function of pad multiplicity. The data follows a power law with a slope consistent with the cosmic ray spectrum, thus showing the physical consistency of the detected showers.

In the left plot of Fig.3 a preliminary angular resolution vs pad multiplicity, calculated via the even-odd method on 6 Clusters ($\sim 17 \times 15$ m^2), is displayed. As can be seen, the angular resolution is $\leq 1°$ for $N_{pad} > 300$, without any lead layer added on the RPCs.

Scaler mode

Data from 16 Clusters have been continuously collected since June 2004, with this part of the detector kept in stable conditions while the rest of the carpet was under mounting and calibration. Single particle rates have been collected with a gating time of 500 ms; for each Cluster multiplicities from ≥ 1 to ≥ 4 have been collected. For

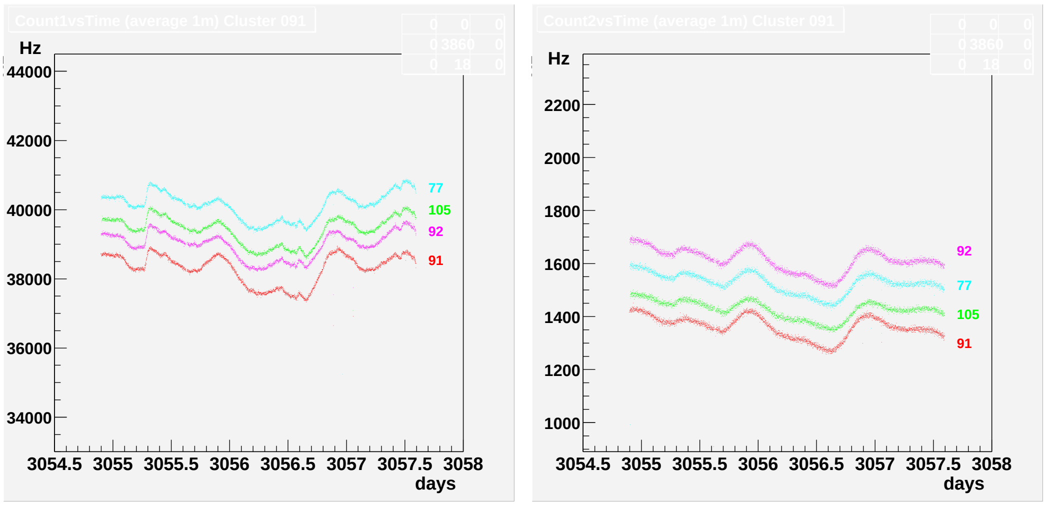

FIGURE 4. The counting rate frequency as a function of time for both singles (≥ 1, left) and doubles (≥ 2, right) of 4 Clusters during 3.5 days of data taking.

this measurement, since any signal is detected as an increase in the absolute counting rate, it is of crucial importance to keep the detector under control and check its stability compared with the expected statistical poissonian fluctuations. For this reason both environmental and detector parameters, namely atmospheric pressure, external air temperature, high voltage power supply, current drawn by each RPC, gas temperature and humidity, are continuously monitored. The intrinsic detector stability can be checked by measuring the deviations from the expected statistical distribution of counting rates, after applying the corrections for the detection efficiency and the environmental parameters. The same result can be obtained by plotting the counting rate for short periods, during which both detector and atmospheric parameters can be considered constant.

Fig. 3 (right side) shows the counting rate spectrum of Cluster 91 during 1 hour of data taking. The total counting rate is obtained from $\geq n$ counting using the formula:

$$N_{tot} = N_1 + 2N_2 + 3N_3 + 4N_4 \tag{1}$$

with

$$N_i = N_{\geq i} - N_{\geq i+1} \tag{2}$$

From the above formulae, with the approximation $N_4 = N_{\geq 4}$, we obtain:

$$N_{tot} = N_{\geq 1} + N_{\geq 2} + N_{\geq 3} + N_{\geq 4} \tag{3}$$

$N_{\geq i}$ counts are expected to be poissonian, but not their sum, because they are not independent; the total counting rate is expected to be gaussian.

From relation (1) the distribution width can be obtained; for the plot in Fig.3 a value of 154 is calculated, while a width of 153 is expected. These values are compatible, demonstrating that, at least for short periods, the detector acts as a *statistical* detector.

Fig. 4 shows the counting rate frequency as a function of time for both singles (≥ 1, left) and doubles (≥ 2, right) of 4 Clusters during 3.5 days of data taking. As can be seen from the left plot, the single counting rate, that has higher sensitivity due to the higher frequency, is coherent for all Clusters at a level of a fraction of per cent, showing that all Clusters react homogeneously to external inputs, without autonomous behaviours due to intrinsic noise fluctuations. The different counting rates of the Clusters is due to different efficiencies and/or different background.

The same result is obtained for double counting rates (right plot), even if with lower significance due to the lower frequency.

With this simple technique, a good sensitivity at low energies can be achieved; MonteCarlo calculations show that even considering a low multiplicity for the *shower mode* trigger (≥ 6), the *scaler mode* is more sensitive for energies ranging from 10 to 40 GeV [6, 7]. Since the counting rates for different multiplicities correspond to different mean energies of incoming primaries, if a positive detection is obtained it is possible to give an indication of the signal energy spectrum. As an example, a rough measurement of the mean primary energy can be done comparing the ratio ≥ 2 to ≥ 1 counting rates with MC predictions. Since this ratio depends on the primary energy, even if slightly, increasing for protons from 5.8% at 10 GeV to 6.8% at 100 GeV and 12.9% at 1 TeV, the measured ratio of 5.4% is consistent with the quoted 10 GeV mean energy of primary particles.

Conversely, since the arrival direction of the incoming signal can not be determined, an independent confirmation by a directional detector is required even if a big excess is detected.

CONCLUSIONS

The low energy threshold and the large field of view make ARGO-YBJ a γ-ray detector suitable to monitor the γ-ray sky searching for unknown sources and unexpected events.

Presently, about 1700 m^2 of the detector (40 Clusters) have been instrumented and put into operation for calibration runs devoted to test the performance of the individual components and their integrated operation. The detector performance turns out as good as expected.

At the end of this year all the 40 mounted Clusters will be put into stable data taking, which means a detecting area large enough for Solar flare and GRB searches. The central carpet will be completed by the end of 2005 and put into stable data taking early in 2006.

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