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Air shower detection by the ARGO-YBJ experiment

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The ARGO-YBJ detector, currently under installation at the Yangbajing Cosmic Ray Laboratory (4300 m a.s.l.), exploits the full-coverage technique in order to study the astrophysical radiation at few hundreds GeV threshold. About 1900 m^2 of detector are presently in data taking for shower detection runs. First data have been analyzed with special emphasis on shower reconstruction. We report the main results and discuss the opportunity offered by such an apparatus to image the shower front.

1. Introduction

The ARGO-YBJ (Astrophysical Radiation with Ground-based Observatory at YangBaJing) experiment is under construction at the Yangbajing High Altitude Cosmic Ray Laboratory (4300 $m\ a.s.l.$, 606 g/cm^2), 90 km North to Lhasa (Tibet, P.R.China), as an Italian-Chinese collaboration project. It will be operating over the next years with the aim of studying cosmic rays, mainly cosmic γ-radiation, at an energy threshold of few hundreds GeV, by detecting small size air showers at high altitude with wide-aperture and high duty cycle capability.

The apparatus is a full coverage detector of dimension $74 \times 78\ m^2$, made of a single layer of Resistive Plate Counters (RPCs). In order to improve the apparatus performance in the detection of showers with the core outside the full coverage carpet, the fiducial area will be enlarged by partially instrumenting the area surrounding the central detector with a guard ring of RPCs, up to $\sim 100 \times 110\ m^2$. A 0.5 cm thick lead converter will cover uniformly the RPC plane to increase the number of charged particles by conversion of shower photons and to reduce the time spread of the shower front. The site location (longitude $90^\circ\ 31'\ 50''\ E$, latitude $30^\circ\ 06'\ 38''\ N$) will allow the monitoring of the Northern hemisphere in the declination band $-20^\circ < \delta < 80^\circ$.

The detector is organized in modules of 12 RPCs, each RPC of dimensions $280 \times 125\ cm^2$. This group of RPCs (area = $5.7 \times 7.9\ m^2$), called 'Cluster', is the basic detection and Data Acquisition unit in a logical subdivision of the apparatus. The percentage of active area in the central detector, made of 130 Clusters, will be $\sim 92\%$.

At present about 3500 m^2 of the central detector have been instrumented and $\sim 1900\ m^2$ (42 Clusters) are in data taking since December 2004. In particular, a 'shower mode' trigger for the cosmic ray shower detection is implemented. A detailed status report of the experiment can be found in [1]. This work will be focused on the procedures used to reconstruct the main features of shower events and on their results.

2. Event reconstruction

The performance of a detector in sampling and reconstructing the shower front of atmospheric cascades is primarily determined by its intrinsic time resolution and space-time granularity. In ARGO-YBJ the single particle signals from each RPC are picked-up with 80 read-out strips, each one of dimensions $6.7 \times 62\ cm^2$, which provide the space information. The 'Fast-OR' of 8 strips defines a logic unit called 'pad' ($56 \times 62\ cm^2$). The pad signal is used for timing (so it defines the 'time granularity' of the detector) and for trigger formation. The intrinsic time resolution of the RPC is $\sim 1\ ns$.

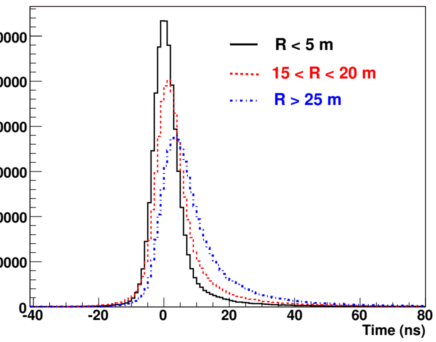

Figure 1. Shower time profile for different intervals of hit distance R from the reconstructed core.

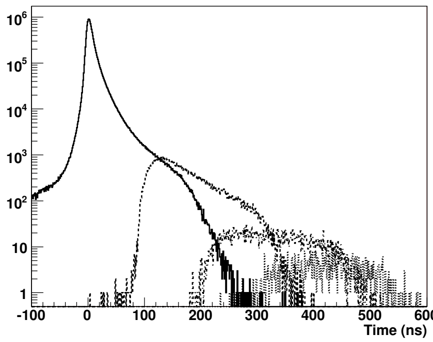

Figure 2. Time distributions of 1st, 2nd, 3rd and 4th hits on the same pad.

The bulk of data here considered was collected by a shower trigger requiring at least 60 fired pads, into a proper coincidence time window, out of a total of about 5,000 pads on the entire operating carpet. The resulting trigger rate matching this requirement is $\sim\ 200\ Hz$. It is worth to point out that, for the first time, the digital readout allows to count all the particles in a shower inside the detector area down to very low densities ($\sim 0.03\,particles/m^2$, in the present configuration).

Shower time profile - The accuracy in the reconstruction of the shower arrival direction mainly depends on the capability of measuring the relative arrival times of the shower particles. Such a direction is obtained after reconstructing the time profile of the shower front by using the time information of each pad of the detector. The time resolution of each pad is the result of: the RPC intrinsic resolution, the propagation of the signal along the strip ($62\,cm$) and the electronic time resolution.

An additional factor arises from the timing offset between different read-out channels due to differences in the discharge time of the RPCs, different cable delays and other instrumental effects. So, as a preliminary step, a 'detector time calibration', that is a correction for the relative time offset among different pads, has been performed (the procedure is described in detail in [2]).

For particles not far from the core (within few tens of meters), the shower front shape is expected to appear conical. In particular, according to the results of simulations at the Yangbajing depth, the slope of the conical shape is expected to range from $\sim 0.01\,ns/m$ (for the foremost particles of the front) up to $\sim 0.1\,ns/m$.

The procedure used to reconstruct the arrival direction of the shower follows 2 steps: (1) times and positions of all pad hits in the event are fitted to a plane by a χ^2 minimization; (2) fit of the same space-time coordinates to a cone, by adding a conical correction $\alpha\ R_i/c$, where R_i is the distance of the i-th pad from the reconstructed core and $\alpha/c = 0.03\,ns/m$.

Both steps can be iterated several times, by rejecting at each cycle the outlying times by means of a $k\ \sigma$ cut (σ being the standard deviation of the time distribution around the fitted shape and $k = 2.5$ in this analysis). The procedure is rather fast, because both fits make use of analytic formulas.

Fig.1 shows the time profile of a shower sample after the direction reconstruction, that is the hit time distribution with respect to the fitted conic front, for three different intervals of the hit distance from the core. The enlargement due to the shower front thickness as a function of the core distance can be appreciated. The pad Fast-OR signals sent to TDCs are shaped to $90\ ns$, thus we are able to detect also 'multiple hits', that is the times of several particles hitting the same pad with a minimum time delay can be recorded. This is represented in Fig.2, where, besides firsts hits, second, third and forth hits are shown too. Moreover, due to the TDC set-up,

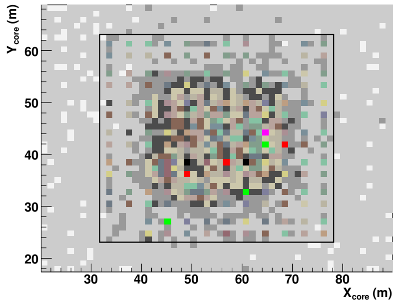

Figure 3. Distribution of the reconstructed core positions by means of the Maximum Likelyhood method. The box indicates the current detector boundaries (42 Clusters).

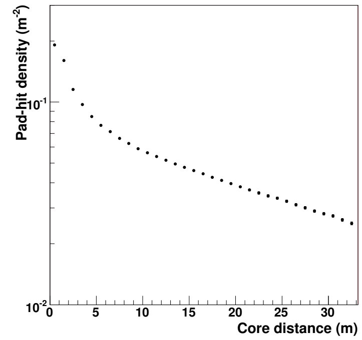

Figure 4. Lateral density profile of pad-hits with respect to the reconstructed core position.

very delayed particles in the same cascade could be also recorded, up to a maximum time delay of about $1.3\ \mu s$ with respect to the shower front.

Density distributions - In order to fit the shower particle to a conic shape, the position of the shower core is needed in the procedure. Several algorithms have been implemented in ARGO-YBJ for reconstructing the shower core position. One of these is based on the use of a Likelihood function applied to the lateral density profile of the hit distribution and is able to find out the core position near the edge of the detector carpet or outside it. This is evident from Fig.3, which shows the scattered distribution of reconstructed core positions over an area larger than the detector.

Fig.4 represents the lateral density distribution of a sample of quasi-vertical showers (i.e. with reconstructed arrival direction in the zenith angle range $0 \div 20°$), when the hit distances are referred to the core position as determined by the Maximum Likelihood method.

The differential density spectrum of EAS is useful in order to obtain information on the size spectrum, since both spectra follow a power law with close indexes. Fig.5 shows the density spectrum for three intervals of zenith angle: the shapes of the spectra are very similar and the average slope is $\beta = -2.47$. This result is expected because the integral density spectrum changes very slowly with altitude and particle density.

Angular distribution - The zenith angle distribution of events with particle density exceeding a given value is expected to follow an exponential behaviour $I(\geq \rho, \theta) = I(\geq \rho, 0)\ e^{-x_0/\Lambda_{att}(sec\theta-1)}$, where x_0 is the vertical depth and Λ_{att} is the attenuation length of showers with particle density exceeding ρ. The validity of this behaviour extends over an angular range where the atmospheric overburden increases as $1/cos\theta$. Fig. 6 reports the angular distribution of ARGO-YBJ events: as it can be observed, the data can be fitted out to $\sim 60°$ by means of an $e^{-\alpha\ (sec\theta-1)}$ law, with $\alpha = 5.62 \pm 0.11$. As a consequence, due that for the Yangbajing altitude $x_0 = 606\ g/cm^2$, we obtain $\Lambda_{att} = (108 \pm 2)\ g/cm^2$. The deviation from this law for angles $> 60°$ is mainly due to misreconstructed events, horizontal air showers and showers locally produced in the roof and the walls of the sourrounding building.

3. Shower phenomenology

Thanks to the high space-time granularity of the detector and through the proper trigger logic, ARGO-YBJ is able do detect several kinds of events, characterized by different topologies and time structures. This allows to deeply inspect a wide and possibly unexpected phenomenology of extensive air showers. Some examples of

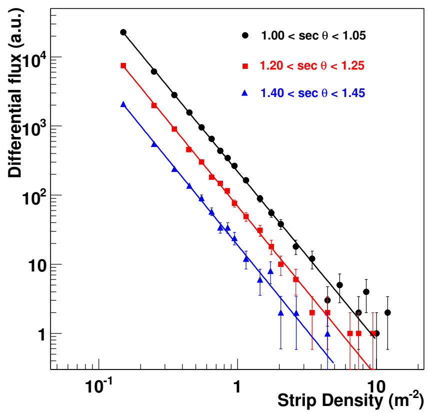

Figure 5. Differential strip density spectrum measured for different intervals of the zenith angle.

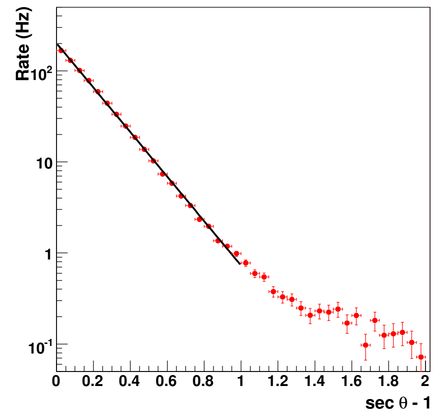

Figure 6. Zenith angle distribution of detected showers. The slope parameter for $sec\theta < 2$ is $\alpha = 5.62 \pm 0.11$.

this phenomenology are presented in Fig. 7 and Fig. 8, where the space patterns (at pad level) of two events, as imaged by ARGO-YBJ, are sketched. The first one shows a very localized event (spot dimensions $\sim 3\ m$), probably induced by a primary proton interacting very deeply in the atmosphere. Fig. 8 is the display of a large shower, produced by a very energetic cosmic ray primary, with the core reconstructed in the detector carpet.

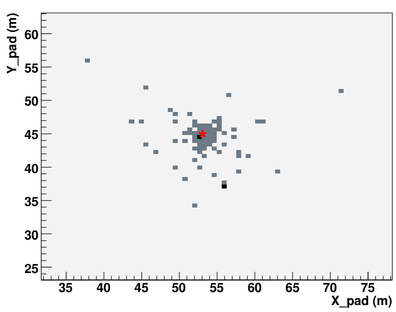

Figure 7. Display (space pattern) of a very localized shower event.

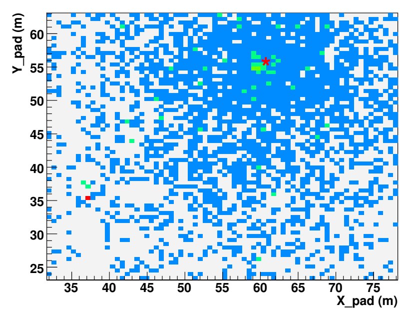

Figure 8. Display of a very big shower. The star indicates the core reconstructed in the detector area.

4. Conclusions

ARGO-YBJ has the capability to image with an unprecedented granularity the extensive air shower front and to reconstruct with many details several shower features, in particular the space pattern and the time structure. Moreover, the shape of the zenith angle distribution demonstrates that the physical effect of atmospheric absorbtion is dominating the data and no relavant instrumental effects are present.

References

[1] Z. Cao, ”The status of ARGO-YBJ experiment”, these proceedings.
[2] P. Bernardini et al.,”Time calibrations of the ARGO-YBJ experiment”, these proceedings.