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ARGO-YBJ: PRESENT STATUS AND FIRST INVESTIGATIONS IN COSMIC-RAY ASTROPHYSICS

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Abstract

The ARGO-YBJ experiment has been taking data for one year with a 6000 m^2 full-coverage carpet of resistive plate chambers. The status of the detector and its present performance are discussed, in connection with the first results of the experiment in cosmic-ray astrophysics.

1 Introduction

The ARGO-YBJ experiment was designed to study some major topics in astroparticle physics, and in particular:

- search for point-like γ-ray sources at a lower energy threshold of few hundreds of GeV;
- detection of γ-ray bursts;
- measurement of the $\bar{p}/p$ ratio at ~ 1 TeV energy;
- measurement of the cosmic-ray spectrum and composition close to the "knee".

Ground-based experiments aiming at performing precise measurements on the above-mentioned items must determine the arrival direction of primary cosmic rays at Earth. This is mainly dealt with by two different techniques: planar arrays for reconstructing the fronts of the extensive air showers produced by the incoming primaries, and air-Cherenkov telescopes detecting the Cherenkov light emitted by air showers. The ARGO-YBJ experiment [1] is based on a full-coverage planar array at high altitude, in order to lower the primary energy threshold with respect to standard grid arrays down to a few hundreds of GeV for gamma-initiated showers, and cover a dynamical range from few hundreds of GeV up to more than 1 PeV. The full-coverage technique is presently also being exploited by the Milagro experiment [2], which reconstructs the air-shower fronts using the Cherenkov-light emission in water of the incoming secondaries. The full-coverage technique allows continuous monitoring of a $\sim$ 2-sr angular sector of the sky.

Here the ARGO-YBJ detector layout and performance are described. In addition, the preliminary results obtained by the experiment on a few important issues in cosmic-ray astrophysics are reported.

2 The ARGO-YBJ detector

The ARGO-YBJ experiment is located at Yang Ba Jing (China), at 4300 m a.s.l. on the Tibet plateau ($90°31'50''$ E; $30°06'38''$ N). The experiment was designed so that the following requests were fulfilled:

- high altitude, closer to the shower maximum where the shower front is denser, allowing more precise reconstruction of the primary arrival direction;
- full coverage, so that smaller showers can be detected and a lower energy threshold can be reached.

The ARGO-YBJ detector is a full-coverage array of resistive plate chambers (RPCs) operated in streamer mode [3]. The sensitive part of the ARGO-YBJ RPCs is a 2-mm wide gas volume made of two 2-mm thick plastic-laminate resistive plates ($\rho \sim 10^{12}$ Ω·cm). The RPCs operate in streamer mode with a 3-component gas mixture ($C_2H_2F_4$/Ar/iC_4H_{10}=75/15/10). The outer faces of the plates are painted with a thin graphite layer, so that the electric field across the gap is obtained by applying a 7.2 kV voltage and capacitive read-out metal strips (62×7 cm^2 each) pick up the detector signal across the electrodes. In addition, two metal big pads pick up the analog signal on the opposite side of the gas volume. These additional pads are needed to extend the dynamical range of the detector up to few PeV, since the digital information coming from the read-out strips is saturated at energies $\gtrsim$ 100 TeV. A sketch of the transverse section of an ARGO-YBJ RPC is shown in Fig. 1. Twenty-four

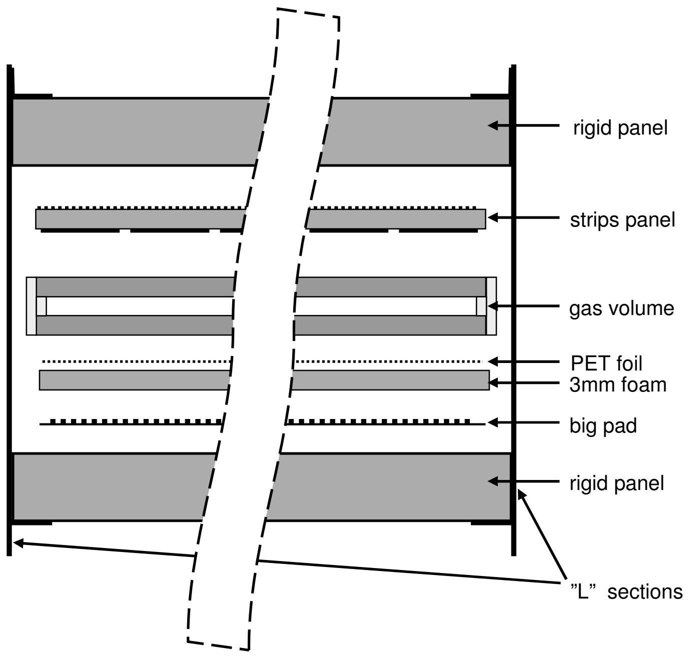


Figure 1: Scheme of the transverse section of an ARGO-YBJ resistive plate chamber.

additional outer clusters form a "guard ring" allowing better reconstruction of the shower core for events not entirely contained in the central carpet; these clusters will be activated before the end of 2007.

The detector layout is shown in Fig. 2, where the details of the detector structure are evidenced. Each RPC has a surface of 1.26×2.85 m^2. The RPCs in the central carpet (78×74 m^2) are arranged in a full-coverage array. A group of 12 close chambers is called a *cluster* (7.64×5.72 m^2), and the logical acquisition unit is a group of 8 adjacent read-out strips in a chamber, called a *pad* (0.62×0.56 m^2). The 130 clusters of the central full-coverage array have been taking data since July 2006.

The front-end electronics of the ARGO-YBJ RPCs [4] is based on a full-custom GaAs circuit. In one single die it includes 8 channels, each one com-

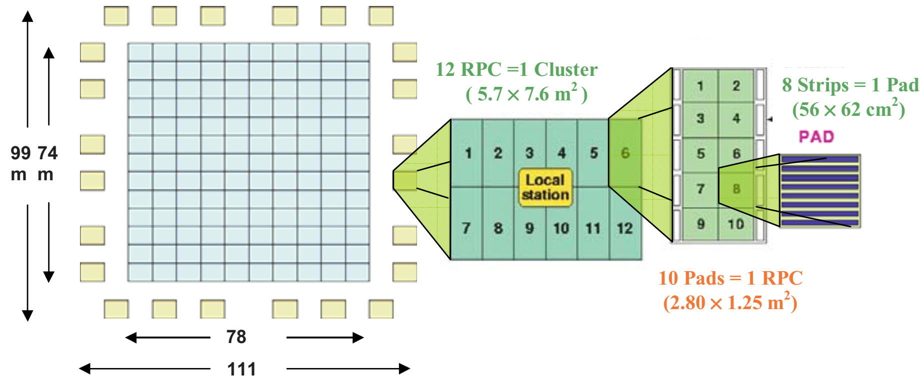


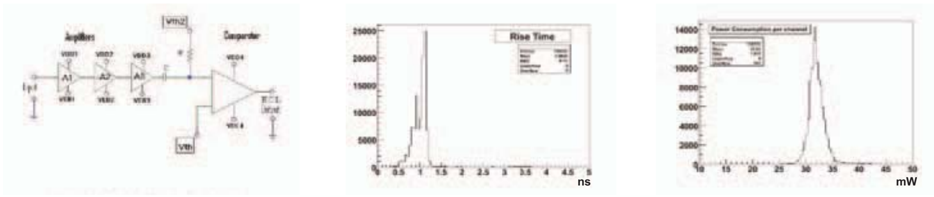
Figure 2: Scheme of the ARGO-YBJ detector layout. The details of the detector geometry and structure are also shown.

posed of a 3-stage voltage amplifier, a variable-threshold comparator and a digital AC-coupled ECL driver. All the front-end boards were carefully tested before being inserted into the chambers. Fig. 3 shows: (a) a scheme of the front-end circuit for one channel; (b) the rise-time distribution for all the tested channels (the mean value is about 1 ns); (c) the power-absorption distribution per channel (the mean value is about 32 mW). So, the ARGO-YBJ RPCs provide single-pad time information with a 1-ns time resolution and a total dissipated power less than 5 kW on a $\sim 10^4$ m^2 surface.

The ARGO-YBJ acquisition hardware and the trigger algorithm have already been described in other papers [5].

An example of a partially-contained shower detected in the ARGO-YBJ central carpet is shown in Fig. 4.

The monitoring data [6] show a good distribution for the current absorbed by the chambers, as shown in Fig. 5, with a mean value of about 3 μA. A more detailed study shows a good linear correlation between the RPC absorbed current and the local temperature if a suitable time delay is accounted for, as shown in Fig. 6. This kind of studies provides better understanding of the detector operation in the particular environmental conditions of the experimental site, and the increasing expertise coming from this will be used to keep the ARGO-YBJ detector operating in a stable and reliable way in the forthcoming years.



a. b. c.

Figure 3: (a) Scheme of the ARGO-YBJ RPC front-end circuit. (b) Rise-time distribution for all the tested front-end channels. (c) Power-absorption distribution per channel.

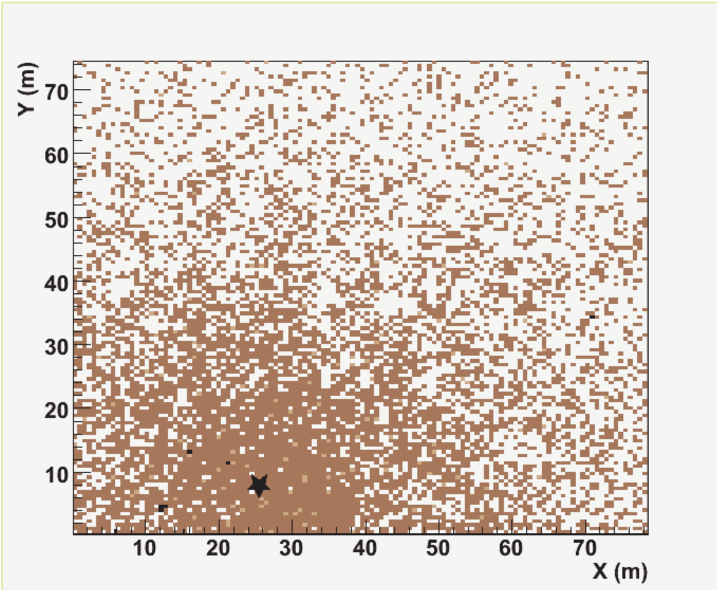


Figure 4: Hit map of an air shower on the ARGO-YBJ central carpet. The horizontal and vertical coordinates are measured with respect to the lower left corner of the carpet. The position of the shower core is shown.

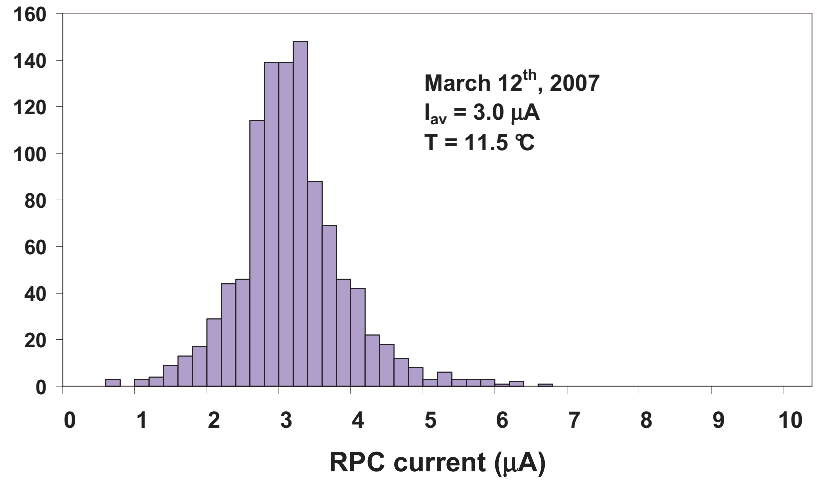


Figure 5: Distribution of the current absorbed by the ARGO-YBJ RPCs (March 2007 data).

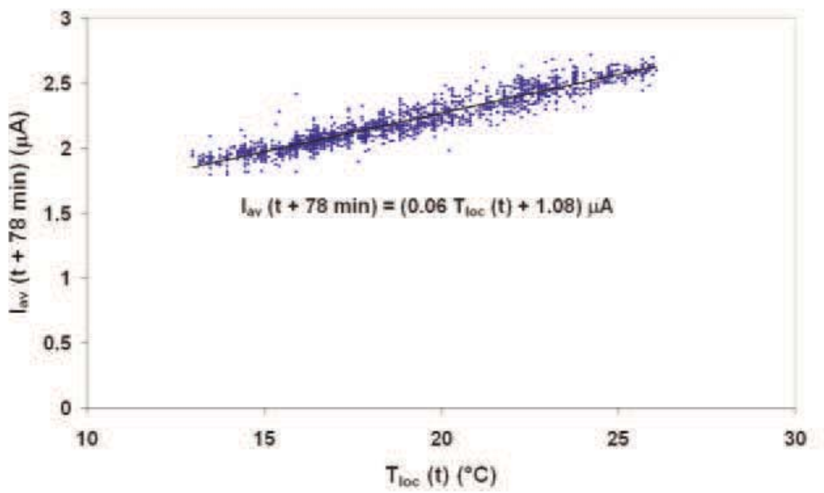


Figure 6: Correlation plot of the 78-minute delayed average RPC current and the local temperature for one ARGO-YBJ cluster near the carpet center (Cluster 91). The result of the linear fit is also shown.

3 First results in cosmic-ray astrophysics

The preliminary results from ARGO-YBJ concerning the detection of γ rays from the Crab Nebula and from MRK 421 during its July 2006 flare were reported separately in this Workshop [7]. Here we will summarize the results of other important studies performed by the collaboration in cosmic-ray astrophysics.

A crucial investigation concerns the features of the shower fronts [8]. Two parameters can be measured: the *curvature*, which is the mean value of the time residuals with respect to a planar fit of the shower front; the *thickness*, which is the RMS of the residuals with respect to a conical fit (see Fig. 7). The experimental results for these two parameters as a function of the distance from the shower core for three different pad-multiplicity ranges (corresponding to three different mean primary energies) are shown in Fig. 8. The events were selected with a zenith angle less than 15°. A detailed Monte Carlo simulation shows that these parameters may be crucial to perform γ-hadron separation on a statistical basis.

Another study in progress is the measurement of the proton-air inelastic cross section at energy greater than 1 TeV [9]. For a given pad-multiplicity interval (corresponding to a given mean primary energy) the frequency of showers as a function of the zenith angle θ (for a fixed distance X_{DM} between the detector and the shower maximum) is related to the probability distribution of the depth of the shower maximum $P(X_{max})$, with $X_{max} = h_0 \sec\theta - X_{DM}$, where h_0 is the observational vertical depth. For large X_{max} values, $P(X_{max})$ has a decreasing exponential behaviour with attenuation length $\Lambda = \kappa\lambda_p$, where κ (to be evaluated with a Monte Carlo simulation) is an adimensional parameter depending on the shower development and the detector response, and $\lambda_p(g/cm^2) \simeq 2.41 \cdot 10^4/\sigma_{p-Air}(mb)$. In order to select showers from primaries interacting deeper in the atmosphere, it was required that 70% of the fired strips were contained within 25 m from the reconstructed shower core. This event selection is independent of shower fluctuations for $\theta < 40°$, which is also the applied cut for the selected events. The experimental $\sec\theta - 1$ distributions for pad-multiplicity ranges $300 \leqslant N_{pad} \leqslant 1000$ (corresponding to a mean primary energy of (3.9±0.1) TeV) and $N_{pad} > 1000$ (corresponding to a mean primary energy of (12.7±0.4) TeV) are shown in Fig. 9 (upper and lower plot respectively). From these plots the values of κ can be obtained by comparison with the Monte Carlo simulation. The result for σ_{p-Air}, after correcting for the contribution of primaries heavier than protons, is (275 ± 51) mb for the lower multiplicity range and (282 ± 31) mb for the upper one. These values are in good agreement with the results of other experiments. The possibility of performing a measurement of σ_{p-Air} at energy ~1 PeV with a suitable selection of the shower development stage, also using the RPC analog read-out system, is being considered.

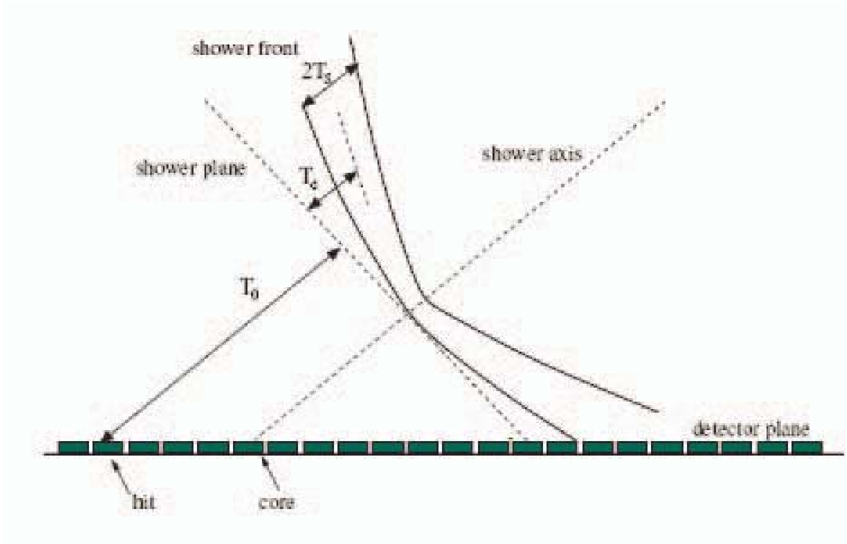


Figure 7: Scheme of the transverse view of an air-shower front hitting the ARGO-YBJ detector. The shower curvature T_d and thickness T_S at a given distance from the core are shown.

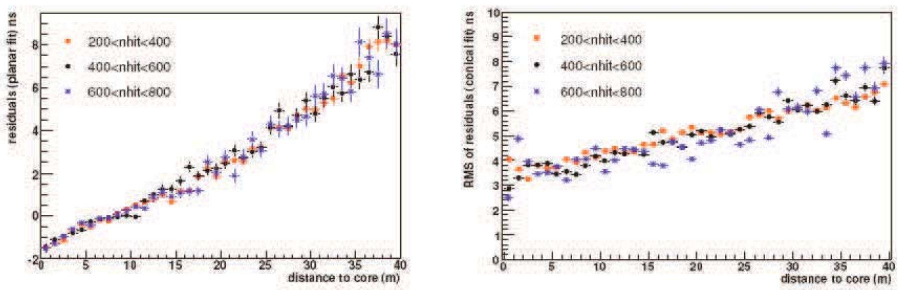


Figure 8: Left: shower curvature vs. the distance from the core, for three different pad-multiplicity ranges. Right: shower thickness vs. the distance from the shower core, for three different pad-multiplicity ranges.

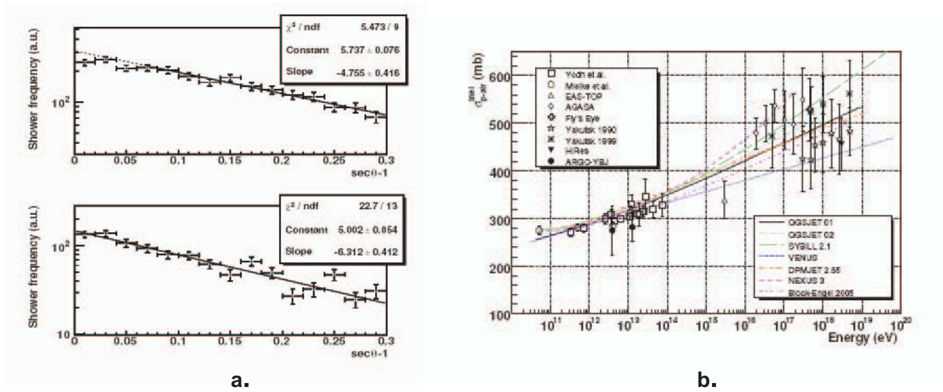


Figure 9: **a.** Upper: experimental $\sec\theta$ distribution ($\theta < 40°$) for pad multiplicity $300 \leqslant N_{pad} \leqslant 1000$. Lower: experimental $\sec\theta$ distribution ($\theta < 40°$) for pad multiplicity $N_{pad} > 1000$. **b.** Inelastic p-air cross section measured by several experiments including ARGO-YBJ, with the prediction of different hadronic interaction models.

4 Conclusions

The performance of the ARGO-YBJ detector after the completion of the full-coverage central carpet (July 2006) is good. The first studies in γ-ray and cosmic-ray astronomy are giving excellent results and providing a good amount of information. The constant monitoring of the environmental and operational parameters is giving a better understanding of the detector and of the conditions which are needed in order to keep the operation stable for a long time. Before the end of 2007 the complete detector will be working, including the guard-ring clusters. The installation of the analog read-out system on all the clusters will be crucial to investigate the energy range from few hundreds of GeV up to few PeV.

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