VERY HIGH ENERGY GAMMA-RAY ASTRONOMY AND COSMIC RAY PHYSICS WITH ARGO-YBJ

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Very high energy gamma ray astronomy is one of the scientific goals of the ARGO-YBJ experiment. The detector, which is located in Tibet (China) at 4300 m a.s.l., is a full coverage Extensive Air Shower array consisting of a carpet of Resistive Plate Chambers (RPCs) of about 7000 m^2. The high altitude and the full coverage ensure a very low energy threshold (few hundreds of GeV for primary photons), while the detector time resolution ($\sigma_t \simeq 1$ ns) gives a good pointing accuracy, thus allowing a high sensitivity to γ-ray sources, with a field of view of more than 2 sr and a duty cycle close to 100%. The detector layout, performance and location, offer a unique possibility to make also a deep study of several characteristics of the hadronic component of the cosmic ray flux up to energies of several hundreds of TeV. In particular, the topological structure of the shower, the lateral distribution, the energy spectrum and the space and time flux modulations can be measured with high sensitivity. Moreover, the use of a full coverage detector with a high space granularity gives detailed images of the shower front, that can be used to test different hypotheses on the cosmic ray interaction model, the shower development in the atmosphere and particle physics at very high energies. In this work the general layout of the detector and its performance will be described, together with some of the first results coming from the analysis of a data sample collected with a relevant fraction of the apparatus that is already in continuous data taking.

Keywords: cosmic ray physics; gamma-ray astronomy; EAS detectors

1. The ARGO-YBJ experiment: detector layout and operation

The ARGO-YBJ experiment is the result of a collaboration between Italian and Chinese institutions, aiming at the study of several characheristics of the high energy cosmic radiation with a full coverage extensive air shower array [1]. The laboratory is located near Lhasa in the Tibet region (People's Republic of China) at an altitude of 4300 m above sea level, corresponding to an atmospheric depth of about 600 g/cm^2. The detector is logically divided into 154 units called *clusters* ($7.64 \times 5.72\,m^2$) each made by 12 Resistive Plate Chambers (RPCs) operated in streamer mode with a mixture of argon (15%), isobutane (10%) and tetrafluoroethane (75%), and read out by a single Local Station. As shown in Fig.1(a), each RPC ($1.26 \times 2.85\,m^2$) is read out by using 10 pads ($62 \times 56\,cm^2$), which are further divided into 8 different strips ($62 \times 7\,cm^2$) providing a larger particle counting dynamic range[2]. The FAST-OR of the signals coming from all the strips of a given pad are sent to the same channel of a multihit TDC. The whole system is designed in order to provide a single hit (pad) time resolution at the level of 1 ns, which allows a complete and detailed three-dimensional reconstruction of the shower front, determining also the incoming direction of the primary particle. Finally a 0.5 cm thick lead converter will uniformly cover the detector in order to reduce the time fluctuactions of the detected shower particles and then to further improve the angular resolution.

Data gathered with ARGO-YBJ will allow to face with a wide range of fundamental issues. These include:

- Hadronic Cosmic Ray (hereafter

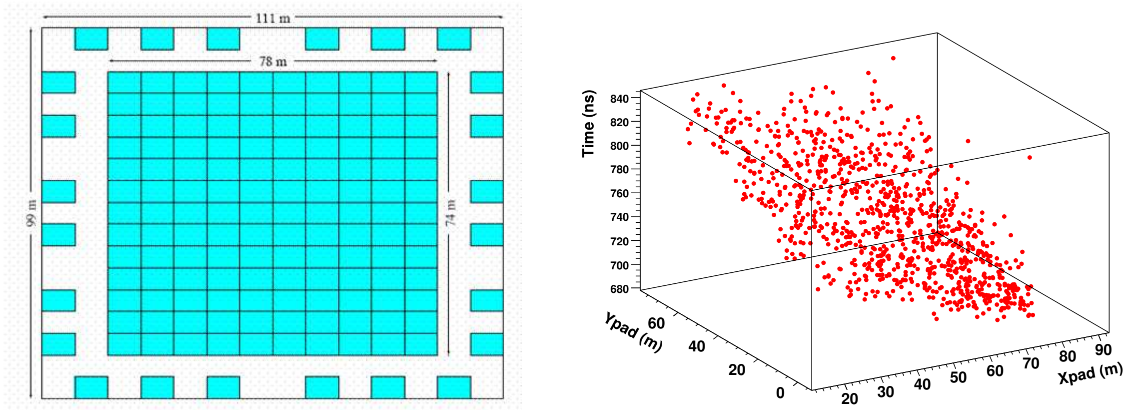

Fig. 1. *Left side (a): Layout of the 154 RPC clusters for the full ARGO-YBJ configuration. Right side (b): Three dimensional view of a shower event event recorded by ARGO-YBJ in an intermediate configuration (104 RPC clusters in acquisition).*

CR) physics between about 1 TeV and 1000 TeV:
measurement of the primary energy spectrum, mass composition, antiproton/proton ratio, hadron-air cross section , etc.;

- γ-ray astronomy between few hundreds of GeV and few tens of TeV:
search for point or diffuse (galactic and extra-galactic) sources, with a field of view of more than 2 sr and a duty cycle close to 100%;
- Gamma Ray Burst (GRB) physics:
extending the satellite measurements over the GeV-TeV energy range;
- Sun and Heliosphere physics ($E >$ 10 GeV):
looking for CR modulations, Forbush decreases, monitoring the interplanetary magnetic field and observing flares of high energy photons and neutrons from the Sun.

Two different operation modes have been designed for the data acquisition: the *shower mode* and the *scaler mode*. In the first one, the trigger requires a minimum pad multiplicity on the central carpet, with a space/time pattern consistent with the one expected from a shower front. In the *scaler mode* the pad rate is measured from each cluster, with an integration time of 0.5 s. This last DAQ mode is devoted to the apparatus monitoring and the detection of unexpected variations in CR flux, as an effect of GRBs, or solar activity. The RPC operation is also successfully monitored by a Detector Control System (DCS), able to record HV, currents, temperature, humidity, pressure and gas flow.

From November 2003 to December 2004, 16 clusters have been operated for a complete and successful data taking test. Afterward, from December 2004 to July 2005, 42 clusters have been in data taking for more than 2140 hours. In this period about $2 \cdot 10^9$ cosmic ray events have been recorded, corresponding to about 7 TB of data on tapes. Nowadays 130 clusters of RPCs are in continuous data taking, covering a surface of about 6000 m^2, corresponding to the whole central detector carpet (see Fig.1(a)). The last 24 RPC clusters, corresponding to the external guard ring, are now being installed to complete the full detector design by the end of 2006.

In this paper some of the results concerning the analysis of data collected with

42 clusters will be presented. These are in full agreement with those coming from data collected with 16 clusters and with what is expected from CR and EAS properties.

2. Detector Performance and First Physics Results

As mentioned above, the use of a full coverage detector with a high space-time resolution gives detailed images of the shower front: an example is reported in Fig.1(b). The detector capabilities are clearly evident.

As a first step towards event analysis, an offline time calibration procedure has been set in order to remove systematic time offsets among the pads, due to different cable lengths or any other electronic effect. Once the time calibration has been performed, the angular resolution of the 42 clusters carpet has been estimated by dividing the detector into two independent sub-arrays (made by "odd" and "even" pads respectively) and studying the angular difference $\Delta\psi$ between the reconstructed shower directions. A complete agreement between data and simulations is present, thus validating our Monte-Carlo code. We therefore estimated the angular resolution for the full detector configuration by using the same simulation tool. The resulting resolution is less than about $0.5°$ for showers with at least 100 hits and at the level of $0.1°$ for very large multiplicity events.

A check of both the detector estimated angular resolution and absolute pointing can be made by looking at the Moon shadow in the cosmic ray flux [3,4]. The shadow shape and dimensions give an independent measurement of the angular resolution, while its position in the sky must be consistent with the expected shift, with respect to the Moon real position, due to the effect of magnetic fields on CR particles trajectories. Two independent analyses were perfomed on the 42 clusters data in order to detect this effect. They are in good agreement with each other and are consistent with the estimated detector figures (angular resolution, etc.). Moreover the statistical significance of the detected deficit (about 4σ) and, principally, its increasing rate with exposure, exactly follow the expectations.

As a further check of the detector operation, the distribution of the reconstructed shower axis zenith angle θ has been studied and compared with what is expected from the CR flux and the atmosphere properties. The results are in excellent agreement with previous measurements [1].

In the following some of the physics results obtained will be briefly mentioned and discussed. More details can be found in [5].

2.1. *Cosmic Ray Spectrum below 100 TeV*

As outlined above, the detector layout, performance and location, offer a unique possibility to make a deep study of several characteristics of the hadronic component of the cosmic ray flux in the $\sim 1 \div 1000$ TeV energy range, thus providing an excellent "bridge" in the transition region from direct to indirect measurements.

Interesting results on the primary energy spectrum, mass composition, antiproton/proton ratio, hadron-air cross section, can be obtained from ARGO-YBJ data. Moreover, the use of a full coverage detector with a high space granularity (see Fig.1(b)) allows a deep study of the *"shower phenomenology"* including figures like the time structure of the front (both shape and width), the lateral distribution, etc.

In order to have an energy estimator the number of particles in the shower has to be determined. This is done by just counting the number of fired pads in a given event. Obviously this assumption is valid untill saturation is reached, then the strip multiplicity can be used to extend the energy region.

As a further extension, the analog output of each RPC is readout, thus allowing a detector response which is linear up to energies of the order of about 1000 TeV. Here we will report the first results concerning the energy spectrum, as obtained with data from the detector in the 42 clusters configuration. A preliminary study of the strip size (N_s) spectrum has been performed. Values up to $N_s = 10^4$ have been considered in the analysis, corresponding to primary hadrons with energies up to about 100 TeV. The result shows a fair agreement of the data with the RUNJOB model, in particular at energies smaller than 50 TeV [5]. The errors are still large (at the level of 10%), but this preliminary result can be considered as a good test of the analysis, which is going to be applied to the data with the full detector configuration.

2.2. *All Sky Survey for Point γ-ray Sources and GRBs*

Based on the angular resolution found above, a full simulation has been performed in order to evaluate the ARGO-YBJ sensitivity to point gamma ray sources. The detector has been found to be able to detect TeV gamma ray emission from a standard source like the Crab at a significance level of 18 σ per year. The ARGO-YBJ experiment, in one year of observation, will be then able to detect any point source above the horizon with a flux of 0.3 Crab units at a 5σ level. A proper γ/hadron discrimination method would significantly increase the detector sensitivity. Relative studies are under way and are showing promising results [5].

Here we report the results of a first analysis performed with the 42 clusters data recorded from December 24, 2004 to March 23, 2005, for a total running time of 1007 hours. The average event rate is about 160 Hz. The events with zenith angle $\theta \leq 50°$ have been considered. The declination band $-20° < \delta < 80°$, corresponding to 8.3 sr (66% of the celestial sphere) is monitored. No gamma-hadron discrimination is applied in this preliminary analysis. In the 1007 hours of measurement no gamma ray source with an average flux larger than 5 Crab units has been observed.

3. Conclusions

The first results coming from the analysis of a data sample collected with a relevant fraction of the ARGO-YBJ apparatus have been described, showing the experiment capabilities in facing a wide range of cosmic ray physics issues. In particular, the results of the first data analyses on hadronic cosmic ray physics, and γ-ray astronomy have been given, while results on GRB search, and solar physics can be found in [5,6,7]. The detector capability in providing an unprecedented information on the shower front space-time pattern, which gives new insights into shower development processes and surface arrays observables, has also been reported.

References

1. C.Bacci et al. (ARGO-YBJ Coll.), Astroparticle Phys. **17**, (2002) 151 and references therein
2. G.Aielli et al. (ARGO-YBJ Coll.), Nucl. Instr. & Meth. in Phys. Res. A **562** (2006) 92
3. G.W. Clark, Phys. Rev. **108** (1957) 450
4. M. Ambrosio et al., Astroparticle Phys. **20** (2003) 145, and references therein
5. I. De Mitri et al. (ARGO-YBJ Coll.), Proceedings of the Cosmic Ray Intenbational Seminar (CRIS06), Catania, Italy (2006), and references therein. In publication on Nuclear Physics B.
6. G. Di Sciascio, T. Di Girolamo et al. (ARGO-YBJ Coll.) astro-ph/0609317, to be published in the proceedings of the workshop "The Multi-Messenger Approach To High Energy Gamma-Ray Sources", Barcelona, Spain (2006)
7. H.Y. Jia et al. (ARGO-YBJ Coll.), Proceedings of the 29th International Cosmic Ray Conference, Pune, India (2005), vol.1, 137