PROCEEDINGS OF SCIENCE

Very High Energy Gamma Ray Astronomy and Cosmic Ray Physics with the ARGO-YBJ experiment

Ivan De Mitri[*†]
Dipartimento di Fisica, Università di Lecce and INFN Sezione di Lecce, Italy
E-mail: ivan.demitri@le.infn.it

Gamma ray astronomy at energies $10^{11} \div 10^{13}$ eV, which are strictly related to the identification and study of the cosmic ray acceleration sites, is the main scientific goal of the ARGO-YBJ experiment.
The detector, which is now being assembled 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 covering a surface of about 7000 m^2. The high altitude (atmospheric depth ~ 600 g/cm^2) and the full coverage ensure a very low primary photon energy threshold at few hundreds GeV (close to the limits of the satellite technology), while the detector time resolution $\sigma_t \simeq 1$ ns gives a good pointing accuracy, thus allowing a high sensitivity to γ-ray sources. Moreover the large field of view and the high duty-cycle ensure the continuous monitoring of the sky in the declination band $-20° \leq \delta \leq 80°$.
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 hundreds of TeV. In particular, the structure of the shower core, the lateral distribution, the energy spectra and the angular (e.g. anisotropies) and time (e.g. solar flares) 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 interactions, 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 data analysis of a relevant fraction of the apparatus that is already operating.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

[*]Speaker.
[†]On behalf of the ARGO-YBJ Collaboration

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

The ARGO-YBJ detector is logically divided into 154 units called *clusters* ($7.64 \times 5.72\,m^2$) each made of 12 Resistive Plate Chambers (RPCs) operated in streamer mode with a mixture of argon (15%), isobutane (10%) and tetrafluoroethane (75%). The detectors are arranged in a central continuous carpet (130 clusters) and a guard ring (24 clusters). Each RPC ($1.26 \times 2.85\,m^2$) is read out with 10 pads ($62 \times 56\,cm^2$), which are further divided into 8 different strips ($62 \times 6.7\,cm^2$) providing the highest available space resolution. 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, thus allowing a complete and detailed three-dimensional reconstruction of the shower front. A 0.5 cm thick lead converter will uniformly cover the detector in order to further improve the angular resolution [1].

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

- γ-ray astronomy, looking for point sources (galactic and extragalactic) with an energy threshold of a few hundreds of GeV and for diffuse fluxes from the Galactic plane and/or SuperNova Remnants;
- Gamma Ray Burst (GRB) physics, extending the satellite measurements over the GeV-TeV energy range;
- Cosmic Ray (CR) physics, that is the measurement of the antiproton/proton ratio at TeV energies, the study of the spectrum and composition around the knee ($E > 10\,TeV$), etc.;
- Sun and Heliosphere physics ($E > 10$ GeV), looking for CR modulation, monitoring the interplanetary magnetic field and observing flares of high energy photons and neutrons from the Sun.

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

At present about 100 clusters of RPCs have been already installed, covering a surface of about $4000\,m^2$, corresponding to 68% of the foreseen central detector carpet. From November 2003 to December 2004, 16 of these clusters operated for a complete data taking test. Afterward, from December 2004 to July 2005, 42 clusters have been put in data taking for more than 2140 hours. In this period more than 10^9 CR events have been recorded, correponding to about 7 TB of data on tapes. Other clusters are now being added into the main acquisition system.

In this paper some of the results concerning the analysis of data collected with 42 clusters from December 2004 to July 2005 will be presented. These are in full agreement with those coming

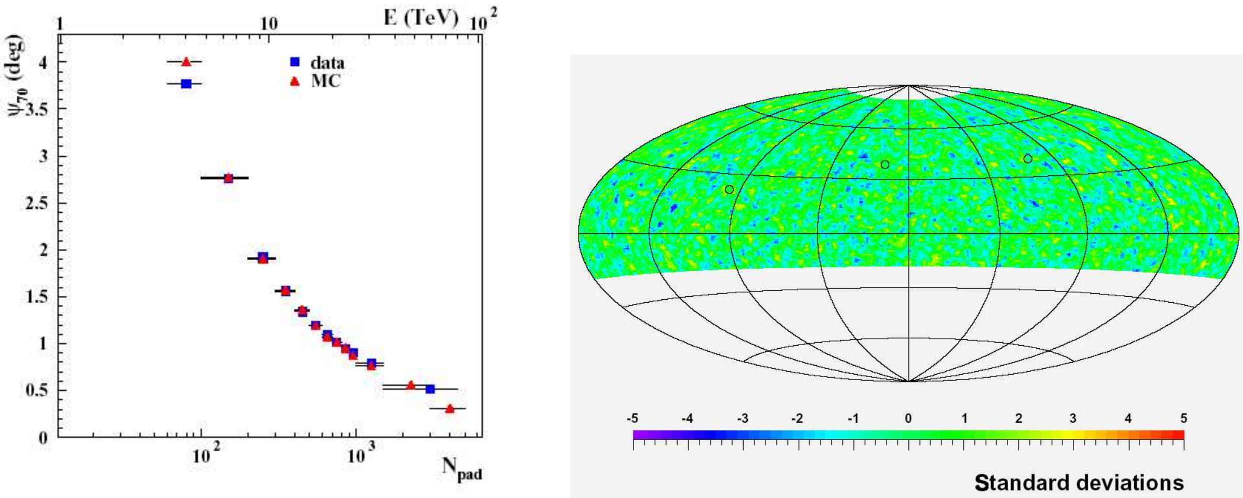

Figure 1: *Left side (a): Angular resolution (ψ_{70} as estimated with the "even-odd pads" method). Right side (b): Sky map resulting from the search for γ-ray point sources (see text).*

from data previously collected with 16 clusters alone and with what is expected from CR and EAS properties.

The installation schedule foresees 130 clusters by the spring of 2006, thus reaching the completion of the central detector carpet, while the full detector configuration will be ready by the end of 2006.

2. Detector performance and first physics results

An offline time calibration procedure has been set in order to remove systematic time offsets among the pads, due to different cable lenghts or any other electronic effect. Once the time calibration has been performed, the angular resolution of the 42 cluster 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 $\Delta\varphi$ between the reconstructed shower directions. The angular resolution depends on the width of the $\Delta\varphi$ distribution [1] and decreases with the hit multiplicity. As can be seen in Fig. 1(a), this is in complete agreement with MC expectations.

With the above angular resolution, a full simulation has been performed in order to evaluate the ARGO-YBJ sensitivity to gamma ray point sources. The detector, in its full configuration with 154 RPC clusters and the lead converter, has been found to be able to detect TeV emission from a standard source like the Crab nebula at a significance level of 18 σ per year. The ARGO-YBJ experiment, in one year of observation, will thus be able to detect point sources with a flux of 0.3 Crab units at a 5σ level [2]. A proper γ/hadron discrimination method would significantly increase the detector sensitivity. Relative studies are under way and are showing promising results [3].

As a further check on 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 [2].

2.1 All sky survey for γ-ray point sources and GRBs

The data set used in this analysis has been 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. The resulting sky map, giving no statistically significant excess, is reported in Fig. 1(b) where the position of some of the known VHE γ-ray emitters are also shown (i.e. the Crab, Mkn421, and Mkn501). A data analysis looking for GRBs has also been performed: it gives no evidence for a significant transient of duration between 10 s and 300 s.

2.2 CR Spectrum below 100 TeV

As reported in Sec.1, each induction strip provides the highest available space resolution and can be used as a shower particle counter. 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 CRs with energies up to about 100 TeV. The result shows a fair agreement with RUNJOB measurements, in particular at energies smaller than 50 TeV [2].

2.3 Study of Solar Activities with the Scaler Mode

After air pressure correction, the data taken in *scaler mode* from January 15 to 27, 2005 have been used to search for the Forbush Decrease (FD) that has been well measured at lower energies by devices such as neutron monitors [2]. The FD around noon on January 17, 2005 has been observed by our detector. The rates with multiplicity $m \geq 1$ and $m \geq 2$ clearly decrease correspondingly. The maximum amplitudes of the FD are about -5% and -4%, respectively. Moreover all the peculiar structures of the light curves are similar to those resulting from neutron monitors. The rates of multiplicities $m \geq 3$ and $m \geq 4$ do not show evidence for a decrease. Furthermore the solar flare (Class X7) of January 20, 2005, connected to a Ground Level Enhancement (GLE) and detected by the Milagro scaler system [2], has been studied. There is no evidence for it in the ARGO-YBJ data: the reason for this might be due to the large difference in the longitudes of the two experiment sites (about 165°).

References

[1] C.Bacci et al. (ARGO-YBJ Coll.), Astroparticle Phys. **17**, (2002) 151

[2] Z. Cao et al. (ARGO-YBJ Coll.), Proceedings of the 29th Int. Cosmic Ray Conf. (Pune, India 2005) and references therein

[3] I. De Mitri et al. (ARGO-YBJ Coll.), Nucl. Instr. & Meth. in Phys. Res. A **525** (2004) 132 and references therein.