The ARGO-YBJ experiment in Tibet(*)

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Summary. — The ARGO-YBJ experiment (Astrophysical Radiation Ground-based Observatory at YangBaJing) is under construction in Tibet, 90 km to the north of Lhasa. The full coverage approach and the high altitude location allow the study of many physics items in the field of low energy cosmic rays, namely gamma-ray astronomy, diffuse gamma-rays, gamma-ray bursts (GRBs), proton/antiproton ratio, primary proton spectrum and heliosphere physics. In this paper the expected sensitivities of ARGO-YBJ for gamma astronomy and GRB physics are presented and compared with the present experimental techniques and results. The performance of a test-module of ~ 50 m^2 operated on-site is also discussed.

PACS 98.70.Rz – Gamma-ray sources; gamma-ray bursts.
PACS 98.70.Sa – Cosmic rays (including sources, origin, acceleration, and interactions).
PACS 95.55.Vj – Neutrino, muon, pion and other elementary particle detectors; cosmic ray detectors.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The study of γ radiation in the energy range 100 GeV–20 TeV is mainly devoted to γ-astronomy, for both point and diffuse sources, and gamma-ray bursts (GRBs) physics. Point sources are galactic and extragalactic objects; diffuse sources include the Galactic Plane, molecular clouds and Supernova Remnants. At these energies the paucity of the fluxes hampers the detection from space; the highest energy detected till now is few tenth of GeV from the EGRET experiment on board the CGRO satellite. Since the detection of the Crab Nebula in 1989 by the Whipple Collaboration [1], ground-based γ-astronomy has collected brilliant results by means of Čerenkov telescopes; up to now 5 galactic and 3 extragalactic objects have been discovered in the TeV energy region. During these years this technique has been well developed, reaching a low energy threshold (≈ 300 GeV, and even less for solar power facilities used as light collectors) and a high sensitivity for point sources ($\lesssim 1/10$ of the Crab flux, the "standard candle" for TeV astronomy). The limits are the low duty-cycle ($\sim 5\%$), since observations can be done only during clear moonless nights, and the small field of view ($\Delta\vartheta < 4°$). This means that only one candidate, selected source at a time can be observed, with no discovery potential for unknown sources. A large field of view is even more crucial for GRBs detection, the probability of occurrence of these unpredictable events by chance in the field of view of a Čerenkov telescope being negligible ($< 10^{-4}$).

A different approach has been done using EAS arrays, that sample continuously and with a large field of view ($\Omega \sim \pi$ sr) the lateral distribution of extensive air showers. But due to the poor or lacking cosmic rays background rejection, and to the higher energy threshold ($E > 10$ TeV), no highly reliable detection has been done so far; a low energy threshold, particularly for extragalactic sources (AGNs and GRBs), is required due to the γ-ray absorption in the intergalactic space by interaction with starlight photons.

From these considerations we can deduce the necessity of a detector with a large field of view, high duty-cycle and low energy threshold to perform a continuous monitoring of a large portion of the sky. The ARGO-YBJ detector has been designed to match

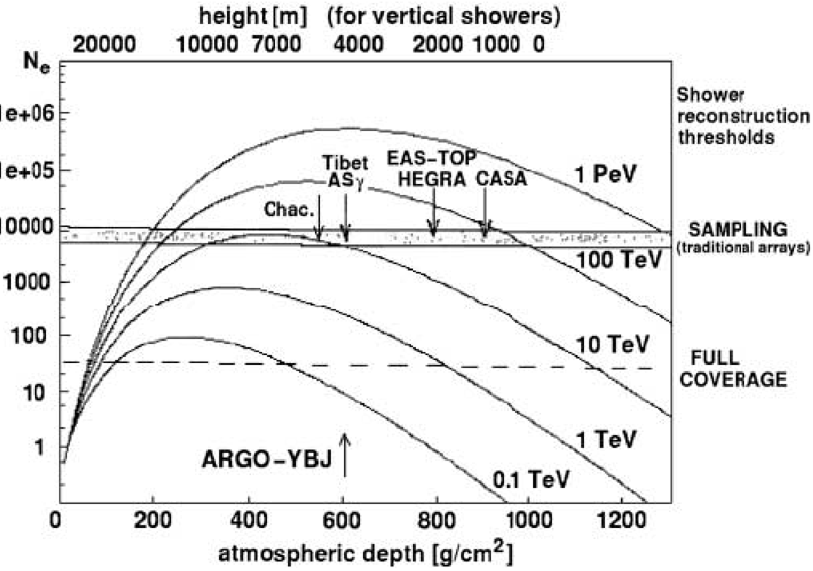

Fig. 1. – Comparison between the longitudinal development of γ-induced showers of primary energy 100 GeV–1000 TeV and the shower reconstruction threshold for different techniques at various heights.

these requirements, imaging the electromagnetic component of small air showers at high altitude with: high space-time resolution, to get a high granularity picture of the shower; full coverage, to decrease the energy threshold without losing shower details and large collecting area to increase the sensitivity and the energy range. The combined effect of the full coverage and high altitude location on the threshold energy can be seen in fig. 1, where the longitudinal development of γ-induced showers of different energies is compared with the typical sensitivities of two different techniques located at different altitudes. The threshold energy of a traditional sampling array operating at 2000 m a.s.l. can be lowered from $\sim$ 50 TeV to $\sim$ 1 TeV using a full coverage carpet and to $\sim$ 200 GeV moving from 2000 to 4000 m a.s.l., with a total gain factor as high as 250.

With these features the GeV (satellites) and TeV (Čerenkov telescopes) energy regions can be bridged and the energy range between 20 GeV and 300 GeV, that is, for the time being, completely unexplored, can be at least partly accessed.

2. – The detector

The ARGO-YBJ detector [2] is located in Tibet, China, at the Yangbajing High Altitude Cosmic Ray Laboratory (30°.11 N, 90°.53 E, 4300 m a.s.l., 606 g/cm^2). It consists of a single layer of Resistive Plate Chambers (RPCs) of dimensions 78 $\times$ 74 m^2 with full coverage (active surface $\sim$ 92%). The area surrounding the central carpet is partially ($\sim$ 20%) instrumented with RPCs up to 111 $\times$ 99 m^2, the total active surface being 6700 m^2. A schematic plan of the detector is shown in fig. 2.

The RPCs performance, in terms of temporal and spatial resolution, at a reasonable cost makes this device an optimum detector for large area covering. A layer of 0.5 cm lead on the RPCs plane converts shower photons improving the angular resolution and lowering the energy threshold. The detector has a modular structure, both for

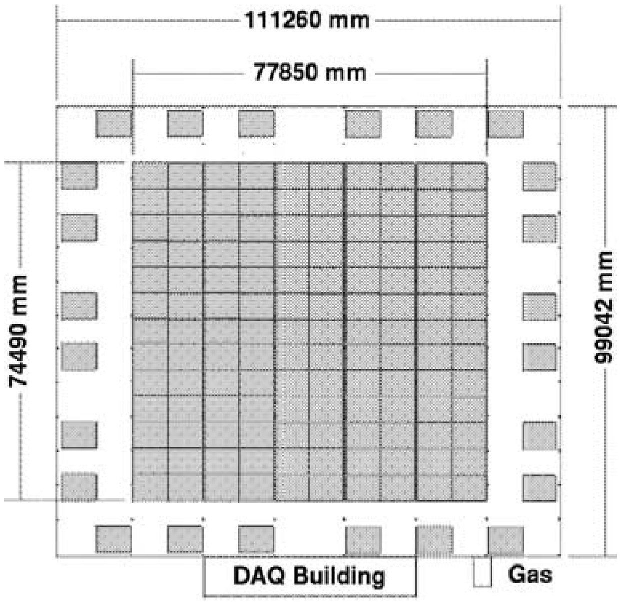

Fig. 2. – Schematic view of the ARGO-YBJ building and detector.

construction, triggering and data acquisition, the basic module being a "cluster". Each cluster has a surface of 44 m^2 and is built by 12 RPCs; each RPC is read by means of 10 "logical pads" 60×56 cm^2, corresponding to 8 strips ORed. One pad 0.34 m^2 area corresponds to one pixel, giving the granularity of the detector for timing and particle density measurements. Fired strips coordinates can be recorded to give a better particle location if needed. For each event the trigger multiplicity (number of fired pads), the coordinates of fired pads, their timing and the number of fired strips (corresponding to the number of detected particles) are recorded. The trigger threshold is set to a minimum number of fired pads; the expected trigger rate for at least 15 pads fired (based on the measured pad rate at YBJ ~ 400 Hz) is ~ 20 KHz. The huge amount of data that has to be collected, analyzed and recorded represents one of the greatest challenge for this experiment.

3. – Sensitivity to point sources and GRBs

Figure 3 shows the expected sensitivity of the ARGO-YBJ detector for 1 year of data-taking and 5 standard deviations statistical significance, compared with the Crab Nebula flux. It can be seen that the expected sensitivity is about 1/10 the Crab flux over the whole energy range 100 GeV–20 TeV.

The expected sensitivity of ARGO-YBJ to GRBs is shown in fig. 4 for Single Particle (SP) and Low Multiplicity (LM) techniques. With Single Particle technique the counting rate of the detector is recorded at fixed time intervals; a burst is detected if it gives a counting rate significantly higher than the background, with no information on the arrival direction. The Low Multiplicity technique consists in the detection of very small air showers that are analyzed and their arrival direction is reconstructed; a significant excess in the GRB direction provides its detection (for more details about these techniques see [3, 4]). Due to their extreme variability, some assumptions about GRBs emission

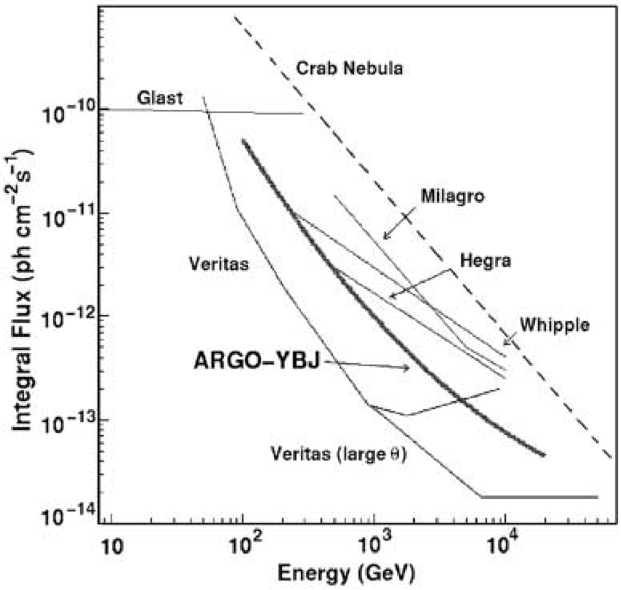

Fig. 3. – Minimum flux from point sources detectable by ARGO-YBJ during 1 year of data taking and 5 s.d. statistical significance, compared with the Crab Nebula flux. Reported sensitivities of other experiments are only indicative.

have to be done: a power-law γ-ray flux $\frac{dN}{dE} = KE^{-\alpha}$ ph m^{-2} up to $E_{\max}$ is assumed, with spectral slope $\alpha = 2.0$ (the average spectral slope measured by EGRET in the 30 MeV–10 GeV region being $\alpha = 1.95 \pm 0.25$), time duration $\Delta t = 1$ s and statistical significance $\sigma = 4$ s.d.. Moreover it is convenient to express the GRBs sensitivity in terms of $F_{\min}$, *i.e.* the minimum detectable fluence for a GRB emitting in the energy range 1 GeV–$E_{\max}$ with spectral slope α. In fig. 4 the fluence of the GRBs detected by EGRET is also reported, extrapolating their spectrum up to 100 GeV with their individual spectral index. It can be seen that if their spectra extend at least up to 100 GeV, most of them could be detected by ARGO-YBJ.

4. – The ARGO-test at Yangbajing

The test [5, 6] has been carried out in the period February-May 1998. Fifteen RPCs (corresponding to about one cluster prototype) have been put in operation, for a total area of 51 m^2 and an active area of 46.2 m^2 (91% coverage). Different gas mixtures have been tested to choose the best working conditions due to the low atmospheric pressure. Data have been collected with and without a 0.5 cm lead converter. The time jitter distribution of pad signals is uniform for all pads with an average s.d. of 1.3 ns; the resulting intrinsic RPC time resolution is ~ 1 ns. The angular resolution, obtained by dividing the pad array into two independent sub-arrays (chess-board method) and comparing the two reconstructed shower directions is $\sigma_\vartheta \sim 2°$ for events with pad multiplicity ~ 100. The effect of the lead layer is more important at low multiplicity, as expected, lowering the angular resolution from $\sim 8°$ to $\sim 5°$ for pad multiplicity ~ 35. For the final detector, due to its larger dimensions, the expected angular resolution is $\sim 0.4°$ for pad multiplicity ~ 100.

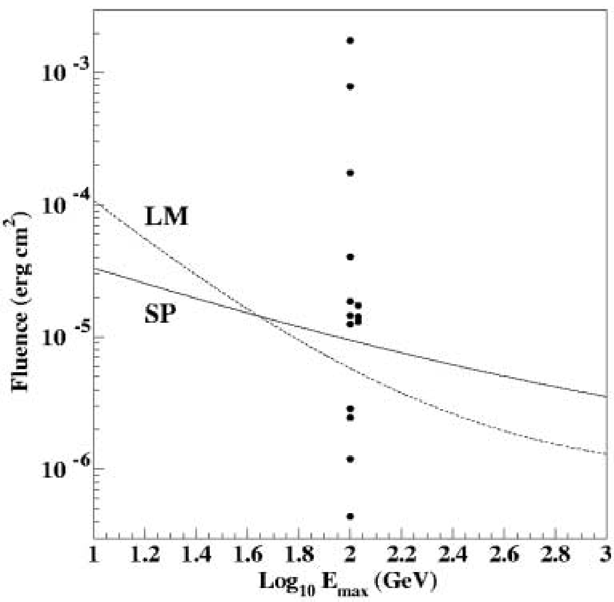

Fig. 4. – Minimum fluence from GRBs observable by ARGO-YBJ as a function of the cut-off energy $E_{\max}$ for Single Particle (SP) and Low Multiplicity (LM) techniques (see text). The points are the extrapolation up to 100 GeV of 14 EGRET spectra.

The overall results of the test look well promising for future operation of the full ARGO-YBJ detector.

5. – Conclusions

The ARGO-YBJ detector has the unique possibility to bridge the GeV and TeV energy regions, providing full complementarity to several satellite programs. For the first time a $\sim$ 50 m^2 RPCs carpet has been successfully operated at high altitude, confirming that RPCs can be used efficiently ($\epsilon \geq 95\%$) to detect air showers with excellent time resolution ($\sim$ 1 ns).

The results of the analysis of data collected on-site confirm the efficiency and time resolution assumed in the sensitivity computation for the full detector. The building has been finished and the installation of the RPCs started in November 2000. Data taking will start during 2001 with a 800 m^2 carpet, addressed to GRBs physics.

REFERENCES

[1] Weekes T. C. *et al.*, *Astrophys. J.*, **342** (1989) 379.
[2] Abbrescia M. *et al.*, *Astroparticle Physics with ARGO*, (1996), and Bacci C. *et al.*, *The ARGO-YBJ Project*, (1998).These unpublished documents can be downloaded at the URL: `http://www1.na.infn.it/wsubnucl/cosm/argo/argo.html`.
[3] Vernetto S. *et al.*, *Proc. 26th ICRC (Salt Lake City)*, vol. **4** (1999) p. 28.
[4] Vernetto S., *Astropart. Phys.*, **13** (2000) 75.
[5] Bacci C. *et al.*, *Nucl. Instrum. Meth. A*, **443** (2000) 342.
[6] Bacci C. *et al.*, *Nucl. Phys. Proc. Suppl.*, **85** (2000) 338.