The use of RPC in the ARGO–YBJ project

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We present the ARGO–YBJ experiment, a full coverage detector placed at high altitude ($\sim$ 4300 m a.s.l.) that exploits the RPC technique. Results of a test experiment performed at Yanbajing site, with a full coverage RPC carpet of 50 m^2 are also presented.

1. THE ARGO–YBJ PROJECT

ARGO–YBJ is an experiment especially designed to measure small size extensive air shower. It exploits the concept of "full coverage" at high altitude to reach unprecedented sensitivity in many items of the astroparticle physics.

A detailed description of the physics goals and of the experimental set–up of the ARGO–YBJ experiment is contained in the two documents: "ASTROPARTICLE PHYSICS WITH ARGO" and "The ARGO–YBJ project" [1].

Here we briefly report a summary of the main physics items that this detector can explore:

1) Gamma–astronomy, at a $\sim 100\,GeV$ threshold energy. More than 300 galactic and extragalactic point candidate sources can be continuously monitored, with a sensitivity to unidentified sources about 10% of the Crab flux.

2) Diffuse Gamma–Rays from the Galactic plane, molecular clouds and SuperNova Remnants (SNR) at energies $\geq 100\,GeV$ never observed so far.

3) Gamma Ray Burst (GRB) physics, by allowing the extension of the satellite measurements over the full GeV/TeV energy range.

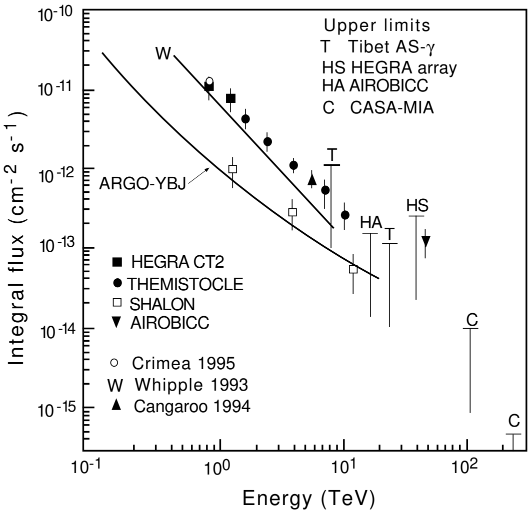

Figure 1. The expected ARGO–YBJ sensitivity (5σ in 1 year) to point the gamma sources compared to experimental data from Crab.

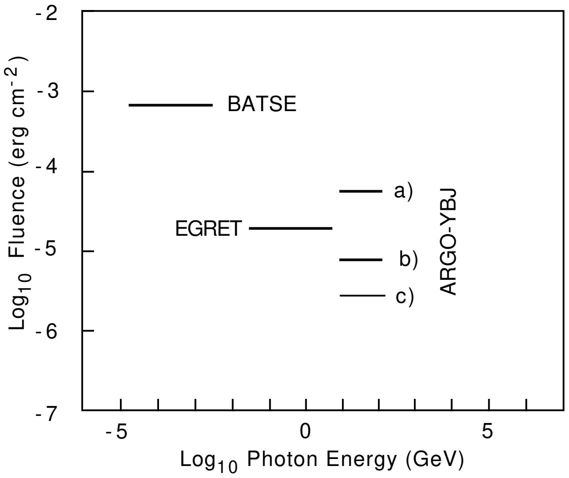

Figure 2. The minimum energy fluence, in the energy range $1 \div 100\ GeV$, detectable by ARGO–YBJ for GRB of duration of 1 s. The burst spectrum is assumed to be a power law in the range $1 \div 100\ GeV$ with slope of 3, 2 and 1 [*a), b), c)*]. The fluences measured by BATSE and EGRET during the powerful event GRB 940217 are also shown.

4) $\overline{p}/p$ ratio at energies $300\,GeV \div \sim TeV$ not accessible to satellites, with a sensitivity adequate to distinguish between models of local (galactic) $\overline{p}$ production and models accounting for an extragalactic origin.

5) The primary proton spectrum in the $10 \div 200\,TeV$ region, with sensitivity sufficient to detect a possible change of the slope of the energy spectrum.

6) Sun and Heliosphere physics, including cosmic ray modulations at $10\,GeV$ threshold energy, the continuous monitoring of the large scale structure of the interplanetary magnetic field and high energy gamma and neutron flares from the Sun.

Additional objectives come from using this detector as a traditional EAS array covering the full energy range from 10^{11} to $10^{16}\ eV$. Since the detector provides a high granularity space–time picture of the shower front, detailed study of shower properties as, for instance, multicore–events, time distributions of EAS particles, multifractal structure of particle densities near the core, can be performed with unprecedented resolution. At an altitude $> 4000\,m\,a.s.l.$ the electron size of the shower produced by primaries energies $10^{15} \div 10^{16}\ eV$ around the 'knee' of cosmic ray spectrum is practically independent of their mass. This fact could be exploited to get information about the composition at the knee by measuring other parameters distinguishing showers developed by primaries of different mass.

We summarize the expected performance of this detector to the main physics items in the figures 1, 2 and 3 that show respectively the sensitivity for detecting gamma rays from point sources, the minimum detectable fluence of 1 second GRB and the sensitivity for measuring the antiproton proton ratio in primary cosmic rays at energy around 1 TeV.

2. THE DETECTOR LAY–OUT

The ARGO–YBJ detector is a full coverage detector of dimensions $\sim 71 \times 74\ m^2$ realised with a single layer of RPC's of dimensions 125×280

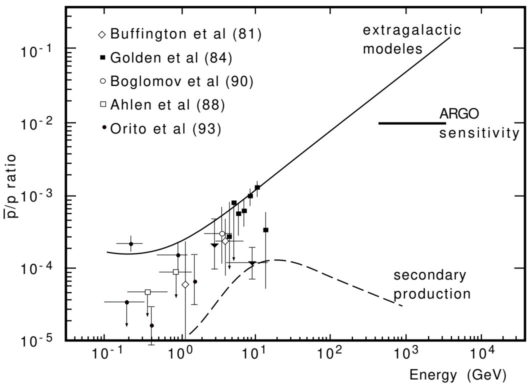

Figure 3. Upper limit at 90% c.l. on the $\bar{p}/p$ ratio set by ARGO–YBJ in case of no signal detection in three years of data taking

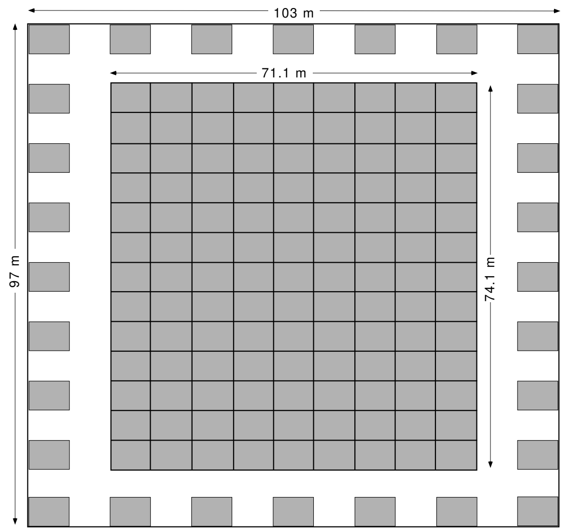

Figure 4. Top view of the ARGO–YBJ detector. The shaded area is the active part of the detector. The rectangles represent a logic subdivision of the detector (CLUSTER) consisting of 12 RPC's. The whole detector counts 145 CLUSTER's

cm^2. The area surrounding the central detector core, up to $\sim 100 \times 100$ m^2, is partially ($\sim 50\%$) instrumented with the same kind of detector (see figure 4) to improve the detector performance, enlarging the fiducial area, for the detection of the showers with the core outside the full coverage carpet. The proposed lay–out allows to achieve a coverage, ratio between active to total area, of about 90% in the full coverage part.

The detector will be hosted in a building with a modular structure to permit at the same time either the construction of the building or the RPC installation and data–taking (with a fraction of the apparatus). The building protects the detector from the weather and keeps the temperature in the operating range for the RPC ($\sim 8^o$ to 30^o degrees centigrade).

The ARGO-YBJ detector will be installed at the Yanbajing(Tibet) High Altitude (4300 m a.s.l.) Cosmic Ray Laboratory, 90 km North to Lhasa and easily reachable from Lhasa with an asphalt road. The site has coordinates 30.11^oN – $90.53°$ E and permits to monitor the Northern hemisphere in the declination band $-10° < \delta < 70°$. It is worth to note that the Crab nebula, the "Standard Candle" for γ rays astronomy in GeV$\div$TeV range, is in this range of declination.

The site as a good climate with respect to its altitude and this is due to the shield effect of the Hymalaya mountains. In fact the average temperature over one year is 2.5 °C, temperature excursion over many years is $-30 \div +25$°C , the average water fall is 328 mm/year and the average snowfall days are 26.4 per year with a maximum snow depth of ~ 7 cm.

The electronics, the triggers and DAQ system, that will be used in the ARGO–YBJ experiment, are fully described in the documents of reference [1].

3. THE TEST EXPERIMENT AT YANBAJING

To investigate the performance of RPC's operated at 4300 m a.s.l., a full coverage carpet of 50 m^2 area has been installed at YBJ site. It consists of 15 chambers placed in 5 columns with a surface covering of $\sim 90\%$.

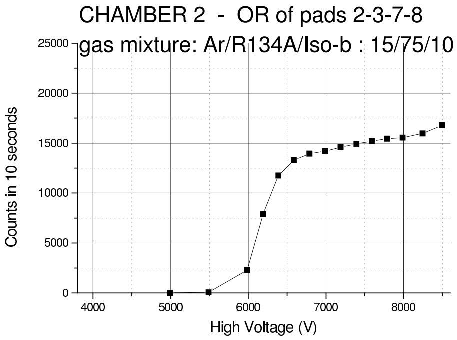

Figure 5. RPC single rate of the four OR-ed pads as function of High Voltage

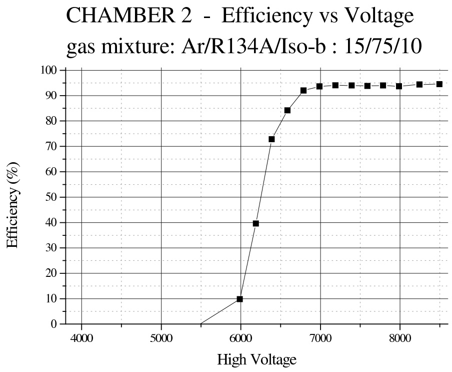

Figure 6. RPC efficiency curve as a function of High Voltage.

The detector consists of single-gap RPC's, made of bakelite ($\rho > 5{\times}10^{11}\Omega{\cdot}cm$) $280{\times}112\,cm^2$ area. The RPC's read-out is performed by means of Al strips 3.3 cm wide and 56 cm long at the edge of which the front–end electronics is connected. The FAST OR of 16 strips defines a logic unit called pad. Ten pads ($56{\times}56$ cm^2) cover each chamber. The FAST-OR signal from each pad is sent via coaxial cable, to dedicated modules that generate the trigger signal and the STOP signals to the TDC's [2]. Each channel of the TDC's measures, with a time resolution of about 1 ns, the arrival times (up to 16 hits per channel) of the particles hitting the pads. The trigger logic allows to select events on the base of the pad multiplicity.

The RPC's have been operated in streamer mode with gas mixtures based on argon (15%), isobutane (10%) and tetrafluoroethane $C_2H_2F_4$, (75%).

The single rate of the OR of four pads belonging to the same RPC is shown in figure 5 as a function of HV: the curve presents a well defined plateau corresponding to a rate of about 400 Hz per pad.

The plot of figure 6 shows a typical efficiency curve; the measured efficiency af all the 150 pads of the carpet, turns to be about 94%.

In order to obtain the overall time resolution, we have measured the time difference between the pad signals and the external trigger provided by the telescope.

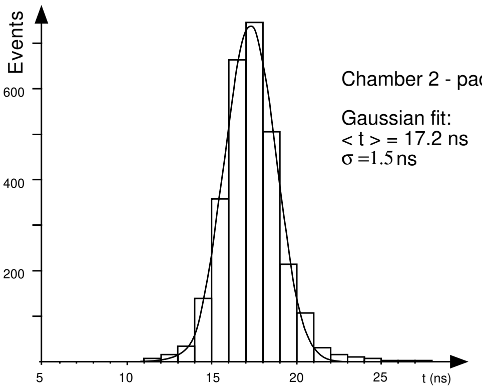

Figure 7. Typical time distribution of pad signals from one pad.

The RPC's have been operated at 7400 V, about 500 V above the plateau knee with an average current absorbtion of $7\mu A$. One typical time distribution of the RPC signals from one pad is shown in figure 7. Fitting the distribution with a gaussian curve, we obtain a typical resolution of $1.3 \div 1.5\; ns$. This result includes the time spread due to the electronics (front-end and TDC about 0.7 ns) and to the length of the strips.

Data were taken either with or without a 5 mm layer of lead on the whole carpet. Different triggers based on pad multiplicity have been used to

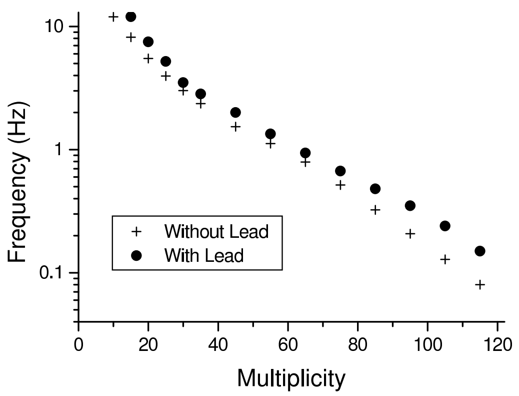

Figure 8. The integral rate as a function of the pad multiplicity with and without lead.

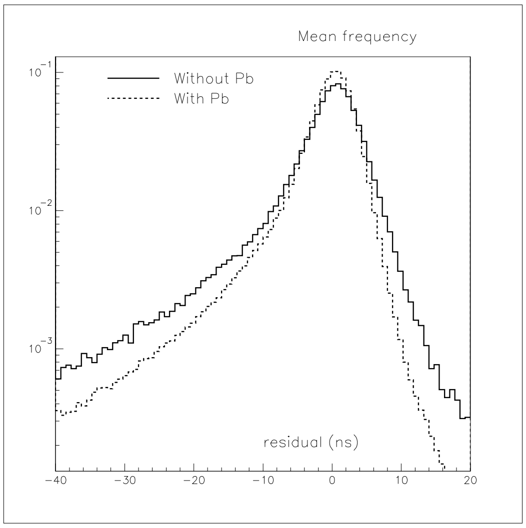

Figure 9. Residual distribution for events with pad multiplicity in the range 60–70 hits with and without lead.

collect about 70000 shower events without lead and about 10^6 shower events with lead on the top. The events represent a very detailed space–time picture of a small portion of the shower front.

The integral rate as function of the pad multiplicity is shown in figure 8 for both conditions. Since the pad rate is about 400 Hz and the pad signal is shaped to 1.5 μs the trigger rate of multiplicity greater then 6 is unaffected by accidentals.

Events with a pad multiplicity ≥ 30 has been selected to study the time profile of the shower front. In the very good approximation of a planar shape of the shower front the expected arrival time of the particles is a linear function of the position. The time spread around the fitted values gives information on the shower time thickness folded with the detector time resolution.

A typical distribution of the residual times with respect to the fitted plane is presented in figure 9, for the interval (60—70) hit of pad multiplicity, with and without lead. The effect of the lead consists in a shrinking the time thickness of the shower, since the lead absorbs low energy electrons, which mostly contribute to the tail of the time distribution, and converts the shower photons.

We have studied the angular distributions of the shower direction hitting the carpet. This direction is obtained as the normal to the plane fitted using the measured arrival times. The results for the theta and the azimuth distributions, are consistent with the expectation. The zenith distribution is shown in the figure 10.

The angular resolution of the detector has been investigated using the chess board method [3]. Events with N pads have been selected according to the constraint N_e(even pads) $\simeq$ N_o(odd pads $\simeq N/2$). The arrival shower direction has been reconstructed for both subsamples. The space angle difference $\Delta\theta$ between these directions is shown in figure 11 for events with $N = 130 \div 140$. The detector angular resolution σ_θ can be estimated by means of the following relation

$$\sigma_\theta = \frac{M_{\Delta\theta}}{1.177 \cdot 2} \quad (1)$$

where $M_{\Delta\theta}$ is the median of the $\Delta\theta$ distribution. From data collected with the lead layer we obtain $\sigma_\theta \simeq 3.8^o$, a factor of 1.5 better than the result obtained without lead.

4. CONCLUSIONS

For the first time a 50 m^2 RPC carpet has been operated at high altitude with remarkable success. The test performed confirms that RPC is a suitable detector for astroparticle physics for:

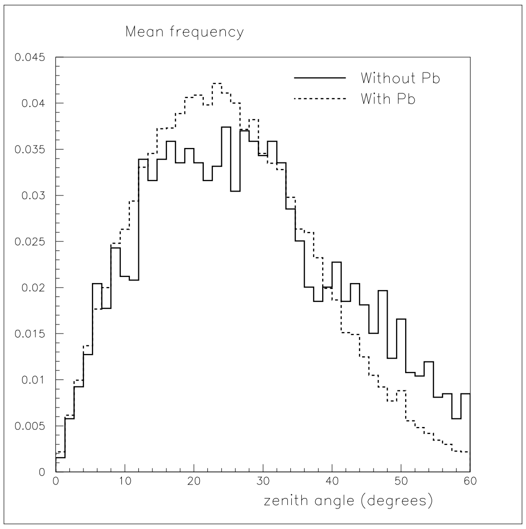

Figure 10. Zenith angle distributions in the range $50 - 70$ hits with and without the 5 mm Pb layer.

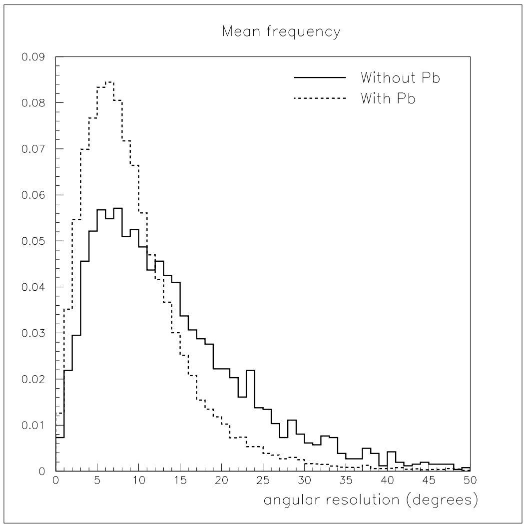

Figure 11. The space angle difference between odd numbered pads and even numbered pads for events with a total number of hits in range 60–70, with and without the 5 mm Pb layer.

- *good spatial resolution* $\sigma \simeq 1cm$
- *good time resolution* $\sigma \simeq 1ns$
- *low cost*

Moreover the results of the experimental test performed in YBJ laboratory confirms the performance of the full detector (efficiency and time resolution) assumed in the sensitivity computation. The ARGO–YBJ experiment will be the first large area astroparticle detector that exploiting the RPC technique at high altitude will explore a piece of astroparticle physics still largely unknown.

REFERENCES

1. These two documents can be downloaded from the web site: `http://www.fis.uniroma3.it/~nucleare/argo/argo.html`
2. M.Passaseo et al. N.I.M. A367(1995)418
3. D.E. Alexandreas N.I.M. A311(1992)350