The ARGO-YBJ Experiment in Tibet

R. Assiro [1], P. Bernardini [1,2], C. Bleve [1,2], A.K. Calabrese Melcarne [1,2], A. Corvaglia [1], P. Creti [1], I. De Mitri [1,2], G. Mancarella [1,2], G. Marsella [1,3], D. Martello [1,2], M. Panareo [1,3], L. Perrone [1,3], C, Pinto [1,2], A. Surdo [1], G. Zizzi [1,2]

[1]Istituto Nazionale di Fisica Nucleare sez. di Lecce, Italy

[2]Dipartimento di Fisica, Università del Salento, Italy

[3]Dipartimento di Ingegneria dell'Innovazione, Università del Salento, Italy

1. Detector description

As a result of the collaboration between INFN (Italy) and Chinese Academy of Sciences, the ARGO-YBJ (*Astrophysical Radiation with Ground-based Observatory at YangBaJing*) experiment (see [1] and references therein) is operating at the YangBaJing Cosmic Ray Laboratory (Tibet, P.R. China, 4,300m a.s.l.). It is the only air shower array in the world exploiting the full-coverage technique at very high altitude presently in data taking. Location and detector features make ARGO-YBJ capable of investigating a wide range of fundamental issues in Cosmic Ray and Astroparticle Physics at relatively low energy threshold. Its main scientific goals are γ-ray astronomy with a few hundreds GeV energy threshold and cosmic ray physics below and around the knee of the primary energy spectrum ($10^{12} - 10^{16}\ eV$), where the transition from direct to indirect measurement techniques takes place.

The ARGO-YBJ detector consists of a single layer of Resistive Plate Chambers (RPCs) operating in streamer mode [2]. The full-coverage central detector, having an extension of about $5,800 m^2$ ($\sim$ 92% of active area), is surrounded by a partially instrumented ($\sim$ 40%) guard ring mainly to improve the discrimination capability of external events. The apparatus has a modular structure, the basic element being a *cluster* (the DAQ basic unit), of dimensions $5.7 \times 7.6\ m^2$, constituted by 12 RPCs ($1.25 \times 2.80\ m^2$ each). Each RPC is read by 80 strips ($6.75 \times 61.8\ cm^2$ each) representing the spatial pixels, logically organized in 10 pads of $55.6 \times 61.8\ cm^2$, which are individually acquired and constitute the detector time pixel. The full detector is made by 153 clusters for a total active surface of $\sim 6,700\ m^2$ [3].

The detector space granularity and time resolution (better than 2 ns [4]) allow the three-dimensional reconstruction of the shower front with unprecedented details (Fig. 1 and 2).

The RPC charge read-out has also been implemented by instrumenting every chamber with two large size pads ($125 \times 140\ cm^2$ each), in order to extend the dynamic range up to $\sim PeV$ energies (*Analog Read-out System*) [5].

The detector operates simultaneously in two different and independently working modes: *shower* and *scaler*. In *shower* mode, for each event the position and timing of every detected particle is recorded, allowing the reconstruction of the core location, the lateral distribution and the arrival direction of the shower. In *scaler* mode the

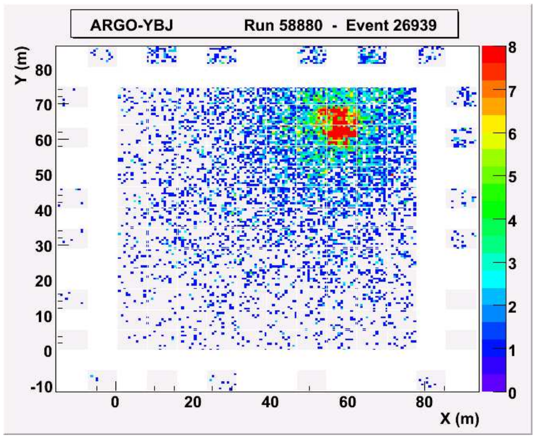

Figure 1. The pad image of a shower detected by ARGO-YBJ. The colour scale represents the strip multiplicity of each fired pad.

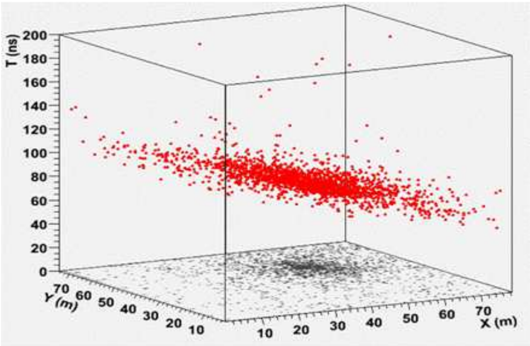

Figure 2. Space-time view of the shower front.

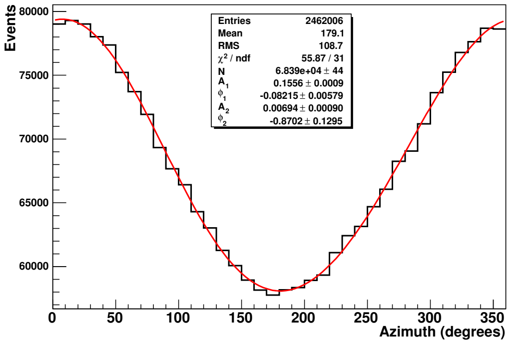

Figure 3. Azimuth distribution before the calibration procedure. The fit with a two-harmonics function is superimposed.

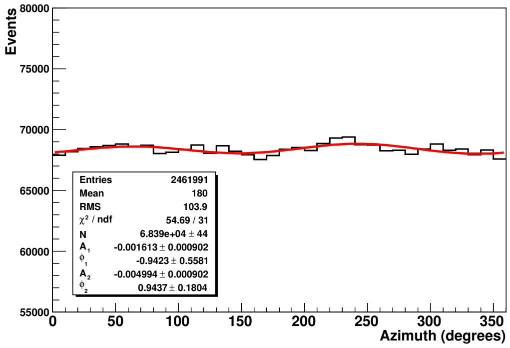

Figure 4. Azimuth distribution after the calibration procedure. The fit with a two-harmonics function is superimposed.

total counts on each cluster are measured every 0.5 s, with limited information on both the space distribution and arrival direction of the detected particles, in order to lower the energy threshold down to ∼1 GeV [6].

The Lecce group has been strongly involved in design, production and installation of the electronic devices for the distributed trigger and data acquisition system. In particular, the *Local Station* [7] (the basic trigger and single cluster data read-out unit) and the Control Board of the *Analog Read-out System* [8] (for the control of digitization and ADC data read-out and calibration) were entirely designed and produced in Lecce (see [3] for more details).

Moreover, our group has given a very relevant contribution to the development and implementation of the software tools for timing calibration, detector response simulation (*Argo-G* code, based on the *GEANT3.21* package) and event reconstruction and analysis (*Medea++*, an Object Oriented C++ code).

Sections 2 and 3 will report on software tools for detector timing calibration and monitoring mainly developed in Lecce (see also [3]), while the main effort of our group is presently devoted to data analysis, both in the field of gamma Astronomy and Cosmic Ray physics. In the companion Reports the main physics results of ARGO-YBJ experiment will be discussed, focusing the attention to that items where our group contribution has been most relevant.

2. Timing calibration of the detector

The timing calibration of the detector, that is the alignment of the $18,360$ pad-TDC channels, is crucial in order to get the angular resolution and the absolute pointing accuracy required for the astronomy goals. It mainly removes the systematical time offsets among the read-out channels due to differences in the length of the cables, in the discharge time in the chambers, in the electronic circuits and so on. It is performed periodically by means of an innovative software method [9], developed with the relevant contribution of the Lecce group, which does not require a dedicated data-taking. The method, called Characteristic Plane (CP) method, takes the secondary particles in a shower as the calibration beam which is quasi-parallel to the primary direction. The primary direction is reconstructed using the space-time information of the detector units fired in a shower. Due to the detector time offsets, there exists a systematic error between the reconstructed primary direction and the true one, which corresponds exactly to the slope of a CP defined by the time offsets of the detector units fired by the event. Events firing the same units have the same CP, whose direction cosines are exactly the averages of the direction cosines of the event set if the shower azimuth is uniformly distributed. In practice, the CP is estimated by the average over the whole event set. The reconstructed directions of the events are then corrected accordingly and used to calculate the detector time offsets. Finally the time offset of each detector unit is averaged over the whole event set.

The calibration procedure is iterated, i.e. the resulting time offsets are removed from the TDC times in the next iteration, thus the reconstructed directions gradually approach the true ones and the time offsets decrease. The effective goal of the CP procedure is to push to about 0 the mean values of fit residuals and direction cosines. The iteration finishes when the differences of the time offsets between two steps are small enough. Generally the iteration converges after several steps. Anyway the whole procedure is very fast.

Events with a large number of hits sample almost all parts of the array thus they have approximately the same CP which corresponds to that of the whole carpet. Indeed for the ARGO-YBJ experiment, events with more than 1500 hits (nearly 10% of all the pads are fired) and with the reconstructed core located inside the central carpet are selected for calibration purposes.

Another calibration procedure, always based on the CP method, was also tested: in a first step the standard residual corrections were applied twice, in a second step a systematical tilting correction was applied according to the mean values of the direction cosines. No significant differences with respect to the results of the calibration procedure presented before were observed.

The azimuth distribution of reconstructed showers is generally not uniform in most EAS arrays, e.g. the geomagnetic field causes the asymmetry of the efficiency along the azimuth angle and introduces quasi-sinusoidal modulation to the azimuth distribution. A large modulation is visible in the angular distribution before the calibration (Fig. 3). Indeed the reconstructed azimuth angles are shifted because the showers are reconstructed with respect to the Characteristic Plane. This modulation almost disappears after the calibration (Fig. 4) because the showers are correctly reconstructed with respect to the horizontal plane. Neverthless, a small remnant modulation ($\sim 1\%$) of the azimuth (ϕ) distribution is visible, due to the geomagnetic field effect on secondary particles in the shower (pre-modulation). According to the CP method a new systematical correction is needed in order to carry back the modulation to the values expected because of the geomagnetic field. A very careful analysis has been achieved by our group in order to evaluate the new correction requested by the premodulation effect. Such correction was found to be very small ($< 10^{-2}$) and as a first approximation can be neglected.

3. Detector monitoring

One of the major problems in experiments producing a very large amount of data like ARGO-YBJ is to have fast and efficient tools to check their quality and select them for a given analysis.

Up to now the Collaboration set up several important tools:
(a) online monitoring of the detector operation (Detector Control System, DCS);
(b) online monitoring of the whole data taking process and detector performances (online spy jobs, first data quality checks, display tools, ...);
(c) offline analysis of detector operation and data consistency (Detector Check Manager, DCM);
(d) offline reconstruction of measured quantities (the above mentioned program *Medea++*);
(e) tools for reconstructed data analysis and evaluation of physical quantities.

Steps (a) and (b) are performed at YangBa-Jing, while (c) and (d) at CNAF-Bologna or IHEP-Beijing on dedicated computer farms. The last step is left to the single user or working group.

By the way, a necessary intermediate step before starting each analysis (i.e. before step (e)) is the setting up of a procedure able to select a list of good runs (or data taking periods) on the basis of data quality and/or detector performances. Since this is a general need, that is independent of the kind of analysis which is going to performed, we decided to set up such a procedure and to give a set of easy tools to the potential users: **IDAS** (**I**mplementing **DA**ta **S**election) [10].

The general idea is to read interesting information concerning the data quality from the different outputs that are now currently being used in different frameworks. Therefore we produced different scripts that pickup information from:
- environment parameters (atmospheric pressure, temperature, humidity, etc.) recorded by DCS;
- DAQ output information, like the number of clusters actually being acquired, the current trigger threshold, etc.;
- output information by the DCM;
- measured quantities included in the default *Medea++* ntuple after the event reconstruction.

In this way a set of information is produced for each considered run and stored in a ROOT ntuple. It can then be used to monitor the data quality of a given period, to set quality cuts and then to produce a list of *good runs* that can be analysed for a given purpose (i.e. cosmic ray studies, γ-ray astronomy, ...). Up to now all the data from 2006 have been analyzed with IDAS and the information has also been used to study the dependencies of soma parameters like the trigger rates on atmospheric environmental quantities.

REFERENCES

1. C. Bacci *et al* (ARGO-YBJ Coll.), Astropart. Phys 17 (2002) 151 and references therein
2. G. Aielli *et al* (ARGO-YBJ Coll.), Nucl. Instr. and Meth. in Phys. Res. A562 (2006) 92.
3. R. Assiro *et al*, 2008 Annual Report (*ARGO-YBJ Experiment in Tibet*).
4. G. Aielli *et al* (ARGO-YBJ Coll.), Nucl. Instr. and Meth. in Phys. Res. A608 (2009) 246
5. M. Iacovacci *et al* (ARGO-YBJ Coll.), Proc. XXXI ICRC, No.1388, 2009; G. Aielli *et al* (ARGO-YBJ Coll.), to be published on Nucl. Instr. and Meth. in Phys. Res. A.
6. G. Aielli *et al* (ARGO-YBJ Coll.), Astropart. Phys. 30, 85, 2008.
7. R. Assiro *et al* (ARGO-YBJ Coll.), Nucl. Instr. and Meth. in Phys. Res. A518 (2004) 549
8. P. Creti *et al* (ARGO-YBJ Coll.), Proc. of the 29th ICRC, Pune, India (2005)
9. H.H. He *et al*, Astropart. Phys 27 (2007) 528; G. Aielli *et al* (ARGO-YBJ Coll.), Astropart. Phys 30 (2009) 287
10. C. Bleve *et al*, ARGO-YBJ Internal Note 2006-001.