Stability and calibration of the analog RPC readout in ARGO-YBJ

M. IACOVACCI[1,2], S. MASTROIANNI[2] FOR THE ARGO-YBJ COLLABORATION
[1] *Dipartimento di Fisica, Università degli Studi di Napoli Federico II and INFN sez. di Napoli*
[2] *INFN sez. di Napoli*
michele.iacovacci@na.infn.it

Abstract: The RPC charge readout, which is in operation on the entire central carpet (about 5800 m^2) of ARGO-YBJ since December 2009, extends the energy range of measurement, allowing the study of the cosmic radiation up to PeV energies. Here we will describe the chain of steps that, starting from raw data, allows the measurement of the shower size by the ARGO-YBJ detector. Special attention will be paid to the stability of the results and to the systematic errors due to the above mentioned procedure.

Keywords: RPC, Charge Readout, Calibration, High Particle Density

1 Introduction

The ARGO detector [1] is constituted by a central carpet ∼78×74 m^2, made of a single layer of Resistive Plate Chambers (RPCs) with ∼93% of active area, enclosed by a guard ring partially (∼20%) instrumented up to ∼110×100 m^2. The apparatus has a modular structure, the basic data acquisition unit being a cluster (7.6× 5.7 m^2), made by 12 RPCs (1.25 ×2.80 m^2 each). The full detector has 153 Clusters (130 in the central carpet, 23 in the guard ring) with a total active surface of about 6700 m^2. Each RPC is read out by means of 80 pick-up strips (61.8×6.75 cm^2, the spatial pixels) facing the upper side of the gas volume. The fast-OR signal of 8 contiguous strips defines the logical pad (61.8 × 55.6 cm^2, the time pixel) which is used for timing and triggering purposes. A manifold coincidence ($\geq N_{trig}$) of fired pads of the central carpet (N_{pad}), in a time window of 420 ns, implements the inclusive trigger that starts the event data acquisition. The apparatus, in its full configuration of 153 clusters, is in smooth and stable data taking since November 2007 with the trigger $N_{pad} \geq N_{trig}$ = 20; the trigger rate is ∼ 3.5 kHz with a duty cycle $\geq 86\%$. The high granularity of the detector and its time resolution provide a detailed three-dimensional reconstruction of the shower front. The digital pick-up of the RPC, which has a density of 23 strips/m^2, can be used to study the primary spectrum up to energies of a few hundred TeV; above these energies its response saturates as shown in [2]. In order to extend the measurable energy range and fully investigate PeV energies, where particle densities are larger than 10^3/m^2, each RPC has been equipped also with two large size electrodes of dimension 1.23 × 1.39 m^2. These pick-up electrodes, called Big Pads (BP), face the lower side of the RPC gas volume and provide a signal whose amplitude is expected to be proportional to the number of charged particles impinging on the detector. In this work, we report on stability and calibration of the RPC analog readout in ARGO-YBJ. The analog readout system is shortly described, then the detector performance are shown along with some specific effect, finally the step of the calibration procedure are explained and relative results are discussed.

2 The analog readout system

At present, the analog system has been completely assembled at YBJ in its final form on the 130 central clusters and it has been taking data since December 2009. The RPCs are operated in streamer mode, with a gas mixture of Argon (15%), Isobutane (10%) and R134a (75%). The operating voltage is 7.2 kV. This setting provides a typical efficiency $> 95\%$ with an intrinsic time resolution of about 1 ns .

The amplitude of the BP signal ranges from mV to tens of V. In each cluster a custom crate[4] containing three Analog to Digital Converter (ADC) boards and one control module manages the analog data. The system allows the operation with full scale (f.s) set by a 3-bit programmable register, namely 0.33, 0.66, 1.3, 2.5, 5, 10, 20 and 40 V. For electronic calibration purpose, a 12-bit DAC with step of 6.06 V has been implemented on the control board; the device linearity has been checked in the whole range 0-25 V. The ADC digitization and data collection [3, 4] in each cluster starts when the local multiplicity of hits (trigger) gets higher than a programmable threshold, namely $\geq 16, \geq 32, \geq 64$ and ≥ 73 hits. The data transfer to the central data acquisition system occurs when the local trig-

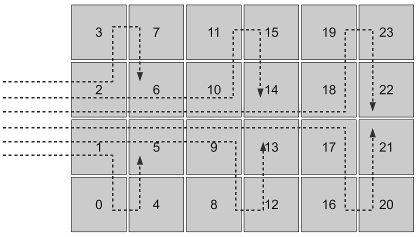

Figure 1: Gas distribution in a cluster. The BP are numbered from 0 to 24, as in the hardware setup. The arrows show the gas flow in the 6 bicamera (see text).

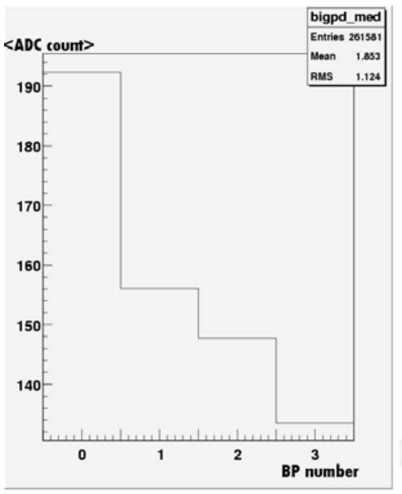

Figure 2: Average ADC count in the 4 BP of a bicamera, f.s. is 0.3 V.

ger is confirmed by the experiment trigger. Starting from December 2009, the analog readout system has been operated with different f.s., namely from December 2009 till end of June 210 it was operated at 330 mV f.s., the most sensitive one, whose particle density range overlaps with the particle density measurable by the digital readout system; these data have been used both to study the detector behavior and for calibration purposes. From July to middle August 2010, the system was operated at the intermediate f.s., which corresponds to about 2.5 V; since middle August 2010 the f.s. has been set to 20 V, not the highest one, which instead is 40 V. The number of BP in the central carpet is 3120, apart from dead channels or channels with some problems which are in the order of 3%.

2.1 Gas Effect

This is the first time the RPCs are used in analog mode. We know that gas detector are delicate and sensitive, with strong dependence on environmental parameters. Here we show two effects related to the gas; before we will give a short view of the gas distribution system. The elemental "gas channel" is a couple of RPCs in series (bicamera) which has at the input a capillary tube (glass, 32 mm long and 0.6 mm diameter) with so high impedance that the gas flux in the bicamera does not depend on the length of the distribution pipes. The distribution scheme for a cluster is shown in Fig.1 where the gas flow is displayed by arrows in each bicamera; as in one bicamera we have 4 different BP, the entire carpet can be considered as essentially a set of 4 different BP from the gas flow point of view, namely the first along the gas arrow (BP0), the second (BP1), up to the fourth (BP3). The gas volume of the 153 clusters is 19 m^3, and the flux of the mixture guaranties 4 gas-volume changes/day. It has been observed an effect related to the gas arrow, namely the BP0 has a signal amplitude higher then the other BP in the bicamera; moreover there is a decreasing behavior of the BP amplitude along the gas flow arrow . Taken a dataset and summing up the signals in all BP0, then repeating the same for the other BP, we see that the mean amplitude of BP3 is about 0.65 times the mean amplitude of BP0 (Fig.2). This effect has been observed also in the single clusters, so confirming that it refers just to the gas arrow. Moreover, while the mean amplitudes of BP1, BP2 and BP3 are quite constant, the amplitude of BP0 changes in a much wider band, as will be shown later on. This effect was unexpected and is still matter of investigation.

3 The calibration procedure

In order to translate ADC count to particles two steps are needed, namely first converting the ADC count to an amplitude, then the amplitude to the number of particles. The first step is referred to as electronic calibration, the second one as gain calibration. Electronic calibration runs [4, 5] have been performed at the different f.s. the detector has been operating; the relation between ADC count and input amplitude has been fitted with a polynomial function, as shown in Fig.3; the coefficient of the linear term (P1), which is the dominant one, comes out to have a spread in 1.5-4% depending on the board production, which in fact was achieved in three different bunches. To check the electronic stability as regards time, calibration runs have been issued several times after weeks and months; the results showed a stability within about 1 % . The gain calibration has been done by using the data taken at 330 mV f.s., which is the most sensitive scale, where the same particle density is measured at the same time both by the digital readout system and by the analog system. Taken each single BP, and after the electronics calibration was applied , the measured amplitude has been plotted with respect to the number of fired strips, as shown in Fig. 4: there is a linear relation between amplitude and number of fired strips, unless the probability to have more than one strip per particle is high. Accordingly, we concluded the density effect sets in above 15 strips, whereas below a few fired strips both elec-

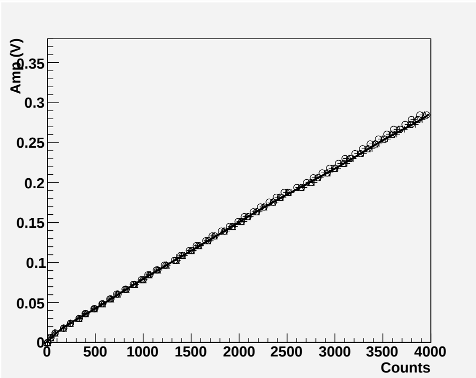

Figure 3: Calibration polynomials (lines) of the analog channels in a board.

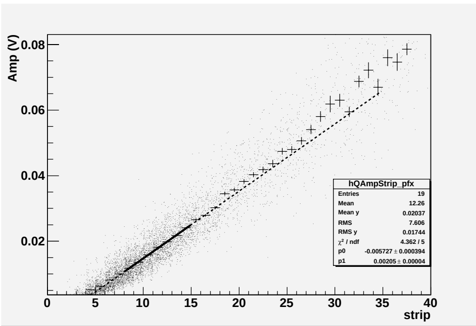

Figure 4: Single BP amplitude versus number of strips; the fit has been performed in the range 8-15 strips (heavy line).

tronic noise and low sensitivity dominate; therefore a linear fit was performed in range 8-15 strips so getting to the gain (mV/particle) of the specific analog channel. In case of a BP with dead strips the fit range has been suitably rescaled. Actually we have about 1.2 fired strips/particle, so the gain should be corrected accordingly; in what follows this correction has not been applied. The statistics in each plot has been determined so to have an uncertainty lower than 2% in the gain determination; it roughly corresponds to 1 hour data. Dividing the data sample accordingly, then repeating the procedure all over the sub-samples, and for all the pads we obtained the gain of each BP as for the time. About 95$\%$ of the BP channels have been calibrated with this procedure. The data used for gain calibration have been collected between the day 80th and day 160th of 2010. The gain values have been monitored all long the period and the dependence on atmospheric pressure and temperature has been investigated. These environmental parameters are measured with an high accuracy, namely $\pm 0.25\mathrm{K}$ and $\pm 0.5\mathrm{mbar}$ respectively and recorded by the Detector Control System. In order to display the gain dependence on P and T, all BP of the same kind , that is having the same position along the gas arrow (BP0, BP1, BP2 and BP3), have been grouped and their mean gain calculated. Fig. 5 shows the behavior of the BP3 gain in about 8 days; as expected the gain is daily modulated and correlated to both atmospheric pressure and temperature, which are reported

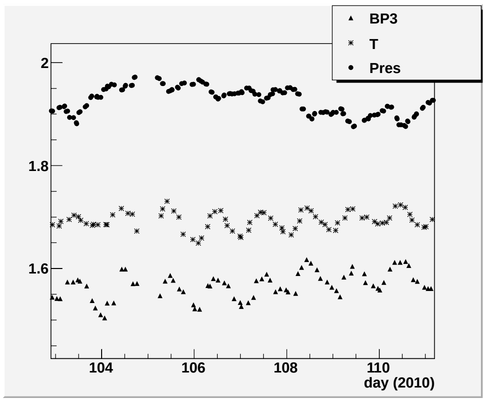

Figure 5: BP3 gain (mV/particle) in 8 days; temperature and pressure, suitably rescaled, are also reported.

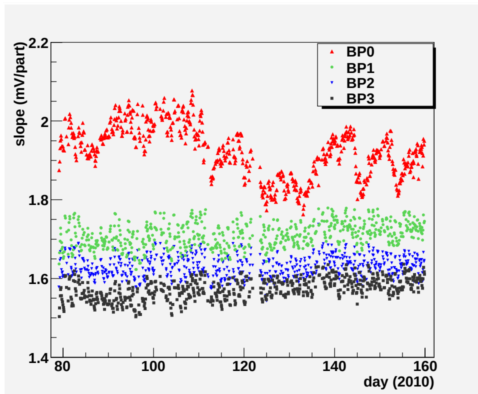

Figure 6: Gain behavior in 70 days of the 4 BP in a bicamera.

after suitable modification. Fig. 6 shows the gain behavior of the four channels: while BP1, BP2 and BP3 are found to be well correlated with the environmental parameters, BP0 appears to suffer of much higher variations, showing some additional dependencies. If we correct each channel for P and T dependence according to the relation:

$$BP(i) = BP(i)_0 \frac{P_0}{P} \frac{T}{T_0} \qquad (1)$$

where P_0 and T_0 are arbitrarely chosen and $BP(i)_0$ is the gain of specific BP at the reference P_0 and T_0, then grouping the channels according to the gas arrow, the result is shown for BP3 in Fig. 7; the rms of the gain distribution reduces. This happens also to BP1 and BP2, not to BP0 even though things get better on the single day base. This is summarized in Tab.1, consequently we can claim the detector to have a quite good stability which is presently estimated to be about 4$\%$, but if BP0 is excluded it gets close to 2$\%$. As seen, this procedure guarantees an easy way to off-line calibrate the analog system providing to each BP channel its own gain, on a run by run base; we used only but the overlap between analog and digital information. Therefore the method can not be directly applied to the other scales where the overlap between digital and analog information is poor, nevertheless a solution has been

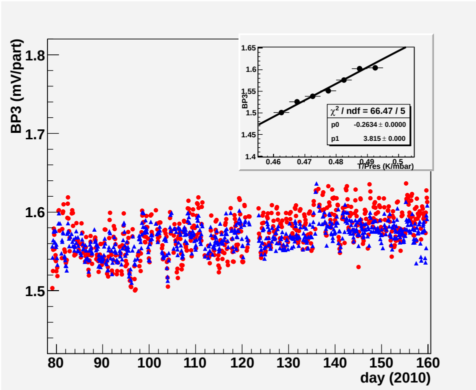

Figure 7: BP3: gain behavior (three months of data) before and after the P/T correction. In the small upper-left square is also reported the best fit between gain and T/P (mbar/K).

$<> \pm rms$ $(<> /rms)$	Before	After
BP0	1.93 ± 0.06 (3.1%)	1.92 ± 0.07 (3.6%)
BP1	1.71 ± 0.03 (1.8%)	1.71 ± 0.02 (1.2%)
BP2	1.63 ± 0.03 (1.8%)	1.63 ± 0.02 (1.2%)
BP3	1.57 ± 0.03 (1.9%)	1.57 ± 0.02 (1.3%)

Table 1: Gain of the 4 BP in a bicamera, before and after P/T correction. Here the mean of all BP of the same kind is reported; therefore the detector simply corresponds to 4 channels, namely BP0,BP1,BP2 and BP3.

adopted and we will discuss it just for the highest used f.s, that is 20 V. The higher f.s. data have been calibrated by using the gain calculated at the 0.3 V f.s. The reference gain for each BP has been taken as the mean gain, at the reference T_0 and P_0 representing the starting conditions of the specific f.s. data; then a P/T correction has been applied so getting to the gain of the specific channel on a run by run base. This procedure relies on detector stability, which has been demonstrated at 0.3 V f.s. In order to estimate to goodness of the calibration procedure, taken each BP, a fit was performed in log-log scale first on the ADC count distribution, then on the amplitude distribution and finally on the particle distribution, so obtaining the 3 corresponding slopes: if the calibration procedure operates correctly, then the slope distribution get tighter and tighter as going from ADC count to particles. This check has been done for both 0.3 V and 20 V f.s data, the results are summarized in Tab.2. Looking at values in Tab.2 a few considerations can be done, namely: a) the spread of the slope distributions in case of the ADC count are almost independent of f.s. (ADC count row); b) the electronic calibration (Ampl row) seems to perform better at higher f.s. but this is due just to the calibration procedure, in fact more points are used at higher f.s.. To be noticed instead that the mean slopes are consistent; c) the r.m.s. of the particle slopes (Part row) seem to be a little higher at higher f.s., this is probably due to statis-

$<> \pm rms$ $(<> /rms)$	0.3 V f.s.	20 V f.s.
ADCcou	2.39 ± 0.19 (8.2%)	1.90 ± 0.18 (9.4%)
Ampl	2.55 ± 0.18 (7.1%)	2.56 ± 0.13 (5.1%)
Part	2.51 ± 0.11 (4.4%)	2.51 ± 0.16 (6.3%)

Table 2: Mean value and rms of the slope distributions (see text), for all BPs, in case of lowest and highest f.s..

tics. Finally, 5% is a good estimate for the homogeneity among channels .

4 Conclusions

The ARGO-YBJ detector is being using RPCs with analog readout. The operation of the analog detector has started on the central carpet (5800 m^2) since December 2009; three periods have been considered to the present analysis when the detector has been operated at different f.s. of the analog signal. The procedure to calibrate the detector has been described and demonstrated to be effective. After calibration, the detector shows a quite good stability, evaluated at about 4%,which could be improved down to 2%, and homogeneity among channels estimated at 5% level.

References

[1] G. Aielli et al., "Layout and performance of the RPCs used in the ARGO-YBJ experiment", *Nucl. Instr. Meth. A, vol. 562 , pp 92-96, 2006*

[2] L. Saggese et al., "Feasibility of measurements of cosmic ray composition by means of RPC digital read out in ARGO-YBJ" *Nucl. Instr. Meth. A, vol. 533, pp. 55-59, 2004*

[3] P. Creti et al., "The RPC charge read-out in the ARGO-YBJ experiment" *Proceedings of the 29th ICRC, Pune, 2005, 101*

[4] M. Iacovacci et al., "The RPC charge readout system of the ARGO-YBJ experiment" *Proceedings of the 31st ICRC, Lodz, 2009*

[5] S. Mastroianni et al., "Integration of the Analog Readout in the ARGO-YBJ DAQ System" *in press on IEEE*