Natural radioactivity effects on the scaler operation mode of the ARGO-YBJ detector

Claudio Cattaneo§, Elio Giroletti*§, Giuseppe Liguori*§, Paola Salvini§
on behalf of the ARGO-YBJ Collaboration
*Dipartimento di Fisica Nucleare e Teorica, Università di Pavia
§ Istituto Nazionale di Fisica Nucleare, Sezione di Pavia

***Abstract.* ARGO-YBJ is an extensive air shower detector located at the Yangbajing Cosmic Ray Laboratory (4300 m a.s.l., $606\ \mathrm{g/cm^2}$ atmospheric depth). It is made by a single layer of Resistive Plate Chambers (RPCs, total surface ~ 6700 m^2) grouped into 153 units called ”cluster”. The lower energy threshold of the experiment is obtained using the ”scaler operation mode”, i.e. counting all the particles hitting the detector without measurement of the energy and arrival direction of the primary cosmic rays. For each cluster the signals generated by these particles are put in coincidence in a narrow time window (150 ns) and read by four independent scaler channels, giving the counting rates of ≥ 1, ≥ 2, ≥ 3 and ≥ 4 hits. The study of these counting rates has given unexpected results: while the MC simulations can account fairly well for the coincident counting rates, the expectation for channel ≥ 1 is about half of the measured value. Moreover as discuss in [2], the regression coefficient with the atmospheric pressure for channel ≥ 1 is also about half of the value measured for the coincident counting rates: seemingly half of these counts did not cross the atmosphere. A measurement of the radioactivity of the ground below the detector and a MC simulation to estimate the contribution from this local effect on our counting rates is presented and discussed.**

***Keywords*: Low energy cosmic rays, Natural radioactivity, Extensive air shower**

I. The detector and the operation mode

The ARGO-YBJ experiment is an Extensive Air Shower (EAS) array installed at the International Laboratory of Yangbajing in Tibet (P.R. China) at 4300 m a.s.l. and allowing a continuous all-sky survey of the Northern hemisphere in the declination band $-10^0 < \delta < 70^0$ at few GeVs energy thresholds. The detector consists of a single layer (carpet) of 1836 Resistive Plate Chambers (RPCs) and has a modular structure: the basic module is a cluster (5.7×7.6 m^2) divided into 12 RPCs (2.850×1.225 m^2) and the whole carpet is made by 153 Clusters. The carpet central part (130 clusters) has a full coverage surface of ~ 5600 m^2 and $\sim 93\%$ of active area and it is surrounded by the 23 clusters of the guard ring, extending the detection area to ~ 6700 m^2 (see [1] and references therein for a complete apparatus description).

The detector has been designed to operate in two different modes: the shower and the scaler modes.

In the shower mode, for each event the location and timing of the secondary particles are recorded so that it's possible to reconstruct the shower lateral distribution and the arrival direction with a threshold energy of a few hundreds of GeVs.

The lowest energy limit ($E \sim 1$ GeV) is reached by the scaler mode technique: the total counting rates of each cluster are recorded every 500 ms without any information about the timing and spatial distribution of the detected particles. Each chamber (RPC) is read by 80 strips, logically organized in 10 pads: the counts from different pads of the same cluster are put in coincidence in a narrow time window (~ 150 ns). Four low multiplicity channels in each cluster are implemented corresponding to event multiplicities from ≥ 1 to ≥ 4 hits: the mean measured counting rates are respectively ~ 40 kHz, ~ 2 kHz, ~ 300 Hz and ~ 120 Hz. In fig. 1 the detector layout is shown putting in evidence the modular structure in “clusters”, “chambers” and “pads”.

As it's shown in ref. [2], [4] while the cluster counting rates for each multiplicity channel follow a Poissonian distribution for time intervals shorter than 30 minutes, for time intervals longer than this they are influenced by meteorological effects, mainly pressure and temperature variations.

In [2] experimental regression coefficients with these two variables were found for each cluster. In particular the barometric coefficient for scaler ≥ 1 ($\sim 0.4\ \%/\mathrm{mbar}$) turned out to be nearly half the ones found for all the higher multiplicities ($\sim 0.9\ \%/\mathrm{mbar}$), these last being consistent with values found by similar apparatuses. Moreover as discuss in [2], a simulation of the cosmic ray trigger rate at the Yangbajing atmospheric depth well reproduce the counting rates for multiplicites ≥ 2, ≥ 3 and ≥ 4 (respectively 2.1 kHz, 310 Hz, 117 Hz) while the expectation value for ≥ 1 is nearly half the measured one (26.5 kHz instead of ~ 40 kHz).

From these results it was suggested that a consistent part (nearly half) of the ≥ 1 counts were not due to cosmic rays. In this paper we study the fraction of counting rate possibly due to the ionizing radiation background at Yangbajing, on the basis of local measurements.

A gamma ray spectroscopy analysis has been performed over a sampling of the ground beneath the detector. The results are shown in Table I, where the activity measured for the Tibet sample [14] is compared

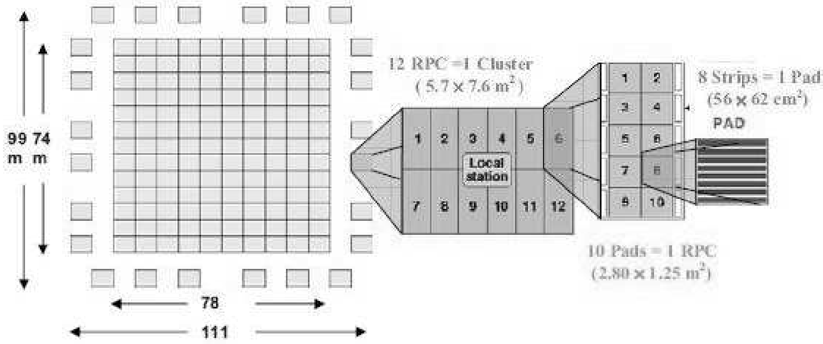

Fig. 1: Scheme of the ARGO-YBJ detector layout, with details of the detector geometry and structure.

with the mean values measured in the world [10] . As an experimental check, the values in Tab.I have been used to evaluate (by a naive Monte Carlo) the number of gammas crossing the concrete floor and reaching the surface.

TABLE I: Soil measured radioactivity

Isotope	Activity (Bq kg^{-1})			Activity (Bq kg^{-1})
	Mean	Min	Max	Yangbajing
^{238}U	35	16	110	449
^{232}Th	30	11	64	697
^{40}K	400	140	850	4624

II. Monte Carlo simulation

We performed a careful simulation of an ARGO-YBJ cluster in order to estimate the fraction of the measured counts attributable to natural radioactivity.

We simulated an isotropic, homogeneous and extended source correspondent to a ground portion of 800 m^2 of surface (much wider than the cluster surface) and a depth of 1 m (i.e. assuming that γs emitted deeper in the ground are absorbed before reaching the apparatus) of mono-energetic γ particles emitted by three isotopes uniformly distributed: ^{238}U, ^{232}Th, ^{40}K. Energies, and branching ratios used for the source simulation are summarized in Table II.

TABLE II: Energies and Branching Ratios for higher energy γ emitted by isotopes ^{238}U, ^{232}Th, ^{40}K; in the last column are given the number (N) of γs surviving after the concrete floor estimated from a rough Monte Carlo [14]. The contributions of lowest energy γs are ignored because largely absorbed by the soil.

Isotope	Energy (keV)	Br %	Emitted γ (N/s/m^2)	Surviving γ (N/s/m^2)
^{238}U	1120.4	15.2	40949	6366
	1377.8	4.8	12931	2154
	1764.7	15.4	41488	7636
^{232}Th	911.1	29.0	121278	18033
	968.9	17.5	73185	11287
	2614.7	36.0	150552	31940
^{40}K	1460.8	10.7	296861	59550

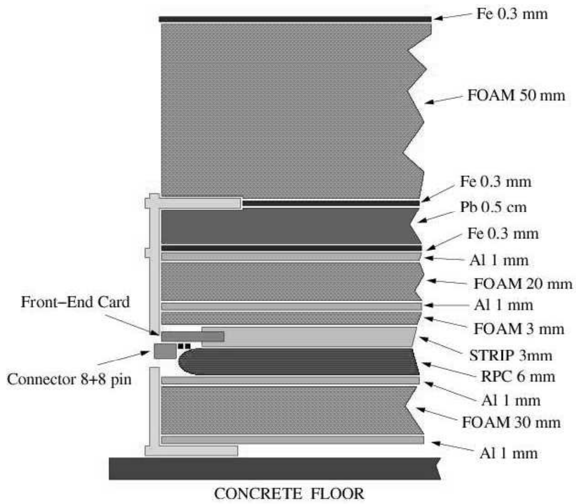

Fig. 2: Schematic cross-section of an ARGO-YBJ RPC

In order to characterize the ground composition at Yangbajing we used a typical wet soil composition, given in Table III [11], and we assumed a ground density of 2.0 g cm^{-3}.

TABLE III: Wet ground composition used in Monte Carlo simulation. Atom density is in atom b^{-1} cm^{-1}

Chemical composition	Atom density	Percent by mass
H	3.085×10^{-2}	3.04
C	7.043×10^{-4}	0.83
O	3.759×10^{-2}	58.74
Na	5.451×10^{-4}	1.22
Al	2.061×10^{-3}	5.43
Si	9.315×10^{-3}	25.55
Cl	2.541×10^{-6}	0.01
K	7.191×10^{-4}	2.75
Ca	1.583×10^{-4}	0.62
Ti	2.567×10^{-5}	0.12
Mn	6.659×10^{-6}	0.04
Fe	2.482×10^{-4}	1.35

The concrete floor has been taken into account and the RPC detailed structure is shown in Fig. 2.

The sensitive gap is filled with a gas mixture of Freon (R134A), IsoButane and Argon (the active com-

TABLE IV: Simulated counting rates for multiplicity ≥ 1. The simulated rate (fifth column) is referred to the number of emitted γ for an estimated active cluster area of $\sim 40.0 \cdot 10^4$ cm^2 (cluster area is 41.9 m^2 included the not active regions) and $6 \cdot 10^6$ primary γs simulated.

Isotope	Isotope Activity Bq	Energy keV	Br %	Emitted γ N_γ s^{-1}	Simulated rate N_{hit} s^{-1} cluster
^{238}U	$7.18 \cdot 10^8$	1120.4	15.2	$1.09 \cdot 10^8$	368
		1377.8	4.8	$3.45 \cdot 10^7$	198
		1764.7	15.4	$1.11 \cdot 10^8$	1040
^{232}Th	$1.12 \cdot 10^9$	911.1	29.0	$3.23 \cdot 10^8$	656
		968.9	17.5	$1.95 \cdot 10^8$	498
		2614.7	36.0	$4.01 \cdot 10^8$	7762
^{40}K	$7.40 \cdot 10^9$	1460.8	10.7	$7.92 \cdot 10^8$	4964
Total rate					15486

ponent of the gas mixture) in the following proportion $75 : 10 : 15\%$. Because the Argon ionization energy is 15.8 eV, we use this value both as energy threshold for the development of ionization avalanche in the chamber ($E_{\rm secondary} \geq V_{\rm Ar}$) and for tracking energy threshold of particles inside the materials.

This model was implemented in FLUKA [5], [6] using graphics user interface (GUI) FLAIR [7]: FLUKA handled the complete physics model (in our simulation we use Electromagnetic cascade) for interaction and shower component, the ARGO geometry description and the graphical interface.

III. MONTE CARLO RESULTS

In this section the simulation results of our analysis are presented: in order to ease the reader we describe with some details the calculus made for the ^{40}K isotope and summarize the results for all the other isotopes in Table IV.

Given the source described in the previous paragraph, the soil characteristics in Table III and the measured activity for ^{40}K (see Table I), the activity of ^{40}K source (800 m^3 of volume) is $7.40 \cdot 10^9$ Bq. Taking into account the branching ratio for γs with emission energy of 1460.8 KeV (10.7 %) we obtain $79.2 \cdot 10^7$ γs emitted per second from ^{40}K. A similar evaluation has been performed for the higher energy γ emissions of the ^{238}U and ^{232}Th.

We simulated $6 \cdot 10^6$ γs for each of the seven energies in Table III and for each one of those emissions we estimated a simulated counting rate , assuming that each particle reaching the RPC sensitive gap with an energy greater than the Argon ionization potential gives a hit (37.6 secondary particles giving hits on a cluster, for ^{40}K, as in Table IV). This procedure is somewhat similar to that previously used to estimate the RPC neutron sensitivity [12]. The rate so obtained must obviously be renormalized for the number of effectively emitted γs in one second: that is, it must be multiplied by the ratio between the number of effectively emitted γs in one second ($79.2 \cdot 10^7$) and the number of simulated ones ($6 \cdot 10^6$), obtaining about 5 kHz counting rate from ^{40}K decay.

As an overall check of our procedure we resort to the data in Table II where, by a rough Monte Carlo, the number of γs for each decay energy crossing the concrete floor and reaching the surface are estimated. Taking into account an experimental detection efficiency of 6.6 10^{-3}, estimated in [13] for γ energies between 1 and 10 MeV for RPCs of similar structure but operating at sea level (i.e. with a different gas mixture and pressure), we get for the 2.6 MeV emission from ^{232}Th series an expected counting rate of 8432 Hz ,which is of the same order of magnitude than the simulated value in Table IV. We stress that the difference between the two values can be explained by the fact that the $E_\gamma = 2.6$ MeV is at the lower extreme of the energy range for which the efficiency in [13] is given.

The last column of Table IV shows the results obtained for all the γ decays used in Monte Carlo simulation: in the last row we can observe that the total rate obtained summing up all the rates is ~ 15.5 kHz, in accordance with our expectations. This value (as the values in Table IV) is affected mainly by a systematic error due to hypothesis on the ground density and composition (i.e. moisture). Trying different ground densities, the systematic error on the total rate can be evaluated around 20%.

IV. SUMMARY AND CONCLUSION

The study of the influence of natural soil radioactivity on the scaler mode counting rates has shown that the measured local radioactivity at Yangbajing could well account for the excess in the ≥ 1 counting rate.

Monte Carlo simulation on the high energy γ emissions from the three natural radioactive series in Table II gives an expected counting rate of ($\sim$ 15.5 kHz) for multiplicity ≥ 1: that leaves only ~ 25.0 kHz to cosmic rays exposure, in agreement with what expected at the Yangbajing atmospheric depth.

In the future a complete simulation of all the γ energies emitted by ^{238}U, ^{232}Th, ^{40}K will be performed, as well as a measurement of the RPC detection efficiency to γs around 1 MeV and a γ spectroscopy of soil.

V. ACKNOWLEDGMENTS

We would like to thank G.Battistoni and FLUKA team for discussions and explanations about FLUKA use. Also we thank V. Roca for chemical and physical analysis of Yangbajing soil.

References

[1] G.Aielli et al., Nucl. Instr. Meth., A562 (2006) 92
[2] G.Aielli et al., Astroparticle Physics 30 (2008) 85-95.
[3] Z. C. et al., 29^{th} International Cosmic Ray Conference Pune, India 5 (2005) 299-302.
[4] A. Cappa et al., 30^{th} International Cosmic Ray Conference Mérida, Mexico 1 (2007) 621-624.
[5] G. Battistoni et al., The FLUKA code: Description and benchmarking, Proceedings f the Hadronic Shower Simulation Workshop 2006, Fermilab 6-8 September 2006, M. Albrow, R. Raja eds., AIP Conference Proceedings 896 (2007) 31-49.
[6] A. Fassò et al., FLUKA: a multi-particle transport code, CERN-2005-10 (2005), INFN/TC-05/11, SLAC-R-773.
[7] http://www.fluka.org/flair
[8] P.Camarri, ARGO-YBJ: present status and first investigation in cosmic-ray astrophysics, Frascati Physics Series Vol XLV (2007) 225-234.
[9] C. Bacci et al., Performance of the RPCs for the ARGO- detector operated at the Yangbajing laboratory (4300 m a.s.l.), Nucl. Instr. Meth., A508 (2003) 110-115
[10] UNSCEAR 2000 Report of the United Nations Scientific Committee on the effects of atomic Radiation to the General Assembly, Washington, 2000
[11] R. Santoro et al., Radiation transport calculation for Hiroshima and Nagasaki in Reassessment of the Atomic Bomb Radiation Dosimetry for Hiroshima and Nagasaki, DS02 vol. 1 Radiation Effects Research Foundation (2005) 139-155.
[12] S.Altieri et al., Nucl. Instr. Meth. A461 (2001) 57
[13] M.Widgoff et al., SSC-GEM-TN-Rev.A(1992)92-206
[14] V. Roca, Internal communication