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Background radioactivity in the scaler mode technique of the Argo-YBJ detector

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Abstract. ARGO-YBJ is an extensive air shower detector located at the Yangbajing Cosmic Ray Laboratory (4300 m a.s.l., 606 g cm^{-2} atmospheric depth, Tibet, China). It is made by a single layer of Resistive Plate Chambers (RPCs, total surface $\sim 6700\,\mathrm{m}^2$) grouped into 153 units called "clusters". The low energy threshold of the experiment is obtained using the "scaler operation mode", counting all the particles hitting the detector without reconstruction of the shower size and arrival direction. 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 channel ≥ 1, ≥ 2, ≥ 3 and ≥ 4 hits. The study of these counting rates pointed out a different behavior of channel ≥ 1 respect to the higher multiplicity channels: while the MC simulations can account fairly well for the coincident counting rates, the expectation for channel ≥ 1 is sensibly less than the measured value. Moreover, 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.Measurements of the natural radioactivity background in the air of the detector hall and a MC simulation to estimate its contribution on our counting rates are presented and discussed.

1 Introduction

The Argo-Ybj experiment, located at Yangbajing (Tibet, China) at an altitude of 4300 m a.s.l., is designed for VHE γ-astronomy and cosmic ray observation with energies ranging up to the PeV range. The detector consists of a single layer of RPCs operated in streamer mode divided into modules called "cluster" ($5.7 \times 7.6\,\mathrm{m}^2$ of surface) composed of 12 RPCs, each one equipped with pick-up strips and grouped into logical units called PADs ($56 \times 62\,\mathrm{cm}^2$) of 8 strips each. Hundred and thirty clusters are installed to form a carpet of about $5600\,\mathrm{m}^2$, with 93% of active area, surrounded by 23 additional clusters to reach a total detector area of $100 \times 110\,\mathrm{m}^2$. Details about the detector and RPC performances can be found in Aielli et al. (2006). The detector has two independent data acquisition systems, corresponding to the shower and the scaler operation modes. The shower mode requires at least 20 particles detected by the whole carpet within a time window of 420 ns; it reconstructs the shower front and the primary direction with an energy threshold of approximately 100GeV: further details on the experiment performances operating in shower mode can be found in Aielli et al. (2010) and refs.quoted therein. In scaler mode the total counts are measured every 0.5 s: for each cluster the signals coming from its 120 PADs are added up and put in coincidence in a narrow time interval (150 ns), giving the counting rates of 1, 2, 3 and 4 PADs, read by four independent scaler channels. These counting rates are referred in the following as C1, C2, C3, and C4, respectively, and their corresponding average rates are $\approx 40 \cdot 10^3\,\mathrm{s}^{-1}$, $\approx 2 \cdot 10^3\,\mathrm{s}^{-1}$, $\approx 300\,\mathrm{s}^{-1}$ and $\approx 120\,\mathrm{s}^{-1}$. The scaler mode technique does not provide information about the energy and arrival direction of primary particles; nevertheless it allows the detection of transient emissions with an energy threshold of ≈ 1 GeV, provided that the secondary particles generated by the primaries give a statistically significant excess of events.

As described in Aielli et al. (2008) the cluster counting rates, in absence of physical signals, follow a Poissonian distribution for time intervals shorter than about 15 min, while for longer periods they are influenced by meteorological effects, mainly pressure and temperature variations. In particular variations in the atmospheric pressure are known to affect the secondary particle flux: an increase (decrease) of

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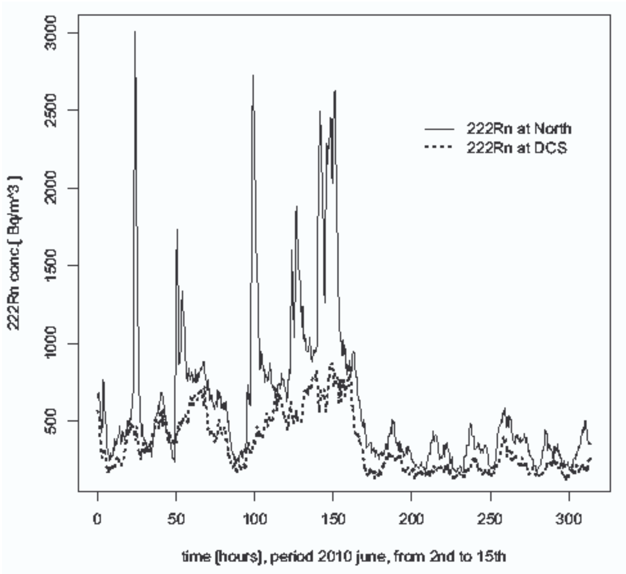

Fig. 1. ^{222}Rn concentration (Bq/m^3) for 13 days (time in hours on the X axis) between the 2nd and the 15th of June. Solid and dashed lines are referred to measurements at the north side and at the center of the carpet (DCS site), respectively.

the ground level atmospheric pressure results in a reduction (enhancement) of the background rate, because of the larger (smaller) absorption of the electromagnetic component. By monitoring the pressure at the detector position it is possible to correct the data for this effect. Moreover, the experimental hall temperature modifies the detector performances, changing the gas density inside the RPCs and the bakelite electrodes resistivity (Aielli et al., 2009). The cosmic ray background variations due to these parameters are not negligible and they must be taken into account when analyzing signals lasting more then about 15 min.

In Aielli et al. (2008) the linear regression coefficients for the C2, C3 and C4 rates vs. the atmospheric pressure were reported with values around $\mu = 0.9-1.2\%$/mbar while it was stressed that C1 showed much different values ($\mu = 0.3-0.5\%$/mbar) with consistent changes for different time periods or different carpet regions. Moreover, a simulation obtained folding the effective areas with the primary spectrum reproduces well the higher multiplicity rates but gives a rate value for the “single channel” counts C1 which is nearly half the measured one. In Cattaneo et al. (2009) we showed that part of the C1 counts could be ascribed to the local radioactivity background, in particular to radionuclide’s (^{238}U,^{232}Th and ^{40}K) present in the Yangbajing soil. On the other hand, the C1 contributions we took into account in Cattaneo et al. (2009) (due to radionuclides in the soil) are supposed to be nearly constant in time, while the Radon gas escaping the soil and entering the experimental hall varies its concentration depending on geological, meteorological and hall ventilation conditions, in a way which could easily hinder the study of the C1 dependence on the atmospheric pressure or other physical parameters.

We now claim that C1 counts are influenced by the Radon (^{222}Rn) gas concentration in the air of the experimental hall, by means of the γs emitted by its daughters, at a level of about 1% every 500 Bq/m^3.

2 Measurements on site

The Radon concentration at the Argo site is continuously monitored both at the north side and at the center (DCS site) of the carpet using two lucas cells calibrated for measurements at 4300 m a.s.l (with an average pressure of 550 – 600 mbar). In Fig. 1 Rn concentration (Bq/m^3) behavior over a short time period at the two different sites is shown. The noble gas ^{222}Rn is extremely volatile and, given the surprisingly high concentration at the north side of the experimental hall, it appears that Radon enters mainly from that side and diffuses within the hall, where is partly removed by ventilation (Bolognino et al., 2010; NCRP, 1989). We stress that the Rn measured at the carpet center can be better taken as the average radon concentration over the Argo carpet for time periods of hours (the time we need to correlate Rn with its daughters concentration); on the contrary the north-side concentration varies much more abruptly, depending on the hall ventilation and on the local meteorological conditions. We performed an accurate measurements campaign on the Argo site to study the radioactivity level variations and its effects on C1. The ambient equivalent dose ($H^*(10)$) has been measured in different conditions and places with a AT1123A plastic scintillator (photon energy range: 60 keV – 10 MeV). We observed that, although the $H^*(10)$ is quite homogeneous over different carpet regions, it’s higher on the north side for about 10% respect to the other regions. The effect is confirmed comparing the C1 rates of clusters taken in different positions along the direction North-South and it can be explained with the hypothesis either that 222Rn enters the experimental hall from some wide concrete floor cracks located on the north side either thinking of a not homogeneous radioactivity distribution in the underground itself. Moreover, the presence of ^{238}U,^{232}Th families and ^{40}K in the Yangbajing soil has been confirmed looking at the γ-ray spectra of a Na(I) scintillator (chosen because of his best handling ability). The time-averaged Rn spatial distribution over the Argo carpet has also been studied with CR-39 passive detector allowing to further confirm the presence of ^{222}Rn inside the hall and its distribution with, in the average, higher concentrations on the north side respect to the carpet center. In this paper we are mainly interested in evaluating how ^{222}Rn variation contributes to ≥ 1 Argo counting: the job will be performed with two Rn monitors located inside the experimental hall.

Table 1. γ-emitters belonging to the ^{222}Rn decay chain: γ energies and half-life.

Rn daughter	$T_{1/2}$	Energy (keV)
^{214}Bi	19,9 min	609
		1120
		1238
		1764
^{214}Pb	26,8 min	83
		242
		295
		352
^{212}Pb	19,9 min	83
		239
		301

3 Simulation

The simulation, performed with the Fluka code (Fasso et al., 2005; Battistoni et al., 2007), takes into account the γ emissions from ^{222}Rn daughters listed in Table 1. The experimental efficiency has been simulated assuming that a hit is given by any particle entering the chamber volume with an energy greater than the ionization energy of the Argon gas (main component of our RPC gas mixture): this efficiency has been checked with the experimental one measured in Angelone et al. (1995); Altieri et al. (2001) with radioactive sources at the energies of 1.2 MeV (^{60}Co) and 0.6 MeV (^{137}Cs). The counting rates C1 were simulated for different ^{222}Rn concentrations in air, taking into account that Rn reach the secular equilibrium with its daughters within few hours (has it's shown by $T_{1/2}$ in Table 1). It is known that while ^{222}Rn is a gas homogeneously distributed in the air, its γ-emitters daughters (whose concentration is the only one relevant for our apparatus) may deposit onto surfaces. The simulation results in Table 2 show both the contribution to C1 from the Rn daughters distributed in the air over a cluster and from the ones deposited on it (assuming a homogeneous distribution within a layer of 3 mm, where the geometrical acceptance is approximately 2π) for different values of the equilibrium factor f (i.e. of the percentage of Rn daughters still floating in the air). From Table 2 one could see that the expected contribution to the single counts rate C1 due to ^{222}Rn (more precisely to γ emitters Rn daughters) concentration in the air of the experimental hall is about $1.-1.7\,\mathrm{countings}\cdot\mathrm{s}^{-1}$ per Bq/m^3 of ^{222}Rn concentration in air with an error mainly due to the assumptions taken in the analysis: assuming secular equilibrium between Rn and its daughters, neglecting concentration variations during the time needed to reach the equilibrium and using the value in Table 2 for the equilibrium factor. We stress that our simulation neglects that while the equilibrium is reached (in a few hours) the Rn daughters may be removed from the hall by ventilation and that the Radon concentration itself varies: this will hinder, in our analysis, a clear correlation between the Rn concentration and C1 with a time lag correspondent to the time needed to reach the secular equilibrium.

Table 2. Single counting rates C1 for different ^{222}Rn concentrations (Bq/m^3) and different equilibrium factor values (see text).

^{222}Rn (Bq/m^3)	500	500	500	1000	3000
equilib. factor f	1	0.5	0.7	0.7	0.7
C1 (s^{-1}) air	500	250	350	700	2100
C1 (s^{-1}) deposited	0	628	377	754	2261
C1 (s^{-1}) total	500	878	727	1454	4361

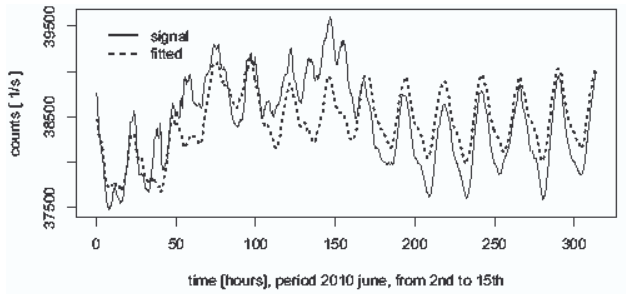

Fig. 2. From 2 June to 15 June single counts C1 (solid line) and $C1_{\mathrm{fitted}} = (a - bP + cT)$ (dashed line) for cluster 104. The difference between the two plots represents the term $C1_{\mathrm{res}}$.

4 Data analysis

To pick out a correlation between Argo single counting rates and Radon concentration we have at first to remove their stronger dependency (see Aielli et al., 2008) on the atmospheric pressure and on the local temperature. We wrote C1 as the sum of the result of its linear fit on temperature T (in degrees) and pressure P (mbar) and a residual term ($C1_{\mathrm{res}}$) whose variations are no more correlated with P and T:

$$C1 = a - bP(\mathrm{mbar}) + cT(^{\circ}\mathrm{C}) + C1_{\mathrm{res}} \quad (1)$$

where a,b and c are fit parameters. We checked that the correlation factors between $C1_{\mathrm{res}}$ and P or T for different clusters vary within ± 0.3, meaning that the fit on C1 removed the dependence on pressure and temperature and the $C1_{\mathrm{res}}$ fluctuations must be due to some other physical phenomena (be that cosmic rays intensity or ^{222}Rn concentration variations). The fit result, for one of the carpet cluster and for a time period ranging from the 2nd to the 15th of June, is shown in Fig. 2: some important discrepancies, in particular in a large time region around hour 300, between fitted and measured data can be seen. We stress that that's the time region where in Fig. 1 we see a maximum in the Rn concentration. To emphasize the difference between fitted and experimental data

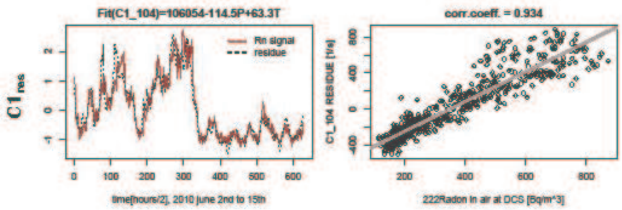

Fig. 3. On the left side normalized $C1_{res}$ variations (see text) and normalized Rn concentration variations are reported, as a function of time. On the right side $C1_{res}$ vs. Rn concentration is shown.

we referred to the normalized variations of $C1_{res}$ ($C1^{scal}$), i.e. to the difference between $C1_{res}$ and its average, normalized to the standard deviation σ_{C1} over the time period in examination:

$$C1^{\mathrm{scal}} = \left(C1_{\mathrm{res}} - \left(\sum_{i=1}^{N} C1_{\mathrm{res}}/N \right) \right) / \sigma_{C1} \tag{2}$$

In Fig. 3, for the same cluster and period, the normalized variations of $C1_{res}$ and the Rn concentration at carpet center are shown: the big difference around hour 300 in Fig. 2 could be explained by the raise of Rn concentration. Moreover, the correlation factor corresponding to Fig. 3 is 0.94 and the linear regression coefficient for the straight line fit in the figure is $1.3 \cdot 10^{-3}$, of the same order of magnitude as the one expected from the simulation. We stress that the same procedure, applied to different clusters, gave slightly different results: the worst correlation factor between $C1_{res}$ and Rn concentration at carpet center (0.7) has been found for a cluster belonging to the northern region of the carpet; however the correlation didn't improve using the north-side Rn measurements, probably because of the Rn and Rn daughters variations effects mentioned above.

5 Conclusions

Local radioactivity in air influences Argo single counting rates modulations at the level of about $0.5 - 1.7 \cdot 10^3\ \mathrm{s}^{-1}$ per $\mathrm{Bq/m^3}$ of ^{222}Rn concentration because of the γ emitted by Rn daughters, as expected by simulation and in addition at the important contribution, but constant in time (i.e. not responsible for time variability of C1), due to all radioactive nuclei present in the YangbaJing ground and discussed in Cattaneo et al. (2009). Some discrepancies between cluster responses are consistent with the strong variability, either in time and space, of the Radon and its daughters concentrations in air. To verify our conclusions we applied the same analysis between the C2 counting rates (where we don't expect any contribution from local radioactivity, due to the time coincidence requirement for the ≥ 2 multiplicity) and Rn concentration and we checked that no correlation was shown (correlation factor values for different clusters and time periods stay between ± 2). ^{222}Rn concentration is now being continuously measured at two different locations of the experimental hall, in order to be able to correct our counts for the Rn counts, sensibly improving Argo sensitivity at its lowest energy threshold.

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