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On the altitude dependence of γ-rays spectra in the Earth's atmosphere

S. Cecchini[a,b,c], T. Chiarusi[d], A. Pagliarin[a] and G. Giovannini[a]

a. Dip. Fisica dell'Universita di Bologna, I-40127 Bologna, Italy
b. INFN, Sez. di Bologna, I-40127 Bologna, Italy
c. INAF/IASF Sez. di Bologna, I-40129 Bologna, Italy
d. Dip. Fisica "La Sapienza", I-00185 Roma, Italy
Presenter: S. Cecchini (cecchini@bo.infn.it), ita-cecchini-S-abs3-sh35-poster

A comparison is made between the measurements of the gamma ray spectra in the range 3-15 MeV at different atmospherics depths (from sea level to 8 km a.s.l.) and Monte Carlo simulations of atmospheric cascades. The agreement between data and simulations is good and allow to estimate the attenuation length of the gamma ray component in the atmosphere and its spectral shape.

1. Introduction

Primary cosmic rays in their interactions with atmospheric nuclei produce large families of secondary charged particles and gamma rays. The flux of these latter is expected to vary in space and time as a result of the geomagnetic cut-off rigidity and solar modulation of the galactic cosmic radiation. Moreover gamma ray intensity and energy spectra change with the atmospheric depth as a consequence of their production, absorption and diffusion by electromagnetic and neutron-induced processes. Thus the study of the altitude dependence of the gamma energy spectra can give useful information on the secondary energy balance and the relative role of the two processes. Further information are contained on the characteristic gamma lines emitted by nuclear de-excitation of ^{14}N and ^{16}O nuclei after scattering or capture of neutrons produced in nuclear collisions and in the electron-positron annihilation line [1]. Observations of the atmospheric gamma ray spectra in the energy range up to approximately 10 MeV have beed carried out with scintillation telescopes during balloon flights [2] [3] at one rigidity and solar activity level. More recently satellite observations have studied the latitude and time variation of the albedo gamma radiation during a solar cycle in the energy range 0.3-8.5 MeV [4].

Here we present preliminary results on a comparison of the gamma rays spectra between 3 and 15 MeV measured at different depths (from ground level to 350 gcm^{-2}) [5] [6] with MonteCarlo simulations. Previous comparisons between observations in the same energy on board a balloon and theoretical computations [3],[7],[8],[9] were made in [2].

2. The measurements

Since 1995 we have started a world-wide survey in order to study in a systematic way, the time and spatial variations of the Environmental Radiation (low energy gamma rays with E$>$ 50 keV from secondary cosmic rays and from products of natural and/or artificial radioactivity sources) [10]. During our measurement campaigns we used 3 different types of detector, all based on a NaI(Tl) cylindrical monocrystal (10 cm $\times$ 20cm$\oslash$). The first type has been already described in [11]. The detector identified as type 2 was described in [5] and type 3 in [6]. The summary of our campaigns (site, altitude, geographic position, vertical cut-off rigidity, time period and detector type) is presented in Table 1.

Table 1. Parameters of the observation sites

Site	m a.s.l.	Lat.N	Long.E	P_c [GV]	Year	Detct. type
Indian Ocean	0	6.4	59.3	16.6	1995-97	1
Ny Alesund	0	78.9	11.9	<0.2	1999-02	1
Bologna	45	44.5	11.4	6.2	1995-97	1
LNGS	1000	42.5	13.9	6.3	1996	1
EASTOP Lab.	2050	42.5	13.9	6.3	1996	1
Mt. Cimone Obs.	2160	44.2	10.7	6.2	2002	1
Lab. Piramide	5050	28	86.5	14.4	1997	2
Aircraft	>7000	58	80	1.7-2.4	1999	3

3. The Monte Carlo simulations

For the comparison the COSMOS shower simulation code [12] was used. This is a omni-purpose code for the generation and propagation of cosmic rays through the atmosphere in a wide energy range. Various codes developed for accelerator experiments are included. The package provides automatic geomagnetic field computations and rigidity cut-off tables for a given location. Observation levels, from sea levels up to the top of the atmosphere, can be selected. It has been extensively used for neutrino flux simulations [13].

This kind of code appears very suitable for computing the expected spectra for the different sites and for different periods of the solar cycle at which our observations were made (see Table 1). We run the code with a generator in accordance with the primary cosmic ray composition resulting from the fit in [14]. The atmosphere model adopted was the one by M. Shibata given in [15]. The number of particles used in the simulation for each depth was 10^5.

4. Results and conclusions

The results of the simulations for all the sites of Table 1 are shown in Fig. 1. It is possible to see that for ground observations there is a strong dependence on the solar activity level and vertical cut-off rigidity. These spectra also present fluctuations which are consequence of the small number of particles injected into the code. We are now processing more particles in order to reach a high statistic for a better definition of the spectra at depths $>$ 400 gcm^{-2}.

The comparison between our data and the results of the Monte Carlo simulations are shown in Figure 2. All our measurements have been corrected for the pressure effect with the coefficient given in [5], [6], [11]. An efficiency of 52% of our detector was assumed. The spectral shape that fits the data follow the form $A/(1+E_\gamma)^{-\beta}$ with β= 1.2. The spectra exhibit almost the same shape at all different depths indicating the equilibrium nature of dawnward γ rays with the attenuation length λ = 180 g/cm^2. The only spectrum that seems to deviate from this behaviour is the one of the 550 gcm^{-2} depth. These results confirm the conclusions already reached in [6].

These are preliminary results. In order improve the quality of the comparison we are now running more Monte Carlo simulations to increase the statistics, including detector response simulations for the different types. We intend also to study by this way the formation of atmospheric gamma lines.

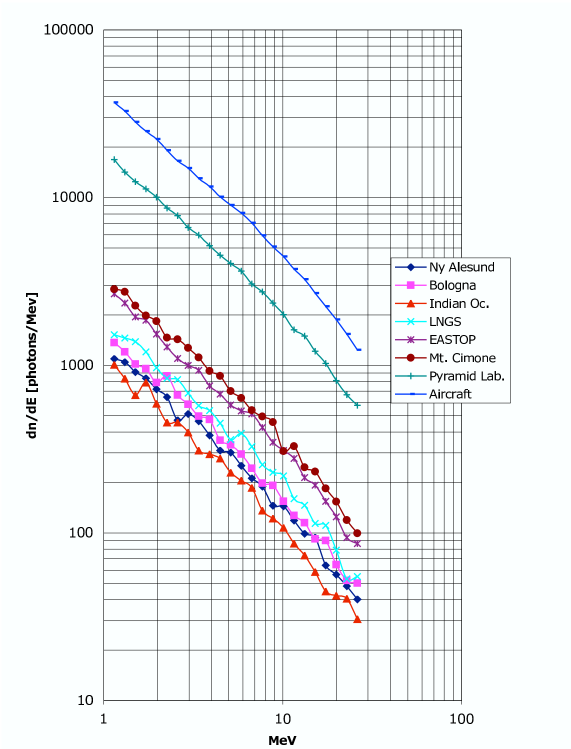

Figure 1. Photon differential spectra from Monte Carlo simulations for the different sites and times corresponding to our measurements.

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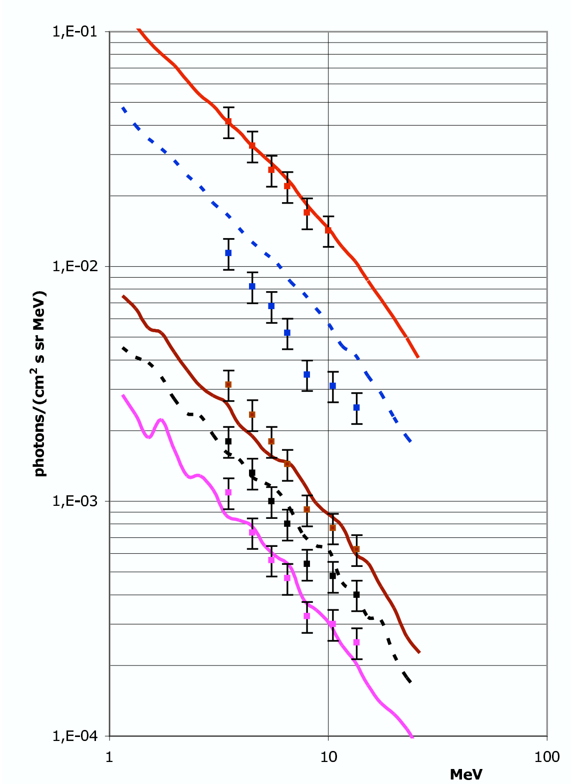

Figure 2. Comparison between measured differential spectra (from top to bottom: aircraft, Piramide Lab., EASTOP site, LNGS and Indian Ocean) and Monte Carlo simulations.

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