29th International Cosmic Ray Conference Pune (2005) **8**, 9-12

Status of the GAMMA experiment

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The ground-based GAMMA experiment (Mt. Aragats, Armenia) is designed to study Extensive Air Showers (EAS) at 700 g/cm^2 of atmospheric depth in the primary energy range 10^2 - 10^5 TeV. The present status of the GAMMA facility consisting of an enlarged surface EAS array (108 scintillation detectors) and underground muon carpet (150 m^2 detectors) is described. The response of the detectors and the EAS parameter reconstruction method are presented with their respective accuracies.

1. Introduction

The cosmic-ray energy region 10^{14} – 10^{17} eV continues to be very interesting because of many unsolved problems connected with energy spectrum of the primary particles, their mass composition, the origin of cosmic rays etc. In the energy range above 10^{14} eV direct measurements are very limited and the data lack statistical accuracy because of steeply decreasing flux and the limited detector area and exposure time. From this point of view ground–based experiments have evident advantages. On the other hand there are essential imperfections also for ground-based experiments. The main ones are necessity to build very large installations covering an area with tens of thousands sq. meters and the intrinsic fluctuations of EAS particle distributions which increase with atmospheric depth. This is why experiments on the mountain levels should be very useful for a solution of the cosmic–ray problems in "knee" region of the all-particle energy spectrum and above.

2. Construction and evaluation of the GAMMA facility

The basic concept of the GAMMA experiment is to study both electromagnetic and high-energy muon components of EAS to estimate the energy and the nature of the primary cosmic-rays. At the same time one of the main topics of the GAMMA experiment is investigation of very-high energy primary gamma-rays. Construction of the GAMMA installation was begun in the middle of the 1980s on Mt. Aragats in Armenia (3200 m a.s.l., 700 g cm^{-2} of the atmospheric depth) in the frame of the project ANI [1] under the direction of E.Mamidjanian (Yerevan Physics Institute) and S.Nikolsky (Moscow P.N.Lebedev Institute). In Figure1 a diagrammatic layout of the GAMMA facility is presented. The first launching of the GAMMA was at the end of the 1980s and consisted of only 9 surface stations – 27 plastic scintillation detectors (each of 1 m^2), and 75 similar detectors in the underground tunnel. Since then, the GAMMA installation underwent many structural changes. At the end of 1990s the GAMMA surface array was enlarged up to 75 scintillation detectors placed at 25 stations (with 3 detectors in each station) and arranged on concentric circles at 17.5, 28, 50 and 70 meters from the array center [2]. Each of the 25 stations was equipped with a timing channel to determine EAS zenith and azimuth angle coordinates. The number of muon detectors was also increased up to 150. 60 of them were placed in the underground Hall with muon energy threshold 5 GeV and 90 were arranged in the tunnel with a muon energy threshold 2.5 GeV. The GAMMA array with this configuration was operating in 1998-2002. During this time the EAS characteristics at shower size $N_e = 10^5$-10^7 were investigated [2]. On the basis of 1998-2002 data set and using the event-by-event α-parametric method, suggested in [3] and developed for GAMMA in [4], the all-particle energy spectrum was obtained [5,6]. In 2002, 60 muon detectors were removed from the Tunnel to the Hall to increase the effective area of the muon detectors with 5 GeV energy threshold up to 120 m^2, which noticeably decreased dispersion of the muon number estimation at $N_e = 10^5 - 10^7$ [6]. During the summer-autumn season of 2004 the GAMMA facility was again modernized. The present disposition of the surface and muon detectors are shown in Figure 1. 24 additional scintillation detectors were mounted in 8 stations placed at 100 meters from the array center. Each of these stations is also equipped with a timing channel. This modernization will give us two essential advantages:

1. increasing of radius of the high energy shower selection up to 70-80 meters;
2. increasing of the maximal distance between timing channels from 140 m to 200 m and, as a consequence, improving the shower angular characteristic determination.

The configuration of the muon detectors was also changed. Now all 150 muon detectors are concentrated in the underground Hall with the same energy threshold, 5 GeV.

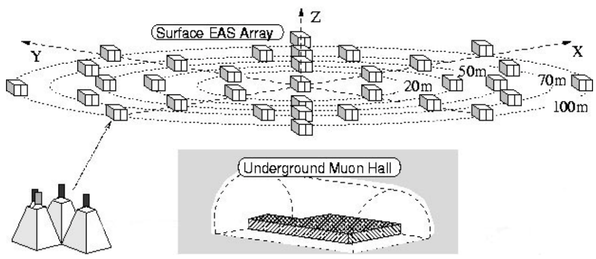

Figure 1. Diagrammatic layout of the GAMMA facility

3. Reconstruction of EAS parameters

In the period 2002-2004 ~$2x10^6$ EAS with $N_e > 10^5$ were detected with the GAMMA array. For analysis the showers at $\theta < 30^0$ and EAS core location within R < 25 m from the center of the GAMMA array were selected. The main experimental results obtained during this period are described in [7] and presented at this conference in comparison with the corresponding MC-simulated data in the framework of the SIBYLL [8] and QGSJET [9] interaction models. All results are derived taking into account the detector response, reconstruction uncertainties of EAS parameters and fluctuation of EAS development. EAS angular coordinates θ and φ (where θ and φ – zenith and azimuth angles, correspondingly) are estimated on the basis of the measured shower front arrival times by 25 fast-timing surface detectors, applying a maximum likelihood method and flat-front approach [10,11]. Corresponding uncertainties are tested by consistency in experimental data and are equal to: $\sigma(\theta) \simeq 1.5^0$ and $\sin\theta\cdot\sigma(\varphi) \simeq 1.5^0$. The reconstruction of the EAS size (N_{ch}), shower age (s) and core coordinates (x_0, y_0) are performed based on the NKG approximation of measured charged particle densities ($\{n_i\}$, i = 1,…,m) using χ^2 minimization to estimate x_0, y_0 and a maximum likelihood method to estimate N_{ch} taking into account the measurement errors. The logarithmic transformation $L(n_i) = \ln n_i - (1/m)\sum \ln n_i$ at $n_i \neq 0$ allows to obtain the analytical solution for the EAS age parameter (s) with χ^2 minimization [11,12]. Unbiased (< 5%) estimations of shower parameters N_e, s, x_0,y_0 are obtained at $N_e > 5x10^5$, 0.3 < s < 1.6 and distances of shower core from the center of the EAS array R < 25 m. Corresponding accuracies were derived from MC-simulations by CORSIKA(EGS) [13] and are equal to: $\Delta N_e/N_e \simeq 0.1$, $\Delta s \simeq 0.05$, $\Delta x, \Delta y \simeq 0.5 \div 1$ m. The reconstruction of the total number of EAS muons (N_μ) by the detected muon densities ($\{n_{\mu,j}\}$, $j = 1,\ldots,150$) from the underground muon Hall detectors are carried out restricting the distance to $R_\mu < 50$ m from the shower core (so-called "truncated" EAS muon size [14]) and the Greisen approximation of the muon lateral distribution function. The truncated muon size $N_\mu(R<50\text{m})$ is estimated at shower core coordinates in the underground muon Hall known from EAS surface array. Unbiased estimations for muon size are obtained at $N_\mu > 10^3$ using a maximum likelihood method and assuming the Poisson fluctuations of detected muon numbers. The reconstruction accuracies of the truncated muon size are equal to $\Delta N_\mu/N_\mu \simeq 0.2 \div 0.35$ at $N_\mu \simeq 10^5 \div 10^3$ respectively [7].

4. Measurement errors and density spectra

The close disposition of k = 1,2,3 scintillators in each (i-th) surface station allows to auto-calibrate the measurement error by detected EAS data. The measured and simulated particle density divergences $(n_k - \rho)/\rho$ versus average value $(1/3)\ \Sigma n_k$ at $R_i > 10$ m distances from shower core are shown in Figure 2 (circle symbols, left panel). The obtained dependences are completely determined by Poisson fluctuations and measurement errors. The agreement of the measured and simulated dependences allowed for extraction the real measurement errors of the GAMMA detectors. In Figure 2 the corresponding results are shown (square symbols, left panel). The background single particle spectra (in the units of ADC code) detected by GAMMA surface scintillators for 78 sec operation time are shown in Figure 2 (dotted lines, right panel). The symbols and solid lines in Figure 2 display the corresponding expected spectra obtained by MC-simulation taking into account the measurement errors (symbols) and without errors (line) respectively. The minimal primary energy in simulation of the background particle spectra was confined to the 7.6 GV primary particle's geomagnetic rigidity. Primary energy spectra were taken from approximations of the balloon and satellite data [15].

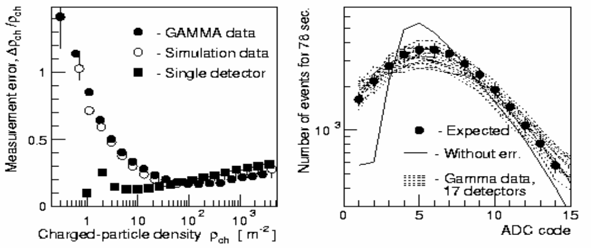

Figure 2. Left panel: Particle density divergences (circle symbols) and measurement errors of single detector (square symbols) versus charged-particle density. Right panel: Background single particle spectra (dotted lines). The symbols (solid line) are the expected spectra taking into account (without) measurement errors.

The detected and expected particle density spectra of surface (left panel) and underground (right panel) scintillation detectors are shown in Figure 3 (a, b). It can be seen a good agreement of the expected and observed data for surface detectors (EAS charge particles, N_{ch}) in the full measurement range (about four orders of magnitude). However, the agreement of the detected muon density spectra with expected ones is attained only at $N_{ch}<10^7$. The observed discrepancies at $N_{ch}>10^7$ are unaccounted for at present and demand subsequent investigations.

Recent results obtained with the GAMMA facility are presented at this conference. In [16] the energy spectra and mass composition of the primary cosmic rays are derived in the 10^3-10^5 TeV energy range. In [17] the all-particle energy spectra obtained by a parametric event-by-event method of determination of the primary energy on the basis of experimental N_{ch}, N_μ (E_μ>5GeV), age (s) and θ EAS parameters are presented. The study of diffuse flux of very-high energy primary gamma-rays as well as search for PeV gamma-ray sources are also topics of the GAMMA experiment. Preliminary results of a search for enhancement of the cosmic ray flux in particular arrival directions, and discussion of the consequences for claimed local astrophysical sources were presented in [18]. Examination of the prospects for gamma-ray astronomy in the PeV energy domain using the GAMMA array is presented in [19]. The gamma-ray fluxes, which could be expected from the sources of Galactic cosmic rays, based on extrapolation of recent observations in the TeV energy domain, are also discussed.

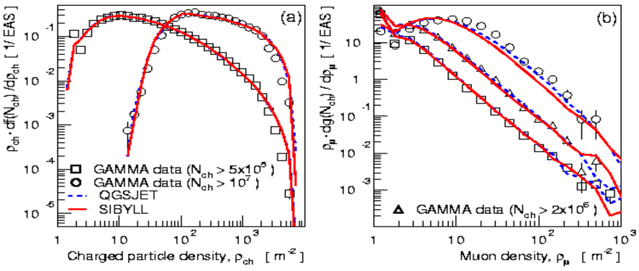

Figure 3. Detected (symbols) and expected (lines) particle density spectra of surface scintillators (a) and underground muon scintillators (b).

4. Acknowlegments

The GAMMA experiment has been partly supported by the research grant No1465 of the Armenian government, NFSAT grant AS084-02/CRDF 12036, CRDF grant AR-P2-2580-YE-04 and by the “Hayastan” All-Armenian Fund and the CNRS in France.

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