Recent upgrade and current status of the GAMMA facility at Mt. Aragats

R. MARTIROSOV[1], H. BABAYAN[2], Y. GALLANT[4], A. GARYAKA[1], A. ERLYKIN[3], L. JONES[5], J. KEMPA[6], N. NIKOLSKAYA[3], B. PATTISON[7], J. PROCUREUR[8], CH. SPIERING[9], S. TER-ANTONYAN[10], H. VARDANYAN[1]

[1] *Alikhanyan National Laboratory, Yerevan, Armenia*
[2] *State Engineering University of Armenia, Yerevan, Armenia*
[3] *P.N.Lebedev Physical Institute of the RAS, Moscow, Russia*
[4] *LUPM, Université Montpellier II, CNRS/IN2P3, Montpellier, France*
[5] *Department of Physics, University of Michigan, USA*
[6] *Warsaw University of Technology, Branch in Plock, Poland*
[7] *CERN, Geneva, Switzerland*
[8] *Centre d'Etudes Nucléaires de Bordeaux-Gradignan, Gradignan, France*
[9] *DESY, Germany*
[10] *Department of Physics, Southern University, Baton Rouge, USA*

lwjones@umich.edu

Abstract: In November 2011-March 2012 the GAMMA array has been upgraded with 60 additional scintillation counters in the underground muon detector. In this paper we describe how this modernization can improve selection of the muon-poor showers to study characteristics of the high-energy primary gamma rays.

Keywords: GAMMA experiment, recent upgrade, muon-poor shower selection, high energy gamma rays

1 Introduction

One of the tasks of the GAMMA experiment is study of the primary γ-rays, including the diffuse flux and a search for local sources (gamma-astronomy). The study of characteristics of the diffuse γ-ray flux at energies greater than $0.1 PeV$ is connected, practically without any alternative, with the registration and the selection of extensive air showers (EAS) with an abnormally small relative content of muons and hadrons. The separation between hadronic and γ-ray muon-poor showers is a main problem. Geometry of muon detector and selection criteria are most important for efficiency of separation. From this point of view total number of muon detectors for registration of the EAS muon component as well as its arrangement should play important role for selection of muon-poor EAS to study characteristics of EAS generated by primary γ-rays.

2 Recent upgrade and present status of the GAMMA facility

The GAMMA experiment was realized for the experimental study of the energy spectrum and mass composition of the primary cosmic radiation in the energy range of $0.1-100 PeV$, as well as to search for and study the very-high energy primary γ-rays. GAMMA array [1, 2] is located at the Mt. Aragats (3200m a.s.l.). At present, after several modifications, the GAMMA consists of surface and underground parts for registration of the EAS electromagnetic and muon components respectively.

The surface stations of the EAS array are arranged in seven concentric circles of radii $14, 20, 28, 34, 50, 70$ and $100m$ (Fig. 1), and each station contains three square plastic scintillation detectors with the following dimensions: $1.0 \times 1.0 \times 0.05m^3$. Each of the nine central stations contains an additional (4th) small scintillator with dimensions $0.3 \times 0.3 \times 0.05m^3$ for high particle density ($>> 10^2 particles/m^2$) measurements. A photomultiplier tube is positioned on top of the aluminum casing covering each scintillator. One of the three detectors of each station is examined by two photomultipliers, one of which is designed for fast-timing measurements. From 2003 to November 2011 one hundred and fifty underground muon detectors (muon carpet) were compactly arranged in the underground hall under $2.3 kg/cm^2$ of the concrete and rock (Fig. 2, open squares).

The scintillator dimensions, casings and photomultipliers are the same as in the EAS surface detectors. On the basis of the 2003-2010 data set the main EAS characteristics, energy spectrum and mass composition of the very-high energy primary cosmic rays, as well as the upper limit of γ-ray differential flux at an energy about 175 GeV were obtained [1, 2, 3].

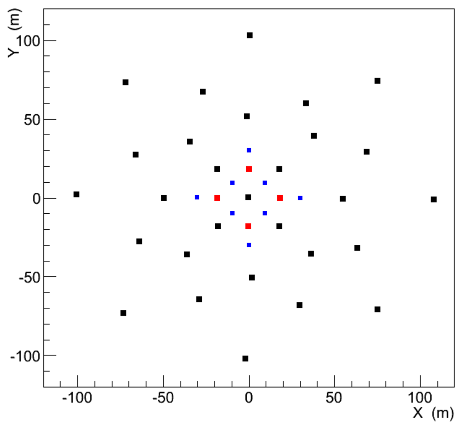

Fig. 1: Arrangement of the surface detector stations. Black and red squares 33 stations with 3 (or 4) of 1 m^2 scintillation detectors in each. Blue squares, 8 stations with 1 detector in each.

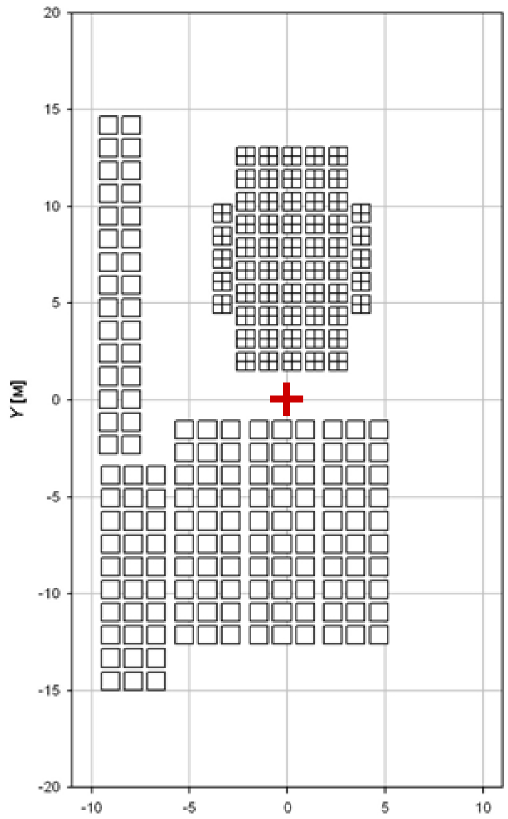

Fig. 2: Diagrammatical view of the underground muon carpet. Open squares – arrangement of 150 muon detectors before modernization. Crossed squares – 60 additional detectors. Central cross is the geometrical center of the GAMMA installation.

The recent upgrade of the GAMMA experiment with 60 additional detectors for the muon carpet was carried out in November 2011 - February 2012 (Fig. 2 crossed squares) [4]. The area of the new muon detectors are also (as are the older 150) one square meter.

We already published an all-sky upper limit on diffuse γ-ray emission [3], but more detailed investigations need to be performed. In our earlier study [3], events were selected based on the reconstructed shower core position (X,Y) at ground level $(Z = 0)$, with a selection radius, R, relative to the center of the installation (about which the surface detectors are symmetrically distributed). The events used in [3] were selected by the shower core position and zenith angle with the criteria: $R < 15m$ and $\theta < 30°$.

In order to improve the selection power for muon-poor showers, we studied more recently the detected muon content of showers as a function of their extrapolated shower core position (X_μ, Y_μ) at the level of the underground muon detector hall where $Z = -13.98m$. This approach has been discussed in [4].

In Fig. 3, 4 for comparison the 2D color map shows the average number of fired muon detectors as a function of reconstructed shower core coordinates in the (lower) muon detector plane for old (Fig. 3) and new (Fig. 4) muon detectors configuration. The shaded areas show the approximate locations of the muon detectors. The showers included were selected in charged particle size, with $10^5 < Ne < 4 \cdot 10^5$. It can be seen from Fig. 3, 4 that:

- After modernization the *geometry* (number) of fired muon detectors is now more symmetric about the geometrical center of the array (marked with the big cross);
- more importantly, the average number of fired muon detectors for showers near the center is significantly higher than before, reaching about 35 versus about 25 before.
- The average number is also significantly higher throughout the domain.

Fig. 5 displays the EAS muon density spectra measured by the underground single muon detector with different EAS size thresholds: $N_{ch} > 5 \cdot 10^5$, and $N_{ch} > 2 \cdot 10^6$. The showers

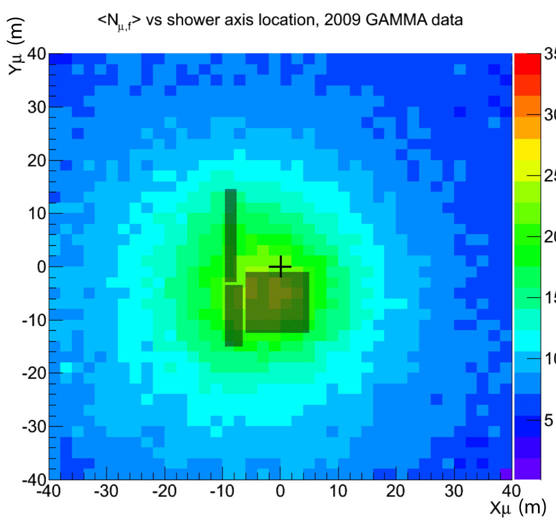

Fig. 3: Distribution of the average number of fired muon detectors $N_{\mu,f}$ as a function of the shower axis position (X_μ, Y_μ) in the muon detector plane (2009 GAMMA data).

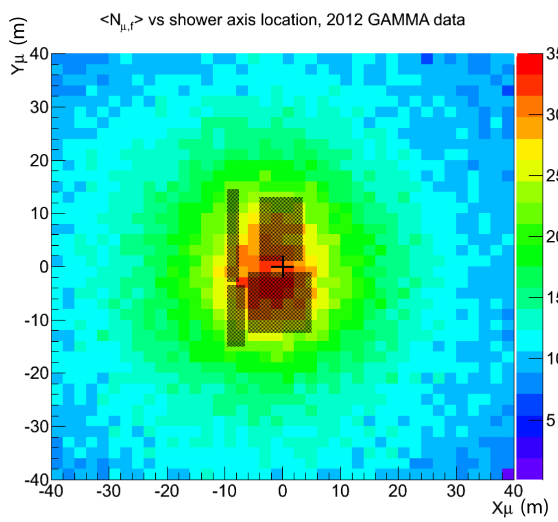

Fig. 4: Distribution of the average number of fired muon detectors $N_{\mu,f}$ as a function of the shower axis position (X_μ, Y_μ) in the muon detector plane (2012 GAMMA data).

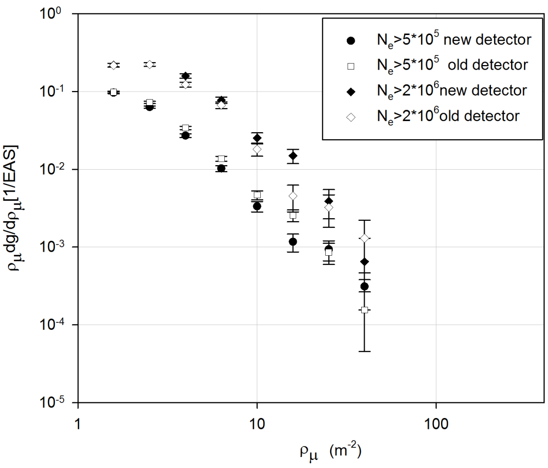

Fig. 5: Detected particle density spectra measured by the underground single muon detectors from old and new (additional) arrangements are presented. Experimental data of 2012-2013.

were selected with $\theta < 30^\circ$ and shower core location in the $R < 25m$ range from the center of the GAMMA facility. On the graph, the vertical scale is the number of events of a given muon density per square meter, versus the muon density. The results are from one old and one new detector, both chosen to be relatively close to the geometrical center of the GAMMA facility. It is seen that old and new detectors are practically identical for various ranges of N_{ch}.

Summarizing, the modernization of the underground muon carpet will certainly improve the separation between hadronic and muon-poor γ-ray showers, and increase the effective selection area where we can achieve a similar separation as before. It should also improve the muon size reconstruction for hadronic cosmic ray composition studies.

3 Acknowledgment

This work has been partly supported by the research grant no. 11-1c 345 from the Armenian Government, by the Moscow P.N. Lebedev Institute, DESY, the CNRS-SCS exchange grant no. 24947 and the "Hayastan" All-Armenian Fund.

References

[1] A.P. Garyaka, R.M. Martirosov, S.V. Ter-Antonyan et al., Astropart. Phys., 2007, vol. 28, p. 169.
[2] A.P. Garyaka, R.M. Martirosov, S.V. Ter-Antonyan et al., 2008, J.Phys.G: Nucl. Part. Phys., 35, 115201.
[3] R.M. Martirosov, S.V. Ter-Antonyan, A.D. Erlykin et al., 2009, Proc. of the 31st ICRC, Łódz (arXiv:0905.3593 [astroph]).
[4] R.M. Martirosov, H. Babayan, A.D. Erlykin et al., 2012, Proc. of the 17^{th} ISVHECRI, Berlin.