Worldwide network of particle detectors SEVAN; 10 years ofoperation

A.Chilingarian, T.Karapetyan

Abstract

1. Introduction

In 1957, in a display of unprecedented international cooperation, more than 66.000 scientists and engineers from 67 nations participated in the International Geophysical Year (IGY1957). Fifty years on, the International Heliophysical Year (IHY 2007) again drew scientists and engineers from around the globe in a coordinated observation campaign of the heliosphere and its effects on planet Earth. The United Nations Office for Outer Space Affairs, through the United Nations Basic Space Science Initiative (UNBSSI) assists scientists and engineers from all over the world in participating in the International Heliophysical Year (IHY). A most successful IHY 2007 program is to deploy arrays of small, inexpensive instruments around the world to provide global measurements of ionospheric and heliospheric phenomena. The small instrument program is a partnership between instrument providers, and instrument hosts in developing countries. The lead scientist will provides the instruments and help to install and run it; the host country place facilities, provides manpower for instrument maintenance and operation to obtain data with the instrument. The lead scientists institution develops joint databases, provides tools for user-friendly access to data from network, assists in staff training and paper writing to promote space science activities in developing countries.
“Space Environment Viewing and Analysis Network” (SEVAN, Chilingarian and Reymers, 2008, Chilingarian et al., 2009) aim to improve the fundamental research on particle acceleration in vicinity of sun and - space environment conditions. The new type of particle detectors simultaneously measure changing fluxes of most species of secondary cosmic rays, thus turning into a powerful integrated device for exploration of solar modulation effects. The SEVAN modules are operating at the Aragats Space Environmental Center in Armenia, in Croatia and Bulgaria, Slovakia and India, see Fig. 1.

The network of hybrid particle detectors, measuring neutral and charged fluxes provide the following advantages over existing detector networks measuring single species of secondary cosmic rays (Neutron Monitors and Muon detectors):

- Measure count rates of the 3 species of the Secondary cosmic rays (SCR): low energy electrons (below 30 MEV), neutral (gamma rays and neutrons and high-energy muons (above 150 MeV);
- Significantly enlarge statistical accuracy of measurements;
- Probe different populations of primary cosmic rays with rigidities from 7 GV up to 20 GV;
- Reconstruct SCR spectra and determine position of the spectral “knees”;
- Classify GLEs in “neutron” or “proton” initiated events;
- Estimate and analyze correlation matrices among different fluxes;

- Significantly enlarge the reliability of Space Weather alerts due to detection of 3 particle fluxes instead of only one in existing neutron monitor and muon telescope world-wide networks;
- Perform research on runaway electron acceleration during thunderstorms; research the enigma of lightning.

We present the results of SEVAN network operation devoted to 10-th anniversary of the IHY-2007.

Figure 1 SEVAN network; red – operating, blue – planned.

2. The basic module (unit) of the SEVAN network

Basic module of SEVAN network (see Figure 1) is assembled from standard slabs of $50x50x5cm^3$ plastic scintillators. Between two identical assemblies of $100 \times 100 \times 5$ cm^3 scintillators (four standard slabs) are located two $100 \times 100 \times 5$ cm^3 lead absorbers and thick $50 \times 50 \times 25$ cm^3 scintillator stack (5 standard slabs). A scintillator light capture cones and PMTs are located on the top, bottom and in the intermediate layers of the detector.

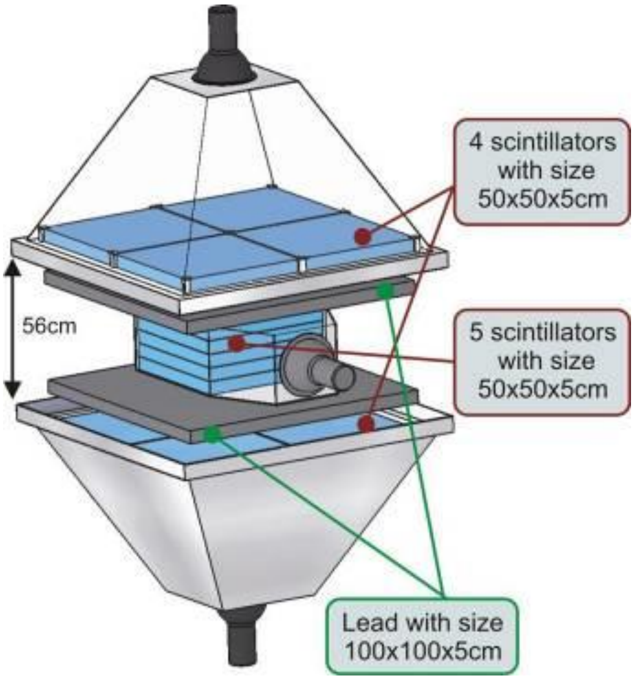

Figure 1 SEVAN detector measuring charged and neutral secondary cosmic rays

Incoming neutral particles undergo nuclear reactions in the thick 25cm plastic scintillator and produce protons and other charged particles. In the upper 5cm thick scintillator charged particles are registered very effectively; however, for the nuclear or photo- interactions of neutral particles there is not enough matter. When a neutral particle traverses the top thin (5cm) scintillator, usually no signal is produced. The absence of the signal in the upper scintillators, coinciding with the signal in the middle scintillator, points to neutral particle detection (gamma-quanta or neutron). The coincidence of signals from the top and bottom scintillators indicates the traversal of high energy muons Microcontroller-based Data Acquisition (DAQ) electronics provides registration and storage of all logical combinations of the detector signals for further off-line analysis and for on-line alerts issuing, thus, allowing to register 3 species of incident particles.

The Data Acquisition electronics (DAQ) allows the remote control of the PMT high voltage and of other important parameters of the detector.

3. The main research possibilities of the SEVAN module obtained by modeling the solar-terrestrial environment

The responses of all SEVAN detecting layers to the “background” Galactic cosmic rays are posted in the Figure 4.3 - Figure 4.5. We can see in the figures that different layers are sensitive to different particles. If upper layer is “selecting” mostly electrons and muons, the middle layer is more sensitive to the neutral fluxes and the lower layer to thee high-energy muons. Also from the figures is apparent that the best location of SEVAN detector is at high altitudes, although location at sea level also will give valuable information on neutral and charged fluxes. Lead absorbers are filtered low energy electrons and gammas. As we can see in the Figure 4.6 the lower layer is sensitive to the high-energy muon flux with “threshold” energy ~250 MeV.

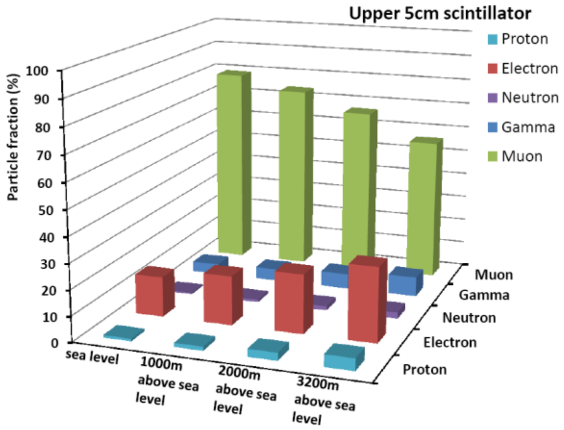

Figure Error! No text of specified style in document..**2:** Fraction of elementary particle detected by the upper layer of SEVAN detector.

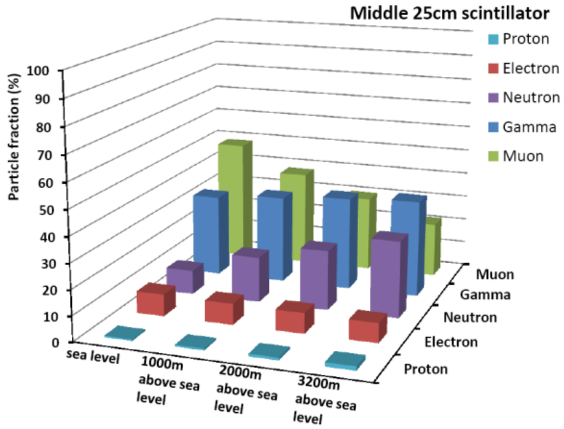

Figure Error! No text of specified style in document..**3:** Fraction of elementary particle detected by the middle layer of SEVAN detector.

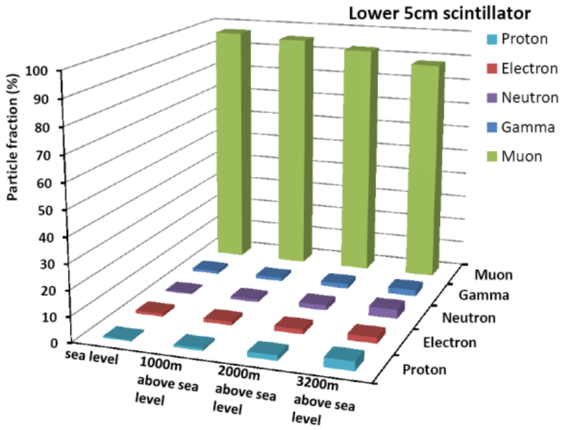

Figure Error! No text of specified style in document..**4:** Fraction of elementary particle detected by the lower layer of SEVAN detector.

As we will see in the next section the selective sensitivity of the layers of SEVAN detector allow us to probe different populations of the primary flux, thus giving information for the "reconstruction" of the primary energy spectra. Also this diversity gives possibility to distinguish very rare and very interesting events when flux of solar neutrons is enough intensive to generate additional counts in the surface particle detectors.

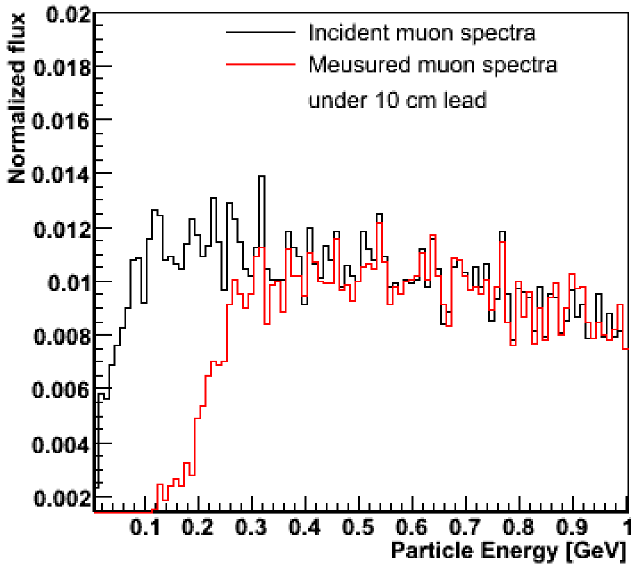

Figure Error! No text of specified style in document.**.5:** The energy spectra of muons registered in upper and bottom 5 cm thick scintillators.The energy threshold of upper scintillator is ~7 MeV, bottom – ~250 MeV.

1.1. Calculation of the response function of SEVAN particle detectors to Galactic and Solar Cosmic Rays (GCR and SCR).

The secondary fluxes measured by SEVAN detector are sensitive to different populations of the primary particles (mostly protons for energies up to 20 GeV of GCR and protons, neutrons and stripped nuclei of SCR) incident on the terrestrial atmosphere. Obviously, to each type of the detected particles corresponds rather broad energy distribution of the primary flux incident on the terrestrial atmosphere. Nonetheless, the modes (most probable energies) of these distributions are shifted from each other. In Table 4.3 we compare the energies of modes of distributions of “parent” protons initiated different elementary particles at various latitudes. We can see that secondary charged leptons are correspondent to the higher primary energies than secondary neutrons and protons.

Table Error! No text of specified style in document.**.1:** Modes of the GCR Energy spectra corresponding to the different types of secondary particles at 3200m above sea level.

Secondary particle type at 3200m	Mode of the GCR Energy spectrum (GeV)
Neutron	8.5
Proton	8.5
Gamma	10.5
Electron	11.5
Muon	12.5

In Figure 4.7 and Figure 4.8 we present the energy spectra of “parent” solar cosmic rays correspondent to power spectra index -4 and -5. Again we can see difference in the median energy of the spectra.

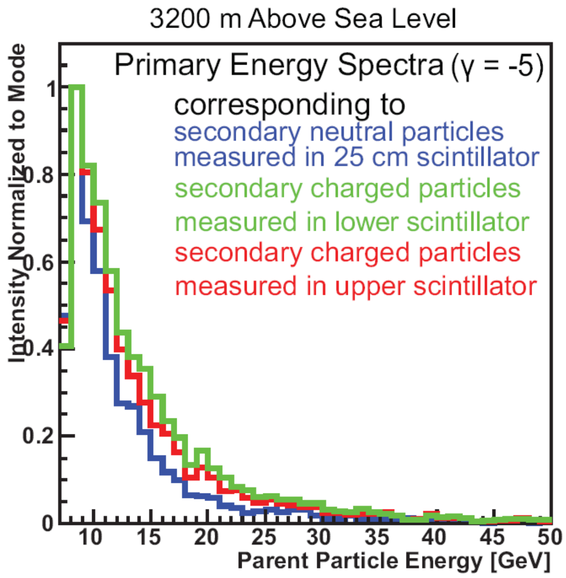

Figure Error! No text of specified style in document.**.6:** Primary "parent" SCR (power index equals to -5) protons spectra initiated counts in different layers of the SEVAN detector.

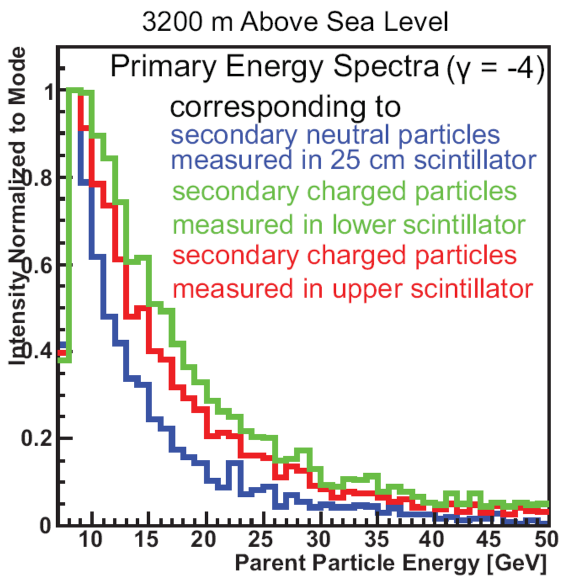

Figure Error! No text of specified style in document.**.7:** Primary "parent" SCR (power index equals to -4) protons spectra initiated counts in different layers of the SEVAN detector.

In Table 4.4 we demonstrate how the layers of the SEVAN detector "select" different energetic populations of the primaries. The difference of 8.5 and 14.5 GeV of the mode of the "parent" energy distribution is huge if we remember that cosmic ray spectra follow the power law with index of ~-2.7.

Measuring simultaneously 3 different species of secondary particles will open additional possibility to reconstruct the energy spectra of the primary flux, distinguish the GLEs initiated by primary protons and neutrons.

Table Error! No text of specified style in document..**2:** Modes of the GCR Energy spectra corresponding to the different species of secondary particles registered by SEVAN detector at 3200m above sea level.

Layers of detector at 3200m	Mode of the parent "GCR" Energy spectrum [GeV]
Upper Layer	11.5
Middle 25cm layer	8.5
Down Layer	14.5

The energy spectra index of the GCR at highest energies is a very good indicator of upcoming abundant SCR protons and ions with energies 50 - 100 MeV, extremely dangerous for the astronauts and high over-polar flights, as well as for satellite electronics.

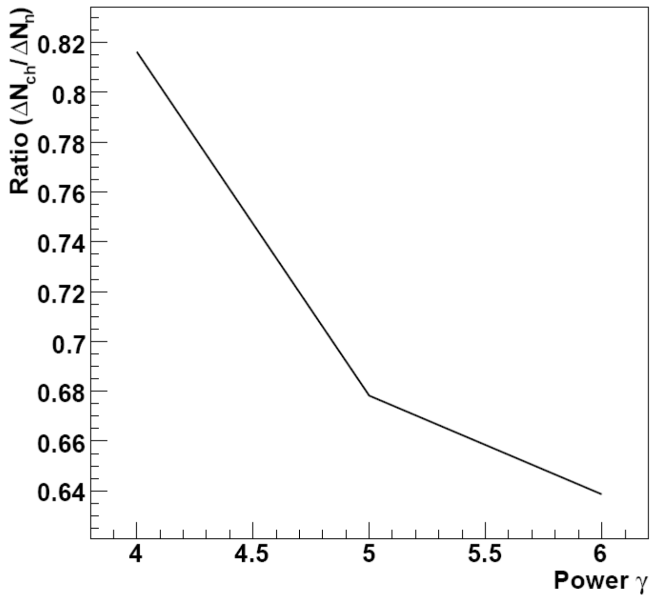

Figure Error! No text of specified style in document..**8:** The ratio of the enhancements of the flux of neutrons and low energy charged particles dependent on the power index of SCR.

Therefore it is very important to estimate the index of power law. Estimation of the energy spectra index using data from NM located at same latitude, but different altitudes was suggested by (Lockwood, 2002). Recently, same methodology was used for the determinations of the radiation dozes received on-board of airplanes during solar particle events (Lantos, 2005) and for estimation of the spectral index of the 20 January GLE from the data of the Aragats and Nor Amberd NM.

Proceeding from detected fluxes by SEVAN detector, it is possible to estimate the power law index of the SCR using the ratio of the enhancements of the flux of neutrons and low energy charged particles. As one can see from Figure 4.9, indeed the ratio of the neutral-to-charge flux is sensitive to the power index and we can estimate power index by comparison of SEVAN counts in different detector layers.

The possibility to distinguish very rare events of significant solar neutrons flux incident on the terrestrial atmosphere is open by the comparison of the count rate enhancement in SEVAN layers. The neutron spectrum at the top of the terrestrial atmosphere was adopted from (Watanabe, 2006) to be as the following in 0.1 – 2 GeV region:

$$I_n(E) = 176E^{-3.6}\left(\mathrm{m}^2\cdot\mathrm{ster}\cdot\mathrm{sec}\cdot\mathrm{GeV}\right)^{-1} \qquad (1)$$

Spectra of secondary particles from the neutron traversal in the terrestrial atmosphere were obtained by the PLANETOCOSMICS code (http://cosray.unibe.ch/~laurent/planetocosmics/). Majority of the secondary particles at 3200 m. are neutrons and gammas. Obtained secondary spectra well coincide with ones reported in (Watanabe, 2006). Simulated secondary fluxes were used as input of GEANT3 code.

The solar proton spectra from 7.6 GeV till 50 GeV was adopted from (Zazyan and Chilingarian, 2005, ACE News, 2006) as follows:

$$I_p(E) = 4.1\times10^5 E^{-5} \left(\mathrm{m}^2\cdot \mathrm{ster}\cdot \mathrm{sec}\cdot \mathrm{GeV}\right)^{-1} \qquad (2)$$

The secondary spectra were obtained in the same way as for the primary neutron flux and were used in the same way as input to GEANT3.

In Table 4.5 we can see that for neutron primaries we see significant enhancement in the thick layer and much less enhancement in thin layer. For the proton primaries situation is visa-verse: the significant enhancement is in the thin layer, and thick layer did not demonstrate unambiguous additional flux.

Table Error! No text of specified style in document.**.3:** Simulated enhancement of the 5-munute count rates due to fluxes (1) and (2).

Detector layer	Solar Protons	Solar Neutrons
Upper 5cm scintillator	4.8σ	2.6σ
Middle 25 cm scintillator	1.7σ	6.4σ

Reference

ACE News #87 – Feb 23, 2005. “Space Weather Aspects of the January 20, 2005 Solar Energetic Particle Event” www.srl.caltech.edu/ACE/ACENews/ACENews87.html

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