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2013 J. Phys.: Conf. Ser. 409 012223

(http://iopscience.iop.org/1742-6596/409/1/012223)

Journal of Physics: Conference Series **409** (2013) 012223 doi:10.1088/1742-6596/409/1/012223

New low threshold detectors for measuring electron and gamma ray fluxes from thunderclouds

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Abstract. Strong electric fields inside thunderclouds give rise to enhanced fluxes of high-energy electrons and, consequently, gamma rays and neutrons. During thunderstorms at mountain Aragats, hundreds of Thunderstorm Ground Enhancements (TGEs) comprising millions of energetic electrons and gamma rays, as well as neutrons, were detected at Aragats Space Environmental Center (ASEC) on 3200 m altitude. The energy spectra of the electrons have an exponential shape and extend in energy range 2- 30 MeV. Recovered energy spectra of the gamma rays is also exponential in energy range 2-10 MeV, then turns to power law and is extending up to 100 MeV. It is of upmost importance to research energy spectra of TGE electrons and gamma rays from the lowest possible energies to clarify the shape of energy spectra and huge multiplication of the avalanche particles. The particle detectors operated at ASEC was designed for the registration of solar modulation effects and the lowering energy threshold was not of first importance. Thus, particle detectors have energy threshold of 7-10 MeV. The new generation of ASEC detectors comprises from 1 and 3 cm thick molded plastic scintillators arranged in stacks (3cm and 1cm STAND detectors) and in cubical structures surrounded thick scintillators and NaI crystals for purification of detected neutral flux (Cube 1 cm and Cube 3 cm detectors). In presented paper we describe new detectors and analyze their operational characteristics, as well as provide examples of TGE detection with new techniques.

1. Design of the STAND stacked detector

"STAND" detector comprise of three-layer assembly of 1 cm thick 1 m2 sensitive area molded plastic scintillators one above the other and one 3 cm thick scintillator located aside (Figure 1). Detector operates in particle counter regime1. Outdoors location, 1-cm thickness and three-layer design allow to measure flux of TGE electrons with 3 different energy thresholds starting from 1.5 MeV and to recover integral spectrum of TGE electrons. Light from scintillator by optical spectrum-shifter fibers is reradiated to the long-wavelength region and passed to the FEU-115M type photomultiplier (PM). Maximum of luminescence is on about 420nm wavelength and luminescence time is about 2.3 ns (http://www.ihep.su/). The tuning of STAND detector consists in selections of PM high voltage and discrimination threshold. The threshold should be chosen to guarantee both high efficiency of signal detection and maximal suppression of noise. Tuning of STAND was made by means of the 8-channel signal analyzer developed in CRD for online experimental data processing in real time [1]. Proper tuning of the detector provides 98-99% signal detection efficiency simultaneously suppressing electronic noise down to 1-2%. The SEVAN DAQ along with separate channel counts is measuring and storing all coincidences of the detector channels. Coincidence "111" means that all 3 layers register particle, minimal energy of charged particles giving signal in all 3 layers should be ~10 MeV;

[1] 4-layered 3 cm thick version of STAND also measures 1-minute histograms of the energy deposit

coincidence "100" means that only upper detector register particle – we estimate the minimal energy of this coincidence to be ~1.5 MeV. The energy threshold of 3cm thick scintillators is ~5MeV.

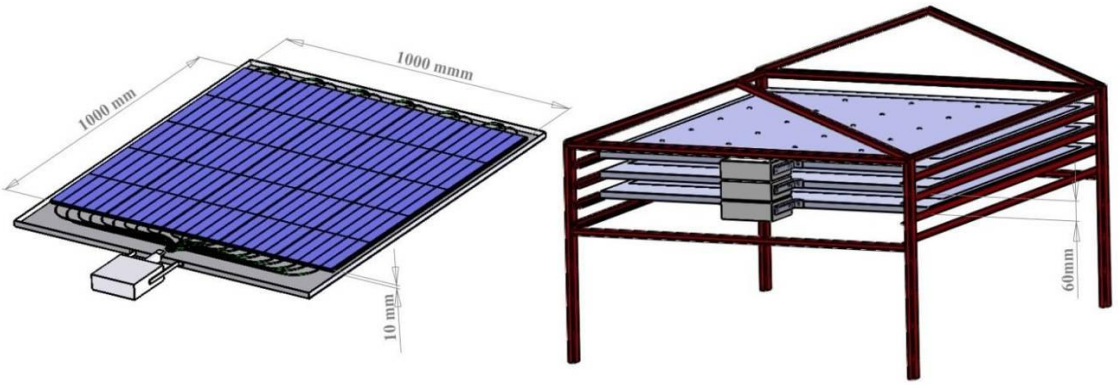

Figure 1.Stand assembly and design of 1 cm thick molded plastic scintillator with optical spectrum-shifter fibers; details of detector construction see in [2].

2. CUBE scintillator assembly design

The CUBE assembly (Figure 2) consists of two 20cm thick scintillation detectors of 0.25 m^2 area each surrounded by 1cm thick 1 m^2 area scintillators. This design ensures that no particle can hit the inside 20cm Detectors without passing through at least one of 1cm scintillators.

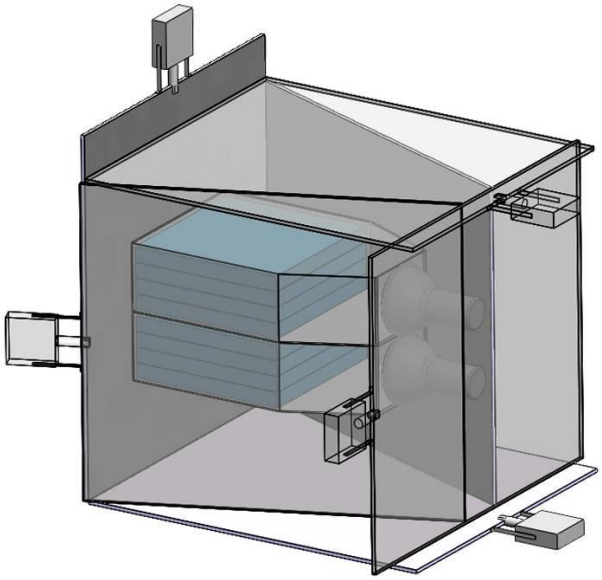

Figure 2.CUBE assembly design.

The 20cm thick plastic scintillator with 0.25 sq. meter area is overviewed by the photomultiplier (PM) ФЭУ-49 with large cathode, operating in low-noise operation mode. Surrounding detectors (6 units) are 1 cm thick molded plastic scintillators fabricated in High Energy Institute of Russian academy of sciences.

The efficiency of neutral component detection by 1cm scintillators calculated by Monte-Carlo simulation is ~2% and weakly depends on energy of gamma ray. The energy deposit of passing muons in 20 cm thick plastic scintillator is ~40 MeV. Taking into account construction material of detector (2 mm plastic and 1 cm thick scintillator above, detection threshold is estimated to be about 9 MeV. The efficiency of gamma ray detection by 20 cm thick scintillator was calculated by GEANT3 code, in the range 10 - 120 MeV. Obtained efficiency of gamma ray registration equals ~30% and weakly depends on energy. Efficiency of neutron detection in the range 4-100 MeV, in 20 cm thick scintillator is ~27%. CUBE assembly has been tested in Yerevan at 1000 m. a.s.l. and in 2010 installed at high altitude "Aragats" research station (3200 m a.s.l.). It has been included into Aragats Space Enviromental Center (ASEC, [3]) since September 15, 2010; the on-line time series are available from the CRD portal: http://adei.crd.yerphi.am/adei/.

3. TGE event at October 4, 2010.

A huge TGE event has been recorded by ASEC particle detectors in October 4, 2010 [4]. The count rate enhancement at maximum minute (18:23 UT) amounts to 232%, 229% and 190% for top, middle and bottom STAND layers respectively (Fig. 3). The total number of additional particles registered in that minute was 103873, 111941 and 73279 accordingly. The total number of TGE particles registered in the 3cm detector amounts to 91200 that is 267% enhancement. The enhancement varies in layers of STAND due to difference in energy thresholds.

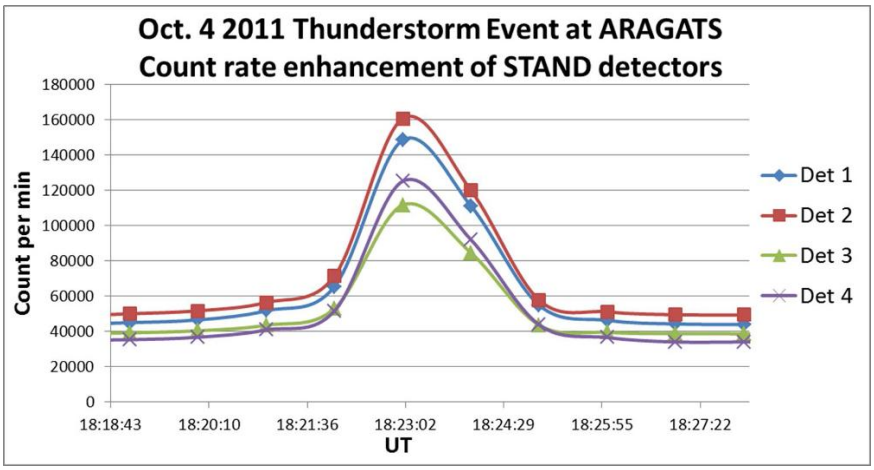

Figure 3. Count rate enhancements for STAND assembly's detectors.

CUBE count rate enhancement at maximum minute (18:23 UT) amounts to 390% and 304% for detectors #7 and #8 respectively (Figure 4). Lower count rate of bottom detector is connected with additional matter above it, which causes attenuation of the gamma ray flux. Number of TGE particles detected by upper thick scintillator (detector surface 0.25 m^2, see Figure 19) at 18:23, 4 October 2010 was N (20cm) = 43,439 with veto and N^{v}(20 cm) = 44,956 without veto, the difference is $N - N^{v} = 1517$. By these counts we recover the flux (number of particles per m^2 per minute) of gamma rays n_g above the detector (see details in [5]) by solving the inverse problem of cosmic rays:

$dE/dn = 5.4e+07 * \exp(-0.25*E)$ for the energy range of 5-10 MeV;

$dE/dn = 1.93e+08 * E^{-3.3}$ for the energy range of 10-50MeV.

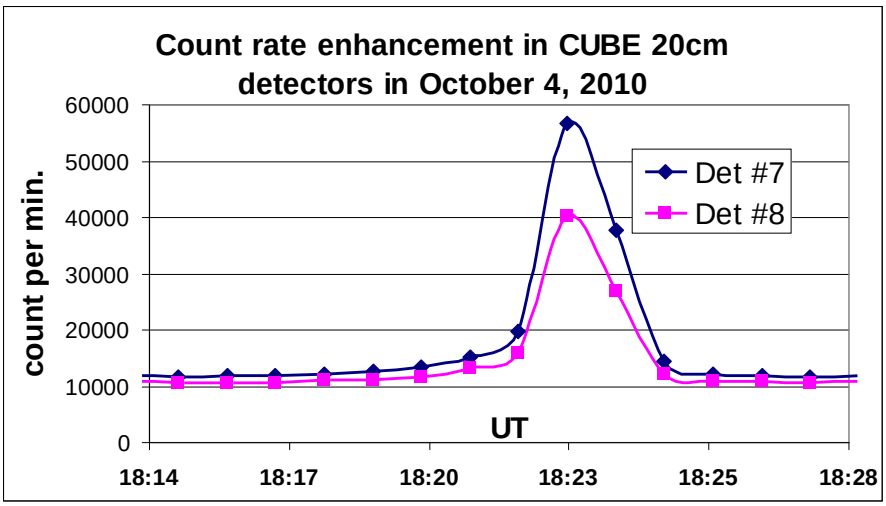

Figure 4. Count rate enhancement of Cube inner scintillators; October 4, 2010

The energy spectrum of gamma rays obtained by the Cube detector was used to calculate the detector response of the STAND detector. In Table 1 we compare the measured at 18:23 4 October 2010 coincidences statistics with simulated detector response on reconstructed by Cube gamma ray energy spectrum.

Table 1. Measured and simulated STAND statistics; 18:23, 4 October 2010.

	100	110	111
Experiment	95025	7366	1836
Simulated gamma rays	62832	3929	1377
Simulated electrons	32193	3437	459

Rather good coincidence of the sum of simulated electrons and gamma rays with measured particle confirms that used gamma ray energy spectrum is valid. Furthermore, by the electron fraction of the total counts we can recover integral spectrum of the TGE electrons.

Conclusion

Cube and STAND type detectors are precisely suited for the TGE research, measuring separately fluxes of electrons and gamma rays with rather low energy threshold. Same type detectors are operating now also in Yerevan (Cube with 3 cm thick) and a 3 cm thick STAND at Aragats, a vertically stacked assembly of the four 3 cm thick molded plastic scintillators with optical guided light-shifters. New ASEC detector has rich possibilities to detect charged and neutral cosmic ray flux. Measured and stored statistics of 4 layered coincidences of scintillator operation will be used to check and confirm the fraction of gamma rays and electrons in TGE; as well as to estimate with high precision the integral energy spectrum of the TGE electrons in energy range from 2 till 30 MeV.

References

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