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# Observation of Thunderstorm Ground Enhancements with intense fluxes of high-energy electrons

Ashot Chilingarian, Levon Vanyan, Bagrat Mailyan *

*Yerevan Physics Institute, Cosmic Ray Division, Yerevan, Armenia*

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ABSTRACT

The high altitude (~3200 m above sea level) of Aragats Space Environmental Center (ASEC) and low elevation of the thunderclouds provides a good opportunity to detect Thunderstorm Ground Enhancements (TGEs), particles of which rapidly attenuate in the atmosphere. In 2012, we have estimated the energy spectra of several TGEs and revealed significant electron fluxes extended till 30–40 MeV. Measured in the one and the same event gamma ray and electron fluxes allow to estimate the height of the thundercloud above the detector. Proceeding from the energy spectra and the height of the cloud we estimate the electron spectra on the exit from the electric field of the thundercloud, the number of excess electrons in the cloud and avalanche multiplication rate.



## 1. Introduction

Thunderstorm Ground Enhancements (TGEs) are direct proof of the high-energy phenomena in the terrestrial atmosphere; see review by Dwyer et al. [15] and references therein.

The origin of a TGE is a strong electrical field in a thundercloud, giving rise to rather complicated physical processes, including the following phenomena:

- Relativistic Runaway Electron Avalanches (RREA, [25,17,3,14, 18];
- Modification of the Secondary cosmic ray (electrons, muons, protons and charged mesons) energy spectra (MOS, [13,20];
- Photonuclear reactions of the RREA gamma rays [10,11,24,4];
- Roentgen and gamma radiation from the lightning [16].

The direct measurement of the RREA by extended surface array of plastic scintillators was performed at Aragats in 2009 [8]. Largest TGEs consist of multiple individual electron/gamma ray avalanches. However, the electron fluxes are very difficult to study due to fast attenuation in the lower atmosphere, till now only for one TGE event it was possible to estimate the electron energy spectrum and calculate avalanche multiplication rate [7,9].

On October 7, 2012 a TGE consisting of two peaks at 14:11 and 15:08 was detected at Aragats Space Environmental Center (ASEC; [5,19]. Different types of the detector assembly operating on Aragats, quipped with sophisticated coincidences techniques, allowed performing electron/gamma ray separation and proving the existence of the large fraction of the high-energy electron flux at 15:08. At 14:11 TGE mainly consists of enhanced gamma ray flux, as the most of TGEs detected at ASEC and worldwide. Because of very fast attenuation of electrons in the atmosphere, usually TGE gamma ray flux significantly exceeds the electron flux; only for very low thunderclouds it is possible to detect electron flux. Thus, even for very low efficiencies of gamma ray registration the gamma ray contamination can be sizable in the overall TGE. To overcome this difficulty, we use in our analysis data from numerous ASEC particle detectors. Among these detectors are STAND3 layered detector and hybrid[1] ASNT (Aragats Solar Neutron Telescope, [6] and Cube detectors [2]. First we will analyze the STAND3 data, for distinguishing the high-energy electrons. Thereafter, we double check for the presence of significant electron fluxes using ASNT data. ASNT data also allows estimating the gamma ray flux. Based on these measurements and assumed spectral shape of the gamma ray flux we decide if the high-energy electrons were detected or only large fluxes of TGE gamma rays are responsible for the detector count rate enhancement. Finally, the estimated flux will be checked with Cube detector data, which allows selecting the neutral component of TGE flux. If the results from these 3 different detectors are consistent, we apply procedures of energy spectra recovery (see details in [9] and get gamma ray and electron energy spectra.

* Corresponding author. Tel./fax: +374 10 34 47 36.
*E-mail address:* mbagrat@gmail.com (B. Mailyan).

[1] Hybrid detectors consist from thick and thin plastic scintillators and due to sophisticated DAQ electronics are sensitive to both charged and neutral fluxes.

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## 2. Experimental data of the October 7, 2012 TGE

The new generation of ASEC detectors comprises from 1 and 3 cm thick molded plastic scintillators arranged in stacks (STAND1 and STAND3 detectors) and in cubical structures surrounding thick scintillators and NaI crystals for purification of detected neutral flux (Cube1 and Cube3 detectors). Light from the scintillators is reradiated by optical spectrum-shifter fibers to the long-wavelength region and passed to the FEU-115 M type photomultiplier (PM). Maximum of luminescence is on about 420 nm wavelength and luminescence time is about 2.3 ns [27]. The tuning of STAND detectors consists in selections of PM high voltage and signal discrimination threshold. The threshold is chosen to guarantee both high efficiency of signal detection and maximal suppression of the electronics noise. Tuning of STAND was made by means of the 8-channel signal analyzer developed at ASEC for online data processing [1]. Proper tuning of the detector provides 98–99% signal detection efficiency simultaneously suppressing electronic noise down to 1–2%. The data acquisition (DAQ) electronics measures and stores all coincidences of the signal appearance in the detector channels. Coincidence "1 0 0 0" corresponds to signal registration only from upper scintillator, "1 1 0 0" – from the first two upper scintillators, and so on. GEANT4 simulations demonstrate that STAND3 detector (see Fig. 1), can measure count rate of incident electrons with energy thresholds 5, 15, 25, 35 MeV (combinations "1 0 0 0", "1 1 0 0", "1 1 1 0" and "1 1 1 1"). The 5 MeV electrons can give signal above the discrimination level only in the upper scintillator, to be absorbed then in the scintillator body, or in the metallic tilts of scintillator housing; the 15 MeV electrons can penetrate and be registered also in the second scintillator, and so on. In this way, measuring the enhancements of count rates of above mentioned 4 combinations of detector layer operation we can recover the integral energy spectra of TGE electrons, of course, after subtracting the gamma ray contamination. The peaks of October 7, 2012 TGE measured by the layers of STAND3 detector are shown in the Fig. 2. The increases of the maximal minute count rate corresponding to various coincidences of STAND3 are shown in Table 1 in standard deviations of the measurements (number of $\sigma$).

As we can see in Table 1, at 15:08 October 7 2012, STAND3 detector registered high-energy electron TGE. Electrons with energies above 35 MeV can reach and be registered by the 1 1 1 1 combination of STAND3 with efficiency dependent on energy. The efficiencies for electron detection by STAND3 detector are shown in Fig. 3. The electronics signal threshold[2] is ~3 MeV, thus, all 4 STAND3 layers can detect gamma rays with energies greater than ~3 MeV, although with much smaller registration efficiencies comparing with electron detection efficiencies. In Fig. 4, the gamma ray detection efficiencies by coincidences of STAND3 detector layers are shown. Gamma rays should have high enough energy to create high-energy charged particles, which can reach bottom layer (the gamma ray energy should be above 40 MeV to generate signal in all 4 layers with probability 1%).

Electrons with energies greater than 35 MeV will contribute to "1 1 1 1" combination. In contrast, only a small fraction of high-energy gamma rays will be detected as "1 1 1 1" combination. Therefore, we conclude that STAND3 data of "1 1 1 1" combination proves the existence of the high-energy particles above 25 MeV at 15:08. Using GEANT 4 simulations and data from ASNT and Cube detectors we will find if there is a sizeable contamination from gamma rays.

In Fig. 5, ASNT detector consisting of upper 5 cm and lower 60 cm thick scintillator layers is depicted. Each layer consists of 4 scintillators and each scintillator has an area of 1 m$^2$. In Fig. 6, the gamma ray detection efficiencies of 5 cm and 60 cm scintillators are presented. Thicker is the scintillator more is the probability of gamma rays to interact and create charged particles, which will deposit their energy in the scintillator.

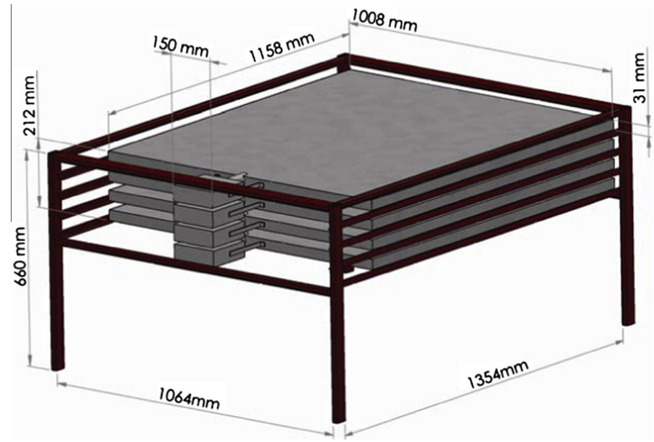


**Fig. 1.** STAND3 detector; each of 4 stacked horizontally plastic scintillators is 3 cm thick and 1 m$^2$ area.

During October 7, 2012 TGE at 15:08, the increase detected by 5 cm scintillators of the ASNT detector was twice larger than that of 60 cm scintillators (see Table 2). However, the neutral particle detection efficiency of the thick scintillator is much higher; especially for the gamma rays with energies above 30 MeV (see Fig. 6). Taking into account energy loses in the material of the roof and the electronics threshold, the minimal energy of electrons should be ~15 MeV to be measured by the 5 cm detector. Only electrons having energies above ~30 MeV can pass through the roof and the upper 5 cm scintillator layer and be detected also by 60 cm scintillator ("11" coincidence).

Detected at 15:08 small increase was measured by ASNT vertical "11" coincidence - a simultaneous signal in both scintillators (see Table 2), the probability of gamma ray detection by this coincidence is vanishingly small (the efficiency of gamma ray detection is near zero at energies <20 MeV). The increase observed by ASNT vertical coincidence confirms the "electron" nature of TGE of 15:08.

In [9], we discussed and analyzed two largest TGEs of September 19, 2009 and October 4, 2010. The September 19, 2009 TGE has the largest ever detected electron intensity. The October 4, 2010 TGE has the largest ever detected gamma ray intensity, with small electron contamination. The ratio of the enhancements in 5 cm and 60 cm thick scintillators of ASNT on September 19 was ~4 and on October 4 ~2; i.e. the largest "electron" TGE has 2 times larger ratio of thin/thick scintillator counts comparing with largest "gamma-ray" TGE. In this concern, it is worth mentioning that for the first peak detected at 14:11 October 7, 2012 the ratio of thin/thick is ~1.21, see Table 2; two times less than at 15:08. Therefore, greater is the ratio, larger is the fraction of electrons reaching the Earth's surface.

Recovered electron/gamma ray ratios above the roof of the laboratory building for the energies above 10 MeV were estimated to be 0.6 and 0.007 for September 19, 2009 and October 4, 2010 TGEs respectively (see details in [9].

The Cube assembly (Fig. 7) consists of two 20 cm thick scintillation detectors of 0.25 m$^2$ area each surrounded by 1 cm thick 1 m$^2$ area scintillators. This design ensures that no particle can hit the inside 20 cm detectors without passing through one of 1 cm scintillators. Both 20 cm thick plastic scintillators are overviewed by the PM FEU- 49 with large cathode, operating in low-noise mode.

[2] The threshold of the shaper-discriminator feed by the PM output.

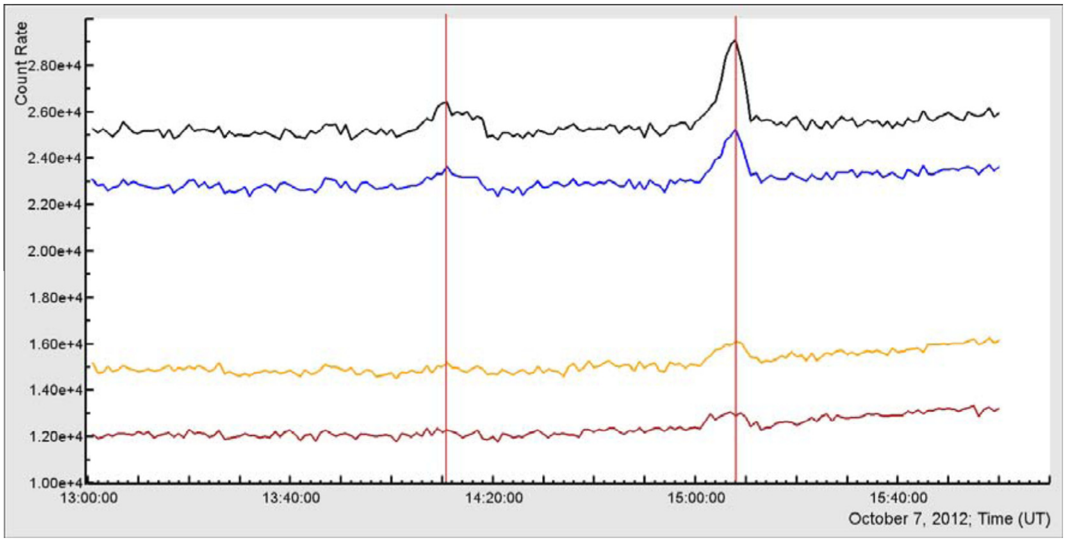


**Fig. 2.** Thunderstorm Ground Enhancements of October 7, 2012 measured by STAND3 detector; the higher count rate corresponds to the upper position of scintillator in the stack. Vertical lines show the minutes of maximal TGE flux, namely 14:11 and 15:08 UT.

**Table 1**
Count rate enhancements (or deficit) detected by STAND3 on October 7, 2012 in standard deviations.

| STAND3 Combinations | [1000] Number of σ | [1100] Number of σ | [1110] Number of σ | [1111] Number of σ |
|---|---|---|---|---|
| 14:11 | 10 | 4 | 1 | 0 |
| 15:08 | 27 | 9 | 5 | 4 |

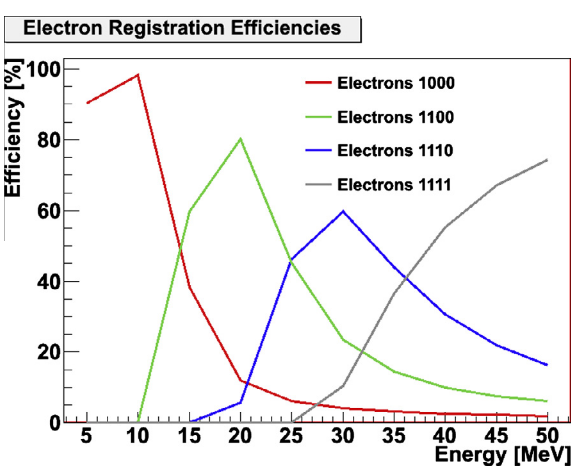


**Fig. 3.** Efficiencies of detection of the electrons by the STAND3 coincidences.

Surrounding detectors (6 units) are 1 cm thick molded plastic scintillators.

Unfortunately, the upper veto scintillator fails on October 7, 2012. Nonetheless, we have used the lower 20 cm Cube scintillator to check for the gamma ray intensity, since electrons with energies less than 50 MeV attenuate till reaching the bottom scintillator. There is no evidence of the presence of such high-energy electrons in the detected at Aragats TGEs and simulations of the RREA also demonstrate that maximal electron energy reaching ASEC detectors is 40–50 MeV [9]. On October 7 2012, Cube lower 20 cm thick scintillator detects a small increase. The increase was ~150 and ~250 particles at 14:11 and 15:08 respectively. We suppose that particles giving these enhancements are gamma rays with energies

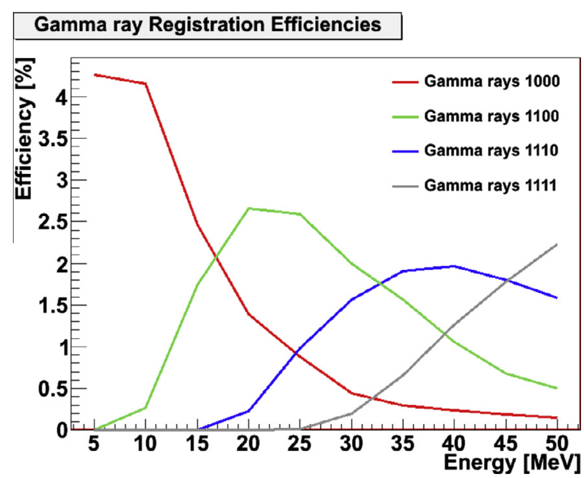


**Fig. 4.** Efficiencies of detection of the gamma rays by the STAND3 coincidences.

above 15 MeV[3], since electrons attenuate in detector substance. This data along with ASNT data helps to check for the gamma ray spectrum of the TGE and consequently to disentangle the electron and gamma ray fractions of the detected TGE.

## 3. Recovered energy spectra of electrons and gamma rays

After demonstrating that the 15:11 TGE contains high energy electrons, we shall investigate the enhancements measured by above mentioned 3 particle detectors in more details having the goal to recover the energy spectra of gamma rays and electrons.

We use the multiple spectra testing method [7] to reproduce in simulations of gamma ray fluxes the observed by STAND3 detector peaks. Dependent on the simulated gamma ray spectrum index, more or less gamma rays have to be generated to fit the measurements: hard $E^{-1}$ spectrum requires simulation of only ~20,000 gamma rays above 10 MeV to get the measured number of STAND3 "1111" coincidence additional counts, softer $E^{-3}$ needs more

[3] On October 7, 2012, due to the high electronics threshold (all energy thresholds along with count rates are registered and stored), the particles depositing less than 15 MeV were not detected by PM.

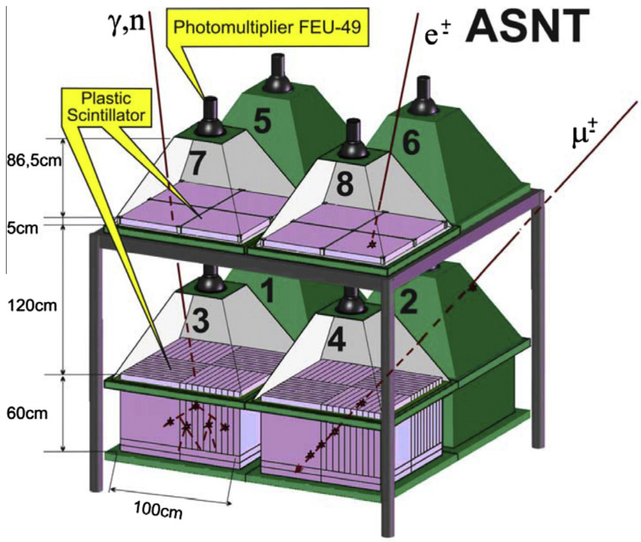


**Fig. 5.** Aragats Solar Neutron Telescope (ASNT).

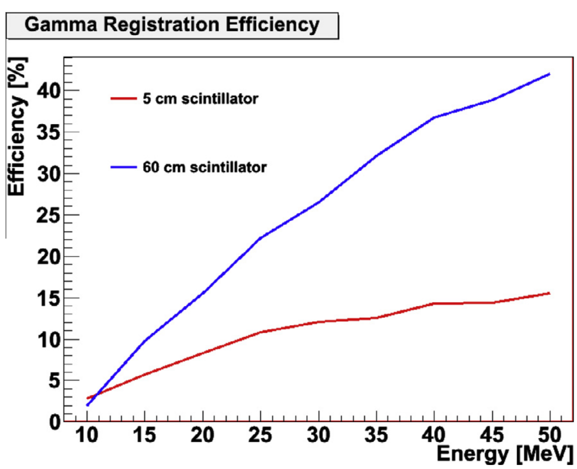


**Fig. 6.** The efficiency of gamma ray registration by ASNT 5 cm and 60 cm thick plastic scintillators.

**Table 2**
The enhancements of ASNT upper and lower layers on 7 October, 2012.

| ASNT | 60 cm | 5 cm | 5 cm/60 cm | "11" coincidence |
|---|---|---|---|---|
| The first peak 14:11 | 919 | 1110 | 1.21 | 99 |
| The second peak 15:08 | 1018 | 2357 | 2.31 | 135 |

particles, ~150,000 to reproduce the observed peaks. Bottom 20 cm scintillator of Cube and ASNT "01" coincidence registers mostly TGE gamma rays. The anticoincidence scheme of ASNT rejects charged particles and electrons should have energy above 50 MeV to be detected by lower scintillator of Cube. In Table 3, we post required in the simulation amounts of gamma rays to reproduce the enhancement measured by the "1 1 1 1" combination of STAND3 and corresponding counts of ASNT 01 and Cube bottom 20 cm scintillator along with actually measured by these detectors enhancements.

As we can see, if we assume that enhancement in "1 1 1 1" coincidence of STAND3 is due to gamma rays, Cube and ASNT should measure much more particles than they do.

If we assume $E^{-2}$ spectrum, and decrease simulated intensity 4 times, we will correctly reproduce intensities measured by ASNT and Cube. Thus, only quarter of the STAND 3 "1 1 1 1" combination increase can be due to gamma rays. In Table 4 we depict the intensities of measured TGE particles, along with estimated gamma ray and electron intensities, assuming $E^{-2}$ shape of the gamma ray spectrum. First supposing that the enhancements measured by STAND3 detector are due to gamma rays only, using Geant4 simulations, we estimate expected count rates of all 4 coincidences of layered detector (third row of Table 4). Then, subtracting the estimated gamma ray flux from the experimentally measured increase we obtain the residual increase, which we relay to the electron flux incident on the detector (the fourth row of Table 4). In this way we determine the fractions of electron and gamma ray fluxes in the total TGE flux from the thundercloud reaching the detector assembly. The intensities presented in Table 4 are in a good agreement with ASNT and Cube data for the high-energy electrons and gamma rays.

From the data of Table 4, we can recover electron energy spectra. The electron integral spectrum is very flat and can be fitted by the $\sim E^{-1}$ function, see Fig. 8, where the background electron spectrum at 3200 m a.s.l. and electron spectra of the largest TGEs on September 19, 2009 and October 4, 2010 are shown as well. Although at high energies the background significantly enhanced the TGE electron flux, nonetheless the relative error of the ASEC detectors is rather small (see [12]) and 2–3% enhancement of the detector count rate can be reliably identified and enumerated. The increases detected by STAND3 at 15:08, October 7, 2012 are 23%, 10%, 10% and 7% for "1 0 0 0", "1 1 0 0", "1 1 1 0" and "1 1 1 1" combinations respectively. The October 2012 TGE significantly differs from the largest TGEs on September 19, 2009 and October 4, 2010 not only by electron/gamma ray ratios, but also by spectral shapes. On September 19, 2009 TGE electron spectrum was best fitted by the exponential function $\sim\exp(-0.3*E)$ and gamma ray spectrum by the power law $\sim E^{-3}$. We have supposed that the reason of the flat spectra can be the shorter electric field lengths, since the RREA spectra will be less modified and closer to the background secondary cosmic ray electron spectra. RREA simulations show that if the length of the electric field is near 500 m, the RREA electron and gamma ray spectra's shapes are close to the seed particle (cosmic ray electron) spectra. While the field length is larger

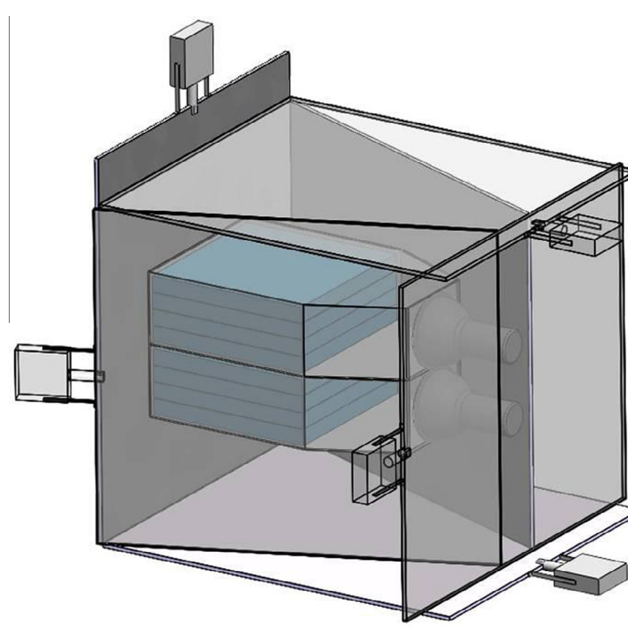

**Fig. 7.** Cube detector assembly; two 20 cm thick plastic scintillators are fully surrounded by the 1 cm thick molded plastic scintillators (veto system).

**Table 3**
Simulated gamma ray flux and corresponding ASNT 01 and Cube bottom 20 cm thick scintillator intensities along with experimentally measured values at 15:11, 7 October 2012.

| | Simulated intensity of required Gamma ray flux reproducing measured enhancement by "1 1 1 1" combination of STAND3 | The same as in second column for the ASNT "01" combination | The same as in second column for the Cube bottom 20 cm thick scintillator |
|---|---|---|---|
| $E^{-1}$ | 20,000 | 3900 | 884 |
| $E^{-2}$ | 50,000 | 3500 | 1288 |
| $E^{-3}$ | 150,000 | 3400 | 2213 |
| Experimental measurements | | ~900 | ~250 |

**Table 4**
Count rates of the STAND3 and estimated numbers of electrons and gamma rays, assuming $E^{-2}$ gamma ray spectrum and electron threshold corresponding to 30% efficiency; 15:11, 7 October 2012.

| STAND3 | >5 MeV (1 0 0 0) | >15 MeV (1 1 0 0) | >25 MeV (1 1 1 0) | >35 MeV (1 1 1 1) |
|---|---|---|---|---|
| Total | 3821 ± 86 | 1531 ± 84 | 763 ± 89 | 319 ± 76 |
| Gamma ray | 2682 | 197 | 85 | 84 |
| Electron | 1139 | 1334 | 678 | 235 |

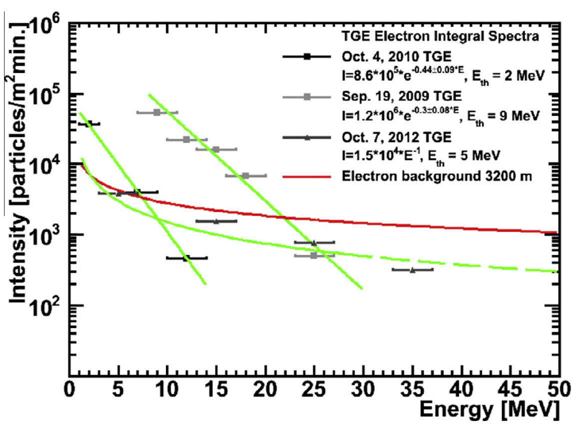


**Fig. 8.** October 7, 2012 TGE electron integral spectrum along with the largest TGE and background cosmic ray electron spectra.

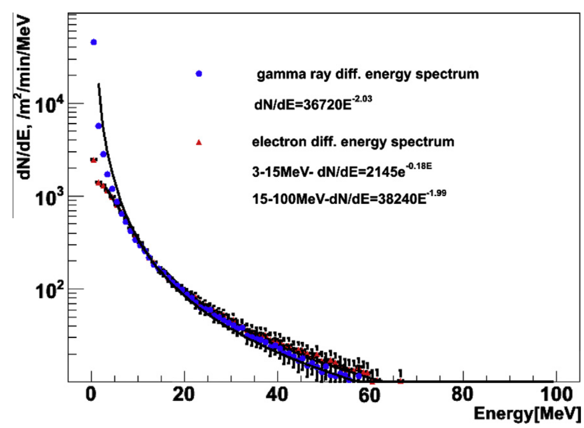


**Fig. 9.** The electron and gamma ray differential energy spectra after the electric field in thundercloud obtained from the simulations of RREA process in 500 m of 1.8 kV/cm electric field.

(1500 m), the TGE spectra differ significantly from the background spectra, due to the greater influence of unleashed runaway avalanches. Shorter electric field length could explain the spectra of 15:08, October 7, 2012 TGE, which are close to the background secondary cosmic ray electron and gamma ray spectra [21].

The results of simulations of RREA process in 500 m of 1.8 kV/cm strength uniform electric field are presented in Fig. 9. As we can see, the spectra of electrons and gamma rays are flatter in comparison to those presented in Chilingarian et al. [9] for the 1500 m of electric field length. The differential spectrum of the electrons after 500 m is well described by power function $\sim E^{-2}$ at energies >15 MeV (smaller energies do not reach the observational level, see [9]. The corresponding electron integral spectrum is fitted by function $\sim E^{-1}$, which coincidences with the recovered energy spectrum rather well. The gamma ray spectrum obtained in simulation is also in a good agreement with the estimated spectrum presented in Fig. 10.

Because of the short electric field length, gamma ray maximal energy does not reach ~100 MeV [9] as for the longer field lengths and ends near 60 MeV. Electron intensity and path length are smaller and less is the probability to emit high-energy gamma rays.

The estimated gamma ray spectrum fitted by the power function $E^{-2}$ is presented in Fig. 10 along with background gamma ray spectrum at 3200 m and spectra of the largest TGEs on September 19, 2009 and October 4, 2010. The enhancements against background are 16, 8, 5 and 4% for >10, >20, >30 and >40 MeV gamma rays respectively.

## 4. The "gamma ray" TGE at 14:11, October 7, 2012

The TGEs like occurring at 15:08 October 7, 2012 with high electron/gamma ray ratio and large maximal energy are rather rare events. The TGE occurred earlier on October 7, 2012 at 14:11 belongs to the class of more frequent events with predominant portion of gamma rays. At 14:11 the thin scintillators of ASNT have detected near the same amount of excess particles as thick scintillators; ratio of thin/thick is 1.21 see Table 2. Moreover, thick scintillators have detected near the same number of excess particles at 14:11 and 15:08. This points on the smaller electron contamination at 14:11 in comparison to the 15:08 peak (see Fig. 6). The reason of the absence of electrons can be the higher thundercloud height at 14:11. Abrupt changes in wind speed, atmospheric pressure (0.5 mbar change in half an hour) and rain rate (reaching 3 mm/h at 14:30, October 7, 2012) measured by Davis Vantage Pro weather station [26], point on the highly variable weather conditions.

Using STAND3, ASNT and Cube data, we estimate the gamma ray intensity at 14:11. From the measurements of STAND3 it is obvious that there are no electrons with energies greater than 15 MeV, since the coincidences "1 1 1 1" and "1 1 1 0" do not show any boost.

We have performed simulations of STAND3 detector response using the multiple spectra selection method to reproduce the ob-

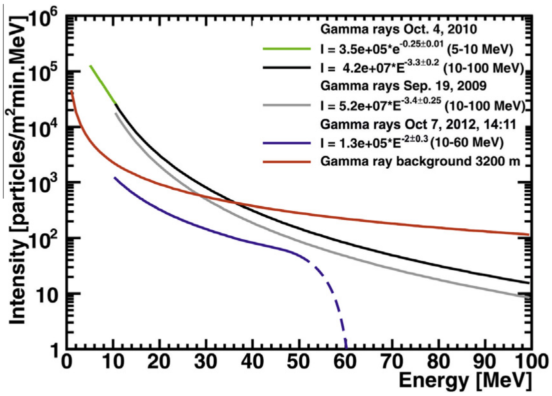


**Fig. 10.** The gamma ray spectrum of October 7, 2012 TGE along with largest TGE spectra and background gamma ray spectrum at 3200 m.

**Table 5**
STAND3 detector response simulations and measurements at 14:11, October 7, 2012.

| STAND3 | [1000] | [1100] | [1110] | [1111] |
|---|---|---|---|---|
| 14:11 | 819 | 334 | 56 | −35 |
| Simulation $\sim E^{-1}$ | 680 | 331 | 226 | 342 |
| Simulation $\sim E^{-2}$ | 906 | 136 | 44 | 63 |
| Simulation $\sim E^{-3}$ | 689 | 34 | 6 | 4 |

**Table 6**
ASNT 01 and Cube lower 20 cm scintillator data and simulation values.

| | ASNT 01 | Cube |
|---|---|---|
| $E^{-1}$ | 5529 | 872 |
| $E^{-2}$ | 1402 | 232 |
| $E^{-3}$ | 267 | 47 |
| 14:11 | ~900 | ~150 |

served peaks in the "1 0 0 0" and "1 1 0 0" combinations. Again the power law spectral shape was used with spectral indexes of −1, −2, −3 and spectral coefficient of 20,000/sq m. The gamma ray energy interval in simulation was 3–100 MeV. In Table 5, the simulation results along with the experimental measurements are presented.

As we can see from Table 5, the small enhancement detected by "1 1 1 0" coincidence can be explained assuming a pure gamma ray flux using $\sim E^{-2}$ spectrum, or other spectra with diminished or increased intensities. However, the data of various coincidences do not agree with each other without involving low energy electron flux (at energies less than 15 MeV). No test spectrum supports the pure gamma ray flux and absence of electrons at all energy ranges. Again, as for the previous analyzed TGE, we use ASNT and Cube lower 20 cm detector data to estimate the number of gamma rays on October 7, 2012 at 14:11. In Table 6, the measurements and simulations are presented. As we can see, the spectrum $\sim E^{-2}$ agrees with experiment after diminishing the intensity ~1.5 times. The spectrum $\sim E^{-3}$ also may provide a good agreement with the measurements after enlarging the incident spectrum 3.5 times; however, the STAND3 data do not support this hypothesis.

Assuming the gamma ray spectrum $\sim E^{-2}$ and diminishing the intensity in a way to fit the Cube lower 20 cm scintillator and ASNT 01 count, we obtain the electron and gamma ray fraction presented in Table 7. As we can see, the estimated >5 MeV electron number is very small in comparison to the largest TGEs and ~4 times smaller than at 15:08.

**Table 7**
STAND3 measurements of 14:11, October 7, 2012 TGE.

| STAND3 coincidence | [1000] | [1100] | [1110] | [1111] |
|---|---|---|---|---|
| Total | 819 ± 86 | 334 ± 84 | 56 ± 89 | −35 ± 76 |
| Gamma ray simulated | 604 | 91 | 29 | 42 |
| Electron simulated | 215 | 243 | – | – |

## 5. Possible systematic errors

We do not estimate the exact length of the electric field in the thundercloud and strength of electric field; however, the obtained spectra are closer to the simulation results for 500 m rather than 1500 m field length. Additional simulation should be performed to find the relation between the field length, strength and the TGE particle spectra. Moreover, in our simulations we assume that seed electrons enter the field region at a definite height; meanwhile, secondary cosmic ray seed particles are distributed in the whole volume of the electric field in the thundercloud and are continuously accelerated from. Also different instrumentation were used to recover the TGE spectra of the largest events and the new events in 2012, which may cause uncertainties connected with the energy threshold estimation, while comparing various TGEs.

## 6. Discussion and conclusions

We have estimated the electron and gamma ray spectra of the TGE observed at 15:08 on October 7, 2013, and the gamma ray spectrum of the preceding TGE at 14:11.

The intensities and spectral indices of gamma ray fluxes are near the same for both TGEs, the difference is due to the more intense electron flux at 15:08. The gamma ray intensities at energy range >10 MeV are ~13,000 particles/min $m^2$, ~10 times less than for the largest gamma ray TGE on October 4, 2010.

Both gamma ray spectra have power law shape at energies above 10 MeV, with a spectral index about −2, which is harder than the spectra for the largest observed TGEs on September 19, 2009 and October 4, 2010. The electron spectrum is also harder than the previously measured spectra [7]. Since the obtained spectra shapes are closer to the background secondary cosmic ray electron spectrum, we proposed that the electric field length for October 7, 2012 TGE at 15:08 UT is shorter in comparison with the largest TGEs. We have checked the hypothesis on the short field lengths using GEANT4 simulations. The results of the simulation also support the hypothesis on short field lengths, based on the rather hard recovered spectra.

After estimating the electron and gamma ray energy spectra at the observational level (3200 m a.s.l), based on the electron/gamma ray ratio, we have estimated the thundercloud height to be ~100 m (we assume electric field strength 1.8 kV/cm and 500 m field length). Thereafter, we have estimated the electron energy spectrum at 3300 m, i.e. ~100 m above the observational level to be ~130,000 per minute per $m^2$. Consequently, the multiplication rate is ~33 and taking into account that the field length is 500 m, we can estimate the e-folding length as ~150 m.

The maximal energy of TGE electrons and gamma rays obtained in simulations is approximately 50 MeV for the field length 500 m, i.e. gamma ray maximal energy is smaller than that obtained for longer field lengths [9]. Thundercloud height was low enough at 15:11, allowing electrons to be observed at 3200 m. We have also calculated the total number of RREA electrons assuming the electric field region having a radius 1 km, after estimating the TGE particle intensities just below the electric field in thundercloud to be $\sim 4.2 * 10^{11}$, which is $\sim 10^2$ times less than for September 19, 2009

TGE and ∼$10^4$ less than for October 4, 2010 TGE. This is another argument supporting the hypothesis of the short electric field.

Tsuchiya et al. [23] had measured the fluence of gamma rays at sea level for energies above 1 MeV to be $\sim 2*10^4\ m^{-2}$, which is comparable to our results. However intensities obtained for Aragats are higher, because of lower thundercloud height.

Experiments carried by the Japanese group [24] are in a good agreement with our results. The estimated gamma ray spectrum index was also ∼2, however the thundercloud height was 600–900 m, which did not allow to measure the electron spectrum.

Tsuchiya et al. [24] have measured TGE gamma ray spectra, whereas, till now only Chilingarian et al. [7] had reported on the TGE electron spectra. The indices of estimated gamma ray spectra are in good agreement also with the measurements of TGF spectrum reported by Tavani et al. [22].

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