On the origin of the particle fluxes from the thunderclouds: energy spectra analysis

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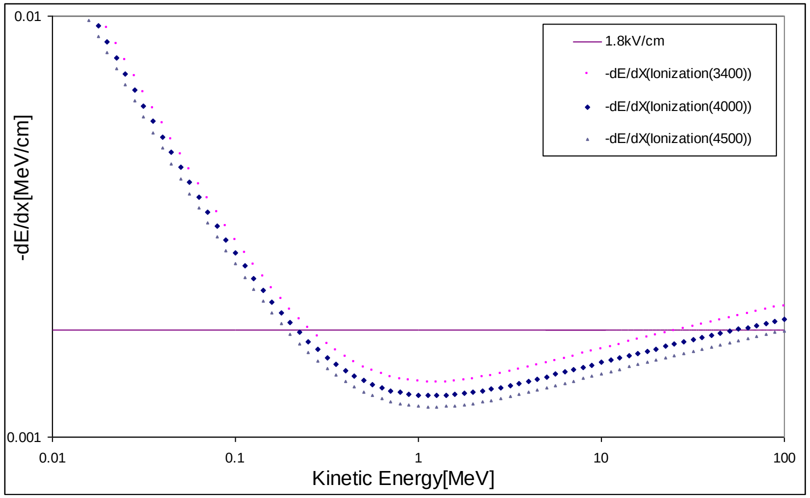
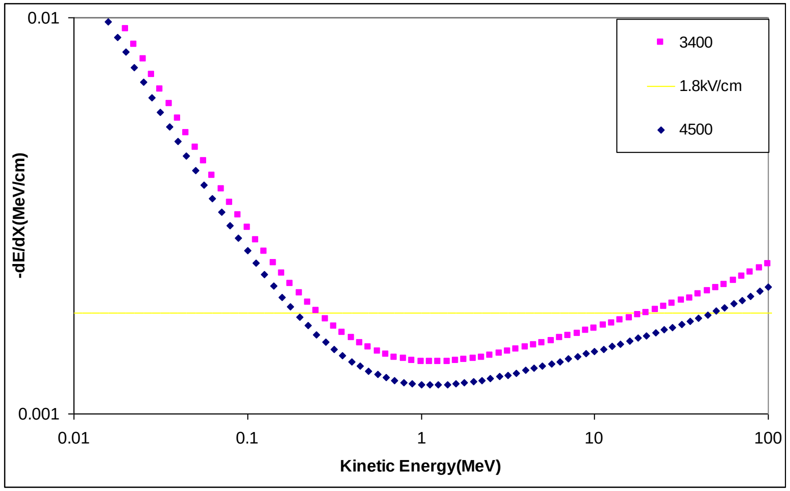
Electron energy losses by ionization(left) + bremsstrahlung (right) in air at different altitudes, compared with energy gained by an accelerating electric field with the strength

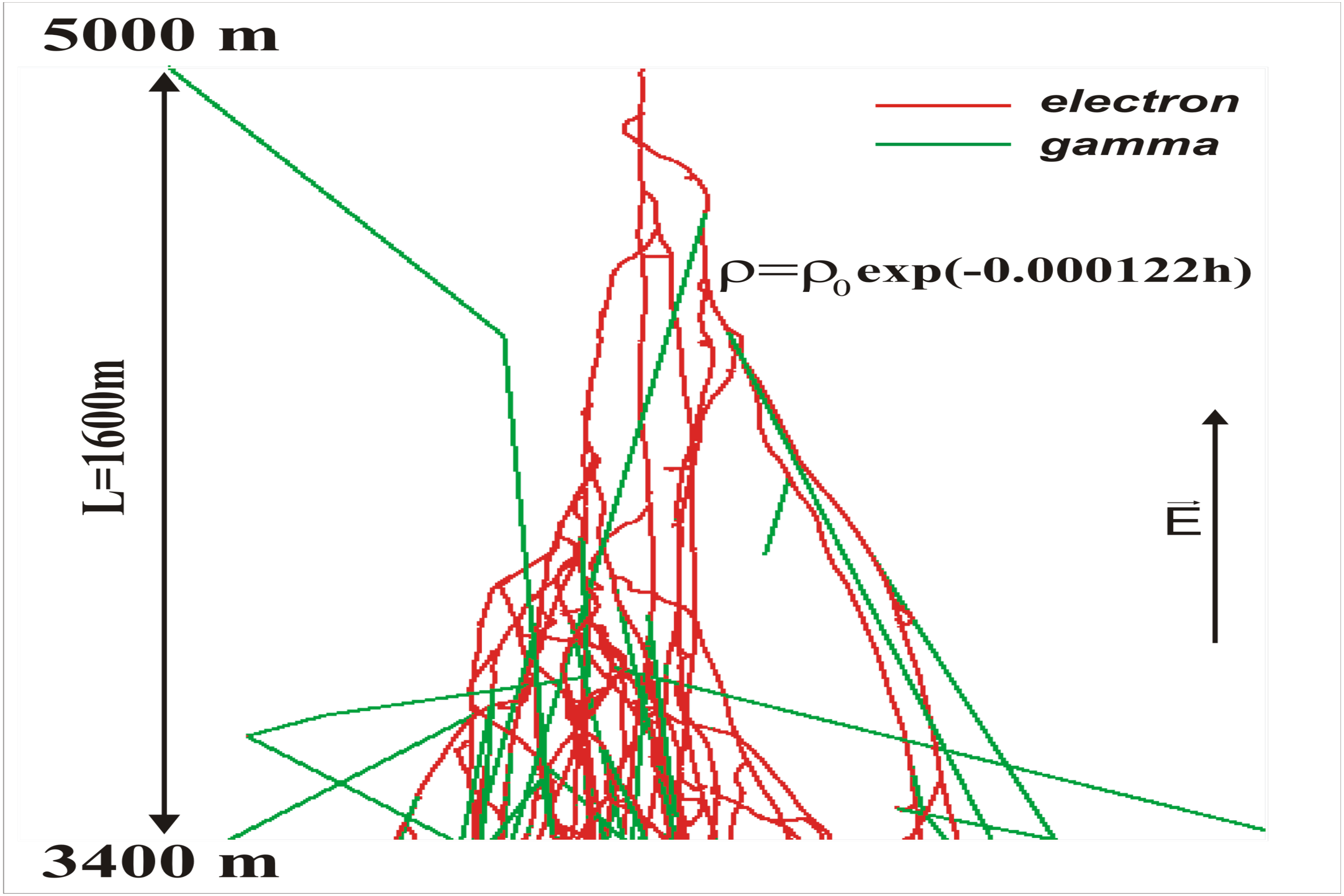
1.8kV/cm



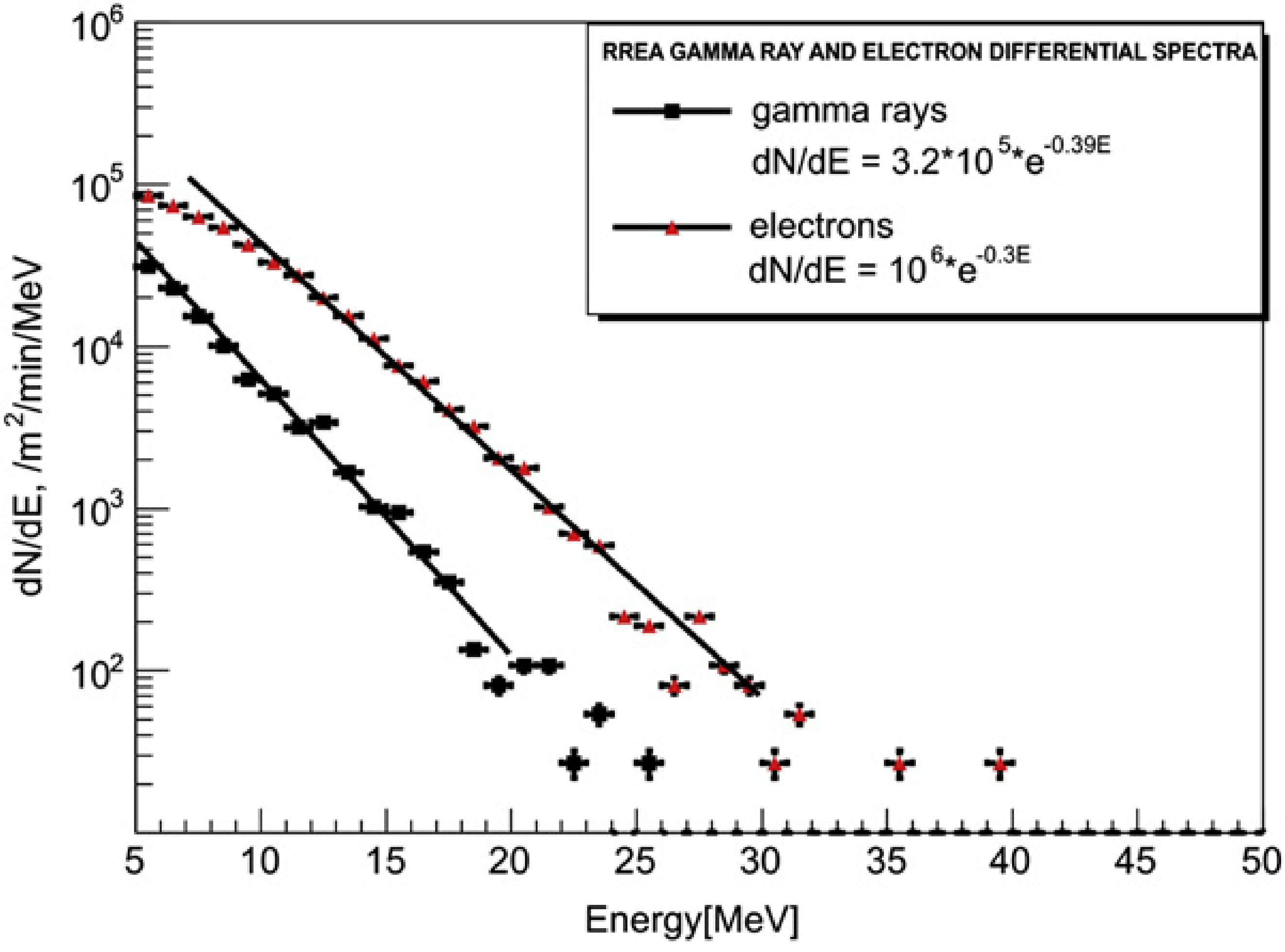


E_{min} = 2.14kV/c increases taking into account elastic scattering of electrons - E_t = 2.84 kV/cm

Runaway Relativistic Electron Avalanches(RREA), visualised by GEANT4



RREA electrons and gamma rays. Electric field strength – 1.8kV/cm. Seeds – 1MeV electrons



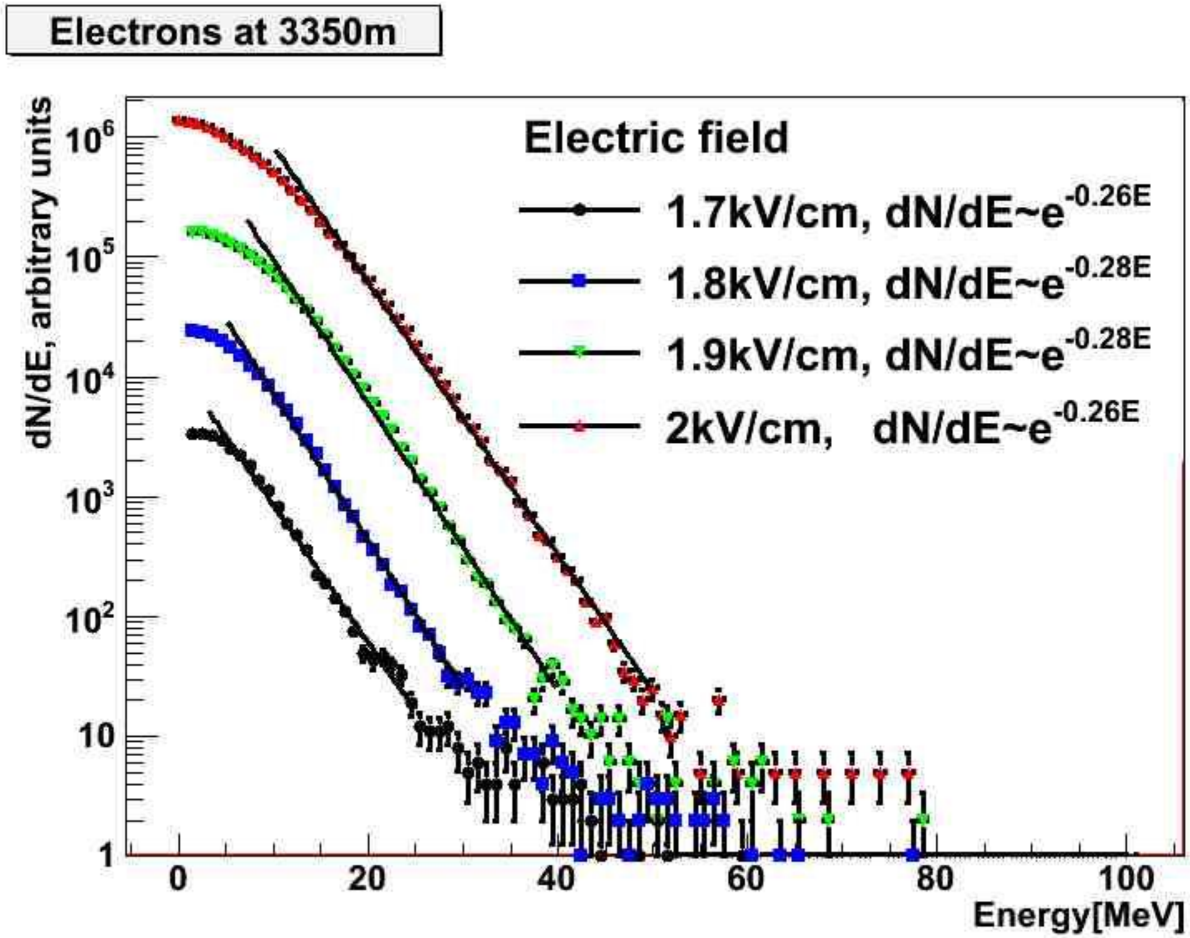
GEANT4 simulation parameters. Trying to describe TGEs with RREA mechanism

- Electric fields with the strengths 1.7,1.8,1.9, 2kV/cm.
- Air density dependence on altitude - $\rho=\rho_0 exp\{-0.000122h\}$
- Electric field elongation – from 5000m to 3400m asl
- For electrons and positrons – ionization, bremsstrahlung, multiple scattering;
- For gamma rays – Compton scattering, conversion, photoelectric effect.
- Seed electrons – secondary cosmic ray electrons; energy spectrum(Expacs Excel-based calculator)

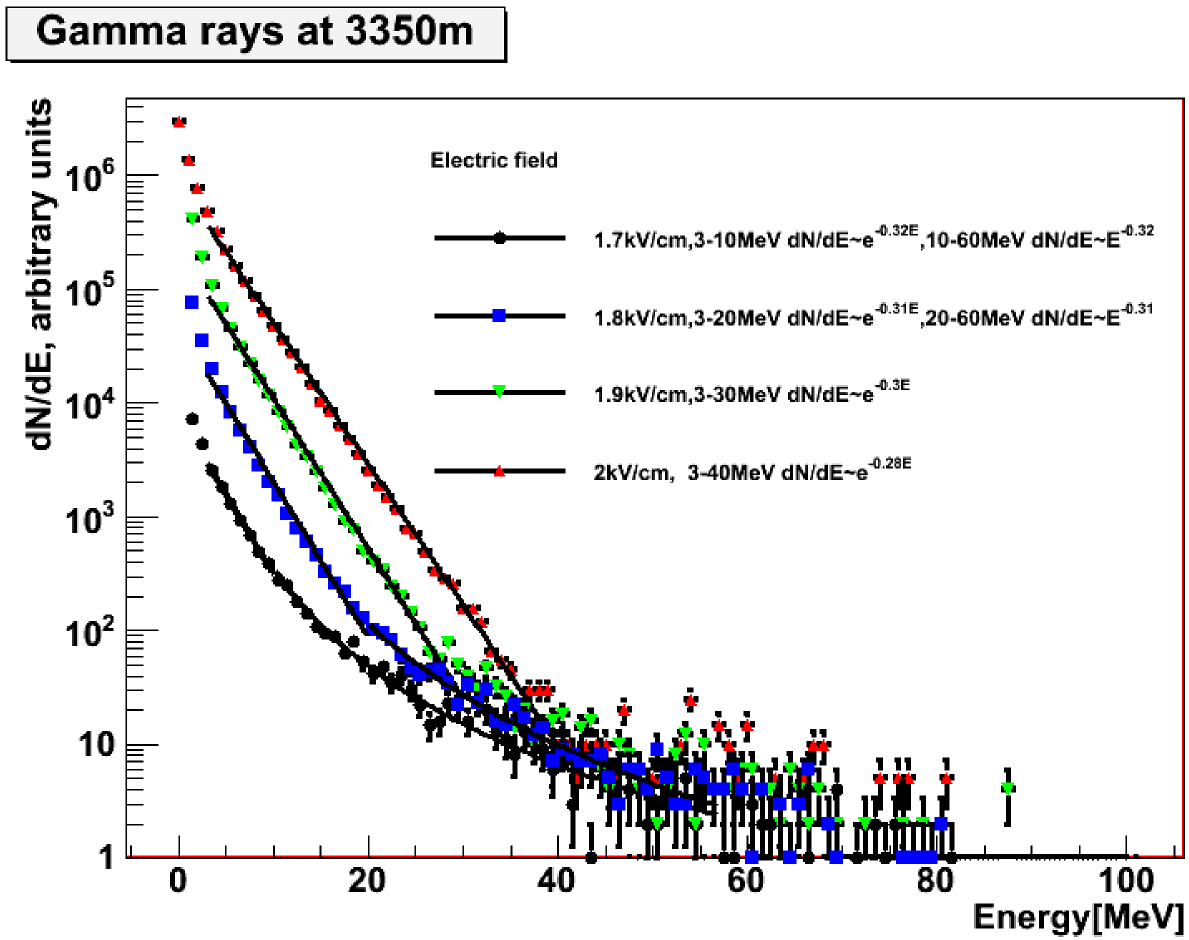
$$dN/dE \sim E^{-1,13} (1\text{-}100MeV)$$

$$dN/dE \sim E^{-2,2} (100\text{-}300MeV)$$

Differential energy spectra of electrons derived from simulations in different electric fields Seed electrons with energies 1-100MeV

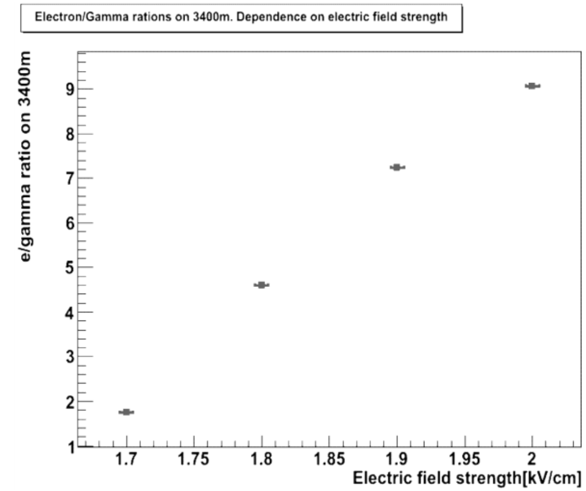


Differential spectra of gamma rays derived from simulations in different electric fields: seed electrons with energies 1-100MeV

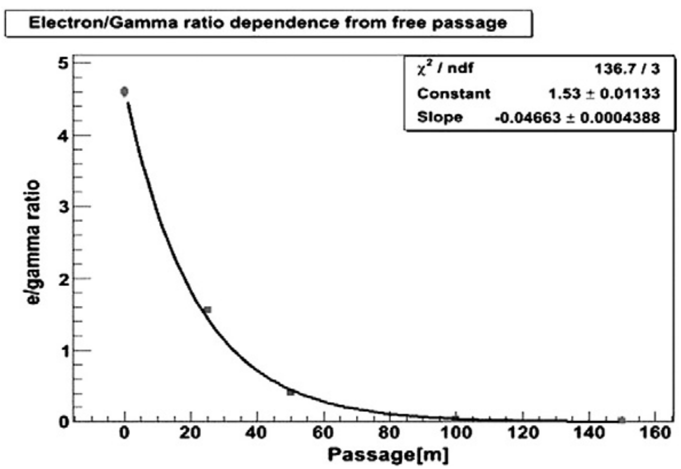


Proportion of electrons in the detected flux (e-/γ ration). Definition of thundercloud heights

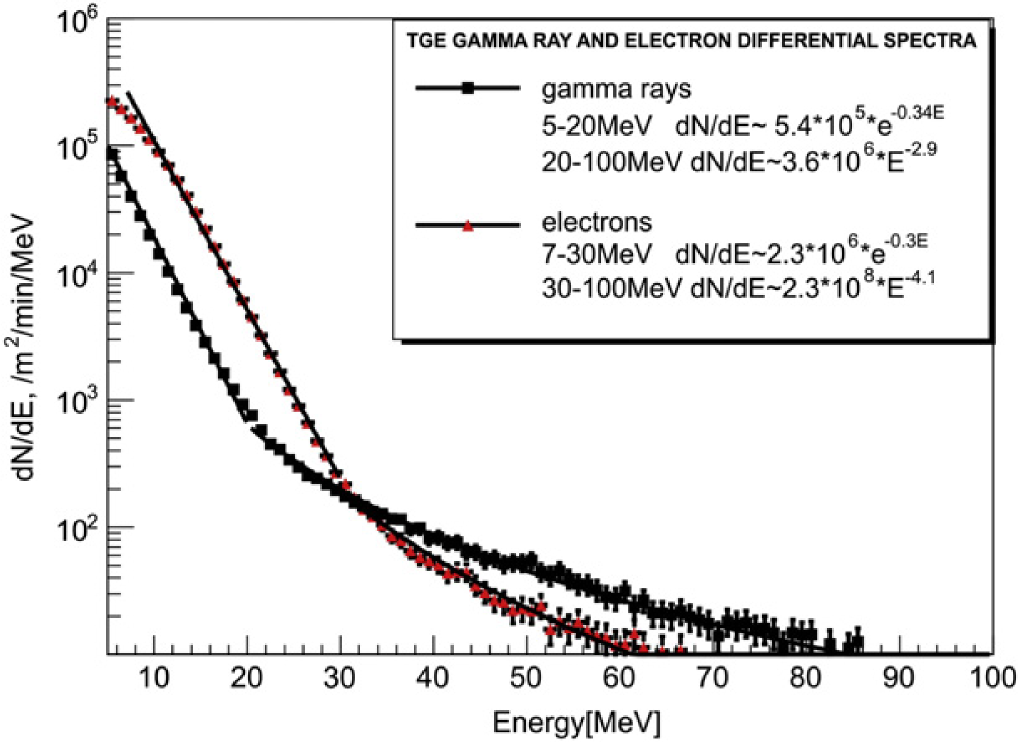
- Electron/ γ ratios at 3350m.: Dependence on electric field strength (E>7MeV)



- Dependence of the electron/gamma ray ratio on the free passage after quitting the electric field region (Electric field strength- 1.8kV/cm)

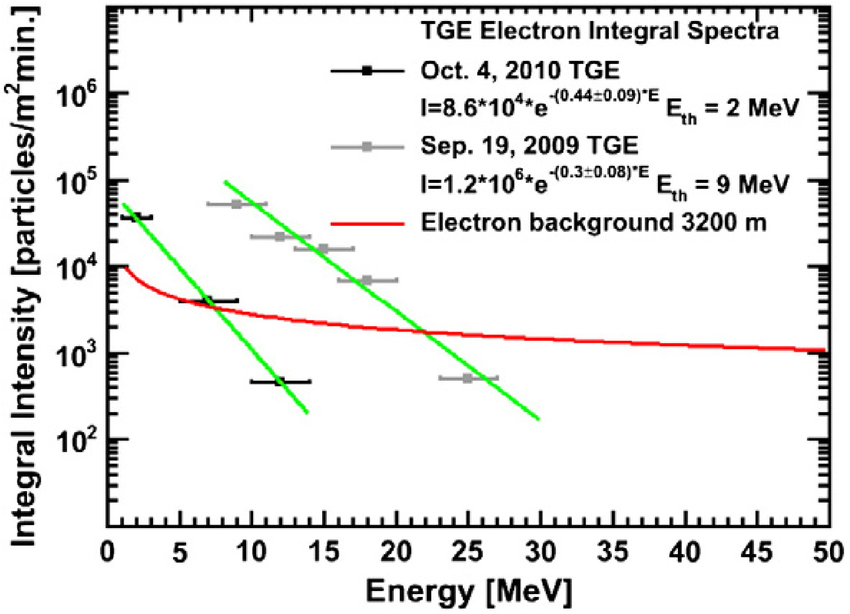


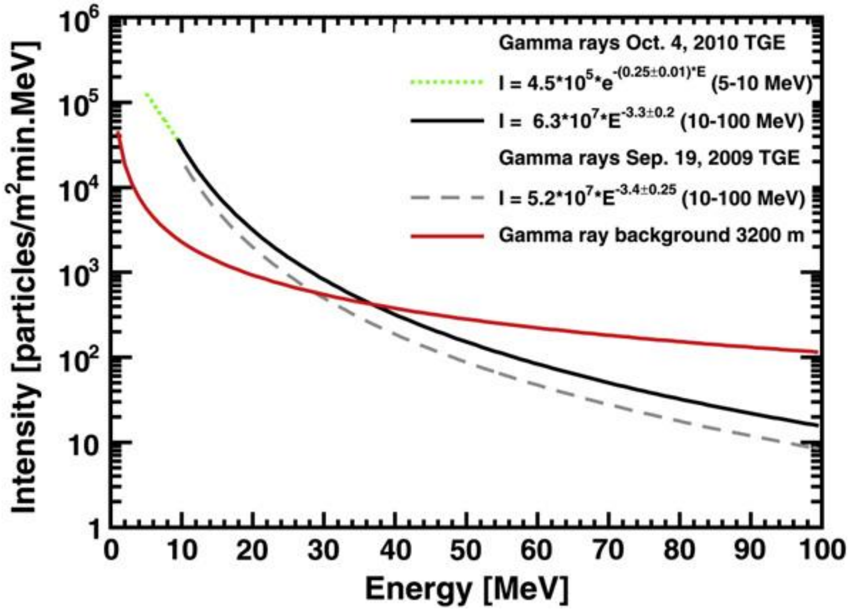
TGE particle spectra(right): differs from RREA spectra not only by exponential indexes, but also by high energy tails, which we can not get from 1 MeV seeds

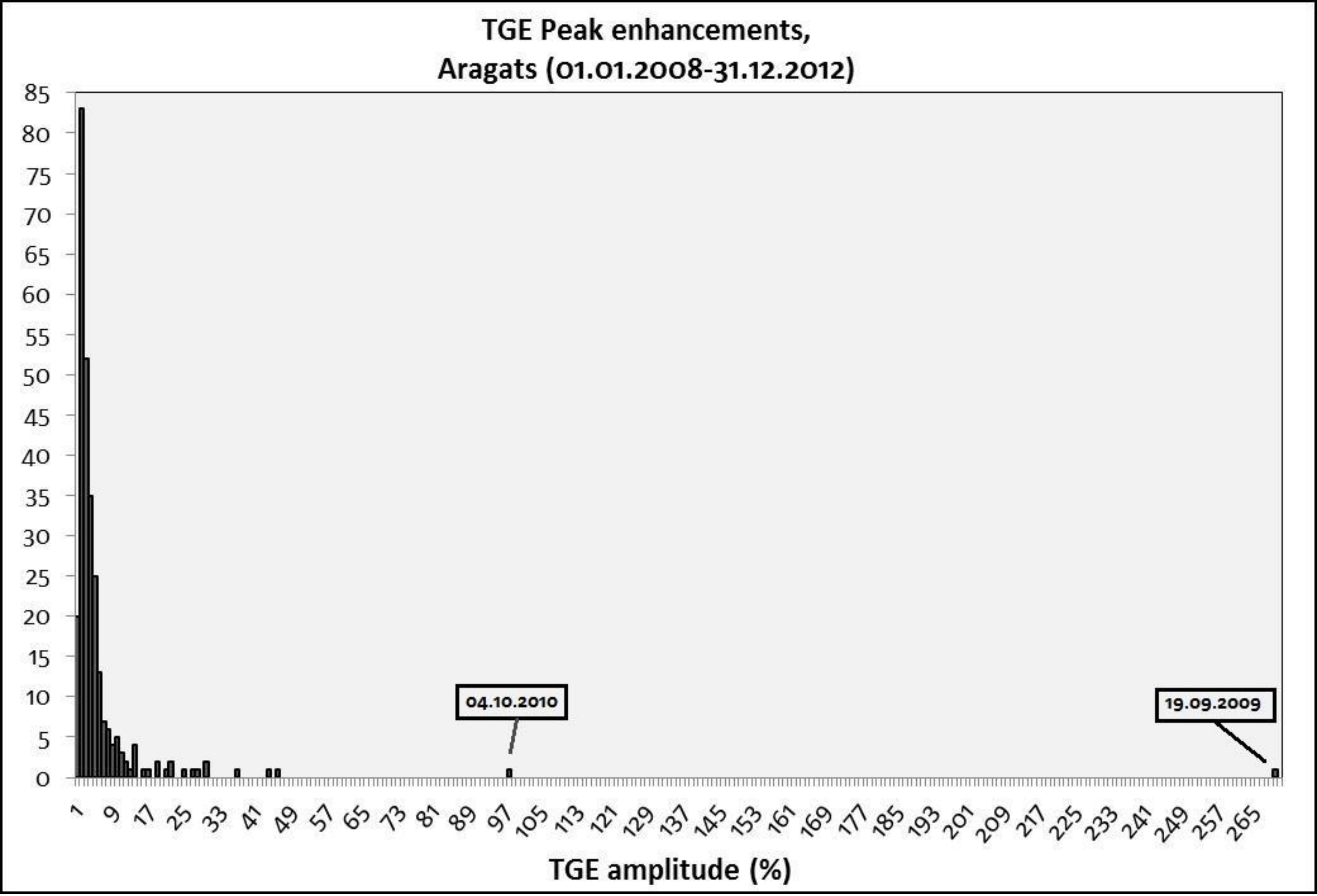


electrons I(1MeV) = $5.6*10^6$ /min/m^2
Gamma rays I(1MeV) = $1.134*10^6$ /min/m^2

Characteristics of two largest TGEs.
Electron and gamma ray spectra







The histogram of TGE amplitudes registered at Aragats in 2008–2012.

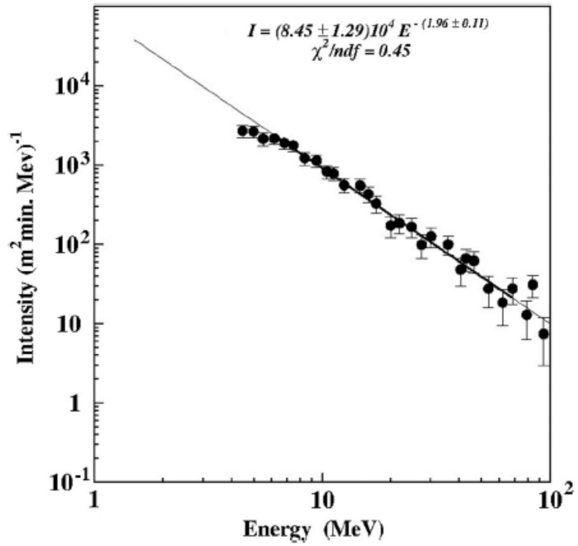


FIG. 8. Differential gamma ray energy spectrum; TGE of May 12, 2013; peak time at 06:36; exposition of 3 minutes.

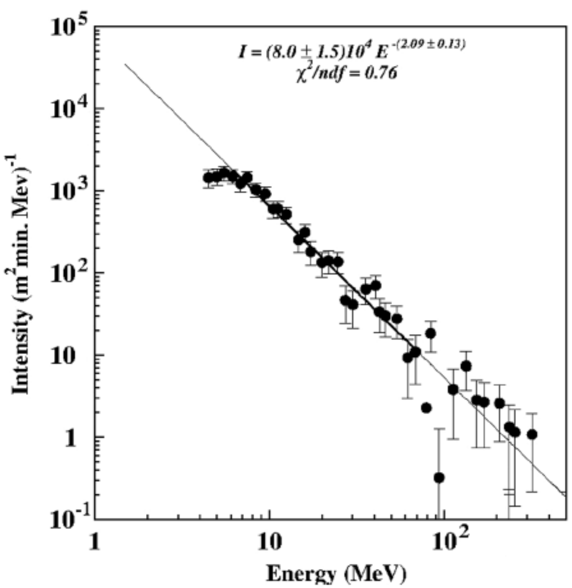


FIG. 9. Differential gamma ray energy spectrum; TGE of May 15, 2013; peak time at 12:30; exposition of 4 minutes.

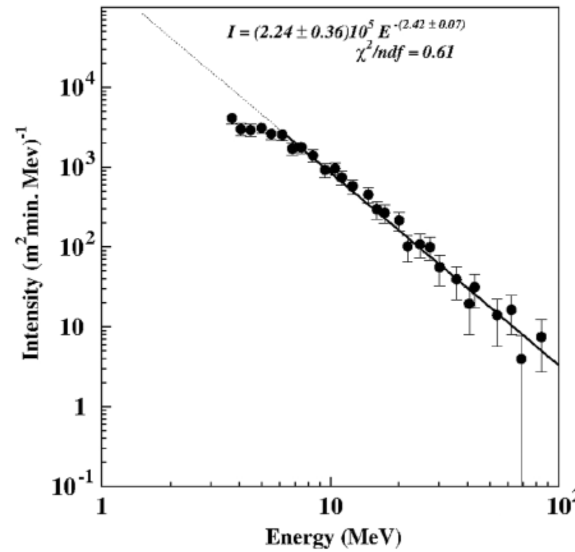


FIG. 10. Differential gamma ray energy spectrum; TGE of June 9, 2013; peak time at 21:47; exposition of 3 minutes.

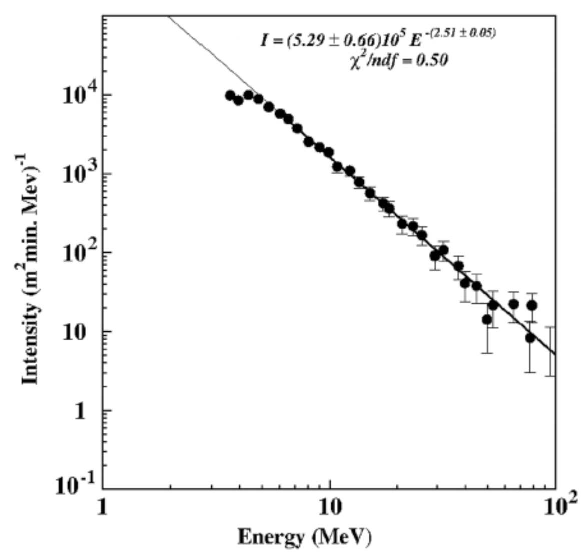
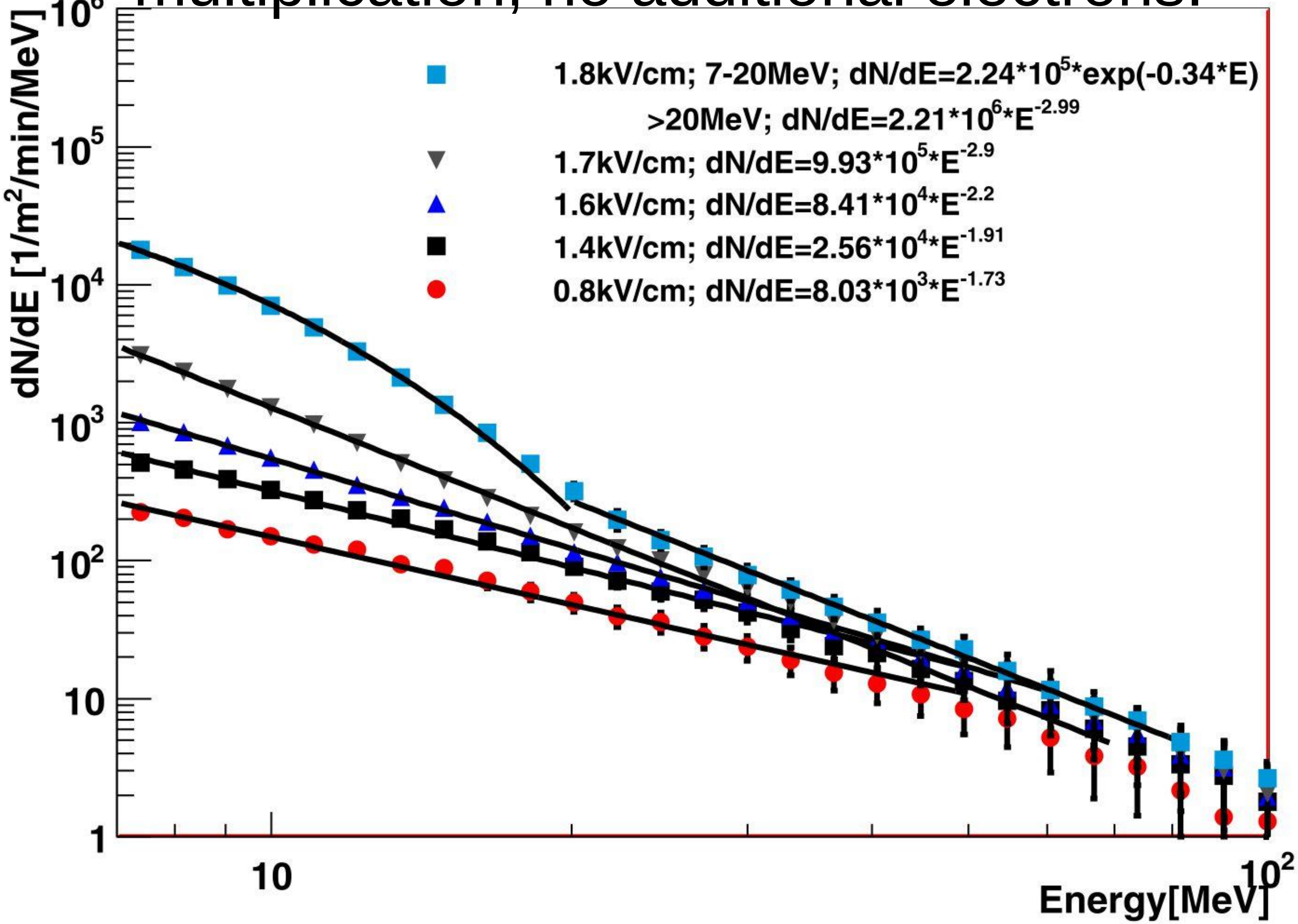
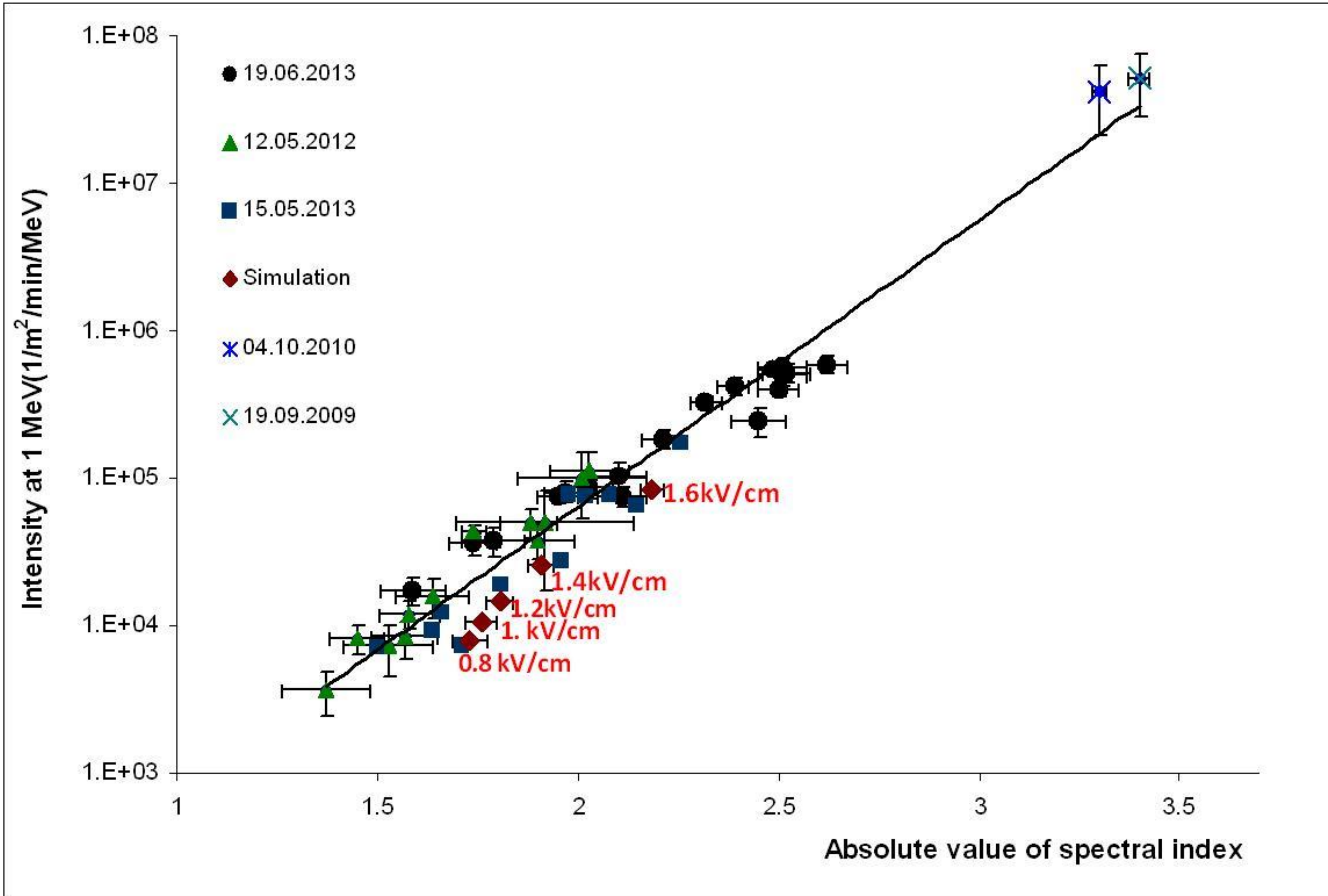


FIG. 11. Differential gamma ray energy spectrum; TGE of June 19, 2013; peak time at 07:36; exposition of 4 minutes.

Additional gamma rays withdrawing from lower than critical electric fields. No electron multiplication, no additional electrons.





1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
19.06.2013
12.05.2012
15.05.2013
Simulation
04.10.2010
19.09.2009
1.6kV/cm
1.4kV/cm
1.2kV/cm
1. kV/cm
0.8 kV/cm
Intensity at 1 MeV(1/m^2/min/MeV)
1
1.5
2
2.5
3
3.5
Absolute value of spectral index

Conclusion

We suggest two component model of TGE generation

- TGE initiation via RREA process. When the atmospheric electric field strength exceeds the critical value and we observe multiplication of seed electrons and large (100%) increases of gamma rays. Very rare registration of such events.
- Initiation via spectrum modification, when the strength of an electric field doesn’t exceed the critical value. However, the electrons gain “additional path length”: The probability of high energy bremmstrahlung increases. The same effect we observe also in cases of bigger than critical electric fields for high energy particles