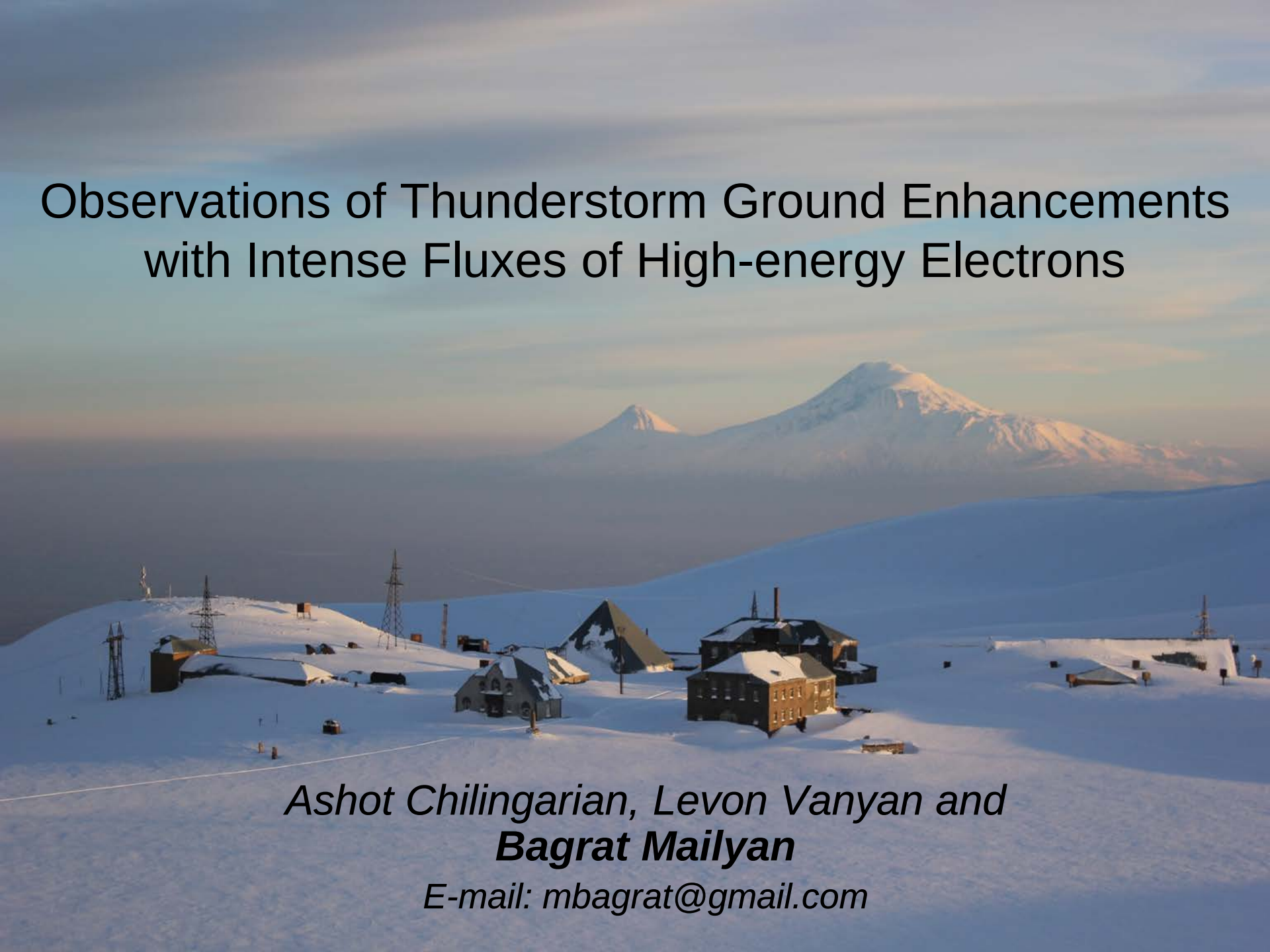
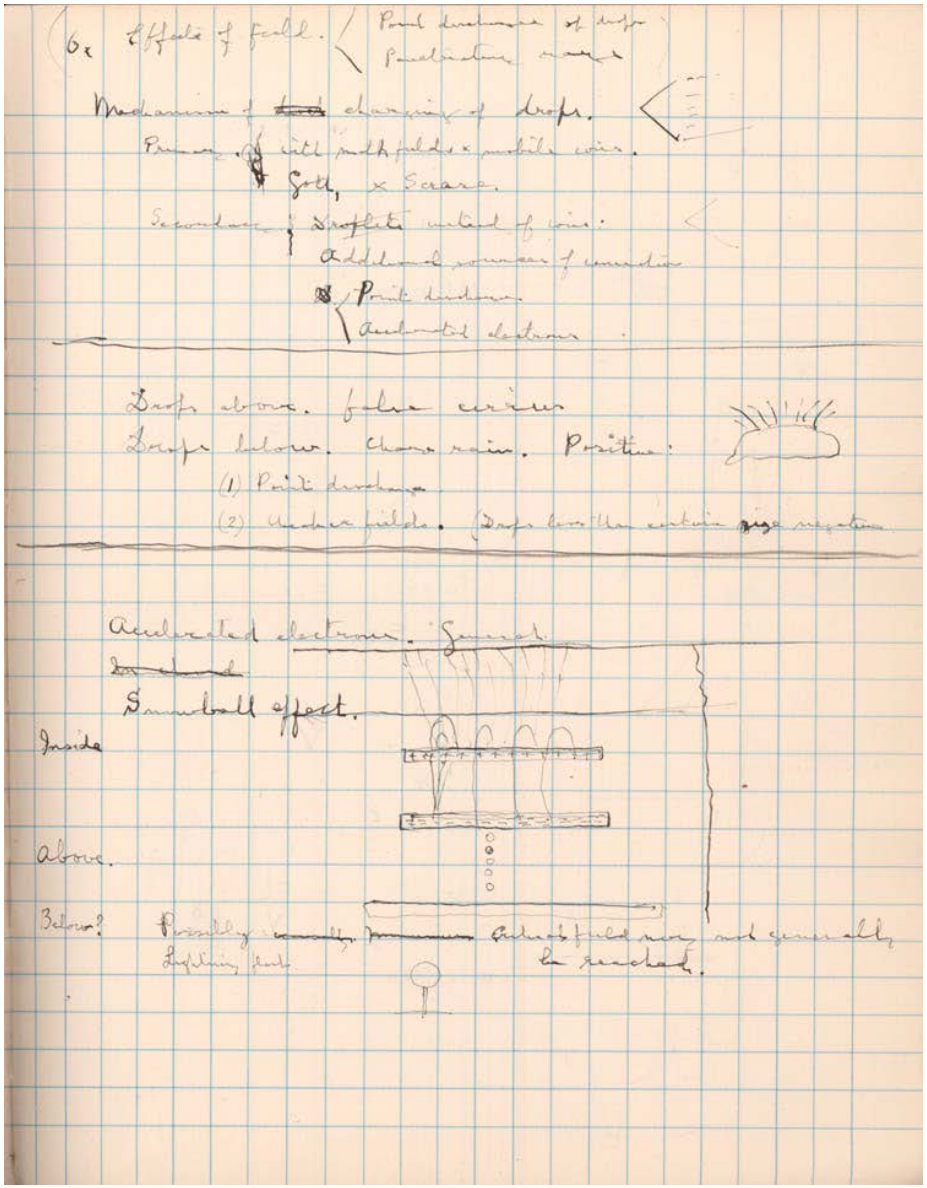
Observations of Thunderstorm Ground Enhancements with Intense Fluxes of High-energy Electrons



Ashot Chilingarian, Levon Vanyan and
Bagrat Mailyan
E-mail: mbagrat@gmail.com

High energy electrons from thunderclouds



Wilson CTR (1925). "The acceleration of beta-particles in strong electric fields such as those of thunderstorms". *Proc. Cambridge Philos. Soc.* **22** (04): 534–8.

“In a field of 20 kV/cm the energy supplied to β-particle will exceed the average loss; so that particle will be continuously accelerated until some accident occurs”.

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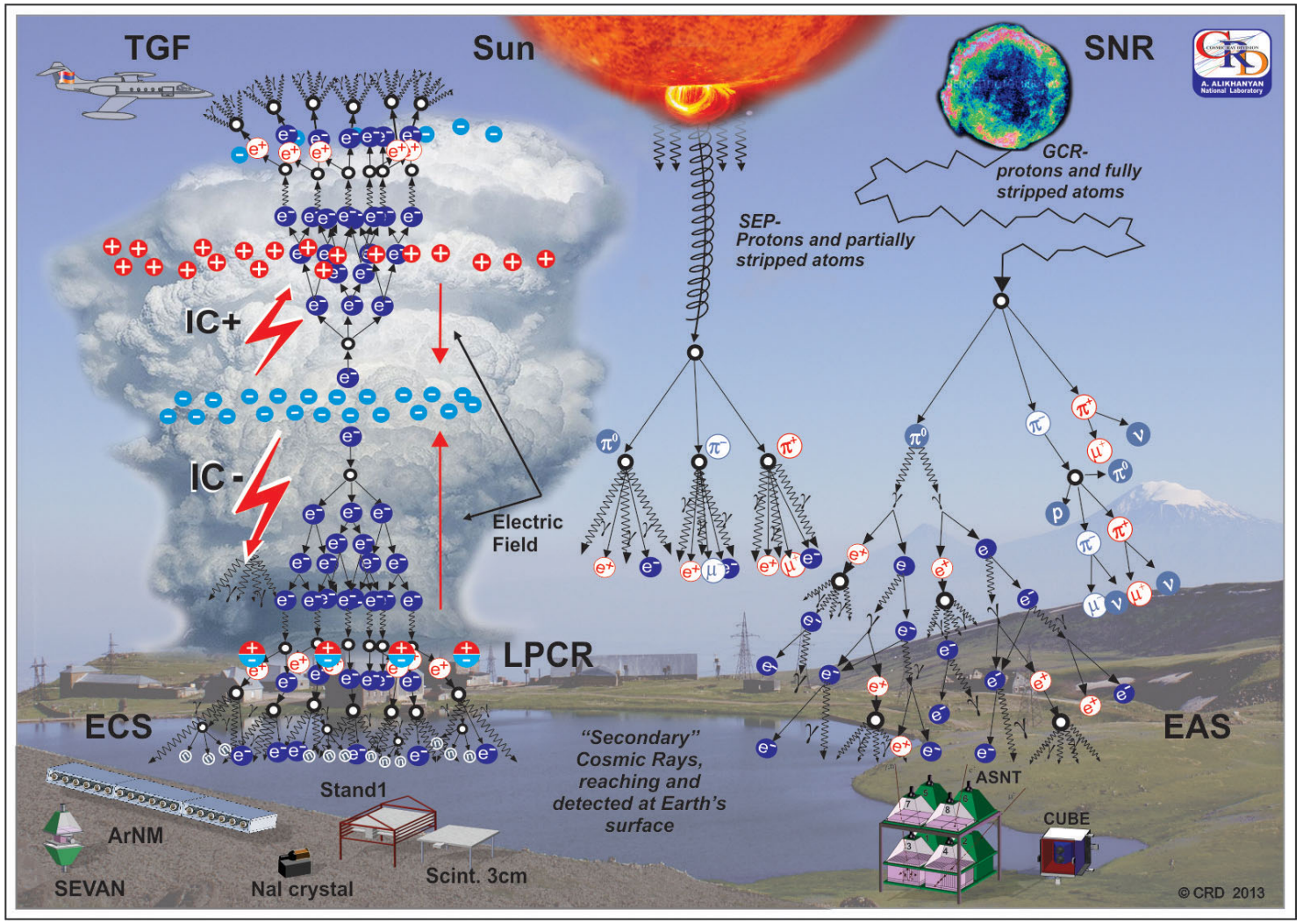
Relativistic Runaway Electron Avalanches (RREA) and Thunderstorm Ground Enhancements (TGEs)



TEPA-2013

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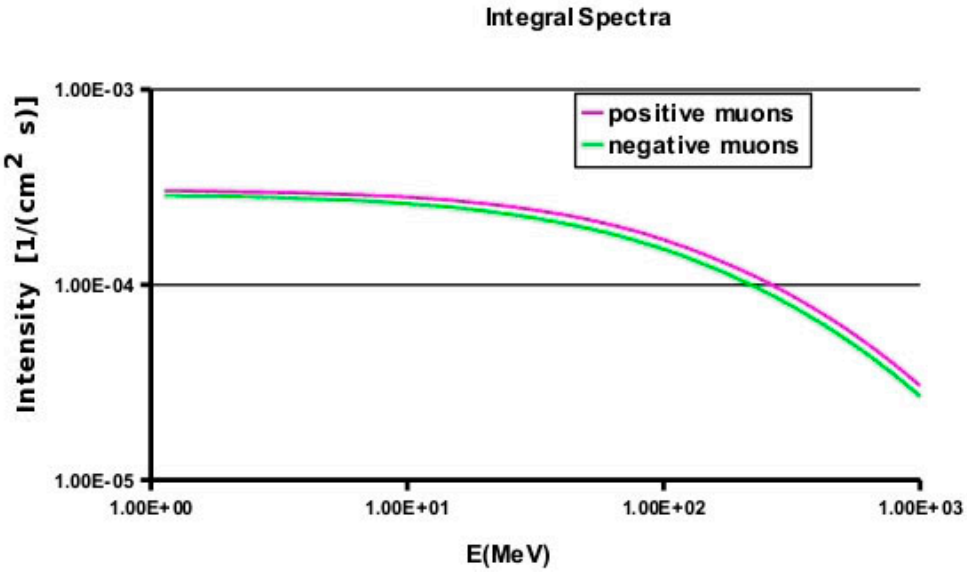
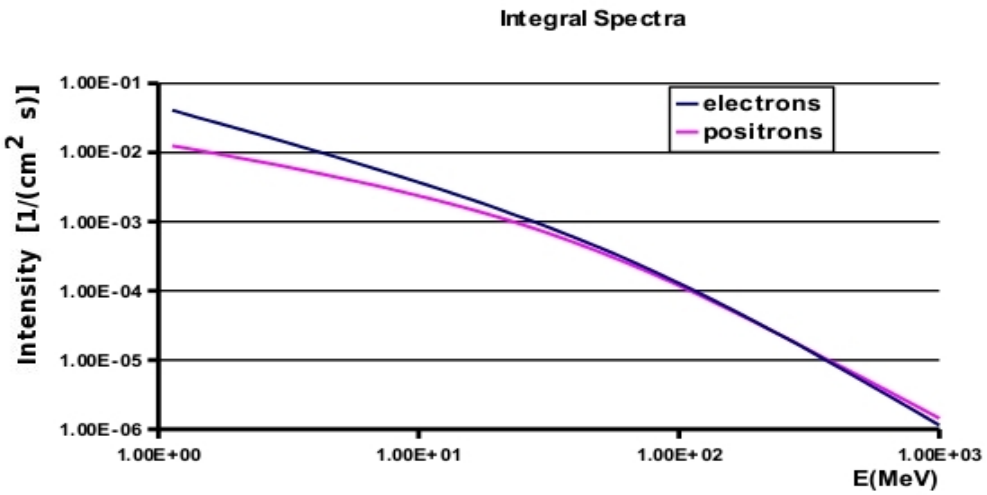
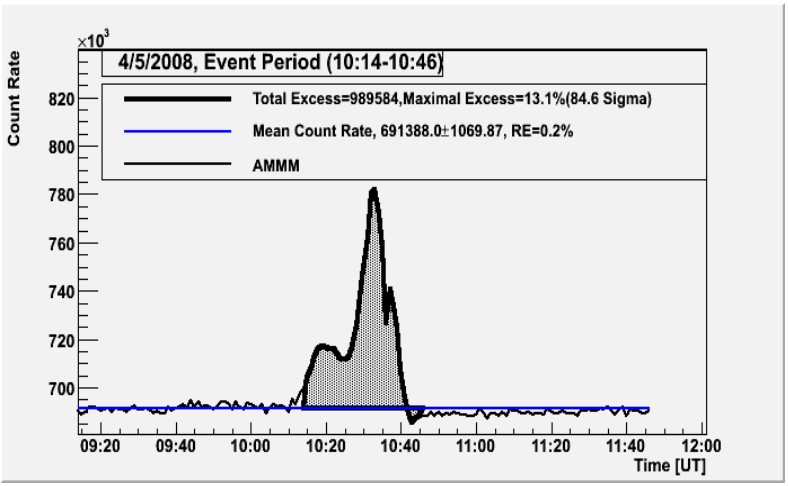
Modification of secondary cosmic ray particle spectra

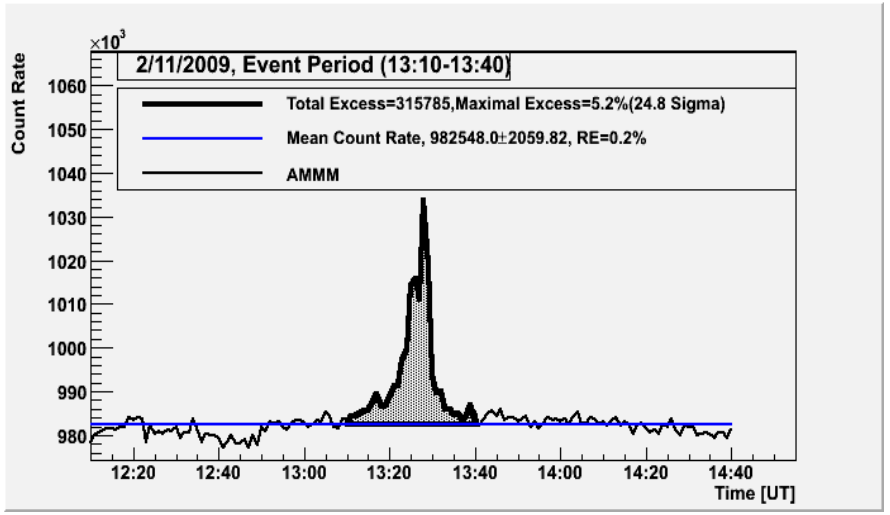


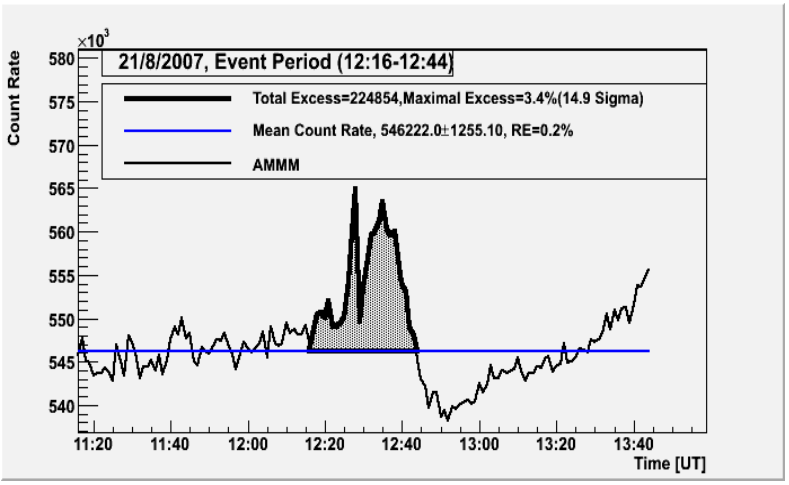


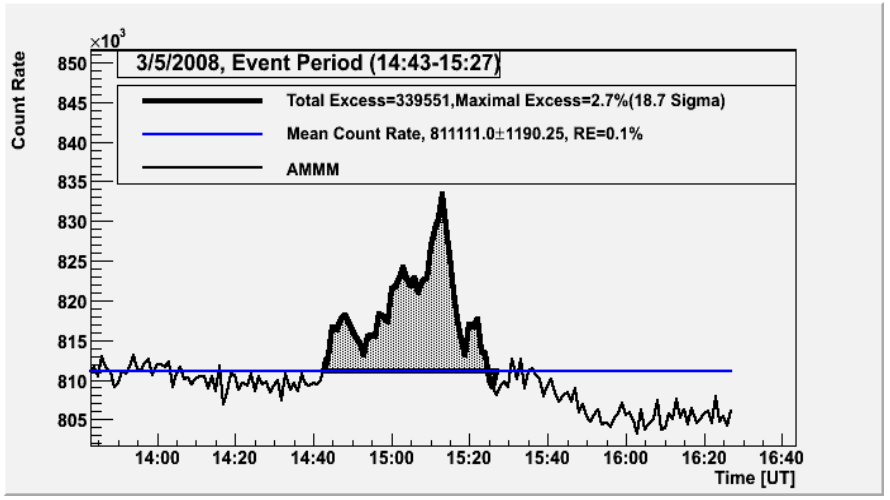
See the presentation by Levon Vanyan on Modification Of Spectra (MOS) effects!

Particle fluxes from thunderclouds



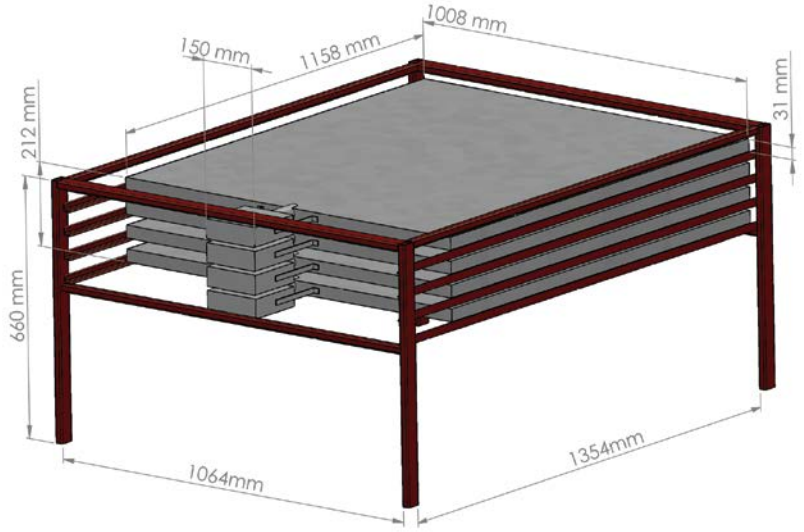


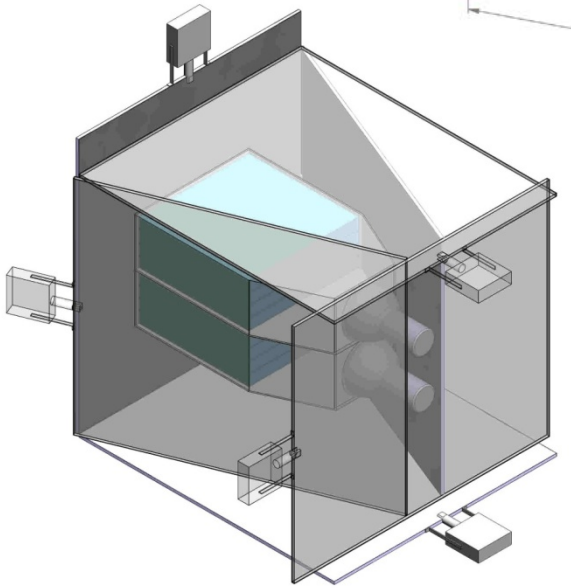


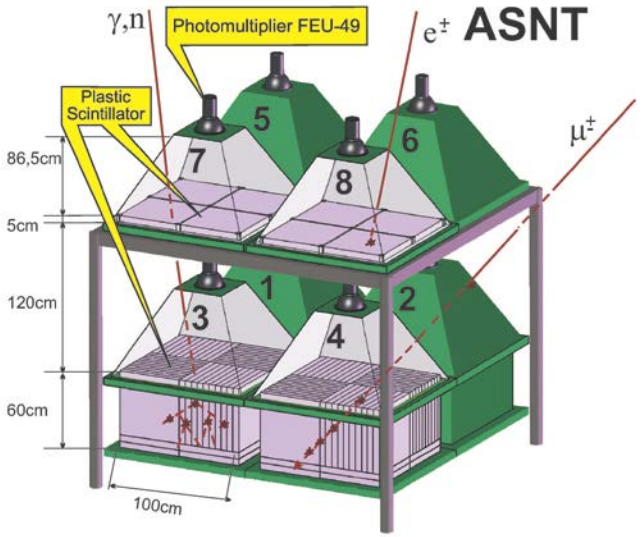


See the presentation by Tigran Karapetyan on the statistical study of TGEs!

Particle detectors enabling TGE particle separation and high energy electron detection







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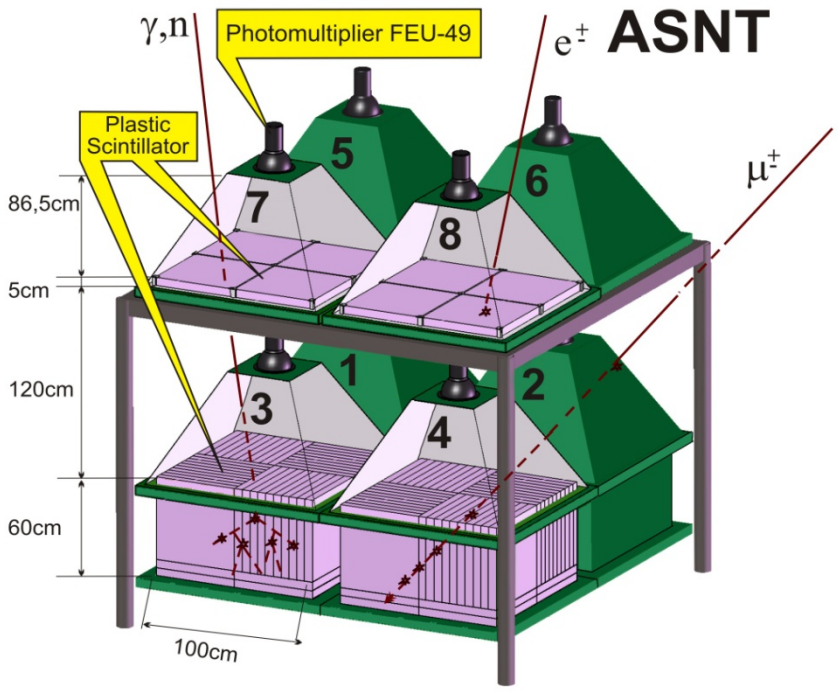
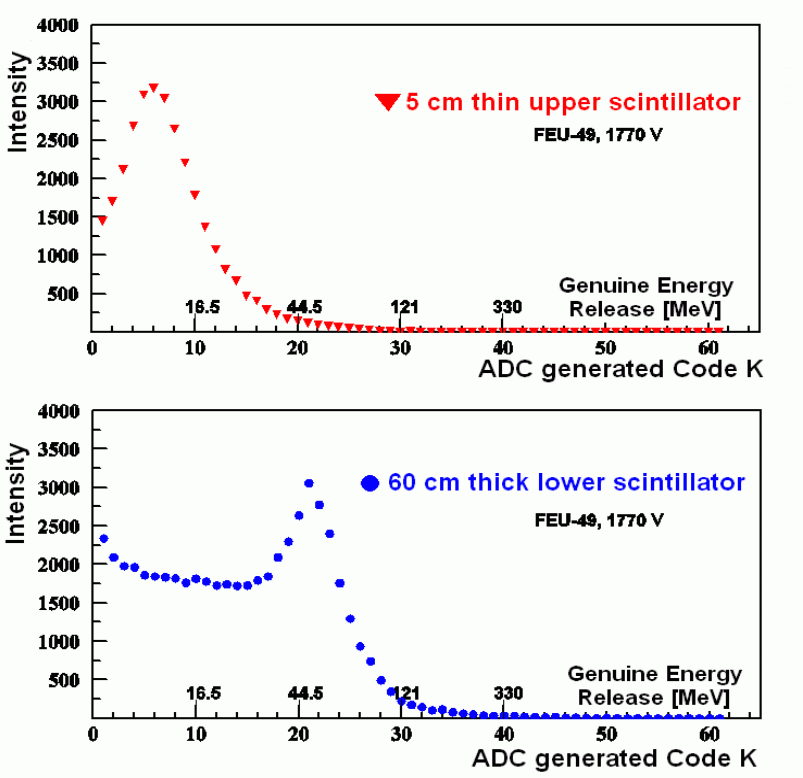
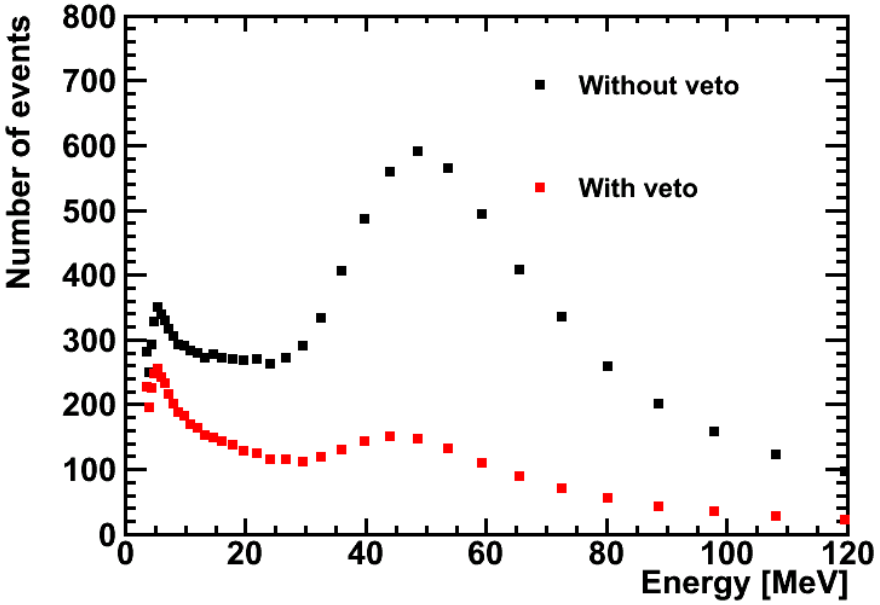
Aragats Solar Neutron Telescope (ASNT)

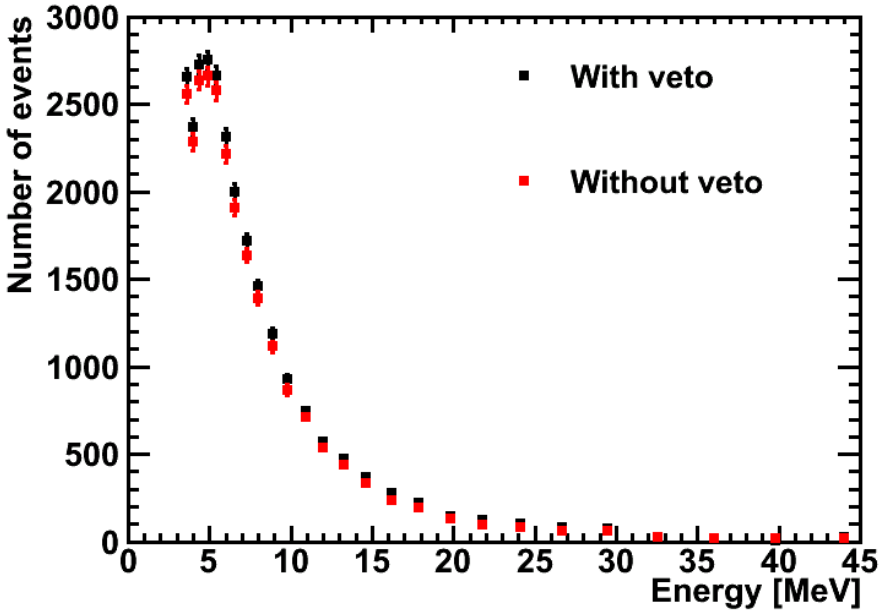




Measuring not only particle count rate, but also energy releases spectra in scintillators!

Cube energy deposit spectra for background cosmic ray particles and October 4, 2010 TGE particles





The TGE gamma ray recovery procedure

The unfolding of the gamma ray spectrum above the roof of the building (if it's an indoor detector) at altitude of 3200 m was made in the following way:

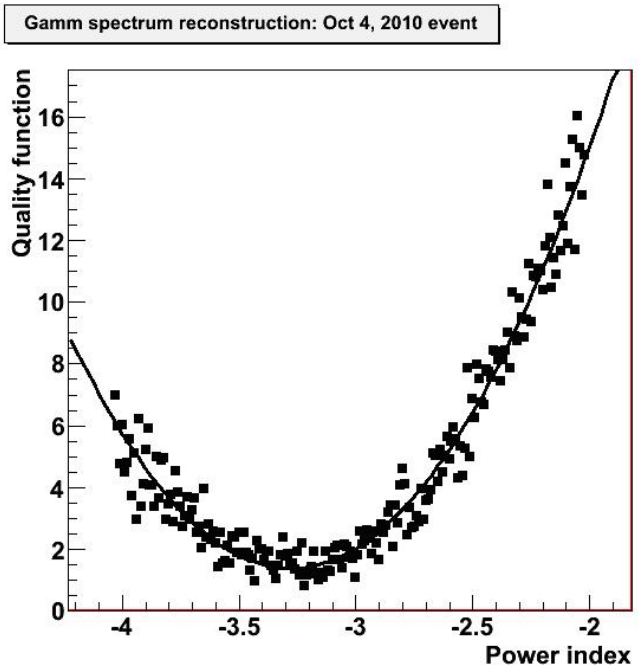
•A power spectrum with initial parameters randomly chosen from predetermined interval is generated;

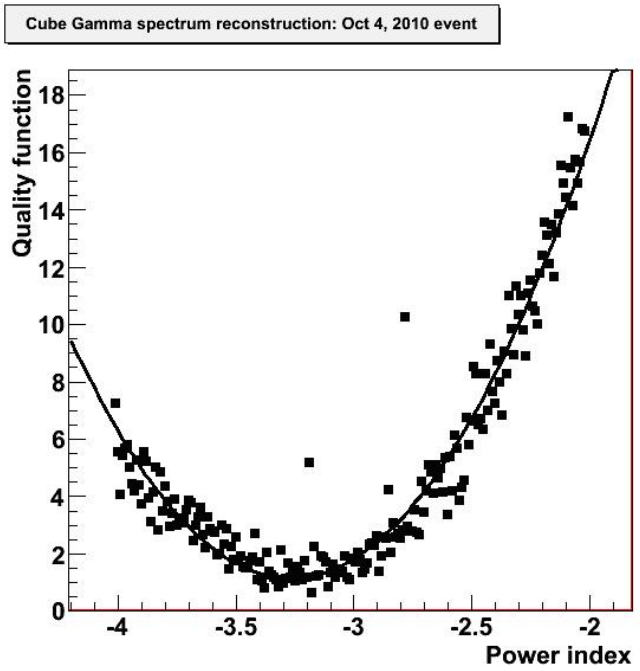
•This spectrum is used to simulate traversal of gamma rays via roof and ASNT detector components to finally obtain simulated energy release spectrum;

•The obtained simulated spectrum is compared with experimental one; the discrepancy (quality function) and initial spectrum parameters are stored;

•If number of iterations is not fulfilled go to step 1.

The TGE gamma ray recovery procedure: October 4, 2010 event





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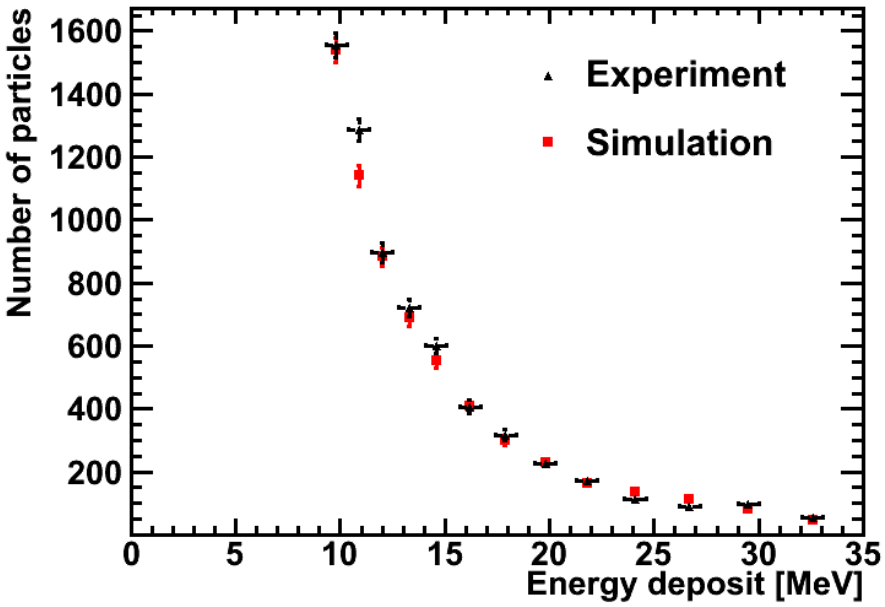
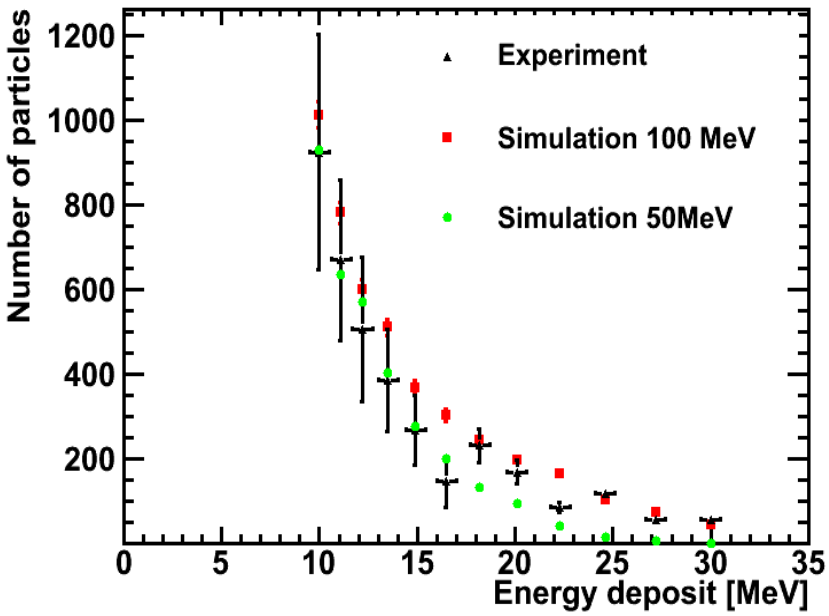
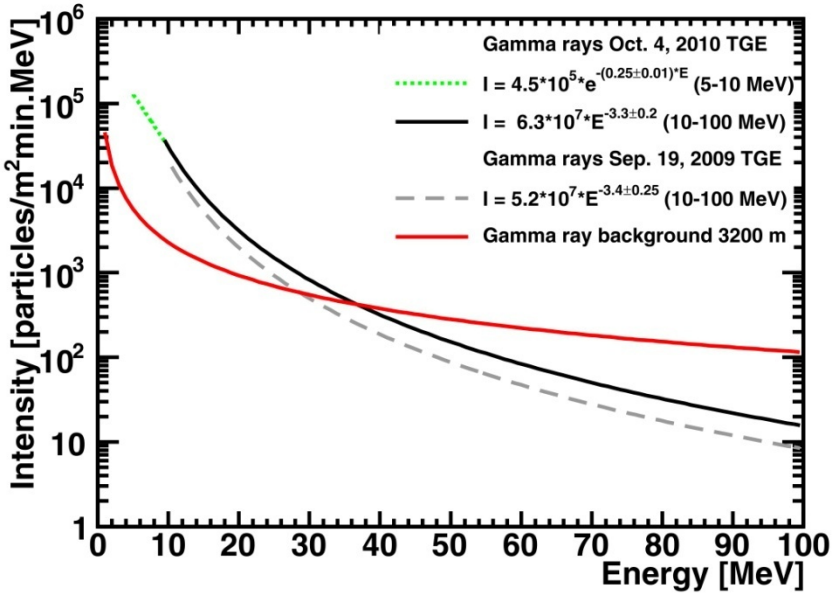
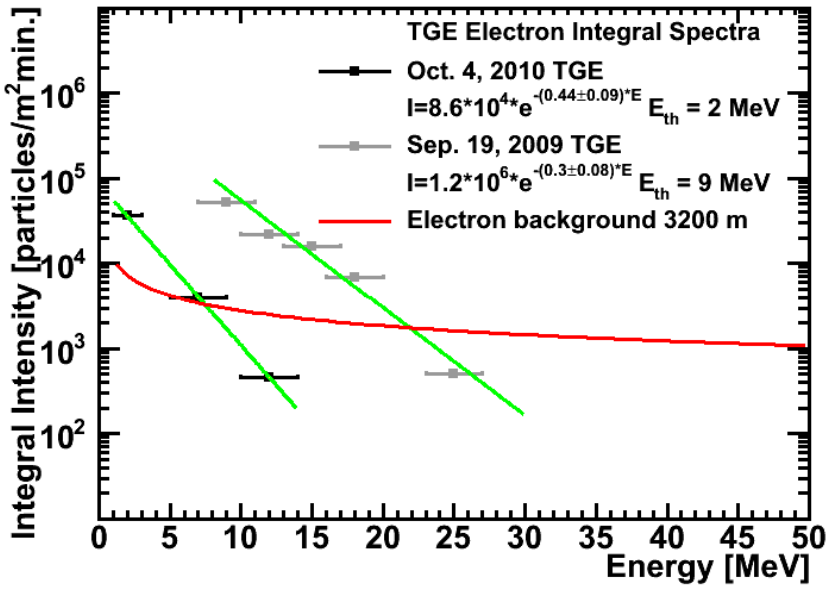
Obtained from simulation and measured energy deposits



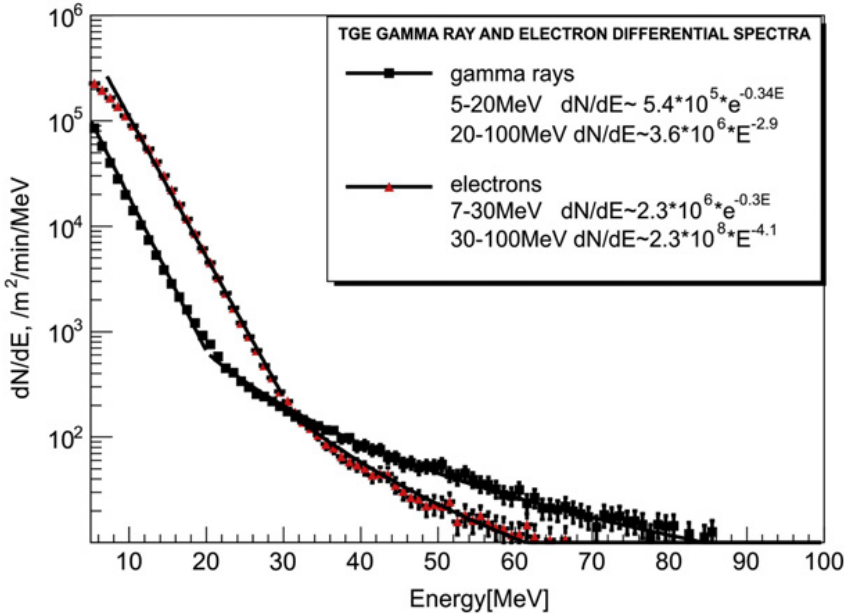


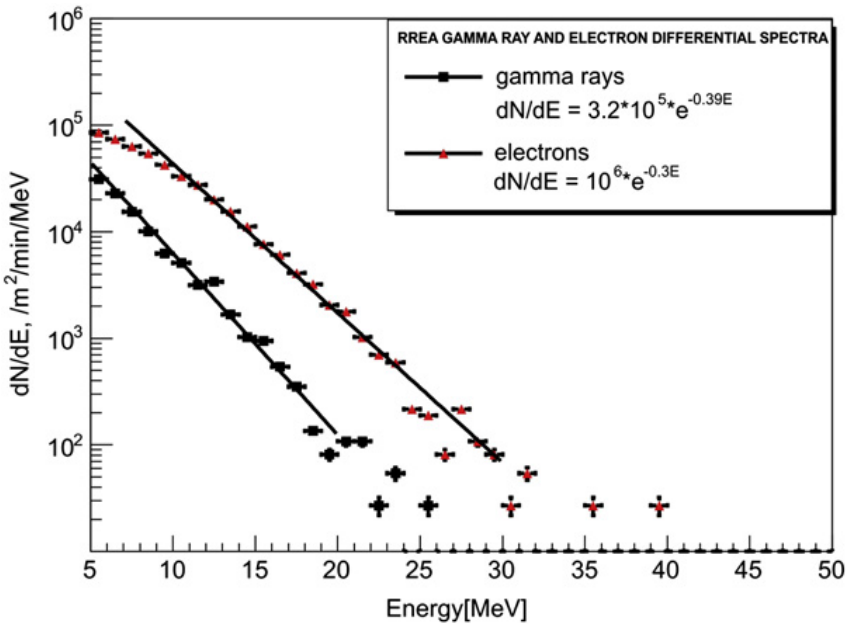
The energy spectra of the largest detected TGEs



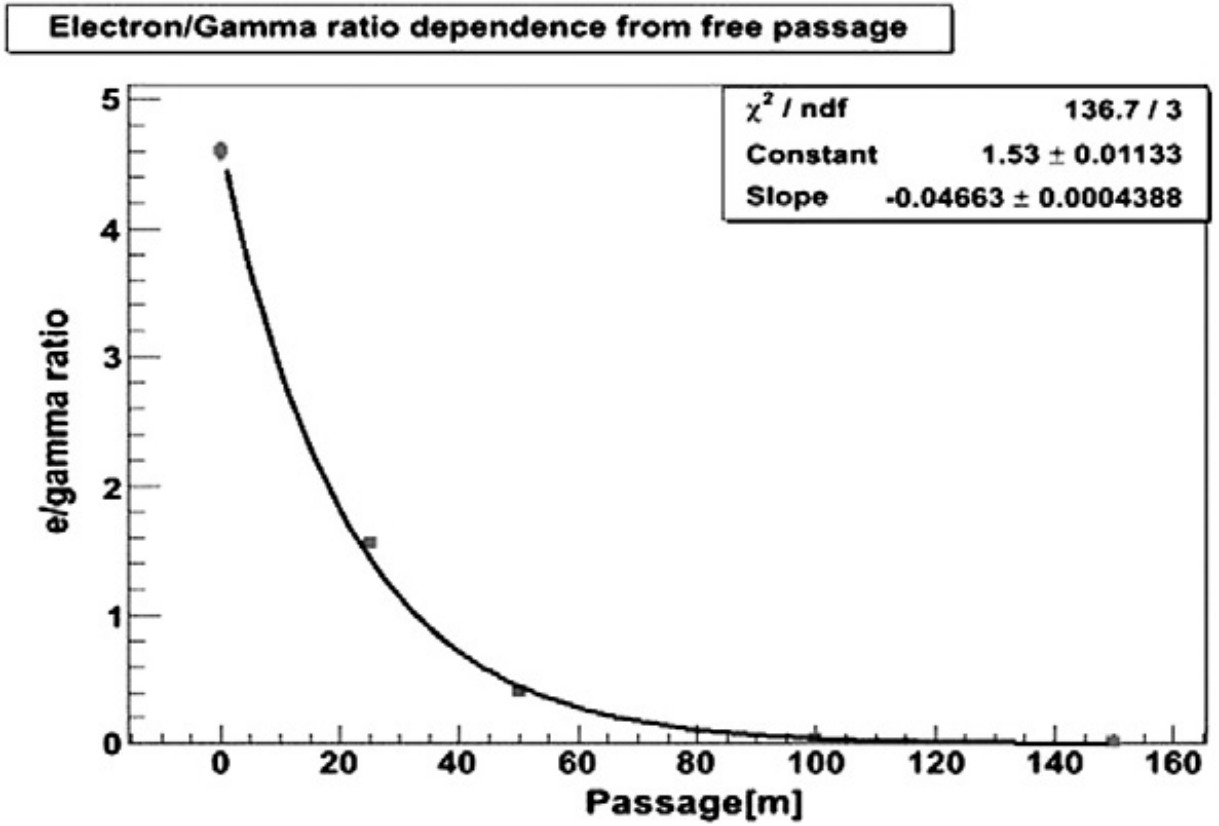


TGE gamma ray and electron spectra(right) and RREA gamma ray and electron spectra (left) 1500 m field length and 1.8.kV/cm field strength



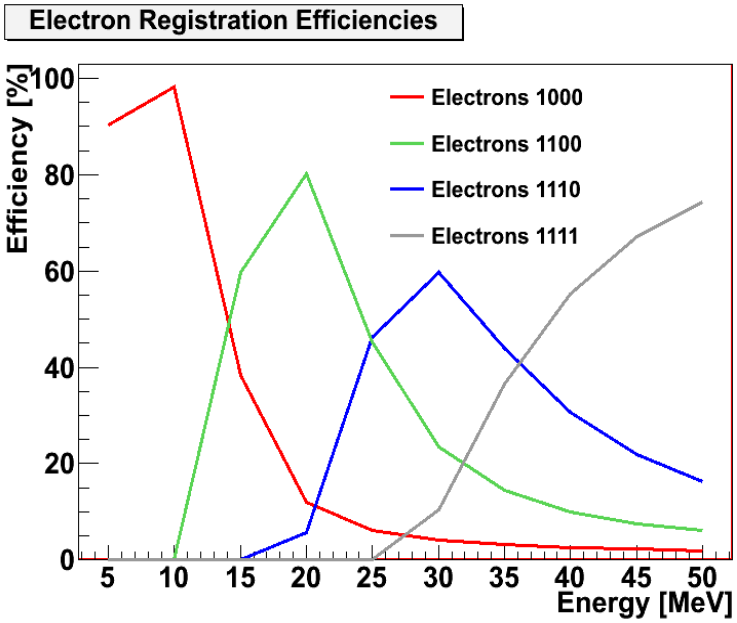


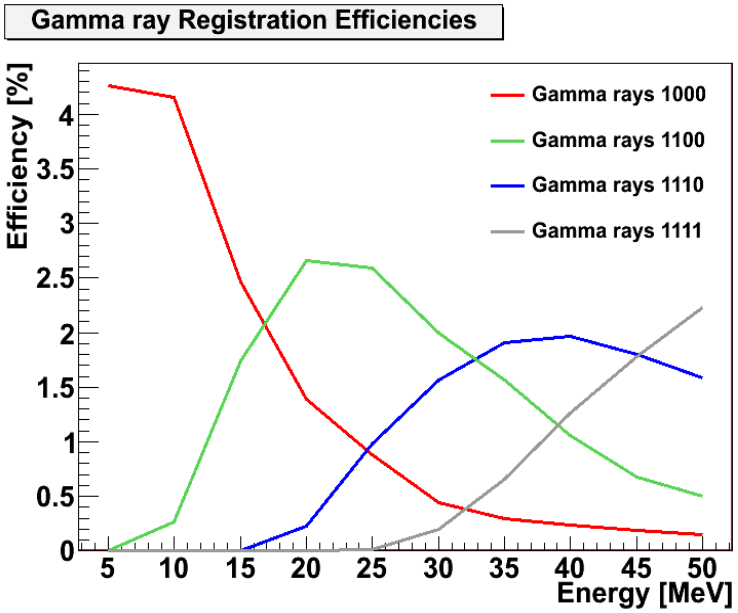
Thundercloud height estimation using e^-/γ ratio dependence on free passage after coming out from electric field region

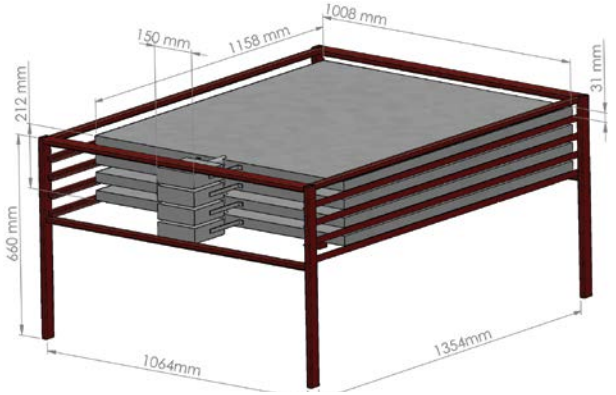


The thundercloud height is ~50-150 m for electron TGEs.

The electron and gamma ray registration efficiencies and October 7, 2012 TGEs detected by Stand3







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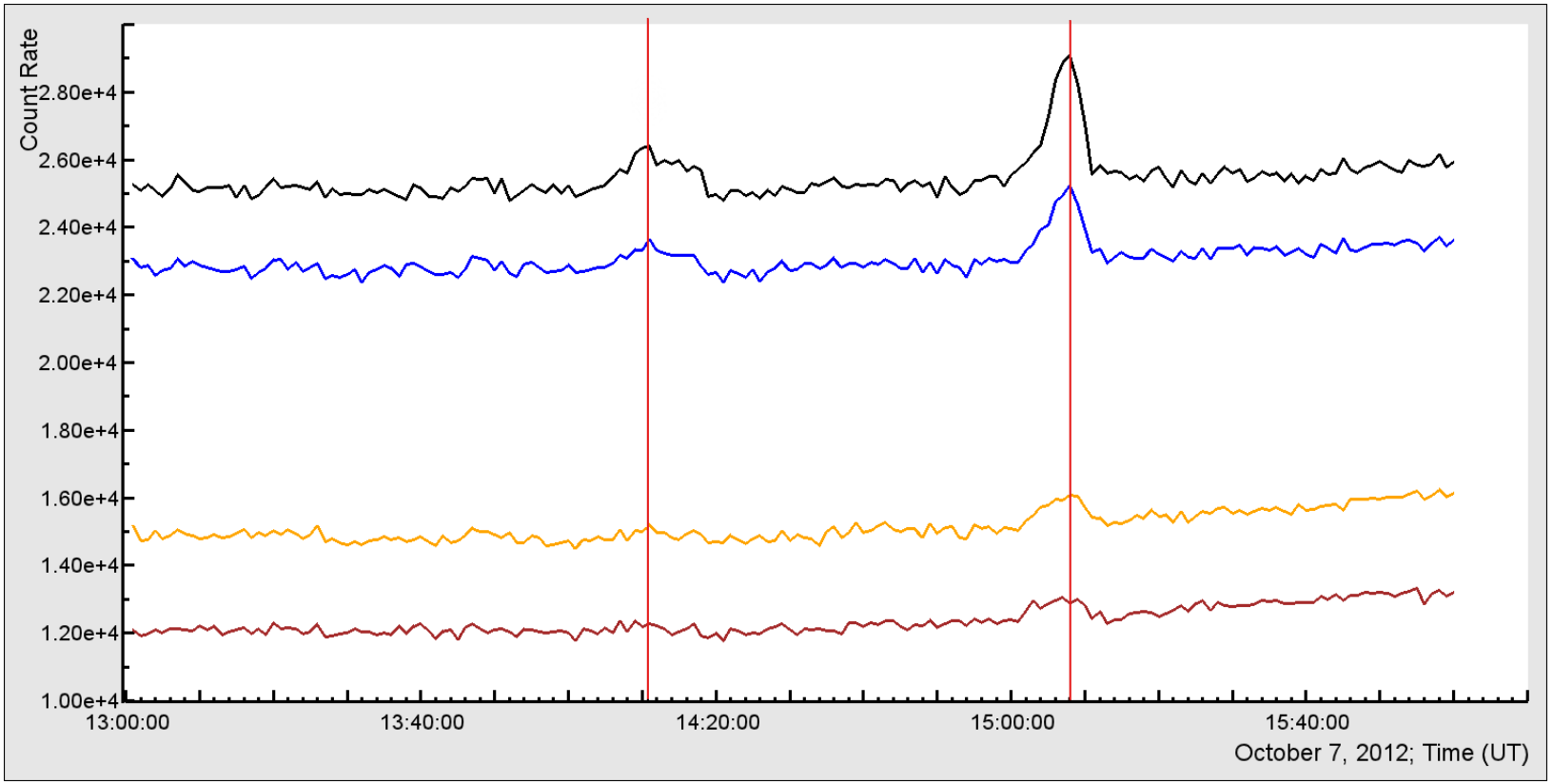
Thunderstorm Ground Enhancements (TGEs) of October 7, 2013



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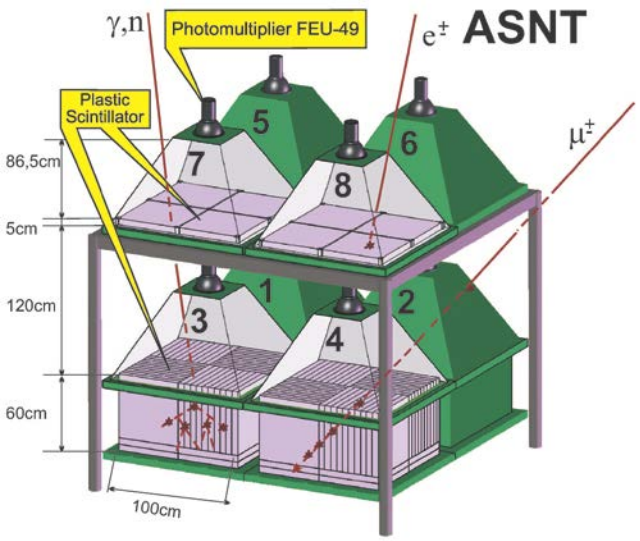
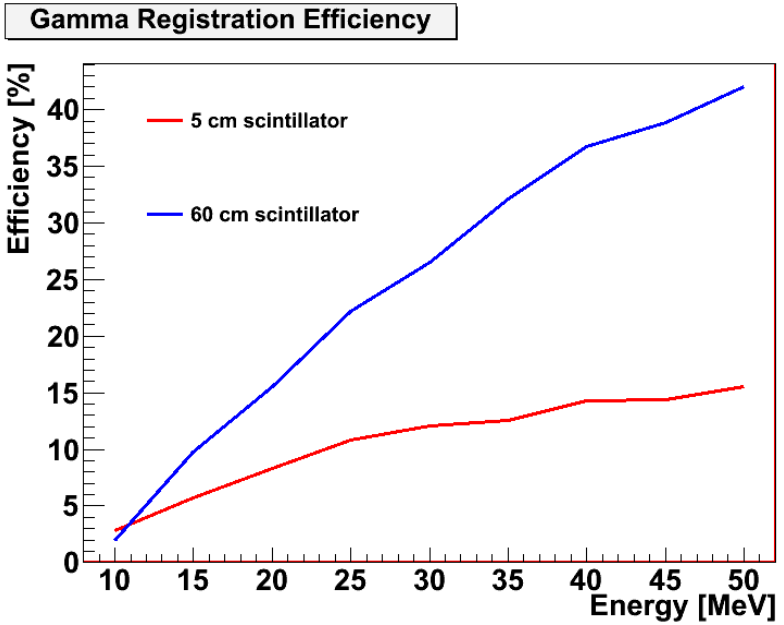
Count rate enhancements (or deficit) detected by STAND3 on October 7, 2012 in standard deviations

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

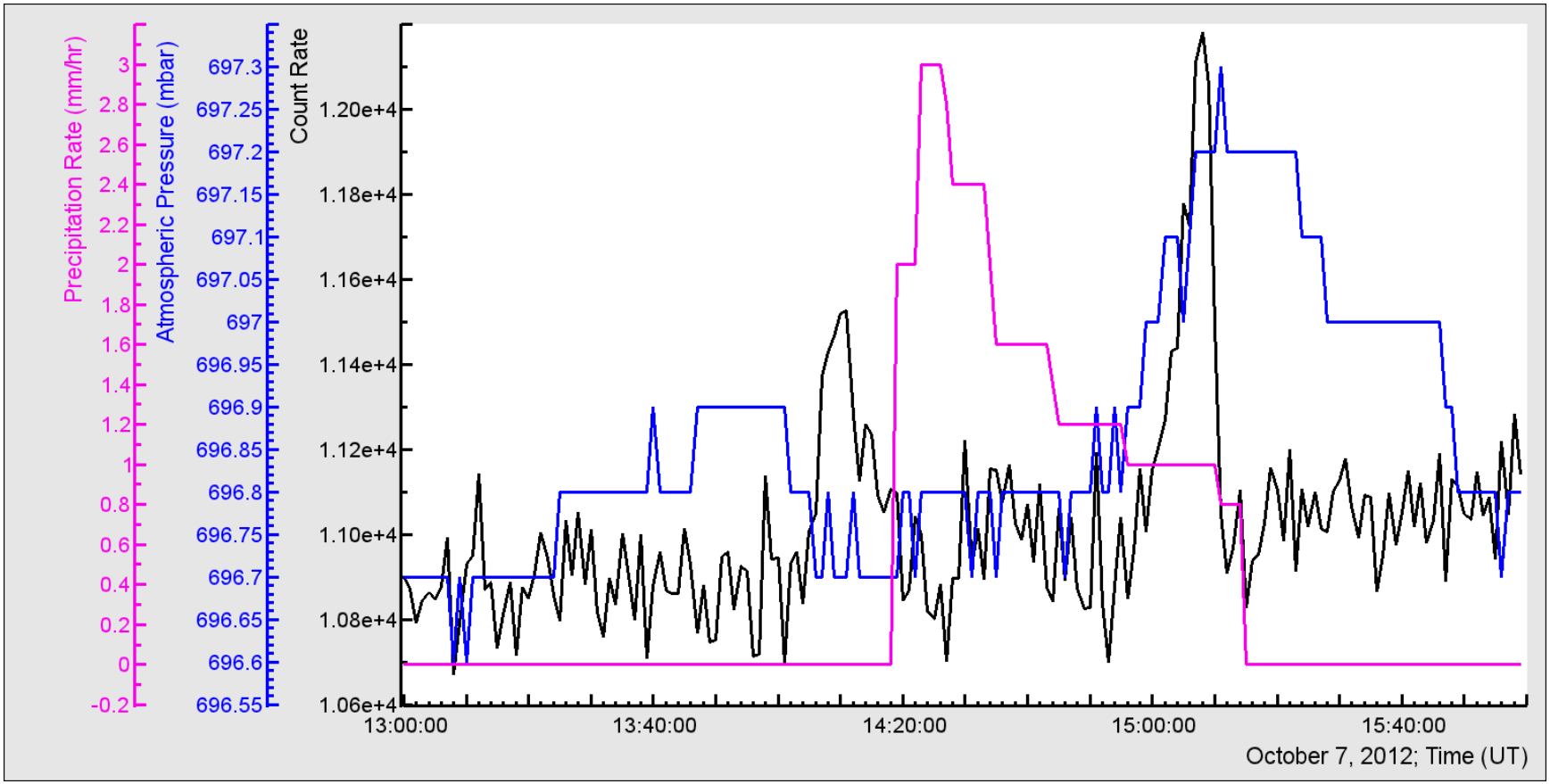
The gamma ray registration efficiencies and October 7, 2012 TGEs detected by ASNT





ASNT layer	60 cm	5 cm
The first peak 14:11	919	1110
The second peak 15:08	1018	2357

Correlations with meteorological parameters



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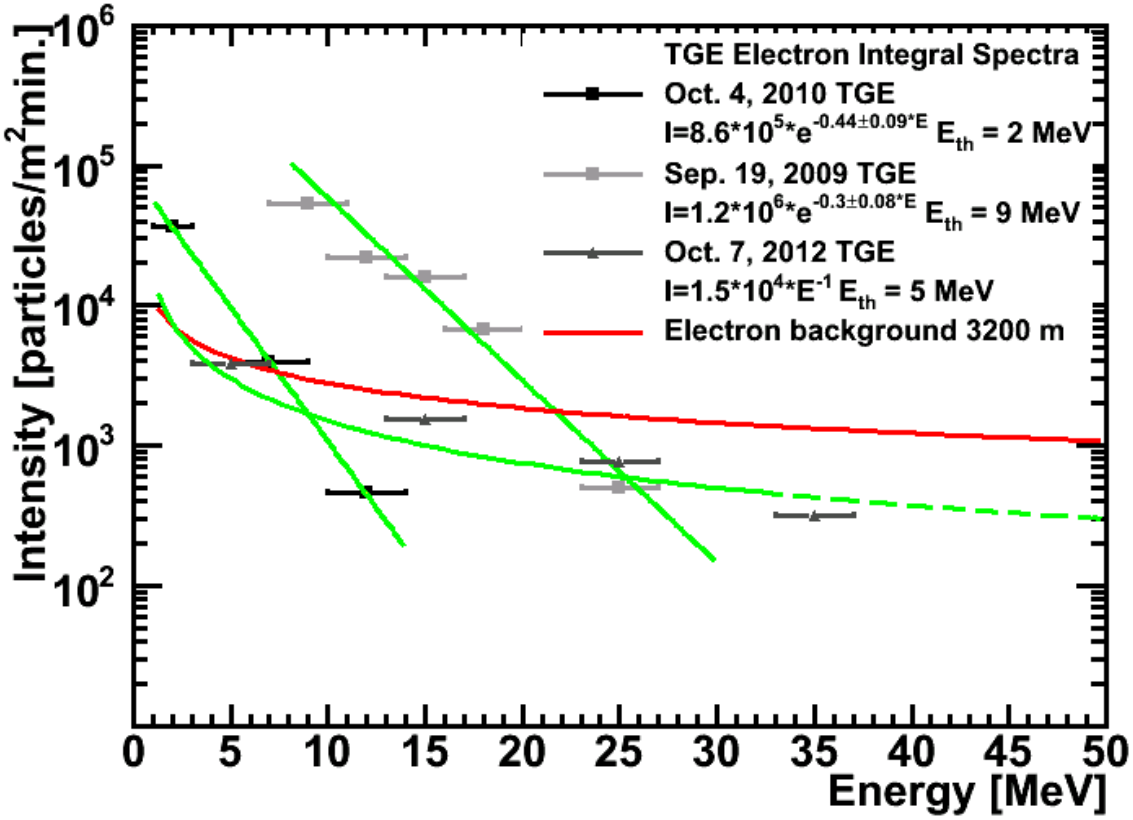
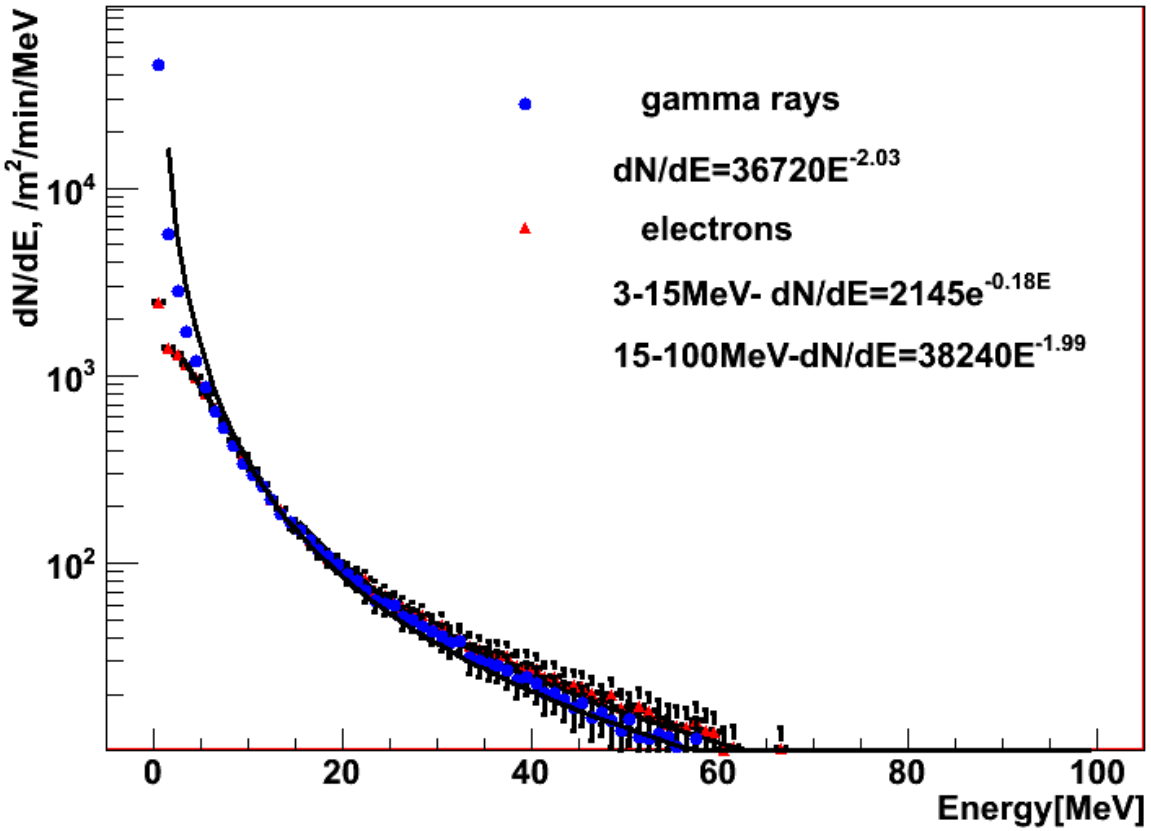
The electron spectra of the TGEs

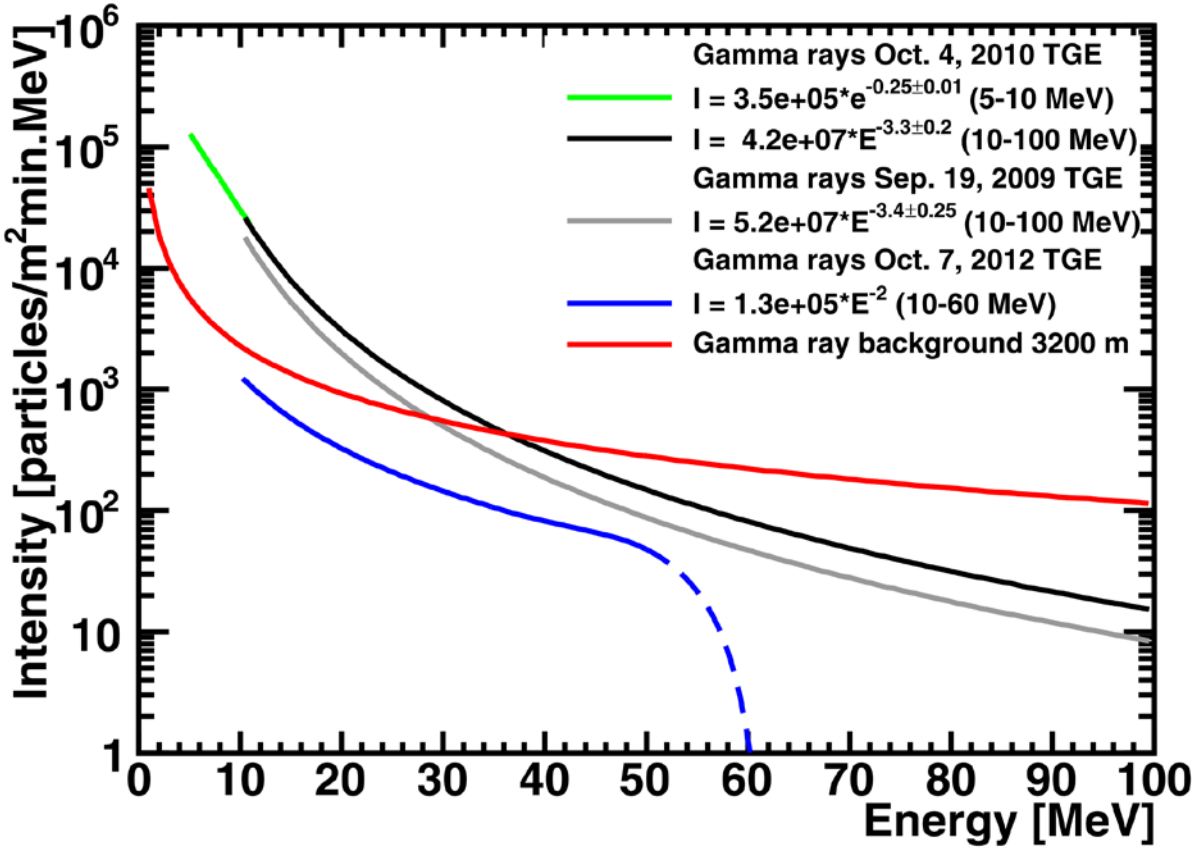


The total number of RREA electrons estimated is ~10^{11} and ~10^{13} for the October 7 and the largest TGEs respectively.

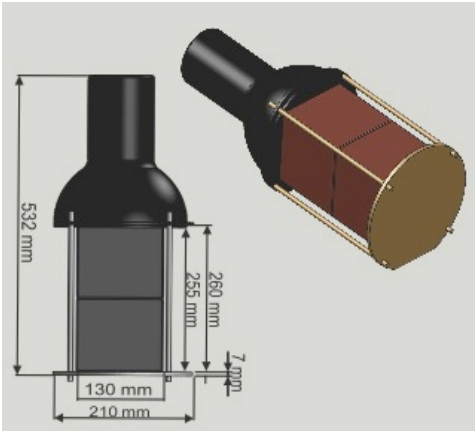
Simulations of RREA process in 500m electric field

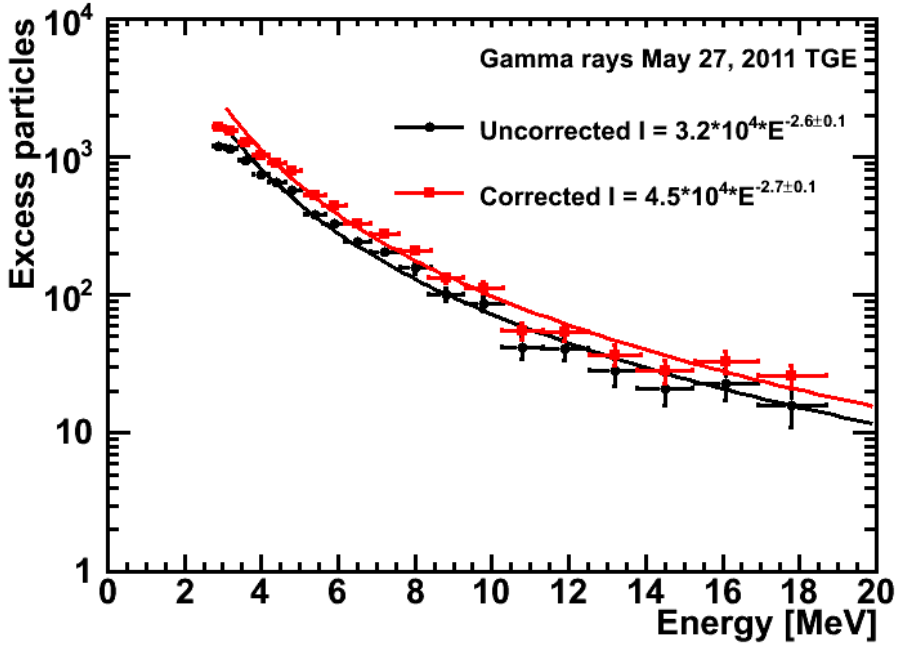


The recovered gamma ray spectra of the TGEs



TGE gamma ray spectra recovered by NaI detectors

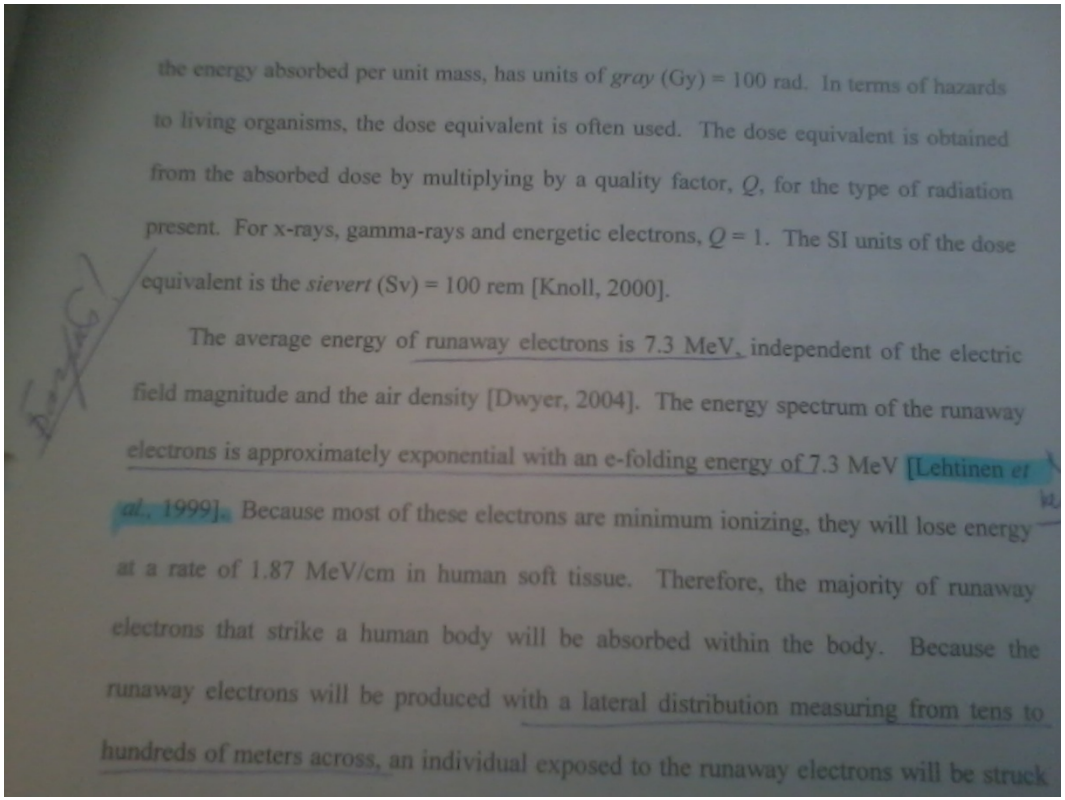




Event date	Peak time	-γ
07.10.2012*	14:09	2.01±0.3
12.05.2013*	06:36	1.96±0.11
15.05.2013*	12:30	2.09±0.33
09.06.2013*	21:47	2.42±0.07
19.06.2013*	07:36	2.51±0.05
19.09.2009**	22:47	3.4±0.25
04.10.2010**	18:23	3.3±0.02

RREA electron spectrum

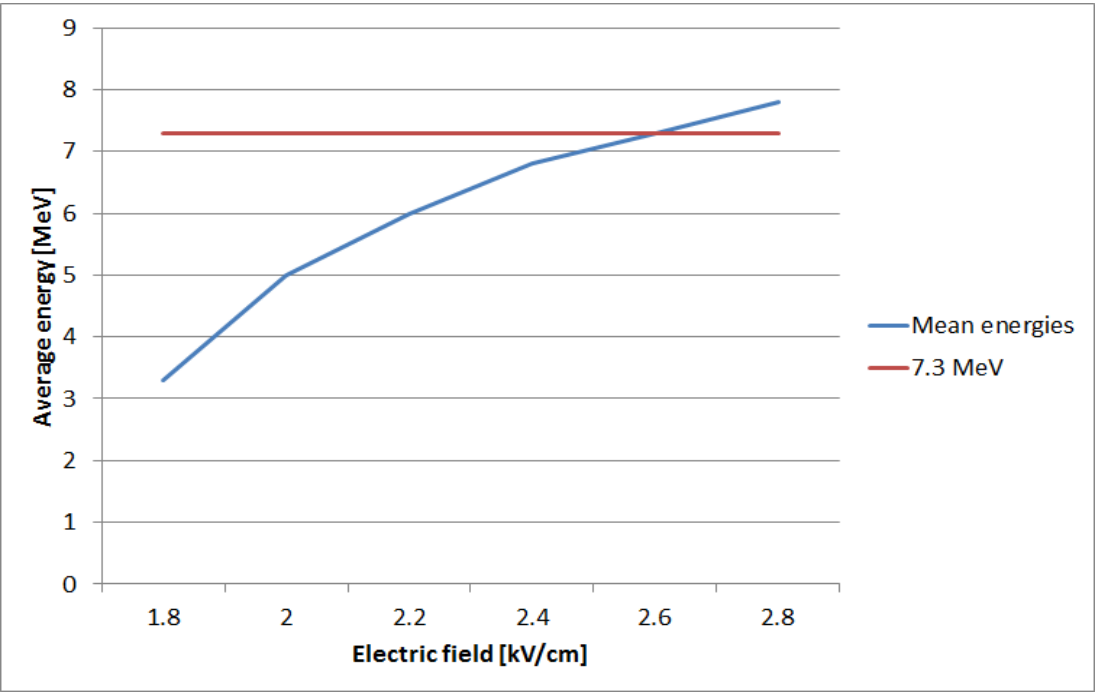
- Marshall et al., 2005 “The maximum measured electric field in the thunderstorm region was 186 kV/m”
- Dwyer et al., 2010 “The average energy of runaway electrons is 7.3 MeV, independent of the electric field magnitude and air density”!

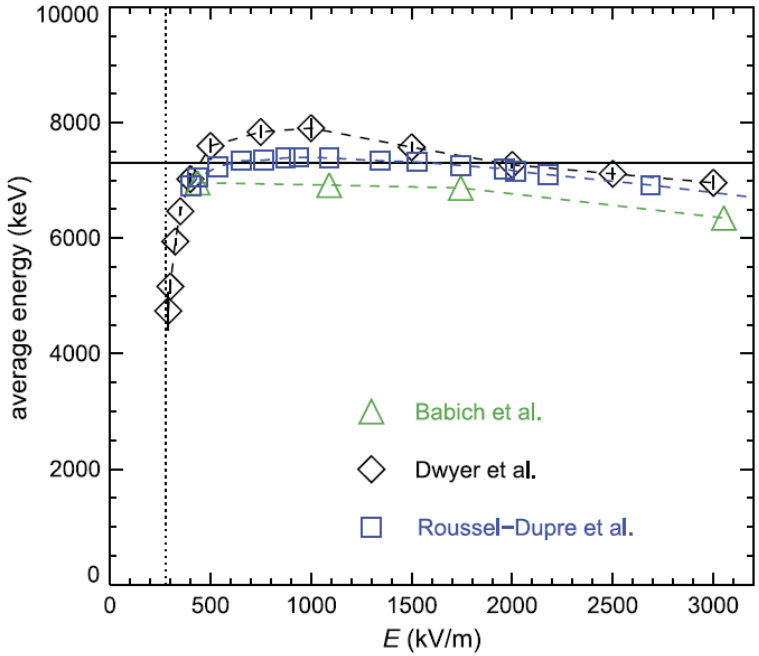


the energy absorbed per unit mass, has units of *gray* (Gy) = 100 rad. In terms of hazards to living organisms, the dose equivalent is often used. The dose equivalent is obtained from the absorbed dose by multiplying by a quality factor, Q, for the type of radiation present. For x-rays, gamma-rays and energetic electrons, $Q = 1$. The SI units of the dose equivalent is the *sievert* (Sv) = 100 rem [Knoll, 2000].

The average energy of runaway electrons is 7.3 MeV, independent of the electric field magnitude and the air density [Dwyer, 2004]. The energy spectrum of the runaway electrons is approximately exponential with an e-folding energy of 7.3 MeV [Lehtinen *et al.*, 1999]. Because most of these electrons are minimum ionizing, they will lose energy at a rate of 1.87 MeV/cm in human soft tissue. Therefore, the majority of runaway electrons that strike a human body will be absorbed within the body. Because the runaway electrons will be produced with a lateral distribution measuring from tens to hundreds of meters across, an individual exposed to the runaway electrons will be struck

RREA simulations and the measured TGEs





Geant4 simulations were done for uniform 1km length electric fields.

See also: Dwyer, Smith and Cummer, High-Energy Atmospheric Physics: Terrestrial Gamma-Ray Flashes and Related Phenomena, Space Sci Rev, June 3, 2012

Conclusions

- Largest TGEs can be explained only by invoking RREA mechanism. The energy spectra of the electrons have an exponential shape and extend up to 30–40 MeV. Recovered energy spectra of the gamma rays are also exponential in energy range 5–10 MeV.

- The RREA process can multiply particle flux up to times above ambient background of secondary cosmic rays; the spectra modification process can provide several percent excess above cosmic rays, however for the much higher energies, extending gamma ray spectrum up to 100 MeV.

Conclusions

- Every TGE is unique due to different structures of electric fields in thunderclouds. The measured TGE (RREA) electron spectra do not have the energy cutoff ~7 MeV as it follows from the theoretical predictions. The ~7 MeV cutoff would be obtained for higher than measured electric fields in thunderclouds. Moreover, the measurements of RREA spectra during TGEs may allow to estimate the atmospheric electric field parameters.

Շնորհակալություն ուշադրության համար

Chilingarian A., Vanyan L., Mailyan B., Observation of Thunderstorm Ground Enhancements with intense fluxes of high-energy electrons, Astroparticle physics, 48, 1-7, 2013.