



TGEs – Thunderstorm Ground Enhancements



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CTR Wilson, 1924: prediction of high-energy phenomena in thunderclouds

Cosmic rays – Atmospheric electricity Particle detectors

“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”

“There is, as well known, some evidence of the existence of penetrating radiation in the atmosphere; possibly some portion of it may originate in the electrical fields of thunderclouds.”

Despite numerous negative results by Basil Schonland, Edward Halliday and others in searching of energetic particles from thunderclouds (as a result of using inadequate equipment) Wilson supported the idea till his last publication in 1956.

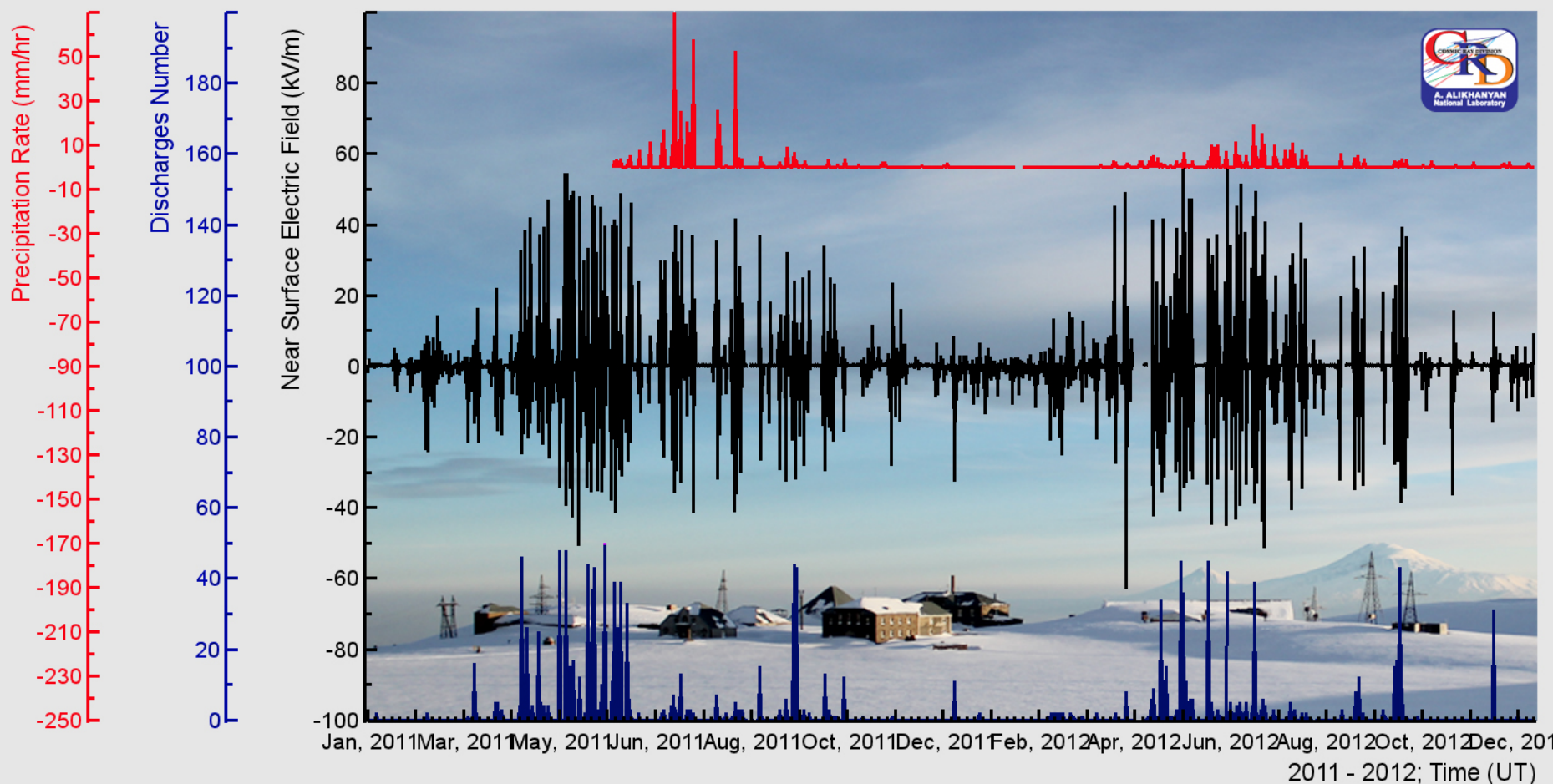
C. T. R. Wilson, the acceleration of β -particle in strong electrical fields of thunderclouds, Proc. Cambridge Philos. Soc. 22, 534, (1925).

E.R.Williams, Origin and context of C.R.T. Wilson's ideas on electron runaway in thunderclouds, JGR, 115, A00E50, 2010.

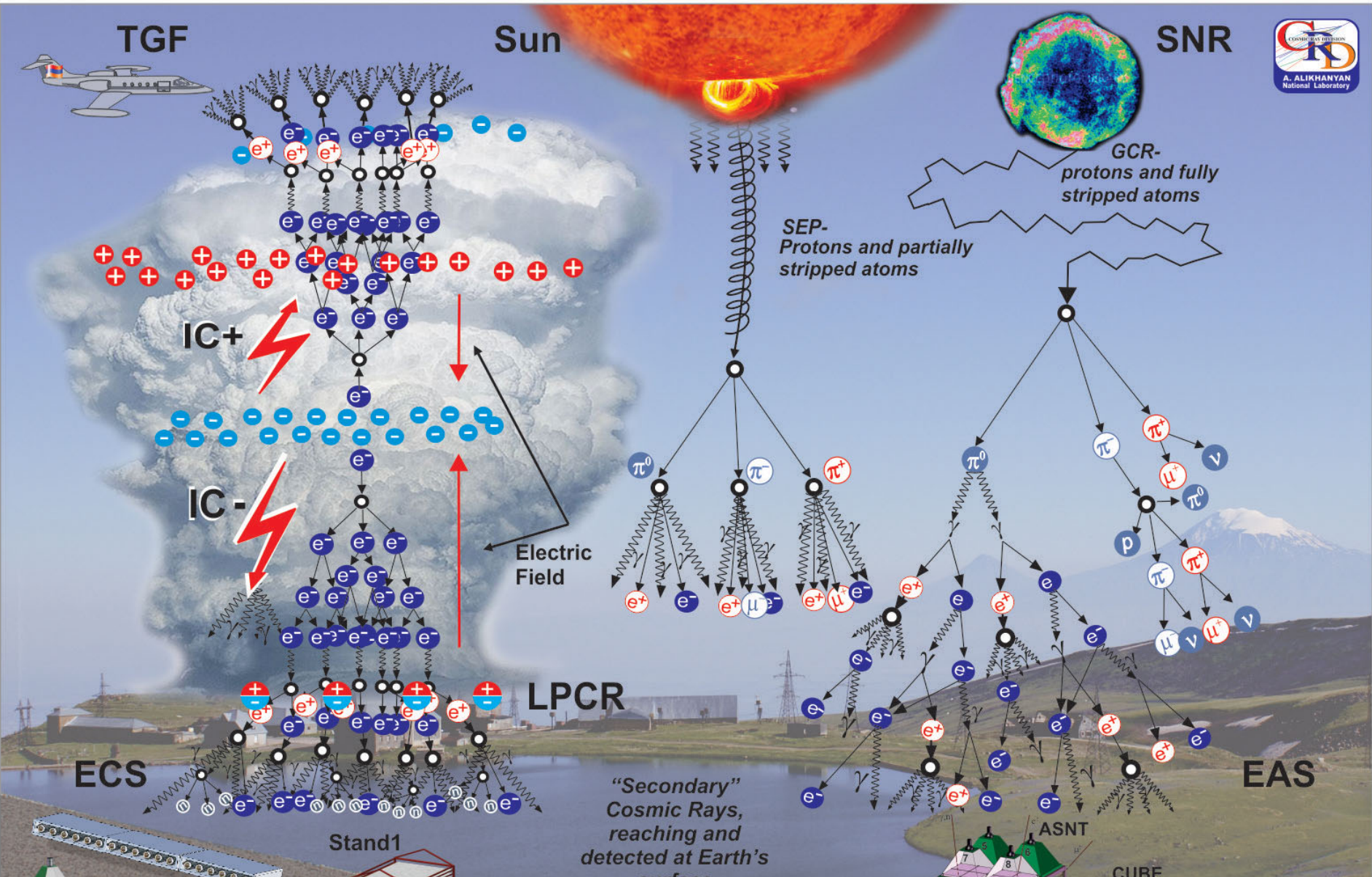


10/03/2011 19:14

Aragats - meteorology 2011-2012



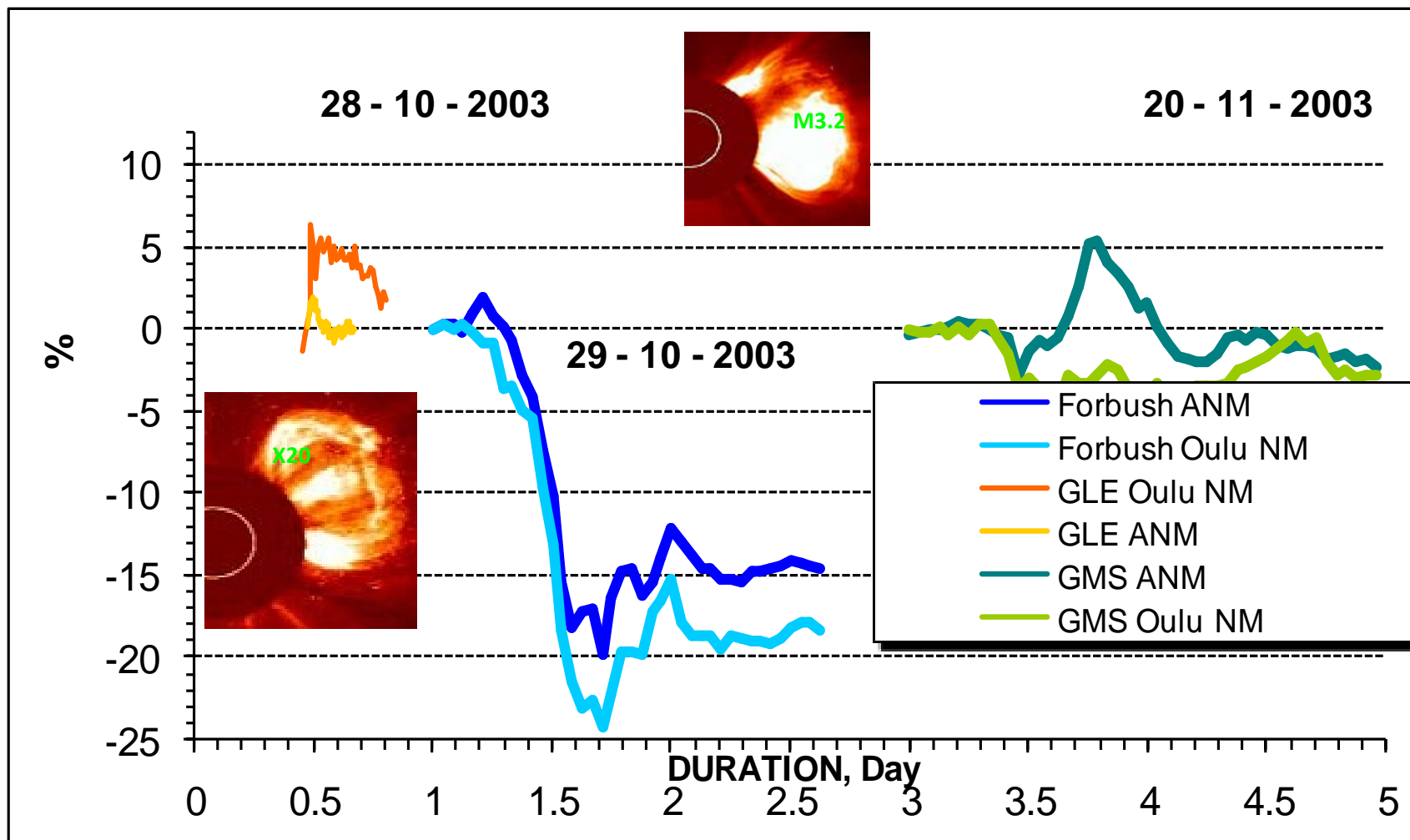
TGE/TGF - most energetic natural electron-photon phenomena on Earth



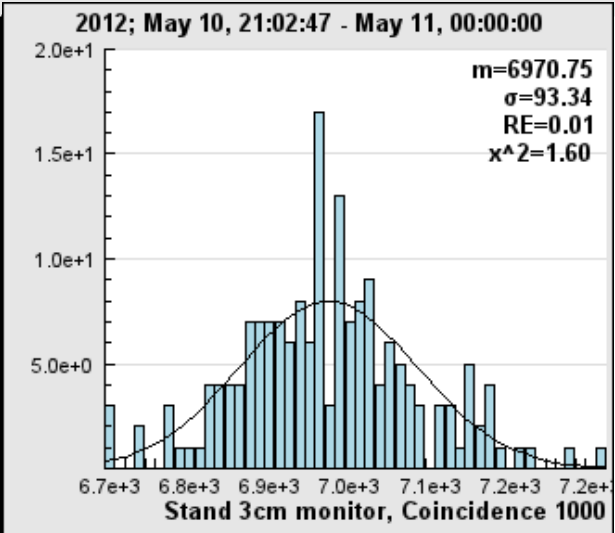
Vocabulary of abbreviations

- GLE – Ground Level Enhancement solar modulation of surface flux;
- TGF – Terrestrial Gamma Flashes – atmospheric modulation of space flux;
- TGE – Thunderstorm Ground Enhancement – atmospheric modulation of the surface flux;
- TLE - Transient Luminous Events;
- RREA – Relativistic Runaway Electron Avalanches – “electromagnetic” and “short” version of EAS!
- MOS – MOdification of Energy Spectra;
- EAS – Extensive Air Shower;
- ECS – Extensive shower spectra;
- LPCR – Lower positive charge region
- RFD - Relativistic feed- back discharges

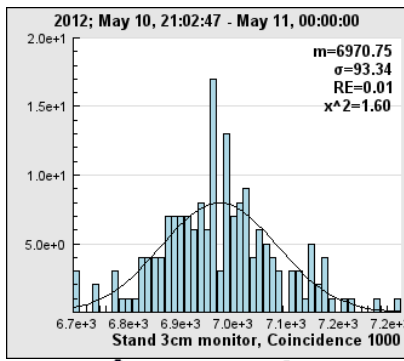
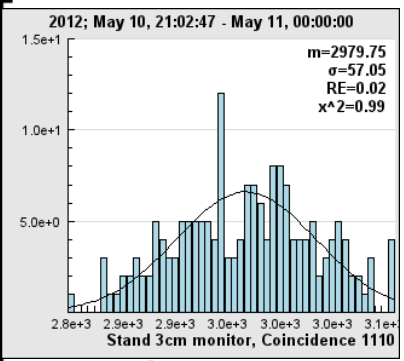
Aragats Space Environmental Center (ASEC) aims to detect the Solar Modulation effects: Ground Level Enhancements, Forbush decreases, Geomagnetic effects; At quit Sun (2007-2011) ASEC measure hundreds of Thunderstorm ground enhancements (TGEs)



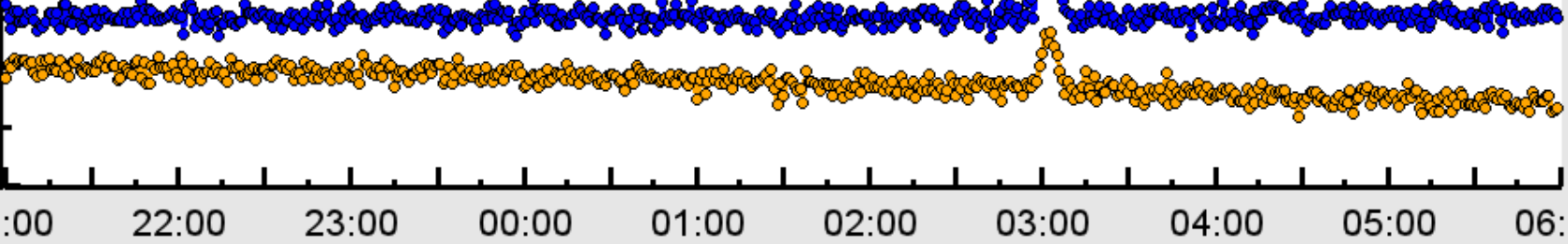
Count Rate



STAND 3 cm thick plastic scintillator 1000. Enhancement $\sim 60\%$, corresponding to $\sim 45\sigma$. Mean and variance were estimated by time series at 21-24 UT, 10 May 2012.



Combinations 1100 and 1110 Enhancement $\sim 33\%$ and 10% , Corresponding to 20σ and 5σ .



May 10 - 11, 2012; Time (UT)

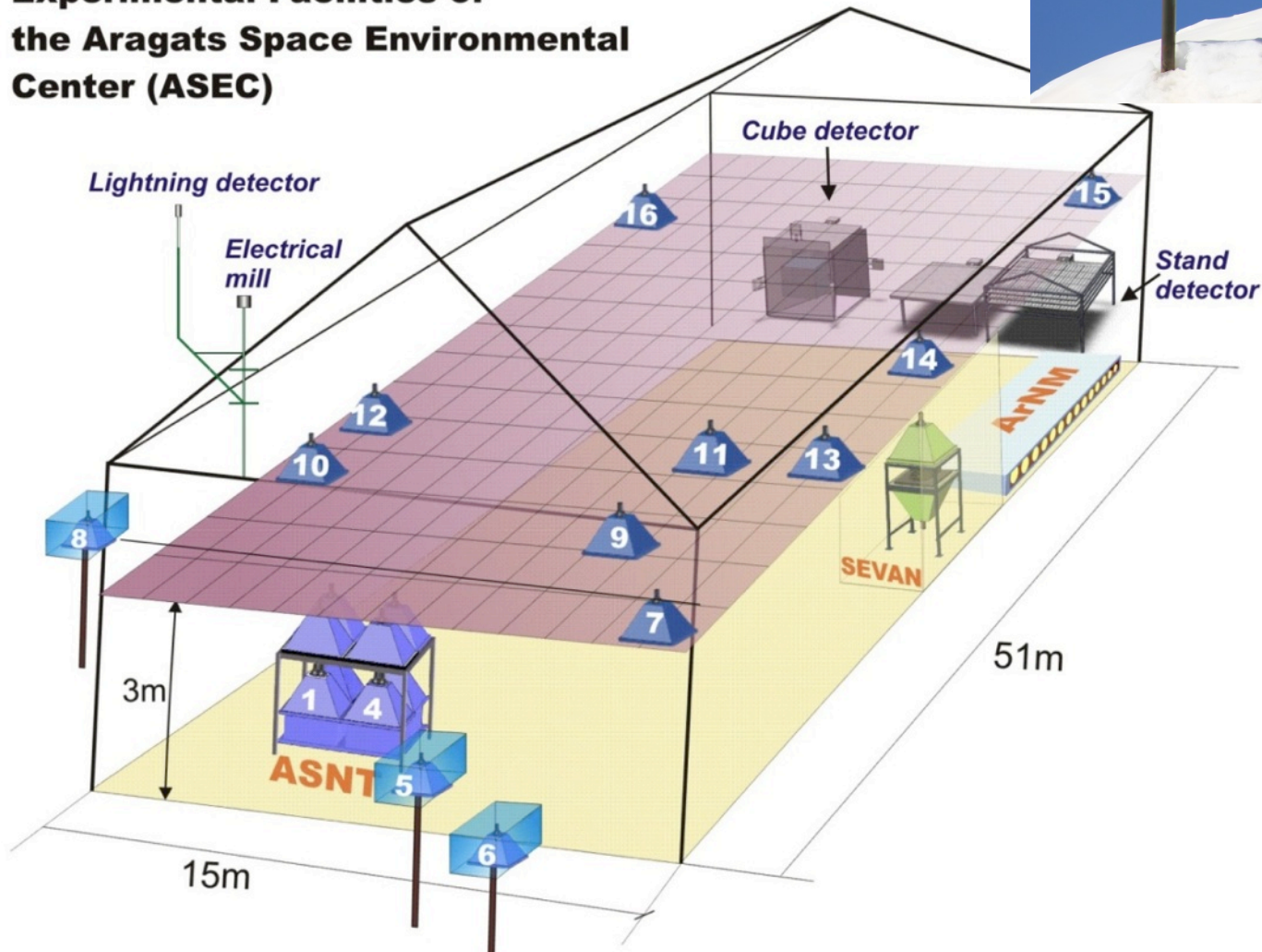
Thunderstorm Ground Enhancements TGEs

The boost of the secondary cosmic ray flux observed during thunderstorms, so-called Thunderstorm Ground Enhancements (TGEs, Chilingarian et al., 2010, 2011), is the manifestation of high-energy processes in the terrestrial atmosphere (Dwyer et al., 2012). Origin of TGE is the strong electrical field in the thundercloud, giving rise to rather complicated physical phenomena, including at least 6 physical processes:

- Relativistic Runaway Electron Avalanches (RREA, Wilson, 1925, Gurevich et al., 1992, Babich et al., 1998, Dwyer, 2003, Khaerdinov et al., 2005, Chilingarian et al., 2010);
- **Modification of the secondary Cosmic ray (CR - electrons, muons, protons and charged mesons) energy spectra (MOS, Dorman et al., 2005, Muraki et al., 2004, Chilingarian Mailyan and Vanyan,, 2012);**
- Photonuclear reactions of the RREA gamma rays (Chilingarian et al., 2012a and 2012b, Tsuchiya et al., 2012, Babich et al., 2013);
- **Attenuation of the cosmic ray muon flux (Lidvansky and Khaerdinov, 2009, Chilingarian et al., 2010);**
- Roentgen and gamma radiation from the lightning (Dwyer et al., 2012b);
- **Prolonged (2-3 hours and more) enhancement of the low energy (1-2 MeV) cosmic ray flux (Germanenko et al., 2011).**

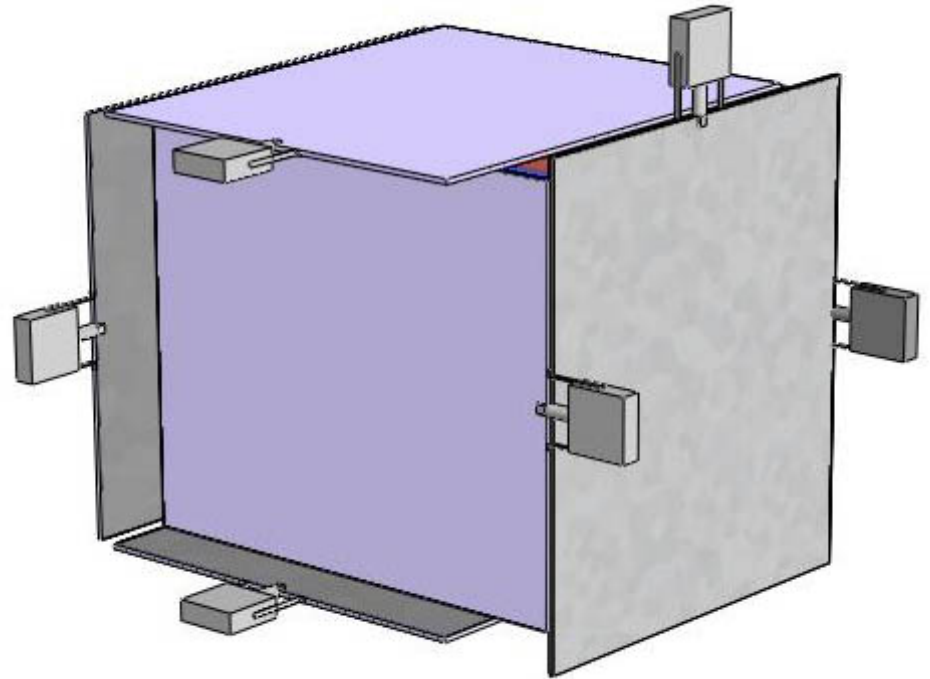
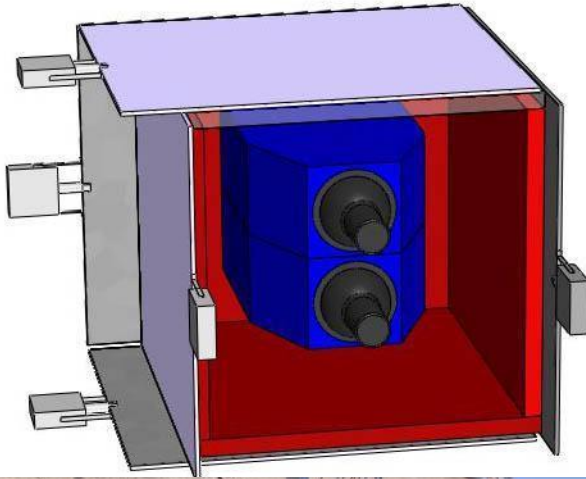
Monitoring of fluxes, fields, meteorological conditions

Experimental Facilities of
the Aragats Space Environmental
Center (ASEC)

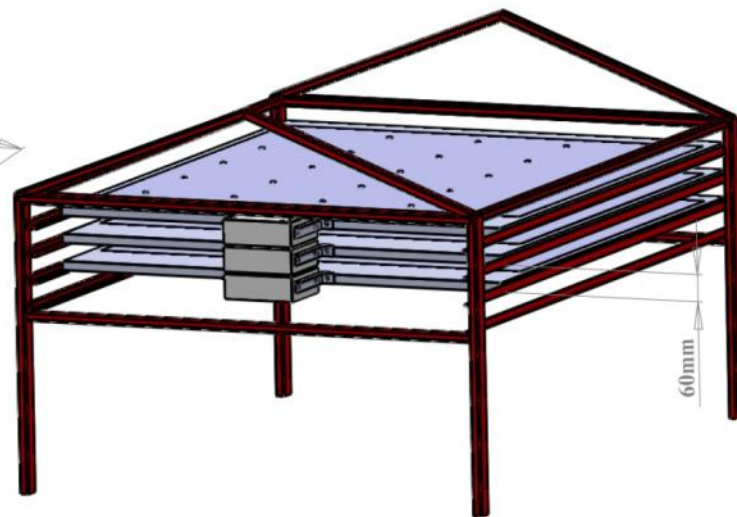
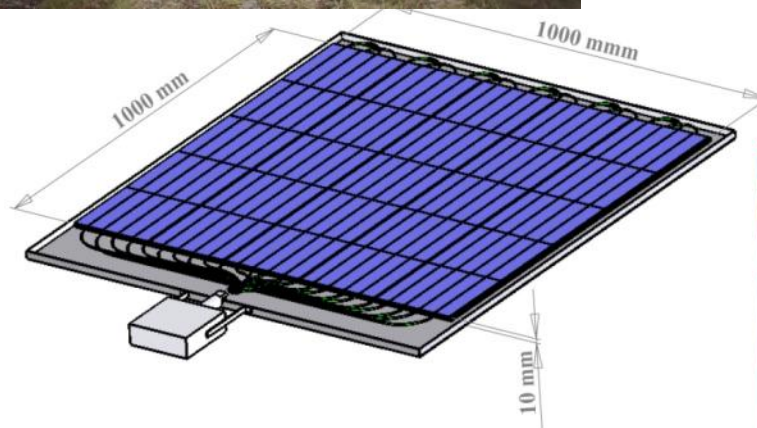
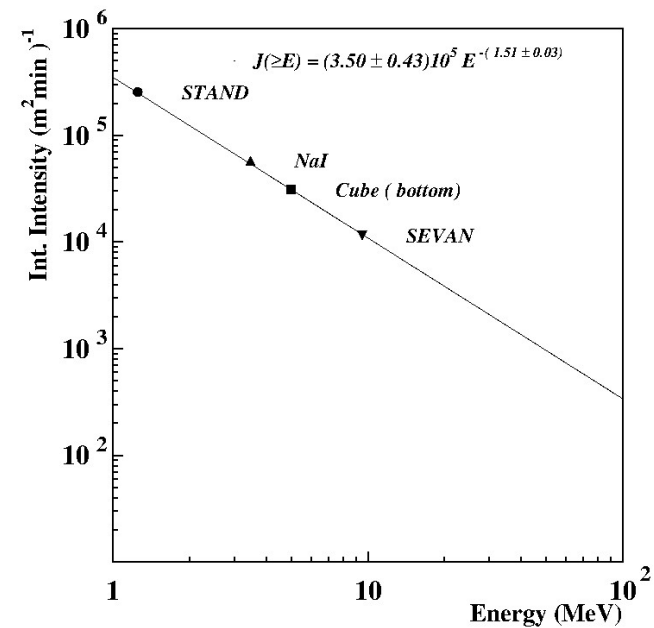


**Boltek EFM 100
electrical mill and
Lightning tracer;
Davis instr. weather
station**

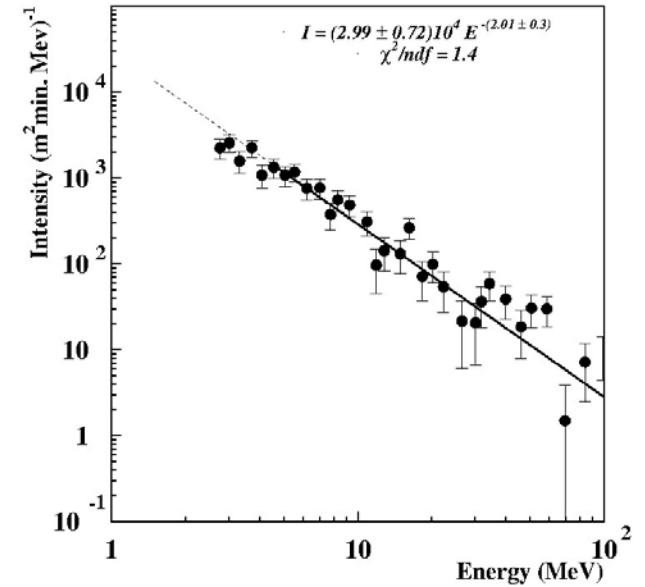
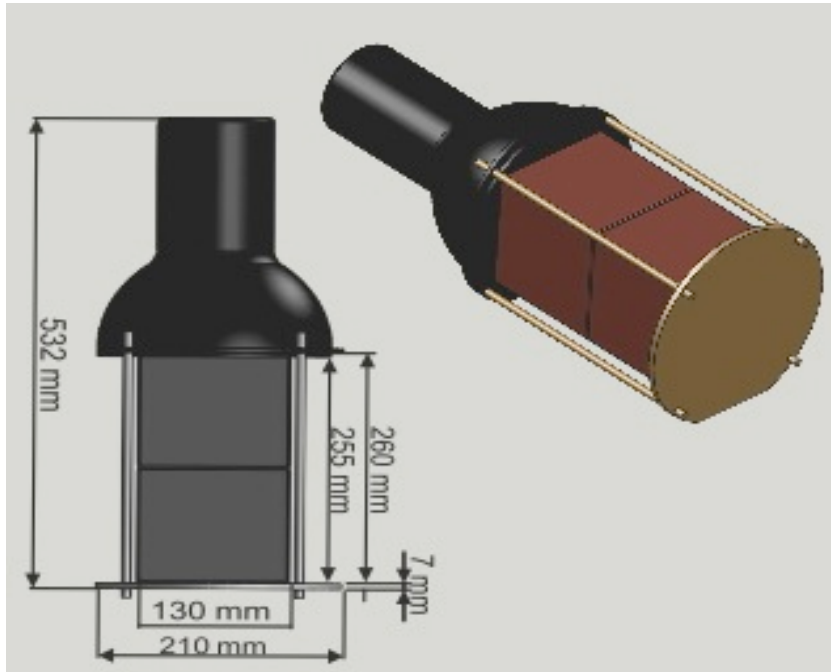
Cube Detector for detection of Neutral particle



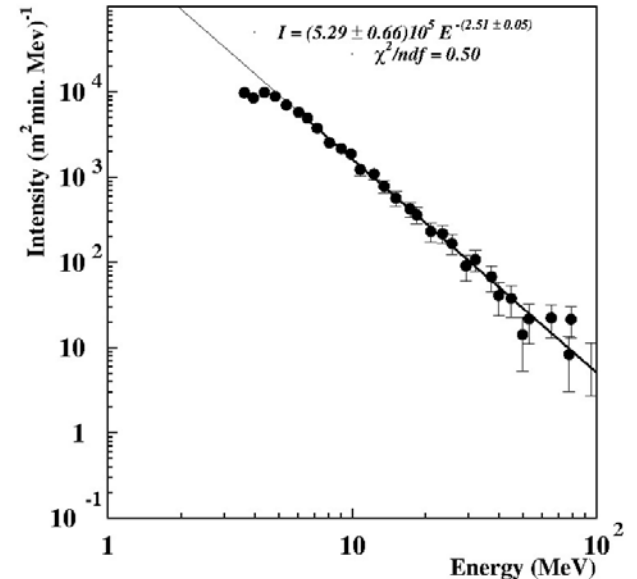
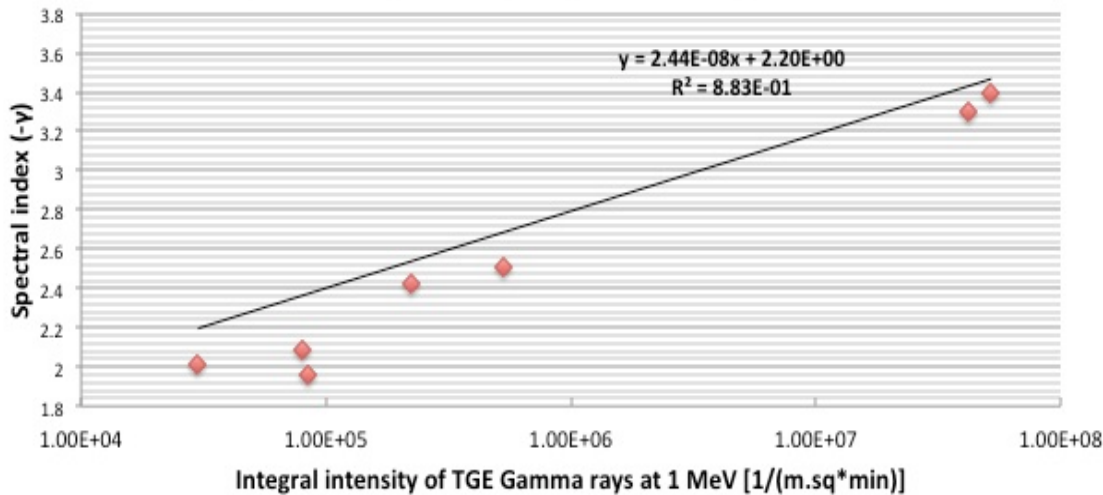
STAND multilayered Detector



NaI network 5 detectors 12.5 x 12.5 x 25 each

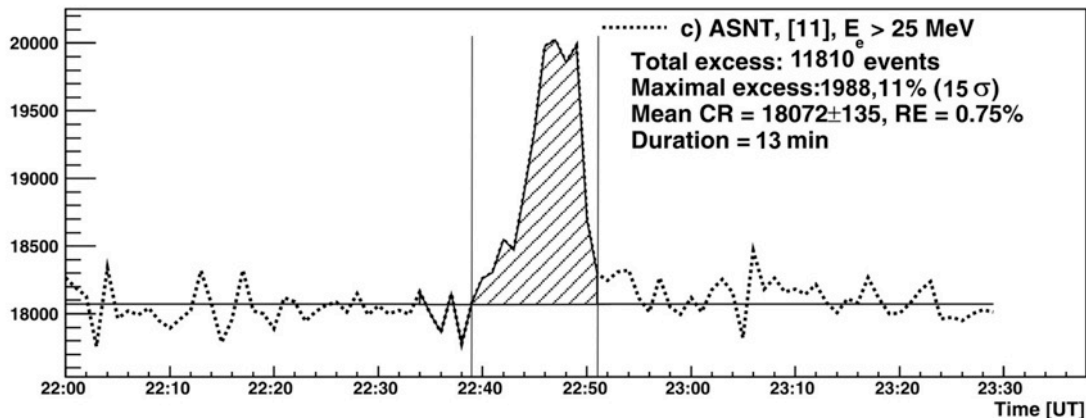
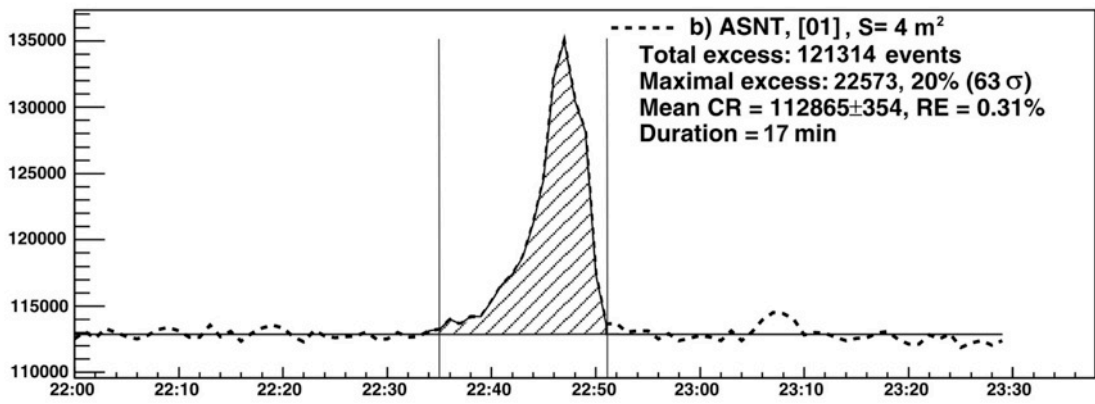
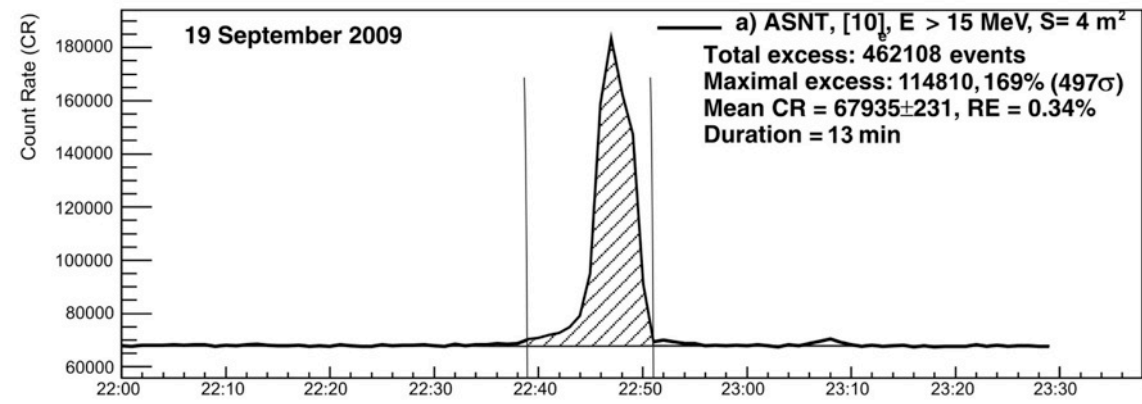


TGE gamma ray intensity vs power law spectral index

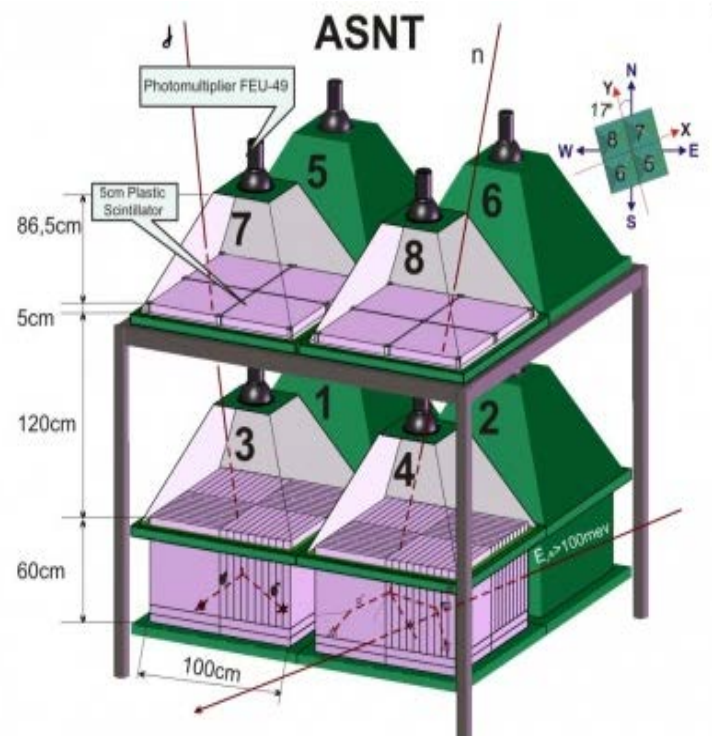


Tray of Geiger counters installed on Aragats in 2012; Energy threshold 1.5 – 2 MeV

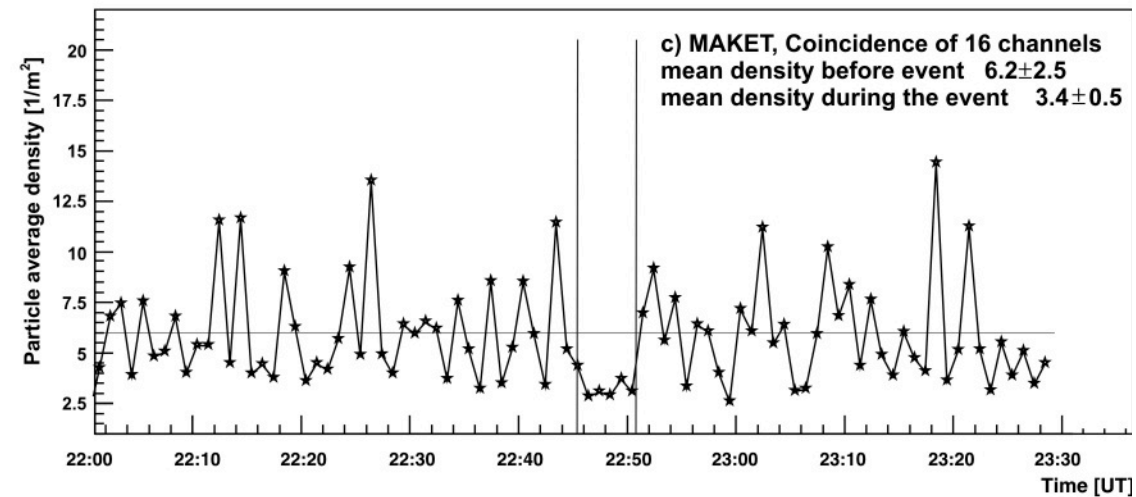
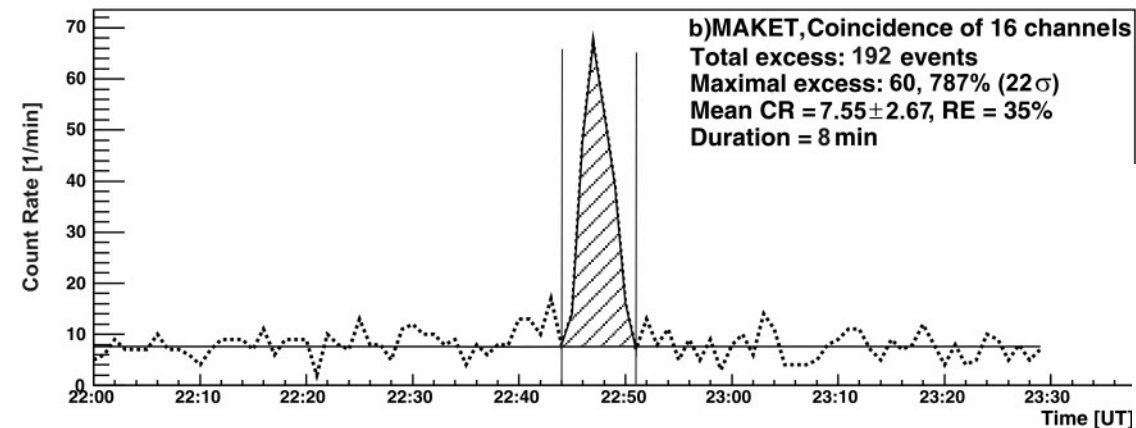
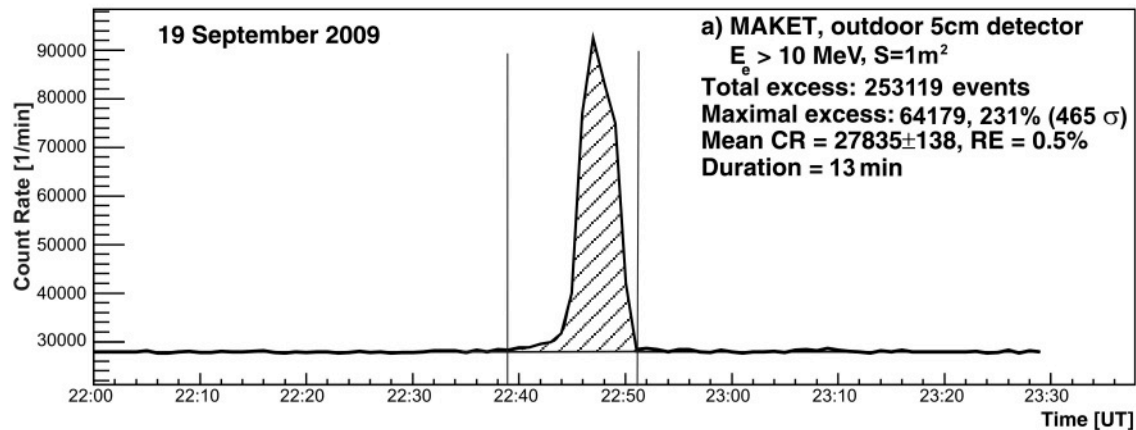




Huge TGE of 19 September, 2009 was detected by all ASEC monitors : ASNT consists of 5 cm and 60 cm thick scintillators (4 modules each 1 m.sq. area; ASNT (11) – electrons $E \sim 30$ MeV -

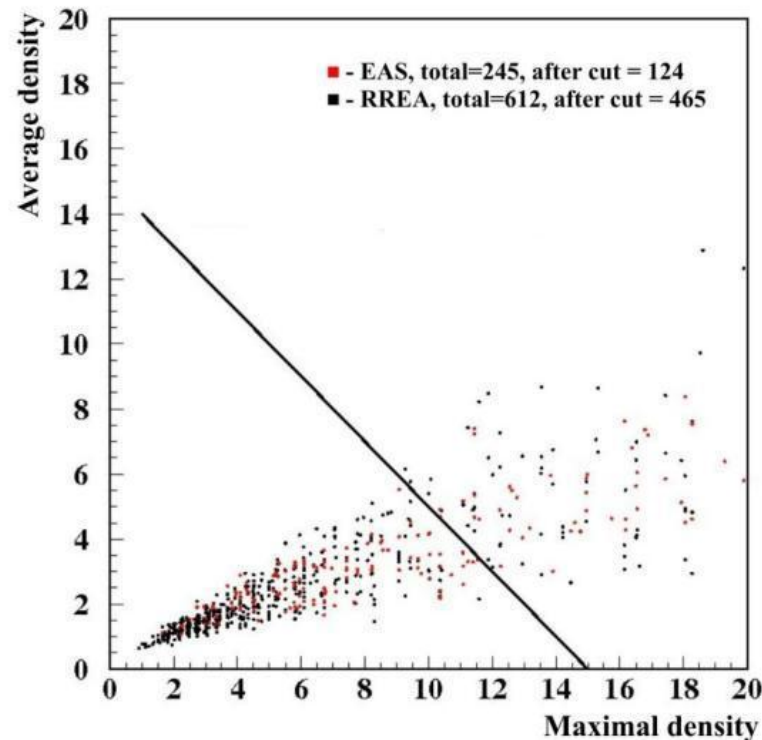


A. Chilingarian, A.Daryan, K.Arakelyan, et al., Ground-based observations of thunderstorm-correlated fluxes of high-energy electrons, gamma rays, and neutrons, Phys.Rev. D., 82, 043009, 2010

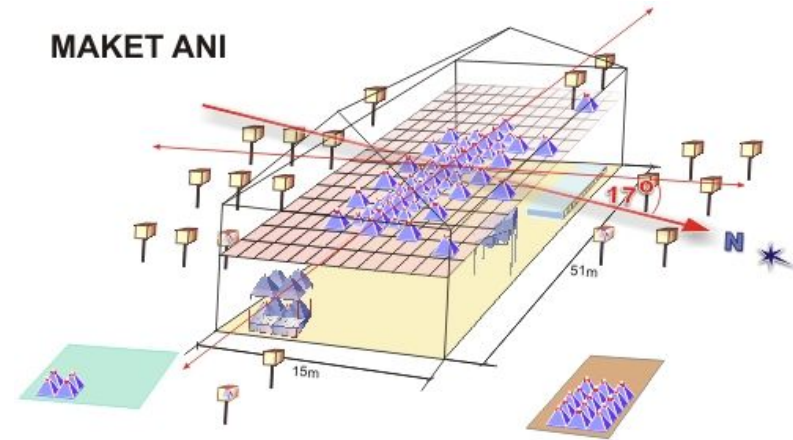
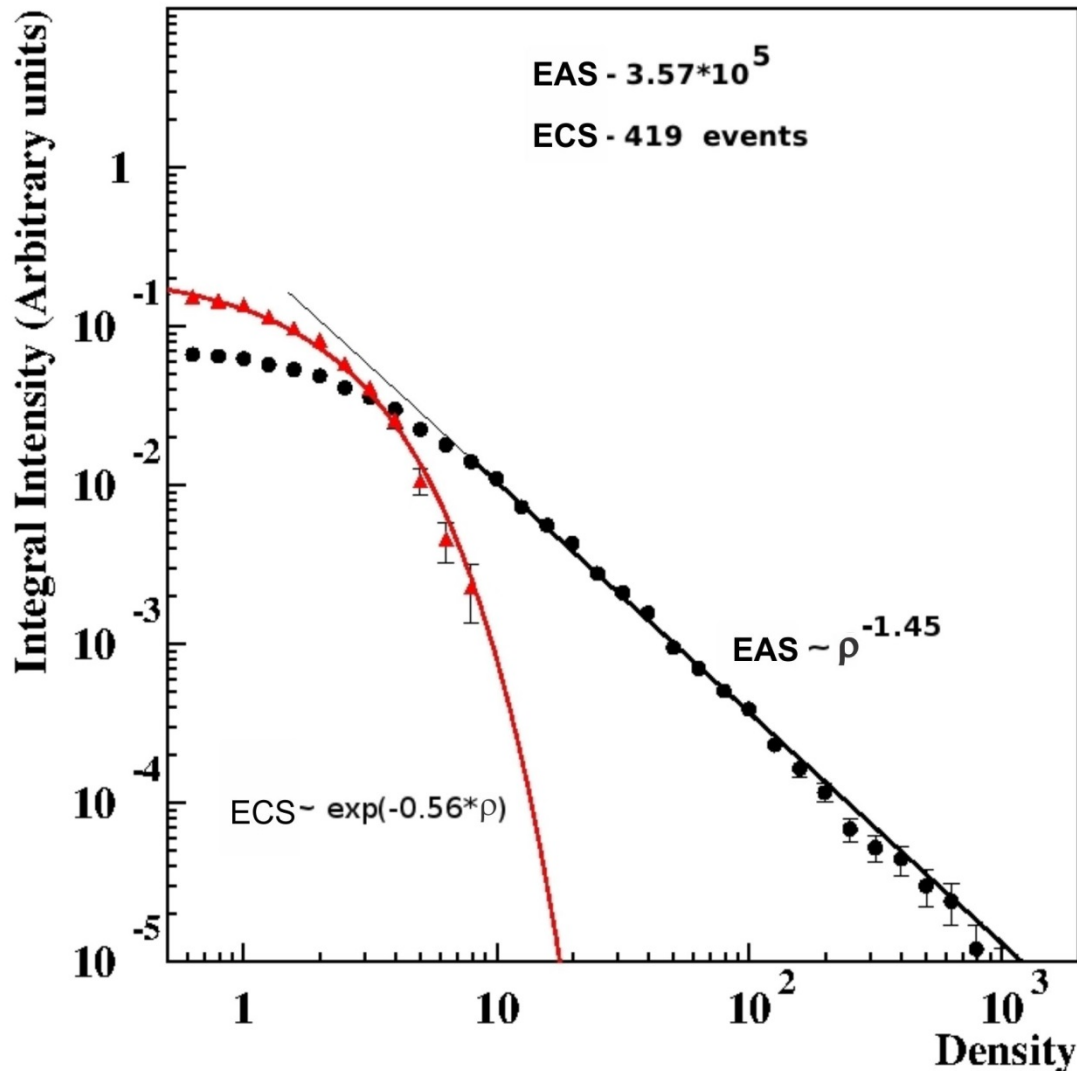


First RRE avalanches detection.
New type of particle showers –
Extensive Cloud Showers (ECS);
50 MeV electrons comes from
thunderclouds!

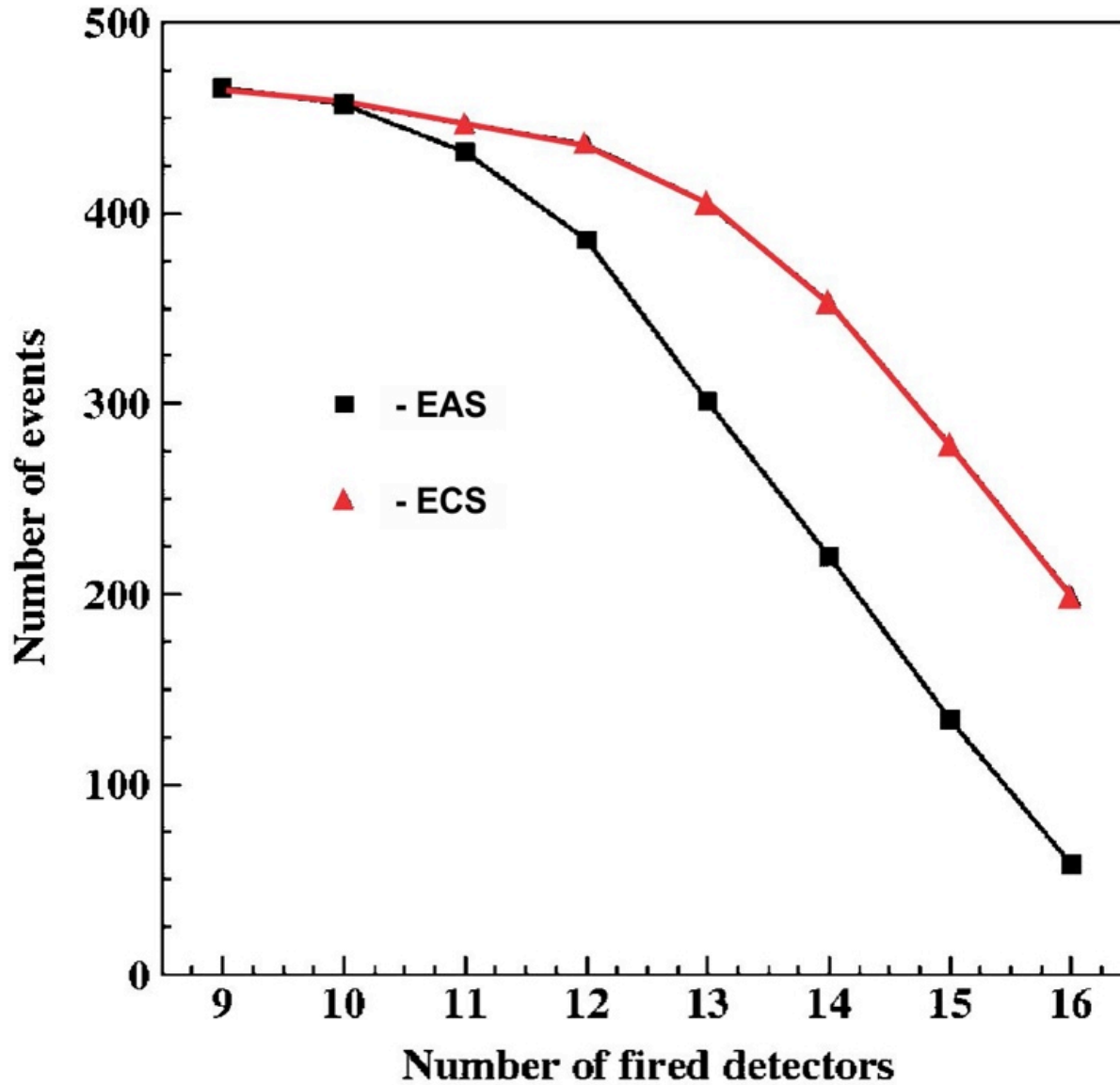
MAKET detect short coherent bursts of
electrons/gamma rays (within 1 μsec);
ECS counts 7 times more than EAS!
ECSs have smaller densities – can be
distinguished from CR EAS.



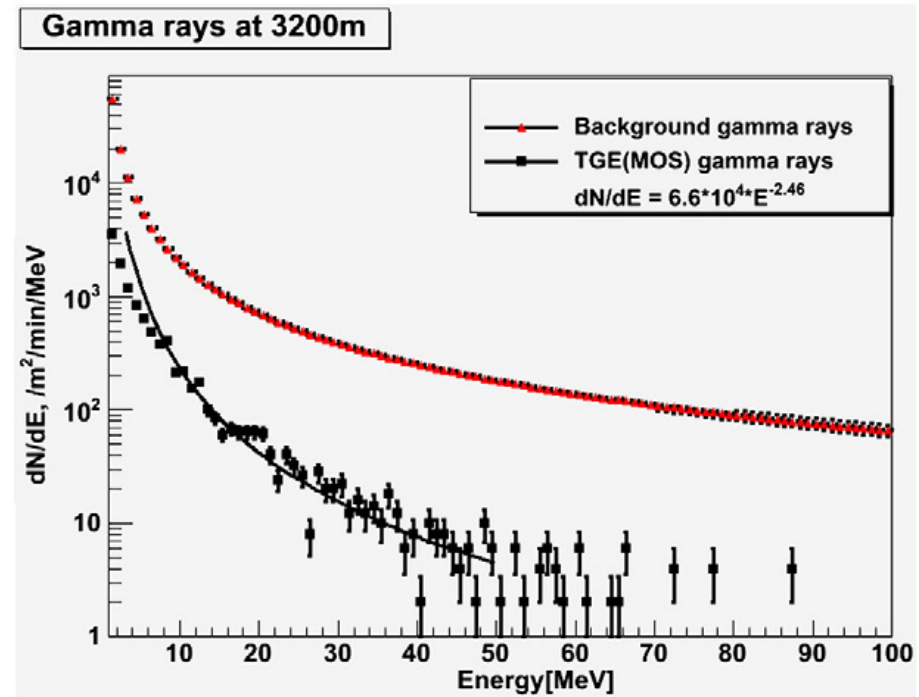
Spectra of Extensive Air Showers (EAS) and Extensive Cloud Showers (ECS)



Extensive Cloud Showers (ECS) extended more than Extensive Air Showers (EAS)



RREA - MOS processes



Detection of TGE neutrons

Source {Time} Axes

Experiment All Measurements

Window Custom

Start 10/4/2010 18:0:0

End 10/4/2010 18:45:0

Apply

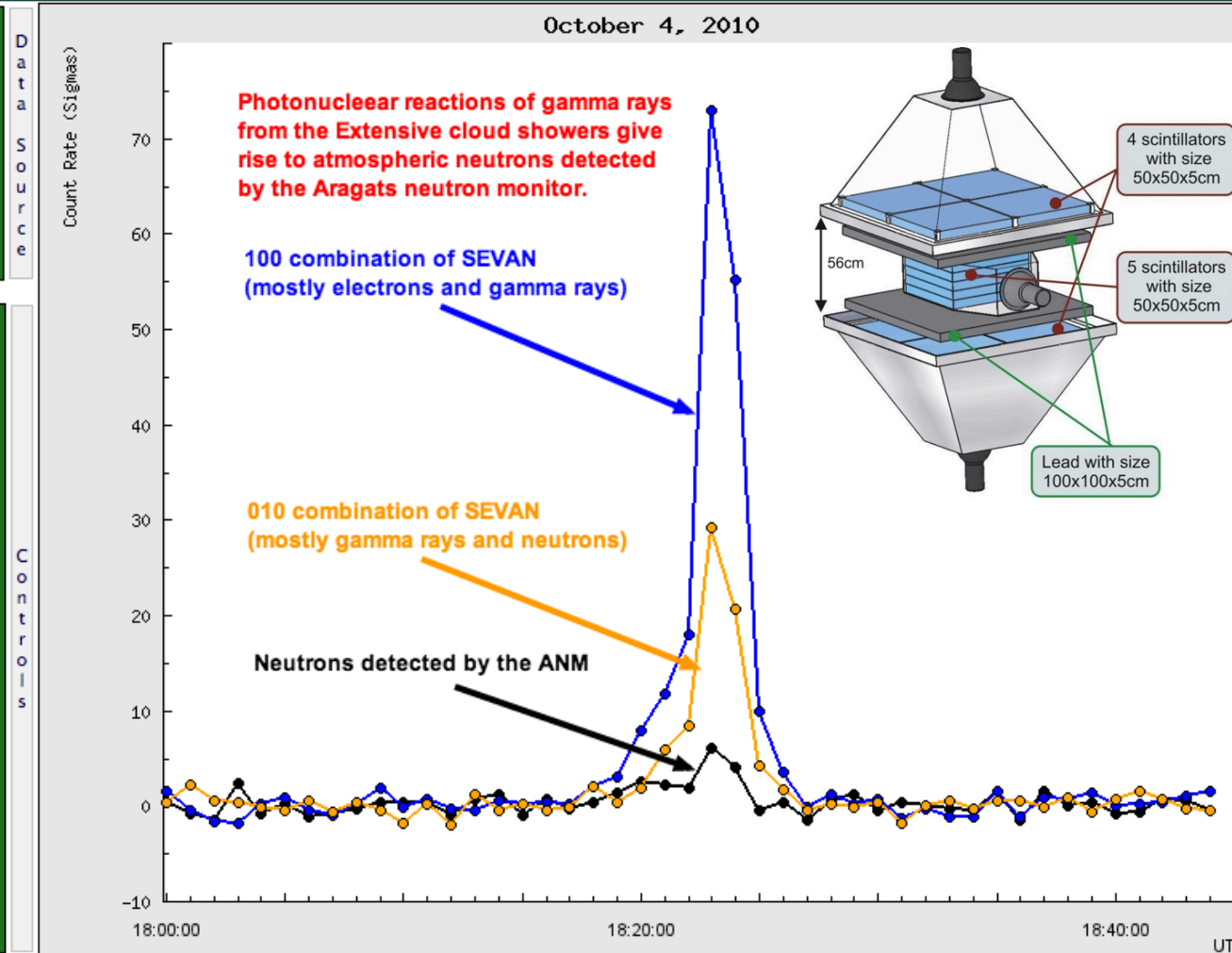
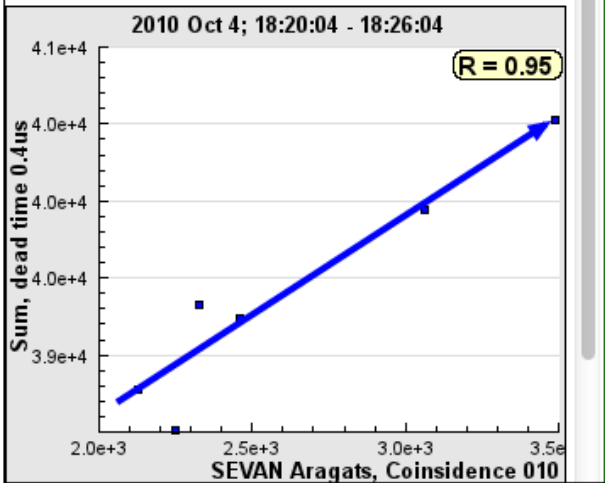
{Info} Search Source Tree

Export Aggregator Plot

Type: Scatter Plot

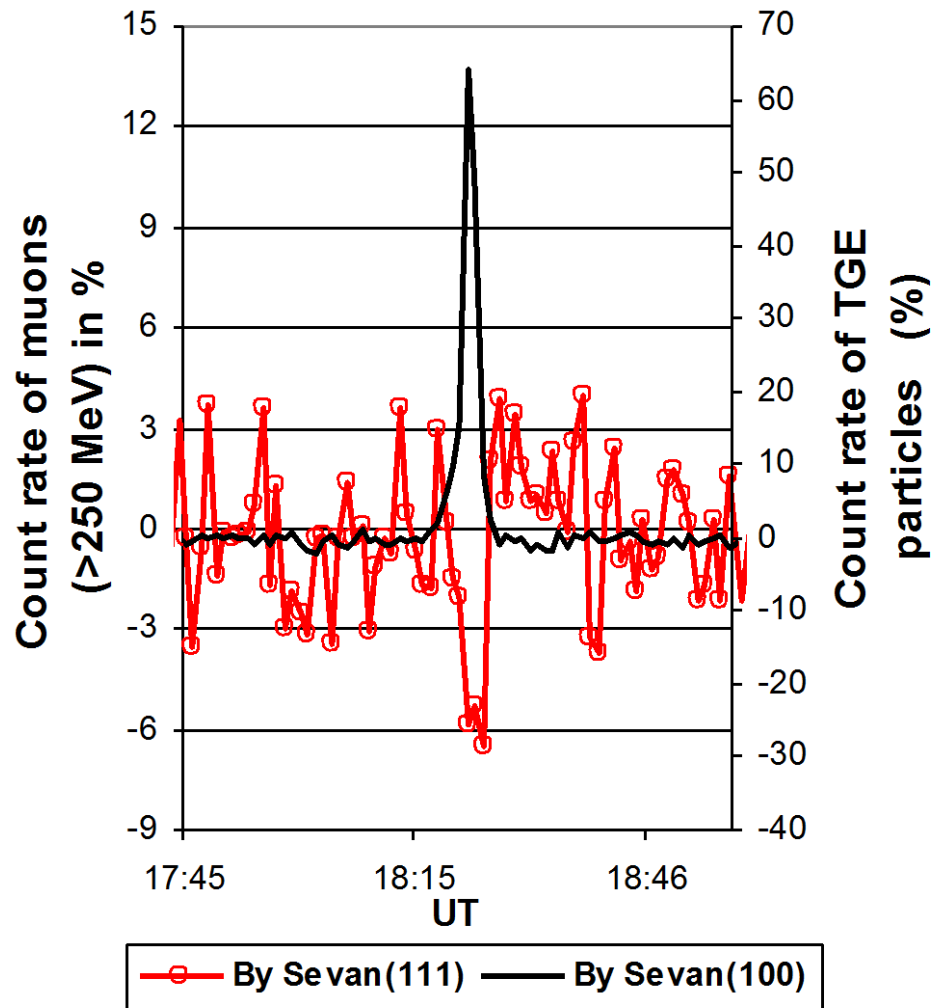
X: SEVAN Aragats, Coincidence 010

y: Sum, dead time 0.4us

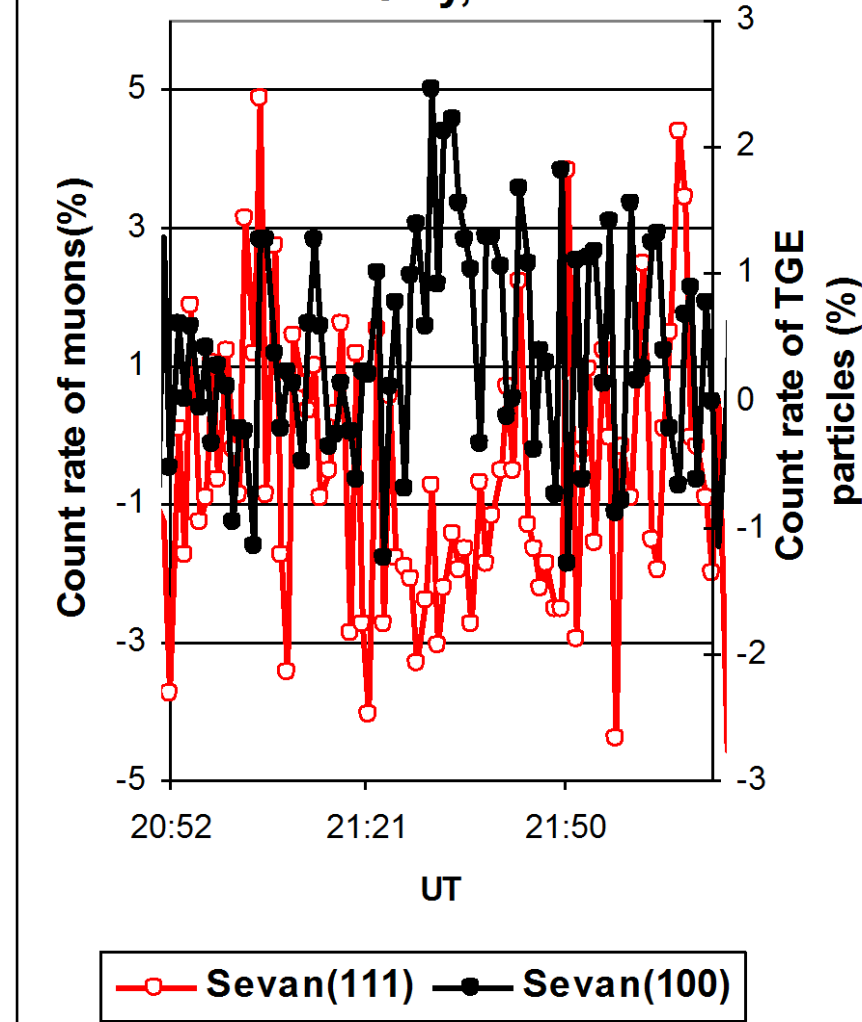


Muon flux depletion simultaneously with electron flux enhancement

4 October, 2010



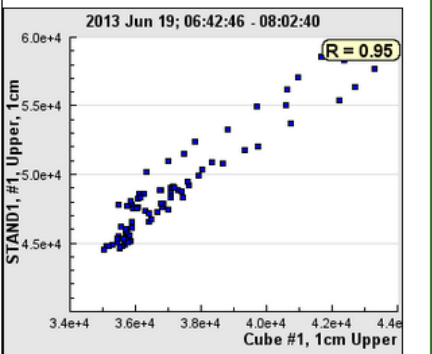
15 July, 2011



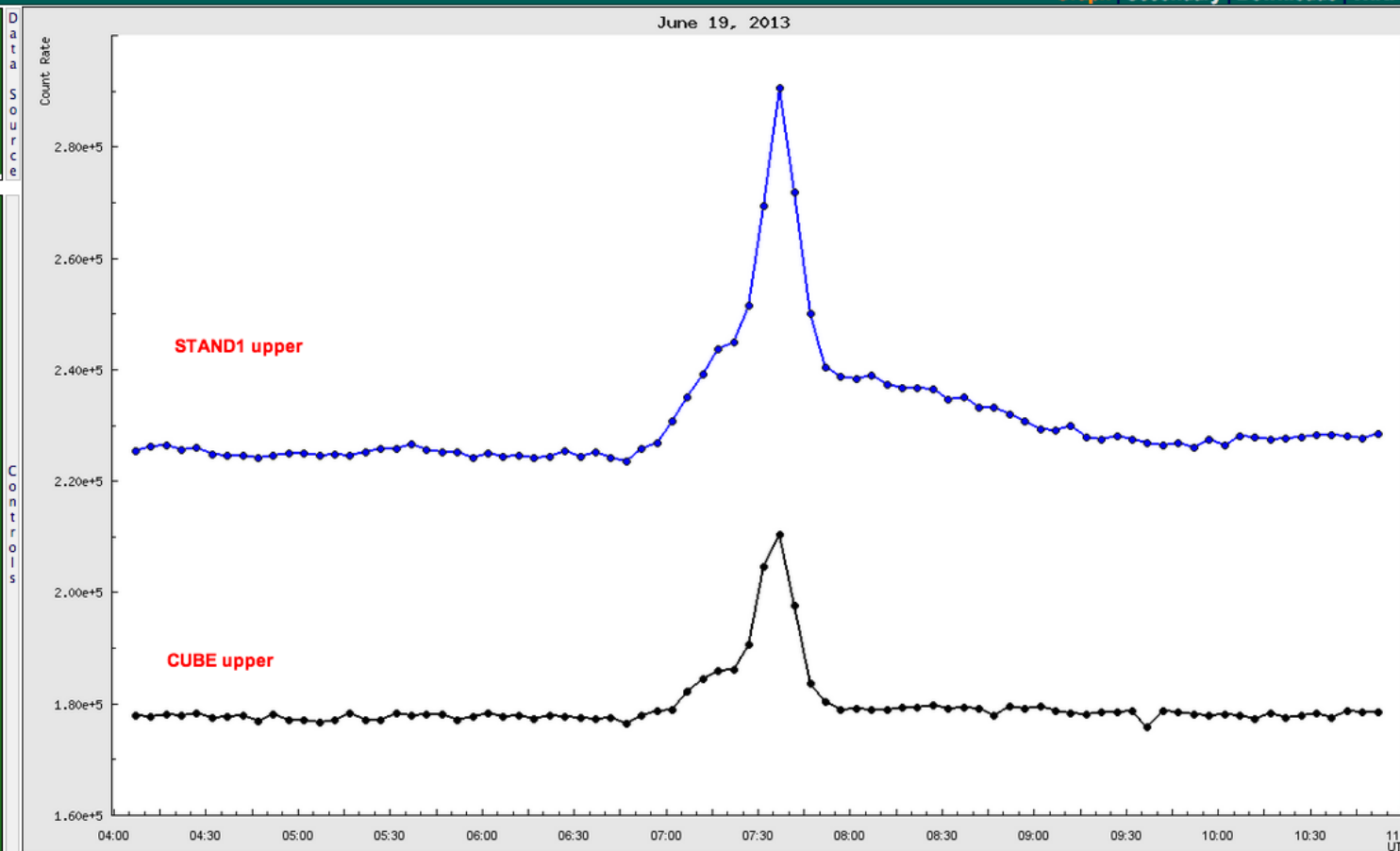
Long duration low energy TGE tails

| Source | {Time} | Axes |
|------------|------------------|------|
| Experiment | All Measurements | |
| Window | Custom | |
| Start | 6/19/2013 4:7:0 | |
| End | 6/19/2013 11:0:0 | |
| Apply | | |

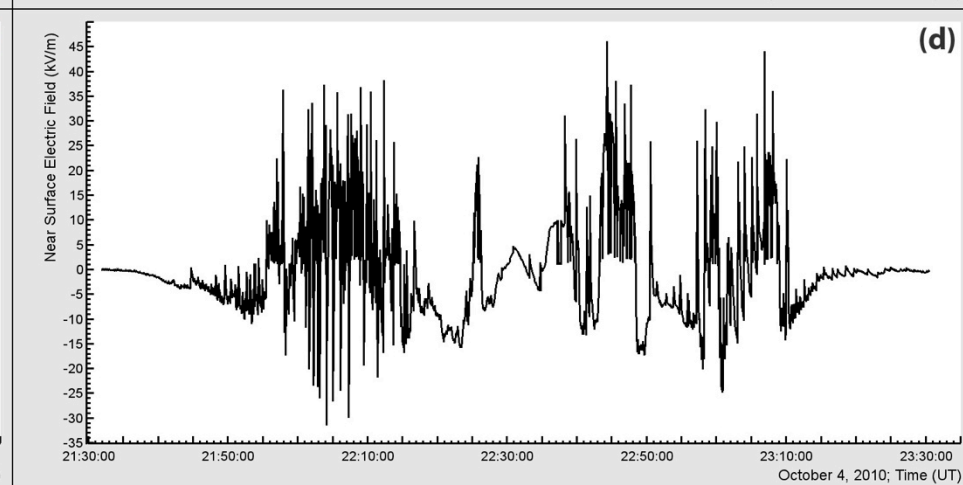
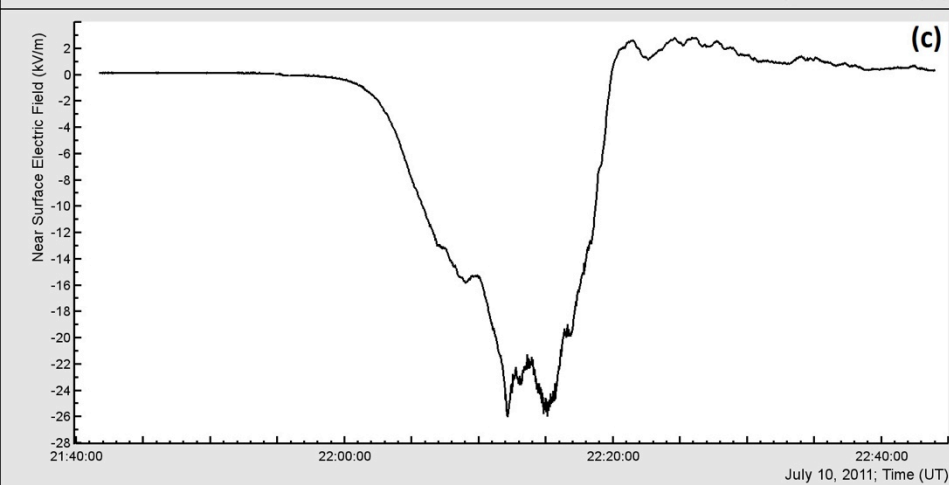
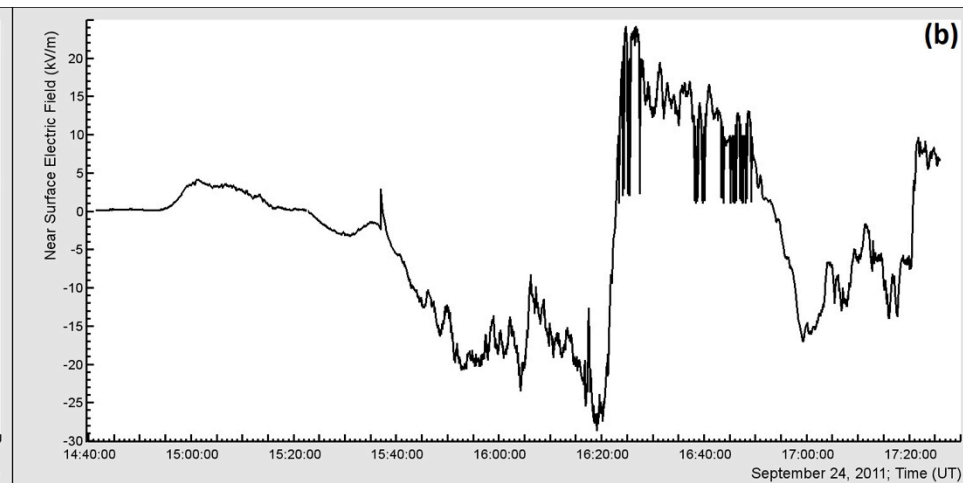
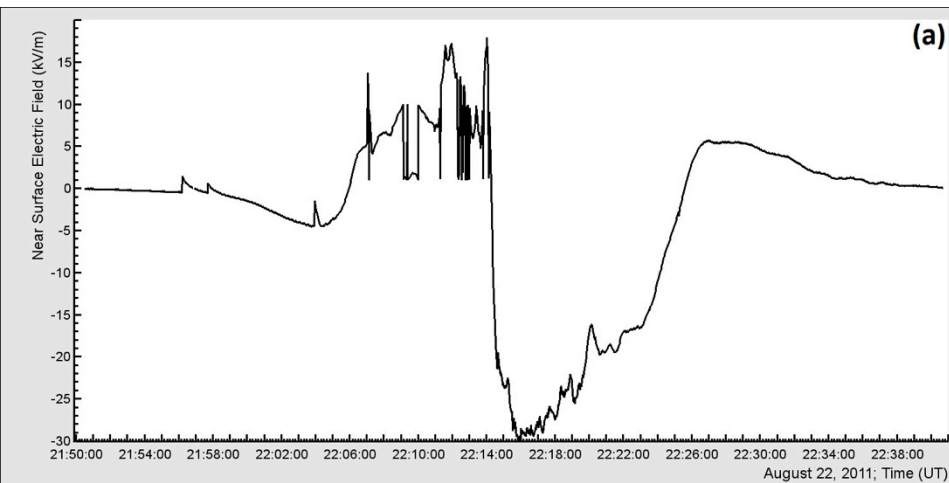
| {Info} | Search | Source Tree |
|---------------------------|------------|-------------|
| Export | Aggregator | Plot |
| Type: Scatter Plot | | |
| x: Cube #1, 1cm Upper | | |
| y: STAND1, #1, Upper, 1cm | | |



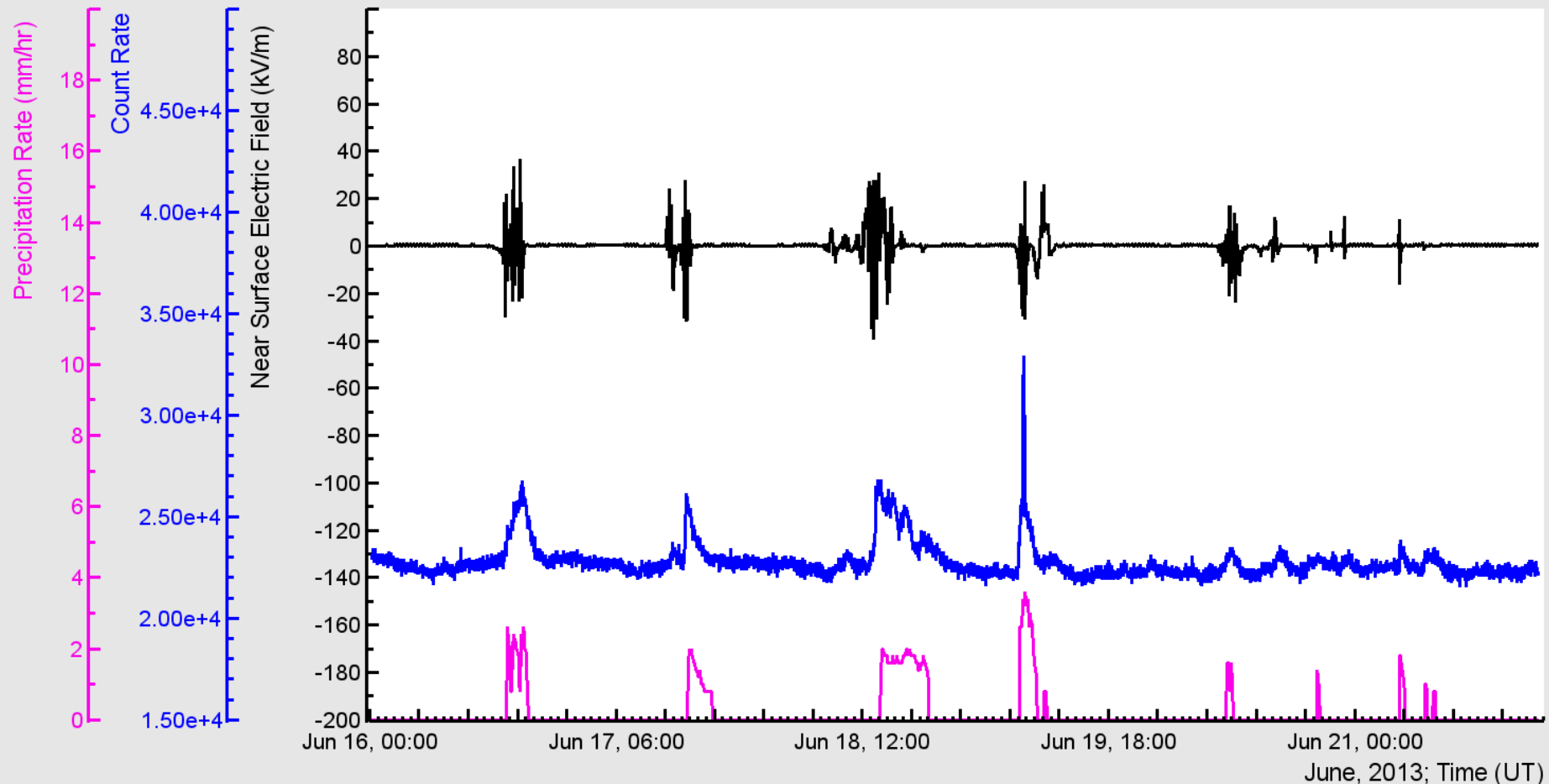
From: 2013-06-19T06:42:46+00:00
To: 2013-06-19T08:02:40+00:00
Resolution: 0
Number of events used:80



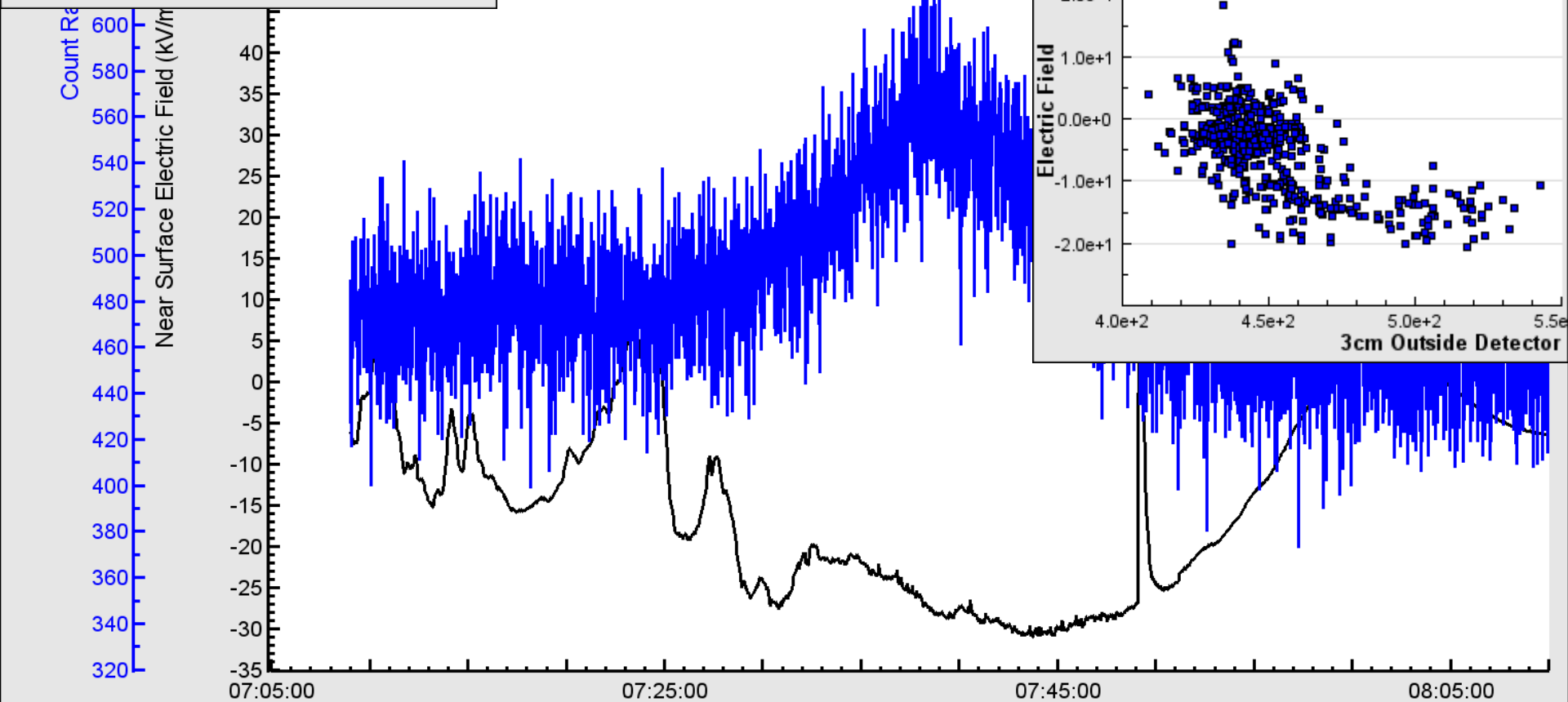
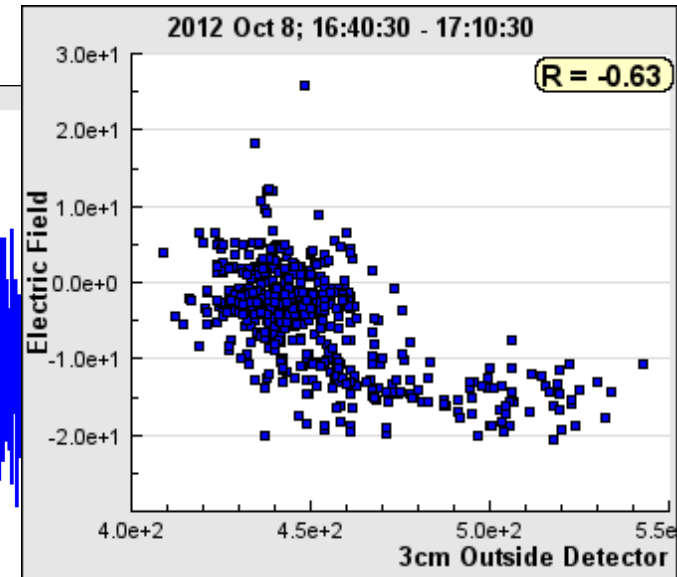
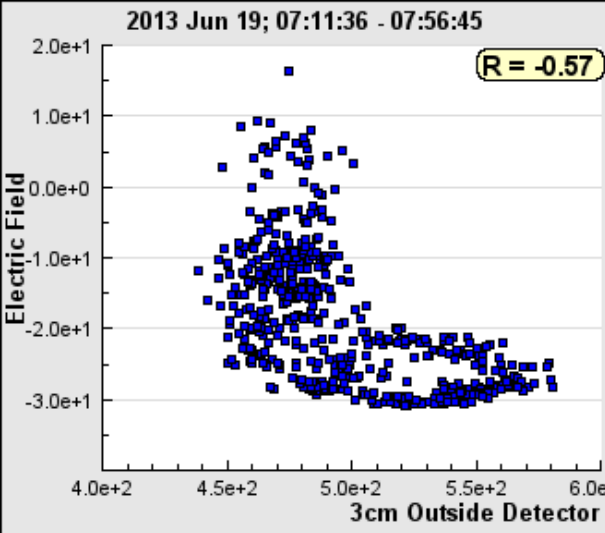
Four Main Patterns of Surface Electrical Field Disturbances



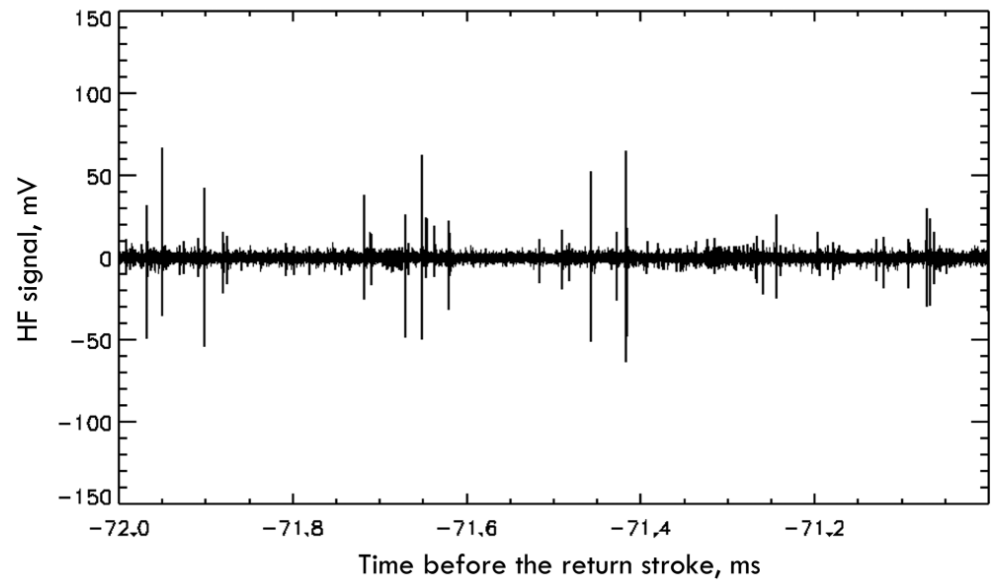
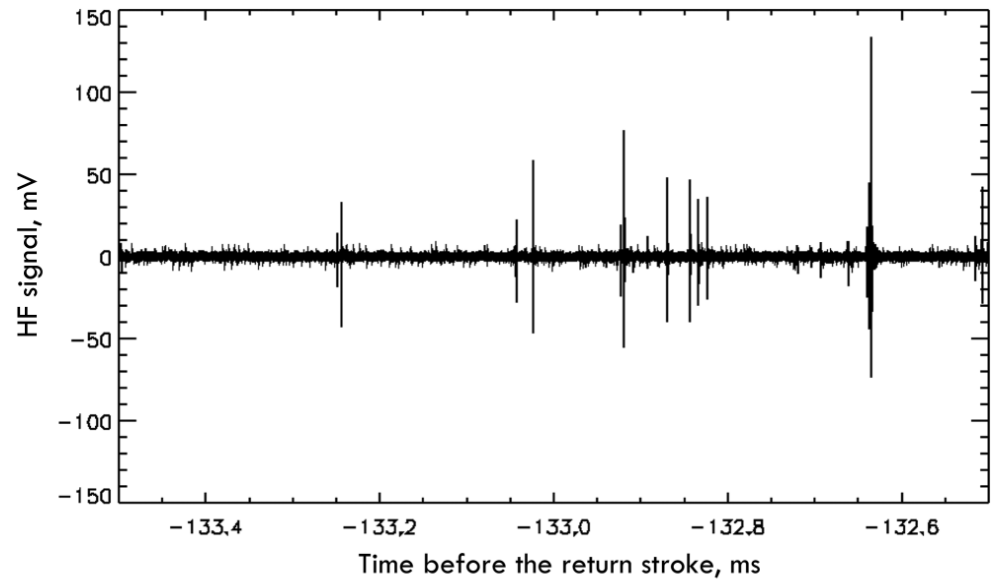
Charge reside on rain droplets



One second time series of EFM-100 and 3 cm outdoor scintillator – correlation of electric field and TGE flux



June 19, 2013; Time (UT)



TGE — no lightning occurrences

Source {Time} Axes

Experiment: All Measurements

Window: Custom

Start: 9/19/2009 22:0:0

End: 9/19/2009 23:8:0

Apply

{Info} Search Source Tree

Export Aggregator Plot

Type: Channel Overview

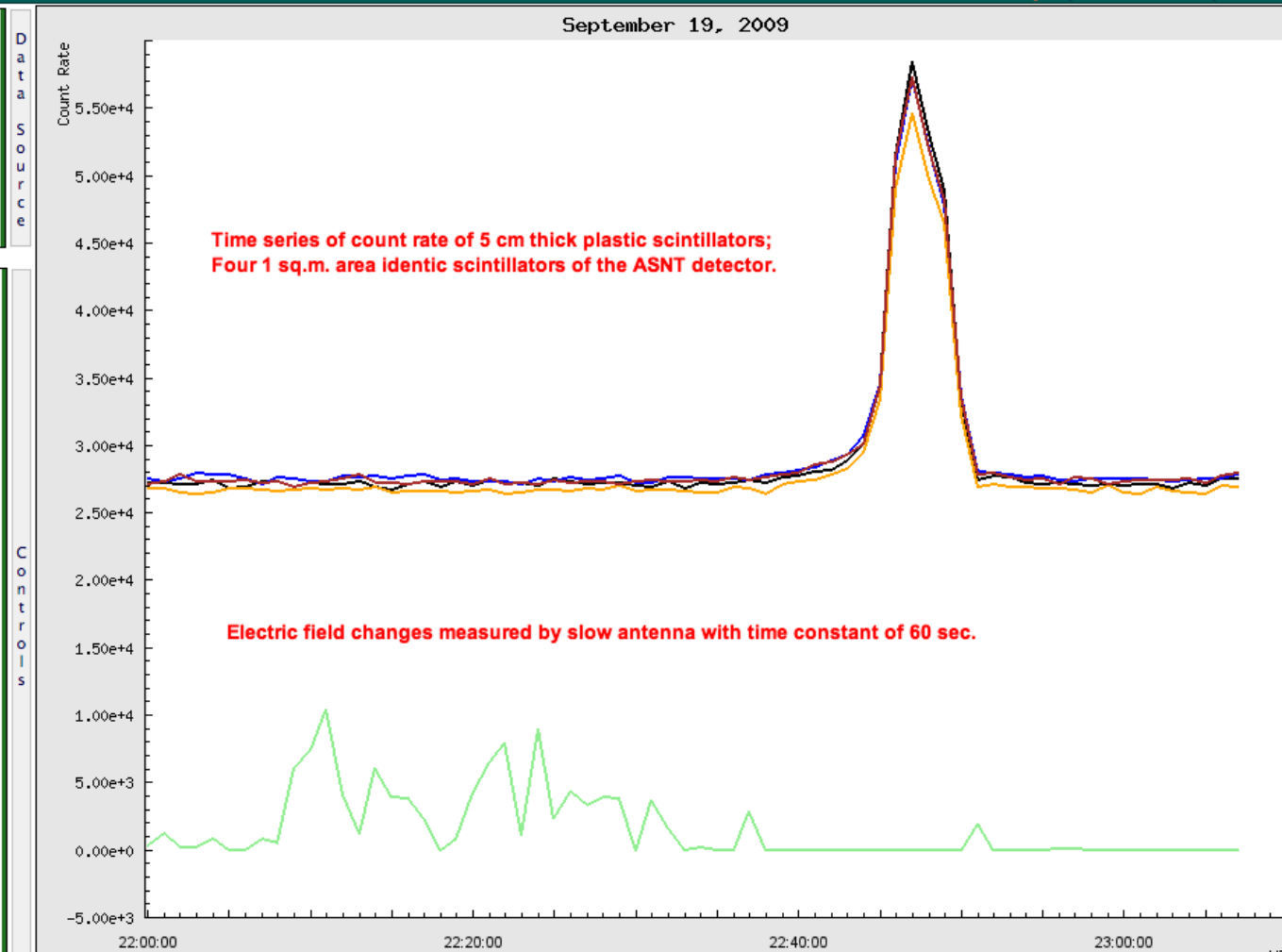
Filter:

Group: ASEC-Aragats - raw - ASNT

| ID | Name | Mean | Range |
|----|-----------------|---------|--------------------|
| 0 | 5cm Detector #5 | 2.90e+4 | 2.66e+4 to 5.85e+4 |
| 1 | 5cm Detector #6 | 2.93e+4 | 2.71e+4 to 5.72e+4 |
| 2 | 5cm Detector #7 | 2.83e+4 | 2.63e+4 to 5.46e+4 |
| 3 | 5cm Detector #8 | 2.91e+4 | 2.69e+4 to 5.74e+4 |

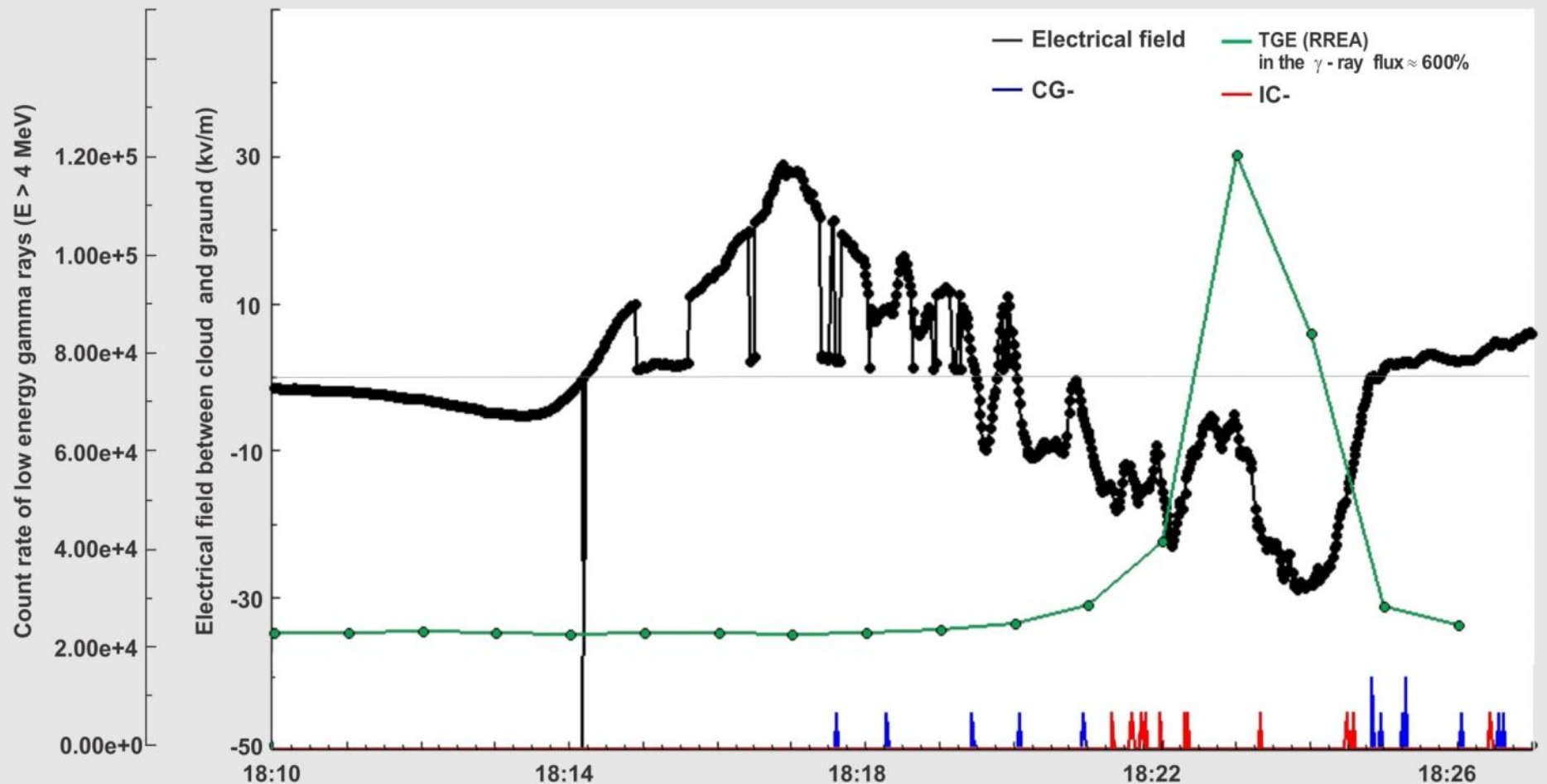
Group: ASEC-Aragats - raw - ArNM

| ID | Name | Mean | Range |
|----|------------------------|---------|--------------|
| 0 | Aragats, Radio Antenna | 1.57e+3 | 0 to 1.04e+4 |



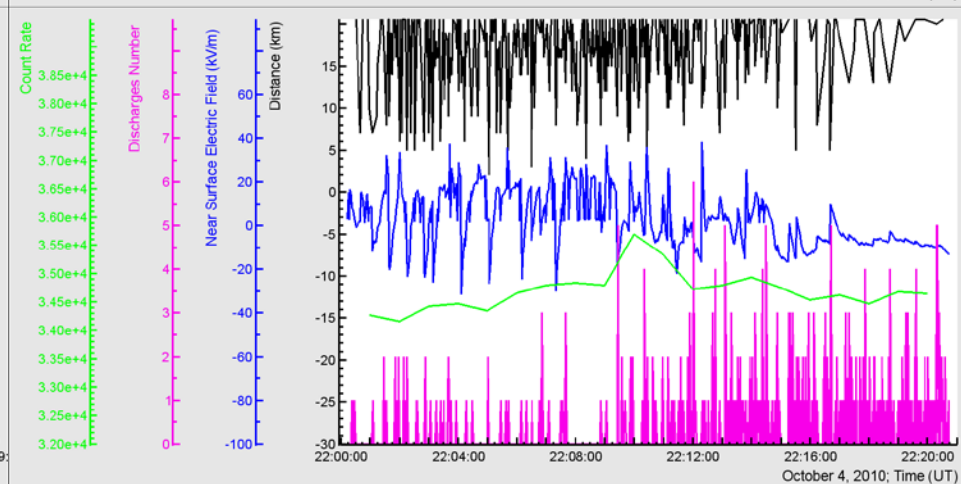
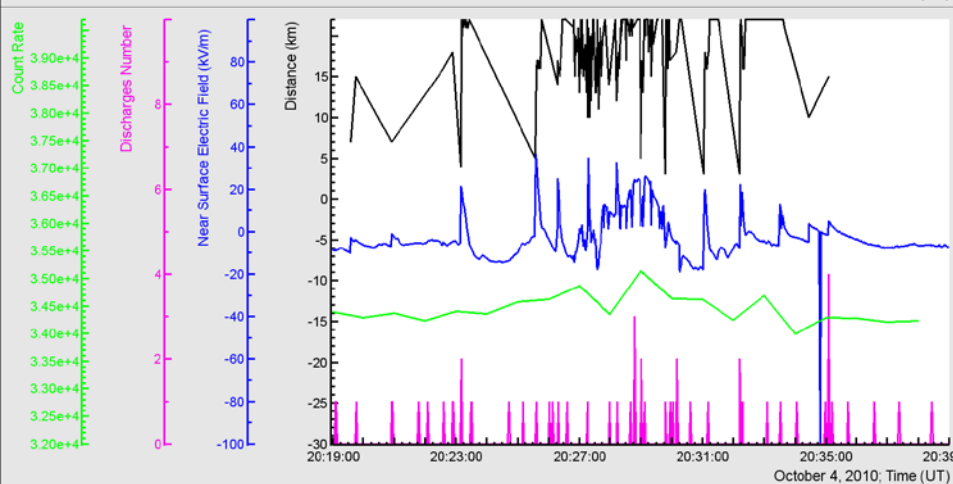
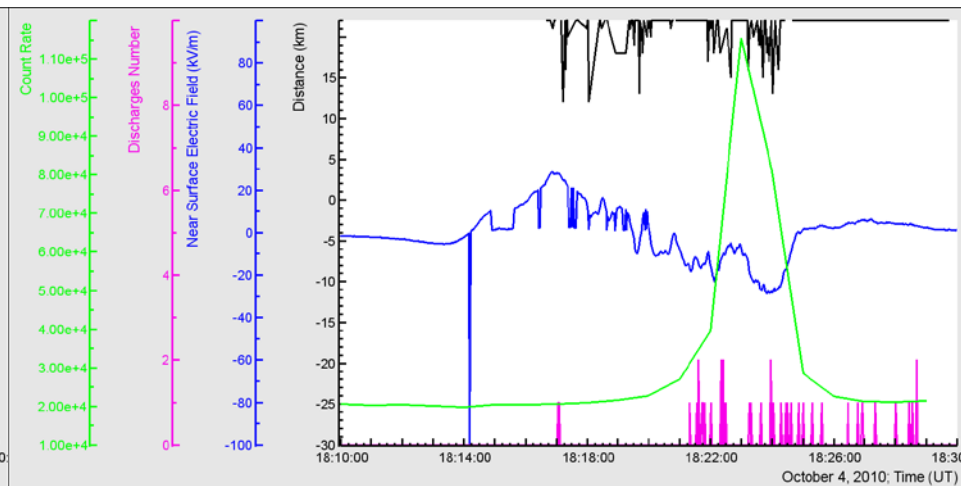
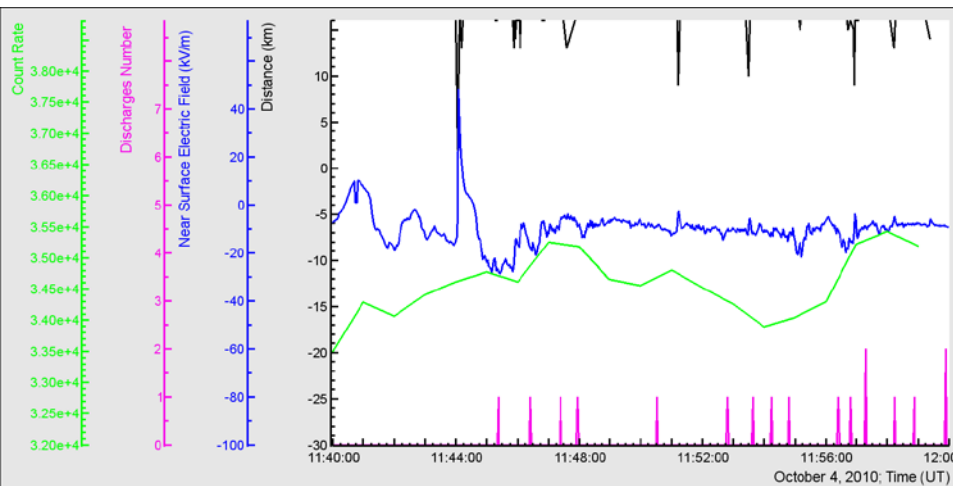
TGE are detected at large negative near-surface electrical field; at the same time CG- are suppressed.

ASEC (Aragats Space Environmental Center; 3200m a.s.l.)



October 4, 2010 Time (UT)

October 4, 2010 – super storm- lightning is not cause of GLE!



What we know about TGEs?

- Lower dipole in thunderclouds transfer effectively field energy to electrons; electrons generate gamma rays and gamma rates by photo-nuclear reactions born neutrons detected on earth's surface;
- **Origin of TGE is mainly mixture of 2 processes RREA (1 -40 MeV, enhancement up to 10 times above CR flux) and modification of CR energy spectra MOS (1- 100 MeV enhancement only few % of CR flux).**
- **RREA generates particle bursts with duration less than 1 μ sec (ECS – “downward” TGFs); overall duration of TGE is \sim 10 minutes, during 10 minutes large amount of ECSes occurs ;**
- Largest TGE events allows to estimate energy spectra: energy spectra of electrons are exponential, of gamma rays - power law in overall;
- **Simultaneously with boost of electrons and gamma rays high energy muon flux attenuates;**
- TGEs usually occurs during negative near surface electrical field varied from -10 to -30 kV/m; TGE flux correlate with strength of electric field and – with spectral index of gamma ray energy spectra;
- **During TGEs only IC- lightning can occur; CG- lightning are suppressed – LCPR stops lightning leader.**

TGF - TGE(ECS) relation

- The generation mechanisms of the space TGFs and downward TGFs (ECSes) share some common features: runaway electron avalanches *in lower dipole and in upper dipole*. TGEs happen in series – hundreds of Extensive Cloud Showers in a second. TGFs represent few RREA cascade lasting milliseconds.
- ECSes are very rare events (detected at Aragats about once a year); number of detected TGFs detected by RHESSY, FERMI LAT and GBM is much larger - reaching hundreds per year. Nonetheless, because of closeness of the particle beam, the number of detected TGEs in 3 series of detection is comparable with number of yearly detected TGFs ~500.
- Recently FERMI confirms that sferics detected in correlation with TGFs are due to TGF itself and not lightning!

Relations between Lightning- radio signals – particle fluxes

- Particle fluxes start before lightning flashes;
- Lightning flashes are numerous and strong without any relation to particle fluxes;
- For initiation of TGE we need electric field, rain droplets and maybe definite relations of other meteorological parameters (humidity-temperature)
- Development of LPCR may accompanied by HF radio emission – coherent discharges of stretched HM with CR (RREA) electrons;
- For TGE we do not need additional seed electrons, do lightning provide seed electrons to TGF?
- Particle fluxes and lightnings are alternative processes – both are initiated by strong electric fields in thunderclouds