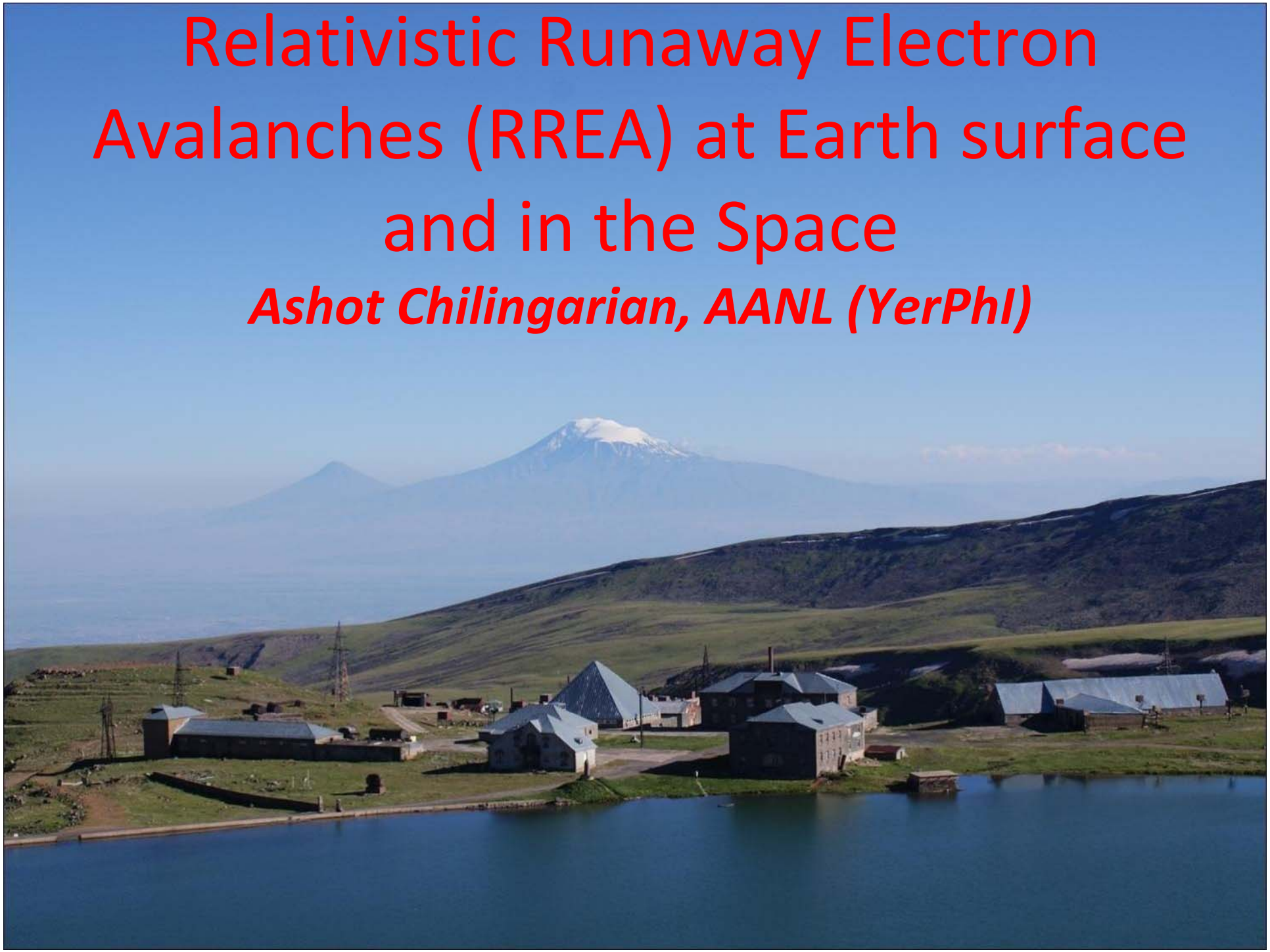
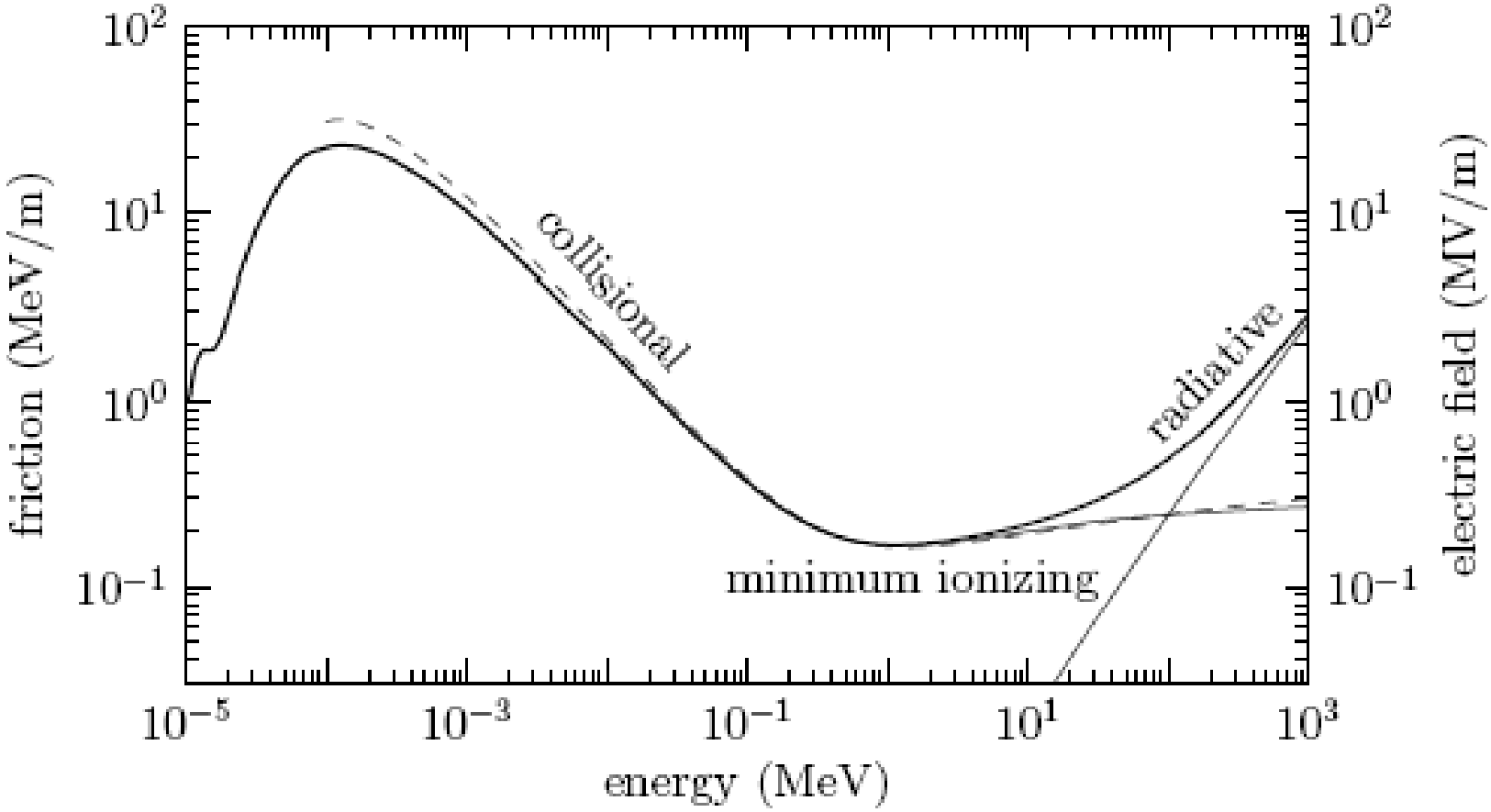
Relativistic Runaway Electron Avalanches (RREA) at Earth surface and in the Space

Ashot Chilingarian, AANL (YerPhI)

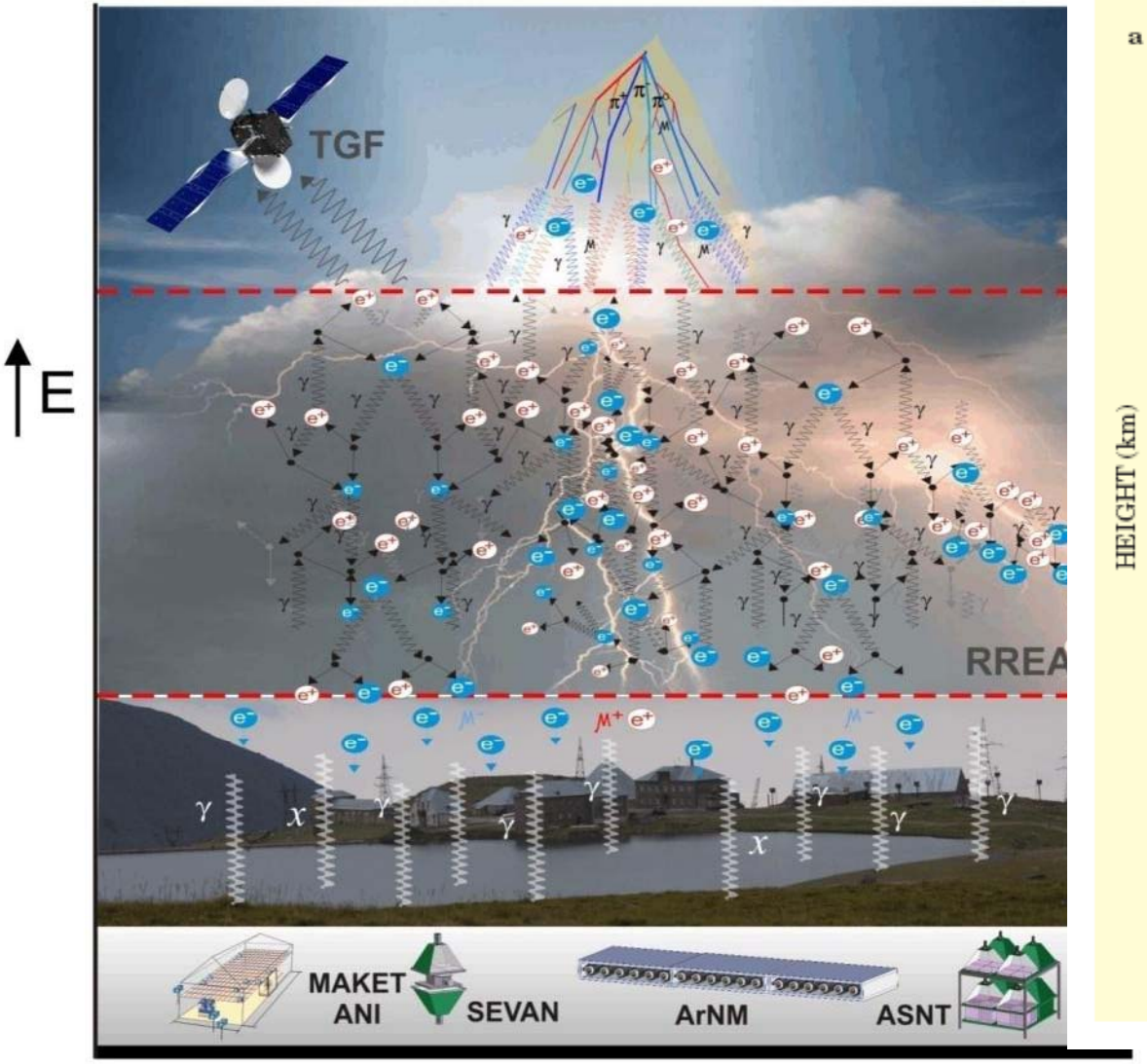


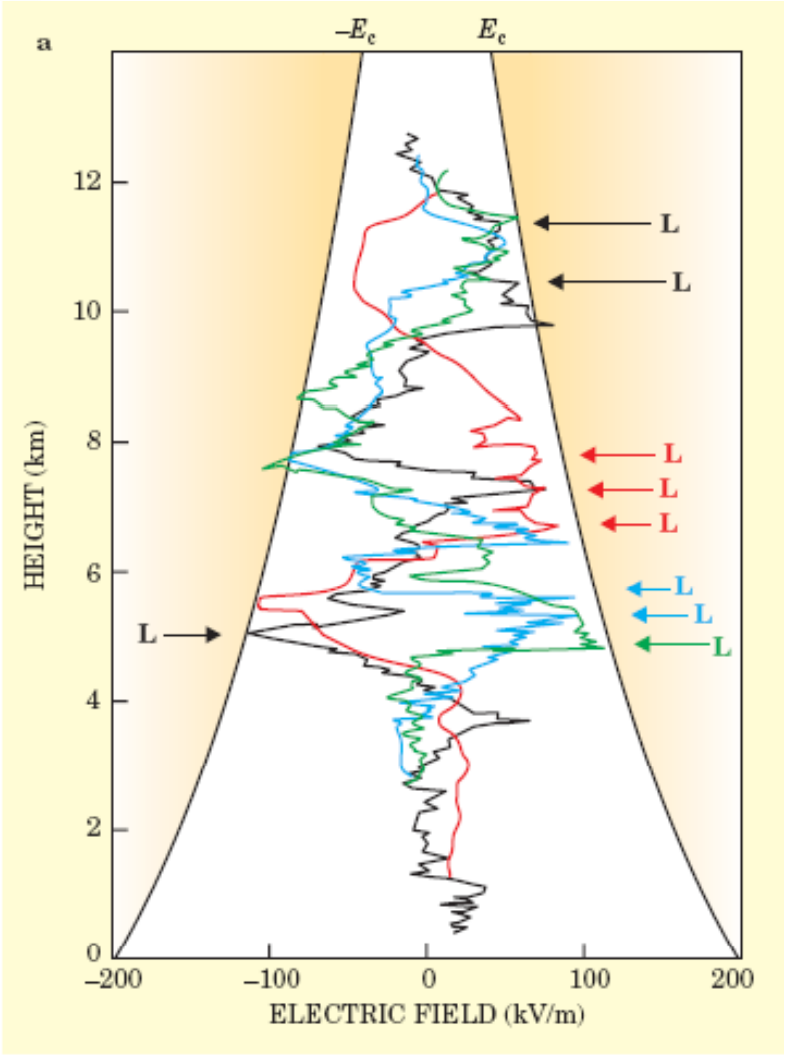
How electrons can “runaway”?



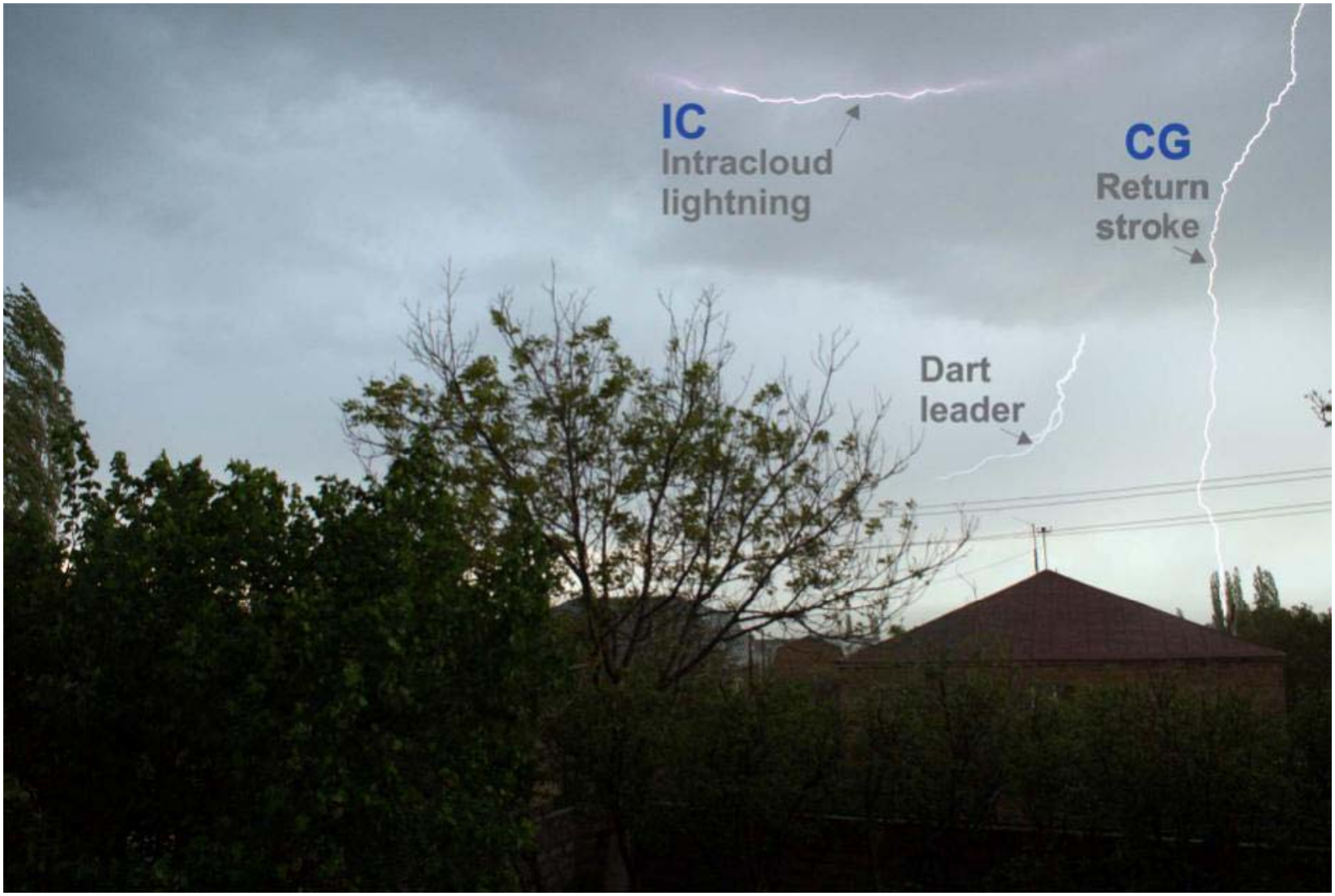
Friction on electrons in air at sea level. Shown as a function of electron energy. The axis on the right indicates the electric field strength required to produce a force on an electron equal to the frictional force.

Cosmic Rays produce population of MeV seed electrons, thunderclouds – electrical field and RREA started





Around tip of IC lightning leader we have both seed electrons and huge electrical field of E > 20 MV/m; RREA (TGF) started

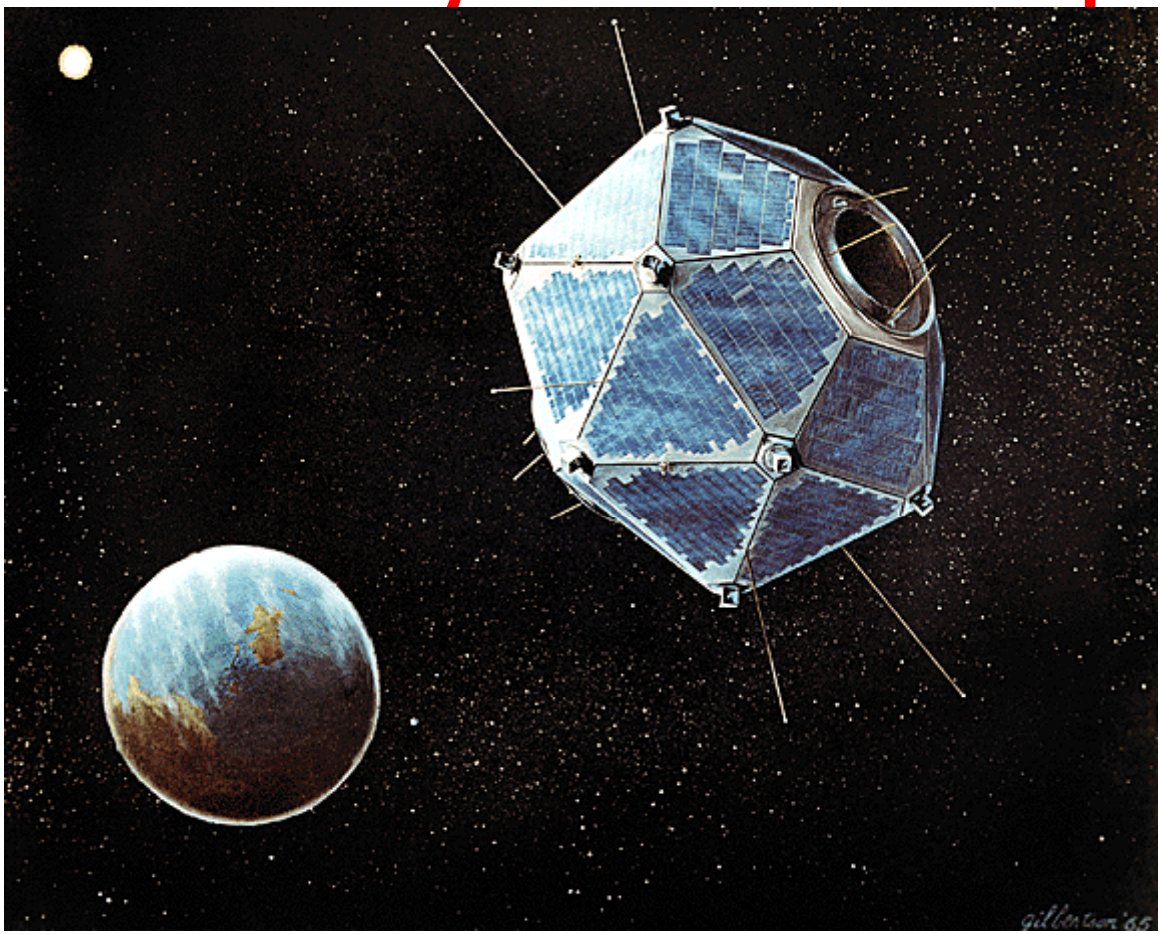


The Godfathers of the Gamma-ray Astronomy

President Kennedy and Chairman Khrushchev meeting in Vienna, 03 June 1961;

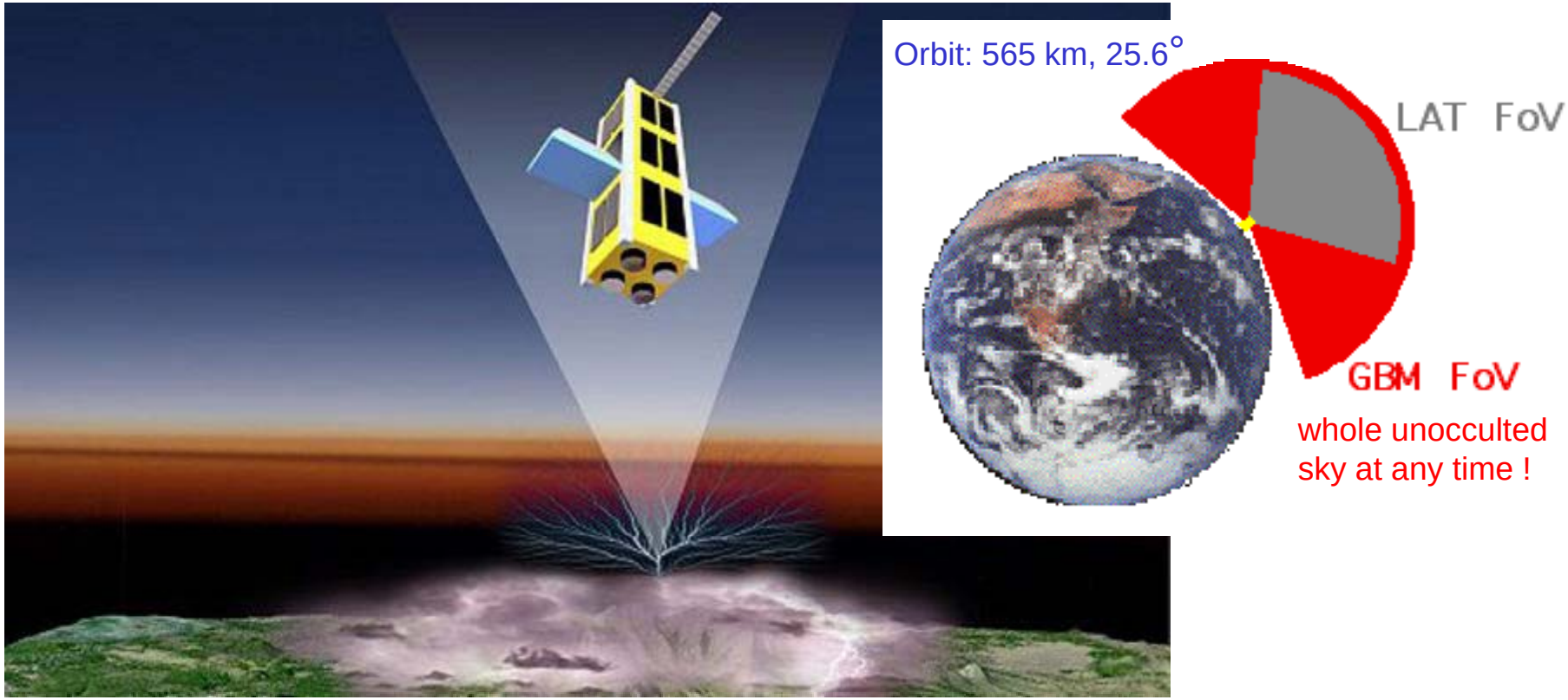
At August 5, 1963, after more than eight years of difficult negotiations, the United States, the United Kingdom, and the Soviet Union signed the Limited Nuclear Test Ban Treaty.

Vela 5 found twelve GRBs which had not coincided with any solar flares or supernovas.



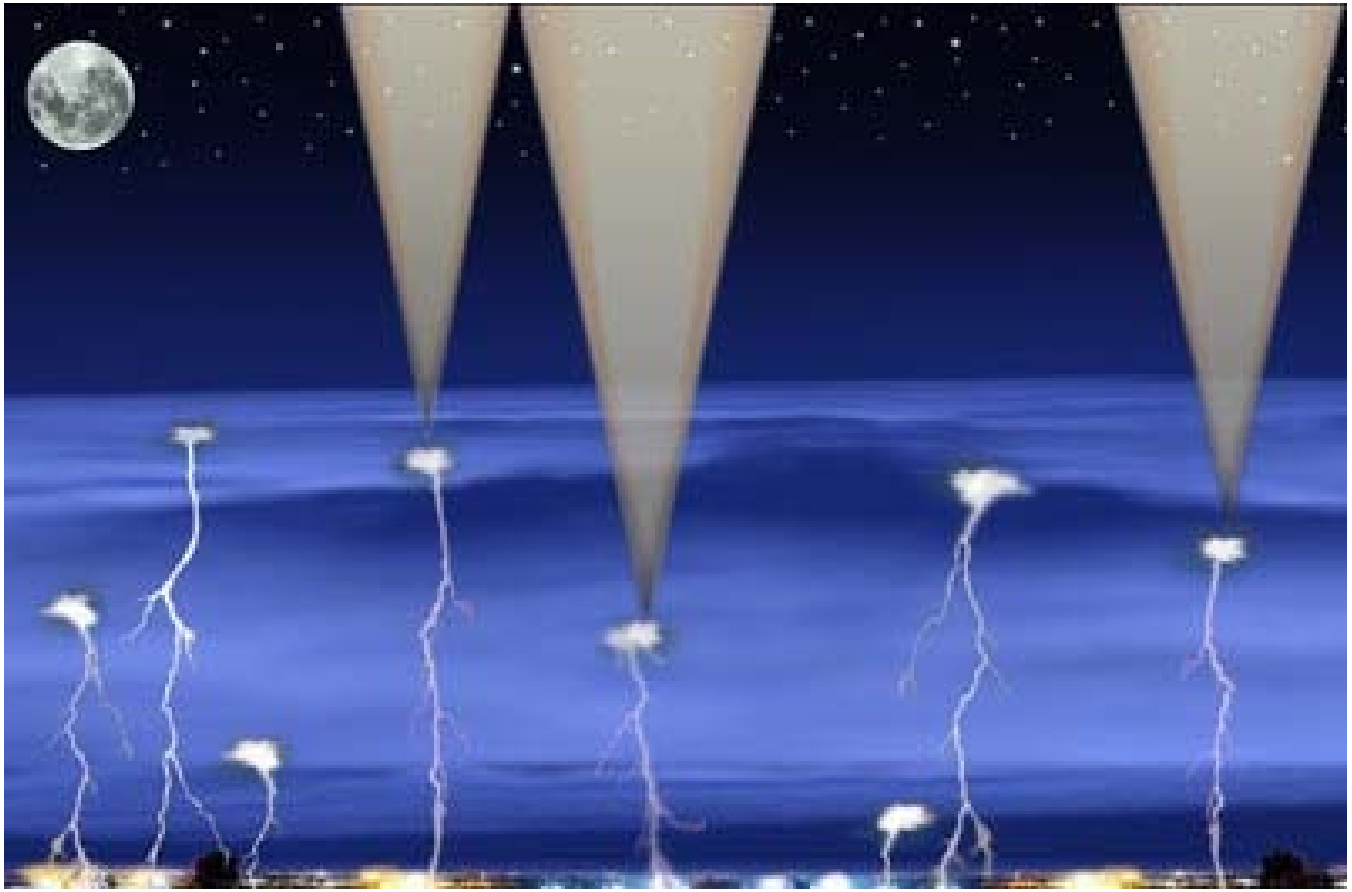
On July 2, 1967, Vela 4 and Vela 3 detected flashes of gamma radiation that were not characteristic of any known nuclear weapons. Nuclear Bombs produce intense burst of gamma rays for less than 10^{-6}s. The gamma rays then gradually fade as nuclei decay. The gamma ray burst detected in 1967 did not have an intense initial flash or a steady fading.In 1969 the data were analyzed by Ray Klebasabel. Klebasabel found a spike in the data, a dip, a second spike, and a long, gradual tail off. His team checked for possible solar flares and supernovae that could be reasonable and found none. [5]

Fermi to Focus on Terrestrial Gamma Ray



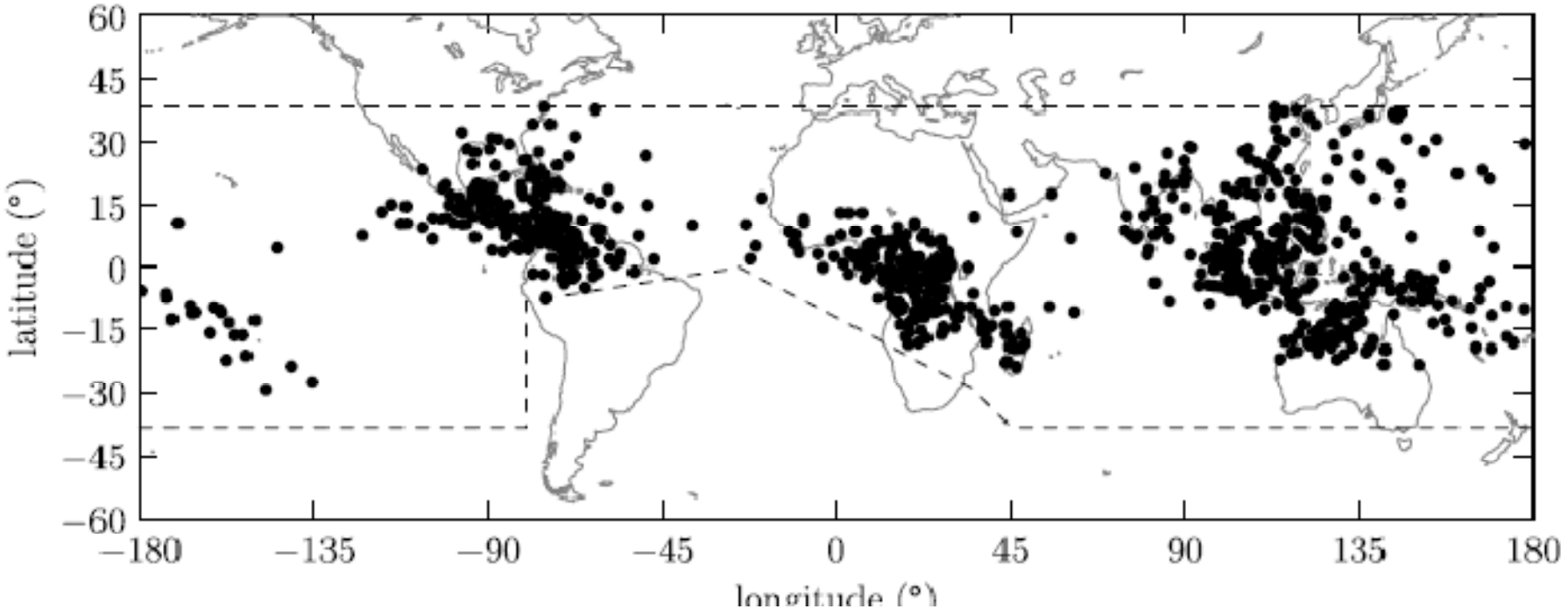
Astronomers operating the NASA Fermi Gamma-Ray Space Telescope have recently announced that they will turn the observatory towards our planet, in a bid to study the peculiar and mysterious events that terrestrial gamma-ray flashes (TGF) are. These events occur during very powerful storms, but thus far experts have had no idea as to why this is happening

Space Telescope Sifts Earth Storms for Radiation Flashes

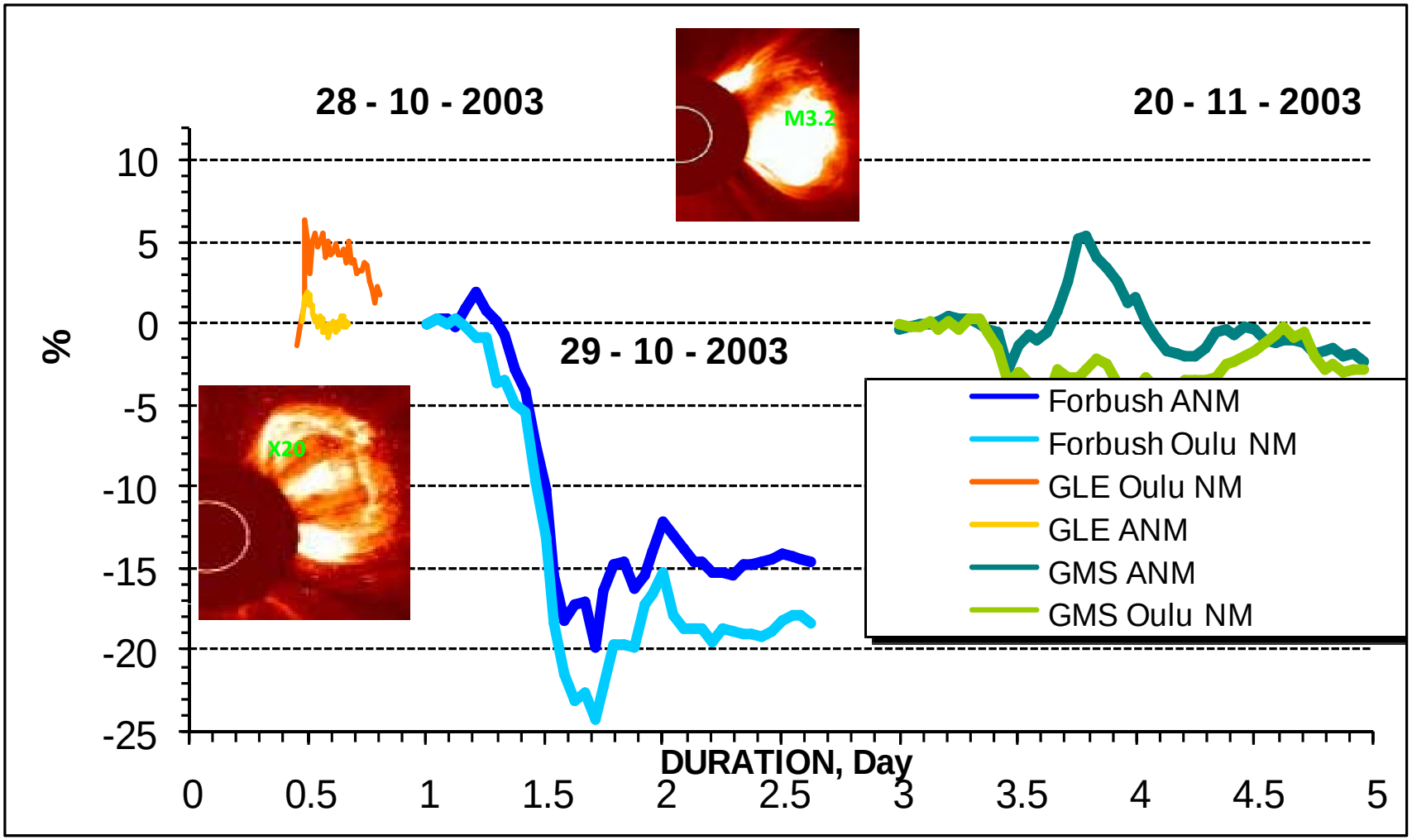


A NASA space telescope hunting for the most powerful explosions in the universe is turning its eye on Earth to hunt for tiny flashes of radiation. Fermi Gamma-Ray Space Telescope has joined the search for TGFs above thunderstorms which are ultra-brief, but could be a concern for air travelers, 400 chest X-rays.

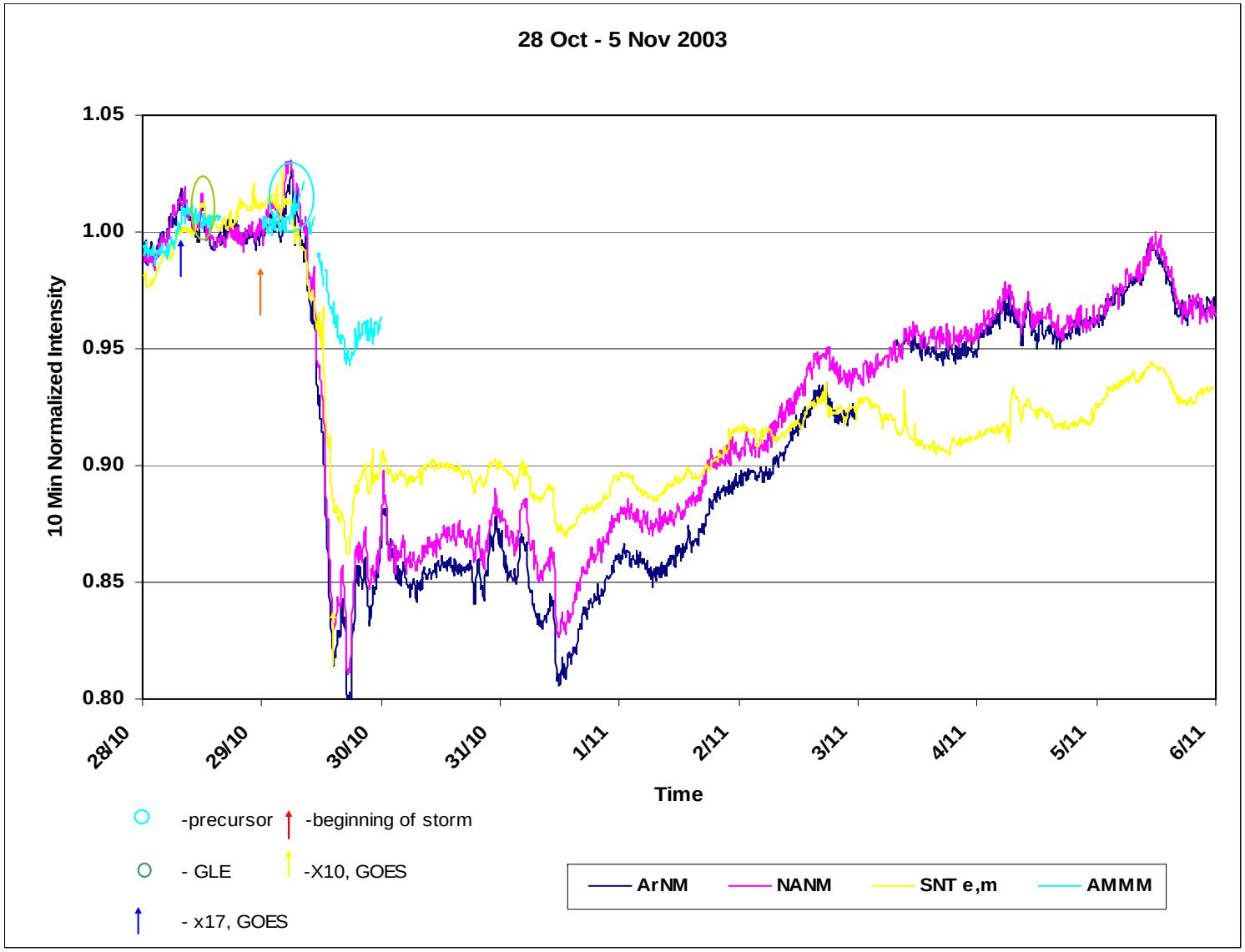
Reconstructed origin of TGFs



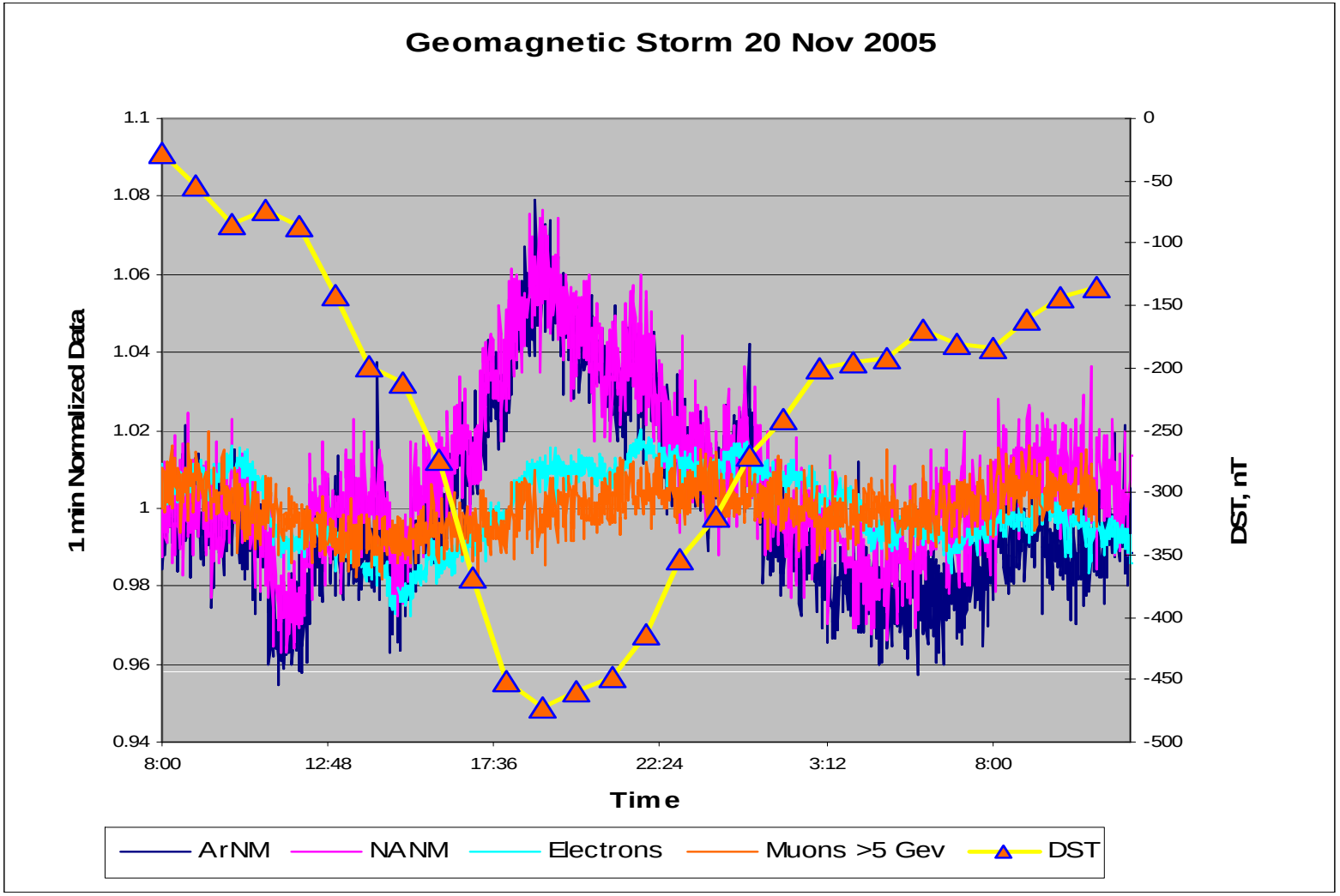
Solar Modulation effects at high and middle latitudes – to detect GLE we need large count rate

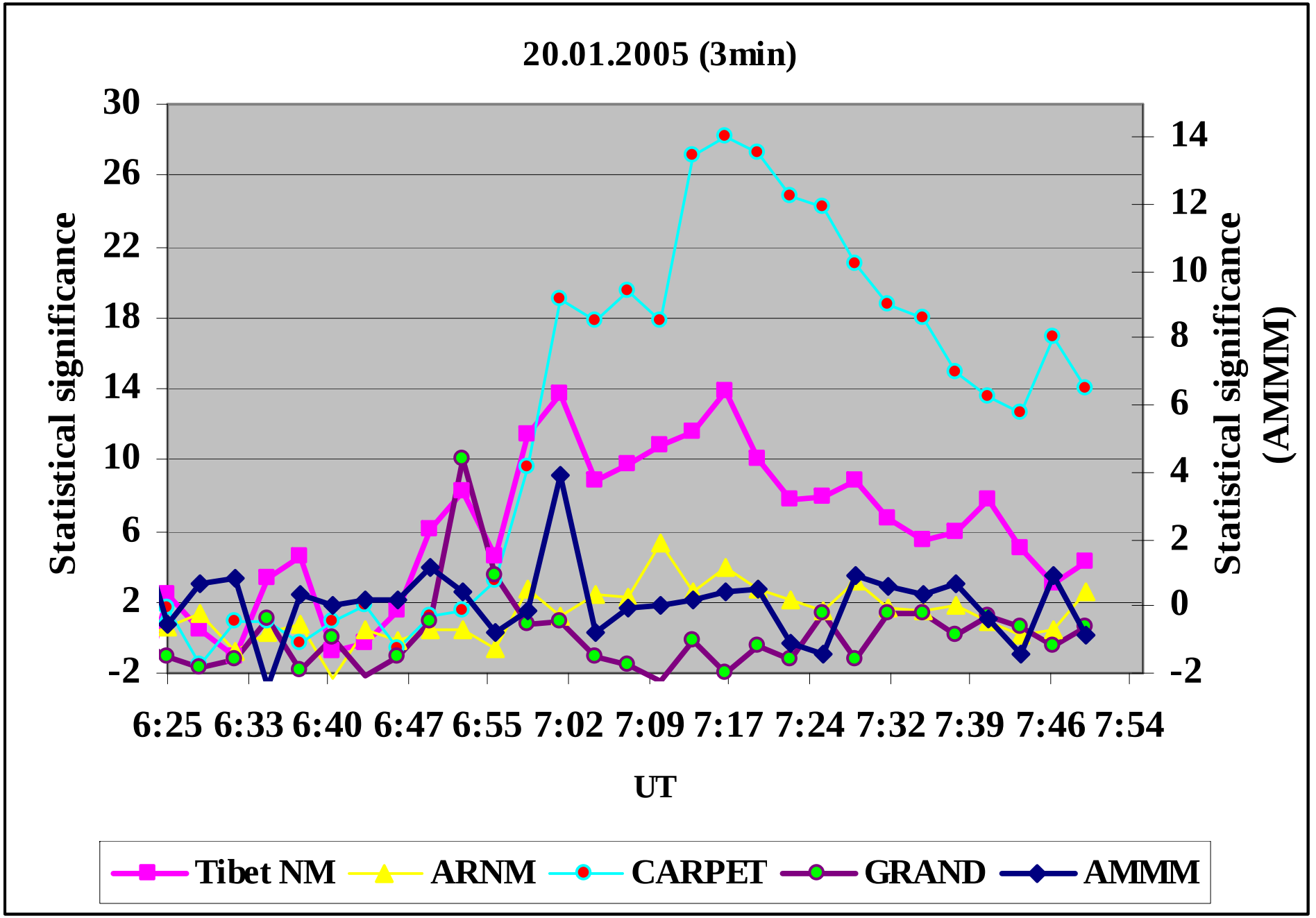


Famous “Halloween” events of 2003, detected in electron & muon and neutron fluxes by ASEC monitors at different altitudes

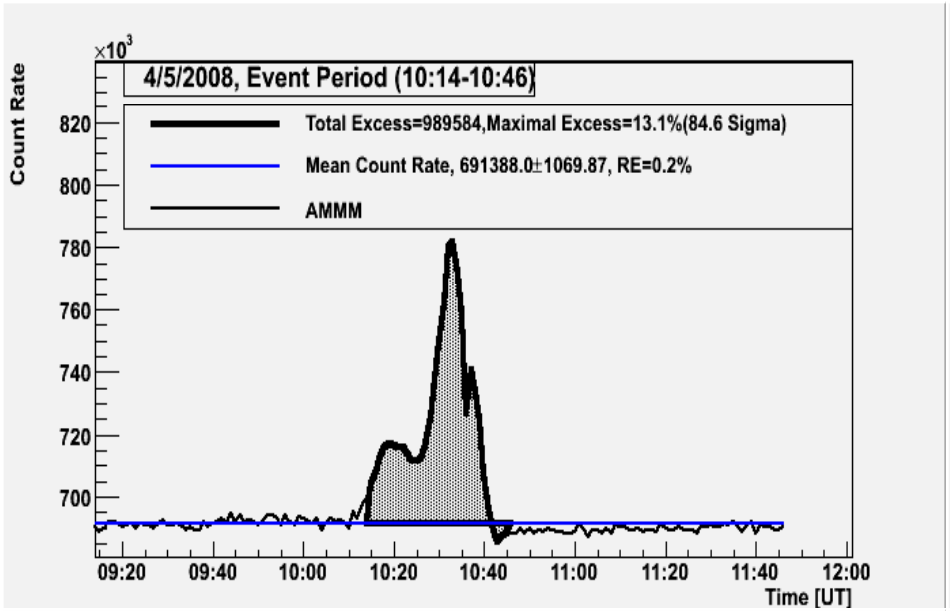


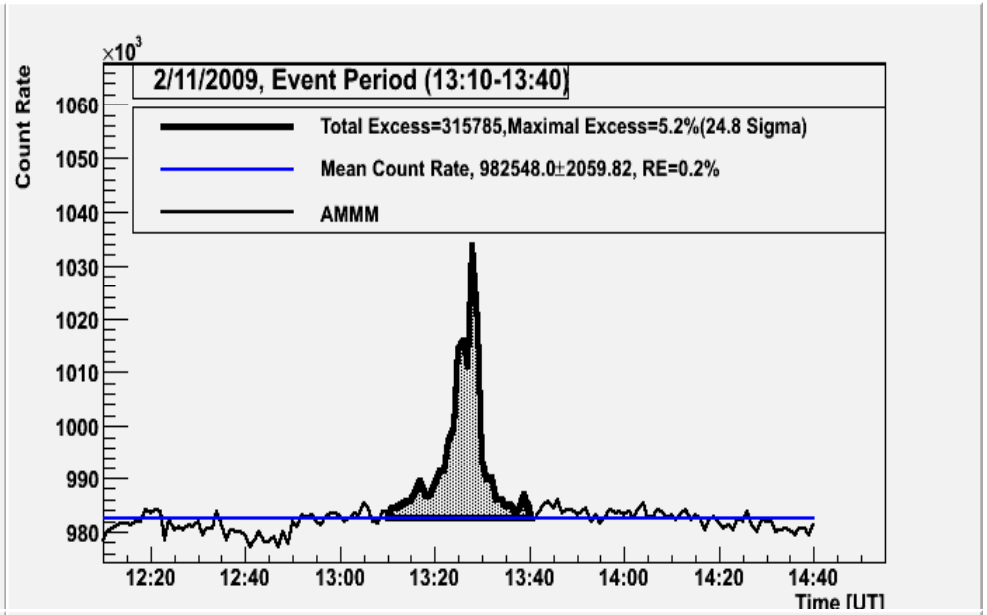
Geomagnetic Disturbance of 20 November 2003

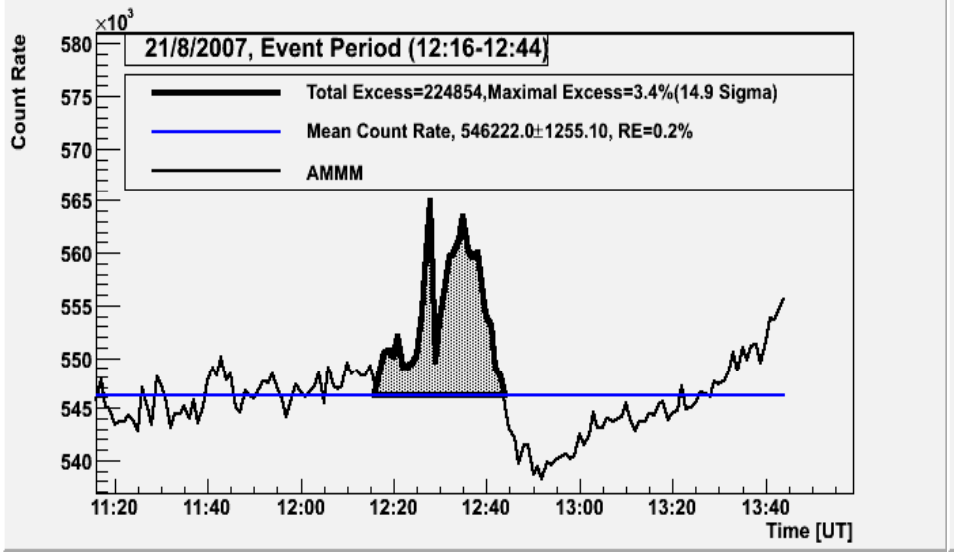


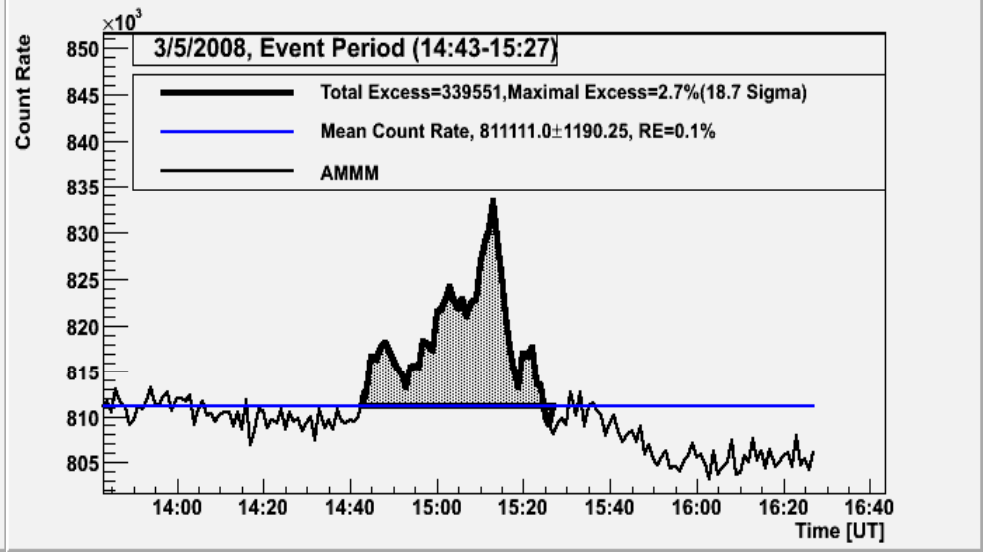

20.01.2005 (3min)
Statistical significance
30
26
22
18
14
10
6
2
-2
14
12
10
8
6
4
2
0
-2
Statistical significance
(AMMM)
6:25 6:33 6:40 6:47 6:55 7:02 7:09 7:17 7:24 7:32 7:39 7:46 7:54
UT
Tibet NM
ARNM
CARPET
GRAND
AMMM

RREA Events – huge lost lasting peaks in particle monitor time series (event library available)

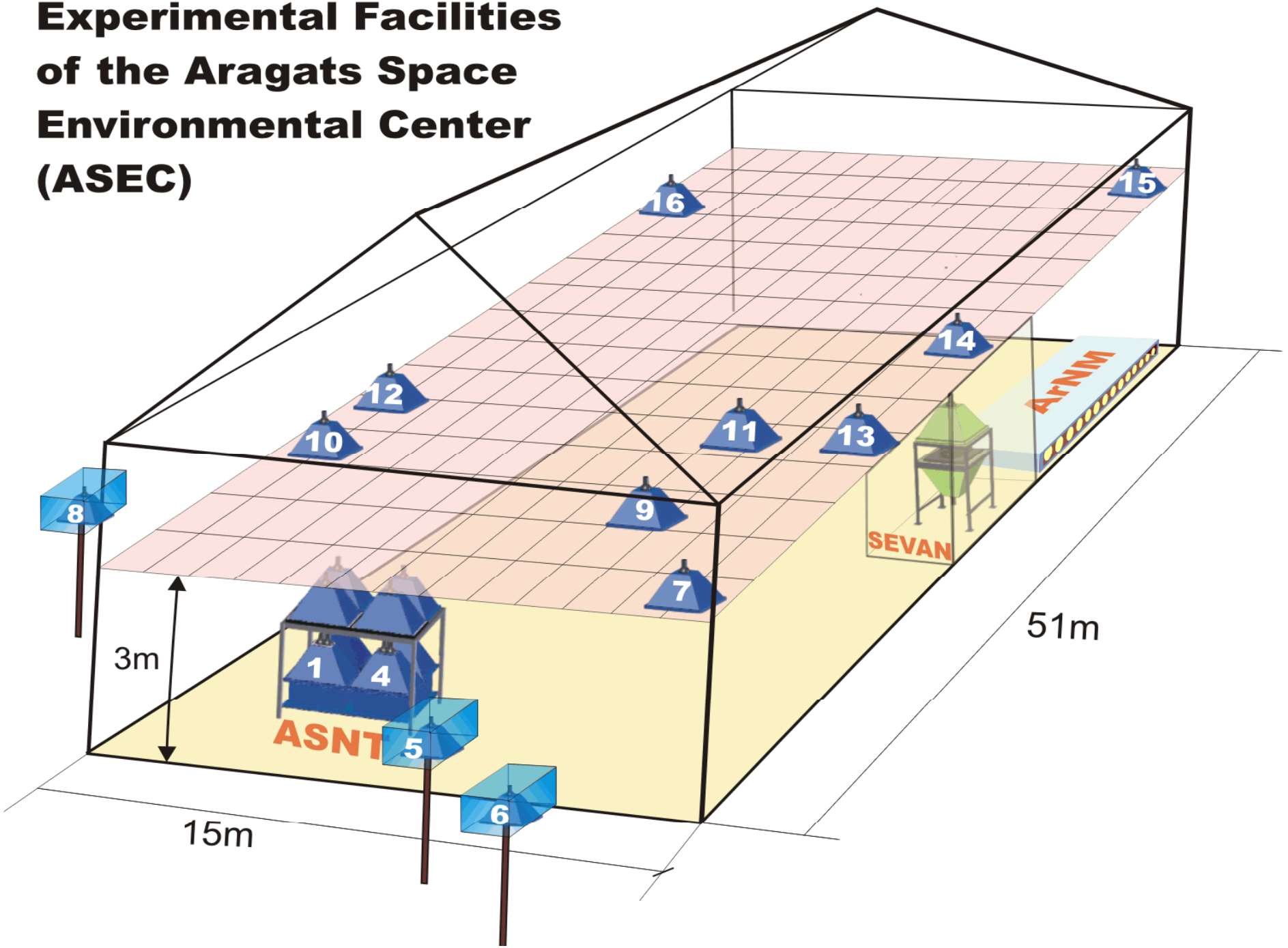




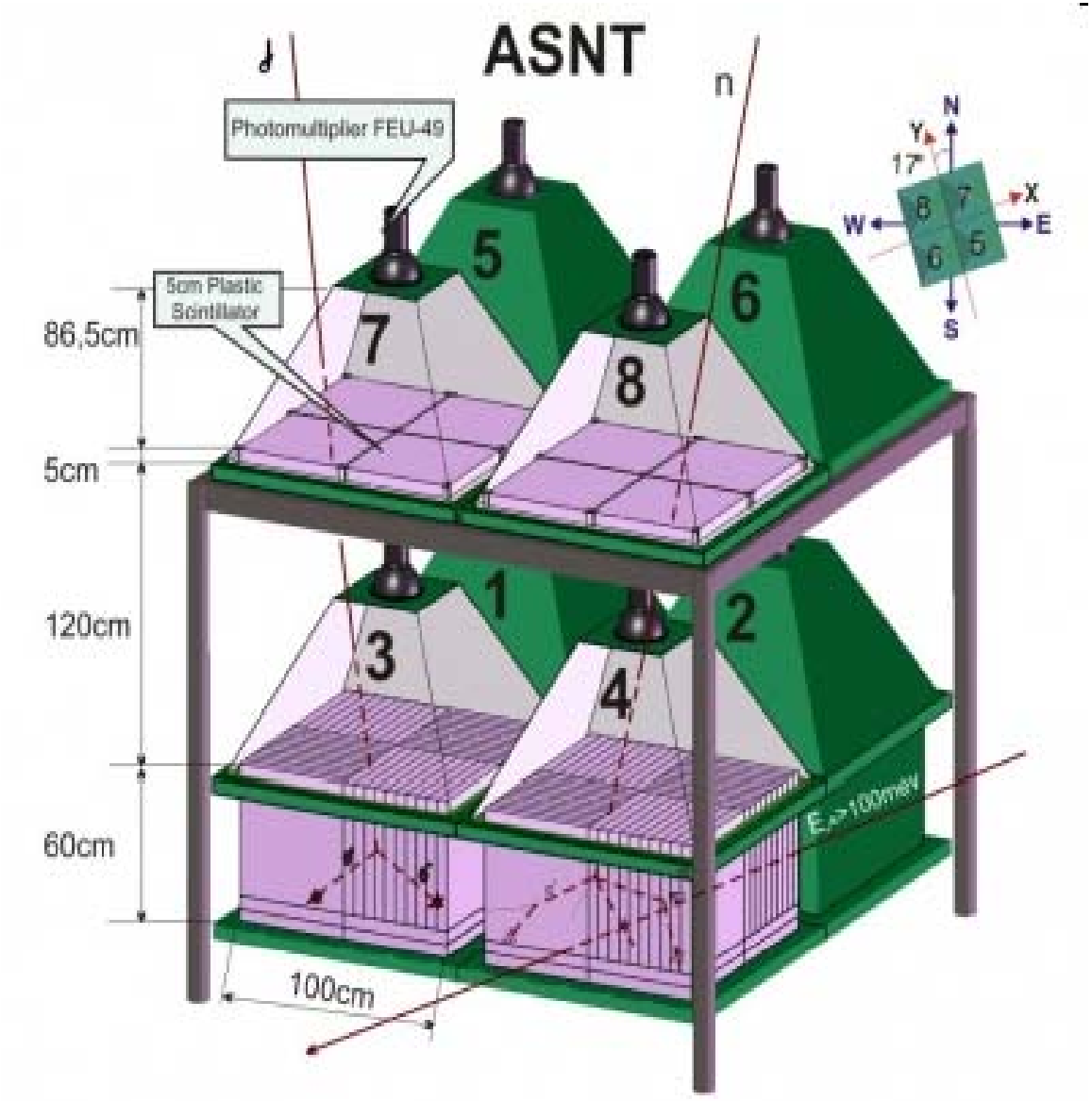


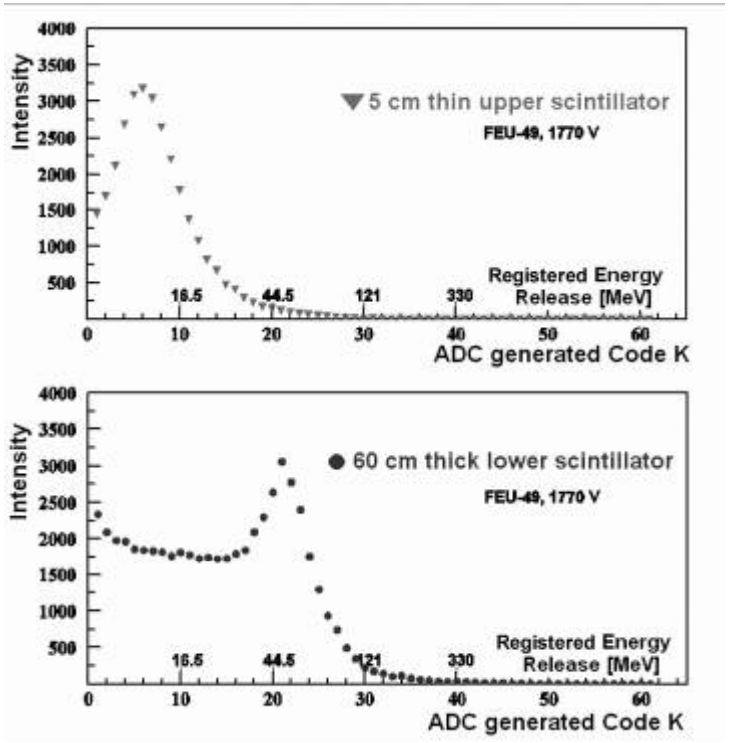


Experimental Facilities of the Aragats Space Environmental Center (ASEC)

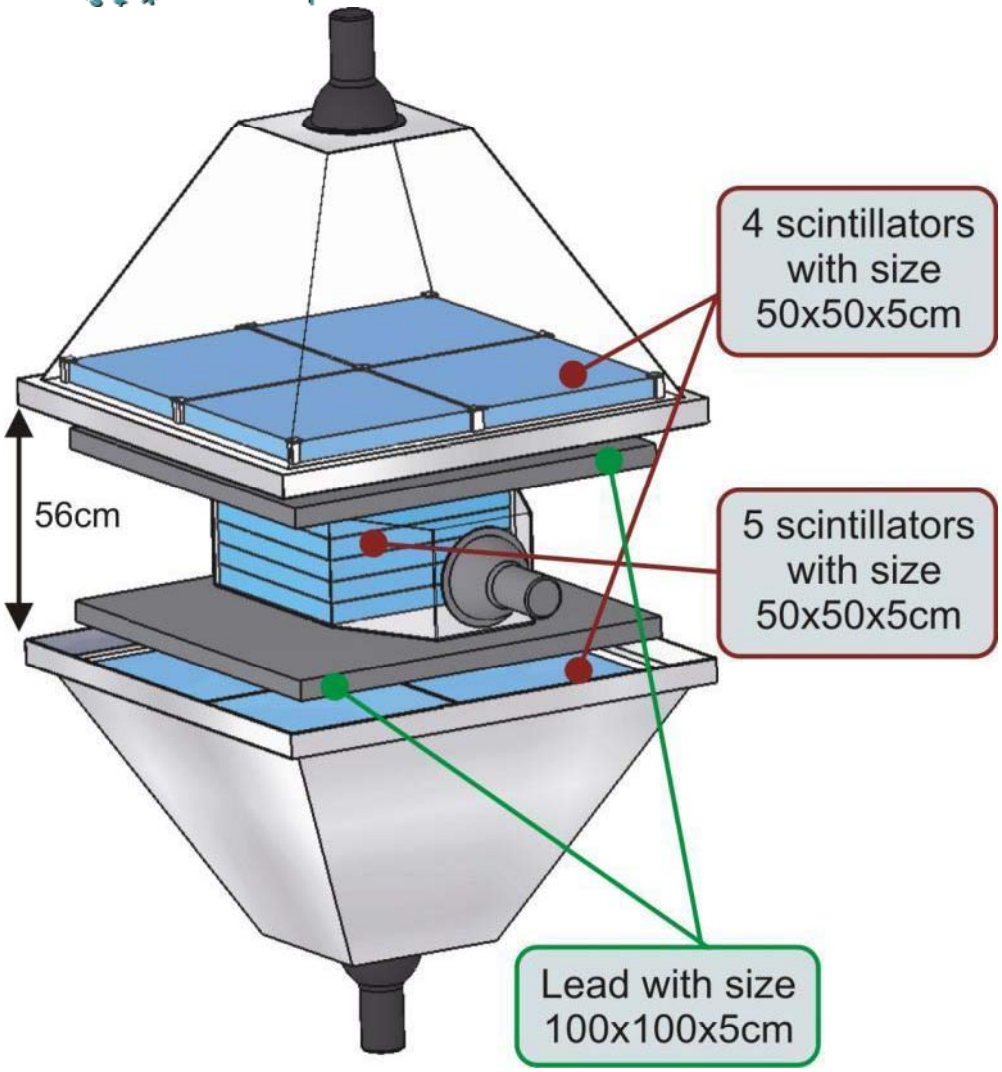


Aragast Solar Neutron Telescope("deep" calorimeter for 10-120 MeV particles)





SEVAN basic unit: monitoring 3 species of secondary CR



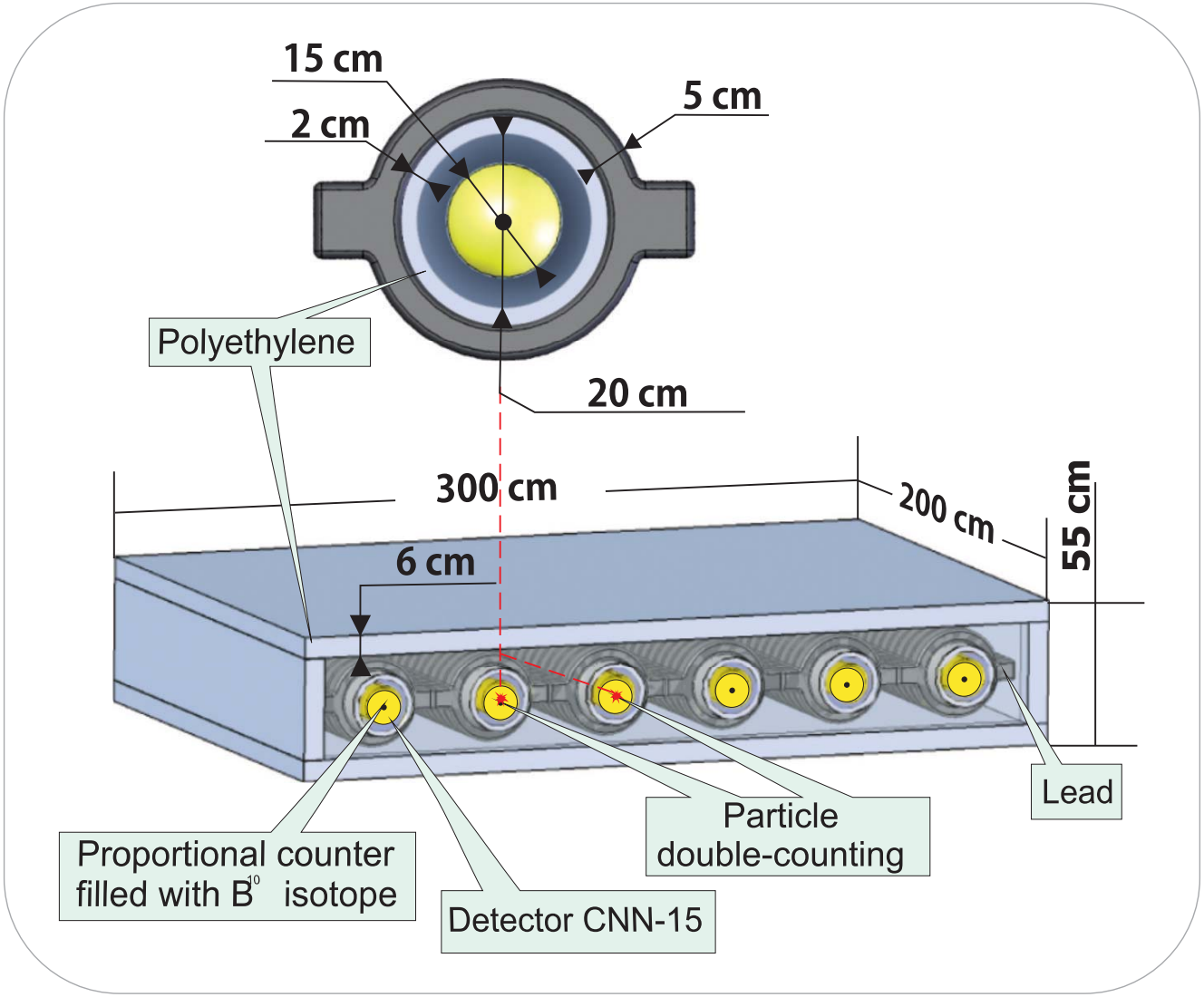
100 – traversal of the low energy charged particle (~<200MeV);

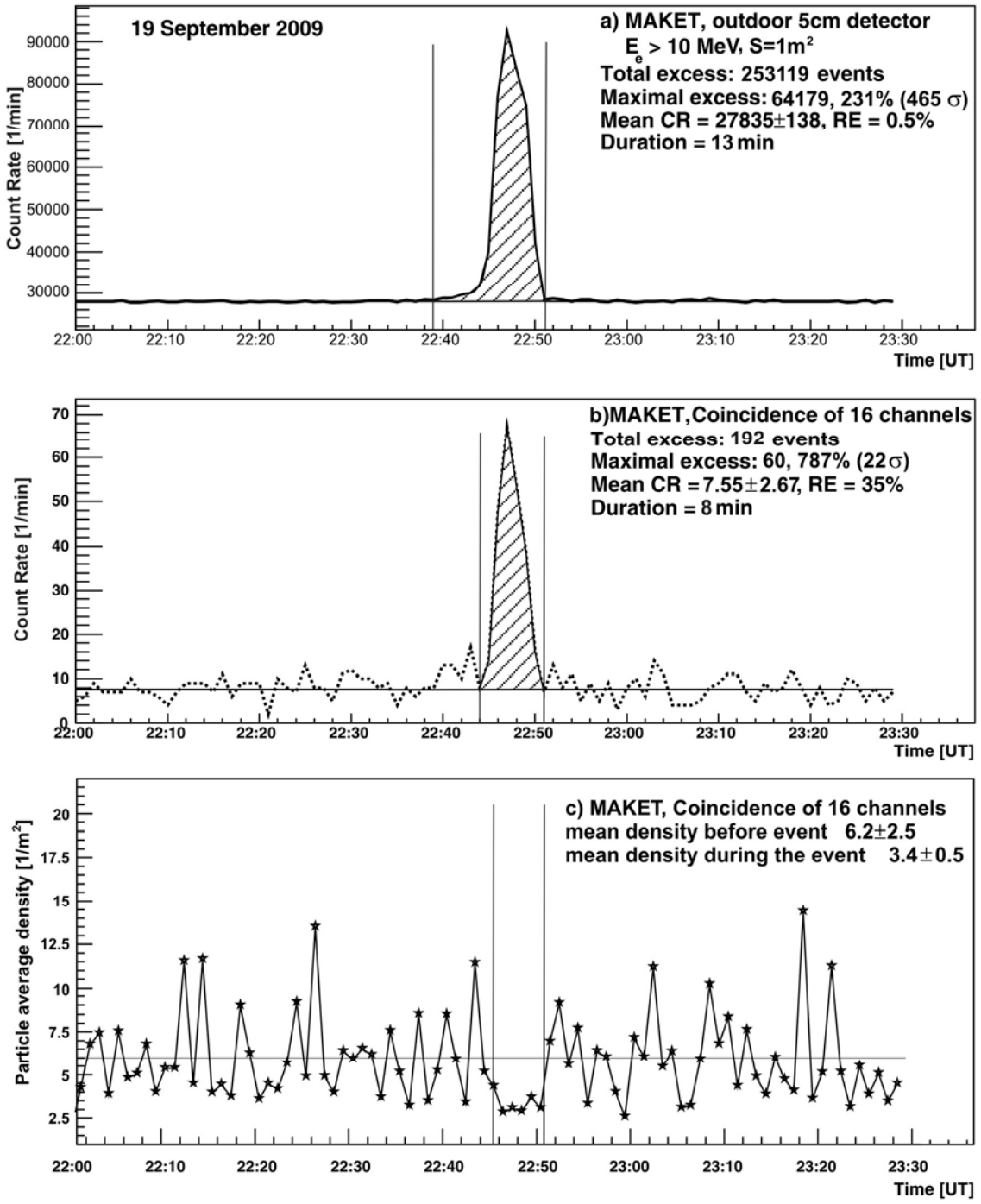
010 – traversal of the neutral particle;

111 & 101 – traversal of the high energy muon (~>250MeV);

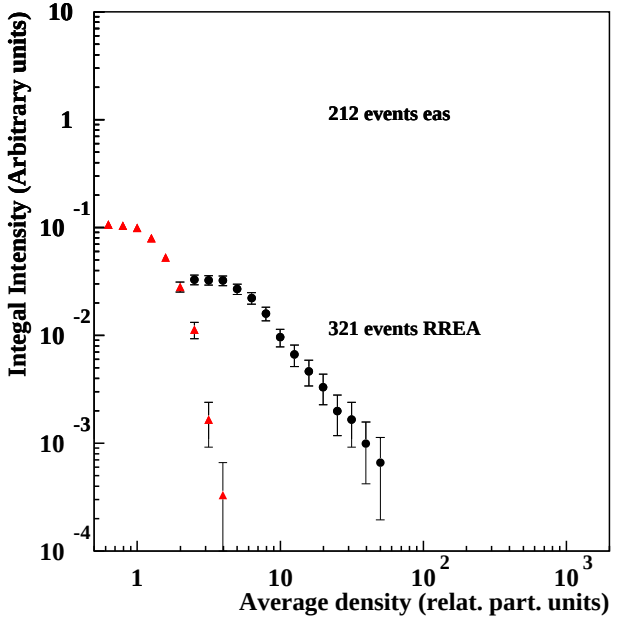
COSMIC RAY DIVISION
Alikhanyan Physics Institute,
Alikhanyan Brothers 2,
Yerevan 375036, Armenia

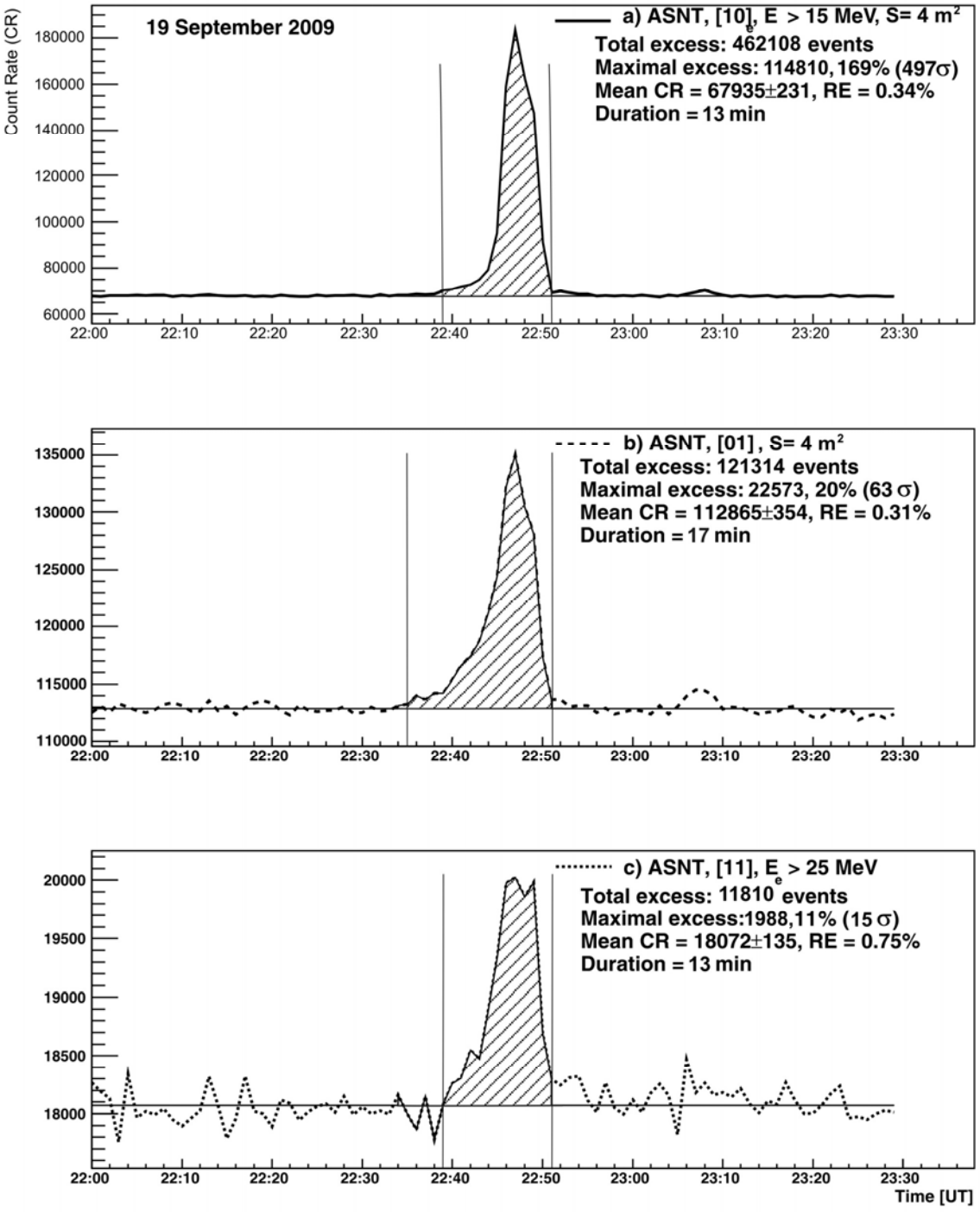
Section of the Neutron Monitor



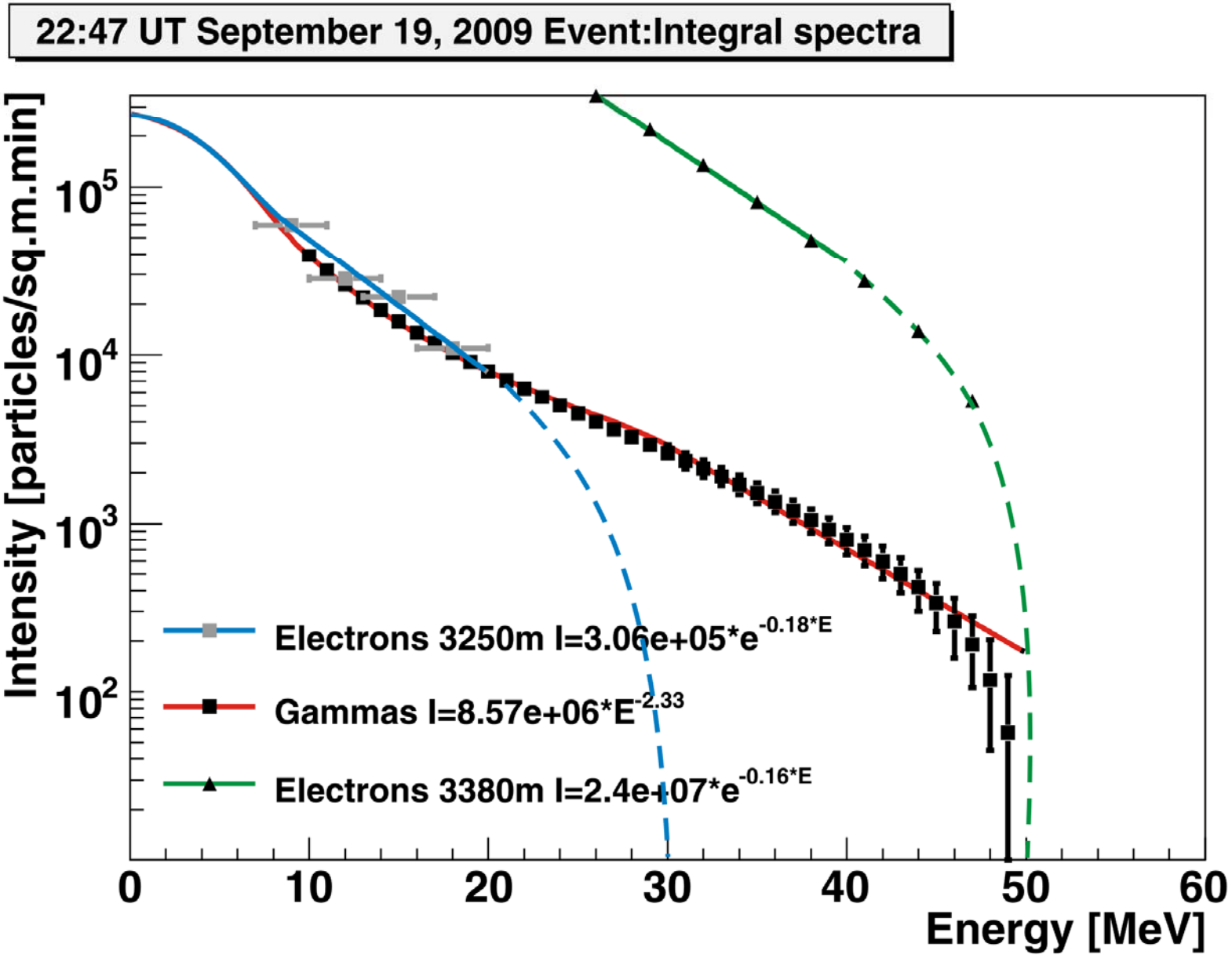


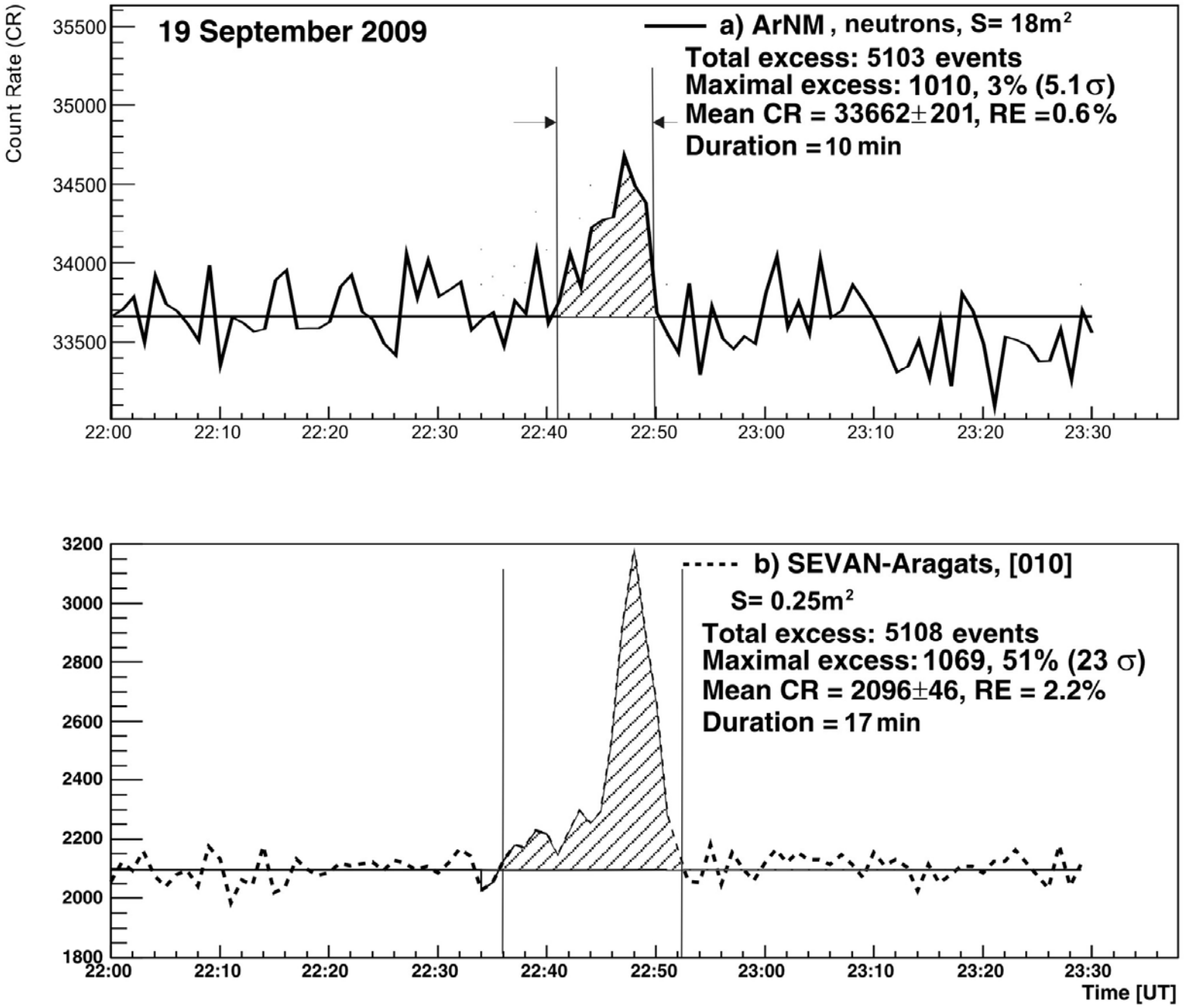
530 MAKET triggers (within 1 usec) registered during 8 minutes consist from background) EAS (~200) and RREA (~350) events. The RREA events are uniform and much less dense comparing with EAS events. Therefore we conclude that their origin is not EAS, but lightning (IC) seeds. The spectral form of both groups of events also indicate a nature of the additional triggers.




19 September 2009
a) ASNT, [10], E > 15 MeV, S= 4 m²
Total excess: 462108 events
Maximal excess: 114810, 169% (497σ)
Mean CR = 67935±231, RE = 0.34%
Duration = 13 min
b) ASNT, [01], S= 4 m²
Total excess: 121314 events
Maximal excess: 22573, 20% (63 σ)
Mean CR = 112865±354, RE = 0.31%
Duration = 17 min
c) ASNT, [11], E > 25 MeV
Total excess: 11810 events
Maximal excess:1988,11% (15 σ)
Mean CR = 18072±135, RE = 0.75%
Duration = 13 min
Count Rate (CR)
Time [UT]

Energy Spectra of RREA Electrons




19 September 2009
a) ArNM , neutrons, S= 18m²
Total excess: 5103 events
Maximal excess: 1010, 3% (5.1σ)
Mean CR = 33662±201, RE =0.6%
Duration =10 min
Count Rate (CR)
35500
35000
34500
34000
33500
22:00
22:10
22:20
22:30
22:40
22:50
23:00
23:10
23:20
23:30
b) SEVAN-Aragats, [010]
S= 0.25m²
Total excess: 5108 events
Maximal excess: 1069, 51% (23 σ)
Mean CR = 2096±46, RE = 2.2%
Duration = 17 min
3200
3000
2800
2600
2400
2200
2000
1800
Time [UT]

Phenomenology of RREA growth

$$\lambda(E) = \frac{7300\,\mathrm{kV}}{E - 276\,\mathrm{kV/m}}$$

$$\mathcal{M} = \exp\frac{L}{\lambda(E)} = \exp\left[L\left(\frac{E - 276\,\mathrm{kV/m}}{7300\,\mathrm{kV}}\right)\right]$$

where L is the length of the electric field region,
M- multiplication rate – avalanche growth.

Electron max energy detected - ~20-25 MeV - height of cloud – 100-150 m.

Number of electrons just at exit from the thundercloud divided to ambient CR population at start of RREA = 330 corresponds to ~ 6 e-foldings;

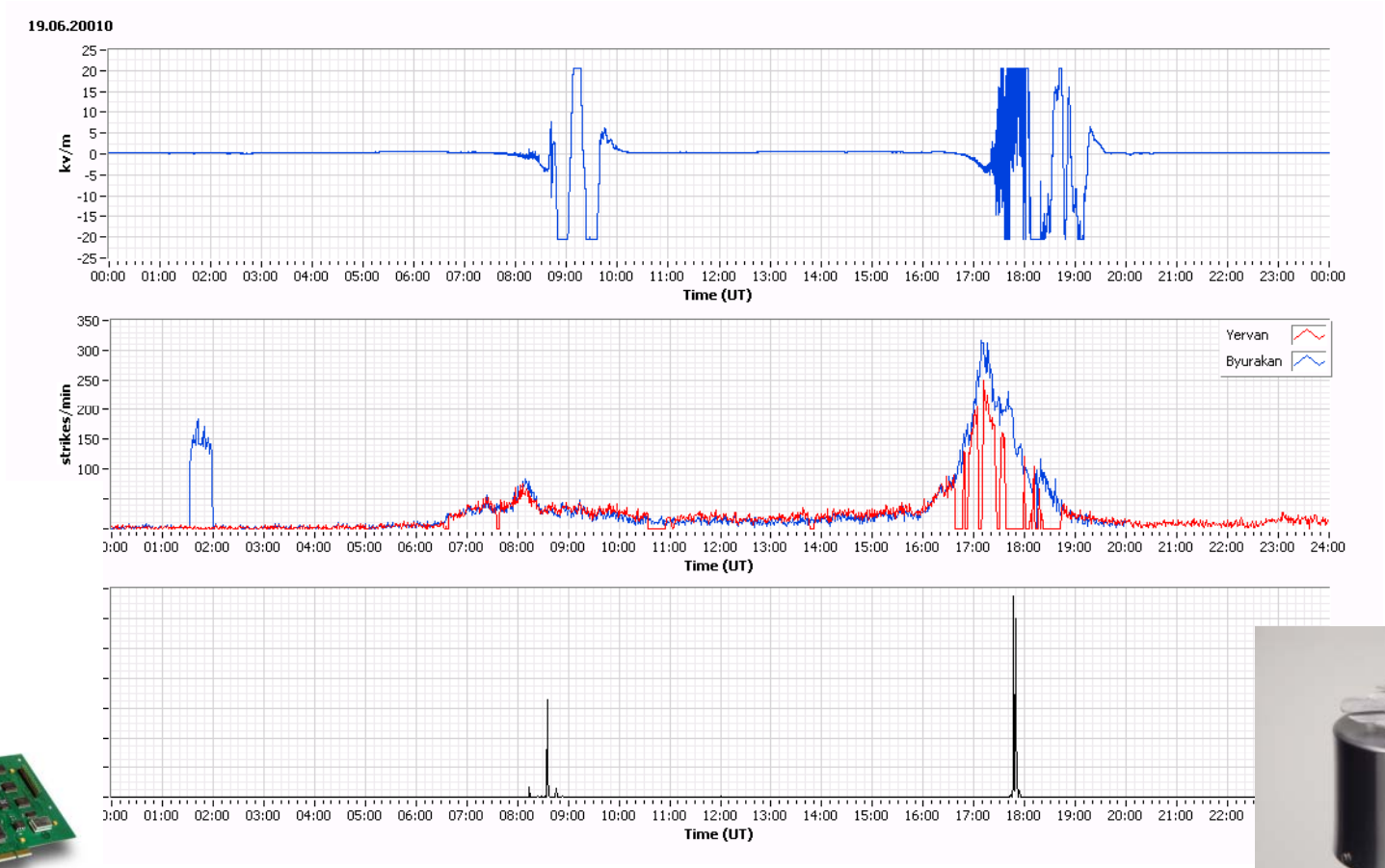
Maximal electron energy =6*7 MeV = 42 MeV

Total number of particles > 7 MeV – 3.8*10^12;
Mean electron energy 6.8 ±0.8 MeV in good agreement with theoretical estimate of 7.3 MeV;

Maximal neutron flux occurs if avalanche length is ~1500 m; e-folding length – 250-300m; Field value - 180-220 kV/m.

BOLTEK Corporation Storm Tracker

Lightning Detection System

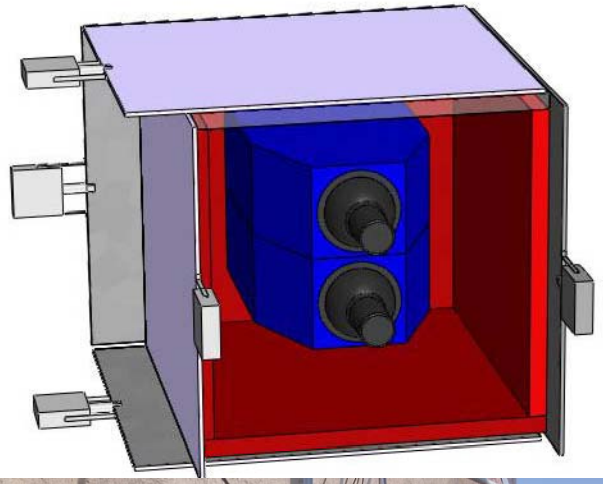


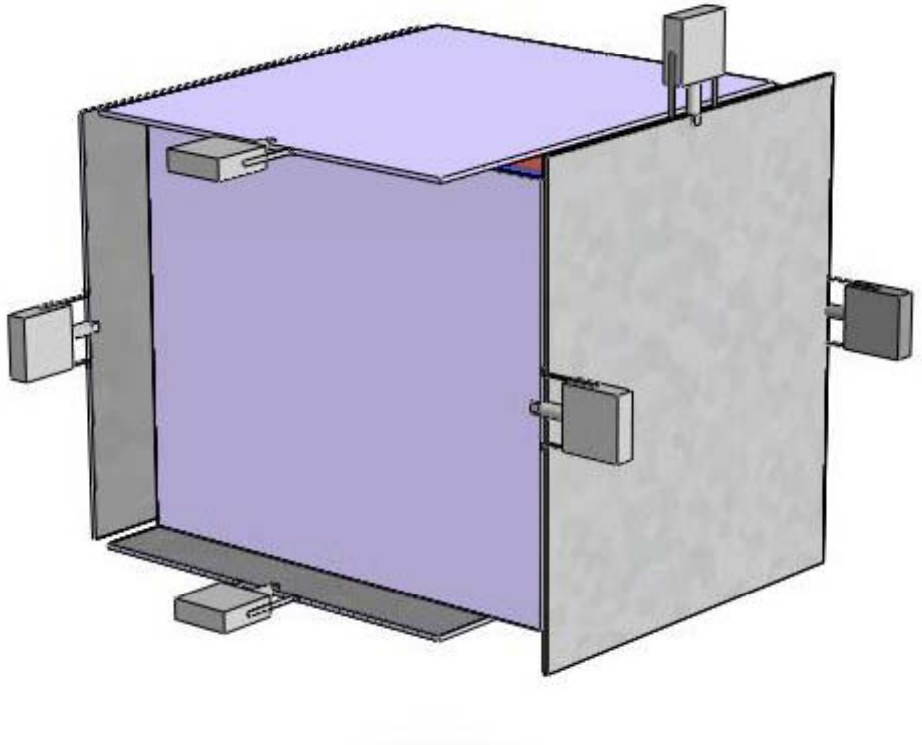
Magneto-electrometry at Aragats

LEMI-417M digital seven-component magnetotelluric station:

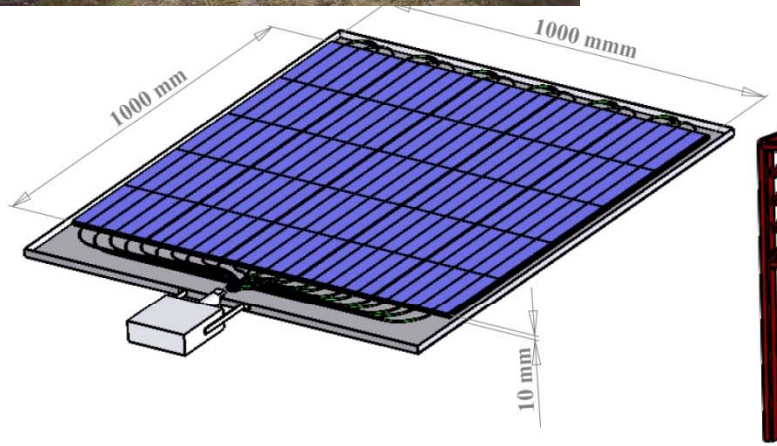
0.01 nT accuracy magnetic sensor of flux-gate type, was manufactured using well-proved technology on the base of marble and quartz combination implementing recent findings in the excitation circuit construction. For electric channels, a filter-free technology of input stages was accepted in order to let to pass super-long period signals. In order to avoid the channels saturation in natural electric field, the automatic compensation circuit is provided at the beginning of the measurements in the range ± 250 mV.

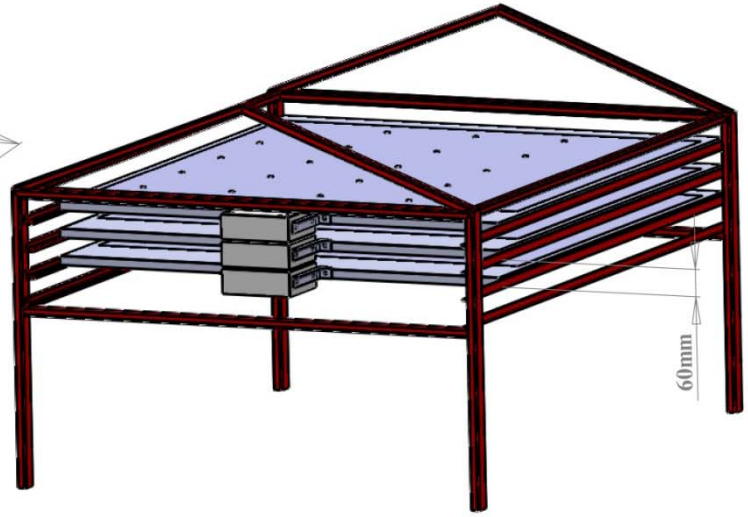
Cube gamma-electron Detector



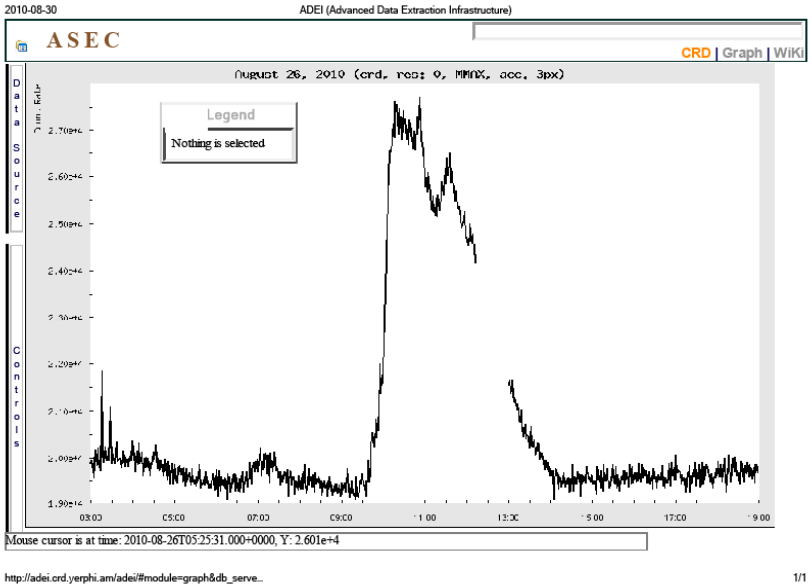


STAND Detector

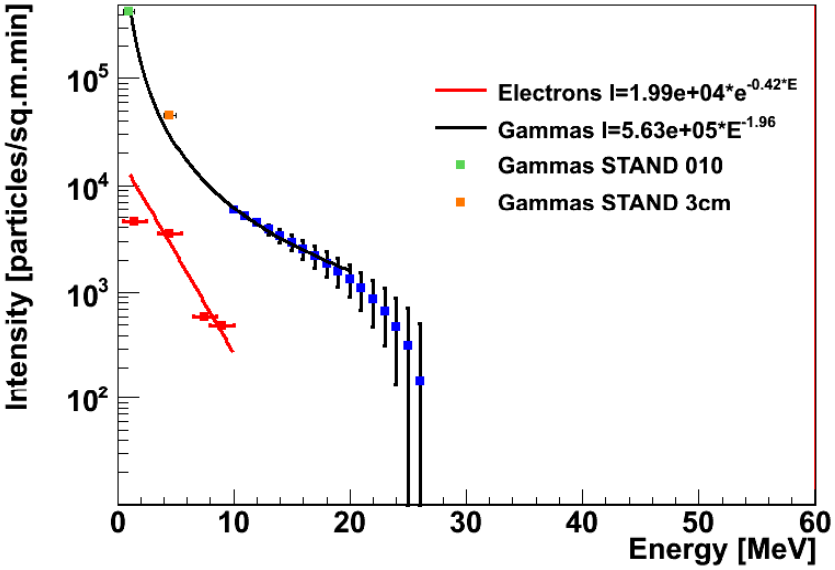


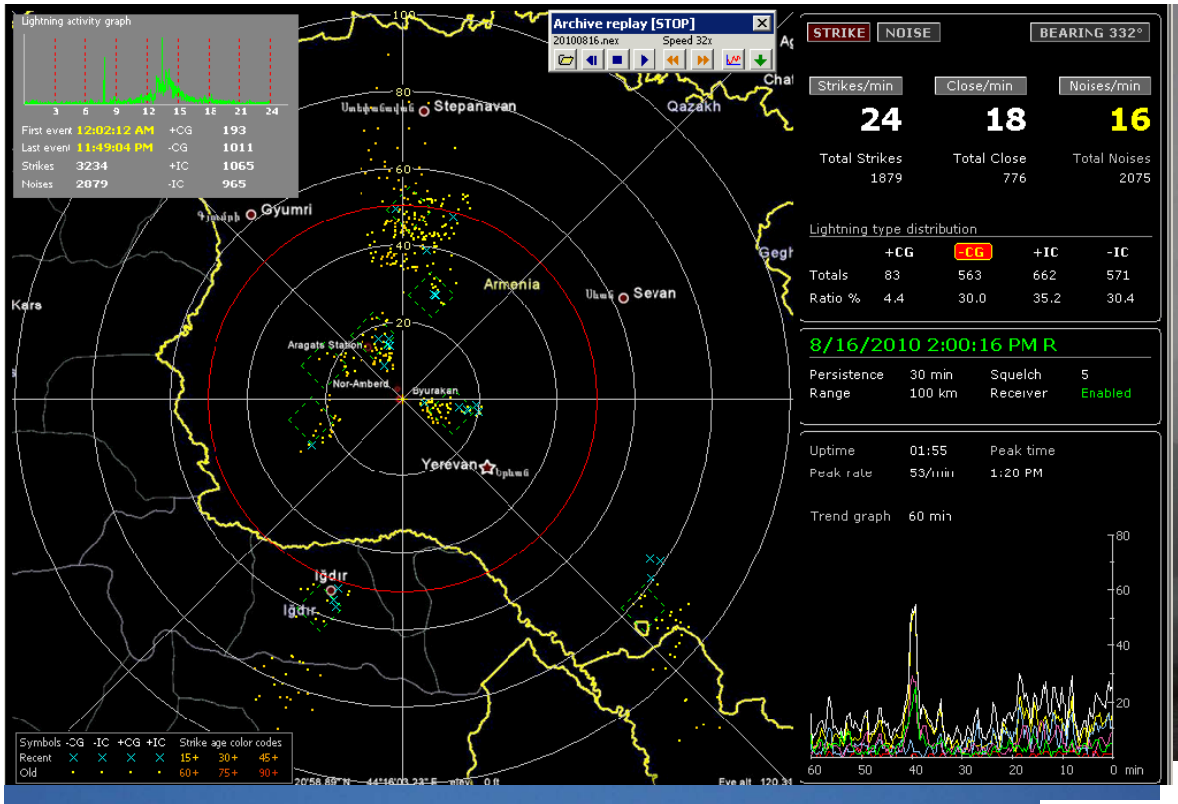


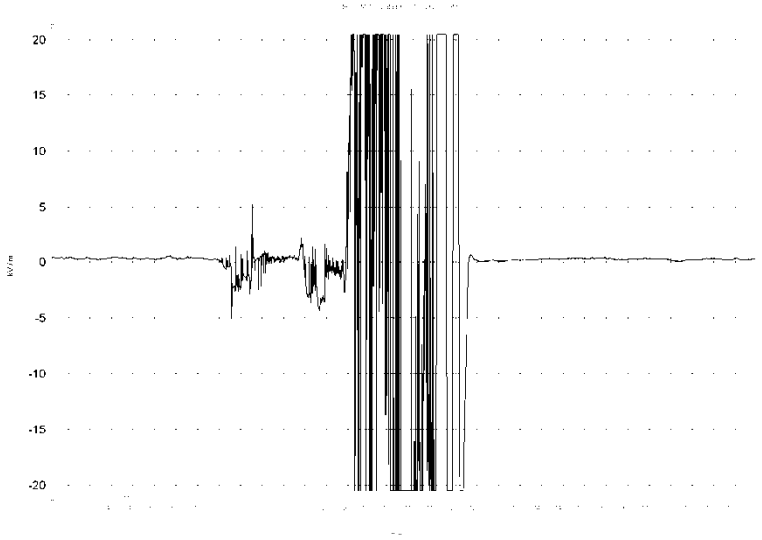
26 August 2010



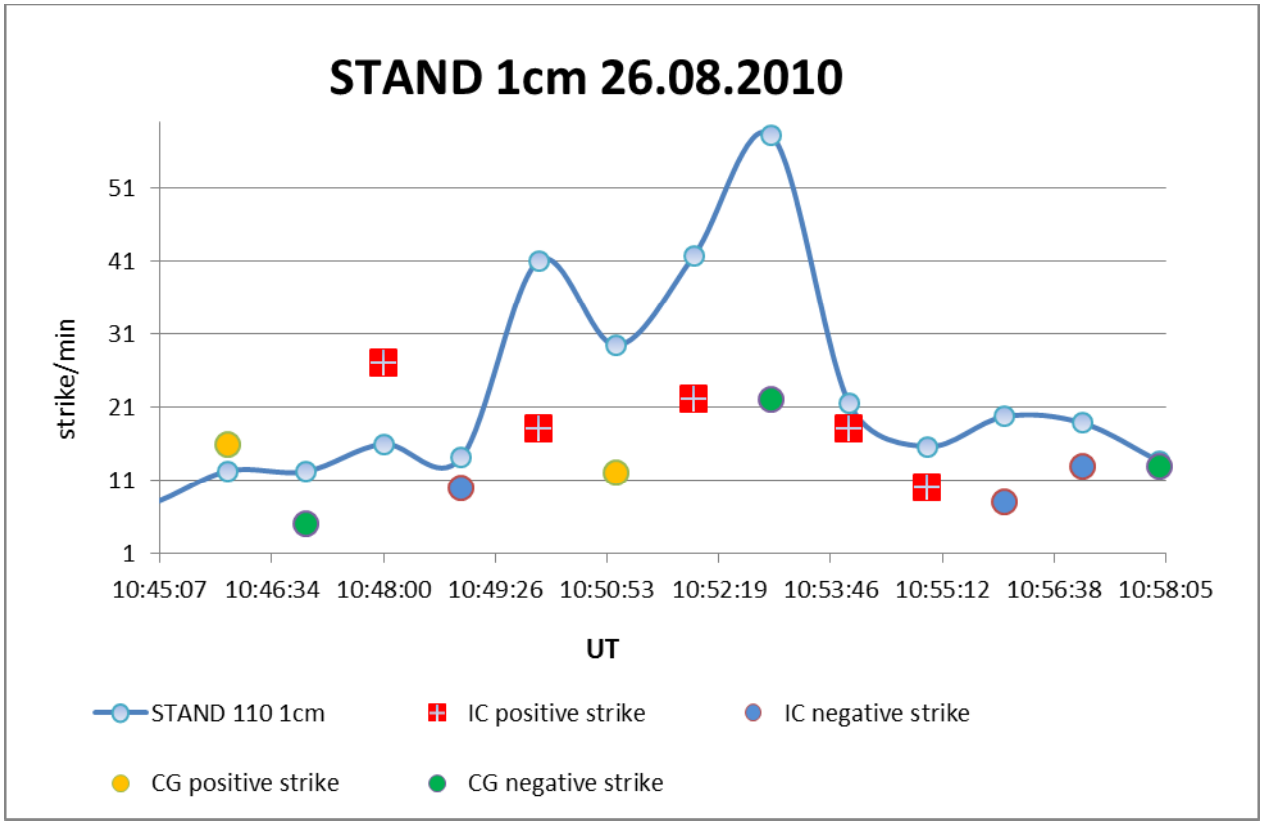
10:51-53 UT Aug 26, 2010 Event:Integral spectra




Lightning activity graph
First event 12:02:12 AM +CG 193
Last event 11:49:04 PM -CG 1011
Strikes 3234 +IC 1065
Noises 2079 -IC 965
Archive replay [STOP]
20100816.nex
Speed 32x
Stepanavan
Qazakh
Gyumri
Armenia
Sevan
Kars
Aragats Station
Nor-Amberd
Byurakan
Yerevan
Iğdır
Symbols -CG -IC +CG +IC
Strike age color codes
Recent
Old
STRIKE
NOISE
BEARING 332°
Strikes/min
Close/min
Noises/min
24
18
16
Total Strikes
1879
Total Close
776
Total Noises
2075
Lightning type distribution
+CG
-CG
+IC
-IC
Totals 83 563 662 571
Ratio % 4.4 30.0 35.2 30.4
8/16/2010 2:00:16 PM R
Persistence 30 min
Range 100 km
Squelch 5
Receiver Enabled
Uptime 01:55
Peak time
Peak rate 53/min
1:20 PM
Trend graph 60 min
60 50 40 30 20 10 0 min


20
15
10
5
0
-5
-10
-15
-20

4 types of lightning – which responsible for particle fluxes?



Conclusions

- 2 types of RREA process were detected: short (~ 1microsec, inverse TGFs) and long (hours, thunderstorm ground enhancements - TGEs);
- The energy spectra of electrons and gamma rays of long RREA were obtained;
- Neutrons also were detected within RREA event;
- Seed particle for the long RREA (TGE) are MeV electrons from EAS and for short RREA – dart leaders of intercloud lightning.