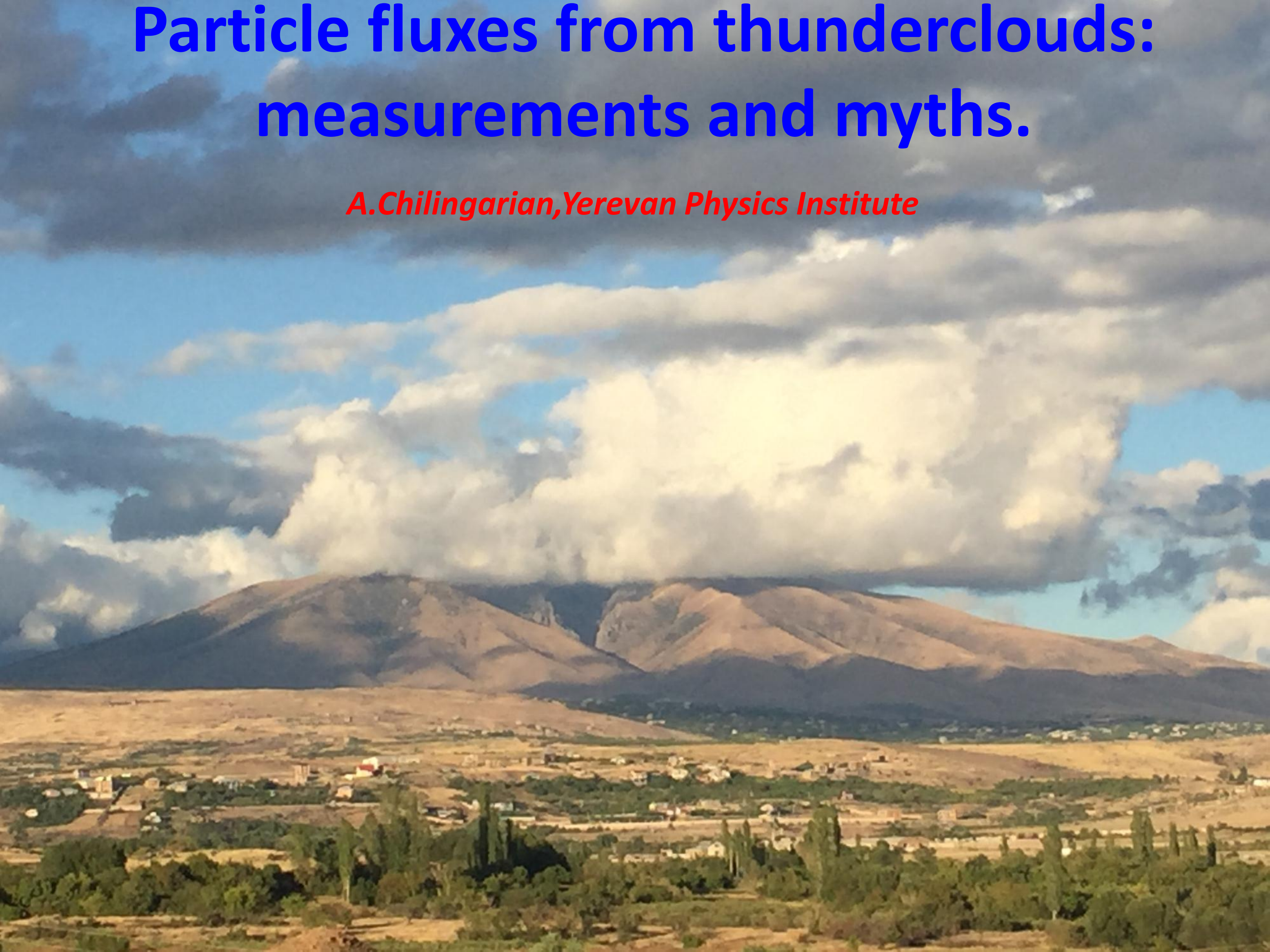
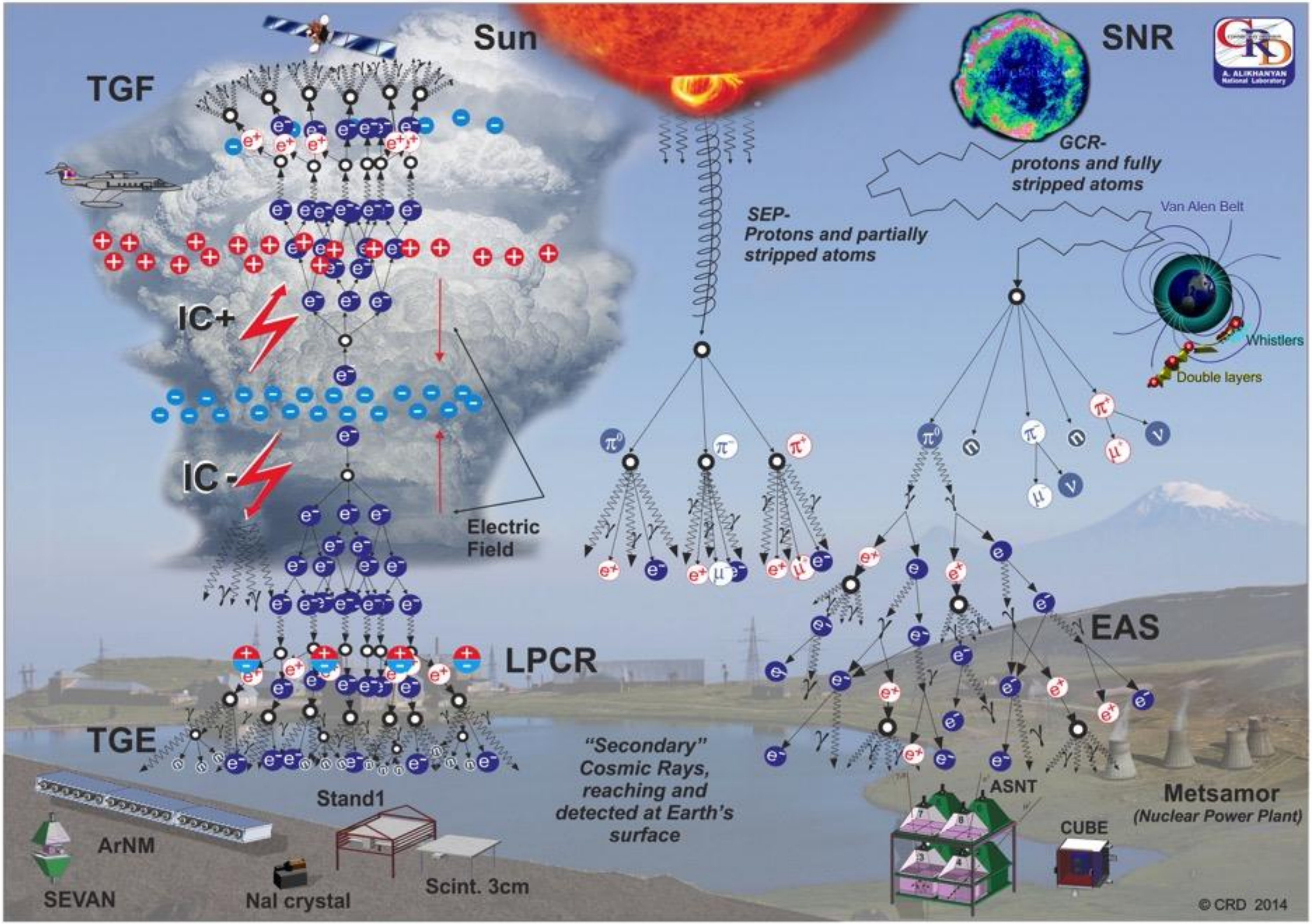
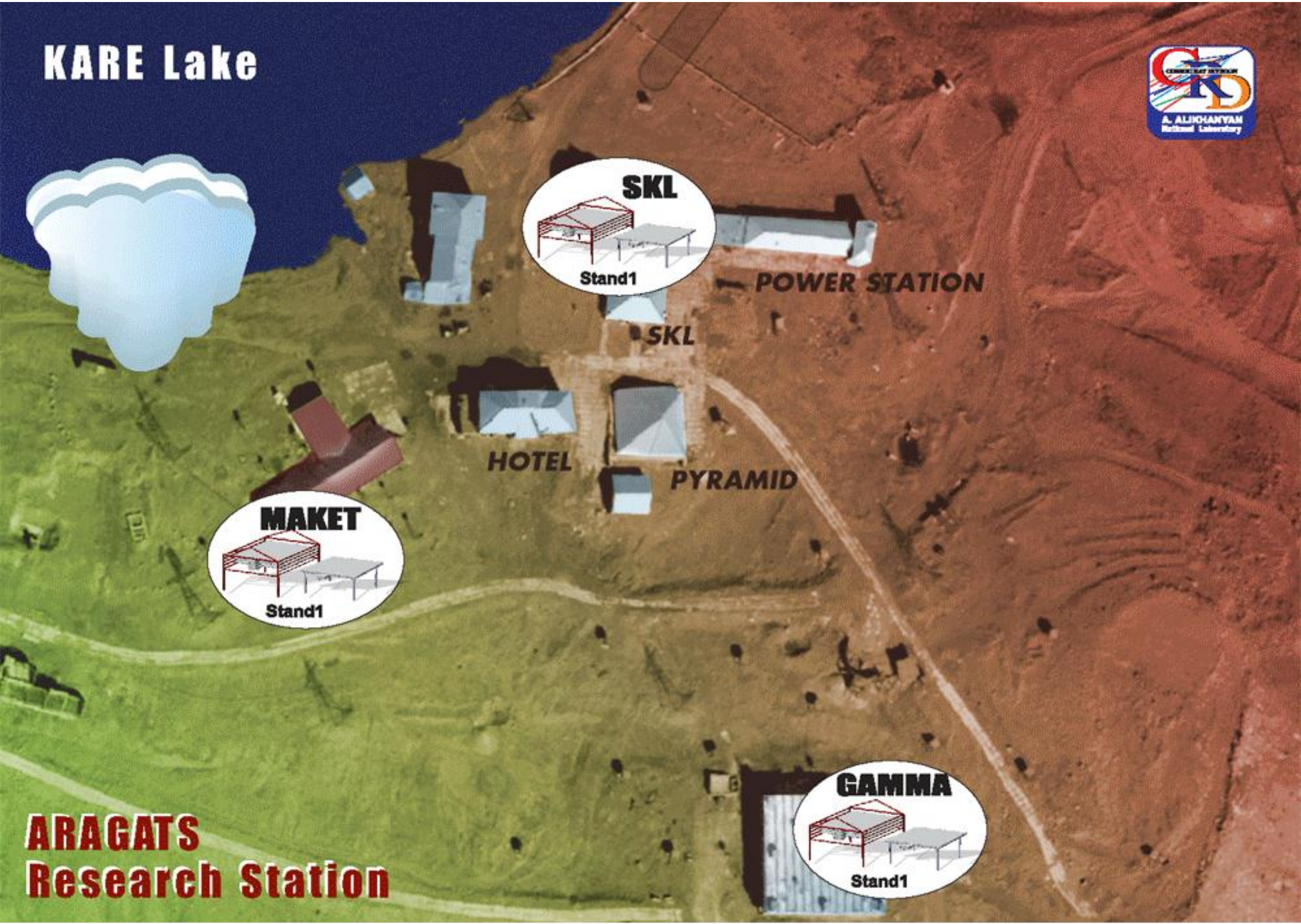
Particle fluxes from thunderclouds: measurements and myths.

A.Chilingarian,Yerevan Physics Institute

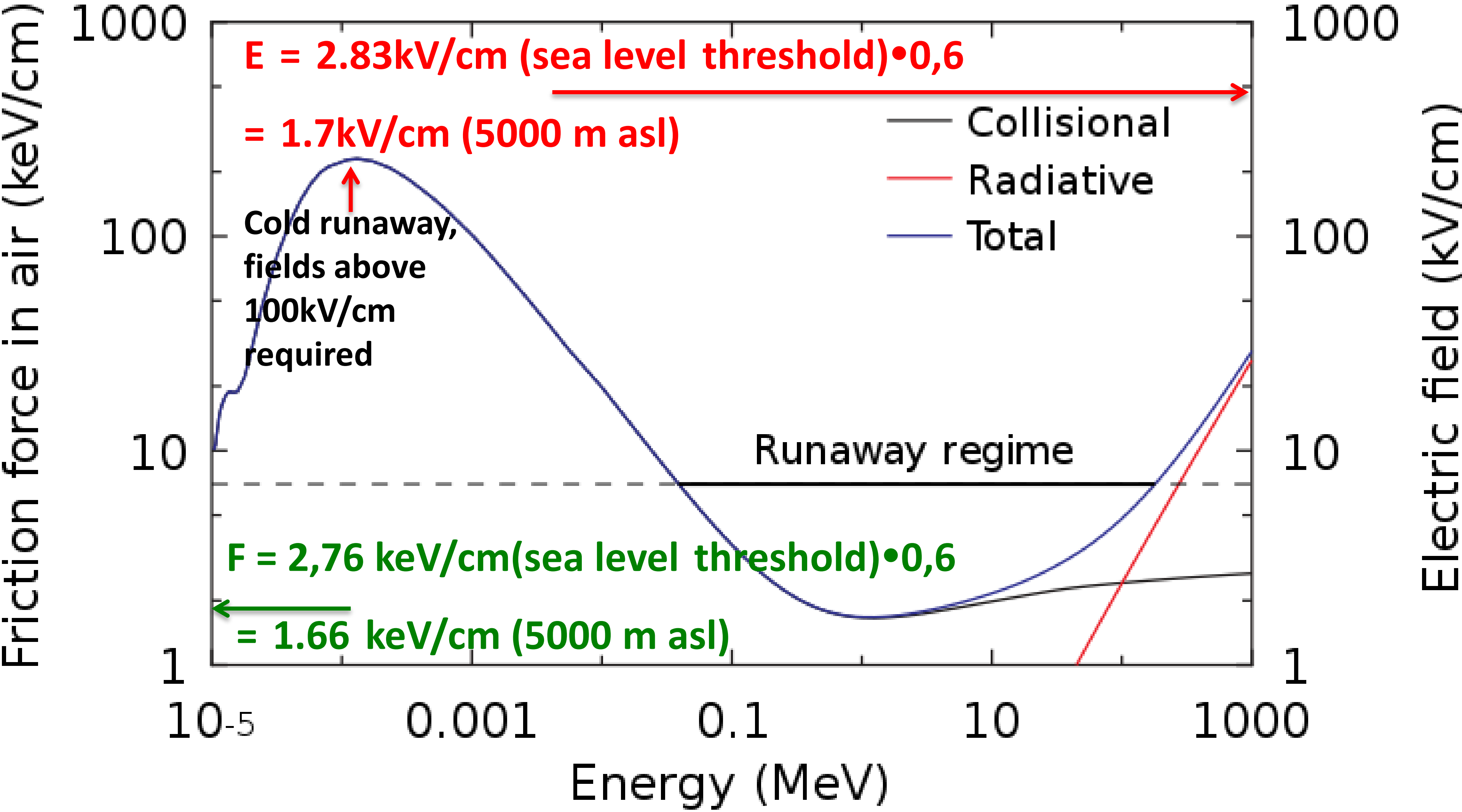


Origin of Secondary Cosmic Rays




KARE Lake
A. ALIKHANYAN National Laboratory
SKL
Stand1
POWER STATION
SKL
HOTEL
PYRAMID
MAKET
Stand1
GAMMA
Stand1
ARAGATS
Research Station

Energy losses and energy gain: RB/RREA process



Gurevich et al., (1992), Symbalisty et al. (1998), Babich et al. (1998), Dwyer (2003), Chilingarian (2014)

What are most intriguing problems of High-Energy Physics in Atmosphere (HEPA)?

- **TGEs and TGFs: relation and classification**
- **Do elementary particles born in lightning bolt(neutrons and gamma rays) or only in RREA process?**
- **Do we need additional mechanisms of seed particle generation (**Relativistic feedback discharge model (RFDM **)?**
- **Confirmation of the *in situ* detection of the RB/RREA cascades – Extensive cloud showers, analog of EASs – Extensive cloud showers** (**particle fluxes on microsecond scale**);
- **What can we understand from observed TGEs about cloud electrification: number of charged layers, horizontal and vertical elongation;**
- **Measure/estimate size of emitting region in the cloud;**
- **How the lightning switching off the RREA and what switching on TGEs (**Role of humidity and precipitation on TGE initiation)**?**
- **How to explain energy spectra of the TGE extended until 100 MeV?**
- **Do RB/RREA "open" conductive channel to lightning?**
- **How lightning started – Preliminary breakdown process;**
- **Which lightnings cause maximal Electromagnetic inference (EMI)?**
- **Do EASs facilitate lightning leader propagation (EAS-RB process)?**
- **Neutron production by RREA, registration of neutrons on the Earth's surface;**

4 km between Byurakan and Nor Amberd;

12.8 km between Nor Amberd and Aragats stations;

39.1 km between Yerphi and Aragats station;

26.5 km between Yerphi and Nor Amberd station.

1.Byurakan

Latitude= 40.3400° N,

Longitude =44.2703° E

2.Nor Amberd Station

Latitude= 40.3750,

Longitude =44.2640

3. Aragats Station

Latitude= 40.4713,

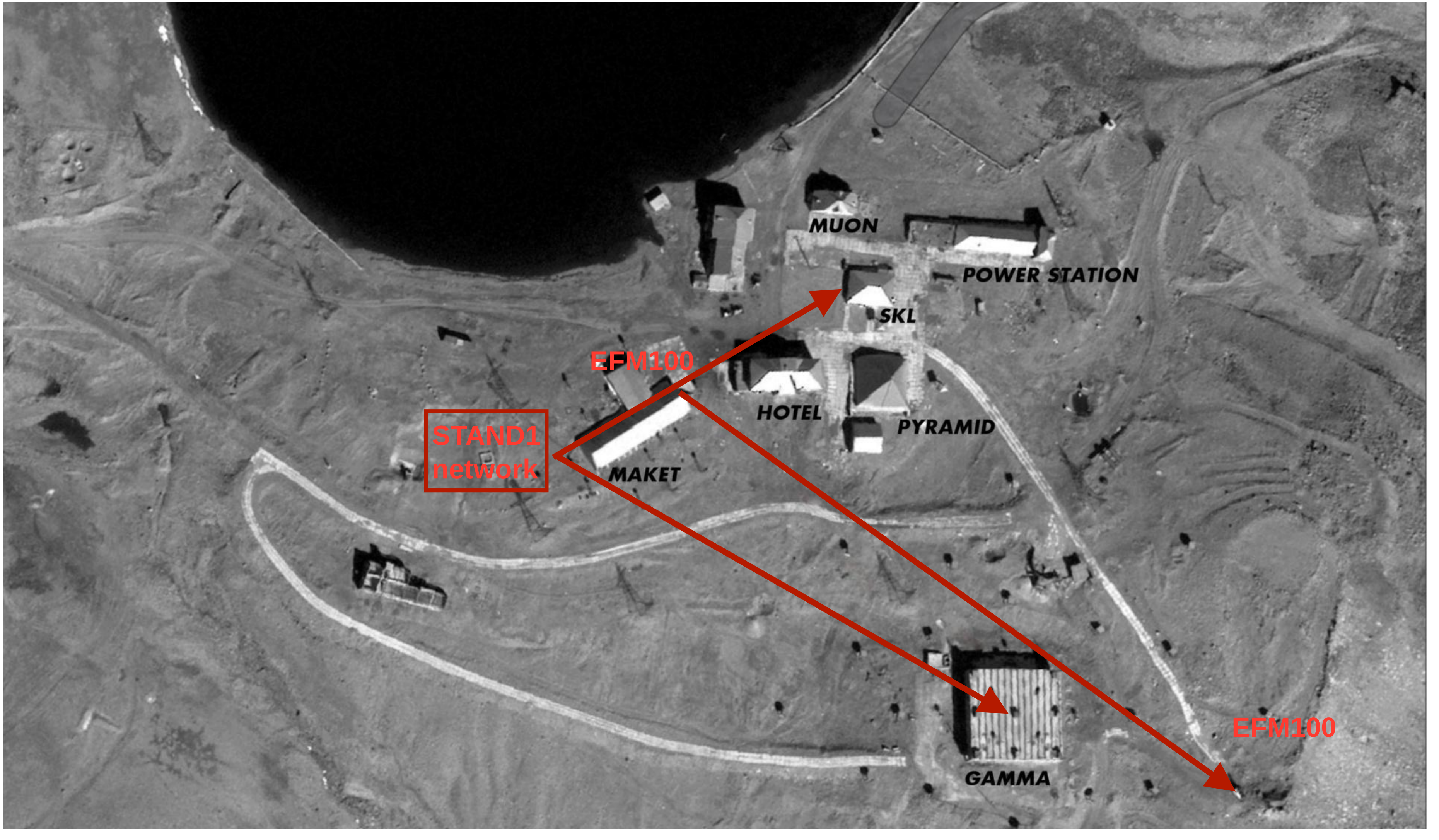
Longitude =44.1819

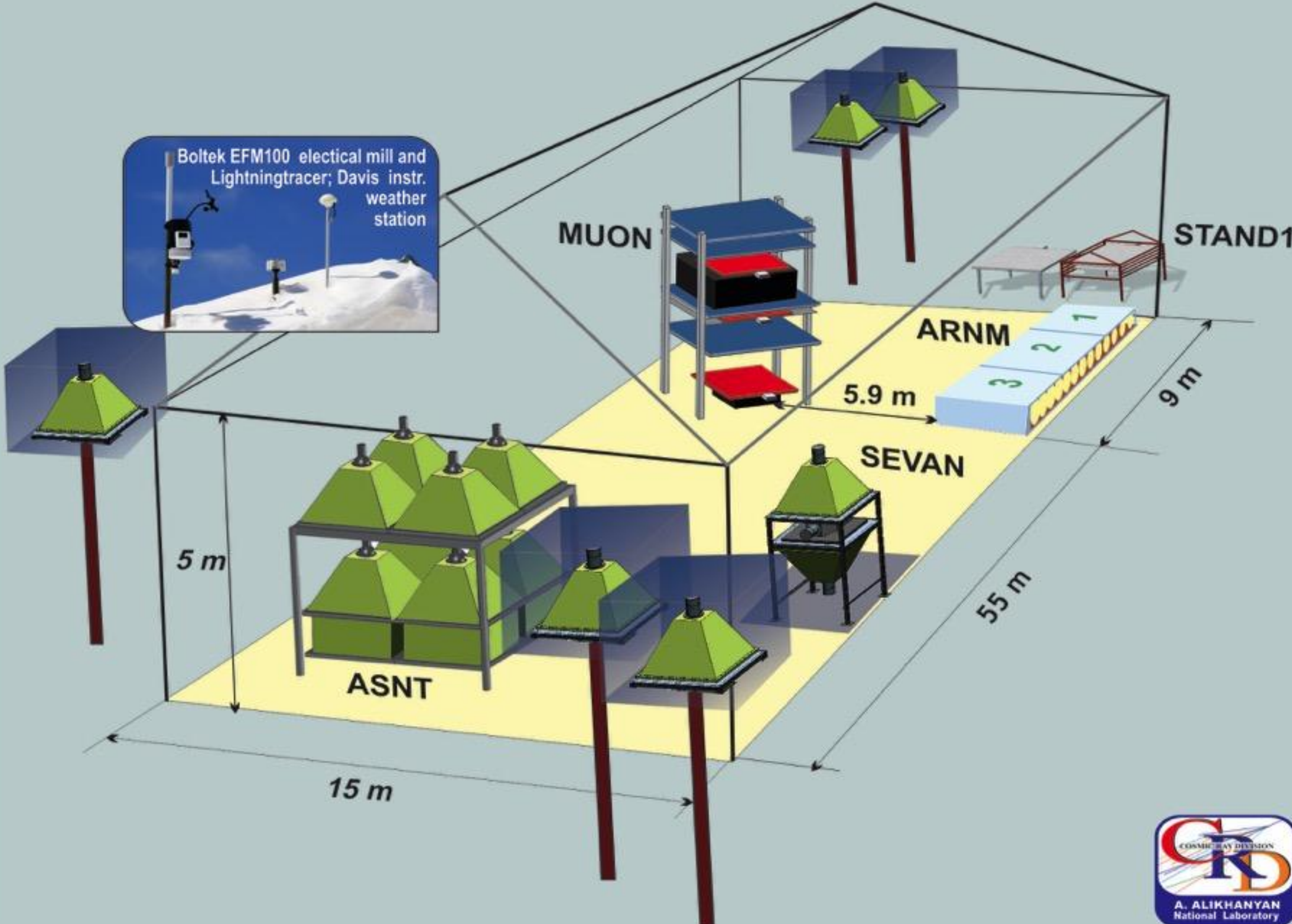
4.Yerevan Physics Institute

Latitude= 40.2067,

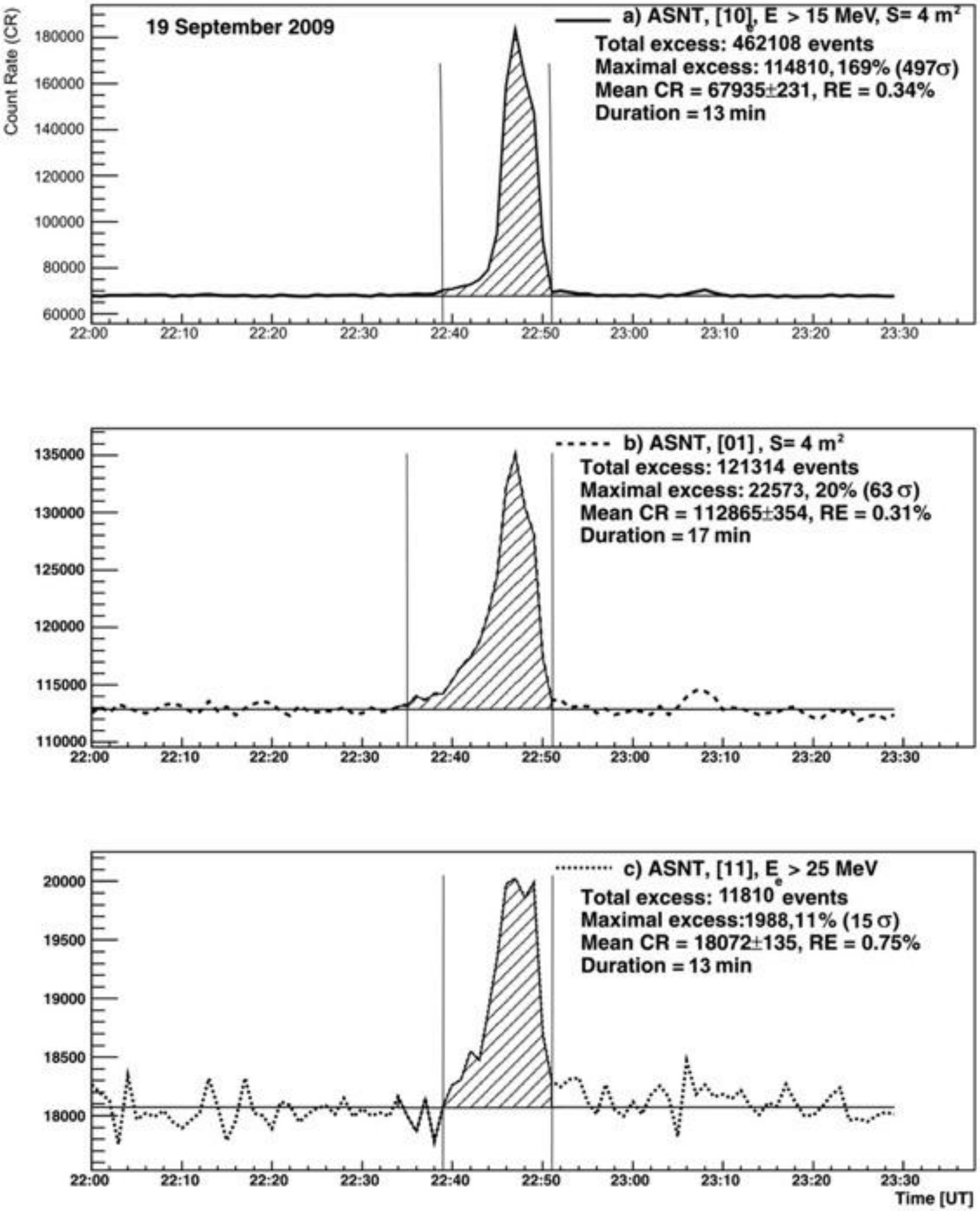
Longitude =44.4857

STAND1 and EFM networks

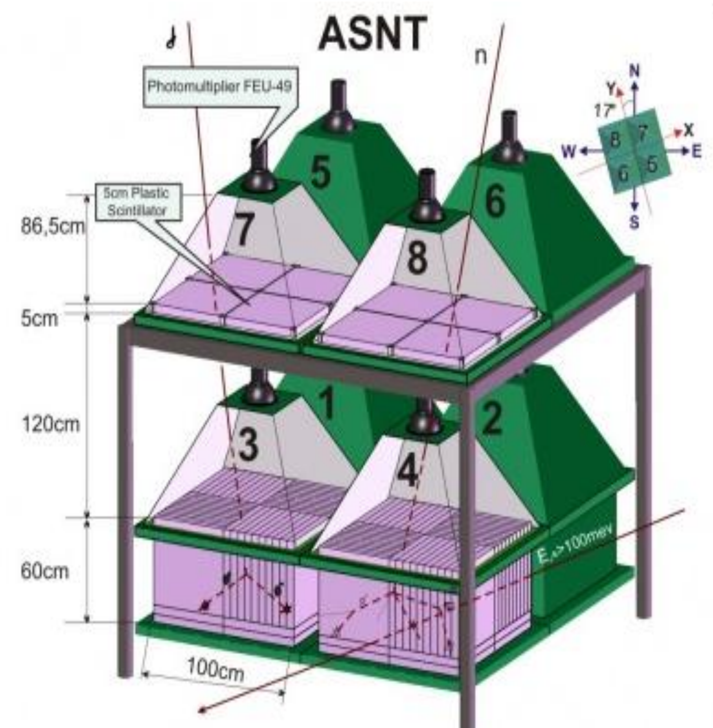




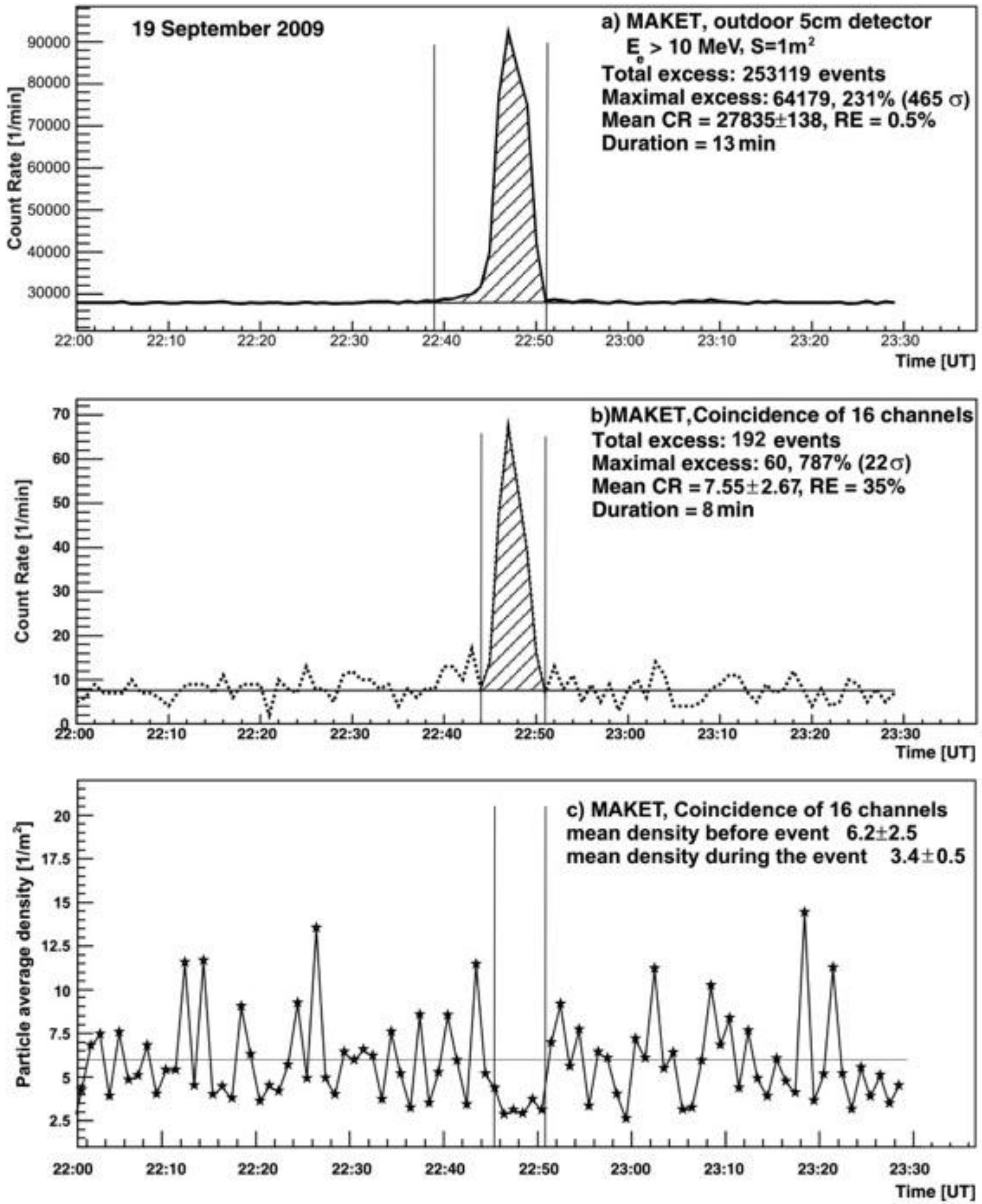
Boltek EFM100 electical mill and
Lightningtracer; Davis instr.
weather
station
MUON
STAND1
ARNM
1
2
3
5.9 m
9 m
SEVAN
5 m
55 m
ASNT
15 m



Huge TGE of 19 September, 2009 was detected by all ASEC monitors :
ASNT (10) – > 5cm (1) and 60 (0)cm thick;
ASNT (01) – 5cm (0) and 60 (1)cm thick;
ASNT (11) – electrons E>25 MeV - 19 September event is only event with high energy



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

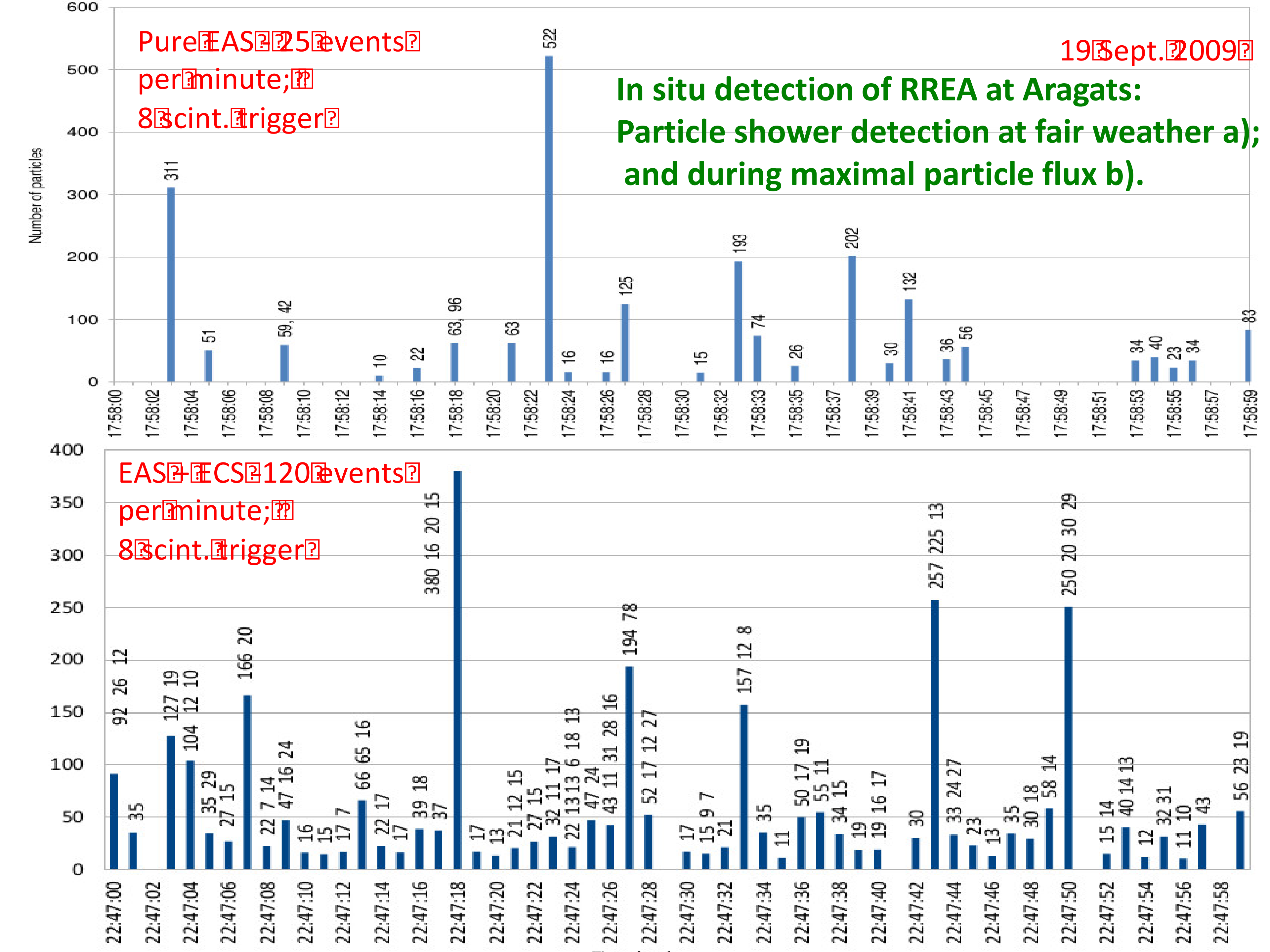


MAKET – a surface array continuously detects Extensive Air showers (EAS)selecting shower axes from area of ~10000 m.sq., Primary particle energy ~100-1000 TeV;

At 19 September 2009 MAKET detects new type of showers – Extensive cloud showers (ECS), Gurevich call it Micro Runaway breakdown (MRB).

ECS (MRB) is short coherent particle burst (within 0.4 μsec) from one Runaway electron; Plenty of ECSs make a TGE lasting several minutes;

ECSs (MRB) can be distinguished from EASs by the lower density.



Pure EAS 25 events
per minute;
8 scint. trigger
19 Sept. 2009
In situ detection of RREA at Aragats:
Particle shower detection at fair weather a);
and during maximal particle flux b).
Number of particles
600
500
400
300
200
100
0
311
51
59, 42
10
22
63, 96
63
522
16
16
125
15
193
74
26
202
30
132
36
56
34
40
23
34
83
17:58:00
17:58:02
17:58:04
17:58:06
17:58:08
17:58:10
17:58:12
17:58:14
17:58:16
17:58:18
17:58:20
17:58:22
17:58:24
17:58:26
17:58:28
17:58:30
17:58:32
17:58:33
17:58:35
17:58:37
17:58:39
17:58:41
17:58:43
17:58:45
17:58:47
17:58:49
17:58:51
17:58:53
17:58:55
17:58:57
17:58:59
EAS + ECS 120 events
per minute;
8 scint. trigger
400
350
300
250
200
150
100
50
0
92 26 12
35
127 19
104 12 10
35 29
27 15
166 20
22 7 14
47 16 24
16
15
17 7
66 65 16
22 17
17
39 18
37
380 16 20 15
17
13
21 12 15
27 15
32 11 17
22 13 13 6 18 13
47 24
43 11 31 28 16
194 78
52 17 12 27
17
15 9 7
21
157 12 8
35
11
50 17 19
55 11
34 15
19
19 16 17
30
257 225 13
33 24 27
23
13
35
30 18
58 14
250 20 30 29
15 14
40 14 13
12
32 31
11 10
43
56 23 19
22:47:00
22:47:02
22:47:04
22:47:06
22:47:08
22:47:10
22:47:12
22:47:14
22:47:16
22:47:18
22:47:20
22:47:22
22:47:24
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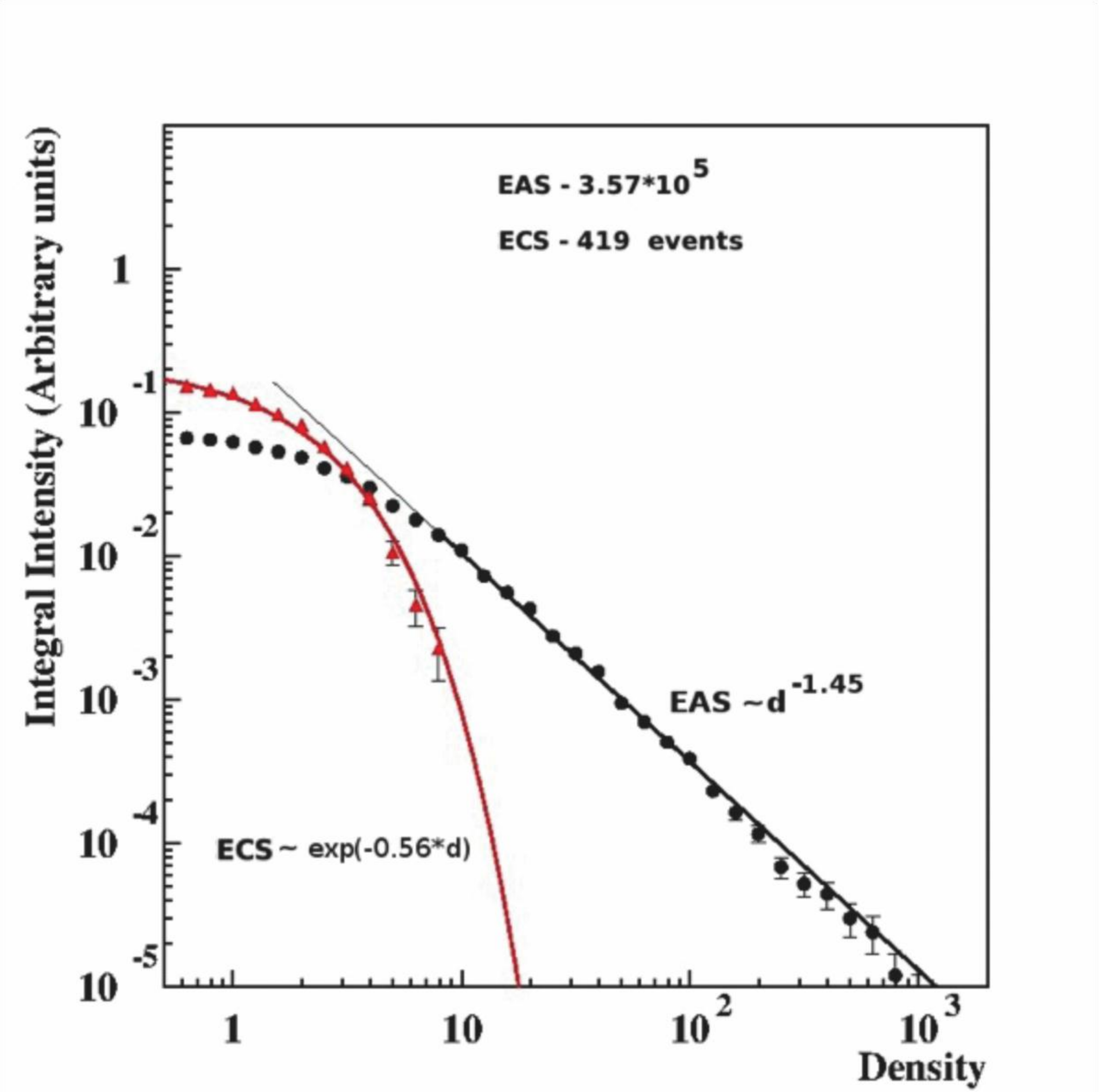
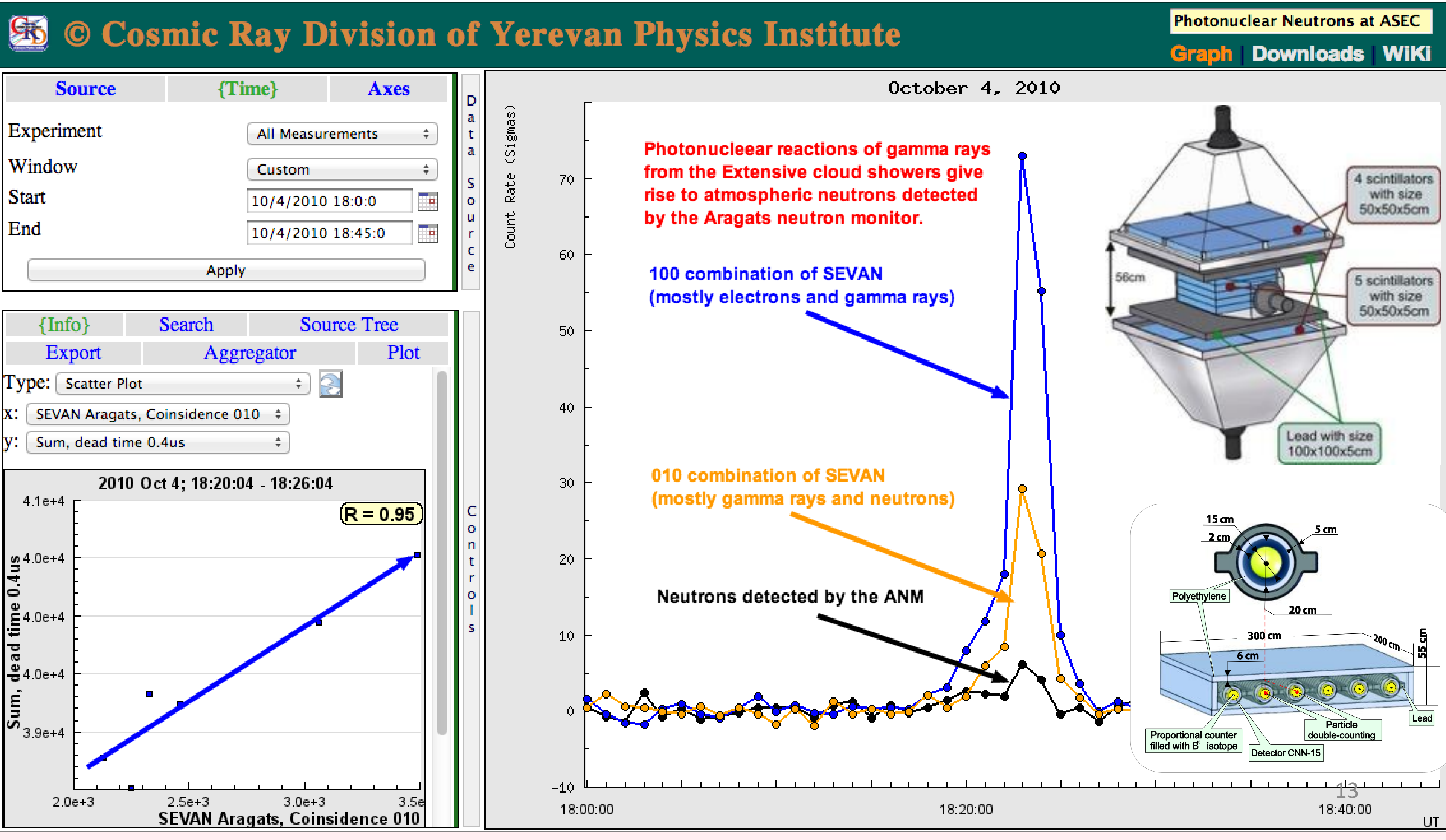
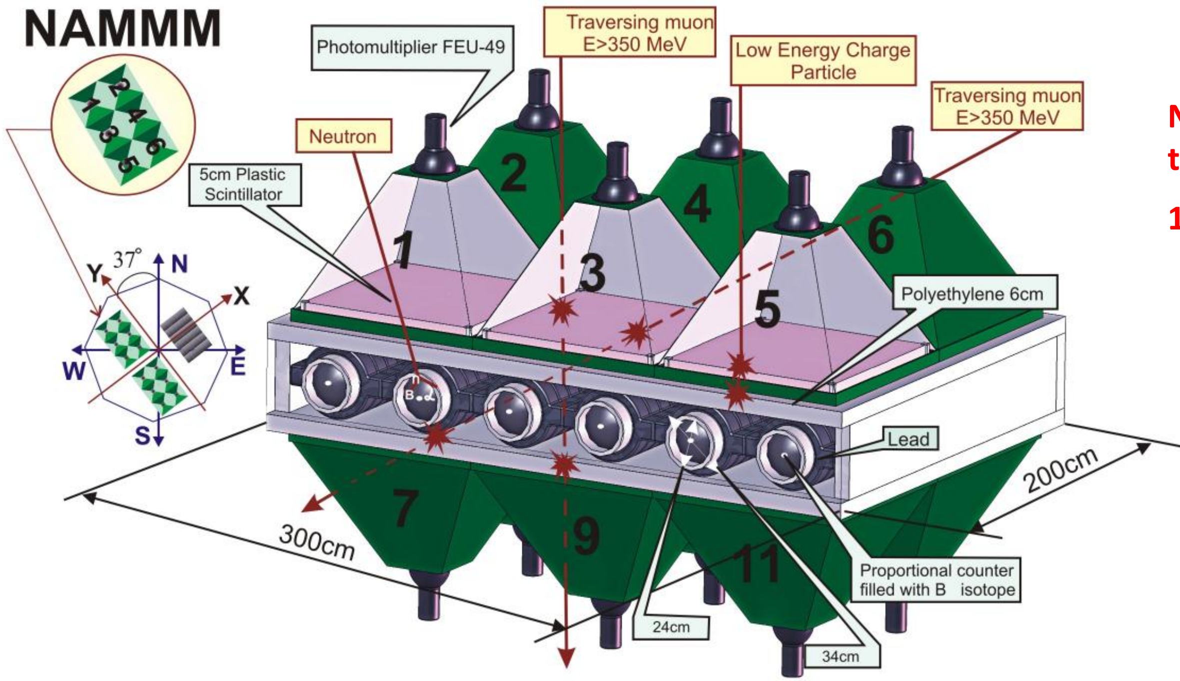
22:47:34
22:47:36
22:47:38
22:47:40
22:47:42
22:47:44
22:47:46
22:47:48
22:47:50
22:47:52
22:47:54
22:47:56
22:47:58

Density spectra of 2 classes: ECS (with ~20% EAS contamination) and pure EAS



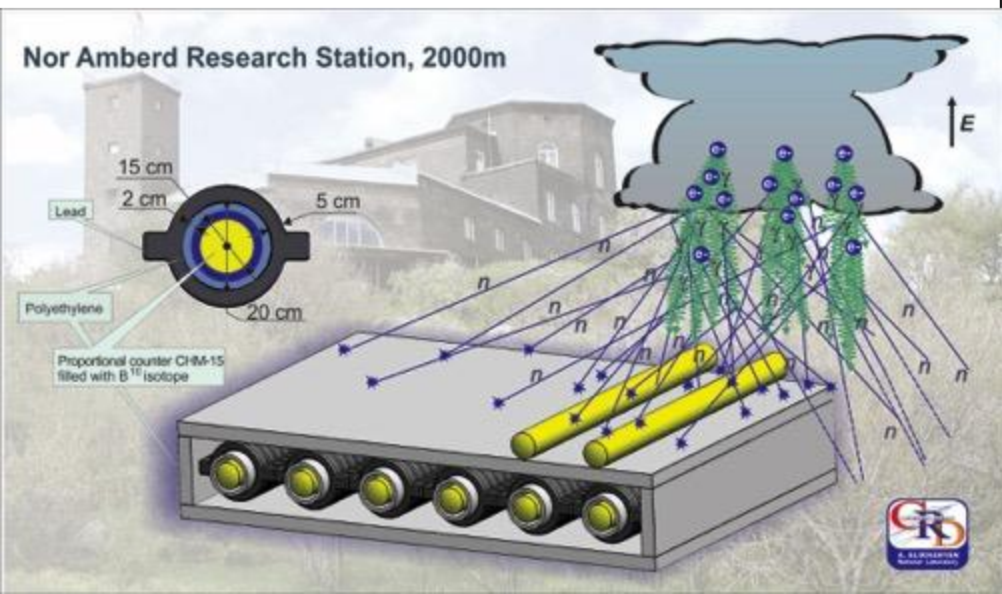
Detection of TGE neutrons

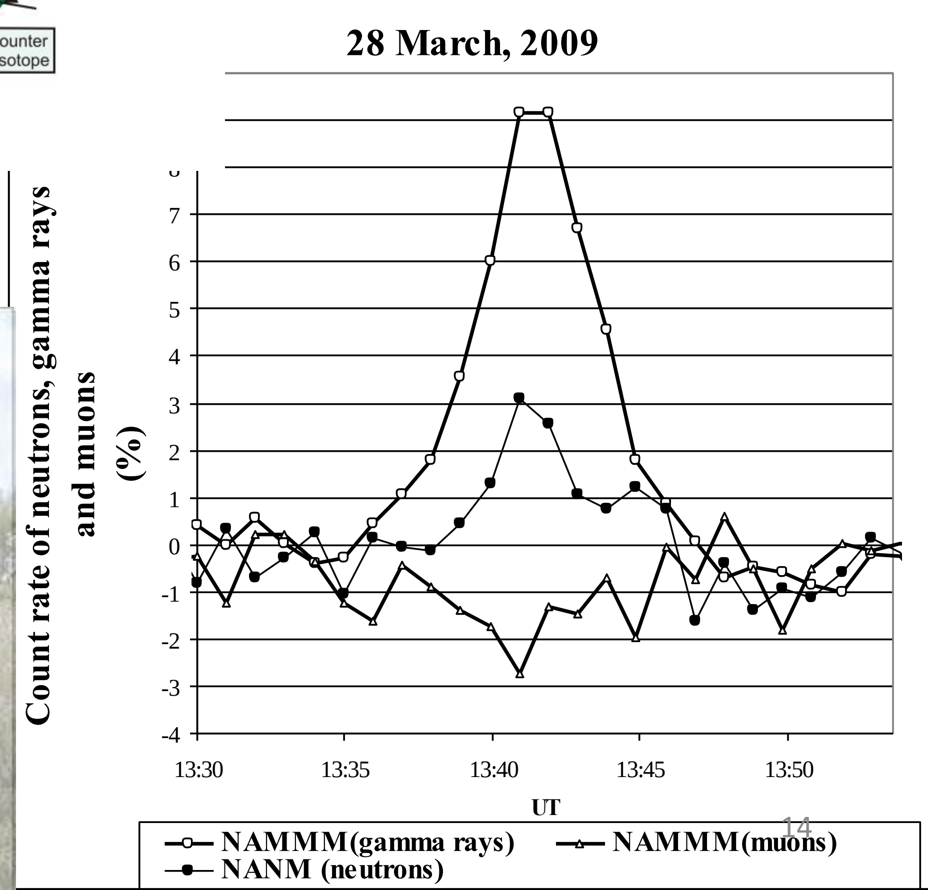




Neutrons born in Atmosphère from the TGE gamma rays

$^{14}N(\gamma,n)\,^{13}N$



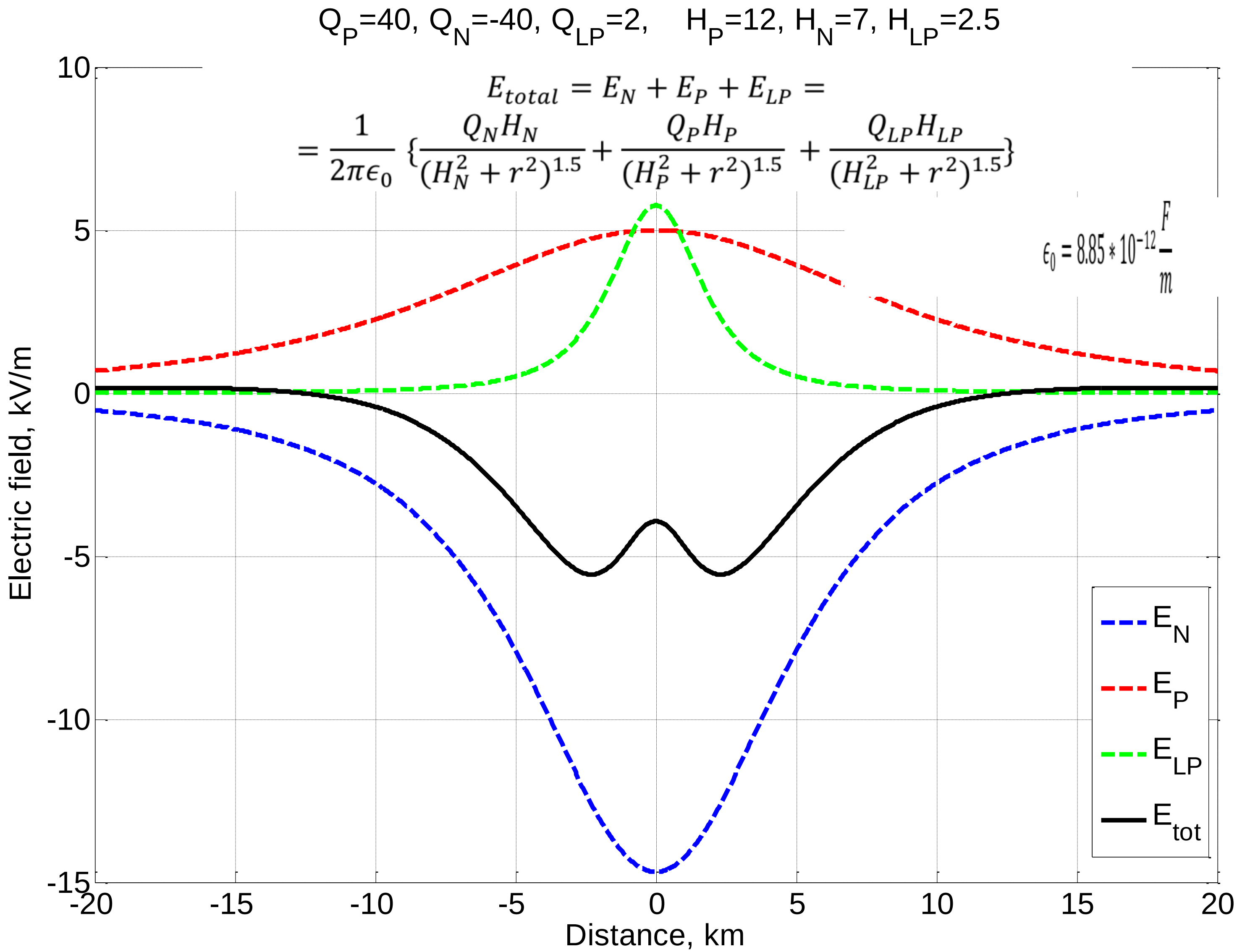


Model: The electric field at ground due to the vertical tripole

$$E_{total} = E_N + E_P + E_{LP} =$$

$$= \frac{1}{2\pi\epsilon_0}\left\{\frac{Q_N H_N}{(H_N^2 + r^2)^{1.5}} + \frac{Q_P H_P}{(H_P^2 + r^2)^{1.5}} + \frac{Q_{LP} H_{LP}}{(H_{LP}^2 + r^2)^{1.5}}\right\}$$

$$\epsilon_0 = 8.85 * 10^{-12}\frac{F}{m}$$



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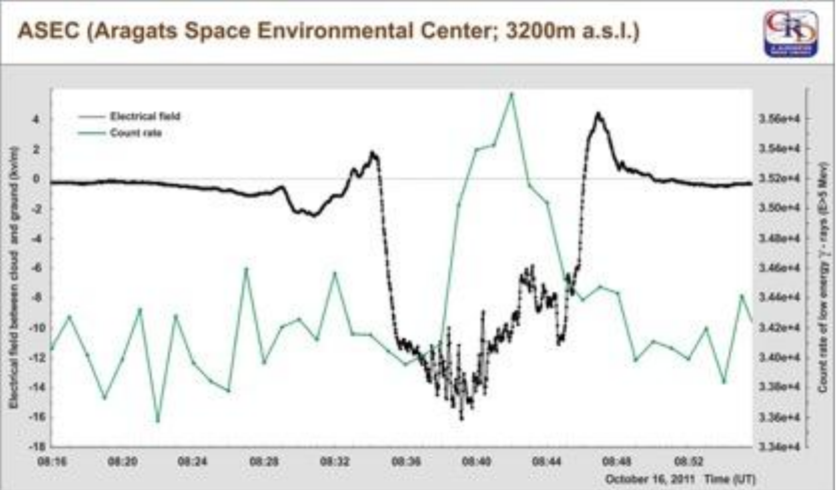
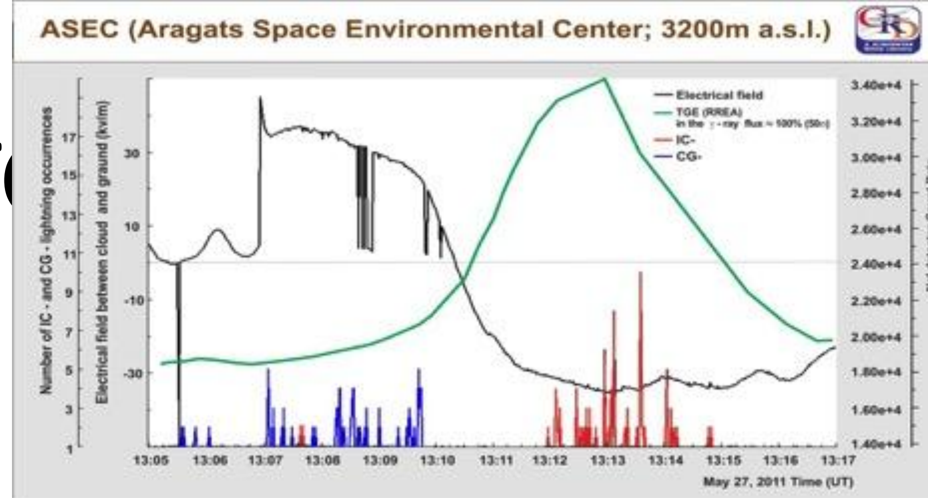
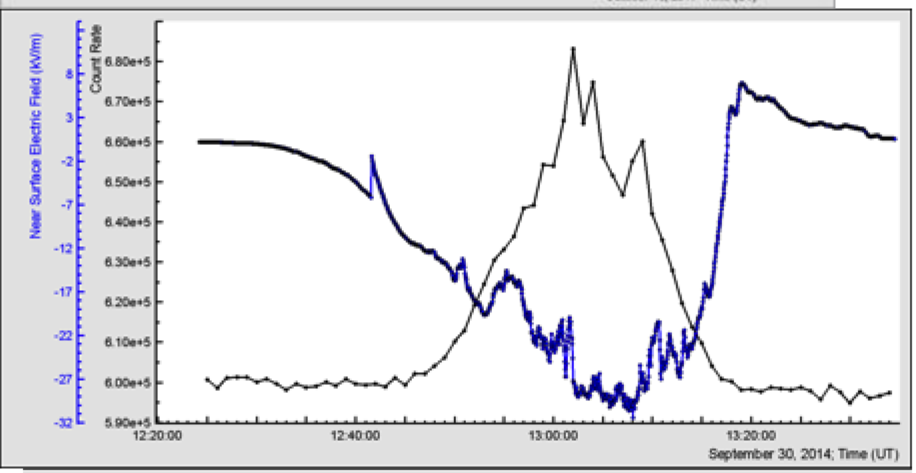
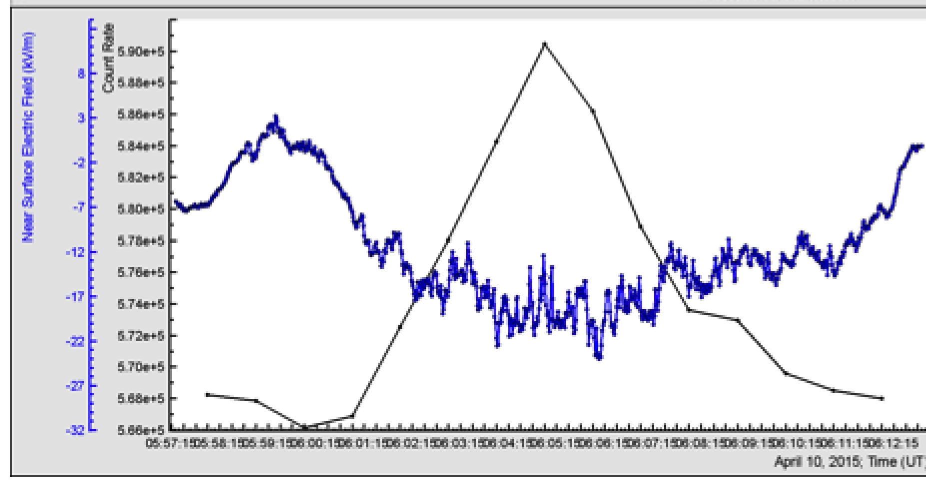
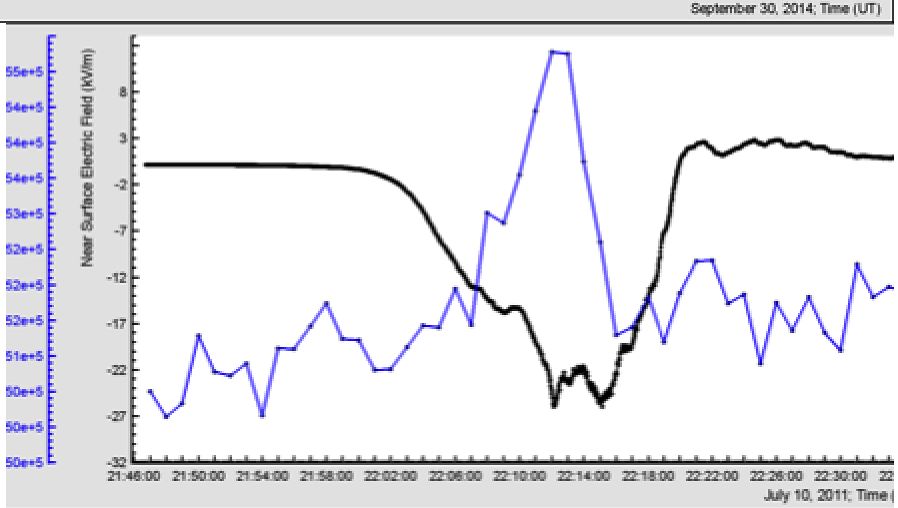
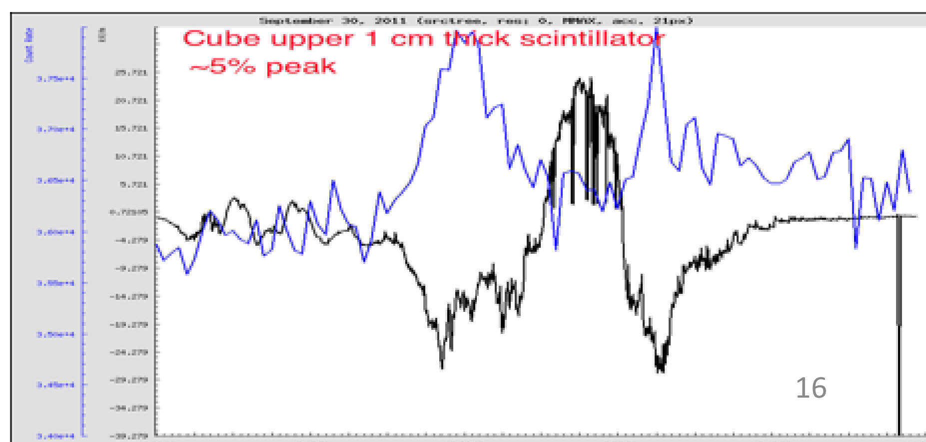

ASEC (Aragats Space Environmental Center; 3200m a.s.l.)
Electrical field
Count rate
Electrical field between cloud and ground (kv/m)
Count rate of low energy γ - rays (E>5 Mev)
October 16, 2011 Time (UT)


ASEC (Aragats Space Environmental Center; 3200m a.s.l.)
Electrical field
TGE (RREA)
IC-
CG-
Number of IC - and CG - lightning occurrences
Electrical field between cloud and ground (kv/m)
NaI detector Count Rate
May 27, 2011 Time (UT)


Near Surface Electric Field (kV/m)
Count Rate
September 30, 2014; Time (UT)


Near Surface Electric Field (kV/m)
Count Rate
April 10, 2015; Time (UT)

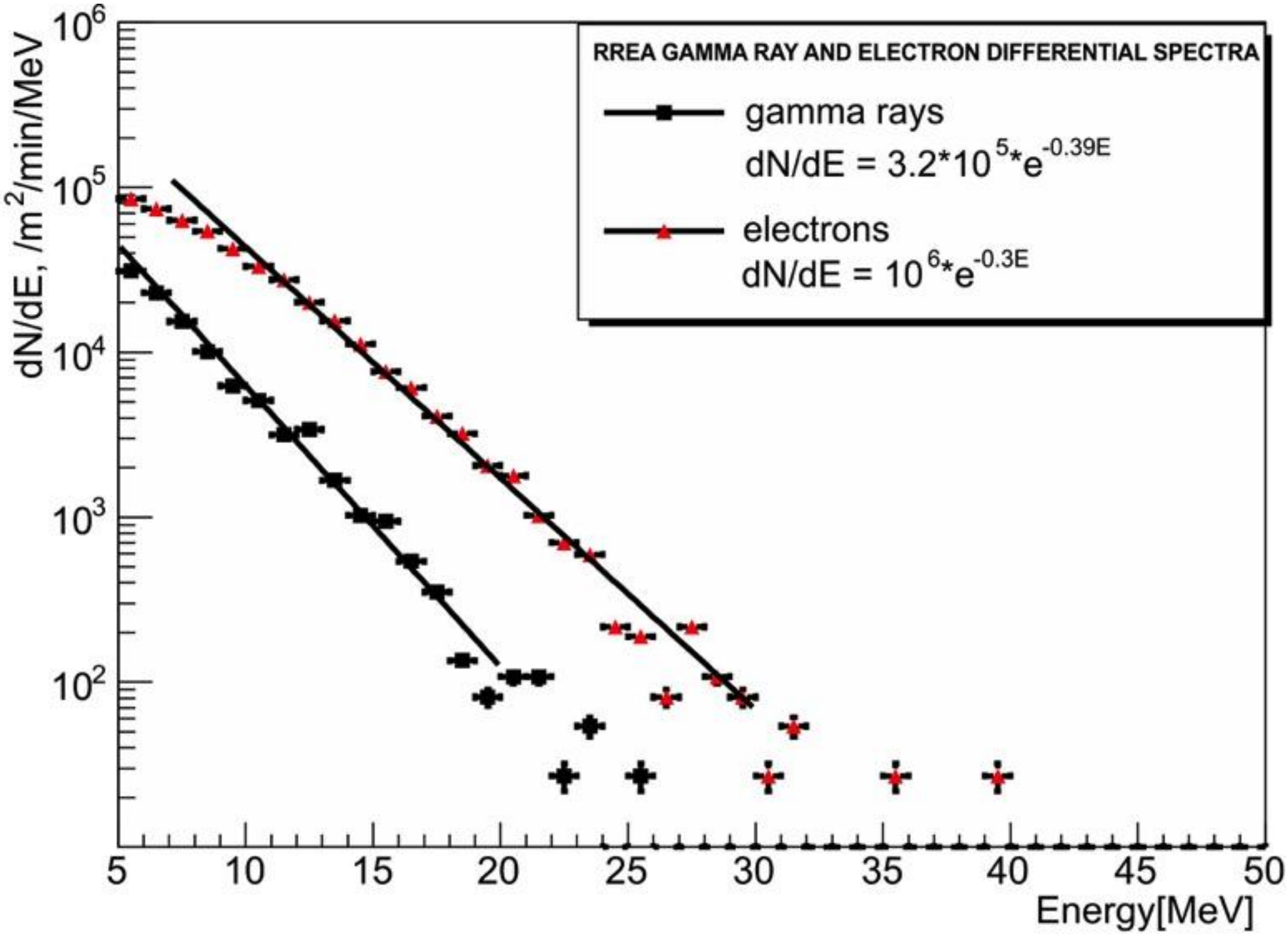

Near Surface Electric Field (kV/m)
July 10, 2011; Time


Cube upper 1 cm thick scintillator
~5% peak

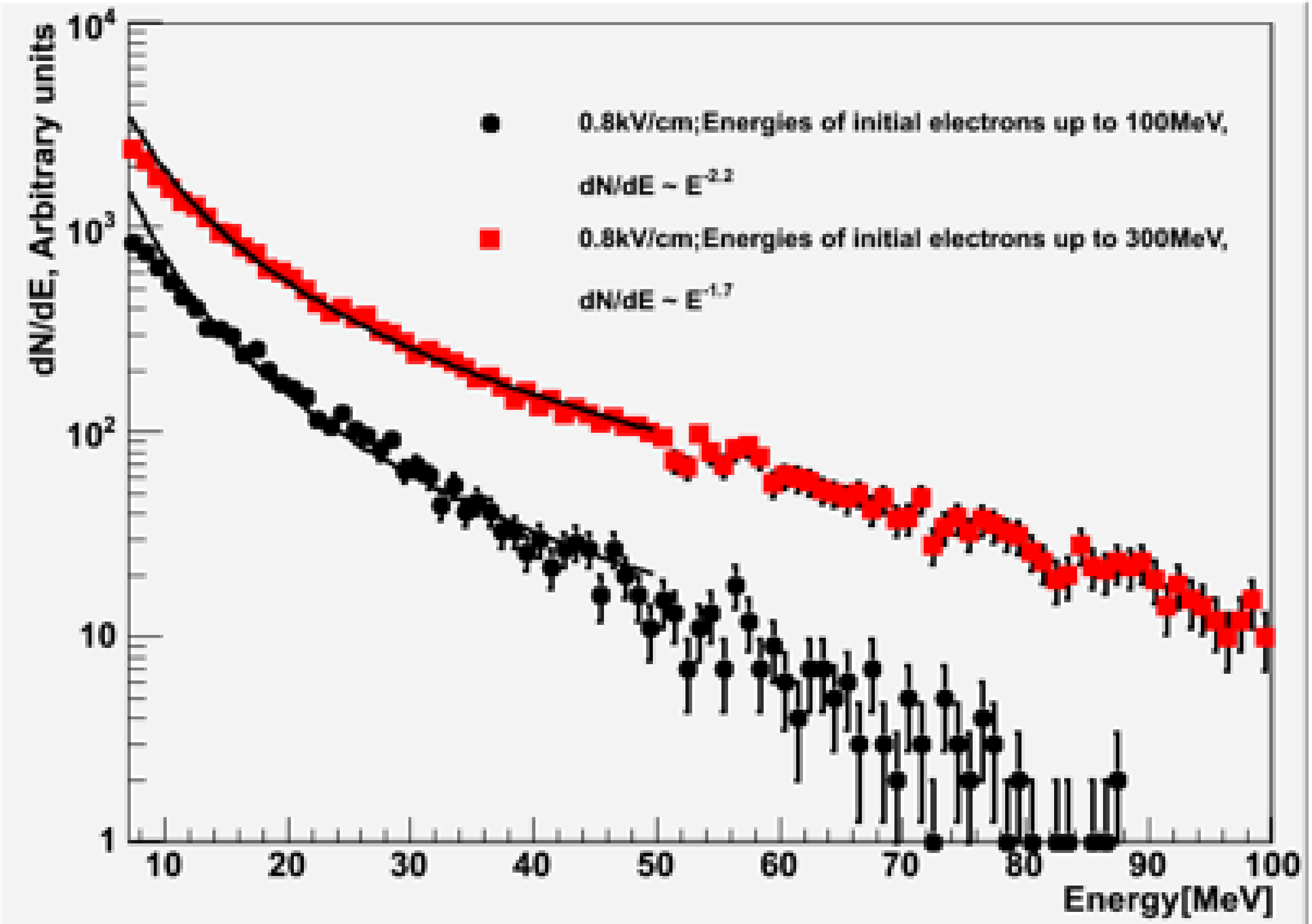
GEANT4 simple simulation

- Uniform electric field above Aragats from 5,000 down to 3400- 3200 m, field strength varied 0.8 - 2 kV/cm;
- Seed particles – Cosmic Ray electrons generated by EXPACS WEB-calculator (PARMA model), energies 0.1 -300 MeV;
- Thinning of atmosphere with height was introduced as well;
- All electromagnetic processes in GEANT4 were switched on.

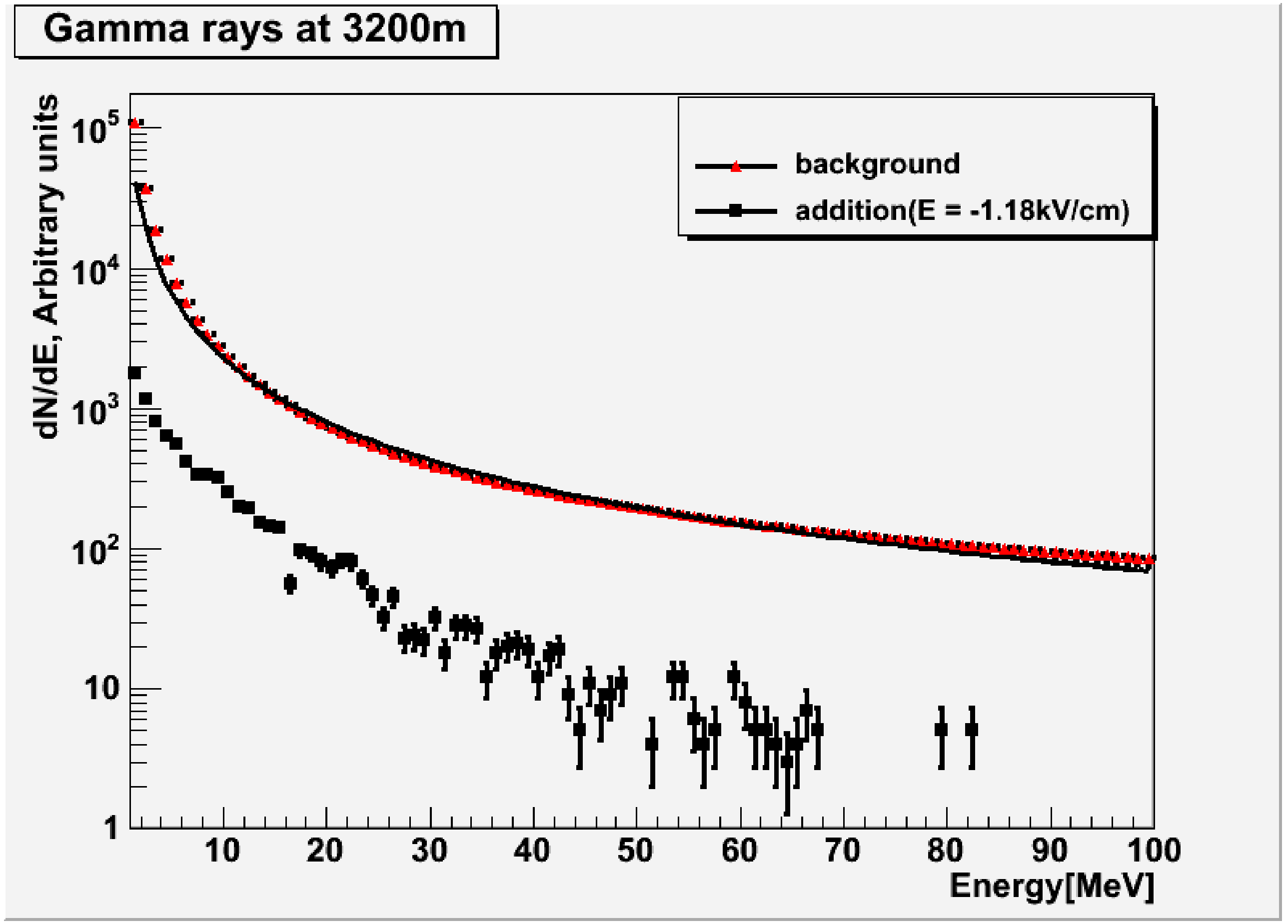
The electron and gamma energy spectra from electrons accelerated in electric field of 1.8 kV/cm prolonged from 5000 till 3400 m with 1 MeV electron as seeds.



MOdification of CR electrons energy Spectra (MOS process) – electric field strength is below RREA threshold; seed particles – CR electrons with energies up to 100 and 300 MeV

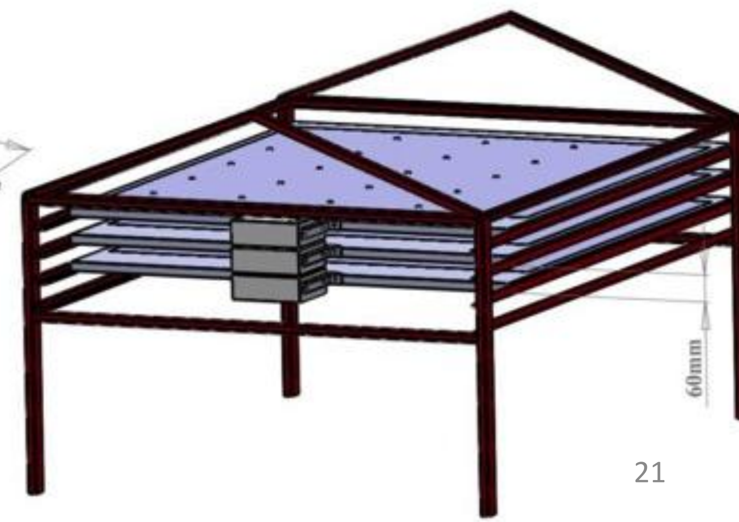


Comparison of background gamma ray spectrum with the MOS gamma rays spectrum

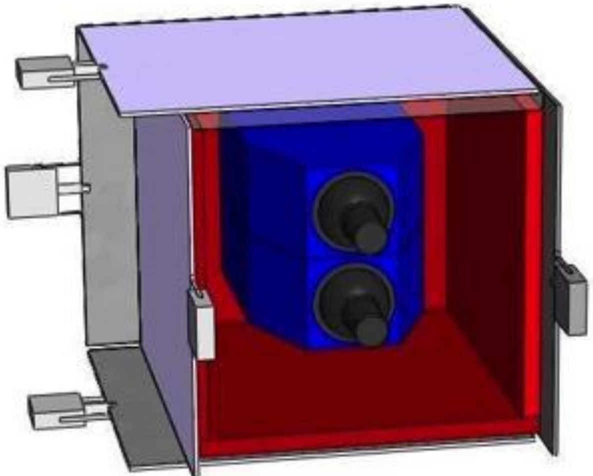


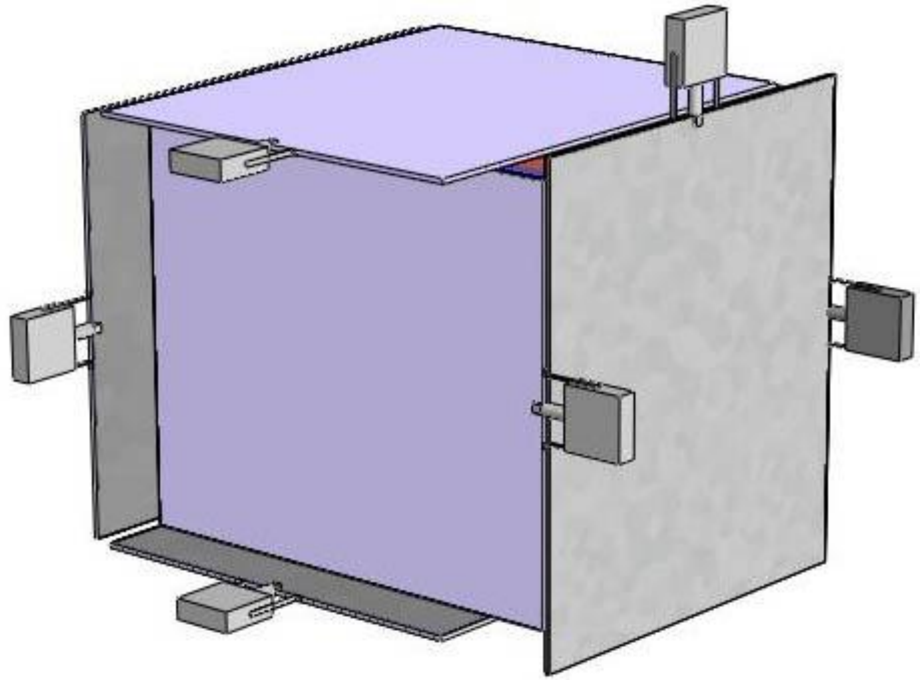
The MOS gamma rays energy spectra comparing with gamma ray “background” spectra on altitude 3200 m. SCR electrons were accelerated in the homogenous field of strength 1.18 kV/cm below the critical field for the RREA initiation

STAND multilayered Detector



Cube Detector vetoing charged particles

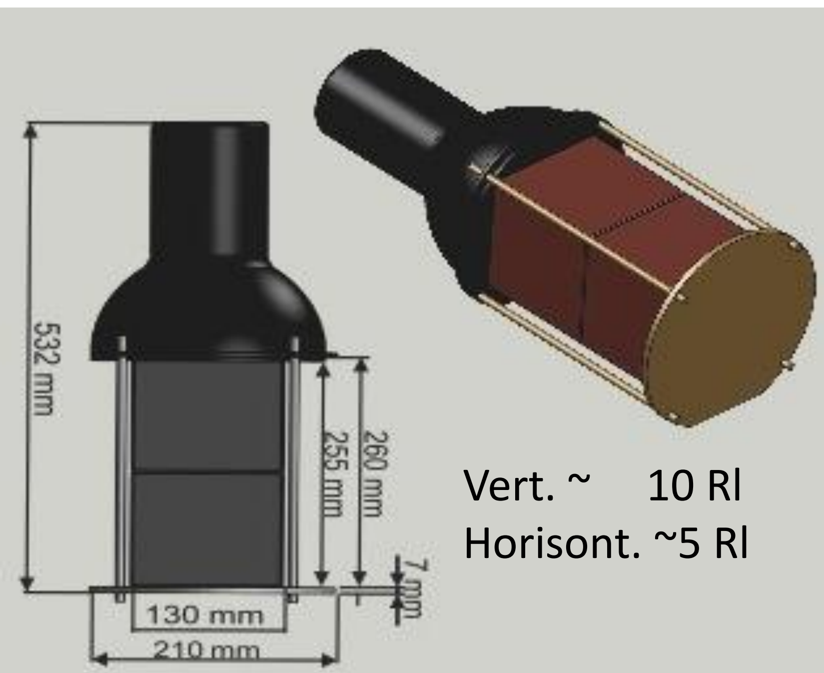


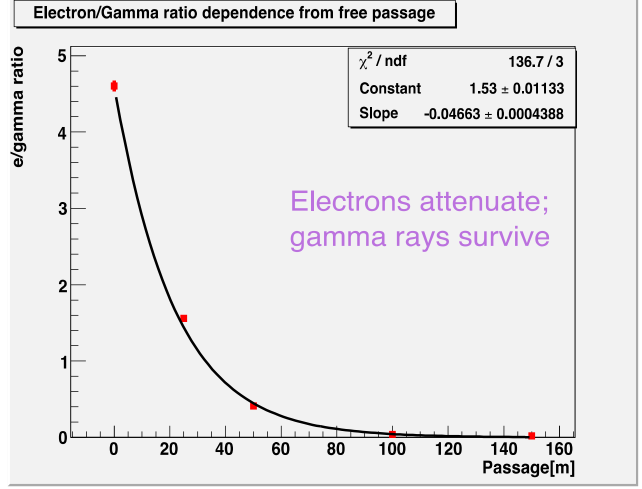


NaI network 7 detectors 12.5 x 12.5 x 25 each; one vertical 5 horizontal, one - outdoors

Material	Radiation length		Density
	g/cm2	cm	g/cm3
Polystyr. scint.	43.72	42.4	1.032
Cesium iodide (CzI)	8.39	1.85	4.53
Sodium iodide (NaI)	9.49	2.59	3.67

NaI – matter above NaI sensitive volume (mg/cm^2):
Al(800)+MgO(300)+Fe(400)=1500
Energy threshold for detecting TGE electrons – 3-4 MeV; Threshold to detect Gamma rays was the same, from 2015 – 0.4 MeV.



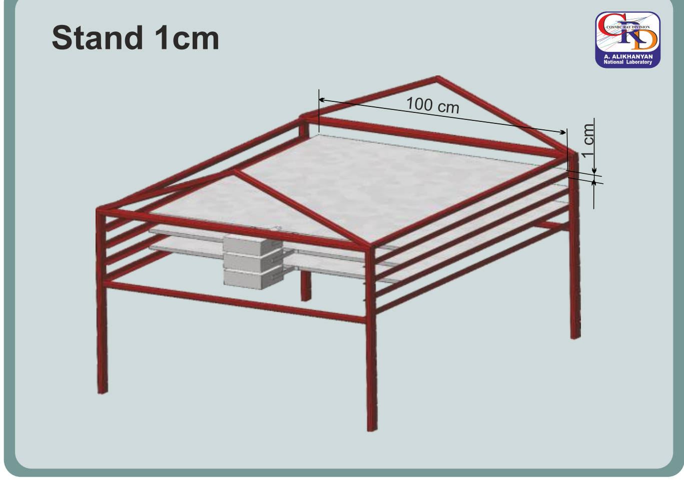


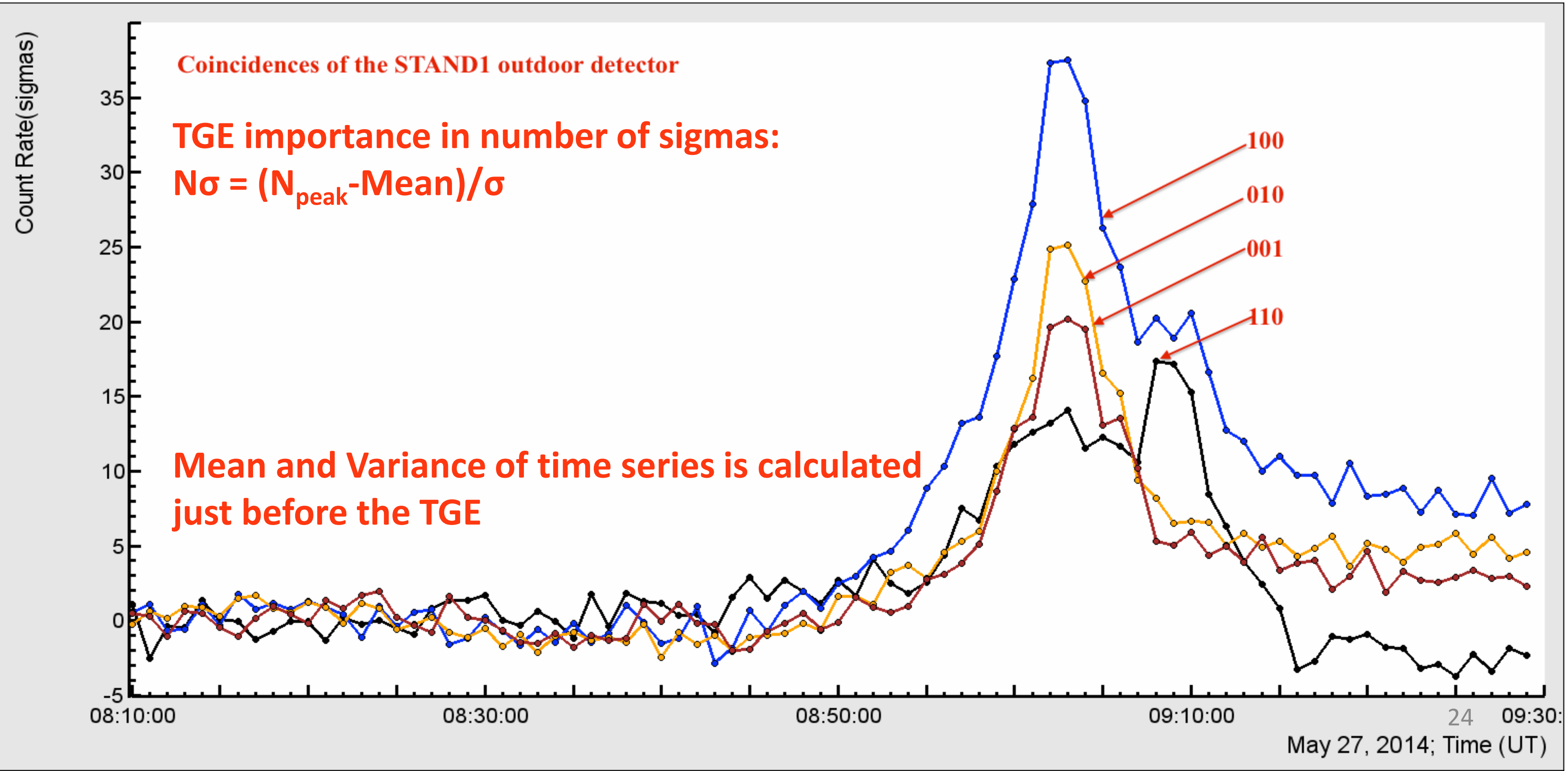
p(1 cm/e) =0.99

p(1 cm/g)=0.02

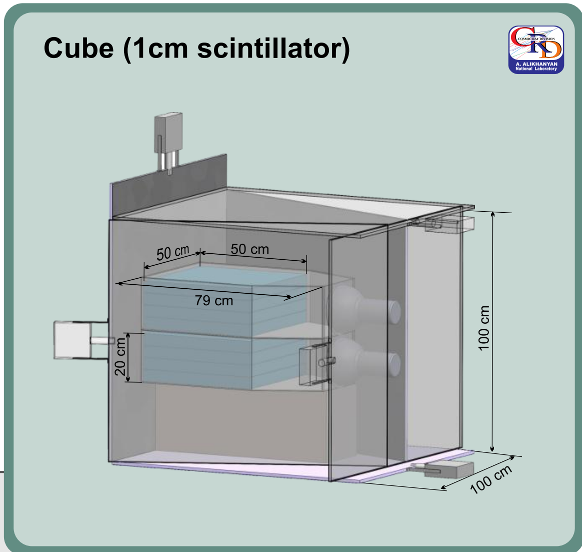
P(110/g)~ 0.0003

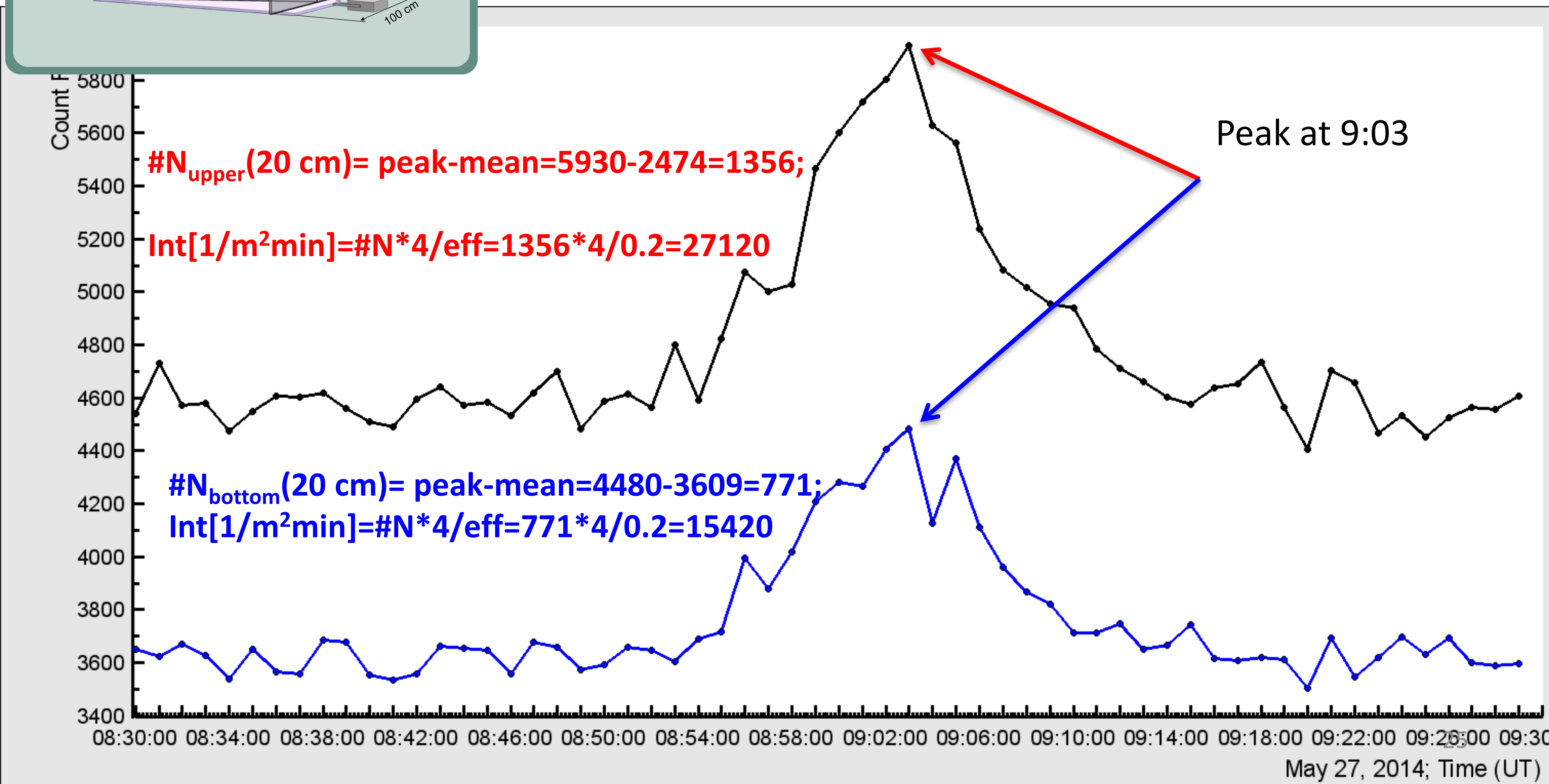
P(001/e) ~ 0.0002



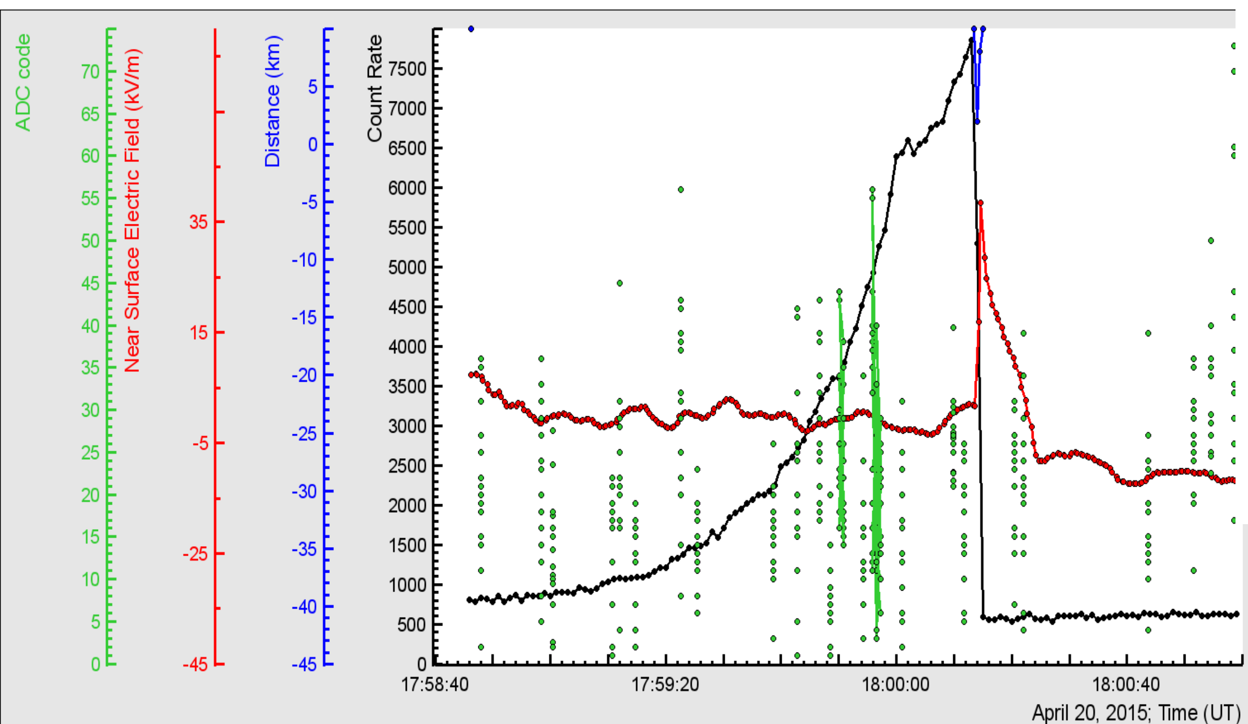


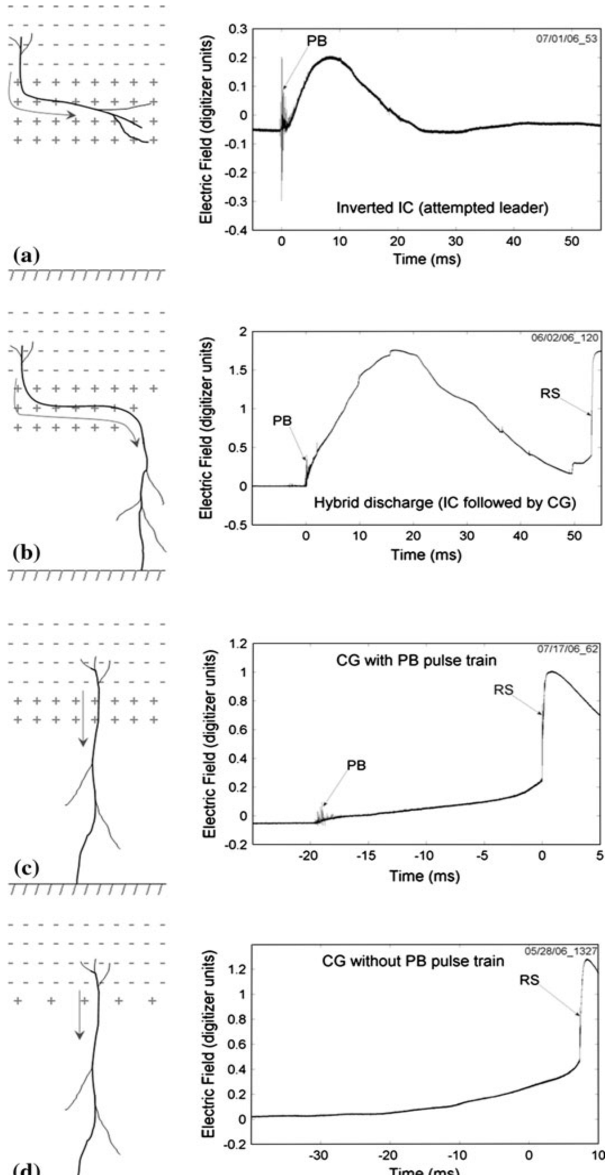
Calculation of the gamma-ray Intensity with Cube detector vetoing charge flux





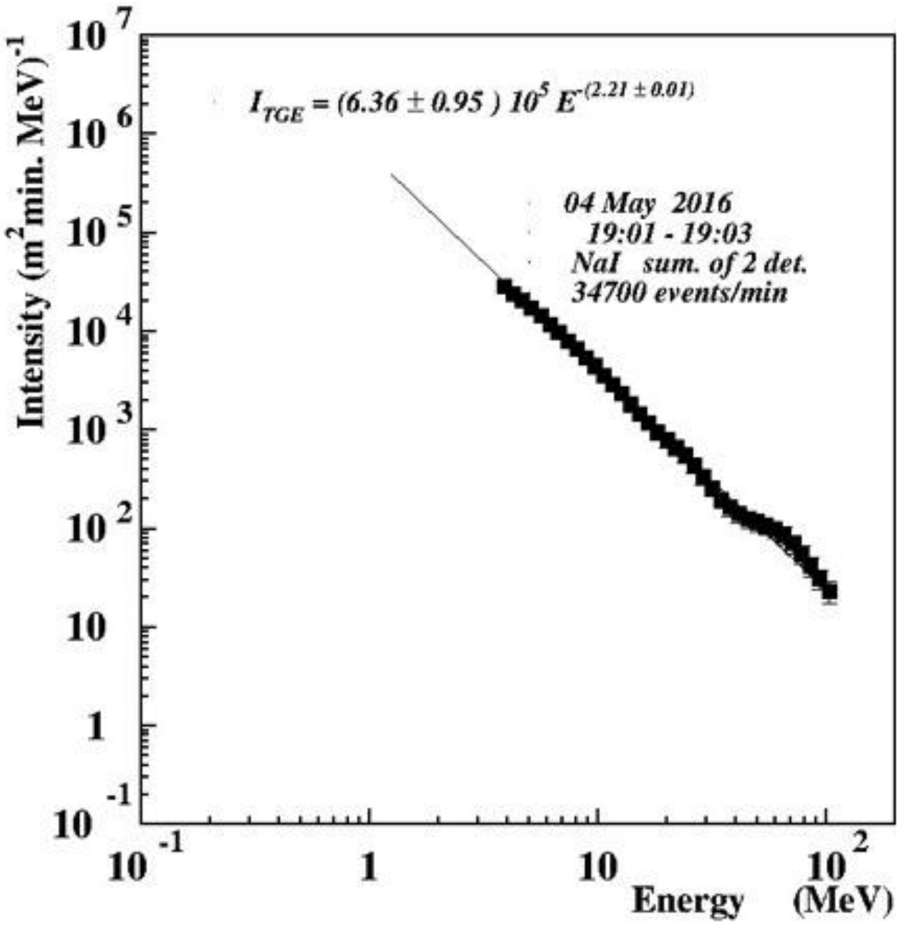
TGE terminated by lightning at the maximum of the flux; red – disturbances of electrostatic field; blue – distance to lightning (~2 km); green small circles are the codes (density of particles) of MAKET-16 array. We expect TGE flux maximum at maximal electric field in cloud and, therefore, at maximal LPCR. Maximal LPCR prevents –CG (Nag and Rakov, 2009); thus we expect TGE termination only on beginning and decaying stages, but we have equal events also at maximum.

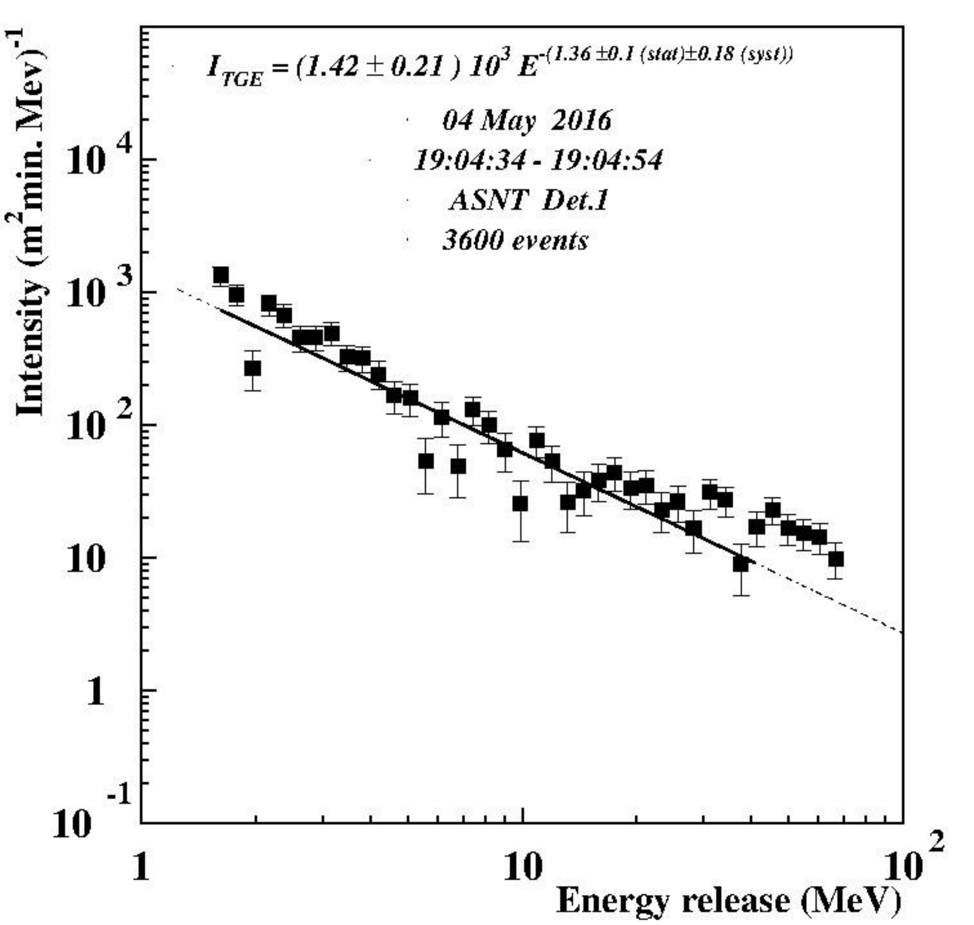




Nag A. and Rakov V. A., 2009. Some inferences on the role of lower positive charge region in facilitating different types of lightning Geophys. Res. Lett., 36, L05815.

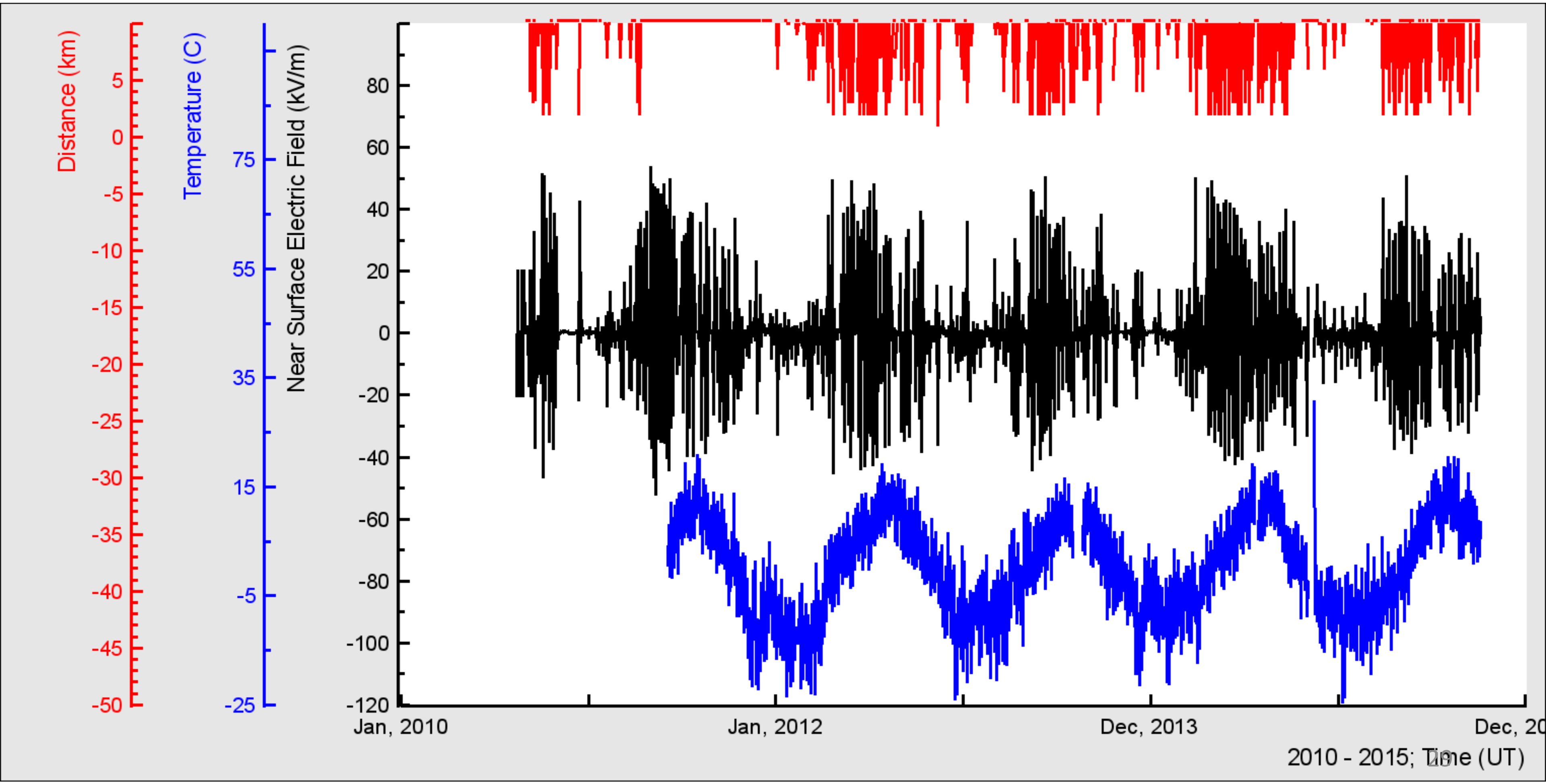
Large TGE May 4;
3 minutes before Lightning
(RREA +MOS)



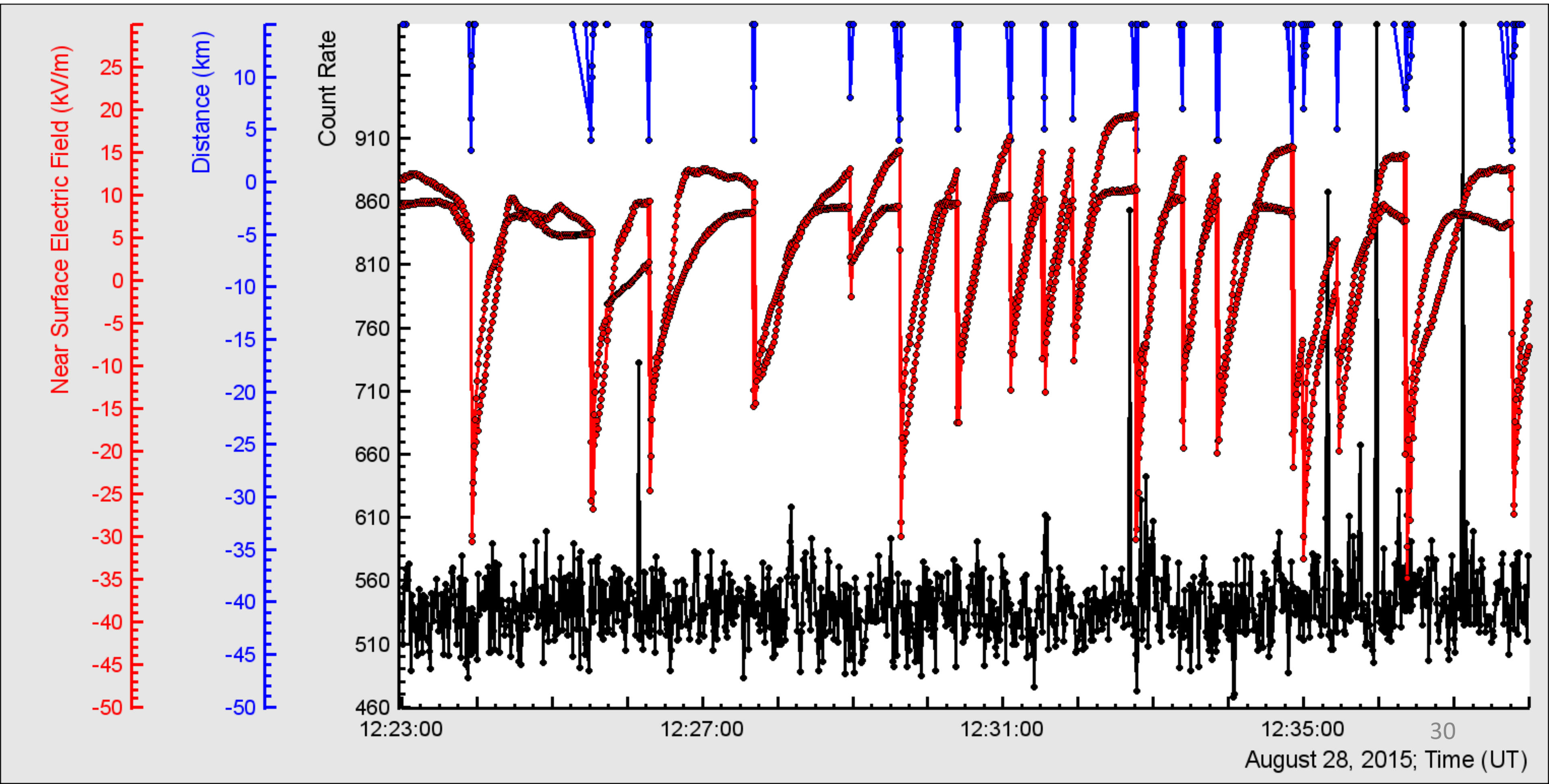


TGE and Lightning

Lightnings are common on Aragats

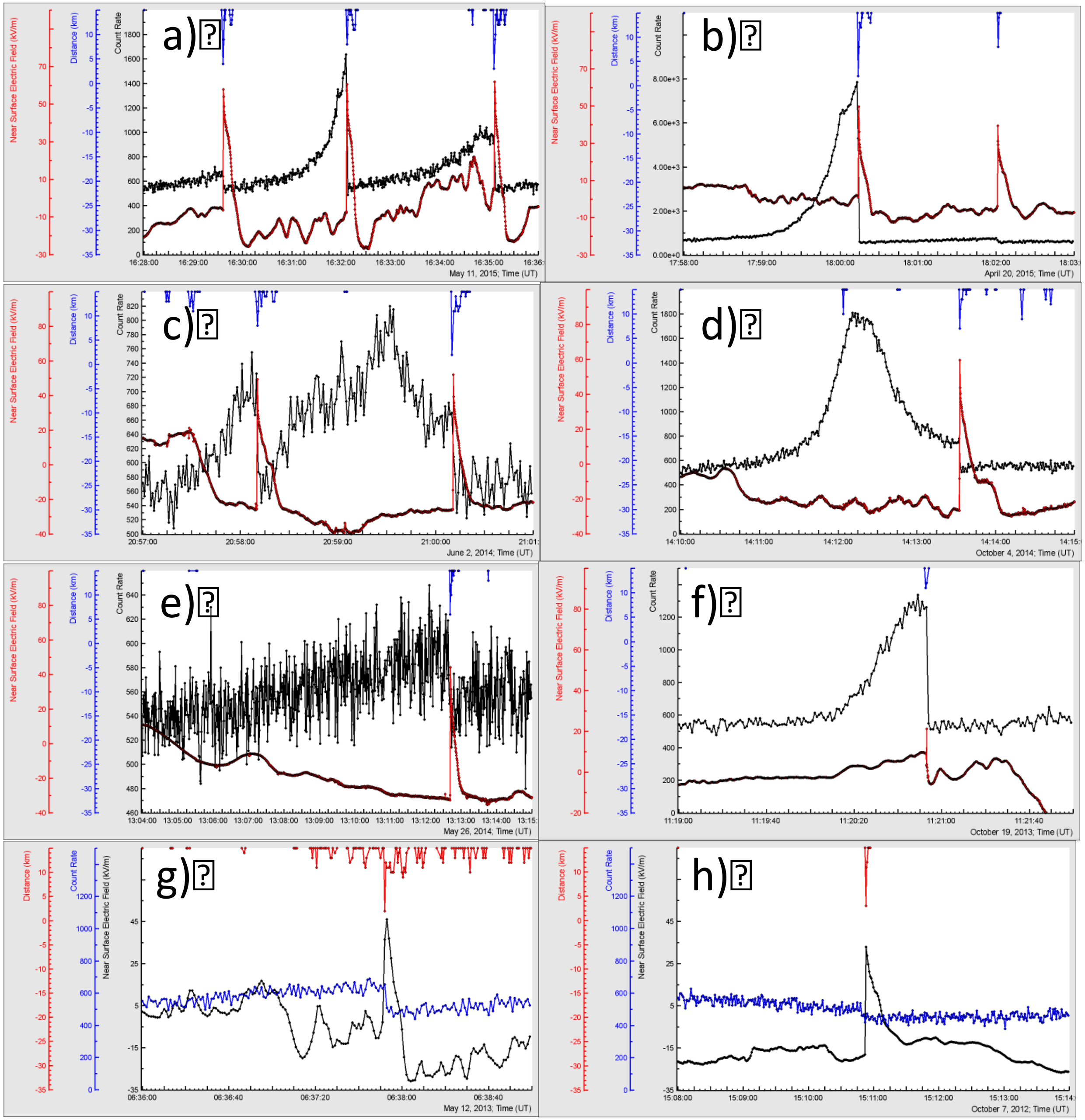


On 28 August 2015 we detect ~100 positive lightnings on Aragats

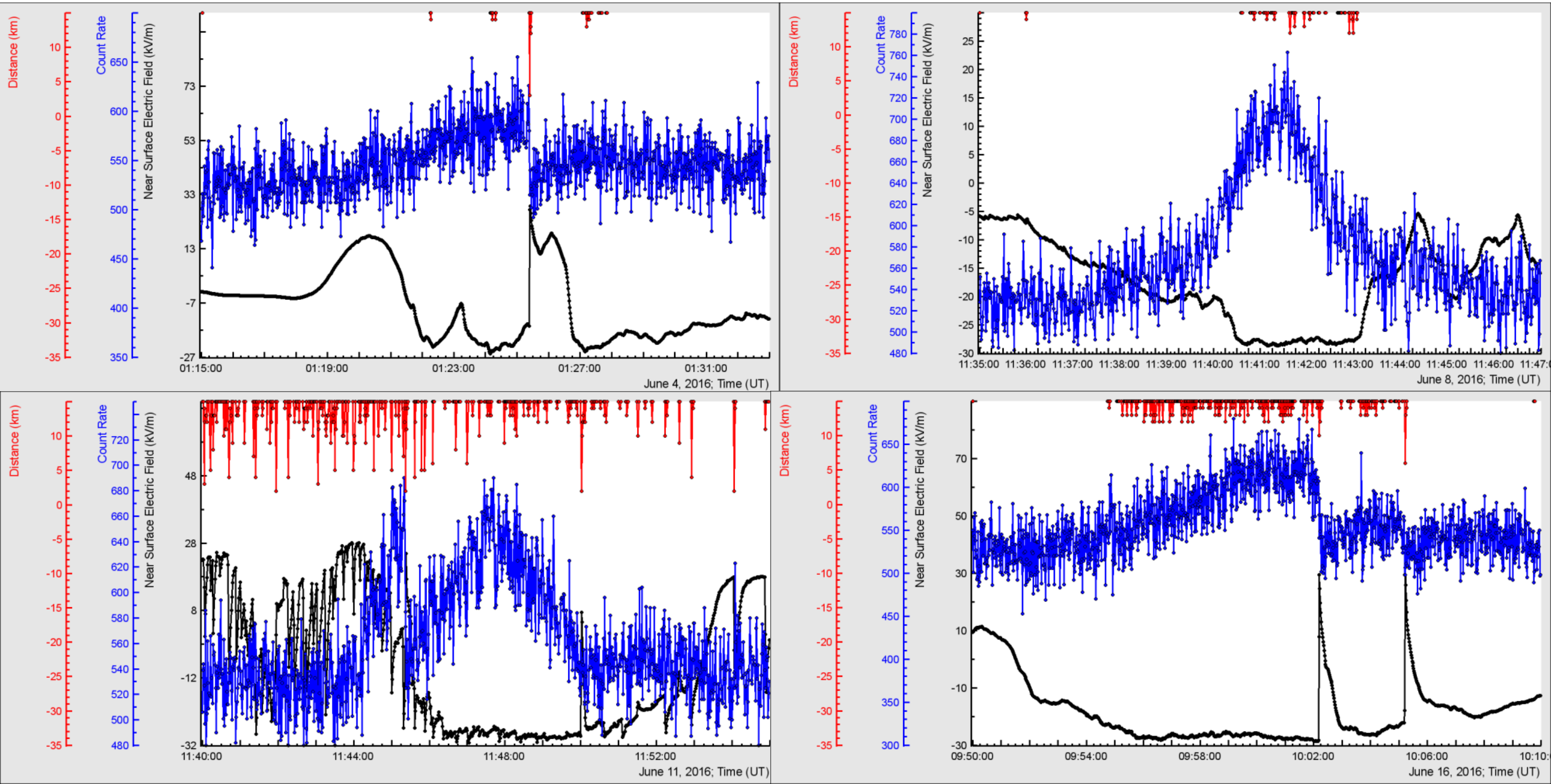



2015/06/03 15:40:01
AraGats CAMERA 1
2015-06-03
15:40:02-26
2015-06-03
15:40:02-27
2015-06-03
15:40:02-28
2015-06-03
15:40:03-01

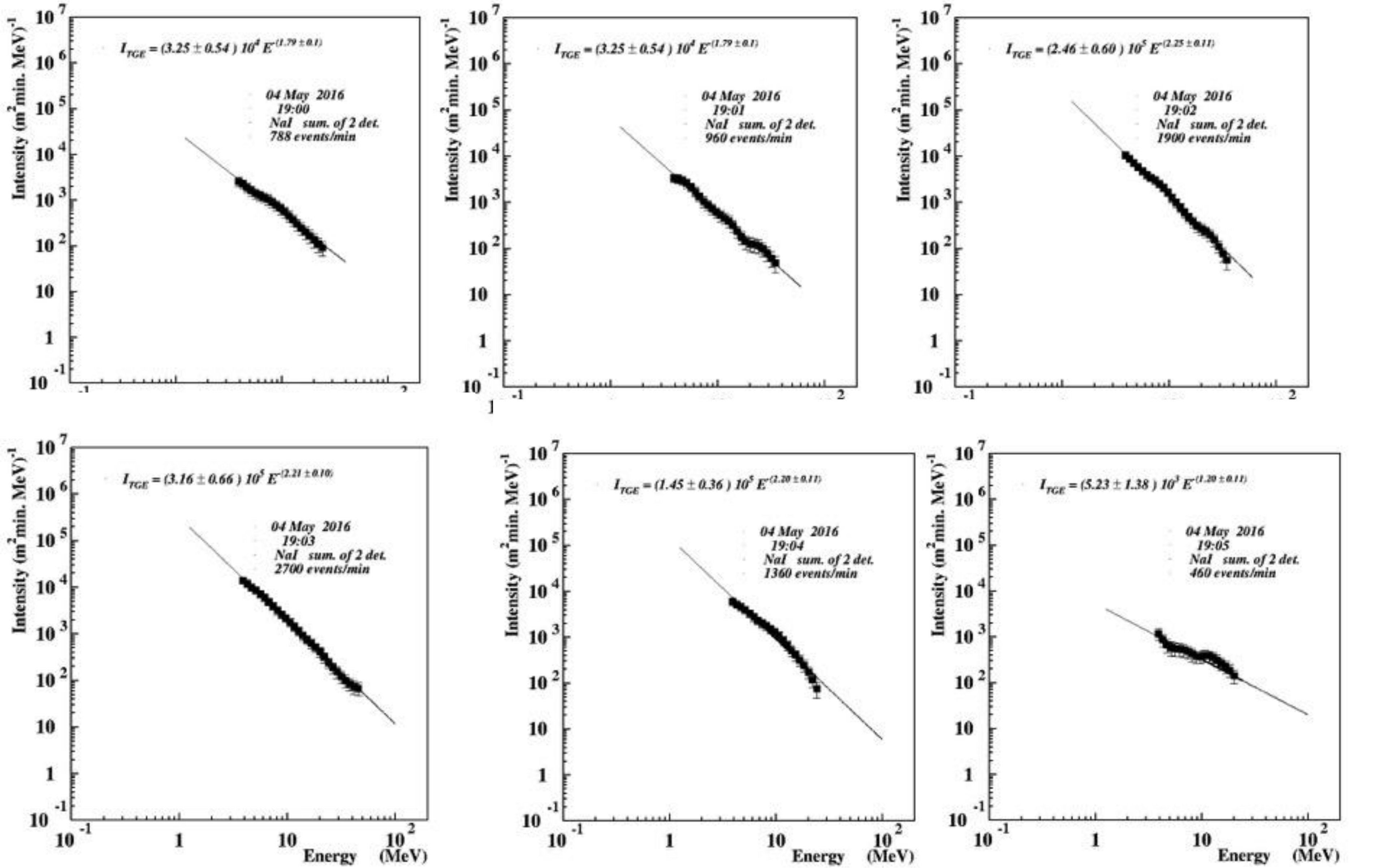
12 Lightnings terminated TGE



2016 TGEs occurs at prolonged (3-7 min)deep negative electrostatic field(~ -30 kV/m); lightning abruptly terminates TGE; largest TGEs occurred when there is no nearby lightnings.

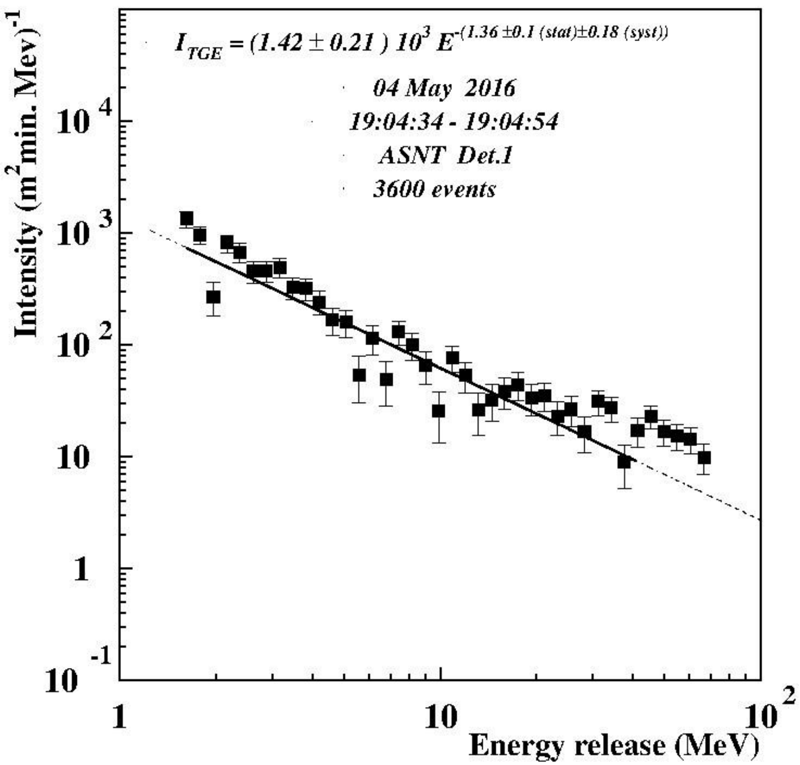


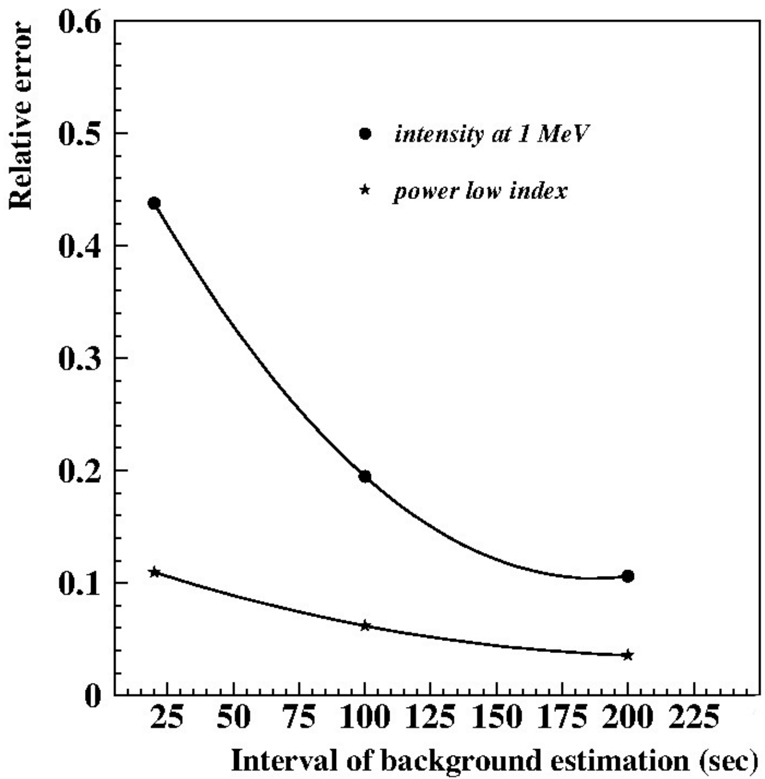
1-minute energy spectra of large TGE observed by NaI spectrometers; Start at 19:00, maximum at 19:03 and decay at 19:05. Runaway electrons accelerated in the thundercloud were abruptly terminated by lightning

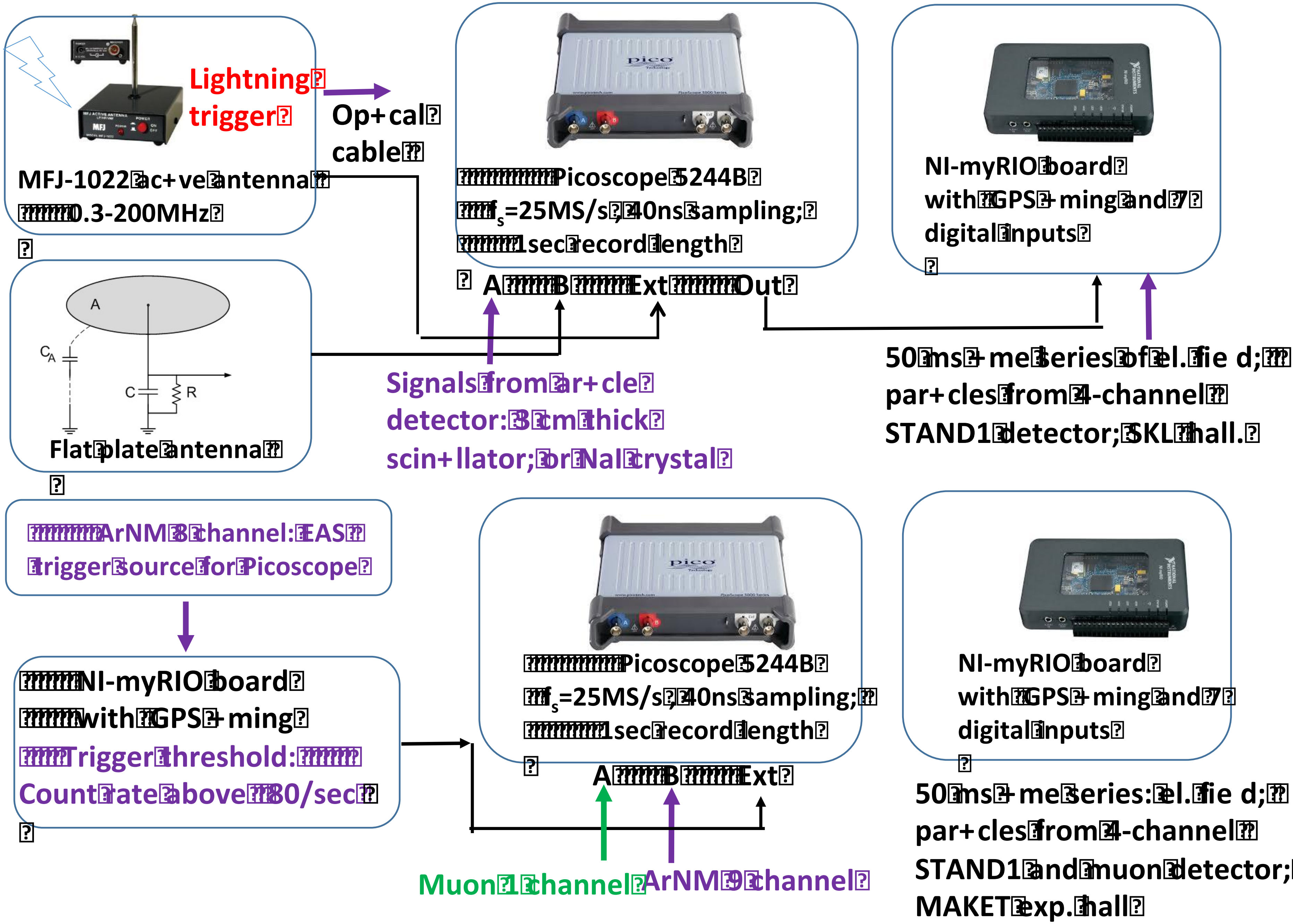


20-second energy release spectra in 60 cm thick plastic scintillator before the lightning occurred at 19:04:33; the enhancement of count rate in the first 13 ADC channels (1.62- 5.09 MeV) to be compared with CR variance (red): no enhancements after lightning!

ADC code	1	2	3	4	5	6	7	8	9	10	11	12	13
Energy(MeV)	1,62	1,78	1,96	2,16	2,37	2,61	2,87	3,16	3,47	3,82	4,2	4,62	5,09
CR mean	1037,5	1158,8	739,9	823,3	871,7	770,9	670,2	604,3	557	534,3	478	443,2	416,4
CR rmse	40,0	30,1	25,1	35,7	24,8	26,7	24,6	25,8	16,7	28,9	26,3	7,0	26,4
19:04:15 - 19:04:34	207,5	164,2	51,1	182,7	174,3	117,1	139,8	163,7	120	112,7	113	88,8	85,6
19:04:15- 19:04:54	-28,5	15,2	35,1	-4,3	27,3	22,1	28,8	66,7	4	-18,3	43	12,8	-23,4

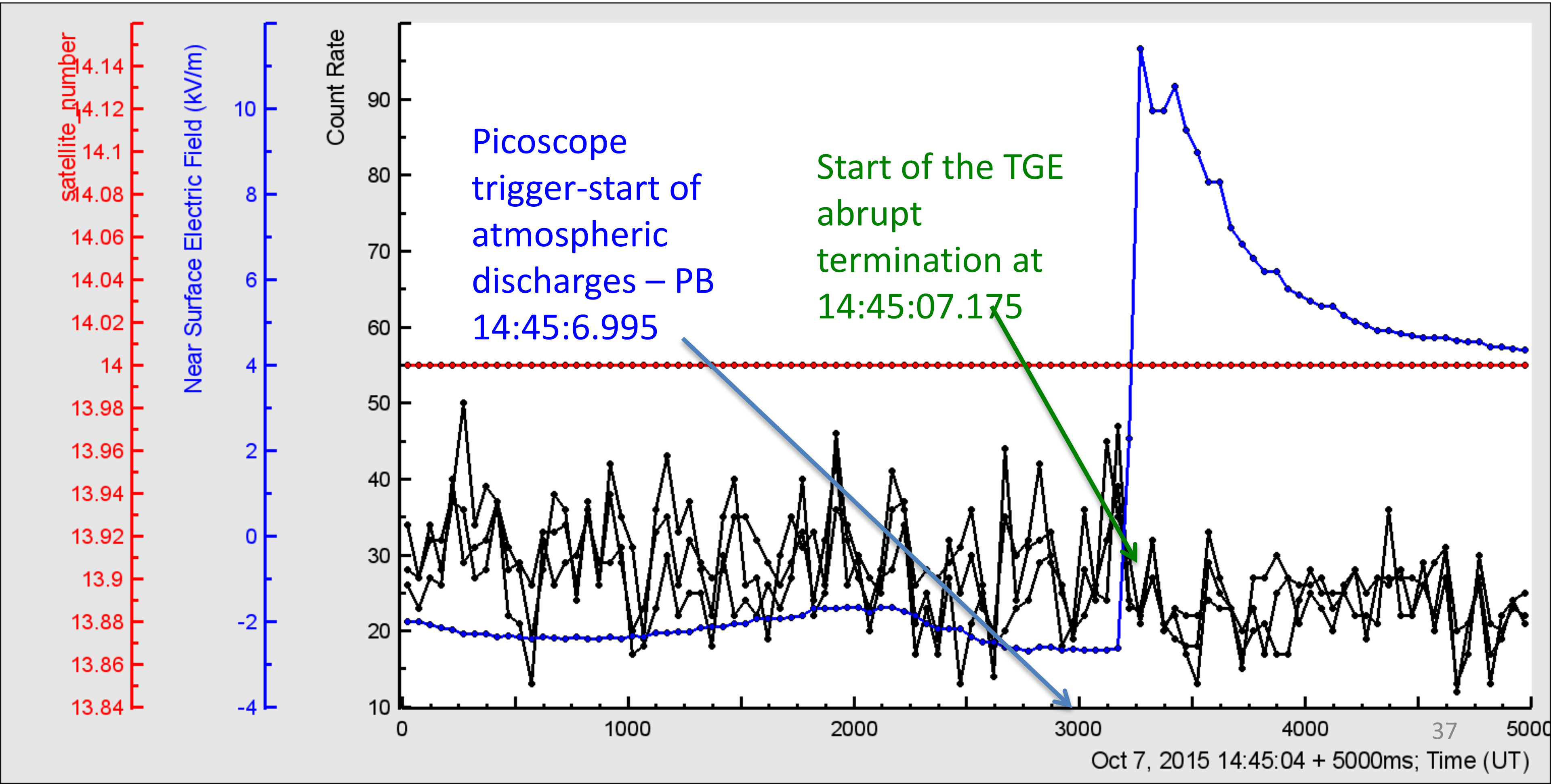




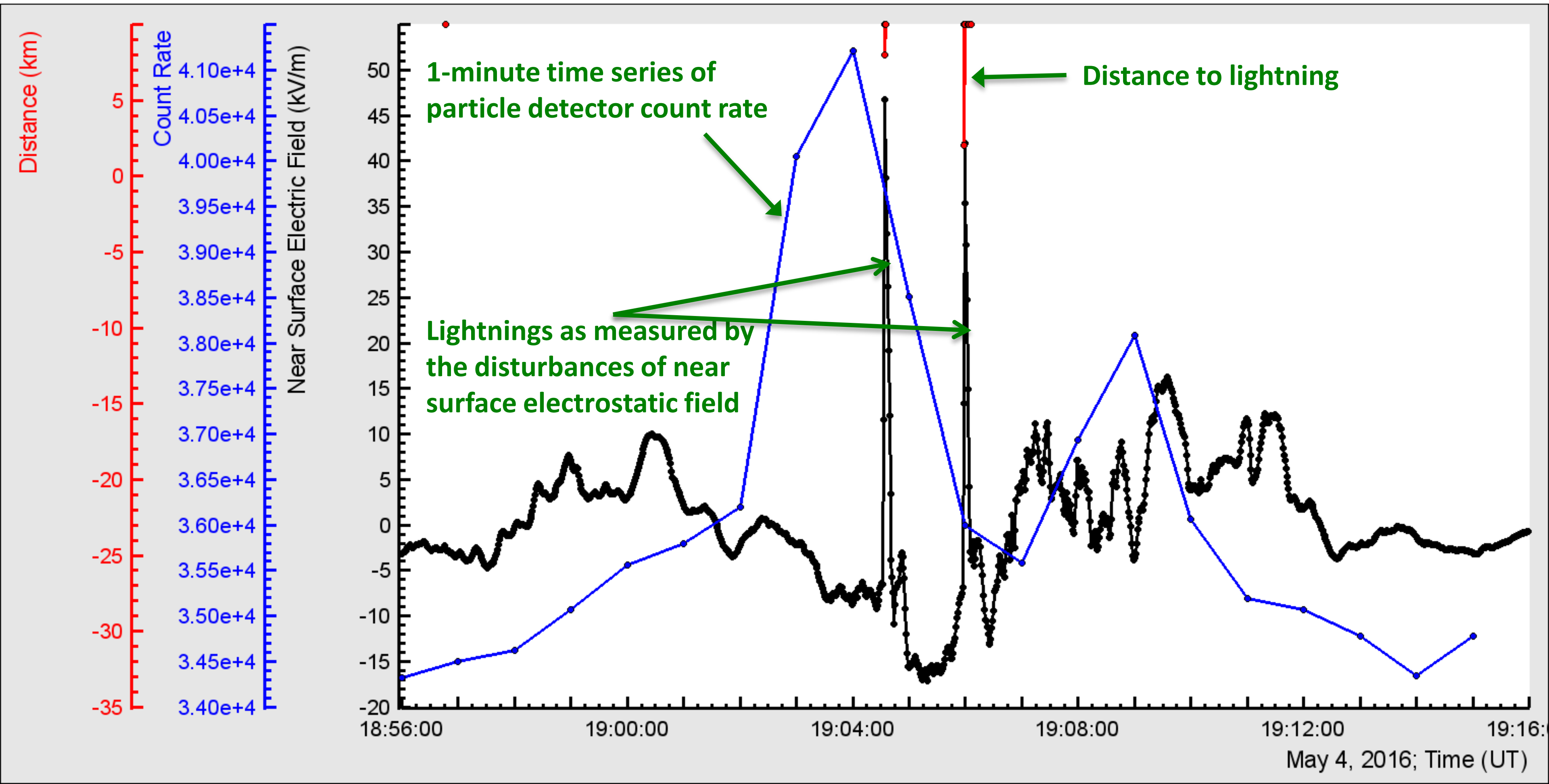


Lightning trigger
Op+cal cable
MFJ-1022 ac+ve antenna
0.3-200MHz
Flat plate antenna
A
C_A
C
R
Picoscope 5244B
f_s=25MS/s; 40ns sampling;
1sec record length
A B Ext Out
NI-myRIO board
with GPS +ming and 7
digital inputs
Signals from par+cle
detector: 3 cm thick
scin+llator; or NaI crystal
50 ms +me series of el. fie d;
par+cles from 4-channel
STAND1 detector; SKL hall.
ArNM 8 channel: EAS
trigger source for Picoscope
NI-myRIO board
with GPS +ming
Trigger threshold:
Count rate above 80/sec
Picoscope 5244B
f_s=25MS/s; 40ns sampling;
1sec record length
A B Ext
NI-myRIO board
with GPS +ming and 7
digital inputs
50 ms +me series: el. fie d;
par+cles from 4-channel
STAND1 and muon detector;
MAKET exp. hall
Muon 1 channel
ArNM 9 channel

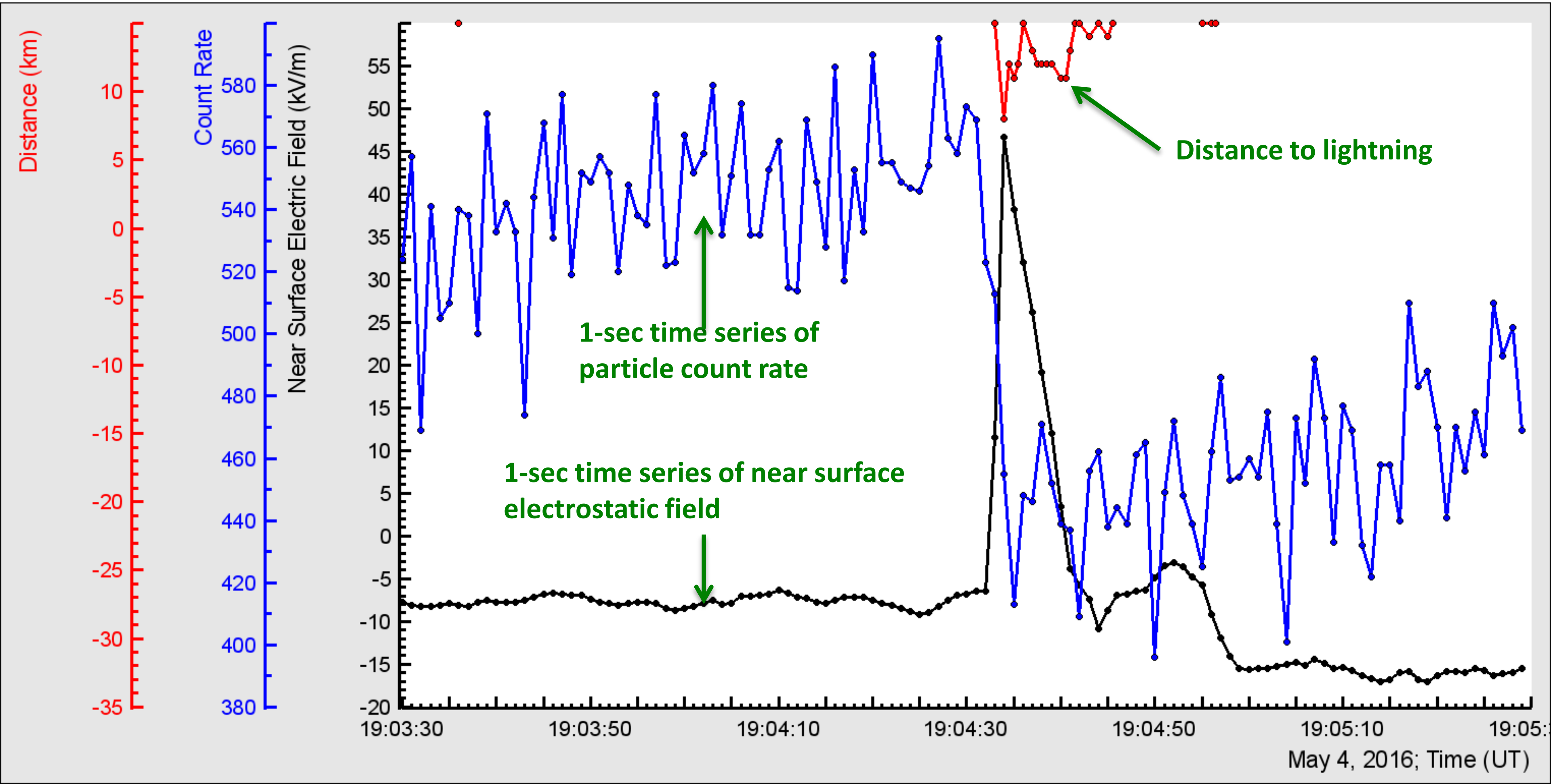
From this picture (SKL STAND1 three layers and SKL field) is apparent that sharp decrease in 50 msec time series of particle flux abrupt started at 14:45:07.175, 175 ms after lightning, and after picoscope trigger!



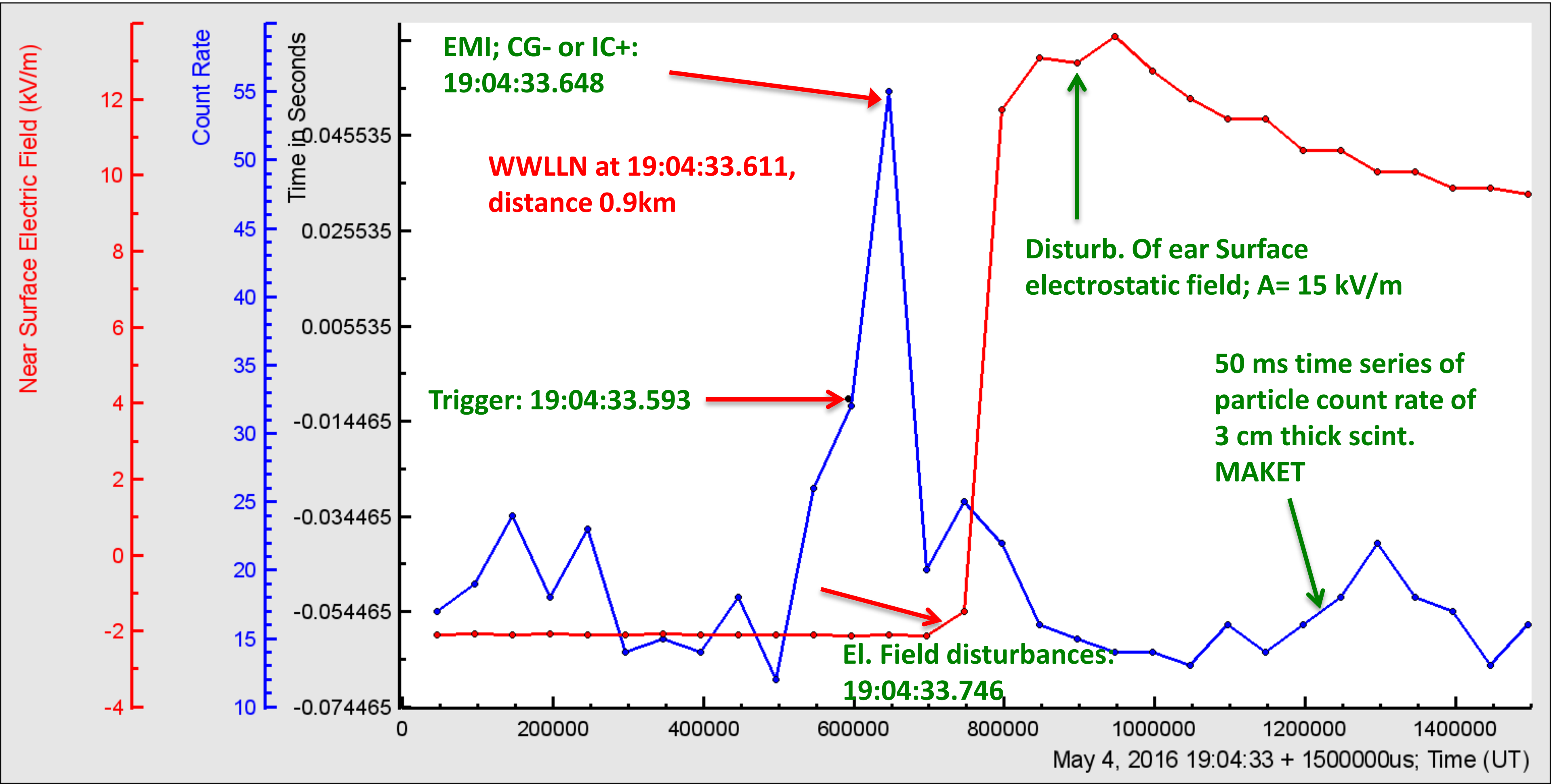
One-minute accuracy timing of 2 peak the TGE; flux enhancement 21% (42σ) and 11.7% (23.7σ)



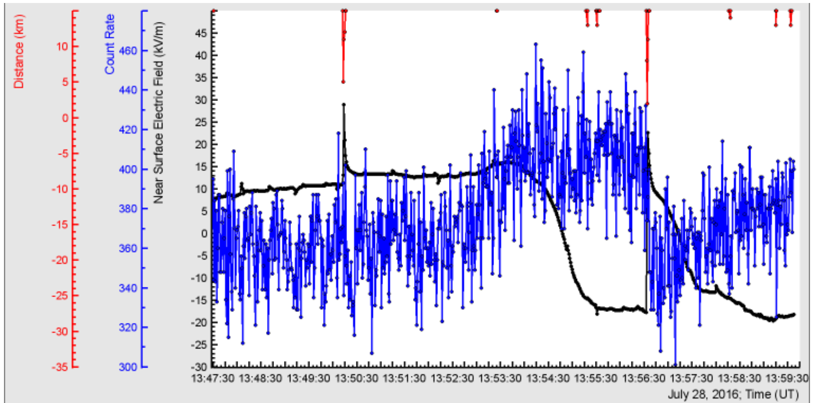
One-second accuracy timing of the negative lightning amplitude (70 kV/m), distance (1.9 km by EFM-100 and 0.9 km by WWLLN) and decline of particle flux(15% in a second)

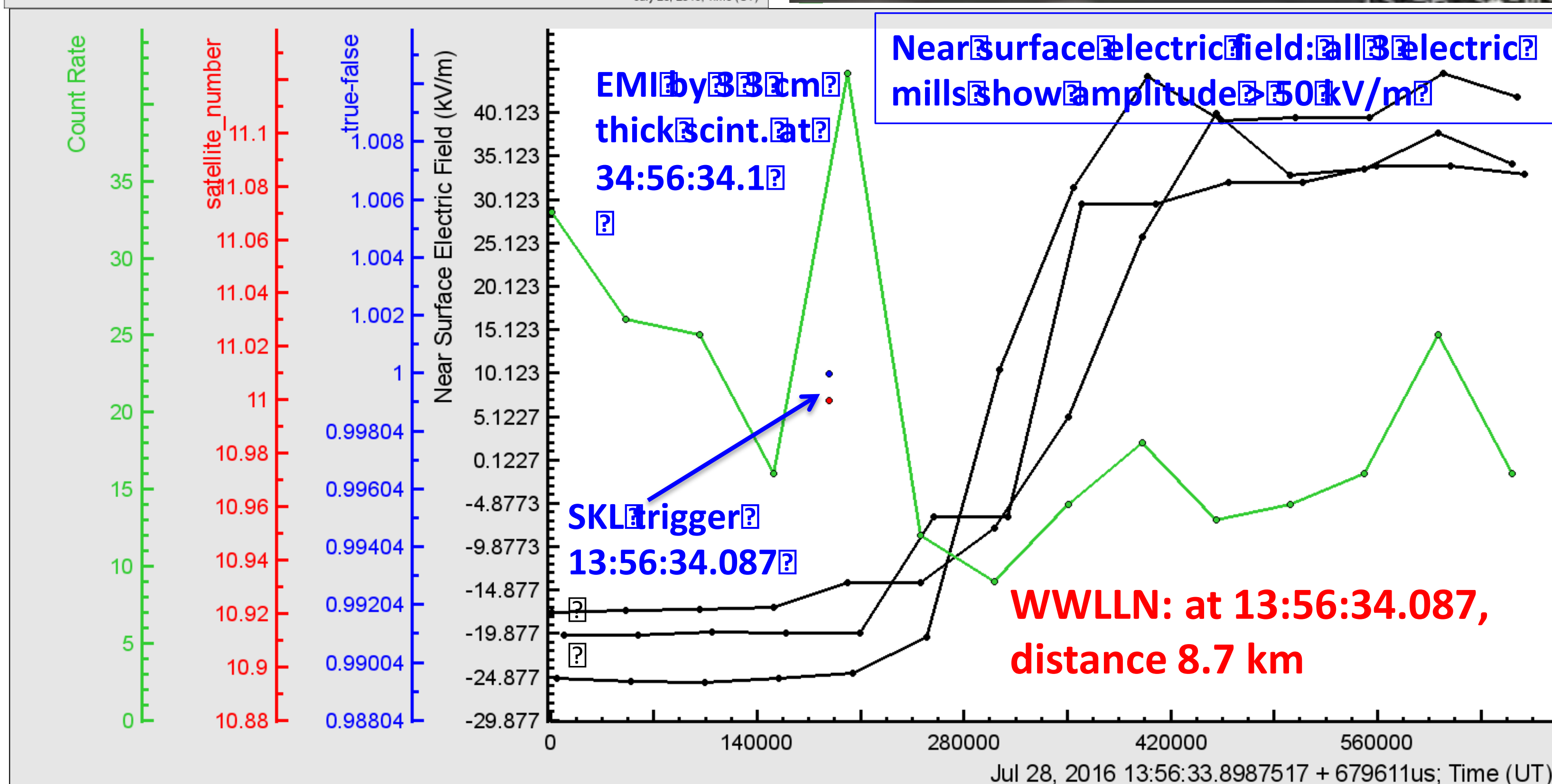


Millisecond accuracy timing of the trigger from digital oscilloscope; negative lightning and disturbances of electrostatic field

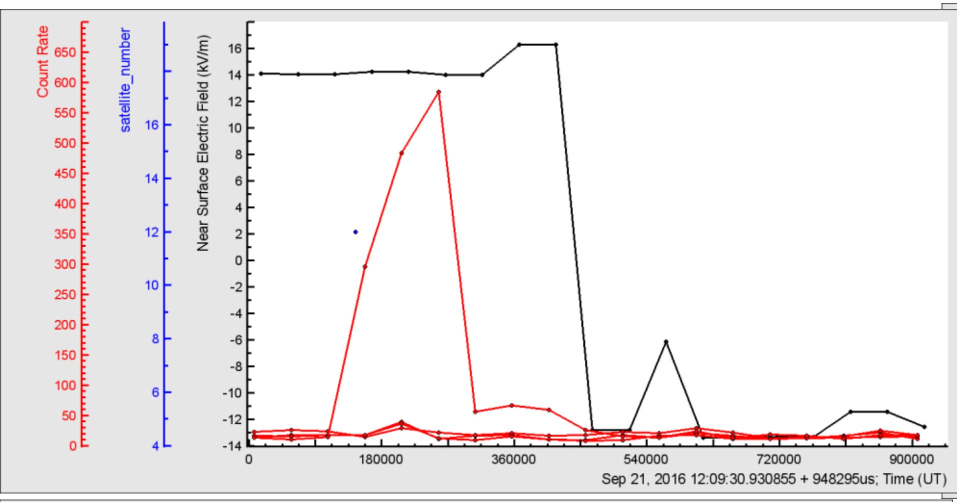


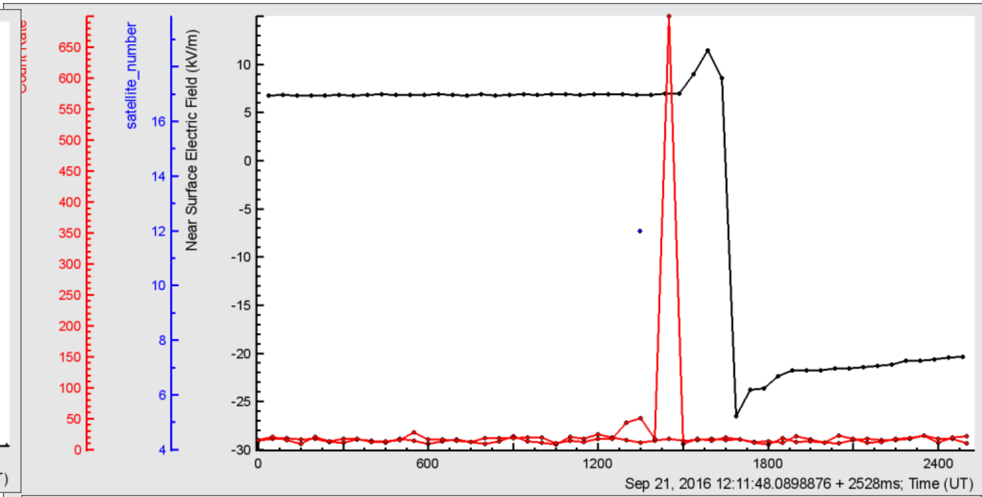
Huge TGE on 28 July observed by all ASEC facilities

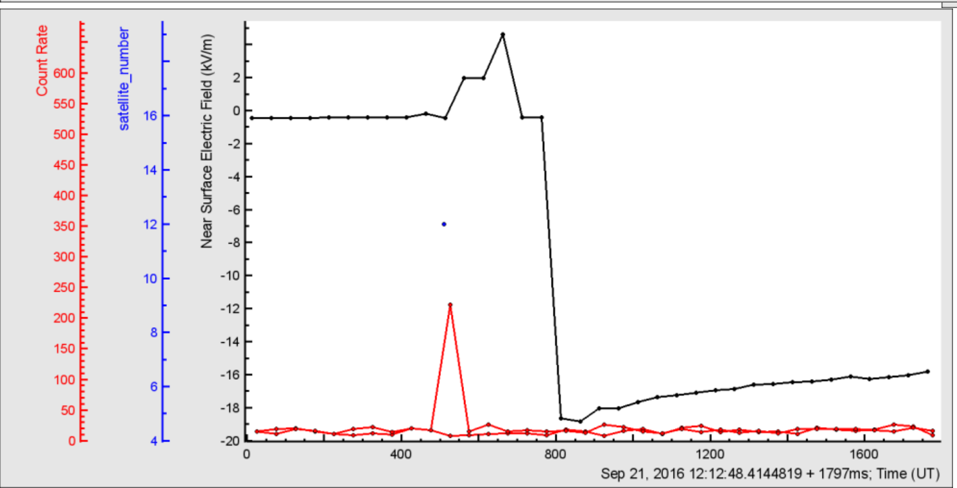


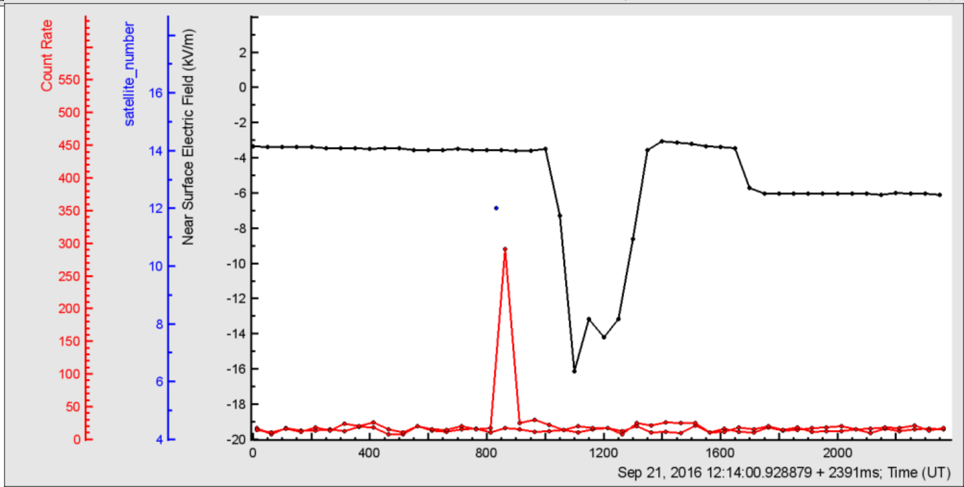


Microsecond accuracy temporal sequence: trigger (initial breakdown)-lightning -rearrangement of the electric field in cloud

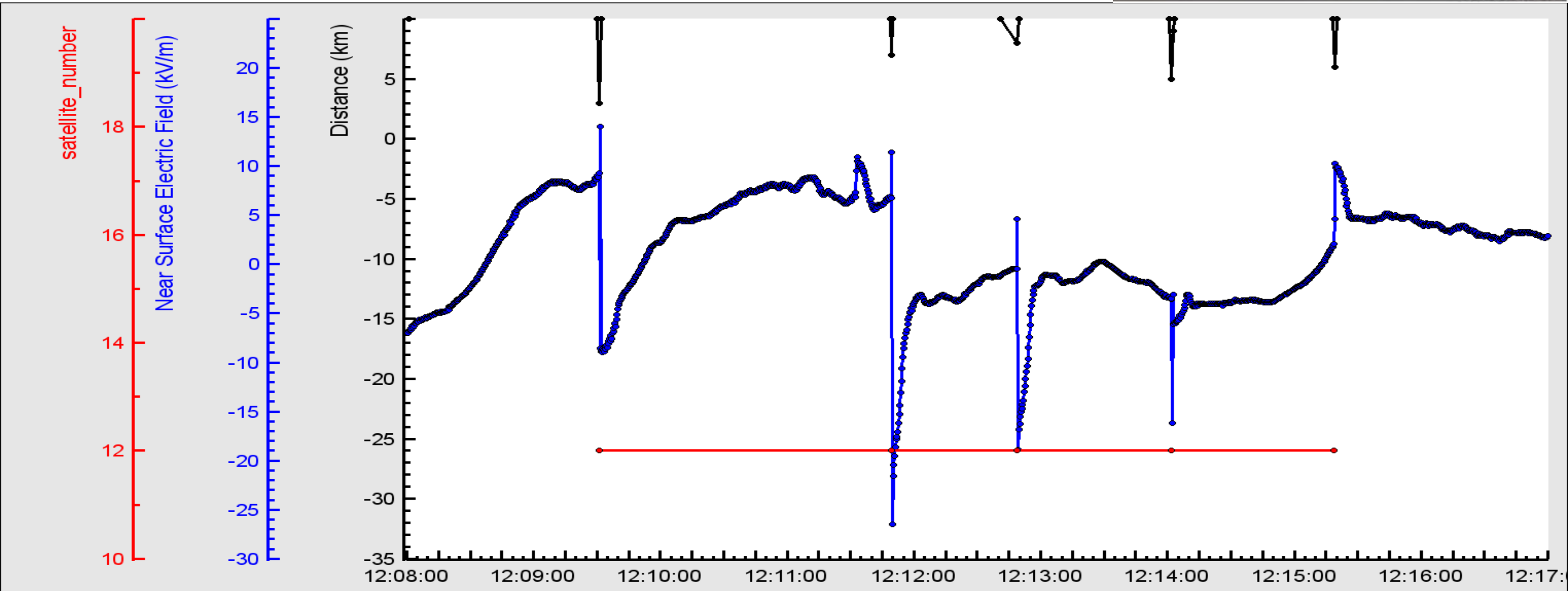




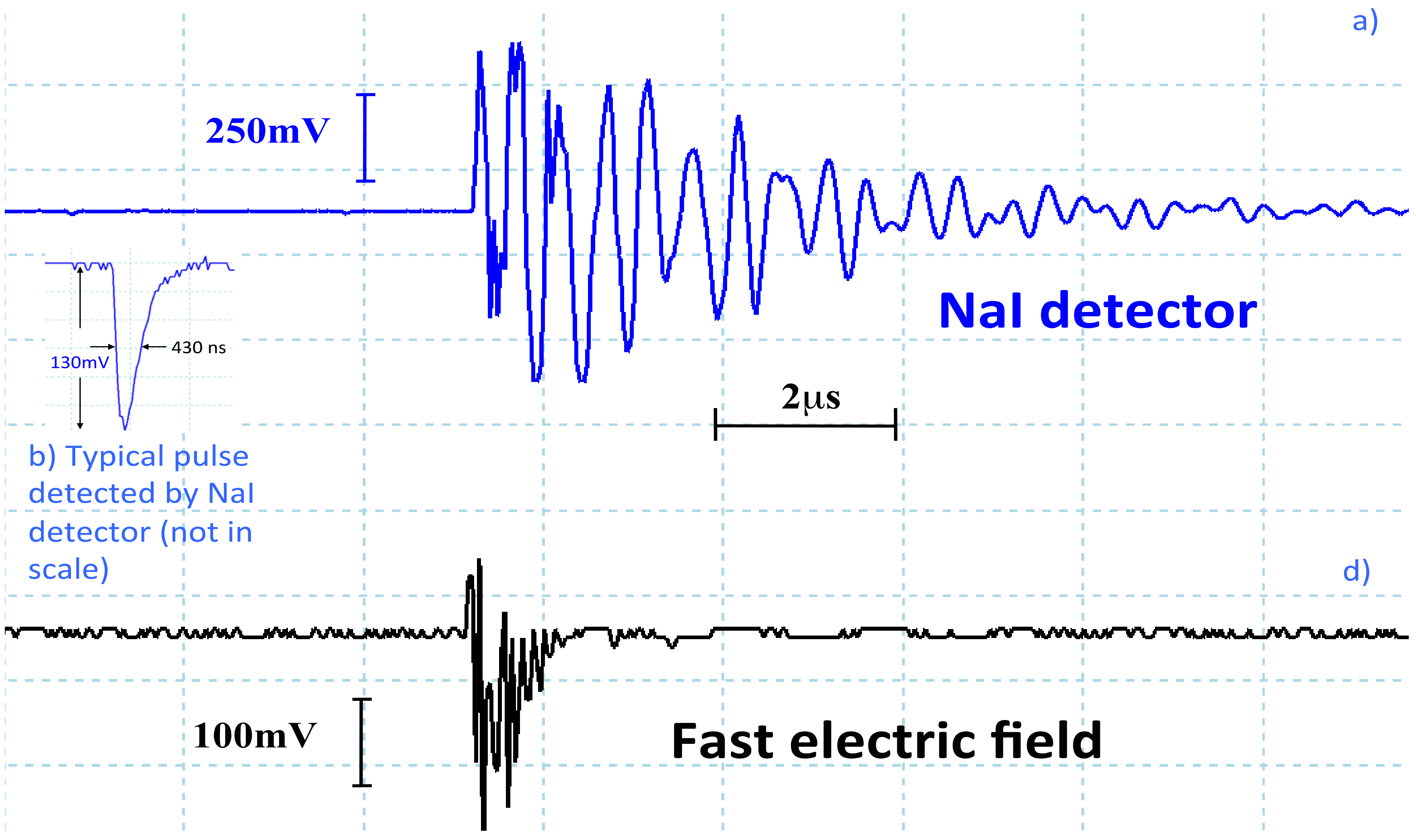


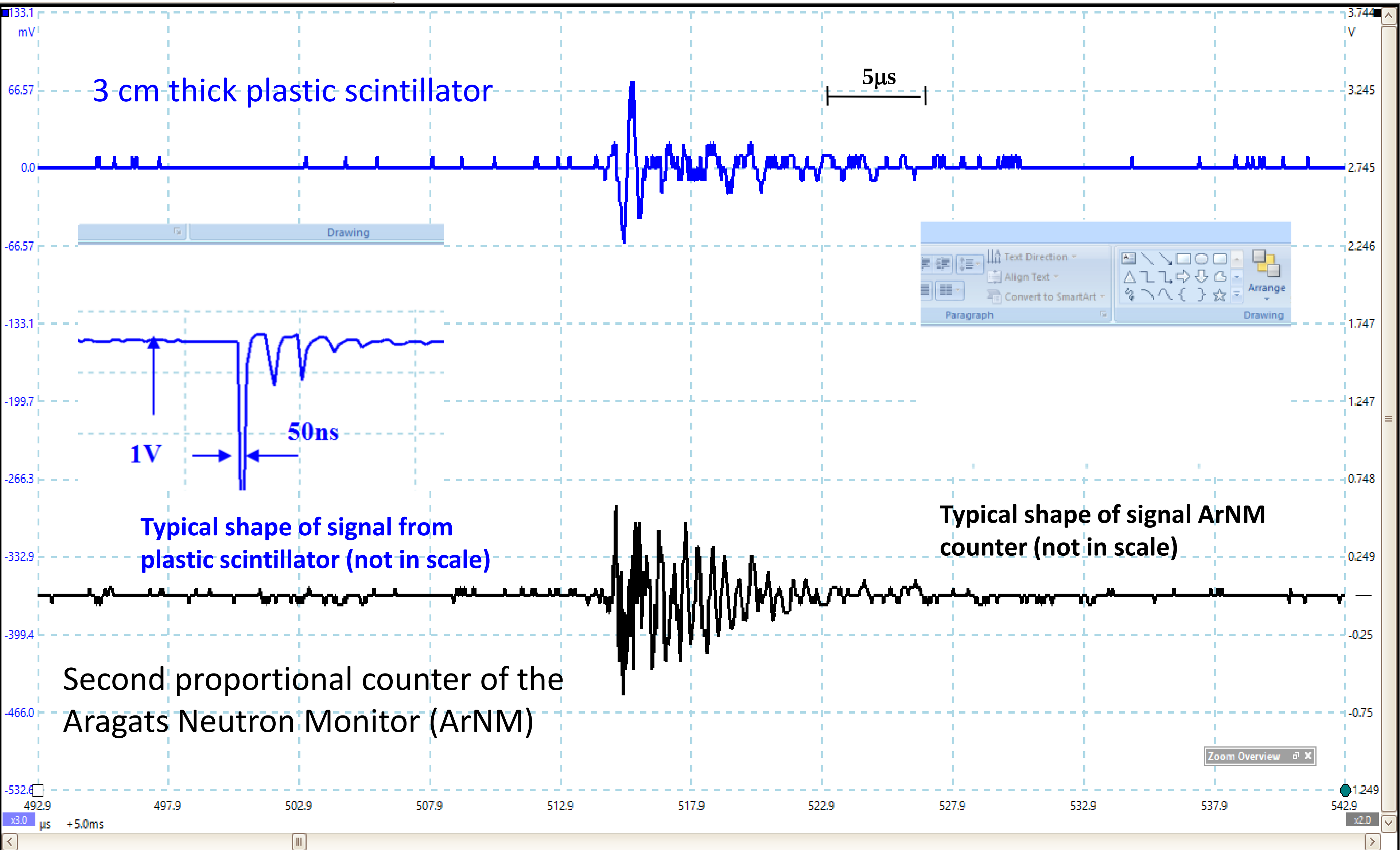


Trigger	Lightning	El.field disturb/ field (kV/m)	El.field disturb/field	Comments
12:09:31.077	12:09:31.188	12:09:31.35/16.5	12:09:31.4/-12.5	positive:29 kV/m in 50 ms
12:11:49.437	12:11:49.540	12:11:49.680/11.3	12:11:49.780/-26.2	positive:38.5 kV/m in 100 ms
12:12:48.928	12:12:48.940	12:12:49.080/4.5	12:12:49.230/-18.5	positive:23 kV/m in 150 ms
12:14:01.765	12:14:01.795	12:14:01.930/-3.5	12:14:02.030/-16	positive: 12.5 kV/m in 100 ms
12:15:18.770	-	12:15:19.030/2.3	12:15:19.230/9.7	negative: 7.4 kV/m in 200 ms no EMI in 3 cm thick scint. SKL

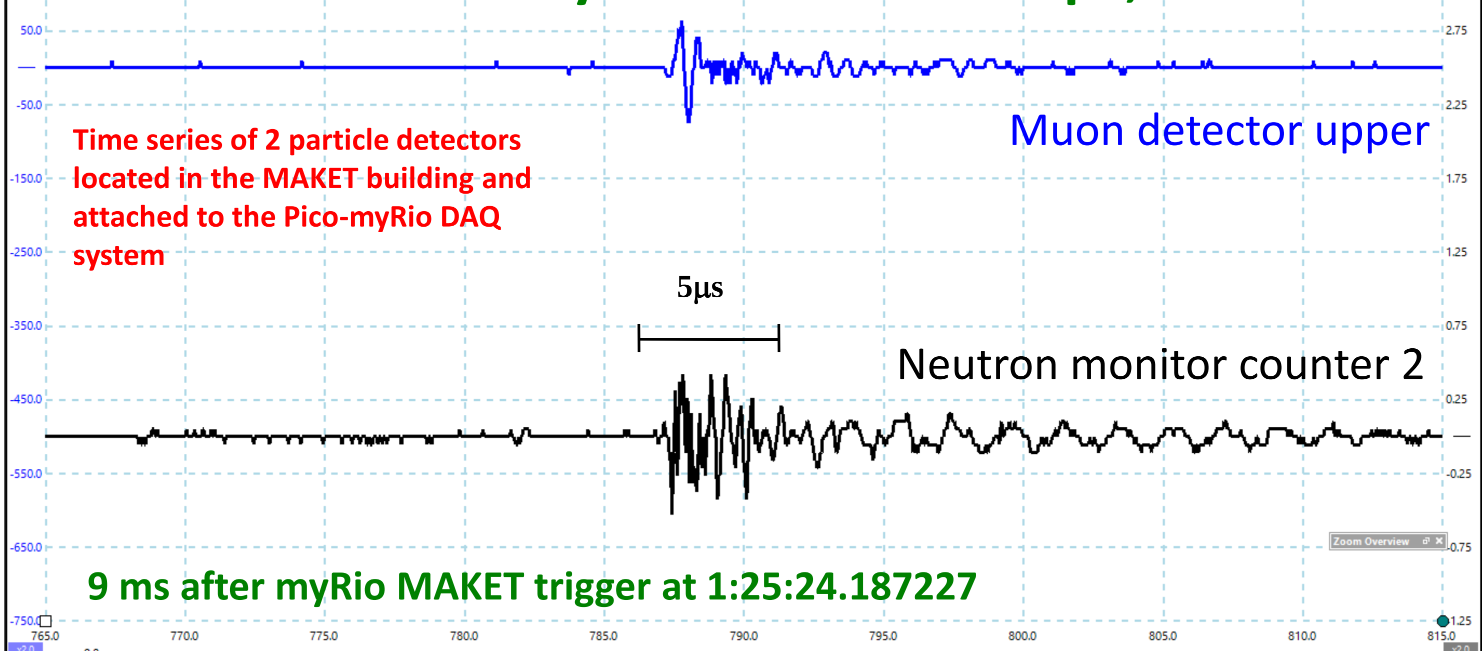


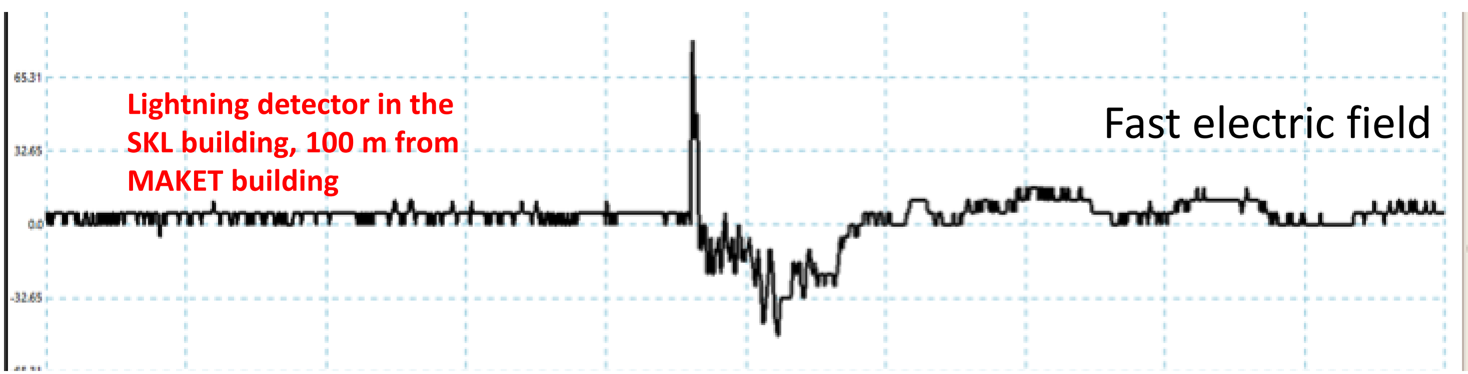
EMI and genuine particles response



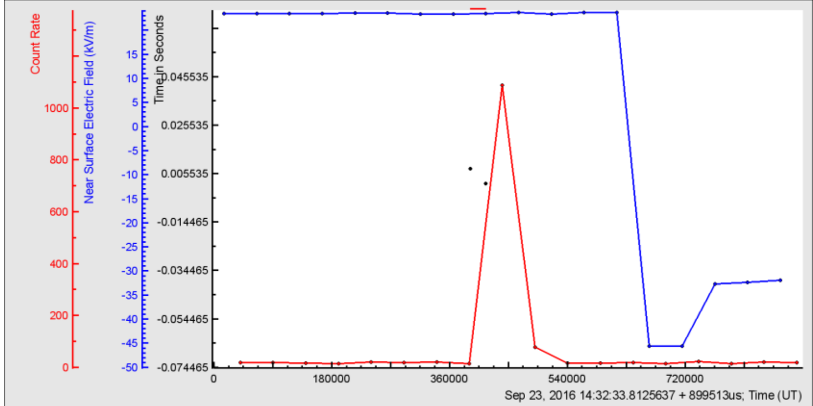

3 cm thick plastic scintillator
5μs
1V
50ns
Typical shape of signal from plastic scintillator (not in scale)
Typical shape of signal ArNM counter (not in scale)
Second proportional counter of the Aragats Neutron Monitor (ArNM)
mV
V
μs
+5.0ms

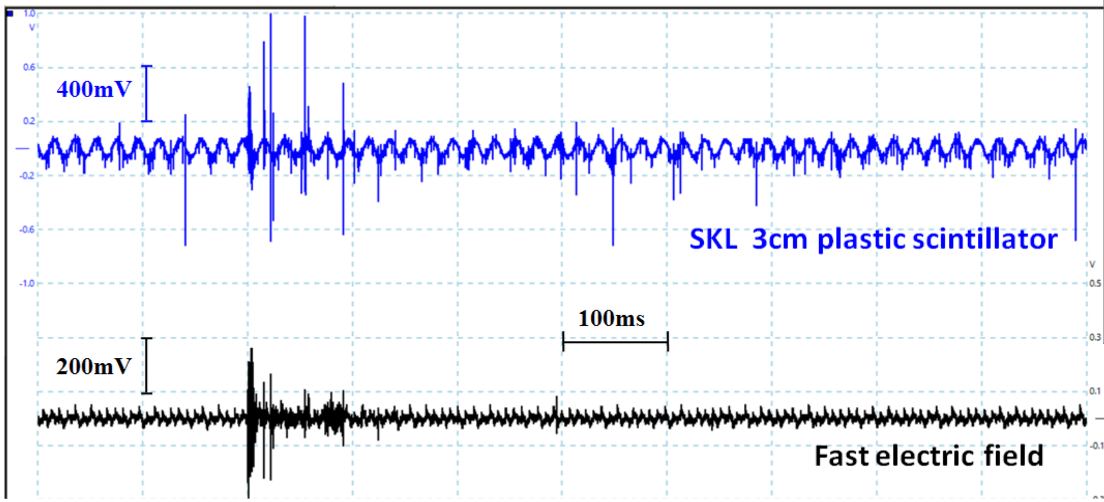
Synchronized time series (Pico files); atmospheric discharge registered in all 3 time series demonstrates synchronization accuracy not worse than 1µs;

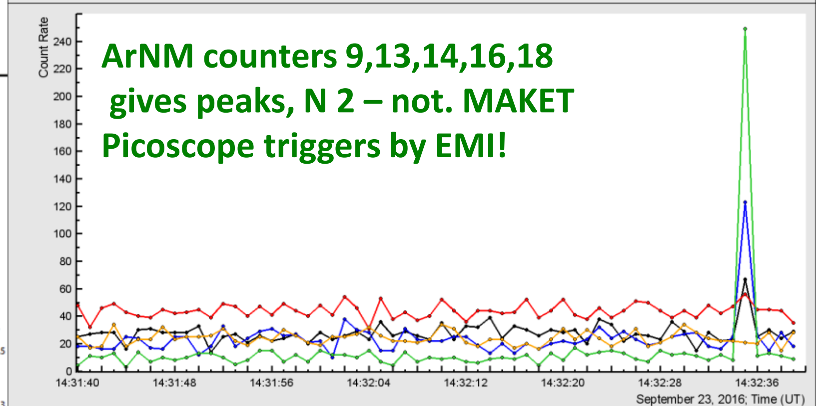




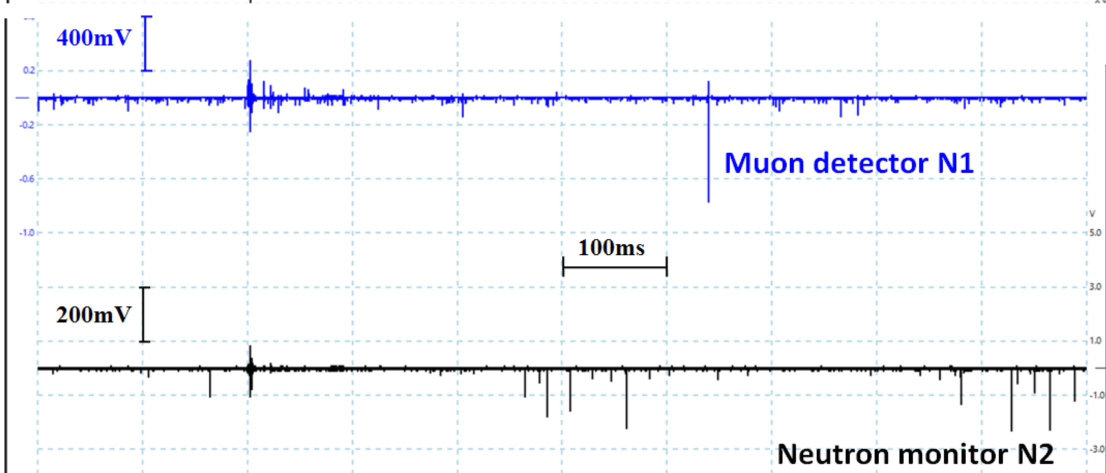
Trigger	CG+ or IC-	El.field disturb/ field (kV/m)	El.field disturb/field	Comments
14:32:34.204	14:32:34.254	14:32:34.430/23.3	14:32:34.480/45.2	positive: 68.5 kV/m in 50 ms; huge EMI, dist 7.8 km
14:35:08.252	14:35:08.308	14:35:08.481/30.5	14:35:08.531	positive: 55 kV/m in 50 ms; huge EMI, dist 9.7 km

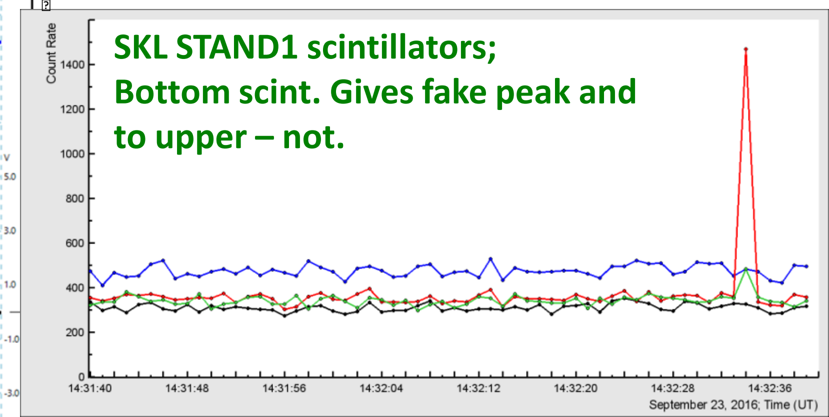




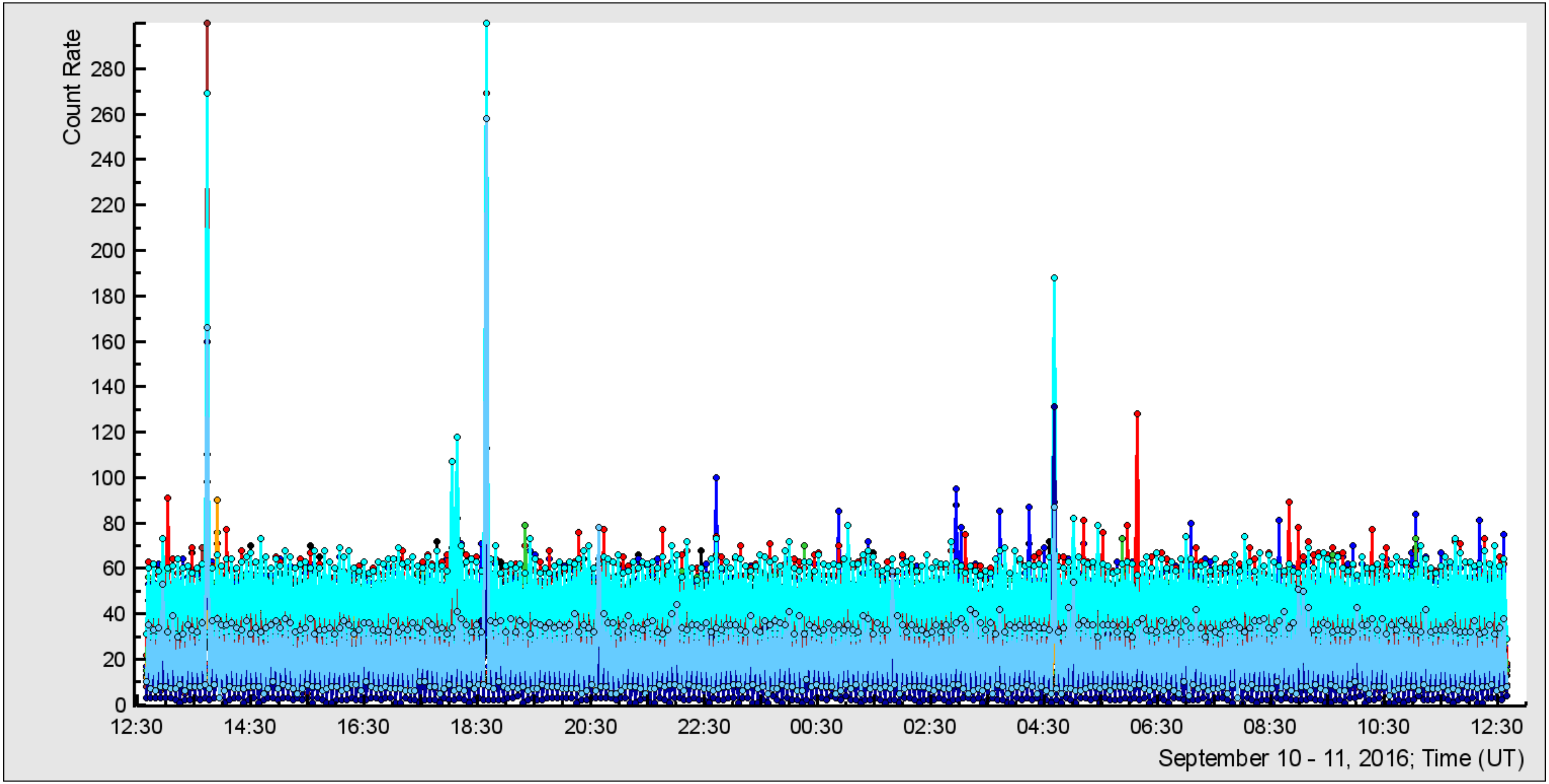


Name	Mean	σ	Min	Max
ArNM #2, dead time 0.4us	26.49	6.38	15 (-1.8σ)	43 (2.59σ)
ArNM #9, dead time 0.4us	25.07	5.51	14 (-2.01σ)	56 (5.61σ)
ArNM #13, dead time 0.4us	22.47	6.03	9 (-2.23σ)	102 (13.18σ)
ArNM #14, dead time 0.4us	43.61	4.75	35 (-1.81σ)	57 (2.82σ)
ArNM #16, dead time 0.4us	10.58	3.69	5 (-1.51σ)	131 (32.61σ)
ArNM #18, dead time 0.4us	23.32	5.74	13 (-1.8σ)	35 (2.04σ

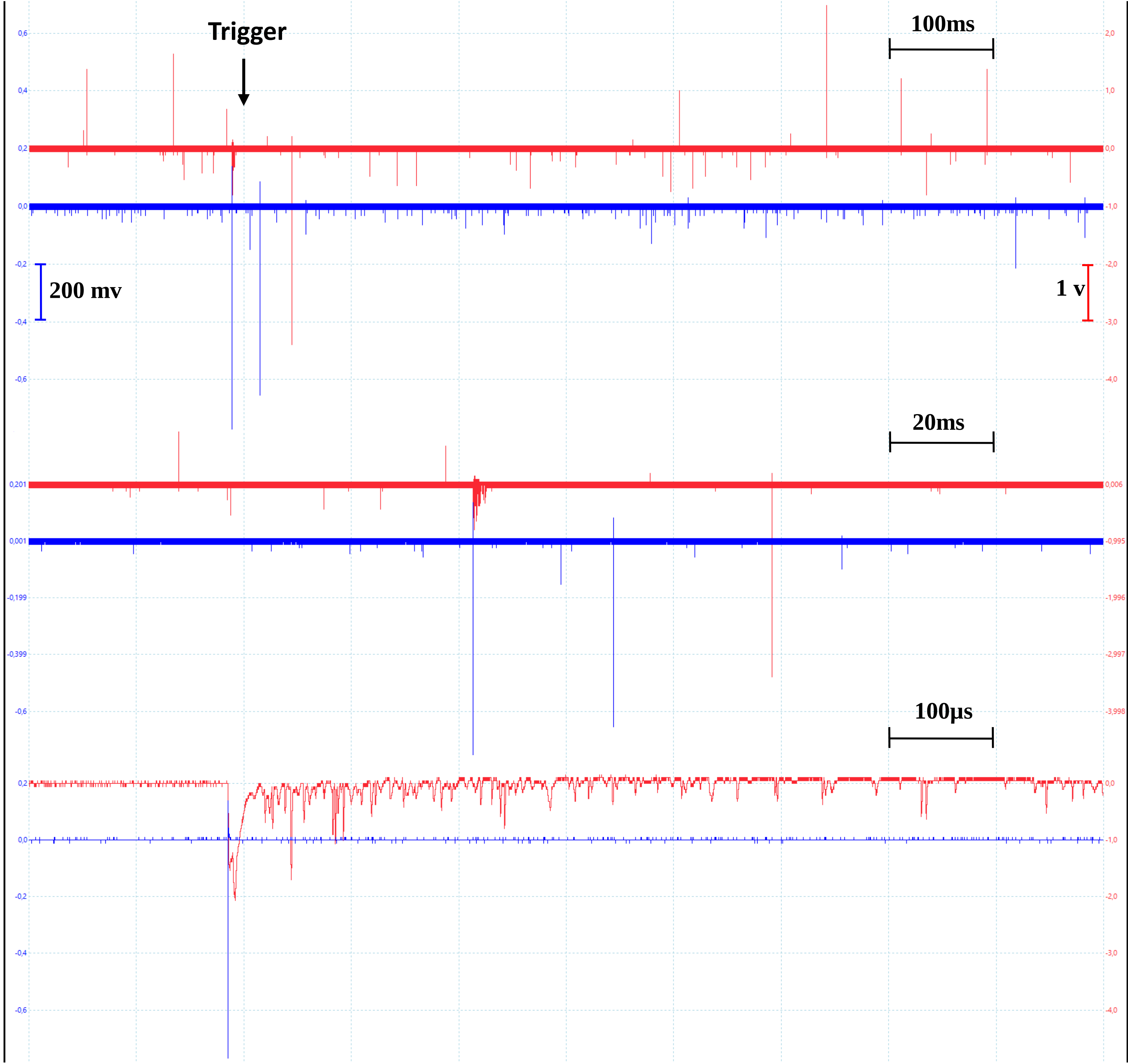




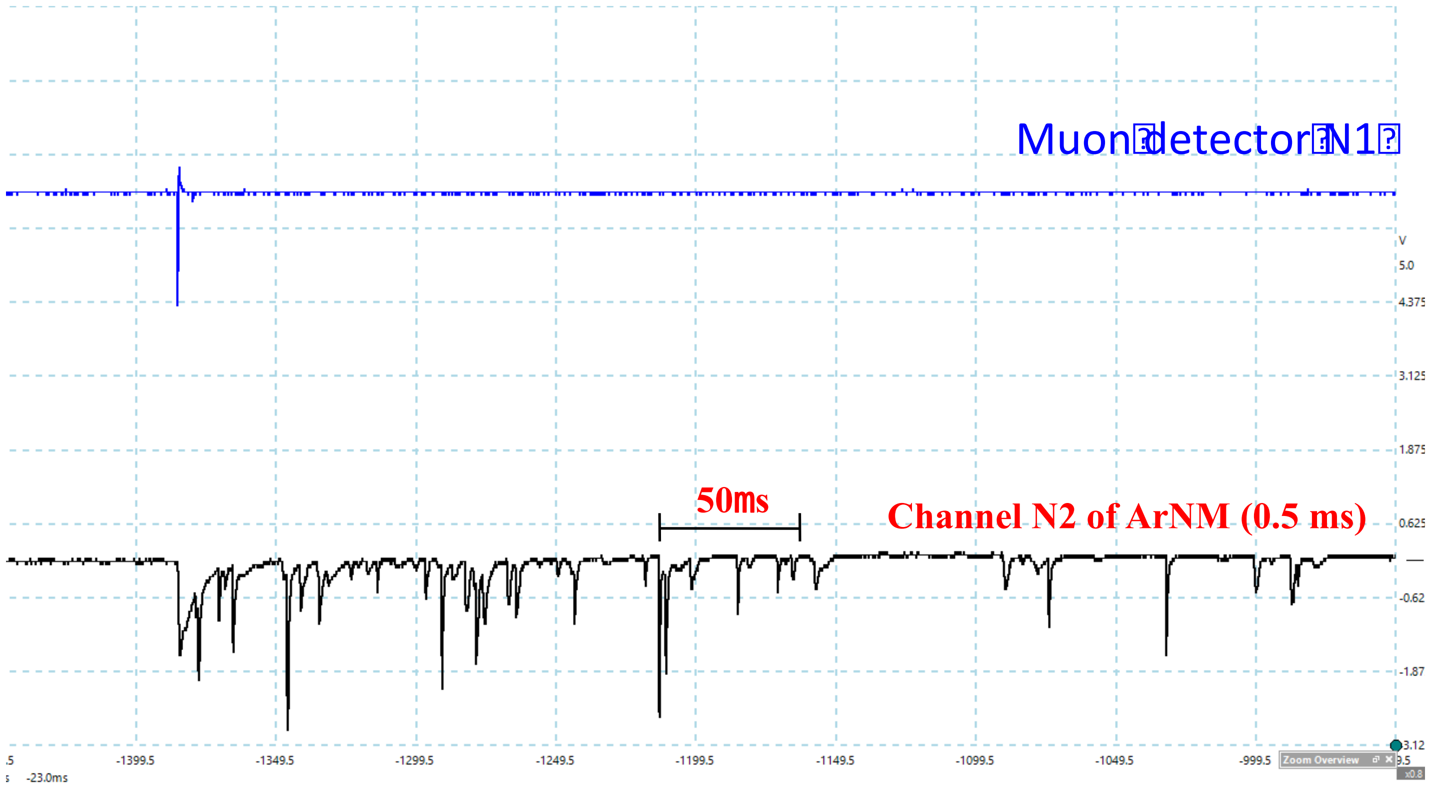
Several EASs detected by Aragats Neutron Monitor

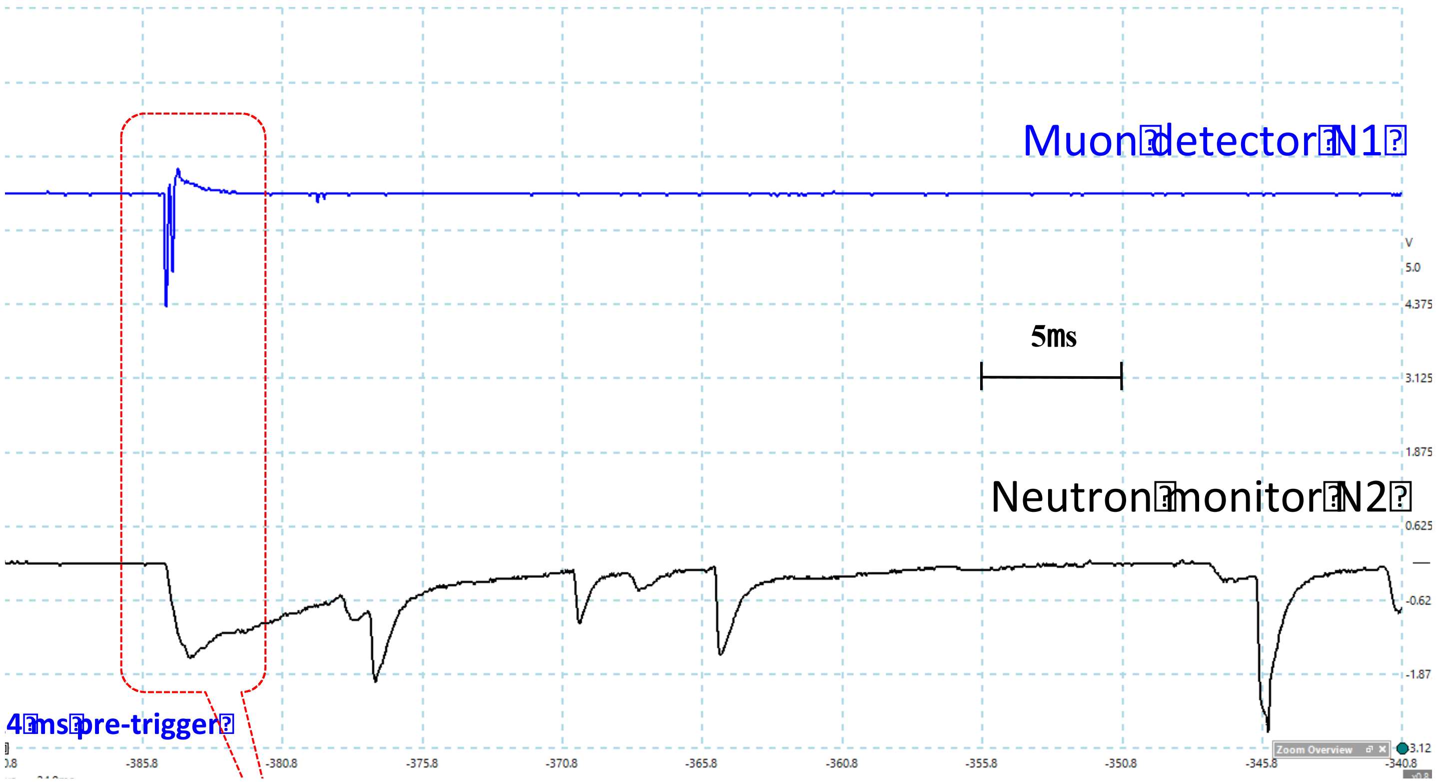


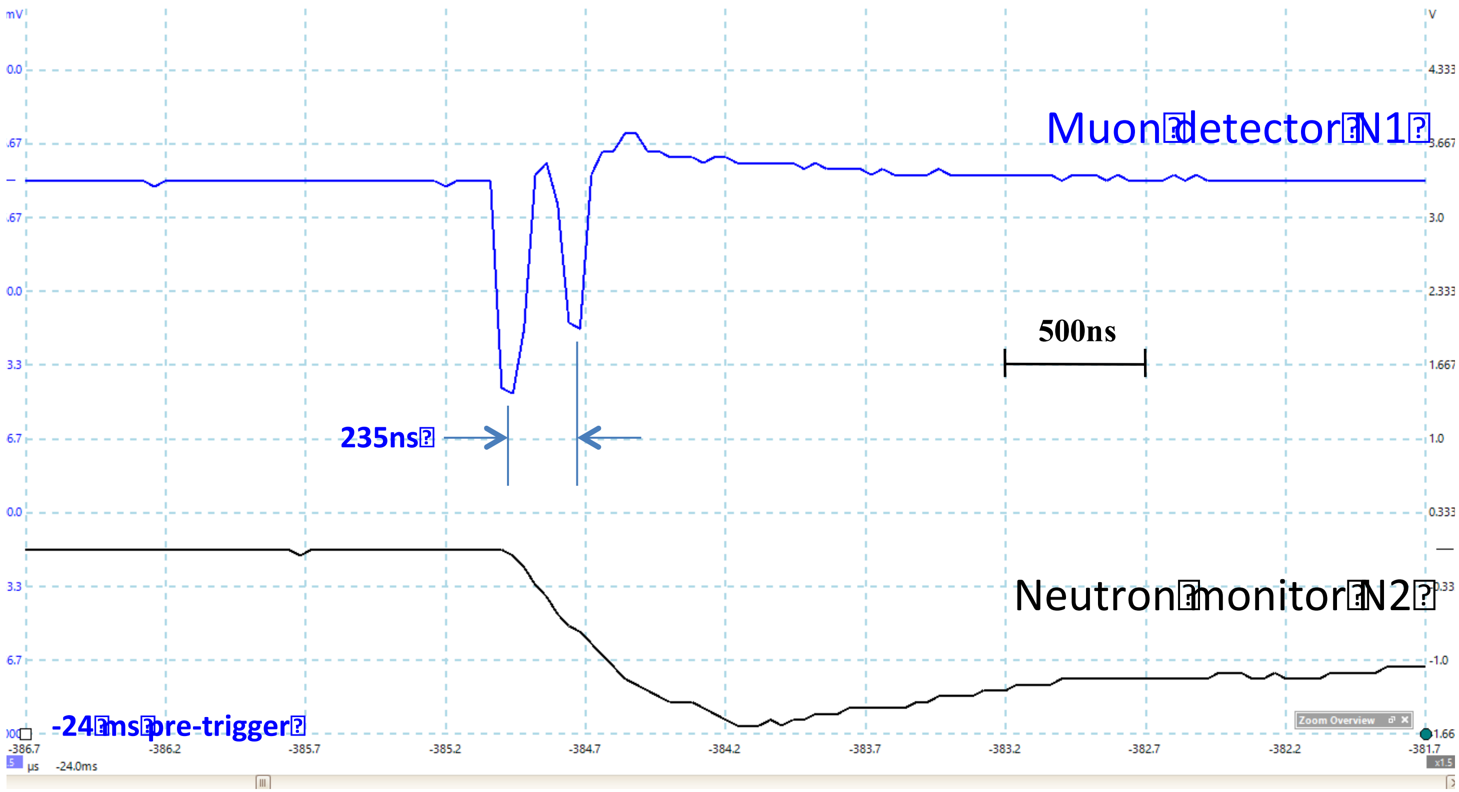
August 10, 2016 10:19:25



A- muon monitor, 1 detector
B- neutron monitor, 9 detector


Muon detector N1
V
5.0
4.375
3.125
1.875
0.625
-0.62
-1.87
3.12
50ms
Channel N2 of ArNM (0.5 ms)
-1399.5
-1349.5
-1299.5
-1249.5
-1199.5
-1149.5
-1099.5
-1049.5
-999.5
-23.0ms
Zoom Overview


Muon detector N1
5ms
Neutron monitor N2
4 ms pre-trigger
V
5.0
4.375
3.125
1.875
0.625
-0.62
-1.87
3.12
-385.8
-380.8
-375.8
-370.8
-365.8
-360.8
-355.8
-350.8
-345.8
-340.8
Zoom Overview


Muon detector N1
500ns
235ns
Neutron monitor N2
-24 ms pre-trigger

Lightnings and particle fluxes

- During numerous thunderstorm on Aragats there were no particles fluxes registered simultaneously with lightnings;
- Near 20 events were detected when lightning abruptly terminate particle flux from clouds;
- Investigations of pulses from particle detectors and atmospheric discharges prove that all pulses from detectors are electromagnetic interferences (EMI) because:

1. only some of particle detectors show pulses, for instanced in stacked detectors upper scintillators don’t count any peaks and the third bottom detector demonstrate huge peak;
2. all peaks consists from bipolar pulses, pulses from genuine particles have unipolar shape;
3. large EASs hitting neutron monitor generate genuine multiple peaks without any relation to lightning.

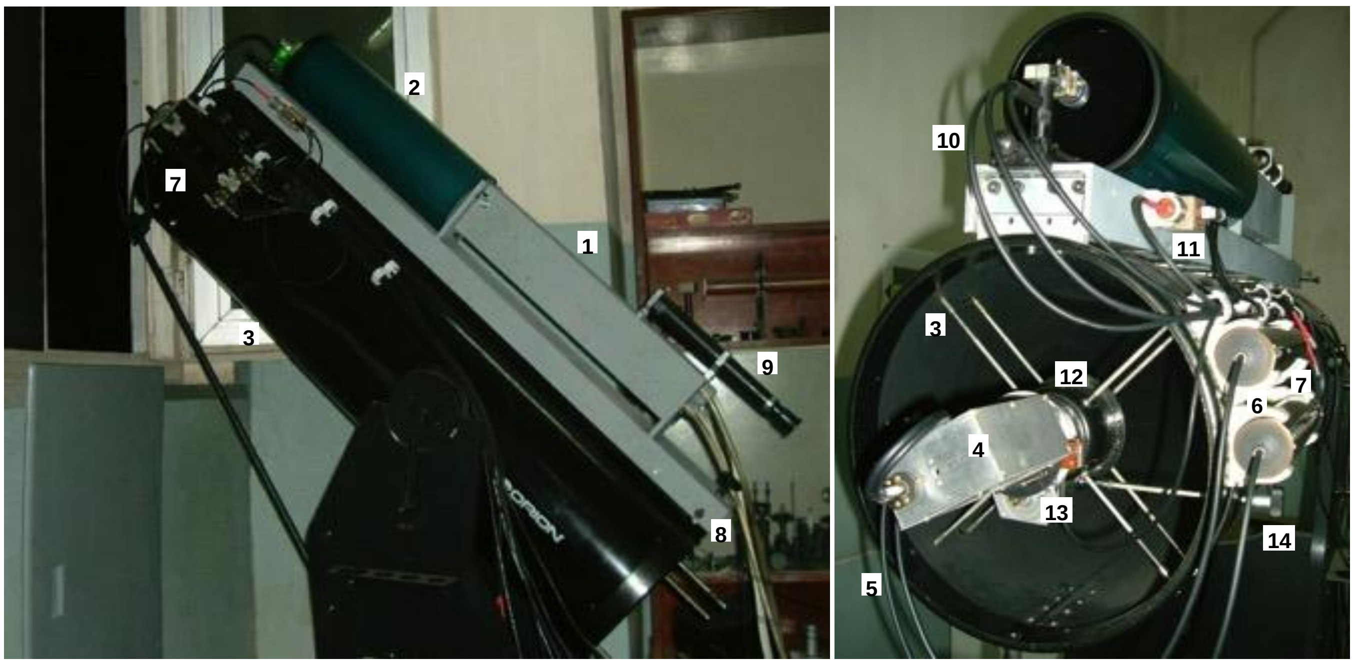
- Only confirmed by fast electronics particle pulses can be accepted as genuine.
- **Observed on Aragats fluxes of electrons, gamma rays and neutrons can be explain with standard RREA + MOS theory with CR electron seeds. Lightnings do not generate high-energy particles!**

TGE and TGF

- TGE and TGF are not processes generated particles, terms are related to the observations and not to mechanism. It is particle registration phenomena on the Earth and in the space. In both cases only RREA/RB process generate particles; To call particle fluxes registered on the Earth's surface TGF is out of logic, they are TGEs!
- We don't need RDFM (Feedback discharge model) for explaining TGE;
- We don't need "cold runaway" injected additional seed electrons for explaining TGE;
- Duration of the particle flux is not essential it is only long or short superposition of very brief cascades from seed electron (ESC and MRB) in strong electric field inside thundercloud;

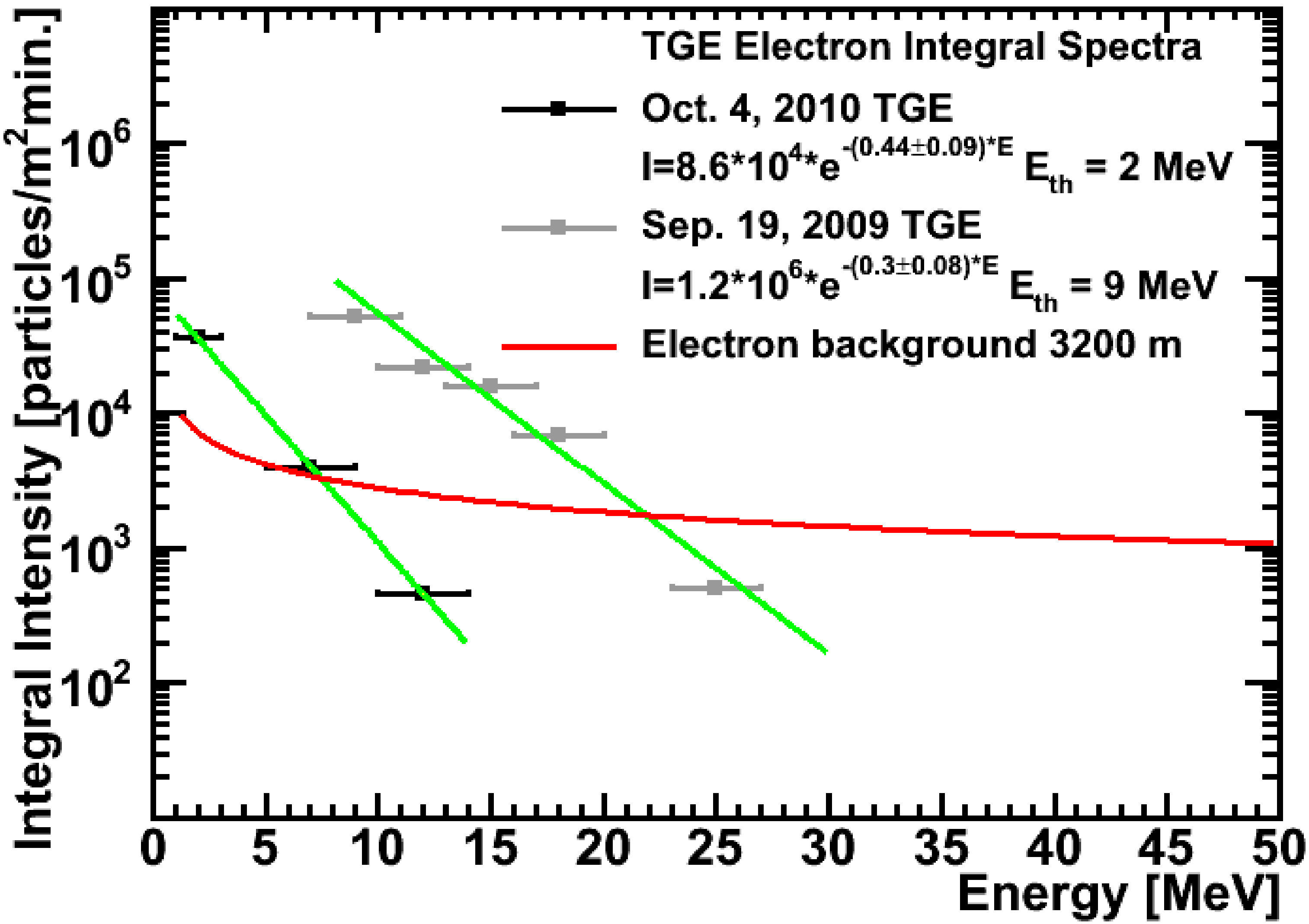
Miscelaneous

Atmospheric Polarization LIDAR System

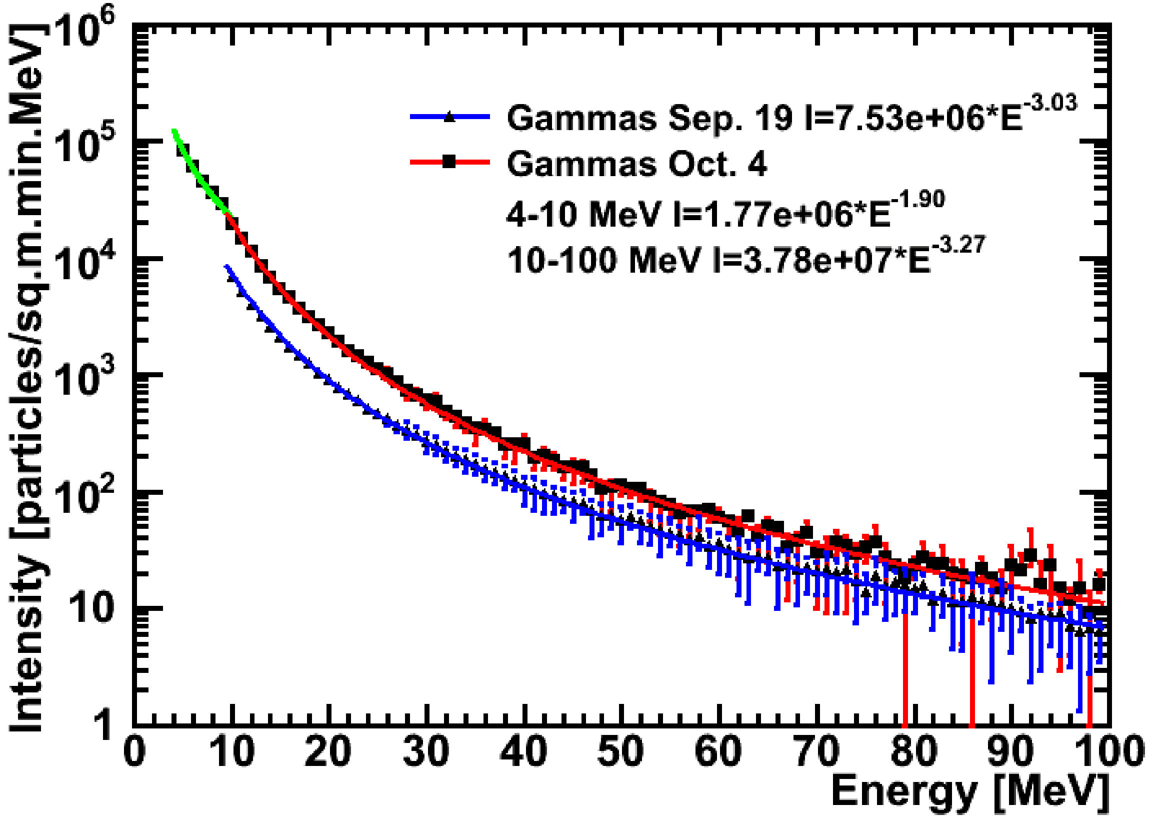


LIDAR (Light Detection And Ranging) system is designed primarily for remote sensing of the atmospheric electric fields. At present, the system is being tuned for measuring vertical atmospheric backscatter profiles of aerosols and hydrometeors, analyze the depolarization ratio of elastic backscattered laser beams and investigate the influence of external factors on the beam.

Electron Integral Energy spectra for 2 largest TGEs

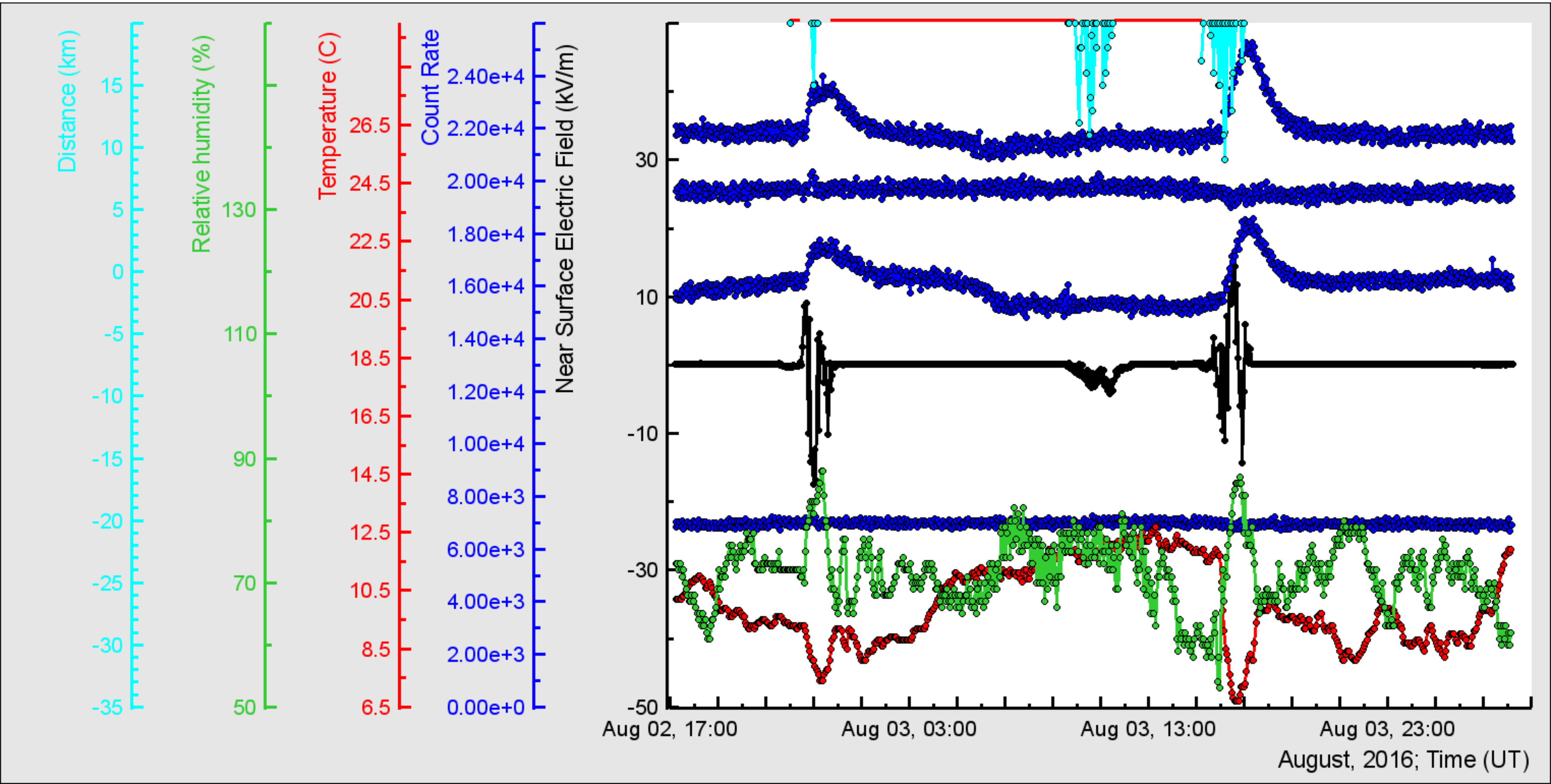


Energy Spectra of RREA gamma-rays: 19 September 2009(blue), 4 October 2010 (green and red)

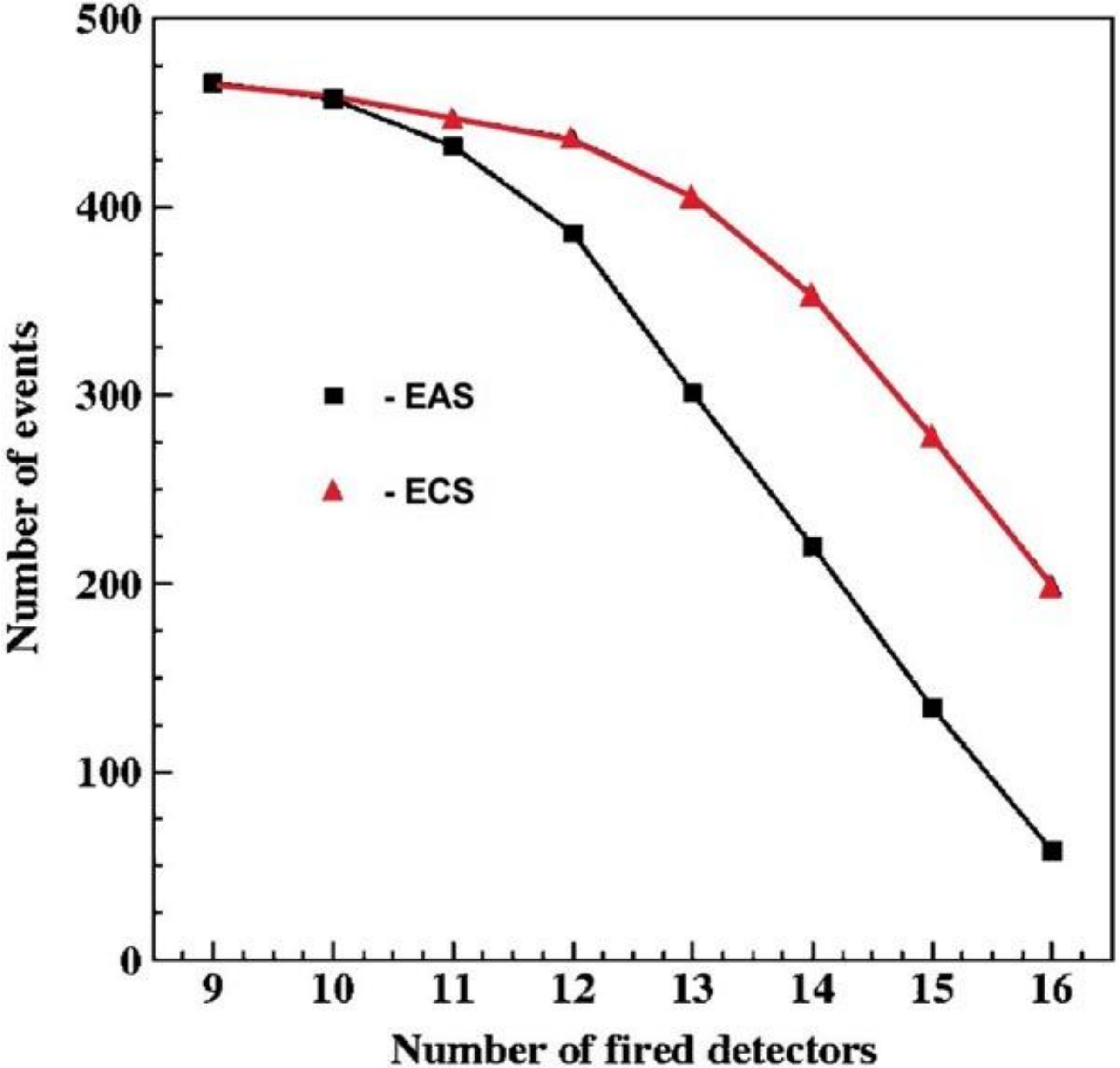


The number of gamma-rays is ~100,000 and ~40,000 particles/sq.m.min., for the October 4 and September 19 events respectively. For the October 4 TGE, we have recovered the gamma-ray spectrum at energies 5-10 MeV by outdoor Cube detector. The spectrum is harder for low energy gammas -1.9±0.4 and the number of particles 5-10 MeV is 250,000 particles/sq.m.min. Agile :cumulative: -2.7; -0.5

TGE events occur almost every day: they are small because humidity is below 80% and temperature 5-6 degrees; at any TGE humidity go up and temperature down and of course the electric field is in negative domain, rising sometimes from deep negative to positive values.

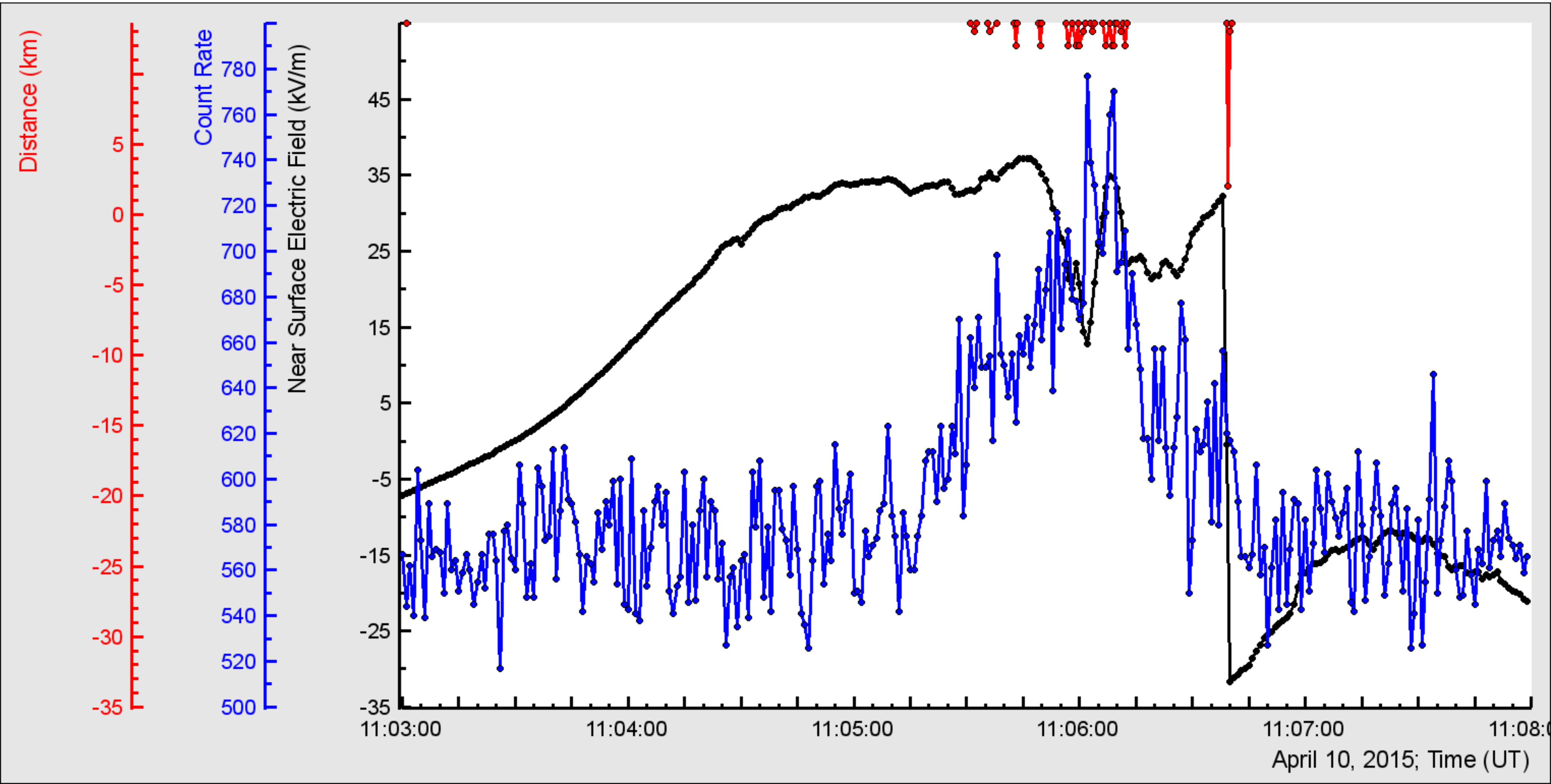


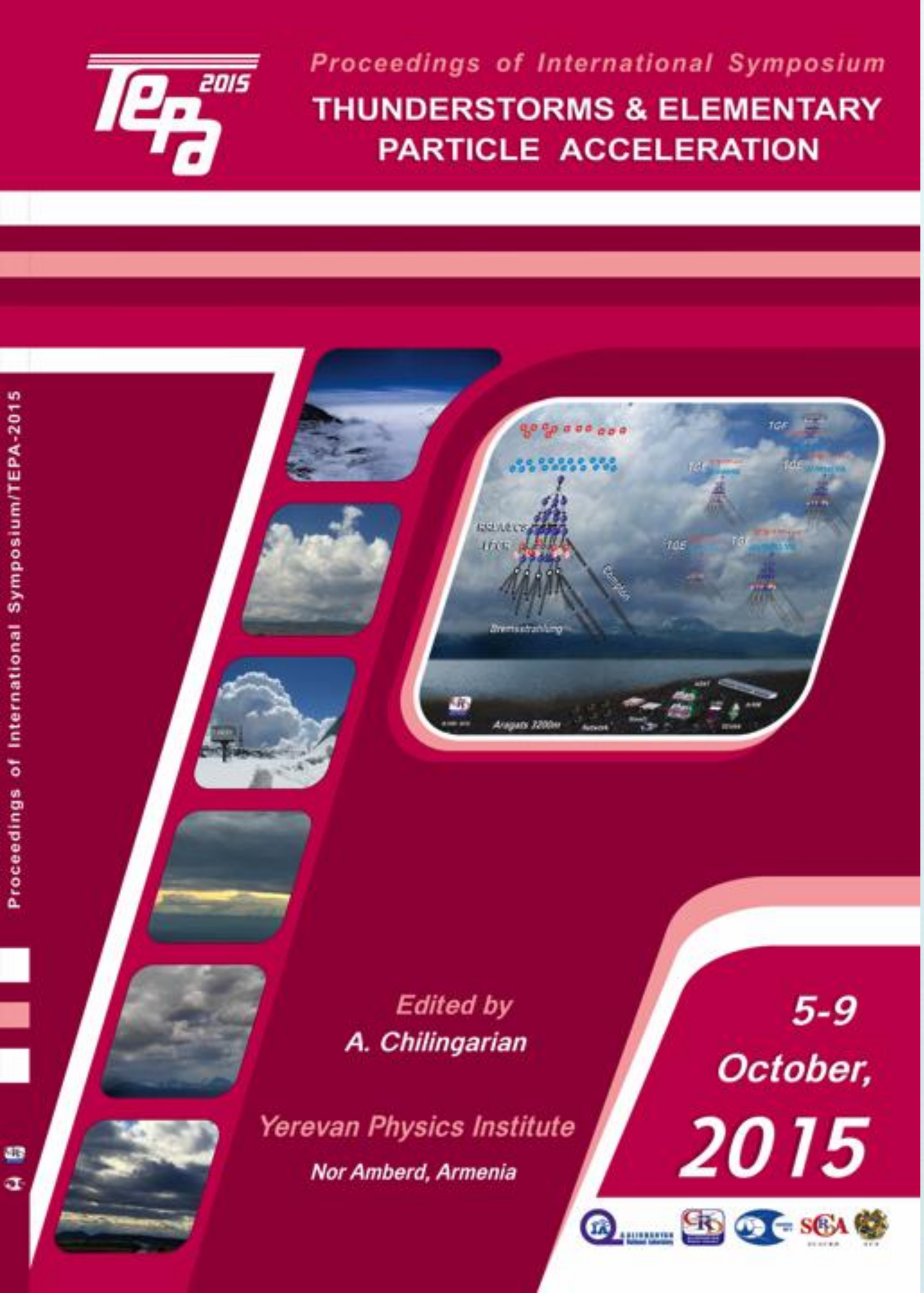
Extensive Cloud Showers (ECS) extended more than Extensive Air Showers (EAS)



An unusual TGE accompanied with the positive nearby lightning. During a short TGE, the near-surface field was in the positive domain (~37 kV/m). The nearby positive lightning (~2 km) at the end of TGE caused the near-surface field to decline from 32 to −31 kV/m.

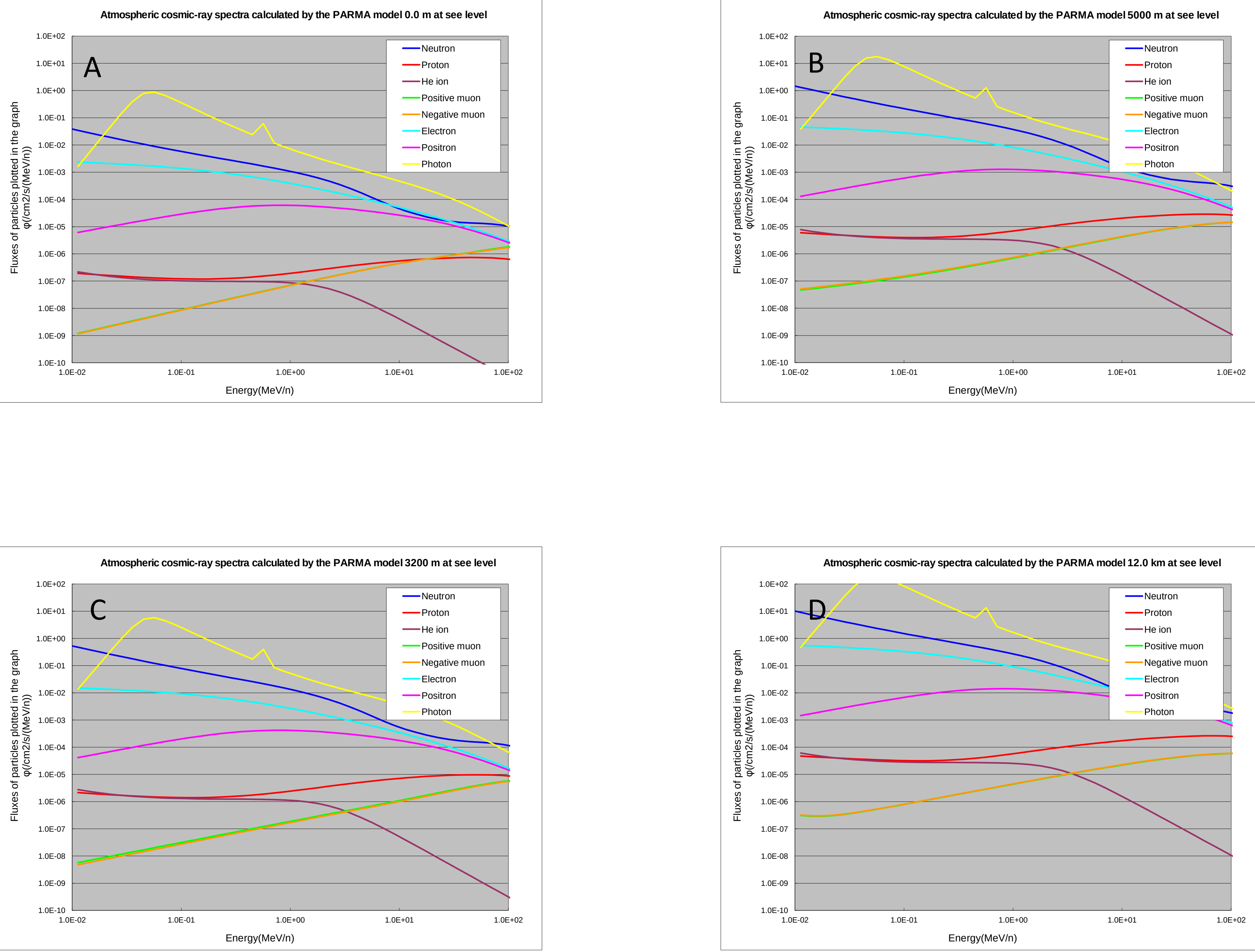
***It is interesting to note that this positive lightning does not terminate the particle flux as the negative ones do*.**



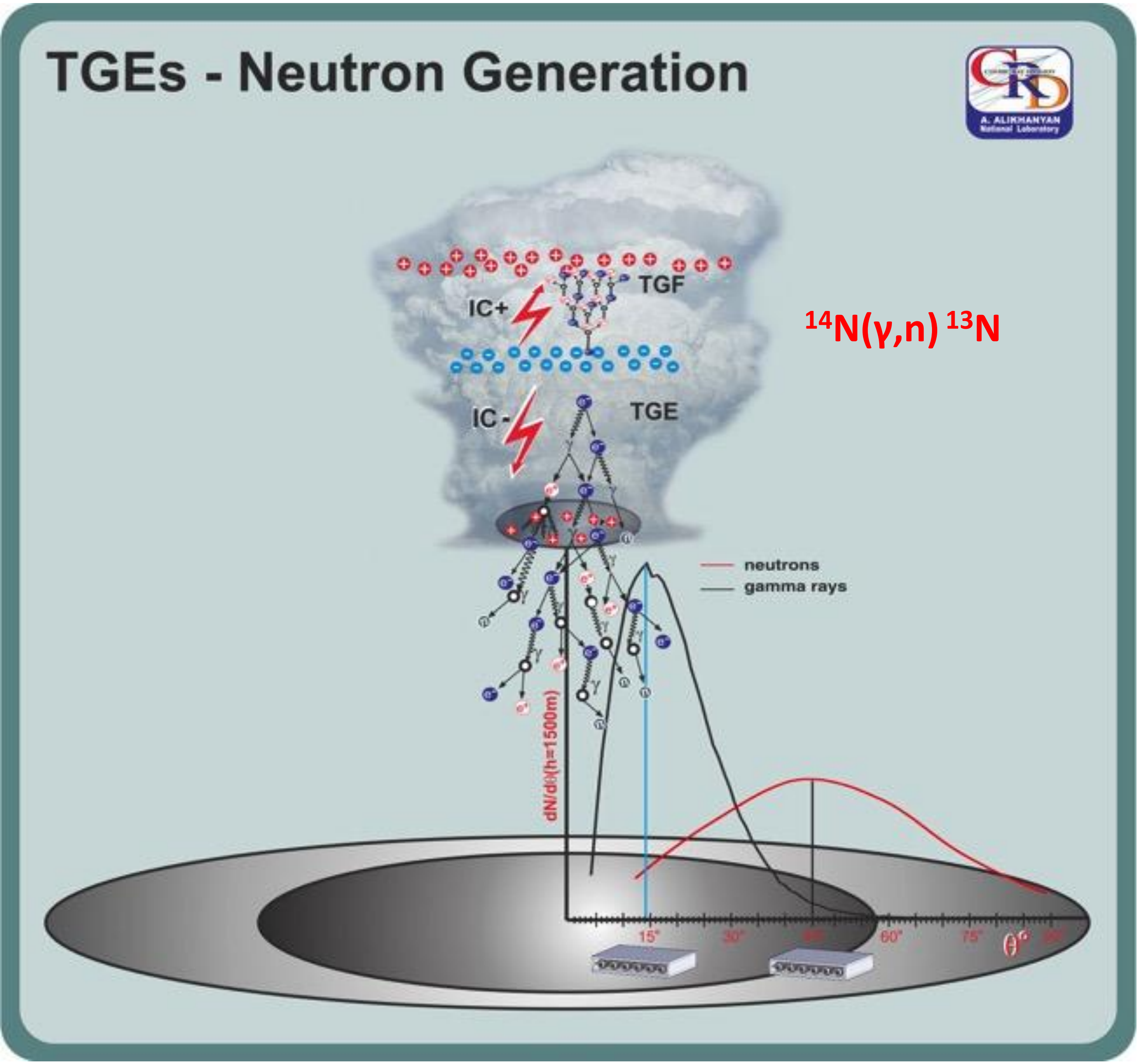

TEPA 2015
Proceedings of International Symposium
THUNDERSTORMS & ELEMENTARY PARTICLE ACCELERATION
Proceedings of International Symposium/TEPA-2015
Edited by
A. Chilingarian
Yerevan Physics Institute
Nor Amberd, Armenia
5-9 October, 2015

Recovered TGE flux intensities (>4 MeV) – May 4, 19:01-19:04

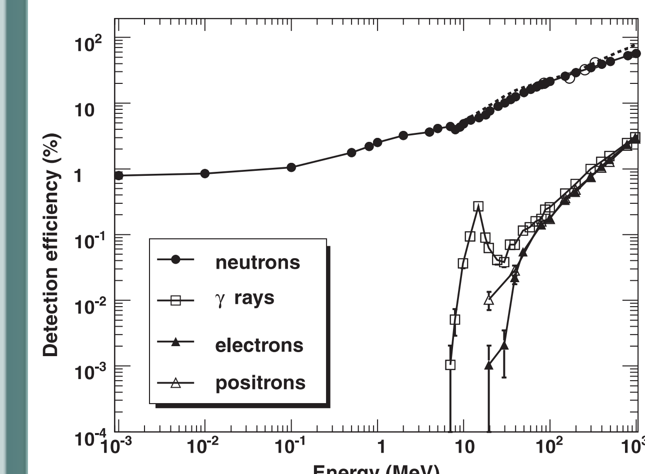
Time	e intensity ($1/m^2min$)	γ intensity ($1/m^2min$)	e/ γ (%)
19:01	288	14452	2.0
19:02	948	22064	4.3
19:03	1240	26336	4.7
19:04	500	17112	2.9


Atmospheric cosmic-ray spectra calculated by the PARMA model 0.0 m at see level
A
Atmospheric cosmic-ray spectra calculated by the PARMA model 5000 m at see level
B
Atmospheric cosmic-ray spectra calculated by the PARMA model 3200 m at see level
C
Atmospheric cosmic-ray spectra calculated by the PARMA model 12.0 km at see level
D
Neutron
Proton
He ion
Positive muon
Negative muon
Electron
Positron
Photon
Fluxes of particles plotted in the graph φ(/cm2/s/(MeV/n))
Energy(MeV/n)
1.0E-10
1.0E-09
1.0E-08
1.0E-07
1.0E-06
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02

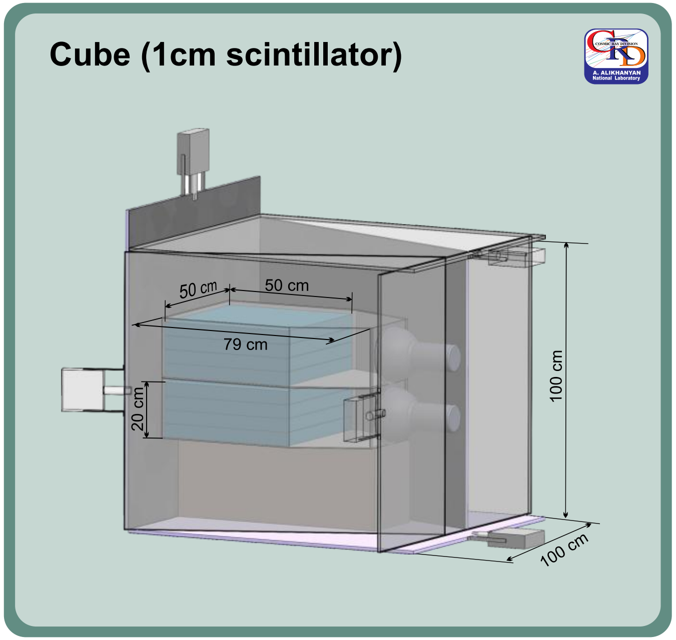
Origin of TGE neutrons (photonuclear reactions: in lead or in atmosphere)



$^{14}N(\gamma,n)\,^{13}N$



Detection efficiency of a NM64 for neutrons, rays, electrons, and positrons, as determined by the GEANT4 simulation.



Recovering of spectra on 27 May, 2014 at 9:03:

$$N(20\text{ cm}) = N_e p(20\text{ cm/e}) + N_g p(20\text{ cm/g})$$

$$N^v(20\text{ cm}) = N_e p^v(20\text{ cm/e}) + N_g p^v(20\text{ cm/g}),$$

$$p(20\text{ cm/e}) = 0.99 \qquad p(20\text{ cm/g}) = 0.2$$

$$p(1\text{ cm/e}) = 0.98 \qquad p(1\text{ cm/g}) = 0.02$$

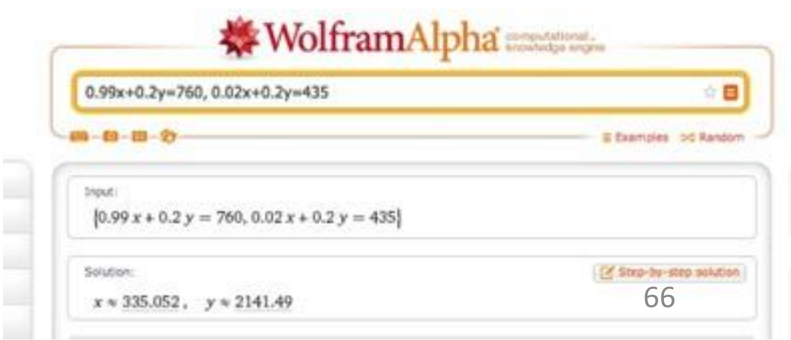
$$p^v(20\text{ cm/e}) = (1\text{-}p(1\text{ cm/e}))p(20\text{ cm/e}) = (1\text{-}0.98)0.99 = 0.0198$$

$$p^v(20\text{ cm/g}) = (1\text{-}p(1\text{ cm/g}))p(20\text{ cm/g}) = (1\text{-}0.02)0.2 = 0.196.$$

Upper
I(e)=91*4 [$1/m^2$min] = 364
I(γ) = 6771*4 = 27084
I(e)/I(γ) = 1.3%

Bottom
I(e)=48*4 [$1/m^2$min] = 192
I(γ) = 3850*4 = 15400
I(e)/I(γ) = 1.2%

http://www.wolframalpha.com/tour/what-is-wolframalpha.html



Characteristics of a sample of a positive lightning occurrences on 28 August 2015 at 12:19 – 12:23

- Mean electric field before the start of the lightning ~ 8-15 kV/m;
- Typical values of the drop of electric field ~ -30 - -40 kV/m.
- After reaching its minimum, the near-surface electric field slowly returned to the pre-lightning values due to continuous charge separation processes in the cloud in 21-31 seconds;
- Time from the start of electric field sharp decrease till its minimum was ~ 0.1 – 0.65 sec;
- Distance to lightning was ~ 3-8 km.

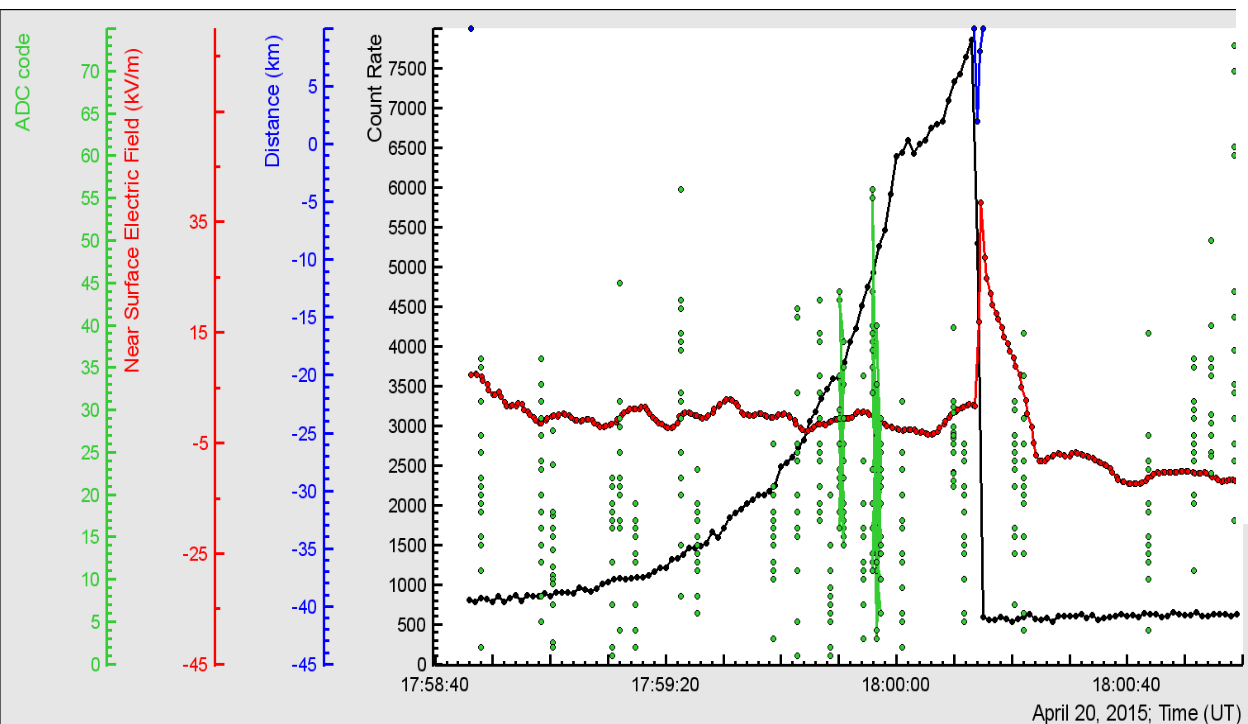
The typical features of the lightning lowering negative charge in the middle layer (-CG or _IC) lightnings terminated TGE are:

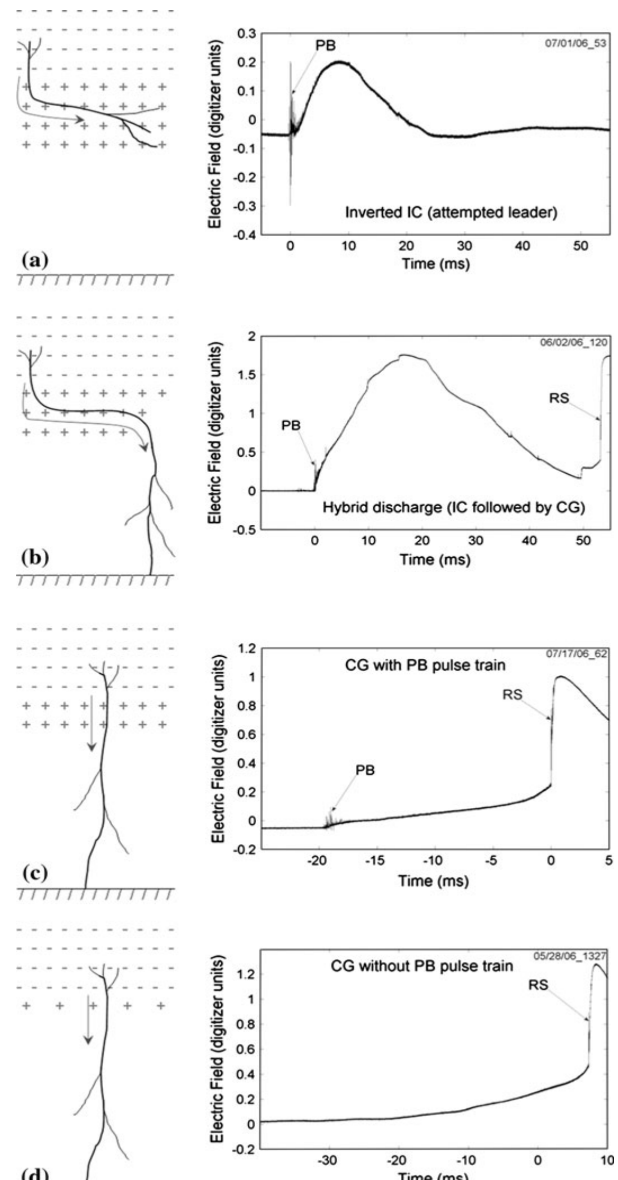
- Mean rise time of the near-surface electrostatic field ~ 242 ± 88 ms;
- Only negative lightnings terminate TGE;
- Lightnings terminate TGE equally on beginning maximum and decay stages;
- Mean field recovery time (FWHM) ~ 4.3 ± 2.3 sec;
- Mean particle flux drop – 37 ± 23%;
- Mean field surge –60 ± 19 kV/m;
- Mean distance to lightning ~ 5.3 ± 2.9 km.

Video: Aragats Lightnings

Video: Aragats Lightnings

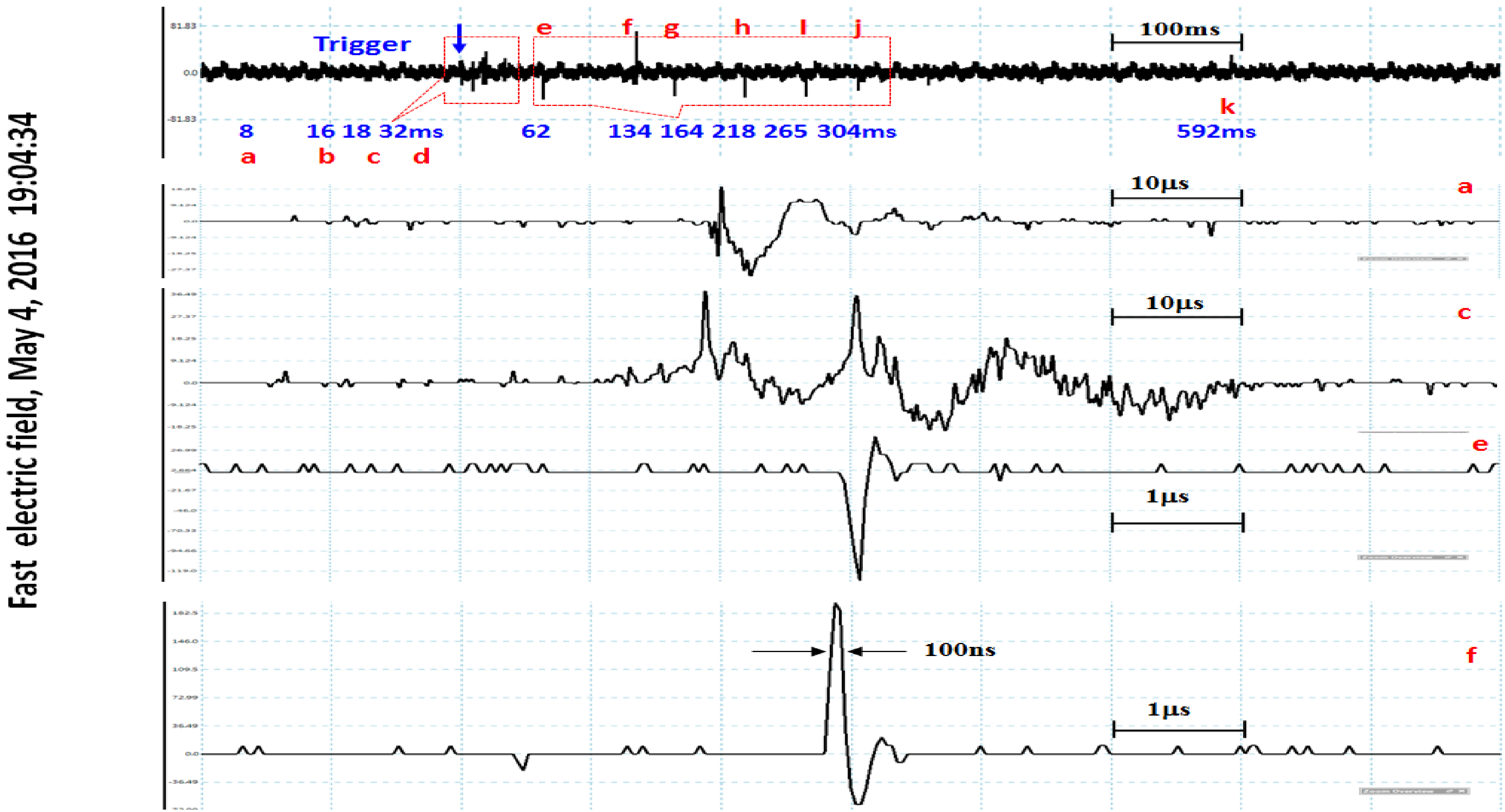
TGE terminated by lightning at the maximum of the flux; red – disturbances of electrostatic field; blue – distance to lightning (~2 km); green small circles are the codes (density of particles) of MAKET-16 array. We expect TGE flux maximum at maximal electric field in cloud and, therefore, at maximal LPCR. Maximal LPCR prevents –CG (Nag and Rakov, 2009); thus we expect TGE termination only on beginning and decaying stages, but we have equal events also at maximum.

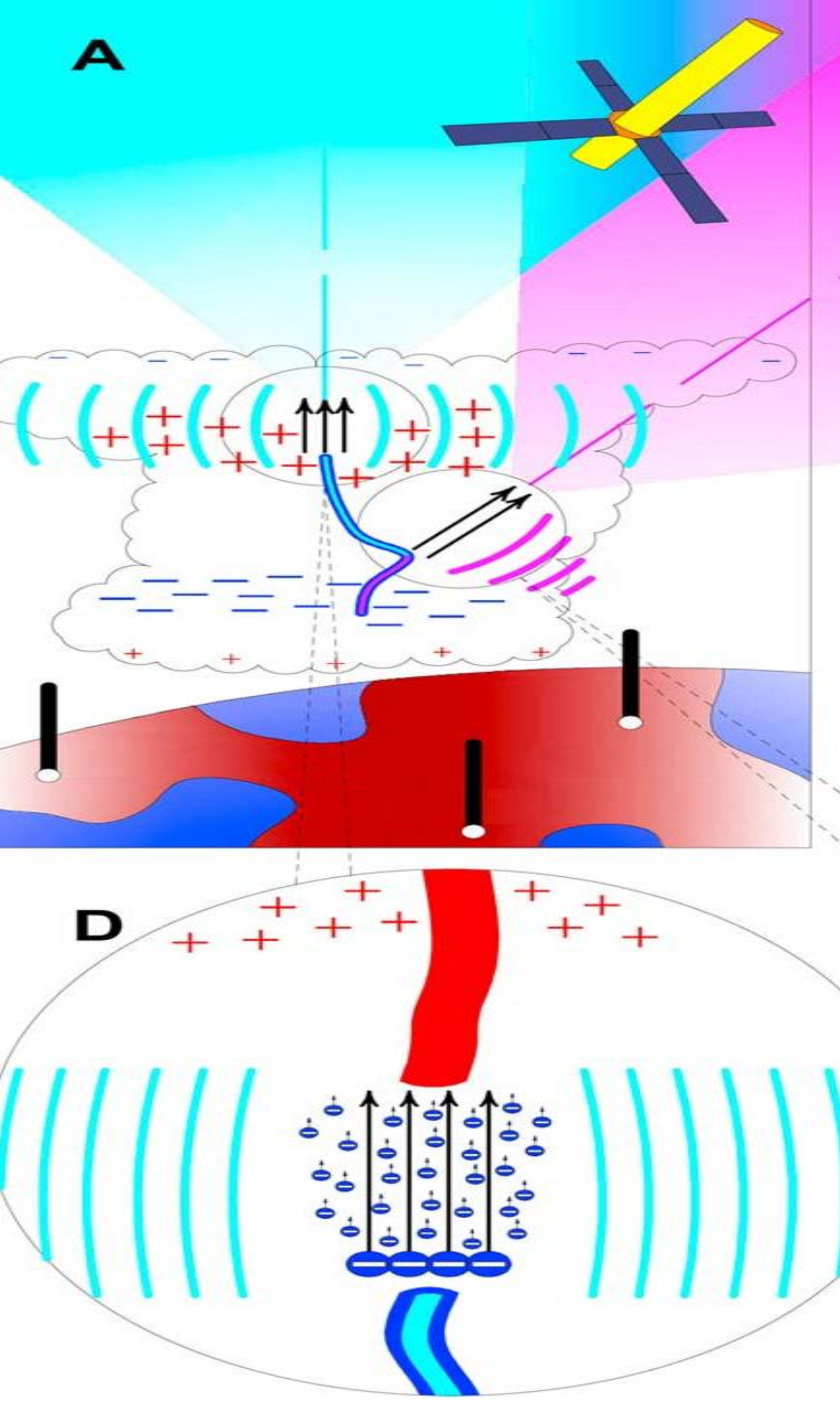


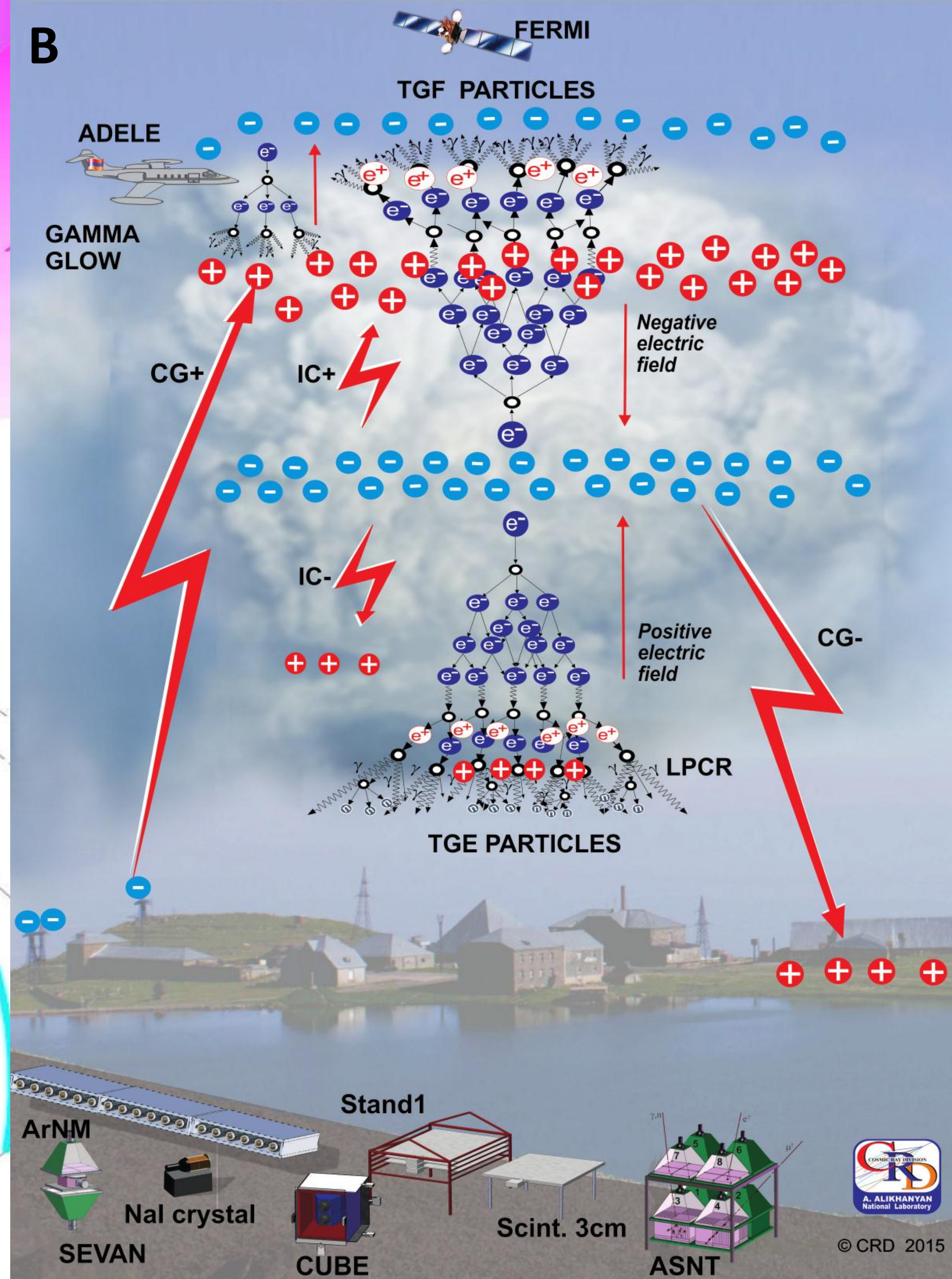


Nag A. and Rakov V. A., 2009. Some inferences on the role of lower positive charge region in facilitating different types of lightning Geophys. Res. Lett., 36, L05815.

Fast electric field waveforms of lightning detected at 19:04:33, May 4,2016




A
D


B
FERMI
TGF PARTICLES
ADELE
GAMMA GLOW
Negative electric field
CG+
IC+
IC-
Positive electric field
CG-
LPCR
TGE PARTICLES
ArNM
Stand1
NaI crystal
SEVAN
CUBE
Scint. 3cm
ASNT
A. ALIKHANYAN National Laboratory
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May 15, 2016, 15:48:25. Zoom of particle detection signal.