MODULATION EFFECTS POSED BY STRONG ATMOSPHERIC ELECTRIC FIELDS ON FLUXES OF SECONDARY COSMIC RAYS

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TEPA 2022 Nor Amberd Prague
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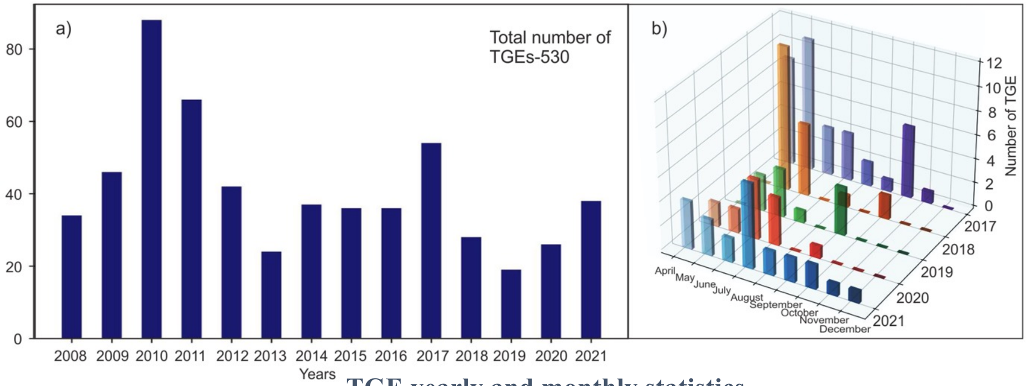
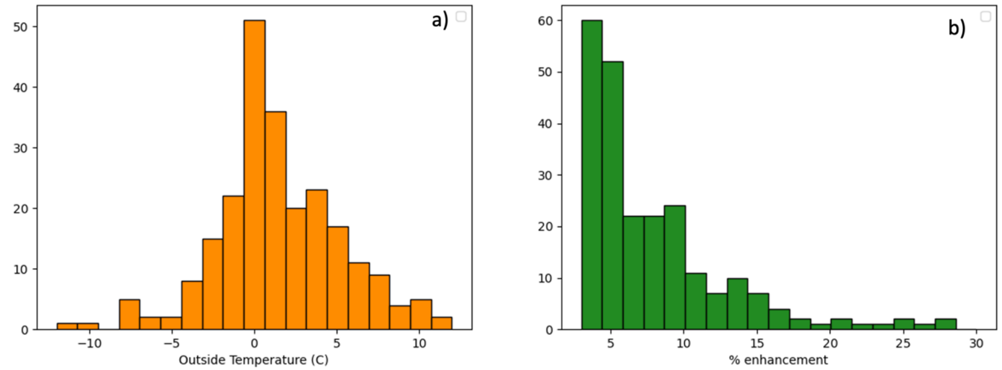
- High energy physics in atmosphere (HEPA): Science goals and objectives
  - **Models of secondary cosmic ray modulation by strong atmospheric electric fields;**
  - **Origination of particle bursts measured on the earth's surface (TGES);**
  - **Vertical and horizontal profiles of the atmospheric electric fields;**
  - **Charge structures in atmosphere supporting the emergence of TGEs;**
  - **Lightning flashes of different energies and types and TLEs and their relation to TGEs;**
  - **Muons: stopping effect;**
  - **Influence of electric fields on EASs: ACTs (MAGIC, HESS, CTA) and high-altitude arrays (HAWK, LHASSO).**
- HEPA: Investigation strategy/techniques
  - **The synergy of Comic Ray physics and Atmospheric physics;**
  - **Continuous monitoring of different species of cosmic rays, electric and geomagnetic fields, lightning locations, meteorological parameters, cloud movements, and TLEs;**
  - **Worldwide networks of identical particle detectors and field meters allowing precise synchronization and mutual analysis of data (Armenian network, East European SEVAN network);**
  - **Electron and gamma ray energy spectra recovering by the scintillation and the NaI crystal spectrometers;**
  - **Possibilities of the online visualization and analysis of the stream of multivariate from hundreds of measuring channels data by the advanced data extraction infrastructure (ADEI platform).**

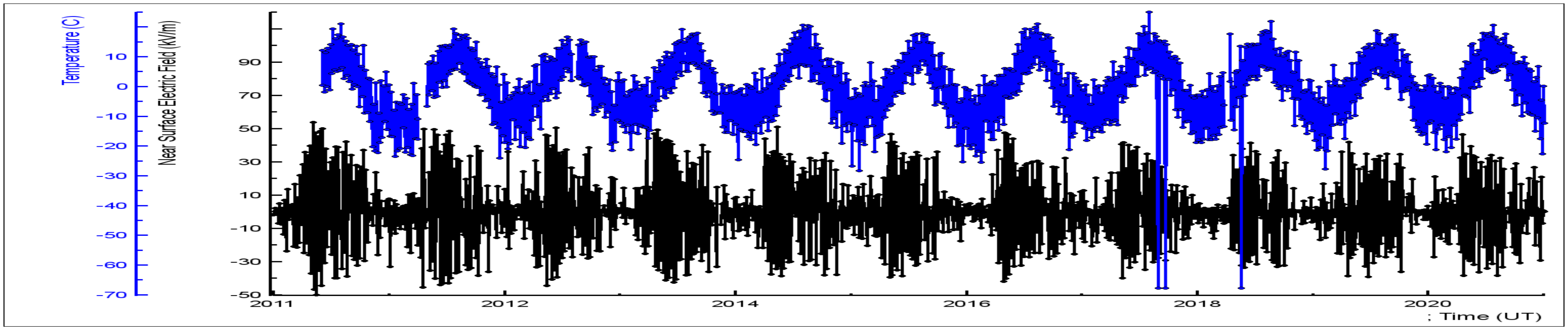
Aragats: TGE statistics ≈600 TGEs registered in 2009-2022



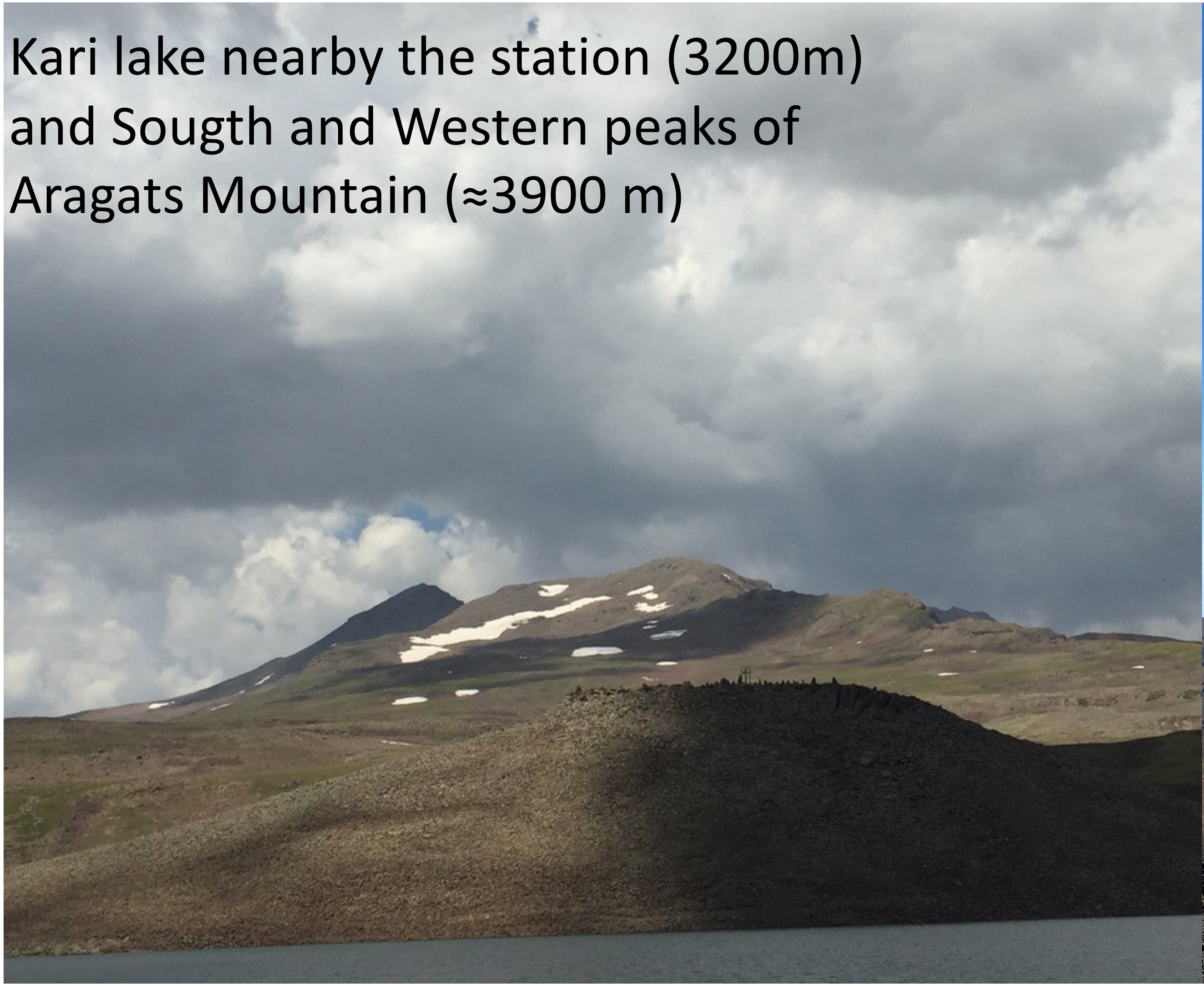
TGE yearly and monthly statistics.

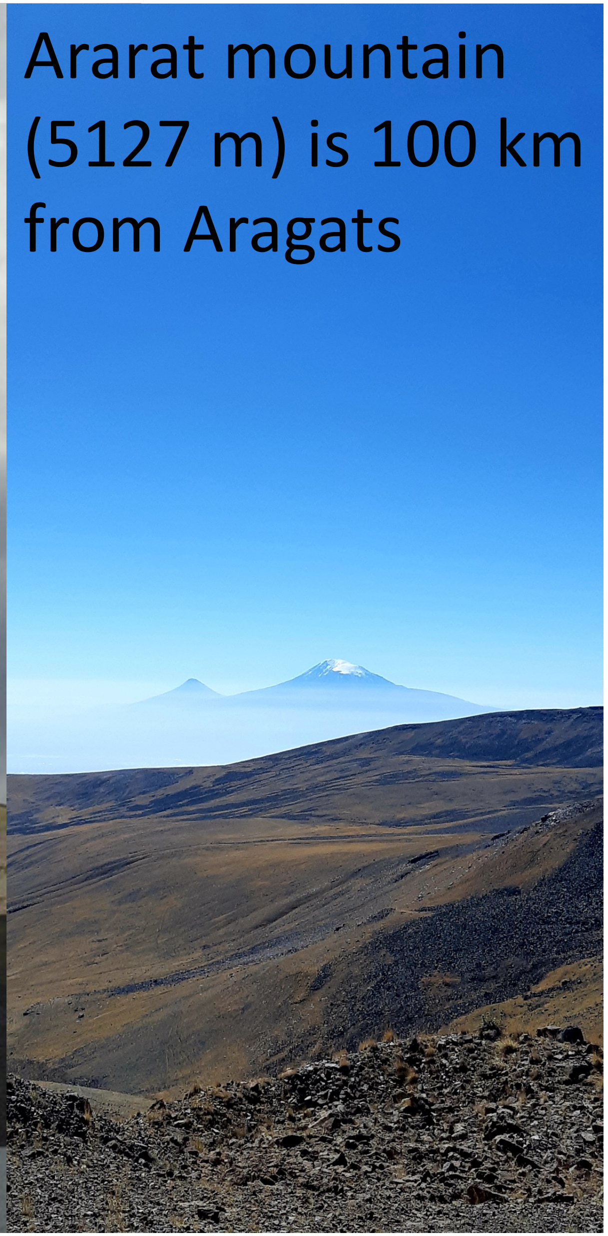


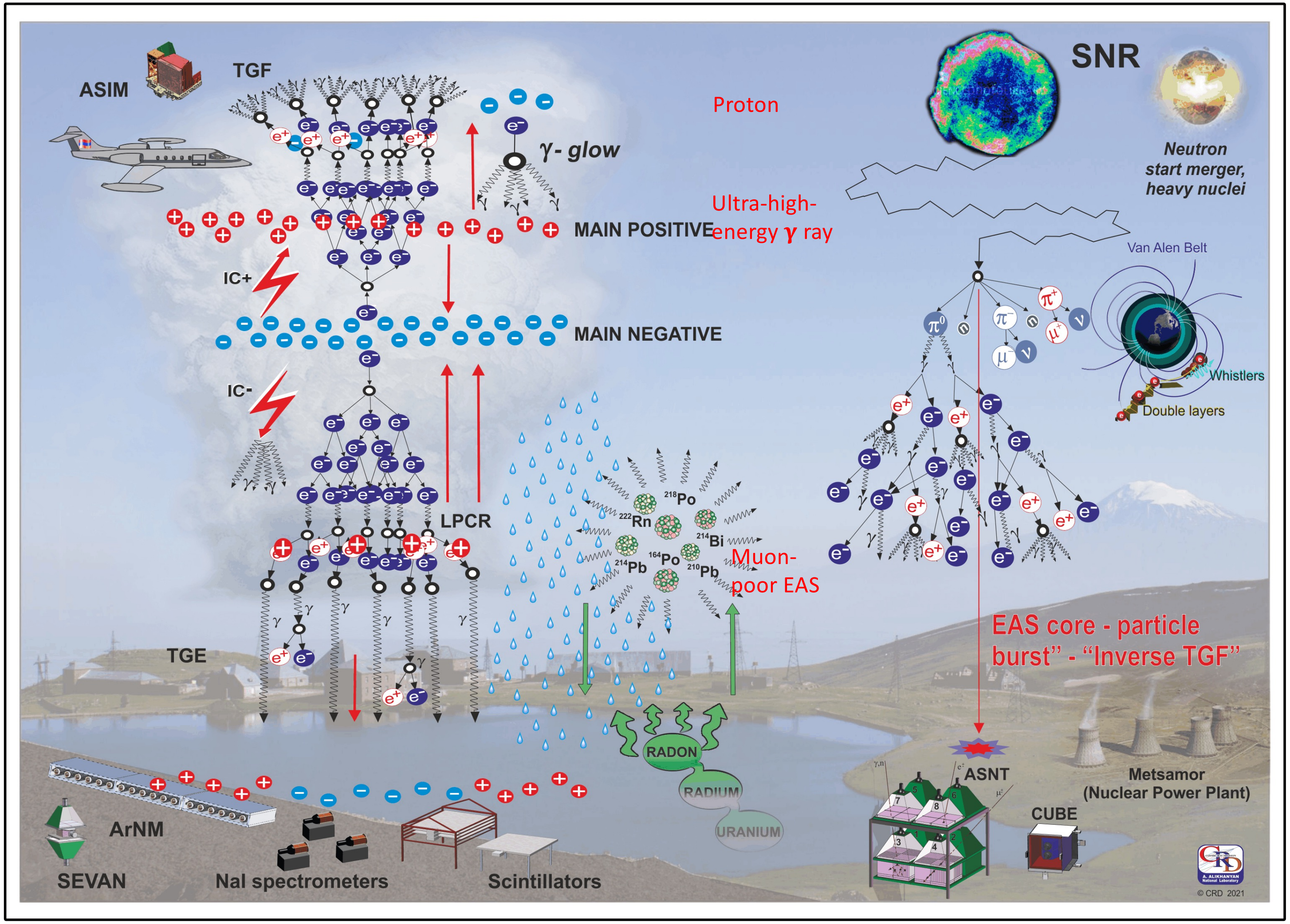
a)The distribution of outside temperatures during TGEs;
b) distribution of TGE significances by 3 cm thick plastic scintillator of STAND3 detector.



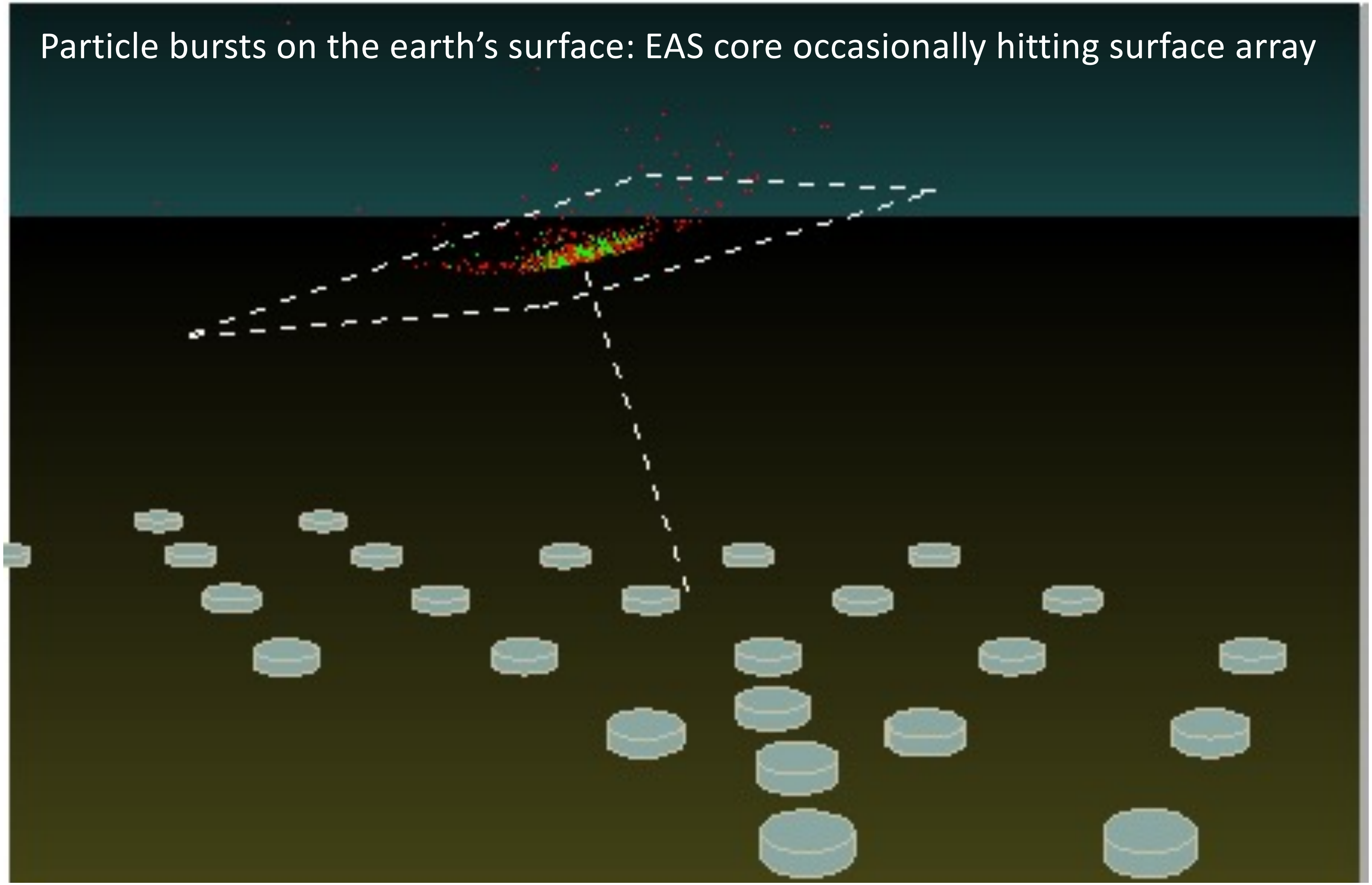
Time series of the NSEF (electric mill EFM-100 by BOLTEK firm, black), and outside temperature (DAVIS weather station, blue)


Kari lake nearby the station (3200m)
and Sougth and Western peaks of
Aragats Mountain (≈3900 m)

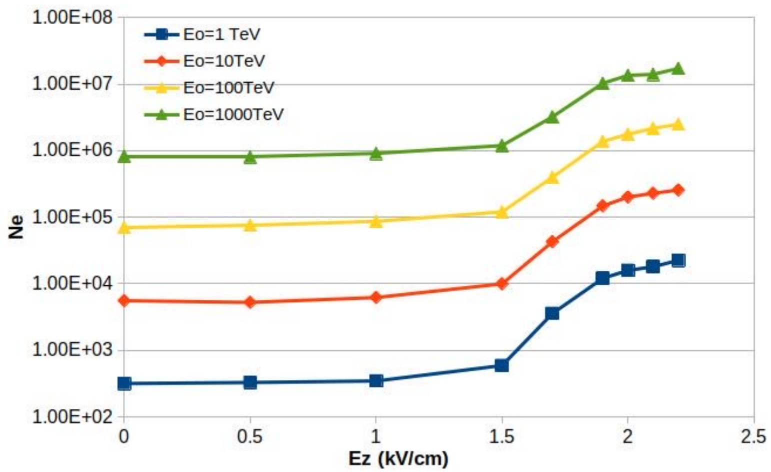

Ararat mountain
(5127 m) is 100 km
from Aragats



Aragats Cosmic Ray station: research of planetary, solar and galactic particle accelerators. Year-round operation from 1943. Coordinates: 40.47N, 44.18E, 3200m a.s.l. Located on highland near Kari lake in the vicinity of Aragats south peak (3897m), the highest North peak is 4090 m.

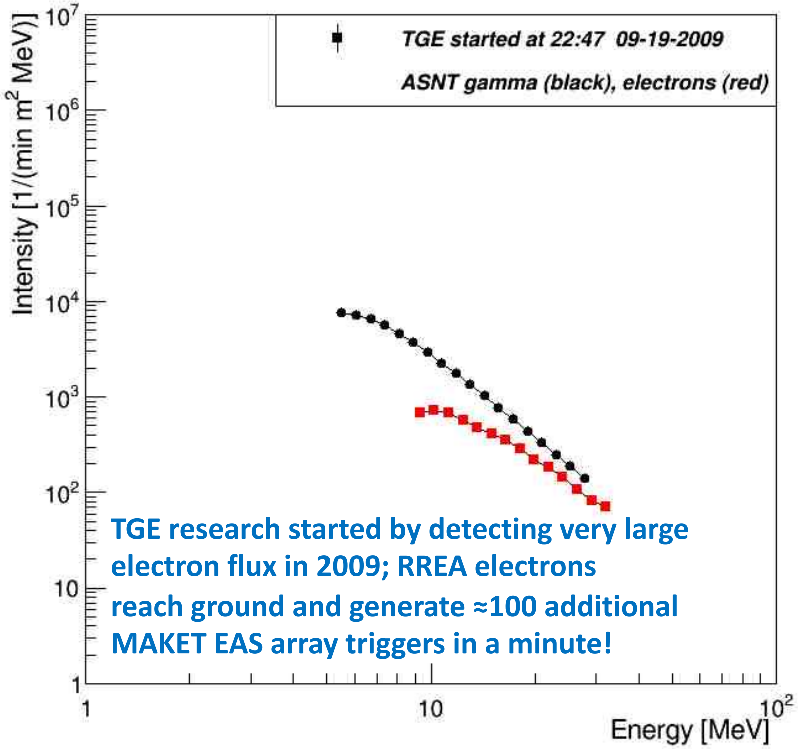

Particle bursts on the earth’s surface: EAS core occasionally hitting surface array

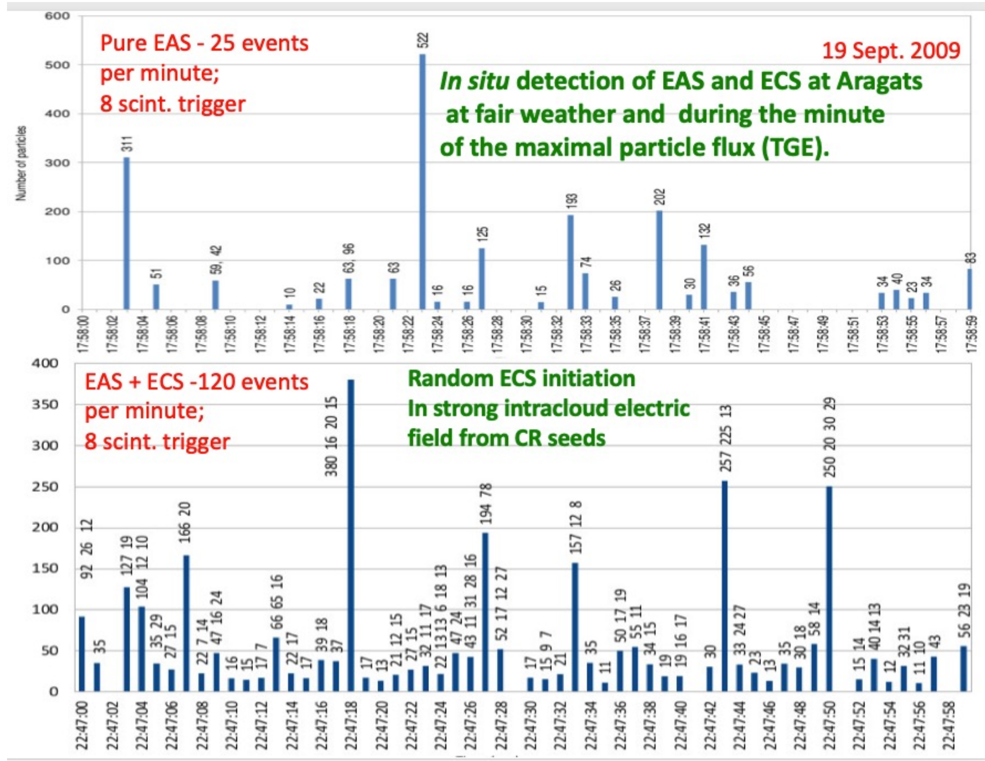
PEVatron detection by LHASSO: possible overestimation of primary gamma ray energies if observations were done during thunderstorms often in Tibetan plateau.

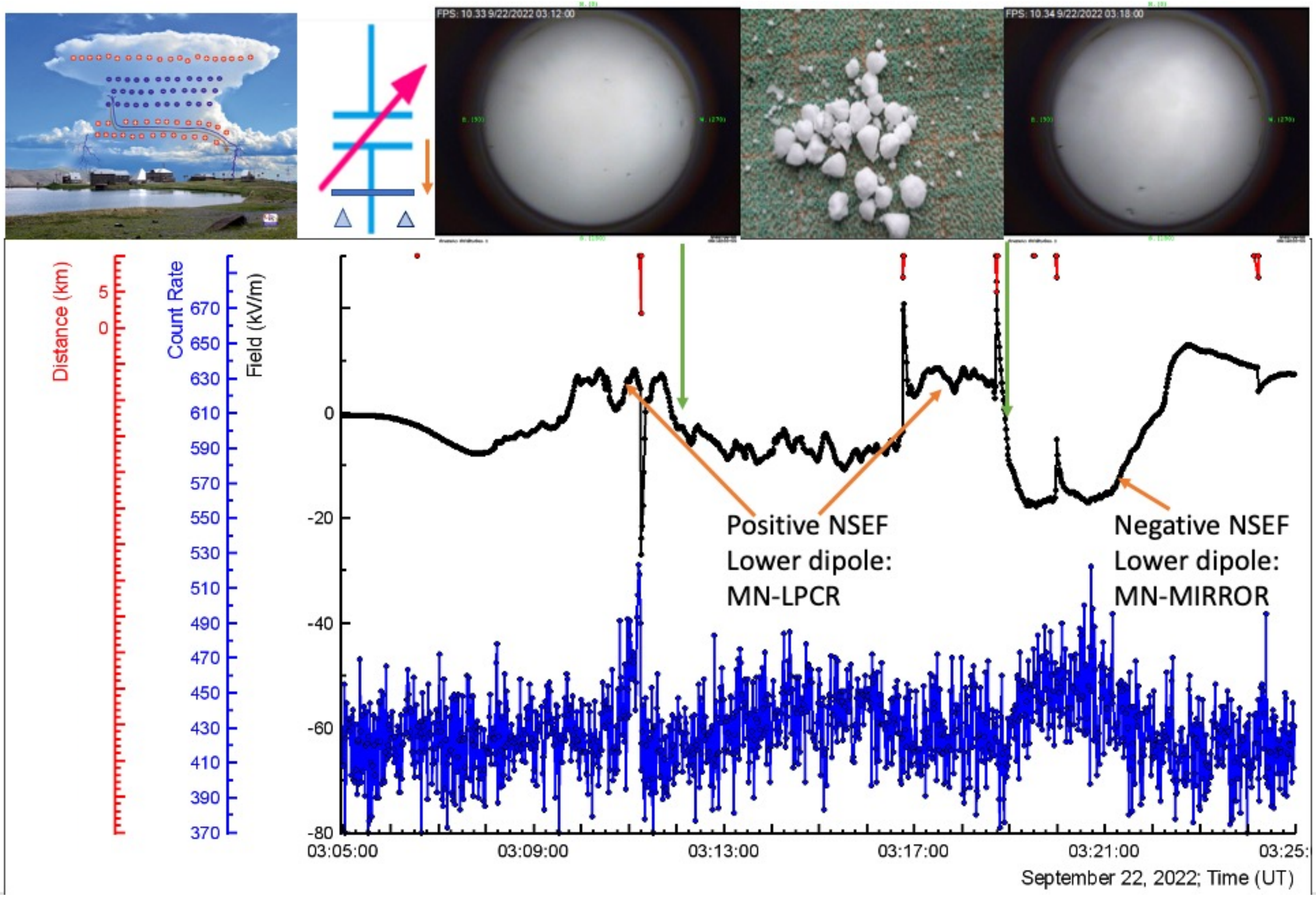


Eo (GeV)	Eest (GeV)
1.00E+03	2.23E+04
1.00E+04	1.34E+05
1.00E+05	6.50E+05
1.00E+06	2.42E+06

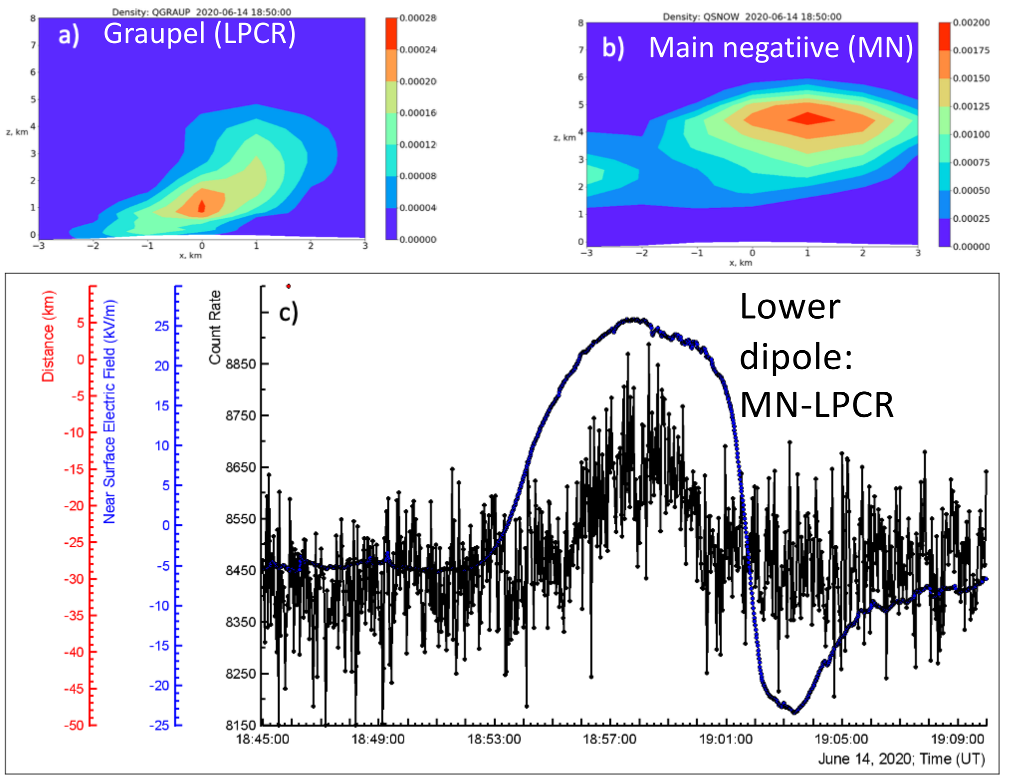
First direct detection of RREA/TGE: MAKET EAS array registered runaway electron avalanches coming randomly in discreet packages (no backpropagation)



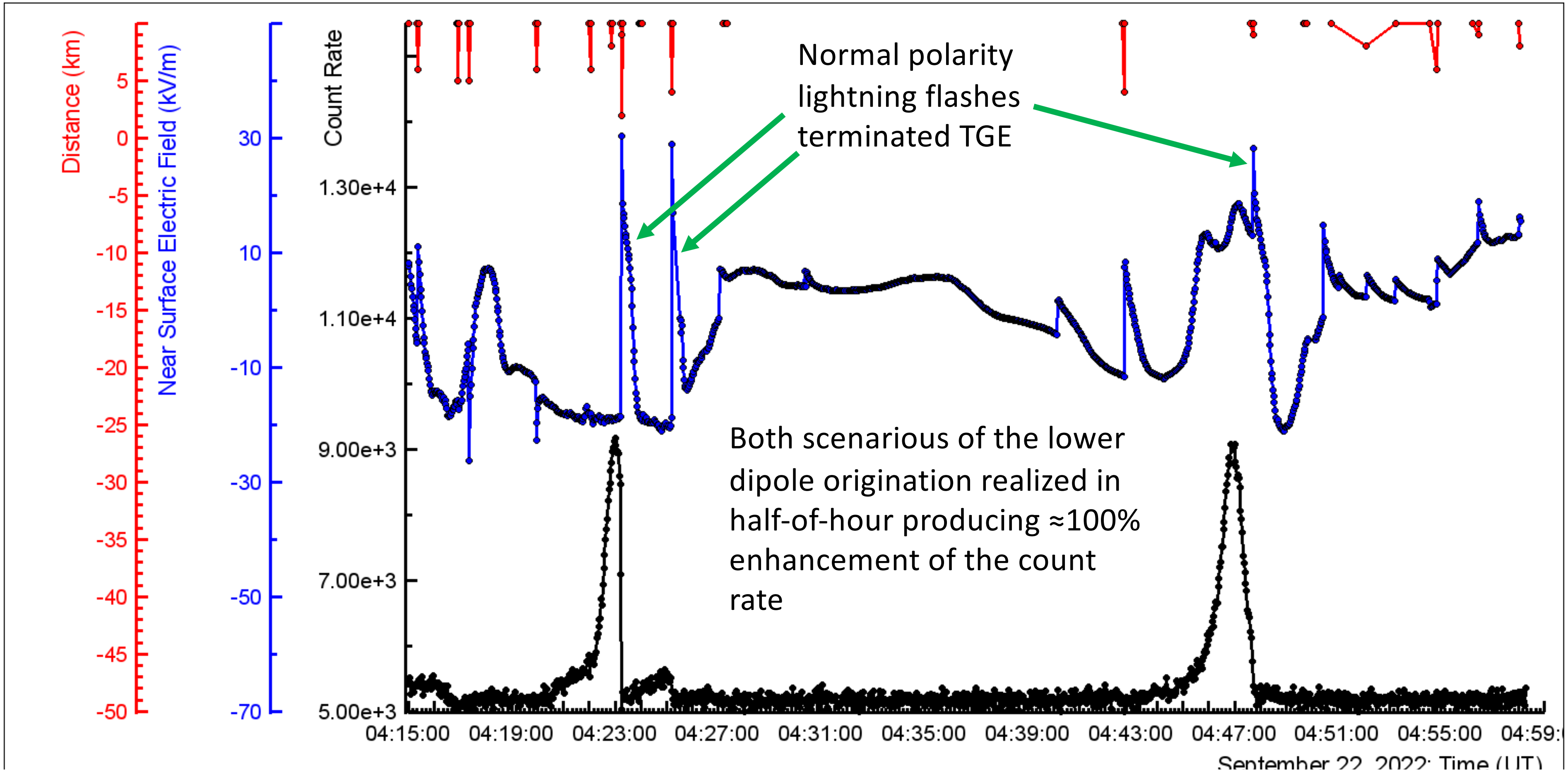



FPS: 10.33 9/22/2022 03:12:00
FPS: 10.34 9/22/2022 03:18:00
Distance (km)
Count Rate
Field (kV/m)
Positive NSEF
Lower dipole:
MN-LPCR
Negative NSEF
Lower dipole:
MN-MIRROR
03:05:00
03:09:00
03:13:00
03:17:00
03:21:00
03:25:
September 22, 2022; Time (UT)

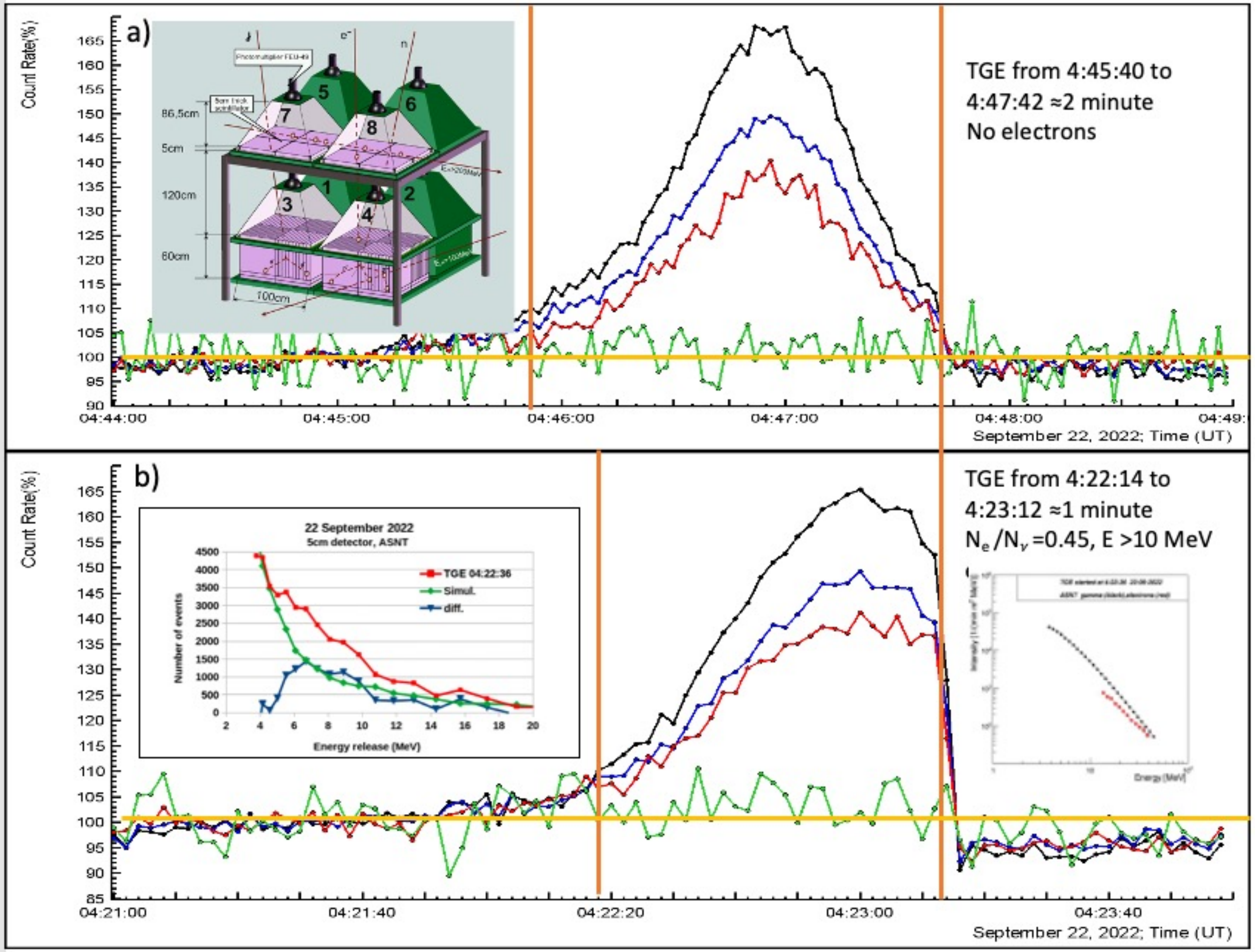
Lower Dipole emergence in the thundercloud above Aragats



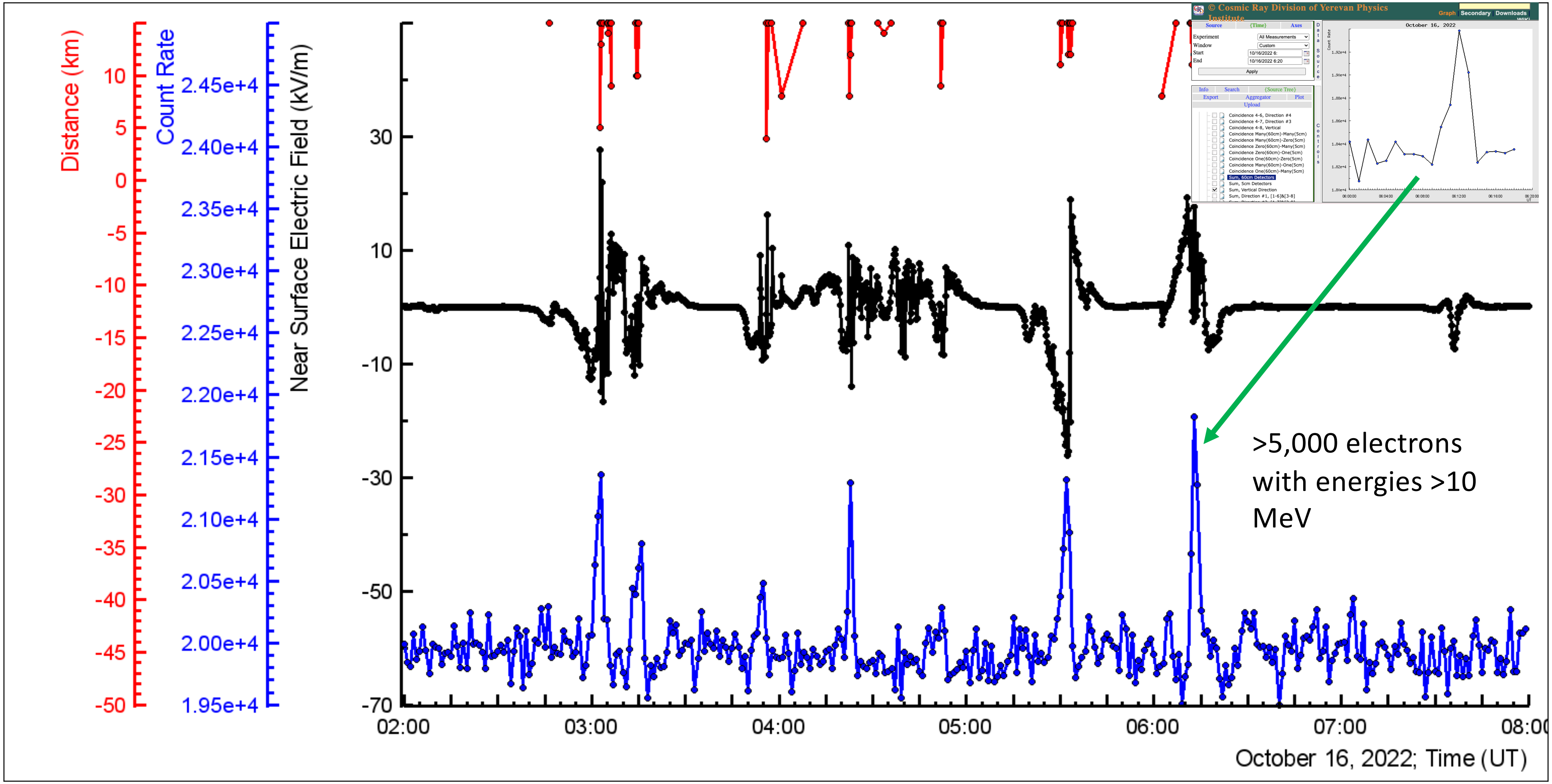
In Fig. a) and b) we demonstrate the 2-dimensional patterns of the hydrometeor density (kg/m^3), according to the simulation of the radar reflectivity using WRF. In Fig c) we show the particle count rate measured with ASNT detector and disturbances of the NSEF measured by EFM-100 electric mill).



Distance (km)
Near Surface Electric Field (kV/m)
Count Rate
Normal polarity lightning flashes terminated TGE
Both scenarious of the lower dipole origination realized in half-of-hour producing ≈100% enhancement of the count rate
1.30e+4
1.10e+4
9.00e+3
7.00e+3
5.00e+3
04:15:00
04:19:00
04:23:00
04:27:00
04:31:00
04:35:00
04:39:00
04:43:00
04:47:00
04:51:00
04:55:00
September 22, 2022; Time (UT)



a)
TGE from 4:45:40 to
4:47:42 ≈2 minute
No electrons
Count Rate(%)
September 22, 2022; Time (UT)
b)
TGE from 4:22:14 to
4:23:12 ≈1 minute
Ne/Nγ =0.45, E >10 MeV
22 September 2022
5cm detector, ASNT
TGE 04:22:36
Simul.
diff.
Number of events
Energy release (MeV)


Distance (km)
Count Rate
Near Surface Electric Field (kV/m)
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
2.45e+4
2.40e+4
2.35e+4
2.30e+4
2.25e+4
2.20e+4
2.15e+4
2.10e+4
2.05e+4
2.00e+4
1.95e+4
30
10
-10
-30
-50
-70
02:00
03:00
04:00
05:00
06:00
07:00
08:00
October 16, 2022; Time (UT)
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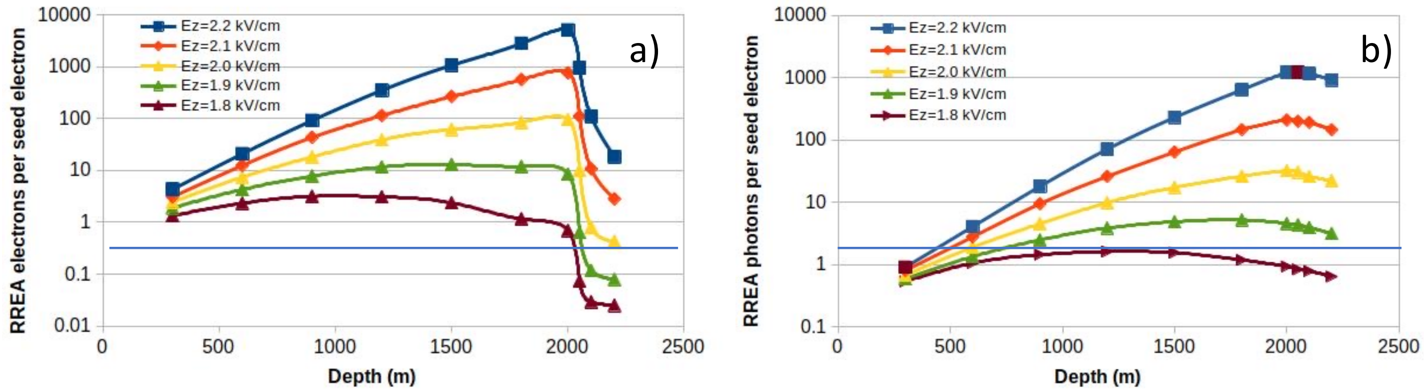
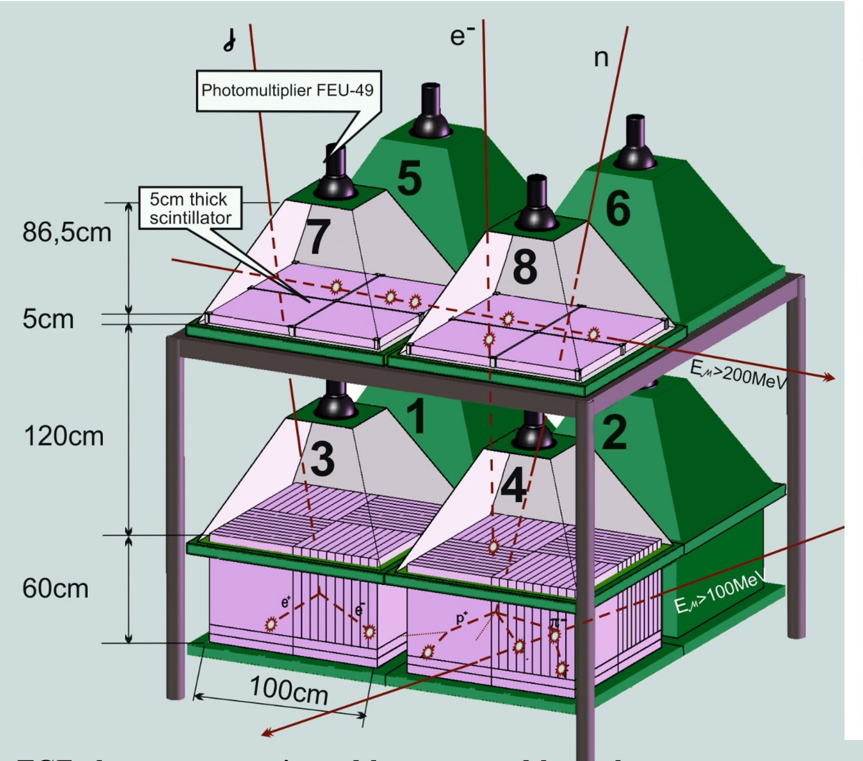
October 16, 2022
>5,000 electrons with energies >10 MeV

Vertical profile of the atmospheric electric field conditioned on the registered TGE compared with CORSIKA simulations



Avalanche started at 5400 m a.s.l. (0 depth), that is 2200 m above the Aragats station. The number of avalanche particles is calculated each 300 m. After exiting from the electric field propagation of avalanche particles is followed additionally 200 m before reaching the station. By blue line, we show the electron and gamma ray number per seed electron for the TGE that occurred on 14 June 2020.

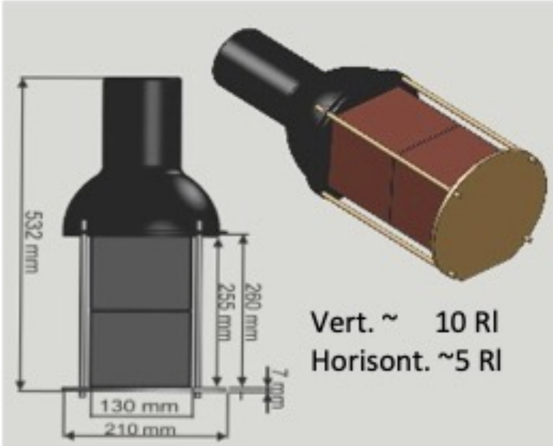
Aragats Solar Neutron Telescope (ASNT) and network of NaI(TL) spectrometers used for recovery of TGE electrons and gamma ray energy spectra in the range of 0.3 – 100 MeV



TGE electrons are registered by upper and lower layers; gamma rays and neutrons – by invoking the veto option (no signals from the upper scintillators), horizontal muons – by the condition of operation of 2 upper scintillators from 4 and no signal in the lower scintillators (to prevent registration of EAS events) and by very large energy release.

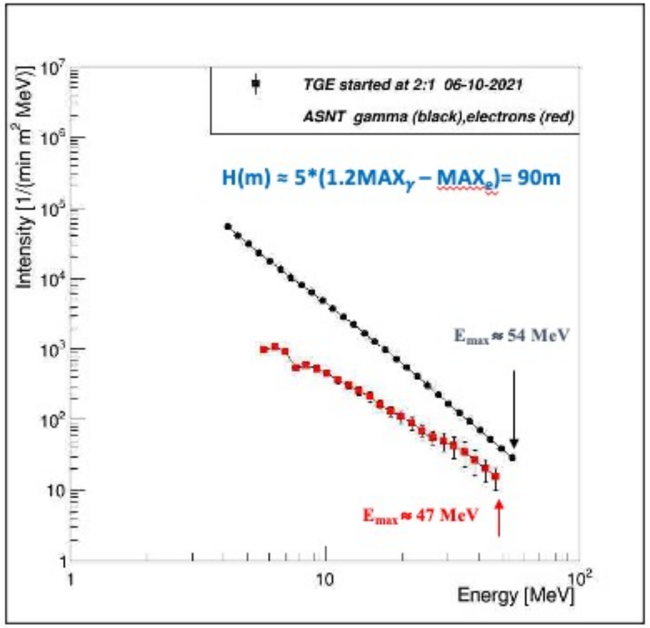
Material	Radiation length		Density
	g/cm2	cm	g/cm3
Polystyr. scint.	43.72	42.4	1.032
Cesium iodide (CzI)	8.39	1.85	4.53
Sodium iodide (NaI)	9.49	2.59	3.67

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, from 2018 – 0.3 MeV.



The difference of attenuation of gamma ray and electron fluxes allows estimation of the height where both fluxes leave the electron acceleration region

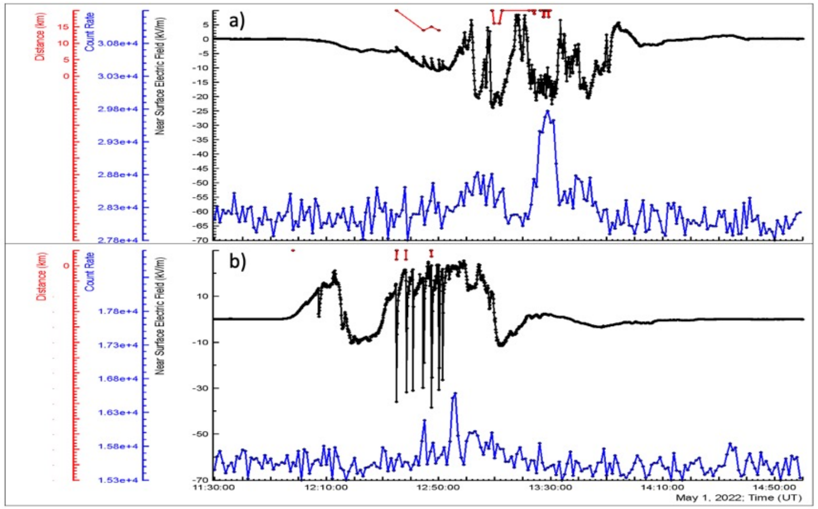
Distance from detector to the bottom edge of the field (m)	Expected gamma absorption (%) and electron ionization losses (MeV)
50	8.67
100	16.6
200	30.44
300	41.98
400	51.62
1000	83.7
10000	99.99999
50	8
100	16.1
200	32.1
300	48.23
400	64.3



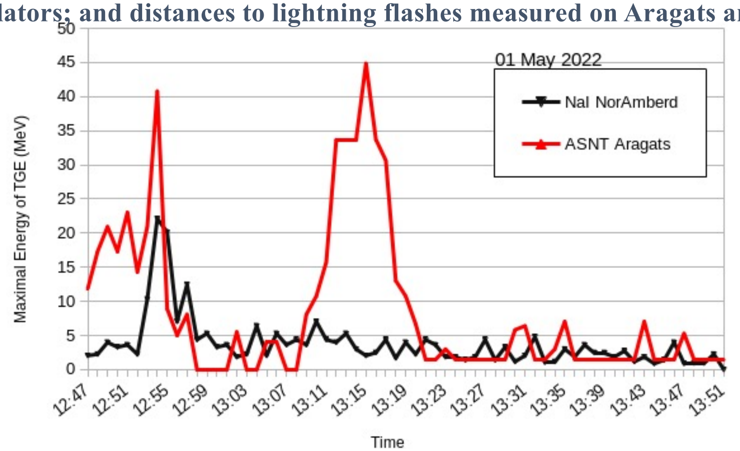
By comparing maximal energy of the recovered electron and gamma ray spectra we show that a strong accelerating field (≈2 kV/cm) can be very low above the earth's surface!

Horizontal profile of atmospheric electric field during TGE

The map of networks of NaI spectrometer locations: five on Aragats (3200 m), one in Burakan (1700 m), and one in Nor Amberd station (2000 m). Electric mills and lightning locators are installed on Aragats (3 units), in Burakan and in Nor Amberd.



The disturbances of the NSEF; 1-minute count rates of 5 cm thick and 1 m^2 area plastic scintillators; and distances to lightning flashes measured on Aragats and in Nor Amberd



The histogram of maximum energies of energy spectra measured on Aragats with a large scintillation spectrometer ASNT, and in Nor Amberd by the NaI

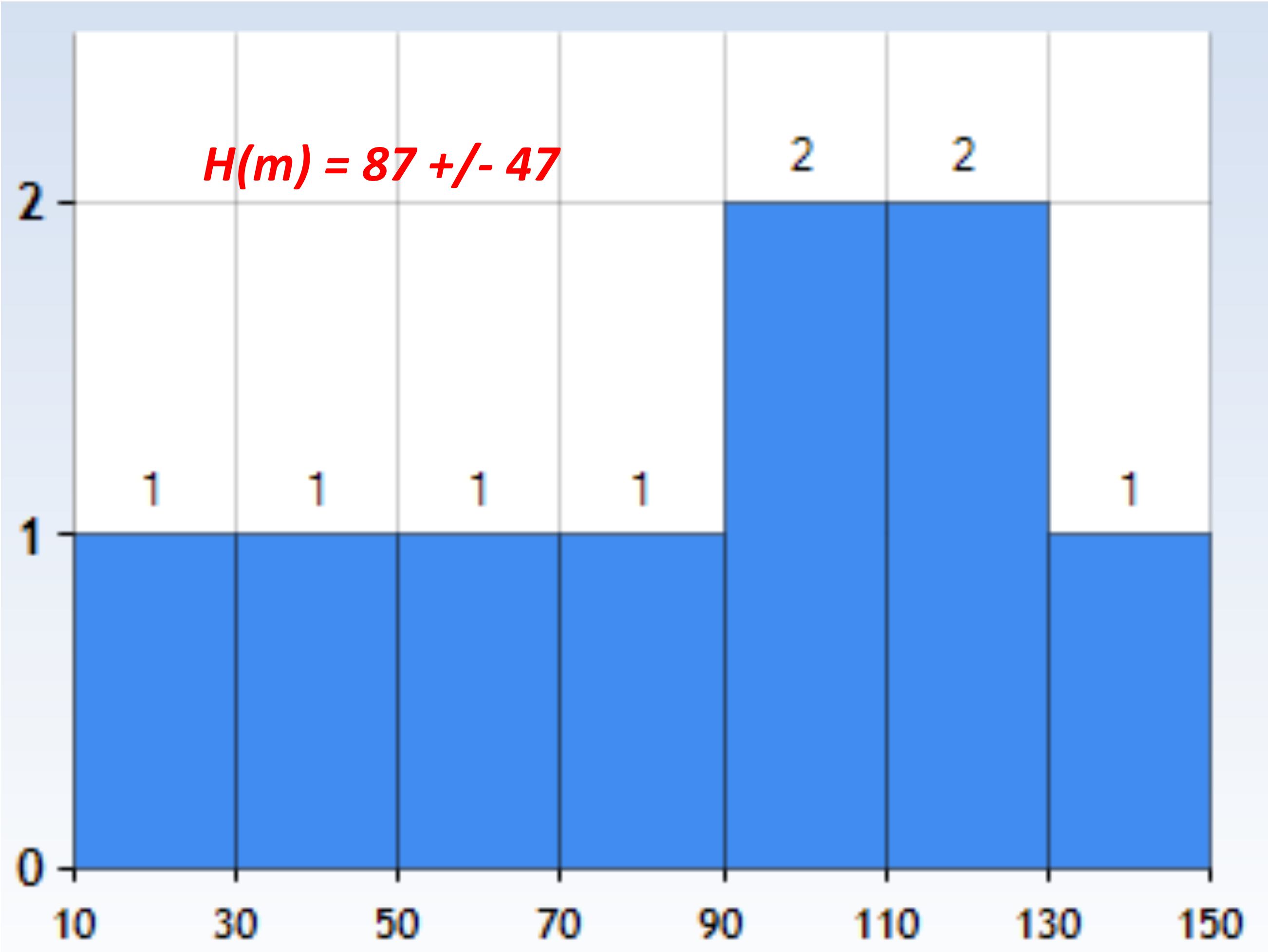
Parameters of Thunderstorm ground enhancements (TGEs) allowing recovering electron energy spectra (2019-2021)*. Selection criteria: Significance of peak enhancement – larger than 5%, Ne/Nγ > 0.06

Date, (month.day. year)	Power law Index el.	Power law index γ-rays	Int. Spectra el.	Int. Spectra γ-rays	Max energy el. (MeV)	Max energy γ-rays (MeV)	TGE significance (%)	El.Field height (m)	TGE duration (min)	Ne/ Nγ	Outside T C°	Cloud height (m)	Dist. to lightning flash (km)	Max. positive NS el. field + (kV/m)	Max.negative NS el. Field - (kV/m)
06.14.19	1.64	2.41	1540	16700	16	25	6	70	3	0.09	5.5	220	1.7	20	0
06.18.19	1.65	2.67	2700	39200	25	40	13	150	6	0.07	3.7	180	2.5	23	25
07.07.19	2.16	2.48	2200	10500	24	28	5	50	4	0.21	7	180	4.2	23	0
06.14.20	2.45	2.89	6500	67000	18	39	20	110	4	0.06	2.8	250	7.5	13	16
06.27.20	1.61	2.64	1000	15700	32	43	9	140	19	0.10	4.6	110	11	0	21
07.23.20	1.63	2.16	1500	17020	24	35	10	90	8	0.09	6.9	170	11	6	15
09.25.20	2.35	2.86	7570	39070	32	32	26	30	5	0.19	7.1	400	5.4	0	26
05.24.21	2.02	2.34	1670	17120	29	45	9	125	13	0.10	1.8	200	12	0	20
10.06.21	2.16	2.8	12170	122800	47	54	46	90	3	0.10	-2.5	100	4.5	6	0
09.24.21	2.18	2.11	2560	9400	29	25	6	10	3	0.27	2.9	200	17	0	22

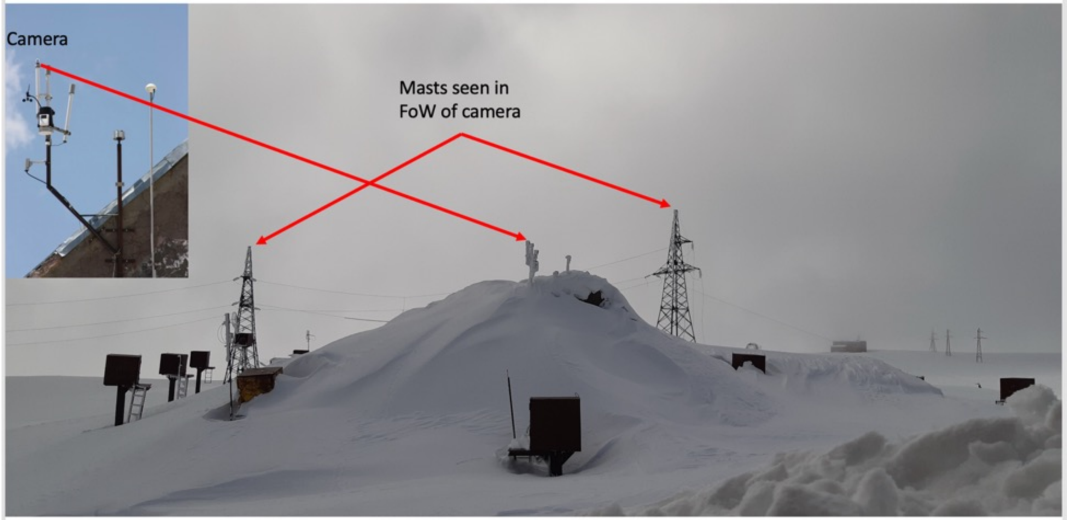
*Mendeley Data, V3, doi: 10.17632/tvbn6wdf85.3

Electron and gamma ray energy spectra are recovered from energy release histograms, cloud height is recovered by outside temperature and dew point.

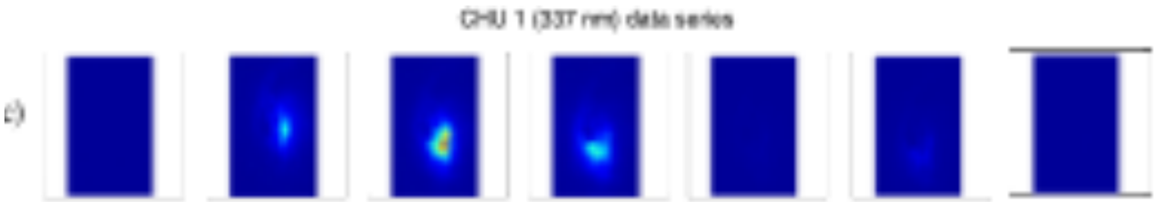
Height above ground where strong accelerated electric field terminated



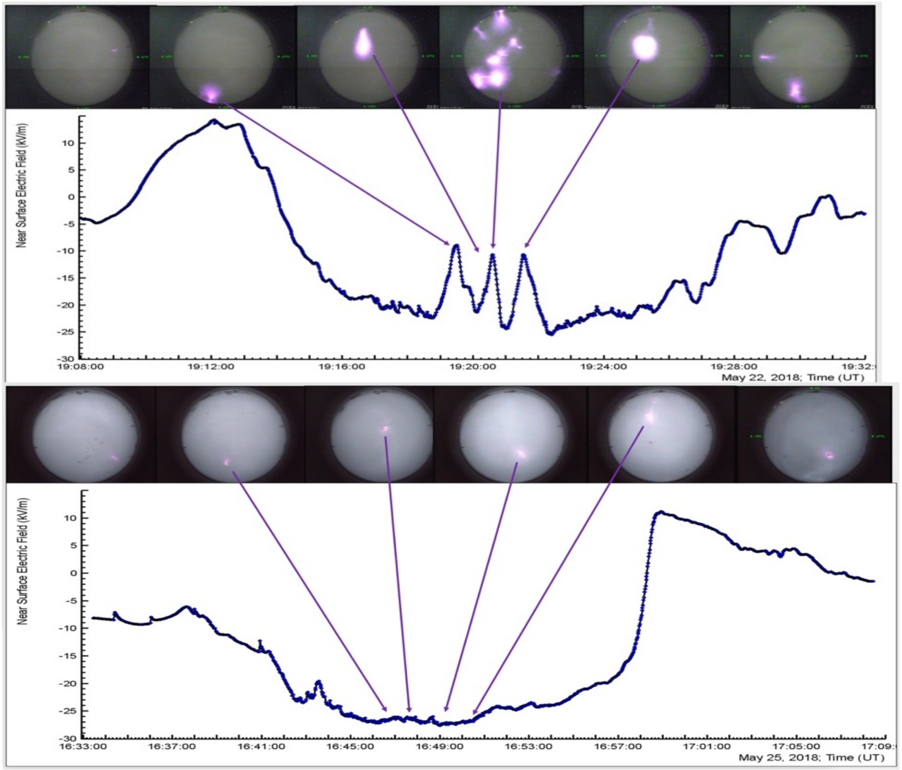
Optical emissions during TGE (Aragats) and TGF (ASIM)



The MAKET experimental hall, in the inset the zoomed ALL SKY CAM surrounded by DAVIS weather station, BOLTEK's electric field sensor, and lightning tracker.

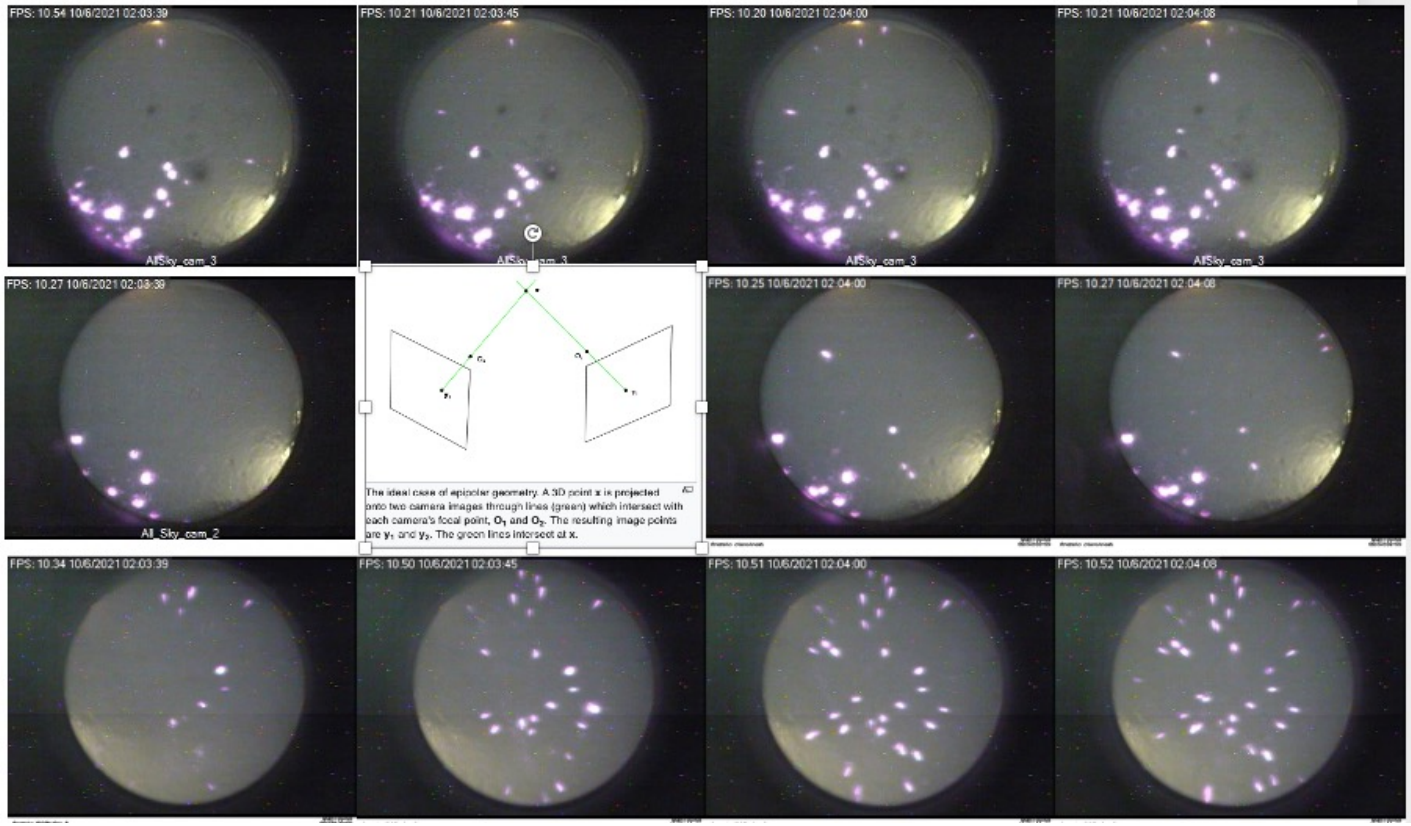


ASIM detection of TGFs, optical emission, and lightning flashes. The 337 nm photometer data with ADC units on the *y*-axis. The lights appear after TGF start and before the lightning flash

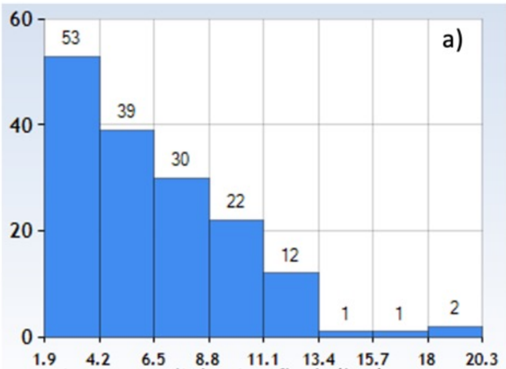


The disturbances of the NSEF during TGE, measured by an EFM-100. In the upper panel, w show the panoramic camera shots of the sky above the station; by a violet arrow, we indic the times when panoramic shots were done.

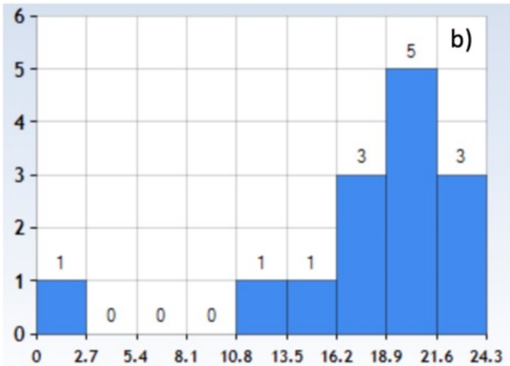
Large TGE occurred on 6 October 2021 was accompanied with intense multiple light spots remaining in skies tens of seconds. Each row represents shots of one from 3 cameras at the same second. Not blue starters not ball lightning, what it can be?



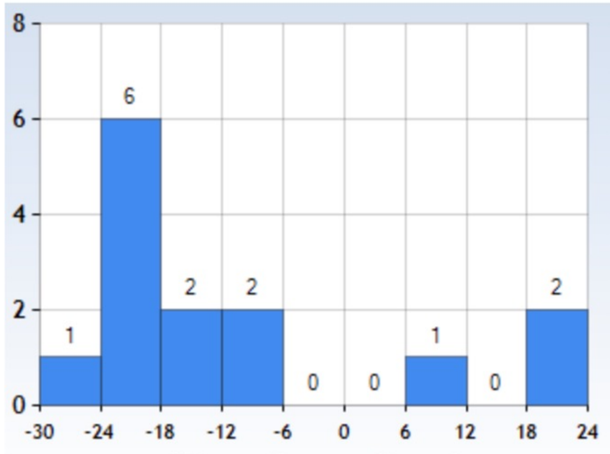
TLEs in the lower Atmosphere: charcateristics



Distance to lightning flash (km).
(130 TGEs terminated by lightning flash)



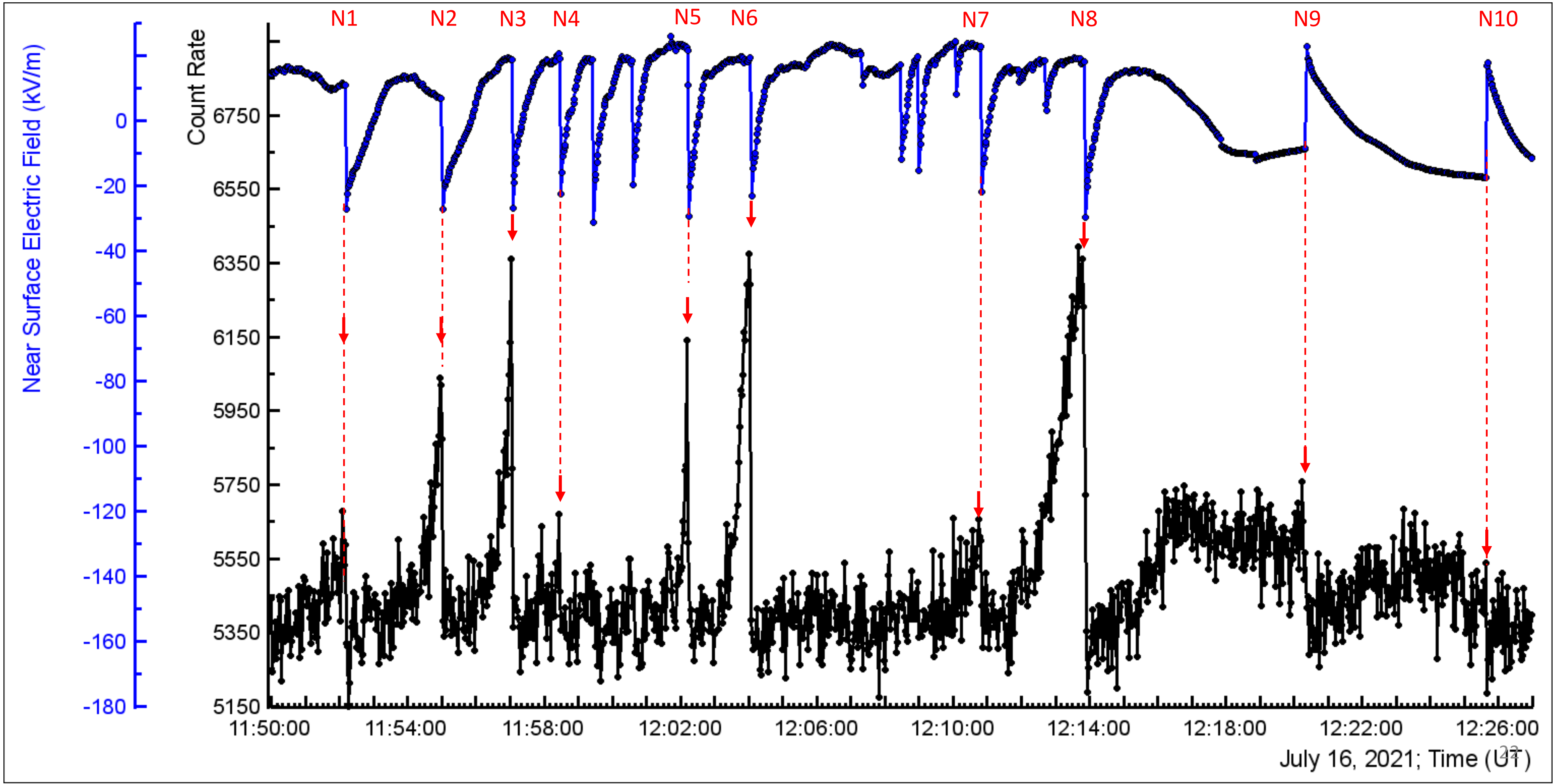
Distance to lightning flash (km).
(14 TGEs accompanied with light glows)



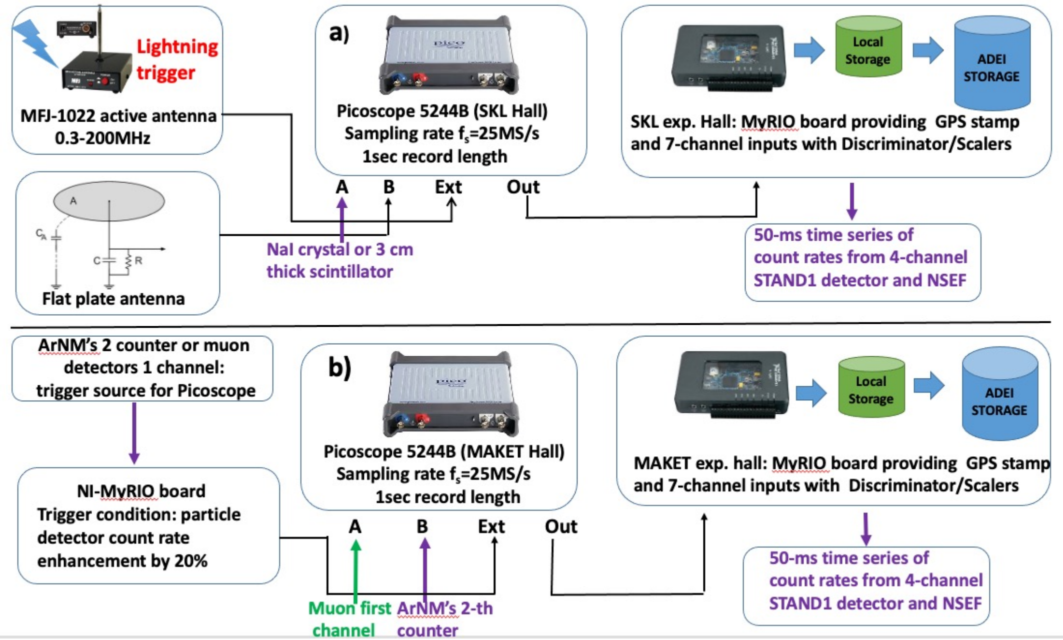
Near-surface electric field (kV/m)

The origin of light glows is under discussion, the possible explanations are intense fluxes of TGE electrons , ball lightning, St. Elmo's fires, and geomagnetic disturbances. However, after examining luminous TGE events, along with lightning location maps and NSEF time series, we think that these unusual luminous phenomena below thunderclouds are a new optical phenomenon. An electrical discharge or starting lightning leader much weaker than a lightning flash could only partially neutralize the charge above, and hence, only partially lowers the corresponding potential difference, allowing the electron accelerator to operate and send particle fluxes in the direction to the earth's surface.

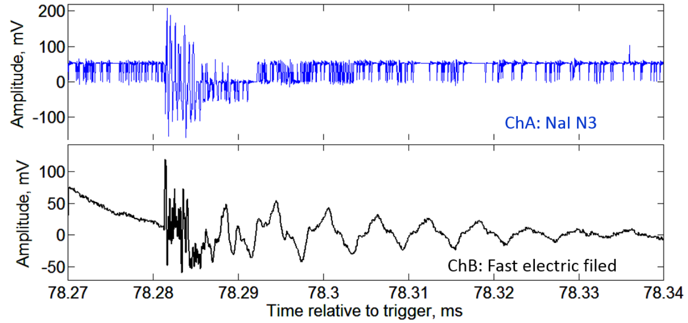
Nearby lightning flashes (distance <10 km) terminate attempts to start TGE or TGE initiates a lightning flash?



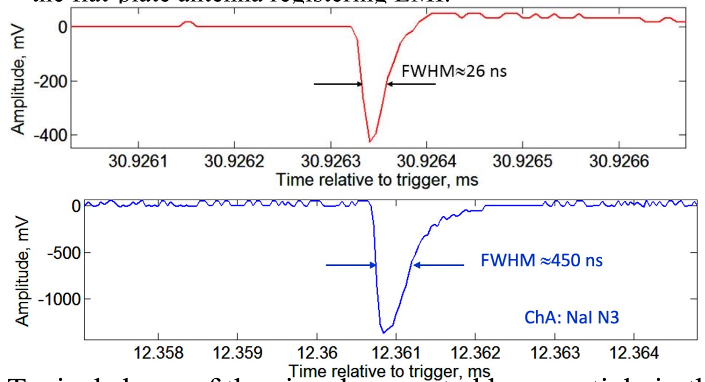
Particles do not originate in the lightning bolt: TGEs and TGFs are precoursors of lightning flashes!



Fast synchronized data acquisition (FSDAQ) for the research of particle–lightning relations, triggered by atmospheric discharges, MAKET hall; in SKL experimental hall (triggered by TGE – 10% enhancement of count rate).

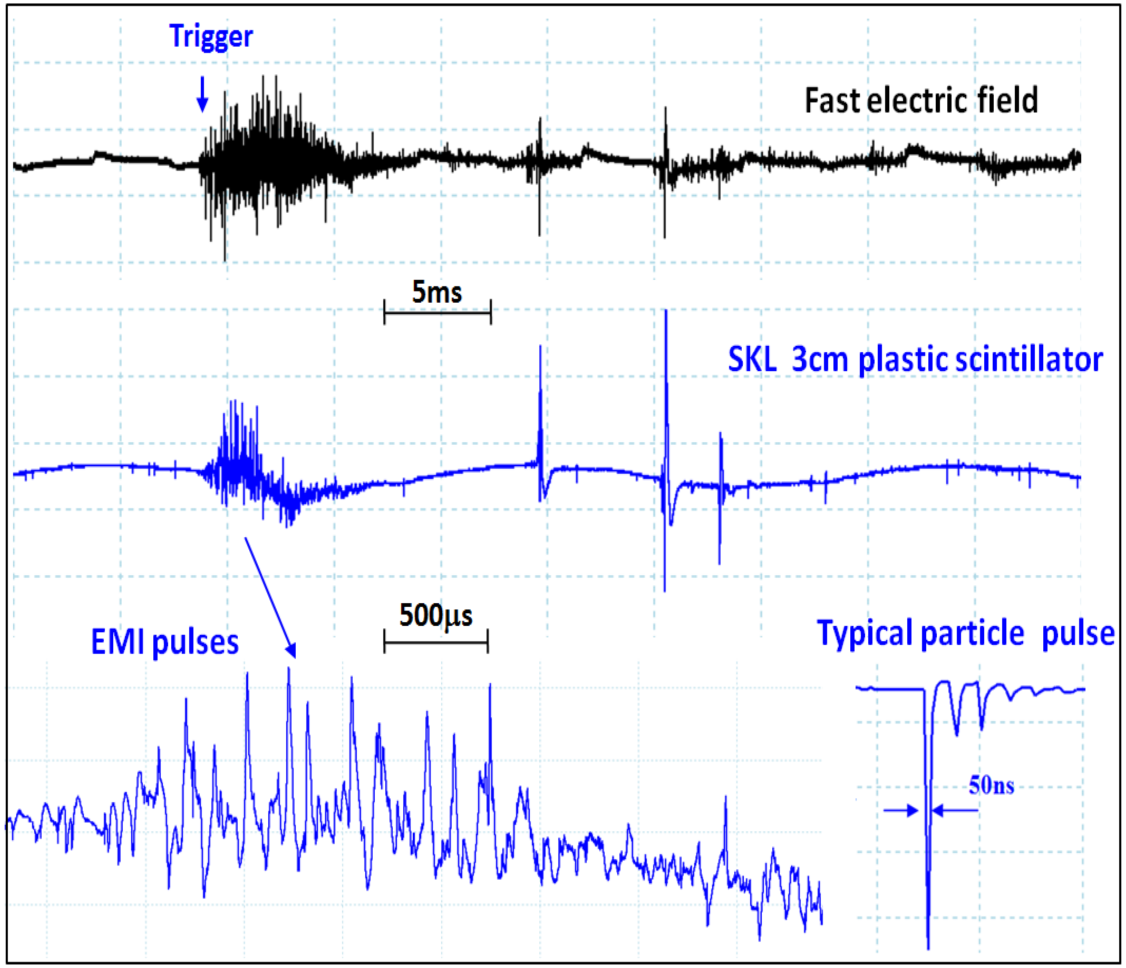


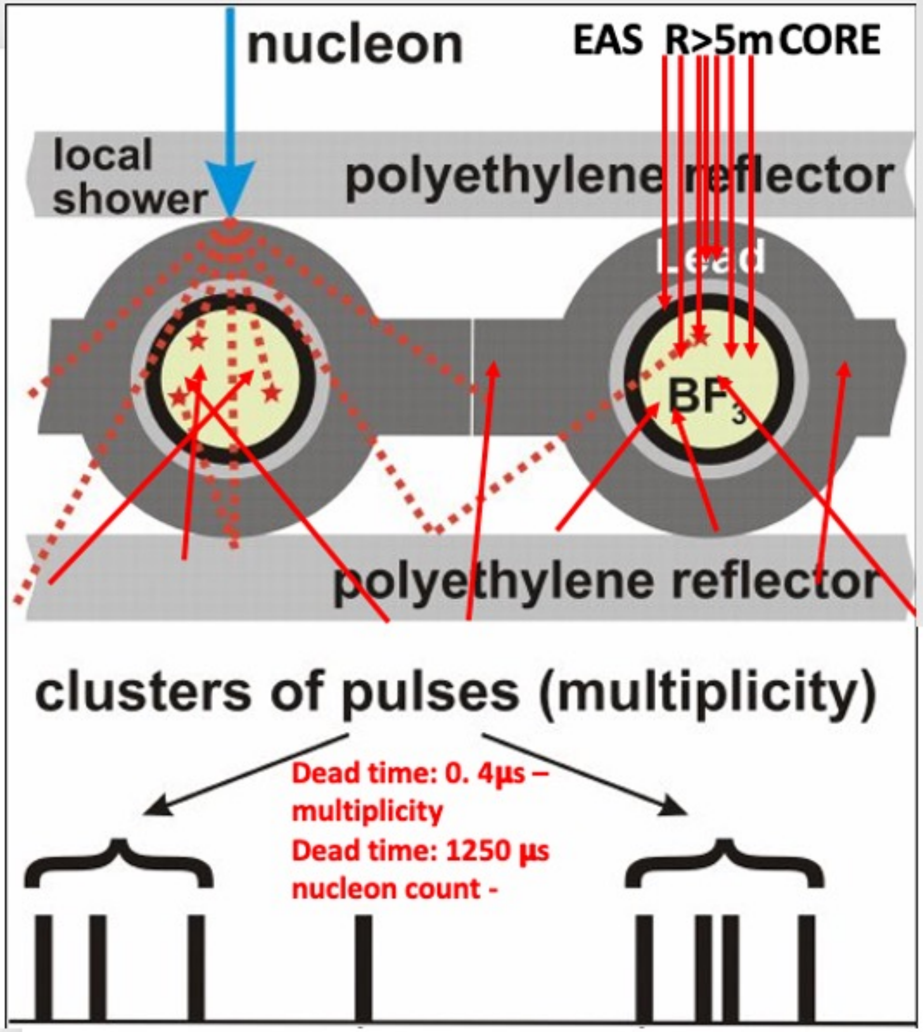
40-ns time series of NaI spectrometer, and the signals from the flat-plate antenna registering EMI.

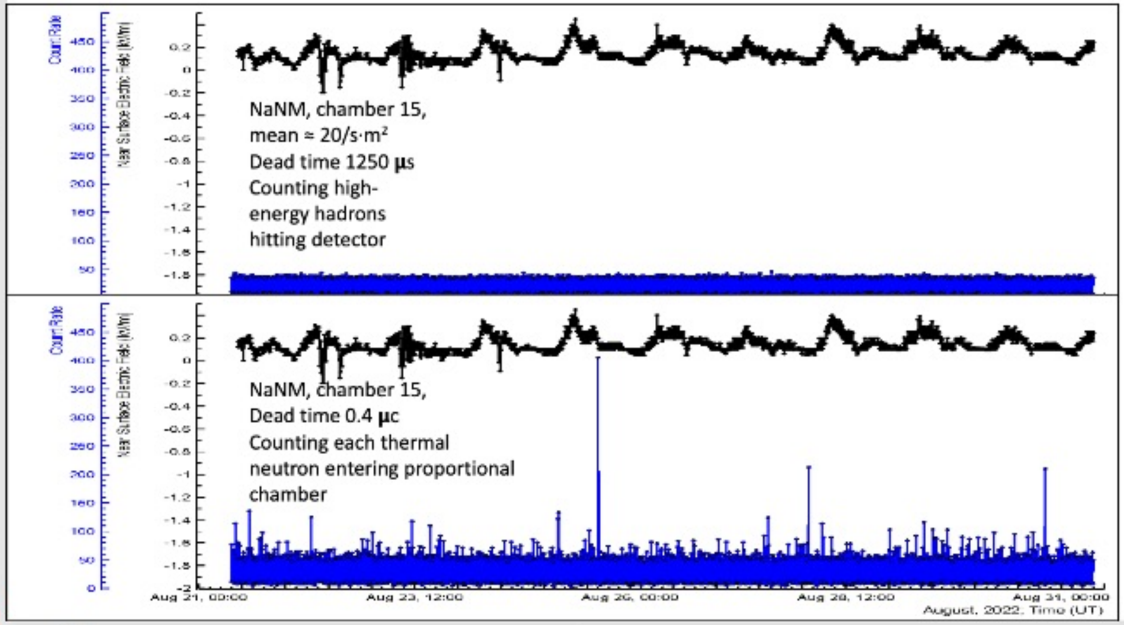


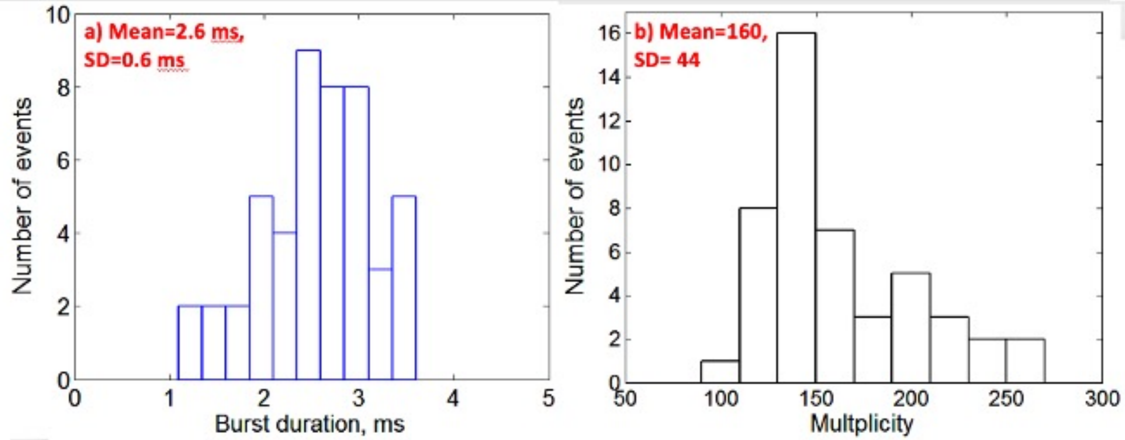
Typical shape of the signal generated by a particle in the large NaI crystal (12 x 12 x 24 cm) and in 1-cm scintillator.

Lightning flashes do not produce MeV particles, they terminate TGE. Typical EMI signature from atmospheric discharges in the particle detector waveform. Synchronized time-series of the pulses of fast electric field and signals from plastic scintillator. SKL trigger occurred at 14:32:34.205

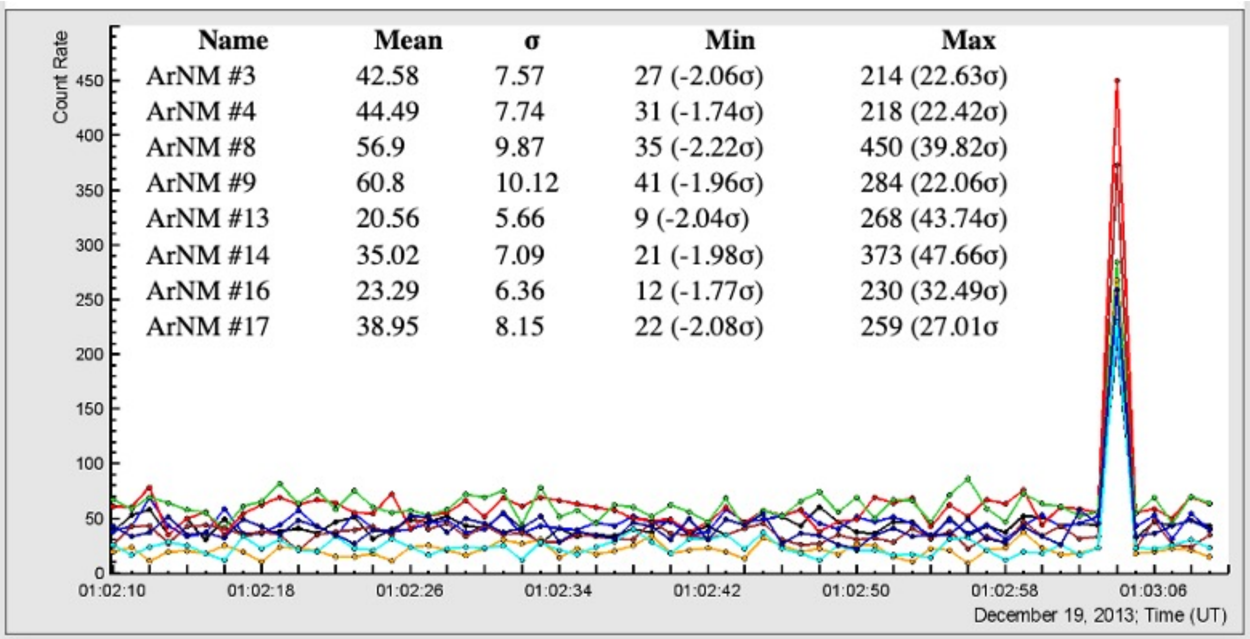




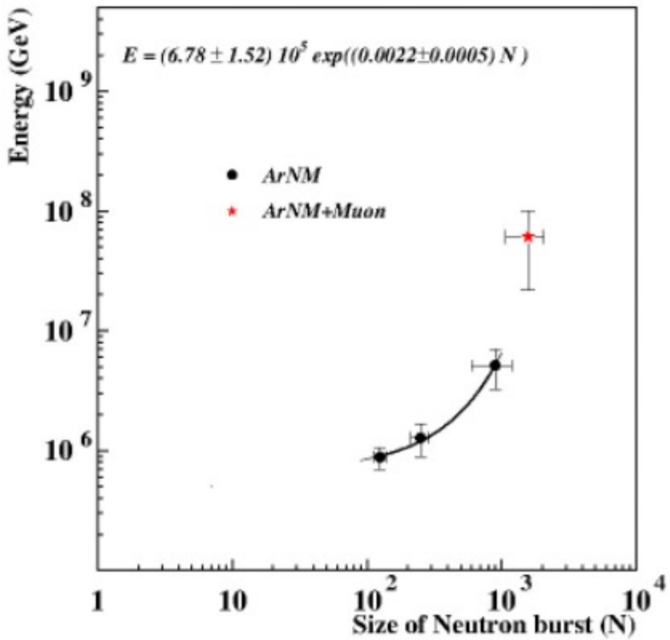




Apatity, Barenzburg, Fine structure of neutron multiplicity on neutron monitors. Yu. V. Balabin, B. B. Gvozdevsk, E. A. Maurchev, et al, Astrophys. Space Sci. Trans., 7, 283-286, 2011.
] Soghomonyan, Suren; Chilingarian, Ashot; Pokhsraryan, David (2021), "Extensive Air Shower (EAS) registration by the measurements of the multiplicity of neutron monitor signal", Mendeley Data, V1, doi: 10.17632/43ndcktj3z.1 https://data.mendeley.com/dat



Time series of ArNM proportional counters registered a large neutron burst at 1:03:4 on 19 October 2013, total multiplicity of 2310 measured by the shortest dead time of 0.4 µs. The multiplicities above 2000 are extremely rare, 1-2 per month; neutron bursts detected by both ArNM and Muon are even rarer, 3-4 per year. The primary particle energies corresponding to these events are well above 10^{16} eV.



The dependence of the multiplicity (size) of neutron burst on energy of primary particle, which initiated EAS (obtained by relation of the frequency of different observed multiplicities (neutron burst sizes) to integral energy spectrum measured by MAKET array. By arrow we show the knee position of the all particle spectrum and by asterisk – the primary particle energy corresponding to the frequency of detecting bursts both in ArNM and muon detector.

Citation: A.Chilingarian A., Hovsepyan G., Kozliner L., Extensive Air Showers, Lightning, and Thunderstorm Ground Enhancements, Astroparticle Physics 82, 21 (2016).

Detectors measuring neutron bursts:

Z. T.Izhbulyakova, A. G. Bogdanov, F. A. Bogdanov, et al., Investigation of the EAS neutron component with the URAN array: first simulation and experimental results, Journal of Physics: Conference Series 1690 (2020) 012071 doi:10.1088/1742-6596/1690/1/012071

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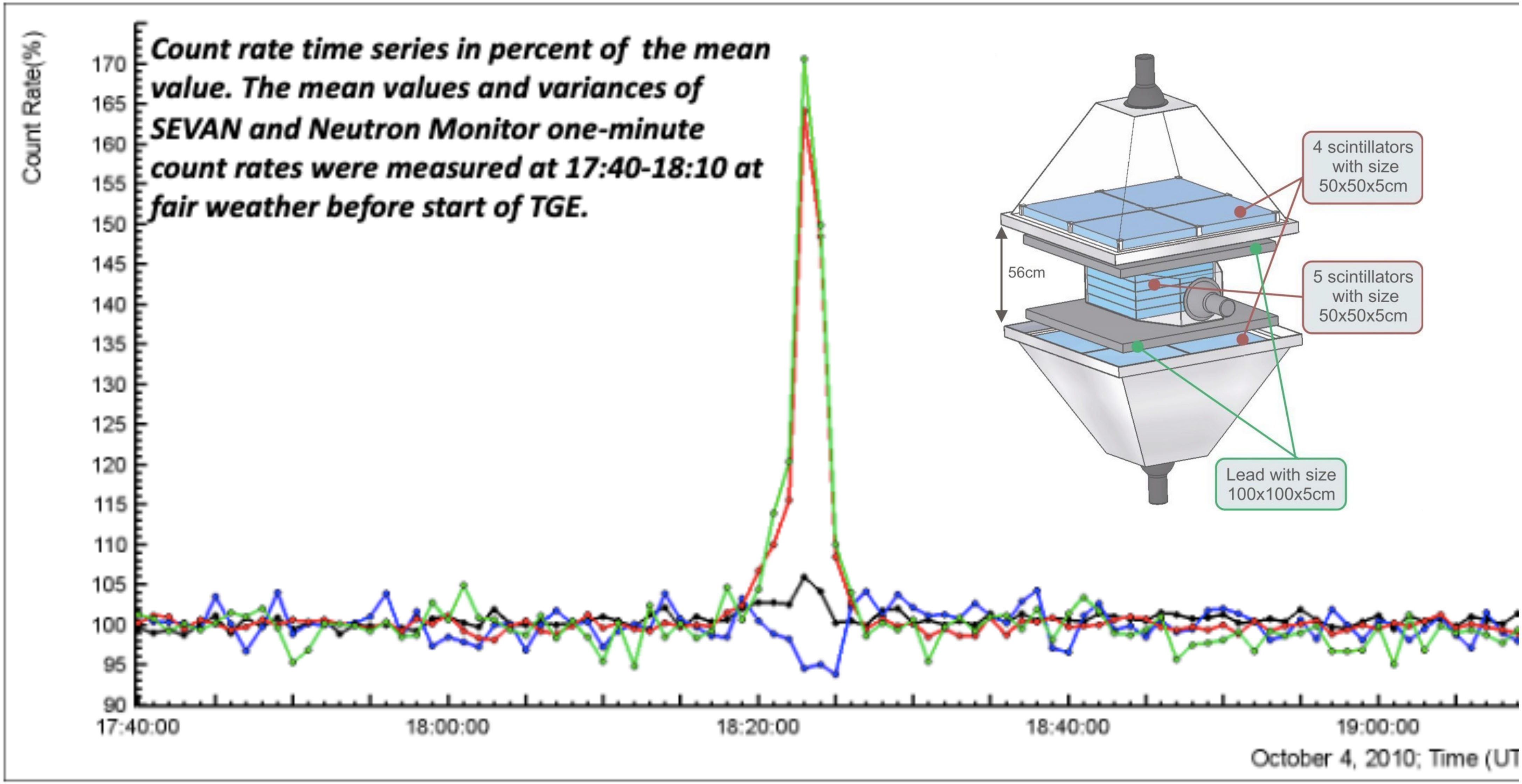
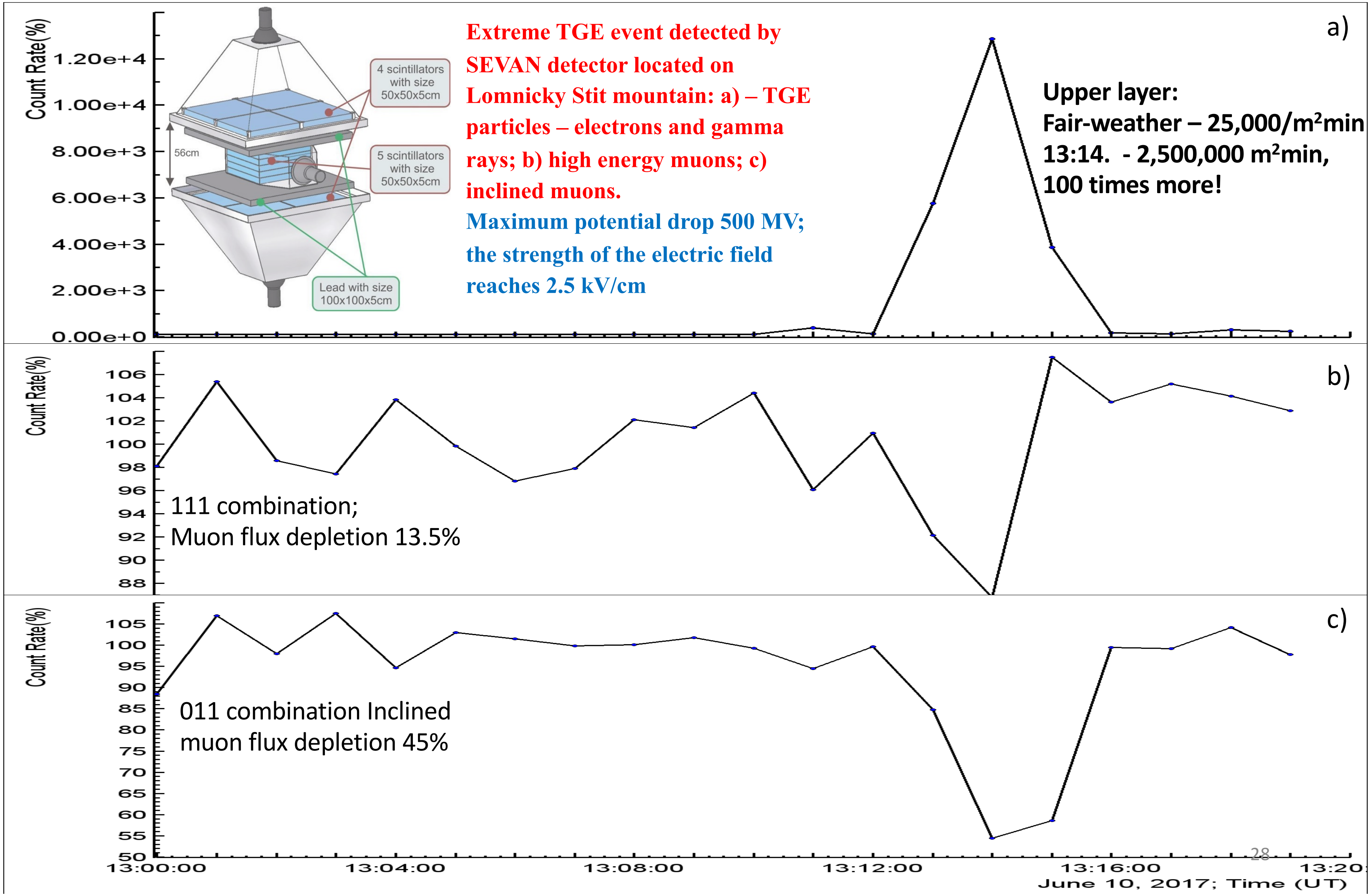
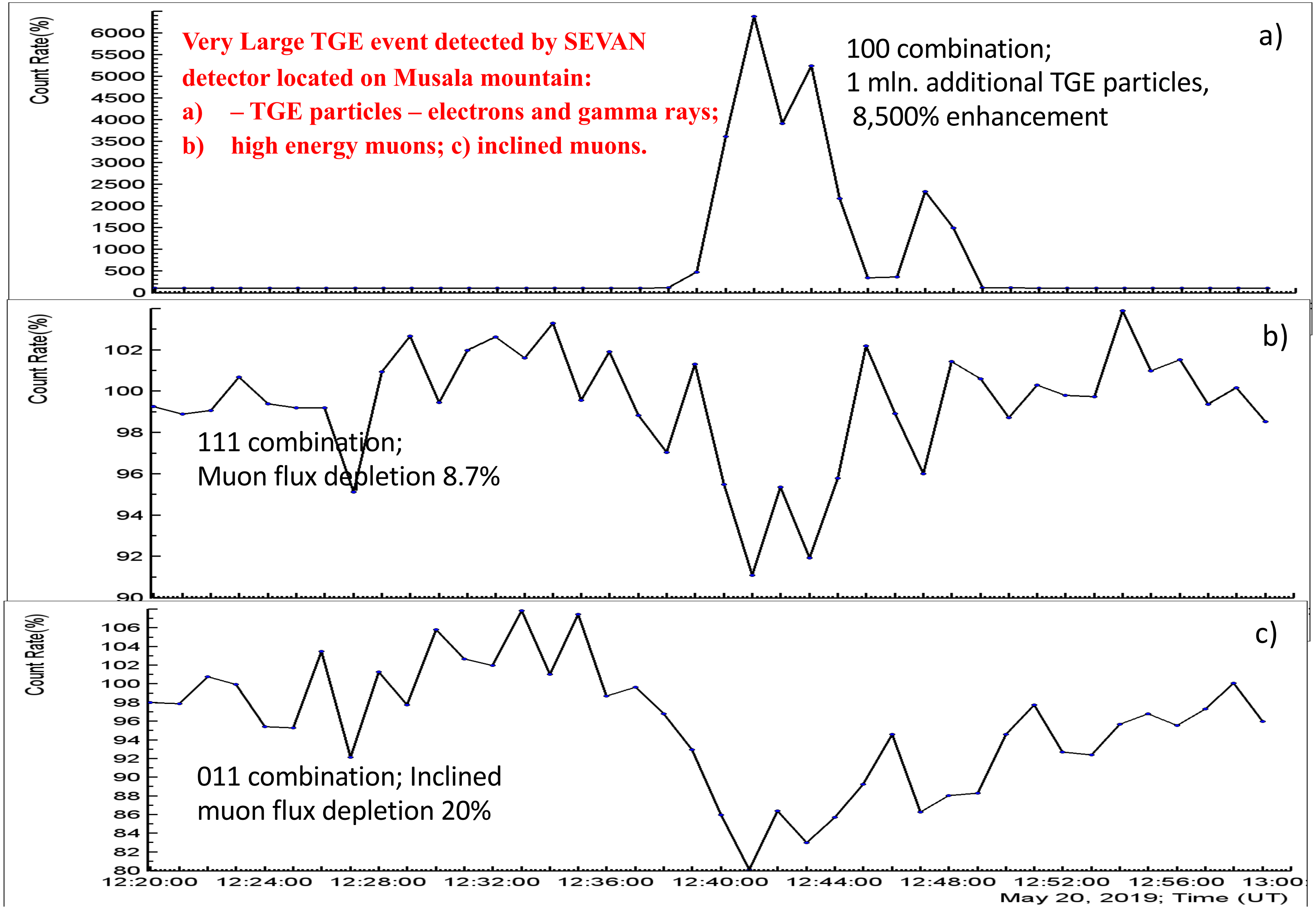
B. Bartoli, P. Bernardini, X.J. Bi et.al., Detection of thermal neutrons with the PRISMA-YBJ array in Extensive Air Showers selected by the ARGO-YBJ experiment, CollaborationsAstropart.Phys. 81 (2016) 49-60

B.-B. Li, V.V. Alekseenko, S.-w Cui, et al., EAS thermal neutron detection with the PRISMA-LHAASO-16 experiment, JINST 12 P12028 (2017) https://doi.org/10.1088/1748-0221/12/12/P12028


Count Rate(%)
Count rate time series in percent of the mean value. The mean values and variances of SEVAN and Neutron Monitor one-minute count rates were measured at 17:40-18:10 at fair weather before start of TGE.
4 scintillators with size 50x50x5cm
5 scintillators with size 50x50x5cm
Lead with size 100x100x5cm
56cm
17:40:00
18:00:00
18:20:00
18:40:00
19:00:00
October 4, 2010; Time (UT


Count Rate(%)
a)
4 scintillators with size 50x50x5cm
56cm
5 scintillators with size 50x50x5cm
Lead with size 100x100x5cm
Extreme TGE event detected by SEVAN detector located on Lomnicky Stit mountain: a) – TGE particles – electrons and gamma rays; b) high energy muons; c) inclined muons.
Maximum potential drop 500 MV; the strength of the electric field reaches 2.5 kV/cm
Upper layer:
Fair-weather – 25,000/m²min
13:14. - 2,500,000 m²min,
100 times more!
b)
111 combination;
Muon flux depletion 13.5%
c)
011 combination Inclined
muon flux depletion 45%
13:00:00
13:04:00
13:08:00
13:12:00
13:16:00
June 10, 2017; Time (UT)


Very Large TGE event detected by SEVAN
detector located on Musala mountain:
a) – TGE particles – electrons and gamma rays;
b) high energy muons; c) inclined muons.
100 combination;
1 mln. additional TGE particles,
8,500% enhancement
a)
b)
c)
111 combination;
Muon flux depletion 8.7%
011 combination; Inclined
muon flux depletion 20%
Count Rate(%)
Count Rate(%)
Count Rate(%)
12:20:00
12:24:00
12:28:00
12:32:00
12:36:00
12:40:00
12:44:00
12:48:00
12:52:00
12:56:00
13:00
May 20, 2019; Time (UT)

Data sources

- Observations/Models needed to support research
  - **TGE energy spectra measured by particle detector networks on Aragats and on the highest peaks of Eastern Europe and Germany (SEVAN network);**
  - **Corresponding measurements of near-surface electric fields, lightning location, skies above particle detectors, and weather parameters;**
  - **Models of the propagation of particle showers in the troposphere with included electric field: CORSIKA, GEANT4.**
- Available data sources and datasets : Database of the cosmic ray division (CRD) of Yerevan Physics Institute.

Time series of particle fluxes measured by hundreds of particle detectors. Data on NSEF, geomagnetic field, weather conditions, shots of panoramic cameras. Data are available in numerical and graphical formats for 20 years of operation **http://adei.crd.yerphi.am/**

Mendeley datasets with selected data on different research topics:

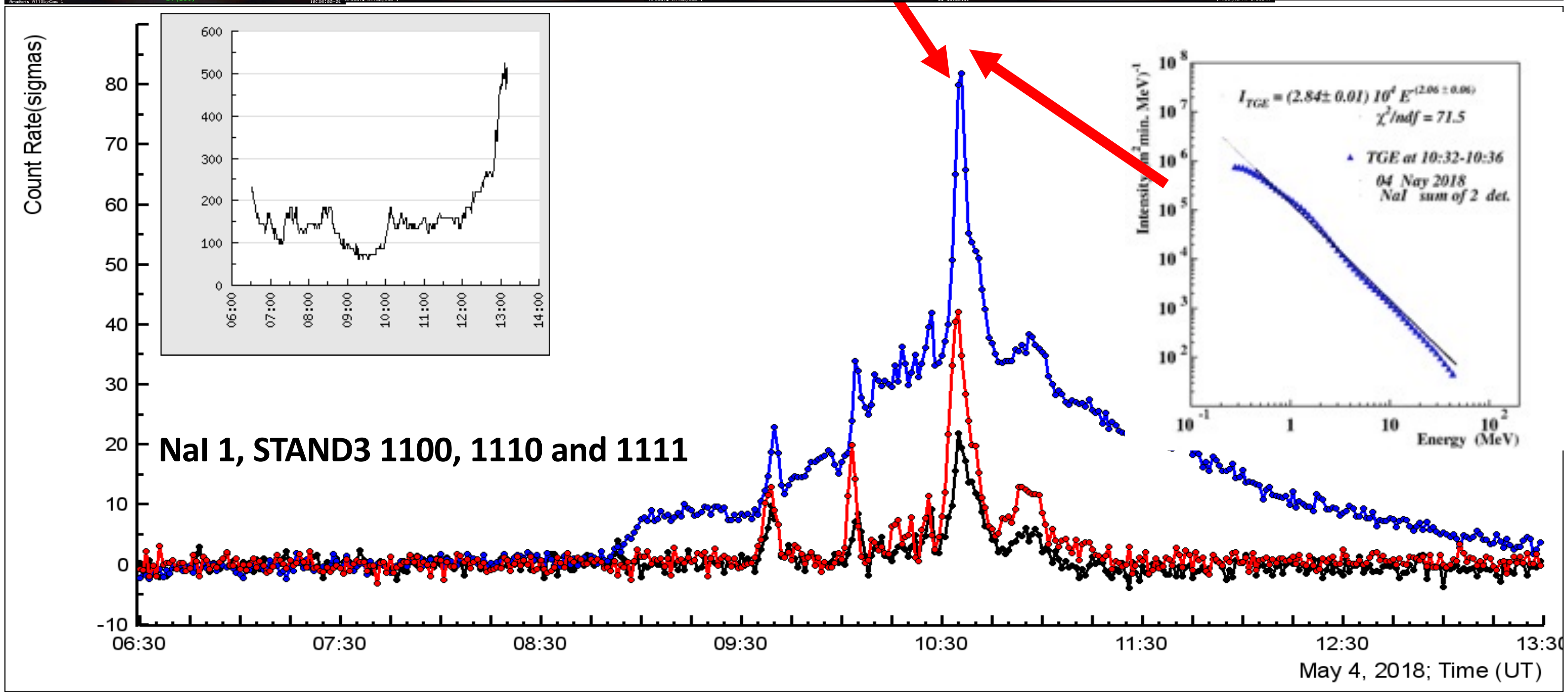
- "Catalog of Sky Glows above Aragats Mountain", Mendeley Data, V1, doi: 10.17632/8ygy98r99d.1
- "Dataset for Thunderstorm Ground Enhancements terminated by lightning discharges", Mendeley Data, V1, doi:10.17632/p25bb7jrfp.1
- "Dataset for 16 parameters of ten thunderstorm ground enhancements (TGEs) allowing recovery of electron energy spectra and estimation the structure of the electric field above earth's surface ", Mendeley Data, V3, doi: 10.17632/tvbn6wdf85.3
- "Thunderstorm ground enhancements abruptly terminated by a lightning flash registered both by WWLLN and local network of EFM-100 electric mills.", Mendeley Data, V1, doi: 10.17632/ygvjzdx3w3.1
- "Extensive Air Shower (EAS) registration by the measurements of the multiplicity of neutron monitor signals", Mendeley Data, V1, doi: 10.17632/43ndcktj3z.1

HEPA main results from the 24/7 monitoring of particle fluxes in Armenia and Eastern Europe (SEVAN network)

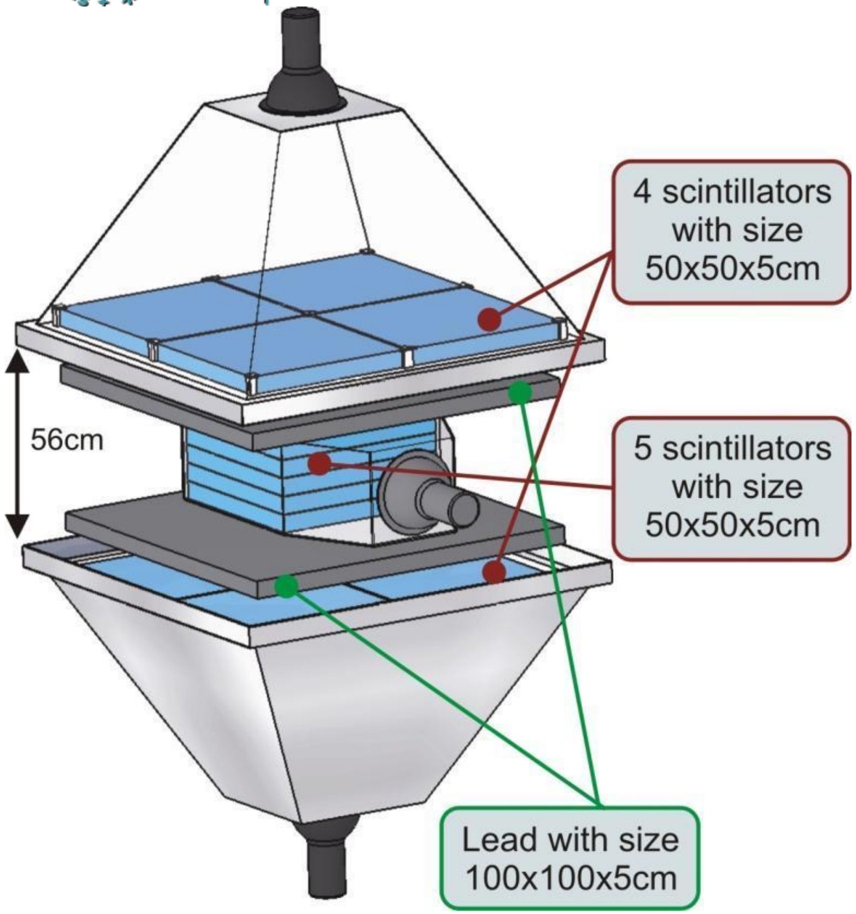
- **Thunderstorm ground enhancements (TGEs) are a universal physical phenomena sending >10^{18} particles (above 100 keV) to the earth's surface each second.**
- **Proven 2 scenarios of electron acceleration in the lower dipole: MN-mirror; MN-LPCR, lower dipole is extending with fallen graupel "capacitor" plate.**
- **Strong accelerating electric field of 1.7-2.2 kV/cm can extend 1-2 km till the earth's surface.**
- **The potential drop in thunderous atmosphere can reach 350-500 MV.**
- **Often TGEs, which produce large electron fluxes produce also yet unknown optical emissions of different shapes.**
- **With SEVAN based modules it will be possible not only research TGE relation to lightning origination and modes of electron acceleration in thunderclouds but also connect both atmospheric and space physics (solar bursts, coronal mass ejections, SEP).**

Miscelaneous

Long duration TGEs observed by spectrometers with low energy threshold (≈0.3 MeV). Radon progeny gamma radiation: mostly ^{214}Pb and ^{214}Bi: Radon isotopes circulation. Graupel detection.



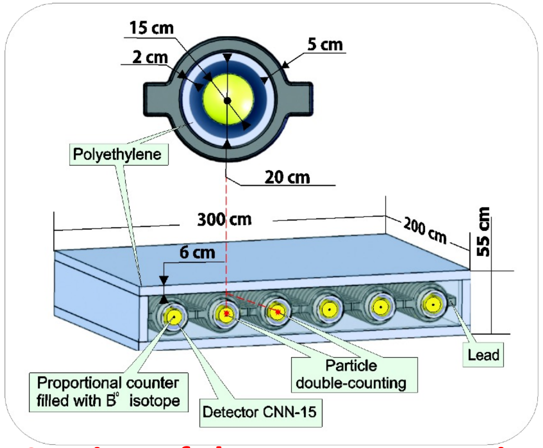
SEVAN basic unit: monitoring 3 species of secondary CR



100 – low energy charged particle;

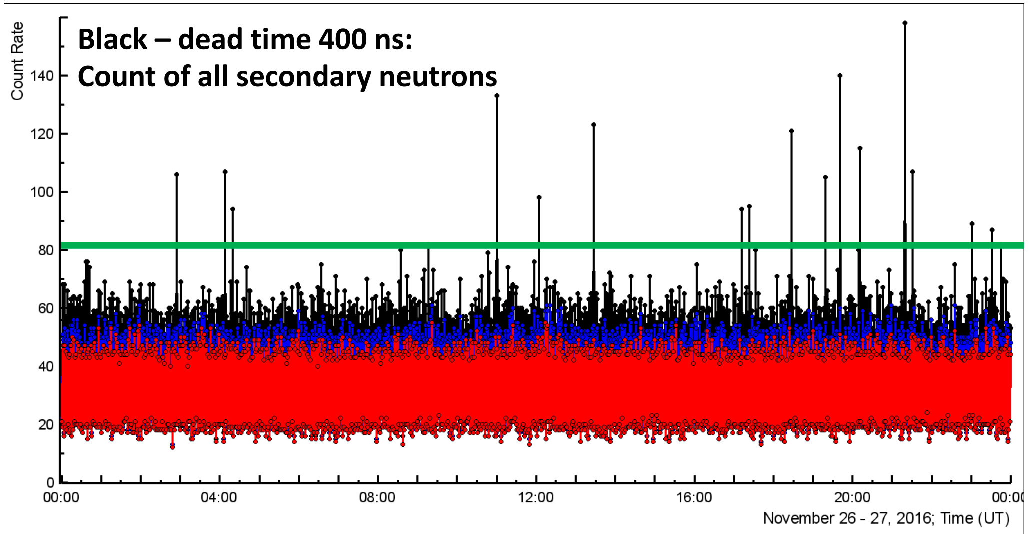
010 – neutral particle (gamma ray or neutron;

111 & 101 – high energy muon (>250MeV);

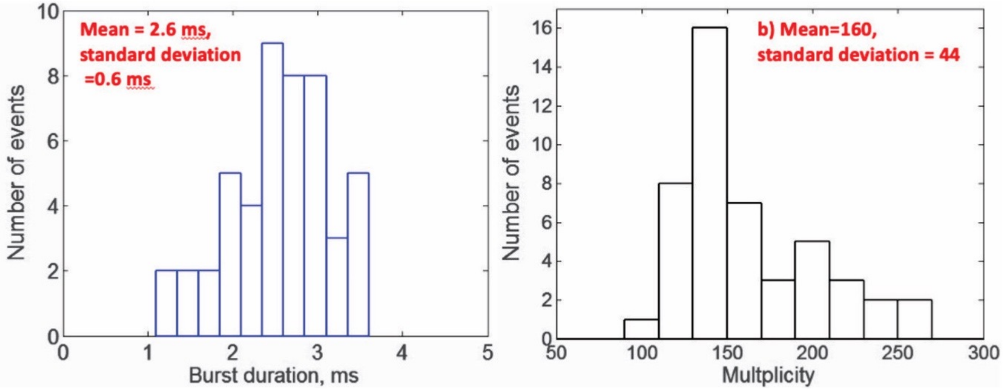


Section of the Neutron Monitor

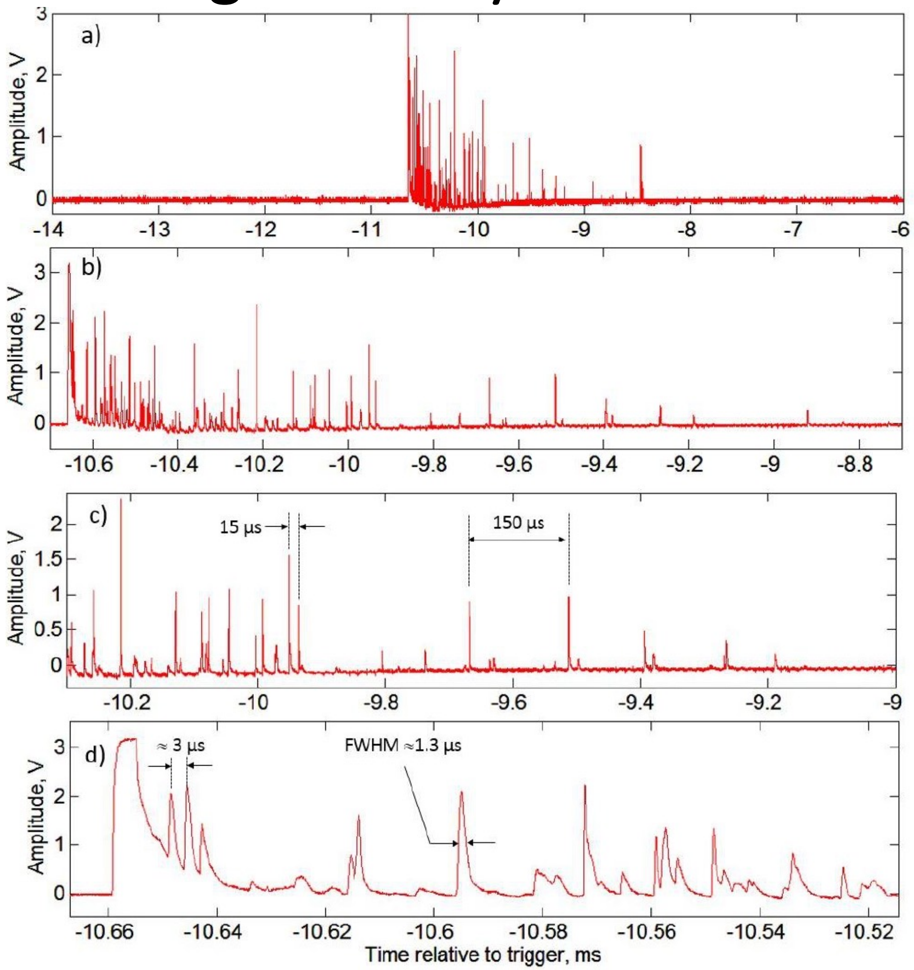
Inverse TGFs – are EAS core particles interacting in soil or lead of neutron monitor: ≈20 signals above 5 sigmas daily!



1-s time series of ArNM multiplicities (dead tine 400 ns); by the red line the multiplicities above 100 are outlined, by the red arrow – the neutron burst shown in Figure to the left.



Neutron burst duration (a) and corresponding multiplicity histogram (b).



Oscilloscope records of neutron burst that occurred at 4:08:05 on 11.26, 2016. The burst duration was ≈ 2.2 milliseconds and the multiplicity is 107 per m^2. The four panels (a-c) show the records of the burst on different time scales.

CRD publications 2021

1. A.Chilingarian, G. Hovsepyan, G.Karapetyan, and M.Zazyan, Stopping muon effect and estimation of intracloud electric field, Astroparticle Physics 124 (2021) 102505.
2. A.Chilingarian, T.Karapetyan, M.Zazyan, G.Hovsepyan, Balabek Sargsyan,Nina Nikolova, Hristo Angelov, Jaroslav Chum, and Rony Langer, Maximum strength of the atmospheric electric field, PRD, 2021, 103, 043021 (2021).
3. A.Chilingarian, High Energy Physics in the Earth's Atmosphere, Природа 3, 11, 2021.
4. A. Chilingarian, D. Aslanyan, B. Sargsyan , On the origin of particle flux enhancements during winter months at Aragats, Physics Letters A 399 (2021) 127296
5. Svechnikova E.K., Ilin N.V., Mareev E.A., A.Chilingarian, Characteristic features of the clouds producing thunderstorm ground enhancements, JGR Atmosphere, 2021, 126, e2019JD030895, doi:10.1029/2019JD030895.
6. A. Chilingarian, G. Hovsepyan, E. Svechnikova, and M. Zazyan, Electrical structure of the thundercloud and operation of the electron accelerator inside it, Astroparticle Physics 132 (2021) 102615 https://doi.org/10.1016/j.astropartphys.2021.102615.
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8. Ashot Chilingarian, The progress of High-Energy Physics in Atmosphere achieved with the implementation of particle physics and nuclear spectroscopy methods, 2021, 37th International Cosmic Ray Conference, DOI: 10.22323/1.395.0366
9. Chilingarian, A., Hovsepyan, G., & Zazyan, M. (2021). Muon tomography of charged structures in the atmospheric electric field. *Geophysical Research Letters*, *48*, e2021GL094594. https://doi.org/10.1029/2021GL094594
10. Soghomonyan, Suren, Chilingarian, Ashot, Khanikyants, Yeghia (2021), "Dataset for Thunderstorm Ground Enhancements terminated by lightning discharges", Mendeley Data, V1, doi: 10.17632/p25bb7jrfp.1
11. Soghomonyan, Suren, Chilingarian, Ashot (2021), "Thunderstorm ground enhancements abruptly terminated by a lightning flash registered both by WWLLN and local network of EFM-100 electric mills.", Mendeley Data, V1, doi: 10.17632/ygvjzdx3w3.1
12. Chilingarian, Ashot, Hovsepyan, Gagik (2022), Dataset for 16 parameters of ten thunderstorm ground enhancements (TGEs) allowing recovery of electron energy spectra and estimation the structure of the electric field above earth's surface, Mendeley Data, V1, doi: 10.17632/tvbn6wdf85.2
13. Soghomonyan, Suren; Chilingarian, Ashot; Pokhsraryan, David (2021), "Extensive Air Shower (EAS) registration by the measurements of the multiplicity of neutron monitor signal", Mendeley Data, V1, doi: 10.17632/43ndcktj3z.1

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1. A. Chilingarian, G. Hovsepyan, T.Karapetyan, B.Sarsyan, and S.Chilingaryan Measurements of energy spectra of relativistic electrons and gamma-rays avalanches developed in the thunderous atmosphere with Aragats Solar Neutron Telescope, Journal of Instrumentation, 17 P03002 (2022).
2. A. Chilingarian, G. Hovsepyan, The synergy of the cosmic ray and high energy atmospheric physics: Particle bursts observed by arrays of particle detectors, New Astronomy, 97 (2022) 101871
3. A. Chilingarian, G. Hovsepyan, T. Karapetyan, Y. Khanykyanc, D. Pokhsraryan, B. Sargsyan, S. Chilingaryan and S. Soghomonyan, Multi-messenger observations of thunderstorm-related bursts of cosmic rays, 2022 *JINST* 17 P07022[4]
4. A.Chilingarian, G.Hovsepyan, T.Karapetyan, B.Sargsyan, and M.Zazyan, Development of the relativistic runaway avalanches in the lower atmosphere above mountain altitudes, EPL, 2022, DOI: https://doi.org/10.1209/0295-5075/ac8763
5. A.Chilingarian, A.; Hovsepyan, G.; Karapetyan, T.; Sargsyan, B.; Svechnikova, E. Transient Luminous Events in the Lower Part of the Atmosphere Originated in the Peripheral Regions of a Thunderstorm. Universe 2022, 8, 412. https://doi.org/10.3390/ universe8080412
6. A.Chilingarian, G.Hovsepyan, T.Karapetyan, B.Sargsyan, and M.Zazyan, Development of the relativistic runaway avalanches in the lower atmosphere above mountain altitudes, EPL, 139 (2022) 50001, https://doi.org/10.1209/0295-5075/ac8763
7. A.Chilingarian, G. Hovsepyan, T.Karapetyan, L. Kozliner, S.Chilingaryan. D. Pokhsraryan, and B. Sargsyan, The horizontal profile of the atmospheric electric fields as measured during thunderstorms by the network of NaI spectrometers located on the slopes of Mt. Aragats, 2022, *JINST* **17** P10011.
8. A. Chilingarian, G. Hovsepyan, D. Aslanyan, T. Karapetyan, Y. Khanikyanc, L.Kozliner, B. Sargsyan, S.Soghomonyan, S.Chilingaryan, D.Pokhsraryan, and M.Zazyan (2022) Thunderstorm Ground Enhancements: Multivariate analysis of 12 years of observations, PRD, in press.
9. A. Chilingarian, G. Hovsepyan, T. Karapetyan, B. Sargsyan, D.Aslanyan, and M.Zazyan (2022) TGE electron energy spectra: Comment on “Radar Diagnosis of the Thundercloud Electron Accelerator” by E. Williams et al. (2022), submitted to JGR.
10. A Chilingarian, G Hovsepyan, M Zazyan, Sinergy of extra-terrestrial particle accelerators and accelerators operated in the terrestrial atmosphere, submitted to Journal of Physics Conference Series.
11. A Chilingarian, G Hovsepyan, T Karapetyan, and B Sargsyan and M Zazyan, On the vertical and horizontal profiles of the atmospheric electric field during thunderstorms, submitted to Journal of Physics Conference Series.