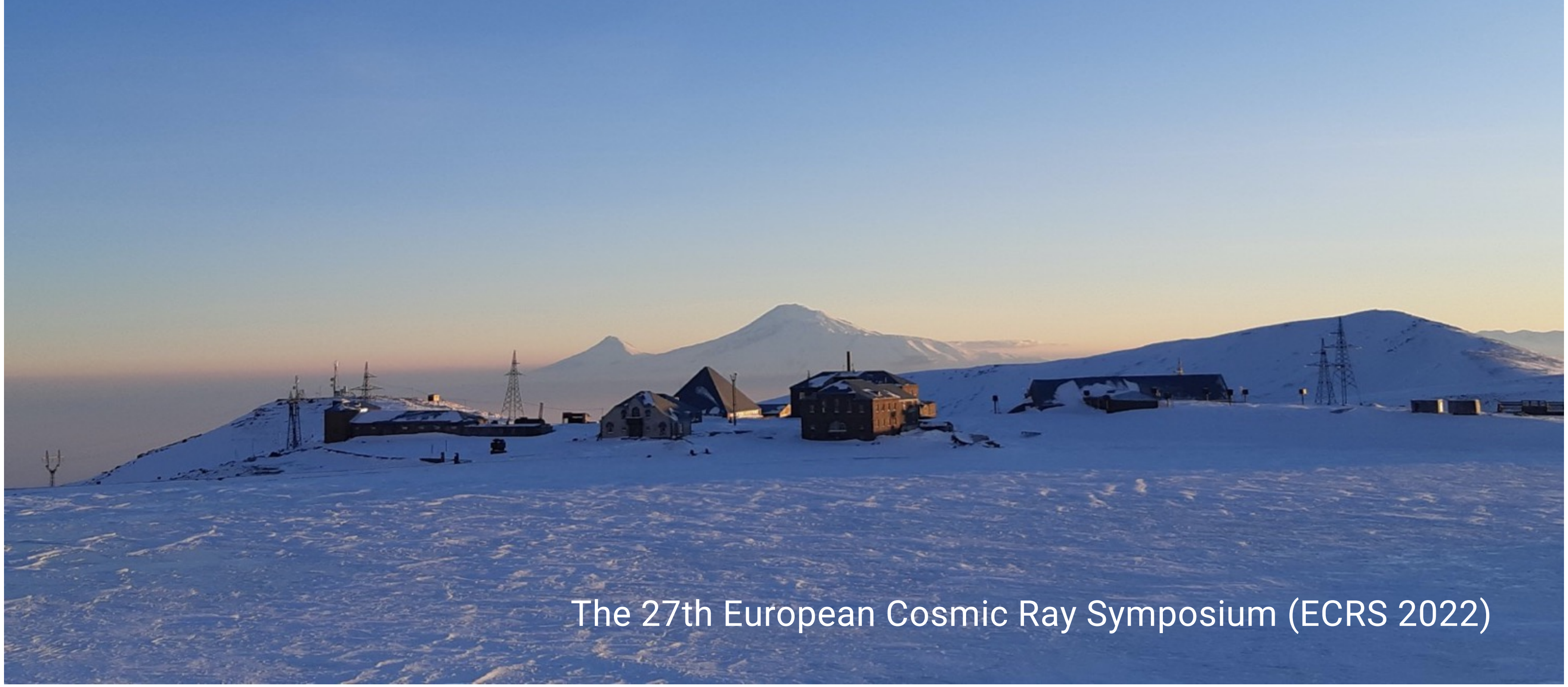
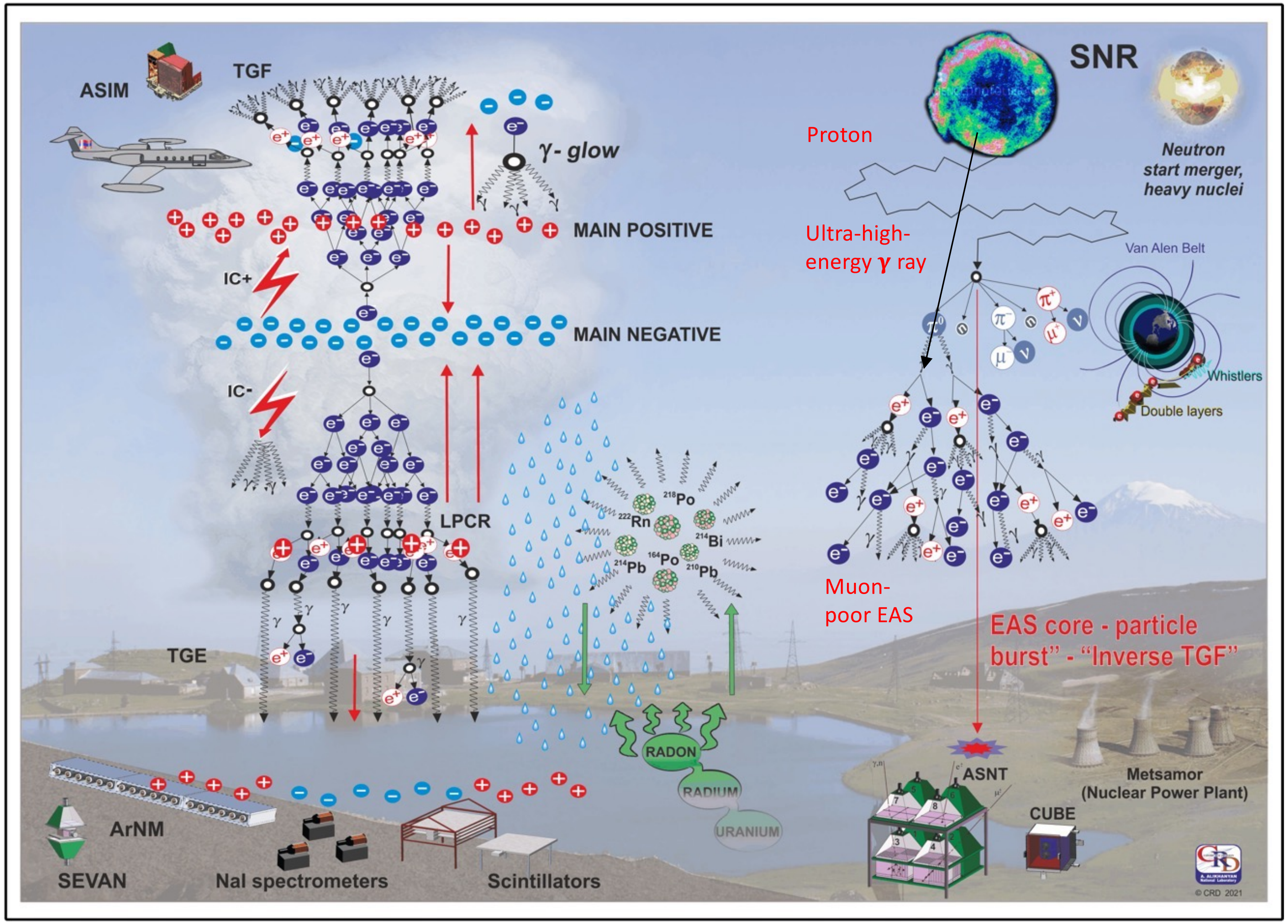
The synergy between High-energy Physics in Atmosphere and Cosmic Ray Physics

A.Chilingarian, G.Hovsepyan, M.Zazyan

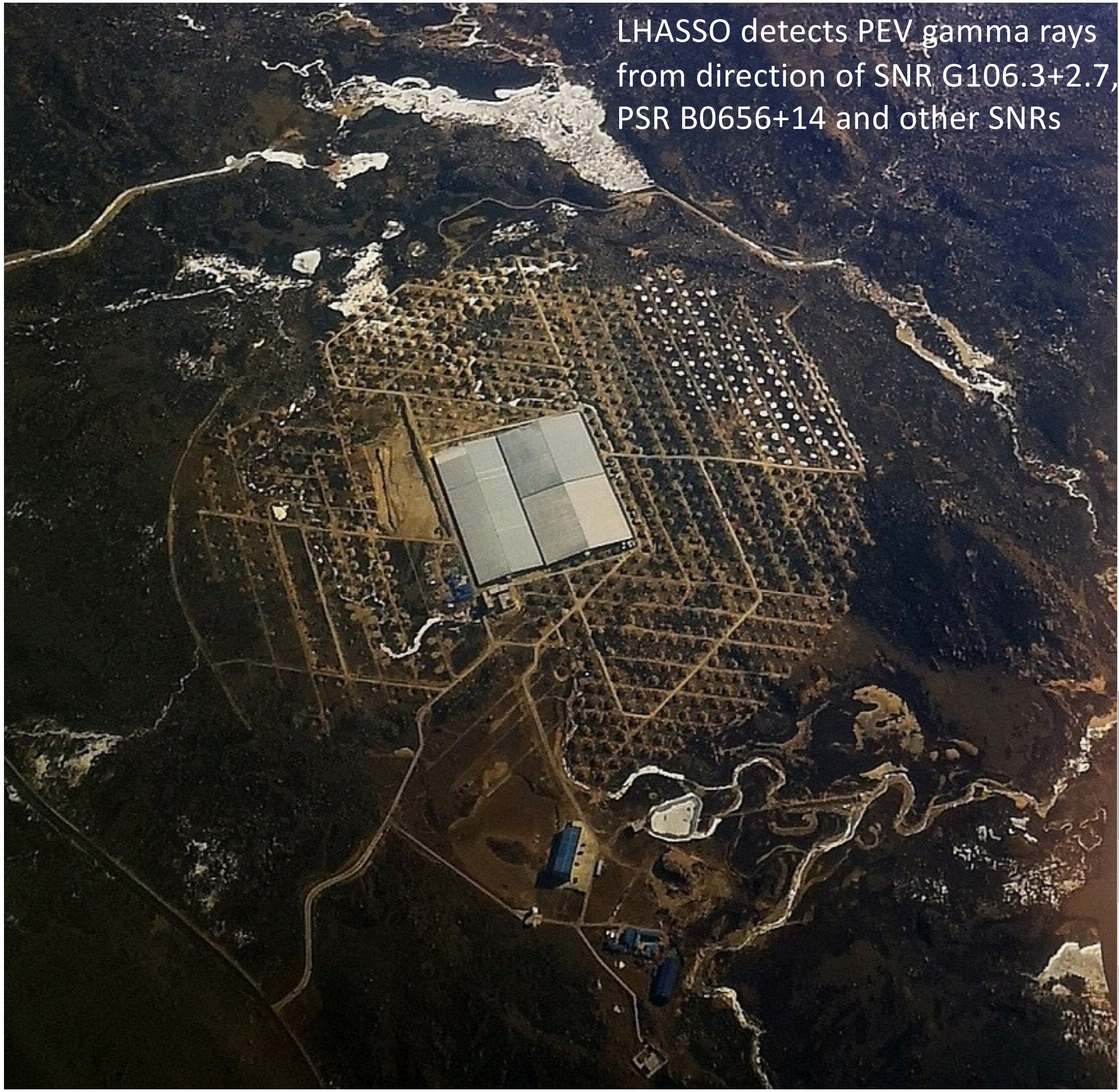
Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia, 0036



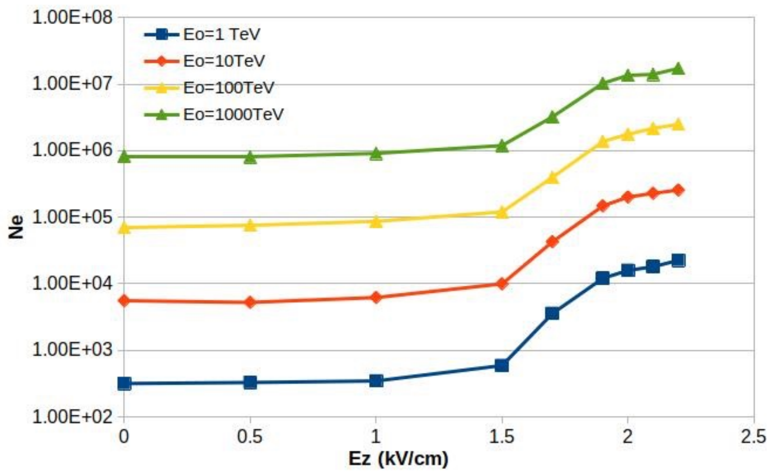
The 27th European Cosmic Ray Symposium (ECRS 2022)



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 Kare lake in the vicinity of Aragats south peak ≈(3700m), the highest North peak is ≈4000 m.

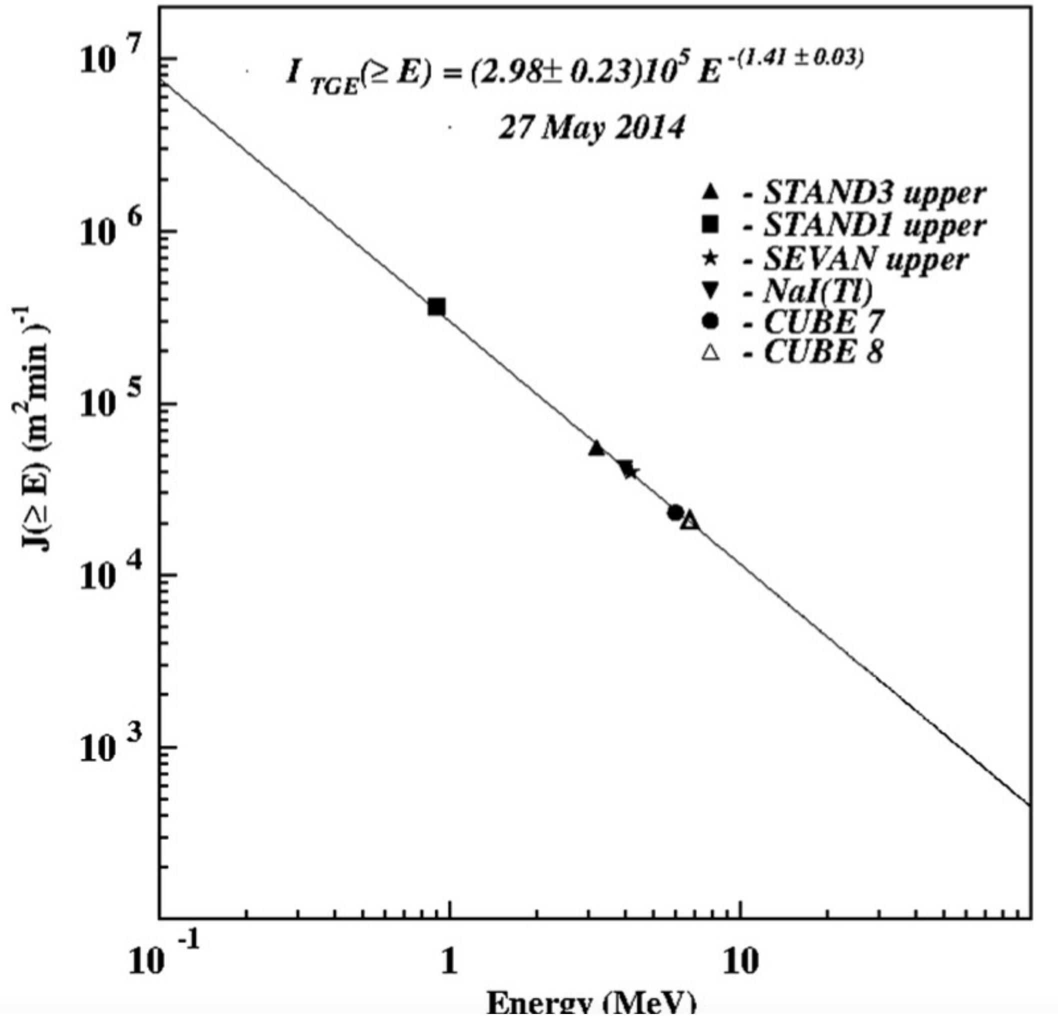


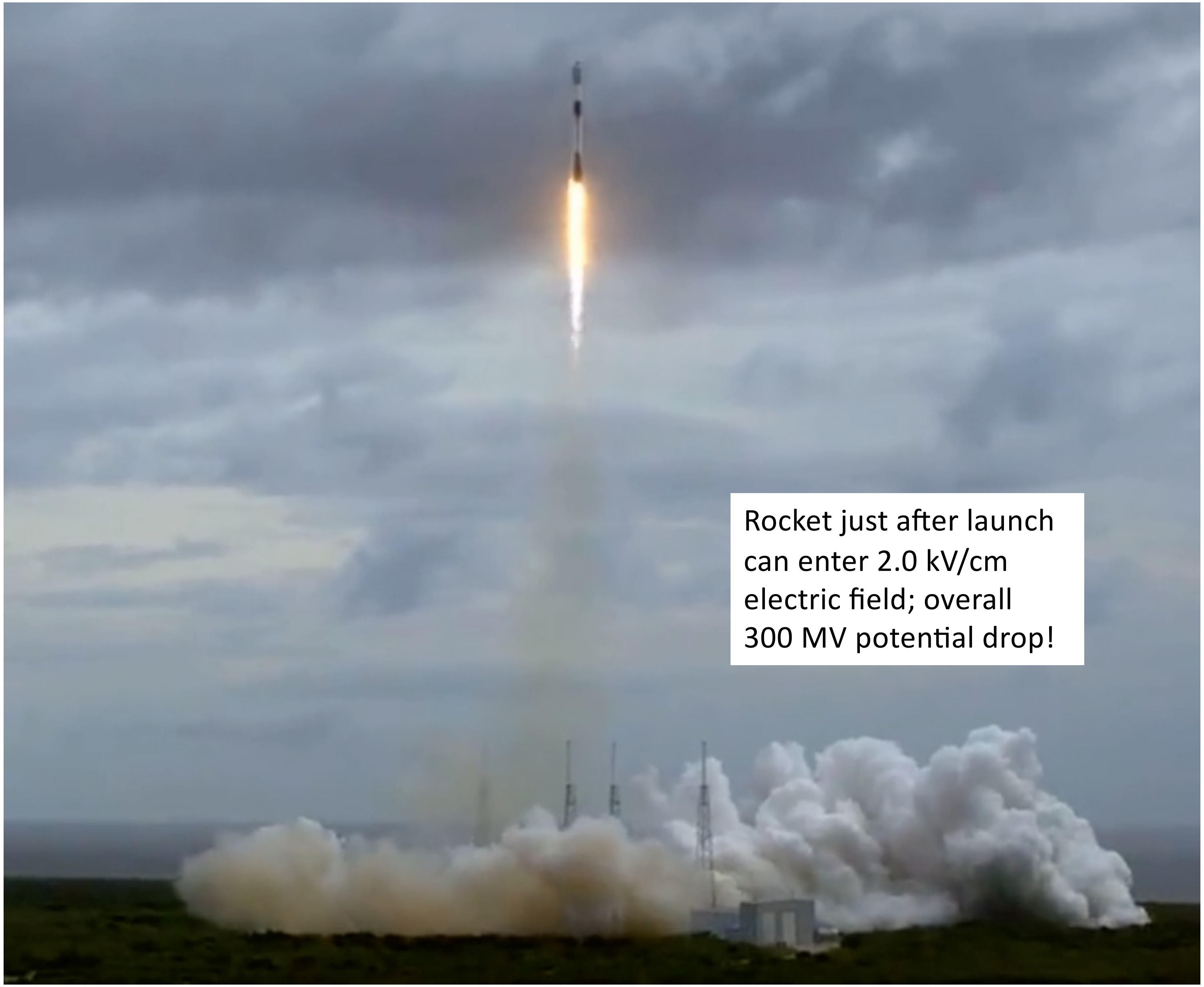
PEVatron detection by LHASSO: possible overestimation of primary gamma ray energies if observations were done during thunderstorms often in Tibetan plateau.



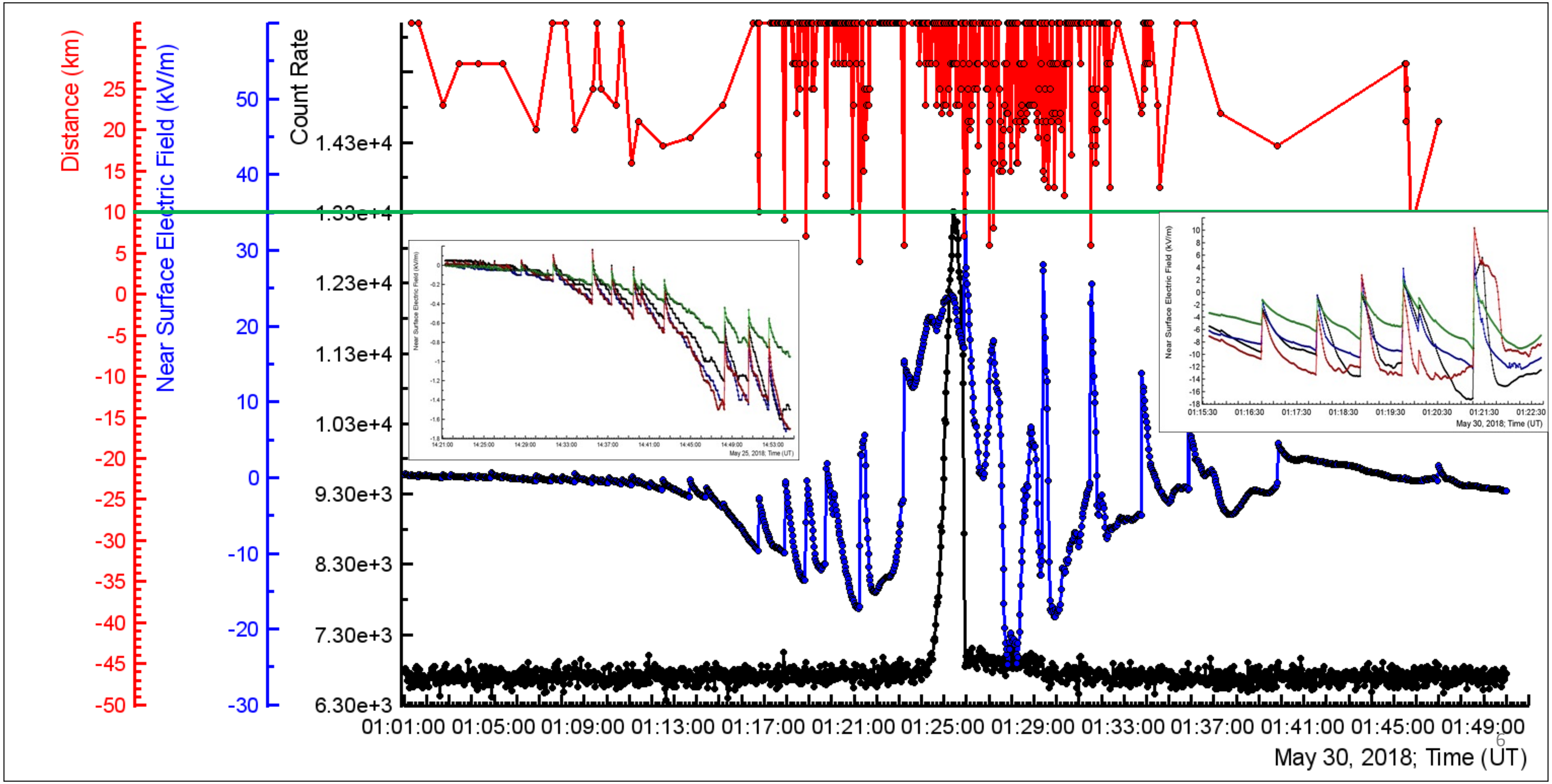
Eo (GeV)	Eest (GeV)
1.00E+03	2.23E+04
1.00E+04	1.34E+05
1.00E+05	6.50E+05
1.00E+06	2.42E+06

The integral energy spectra of the TGE gamma rays with superimposed intensities measured with different ASEC particle detectors (energy thresholds): continuous calibration of the EAS array scintillators

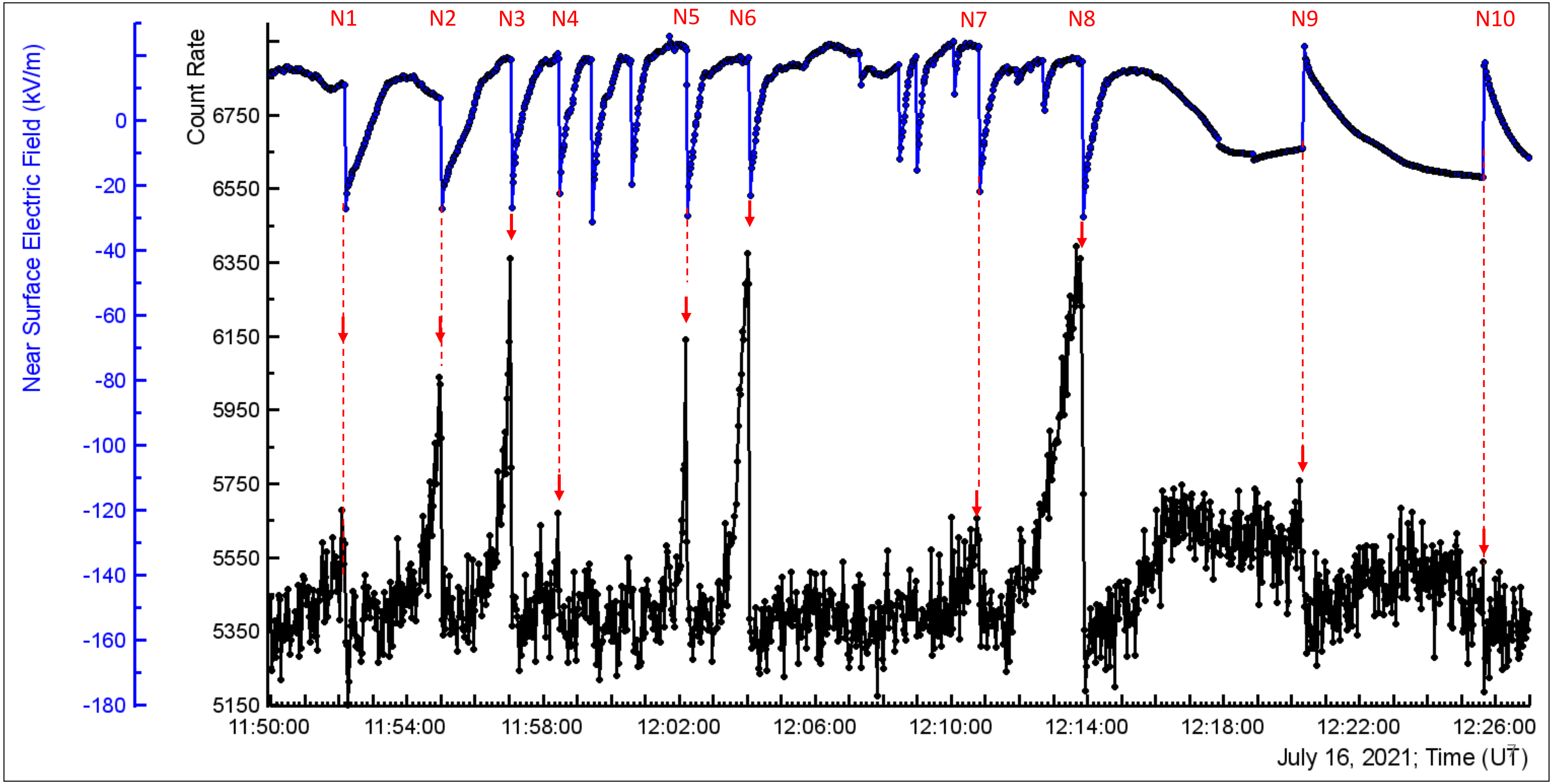



Rocket just after launch
can enter 2.0 kV/cm
electric field; overall
300 MV potential drop!

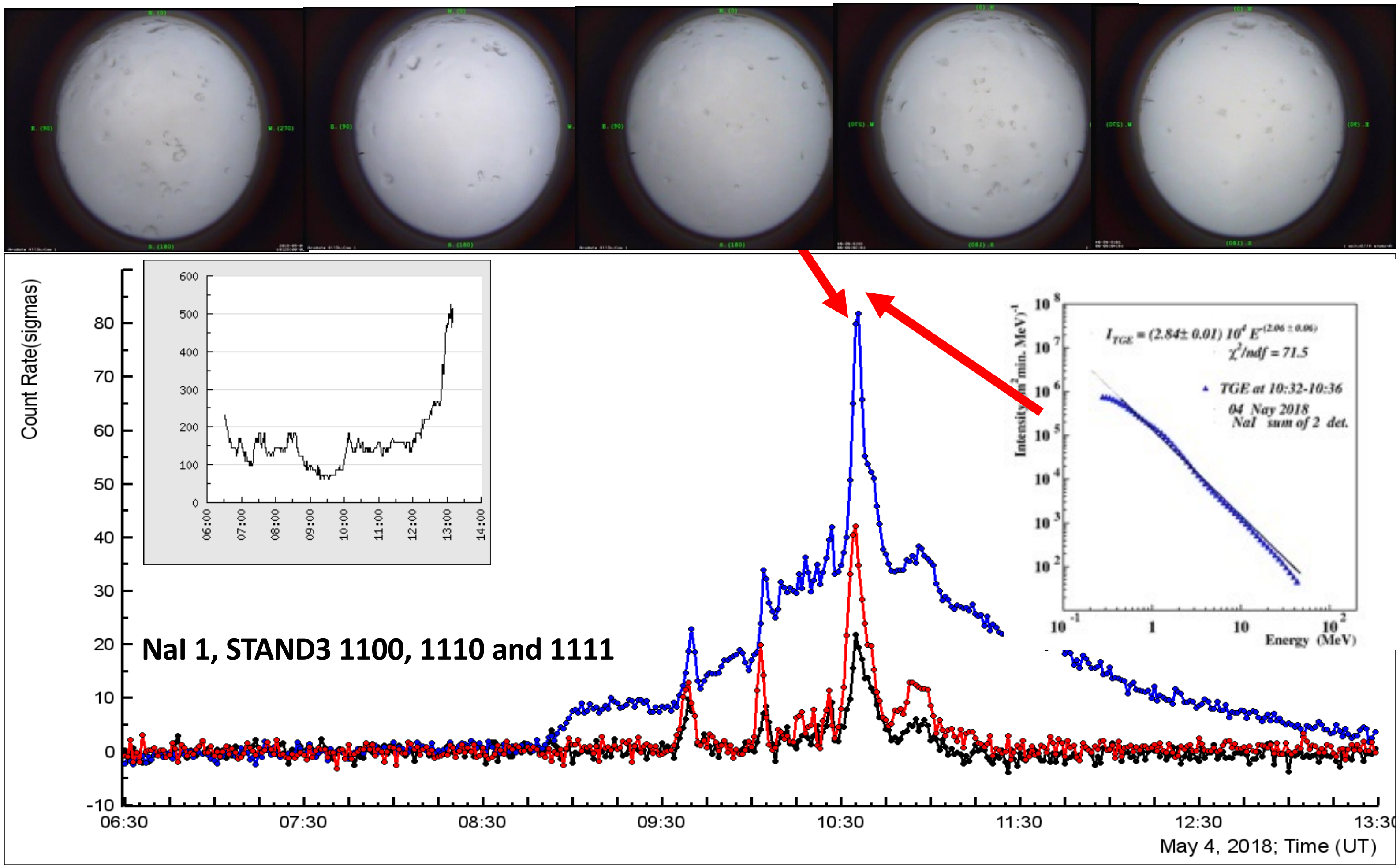
15 years of monitoring of Lightning location, Near-surface electric field (NSEF) and particle fluxes measured by multiple spectrometers…



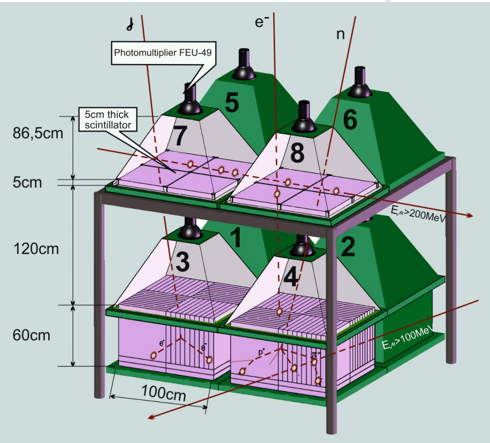
TGE terminations by nearby (distance <10 km) lightning flashes: NSEF disturbances and particle detector count rates

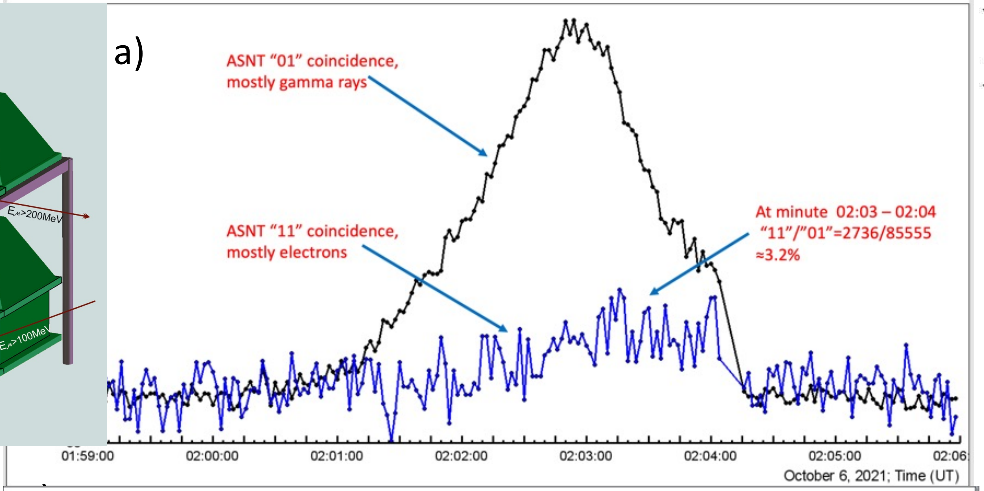


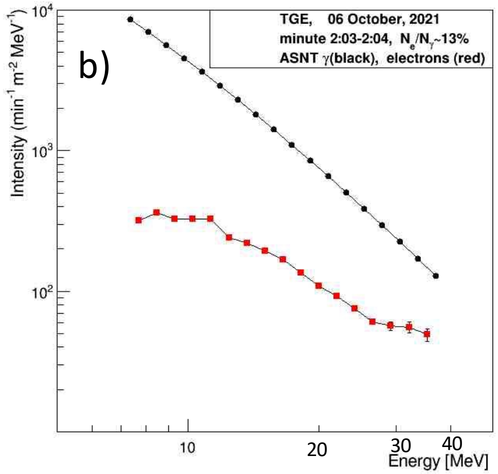
Long duration TGEs observed by spectrometers with low energy threshold (≈0.3 MeV). Radon progeny gamma radiation: mostly 214Pb and 214Bi: Radon isotopes circulation. Graupel detection.

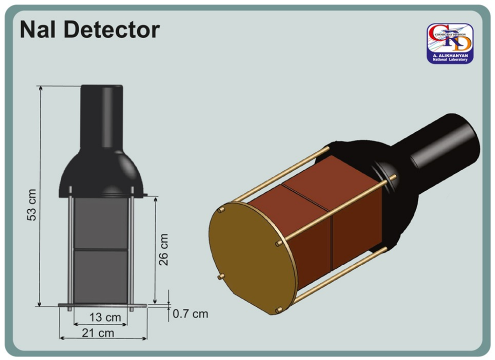


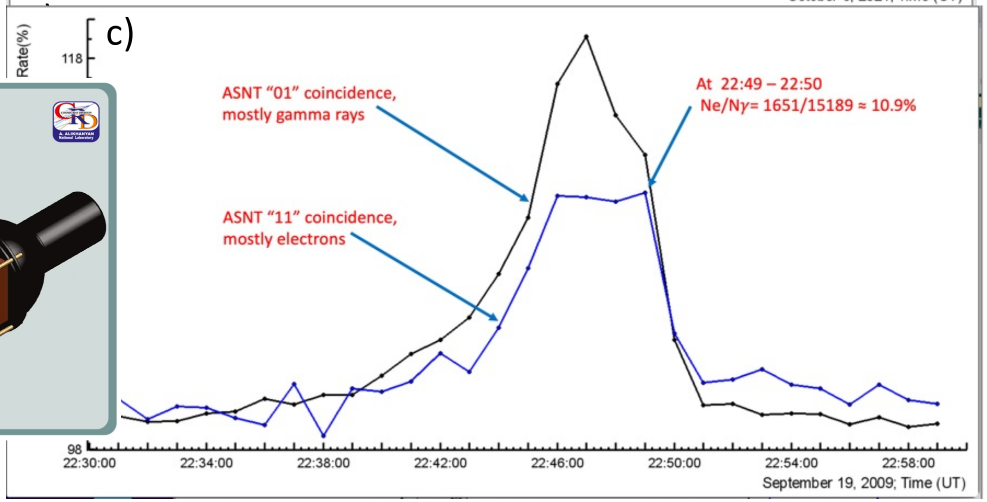
Recovering of the TGE gamma ray and electron energy spectra in the energy range 0.3 – 60 MeV

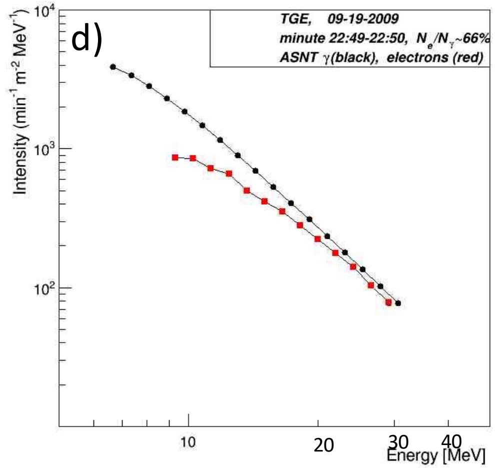




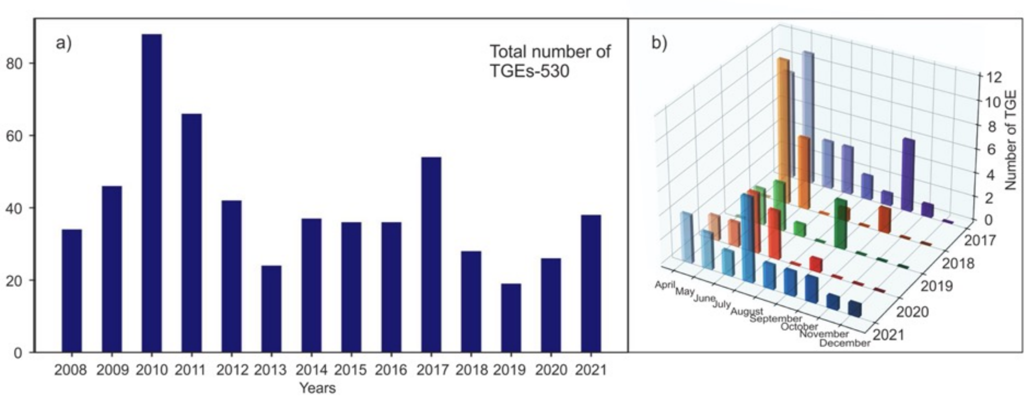




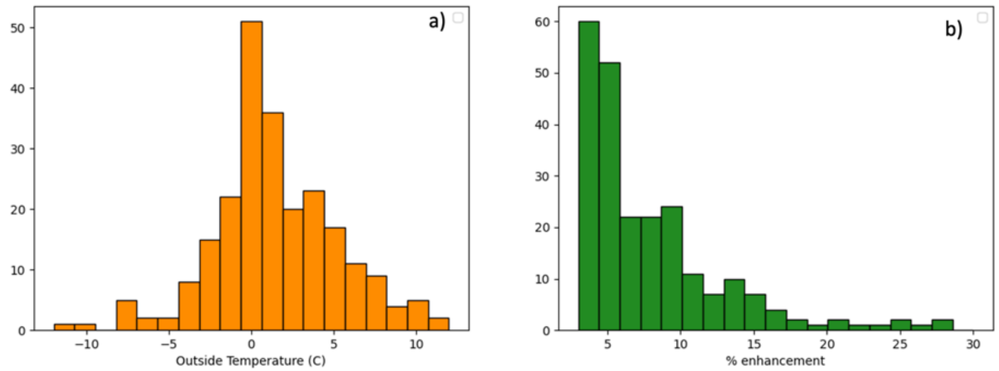




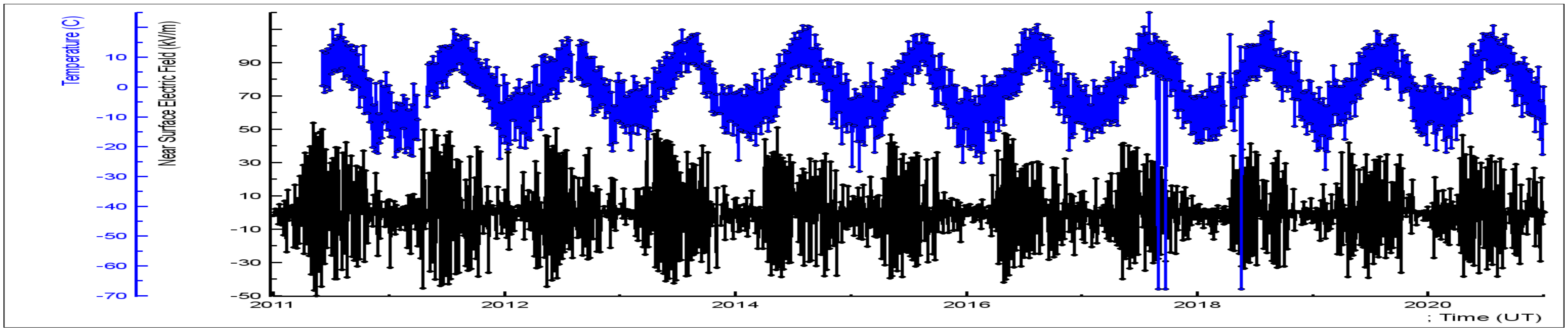
TGE statistics ≈550 TGEs registered in 2009-2021



TGE yearly and monthly statistics.



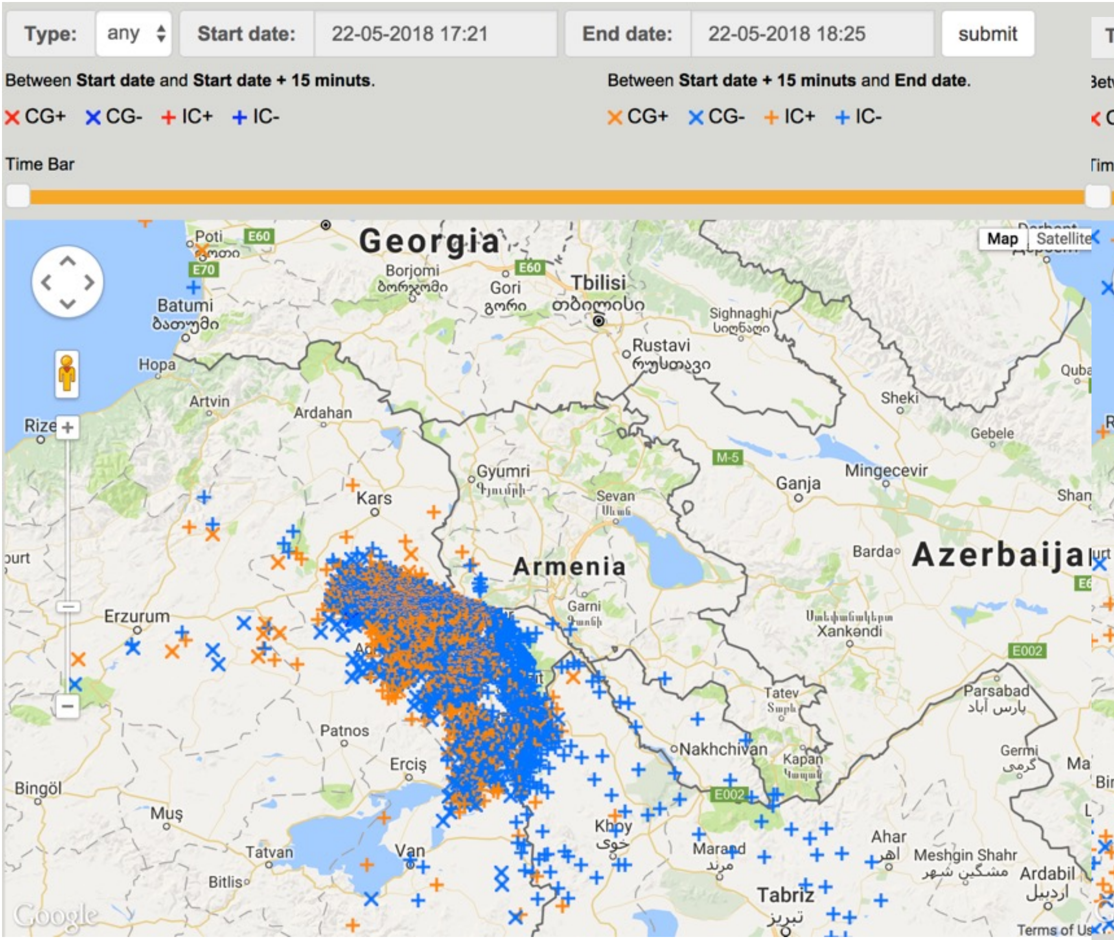
a)The distribution of outside temperatures during TGEs;
b) distribution of TGE significances by 3 cm thick plastic scintillator of STAND3 detector.

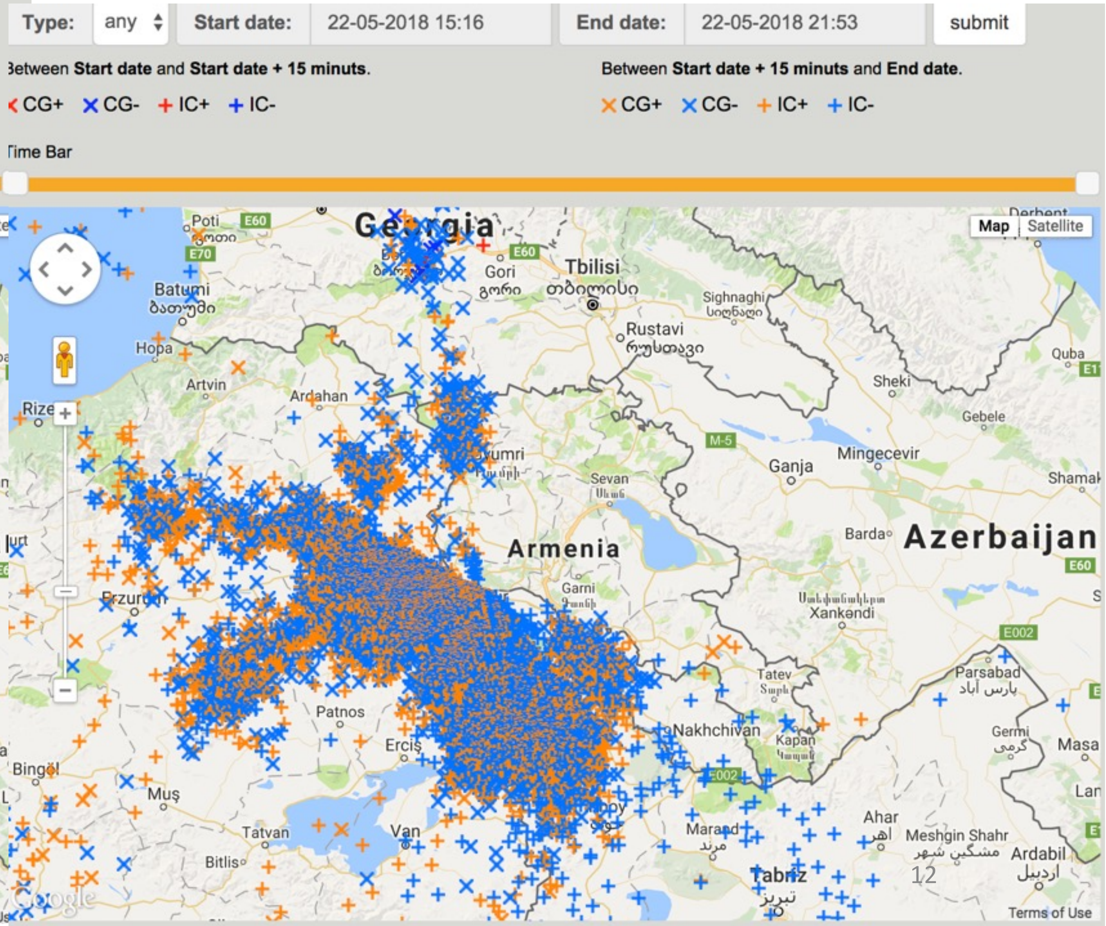


Time series of the NSEF (electric mill EFM-100 by BOLTEK firm, black), and outside temperature (DAVIS weather station, blue)

Thundeclouds above
Aragats highland

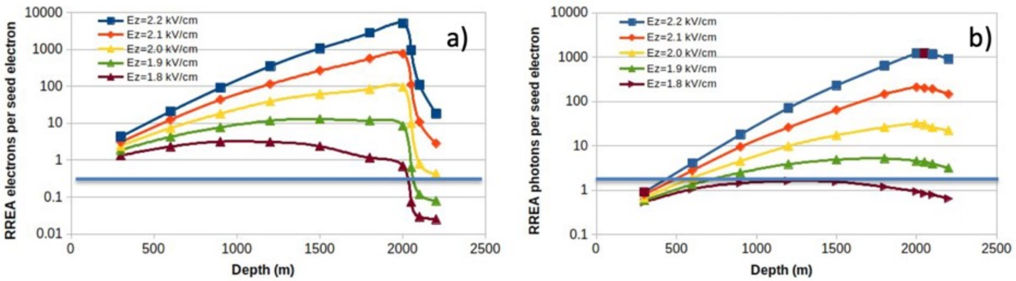
Huge thunderstorms with hundreds of lightning flashes are usual on Aragats.





Vertical profile of the atmospheric electric field conditioned on the registered TGE

The energy spectrum of seed electrons was adopted from the EXPACS WEB calculator following the power low with power index - 1.173 in the energy range 1-300 MeV. The number of seed electrons from the ambient population of secondary cosmic rays was obtained from the same calculator, to be 42,000 with energies above 1 MeV. The estimated distance to the cloud base during large "electron" TGE is usually 25 – 200 m, thus in our simulations presented in Table 1, the particle avalanches continued propagation in the dense air additionally 50, 100, and 200 meters before registration. Simulation trials include from 10^3 to 10^4 events for the electric field strengths of 1.8-2.2 kV/cm. The propagation of electrons and gamma rays were followed in the avalanche until their energy decreased down to 0.05 MeV.



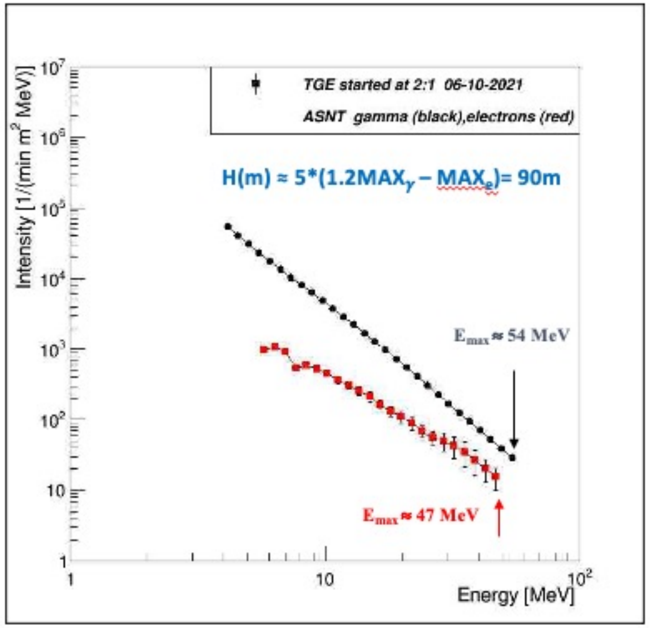
RRE avalanche in the atmosphere a) – electrons, b) gamma rays. Avalanche started at 5400 m a.s.l. (0 depth), that is 2200 m above the Aragats station. The number of avalanche particles is calculated each 300 m. After exiting from the electric field propagation of avalanche particles is followed additionally 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.

	Height of termination of el. field above detectors	N of el. E> 4 MeV per seed electron	N of γ rays E> 4 MeV per seed electron
1.8 kV/cm	100	0.03	0.78
1.9 kV/cm	100	0.12	3.9
1.9 kV/cm	200	0.08	3.1
2.0 kV/m	200	0.43	22
14/6/2020	-	0.14	1.26
27/6/2020	-	0.041	0.51
23/7/2020	-	0.059	0.49

Parameters of the simulated RREAs calculated with CORSIKA code and of 3 TGEs observed in 2020.

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

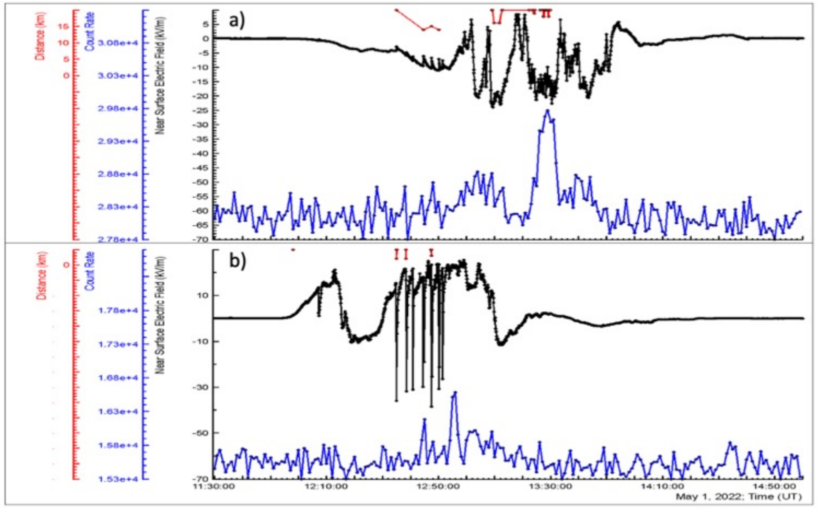
Distance from detector to the bottom edge of the field (m)	Expected gamma absorption (%) and electron ionization losses (MeV)
50	8.67
100	16.6
200	30.44
300	41.98
400	51.62
1000	83.7
10000	99.99999
50	8
100	16.1
200	32.1
300	48.23
400	64.3



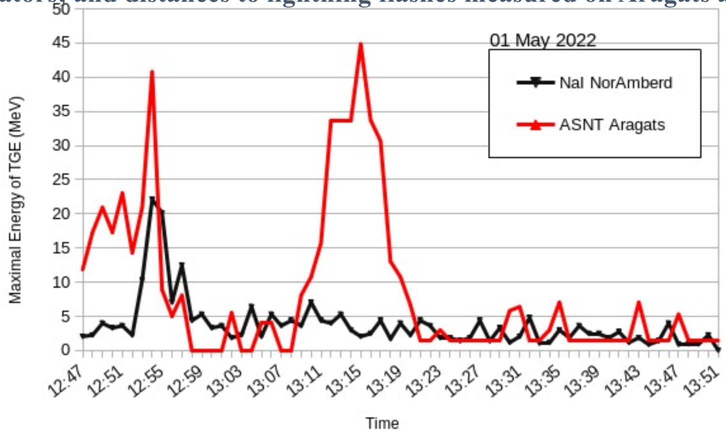
By comparing maximal energy of the recovered electron and gamma ray spectra we show that a strong accelerating field (≈2 kV/cm) can be very low above the earth's surface!

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 (5 units) and in Nor Amberd.

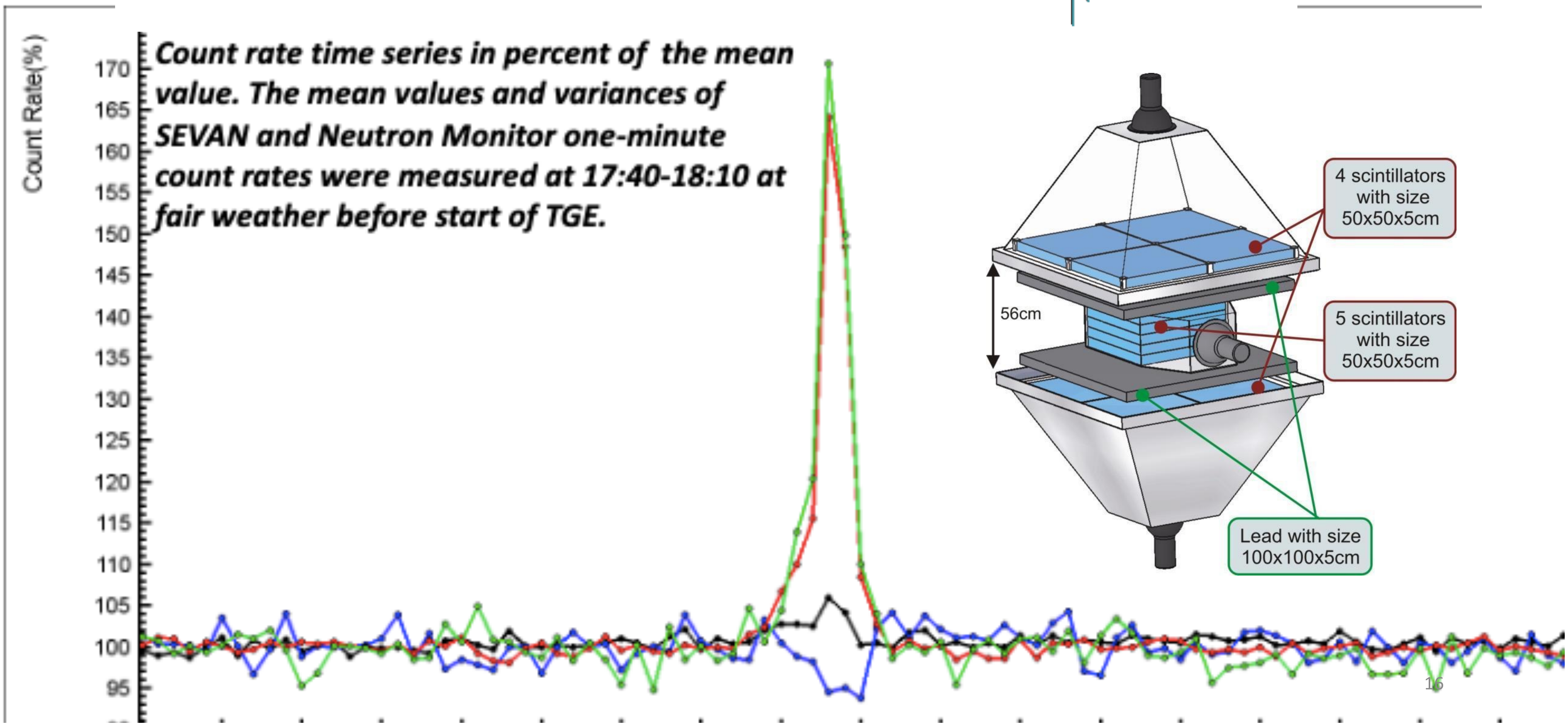


The disturbances of the NSEF; 1-minute count rates of 5 cm thick and 1 m^2 area plastic scintillators; and distances to lightning flashes measured on Aragats and in Nor Amberd



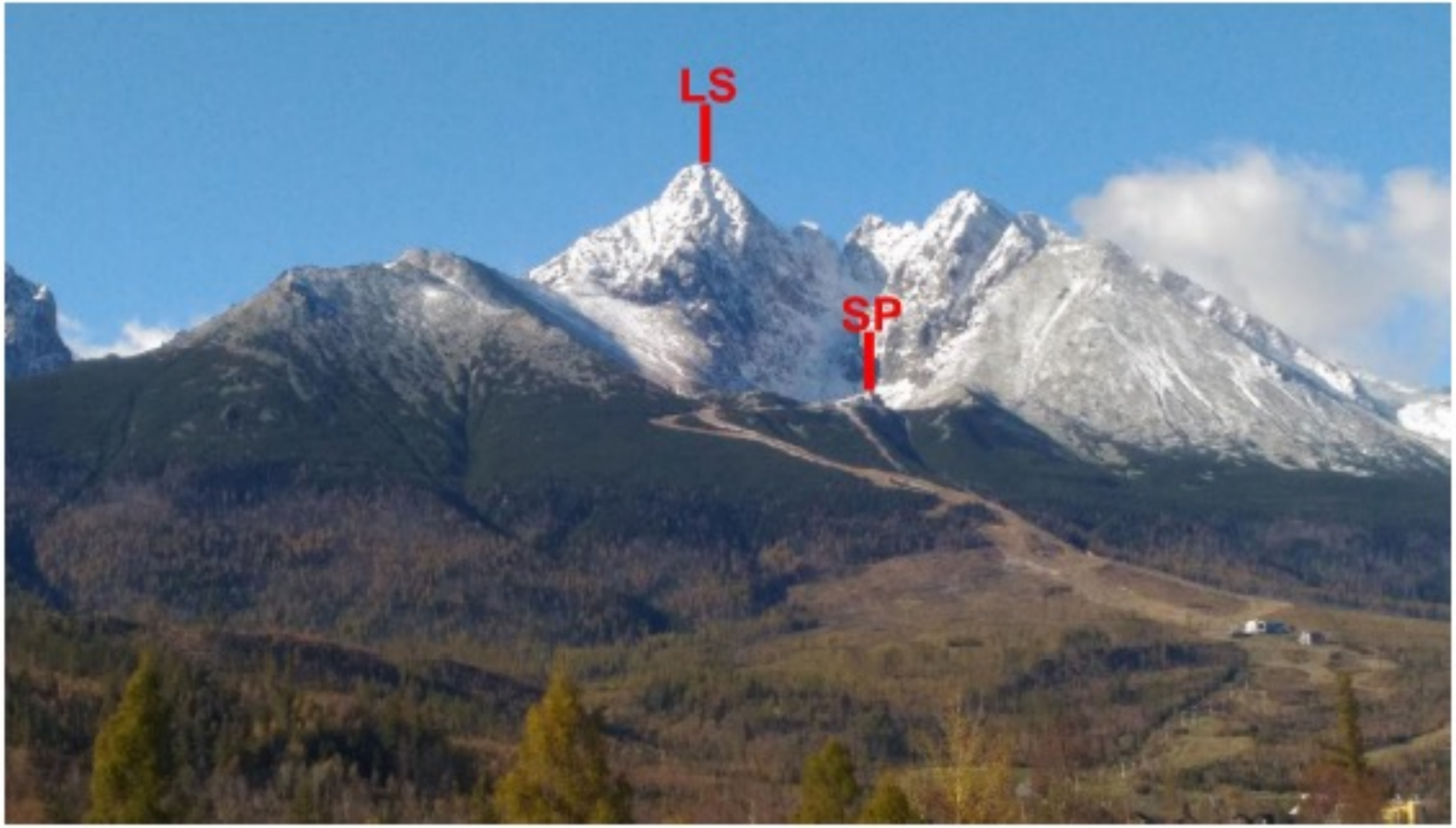
The histogram of maximum energies of energy spectra measured on Aragats with a large scintillation spectrometer ASNT, and in Nor Amberd by the NaI

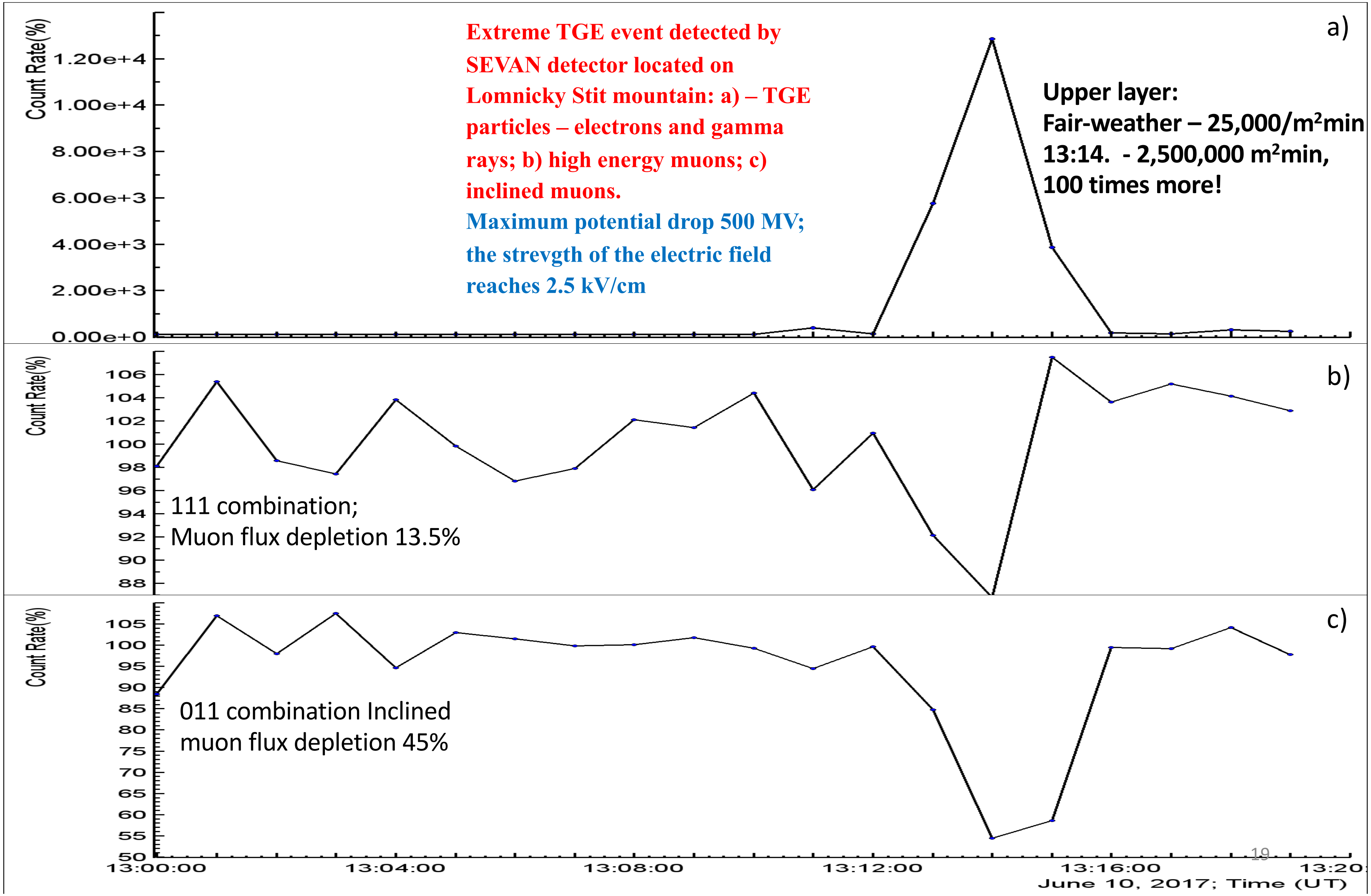
SEVAN basic unit: monitoring 3 species of secondary CR



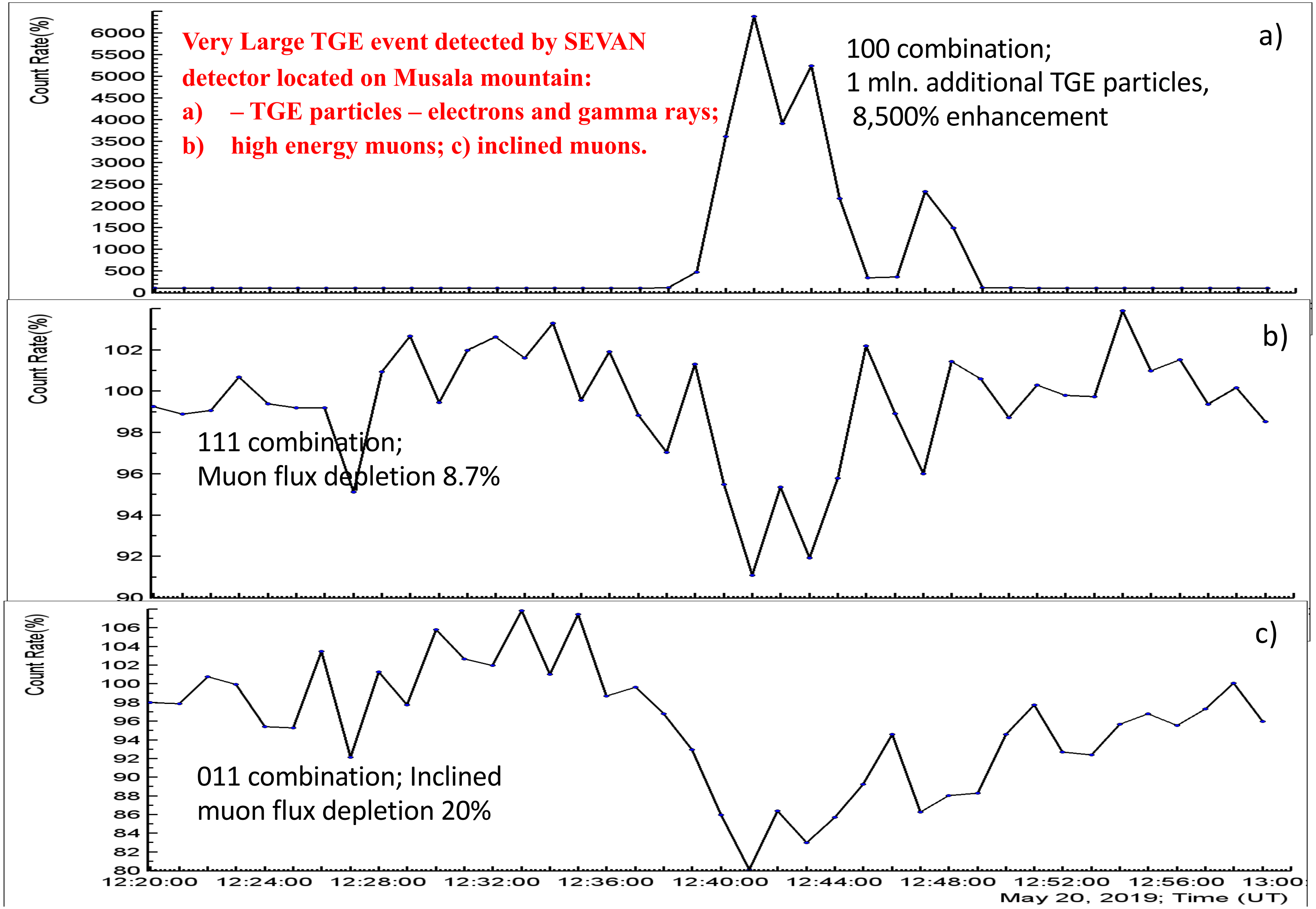
MUSALA Latitude - 42º11’N, 23º35’ E
2925 m,

Lomnický štít (LS) 49.1952 N 20.2131 E 2634 m





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 strevgth 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!
a)
b)
c)
Count Rate(%)
1.20e+4
1.00e+4
8.00e+3
6.00e+3
4.00e+3
2.00e+3
0.00e+0
106
104
102
100
98
96
94
92
90
88
111 combination;
Muon flux depletion 13.5%
105
100
95
90
85
80
75
70
65
60
55
50
011 combination Inclined
muon flux depletion 45%
13:00:00
13:04:00
13:08:00
13:12:00
13:16:00
13:20:
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)
Count Rate(%)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
b)
111 combination;
Muon flux depletion 8.7%
102
100
98
96
94
92
90
c)
011 combination; Inclined
muon flux depletion 20%
106
104
102
100
98
96
94
92
90
88
86
84
82
80
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)

The main results made by 24/7 monitoring of particle fluxes in Armenia and Eastern Europe (SEVAN network)

High-energy astrophysics and high-energy atmospheric physics have many interactions and influences on each other.

- **Thunderstorm ground enhancements are a universal physical phenomena sending ≈10^{18} particles to the earth's surface each second.**
- **Strong accelerating electric field of 1.8-2.2 kV/cm can extend 2 km vertically till the earth's surface and several kilometers horizontally.**
- **The potential drop in thunderous atmosphere can reach 350-500 MV.**
- **Near-surface electrical field lift the Radon progeny to the atmosphere providing additional gamma radiation, thus enhancing the gamma ray flux in the energy range 0.3 – 3 MeV.**

TEPA
International Conference, 17-20 October
Prague, Czech Republic
THUNDERSTORMS AND ELEMENTARY PARTICLE ACCELERATION
ORGANIZERS:
Cosmic Ray Division
of Yerevan Physics Institute, Armenia
Research Centre of Cosmic Rays and Radiation Events in Atmosphere (CRREAT),
Nuclear Physics Institute of the CAS, Czechia
STRUCTURE OF THE SYMPOSIUM:
We anticipate the following sessions:
1. Multivariate observations of particles from the Earth's surface, in the atmosphere, and from space (TGEs, gamma glows, and TGFs);
2. Remote sensing and modeling of the atmospheric electric field;
3. Correlated measurements of the atmospheric discharges and particle fluxes, time-space structure of particle bursts;
4. Influence of the atmospheric electric field on measurements of experiments using the atmosphere as a target (Surface Arrays and Cherenkov Imaging Telescopes)
5. Instrumentation
We plan also discussions on the most intriguing problems of high-energy physics in the atmosphere and on possible directions for the advancement of collaborative studies.
The new emerging field of high-energy atmospheric physics (HEAP) has been enriched recently by important observations of particle fluxes on Earth's surface, in the troposphere, and in space. HEAP presently includes 3 main types of measurements: Terrestrial Gamma Ray Flashes (TGFs) - a brief bursts of gamma radiation (sometimes also electrons and positrons) registered by orbiting gamma ray observatories in the space, Thunderstorm ground enhancements (TGEs) – short and prolonged electron and gamma ray fluxes registered on the earth's surface, and gamma glows - gamma ray bursts observed in the thunderclouds by instrumentation on balloons and aircraft. Recently to this classification scheme some authors add inverse TGFs, a millisecond duration of intense particle bursts registered on the earth's surface. The central engine initiating the TGE and TGFs is believed to be the Relativistic Runaway Electron avalanches (RREA), which accelerates seed electrons from an ambient population of cosmic rays (CR) in the large-scale thundercloud electric fields. Observation of numerous TGEs by Japanese, Russian, Armenian, Czech, Chinese, Bulgarian, and Slovakian groups proves that RREA is a robust and realistic mechanism for electron acceleration and multiplication. The origin of gamma glows can be also the MOS process, modification of electron energy spectrum in the atmospheric electric field leading to additional gamma ray radiation. The hypothesis of the "lightning origin" of inverse TGFs is still under debate. TGE electron and gamma ray energy spectra give a new clue for recovering the vertical profile of the atmospheric electric field and for testing models of electron acceleration in the atmosphere. Models using GEANT4 and CORSIKA codes support in situ measurements of electron and gamma ray energy spectra at Aragats. Numerous observations of TGEs made on Aragats during the past 13 years can be widely used for the validation of models aimed to explain TGF phenomena. CRREAT project is making good progress in establishing instrumentation for the comprehensive measurements of the particle fluxes, lightning monitoring with fast cameras and various atmospheric parameters, including radar measurements of the hydrometeor evolution during storms. Many questions about thundercloud electrification and discharge mechanisms, lightning initiation, propagation and attachment processes, the global electrical circuit, and transient luminous events do not have yet a commonly accepted explanation. The estimated horizontal profile of the atmospheric electric field, that emerges during thunderstorms is still badly understood. The estimate of the size of the particle emitting region in the thundercloud, made a decade ago by Japanese and Armenian physicists (≈1km radii) seen to be largely undervalued. Enigmatic light glows observed on Aragats during TGEs still waiting for an explanation. The new view of thunderclouds as media full of radiation can help to establish a comprehensive theory of cloud electrification and estimate the possible role of cloud radiation on climate change. The influence of the electrifying atmosphere on the fluxes of electrons and other charged particles can be important for experiments registering very-high-energy photons (Atmospheric Cherenkov telescopes) and hadrons (Surface arrays registering Extensive Air Showers). The TEPA meeting is a great opportunity for the scientists to establish synergy between Atmospheric and Cosmic ray physics, discuss new ideas, and make new bridges for collaborative works.
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