ABSTRACTS & PROGRAMME OF TEPA-2024

THUNDERSTORMS & ELEMENTARY PARTICLE ACCELERATION

80 years of cosmic ray monitoring on Aragats, 15 years of TGE observation

October 14-17, 2024

LOCATION: Cosmic Ray Division of the Yerevan Physics Institute,

Yerevan, Alikhanyan Brothers 2, Armenia.

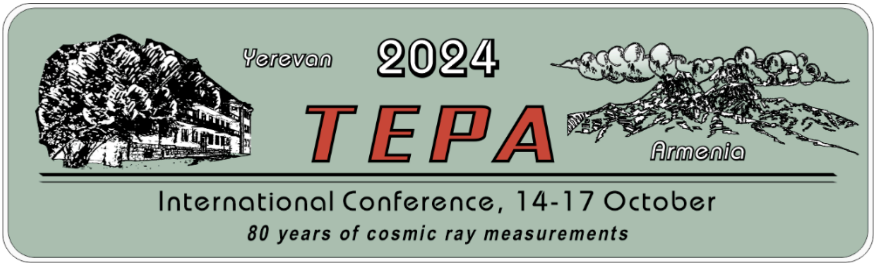
SYMPOSIUM WEBSITE:

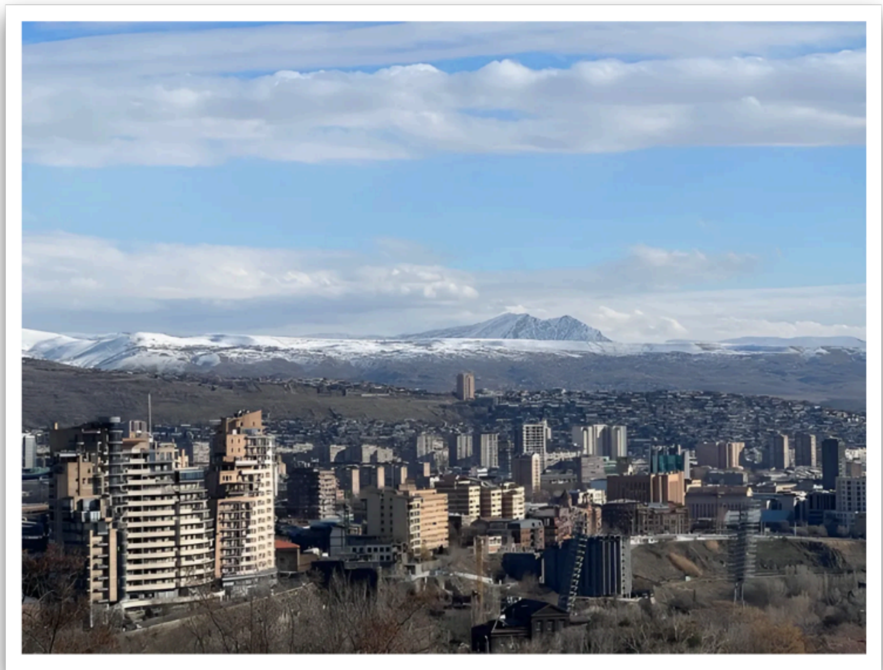
http://crd.yerphi.am/TEPA_2024

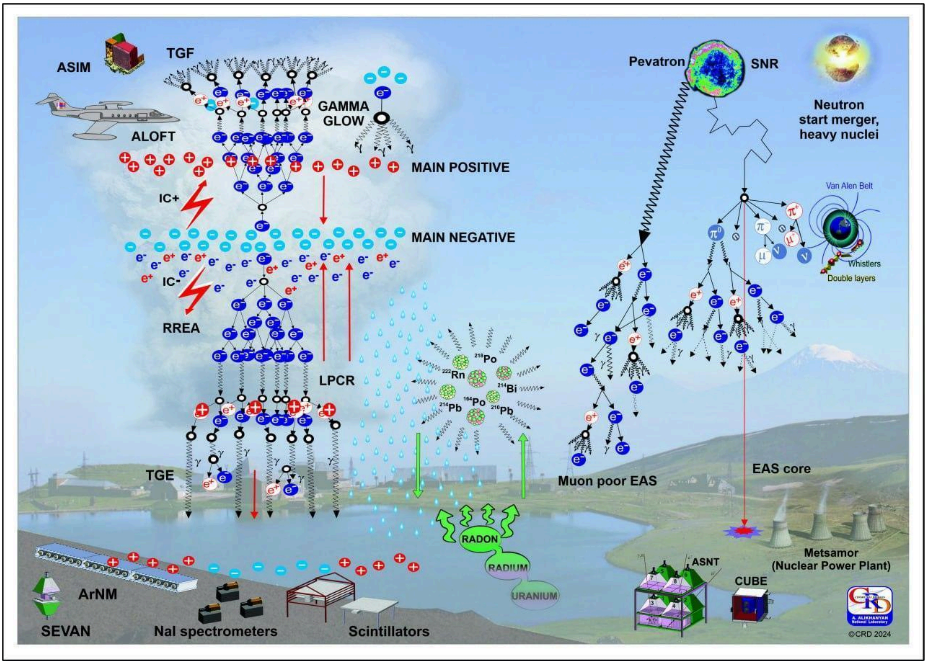
ORGANIZER:

Cosmic Ray Division
of Yerevan Physics Institute, Armenia

PROGRAMME


Yerevan
2024
TEPA
Armenia
International Conference, 14-17 October
80 years of cosmic ray measurements





On the left: Electron accelerators emerging in strong atmospheric fields originate RREAs in the lower and upper atmosphere-initiated TGEs and TGFs. Surface detectors and detectors on board aircraft measure millions of particle bursts with duration from microseconds to tens of minutes. In the center: Emanation of the Radon progeny lifted to the atmosphere by near-surface electric fields and contributed to the TGE flux at low energies. To the right: Sources of the galactic and extragalactic cosmic rays initiated extensive air showers in the terrestrial atmosphere – a source of seed electrons for TGEs and TGFs.

We also plan to discuss the most intriguing problems of high-energy physics in the atmosphere and possible directions for advancing collaborative studies. Topics to be covered during oral and poster sessions:

- Energy spectra of electrons and gamma rays measured on the earth’s surface, in the atmosphere, and space; their relation to the strength and location of the electric field;
- Abrupt termination of the particle flux by the lightning flash;
- Registration of neutron and positron fluxes during thunderstorms;
- SEVAN particle detector network as a tool of HEPA research;
- Methods of remote sensing of thundercloud charge structure and atmospheric electric fields;
- Relations to the climate and space weather issues;
- Monitoring of lightning flashes by fast cameras;
- Influence of the atmospheric electric fields on Extensive Air Showers (EASs);
- The possibility of joint observations by aircraft and ground-based facilities.

Monday, 14 October

10:00 – 11:00 Registration

11:00 – 11:20 Opening Ceremony

Session 1: Multivariate observations of particles and fields
Chairperson – Johannes Knapp

11:20 – 12:00 ***Ashot Chilingarian,*** Yerevan Physics Institute,
High Energy Physics in Atmosphere, HEPA-2024

12:00 – 12:30 ***Coffee break***

12:30 – 13:15 ***Razmik Mirzoyan,*** Max-Planck-Institute for Physics, Garching, Germany,
Important Transformations in Ground-based Gamma- and Cosmic Ray Astrophysics

13:15 – 15:00 ***Lunch***

15:00 ***Session 1: Chairperson - Johannes Knapp***

15:30 – 15:50 ***OndřejPloc,***Department of Radiation Dosimetry, Nuclear Physics Institute of the Czech Academy of Sciences,
Advancing the Detection and Analysis of Thunderstorm-Related Radiation Phenomena: Progress of the GASTRON Project

15:50 – 16:10 ***Martin Kákona,*** Department of Radiation Dosimetry, Nuclear Physics Institute of the Czech Academy of Sciences,
Simultaneous Monitoring of Electric Field and Lightning Brightness for Cloud Charge Mapping

16:40 – 17:00 ***Nikolaj Budnev,*** Irkutsk University,
Perspective to add thunderstorm phenomena, including TGE research into the TAIGA program.

	GagikHovsepyan,*Yerevan Physics Institute,*
	Parameters of spectrometers operated on Aragats and Zugspitze.
17:00 – 17:30	**Coffee break**
17:30 – 17:50	***Pavel Klimov,***Lomonosov Moscow State University, *Optical response of the atmosphere to the relativistic electrons microbursts: results of PAIPS project*
17:50 – 18:10	***Mary Zazyan,*** Yerevan Physics Institute, *Do VHE gamma rays migrate to UHE? Synergy of Galactic and Atmospheric Accelerators.*
18:10 - 18:30	***Liza Hovhannisyan,***Yerevan Physics Institute, *Modeling of Relativistic Runaway Electron Avalanches (RREA) in the air above Aragats*

Tuesday, 15 October

Session 2. Instrumentation and data analysis
Chairperson – MirzoyanRazmik

10:00 - 10:20	***S.S. Timakov, A.A. Petrukhin,***National Research Nuclear University MEPhI, *A new method for studying atmospheric processes using the azimuthal distribution of the muon flux*
10:20 – 10:40	***L.G.Tkachev,***Joint Institute for Nuclear Research, *The TUS detector calibration in flight by anomalous events*
10:40 - 11:00	***Aleksandr Belov***, Lomonosov Moscow State University, *Imaging near-UV photometer as an effective instrument for high energy physics of atmosphere, magnetosphere, and cosmic rays*
11:00 – 11:20	**Lev Kozliner,** Yerevan Physics Institute, *Reestablishing the Yerevan site for TGE particle and atmospheric parameters monitoring*
11:20 - 12:00	***Coffee break***

12:00 – 12:20	***TigranKarapetyan,***Yerevan Physics Institute, *Solar Events observed by the SEVAN particle detector network in the 25th solar activity cycle*
12:20 – 12:40	***BalabekSargsyan,*** Yerevan Physics Institute, *Thunderstorm ground enhancements (TGEs) originated by RREA and Radon progeny gamma radiation.*
12:40 – 13:00	***QajikPiliposyan,***Yerevan Physics Institute, *The horizontal profile of the atmospheric electric fields as measured during thunderstorms by the network of particle detectors located on the slopes of Mt. Aragats*
13:00 – 13:20	**GagikHovsepyan,**Yerevan Physics Institute, *Parameters of spectrometers operated on Aragats and Zugspitze.*
13:20 – 15:00	***Lunch***
15:00 – 15:20	**Suren Chilingaryan**, Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, *Data analysis infrastructures in Cosmic Ray physics: experience from Aragats*
15:20 – 15:40	**Sandro Melissano,**Institute for Data Processing and Electronics, Karlsruhe Institute of Technology *Six dimensions of benchmarking: New Perspectives on Time Series Data for Monitoring Applications.*
15:40 – 16:00	**Nicholas Tan Jerome,**Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, *BORA: A Personalized Data Display for Large-scale Experiments*
16:00 – 16:30	***Coffee break***
16:30 – 16:50	**David Pokhsraryan,**Yerevan Physics Institute, *Space-temporal structure of the thunderstorm ground enhancements (TGEs)*
16:50 – 17:10	**SergejAbovyan,** Yerevan Physics Institute, *Electronics of collider and Cosmic ray experiments*

17:10 – 17:40	**Suren Arutunian,** Yerevan Physics Institute, *Long-term measurements of atmospheric pressure fluctuations by vibrating wire flowmeter*

Wednesday, 16 October

10:00 - 11:00	**Discussion:***Origin of particle fluxes from thunderclouds: TGEs, TGFs, downward TGFs, upward TGEs*
11:00– 12:00	***Zara Asaturyan,***Yerevan Physics Institute, *CRD projects: "Install your detector on Mount Aragats"and others*
12:00-12:15	***Discussion on Further collaborations on Aragats Cosmic Ray Observatory***
	Closing Ceremony
12:15 - 13:30	***Lunch***
14:30 – 17:00	***Excursion to Aragats Cosmic Ray Station; Introduction to Aragats Space Environmental Center particle monitors***
18:00	***Conference dinner in Nor Amberd***

Thursday, 17 October

11:00- 12:30	***ASEC collaboration board meeting***

TEPA 2024 REPORTS

High Energy Physics in Atmosphere, HEPA-2024

Ashot Chilingarian

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

High-energy physics in the atmosphere (HEPA) has undergone an intense reformation in the last decade. Correlated measurements of particle fluxes modulated by strong atmospheric electric fields, simultaneous measurements of the disturbances of the near-surface electric fields, lightning location, and registration of various meteorological parameters have led to a better understanding of the complex processes in the electrified atmosphere. The cooperation of cosmic rays and atmospheric physics has led to the development of models for the origin of particle bursts recorded on the Earth's surface, estimation of vertical and horizontal profiles of electric fields in the lower atmosphere, recovery of electron and gamma-ray energy spectra, the muon deceleration effect, etc. The main goal of this report is to demonstrate how the measurements performed at the Aragats Cosmic Ray Observatory led to a new understanding of HEPA. We monitored particle fluxes around the clock using synchronized networks of advanced sensors that recorded and stored multidimensional data in databases with open, fast, and reliable access. Visualization and statistical analysis of particle data from hundreds of measurement channels disclosed the structure and strength of the atmospheric electric fields and explained observed particle bursts. Consequent solving of direct and inverse problems of cosmic rays revealed the modulation effects of the atmospheric electric field on cosmic ray fluxes.

Important Transformations in Ground-based Gamma- and Cosmic Ray Astrophysics

Razmik Mirzoyan

Max-Planck-Institute for Physics, Garching, Germany

In this report we plan to dwell on recent important developments in ground-based gamma-ray astrophysics. Very high energy gamma rays have been studied with the Imaging Atmospheric Cherenkov Telescopes (IACT) using Cherenkov light emission from air showers. Other types of ground-based detectors, such as, for example, LHAASO and HAWC, measure elementary particles from air showers. While an IACT can measure gamma-ray sources for at most ~200 h per year, the high-altitude particle detectors measure sources in their field of view for about 2000 h per year. The field of view of an IACT is typically 10-15 deg^2, while it is ~2 steradian for particle detectors. The angular resolution of particle detectors is 5-6 times worse than the IACT technique. Despite major differences in detection techniques, the sensitivity of both is similar. We plan to discuss some selected source detections using these different techniques, for example, the detection of TeV gamma rays from the direction of the Sun, and outline the prospects for future developments.

Forbush decreases observed by the SEVAN particle detector network in the 25th solar activity cycle

Tigran Karapetyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan,Armenia AM0036

The temporal variations of cosmic-ray intensity, measured by ground-based detectors at various latitudes, longitudes, and altitudes, are related to the geophysical and solar phenomena. The latter are interplanetary coronal mass ejections and fast solar wind from coronal holes, which cause abrupt variations of the interplanetary magnetic field (IMF) near Earth. Interacting with the magnetosphere, they cause sudden global decreases (Forbush decreases, FDs) of intensity followed by gradual recovery. The amplitude of the flux depletion depends on the type and energy of the registered particle, which in turn depends on geographical coordinates and the detector's energy threshold and selective power. The SEVAN particle detector network with nodes in Europe and Armenia selects three types of particles corresponding to different energy galactic protons interacting with disturbed magnetospheric plasmas, demonstrating coherent depletion and recovery.In this report, we present measurements of these FDs performed on mountain altitudes on Aragats (Armenia), Lomnicky Stit (Slovakia), Mileshovka (Czechia), and at sea level DESY (Hamburg, Germany). We compared FD measurements made by SEVAN detectors and neutron monitors located on Aragats and Lomnicky Stit and made a correlation analysis of FD registration at different locations.

Atmospheric positron flux and charged structure of the lower atmosphere

Balabek Sargsyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

On July 11, 2023, we observed a remarkable 500% increase in positron flux, coinciding with a significantThunderstorm Ground Enhancement (TGE). The enhanced flux of electrons and gamma rays was attributed to relativistic runaway electron avalanches (RREAs) generated within the dipole formed between the main negatively charged layer in the middle of the thundercloud and the Lower Positively Charged Region (LPCR) at thebottom of the thundercloud. Concurrently, a substantial enhancement in the 511 keV gamma-ray flux resulting from electron-positron annihilation was recorded. This surge is intricately linked to the LPCR within the thundercloud. The emergence of the LPCR induces a polarity change in the atmospheric electric field (AEF) below the LPCR (fourth dipole), leading to the deceleration of electrons and the acceleration of positrons. Particle flux measurements were conducted using scintillation and NaI(TL) spectrometers. To mitigate the contamination of natural gamma radiation and refine the 511 keV flux measurements, the ORTEC spectrometerwas shielded with a 4 cm thick lead filter. Highlighting the synergy between high-energy physics in the atmosphere and astroparticle physics, we introduce a new scenario to elucidate the enigmatic large flux of galactic positrons measured by the Alpha Magnetic Spectrometer (AMS) aboard the International Space Station (ISS).

Thunderstorm ground enhancements (TGEs) originated from RREA and Radon progeny gamma radiation.

Balabek Sargsyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

From 2008 to 2023, the Aragats Space Weather Center (ASEC) particle detectors detected 650 TGEs, some of which exceeded the flux rate by a factor of ten. Thunderstorm activity on Aragats is extremely high in May and June. Thunderclouds are usually located below the mountain's southern peak and sometimes only 25–50 m above the station. Therefore, the most energetic TGEs contain copious electrons, such as the TGE recorded on September 19, 2009, or November 6, 2023. The recovered electron spectra prove the RREA origin of TGEs. Further experiments showed that the electron avalanches are distributed over thousands of square meters. A comparative analysis of the observed TGE and radon isotope spectrograms made it possible to provide a phenomenological description of the TGE, consisting of:

- RREA phase: Intensification of the particle flux, sometimes exceeding 100% of the background flow, lasting from tens of seconds to 30 minutes with particle energies reaching tens of MeV. The particles are concentrated in an almost vertical cone. The flow of particles is often interrupted by lightning rarefaction.

- Gamma radiation of unstable isotopes: low-energy (<3 MeV) radiation is not interrupted by lightning; The particle flux is isotropic.

- Decay Phase: The decay of radioactive isotopes remaining in the air after the storm. The measured half-life of TGE is consistent with the lifetimes of the isotopes 214Pb (~300 keV peak) and 214Bi (~600 keV peak).

Do VHE gamma rays migrate to UHE? Synergy of Galactic and Atmospheric Accelerators.

Mary Zazyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

Particle accelerators abound in space plasmas, saturating the cosmos with fully stripped nuclei and gamma rays, with energies surpassing the capabilities of human-made accelerators by orders of magnitude. Upon reaching Earth's atmosphere, these particles trigger extensive air showers (EASs), generating millions of secondary cosmic rays of lower energies. Free electrons from millions of EASs developing in the atmosphere serve as seeds for atmospheric electron accelerators. Strong atmospheric electric fields (AEFs) evolving during thunderstorms act as accelerators, amplifying the intensity of electrons many times, thus significantly enlarging the EAS size (number of electrons). Thus, the energy of the primary cosmic ray recovered by EAS size can be significantly overestimated. Recently discovered by high-altitude EAS arrays, PeVatron candidates (very-high-energy astrophysical gamma-ray sources) must be carefully examined according to the atmospheric conditions during EAS detection. LHAASO and HAWC arrays are located in regions of frequent thunderstorms, and AEF's strength can reach and surpass the critical energy to start relativistic runaway electron avalanches (RREA). A few registered gamma rays from stellar sources, whose energies surpass 300 TeV, can be registered at just this time when the AEF highly enhances the EAS size and consequently overestimates primary gamma-ray energy. Thunderstorm ground enhancements (TGEs) registered at mountain peaks of Eastern Europe, Germany, and Armenia comprise millions of particles with energies above several MeV to 50 MeV, well above the threshold energy of EAS particle sensors. Thus, the overestimation of the energy of primary particles is not an exotic process but a consequence of already well-established physical phenomena. Consequently, a report on each registered very-high-energy gamma-ray should include the recorded time and corresponding weather conditions. We present the simulation study of the LHAASO detected UHE gamma rays and demonstrate that the primary gamma ray's energy can be ten-fold overestimated.

The horizontal profile of the atmospheric electric fields as measured during thunderstorms by the network of particle detectors located on the slopes of Mt. Aragats

Qajik Piliposyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

Thunderstorm ground enhancements (TGE) observed in remote sites on slopes of Mt. Aragats shed light on the origin of TGEs and the strength and horizontal and vertical profiles of atmospheric electric fields. The network of large NaI spectrometers and SEVAN detectors on slopes of Mt. Aragats 24/7 monitored secondary particle fluxes from 2013 until now, highly contributing to understanding how RREAs are developed in the atmosphere. In 2022, we enlarged the NaI network with two remote detectors located at altitudes 2000 and 1600 m and 13 and 16 km apart from the Aragats station to investigate the horizontal profile of the atmospheric electric field. We found that the previously estimated values of the regions in the atmosphere where RREA emerges were highly underestimated. In the present report, we describe the SEVAN and NaI particle detector's networks and present the first results of the experiment demonstrating that the particle fluxes from the atmospheric electron accelerators can cover many cubic kilometers in the atmosphere and produce particle showers covering many square kilometers on the Earth's surface.

Reestablishing the Yerevan site for TGE particle and atmospheric parameters monitoring

Lev Kozliner

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

On the slopes of Mt. Aragats are operating three sites with wide possibilities for monitoring particle fluxes, electric and geomagnetic fields, and atmospheric parameters. In 2024 Yerevan site, 40 km from Aragats, added data to the ADEI data analysis platform for correlating thunderstorms and particle fluxes on surfaces that covered many square kilometers. Yerevan Sire comprises one and 3 cm thick plastic scintillators, NaI spectrometers, an EFM 100 electric field sensor, a DAVIS weather station, and a World-Wide Lightning Location Network (WWLLN) node. We already measure coherent changes of the near-surface electric field on Aragats and in Yerevan, accompanied by the significant enhancement of the intensity of low-energy gamma rays from the Radon daughter’s gamma radiation. The report will present details of the operated equipment and measured count rates in correlation with disturbances of atmospheric electric field and weather parameters.

New CRD Projects: “Install Your Detector on Mount Aragats” and Future Initiatives

Zara Asaturyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

The Cosmic Ray Division (CRD) of the A.I. Alikhanyan National Laboratory, home to the world’s largest high-altitude cosmic ray research station, announces an open competition for a new project in High-Energy Physics in the Atmosphere (HEPA) on Mount Aragats. Aragats is a uniquely advantageous location for HEPA research, where tens of intense Thunderstorm Ground Enhancements (TGEs) occur annually in May-June and September-October. These phenomena result in the exposure of particle detectors to millions of electrons and gamma rays, with occasional neutron events. In addition to HEPA, Aragats serves as a hub for solar physics, space weather, and atmospheric and environmental physics research, supported by a comprehensive, multidisciplinary approach to data analysis.

For 2024, the CRD introduces the “Put Your Detector on Aragats” competition to invigorate international collaboration. This competition invites researchers to propose experiments leveraging the laboratory’s state-of-the-art facilities. The lab, a specially designated 9 m^2 area, is equipped with particle detectors, an electric field sensor, a weather station, and two all-sky cameras. These resources will be available to winning projects for comprehensive research on atmospheric phenomena such as TGEs, airglows, electric fields, lightning occurrences, and natural gamma radiation. Researchers and students can enhance their experiments by integrating additional particle detectors, photometers, high-speed cameras, and other scientific equipment. Standard data-acquisition (DAQ) electronics and online computers will support the facility, and the installed systems can be calibrated using existing particle spectrometers, weather stations, and geomagnetic and near-surface electric field monitoring tools already in operation at the Aragats station. CRD will provide an internet connection, database access, and an analysis platform to ensure seamless data storage and retrieval.

In addition to this competition, CRD is actively involved in several forward-looking projects, including Horizon Europe’s MSCA initiative on high-energy phenomena and the ISTC SEVAN-M project, which focuses on modernizing the SEVAN network. These projects aim to enhance the global understanding of cosmic ray interactions, space weather, and atmospheric processes. The first results of the "Put Your Detector on Aragats" competition will be reported, alongside updates from these and other CRD initiatives, to foster continued innovation and discovery.

Parameters of spectrometers operated on Aragats and Zugspitze.

Gagik Hovsepyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

The energy spectra of Thunderstorm ground enhancement (TGE) electrons and gamma rays are the key evidence for proving the origin of enhanced particle fluxes from thunderclouds. Till now, the electron energy spectrum was measured only by the Aragats large scintillation spectrometer ASNT. We changed the electronics board of the SEVAN detector installed at the Umwelt-Forschungs-Station (UFS, Schneefernerhaus, 2650 m asl) to allow these vital measurements near the top of the Zugspitze. The new electronics of the SEVAN detector, supplied with logarithmic ADC, for the energy release measurements up to 100 MeV. By measuring energy releases well above 3 MeV, we unambiguously separate Radon progeny gamma radiation and the electrons and gamma rays from relativistic runaway avalanches. Using the “veto” option allows for separating charged and neutral particles, enabling the disentangling of electron and gamma-ray energy spectra. In the report, we will explore and explain the new capabilities of the SEVAN detector installed on Zugspitze and the rearranged similar detector on Aragats. We present the methods of energy spectra recovery and compare energy spectra from all three spectrometers operated on Aragats. We compare and discuss the energy resolution of 60 cm, 20 cm, and 5 cm thick spectrometers.

Space-temporal structure of the thunderstorm ground enhancements (TGEs)

David Pokhsraryan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

We analyzed the structure of the Thunderstorm Ground Enhancement (TGE) using a particle detector network on Aragats and a fast data synchronization system (FSDAQ) based on the National Instrument's MyRIO. Our findings confirm that the TGE is a mixture of multiple runaway electron avalanches that arrive independently and provide stable particle flux.

1 cm and 3 cm thick scintillators (both of area 1 m^2) were attached to fast digitizing oscilloscopes (Picoscope 6403D and Picoscope 5244B). The record length of both oscilloscopes was 200 ms, and the sampling rate of signals is 250 MS/s and 156.25 MS/s, corresponding to the sampling intervals of 4 ns and 6.4 ns. The typical duration (full width on half maximum, FWHM) of individual pulses from the scintillators is 20-30 ns. Thus, usually, the signal occupied several sampling intervals. One scintillator, attached to the National Instruments (NI) MyRIO board, registers the 1-second count rate. If the count rate of the 1-second time series exceeded the prechosen limit (usually set to 50% larger than the average count rate), the MyRio board triggered the oscilloscope. The oscilloscope's trigger-out synchro-pulse was relayed to the board, which produced the GPS time stamp of the record. This feature enables accurate time synchronization, with time stamps estimated to have an absolute accuracy of tens of nanoseconds.

Electronics of collider and Cosmic ray experiments

Sergej Abovyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

The report will showcase how the chip designed for the MAKET ANI surface array, which detects EAS arrival times, is integrated into the ATLAS experiment at CERN.

Modeling of Relativistic Runaway Electron Avalanches (RREA) in the air above Aragats

Liza Hovhannisyan

Yerevan Physics Institute, Alikhanyan Brothers 2, Yerevan, Armenia AM0036

We consider possible scenarios for developing relativistic runaway electron avalanches (RREA). We use the CORSIKA code, introducing a uniform electric field above particle detectors and testing different seed electron energies and strengths of the intracloud electric field. The RREA threshold electric field was estimated to be 284 kV/m at sea level and is proportional to the air density (relative to sea level value of 1.225 kg/m^3). Thus, at 5000 m (air density 0.7364 kg/m^3), the threshold field will be 170 kV/m, i.e., 23% higher than used in simulation 220 kV/m. At 3000 m (air density 0.9093 kg/m^3) necessary electric field strength is 210 kV/m, only 5% exceeding the threshold value. When we introduce a uniform electric field of 190 kV/m, on 5000 m, it is only 6% higher critical energy, and on 4000 m is equal to critical energy. For the large electric field strengths in simulations, the maximum energy of RREA electrons can reach ≈70 MeV and gamma-rays ≈50 MeV, i.e., at the exit from the accelerating field, the maximum energy of electrons exceeds the maximum energy of gamma-rays by ≈20%. However, in the thick air, the maximum energy of electrons quickly diminished due to ionization losses down to ≈30 MeV for the electric field strengths 210 and 220 kV/m; the energy of gamma-ray, in contrast, still is ≈45 MeV. Thus, when the measured maximum energies of electrons and gamma-rays are comparable, we can conclude that the electron-accelerated electric field extends down almost to the 3200 m where particle detectors are located if the maximum energy of the gamma-ray flux is significantly larger than the electron maximum energy, the acceleration stops on ≈200 m above detectors. We investigate the efficiency of different energies of seed electrons, from 1 to 300 MeV. Also we research the development of RREA on short distances.

A new method for studying atmospheric processes using the azimuthal distribution of the muon flux

S. Timakov, A. Petrukhin

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This research considers a new method of muon flux processing for detectors capable of distinguishing azimuthal angles of muon trajectories. It consists of simultaneously analyzing muon fluxes in different solid angles and comparing the analysis results between several detectors. The method uses wavelet analysis to study the muon count rate series from different azimuthal directions. After special filtering of the wavelet transformation coefficients, we obtain the responses.

The method is based on the dependence of the muon flux characteristics on the parameters of the atmosphere. The resulting responses allow the detection of atmospheric perturbations and even the estimation of some of their spatial characteristics. To demonstrate the method's capabilities, the responses are compared with different sources of information: satellite imagery, weather radar network data, and GDAS data. Determining the movement direction of some atmospheric fronts and other atmospheric phenomena is possible.

The TUS detector calibration in flight by anomalous events

Leonid Tkachev

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The main goal of the TUS experiment was to search for and study ultra-high energy cosmic rays with energies E > 70 EeV. In addition, the TUS detector registered several strange events, the origin of which are probably due to out-of-aperture Terrestrial Gamma-ray Flashes (TGFs) accompanied by lightning discharges. The possibility of using the TUS photodetector for calibration in flight by anomalous events is considered. The results of such calibration are presented.

Perspective to add thunderstorm phenomena, including TGE research into the TAIGA program

N. Budnev, R. Monkhoev for TAIGA-collaboration.

Irkutsk University, RF

The main purpose of the TAIGA gamma-ray observatory is to study the origin of ultrahighenergy cosmic rays and the nature of their sources. The research

method consists of registrationof various components of extensive atmospheric showers (EAS) developing as a result ofinteraction of high-energy particles and gamma-quanta with the atmosphere. The peculiarity ofthe TAIGA complex is the single-system integration of facilities and detectors of different typesfor registration of both Cherenkov radiation (Tunka-133, TAIGA-HiSCORE, TAIGA-IACT) andcharged component (electrons and muons) of EAS (Tunka-Grande, TAIGA-Muon), as well asother instruments and systems distributed over an area of 3 km^2. The unique composition of thedetectors and facilities of the TAIGA astrophysical complex allow for interdisciplinary researchnot only in gamma-ray astronomy, cosmic ray, elementary particle physics, and opticalastronomy, but also in Earth sciences, particularly atmospheric physics and geophysics.

The report will present a plan for the modernization of the TAIGA astrophysical complex tostudy thunderstorm phenomena, including TGE, charged particle fluxes during thunderstorms,optical radiation accompanying lightning discharges, and so on.

A database of joint observations of EAS and thunderstorm optical atmospheric phenomena willbe created, and information on the correlation and interrelation of lightning discharges, intracloudprocesses and EAS will be obtained. Comparison of the results obtained in the conditions of theTunka Valley (altitude 651 m above sea level) with the results of studies carried out at the NorAmberd research station, located on Mount Aragats at an altitude of 2000 m, and the HighAltitude Station at 3200 m above sea level will be carried out.

Imaging near-UV photometer as an effective instrument for high energy physics of atmosphere, magnetosphere, and cosmic rays

A. Belov, P. Klimov, A. Murashov, et al.

M.V.Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Russia

Radiation of the Earth's atmosphere, including the near UV range (300–400 nm), is an important manifestation of various processes occurring in the atmosphere. These are processes of both an internal nature, such as thunderstorm phenomena (lightning, transient luminous events, terrestrial gamma-ray bursts), and the result of an external impact on the Earth’s atmosphere: penetration of energetic ionizing radiation, cosmic rays in a wide range of energies, the passage of meteors, etc. In the auroral zone, optical emission is caused by energetic particle precipitation from the magnetosphere. Measurements of the spatiotemporal structure of the near-UV emission make it possible to study the physical mechanisms of various processes in the Earth’s atmosphere and the sources of their origin. Thus, an imaging photometer can be an effective instrument for research in various fields of physics. A pair of imaging photometers were developed in the frame of the PAIPS project and provided stereoscopic measurements of pulsating aurora in the Murmansk region. One of these detectors was installed at Aragats station in June 2024 to measure near-UV emissions of thunderstorms and extensive air showers.

The results of the photometer measurements in the auroral region, the first data from the Aragats station, and the possible application of compact imaging photometers for EAS measurements are presented.

This research was founded by Russian Science Foundation grant number 22-62-00010 ().

Optical response of the atmosphere to the relativistic electrons microbursts: results of PAIPS project

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Relativistic electron microbursts (REMs) are intense pulses of electron precipitation that typically last nearly 100 ms. The first indirect measurements of microbursts were done by balloon-borne registration of bremsstrahlung X-rays in the auroral zone. They later were studied in detail in the satellite experiment SAMPEX. REMs usually appear as clusters or series of sharp peaks. Microbursts in near-UV (300-400 nm) wavelength range with a similar temporal structure were observed by the PAIPS project photometers. PAIPS (Pulsating Aurora Imaging System) is being deployed at the Kola peninsula and is aimed to conduct stereo measurements of pulsating aurora (PsA) with high temporal resolution (1 ms). Imaging photometers allow us to determine the spatial structure of emission, and it was shown that microbursts can take the form of local spots, arches, and extensive diffuse glow spots, arcs, and diffuse glow. UV microbursts are observed at various geomagnetic activity conditions, mainly during the substorm recovery phase. In this work, we present the results of the search and analysis of the spatio-temporal structure of UV-microbursts, comparison with satellite measurements of relativistic electrons and all-sky cameras of the Polar Geophysical Institute.

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Data analysis infrastructures in Cosmic Ray physics: experience from Aragats

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The data mining, visualization, and statistical analysis of the big data coming from modern obser- vatories, which study the high-energy phenomena in space and the atmosphere, have become an important tool in scientific research. Multivariate analysis of variations of fields, radiation, and particle fluxes can provide new information on the development of thunderstorms, including those of catastrophic nature. Such analysis presents a challenge due to the large quantity of acquired data. A huge amount of time series should be processed and identified in real-time for forecasting and alerts, as well as for reporting and paper preparation. Usually, researchers have no time to access archives if the data stream is pressing and new interesting events appear each new day. Therefore, to support researchers in data mining and finding ‘‘new physics,’’ a multivariate visualization platform should be supplemented with tools of elementary statistical analysis (histograms, moments, correlations, comparisons), figure preparation, and archiving, i.e., with a data exploration system. The free-access ADEI platform, operated for CRD for over 15 years, allows users to analyze data quickly, prepare figures and slides, perform joint data analysis with remote groups, test hypotheses, and draw physical inferences. Alerts and forewarnings sent by e-mail make it possible to follow the progress of solar and thunderstorm events in real time. In the report, the perspective of ADEI development will be discussed.

Six dimensions of benchmarking: New Perspectives on Time Series Data for Monitoring Applications.

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To assess the capability of any database system, we need first to understand how they work, and then benchmark them with exactly the workloads they will deal with in production. This report presents the development of an improved

benchmark with novel features and the benchmark of four different database architectures, all specialized in time series data for monitoring applications. For the first time, a benchmark stressed a system comparing regular time series to irregular ones, with various data cardinalities (means, with data points, having multiple values) and under a certain type of mixed workloads (writing, meanwhile reading, and calculating aggregations). These workload characteristics are present in applications like KATRIN's monitoring system. Finally, we evaluate which database system and architecture is the most suitable for this use case.

BORA: A Personalized Data Display for Large-scale Experiments

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In this work, we present BORA (personalized collaBORAtive data display), a visualization framework supporting large-scale experiments by generating personalized data displays and enabling the human-in-the-loop concept within the experiment. Despite the complex experiment setup, BORA allows scientists to build their desired data displays with minimal effort. There are two facets to the framework, with the first facet being a read-only data display, which helps scientists monitor the health of the experiment subsystems. The second facet enables scientists to control the systems and data acquisition parameters. It enables feedback for multiple data processing pipelines that interact with the large volume of data in real time. Bora is built around RESTful APIs and supports various standard protocols through plugin extensions for databases (e.g., Redis) and control protocols (e.g., OPC). One unique feature of BORA is that it supports video streaming analysis of experimental data, allowing visual representation of the subsystem, e.g., surface temperature monitoring and detector heatmap.

Simultaneous Monitoring of Electric Field and Lightning Brightness for Cloud Charge Mapping

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We aim to compare electric field measurements using the Electric Field Mill (EFM) THUNDERMILL01 with lightning video recordings captured by a high-speed all-sky camera operating at 1600 frames per second. We examine the difference between a conventional EFM, where the detector's response depends on the rotor's rotation speed, and the THUNDERMILL01, which, in rapidly changing electric fields, is limited only by the ADC sampling frequency. This approach enables simultaneous data collection on both slowly and rapidly varying charges. The brightness of the lightning channel indicates the current intensity of discharging charge regions within the cloud. Therefore, we propose combining both measurement methods to determine the horizontal position of charge wells in the cloud.

Advancing the Detection and Analysis of Thunderstorm-Related Radiation Phenomena: Progress of the GASTRON Project

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The Gamma Spectrometry of Thunderstorm Radiation Observatory Network (GASTRON) aims to study high-energy radiation events associated with thunderstorms, such as Terrestrial Gamma-ray Flashes (TGFs) and Thunderstorm Ground Enhancements (TGEs). Thunderclouds can act as natural particle accelerators through their dynamic electrical properties, producing these phenomena, which are key to understanding atmospheric particle acceleration processes. The GASTRON project utilizes a network of gamma spectrometers distributed across European high-altitude observatories, including Milešovka (Czechia), Lomnický Štít (Slovakia), Musala (Bulgaria), Zugspitze (Germany), and Jungfrajoch (Switzerland).
In 2024, the project made significant strides in expanding its network and developing a comprehensive catalog of thunderstorm-related radiation events. Using gamma spectrometers equipped (mostly) with NaI(Tl) crystals and precise GPS timing, the system records parameters such as time, energy, duration, environmental conditions, and lightning activity. These observations allow for detailed characterization and comparison of TGFs and TGEs across different geographic locations. Notably, the SEVAN detector at Milesovka, Czechia, played a key role in TGE detection, and the new neutron detector SND recorded a TGF event there.
The ongoing development of the radiation event catalog will provide a robust platform for future quantitative analysis and cross-regional comparison of radiation phenomena. This paper presents updates on the GASTRON project's progress and its contributions to understanding thunderstorm-related radiation events.

Long-term measurements of atmospheric pressure fluctuations by vibrating wire flowmeter

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The relationship between atmospheric pressure fluctuations and various other environmental parameters has been discussed in the literature (correlation with electric field strength, CO2 fluctuations etc.). We propose to measure atmospheric pressure variations using developed by us vibrating wire flowmeter with large aperture, fast response, better than anemometric sensors, and the ability to measure bidirectional flows. The flowmeter is loaded on a rigid receiver. When the atmospheric pressure varies, pressure equalization in the receiver creates air flows through the flowmeter. Observations of atmospheric pressure variations in combination with measurements of other physical parameters may be of interest to the research conducted by the Cosmic Ray Division of AANL (Yerevan Physics Institute), especially in areas of thunderstorms research.

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