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Book of Abstracts

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THE INFLUENCE OF REDUCED ATMOSPHERIC TRANSMISSION ON THE CTA-NORTH PERFORMANCE

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The Cherenkov Telescope Array (CTA) is the next generation ground-based observatory for gamma-ray astronomy at very-high energies which will consist of the northern (CTA-N, La Palma, Spain) and southern (CTA-S, Paranal, Chile) arrays. The atmosphere, as an integral part of the Cherenkov telescope detector, has a great impact on the observed data, especially in means of reduced sensitivity. One of the main contributions to the systematic uncertainties arises from the presence of clouds. To minimize these systematic uncertainties a calibration of the detector response is of great importance. For this purpose, the influence of cloud altitude and optical depth on the CTA-N performance using detailed Monte Carlo simulations has been investigated. The degradation effect of the presence of clouds is primarily observed at low and middle energies but spans across the entire energy range.

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Observation of the Cumbre Vieja volcano plume above the Observatorio del Roque de los Muchachos with the Barcelona Raman lidar

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The Cherenkov Telescope Array (CTA), currently under construction, is the next-generation very-high-energy gamma-ray observatory, providing the coverage for photons in enegy range 20 GeV to 300 TeV. CTA will increase detection sensitivity in the 100 GeV to 10 TeV range for a factor of 5 – 10 with respect to present experiments. It retrieves the properties of very-high-energy gamma-rays by measuring Cherenkov light, emitted by atmospheric showers of secondary particles that incident gamma rays produce in upper layers of the atmosphere. The key for reaching the required energy measurement accuracy is precise knowledge of atmospheric transmittance for Cherenkov light, which can be obtained using a dedicated Raman lidar. The device should operate at 355 nm (near the maximum of Cherenkov light spectrum) and have the capability of taking data at specific azimuth and zenith angles up to distances of 30 km, so that atmospheric transmission along all possible air-shower directions can be determined. The *Barcelona Raman Lidar* (BRL) is the official CTA Pathfinder prototype, developed for atmospheric characterization of the Northern CTA Site at the Observatorio del Roque de los Muchachos (ORM) on the Canary island of La Palma. BRL was deployed at ORM for extensive tests between February 2021 and May 2022. We report on the commissioning results, including the remote operation capabilities of the system and its contribution to the understanding of atmospheric phenomena during its deployment period. In particular, we report on the properties of the volcanic plume from the eruption of the Cumbre Vieja volcano on 22 September 2021.

LIDAR tecnique applied to UHECR and Gamma Ray experiments / 3

Correcting MAGIC Telescope data taken under non-optimal atmospheric conditions with an elastic LIDAR.

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The Major Atmospheric Gamma-ray Imaging Cherenkov (MAGIC) telescopes are a system of two Imaging Atmospheric Cherenkov Telescopes (IACTs). IACTs make calorimetric use of the Earth's atmosphere, which allows them to reach large effective areas, but also makes them strongly dependent on the quality of the atmosphere at the time of the observations. Dust intrusions or clouds obscuring the observed Cherenkov light can then lead to a wrong reconstruction of the gamma-ray data. In order to mitigate this problem, the MPP group built and has been operating a single wavelength elastic LIDAR (LIght Detection And Ranging) system to perform real time ranged-resolved measurements of the aerosol transmission. This information is then used to quantify the quality of the telescope data, as well as to correct the data taken under suboptimal aerosol conditions. In this talk, the correction of atmospherically impaired IACT data will be described and the first systematic evaluation of the correction capabilities of the LIDAR system will be presented. The results describe the impact of the LIDAR corrections for a variety of atmospheric and observational conditions, and therefore contribute to a better understanding of the telescope's performance and related systematic uncertainties.

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Measuring Cloud Base Height and Cloud Coverage using Elastic Multiangle Lidars at Pierre Auger Observatory

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Cloud features above the Pierre Auger Observatory (Mendoza Province, Argentina) produce significant effects on the reconstruction of Extensive Air Showers.
In this work, we present seasonal variations of cloud-base height, cloud coverage, and correlation between different sites using the information of elastic multiangle lidar data.
This system locates the presence of clouds by measuring the spikes in the backscattered photons detected in the direction of the sweep performed during each lidar scan, outside the field of view (FOV) of the fluorescence detectors. Horizontal homogeneity should be assumed to translate these results to the full array. This ansatz is verified by a set of dedicated horizontal lidar shots performed for a few seconds every hour inside the FOV of the fluorescence detectors.
Here we present the results for the period 2007 to 2018, using all the continuous lidars scan available in the lidar database. The analysis algorithm used for the cloud retrieval has been upgraded and based on a different concept than the previous one.
How clouds parameters vary across seasons are investigated, and conclusions about cloud homogeneity across the Pierre Auger array are given.

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Assessing aerosol induced errors in Monte Carlo based air-shower reconstruction for atmospheric Cherenkov detectors

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Aerosol levels influence the wavelength dependent transmission properties of the atmosphere. Variations in aerosol levels therefore affect the amount of Cherenkov light from air showers that can reach an atmospheric Cherenkov detector. As the amount of detected Cherenkov light is directly related to a primary shower particle's energy, deviations between actual and assumed atmospheric transmission properties yield errors in reconstructed particle energies as well as energy axes of instrument response functions (IRFs).
In this work, a scheme is presented to assess this influence and potentially reduce related errors in the air-shower reconstruction. The proposed scheme relies on estimations or measurements of the aerosol optical depth (AOD) and atmospheric density profiles which are then used in radiative transfer simulations to generate atmospheric transmission profiles. In combination with detector specific quantum efficiencies and generalised shower evolution models, the scheme does not rely on detailed simulations of the different atmospheric conditions but only on the transmission profile on which the initial reconstruction algorithm is based on.
The scheme is derived and presented on the example of the H.E.S.S. Experiment which employs Imaging Atmospheric Cherenkov Telescopes in the Khomas Highland of Namibia to detect cosmic gamma rays in the GeV to TeV energy range.

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Passive measurement of distance to cloud

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The Telescope Array (TA) experiment detects airshowers induced by ultra high energy cosmic rays. The atmospheric Fluorescence telescopic Detector(FD) observes cosmic ray airshower, which is incident very far from the telescope. The observation does not take place in overcast night. However, the cloud status changes quickly and sometimes there are some isolated clouds. For airshower reconstruction, the effect of cloud depends on whether the cloud is foreground or background to airshower. For the isolated foreground cloud, the problematic event can be rejected by airshower profile at reconstruction. However, the estimation of exposure with isolated cloud is difficult. And it should be affected more at higher energy event with relatively further from the telescope, which is lower statistics and more important for the ultra high energy cosmic ray physics. Therefore, to test the method for evaluating the correction of exposure, I installed stereo cloud cameras near one of FD sites. I report the status of the study of this measurement.

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Classification and Reconstruction of single and multiple ELVES in AUGER

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ELVES are regularly being studied since 2013 with the twenty-four FD Telescopes of the Pierre Auger Observatory, exploiting a dedicated trigger and extended readout.
A large fraction of the observed events shows double ELVES within the time window, and, in some cases, even more complex structures are observed. We classify double ELVES using radial variation of the time gap and the photon flux ratio between flashes.
Such parameters may be related to the different types of lightning in which they are originated. We will review the cross correlations of the ELVES light emissions with the radio waves detected by the antennas of the ENTLN network, active in Argentina since late 2018. Further improvements of our detection and classification algorithms were achieved by detecting ELVES from closer lightning: since December 2020, the ELVES trigger was extended to the three High Elevation Auger Telescopes (HEAT), which observe the night sky at elevation angles between 30 and 60 degrees, with an enhanced time resolution (50 ns time binning). Both single and double ELVES are recorded with unprecedented time and space resolution. Events from the first year of data taking will be shown.

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The Auger Raman Lidar: 2013-2022 continuous observations.

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The Raman lidar (RL) at the Central (Raman) Laser Facility (CRLF) of the Pierre Auger Observatory in Argentina, has been operational since September 2013.
In this talk, the Auger RL performances are discussed in terms of the data quality for the assessment of the aerosol contribution to the atmospheric UV optical transparency, and how much this is important for the reconstruction of the UHECR properties, based on the Auger Fluorescence Detector observations.

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Interference of extraterrestrial particle accelerators and accelerators operated in the terrestrial atmosphere

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Different kinds of particle accelerators are operating in the intergalactic plasmas filling the space with high-energy hadrons and gamma rays, which reach the earth's atmosphere and unleash extensive air showers (EASs) consisting of millions and billions of elementary particles covering several km2 on the ground. During thunderstorms, emerging strong electric fields modulate the EAS particles significantly altering their energy spectra. When researching the operation of the electron accelerators in the thunderclouds the ambient population of the cosmic rays from the small and large EASs constitutes a background during measurements of the particle enhancements (so-called thunderstorm ground enhancements –TGEs) from the electromagnetic avalanches reaching the earth's surface. Thus, both processes are interconnecting and measured energy spectra of EAS and TGE particles should be disentangled carefully.
A major challenge of EAS experiments is the energy scale calibration. The shower size (Ne) is rather well correlated with the energy of the primary particle. However, the particle type identification and large fluctuations of first interaction depth (shower size) smear the E-Ne relation. Additional difficulty poses possible biases due to emerging atmospheric electric fields. In the presented report, we will discuss how the emerging electric fields can introduce a bias in the energy estimation made by one square kilometer array of scintillator detectors and muon detectors of the Large High-Altitude Air Shower Observatory (LHAASO). Due to the large surface of detectors and high location, LHASSO has a very low energy threshold (1 TeV) and excellent rejection of hadron-induced extensive air showers (reaching 10-5 at PeV energies). We select the LHASSO array not only because recently they identified 12 PeVatron candidates, which have been previously observed by imaging atmospheric Cherenkov telescopes. LHAASO site locates at Haizi Mountain, Daocheng County, Sichuan Province, which is the edge of Tibetan Plateau with an altitude up to 4410 m.
The Tibetan plateau is also known as a place of frequent thunderstorms and a very large intracloud electric field, that vertical profile can extend to 1-2 km. We perform simulations of gamma ray transport in the thunderous atmosphere above the LHASSO array and obtain possible biases in the energy estimation (we use a very simple estimator based on shower size Ne only). For the low primary energies (1 TeV) the bias was ten-fold and more, for the higher primary energies (1 PeV) 2-3 times. We demonstrate as well the threshold effect of intracloud electric field for starting a runaway process, that exponentially multiplied the free electrons entering a strong atmospheric electric field.

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The vertical profile of the atmospheric electric field during thunderstorms

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We introduce a novel method for remote sensing of atmospheric electric fields. Advanced particle spectrometers operated on the mountain altitudes on Aragats station are tuned for the measurement of energy spectra of charged and neutral particles separately. This gives the possibility to estimate the strength of the electric field in the lower atmosphere and estimate the particle flux incident on the earth's surface from the most powerful natural electron accelerators. Our measurements show that relativistic runaway electron avalanches (RREAs) can reach very low altitudes above the earth' s surface. On the earth's surface RREAs are registered by the particle detectors as thunderstorm ground enhancements (TGEs) –large enhancements of electron and gamma ray fluxes, sometimes exceeding the fair-weather background fluxes up to a hundred times. Due to different mechanisms of the energy losses by comparing energy spectra of electrons and gamma rays it is possible to estimate the height above the ground where RREA terminates and avalanche particles exit the accelerating field. More than 2,000 thunderstorms are active throughout the world at a given moment, producing on the order of 100 flashes per second. The overall surface of the thunderous atmosphere each

moment can be estimated as ≈ 200,000 km2, and according to our estimates, ≈ 1018 gamma rays are hitting the earth's surface each second.
The main results to be reported are as follows:
• Elaborated electric field remote sensing by monitoring particle fluxes provides several advantages over balloon-launched electric field meters;
• The strong accelerating electric field can extend very low above the mountain altitudes, reaching ≈2.0 kV/cm at altitudes ≈3-5 km, 50-150 m above the earth's surface. Such strong electric fields just above the arrays of particle detectors located at high altitudes (for instance LHAASO at 4410 m) will significantly enhance the size of showers introducing a large bias in the estimated energy of the primary particles.
• The most powerful electron accelerators operated in thunderclouds send ≈1018 gamma rays in direction to the earth's surface.

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Aerosol Measurements at Sub-per-cent Precision Using Wide-field Stellar Photometry

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Wide-field stellar photometry –the process of simultaneous comparison of apparent and catalog brightness of a large amount of stars –has long been a promising method of atmospheric monitoring, as it can provide atmospheric transparency measurements with high temporal and spatial resolution without any artificial illumination of the sky which would disturb nearby optical experiments. However only recently we have developed methods of data analysis that allow an overall uncertainty in the Vertical Aerosol Optical Depth (VAOD) better than one per cent. Such a feat requires precise laboratory measurement of spectral and signal responses of the instruments as well as careful analysis of all systematic effects that can appear during the extraction of stellar signal from the images. We will present a summary of the method with emphasis on the reliability of the estimates of uncertainties. Furthermore, we will discuss various possible applications of the method in different modes of operation, a comparison with other methods of aerosol measurement and a selection of open questions and areas for further improvement.

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Observations of the Origin of Downward Terrestrial Gamma-ray Flashes with the Telescope Array Surface Detector

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We present an overview and most recent observations of the lightning research program being conducted in conjunction with the Telescope Array cosmic ray observatory in Utah, U.S.A. This program focuses on understanding the initial breakdown stage of lightning through observations of downward Terrestrial Gamma-ray Flashes (TGFs).

Recent observations have demonstrated that Terrestrial Gamma-ray Flashes (TGFs) detected by satellites are associated with high-current energetic in-cloud pulses during ascending negative leaders. Meanwhile, a relatively small number of observations have been made of TGFs on the ground, owing to the greater atmospheric attenuation of gamma rays and the relatively rare occurrence of TGFs sufficiently close to detectors.

The Telescope Array Surface Detector (TASD) is a 700 square kilometer array of plastic scintillator detectors located in Utah's western desert. It consists of 507 three-square-meter detectors on a 1.2 km grid. The TASD was designed to detect particle showers generated by the interaction of ultra-high energy cosmic rays with the Earth's atmosphere.

Previously (Abbasi et al 2018, Belz et al 2020) we reported joint observations by TASD, Lightning Mapping Array (LMA), sferic sensor and broadband interferometer of particle showers coincident with lightning. These consisted of energetic showers of approximately 5 microsecond duration with footprints on the ground of order 10 square kilometers, originating in the first one to two milliseconds of downward lightning leaders and coincident with high-current processes within the leaders. Scintillator waveform and simulation studies confirmed that these showers must consist primarily of gamma radiation, thus the observations were identified as low-fluence TGFs near their initiation threshold. The TASD downward TGFs were in general of shorter duration and lower fluence than their satellite-detected upward counterparts.

Here, we report the new observation of several events of significantly longer duration and higher fluence, bridging the gap between the TASD and satellite based detections. These events further demonstrate the similarity between the upward and downward TGF varieties and the likelihood of a common origin for their production.

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Raman LIDAR measurements at Roque de los Muchachos Observatory.

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The ARCADE Raman Lidar (RL) has been installed at ORM in October 2018 for the pre-production phase of Cherenkov Telescope Array (CTA). The RL has collected vertical profiles of aerosol optical properties and water vapour two times a day, at sunrise and sunset, in automatic and unattended mode. Although the on-site services have been less than scheduled, mainly because the COVID-19 outbreak, and taking also into account the characteristics and the operation constrains of the instrument, the data are of good quality. The data analysis has been tested and improved also by comparison with aerosol measurements taken by a nearly located AERONET sunphotometer. A general overview of the profiles retrieved as well an analysis of case studies (e.g. Saharan dust events, volcanic aerosols during the Cumbra Veja eruption etc.) is discussed and commented along with the technical upgrades designed for the instrument to improve its performances. A first assessment of the atmospheric aerosol optical properties climatology is reported.

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Improved Point Spread Function Correction for Aerosol Measurements Using Wide-field Stellar Photometry

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When using wide-field stellar photometry to measure Vertical Aerosol Optical Depth (VAOD), we model the dependence of measured stellar fluxes on the star color and position within the field of view of the imaging system in order to control systematic uncertainties introduced through those dependencies. In wide-field imagers, the Point Spread Function (PSF) varies significantly across the instrument's field of view (FOV) as the deformation of star images increases with the distance from the center of the FOV. While such dependence can be compensated using a synthetic flat-field correction created through the simultaneous analysis of many images, such an approach fails to account for the image-to-image changes in this correction due to minute changes in focus over time. This effect is believed to be the main reason for fluctuations in the conversion factor between measured photometric flux and actual star brightness(also known as zeropoint) as determined by self-calibration scans, which is the dominant source of uncertainty for single-image VAOD measurements. We study the possibilities and limitations of using the PSF Extractor code to extract the precise model of the PSF from wide-field images and compare the modeled PSF with the actual star shapes and search for optimal choices of global PSF extraction methods,including dividing the frame into smaller segments, across which the PSF is more stable.

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Improving the measurement of TGF candidates at the Pierre Auger Observatory

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The Pierre Auger Observatory is designed to measure the highest energy
cosmic-rays.
However, the surface detector, covering 3\,000\,km^2, is also sensitive to
events associated with atmospheric electricity.
These events can be distinguished from normal cosmic-ray events in both
temporal and spatial structure.
With signals lasting around 10 μs, they are about an order of
magnitude longer than cosmic-ray events.
Their circular footprints on the ground are also different and larger than those
of typical cosmic-ray showers.
Due to their association with thunderstorms and topology, these events are candidates for downwards going terrestrial gamma-ray flashes (TGFs).
We collect such TGF candidates at a rate of about two per year.

We will present a detailed analysis of the effects that the data taking
system has on recording TGF candidate events, and show the repeating nature of
some of them.
Furthermore, we present a recently implemented special trigger flag
aimed at increasing the data taking efficiency for TGF candidates.

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A New Network of Electric Field Mills at the Pierre Auger Observatory

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The Pierre Auger Observatory is the largest ground-based experiment for the detection of ultra-high energy cosmic rays. In a hybrid approach, many detectors - including radio antennas - observe the extensive air showers induced by cosmic rays. As part of the AugerPrime upgrade, new antennas will be installed on each of the surface detector stations covering a total area of around 3000 km^2. This will allow us to study the mass composition of cosmic rays arriving with large inclination angles.
The radio emission of air showers is heavily influenced in the presence of strong atmospheric electric fields during thunderstorm conditions. In that case measured data are difficult to interpret and therefore the atmospheric electric field over the array has to be monitored. We present the design and status of a new network of electric field mills that will be used to take on this task. We show how we plan to have the measurements with an absolute calibration. In addition, the electric field data will be useful for other studies related to atmospheric electricity.

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Thunderstorms and Atmospheric Gamma-ray Observations at the Telescope Array Detector.

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In this talk I will present observations of lightning and terrestrial gamma ray initiation at the Telescope Array (TA) detector. The Telescope Array detector is located in the southwestern desert of the State of Utah. The combination of size and elevation makes it a unique tool that allows us to study thunderstorms. Currently it is the largest ultra high energy cosmic ray experiment in the Northern Hemisphere. The surface detector array part of the TA experiment, used in these observations, is composed of 507 scintillator detectors on a 1.2 km square grid covering a 700-kilometer square in area, 1400 m above sea level.

I will present observations by the Telescope Array Surface Detector (TASD) of the effect of thunderstorms on the development of the low-energy cosmic ray showers.
Using the TASD, we can study the electric field inside thunderstorms, on a large scale, as it progresses on top of 700-kilometer square in area. Such observations allow us to study the electric field inside thunderstorms on a large scale without dealing with all the limitation of narrow exposure in time and space using balloons and aircraft detectors. Simulation work that aims to interpret these observations will also be discussed.

I will also present the first and new observation of the optical emission counterpart of an extremely energetic downward-directed terrestrial gamma ray flash (TGF). The optical emission was observed by a high-speed video camera Phantom v2012 in conjunction with the Telescope Array surface detector, lightning mapping array, interferrometer, fast antenna, and the national lightning detection network. Results from this study allow us to further the understanding of the initiation mechanism of terrestrial gamma ray flashes. In addition, they allow us to further our ability to compare the most recent satellite optical emissions counterpart of upward-directed TGFs to that of downward-directed TGFs.

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Elastic LIDAR Monitoring of the Night-sky Brightness over the Observatory Roque de los Muchachos

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Every large world-class observatory must operate in a very dark environment that is as free as possible of anthropogenic sources of light pollution, which can degrade the quality of ground-based astronomical observations. Any LIDAR is able to measure, and subtract from its laser return signals, a corresponding contribution from the night-sky brightness. Our elastic LIDAR system is operated in semi-continuous mode at night, very closely following the observation schedule of the MAGIC Telescopes on Canary island La Palma, Spain. For the comparative monitoring of the night-sky brightness, median LIDAR background rates, as well as the currents in the PMTs and SBig Star-guider cameras of the MAGIC Telescopes, have been used. In this talk, results from data taken with the MAGIC LIDAR over seven years, from March 2013 until March 2020, will be presented and discussed.

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Seven years of quasi-continuous LIDAR data

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We present a full analysis of the seven years of quasi-continuous LIDAR data
taken during those nights when the MAGIC telescopes were operating. Characterization of the nocturnal ground layer yields zenith and azimuth angle dependent aerosol
extinction scale heights for clear nights. We derive aerosol transmission statistics for light emitted from various altitudes throughout the year and separated by seasons. We find further seasonal dependencies of cloud base and top altitudes, but none for the LIDAR ratios of clouds.

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Intensely Radiating Negative Leaders Observed by LOFAR and their possible connection to TGFs

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Multiple recent works by the LOFAR lightning team have established the existence of a type of negative leader that emits extremely intense radio radiation. In addition, these leaders propagate about ten times faster than normal negative leaders (10^6 m/s vs 10^5 m/s). We refer to this phenomena as Intensely Radiating Negative Leaders or IRNLs; it is plausible they could be related to previously described beta leaders. We have observed IRNLs during the initial stage of every lightning flash, but they can also occur later in the lightning flash; possibly whenever a negative leader propagates through a small high-field region. During the beginning of the lightning initial stage an IRNL starts out as one branch which has powerful corona bursts at its tip. These corona bursts play a role in producing initial breakdown pulses (IBPs) observed by a lower-frequency magnetic loop antenna. However, unlike other observations, we do not see any evidence for fast breakdown (propagation speed is always well below 10^7 m/s). The IRNL quickly branches into an uncountable number of densely packed channels such that the radio emission can no longer be separated into individual IBPs. Once the IRNL hits the positive cloud charge region it expands out in a ring of uncountable number of plasma channels that can only be described as a multi-kilometer sized plasma explosion. Since this phenomena is so energetic and closely linked to both the lightning initial stage and initial breakdown pulses, it is a very strong candidate for TGF emission.

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Measurement of aerosols above the Pierre Auger Observatory using the side-scattered light from the laser of the Aeolus satellite

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The Pierre Auger Observatory is a large-scale experiment for the investigation of ultra-high-energy cosmic rays. A combination of Surface Detector and Fluorescence Detector is used to measure the extensive air showers that are initiated by cosmic ray particles.

Aeolus is a satellite that is operated by the ESA with the purpose of making wind profile measurements on a global scale. To this end, beams of a UV-LIDAR are emitted towards the surface of Earth. As the satellite passes over the Pierre Auger Observatory, light that gets scattered off the laser beam in the atmosphere can be detected by the Observatory's Fluorescence Detector, allowing for the reconstruction of the beam from the Observatory data.
In this manner, the laser beam can be measured several hundred times for each satellite passage with a wide range of distances between the laser track and telescopes. This makes it possible to use the laser data for studies of the atmosphere above the Observatory and provides a unique opportunity for cross-checks with the atmospheric monitoring devices employed at the Pierre Auger Observatory.

In this contribution, we will explain the process of reconstructing laser shots from the Fluorescence Detector data, show the results of these reconstructions and introduce a method for extracting information about the aerosol content of the atmosphere from this data.

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Atmospheric Electric Activity in central Argentina and its relationship with phenomena observed at the Auger Observatory

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Due to its orography and southern extension, there is a great spatial variability of thunderstorms in Argentina that corresponds to mechanisms of different space-temporal scales. The central area of the country where the Pierre Auger Observatory is located (Mendoza Province, Argentina) presents unique meteorological and geographical conditions that result in a high spatial density of convective storms in a variety of thunderstorm modes that form under the shelter of a unique continental and mesoscale topography.
It is well known that this atmospheric electrical activity (AEA) produces Transient Luminous Events (TLEs) of which elves are the most prominent members of an extraordinary family that includes halos and jetstorms and sprites. Previous studies have indicated that the southern regions of Brazil and northern Argentina are prolific producers of TLEs, which can be observed at the Pierre Auger Observatory by means of the 24 UV telescope of the Fluorescence Detector (FD).
To help to understand which of the dynamic or microphysical processes could act in the formation of these events, we present in this work, the characterization of the AEA of the working area and the most important characteristics at meteorological level.

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Exploration of the stratosphere with cosmic-ray muons detected underground

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Cosmic radiation is a potential additional tool for atmospheric monitoring. High-energy cosmic rays, interacting in atmosphere, produce secondary particles, the production and propagation of which is ruled by the state of the atmosphere. In particular, atmospheric muons carry information on the stratosphere, as its temperature modulates their intensity.
We present a comprehensive investigation of the 24-years series of the muon flux recorded underground with the Large Volume Detector in the Gran Sasso Laboratory in Italy. Using advanced spectral-analysis methods, we reveal, in addition to the well-known annual cycle, two significant variations with periods of about 4 and 10 years, the former observed for the first time in a muon time series.
These two multiannual components, however, are not present in the series of the so-called effective temperature – an average parameter commonly used to describe the entire atmospheric profile in relationship to the detected muon flux –, but we find them in the series of the raw temperatures in the lower stratospheric levels. We show that the weaker multiannual cycles emerge in the temperature series thanks to the dampening of the dominant annual radiative cycle at these levels, which

are affected by higher-frequency variability related to transport and wave processes.
We also show that the multiannual variations are not typical only of the Gran Sasso area but are present at large scales throughout the Northern Hemisphere. The analysis of the series of the muon flux reveals also evidence of daily- to monthly-scale variations, especially during the highly variable winter period. Although such short-term modulations are also found in the series of the effective temperature, we show that the variations of the two series are brought to better agreement when considering only specific layers of the atmosphere depending on the particular event. The amplitudes of the multiannual variations are significantly larger than those expected on the basis of the temperature modulations. Such differences may be due to acknowledged difficulties of the adopted temperature reanalysis-dataset to thoroughly represent long-term variability scales, so that long-term modulations in the raw temperature series, and, consequently, in the effective temperature record, would result artificially attenuated.
The muon flux therefore may be envisaged as a high time-resolution integrated proxy of lower stratospheric temperatures.

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Site environment characterization for Southern Wide-field Gamma-ray Observatory

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The Southern Wide-field Gamma-ray Observatory (SWGO) is a proposed gamma-ray observatory based on the ground-level particle detection technique, with close to 100% duty cycle and an order of steradian field of view. SWGO will be located in South America at a latitude between 10 and 30 degrees south and an altitude of 4.4 km or higher, covering an energy range from hundreds of GeV to PeV. The SWGO Site Working Group is gathering, among other information, relevant environmental data to characterize the proposed sites using the AEROSITE instrument. Also atmospheric transparency is monitored to allow for potential enhancement of SWGO with a Cherenkov telescope. This contribution describes our activities in the study of the atmospheric conditions of selected candidate sites using instruments located onsite or installed at nearby stations.

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Potential for atmospheric monitoring using FAST telescopes

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The Fluorescence detector Array of Single-pixel Telescopes (FAST) is a design for a next-generation ground-based ultra-high energy cosmic ray observatory, addressing the requirements for a large-area, low-cost detector suitable for measuring the properties of the highest energy cosmic rays with an unprecedented aperture. Three telescope prototypes are installed nearby the fluorescence telescopes of Telescope Array and one prototype is located at the Pierre Auger Observatory. Apart from detecting cosmic ray showers, the FAST prototypes offer the possibility of detecting laser pulses from atmospheric facilities such as CLF. The first part of the contribution describes the theoretical modeling of the photon scattering processes for different atmospheric models, and the raytracing of photons from the laser shot to and inside the FAST telescope. Simulations will be performed for different types of scattering conditions dependent on e.g. the size of the scattering centers or other parameters such as humidity.
The ultimate goal is to create a software tool simulating the measured signals in the FAST telescopes from distant laser shots with proper treatment of light propagation trough the atmosphere and trough the detector. Such simulation toolkit for FAST prototypes at the Pierre Auger Observatory will benefit from existing attempts done for the Telescope Array site. Another part of the contribution will concern the real data of the observed CLF shots by the FAST prototypes both at the Pierre Auger Observatory and Telescope Array. Moreover, we can focus on the comparison of measured CLF shots by FAST prototype with the available data recorded by the full-scale fluorescence telescopes of the Pierre Auger Observatory.

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LIGHT-1: A 3U Cubesat Mission for the detection of Terrestrial Gamma- Ray Flashes

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Serendipitously discovered by the BATSE mission in the nineties, Terrestrial Gamma-ray Flashes (TGFs) represent the most intense and energetic natural emission of gamma rays from our planet. TGFs consist of sub-millisecond bursts of gamma rays (energy up to one hundred MeV) generated during powerful thunderstorms by lightenings and are in general companions of several other counterparts (electron beams, neutrons, radio waves). The ideal observatory for TGF is therefore a fast detector, possibly with spectral abilities and orbiting around Earth in LEO (Low Earth Orbit). To date, the benchmark observatory is ASIM, an instrument flying onboard the International Space Station (ISS), however TGF science is being addressed by new instruments, few of them orbiting in free flight around Earth: among these, LIGHT-1, a 3U Cubesat mission launched in December 21st, 2021 and deployed from the ISS on February 3rd, 2022. The LIGHT-1 payload consists of two similar instruments conceived to effectively detect TGFs at few hundred nanoseconds timescale. The detection unit is composed of a scintillating crystal organised in four optically independent channels, read out by as many photosensors. The detection unit is surrounded by a segmented plastic scintillator layer that acts as an anti coincidence VETO for charged particles. The customised electronics embeds power supplies and detector readout, signal processing, detector controls and act as interface with the bus of the spacecraft. LIGHT-1 makes the use of two different scintillating crystals, namely low background Cerium Bromide and Lanthanum Bromo Chloride, and two different photo sensing technologies based on PhotoMultiplier Tubes (R11265-200 manufactured by Hamamatsu) and Silicon Photomultipliers (ASD-NUV1C-P manufactured by Advansid and S13361-6050AE-04 manufactured by Hamamatsu). Payload performance and detailed description will be provided, along the results of commissioning and preliminary flight data.

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Atmospheric Aerosols Light Attenuation using the Telescope Ar-

ray Central Laser Facility

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The Telescope Array (TA) experiment measures the properties of ultra-high energy cosmic ray (UHECR) induced extensive air showers. TA employs a hybrid detector comprised of a large surface array of scintillator detectors overlooked by three fluorescence telescopes stations. TA has been collecting data since ~2008. The TA Low Energy extension (TALE) detector, comprised of 10 fluorescence telescopes has operated as a monocular Cherenkov/fluorescence detector for since ~2013, and for the past few years has been operating as a hybrid detector, along with a closely-spaced surface array, optimized for CR energies around 1017 eV. Currently, The TAx4 upgrade is underway and aims to, as the name suggests, quadruple the size of the surface array to improve statistics at the highest energies. TAx4 employs three additional fluorescence-detector stations with telescopes pointing at low elevation angles and overlooking the expanded surface detector deployment sites.

The analysis of the air fluorescence detectors (FD) data requires knowledge of the degree of the atmospheric attenuation of UV light produced by shower particles. This attenuation depends on the Rayleigh scattering by air molecules and also on the amount of aerosols present in the atmosphere at the time of shower observation. Being highly variable, real-time measurement of the aerosols light attenuation is accomplished through the use of a central laser facility (CLF) located at the center of the surface array, and in the field of view of the three main TA FDs, as well as, the TALE FD.

In this talk we will provide an overview of the analysis and use of the CLF data for the calibration of the energy of observed cosmic ray showers. I will briefly describe some of the other atmospheric monitoring systems and studies used for various analyses of TA, TALE, and TAx4.

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Atmospheric monitoring at the Pierre Auger Observatory and effects of aerosol attenuation on UHECR detection

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The Pierre Auger Observatory is detecting ultra-high energy cosmic rays (UHECR) since the early 2000s years in the Pampa Amarilla, Argentina. It is composed of different detection techniques which requires the monitoring of several aspects of atmospheric conditions along with the UHECR detection. We are presenting the multitude of atmospheric monitoring devices and their application in air shower reconstruction at the Pierre Auger Observatory. Special emphasis is put on the measurement of the aerosol attenuation of fluorescence light in the atmosphere. The temporal variability of aerosols is discussed together with the impact on air shower reconstruction. The effect of the use of average fixed aerosol attenuation is presented, in comparison to use of hourly measurements.