International Symposium on Future Directions in UHECR Physics

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Book of abstracts

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Welcome address

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Review of space-based approaches

The idea looking down the Earth to observe air-showers from space is not new. In fact, John Linsley already in 1979, has proposed to use a space telescope for the observation of UV emission from air-showers. Since then, a few missions are proposed to achieve this next generation technology for the exploration of the high energy universe. Space-based ultra-high energy observatories have important advantages compared with ground detectors: 1) the huge exposure area, 2) the well constrained distance to a shower, 3) the dust-free atmosphere in the above half troposphere, 4) the almost uniform exposure covering both hemispheres. Currently four space missions, dedicated to air-shower observation, have been proposed and planned by international collaborations of scientists and gencies, those are TUS (Tracking Ultra-violet Set up), JEM-EUSO (Extreme Universe Space Observatory on board Japanese Experiment Module), KLPVE, and Super-EUSO. In this presentation, I will review those missions and discuss a sound way to construct the solid basis of this new technology and possible collaborations between space and ground based facilities.

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Are UHECR and multiplet also galactic?

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Since last decades UHECR models teach us that at EeV energy UHECR are mostly of extragalactic origin. Moreover earliest (2007) AUGER at 55 EeV energy events were suggesting an UHECR GZK cut off and arrival map correlated with super-galactic plane, SGP,inside the expected GZK volume traced by protons. However the same AUGER composition imprint favoured nuclei (heavy or light) and not nucleons. Finally last (2010) UHECR map fade any SGP correlation while earliest Cen A (nearest AGN source) correlation reinforsed and survived. Since early 2008 we interpret the signals as lightest He-like UHECR, that cannot fly more than few Mpc explaining Virgo absence and smeared Cen A unique traces. We foresaw (and now we observe) multiplets (at 20 EeV) by He fragments overlapping Cen A. We noted also a Vela triplet, eventual multiplet along Cen A; unexpected multiplet rose also along Magellanic stream. Therefore we ask the key question of present article: beyond Cen A may our galaxy and local group hide important sources, contrary to extra-galactic (GZK) UHECR models?

Theory and measurement of UHECR flux and composition / 23

Recent results from LHCf

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The Large Hadron Collider forward experiment measured very forward neutral
particle spectra in LHC proton-proton collisions in early 2010.
In this talk we will discuss the energy and transverse momentum spectra of neutral pion at the 7TeV proton-proton collision, and also present the inclusive photon energy spectra taken at the 900GeV collisions.
The spectra in both collision energy are also compared with the predictions of
several hadronic interaction models that are often used for high energy particle
physics and for modeling ultra high energy cosmic ray showers.
Finally we will argue the capability of LHCf to measure a proton-lead collision events that is under discussion for the 2012.

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The impact of the fluorescence yield on the energy reconstruction of UHECR showers

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The fluorescence yield FY is a key parameter in the determination of the primary energy of UHECRs using the fluorescence technique. For a given fluorescence signal, the reconstructed primary energy is strongly dependent on the assumed FY parameters (absolute value, wavelength spectrum, pressure dependence, etc.). Auger, HiRes and TA experiments have used different FY assumptions. In this work we will show results on reconstructed energy against the assumed FY parameters for those used in the above experiments. These results provide useful information on the corresponding energy scales

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On the energy deposition by electrons in air and the accurate determination of the air fluorescence yield

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The uncertainty in the absolute value of the fluorescence yield FY still puts a severe limit on the accuracy of the primary energy of UHECRs. Accurate measurements of the fluorescence yield are being carried out in many laboratories around the world. The determination of the energy deposited in the field of view of the collision chamber is subjected to uncertainties that have to be taken into account for a correct evaluation of the FY precision. In this work we discuss on the calculation of this energy deposition and its accuracy.

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High Energy Neutrinos from Charm in Astrophysical Sources

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We present results for neutrino fluxes from astrophysical sources.
We show that charm production enhances a flux of very high energy neutrinos from astrophysical sources with jets driven by central engines, such as gamma ray bursts or supernovae with jets. The neutrino flux from semi-leptonic decays of charmed mesons is subject to much less hadronic and radiative cooling than the conventional flux from pion and kaon decays and therefore has a dominant contribution at higher energies, of relevance to future ultrahigh energy neutrino experiments.

New detection techniques and detector designs / 27

On the astrophysical value of larger, yet achievable UHECR detectors

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The last decade has established UHECR physics as a phenomenologically rich and experimentally mature science. Key observations related to the UHECR energy spectrum, composition and distribution over the sky have clarified a few basic open question, and raised new, unexpected ones. The absence of a clear signal of anisotropy or correlation with some classes of astrophysical objects, although in line with some indications of the presence of heavy nuclei among the UHECRs, has raised doubts about the utility of pursuing the quest for the highest energy particles in the universe. We discuss why the quest should not stop now, and argue that expanding our observational capabilities at 10^20 eV is bound to give us key information. In particular, we show that the GZK effect remains our best ally to reduce the number of contributing sources to a handful, easier to separate on the sky, from which the deflection angular size, the source density, and thus the individual source power or UHECR energy budget can be obtained. This would be of tremendous value for the astrophysical understanding of UHECRs, of their sources and of their acceleration mechanism. An acceptance close to 10^6 km2 sr yr, with full sky coverage at 10^20 eV may thus be regarded as a high priority goal in astroparticle physics as well as high-energy astrophysics in general.

Sources and Propagation / 28

Transition from Galactic to Extragalactic Cosmic Rays and cosmic ray anisotropy

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We constrain the energy at which the transition from Galactic to extragalactic cosmic rays occurs by computing the anisotropy at Earth of cosmic rays emitted by Galactic sources. Since the diffusion approximation starts to loose its validity for E/Z >10^(16-17) eV, we propagate individual cosmic rays using Galactic magnetic field models and taking into account both their regular and turbulent components. The turbulent field is generated on a nested grid which allows spatial resolution down to fractions of a parsec. If the primary composition is mostly light or intermediate around E ~ 10^18 eV, the transition at the ankle is ruled out, except in the unlikely case of an extreme Galactic magnetic field with strength >~ 10 {\mu}G. Therefore, the fast rising proton contribution suggested by KASCADE-Grande data between 10^17 eV and 10^18 eV should be of extragalactic origin. In case heavy nuclei dominate the flux at E >~ 10^18 eV, the transition energy can be close to the ankle, if Galactic cosmic rays are produced by sufficiently frequent transients as e.g. magnetars.

Theory and measurement of UHECR flux and composition / 29

New technique and results of cosmic ray investigations in the energy interval 10^15 – 10^19 eV

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New technique of EAS investigations by means of the method of local muon density spectra (LMDS) is developed. Application of this method to investigations of inclined EAS allows exploration of CR energy interval from 10^15 to 10^19 eV by means of a relatively small detector with area ~100 m^2 due to very strong dependence of EAS muon density on zenith angle. During 2002-2007, long-term NEVOD-DECOR experiment (about 20 thousand hours) was conducted and more than two million muon bundles in zenith angle interval 30 – 88 degrees were registered. Comparison of experimental data with results of CORSIKA simulations showed that the new method is sensitive to all main peculiarities of CR energy spectrum: the knee, increase of the energy spectrum slope with energy, the second knee. But the observed progressive excess of muon bundles with increasing primary CR energy in comparison with simulations (even for pure iron composition) indicates the appearance of new processes of muon generation. This result, together with observations of numerous unusual events and phenomena in various CR experiments – halos, alignment, penetrating cascades, long-flying component, large transverse momenta, Centauros, excess of VHE (~ 100 TeV) single and multiple muons, etc. – can be explained in frame of a single model if to suppose the production of blobs of quark-gluon plasma with large orbital momentum in nuclei collisions. This hypothesis drastically changes all cosmic ray physics at energies above the knee and interpretation of the results of all experiments at these energies. The correctness of this hypothesis can be checked both in LHC experiments and in CR investigations. At that, CR experiments have some advantages in comparison with LHC experiments, since the main signature of new processes are muons which will have energies ~ 100 TeV in cosmic rays and about several tens GeV in LHC experiments. It is difficult to separate such muons from particles produced in usual processes. Preliminary results of CR muon energy spectrum measurements (BUST in Russia and IceCube in Antarctica) exhibit a noticeable excess of muons with energies > 100 TeV, which evidences in favor of the new model of hadron interaction. In this case, for correct investigations of EAS, the experimental arrays must be supplemented by detectors which can measure or evaluate the energy of muons.

New detection techniques and detector designs / 30

What the radio signal tells about the cosmic-ray air shower.

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The physics of radio emission from cosmic-ray induced air showers is shortly summarized. It will be shown that the radio signal at different distances from the shower axis provides complementary information of the longitudinal shower evolution, in particular the early part, and the distribution of the electrons in the shower core. This complements the information obtained from surface, fluorescence, and muon detectors and is very useful in getting a comprehensive picture of an air shower.

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A method to search for correlations of UHECR masses with the large scale structures in the local galaxy density field

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One of the main goals of investigations using present and future giant extensive air shower (EAS) arrays is the mass composition of ultra-high energy cosmic rays (UHECRs). A new approach to the problem is presented, combining analysis of arrival directions with the statistical test of paired EAS samples. An idea of the method is to search for possible correlations of UHECR masses with their (separate) sources.

The method is based on non-parametric statistical test, specifically Wilcoxon rank sum routine, which does not depend on the populations fitting any parameterized distributions. Two particular algorithms are proposed: first, using measurements of the depth of EAS maximum position in the atmosphere, and second, relying on the age variance of air showers initiated by different primary particles.

The formulated method is applied to the Yakutsk array data in order to constrain a possible difference in average mass composition of two paired UHECR sets arriving from the supergalactic pancake and a complementary region.

Source models and theory challanges of UHECRs / 32

Constraints on inductive acceleration of UHECRs in astrophysical sources.

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I discuss possible sites of acceleration of UHECRs by regular electromagnetic fields in astrophysical sources. A plausible mechanism of acceleration works in the vicinity of supermassive black holes in active galactic nuclei. It is motivated by relatively high density of UHECR sources as suggested by both statistics of clustering and the shape of the GZK cutoff. However, I demonstrate that the model is strongly constrained by FERMI-LAT observations of the secondary gamma-ray background. I also briefly discuss potential Galactic sources where this mechanism might be at work.

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Multimuon detector for quasi horizontal EAS

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Quasi horizontal showers produced by charged CR and gammas are constituted exclusively by muons, the other components being absorbed in the thick layer of the atmosphere they must cross to reach a detection system on the Earth surface. Their transverse dimensions are increased by the distance they must travel as well by the terrestrial magnetic field which tends to extend muon cloud and separate positive muons from negative ones. The extended wide transverse dimensions allow increasing the rate of detection of EAS produced by high energy CR by means of a single detector which samples the muon density in the shower. This concept has been already applied in the NEVOD-DECOR experimental complex at MEPhI in Moscow that could detect muon density of showers produced by very high energy CR up to more than 10^18 eV. Due to the vertical orientation of DECOR planes and the presence of coordinate detector supermodules faced in two orthogonal azimuth directions, the azimuth acceptance of NEVOD-DECOR complex is nearly uniform and allows collection of near horizontal multimuon events arriving from all azimuth angles. If several such azimuthally symmetric muon detectors could be provided, the total rate could be further increased, and muon density in several regions of each shower could be sampled, what allows in many cases to determine the position of the axis of the shower and therefore evaluate its energy event by event. An exercise based on 9 of such nearly azimuthally symmetric muon detectors is illustrated and evaluated. Furthermore, including in some of them iron magnets, the measurements of muon density could be complemented by measurements of the energy density, improving therefore the localization of the shower axis and the energy estimation of the shower.

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FAMOUS - A Prototype Silicon-Photomultiplier-Telescope for the Fluorescence Detection of Ultra-High-Energy Cosmic Rays

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Due to their high photon detection efficiency, silicon photomultipliers (SiPMs) promise to increase the sensitivity of today's fluorescence telescopes which use photomultiplier tubes to detect light originating from extensive air showers. On the other hand drawbacks like a small sensitive area, a strong temperature dependence, a high noise rate and a reduced dynamic range have to be managed.
We present plans for FAMOUS, a prototype fluorescence telescope using SiPMs and a special light collecting optical system of Winston cones to increase the sensitive area. The prototype will make use of a Fresnel lens with imaging properties which fulfill all functional requirements for the application within the detector. For several different types of SiPMs, we measured the photon detection efficiency and its dependence on the incident angle of light. Further measurements include noise effects of the SiPM as well as its temperature dependencies, and we offer methods how to overcome these challenges. Moreover, we will present the R in compact modular electronics using photon counting techniques. Since the main background to the fluorescence signal derives from the night-sky brightness, a single-pixel-SiPM-telescope measured the photon flux of the night-sky. This allows the evaluation of the performance of the optical telescope design by means of a full detector simulation.

Experimental challenges of UHECR / 35

Nitrogen fluorescence in air for observing extensive air showers

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Extensive air showers initiate the fluorescence emissions from nitrogen molecules in air. The UV-light is emitted isotropically and can be used for observing the longitudinal development of extensive air showers in the atmosphere over many kilometers. This measurement technique is well established since it has been used since many decades by several cosmic ray experiments. However, a fundamental aspect of the air shower analyses is the description of the fluorescence emission in dependence on varying atmospheric conditions. Different fluorescence yields affect directly the
energy scaling of air shower reconstruction. In order to explore the various details of the nitrogen fluorescence emission in air, few experimental groups were performing dedicated measurements
over the last decade. Most of the measurements are now finished. These experimental groups have been discussing their techniques and results in a series of Air Fluorescence Workshops commenced
in 2002.
At the 8th Air Fluorescence Workshop 2011, it was suggested to develop a common way of describing the nitrogen fluorescence for application to air shower observations. Here, first analyses
for a common treatment of the major dependences of the emission procedure are presented. Aspects like the contributions at different wavelengths, the dependence on pressure, the temperature
dependence of the collisional cross sections between molecules involved, and the collisional de-excitation by water vapor are discussed.

New detection techniques and detector designs / 36

Ultra high energy particle physics and astrophysics. The need for multicomponent EAS measurement and primary particle identification.

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We show that a fundamental element for future generations of UHECR observatories is the multicomponent measurements of extensive air shower.
Such measurements may allow an event-by-event identification of the primary cosmic ray type and would radically impact on the study of various aspects of UHECR physics. From detailed hadronic physics studies to sources discovery via Galactic and extra-galactic magnetic fields determination and LIV tests we expose some of the expected progresses. We also present a promising detection system, based on the close integration of particles and microwave radio detectors, which allows, in principle, to measure separately the EM and muon cascade evolution of EAS. Our purpose is illustrated by presenting the progress of the EASIER upgrade currently underway at the Pierre Auger Observatory.

Source models and theory challanges of UHECRs / 37

A strategy to unveil transient sources of ultra-high-energy cosmic rays

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The origin of ultra-high-energy (UHE) cosmic rays (CRs) is still unknown and one of the biggest mysteries in modern astrophysics. The uncertainty of their composition makes this problem more complicated. If protons are dominant in UHECRs and are produced by phenomena related to astrophysical jets or outflows, there are few steady source candidates in local Universe which have luminosities enough to accelerate protons up to 10^{20} eV via statistical particle acceleration mechanisms. Since the few steady sources are difficult to reproduce isotropy observed by recent UHECR experiments, promising source candidates are astrophysical transients such as flares of active galactic nuclei and gamma-ray bursts. In this presentation we discuss how evidence of transient sources can be found and how future UHECR experiments can constrain transient source population of UHE protons.

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The Pierre Auger Research and Development Array (RDA) in southeastern Colorado – R for a giant ground array

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The Pierre Auger Research and Development Array was originally designed to be the precursor of the northern Auger observatory, an hybrid array of 4400 surface detectors and 39 fluorescence detectors deployed over 8,000 square miles. It is conceived as a test bed aiming at validating an improved and more cost-effective 1-PMT (instead of 3 in the current design) surface detector design and a new peer-to-peer communication system. The array of ten surface detectors and ten communication-only stations is currently being deployed in southeastern Colorado and will be operated at least until the end of the year. It is configured in such a way that it allows testing of a new peer-to-peer communication protocol, as well as a new surface detector electronics design with a larger dynamic range (22 bits instead of 15 in the current design) aiming at reducing the distance from the shower core where saturation is observed. All these developments are expected in the short term to improve the performance of the Pierre Auger Observatory and enable future enhancements. In the longer term, it is hoped that these new developments will also contribute to the design of a next-generation giant ground array.

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Using CORSIKA to quantify Telescope Array surface detector response

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Historically, studies of surface detector response have been severely limited by the inability to simulate charge density fluctuations at the distance scale of individual detector units. We present a two-prong solution. First, we have developed a technique that allows us to run the unmodified CORSIKA in parallel mode. This has allowed us to simulate ~100 non-thinned CORSIKA showers in the 10^{19}~eV epoch. Second, we have developed a dethinning algorithm that enables us to reconstruct the information lost using the CORSIKA thinning option. This algorithm is validated by comparison with the unthinned parallel showers mentioned above. By convolving a 10^{4} event shower library of dethinned CORSIKA events with the Telescope Array surface detector response, we will characterize our surface detector observational capabilities and present extensive Data/Monte Carlo comparisons.

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The current status of LHCf experiment and Future plan

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The Large Hadron Collider forward (LHCf) experiment has successfully finished the first phase of data taking at LHC $\sqrt{s}=0.9TeV and 7TeV$ proton-proton collisions in 2010.
In this poster, the status and future plan of the LHCf experiment is presented.

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Atmospheric monitor for Telescope Array experiment

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Atmospheric monitoring is very important for the observation of air showers by the air fluorescence technique.
In the Telescope Array (TA) experiment, the LIDAR (LIght Detection And Ranging) system and the CLF (Central Laser Facility) system are used for the measurement of atmospheric transparency. The LIDAR system is located southeast of TA site, and the CLF is located in the center of the TA site. The usefulness of the CLF and LIDAR systems are demonstrated by analyzing the time variation of atmospheric transparency with the systems. The two atmospheric monitor systems are complementary. We have installed a new LIDAR system at the CLF location, and we believe this will yield valuable data.
Clouds are observed with a CCD camera, an IR camera and by visual checks. In addition, we have also measured atmospheric parameters at the ground level using several weather systems. In the talk, these detector systems will be described.

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Characteristics of p-air interactions in the ultra-high energy region measured at the Yakutsk EAS array

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We present estimation of proton-air inelastic interaction cross-section obtained for different energy values are. Results are compared with different hadron interaction models.

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Cosmic ray energy spectrum and mass composition at energies 1015 - 1018 eV

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A spectrum of cosmic rays within energy range 1015-3*1017 eV was derived from the data of the small Cherenkov setup, which is a part of the Yakutsk complex EAS array. In this, work a new series of observation is covered. These observations lasted from 2000 till 2010 and resulted in increased number of registered events within interval 1016-1018 eV, which in turn made it possible to reproduce cosmic ray spectrum in this energy domain with better precision. A sign of a thin structure is observed in the shape of the spectrum. It could be related to the escape of heavy nuclei from our Galaxy. Cosmic ray mass composition was obtained for the energy region 1016 - 1018 eV. A joint analysis of spectrum and mass composition of cosmic rays was performed. Obtained results are considered in the context of theoretical computations that were performed with the use of hypothesis of galactic and meta-galactic origin of cosmic rays.

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The composition of the primary particles at energies 3·1017 -3·1019 eV

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Calculations of signals in surface and underground scintillation detectors of the Yakutsk array from particles of extensive air showers in terms of QGSJET-II and GEISHA 2002 models with the help of the CORSIKA 6.616 and GEANT4 codes with parameter ε=10-8 of the thinning procedures have been carried out to estimate muon fraction at 600 m from the shower axis at energies 3·1017 -3·1019 eV. Comparison of results of these calculations with the Yakutsk data shows rather heavy composition of the primary radiation in this energy region. But it was shown that calculations in terms of the QGSJET-II model at energies above 100 GeV underestimate the number of muons by a factor of ~1.5. Besides, it was also shown that calculations in terms of the of GEISHA 2002 model at energies below 100 GeV underestimate the number of muons by a factor of ~1.1 comparing with the FLUCA results. To interpret data one has also to take into account results observed at the Telescope array which show 1.27 difference in calculated in terms of models and observed with help of fluorescent light energy estimates of extensive air showers. Taken together all these corrections show the proton composition of the primary radiation in the energy region 1018 -3·1019 eV. At energies in the interval of 3·1017 - 1018 eV composition is probably heavier. It is not excluded that at energies above 3·1019 eV composition may be also more heavier as illustrated by the trend of data.

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Extension of the dynamic range of large photocathode PMTs for a UHECR detector

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Ground arrays for UHECR shower detection based on traditional counters, water Cherenkov tanks or scintillator modules, are unavoidably limited by the saturation suffered by the counters nearest to the shower axis and exposed to the largest particle density. The incomplete response from these detectors hampers the knowledge of the shower development near the shower core, limiting the accuracy in the reconstruction of the lateral density distribution and increasing the uncertainty on the energy estimation. Reducing to a negligible level the number of events recorded with one or more saturated counters should be mandatory in a future UHECR ground array. At the particle density of interest, the detector saturation is directly related to the finite extension of the linear range of the photomultipliers used. In principle, the use of the signals extracted from the internal dynodes, where the number of multiplication electrons is much lower than at the anode and the saturation by the space charge effect strongly reduced, can offer an elegant and inexpensive way to increase the linearity of a PMT. The viability of this technique has been explored studying a sample of 3 Hamamatsu R5912-mod photomultipliers and their performances. The PMTs were operated and monitored in the INFN-Torino laboratory with the Auger North control station electronic unit, front-end, and LED-based control system developed in the context of the Auger North RDA (Research & Development Array). Exploiting the signal from the fifth dynode, a linear response up to an equivalent anodic peak current larger than 1A (@ <G=2 x 10^5>) has been measured for all the studied PMTs. The feasibility of this technique in the context of a new ground array for UHECR studies has to be verified with a much larger sample of photomultipliers.

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AugerNext: Innovative Research Studies for the Next Generation Ground-Based Ultra-High Energy Cosmic-Ray Experiment

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Andreas Haungs and the AugerNext consortium for the Pierre Auger Collaboration

The findings so far of the Pierre Auger Observatory and the Telescope Array define the requirements for a possible next generation experiment: it needs to be considerably increased in size, it needs a better sensitivity to composition, and it should cover the full sky. AugerNext aims to perform innovative research studies in order to prepare a proposal fulfilling these demands. Such R studies are primarily focussed in the areas i) consolidation of the detection of cosmic rays using MHz radio antennas; ii)proof-of-principle of cosmic rays microwave detection; iii) testing the large-scale application of new generation photo sensors; iv) generalisation of data communication techniques; and v) developing new ways of muon detection with surface arrays. These AugerNext studies for a next generation cosmic ray experiment and the utilization of such new innovative detection methods are performed at the Pierre Auger Observatory. The AugerNext consortium consists presently of 14 partner institutions from 9 European countries supported by a network of European funding agencies and is a principle element of the ASPERA/ApPEC strategic roadmaps.

New detection techniques and detector designs / 47

Reconstruction of Muon Production Depth in grounded array based on the TTC (Time Track Complementarity) method

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The muon longitudinal profile along the shower axis is strictly connected to the primary nature and primary hadronic interaction with air nuclei. The detection of muonic component inside showers generated by Very High Energy Cosmic Rays provides a very powerful tool for sensing high energy interactions between cosmic ray particles and air molecules. Fundamental parameters as the interaction cross section, inelasticity, hadron production and multiplicity can be measured comparing the development of shower electromagnetic component with that of muonic component. Since 1992 a method has been developed to combine the muon arrival direction in a ground based array for cosmic ray detection with their arrival delay respect to the shower axis in the shower core. This combination permits to select high energy muons weakly scattered from atmosphere and reconstruct their height of production with good accuracy. In this talk we discuss on the possibility to realize a “dual” apparatus able to detect both electromagnetic and muonic components at primary energy greater than 10^17.

Sources and Propagation / 48

Ultra High Energy Nuclei Propagation and the Spectrum of UHECR

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We will discuss the main features of ultra high energy nuclei propagation in the intergalactic space, presenting a novel analytical approach to pursue such studies. We will also discuss a new interpretation of the experimental observations of UHECR.

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The Air Microwave Yield (AMY) experiment to measure the GHz emission from air shower plasmas.

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The aim of the AMY experiment is to measure and characterize the GHz radiation emitted from an electrom beam induced air plasma. The final purpose is to investigate the new
microwave detection techinque for Ultra-High Energy Cosmic Rays. We present the results of a first test performed at the Beam Test Facility (BTF) of Frascati INFN National Laboratories. The measurements have been performed with 510 MeV electron beam a in a wide frequency range between 1 and 20 GHz.

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Development of new photon detection device for Cerenkov and fluorescence radiation

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Recent progress on development of new solid state detectors allowed the use of finely pixelled photocathodes based on the use of silicon semiconductors. SiPM detectors seem to be an ideal tool for detection of Cerenkov and fluorescence light in spite of their not yet resolved criticism for operating temperature and intrinsic noise. The main disadvantage of SiPM in this case is the poor sensitivity in the wavelength range 300-400 nm, where the Cerenkov light and Fluorescence radiation are generated. We report on a new kind of finely pixelled detector based on the use of silicon substrate and Carbon Nanotube compounds, much more sensitive to the near UV radiation. Also if at the very beginning, the development of such detector appears very promising and useful for Astroparticle Physics, both in ground based array and in space experiments. First detectors are ready to be operated in conditions of measurements without signal amplification.

New detection techniques and detector designs / 51

Status of the microwave detection of cosmic rays program at the Pierre Auger Observatory

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Radiation in the microwave band from the passage of charged particles through air has been detected in the laboratory. Applied to extensive air showers this radiation could provide a novel technique for ultra-high energy cosmic rays detection over large area, with 100% duty cycle and virtually no atmospheric attenuation. Detection in the GHz band is being actively pursued at the Pierre Auger Observatory. The status of microwave R activities at Auger will be reported, and in particular the design and performances of AMBER and MIDAS, two different prototypes of an imaging parabolic dish detector, will be reviewed.

Source models and theory challanges of UHECRs / 52

Extragalactic and galactic sources: new evidence, new challenges, new opportunities

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First, I will present new evidence, from gamma-ray observations of blazars, that cosmic rays are, indeed, accelerated in AGNs. Second, I will discuss the plausibility of a substantial contribution of transient galactic sources, such as past GRBs and hypernovae, to the observed flux of cosmic-ray nuclei. The likely contamination of UHECR data by the nuclei from past galactic stellar explosions creates new challenges for cosmic-ray astronomy. At the same time, it creates new opportunities for reconstructing galactic magnetic field and for "astro-archaeology". Finally, I will discuss some observational signatures of astrophysical nuclear accelerators.

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LHCf plan for p-Pb forward particle measurement

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LHCf is planning to measure very forward particle emission in the LHC p-Pb collisions foreseen in the end of 2012. The measurement is expected to constrain the nuclear effect in the forward particle emission relevant to the CR-Air interaction. Model discrimination power of this measurement is presented together with some detail in technical feasibility.

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Disentangling the Air Shower Components Using Scintillator and Water Cherenkov Detectors.

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The current challenge in studying ultra-high energy cosmic rays is inferring the primary mass-composition. In order to get a better handle on mass-composition it is vital that we disentangle the contributions from the different components of the air shower, as this relates to the primary mass as well as possible systematic uncertainties arising from the use of Monte Carlo hadronic interaction generators. We therefore consider a ground array of scintillator and water Cherenkov detectors. The different response characteristics of these two types of detectors to the components of the air shower could provide a way to infer their relative contributions. We use a detailed simulation in order to estimate the impact of parameters, such as scintillator detector size, in the determination of the size of the muon component.

New detection techniques and detector designs / 55

The JEM-EUSO mission: context and status

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JEM-EUSO, the Extreme Universe Space Observatory on board the Japanese Experiment Module of the ISS (International Space Station), is expected, within this decade, to explore the ultra-high energy (UHE) Universe with unprecedentedly large effective area and uniform exposure.
In this talk we first summarize the scientific context of the mission, including its scientific requirements, and we discuss its role in the framework of the development of next- generation UHE observatories. We then report 1) on the status of the instrument, describing the most recent technical developments; and 2) on the mission aspects of the observatory. In addition, the current programmatic status will be presented.

New detection techniques and detector designs / 56

Performances of JEM-EUSO

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Designed as the first mission exploring the Ultra High Energy Universe from space, JEM-EUSO will monitor the Earth's atmosphere to record UV (300-400 nm) tracks generated by Extensive Air Showers produced by UHECR primaries. In this contribution, the expected performances of JEM-EUSO will be reviewed. In particular, by detailed simulation studies performed with realistic trigger and reconstruction efficiencies, the observational duty cycle and rôle of clouds are calculated. The estimate of aperture and exposure, as well as of the expected angular, energy, and Xmax resolutions will be presented. In addition, the obtained performance will be discussed in the context of the scientific goals of the JEM-EUSO mission.

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Astrophysics questions to be answered by JEM-EUSO

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JEM-EUSO will be the first space observatory to explore the UHECR sky. It will use the fluorescence technique to achieve a 3D-reconstruction of extensive air shower tracks, achieving unprecedentedly large effective aperture and a very uniform exposure in declination. These characteristics will allow precision measurements of the energy spectrum at the highest energies, including the region of a possible recovery, and unprecedented anisotropy studies. Particularly relevant to the latter is the possibility of point source charged particle astronomy leading to a break-through in the research area. Furthermore, the orbital nature of observatory, which forces its crossing of a wide range of geomagnetic latitudes, is ideal for the study of photon induced showers. In this talk we will discuss the scientific potential of JEM-EUSO as an astrophysical instrument and its impact as part of a global experimental strategy for the field.

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The Atmospheric Monitoring System of the JEM-EUSO Space Mission

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An Atmospheric Monitoring System (AMS) is mandatory and a key element of a space-based mission which aims to detect Ultra-High Energy Cosmic Rays. JEM-EUSO has a dedicated atmospheric monitoring system that plays a fundamental role in our understanding of the atmospheric conditions in the field of view of the telescope. Our AMS consists of an infrared camera and a LIDAR device that are being fully designed with space qualification to fulfil the scientific requirements of this space mission. This Atmospheric Monitoring System will provide information of the cloud cover in the FoV of JEM-EUSO, as well as measurements of the cloud top altitudes with an accuracy of 500 m and the optical depth profile of the atmosphere in the direction of each air shower with an accuracy of 0.15 degree and a resolution of 500 m. This should ensure that the energy of the primary ultra-high energy cosmic ray particle and the depth of maximum development of the extensive air shower are measured with an accuracy better than 30% and 120 g/cm2 for extensive air showers occurring either in the clear sky or with the depth of maximum above optically thick cloud layers. Moreover, a novel stereoscopic technique and radiometric retrieval from the data provided by the infrared camera are under development.

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Calibration of the JEM-EUSO detector

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In order to unveil the mystery of ultra high energy cosmic rays (UHECR's), JEM-EUSO (Extreme Universe Space Observatory on board of the Japan Experiment Module), launched ~2017, will observe extensive air showers induced by UHECR's from the International Space Station orbit with a huge acceptance. An accurate calibration of the JEM-EUSO instrument, which consists of Fresnel optics and a focal surface detector of 5000 MAPMTs, is very important to study the origin of UHECR's precisely. In this contribution, the calibration system before launch and on-orbit will be reported: the calibration before flight with integrating spheres, on-board calibration light source, and ground light source for on-orbit calibration from ground. We expect precise relative calibration at a few percent levels with several kinds of light sources and ~20% level absolute calibration using the moon.

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The EUSO-BALLOON pathfinder

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EUSO-BALLOON is a pathfinder mission for the Extreme Universe Space Observatory on-board the Japanese Experiment Module (JEM-EUSO) mission. Through a series of stratospheric balloon flights performed by the French Space Agency CNES, EUSO-BALLOON will serve as an evolutive test-bench for all the key technologies of JEM-EUSO, as well as other future missions dedicated to the observation of extensive air shower from space. The objectives of EUSO-BALLOON are (1) to perform a full end-to-end test of a JEM-EUSO qualification model consisting of all the main subsystems of the space experiment, (2) measure the critical atmospheric and terrestrial UV background components, and (3) perform the first detection of air-showers by looking down unto the atmosphere.

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Calibration and testing of a prototype of the JEM-EUSO telescope on Telescope Array site

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The TA-EUSO project aims to install a prototype of the JEM-EUSO telescope on the Telescope Array site in Black Rock Mesa, Utah. The detector consists of one Photo Detector Module (PDM), identical to the 137 present on the JEM-EUSO focal surface. Each PDM is composed by 36 Hamamatsu multi-anode photomultipliers (64 channels per tube), for a total of 2304 channels. Front-End readout is performed by 36 ASICS, with trigger and readout tasks performed by two FPGA boards that send the data to a CPU and storage system. Two 1.5m diameter Fresnel lenses provide an 8 degrees field-of-view of the telescope. TA-EUSO will be housed in a container located in front of the fluorescence detector of the Telescope Array collaboration, looking in the direction of the ELF (Electron Light Source) and CLF (Central Laser Facility). Aim of the project is to cross-calibrate the response function of the EUSO telescope with the TA fluorescence detector in presence of a shower of known intensity and distribution. An initial run of about six months starting from fall 2012 is foreseen, during which we expect to observe – triggered by TA electronics – a few cosmic ray events which will be used to further refine the cross-calibration between the two instruments. In case of continuation in the context of a longer term program, we are considering to increase the number of PDM and the field of view.

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Challenge and objectives of the radio detection technique from the CODALEMA collaboration viewpoint

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The interest of the cosmic ray community toward radio detection has largely grown over the past decade and numerous related physics programs have been developed besides pioneering experiments like CODALEMA and LOPES. However, this very promising new detection tool is still under development and a number of objectives have to be met.

We intend to sketch an up to date picture of the radio technique by reviewing successful achievements and remaining open questions in light of the latest CODALEMA results. This will lead us to the objectives to be tackled by the last generation of radio experiments toward the elaboration of a dedicated large scale instrument.

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Tunka-133: the First Results and Perspectives

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Registration of EAS Cherenkov light at the new Tunka-133 array let us use the Earth atmosphere as a huge calorimeter for very high energy primary particles. The preliminary all particles energy spectrum in the range 6.1015 – 1018 eV is collected during two winter seasons since 2009 till 2011. The depth of EAS maximum Xmax for each event is derived from the measured steepness of the Cherenkov light lateral distribution function. The mean Xmax vs. primary energy in the range 6.1015 – 3.1017 eV and the analysis of Xmax distributions in the narrow energy bins are discussed. The Tunka-133 array was upgraded last year with 6 remote clusters enlarging the effective area to about 4 times. The perspectives of this new array version are presented.

Source models and theory challanges of UHECRs / 65

Deflection of ultra-high energy heavy nuclei in magnetic fields

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In this work, we investigate the impacts a potential shift towards a heavy composition at the end of the spectrum would have on the future data. We present detailed simulations for the propagation of ultra-high energy heavy nuclei, with E > 60 EeV, within recent Galactic Magnetic Field (GMF) models. We both consider the regular and turbulent components of the GMF. We show that with UHE heavy nuclei, there is no one-to-one correspondence between the arrival directions of cosmic rays measured at Earth and the direction of their extragalactic sources. Sources can have several distorted images on the sky. We compute images of galaxy clusters and of the supergalactic plane in recent GMF models and show the challenges, but also the possibilities, of "UHECR astronomy" with heavy nuclei. Finally, we present a quantitative study of the impact of the GMF on the (de-)magnification of source fluxes, due to magnetic lensing effects. Such effects cannot be neglected in case of a heavy composition.

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Absolute energy calibration of the Telescope Array fluorescence detector with an electron linear accelerator

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The Electron Light Source (ELS) is a new light source for the absolute energy calibration of cosmic ray Fluorescence Detector (FD) telescopes. The ELS is a compact electron linear accelerator with a typical output of 10^9 electrons per pulse at 40MeV. We fire the electron beam vertically into the air 100 m in front of the telescope. The electron beam excites the gases of the atmosphere in the same way as the charged particles of the cosmic ray induced extensive air shower. The gases give off the same light with the same wavelength dependence. The light passes through a small amount of atmosphere and is collected by the same mirror and camera with their wavelength dependence. In this way we can use the electron beam from ELS to make an end-to-end calibration of the telescope. In September 2010, we began operation of the ELS and the FD telescopes observed the fluorescence photons from the air shower which was generated by the electron beam. In this report, we will present the status of the ELS.

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TA anisotropy update

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We search for anisotropy of ultra-high energy cosmic ray (UHECR) events collected by the Telescope Array detector in the first 3.5 years of operation. Following earlier studies, we consider the event sets with energy thresholds of E>10 EeV, E>40 EeV, and E>57 EeV. First, we calculate the autocorrelation function of the cosmic ray events and find no significant deviations from isotropy at angular scales from 0 to 40 degres in any of the three sets. Next, we check the events with E>57 Eev for correlations with nearby active galactic nuclei and find no significant correlations. Finally, we examine all three sets for correlations with the large-scale structure of the Universe. We find that the two higher-energy sets are compatible with both an isotropic distribution and the hypothesis that UHECR sources follow the matter distribution of the Universe (the LSS hypothesis), while the event set with E>10 EeV is compatible with isotropy and not compatible with the LSS hypothesis at 95% CL at angular scales smaller than ~15 degrees. We also check whether accounting for the regular Galactic magnetic field can make this set compatible with the LSS hypothesis.

New detection techniques and detector designs / 68

Microwave emission from extensive air showers as seen by CROME

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A measurement of extensive air showers in the microwave range has been considered as a possible successor to current measurement techniques. The CROME (Cosmic Ray Observation via Microwave Emission) experiment consisting of several parabolic antennas measures radiation from the atmosphere in coincidence with air showers detected by the KASCADE-Grande experiment. Nanosecond radio pulses are expected for vertical showers and thus, fast read-out electronics is used. Tens of KASCADE-Grande showers have crossed the field of view of our antennas after one year of data taking. A preliminary limit on microwave emission from air showers is presented.

New detection techniques and detector designs / 69

Interdisciplinary Science with Large Aperture Cosmic Ray Detectors

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Large aperture detector systems to measure high energy cosmic rays, also offer unique opportunities in other areas of science. Disciplines include geophysics such as seismic and volcanic activity, and atmospheric science ranging from clouds to lightening to aerosols to optical transients. This talk will discuss potential opportunities based on the ongoing experience of the Pierre Auger Observatory.

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The Telescope Array Low Energy Extension (TALE)

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The Telescope Array Low Energy Extension (TALE) will consist of an array of scintillation counters and fluorescence telescopes designed to lower the minimum energy of the Telescope Array (TA) experiment by about an order of magnitude. The fluorescence detector will have 10 telescopes which cover elevation angles between 31 and 59 degrees, and 95 degrees in azimuth. There will be 45 scintillation counters with 400m spacing, 31 with 600m spacing, and 37 counters with the same 1200m spacing as the existing TA surface array. The physics aims of TALE are to study the second knee of the cosmic ray spectrum and the galactic-extragalactic transition, and to characterize cosmic ray showers at 1017 eV to compare with LHC measurements at the equivalent center of mass energy.

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Anisotropy search above 1 EeV using the Telescope Array surface detector data

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In 1999, the Akeno Giant Air Shower Array (AGASA) reported a 4 sigma excess in the 1 - 2 EeV cosmic ray intensity near the Galactic Center (G.C.) and a 4 sigma deficit near the Galactic Anti-Center (G.A.C.) . In 2007, a similar 3.5 sigma deficit near the G.A.C. was seen by the High Resolution Fly's Eye (HiRes) experiment, while a search near the G.C. was inconclusive. We have performed an independent test of HiRes and AGASA results using 3 years of the Telescope Array (TA) surface detector (SD) data, collected in the period May, 2008 – May, 2011. We describe our methods of calculating the exposure on the sky by a detailed Monte-Carlo simulation and its application for determining the statistical significance of the results and testing the anisotropy search methods. We present a significance map of cosmic ray arrival directions as seen by the TA SD, a full-sky harmonic analysis in right ascension, and compare these results with HiRes and AGASA.

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RASTA - Radio detection of cosmic rays at South Pole

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The Radio Air Shower Test Array (RASTA) project explores the opportunity to enhance the IceCube Neutrino Observatory by measuring cosmic ray air-showers using radio detection. Radio signals in the 10-250 MHz region are produced by the deflection of the charged constituents of cascades in the Earth's magnetic field, providing a calorimetric measurement of the electron/positron component of air-showers at altitude. This technique can supplement measurement of energetic muons by IceCube's deep ice sensors and of the electromagnetic component at the surface by IceTop. It will thus improve Icecube's measurement of cosmic ray primary composition. Since January 2011 continuous data taking at a test installation using two antennas provides unprecedented precision on the radio background at South Pole. First self triggered air showers will be measured with an improved setup to be installed in January 2012. We will present results of these measurements and status of simulations showing the potential of such a detector.

Experimental challenges of UHECR / 73

HiRes and TA Spectrum Measurements

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HiRes was the first experiment to observe the GZK Cutoff. This was accomplished using the fluorescence technique with monocular reconstruction with a heavy reliance on Data/MC comparison techniques borrowed from particle physics. This result was later confirmed using stereo reconstruction and by the Pierre Auger Observatory. The HiRes result is consistent with the original motivation for the GZK Cutoff, protons interacting with the Cosmic Microwave Background Radiation to produce the delta resonance. Telescope Array has now also measured the ultra-high energy spectrum, showing remarkable agreement in detail with the HiRes measurements despite using significantly different observational methods, namely a hybrid measurement involving both surface detectors and fluorescence detectors. Both the use of a fluorescence energy scale and the reliance on Data/MC comparison techniques in determining the aperture link the TA and HiRes results.

New detection techniques and detector designs / 74

TARA: Forward-Scattered Radar Detection of UHECR at the Telescope Array

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Increased event statistics will be required to definitively answer the question of the origin(s) of Ultra-High Energy Cosmic Rays (UHECR). Using current technologies however, achieving the necessary statistics may be financially and practically impossible.

We describe the status and plans of the TARA project, an effort to detect Ultra-High-Energy Cosmic Rays by their forward scattered or "bistatic" radar signature. Bistatic radar holds promise as a new remote sensing technique for UHECR, without the duty cycle limitations of nitrogen fluorescence detectors. Such a technique could prove key in advancing the study of UHECR beyond the constraints of the current generation of cosmic ray observatories.

TARA consists of a low-VHF television transmitter illuminating the air above the Telescope Array (TA), and a set of radio receivers on the far side of TA approximately 50 km distant from the transmitter. We have collected radar data since April 2011 using a 2 kW transmitter at 54.1 MHz. Recently, we received permission to increase our broadcast power to 40 kW and our effective radiated power (ERP) to 6 MW. On the receiver end, we are employing software-defined radio receivers and developing real-time trigger algorithms based on the expected air shower radar echo.

In addition to presenting an overview of the project status and future plans, we will present the most recent results of searches for coincidences between radar echoes and Telescope Array air shower events.

UHECR and particle shower / 75

HiRes and TA Composition Measurements

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In order to clarify the origin of ultra high energy cosmic rays (UHECRs),
it is very important to determine the mass composition.
The most effective strategy to determine the mass composition is
Xmax technique.
Xmax is the atmospheric depth of air shower maximum measured by
fluorescence detectors (FDs).
HiRes has reported Xmax measurement by FDs which indicated
proton dominated mass composition.
Now, Telescope Array (TA) experiment has also measured UHECRs with FDs.
In this presentation, the detail of mass composition analysis and result
of TA experiment will be reported and compared with HiRes experiment.

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Search for ultra-high energy photons and neutrinos using Telescope Array surface detector

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We search for ultra-high energy photons by analyzing geometrical properties of shower fronts of events registered by the Telescope Array surface detector. By making use of an event-by-event statistical method, we derive upper limits on the absolute flux of primary photons with energies above 10^19, 10^19.5 and above 10^20 eV based on the three years data from Telescope Array surface detector (May 2008 - May 2011). We report the results of down-going neutrino search based on the analysis of very inclined events.

77

Search for molecular bremsstrahlung radiation signals in Ku band with coincidental operations of radio telescopes with air shower detectors

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Microwave radiation from extensive air showers is expected to provide a new technique to observe UHECR. We developed a set of radio telescopes each of which consists of a 0.45 m parabola antenna in Ku band, a power detector and a waveform digitizer. Firstly, we had coincidentally operated the radio telescopes with an air shower array consists of nine plastic scintillators with about 10 m separation for several months. Secondly, we moved and installed the telescopes just beside the Black Rock Mesa fluorescence detector (FD) station of the Telescope Array experiment, and we operated the radio telescopes coincidentally with FD event trigger. We report the experimental setups and the results of these measurements.

New detection techniques and detector designs / 78

Future plans of the Telescope Array experiment

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The Telescope Array (TA) experiment is the world's first and the only air shower detector to be directly calibrated by an on-site accelerator beam. For wider and deeper understanding of cosmic rays via high precision measurements, we have several future plans for the TA experiment. One extension plan is called TA low energy extension (TALE), to extend the sensitive energy range to 10^16.5 eV in order to study the second knee of the cosmic ray spectrum and the galactic-extragalactic transition, and to
characterize cosmic ray showers to compare with LHC measurements. TALE is an ongoing project. A second plan is to install a huge number of SDs and/or FDs in order to obtain the world's largest exposure and the finest accuracy to open a new window on astronomy with ultra high energy particles.

79

Searches for sources of astrophysical neutrinos with the ANTARES detector

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The first years of data from the ANTARES neutrino telescope have been extensively used to search for neutrinos of astrophysical origin. In this contribution an overview over various analysis will be given. We will present searches for point-like neutrino sources and the search for a high energy excess over the atmospheric neutrino flux. Exploiting the close connection between gamma ray and neutrino emission mechanisms in potential astrophysical cosmic ray accelerators, searches for correlations with gamma ray sources will be discussed using both time integrated and time dependent methods.

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Hybrid analysis for the Telescope Array

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The Telescope Array (TA) experiment is the largest Ultra-High Energy Cosmic Ray (UHECR) observatory in the northern hemisphere, and is located in the west desert of Utah. It is a hybrid UHECR experiment using two types of detectors: three stations of Fluorescence Detectors (FDs) and 507 Surface Detectors (SDs). The three FD stations (at Middle Drum (MD), Long Ridge (LR), and Black Rock (BR)) overlook the SD array. The MD station consists of 14 refurbished HiRes-I telescopes. The BR and LR stations are newly constructed for the TA experiment. The events detected by both SD and FD are reconstructed by the hybrid technique, which uses information from both the SD and FD. The resolution reaches < 1 degree for arrival directions and < 10% in energy. Hybrid events are used to compare the FD and SD energy scales, measure the spectrum, and determine the composition of cosmic rays. In this talk we present the performance of the hybrid technique for the BR, LR, and MD stations.

81

A measurement of the muon number in showers using inclined events detected at the Pierre Auger Observatory

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The average muon content of measured showers with zenith angles between 60 and 80 degrees detected at the Pierre Auger Observatory is
obtained as a function of shower energy using a reconstruction method
specifically designed for inclined showers and the hybrid character of the detector. The reconstruction of inclined showers relies on a comparison between the measured signals at ground and reference patterns at ground level from which an overall normalization factor is obtained. Since inclined showers are dominated by muons this factor gives the relative muon size. It can be calibrated using a subsample of showers simultaneously recorded with the fluorescence detector (FD) and the surface detector (SD) which provides an independent calorimetric measurement of the energy. The muon size obtained for each shower becomes a measurement of the relative number of muons with respect to the reference distributions. The precision of the measurement is assessed using simulated events which are reconstructed using exactly the same procedure. We compare the relative number of muons versus energy as obtained in simulations with that measured in data. Proton simulations with QGSJETII show a factor of 2.13 +- 0.04(stat) +- 0.11(sys) at 10^19 eV without significant variations in the energy range explored between 4.10^18 eV to 7.10^19 eV. We find that none of the current shower models, neither for proton nor for iron primaries, are able to predict as many muons as are observed.

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Search for correlation with the TA events and various classes of objects

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The origin of ultra-high energy cosmic rays (UHECRs) is still a mystery in astrophysics. In order to clarify the origin of UHECRs, their arrival directions are of special importance. We searched for correlations between the arrival directions of the UHECR events observed by Telescope Array (TA) with energies greater than 10EeV and the positions of astronomical objects of various classes. The data used in this work is from the first three year observation by the surface detectors of TA. We used several public catalogs from surveys at various wavelengths, including the VC catalog 13th ed., the IRAS PSCz catalog, the Fermi 2FGL catalog, the 2MRS catalog, the Swift-BAT catalog and the 3CRR catalog. The results of the correlation searches and their statistical significances will be discussed.

83

Simulation of Ultra-High Energy Cosmic Ray Propagation

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A future Ultra-High Energy Cosmic Ray (UHECR) Observatory will provide an unprecedented amount of high quality UHECR data. The astrophysical interpretation of this data requires a detailed Monte Carlo simulation of UHECR propagation. The publicly available code CRPropa allows such a simulation, taking into account all relevant energy losses in ambient photon fields and deflections in structured magnetic fields. In this talk the CRPropa software is introduced, recent developments like the extension to UHE nuclei propagation as well as future challenges are discussed.

Theory and measurement of UHECR flux and composition / 84

Measurement of the proton-air cross section with the Pierre Auger Observatory

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Authorship: The Pierre Auger Collaboration.
Using the tail of the distribution of the depth of shower maxima observed with the Pierre Auger Observatory, we derive an estimate of the proton-air cross section for particle production at center-of-mass energies of 57 TeV. Air showers observed with the fluorescence detector and at least one station of the surface array are analyzed in the energy range from 10^18 to 10^18.5 eV. Systematic uncertainties of the cross section estimate arising from the limited knowledge of the primary mass composition, the need of using shower simulations, and the selection of showers are studied in detail.

85

Hadronic Interactions in Extensive Air Showers

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The detailed analysis of cosmic ray induced extensive air showers requires a good knowledge of hadronic particle production in the shower cascade. For ultra-high energy cosmic rays this depends on the extrapolation of the available accelerator data by the models over wide ranges in energy but also into the forward phase space. We demonstrate how the extrapolation of different particle production features impacts the prediction of important air shower observables.

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Search for ultra-high energy photons at the Pierre Auger Observatory

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The Pierre Auger Observatory has a significant sensitivity to search for ultra-high energy photons using data from the ground detector alone or in hybrid mode. Recent upper limits on the photon flux are already below the percent-level with regard to the total flux. The current status and details of the analysis methods are presented.

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Missing energy estimate in the light of the muon discrepancy

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The determination of the primary energy of extensive air showers using the fluorescence technique requires an estimation of the energy carried away by particles (muons, neutrinos) that do not deposit all their energy in the atmosphere. This estimation is typically made using Monte Carlo simulations and is thus dependent on the hadronic interaction model, specially on the predictions for neutrino and muon production. In this contribution we show a new method to obtain the missing energy directly from events measured simultaneously with the fluorescence and the surface detectors of the Pierre Auger Observatory. At 10 EeV, the average missing energy estimated with this method is more than 60% higher than the prediction from QGSJETII for protons. This result is compatible with the muon deficit in simulations of extensive air showers found by the Pierre Auger Collaboration (presented at this conference elsewhere)

Theory and measurement of UHECR flux and composition / 88

Measurements of the muon shower content at the Pierre Auger Observatory

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Various methods of estimation of the muonic part of the signal observed in the surface Cherenkov detectors have been developed within the Pierre Auger Collaboration in the recent years. Muon shower content, derived from data with these methods, is larger in comparison with predictions of QGJSET II and EPOS 1.99 interaction models. The zenith angle dependence of the muon deficit in simulations with respect to data is discussed.

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Radar reflection off extensive air showers

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We investigate the possibility of detecting extensive air showers by the radar technique. Considering a bistatic radar system and different shower geometries, we simulate reflection of radio waves off the static plasma produced by the shower in the air. Using the Thompson cross-section for radio wave reflection, we obtain the time evolution of the signal received by the antennas. The frequency upshift of the radar echo and the power received are studied to verify the feasibility of the radar detection technique. Preliminary results will be shown.

New detection techniques and detector designs / 90

A conceptual design for a large ground array of Fluorescence Detectors

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In order to understand the composition and hadronic interactions of ultra-high energy cosmic rays above $10^19.5$ eV, currently limited by statistics, the next generation of experiments must provide a precise measurement of the maximum shower development with a large aperture. We propose a novel design of fluorescence detectors arranged in a large (≥ 40000 km^2) ground array. The shower reconstruction is obtained from the time development of the fluorescence signal only, with a significant simplification of the detector design and reduction of costs. Simulations of the conceptual design are presented.

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Neutrinos and Gamma Rays from the First Ultra-High Energy Cosmic Rays in the Universe

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Population III stars, the very first, metal-free stars to form in the Universe, may give rise to gamma-ray bursts (GRBs) with much greater energy compared to ordinary GRBs. Such Pop III GRBs can produce ultra-high energy cosmic rays (UHECRs) with a correspondingly larger energy budget. Despite their typically high redshifts (z~10-20) and modest expected burst rates, the consequent cosmogenic neutrino flux due to the interactions of these UHECRs with cosmic background radiation fields may be potentially observable. Employing different available models for the Pop III GRB rate, we show that current upper limits from IceCube-40 may already rule out the most optimistic combinations of GRB energetics and formation rate. Future observations by the completed IceCube or KM3NeT may possibly detect the neutrinos and distinguish them from the lower-redshift contribution through their spectra. We also evaluate the accompanying flux of cascade gamma rays and discuss the constraints from current Fermi LAT measurements. Such neutrinos and gamma rays can provide a unique and important probe of the very first UHECRs that appear in the Universe.

New detection techniques and detector designs / 92

First results from the Microwave Air Yield Beam Experiment (MAYBE): measurement of GHz radiation for Ultra-High Energy Cosmic Rays detection

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We present measurements of microwave emission from an electron-beam induced air plasma performed at the 3 MeV electron Van de Graaff facility of the Argonne National Laboratory. Results include the emission spectrum between 1 and 15 GHz, the polarization of the microwave radiation and the scaling of the emitted power with respect to beam intensity. MAYBE measurements provide further insight on microwave emission from extensive air showers as a novel detection technique for Ultra-High Energy Cosmic Rays.

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Search for ultra-high energy neutrinos at the Pierre Auger Observatory

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The Pierre Auger Observatory has the capability of detecting ultra-high energy neutrinos of all flavours. They interact through charged and neutral currents in the atmosphere (downward-going) and through the ``Earth-skimming'' mechanism (upward-going). The main challenge in detecting ultra-high energy neutrinos with the Pierre Auger Observatory is to identify a neutrino-induced shower in the overwhelming background of showers initiated by ultra-high energy cosmic rays, possibly protons, heavy nuclei or even photons. The neutrino search analyses and the most up-to-date upper limits on the neutrino fluxes are reported.

94

A HiSCORE prototype at the Tunka-EAS array

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A proof-of-principle experiment for the HiSCORE detector, a ground-based large-area wideangle γ -ray and cosmic-ray experiment focusing on the energy range beyond 10 TeV and up to 1 EeV, is planned at the Tunka-133 Cherenkov EAS array. The HiSCORE prototype units will be installed in 2012 and 2013. The calibration of the new detectors will be done by simultaneous observations with the Tunka-133 Cherenkov array, using the Earth atmosphere as a huge calorimeter. We review the main characteristics of HiSCORE, and plans for the next steps.

New detection techniques and detector designs / 95

Results from the Auger Engineering Radio Array

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The Auger Engineering Radio Array (AERA) is one of the low energy enhancements of the Pierre Auger Observatory. AERA is based on experiences obtained with the LOPES and CODALEMA experiments in Europe and aims to study in detail the emission mechanism of radio signals in the MHz region from extensive air showers. The data from AERA will be used to assess the sensitivity of MHz radiation to the mass composition of cosmic rays and because of the energy threshold at 2 10{17} eV the dip region in the cosmic-ray flux spectrum can be studied in detail. We will present first results of AERA and of its prototypes.

Source models and theory challanges of UHECRs / 96

The Need for Hard Spectrum Local Sources of UHECR Nuclei

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Using the recent Auger energy spectrum and composition analysis results, an investigation is carried out into the requirements placed on the UHECR sources. The spatial distribution of these sources is investigated along with the energy distribution of UHECR they output. These investigations reveal the need for local UHECR sources which output a hard spectrum of intermediate/heavy UHECR. These results demand that local (<80 Mpc) UHECR sources exist, placing exciting and difficult requirements on the local extragalactic candidate sources. None negligible (>0.01 nG) extragalactic magnetic fields are noted to further strengthen these results

Experimental challenges of UHECR / 98

The Yakutsk array experiment: main results and future directions

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The results of the Yakutsk array experiment aimed at investigations of ultra-high energy cosmic rays are presented. We outline the current status of the instrument and an outlook for future directions and areas of study.

Theory and measurement of UHECR flux and composition / 99

Estimates of the proton-proton cross section at UHE energy

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This contribution discusses possible methods to measure the proton-proton total cross section from observations of Ultra High Energy cosmic rays, and the theoretical uncertainties associated with these methods.

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Measurements of the Longitudinal Shower Development with the Pierre Auger Observatory

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In this work we explain how the Pierre Auger Observatory measures and reconstructs the longitudinal development of air showers. The measurement of the energy deposit in the atmosphere by the detection of the emitted fluorescence light is going to be briefly reviewed and the reconstruction procedure is going to be explained in details. The two main outputs of this analysis are: a) the depth in which the shower reaches its maximum (Xmax) and b) the shower energy.
In this work we concentrate on the analysis techniques developed with the aim to evaluate the unbiased Xmax distributions. We show how using measured events it is possible to determine the depth ranges in which the detectors are able to measure an unbiased Xmax distribution. Using this analysis method we managed to obtain unbiased data without the use of shower and detector simulations. Another important point we are going to present in this work is how the detector resolution have been calculated and how they are taken into account in our final results. The analysis procedure explained here is a fundamental step in the composition studies and in the measurements of the proton-air cross section published by the Pierre Auger Collaboration.

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Measurement of the Muon Production Depth

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The surface detector array of the Pierre Auger Observatory allows for an experimental estimation of the muonic longitudinal development of extensive air showers in an indirect way. From the FADC traces of the surface detectors far from the core it is possible to reconstruct the Muon Production Depth distribution (MPD). We characterize the goodness of this reconstruction for zenith angles around 60 degrees and different energies of the primary particle. The maximum of this distribution, X?max, interpreted as the point where the muon production reaches a maximum along the cascade development, is explored as a sensitive parameter to infer the mass composition of cosmic rays.

Experimental challenges of UHECR / 102

Measurement of the energy spectrum of cosmic rays at highest energies using the Pierre Auger Observatory

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We report a measurement of the flux of cosmic rays with unprecedented precision and statistics using the Pierre Auger Observatory. Based on fluorescence observations in coincidence with at least one surface detector we derive a spectrum for energies above 10^18 eV. We also report on the energy spectrum obtained with surface detector arrays of 1500m and 750m spacing for events with zenith angles less than 60 degrees and 55 degrees respectively. The spectrum derived from inclined events will be given account as well. The spectral features are presented in detail and the impact of systematic uncertainties on these features are addressed.

Theory and measurement of UHECR flux and composition / 103

New Physics at UHE energies

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Ultrahigh energy cosmic rays (UHECRs) are the highest energy particles in the Universe, recorded to have energies up to 100 million times greater than the LHC beams. Whether they are protons or nuclei and how they are accelerated are presently unknown. The particle cascades created when these UHECRs interact in the atmosphere are not well-described by
simulations, but since the primary composition is unknown and the particle physics models must be extrapolated far beyond accelerator energies, the origin and extent of the discrepancies have not been clear. By combining information from the longitudinal and lateral properties of the showers, measured in detail by the Pierre Auger Observatory, we are lead to the seemingly-inescapable conclusion that there is a fundamental change in the nature of the final states produced in ultrahigh energy interactions. It has distinctive features which suggest that a new phase of matter is being produced, and we conjecture it results from the restoration of chiral symmetry in a new high temperature regime of Quantum Chromodynamics, not accessible in accelerator experiments. In the conditions probed in particle physics experiments to date, chiral symmetry is broken and the lightest strongly interacting particle is the pion, a quark - anti-quark bound state. Chiral symmetry restoration has been predicted theoretically at temperatures above the Deconfinement Phase Transition, responsible for the Quark-Gluon Plasma created in relativistic heavy ion collisions, but its possible creation in 1 UHE collisions was not anticipated. Although pions and other mesons would not exist in
a chiral symmetric phase, we present theoretical arguments that baryons and anti-baryons remain bound. As a result, baryons and anti-baryons could be produced much more abundantly relative to mesons, than at accelerator energies. This picture provides the first consistent description of the published Auger observations on both the magnitude and zenith angle dependence of the ground signal, and the longitudinal profiles. Auger measurements should be able to test our claim that new physics is needed to explain UHE air showers, explore how the meson-baryon balance evolves with energy, and possibly determine the composition of the UHECRs. With a substantially larger sample of UHE hybrid events, it should be possible to investigate in considerable detail the production and properties of this ultimate phase of
matter.

UHECR and particle shower / 104

Mass Sensitive Observables of the Pierre Auger Observatory and Their Possible Implications

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In this presentation we will discuss measurements of the longitudinal development of air showers at the Pierre Auger Observatory. The longitudinal development can be directly observed by the fluorescence telescopes of Auger and we will present the results on the evolution of the average of the shower maximum and its fluctuations as a
function of energy. Moreover, two observables from the surface detector, the asymmetry of the rise time and the muon production depth, will be discussed and the measurements will be compared to predictions from air shower simulations for different primary particle types.

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Anisotropy studies with the Pierre Auger Observatory

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We report recent results from the Pierre Auger Observatory about the anisotropy of ultra-high energy cosmic ray arrival directions. In the EeV energy range, we present the results on a search for a large scale dipolar anisotropy pattern. In the same energy range, we show the results of a search for localized excesses of cosmic ray neutrons. For cosmic rays with energies above 20 EeV, we discuss the results of the search for multiplets of aligned events. Finally, we present an update on the search for correlations between events with energy above 55 EeV and the positions of active galactic nuclei from the V\'eron-Cetty and V\'eron catalog, and in particular within the Cen A region.