

At the Doorway to UHE Cosmic Ray Astronomy – Recent Results from the Pierre Auger Observatory –

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Abstract. The Pierre Auger Observatory has been designed to measure the most energetic particles in nature. It is located on a plateau in the Province of Mendoza, Argentina, and covers an area of 3000 km². The construction has been completed in June 2008 with more than 1600 water Cherenkov detectors positioned on a 1.5 km hexagonal grid and with 24 large area fluorescence telescopes erected at the perimeter of the array. Data taking has been started in 2004 with only 100 tanks and three telescopes taking data. After briefly sketching the design of the observatory, we shall discuss selected first results covering (i) the energy spectrum of cosmic rays with the observation of a flux suppression starting at the GZK energy-threshold, (ii) upper limits of the photon and neutrino flux, (iii) the chemical composition of cosmic rays, and (iv) studies of anisotropies in the arrival direction of cosmic rays including the observation of directional correlations to nearby AGNs.

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INTRODUCTION

Understanding the origin of the highest energy cosmic rays is one of the most pressing questions of astroparticle physics. Cosmic rays (CR) with energies exceeding 10²⁰ eV have been observed for more than 40 years (see e.g. [1]) but due to their low flux only some ten events of such high energies could be detected up to recently. There are no generally accepted source candidates known to be able to produce particles of such extreme energies. An excellent review, published by Michael Hillas more than 20 years ago, presented the basic requirements for particle acceleration to energies $\geq 10^{19}$ eV by astrophysical objects [2]. The requirements are not easily met, which has stimulated the production of a large number of creative papers inventing new astrophysical and particle physics scenarios to explain the origin of the most energetic particles. Moreover, there should be a steeping in the energy spectrum near 10²⁰ eV due to the interaction of cosmic rays with the microwave background radiation (CMB). This Greisen-Zatsepin-Kuz'min (GZK) effect [3] severely limits the horizon from which particles in excess of $\sim 6 \cdot 10^{19}$ eV can be observed. For example, the sources of protons observed with $E \geq 10^{20}$ eV need to be located within a distance of less than 50 Mpc [4]. The non-observation of the GZK-effect in the data of the AGASA experiment [5] has motivated an enormous number of theoretical and phenomenological models trying to explain the absence of the GZK-effect and

has stimulated the field as a whole.

Besides astrophysics, there is also a particle physics interest in studying this energy regime. This is because CRs give access to elementary interactions at energies much higher than man-made accelerators can reach in foreseeable future. This opens opportunities to both measuring particle interactions (e.g. proton-nucleus, nucleus-nucleus, γ -nucleus, and ν -nucleus interactions) at extreme energies as well as to probe fundamental physics, such as the smoothness of space or the validity of Lorentz invariance in yet unexplored domains.

After decades of very slow progress because of lack of high statistics and high quality data, the situation has changed considerably during the last year. This is mostly due to the advent of the hybrid data from the Pierre Auger Observatory (PAO). Both, the HiRes and the Pierre Auger experiments have reported a flux suppression as expected from the GZK-effect [6, 7]. The very recent breaking news about the observation of directional correlations of the most energetic Pierre Auger events with the positions of nearby AGN [8] complements the observation of the GZK effect very nicely and provides evidence for an astrophysical origin of the most energetic cosmic rays. Another key observable allowing one to discriminate different models about the origin of high-energy cosmic rays is given by the mass composition of CRs. Unfortunately, the interpretation of such data is much more difficult due to the strong dependence on hadronic interaction models. Only primary photons and neutrinos can be discriminated safely from protons and nuclei and recent upper limits to their fluxes largely rule out top-down models, originally invented to explain

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the apparent absence of the GZK-effect in AGASA data.

THE PIERRE AUGER OBSERVATORY

The two most important design criteria for the Pierre Auger Observatory were to achieve a sufficiently large aperture at $E \gtrsim 10^{19}$ eV so that the answer about the existence of the GZK-effect could already be given within the first years of operation, and to measure CR induced air showers simultaneously by two independent observation techniques in order to better control systematic uncertainties in the event reconstruction. This is called the *hybrid* approach. Another important objective was to achieve a uniform full sky-coverage to allow studying global anisotropies of CRs and correlations with matter concentrations in the nearby Universe. This is planned to be realized by one observatory each on the southern and northern hemisphere. Because of funding constraints, the Pierre Auger Collaboration decided to start constructing the southern site first with the northern one to follow as soon as possible.

The first of the two design criteria asked for a detector area of $\gtrsim 3000 \text{ km}^2$ in order to collect about one event per week and site above 10^{20} eV, depending on the extrapolation of the flux above the GZK threshold. The most cost-effective hybrid approach was found to be a combination of an array of surface detectors (SD) of water Cherenkov tanks, operating 24 hours a day and a set of air fluorescence detectors (FD) observing the light emission of extensive air showers above the array in clear moonless nights.

The ground array at the southern site comprises 1600 cylindrical water Cherenkov tanks of 10 m^2 surface area and 1.2 m height working autonomously by solar power and communicating the fully digitized data by radio links. The tanks are arranged on a hexagonal grid with a spacing of 1.5 km yielding full efficiency for extensive air shower (EAS) detection above $\sim 5 \cdot 10^{18}$ eV. By now (October 2008), more than 1600 tanks are in operation and taking data. Some of the tanks are operated on a denser grid to improve the understanding of the lateral particle distribution function.

Charged particles propagating through the atmosphere excite nitrogen molecules causing the emission of (mostly) ultraviolet light. The fluorescence yield is very low, approx. four photons per meter of electron track (see e.g. [9]), but can be measured with large area imaging telescopes during clear new- to half-moon nights to achieve a duty cycle of $\approx 10\text{-}15\%$. The fluorescence detector of the southern site comprises 24 telescopes arranged into four observation sites located at the perimeter of the ground array. Each of the four sites houses six Schmidt telescopes with a $30^\circ \times 30^\circ$ field of view (f.o.v.). Thus, the 6 telescopes of an observation

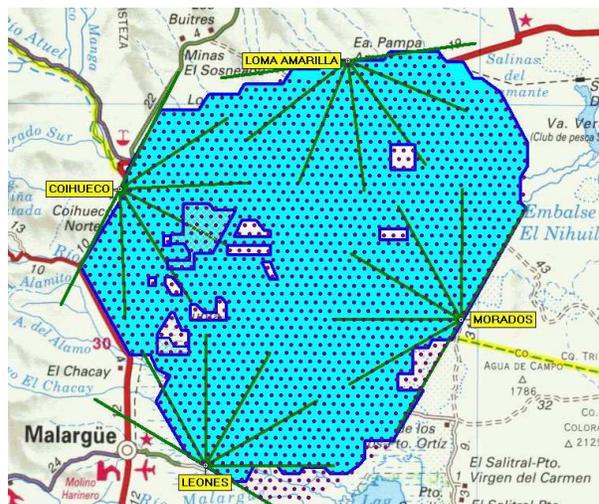


FIGURE 1. Layout of the southern site with the locations of the surface detector tanks indicated. Also shown are the locations of the fluorescence observation sites with the f.o.v. of their telescopes. The blue region indicates the part of the ground array currently in operation (May 2008). Furthermore, all 24 telescopes distributed over the four sites Los Leones, Coihueco, and Loma Amarilla and Los Morados are in operation.

site provide a 180° view towards the array center and they look upwards from 1° to 30° above the horizon. All 24 telescopes are in operation and taking data.

The layout of the southern site and its current status is depicted in Fig. 1. It shows the locations of the four fluorescence detector observation sites and of the water tanks in operation. At present, small spots still remain without water tanks being deployed. This is because of few landowners prohibiting us to access to their lands. Further details about the experiment and its performance can be found in Refs. [10, 11]. Already before completion of the southern site, the collaboration has selected southeast Colorado to site the northern detector and started to perform related R&D work and local environmental and atmospheric studies.

THE ENERGY SPECTRUM

A very important step towards unveiling the origin of the sources of UHECR is provided by measurements of the CR energy spectrum. The *ankle* observed at $E \simeq 4 \cdot 10^{18}$ eV is believed to be either due to the onset of an extragalactic CR component or due to energy losses of extragalactic protons by e^+e^- pair production in the CMB [12]. At energies above $E \simeq 6 \cdot 10^{19}$ eV the GZK-effect [3] is expected due to photo-pion production of extragalactic protons in the CMB. Nuclei suffer energy losses on similar length scales and above about the same thresh-

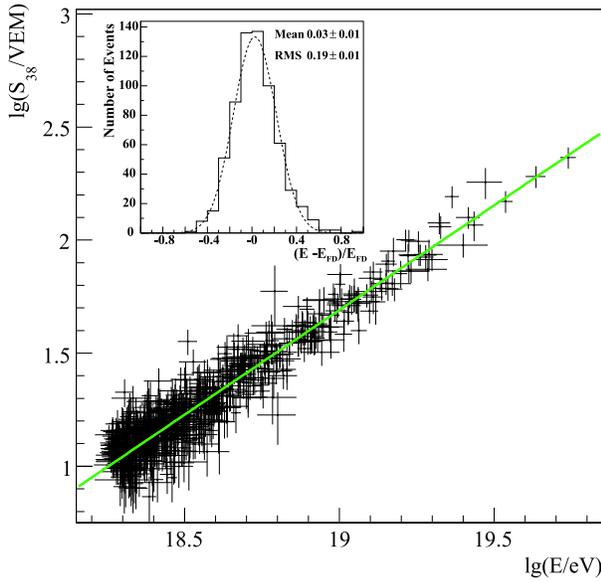


FIGURE 2. Correlation between $\lg S_{38^\circ}$ and $\lg E_{FD}$ for hybrid events. The full line is the best fit to the data. The fractional difference between the FD and SD energies is shown in the inset [7].

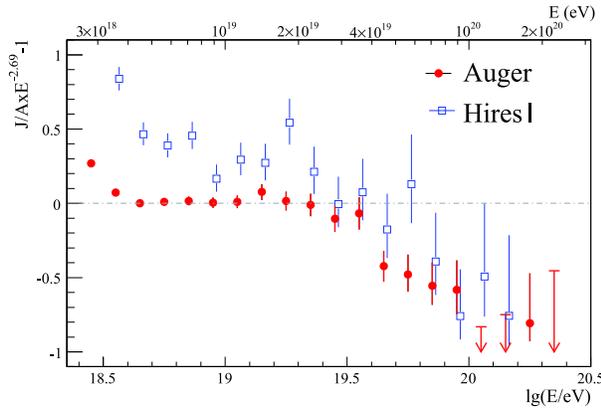


FIGURE 3. Fractional difference between the derived energy spectrum and an assumed flux $\propto E^{-2.69}$ as a function of energy [7].

old energy by photodisintegration in the CMB field.

Recent measurements of the CR energy spectrum by AGASA and HiRes have yielded results which differ in their shape and overall flux [13]. This may be explained by the fact that the energy determination of CR particles by ground arrays like AGASA relies entirely on EAS simulations with their uncertainties originating from the limiting knowledge of hadronic interactions at the highest energies, most importantly the total inelastic cross sections, particle multiplicities, and inelasticities. For example, SENECA simulations [14] have shown that the

muon density at ground predicted by different hadronic interaction models differ by up to 30 %.

Fluorescence telescopes, such as operated by HiRes and the PAO, observe the (almost) full longitudinal shower development in the atmosphere. In this way, the atmosphere is employed as a homogenous calorimeter with a vertical absorber thickness of 30 radiation lengths or 11 hadronic interaction lengths. Corrections for (model dependent) energy ‘leakage’ into ground - mostly by muons and neutrinos - are below 10% and their uncertainties are only a few percent of the primary energy. As a consequence, fluorescence detectors provide an energy measurement which is basically independent from hadronic interaction models including unknown features of particle production at the highest energies, such as heavy quark production, etc.. Uncertainties in the energy scale arise most dominantly from the fluorescence yield in the atmosphere and from the photometric calibration of the telescopes. Several measurements of the fluorescence yield have been performed in the past, e.g. the Auger Collaboration uses the fluorescence yield by Nagano et al. [15] and HiRes uses the integrated yield by Kakimoto et al. [9] and the spectral distribution by Bunner [16]. Major international efforts have been started to remeasure the fluorescence yield as a function of temperature, pressure and humidity with high precision [17] in order to reduce this source of uncertainty.

Taking benefit of the Auger hybrid detector, the Auger Collaboration has used a clean set of hybrid data, in which EAS have been detected simultaneously by at least one fluorescence telescope and the ground array, to calibrate the observatory. This is shown in Fig. 2, where the shower size parameter $S(1000)$ extracted from lateral particle density distribution of EAS at a distance of 1000 m (and normalized to zenith angles of 38°) is plotted versus the CR energy determined from the fluorescence telescopes. The straight line represents the fitted calibration relation which is applied to the much larger data set of the ground array. The 19% rms value shown in the inset of the figure is found to be in good agreement to the quadratic sum of the S_{38° and E_{FD} uncertainties.

The resulting energy spectrum based on ~ 20000 events is displayed in Fig. 3. To enhance the visibility of the spectral shape, the fractional difference of the measured flux with respect to a chosen reference flux $\propto E^{-2.69}$ is shown. The suppression of the flux above $\sim 5 \cdot 10^{19}$ eV and the ankle at $E \simeq 4 \cdot 10^{18}$ eV are evident. Data from HiRes-I [6] are also shown. In the region where our index is measured as -2.69 , the HiRes data indicate a softer spectrum. This may be related to the poorer energy resolution of the HiRes monocular data.

Using different statistical approaches, a significance for flux suppression at a level of more than 6 standard deviations can be derived from the Auger data [7], inde-

pendent from uncertainties in the absolute energy scale. Such a feature is expected from the GZK-effect. However, this by itself does not unambiguously prove the observation of GZK-effect, yet. This is because the sources could happen to run out of acceleration power just at the value of the GZK threshold. However, this would be a strange coincidence and in fact is not supported by Pierre Auger data (see Sect.).

PHOTON AND NEUTRINO LIMITS

Primary photons can experimentally be well separated from primary hadrons as they penetrate deeper into the atmosphere, particularly at energies above 10^{18} eV. Their EAS development is also much less affected by uncertainties of hadronic interaction models due to the dominant electromagnetic shower component. Only, at the highest energies the Landau-Pomeranshuk-Midgal (LPM) effect leads to a suppressed and the preshowering effect in the Earth magnetic field to an enhanced shower development in the atmosphere (see [20] for a review on photon showers). Primary photons are of interest for several reasons: top-down models, originally invented to explain the apparent absence of the GZK-effect in AGASA data, predict a substantial photon flux at high energies [20]. In the presence of the GZK effect, UHE photons can also act as tracers of the GZK process ($p + \gamma_{CMB} \rightarrow p + \pi^0 \rightarrow p + \gamma\gamma$) and provide relevant information about the sources and propagation. Moreover, they can be used to obtain input to fundamental physics (see below) and UHE photons could be used to perform EHE astronomy.

Experimentally, photon showers can be identified by their longitudinal shower profile, most importantly by their deep X_{\max} position and low muon numbers. Up to now, only upper limits could be derived from various experiments, either expressed in terms of the photon fraction or the photon flux. Figure 4 presents a compilation of present results on the photon fraction. The most stringent limits are provided by the Auger surface detector [19]. Current top-down models appear to be ruled out by the current bounds. This result can be considered an independent confirmation of the GZK-effect seen in the energy spectrum. The lowest model curve in figure 4 represents most recent super-heavy dark matter (SHDM) calculations [18] which are still compatible with the Auger energy spectrum and current photon limits. However, the contribution would have to be subdominant and the decaying mass $M_X > 10^{23}$ eV. To extend the limits down to photon energies of approx. 10^{18} eV, PAO hybrid data have been analyzed by studying the longitudinal shower profiles observed in the FDs [22]. In future measurements and after several years of data taking it will be very exciting to possibly touch the flux levels expected

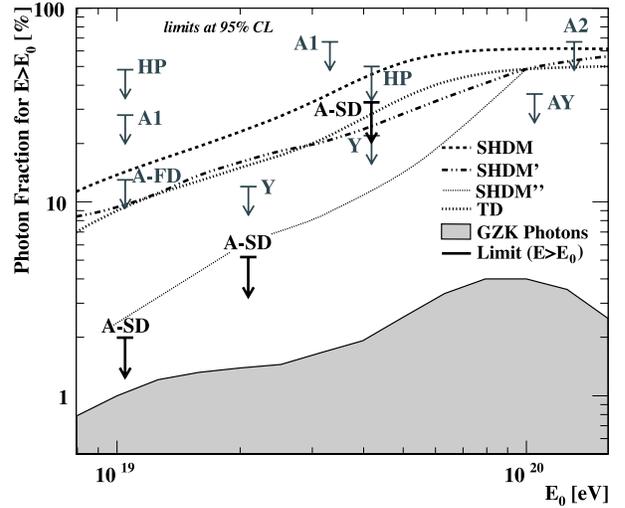


FIGURE 4. Upper limits on the fraction of photons in the integral CR flux compared to predictions. The lower curve is for a subdominant SHDM contribution assuming $M_X = 10^{14}$ GeV [18]. For other references see [19].

for GZK-photons ($p + \gamma_{CMB} \rightarrow p + \pi^0 \rightarrow p + \gamma\gamma$).

The detection of UHE cosmic neutrinos is another long standing experimental challenge. All models of UHECR origin predict neutrinos from the decay of pions and kaons produced in hadronic interactions either at the sources or during propagation in background fields. Similarly to GZK-photons one also expects GZK-neutrinos, generally called ‘cosmogenic neutrinos’. Moreover, top-down models predict dominantly neutrinos at UHE energies. Even though conventional acceleration and top-down scenarios generate pions which decay to produce a neutrino flavor ratio of $\nu_e:\nu_\mu = 1 : 2$ with ν_τ ’s heavily suppressed at the source, neutrino oscillations with maximal θ_{23} -mixing will lead to equal numbers of ν_e , ν_μ , and ν_τ at Earth. At energies above 10^{15} eV, neutrinos are absorbed within the Earth so that upgoing neutrino induced showers cannot be detected anymore. Only τ -neutrinos entering the Earth just below the horizon (Earth-skimming) can undergo charged-current interactions to produce τ leptons which then can travel several tens of kilometers in the Earth and emerge into the atmosphere to eventually decay in flight producing a nearly horizontal air shower with a significant electromagnetic component above the detector.

Neutrino induced air showers can be searched for in ground arrays and fluorescence detectors (see e.g. [23] and references therein). Simulations have shown that the PAO is most sensitive to neutrino induced showers in the EeV energy range. From the absence of any event candidates observed in the SD, upper limits on the diffuse τ -neutrino flux can then be derived. This is shown in Fig. 5 together with other experimental results. The upper limit

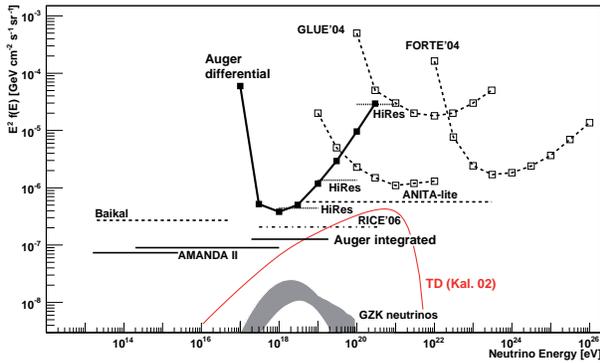


FIGURE 5. Limits at the 90 % C.L. for a diffuse flux of ν_τ assuming a 1:1:1 ratio of the 3 neutrino flavors ([24] and references therein) and predictions for a top-down model [25].

of $E_\nu^2 dN_{\nu_\tau}/dE_\nu < 1.3 \cdot 10^{-7} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ at 90 % C.L. [24] provides at present the best upper limit up to diffuse EeV neutrino fluxes. Similarly to the photons discussed above, they already constrain top-down models and are expected to reach the level of cosmogenic neutrinos after few years of data taking.

COSMIC RAY COMPOSITION

As already mentioned, determining the composition of cosmic rays is among the most difficult tasks in CR physics owing to the fact that EAS simulations need to be invoked for comparing measured and simulated observables that are sensitive to the primary mass. On the other hand, the chemical composition is of crucial importance for understanding the origin of CRs [26]. Mostly due to the high quality KASCADE data [27], there is general consensus now that the composition gets heavier above the knee [26]. At energies above 10^{17} eV the situation is less clear, mostly because of the increasing uncertainty of the interaction models. The most robust and reliable observable to determine the primary mass in this energy range is given by the position of the shower maximum, X_{max} , which is directly observed by fluorescence telescopes. New results based on the PAO hybrid data are depicted in Fig. 6 in comparison to HiRes data [28, 29]. Both data sets agree very well up to $\sim 3 \cdot 10^{18}$ eV but differ slightly at higher energies. The differences between the two experiments is of the same order as the differences observed between p- and Fe-predictions for different hadronic interaction models. The systematic uncertainties of the PAO data points are at a level of 12 g/cm^2 [28] and are smaller than the present uncertainties of the interaction models, particularly for proton primaries. With these caveat kept in mind, both experiments suggest an increasingly lighter composition towards the

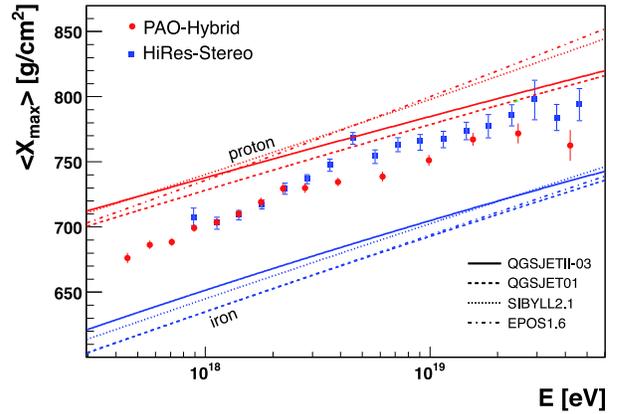


FIGURE 6. $\langle X_{\text{max}} \rangle$ as a function of energy for the PAO hybrid [28] and HiRes Stereo data [29] in comparison to proton and iron predictions using different hadronic interaction models and different models of EHECR origin.

ankle. At higher energies, the HiRes measurement yields a lighter composition than Auger which favors a mixed composition.

ARRIVAL DIRECTIONS AND CORRELATIONS WITH AGN

Recently, the Pierre Auger Collaboration reported the observation of a correlation between the arrival directions of the highest energy CRs and the positions of nearby AGN from the Véron-Cetty - Véron catalogue at a confidence level of more than 99 % [8, 30]. Since several claims about seeing clustering of EHECRs were already made in the past with none of them being confirmed by independent data sets, the Auger group has performed an ‘exploratory’ scan of parameters using an initial data-set and applied these parameters to a new independent data-set for confirmation. With the parameters specified *a priori* the analysis avoids the application of penalty factors which otherwise would need to be applied for in *a posteriori* searches. The correlation has maximum significance for CRs with energies greater than $5.7 \cdot 10^{19}$ eV and AGN at a distance less than ~ 71 Mpc. At this energy threshold, 20 of the 27 events in the full data set correlate within 3.2° with positions of nearby AGNs with 5.6 expected by chance if the flux were isotropic. This corresponds to a net chance probability P of $\sim 10^{-5}$.

Observing such kind of anisotropy can be considered the first evidence for an extragalactic origin of the most energetic CRs because none of any models of galactic origin even when including a very large halo would result in an anisotropy such as observed in the data. Besides this, the correlation parameters itself are highly interesting as the energy threshold at which the correla-

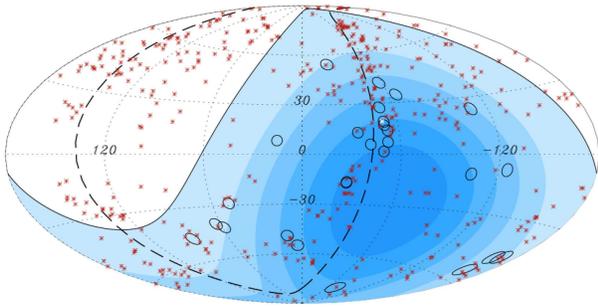


FIGURE 7. Aitoff projection of the celestial sphere in galactic coordinates. The positions of the AGN within $D < 71$ Mpc (stars) and of the events with $E > 57$ EeV (circles) are marked. The colors indicate equal exposure [8, 30].

tion becomes maximized matches the energy at which the energy spectrum shows the GZK feature ($\sim 50\%$ flux suppression), i.e. CRs observed above this threshold - irrespective of their masses - need to originate from within the GZK-horizon of ~ 100 - 200 Mpc. This number again matches (within a factor of two) the maximum distance of AGN for which the correlation is observed. Thus, the set of the two parameters suggests that the suppression in the energy spectrum is indeed due to the GZK-effect, rather than to a limited energy of the accelerators. Thereby, the GZK-effect acts as an effective filter to nearby sources and minimizes effects from extragalactic magnetic field deflections. On top of this, it is also the large magnetic rigidity which helps to open up the window for performing charged particle astronomy.

The correlation may tell us also about the strength of galactic and extragalactic magnetic fields. The galactic fields are reasonably well known and one expects strong deflections for particles arriving from nearby the galactic plane even at energies of 60 EeV. And in fact, 5 of the 7 events that do not correlate with positions of nearby AGN arrive with galactic latitudes $|b| < 12^\circ$. The angular scale of the observed correlation suggests that the intergalactic magnetic fields do not deflect the CRs by more than a few degrees and one can constrain models of turbulent magnetic fields to $B_{\text{rms}}\sqrt{L_c} \leq 10^{-9} \text{ G}\sqrt{\text{Mpc}}$ within the GZK horizon assuming protons as primary particles [30].

The results have stimulated a large number of papers discussing the correlation results and their interpretation and/or applying the Auger correlation parameters to other data-sets, part of which will be discussed below.

DISCUSSION

Remarkable progress has been made in cosmic ray physics at the highest energies, particularly by the start-up of the just completed Pierre Auger Observatory. The

event statistics above 10^{19} eV available by now allows detailed comparisons between experiments and indicates relative shifts of their energy scales by $\pm 25\%$. Given the experimental and theoretical difficulties in measuring and simulating extensive air showers at these extreme energies, this may be considered a great success. On the other hand, knowing about overall mismatches of the energy scales between experiments, particularly between ground arrays and fluorescence detectors, may tell us something. Clearly, in case of fluorescence detectors better measurements of the fluorescence yields and their dependence on atmospheric parameters are needed and will hopefully become available in the very near future [17]. This should furnish all fluorescence experiments with a common set of fluorescence light yields and spectral responses. Differences in the calibration between surface detectors and fluorescence telescopes, best probed by hybrid experiments like the PAO and in the future also by the Telescope Array [31], may then be used to test the modelling of EAS. The muon component at ground, known to be very sensitive to hadronic interactions at high energies [14], could in this way serve to improve hadronic interaction models in an energy range not accessible at man-made accelerators. In fact, several studies (e.g. [32]) indicate a deficit of muons by 30% or more in interaction models like QGSJET.

Irrespective from the details in the energy calibration, the observation of the highest energy events from different directions in the sky and from distances larger than the scale of the solar system has been used to derive the best present limits about the smoothness of classical space-time [33]. This conclusion is based on the absence of vacuum Cherenkov radiation which would degrade the CR energy already on very short distance scales. The obtained direct laboratory bounds (the atmosphere can be considered our laboratory) on the 9 non-birefringent Lorentz-violating dimensionless parameters of modified-Maxwell theory range from the 10^{-7} to the 10^{-16} level. Measurements of air showers initiated by UHECRs and neutral primaries (TeV γ -rays) improve these numbers to indirect bounds ranging even from the 10^{-15} to the 10^{-19} level [34]. These bounds provide interesting implications also for cosmology and the vacuum energy.

General constraints on Lorentz invariance violation (LIV) dispersion relations in the QED sector can be obtained also from the propagation of UHE photons [35, 36]. Basically, in presence of the GZK effect, one expects high energy photons from the π^0 -decay resulting from $p + \gamma_{\text{CMB}} \rightarrow p + \pi^0$ interactions. The photons then rapidly cascade down to low energies by pair production. However, in many models of LIV, the dispersion relation is modified to $\omega^2 = k^2 + m^2 + \xi_n k^2 (k/M_{\text{Pl}})^n$ so that the cascading of photons would be suppressed dependent on the LIV parameters ξ_n resulting in high γ /hadron-ratios. Again, the limits on LIV based on the Auger photon data

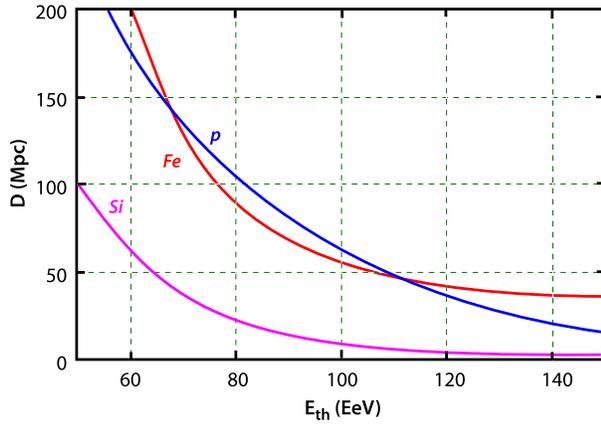


FIGURE 8. GZK-horizon, defined by 90 % of the observed particles originating from within the horizon scale, for p, Si, and Fe nuclei assuming an energy spectrum $\propto E^{-2.7}$. (Data from [4].)

are better by several orders of magnitude compared to previous ones. All of these results come for free, just making use of the enormous energies of the observed CRs.

The measurement of the primary CR energy and its systematic uncertainty is of relevance also for the interpretation of the directional correlation with AGN, discussed in the previous section. As shown in [30], the correlation sets in rather sharply at a threshold energy of about 57 EeV. Fig. 8 shows that the GZK horizon for protons at this energy threshold would be about 200 Mpc [4]. However, the distance parameter of the correlation is 71 Mpc which may indicate a mismatch of the energy scale. If the true energy threshold would only be 20% higher, the GZK horizon would shrink by more than a factor of two to become more consistent to the correlation parameter. Only, if the primaries were of intermediate nuclear mass, as indicated by the X_{max} -distributions in Fig. 6, the energy threshold and distance parameter tend to agree (see Fig. 8).

However, the fact that 90 % of the events (20/22) off the galactic plane are correlated to within $\sim 3^\circ$ with AGN positions makes this reasoning very problematic. Protons at these energies may be deflected by galactic magnetic fields by much as a few degrees, in rough agreement to the correlation parameter of 3.1° . However, it is hard to conceive that nuclei could be deflected only that little. Before drawing conclusions again about imperfections of the employed hadronic interaction models which suggest the observation of intermediate mass CRs, it should be pointed out that the technique employed to search for directional correlations with the AGN positions may not be free of biases, either. Obviously, the more AGNs there are offered by the chosen catalogue within a certain redshift distance and the more EAS events there are in

the data sample above the chosen energy threshold, the smaller the opening angle will be for maximizing the correlation. Such kind of biases and pitfalls should be kept in mind when trying to interpret the correlation parameters too literally.

Despite these caveats, the new high quality Auger hybrid data have provided an enormous stimulus to astroparticle physics in general. A large number of papers have appeared attempting to interpret the results or to find directional correlations other than the one reported in [8]. For example, Ref. [37] points out a more global correlation of the PAO events to the nearby large scale structure, Ref. [38] points out the correlation with the supergalactic plane, Ref. [39] speculates that the observed CRs could originate from only a very small number of sources, most dominantly Cen-A, Ref. [40] gives some reasoning why there are several events observed from the directions of Cen-A but none from the Virgo region, and Refs. [41, 42, 43] discuss multi-messenger signals of UHECR with TeV neutrinos and γ -rays and they constrain the fluxes of local sources, to cite only a few. The HiRes Collaboration analyzed previously unpublished stereo data but could not find a significant correlation to AGN directions using the Auger correlations parameters [44]. The interpretation of this finding is rather complicated by several facts. For example, the correlation strength is known to be very sensitive to the applied energy threshold, but the energy scales of the two experiments are different. Moreover, there is no exposure given for the stereo data set, and it is surprising that most of the HiRes events fall into the aperture of the PAO, indicating that there is a strong bias towards highly inclined showers.

All of this tells us that the near future will be highly exciting: The question of the energy scales will soon be settled and more detailed comparisons between experiments will become possible. The shape of the energy spectrum in the GZK region will tell us about the source evolution, the composition in the ankle region will answer the question about the galactic-extragalactic transition, observations of cosmogenic photons and neutrinos are in reach and in case of neutrinos will probe the GZK effect over larger volumes, the correlations will be done with better statistics, with improved search techniques and with more appropriate source catalogues and source selection parameters to tell us about source densities, and finally about the true sources of EHECRs. Very important to note is that different pieces of information start to mesh and are being accessed from different observational techniques and can be cross-checked.

Given the scientific importance of this, it would be a mistake to have only one observatory taking data - even when operated as a hybrid detector. Auger-North will be imperative and needs immediate vigorous support. It will be located in southeast Colorado and consist of

4400 surface detector stations spread out over an area of more than 20 000 km², providing essentially a seven-fold larger acceptance for UHECRs. Baseline plans also call for full coverage with fluorescence detectors to maximize the number of extremely well reconstructed hybrid-events and to allow for cross-calibration of the SD and FD up to the highest energies. To minimize costs, we plan for only one instead of three PMTs per tank and we will increase the spacing between tanks to $\sqrt{2}$ miles. The proposal is presently being finalized based on experience from Auger south and on results of multi-national R&D-efforts.

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