Summary: ZeV Air Showers Where do we Stand?

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Abstract. Here an attempt is made at summarizing the presentations, most of which were about the highest energy particles observed in nature. Particular attention is paid to the solutions to the Ultra High Energy Cosmic Ray particles, to the new and forthcoming data, to the new proposals for experiments and to the role of primary composition, that were amongst the most discussed subtopics.

INTRODUCTION

The discovery of events with energies above 10^{20} eV dates back to the 1960's, to the early days of air shower detection experiments [1]. In fact the cosmic ray spectrum has been observed as a continuum at all energies since the beginning of the 20th century, apparently only limited by the acceptance of the existing detectors. The prediction of the Greisen-Zatsepin-Kuz'min (GZK) cutoff dates back to the same decade of the 1960's [2]. The cutoff should appear at energies just above 4 10^{19} eV because of proton attenuation in the Cosmic Microwave Background (CMB) . Heavy nuclei are also attenuated in both the infrared and cosmic microwave background radiation fields, at roughly the same energies through photodisintegration and pair production. The mean free path for these processes is of order a few Mpc and even allowance of successive interactions with small fractional energy loss rises the attenuation length to roughly 50 Mpc. The attenuation distances for photons in the same background fields are even smaller.

If these events are coming from extragalactic distances, as suggested by the close to isotropic distribution in the relatively well known galactic fields, they should show the GZK cutoff just below the 10^{20} eV range. If on the contrary they are not extragalactic, we are facing with an unknown source of the highest energies particles ever discovered, which is quite close on cosmological scales, either challenging dimensional analysis of acceleration processes or opening up the way to new physics. A large number of hypotheses have been put forward including new astrophysical objects, new particles, new interactions or the violation of well established principles. The nature of most of these hypotheses, which span a number of research fields which are traditionally very far apart, is clearly a sign that we are debating a remarkable problem. Nonetheless this problem has resisted the efforts of theorists and experimentalists chasing for an acceptable solution for over 40 years.

In this very successful conference we have heard about recent developments in the field both from the theoretical and experimental sides. One of the main ideas that sprouts from it is that a new generation of large aperture experiments has just started. It will drastically speed up the remarkably low pace in building up statistics dictated by fluxes below one particle per square kilometer per century. These detectors will also help to determine the primary composition.

In this article I attempt to summarize the material presented in the conference. This is by no means an easy task and inevitably I will present the field in a subjective way and I will make omissions for which I apologize in advance. I first briefly comment on the mystery of the ultra high energy cosmic rays, to then refer to some of the alternative solutions which were discussed that I have divided in three groups, those models that require acceleration, those models that require fragmentation and decay of massive particles and those that avoid the GZK effect. I then discuss the importance of composition, one of the issues that was most addressed in the conference. Finally I refer to the experiments that were discussed and conclude.

THE POST GZK FLUX PUZZLE

The high energy tail of the measured cosmic ray flux, those particles arriving well above the energy of the Greisen-Zatsepin-Kuz'min cutoff, presents a complex challenge that is still unresolved as was pointed out in many of the talks [3–15]. If we conservatively assume that the high energy end of the cosmic ray spectrum is due to well established particles such as protons or nuclei (that constitute the low energy end of the cosmic ray spectrum) or even photons, we can be fairly confident that their interactions with magnetic fields and background radiation fields are well understood. If these particles are coming from distances exceeding a few tens of Mpc the observed flux should have an imprint of the interactions with the background radiation fields, that is it should display the GZK cutoff at about $4\ 10^{19}$ eV.

The actual measurements are quite limited to the primary energy spectrum, the arrival directions and some information related to the nature of the arriving particles (mass composition) based on shower development. As more data has accumulated over the years from different experiments and efforts have been made to analyze the combined data [16] it has become rather clear that: a) The data exhibit a hardening of the spectral index at an energy of $8\ 10^{18}$ eV [1] and b) That

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1) There is however data from the Fly's Eye experiment, using the fluorescence technique, that suggests the change of slope occurs at about half this energy.

there is no evidence of the GZK cutoff, with data reaching 3 10^{20} eV. [2] The change of spectral index is very suggestive of a different component of the spectrum above 10^{19} eV, the Ultra High Energy Cosmic Rays (UHECR) which provide the central topic of this conference. Throughout this article I will also refer to such a component as the post GZK particle flux.

According to the observations these particles are unlikely to be coming from distances exceeding about 50 Mpc. This distance scale was discussed as an observational "horizon" for protons (or nuclei) because of their interactions with the background fields [10]. So far only two mechanisms have been suggested by which particles can attain the highest energies, namely: a) Direct acceleration of charged particles and b) Fragmentation of the decay products of other particles.

If the particles are accelerated, the exceptional energies achieved are very demanding on possible sources that could accelerate them. The constraint comes from basic dimensional arguments. The acceleration of a particle of charge Ze to an energy E requires a minimum value for the product of the size of the accelerator L and its magnetic field B, namely:

$$E < ZeBcL \tag{1}$$

where c is the speed of light. This is traditionally illustrated by the Hillas plot [17] and several versions of it have been discussed at the conference [5,12,13,9]. Few of the astrophysical objects and structures known satisfy the constraint. Moreover those that do must be very efficient in reaching the maximum energy and many of them are either too large or too distant compared to the 50 Mpc horizon. There are however possible acceleration sites that cannot be excluded yet.

The difficulties in acceleration scenarios has opened the way to alternative proposals in which the post GZK particles either avoid the interactions with the CMB or they are postulated to be a secondary flux produced locally from the decay of other particles.

On pretty general grounds all models for the origin of the post GZK particle flux are very dependent on at least three assumptions in a very interrelated fashion, namely:

- Hypothesis about the possible production sites for these particles which determine both the source distributions and the distance travelled before reaching us.
- Assumptions about the nature of the particles themselves which determine their interactions with the magnetic fields and background radiation fields in their path to us.
- Models for magnetic field distributions in the Galaxy, galactic halo, clusters of galaxies and intergalactic space that condition the distribution of arrival directions.

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2) The highest energy event seen with the fluorescence technique provides a calorimetric measurement of shower energy, reinforcing the results obtained with particle detector arrays.

Part of the puzzle lies in the fact that it is very difficult to extract unconditional conclusions with the limited available data. Each model has to be tested against observations. The interpretation of the information on the post GZK particle arrival directions is completely dependent on these three hypotheses. Moreover the knowledge of the magnetic fields are pretty limited outside the light-matter distribution of our galaxy. As an example it was pointed out that it is possible that the magnetic field distribution provides strong flux magnification and depletions in preferred directions, that could explain the apparent absence of the GZK cutoff and the observed multiplicities in the arrival directions [8].

In a way the difficulties associated with this intricate interdependence of assumptions makes these particles so attractive to different fields of research including particle physics at extreme energies, astrophysical objects and the study of extragalactic magnetic fields.

MODELS

The different types of alternatives for the origin of the UHECR were reviewed by Angela Olinto [12] who classified them in two main groups: Those that push these conventional acceleration ideas to extremes in order to accommodate the data or *Zevatrons* and those that invoke new physics. Particular attention was paid in her review to the differences in the arrival direction distributions, the spectral features and primary composition that can be expected from different models. It was stressed that most models imply strong requirements on the magnetic fields to fit the observations [12]. A number of proposals were critically discussed by several speakers. I will select a few.

Standard Fermi Acceleration Models

Stochastic particle acceleration in the interaction of particles with astrophysical shocks is the conventional astrophysical answer to the question about the origin of the cosmic rays below the GZK cutoff. The mechanism can be extended to the Zevatron models to also explain the origin of the post GZK flux. These models are also called "bottom-up" scenarios in contrast to a solutions which avoid acceleration by assuming particles are created with high energy already, the so called "top-down" models.

A first general approach to these models was made by Thomas Gaisser [7] on a energy balance argument. The power density needed to be injected in cosmic rays to produce the higher energy region of the cosmic ray spectrum can be computed for a given type of object with a known distribution and assuming a nominal spectral index of $\gamma = 2$ characteristic of Fermi acceleration, mimicking the well known argument supporting Fermi acceleration in Super Nova Remnants for the origin of the bulk of cosmic rays. It turns out that for galaxies, clusters of galaxies, Active Galactic Nuclei (AGN) and Gamma Ray Bursts (GRB) the UHECR power requirement is a reasonably small fraction of the power density emitted by each of these classes of objects. The argument can be reconsidered for strong relativistic shocks such as those expected to be found in AGN's and GRB's, which typically result in steeper spectral indices $\gamma \simeq 2.2 - 2.3$. In these shocks the particle can be accelerated provided it achieves a minimum energy by some other means. The resulting power balance is very dependent on both the spectral index and the injection energy. Part of the extra power that would be required because of the steeper spectrum is compensated by an increased injection energy. Simple energetic considerations open up these possibilities and do not allow much discrimination between them [7].

Fermi Acceleration in Gamma Ray Bursts has been suggested as a possible UHECR source [18]. Although the energetics may be adequate, the implied assumption that the bursts have a comoving density which is independent of redshift is somewhat contrived [19]. We should probably have to wait for a better understanding of these interesting phenomena before this possibility can be critically revised. In this respect we heard of an interesting proposal for GRB observations which could shed some light into the general GRB problem [20].

Powerful radiogalaxies are certain candidates for post GZK acceleration. It was stressed that these objects provide the largest shock waves known and that the standard radioastronomical observations already demand highly energetic particles to explain the energy transport along the jets [3]. It has been claimed that a single source could provide the solution of the UHECR problem [21]. It is possible to devise reasonable magnetic field models in which backtracking of post GZK particles under the assumption of mostly proton primaries and one helium nucleus, leads to M87, a nearby radiogalaxy in the Virgo cluster [21,3]. These hypotheses will be further tested once the statistics builds up. Very interesting results for magnetic field flux magnifications and spectral deformations in general and for this particular model were presented [8]. These local magnifications could significantly affect power requirement estimates and the arguments based on them.

The shape of the spectrum at the cutoff is a signature of the source distribution and an indirect handle on the distance to the production sites. If the post GZK particles are of extragalactic origin but they are produced at higher rates in a region close to us relative to the 50 Mpc proton horizon, the GZK cutoff effect is mitigated [22,23]. A recent simulation of this effect was discussed at the conference [4] assuming the post GZK flux is correlated with the dark matter distribution. The spectral index assumed for the injection spectrum becomes important and the observed flux above 10^{20} eV would require a hard spectral index for injection with $\gamma \sim 2$. A distinct signature for this scenario is the anisotropy of arrival directions. Certainly if local density enhancements are responsible for the post GZK particles the arrival directions should map these density enhancements. Large magnetic fields would be needed to explain observed distribution of arrival directions but this is consistent with what we know about magnetic fields [3]. Some claims for an excess in the direction of the supergalactic plane have been made [24], but the level of confidence is still low because the statistics is poor.

A recent model for acceleration of iron like nuclei in the galaxy was addressed [25]. These nuclei are stripped off the neutron star surface with high magnetic fields that allow acceleration to the observed high energies. As the magnetic flux of a rotating neutron star reaches the light cylinder it can be converted into kinetic energy of the particles in a relativistic wind. If the magnetic field is high and the neutron star has a rapid rotation the acceleration can reach GZK energies. This alternative demands large galactic magnetic fields to reproduce the small enhancement in the direction of the galactic plane. The enhancement should increase as the energy of the observed particles rises. A particularly distinctive characteristic is the spectral index at production which is $\gamma \simeq 1$ [12]. Such a hard spectral index puts most of the energy in the high energy end of the spectrum and new experiments extending the energies to the ZeV region should be able to measure the spectral index.

Alternative Solutions

Most of the solutions avoiding Fermi acceleration in nearby objects are motivated by physics beyond the standard model and would correspond to new physics in Angela Olintos's review [12]. As regards the observations from the expected fluxes two very different categories emerge. In one class of alternatives the post GZK flux involves standard model particles from the decay and fragmentation of other particles. A second class avoids the cutoff mechanism either with new particles or with standard model particles that have unexpected behaviours.

Fragmentation Origin

Most of the alternative models share the feature of producing the bulk of the post GZK particle flux by fragmentation into pions. These models span very different scenarios, for instance the pions can be due to quarks which are in turn the decay products of a more massive particle such as a light electroweak Z boson [15], a Wimpzilla [26] which is a non thermal long lived particle, or a much heavier X particle [27] from a possible extension of the Standard Model into a Grand Unification Theory (GUT). These decaying particles are conjectured to be produced in a variety of mechanisms including, primordial origin, couplings to gravity, annihilations of topological defects and local interactions of distant ultra high energy neutrinos, some of which were addressed by several speakers [12,13,15,6,11]. The produced massive particles usually decay into quarks which fragment into hadrons, mostly pions that in turn decay into photons and neutrinos. There are models however in which the quarks can be emitted directly, for instance in primordial black hole evaporation [28]. As a final result the fragmentation and decay chain eventually ends up as photons, neutrinos and protons and no heavy nuclei can be expected. Such different scenarios ultimately predict roughly similar relative rates for the different particles because they rely on the same production mechanism.

Annihilation of topological defects were historically one of the first mechanisms postulated as a source of massive particles that give rise to post GZK particles as fragmentation products [27]. Under the heading of topological defect a large variety of objects can be included such as monopoles, cosmic strings [29], vortons which are classically stable loops of superconducting cosmic strings [11,30], and combinations of these such as necklaces that combine strings and monopoles [31], or monopole-antimonopole pairs connected by a string [32] just to name a few. A number of reviews have dealt with these objects [13,33]. The possibilities are already heavily constrained by various arguments and observations, such as the expected abundances, their effects on Big Bang Nucleosynthesis, and the expected secondary fluxes of photons and neutrinos [13,33].

A particularly important feature of these alternative sources concerns their cosmological distributions. The possibility that the post GZK particles are locally produced in our galactic halo following the fate of cold matter is recently gaining more attention [4,35,34]. If the clustering is on scales smaller than the 50 Mpc scale the GZK cutoff effect on the spectrum will be mitigated. In many of the proposed models involving fragmentation the sources are expected to be clustered. An interesting signature of the clustering sources is the expected dipole asymmetry associated to our position not being central in the halo and clearly related to the halo size.

Clustered sources: One possibility is that the post GZK particles are due to decays of heavy metastable particles that cluster in our galactic halo following the fate of cold matter and eventually decay. They are mostly motivated by and different aspects of string and M-theories. Some of these were addressed in the conference for instance *pentons* motivated by M-Theory compactifications and *cryptons* that are supermassive bound states from string hidden sectors [6].

Another model predicting a locally enhanced cosmic ray density is motivated by the recent findings about neutrino oscillations, and gives qualitatively similar predictions. The model was discussed in several talks and involves the production of Z-bosons in neutrino-antineutrino annihilations as discussed by several speakers [15,13]. The model requires a very high energy neutrino flux that could originate far beyond the proton horizon of 50 Mpc and a target which is provided by massive relic neutrinos that could cluster in our galactic halo. No assumptions are made on the origin of the neutrino beam but some suggestions have been made [36]. The maximum neutrino energy has to be pushed even further firstly because the observed particles are secondary products of the neutrino interactions and secondly because the neutrinos themselves can also be expected to come from decays of other particles. This model is subject to important restrictions because of neutrino flux bounds mainly from the absence of observations of horizontal or upward going air showers [37].

All these models have become less likely in the view of very recent studies of composition for energies above 10^{19} eV, that put the first limits on photon abundance [38,39]. The restriction is strongest for models in which the sources are clustered in the vicinity of our galaxy so that the photon flux does not travel long enough distances to become relatively suppressed with respect to the proton flux.

Solutions without Fragmentation

A number of solutions to the Ultra High Energy puzzle has been suggested invoking particle behaviours that avoid the GZK cutoff. Some are familiar standard model particles that develop unexpected behaviours at large energies. They include hadronic-like cross sections for neutrinos that can mimic proton interactions in the atmosphere [40,41]. Alternatively it has also been suggested that Lorentz invariance could be broken [42,43]. Other solutions invoke new stable particles usually motivated by supersymmetry, also called *uhecrons* which have higher threshold energies in their interaction with the background photon fields but but do interact with matter [44,6].

Particular attention was paid to the recent suggestion that Lorentz invariance could be broken. At these extreme energies space-time can have a non trivial structure because of quantum fluctuations due to the recoil of the vacuum. High energy particles see distortions of the metric, a *spacetime foam* in which their speed becomes reduced. The Lorentz invariance break implied prevents particle production and particularly the photoproduction process that is mostly responsible for the GZK cutoff [6]. Most interesting where the first experimental constraints on these ideas searching for correlations of delays and distances in the radiation received form GRB's in different energy bins. The observations imply that the possible quantum-gravity scale M has a lower bound $M > 10^{15}$ GeV. Lorentz symmetry violations were also suggested from a CP-violating kinematic structure [45].

Lastly there are solutions involving other particles such as heavy or light monopolia [46,15,14] or dust grains. In the monopole models the monopoles themselves would induce the observed air showers, which have however a distribution of arrival directions which strongly disfavours such a hypothesis [51]. The dust grain alternative is ruled out by the shower development curve observed for the highest energy event [47] but there is no knowledge of the behaviour of monopole induced showers [15].

COMPOSITION

Composition was discussed by several speakers as a fundamental tool to distinguish between different models which is crucial for the correct interpretation of the distribution of arrival directions which is mass dependent.

Particle production in models relying on decays of more massive particles is governed by the fragmentation processes. If the bulk of the post GZK particles are due to fragmented hadrons from heavier particle decays, the relative fluxes of different particle species can be extrapolated from lower energy fragmentation processes that are well known from e^+e^- collisions in accelerators. In fragmentation processes pions are typically produced at a rate which is of order ten times higher than protons. Photons arise from neutral pion decays while neutrinos are mostly produced in the decays of charged pions. The fragmentation and decay chain process is thus expected to produce a significantly larger fraction of photons and neutrinos than protons (neutrons decay and end up as protons) and no heavy nuclei. [3]

One must note that measurements of these fluxes have already proven to be very useful in constraining production models [13,7]. These neutral particles if observed will provide non deflected information on the fluxes, thus directly reflecting the source distribution anisotropy independently on assumptions about the magnetic fields which would be a most valuable piece of information.

As a result one can roughly expect flux ratios of order ten for photons and neutrinos with respect to protons. The photon ratio is further modulated by interactions with the background radiation fields. If the model produces more particles near the Galaxy, the photon fraction is of order 10 [6,13,12,9] while this value can be modified depending on distance to the source and fragmentation details to drop to values about 1-3 when the average distance travelled by the particles is in the scale of tens of Mpc [48,49,13]. On the other hand the neutrino flux will not be attenuated and the neutrino to proton flux ratio can be expected to be of order ten or higher if there is proton attenuation.

One must remark that the predictions for the secondary fluxes are rather sensitive to proton, electron and photon absorption both at the production site and during transport. If photons are attenuated, pair production and synchrotron losses dump the photon energy density into the MeV region of the gamma ray spectrum, linking it to the unknown magnetic fields [50,13].

Alternatively stochastic acceleration mechanisms require charged particles. If the accelerated particles are heavy nuclei higher energies can be achieved. The possibility that these ultraenergetic particles are heavy nuclei is attractive on a double basis because these nuclei are more easily isotropized in a given magnetic field and because acceleration models are less constrained by Eq. 1. Nuclei heavier than iron such as gold have been also proposed as a plausible solution [14]. Although the mean free path for interactions with the background radiation fields is small, the emerging depleted nuclei can undergo successive interactions and reach distances in the 100 Mpc range keeping a substantial fraction of the original energy [19]. Heavy nuclei thus relax the constrains on both source distance and intensity of the magnetic fields that observations impose.

If the bulk of the post GZK particles are charged, the study of the arrival directions will allow improvements of the current bounds on the poorly known magnetic fields outside the galaxy. These bounds will be stricter if composition can be determined. There are models with heavy nuclei involving both galactic and

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3) Incidentally it was pointed out during this conference that these extrapolations are not free of uncertainty and that they should be carefully reconsidered for instance in connection to supersymmetric extensions of the standard model [13,4,6].

extragalactic sources for which magnetic effects should be most important. They will be tested against future data on both the energy spectrum and anisotropy measurements.

Acceleration models are also expected to produce secondary fluxes of photons and neutrinos. The mechanism is the interaction of the protons with matter or radiation and this can happen both at the source or during transport. Depending on details of the models themselves the secondary fluxes will have however different magnitudes [7,13]. Even if no interactions take place at the source itself the GZK cutoff mechanism should produce a minimum flux of secondaries in these models. In practically all cases however the relative fluxes of neutrinos and photons at energies above the GZK cutoff is expected to be less than that of protons, unless there is a high attenuation of the protons themselves at origin.

In models relying on fragmentation, photons are expected to present a significant fraction of photons in the post GZK flux. In this respect the measurements of photon composition will be crucial because they provide an indirect handle on the clustering process for the post GZK sources. Neutrino searches however will extend the observation horizon to distances well beyond the 100 Mpc range and will confirm clustering scenarios. Interesting new ideas were reported for establishing the photon composition of the post GZK flux which will be further discussed below. These ideas will certainly prove extremely valuable in selecting between acceleration and fragmentation mechanisms.

EXPERIMENT: EXPLORING THE POST GZK FLUX

Altogether only seventeen events with energies exceeding 10^{20} eV have been reported. Sixteen of them are from four array experiments, one from Volcano Ranch [52], six from Haverah Park [53], one from Yakutsk array [54] and eight from AGASA [55]. The other event, which is the highest energy event observed, was detected with Fly's Eye [56], a different detector concept that measures the fluorescence light from nitrogen as the shower develops in the atmosphere. The accumulation of events as a function of time is shown in Fig. 1 including an ultrahigh energy event detected in 1999 by AGASA [57], and two events in a new analysis of the Haverah Park data for zenith angles above $60°$ [58] which have been discussed in this conference.

Although the statistics are now enough to convince the few remaining skeptics, the field clearly demands more data. On the one hand more and more precise data on the flux measurements themselves is needed to build up statistics for the spectral and anisotropy studies. This need is the drive for a number of projects that were presented in this conference. Some are already in construction but many presentations were concerned about experiments in planning. The importance of additional information in the search of the origin of the post GZK particles has already been stressed. Experiments and techniques that are sensitive to primary composition and to secondary fluxes of gamma rays and neutrinos played a central part in the conference.

Existing Detectors

We heard reports on data obtained with three cosmic ray detectors: AGASA, Haverah Park and HiRes.

AGASA: The status report of this ongoing experiment [59,57] was centered on the 8 events detected above 10^{20} eV and on the anisotropy of arrival directions. The search of coincidences in arrival directions within the angular resolution of the experiment for events with energies above 4 10^{19} eV results in one 3-fold coincidence and four 2-fold coincidences with an estimated 0.3% chance probability. The recently reported 10% anisotropy observed in the region of the galactic center and anti-center for energies above 10^{18} eV [60] was also addressed. Although this effect suggests a galactic origin, it is observed at a threshold energy well below the GZK cutoff and may not have much to do with the origin of the UHECR if as expected they indeed are a different component.

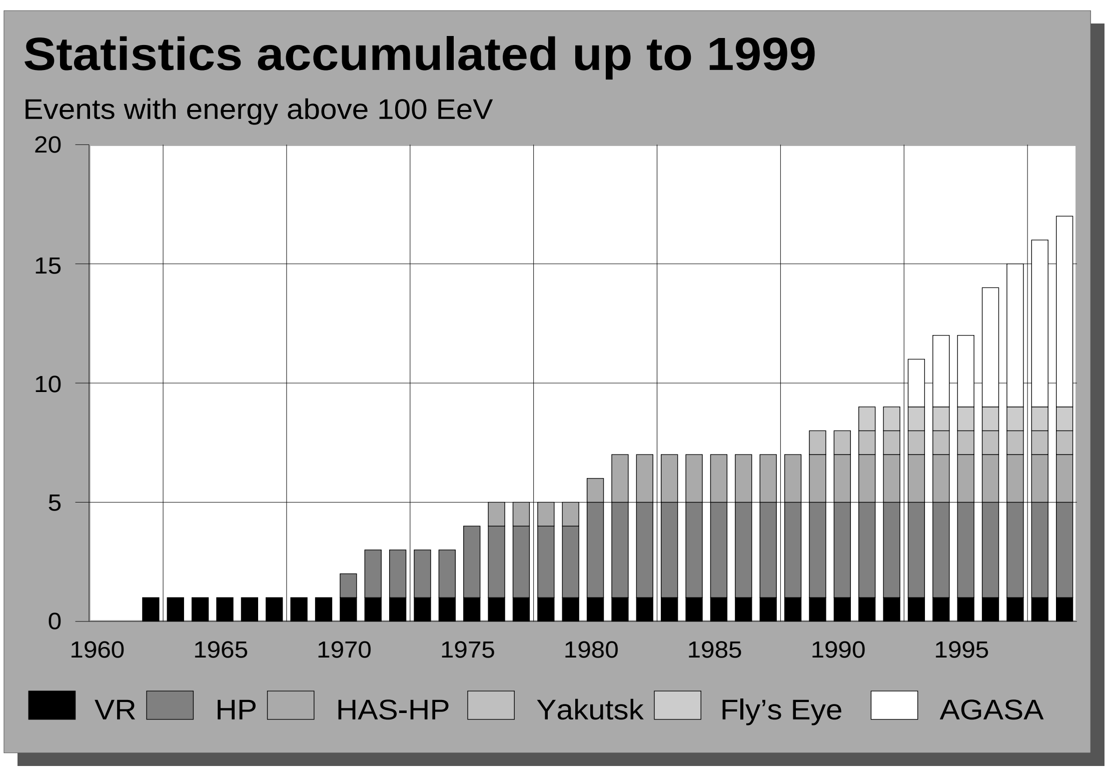

FIGURE 1. Accumulated events of energy exceeding 10^{20} eV plotted as a funtion of time as detected by different experiments: Volcano Ranch (VR), Haverah Park (HP), Horizontal Air Showers in Haverah Park (HAS-HP), Yakutsk, Fly's Eye and AGASA.

Haverah Park: The interest of Horizontal Air Showers (HAS) was shown not to be limited to neutrino detection. We also heard a report on the first analysis of inclined HAS induced by UHECR [38]. A recently developed model for muon density maps at ground level [61] allows event reconstruction. As a first application, the analysis of the Haverah Park data has resulted in 7 (2) new events above $4\ 10^{19}$ eV (10^{20} eV) [58].

HiRes: HiRes [63] [62] is the first large aperture detector that has recently started operation based on the nitrogen fluorescence technique. The detector has two wide aperture *eyes* and when operating in the stereo mode it is expected to measure the energy of cosmic rays between 0.1 and 200 EeV with a 20% resolution, with improved sensitivity to the position of shower maximum and to the determination of the arrival directions. About five more events with energy above 10^{20} eV can be expected from the preliminary results of the first six months of data [63]. The forthcoming data analysis of HiRes data is eagerly expected because there is only one calorimetric measurement of an event with energy above 10^{20} eV. It will also help to resolve small discrepancies between different experiments.

Detectors in Planning

Most advanced plans are for ground detectors using well established technologies. The Auger observatory will be the first one and the Telescope Array and IceCube may be the following ones, but new projects involving detection from satellites are already quite advanced in planning and could start operating in the second half of the 2000's decade.

Ground Experiments:

Auger: The southern Auger observatory is now in construction in *Pampa Amarilla*, Mendoza, Argentina and will be the next large aperture detector to become operative [5]. The engineering array is expected to be finished in less than a year time. Detailed progress on tank monitoring and calibration [64], tyvek reflectivity [65], photomultipliers [66] and on Fresnel mirrors for the fluorescence [67] was reported. The analysis of HAS induced by cosmic rays [38] has shown that the commonly estimated acceptance for cosmic rays with zenith angles below 45° can be doubled for the highest energy end of the spectrum. As it is a hybrid detector designed to combine the fluorescence and the particle density sampling techniques, and it is the first one that will perform such hybrid measurements for showers with energy exceeding 10^{19} eV, it will be most adequate for cross calibration of the two different techniques and will provide key information to the development of the field.

Telescope Array: The Telescope Array (T.A.) is a project consisting on an array of eight stations each with 42 3-m diameter mirrors covering the solid angle from the horizon to 58° of zenith angle and having a similar aperture to the Auger observatories. It will have 6% energy resolution and angular resolution of 0.6° [59]. Decisions on its funding are expected within a year from now.

IceCube: The IceCube proposal [7,68] is a well advanced project aiming to expand the proven AMANDA [69] technology to a full scale detector instrumenting one km^3 of deep clear ice. The expected rates of neutrinos depend both on the production mechanism and on the attenuation of cosmic rays during transport. The mechanism determines the ratio of neutrinos to protons and photons. Depending on the maximum energy of the neutrinos the flux normalization can span a wide range of values in plausible scenarios. The expected rates in IceCube in many of these scenarios are at the detectable rate [7].

Detectors from Space:

Observation of the fluorescence light induced by extensive air showers from a satellite is a promising alternative. The thin upper atmosphere allows distant detection and a large aperture can be achieved by placing the satellite at the planned orbit of the International Space Station (ISS) of about 400 km. Several initiatives were discussed in a number of presentations. These systems are sensitive both to UHECR and to UHE neutrinos by looking for deeply penetrating air showers. The Čerenkov light reflected from the clouds, earth or the sea can be used for distance calibration [71,72].

EUSO: The Extreme Universe Space Observatory (EUSO) [71,73,67] is a multinational joint effort which has been approved by the European Space Agency for an accommodation study. It is planned to have a field of view of 60° spanning 200×200 km^2, Fresnel lens optics [73,67] and a finely segmented focal plane that will allow the registration of the fluorescence light from air showers. It could start operation in 2006 and is scheduled to operate for three years.

KLYPVE: Another version of the same technique adapted to the Russian section of the ISS is provided by the KLYPVE project [72,74,75]. It has a smaller field of view of 15° that will cover an area of 100×100 km^2 [74], 10 m Fresnel mirrors optics and 5 mrad pixels [72].

This class of experiments is based on a well understood technique so they can be expected to be viable but it relies on significant technological developments. The technique has not yet been proven and in that respect the TUS (Track Ultraviolet from Space) project is a preparatory smaller Russian project using 1.5 m mirrors. It is expected to be hosted by the Resource-DK satellite to be launched in 2002-2003 [74]. Upgrades of these detectors were also discussed such as MULTIOWL and SUPEROWL as part of a Grand Observatory in Space [76]. They intend to enhance the performance of EUSO or KLYPVE by tilting the system with respect to nadir, having a higher altitude orbit and using more mirrors to measure ZeV ($E > 10^{21}$ eV) cosmic rays and neutrinos.

New Ideas for Composition

As was pointed out by many speakers composition is a fundamental clue in the search of the origin of the post GZK flux [12,15,13]. The unavoidable need of using indirect detection techniques makes it hard to accurately determine the nature of the particles themselves because the differences in atmospheric showers developed by different primaries are rather subtle. Most of them can be related to either the shower development or to the muon content in the showers which can be explored by different techniques. Intresting new ideas were discussed for the study of the nature of the post-GZK particles.

Neutrinos: All the detectors for measuring the post GZK flux in construction or planning are sensitive to neutrinos by searching for deeply penetrating showers [78,79] and much use has been made of this technique to constrain high energy neutrino fluxes [80]. An interesting new idea for the detection of tau decays in the southern Auger observatory [9]. Tau neutrinos can be expected in flavour mixing scenarios which are motivated by atmospheric neutrino measurements. The taus are produced in charged current tau neutrino interactions with the Andes mountains. For neutrinos in the energy range $10^{17} - 5\,10^{18}$ eV the tau decays can give a detectable signal in the Auger tanks in spite of the solid angle being small. It was pointed out that it may not be possible to search for similar effects with fluorescence satellite detectors because their energy threshold would prevent the tau from decaying in the detector field of view [9].

Photons: Two new ideas were discussed for the identification of a photon component in the post GZK particle flux:

The first one is due to a competition between the Landau-Pomeranchuck-Migdal (LPM) suppression of pair production and bremsstrahlung because of collective effects of the atmospheric nuclei and the interaction of photons with the geomagnetic field of the Earth. The LPM effect changes shower development in a dramatic fashion above an effective threshold. The shower develops much later becoming more elongated and a ground particle array would detect a much younger shower with a characteristic steep lateral profile. On the other hand the interaction of a photon with the Earth magnetic field can happen long before the start of shower development and has the effect of distributing the photon energy among lower energy secondary photons, electrons and positrons that add up to the primary photon energy. Provided the photon does not travel parallel to the magnetic field this interaction prevents the development of LPM showers and the atmospheric shower that follows is a scaled up version of the well established lower energy showers. There are however preferred directions along which the photon is unlikely to interact with the magnetic field of the Earth and the shower develops these strange LPM behaviour that have been carefully studied for the southern Auger observatory [81]. The alignment of the magnetic fields gives “holes” for LPM showers. This possibility was discussed as a means to establish the photon fraction in cosmic rays for both particle arrays [59] and for the fluorescence technique [71].

A second idea was discussed in connection to the detection of horizontal air showers (HAS). Inclined showers induced by protons, nuclei or photons develop early in the atmosphere and only their muon component can be detected with particle arrays. The recent study of geomagnetic effects of the muon distributions at ground level [61] allows the study of events above 60°. The expected HAS rates have been shown to be very dependent on composition because of the relative content of muons in the showers induced by different primaries, particularly between photons and protons or nuclei. As a result the combined measurement of vertical and horizontal air shower rates provides an new handle on composition. These ideas have been applied to Haverah Park data which are inconsistent with a model in which photons are more than 42% of the cosmic ray flux above 10^{19} eV, which provides a severe constrain on models which have locally enhanced cosmic ray production by fragmentation [39,38]. Since the number of muons in a photon shower is expected to be smaller by a large factor with respect to a proton (or nucleus) of the same total energy the results are fairly robust. These ideas can also be used for setting bounds on the heavy ion fraction, but the results are more dependent on the muon production of the assumed interaction model.

The Intermediate Energy Range

Some of the talks referred to experiments designed to measure lower energy particles. Low energy fluxes can be related to UHECR although the bulk of the radiation received in the low energy region is expected to be from a different origin from the UHECR [7].

AMS: The Anti Matter Spectrometer (AMS) also discussed in the conference [77]. It is an advanced detector to be flown in the ISS in 2003 for precision measurements of cosmic ray composition in the GeV energy range that has an important mexican involvement [82]. A successful prototype has already been flown.

Ground Based GRB watch: Gamma Ray Bursts may be the source of UHECR. A review was presented of the unique Chacaltaya observatory located 5230 m above sea level at an atmospheric depth of only 540 g cm^{-2}. It included a recent proposal to transport an extensive air shower array combining scintillator detectors and air Čerenkov collectors to be used in combination with a 100 m^2 calorimeter [20]. The arrangement could allow measurements of inelasticity by identifying the low energy subshowers of quasielastic events with Čerenkov collectors on the surface and could have a sensitivity to gamma rays of 16 GeV from Gamma Ray Bursts. An interesting proposal was made for a gamma ray watch in the 1-100 GeV range combining different ground experiments such as Chacaltaya, MILAGRO and the Auger Observatory. These experiments would be operated in a low threshold energy mode using correlated excess in the single particle counts [20].

Dark Matter Searches: Searches for supersymmetric dark matter were reviewed by John Ellis [6]. These particles can be detected via their annihilation in the galactic halo producing antiparticles which could be detected by satellites such as AMS and other satellites searching for gamma rays. Alternatively this possibility can be explored by searching for excess neutrinos in the directions of the Sun or the Earth center produced by annihilations of the supersymmetric particles trapped in the corresponding gravitational potentials. This method is the most sensitive and many specific models can be ruled out with 10 km^2 y of neutrino data. Lastly they can be searched for directly by looking for their elastic scattering in a detector and there is a recent unconfirmed claim of evidence for such scattering [83], but the final answer may come after LHC starts running in 2006.

EPILOGUE: THE FUTURE OF THE FIELD

The frustratingly inconclusive statistics reached at present will cease to be a problem in the near future as it is illustrated in Fig. 2 where the number of events

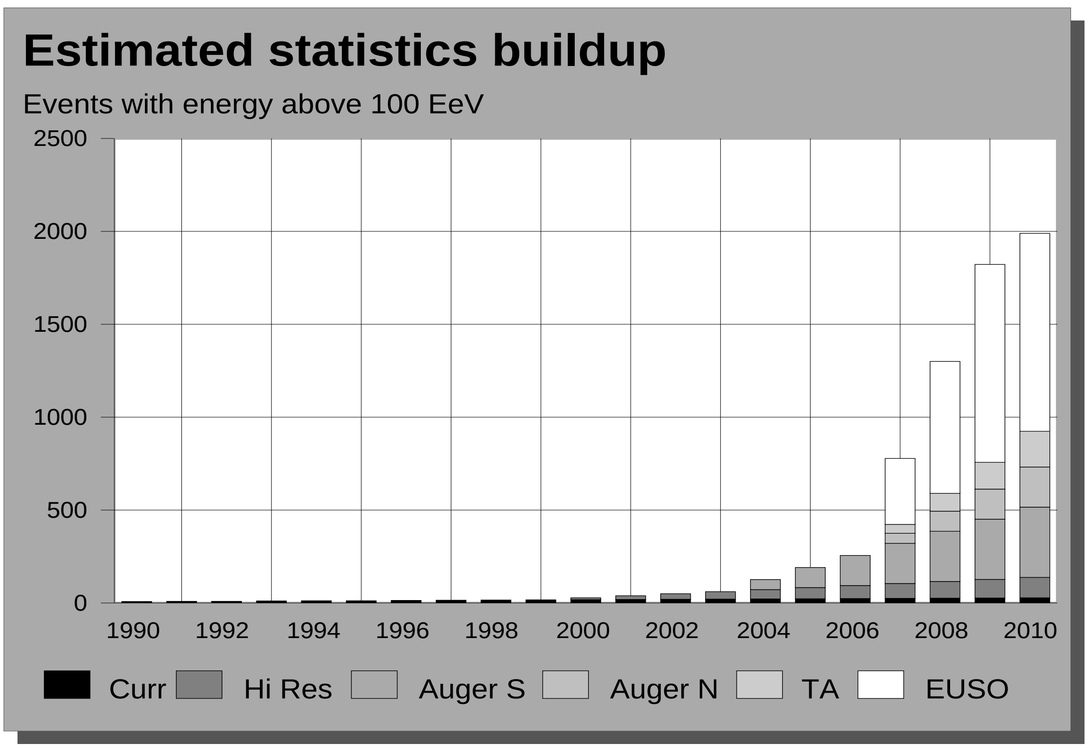

FIGURE 2. Accumulated events of energy exceeding 10^{20} eV expected to be detected by possible future and current experiments as a function of time: Current experimental data from Fig. 1 (Curr), HiRes, South and North Auger observatories (Auger S,N), Telescope Array (TA) and EUSO. The plotted HiRes detection rate was taken from this conference [63], all the other detectors are normalized to the flux detected up to now by AGASA. Data for Auger observatories assumes 9000 km^2 sr acceptance and includes all zenith angle showers, EUSO expectations are obtained for a 400 km orbit, considering zenith angles from 0 to 70°, assuming the project operates for three years with a 10% duty cycle.

detected above 10^{20} eV is plotted as a function of time. The statistics will be more than doubled in two years with forthcoming HiRes data. By the end of the year 2005 we should have two years of data from the Auger detector and more than ten times the statistics we now have. The rising statistics trend will be continued with even more ambitious projects such as EUSO, KLIPVE and/or the Telescope Array.

The new experiments will not only bring more accurate measurements of the post GZK spectrum, they will also bring about new handles on composition. All the experiments in planning or construction are also sensitive to high energy neutrinos by looking for horizontal air showers. In the EeV energy range the neutrino flux is expected to be related to the production mechanisms of the cosmic rays themselves. Such flux will be further explored by dedicated under-water or under-ice neutrino experiments in construction [69] or development [70], quite possibly with the Ice-Cube proposal to extend AMANDA to a km^3 size detector and also by searching for horizontal air showers with all the projects that are sensitive to ZeV Air Showers.

The coming decade of the 2000's will bring the eagerly expected data that will answer many of the open questions of the post GZK flux. All these experiments must be regarded as a whole effort towards the understanding of the highest energy particles in the Universe. Different techniques for the detection of Ultra High Energy particles will complement each other, resolve uncertainties which are still present and will open the way to many different and interesting aspects of high energy particle physics, astrophysics and cosmology.

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