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Search for anisotropy and point sources of cosmic rays with the KASCADE-Grande experiment

S. OVER[e], M. STÜMPERT[c], W.D. APEL[a], J.C. ARTEAGA[a], F. BADEA[a], K. BEKK[a], M. BERTAINA[b], J. BLÜMER[a,c], H. BOZDOG[a], I.M. BRANCUS[d], M. BRÜGGEMANN[e], P. BUCHHOLZ[e], A. CHIAVASSA[b], F. COSSAVELLA[c], K. DAUMILLER[a], V. DE SOUZA[c], F. DI PIERRO[b], P. DOLL[a], R. ENGEL[a], J. ENGLER[a], M. FINGER[c], D. FUHRMANN[f], P.L. GHIA[g], H.J. GILS[a], R. GLASSTETTER[f], C. GRUPEN[e], A. HAUNGS[a], D. HECK[a], J.R. HÖRANDEL[c], T. HUEGE[a], P.G. ISAR[a], K.-H. KAMPERT[f], D. KICKELBICK[e], H.O. KLAGES[a], Y. KOLOTAEV[e], P. LUCZAK[h], H.J. MATHES[a], H.J. MAYER[a], C. MEURER[a], J. MILKE[a], B. MITRICA[d], A. MORALES[a], C. MORELLO[g], G. NAVARRA[b], S. NEHLS[a], J. OEHLSCHLÄGER[a], S. OSTAPCHENKO[a], M. PETCU[d], T. PIEROG[a], S. PLEWNIA[a], H. REBEL[a], M. ROTH[a], H. SCHIELER[a], O. SIMA[i], G. TOMA[d], G.C. TRINCHERO[g], H. ULRICH[a], J. VAN BUREN[a], W. WALKOWIAK[e], A. WEINDL[a], J. WOCHELE[a], J. ZABIEROWSKI[h].

[a] *Institut für Kernphysik, Forschungszentrum Karlsruhe, Germany*
[b] *Dipartimento di Fisica Generale dell'Università Torino, Italy*
[c] *Institut für Experimentelle Kernphysik, Universität Karlsruhe, Germany*
[d] *National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[e] *Fachbereich Physik, Universität Siegen, Germany*
[f] *Fachbereich Physik, Universität Wuppertal, Germany*
[g] *Istituto di Fisica dello Spazio Interplanetario, INAF Torino, Italy*
[h] *Soltan Institute for Nuclear Studies, Lodz, Poland*
[i] *Department of Physics, University of Bucharest, Romania*
over@hep.physik.uni-siegen.de

Abstract: The KASCADE-Grande experiment, located on site of the Forschungszentrum Karlsruhe in Germany, is a multi-detector setup for measuring extensive air showers of primary energies up to 1 EeV. The main component for measuring showers of the highest energies is the newly added Grande array, which consists of 37 scintillation detector stations, spanning an area of nearly $0.5\,\mathrm{km}^2$. Based on the reconstruction of the arrival directions of individual showers, searches for both large scale anisotropies and point sources are performed. The present state of the ongoing analysis will be presented.

Introduction

Charged cosmic rays are deflected by galactic magnetic fields, causing an almost isotropic distribution of their arrival directions. Low energy charged cosmic rays from distant sources cannot be traced back to their origin, whereas at large energies this effect decreases substantially, so even particles from more remote sources can keep their directional information. Small scale anisotropies, thus clustering of arrival directions, could lead to the identification of point sources. Also neutrons, which are not affected by magnetic fields but have limited range due to decay, can reach further at higher energies. Therefore the search for point sources should be focussed on the highest available primary energies. On the other hand, the quantification of the large scale anisotropy can yield valuable results for the discussion of models of cosmic ray propagation in our galaxy.

The KASCADE-Grande experiment

The KASCADE-Grande experiment[1] is located on site of the Forschungszentrum Karlsruhe, Germany (49.1° north, 8.4° east, 110 m above sea level). It has primarily been designed for the observation of cosmic rays in the energy range around 100 PeV, where a drop of the flux of the heavy elements (the 'iron knee') is suggested by the findings of the KASCADE experiment[2]. Since then, the original KASCADE setup has been extended by the Grande array to form the KASCADE-Grande experiment. While KASCADE is already a multi-detector setup, including an array of 252 scintillator detectors placed in a regular squareshaped grid with an edge length of 200 m, the added Grande array consists of 37 scintillator detector stations, spanning a much bigger area of nearly 0.5 km^2. Thus the Grande array aims to raise the experiment's energy range to up to 10^{18} eV. The full setup of KASCADE-Grande performs continuous and stable data taking since January 2004. Following the multi-detector approach, a common trigger signal induces joint data taking of all components.

In the analysis presented here, only data from the Grande array were used. The shower directions, which are of particular interest for the anisotropy search, are reconstructed by evaluating the arrival times of the first particles hitting each detector, as well as the energy deposits. The accuracy of the shower axis reconstruction typically amounts to values around 0.8°. Depending on shower size and inclination angle, it is worse for more inclined showers, reaching about 1.5° for a zenith distance of 42°. See figure 1. Showers even more inclined are cut from the data set, not only due to the less accurate reconstruction, but also because of low statistics in this zenith angle range.

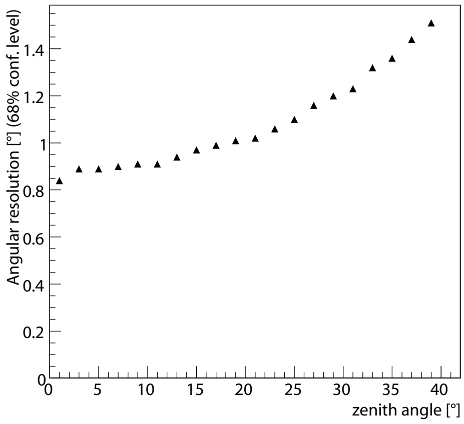

Figure 1: Angular resolution of the Grande array versus inclination angle, derived from Monte Carlo studies.

Large scale anisotropy

The large scale anisotropy is investigated by means of a harmonic analysis of the right ascension distribution of the air shower arrival directions. The Rayleigh formalism produces an amplitude value A, as well as a phase Φ, which corresponds to the right ascension of the direction of the excess. The procedure is sensitive to changes of the event rate during data taking, caused by metereological effects. To reduce these influences, a small fraction of events is discarded or counted double respectively, depending on measured air temperature and barometric pressure at the time of data taking. The resulting effective event rate is considerably less fluctuating. Much more hazardous are interruptions of data taking, which is why usually only periods of full sidereal days are taken into account for this kind of analysis. In the case of the present data set, this approach would lead to a reduction of the available statistics of 45%. Therefore, a modification of the Rayleigh formalism[3] has been developed, which takes right ascension dependent exposure times into account, allowing analysis of the full data set and thus increasing the available statistics almost by a factor of two.

Figure 3 shows the obtained upper limits at 95% confidence level for the Rayleigh amplitude versus estimated primary energy, in comparison to results of other experiments. An independent analysis of the KASCADE-Grande data with the east-west method[4] delivers an additional limit for $3 \cdot 10^{15}$ eV.

Autocorrelation analysis

An autocorrelation analysis can give evidence for clustering of air shower events and thus for the presence of point sources, while it cannot deliver any information on the number or location of such sources. For a given data set, the angular distance for each combination of two events is calculated. The distribution of these is compared with one created from an artificial data set, which represents the hypothesis of an isotropic distribution and was created from the original data set using the shuffling technique[5]. Figure 4 shows the autocorrelation as proposed in [6]: $w_{\mathrm{LS}} = (DD - 2DR + RR)/RR$, where DD, DR and RR denote the angular distance distributions of data-data, data-random (i.e. from the isotropic set) and random-random combinations of events. Since the number of angular distances to be computed increases quadratically with the number of events considered, this analysis was limited to the 1000 events of highest estimated primary energy.

Point sources would lead to an excess of small angular distances. As shown in figure 4, no such excess can be seen. No data points contradict with the assumption of an isotropic distribution, for which a two sigma confidence interval is indicated by the shaded area.

Search for point sources

The search for point sources is accomplished by comparing the measured arrival direction distribution in equatorial coordinates with an isotropic background distribution, obtained from the original data, using again the shuffling technique. The background distribution is made to contain 50 times as many events as the original data set. For each bin of the sky map, the significance of the excess of real data compared to the background is calculated according to Li and Ma[7]. The resulting significance map, with a bin width of 1° is shown in figure 5. Figure 2 shows the distribution of significances from the sky map. The expected shape of this distribution is a gaussion function with a mean value of 0 and a spread of 1. The histogram obtained from the data is in good compliance with this. Point sources present in the data set would lead to a distortion of this distribution.

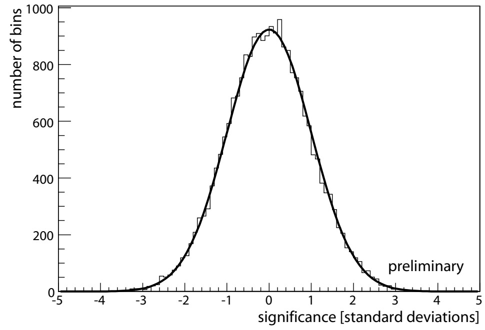

Figure 2: Distribution of the significance values of the 23 216 bins containing events of the sky map. The plotted function depicts the expected behaviour: a gaussian function centered at 0 with a sigma of 1.

Conclusions

We present results of the KASCADE-Grande experiment on anisotropy of cosmic rays on both the small scale (i.e. point sources) and the large scale (i.e. dipole like). The Rayleigh analysis of the measured right ascension distribution sets significant upper limits over the whole energy range. It is shown that with the full KASCADE-Grande statistics improved anisotropy measurements will be obtained over a crucial energy region.

Data taken by KASCADE-Grande reveal no evidence for point sources of cosmic rays. Neither the angular correlation analysis, nor the direct search for significant excesses of certain arrival directions can contradict the assumption of isotropy. For advanced analyses, the data set will be restricted to either the highest energy events, or to muon-poor air showers, enriching the data set with possible candidates of photon induced air showers.

References

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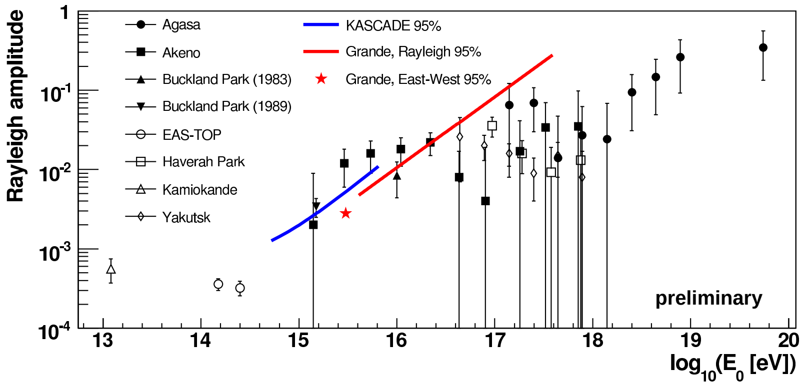

Figure 3: Upper limits for the Rayleigh amplitude, as obtained by a harmonic analyses of the distribution of the right ascension of arrival directions, compared to the results of other experiments.

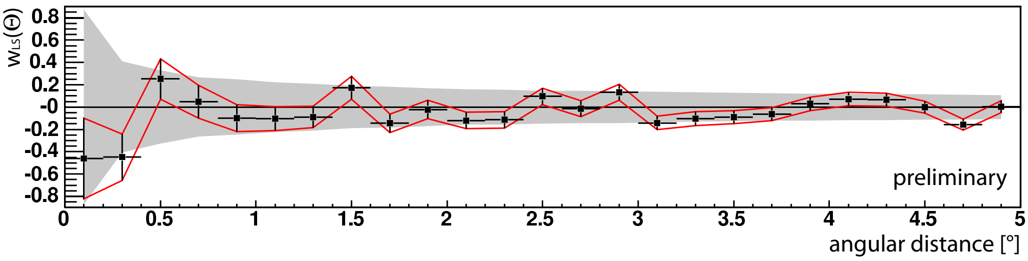

Figure 4: Autocorrelation of the arrival directions of the 1000 showers of highest estimated primary energy. The shaded area is the 2σ confidence region for isotropic distributions.

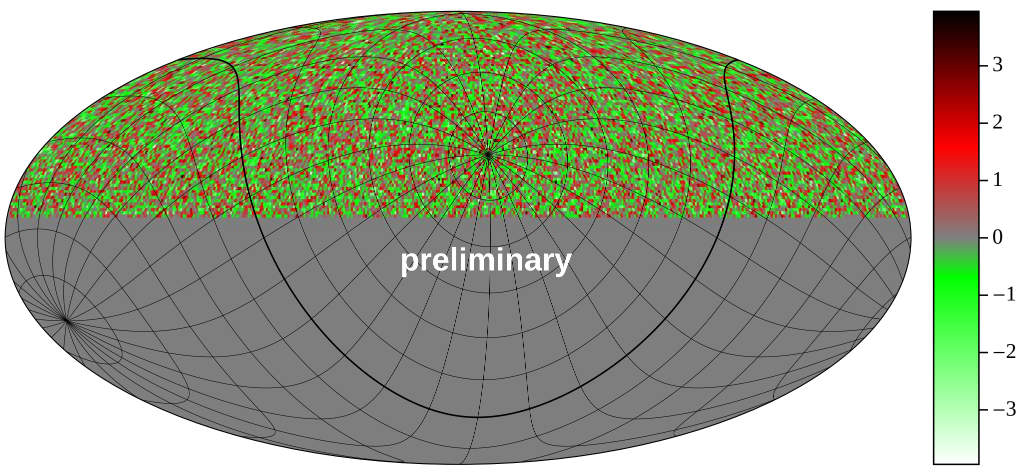

Figure 5: Significance map in equatorial coordinates. The exclusion of events more inclined than 42° results in the clear cut-off at declination 7°. The grid indicates galactic coordinates, with the thick curve representing the galactic plane.