Search for High Energy Gamma Rays with the KASCADE Experiment

T. Antoni[a], W.D. Apel[a], F. Badea[b], K. Bekk[a], K. Bernlöhr[a,1],
H. Blümer[a,d], E. Bollmann[a], H. Bozdog[b], I.M. Brancus[b],
C. Büttner[a], A. Chilingarian[c], K. Daumiller[d], P. Doll[a], J. Engler[a],
F. Feßler[a,2], H.J. Gils[a], R. Glasstetter[d], R. Haeusler[a],
W. Hafemann[a,3], A. Haungs[a], D. Heck[a], J.R. Hörandel[d], T. Holst[a],
K.–H. Kampert[a,d], J. Kempa[e], H.O. Klages[a], J. Knapp[d,4],
H.J. Mathes[a], P. Matussek[a], H.J. Mayer[a], J. Milke[a],
D. Mühlenberg[a], J. Oehlschläger[a], M. Petcu[b], H. Rebel[a], M. Risse[a],
M. Roth[a], G. Schatz[a,5], T. Thouw[a], H. Ulrich[a], A. Vardanyan[c],
B. Vulpescu[b], J.H. Weber[a], J. Wentz[a], T. Wiegert[a], J. Wochele[a],
J. Zabierowski[f], S. Zagromski[a]
The KASCADE Collaboration

[a] *Institut für Kernphysik, Forschungszentrum Karlsruhe, P.O. Box 3640, D-76021 Karlsruhe, Germany*
[b] *Institute of Physics and Nuclear Engineering, RO–7690 Bucharest, Romania*
[c] *Cosmic Ray Division, Yerevan Physics Institute, Yerevan 36, Armenia*
[d] *Institut für Experimentelle Kernphysik, Universität Karlsruhe, D–76021 Karlsruhe, Germany*
[e] *Department of Experimental Physics, University of Lodz, PL–90236 Lodz, Poland*
[f] *Soltan Institute for Nuclear Studies, PL–90950 Lodz, Poland*

Abstract. The experimental results of the KASCADE Extensive Air Shower experiment have been searched for events which might be attributed to high energy primary gamma rays. The observed data are compared with simulated gamma showers. Events with a very low muon to electron ratio, a smooth lateral electron distribution and an age characteristic of gamma induced events are selected. This contribution describes the applied methods. So far only a very small fraction of the KASCADE results has been studied and no positive identification can yet be claimed.

1) now at Humboldt University, Berlin, Germany
2) corresponding author
3) now at: University of Heidelberg, Heidelberg, Germany
4) now at: University of Leeds, Leeds LS2 9JT, U.K.
5) present address: Habichtweg 4, D-76646 Bruchsal, Germany; e-mail: bgschatz@t-online.de

INTRODUCTION

Extraterrestrial gamma rays have been identified up to c. 50 TeV by the imaging atmospheric Cherenkov technique [1]. Searches for gamma rays with higher energies performed with air shower arrays [2–4] have been unsuccessful so far and established upper limits of c. 10^{-4} for the gamma ray fraction of cosmic rays above a few 100 TeV. On the other hand, gamma rays in this energy region are expected to be produced by the interactions of hadrons with interstellar matter in the Galaxy. Hence we have started to scan the extensive air showers (EASs) registered by the KASCADE experiment [5] for events which might be attributed to primary gamma rays. The energy range of our experiment coincides with the maximum of the absorption of gamma rays by the cosmic microwave background radiation. But the minimum absorption length of 7 to 8 kpc still allows a considerable fraction of the Galaxy to be observed whereas no signals are expected from extragalactic sources (at least if conventional physics prevails, cf. [6]).

Our basic procedure is to compare observed events with simulated gamma ray showers. Since the electromagnetic interaction is well known even to high energies this method is to a large extent free of the uncertainties of high energy strong interactions. The predominant feature exploited to distinguish gamma from hadron primaries is the number of muons observed in the EASs. In addition, the steepness and smoothness of the electron lateral distributions are utilized. So far only a few percent of the KASCADE data have been analysed and we do not claim any positive identification of high energy gamma rays. But the results obtained so far demonstrate, in our opinion, the usefulness of the developed procedures.

THE APPARATUS

The KASCADE EAS experiment has been described in detail elsewhere [5]. This analysis makes use of the 252 detector stations of the array, arranged on a square lattice of 16 x 16. The inner 60 of these contain scintillation detectors for electrons of 3.14 m^2 each, the full outer 192 house electron detectors of 1.57 m^2 and, in addition, 3.24 m^2 scintillation counters for muons below a lead-iron shielding of 20 radiation lengths thickness. In addition the layer of 456 scintillation counters for muons of 0.45 m^2 each incorporated in the central detector were used. Thus the whole detector system contains 490 m^2 of electron and 820 m^2 of muon detectors.

ANALYSIS

The signals from electron and muon detectors are analysed by the usual KASCADE procedures [7]. The electron data are fitted with a NKG function which yields core position, total electron number and the steepness of the lateral distribution ('age'). The time signals of the electron counters are also used to determine

the direction of incidence with an accuracy of c. 1° near the threshold of a few hundred TeV and 0.5° above 5 PeV. The signals from all muon detectors are analysed jointly although the threshold of the array detectors is somewhat lower which increases their count rate by c. 10 %. They are fitted with a NKG function of fixed shape. Scintillators in the central detector closer than 20 m and array detectors closer than 40 m to the shower axis are disregarded in order to avoid punch-through of high energy electrons and of hadrons. This analysis yields electron and muon numbers for each individual shower. These are then corrected for differing atmospheric absorption due to varying air pressure and different zenith distances. Here an exponential decrease is assumed. The attenuation lengths applied, 202 g/cm^2 for electrons and 800 g/cm^2 for muons, were derived from the observed shift of the 'knee' in the respective intensity distributions with zenith distance.
The results of this analysis are displayed in the left part of the figure. Each light gray point represents an observed event in the plane $logN_\mu$ versus $logN_e$. Note that in this presentation the steep increase of intensity from upper right to lower left is not obvious. Superimposed on the observed data are simulated showers induced by gamma rays of various energies between 0.5 and 10 PeV and two zenith distances. The simulations used the CORSIKA program [8] and a full detector Monte Carlo. These synthetic data were then processed in the same way as the experimental ones. It is obvious that, except near threshold, the simulated gamma ray showers are well separated from the bulk of the observed ones. The narrow horizontal band at $logN_\mu = 2$ represents showers with no registered muon (and hence an estimated total muon number of 0).

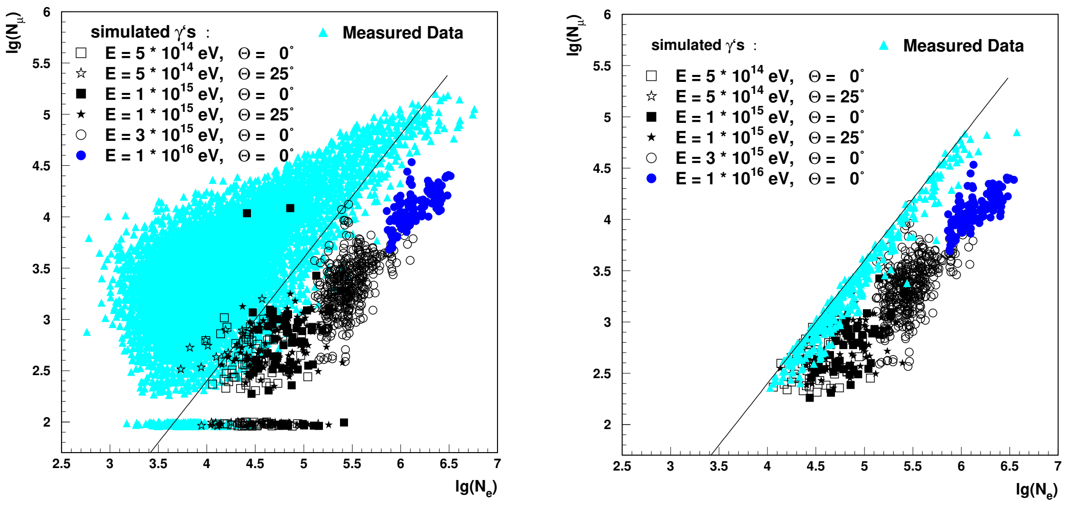

FIGURE 1. Left: Distribution of observed (gray) and simulated events in the plane $logN_\mu$ versus $logN_e$. The narrow horizontal band at $logN_\mu$=2 represents showers without registered muons (and hence an estimated total muon number of 0); right: Distribution of the events surviving the age and smoothness cuts.

Since the muon to electron ratio of EASs increases with primary mass, proton induced showers are expected to lie at the lower edge of the experimental range in the figure. Proton showers are also known to show large fluctuations of all their observables. Therefore two additional criteria are applied to distinguish gamma from hadron showers. Proton showers, especially if muon poor, are expected to exhibit a steep decline (small 'age'). We therefore applied an additional cut in the plane of observed age versus $logN_e$. Another feature distinguishing gamma from hadron showers is the smoothness of the electron lateral distribution. This fact is exploited for gamma hadron separation in imaging atmospheric Cherenkov experiments [9]. We have therefore calculated the χ^2 deviation between the observed and fitted electron lateral distributions and discarded all showers which exhibit larger fluctuations than simulated gamma showers. These two cuts were chosen in such a way that more than 90 % of the simulated gamma showers survived. These surviving events are displayed in the right part of the figure. This time, the observed events are superimposed upon the simulated ones.

DISCUSSION

The total number of analysed events displayed in the figure is c. 290000 which represent less than 2 % of the events registered by KASCADE up to now. In spite of the cuts based on age and smoothness almost all observed events in the right part of the figure cluster near the straight boundary line. This indicates that they are hadronic showers fluctuating towards low muon numbers. Above 1 PeV less than 10 events are found in the region occupied by the simulated gamma events. Thus we do not claim any positive identification of gamma induced showers on the basis of the data presented here. But our results indicate, in our opinion, that the procedures presented here are well suited to discriminate between gamma and hadron induced showers at least above 1 PeV and that our sensitivity is comparable to that of previous work [2] [3] [4]. At lower energies fluctuations increase and discrimination will be more difficult. But in this region the showers without registered muons which have not been looked at so far, may offer additional possibilities.

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