Search for Extremely High Energy Gamma Rays with the KASCADE Experiment

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Abstract

Data observed with the KASCADE extensive air shower experiment have been analyzed with respect to a possible contribution by primary gamma rays in the energy range of 0.3 to 10 PeV. Possible gamma induced events are identified by their low muon to electron ratios and by the steepness and smoothness of their electron lateral distributions. Our results confirm and to some extent improve upper limits of a possible gamma contribution established by previous experiments.

1. Introduction

Gamma rays represent a small but important fraction of primary cosmic rays. Their importance among primary cosmic rays derives from the fact that they are electrically neutral and hence not deflected by interstellar or intergalactic magnetic fields. Therefore their directions of incidence points back to their points of production. The highest gamma ray energies identified up to now by the imaging atmospheric Cherenkov technique [7] are close to 50 TeV [13]. But the gamma ray spectrum is expected to extend to much higher energies due to

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the production of neutral pions by charged particles interacting with interstellar matter. It therefore appeared worthwhile to search the data registered by the KASCADE experiment for events which might be attributed to primary gamma rays. This contribution updates a previous one [8]. More details can be found in Ref. [9].

Previous experiments [1,6] have set upper limits of the order of 10^{-5} to 10^{-4} for the gamma ray fraction among primary cosmic rays in the energy range above a few hundred TeV. Identifying such a small fraction is obviously not trivial, especially in view of the large fluctuations inherent in extensive air showers (EASs) which are the only means at present to register high energy cosmic rays. The main feature which can be exploited for discriminating primary gamma rays from charged cosmic ray particles is the ratio of electrons to muons on observation level. Gamma rays interact in the atmosphere predominantly by producing electron-positron pairs. It is only via the photoproduction of hadrons that muons occur to an appreciable extent in EASs induced by gamma rays.

2. Measurements and data analysis

The KASCADE experiment is described in detail elsewhere [5]. The main features relevant for the present analysis are the array with its 490 m^2 of scintillation detectors for registering electrons and 620 m^2 for the measurement of muons. Of the central detector, only the 205 m^2 scintillation detectors of the trigger plane were used to register muons. The signals from the detectors were analysed to yield core position, electron number N_e, steepness of the lateral electron distribution ('age'), muon number N_μ and, from timing, the direction of incidence of the shower. For more details of this analysis cf. Ref. [4].

3. Gamma hadron discrimination

Fig. 1 shows the distribution of the reconstructed events in the $lg(N_e) - lg(N_\mu)$ plane as the light data points. Superimposed are simulated gamma events of fixed energy and zenith angle which concentrate along the lower edge of the observed showers, as expected. These simulations include a complete detector Monte Carlo [4]. For further analysis we concentrate on the events below the straight line in Fig. 1. They amount to 97097 out of a total of 29.5 millions. In the region above this line the density of observed events is so large that identification of the few possible gamma induced events appears hopeless. The events near to and overlapping the simulated gamma events are expected to be mainly due to primary protons because EASs induced by heavy nuclei exhibit a larger muon to electron ratio. A further reduction of this hadron background is obtained by an age cut and by selecting EASs with a smoother lateral distribution. The latter feature is exploited very advantageously for gamma/hadron separation by

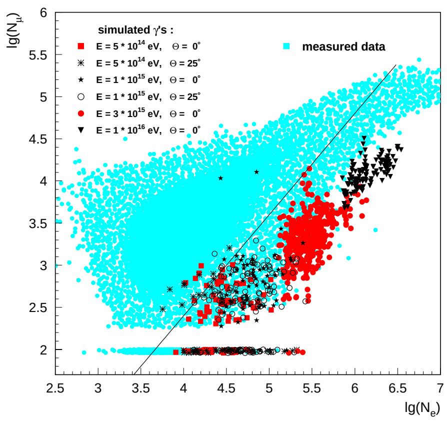

Fig. 1. Distribution of the observed events in the $lg(N_e) - lg(N_\mu)$ plane (light blue) with simulated gamma showers superimposed. The horizontal band at $lg(N_\mu) = 2$ represents EAS with no registered muon (and hence an estimated muon number 0).

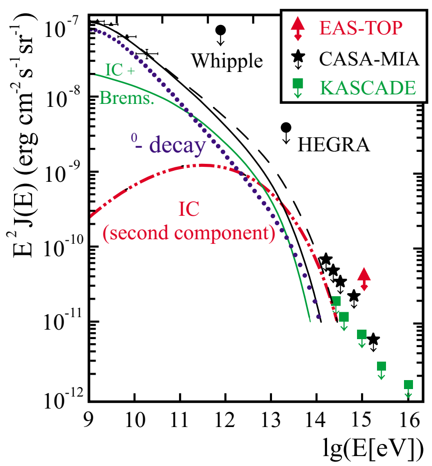

Fig. 2. Comparison of our derived upper limits with previous results by the CASA-MIA [6] and EAS-TOP [1] experiments and with theoretical spectra from Ref. [3].

the imaging atmospheric Cherenkov technique (cf. Fegan [7]). For details of our procedure cf. Ref. [9]. These two cuts reduce the number of events remaining to 43538 and 38531, respectively.

The usual method applied by previous experiments [1,6,11] to set an upper limit to the number of gammas among the observations is to choose a separating line (in our case in the $lg(N_e) - lg(N_\mu)$ plane) and assume that all events on one side of the line represent gamma rays. In our opinion this procedure is unnecessarily conservative because the distribution of observed events in the region of simulated gamma ray showers does not bear any resemblance with the one expected for gamma rays. Therefore another statistical procedure was developed which exploits the shape difference between the two types of distributions. Detailed descriptions of this procedure and of the algorithm employed are beyond the scope of this paper but can be found in Refs. [9,12].

4. Results

Fig. 2 compares our results with other experiments and with theoretical values by Aharonian and Atoyan [3]. The results of the CASA-MIA [6] and EAS-TOP [1] experiments displayed in this figure have been calculated by multiplying their quoted maximum gamma ray fractions with their observed spectra (Refs. [10] and [2], respectively). Experiments and theory are obviously well compatible with each other. Our lowest points are intriguingly close to the uppermost (dashed) theoretical curve. Since this assumes a hypothetical population of high energy electrons, required to explain the x-ray spectrum, an improvement of the limit might confirm or otherwise this population and would hence be of considerable astrophysical relevance.

No local enhancement indicative of a point source was observed. The diffuse flux results mainly from interactions of charged cosmic rays with interstellar matter which is concentrated in the Galactic plane. Hence an excess along this plane may be expected. We have therefore investigated the distribution on the sky of the 143 events which appear most 'gamma-like' (i.e. whose distance to the straight line in fig. 1 is the largest). A Kolmogorov-Smirnov test comparing their distribution in Galactic latitude to those of all events after the first and third cuts yields chance probabilities of order 0.05. Hence no observation of gamma rays from the Galactic plane can be claimed. Gamma rays from extragalactic sources are not expected to show up in our data because absorption of gammas rays by the cosmic microwave background radiation attains its maximum in the energy range of this investigation.

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