Search for isotropic γ radiation between 65 and 200 TeV: constraints on topological defects and galactic dark matter in the form of molecular hydrogen

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Abstract

An upper limit (90 % C.L.) is presented on the ratio of primary γ to charged cosmic rays in the energy interval 65 - 160 TeV of $10.3 \cdot 10^{-3}$. Data from the HEGRA scintillator array and the wide angle air Čerenkov array (AIROBICC) have been used to discriminate γ-ray and hadron induced air showers. The result can be used to give constraints on scenarios with topological defects as a source of highest energy cosmic rays and existence galactic dark matter in the form molecular hydrogen

1 Introduction

The energy range up to 100 TeV is of particular interest for γ-astronomy. At higher energies photons will interact with the universal microwave background radiation (MBR) and therefore the pathlength of photons is limited to galactic distances. However, the photons form a pair-Compton-cascade and the products of the cascade are expected to pile up in a relatively narrow energy interval below 100 TeV[1]. Below this energy, the universe suddenly gets much more transparent to γ rays.

Cosmic rays have been observed up to energies around 10^{20} eV, however, their origin is unknown. A possible source for the observed cosmic radiation above 10^{19} eV could be topological defects [2]. In such a scenario, investigated by Aharonian et al. [3], the decay products of the topological defects would inject electromagnetic energy at these highest energies.

Another important reason to search for diffuse γ radiation is the search for galactic dark matter: it has recently been proposed by de Paolis et al.[4] that the galactic dark matter might consist of clouds of primordial molecular hydrogen in an extended halo around our Milky Way. This matter has to interact with cosmic radiation thus producing γ rays. The resulting γ intensity around 100 MeV has been discussed in detail by Luo and Silk[5]. Their discussion and similar numbers from de Paolis et al. show that this mechanism

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could explain quantitatively (within the relatively large uncertainties of such a calculation) the origin of the diffuse γ background above 100 MeV observed by SAS-2 and EGRET.

In the following we report on a search for isotropic γ radiation with the HEGRA air-shower experiment in the energy interval from 65 - 100 TeV. The discrimination of γ-ray and hadron induced showers has been carried out by applying a novel method based on the knowledge of the lateral distribution of the Čerenkov light as measured with the Čerenkov array AIROBICC [6] and the shower size N_e from charged particles at ground level, measured with the scintillator array. Monte-Carlo simulations used in this analysis are described in [7] and the method to separate γ's and hadrons can be found in [8, 9]. For a more detailed description of the material in this contribution see Ref.[10].

2 Event reconstruction and data selection

The scintillator data were used to determine the shower size N_e at ground level [7, 8]. The lateral distribution of the Čerenkov light density ρ_p as a function of the distance r to the shower core position is well approximated [6, 8] by a single exponential for 10 m $<$ r $<$ 90 m: ρ_p= a $\cdot$ exp$(-r/r_0)$. The free parameters are a (in units of photons/m^2) and the "light radius" r_0 (in units of m) are determined by a χ^2-fit of the experimental amplitudes.

Monte-Carlo-simulations have been made of air showers at zenith angles of 10 and 25 degrees, and a realistic chemical composition of 70% low, 20% medium and 10% heavy primaries were subjected to the same analysis and cuts as the real data. Details of the calibration of the absolute Čerenkov photon density as well as the electron density are described elsewhere [6].

Data from 4 nights in February and March 1993 of best atmospheric conditions with a total of $7 \cdot 10^5$ events were selected for the present analysis. Several quality cuts were applied both, to the real and the MC data: the χ^2 of the fits must be ($\chi^2_{red} < 2$), the shower core position has to fall $>$ 25 m inside of the array and the light radius r_0 has to be in the interval 25-140 m. Only showers with more than 30 scintillator and 20 AIROBICC stations over threshold were used. We ensured in the MC data that the cuts do not reject photon induced showers preferentially. Finally, the photon density at a distance of 90 m was used to restrict the energy range: 15000/m^2 $<$ L_{90} $<$ 40000/m^2. In the following we present the result for a sample of 2796 showers with zenith angles $<18\ ^o$, corresponding to an energy form 65 - 160 TeV [6].

3 Analysis for γ/hadron ratio and conclusion

The method to distinguish between primary photons and hadrons [8, 9] makes use of three measured parameters:

- The number of Čerenkov up to 100 m, L_{0-100}
- the number of electrons at ground level, N_e

- the slope of the light distribution, defined as the light radius r_0.
At a given number of electrons at ground level photon induced showers have more light than hadronic showers. The light radius can be used as a measure of atmospheric depth of the shower maximum. One compares the light electron ratio only for showers with the same height of the shower maximum. Using these observables a parameter (LES) can be defined, which is suitable to separate γ ray and hadron showers. Fig. 1 shows the LES distribution for simulated γ's, hadrons and for experimental data.

For the determination of an upper limit of the fraction P_γ of γ-showers, we consider all events observed in the accepted region as "γ-ray candidates" (below the cut line in fig. 1). An upper limit on P_γ is derived directly on the ratio of the number of "γ ray candidates" to the total sample size. With the condition LES<0.275, an acceptance S_γ = 9 % of the γ-showers (22 out of 249) are accepted, while 99.86 % of the experimental data are excluded: only 4 out of 2796 are accepted. Systematic errors arising from the imprecision of the MC simulation and remaining instrumental uncertainties are estimated as 48 % on S_γ.

Figure 1: The LES-parameter distribution is shown for the MC simulation of γ's and hadrons, and for experimental data.

Using standard techniques [11] we calculated a Poissonian upper limit on the number of "γ candidates" in the LES distribution of the experimental data. This number was increased by the systematic error and divided by the total sample size and S_γ to get an upper limit on the fraction P_γ of γ in the sample. To finally obtain an upper limit f_γ on the ratio of the total cosmic ray to the primary γ ray flux one has to take into account the different energy threshold for γ's and hadrons of about a factor of 3.
The final results are 90 % C.L. upper limits on the ratio f_γ of the primary photon flux F_γ to the total cosmic-ray flux F_{CR}:
$f_\gamma(> 65 \text{ TeV}) = \frac{F_\gamma(65TeV<E<160TeV)}{F_{CR}(E>65TeV)} < 10.3 \cdot 10^{-3}$

A slightly lower limit has been obtained for showers with larger zenith angle ($< 0.78\%$ for E $>$ 80 TeV). The accepted events were scanned individually, and found to have no distinctive properties except their low N_e to light ratio. The model of Aharonian et al.[3] predicts an f_γ up to 4 %, its parameters are therefore constrained by the present measurement.
In order to predict the intensity expected from the mechanism of cosmic rays interacting with molecular hydrogen in the outer galaxy in our energy range, one has to take into account that in the outer halo the cosmic ray spectrum is expected to be unmodified by propagation effects which soften the primary spectrum in the inner galactic disk. We therefore probably have to extrapolate the spectrum observed around a GeV with the source spectrum which is expected to be about proportional to $E^{-2.1}$ where E is the primary energy. EGRET data for the 'extragalactical flux' have a spectral index of -2.11$\pm$0.05 in good agreement with this expectation and an integral flux above 100 MeV of $1.1\pm0.05 \cdot 10^{-5}$ cm^{-2} $sec-1$[12]. From this we expect an intensity ratio $f_\gamma = I_\gamma / I_{cr}$ in our case of $5 \cdot 10^{-4}$ about a factor of 20 below our upper limit. Our data were taken near the galactic equator (b $\simeq$ -5 - 55 ^{o}) in the direction of the galactic anticenter (l $\simeq$ 160 - 250 ^{o}), so for a flattened halo higher expected values are possible, however.

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