AstroParticle Physics 2003/04 (De Angelis)

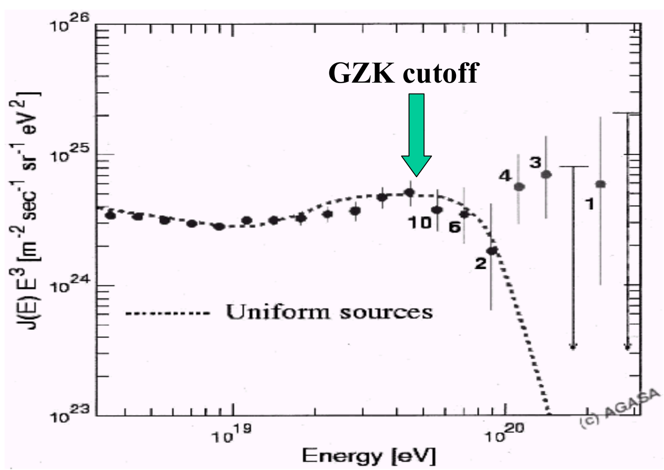
Laboratory 2
The GZK cutoff

1. Purpose and Introduction

The purpose of this laboratory exercise is to determine what is the energy beyond which protons, colliding with photons from the Cosmic Microwave Background (CMB), enter in the region of the resonances (unstable baryons). When the threshold for the process

$$p + \gamma_{CMB} \rightarrow \Delta \rightarrow N\,\pi \qquad (1)$$

(where N is a generic nucleon) is reached, the proton energy is degraded. This energy is thus a cutoff for the propagation of protons through astronomical distances; it is called the GZK cutoff, from the initials of the authors who first foresaw the effect [1].



Despite the fact that we can demonstrate the existence of such a cutoff, the AGASA experiment [2] has observed a dozen of events beyond the limit. Several explanations have been proposed; you will see for example that the cutoff calculation probes the theory of relativity at extreme limits.

2. Procedure

First one has to determine the peak energy for photons in the CMB. Taking as a central value for the temperature of the Universe T = 2.72 K [3], by applying Wien's law

$$\lambda_{peak} = 2.9\ 10^6/T$$

(λ in nm, T in K) one can obtain the peak value for the wavelength λ, and then, from $E = hc/\lambda$ (where hc=1240 eVnm is Planck's constant times the speed of light) the central value for the energy

λ_{peak} = ___________________ nm

E_{peak} = _____________________eV

Note: compare the expression obtained with the relation obtained in thermodynamics for a free gas

$$E = 3/2\ k_B\ T$$

where $k_B = 8.6\ 10^{-5}$ eV/K is Boltzmann's constant.

Then one can write the 4-vectors of a proton and of a γ from CMB in the most favourable case for the production of a Δ; (head-on collision), and compute the minimum energy E_{cutoff} for a proton, at which a Δ can be produced.

E_{cutoff} ~ _____________________ GeV

(note: take for the Δ mass a value of1.23 GeV/c^2, and for the proton mass a value of 0.94 GeV/c^2).

This cutoff energy is quite large: as an example, a single proton of this energy it might lift a mass of 1 kg by _________ cm.

References

[1] K. Greisen, Phys. Rev. Lett. 16 (1966) 748;
5. G. T. Zatsepin and V. A. Kuz'min, JETP Lett. 4 (1966) 78.
[2] http://www-akeno.icrr.u-tokyo.ac.jp/AGASA/
[3] http://lambda.gsfc.nasa.gov/product/map/wmap_parameters.cfm