Signatures of UHE Gamma Ray Flux for Fluorescence Detectors

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1 Introduction

The observation of an apparent continuation of the UHE cosmic ray flux beyond the GZK cutoff [1] has stimulated a number of novel ideas about the origin of such cosmic rays. These models have included the decays of cosmic strings [2],ee resonance production of Z bosons on the remnant neutrino background by UHE neutrinos [3], and decays of superheavy cold dark matter particles [4]. A common thread among these models is the prediction of gamma and neutrino fluxes which are similar or large compared to the hadronic flux. While the observation of neutrinos is made difficult by the small interaction cross-section, most of the UHE gamma rays incident on the atmosphere will produce an EAS and will be detected by ground or atmospheric fluorescence detectors. The problem is establishing that the showers are produced by gamma rays and not by the ubiquitous proton and heavy nucleon flux which appears to dominate the spectrum at lower energies. Two mechanisms that operate only at the highest energies will cause the gamma-ray induced EAS to deviate markedly from expectations. These are the LPM [5] and magnetic bremstrahlung [6] effects. These new mechanisms are, to first order, only effective for electron and gamma ray induced showers, at least in the energy range below 1000 EeV. We investigate possible signatures that these mechanisms imply for identification of a gamma ray flux in fluorescence detector data.

2 LPM effect

The LPM effect results in the suppression of the Bethe-Heitler cross-section for the highest energy component of showers and the subsequent significant elongation of the EAS shower. Its threshold depends on the ratio of energy of the primary particle to the density of the interaction medium. In the atmosphere, the effect becomes important for gamma rays and electrons above 10 EeV, while for protons significant effects are delayed until nearly 1000 EeV energies are reached. It is now incorporated in two widely used shower generation programs, CORSIKA and AIRES as well as the Japanese program COSMOS. We have used the CORSIKA and AIRES programs and checked their results for consistency. We find only very minor differences in their implementation of both the Bethe-Heitler and LPM effects. Fig. 1 shows the effect of turning on the LPM effect for gamma rays of 1000 EeV energy with respect to standard Bethe-Heitler-type shower development, averaged over 200 showers. The main effect is a significant widening of the shower and consequent decrease in the number of particles at shower maxima. A related phenomenon is an increase in shower development fluctuation, due to the smaller interaction cross-sections.

3 Magnetic Bremstrahlung

Gamma ray showers must traverse the Earth's magnetosphere before impacting on the atmosphere and generating secondary shower particles. Even though the Earth's magnetic field intensity is low, at high enough energies magnetic brehmstrahlung and pair production can become important. For gamma rays and electrons, this threshold is effectively near 100 EeV. The net effect is that greater than 100 EeV gamma ray showers will generate a spectrum of secondary gamma rays and electrons in the magnetosphere. The resultant EAS

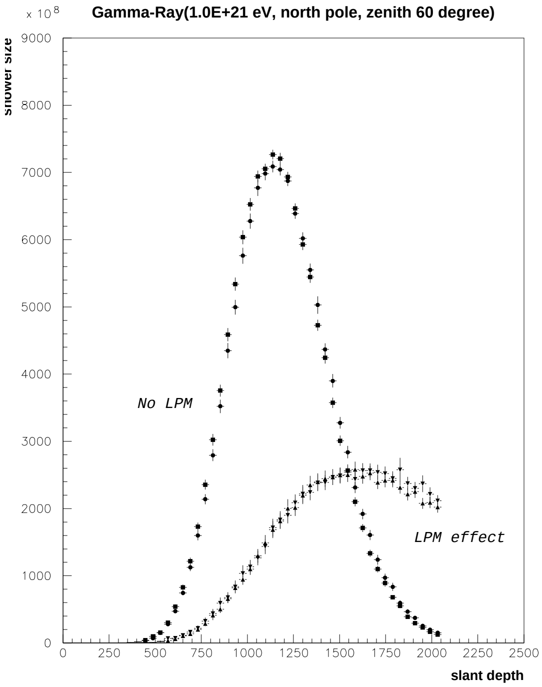

Figure 1: Effect of LPM on 1000 EeV gamma ray

shower in the Earth's atmosphere is then a superposition of these lower energy gamma rays. The effect depends on the magnitude of the perpendicular component of the magnetic field with respect to the direction of the primary particle. Hence the effect will depend on the arrival direction of the particle with respect to the Earth's coordinate system referenced to the North and South magnetic poles. Neither CORSIKA nor AIRES presently incorporate this effect. We have used the results of a calulation by Stanev and Vankov [6] for a 320 EeV gamma ray. These authors present a distribution of secondary gamma rays impacting the top of the atmosphere. We have taken this distribution and used it to generate a superposition of showers using standard CORSIKA and AIRES code and incorporating the LPM effect. At 320 EeV, the main effect is to shift the most probable gamma ray energy impacting the top of the atmosphere from 320 EeV to near 30 EeV, i.e., one would expect that the shower maximum would move to shallower depths in the atmosphere with respect to the standard Bethe-Heitler model, in this case by about 80 gm/cm2. The severity of the shift is mitigated by the LPM effect which is important for the highest energy sub-showers and tends to cancel this shift. Fig. 2 shows the effect of magnetic brehmstrahlung on a 320 EeV gamma ray.

4 Effect of Combined LPM and Magnetic Bremstrahlung on Gamma Rays

Since any incident gamma ray flux is expected to be isotropically distributed with respect to the Earth's magnetic field direction, we expect to see a continuum of effects on the EAS from near pure LPM effect for particles entering along magnetic field lines to magnetic bremstrahlung dominated showers. This modulation from shallower Xmax and near normal shower width to deep Xmax and wide longitudinal shower development depends effectively on the azimuthal angle with respect to North or South magnetic pole and should be a useful signature for the presence of gamma rays. Fig. 3 shows the Xmax vs. energy plot for several extreme

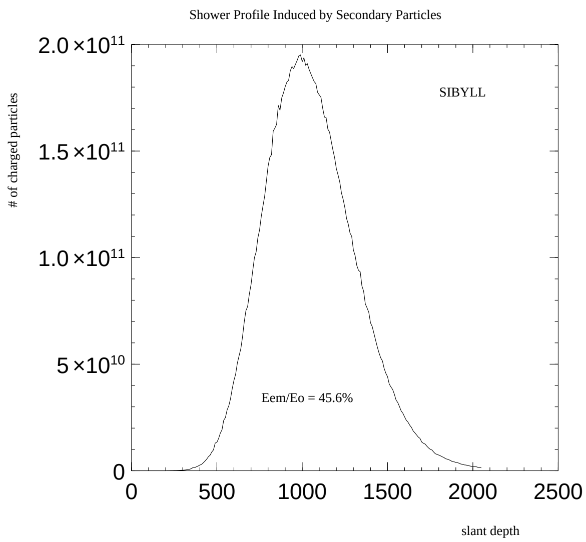

Figure 2: Effect of Magnetic Bremstrahlung on 320 EeV Gamma Ray

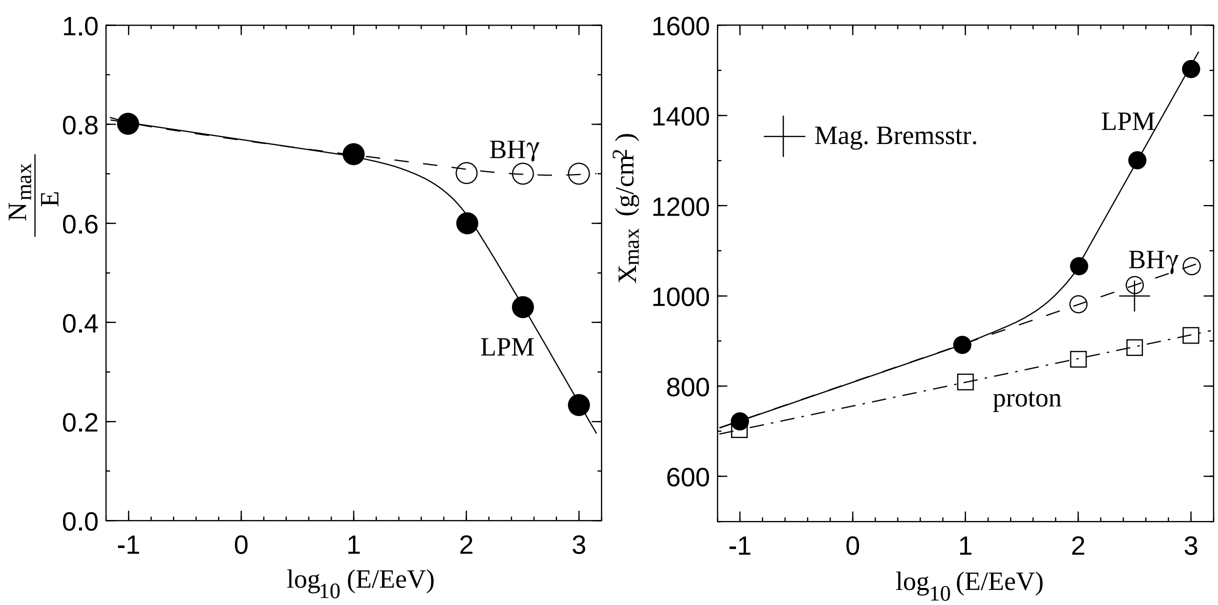

Figure 3: Effect of LPM and Magnetic Brehmstrahlung on Xmax and Nmax

cases. Because the elongation rate for hadronic showers is near 50 gm/cm2 per energy decade, while the electromagnetic elongation rate is near 85 gm/cm2, even the pure Bethe-Heitler EAS are well separated from protons above 100 EeV. The effect of turning on the Earth's magnetic field is indicated by the cross at 320 EeV. The shift is towards the protons, but is only about 25 gm/cm2. At these energies, to a first approximation, the effect of magnetic bremstrahlung is to negate the LPM effect. Those showers coming from the North magnetic directions will therefore have Xmax distributions given by the Bethe-Heitler line, while those coming from the E and W will approach the Xmax distribution given by the LPM line. At 320 EeV, the separation between the two lines is nearly 300 gm/cm2. Thus, this is a very significant effect and should in principle be easy to recognize. Fig. 4 shows the dependence of Nmax, the number of particles at shower maximum on energy. For Bethe-Heitler showers, the ratio of Nmax/E is very constant, changing from about .8 particles/GeV to about .7 over the energy range. For those particle arrival directions where the LPM effect is important, this ratio drops by more than a factor of two by 1000 EeV. Fluorescence detectors can measure the energy by integrating the longitudinal shower shape and also measure Nmax from the resultant shower fit. Hence the combined measurement of Nmax, E, and Xmax as a function of azimuthal angle will be a powerful tool for searching for the presence of a gamma ray flux. It should be noted that events with strong LPM development may have a somewhat different aperture than magnetic bremstrahlung events since the intrinsic shower luminosities will be different. Careful accounting of these difference must be made in estimating the final sensitivity to a gamma ray flux by a fluorescence detector. This work is in progress and will be presented at the ICRC meeting.

5 Acknowledgment

This work is funded by NSF Grants PHY 93-22298, PHY 93-21949, PHY 95-12810, The support the Center for High Performance Computing is gratefully acknowledged.

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