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# Limit on the flux of ultra-high energy photons from the HiRes Stereo Data

A.C. O'Neill and S. Westerhoff for the HiRes Collaboration

*Physics Dept, Columbia University, New York, NY, USA*

Presenter: A.C. O'Neill (oneill@phys.columbia.edu), usa-oneill-A-abs1-he14-oral

Top-down models for the origin of extragalactic cosmic rays predict a substantial photon fraction in the cosmic ray flux above $10^{19}$ eV. The HiRes air fluorescence detector is capable of discriminating between photon and hadronic events and can place a limit on the photon fraction.

When modeling the passage of primary photons towards the earth, we have to take into account that photons above $10^{19}$ eV are capable of pair production in the geomagnetic field, which causes an electromagnetic shower to occur before atmospheric interactions begin. We have created a Monte Carlo simulation of this preshower physics and use it to calculate the photon fraction in the HiRes stereo data above $10^{19}$ eV. We compare our limit to predictions of various top-down models.

## 1. Introduction

Gamma Rays above $10^{19}$ eV have sufficient energy to interact with a geomagnetic photon and pair produce before entering the atmosphere. The resulting pair can emit several hundred secondary photons via Bremsstrahlung before atmospheric effects become important. This geomagnetic preshower has the effect of reducing the depth of shower maximum ($X_{max}$). This change is particularly important when considered in conjunction with the Landau-Pomeranchuk-Migdal[1] effect which reduces the Bremsstrahlung cross section considerably at this energy.

The change in shower development due to geomagnetic preshowering is important for air fluorescence detectors since $X_max$ is used in determining the composition of the primary particle. By reducing the atmospheric depth of the shower maximum the effect also increases the sensitivity of air fluorescence detectors to high-energy gamma rays. These factors must both be considered in calculating a limit on the gamma ray flux.

We have created a Monte Carlo simulation of gamma rays in the geomagnetic field and applied it to measuring the fraction of photons present in the HiRes stereo data above 40 EeV. This is similar in concept to simulations created by Homala et al[2] and Vankov et al[3].

## 2. Pair Production and Bremsstrahlung in the Geomagnetic Field

The process of pair production at high energy (or in strong magnetic fields) is well understood. The mean free path for a photon of energy $E_\gamma$ in a transverse magnetic field $B_\perp$ is given by [4]

$$\lambda = \frac{2\lambda_C B_{crit}\chi}{\alpha B_\perp 2\pi 0.16 K_\nu^2(\frac{2}{3}\chi)} \tag{1}$$

where

$$\chi = \frac{E_\gamma B_\perp}{2m_e B_{crit}} \tag{2}$$

and $B_{crit} = 4.41x10^9 T$. At low gamma energy, the electron and positron receive approximately equal energy, but at large values of $\chi$ the energy distribution of the pair becomes highly assymetric.

The magnetic Bremsstrahlung process for a relativistic electron is also well described in the literature[5]:

$$\lambda = \frac{1}{\int_0^{E_e} \frac{I(E_\gamma, E_e, B_\perp)}{E_\gamma}\, dE_\gamma} \tag{3}$$

where the Bremsstrahlung spectrum $I(E_\gamma, E_e, B_\perp)$ is given by

$$I(E_\gamma, E_e, B_\perp) = \frac{W_{cl} f(y) E_e}{\xi (E_e - E_\gamma)^2}, \tag{4}$$

$W_{cl}$, the classical Bremsstrahlung radiation per unit distance is

$$W_{cl} = \frac{8\pi r_0^2 B_\perp^2 E_e^2}{\mu_0 m_e^2 c^4}, \tag{5}$$

and the function $f(y)$ is

$$f(y) = \frac{9\sqrt{3}}{8\pi(1+\xi y)^3} \left( \kappa(y) + \frac{y^3 \xi^2 K_{\frac{2}{3}}(y)}{1+\xi y} \right). \tag{6}$$

The auxillary Bremsstrahlung function $\kappa(y)$ is given by

$$\kappa(y) = y \int_y^\infty K_{\frac{5}{3}}(x)\, dx \tag{7}$$

and the parameter $\xi$ is

$$\xi = \frac{3 E_e B_\perp}{2 m_e B_{crit}}. \tag{8}$$

We use the International Geomagnetic Reference Field to get $B_\perp$.

Incoming photon primaries are simulated by a Monte Carlo code implementing the above results. The electromagnetic preshower is then used as an input to the CORSIKA air shower simulation, and the results processed using the HiRes detector simulator.

## 3. Effect of Preshower on Shower Development

Because of the directionality of the geomagnetic field, the preshower effect is highly dependent on arrival direction. We have identified the directions of maximum and minimum preshower probability, which correspond to the maximum and minimum transverse magnetic field. At the HiRes detector in Utah the maximum is at 10 degrees East of North, 30 degrees above the horizontal and the minimum is found at 10 degrees West of South, 60 degrees above the horizontal.

Figure 1 shows the elongation rate ($\langle X_{max} \rangle$ as a function of energy) for preshowered gammas from these two directions, along with that of protons and iron.[6]

It can be seen that the preshower effect does not cause $\langle X_{max} \rangle$ for photons to be close to $\langle X_{max} \rangle$ for hadrons. The reduced depth does however improve the acceptance, particularly for less inclined showers.

The large spread in the $X_{max}$ distribution for gamma showers from the North between $10^{19.6}$ and $10^{19.7}$ eV is due to some showers which have pair produced and preshowered and some which did not cause a pair production event before entering the atmosphere.

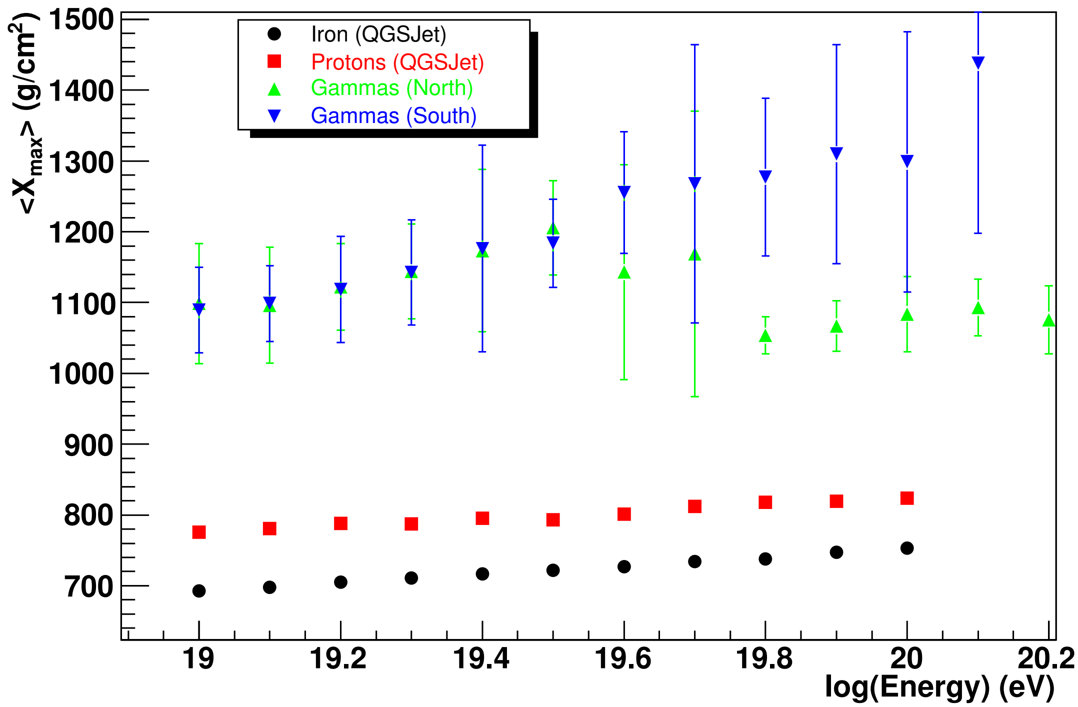


**Figure 1.** Elongation Rate for Preshowered Gamma Rays at the HiRes Location

## 4. Calculating the Fraction of Gamma Rays in the HiRes Data

Rather than using the simulated elongation rate to determine composition, we have applied a likelihood method[7] to determine a limit on the number of photons in the HiRes data above the GZK limit. This involves comparing the simulated gamma $X_{max}$ distribution with the observed distribution, and has the advantage of reducing dependence on factors such as the spectrum of simulated events or hadronic model used in simulation.

The simulated gamma ray showers have been compared to the 50 events above 40 EeV in the HiRes stereo data.

## 5. Conclusions

One can place a useful upper limit on the flux of ultra high energy photons using the HiRes stereo data which will have interesting implications to many top-down models of super-GZK cosmic rays. The likelihood method allows us to calculate a limit on the number of photons in the HiRes data.

Further results will be presented at the conference.

## 6. Acknowledgements

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