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Cascading parameters of EHE primary photons in the Sun's magnetic field

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Abstract. The study of cascading initiated by Extremely High Energy (EHE) photons in the Sun's magnetic field is an effective tool for solving the problem of primary compositions and investigating the photon content in the EHE cosmic ray spectrum. The processes of the magnetic pair production and bremsstrahlung are the basic mechanisms by which our Monte Carlo simulation of photon primary in Sun's magnetic field is taken into account. Such process has been simulated in the magnetic field near the Sun's surface for predicting the cascading parameters of these extraordinary showers. Upon our simulation results, such cascading particles produced by primary photon with an energy exceeds 10^{19} eV could be detected on the Earth's surface within a solid angle within 6.12 x 10^{-4} sr from the Sun's position. The characteristics of cascading of gamma-ray initiated in such strong magnetic field near the sun are discussed through the simu lation study.

1 Introduction:

The paths of cosmic rays through the cosmos are deflected by galactic and extragalactic magnetic fields, making it difficult to identify source directions. Although there is evidence that the highest energy particles are predominantly protons (D.J. Bird et al., 1993), the number of photons at energies above 10^{19} eV may be significant for two reasons. The EHE cosmic ray protons, distributed uniformly in the universe, produce many photons in collisions with the microwave background radiation photons (J. Wdowczyk and A.W. Wolfendale, 1990; F. Halzen et al., 1990). The EHE photons can be also efficiently produced from the decay of massive particles (e.g. Higgs and gauge bosons) as predicted by some more exotic theories (P. Bhattacharjee and G. Sigl, 1999). Interestingly, this last model predicts that a new component in the cosmic ray spectrum should emerge above ~ 10^{20} eV, composed mainly from photons and neutrinos.

Accelerated by strong magnetic fields, high energy particles with energy (up to ~ 10 TeV) move along curved magnetic field lines and emit curvature photons. The energy of these photons is enough to produce electron-positron pairs in the magnetic and electric fields (V Anguelov and H Vankov, 1999).

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The sequence quantized synchrotron radiation by pairs will convert to a second generation of pairs and then electromagnetic cascade develops. In the present paper, we inserted such mechanisms (magnetic pair production and bremsstrahlung) in our Monte Carlo simulation code.

2 Interaction Processes :

The non-zero probabilities of the pair production and the magnetic bremsstrahlung for an EHE photon with energy E_γ in a magnetic field of strength B depends on (Erber T 1966) the parameter χ given by :

$$x = \frac{Eg}{mc^2}\frac{B}{B_{cr}} \tag{1}$$

Where mc^2 is the electron rest mass and $B_{cr} \approx 4.414 \times 10^{13}$ G . We simulated such processes using Monte Carlo method, and Erber's rates have been used for getting the exact quantum mechanical rates for $e^{\pm}$ pair production by γ-ray photon and synchrotron emission by secondary $e^{\pm}$ pairs .

3 The Sun's magnetic field

The sun's magnetic field is the source of most (if not all) the solar activity. Solar flares and sun spots are typical phenomena occurred by giant magnetic storms that not only alter the sun's surface, but also ejection of powerful bursts of energy out into the solar system. At the peak of the solar activity (solar maximum), it is difficult to predict the profile of the sun's magnetic field since it depends upon the location and the size of the solar flare. Following the solar maximum, the magnetic field begins to unwind and activity on the sun subsides (solar minimum).

Neglecting the influence of the active regions on the sun's surface, the magnetic dipole moment of the sun assumed as 6.87 x 10^{32} G.cm^3.

4 Simulation Results

Taking the direction of the sun's magnetic dipole moment (SMDM) as a standard level, we injected photons with different energies in two directions (parallel and perpendicular to the SMDM) within a circle of radius nR_s around the sun, (where n is an integer number ranges from 0 to 3, and R_s is the sun's radius).

Magnetic cascading initiated by primary monoenergitic photons with energies within the range of $10^{17} \sim 10^{20.5}$ eV with step $\Delta\log E = 0.5$ eV are averaged over 10 simulated showers.

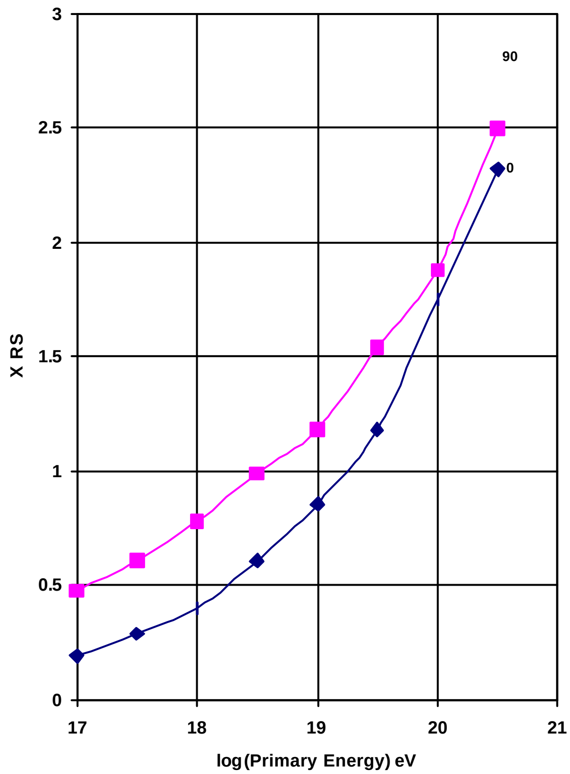

Fig. 1 First interaction point as a function of the incident energy

Our simulation shows that the probability of interaction depends not only on the event energy but also on the angle of incidence. Figure 1 is a good example for that which shows the first interaction point (measured from the sun's surface) as a function of the energy of the incident primary photons injected into the two directions mentioned before.

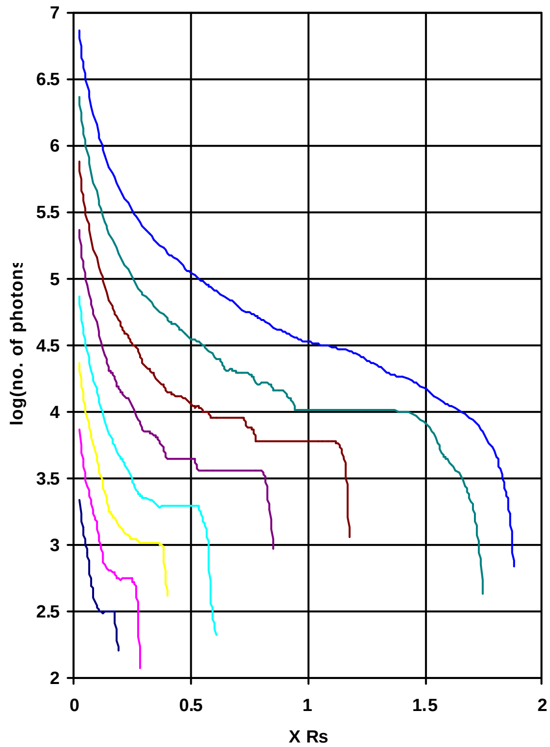

Fig. 2
Longitudinal development of photons

The figure also shows that perpendicular showers cascade much deeper than the parallel showers to the SMDS. For the highest energy parallel showers with energy of $10^{20.5}$ eV, cascading starts at a distance equal $2.5R_s$ from the sun's surface, this value is reduced to $0.25R_s$ in a case of perpendicular showers. The difference between the two curves becomes much wider ($\approx 0.3R_s$) for the lowest energy showers with primary photon energy 10^{17} eV which cascade very near to the sun at distance $0.5R_s$ from the sun's surface.

It is known that the longitudinal development of EHE air showers dependent on the mass composition and nuclear interaction peculiarities of primary particles. We studied the characteristics of magnetic cascading initiated by EHE photons. Figure 2 shows the development of magnetic cascading for EHE photons with energies 10^{17} ,$10^{17.5}$,10^{18} ,$10^{18.5}$,10^{19} ,$10^{19.5}$,10^{20} and $10^{20.5}$ eV. In the case of EHE photon, cascading in strong magnetic field near the sun strongly depend on the magnetic field strength and arrival directions of initiated photons.

More detail features on integrated energy spectra and weighted energy spectra of photons are shown in figures 3,4 respectively.

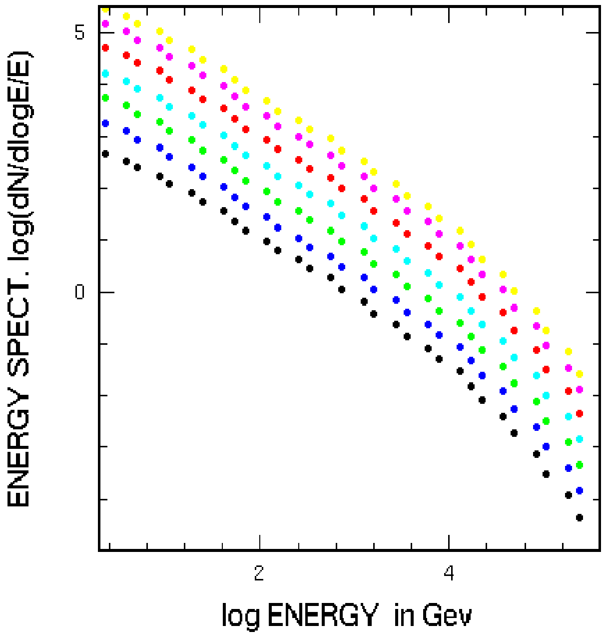

Fig. 3 Energy Spectrum of photons

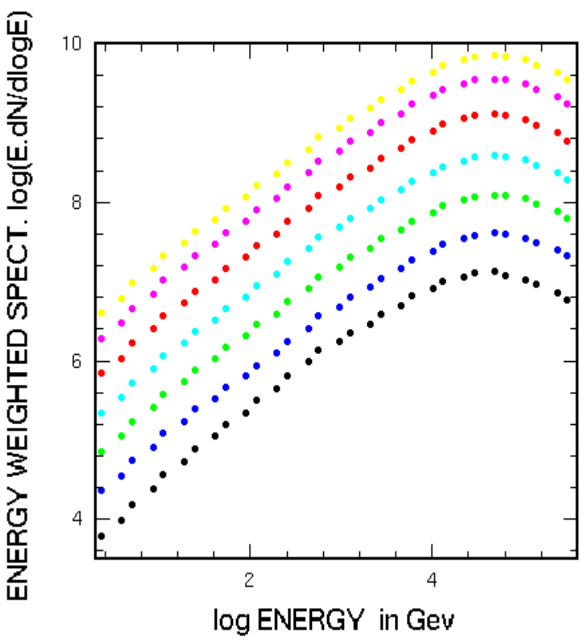

Fig. 4 Weighted Spectrum of photons

5 Discussion :

The EHE gamma-ray initiated with energy exceeds 10^{19} eV starts cascading in the sun's magnetic field within a circle of radius 2 ~ 3 times radius of the sun. If we trying to observe such showers on the earth with air shower arrays or air fluorescence detectors, these showers should be detected within a solid angle equal $\Delta\Omega \approx 6.12\text{x}10^{-4}$ sr from the sun's position.

The question arise now is how to distinguish such unusual shower from ordinary showers, if the case of photon dominant in the cosmic ray spectrum (W. Bednarek, 1999) above 10^{19} eV, simply the answer is that secondary photons of their cascades produced in the sun's magnetosphere arrive to the Earth's atmosphere with the significant perpendicular extend which is the result of deflection of paths of secondary electrons by the sun's magnetic field.

The number of events which satisfy such condition are very rare which means that much statistics of EHE cosmic rays with energy exceeds 10^{19} eV from the direction of the sun in required for this kind of analysis, and its detection will be expected in the planed feature experiments like Telescope Array and AUGER.

Acknowledgments

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