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A New Preshower MC code for AIRES

D. Badagnani[a], S. J. Sciutto[a]

(a) Departamento de Física and IFLP (CONICET) cc 67, La Plata, Argentina

Presenter: D. Badagnani (daniel@fisica.unlp.edu.ar), arg-badagnani-D-abs2-he21-poster

We have developed an AIRES special primary module to simulate geomagnetic photon preshowers. It includes detailed EM interactions and various alternative propagation algorithms have been implemented for cross-checking purposes. The module returns also the pre-conversion probability, and allows the user to enforce either conversion or non-conversion. Electrons and positrons can also be injected as primaries. This new software has been used to reanalyze AGASA data with high accuracy and to produce a large photon library for AUGER.

1. Introduction

As it is well known, high energy photons in a magnetic field can produce an electromagnetic cascade due to e^+-e^- pair production and bremsstrahlung [1]. The parameter controlling the strength of these interactions is $\chi = (E/2m_ec^2)((B_\perp/B_{cr})$, where E is the particle energy, m_e is the electron mass, $B_\perp$ is the magnetic field perpendicular to the direction of motion, and $B_{cr} \sim 4\ 10^9$ T. That is, when χ is of order unity or higher, photons have a good chance to convert and electrons or positrons can radiate hard photons (that is, photons with energy comparable to that of the particle) which in turn can undergo pair production. If some of the highest energy cosmic rays happen to be photons, the Earth magnetic field is strong enough to induce such cascading, the so-called "preshower". When this happen, it is said that the photon "is converted", and the resulting EAS is produced by an ensemble of much lower energy photons. This mechanism is very relevant for the development of the shower, since those lower-energetic photons are much less affected by the LPM effect. So, in order to study gamma EHECR EAS, detailed and reliable simulations of preshowering are needed. Some simulations have been performed using AIRES [2] and Corsika [3], and there is already a public code for preshowering [4] with Corsika.

MaGICS (Magnetic Gamma Interaction Computer Simulations) was conceived as a way to provide all the relevant utilities needed for preshower simulations, functionally integrated to the AIRES framework. On one side, several propagation algorithms with different QED aproximations and Monte Carlo event generation are implemented in order to study the impact of changing between the commonly used computations on the preshower spectrum entering the atmosphere, and having possible biases or systematics under control. On the other side, a complete and easy to use interface allows to set all features needed for gamma shower production.

2. The propagation algorithms

We call here propagation algorithms to the way in which the particles in the cascade are tracked and their interactions computed. Mainly there are two features relevant to such algorithm: the electromagnetic interaction model and the Monte Carlo event generator.

The photon mean free path is easy to calculate accurately. However, the calculation of the bremsstrahlung radiation probabilities need subtle approximation techniques. There are mainly two approximate calculations used in cascade simulations: one is summarized in a classical review by Erber [5], and the other appeared first in a work of Klepikov **??**. The first can be obtained as an approximation of the seccond. In figure 1 we show how the radiation probabilities differ for $\chi = 1$ (the higher the χ, the greater the discrepance). In the figure it

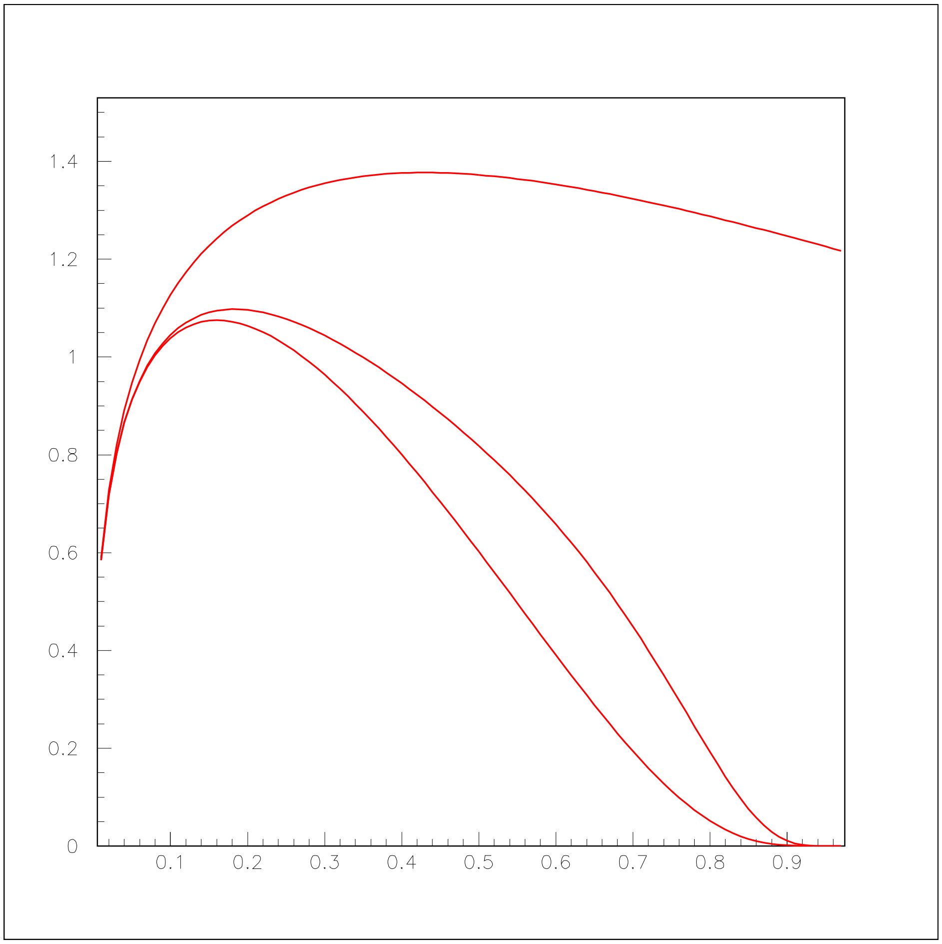

Figure 1. Relative radiation intensity, in arbitrary units (vertical axis), as a function of the emitted photon energy / primary energy ratio (horizontal axis), for bremsstrahlung with $\chi = 1$ for, from top to bottom, the classical prediction, the Klepikov approximation and the Erber approximation.

can be seen that the Klepikov's spectrum is harder than the Erber's one. So it is worth to implement both and study the possible impact of such differences.

The other aspect relevant from the point of view of the interaction is the final product distributions. The default propagation algorithm uses a $1D$ version of the Klepikov approximation, and also the one using Erber approximation is $1D$. The QED distribution for final particles as arising in the above mentioned approximations is otherwise fully implemented. We include in the code the option of $3D$ propagation (under Kolmogorov approximation) for completeness, but it is slower and no significant difference with the $1D$ case can be observed.

Finally, some Monte Carlo strategy has to be implemented. For each interaction approximation, we implemented two different philosophies for the statistical sampling, in order to detect any possible bias by cross checking. A remarkable aspect of this kind of cascades is that no particle sample nor energy cut are needed: the number of particles remain finite an manageable. The only choices to be done in this respect are how we use the probabilities to generate random events and how we process the list of particles produced in the cascade. The default MC strategy consists in taking one particle at a time and propagate it until it reach the atmosphere or disappear, selecting the time steps to be adapted to the mean free path for that particle at that time, and stacking the newly produced particles to be processed later[1]. The other MC option (maybe the more straightforward) is to subdivide the whole process in time slices (such that production probabilities are reasonably small) and decide at each step if some reaction happen for every particle (and create or destroy particles as needed). When this is done, a subtelty arises in the bremsstrahlung: if a hard photon is emitted the interval has to be broken in two in order to calculate the soft part. This choice is not optimal since we have to process all particles with time slicing appropriate to fit the smallest mean free paths in the list, but otherwise it is seen to be equivalent.

3. Magics Features

MaGICS is an AIRES special primary module. Once compiled and linked it is an executable file invokable from the AIRES kernel and controllable and configurable with AIRES directives appropiately placed within any input file (see AIRES manual [2] for details). The user can select the propagation algorithm (the default being the 1D one known to be the more accurate) and a mode ("ForceConversion" or "NoForceConversion"). The primary is injected at a (configurable) initial altitude and the cascade is propagated until the top of the atmosphere is reached. Then, control is returned to the AIRES kernel, together with the complete list of particles produced, the probability of conversion (wich AIRES records in the compressed output files), the altitude of conversion and the number of trials until conversion (0 if conversion is not enforced).

One of the propagation algorithms just move the photon from its injection point to the top of the atmosphere, and compute the conversion probability. This option is useful if one is willing to study conversion probability only or testing it before deciding to enforce the conversion.

If a nontrivial propagation algorithm is in use, the program admits the option of enforcing the conversion. In that case the photon propagation is repeated until conversion does occur. Then, taking a converted and an unconverted shower weighted by their probability is statistically equivalent to consider an ensemble of showers without forced conversion.

The source code is written in C language, and uses the AIRES (2.8.0 or higher) libraries both for retrieving and sending data from (to) the AIRES kernel and for employing AIRES random number generator[2] and the IGRF model for calculating the magnetic field. It uses also the CERN libraries for the special functions that are needed in the calculations of mean free paths and probabilities.

4. Final Remarks

We have first used the code to study general properties of preshowers. It should be said first that, as expected, both Monte Carlo strategies were seen to be equivalent. More interesting, we have seen that the difference in interaction approximations is almost unobservable, since the properties of the final spectrum depends only on the last conversions, when χ is a fraction of unity and both approximations tend to converge. Even more simplified algorithms, in which final particles in pair production are assigned arbitrary energy distribution (compatible with its conservation) leads to very similar preshower spectra.

[1] Observe that it is valid since we are not considering any interaction between particles

[2] This permits to extend the good control and reproducibility of random number generation of AIRES to the whole simulation, which is useful for debugging purposes

MaGICS has been used recently to produce series of high quality Monte Carlo gamma initiated EAS simulations with AIRES. One of that series has been used for reanalyzing AGASA data in the search of gamma primaries [7]. Another library has been produced for the Southern Auger site and is being used for analysis purposes by the Auger Collaboration.

The source code and the documentation can be downloaded from the AIRES home page (www.fisica.unlp.edu.ar/auger/aires). For questions and comments on MaGICS code please contact us at daniel@fisica.unlp.edu.ar.

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