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Diffraction, semi-inclusive reactions and consequences for background in ground-based gamma ray astronomy

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Abstract. The estimation of the cosmic ray background is crucial for ground-based gamma ray astronomy. For VHE gamma-rays (100 GeV–10 TeV), it is generally admitted that the ratio of the gamma Cherenkov radiation and the proton one's is about 3. However, this is only true on average and for fixed primary energies. The study of the electromagnetic component, taking into account the steepness of the primary spectrum, for fixed multiplicities (semi-inclusive reactions) and for diffractive collisions gives us more realistic clues on the cosmic background.

1 Introduction

Very high energy (VHE) gamma rays are of great interest because they provide information about their possible sources such as active galaxies, pulsars and supernova remnants. They give us a completely different view of the universe from other types of radiation. Another good reason for studying VHE gamma rays is to determine the origin of cosmic rays. As they are not charged, their directions are not scrambled by the galaxy's magnetic field. That means that they act like ”tracers” showing us where the cosmic rays come from.

Nevertheless, VHE gamma rays are very rare. As a result, any experimental device built to detect this radiation must be very large. And flying such a detector with a balloon or on a satellite would be of a prohibitive cost. Ground-based gamma astronomy overcomes this problem by making the atmosphere part of the detector.

Indeed, when VHE gamma rays enter the atmosphere they create cascades of secondary particles termed as air showers. Some of these particles are very energetic and their velocities may be greater than the speed of light in the medium in which they are travelling. When this happens, the so-called Cherenkov radiation is produced. Hence, the particles in the showers are accompanied by a ”pool” of Cherenkov light which can be measured by ground detectors.

However not only do the VHE gamma rays produce Cerenkov radiation, but so do cosmic rays which act here as a background. In fact, less than 1% of the detected events are actually due to gamma rays than cosmic rays. The main problem is then how to reject this important background.

In this work, we are investigating the influence of semi-inclusive and diffractive reactions on the estimation of the cosmic ray background. We have used for these calculations the program CORSIKA (Heck *et al.* 1998) coupled with HDPM algorithm (Capdevielle 1989) for the treatment of high energy interactions above 80 GeV and Gheisha code (Fesefeldt 1985) for hadronic interactions at lower energies.

2 Semi-inclusive and diffractive reactions

It is important to note that an air shower is the result of a great number of individual interactions of different types (non-diffractive, diffractive . . .) and different energies. This is more complicated than collisions performed in laboratories where the energy is fixed beforehand and the reaction type readily selected. Prior to any interpretation in ground-based gamma astronomy, it is therefore necessary to make sure that the model used for hadronic interactions reproduces correctly the experimental data obtained at accelerators, not only for inclusive reactions but also for semi-inclusive and diffractive ones.

2.1 Semi-inclusive reactions

Semi-inclusive reactions are characterized by the same multiplicity for a particular produced particle. As an illustration, figure 1 shows the pseudorapidity distribution for charged particles obtained with HDPM model (Capdevielle 1989) at $\sqrt{s} = 24$ GeV with $10 \leq n_{\mathrm{ch}} \leq 14$ (Fig. 1a) and $\sqrt{s} = 63$ GeV with $15 \leq n_{\mathrm{ch}} \leq 19$ (Fig. 1b). A good agreement with experimental data (Thome *et al.* 1977) is found.

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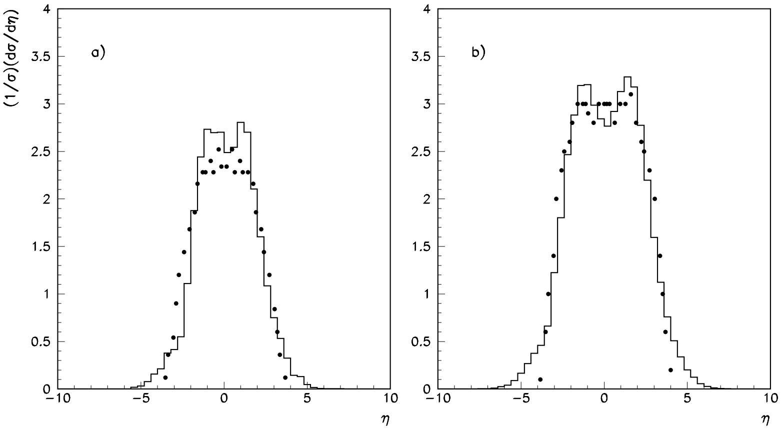

Fig. 1. Pseudorapidity distribution for charged particles at $\sqrt{s} = 24$ GeV with $10 \leq n_{\mathrm{ch}} \leq 14$ (a) and $\sqrt{s} = 63$ GeV with $15 \leq n_{\mathrm{ch}} \leq 19$ (b). Experimental data (●) are from Thome *et al.* (1977).

2.2 Diffractive reactions

In diffractive collisions, the projectile or/and the target are carried to an excited state before decaying. To describe this phenomenon, HDPM considers that the final state for a single diffractive reaction is similar to the final state for a non-single diffractive one, provided the energy of the center of mass $\sqrt{s}$ is replaced by the energy of the diffractive mass M (Bernard *et al.* 1986). The diffractive mass M is generated according to the distribution:

$$\frac{\mathrm{d}N}{\mathrm{d}\,(M^2/s)} \sim \frac{1}{M^2/s} \tag{1}$$

Moreover, M must fullfill the condition (Goulianos 1983):

$$\frac{M^2}{s} \leq 0.05 \tag{2}$$

3 Background in ground-based gamma ray astronomy

To investigate the influence of semi-inclusive and diffractive reactions on the cosmic ray background, we have simulated the development in the atmosphere of air showers initiated by vertical protons and γ-rays. We have focused our attention on the longitudinal development of the electromagnetic component because most of the Cherenkov light is produced by electrons and positrons. For accuracy, electromagnetic interactions have been fully treated with the EGS4 code (Nelson *et al.* 1985).

Figures 2 and 3 compare the longitudinal development of electrons and positrons above the Cherenkov threshold energy for a primary γ-ray and a primary proton. The first interaction of the latter is fixed at first at one mean free path (MFP) and then at 2 MFP. In addition, in figure 2 the fraction of charged particles produced in the first interaction z ($\equiv n_{\mathrm{ch}}/ < n_{\mathrm{ch}} >$) is fixed 0.30 while in figure 3 the diffractive mass M is fixed at 5 and 10 GeV.

Figures 2 and 3 clearly indicate that primary protons of low z (or M) and high interaction lengths at the first interaction induce longer tails for the longitudinal development of the electromagnetic component and hence higher amounts of Cherenkov light. This is due to the fact that electrons and positrons at low altitude produce much more Cherenkov light than at high altitude because of the absorption of the Cherenkov photons by the atmosphere.

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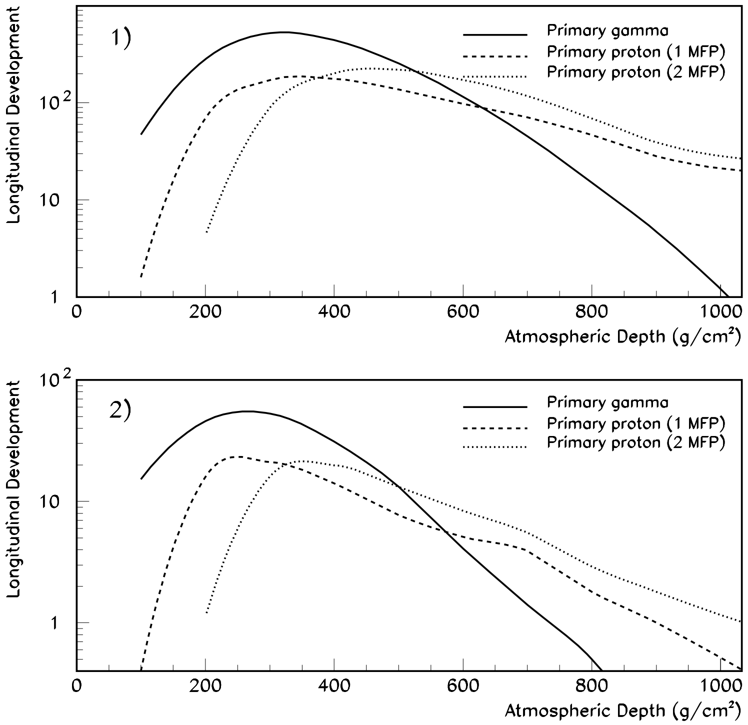

Fig. 2. Longitudinal development of electrons and positrons above the Cherenkov threshold energy at 1 TeV (1) and 100 GeV (2) for a primary γ-ray (full line), a primary proton with its first interaction fixed at one MFP (dashed line) and a primary proton with its primary interaction fixed at 2 MFP (dotted line). Moreover, the fraction of charged particles produced in the first interaction ($z = n_{\rm ch}/ < n_{\rm ch} >$) is fixed at 0.3.

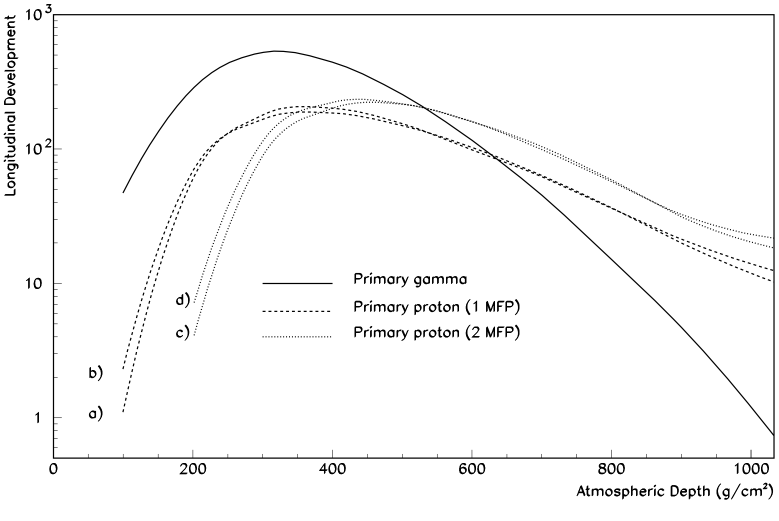

Fig. 3. Longitudinal development of electrons and positrons above the Cherenkov threshold energy at 1 TeV for a primary γ-ray (full line), a primary proton with its first interaction fixed at one MFP (dashed line) and a primary proton with its primary interaction fixed at 2 MFP (dotted line). Moreover, the diffractive mass M in the first interaction is fixed at 5 GeV (a and c) and 10 GeV (b and d).