OG 10.3.9

Monte Carlo Simulation for the Mini-GRAAL project

F.Arqueros[1], M.Berenguel[2], D.M.Borque[1,a], F.J.García-Martín[2],
H.-J.Gebauer[3], S.Martínez[1], R.Plaga[3], and G.Weinrebe[4,b]

[1] *Facultad de Ciencias Físicas, Universidad Complutense, E-28040 Madrid, Spain*
[2] *Escuela Superior de Ingenieros, Universidad de Sevilla, E-41012 Sevilla, Spain*
[3] *Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany*
[4] *DLR Hauptabteilung MD-PSA, Plataforma Solar de Almería, E-04080 Almería, Spain*

ABSTRACT

A detector simulation of the CESA-1 heliostat field at the 'Plataforma Solar de Almería' (Spain) as a γ-ray telescope has been carried out. The development of air-showers initiated by both γ-rays and protons in the energy range 50 GeV - 1000 GeV has been simulated using the CORSIKA code. Individual photons have been tracked through the various optical elements of the heliostat field. Time spread of the Cherenkov light pulses on the photomultipliers as well as other hardware effects have been taken into account. The setup simulated is the one used during the measurement periods in Dec'96 and March'97. Results on the Mini-GRAAL project and their comparison with real data are shown.

INTRODUCTION

Recently, several experimental groups have proposed the use of solar power plants as γ-ray telescopes (CELESTE 1996, Ong et al. 1995). Because of their large mirror area for collection of the Cherenkov light generated by the extensive air showers, these installations are expected to provide very low energy thresholds. In this framework the GRAAL project (Gamma Ray Astronomy at Almería) is based on the usage of the CESA-1 heliostat field at the PSA (Plataforma Solar de Almería). In order to test the feasibility of such projects and to gather experimental and Monte Carlo (MC) results for further steps in ground-based γ-ray astronomy with low energy threshold, the Mini-GRAAL experiment has been devised (Arqueros et al. 1997). Presently Mini-GRAAL collects the Cherenkov light of 27 heliostats (of 39.6 m^2 each) onto two truncated Winston cones (13/14 heliostats per cone) of 10^o opening angle which are located inside the central tower, 60 m above ground. Each cone guides the light to a fast photomultiplier (PMT).

This paper presents the results of MC simulations of Mini-GRAAL for incident γ-rays and protons in the energy range of 50 - 1000 GeV. A detailed detector simulation has provided predictions on the telescope performance which can be compared with recent data taken during the measurement periods in Dec'96 and March'97.

THE MONTE CARLO SIMULATION

Extensive Air Showers

For the simulation of the EAS the CORSIKA code (version 4.11) developed by Capdevielle et al. (1992) has been used. Single Cherenkov photons were tracked down to the observation level (550 m a.s.l.). Atmospheric attenuation due to ozone absorption, Rayleigh scattering and aerosol dispersion was taken into account. Showers initiated by

[a] Corresponding author :borque@eucmos.sim.ucm.es
[b] present address : IER, University of Stuttgart, Germany

primary γ-rays with fixed energies of 50, 100 and 200 GeV, and proton showers of 250, 350, 500, 750 and 1000 GeV have been simulated. The incoming direction of the showers is 28.2 degrees zenith angle and 49.5 degrees azimuth (Southwest). This direction was chosen to allow comparison with a subsample of real data of high quality. While the incidence angle of γ-showers was exactly this angle, thus simulating a point γ-source, protons were allowed to come into a solid angle of $9.57 \cdot 10^{-4}$ sr (1^o wide) around this direction to simulate the expected isotropic background. The contribution of heavier nuclei was not taken into account.

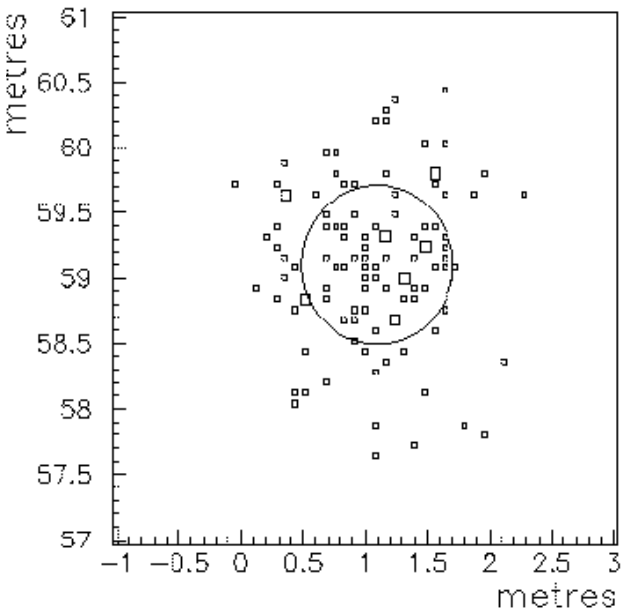

Fig. 1. Image of a 50 GeV gamma generated shower on the tower. The circle is the size of the cone entrance

Detector

Detector effects have been simulated in detail. Individual heliostats have been modelled as spherical mirrors of rectangular shape with realistic surface irregularities in such a way that the simulated image of the Sun on the central tower is similar to that observed experimentally (Haeger et al., 1994). The varying reflectivity of the silvered heliostat mirrors with the wavelength was considered. Figure 1 shows the image of a γ-ray shower of 50 GeV at the receiver plane. The Winston cone receivers were simulated, taking into account their response to off-axis photons. Finally, for each individual photon the quantum efficiency of the PMTs was taken into account.

The convergent viewing technique has been used in the real experiment and therefore it has also been assumed for the simulation (detector efficiency is increased when the optical axes of individual heliostats point at the same position of the shower maximum but not at the source). Figure 2 shows X_{max} versus the primary energy according to our simulations for both protons and γ-rays. From these results it was decided to aim the heliostats at an observation depth of about 230 g/cm^2 (shower maximum of 200 GeV γ-rays). Since the shower maximum for primary protons is widely spread, convergent viewing increases background rejection. The contribution of the light of night sky (LONS) was taken into account in the simulated signals. The electronic gain, carefully measured during the observing periods, has been used in the simulation.

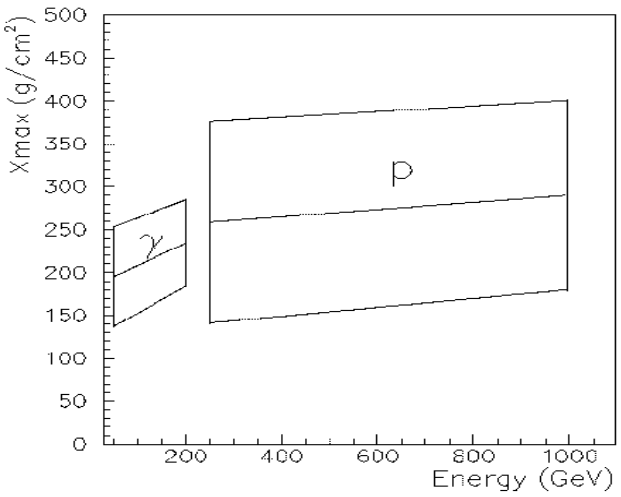

Fig.2. Depth of the shower's maximum development versus primary energy.

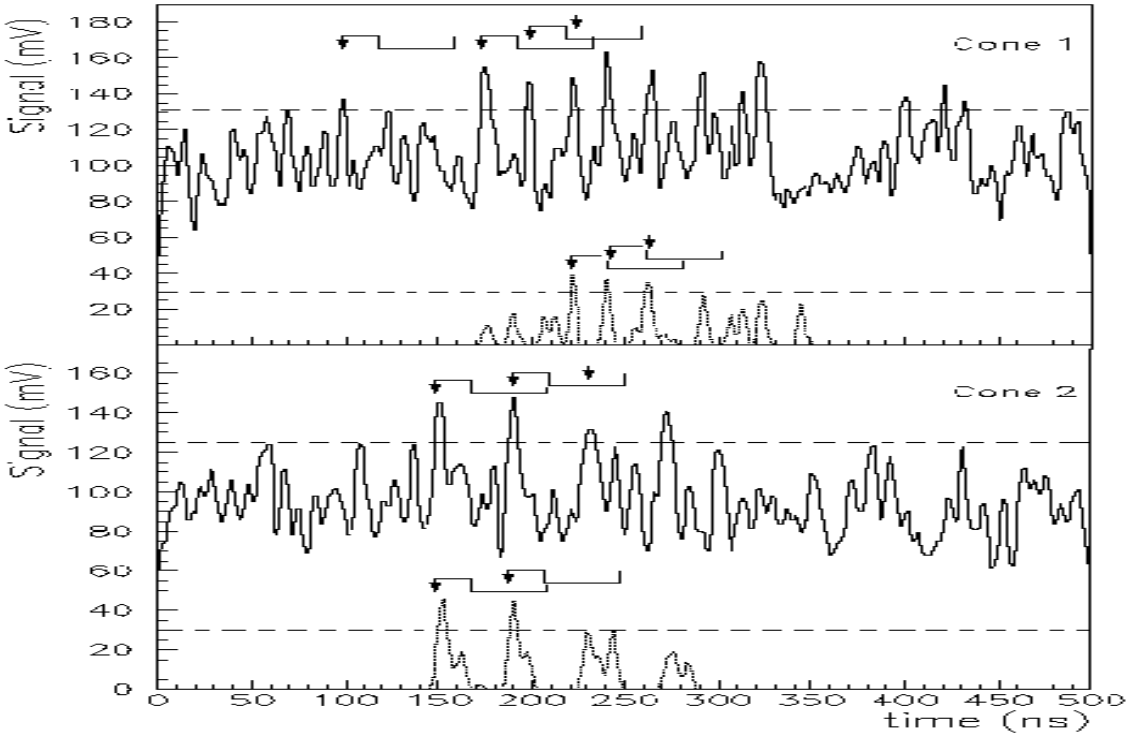

Fig.3. Output signal as given in both cones by a simulated typical 100 GeV γ-shower. Continuous (dashed) line represents the signal with (without) LONS noise. Triggering pulses and trigger sequence are shown.

Trigger

The used trigger mask required from each cone a pulse of at least 30 mV above the mean value of LONS contribution (=$1.4 \cdot 10^{12}$ ph/m^2/sr/s) followed by another pulse (between 20 and 60 ns later) and a third one with a similar delay condition with respect to the second one. Figure 3 shows a typical signal for a γ-ray of 100 GeV which surpasses the above trigger condition. In the plots without noise of this figure 14 peaks can be seen for the first cone, each one corresponding to an individual heliostat, while for the second cone only 9 peaks are visible. This is due to the overlapping of the signals coming from different heliostats. A detailed study of this overlapping effect and its dependence with the observation direction is being carried out as it could lead to a substantial lowering of the energy threshold.

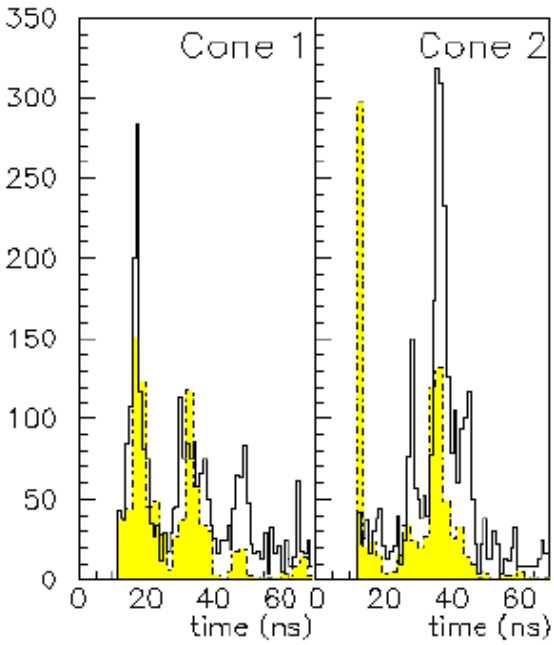

Fig.4. Time interval between the first two peaks out of the four highest ones for real (shaded region) and simulated data.

RESULTS

The time features of the signals have been studied in detail. For both real data and MC data, the distribution of time intervals between Cherenkov light pulses arising from different heliostats have been compared. As can be seen in figure 4 the delay

between the first two peaks (out of the four highest ones) for real data agree with the MC predictions except for short time intervals in cone 2 where a large excess appears, very likely due to electronic effects not taken into account in the simulation.

The effective area versus energy plot has been obtained for both primaries in the energy range of this work. In this figure it can be seen that the LONS contribution increases the effective area as expected, since LONS fluctuations helps the signal to surpass the trigger condition. In fact, the predicted trigger rate is very sensitive to LONS level. If the parameters are simulated as good as possible as in the experiment, a rate of 12 Hz is predicted. If the threshold is raised by only 16% (which is within the systematical errors for the experimental gain determinations) the predicted rate drops to 5 Hz. For no LONS at all a similar rate is predicted. The experimentally determined rate is about 2.2 Hz (Arqueros et al., 1997). The reason for this discrepancy is unclear at the moment and requires further experimental and MC comparison work.

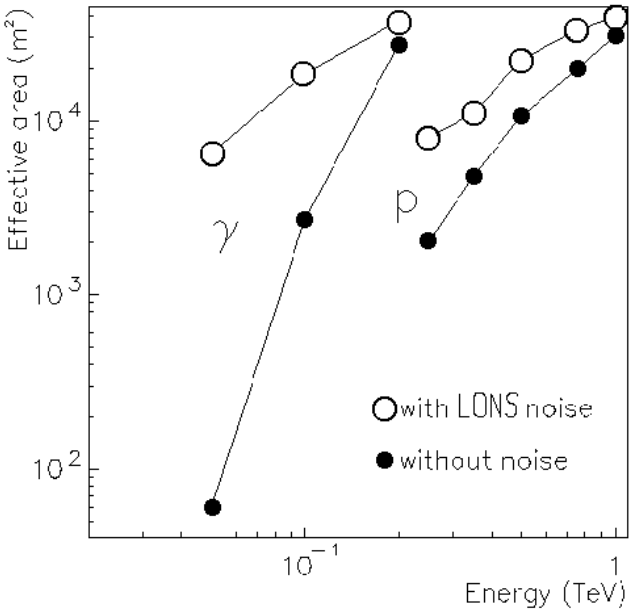

Fig.5. Effective areas for the Mini-GRAAL experiment.

Heliostat-field detectors are expected to be fully sensitive only for core positions within a certain ‘‘fiducial area” on the ground, which has a size of about 2500 m^2. The results in fig.5 are therefore not in contradiction with the estimated threshold of 70 GeV in Arqueros et al.,1997).

AKNOWLEDGMENTS

We thank the staff at the PSA, especially A.Valverde, for their enthusiastic support. We thank DFG, DAAD and DGICYT for support. We are also indebted to the authors of the CORSIKA code. One of us (D.M.B.) acknowledge the support of the Gobierno Vasco through a PhD. grant of the Programa de Formación de Investigadores del Departamento de Educación, Universidades e Investigación.

REFERENCES

Arqueros, F. et al., these proceedings. OG 10.3.8

Capdevielle, J.N. et al., KfK Report 4998, Kernforschungszentrum, Karlsruhe (1992)

CELESTE experimental proposal (1996)

Haeger, M., PSA Report R 24/94 KB (1994)

Ong, R.A. et al, *A new atmospheric Cherenkov detector using the heliostat of Solar two.*(1995)

Wiebel, B., *Chemical composition in high energy cosmic rays, University of Wuppertal. Report WUB 94-08* (1994)