The GRAAL project

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Abstract

The GRAAL Project (Gamma Ray Astronomy at ALmeria) makes use of the CESA-1 heliostat field at the “Plataforma Solar de Almeria” (Spain) as a gamma-ray telescope with an energy threshold of about 100 GeV. Cherenkov light generated by EAS is reflected by the heliostats and collected into photomultipliers (PMTs) with nonimaging secondary optics. Each PMT collects the light reflected by 13 - 18 heliostats of 40 m^2 using a Winston cone. After successful tests with two collecting cones, a more advanced setup on a dedicated platform, using four collectors and 63 heliostats (total reflecting area of about 2500 m^2) is being installed. A description of this setup together with Monte Carlo results about its excellent capabilities in the precise determination of pulse arrival times are presented.

1 Introduction

Ground-based measurements of cosmic γ-radiation at energies below about 200 GeV promise to provide crucial insights into the high-energy astrophysics and cosmology. In order to reach low thresholds with techniques based on Čerenkov light large mirror collection areas are needed. GRAAL, like two similar experiments CELESTE and STACEE (see these proceedings), employs the large mirror area of an existing solar-power plant. The optical principle of Mini-GRAAL is different from these two experiments, however.

Čerenkov light from four groups of heliostats (with 13,14,18,18 members, respectively) is directed onto four single non-imaging “cone concentrators” each containing a single large-area PMT. The light collecting cones have the form of truncated Winston cones with an opening angle of 10^o. Each cone is directed onto a point on the ground in the heliostat field and collects the light from all heliostats which are located within the ellipse projected by the cone opening angle on the ground (see figure 1). The incoming light from an air shower consists of a train of pulses from the different heliostats ususally fully separated by pathlength differences. which are registered with four high-resolution flash ADCs.

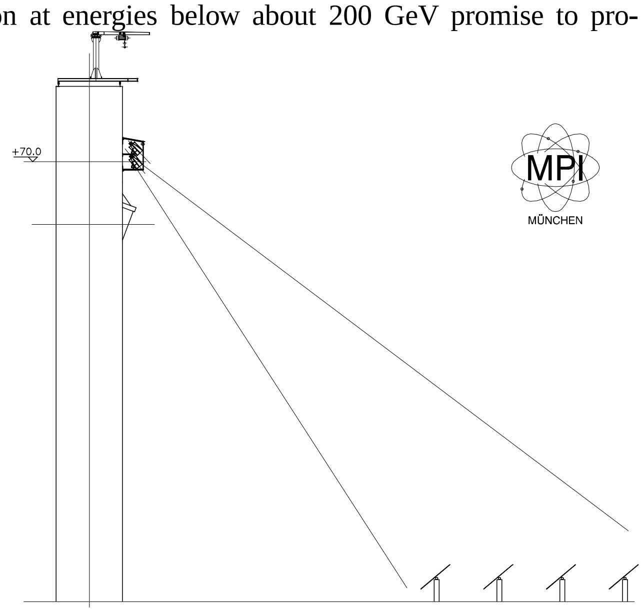

Figure 1: Setup of the experiment. A dedicated platform on the 70 m level of the central tower of the CESA-1 field houses four Winston comes which receive light form 13 - 18 heliostats in the field.

After successful experimental tests of the principle with two cones, using 27 heliostats, on a general purpose platform in the central tower (Arqueros et al. 1997) GRAAL has been funded for a 4 cone-setup in a newly constructed dedicated platform on the 70 m level of the central tower. The data taking is planned to begin in June 1999 in every clear moonless night. The technical setup will eventually allow a remote control of the experiment, only under the surveillance of a field operator. Besides its technical aims of low energy threshold and very high time resolution, this low-cost experiment is an important addition to the very small number of experiments which can take data in this energy range. The fact that no new VHE γ-ray sources were detected since the last ICRC might be connected to the fact that our poor understanding of high-energy astrophysics in general has not allowed to select the right targets. E.g. it has become clear recently that distance and brightness of γ-ray bursts (GRBs) are essentially uncorrelated, thus withdrawing the basis of the usual strategy to monitor only the brightest GRBs in the VHE because they were thought to be near and thus suffering relatively little absorption in the infrared background radiation. Our low-cost observing facility will be able “to take some risk” in the selection of targets.

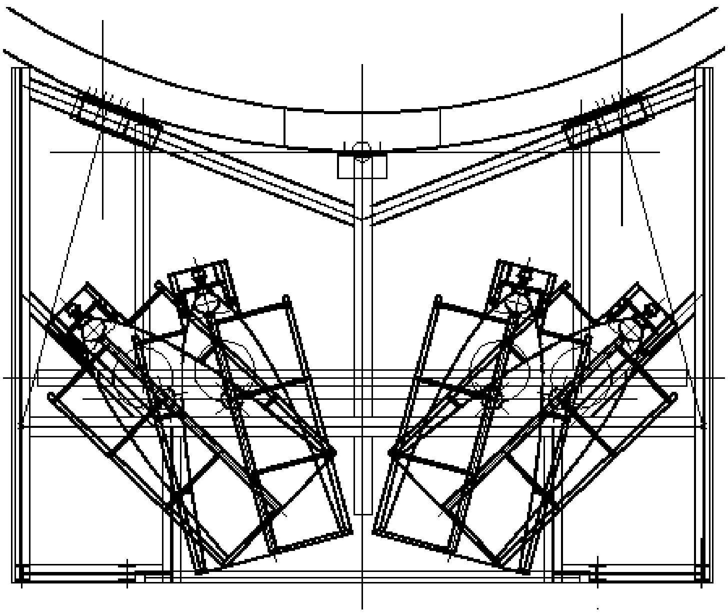

Figure 2: Location of light collecting cones with PMTs at the end (front diameter 1.06 m) in the platform seen from top. The tower is the curved structure on top.

2 Hardware setup

The platform is an enclosure on the outside of the central tower housing the cones with the PMTs. The electronics is located inside the tower electromagnetically shielded from the cones (fig.2). In general GRAAL can achieve a very good time resolution because there exist only four short cables that run exclusively within the platform enclosure (length several meters) from the photomultipliers to the data acquisition. To take full advantage of this fact we register all four pulse train in only one Digital Oscilloscope (Le Croy LC 564A) with a bandwidth of 1 GHz and a time bin of 500 psec. This ensures that the FWHM of individual pulses (about 3.5 nsec from our test, corrected for the larger bandwidth used in this experiment) is solely determined by mirror geometry and PMT properties. The digital scope is read out in sequence mode over a GPIB interface into a PC, reaching a speed of about 260 “waveforms” (i.e. 1000 time bins of 0.5 nsec width with 1 byte each)/sec, which is sufficient for a dead time below 10 % for our master trigger rate which is expected to remain below about 10 Hz (each trigger containing four waveforms).

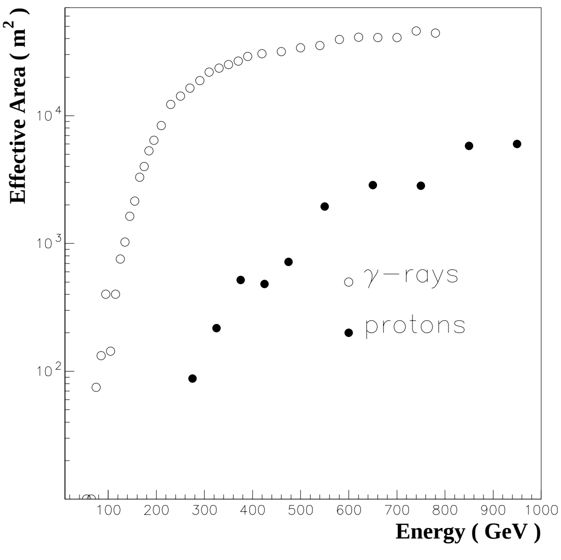

Figure 3: Expected effective area as a function of the primary energy for the 4-cone setup.

Our trigger identifies a pulse train of four pulses with NIM electronics in the two central cones and de-

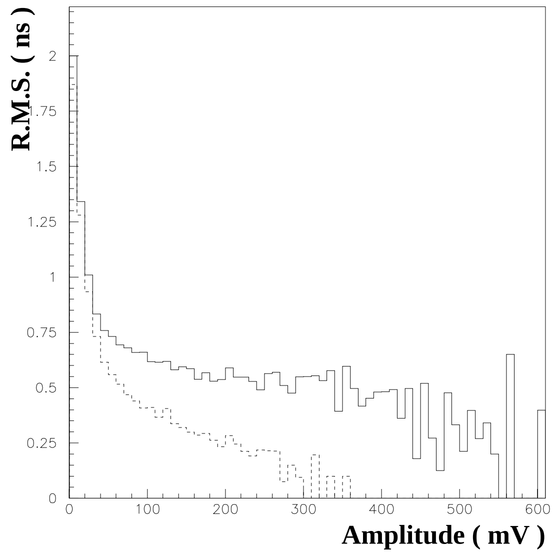

Figure 4: Time resolution as a function of the pulse amplitude both for all identified peaks (solid line) and only for non-overlapping peaks (dashed line).

mands a certain total light level in all four cones in coincidence with the sequence trigger. The time and amplitude calibration of our setup is performed using blue LEDs (Nichia NSPB 500, maximal output at 450 nm) with a calibrator module that is fastened at the window of the Winston cones. The LED in the module emits a large part of its light in the forward direction towards the heliostat field. A very small fraction (adjustable with a screw) is reflected back via total reflection into the cone. The amount of light emitted in the backward direction is determined with a Quantacon RCA C31000 that was previously calibrated by determining its single p.e. peak and fluctuation behaviour. The LED operating voltage is adjusted so that one LED pulse corresponds to about 100 p.e. These LED pulses are regularly used in each run to verify time and amplitude calibration. This calibration is cross checked by measuring the forward output both with the calibrated PMT and via the current of a calibrated photodiode when the LED is pulsed at 10 kHz. The forward output shines on the heliostat field. When the heliostats are brought into a "back reflection" position, the reflected LED pulses are used to verify the geometry and check the mirror quality in regular intervals.

3 Monte Carlo results

A detailed MC simulation which uses the CORSIKA code (Capdevielle et al. 1992) and which takes into account all experimental uncertainties and night sky background (LONS) was performed (see Arqueros et al. 1997 for a more detailed description). The trigger parameters have been adjusted in order to get a background detection rate of about 10 Hz including accidental coincidences ($\approx$ 2 Hz). The effective area of the telescope has been calculated as a function of the primary energy both for gamma-rays and protons. As an example, figure 3 shows the result for a zenith angle of 20 degrees. From this figure, an effective area of about 9000 m^2 for gamma-rays of 200 GeV is expected while the effective area for protons of the same energy is lower by a factor of about 100. A method to identify the Cherenkov pulses out of the noise and the corresponding heliostats has been developed, with very good results (about 95% of success). Figure 4 shows the r.m.s. of the time error distribution as a function of the fitted pulse amplitude. In this figure the amplitude values of 10, 20, 50 and 150 mV correspond to 4, 14, 30 and 63 photoelectrons respectively. As expected, the time resolution is worse for those incident direc-

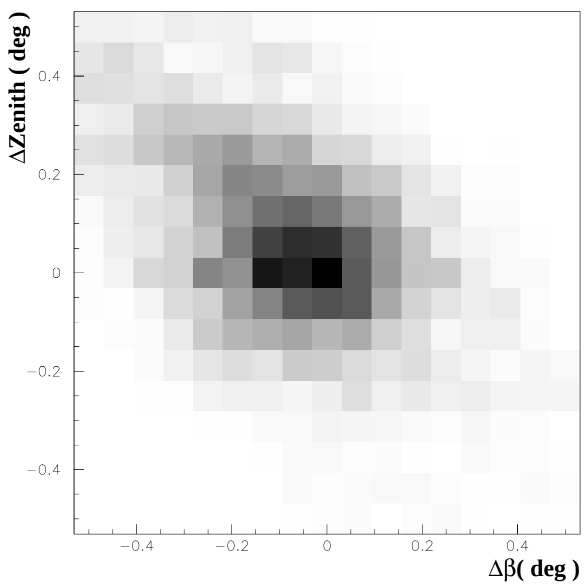

Figure 5: Angular resolution for gamma-rays in the range 200 - 400 GeV incoming from South-West with a zenith angle of 20 deg.

tions in which strong peak overlapping (F.Arqueros et al. 1997) takes place (compare solid and dashed lines in figure 4). This figure shows a very good time-resolution with an uncertainty well below 1 ns for not very small peaks. The very good time resolution achieved with our set-up allows an accurate reconstruction of the Cherenkov-light front and thus the measurement of the incident direction of the primary particle. For each event, the Cherenkov-light front was fitted to a plane, its director vector being the most probable incoming direction of the EAS. For those input directions showing peak overlapping we have chosen the peak identification which gives the lowest χ^2 value in the front fitting. Figure 5 is a 2-dimensional histogram of the error in the reconstructed direction for gamma-rays in the energy range between 200-400 GeV. The strong asymmetry shown in this angle distribution is correlated with the spatial asymmetry of the mirrored area at ground. From this data we have inferred an angular resolution of about 0.2 deg; i.e. 63% of the reconstructed events are included within 0.2^o of the real direction.

From the MC results we can infer some prediction on the sensitivity of the telescope. Assuming a cosmic background dominated by protons with a differential energy spectrum following a power law with index 2.7, a detection of the Crab nebula (using the flux and spectrum data determined by the Whipple collaboration (Hillas et al. 1998)) at a 5 σ level is expected after about 20 hours of on-source data gathering without any cuts. The appropriate cut in reconstructed angle (figure 5) reduces this time down to about 2 hours. A further increase in sensitivity will be achieved by hadron rejection. A method for gamma/hadron (g/h) separation based solely on the time properties of the shower front is under development. From this work we show in figure 6 the χ^2 value of the front fitting as a function of the core distance, for gamma-ray showers. This figure shows an average time deviation squared on the order of 1 ns for showers hitting the centre of the field increasing up about 3 ns for showers at about 120 m core distance. For proton showers the front fluctuations are stronger and thus higher χ^2 values are expected. The small χ^2 near the shower core also allows an estimation of the shower-core position.

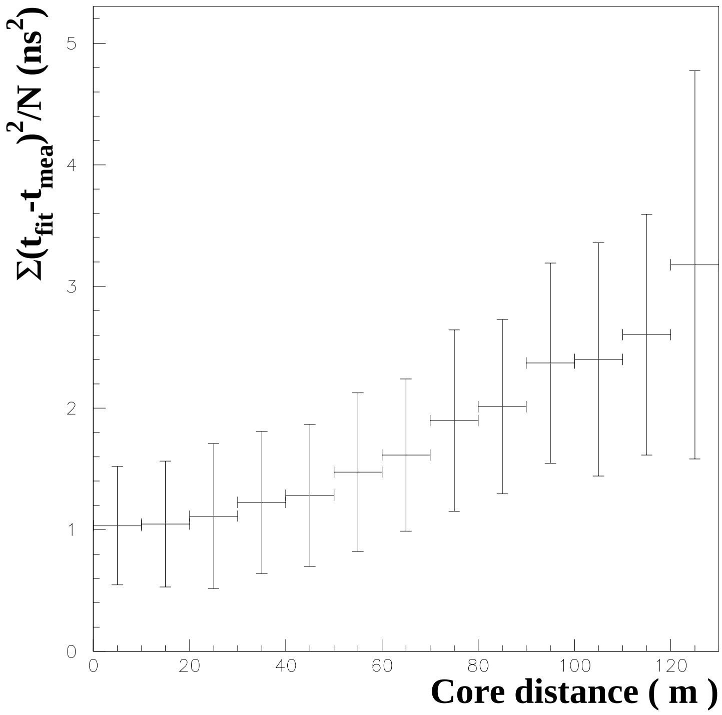

Figure 6: Reduced χ^2 of the fit to the shower front in time as function of shower-core distance from the centre of the field.

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