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First results from the Mini-GRAAL project for gamma-ray astronomy above 50 GeV

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ABSTRACT

The technical setup and measurement results with the Mini-GRAAL experiment at the solar heliostat field CESA-1 at the Plataforma Solar de Almeria are described. The experiment aims to detect γ-rays via their Čerenkov light with an energy threshold of about 50 GeV. The light from 27 heliostats with a total mirror area of 1069 m^2 was focused into two non-imaging cone detectors in the central tower. The light pulses from individual heliostats are resolved measuring their arrival time with a resolution of 1 nsec. Timing and intensity properties of the detected showers are discussed. We estimate that an energy threshold for γ-ray initiated showers of about 70 GeV was reached with the present two-cone setup.

INTRODUCTION

In this contribution the technical set-up, first results and status of the Mini-GRAAL (Gamma Ray Astronomy at ALmeria) experiment are reported. For information about the method and results of a full Monte Carlo simulation of this experiment see a companion contribution (Arqueros et al., 1997b). 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 very low thresholds with techniques based on Čerenkov light large mirror collection areas are needed. Mini-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 two groups of heliostats (with 13 and 14 members, respectively) is directed onto two single non-imaging "cone concentrators" which contains a single photomultiplier tube. The light collecting cone has the form of a truncated Winston cone with an opening angle of 10^o. It 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 major disadvantage of our approach is that the NSB, which is continuous in time, adds up for all the heliostats "viewed" by one cone. This leads to a higher random noise in the photomultiplier tube which detects the signals and consequently

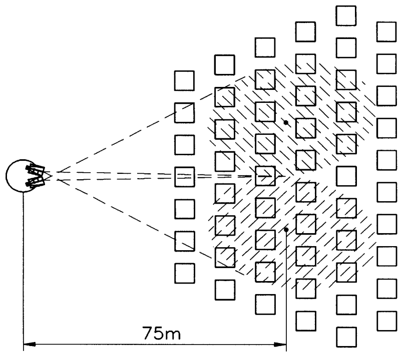

Fig. 1: Principle of Mini-GRAAL. 27 mirrors in two subfields are viewed by 2 cones in the central tower.

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to a higher minimum energy threshold than in the "one heliostat-one detector" approach followed by other solar-field experiments. The expected gain by this fact alone is relatively modest however (the threshold can be about 30-40 % lower) because with the relatively modest mirror areas of existing heliostats (about 40 m^2) one enters the regime of Poissonian statistics in their approach. The advantage of our approach is the much greater simplicity which leads to smaller systematic errors and enormous cost savings. The Plataforma Solar (2^o 21' E; 37^o 05'N) is a European research institution for solar thermal concentrating technologies operated by the Spanish "Centro de Investigaciones Energeticas Medioambientales y Tecnologicas" (CIEMAT) and the German "Deutsche Forschungsanstalt für Luft und Raumfahrt"(DLR). The CESA-1 field is an array of nominally 300 heliostats to the north of a solar tower. For information about the PSA as an atronomical site see Plaga (1995). Each heliostat has a total mirror area of 39.6 m^2 subdivided in 6 or 12 segmented parabolic mirrors ("facets"). The 27 heliostats used for measurements described here were located in two ellipse-shaped areas symmetrical to the north direction (up to about 35 m east and west respectively) near the central tower. The used heliostats were canted "on axis"(Monterreal, 1995), i.e. all the facets were adjusted to analytically determined tangential planes of a spherical surface with a focal length given by the distance to the experimental platform in the central tower. The positions were controlled with a Laser mechanically mounted on the heliostat near its optical center.The quality of the heliostats and the tracking was regularly controlled during our measurement period by photographing the sun image of individual heliostats. The diameter values d of the sun image for the 27 heliostats were in the range d/dist=0.013 $\pm$ 0.02 (where dist is the distance measurement platform-heliostat which was in the range between 82m and 115m corresponding to beam quality of 0.2 ^{o}. Similar measurements were carried out at night with stars.

TECHNICAL SETUP

The shape of the light concentrators is a truncated Winston Cone with 10^o opening angle. The two cones were fabricated from epoxy resin using a wooden mold and are stabilized by aluminum bars. The interior is covered with aluminized mylar foil. The total efficiency and angular acceptance of the cone was measured with blue LEDs in the pulse mode. The efficiency (0.89$\pm$0.04 for incidence on the optical axis) agrees with a Monte Carlo calculation taking into account the reflectivity of mylar foil. Two cones are installed at the 60 m level of the central tower, viewing left and right field respectively, see fig.2. The heliostat control was done with a special program using "convergent viewing".

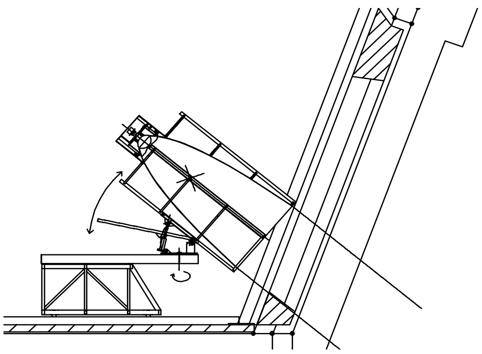

Fig. 2: View of the receiver room in the central tower with one of the two light collecting cones.

A signal of cosmic-ray shower at a typical position in the sky (azimuth 49 ^{o} (south=0^o, counting up towards west), zenith angle 28^o) is shown in fig.(3). One sees that the total length of the pulse train from the various heliostats is about 200 nsec, while the interval between the individual heliostats is on the order of 20-60 nsec. The lowest threshold can be reached if a discriminator identifies Čerenkov signals only at those times when they are expected according to the specific heliostat geometry at a given time. This demand was realized in our setup in an approximate way: The analog signals from the Linear Fan Out are fed into a leading edge discriminator which sets the threshold (usually -30 mV) for single pulses. The resulting NIM

logic-signals are split with a Logic Fan Out and fed into a chain of three coincidence units. The widths of the logic pulses and the internal and cable delays are adjusted to form a trigger mask which triggers on a time sequence of at least n_s signals which fulfill the following condition:
-each logic pulse has to follow its predecessor within a time window of 20-60 nsec. With n_s=3 or 4 this results in a highly selective trigger for cosmic-ray showers.
All events were registered with a fast (350 MHz bandwidth) 4-channel digital storage oscilloscope (Tektronix TDS 640 A), which was read out via a GPIB interface in a CAMAC crate. The CAMAC data acquisition was controlled by a PC (Apple MacIntosh II). The events were sampled for a total time of 500 nsec (1 nsec/bin) with a pretrigger of 250 nsec for both cones individually. The readout dead time was about 190 msec per event (dominated by the slow GPIB transfer) leading to a dead time of 30 % in good nights with a raw trigger of about 2.3 Hz. The trigger threshold in number of photoelectrons was determined in 3 different ways (single p.e. peak, fluctuation analysis of small pulses and derivation from measured current gain of PMT) as about 8 (10) p.e. for cone 1 (2). Simple estimates and the results of Monte Carlo calculations (Arqueros, 1997b) then lead to an energy threshold for γ-rays of about 70 GeV.

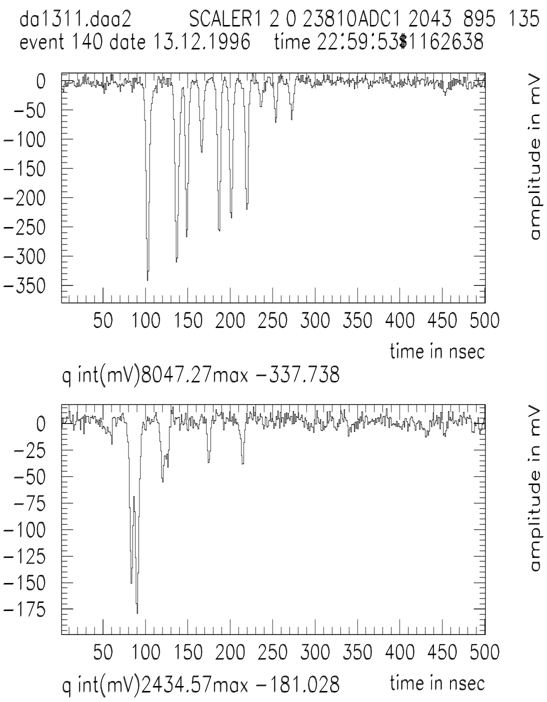

Fig. 3: A registered shower. The arrival times of the signals on the x-axis are determined by the positions of the heliostats. 30 mV on the y-axis are about 10 p.e.

RESULTS

There have been three measurement periods in May 1996 (for tests) and December 1996 and March 1997 (with data taking). A total of 73000 events was recorded with full waveforms. The weather was not ideal in the last two periods. Because of this only about 20000 events were registered under good meteorological conditions practically all during March. The observation targets in March were the Crab nebula, Mkn 421 and 501 and the EGRET source 4C 38.41.
The data were mostly taken in an on/off mode where the source was tracked for 10 minutes and then an off-source position was tracked about 4 ^{o} offset in right ascension also for 10 minutes such that the same elevation/azimuth region on the sky as for the source was covered. A problem that regularly occured is that the off source region had a different NSB level (recognizable with the DC current of the PMT) which led to different raw-triggering rates in the on/off source region due to increased fluctuations of the NSB (see also the Monte Carlo results concerning this effect). This effect typically led to differences in the trigger rate of a few percent. This makes it impossible to draw conclusions about γ-ray emission from the pure on/off event numbers at the moment. Such effects are expected for **all** Čerenkov telescopes which work very near the NSB.
In order to reliably determine γ-ray fluxes additional information about the direction, or the specific shower properties of electromagnetic showers is necessary. The directional information is contained in the data taken in form of the exact arrival times for the heliostats which can

be determined from the oscilloscope traces to about 300 ps. Simulations about the lateral distribution of Čerenkov light from very low energy showers (Portocarrero and Arqueros,1997) show that γ-ray initiated showers have a much smoother lateral distribution. This fact can be analyzed in the data using the amplitudes of the single peaks, which are measured with a precision limited only by statistical fluctuations. It requires further work to learn how to use this information, because due to the limited acceptance of the cone and the different positions of the heliostats the peak heights are determined by a complicated interplay of image and lateral distribution parameters. Work to analyze the data in these ways is in progress.

The typical rate (zenith angle about 30 ^{o}) for both cones under good conditions was about 0.4 - 1.2 MHz for singles, 0.1-2 kHz for sequential 3-triggers and 2.2 Hz for the total dead-time less trigger rate with both cones in coincidence. The detected pulses from single heliostats are observed to have widths which are mainly determined by PMT properties ($\simeq$ 4 nsec). The expected pattern of arrival times for a given source direction was compared with the Monte Carlo expectation and good agreement was found (Arqueros et al.,1997b). The properties of the recorded showers from the left and right subfield recorded with Cone 2 and 1 respectively were found to be quite symmetric also at azimuth angles different from zero. As an example fig.(4) shows the fraction by which the third highest signal is smaller than the highest one in a given recorded shower for both subfields (a parameter which is important for γ-hadron separation studies) for both fields in comparison. It is planned that Mini-GRAAL will operate with four cones in parallel with solar experiments or on a dedicated platform on the 70 m level. An interesting possibility for the future is to install on the order of 30 new technology ASM heliostats (Weinrebe et al.,1996) near the central tower in collaboration with solar-energy projects. A prototype for these stretched membrane heliostats (total mirror area 150 m^2) which are envisaged to be used for a projected large solar-power plant has been set up at the PSA recently. Its angular resolution is better than 1 mrad and therefore fully sufficient for Čerenkov light detection. Using central receivers of the type described here, an energy threshold of about 30 GeV would be achievable.

ACKNOWLEDGMENTS

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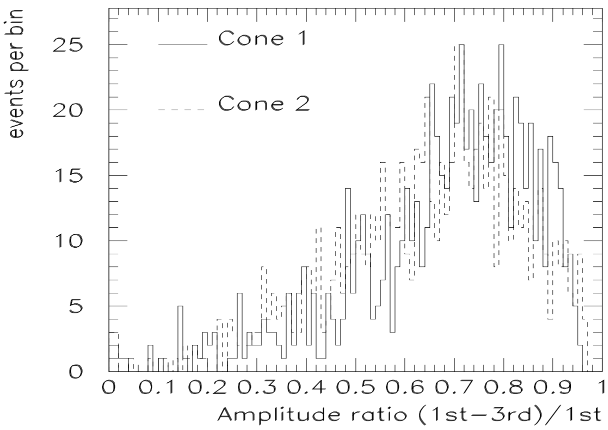

Fig. 4: Fraction by which the third highest signal is smaller than the highest one in a given recorded shower for one data run. It is seen that this important shower property is symmetric for both subfields. The azimuth/zenith angle of the source position in this run was (47^o-51^o)/28^o.