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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

A background-free detector for cosmic ray showers in the atmosphere

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A detector of new design is planned to detect Cherenkov light in high energy cosmic ray showers. It is based on the detection of the middle-UV radiation by TMAE photosensitive chambers, giving detailed imaging of the shower, combined with the beneficial background screening of the ozone in the upper atmosphere. This allows us to greatly improve the duty-cycle, the sensitivity and the range of observations with respect to traditional Cherenkov experiments in the visible. A further advantage is the achievable big angular aperture which makes it possible to search for new sources with an efficiency similar to extensive air shower experiments. Details of the technique and achievable physics goals are presented.

1. Introduction

We present an apparatus which is aimed to detect UV Cherenkov light produced by secondaries in showers initiated by very high energy (VHE) cosmic rays. The basic idea is to take advantage of the efficient screening, performed by the ozone layer in the upper atmosphere, of the background UV radiation in the frequency region where the TMAE photosensitive chambers we plan to use are efficient (middle UV). This absence of background from the luminosity of the sky will enable us to lower the detection threshold and to increase the acceptance of our system without spoiling the angular accuracy. Another strong advantage is the improvement of the duty cycle, since our apparatus will be able to run in the moonlight and during part of the daylight hours.

2. Technique

When solar blind photomultipliers became available, a number of authors pointed out the potentialities of cosmic-ray shower spectroscopy using ultraviolet Cherenkov light. In fact all background UV light is blocked by the ozone layer, whereas most of the Cherenkov light from the shower, which develops in the lower atmosphere, reaches a detector located at

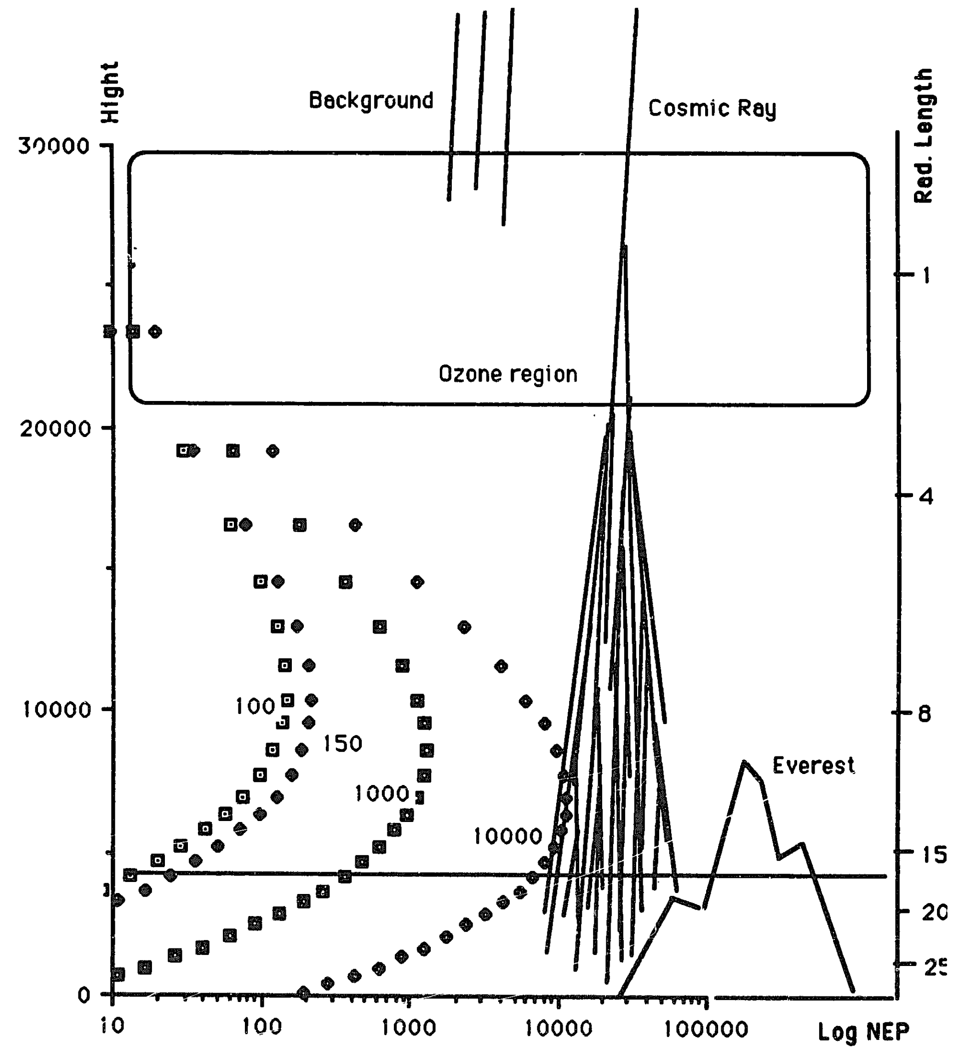

Fig. 1. Schematic view of the measurement principle and several profiles of showers of different energies.

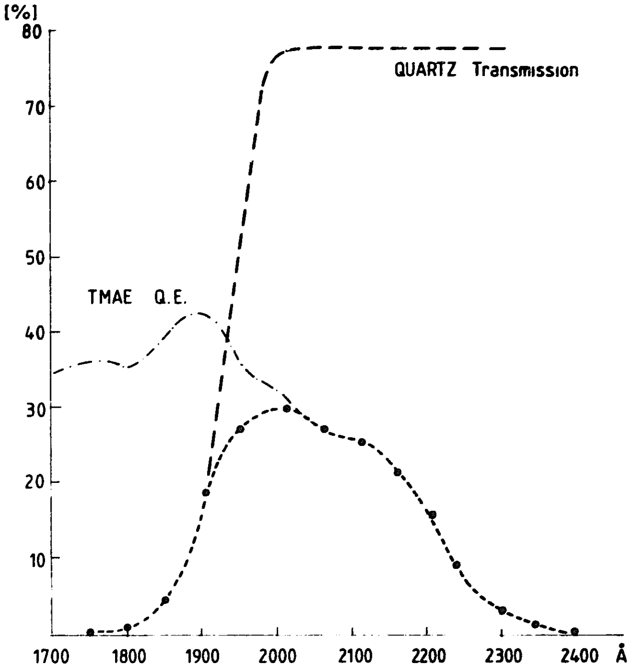

Fig. 2. Quantum efficiency of TMAE and quartz transmission.

ground level. Fig. 1 pictures this scheme. It can be seen that most of the ozone is located at altitudes between 30 and 20 km. At this last level a cosmic ray has penetrated only 4 or 5 radiation lengths (see right-hand scale), so most of the shower develops underneath the ozone layer. In the same picture are superimposed several profiles of showers of different energies, the profile representing the log of the number of particles at different altitudes.

We propose to measure the Cherenkov light produced by a shower with photosensitive chambers located in the focal plane of aluminized parabolic mirrors. The chambers work with a small quantity of photosensitive vapors (TMAE) added to a standard hydrocarbon mixture [1].

The choice of chambers (instead of solar blind photomultipliers) is cost effective, because it allows to cover a much larger photocatodic area with high granularity and good quantum efficiency. Another argument is that solar blind photomultipliers have a residual quantum efficiency (10^{-3}) in the visible which may hurt in some case, for instance one cannot point directly to the Moon. Fig. 2 gives the quantum efficiency of TMAE together with the quartz (window) transparency. It can be deduced that the accessible wavelengths range from 195 to 235 nm.

3. Design and construction of the chamber

Reliability, ruggedness, cost and simplicity of operation where the main topics of the chamber design [2]. Among several options we have chosen an electrode scheme similar to a MWPC with readout on the cathode pads. The analog sum of the signals on all the wires was formed at the high-voltage input, then amplified and analyzed. Fig. 3 shows a schematic layout of the electrodes. Anodes are 20 μm AuW wires, 4 mm apart, all connected to positive voltage (3000–3200 V). Cathodes (grid and pad plane) are tied to ground. The grid is made with a mesh of stainless-steel wires. 50 μm in diameter. The pad plane (256 pads 12 × 12 mm) is a printed circuit board in a G 10-Cu substrate, also carrying connections and connectors for preamplifies on the back side.

The mechanical mounting (see fig. 4) consists of three items: (a) the quartz window and grid mount, (b) wire and pad assembly glued together with epoxy, also incorporating gas flow connections, and (c) the backplane which only provides mechanical stiffness and heat conditioning for the chamber, to compensate for large outdoor temperature variations. To this end, a water circulation system is embedded in the frame. Items (a) and (b) are coupled by an O-ring which seals the gas volume. We built several chamber prototypes and made systematic studies of electrode geometry to investigate the most suitable working conditions for our application. We did not work with the chamber pressurized or underpressurized, as is often done in optical applications, because of the inherent complications and the necessary increase in quartz thickness and consequent cost.

Each single pad was amplified by a low-noise preamplifier, the output of which went on a LeCroy 2282B ADC in a common camac crate. A charge injection circuit at the preamplifier input allowed channel-by-channel corrections of electronic offsets.

4. Physics

The experiment was originally conceived as a matrix of 64 units covering an area of 10^5 m^2. This array would allow us to make gamma-ray astronomy in a very competitive way with any other existing experiment.

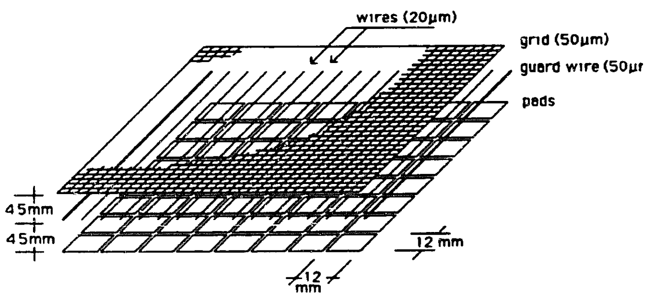

Fig. 3. Basic geometry of the chamber and schematic lay-out of the electrodes.

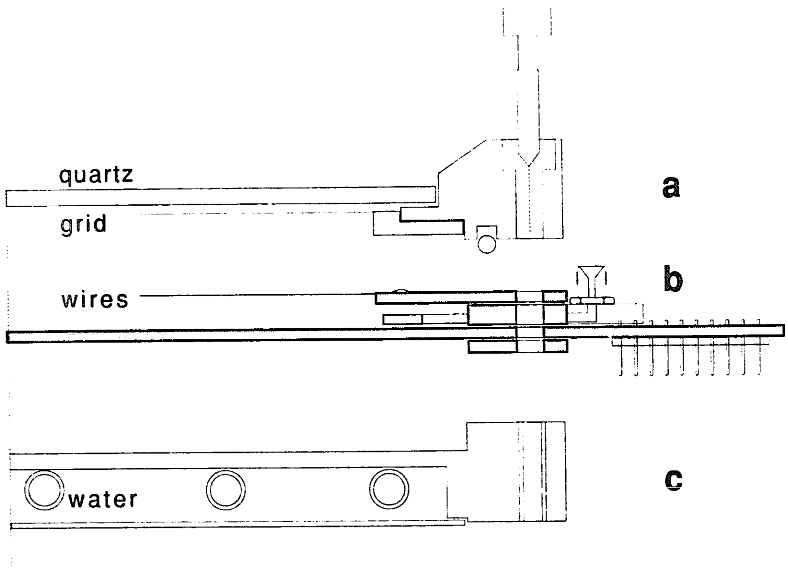

Fig. 4. Cross section of the chamber general assembly: (a) quartz window frame, (b) wires and pads subassembly, (c) back plane and heating system.

Table 1 summarize the main parameters of the detector. At this stage we are in the process of setting up a smaller matrix of 9 units, sufficient to allow a full understanding of the characteristics of the detector and of its performance. Such apparatus will furthermore allow to complete in a reasonable time of data collection several interesting physical measurements.

Table 1
Main parameters of the CLUE Experiment

Altitude	[m]	3500–4500
Latitude	[deg]	20N–20S
# of units		64
Dist. between units	[m]	45–55
Total target area	[m^2]	$\sim 2\times10^5$
Diameter of mirror	[m]	1.8
Focal number		1.25
Area of chamber	[m^2]	0.09
# of pixels/chamber		576 (24×24)
Total # of channels		36864
Sensitivity range	[nm]	205–235
Quantum efficiency	[%]	25–30
Attenuation length	[m]	1500–2000
Angular opening	[deg]	±5
Angular accuracy	[mrad]	2–3
Energy threshold	[TeV]	0.5–1
Energy res.	[$\%/\sqrt{E}$ [TeV]]	20–40
Duty cycle	[%]	50–60
Trigger capability	[Hz]	10 K
DAQ capability	[Hz]	100

An important item will be to measure the dip of the hadron shower count in direction of the Moon, which is displaced by the earth magnetic field by an amount related to the energy of the primary. This will give a direct energy calibration of the system. We can attempt some charge spectroscopy of the incoming cosmic-ray [3]. .

An other interesting subject is to tune the algorithms to sort photon initiated showers from hadron initiated showers. This will take advantage of the good granularity of the system and of the multimirror image of the shower. On the basis of those algorithms we plan to observe the potential gamma ray sources regardless of their position in the sky. In particular Cyg X1 (by far more intense than Cyg X3 in the X-ray range) can be observed in the UV and not in the visible because of a bright star near by.

Other observations aimed to gamma ray astronomy or detailed spectroscopy of the primary would require collecting times and running costs which are too high to be pursued with this reduced apparatus and are in the plans of the collaboration when the full matrix of 64 will be implemented.

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