

Optical Pulses associated with UHE Cosmic Rays

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Detection of UHE Cosmic Rays ($E_p > 10^{17}$ eV) provides important information on characteristics of High Energy nuclear interaction and also helps to solve astrophysical problem of Cosmic Ray origin, beyond the Greisen-Zatsepin-Kuz'min cut off ($> 10^{20}$ eV). Čerenkov Radiation (CR) associated with Ultra High Energy Cosmic Rays passing through earth's atmosphere are detected using a Čerenkov detector consisting of a 5" photo multiplier tube (PMT, type 9792KB make EMI) to be operated in coincidence with the mini-array of Physics Department., Gauhati University, The Čerenkov detector is calibrated using Čerenkov photons produced in a tank of distilled water through which secondary cosmic rays (mainly muons) of known average flux pass. In this paper, we report Čerenkov pulse spectrum using Multi Channel Analyser (MCA) for calibration and simulated spectrum triggered by mini-array events within the energy window $10^{17} - 10^{18}$ eV.

1. Introduction

The ultra relativistic electrons and positrons in an EAS while traveling down the atmosphere produce Čerenkov Light flash, which can be detected using a PMT in a moonless night. This detector is designed to be operated in coincidence with the existing particle detector array (mini array) for detecting UHE Cosmic Rays of energy 10^{17} to 10^{18} eV [Ref.1,2,3]. It is well known that optical pulses bear information about primary mass composition, which is not yet conclusively established in the UHE range of primary spectrum. The slope of the lateral distribution of Čerenkov radiation is linearly related to the depth of shower maximum [Ref.4], which is different for different primary mass and energy. Hence, measurement of particles and Čerenkov components of an EAS provide estimates of primary energy and mass composition.

2. Calibration of Čerenkov Detector

For calibration, we use a water tank of radius 20cm and height 32 cm, filled with distilled water up to a height of 22cm and its outer surface is coated black to make it light tight. The PMT is placed at the bottom of the water tank with a thin transparent plastic sheet separating the tank. The anode pulses are fed to the emitter follower placed very close to the PMT. This arrangement including emitter follower circuit is finally placed inside a light tight enclosure. The output of the emitter follower is carried via co-axial cable to the polarity inverter and inverted pulses are fed to the Multi Channel Analyser (MCA, Type -NETS-3M/U) for recording. Čerenkov events are due mostly to secondary Cosmic Ray muons of average intensity $180 \text{ m}^{-2}\text{s}^{-1}$. Events are recorded for 5 hours with average count rate of 17 per minute.

2.1 Method of Calibration

Points of incidence of vertical muons are chosen at random over the cross-section of the water tank, taking the origin at the centre of the water surface. For vertical muons of average energy 2GeV, $\theta_c = 41^\circ$ (in water). The effective path length in water and the area over which Čerenkov photons are distributed are calculated from the geometrical consideration. The number of photons emitted by the effective path length z is estimated from the number of photons emitted per cm (~ 200). [Ref.5] Assuming these photons to be distributed uniformly over area A , the actual number of photons collected by the PMT is estimated from the

fractional area of overlap by the photocathode area. The absorption of photons in distilled water is also taken into account. One thousand events are simulated using Monte-Carlo method and frequency distribution of the number of photons collected in each case is plotted using suitable class intervals.[fig.3]

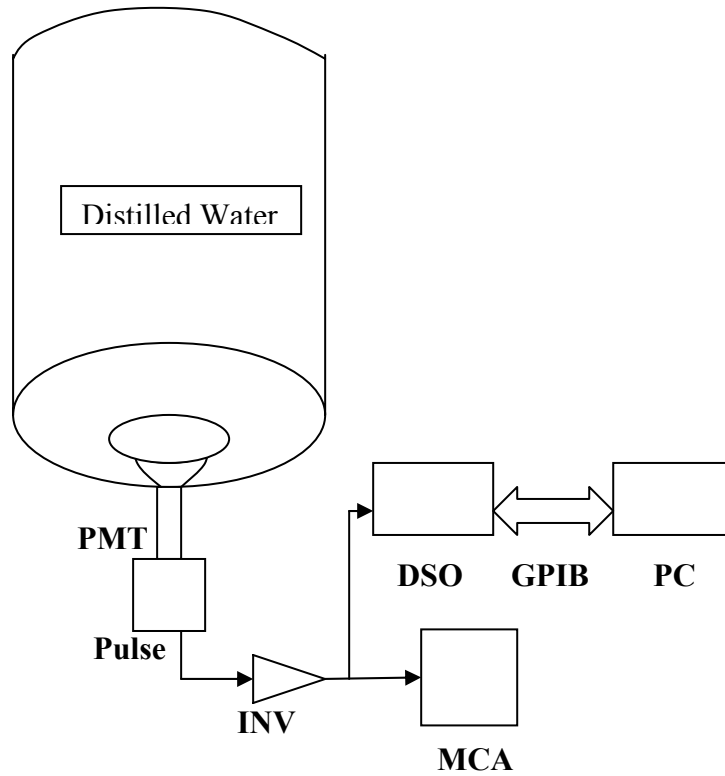


Figure 1. Experimental Setup for Calibration of Cerenkov Counter.

2.2 Simulation of Čerenkov Spectrum triggered by Mini-array events

The Optical Čerenkov detector placed at the centre of the mini-array is calibrated for estimating primary mass composition using simulated events by Monte Carlo method. The acceptance area of the mini-array is an annular ring of inner radius determined by the minimum time spread (100nS) and outer radius determined by minimum particle density (at least 3 particles per 2m² area) EAS events are simulated with random core positions within the acceptance area of the mini-array. Two sets of events are simulated for primary energy E=10¹⁷eV and 10¹⁸eV assuming first pure proton composition. The point of first interaction X₁ is simulated using exponential distribution with proton mean free path of λ = 80 g/cm² . The depth of maximum t_{max} (in unit of radiation length X₀) is computed for the first interaction point, using GIL formula [Ref.6].

$$t_{max} = a + b [\ln (E / \epsilon) - \ln A] \text{ ----- (1)}$$

where $\epsilon = 81 \text{ MeV}$ (critical energy), $b = 0.76$, $a = 1.7$

Cerenkov Lateral Distribution Function(LDF) is assumed to be a power law, [Ref.4],

$$\Phi (r) = C (R + 50)^{-\delta} \text{ -----(2)}$$

$$\delta = 0.0014 X_{max} + 1.32 \text{ -----(3)}$$

For each primary energy and core distance, shower size and particle density are estimated using mini-array reanalysis result using CORSIKA [Ref.7]. The number of photons falling on the Čerenkov detector PMT is calculated using equation (2) and track length integral [Ref.8]. The whole procedure is repeated assuming pure iron composition.

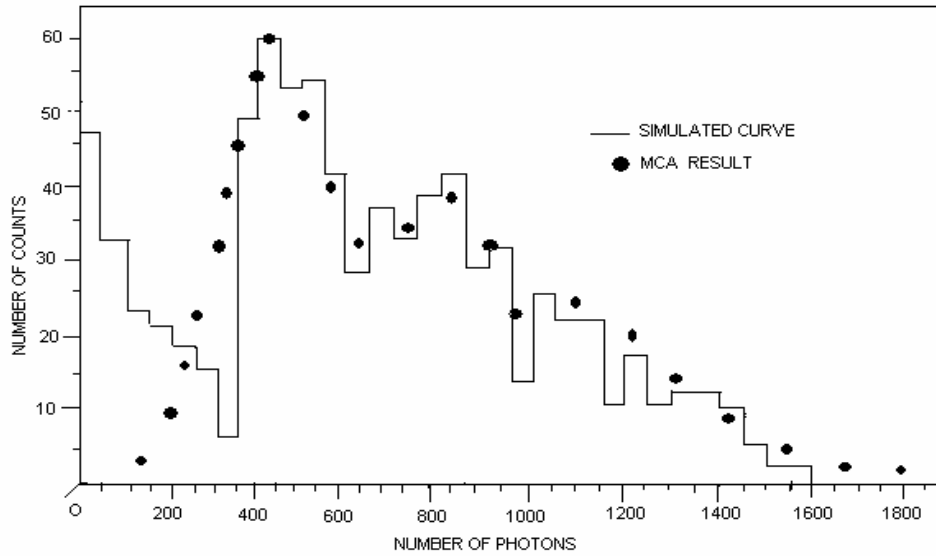


Figure 2. Simulated and MCA Pulse Height Distribution

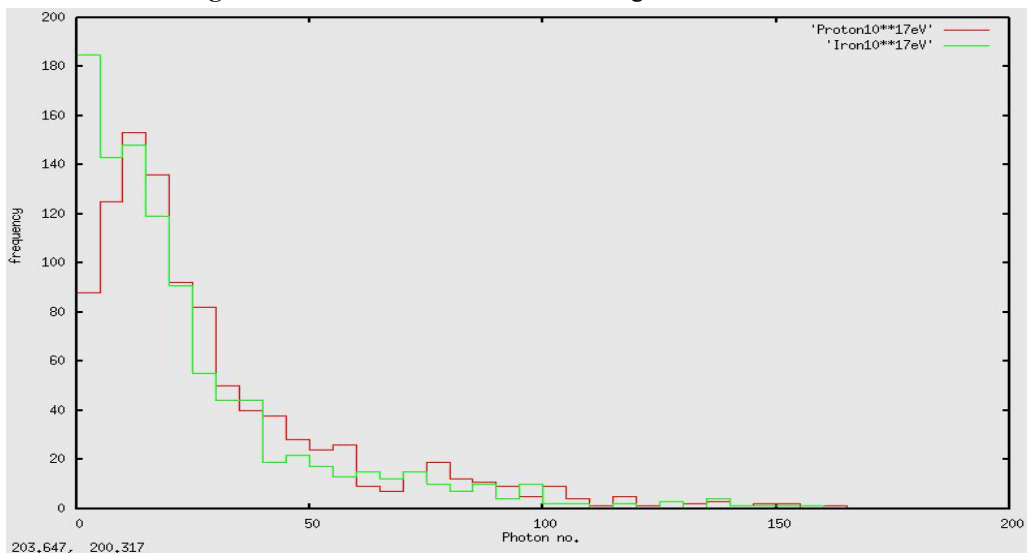


Figure 3. Simulated spectrum of 10^{17} eV Čerenkov pulse triggered by mini-array events .

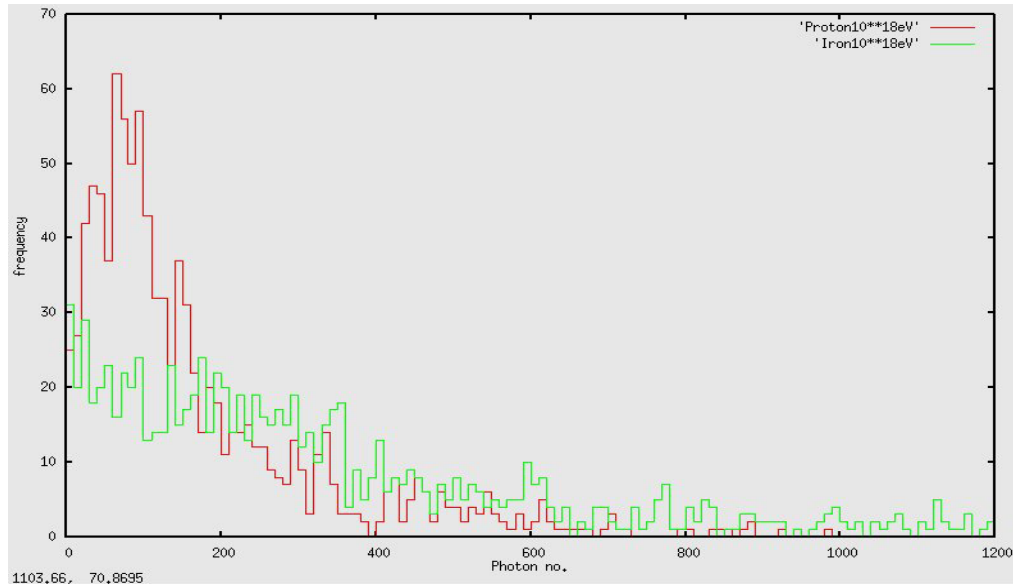


Figure 4. Simulated spectrum of 10^{18} eV Čerenkov pulse triggered by mini-array

3. Results and Discussion

The experimental pulse height distribution and the simulated frequency distribution for the water Čerenkov, are shown in fig.2. The shape of the two distributions are remarkably similar except for the lowest photon numbers. The position of MCA peaks are correlated with the simulated spectrum and the detector is calibrated for the number of photons. Čerenkov pulse height spectra obtained from a model detector triggered by mini-array event of Primary energies 10^{17} eV and 10^{18} eV, under the assumptions of pure proton and pure Iron compositions, are shown in fig.3 and fig.4. Results show visible difference at the higher energy, 10^{18} eV.

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