Coincident Observation of Cosmic Ray Flux and Atmospheric Electric Field During Thunderstorm

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***Abstract*. CRITE (Cosmic Ray Interaction in Terrestrial Environment) is a cosmic-ray out-reach program in Taiwan. There are two major goals, one is to develop compact data acquisitions (DAQ) system for future expansion to a larger network such as Quarknet-TW. The other is to search correlation between cosmic ray flux and thunder storm activity. During the last two years, we had developed a compact data acquisition system for cosmic rays detectors. This system consists of electronics for photomultiplier trigger and world-wide-web database and interface. A prototype experiment is set up in our campus to detect cosmic ray fluxes by two scintillators, together with weather station and atmospheric electric field meter. Coincident variation in cosmic ray fluxes and atmospheric electric field were observed during thunderstorm. During the first year operation of a prototype detector, we don not see significant corelation of changes in cosmic ray flux during thunder storm or lightning.**

***Keywords*: Cosmic rays, lightning, Data acquisition system**

I. Introduction

Since the discovery of the highest energy cosmic rays with energy as high as 3.2×10^{20} eV in 1993 [1], cosmic ray researches had expand rapidly, in terms of experiments, researchers, and journal papers. Because of extremely low flux of ultra high energy cosmic rays, one event (E$> 10^{18}$ eV) per km^2 per century, their detectors must cover very large area. The primary cosmic rays interact with atmosphere and produce many secondary particles in a process called extensive air shower. Most secondary particles are charged, also known as secondary cosmic rays, which distributed over large area and can be detected by various detectors. For instance, Hires telescope can detected faint light as far as 40 km away [2]. Pierre Auger experiment cover ground area of 3000 km^2 [3]. Some out-reach programs try to build cosmic ray detectors in many high schools or similar campus. By linking different number of schools, it could be used to study cosmic flux at various energy ranges. Quark-Net is one of those programs. Fermi lab is leading this out-reach project and help in developing detector technology [4].

Since the confirmation of GZK cutoff [5], [6] passion for ultra high energy cosmic rays may subside. However, there are growing interests in the effect of cosmic rays in climate [7] and weather, especially thunder storm and lightning. This new territory may be good topics for many school base cosmi ray projects.

Since secondary cosmic rays are charged, they can be accelerated/decelerate in severe electric field, such as thunder storm. For a typical atmospheric field of 1 KV/m, it is possible to gain MeV energy in between cloud and ground. High energy photons could be produced from acceleration of electrons. There had been report of TGF (Terrestrial Gamma-ray Flash) was observed in space since 1960s and recent observation shows that TGF are related to thunder storm aactivity at lower atmosphere [8]. Increase of gamma ray dose during winter storm and thunder storm were reported too [9], [10]. X rays were detected along rocket triggered lightning [11] and thunderstorm [12].

Cosmic ray flux may change during thunder storm, especially during lightning[13], [14]. The effect could even change the shower development [15]. On the other hand, there are some speculations about the high energy cosmic rays may provides seed particles to trigger lightning. The trigger mechanism of lightning maybe due the effect of ”run-away breakdown” theory[16]. However, some arguements about the exact mechanism of breakdown still exists [17].

Those studies are still in the beginning phase and need more data. A net-work of cosmic ray detectors may measured cosmic ray flux variation in large area and track the movement of thunder-storm. We believe such down-to-Earth experiment is a great topic for high school student and even projects for college students.

To establish a cosmic-ray out-reach program in Taiwan, named as CRITE (**C**osmic **R**ay **I**nteraction in **T**errestrial **E**nvironment), we had build a small cosmic ray detector. There are two goals. One is to develop compact data acquisitions (DAQ) system for future expansion of such high school base project into a larger network such as Quark-Net-TW, which is a subnetwork of Quark-Net in Taiwan. The other is to search correlation between cosmic ray flux and thunder storm activity. Prototype CRITE detector have been operated for 6 months. In this paper, we report the DAQ system of this project and present some results during the last year.

II. CRITE experiment

To accommodate different size and numbers of school campus, a key requirement of such school-base project is flexibility. We design a three stage detector and trigger system. Figure 1 shows the system block diagram.

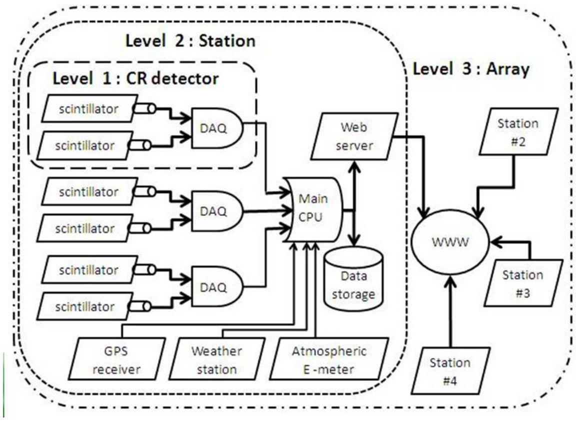

Fig. 1. System block diagram of CRITE detector and array.

A basic unit of CRITE detector consists of two plastic scintillators separated at some distance. Each scintillator is connected to photomultiplier tube (PMT) through a fish-tail light guide. Two sets of signal and high voltage cables from PMTs are connected to an electronic box, where high voltage and low voltage suppliers, readout electronics are all included. Only AC power and signal cables are connected to outside of box. First level trigger is coincident trigger from both upper and lower scintillators in one unit. Section 3 will describe details of this counter unit.

The second level is station, which consists of at least three detector units and a central computer. All units are connected to central computer by RS485 cables, which allow the maximum distance as far as 100 m. Central station has a GPS receiver, weather station, and atmospheric electric field-meter. The second level trigger can be set as 1 to 3 units trigger among all units. All data are recorded in database and can be displayed and accessed by web-server. For a school based project, each school host one or more stations. Section IV will describe details of central computer and web-base data acquisition system.

The third level is array, which link many stations by world-wide-web. By combining data from multiple stations, user can estimate primary cosmic rays energy and flux. Since we build only one station for prototype now, we will not discuss third level in this paper.

III. Cosmic ray detector unit

The basic components of cosmic ray detector unit are scintillators, PMTs, readout electronics, and their supporting high/low voltage suppliers.

A. Cosmic ray detector

Two 50cm x 60cm plastic scintillators (part number such as BC420) are used to detect charged particles of cosmic ray secondary particles. Scintillation photons are collected through fish-tail light guide and feed to PMT.

Two scintillator are separated by a distance of 40 cm. Coincident event must pass through two scintillators within one clock-cycle of 25ns. This geometry provide effective geometrical acceptance of 3087 cm^2 sr.

We use 2” flat head PMT (Hammamatsu R2154-02) and resister-chain socket (Hammamatsu E1198-07) . The rising time of PMT is 4.5 ns, which match the decay time 4.2 ns of scintillator BC420.

Each PMT is connected to a compact high voltage power supply (Matsuda, TC-1.5N), which can be mounted on printed circuit board. Output voltage is controlled by a 0 - 6 VDC, which is manually adjusted by a variable resister. PMT voltage is determined from a plateau test, which use a radioactive source and measure the counting rate as a function of PMT HV. Proper HVs are the region that counting rate stay in constant value, which reflects the true event rate of radioactive source. See figure 2 for a set of scintillators detectors.

Fig. 2. Assembly of PMT, light guide, and scintillators.

B. PMT Readout electronics

The Counter Unit consists of two sections, front-end and back-end circuits, connected by opto-coupler. Figure 3 shows a picture of DAQ circuit board.

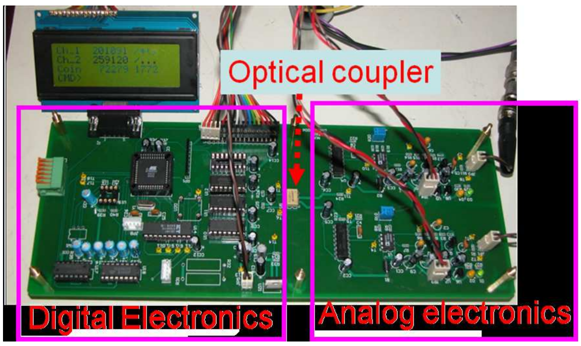

Fig. 3. CRITE PMT Readout circuit board.

The front-end circuit processes signals coming from PMT. This analog circuit make pre-amplification on small PMT signal, to raise the S/N ratio then capture signal by comparator of adjustable threshold. The transmission line effect in coaxial cable from PMT to amplifier is considered by matching impedance between both ends. For typical thermal noise of 25 mV and PMT output resistance of 50Ω, the bias current of this common-base amplifier (BJT, PH2369) has been designed to be 0.5mA. The amplifier provides an ac voltage gain around 30 (V/V) which can raise the ac output voltage to about 1∼1.5V, which is large enough for comparator (AD8561, Analog Device Inc.). There is a potentiometer to adjust the threshold voltage for available trigger. The pulse width of the one-shot circuit is designed to be ∼500ns, which is a practical specification for application of counting rate less than 1MHz.

The back-end circuits take the trigger from front-end circuit and find the coincident events and count event numbers. Real time coincidence are processed by a CPLD (XC9572XL, Xilinx), which is a low-cost programmable PLD and runing at 20MHz. It had 3-channels x 8-bit A function-enhanced 8051-base MCU (MPC82G516A, Megawin) is used to accomplish the real time DAQ, the serial communication interface for GPS and Central Computer. A Master-Slave type RS-485 network is used to link different Counter Units in a same station for level 2 trigger.

The digital circuits are often noisier, while analog circuits require cleaner ground level. Another requirement is our detector must be operated during thunder-storm, when atmospheric electric field may change rapidly, which cause fluctuation of ground level significantly. To prevent contamination from digital to analog circuits, a high speed opto-coupler(PC9D10) is used to be an isolated buffer. Ideally, the noisy ground bounce from the digital circuit (back-end) will never disturb the analog circuit (front-end).

C. *Electronic Box & Detector box*

The low voltage power supply (LVPS) consists of 3 low power DC-DC Voltage regulators (LM1086) with isolated ground. Two for Analog circuit and one for Digital circuit, Only AC power and signal cables are connected to outside of electronics box.

Both scintillator-PMT assembly and DAQ electronics are housed in a weather-proof detector box. This detector box can be transported to different place as required by the design of array. However, due to limitation of RS485 (at Baudrate 10kbps), the maximum distance between detectors is 100 m.

IV. WEB-BASED DAQ SOFTWARE AND ATMOSPHERE/WEATHER MONITORING DEVICE

Every detector stations, which may links with many detector units within one campus, equip with a central computer, a GPS receiver, a weather station and an atmospheric electric field meter.

Extensive air shower from high energy cosmic rays are selected by coincident triggers from many detectors, This industry-matured RS485 network not only serves as the real time data collection of the whole station, but also the synchronization between different Counter Units by broadcasting synchronous signal at 3ms period from central computer. This timing signal is used to synchronize clock of all units. In each unit, the 20 MHz system clock is used to generate 50ns clock pulse.

A weather station and an atmospheric electric-field-meter are also connected to central computer. We use Vantage Pro weather station to measure temperature, pressure, precipitation, wind speed and direction, visible and UV light intensity. Weather data can be updated every second.

Atmospheric electric-field-meter (Boltek EFM-100) is a field-mill, which uses a rotating mill to open/close sensing electrode to external electric field, then measure currents through a resistor to ground. This AC signal is then digitize and the digital signal is transmitted to central computer by an optical fiber cable to prevent interference during thunderstorm.

Data from all detectors (CR counters, weather station, and electric-field-meter) are stored in a MySQL data base. Using PHP language, a world-wide-web is set up for event display. The central computer is also a web server. So user in any location at any time can access / retrieve data using simply a web browser, no special software or platform required. Because of this simple design, central computer can be any computer with internet connection and proper software (MySQL, PHP, web server) installed.

V. RESULT FROM TEST RUN OF PROTOTYPE

We had setup a prototype station in our campus for one year. This prototype links with one detector units (two scintillators), see figure 1. Operation starts in summer 2007 and continues to summer 2008. Two typical event display during thunderstorm is shown in figure 4. A typical cloud to ground lightning produces a bi-polar pulse in electric field-meter. There may be several clouds to clouds lightning after first stroke. This figure shows cosmic ray fluxes are stable even under large variation of atmospheric electric field.

Thunder storm can be identify by weather data and atmospheric electric field. There are more than 10 thunder storm passing over our campus during this period. Preliminary analysis shows conflicting results. We saw some lighting followed by decrease of cosmic rays flux, but some followed by increase of cosmic ray flux. No significant correlation of cosmic rays flux and atmospheric electric field can be concluded, contray to some previous reports[]

The reason may be due to positive and negative particles are almost equal in air shower. The electric field may accelerate one types of particles and decelerate other types of particles, therefore the number of events reach ground would be similar to a situation without perturbation of atmospheric electric field.

VI. CONCLUSION AND FUTURE DEVELOPMENT

We had build a CRITE prototype and operate for one year. This prototype includes scintillators, PMT, readout

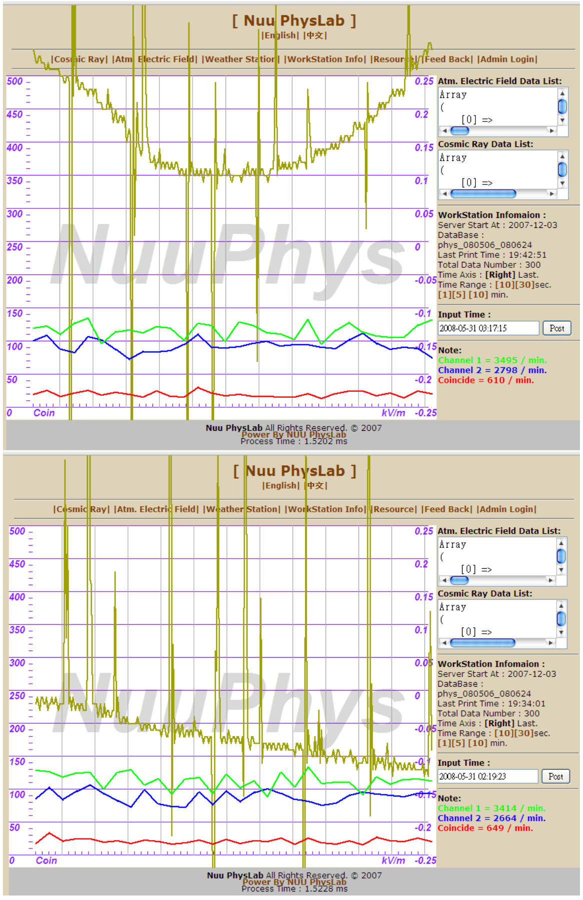

Fig. 4. Screen shots of DAQ web pages. The horizontal axis is time, whole frame is 60 minutes. The green and blue lines are counting rate of top and bottom scintillators. The red line is the coincident trigger rate. All event rates are counts per minute and use vertical axis on the left side. The spiky dark green lines are atmospheric electric field (use vertical axis on the right side).

electronics, and web-base DAQ software. We do not see clear evidence of cosmic ray flux variation due to thunder storm activity.

There are speculations of triggering of lightning by very high energy cosmic rays. Currently, we are updating electronics to 8 channels coincident circuit, By extending to larger area covered by cosmic ray counters, we may see higher energy events and study their correlation. Meanwhile, this 8 channels cosmic rays detector system is reorganized as a “cosmic gate” for a exhibition in Taipei Astronomical Museum.

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