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Discrimination of cosmic-ray in scintillation region and light-guide for plastic scintillation detectors using 5GSPS readout system

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Abstract: At sea level, the measurement of energy spectrum for cosmic-ray flux determination using two-coincidence plastic scintillation detectors with "traditional" electronic-readout system may include not only cosmic-ray in scintillator region but also light-guide region. In this work, we carry out a measurement of cosmic-ray using two-coincidence plastic scintillation detectors with size of each 80cm×40cm×3cm thick, and an electronic-readout system of 5GSPS (i.e. 200 ps sampling-time resolution). With the readout system, the shapes of pulses from scintillation detectors can be observed. The behavior of time responses of pulses in a plastic scintillator and a light-guide may be different. Based on some characteristics of these responses (such as pulse width, its falling edge, etc.), it is possible to discriminate cosmic-ray in scintillation region from light-guide region. The vertical cosmic-ray flux was measured to 0.1×10^{-3}count.s^{-1}cm^{-2}. The obtained results will be presented and discussed in detail. The experiment was set up and measured at the Nuclear laboratory, Department of Nuclear Physics, University of Science, HCMC-Vietnam National University.

Keywords: *Cosmic-ray, plastic scintillation detector, 5GSPS readout system*

I. INTRODUCTION

Primary cosmic-ray particles are mainly consisting of protons (90%), alpha particles (9%) and heavier nuclei that bombard the upper atmosphere with a flux of about 1000 particles per m^2 per second. During their interactions with atmospheric nuclei (mainly nitrogen, oxygen), they produce secondary particles shower. Soft components of cosmic-ray (electrons and photons) can be easily shielded by a concrete building. Protons from the nucleonic component of cosmic radiation have low intensity compared to neutrons and, moreover, they are converted to neutrons in nuclear reactions with shielding materials of the building. Therefore only muons and neutrons (hard components of cosmic-ray) are important for energy spectrum induction of cosmic-ray flux determination at ground laboratory [1]. Plastic scintillators exhibit very short response times and are extensively utilized for experiments where accurate measurements at very short time intervals (ns) are conducted [2]. Their applications are for cosmic-ray research [3], and anti-cosmic shielding of detectors to

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"guard" high-resolution detectors against background radiation (such as the low background gamma spectrometer) [4]. At an under-ground laboratory, the measurement of energy spectrum for cosmic-ray flux determination using two-coincidence plastic scintillation detectors with “traditional” electronic-readout system may include not only cosmic-ray of interest in scintillation region but also in light-guide region and gamma ray background. The background is mainly caused by radioactive decays in rocks, the building, radon and daughters in the air surrounding the detectors. The background spectrum lies in a lower energy domain in comparison to muon events having a longer tail overlapping with the muon spectrum. Energy deposition of a relativistic muon in plastic scintillator depends only on the scintillator thickness. Thus one solution is to use thicker scintillator plates to set energy thresholds for both muon detection efficiency and background rejection. Addition, the background is also caused by cosmic-ray interaction in light-guide region. The background spectrum’s long tail decreases the efficiency of the background reduction. A pulse shape discrimination (PSD) technique is necessary. The behavior of time response in plastic scintillation detectors between charged cosmic-ray in light-guide and cosmic-ray in scintillator region may be different. Based on the time responses of pulses, it is possible to discriminate cosmic-ray from background.

Recently, with a rapid development of fast Analog to Digital Converters (ADC) and digital signal processors, Digital Pulse Shape Discrimination (DPSD) methods have been reported. Most of them utilize digital sampling oscilloscopes or generic digitizer cards to sample the analog pulse signals in response to neutrons, gamma rays or both, and then transfer the data stream to a generic processing unit to process and analyze [5]. In this work, we carry out a measurement of cosmic-ray using two-coincidence plastic scintillation detectors with an electronic-readout system of 16bit-5GSPS Flash ADC (i.e. 200 ps sampling-time resolution) and embedded FPGA-based logic trigger for offline analysis by a C++ code. We applied DPSD method(s) for cosmic-ray in light-guide and in scintillation discrimination. The algorithms applied in our discriminator based on width of pulse to separate cosmic-ray in light-guide from cosmic-ray energy spectrum. Pulse measurement definitions are defined by the IEEE Std 181-2003 "IEEE standard on transitions, pulses, and related waveforms" for the width of pulse. First, the maximum value method is applied to search a digital peak. It selects the maximum amplitude from the pulse data once the end of the pulse has been reached. Next, 10% amplitude at left side of the digital peak and 10% one at right side are determined. Finally, the time interval from 10% (at left side) to 10% (at right side) is width of pulse (Fig.1). The time response spectrum and the charge spectrum of events measured with the scintillator counter in the surface laboratory will be presented and discussed in detail. The experiment was set up and measured at the Nuclear laboratory, Department of Nuclear Physics, University of Science, HCMC-Vietnam National University.

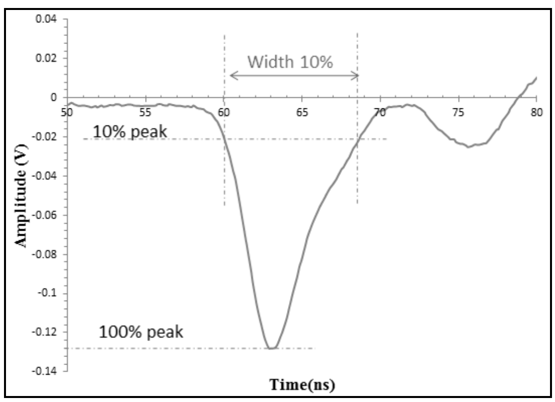


Fig.1. Definition of a pulse width at 10% peak from left side to right side

II. EXPERIMENT SETUP

We established the experiment with two plastic scintillator detectors paralleled with a distance of 30cm to form a coincidence system, shown in Fig.2. The plastic scintillation detector, shown in Fig.3, consisted of plastic scintillator plates each 80cm long, 40cm wide and 3cm thick, mounted to 40cm long of light guide and optically connected to Hamamatsu-made R329-02 photo-multiplier tube (PMT) [6] which was operated by a negative high-voltage supply, type of 556, manufactured by Ortec Inc [7]. When a radiation hits two scintillator plates, it excites their atoms, leading to photon emission. The PMTs are responsible for collecting scintillation photons from plastic plates. The photons strike photocathodes of the PMTs and stimulate electrons of the photocathodes, resulting in the emission of photoelectrons. Later, a number of photoelectrons hitting electrodes are counted. All signals collected at PMT anodes were recorded using the 16-bit high resolution DRS4 waveform digitizer [8] with sampling rate of 5GSPS for offline analysis. The DRS4 Evaluation board contains the DRS4 chip, a FPGA and an USB interface. The DRS4 chip has been designed at the Paul Scherrer Institute, Switzerland by Stefan Ritt and Roberto Dinapoli [8]. The DRS4 oscilloscope user interface was used to controlling trigger and taking event-by-event data from DRS4 board via the USB port. The signal was triggered with a 25mV threshold equivalent to the energy of 2.0 MeV. The sampling-time resolution is configured at 0.5ns/sampling point.

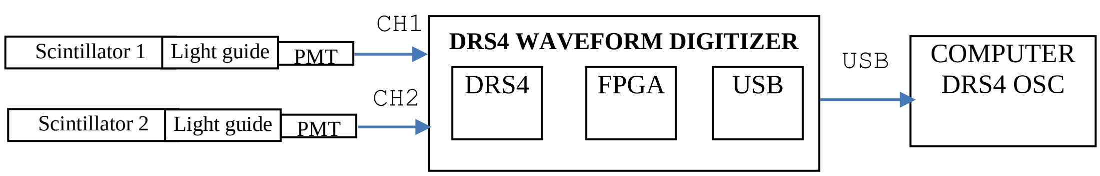


Fig.2. Schematic diagram of the cosmic-ray measurement with two plastic scintillation detectors, DRS4 waveform digitizer and DRS4 Oscilloscope user interface.

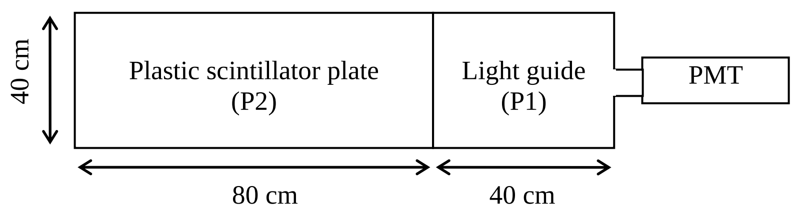


Fig.3. Plastic scintillation detector.

III. RESULT AND DISCUSSION

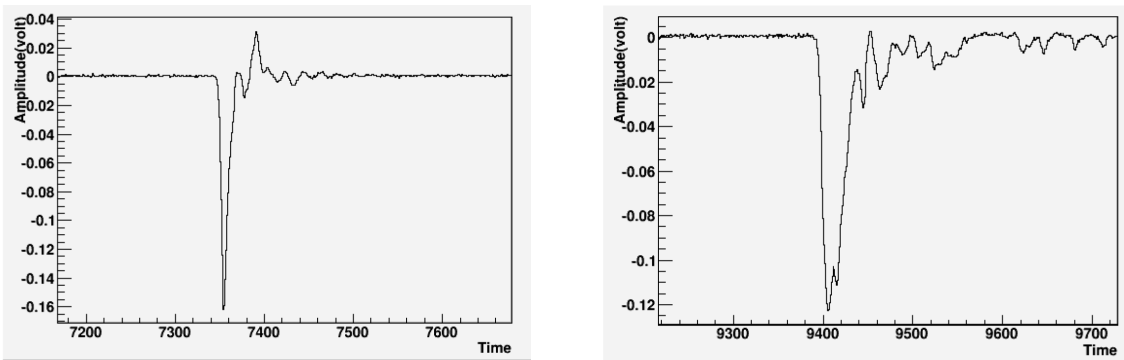
Signal response between scintillator and light guide

In order to observe signal a response between the scintillator plate and the light guide plate, a “test” detector was employed. The detector is a plastic scintillator plates each 40cm long, 30cm wide and 1cm thick. It is placed above the light guide plate (P1) or the scintillator plate (P2). If a coincident event occurred at two detectors, a charged particle would pass through the light guide plate (P1) or the scintillator plate (P2). Fig.4a shows a signal response of the scintillation detector when a charged particle hit at the light guide plate. This signal resulted from Cherenkov radiation effect. Fig.4b shows a signal response when a charged particle hit the scintillator plate. This signal resulted from scintillation photon. Based on the widths of pulses, it is possible to distinguish signals from scintillation plate or light guide plate.

Discrimination of cosmic-ray in scintillation region and light-guide for plastic scintillation detector

For coincidence measurement with the uses of two plastic scintillation detectors, the energy spectrum always includes cosmic-ray hitting the scintillator plate and the light guide plate. It means for flux measurement of cosmic-ray, it may get uncertainty of counts. In this work, it is possible to distinguish cosmic-ray event hitting at the scintillator and the light guide based on widths of pulses.

Fig.5a and Fig.5b shows the width of pulse spectrum of plastic scintillation detector 1, and plastic scintillation detector 2, respectively. Here, the width of pulse is calculated at 10% of peak. The width of pulse caused by the light guide has 10 ns, while the width of pulse caused by the scintillator has (20-30) ns. Based on those Figs, it is possible to distinguish signals from the scintillator and the light guide.



(a) (b)

Fig.4. Signal from PMT recorded by DRS4 module.
a. Signal response from light guide
b. Signal response from scintillator

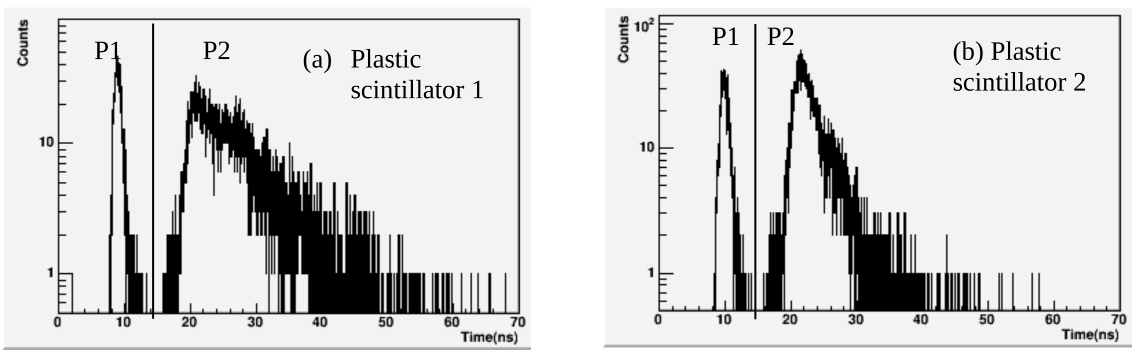


Fig.5. The width of pulse spectrum of each plastic scintillation detector

Fig.6 shows two-dimensional spectrum for the cut applied to the cosmic-ray in the light-guide (P1) and in the scintillator (P2). The spectrum shows the width of pulse in ns on the x-axis, and the deposited energy on the y-axis for cosmic-ray. The events marked by P1 region for cosmic-ray in the light-guide and by P2 region for cosmic-ray in the scintillator.

The obtained results observed with cosmic-ray flux determination using two-coincidence plastic scintillation detectors are shown in Fig.7. It clearly demonstrates that the obtained peaks in the spectrum are the high-energy cosmic-ray events (total line). However, in the low-energy region at each scintillator, there are some events coming from cosmic-ray interaction with the light-guide (P1 line). The event-cut based on width of pulse was carried out to eliminate those unexpected events with both low-energy events and high-energy events (which are) overlapping with the cosmic-ray in scintillation spectrum (P2 line). A number of events in this region are 6948 (corresponding to 0.32 count/s and 0.1×10^{-3}count.s^{-1}cm^{-2} of cosmic-ray flux) from 8734 events observed in 6 hour determination.

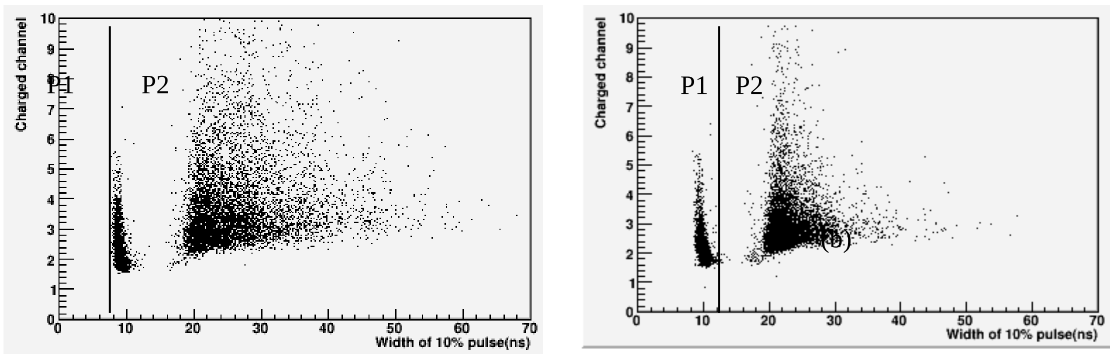


Fig.6. The two-dimensional spectrum for the cut applied to the cosmic-ray in light-guide (P1) and in scintillator (P2).

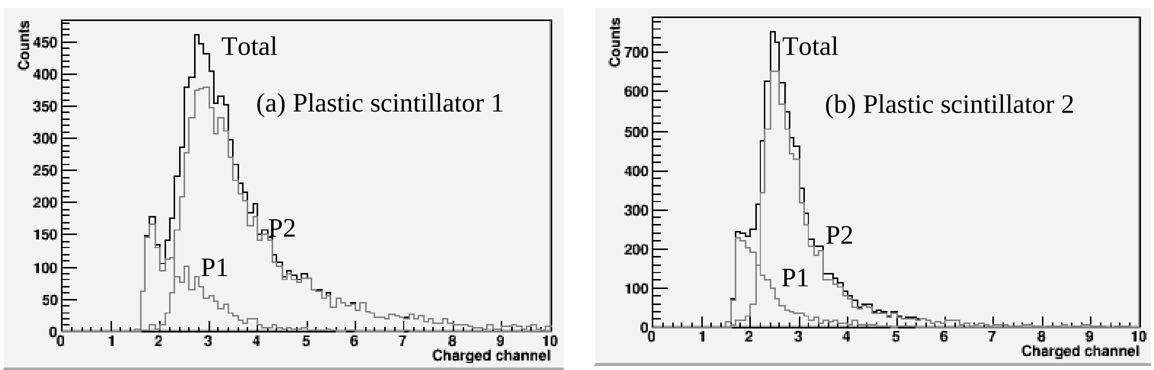


Fig.7. Spectrum for the raw energy in two plastic scintillation detectors

IV. CONCLUSIONS

The measurements of cosmic-ray flux at ground level have been carried out at University of Science, HCMC-Vietnam National University using two-coincidence plastic scintillation detectors and an electric-readout system of 5GSPS which used for triggering system and acquiring energy spectrum. We applied Digital Pulse Shape Discrimination (DPSP) method(s) for cosmic-ray in light-guide and cosmic-ray in the scintillator discrimination based on the width of pulse. The energy spectrum obtained from the scintillators showed the deposited energy peak of high-energy cosmic-ray and interaction of cosmic-ray with the light-guide region and the scintillator region of plastic scintillation detector.

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