Development of the Trigger Module for CANGAROO-III

Kyoshi NISHIJIMA, Tomokazu NAKASE, Hisako MORO and Kazuha URUMA
Department of Physics, Tokai University, 1117 Kita-Kaname, Hiratsuka, Kanagawa 259-1292, Japan
Hideki KUBO
Department of Physics, Kyoto University, Kitashirakawaoiwake-cho, Sakyo-ku, Kyoto 310-8512, Japan
for the CANGAROO-III Collaboration

Abstract

In order to lower the energy threshold for very high energy gamma-ray observations with the CANGAROO-III imaging air Cherenkov telescope to around 100 GeV, we undertook Monte Carlo simulation studies to find the optimum trigger conditions, and manufactured the trigger module for our new camera using complementary programmable logic devices (CPLD). Under the condition of 1kHz data aquisition rate, we found that the simple T2a trigger condition where any adjacent two PMTs have signals over five or six photoelectrons assuming night sky background of 170 to 350 photons/events can realize a trigger efficiency exceeding 25% for gamma-ray energies above 100GeV and 90% above 500GeV respectively. For a four or five photoelectrons threshold, the T3a trigger condition also realize almost the same trigger efficiency. Based on these results we have developed a new trigger module for the CANGAROO-III single telescope.

1. Introduction

Considering the lack of data in the energy range between several tens and several hundreds of GeV and the shape of energy spectra particularly those of active galactic nuclei, an extension of sensitivity to lower energy is one of the key new developments in ground based imaging air Cherenkov telescopes.

One of the important factors preventing the lowering of the energy threshold is the chance coincidence rate due to the night sky background light. Following Jelly's estimation, our imaging camera is expected to receive more than ten billion photons per second, easily making the trigger rate too high for the recording of data if we lower the trigger threshold. Therefore, we need an intelligent trigger system in order to reduce the probability of coincident source and background

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photons.

We undertook Monte Carlo simulation studies to find the optimum trigger conditions. First we select the trigger condition which satisfies our DAQ capacity. Then, we investigate the trigger efficiency of gamma-ray events. Following these results, we manufactured a new trigger module.

Here we report the details of results of the Monte Calro simulation studies and the characteristics of newly developed trigger module.

2. Monte Carlo Simulation

Event generation and analysis has been done using FULL, which is our simulation and analysis tool based on GEANT. Power law energy spectra with photon indices of -2.0, -2,2, -2.5, and -3.0 are assumed for gamma-rays in the energy range between 100 GeV and 500 GeV. Considering the parameters for the CANGAROO-III telescope summarized in table 1., the night sky background is estimated to be about 170 photo-electrons/event for 10 nsec gate width.

Table 1. Parameters for the CANGAROO-III telescope

Diameter of each spherical mirror facet	0.8 m
The number of spherical mirrors	114
Reflectivity of each mirror	70 %
Collection efficiency of the light guide	70 %
Quantum efficiency of PMTs	20 %
Field of view of imaging camera	3.9deg
Gate width	10 nsec

We assume three cases for the night sky background of 170, 250 and 350 p.e./event. These correspond to gate widths of 10, 15 and 20 nsec, respectively. We investigate two types of trigger patterns. One is the Tna trigger where adjacent n PMTs have signals over threshold. The other is the simple *any* n trigger where any n PMTs have signals over threshold. Tested ranges of n are between 2 and 6 for Tna trigger and between 3 and 10 for *any* n trigger, respectively. The threshold for each PMT is set by the number of photoelectrons, which was varied between 1.0 and 6.0.

3. Results of the Trigger Simulation

We first investigate the trigger rate and select trigger conditions which give a trigger rate less than 1 kHz as required by our DAQ system. The trigger

Table 2. Trigger conditions which give a trigger rate less than 1 kHz.

NSB(p.e./event)	Threshold(p.e.)	T*n*a	*any n*
170	3	T5a$\leq$	-
	4	T3a$\leq$	*any* 6$\leq$
	5	T2a$\leq$	*any* 3$\leq$
250	3	T6a$\leq$	-
	4	T4a$\leq$	*any* 8$\leq$
	5	T3a$\leq$	*any* 4$\leq$
	6	T2a$\leq$	*any* 3$\leq$
350	4	T4a$\leq$	-
	5	T3a$\leq$	*any* 5$\leq$
	6	T2a$\leq$	*any* 3$\leq$

conditions satisfying this restriction are listed in table 2.. As is expected, Tna triggers are enough with lower threshold and fewer coincidece of PMTs than *any* n trigger.

Then we investigate the energy dependence of trigger efficiency for gamma-rays for selected trigger conditions. Figs.1. and 2. show the results for the case of a night sky background of 170p.e./event, threshold of 4p.e., and spectral index of 2.2 for *any* n and Tna triggers, respectively. It is clear that the Tna trigger is more effective than the *any* n trigger in lowering the energy threshold for the same PMT threshold. In cases of other PMT threshold and night sky background, the result is the same.

Fig. 3. shows the differential energy spectrum of triggered gamma-rays for the same conditions as above. For a T3a trigger, the energy threshold is expected to be less than 100 GeV.

Fig.4. shows the trigger efficiency of gamma-ray events for the case of T3a trigger in three night sky background cases. In a case of 350 p.e./event as night sky background which corresponds to measuring the gate width by a factor of 2, the trigger efficiency decreases by about 10% compared to the previous case. However this is still sufficient for lowering the energy threshold. From this study, we found that T2a with a 6 p.e. threshold and T3a with a 4 p.e. threshold are expected to realize trigger efficiencies of about 20% and 85% for around 100 GeV and 500 GeV, respectively, even if twice the gate width is assumed.

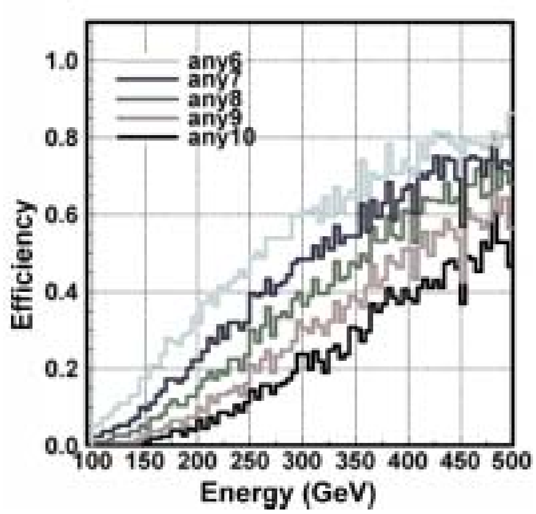

Fig. 1. The trigger efficiency for gamma-rays for *any n* triggers for the case of night sky background of 170p.e./event, threshold of 4p.e. and spectral index of 2.2.

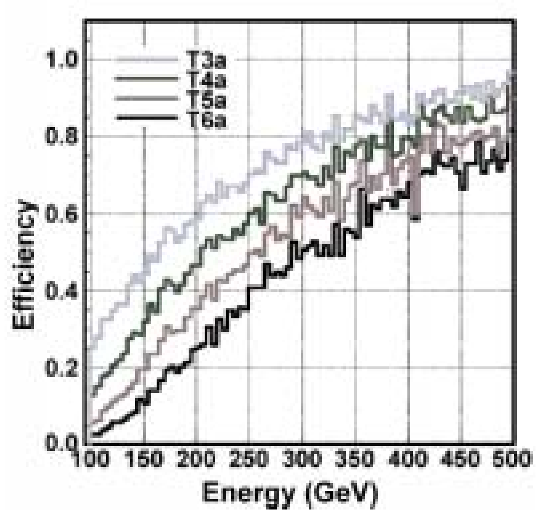

Fig. 2. The trigger efficiency for gamma-rays for Tna triggers. Assumed conditions are the same as the case in Fig. 1.

4. Selection of Trigger Device

Our imaging camera consists of 427 PMTs. Our requirements for the trigger module are that the decision should be made within 60 nsec using 427 signals from the camera within a 30 nsec gate width. We choose a CPLD manufactured by ALTERA as the logic device, because we can set any trigger logic by configuring the CPLD.

First, we simulate the function and timing for the T3a trigger pattern for several CPLD families using the development tool "MAX+plus II". Simulations are done not only for one device but also for a composition of multi devices. Then we tested some of these using a CPLD mounted on a test board to confirm the reliability of the simulation.

As a result, a combination of four EPF10K130EQC240-1 is expected to give the best performance for a decision time less than 30 nsec. Its fluctuation is less than 15 nsec and this is sufficient for our requirements.

5. Trigger Module

We manufactured the new trigger module using four CPLDs on a single board. The camera is divided into four overlapping areas corresponding to each of the CPLD devices. There are 427 TTL inputs from the front-end modules.

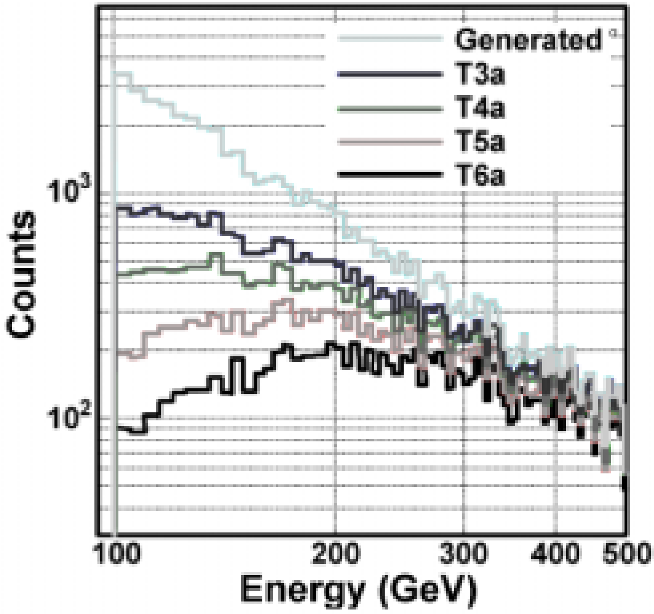

Fig. 3. The differential enegy spectrum of triggered gamma-rays for the same parameters assumed in Fig. 2.

Considering the overlap at least for T3a, those signals are distributed into four CPLDs. Trigger logic is set through configuration of the ROM. Trigger outputs of NIM signal are transmitted to the interrupt register and scaler.

6. Summary

In order to find the optimum trigger conditions, we manufactured the trigger module for our new camera using complementary programmable logic devices (CPLD). Under the condition of 1kHz data aquisition rate, choosing four or five photoelectrons threshold, the T3a trigger condition realizes almost the same trigger efficiency. Based on these results, we have developed the new trigger module for CANGAROO-III single telescope.

We developed the new trigger module using CPLDs in order to lower the energy threshold for very high energy gamma-ray observations with the CANGAROO-III imaging air Cherenkov telescope. Following the Monte Carlo simulation studies, we found that the simple T2a trigger condition where any adjacent two PMTs have signals over proper photoelectrons can realize the trigger efficiency of gamma-rays exceeding 25% above 100GeV and 90% above 500GeV respectively.

The first trigger module is set to T3a logic and its function and timing have been tested in the laboratory. The results are consistent with expectations.

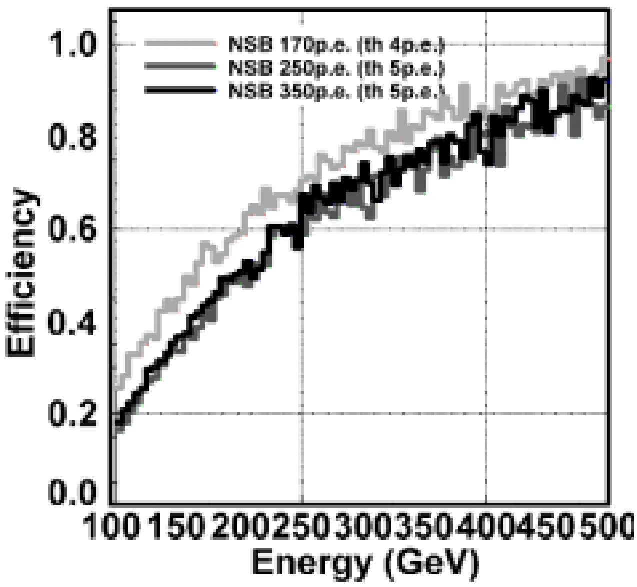

Fig. 4. The trigger efficiency of gamma-ray events for a T3a trigger in three night sky background cases.

Final tests at the observation site will be carried out in November, 2002.