Performance of 10 - 100 GeV Gamma-ray Camera, "CheSS" For The SUBARU Optical-infrared Telescope

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Abstract

We developed the gamma-ray camera for the SUBARU infrared-optical telescope[9], named "CheSS" (Cherenkov light detecting System on Subaru). CheSS was designed based on the Imaging Atmospheric Cherenkov Technique (IACT) which has been established by detections of high energy gamma-ray sources in the last decade. According to our Monte Carlo simulation, the energy threshold of CheSS for the Crab reaches 30 GeV at zenith angle of 10 degrees, and the expected sensitivity for the unpulsed component may reach $\sim 10\sigma$ level and more for pulsed one during 10 hours of on-source pointing.

1. Introduction

The energy region between 10 and 100 GeV is quite important to study the emission mechanism of gamma-ray pulsars[7]. There are two classes of models to explain high-energy pulsed emission from pulsars. One class of models, called "polar cap" models, assumes that pulsed emission comes from high-energy electrons accelerated just above the polar of a neutron star. The other class, called "outer gap" models, postulates it comes from such electrons accelerated in potential gaps between open field lines of magnetic field and a neutral sheet in the

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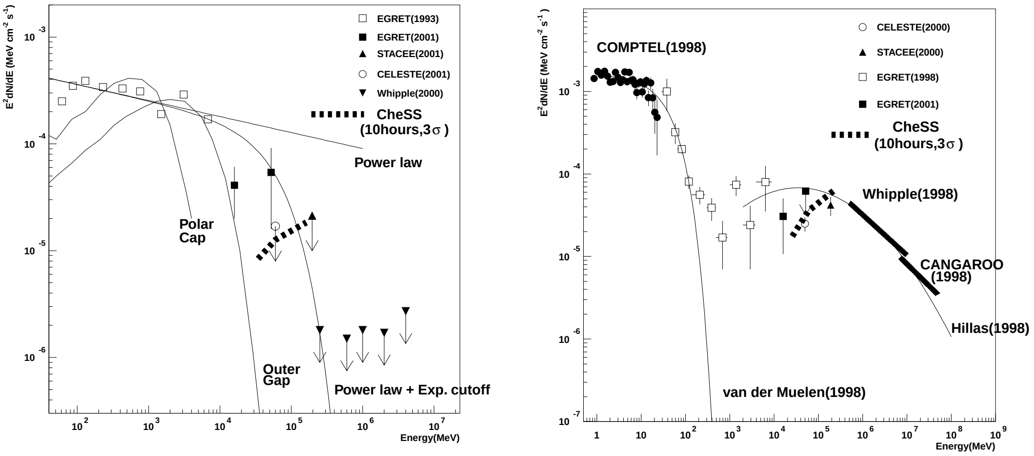

Fig. 1. The energy spectrum of the Crab. The left panel shows pulsed component[11][4] and the right panel shows unpulsed component[6]. Note that 'EGRET (2001)' points[2] are based on rough estimate. Also shown are the expected 3 sigma sensitivities of CHESS in 10 hours of observation. Just only ON-OFF chopping (no imaging analysis) enables to detect 30 GeV gamma-ray from the Crab pulsar/nebula.

outer magnetosphere of a pulsar. Both two types of models can explain the wide-band pulsed emission below the GeV region fairly well, but they predict clearly different behaviors above the 10 GeV region. All polar cap models predict very steep cutoff at lower energies than those predicted by outer gap models, which can be distinguished by observations in the 10 GeV to 100 GeV range. Figure 1. shows the predictions of gamma-ray emissions from the Crab by these two pulsar models, and the observation results of various detectors.

Although ground-based detectors can achieve large collection areas, it is difficult for them to detect Cherenkov light caused by gamma-ray showers below 100 GeV since the photon density is too small. According to our simulation, however, Cherenkov light density caused by cosmic rays is 4 times larger at high altitude (4000m) than at sea level. This result means that the combination of "high altitude" and "large mirror" enable us to observe the 10 GeV energy region. The SUBARU optical-infrared telescope is located on the top of Mt. Maunakea, altitude 4200m. Our gamma-ray camera, named "CheSS" (Cherenkov light detecting System on SUBARU), was designed to investigate this unexplored region by SUBARU's 8.2m fine mirror.

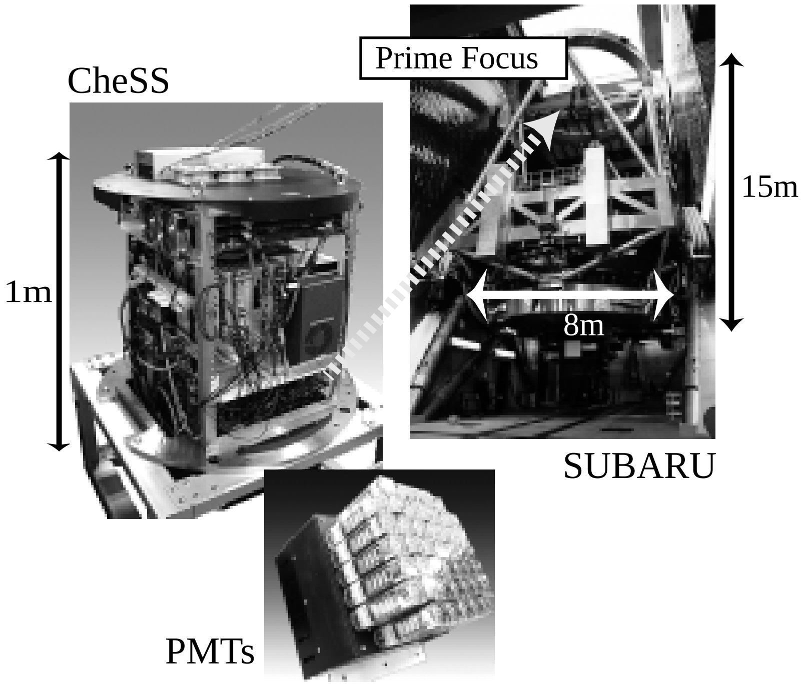

Fig. 2. CheSS Overview.

2. Instruments

CheSS is installed on the prime focus of SUBARU(Fig. 2.). Detailed infomation about instruments is described in [1].

Important parameters of the CheSS and SUBARU are following: FOV is 0.75deg, Number of PMTs is 44, Focal length is 15m, and Mirror diameter is 8.2m. In the simulation, we take into account the wavelength dependency of the quantum efficiency of PMTs, reflectivity of mirror, and transmittance of correction lens which is set in the front of the prime focus.

3. Monte Carlo Simulation

We have simulated air showers generated by gamma-rays, protons, and electrons using CORSIKA[8] package.

At first, we calculate how much the night sky background makes effect on the observation of CheSS. According to Jelley's data[10], the night sky background is estimated to be about 6 photoelectrons per event.

We simulated the energy spectrum detected by CheSS under the night sky background as shown in Fig.3. (triangle). In this simulation, we used the extrapolated flux of the Crab pulsar/nebula from the GeV region[5], and the observed

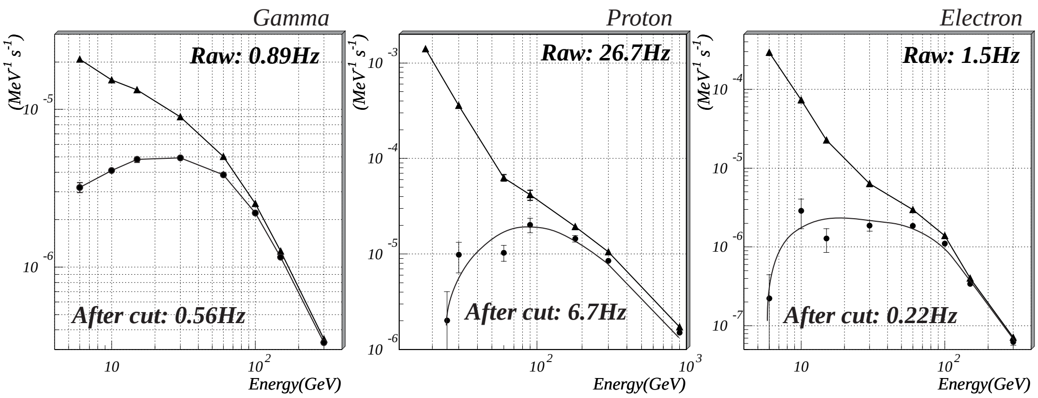

Fig. 3. Expected energy spectrum of SUBARU with CheSS under the night sky background. Left panel: gamma. Middle panel: proton. Right panel: electron. Triangle points means expected energy spectrum without any cut. Circle points means expected energy spectrum after ADC cut to reject the night sky background.

fluxes of electrons[12] and protons[3] above 10 GeV. Then we set the trigger condition, “ The event trigger is generated when two or more PMTs detects three or more photo-electrons within 20 nsec”, which was also used in the observation. Expected trigger rate which is estimated from the energy spectrum is about 26.7 Hz for protons, 0.9 Hz for gamma-rays, 2.2 Hz for electrons. Thus the total trigger rate was expected to be about 30Hz, which was consistent with that in the real observation in December 2001(section 4.).

In order to reduce the night sky background and improve the signal to noise ratio, we rejected the events if the sum of photo-electrons is less than 7 photoelectrons. After this cut, we obtained the energy spectrum shown in Fig. 3. (circle), and the energy threshold for gamma-ray flux is about 30GeV. The total expected number of gamma-rays in 10hours observation is 8×10^3 counts (backgrounds - proton and electron - are 2.5×10^5 counts in total). Thus, the expected sensitivity for the unpulsed component possibly reaches $\sim 10\sigma$ level and more for pulsed one for 10 hours of on-source pointing (Fig. 1.). In the actual analysis, more cuts will be applied, and the signal to noise ratio have to be improved to get clean signals.

4. Observation of the Crab

Due to the narrow field of view of this observation, separation ability of Imaging parameters was considered not to be enough. Then we adopted the chopping observation. The telescope was pointed in the direction of the Crab

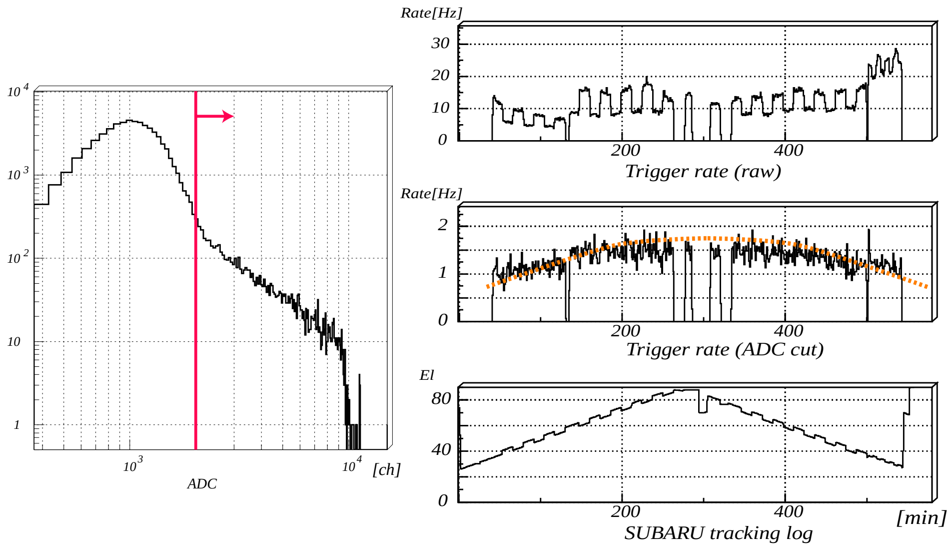

Fig. 4. Left: Distribution of total ADC channel for each event observed in December 2001.This figure was made from all off-source data over 20 degree of zenith angle. The dotted-line was used by "ADC-cut" (2000channel). The drop-off around 10000 channel is due to the saturation of hardware. Right: top panel shows the trigger rate without any cuts, and middle panel shows trigger rate after ADC-cut. We can find the zenith angle dependency (compare with bottom panel which shows telescope movements).

and three different OFF points every 5, 10 and 12 minutes away from the Crab, in which chopping interval was changed in order to reduce the systematic error. Observation was carried out three days (17, 18, and 19th December 2001), and total observation time was about 12 hours for on-source and off-source runs, respectively.

Trigger rate at each OFF point were distributed between 5 Hz and 40Hz, which depends on the condition of the night sky background. Figure 4. shows the distribution of total pulse height. We can see the hump around 2000 channel which is attributed to the night sky background, then the data over 2000 channel was used to eliminate the night sky background ("ADC cut"). After the ADC cut, trigger rate became 1.4$\pm$0.5 Hz, and show the dependency of zenith angle appears as shown Fig. 4. It seems a clear evidence that we detect air shower event on altitude 4000m. Most of all these events are, however, caused by protons. Now we are selecting the gamma-rays.

5. Summary

We developed the gamma-ray camera for the SUBARU prime focus, using Imaging Atmospheric Cherenkov Technique. According to our simulation, CheSS has a possibiliy to detect gamma-rays in the 30 - 100 GeV region. The expected sensitivity for the unpulsed component of the Crab nebula possibly reaches $\sim 10\sigma$ level and more for pulsed one during 10 hours on-source pointing.

On 17th, 18th, and 19th December 2001, the SUBARU telescope with CheSS was pointed in the direction of the Crab. Total observation time was about 24hours(ON-OFF total). Now the data analysis is underway.

Acknowledgments

The authors express their thanks to all the staffs of SUBARU telescope, NAOJ. A.A and R.O are financially supported by the Japan Society for the Promotion of Science. Part of this study was supported by the Yamada foundation.

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