Performance of Newly Developed Hard X-ray Polarimeter with Multianode PMT

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Abstract

We designed a Compton scattering type polarimeter using a multianode photomultiplier and segmented scintillators. Though optical cross talk for the multianode photomultiplier is observed, we succeeded in much reducing the affection. Considering results of basic experiments, we carried out computer simulations to estimate the basic performance of the polarimter. We recognized that the polarimeter can obtain the modulation factor of 48 % and the detection efficiency of ∼13 % in the energy range between 40 keV and 300 keV.

1. Introduction

The X-ray astronomy has been much advanced with the observation of energies, timing, and imaging. On the other hand, the observation of the polarization has not been carried out for 20 years because it is difficult to develop polarimeters with high sensitivity. In particular, polarization observation is more important in hard X-ray region where non-thermal emission such as synchrotron radiation is dominant. So we are challenging the development of a novel Compton scattering type hard X-ray polarimeter sensitive to the energy range from 40 keV to 300 keV. The differential cross section for Compton scattering is expressed by Klein-Nishina equation of Eq.1.

$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}\frac{k^2}{k_0^2}\left(\frac{k_0}{k} + \frac{k}{k_0} - 2\sin^2\theta\cos^2\phi\right) \tag{1}$$

r_0 : classical electron radius
θ : scattering angle for the incident direction
ϕ : scattering azimuthal angle for the polarization vector of incident X rays
k_0 : the energy of incident X ray
k : the energy of scattered X ray

Since the azimuthal angle for Compton scattering depends on the polarization vector of incident X rays, the information on the polarization can be obtained by detecting the azimuthal direction of the scattered X rays.

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The sensitivity of polarimeters can be expressed by a parameter of Minimum Detectable Polarization (MDP). It is determined with the following Eq.2. As shown in this equation, it is important for polarimeters to obtain both high analyzing power for polarization (modulation factor) and high detection efficiency. However, it is in general very difficult to improve the two parameters simultaneously. So we designed a polarimeter with high modulation factor and moderate detection efficiency, using a multianode photomultiplier (MAPMT) and segmented two kinds of scintillators. We will report the design and the basic performance.

$$MDP = \frac{429}{A\eta SM}\sqrt{\frac{A\eta S + B}{T}} \tag{2}$$

A	:	Detection Area [cm^2]
S	:	Count rate of signal [$sec^{-1}cm^{-2}$]
η	:	Detection Efficiency
M	:	Modulation Factor
B	:	background rate [sec^{-1}]
T	:	observation time [sec]

2. Detector

The polarimeter consists of many unit counters. The unit counter consists of the MAPMT H8500 with 8×8 anodes, 36 pieces of plastic scintillators, and 28 pieces of CsI(Tl) scintillators. The plastic scintillators and the CsI(Tl) scintillators are mounted on the central region and the rest region of the MAPMT, respectively. The size of each scintillator is $5.5 \times 5.5 \times 40$ mm^3. The size of the MAPMT is $52 \times 52 \times 33$ mm^3 including the breeder and the size of each anode is 6.0×6.0 mm^2. The schematic view of the unit counter is shown in Figure.1. As incident X ray enters one of the plastic scintillators, the X ray is scattered with Compton scattering. As the plastic scintillator has low atomic number, hard X rays are easy to be scattered. The scattered X ray is absorbed by one of the CsI(Tl) scintillators. Detecting both the scattering position and the absorption position, the information on the polarization of incident X rays can be obtained. Because the scintillators are segmented, the scattering azimuthal angle can be fairly determined.

Since the deposited energy in the plastic scintillator is only a several keV for the incident hard X rays of several tens keV, the key technology for this polarimeter is to read out the low energy deposit from the plastic scintillator. Actually, we succeed in detecting the energy deposit of 5.9 keV from the plastic scintillator with 87 % efficiencies. On the other hand, CsI(Tl) scintillator emits many photons because the energy deposit in the CsI(Tl) is much higher than that in the plastic scintillator and the CsI(Tl) has high light yields. Therefore, the

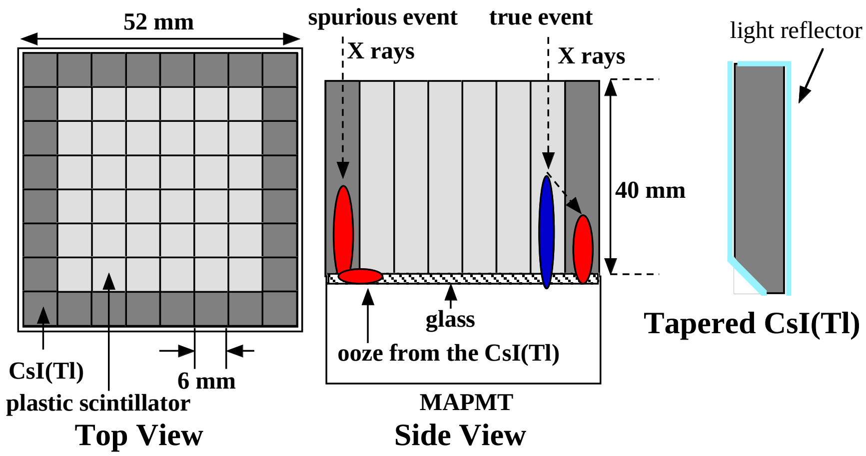

Fig. 1. The left figure and the central figure show the top view and the side view of the unit counter, respectively. The examples of true events and spurious events are also drawn. The right figure shows the schematic view of tapered CsI(Tl) actually used.

light ooze from CsI(Tl) scintillators to the channels for the plastic scintillators can be serious problem. It is called sprious events (see Figure.1.). So we reduced the affection with the following three methods. At first, we applied the tapered CsI(Tl) shown in Figure.1. With this method, the direct ooze of the light from the CsI(Tl) scintillator was shut. Even so, the ooze through the surface glass of the MAPMT remained. So we improved the circuit for the unit counter to figure out this problem. The schematic view of the circuit is shown in Figure.2. As shown in this figure, the shaping time of the shaping amplifier for the plastic scintillator and the CsI(Tl) scintillator is different. The decay time of the light from plastic scintillators is much shorter than that from CsI(Tl) scintillator. So the pulse due to the ooze from the CsI(Tl) to the channel for the plastic scintillator is much attenuated with fast shaping time. Moreover, the arrival time of the signal from each channel is measured with the timing circuit. For spurious events, there is no apparent time difference of two signals from the adjacent channels, while there is the time difference of $\sim$20nsec for true events. It is because the signal from the plastic scintillator is much faster than that from the CsI(Tl). So the sprious events were rejected with the timing circuit. With three methods, the sprious events due to the ooze has been successfully reduced to 6 %.

3. Computer Simulations

With computer simulations, the modulation factor and the detection efficiency were calculated for each energy taking into account the detection efficiencies of recoil electron in the plastic scintillator and the affection of the light ooze. The

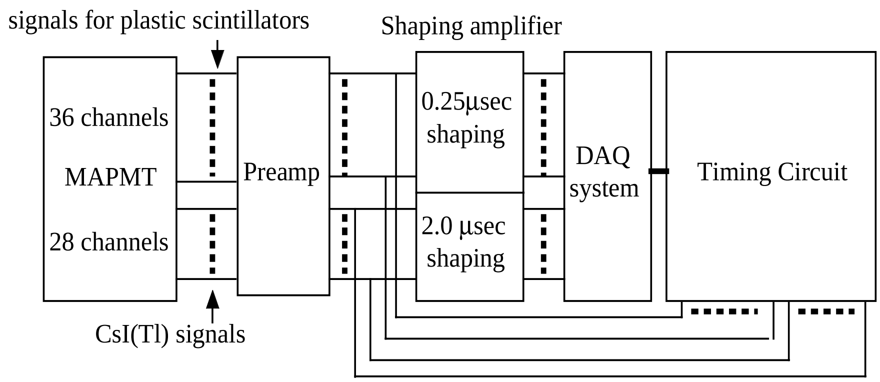

Fig. 2. The schematic view of the electronic circuit for the unit counter. The signal from each anode is fed to preamplifiers and the output is divided by two. The one signal is fed to shaping amplifiers and the other one is fed to discriminators. The shaping time of the shaping amplifier is 2μsec for the channels of CsI(Tl) scintillators and 0.25μsec for those of plastic scintillators, respectively. The output from the discriminator is used for measuring the difference of the arrival time for each signal.

results are summarized in Table.1. As shown in this table, the polarimeter can

Table 1. The modulation factor and the detection efficiency for the designed polarimeter. For the detection efficiency, we take into account the detection efficiencies of the recoil electron in the plastic scintillator and the light ooze.

Energy [keV]	60	100	150	200
Modulation Factor [%]	48	48	48	47
Detection Efficiency [%]	12	15	14	12

obtain the detection efficiency of ∼13 % and the modulation factor of 48 % in the energy range between 40 keV and 300 keV.

4. Conclusions

We designed the polarimeter using the multianode photomultiplier and the two kinds of segmented scintillators. With the three methods, the ooze of the light from the CsI(Tl) scintillator to the channel for the plastic scintillator has been reduced to 6 %. From the results of computer simulations, it was recognized that the polarimeter can obtain the detection efficiency of 13 % and the modulation factor of 48 %. We will confirm the performance using polarized hard X rays in KEK and then carry out the balloon-borne experiment in autumn 2003 with one unit counter to confirm the performance at the ceiling of the atmosphere.