Study of GSO scintillator for upgrade of LHCf detectors

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Abstract: Gd_2SiO_5 (GSO) scintillator has very excellent radiation resistance with fast decay time and large amount of light yield. The radiation hardness of GSO was examined by using Carbon ion beams at Heavy Ion Medical Accelerator in Chiba (HIMAC). Through two nights of irradiation a GSO scintillator was received 7×10^5 Gy of total dose and no decrease of light yield was observed. On the other hand an increase of light yield by 25% was observed. The increase is marginally proportional to the total dose at the rate of 0.025%/Gy and it is saturated at 1 kGy. Recovery to the initial light yield was also observed during the day between two nights. The time scale of recovery is about 15,000 seconds. In case of the LHCf experiment, very forward region (pseudo-rapidity $\eta > 8.4$) experiment at the LHC, the irradiation rate is expected to about 100Gy for 10nb^{-1} of data taking at $\sqrt{s} = 14$TeV proton-proton collisions. Expected increase of less than a few % will not be a big problem for the LHCf experiment.

Keywords: GSO scintillator, Radiation Resistivity, LHC

1 Introduction

The LHCf experiment is an experiment dedicated to verify the interaction processes between extremely high energy cosmic rays and the atmosphere by using LHC (Large Hadron Collider) [1]. The LHCf succeeded to obtain data at $\sqrt{s}$ = 7 TeV p-p collision in 2010 and uninstalled the detectors from the LHC.
The current LHCf detectors are composed of EJ260 plastic scintillators. The decrease of light yield of the EJ260 scintillator by the radiation exposure was observed [1], and it affects to the LHCf measurement in energy estimation. Thus, the LHCf detectors have to be upgraded for LHC $\sqrt{s}$ = 14 TeV p-p collisions planed after 2014. Gd_2SiO_5 (GSO) scintillator is known to have very excellent radiation resistance with similar decay time and amount of light yield to EJ260. Because of these features, GSO will be used to upgrade the current LHCf detectors. The features of GSO were examined by using heavy ion beams at the Heavy Ion Medical Accelerator in Chiba (HIMAC). The radiation hardness of GSO was measured by using 290MeV/n Carbon ion beams (Section 2). The linearity of PMT R7400 that were used in the current LHCf detectors for the large light yield of GSO with a ^{132}Xe beam was also tested at HIMAC (Section 3).

2 Radiation hardness of GSO

The radiation hardness of GSO scintillator was examined by using Carbon (^{12}C) beams with energy of 290 [MeV/n]. It was already examined by previous measurements with gamma-rays [2] [3] and protons [4]. In this study, the ion beam (Carbon) was used.

Irradiation was continued over two nights in HIMAC. For the first night, the irradiation rate increased step-by-step (10^{6-9} particle/spill). For the second night, constant high rate (10^9 particle/spill) was used. In a day between the two nights, the recovery of light yield was examined.

2.1 Setup of the experiment

The ^{12}C beam was collimated within ϕ=10mm by the 200mm thick aluminum collimator. The number of beam particles passing through the GSO scintillator were counted by integrating the current from the ionization chamber (IC) that has two 2mm air-gaps and was placed behind the collimator. It was also used to monitor the beam intensity not only to calculate the exposed dose of GSO. The beam profile was monitored with a profile monitor placed behind the ionization chamber.

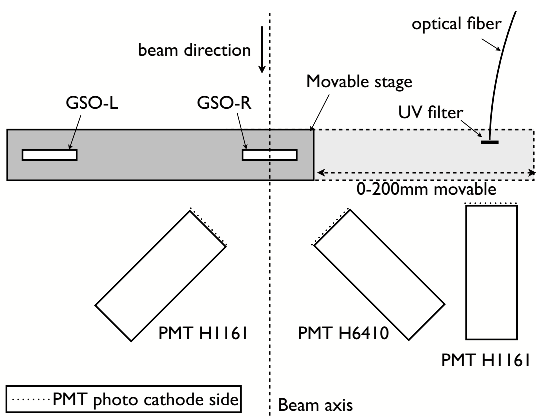

Figure 1: The experimental setup of GSO radiation hardness test inside dark box : dashed line indicate the beam axis

As shown in figure1,two GSO scintillator plates (32mm × 32mm × 1mm^{t}) were set on the movable stage (Sigma-Koki SGSP26-200: movable 0-200mm). One was placed on the beam axis (GSO-R), and the other was placed far from the beam axis (GSO-L) as shown in figure1.

The radiation hardness was evaluated by its response to the very low intensity(10^3 particle/spill) of ^{12}C beam (probe beam) for each GSO sample. The interval of a single spill was 3.3sec and the particles were extracted in 1.2sec. The light yield was measured by the two PMTs (Hamamatsu H1161 for the left "PMT-L" and Hamamatsu H6410 for the right "PMT-R") for redundancy. The response of GSO-R to the probe beam was measured immediately after the high intensity irradiation was stopped. The GSO-L was moved to the beam axis by using the movable stage, and the response of GSO-L to the probe beam was measured as a reference of no irradiation.

The exposures and measurements were repeated ten times.

2.2 Result of radiation hardness

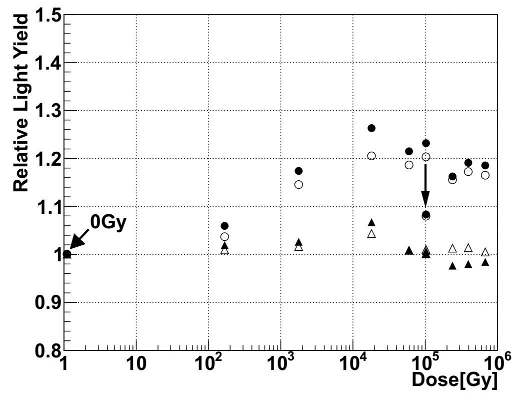

Figure 2: The change of GSO light yield as a function of absorbed dose: The closed (open) markers indicate the yield of PMT-L (PMT-R). The circle (triangle) markers indicate the light yield of GSO-R (GSO-L). The arrow around 10^5 Gy shows a decrease of light yield in the daytime between two nights.

GSO-R has received total 6.84×10^5 Gy of exposed dose in this experiment. The relative light yield as a function of dose is shown in figure2. The closed markers indicate the output of PMT-L while the open markers indicate that of PMT-R. The circle (triangle) marker indicate the light yield of GSO-R (GSO-L). No decrease of light yield but the increase of light yield was observed. The amount of increase reached up to $\sim 25\%$. Only the output of GSO-R shows increasing tendency, while the output of GSO-L doesn't show such tendency. Even considering the difference between PMT-R and PMT-L as a systematic uncertainty, the output of GSO-R was significantly increased. In figure2, an arrow around 10^5Gy means the recovery during the day between the experimental nights.

The increase was also reported in a previous measurement using ^{137}Cs gamma-ray source[2]. In addition, they reported that the increase was proportional to irradiation rate as shown in figure 3. Triangle markers show the result from the previous experiment. Three pairs of circle markers (open and closed) correspond to our data carried out at the lowest beam intensity. In lower dose rate, a good agreement with the previous gamma-ray result with a coefficient of proportion 0.025%/Gy. However the increase of light yield seems to saturate beyond a certain beam intensity.

The effect of the increase to the LHCf detectors can be estimated from this result. In $\sqrt{s} = 14\,\mathrm{TeV}$ run at LHC, the total dose is expected to be 100 Gy after integrating the luminosity up to $10\,\mathrm{nb}^{-1}$ that is required by LHCf. A few % of increase expected after this dose is visible with respect to the LHCf resolution, but may not have critical effect. A recovery discussed below will also moderate the increase.

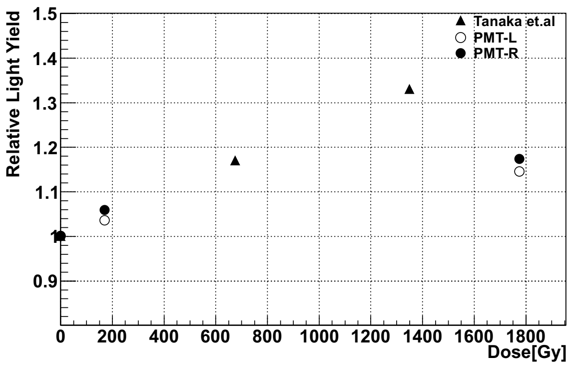

Figure 3: Total dose vs. increase of light yield. Triangle markers show the result of reference[2]. Circle markers show the result of this study.

2.3 Recovery measurement

As mentioned above, it was observed that once the irradiation to GSO was stopped the light yield recovers with the time passage. To obtain the recovery time scale a change of the light yield was measured during the day time between two nights. The Xe flash lamp Hamamatsu L4633C was used in this measurement. The lamp was set in another dark box next to an experimental dark box with a monitor PMT (Hamamatsu H3164).

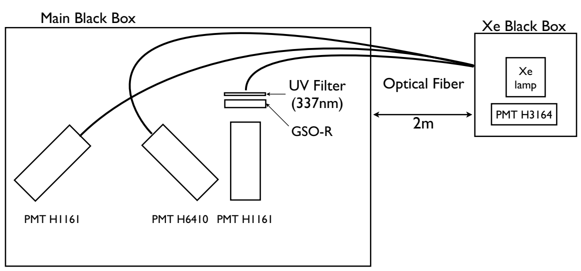

Figure 4: Setup of the recovery test: The light from Xe lamp was lead by using optical fiber to PMTs and GSO-R from Xe dark box.

Figure4 shows the setup of this measurement. Two boxes were connected with the optical quartz fibers. The PMTs used in the irradiation test were also used as monitor PMTs. The UV transmitting filter (337nm) was set in front of GSO-R at the moved position. Only UV component can reach the GSO surface, and it can directly excite GSO (GSO-R). It was already confirmed that UV-light (337nm) can directly excite the GSO scintillator. Its response was measured by the PMT Hamamatsu H1161.

Monitor PMTs were used to cancel the instability of the Xe lamp, and the output signal from the GSO scintillator was corrected by each monitor output signal. The relative light output as a function of the elapsed time from DAQ start timing is shown in figure5. Black, red and blue dots correspond to the signal of GSO divided by the signal of PMT-L, PMT-R and Xe-monitor PMT, respectively.

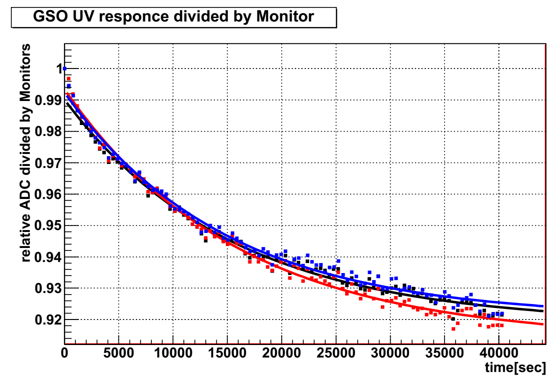

Figure 5: Recovery:Relative light output from GSO-R during the recovery test. Plots and curves with three different colors indicate the results corrected for the Xe instability by using three different PMTs. Black (Red) correspond to the signal of GSO divided by PMT-L (PMT-R) and blue correspond to it divided by Xe-monitor PMT.

To estimate the recovery time scale (τ), data points were fitted with a function $f(x) = \exp(a + bx) + C$. The results are shown as three color lines (black, red, blue).
The time scale given from the fitting is

$$\tau = 1.46 \times 10^4 \sim 1.59 \times 10^4 \ \ [\text{second}] \qquad (1)$$

It corresponds to about 5 hours and is too long time compared with our aforementioned measurements that were only about ten minutes. However, a faster time scale recover was also observed during the run measuring response to the probe beam just after exposure.

3 Linearity of PMT R7400

PMT R7400 (Hamamatsu) used in the current detectors will be also used in the upgraded detectors. The linearity of PMT R7400 for GSO light output is very important to keep the wide dynamic range from 100 GeV to 7 TeV. The linearity was investigated at HIMAC by using ^{132}Xe ion beam. The experimental setup is shown in Fig6.

The light output of GSO scintillator was measured for various impinging ion energies and high voltages using aluminum degraders. The aluminum degrader was used to adjust beam energy by changing the thickness of the aluminum. In this experiment, ^{132}Xe beam with E = 290 MeV/u was used. The PMT H6410 (Hamamatsu) that have a good linearity was used for monitoring the light from the GSO scintillator. The result is shown in Fig7. Horizontal axis represents the ADC value of the PMT H6410 and vertical axis correspond to ADC value of PMT R7400. As a result, the PMT R7400 has a good linearity

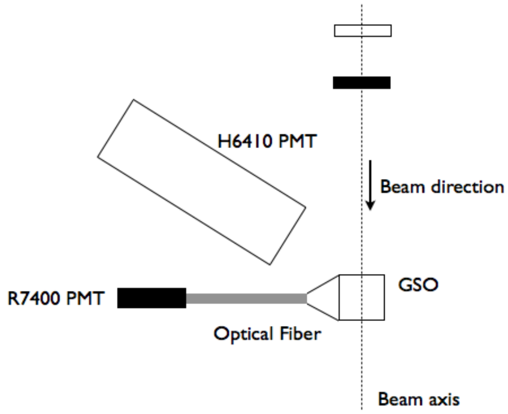

Figure 6: Experimental Setup:GSO was excited by Xe beam and the light output was measured by two PMTs simultaneously.

within ± 1% up to the signal level corresponding to energy deposit of 6 TeV EM shower maximum in the LHCf calorimeter.

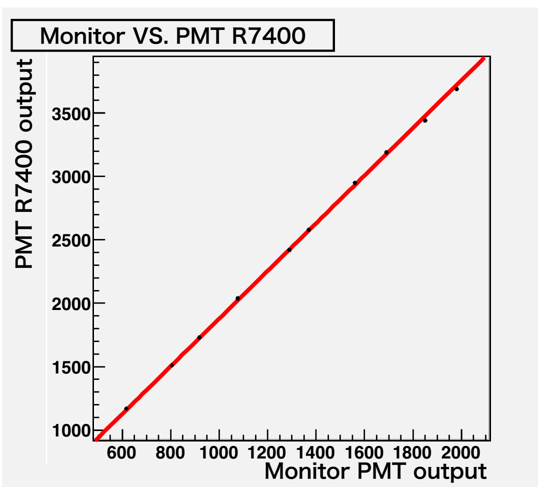

Figure 7: Linearity of PMT R7400:The red line shows the linear fit result. The deviation from the linear fitting is within ±1%

However, for $\sqrt{s} = 14$ TeV run at LHC, the linearity must be checked against larger signal corresponding to energy deposit of 7 TeV EM shower. Further test using Nitrogen laser is ongoing, and will be shown in the ICRC poster session.

4 Summary

For the upgrade of the LHCf detectors in respect of radiation resistivity, the features of the GSO scintillator were examined. The radiation hardness of the GSO scintillator was checked by using ^{12}C beam in HIMAC. After exposure of 7×10^5 Gy, the light yield of GSO did not decrease, but an increase of light yield up to about 25% was observed. This results performed with Carbon ion beam are consistent with previous study performed with ^{60}Co gamma-ray source. The increase depends on the total dose, but it seems to be saturated at the total dose of 1 kGy. The recovery of light yield is also observed and the time scale was estimated to be about 1.5 $\times10^4$ seconds with another faster component.

The linearity of PMT R7400 used in the current LHCf detectors was examined with Xe beam in HIMAC. PMT R7400 has a good linearity within ± 1% up to the signal level corresponding to energy deposit of 6 TeV EM shower maximum in the LHCf calorimeter.

It can be said that GSO is useful from the aforementioned result. A further tests and calibrations are planed in this year.

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