Development Of The Bragg-Peak Position Monitoring System In Particle Therapy By Using e^+ e^- Pair Production Events

Shota KIMURA[1,*], Yusaku EMOTO[1], Kento FUJIHARA[1], Hiroshi ITO[1], Hideyuki KAWAI[1],
Atsushi KOBAYASHI[1], Hiroyoshi MATSUNAGA[2], Takahiro MIZUNO[1], Taichi NAKAMURA[1],
Taiki TANAKA[2], and Takamichi YUZAWA[2]

[1]Graduate School of Science, Chiba University, Chiba, Japan.
[2]Faculty of Science, Chiba University, Chiba, Japan.

I. INTRODUCTION

IN particle therapy, cancer cells can be killed by matching the Bragg-peak position and the cancer position. Conversely, if the position of the Bragg-peak deviates from cancer cells even a little, normal cells could be killed. Thus, in particle therapy, it is important to monitor the Bragg-peak position. To monitor the Bragg-peak position, positron emission tomography (PET) detectors [1], Compton cameras [2] have been studied.

We simulated on GEANT4 Monte Carlo Simulation Code that the distribution of secondary generated gamma rays on the carbon beam therapy and the proton beam therapy. The results of proton beam are shown in Fig.1 and parameters of simulations are on Table I. This simulation shows that gamma rays whose energy is 10 MeV or more are intensively generated at the Bragg-peak position. On the other hand, gamma rays whose energy is around 0.511 MeV are widely distributed in the body. Thus, it is clear that using high energy gamma rays is the best way to monitor the Bragg-peak position.

II. METHODS

Most of the reaction of gamma rays which enrgy is 10 MeV or more are pair production [3]. The momentum direction of the gamma ray can be determined by measuring passing points and energy of e^+ and e^- generated by pair production. The Bragg-peak position can be determined by obtaining the intersection of the trajectory of the gamma ray and the trajectory of the particle beam.

We are developing the system to monitor the Bragg-peak position which can measure pair production events occurred in the detector by gamma rays from irradiation points. Fig.2 is a schematic diagram of the system. This system has 5 parts. The first is the conversion part. This part consists of several layers. Each layer is composed of a La-GPS ($(Gd_{0.75}La_{0.24}Ce_{0.01})_2Si_2O_7$) scintillator plate and wavelength-shifting fibre (WLSF) sheets. The size of the scintillator plate is 300 mm×300 mm×1 mm. The sheets are made by arranging 1500 WLSFs with a diameter of 0.2 mm. The scintillator plate is sandwiched between sheets, where the directions of the sheets are in orthogonally x and y directions. In this part, gamma rays are converted to e^+ e^- pairs and the position where the conversion occured is determined. The second is the tracking part. This part consists of 2 layers of scintillating fibre tracker. Each layer has 6 scintillating fibre sheets for x, x', u, u', v, and v'. Fig.3 shows construction of the layer. The third is the energy measurement part. It measures the energy of e^+ and e^- by plastic scintillator array and SiPM. Each scintillator is the size of 20 mm×20 mm×100 mm. The fourth is the veto counter for bremsstrahlung gamma rays from e^+ and e^-. This part consists of 60 layers of simplyfied detectors of conversion part. WLSF sheet is just on the single surface, and WLSFs are connected to the Photomultiplier tube (PMT) collectively. In this part, 99% efficiency is expected. The fifth is the beam monitor. This part is a small version of the tracking part.

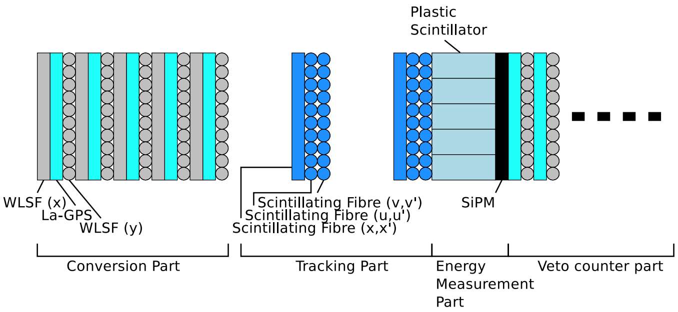
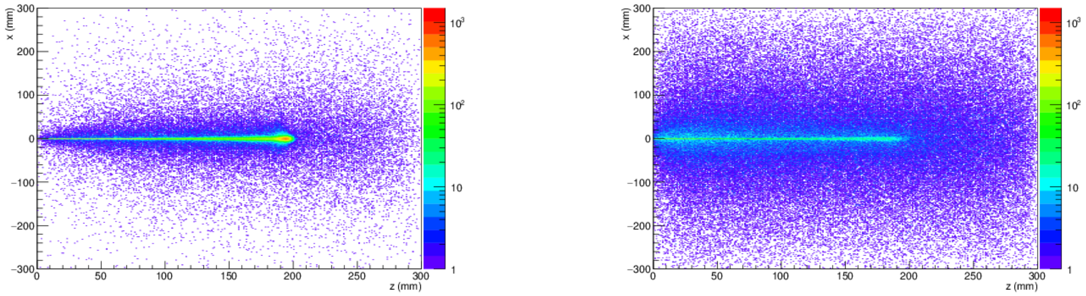


Fig. 2. A schemetic diagram of the system

We confirmed the basic performance of the system by experiments. We measured the number of photoelectrons when the charged particle pass through La-GPS plate scintillator of 1 mm thickness with a WLSF (B-3(300)MJ, ϕ0.2 mm, Kuraray) sheet. We also measured the number of photoelectrons when a beta ray from ^{90}Sr source passes through a scintillating fibre (SCSF-78, ϕ1.0 mm, Kuraray). Just one side of the fibres are connected to the PMTs. Setup of the experiment is on Fig.4.

III. RESULTS

The number of photoelectrons to 0.511 MeV gamma rays was measured as 14.7 in average [4]. We measured 9.7



(a) over 10 MeV

(b) 0.511 MeV (0.420-0.602 MeV)

Fig. 1. Simulated results of the distribution of secondarily generated gamma rays' final scattered points on the proton beam therapy. Horizontal axis means the depth of the body, and vertical axis means the vertical position of the body.

TABLE I
PARAMETERS OF THE SIMULATION

Particle	Proton	Carbon
Beam Energy	175 MeV	290 MeV/n
Physics List	QGSP_BIC_HP G4RadioactiveDecayPhysics	FTFP_BERT_HP G4RadioactiveDecayPhysics
Material of Phantom	G4_MIX_D_WAX (H: 13.4%, C: 77.8%, O: 3.5%, Mg: 3.9%, Ti: 1.4%)	

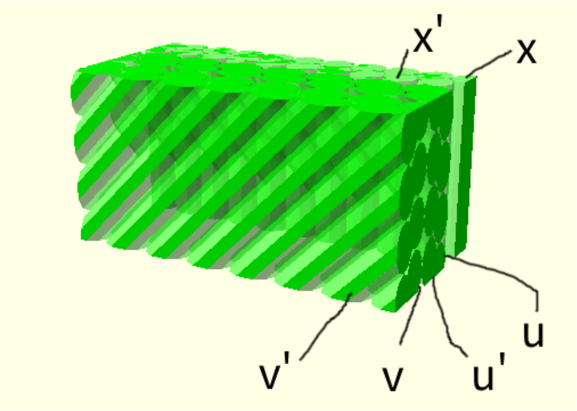


Fig. 3. Construction of scintillating fibre traker.

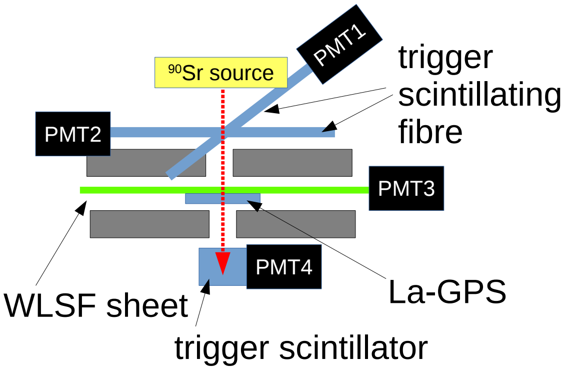


Fig. 4. Setup of the experiment

photoelectrons in average from a WLSF sheet when a beta ray from ^{90}Sr source passes through the La-GPS scintillator plate, and 7.6 photoelectrons in average from a scintillating fibre.

IV. CONCLUSION

The best way to monitor the Bragg-peak position is using gamma ray of several dozen MeV. To monitor with such gamma rays, using pair production events such as our system is the most reasonable. According to the experiment, each component of our system has sufficient amount of luminescence.

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