Development of a Beam Trajectory Monitoring System Using e^+/e^- Pair Production Events

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***Abstract*—In particular therapy, it is important to monitor the Bragg-peak position. It was simulated by Geant4 simulation toolkit that the distribution of secondary generated gamma rays on the carbon beam therapy and the proton beam therapy. This simulation shows that gamma rays whose energy is 10 MeV or more are intensively generated at the Bragg-peak position. 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. The momentum direction of the gamma ray can be determined by measuring passing points and energy of e^+ and e^- generated by pair production. This system has 6 parts. The first is the conversion part. This part consists of several layers. Each layer is composed of a La-GPS ($(Gd_{0.75}La_{0.24}Ce_{0.01})_2Si_2O_7$, C&A Corp.) scintillator plate and wavelength-shifting fibre (WLSF) sheets. 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 occurred 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'. The third is the energy measurement part. It measures the energy of e^+ and e^- by scintillator array and Silicon Photomultiplier. The fourth and fifth is the veto counter for bremsstrahlung gamma rays and for charged particles. The sixth is the beam monitor. By experiment, the number of photoelectrons of La-GPS with a WLSF (B-3(300)MJ, Kuraray) sheet when charged particle passed was measured as 18 and position resolution was measured as 0.403 mm.**

***Index Terms*—particle therapy, pair production, Geant4**

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.

Only high energy gamma rays or fast neutrons are generated only from the beam line. Such gamma rays are generated due to the shell structure of the nucleus. Lower energy gamma rays are also generated from the beam line, however these are also generated from whole body.

II. Simulation

We simulated the distribution of secondary generated gamma rays on the carbon beam therapy and the proton beam therapy on the Geant4 simulation toolkit. The geometry of the simulation is shown on Fig.1, and parameters are shown on Tab.I. The beams are irradiated to the phantom. The phantom is a cylinder with a diameter of 30 cm. The results of the proton beam are shown in Fig.2. 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.

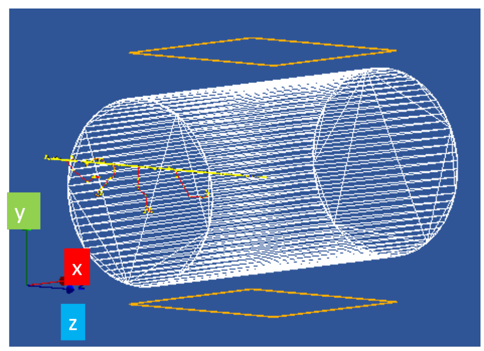

Fig. 1. Geometry of the simulation. The beams are irradiated to the phantom that is represented by a cylinder with a diameter of 30 cm.

III. 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.3 is a schemetic diagram of the system. This system has 6 parts. The first is a VETO counter for charged particles. This part consists of a plastic scintillator plate and a Photomultiplier tube (PMT). The second 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.

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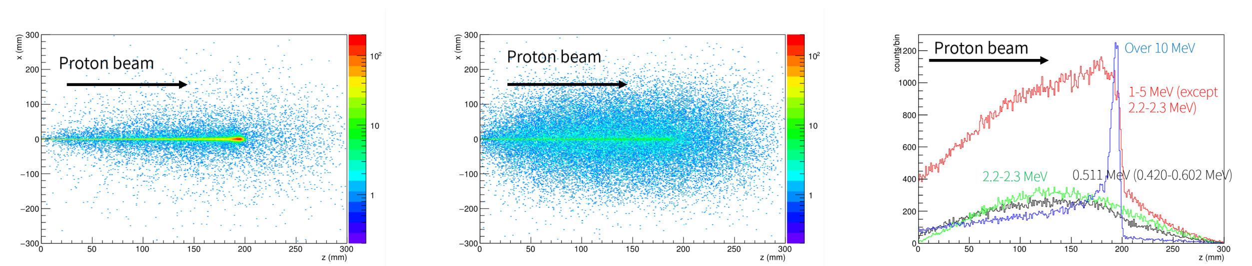
TABLE I
PARAMETERS OF THE SIMULATION

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%)	



(a) over 10 MeV (b) 0.511 MeV (0.420-0.602 MeV) (c) Distribution along z axis

Fig. 2. 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 on (a) and (b). On (c), vertical axis means counts per bin.

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 third 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.4 shows construction of the layer. The fourth is the energy measurement part. It measures the energy of e^+ and e^- by plastic scintillator array and Silicon Photomultipliers. Each scintillator is the size of 20 mm×20 mm×100 mm. The fifth 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 PMT collectively. In this part, 99% efficiency is expected. The sixth is the beam monitor. This part is a small version of the tracking part.

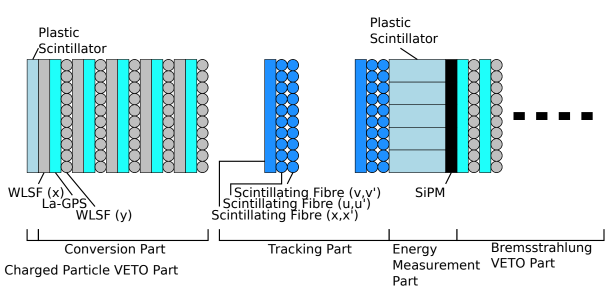


Fig. 3. A schemetic diagram of the system

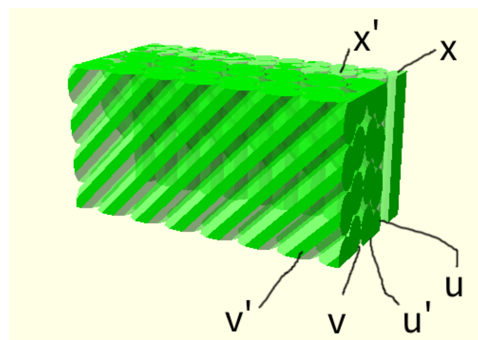


Fig. 4. Construction of scintillating fibre traker.

IV. EXPERIMENTS

We measured the number of photoelectrons when a beta ray from ^{90}Sr source passes through High Growth Rate La-GPS scintillator plate (20 mm×20 mm×0.5 mm, C&A Corp.) with a WLSF (B-3(300)MJ, ϕ0.2 mm, Kuraray) sheet. We also measured the number of photoelectrons when a beta ray passes through a scintillating fibre (SCSF-78, ϕ1.0 mm, Kuraray). Setup of the experiment is on Fig.5.

Position resolution of La-GPS (10 mm×10 mm×0.5 mm, C&A Corp.) with WLSF (B-3(300)MJ, ϕ0.2 mm, Kuraray) are also measured. An illustration of setup is on Fig.6. PMTs are connected to each WLSFs.

V. RESULTS

We measured 22 photoelectrons in average from a WLSF sheet when a beta from ^{90}Sr source passes through the La-GPS scintillator plate, and 7.6 photoelectrons in average from a scintillating fibre. The distribution of the number of photoelectrons and estimated distributions of the number of photoelectrons when WLSF sheet is on the both side of the scintillator plate (both side reading) and of the number of

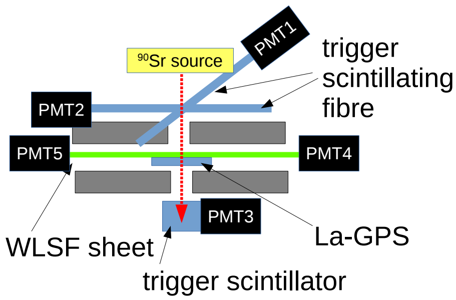


Fig. 5. Setup of the experiment

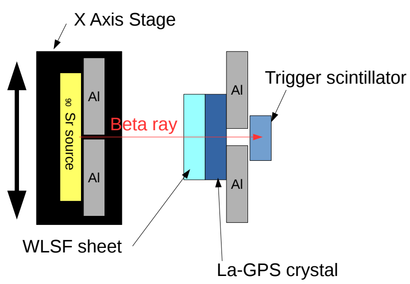


Fig. 6. Setup of the experiment

photoelectrons when two charged particles (e^+ and e^-) pass through the scintillator plate with both surface reading are on the Fig.7. This figure shows that two particles passing and one particle passing can easily distinguish with both side reading.

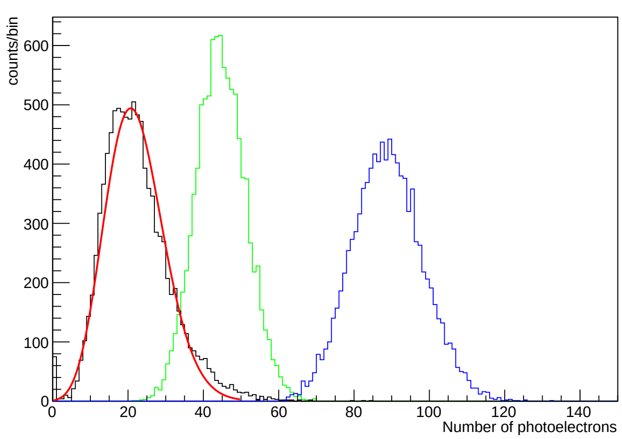


Fig. 7. The distribution of the number of photoelectrons (black) and estimated distributions of the number of photoelectrons with both side reading (green) and of the number of photoelectrons when two charged particles (e^+ and e^-) pass through the scintillator plate with both surface reading (blue).

A one of distribution of reconstructed positions is shown on Fig.8. Position resolution was measured as 0.403 ± 0.082 mm.

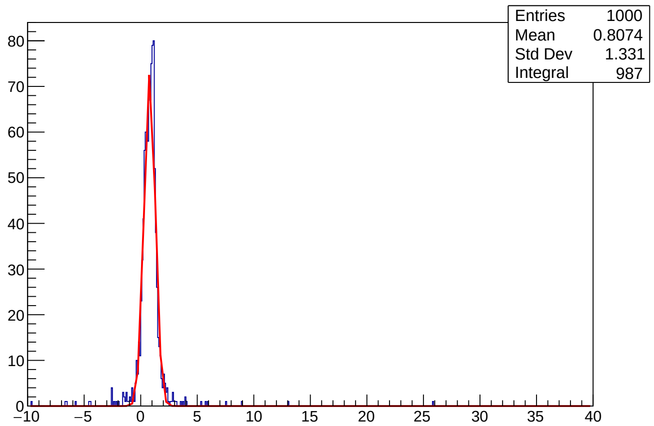


Fig. 8. Distribution of reconstructed positions

VI. 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 and conversion part's position resolution is 0.403 mm.

VII. Acknowledgement

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