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

Shota KIMURA, Yusaku EMOTO, Kento FUJIHARA, Hiroshi ITO, Hideyuki KAWAI,
Atsushi KOBAYASHI, and Takahiro MIZUNO
Graduate School of Science, Chiba University, 1-33, Yayoi-cho, Inage-ku, Chiba, 263-8522, Japan

Abstract

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. Some of its basic performances were measured.

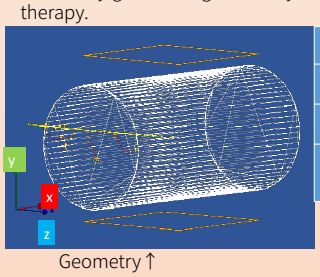
Introduction

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 detectors [1], or Compton cameras [2] have been studied.

Only gamma rays over 10 MeV 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.

Simulation

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.

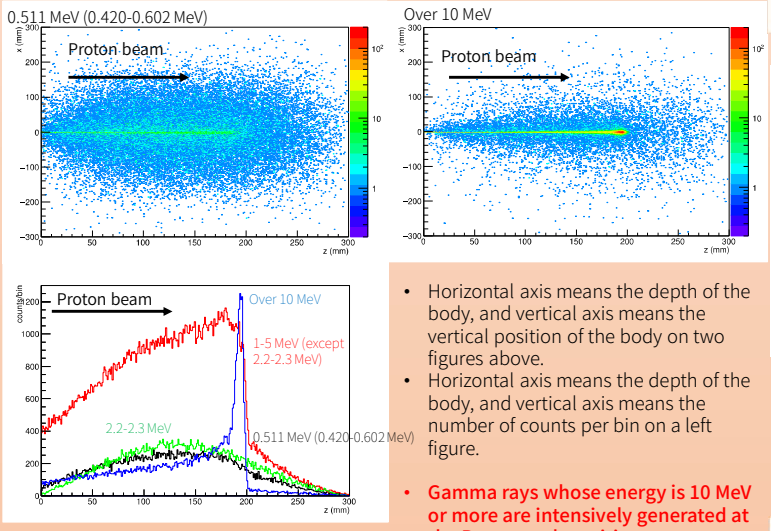


Geometry ↑

Particle	Carbon	Proton
Beam Energy	290 MeV/n	175 MeV
Physics List	FTFP_BERT_HP G4RadioactiveDecayPhysics	QGSP_BIC_HP G4RadioactiveDecayPhysics
Material of Phantom	G4 MIX D WAX (H: 13.4%, C: 77.8%, O: 3.5%, Mg: 3.9%, Ti: 1.4%)	

Parameters ↑

Results (Proton beam)

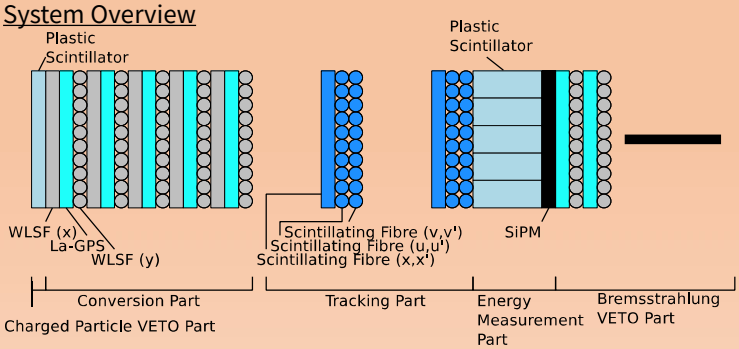


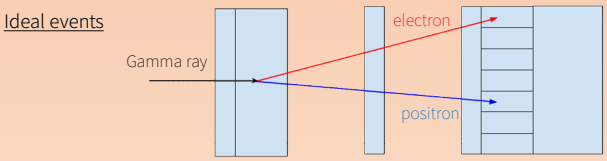
- Horizontal axis means the depth of the body, and vertical axis means the vertical position of the body on two figures above.
- Horizontal axis means the depth of the body, and vertical axis means the number of counts per bin on a left figure.
- **Gamma rays whose energy is 10 MeV or more are intensively generated at the Bragg-peak position.**

Method

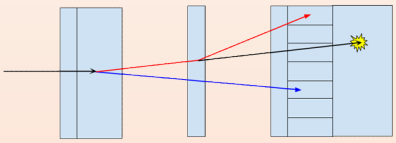
- Most of the reaction of gamma rays which energy is 10 MeV or more are pair production [3].
- The momentum direction of the gamma ray can be determined by measuring passing points and energy of e^+ and e^- generated by pair production.
- The Bragg-peak position can be determined by obtaining the intersection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

System Overview

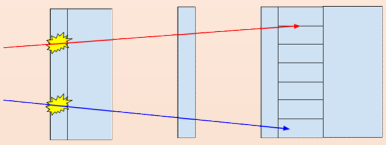




VETO events



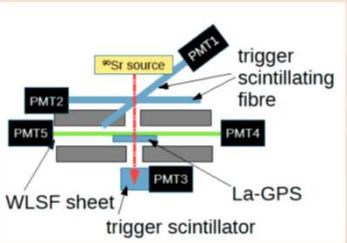
When a charged particle is scattered



When two charged particles come into the detector

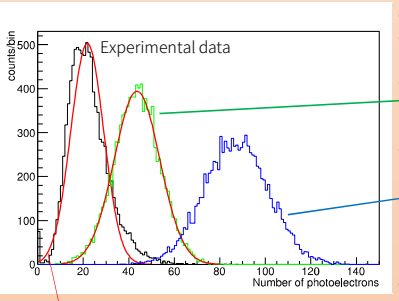
Experiment

Setup



- The number of photoelectrons was measured.
- High Growth Rate La-GPS ($(Gd_{0.75}La_{0.24}Ce_{0.01})_2Si_2O_7$, 20 mm x 20 mm x 0.5 mm, C & A Corp.)
- Wavelength-shifting fibre (B-3(300)MJ, φ0.2 mm, Kuraray)

Results

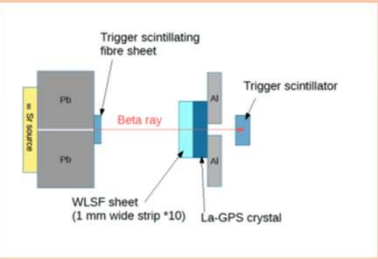


- 22 p.e. was observed in average.
- Histogram was fitted as Poisson distribution.
- The number of p.e. when WLSF sheet is also on the other surface (both surface reading) was estimated.
- The number of p.e. when two charged particles pass through the scintillator with both surface reading was estimated.

Fitting function
Gaussian function
(const. = 503, mean = 21.8, sigma = 7.20)

- Two particles passing and one particle passing can easily distinguish with both surface reading.
- More detailed results and other results are shown on poster 33.

Experiment2



- Position resolution of La-GPS and WLSF was measured.
- Illustration of setup is on left.
- Normal crystal of La-GPS (10 mm x 10 mm x 0.5 mm, C & A Corp.)
- WLSF were bounded in 1 mm strips.
- Position resolution was measured as 1.068 ± 0.017 mm in sigma.
- More detailed results are also shown on poster 33.

Conclusion and Future Work

- **The best way to monitor the Bragg-peak position is using gamma ray of several dozen MeV.**
- **According to the experiment, conversion part has sufficient amount of luminescence and its position resolution is expected to be 1 mm or less.**
- **We will explore the limit of position resolution, and its of tracking part.**

Acknowledgements

We are grateful to Prof. KAMADA (Tohoku Univ., C & A Corp.) for offering the samples of La-GPS crystal.

References

[1] T. Nishio, T. Ogino, K. Nomura, and H. Uchida, "Dose-volume delivery guided proton therapy using beam on-line pet system," Medical physics, vol. 33, no. 11, pp. 4190–4197, 2006.
[2] S. Peterson, D. Robertson, and J. Polf, "Optimizing a three-stage Compton camera for measuring prompt gamma rays emitted during proton radiotherapy," Physics in medicine and biology, vol. 55, no. 22, p. 6841, 2010.3
[3] M. Berger, J. Hubbell, S. Seltzer, J. Chang, J. Coursey, R. Sukumar, D. Zucker, and K. Olsen, "Xcom: Photon cross sections Database," https://www.nist.gov/pml/xcom-photon-cross-sections-database.