Proposal of a Dose Monitor for Cancer Therapies with Charged Particle Beams by Measuring the Pair Creations

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Introduction

There are several researches to develop the dose monitors at Cancer Therapies with Charged Particle Beams. Almost all studies are PET detectors and Compton cameras. There are few studies got good results. We propose a new dose monitor to measure a pair creation reaction. Charged particles create short life nuclei. The density of short life nuclei is proportional to amount of dose. Some nuclei emit high energy gamma-rays such as more than 10 MeV. The high energy gamma-rays create electron positron pairs in the detector. The direction of the center of the pair is almost same as the directions of the incident gamma-ray. Fig.1 shows the concept of our dose monitor. A trajectory of a charged particle is easily measured by scintillation fiber trackers and plastic scintillators with the position resolution of 0.1mm and the time resolution of 1 ns. The position and time of the pair creation can be measured by our detector. If the difference between two trajectories is less than few mm and the time difference is less than few ns, we can considerer that the meeting point of two lines is high dose point. The density of meeting point is proportional to the density of amount of dose.

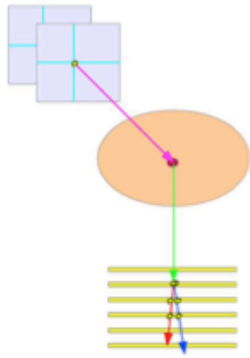

Fig. 1. The concept of our dose monitor.

Recently we developed new gamma-ray detectors for 511 keV PET gamma-rays. This detector is consisted of scintillator plates, WaveLength Sifting Fibers.[1][2] Then we found that the reaction point can be measured in this detector. GEANT4 simulation shows that this detector has excellent performance for high energy gamma-rays such as 1 GeV[3] and medium energy gamma-rays such as 20 MeV.

Structure of detector

Our detector consists of 10 layers. The distance between each layers is 10 mm. Each layer consists of 10 times 10 scintillator plates. The size of each scintillator plate is 30 mm times 30 mm times 1 mm. 144 WLSFs cover each 30 mm times 30 mm surface of each plate(Fig.1(a)). For one side of the ends of 144 WLSFs, the 1-12th fibers are connected to 1st PPD, 13-24th fibers are connected to 2nd PPD and so on. For the other side of the ends, the (12 k + i)th fibers are connected to the ith PPD. Thus, 48 PPDs are used in each layer to measure the position of an electron-positron pair.

15 plus 14 WLSFs are attached on each side surface(Fig1.(b)). Thus there are 2 X-sheet + 2 Y-sheets attached to each scintillator plates. One ends are connected to the up-down direction, second ends are connected to the left-up right-down direction, third ends are connected to the left-down right-up direction and last ends are gathered to one big bundle and connected to a photomultiplier tube (PMT). (10 + 19 + 19) × 2 = 116 PPDs are used to identify the fired plate and to measure the assumed energy, and 2 PMTs are used to create the trigger signal.

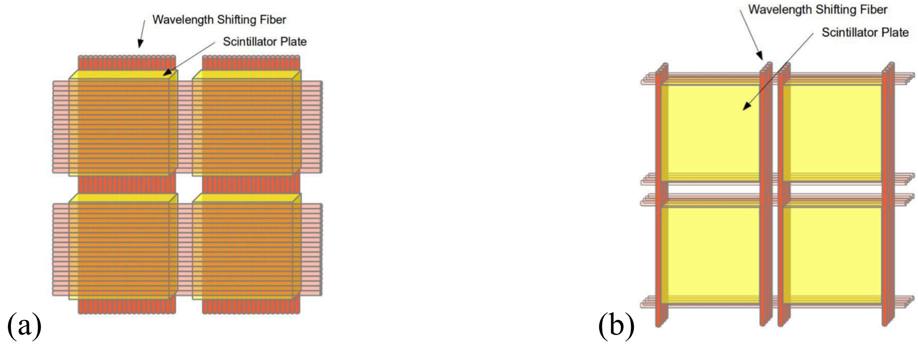

Fig.2. These figures are small Layer samples which consist of 4 scintillators. (a) WLSFs attached to the surface. (b) WLSFs attached to the side. Bending Fibers solves a problem that fibers intersect.

GEANT4 simulations

Fig.3 shows the typical event of GEANT4 simulations.

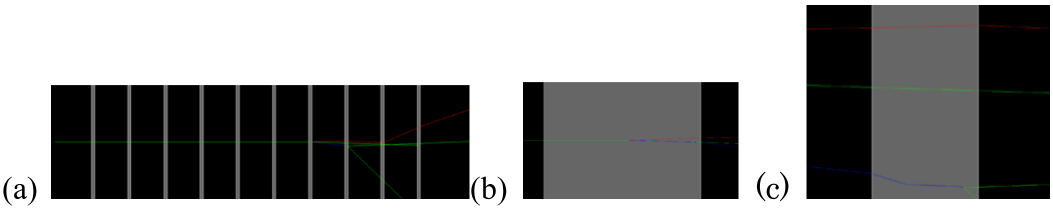

Fig. 3. These figures are typical distribution of electromagnetic shower. Gamma-ray which has kinetic energy of 20 MeV pass from left to right. Yellow, red and blue lines show gamma-rays, electrons and positrons, respectably. (b) shows expandion figure of the 7th layer nad (c) that of the 8th layer.

An electron-positron pair production is occurred in the 7th layer. At the downstream of the 7th layer the positron create an another bremsstrahlung gamma-ray. At the 8th layer several small angle scattering occur on the electron and a positron. In this event the assumed energies at the 7th and the 8th are between 1.5 to 2.5 MeV. The angle between the center of electron and positron pair and incident gamma-ray is about 10 mrad.

GEANT4 simulations shows about 22 % of 20 MeV gamma-rays occur the electron positron pair production in this detector, 5% occur the Compton scattering and 73% pass through. The average of assuming energies at first two layers is 2 MeV for a pair production events and 1 MeV of Compton scattering events. Thus Compton scattering events will be easily rejected by the light yield measurements of WLSFs attached at side surfaces.

We are constructing the prototype detectors and we will perform the test beam experiment in this autumn. The result will be shown in this conference.

Reference

[1] H.ITO, et al., IEEE Medical Imaging Conference 2014, 8-15 Nov. 2014, Seattle, Washington, USA

[2] N.NAOMI, et al., Advancements in Nuclear Instrumentation Measurement Methods and their Applications, 220, Apr. 20-24 2015, Lisbon Convention Center, Portugal

[3] A.KOBAYASHI, et al., International Symposium on Radiation Detectors and Their Uses, 206, Jan. 18-21 2016, KEK, Japan