Development of gamma-ray detectors for PET with high efficiency

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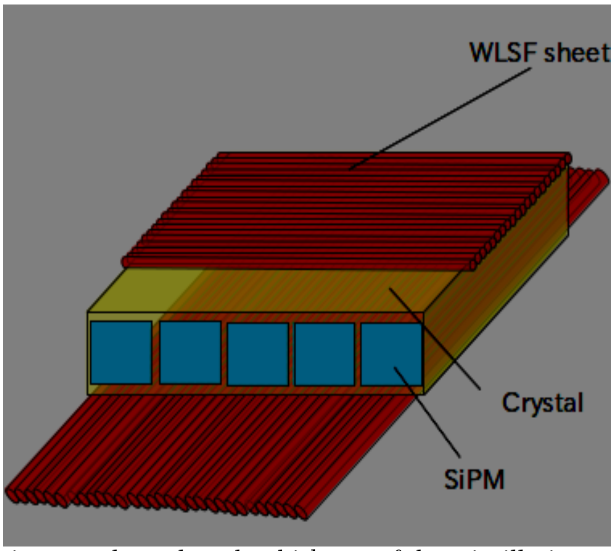
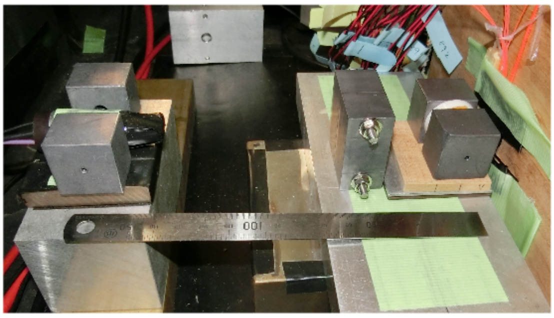
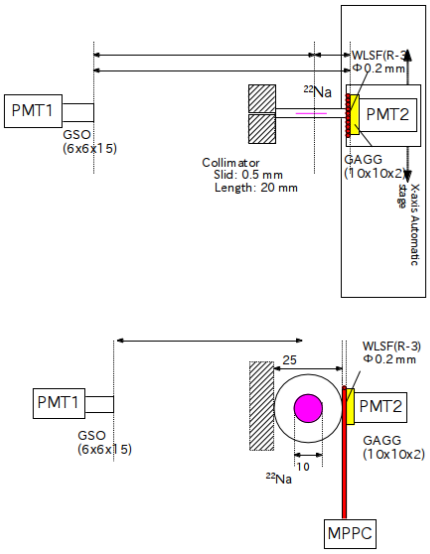
Introduction

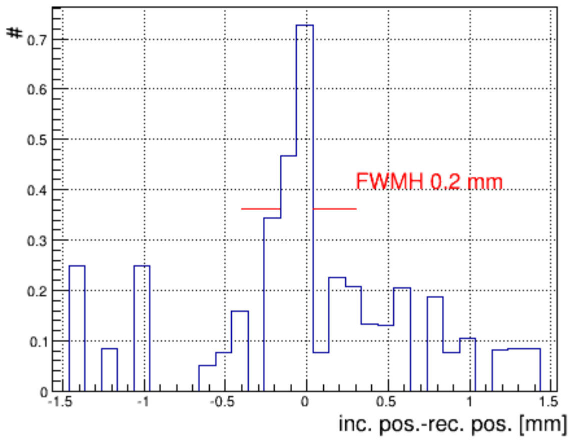
We are developing new type of gamma detectors [1]. The right figure shows the structure. The typical size of the scintillator crystal is 34mm times 34mm and the thickness is 1~5mm. The Wave Length Shifting Fibers with the diameter of 0.2mm cover the top and bottom surfaces of the crystal plate. SiPM's are attached on the four side surfaces. In the case that high energy and time resolutions are not needed, WLSF sheets are attached instead of SiPM's. The X and Y coordinate of the scintillation emission is measured by the bottom and top WLSF's, respectively. The sum of the numbers of hit fibers of both surfaces is constant and the difference of those is linear to the Z coordinate of the scintillation emission. The position



resolutions are depend on the thickness of the scintillation plate. The left picture shows the experimental apparatus to estimate the position resolution with 1mm thickness GAGG crystal. The result is 0.2mm. The number of measured photo-electron for a 511keV gamma is about 20. This measurement method is useful for gammas of 50keV or







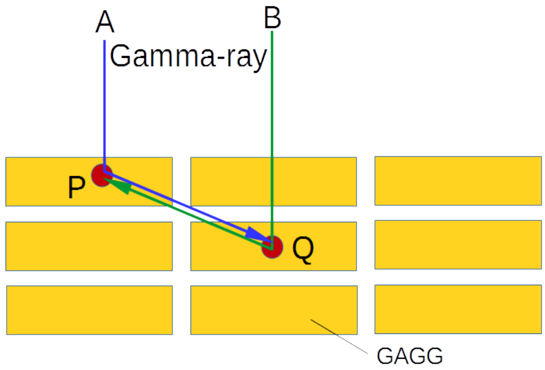
higher. Our detectors are useful for the measurement of high energy (more than 1 GeV) gamma-rays in particle physics experiments [2] and for the dose monitors in cancer therapy systems with proton and heavy ion beams . In this paper, we propose our detector for a whole body PET system for a cancer inspection.

Whole body PET system

We proposed a PET system with the position resolution of 0.2mm and cost of one million dollars in Ref.1 but such high position resolution is not suitable for the standard PET. PET system with high detection efficiency (low dose rate) and low cost are expected. Our whole body PET system consists of 6 blocks. One block consists of 8 layers. One layer consists of (8×8=) 64 scintillation plates. The size of each scintillation plate is 34×34mm^2 and 4mm thickness. Five WLSF's are connected and each end of fiber bundle is attached to a SiPM. 10 SiPM's with the effective area of 3×3mm^2 are attached on each side surface. The number of measured photo-electrons with 40 SiPM's for 511keV gamma is 2500 (5 photons/keV). The energy resolution is 10keV (RMS). The typical time resolution of each SiPM signal is 500 psec.

Compton scattering events

Compton scattering events are not used in the conventional PET system because only the center of scintillation is measured. In our system, the position and light yield of each layer are measured. If the scattering angle is 45 degree (case A), the consumed energy at P and Q is 116 and 395keV, respectively. If the scattering angle is 135 degree (case B), the consumed energy at P and Q is 189 and 322keV, respectively. The expected number of photo-electrons for (116+189)/2=150keV is 750 and the expected energy resolution is 5.5keV. It is easy to identify which is the first incident point P or Q. If multi scintillation occur in the same plate or plates in the same layer, the scattering angle is near 90 degree and the consumed energies at P and Q are near 256keV. Our PET system will record events when multi scintillator plates in the different layers fire. Monte Carlo simulations show that our system can choose the incident point for Compton scattering events with the scattering angles between 28 and 61 degree. When the scattering angle is between 3.5 and 28 degree, the consumed energy at P is too small to measure the position from WLSF but the number of photo-electrons from side SiPM's are 5 or more, which is enough to recognize that the Compton scattering is occur. Monte Carlo simulations show that the efficiency of our system is 2~3 times higher than that of conventional PET systems.



Time resolution

It is well known that the error of the average is inversely linear to the square root of the number of measurements. It was proved by the simple test measurements. The time resolution of our detector is expected to be less than 100 psec.

Cost

Our PET system consists of 64×8 layers×6 blocks=3072 scintillator plates. The price of the scintillator plate depends on the type of the crystal and 100~300 dollars per plate. WLSF bundles of the same layer are gathered and 34×2 (both end) ×2 (X and Y)=136 SiPM's are used at each layer. The number of SiPM's is 136×8layers×6blocks =6,528 (attached to WLSF) and 40×64plates×8layers×6blocks=122,880 (attached at side surfaces). There are an ADC for a scintillator plate and 40 TDC's for a layer. Total electronics circuits are 6,528 bits of input resister, 3,072 ADC channels and 1,920 TDC channels. It is expected that the total cost is about 3 million dollars.

References

1 N. Kaneko et al. , ANIMMA2015 **220**, Apr 2015, Lisbon, Portugal

2 A. Kobayashi et al. ISRD2016 **203**, Jan 2016, Tsukuba, Japan