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Determination of spatial resolution of plastic scintillation fiber array with a simple method

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Abstract The spatial resolution of a position sensitive gamma-ray detector configuration based on plastic scintillation fiber array was measured using a Monte Carlo simulation method. Both point spread function and modulation transfer function (MTF) were presented. The factors that influence the spatial resolution were also discussed. The results of the simulation showed that the intrinsic spatial resolution was consistent with the size of the physical pixels and a few centimeters spatial resolution could be obtained under certain circumstances.

Keywords Plastic scintillation fiber, Spatial resolution, Modulation transfer function, Geant4

CLC numbers TN25, O571.33

1 Introduction

In the last decade a great effort has been made in the development of a position-sensitive device for gamma-ray imaging[1] and pixel detectors. Scintillation[2] or semiconductors[3], have been widely used. As one kind of pixel detectors, scintillation fibers have the advantage that they may achieve both spatial and energy resolution in detecting γ-rays. In a scintillating fiber detector, a portion of light converted from the incoming γ-rays is channeled along the fiber through total internal reflections; an Extra Mural Absorber (EMA) absorbs the remainder[4]. Such a design, in principle, does not require any compromise in the length of the fiber and the spatial resolution. Thus, utilizing the geometric channeling of fibers in guiding the photons' propagation can provide better spatial resolution in detecting γ-rays compared with the bulk crystals. Among various scintillation fibers, plastic scintillation fibers (PSFs) have been used extensively in the detection of high energy particles. The physical characteristics of many different PSFs are well-documented[5,6]. PSFs of various sizes are commercially available, and the cost is significantly less than that of bulk scintillation crystals, which makes the construction of detectors for practical γ-ray imaging feasible[7, 8]. Furthermore, PSFs are flexible, and thus can be easily built into an area detector with geometry best matched to that of the object being imaged, to achieve maximum efficiency and reduce the complexity.

A simple MeV γ-ray spectrum detector was proposed using plastic scintillation fibers and rods, as illustrated in Fig.1. In this article, the Modulation Transfer Function (MTF) of the apparatus was presented in a simple method through simulation. The factors that influence the spatial resolution were also discussed.

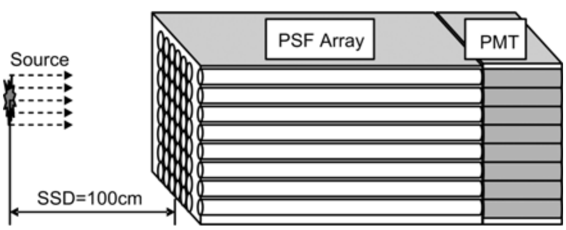

Fig.1 An illustration of simulation configuration.

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2 Simulation

The Monte Carlo simulation was carried out using Geant4 (Geometry and Tracking 4), which is a simulation toolkit based on object-oriented technology[9,10]. The software was designed initially for simulating and studying the performance of detectors for nuclear and high energy physics experiments[11]. The toolkit nowadays finds a wide range of applications, such as, in radiation analysis, space and cosmic ray analysis and, more recently, medical oncology analysis and evaluations[12]. The design and the accessibility of the software provide a transparency for implementation of various physics parameters and allow an easy understanding of the physics model used. A set of models that describe the interaction of photons and electrons with matters at various energies have been implemented in the toolkit. The physical processes involved include photoelectric effect, Compton scattering, Rayleigh effect, bremsstrahlung, and ionization[9,10].

The simulation object is a fiber array coupled with photomultiplier tubes (PMT) and is irradiated by a gamma-ray source, as described in Fig.1. All the physical and chemical parameters of the fiber were chosen to be the same as that of BCF-20, a plastic scintillation fiber manufactured by Bicron[4], and have been described in detail in the previous report[13]. The length of the fibers is chosen to be 30 cm and the source to surface distance is chosen to be 100 cm. The simulated results are not strongly affected by the length of the fibers, as in the energy regime chosen here, energy deposition increases slowly with the length of a PSF[14]. A perfect match is assumed between the fibers and the PMTs (no signal leakage in the interface). For organic scintillators, the relation between the emitted light and the energy deposited by an ionizing particle, in general, is linear[15]. Therefore, in this simulation, the incoming photons and the secondary particles created by the photons were tracked, and their energy deposition in the fibers was traced. The number of events simulated in this study was 100,000 for each case.

3 Results and discussion

Spatial resolution of an imaging device can be characterized by the point spread function and modulation transfer function[16]. The modulation transfer function (MTF) is a mathematical description of the capability of a system to produce in the image the whole range of spatial frequencies in the object[16,17]. The calculation of the MTF will be given for γ-ray photons of 4MeV for two radii, 8mm and 10mm of fiber. First the point spread function needs to be obtained.

The fiber array with 0.8 cm and 1 cm radius was scanned, with a collimated beam by step of 2.5 mm, to get the counts versus measured position minus true position. The beam width here was chosen to be 5 mm, which also influenced the spatial resolution. Thus by fitting the data with a Gaussian function an average point spread function was obtained [1,18,19], which is illustrated in Figs.2 and 3, for 0.8 mm and 1 mm fiber radius, respectively. As can be seen, an intrinsic spatial resolution of about 17.24 mm and 21.54 mm FWHM could be obtained, consistent with the physical pixel size of 16mm and 20mm, respectively.

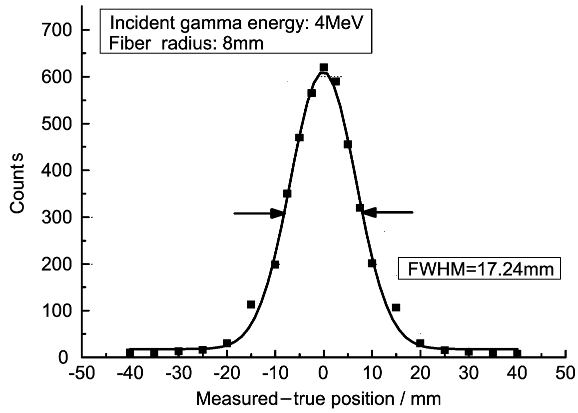

Fig.2 Obtained point spread function by Gaussian fitting simulated counts versus measured minus true position, with 8 mm fiber radius.

It was also found that both the scan step and the beam width could influence the spatial resolution. Figs.4 and 5 show the variation of FWHM with the two variables, respectively. As can be seen, when the scan step was set at 2.5 mm, FWHM kept to about 17.2 mm. However, as the beam width increased to above 6 mm, the spatial resolution deteriorated considerably. This could be because, when the beam width could compare to the fiber radius, the scan would be somewhat independent of the position, which induced the transient of the FWHM, as illustrated in Fig.4. When the scan step was a variable, as plotted in Fig.5, the variation of FWHM was a little less and the distribution was more random compared to that in Fig.4.

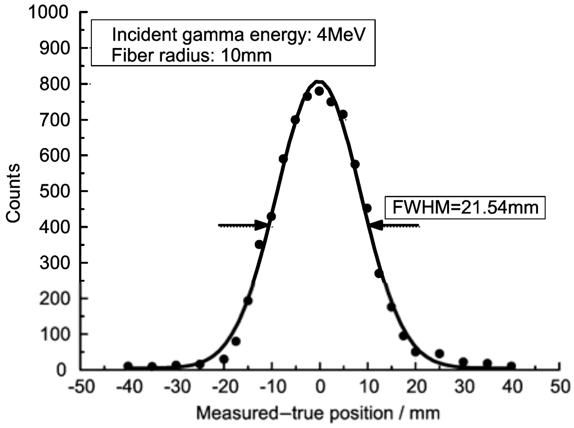

Fig.3 Obtained point spread function by Gaussian fitting simulated counts versus measured minus true position, with 10 mm fiber radius.

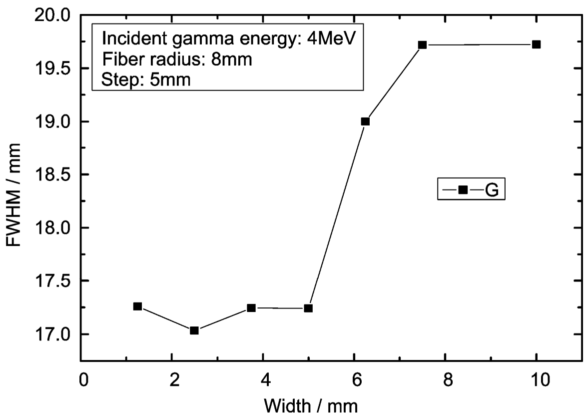

Fig.4 Simulated FWHM versus beam width, with 2.5 mm scan step.

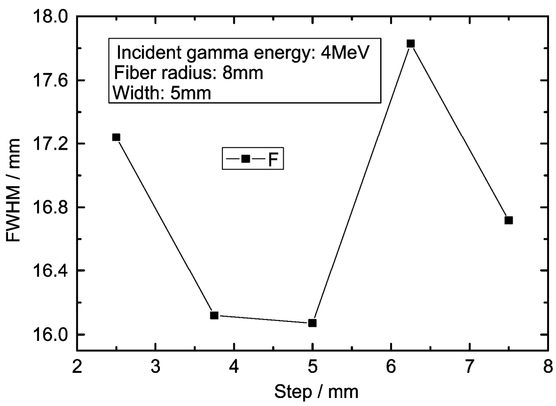

Fig.5 Simulated FWHM versus scan step, with 5 mm beam width.

By definition, the MTF is the Fourier transform of the point spread function[17, 20]. Fig.6 is the calculated MTF for 8mm and 10 mm radius scintillation fiber arrays. The figure shows that the maximal spatial frequency is about 0.025 ~ 0.030 lp/mm, which is a further confirmation of the upper results. According to the curves, the MTF of 20% is achievable with a spatial frequency of about 0.03 ~ 0.04 lp/mm, increasing when the radius of the fiber decreases.

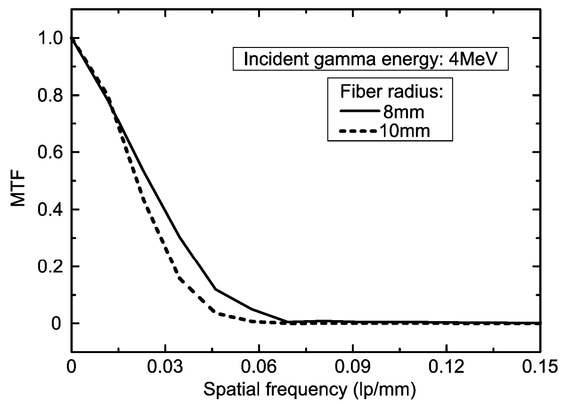

Fig.6 Calculated modulation transfer functions for fibers with radii of 8 mm and 10 mm, respectively.

The results presented above show that the intrinsic spatial resolution of the system is consistent with the physical pixel size and the value of MTF also supports the results. It should be noted that the detecting efficiency for PSF in this energy is quite low; it is about 15% or less[14]. There exists a contradiction for obtaining both high detecting efficiency and good spatial resolution. Thus the proposed configuration will be useful for a situation where the low detecting efficiency for the energy and low spatial resolution can be tolerated.

4 Conclusions

In summary, a simple method has been used to measure the spatial resolution for our gamma-ray detector configuration based on plastic scintillating fiber array. Both point spread function and modulation transfer functions are presented. The results of the simulation show that the intrinsic spatial resolution strongly relies on the size of the physical pixels. The factors that influence the spatial resolution include scan step and scan beam width. These results suggest that the detector configuration may be used for achieving both energy resolution and spatial resolution when detecting γ-rays under certain circumstances.

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