Determination of effective light attenuation and interaction point in plastic scintillator strips used in J-PET scanner

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Abstract

A prototype of Positron Emission Tomography scanner is being developed by the J-PET collaboration at the Jagiellonian University. Good timing properties of plastic scintillators, from which the J-PET detector is built, make it possible to use predominantly time of registered signals for the reconstruction of gamma quanta hit position. To improve resolution of the hit position determination and to perform independent crosscheck one can also use charge of observed signals for the hit position determination.

1. Time-of-Flight (TOF) method with detector made of organic plastic scintillators

Usage of organic scintillators as a detector of gamma quanta in Positron Emission Tomography is a novel concept [1]. These scintillators are characterized by an excellent time resolution. Detector built out of plastic scinntilators will be able to obtain the time resolution better than 230 ps [2] compared to 600 ps achievable in current TOF-PET scanners [3]. This solution would also enable effective usage of the TOF method permitting the determination of the annihilation point. Schematic view of the J-PET detector is shown in Figure 1 .

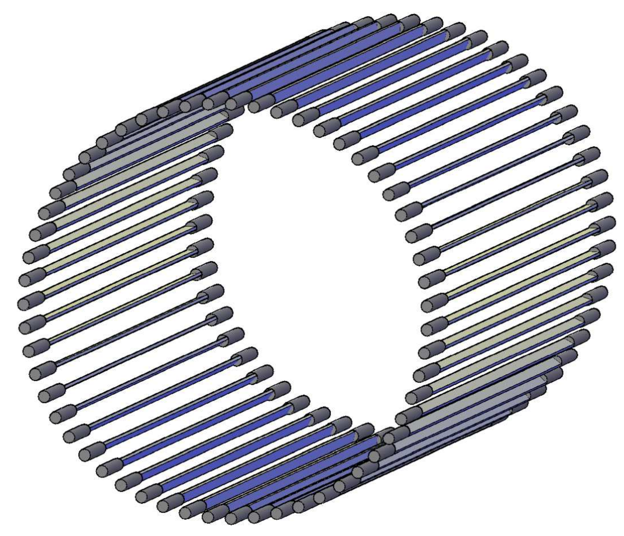

Figure 1. Schematic view of J-PET detector chamber build out of plastic scintillating strips.

2. Idea of position determination

Light traveling in a scintillator medium can be absorbed. Charge of signals registered by detectors can be expressed as number of photons which reached the detector [4]. The knowledge about amount of light which is absorbed in the scintillator medium at a given distance allows to define how many photons were at particular position along the scintillator. Figure 2 shows photons number constituting the signal as a function of position along the scintillator. As it is shown in Figure 2 there is only one position at which photons emission could occur resulting in observed number of photons at both detectors. Therefore information about number of photons can be used for hit position determination.

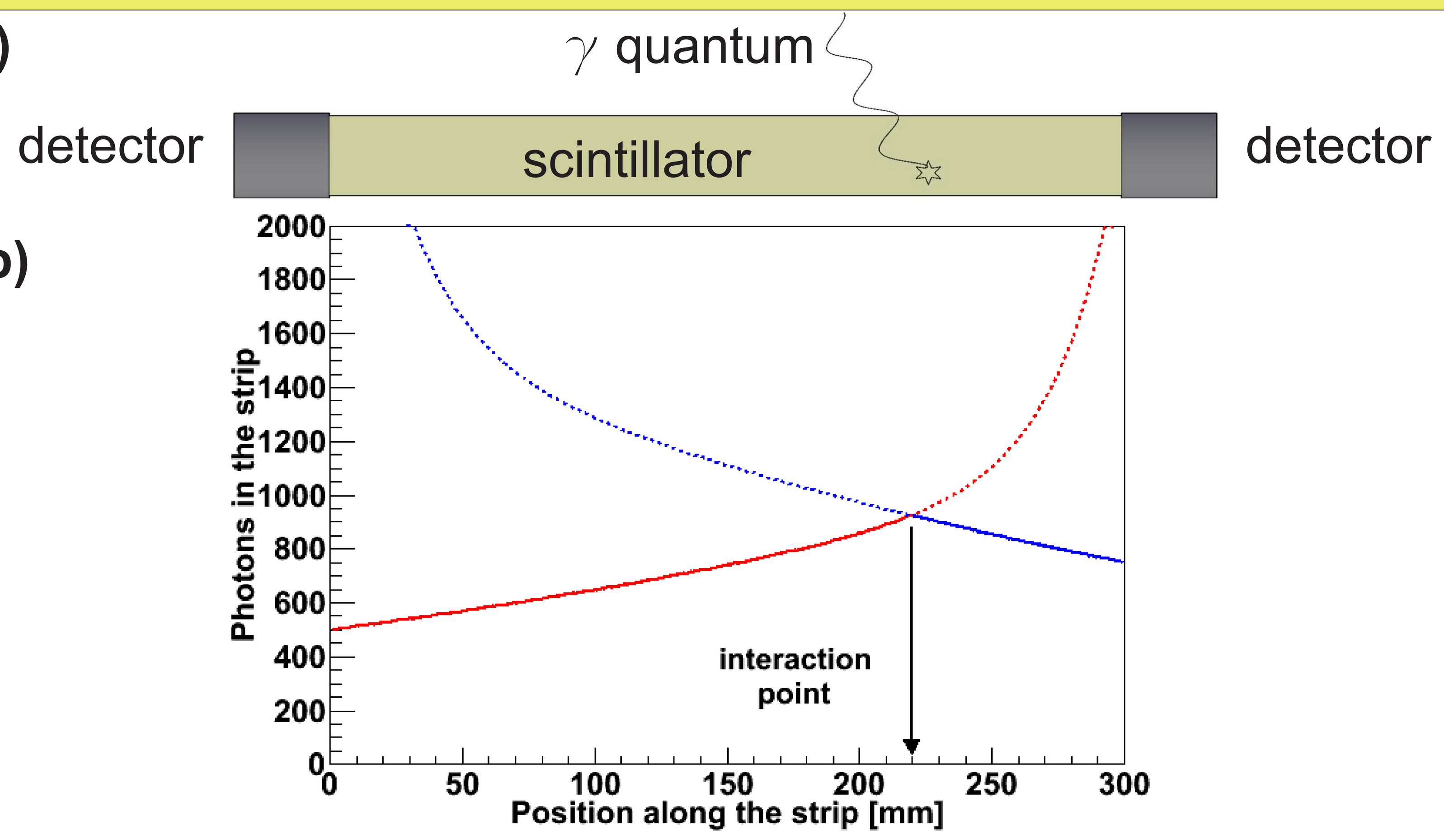

Figure 2. a) Schematic view of two detectors attached to scintillating strip and γ quantum interacting with the scintillator. b) Number of photons along the strip in case when 500 photons reached to the left photomultiplier (red line) and 750 photons reached to the right photomultiplier (blue line).

3. Effective light attenuation length

An effective light attenuation length includes absorption in the medium as well as effects related to geometrical parameters of the scintillating strip. Dependence of relative amount of photons on the distance between emission and detection points can be written as follows:

$$\beta(x) = c_1 * \exp(x/\lambda_1) + c_2 * \exp(x/\lambda_2), \qquad (1)$$

where c_1 and c_2 are constants, x is distance, λ_1 and λ_2 are effective light attenuation lengths. λ_1 is responsible for photons absorption in the medium and λ_2 is linked to edge effect (change of number of photons which can hit detector directly i.e. without reflections). Values of λ parameters are obtained from a fit of Eq.1 to data as it is shown in Figure 3.

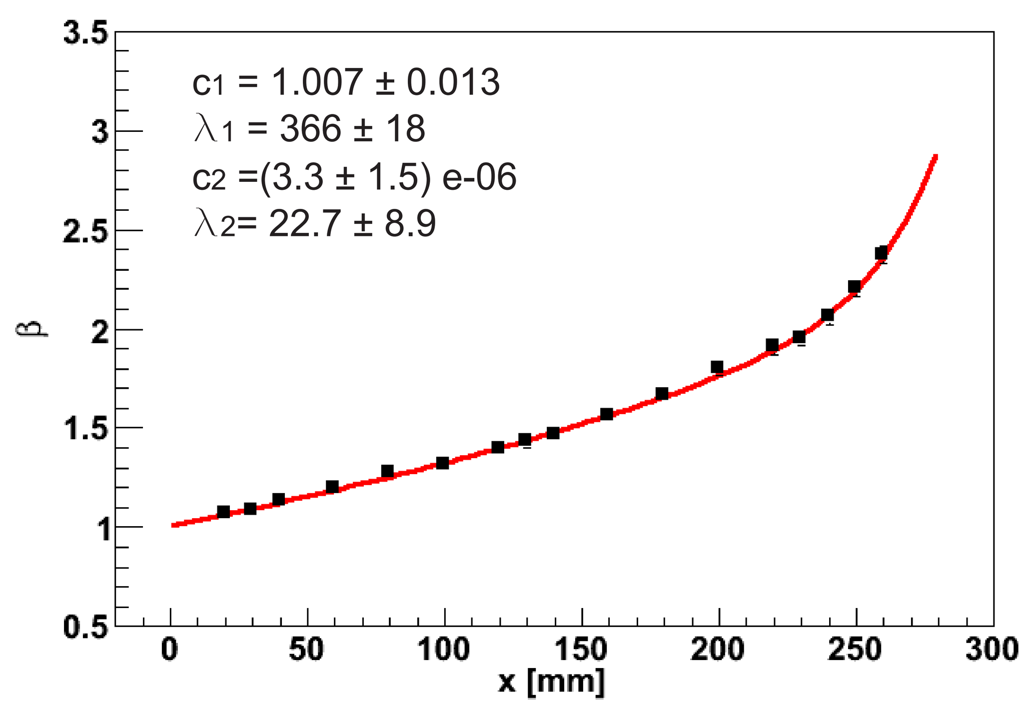

Figure 3. Relative amount of light (β) in the scintillating strip as a function of distance (x) between the detector and gamma hit position. Red line denotes function from Eq.1 while black points are experimental data.

4. Position determination resolution

Combining Eq. 1 for the left detector with a corresponding equation for the right one:

$$\beta(x) = c_3 * \exp(L-x/\lambda_1) + c_4 * \exp(L-x/\lambda_2), \; (2)$$

one can derive a position of gamma quantum interaction along the scintillator strip. Resolution of hit point determination as a function of the interaction position is shown in Figure 4. Better resolution at the edges of scintillating strip is caused by decrease of statistical fluctuation of number of photons.

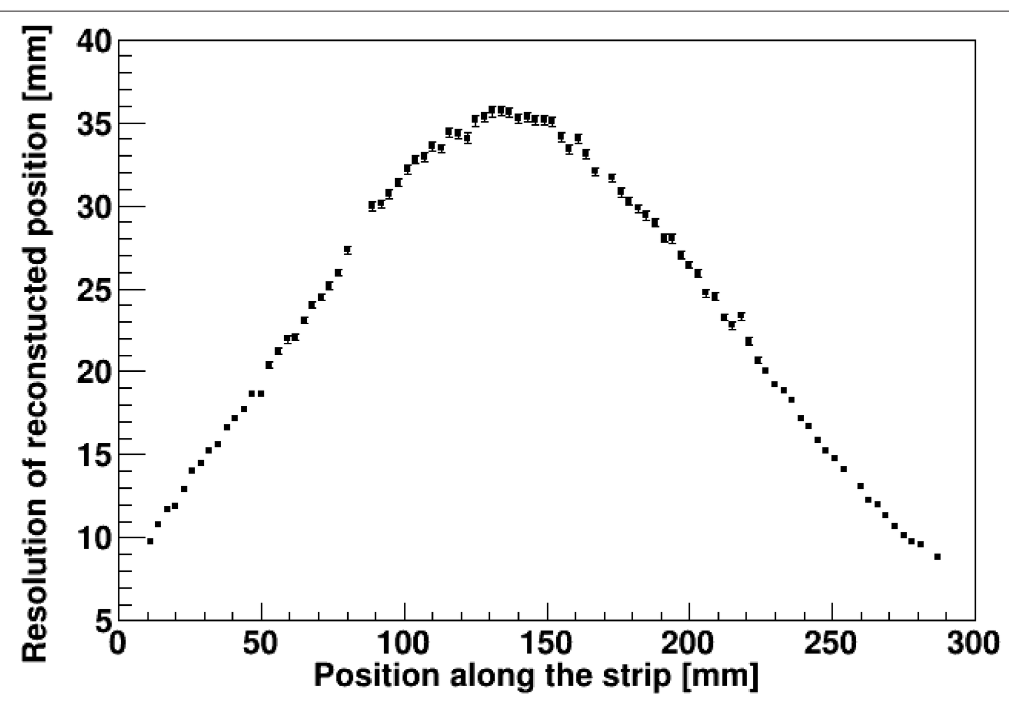

Figure 4. Resolution (CL= 68%) of interaction point determination as a function of position along the scintillating strip.

References:

[1] P. Moskal, T. Bednarski, et al., Radiotheraphy and Oncology 110 (2014) S69.
[2] P. Moskal, et al., Test of a single module of the J-PET scanner based on plastic scintillators, Nuclear Instruments and Methods, inpreparation.
[3] J. S. Karp et al., J. Nucl. Med. 49 (2008) 462.
[4] T. Bednarski, E. Czerwiński, P. Moskal, et al., Bio-Algorithms and Med-Systems 10 (2014) 13.

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