Estimation of photon's interaction position in plastic scintillator with the WLS strips readout using artificial neural networks

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Abstract

The J-PET group is developing a cost-effective total-body PET based on plastic scintillators [1, 2]. While the achieved radial and tangential spatial resolution of the J-PET prototype is comparable with the state of the art PET systems, the axial one is few times worse [3]. Here, we present a method for improvement in axial resolution by the application of an additional array of wavelength shifter (WLS) strips [4].

Detection system

In order to simulate the WLS response, a dedicated simulation software has been developed. It enables partial tracing of scintillation photons and provides detection time information on the plastic scintillator's sides.

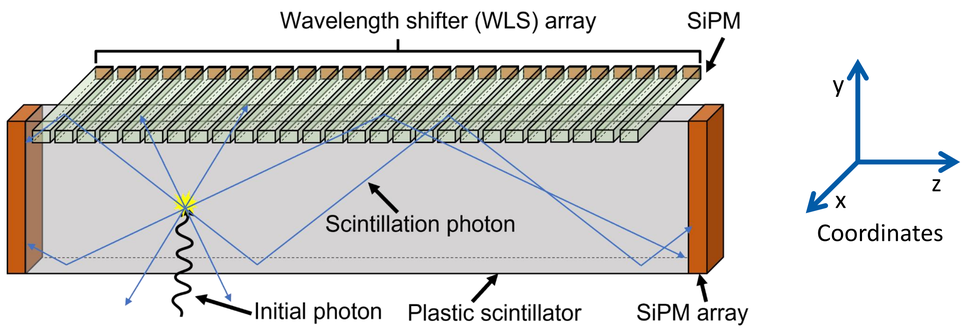
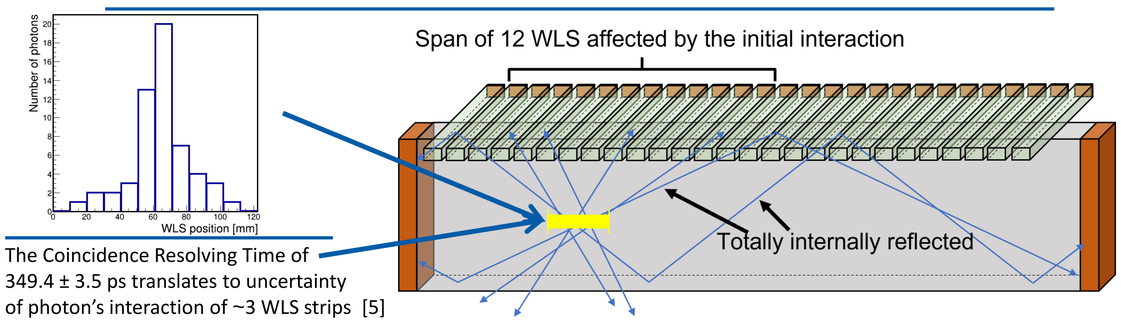


Fig. 1.: Scheme of the detection system based on the plastic scintillator strip with an additional array of wavelength shifter strips.

Full simulated detection system:

- Plastic scintillator strip of dimensions: 6 mm × 24 mm × 500 mm
- Array of 40 WLS strips of dimensions: 100 mm × 3 mm × 10 mm and with 0.2 mm gap between



The Coincidence Resolving Time of 349.4 ± 3.5 ps translates to uncertainty of photon's interaction of ~3 WLS strips [5]

Fig. 2.: (Left) Exemplary simulated distribution of signal on WLS. (Right) Scheme of the impact of single interaction within plastic scintillator.

Reduced simulated detection system:

- Plastic scintillator strip of dimensions: 6 mm × 24 mm × 122.2 mm
- Array of 12 WLS strips of dimensions: 100 mm × 3 mm × 10 mm and with 0.2 mm gap between

Data sets:

- Training set: Blue points (see Fig. 3.) from 6 mm × 24 mm × 122.2 mm scintillator strip
- Testing set: Blue points (see Fig. 3.) from 6 mm × 24 mm × 122.2 mm scintillator strip
- Validation set: Blue + Red points (see Fig. 3.) from 6 mm × 24 mm × 122.2 mm scintillator strip
- Flood set: Interactions taken uniformly from whole 6 mm × 24 mm × 500 mm scintillator strip

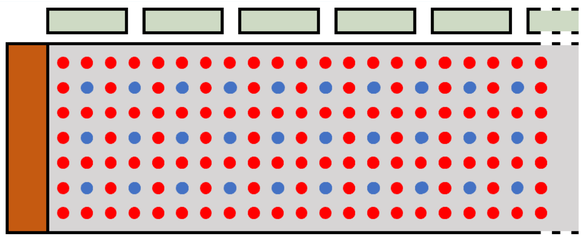


Fig. 3.: Schematic view of positions of simulated interactions.

Artificial Neural Network

- Neural Network: regression MultiLayer Perceptron (MLP) from the Toolkit for Multivariate Data Analysis (TMVA) with ROOT software [6]
- Input layer: 12 nodes (12 WLS strips)
- Hidden layers: 1 layer; 6, **12**, 24 or 48 neurons
- Activation function: tanh
- Training method: Back-Propagation
- Output layer: 1 node („z" position along the scintillator)
- Training set: 1000, 2000 or **4000** events per position
- Testing set: 1000 events per position

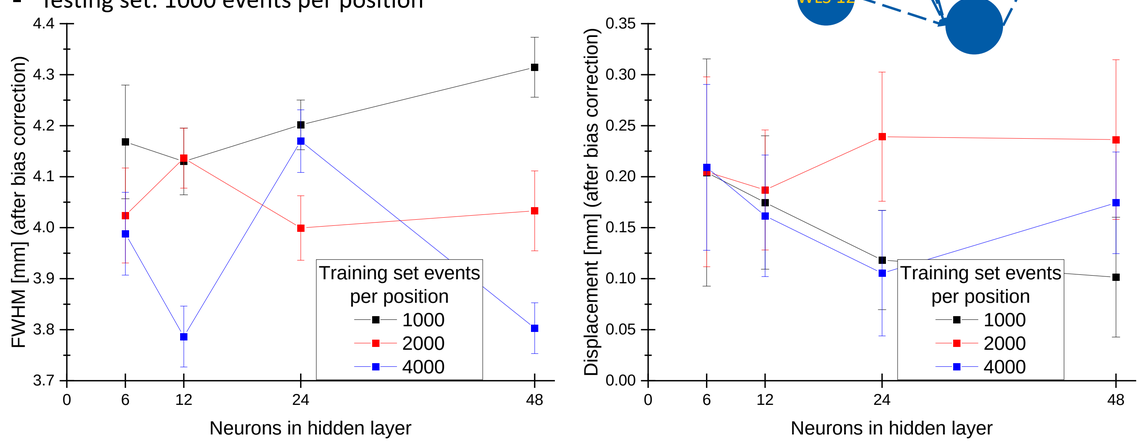


Fig. 4.: (Left) Mean FWHM values from corrected distributions of reconstructed „z" positions. (Right) Mean displacement of corrected distributions of reconstructed „z" positions from true „z" positions. In both cases connecting lines were drawn only to guide the eye, they do not resemble any physical dependence.

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The abovementioned work is presented on behalf of the J-PET Collaboration. This work was supported by the TEAM POIR.04.04.00-00-4204/17 program, the NCN grant no. 2021/42/A/ST2/00423 and the SciMat and qLife Priority Research Areas budget under the program Excellence Initiative - Research University at the Jagiellonian University. The study was funded by "Laboratories of the Youth" as part of the "Excellence Initiative - Research University" program at the Jagiellonian University in Kraków.

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Analysis

1 Application of trained network on validation data set

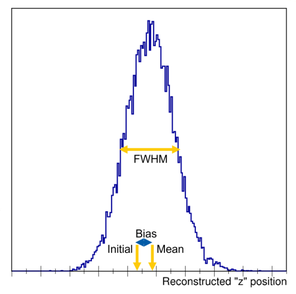

Fig. 5.: Distribution of reconstructed „z" position for one initial „z" position.

2 Analysis of distribution's selected characteristics

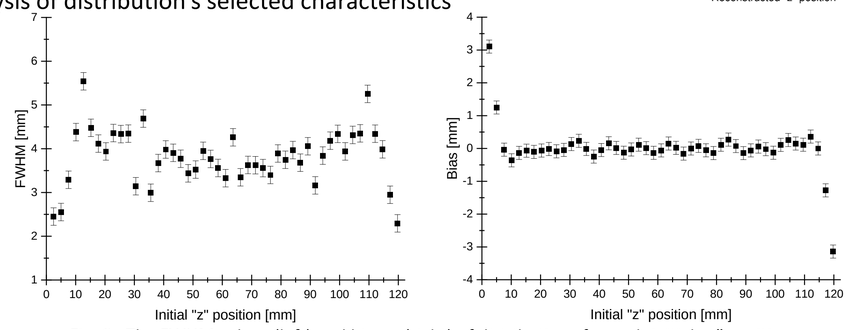

Fig. 6.: The FWHM values (left) and biases (right) of distributions for each initial „z" position.

3 Bias (displacement) correction investigation

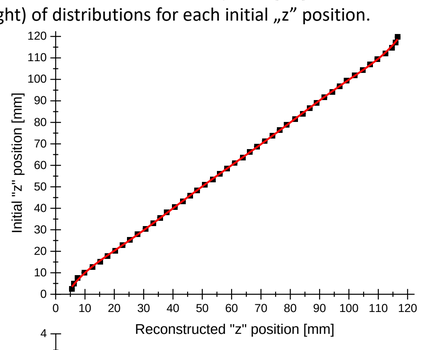

Fig. 7.: The bias correction line together with fitted function (7th order polynomial) [7].

4 Application of bias correction

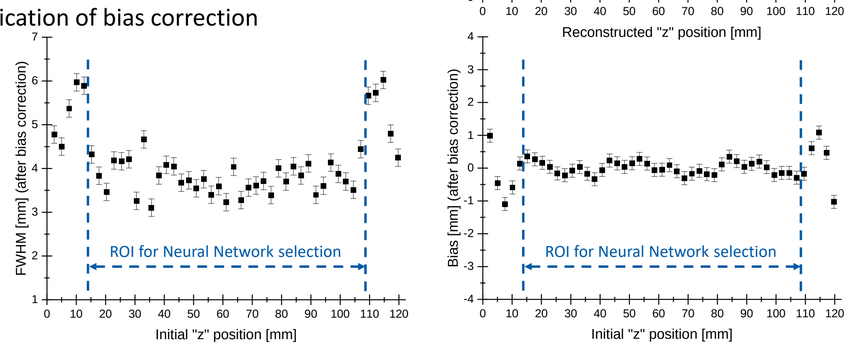

Fig. 8.: The FWHM values (left) and displacements (right) of bias-corrected distributions for each initial „z" position.

5* Redistribution of events shifted outside of scintillator

I. Investigation of probability of shifting outside of scintillator
II. Modelling of describing function
III. Redistribution according to selected function

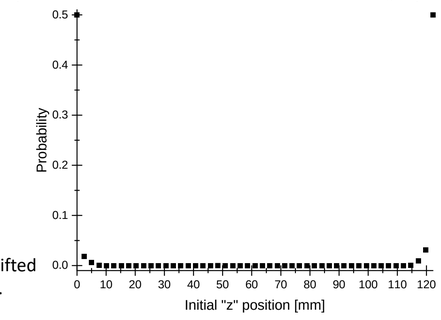

Fig. 9.: Probability for each initial „z" position to be shifted outside of the scintillator after bias correction [7].

6* Application of **chosen** network on flood data set

I. Selection of 12 WLS strips corresponding to interaction position based on the TOF information
II. Application of neural network
III. Bias and shift correction
IV. Repositioning of reconstructed „z" positions into full detection system

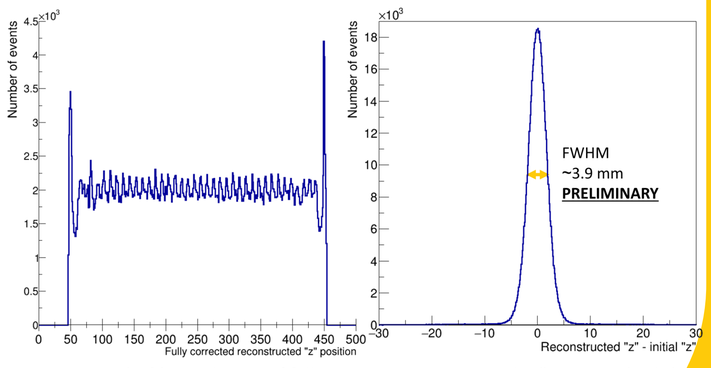

Fig. 10.: (Left) Distribution of fully corrected reconstructed „z" position. (Right) Distribution of difference between reconstructed and initial „z" position.

Summary

If an initial photon's interaction in a scintillator strip occurres near the WLS array, the emitted scintillation photons are largely interacting in the nearest region. In case of further position of interaction, this region correspondingly expands. Additional combination with timing information on plastic strip's ends narrows down the region of possible interaction even greater. Utilization of machine learning in such multivariable problem have already been inspected as a viable option for interaction position reconstruction [7, 8].

The performed simulations and analysis indicate that the proposed method enables to achieve the axial spatial resolution of the J-PET system constructed with WLS strips of 10 mm axial length of about **3.9 mm of FWHM (PRELIMINARY)**. Transition to even finer WLS strips can even further enhance the axial resolution of photon's interaction reconstruction.

References

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