Review of the Ph. D. Thesis entitled:

Double-strip prototype of polymer time-of-flight positron emission tomograph based on multi-level analog electronics

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The presented thesis describes the design, construction and characterization of the performance of the double-module prototype of the positron emission tomography scanner built from plastic scintillators. This thesis concerns applications of nuclear physics techniques in medical diagnostics.

Positron emission tomography (PET) is well known diagnostics method which provides metabolic images of the chosen pharmaceuticals. It enables to detect cancer at the stage where it is still not recognizable via anatomical (CT) or morphological imaging (MRI).

Pharmaceuticals used in PET diagnosis are labeled with beta-plus radioactive isotopes which emits positrons. Positrons in the human body thermalize and annihilate with electrons. In most of the cases as a result of positron-electron annihilation two 511 keV (collinear) photons are created. Currently used PET scanners register these 511 keV photons with inorganic crystal scintillators arranged in rings surrounding the patient. Each crystal is read out by the matrix of photomultipliers. In the newest PET scanners the SiPM photomultiplier matrices are used. Distribution of the amplitude of signals produces in photomultipliers enables determination of the position of interaction of registered 511 keV photons. Determination of the position of interaction for both photons allows to reconstruct the direction of flight of the registered photons (often referred to as line of response). Next the collected list of line of responses is used to reconstruct an image of the density distribution of the annihilation points. This distribution is correlated with the density distribution of the radioactive isotope which in turn reflects the rate of the metabolism of the pharmaceutical administered to the patient.

Over forty years of development (starting from first prototypes in 1975) PET devices evolve to the whole-body hybrid PET-CT and PET-MRI scanners enabling both anatomical and metabolic imaging of the whole human body. PET-MRI were introduced in the clinical practice only in the last decade. However due to the limited axial field of view (typically about 20cm) the whole body PET imaging requires sequence of independent measurements by moving the patient in steps along the scanner. Therefore the present challenge in the PET research and development is the construction of the total-body scanner which would enable imaging of all parts of the body at the same time.

These facts, including the description of the current PET scanners, are all fairly well documented in the Part I of the presented work and the reader is lead to Part II which comprises description of the new PET scanner which may be constructed form the strips of

plastic scintillators. Usage of plastic scintillators for PET is a new idea, however similar designs were already used for the registration of charged particles as e.g. in experiments performed at the zero-degree spectrometer COSY-11 including S1 scintillator hodoscope which is properly given credit in the present work.
Plastic scintillators are much less expensive than inorganic crystal and when arranged axially around the patient with the electronic readout (only at the edges of the scanner) may allow for the construction of the total-body PET in a cost effective way. However there are two main disadvantages of plastic scintillators when applied to PET. Firstly, the efficiency for the detection of 511 keV photons in plastic scintillators is much smaller with respect to inorganic crystals and secondly 511 keV photons interact in plastics in practice only via Compton scattering. While in inorganic crystals the large fraction of interactions undergoes via photoelectric effect thus enabling suppression of events when one or both of the 511 keV photons were scattered in the patient. The problem of efficiency and lack of photoelectric effect was addressed also in Part II of the thesis. Author quoted recent Monte-Carlo simulations showing that the low registration efficiency of 511 keV photons in plastic scintillators with respect the inorganic crystals detectors may be compensated by the large geometrical acceptance and the application of more than one detection layer. In this part it is also shown (based on the Monte-Carlo simulations) that the measurement of the energy deposition caused by Compton interaction in plastic scintillators can be used for the reduction of the background due to the scattering of photons in the patient.

Thus, after the general introduction and discussion based on simulations, consequently the detector system is introduced in Part III. In this part Author describes the two-strip PET prototype and discuss (i) properties of scintillators and photomultipliers, (ii) digital scope used for the data acquisition and (iii) basics of the analysis software. In this part the choice of the type of scintillators and photomultipliers is justified. The description is correct but it seems to be too concise and could be improved e.g. by the explicit comparison between the emission spectra of the considered scintillators and the quantum efficiency spectra of photomultipliers. After the description of the experimental setup in Part IV the discussion about experimental aspects continues with the presentation of the method of sampling in voltage domain and determination of relations between signals charge and the time-over-threshold (TOT).

In Part V the three possible design of the electronic readout are presented. The concept of the multi-level readout board is descried quite clearly. This solution, based solely on the field programmable gate arrays (FPGA) was applied in the further experiments. However, the other two analog electronics boards which were finally not used in the J-PET tomograph, are described very roughly and sloppy, and it would be perhaps better not to include their description in this thesis at all, as they were not used later.

I appreciate very much the thorough analysis presented in parts VI and VII of the optimization of the thresholds, supply voltages and time offset determination including the correction for the time walk effect which is very essential for the improvement of the uncertainty achievable. One of the interesting and important results of these parts is the comparison of the time walk corrections performed based on the charge and on the TOT values. Author has shown that it in practice the achievable time resolution is the same independent of whether it is performed assuming that the walk effect is linearly dependent on 1/sqrt(charge) or on 1/TOT.

Finally Parts VIII and IX are devoted to the measurements with the different configurations of the ^{22}Na sources. The collected data were selected and analyzed using methods described in the previous parts. The images of the sources were reconstructed as scatter plots as well as results of the application of the Maximum Likelihhod Expectation Maximization (MLEM) image reconstruction alogorithm. The main result of these parts and in general of this thesis is that it is possible to reconstruct PET images using plastic scintillator strips as detectors of 511 keV photons.

In conclusion, Szymon Niedźwiecki demonstrated by this thesis his original work of construction, calibration of the two-strip plastic PET prototype and fairly advanced analysis of the data collected with the ^{22}Na beta-plus emitter.

In general the thesis is fair and well written and presents an original results showing experimentally that it is possible to make PET images using plastic scintillator strips and therefore I recommend continuing the Ph.D. procedure at the Jagiellonian University since I am convinced that it will be successfully completed.

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