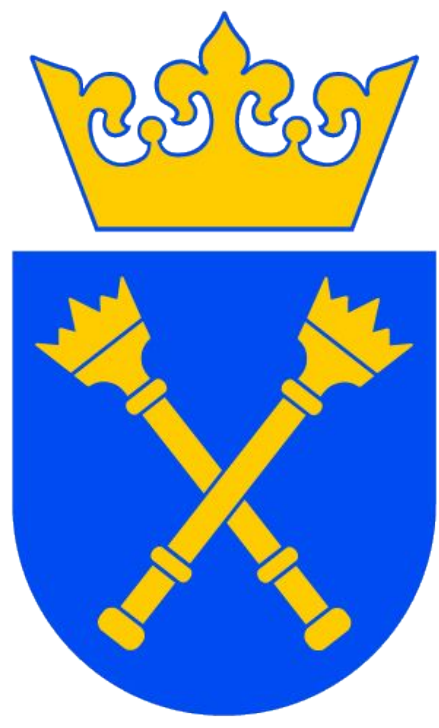




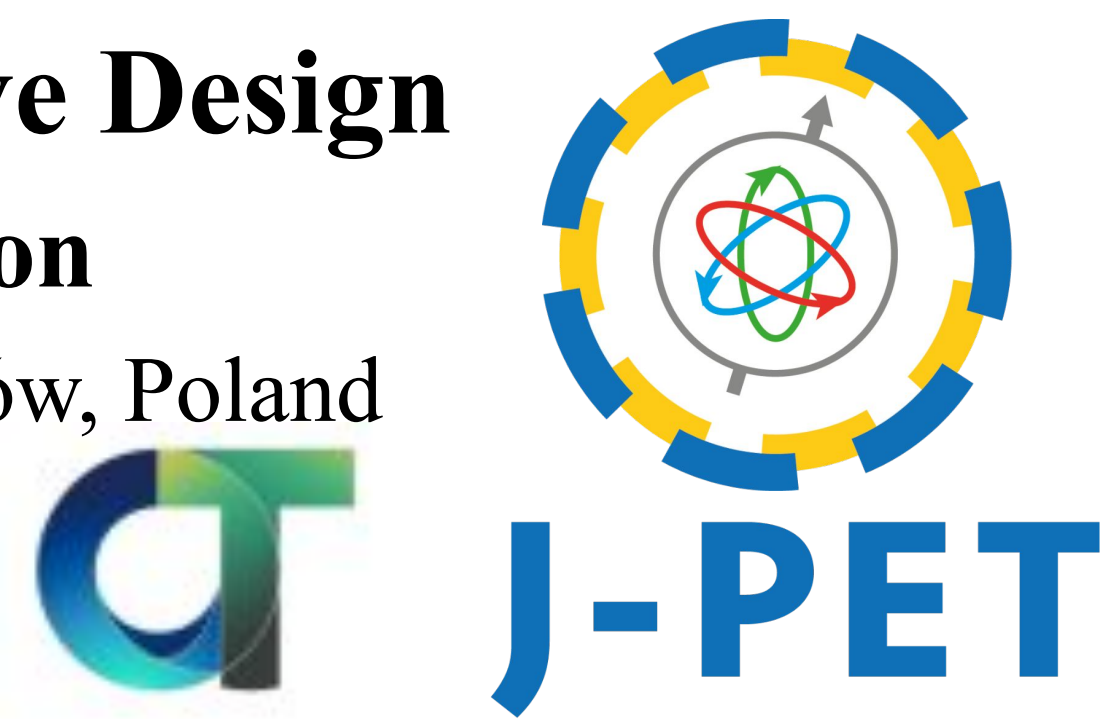
Development of a Cost-Effective Total Body J-PET from Plastic Scintillators: Definitive Design

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Abstract:

Total-body Positron Emission Tomography (TB-PET) is now being used in clinical practice; however, wider adoption in hospitals requires a reduction in construction costs [1]. We are developing a cost-efficient TB-PET system utilizing plastic scintillators [2,3]. This study discusses the current development status, including tests of individual detectors with SiPMs and new simulation results based on the finalized design. During the experimental phase, we tested individual detector units using SiPMs connected to the axial ends of plastic scintillator strips with a collimated beam of 511 keV photons from a Na-22 isotope source. We characterized the detector performance using two types of SiPMs, from Hamamatsu and Onsemi. Based on these characterization results, we evaluated performance across different scintillator lengths and selected two lengths for use in the final design of the total-body Jagiellonian PET (TB-J-PET). With these selected lengths (33 cm and 60 cm), the TB-J-PET geometry was redesigned, and simulations were conducted using GATE [4] to evaluate system sensitivity, scatter fraction, and spatial resolution. TB-J-PET will be built using the latest generation of J-PET technology, which is presented and discussed in this study. The first generation of the J-PET scanner was built using 192 plastic scintillator strips, each 50 cm long, and read out by PMTs [5,6]. The second generation is a modular, portable PET scanner constructed from 312 plastic strips, also with an AFOV of 50 cm, and read out by SiPMs [7,8]. In this work, we report on a 254 cm long system currently under construction, funded by the Polish Ministry of Science and Higher Education.

Experimental setups:

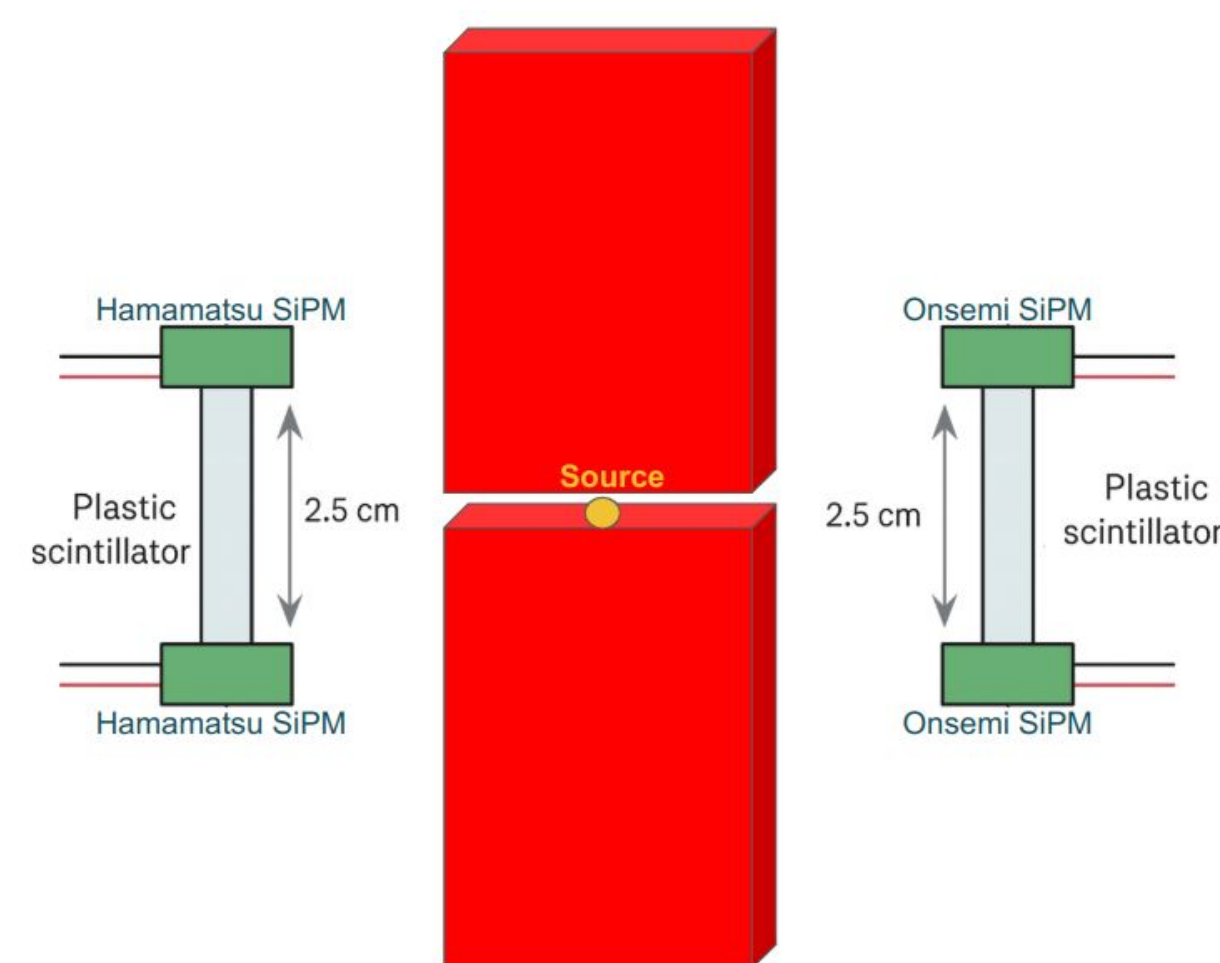


Figure 1. Schematic view of the experimental setup for SiPM performance characterization (Hamamatsu vs. Onsemi).

Scintillator Lengths: 2.5 cm

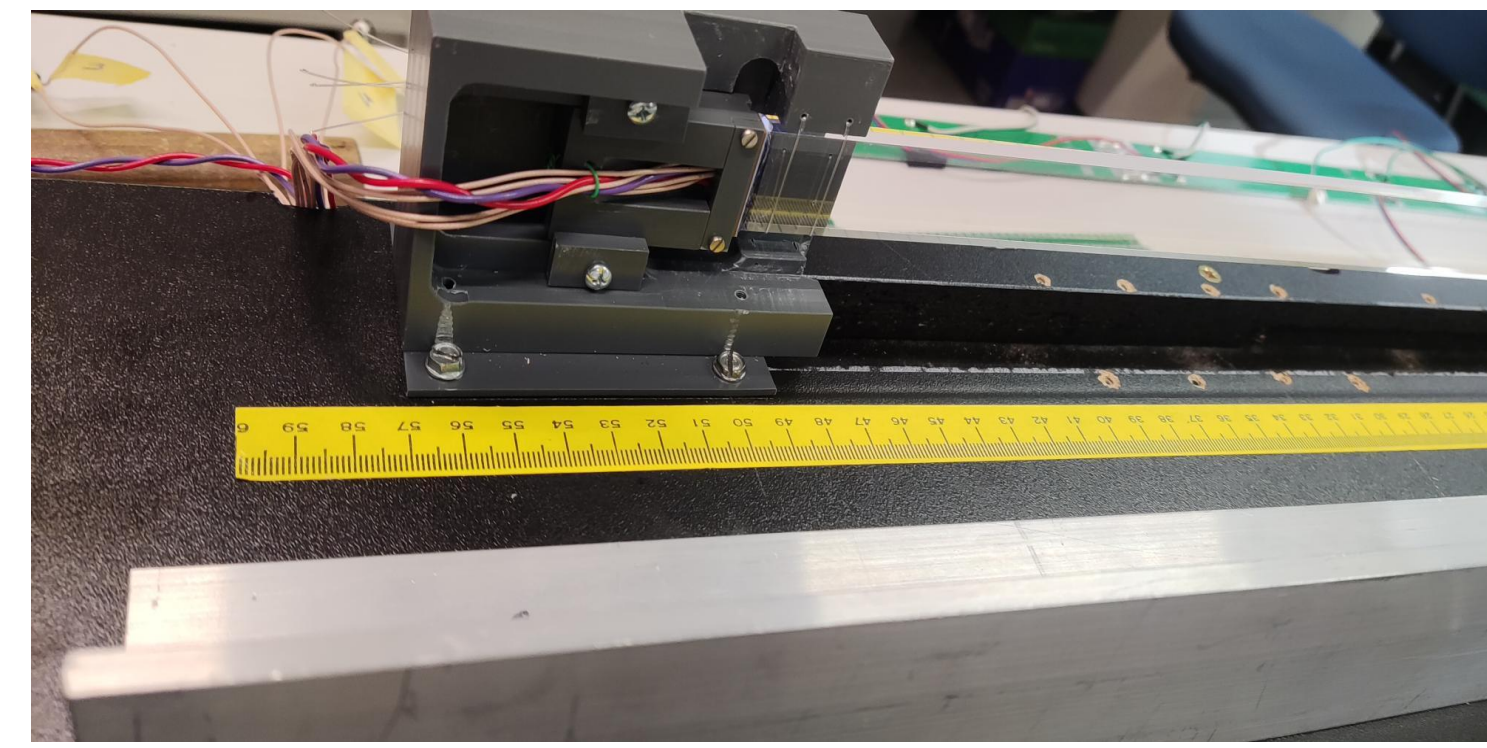
Scintillator: EJ-200

SiPM:

1. Hamamatsu S14160-6050HS
 - Breakdown voltage = 38 V
 - Applied over voltage = +6 V
2. Onsemi MICROFJ-60035-TSV
 - Breakdown voltage = 25 V
 - Applied over voltage = +6 V

Scintillator: EJ-200

Source: Na



SiPM A

SiPM B

Figure 2. Schematic view of the experimental setup for optimizing the length of plastic scintillator.

Scintillator Lengths: 100, 60, 33 and 5 cm.

Scan in the different position of the scintillators:

±25% of the length & center & ±3.5 cm from the edge of the scintillators

SiPM: Hamamatsu S13361-6674

Breakdown voltage = 53 V

Over voltage = +3 V

Scintillator: EJ-200

Source: Na

SiPM characterization Hamamatsu vs. Onsemi:

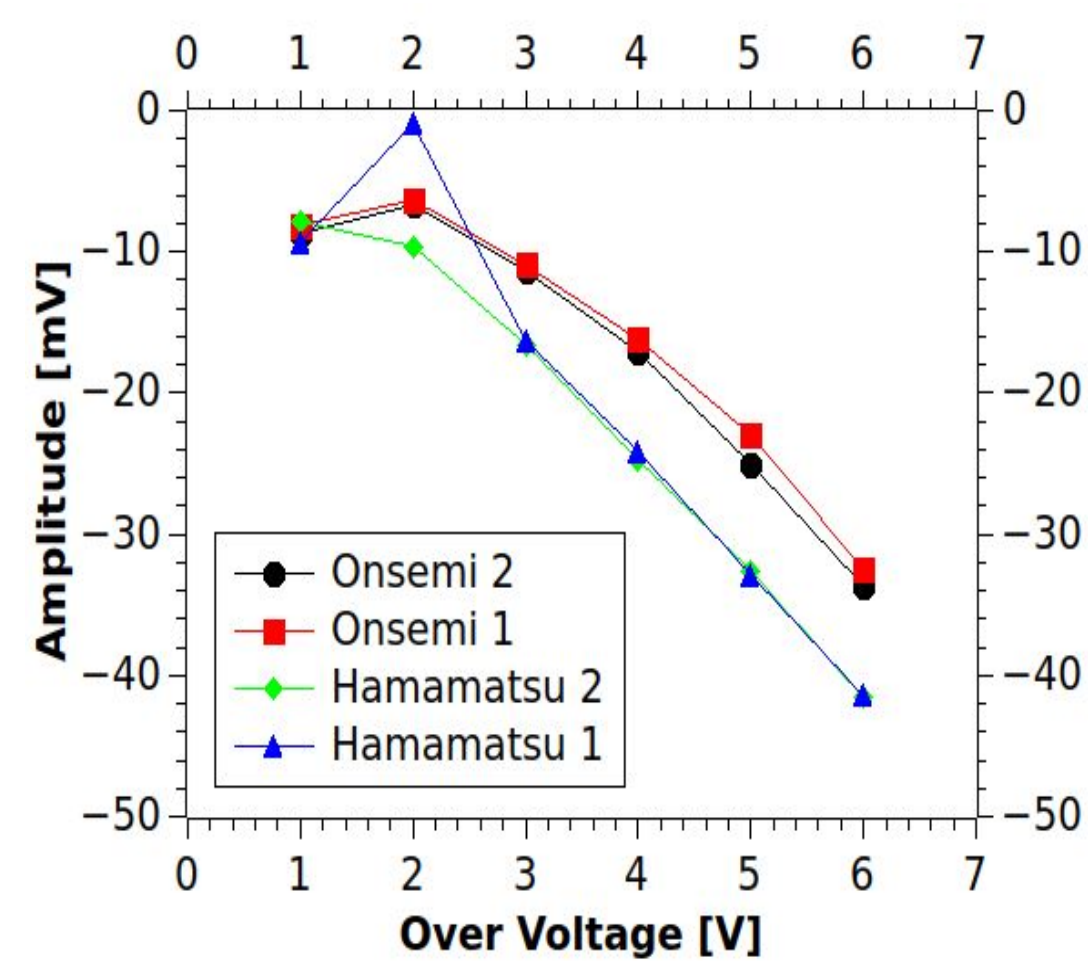


Figure 4. Amplitude based on different over voltage

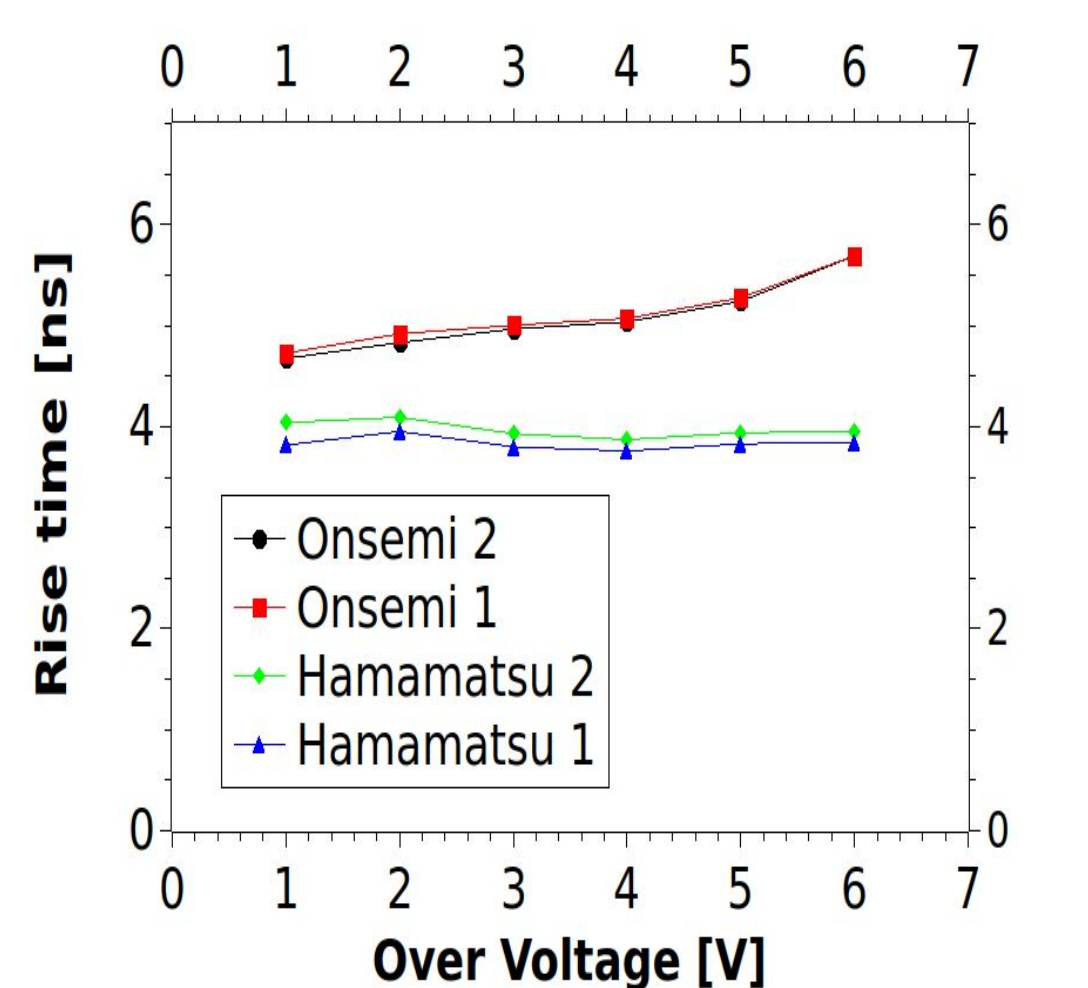


Figure 5. Rise time based on different over voltage

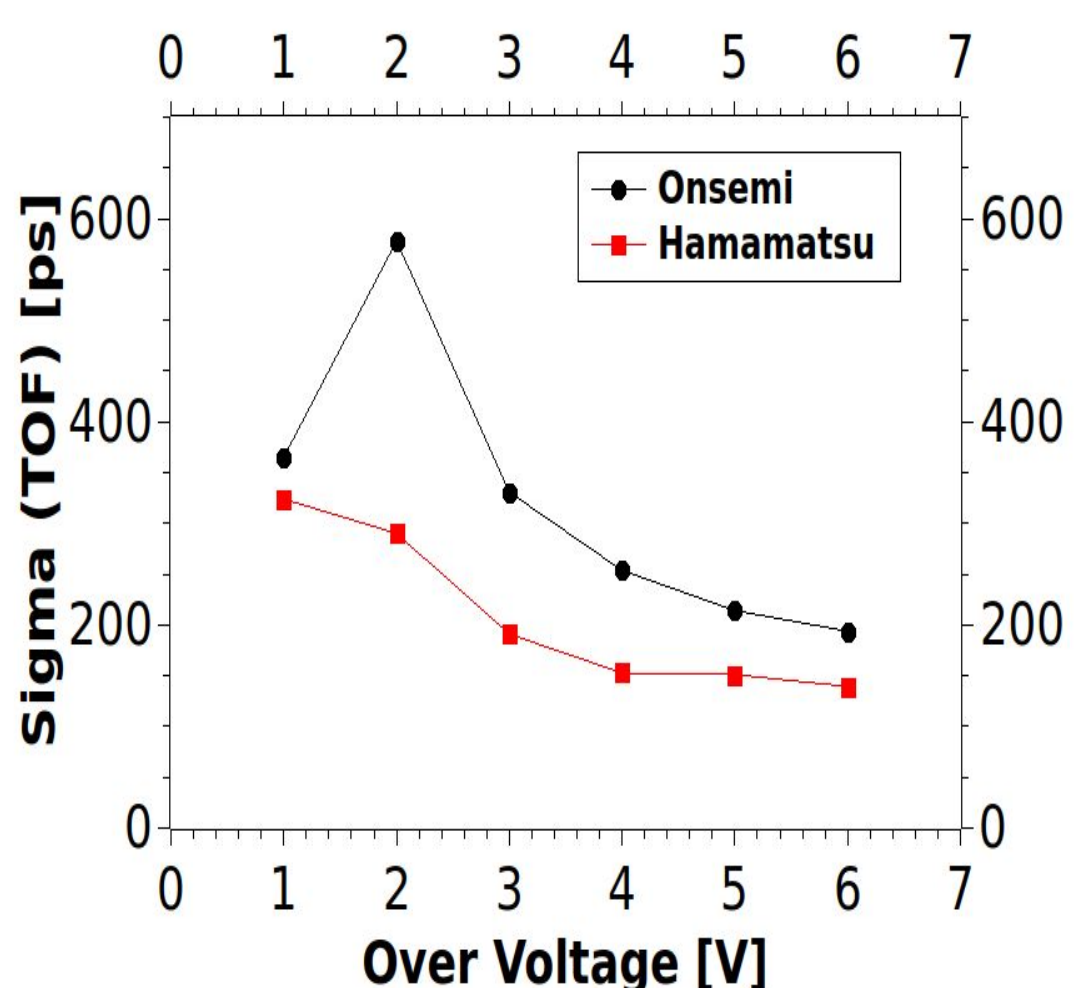


Figure 7. Sigma (TOF) based on different over voltage

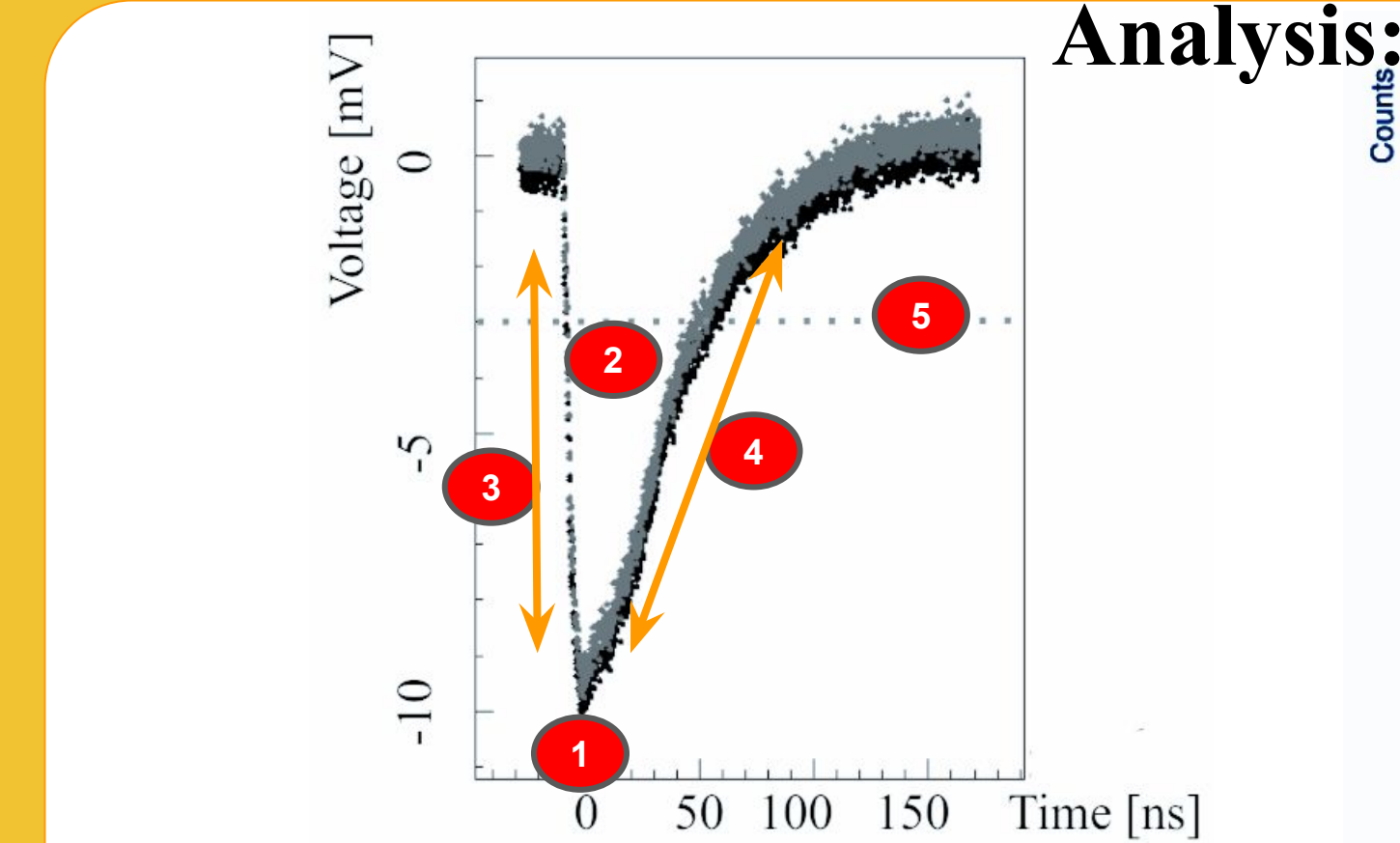


Figure 3. (Left) Sample of the one signal. (Right) raw charge sum spectra.

1- Amplitude (Minimum pick) 2- charge (area under the red signal) 3- Rise Time (based on 10-90% of amplitude) 4- Fall Time (based on 90-10% of amplitude) 5- Time difference (is the difference between the rising edge in constant threshold from both SiPMs).

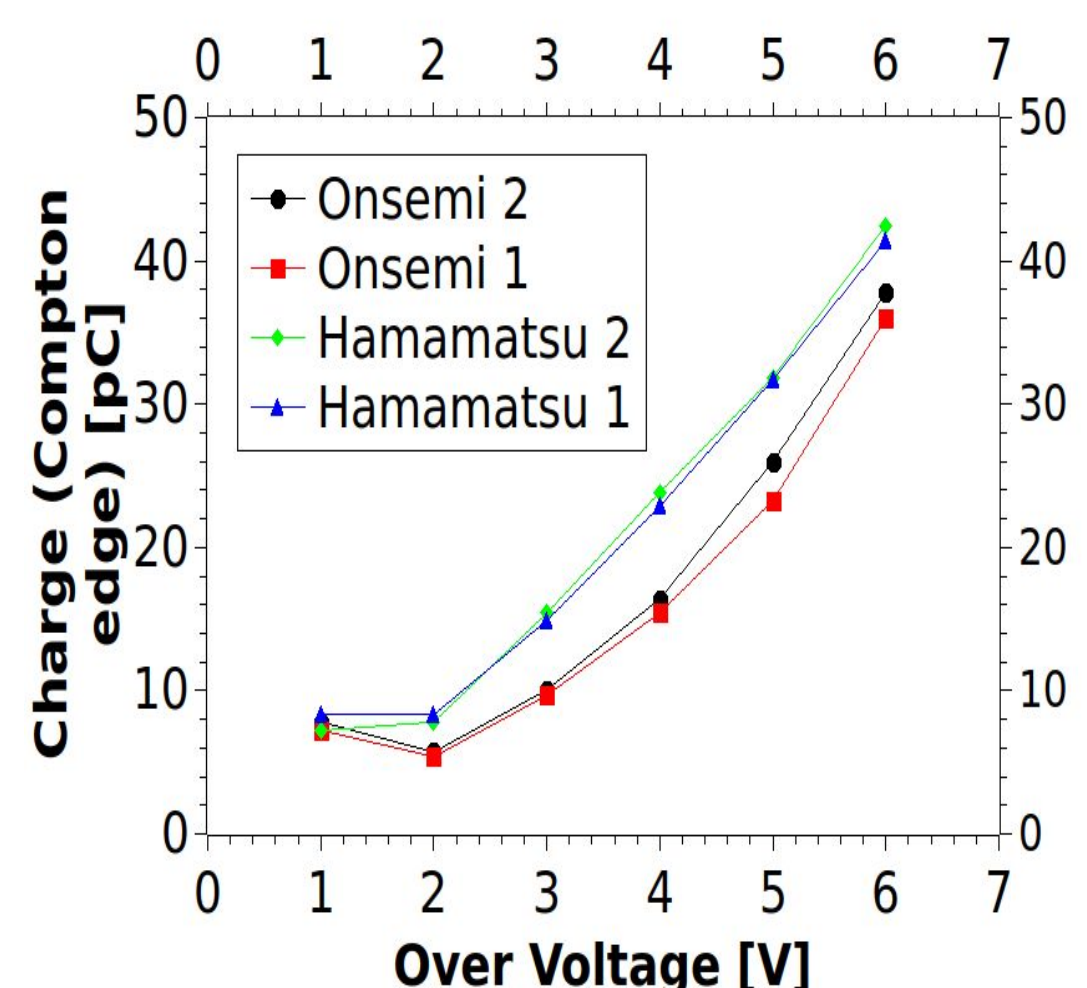


Figure 6. Charge based on different over voltage

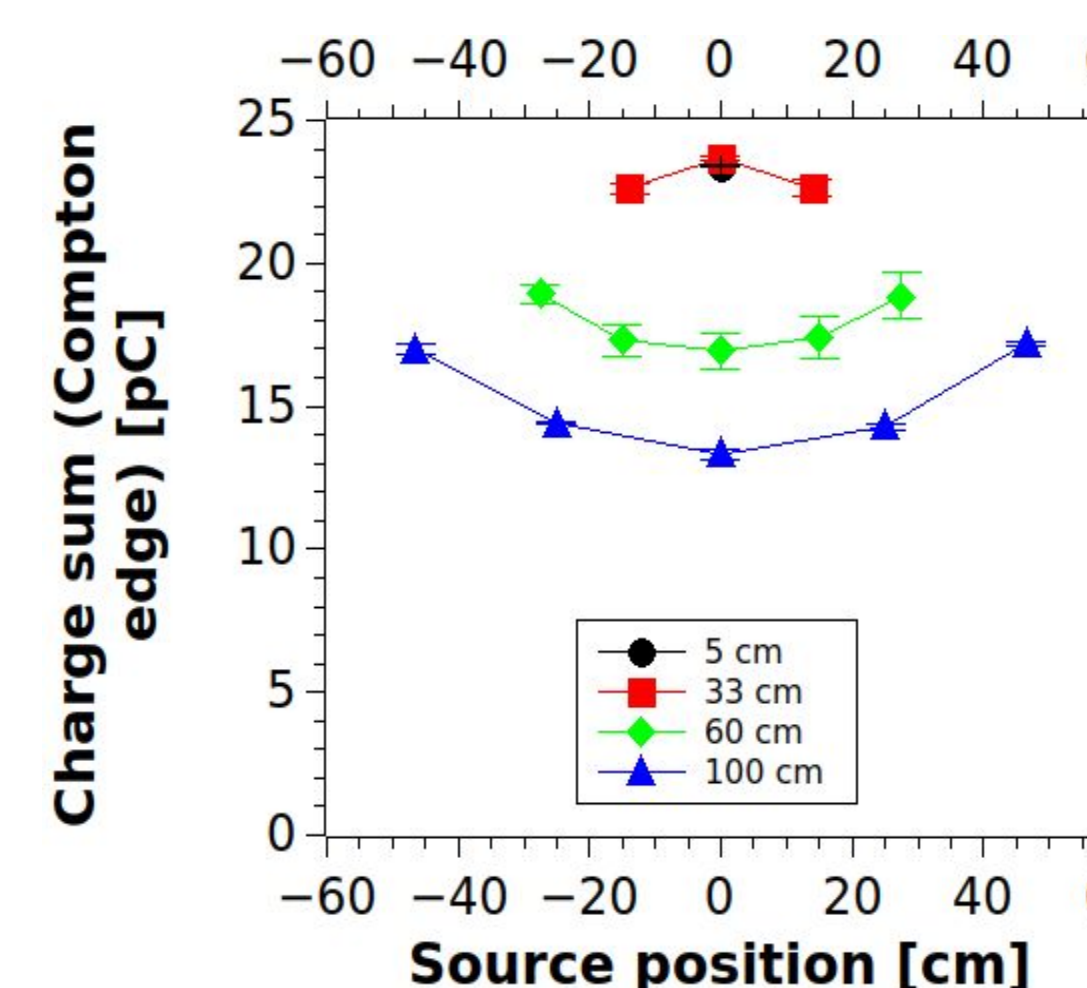


Figure 10. Charge sum based on different positions and lengths of the scintillator

Optimizing the length of plastic scintillator:

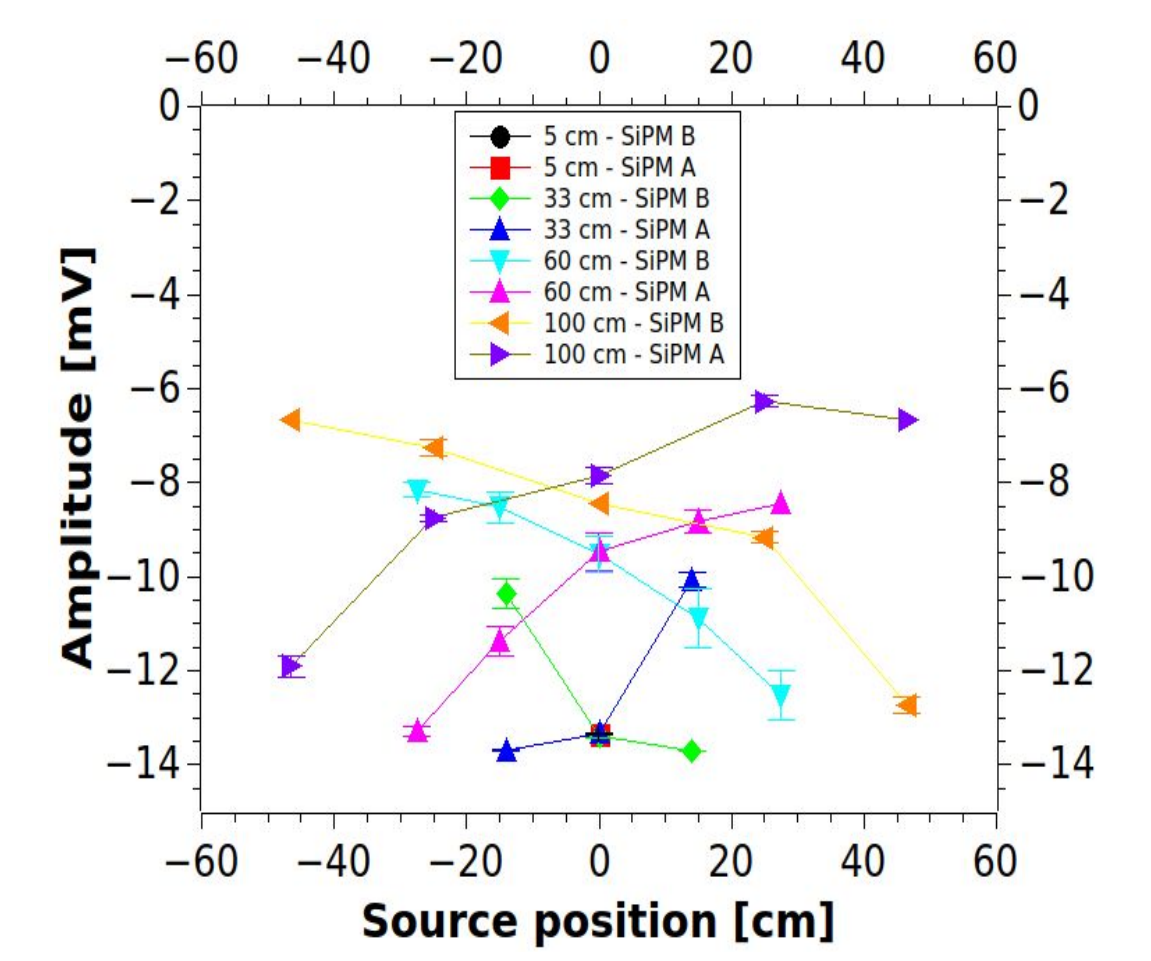


Figure 8. Amplitude from both SiPM based on different positions and lengths of the scintillator

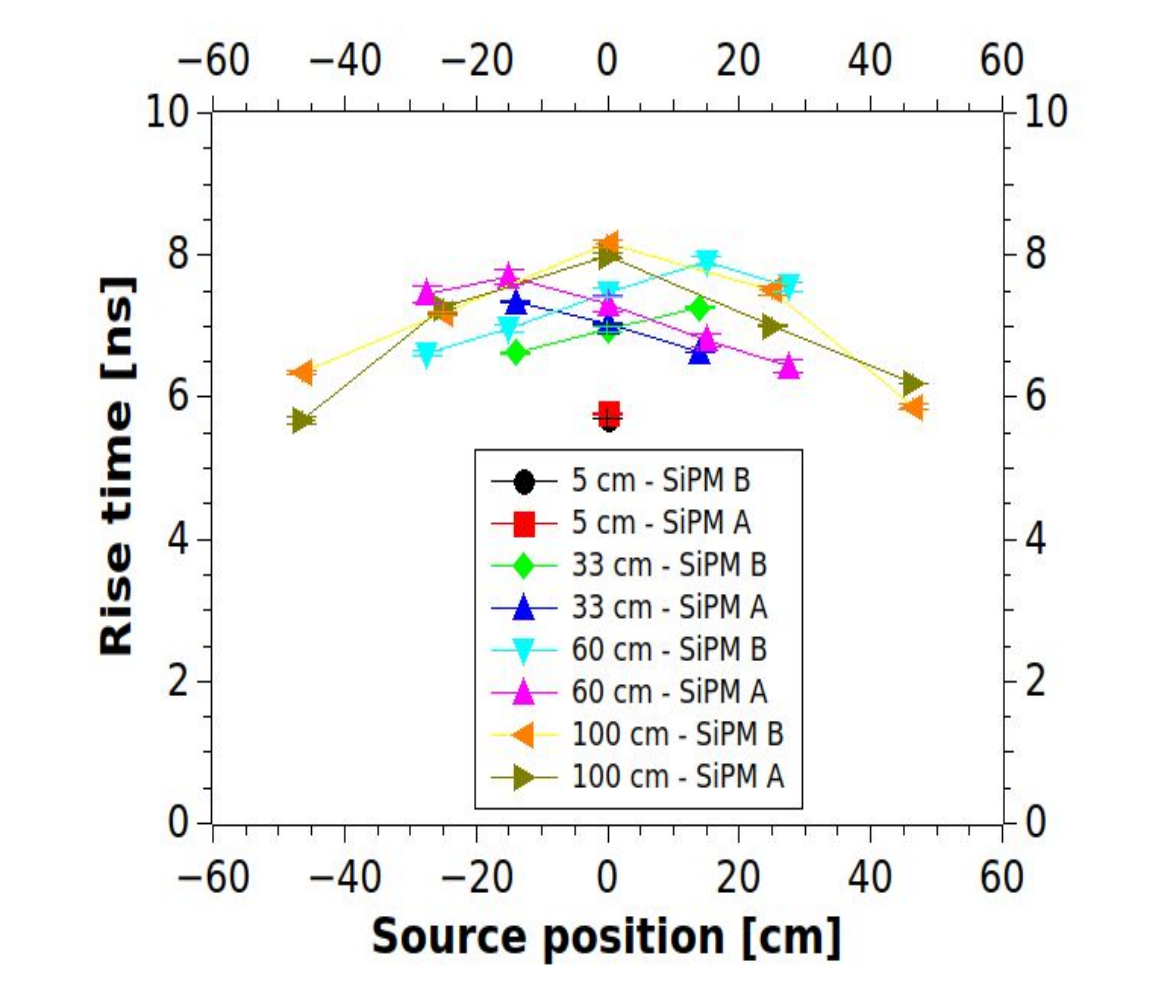


Figure 9. Rise time based on different positions and lengths of the scintillator

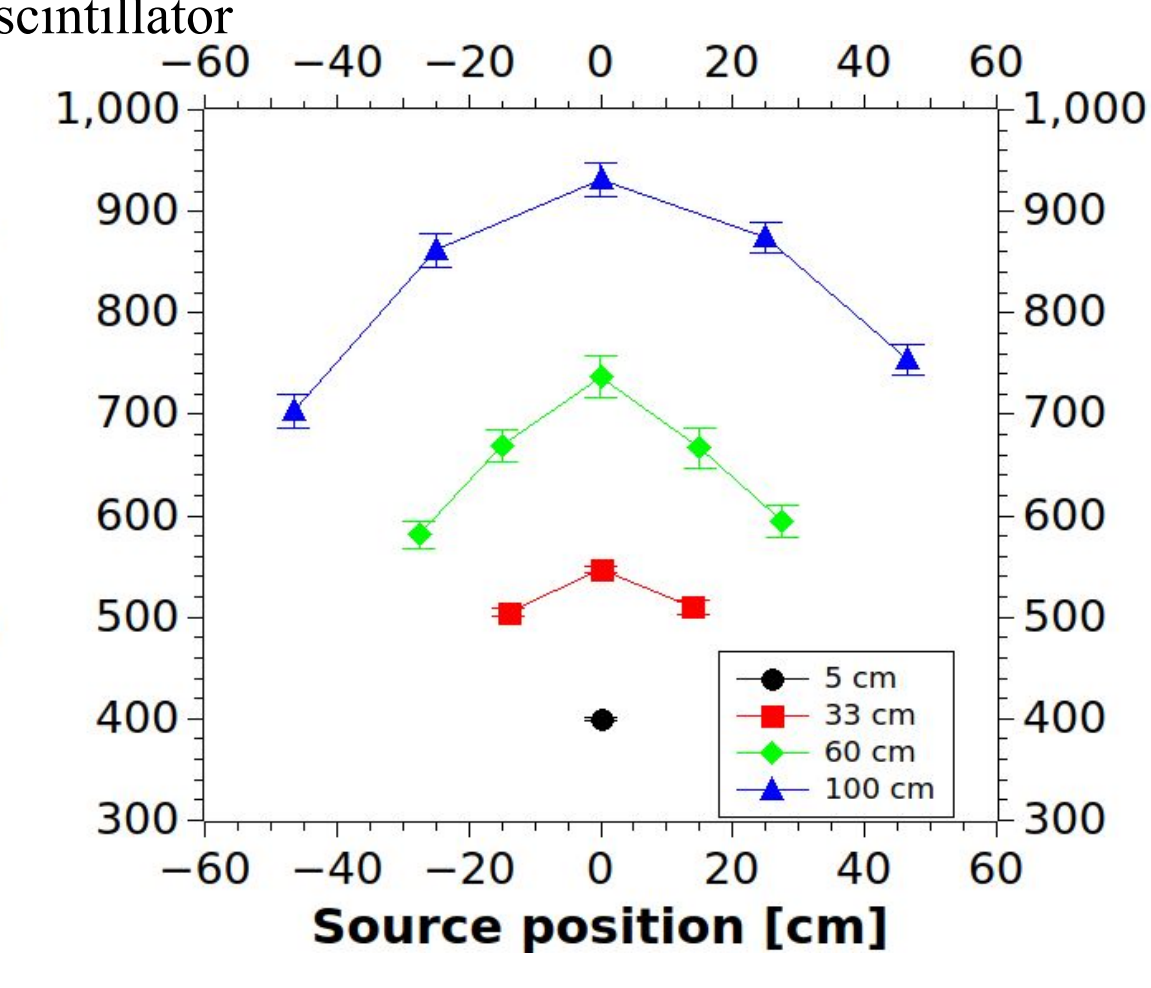


Figure 11. Sigma (TOF) based on different positions and lengths of the scintillator

Total Body J-PET (Definitive Design):

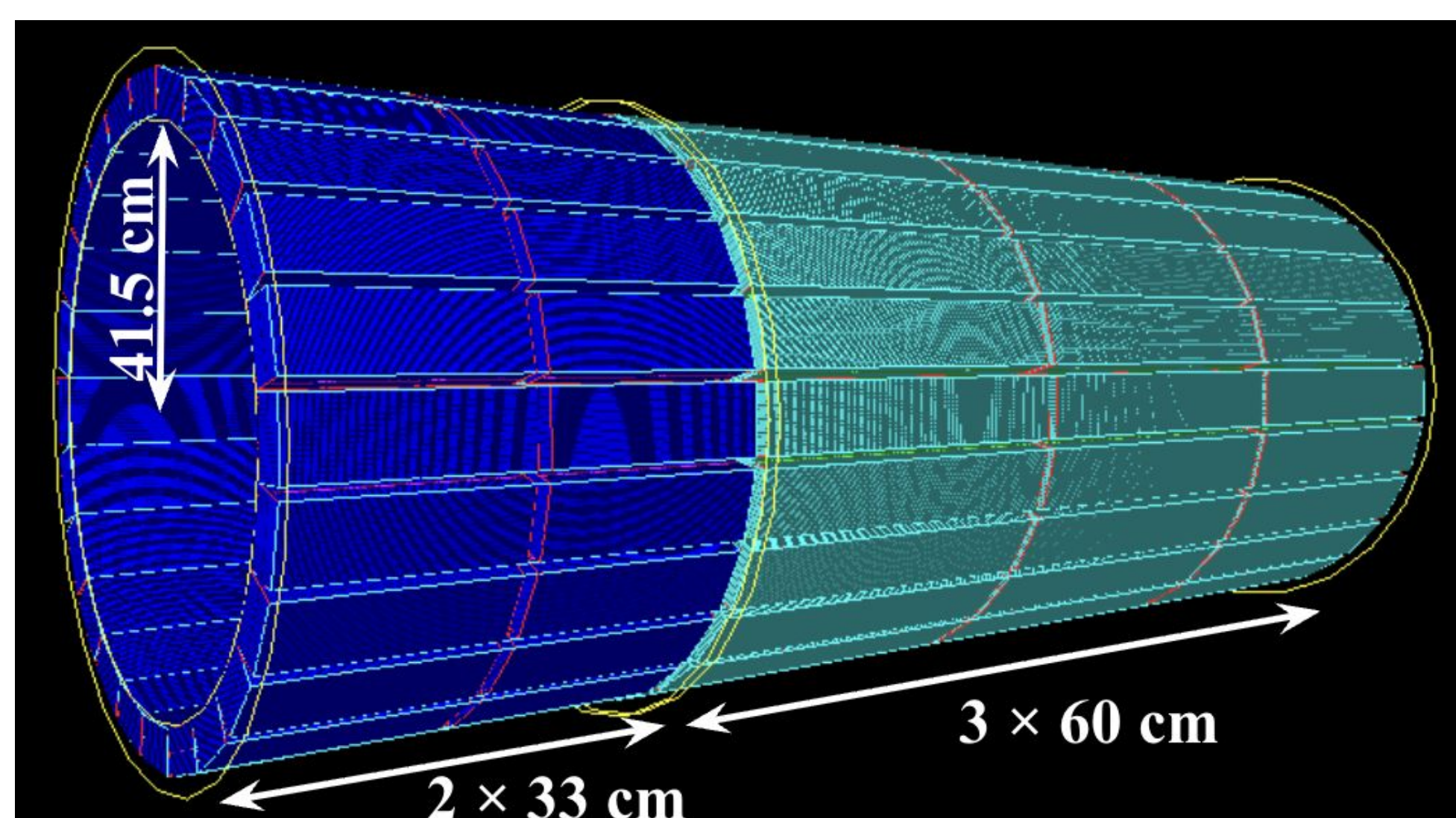


Figure 13. Schematic view of the simulated TB-J-PET consists of five detection rings with an axial field of view (AFOV) of 254 cm. The configuration includes two rings, each 33 cm in length, and three rings, each 60 cm in length, with a 2 cm gap between rings. Each ring contains 24 modules, arranged with an inner radius of 41.5 cm.

- Total configuration: 5 rings × 24 modules/ring
- 2 cm gaps between the rings
- AFOV: 254 cm
- Module design: 2 plastic layers + 1 WLS layer (sandwiched)
 - Rings with 33 cm strips
 - 2 rings
 - 16 plastic scintillators per layer
 - Dimensions: 30 × 6 × 330 mm
 - 50 WLS strips between layers
 - Dimensions: 6 × 3 × 108 mm
 - Rings with 60 cm strips
 - 3 rings
 - 16 plastic scintillators per layer
 - Dimensions: 30 × 6 × 600 mm
 - 90 WLS strips between layers
 - Dimensions: 6 × 6 × 108 mm

Energy window	> 200 [keV]
Time window	4 [ns]
CRT	~ 350 - 400 [ps]
Sensitivity in the center	~ 36 [cps/kBq]
Scatter Fraction	(37.59 ± 0.04)%
FWHM (Radial, Tangential, Axial) at (x = 1 cm, y = 0, z = 0)	(4.77, 4.71, 14.23) [mm]

Table 1. Simulated performance characteristics of the TB-J-PET system (GATE v9.4).

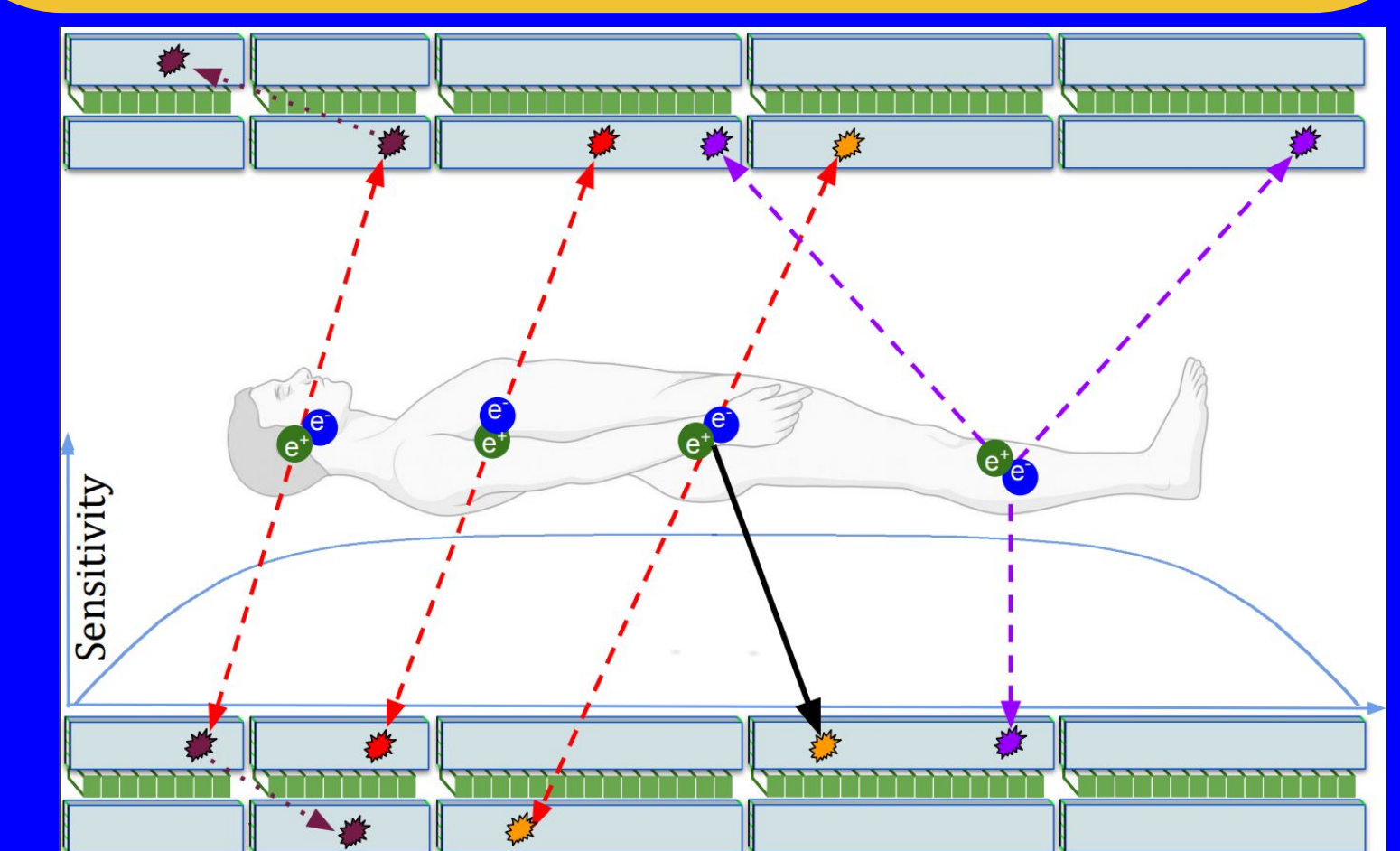


Figure 12. Sigma (TOF) at the center position of the scintillator with the length of 60cm and 33 cm at various constant thresholds based on different voltages.

Acknowledgment:

We appreciate the support from the National Science Centre of Poland through grant no. 2021/42/A/ST2/00423, 2021/43/B/ST2/02150, 2022/47/1/NZ7/03112 and Ministry of Science and Higher Education of Poland through Grant No. 1AL/SP/596235/2023 and European Union through ERC Advanced Grant POSITRONIUM no. 101199807 and via SciMat and qLife Priority Research Areas under the Strategic Programme Excellence Initiative at the Jagiellonian University and PLGrid (ACK Cyfronet AGH, PLG/2024/017688).

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