



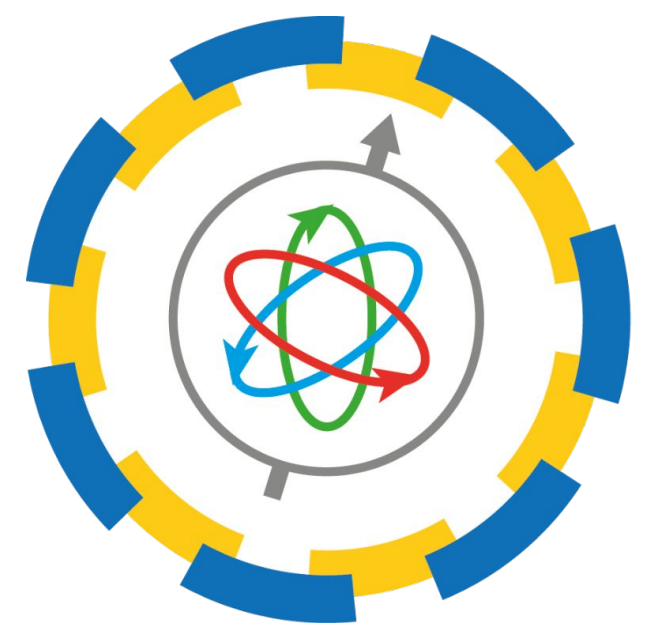
Development of Total Body J-PET from plastic scintillators

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Abstract:

PET scanners play a crucial role in medical diagnostics and treatment monitoring, typically using crystal scintillators to detect annihilation photons via the photoelectric effect. However, most PET scanners have a limited AFOV of 15–26 cm. Efforts to expand the AFOV aim to improve performance and reduce costs for wider hospital use. Our project focuses on developing cost-effective total body PET scanners using plastic scintillator strips aligned axially, with SiPM located at the strip ends, and gamma detection is achieved through Compton scattering [1, 2].

This study discusses the preparation status based on new simulation results and the test of single detectors with the SiPMs. The simulation part has been carried out using the GATE version 9 with the digitizer "simulation toolkit" to investigate sensitivity, scatter fraction, and spatial resolutions of the total body J-PET. The analysis process relies on the coincidences section of the digitizer output. An energy window larger than 200 keV within a fixed time window of 3 ns was chosen. In the experimental phase, we tested the single detector units employing SiPMs connected to the plastic scintillator strips at the axial ends. Using a collimated beam of 511 keV photons from the Na-22 isotope we characterized the detector performance for different lengths of the scintillator.

Total body J-PET:

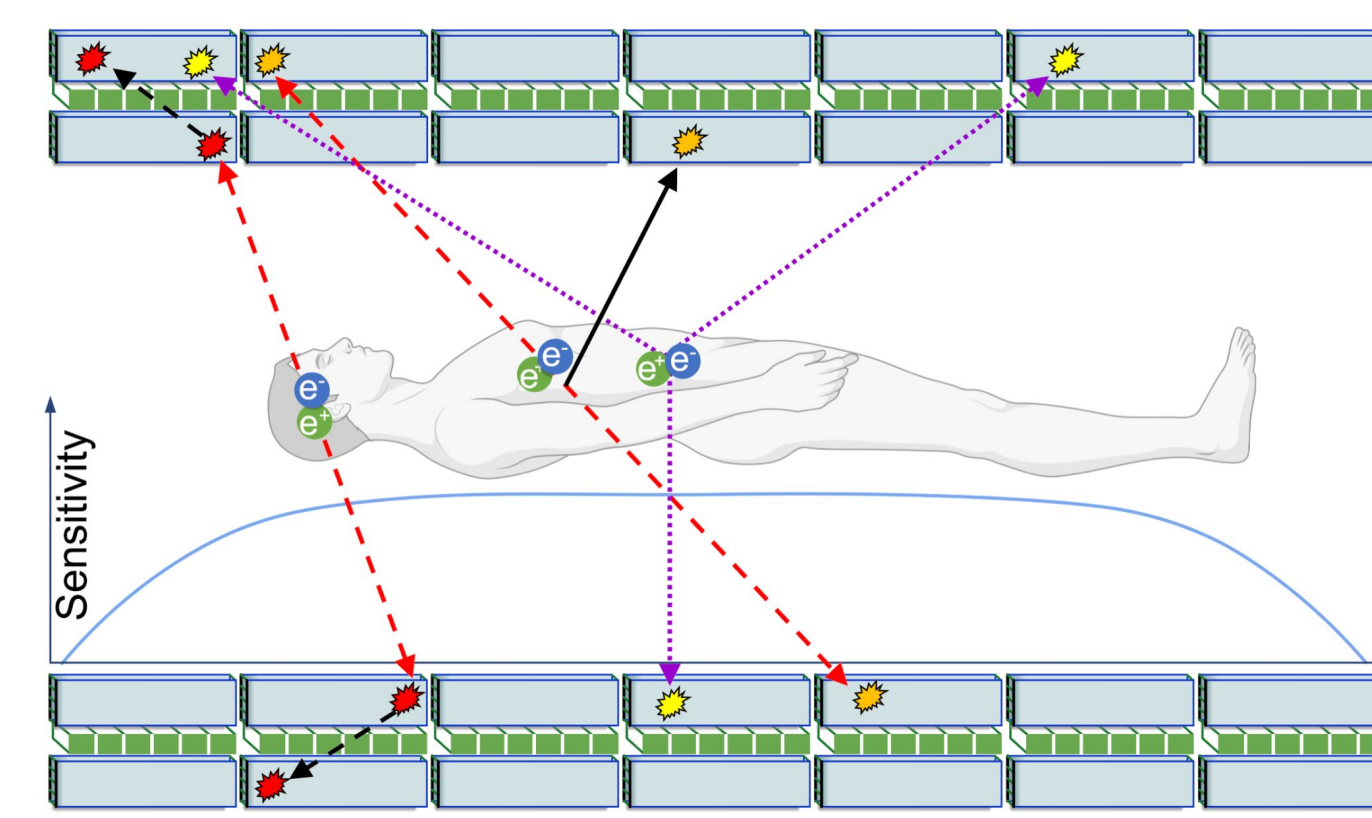


Figure 1. Example of the total body J-PET geometry consisting of several rings [3].

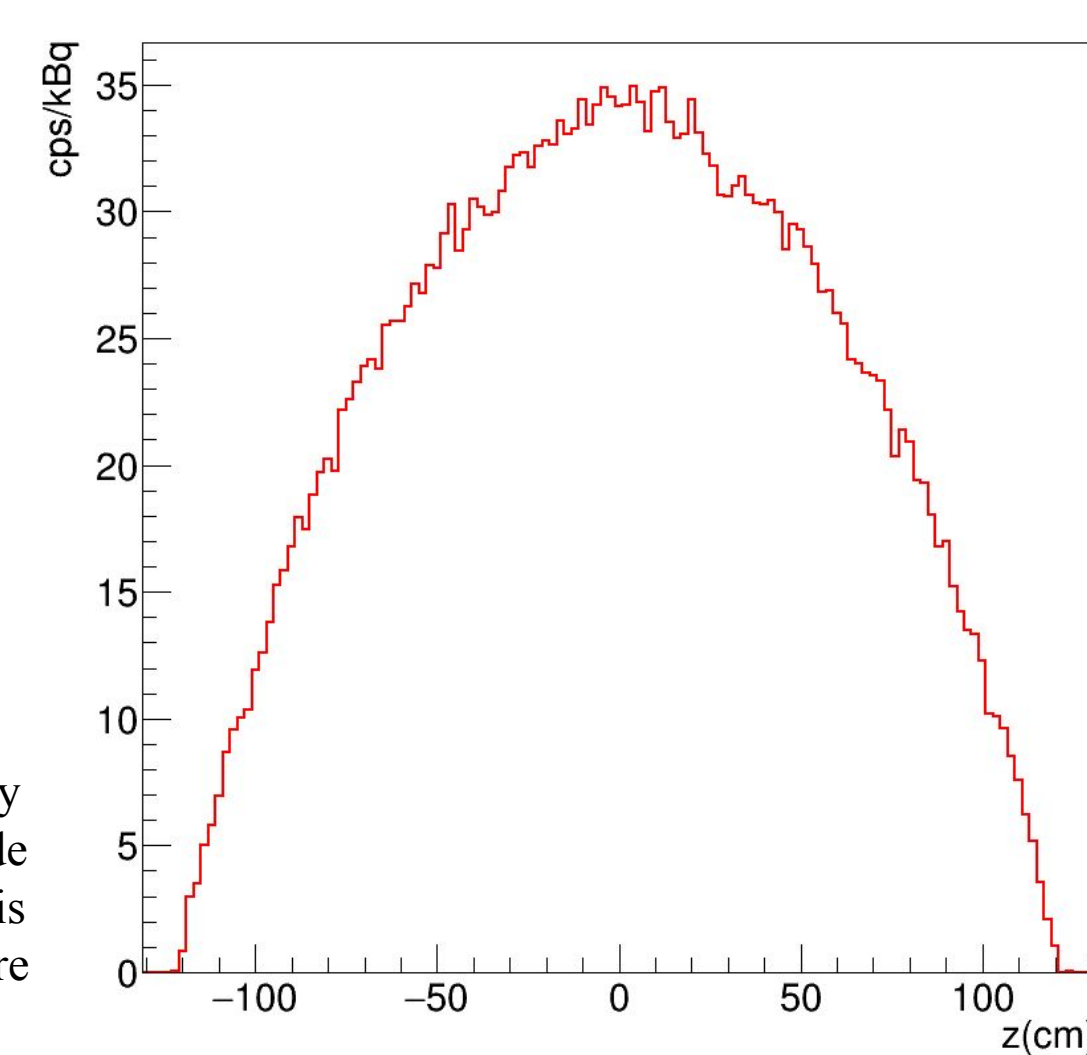
Simulation:

Sensitivity

The sensitivity of a PET is expressed as the rate in counts per second that true coincidence events are detected for a given source strength.

- 261 cm Line source
- The diameter of the source is 1mm
- Activity of the source 1 MBq
- Back-to-back gamma photons

Figure 2. Preliminary results of Axial sensitivity profile for 7 rings of Total Body J-PET in the central position for the line source with the length of 261 cm inside the scanner. On the X-axis position of the Z coordinate of the annihilation place is shown, while on the Y-axis counts per second per kBq of activity of the source are presented.



Spatial resolution

Ability to distinguish between two points after image reconstruction.

Purpose: Characterize the widths of the reconstructed image point spread functions (PSF) of compact radioactive sources.

Point Spread Function (PSF) must be determined for each one of the source in three different axes:

- Radial
- Tangential
- Axial

	FWHM Radial [mm]	FWHM Tangential [mm]	FWHM Axial [mm]
(1,0,0)	4.77	4.71	14.23
(10,0,0)	7.13	4.72	14.23
(20,0,0)	11.93	9.44	14.23
(1,0,91.125)	4.72	4.76	9.46
(10,0,91.125)	7.12	7.15	11.85
(20,0,91.125)	11.93	9.48	16.59

Scatter Fraction

Scatter fraction is a dimension-less value which is the fraction of a number of the scatter per sum of the true and scatter coincidences

Phantom:

Scatter phantom is a polyethylene solid right circular cylinder with:
Specific gravity: 0.96 ± 0.01
Outside diameter: 203 ± 3 mm
Overall length: 700 ± 5 mm
Special hole with an outside diameter equal to 6.4 ± 0.2 mm

Source:

Line source with the 70 cm length
Polyethylene tube with a diameter of 4.8 mm filled with a known activity
Source: Gamma back-to-back
Activity: 1 MBq

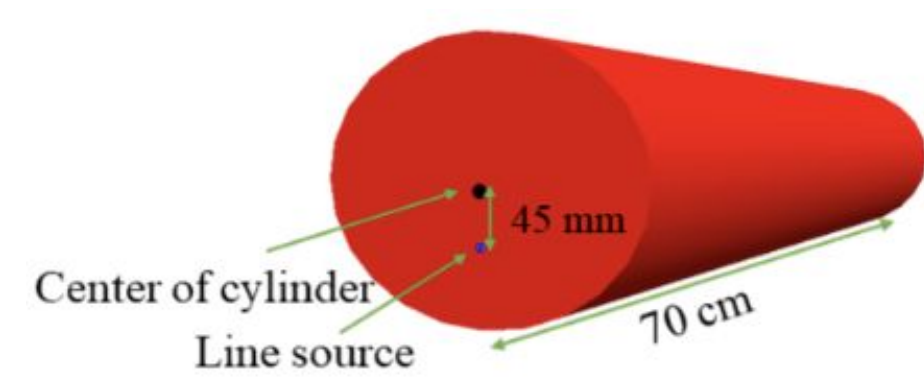


Figure 3: Schematic view of the simulated phantom model

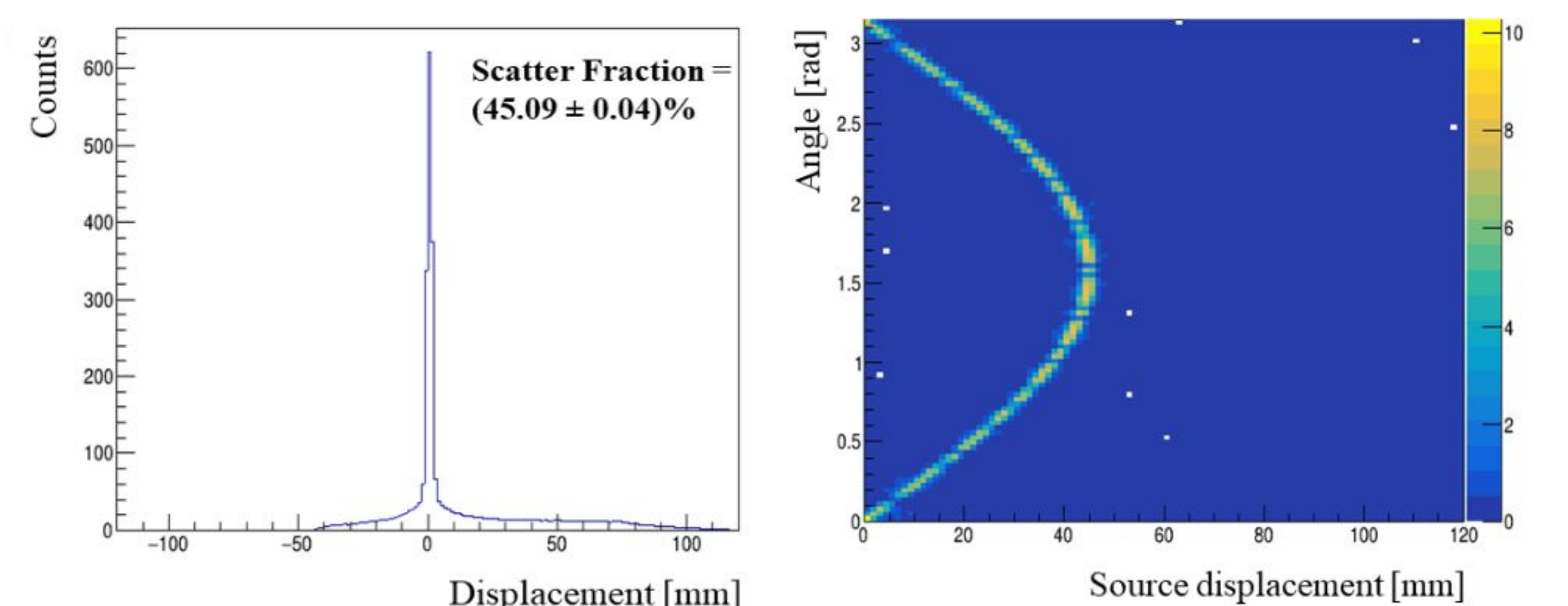


Figure 4. Simulations result for the Total-Body J-PET scanner with the WLS layer; with the 70 cm long source and 1 MBq total activity. Right: Aligned to zero and summed sinogram. Left: Sinogram for a whole scanner.

Experimental:

Method and Material:

Scintillator Lengths: 100, 60, 33 and 5 cm.
Scan in the different position of the scintillators: $\pm 25\%$ of the length & center & ± 3.5 cm from the edge of the scintillators
SiPM: Hamamatsu S13361-6674
Breakdown voltage = 53 V
Over voltage = +3V
Scintillator: EJ-200
Source: Na

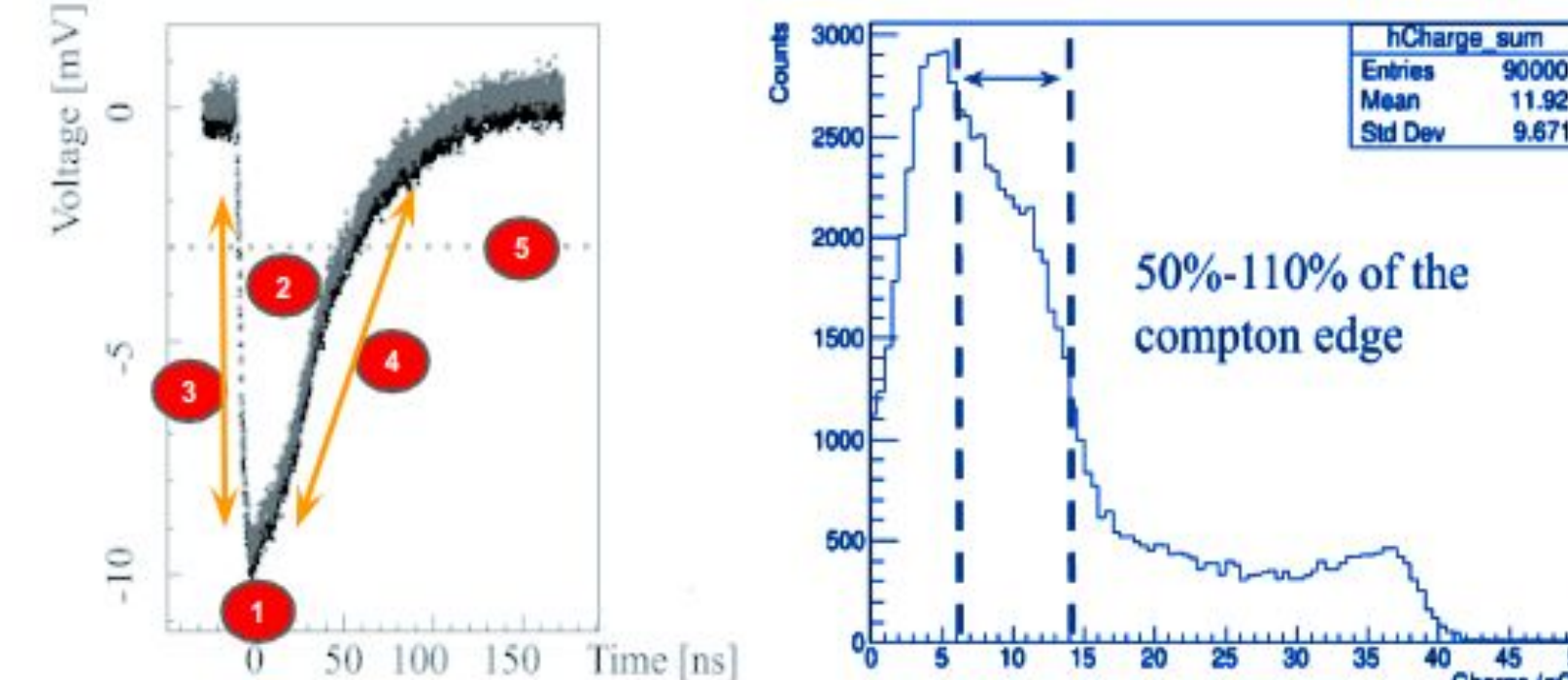


Figure 5. (Left) Sample of the one signal. (Right) raw charge sum spectra. 1- Amplitude (Minimum pick) 2- charge (area under the red signal) 3- Rise Time (based on 10-90% of amplitude) 4- Fall Time (based on 90-10% of amplitude) 5- Time difference (is the difference between the rising edge in constant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

Results

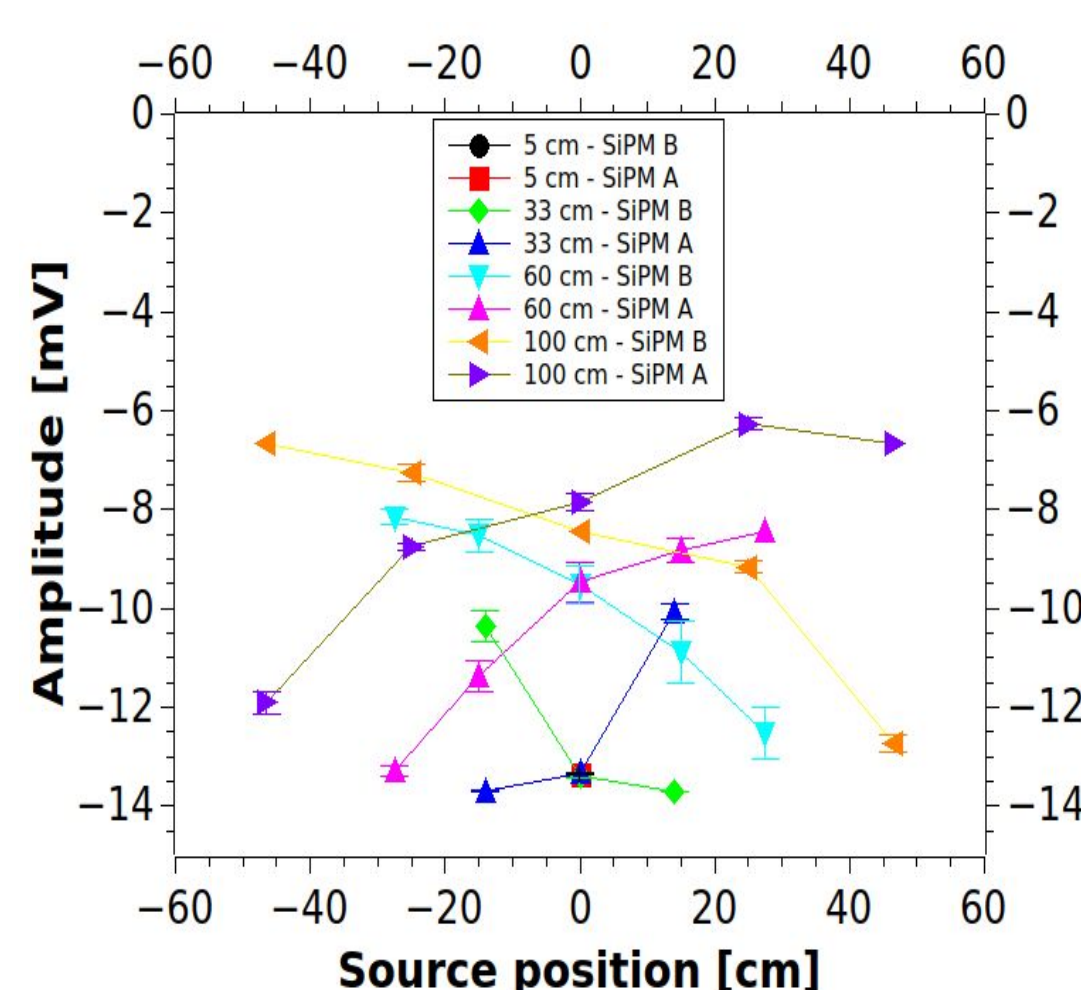


Figure 6. Amplitude from both SiPM based on different positions and lengths of the scintillator

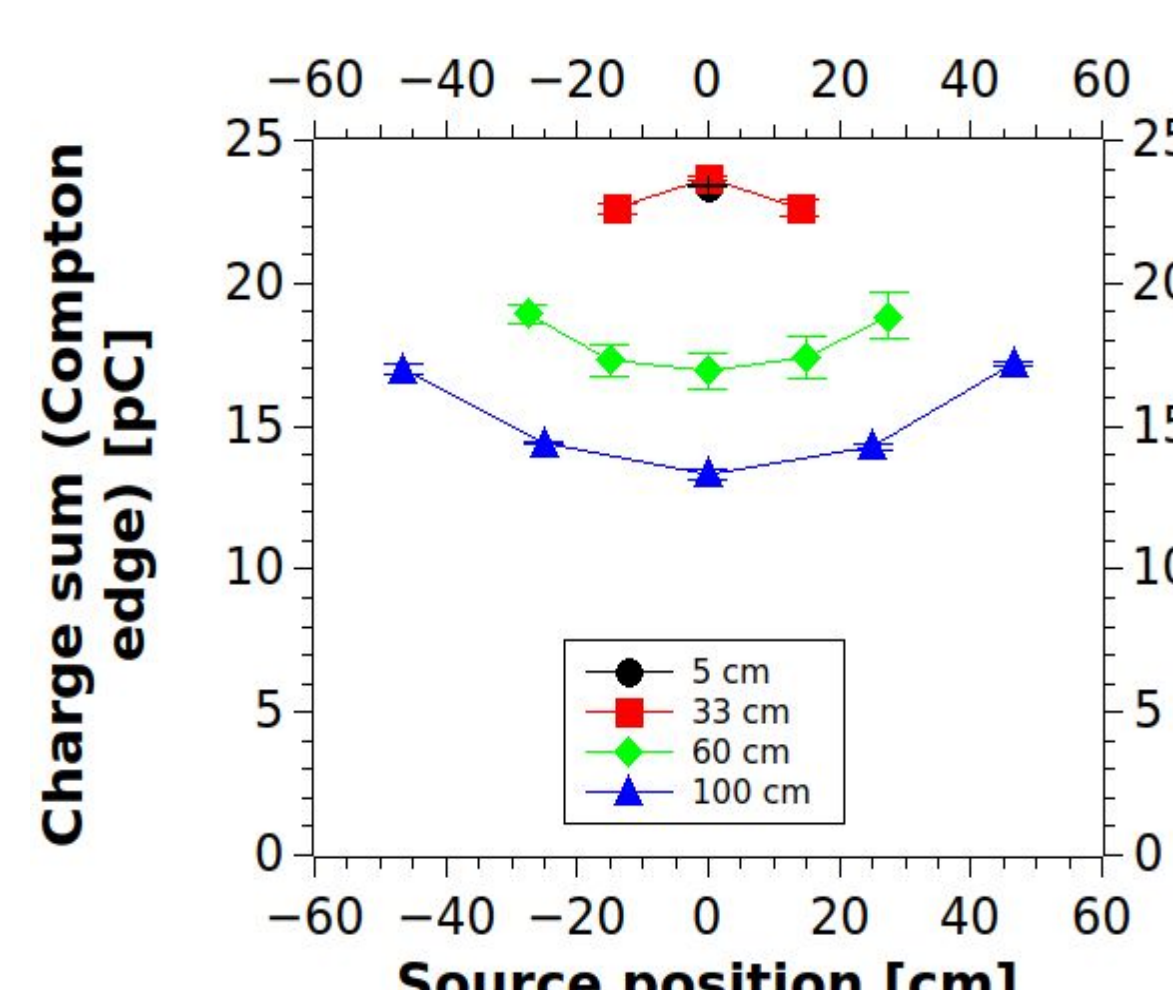


Figure 7. Charge sum based on different positions and lengths of the scintillator

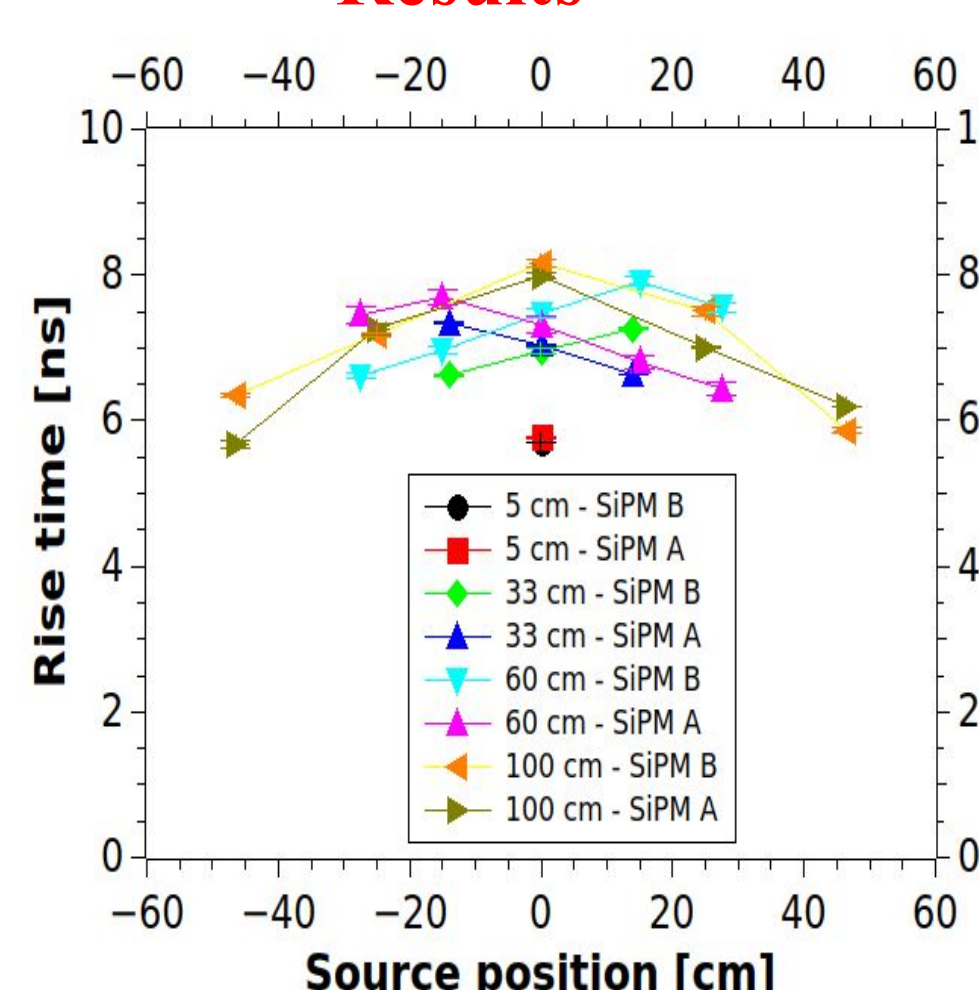


Figure 8. Rise time based on different positions and lengths of the scintillator

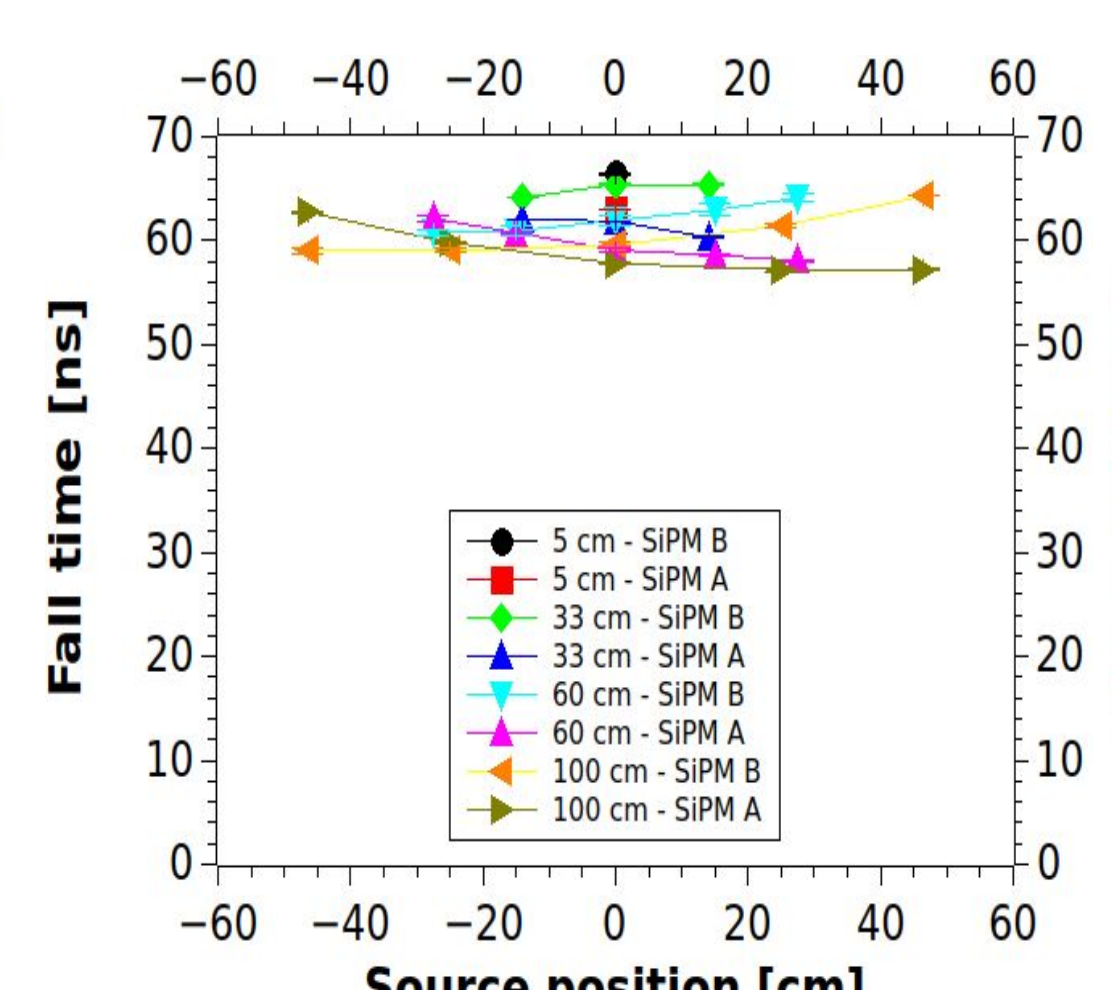


Figure 9. Fall time based on different positions and lengths of the scintillator

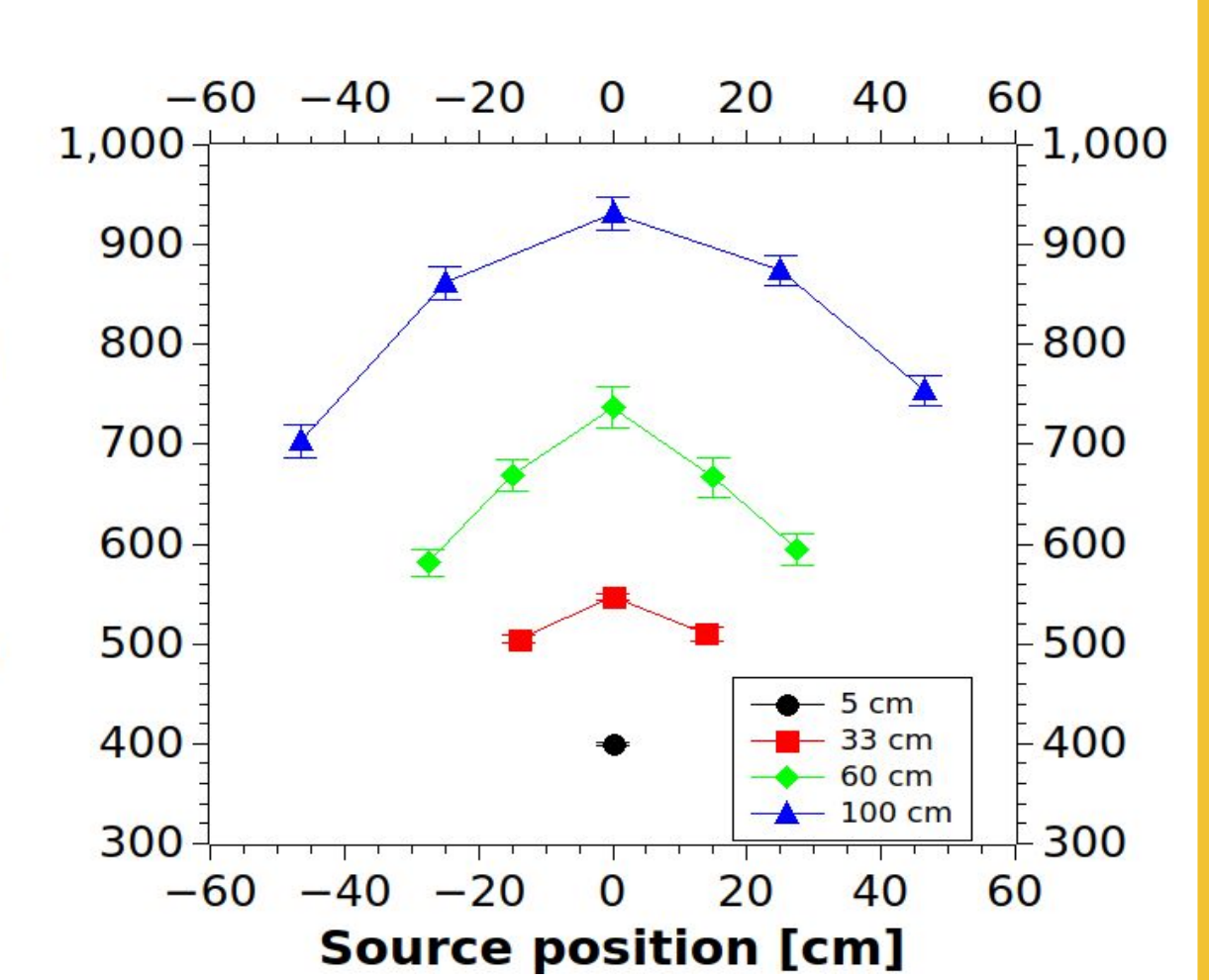


Figure 10. Sigma (TOF) based on different positions and lengths of the scintillator

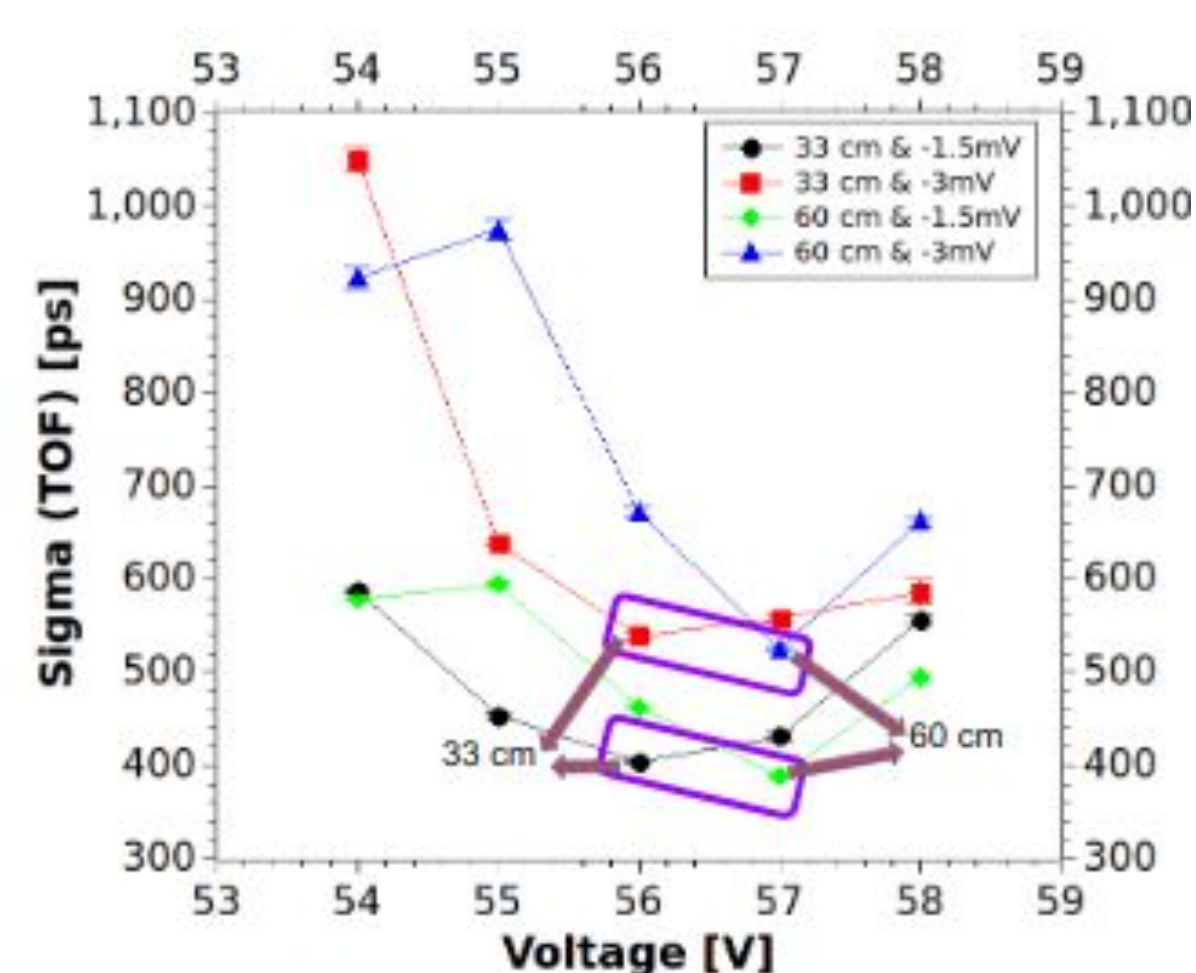


Figure 11. Sigma (TOF) at the center position of the scintillator with the length of 60cm and 33 cm at various constant thresholds based on different voltages.

On the way to developing Total-Body J-PET

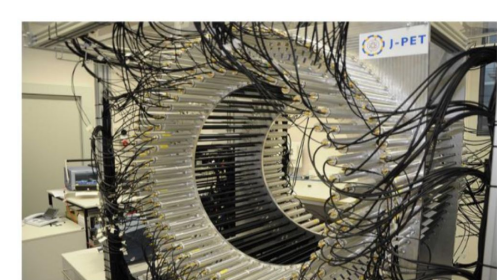


Figure 12. Big Barrel, 1st generation of J-PET tomography with 50 cm AFOV based on the PMT (Completed 2016)



Figure 13. 24 modular J-PET, 2nd generation of J-PET tomography with 50 cm AFOV based on the SiPM (Completed 2021)

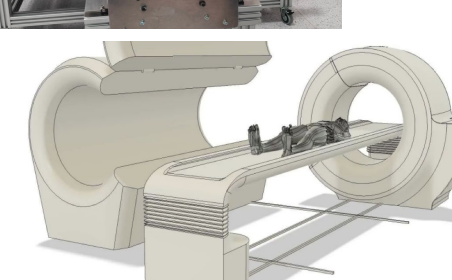


Figure 14. Total Body J-PET, 3rd generation of J-PET tomography with 243 cm AFOV based on the SiPM (Aim 2028)

Summary:

The TB J-PET design incorporates plastic scintillators. The dimensions are determined based on insights from prior prototypes, simulations, and laboratory studies involving SiPM with scintillator strips of varying lengths. By using the GATE for simulation, we have accurately estimated key parameters for the final TB J-PET geometry. The performance characteristics of the single detector unit were established experimentally. The TB-J-PET will be able to do standard PET imaging, positronium imaging, multi-photon imaging, and photon polarization imaging [4-7].

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