Optical properties and time-of-flight resolution of plastic scintillators for the total-body J-PET scanner

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Introduction and objectives

Total-body Jagiellonian positron emission tomography (TB-J-PET) is based on long plastic scintillators [1] which decrease cost of the scanner [2]. Total-body PET scanners enable positronium imaging [3], measurements of discrete symmetries [4], entanglement of photons [5], and beam therapy monitoring [6]. Development of the TB-J-PET requires application of transparent plastic scintillators with low light attenuation [7] to build long modules with silicon photomultipliers attached at both ends of the scintillators. For the modular TB-J-PET construction, we chose BC-408, one of the most transparent plastic scintillator from our previous measurements [8]. Before the construction of the J-PET detector, plastic scintillators undergo multi-stage quality control: optical and mechanical defects are inspected; dimensions, optical homogeneity, transparency and technical light attenuation length are measured [9]. The purpose of this research is to:

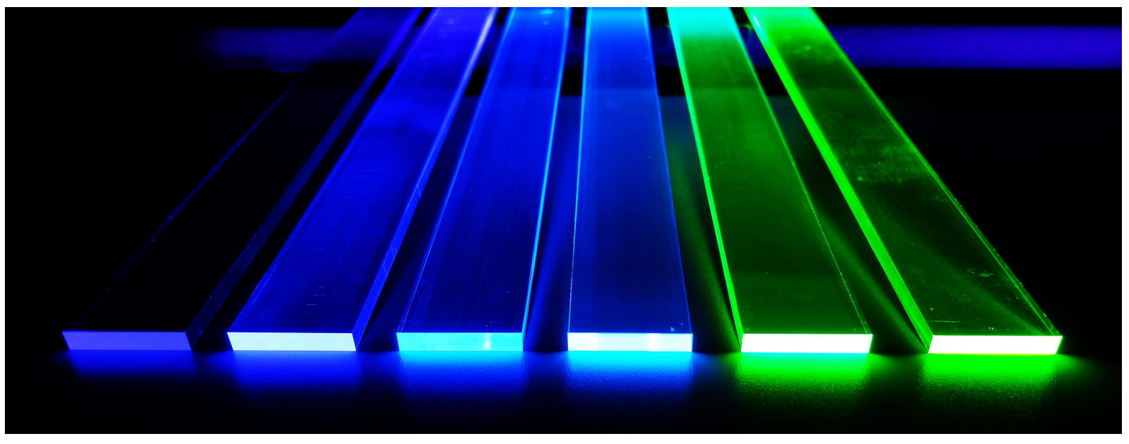
- select the best plastic scintillator with the lowest time resolution and uniform time resolution along the scintillator strip, to be used to build the TB-J-PET tomograph;
- verify transverse and longitudinal transparency of the scintillator: transmittance at the wavelength of maximum emission and technical attenuation length.

Materials and methods

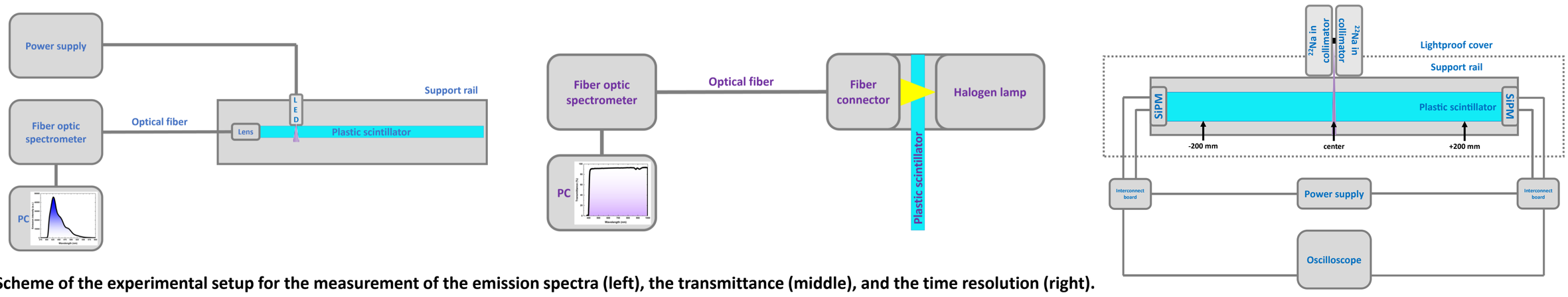
Properties of the plastic scintillators used in this study.

Eljen Technology plastic scintillator	Luxium Solutions equivalent	Wavelength of maximum emission (nm)	Light output (ph/MeV)	Rise time (ns)	Decay time (ns)	Bulk light attenuation length (cm)
EJ-230	BC-420	391	9700	0.5	1.5	120
EJ-204	BC-404	408	10400	0.7	1.8	160
EJ-200	BC-408	425	10000	0.9	2.1	380
EJ-208	BC-412	435	9200	1.0	3.3	400
EJ-262	none	481	8700	0.9	2.1	250
EJ-260	BC-428	490	9200	1.5	9.2	350

Photos of the plastic scintillators under UV light, from left to right: EJ-230, EJ-204, EJ-200, EJ-208, EJ-262, EJ-260.

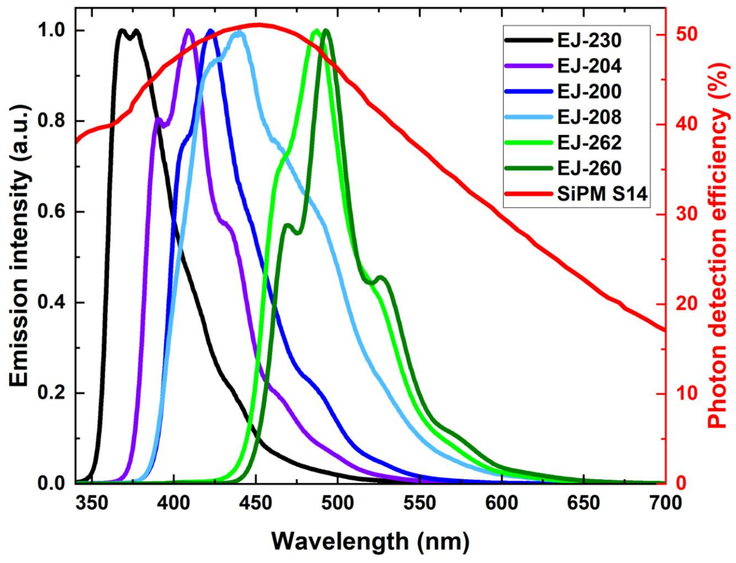


- Six types of polyvinyltoluene-based plastic scintillators with emission spectra covering the maximum quantum efficiency of light detection of silicon photomultipliers, were measured.
- The plastic scintillators had dimensions of 6 mm × 30 mm × 500 mm, polished surfaces: faces as-cast and edges diamond-milled, and were manufactured by Eljen Technology.
- The emission spectra and the transmittance at the wavelength of maximum emission through 6 mm thick scintillator, were measured on a linear CCD array spectrometer.
- The time resolution was measured at three points along the scintillator using a setup consisting of silicon photomultipliers, oscilloscope, black box and collimated Na-22 source.

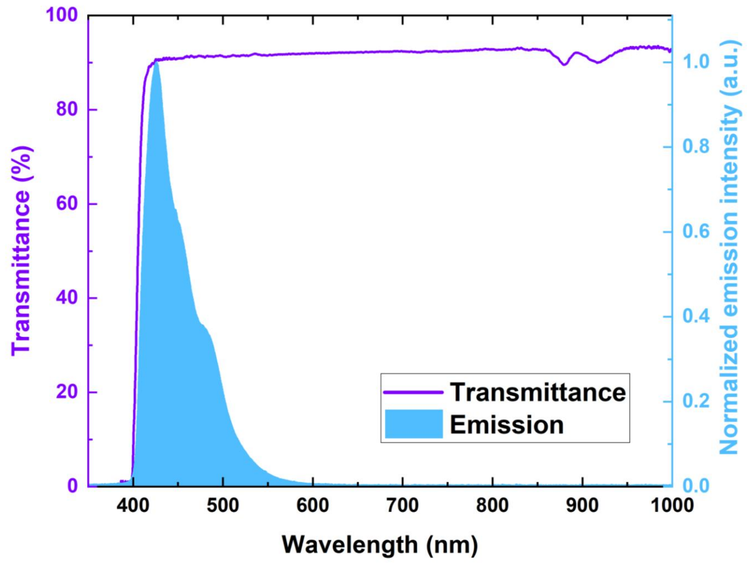


Scheme of the experimental setup for the measurement of the emission spectra (left), the transmittance (middle), and the time resolution (right).

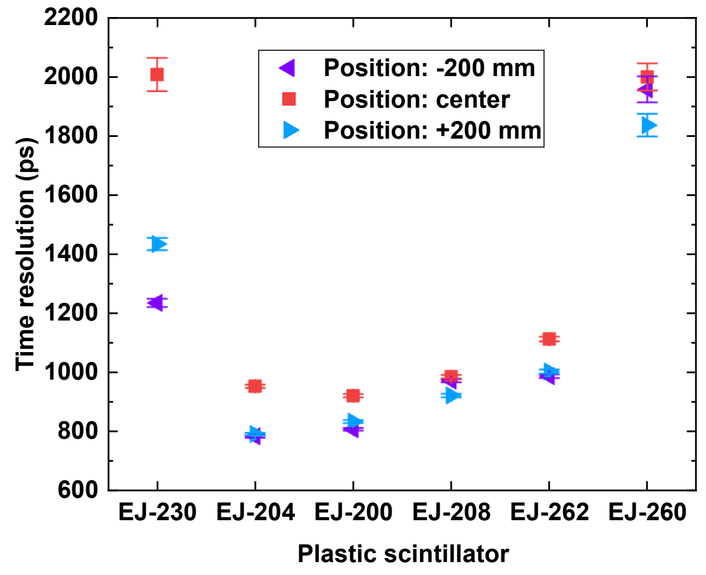
Results



Emission spectra of the investigated plastic scintillators superimposed on photon detection efficiency of SiPM.



Example of transmission spectrum of EJ-200 plastic scintillator strip superimposed on its emission spectrum.



Time resolution (sigma) of the investigated plastic scintillators measured with Na-22 source and SiPMs.

Conclusions

- Obtained results confirm high transparency of selected plastic scintillators for construction of long modules of the TB-J-PET scanner.
- Regarding timing properties, the best plastic scintillator type for the next generation total-body J-PET scanner is EJ-200 and its equivalent BC-408.
- The EJ-200 plastic scintillator combines the best time resolution with uniform time resolution along the scintillator strip.

References

[1] P. Moskal, E. Stępień, PET Clinics 15 (2020) 439
[2] P. Moskal et al., Physics in Medicine and Biology 66 (2021) 175015
[3] P. Moskal et al., Science Advances 10 (2024) eadp2840
[4] P. Moskal et al., Nature Communications 15 (2024) 78
[5] P. Moskal et al., Science Advances 11 (2025) eads3046
[6] K. Parodi, T. Yamaya, P. Moskal, Journal of Medical Physics 33 (2023) 22
[7] Ł. Kapłon, IEEE Transactions on Nuclear Science 67(10) (2020) 2286
[8] Ł. Kapłon et al., Nuclear Instruments and Methods in Physics Research A 1051 (2023) 168186
[9] Ł. Kapłon et al., Journal of Instrumentation 20 (2025) P09019

Acknowledgments

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