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Performance of Extruded Polystyrene-Based Plastic Scintillators

Hana Burešová[1], Rastislav Hodák[2,*], Eva Kolářová[1], Radek Pjatkan[1], Ivan Štekl[2]

[1]*NUVIA a.s., Hrotovická-Průmyslová Zóna 168, 674 01 Střítež, Czech Republic*

[2]*Institute of Experimental and Applied Physics, Czech Technical University in Prague, Husova 240/5, CZ-11000 Prague, Czech Republic*

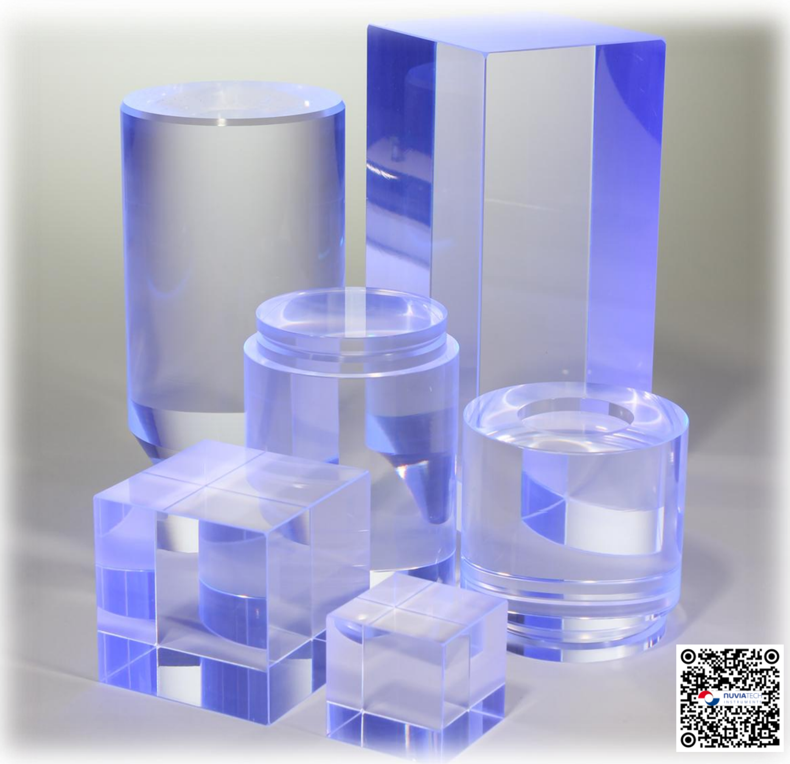
*Corresponding Author Email: rastislav.hodak@utef.cvut.cz

Abstract (full version at)

In cooperation with NUVIA a.s., we developed polystyrene-based plastic scintillators produced by extrusion as an alternative to conventional bulk polymerization. Different extrusion parameters, scintillator geometries, and pTP concentrations were investigated and compared with standard polymerized scintillators. The optical performance, including light output (LO) and technical attenuation length (TAL), was characterized using a tunable monoenergetic electron beam (200 keV - 1.6 MeV) [1,2]. The results demonstrate that extrusion is a flexible and scalable method for producing plastic scintillation detectors with competitive performance.

NuDET Plastic Scintillators

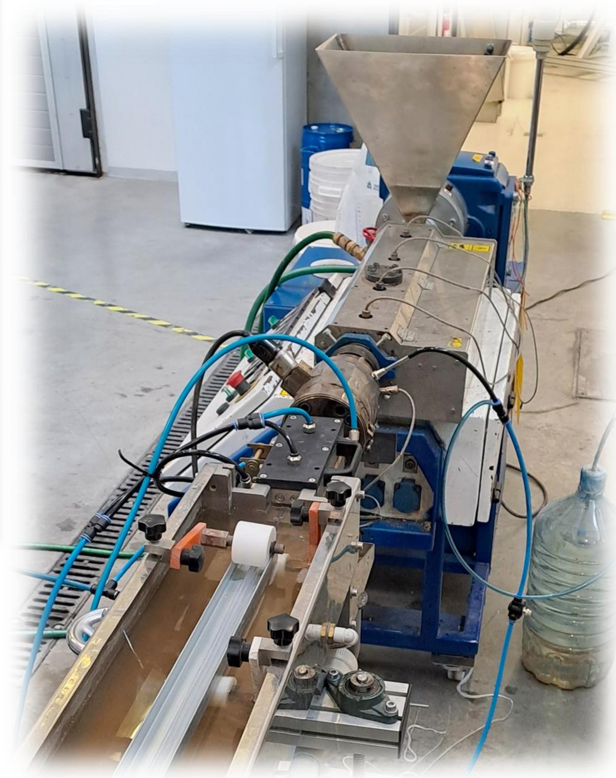
Styrene Monomer Purification → Addition of Fluors: - pTP (primary) - POPOP (WLS) → Homogenization & Degassing (removal of O_2) → Filling into Glass Molds → Thermal Polymerization (controlled heating) → Slow Cooling & Stress Release → Machining & Surface Polishing



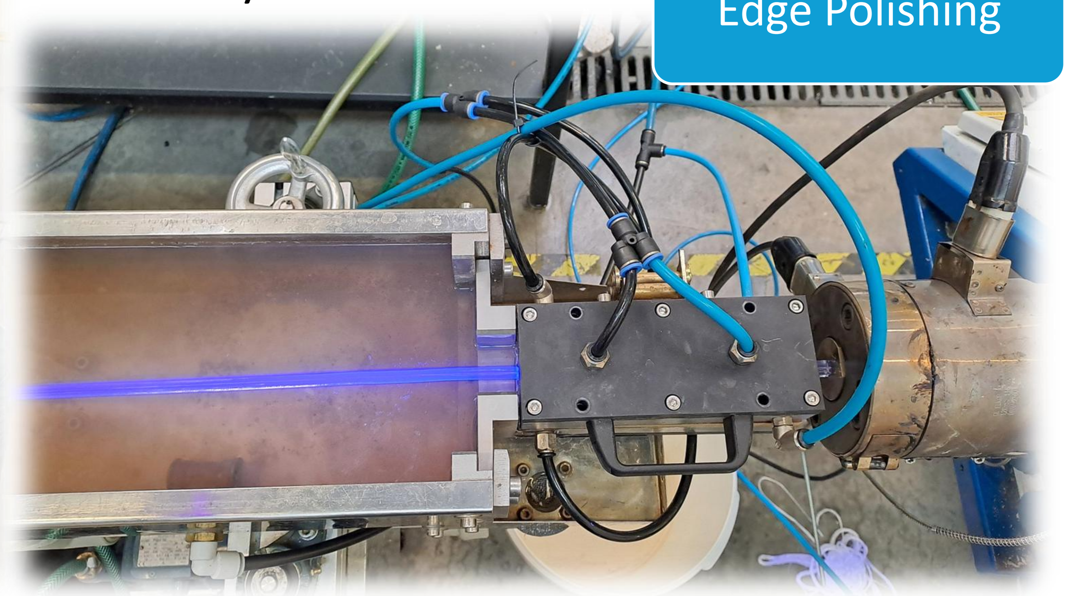
Standard Blue-Emitting Scintillators (SP32)	
Polymer base	polystyrene
Density	1.03 g/cm³
Refractive index	1.57
Softening point	70-75°C
Light output (w.r.t. anthracene)	56%
Decay time	2.5 ns
Emission peak	425 nm

Extruded Scintillators

Dopped PS Pellets → Heating & Extrusion → Continuous Shaping & Cooling → Cutting & Edge Polishing

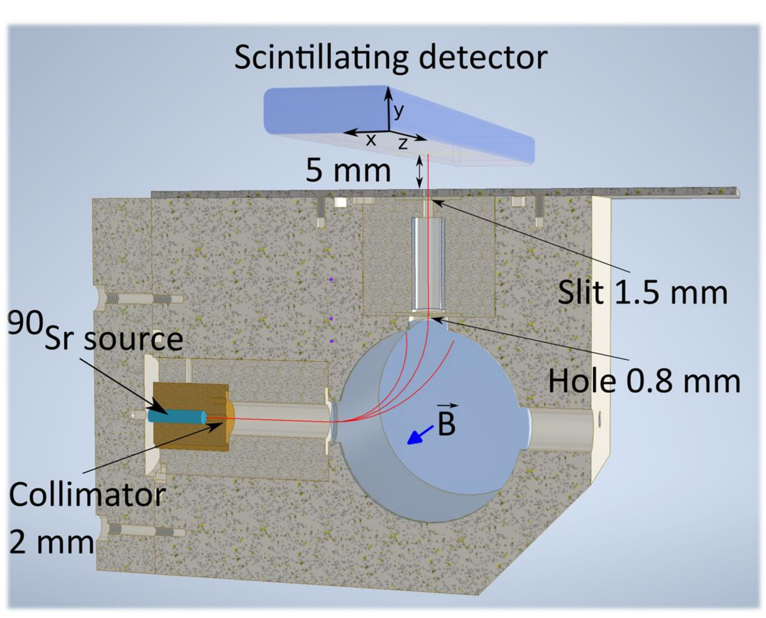


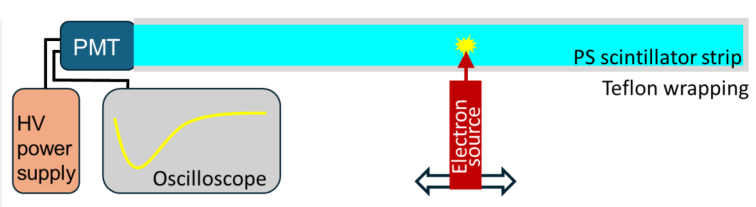
Laboratory extruder



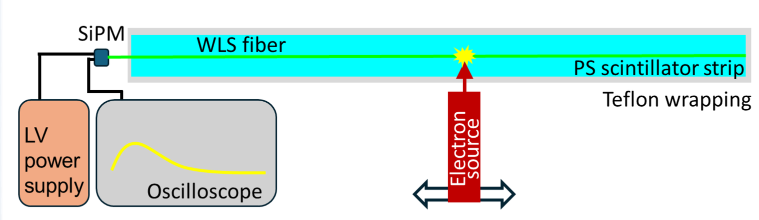
Experimental Setup & Procedure

Tunable monoenergetic electron source (**200 keV - 1.6 MeV**)



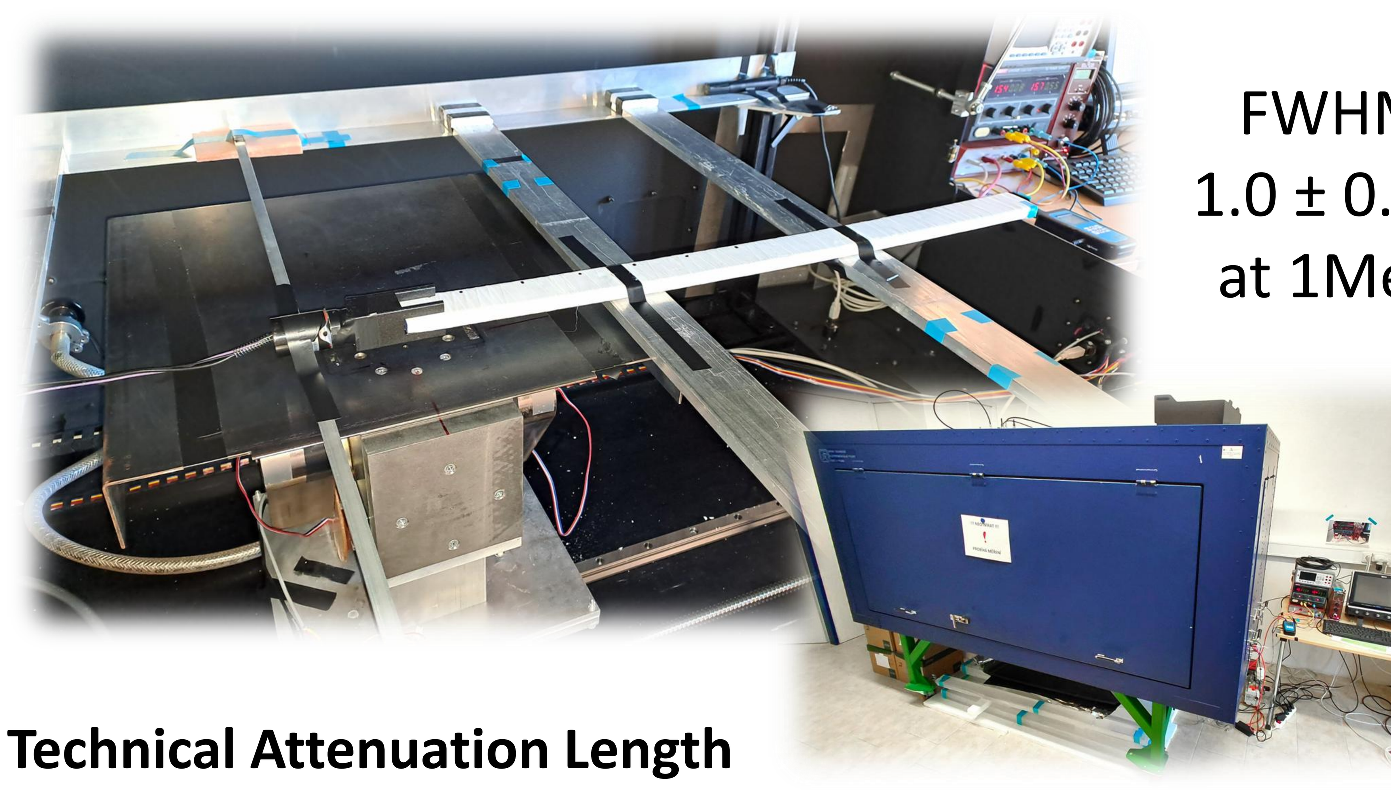


Scheme with PMT (Hamamatsu R1924A).



Scheme with SiPM (SensL MicroFC−30035) connected to WLS fiber.

Photo of the experimental setup (with PMT)



FWHM
1.0 ± 0.2%
at 1MeV

Technical Attenuation Length

TAL [3] describes the decrease of scintillation light intensity during propagation through the scintillator due to absorption, scattering, and optical imperfections:

$$I(x) = I_0\, e^{-\frac{x}{\lambda_{att}}}$$

where I_0 is initial light intensity, $I(x)$ is light intensity after traveling distance x, and λ_{att} is the AL. After traveling one AL, the light intensity decreases to $1/e \approx 37\%$ of its initial value.

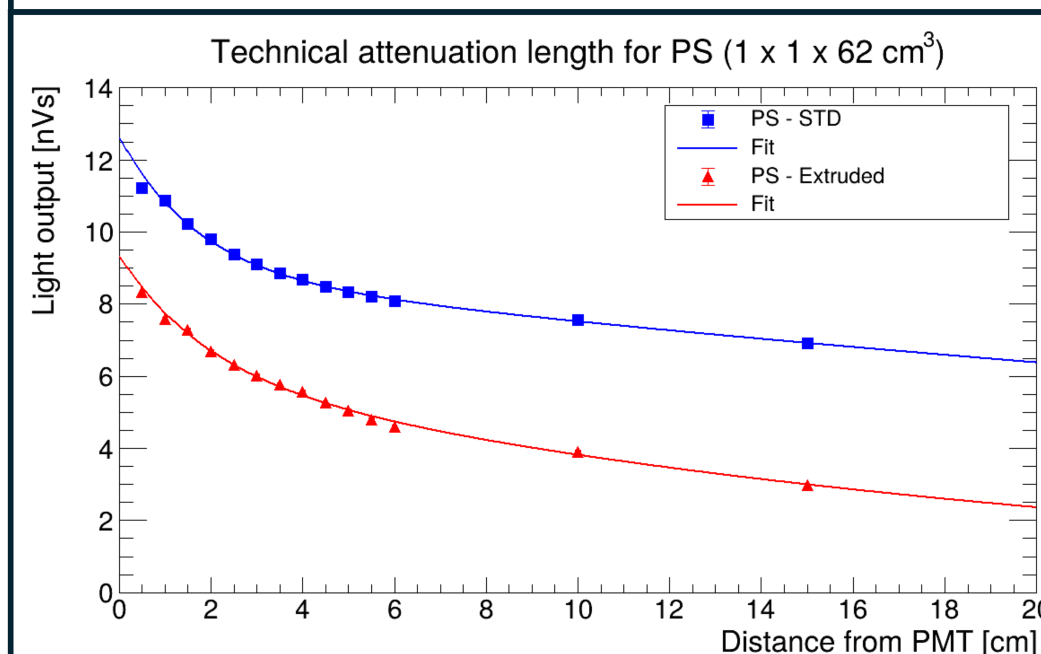
Two-Component Attenuation

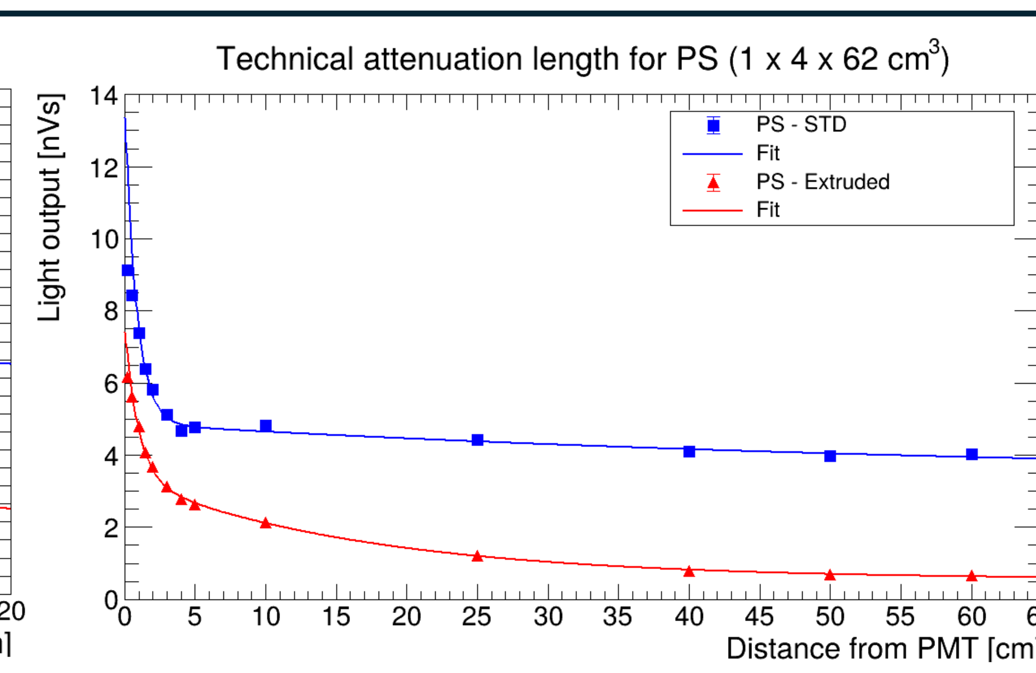
TAL in plastic scintillators is often described by two exponential components due to different photon propagation mechanisms, plus a constant background term:

$$I(x) = A_S\, e^{-\frac{x}{\lambda_S}} + A_L\, e^{-\frac{x}{\lambda_L}} + C$$

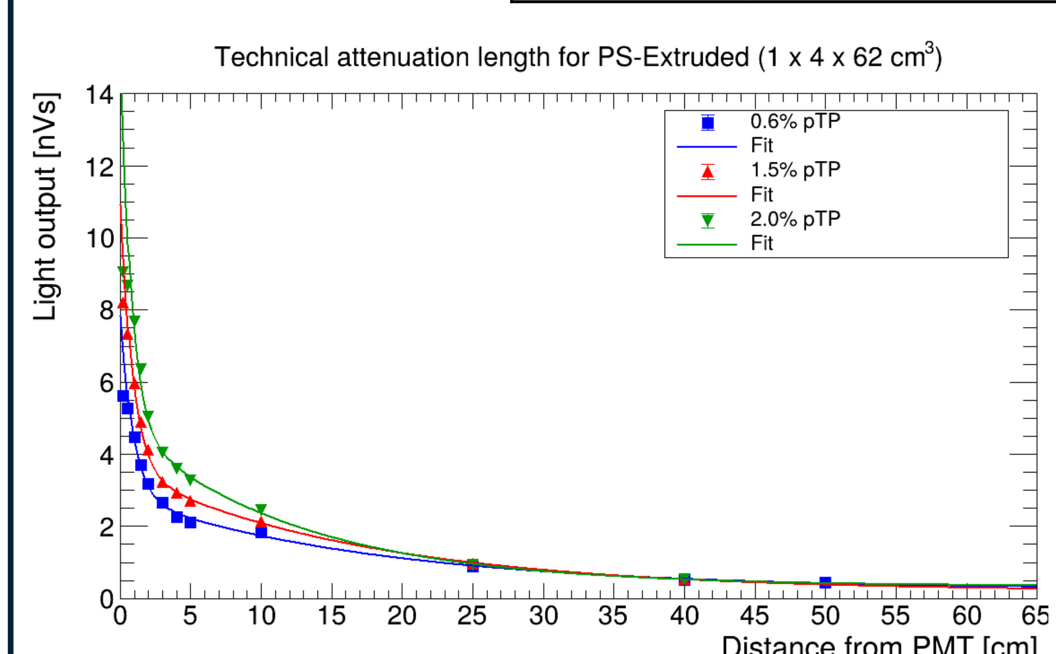
λ_S (short): direct light affected by self-absorption and local scattering;
λ_L (long): reflected light propagating via total internal reflections.

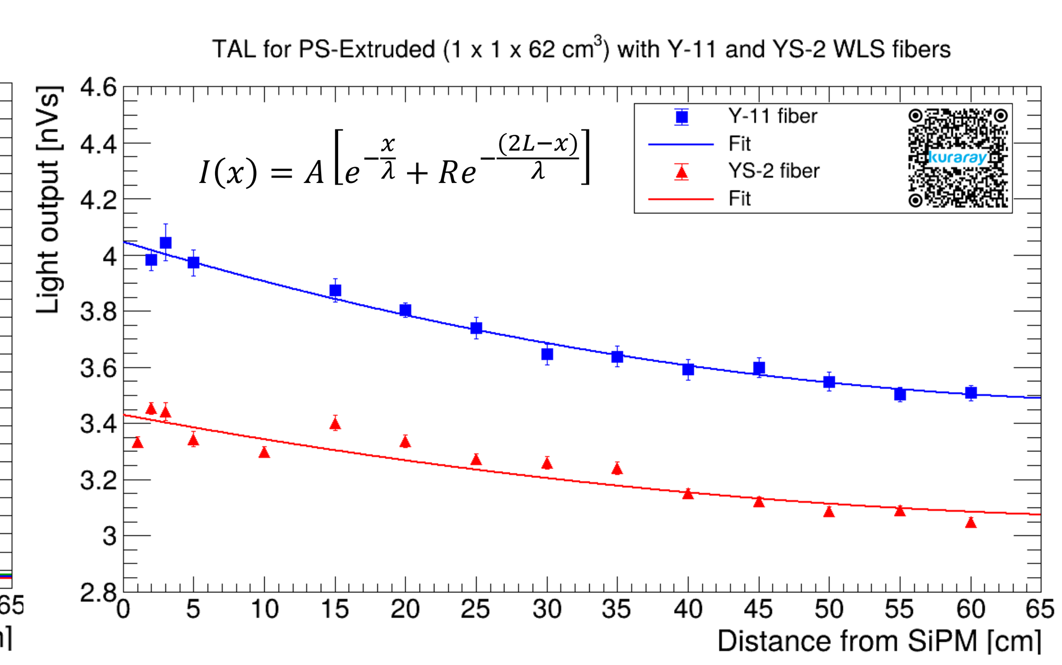
Results (Light Output vs. Distance; TAL)





PS type	PS dimensions [cm³]	TAL [cm]	
		λ_S [cm]	λ_L [cm]
PS - Extruded	1 × 1 × 62	1.94 ± 0.07	21.01 ± 0.25
PS - STD	1 × 1 × 62	1.72 ± 0.05	61.02 ± 1.15
PS - Extruded	1 × 4 × 62	0.98 ± 0.03	17.04 ± 0.10
PS - STD	1 × 4 × 62	0.84 ± 0.02	64.16 ± 4.97





pTP [%]	PS dimension [cm³]	TAL [cm]	
		λ_S [cm]	λ_L [cm]
0.6 %	1 × 4 × 62	0.89 ± 0.03	18.22 ± 0.17
1.5 %	1 × 4 × 62	0.87 ± 0.03	17.32 ± 0.22
2.0 %	1 × 4 × 62	0.77 ± 0.04	12.61 ± 0.11

WLS fiber	PS dimension [cm³]	TAL [cm]	AL* [cm]
Y-11	1 × 1 × 62	136.45 ± 4.85	> 350
YS-2	1 × 1 × 62	165.53 ± 4.31	> 350

Kuraray datasheet values for attenuation length (AL).

Conclusions

- **Extruded** plastic scintillators achieved **≈80% of the LO** and **≈30% of the λ_L** compared to **STD**.
- **Increasing** the **pTP** concentration resulted in **higher LO**, while the **λ_L decreased**, indicating increased self-absorption losses.
- Measurements using a SiPM coupled to Y-11 and YS-2 WLS fibers showed a **gradual decrease of LO** by **≈10-15%** over the total scintillator length.
- The **extrusion** process enables **continuous, scalable,** and **cost-effective production** with reduced fabrication complexity.
- Further **optimization** of **extrusion parameters**, **dopant concentrations**, and optical quality is required to **improve** scintillation **performance**.

References

[1] C. Marquet et al., High energy resolution electron beam spectrometer in the MeV range, JINST 10 (2015) P09008.
[2] B. Ali et al., Study of electron tracks in Timepix3 detector at kinetic energies of 1 and 1.5 MeV, JINST 20 (2025) P06020.
[3] L. Kaplon, Technical Attenuation Length Measurement of Plastic Scintillator Strip …, IEEE Transactions on Nuclear Science 67 (2020) 2286.

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