JAGIELLONIAN UNIVERSITY IN KRAKÓW

J-PET

Technical attenuation length measurement of long plastic scintillators for the total-body J-PET scanner

Łukasz Kapłon

Faculty of Physics, Astronomy and Applied Computer Science

Jagiellonian University

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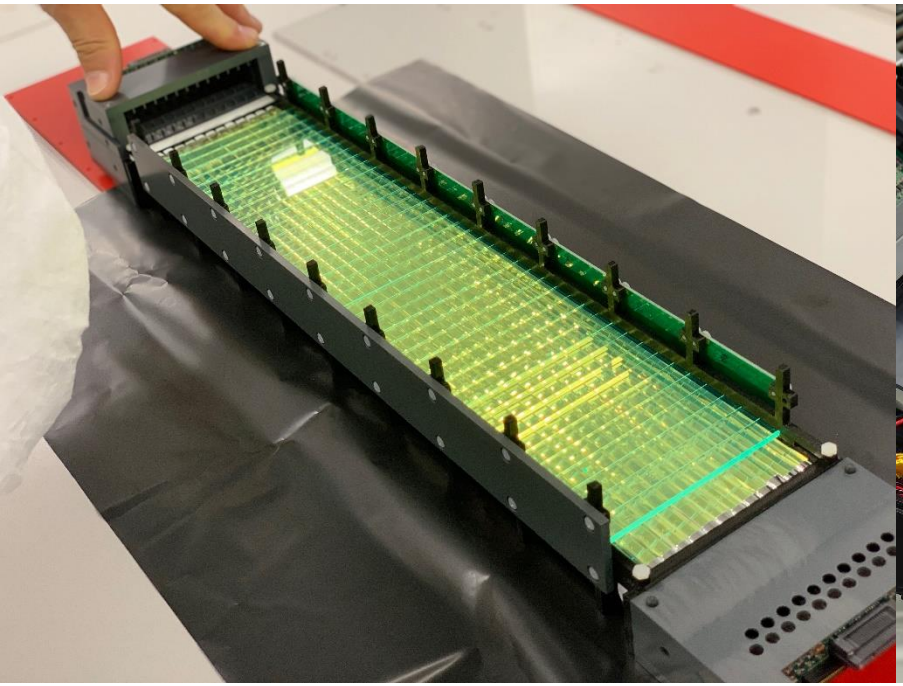
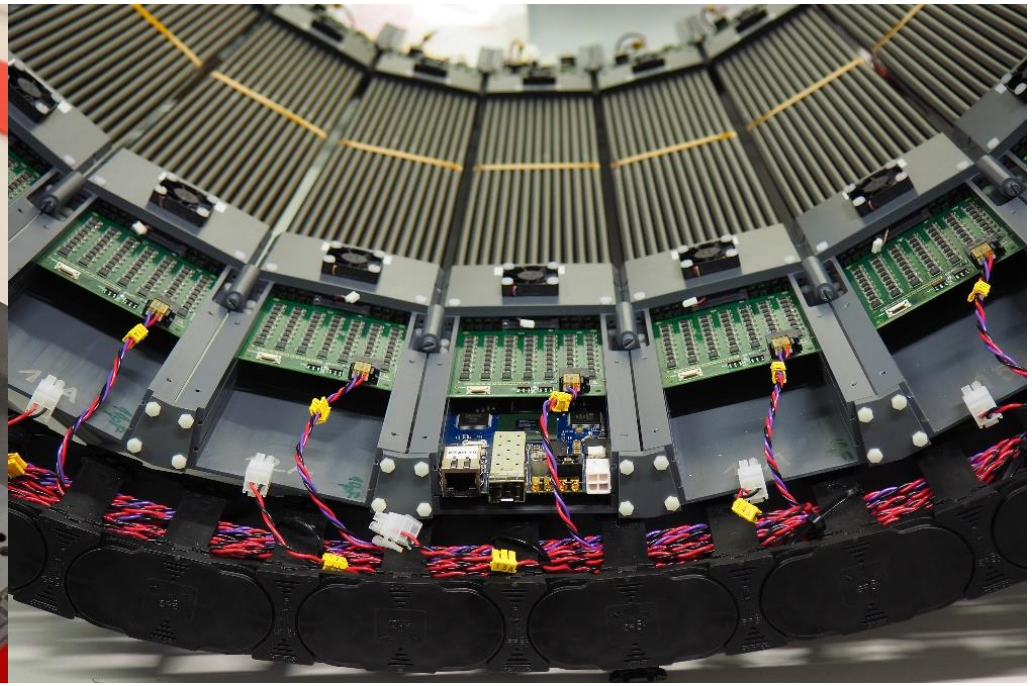
Outline

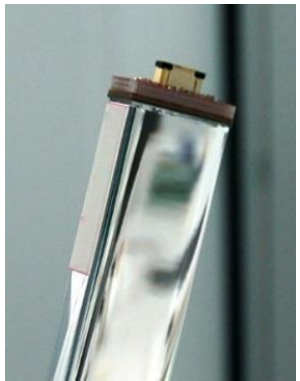
1) Principles of plastic scintillators
2) Technical attenuation length (TAL) of plastic scintillators
3) Setup for TAL measurements
4) TAL of 6x24x1000 mm^3 long plastic scintillator strips
5) TAL of 500 mm long plastic scintillator strips with different cross-sections
6) Optical coating for plastic scintillators

Motivation

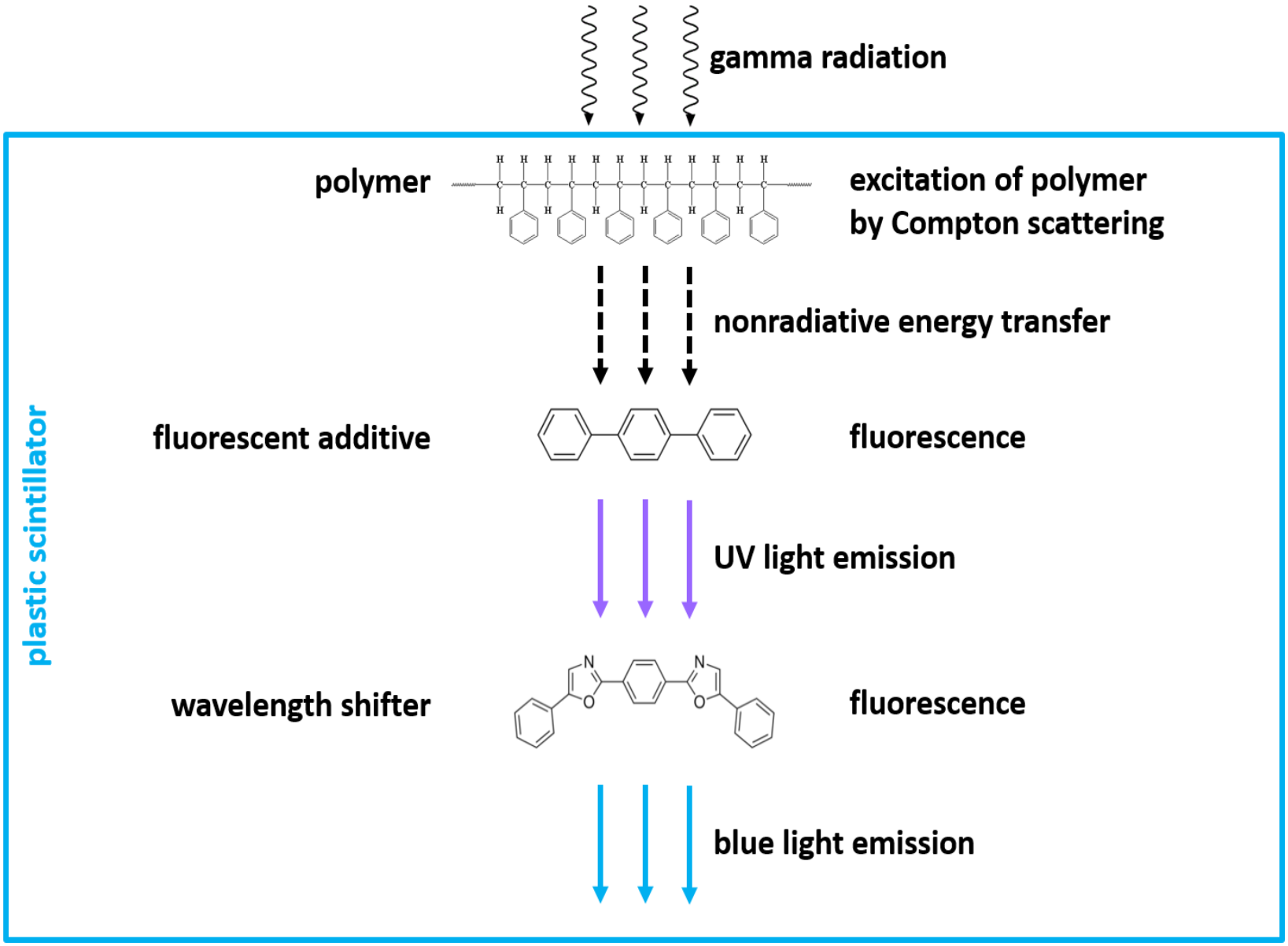
- Measure properties of commercial scintillators and choose the best for prototypes building.



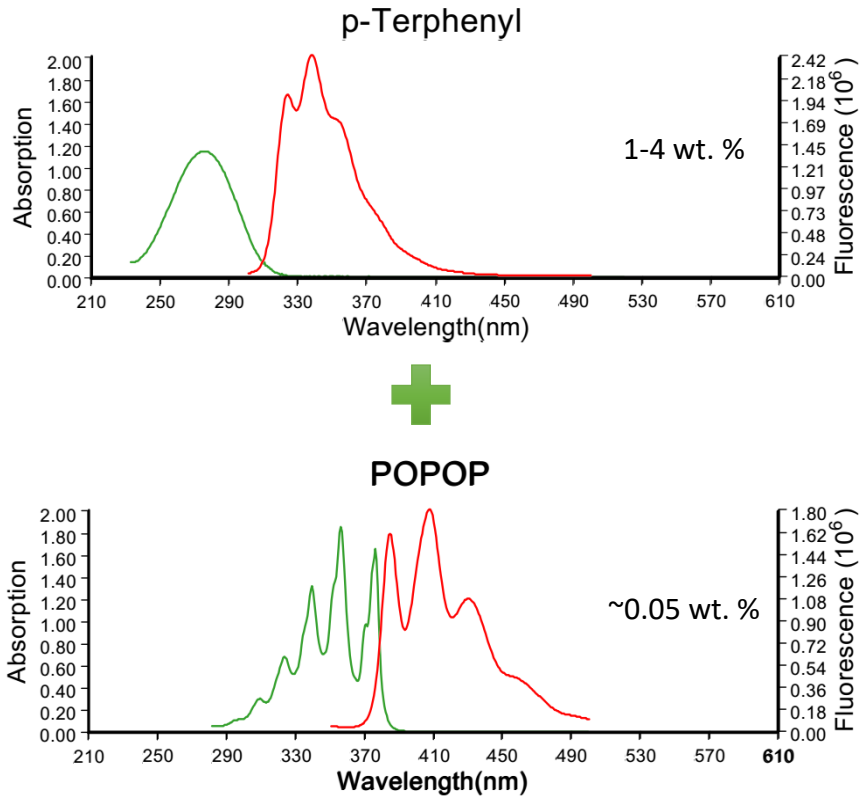




Scintillation principles: light emission mechanism

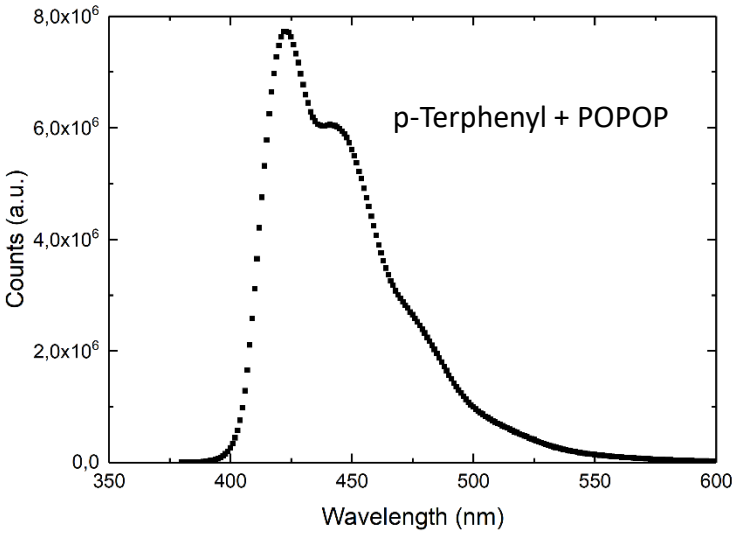


Scintillation principles: emission and absorption spectra



Absorption (green) and emission (red) spectra of two fluorescent substances commonly used in plastic scintillators

p-Terphenyl emission spectrum
overlaps with
POPOP absorption spectrum



Emission spectrum of plastic scintillator with p-Terphenyl and POPOP

Technical attenuation length

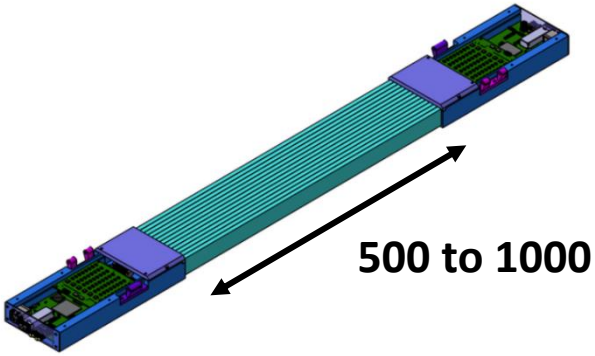
- The technical attenuation length (TAL) of a plastic scintillator bar is defined as the length of scintillator reducing the light signal by a factor of *e* and depending upon:

➢ bulk transmission of the scintillator,

➢ scintillator thickness,

➢ shape of scintillator,

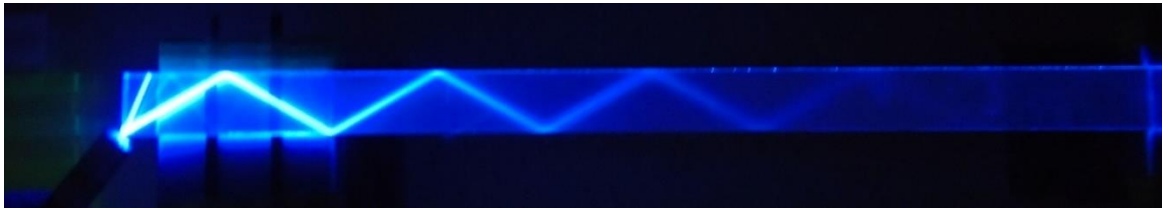
➢ reflective property of the surfaces.



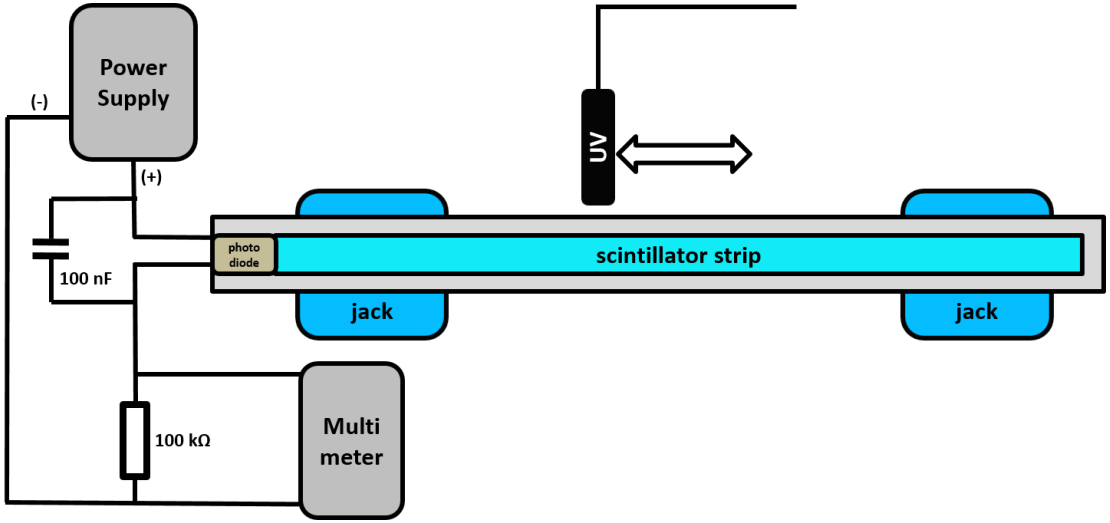
500 to 1000 mm long scintillators

$$I(x) = A_1 * e^{\left(-\frac{x}{t_1}\right)} + A_2 * e^{\left(-\frac{x}{t_2}\right)} + y0$$

A1, A2 – amplitudes
x - distance from light detector
t1 - technical attenuation length
y0 - background

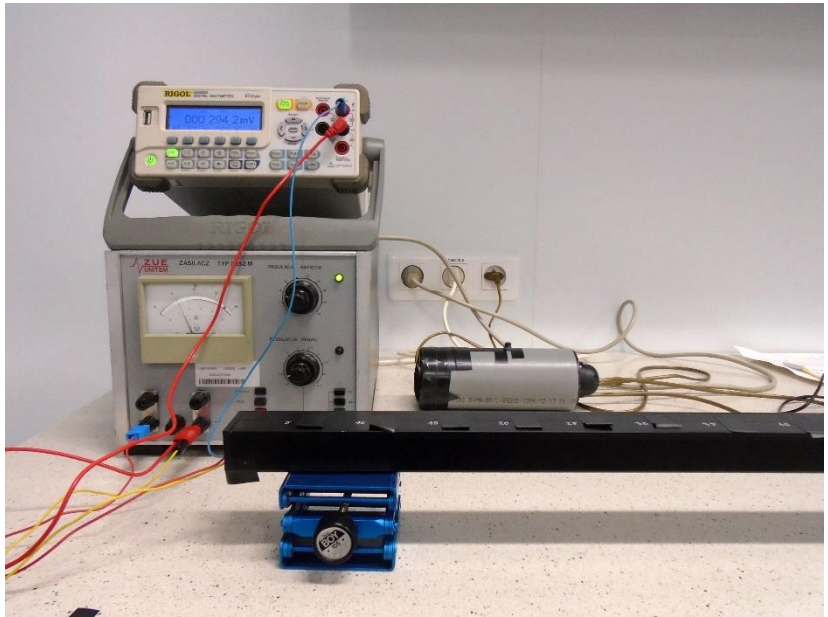


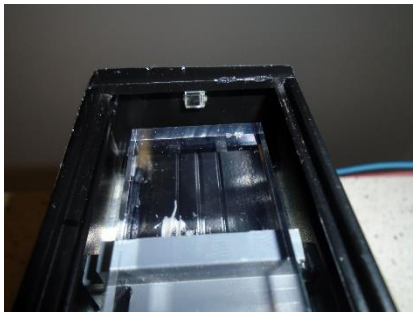
Setup for TAL measurements

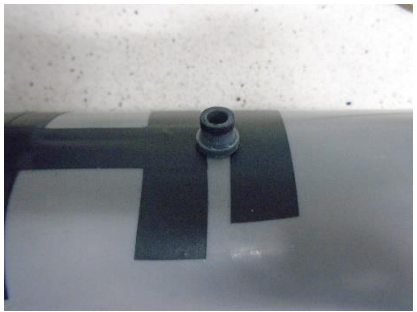


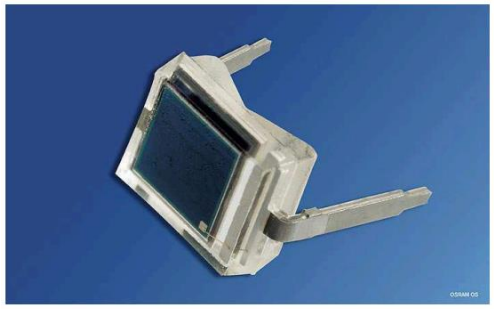
In measurement following equipment was used:

- UV lamp with 365 nm wavelength of maximum emission;
- silicon PIN photodiode BPW 34 B with 2.73x2.73 mm^2 active area;
- digital multimeter Rigol DM 3064;
- power supply ZUE 5352 M;
- aluminium rail with 8 mm diameter holes drilled every 50 mm.



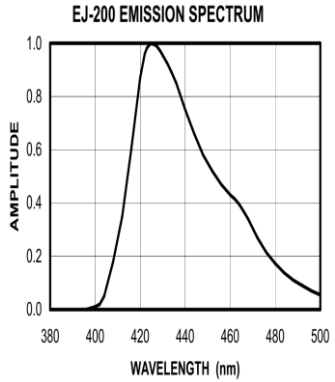


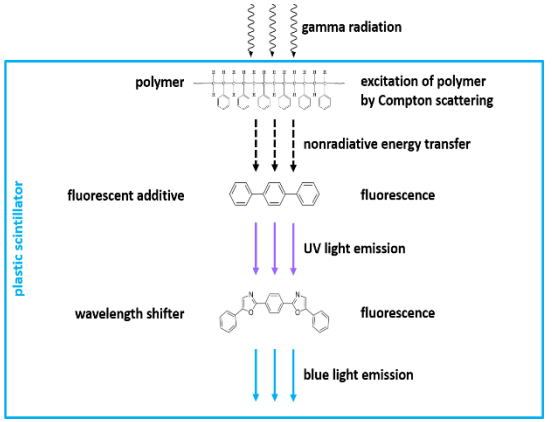




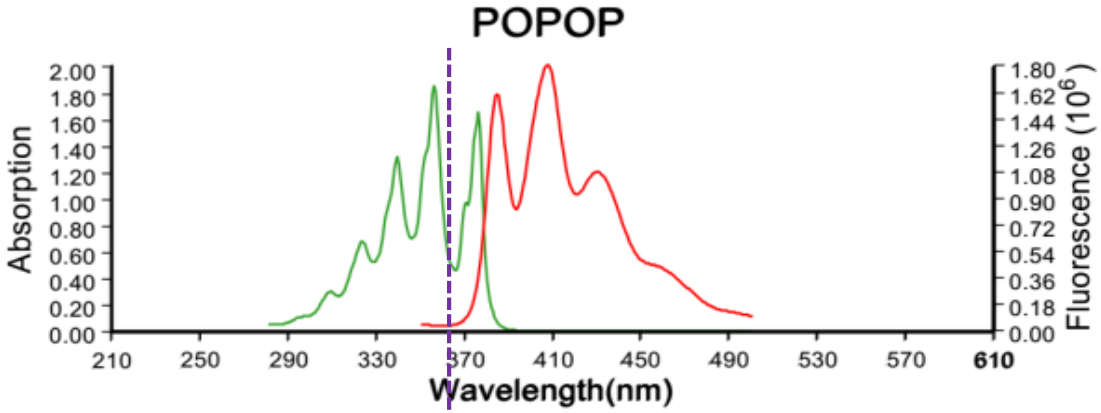
BPW 34 B

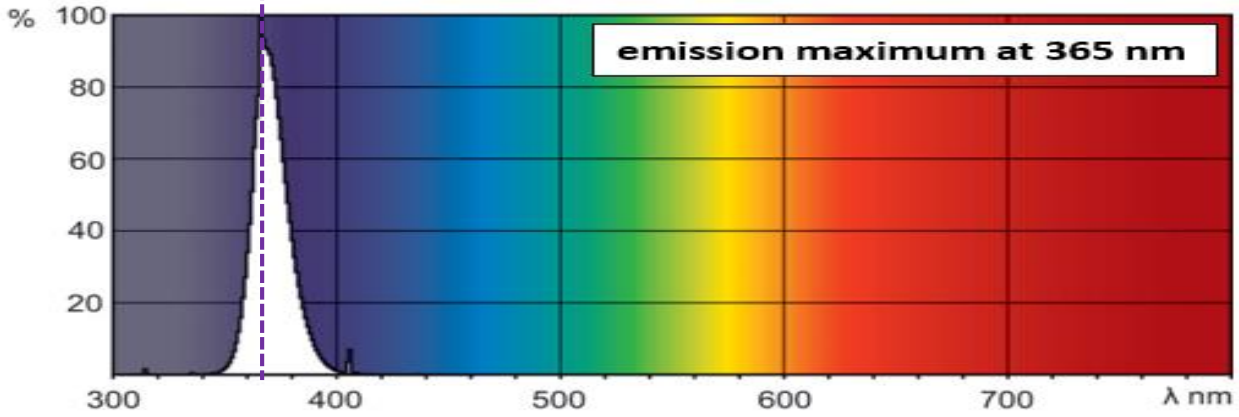
Overlapping of 365 nm UV lamp emission spectra and scintillator absorption





UV light

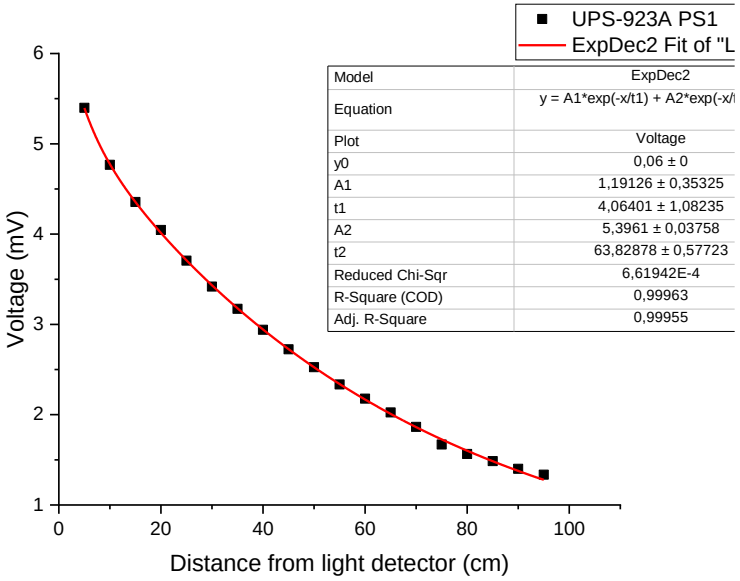


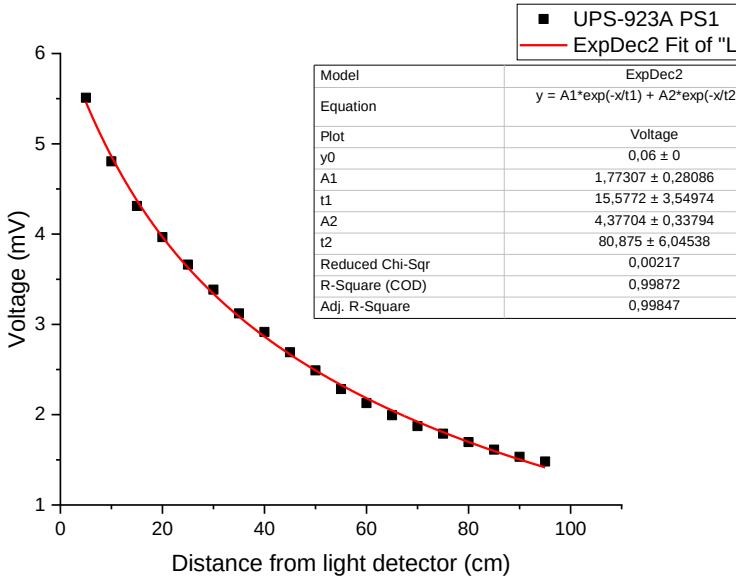


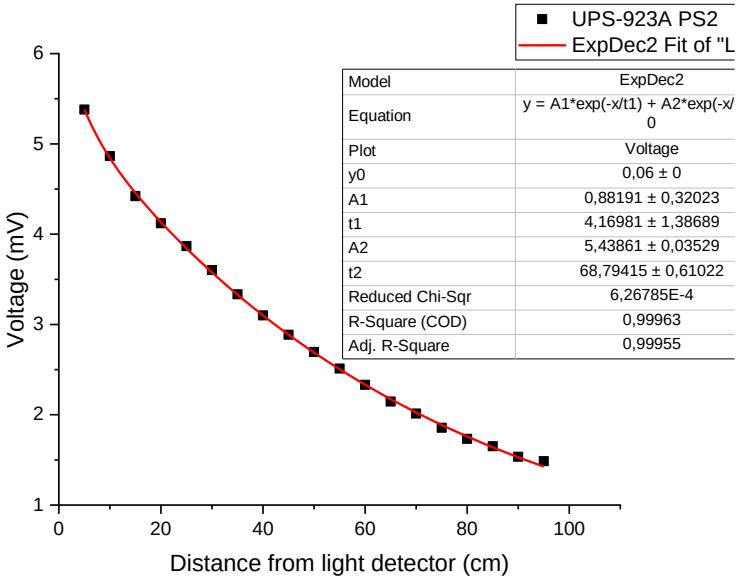
Plastic scintillator strips used in J-PET

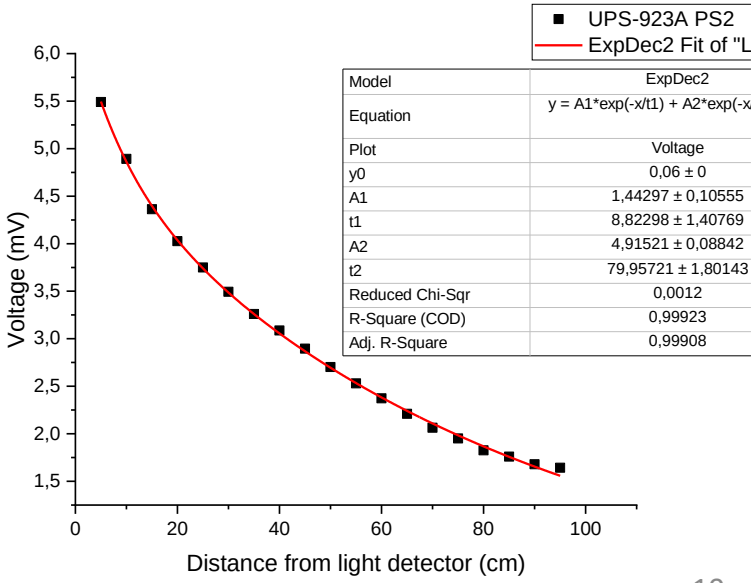
	BC-420	EJ-230	BC-404	EJ-200	UPS-923A	SP32	Epic PS
Dimensions [mm^3]	5x19x300	7x19x500	6x24x500	6x24x1000	6x24x1000	6x24x1000	6x24x1000
Used in J-PET prototype	24 strips small barrel with PMTs	192 strips big barrel with PMTs	312 strips modular PET with SiPMs	1m long with WLS and SiPMs	Research for one meter module with SiPMs		
Data from manufacturers							
Decay time [ns]	1.5	1.5	1.8	2.1	3.3	2.5	2.4
Light output [% of anthracene]	64	64	68	64	56	56	50-60
Wavelength of maximum emission [nm]	391	391	408	425	418	425	415
Light attenuation length [cm]	**110**	**120**	**160**	**380**	**400**	**NA**	**200**
Polymer base	**PVT**	**PVT**	**PVT**	**PVT**	**PS**	**PS**	**PS**

Results for UPS-923A PS, 6x24x1000 mm^3 strips

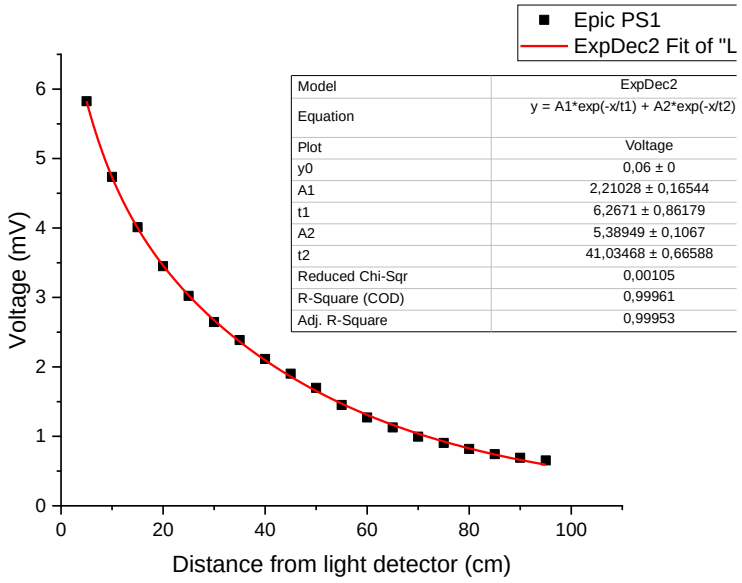




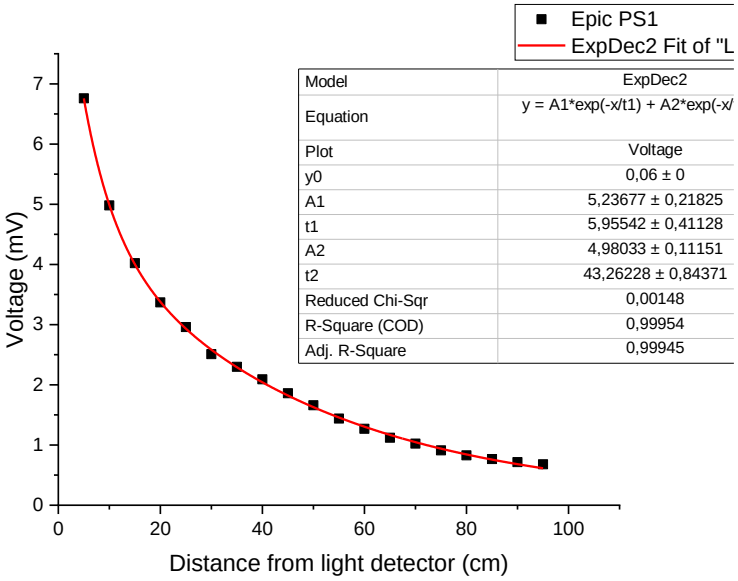




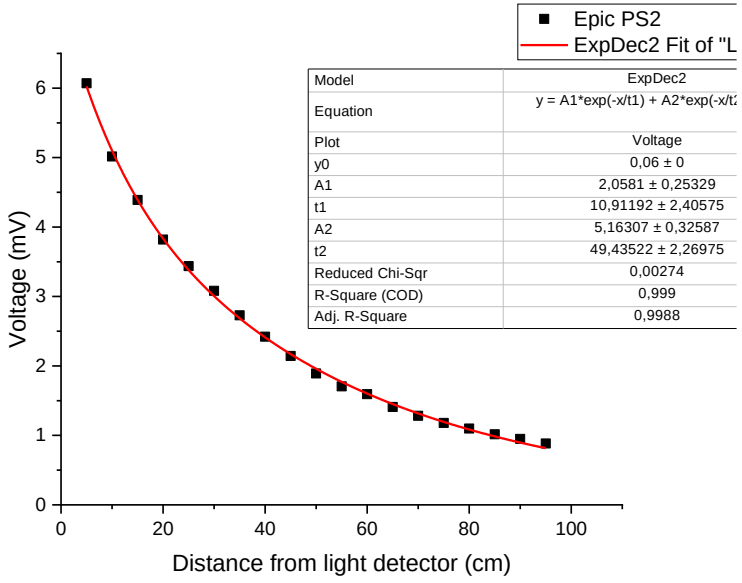
Results for Epic PS, 6x24x1000 mm³ strips



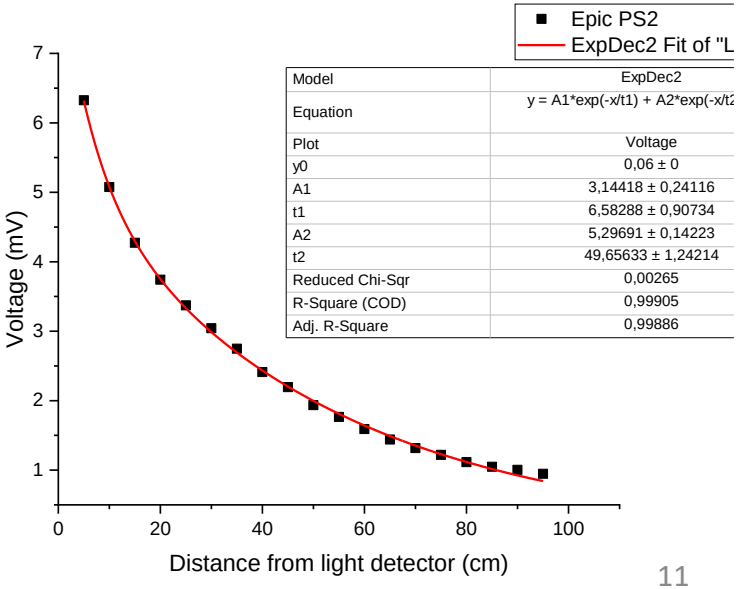
Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2)
Plot	Voltage
y0	0,06 ± 0
A1	2,21028 ± 0,16544
t1	6,2671 ± 0,86179
A2	5,38949 ± 0,1067
t2	41,03468 ± 0,66588
Reduced Chi-Sqr	0,00105
R-Square (COD)	0,99961
Adj. R-Square	0,99953



Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/
Plot	Voltage
y0	0,06 ± 0
A1	5,23677 ± 0,21825
t1	5,95542 ± 0,41128
A2	4,98033 ± 0,11151
t2	43,26228 ± 0,84371
Reduced Chi-Sqr	0,00148
R-Square (COD)	0,99954
Adj. R-Square	0,99945

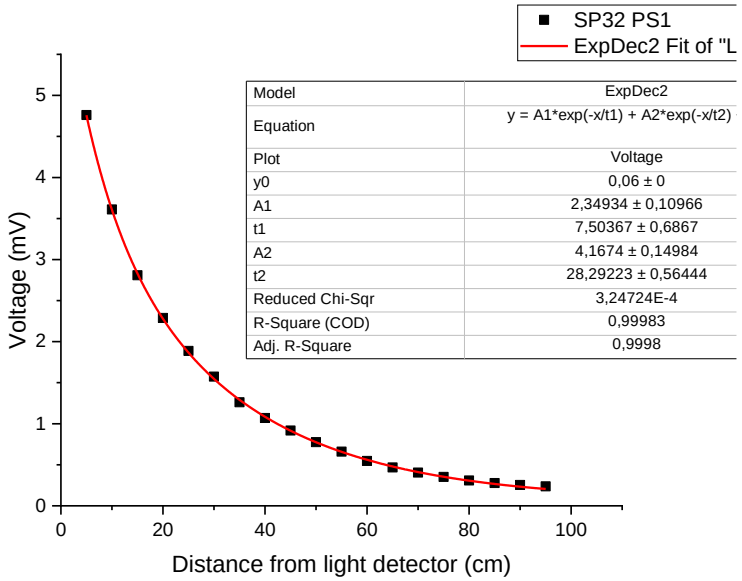


Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t
Plot	Voltage
y0	0,06 ± 0
A1	2,0581 ± 0,25329
t1	10,91192 ± 2,40575
A2	5,16307 ± 0,32587
t2	49,43522 ± 2,26975
Reduced Chi-Sqr	0,00274
R-Square (COD)	0,999
Adj. R-Square	0,9988

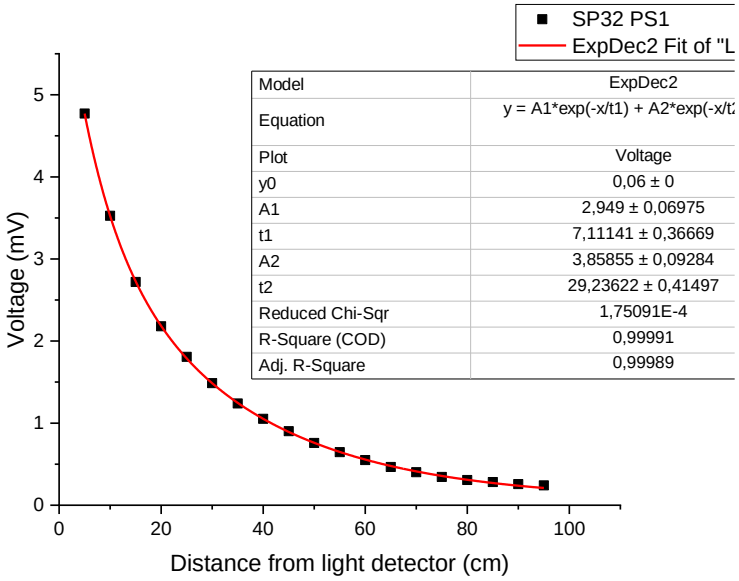


Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t
Plot	Voltage
y0	0,06 ± 0
A1	3,14418 ± 0,24116
t1	6,58288 ± 0,90734
A2	5,29691 ± 0,14223
t2	49,65633 ± 1,24214
Reduced Chi-Sqr	0,00265
R-Square (COD)	0,99905
Adj. R-Square	0,99886

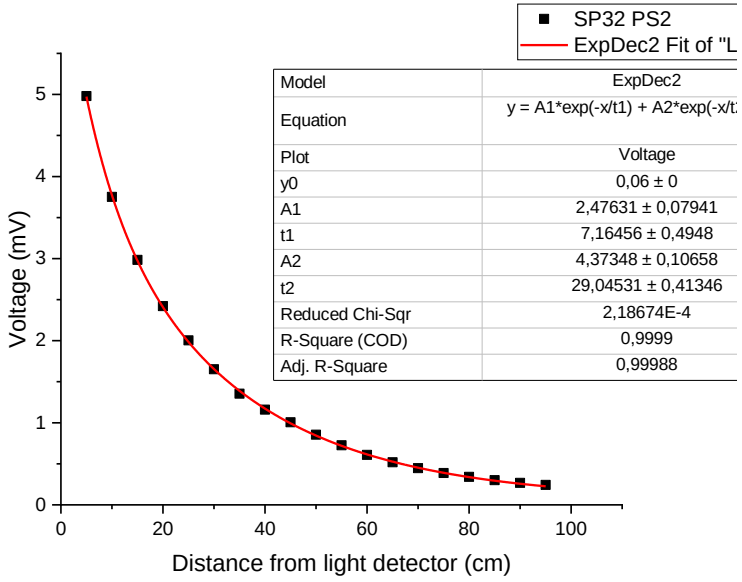
Results for SP32 PS, 6x24x1000 mm³ strips



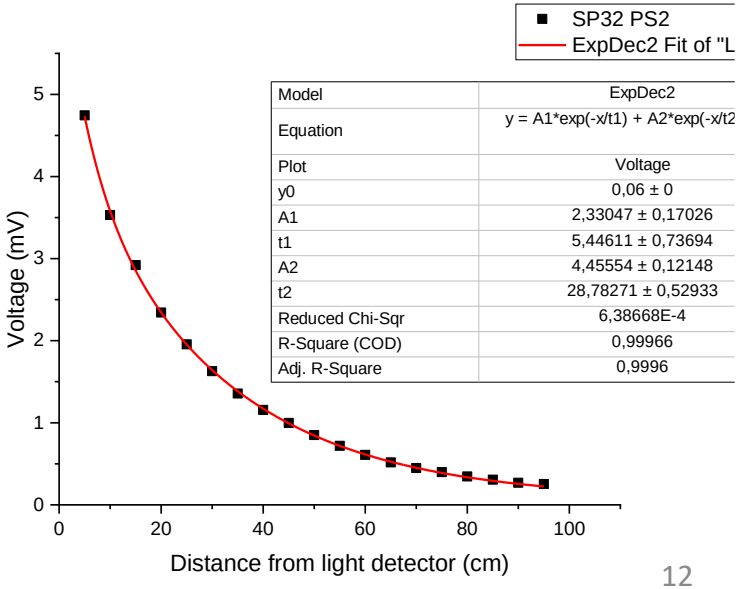
Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2)
Plot	Voltage
y0	0,06 ± 0
A1	2,34934 ± 0,10966
t1	7,50367 ± 0,6867
A2	4,1674 ± 0,14984
t2	28,29223 ± 0,56444
Reduced Chi-Sqr	3,24724E-4
R-Square (COD)	0,99983
Adj. R-Square	0,9998



Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2
Plot	Voltage
y0	0,06 ± 0
A1	2,949 ± 0,06975
t1	7,11141 ± 0,36669
A2	3,85855 ± 0,09284
t2	29,23622 ± 0,41497
Reduced Chi-Sqr	1,75091E-4
R-Square (COD)	0,99991
Adj. R-Square	0,99989

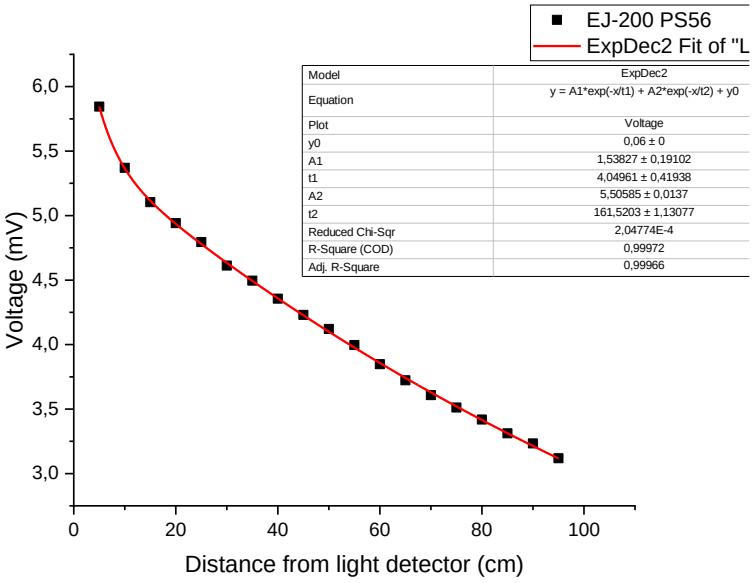


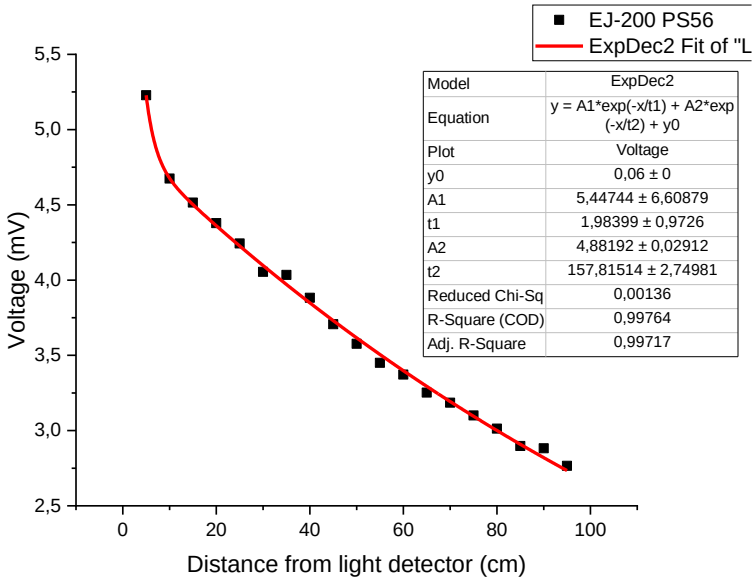
Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t
Plot	Voltage
y0	0,06 ± 0
A1	2,47631 ± 0,07941
t1	7,16456 ± 0,4948
A2	4,37348 ± 0,10658
t2	29,04531 ± 0,41346
Reduced Chi-Sqr	2,18674E-4
R-Square (COD)	0,9999
Adj. R-Square	0,99988

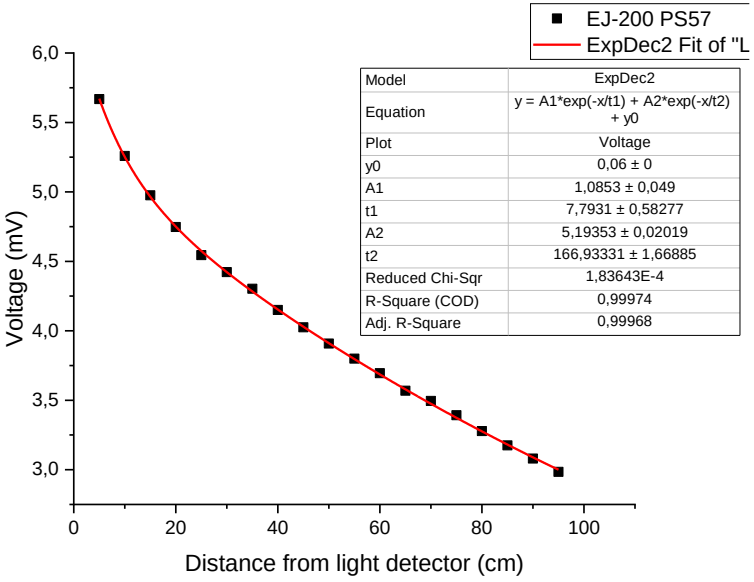


Model	ExpDec2
Equation	y = A1*exp(-x/t1) + A2*exp(-x/t2
Plot	Voltage
y0	0,06 ± 0
A1	2,33047 ± 0,17026
t1	5,44611 ± 0,73694
A2	4,45554 ± 0,12148
t2	28,78271 ± 0,52933
Reduced Chi-Sqr	6,38668E-4
R-Square (COD)	0,99966
Adj. R-Square	0,9996

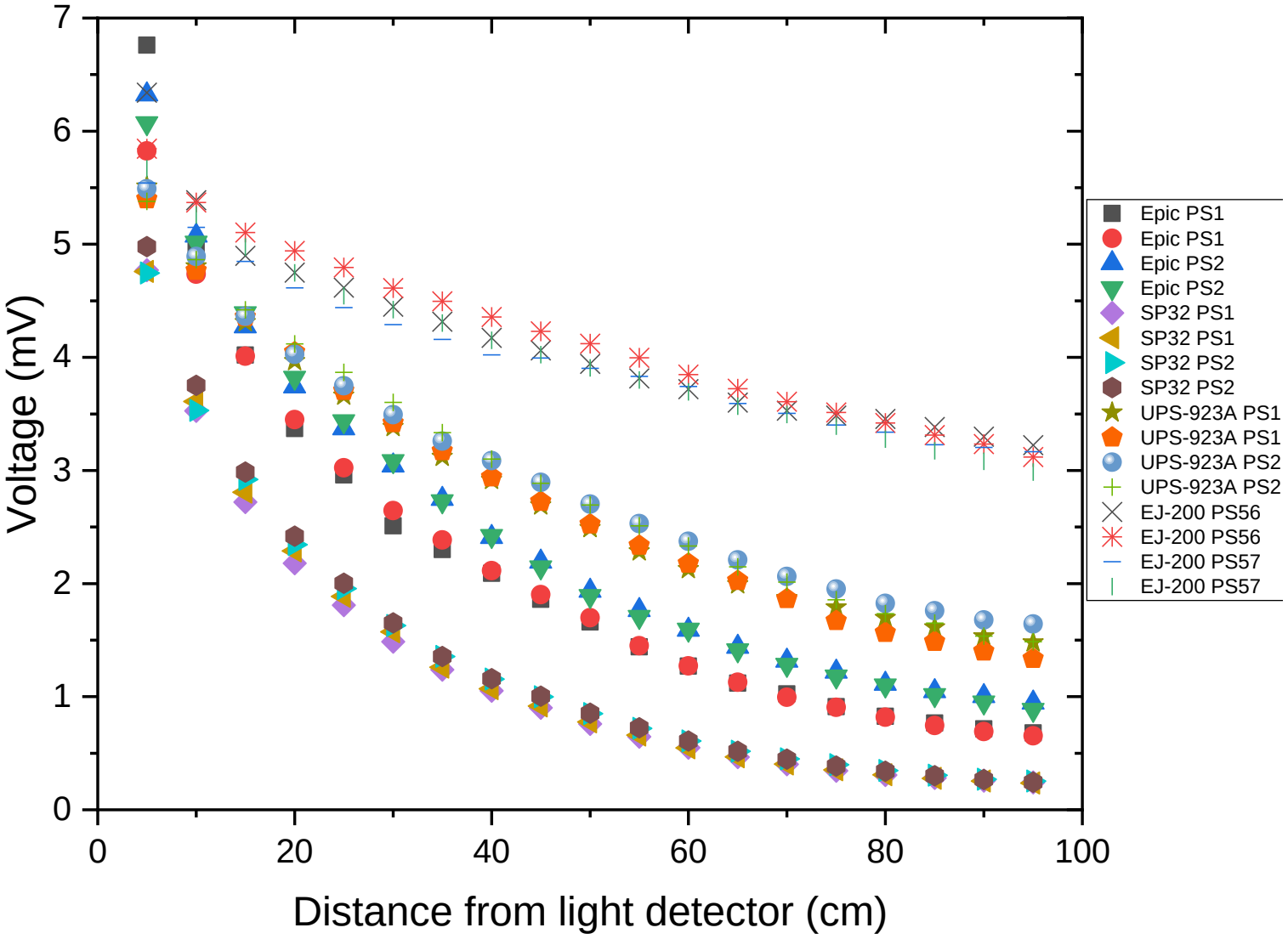
Results for EJ-200 PS, 6x24x1000 mm³ strips







Summary results for 6x24x1000 mm^3



Summary results 6x24x1000 mm^3

Scintillator 6x24x1000 mm^3	TAL for LR scan [cm]	TAL for RL scan [cm]	TAL from specification [cm]
EJ-200 PS56	t1 = 4.05 ± 0.42 t2 = 161.52 ± 1.13	t1 = 1.98 ± 0.97 t2 = 157.82 ± 2.75	380
EJ-200 PS57	t1 = 1.08 ± 0.05 t2 = 166.93 ± 1.67		
UPS-923A PS1	t1 = 4.06 ± 1.08 t2 = 63.83 ± 0.58	t1 = 15.57 ± 3.55 t2 = 80.88 ± 6.05	400
UPS-923A PS2	t1 = 4.17 ± 1.39 t2 = 68.8 ± 0.61	t1 = 8.82 ± 1.41 t2 = 79.96 ± 1.8	
Epic PS1	t1 = 6.27 ± 0.86 t2 = 41.03 ± 0.67	t1 = 5.95 ± 0.41 t2 = 43.26 ± 0.84	200
Epic PS2	t1 = 5.16 ± 0.33 t2 = 49.43 ± 2.27	t1 = 6.58 ± 0.91 t2 = 49.66 ± 1.24	
SP32 PS1	t1 = 7.5 ± 0.69 t2 = 28.29 ± 0.56	t1 = 7.11 ± 0.37 t2 = 29.24 ± 0.41	NA
SP32 PS2	t1 = 7.16 ± 0.49 t2 = 29.04 ± 0.41	t1 = 5.45 ± 0.74 t2 = 28.78 ± 0.53	

Results for 500 mm long EJ-230 strips with different cross-sections

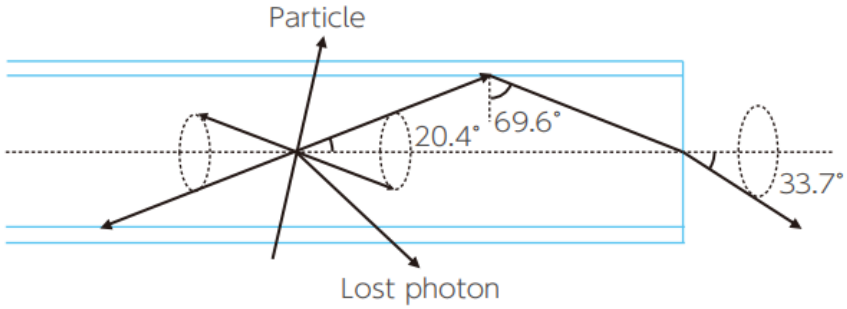
Scintillator 500 mm	TAL for LR scan [cm]	TAL for RL scan [cm]	Cross-section surface [mm^2]
Hexagonal, 9 mm side	t = 50.17 ± 1.83	t = 59.39 ± 1.92	210
Square, 14x14 mm	t = 47.86 ± 3.36	t = 47.02 ± 1.45	196
Triangle, 17 mm side	t = 35.76 ± 1.37	t = 40.78 ± 1.11	125
Rectangular, 5x19 mm	t = 31.56 ± 0.74	t = 29.85 ± 0.55	95
TAL from specification = 120 cm			

Moisture cured low refractive index optical coating

Cladding and Transmission Mechanism

Single cladding

Single cladding fiber is standard type of cladding.



Increase trapping efficiency: coating reflects more light to the end of scintillator.
Cover saw marks from polishing and scratches at the surface.

AR-139: Optical Coating

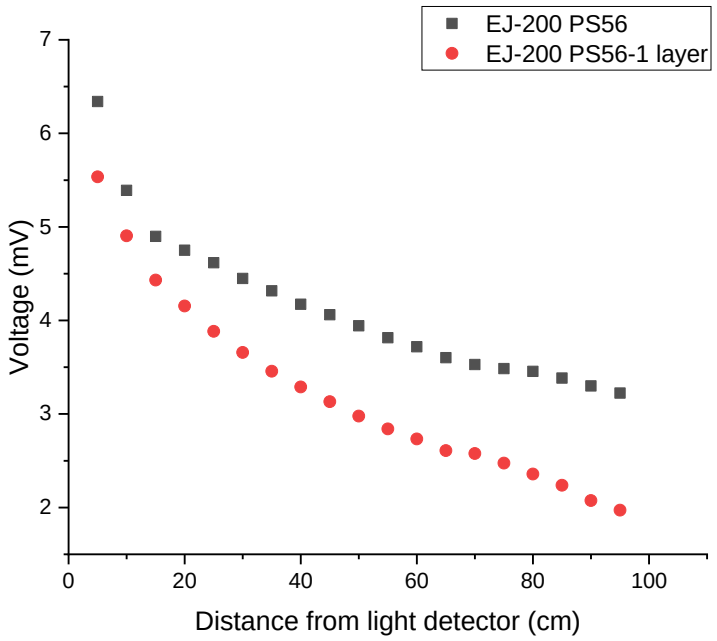
AR-139 is a Moisture Cured hard anti reflective coating, with a refractive index of 1.39. It has a Pencil Hardness of 2H. It has good adhesion to glass, metals, oxides and plastics. It is a strong liquid repellent, allowing non-stick properties and easy removal of grease, various oils, solvents, and water. It allows for easy slipping of a finger, which is important in touch screens.
The product is supplied as a 60% solids content diluted in a mixture of fluorinated and non-fluorinated solvents. The non-diluted product is a highly viscous resin at ambient conditions.
The material cures upon exposure to ambient moisture. The cured product is an inert with a very low surface energy.

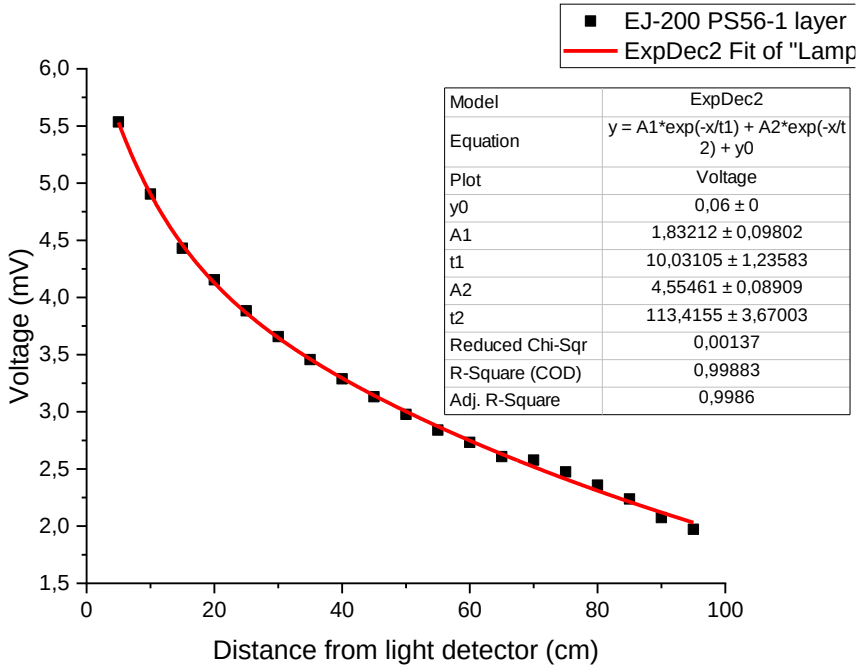
Properties

	Liquid state
RI liquid at 589 nm	1.391
Density (non-diluted), g/cm^3	1.41
Viscosity, cps @ 25°C	100-400
	Cured state
RI cured at 589 nm	1.395
RI cured at 950 nm	1.391
Hardness	2H
Adhesion	Strong adhesion to glass, metals and some plastics.
Appearance	Clear Colorless Hard Solid

http://www.mypolymers.com/

Results for 6x24x1000 mm^3 coated strip





TAL drops from 161 to 113 cm for one 0.1 mm layer of optical coating.

Summary

- Setup and method of fast TAL measuring were created.
- Technical attenuation lengths were measured to choose the best scintillator for J-PET construction (EJ-200).
- Increasing cross-section surface of scintillators increase TAL value.
- More research is needed for optical coatings.

Thank you!