R&D: New Plastic Scintillating Materials for Scintillator Calorimeters

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Acknowledgements

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Scintillation Detectors

- Scintillation detectors are devices that emit light when exposed to nuclear particles or radiation.

Challenges for future scintillator-based detectors in High-Energy Physics

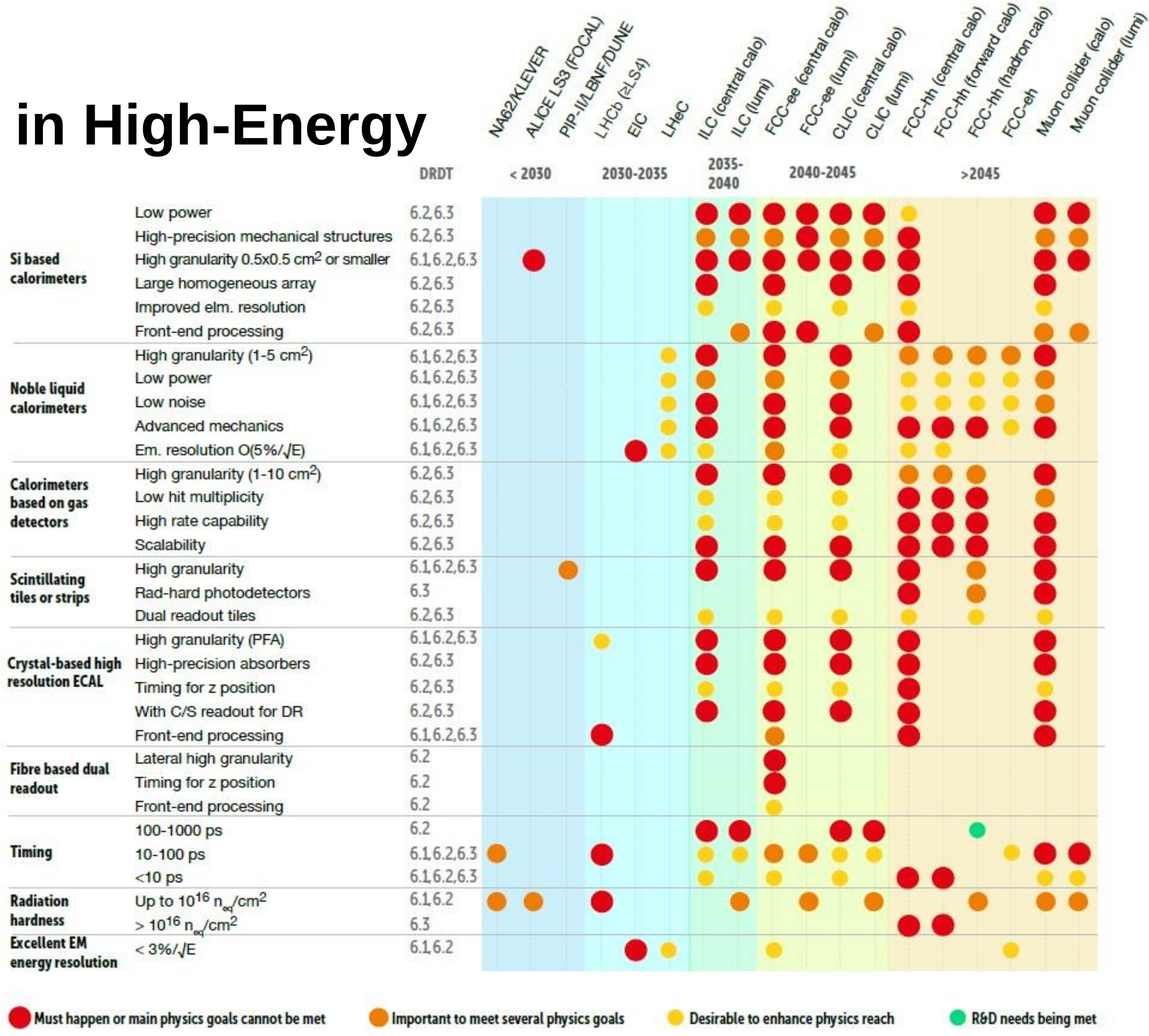
- Future precision/high energy colliders will impose stringent requirements on next generation detectors
- R&D starting now to ensure that key technologies are ready at the time of construction

Scintillator Requirements [1]:

- Large light response;
- Fast signals;
- High radiation hardness

For FCC-hh [2] [3] [4]:

- Doses of up to 5 GGy are expected in the forward calorimeters.



cds.cern.ch/record/2784893

Plastic Scintillator Detectors

- Scintillating Plastic has low cost/weight and is malleable
- Typical organic polymer bases:
  - Polystyrene and Polyvinyltoluene
  - Doped with wavelength shifters (WLS) in residual concentrations

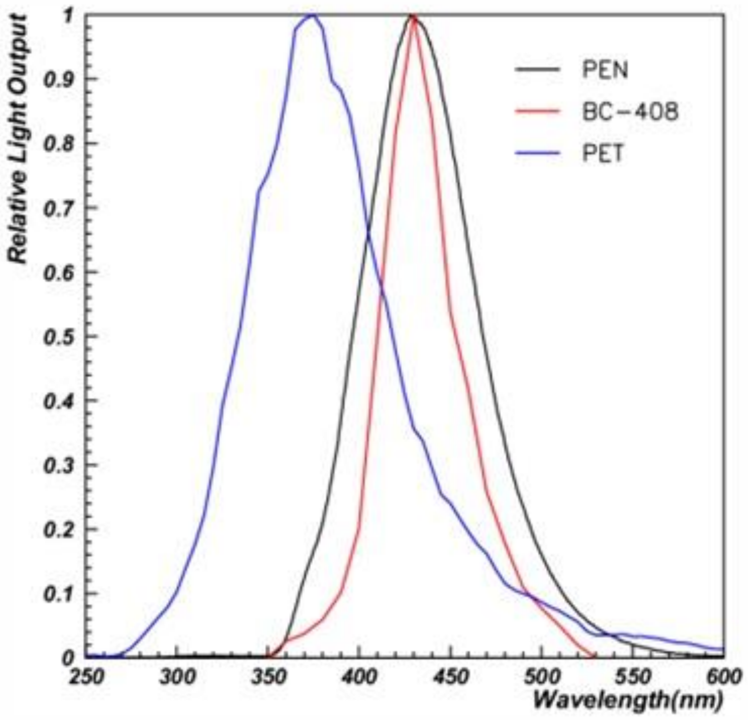
Scintillation Properties of PEN (Polyethylene Naphthalate) and PET (Polyethylene Terephthalate)

- PEN [5];
  - Competitive light response (10.500 phot/MeV)
  - Emits light ≈ in the same λ as some commercial scintillators (BC-408)

- PET has a faster light pulse than PEN (35 ηs vs. 7 ηs) [6], [7], [8]

- PET/PEN have a good recovery when exposed to radiation [9]

- PEN degrades less and recovers faster, PET has a larger total recovery [9]



Emission Spectra [5]

Objectives

Research new plastic scintillating materials, PEN and PET, with a specific focus on their optical and scintillation properties.

- *Do PET and PEN blend with synergy?*
  - *PEN (high light response, radiation hardness)*
  - *PET (damage recovery, faster timing)*

Outline:

- Production of Scintillator Samples: pure PET/PEN, PET:PEN blends and PET+Dopants
- Characterization of samples:
  - Emission Spectra
  - Measurement of Light Response
- Summary and Future work

Sample Production

Granulated raw materials (PET/PEN) are used

- The samples were produced in collaboration with the Institute of Polymers and Composites (IPC) of the University of Minho
- Manufacturing Processes: Injection molding.
- Samples measure 30 x 30 x 2 mm^3

INSTITUTE FOR POLYMERS AND COMPOSITES

Samples Produced	Quantity
PEN	44
PET	25
PET + BBOT	11
PET + POPOP	11
PET90PEN10	22
PET75PEN25	21
PET50PEN50	34
PET25PEN75	34
PET10PEN90	18
PET75PEN25 + POPOP (0.022%)	11
PET75PEN25 +BBOT (0.022%)	10
PET50PEN50 + POPOP (0.022%)	15
PET50PEN50 + BBOT (0.022%)	16
PET90PEN10 + POPOP (0.022%)	16
PET90PEN10 + BBOT (0.022%)	20
PET50PEN50+BBOT (0.05%)	15
PET50PEN50+POPOP (0.05%)	15
Total	338

- Scintillator properties depend on production parameters:
  - Material flow
  - Injection speed
  - Pressure
  - Cooling time
  - Melting temperature

Emission Spectra

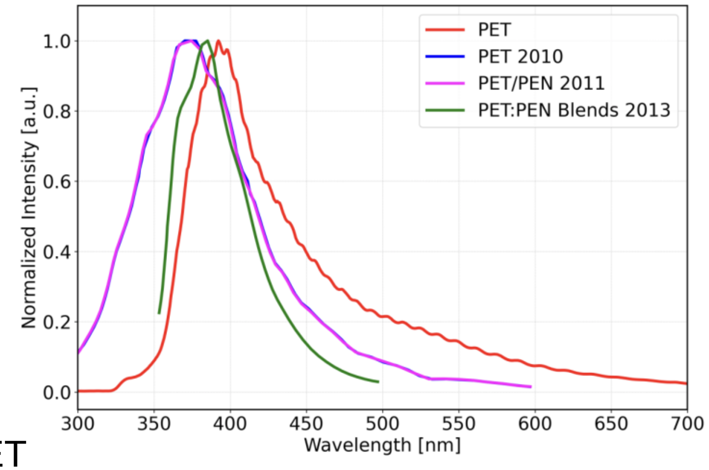
- PET sample:
  - Peak ~ 395 nm
  - Shape and peak are similar with Literature

- PEN sample:
  - In the literature, the spectra vary a lot from each other
  - Main peak ~ 405 nm, slightly below the Literature
  - 2nd peak ~ 450 nm, could be attributed to differences in the source material composition

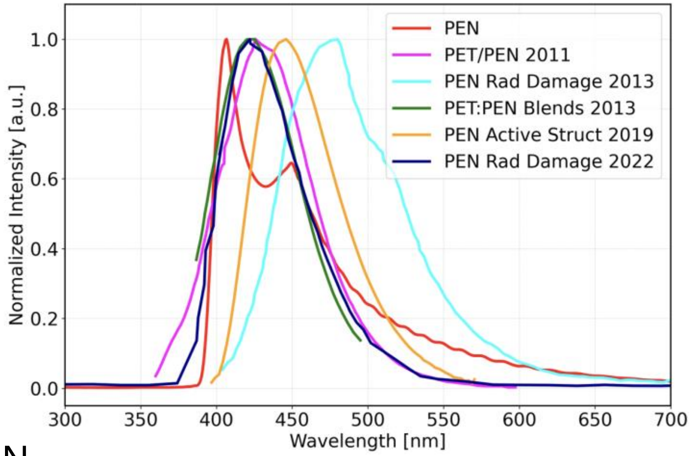
- As expected, adding POPOP and BBOT to PET causes the WLS of the original scintillation light

- Resulting peaks:
  - PET+POPOP ~ 425 nm
  - PET+BBOT ~ 455 nm

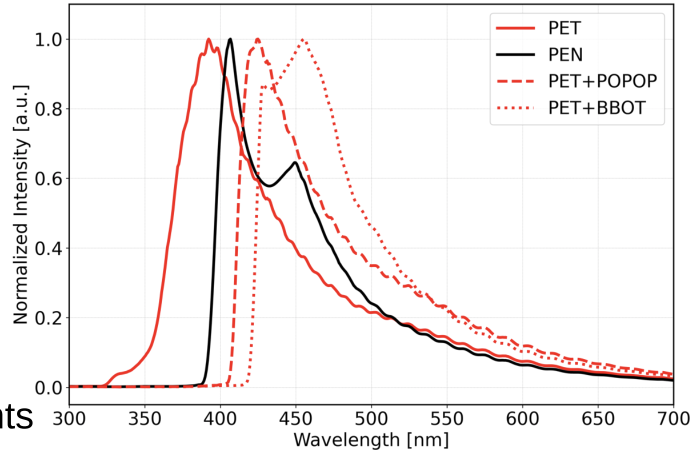
PET 2010 [10], PET/PEN 2011 [11], PET:PEN Blends 2013 [12], PEN Rad Damage 2013 [13], PEN active struct 2019 [14], PEN Rad Damage 2022 [6]



a) PET



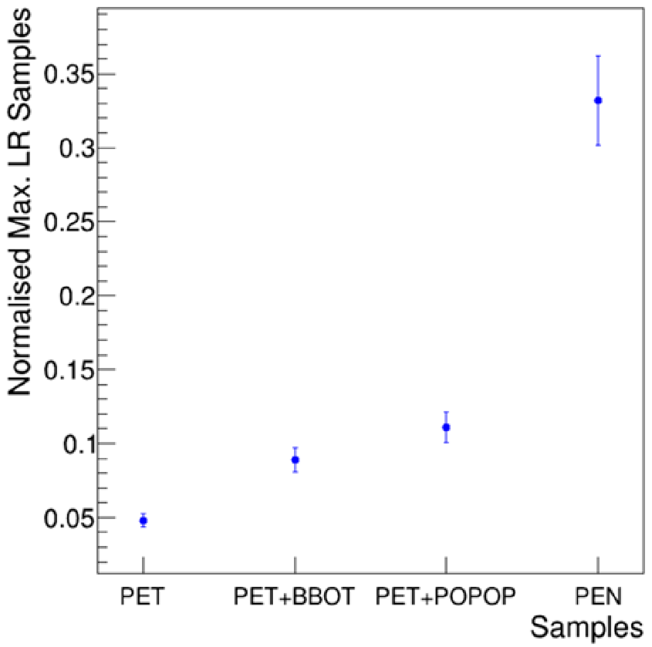
b) PEN



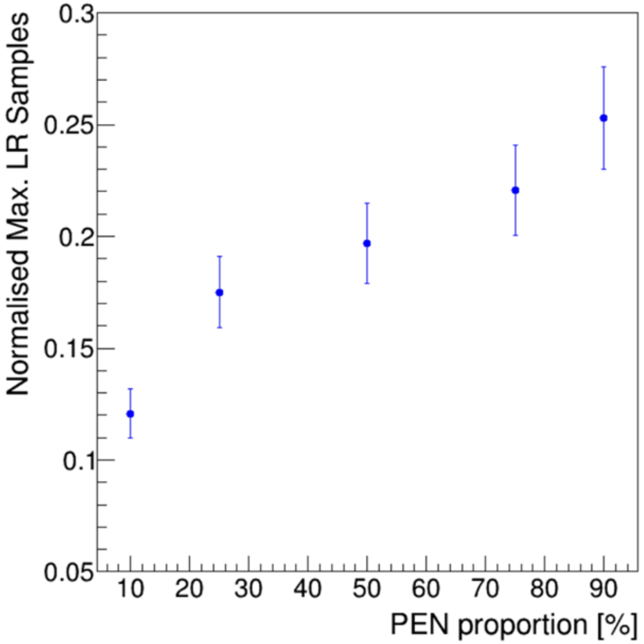
c) PET+dopants

Normalised LR Samples to PEN/PET, Blends and PET+dopants

- Light Response measured with ^{90}Sr source (Beta source)
- PEN has 7 times higher light response than PET
- Addition of dopants to the PET-base material potentiates the light emission:
  - Dopants in 0.22% mass concentration
  - BBOT: increase in the maximum LR by 80%
  - POPOP: increase in the maximum LR by 120%



- Different PET:PEN mixtures as a function of the PEN proportion;
- Increase in light response with the proportion of PEN, expected given the higher light response of PEN compared to PET;



Summary and Future Work

- Future HEP experiments with scintillator detectors will need cheap materials with high scintillation efficiency and radiation hardness.

- R&D of pure PEN and PET samples , PET+dopants, and PET:PEN mixtures in different proportions:
  - Light response of PEN is about 7 times higher than PET
  - Addition of dopants to PET doubles its light response
  - PET with dopants exhibits wavelength shifting (WLS) in light emission
  - For PEN/PET blends, light response increases with the PEN proportion
  - For blends, PEN has predominant spectrum
- This work was published in NIM-A (DOI:10.1016/j.nima.2024.169627)

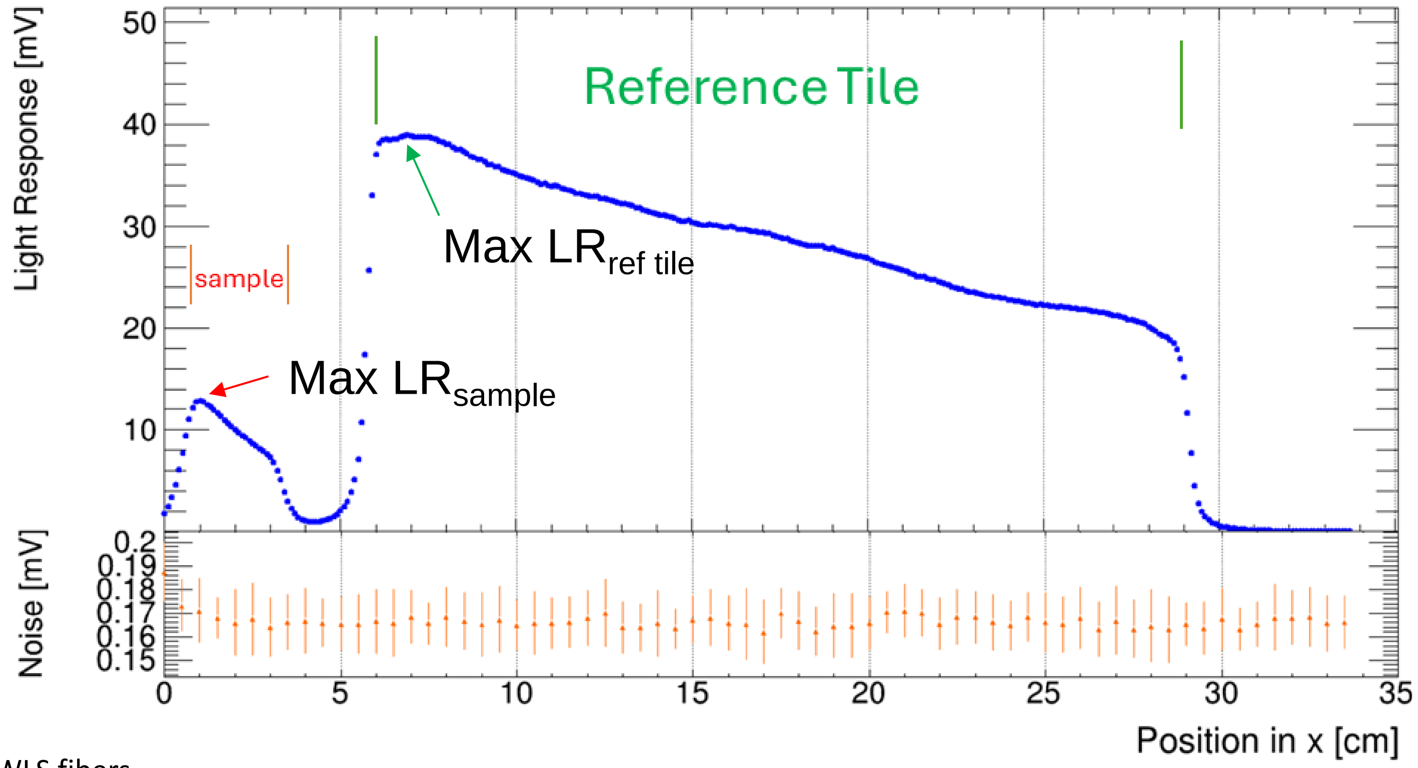
Future work:

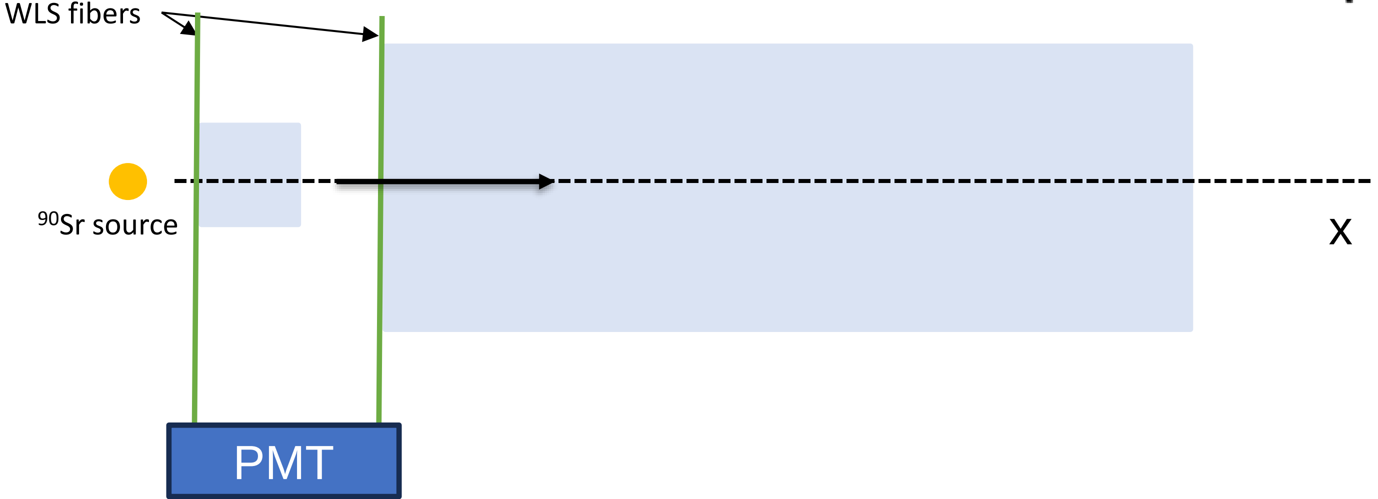
- Measurement of the signal time properties of the existing samples
- R&D for the production of larger samples
- Study of the radiation hardness of PEN/PET and PET:PEN blends

Thank you
for your attention

BACKUP

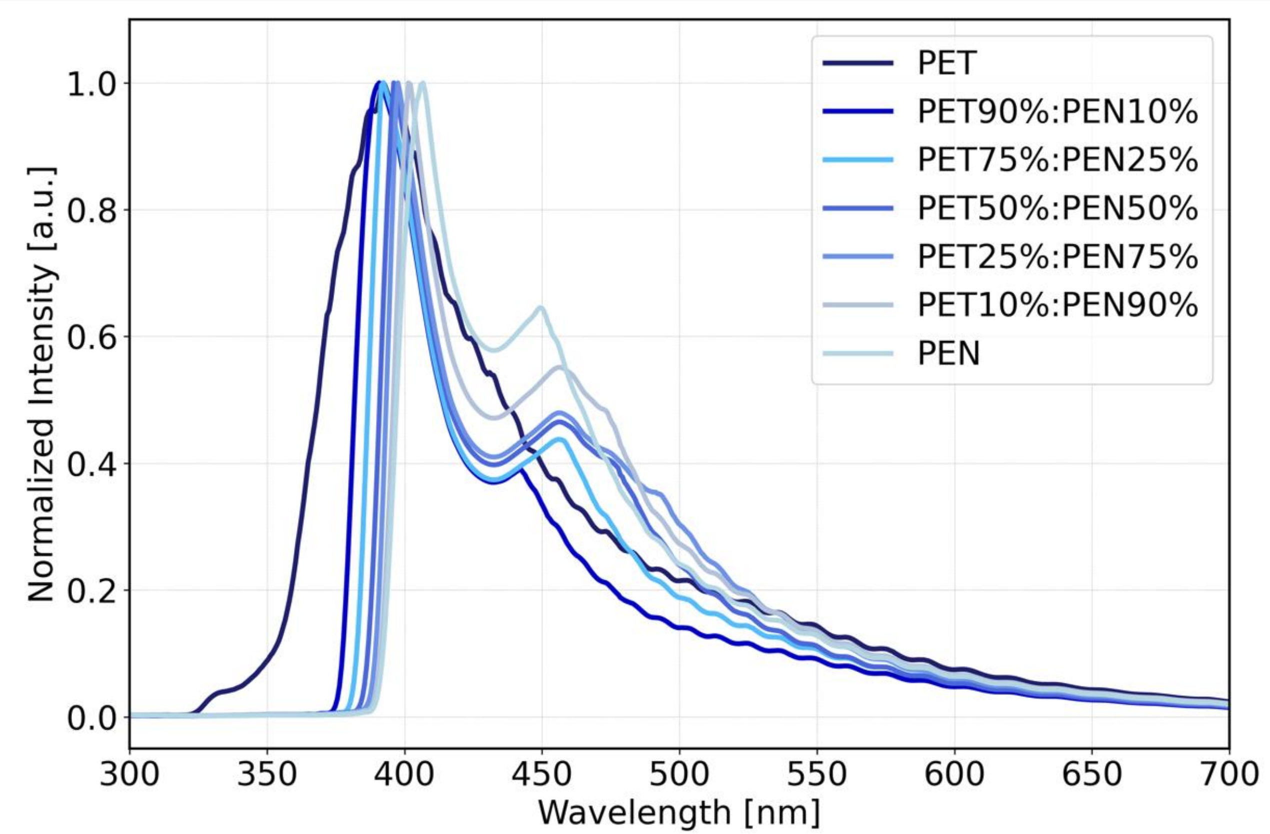
^{90}Sr scan Measurements





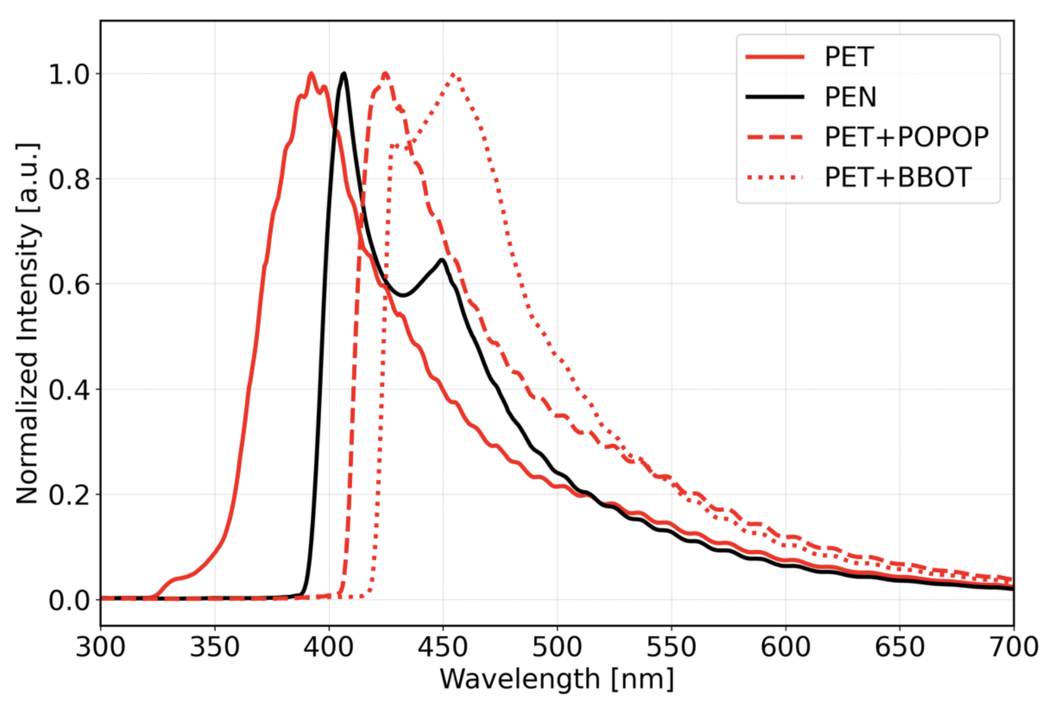
- Light response (LR in mV) as a function of ^{90}Sr source position
- Two scintillators are measured:
  - Reference Tile: 3 mm thick scintillator (ATLAS/LHC Tile Calorimeter - tile #4)
  - Sample: Manufactured scintillator (2 mm thick)
- Two values are extracted from the scan
  1. Maximum LR in the sample
  2. Maximum LR on the reference tile
- Max normalized LR is $\frac{Max\ LR_{sample}}{Max\ LR_{ref\ tile}}$
  - is the main metric for evaluating performance of different composition samples

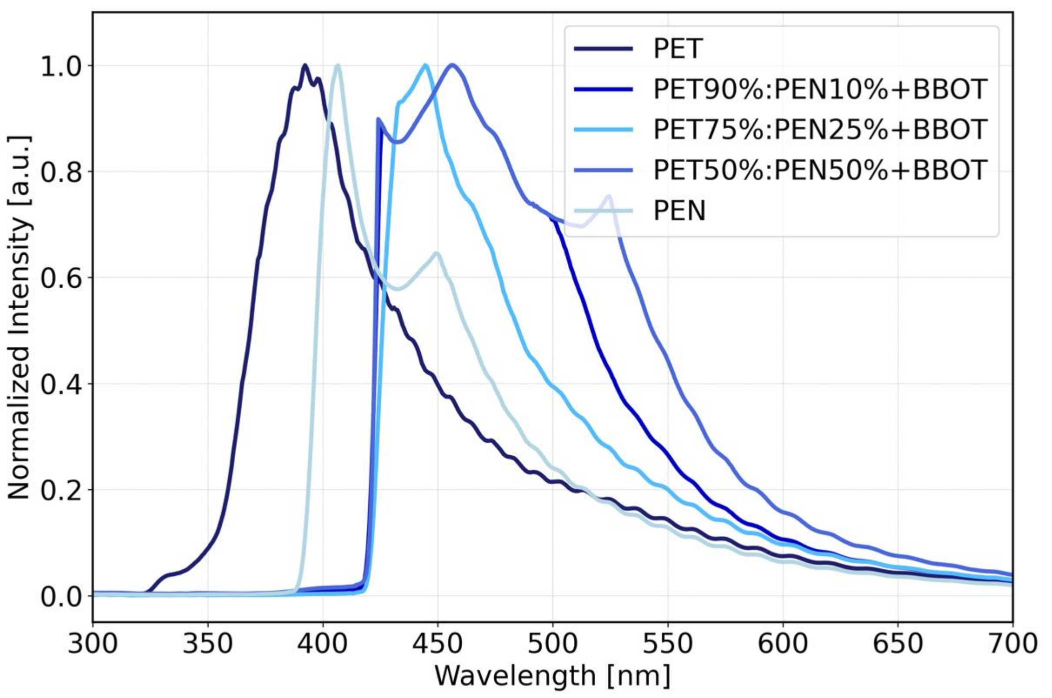
Emission Spectra

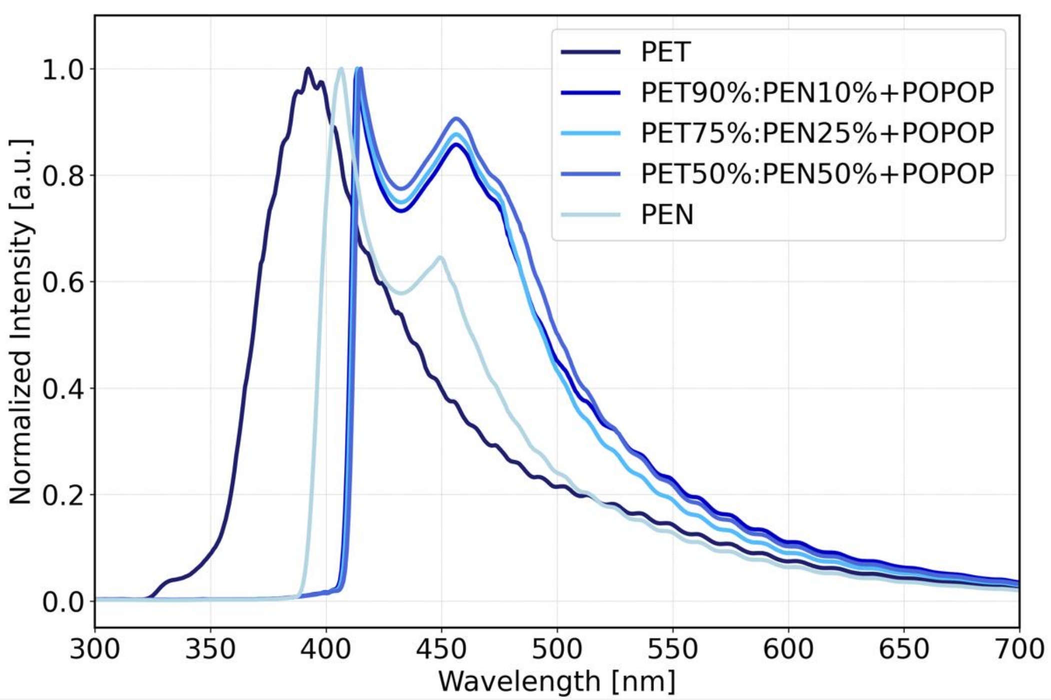


- PET:PEN mixtures:
  - Spectra are similar to the PEN spectrum
  - Peak gradually shifts 390 nm → 410 nm with increasing PEN proportion

Emission Spectra



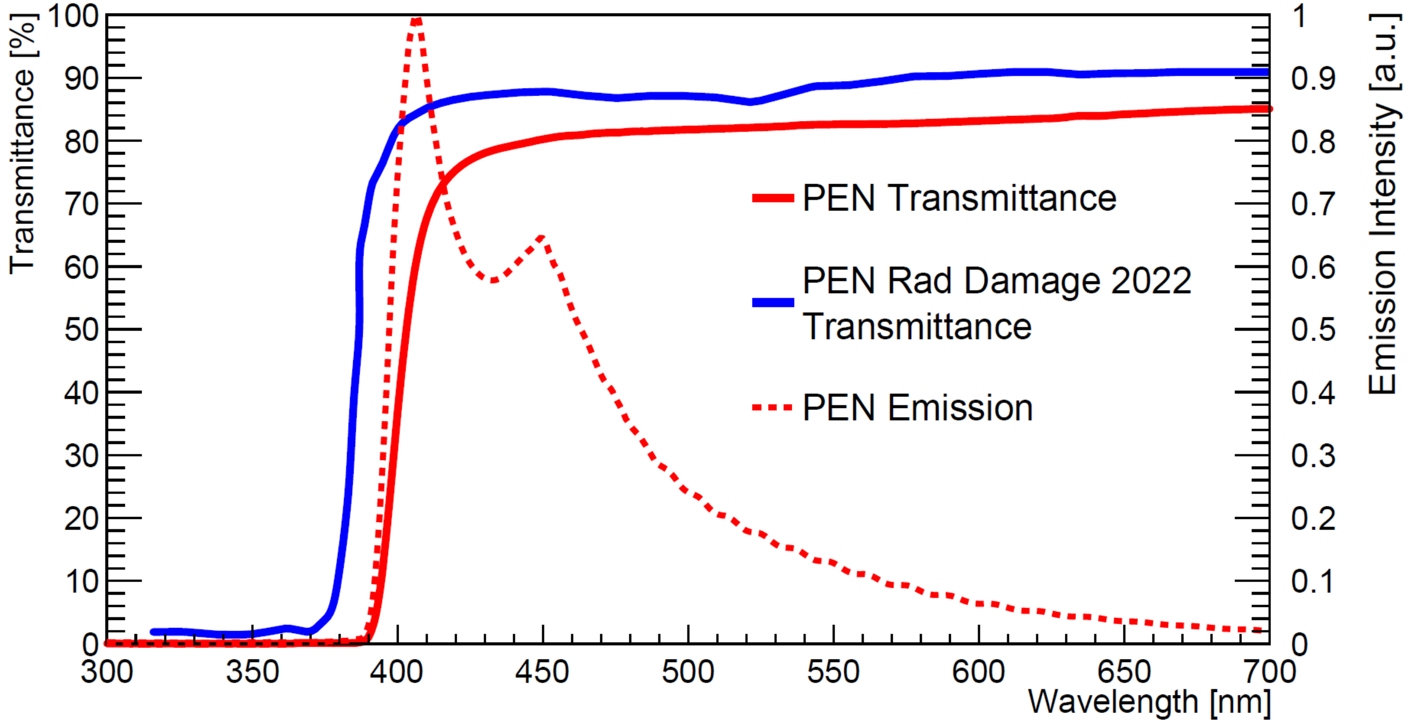




- As expected, adding POPOP and BBOT to PET causes the WLS of the original scintillation light
- Resulting peaks:
  - PET+POPOP ~ 425 nm
  - PET+BBOT ~ 455 nm
- Emission Spectra of all blends are similar in terms of peaks and shape
- Seems that BBOT interacts differently for each type of mixture

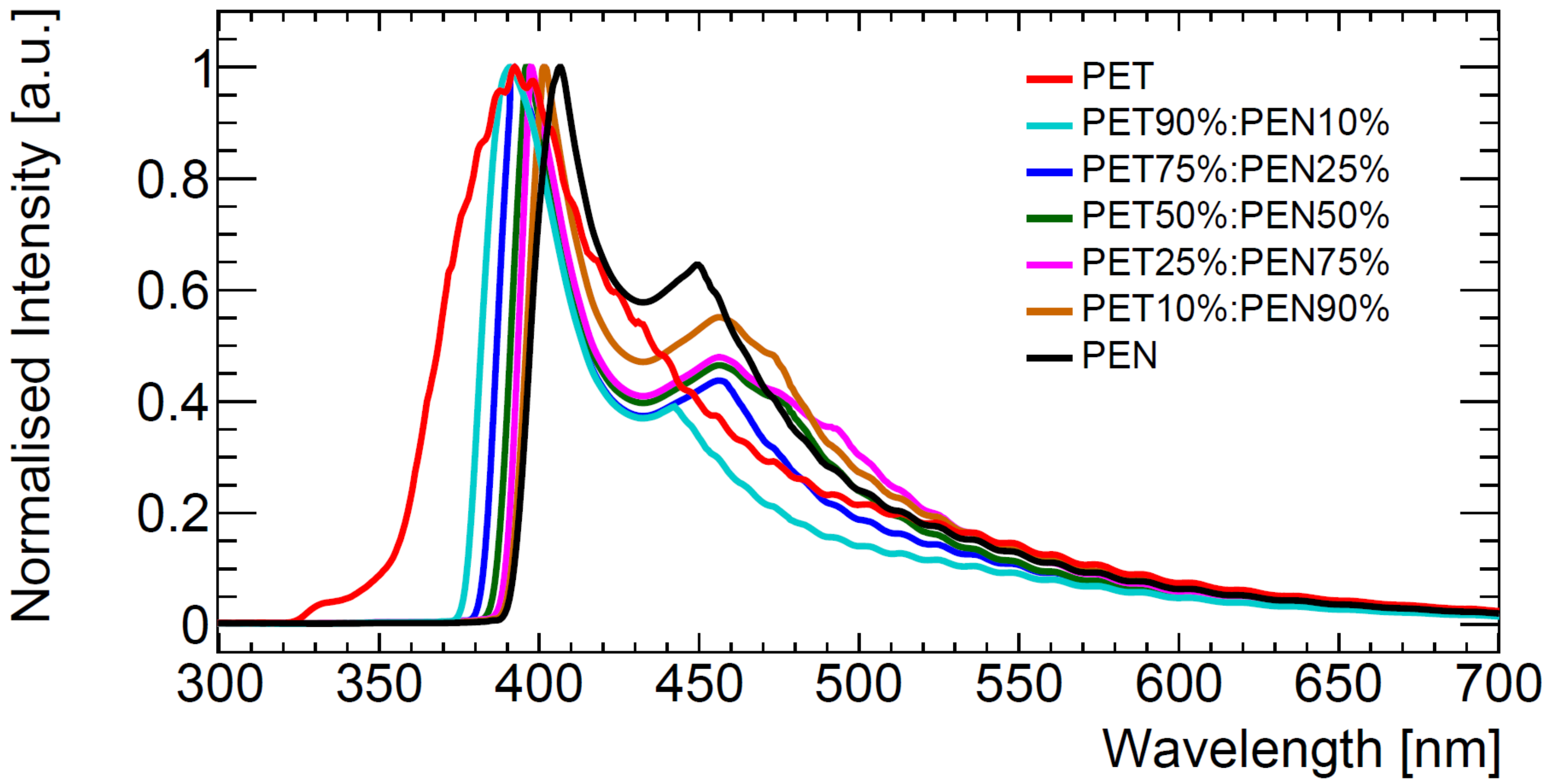
PEN Transmittance

- Results show good agreement
  - PEN: ~ 80 %
  - PEN Literature: ~ 90 %
- Difference (our and Literature PEN) in transmittance is probably due to the different thicknesses
  - PEN sample: 2 mm
  - Literature: 0.1 mm
- PEN exhibits transparency above 400 nm
  - Scintillation below 400 nm is attenuated by the transmission characteristics
  - PEN's Light yield might improve by adding an adequate WLS



PEN Rad Damage 2022 [6]

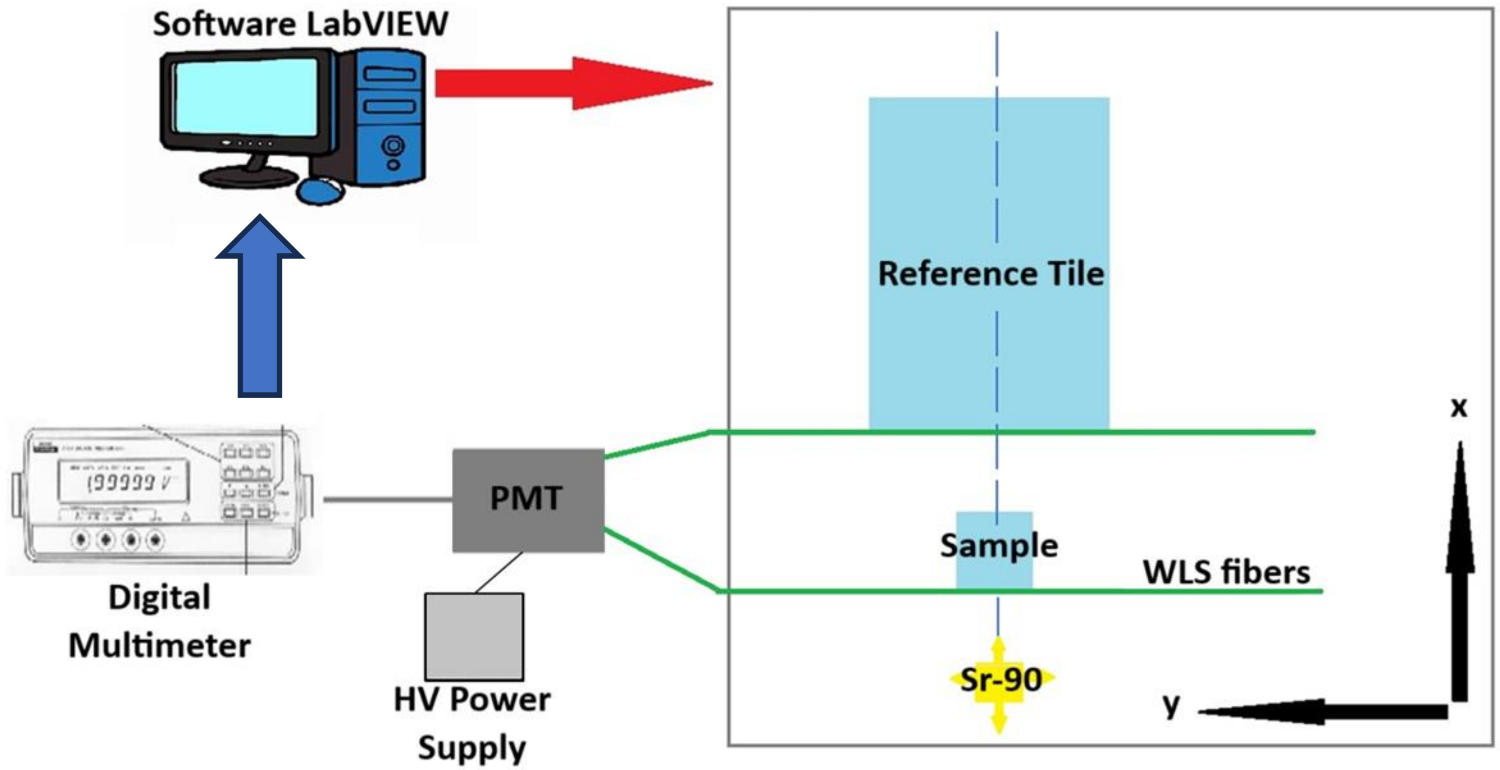
Emission Spectra



a) PET:PEN blends

- PET:PEN mixtures:
  - Spectra are similar to the PEN spectrum
  - Peak gradually shifts 390 nm → 410 nm with increasing PEN proportion

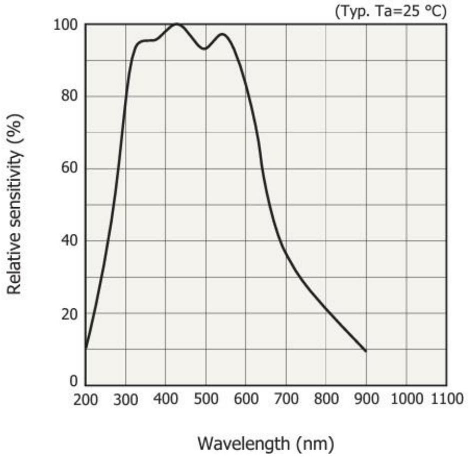
Setup for Measuring the Light Response (LR)



- Scintillator signal: each point is the average of 30 measurements.
  - a measurement is the PMT signal integrated over 400 ms;
- Noise value is updated at each 5 scan points
  - source outside the scintillator area;
- Light response (LR) is defined as measured signal after noise subtraction

* ^{90}Sr source scans the scintillators
* PMT
* Multimeter
* Control and data acquisition software (LabVIEW)
* WLS fibers
* HV Power Supply

Experimental Setup for the Emission Spectrum measurement

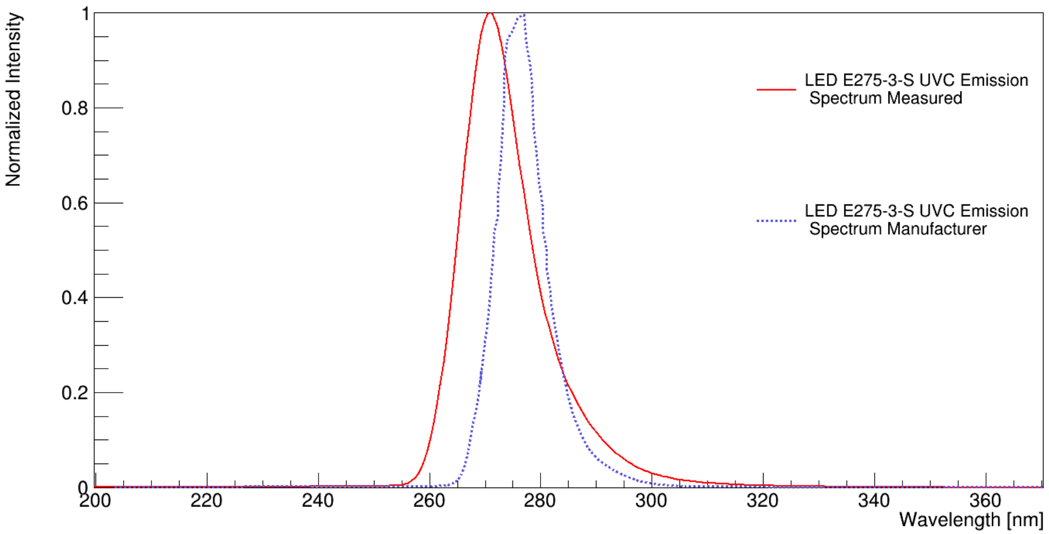


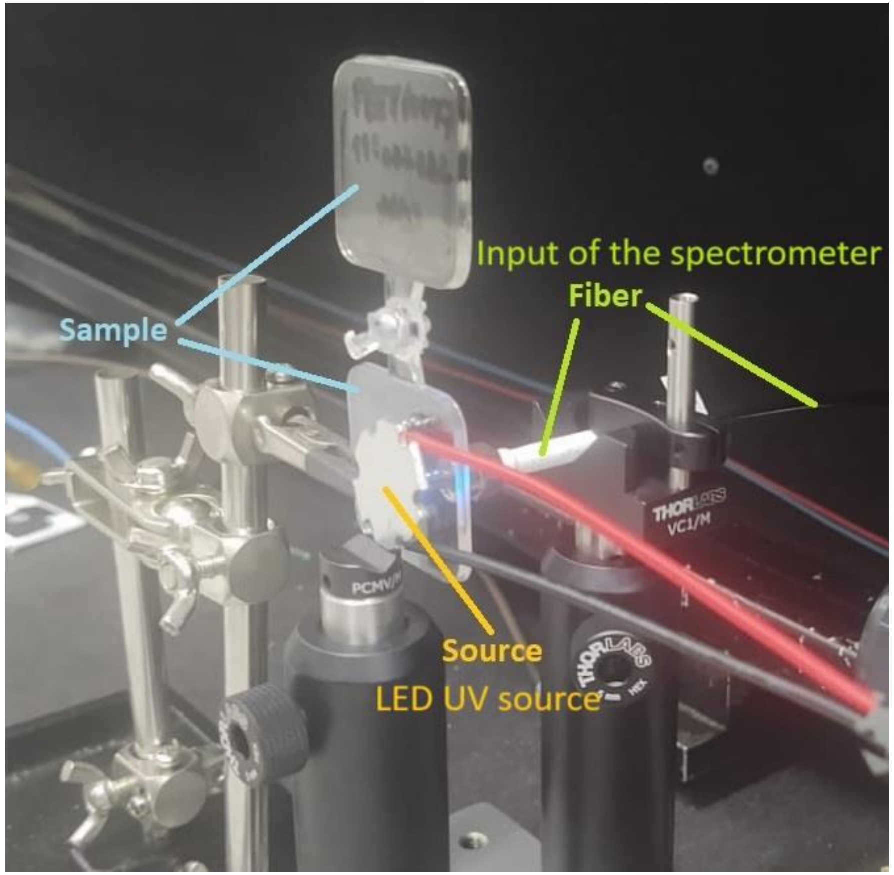
Spectrometer

C10082MD, for UV to near IR (200 to 800 nm)

Measured with the spectrometer

- LED source: E275-3-S UVC LED
- Manufacturer information: peak between 270-280 nm
- Our measured Peak ≈ 271 nm





Sample Production Parameters

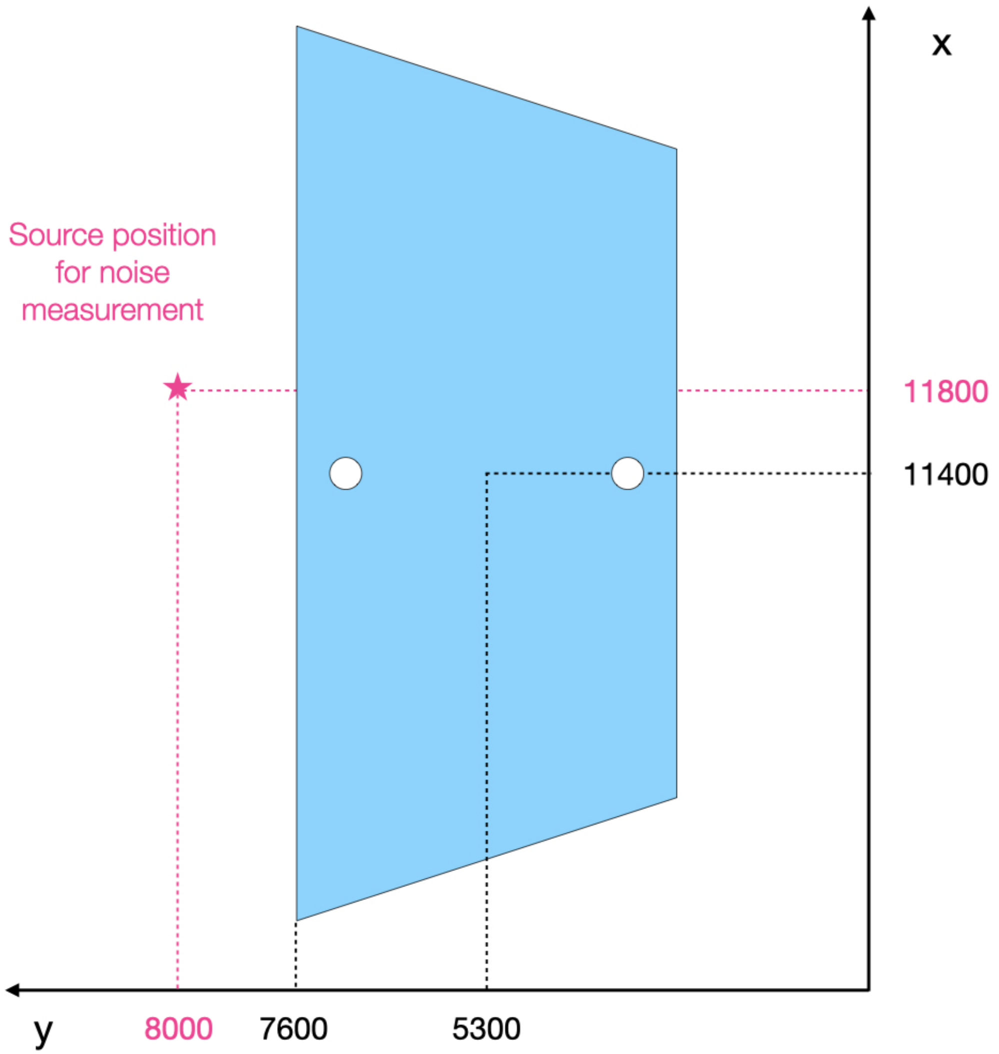
					Injection				2nd Injection				Dosing							
Samples	Period	Process	Model	Dried material	Dosing cm^3	Comutation cm^3	Speed cm^3/s	Pressure bar	Pressure time (s)	Comutation cm^3	Speed cm^3/s	Pressure bar	Dosing mm^3	Comutation mm^3	Speed mm/s	Pressure bar	Temperature Set Nozle/T5/T4/T3/T2/T1 (°C)	Cycle Time (s)	Cooling time (s)	Residence time (min)
PET + BBOT	September-23	Injection	Boy 22A	4h, 60°C	8.5	2.7	30	1500	4	2.7	2.5	400	8.5	2.7 cm^3	150	30	*/265/260/250/250/245	50.73	20	Not needed
PET + POPOP	September-23	Injection	Boy 22A	4h, 60°C	8.5	2.7	30	1500	4	2.7	2.5	400	8.5	2.7 cm^3	150	30	*/265/260/250/250/245	47.05	20	Not needed
PET75PEN25	12-Oct-23	Injection	Boy 22A	PET: 4h, 60°C; PEN: 4h, 110°C	8.5	2.7	30	1500	3	5 mm^3	10 mm/s 2.5 cm^3/s	300	8.5	2.7 cm^3	150	10	*/295/290/280/260/250	52.1	20	5
PET:10/PEN:90	13-Oct-23	Injection	Boy 22A	PET: 4h, 60°C; PEN: 4h, 120°C	8.5	2.7	30	1500	4	5 mm^3	10 mm/s 2.5 cm^3/s	300	8.5	2.7 cm^3	150	30	*/300/285/280/275/255	51.6	20	5
PEN	6-Nov-23	Injection	Boy 22A	PEN: 6h, 110°C	8.5	2.7	30	1500	4	2.7	2.5 ccm/s	600	8.5	2.7	150	20	*/295/290/285/280/250	52.85	20	5
PET	7-Nov-23	Injection	Boy 22A	6h, 70°C	8.5	2.7	30	1500	4	2.7	2.5	600	8.5	2.7	150	20	*/275/270/265/260/250	47.05	20	Not needed

Manufacturing PET/PEN

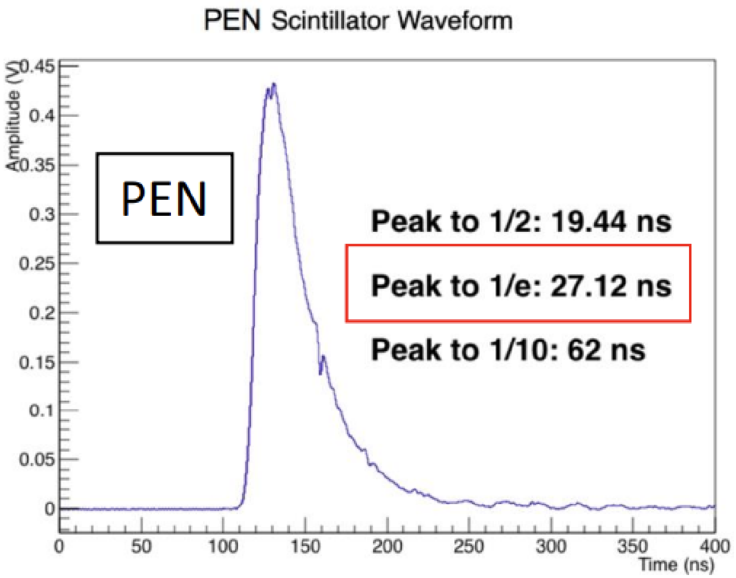
PET			
Samples/Articles	**Brand/Type**	**Material Form**	**Sample Size**
Our PET Sample, doi:10.1016/j.nima.2024.169627	Selenis Selekt™ BD 110	granulate	30 x 30 x 2 mm3
doi:10.1098/rspa.2010.0118 (PET 2010)	Mitsui Chemicals Inc., Japan	lump of PET bottles	110×50×5mm3
doi:10.1209/0295-5075/95/22001 (PET/PEN 2012)	Teijin Chemicals Ltd.	plate	35 × 35 × 5 mm3
doi:10.1016/j.radmeas.2013.06.006 (PET:PEN blends2013)	--	plate	31 x 31 x 5 mm3

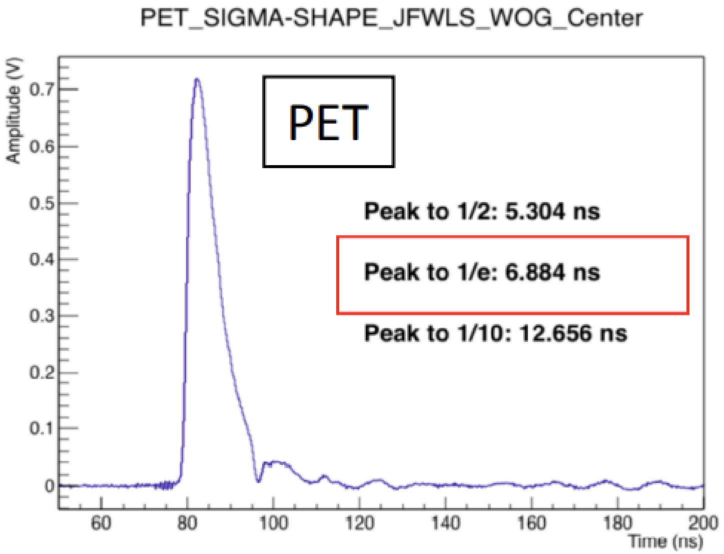
PEN			
Samples/Articles	**Brand/Type**	**Material Form**	**Sample Size**
Our PEN Sample, doi:10.1016/j.nima.2024.169627	GoodFellow Cambridge Ltd.	granulate	30 x 30 x 2 mm3
doi:10.1016/j.radmeas.2013.06.006 (PET:PEN blends2013)	--	plate	31 x 31 x 5 mm3
doi:10.1016/j.nimb.2013.03.027 (PEN Rad Damage 2013)	Teonex®, Teijin DuPont, Japan	film	9 µm thick
doi:10.1063/1.5019011 (PEN Active struct 2018)	Tejin-DuPont:TN-8065S and TN-8050SC (Teonex®)	pellets	30 x 30 x 3 mm3
doi:10.1088/1748-0221/14/07/P07006 (PEN Active struct 2019)	Tejin-DuPont:TN-8065S and TN-8050SC (Teonex®)	pellet or granulate	30 x 30 x 3 mm3
doi:10.1140/epjc/s10052-019-6810-8 (PEN WLS in Lar 2019)	Teijin DuPont:(Teonex® Q83)	film	125 µm thick
doi:10.3390/ma15196530 (PEN Rad Damage 2022)	Teonex® (Mod. Q65HA)	flexible film	40 x 30 x 0.1 mm3

Coordinates in the scan for noise acquisition

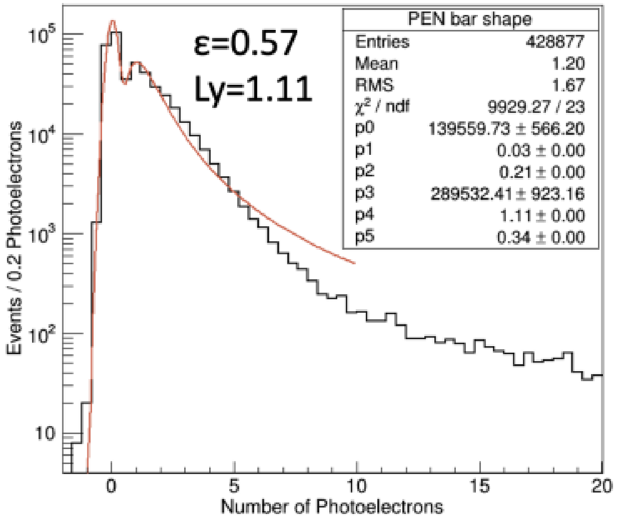


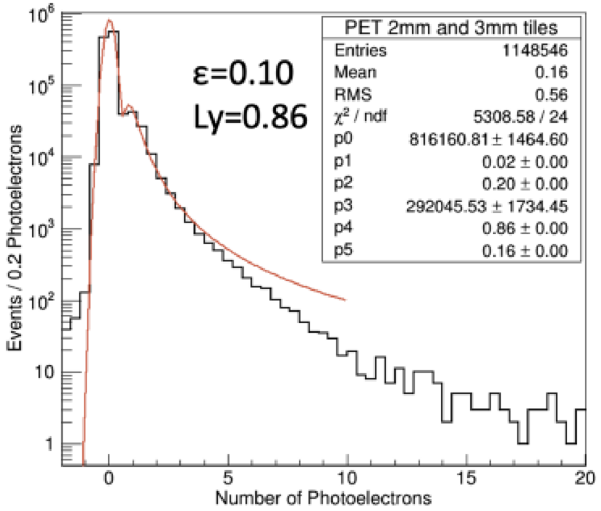
Timing and Efficiency





The signal timing of PEN and PET in response to the pulsed nitrogen laser.





[8]

The detection efficiency and light response of PEN and PET in response to 150 GeV muons of CERN test beam

- PET has a faster light response than PEN, but a lower light response.
- PEN has a detection efficiency of approximately 60 % and PET has an efficiency of 10 %