Measurement of Light Yield, Timing and Radiation Damage and Recovery of Common Plastic Scintillators

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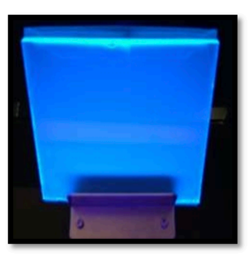
PEN and PET (polyethylene naphthalate and terephthalate) are common plastics used for drink bottles and plastic food containers. They are also good scintillators. Their ubiquity has made them of interest for high energy physics applications, as generally plastic scintillators can be very expensive. However, detailed studies on the performance of the scintillators has not yet been performed.

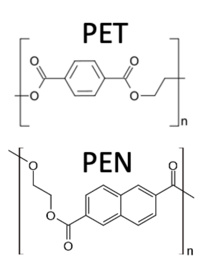
At various tests, we measured the light yield and timing properties of PEN and PET with Fermilab and CERN test beams. We also irradiated several samples to varying gamma doses and investigated their recovery mechanisms. Here we report on the measurements performed over the past few years in order to characterize the scintillation properties of PEN and PET and discuss possible future implementations.

Intrinsically Rad-Hard Scintillators

Commercially Available Scintillating Materials:

- Polyethylene Naphthalate (PEN)
- Polyethylene Terephthalate (PET)



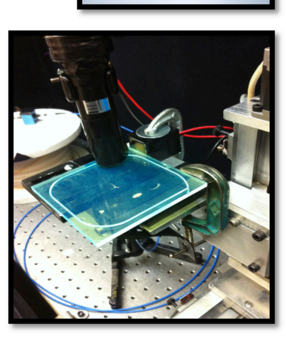


PEN:

- ✓ Intrinsic blue scintillation (425 nm)

PET:

- ✓ A common type polymer
- ✓ Plastic bottles and as a substrate in thin film solar cells.
- ✓ Emission spectrum of PET peaks at 385 nm [Nakamura, 2013]



Intrinsically Rad-Hard Scintillators

HEM/ESR: sub-μm film stack of Poly(Ethylene-2,6-Naphthalate)/PEN, polyester, polyethylene terephthalate (PET): *intrinsic blue scintillation!*

425 nm; 10,500 photons/MeV; ….

epl A Letters Journal Exploring the Frontiers of Physics — July 2011

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Evidence of deep-blue photon emission at high efficiency by common plastic

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Table 1: Properties of the three samples used in the present study.

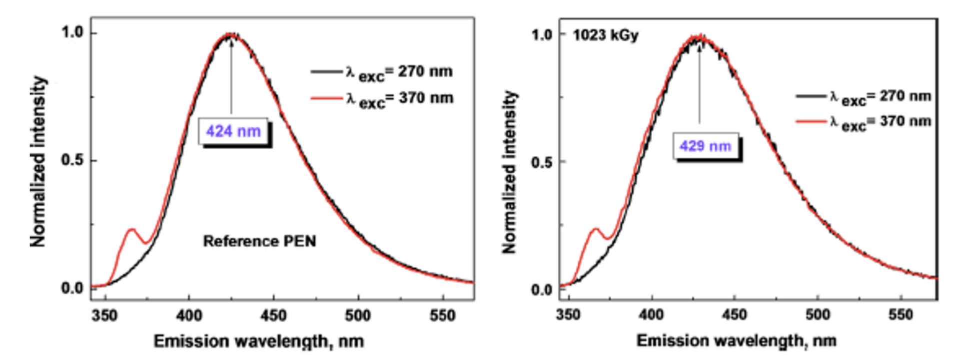
Material	Polyethylene naphthalate	Organic scintillator (ref. [14])	Plastic bottle (ref. [13])
Supplier	Teijin Chemicals	Saint-Gobain	Teijin Chemicals
Base	$(C_{14}H_{10}O_4)_n$	$(C_9H_{10})_n$	$(C_{10}H_8O_4)_n$
Density	$1.33\,g/cm^3$	$1.03\,g/cm^3$	$1.33\,g/cm^3$
Refractive index	1.65	1.58	1.64
Light output	~10500 photon/MeV	10000 photon/MeV	~2200 photon/MeV
Wavelength max. emission	425 nm	425 nm	380 nm

Intrinsically Rad-Hard Scintillators - PEN

100 MRad (1 MGy) Radiation Resistance!

<u>N. Belkahlaa</u> et al., *Space charge, conduction and photoluminescence measurements in gamma irradiated poly (ethylene-2,6-naphthalate)* Rad. Physics & Chem,<u>V101</u>, August 2014

Abstract: *Polyethylene naphthalate (PEN) thin films were subjected to gamma rays at different doses and changes in both the dielectric and photophysical properties were investigated. Samples were irradiated in air at room temperature by means of a 60Co gamma source at a dose rate of ~31 Gy/min. Total doses of 650 kGy(344 h) & 1023 kGy(550 h) were adopted. The high radiation resistance of PEN film is highlighted.*

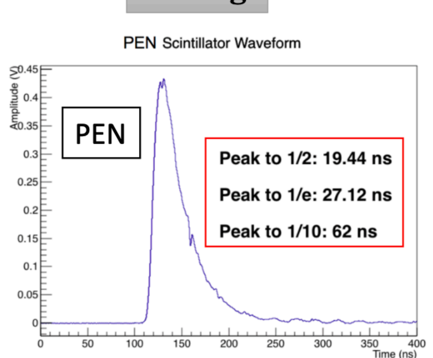


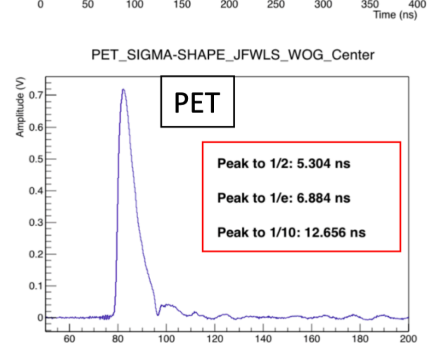
PL intensity at peak maximum (relative units) versus irradiation dose.

Excitation wavelength	Reference-PEN	650 kGy	1023 kGy
λ_e=270 nm	1	0.98	0.95
λ_e=370 nm	1	0.98	0.96

Laboratory Measurements

Timing

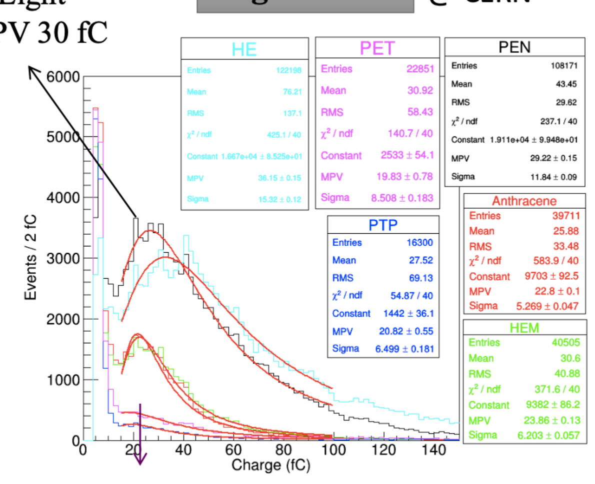




Beam Test Results

Light Yield 150 GeV muons @ CERN

PEN → Light yield MPV 30 fC

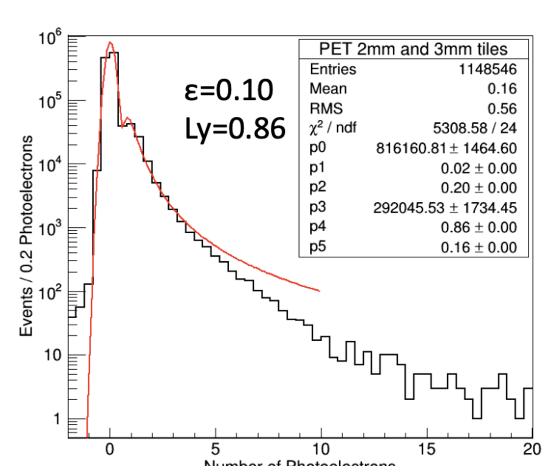


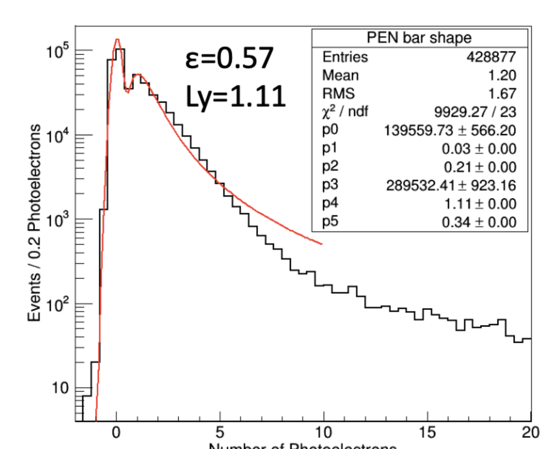
PET → Light yield MPV 20 fC

- PET is faster but emits less light. PEN is radiation resistant up to 10 Mrad and it has a significant light yield but it is too slow.

PEN Performance in Beam Measurements

We tested 2 - 4 mm thick PEN and PET tiles read out with green wavelength shifting fibers with 150 GeV muons.

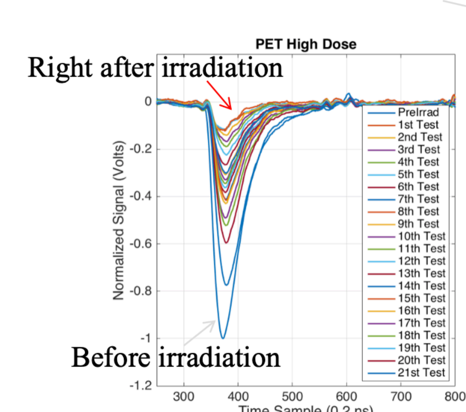




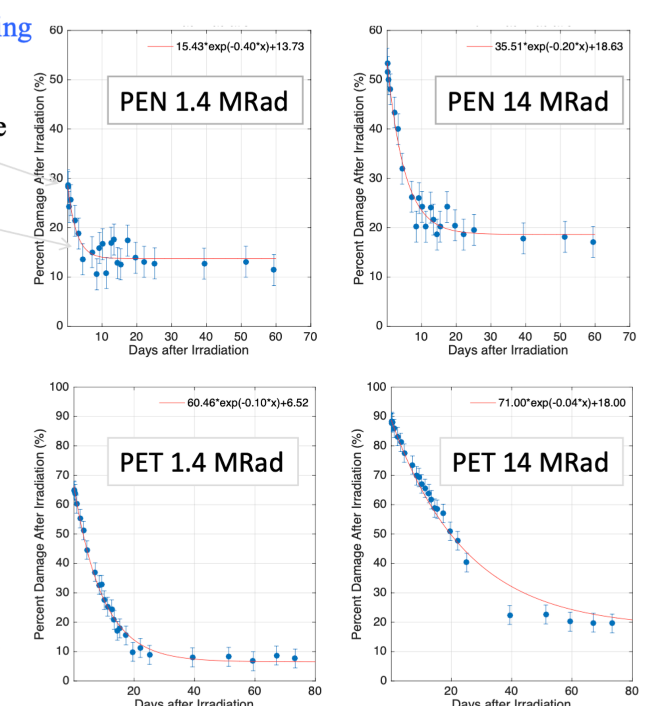
Radiation Damage Studies (Iowa)

We irradiated scintillator samples with using ^{137}Cs gamma source at Iowa Rad Core

1.4 Mrad and 14 Mrad



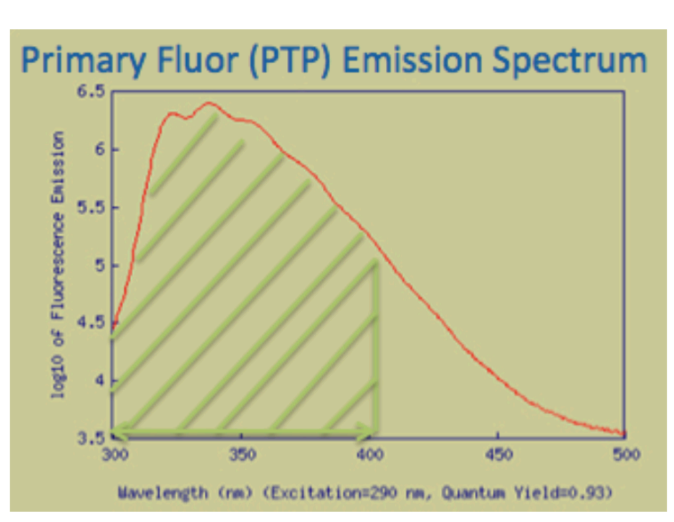
- Damage was calculated in terms of light yield

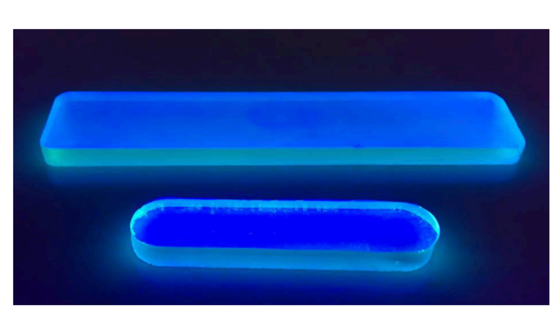


JINST 11, P08023, 2016

New SiX Scintillators

- The scintillators have a base material, primary fluor, and secondary fluor.
- The main scintillation comes from the primary fluor.
- The secondary fluor, or waveshifter, absorbs the primary's emissions and re-emits to a wavelength that is desirable for optimum efficiency.





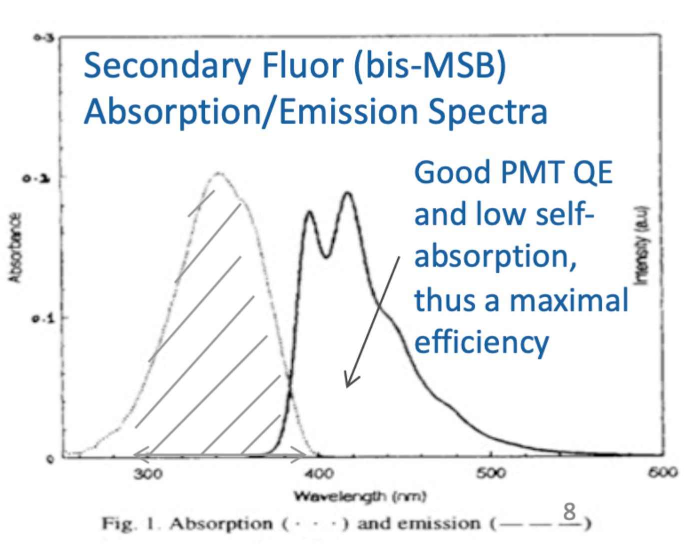
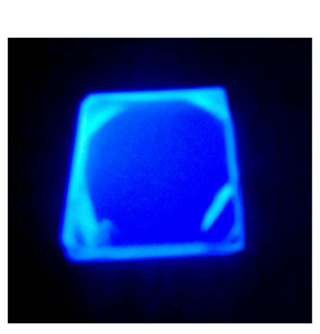
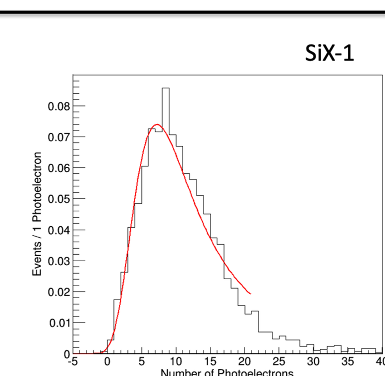


Fig. 1. Absorption (· · ·) and emission (—)

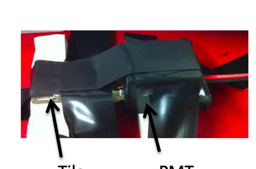




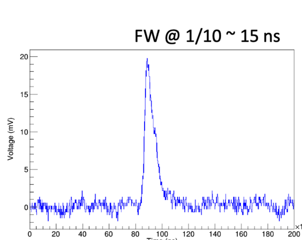
Small sample: 2 cm x 3 cm x 6 mm

The edge coupling the PMT is polished.

No reflective wrapping.

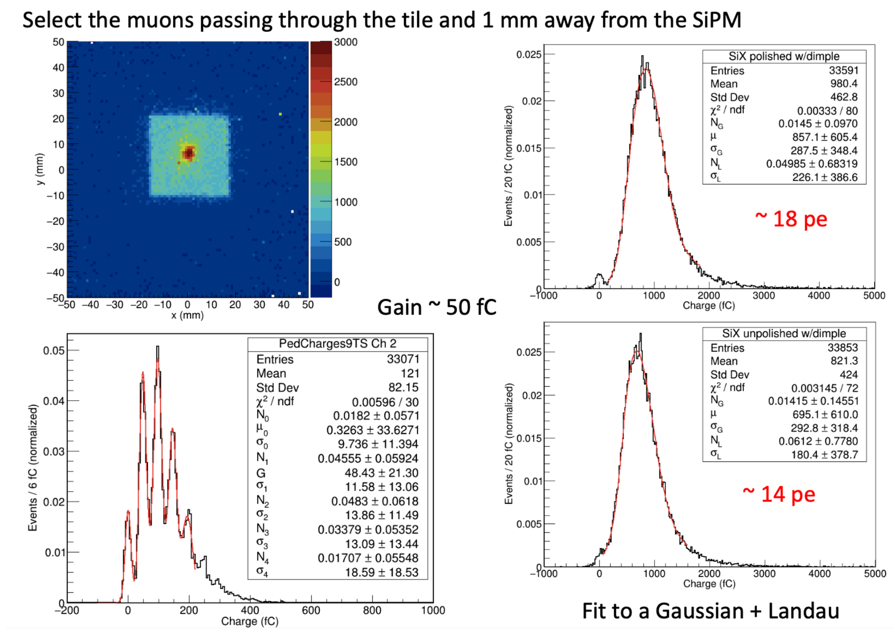


FW @ 1/10 ~ 15 ns



SiX in Test Beam

Scintillator-X response to 150 GeV muons
SiPM directly coupled to dimple (Hamamatsu S12572-010)
Tile size 3 cm x 3 cm
Select the muons passing through the tile and 1 mm away from the SiPM

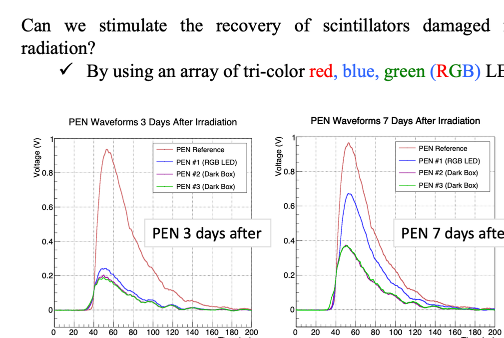


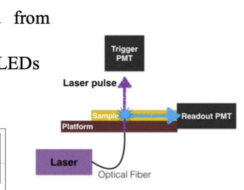
Fit to a Gaussian + Landau

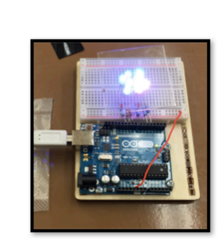
LED Stimulated Recovery

Can we stimulate the recovery of scintillators damaged from radiation?

- ✓ By using an array of tri-color red, blue, green (RGB) LEDs





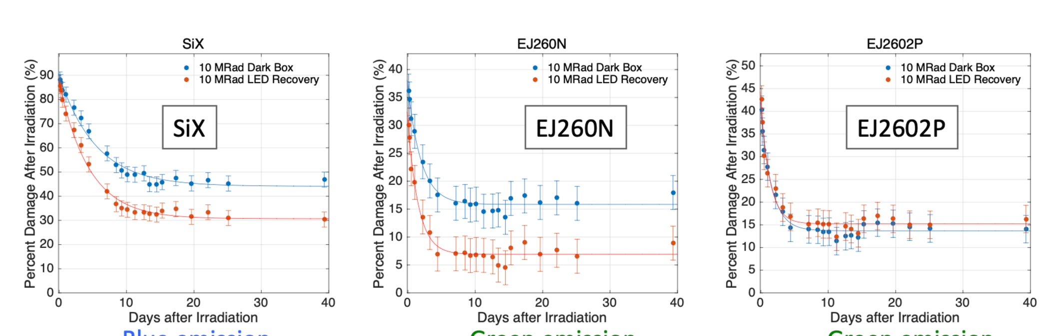


Different Materials:

- Eljen brand EJ-260 (N) and overdoped version EJ2P.
- Lab produced plastic scintillator (SiX)

NIM B395, 13, 2017

LED Stimulated Recovery



Tile	'a', Total Recovery	'c', Permanent Damage
SiX RGB	56.3 ± 2.4%	30.7 ± 1.6%
SiX dark box	45.7 ± 2.5%	44.1 ± 1.9%
EJN RGB	24.0 ± 2.2%	6.92 ± 0.7%
EJN dark box	21.1 ± 1.8%	15.9 ± 0.6%
EJ2P RGB	26.9 ± 3.1%	15.2 ± 0.9%
EJ2P dark box	26.5 ± 2.2%	13.7 ± 0.7%

Very useful to implement on the on-detector electronics!

- SiX showed significant effect, the sample on RGB LED recovering 10% more and faster (4.5 vs 5.5 days)
- Neither EJN and EJ2P showed significant effect.
- 'Blue' scintillators respond to color spectrum but 'green' scintillators are affected very little.

NIM B395, 13, 2017

- The options of intrinsically radiation-hard scintillators are being expanded with the addition of Scintillator-X. Different variants of Scintillator-X should be probed.
- Intrinsically radiation hard plastics PEN and PET remain to be feasible and cost-effective solutions.
- LED mediated recovery techniques are a possible solution to speed up radiation damage recovery. The techniques can now be implemented with on-detector electronics.